INPC 2013

INTERNATIONAL NUCLEAR PHYSICS CONFERENCE

FIRENZE, ITALY 2-7 JUNE 2013

Book of Abstracts

03 - Nuclear Reactions

Foreword

In the present booklet we have collected the one-page abstracts of all contributions (invited, oral and poster) accepted at the INPC2013 Conference in the topic

Nuclear Reactions

The submitted abstracts have been divided into the various topics of the Conference following mostly the indication given by the authors. In few cases, where the subject was on the borderline of two scientific areas or it appeared misplaced, the abstracts have been moved to the booklet of the more appropriate topic.

The abstracts are numbered and arranged alphabetically according to the name of the first author. In the parallel and poster sessions of the Conference, each contribution will be identified by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

Nuclear Reactions (NR)

NR 001.	Cumulative protons from ^{12}C fragmentation at intermediate energy *B.M.Abramov, P.N.Alexeev, Yu.A.Borodin, S.A.Bulychjov, I.A.Dukhovskoi, A.I.Khanov, A.P.Krutenkova,V.V.Kulikov, M.A.Martemianov, M.A.Matsuk, E.N.Turdakina* Contact email: *anna.krutenkova@itep.ru*
NR 002.	Nuclear reactions at near-barrier energies with quantum diffusion approach *G.G. Adamian* Contact email: *adamian@theor.jinr.ru*
NR 003.	Near barrier fusion of the (^{7}Be, ^{8}B) + ^{58}Ni systems *E. F. Aguilera, E. Martinez-Quiroz, D. Lizcano, A. Gómez-Camacho, P. Amador-Valenzuela, J. J. Kolata, F. D. Becchetti, and T. L. Belyaeva* Contact email: *eli.aguilera@inin.gob.mx*
NR 004.	Nuclear Level Density and Dinuclear System Model *S. A. Alavi, M. R. Pahlavani* Contact email: *a.alavi@stu.umz.ac.ir*
NR 005.	Probing the Incomplete Fusion Dynamics at Energy ~ 3-8 MeV/A *Rahbar Ali, D. Singh, M. Afzal Ansari, Harish Kumar, R. Kumar, S. Muralithar, K. S. Golda, R. P. Singh, M. H. Rashid, R. Guin, S. K. Das and R. K. Bhowmik* Contact email: *rahbarali1@rediffmail.com*
NR 006.	Effect of projectile and target structure on the fusion-barrier distribution *Sabir Ali, Tauseef Ahmad, Kamal Kumar, I. A. Rizvi, Avinash Agarwal, S. S. Ghugre, A. K. Sinha, A. K. Chaubey* Contact email: *sabirjhk@gmail.com*
NR 007.	Two-nucleon overlaps from realistic nuclear wave functions *M. Alvioli, C. Giusti, D. N. Kadrev* Contact email: *alvioli@pg.infn.it*
NR 008.	Study of pairing in light nuclei and clusterization through nuclear break-up *M. Assié, J.-A. Scarpaci, E528s collaboration, E582 collaboration* Contact email: *assie@ipno.in2p3.fr*
NR 009.	Role of model ingredients on the directed flow and its disappearance using isospin dependent quantum molecular dynamics model *Rajni Bansal* Contact email: *rajnijain88@gmail.com*

NR 010.	On the relative contribution of symmetry energy and Coulomb effect on fragment multiplicity near the Fermi energy regime *Rubina Bansal, Suneel Kumar* Contact email: *rubinabansal98@gmail.com*
NR 011.	Collective features of nuclear dynamics with exotic nuclei within microscopic transport models *V. Baran, B. Frecus, M. Colonna, M. Di Toro, R. Zus* Contact email: *virbaran@yahoo.com*
NR 012.	Exploring the alpha cluster structure of nuclei using the thick target inverse kinematics technique for multiple alpha decays *M. Barbui, K. Hagel, V.Z. Goldberg, J.B. Natowitz, H. Zheng, G. Giuliani, G.Rapisarda, S.Wuenschel and X.Q. Lin* Contact email: *barbui@comp.tamu.edu*
NR 013.	Two-proton femtoscopy in BUU transport models *B.W. Barker, G. Verde, P. Danielewicz* Contact email: *barker@nscl.msu.edu*
NR 014.	Role of shell closure on nuclear dissipation via evaporation residue cross-section measurement for $^{19}F+^{194,196,198}Pt$ Systems *B.R. Behera, Varinderjit Singh, Maninder Kaur, N. Madhavan, S. Nath, J. Gehlot, G. Mohanto, A. Jhingan, Ish Mukul, T. Varughese, J. Sadhukhan, S. Goyal, A.Kumar, K. P. Singh, S. Santra, A. Saxena, S. Kailas* Contact email: *bivash@pu.ac.in*
NR 015.	Effect of N/Z in pre-scission neutron multiplicity for $^{16,18}O+^{194,198}Pt$ systems *B.R. Behera, Rohit Sandall, Varinderjit Singh, Maninder Kaur, A. Kumar, G. Singh, K. P. Singh, P. Sugathan, A. Jhingan, K. S. Golda, M. B. Chatterjee, R. K. Bhowmik, Sunil Kalkal, D. Siwal, S. Goyel, S. Mandal, E. Prasad, J. Sadhukhan, K. Mahta, A. Saxena, Santanu Pal* Contact email: *bivash@pu.ac.in*
NR 016.	Cluster states ^{11}B with abnormally large radii *T.L.Belyaeva, S.A.Goncharov, A.N.Danilov, A.S.Demyanova, A.A.Ogloblin, W. Trzaska, P.Heikkinen, N.Burtebaev, T.Zholdybaev, N.Saduev, Yu.G.Sobolev, S.V.Khlebnikov* Contact email: *danilov1987@mail.ru*
NR 017.	Neutron asymptotic normalization coefficients and halo radii of the first excited states of ^{13}C and ^{11}Be *T. L. Belyaeva, A. S. Demyanova, S. A.Goncharov, and A. A Ogloblin* Contact email: *tbl@uaemex.mx*

NR 018.	Breakup, fusion, and elastic scattering analysis for $^{8}B + {}^{58}Ni$ at low energies using the continuum-discretized coupled channels method *T. L. Belyaeva, P. Amador-Valenzuela, E. F. Aguilera, E. Martinez-Quiroz, and J. J. Kolata* Contact email: *tbl@uaemex.mx*
NR 019.	Search for rotational state of Hoyle state in complete kinematic experiment $^{12}C(\alpha,\alpha)3\alpha$ *C. Bhattacharya, T. K. Rana, S. Bhattacharya, S. Kundu, K. Banerjee, T. K. Ghosh, G. Mukherjee, R. Pandey, M. Gohil, A. Dey, J. K. Meena, G. Prajapati, P. Roy, H. Pai, M. Biswas* Contact email: *tapan@vecc.gov.in*
NR 020.	Analytic Continuation of Scattering Data as a Method of Obtaining Characteristics of Bound States *L.D. Blokhintsev, D.A. Savin* Contact email: *blokh@srd.sinp.msu.ru*
NR 021.	Evolution of fragmentation modes in central reactions at Fermi energies: theory and experiment *E. Bonnet, M. Colonna* Contact email: *eric.bonnet@ganil.fr*
NR 022.	Reaction dynamics and γ-spectroscopy of neutron-rich Ne isotopes by heavy-ion reactions *S. Bottoni, G. Benzoni, S. Leoni, D. Montanari, A. Bracco, E. Vigezzi, F. Azaiez, L.Corradi, D. Bazzacco, E. Farnea, A. Gadea, S. Szilner, G. Pollarolo* Contact email: *simone.bottoni@mi.infn.it*
NR 023.	Light cluster production in 32 A.MeV $^{136,124}Xe+{}^{124,112}Sn$ reactions *R. Bougault* Contact email: *bougault@lpccaen.in2p3.fr*
NR 024.	System Size and Energy Dependence of Dilepton Production in Heavy-Ion Collisions at SIS Energies *E. Bratkovskaya, J. Aichelin, M. Thomere, S. Vogel, and M. Bleicher* Contact email: *Elena.Bratkovskaya@th.physik.uni-frankfurt.de*
NR 025.	Systematic study of α half-lives of superheavy nuclei *A. I. Budaca, I. Silişteanu* Contact email: *abudaca@theory.nipne.ro*
NR 026.	Thermodynamic mechanisms of the proton induced multifragmentation phenomena *L.A. Bulavin, K.V. Cherevko, V.M. Sysoev* Contact email: *Konstantin.Cherevko@gmail.com*

NR 027.	Hydrodynamic mechanisms of the exotic structures formation in the head-on heavy ion collisions *L.A. Bulavin, K.V. Cherevko, J. Su, V.M. Sysoev, F.S. Zhang* Contact email: *Konstantin.Cherevko@gmail.com*
NR 028.	Different partitioning modes of the ^{197}Au + ^{197}Au system at 23*A* MeV *T. Cap, K. Siwek-Wilczyńska, I. Skwira-Chalot, J. Wilczyński* Contact email: *Tomasz.Cap@fuw.edu.pl*
NR 029.	The ratio method: a new way to look at halo nuclei *P. Capel, R. C. Johnson, and F. M. Nunes* Contact email: *pierre.capel@ulb.ac.be*
NR 030.	New structures in the continuum of light nuclei populated by two-neutron transfer reactions *D. Carbone, F. Cappuzzello, C. Agodi, A. Bonaccorso, M. Bondì, M. Cavallaro, A. Cunsolo, M. De Napoli, A. Foti, R. Linares, D. Nicolosi, S. Tropea* Contact email: *carboned@lns.infn.it*
NR 031.	Light exotic nuclei transfer reactions with CHIMERA detector at LNS *G.Cardella, L.Acosta, F.Amorini, L.Auditore, I.Berceanu, M.B.Chatterjiee, E.DeFilippo, L.Francalanza, R.Gianì, L.Grassi, E.La Guidara, G.Lanzalone, I.Lombardo, D.Loria, T.Minniti, A.Pagano, E.V.Pagano, M.Papa, S.Pirrone, G.Politi, A.Pop, F.Porto, F.Rizzo, E.Rosato, P.Russotto, S.Santoro, A.Trifirò, M. Trimarchi, G.Verde, M.Vigilante* Contact email: *cardella@ct.infn.it.*
NR 032.	Experimental Study of the $^{12;13;14;15}$C+^{12}C fusion reactions with MUSIC *P.F.F. Carnelli, S. Almaraz-Calderon, D. Henderson, K.E. Rehm, M. Albers, M. Alcorta, P. F.Bertone, H. Esbensen, J. O. Fernandez-Niello, C. L. Jiang, S. T. Marley, O. Nusair, T.Palchan-Hazan, R. C. Pardo, M. Paul* Contact email: *salmaraz@phy.anl.gov*
NR 033.	Evidence of correlated 2*n* transfer in the ^{12}C(^{18}O,^{16}O)^{14}C reaction *M. Cavallaro, F. Cappuzzello, M. Bondì, D. Carbone, V. N. Garcia, A.Gargano, S.M.Lenzi, J. Lubian, C. Agodi, F. Azaiez, M. De Napoli, A.Foti, S. Franchoo, R. Linares, D.Nicolosi, M. Niikura, J. A. Scarpaci, S. Tropea* Contact email: *manuela.cavallaro@lns.infn.it*
NR 034.	Coulomb breakup of ^{31}Ne within the finite range DWBA *Rajdeep Chatterjee, Shubhchintak* Contact email: *rcfphfph@iitr.ernet.in*
NR 035.	Experimental investigation of symmetric and asymmetric fission of heavy systems *A.Chbihi, L. Manduci, E. Bonnet, J. D. Frankland* Contact email: *chbihi@ganil.fr*

NR 036.	Non-compound nucleus contribution in $^{12}C+^{93}Nb$ reaction *Sahila Chopra, Manie Bansal, Manoj K. Sharma, Raj K. Gupta* Contact email: *chopra.sahila@gmail.com*
NR 037.	Retarding friction versus white noise in the description of heavy ion fusion *M.V. Chushnyakova* Contact email: *mashutka.omsk@mail.ru*
NR 038.	Studies of the Three-Nucleon System Dynamics in the Deuteron-Proton Breakup Reaction *Izabela Ciepał, B. Kłos* Contact email: *izabela.ciepal@uj.edu.pl*
NR 039.	Exploring the influence of transfer channels on fusion reactions: the case of $^{40}Ca+^{58,64}Ni$ *S. Courtin, F. Haas, A.M. Stefanini, G. Montagnoli, L. Corradi, E. Fioretto, D. Montanari, F. Scarlassara, N. Rowley and S. Szilner* Contact email: *sandrine.courtin@iphc.cnrs.fr*
NR 040.	Interplay between multiple intranuclear scattering and pickup in proton-induced emission of ^{3}He into the continuum *A.A.Cowley and J. J. Van Zyl* Contact email: *aac@sun.ac.za.*
NR 041.	Structure and reaction interplay for the scattering of halo nuclei on a proton target *R. Crespo, E. Cravo, A. Deltuva* Contact email: *Raquel.crespo@ist.utl.pt*
NR 042.	Differential HBT Method to Analyse Rotation *L.P. Csernai* Contact email: *csernai@ift.uib.no*
NR 043.	The Liège Intranuclear Cascade model. Towards a unified description of nuclear reactions induced by nucleons and light ions from a few MeV to a few GeV. *J. Cugnon, A. Boudard, J.-C. David, S. Leray, D. Mancusi* Contact email: *cugnon@plasma.theo.phys.ulg.ac.be*
NR 044.	Four-nucleon reactions above the four-cluster breakup threshold *A.Deltuva, A. C. Fonseca* Contact email: *deltuva@cii.fc.ul.pt*

NR 045.	Projectile structure effects in the collisions $^{6,7}Li$ + ^{64}Zn around the Coulomb barrier *A. Di Pietro, P. Figuera, E. Strano, M. Fisichella, M. Lattuada, C.Maiolino, M.Milin, A. Musumarra, M.G. Pellegriti, D.Santonocito, V.Scuderi, D.Torresi, M. Zadro* Contact email: *figuera@lns.infn.it*
NR 046.	Elastic and break-up of the 1n-halo ^{11}Be nucleus. *A. Di Pietro, A.M. Moro, L. Acosta, F. Amorini, M.J.G. Borge, P. Figuera, M. Fisichella, L.M.Fraile, J. Gomez-Camacho, H. Jeppesen, M. Lattuada, I. Martel, M. Milin, A.Musumarra, M.Papa, F.Perez-Bernal, R. Raabe, G. Randisi, F. Rizzo, V. Scuderi, O. Tengblad, D. Torresi, A.Maira Vidal, D. Voulot, F. Wenander, M. Zadro* Contact email: *dipietro@lns.infn.it*
NR 047.	Measurement of the ^{237}Np(n,f) cross section with the FIC detector at the CERN n_TOF facility *M. Diakaki, D. Karadimos, R. Vlastou, L. Audouin, U. Abbondanno, G. Aerts, H. Alvarez, F. Alvarez-Velarde, S. Andriamonje, J. Andrzejewski, P. Assimakopoulos, G. Badurek, P. Baumann, F. Becvar, F. Belloni, E. Berthoumieux, F. Calvino, M. Calviani, D. Cano-Ott, R. Capote, C. Carrapi¸ P. Cennini, V. Chepel, E. Chiaveri, N. Colonna, G. Cortes, A. Couture, J. Cox, M. Dahlfors, S. David, I. Dillmann, C. Domingo-Pardo, W. Dridi, I. Duran, C. Eleftheriadis, L. Ferrant, A. Ferrari, R. Ferreira-Marques, K. Fujii, W. Furman, S. Galanopoulos, I. F. Goncalves, E. Gonzalez-Romero, F. Gramegna, C. Guerrero, F. Gunsing, B. Haas, R. Haight, M. Heil, A. Herrera-Martinez, M. Igashira, E. Jericha, F. Kappeler, Y. Kadi, D. Karamanis, M. Kerveno, P. Koehler, V.Konovalov, E. Kossionides, M. Krticka, C. Lampoudis, C. Lederer, H. Leeb, A. Lindote, I. Lopes, M. Lozano, S. Lukic, J. Marganiec, S. Marrone, T. Martınez, C. Massimi, P. Mastinu, E. Mendoza, A. Mengoni, P.M. Milazzo, C. Moreau, M. Mosconi, F. Neves, H. Oberhummer, S. O'Brien, J. Pancin, C. Papadopoulos, C. Paradela, A. Pavlik, P. Pavlopoulos, G.Perdikakis, L. Perrot, M. T. Pigni, R. Plag, A. Plompen, A. Plukis, A. Poch, J. Praena, C. Pretel, J. Quesada, T. Rauscher, R. Reifarth, M. Rosetti, C. Rubbia, G. Rudolf, P. Rullhusen, L. Sarchiapone, R. Sarmento, I. Savvidis, C. Stephan, G. Tagliente, J. L. Tain, L. Tassan-Got, L. Tavora, R. Terlizzi, G. Vannini, P. Vaz, A. Ventura, D. Villamarin, V. Vlachoudis, F. Voss, S. Walter, M. Wiescher and K. Wisshak* Contact e-mail: *diakakim@central.ntua.gr*
NR 048.	Mass-Asymmetry effects in heavy ion reactions: Complete fusion Vs incomplete fusion *Sunil Dutt, Avinash Agarwa, Munish Kumar, I.A. Rizavi, R. Kumar, A. K. Chaubey* Contact email: *sunilduttamu@gmail.com*
NR 049.	Pairing effects in heavy-ion collision studied with Canonical-basis Time-Dependent Hartree-Fock-Bogoliubov theory *S. Ebata, T. Nakatsukasa* Contact email: *ebata@cns.s.u-tokyo.ac.jp*

NR 050.	Democratic decay of ^{6}Be studied in knockout reaction *I.A. Egorova, R. J. Charity, L. V. Grigorenko, M. V. Zhukov* Contact email: *i.a.egorova@gmail.com*
NR 051.	Probing the semi-magicity of ^{68}Ni via the ^{3}H(^{66}Ni,^{68}Ni)^{1}H and ^{2}H(^{66}Ni,^{67}Ni)^{1}H transfer reactions in inverse kinematics *J. Elseviers* Contact email: *jytte.elseviers@fys.kuleuven.be*
NR 052.	Angular Distributions of Quasifission and Fission Fragments within the Dynamical Model *D.O.Eremenko, V.A.Drozdov, O.V.Fotina, S.Yu.Platonov, O.A.Yuminov* Contact email: *eremenko@sinp.msu.ru*
NR 053.	Exotic structure of ^{15,17}B probed through charge changing cross section *A. Estrade, R. Kanungo, I. Tanihata, F. Ameil, J. Atkinson, Y. Ayyad, D. Cortina-Gil, I.Dillman, A. Evdokimov, F. Farinon, H. Geissel, G. Guastalla, R. Janik, J. Kurcewicz, R.Knöbel, Y. Litvinov, M. Marta, M. Mostazo, I. Muhka, C. Nociforo, S. Pietri, A. Prochazka, C. Scheidenberger, B. Sitar, P. Strmen, H-J. Ong, M. Takechi, J. Tanaka, S. Terashima, Y.Vargas, H. Weick, and J. Winfield* Contact email: *ritu@triumf.ca*
NR 054.	Microscopic study on proton elastic scattering of Helium, Lithium, and Beryllium isotopes at energy range of 1-160 MeV/nucleon. *M. Y. H. Farag, E. H. Esmael, H. M. Maridi* Contact email: *h.maridi@yahoo.com*
NR 055.	Systematic Study of (d,n) Reactions at E_d = 16 MeV Using a Deuterated Scintillator Array *M. Febbraro, F.D. Becchetti, R.O. Torres-Isea, A. M. Howard, J. Riggins, C. Lawrence, J. J. Kolata* Contact email: *febbraro@umich.edu*
NR 056.	Measurement of Li+Sn fusion excitation functions around the Coulomb barrier using an improved activation technique *M. Fisichella, A. Shotter, A. Di Pietro, P. Figuera, M. Lattuada, C.Marchetta, A.Musumarra, M.G. Pellegriti, C.Ruiz, V. Scuderi, E.Strano, D.Torresi, M.Zadro* Contact email: *fisichella@lns.infn.it*
NR 057.	Ab initio approach to the structure and reactions of light nuclei *Christian Forssén, Jimmy Rotureau, G. Papadimitriou, B. R. Barrett, N. Michel, M. Ploszajczak* Contact email: *christian.forssen@chalmers.se*

NR 058.	Pre-equilibrium α-particle emission as a probe to study α-clustering in nuclei *O.V. Fotina, S.A. Goncharov, D.O. Eremenko, O.A. Yuminov, S.Yu. Platonov, V.L. Kravchuk, F. Gramegna, T. Marchi, M. Cinausero, M. Degerlier* Contact email: *Fotina@srd.sinp.msu.ru*
NR 059.	Exploring reaction mechanisms and their competition in $^{58}Ni+^{48}Ca$ collisions at E=25 AMeV *L. Francalanza* Contact email: *laura.francalanza@ct.infn.it*
NR 060.	Investigating the astrophysical $^{22}Ne(p,\gamma)^{23}Na$ reaction with a multi-channel scattering formalism *P. R. Fraser, L. Canton, J. P. Svenne, K. Amos, S. Karataglidis, D. van der Knijff* Contact email: *prfraser@unimelb.edu.au*
NR 061.	Investigation of the unbound ^{21}C nucleus via transfer reaction *T. Fukui and K. Ogata* Contact email: *tokuro@rcnp.osaka-u.ac.jp*
NR 062.	Microscopic coupled-channel method based on the complex G-matrix *T. Furumoto and Y. Sakuragi* Contact email: *sakuragi@sci.osaka-cu.ac.jp*
NR 063.	Global optical potential for heavy ions up to driplines *T. Furumoto, W. Horiuchi, M. Takashina, Y. Yamamoto and Y. Sakuragi* Contact email: *sakuragi@sci.osaka-cu.ac.jp*
NR 064.	Universality in Particle-Dimer Scattering below threshold: from atomic to nuclear physics *M. Gattobigio, A. Kievsky* Contact email: *mario.gattobigio@inln.cnrs.fr*
NR 065.	Role of symmetry energy towards N/Z dependence of energy of vanishing flow *Sakshi Gautam, Aman D. Sood* Contact email: *sakshigautm@gmail.com*
NR 066.	Probing the symmetry energy at low density using observables from neck fragmentation mechanism *S. Gianì, F. Amorini, L. Auditore, V. Baran, I. Berceanu, C. Cardella, M. Colonna, E. De Filippo, L. Francalanza, E. Geraci, L. Grassi, A. Grzeszczuk, P. Guazzoni, J. Han, E. La Guidara, G. Lanzalone, I. Lombardo, C. Maiolino, T. Minniti, A. Pagano, E.V. Pagano, M. Papa, E. Piasecki, S. Pirrone, G. Politi, A. Pop, F. Porto, F. Rizzo, P. Russotto, S. Santoro, A. Trifirò, M. Trimarchi, G. Verde, M. Vigilante, J. Wilczynski, L. Zetta* Contact email: *ritagiani@libero.it*

NR 067.	Dynamical Dipole and EOS in N/Z asymmetric fusion reactions *A.Giaz, A.Corsi, F.Camera, S.Barlini, V.L.Kravchuk, R.Alba, P.Bednarczyk, A.Bracco, G.Baiocco, L.Bardelli, G.Benzoni, M.Bini, N.Blasi, S. Brambilla, M.Bruno, G.Casini, M.Ciemala, M.Cinausero, M.Chiari, M.Colonna, F.C.L. Crespi, M.D'Agostino, M.Degerlier, M.Di Toro, F.Gramegna, M.Kmiecik, S.Leoni, C.Maiolino, A.Maj, T.Marchi, K.Mazurek, W.Meczynski, B.Million, D.Montanari, L.Morelli, A.Nannini, R.Nicolini, G.Pasquali, S.Piantelli, A.Ordine, G.Poggi, V.Rizzi, C.Rizzo, D.Santonocito, V.Vandone, G.Vannini, O.Wieland* Contact email: *agnese.giaz@mi.infn.it*
NR 068.	Operator Energy Approach to Dynamical Stark Effect for Nuclei in Super Strong Laser Field and Resonance Phenomena in Heavy Nuclei Collisions *A.V. Glushkov* Contact email: *dirac13@mail.ru*
NR 069.	Calculation of fusion barriers, elastic and fusion cross sections for weakly-bound/halo nuclei using the optical model and the Continuum Discretised Coupled Channels method *A.Gómez Camacho, J. Lubian, A. Díaz Torres and P.R.S. Gomes* Contact email: *arturo.gomez@inin.gob.mx*
NR 070.	Study of the structure of the Hoyle state by refractive α-scattering *S.A. Goncharov, A.S. Demyanova, Yu.A. Gloukhov, A.A. Ogloblin, T.L. Belyaeva, Yu.G. Sobolev, W.Trzaska, S.V. Khlebnikov, G.P. Tuyrin* Contact email: *gsa@srd.sinp.msu.ru*
NR 071.	Problem of the apparently large diffuseness of the nucleus-nucleus fusion potential: possible solution using M3Y *NN*-forces *I.I. Gontchar* Contact email: *vigichar@hotmail.com*
NR 072.	Advances and prospects in the theoretical studies of few-body decays *L. V. Grigorenko, I. A. Egorova, P. G. Sharov, Yu. L. Parfenova, M. V. Zhukov* Contact email: *lgrigorenko@yandex.ru*
NR 073.	Pseudo-critical clusterization in nuclear multifragmentation *D. Gruyer, J.D. Frankland, A. Chbihi, R. Botet, M. Płoszajczak, E. Bonnet* Contact email: *gruyer@ganil.fr*
NR 074.	In-Medium Effects and Low Density Nuclear Matter *K. Hagel* Contact email: *hagel@comp.tamu.edu*
NR 075.	Scales of Nuclear Giant Resonances *W.D. Heiss* Contact email: *dieter@physics.sun.ac.za*

NR 076.	Elastic scattering of the halo nucleus ^{11}Be on ^{64}Zn *M. Hemalatha* Contact email: *hema@cbs.ac.in*
NR 077.	Mass-angle distributions: providing extensive insights into the dynamics and time scales of reactions forming heavy elements *D.J. Hinde, C. Simenel, R. du Rietz, A. Wakhle, E. Williams, M. Dasgupta, M. Evers, D.H. Luong, K. Ramachandran and Y. Aritomo* Contact e-mail*: david.hinde@anu.edu.au*
NR 078.	Results from single-neutron adding reactions on light neutron-rich nuclei with HELIOS *C. R. Hoffman, M. Albers, M. Alcorta, S. Almaraz-Calderon, S. I. Baker, B. B. Back, S. Bedoor, P. F. Bertone, J. A. Clark, C. M. Deibel, S. J. Freeman, B. P. Kay, J. C. Lighthall, S. T. Marley, T. Palchan-Hazan, G. Perdikakis, K. E. Rehm, A. M. Rogers, A. Rojas, D. Santiago-Gonzalez, J. P. Schiffer, D. K. Sharp, D. V. Shetty, J. S. Thomas, I. Wiedenhover, and A. H. Wuosmaa* Contact email: *crhoffman@phy.anl.gov*
NR 079.	Microscopic optical potential from chiral nuclear interactions *J. W. Holt, N. Kaiser, G. A. Miller and W. Wei* Contact email: *jwholt@uw.edu*
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NR 149.	Synthesis of $^{250-253}No$ in $^{206}Pb+^{48}Ca$ reaction *Niyti, Raj K. Gupta* Contact email: *sharmaniyti@gmail.com*
NR 150.	Analyzing powers for $1s_{1/2}$-knockout (p, $2p$) and (p, pn) reactions. *T. Noro, Y. Yamada, M. Dozono, K. Hatanaka, D. Ishikawa, M. Itoh, Y. Maeda, H. Matsubara, K. Sagara, H. Sakaguchi, Y. Sakemi, A. Tamii, T. Wakasa, Y. Yasuda, H. P. Yoshida, and J. Zenihiro* Contact email: *noro@phys.kyushu-u.ac.jp*
NR 151.	Coupled channel effect on the far-side component of the $^{16}O+^{27}Al$ elastic scattering angular distribution at 100 MeV and above *J.R.B. Oliveira, F. Cappuzzello, L.C. Chamon, C. Agodi, M. Bondí, D. Carbone, M. Cavallaro, A. Cunsolo, M. De Napoli, A. Foti, L.R. Gasques, P.R.S. Gomes, R. Linares, J.Lubian, D. Nicolosi, S. Tropea* Contact email: *zero@if.usp.br*
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NR 153.	Proton-proton femtoscopy and access to early dynamical sources at intermediate energies *E.V. Pagano, T. Minniti, G. Verde, P. Danielewicz, B.Barker* Contact email: *epagano@lns.infn.it*

NR 154.	Fusion Cross Sections of ^{8}B + ^{28}Si at near barrier energies *A.Pakou, E. Stiliaris, D. Pierroutsakou, M. Mazzocco, N. Alamanos, A. Boiano, C. Boiano, D. Filipescu, T.Glodariu, J. Grebosz, A. Guglielmetti, M. La Commara, C. Parascandolo, B.A. M.Sánchez-Benítez, C.Signorini, O. Sgouros, F. Soramel, E. Strano, L. Stroe, C.V. Soukeras, D.Torresi, K. Zerva* Contact email: *apakou@cc.uoi.gr*
NR 155.	Excitation of isomeric states in reactions (γ,n) and (n,2n) on ^{113}In and $^{198,200}Hg$ nuclei *S.R. Palvanov* Contact email: *satimbay@yandex.ru*
NR 156.	SPY: a new microscopic scission-point model to predict fission fragments properties *S. Panebianco, N. Dubray, H. Goutte, S. Hilaire, J-F. Lemaître, J-L. Sida* Contact email: *stefano.panebianco@cea.fr*
NR 157.	Asymmetric nuclear matter calculations and many-body correlations in Semiclassical Molecular Dynamics *M. Papa* Contact email: *papa@ct.infn.it*
NR 158.	Investigation of the Dynamical Dipole Mode in the $^{40,48}Ca$+$^{152,144}Sm$ fusion-evaporation and fission reactions at 11 MeV/nucleon *C. Parascandolo, D. Pierroutsakou, C. Agodi, R. Alba, V. Baran, A. Boiano, M. Colonna, R. Coniglione, E. De Filippo, A. Del Zoppo, M. Di Toro, U. Emanuele, F. Farinon, A. Guglielmetti, M. La Commara, C. Maiolino, B. Martin, C. Mazzocchi, M. Mazzocco, C. Rizzo, M. Romoli, M. Sandoli, D. Santonocito, C. Signorini, R. Silvestri, F. Soramel, E. Strano, D. Torresi, A. Trifirò and M. Trimarchi* Contact email: *concetta.parascandolo@pd.infn.it*
NR 159.	Effect of breakup coupling on elastic scattering in the reactions of ^{7}Li + ^{27}Al, ^{159}Tb *D. Patel, B. K. Nayak, S. Mukherjee, D. C. Biswas, S. Santra, A. Saxena, E. T. Mirgule* Contact email: *dipika.physics@gmail.com*
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Cumulative protons from ^{12}C fragmentation at intermediate energy

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One of the most interesting puzzles of relativistic nuclear physics is an origin of cumulative particles which kinematic lies in a region forbidden for interactions of free nucleons. Though a lot of efforts have been spent over decades for measurement and an analysis of such processes in hadron-nucleus interactions the origin of these particles is still an open question. Ion beams can shed new light on above mentioned problem. In our present study we made a step in this direction by high sensitivity measurement of high momentum protons at a small angle from ^{12}C fragmentation. Projectile fragmentation at intermediate energies made it possible to study both cumulative and evaporation momentum regions in a single experiment. In a framework of the FRAGM experiment at ITEP heavy ion facility we have measured yields of protons from ^{12}C fragmentation at energies from 0.2 to 3.2 GeV/nucleon on a Be-target. Main attention was given to the region of high momentum where proton velocity exceeds the projectile velocity. The obtained data cover about six orders of the differential cross section magnitude and the range of cumulative variable $x \approx p/p_0$ up to $x = 2.4$ (p_0 and p are momentum per nucleon of the projectile and proton, respectively). Proton momentum spectra were analyzed in the framework of multi-quark cluster model with fragmentation functions calculated in the Quark-Gluon string model [1]. The multi-quark cluster probabilities were estimated and compared with the available theoretical calculations and experimental data. These probabilities are in reasonable agreement with similar estimates, based on another methods [2,3]. It supports the hypothesis of quark nature of cumulative effect. Systematic uncertainties of the model used are discussed. It is worth to mention that this approach is also an effective tool for parametrization of high-momentum part of the proton spectrum in nuclear fragmentation, where models of ion-ion interactions are far from agreement with experiment.

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Nuclear reactions at near-barrier energies with quantum diffusion approach

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The quantum diffusion approach was applied to study the sub-barrier capture reactions with well and loosely bound nuclei [1]. We demonstrated a good agreement of the theoretical calculations with the experimental data. We found that the influence of the neutron transfer on the capture cross section occurs owing to the change of the isotopic composition and the deformations of the reaction partners. The $1n-$ or $2n-$transfer indirectly influences the quadrupole deformation of the nuclei. When after the neutron transfer the deformations of nuclei do not change or decrease, the neutron transfer weakly influences or even suppresses the capture cross section. Good examples for this effect at sub-barrier energies are the capture reactions ^{32}S+^{96}Zr,^{94,96,98,100}Mo,^{100,102,104}Ru, ^{104,106,108,110}Pd,^{112,114,116,118,120,122,124}Sn. The relative enhancement of the sub-barrier fusion cross sections for the reactions with ^{32}S to those with ^{36}S is mostly related to the deformation of the light nucleus. The point of view that the sub-barrier capture (fusion) cross section strongly increases if the neutron transfer has with a positive Q value has to be revised. The neutron transfer can enhance and suppress the sub-barrier fusion.

Our approach revealed that due to the change of the regime of interaction (the turning-off of the nuclear forces and friction) at sub-barrier energies, the first derivative in energy of the cross sections is changed at about 3.55.0 MeV below the barrier [2]. This change is reflected in the logarithmic derivative $L(E_{\mathrm{c.m.}})$ and astrophysical $S(E_{\mathrm{c.m.}})$ factors.

By analyzing the extracted breakup probabilities, we showed that there are no systematic trends of breakup in the reactions studied [3]. Moreover, for some system with larger (smaller) Z_T we found the contribution of breakup to be smaller (larger). Almost for all reactions considered we obtained a satisfactory agreement between calculated capture cross section and experimental fusion data, if the calculated capture cross section or the experimental fusion data are renormalized by some average factor that does not depend on the bombarding energy.

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Near barrier fusion of the (^{7}Be, ^{8}B) + ^{58}Ni systems*

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Recently, fusion data were reported for the exotic proton-halo system ^{8}B + ^{58}Ni [1]. Remarkably, a strong enhancement both below and above the Coulomb barrier was observed with respect to Barrier Penetration Model (BPM) predictions for a bare potential. This behavior is qualitatively different from the usual sub-barrier enhancement observed for many heavy-ion systems and, in particular, it is quite different from the behavior observed for neutron-halo systems. While fusion tends to saturate the total reaction at high energies for the above proton-halo system, the corresponding excitation function $\sigma_{fus}(E)$ is always below $\sigma_R(E)$ in the case of measured data for the neutron-halo projectile ^{6}He.

When comparing total reaction cross sections for both types of systems, however, they show a striking similarity. Indeed, the experimental $\sigma_R(E)$ curves for systems with ^{8}B and ^{6}He projectiles, follow the same trajectory [2] when the data are properly reduced to eliminate trivial effects of size and charge. In fact, it has been shown that, in the reduced plot, this trajectory is enhanced with respect to the one followed by weakly-bound non-halo systems and the latter in turn lies above the one corresponding to tightly bound projectiles [2]. Within this context, it would seem that the halo nature of the projectiles provides in each case the mechanisms that enhance the total reaction cross sections, making them comparable to each other, but the fusion process is capable of distinguishing some important feature characteristic of the particular halo state.

The different halo charges could be such a feature. It is possible that a dynamic effect of Coulomb polarization might be important in defining the fusion mechanism for halo systems. For the case of Coulomb breakup, it has been shown that both the halo nature and the Coulomb polarization of the ^{8}B projectile play important roles [3]. Coulomb polarization effects, if present, would affect differently the fusion process for the cases of proton- as opposed to neutron-halo projectiles, which could explain the mentioned differences in the respective fusion data. Within this context, the possible importance of the true halo nature of ^{8}B can be tested by comparing the respective fusion cress sections to similar data for other proton-rich nuclei.

The ^{7}Be nucleus is an excellent reference to compare with. It certainly has a proton excess, it is weakly bound (E_{th} = 1.59 MeV) and, in addition, it is the core for ^{8}B. In the present work, a comparison is made between fusion data for the (^{7}Be, ^{8}B) + ^{58}Ni systems. It is shown that, similar to ^{8}B, the system with the ^{7}Be projectile also presents an enhancement above the barrier, but to a lesser degree. The data are discussed and simple arguments are given that support the idea that Coulomb polarization might be responsible for the fusion enhancement in these systems.

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Nuclear Level Density and Dinuclear System Model

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The synthesis of superheavy nuclei as evaporation residues in heavy ion fusion reaction has been investigated by theoretical model of the dinuclear system (DNS) [1,2]. The evaporation residue cross section has been considered as product of the partial capture cross section responsible for the transition of the projectile nucleus through the entrance Coulomb barrier and the DNS formation, the probability of the formation of the compound nucleus after the capture and the survival probability of the formed compound nucleus. The dependence of the compound nucleus formation probability on the nuclear temperature and compound nucleus survival probability on the nuclear level density (NLD) [3,4] has been analyzed by considering different models of the NLD and level density parameter.

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Probing the Incomplete Fusion Dynamics at Energy ~ 3-8 MeV/A

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The study of incomplete fusion (ICF) dynamics at energy ~3-8 MeV/A has been topic of considerable interest for last few decades [1-3]. At higher angular momentum ($\ell > \ell_{crit}$), a part of the projectile fuses with target nucleus while remnant moves with the same beam velocity as that of incident ion beam. The information of ICF has been obtained from the measurement of excitation function (EF) of ERs populated in ^{20}Ne + ^{55}Mn, ^{20}Ne + ^{159}Tb and ^{16}O + ^{156}Gd systems. Sizable enhancement in the measured cross-sections has been observed in α-emitting channels over theoretical predictions, which has been attributed to ICF of the projectile. It has been observed that ICF-fraction is sensitive for mass-asymmetry of interacting partners and supports the Morgenstern *et al;* systematics [4]. In order to confirm the findings of the measurements and analysis of EFs, the forward recoil range distributions of ERs populated in ^{20}Ne + ^{159}Tb (E ~165MeV) and ^{16}O + ^{156}Gd (E ~ 72, 82 & 93MeV) systems, have been measured. It has been observed that peaks appearing at different cumulative thicknesses in the stopping medium are related with different degree of linear momentum transfer from projectile to target nucleus by adopting the break-up fusion model consideration. In order to deduce the angular momentum involved in various CF and / or ICF reaction products, spin distribution and side-feeding intensity profiles of radio-nuclides populated via CF and ICF channels in ^{16}O + ^{160}Gd system at energy, E ~ 5.6 MeV/A, have been studied. Spin distribution of ICF products are found to be distinctly different than that observed from CF products. It has been observed that in ICF-products, mean input angular momentum increases with fusion incompleteness as compared to CF-products. The present observation clearly indicates that production of fast α-particles arises from relatively high angular momentum, which leads to peripheral interaction.

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Effect of projectile and target structure on the fusion-barrier distribution

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Fusion excitation function measurement has been carried out for the ^{20}Ne + ^{51}V system to obtain a representation of the fusion barrier distribution. Using the present data along with previously measured result on ^{12}C, ^{16}O + ^{51}V[1,2] systems, a systematic analysis has been carried out to investigate the role of target and/or projectile structure on fusion barrier distribution. It was shown by Rowley et al. [3] that, under certain approximations, the distribution in energy of a discrete spectrum of barrier could be obtained from precise fusion cross-section σ by taking the second derivative with respect to centre-of-mass energy $E_{c.m}$ of the quantity $(E_{c.m}\sigma)$. When quantal tunneling are considered, $d^2(E_{c.m}\sigma)/dE^2_{c.m}$ becomes continuous and each barrier is smoothed in energy with a full width at half maxima (FWHM) of $0.56\hbar\omega$, where $\hbar\omega$ is the barrier curvature. In this work it is observed that the excitation functions are not smooth and featureless, rather each is unique and is shown to depend on the details of the structure of the interacting nuclei.

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Two-nucleon overlaps from realistic nuclear wave functions

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The calculation of the cross section for processes with nuclear targets and knocked out nucleons, with the residual system in a given final state, requires the knowledge of the target nucleus and final state wave functions. Processes with two-nucleon emission can be calculated by means of the two-nucleon overlap functions, exploting the relationship between the eigenstates of the (A-2) nucleon system with the asymptotic part of the two-body density of the target nucleus ground state [1,2]. We consider a realistic description of two-body nuclear densities obtained within the linked cluster expansion method for complex nuclei [3,4,5], taking into account the short-range correlations induced by realistic potentials, and we use it to obtain two-body overlaps for processes both with two like nucleons and two unlike nucleons in the final state. This work represent a generalization of existing calculations for processes with two protons in the final state, where the Jastrow method were used to generate nucleon-nucleon correlations [6,7]. Including the full state-dependent nucleon-nucleon correlations will make it possible to address in a quantitative way the calculation of processes investigated in recent experiments with the carbon nucleus target [8,9,10] aimed at directly measuring two-nucleon short range correlations and the role of the tensor force in enhancing the proton-neutron correlations with respect to the proton-proton ones [11,12], as well as to calculate the pair spin and isospin dependence of correlations in nuclei. Moreover, our calculations will be relevant to the upcoming results from the data mining project at Jefferson Lab and of new experiments with the upgraded facility.

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Study of pairing in light nuclei and clusterization through nuclear break-up.

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Nuclear break-up occurring at few tens of MeV per nucleon is an efficient tool to study clusterization into nuclei. A landscape of information extracted through nuclear break-up will be given.

Firstly, spatial pairing correlation can be studied. Pairing plays an important role to understand various aspect of nuclear physics but also nuclear astrophysics. Halo nuclei are the best place to study pairing effect in low-density matter. The case of ^{6}He borromean nucleus was investigated at GANIL with an exclusive measurement in order to disentangle between the di-neutron and cigar configuration [1]. A theoretical reaction model going beyond mean-field was developed to understand the experimental data [2]. It shows very strong di-neutron contribution.

The alpha clusterization phenomenon was also studied in ^{40}Ca and ^{40}Ar to compare this effect in symmetric and asymmetric matter. The angular distribution of the emitted alpha particle are compared to Time Dependent Schrödinger Equation calculations to extract spectroscopic factors for the ground state [3].

According to AMD calculations, clusterization may show up in light nuclei close to the driplines. In the future, studies of isotopic chains up to the dripline are foreseen.

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Role of model ingredients on the directed flow and its disappearance using isospin dependent quantum molecular dynamics model

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The collective flow is an ordered motion characterized by different space momentum correlations that can be generated by the dynamics. Different kinds of collective flow that has been suggested are radial, directed, elliptic and differential flow. Among all the above mentioned flows directed flow (alternatively known as in-plane flow or sideward flow) is directly connected to the dynamic evolution of the reaction. Also the beam energy dependence of directed flow leads to its disappearance at a particular energy, known as balance energy or energy of vanishing flow. The directed flow is found to be affected by nuclear mean field potential, nucleon- nucleon cross section and as well as by various entrances channel parameters such as incident energy, colliding geometry and system size [1]. Here we aim to understand role of nucleon-nucleon cross section and its isospin dependence, different equation of state as well as various other model ingredients such as width of Gaussian, coulomb force, symmetry energy and structural effects like the radii of the colliding nuclei on the mass dependence of directed flow and its disappearance using isospin dependent quantum molecular dynamics model [2]. We notice that all the model ingredients have sizeable effect on the above mentioned quantities.

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On the relative contribution of symmetry energy and Coulomb effect on fragment multiplicity near the Fermi energy regime

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We study the relative contribution of symmetry energy and Coulomb effect on the fragment production for asymmetric colliding nuclei near the Fermi energy (20 -100 MeV/nucleon). For the present analysis, we simulate the reactions for the whole mass range (from ^{12}C + ^{197}Au to ^{197}Au + ^{197}Au). The analysis is carried out with in the frame of isospin quantum moleular dynamics (IQMD) model [1]. Our study shows that the role of Coulomb interactions decreases with increase in energy. The density dependence of symmetry energy places a significant role at higher densities.

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Collective features of nuclear dynamics with exotic nuclei within microscopic transport models

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We employ a transport model based on Landau-Vlasov equation to explore the dipolar response of neutron rich systems and its dependence on symmetry energy.

We present evidences for collective features of the pygmy dipole resonance and study its dependence with the mass number. We extract a parametrization $42A^{-1/3}$ for the energy centroid which agrees quite well with data for Ni, Zr, Sn and Pb.

In the second part we apply a transport model, Stochastic Mean Field, which also relies on Landau-Vlasov kinetic equation, to heavy ions collisions and investigate the correlations between the collective flow of Intermediate Mass Fragments and their isospin content, which can provide new informations about the early stages of isospin and fragmentation dynamics at Fermi energies.

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Exploring the alpha cluster structure of nuclei using the thick target inverse kinematics technique for multiple alpha decays

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The alpha cluster structure of nuclei with an equal number of protons and neutrons (alpha conjugate nuclei) was proposed in the 1968 by Ikeda et al. [1] to explain some excited states not reproduced by the shell model. Since then many studies have been performed and now the alpha clustering in light nuclei is well established [2]. However further investigation is required to fully understand the clusterization in medium light and heavy nuclei. In particular states analogous to the Hoyle state, in which the nucleus is described by a cluster of n alpha particles, have not yet been unambiguously identified in nuclei larger than ^{12}C.

We investigated the reaction ^{20}Ne+α using the Thick Target Inverse Kinematics (TTIK) technique [3]. This technique is particularly suited for this study because it allows exploration of a large range of incident energies in the same experiment. Moreover, in the inverse kinematics, the reaction products are focused at forward angles and can be detected with detectors covering a relatively small portion of the solid angle in the forward direction.

^{20}Ne beams of energy 3.7 AMeV and 11 AMeV were delivered by the K150 cyclotron at Texas A&M University. The reaction chamber was filled with ^{4}He gas at a pressure sufficient to stop the beam at 10 to 4 centimeters from the detectors (10.3 and 50 PSI respectively). In this way we could detect particles emitted at zero degrees. The energy of the light reaction products was measured by three silicon detector telescopes placed at a radial distance of 48 cm from the entrance window. Each telescope consisted of two 5x5 cm^2 Micron Semiconductors DC quadrant detectors (Design G). The time of flight of the detected particles was also measured relative to the cyclotron radiofrequency. A monitor detector was used to measure the intensity of the incident beam.

For the first time the TTIK method was used to study multiple α-particle decays and single α-particle emission. New results will be shown on the elastic resonant α scattering, as well as on inelastic processes leading to high excitation energy systems decaying by multiple α-particle emission. According to the Ikeda picture ^{24}Mg can be described as ^{20}Ne + α, ^{16}O + 2α, ^{12}C + 3α or a cluster of 6 α particles. Each configuration is expected to be observable at excitation energies around the corresponding threshold values. We observed alpha particle multiplicities up to 3, when the ^{20}Ne beam energy was 3.7 AMeV, while at 11 AMeV we observed alpha particle multiplicities up to 6.

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Two-proton femtoscopy in BUU transport models

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The study of heavy-ion collisions at intermediate energies provides tools to explore the equation of state (EOS) of nuclear matter. This is commonly accomplished by comparing measured observables to transport model simulations such as BUU, QMD, CoMD, etc. [1]. Among the available observables, two-proton correlation functions have extensively been used a space-time probes of reaction dynamics, leading to the extraction of emitting source sizes and lifetimes [2]. Such "femtoscopic" probes are also expected to be sensitive to important nuclear transport properties.

Imaging experimental two-proton correlation functions provides the profile of the emitting source that can be compared to transport model simulations to test details about the in-medium nucleon-nucleon cross section [3]. Similar studies with IBUU simulations [4] have also shown that pp, nn and np correlation functions can be studied to probe the density dependence of the symmetry energy in asymmetric nuclear matter. However, two-proton correlation functions are strongly affected by the presence of long-lived emitting sources that dominate the late stage of the reaction through the existence of secondary decays by excited primary fragments; such long-lived emissions are not handled properly by BUU simulations.

In this contribution we present a study of two-proton correlations with the BUU model, isolating early dynamical emitting source contributions. The aim is to improve the comparison to experimental data by reducing the sensitivity to late emitting sources that are difficult to treat in the model.

Simulations of central and semi-central collisions of ^{40}Ar+Sc, ^{86}Kr+Nb, ^{112,124}Sn+^{112,124}Sn, and ^{129}Xe+Au collisions at $E = 50$–$150\,$MeV/nucleon are studied and we show that high transverse momentum ($p_\perp/m$) gates on emitted protons suppress contributions originating from the late stages of the reaction, thus providing an experimentally measurable quantity, $p_\perp/m$, that isolates dynamical emitting sources. This result is discussed in view of comparisons to experimental data that are key to testing transport theories and probing the density dependence of the symmetry energy in future experiments with correlations and femtoscopy.

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Role of shell closure on nuclear dissipation via evaporation residue cross-section measurement for $^{19}F+^{194,196,198}Pt$ Systems

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Study of presence and magnitude of nuclear dissipation is one of the active fields in the present day nuclear physics research. Experimental signatures for dissipation are observed through large excess in pre-fission neutrons, giant dipole resonance (GDR) γ-rays from the compound nucleus, light charged particles and evaporation residues (ER) as compared to the standard statistical model, for the heavy-ion induced fusion-fission or fusion-evaporation reactions [1-2]. Most of these probes are not sensitive to the dissipation within the saddle. The ER cross-section is a probe which is sensitive to the dissipation within the saddle point. With the motivation to see the effect of shell closure on pre-saddle nuclear dissipation, the ER cross-sections for $^{19}F + ^{194,196,198}Pt$ systems are measured using Hybrid Recoil Mass Analyzer (HYRA), at beam energy of 101 to 137.3 MeV (Excitation energy range of 50 to 92 MeV) at the pelletron+LINAC accelerator facility of IUAC, New Delhi. Out of these reaction one reaction ($^{19}F+^{194}Pt$) is populating a shell closed compound nucleus (CN) ^{213}Fr (Neutron number N_c = 126) and other two compound systems ^{215}Fr and ^{217}Fr are away from the shell closure (N_c=128 and130). At the first instant, the measured ER cross-sections are compared with the prediction of the statistical model code PACE using the default parameters. It is observed that the model calculations under predicts the experimental ER cross-sections through out the energy range. It clearly indicates the presence of dissipation effect in the fusion-evaporation reactions. The PACE calculations are further carried out using the parameters obtained by simultaneous fitting of the fission and ER cross-sections at low energies [2]. It is observed that the experimental ER cross-sections, for ^{213}Fr (Nc=126) are explained very well with PACE prediction, but could only explain the cross section at the lowest energy for $^{217,215}Fr$ compound system and deviate considerably at higher energies. This observation also support Back *et al.*'s [2] observation of low dissipation for shell closed CN. Since ^{213}Fr is a shell closed CN, so it is expected to have low dissipation, hence PACE code could explain the ER cross sections. Calculations are further performed using Kramer's modified fission width and treating the dissipation coefficient (β) as free parameters. The extracted β values are similar for ^{215}Fr and ^{217}Fr, but is different for the shell closed ^{213}Fr CN.

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Effect of N/Z in pre-scission neutron multiplicity for ^{16,18}O+^{194,198}Pt systems

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It is well established that the pre-scission neutron multiplicity is one of the most efficient probes to study the fission time scale in heavy-ion induced fusion-fission reactions [1]. It has been observed that the experimental multiplicities of pre-scission neutrons were in clear excess of the predictions of the standard statistical model of compound nuclear decay [1]. The excess in multiplicities indicates the presence of dynamical hindrance of the fission process and the fission dynamics of an excited compound nucleus is dissipative in nature at high excitation energies. The problem of the origin and the nature of nuclear dissipation is presently one of the most interesting questions in nuclear physics at low and intermediate energies. It is therefore of considerable interest to explore the effect of N/Z in compound nuclei for a given element on the strength of nuclear dissipation. Measurement of pre-scission neutron multiplicities from an isotopic chain will be a suitable tool for the above purpose. This abstract report the experimental measurement of pre-scission neutron multiplicities from four compound nuclei, namely ^{210,212,214,216}Rn, and statistical model analysis of the data. The compound nuclei ^{210,212,214,216}Rn having N/Z values as 1.441, 1.465, 1.488, 1.511 respectively are populated through the ^{16,18}O+^{194,198}Pt reactions at excitation energies of 50, 61, 71.7 and 79 MeV. The experiments were carried out at Pelletron+LINAC accelerator facility of IUAC, New Delhi, using the National Neutron Detector Array (NAND) facility. The measured pre-scission neutron multiplicities increases with the increase of N/Z of the compound nuclei at all excitation energies except at the lowest one. Pre-scission multiplicities measured at the lowest excitation energy display a minimum at the compound nucleus ^{212}Rn with N=126. The measured neutron multiplicities are further analyzed with the statistical model of nuclear decay where fission hindrance due to nuclear dissipation is considered. The dissipation strength is treated as an adjustable parameter in order to fit the experimental data. The N/Z dependence of the dissipation strength at lowest excitation energy of the compound nuclei suggests shell closure effects. However, such effects are not observed at higher excitations where the variation of the dissipation strength with N/Z does not show any specific trend [2].

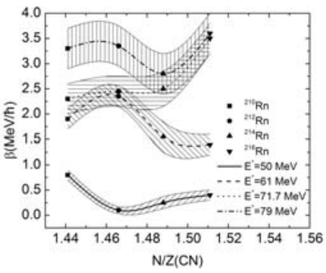

Figure 1: *Variation of the best-fit values of β with N/Z of the compound nuclei at different excitation energies. The shaded areas represent the uncertainty in β associated with the experimental error in M^{pre}.*

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Cluster states ^{11}B with abnormally large radii

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There are predictions [1,2] based on the model of antisymmetrized molecular dynamics (AMD) and alpha-condensate models that two states in ^{11}B: ½$^-$, E* = 8.56 MeV and ½$^+$ (possibly E*=12.56 MeV), have mean-square radii RMS, which are much larger than the radius of the ground state. Especially intriguing was suggestion [2] that RMS radius of the 12.56 MeV state ^{11}B is larger than uranium nucleus!

For verification of this prediction two experiments on ^{11}B+α scattering were performed at E_α=65MeV and 40MeV (last data were partly published in [3]). Goal of these experiments was to determine radius values of exciting states in ^{11}B using Modified Diffraction Model (MDM). Preliminary value of 8.56MeV state radius was determined: <R> = 2.68 ± 0.15 fm, which is 0.4 fm larger than radius of the ground state. This value is in agreement with previous data and AMD calculations [1].

For 12.56 MeV (½$^+$) ^{11}B exist contradictory information about its isospin. Model [2] requires that T = ½. And in the case of T = 3/2, this state should not be excited in the inelastic alpha particle scattering. 12.56 MeV state was not observed in both experiments (a typical spectrum is shown on Figure 1), although well-known neighbor states with T = ½ are visible. Also this state was not detected in resonance reaction ^{7}Li+α [5].

Thus, we can conclude that this state has isospin T = 3/2. And more general conclusion is that the variant of alpha-condensate model used in [2] does not lead to obtaining of correct results.

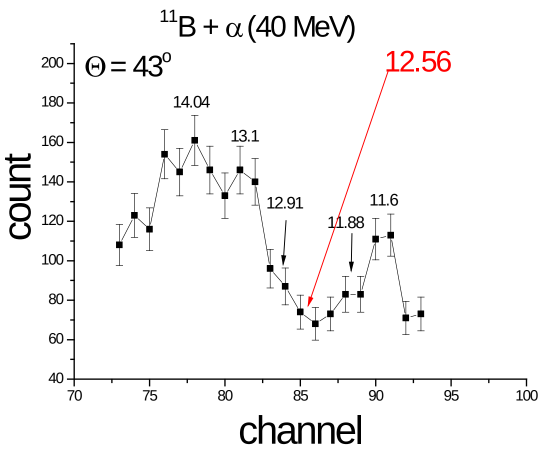

Figure 1: *Part of the spectrum ^{11}B+α, E_α=40MeV, Θ=43°*

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Neutron asymptotic normalization coefficients and halo radii of the first excited states of ^{13}C and ^{11}Be

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In this presentation, we show that (d,p) neutron transfer reactions can be a useful tool for investigating exotic nuclear structure. A rebirth of interest to their studies is related, in particular, to the possibility of finding neutron halos in the radioactive nuclei using inverse kinematics. Neutron halos have been almost exclusively observed in ground states of some neutron-rich radioactive nuclei located close to the neutron drip line. Nevertheless, an appearance of neutron halos in the excited states of the stable nuclei, for instance, in the first ($1/2^+$, E_x = 3.089 MeV) state of ^{13}C was discussed in the 1990s. Recently the enlarged rms radius of ^{13}C in this state was found by applying the modified diffraction method [1]. We present the calculations of the (d,p)-reaction angular distributions, spectroscopic factors S_{exp}, asymptotic normalization coefficients (ANCs) and calculated rms radii of the last neutron in the first excited states of the stable ^{13}C and the radioactive ^{11}Be nuclei, calculated within the coupled reaction channels method. Our calculations confirm the existence of neutron halos in these states by a comparison with the states having normal densities. We found that the neutron transfer dominates at energies about 12 and 30 MeV (an example is shown in Fig. 1) and demonstrated that the states with enlarged radii are formed in the reactions of a peripheral type, which satisfy to the criterion of a peripherality: $C^2=S_{exp}b^2=const$, where C is the ANC and b is the “single-particle” ANC.

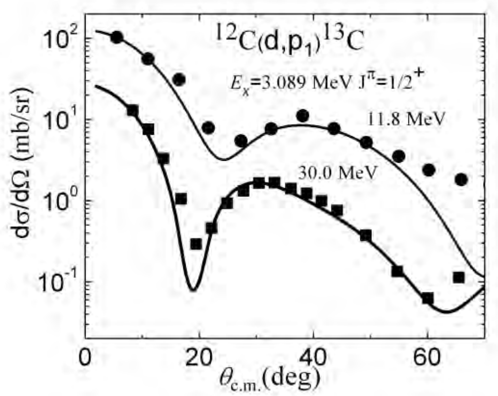

Figure 1: *The contribution of the direct neutron transfer (solid lines) comparing with the experimental data Refs. [1,3]*

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Breakup, fusion, and elastic scattering analysis for ^{8}B + ^{58}Ni at low energies using the continuum-discretized coupled channels method

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In the last years, some evidence has been presented showing that for the neutron-halo ^{6}He and proton-halo ^{8}B projectiles, the reaction cross sections can be entirely accounted for by interactions of the halo state of ^{6}He plus reactions that occur with the ^{4}He core, as well as, by breakup of the halo state ^{8}B plus reactions that occur with the ^{7}Be core. Comparison of the reaction and fusion cross sections for ^{8}B and ^{6}He projectiles with those for normal nuclei showed a remarkable enhancement, related to their exotic structure.

In this presentation, we report the results of an analysis for the ^{8}B+^{58}Ni system, with the method of continuum-discretized coupled channels (CDCC), in the energy interval 18 – 28.4 MeV in the laboratory system. This covers the region both below and above the Coulomb barrier ($V_{c.m.}$ = 20.8 MeV). We carried out CDCC calculations for the breakup, fusion, and elastic scattering of ^{8}B on ^{58}Ni, and compared the results with the differential cross sections and the excitation functions measured in Refs. [1-3].

The first aim of our analysis was to study the coupling between breakup, fusion and elastic scattering and the influence of the ^{7}Be core – target optical potential (OP) and *p* – target OP on the breakup and fusion cross sections. For this aim, the data for the elastic scattering of the (^{7}Be, ^{8}B) + ^{58}Ni systems [3], and for breakup [2], fusion and reaction cross sections [1,3] for ^{8}B + ^{58}Ni were analyzed. We found energy-dependent OPs, for which the real and imaginary volume integrals have smooth energy dependence. The second aim of the work was to reproduce the experimental fusion and total reaction cross sections and to predict their behavior at low incident energies.

A theoretical analysis within the CDCC model was made for breakup of ^{8}B using a more extended model space as that in [4]: inelastic excitations in the ^{7}Be-proton system from the ground state to excited states with orbital angular momenta L = 0-5 and energies up to 8 MeV in the continuum were taken into account. Finally, we found a considerable coupling between breakup, fusion and elastic scattering and were able to adjust completely the experimental breakup, fusion, and total reaction cross sections in the energy interval mentioned earlier, simultaneously with the ^{8}B-^{58}Ni elastic scattering differential cross sections.

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Search for rotational state of Hoyle state in complete kinematic experiment $^{12}C(\alpha, \alpha)3\alpha$

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The Hoyle state of ^{12}C, at the excitation energy (E_x) of 7.65 MeV, has been predicted by F. Hoyle in 1952 based on the ^{12}C abundance in the universe [1] but its precise properties is still not known properly. From nuclear structure point of view too, there are many unanswered questions regarding the configuration of this state; theoretically, it is conjectured as the lowest state corresponding to a different configuration (member of either a β- band of the three-α molecule like structure [2-4] or a Bose Einstein condensate like structure (BEC) [5]) originating from 3α clustering in ^{12}C, and the standard shell model approaches, even the advanced no-core shell model calculations failed to reproduce the state [6]. According to the above models, cluster configuration of the Hoyle state should also have higher excited states; the lowest excited state has been predicted to be a 2^+ state at excitation energy excitation energy close to 10 MeV. This 2^+ state is strongly coupled to the 0_2^+ Hoyle state and is likely to decay mostly via the Hoyle state. However, in spite of vigorous experimental efforts in the recent years, there is no conclusive evidence so far. In inelastic proton scattering $^{12}C(p, p')^{12}C^*$ experiments, small angle angular distribution measurement near the diffractive minimum of the broad 0_3^+ background has indicated the presence of a 2^+ possible state at 9.6 (1) MeV of width ~ 600 keV [7, 8]. Recent inelastic scattering angular distribution studies also indicated the presence of a 2^+ state at ~ 9.8 MeV of width ~ 1 MeV [9]. On the other hand the study of $^{12}C^*$, produced in the Beta decay of ^{12}N and ^{12}B, decaying into 3α continuum has however, not found clear evidence for the existence of the 2^+ state at 10 – 12 MeV excitations [10, 11]. Recently, gamma induced ^{12}C dissociation studies via $^{12}C(\gamma, 3\alpha)$ reaction have also indicated the presence of a 2^+ state below 10 MeV [12]. It is thus clear that even though there are definite indications about the existence of the elusive 2_2^+ state (the first excited state of the Hoyle state), clear identification of this state is still missing. A complete kinematic measurement of the inelastic α particles emitted in the $^{12}C(\alpha, \alpha')$ 3α reaction in coincidence with the decay of the Hoyle state at beam energy 60 MeV will be reported here. The present study clearly demonstrates the presence of an excited state of ^{12}C at the excitation energy of 9.65 ± 0.02 MeV which has a width (FWHM) of 607 ± 55 keV. Since this new state is decaying via the 0_2^+ Hoyle state and also close to the predicted energy and width of 2_2^+ state, it may be the rotational excited state of the Hoyle state but however angular distribution of the state is needed for further confirmation of its spin and parity, which is beyond the scope of this paper. The measurement and analysis detail will be discussed here.

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Analytic Continuation of Scattering Data as a Method of Obtaining Characteristics of Bound States

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An asymptotic normalization coefficient (ANC) determines the asymptotics of a wave function of a nucleus *A* in a binary channel *b+c*. ANCs are proportional to nuclear vertex constants (NVC), which are on-shell matrix elements of the virtual processes *a*↔*b+c*. The NVC for the *a*↔*b+c* vertex is expressed directly in terms of the residue of the elastic *bc* scattering amplitude at the pole corresponding to the bound state *a* [1]. NVCs and ANCs are fundamental nuclear characteristics. They are used actively in analyses of nuclear reactions within various approaches. The ANC for the channel *a*↔*b+c* determines the probability of the configuration *b+c* in nucleus *a* at distances greater than the radius of nuclear interaction. Thus ANCs arise naturally in cross sections of nuclear reactions between charged particles at low energies, in particular, of astrophysical nuclear reactions. It was shown [2] that the cross section of the astrophysical $b(c,\gamma)a$ reaction with a good accuracy is determined by the value of the ANC in the *b+c* channel. This conclusion made it possible to calculate the astrophysical *S* factor for a number of radiative capture processes.

ANC values could be determined in principle from microscopic calculations but such calculations are rather tedious. Theoretical results should be matched to the empirical ones obtained from data on scattering and reactions. One of the promising methods to extract ANCs is the analytic continuation of *bc* scattering data to a pole of a scattering amplitude corresponding to a bound state *a* and lying in the unphysical region of negative energies. The most effective way of realization of that procedure is the analytic continuation of the scattering (or effective range (ER)) function. This approach was employed in papers [3-5] for one-channel scattering to get the ANC and NVC values for several light nuclei. In papers [6] the method of the analytic continuation of the ER function was generalized to the two coupled elastic channels what is important for the scattering of two particles with spins ½ or spins 1 and 0.

In the given work the method of the analytic continuation of the ER function is applied to obtain the ANCs for ^{6}Li nucleus in the α+*d* channel. The ANC values for this system determine the cross section of the radiative capture ^{4}He(d,γ) ^{6}Li, which is the only process of ^{6}Li formation in the Big Bang model. The available data on the values of the ANCs C_l for that channel are characterized by a large spread, especially for $l = 2$ ($l = 0, 2$ is the channel orbital angular momentum). Several sets of scattering phases obtained from the phase-shift analyses as well as from Faddeev calculations [3] are used as an input. Since the α+*d* system possesses the low-lying inelastic threshold due to the dissociation of a deuteron, the approach used is generalized to include inelastic channels. Account of inelasticity effects is performed by several differing methods. One of them makes use of adding an imaginary part to the *K* matrix, which is fitted to the experimental inelasticity coefficients. Another metod consists in direct including of imaginary terms into the ER expansion. These terms are constructed in such a way as to guarantee the correct analytic behaviour of a scattering amplitude near the inelastic threshold. The sensitivity of the obtained ANC values to the elastic channels coupling and to account of the inelastic channel is investigated.

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Evolution of fragmentation modes in central reactions at Fermi energies: theory and experiment

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Recently, the INDRA collaboration has investigated links between entrance channel, collective expansion and fragmentation features, in the context of heavy ion collisions at Fermi energies [1]. To go further in this direction, a full comparison between transport theory results (the Stochastic-Mean-Field (SMF) [2] approach is employed) and multifragmentation data [3] will be discussed.

In a first part, the question of centrality selection is addressed. Starting from simulation events in the range of impact parameter 0-4 fm, we apply the same dynamical selection as that used experimentally to sort out the so-called ”Quasi-Fusion” sources.

To probe the link between the fragmentation regime and the system collective expansion, we analyse reactions in the beam-energy range between 25 and 50 MeV/A. Then we extract, looking at the evolution of the spatial density profile in the simulations, the corresponding evolution of the collective expansion energy, which turns out to be in very good agreement with the experimental results reported in [1].

The simulations also indicate a change in the fragmentation mechanism, from sequential decay of a composite source to prompt multifragmentation. We investigate the connection between the evolution of the fragmentation regime and the trend experimentally observed for the amount of stopping reached in heavy ion reactions [4], which is also determined by the interplay between one-body (mean-field) and two-body (nucleon-nucleon collisions) effects.

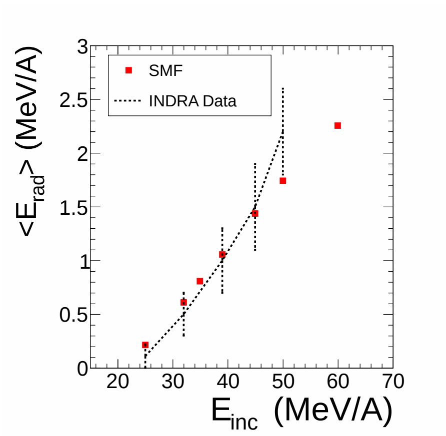

Figure 1: *Evolution of the collective expansion energy (E_{rad}) with incident energy (E_{inc}) of the projectile for the reaction Xe+Sn for SMF simulation (red squares) and INDRA data (dotted lines).*

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Reaction dynamics and γ spectroscopy of neutron-rich Ne isotopes by heavy-ion reactions

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Heavy ions are one of the most important tool in the study of nuclear reaction mechanisms and nuclear structure. Multi-nucleon transfer reactions, for instance, allow to investigate the properties of exotic systems, moving away from the valley of stability [1]. The combination of a large acceptance magnetic spectrometer with a high efficiency and a high resolution multi-detector array for γ spectroscopy is a key instrument for this purpose, since it allows to perform both reaction dynamics and nuclear structure studies of weakly populated channels [2,3]. In this work, the heavy ion reaction ^{22}Ne+^{208}Pb at 128 MeV beam energy is discussed. The experiment has been performed at Laboratori Nazionali di Legnaro of INFN using the PRISMA-CLARA apparatus [4]. We focus on the study of particle-γ coincidences to investigate the reaction mechanisms and nuclear structure properties of neutron reach Ne isotopes and neighbouring nuclei. Elastic, inelastic and one nucleon transfer cross sections have been measured and angular distributions have been obtained. The data are compared with semiclassical calculations, performed with the code GRAZING [5,6], and with DWBA predictions obtained with the code PTOLEMY [7,8]. In particular, the angular distribution of the 2^+ state of ^{22}Ne has been analysed by DWBA and a similar calculation has been performed for the unstable ^{24}Ne nucleus, using existing data from the reaction ^{24}Ne+^{208}Pb at 182 MeV of bombarding energy (measured at SPIRAL with the VAMOS-EXOGAM setup [9]). The theoretical model gives a good reproduction of the experiment in both cases, pointing to a strong reduction of the β_2^C charge deformation parameter in ^{24}Ne. This follows the trend predicted for the evolution of the quadrupole deformation along the Ne isotopic chain and calls for additional experimental investigation on the collectivity in ^{24}Ne, a nucleus of key importance for understanding the evolution of shell gaps in light systems. The present work demonstrates the validity of heavy ion reactions for both dynamics and nuclear structure studies, providing a useful method which could be further exploited in the future for the investigation of very exotic species.

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Light cluster production in 32 A.MeV ^{136,124}Xe+^{124,112}Sn reactions.

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The 4π multi-detector INDRA was used to study four reactions with beams of ^{136}Xe and ^{124}Xe, accelerated at 32 MeV/nucleon, and thin (530 μg/cm^2) targets of ^{124}Sn and ^{112}Sn. Recorded event functionality was activated under a triggering factor based on a minimum number of fired detectors over 4π. For the studied reactions the INDRA multi-detector possesses excellent detection performances in the center of mass forward hemisphere whereas in the backward part, energetic detection thresholds prevent the detection with full efficiency of fragments from peripheral reactions. This study is thus performed on the forward part of the c.m and all measured quantities are related to this half hemisphere. Light charged particle (lcp) total transverse energy ($(\Sigma E_t)^{lcp}_{AvCM}$) is used as impact parameter evaluator. Lcp multiplicities (forward c.m) are examined as a function of the impact parameter evaluator (figure 1). It is seen that all multiplicities increase with decreasing impact parameter. This increase is first steep and then reaches a sort of saturation. The saturation is not a plateau-like behavior since the impact parameter evaluator and the lcp multiplicities are self-correlated. By comparing the multiplicity values between the four systems it is possible to extract general evolutions. For very peripheral collisions, data are grouped in two categories (black points and white points, ^{136}Xe and ^{124}Xe projectiles respectively). In that case, the multiplicity evolution depends more on the nature of the projectile than on target N/Z. Decreasing the impact parameter, particle production deviates from this first order target independent behavior towards a dependence on the combined (projectile+target) system N/Z. This is evidenced by almost identical production, for central collisions, of most of the isotopes for ^{124}Xe+^{124}Sn and ^{136}Xe+^{112}Sn systems. The exception is ^{3}He whose trend seems linked to memory of projectile N/Z for all impact parameters.

Ratio of particle production between the different systems will be presented and compared to transport model calculations using different density dependence of the symmetry energy.

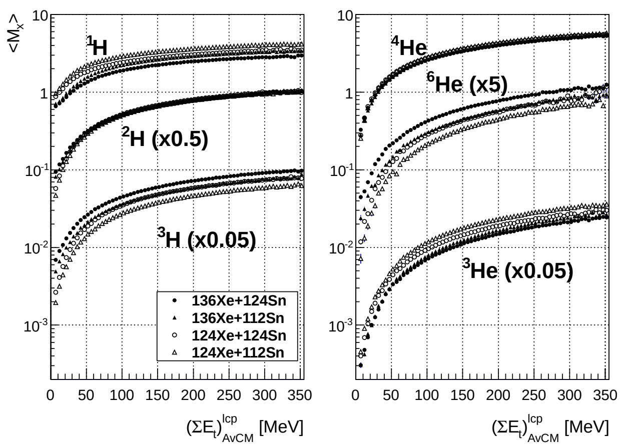

Figure 1: *Average lcp isotope multiplicities (forward c.m) as a function of centrality parameter evaluator for the four systems from peripheral (left) to central collisions (right).*

System Size and Energy Dependence of Dilepton Production in Heavy-Ion Collisions at SIS Energies

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We study the dilepton production in heavy-ion collisions at energies of 1-2 $AGeV$ as well as in proton induced pp, pn, pd and $p + A$ reactions from 1 GeV up to 3.5 GeV where data have been taken by the HADES collaboration - cf. [1]. For the analysis we employ three different transport models - the microscopic off-shell Hadron-String-Dynamics (HSD) transport approach, the Isospin Quantum Molecular Dynamics (IQMD) approach as well as the Ultra-relativistic Quantum Molecular Dynamics (UrQMD) approach. We find that the HSD and IQMD models provide a good description of the presently available experimental data and agree with each other reasonably well. This allows to obtain model independent conclusions on the underlying physical phenomena. In particular, we confirm the experimentally observed enhancement of the dilepton yield (normalized to the multiplicity of neutral pions N_{π^0}) in heavy-ion collisions with respect to that measured in $NN = (pp + pn)/2$ collisions. We identify two contributions to this enhancement: a) the pN bremsstrahlung which scales with the number of collisions and not with the number of participants, i.e. pions; b) the dilepton emission from intermediate Δ's which are part of the reaction cycles $\Delta \to \pi N; \pi N \to \Delta$ and $NN \to N\Delta; N\Delta \to NN$. With increasing system size more generations of intermediate Δ's are created. If such Δ decays into a pion, the pion can be reabsorbed, however, if it decays into a dilepton, the dilepton escapes from the system. Thus, experimentally one observes only one pion (from the last produced Δ) whereas the dilepton yield accumulates the contributions from all Δ's of the cycle. We show as well that the Fermi motion enhances the production of pions and dileptons in the same way. Furthermore, employing the off-shell HSD approach, we explore the influence of in-medium effects like the modification of self-energies and spectral functions of the vector mesons due to their interactions with the hadronic environment. We find only a modest influence of the in-medium effects on the dilepton spectra in the invariant mass range where data with small error bars exist.

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Systematic study of α half-lives of superheavy nuclei

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Studies of decays and reactions involving weakly bound states of superheavy nuclei (SHN) coupled to an environment of scattering states, need to develop new theoretical techniques and computational methods. In this work α half-lives are obtained from the microscopic (shell model) formation amplitudes and the resonance scattering amplitudes given by self-consistent models for the nuclear structure and reaction dynamics. The dynamic and structure effects are systematically explored and this allows us to put α-decay on solid theoretical grounds and to give accurate predictions for the absolute α-decay rates. One of the aims of this work is to relate the most important decay data (reaction energies E_α and emission rates T_α, Γ_α) to the information on exotic nuclear structures and reaction dynamics which would directly prove the underlying nature of phenomenon. In this work a brief summary of the experimental results and theoretical ideas defining the field of α-decay of SHN is presented together with some crucial questions concerning the systematics of the α half-lives. Two different descriptions of α-decay rates, namely, microscopic shell model approach and phenomenological description are emphasized to calculate the α-decay properties of SHN. Theoretical results are confronted to available data and results of other relevant approaches in order to obtain the net contributions of the shell structure and finite size to the absolute emission rates. Also, we compare the systematic of experimental (T_α^{exp}, Q_α^{exp}) and theoretical shell model (T_α^{SM}, Q_α^{exp}) results in order to obtain insight into the accuracy of structure models.

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Thermodynamic mechanisms of the proton induced multifragmentation phenomena

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Understanding the behavior of nuclear matter in the heavy ion collisions is of great relevance either for theoretical nuclear physics or for nuclear astrophysics when studying the supernova explosions and the properties of neutron stats.Different models/approaches (statistical, percolation, various molecular dynamics simulations) and different mechanisms (liquid-gas phase transitions, spinodal decomposition, sequential evaporation from the expanding-emitting source, etc.) are being used for explaining the existing data. Inspite of a long history and a high number of different approaches used there is still a number of problems left that have no explanation and the underlying physical mechanism is still unclear.The aim of the presented work is to proceed with the general macroscopic picture of the proton-induced nuclear multifragmentation rather than its microscopic description or precise quantitative calculations. Based on the thermodynamic analysis of the proton-induced multifragmentation phenomena the most appropriate decay channel is chosen [1]. Within this channel pressure is treated as the main factor causing production of the intermediate mass fragments (IMF) in the observed phenomena. In this case the IMF production should take place in a compact system rather than in a freeze-out volume. In our work we try to use as simple model (corresponding to the appropriate phase trajectory of the nuclear system that represents the process with the high pressure being initialized in the inner part of the nuclei) as possible allowing straight forward thermodynamic analysis in order to have the clear macroscopic picture of the phenomenon. Based on a simple thermodynamic model preliminary quantitative calculations of corresponding macroscopic parameters (energy, pressure) are done and therefore the model verification on thermodynamic level is held. It is shown that the suggested mechanism of the breakdown of the thermodynamic system in a single-phase process that may be followed by metastable boiling seems to be a good and quite adequate candidate for explaining the proton-induced multifragmentation phenomena.

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Hydrodynamic mechanisms of the exotic structures formation in the head-on heavy ion collisions

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Current work was inspired by the theoretical predictions [1] and experimental confirmation [2] of the exotic structures being formed in the head-on heavy ion collisions at energies 50-75 MeV/A. Theoretical predictions of ”bubble” and ”doughnut” strictures depending on the stiffness of the equation of state (EOS)were made in the framework of the Boltzman-like transport theory. Unfortunately up to now there is no clear physical picture of the phenomena. In the presented work we analyze the head-on heavy ion collisions from a hydrodynamic point of view in the energy range 50-100 MeV/A. Symmetry of the phenomena allowed to use a simple model of a nuclei impact on a rigid wall with slip boundary conditions to describe the process. Within the introduced model the stiffness of the EOS plays an important role in the initial stage of the collision due to its influence on the sound velocity of the nuclear matter. During this stage the final geometry of the colliding system is determined and different hydrodynamic mechanisms of the fragment production are switched on. Within the proposed model in the case of stiff EOS lateral jetting occurs earlier and the system evolves through a cup-shaped lamella to an expanding thin sheet with the rim being formed at the edge at the time of the maximum expansion. This leads to the formation of the ”doughnut” structure that corresponds to the Boltzmann-like transport theory calculations for the stiff EOS [1] and the experimental data [2] existing in the literatures. For the case of soft EOS the shock waves produced on impact when being reflected from the free boundary cause rarefication along the symmetry axis. This leads to the cavity formation which when collapsing forms the bubble structure. Both mechanisms give the low values of the expanding velocities at the final state that corresponds to the low kinetic energy of the fragments obtained in Boltzmann-like transport theory calculations. From the obtained results we suggest that hydrodynamic mechanism of the exotic structures formation in the head-on heavy ion collisions explains the qualitative picture observed in the experiments for the energy range under consideration and with the results the Boltzman-like transport theory calculations. For obtaining the precise quantitative results the instability of the expanding rim is to be studied in more details.

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Different partitioning modes of the ^{197}Au + ^{197}Au system at $23A$ MeV

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Collisions of typical, not very heavy nucleus-nucleus systems at low energies (below 20 MeV/nucleon) predominantly lead to two types of reactions: either to fusion or to basically binary deep-inelastic or fast fission reseparation processes. While fusion occurs at central and semiperipheral collisions, the binary reseparation processes cover the remaining range of peripheral collisions. However, for heavier and for more symmetric systems, the range of partial waves leading to fusion shrinks. New modes of reseparation of the colliding system, different from binary deep-inelastic processes, can be then expected. Especially, collisions of the heaviest systems, which due to the strong Coulomb repulsion cannot fuse at all, can reveal new interesting and exotic modes of partitioning.

A study of the ^{197}Au + ^{197}Au reaction at an energy of $15A$ MeV carried out previously [1, 2] by the CHIMERA Collaboration has shown that, in sufficiently inelastic collisions, the colliding system splits into three or four massive fragments of comparable size. It was shown that in the dominant part of events, all the fragments are nearly aligned along the axis of reseparation of the combined system into the primary projectile-like fragment (PLF) and primary target-like fragment (TLF). The effect of alignment points to a very short time scale of the reseparation mechanism [3]. In the present work a new experiment, aimed to study the same very heavy ^{197}Au + ^{197}Au system but at a significantly higher bombarding energy of $23A$ MeV, was performed at the INFN Laboratori Nazionali del Sud (LNS) in Catania. The Charged Heavy Ion Mass and Energy Resolving Array (CHIMERA), arranged in 4π geometry, was used as the detection system.

We present first results of the analysis of the new phenomenon of fast (aligned) ternary and quaternary breakup of the ^{197}Au + ^{197}Au system at the higher energy of $23A$ MeV, showing the evolution of this new reaction mechanism with the increasing bombarding energy. Special attention is paid also to ternary reactions in which in addition to two main fragments, TLF and PLF, a third, not very massive fragment (of A less than, say, 20), usually called an "intermediate-mass fragment" (IMF), is formed. Emission of IMFs has been interpreted as a process of neck fragmentation during reseparation of the colliding system, however this phenomenon was usually observed in previous experiments at higher bombarding energies. Observation of the intense emission of IMFs in the present experiment demonstrates that in collisions of very heavy systems the emission of neck-originated IMFs plays an important role already at relatively low energies.

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The ratio method: a new way to look at halo nuclei

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The advent of radioactive-ion beams has enabled the exploration of the nuclear landscape far from stability. This technological breakthrough has led to the discovery of exotic nuclear structures, such as halo nuclei. Halo nuclei exhibit a large matter radius in comparison with their isobars. This peculiarity is qualitatively explained by the small binding energy of one or two valence nucleons, which then have a significant probability of presence at a large distance from the core of the nucleus. They thus exhibit a strongly clusterised structure in which one or two loosely-bound nucleons form a diffuse halo around a dense core.

Being far away from stability, halo nuclei cannot be studied through usual spectroscopic techniques, and we have to rely on indirect methods, such as reactions, to infer information about their structure. Unfortunately, the complexity of the reaction mechanisms and the uncertainty in the choice of projectile-target interactions can cause ambiguities in the analysis of reaction measurements. To reduce the sensitivity of the measurements to the reaction mechanisms, we present a new way to extract information about the structure of halo nuclei through reactions: the *ratio method*. The basic idea of this new method is to study the ratio of angular distributions for breakup and scattering. According to the Recoil Excitation and Breakup model (REB) [1], this ratio should depend only on the projectile structure. In a first exploration of this idea [2], we have confirmed that prediction by comparing the REB results to calculations performed within the Dynamical Eikonal Approximation (DEA) [3], which has been shown to describe accurately elastic scattering and breakup observables of reactions involving halo nuclei at intermediate energies.

In this contributions, we present a more detailed analysis of the ratio method. Besides the domain of validity of the method (beam energy, angular range. . .), we also illustrate how it can be used to infer accurately information about the projectile structure such as binding energy, partial-wave configuration and radial wave function of the halo. We believe this new method will open a new era in the study of exotic nuclear structure as it provides a unique way to infer information about halo nuclei.

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New structures in the continuum of light nuclei populated by two-neutron transfer reactions

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A systematic study concerning different light nuclei was performed at the Catania INFN-LNS laboratory by the (^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV incident energy. Several solid light targets (^{9}Be, ^{11}B, $^{12,13}C$, ^{16}O) were used. The ^{16}O ejectiles were momentum analyzed by the MAGNEX magnetic spectrometer [1]. The energy spectra were obtained up to about 20 MeV excitation energy, with an energy resolution of about 150 keV. Several known bound and resonant states of the residual nucleus have been identified together with some structures above the two-neutron emission threshold. As an example, in the ^{15}C case, two unknown structures at 10.5 ± 0.1 MeV and 13.7 ± 0.1 MeV were observed, as shown in Fig.1.

Calculations based on the removal of two uncorrelated neutrons from the projectile describe a significant part of the continuum observed in the energy spectra. The main contribution comes from the absorption of the two neutrons. The resulting calculation for the ^{15}C case is shown as the red line in Fig.1. The structure at 10.5 MeV is dominated by a resonance near the ^{13}C+*n*+*n* threshold [2]. Similar results are found for the nearby nuclei, such as ^{14}C, ^{11}Be and ^{13}B and will be shown for the first time at the conference. In order to understand the origin of the strength distribution in the spectra, an estimate of the contribution of each single orbital to the total sum was also evaluated.

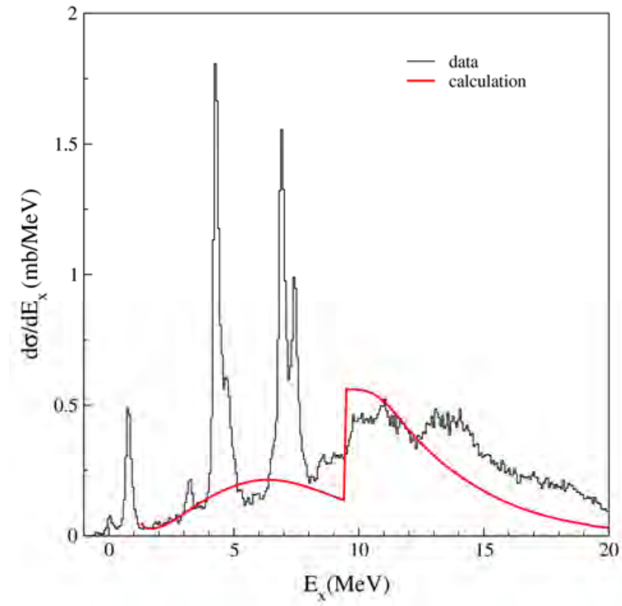

Figure 1: *Inclusive energy spectrum of the reaction $^{13}C(^{18}O,^{16}O)^{15}C$ at 84 MeV incident energy. The break-up calculations folded with the experimental resolution are indicated as the red line.*

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Light exotic nuclei transfer reactions with CHIMERA detector at LNS

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Relatively large yields of various neutron rich exotic beams (^{6}He, ^{8,9}Li, ^{10,11}Be, ^{13}B, ^{16,17}C), produced through the inflight fragmentation of ^{18}O beams at 55 A·MeV, are available at LNS [1]. Using the CHIMERA detector [2,3], we started a campaign to study transfer reactions, with proton and deuteron enriched targets. The kinematical coincidence method was used to extract high resolution angular distributions of binary reactions from the measured light particle energy spectra [4]. An example is shown in figure for the reaction ^{10}Be+p→^{9}Be+d, previous data on d+^{10}Be→t+^{9}Be [5] are also shown. We were able to disentangle some excited levels, exploiting the γ-rays detected in the CsI(Tl) detectors of the Chimera telescopes. Preliminary data on some reaction channels will be presented. The complete analysis of these data will be part of a systematic research for a dependence of cross sections by the observed or claimed halo structures of light neutron rich nuclei.

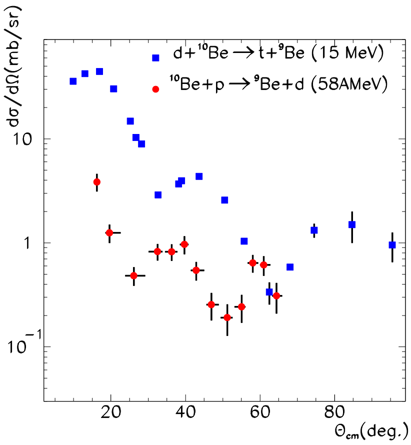

Figure 1: *Angular distribution for the reaction ^{10}Be+p→^{9}Be+d from ref. [4]*

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Experimental Study of the ^{12,13,14,15}C+^{12}C fusion reactions with MUSIC

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Fusion cross section measurements are of great interest in nuclear structure and nuclear astrophysics. New excitement in this field has been generated with the advent of radioactive nuclear beams opening new frontiers for fusion reaction studies. We have developed a new detector, the MUlti-Sampling Ionization Chamber (MUSIC), which is a small volume, active-target ionization chamber filled with CH_4 gas intended for studies of fusion cross sections induced by stable and radioactive nuclear beams. The high efficiency and flexibility to measure the excitation function of fusion reactions in a wide energy range with a single beam energy make the MUSIC detector an ideal tool for performing measurements of fusion cross sections with low intensity radioactive nuclear beams.

We have performed a systematic study of fusion cross section of stable and radioactive carbon isotopes; ^{12,13,14,15}C + ^{12}C above the Coulomb barrier using beams from ATLAS and the MUSIC detector. The excitation functions of these systems are not well understood. There are discrepancies between different measurements as well as between recent coupled-channel calculations and experiments [1,2].

We have measured for the first time, the excitation functions of fusion cross section for ^{15}C+^{12}C and revised previous measurements on the ^{12,13,14}C+^{12}C systems. We have probed the MUSIC detector as an efficient, flexible and powerful tool for these type of measurements. We present the experimental results and compare them with previous experimental data when available and theoretical models.

This work is supported by the U.S. DOE Office of Nuclear Physics DE-AC02-06CH11357 (ANL) and the Universidad Nacional de San Martin, Argentina, grant SJ10/39 (TANDAR).

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Evidence of correlated 2*n* transfer in the ^{12}C(^{18}O,^{16}O)^{14}C reaction

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A study of the (^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV incident energy was pursued at the Catania INFN-LNS laboratory. The experiments were performed on several solid targets from light (^{9}Be, ^{11}B, ^{12,13}C, ^{16}O, ^{28}Si) to heavier ones (^{58,64}Ni, ^{120}Sn, ^{208}Pb). The ^{16}O ejectiles were detected at forward angles by the MAGNEX magnetic spectrometer [1]. Exploiting the large momentum acceptance (20%) and solid angle (50 msr) of the spectrometer, energy spectra were obtained with a relevant yield up to about 20 MeV excitation energy [2]. The application of the powerful trajectory reconstruction technique did allow to get energy spectra with energy resolution of about 150 keV and angular distributions with angular resolution better than 0.3°. In the energy spectra, several known low lying and resonant states of the product nuclei have been observed.

The measured absolute cross-section angular distributions are analyzed by Exact Finite Range Coupled Reaction Channel calculations based on a parameter free double-folding optical potential [3]. The form factors for the (^{18}O,^{16}O) reaction are extracted within an extreme cluster and independent particles scheme with shell model derived coupling strengths. The results show that the measured cross-sections are accurately described for the first time without the need of any arbitrary scaling factor.

This is a completely new result that opens the door to the use of the (^{18}O,^{16}O) as powerful tools for quantitative spectroscopic studies of single-particle and pair configurations in nuclear states. As a consequence, the controversial concept of spectroscopic factor for two-neutron pair states can be better defined.

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Coulomb breakup of ^{31}Ne within the finite range DWBA

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Coulomb breakup of nuclei away from the valley of stability have been one of the most successful probes to unravel their structure. However, it is only recently that one is venturing into medium mass nuclei like ^{23}O and ^{31}Ne. This is a very new and exciting development which has expanded the field of '*light exotic nuclei*' to the '*deformed medium mass*' region.

In this contribution we report an extension of the previously proposed [1,2] theory of Coulomb breakup within the post-form finite range distorted wave Born approximation to include *deformation* of the projectile. The electromagnetic interaction between the fragments and the target nucleus is included to all orders and the breakup contributions from the entire nonresonant continuum corresponding to all the multipoles and the relative orbital angular momenta between the fragments are taken into account. Only the full ground state wave function of the *deformed* projectile, of any orbital angular momentum configuration, enters in this theory as input, thereby making it is free from the uncertainties associated with the multipole strength distributions that may exist in many of the other theories.

We shall present the angular distributions, parallel momentum distributions, relative energy spectra, one neutron removal cross section (Fig. 1) and other reaction observables in the Coulomb breakup of ^{31}Ne on heavy targets at 234 MeV/nucleon beam energy. The effect of deformation on various reaction observables will be studied.

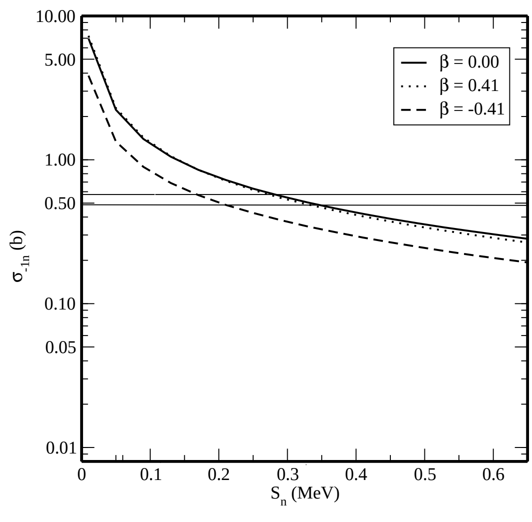

Figure 1: *Total one neutron removal cross section for the Coulomb breakup of* ^{31}*Ne on Pb target at* 234 *MeV/nucleon beam energy, calculated for 'possible' values of one neutron separation energy,* S_n*, of* ^{31}*Ne. The solid, dotted and dashed lines corresponds to deformation parameter* $\beta_2 = 0, 0.41$ *and* -0.41*, respectively. The horizontal lines parallel to the* S_n *axis show the limits of the experimental data [3].*

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Experimental investigation of symmetric and asymmetric fission of heavy systems

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Collisions of Xe+Sn in the energy range E/A = 8-29 MeV and Xe + Au at E/A = 15 MeV leading to fusion-like heavy residues are studied using the 4 INDRA multidetector. The fusion cross section was measured and shows a maximum at E/A = 18-20 MeV. A decomposition into four exit-channels characterized by the number of heavy fragments produced in central collisions has been made. Their relative yields are measured as a function of the incident beam energy. Detailed study of fission exit channel was performed. The charge distributions of fission fragments show symmetric as well as asymmetric fission component increasing with impinging energy, except at the lowest incident energy where only symmetric fission is observed. This characteristic of binary asymmetric fragmentation occurring at high energy is reported for the first time. The cross section of the two components is given. Relative velocity correlation function technique between the fission fragments and light charged particles is applied in order to estimate the primary and secondary decay contributions for symmetric and asymmetric fission. Other pertinent results of the fission mechanism will be presented. The big size of the surviving residues observed in this work should bring important information for the synthesis of super heavy elements.

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Non-compound nucleus contribution in $^{12}C+^{93}Nb$ reaction

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Excitation functions (EFs) of various evaporation residues (ER) are measured recently [1] in the decay of compound nucleus $^{105}Ag^*$ formed in $^{12}C+^{93}Nb$ reaction at below barrier energies. The observed decay products are the heavy residues whose complementary fragments are the light particles (LPs, with mass≤4) and intermediate mass fragments (IMFs, 4≤mass≤13), which when compared with statistical model code PACE2, gives the complete fusion (CF) cross-section σ_{ER} consisting of 2n, 3n, 4n and possibly also ^4H, and its disagreement with IMFs is considered as signatures of incomplete fusion ICF consisting of (complementary fragments) of $^{4,5,6}H$, $^{4,5}He$, ^8Li, $^{9,10,11}Be$, ^{12}B, and ^{13}C. Note that PACE2 does not predict the 1n emission, which is true in general (e.g., σ_{1n}=0 for $^{64}Ni+^{100}Mo$ reaction also [2, 3]). In this paper, we attempt to understand this reaction, i.e., σ_{ER} and σ_{IMFs}, on the dynamical cluster-decay model (DCM) of Gupta and collaborators [3, 4] which defines the compound nucleus decay cross section for ℓ partial waves as

$$\sigma(E_{c.m.},\theta_i,\Phi)=\frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P\,; \qquad \mathrm{k}=\sqrt{2\mu \mathrm{E}_{c.m.}/\hbar^2}\,. \tag{1}$$

The DCM includes deformation effects up to hexadecapole deformations (β_2, β_3, β_4), with compact orientations θ_c of hot fusion process, used here for the case of co-planer ($\Phi=0^0$) nuclei.

Figure 1 shows our calculations at $E_{c.m.}$=54.2 MeV, presenting that σ_{1n} is large if only the σ_{xn} (x=1-4) are fitted, but if the σ_{IMFs} (IMFs taken as a sum of A_2=5-13) are also included, i.e., complete EFs are fitted, then σ_{1n} reduces to almost zero, to be compared with σ_{1n}=0 in the experiment [1] (see Fig. 1(a)), and that an extensively large non-compound nucleus (nCN) contribution is required in 3n and 4n cross-sections, as shown in Fig. 1(b). Large nCN effect is perhaps noted for the first time.

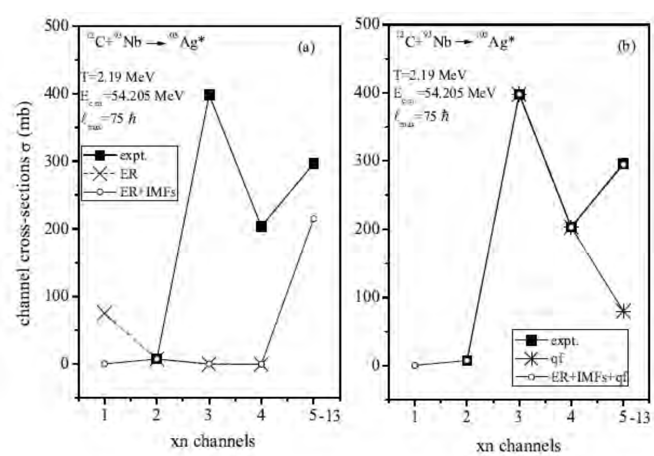

Figure 1: *Calculated fusion excitation functions for $^{105}Ag^*$ formed in $^{12}C+^{93}Nb$ reaction, compared with experimental data at $E_{c.m.}$=54.205MeV.*

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Retarding friction versus white noise in the description of heavy ion fusion

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During last three decades significant efforts had been undertaken in modeling the capture process in the collision of the complex nuclei at the energies well above the Coulomb barrier [1-3]. However, we did not manage to find out any quantitative systematic study of the influence of accounting for the thermal fluctuations in comparison with the memory effects on the calculated cross sections. We revealed recently that it is possible to describe the modern high accuracy capture data within the framework of a classical dissipative trajectory model [4]. Thus the primary goal of the present work is to study the significance of the fluctuations in comparison with the retarding friction.

Our model stems from the one of Ref. [1]: we account for the dissipative character of the nucleus-nucleus collision and consider the surface friction mechanism. The potential used in our model is different from that of [1]: this is the double folding potential based on the microscopically well founded density dependent M3Y *NN*-forces with the finite range exchange part. The novel feature of our work is that we account for the retarding friction and for the thermal fluctuations as well. The modeling was performed for $^{16}O+^{208}Pb$ reaction. Results are illustrated by Fig.1. They show that accounting for the fluctuations (white noise) alternate the calculated fusion cross sections within 5% (triangles). On the other hand, accounting for the retarding friction results typically in the increase of the cross sections by some 20% (squares). The supplement of the last calculations with fluctuations (colored noise) does not change the results within the errors (circles).

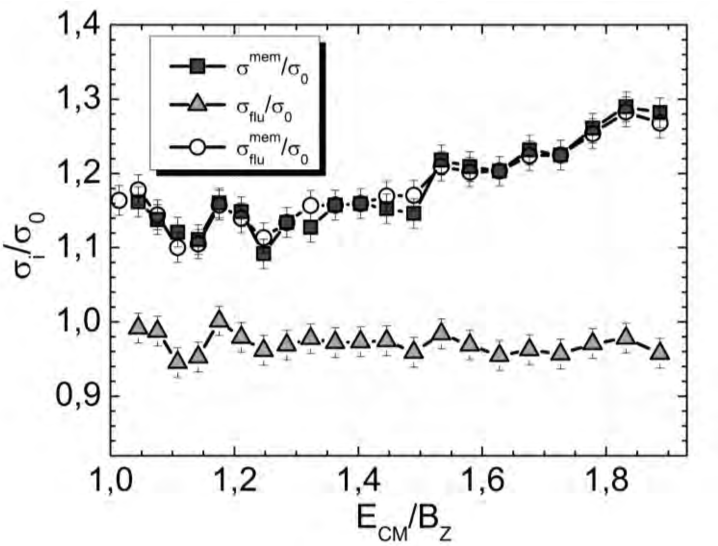

Figure 1: *The calculated capture cross section accounting for the thermal fluctuations (triangles), memory effects (squares) or both (circles) over the purely dissipative deterministic one for $^{16}O+^{208}Pb$ reaction.*

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Studies of the Three-Nucleon System Dynamics in the Deuteron-Proton Breakup Reaction

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Experimental study of deuteron-proton breakup reaction can serve as a valid tool for investigation of interaction between nucleons. Especially, the differential cross section for the breakup process is very sensitive to different pieces of the system dynamics like three-nucleon force (3NF), Coulomb interaction or relativistic effects, which reveal their influence at various parts of the phase-space. In medium energy domain the properties of few-nucleon systems are described mainly by pairwise nucleon-nucleon (NN) interaction and are successfully modeled with the use of the realistic potentials, coupled-channel (CC) method or Chiral Perturbation Theory (ChPT). However, at certain level of precision, much subtle effects can be studied. The calculations, which describe those additional dynamics include the model of 3NF and/or the long-range Coulomb force.

Experiments devoted to study such subtle ingredients of the nuclear dynamics were carried out with the use of the $^{1}H(d,pp)n$ breakup reaction at 130 MeV deuteron beam energy. First new-generation experiments were performed in KVI Groningen [1,2,3] and provided a rich set of differential cross section data, which were measured in a large phase space region. These results proved not only the importance of the 3NF but also revealed surprisingly large effects of the Coulomb force in the range of very small polar angles. These findings conduce to inclusion of the electromagnetic interaction into calculations based on the CC approach. Moreover, they were a motivation to continue research in FZ-Juelich laboratory [4,8] and confirm the role of the Coulomb force in the investigated observables. In this experiment a region of small polar angles (4°–14°) was explored, not attainable in any other laboratory and crucial to investigate action of the Coulomb force.

The obtained high precision data of the diffrential cross section will be confronted with various theoretical predictions, among them calculations with the Argonne (AV18) potential [9] combined with Urbana IX 3NF model [5] in which recently the Coulomb interaction was successfully implemented [6,7].

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Exploring the influence of transfer channels on fusion reactions: the case of ^{40}Ca+^{58,64}Ni

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Fusion-evaporation is the dominant reaction mechanism in medium-light heavy-ion collisions at relatively low bombarding energies. The dominant features observed at these energies, are the enhancement of the fusion cross-section at the Coulomb barrier (CB) and at moderate subbarrier energies, and the hindrance of the cross-section at deep subbarrier energies. Fusion cross-sections around the CB have been discussed extensively to be driven by couplings of the relative motion of the colliding nuclei to their low energy surface vibrations and/or stable deformations. The corresponding coupled-channel calculations of the distributions of barriers and their extraction from precise cross-section measurements have revealed to be a powerful tool to better understand the role of couplings to collective degrees of freedom of the target and projectile [1].

This contribution reports on a recent study of the fusion process in the Ca+Ni systems. This work has been triggered by outstanding results obtained recently in the Ca+Ca [2] systems, and also by the pioneering studies of the Ni+Ni systems [3]. Previous fusion measurements of the symmetric ^{40}Ca+^{40}Ca and ^{48}Ca+^{48}Ca and the asymmetric ^{40}Ca+^{48}Ca systems have been performed at the LNL (Laboratori Nazionale di Legnaro, Italy) down to very low subbarrier energies. All Ca+Ca systems have shown large fusion hindrance at deep subbarrier energies [2]. For the asymmetric system, ^{40}Ca+^{48}Ca, hindrance effects show up a lower energies than in the other systems and it has been concluded that it is necessary to take into account the positive Q value transfer channels to reproduce the fusion cross-section below CB. In a similar way, effects on the fusion excitation function attributed to transfer channels have been invoked in a pioneering study of the fusion excitation function of the ^{58}Ni+^{64}Ni system by Beckerman et al. [3].

Based on these two observations, we have decided to perform accurate cross-section measurements in the « cross-systems » Ca+Ni to identify eventual effects of the neutron excess on fusion in the distribution of barriers energy range. Experimental data have been taken at the LNL for the ^{40}Ca+^{58,64}Ni systems taking advantage of the LNL electrostatic deflector in its upgraded version, making use of large size micro-channel plate and silicon detectors. We have thus been able to extend to much lower energies previous ^{40}Ca+^{58}Ni [4] data and to measure for the first time a fusion excitation function for the ^{40}Ca+^{64}Ni system. The corresponding cross-sections and distributions of barriers extracted from accurate data will be presented.

State-of-the-art coupled-channel calculations will be presented to discuss the subbarrier fusion excitation function behavior in terms of the influence of neutron transfer channels in the ^{40}Ca+^{64}Ni system.

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Interplay between multiple intranuclear scattering and pickup in proton-induced emission of ^{3}He into the continuum

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Recently proton-induced emission of ^{3}He into the continuum has been clearly linked to two-particle pickup as a final process in an intranuclear multistep chain [1-3]. The incident-energy quenching [1] of the analyzing power, for example, is correctly reproduced. However, at the incident energies explored, current information on two-nucleon pickup reactions to discrete final states, which is a subject that ceased to be of primary interest many years ago, is inadequate to interpret the exact interplay between multistep and pickup processes. For that reason we have performed a new experiment on ^{58}Ni(p,^{3}He)^{56}Co between 80 and 120 MeV to address the deficiency.

As would be required, a simple macroscopic zero-range distorted wave Born approximation gives an excellent theoretical representation of the new experimental cross section and analyzing power angular distributions. The observed incident energy dependence of the (p,^{3}He) reaction to discrete final states explains why the characteristic signature of the multistep-pickup process in the continuum disappears as the incident energy increases beyond about 160 MeV.

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Structure and reaction interplay for the scattering of Halo nuclei on a proton target

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Breakup reaction studies of halo nuclei have often been used to extract structure information about these nuclei by comparing the calculated cross sections with the experimental data. These studies can be done presently within an energy range of 100-700 Mev/u.

The breakup of a one-neutron halo projectile, ^{11}Be or ^{15}C, on a proton target is investigated. The halo nucleus is assumed to be well described by a valence neutron n and a core C. The semi-inclusive (momentum distributions of the core, energy spectrum, angular distributions) and fully exclusive (where any of the two interacting particles are detected) reaction observables are calculated, as a function of the projectile energy, using the few-body Faddeev/Alt-Grassberger-Sandhas (Faddeev/AGS) reaction framework [1,2].

Recently, several studies have pointed out that a tight control of the reaction mechanism and of the excitation mechanisms need to be achieved in order to extract meaningful information from the experimental data [3,4].

Another important and unexplored issue so far is to know to what extent the incomplete knowledge of the full structure of the projectile and its energy spectrum may affect the reaction observables.

Recently [5], we have studied the sensitivity of the calculated observables on the core-valence neutron interaction, in particular with the introduction of an imaginary component in some partial waves due to some possible unknown dissipation effects. We study here in detail which observables are more sensitive to such effects. In addition, we analyse the dependence of these effects on the projectile energy.

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Differential HBT Method to Analyse Rotation

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Two particle correlations are studied for peripheral relativistic heavy ion reactions where the initial state has substantial angular momentum. The earlier predicted rotation effect and Kelvin Helmholtz Instability, leads to space-time momentum correlations among the emitted particles. A specific combination of two particle correlation measurements is proposed, which can sensitively detect the rotation of the emitting system. The method is studied in simple models and in numerical fluid dynamic model results.

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The Liège Intranuclear Cascade model. Towards a unified description of nuclear reactions induced by nucleons and light ions from a few MeV to a few GeV.

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The renewed interest in spallation reactions, driven by various applications (nuclear waste transmutation, neutron spallation sources, protection against space radiation, hadrontherapy, etc) has strengthened the idea that these reactions proceed through a two stage process, an intranuclear cascade (INC) stage followed by evaporation of a remnant, has established that this mechanism is dominant in nucleon-induced reactions from about 250MeV to a few GeV and has given an impetus to the improvement of the theoretical tools. We report here on the last developments of the Liège Intranuclear Cascade model (INCL). From a recent intercomparison, organized by the IAEA [1] two years ago, it appears that this model, when coupled to the Abla07 de-excitation model [2], provides the best global description of the various experimental quantities in the 150MeV-3GeV incident energy range. In particular, we here focus on the last developments of INCL that have been worked out afterward and that are embodied in the last version INCL4.6 [3] of the model. They bear on: (1) the production of clusters in the course of the cascade phase, which is made possible through a dynamic coalescence model, (2) the extension of the model below the putative low energy limit of validity of INC models (about 250MeV), (3) the extension of the model to reactions induced by light clusters (up to Carbon and Oxygen), managing complete and incomplete fusion, (4) the extension of the model to higher incident energy, up to 10-15 GeV, based on multipion production in nucleon-nucleon collisions. The validation of these improvements is provided by an extensive and successful comparison with relevant observables.

Two more fundamental points will also be illustrated. First, the validity of INC models well below the low energy limit alluded above will be discussed. The role of the Pauli principle will be shown to be crucial in that respect. It will also be shown that the introduction of an intermediate stage between cascade and evaporation is not necessary. Theoretical and circumstantial arguments supporting the neglect of this stage will be given, opening so the possibility of having a single and unified model for reactions, operating from a few MeV to a few GeV incident energy range. The second point deals with the recoil velocity of the residues. The distributions of the latter quantity display typical properties of a diffusion problem. The latter can be viewed as a direct consequence of the basis of INC model, namely the succession of independent binary collisions.

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Four-nucleon reactions above the four-cluster breakup threshold

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The four-nucleon $(4N)$ scattering problem gives rise to the simplest set of nuclear reactions that shows the complexity of heavier systems. The n-^{3}H and p-$^3\mathrm{He}$ scattering is dominated by the total isospin $\mathcal{T} = 1$ states while d-d scattering by the $\mathcal{T} = 0$ states; the reactions n-$^3\mathrm{He}$ and p-^{3}H involve both $\mathcal{T} = 0$ and $\mathcal{T} = 1$ and are coupled to d-d in $\mathcal{T} = 0$. All these complex features make the $4N$ scattering problem the natural theoretical laboratory to test different force models of the nuclear interaction.

In Ref. [1] we have developed an efficient numerical approach to the solution of the 4N Alt, Grassberger, and Sandhas (AGS) equations [2]. After partial wave decomposition they become a large system of three-variable integral equations. The three Jacobi momentum variables in $1 + 3$ and $2 + 2$ configurations are discretized on a finite mesh and the number of $2N$, $3N$ and $4N$ partial waves increased up to what is needed for the full convergence of the results. Furthermore, using the screening and renormalization approach to treat the Coulomb force between protons, we have obtained results for observables in p-$^3\mathrm{He}$ elastic scattering [3] and all elastic and transfer reactions initiated by n-$^3\mathrm{He}$, p-^{3}H and d-d at energies below the three-body breakup threshold [4].

Recently we extended our calculations to energies above the four-body breakup threshold where the singularity structure of the AGS equations becomes very complicated. We combined the complex-energy method [5] with the use of special weights for the integration [6]. The use of special weights reduces drastically the number of mesh points needed for convergence thereby making the method much more efficient as compared to the original complex-energy method [5] using standard integration meshes. Results have been obtained for n-^{3}H elastic scattering and breakup [6] and for $n + n + d$ recombination into n+^{3}H [7]. Extension to p-$^3\mathrm{He}$ scattering and to coupled n-$^3\mathrm{He}$, p-^{3}H and d-d reactions is in progress.

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Projectile structure effects in the collisions ^{6,7}Li+^{64}Zn around the Coulomb barrier

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The study of nuclear collisions involving halo or, more in general, weakly bound nuclei at energies around the Coulomb barrier had a considerable interest in the last decade, since the peculiar structure of the colliding nuclei can deeply affect the reaction mechanisms (see e.g. [1,2,3] and refs. Therein). Elastic scattering angular distributions and heavy residue production cross sections at several energies around the Coulomb barrier have been measured in the collisions ^{6,7}Li+^{64}Zn. Elastic scattering angular distributions have been reproduced within the Optical Model using renormalized double folding potentials for the real and imaginary part. The extracted energy dependence of the renormalization factors clearly show absence of the usual threshold anomaly in the optical potential, as observed in other systems involving weakly bound nuclei.

The heavy residue production cross sections have been measured by using an activation technique, detecting off line the atomic X rays following the E.C. decay of the residues, allowing their mass and charge identification. The heavy residue excitation function ratio $\sigma(^6$Li+^{64}Zn$)/\sigma(^7$Li+^{64}Zn$)$ shows an increasing trend as the energy is decreased below the barrier as observed by other authors for different similar systems (see e.g. [4] and refs. therein). The experimental relative yields of the heavy residues have been compared with the predictions of the statistical model code CASCADE. Such comparison suggests that heavy residue production is dominated by complete fusion (CF) at above barrier energies whereas, in the region below the barrier, other mechanisms such as incomplete fusion (ICF) are dominating. The large yield of ^{65}Zn observed in the low energy region suggests that, together with ICF, an important n-transfer contribution could also be present. Results confirm, to our opinion, that the study of fusion reactions induced by light weakly bound nuclei on medium mass targets presents a number of experimental challenges. The experimental problems related with the low energy of the produced evaporation residues can be overcome by using activation or on-line gamma ray techniques, however a clear separation of CF, ICF and transfer cannot be easily achieved and transfer processes might contaminate the measured total fusion excitation functions.

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Elastic and break-up of the 1n-halo ^{11}Be nucleus.

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Huge efforts have been done in the last years in major laboratories around the world to understand the reaction dynamics around the Coulomb barrier with neutron halo nuclei. Reactions induced by n-halo nuclei have been extensively studied, in a wide range of energies and on different targets, in order to understand the role played by the halo on the reaction dynamics (see e.g. [1] and ref. therein). In collisions induced by halo nuclei, direct reactions, as for instance transfer or break-up, may be favored owing to the low binding energy, the extended tail of "valence nucleons" and the large Q-value for selected transfer channels. Moreover, the effects of the coupling to the continuum is expected to play a major role on the reaction dynamics. Elastic scattering studies can be an ideal tool to investigate the effect of the long tail of the halo matter distribution. Experimentally, almost all elastic scattering and reaction mechanism studies around the barrier performed with halo nuclei have been made using the 2n-halo nucleus ^{6}He and only recently, results have been published with the 2n-halo ^{11}Li [2]. Only very few experiments have been performed with 1n-halo ^{11}Be [3]. Thanks to the availability of a post-accelerated ^{11}Be beam at Rex-Isolde a rather precise measurement of the elastic scattering and break-up cross-sections for ^{11}Be was possible. In this contribution the results concerning the collisions ^{11}Be+^{64}Zn at energy close to the Coulomb barrier will be reported. The analysis of elastic scattering shows a damping in the angular distribution in the angular region where nuclear and coulomb scattering interfere, signature of long range absorption. In order to evaluate the effects of coupling to the break-up, Continuum Disctretised Coupled Channel calculations have been performed to compute both the elastic scattering angular distribution and the break-up cross-section [4]. The analysis shows that coupling with elastic break-up is of primary importance to produce the observed dumping. Coulomb break-up is responsible for the long range absorption whereas nuclear break-up is affecting the elastic phase-shift and is responsible for an increase of the elastic cross-section at large angles. The energy spectra and angular distribution for break-up have also been extracted. From the comparison with the calculations it seems that direct break-up is not the only mechanism responsible for this cross-section.

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Measurement of the ^{237}Np(n,f) cross section with the FIC detector at the CERN n_TOF facility

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There is an increasing need for accurate cross section data on neutron-induced reactions -especially fission- for nuclear technology applications, concerning the design of new systems for safe and clean energy production and nuclear waste transmutation, such as the subcritical Accelerator Driven Systems (ADS) or the future Generation-IV fast nuclear reactors. The long-lived ^{237}Np is the major component of the spent nuclear fuel in existing reactors, mainly produced by neutron captures in ^{235}U and (n,2n) reactions in ^{238}U, thus the transmutation of this isotope is a very important issue. There is a number of data in literature on the ^{237}Np(n,f) reaction that present discrepancies up to 8% while the new evaluations ENDF/B-VII.1 and JENDL-4.0 present differences up to 3% above 2 MeV.

The ^{237}Np(n,f) cross section has been measured, relative to ^{235}U and ^{238}U cross sections, at the n_TOF facility, CERN, from ~300keV to hundreds of MeV [1-2]. The most important features of this setup is the high instantaneous neutron flux and the excellent energy resolution. The fission fragments were detected with use of a fast ionization chamber (FIC) [3], and fast electronics were used, including Time to Digital Converters (TDC) and Flash Analog to Digital Converters (FADC). An adapted analysis procedure has been developed [4] in order to obtain the relative cross sections of each actinide. The high accuracy ^{237}Np(n,f) cross section data from this analysis will be presented, and their comparison to previous data and evaluations will be discussed.

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Mass-Asymmetry effects in heavy ion reactions: Complete fusion Vs incomplete fusion

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The investigation of reaction mechanism in heavy ion (HI) induced reactions at projectile energies in the range of 4-10MeV/A has become a phenomenon of interest in the field of nuclear reactions. The study of incomplete fusion reactions is still an active area of debate due to the complex nature of incomplete mass transfer and its indistinct dependence on various entrance channel parameters like projectile type & energy, entrance channel mass-asymmetry, alpha-Q-value and imparted input angular momentum of the system (1 – 3). In the present study attempts have been made to probe mass asymmetry dependence of incomplete fusion dynamics in HI induced reactions. The excitation functions for ^{59}Co(C, pn)^{69}Ge, ^{59} Co(C, 2pn) ^{68}Ga, ^{59} Co (C, p4n) ^{66}Ge, ^{59} Co (C, αp4n) ^{62}Zn reactions for ^{12}C + ^{59}Co projectile-target system have been measured for the first time, in addition to our previous work (4).The recoil catcher technique followed by offline γ-ray spectroscopy with HPGe detectors was used. The ERs were identified by their characteristic γ-rays and half-life measurements by decay curve analysis. The measured excitation functions are compared with the calculations based on the available statistical model codes e.g. PACE-4, ALICE-91 and CASCADE. The effect of variation of different parameters including level density parameter involved in these codes has also been studied to optimize the input parameters. Measured independent cross sections are found to be in good agreement with ALICE-91 predictions for complete fusion channels along with PACE-4 calculations. The enhancement in the experimental cross section for α-emitting channels over theoretical predictions is attributed to incomplete fusion (ICF) of 4He/8Be with the target. These data also suggest the increase in the probability of incomplete fusion with the projectile energy. Moreover, the incomplete fusion probability is found to increase with the entrance channel mass asymmetry of the projectile-target systems for the same relative velocity (5). The effect of α-break-up energy (Q_α) on the ICF probability is also studied with the available data. This supports the fact that the incomplete fusion probability decreases with the increase in alpha Q-value of the projectile.

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Pairing effects in heavy-ion collision studied with Canonical-basis Time-Dependent Hartree-Fock-Bogoliubov theory

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The time-dependent Hartree-Fock (TDHF) theory is well-known as a useful tool to study heavy-ion collision, however it does not include effects of nuclear pairing correlation. Although the time-dependent Hartree-Fock-Bogoliubov (TDHFB) theory is capable of treating the pairing correlation in nuclear dynamics self-consistently. No study on heavy-ion collision has been carried out using TDHFB with a modern effective interaction in three-dimensional (3D) space. To facilitate the study of nuclear dynamics with the pairing correlations, we proposed a new time-dependent scheme, which is named the canonical-basis TDHFB (Cb-TDHFB)[1]. The Cb-TDHFB is derived from full TDHFB equations represented in canonical basis which diagonalizes density matrix, and with a Bardeen-Cooper-Schrieffer (BCS)-like approximation for pairing functional.

We carried out a simulation of heavy-ion collision using the Cb-TDHFB in 3D Cartesian coordinate space with the full Skyrme functional of SkM* parameter set and with a contact pairing functional. We have found an interesting behavior of the gap energy which decreases and vibrates while colliding, which leads to a different consequence in fusion processes between Cb-TDHFB and TDHF. Figure 1 shows an example of the time evolution of neutron-density distributions in ^{20}O + ^{20}O head-on collision.

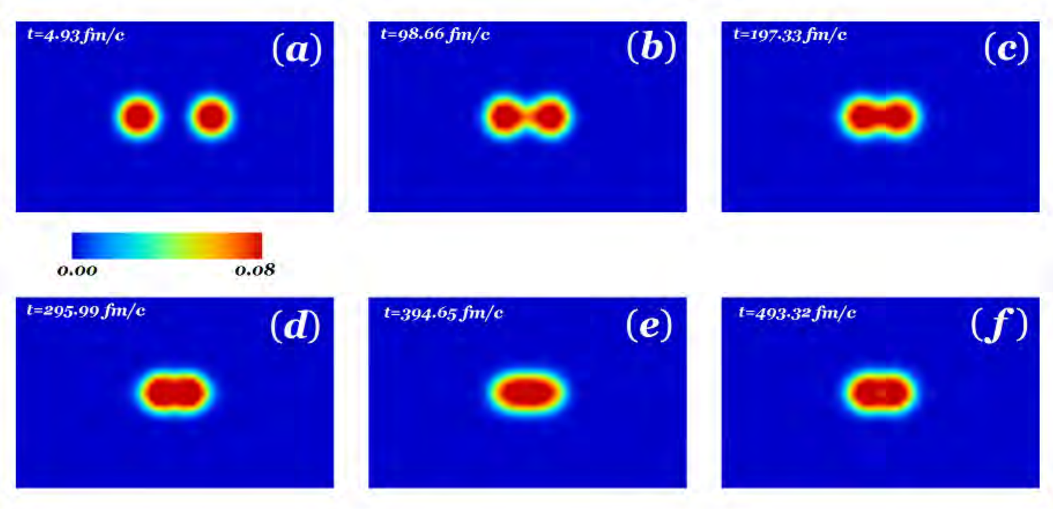

Figure 1: Neutron density distributions of XZ-plane in ^{20}O + ^{20}O collision at t=(a)4.93, (b)98.66, (c)197.33, (d)295.99, (e)394.65 and (f)493.32 fm/c. The horizontal direction corresponds to Z direction. The incident energy $E_{\rm in}$ is 20 MeV in laboratory frame.

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Democratic decay of ^{6}Be studied in knockout reaction

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The recent progress in research with radioactive ion beams (RIB) leads to increase of interest to nuclear systems close to the driplines and even beyond. Many of these systems have three-body decay modes. Being the lightest ground state two-proton emitter the ^{6}Be nucleus has a special interest as possible benchmark system for studies of such complex phenomena as three-body Coulombic decays and two-proton radioactivity in general. For these reasons in the last years this system began to attract special attention of researchers.

Several years ago the spectrum and three-body correlations for the ground-state decay of ^{6}Be were well studied both theoretically [1] and experimentally [2] with high precision. Special methods were developed later to further improve the convergence of the theoretical energy and angular correlations [3].

In the recent experiment at MSU [4] the experimental data on three-body correlations of unprecedented quality has been obtained. The ^{6}Be states up to 10 MeV of excitation were populated in a neutron knockout reaction from ^{7}Be beam. Available data comprising several millions of events allowed us to get deep insights into the interpaly and transition between the different decay mechanisms in a broad range of ^{6}Be excitations, see Figure 1. Several results of these studies can be found as paradoxical and thus openning new prospects in the studies of three-body decays.

Several important theoretical findings deserved special disscusion [5]. These are first of all (i) the sensitivity of three-body decays to the reaction mechanism and the initial structure, and (ii) important effects of interference and alignment of different states on the three-body correlation patterns.

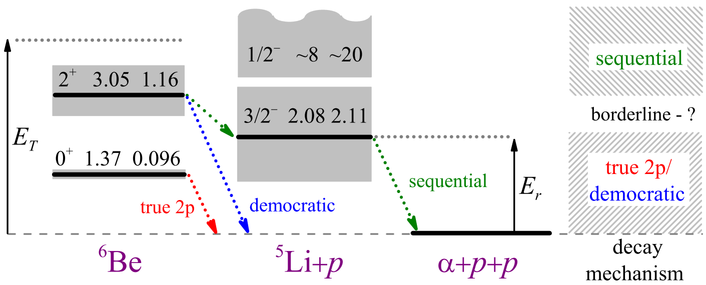

Figure 1: *Level and decay schemes for ^{6}Be illustrates possible decay mechanisms. For low-energy part of ^{6}Be spectrum the decay should be either "true three-body" or "democratic". It has been always expected that for higher excitations the decay mechanism should become sequential via the energetically accessible states in the ^{5}Li subsystem. New results [4] indicate that actual situation is different: sequential decay do not become a dominant mechanism in the studied energy range.*

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Probing the semi-magicity of ^{68}Ni via the ^{3}H(^{66}Ni,^{68}Ni)^{1}H and ^{2}H(^{66}Ni,^{67}Ni)^{1}H transfer reactions in inverse kinematics

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The region around the nucleus ^{68}Ni, with a shell closure at Z = 28 and a sub-shell closure at N = 40, has drawn considerable interest over the past decades. ^{68}Ni has properties that are typical of a doubly-magic nucleus, such as a high excitation energy and low B(E2:2^+-0^+) transition probability for the first excited 2^+ level [1-3] and a 0^+ level as the first excited state [4]. However, it has been suggested that the magic properties of ^{68}Ni arise due to the fact that the N = 40 separates the negative parity pf shell from the positive parity $1g_{9/2}$ orbital [5,6], and indeed, recent mass measurements [7,8] have not revealed a clear N = 40 shell gap. Despite all additional information that was acquired over the last decade the specific role of the N = 40 is not yet understood.

Transfer reactions are a powerful tool to constrain spin and parities of excited states and to determine (relative) spectroscopic factors. Therefore two experiments were performed at ISOLDE, CERN, using one- and two-nucleon transfer reactions. In a first experimental campaign in 2009, the excitation spectrum of ^{67}Ni was studied by performing a (d,p)-reaction on ^{66}Ni in inverse kinematics. A ^{66}Ni beam of 2.85MeV/u was projected onto a 100μg/cm² CD_2 target and the resulting particles and gamma rays were detected using the MINIBALL setup [9] in combination with the T-REX particle detection array [10]. The excitation spectrum of odd mass nuclei, e.g. ^{67}Ni, in the direct neighborhood of closed shells, such as ^{68}Ni, is usually governed by single particle excitations. By measuring effective single-particle energies the shell gaps can then be fixed in order to further update the existing nuclear models.
In a second experimental campaign in 2011, ^{68}Ni was studied through a (t,p)-reaction on ^{66}Ni, using the same set-up as in the 2009 campaign. In this case a 2.6MeV/u ^{66}Ni beam was projected onto a tritium-loaded titanium target of 500μg/cm². Thus, in this experiment a radioactive beam in combination with a radioactive target was used. The aim of this campaign was to measure the cross section for the population of the 0^+ ground state and characterize the 0^+ and 2^+ excited states in ^{68}Ni.

The excitation spectrum and the angular distribution of the emitted protons can be used to determine the spin and parity of the states populated in ^{67,68}Ni. Further, excited states can be identified by using proton-gamma correlations. Preliminary results of such coincidence analysis, revealing the most populated states in the reactions, will be presented.

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Angular Distributions of Quasifission and Fission Fragments within the Dynamical Model

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It is well known that the angular distributions of quasifission and fission fragments are very sensitive probe to the dynamics of heavy ion induced reactions [1, 2]. In particular, information on the angular distributions is frequently used to extract the quasifission fraction in the total fragment yield [3, 4]. However the standard statistical models (based on the transitional state approach) are inapplicable for analysis of the quasifission process because of incomplete equilibration of the tilting mode [2]. The present work is aimed at studying dynamics of formation of angular distributions of quasifission fragments. It is shown that the dynamic model proposed in [5, 6] is a suitable theoretical tool for the consistent analysis of the angular distributions of both quasifission and fission fragments produced in the reactions with heavy ions. In this model, the angular distributions are determined by the relation between the relaxation time for the tilting mode and duration of different stages of decay of the excited nuclear system.The model is approved in the description of the experimental anisotropy of the angular distributions of the fusion – fission and quasifission fragments for the $^{32}S + ^{232}Th$ [7], ^{32}S, $^{28}Si + ^{208}Pb$ reactions [2, 8]. On the example of the description of the in the $^{64}Ni + ^{197}Au$ reaction at 418 and 383 MeV incident energies [4] it is shown that the model is applicable to describe the experimental data on the mass-angular correlations in the quasifission fragment yields. The analysis was performed with the angular momentum and deformation dependent relaxation time of the tilting mode. Information on the dinuclear system lifetimes was also obtained.

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Exotic structure of ^{15,17}B probed through charge changing cross section

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In the neutron-rich zone of the nuclear landscape, nuclei develop unconventional forms such as neutron halo and skin with a surface largely made up of neutrons. This large difference of the proton and neutron distributions give rise to unexpected phenomena whose complete understanding is closely tied to gaining knowledge on correlation between nucleons and features of the nuclear interaction. The exotic structures are intimately related to new characteristics of nuclear shell structure.

The study of the effect of neutron excess on the proton distribution is gradually unfolding before us a more comprehensive understanding on the structure and correlations of the excess neutrons. The presentation will discuss the new technique of charge changing cross section measurements for determining the charge radii of neutron-rich nuclei using the fragment separator FRS at GSI.

New observations for neutron-rich boron isotopes, ^{15,17}B, will be presented. The knowledge of charge radii coupled together with information on matter radii can help to elucidate the correlated three-body structure of the borromean nucleus ^{17}B.

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Microscopic study on proton elastic scattering of Helium, Lithium, and Beryllium isotopes at energy range of 1-160 MeV/nucleon.

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The proton elastic scattering data on ^{4,6,8}He, ^{6,7,9,11}Li, and ^{9,10,11,12}Be nuclei at energies below than 160 MeV/nucleon are analyzed using the single folding optical model. The real, imaginary, and spin-orbit parts of the optical potential (OP) are constructed only from the folded potentials and their derivatives using M3Y effective nucleon-nucleon interaction and microscopic densities. The Green function mont carlo (GFMC) density is used for the stable nuclei whereas the large-scale shell model (LSSM) density is used for the exotic nuclei and the sensitivity of the cross-sections to these densities is tested. The imaginary OP within high energy approximation (HEA) is used and compared with the single folding OP with M3Y interaction. The renormalization factors and volume integrals of the OP parts are studied and it is found that they show clear dependencies on energy and mass number. The obtained results of the differential and the reaction cross sections are in good agreement with the available experimental data. In general, this OP with few and limited fitting parameters, which have systematic behavior with incident energy, successfully describes the proton elastic scattering data with stable and exotic light nuclei at energies from 1 MeV/nucleon up to 160 MeV/nucleon. Figure 1 present some results from the presentation.

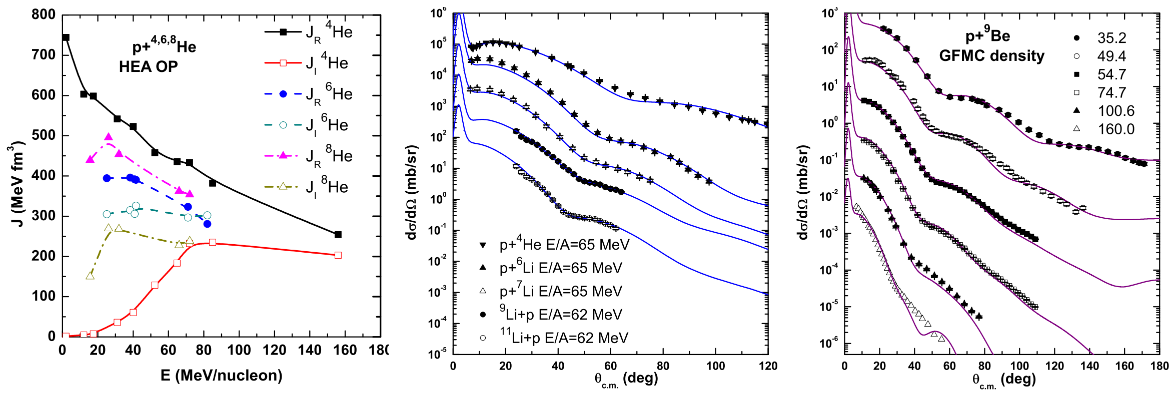

Figure 1: *(a) The dependence of the volume integrals for the proton elastic scattering with Helium isotopes. (b)The differential cross sections for the protonelastic scattering with Lithiume isotopes at about 60-65 Mev/nucleon. (c)The differential cross sections for p+^{9}Be at different energies(in Mev/nucleon).*

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Systematic Study of (d,n) Reactions at E_d = 16 MeV Using A Deuterated Scintillator Array

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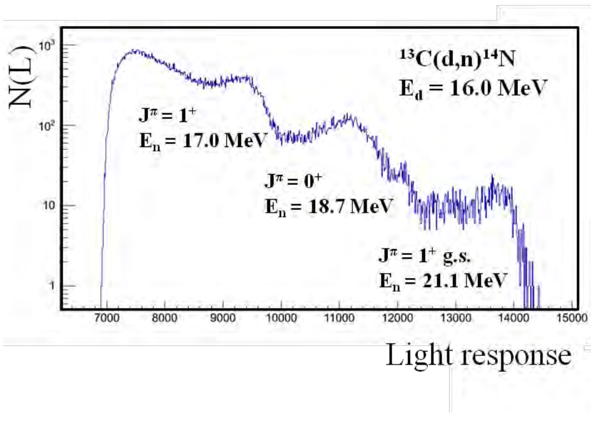
Deuterated liquid scintillation detectors have shown promise as neutron detectors for nuclear science as well as applications in nuclear non-proliferation and safeguards. In particular, they can provide neutron spectroscopic information without time of flight [1]. This capability allows for the study of nuclear reactions involving neutrons such as the (p,n), (d,n), and (^{3}He, n) reactions with neutron energies above 5 MeV. Because time of flight (ToF) is not necessary [1], the detectors can be located in close proximity to the reaction chamber allowing for good angular coverage and absolute detector efficiency compared to traditional long-path ToF systems. We have developed a multi-element deuterated liquid scintillator array utilizing high-speed digital signal processing for the study of reactions involving neutrons [2]. A systematic study of (d,n) reactions at E_d = 16 MeV on ^{9}Be, ^{11}B, ^{13}C, ^{14}N, ^{15}N and ^{19}F has been conducted from 10^o to 160^o (lab). Some recent data are shown in Figs. 1 and 2. In addition to previously un-measured back-angle cross sections, these data can compliment (^{3}He,d) measurements as an analog of (p,γ) for nuclear astrophysics. This work is supported by NSF grant PHY 0969456.



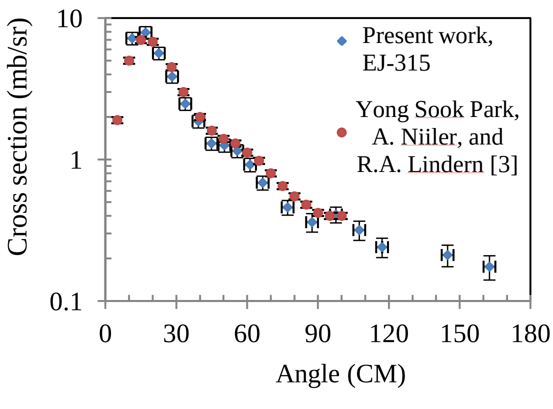


Figure 1(left): Excited states in ^{14}N for the ^{13}C(d,n)^{14}N reaction at E_d = 16 MeV observed directly in the deuterated scintillator when gated on recoil deuterons.
Figure 2 (right): Cross section of ^{9}Be(d,n)^{10}B g.s. reaction at E_d = 16 MeV measured without ToF compared with a previous measurement using ToF [3].

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Measurement of Li+Sn fusion excitation functions around the Coulomb barrier using an improved activation technique

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In the last years, a lot of experimental and theoretical work has been done with the aim of studying the possible dependence of the sub-barrier fusion cross section enhancement on the neutron transfer Q-value (see e.g. [1]). A semi-classical model of sequential fusion [2] has been proposed suggesting that an intermediate rearrangement of valence neutrons having positive Q-value leads to a gain in kinetic energy of the colliding nuclei and, consequently, in an enhancement of the fusion cross-section. On the other hand a recent work [3] arrived at the opposite conclusion that the presence of positive Q-value channels is not necessarily correlated with an enhancement of the sub-barrier fusion cross section. To further investigate the possible influence of the entrance channel neutron transfer Q-value on the fusion cross section, we planned to study the fusion excitation function for the ^{6}Li+^{120}Sn, ^{7}Li+^{119}Sn, ^{8}Li+^{118}Sn and ^{9}Li+^{117}Sn systems, which are characterised by different Q-values for one- and two- neutron transfer. In principle, the comparison of similar systems should help to isolate the effects of transfer couplings with respect to inelastic channels. Moreover, in our case, the choice of different combinations of Li and Sn isotopes allows also to make the entrance channels of the four systems very similar from a kinematic point of view. Thus, by the comparison of the sub-barrier fusion excitation functions for the four systems, it should be possible to evidence the possible effects due to the different Q-values for neutron transfer and form the same compound nucleus.

Since our projectiles are weakly bound nuclei, by comparing, at energies above the barrier, the fusion excitation function for each system with the predictions of the one dimensional penetration model (1D BPM), we can investigate the suppression of the complete fusion excitation function [4] in a target mass range never studied before.

In this contribution, the results concerning two experiments on the ^{6}Li+^{120}Sn and ^{7}Li+^{119}Sn systems, performed at the Laboratori Nazionali del Sud, Catania, will be presented and discussed. In these experiments the fusion cross section has been measured by using a stack activation technique. Although many fusion excitation function measurements have been performed using this technique, to our knowledge only in few cases (see e.g. [5]) the drawbacks of this technique have been investigated and properly taken into account. We analysed in detail these drawbacks, focusing in particular on the effects that the target non-uniformity could generate in the determination of the fusion excitation function.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Ab initio approach to the structure and reactions of light nuclei

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Over the last decade we have seen significant progress in several areas that has been key for the achievement of successful ab initio descriptions of nuclear structure for light nuclei. This exciting trend in modern nuclear theory is now continuing with the evolution of methods to treat bound, scattering, and resonance states within a single unified formalism. The development of such a capability is crucial for obtaining a fundamental understanding of the structure of exotic nuclear systems; currently being investigated at radioactive beam facilities. Such methods would also form the foundation for a microscopic treatment of low-energy nuclear reactions on light nuclei.

An overview of this very active field of research will be presented with focus in particular on our understanding of low-energy, effective nuclear interactions based on chiral perturbation theory, and challenges in the development of a unified description of nuclear structure and reactions. In particular, the importance of many-body degrees of freedom together with a consistent treatment of couplings to open channels.

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Pre-equilibrium α-particle emission as a probe to study α-clustering in nuclei

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The method of description of the pre-equilibrium alpha-particle emission during the non-equilibrium stage of the nuclear reactions is discussed. An approach was developed to describe the double differential spectra of secondary particles formed in heavy ions reactions. Griffin model of non-equilibrium processes was used to account for the non-equilibrium stage of the compound system formation. Simulation of de-excitation of the compound system was carried out using the Monte – Carlo method. Fission and γ-ray emission were also considered after equilibration. Analysis of the probabilities of neutron, proton and α-particle emission was performed both in equilibrium, and in the pre-equilibrium stages of the process. The theoretical modeling which take into account the possible influence of the cluster structure in the projectile nucleus excited by collision will be discussed together with the comparison between simulated and experimental double differential cross sections of p, α-particles for the E =250MeV ^{16}O +^{116}Sn reaction, where different clusterization probabilities have been considered.

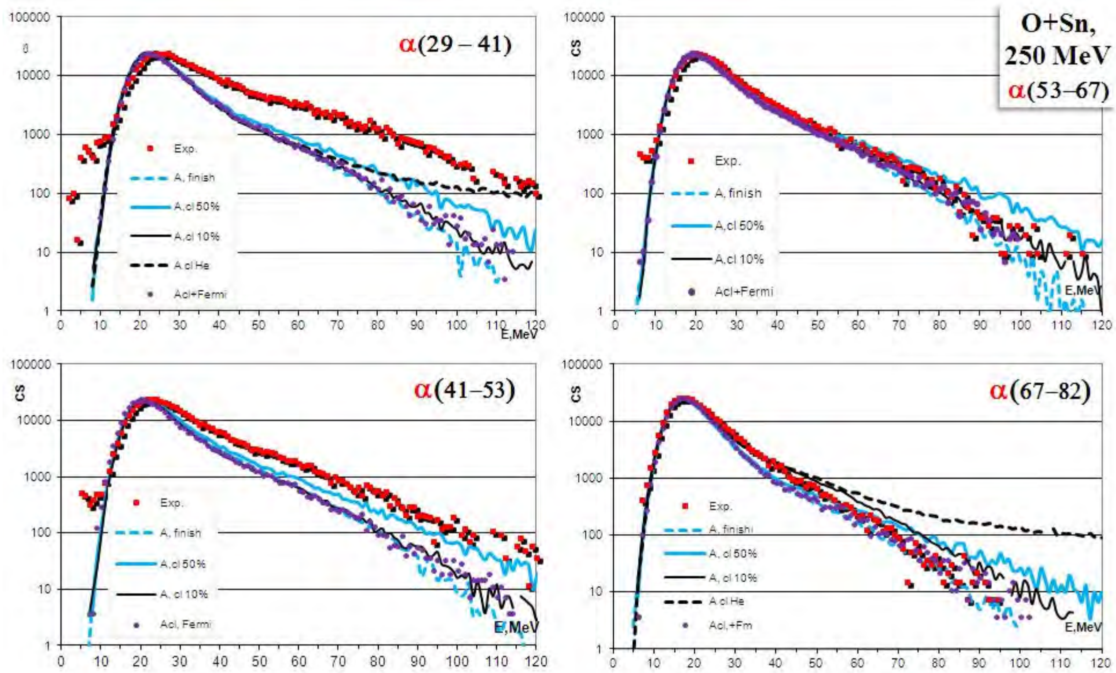

Figure 1: *Double differential spectra (Cross-Section (CS) in arbitrary units) for α particles for the 250 MeV ^{16}O + ^{116}Sn reaction. Experimental data [1,2] are shown in red. Other lines - the results of estimates for different probabilities α-clustering in nuclei*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Exploring reaction mechanisms and their competition in ^{58}Ni+^{48}Ca collisions at E=25 AMeV

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Latest results concerning the study of central collisions in ^{58}Ni+^{48}Ca reactions at E_{lab}(Ni)=25 AMeV are presented. The experimental data, collected with the CHIMERA 4π device, have been analyzed in order to investigate the competition among different reaction mechanisms for central collisions in the Fermi energy domain. The method adopted to perform the centrality selection refers to the global variable "flow angle", that is related to the event shape in momentum space, as it is determined by the eigenvectors of the experimental kinetic-energy tensor. By means of several cuts applied to this Flow Observable, the most central events can be disentangled from the dominant yield of peripheral and semi-peripheral events which are characterized by low values of the flow angle. The main features of the reaction products were explored by using different constraints on some of the relevant observables, such as mass and velocity distributions and their correlations. Much emphasis was devoted to the competition between fusion-evaporation processes with subsequent identification of a heavy residue and a possible rapid multifragmentation mechanism of a nuclear system far from stability**.** In particular, in out study much emphasis was devoted to modeling dynamical evolution of the system from the early phase of the binary reaction and pre-equilibrium emission to the late multi particle stage, where fragments were clearly identified in the final state. The reaction mechanism was simulated in the framework of transport theories (dynamical stochastic BNV calculations, followed by sequential SIMON code) and further comparison with dynamical calculations from transport model (QMD, CoMD) are in progress. Moreover, an extension of this study taking into account for the light particles has been started. A comparison between calculated and experimental observable, such as multiplicities, energy spectra of pre-equilibrium emissions is envisaged in order to pin down th**e** relevant features of the emitting process ,like temperature, excitation energy and density. Furthermore, this study will be also useful in providing useful information for a recent work in progress by the CHIMERA group in order to upgrade of the 4pi apparatus for possible future neutron detection and identification fully integrated with the present signal of charged particles.

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Investigating the astrophysical ^{22}Ne$(p,\gamma)^{23}$Na reaction with a multi-channel scattering formalism

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The reaction ^{22}Ne$(p,\gamma)^{23}$Na is key to the NeNa cycle of stellar nucleogenesis [1,2]. Accordingly, we have studied it using a multi-channel algebraic scattering (MCAS) formalism for low-energy nucleon-nucleus scattering, recently expanded to investigate radiative capture [3]. MCAS incorporates a mechanism to include the Pauli principle in interaction potentials stemming from collective models, and separates these interactions into an 'optimal' set of functions for algebraic treatment of driving equations [4]. Firstly, interaction parameters are set for the elastic scattering ^{22}Ne$(n,n)^{22}$Ne, after which a Coulomb potential is added to model ^{22}Ne$(p,p)^{22}$Ne, and finally the radiative capture is considered.

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Investigation of the unbound ^{21}C nucleus via transfer reaction

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Interpretation of the properties of unbound nuclei which populate beyond the drip-line or as exited states of the unstable nuclei, is one of the most important subjects in nuclear physics. This will be helpful to determine the drip-line in the nuclear chart. Very recently, for example, evidence for an unbound ground state of ^{26}O was reported [1], which could extend the definition of the region for the existence of nuclei to the unbound state region. Unbound nuclei can exist as a product of a nuclear reaction because the life-time of unbound nuclei is much shorter than that of usual unstable nuclei. Therefore reaction studies are important to investigate the properties of unbound nuclei.

In this paper we focus on ^{21}C which is unbound nucleus beyond the neutron drip-line, and describe the transfer reaction ^{20}C$(d,p)^{21}$C. In this reaction ^{21}C can be reproduced with various energy states owing to the neutron transfer to the ^{20}C, which may be $d_{3/2}$ resonance state or nonresonant continuum states. We can calculate the coupling between those states by using the continuum-discretized coupled-channels method (CDCC) [2-4]. CDCC is a powerful reaction model which can describe precisely the coupling between bound states and continuum states including resonances.

Our purpose of this study is to investigate how the coupling between resonant and nonresonant states is strong, and see its effects on the transfer cross section. This cross section brings the energy spectrum of the n-^{20}C system, which will reveal the *figure* of ^{21}C formed by the ^{20}C(d,p) reaction.

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Microscopic coupled-channel method based on the the complex G-matrix

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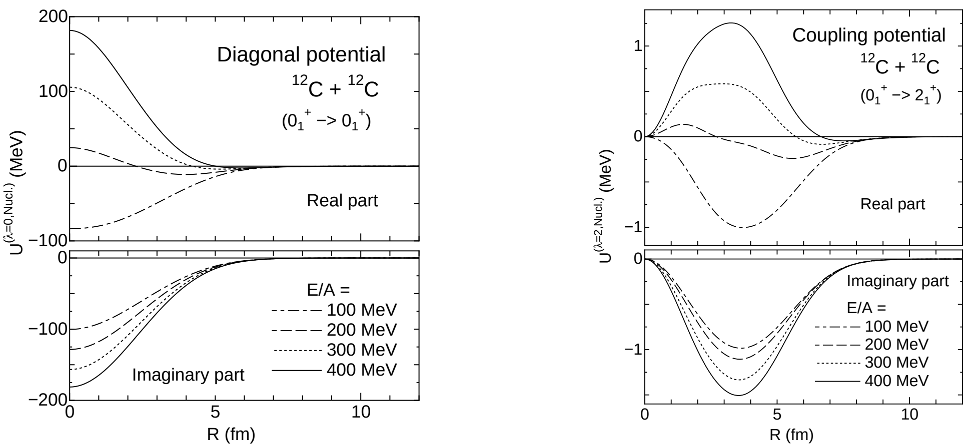
Recently, the present authors and their collaborators proposed microscopic optical-model potential (OMP) for heavy-ion systems based on the double-folding model with the new complex G-matrix interaction CEG07 [1] with a remarkable success [2] and predicted that the real part of heavy-ion optical potentials changed its character from attraction to repulsion around the incident energy per nucleon $E/A =$ 200–300 MeV [3]. We extend the present microscopic OMP based on the complex G-matrix interaction to the microscopic coupled-channel (MCC) calculation of heavy-ion scattering. We here demonstrate it in the case of elastic and inelastic scattering of the ^{12}C + ^{12}C system at E/A=100–400 MeV.

The present MCC method predicts the drastic energy dependence of the shape and strength of the complex coupling potential to the inelastic channels (right figure), that is very similar to that of the microscopic OMP in the elastic channel (left figure), which leads to the drastic energy dependence of the channel-coupling effects on the elastic and inelastic scattering.

The coupling effect on the elastic scattering is analyzed in terms of the dynamical polarization potential (DPP). The calculated DPP drastically changes with the incident energy. Namely, the real part of DPP changes its sign from positive (repulsive) to negative (attractive) in the energy evolution from E/A=100 to 400 MeV, whereas the imaginary part changes from negative (absorptive) to positive (creative). These transitions reflect the characteristic energy dependence of the complex coupling potential, which is clearly understood by the close relation between the real and imaginary parts of the DPP and the real and imaginary parts of the complex coupling potential.

The inelastic cross sections at these incident energies are dominated by the imaginary part of the coupling potential, which also reflect the characteristic energy dependence of the real and imaginary parts of the coupling potential. This suggests that the measurement of the absolute magnitude of the inelastic cross sections at very forward angles at these incident energies will provide a crucial test for the validity of microscopic interaction models and removes the ambiguity of the strength of the imaginary coupling potential. Further details will be found in Ref. [4].



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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Global optical potential for heavy ions up to driplines

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We present a new global optical potential (GOP) for nucleus-nucleus systems, including neutron-rich and proton-rich isotopes up to driplines, in the energy range of 50–400 A MeV [1]. The GOP is derived from the microscopic folding model based on the complex G-matrix interaction CEG07 [2] and the global density presented by São Paulo group [3]. The folding model well accounts for realistic complex optical potentials of nucleus-nucleus systems and reproduces the existing elastic scattering data for stable heavy-ion projectiles at incident energies per nucleon E/A above 50 MeV. We then calculate the microscopic folding-model potentials (FMP) for projectiles of even-even isotopes $^{8-22}$C, $^{12-24}$O, $^{16-38}$Ne, $^{20-40}$Mg, $^{22-48}$Si, $^{26-52}$S, $^{30-62}$Ar and $^{34-70}$Ca [shown in Fig. 1] scattered by stable target nuclei of ^{12}C, ^{16}O, ^{28}Si, ^{40}Ca, ^{58}Ni, ^{90}Zr, ^{120}Sn, and ^{208}Pb at $E/A =$ 50–400 MeV.

The calculated FMP is represented, with a sufficient accuracy, by a linear combination of 10-range Gaussian functions. The expansion coefficients depend on the incident energy, the projectile and target mass numbers, and the projectile atomic number, while the range parameters depend only on the projectile and target mass numbers. The adequate mass region of the present GOP by the global density is inspected in comparison with folding model potential by realistic density. The full set of the range parameters and the coefficients for all the projectile-target combinations at each incident energy are provided on a permanent open-access website [4] together with a Fortran program for calculating the microscopic-basis GOP (MGOP) for a desired projectile nucleus by the spline interpolation over the incident energy and the target mass number.

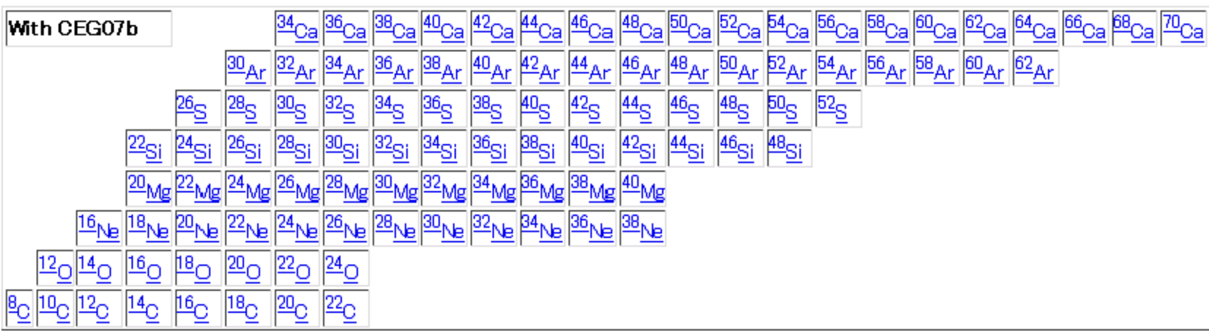

Figure 1: *The projectile nuclei covered by the present global optical potential given on the website [4].*

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Universality in Particle-Dimer Scattering below threshold: from atomic to nuclear physics

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Scattering of two particles at very low energy shows universal behavior encoded in the scattering length a and in the effective range r_s. In fact, systems with different interactions sharing the same scattering length and the same effective range have the same effective range function, $k\cot\delta = -1/a + r_s k^2/2$, and, accordingly, the same low energy behavior. In the limit $a \gg r_0$, where the scattering length is much greater than the typical range r_0 of the potential, not only the scattering process is universal, but also some bound-state properties. In fact, when $a \to +\infty$ (known as unitary limit), the two-particle system has a shallow-bound state with the bound-state energy $E_2 \approx \hbar^2/ma^2$ fixed by the scattering length. In this limit, the physics is scale invariant.

In the 1970s, V. Efimov [1,2] showed that the scale invariance is broken in the s-wave three-body sector of a bosonic system. The residual symmetry is the discrete scale invariance (DSI) that constrains the form of the observables to be log-periodic functions of the control parameter. For instance, for collisions below the dimer breakup threshold, DSI imposes the following universal form for the effective range function

$$ka\cot\delta = c_1(ka) + c_2(ka)\cot[s_0\ln(a\kappa_*) + \phi(ka)]\,, \tag{1}$$

with δ the particle-dimer phase-shift, κ_* a three-body parameter, and c_1, c_2, ϕ universal functions of the dimensionless variable ka, where $k^2 = (4/3)E/(\hbar^2/m)$, being E the center of mass energy of the process.

We report on our detailed study [3] of the universal behavior of the effective range function $ka\cot\delta$. To this aim we use the family of atomic ^{4}He–^{4}He potentials derived in Ref. [4] to parametrize the universal form Eq. (1), and to find its finite-range corrections.

Moreover, we show that the universal character of the effective range function can be used to evaluate a very different system: low energy nucleon-deuteron scattering. It is well known that the nucleon-deuteron effective range function presents a pole structure that has been related to the presence of a virtual state [5]. We shown that this structure is related to the universal form given by Eq. (1) and, using the parameterization determined in the atomic three-helium system, we shown that this equation can be used to describe nucleon-deuteron scattering as well. In this way, the universal behavior imposed by the DSI is analyzed in systems with natural lengths that differ of several order of magnitude.

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Role of symmetry energy towards N/Z dependence of energy of vanishing flow

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The nuclear symmetry energy is of great interest to nuclear physics community as well as to astrophysics community as it sheds light on nucleon-nucleon interactions and properties of neutron stars. In this direction, various observables which are sensitive to the nuclear symmetry have been proposed for the last couple of decades [1]. In the present work, we show that the isospin dependence (neutron/proton ratio) of energy of vanishing flow EVF (energy at which flow disappears) is sensitive to the nuclear symmetry energy and is insensitive to isospin dependence of nucleon-nucleon cross section. We use isospin-dependent quantum molecular dynamics model [2] and simulate the reactions of Ca+Ca and Xe+Xe at semicentral colliding geometry. In Figure 1, we display the N/Z dependence of EVF (solid symbols) for Ca+Ca (upper panels) and Xe+Xe (lower) for all nucleons (left panels), neutrons (middle) and protons (right). From figure, we see that EVF decreases with increase in neutron content. This is due to the dominant role of repulsive symmetry energy. We also calculate the EVF without symmetry energy and results are displayed by open squares. We see that EVF increases throughout the isotopic series, though the N/Z dependence decreases. To check the sensitivity of isospin dependence of cross section, we further make the cross section isospin independent (open squares). From figure, we see that EVF further increases though N/Z dependence is almost similar to that with symmetry energy. These calculations show that N/Z dependence of EVF is sensitive to symmetry energy and insensitive to isospin dependence of cross section. We also notice that these results hold good for neutrons and protons EVF also.

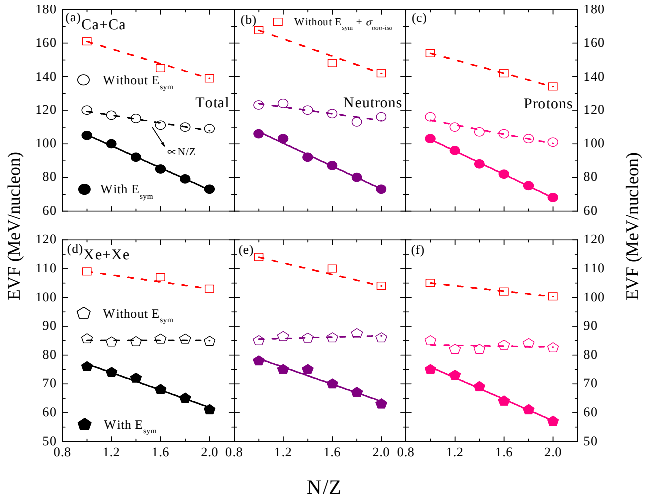

Figure 1: *The energy of vanishing flow as a function of N/Z of colliding pair for Ca+Ca and Xe+Xe reactions. Various symbols are explained in the text.*

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Probing the symmetry energy at low density using observables from neck fragmentation mechanism

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We present new data from the ^{64}Ni + ^{124}Sn (neutron rich) and ^{58}Ni + ^{112}Sn (neutron poor) studied in direct kinematics and compared with the same reaction in reverse kinematics at the same beam incident energy (35 A MeV), using the CHIMERA 4π detector. Data of the two experiments collect a unique set of information on the midrapidity neck fragmentation mechanism in semi-peripheral dissipative collisions. In particular we have studied angular and velocity correlations of intermediate mass fragments (IMF) emitted at mid-velocities respect to both projectile-like and target-like fragments. In this way it is possible to disentangle the pattern of dynamically emitted fragments (characterized by short emission time and asymmetric angular distributions) and study their isotopic composition. By comparing data of the reverse kinematics experiment with a stocastic mean field (SMF) + GEMINI calculations we show that observables from neck fragmentation mechanism add valuable constraint on the symmetry energy term of EOS at subsaturation density [1]. Perspectives and projects for the next future using stable and radiactive beams will be also given.

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Dynamical Dipole and EOS in N/Z asymmetric fusion reactions

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The study of the collective properties of a nuclear system is a powerful tool to understand the structure of the nuclei. A successful technique which was used in this field is the measurement of the decay of the giant dipole resonance which can be used as a clock for the thermalization process.

Using fusion-evaporation reactions, it was recently possible to study the yield of the high-energy gamma-ray emission from Dynamical Dipole (DD) mechanism which takes place during fusion processes when there is a N/Z asymmetry between projectile and target. A good understanding of the DD is important because this emission depends on several key parameters like the Nuclear Equation of State (EOS) and the in medium N-N cross sections. This is more relevant using exotic systems which have a large N/Z asymmetry. In addition, the DD yield is expected to depend on the energy of the projectile and on the size of the D(0) parameter defined as weighted difference between the projectile and target N/Z asymmetry [1].

It was observed and it will be shown that, using stable projectiles and targets in particular experimental conditions, different EOS produce different DD yield and that this difference increase significantly using to exotic beams like ^{132}Sn. It was found that in reactions with a small impact parameters, the DD centroid energy and yield strongly depends on the used EOS. This effect greatly increases with the N/Z asymmetry and predictions will be given for various cases as the extreme case ^{132}Sn+^{58}Ni for different beam energies.

From the experimental side, a campaign focused on the measurement of the total DD yield in the mass region A ≈ 132 was performed at the Laboratori Nazionali di Legnaro using GARFILED-HECTOR arrays (respectively for light charged particles and gamma-rays detection) coupled to phoswich detectors (for the measurement of fusion residues). In this campaign the DD emission in the fusion reaction ^{16}O (E_{lab}=192 MeV) + ^{116}Sn was measured in function of beam energy (in particular at 8.1 MeV/u, at 12 MeV/u and at 15.6 MeV/u) [2]. Furthermore the particle emission was measured, because it is a key parameter in the determinations of the excitation energy of the compound nucleus The measured DD yields and angular distributions will be compared with the theoretical results and with the already existing experimental data in the same mass region [3],[4].

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Operator Energy Approach to Dynamical Stark Effect for Nuclei in Super Strong Laser Field and Resonance Phenomena in Heavy Nuclei Collisions

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We present new approach for studying interaction of the finite Fermi systems (nuclei) with an superintense external fields (electric and laser fields). It is the combined relativistic operator perturbation theory (OPT) and energy formalism [1]. The OPT formalism includes a new quantization procedures of states for finite Fermi-systems in a strong field. The zeroth order Hamiltonian H0 of this PT possesses only stationary bound and scattering states. To overcome formal difficulties, the zeroth order Hamiltonian was defined by the set of the orthogonal eigen values and eigen functions without specifying the explicit form of the 0th potential. We present the preliminary results of AC Stark shifts of single proton states in the nuclei ^{16}O, ^{168}Er and compared these data with known results by Keitel et al [2]. New data are also listed for the ^{57}Fe,^{171}Yb nuclei. Shifts of several keV are reached at intensities of roughly 10^{34} W/cm^2 for O and 10^{32} W/cm^2 for heavier nuclei. Naturally, the transitions studied will not be excited by the considered laser energies of O(keV) in the nuclear rest frame. Lower excitations of even parity are possible in the two- or higher-order photon processes, and their energies are still more than 20 keV above the ground state energy.

Further a new unified quantum approach (the OPT formalism relativistic energy approach, based on the S-matrix Gell-Mann and Low formalism) [1] is used for studying the electron-positron pair production (EPPP) in the heavy nuclei collisions and treating a compound nucleus in an extreme electric field. Heavy ions collisions near the Coulomb barrier are surrounded by existence of narrow e+ line in a positron spectra [1,3]. The positron spectrum narrow peaks as a spectrum of the resonance states of compound super heavy nucleus are treated. The nuclear and electron subsystems are considered as two parts of the complicated system, interacting with each other through the model potential. The nuclear system dynamics is treated within the Dirac equation with an effective potential. All the spontaneous decay or the new particle (particles) production processes are excluded in the 0th order. The calculation results for cross-sections at different collision energies (non-resonant and resonant energies), corresponding to energies of s-resonances of the compound ^{238}U+^{238}U, ^{232}Th+^{250}Cf nuclei are presented.

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Calculation of fusion barriers, elastic and fusion cross sections for weakly-bound/halo nuclei using the optical model and the Continuum Discretised Coupled Channels method

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Fusion radial barrier distributions (*s=0*) for ^{8}B+^{58}Ni and ^{6}Li+^{58}Si at several bombarding energies around the Coulomb barrier, are determined from a simultaneous optical model analysis of elastic scattering and fusion cross section data. Besides the nuclear bare potential V_{bare}, energy dependent optical Woods-Saxon polarization potentials, U_F (volume) and U_{DR} (surface) are assumed. Where, U_F is a potential that accounts for polarization effects emerging from couplings to the fusion channel and U_{DR} for effects due to direct reaction absorption couplings. Each of these potentials U_F and U_{DR} are in turn, splitted into real and imaginary potentials V_F, W_F and V_{DR}, W_{DR} respectively, which are related via the dispersion relation. The potential parameters of all of these potentials are determined from a simultaneous fit to elastic scattering and fusion cross section data. It is found that, the position and height of the fusion radial potential barriers are affected by the polarization potentials. The effect of the breakup processes, accounted for, by the direct reaction polarization potentials V_{DR} and W_{DR}, on fusion cross section is studied in detail. It is found that fusion is hindered by these potentials for energies around and below the barrier energy V_B. The effect of breakup (^{8}B→ p+^{7}Be, for ^{8}B+^{58}Ni and ^{6}Li →α+d, for ^{6}Li+^{58}Si, is further investigated by Continuum Discretised Coupled Channel Calculations (CDCC).

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Study of the structure of the Hoyle state by refractive α-scattering

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Nuclear rainbow scattering is a powerful instrument for studying the structure of nuclei interior. ^{12}C + α elastic and inelastic (to the 0^+_2, 7.65 MeV Hoyle state) differential cross-sections were studied at the energies 60 and 65 MeV with the aim of testing the microscopic wave function [1] widely used in modern structure calculations of ^{12}C. A pronounced minimum at about 70^o was observed in the inelastic scattering angular distributions (Fig.1). It is shifted by ~ 7^o to the smaller angles in 65 MeV data relatively the similar minimum at 60 MeV according to the known 1/E – dependence of the nuclear rainbow minima positions. The rainbow (Airy) minima in the elastic scattering cross-sections are located at much smaller angles (~ 45 – 50 deg), and this is an indication of the enhanced radius of the Hoyle state [2]. We analyzed the data in the frame of semi-microscopic approach in DWBA (similar to one used in [3]). Use of the wave function [1] can not reproduce either the shape of the angular distributions in the region of the main Airy minimum or even its position (the latter exhibits in the far-component with zero absorption at ~ 65^o), as one can see in Fig.1, dashed curves. It was also shown that the position of this minimum depends not only on the transition density, but also on the matter density distribution in this state and, consequently, the radius of the latter. Using the model density with *RMS* radius of 2.9 fm (the value obtained from the diffraction scattering analysis [4] and calculated in [5]) we obtained the correct position of the Airy minimum at 72^o (solid lines in Fig.1). The shape of the minimum itself possibly is influenced by the interference with the ^{8}Be transfer reaction studied in [3].

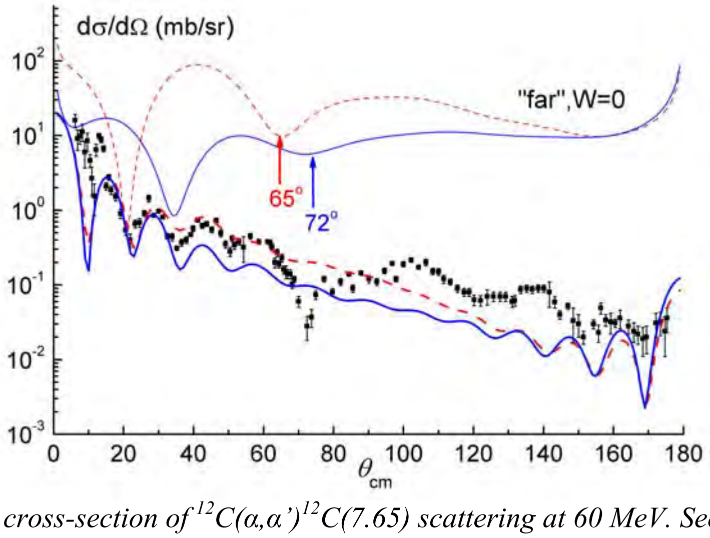

Figure1: *Differential cross-section of ^{12}C(α,α')^{12}C(7.65) scattering at 60 MeV. See text for the details*

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Problem of the apparently large diffuseness of the nucleus-nucleus fusion potential: possible solution using M3Y *NN*-forces

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The problem of the apparently large diffuseness of the Woods-Saxon nucleus-nucleus potential needed to reproduce a large number of precision capture excitation functions was formulated in Ref. [1]. In that work it was suggested that the large diffuseness probably was an artifact masking some dynamical effects. In the present work we try to confirm or disprove this presumption. For this aim we develop a dynamical dissipative model in which the dissipative character of the nucleus-nucleus collision is accounted for by means of the surface friction mechanism [2]. The novel features of our work are: (i) it is based on the double folding potential with the microscopically well founded density dependent M3Y *NN*-forces, (ii) it is accounting for the non-Markovian thermal fluctuations, (iii) it includes the retarding friction. Some parts of the model are described in [3].

Using this model we analyze the precision capture excitation function for $^{16}O+^{144}Sm$ measured in [4]. Calculations were performed using the following three options: (i) Deterministic trajectories with the Instant friction (M3Y DI); (ii) accounting for the Memory friction but without fluctuations (M3Y DM); and including both the Fluctuations (Colored noise) and the Memory friction (M3Y FCM).

Results are shown in Fig. 1. They suggest that the M3Y DI calculation is in good agreement with the data (except two high energy points) whereas accounting for the memory effects destroys this agreement completely.

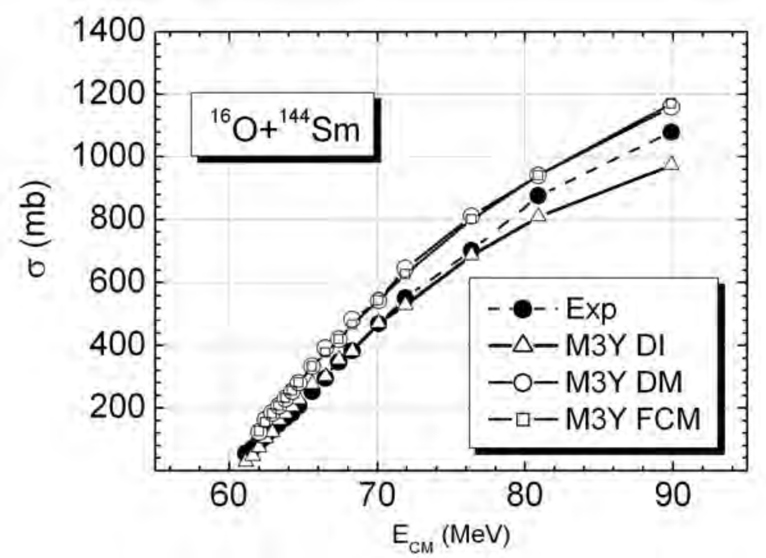

Figure 1: *The capture cross sections for $^{16}O+^{144}Sm$ reaction. Exp – experimental values [4]. For other notations see the text.*

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Advances and prospects in the theoretical studies of few-body decays

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Genuine (or "true") few-body decays take place due to specific energy conditions making the sequential emission of particles energetically prohibited. The systems exhibiting phenomena of this class are actually widespread in the proximity of nucleon driplines, see Figure 1. The genuine few-body emitters demonstrate different lifetime systematics compared to two-body decays, unusual excitation functions for population in reactions, and complicated correlations among the decay products. Among the phenomena connected with few-body dynamics the following are attracting nowadays the most attention.
(i) *Two-proton radioactivity*. This is the most recently (2002) discovered mode of radioactive decay. Within the decade since the discovery several examples were found (^{45}Fe, ^{19}Mg, ^{48}Ni, ^{54}Zn) and some of them well studied. The status of the research in this field is summarized in the recent review [1].
(ii) *Democratic decay*. This is the form of true three-body decay connected with availability of broad states in the two-body subsystems. The light two-proton (^{6}Be, ^{12}O, ^{16}Ne) and presumably majority of true two-neutron emitters (like ^{5}H, ^{10}He, ^{13}Li, etc.) belongs to this class. Interesting features of democratic decays are uncovered by the recent studies of ^{6}Be [2,3] and ^{10}He [4] isotopes.
(iii) *Soft dipole excitation modes* are expected in continuum of halo systems. Well understood for the two-body haloes these excitations could be quite complicated for studies and understanding in the three-body systems, such as ^{6}He, ^{8}He [5], ^{6}Be [6], and ^{17}Ne.
(iv) Existence of the *ground state neutron radioactivity* is highly improbable. However, possibility of $2n$ and even $4n$ radioactivity was demonstrated and prospects of experimental studies were discussed in [7].

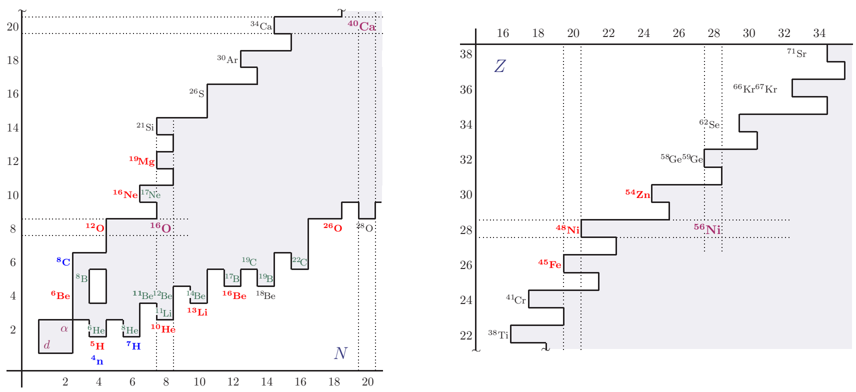

Figure 1: *Driplines in the region of light nuclei achieved for today experimentally. Known isotopes with exotic properties are indicated by coloured labels: green for halo nuclei, red for $2p/2n$ emitters, blue for $4p/4n$ emitters. The gray colour indicates the predicted but not yet discovered nuclei of the above kinds.*

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Pseudo-critical clusterization in nuclear multifragmentation

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Nuclear multifragmentation produced in heavy ion collisions can be described in terms of phase transitions and critical phenomena. For this purpose, the size (charge) distribution of the largest fragment produced in each event has been studied in terms of a decomposition into two contributions : one from an ordered and one from a disordered phase. In the theoretical description of aggregation processes (percolation and Smoluchowski models), where the order parameter is the size of the largest cluster, such a decomposition is also observed and allows to define the critical domain of the underlying phase transition. By analogy with these models, we use the evolution of the relative population of the two phases with bombarding energy to localize the critical domain for experimental multifragmentation data measured with INDRA. In a second step we present a more detailed comparison with the Smoluchowski aggregation scenario to address the time-scale of the multifragmentation process.

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In-Medium Effects and Low Density Nuclear Matter

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Thermal coalescence models were employed to extract densities and temperatures for evolving systems formed in collisions 47 MeV/u Ar projectiles on several targets using the 4π multi-detector, NIMROD. Yields of d, t, ^{3}He, ^{4}He were determined at densities ranging from 0.002 to 0.032 nucleon/fm^{3}. Equilibrium constants derived from the experimental data are compared with those predicted by a number of astrophysical equations of state. Experimental in-medium binding energies and Mott points for d, t, ^{3}He and ^{4}He clusters in low density nuclear matter formed in these collisions will be presented. The experimentally derived in-medium binding energies are in good agreement with theoretical predictions that implement Pauli blocking effects in a quantum statistical approach. Free symmetry energy coefficients derived from the experimental data as well as the corresponding symmetry energy coefficients will also be presented. In medium effects are shown to be an important ingredient in describing the data.

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Scales of Nuclear Giant Resonances

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We propose a general and schematic approach to characterise fluctuations of measured cross sections of nuclear giant resonances. Cross sections are obtained from simulated, yet representative, forms for the self-energy that contains all information about fragmentations. Using a wavelet analysis, we demonstrate the extraction of time scales of cascading decays into configurations of different complexity. We argue that the spreading widths of collective excitations in nuclei are determined by the number of fragmentations as seen in the power spectrum. An analytic treatment of the wavelet analysis using a Fourier expansion of the cross section confirms this principle. A simple rule for the relative lifetimes of states associated with hierarchies of different complexity is given.

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Elastic scattering of the halo nucleus ^{11}Be on ^{64}Zn

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There is renewed interest in the study of nuclear reactions due to the observation of exotic phenomena like the neutron halo in nuclei. Halo nuclei, for example ^{11}Li and ^{11}Be, are characterised by a compact core and an extended neutron distribution. Elastic scattering is an excellent tool to study halo nuclei as it probes the tail of the wave function. One of the interesting aspects is to understand the effect of a halo structure on cross sections at near-Coulomb barrier energies.

Elastic scattering cross sections based on a potential derived from the double folding (DF) model for ^{9,10,11}Be on ^{64}Zn target at an energy around the Coulomb barrier are compared with experiment [1]. The effect of an additional neutron in Be projectiles scattering of a ^{64}Zn, on the angular distributions, has been investigated in terms of the optical model. The folding model directly links the density profile of the nucleus with the elastic scattering cross section. In this approach, we determine the optical model potential (OMP) by folding a complex, energy-dependent effective interaction (M3Y) with the nuclear density distributions. Once the parameters of the OMP are fixed, the analysis is then sensitive only to the nuclear density distributions. The one-neutron halo nucleus ^{11}Be is considered to be composed of a ^{10}Be core and one neutron. Here, the density of the ^{10}Be core is considered to have a Fermi form with rms radius of 2.45 fm. The density of the one-neutron halo is ascribed a Gaussian form and the parameters of this density are adjusted to obtain rms radius of 2.73 fm for ^{11}Be. The density of ^{9}Be is independently assumed to have a Fermi form with rms radius of 2.50 fm. The real part of the OMP is calculated using DF model employing the M3Y effective N-N interaction and the above densities. The imaginary part of the OMP is obtained phenomenologically using Woods-Saxon (WS) form for consistency with the data. In the present analysis, the spin-orbit part of the potential has been switched off as it has only a small effect on the calculated cross sections. To minimise the number of parameters, the normalisation factor for the real DF potential was kept fixed at unity and the depth of the imaginary volume term in the WS potential was taken to be 45 MeV. We have carried out a search on the radii and diffuseness parameters simultaneously to minimise χ^2 in fitting differential cross-section data. These values were then used in the code ECIS94 to get the total reaction and differential cross sections. The angular distributions of ^{9,10,11}Be + ^{64}Zn elastic scattering at centre of mass energy of $\approx$ 24.5 MeV are presented in Figure 1. Clearly, the semi-microscopic calculations reproduce the peak due to Coulomb-nuclear interference that is observed in the corresponding data [1] for ^{9,10}Be. For ^{11}Be, a better fit than the one indicated in the figure at small scattering angles can be achieved by adding to the imaginary part of the potential, a dynamic polarisation potential arising from the dipole coupling [2].

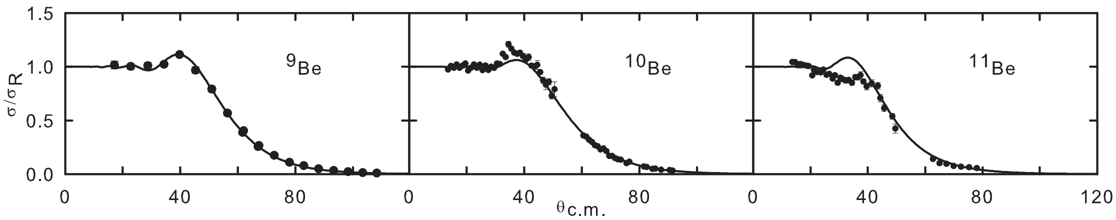

Figure 1: *Calculated angular distributions for elastic scattering of* ^{9,10,11}*Be on* ^{64}*Zn.*

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[2] M.V. Andres and J. Gomez-Camacho, Phy. Rev. Lett. 82, 1387 (1999).

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Mass-angle distributions: providing extensive insights into the dynamics and time scales of reactions forming heavy elements

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The formation of heavy elements is suppressed by fission occurring before a compact compound nucleus is formed, a process known as quasifission. A full understanding of the underlying physics of quasifission is crucial to map opportunities to form more superheavy nuclei. Quasifission is associated with the large Coulomb energy of two massive nuclei in contact, which inhibits fusion by quickly tearing the system apart. Thus a defining characteristic of quasifission is its shorter time scale. Reproducing experimental quasifission time scales is a key constraint to theoretical dynamical models. The direct time scale information carried in mass-angle distributions (MAD) is compared with new model calculations, and with times inferred from measurements of crystal blocking and pre-scission neutrons.

As well as the Coulomb energy, nuclear structure can significantly influence reaction outcomes. Recent detailed measurements of MAD at the ANU will be shown, demonstrating the role of entrance-channel static deformation alignment, spherical magic numbers, and N/Z asymmetry, as well as mass-asymmetry. As an example, for collisions of heavy projectiles, Fig.1 shows that experimental MAD and mass-widths for reactions having *several magic numbers* in the entrance channel have little mass-angle correlation and narrow mass distributions [1]. These correspond to longer sticking times, implying increased probability for fusion (as seen for ^{16}O+^{238}U). It is proposed that the effect is due to the reduced energy dissipation for spherical magic numbers [1]. However, it is only found for small N/Z asymmetry in the entranc … nificant. TDHF calcu … of the collision par … etition.

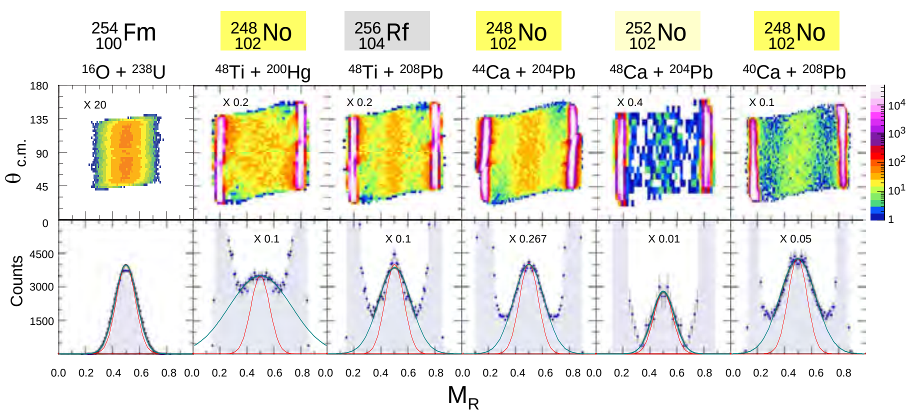

Figure 1: *Mass-ratio M_R vs. angle distributions (MAD) for reaction forming similar composite nuclei as indicated. The projected mass ratio spectra (lower panels) include Gaussian fits to the region around M_R=0.5 (turquoise lines), and Gaussian functions (red lines) with fixed $\sigma_{MR} = 0.07$ for reference [1].*

[1] C. Simenel *et al.* Phys. Lett. B **710** (2012) 607, and references therein.

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Results from single-neutron adding reactions on light neutron-rich nuclei with HELIOS*

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The distribution of the single-neutron strength in the sd shell was investigated through a series of neutron-adding experiments utilizing radioactive beams produced by the Argonne National Laboratory ATLAS in-flight facility[1]. The ^{19}O(d,p) and ^{17}N(d,p) direct reactions at beam energies of 6.6 MeV/u ($\sim 10^5$ pps) and 13.5 MeV/u ($\sim 10^4$ pps), respectively, were carried out in inverse kinematics. Outgoing protons were measured in coincidence with heavy-ion recoils by the helical orbit spectrometer (HELIOS)[2]. Eight levels in ^{20}O up to an excitation energy of ~ 6 MeV, including a previously unobserved $J^\pi = 3^+$ level at $E^* = 5.23$ MeV, were observed. In addition, three strongly populated states in ^{18}N below S$_n = 2.8$ MeV, including a previously unobserved $J^\pi = 1^-$ level at $E^* = 1.2$ MeV, were measured. Spectroscopic factors have been extracted from angular distributions through a distorted wave Born approximation.

Information from the ^{19}O$(d,p)^{20}$O reaction has established empirical $\ell = 0$ and 2 strength distributions in this region ($Z = 8, N = 12$). The measurements are well reproduced by shell model calculations confined only to the sd shell. Furthermore, the data has allowed for a determination of the $J = 0, 2$ and 4, $T = 1$ $\langle (0d_{5/2})^2 J|V|(0d_{5/2})^2 J\rangle$ empirical two-body matrix elements of the NN interaction which showed consistency with those previously deduced from ^{17}O$(d,p)^{18}$O data and a global survey. The $J^\pi = 2^-$ and 3^- levels in ^{18}N at 0.12 MeV and 0.74 MeV, respectively, were identified in the present work as having dominant $\nu(0d_{5/2})^3_{J=5/2}$ neutron configurations coupled to an unpaired $\pi(0p_{1/2})^{-1}$ proton configuration. These levels, along with a newly found $J^\pi = 1^-$ level at 1.2 MeV, provide a glimpse of the energy centroid evolution for the neutron $(0d_{5/2})^3_{J=5/2,J=3/2}$ and $(0d_{5/2})^2(1s_{1/2})^1_{J=1/2}$ configurations along the $N = 11$ isotones. This region runs from ^{19}O, which has a $J^\pi = 5/2^+$ ground state, a high lying $1/2^+$ excited state, and a nearly filled proton $0p_{1/2}$ orbital, to the exotic ^{17}C nucleus having a ground state $J^\pi = 3/2^+$ spin-parity and an almost vacant $0p_{1/2}$ proton orbital. Additional discussion will take place on these data in terms of modern shell-model calculations using interactions confined to the $0p$-$1s0d$ and $1s0d$ orbitals.

*This work is supported in part by the U.S. DOE, under Contract No. DE-AC02-06CH11357 and No. DE-FG02-04ER41320, the NSF under Grant Nos. PHY-02-16783, PHY-07-54674, PHY-07-58099, and the UK S&T Facilities Council.

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[2] A. H. Wuosmaa *et al.*, Nucl. Instr. Meth. A **580**, 1290 (2007). J. C. Lighthall *et al.*, Nucl. Instr. Meth. A **622**, 97 (2010).

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Microscopic optical potential from chiral nuclear interactions

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Neutron-capture cross sections on exotic, neutron-rich isotopes are important for a detailed understanding of r-process nucleosynthesis, but their direct experimental observation remains unfeasible in the near future. Neutron capture can, however, be studied indirectly in current and future rare isotope experiments through the (d, p) stripping reaction, a process that is most easily modeled as a three-body problem requiring the nucleon-nucleon potential as well as the nucleon-nucleus optical potential. In the present talk, we will describe our work to construct a microscopic nuclear optical potential within the framework of many-body perturbation theory from realistic chiral two- and three-nucleon forces. In particular, we emphasize the effects of the N^2LO chiral three-nucleon force, which at first order in perturbation theory produces a repulsive real mean field that grows strongly with the nuclear density but which exhibits only a weak dependence on the projectile energy. Higher-order perturbative effects are discussed, and comparisons between our microscopic optical potential and globally-fitted phenomenological potentials are presented.

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'Cooperative colliding' d+d reaction caused in liquid Indium bombarded by low-energy D_3^+ molecular beam

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In a series of low-energy deuteron beam experiments to explore enhanced nuclear reactions in various environments, it was found that the d+d reaction in liquid Indium induced by D_3^+ molecular beams behaved quite interestingly. In the present work we report, for the first time, that there exists a reaction mechanism which is unique to the molecular beam.

Experimental setups were almost same as reported in [1]. Solid and liquid In were bombarded by D_3^+ beams from 15 to 60 keV (E_d = 5~20 keV). For the liquid, the metal In was liquefied by heating up above the melting point (156.6°C). Protons and tritons from the d(d,p)t reaction were measured by a Si detector with the energy resolution of about 20 keV.

Of particular interest are the following results on the d+d reaction in liquid In: ①Energy spectra are quite odd. Such an example of proton spectra is shown in Fig. 1 with solid circles. The observed shape is very broad and is largely skewed. Moreover, the peak position shifts to higher energy side as compared with the normal spectrum measured for the solid In (shown by an arrow). ②An excitation function of the yield cannot be explained by the thick target yield of the d(d,p)t reaction. The yield for the liquid In decreases much slower with decrease of incident energy than the normal thick target yield measured for the solid In. ③ When bombarded by an atomic D^+ beam, the yield of the d+d reaction diminishes very much, at least less than 1/20 of that by the D_3^+ beam. These strongly indicate that the d+d reaction in the liquid In is not a two-body reaction and its mechanism should be closely related with use of the molecule beam.

We have inferred a reaction mechanism in which two deuterons in a molecule play an essential role. It is shown schematically in Fig. 2: one deuteron in a molecule is elastically scattered by In, and, then, it collides with the other to cause the d(d,p)t reaction. Since the reaction occurs with the partner in the molecule, a trajectory (the initial position and the collision point) is inevitably determined; thus we call it cooperative colliding. The solid curve in Fig. 1 is a proton spectrum calculated by the cooperative colliding mechanism with simple assumptions for the D_3 molecule. The calculation reproduces well not only the energy spectra, but also the excitation function. Detailed analyses will bring valuable information on the screening potential between deuterons surrounded by conduction electrons as well as between In and deuteron.

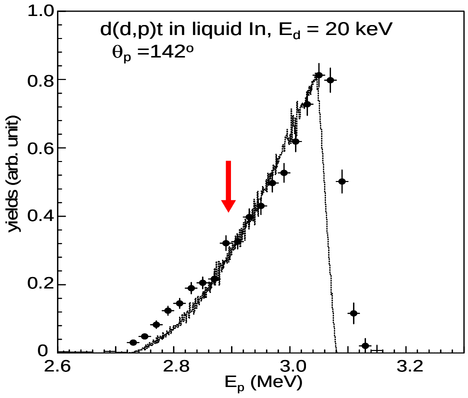

Figure 1: *Proton spectrum measured at θ = 142°.*
An arrow shows the peak position of protons emitted from the normal d(d,p)t reaction.

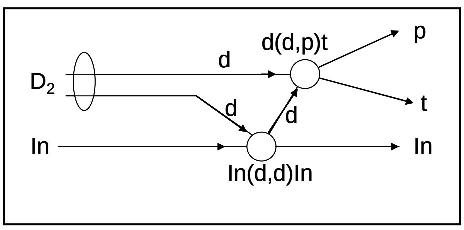

Figure 2: *Cooperative colliding reaction.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Fusion studies of low-intensity radioactive beams using an active-target time projection chamber

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The next generation of radioactive-beam facilities, due to enter service in the coming years, offer the opportunity to study nuclei with extreme values of isospin. The fusion characteristics of these exotic systems is of considerable interest as a means of probing the underlying nuclear structure. The development of neutron and proton halos, for example, has been observed to result in fusion cross sections in the vicinity of the Coulomb barrier significantly enhanced relative to those expected from one-dimensional barrier calculations [1]. The magnitude of this enhancement is expected to be sensitive to the spatial extent of the halo wavefunction, with evidence emerging for a decoupling of the halo from the core. Traditional thin-target fusion experiments will be unsuitable for the most exotic beam species due to the low beam intensities expected. An active-target time projection chamber (AT-TPC) is under development at the National Superconducting Cyclotron Laboratory for use with the forthcoming re-accelerated beam facility, ReA, which addresses this issue. The use of a TPC permits an arbitrarily-thick target to be presented, greatly extending the domain of nuclei which may be studied. Furthermore, it enables the simultaneous measurement of beam breakup, an understanding of which is vital to the interpretation of fusion cross sections. A half-scale prototype of the AT-TPC has recently been commissioned using the TwinSol radioactive-beam facility at the University of Notre Dame [2]. We report here on the fusion of neutron-rich ^{6}He and ^{12}B beams with an ^{40}Ar target at near- and sub-barrier energies. Preliminary results will be presented and the scope for future work using the full-scale AT-TPC, and similar devices, discussed.

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Timescale for equilibration of N/Z gradients in dinuclear systems

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Equilibration of N/Z in binary breakup of an excited and transiently deformed projectile-like fragment (PLF*), produced in peripheral collisions of ^{64}Zn + ^{27}Al, ^{64}Zn, ^{209}Bi at E/A = 45 MeV, is examined. The composition of emitted light fragments ($3 \leq Z \leq 6$) changes with the decay angle of the PLF*. The most neutron-rich fragments observed are associated with a small rotation angle. A clear target dependence is observed with the largest initial N/Z correlated with the heavy, neutron-rich target. Using the rotation angle as a clock, we deduce that N/Z equilibration persists for times as long as 3-4 zs (1zs = 1 x 10^{-21}s = 300 fm/c). The rate of N/Z equilibration is found to depend on the initial neutron gradient within the PLF*.

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Shell structure effects in proton inelastic scattering from ^{15}C nuclei at intermediate energies

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Carbon isotopes have been studied intensively in the last decades due to both the high rate of stable ^{12}C and the fact that the beams of unstable isotopes $^{15,16,17,19,20,22}C$ are obtained at a wide energy range from tens to hundreds of MeV / nucleon at facilities in GANIL, NSCL MSU, RIKEN, etc.

Within the framework of the diffraction Glauber's theory the calculation of the amplitude of inelastic scattering (for the level $J^{\pi} = 5/2^{+}$) of protons on neutron-rich ^{15}C nucleus in inverse kinematics was conducted. In the operator of multiple scattering, the members of the first and the second order had been considered. We used the ^{15}C wave function (WF) in the multi-particle shell model allowing calculate both the differential cross sections (DCS) and the contribution of proton scattering on nucleons of different shells.

The figure shows the DCS at energies of 0.2 (curve 1), 0.6 (curve 2) and 1.0 (curve 3) GeV/nucleon. At zero angle, scattering DCS tends to zero because of the orthogonality of the wave functions of the initial and final states. With increasing energy, there is a more distinct diffraction pattern: if there is one minimum at θ ~ 33° for E = 0.2 GeV/nucleon, then there are two minima for E = 1.0 GeV/nucleon at θ ~ 12 and 27°.

The cross section of single inelastic scattering is only contributed by one component of the WF corresponding to proton scattering on 1d-shell nucleon. For double collisions, scattering on nucleons of (1p, 1d)-shells is dominant at small angles, and the cross section is irregular at large ones due to the competition of two partial (1s, 1d)- and (1p, 1d)-amplitudes which have different signs and similar absolute values.

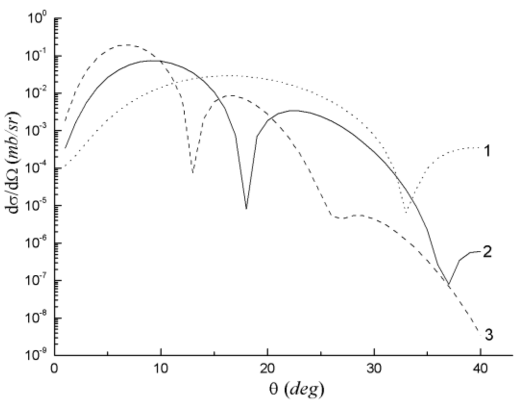

Figure 1: *Differential cross sections of inelastic $p^{15}C$-scattering at various energies. Explanations are given in the text.*

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Microscopic calculations of differential cross section of p^{15}N scattering in the optical limit of diffraction theory

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At intermediate energies (from hundreds of MeV to tens of GeV), the process of pA-scattering the most adequate is described by Glauber diffraction theory. The input parameters of the theory are the wave function (WF) of the target nucleus and the elementary nucleon-nucleon amplitude. Glauber's theory is attractive because it allows you to split the structural (depending on WF of the target nucleus) and dynamic (depending on the operator of multiple scattering) components of the scattering amplitude. Calculating the DCS in the optical limit (OL) (when only single collisions are taken into account in the operator of multiple scattering), we can take into account the contributions to the cross section of scattering by nucleons at different shells of nucleus. As shown in previous studies [1-2], this approximation adequately describes the DCS only in the front angles. Obviously, this approach can adequately describe the DPS only in the front angles.

We calculated the DCS of p^{15}N-scattering in OL approximation at 0.2, 0.6 and 1.0 GeV energies. We used the wave function ^{15}N in the shell model with $(1s)^4(1p)^{11}$ configuration.

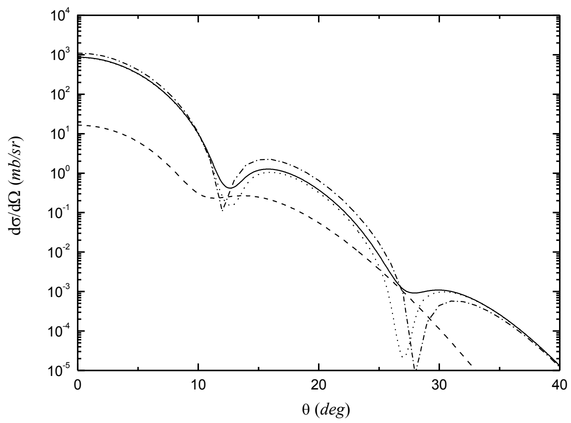

Figure 1: *Contribution to the DCS of p^{15}N-scattering of partial cross sections from scattering on nucleons of 1s- and 1p-shells at E = 1 GeV. Explanations are given in the text.*

The figure shows the calculation of DCS at E = 1 GeV. Dashed and dotted curves - scattering on nucleon of 1s- and 1p-shells, solid and dot-dashed curves - total cross section "without" and "with" the interference of scattering on nucleons of different shells. It can be seen that the main contribution to the cross-section is made by scattering on 1p-shell nucleons. At zero angle contribution from scattering on nucleons of 1s-shell is less by two orders than contribution of 1p-shell nucleons and compared to the last only at θ> 25°, where the accuracy of the calculations in the OL is not high. Accounting the interference from scattering on nucleons from different shells leads to some deeper minima in the cross-section.

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Calculation of vector analyzing power in the p+^{6,8}He elastic scattering at intermediate energies

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The first reliable measurements of the vector analyzing power in elastic p^6He-scattering at 71 MeV/nucleon were obtained recently at the accelerator in RIKEN [1]. Their appearance makes it possible to test different model calculations that take into account the spin-orbit interaction, since the direct indication of the spin-orbit coupling in nuclei are polarization phenomena in nuclear elastic scattering.

We present calculations of the analyzing power (A_y) of the elastic scattering of protons on the isotopes ^{6}He and ^{8}He made in the framework of the Glauber multiple diffraction scattering at E = 71 and 717 MeV / nucleon. There were used the wave functions (WF) obtained in the three-body αnn-model (for ^{6}He) [2] and the density distribution function in LSSM (for ^{8}He) [3].

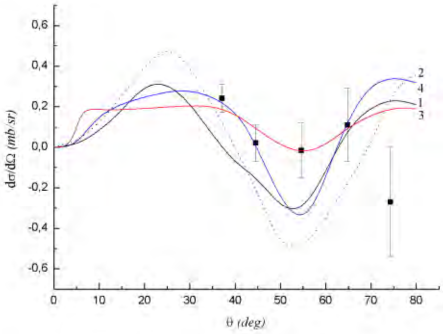

Figure 1: *Analyzing power for p^6He-scattering. Explanations are given in the text.*

The figure shows the vector analyzing power of the p^6He-scattering for the energy E = 71 MeV/nucleon. Curve 1 is calculated from the three-particle wave function, curve 2 – from the shell one. Experimental data and curves 3 and 4 are taken from [1].

Comparison of our calculations with experiment shows only qualitative agreement, in particular, all the curves change the signs from positive to negative at θ ~ 40°. Curves 3 and 4 were calculated in [1] in the optical model using the phenomenological optical potential (curve 3) and the cluster folding potential (curve 4) with selected parameter values.

The upgrade of the RIKEN facility will in principle allow measurement of the angular distribution of the A_y for the elastic scattering of ^{6}He at somewhat higher energies. Thus we investigated the predictions for the A_y at E = 717 MeV/nucleon which better corresponds to Glauber approach.

Comparison of analyzing powers of p^6He- and p^8He-scattering shows that they are close to each other at both energies, but the mass effect of valence neutrons reflects in the fact that the maxima and minima of the p^8He-scattering curve are somewhat shifted to small angles.

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Fission dynamics of superheavy compound nuclei

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The time evolution of superheavy synthesis including fusion and fission dynamics is presented based on time-dependent density functional calculations. Despite some shortcomings of the present method (some of them is actually removed in this research), we have a microscopic and self-consistent treatment for many-body quantum dynamics. In this paper, the fission properties of compound nuclei are investigated using the method explained in Refs. [1,2]. Note that there has not been any microscopic theories treating the time evolution of fission sufficiently [3]. As a result of our investigation, several non-trivial things are found; first, the fission of compound nuclei is reproduced within the time-dependent density functional calculations; second, the required duration time for fission is quantitatively obtained to be less than 10^{-20} sec; third, for the first time, the fissibility (fissility) is defined in a microscopic manner [4]. Finally, the impact of ternary collision events to the formation of superheavy nuclei in both laboratory and the universe is presented [5]. It provides a way to keep the compound nuclei in the superheavy synthesis against fission with the help of rotational stabilization.

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Sensitivity of the transition energy towards mass asymmetry of the colliding nuclei

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We investigate the role of the mass asymmetry on the transition energy by studying asymmetric reactions using the isospin dependent quantum molecular dynamics (IQMD) model [1]. Our results are almost independent of the system size as well as of the colliding geometries. Moreover, substantial and the uniform effect of the asymmetry of the reaction has been observed on the transition energy.

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Transfer reaction studies of ^{10,11,12}Be

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The three neutron rich beryllium isotopes, ^{10,11,12}Be, have been studied in direct reactions (scattering and one-neutron transfers). The direct reactions were performed at ISOLDE using a low-energy (2.85MeV/u) ^{11}Be beam incident on a deuteron target. The T-REX silicon detector setup was used along with the MINIBALL germanium clusters. This setup provided detection of both charged particles and gammas. The gamma detection enabled a clear identification of all but one bound state in the three nuclei. The only bound state not seen in the experiment, was the 0_2^+-state in ^{10}Be, which is only weakly populated in the transfer reaction. Differential cross sections for the populations of the bound states are determined from the experimental data in a range from 60 to 120 degree in center of mass. The experimental cross sections are compared to preliminary theoretical calculations. Furthermore, a tentatively investigation of the lowest resonance in ^{12}Be has been performed including a study of the decay of the resonance.

The main aim of the experiment was to investigate the mixing of the $0p_{1/2}^2$ shell and the $1s_{1/2}0d_{5/2}$, wich is well known to occur in both ^{11}Be and ^{12}Be. The mixing leads to the inversion of states in the former and the breaking of the N=8 magic number in the latter. The strength of the mixing in ^{12}Be is investigated by populating single particle excitations in the nuclei using a (d,p)-transfer reaction. The 0_2^+-state in ^{12}Be plays an important role in the study of the mixing. A previous ^{11}Be(d,p)^{12}Be performed at TRIUMF was unable to cleanly separate the 0_2^+-state from the 2_1^+-state [1]. The gamma detection in this experiment has enabled a clear identification of the 0_2^+-state in ^{12}Be, leading to a more reliable cross section for the state. Both decay lines of the 0_2^+-state have been identified and a detailed study of the decay of the state has lead to a confirmation of the values given by S. Shimoura et al. [2,3].

Another important aspect of the experiment was the study of the influence of the halo structure. Both ^{11}Be and the deuteron is known halo nuclei. The halo structure is expected to strongly influence the direct reactions. The low binding energy would lead to a strong coupling to the continuum in the reactions. The low lying $1/2^-$-state in ^{11}Be is also expected to play an important part. The effect of the halo in scattering experiments have been theoretically investigated by A. Bonaccorso et al. [4] and scattering on heavy targets have been performed with ^{11}Be [5]. The halo is also expected to influence the transfer reactions and a good understanding of the scattering cross sections is required to fully understand the transfer reactions. The experimentally determind differential cross section for the elastic scattering will be presented along with some simple optical model calculations, showing the importance of higher order terms.

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Origins of the Fundamental Correlations in the Differential Cross-Sections of Nuclear Fission Reactions by Cold Polarized Neutrons

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In the quantum fission theory framework it is demonstrated that the basic mechanisms of the fundamental correlations formation in angular distributions of products of nuclear binary and ternary fission by cold polarized neutrons with polarization vector $\mathbf{p}_n$ and wave vector $\mathbf{k}_n$ are realized for following types of these correlations: P-odd, T-even $(\mathbf{p}_n,\mathbf{k}_{LF})$ (a), P-even, T-even $(\mathbf{k}_n,\mathbf{k}_{LF})$ (b) and P-even, T-odd $(\mathbf{p}_n,[\mathbf{k}_n,\mathbf{k}_{LF}])$ (c), $\left(\mathbf{p}_n,\left[\mathbf{k}^0_{LF},\mathbf{k}_{LF}\right]\right)$ (d), where $\mathbf{k}_{LF}$ and $\mathbf{k}^0_{LF}$ are wave vectors of light fission fragment for asymptotic region and region being near the scission point of fissile nucleus, and $\left(\mathbf{p}_n,\left[\mathbf{k}_{LF},\mathbf{k}_3\right]\right)$ (e), where $\mathbf{k}_3$ is asymptotic wave vector of the third particle for ternary fission.

It is shown that correlations (a) – (c) are defined [1] by the interference of fission amplitudes of s- and p-neutron resonances of the fissile compound nucleus with taking into account P-violation (for correlation (a)) and P-conservation (for correlation (b) – (c)) interactions, and correlations (d) – (e) are defined [2,3] by the analogous interference for s-neutron resonances with taking into account the influence of the collective rotation of polarized compound fissile nucleus onto the amplitudes of angular distributions of fission fragments and prescission third particles. It is demonstrated that combinations of the correlations (a) – (c) with angular distributions of the prescission and evaporation third particles $W_3\left(\left(\mathbf{k}_{LF},\mathbf{k}_3\right)\right)$ give the possibility to receive the P-odd, T-even $(\mathbf{p}_n,\mathbf{k}_3)$ and P-even, T-even $\left(\mathbf{k}_n,\mathbf{k}_3\right)$, P-even, T-odd $\left(\mathbf{p}_n,\left[\mathbf{k}_n,\mathbf{k}_3\right]\right)$ correlations for angular distributions of named above third particles in the true and delayed ternary fission. It is shown that combinations of correlation (d) with the additions $\Delta W_3\left(\mathbf{k}^0_{LF},\mathbf{k}_3\right)$ to the evaporation third particle's angular distributions, caused [3] by the appearance of connected with wriggling-vibrations of fissile nucleus near it's scission point the big values of fission fragments spins and their orientation in the plane perpendicular to vector $\mathbf{k}^0_{LF}$, give the possibility to receive the P-even, T-odd correlations of type (e) for angular distributions of evaporation third particles (neutrons, gamma-quanta) in the delayed ternary fission.

It is found that all T-even and T-odd correlations for binary and ternary fission (a) – (e) are qualitatively described on the basis of T-invariant Hamiltonians of analyzed nuclear systems.

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Photon- and proton-induced fission of heavy targets at intermediate energies

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In this work we present the analysis of the yields of fission fragments induced by Bremsstrahlung with end-point energies of 50 and 3500 MeV on ^{232}Th and ^{238}U targets, and by protons at energy 660 MeV on ^{241}Am, ^{238}U and ^{237}Np targets using the simulation code CRISP. In CRISP model the reaction proceeds in two steps. The first one corresponds fast cascade, where a series of individual particle-particle collisions occurs within the nucleus. It leaves a highly excited cascade residual nucleus, assumed to be in thermal equilibrium. Subsequently, in the second step the excited nucleus releases its energy by evaporation of neutrons and light charged particles as well. A multimodal fission option had been added to this code and an extension of the calculation to the properties of the fission products is presented. Those calculations allow direct evaluation of the spectrum of fissioning nuclei. By dividing the fissioning nuclei according to their fissionability, an approach is introduced which accounts for the contribution of symmetric and asymmetric fission. By adopting this procedure, it was possible to calculate the main parameters for the fission fragments charge distribution such as the most probable charge for a given fission product mass chain and its corresponding width parameter. Also, it was possible to reproduce features of fragment mass distribution and evaluates the fissility of fissioning nuclei for photon- and proton-induced fission of ^{232}Th, ^{237}Np, ^{238}U and ^{241}Am. The results presented in this paper shows a fair agreement between calculation and experiment. We conclude that our two step model provides a reasonable description of the medium energy photon- and proton-induced fission.

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Effects of deformation in the decay of ^{56}Ni* formed in ^{32}S+^{24}Mg reaction

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The Dynamical Cluster-decay Model (DCM) a non-statistical approach developed by Gupta and collaborators [1] for the studies of low energy fusion-fission reactions has been recently reformulated by us [2] to study the effect of different temperature dependent binding energies. The reformulated DCM had been applied first to study the decay of ^{56}Ni* formed in the ^{32}S+^{24}Mg reaction at two energies *viz.*, $E_{c.m.}$=51.6 and 60.5 MeV. Later in a recent work [3] the role of mass parameters entering in the inertia part of the equation of motion is analysed for the decay of ^{59}Cu*. In these earlier studies the interactions and inertia are calculated by considering the fragments as spherical. Now the model is further refined by incorporating deformation effects of the fragments and is applied to the decay of ^{56}Ni* formed in ^{32}S+^{24}Mg reaction at an incident energy of $E_{c.m.}$=51.6 MeV. The results presented here are carried out

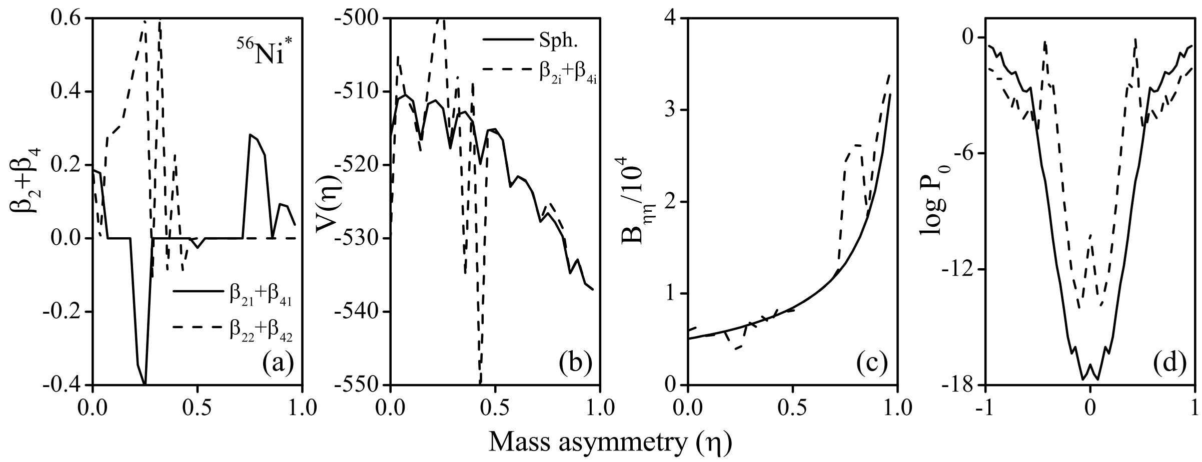

Figure 1: *Role of deformations (β_2+β_4, dashed line) in fragmentation potential (V_η), mass parameters ($B_{\eta\eta}$), preformation probability (P_0) are shown along with spherical (solid line) calculation.*

for the temperature T=3.39 MeV at R=R_1+R_2 fm and ℓ=0 $\hbar$. Fig.1 (a) presents the deformation values (β_2+β_4; the contribution of β_3 is very negligible) of the charge minimized binary exit channels. For the use of these deformation values, the fragmentation potentials (V_η), the mass parameters ($B_{\eta\eta}$) and preformation probability values (P_0) are calculated and presented in panels (b), (c) and (d) of Fig. 1 as dashed line and are compared with spherical calculations (solid line). The effect of deformation is clearly reflecting in the potentials, mass parameters and preformation probabilities. Particularly, there is an enhancement in P_0 values for η=0 which will reflect in the cross-sections which in DCM is defined to depend on barrier transmission probability and preformation probability for different ℓ-values upto a critical ℓ-value. The results obtained *viz.*, cross-sections, total kinetic energies of the fragments will be presented by comparing with spherical calculations, experimental values and other model results.

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$^4He(\gamma,d)d$ and $^3He(\gamma,p)d$ reactions in nonlocal covariant model

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Photonuclear reactions research is of great interest to obtain information about the structure of nuclei. Structural effects investigation requires certain provisions about the reaction mechanism. It is particularly important to identify the mechanisms based on the fundamental principles of covariance and gauge invariance. In the first section of the article we consider the process $^4He(\gamma,d)d$. This process comes at the expense of the quadrupole absorption of γ-rays, while the dipole transition is suppressed. This property is a consequence of the isospin selection as well as the identity of the particles in the final state. Requiring preservation of composite hadrons electromagnetic currents we determine the minimal necessary set of the process mechanisms. This procedure ensures accounting of single-particle and many-particle contributions with each other and with the intranuclear dynamics. Obtained results describe the energy range from threshold (20 MeV) to 140 Mev. We analyze the two-particle disintegration of ^3He nuclei by photons in the second section. Our interest caused by the fact that ^3He is the simplest many-particle system which admits exact solutions. There is still a number of unsolved questions and conflicting conclusions for the photodisintegration process of three-nucleon systems at low and medium energies, despite numerous theoretical investigations[1,2] Present paper is devoted to determine the roles of different reaction mechanisms and to solve problems above.

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α+^{12}C rotational bands in ^{16}O

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^{16}O nuclei have the well-known characteristic structure, the states described by the shell model and α cluster model coexist in low excitation energies (e.g. [1]). The 0_2^+ state is thought to have the α+^{12}C configuration. Considering it microscopically, the 0_2^+ state is dominated by the wavefunction with the total quantum number $N = 6$, because the ground state is dominated by the lowest quantum number $N = 4$ from the Pauli principle. This means that the rotational band starting from the 0_2^+ state does not have the 8^+ state. If the 4p4h configuration describes the state, the 8^+ state exists in the rotational band. The quest for the missing 8^+ state is yet unsolved in the study of ^{16}O. In this presentation, I would like to show the results from our investigation of α+^{12}C elastic scattering, and show that the even-parity band is $N = 8$ and the odd-parity band is $N = 9$ [2].

Considering the high-spin states experimentally, the 8^+ state may seem to be at $E_x \approx 30$ MeV with a large α-particle width, although it was thought to be found at $E_x \approx 20$ MeV from the naive extrapolation of the rotational band [3]. The experimental studies of ^{12}C(^{12}C,^{16}O*)^{8}Be show that the excited ^{16}O* decays into the ^{8}Be+^{8}Be channel at $E_x \approx 30$ MeV with $J^\pi = 8^+$ [4]. The $L = 8$ broad peak has been observed in the excitation function of ^{12}C(α,^{8}Be)^{8}Be [5]. The elastic cross section is enhanced from the pure Coulomb scattering [6], and the possibility of the high-spin states has been discussed from elastic scattering and inelastic scattering [7].

The $J^\pi = 8^+$ and 9^- states can be predicted in the rotational bands by the potential models of the α+^{12}C configuration [8,9]. The tetrahedral router model predicts $J^\pi = 8^+$ at $E_x \approx 30$ MeV [10]. In this presentation, the elastic cross sections in the energy range of $E_{c.m.} = 21.15$ – 26.625 MeV [6] are evaluated with the optical model in order to investigate the possibilities of the high-spin 8^+ and 9^- states. The internuclear potential between the α-particle and ^{12}C nuclei should have the appropriate strength (e.g. [11,12]). We adopt the optical potential deduced from the one describing elastic cross sections at high energies where the refractive phenomena are observed.

In the results, the elastic cross sections enhanced from pure Coulomb scattering can be reproduced by the calculated results with the parity-dependent potential. The phase shifts, S-matrix, and excitation functions of $L = 8$ and $L = 9$ show the resonant feature at the prospective energies around $E_x \approx 30$ MeV. The effective potentials for $L = 8$ and $L = 9$ have a pocket making a quasi-bound state. The nuclear potential predicted from refractive scattering at high energies is deep enough to bind the resonant state, balancing with the strong centrifugal force. The 8^+ resonance is found to be observed at $E_x \approx 29$ MeV with a large width. Consequently, the rotational band starting from the 0_2^+ state ($E_x = 6.05$ MeV) is confirmed to have $N = 8$. Likewise, the 9^- state of the negative-parity band is at $E_x \approx 30.2$ MeV.

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Role of colliding geometry on the peak mass production

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Nuclear multifragmentation gives possibility to study the nuclear matter at the extreme conditions of temperature and density. With the advent of secondary radioactive ion beam (RIB) facilities around the world, an increasing interest is seen for the collisions of nuclei away from the line of stability. Several studies have been conducted to explore the isospin effects in multifragmentation and the neutron content of a colliding pair is found to affect the fragmentation [1]. It is now well established that the multiplicity of intermediate mass fragments (IMFs) shows a rise and fall behavior with increase in the incident energy for stable as well as neutron-rich/neutron-poor systems. The peak center-of-mass energy ($E_{c.m.}^{max}$) increases linearly with system mass whereas peak IMF multiplicity ($<N_{IMF}>^{max}$) shows a power law dependence. $E_{c.m.}^{max}$ is also found to be sensitive to the isospin asymmetry of colliding pairs. The above mentioned study has been carried out for central collisions. Here, we see the effect of colliding geometry on $<N_{IMF}>^{max}$ and $E_{c.m.}^{max}$ and correlate how the colliding geometry alters the peaks of $<N_{IMF}>^{max}$ using isospin dependent quantum molecular dynamics (IQMD) model [2]. We notice that colliding geometry affects both $<N_{IMF}>^{max}$ and $E_{c.m.}^{max}$.

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Nuclear fragmentation studies with antiproton-nucleus annihilations

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This work aims at collecting experimental data on low energy antiproton-neucleus annihilation, especially on nuclear fragmentation, by using emulsion films. In spite of their importance in many fields such as nuclear physics, astronomy and radiology, the characteristics (*e.g.* hadronization and fragmentation multiplicities) of the stopping antiprotons annihilating on nuclei are not well known. For our study we exposed several thin targets (Al, Si, Ti, Cu, Ag, Au and Pb) to a very low energy antiproton beam from the CERN Antiproton Decelerator, delivering antiprotons to the AEgIS experiment (AD6). We used OPERA-type emulsion films [1] to detect and reconstruct the charged particle tracks emerging behind the targets. Emulsion films have excellent resolution (of the order of 1 μm) to detect the nuclear fragments, and the ability to distinguish between highly ionizing particles (such as nuclear fragments or protons) and annihilation products such as pions and kaons.

Figure 1 shows examples of the observed tracks that emerge from common annihilation vertices in the Ti-target. The tracking was performed with the scanning facility available at the University of Bern. The thicknesses of the targets were 5 μm for Al, Ti, Ag, Au and Pb, 40 μm for Cu, and 400 μm for Si. This talk will present the first results and a discussion of nuclear fragmentation from very low energy antiproton-nucleus annihilations.

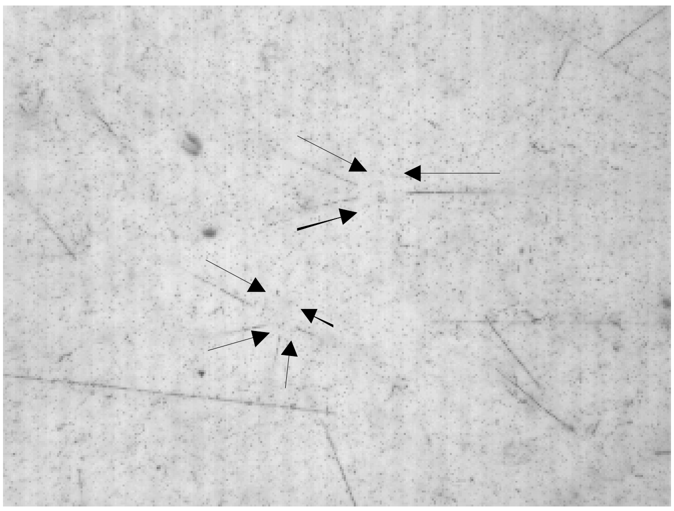

Figure 1: *Antiproton-nucleus annihilation tracks and vertices observed in an emulsion film behind a thin Ti-target. The area covered by the view is 300 x 380 μm^2.*

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Fusion using time-dependent density-constrained DFT

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The investigation of internuclear potentials for heavy-ion collisions is of fundamental importance for the study of fusion reactions as well as for the formation of superheavy elements and nuclei far from stability. Recently, we have developed a new microscopic approach based on a time-dependent density-constrained DFT calculations. The theory is implemented by using densities and other information obtained from time-dependent Hartree-Fock time-evolution of the nuclear system as a constraint on the density for DFT calculations. In essence, this provides us with the dynamical path in relation to the multi-dimensional PES of the combined nuclear system. Since TDHF directly provides us with the most probable fusion path in the mean-field limit there is no need to calculate the entire PES to determine the fusion path as in the case of computation of fission barriers. Some of the effects naturally included in these calculations are: neck formation, mass exchange, internal excitations, deformation effects to all
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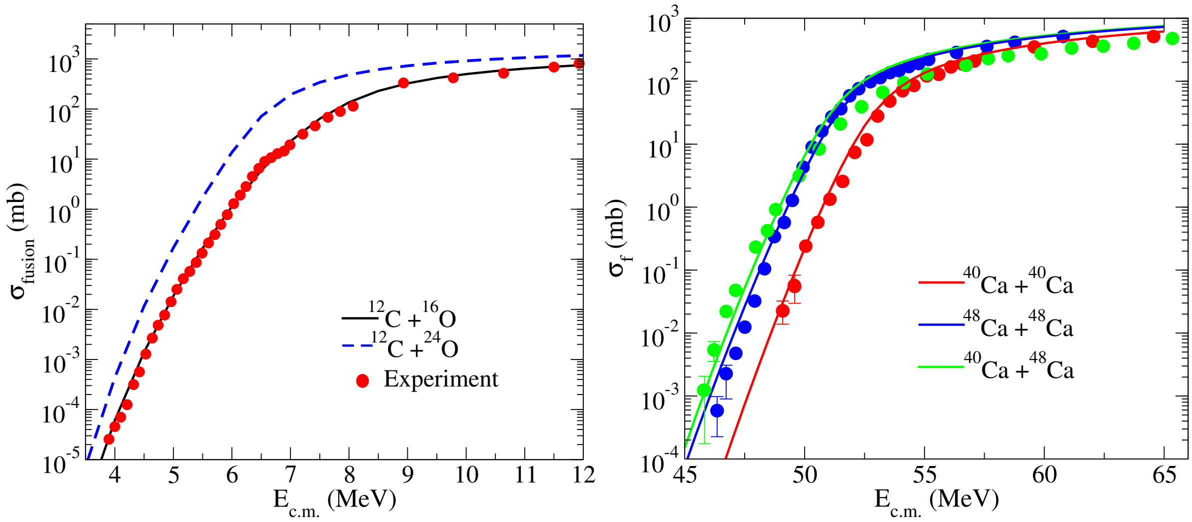

Figure 1: *Calculated fusion cross-sections for C+O system (left) and various isotopes of the Ca+Ca system (right) compared with experiment.*

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Analysis of p-^{4,6,8}He and p -^{6,7,9,11}Li scattering using Glauber model

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In the last decades, we have witnessed a great interest in the study of very light neutron-rich nuclei up to and even beyond the neutron drip line. One of the most exciting phenomena in such nuclei is the neutron halo, which is understood in terms of the extended neutron distributions required to reproduce the available data. The neutron distribution in nuclei can be obtained only indirectly, in contrast to the corresponding proton distribution which can be reliably determined through electron scattering. Proton-nucleus scattering provides a useful tool to determine either the parameters entering in the assumed shape of the neutron distribution or to test the reliability of the theoretically calculated neutron distribution. The present calculations employ the Coulomb modified correlation expansion of the Glauber amplitude for p-nucleus scattering; the first term of the expansion is the uncorrelated part involving all orders of scattering, while the other terms are the correlation terms which can be considered as the correction to the uncorrelated part. However, keeping in view the energy range considered in this work, we assume that the correlation terms may not provide significant change in the results obtained with the uncorrelated part only. Thus the uncorrelated part seems to be a good approximation to the full correlation expansion of the Glauber amplitude.

We present here systematic analysis of p-^{4,6,8}He and p-^{6,7,9,11}Li scattering data within the framework of the Coulomb modified (uncorrelated) Glauber model. The calculation requires mainly two inputs: (1) the (spin-dependent) nucleon-nucleon (NN) amplitude and (ii) the nucleon density distributions in target nuclei. The scaler part of the NN amplitude is fairly accurately known from the available NN scattering data at energies of our interest. To find the spin-dependent part of the NN amplitude, we have used the p-^{4}He scattering data to fix its parameter values. For target nuclei, we have used several model nucleon density distributions in order to study the sensitivity of the calculated observables such as the differential cross sections and polarization on the nucleon density distributions used. It is found that the NN amplitude, as obtained in this work, and different density distributions satisfactorily reproduce the experimental differential cross sections whereas the calculated polarization is more sensitive to the density distributions used. Thus the polarization data impose an additional constraint on the determination of nucleon (especially neutron) density distributions in nuclei. The calculations also consider the phenomenological treatment of nuclear medium corrections, and provide the behaviour of NN amplitude in the nuclear medium. It is found that the medium effects, relating Pauli blocking, provide an overall better description of the data in all the cases.

Relative Importance of Energy Dependent Diffuseness Parameter and Barrier Position in the Analysis of Fusion Excitation Function Data

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The sub-barrier heavy ion fusion reactions provide a very good insight into nuclear structure and nuclear interaction [1]. The interaction potential between heavy ions which consists of Coulomb, centrifugal and nuclear terms plays a very crucial role in the description of fusion dynamics because of the fact that the sum of these terms forms the Coulomb barrier which must be overcome for occurrence of fusion. The Coulomb and centrifugal terms are well understood whereas many ambiguities are associated with the nuclear potential. Since the predictions of fusion excitation functions in sub-barrier energy regions are very sensitive to the shape of nuclear potential, the success of any model for fusion depends strongly on the nuclear potential model employed in the analysis. As a result various potential models ranging from the simple phenomenological to realistic microscopic models have been proposed and used to explain the fusion excitation functions data. Generally, the three parametric Woods-Saxon potential remains the most frequently used potential for the description of compound nuclear reactions. Among the three parameters, depth, range and diffuseness parameter, there exist, large ambiguities in the determination of the accurate value of the diffuseness parameter. It was observed that a wide range of values from $a = 0.65\,fm$ to $a = 1.5\,fm$ of diffuseness parameter are required to describe various nuclear phenomenon. As the value of diffuseness parameter increases beyond $a = 0.65\,fm$, the potential pocket becomes more and more shallow and disappears for large values and the fusion barrier radius decreases rapidly. Recently, an energy dependent parameterization scheme to determine the value of diffuseness parameter was successfully used to explain the fusion excitation functions of various systems [2]. Since, the barrier position changes with the change in the shape of the potential, the energy dependent potential induces energy dependence in the barrier position also. Here we study the relative importance of the energy dependence of the diffuseness parameter and that of the barrier position in the description of the fusion excitation function data of some heavy ion systems in near barrier energy region using Wong's formula. The effects of the energy dependent diffuseness parameter are found to be much more prominent in comparison to those of barrier position.

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Study of the multi-nucleon transfer reactions of $^{136}Xe+^{198}Pt$ for producing exotic heavy nuclei

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Investigating the ground state properties of exotic neutron-rich nuclei around the mass number of 200 with neutron number of 126, is very important for nuclear astrophysical and nuclear structural reasons. Multi-nucleon transfer (MNT) in heavy nuclear reaction systems such as ^{136}Xe + ^{198}Pt or ^{208}Pb was proposed as a possible way for producing such nuclei [1-3]. However, the experimental identification of MNT reaction channels is not trivial because of their low-energy kinematical characteristics; partial nuclear identification (e.g. only mass measurement), even for projectile-like fragments (or light reaction partner), has been reported. Theoretically, there are also difficulties in treatment of the degree of energy dissipation during the transfer processes and the strength of nucleon pair transfer, which is essential in the estimation of the cross section with high reliability. Therefore, it is highly desirable to measure the projectile-like and the target-like fragments (PLFs and TLFs) simultaneously with a better particle identification for more detailed MNT reaction studies.

We performed an experiment for measuring MNT reaction cross sections in a heavy reaction system of ^{136}Xe+^{198}Pt at GANIL with a beam energy of 8 MeV/u. The large acceptance spectrometer VAMOS++ [4] was used for the direct identification of the PLFs. For the simultaneous identification of the TLFs, the ɣ-array EXOGAM [5] was used by measuring their de-excitation ɣ-rays.

The particle identification of PLFs were successfully carried out, and their cross sections relatively normalized by the elastic channel were estimated. The proton pick-up channels in the present system were observed to be highly favored than in light projectile systems [3] as shown in the Figure 1. The analysis for extracting the absolute cross sections and the transfer probability functions of single and pair nucleon transfer in quasi-elastic reaction is under progress. The preliminary results will be presented and compared with the GRAZING model [6] calculation.

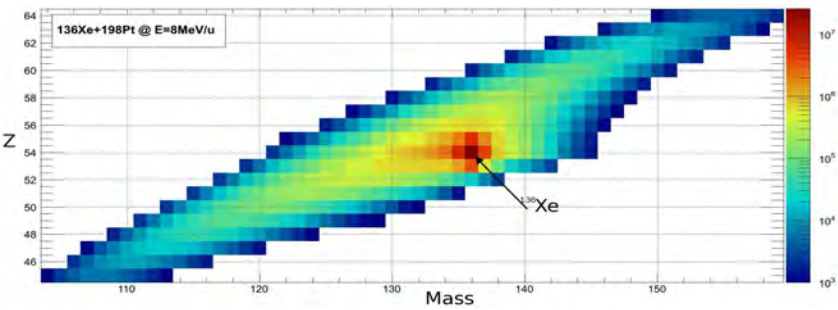

Figure 1*: Experimental yield distribution of Xe-like fragments as a function of Z and Mass*

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Probing three-nucleon system dynamics: Cross-sections of the deuteron-proton breakup

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A basic step towards full understanding of nuclear interactions is proper modeling of all details of the few-nucleon system dynamics. Modern nucleon-nucleon (NN) interaction models, most commonly based on the meson-exchange picture, are able to reproduce the bulk of all NN data with an utmost precision. Their quality can be efficiently probed in the few-nucleon environment by comparing most up-to-date theoretical predictions with the observables measured in precision experiments. Thorough studies of three-nucleon system have led to a conclusion that a proper description of the experimental data cannot be achieved with the use of NN forces alone. This indicates a necessity of including additional dynamics: subtle effects of suppressed degrees of freedom, introduced by means of genuine three-nucleon forces, or, for a long-time neglected, Coulomb force.

Those findings would not be possible without a strong improvement of the experimental methods. New generation experiments in the middle-energy region employing high-resolution, multi-detector arrangements, provide data of unprecedented accuracy. Covering wide phase-space regions of the three-nucleon scattering in continuum, already in the sector of cross-sections contributes significantly to improve modeling of all details of the interaction dynamics. As an example of such studies a large set of high precision, exclusive cross-section data for the ^{1}H(d,pp)n breakup reaction at 130 MeV is considered, originating from a series of experiments in different configurations [1,2,3]. Progress in theory allows now for quasi-rigorous, simultaneous treatment of modern NN potential, phenomenological 3N force and Coulomb interaction [4], providing an opportunity to examine their overall interplay when the calculations are confronted with the measured cross sections. Although including all these dynamical contributions tremendously improves the agreement of the data with the predictions, there still remain unresolved puzzles, which indicate that our understanding of the complexity of nuclear forces is not complete. More general explorations of few-nucleon systems [5,6] support those conclusions and extend the guidelines for the necessary improvements.

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Experimental study of relativistic effects in the dp breakup reaction using the WASA detector

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Few-nucleon systems are ideal laboratories to study nuclear forces. Among them, the system composed of three nucleons (3N) is the simplest nontrivial environment, in which various models of the nucleon-nucleon (NN) interaction can be tested. The breakup observables can be calculated using modern realistic pairwise nucleon-nucleon (NN) interactions, combined with a suitable model of 3N forces. Moreover, the two- and three-nucleon interactions can be modeled within the coupled-channel (CC) framework by an explicit treatment of the Δ-isobar. Alternatively, the dynamics is treated within the Chiral Perturbation Theory (ChPT). The above listed calculations include different pieces of the nucleon-nucleon dynamics like the three nucleon force 3NF, the long-range Coulomb interaction or relativistic effects, which reveal their influence at different parts of phase space. Especially, cross section observables are very sensitive to all these effects. Previous measurements of the cross sections at different deuteron beam energies have demonstrated that inclusion of 3NF or Coulomb force in the theoretical calculations improves the description of the experimental data [1, 2, 3].

In recent years the relativistic treatment of the breakup reaction in 3N system was developed using the NN potential in Ref. [4] and this approach has also been extended for calculations including 3NF in Ref. [5]. It was shown that in some particular region of the breakup phase-space, relativistic effects can increase or decrease the calculated breakup cross sections by up to 60% and even more. At the same time the effects of 3NF may change certain observables by a similar factor. The relativistic effects and their interplay with 3NF become more important with increasing available energy in the three nucleon system. Therefore the investigations at relatively high energies are important to confirm the theoretical predictions for relativistic effects and to unambiguously fix a relevance of the 3NF. The experiment using a deuteron beam of 340, 360 and 400 MeV and the WASA detector has been performed in January 2013 at FZ-Jülich with the aim to study the relativistic effects. The 4π geometry of WASA gives a unique possibility of studying various aspects in the three nucleon (3N) system. The first experimental data collected during this experiment will be presented.

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Inclusive breakup measurement of *N* = 20 – 28 nuclei near neutron drip-line

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One-neutron removal cross sections of Coulomb and nuclear breakup of ^{29,31}Ne, ^{33,35,37}Mg, and ^{39,41}Si have been measured at around 240 MeV/nucleon at RI Beam Factory (RIBF). Additionally, the fragment momentum distributions for ^{28,30}Ne, ^{32,34,36}Mg, and ^{38,40}Si after nuclear breakup have been measured. The Coulomb breakup reaction is sensitive to the soft $E1$ excitation, which have been used to investigate the halo structure. On the other hand, nuclear breakup reaction can tell the configuration of single-particle orbitals. In our analysis, these reactions are utilized in combination to find halo nuclei and obtain the spectroscopic factors, separation energy, and spin parity of the ground state. Namely, we have established a new spectroscopic tool by using both Coulomb and nuclear breakup reactions.

The measured Coulomb breakup cross sections showed significant enhancement for ^{31}Ne [1] and ^{37}Mg, which suggests the halo formation in these nuclei. Additionally, the combined analysis of Coulomb and nuclear breakup reactions provided the separation energy and spin-parity of the ground state. We discuss the results and their shell structure of nuclei near the neutron drip-line. We also report the recent results of fragment momentum distributions for one-neutron removal from ^{19,20}C and two-neutron removal from ^{20,22}C [2].

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Who plays in the Hoyle band?

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The Hoyle state in ^{12}C was discovered over 50 years ago in 1957 and strongly influences the rate of the triple-alpha process in stars. Recently, significant experimental and theoretical effort has been invested to understand, in detail, its unorthodox structure. In particular, identification of excitations of the Hoyle state has been a key goal. This talk will address current progress with an emphasis on possible members of the Hoyle band and the structure implications.

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Study of neutron-neutron interaction in proton pick-up reactions on ^{3}H

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Analysis of data on neutron-neutron quasifree scattering allowed authors [1] to draw a conclusion about the need for a modified strengthened *nn*-interaction in the singlet $^1S_0$ state. This, however, leads to serious changes in the estimated *nn*-scattering length and even to an existence of bound "dineutron". In the present experiment we propose to study *nn*-interaction using as a target tritium nucleus - ^{3}H, containing two neutrons predominantly in the singlet $^1S_0$ state. If we consider the reaction of pick-up of the proton from the ^{3}H-nucleus then two emitted neutrons with high probability will also be in the singlet state which may be quasibound or bound. Similar quasibound state was found recently for two-proton system [2].

The experiment will be performed for the following reactions with two neutrons in the final state d + t →3He + nn and n + t → d + nn. The test of the experimental technique in the d+d →2He+nn reaction is conducted at the deuteron beam of U-120 cyclotron of Skobeltsyn Institute of Nuclear Physics. Reaction d+t → 3He+nn will be investigated using deuteron beam of the Institute for Nuclear Research, NAS of Ukraine, and the reaction n+t → d+nn at the neutron beam RADEX of the Institute for Nuclear Research, RAS. Thus simultaneously will be obtained cross sections in the final state interaction (FSI) geometry and the search of bound or quasi-bound "dineutron" will be performed.

In the experiment we will determine emission angles and energies of charged particle (with charge and mass identification) and two neutrons (or "dineutron"). Thus we will apply the original technique which allows in neutron detector separate (by time of interaction and energy of recoil proton) events from two interacting neutrons (from nn-final state interaction or decay of quasibound state) or bound "dineutron". Analysis of the proposed experiment will verify the theoretical basis underlying the construction of modern neutron-neutron potential.

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^{8}B production in the reaction $^{6}Li(^{3}He,n)^{8}B$ via neutron angular distribution measurement

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The aim of the EUROnu Design Study [1] is to perform a comparative study of three possible future neutrino oscillation facilities (Super Beams, Neutrino Factory and Beta Beams) for Europe. In particular, Beta Beams can produce well collimated pure electron neutrino or antineutrino beams to explore primarily neutrino oscillation physics. The Beta Beam produces neutrinos from the decay of radioactive isotopes with suitable decay time and reaction Q-values. The $^{3}He + ^{6}Li \rightarrow ^{8}B + n$ and $^{7}Li + d \rightarrow ^{8}Li + p$ reactions have been proposed in the work by C. Rubbia et al. [2] to produce the isotope pair ^{8}B and ^{8}Li. Cross sections and angular distributions are fundamental to design the tabletop accelerator and the other necessary equipment that will be used for the production of these isotopes, in particular to assess the performance of an internal target that also serves as a stripper and an absorber for ionization cooling of the circulating beam as proposed in [2].

The total cross section of the ^{8}B production in the $^{6}Li(^{3}He,n)^{8}B$ reaction was measured in the past using the positron decay technique [3]. On the other hand, an earlier measurement of neutron angular distribution [4] reported a larger value for the integrated cross section by about a factor of 3. For this reason we performed a new measurement with higher accuracy using the ^{3}He beam delivered by the Van De Graaf CN accelerator at LNL. The emitted neutrons were measured via the Time-of-Flight (ToF) techniques by using 8 large volume BC501 liquid scintillation detectors of the RIPEN modular array [5]. High statistics was collected through digital processing and pulse shape analysis (PSA) of the electronics signals.

In the neutron ToF spectra the peak due to the population of the ^{8}B ground state was identified. In addition, the population of the ^{8}B first excited state at 0.78 MeV that immediately decay by proton emission, was observed with a very good statistics allowing for the first time an accurate angular distribution measurement.

Results were interpreted in the framework of the Zero Range Knock-out Distorted Wave Born Approximation (ZR-KO-DWBA) using the code DWUCK4 [6] showing a nice agreement with ref. [4]. DWUCK4 calculations extending the projectile energy range up to 25 MeV showed a strong disagreement with the positron decay experiments [3] that needs to be understood performing neutron angular distribution measurement at ^{3}He beam energy above 10 MeV.

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Modelling of the signal induced by particles in silicon detector

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Verification and extensions of the Gaussian cloud dynamics model [1] for the induced current signal in silicon detectors are presented. The approach is based on Ramo-Shockley theorem where, in addition to electrodes field, Coulomb interactions between electron and hole clouds are considered. The preliminary results provide good description of subtle experimental observations gathered by FAZIA collaboration concerning Pulse Shape Analysis (PSA).
Focus is put on ion identification and on the factors impacting this mechanism.

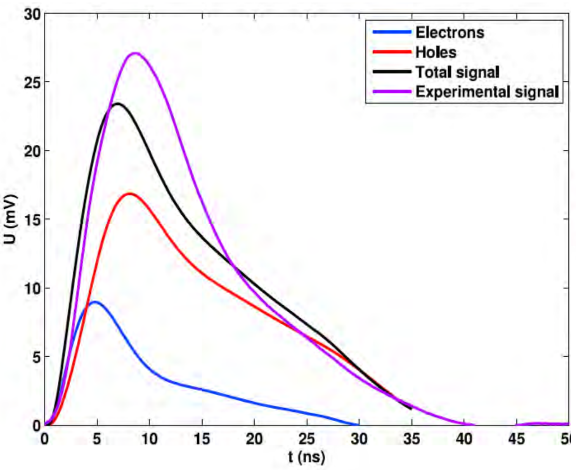

Figure 1: *Model prediction for the current signal induced by an 80 MeV ^{12}C ion*

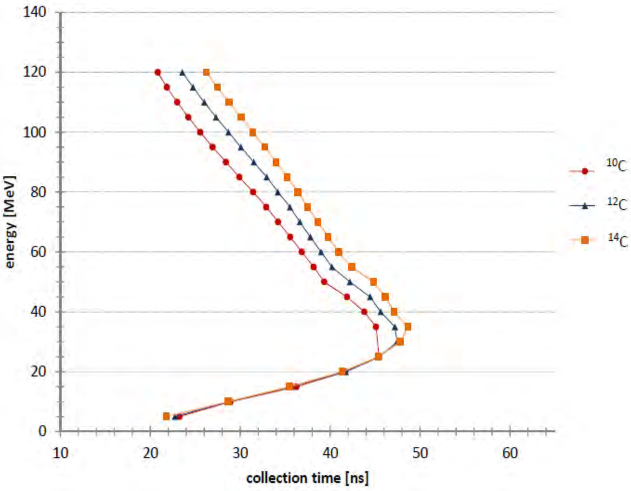

Figure 2: *Model calculation for Carbon isotopes ^{10}C, ^{12}C, ^{14}C*

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Investigation of linear momentum transfer dynamics in incomplete fusion for $^{16}O + ^{175}Lu$ system at $E \approx 96$ MeV

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The study of incomplete fusion (ICF) is still an active area of investigations due to complex nature of incomplete mass transfer mechanism and its ambiguous dependence on various entrance channel parameters: projectile energy and structure, linear momentum transfer, α-separation energy and mass-asymmetry of the target-projectile system. It has been observed from earlier studies that incomplete fusion (ICF) starts competing with complete fusion (CF) at projectile energies just above the Coulomb barrier [1, 6]. Britt and Quinton [7] first pointed out the ICF features at lower projectile energies with the break-up of projectiles like ^{12}C, ^{14}N, and ^{16}O into α-clusters. The most unambiguous evidence for ICF was provided by Inamura *et al.* [8]. Forward recoil range distribution (FRRD) measurements are particularly attractive for the study of fusion incompleteness due to fractional linear momentum transfer from projectile to target nucleus. Owing to the fractional linear momentum transfer, the ICF product follows a shorter range in the stopping medium as that of CF product.

In the present work, to investigate the ICF reaction dynamics, the FRRDs of some evaporation residues have been measured for $^{16}O + ^{175}Lu$ system at ≈ 96 MeV. The recoil catcher activation technique followed by the off-line gamma spectroscopy has been used. The experimentally measured recoil ranges are compared with the recoil ranges calculated using the classical approach and the stopping power and range software SRIM [9] and the residues are interpreted in terms on CF and/or ICF. Different partial linear momentum transfer components are attributed to the transfer of ^{12}C and/or ^{8}Be and/or ^{4}He from the projectile ^{16}O to the target nucleus, which reveals that measurements are consistent with ICF reaction hypothesis of break-up fusion (BUF) model [10] wherein fusion of projectile fragments takes place with the target. It may be concluded from the present study that the residues are not only populated via CF but ICF is also found to play an important role in the production of various evaporation residues involving direct α-cluster emission.

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Role of Projectile Break up in Fusion Reactions

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At moderate excitation energies the dominating fusion processes are (i) Complete Fusion (CF) and Incomplete Fusion (ICF) [1, 2]. However, in recent years at low projectile energies i.e., near and above the Coulomb barrier (CB), the ICF sets in, where the CF supposed to play a key role to the total fusion cross-section. In order to explain ICF reaction dynamics several dynamical models such as SUMRULE model [3], Break-Up Fusion (BUF) model [4], Promptly Emitted Particles (PEP's) model [5] etc. have been proposed. But none of these models is able to explain the presence of ICF reaction processes at such low incident energies, hence, is a topic of current interest.

With these motivations, in the present work the excitation functions (EFs) for several evaporation residues produced via $^{16}O+^{115}In$ interactions have been measured at energies ranging from ≈ 4-7 MeV/nucleon by employing recoil-catcher technique followed by offline γ-ray spectroscopy. These measured EFs have been analyzed in the framework of statistical model code PACE4 [6]. A significant contribution of ICF has been observed in the production of α-emitting channels. To observe the relative importance of CF and ICF and to find out some systematics the ICF fraction has been extracted. The details of the work will be presented.

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Study of the decay of $^{291}115^{*}$ formed in ^{48}Ca+^{243}Am reaction

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Synthesis of super-heavy elements (SHE) and study of their decay properties provide important insight in to the behaviour of nuclear matter under extreme conditions of high *Z*. The deformations and orientations of target and projectile nuclei play a significant role in the synthesis of SHE. Experiments have been performed using projectiles of ^{48}Ca with deformed targets like the isotopes of U, Pu, Am, Cm, Bk and Cf. Such reactions show significant enhancement of fusion cross-sections, compared to ones using doubly magic ^{208}Pb targets. In order to synthesize a new element with Z=115, an experiment was performed recently [1], using the radioactive target nucleus ^{243}Am with ^{48}Ca beam. The 2n, 3n and 4n decay cross-sections at excitation energies E^*=33-45 MeV were measured. In this contribution we study the decay of $^{291}115^*$ formed in above reaction using the dynamical cluster-decay model (DCM) [2] and calculate the xn evaporation residue (ER) cross-sections. The DCM defines the decay cross-section in terms of ℓ partial waves as:

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0 P\,; \qquad \mathrm{k} = \sqrt{2\mu E_{c.m.}/\hbar^2}\,.$$

μ is reduced mass and m, the nucleon mass. P refers to WKB penetrability and P_0, the pre-formation factor. Static and dynamic deformations are included upto β_2, with optimum orientations.

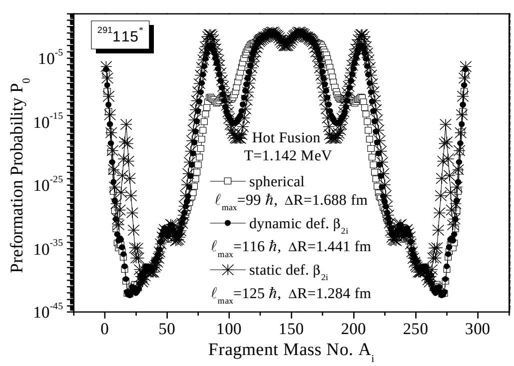

Figure 1: *P_0 for ^{48}Ca+^{243}Am→$^{291}115^*$ reaction as a function of A_i for spherical, static-β_{2i}, dynamic-β_{2i} deformed choices of fragments with optimum hot orientations at E^*=33.37 MeV for ℓ_{max}-values.*

Figure 1 shows that the potential energy surface (PES) for spherical case prefers symmetric fission, where as the same for deformed choice gives asymmetric peaks in heavy mass fragments. The PES are almost identical for static and dynamic choices of deformations, except that for the static case, higher ℓ-values and smaller neck-length parameter ΔR-value are required for fitting of the data. Whereas only the 2n ER cross-section can be fitted with the spherical choice, deformations play a significant role in fitting of 2n, 3n and 4n ER cross-section data of Z=115 super-heavy nucleus, with ΔR remaining within the range of nuclear proximity of ~2 fm.

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A study of proton breakup from exotic nuclei through various reaction mechanisms in 40A - 80AMeV energy range

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Here we have studied the single proton breakup from weakly bound exotic nuclei with several reaction mechanisms separately with their total and interference effect, in order to clarify quantitatively which would dominate the measured observables. We have considered the following mechanism (i) the recoil effect of the core-target Coulomb potential which we distinguish from the direct proton-target Coulomb potential, and (ii) nuclear breakup, which consists of stripping and diffraction. Thus, we have calculated the absolute values of breakup cross sections and parallel momentum distributions(LMD) for 8B and 17F projectiles on a light and a heavy target in a range of intermediate incident energies (40*A*–80*A* MeV) in each reaction mechanism. Furthermore we study in detail the interference among the two Coulomb effects and nuclear diffraction. The calculation of the direct and recoil Coulomb effects separately and of their interference is the new and most relevant aspect of this work.

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Dynamics of projectile and projectile spectator fragmentation in heavy-ion collisions at E = 600 MeV/nucleon

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The symmetry energy and compressibility determination of nuclear matter are uniquely related with the study of heavy-ion collisions at intermediate energies. Many theoretical and experimental efforts have been made to constrain the density dependence of symmetry energy around normal nuclear matter density using neutron skin, Giant Dipole Resonances (GDR), mass measurement, isospin diffusion, double neutrons to protons ration and isoscaling[1-3], but, in contrary very few at supra-saturation densities[4-6]. Parallelly, the compressibility of nuclear matter has been determined to be 235$\pm$14 MeV from Giant Monopole resonance oscillations in heavy-ion collisions[7]. When the community tries to constrain the compressibility at supra-saturation densities, the results were found to vary from soft (200 MeV) to stiff (380 MeV) till date[8-10].

With the recent available data from the GSI, Germany for the multiplicity of neutrons from the projectile spectator decay[11] and multiplicity of intermediate mass fragments from the projectile fragmentation at E = 600 MeV/nucleon[12], has given us an ample opportunity to determine the symmetry energy and compressibility of nuclear matter at supra-saturation densities.

By performing the analysis with IQMD model for the Sn isotopes at E = 600 MeV/nucleon, we observed that (1) The soft symmetry energy can explain the data better for the isospin sensitive obserbavle i.e. multiplicity of neutrons [13] (2) The hard equation of state can justify the nuclear matter at E = 600 MeV/nucleon using the isospin insensitive observable i.e. multiplicity of IMFs. The more study is the need of the time to constrain the symmetry energy as well as compressibility of the nuclear matter at higher incident energies.

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On the sensitivity of nuclear stopping towards the isobaric nuclei in heavy ion collisions

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Nuclear stopping is investigated for the asymmetric collisions by means of isospin dependent quantum molecular dynamics (IQMD) model [1]. The work focuses on the study of nuclear stopping associated with the final heavy fragments in reactions induced by both the neutron-proton symmetric and the neutron-rich projectiles, in the intermediate energy region. The effect of different equations of state (with and without momentum dependent interactions) is also investigated on nuclear stopping. Our result shows that nuclear stopping is strongly affected by the asymmetry of the colliding nuclei as well as by equation of state. Our theoretical results follow the same trend as the experimental findings of FOPI collaboration.

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Sub-Barrier Fusion of Halo and Weakly bound Projectiles with Heavy Nuclei Using Different Proximity Based Potentials

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With the availability of radio-active nuclear beams at several laboratories, it is possible to study the fusion of nuclei with some interesting properties. The nuclei of our interest are halo-nuclei which have abnormal sizes and weakly bound nuclei with large break-up probability. The most interesting thing about the fusion of halo nuclei with heavy nuclei is that they lead to a much larger fusion cross-section than the other isotopes. This enhancement becomes especially large at low energies. Similar is the case with the weakly bound nuclei which have large break-up probability due to the low coulomb barriers associated with breakup. They break-up into charged fragments which can be easily detected. The barrier heights of the systems with weakly bound nuclei are found to be reduced in comparison to systems with their associated stable isotopes. As a result of this reduced height, enhancement is observed in the sub-barrier fusion cross-sections of weakly bound nuclei.
We aim to study sub-barrier fusion of halo-nuclei, weakly bound nuclei with heavy nuclei using different proximity based potentials [1]. This study is carried out using potentials due to AW 95, Bass 80 and Proximity 2010. Earlier, fusion using these potentials is studied in the above barrier region. We planned to study sub-barrier fusion of these special nuclei using these potentials. The fusion cross-section are calculated using a new parameterized form of Wong model [2], since the original Wong parameterization is inadequate to account for the total fusion cross-sections of halo and weakly bound projectiles.

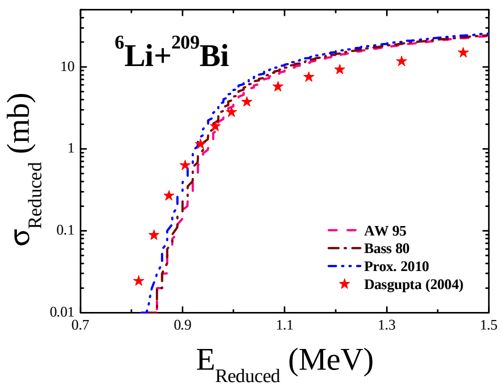

Figure 1: The reduced fusion cross-section $\sigma_{Reduced}$ (mb) as a function of the reduced center of mass energy $E_{Reduced}$ (MeV) for the reaction of $^{6}Li + ^{209}Bi$. The dashed, dash-dotted and dash-double dotted lines represent the calculations for AW 95, Bass 80 and Proximity 2010 potentials respectively. The stars represent the experimental data.

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Decay competition for IMF produced in the collisions ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca at 10 A·MeV

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De-excitation modes of compound systems ^{118}Ba and ^{134}Ba, produced respectively in the ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca collisions at 10 A·MeV, are investigated. In particular, the competition between the various disintegration decay path of medium mass compound nuclei, also referred as Intermediate Mass Fragments (IMF), formed by fusion processes and the isospin dependence of the decay process are studied. Data were taken at the INFN-Laboratori Nazionali del Sud (LNS) by using the CHIMERA array and complement a former experiment performed at GANIL where the same mechanisms were studied at lower excitation energies [1], [2]. First results show evident staggering effects in the Z distributions, as well as different isotopic composition and enrichment for the reaction products in the two systems [3], [4] and [5]. Absolute cross sections calculations of the reaction products are still in progress, and this outcome could shed light on the isospin influence on the reaction mechanism and fragments production. The outcome are interpreted on the basis of dynamical-model calculations.

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Excitations of low-lying dipole states via Nuclear and Coulomb potential in exotic and stable nuclei

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In the last years the properties of collective states in neutron-rich nuclei have been studied. In particular, special attention has been devoted to the presence of dipole strength at low excitation energy. In our previous calculations based on microscopic RPA we have shown that by increasing the neutron number, some strength appears at low energies in the dipole strength distribution, well below the region of the dipole giant resonance. This strength has been often associated to the possible existence of a new collective mode of new nature: the Pygmy Dipole Resonance (PDR). This mode is carrying few per cent of the isovector EWSR, and it is present in many isotopes with a consistent neutron excess.

Therefore their appearance is more pronounced in nuclei far from the stability line but its presence has been established also for very stable nuclei like ^{208}Pb.

In this mode, the transition densities show clearly that the isoscalar and isovector components are strongly mixed. This feature allows the possibility of studying these low lying dipole states by using an isoscalar probe in addition to the conventional isovector one.

We have shown [1] that valuable informations on the nature of the PDR can be obtained by excitation processes involving also the nuclear part of the interaction. These analyses have been carried out on the ^{132}Sn nucleus with different partners of the reaction like ^{4}He, ^{40}Ca and ^{48}Ca. Due to the well known adiabatic cut-off effect, the relative importance of the Coulomb excitation changes with the variation of the incident energies, while the excitation produced by the nuclear interaction is almost independent of the incident energy. Therefore the relative population of the PDR with respect to the GDR may change by varying the parameters of the reactions. In particular, at low incident energy the excitation probability of the PDR state is sensibly higher than the GDR one.

Our results then suggest that the investigation of the PDR state can be better carried out at low incident energy (below 50 MeV/nucleon). At these lower energies, low lying states of higher multipolarities have higher probability to be excited. In some case it may be hard to single out dipole states among all the other ones, although low lying quadrupole and octupole states have very narrow widths. A way to distinguish them can be achieved by mean of differential cross section for the low lying states which show characteristic behaviors at small forward angle. The analysis of inelastic scattering for alpha particles as well as ^{12}C are performed by using the DWBA calculations where we have used our microscopic form factor obtained by a double folding procedure [1]. This is particular important for the PDR since it has been shown that this state does not display the usual collective-type behavior, hence one can not make use of the usual standard collective form factors. The calculation have been performed for the isotope ^{68}Ni. Hopefully it will be possible to test some of the conjectures elaborated here at the Laboratori Nazionali del Sud in Catania where recently a relatively intense beam for this isotope has been produced.

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Coupled-reaction channel effects in the elastic scattering of weakly-bound nuclei

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The exotic nuclei are characterized by new structure phenomena like halo, neutron-skin and shell modification induced by their weak binding energies.
For these weakly-bound nuclei, the continuum coupling is playing a significant role, since the scattering states are much closer to the continuum states than in stable nuclei. This aspect is important for structure and reaction features. Direct reactions on proton target (elastic and inelastic scattering, one and two-neutron transfer) can be used to investigate the new structure properties, provided we take into account the effects due to coupling to continuum and to the main contributions of reaction channels in the reaction framework.

In this talk, these effects will be discussed in the case of the proton reaction analysis of the data collected for the exotic ^{8}He [1,2,3] and ^{10,11}Be [4,5] nuclei. The Coupled Reaction Channel framework will be explained. It is used to obtain a consistent data interpretation of all the reaction channels and to extract the nuclear structure. This approach is also powerful to understand the virtual coupling potential induced by continuum and reaction channels in the elastic scattering.

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Core excitations in the structure and reactions of halo nuclei

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It is well known that, an accurate description of reactions involving weakly-bound nuclei, such as halo nuclei, requires the inclusion of the coupling to the continuum (i.e., unbound) states. For two-body projectiles, a successful technique to describe these processes is the Continuum-Discretized Coupled-Channels (CDCC) method. Here the continuum is replaced by a discrete set of functions, each one representative of a region of the continuum relevant for the reaction. The standard CDCC method uses an average of the scattering two-body wavefunctions in each energy interval (named "bin"). Alternatively, the continuum spectrum can be described by the eigenstates of the two-body Hamiltonian in a basis of square-integrable functions, or pseudo-states (PS).

In this contribution we present a PS basis obtained performing a simple analytic local scale transformation to the harmonic oscillator basis (THO). This THO basis is easy to calculate and reproduces a wide variety of observables, requiring a small number of functions compared to other bases. Moreover, narrow resonances are well characterized by one or two PS. Recently, we have extended this basis to described systems with a valence+core structure (such as the halo nuclei), taking into account the possible excitations of the core [1]. This is the case of ^{11}Be and odd A carbon isotopes. We have considered two models in order to reproduce the valence-core Hamiltonian. One of them is the particle-rotor model. In a second model, the valence-core interaction is calculated from microscopic transition densities of the core. This last model is found to be a good representation of odd halo nuclei. It reproduces the available information about ^{19}C ground state and continuum.

We have applied these two models to the breakup of ^{11}Be on ^{12}C at 70 MeV/nucleon. The reaction is analyzed within the DWBAx framework taking into account the possible excitations of the core. The angular distribution of the breakup shows an important sensitivity with respect to the spectroscopic factors of the valence+core configurations [2] as shown in Fig. 1. Therefore, it is possible to infer such information for resonances even for components where the core is in an excited state. Other reactions usually used to obtain these factors, e.g., transfer reactions, only give information about the components with the core in its ground state for the resonances.

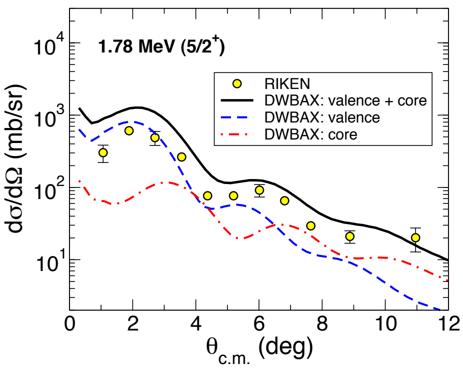

Figure 1: *Angular distribution of the breakup* of ^{11}Be on ^{12}C at 70 MeV/nucleon at the E_x=1,78 MeV state. The dashed line represents the valence contribution, the dot-dashed represents the contribution of the core and the solid line is the coherent sum. The experimental data is obtained from [3].

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Study of the fission fragment angular distribution (FFAD) at the CERN n_TOF facility

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The angular distribution of the fragments (FFAD) produced in the fission of a deformed nucleus is an important observable to investigate the nuclear fission process and the nuclear structure, in particular the properties of transition levels close to the fission threshold [1,2]. In addition a better knowledge of this magnitude will improve the detection efficiency, which is required to achieve more accurate measurements of the fission cross sections [3].

In order to measure the FFAD of neutron-induced reactions, a fission detection setup based on parallel-plate avalanche counters (PPACs) has been developed. It was successfully used at the n_TOF facility (CERN) to obtain the FFAD of the ^{232}Th(n,f), taking full advantage of the accurate neutron energy resolution and the wide energy range (up to hundreds of MeV). This measurement confirmed the large variations of the anisotropy around the fission chances and the perpetuation of the anisotropy in the spallation regime [4].

The ^{234}U(n,f) cross section is higher than the ^{232}Th(n,f), which makes the even-even uranium isotope, a good candidate to study the vibrational resonances in the threshold region. The existing data show large anisotropy values in the threshold region [5,6,7,8] and provides information till 15 MeV [9]. However, the existence of a structure-like behaviour of the anisotropy in the 300 keV region has not been observed yet.

In this work, we present the preliminary results on the analysis of the ^{234}U(n,f) data, which allows us to study the anisotropy in this region and to extend the data beyond 20 MeV.

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Towards reliable nucleon optical potentials in the regime of non-stable nuclei

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Optical potentials are basic ingredients of most reaction calculations and are usually inferred from corresponding elastic scattering cross sections. For exotic nuclei at the limit of binding, studied by means of reaction experiments at radioactive ion beam facilities, experimental data are scarce and the determination of phenomenological optical potentials is hampered. The use of optical potentials of an adjacent stable nucleus or one obtained by extrapolation from this stable nucleus is usually problematic because of the non-standard structure of exotic nuclei. In this contribution (semi)microscopic nucleon optical potentials for exotic nuclei within a nuclear matter approach similar to that of Amos et al. [1] are presented. Especially, compact forms of the density dependent g-matrix [2,3] as well as a reasonable occupancy of shell model states are used to determine nucleon optical potentials at energies between 30 and 150 MeV. The quality of the obtained nucleon optical potentials is tested by comparison with available elastic data of elements with several stable isotopes. The variations of the nucleon optical potentials in the regime of exotic nuclei as well as their impact on corresponding cross section calculations are systematically studied.

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Experiments with a double solenoid system

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Abstract. A recent experiment has been performed in **t**he double solenoid system **Radioactive Ion Beams in Brasil** (RIBRAS) by impinging a pure ^{6}He secondary beam on a thick CH_2 target to measure the ^{6}He+p excitation function. Results of this experiment will be presented.

RIBRAS [1] is presently the only experimental equipment in South America capable of producing secondary beams of rare isotopes. It consists of two superconducting solenoids, installed in one of the beam lines of the 8 MV Pelletron Tandem accelerator of the University of São Paulo. The secondary beam is produced by the in-flight technique and is usually contaminated with particles coming from the scattering and reactions in the primary target such as ^{7}Li, alpha and other light particles as protons, deuterons and tritons. Solenoids are good selectors due to their large acceptance and the double solenoid system provides ways to improve the quality of the secondary beam by using a degrador foil in the midway between the two solenoids. The main contamination of the secondary beam are the $^7Li^{2+}$ particles coming from the primary beam. A degrador placed between the two solenoids is able to separate those particles from the ^{6}He beam providing an additional charge exchange $^7Li^{2+\text{-->}3+.}$ In addition, the differential energy loss in the degrador provides further selection of the light particles as protons, deuterons, tritons and and alpha particles by the second solenoid. Here we present the results of the first experiment performed at RIBRAS using both solenoids. A pure ^{6}He beam was produced and the reaction ^{6}He+p was measured using a thick CH_2 target. Energy spectra of the protons emitted from the ^{6}He+p reaction have been measured at 0, 20 and 25 degrees in the laboratory and a peak at 11.2 MeV ^{7}Li excitation energy was seen in the three angles.

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Sub-barrier Fusion and Neutron Transfer with Positive Q-value

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It has been proposed for about three decades that the fusion cross section (especially at sub-barrier energy) will be greatly enhanced by the nucleon(s) transfer with positive Q-value due to the additional kinematic energy increase [1,2]. Some experimental results do indeed support this point of view. However, a recent experiment on the fusion of the ^{132}Sn+^{58}Ni system didn't show any enhancement caused by the positive Q-values transfer channels comparing to its reference systems [3].

At first, the effects of multi-neutron transfers with positive Q-value on the sub-barrier fusions for the systems recently measured, such as ^{32,36}S, ^{40,48}Ca projectiles bombarding on ^{90,96}Zr, $^{112-124}$Sn targets, are discussed and summarized briefly. Second, for the sake of simplicity, we focus our attention on two-neutron (2*n*) transfer with positive Q-value. The fusion excitation functions of ^{16}O+^{76}Ge and ^{18}O+^{74}Ge at energies spanning the Coulomb barrier were measured by an electrostatic deflector setup at the HI-13 tandem accelerator of the CIAE (cf: Fig.1). Both systems possess very similar nuclear structures and form the same compound nucleus, but the Q-value of 2*n* stripping channel is +3.746 MeV for the latter. Experimental results show that the excitation functions and barrier distributions of these two systems are almost identical, and can be well reproduced by coupled-channels calculations when only the inelastic channels were taken into account. It indicates that no visible effects of positive Q-value 2*n* transfer exist in the ^{18}O+^{74}Ge system.

In order to make clear the effect, a systematic investigation was made on the ^{16,18}O-induced fusions of which the experimental data are available in the literature. However, the situation becomes more complicate, which is beyond the considerations of up-to-date models. The effect of neutron transfer, especially for the case with positive Q-values, on fusion is still an open question.

Details of the experiment, data analysis, systematic investigation, and discussion will be presented in the conference.

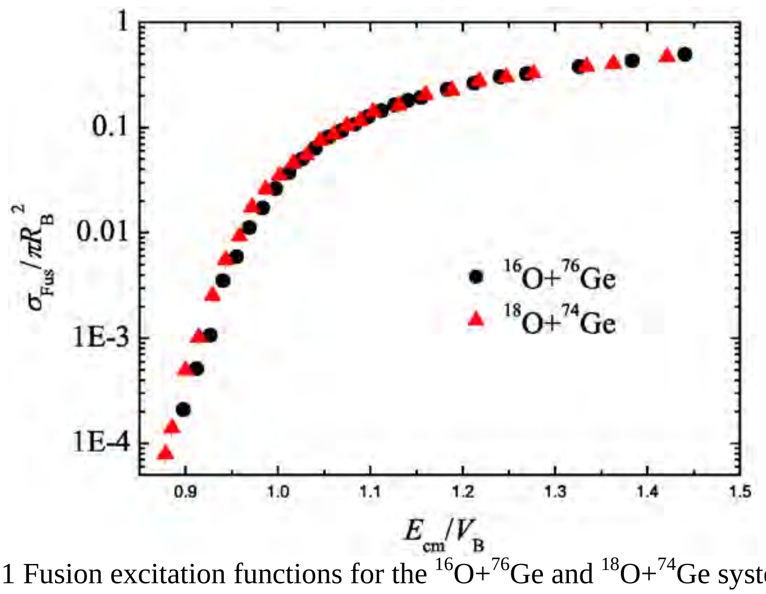

Fig. 1 Fusion excitation functions for the ^{16}O+^{76}Ge and ^{18}O+^{74}Ge systems.

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Spectroscopy of ^{20}Ne via low-energy ^{19}F(p,α) reaction

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We will discuss new results obtained by studying the nuclear reaction ^{19}F(p,α_0) at low bombarding energies, from 540 up to 1034 keV. The experiment has been performed by using the TTT-3MV tandem accelerator at the University of Naples. Thin aluminium foils, placed in front of detectors, have been used to stop ejectiles due to elastic and inelastic scattering. In this way, due to the very large reaction Q-value [1], background free α-particle energy spectra have been obtained. This allows to obtain excitation functions in a large angular range (from 20° to 160° in the laboratory frame, in 10° step). The analysis of angular distributions in terms of cosine powers [2-5] allows to refine the spectroscopy of the self-conjugated compound nucleus ^{20}Ne in an energy region where the existence of quartet excitations has been predicted [6]. For some of these excited states, spin-parity assignments reported in the literature show contrasting values [1,3,4]. From the preliminary analysis of angular distributions obtained in the present experiment, we can assign J^{π}=0$^+$ for the narrow 13.647 MeV state, differently from the alternative J^{π}=2$^+$ assignment reported in Ref. [3].

Angle-integrated cross section and astrophysical factor have been also extracted and compared with direct data reported in the literature. In the energy region around the 840 keV resonance, our data agree well with all data sets coming from previous experiments [3,4]. On the contrary, at $0.68MeV < E_{cm} < 0.75MeV$, our cross-section is 30-50% larger than the (normalized) data obtained by Isoya et al [3] and reported in the NACRE compilation [7]. At low energies, $0.54 < E_{cm} < 0.72MeV$, our data are in good agreement with absolute measurement performed by Breuer [2]; the small increase of the astrophysical factor in the energy region around 500 keV would be in agreement with the possible existence of two broad states at around 400 keV, as suggested by Breuer [2] and reported also in [1]. Preliminary results on these topics will be discussed.

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Nuclear stopping for heavy ions induced reactions in the Fermi energy range : from 1-body to 2-body dissipation

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Properties connected to the transport of nuclear matter like the energy dissipation or the isospin diffusion/migrationin the Fermi energy domain can be probed by measuring the nuclear stopping of the 2 impinging nuclei in central collisions. In this contribution, we will present experimental data concerning nuclear stopping measured with the INDRA 4π array for a large panel of symmetric systems and incident energies covering the overall Fermi energy range. A comparison with realistic dynamical models like the hybrid model HIPSE will be done and the link to fundamental quantities such as the 1-body dissipation provided by the Mean-Field or the 2-body dissipation produced by in -medium Nucleon-Nucleon collisions (NN). In particular, in-medium NN cross sections will be extracted and discussed. We will show that it can bring important constraints to the transport models used in this energy range.

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Probing the EoS of Neutron-rich Matter

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The relationships between energy, pressure, temperature, density and isospin asymmetry $\delta=(\rho_n-\rho_p)/\rho$ within finite nuclear systems, neutron stars or core-collapse supernovae are fundamental properties of nuclear matter. It is an important objective of many laboratory experiments and astrophysical observations to describe these relationships by a nuclear Equation of State (EoS), which can be separated into a symmetric-matter contribution that would be appropriate for equal neutron and proton densities, and a symmetry-energy term, proportional to the square of the asymmetry. Nuclear systems can be momentarily produced in the laboratory at a range of densities and isospin asymmetries. Studies of such systems can provide constraints on the EoS that are relevant to the properties of nuclear matter and to dense astrophysical objects. In this talk, I will discuss some the various laboratory observables that can provide constraints on the EoS [1]. I will discuss some of the measurements that have been performed and the constraints that have been derived from them. I will also discuss some new results and the opportunities for future constraints that may be expected with planned and future experiments.

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Temperature and symmetry energy of neutron-rich fragment in heavy-ion collisions

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The symmetry energy of neutron-rich nucleus and fragment in heavy-ion collisions is one of the most interesting question in nowadays nuclear physics, since it is important both in nuclear physics and nuclear astrophysics. Due to the dependence of nuclear symmetry energy on temperature and density, debated results were shown in supra-saturate nuclear matters, while the symmetry energy is an very important parameter in the searching of drip-line of very neutron-rich nucleus.

In heavy-ion collisions, due to the contribution of entropy the binding energy thus the symmetry energy of the measured fragments at nonzero temperature, which undergo sequential decay after they are formed from the hot and dense emitting source, are different to those for the zero temperature. Realizing the temperature of the measured fragments are quite different to that of the hot emitting source, the isobaric methods were used to determine the symmetry energy of neutron-rich nucleus from its binding energy at zero temperature, and the ratio of symmetry energy to temperature of neutron-rich fragment in heavy-ion collisions. At the same time, reasonable temperature of measured heavy fragments is also determined using isobaric yield ratio method.

Combining these results, the symmetry energy of neutron-rich nucleus at non-zero temperature is extracted. The symmetry energy of nucleus show different trends at zero temperature and nonzero temperature.

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Pygmy and Giant Dipole Resonances by Coulomb Excitation using a Quantum Molecular Dynamics model

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Pygmy and giant dipole resonance (PDR and GDR) in Ni isotopes have been investigated by Coulomb excitation in the framework of the isospin-dependent quantum molecular dynamics model (IQMD). The spectra of gamma rays are calculated and the peak energy, the strength and full width at half maximum (FWHM) of GDR and PDR have been extracted. Their sensitivities to nuclear equation of state, especially to its symmetry energy term are also explored. By a comparison with the other mean field calculations, we obtain the reasonable values for symmetry energy and its slope parameter at saturation, which gives an important constrain for IQMD model. In addition, we also studied the neutron excess dependence of GDR and PDR parameters for Ni isotopes and found that the energy-weighted sum rule (EWSR) PDR**m1**/GDR**m1**% increases linearly with the neutron excess.

Shear viscosity over entropy density ratio of nuclear matter in intermediate-energy heavy ion collision

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Shear viscosity is one of important transport parameters of matter. In heavy-ion collision in a wide beam energy region, a fluid-like nuclear fireball can be created. Experimental results in ultra-relativistic heavy-ion collisions have indicated a near-perfect quark-gluon liquid which has very small ratio (eta/s) of shear viscosity over entropy density has been formed at Relativistic Heavy-Ion Collider (RHIC) energy around 200GeV/c Au + Au collisions with help of hydrodynamic calculations. Extensive studies on eta/s have been performed at RHIC energy. However, the knowledge of eta/s is poor for nuclear matter formed in intermediate energy heavy-ion collision. Based on this motivation, we have simulated Au + Au collisions at hundreds MeV/nucleon energies by an isospin-dependent quantum molecular dynamic (IQMD) model and investigated thermal and transport coefficients of nuclear fireball in central region. Our results present time evolutions of the density, temperature, chemical potential, entropy density and shear viscosity of the fireball. The ratio of shear viscosity over entropy density is studied for the whole collision process. Time evolution of shear viscosity over entropy density ratio shows that a minimal η/s occurs in the largest compression stage, which indicates high density nuclear matter is more close an ideal liquid. Moreover, a local minimum, which is about 0.7 to 0.8, emerges from the temperature dependence of η/s in different freeze-out densities, which may correspond to a liquid-gas phase transition occurring in the intermediate energy heavy-ion collisions.

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Onset of the quenching of the Giant Dipole Resonance in nuclei of mass around 120-130

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The disappearance of collective motion with increasing temperature provides additional information on the properties of hot nuclear matter and can be an additional signature of a phase transition. The Giant Dipole Resonance (GDR) is a collective vibration of protons against neutrons with a dipole spatial pattern that can be built not only on the ground state but also on excited states. The GDR gamma-ray yield in hot nuclei has been extensively studied in Sn region: from the systematics is known that up to approximately 200 MeV excitation energy the GDR properties remain remarkably stable [1]. Its energy remains equal to the ground state energy, the width increases smoothly from about 5 MeV at zero temperature to about 14 MeV [2]. The gamma multiplicity from GDR decay increases as a function of excitation energy in agreement with 100% of the energy weighted sum rule strength. In hot nuclei produced in incomplete fusion reactions at excitation energies ranging from 350 and 550 MeV a saturation of the GDR gamma-multiplicity has been observed [3]. This behavior can be qualitatively understood in the framework of several models which predict a gradual quenching of the GDR gamma-emission taking into account the equilibration time of the dipole oscillations with the different degrees of freedom of the hot compound nucleus. In order to disentangle between different models and gain an insight into the degree of freedom playing the principal role in the saturation, experimental data in an excitation energy interval around the point where the onset of the quenching is expected to appear, are necessary. To this aim an experiment has been performed at LNS Catania where 17 and 23 MeV/A ^{116}Sn beams delivered by the Superconducting Cyclotron have been sent on ^{12}C and ^{24}Mg targets. The evaporation residues coming from fusion reactions were focused using the SOLE solenoid on the MACISTE telescope system while the GDR gamma-rays were detected in coincidence using MEDEA, a 180 barium fluoride multidetector. The different target projectile combinations allowed us to explore the excitation energy region from 150 MeV to 330 MeV. Comparison between experimental data and Cascade calculations including different model predictions will be presented in order to draw conclusions on the origin of the quenching mechanism. A link between GDR disappearance and liquid-gas phase transition will be discussed.

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Heavy ion collisions as a tool to investigate the nuclear equation of state and the structure of nuclei

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Heavy ion collisions are a versatile and powerful tool to investigate both dynamic and thermodynamic features of excited nuclei and nuclear matter and to have an insight into the structure of exotic nuclei. In this talk we will present the first results on the ^{40,48}Ca+^{40,48}Ca at 35 MeV/nucleon experiment performed in GANIL, coupling the VAMOS spectrometer to the 4π charged particle array INDRA, to study the nuclear equation of state probed with isotopic distributions measurements. Such a set-up allows us to uniquely identify in charge and mass forward emitted heavy fragments, while having a complete information on the kinematics of the event by the measure of all the particles emitted in coincidence.
Also, the high granularity and energy resolution of the apparatus open the possibility of applying correlation techniques to investigate alpha-cluster states in the ground state of 40Ca, predicted by a dynamical model, and excited states of exotic nuclei. First results on these topics will also be presented.

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Preliminary results on the elastic scattering of ^{8}He on ^{208}Pb at E_{lab} = 22 MeV

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The particular features of ^{8}He made its scattering with heavy targets attractive for the scientific community. ^{8}He is the lightest skin nucleus and it has the largest neutron to proton ratio of the particle-stable nucleus. Only a few scattering data sets at barrier energies are presently available [1, 2]. Compared with ^{6}He, ^{8}He has more neutrons of valence but more tightly bound and its binding energies for 1n and 2n systems are similar whereas in ^{6}He the binding energy for 1n is bigger. The differences between both helium isotopes are expected to be reflected in the elastic cross section for collisions with heavy targets at Coulomb barrier energies.

In order to investigate the dynamics of ^{8}He we performed an experiment at SPIRAL/GANIL facility (Caen, France), as part of a large experimental project devoted to study radioctive light isotopes by means of nuclear reactions induced at energies around the Coulomb barrier [3, 4]. The elastic scattering of ^{8}He on ^{208}Pb has been measured at laboratory energies of 16 and 22 MeV. The heavy nucleus ^{208}Pb provide a strong Coulomb field for the scattering process and the selected energy region is suitable for near-barrier scattering with the mentioned target, as the barrier energy is about 18 MeV. For studying the process, the angular and energy distributions of elastic channel and the ^{6}He and ^{4}He yields from the reactions induced by ^{8}He on ^{208}Pb are measured. Our array of silicon detectors allow us separating the different reaction channels corresponding to lighter ions in the angular range of interest. This compact, large solid angle, position sensitive array was developed at the University of Huelva. Having a very good angular coverage, it has been designed to study direct nuclear reactions induced by light radioactive beams at energies around the Coulomb barrier and it was used for first time for the study of the scattering of the system ^{8}He+^{208}Pb.

In this contribution, the distribution of the elastic scattering of ^{8}He with a ^{208}Pb target at 22 MeV is presented up to 90 deg and discussed together with preliminary calculations. The analysis of the experimental data performed so far has shown that the angular distribution follows the trend of ^{6}He up to scattering angles around 70 deg. For larger angles the absorption becomes even greater what could be interpreted as an effect of 1n transfer reaction.

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Sub-barrier fusion measurements for the ^{6}Li + ^{58}Ni system *

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Recently, the fusion of the ^{8}B+^{58}Ni system was measured at the University of Notre Dame [1], by using the TwinSol facility to produce nuclear radioactive beams. Due to the construction of this apparatus it is possible to make a simultaneous bombardment with various projectiles having the same magnetic rigidity, in our case a ^{8}B, ^{7}Be, ^{6}Li "cocktail" beam was produced [2].

Therefore, at the same time the fusion for ^{6}Li+^{58}Ni also could be measured. The procedure consists in determining the production cross sections for evaporated protons and then deducing the respective fusion cross sections, using the proton multiplicities predicted by the statistical model, developed in the code PACE. The use of theoretical multiplicities was also validated through calculations with the alternate code LILITA , which for this system predicts very similar proton multiplicities in the whole energy interval considered, with a maximum difference of 8%. These results are also supported by calculations previously reported for other systems [1, 4].

In this work, we present the obtained fusion excitation function in the region of sub-barrier energies and the corresponding barrier parameters extracted from the data. A comparison of our results with previously reported data for similar systems shows very good agreement. In particular, by applying a proper data reduction to eliminate trivial effects of size and charge, a comparison is made with fusion data reported by Beck et al. [5] for the ^{6}Li+^{59}Co system. This shows that our data overlap with the fusion excitation function for the Co target and very smoothly extend it down to lower energies.

Finally, in the framework of the statistical model, an analysis of the possible contribution of incomplete fusion is discussed.

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Production of Energetic Light Fragments in Spallation Reactions

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Emission of light fragments (LF) from various nuclear reactions is an interesting unsolved scientific question. Different reaction mechanisms contribute to their production; with different dependences on incident particle, incident energy, mass number of the target, and the type and emission energy of the fragments. Available models cannot accurately predict emission of LF from arbitrary reactions. However, the emission of LF, especially of intermediate and high energies, is important for many applications, such as cosmic-ray-induced Single Event Upsets, radiation protection, and cancer therapy with proton and heavy-ion beams, to name just a few. The Cascade-Exciton Model (CEM) and the Los Alamos version of the Quark-Gluon String Model (LAQGSM) as implemented in the CEM03.03 and LAQGSM03.03 event generators used in the Los Alamos Monte Carlo transport code MCNP6 describe quite well the spectra of fragments with sizes up to ^{4}He across a broad range of target masses and incident energies (up to ~ 5 GeV for CEM and up to ~ 1 TeV/A for LAQGSM). However, they do not predict high-energy tails for LF heavier than ^{4}He. The current versions of CEM and LAQGSM do not account for preequilibrium emission of LF larger than ^{4}He nor for their coalescence from energetic nucleons emitted during the intranuclear-cascade stage of a reaction. The aim of our work is to extend their preequilibrium and coalescence models to include such processes, leading to an increase of predictive power of LF production in MCNP6. Extending our models by including emission of fragments heavier than ^{4}He at the preequilibrium and coalescence stage, and using an improved version of the Fermi Break-up model, provides much better agreement with various experimental data.

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Transfer *vs.* Breakup in the interaction of the ^{7}Be Radioactive Ion Beam on a ^{58}Ni target at Coulomb barrier energies

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The reaction dynamics induced by light weakly-bound Radioactive Ion Beams (RIBs) in the energy range around the Coulomb barrier is strongly affected by the exotic features of light RIBs. Recent experiments [1] showed that the reaction probability is largely enhanced when compared to reactions induced by stable well-bound projectiles, and that this enhancement is mainly triggered by direct reaction mechanisms, such as transfer and breakup. To investigate the role played by different direct processes and their mutual interplay, we have studied the system ^{7}Be + ^{58}Ni at 22 MeV. The ^{7}Be (S_α = 1.586 MeV) RIB was produced by means of the beam-line EXOTIC [2] at the INFN-Laboratori Nazionali di Legnaro (Italy). A secondary beam intensity of ~ 3x10^5 pps was achieved. Charge reaction products were detected by means of 4 ΔE (40 μm) - E (1000 μm) silicon telescopes of the detector array DINEX [3] in the angular ranges θ_{lab} = [40°,75°] and θ_{lab} = [115°,150°].

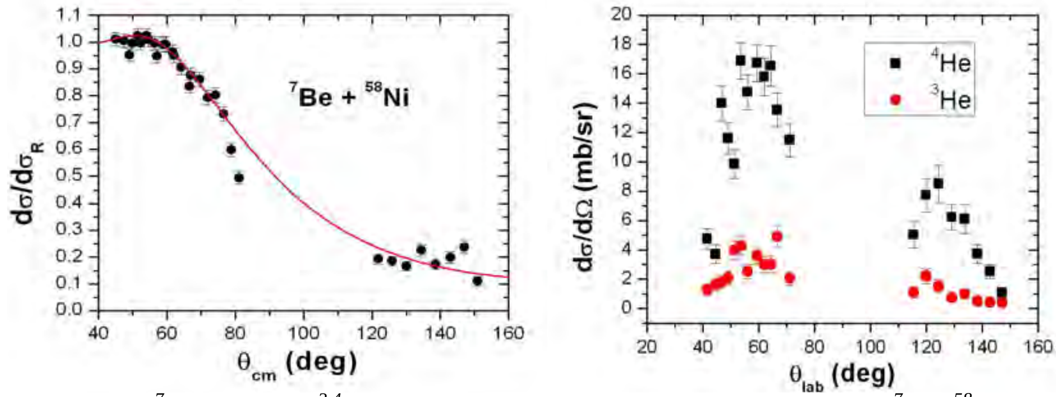

Figure 1: *^{7}Be (left) and ^{3,4}He (right) angular distributions for the system ^{7}Be+^{58}Ni at 22 MeV.*

Fig. 1 left panel shows the ^{7}Be elastic scattering angular distribution, from which we extracted a reaction cross section of 576 ± 20 mb, in good agreement with Ref. [4]. Fig. 1 right panel displays the angular distributions for ^{3,4}He reaction products. Their angle-integrated cross sections sum up to ~ 20 mb and ~ 100 mb for ^{3}He and ^{4}He, respectively. The large difference in the production cross sections for the two helium isotopes indicates that the strongest populated reaction mechanism in this energy range is the ^{3}He-stripping: ^{7}Be + ^{58}Ni → ^{4}He + ^{61}Zn (Q_{gg} = + 9.46 MeV). Moreover, within the statistics collected by our experiment, no ^{3}He-^{4}He coincidences were detected, leading to the conclusion that the breakup channel ^{7}Be → ^{3}He + ^{4}He plays a minor role in the reaction dynamics induced at near-barrier energies by light RIBs (at least) on medium-mass targets.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

^{238}U(n, γ) reaction cross section measurement with C_6D_6 detectors at the n_TOF CERN facility

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Nowadays, nuclear energy appears as an essential source of energy for the future, as the European Strategic Energy Technology Plan points out. Therefore, to achieve a long term sustainability several new nuclear system are being explored to face the major problems of nuclear energy: safety, nuclear waste and economical factors. The design and development of these new reactors requires accuracy and precision that still challenge the present knowledge of basic nuclear data [1, 2]. In this context, the measurement of the ^{238}U(n, γ) reaction cross section is of high priority and is part of the NEA High Priority List [3], a compilation of the most relevant nuclear data requirements. In addition to its importance for nuclear technologies, an improvement in the p-wave resonance parameters of ^{238}U can also improve the determination of parity violation effects observed in ^{239}U resonances [4].

Despite a lot of measurements for the ^{238}U capture cross section, inconsistencies are still present both in the low energy and in the unresolved resonance regions [5]. This uncertainty influences both the fast and thermal reactor systems and contributes to the uncertainty on Pu isotope density at the end of cycles. For these reasons, a proposal was submitted for a series of joint measurements of the ^{238}U(n, γ) reaction cross section at the n_TOF facility at CERN and at the EC-JRC-IRMM facility GELINA, with the goal to reach an uncertainty below 2% in the energy range from few eV to hundreds of keV. The preliminary results of the recent ^{238}U capture cross section measurement, performed in April 2012 at the n_TOF facility using C_6D_6 scintillator detectors, are presented. Thanks to the very high instantaneous neutron flux, the excellent energy resolution and the low repetition rate of the n_TOF neutron beam it has been possible to perform a very high accurate and precise measurement in an energy range from the thermal point to about 500 keV.

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[2] Report of the Numerical results from the Evaluation of the nuclear data sensitivities, Priority list and table of required accuracies for nuclear data. FP-7 IP-EUROTRANS;
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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Study of shell closure effect on evaporation residue survival

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For producing super heavy elements, it is important to know how the shell closure affects the fusion fission dynamics. Shell closure of either of the reaction partners has significant effect on fusion dynamics [1], but the effect of compound nucleus (CN) shell closure is not well studied. There are only a few reports, some of which concluded enhanced evaporation residue (ER) survival [2], whereas, some of the reports suggest lowering of nuclear dissipation [3]. To study the effect of CN shell closure on ER survival, we have measured ER cross sections and ER spin distributions for ^{31}P + ^{170}Er, forming the CN ^{201}Bi. ^{31}P beam was delivered from 15 UD Pelletron + LINAC accelerator at IUAC, New Delhi. ER cross sections were measured using Hybrid Recoil mass Analyzer [4] while the γ-rays were detected in coincidence with ERs using the TIFR-4π spin spectrometer [5, 6]. The spin distribution gives the information of partial waves surviving fission. We have compared the results with the system ^{30}Si + ^{170}Er which forms proton shell closed CN ^{200}Pb. In the conference, we would like to present a comparative study of these two reactions in order to understand the effect of CN shell closure on ER survival.

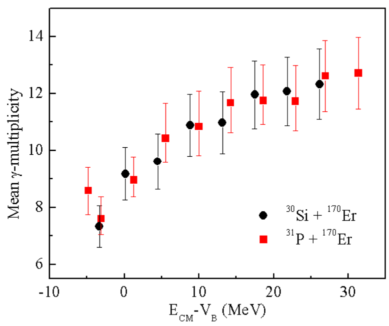

Figure 1: *The mean γ-multiplicities for two reactions ^{30}Si, ^{31}P + ^{170}Er as a function of energy excess over Coulomb barrier.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Inelastic process observed in isobaric charge-exchange reaction of ^{56}Fe at 500 MeV/u

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In the longitudinal-momentum (P_L) distribution of products in isobaric charge-exchange reactions (p, n) and (^{3}He, t), inelastic component, which is attributed to Δ excitation, has been investigated. For example, Udagawa et al. showed that the inelastic component can be a good probe to study nuclear medium effect on Δ excitation [1]. Recently, inelastic component was successfully observed in P_L distribution with ^{208}Pb beam at 1A GeV by using the spectrometer FRS at GSI [2]. In the present study, the P_L distribution in isobaric charge-exchange reaction was observed at E = 500 MeV/u, which is relatively lower than the previous experiments.

The measurement was performed at NIRS. ^{56}Co was produced through isobaric charge-exchange reaction by bombarding a 0.5-mm thick C-target and a 1-mm thick CH_2 target with a primary beam of ^{56}Fe at E=500 MeV/u, provided by HIMAC synchrotron accelerator. The target thickness was selected to make the energy loss equivalent for C and CH_2 target. In order to observe the P_L distributions, the magnetic rigidity of the spectrometer was varied with a step of 0.1% of that corresponding to the primary-beam velocity. The produced ^{56}Co was separated and identified with a high-energy transport system, SB2, used as a doubly achromatic spectrometer. P_L distribution with the proton target is provided by subtracting P_L distribution with C target from that with CH_2 target. As shown in Fig. 1, the inelastic peaks are observed for both target nuclei. P_L distribution with the proton target shows similar behavior to that observed in very recent experiment with a ^{136}Xe beam at 500A MeV [3]. The inelastic peak grows and shifts upward for C target compared with proton target.

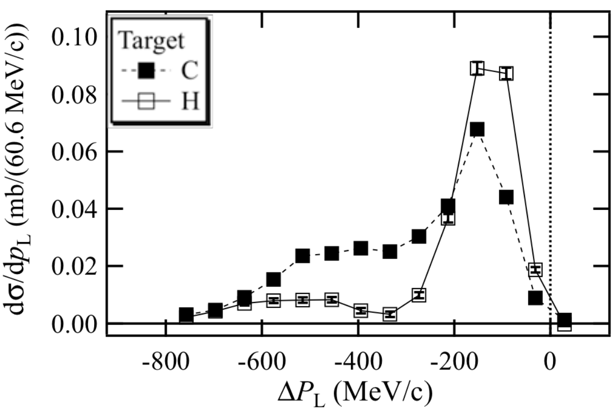

Figure 1: *Observed P_L distribution of ^{56}Co in the frame of primary beam.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Effects of transfer channels on near- and sub-barrier fusion of ^{32}S+^{48}Ca

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The fusion excitation function of ^{32}S + ^{48}Ca has been experimentally studied in a wide energy range, from above the Coulomb barrier down to cross sections in the sub-μb region [1]. The fusion cross section decreases smoothly below the barrier, and the logarithmic slope increases slowly and remains well below the constant S factor limit L_{CS}: no evident hindrance character shows up in the measured energy region (see Fig. 1 panels (a) and (b)). The excitation function for the near-by system ^{36}S+^{48}Ca [2] is much steeper. Those data and the present ones for ^{32}S+^{48}Ca have been analyzed by Coupled-Channels (CC) calculations that are based on the M3Y+repulsion, double-folding potential. While the fusion of ^{36}S+^{48}Ca can be reproduced very well by considering couplings to low-lying states in projectile and target, to explain the data for ^{32}S+^{48}Ca it is necessary to consider explicitly the coupling to pair transfer channels with positive Q-values. The barrier distribution extracted from the ^{32}S+^{48}Ca excitation function has a peculiar shape with two main peaks that the calculations are not able to reproduce in detail. The transfer couplings reduce significantly the disagreement with the data even if the double-peak structure of the barrier distribution remains unexplained.

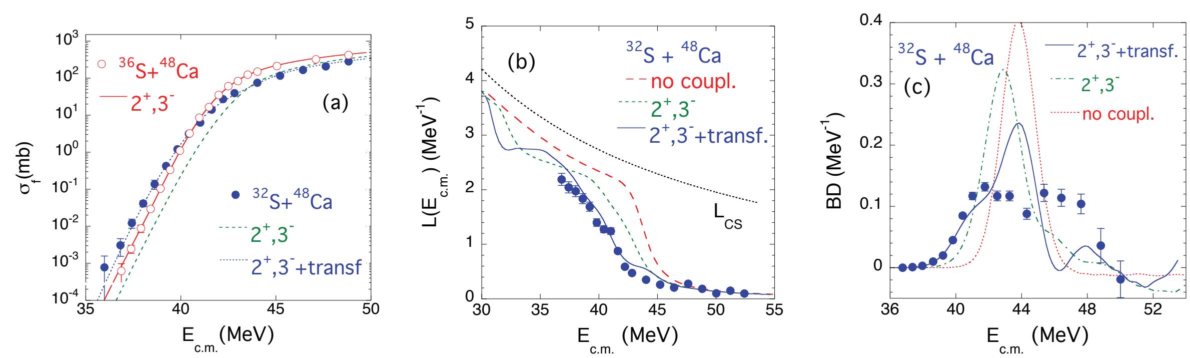

Figure 1: *(a) Experimental fusion cross sections are compared to CC calculations based on the M3Y+repulsion potential. (b) Logarithmic derivative $L(E)$ of the (energy-weighted) cross section; the L_{CS} value is also indicated. (c) Barrier distribution compared with CC calculations*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Sub-barrier fusion of the ^{28}Si+^{28}Si system

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Fusion reactions in the region near and below the Coulomb barrier have been widely investigated in recent years especially in the medium mass region [1,2]. In particular, it has been observed that for some systems at energies far below the barrier the cross section rapidly falls with respect to the theoretical predictions obtained by standard coupled-channel calculations (fusion hindrance). This is appropriately shown by means of the astrophysical S-factor which develops a maximum as a function of the energy when hindrance sets up. This maximum is required when the Q-value for fusion is $Q_{fus}<0$, while it is not needed when $Q_{fus}>0$ [3]. Heavy-ions fusion reactions with positive Q-values play an important role both in the evolution of massive stars (C- and O-burning stages) and in the evolution of the inner crust of accreting neutron stars, where exotic reactions take place (i.e. ^{24}O+^{24}O, ^{28}Ne+^{28}Ne, ^{34}Ne+^{34}Ne). Consequently, it is very important to measure the detailed low-energy behaviour for similar medium-light systems with $Q_{fus}>0$, because this may help in the extrapolation of the low-energy cross-sections for those of astrophysical interest.

We will present in this contribution very recent data for the fusion reaction in the ^{28}Si+^{28}Si system (Q_{fus}=+10.9 MeV). The experiment has been performed at the XTU Tandem of LNL, using a ^{28}Si beam at bombarding energies ranging from above to well below the Coulomb barrier. Evaporation residues have been detected by the electrostatic separator set-up near 0°. The behaviour of the excitation function for this system and its comparison with theoritcal calculations will be discussed.

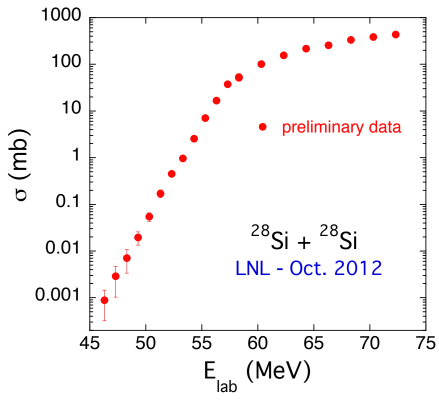

Figure 1: *This is the caption of the figure.*

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Transfer probability measurements in the superfluid ^{116}Sn+^{60}Ni system

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In transfer reactions between heavy ions it is possibile to study at the same time many transfer channels and, in particular, to compare the relative role played by the singel- and the multiple pair-nucleon transfer processes [1]. In particular the study of the two-nucleon transfer mechanism is a powerful tool to investigate correlations of nucleons in nuclei.
At energies below the Coulomb barrier nuclei are at large distances, so that the transfer probabilities depend on the tail of their wave functions and are only slightly influenced by the nuclear potential. In this energy regime, reaction products are excited in a restricted energy region (few MeV). This minimizes the complexity of coupled channel calculations and allows to extract more quantitative information on the correlations close to the ground states [2,3].
A first experiment in inverse kinematics has been performed at the Laboratori Nazionali di Legnaro (LNL) using the large solid angle magnetic spectrometer PRISMA. An excitation function, from above to far below the barrier, for the closed shell system ^{96}Zr+^{40}Ca has been measured [4] and transfer probabilities [5] have been extracted for the neutron transfer channels. Data have been compared with microscopic calculations showing the importance of the transition to the 0^+ excited states.
More recently we performed a study of the main transfer channels in the superfluid ^{116}Sn+^{60}Ni system, where the ground state Q-values for neutron transfers are close to their optimum Q-values. The experiment has been done in inverse kinematics at different bombarding energies from above to well below the Coulomb barrier, detecting the lighter target-like ions with the magnetic spectrometer PRISMA at very forward angles. Measurements of neutrons and protons transfer probabilities have been obtained on the basis of an event-by-event reconstruction of the ion trajectories inside PRISMA [6]. It will be interesting to compare the behaviour of the transfer mechanism to the previously measured closed shell system and to the same kind of theoretical calculations. In this talk the results of this recent measurement will be presented, and a discussion will be made on the possibilities offered in the field by exploiting large solid angle spectrometers.

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[6] D. Montanari et al., Eur. Phys. J.A47, 4 (2011)

Probing the Statistical Decay of Light Hot N = Z Nuclei, α-clustering effects in ^{12}C+^{12}C and ^{14}N+^{10}B reactions.

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A new experimental campaign has recently been proposed at Laboratori Nazionali di Legnaro LNL-INFN, Italy, in order to progress in our understanding of the statistical properties of light nuclei at excitation energies above particle emission threshold, by measuring exclusive data from fusion-evaporation reactions. These properties notably include the excitation energy dependence of the nucleon effective mass, symmetry energy and pairing correlations. In particular, the determination of the nuclear level density in the A$\sim$20 region, the understanding of the statistical behavior of light nuclei with excitation energies $\sim$3 A.MeV, and the measurement of observables linked to the presence of cluster structures of nuclear excited levels are the main physics goals of this work.
Our theoretical efforts in this sense lie in the development of a Monte-Carlo Hauser-Feshbach code for the evaporation of the compound nucleus, which explicitly includes all the experimentally measured particle unstable levels from the online archive NUDAT2.
On the experimental side, a first reaction: ^{12}C+^{12}C at 95 MeV beam energy has been measured, using the GARFIELD + Ring Counter (RCo) apparatuses. Exclusive measurements from fusion-evaporation reactions are used. Results of the data analysis will be shown. The comparison to the code predictions allows us to give constraints on the nuclear level density at high excitation energy for light systems ranging from $\sim$C up to Mg. Residual deviations from a statistical behaviour are observed in α yields and attributed to the persistence of cluster correlations well above the ^{24}Mg threshold for 6 α's decay.
In order to study the same ^{24}Mg compound nucleus at similar excitation energy of our previously studied reaction a new measurement, ^{14}N + ^{10}B at 5.7 A.MeV, was performed at LNL laboratories.
The comparison between the two systems would allow us to further constrain the level density of light nuclei in the mass-excitation range of interest. In this perspective, deviations from a statistical behaviour can be used as a tool to get information on nuclear clustering, both in the ground-state for projectile and target and in the hot source formed in the collisions.

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The experimental liquid-vapor phase diagram of bulk nuclear matter

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The modern investigation of clusters, for which $1 \ll N \ll \infty$, requires a generalization of the thermodynamics developed for infinite systems. For instance, in finite systems, phase transitions and phase coexistence become ill-defined with ambiguous signals. The existence of phase transitions in nuclear systems, in particular of the liquid-vapor kind, has been widely discussed and even experimentally claimed. A consistent and unambiguous approach to this problem requires a connection between finite systems and the corresponding infinite systems. Historically, this has been achieved at temperature $T = 0$ by the introduction of the liquid drop model and the extraction of the volume term, which is a fundamental quantity of nuclear matter. This work extends this approach to $T > 0$, by determining the liquid-vapor coexistence line and its termination at the critical point. Since there is no known experimental situation where a nuclear liquid and vapor are in coexistence, we establish a relationship between evaporation rates and saturated vapor concentration and characterize the saturated vapor with Fishers droplet model. We validate this approach by analyzing cluster concentrations in the Ising and Lennard-Jones models and extracting the corresponding first-order coexistence line and critical temperature. Since the vapor of clusters coexists with a finite liquid drop, we devise a finite size correction leading to a modified Fisher equation. The application of the above techniques to nuclear systems requires dealing also with the Coulomb force. Nuclear cluster evaporation rates can be corrected for Coulomb effects and can be used to evaluate the cluster concentrations in the virtual equilibrium vapor. These cluster concentrations, determined over a wide temperature range, can be analyzed by means of a modified Fisher formula. This leads to the extraction of the entire liquid-vapor coexistence line terminating at the critical point. A large body of experimental data has been analyzed in this manner and the liquid-vapor phase diagram of nuclear matter has been extracted.

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Molecular Dynamics Simulation of Weakly-Bound Projectile Reactions

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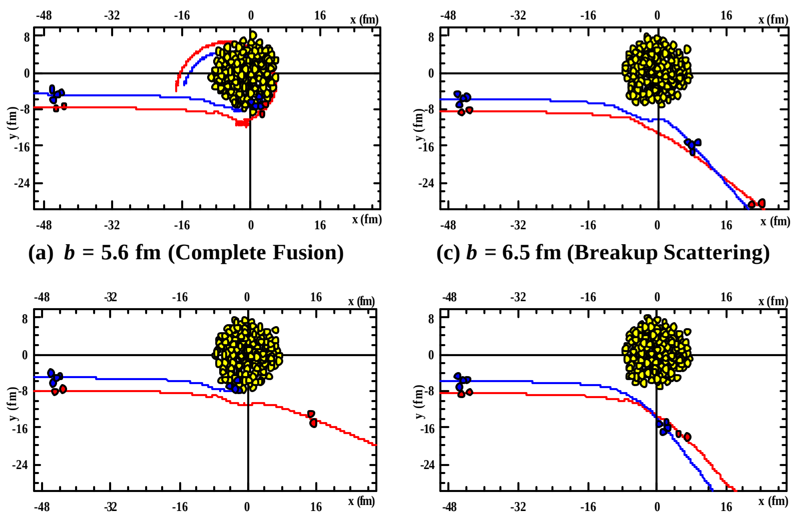
Heavy-ion collisions involving weakly-bound projectiles with heavy targets have been studied using *Continuum Discretized Couple-Channel* (CDCC) method [1], a semi-*classical coupled channel approximation* [2] and a *classical trajectory model* [3]. In the present work we study collisions in a *Classical Molecular Dynamics* (CMD) *model* in which the weakly bound nucleus, say ^{6}Li, is considered as a cluster of ^{4}He and ^{2}H nucleus. The projectile fragments and the target nuclei are constructed in their ground state using a variational potential energy minimization code [4] and an NN potential between all the nucleons reproducing the ground state properties of the nuclei.

The weakly-bound projectile fragments are held together in the projectile nucleus in a configuration corresponding to the observed breakup energy. Initially, the projectile and the target nuclei are brought along their Rutherford trajectories for given initial conditions. The three-body system is then dynamically evolved from a large initial separation upto distances close to the Coulomb barrier using *Classical Rigid Body Dynamics* (CRBD) model [5]. This stage is then followed by CMD [4] evolution of the entire many-body system near and within the projectile-target barrier radius. Thus the Coulomb reorientation effects on the deformed target/projectile and their excitations at close distances are incorporated in the calculations.

Simulation of ^{6}Li+^{209}Bi at a given collision energy and different impact parameters are shown in Figure 1(a-d) in the present model calculations. All the essential features of breakup reactions such as complete fusion, incomplete fusion, no-capture breakup and scattering are demonstrated. Detailed study of the dynamics; and complete and incomplete fusion cross section calculations for ^{6}Li +^{209}Bi, ^{7}Li +^{209}Bi etc. will be presented.

This work is supported by a project grant from DAE-BRNS no. 2009/37/20/BRNS.



(a) *b* = 5.6 fm (Complete Fusion)
(c) *b* = 6.5 fm (Breakup Scattering)
(b) *b* = 5.9 fm (Incomplete Fusion)
(d) *b* = 6.6 fm (Scattering)

Figure 1: *^{6}Li + ^{209}Bi collision at E_{cm}=42.7 MeV for different impact parameters, b.*

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Advancing the theory of low-energy nuclear reactions populating bound states and resonances and application for nuclear astrophysics.

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The talk is devoted to recent advances in low-energy nuclear reaction theory, a subject that has been mostly neglected for many years, but with the development of new radioactive beam facilities, it became the forefront of contemporary nuclear physics. The overarching objective of the work is to advances the theory of deuteron stripping reactions leading to bound states and resonances, utilizing the state-of-the-art theoretical and computational technology. The results of this research will be made available to experimental groups worldwide in form of new codes for analysis of reactions induced by the radioactive isotopes on deuterium targets. A reliable connection between direct and resonance astrophysical (n, γ) processes and (d, p) reactions, which are unique tool to investigate neutron captures, will be provided. I will talk about four recent advances [1-4] in low-energy nuclear reaction theory.

1. Separation of nuclear reactions and spectroscopic factors [1]. This work identifies what model-independent spectroscopic information can be extracted from analysis of transfer nuclear reactions.
2. New theory of deuteron stripping based on the surface integral formalism, generalized R-matrix and CDCC was formulated in [2]. It allows us to parameterize deuteron stripping amplitudes in terms of the same observables as in the conventional R matrix. In particular, for stripping to resonance states partial resonance widths can be extracted from the deuteron stripping in the same way as in the traditional R-matrix method for resonance scattering.
3. The developed new theory provides a new tool in using deuteron stripping reactions as indirect methods in nuclear astrophysics: ANC and Trojan Horse methods [3].
4. Faddeev equations provide an ultimate, most consistent and advanced tool to treat deuteron stripping reactions correctly including all the non-orthogonal coupled channels. For the first time the Faddeev formalism is formulated in terms of the generalized Faddeev equations in the Alt-Grassberger-Sandhas form taking into account target excitations and Coulomb interaction without screening [4].

The work was supported by the US Department of Energy under Grants No. DE-FG02-93ER40773, No. DE-FG52- 09NA29467, and No. DE-SC0004958 (topical collaboration TORUS) and NSF under Grant No. PHY-0852653.

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Systematic application of four-dimensional Langevin dynamics to analysis of data from fusion-fission reactions

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Nuclear fission is one of the most complicated reaction mechanisms, which involves the global rearrangement of initial compound nucleus into separated fragments. During last decades stochastic approach based on multidimensional Langevin equations and employing a macroscopic potential landscape has been extensively and rather successfully used to elucidate many problems of collective nuclear dynamics in fusion-fission reactions at high excitation energies [1,2]. A reasonable choice of collective degrees of freedom for modeling shape evolution and considering particle evaporation allow modeling the complex interplay between static and dynamical effects in fission and succeeding in explaining a wide range of experimental data [3,4]. In the present study, we have performed the extension of the three-dimensional Langevin dynamical model by adding the orientation degree of freedom (K coordinate) [5] to three collective coordinates that describe the shape evolution of the fissioning nucleus [6]. The K coordinate determines the projection of the total angular momentum onto the symmetry axis of fissioning nucleus. We have studied the impact of the new additional degree of freedom on observable features of the fission process. It was found that the K degree of freedom changes the potential energy landscape and allows reasonably well reproduce the wide set of available experimental data for heavy nuclei within the one-body dissipation mechanism with the reduction coefficient from the wall formula $k_s \simeq 0.25$ in contrast with 3D calculations, where a self-consistent description of all observables with the same k_s value was impossible for heavy nuclei [3].

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Interaction cross section measurement of Al isotopes

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Measurements of interaction cross-sections σ_I at relativistic energies allow us to determine nuclear matter radii for unstable nuclei via Glauber model analysis. Since nuclear matter radii $<r_m^2>^{1/2}$ are directly related to the nuclear sizes, the measurements of σ_I are good tools to search for unusual nuclear structures, such as skins and halos [1]. These phenomena can be seen in exotic nuclei at the vicinity of the drip line. The combination of high intensity beam and the new generation fragment separator (BigRIPS) [2] has opened to access such nuclei. One of the recent topics in such exotic nuclei is so-called the "island of inversion" around ^{32}Mg. The magic number of N=20 is vanished around this neutron rich region and the inversion of amplitudes between *sd* normal and *pf* intruder shells has been considered along with nuclear deformation [3]. The nature of the inversion mechanism has been extensively studied but remains unclear, and further experimental studies are needed.

We have measured interaction cross-sections in a long series of Al isotopes on C target at 240 *A*MeV, including ones in and beyond the island of inversion region. We performed the experiment for $^{26\text{-}41}$Al isotopes using the BigRIPS at the RI Beam Factory in RIKEN. We also performed the experiment for lighter isotopes of $^{22\text{-}25}$Al at the HIMAC facility in the National Institute of Radiological Sciences (NIRS) [4]. We used the transmission method to measure the interaction cross sections. We observed the enhancement of interaction cross-sections at neutron rich region (A>30) from the systematics for stable nuclei as well as for Ne isotopes [5]. We will discuss the relation between the enhancement of cross sections and the nuclear deformation in and beyond the island of inversion.

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Quasi-free proton and neutron knock-out from ^{20}O

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Nuclear single-particle models have been very successful in predicting the properties of the atomic nuclei. Nevertheless, it has been observed that the cross sections of nucleon knock-out reactions were smaller than the predictions of the single particle models, as if only a fraction of the nucleon wave function is present in the corresponding shell state [1]. Spectroscopic factors are defined [2] as the ratio of the experimental cross section to the single-particle-model prediction (with a mass-dependent coefficient), and may be used to give a measure of this fraction. The reduction of this ratio from unity is interpreted to be due to the inter-nucleon correlations, and hence provides a unique method of studying single-particle occupancies and their isospin dependence. An intriguing and puzzling problem about the reduction of spectroscopic factors is its dependence on the asymmetry between proton and neutron numbers in a nucleus [3]: the spectroscopic factors of the nucleons of the deficient species, which are more bound in the nucleus, are more quenched.

For a systematic study of this observation, an experiment was performed at the LAND-R3B setup, GSI, Germany. Cocktail beams of radioactive ions with atomic numbers 3 to 10 were produced using the Fragment Separator (FRS) to impinge on a reaction target, surrounded by an array of silicon trackers (SSDs) and a gamma calorimeter (Crystal Ball), as shown in Figure 1. After offline calibration, the kinematic variables of the reaction products were reconstructed using time-of-flight arrays (TFW and DTF) and tracking detectors, including two scintillating fibre detectors (GFIs) and two drift chambers (PDCs).

The ultimate goal of the experiment is to extract the spectroscopic factors of all oxygen isotopes, from ^{14}O to ^{24}O. In this work, the quasi-free knock-out reactions $p(^{20}\mathrm{O},\, pp\,^{19}\mathrm{N})$ and $p(^{20}\mathrm{O},\, n\,^{19}\mathrm{O})p$ are selected. A tracking programme has been employed to reconstruct the mass number and time of flight of the reaction products. These variables are used to calculate the momenta of all reaction products.

In this contribution, we report on the inclusive cross sections of the quasi-free knock-out reactions, and the momentum distributions of the reaction products.

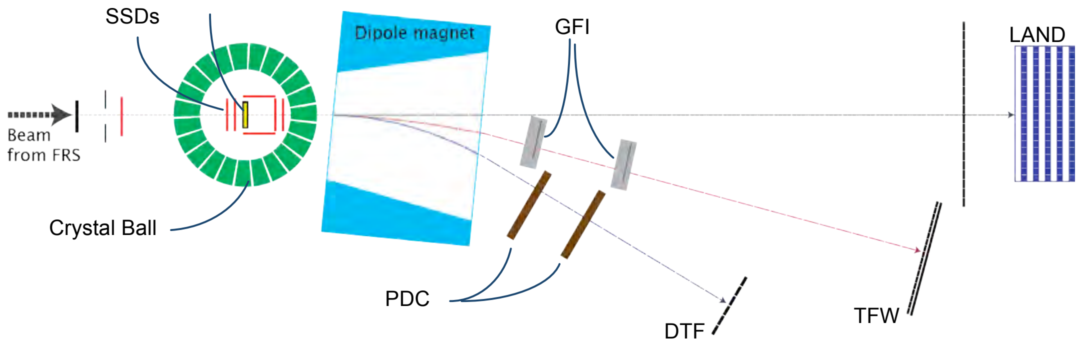

Figure 1: *The experimental setup at GSI, Germany. Ion beams were guided to the setup from left.*

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Bifurcations in dissipative fermionic dynamics

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The occurrence of bifurcations in the dynamical trajectories describing nuclear reactions at Fermi energies is studied within a novel one-body transport approach, based on the solution of the Boltzmann-Langevin equation in three dimensions; this approach handles large-amplitude fluctuations and has a broad applicability for dissipative fermionic dynamics [1].

In particular, the application of the Boltzmann-Langevin One-Body model(BLOB) to dilute systems formed in central collisions indicates that large-amplitude fluctuations at the low-energy threshold of the liquid-gas phase transition spontaneously set in. Consequently, those latter let fluctuations between two energetically favourable mechanisms stand out, so that evolving from the same initial conditions, either the system reverts to a compact shape, or it disintegrates into several fragments.

This result gives quantitative indications about two interconnected aspects. First, the low-energy threshold for multifragmentation in central heavy-ion collisions at Fermi energies can be described and compared to new experimental measurements [2]. Second, this scenario is compatible with recent experimental findings [3] of bimodal distributions for observables characterising fragmentation processes.

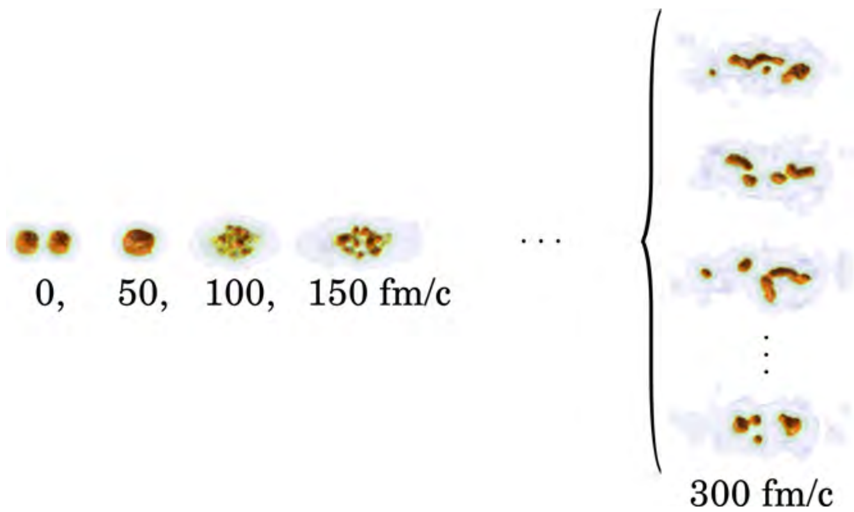

Figure 1: *Simulation of the head-on collision $^{136}Xe+^{124}Sn$ at 32 AMeV: evolution of the projected density profile leading to a variety of fragmenting topologies for the same initial condition.*

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Study of heavy-ion induced fission for heavy-element synthesis

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Fusion reactions using actinide target nuclei have been extensively used to investigate super-heavy nuclei (SHN). The reasons are (1) a relatively neutron rich SHN compared to the cold fusion reactions are produced, thus the decay properties of these nuclei have information on the structure in the vicinity of the spherically closed-shells at Z=114,120 and N=184, (2) nuclei having a relatively long half-lives allow us to study chemical properties, and (3) the cross sections maintain values of a few pico-barn even at the heaviest elements [1]. Understanding of fusion using actinide nucleus is important to estimate the cross sections to produce more exotic SHN and explore this field.

We are studying fusion reaction involving ^{238}U target nucleus using in-beam fission experiment. In the reactions of ^{30}Si,^{31}P,^{34,36}S,^{40}Ar,^{40,48}Ca + ^{238}U, the fragment mass distributions changed drastically with incident energy [2-5]. The data shows the competition between fusion-fission and qasifission, and the results are interpreted by the effects of nuclear orientation arising from the prolate deformation of ^{238}U. We developed a model to calculate the fission-fragment properties in heavy-ion collision based on a fluctuation dissipation model, where orientation effects are taken into account [6]. The calculation reproduced the mass distributions and their incident energy dependence. Fusion probabilities are determined in this approach, which are consistent with those determined from the evaporation residue cross sections of ^{263,264}Sg [3] and ^{267,268}Hs [4], produced in the reactions of ^{30}Si + ^{238}U and ^{34}S + ^{238}U, respectively. We also suggest that the incident beam energy can be extended to the sub-barrier region for the heavy-element synthesis, allowing us to produce more neutron-rich SHN. Discussion will be also given in the ^{48}Ca + ^{238}U reaction, leading to the copernicium isotopes (Z=112) [7,8].

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Synthesis of $^{250-253}$No in ^{206}Pb+^{48}Ca reaction

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The search for super-heavy elements ($Z > 100$) explores the borderline of the nuclear chart towards its upper end where the strong Coulomb force acting between the many protons dominates the nuclear stability and finally terminates the number of elements by instability against fission. In the present work, we choose to synthesize $^{250-253}$No in a hot fusion reaction ^{206}Pb+^{48}Ca where individual light particles (LPs) decay channels σ_{xn}, x=1,2,3,4 neutrons are measured in a Dubna experiment [1] at excitation energies E^* ≈20-45 MeV. We have fitted the LPs decay channels cross-sections of this reaction on Dynamical Cluster-decay Model (DCM) of Gupta and collaborators (see, e.g., [2]), where the effects of deformations upto hexadecupole (β_2-β_4) and compact orientations θ_c are included. ^{48}Ca nucleus forms a compact configuration with ^{206}Pb at θ_c=2^0, a "not-equatorial compact" configuration [3]. In DCM, the compound nucleus decay cross-section in terms of partial waves is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \quad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

where, μ is reduced mass, $E_{c.m.}$, the center-of-mass energy, and angular momentum ℓ_{max}, for σ_{LPs} →0.

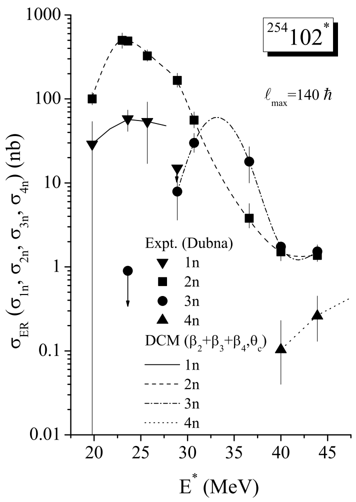

Figure 1: *Excitation functions of individual xn (x=1-4) channels for the fusion reaction ^{206}Pb+^{48}Ca. The symbols denote experimental data [1], and lines our calculations for the best fitted ΔR values.*

In figure 1, we have confronted our calculated cross-sections with data. Clearly, the model gives a good description of the measured decay channels σ_{xn} with in one parameter fitting of the neck length ΔR. Our calculation using ^{204,207,208}Pb, i.e., the isotopic dependence of cross-sections is underway.

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Analyzing powers for $1s_{1/2}$-knockout $(p, 2p)$ and (p, pn) reactions.

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Nucleon quasifree scattering provides one of the most direct means to investigate the NN interactions in nuclear fields. Our group has measured spin observables in $(p, 2p)$ reactions in order to examine possible modification of the NN interactions. We already showed that the analyzing power (A_y) is monotonously suppressed as increase of nuclear density for a wide range of incident energy [1,2] and that the reaction mechanism is simple enough so that this phenomenon strongly suggests existence of some medium effect [3]. It was also shown that a renormalization of meson-exchange model parameters reproduces all the measured spin observables, including spin transfer (D_{ij}), though the result may not be unique [4]. As an extention of this study, we measured A_y in (p, pn) reactions.

The experiment was performed at RCNP by using the spectrometer LAS and a set of plastic scintillator array, NPOL3. The incident beam was a 392 MeV polarized proton beam and the target used were ^{2}H, ^{6}Li and ^{12}C. Figure 1 shows a result of the measurement and comparison with $(p, 2p)$ results. The measured A_y values are plotted as functions of the effective mean densities of the target nuclei, which are estimated in a DWIA framework. As shown in the panel [B] of the figure, the A_y values for the (p, pn) reaction in a p-forward kinematic condition are significantly suppressed from the PWIA and DWIA calculations, which is similar as the case of $(p, 2p)$, the panel [A]. However, in the case of neutron-forward (p, pn), the panel [C], A_y is not suppressed or even slightly enhanced. This imply that only the isoscaler mason exchange part of the NN interaction is modified.

In addition to A_y, the differential cross sections were also measured. One of the observed results is that the cross section ratio between $(p, 2p)$ and (p, pn) reactions for 1p-knockout is consistent with the p-p and p-n cross section ratio in free space, but the ratio is meaningfully different in the case of 1s-knockout. Since the effective density is higher for the 1s-knockout than the 1p-knockout, this also imply existence of some medium effect on the NN interactions.

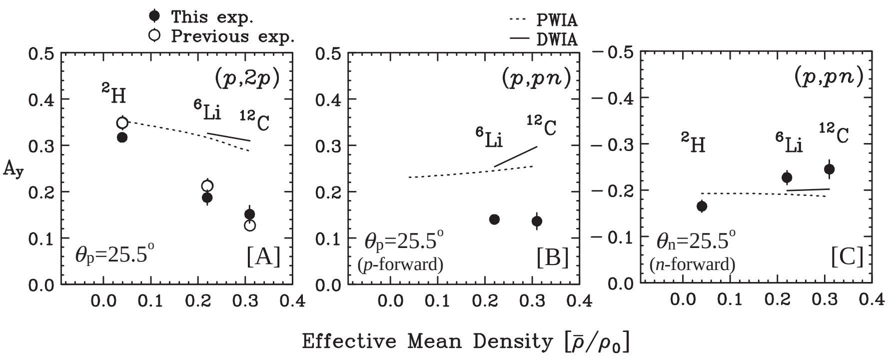

Figure 1: Analyzing powers for 1s-knockout $(p, 2p)$ and (p, pn) reactions. The detection angles of forward outgoing nucleons are always 25.5 deg and those for backward ones are set at 51-60 deg so as to satisfy the zero-recoil conditions.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Coupled channel effect on the far-side component of the $^{16}O+^{27}Al$ elastic scattering angular distribution at 100 MeV and above

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Parameter free coupled channels (CC) calculations [1] based on the São Paulo double-folding potential predict rainbow-like patterns in the elastic scattering angular distributions of relatively heavy systems in various mass regions, contrary to usual optical model expectations in view of the strong nuclear absorption present. Such calculations have been corroborated by recent measurements of the $^{16}O + ^{27}Al$ system at 100 MeV [2,3] and 280 MeV (preliminary results). The decomposition into *near* and *far* components of the angular distributions (Fig. 1) clearly illustrate that the dip between 70 and 80 degrees (in the center of mass), and the bump around 90 degrees of the total elastic cross section are originated in the emerging far-side (refractive) component of the CC calculation. Both the near and far components present Airy-like minima and enhanced cross sections at very large angles, characteristic of rainbow phenomena, in the CC version while the standard optical model (OM) predicts a smooth exponential decay. This type of effect, although already known in molecular scattering, is new on nucleus-nucleus collision, and can provide important information regarding the potential in internal nuclear regions.

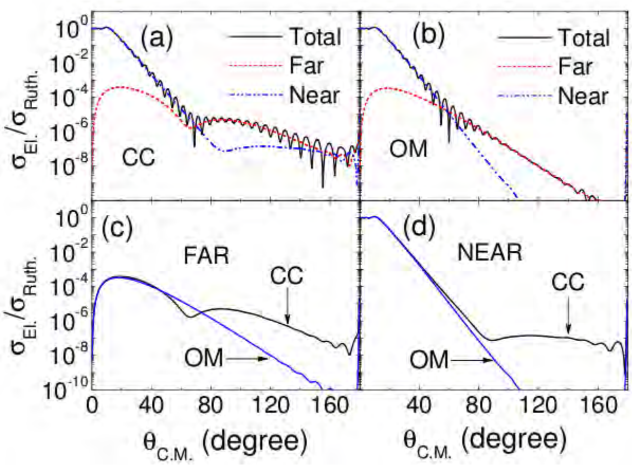

Figure 1: *Total, near-side and far-side elastic scattering cross sections obtained in the CC (a) and standard OM (b) approaches for the $^{16}O + ^{27}Al$ system at 100 MeV. Comparison between the CC and OM results for the far-side (c) and near-side (d) components.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Complete characterization of nuclear breakup reactions in the ^{6}Li + ^{144}Sm system

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Breakup reactions induced by weakly bound ^{6}Li projectiles on a ^{144}Sm target at near barrier energies have been studied and fully characterized through the correlated detection of the emitted light particles. The emphasis of the study has been placed on the extraction of the maximum possible amount of information on a purely experimental basis. For that purpose the analysis has been oriented to the determination of the distributions of all the relevant asymptotic angular and energy variables that describe the complete reaction in terms of its decomposition into a binary stage "followed" by the breakup of the weakly bound projectile. The treatment of the data, including a detailed reproduction of the complex response of the detection system to the three-body kinematics, allows one to obtain absolute differential cross sections with respect to the aforementioned relevant variables. Within the constraints set by the geometrical efficiency a resonant breakup component was found to be dominant at all energies whereas a direct breakup component associated to the lowest alpha-deuteron relative energies could be identified and studied at the lowest bombarding energies. The distribution of the polar angle of the breakup emission in the ^{6}Li reference frame was found to be noticeably anisotropic whereas the azimuthal angular distribution is mostly isotropic. The results are discussed in reference to a classical three dimensional dynamical model that simultaneously treats breakup, complete and incomplete fusion.

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Proton-proton femtoscopy and access to early dynamical sources at intermediate energies

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Heavy-ion collisions allow one to study the properties of nuclear matter under extreme conditions, a very active area of research in nuclear physics. At intermediate energies, during the dynamical evolution of the system, the density can drop to values that are much lower than the saturation one (0.17 fm^{-3}) leading to fragment formation and, possibly, to liquid-gas phase transitions. These studies have recently become very important in view of the perspective of exploring the density dependence of the symmetry energy in asymmetric nuclear matter [1]. The symmetry energy indeed governs important properties of nuclear systems and neutron stars, linking the interests of different scientific communities [2]. However, the dynamical evolution of the system is very complex, occurring over very short time scales that force scientists to measure observables that allow disentangling emitting processes during the reaction. In this respect proton-proton correlation functions have extensively been used as space-time probes of reaction dynamics [3]. Intensity interferometry indeed allows one to extract emitting source functions and thus determine its size and lifetime. These space-time probes are important in order to isolate proton emissions from the early dynamical stages, where the sensitivity to the symmetry energy is expected to be highest [4].
In this contribution we present a study of two-proton correlation functions in Xe+Au and Sn + Sn at E/A=50 MeV, with Gaussian source and imaging analysis techniques [5]. The extracted source functions are studied as a function of total momentum, detection angle, transverse momentum. Evidences for long-lived sources contributing to the correlation functions along with the short-lived ones are found. Attempts to compare to transport model simulations performed with the BUU model show that high transverse momentum gates allow one to select early stages (t<100 fm/c) when protons are emitted over short time scales. This result, providing an observable that reduces contributions from long-lived emissions, open the opportunity of improving comparisons to the extracted experimental dynamical source functions that are expected to be sensitive to important transport properties such as the equation of state, the in-medium nucleon-nucleon cross section and the density dependence of the symmetry energy [6].

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Fusion Cross Sections of ^{8}B + ^{28}Si at near barrier energies

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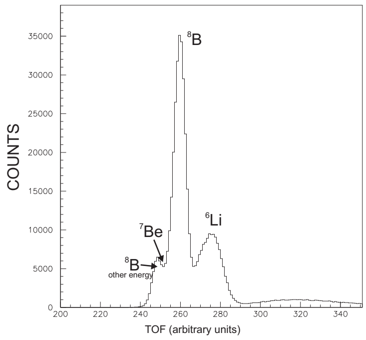
Fusion cross sections were measured for ^{8}B + ^{28}Si at near barrier energies by detecting the alpha particles produced in the evaporation process. The ^{8}B secondary beam was produced at the EXOTIC facility [1] at LNL-Italy of the Instituto Nazionali di Fisica Nucleare by means of the In Flight (IF) technique. Due to the very low counting rate of the beam produced as a cocktail of ^{8}B, ^{7}Be and ^{6}Li nuclei, the active target technique was adopted. By using a stack of three detectors instead of one, the discrimination of alpha particles was possible via a conventional ΔE-E technique, which also prevented any contribution from frame scattering, a usual problem in this type of measurements. Alphas were integrated with a contour in the bidimensional spectrum, a TOF window on boron projectiles (see Figure 1 to the left) and a contour on the beam spot on the target, reconstructed by two beam profilers. The obtained alpha production cross sections were found to be compatible with CASCADE calculations, which justified the estimation of the proton multiplicy in the same context. Fusion cross sections were obtained and are compared with previous results of light weakly bound projectiles on similar targets and previous results of ^{8}B+^{58}Ni, in Figure 1 (right). The results will be discussed.



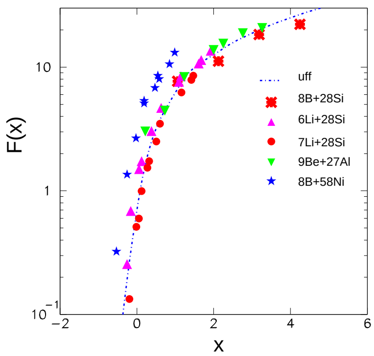


Figure 1: *(Left) TOF between a beam profiler and the target. (right) Fusion functions according to [2] for various light weakly bound projectiles are compared with the present results.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

EXCITATION OF ISOMERIC STATES IN REACTIONS (γ,n) AND (n,2n) ON ^{113}In AND ^{198,200}Hg NUCLEI

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In the present work results of investigation of the isomeric yield ratios and cross-section ratios of the (γ,n) and (n,2n) reactions on nuclei ^{113}In and ^{198,200}Hg are presented. The isomeric yield ratios were measured by the induced radioactivity method. Samples have been irradiated in the bremsstrahlung beam of the betatron in the energy range of 10-35 MeV with energy step of 1 MeV. For 14 MeV neutron irradiation we used the NG-150 neutron generator. The gamma spectra reactions products were measured with a spectroscopic system consisting of HPGe detector CANBERRA with energy resolution of 1,8 keV at 1332 keV gamma ray of ^{60}Co, amplifier 2022 and multichannel analyzer 8192 connected to computer for data processing. The filling of the isomeric and ground levels was identified according to their γ lines. In the range 26-35 MeV the isomeric yield ratios Y_m/Y_g of the reaction (γ,n) on ^{198}Hg are obtained at first. The experimental isomer ratios are compared with those calculated within the framework of the cascade-evaporation model.

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SPY: a new microscopic scission-point model to predict fission fragments properties

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A detailed and predictive description of the nuclear fission process is one of the most challenging tasks in nuclear physics and would have a major impact on a large spectrum of applications in society. For instance, the asymmetric mass yields and the stability of the heavy mass peak in the fission of actinides have been interpreted in terms of the strong influence of the nascent fragments nuclear structure. Recently, a new asymmetric fission has been discovered in the light Mercury region [1], leading to a vast debate on the effective source of the mass asymmetry in nuclear fission. To answer this question, a new statistical scission-point model called SPY (Scission-Point Yields) has been developed using one of the best theoretical knowledge of microscopic nuclear structure. This model, inspired by the approach developed by Wilkins in the late seventies [2], is based on a static energy balance calculation at scission, where the two nascent fragments are supposed to be completely separated so that their macroscopic properties (mass and charge) can be considered as fixed. The probability of a given fragmentation is then related to the energy available at the scission point determined in an absolute form, taking into account a micro-canonical description including the state densities of the fragments. The main improvement brought by this new approach is the introduction of microscopic ingredients for the calculation of both the individual potential energy and the state density of each fragment. These two quantities are calculated in the framework of the HFB formalism using the Gogny D1S effective nucleon-nucleon force, ensuring the overall coherence of the SPY model. They are also are available in the theoretical nuclear database *Amédée*, which contains the mean field potential of more than 7000 nuclei [3]. We will present the main results obtained with this model and discuss the comparison between our calculations and experimental data for a large set of fissioning nuclei. Thanks to the detailed energy balance calculation between the two nascent fragments we will show that the competition between symmetric and asymmetric fission is highly related to shell effects in the fragments, described up to very deformed shapes. In particular, this approach is able to prove that the surprising asymmetric splitting recently measured in the light Mercury region can be understood on the only basis of the nuclear structure of the two nascent fragments at scission [4]. Finally, the ongoing developments on the SPY model, mainly concerning the scission point definition, will be presented.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Asymmetric nuclear matter calculations and many-body correlations in Semiclassical Molecular Dynamics

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Constraint Molecular dynamics CoMD calculations have been performed for asymmetric nuclear matter (NM) by using a simple effective interactions of the Skyrme type [1]. The set of parameter values reproducing common accepted saturation properties of nuclear matter have been obtained for different degree of stiffness characterizing the iso-vectorial potential density dependence. A comparison with results obtained in the limit of the Semi-Classical Mean Field approximation using the same kind of interaction put in evidence the role played by the many-body correlations in to explain the noticeable differences obtained in the parameter values in the two cases. Even if from a numerical point of view the obtained results are strictly valid for the CoMD model [2,3], some rather general feature of the discussed correlations can give a wider meaning to the obtained differences being strongly related to the spacial correlations generated in the semiclassical wave packets dynamics.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Investigation of the Dynamical Dipole Mode in the ^{40,48}Ca+^{152,144}Sm fusion-evaporation and fission reactions at 11 MeV/nucleon

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The *Dynamical Dipole mode (DD)* is a large amplitude collective oscillation of protons against neutrons of the di-nuclear system, formed in charge asymmetric heavy-ion collisions. It decays emitting prompt dipole γ-rays [1-3] and gives information about the dynamics of dissipative reactions. From a theoretical point of view, the DD γ yield should increase as a function of the entrance channel charge asymmetry, becoming maximum for reactions employing exotic nuclei where large N/Z ratios can be reached. A large yield could allow to probe the density dependence of the symmetry energy in the Equation of State at sub-saturation densities, where the DD is active [4]. Furthermore, the DD radiation could be of interest for the synthesis of super-heavy elements in hot fusion reactions as it cools down the formed nucleus on the fusion path through emission of prompt γ-rays. However, by comparing the few existing data in the mass region A~ 130, taken at different beam energies and for different entrance channel N/Z asymmetries, with theoretical calculations we conclude that many aspects should still be clarified.

By performing time-dependent Hartree-Fock calculations it was predicted in [5] that the DD γ yield decreases in collisions involving heavy mass ions since reactions with small nuclei are less damped than those involving heavier ones. To verify such a prediction we investigated the DD in fusion-evaporation and fission reactions in a mass region never studied before. The ^{192}Pb compound nucleus was formed in the ^{40}Ca + ^{152}Sm and ^{48}Ca +^{144}Sm reactions at E_{lab} = 440 MeV and 485 MeV, respectively, by using the same method described in our previous works [2]. The experiment was performed at Laboratori Nazionali del Sud (LNS, Italy), by using the $^{40-48}$Ca pulsed beams provided by the Superconducting Cyclotron. The γ-rays and the light charged particles were detected by using the MEDEA apparatus [6], made of 180 BaF_2 scintillators. The heavy reaction fragments were detected by position sensitive Parallel Plate Avalanche Counters placed symmetrically around the beam direction in order to investigate the DD in both fusion-evaporation and fission events. Preliminary results of the analysis were presented in [7]. γ-ray spectra and angular distributions extracted for central collisions evidence that the DD survives in reactions involving heavier nuclei than those studied before, with a yield of $(8\pm1)*10^{-5}sr^{-1}$ for evaporation and $(10\pm3)*10^{-5}sr^{-1}$ for fission. These results will be compared with those found at different mass regions for fusion-evaporation events and with theoretical calculations performed within a BNV transport model, based on a collective bremsstrahlung analysis of the entrance channel reaction dynamics. Ideas about future experimentation on the DD study by employing also radioactive beams will be discussed.

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Effect of breakup coupling on elastic scattering in the reactions of ^{7}Li + ^{27}Al, ^{159}Tb

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It is a well established fact that elastic scattering of heavy ions at energies near the Coulomb barrier, the real and the imaginary parts of the optical potential show energy dependence, known as threshold anomaly (TA) [1]. A characteristic localized peak is observed in the real part and a decrease of the imaginary part of the potential as the bombarding energy decreases towards the Coulomb barrier. This situation may change in the scattering of weakly bound nuclei [2]. These nuclei have very low breakup threshold energies and they have a large breakup (BU) probability. In order to understand the breakup coupling effects on elastic scattering a detailed CDCC calculations have been carried out for both the ^{7}Li + ^{27}Al, ^{159}Tb systems. Also the results will be interpreted in terms of the energy dependence of the (OM) potential parameters. We have also derived the total reaction cross sections for these systems in order to investigate the role of BU on total reaction cross sections.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Isospin transport and odd-even staggering in ^{84}Kr+^{112,124}Sn reactions at Fermi energies

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In recent years, many experimental [1] and theoretical [2] efforts have been devoted to the investigation of the isospin degree of freedom in heavy ion reactions at Fermi energies (30-50 MeV/nucl.). In particular, comparing reactions involving partners with different N/Z, it was possible to investigate the isospin transport process and its influence on the final products population. From the experimental point of view, this task requires the availability of devices able to measure both charge and mass of the emitted products, in the widest possible range of energy and size of the fragments. In this work we compare the isotopic composition of the products emitted in two reactions with the same projectile and beam energy (^{84}Kr at 35 MeV/nucl.) and different targets: the n-nrich ^{124}Sn and the n-poor ^{112}Sn. The adopted setup, a prototype of the FAZIA detector [3] with extremely good performance in term of mass and charge identification [4], allowed to identify the mass of the products up to Z=20 for fragments emitted at small angles in forward direction in the centre of mass system. In this way, it is possible to compare, for the two reactions, the $<N>/Z$ of fragments coming from the projectile (evaporation residues or fission fragments) or from the neck region. We found that the isospin content of the fragments from the ^{84}Kr+^{124}Sn reaction is always higher than that observed for the reaction with the n-poor target even for fragments originating from the projectile. The observed result is an evidence of isospin diffusion between target and projectile. Moreover, a sampling of the emitted fragments as a function of their velocity showed that for very light fragments the $<N>/Z$ decreases while moving from the centre of mass (neck region) towards the quasi-projectile region; this effect can be interpreted as an evidence of isospin drift, i.e. a neutron enrichment of the more diluted central region of the neck. Data on the odd-even staggering in the two systems are also presented and compared with the results of statistical models that include some basic properties of nuclei (such as separation energies) capable of influencing the relative abundance of the final products.

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Study of reactions induced by ^{6}He

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We present the results of an experiment using ^{6}He beam on ^{9}Be and ^{197}Au targets. The collision was measured at the energies E_{lab}=16.2 MeV and 21.3 MeV, using the RIBRAS system (Radioactive Ion Beams in Brazil) of the Institute of Physics of the University of São Paulo [1]. The ^{6}He secondary beam was produced by the ^{9}Be(^{7}Li,^{6}He) reaction with a ^{7}Li primary beam of 300 nA. The detection system consisted of four ΔE-E silicon telescopes, with 20 microns and 1000 microns thickness respectively, which allow to separate the ^{6}He particles from the ^{7}Li beam contaminant and light particles. A high yield of α-particles has been observed in the ^{6}He+^{9}Be collision which was not present with the gold target. The energy and the angular distributions of those events have been analysed and compared with CDCC calculations for the ^{6}He breakup. Furthermore, a strip of events along the ^{6}He line with energies lower than that of the elastic scattering has been observed in the biparametrical spectra obtained using the ^{9}Be target. Their energy and angular distributions have been obtained and compared with Coupled Channels (CC) calculations considering the ^{9}Be excitation. As the excited states of the ^{9}Be are all unbound one can consider those events as a measurement of the target breakup. The angle integrated cross sections have been obtained and compared with the total α-particle production cross sections. The total reaction cross section has been obtained from an Optical Model, Coupled Channels and CDCC analysis of the elastic angular distributions and compared with other exotic, weakly bound and tightly bound systems. An enhancement in the total reaction cross section has been observed for the exotic ^{6}He projectile with respect to the stable ^{6}Li even for the light target ^{9}Be. We found that this enhancement exactly matches the total α-particle production cross section. All the calculations were performed with the computer code FRESCO [2].

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Reactions with exotic nuclei and active targets

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Already for several years now nuclear reactions have been used to investigate the exotic properties of nuclei far from stability. The types of reactions are linked to the availability of radioactive ion beams (RIBs). While the beginnings of research in this field were characterized by the use of collisions at medium-high energy, upgrades at several production facilities are finally providing RIBs in the range of a few to about 20 MeV/nucleon, energies which are well-suited for direct reactions and transfer reactions in particular. These are a very powerful probe to obtain spectroscopically detailed information on nuclei in regions of the nuclear chart, key to our understanding of the nuclear structure. Interesting and promising results have already been obtained among others at REX-ISOLDE (CERN, Geneva) and GANIL (Caen), for example very recently in the region of neutron-rich Ni nuclei [1,2].

Adequate detection instruments are being developed to respond to the challenges posed by the use of weak beams in inverse kinematics. Gamma-ray detection serves the double purpose of resolving states in nuclei where their density is high, and providing information on intra-nucleus transitions that greatly helps spin assignments [1]. In other cases the use of active targets is the only way to achieve a sufficient luminosity, thanks to the possibility of having a large target thickness without compromising on energy resolution. Some examples will be presented both of performed measurements and of opportunities opening with the development of the new generation of these instruments.

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Ab initio many-body calculations of *d*-nucleus collision and (d, p) transfer reaction

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We perform calculations of binary-cluster nuclear scattering, where both the projectile and target are described in an *ab initio* framework, that is, all the nucleons in the projectile-target system are active degrees of freedom interacting through a realistic nuclear two-body interaction. In particular we consider the specific case of a deuteron (d) projectile impinging on light nuclei with mass number $A > 4$. In this way, we significantly extend the scope and applications of *ab initio* methods to nuclear scattering and reactions.

The adopted formalism is the no-core shell model/resonating-group method (NCSM/RGM) [1], a well-established nuclear many-body approach that allows to treat bound and scattering states of light nuclei within a unified framework, starting from the fundamental internucleon interactions. The actual calculation consists in solving a Schrödinger-like equation in which the relevant aspects of the dynamics of the scattering process are taken into account by adopting accurate nucleon-nucleon (NN) potentials (i.e. those that fit the NN phase shifts with high precision) to describe the interaction between target and projectile nucleons, and by expanding the nuclear wave function over many-body binary-cluster states consistently obtained from the same Hamiltonian.

So far, NCSM/RGM applications concerning collisions and nucleon-transfer reactions with a deuteron projectile have been limited to the description of d-^{4}He (d-α) scattering [2] and both the transfer reactions ^{3}H$(d,n)^4$He and ^{3}He$(d,p)^4$He [3], see Figure. In our work, we push forward the present computational limits of *ab initio* calculations by extending the NCSM/RGM formalism to the treatment of nucleon-transfer reactions with target nuclei heavier than the α particle. This is achieved by introducing a novel algorithm to efficiently handle the large computational scale of the many-body problem under study. Such development will enlarge our ability to test *ab initio* methods against the wealth of data from radioactive-ion beam facilities that are becoming available in the recent years. At the same time, the outcome of such NCSM/RGM calculations has the potential to serve as precious guidance for ongoing experimental investigations of the spectra of exotic nuclei, where the (d, p) reaction is a powerful tool for the study of halo nuclei (see for instance Ref. [4]).

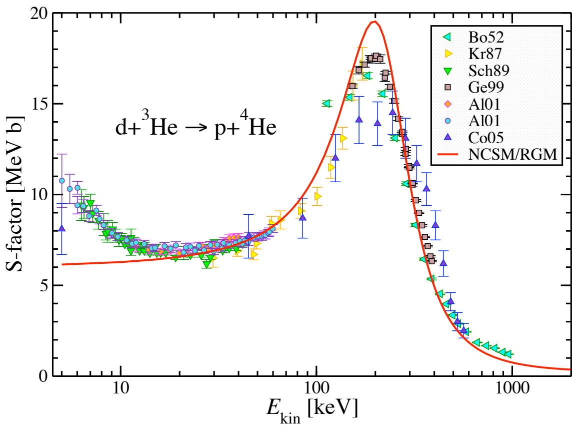

Fig. from Ref. [3]. Calculated S-factors of the ^{3}He$(d,p)^4$He reaction compared to experimental data (see Ref. [3] for details).

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Further limit on 3α decay of Hoyle state

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The Hoyle state, second 0^+ resonant excited state of ^{12}C at excitation energy of 7.654 MeV, plays an important role to understand a variety of problems of nuclear astrophysics as well as the stellar nucleosynthesis process as a whole [1,2]. Recent triple alpha reaction rate calculation assumes that the formation mechanism of ^{12}C is through sequential two step process, i.e. through the intermediate ground state of ^{8}Be nucleus. However, the structure of this state has unusual nature as from the cluster model, it has a linear chain like structure of three alpha particles [3] and at the same time from inelastic scattering it was found that this state has a abnormally larger radius compare to the ground state of ^{12}C [4] and possesses a gas like structure i.e., loosely bound 3α [5, 6]. All these unusual properties of this state may change the decay mode of ^{12}C, from which reaction rates for carbon as well as other heavy elements have been calculated. First experimental effort to estimate the branches of sequential and direct decay mode of Hoyle state have been performed in 1994 by M. Freer, using Dalitz plot for three body decay and its projection in terms of ^{8}Be like pairs, and obtained an upper limit of 4% on direct 3α decay branches bypassing the ground state of ^{8}Be [7]. In a recent work by Raduta et al. [8], two direct decay branches have been identified, direct decays into equal energy (DDE) and direct decay in linear chain (DDL), with a combined direct decay branching of 17(5) %. So, this total direct decay branches not only implies a corresponding percentage of reduction in the reaction rate calculation in triple α process but also for modification of recent theoretical prediction for reaction rate calculation. In Manfredi et. al [9], 2012, they have been estimated the decay branches using ^{8}Be like pairs and root mean square energy deviation methods and obtained for the direct decay in phase space (DDΦ) 3.9 % and DDE is 0.45 % with a upper confidence limit of 99.75 %. More recently, O. S. Kirsebom et. al.[10], estimated using the symmetric Dalitz plot and its radial projection, in a complete kinematical experiments (total detected events of 5000) and have got an upper limit for DDE 0.09%, DDL 0.09% and DDΦ 0.5% at 95% confidence limit. Therefore, it is important to verify the recent result with higher statistics to resolve the ambiguity. Here, we will discuss in details about a new measurement of inelastic scattering of α on ^{12}C at 60 MeV to study the decay channels of Hoyle state in a complete kinematical experiment with a larger statistics than ever use before. We have used here all these three methods (^{8}Be like pairs, root mean square energy deviation and the radial projection of symmetric Dalitz plot, as have been used in references [7-10]) with three body decay Monte Carlo simulation, taking into accounts the experimental effect, to estimate the decay channels of Hoyle state and have been estimated and restricted with an upper limit of DDE 0.6 %, DDΦ 0.9 % and DDL 0.3 % with a 99.75 % upper confidence limit. The experimental measurement and data analysis details will be discussed here.

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Nuclear Temperature from the Evaporation Fragment Spectra and Observed Anomalies

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The extreme back-angle evaporation spectra of alpha, lithium, beryllium, boron and carbon from different compound nuclei near A ≈ 100 (E_X=76 MeV – 210 MeV) have been compared with the predictions of standard statistical model codes such as CASCADE and GEMINI. The data was taken from ref [1-3]. Using the parametrization given in ref [4], the temperature and p-parameters were extracted from both the experimental and statistical model spectra and compared in Table 1. Alpha spectra agree well with the statistical model predictions. However, lithium, beryllium, boron and carbon spectra show significantly gentler slopes implying higher temperature of the residual nuclei, even though the spectra satisfy all other empirical criteria of statistical emissions. The observed slope anomaly was found to be largest for lithium and decreases at higher excitation energy. These results could not be understood by adjusting the parameters of the statistical models or from reaction dynamics and might indicate the quantum mechanical character of the decay process.

Table 1. Comparison of temperature (T) and p-parameters derived from the experimental and statistical model parameters.

System studied	Projectile Energy and E_X of CN (MeV)	Fragment Investigated	Derived parameters from			
			Experimental data		Statistical model calculation	
			P (MeV)	T (MeV)	P (MeV)	T (MeV)
^{16}O	96	^{4}He	4.0±0.4	2.90±0.15	4.0	2.9
+	(^{16}O)	Li	6.0±0.6	4.50±0.3	8.0	2.35
^{89}Y		Be	6.8 ±1.0	3.6± 0.3	12.6	2.0
	^{105}Ag	B	13.1±1.0	3.35±0.2	16.0	2.1
	E_X=76 MeV	C	15.0±1.2	3.5±0.3	18.0	1.65
^{16}O	116	^{4}He	3.5± 0.4	3.5±0.1	4.0	3.4
+	(^{16}O)	Li	3.9± 0.4	4.6±0.2	11.0	2.8
^{93}Nb		Be	10.9±1.0	3.9±0.2	19.0	2.4
	^{109}In	B	11.8±1.2	3.6±0.2	25.0	2.3
	E_X=93.5 MeV	C	23.0±1.0	3.5±0.2	27.0	2.0
^{3}He	90	^{4}He	2.0±0.2	3.0±0.15	2.0	3.0
+	(^{3}He)	Li	3.0±0.3	5.8±0.3	3.0	2.8
Ag	E_X~82	B	8.0±1.0	3.5±0.2	7.0	2.6
	MeV	C	10.9±1.0	3.5±0.3	8.5	2.6

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Fusion dynamics with exotic beams

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The reaction path followed by Heavy Ion Collisions with neutron-rich (or exotic) nuclear beams at low energies is investigated in a transport theory based on a microscopic stochastic mean field approach, where two parametrizations for the density dependence of symmetry energy (Asy-soft and Asy-stiff) are implemented [1]. The goal of this analysis is to pin down specific observables which are sensitive to the symmetry energy, to learn about its poorly known density behavior. We focus on the interplay between reaction mechanisms, fusion vs. break-up (fast-fission, deep-inelastic), that in neutron-rich systems is expected to be influenced by the symmetry energy term at densities around the normal value [2]. Fusion probabilities for reactions induced by ^{132}Sn on $^{64,58}Ni$ targets at 10AMeV are evaluated by the evolution of the phase-space quadrupole collective modes [3]. Larger fusion cross sections are obtained for the more n-rich composite system, and, for a given reaction, with a soft symmetry term (i.e. a rather flat behaviour of the symmetry energy around normal density).

The break-up events appear also sensitive to the stiffness of the symmetry energy. Owing to the lower symmetry repulsion at low densities in the linear (stiff) choice, the neutron-rich neck connecting the two partners can survive a longer time producing very deformed final fragments, eventually leading to ternary/quaternary fragmentation events. ^{197}Au + ^{197}Au collisions at 15 AMeV are simulated to investigate the main modes of re-separation of a heavy nuclear system and their sensitivity to the symmetry energy. For this system a rather fast break-up into three or four massive fragments have been experimentally revealed [4], allowing for a comparison between data and theoretical predictions.

In addition, we investigate the collective charge equilibration mechanism, the Dynamical Dipole Resonance, DDR [1], in fusion and breakup events induced by ^{132}Sn + $^{64,58}Ni$ collisions at 10 AMeV. The strength of the corresponding radiative emission depends on the stiffness of the symmetry term just below saturation and presents clear angular anisotropies [5,6]. We also investigate the effect of the mass asymmetry in the entrance channel for systems with the same overall isospin content and similar initial charge asymmetry [3]. As expected, we find reduced fusion probabilities for the more mass-symmetric case, while the DDR strength appears not much affected. This is a nice confirmation of the prompt nature of such collective isovector mode. Interesting perspectives are opening for new experiments on low energy collisions with exotic beams.

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A new experimental approach for fission studies: ^{238}U+^{12}C transfer reactions in inverse kinematics

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Transfer reactions have been widely used as a surrogate technique in the investigation of neutron-induced fission for nuclei that are not suitable for neutron-irradiation measurements. The method consists in measuring the fission probability of the same compound nucleus that would be produced by neutron capture, but using light-transfer reactions as stripping or pickup between hydrogen- or helium-isotope beams and actinide targets close to the nuclei of interest. Although several successful experiments have been performed, the validity of this technique relies on strong assumptions concerning the spin distribution populated in the compound nucleus and its decay, being nowadays a subject of intense debates [1]. In the present work, we propose to extend the surrogate method to heavy-transfer reactions using inverse kinematics and, therefore, investigate a broader collection of fissioning systems in a single experiment. A ^{238}U beam accelerated up to an energy slightly above the Coulomb barrier was shoot on a 100 μg/cm^2-thick ^{12}C target and heavy actinides from U to Am, with excitation energies below 30 MeV, were produced through inelastic scattering and multinucleon transfer. The energy and angle of the target-like partners in the exit channels were measured in a double annular Si telescope, providing a complete characterization of the produced fissioning systems in atomic and mass numbers, as well as a measurement of the total excitation energy gained in the reaction. In addition, the use of a magnetic spectrometer combined with the inverse kinematics gives access to the complete identification in mass and atomic numbers, ionic charge-state and kinetic energy of the whole fission fragments in the ranges $Z\approx30$–60 and $A\approx80$–160. The set-up also included several clusters of Ge detectors in the target region for coincident γ-ray measurements, allowing the investigation of possible excitation of the target-like partners in the exit channels. These data, which are now available for the first time, are crucial for the interpretation of the fission probabilities, as they define the sharing of excitation energy between the two reaction partners in the exit channel and thus the actual excitation energy carried by the fissioning system. The information gathered in this work brings the possibility of unprecedented studies about the properties of the fission-fragment isotopic distributions for different fissioning systems and excitation energies [2]. At the same time, the measurement of target-like partner excitation and fission probabilities offer us the opportunity of investigating the validity of the surrogate technique, which will be carefully discussed in this contribution.

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On the damping of shell effect in ^{208}Pb region using neutron time of flight measurements

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The shell effect in a nucleus enhances the stability with respect to the average behaviour expected from the liquid drop model. Shell effect also affects the nuclear level density (NLD). There is a long standing theoretical prediction that the shell effect on the NLD parameter damps out with excitation energy (E_X) beyond 40 MeV [1]. It is not easy to populate the ^{208}Pb nucleus at low excitation energy to address the damping of shell effect. The damping of the nuclear shell effect with excitation energy has been measured through an analysis of the neutron spectra following the triton transfer in the ^{7}Li induced reaction on ^{205}Tl. An exclusive measurement of neutron spectra was made at the Pelletron Linac Facility, Mumbai using neutron detector array [2] in coincidence with ejectile alpha particles measured in an array of 8 CsI(Tl) detectors. A control experiment was also made on ^{181}Ta. The statistical model (SM) analysis of the spectra was done using the excitation energy dependence of the NLD parameter a, which includes the shell effect and its damping [3]. Fig. 1(a), (b) demonstrate a large shell correction energy required to explain the measured neutron spectrum near the doubly magic ^{208}Pb and a small value around ^{184}W. We have searched for an acceptable range of $\tilde{a}$ and γ by fixing Δ_S from the SM analysis of the neutron spectra. The extracted damping factor near ^{208}Pb found to be ($0.060^{+.010}_{-.020}$) MeV^{-1} which is different from the value extracted from the compilation neutron resonance data [4]. An exclusion plot of the damping parameter γ and the inverse level density parameter δa has been made for the first time (see Fig. 1(c)).

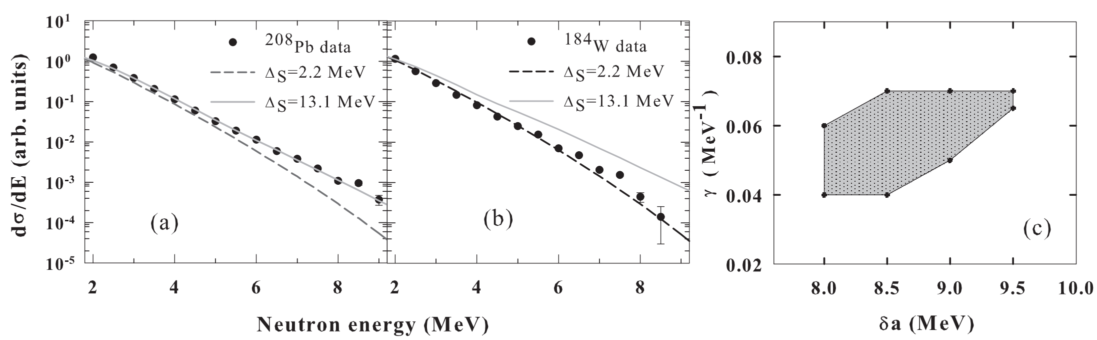

Figure 1: *(a) Neutron spectrum from ^{208}Pb at E_X=20.8 MeV and solid and dashed lines are the SM calculation using shell correction energy (Δ_S) 13.1 and 2.2 MeV, respectively, for $\tilde{a}$=A/8.5 MeV^{-1} and γ=0.055 MeV^{-1}. (b) Same as (a) except for ^{184}W at E_X=20.6 MeV and (c) the exclusion plot between δa (= A/$\tilde{a}$) and γ. The allowed values of $\tilde{a}$ and γ are within the contour.*

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Angular Momentum Dependence of Nuclear Level Density Parameter

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The study of nuclear level density (NLD) is important as it helps us to understand the microscopic properties of the atomic nuclei and also is an important ingredient in both the statistical and pre-equilibrium models of nuclear reactions. It is important and interesting to understand the dependence of NLD on the key parameters such as excitation energy (temperature) and angular momentum. Although in the recent years several experimental and theoretical efforts [1-3] were made to understand the angular momentum dependence of NLD, no conclusive idea was obtained. In order to investigate the angular momentum dependence of NLD further we have measured the neutron evaporation spectra in coincidence with the γ- rays of various multiplicities for the ^{4}He + ^{115}In system. Theoretical analyses of the experimental data were carried out using the statistical model code CASCADE to extract the value of the inverse level density parameter (k) ($k=A/a$, where a is the Fermi gas level density parameter) at different angular momentum regions (J), corresponding to different γ multiplicity. The extracted values of k as shown in Fig.1A were observed to decrease with J at two incident energies. The decrease of k (or increase in a) at higher J is indicative of the fact that NLD increases with angular momentum [3]. To understand the phenomenon in more consistent manner we have simultaneously measured all (major) the light particle (n, p, α) evaporation spectra for the ^{4}He + ^{93}Nb and ^{4}He + ^{58}Ni systems in another experiment. In this case the decrease of k was also observed from neutron, proton and α-particle spectra (Fig.1B (i), (ii) and (iii)) for both the systems consistently. The increase in level density in the first case can be partly understood by the concept of collective enhancement. However, in the second case shape change at higher angular momentum based on RLDM as well as the present prescription of collective enhancement failed to explain the observed variation of NLD with J [4]. Similar measurements has also been performed for systems with A~180 -200. Analysis of the experimental data is being carried out. Detail of the experimental results and their implications will be presented during the conference.

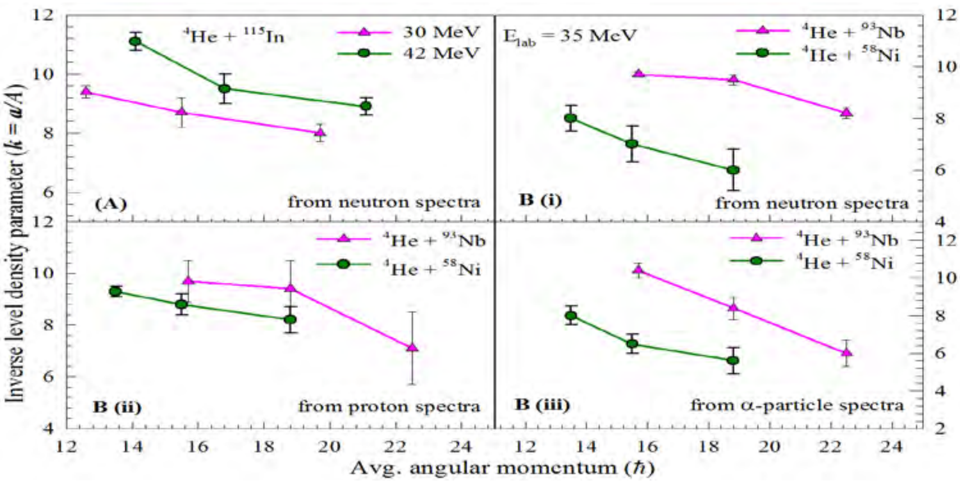

Figure 1: Variation of inverse level density parameter (k) with angular momentum (see text for details).

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The ASY-EOS experiment at GSI: investigating symmetry energy at supra-saturation densities

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The elliptic-flow ratio of neutrons with respect to protons or light complex particles in reactions of heavy-ions at pre-relativistic energies is proposed as an observable sensitive to the strength of the symmetry term in the nuclear equation of state at supra-saturation densities. The results obtained from the existing FOPI/LAND data for $^{197}Au +^{197} Au$ collisions at 400 MeV/nucleon in comparison with the UrQMD model favour a moderately soft symmetry term but suffer from a considerable statistical uncertainty [1]. These results have been confirmed by an independent analysis based on Tübingen QMD [2]. In order to obtain an improved data set for Au+Au collisions and to extend the study to other systems, a new experiment was carried out at the GSI laboratory by the ASY-EOS collaboration in May 2011 [3]. The flows of neutrons, protons and light complex particles were measured for $^{197}Au +^{197} Au$, $^{96}Ru +^{96} Ru$, and $^{96}Zr +^{96} Zr$ collisions at 400 MeV/nucleon using the Large Area Neutron detector LAND, four double-rings of the forward part of the CHIMERA multi-detector, the ALADIN ToF-Wall, the KRATTA Si-CsI triple-telescope array and the Microball detectors. First results, including elliptic flow ratios for Au+Au, will be reported.

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Absolute Cross Sections for Evaporation Residues Produced in $^{12}C+^{204,206,208}Pb$ Reactions

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Production cross sections for Rn and Ra evaporation residues (ER) early observed in the $^{12}C+^{204,206,208}Pb$ reactions study [1] with an electrostatic deflector [2] were reevaluated with taking into account later data on charge distributions of ER atoms [3] and a more reliable approach to the transformation of measured differential cross sections to the integral ones based on simulations of angular distributions for ER [4]. Pb(^{12}C, *xn*)Ra excitation functions resulting from the reevaluation are compared to the similar data obtained earlier and to the calculated excitation functions obtained in the framework of the standard statistical model of a compound nucleus (CN) decay. For the latter, calculated survivability of Ra nuclei is mainly determined by fission barrier heights used in the calculation, which could be estimated with a fit of the calculated evaporation excition functions to the measured ones. The data allow to trace the variation of fission barriers for Ra nuclei in a wide region of the neutron number N, especially at its crossing the spherical shell closure at N=126. In the vicinity of N=126 the effect of the collective enhancement in the nuclear level density should strongly reduce production cross sections of Ra nuclei, as it was observed in the relativistic collisions of a ^{238}U beam with a copper target [5]. This effect was not evidently manifested in the analysis of cross sections for different CN reactions leading to the Po nuclei production and fission in a wide region of N [6]. At the same time, very low production cross sections for very neutron defficient Po nuclei produced in reactions with massive projectiles could not be undoubtedly explained by a steep decrease in Po fission barrier heights. In such reactions quasi-fission effects leading to the suppression of complete fusion of nuclei, which can be described using the fusion probability, $P_{fus}<1$. In this connection, reliable ER cross section data obtained in very asymmetric combinations, such as ^{12}C+Pb, in which the fusion suppression is absent, become important as a reference for the analysis of similar data for ER produced in less asymmetric or symmetric combinations leading to the same or close CN.

In this work, the measured ER production cross sections in the $^{12}C+^{204,206,208}Pb$ reactions are considered in detail. Consequences from these data, which may help to understand better the survivability of heavy nuclei produced in heavy ion CN reactions, are discussed. Quantitative data on the fusion probabilities extracted empiricaly for massive combinations of interacting nuclei are also obtained with the use of the $^{12}C+^{204,206,208}Pb$ ER cross sections and are discussed.

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Isovector density distribution probed via isospin-generalized proton elastic scattering at 170 MeV

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Thickness of neutron skin has recently attracted a considerable interest, since it provides us with fundamental information on the property of asymmetric nuclear matter. One of the approaches of measuring the neutron-skin thickness is to relate a certain observable of giant resonance to skin thickness via structure calculation. However, such approaches have a fundamental weak point that uncertainties originate from the structure model. Another approach is to determine both proton and neutron density distributions by measuring electron and proton elastic scattering. While its analysis is now almost model-independent [1], it is not easy to extend this method to the study of unstable nuclei. This is because the measurement of electron scattering is technically very difficult in the RI-beam experiment.

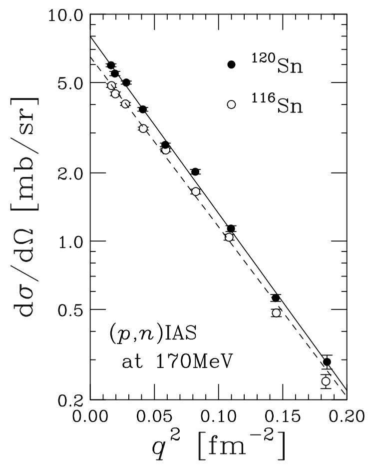

Figure 1: *$d\sigma/d\Omega$ for (p,n)IAS reaction on tin isotopes.*

Our aim is to establish a method to determine the neutron-skin thickness that can be applied to nuclei away from the stability line. As a possible candidate, we propose to use the charge exchange (p,n) reaction to an isobaric analog state. This reaction is equivalent to proton elastic scattering under the isospin symmetry. Proton elastic scattering, induced by an isoscalar part of the optical potential, is sensitive to the "sum" of proton and neutron distributions. On the other hand, the (p,n)IAS reaction is induced by an isovector part of the optical potential, and is expected to be sensitive to the "difference" between proton and neutron distributions. Analyzing both (p,p) elastic scattering and (p,n)IAS reaction in a single theoretical framework, simultaneous determination of proton and neutron density distribution could be possible without measuring the electron scattering.

As a proof-of-principle experiment, we have measured the differential cross sections and vector analyzing powers of both proton elastic scattering and (p,n)IAS reaction from stable tin isotopes ^{116,120}Sn at RCNP, Osaka University at an incident energy of 170MeV. The measurement was realized with a high-resolution neutron detector NPOL3 [2]. Figure 1 displays the low-momentum transfer region of the $d\sigma/d\Omega$ data for (p,n)IAS reaction. The slope of the data is expected to reflect the surface structure of isovector density. While the difference between the skin thickness of ^{116}Sn and ^{120}Sn is only 0.04 fm, a clear difference is observed: The slope of $d\sigma/d\Omega$ for ^{120}Sn is steeper, which can be understood as the result of thicker neutron skin. We will present the results of proof-of-principle experiment, simple interpretation of the data, and future application of this method to the RI-beam experiment.

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Microscopic time-dependent analysis of neutrons transfers at low-energy nuclear reactions with spherical and deformed nuclei

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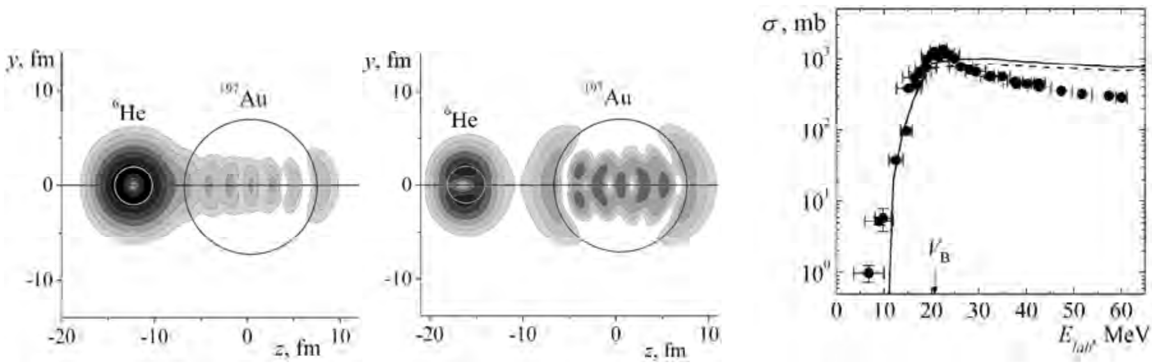
Neutron transfers in the low energy nuclear reactions allow us to obtain new isotopes of atomic nuclei with increased neutron content. The probability of neutron transfer is highest during so-called grazing nuclear collisions. In this case, the distances between the surfaces of the atomic nuclei do not exceed the range of the action of nuclear forces. The most probable transition is the one between the nuclei of the external, most weakly bound neutrons. A new possibility for theoretical study of transfer reactions is provided by numerical solution for the non-stationary Schrödinger equation for external neutrons [1]. In this study the spin-orbital interaction and Pauli's exclusion principle were taken into consideration. Time-dependent Schrödinger equation is numerically solved by difference method for external neutrons of spherical nuclei ^{6}He, ^{18}O, ^{48}Ca and deformed nucleus ^{238}U at their grazing collisions with energies near to a Coulomb barrier. The visual computer animations of probability density evolution (Fig. 1*a*) are calculated and probabilities of transfer of neutrons at reactions ^{6}He+^{197}Au, ^{18}O+^{48}Ca, ^{40,48}Ca+^{238}U are determined as function on minimum inter-nuclear distances. It is found, that the nucleons transfers for small values of full nucleon angular moment projection on an inter-nuclear axis at closed approach of nuclei are most probable. The calculation results of cross section for formation of the ^{198}Au isotope in the ^{6}He+^{197}Au reaction agree satisfactorily with the experimental data [2] in vicinity of the Coulomb barrier (Fig. 1*b*). At reactions ^{6}He+^{197}Au, ^{18}O+^{48}Ca neutrons are predominantly transferred from a smaller nucleus to the greater nucleus. At reaction ^{48}Ca+^{238}U probabilities of neutrons stripping and pick-up are commensurable. Non-stationary quantum approach applied in this work may be used for external protons and internal nucleons too. It may be useful for nucleons transfer experimental data analysis.

This work was supported in part by the Russian Foundation for Basic Research (RFBR) through Grant No 12-02-01325-a.



a *b*

Figure 1: *a) Change in the probability density of the external neutrons of an ^{6}He nucleus with the initial state $1p_{3/2}$ during a collision with the ^{197}Au nucleus at energy in the center of mass system E = 18 MeV. The course of time corresponds to the panels' locations from left to right.*

b) Energy dependence of the cross section for the formation of the ^{198}Au isotope in the ^{6}He+^{197}Au reaction. Dots represent the experimental data from [2]; the dashed line, calculations for the transfer of one neutron; the solid line, calculations for the transfer of one or two neutrons. V_B is the Coulomb barrier.

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Fusion hindrance at deep sub-barrier energies

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Employing the quantum diffusion approach [1-3], we calculated the capture cross sections and compared them with the experimental fusion cross sections to extract the threshold energies at which the capture and fusion cross sections start to deviate from each other. We found the relationship between the threshold energy for a deep sub-barrier fusion hindrance phenomenon and the energy at which the slope of the sub-barrier capture cross section changes. For the reactions ^{4}He + ^{208}Pb, ^{58}Ni + ^{54}Fe, ^{48}Ca + ^{48}Ca,^{90,96}Zr, ^{40}Ca + ^{90,96}Zr, ^{58}Ni + ^{58,60,64}Ni, ^{60}Ni + ^{89}Y, ^{64}Ni + ^{64}Ni,^{100}Mo, ^{90}Zr+^{90}Zr, and ^{16}O + ^{208}Pb,^{238}U, there is a good agreement between the threshold energy E_s for a deep sub-barrier fusion hindrance phenomenon and the energy E_{ch} at which the regime of interaction ((the external turning point r_{ex} leaves the region of the nuclear forces and friction)) changes in the sub-barrier capture process [2]. The values E_s and E_{ch} almost coincide and linearly increase with $Z_1Z_2[A_1A_2/(A_1+A_2)]^{1/2}$. In the special case of the spherical interacting nuclei, E_{ch} is approximately defined as the energy at which the external turning point coincides with the interaction radius R_{int}: $E_{ch} \approx V(R_{int} = r_{ex}, J = 0)$ (V is the nucleus-nucleus potential for s-wave). The agreement between E_s and E_{ch} seems to be contradictory to the conclusions of other approaches.

We predicted the sharp change of the slope of the quasielastic barrier distribution below the threshold energy [2]. This anomalous behavior is expected to be the experimental indication of a change of the regime of interaction in the sub-barrier capture. One concludes that the quasielastic technique could be an important tool in capture (fusion) research. However, to check our prediction, very high precision measurements are required.

The quantum diffusion approach was applied to calculate the capture cross sections for the reactions ^{92}Mo + ^{92}Mo, ^{104}Pd + ^{104}Pd, ^{94}Mo + ^{94}Mo, ^{100}Ru + ^{100}Ru, and ^{78}Kr + ^{112}Sn at extreme sub-barrier energies which are lower than the ground state energies of the compound nuclei [3]. Because the capture cross section is the sum of the complete fusion and quasifission cross sections, and the complete fusion cross section is zero at these sub-barrier energies, one can study experimentally the unique quasifission process in these reactions after the capture. The quasifission near the entrance channel is the unique binary decay process after the capture. The reactions ^{104}Pd + ^{104}Pd, ^{100}Ru + ^{100}Ru, and ^{78}Kr + ^{112}Sn seem to be optimal systems for a experimental study of the true quasifission at extreme sub-barrier energies.

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Complete Set of Deuteron Analyzing Powers for dp Elastic Scattering at Intermediate Energies and Three Nucleon Forces

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Study of three nucleon forces (3NFs) is essentially important in clarifying nuclear phenomena. In addition to the first signals of the 3NF effects in the binding energies of the ^{3}H and ^{3}He, the significance of 3NFs has been recently pointed out for descriptions of discrete states in higher mass nuclei. Three nucleon scattering at intermediate energies ($E/A \sim 200$ MeV) is one attractive approach to investigate the dynamical aspects of 3NFs, such as momentum and/or spin dependences. With the aim of clarifying roles of the 3NFs in nuclei the experimental programs with polarized deuterons beams at intermediate energies are in progress at RIKEN RI Beam Factory (RIBF) [1]. As the first step, we have measured a complete set of deuteron analyzing powers in deuteron–proton (dp) elastic scattering at 70–300 MeV/nucleon.

The vector and tensor polarized deuteron beams were accelerated by three cyclotrons, AVF, RRC and the newly constructed cyclotron SRC. The measurement of deuteron analyzing powers for elastic dp scattering was carried out using the polarimeter BigDpol installed at the extraction beam line of the SRC. The deuteron beams bombarded a polyethylene (CH_2) target in the scattering chamber. Scattered deuterons and recoil protons were detected by plastic scintillators in kinematical coincidence conditions.

A part of the obtained data is shown in Fig. 1. The obtained high precision data are compared with the results of three-nucleon Faddeev calculations based on modern nucleon-nucleon (NN) potentials; $i.e.$ CD Bonn, Argonne V_{18}, Nijmegen I, and II, alone (a blue band in the figure) or combined with Tucson-Melbourne'99 3NFs (a red band). Large discrepancies between pure NN theory and data, which are not resolved by the current 3NFs, are found at the c.m. backward angles for almost all the deuteron analyzing powers with increasing an energy.

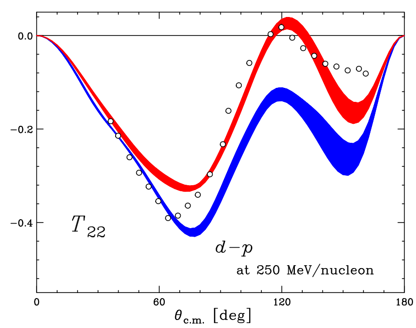

Figure 1: *Tensor analyzing power T_{22} for dp elastic scattering at 250 MeV/nucleon.*

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Measurement of Neutron Activation Cross Sections on Mo isotopes in the Energy Range from 7 MeV to 15 MeV

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Molybdenum is considered as an alloy component in different advanced nuclear energy system developments due to its excellent material properties at elevated temperatures. Improved quality and completeness of the data base are needed for reliable prediction of the behavior of the materials under such conditions. Of particular importance for the integrity of the structural materials is the hydrogen and helium production originating from (n,p) and (n,α) reactions. Improved and more complete experimental data for Mo isotopes will help to determine the parameters of nuclear models in a more systematic way and allow the verification of model predictions.

An experimental study of the ^{92}Mo(n,p)^{92}Nb^{m}, ^{92}Mo(n,α)^{89}Zr, ^{95}Mo(n,p)^{95}Nb^{m}, ^{95}Mo(n,p)^{95}Nb, ^{96}Mo(n,p)^{96}Nb, ^{97}Mo(n,p)^{97}Nb, ^{98}Mo(n,p)^{98}Nb^{m}, ^{98}Mo(n,α)^{95}Zr, ^{100}Mo(n,α) ^{97}Zr, and ^{92}Mo(n,2n)^{99}Mo activation reaction cross sections were carried out in the 7-15 MeV energy range at the CV28 compact cyclotron at Physikalisch-Technische Bundesanstalt, Braunschweig. The PTB time-of-flight (TOF) spectrometer with a D(d,n) source is well suited for this difficult energy range were significant correction for non-monoenergetic neutrons have to be applied. Gamma-ray spectrometry was applied for the measurements of the activity of the reaction products. All cross sections were determined relative to ^{238}U(n,f) and ^{27}Al(n,α)^{24}Na standard cross sections obtained from ENDF/B-VII library. Corrections were applied for the variation of the neutron fluence in time, measurement geometry, dead time effects and coincidence summing effects.

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Recent Developments in the Experimental Nuclear Reaction Data Library - EXFOR

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Nuclear data are needed in different fields of science and technologies. The collection and compilation of experimental nuclear reaction data and the related bibliographic information in the EXFOR database (http://www-nds.iaea.org/exfor/) is the main task of the International Network of Nuclear Reaction Data Centres (NRDC). The Network constitutes of worldwide cooperation of nuclear data centres under the auspices of the International Atomic Energy Agency. The scope of the EXFOR database has evolved since the first neutron-induced reaction data exchange in 1970 and presently compulsory for compilation are neutron-, charged-particle- and photon- induced reaction data for projectile energies up to 1 GeV and incident projectiles up to A=12. However, data for heavier projectiles and higher energies are compiled in EXFOR as well in order to respond to recent developments in science and application. The database presently contains cross section, angular-, energy- and double differential cross section,, analyzing power, resonance parameters, fission yield and fission neutron multiplicity etc. obtained by about 19600 experimental works. Users are provided with sophisticated search options, a user-friendly retrieval interface for downloading data in different formats, and additional output options such as extensive data plotting capabilities. The paper will present some recent IAEA Nuclear Data Section activities related to the development of the EXFOR database and retrieval system.

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Fusion excitation function measurement for ^{6}Li+^{64}Ni at near the V_B

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Reactions with weakly bound stable projectiles have been studied on several targets [1–4] in order to investigate the role of breakup channel on scattering and fusion in different mass region. Breakup is said to suppress the cross section of complete fusion (CF) of the projectile at energies above the barrier compared to the model predictions including the coupled channel calculation. The suppression of complete fusion (CF) is accounted for with the process of incomplete fusion (ICF) of a part of the weakly bound projectile with the target. In general, the suppression is expected to decrease with decreasing charge of the target [5–7]. But in a recent work Kumawat et al. [8] demonstrated the existence of a uniform suppression of about 30% of complete fusion cross section independent of charge of the target for ^{6}Li projectile. The effect was attributed to the dominance of nuclear induced breakup over Coulomb breakup for ^{6}Li. However, an exception of the trend was observed for ^{6}Li+^{59}Co system.
In this context, we intend to present our recent measurement of fusion excitation function for ^{6}Li +^{64}Ni system using the characteristic γ -ray detection technique. The experiment was carried out at the TIFR/BARC Pelletron Facility in Mumbai with ~99% enriched ^{64}Ni target. The excitation function was measured over the incident energy of 11 to 28 MeV with the barrier for the sys-tem being ~13.8 MeV in laboratory. A thin Be-window n-type and an Al-window p-type HPGe were used at for-ward and backward angles. Dominant 2n, 3n and pn evaporation channels coming from purely complete fusion process were identified along with other channels from ICF and transfer processes. A representative spectrum is shown in Fig.1. Extraction of complete fusion cross section for ^{6}Li +^{64}Ni system and subsequent observation of suppression, if any, will be presented.

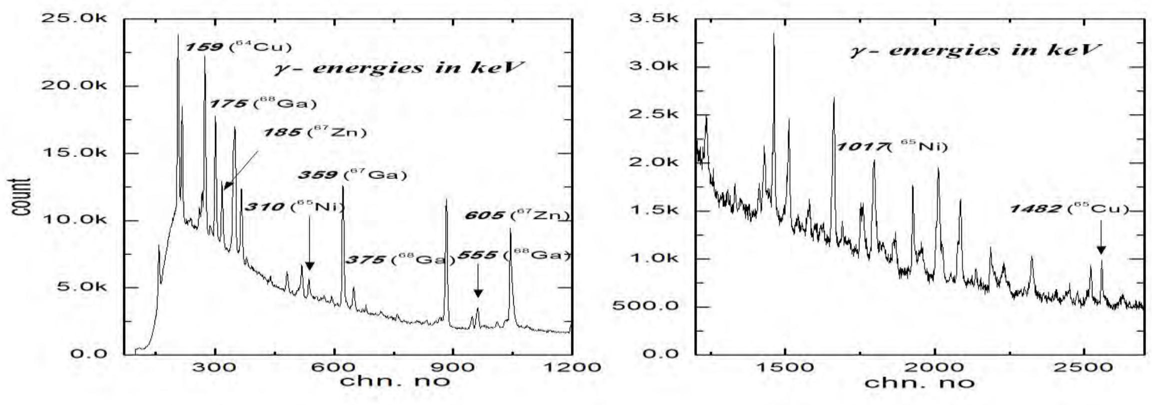

FIG. 1: Representative characteristic γ spectrum from ^{6}Li +^{64}Ni fusion at 26 MeV.

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Incomplete fusion reactions at low energies in $^{13}C+^{169}Tm$ system

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To understand the in-complete fusion (ICF) reaction dynamics at low energies (≈ 4-7 MeV/A), where complete fusion is expected to be the sole contributor, the excitation functions for several radio-nuclides populated in $^{13}C+^{169}Tm$ interactions have been measured and analyzed in the framework of statistical model. These residues were identified by their characteristic γ-rays and were further confirmed from their measured half lives. In these measurements the recoil-catcher technique followed by off-line γ-spectrometry has been used. The experiments for the presently studied system have been performed at the Inter University Accelerator Centre (IUAC), New Delhi, India using 15 UD Pelletron Accelerator facilities. In our investigations, some of the radio-nuclides populated are found to have contributions from their higher charge isobar pre-cursor decay, which have been separated out from the cumulative cross-section using the successive radioactive decays formulations [1]. The xn and pxn-channels are found to be satisfactorily reproduced by theoretical calculations. Further, in order to look into the production mechanism of α-emitting channels, the experimentally measured EFs have been compared with the PACE4 [2] calculations. The measured EFs for α-emitting channels are found to be significantly enhanced over the calculated values. This enhancement may be attributed to the contribution of ICF processes in these reaction channels. In order to achieve information on how does the fraction of ICF depend on various entrance channel parameters, the incomplete fusion fractions (F_{ICF}) have been deduced at these energies. The F_{ICF} is a measure of relative strength of ICF to the total fusion. A survey of the literature shows that, the mass-asymmetry systematic, as suggested by Morgenstern [3], for ICF is modified as a projectile dependent mass-asymmetry systematics given by Singh et. al [4]. According to Morgenstern et al. [3], the onset of ICF takes place as soon as $v_{rel} > 0.06$ (i.e., 6 % of c) and with increasing probability for more mass-asymmetric systems. In a recent communication [5], it has been observed that the ICF starts competing with complete fusion at noticeably lower v_{rel} -value and displays strong projectile dependence. However, Yadav et al. [6], summarized the probability of low energy ICF on the basis of α-Q value systematics, where, F_{ICF} decreases for projectiles having relatively large negative α-Q values. Therefore, in the present work the $^{13}C+^{169}Tm$ data has been compared with the existing ^{12}C, $^{16}O+^{169}Tm$ data [4,7], in order to proclaim the validity of the above systematics at low energies. Further details will be presented.

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Understanding the onset of low energy incomplete fusion

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The onset of incomplete fusion (ICF) at slightly above barrier energies ($E_{lab} \approx V_b$) and its strong influence on complete fusion (CF) at relatively higher energies, where CF supposed to be dominant [1], have been reported recently [2-4]. High quality data on ICF strength function, forward ranges and angular distributions of heavy recoils have conclusively demonstrated the existance of ICF. However, how does ICF show up at such low energies is not fairly understood.

Aiming to probe the dynamics of low energy ICF, an experiment has been performed at the Inter-University Accelerator Center (IUAC), New Delhi. The spin-distributions of various reaction residues populated via xn/pxn/αxn/2αxn-channels in ^{16}O($E_{lab} \approx$5.6 AMeV)+^{169}Tm system have been measured using particle-γ coincidence technique [5]. Prompt γ-rays in coincidence with charged particles (Z=1,2) have been recorded for channel selection. Reaction dependent decay patterns, which eventually led to distinctly different spin-distributions of CF and ICF reaction products, have been observed. The mean value of driving input angular momenta (ℓ) associated with xn/pxn/αxn/2αxn-channels have been obtained from the analysis of spin-distributions. Higher ℓ-values ($\ell \geq \ell_{crit}$), imparted into the system in non-central interactions, are found to be responsible for low energy ICF [5].

In order to confirm the finding reported in our recent letter [5], the similar measurement has been extended at 10 energies (from 1.02V_b to 1.64V_b) for ^{12}C+^{169}Tm systems. The experimental spin-distributions have been analyzed to achieve information on input ℓ-values, and to generate feeding intensity profiles of different reaction products. In general, the ICF-αxn/2αxn channels display the involvement of higher ℓ-values than that observed in CF-xn/pxn/αxn/2αxn channels at the very same projectile energy. The value of ℓ increases with successively opened ICF channels and incident energy. Further, It has been observed that the CF products are strongly fed over a broad spin range, while ICF products are found to be less fed and/or the population of lower spin states are strongly hindered. Experimental results are found to be consistent with that presented in ref.[5].

Detailed results and systematics obtained from this measurement will be presented during the conference.

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Study of the shell effect on nuclear dissipation via neutron multiplicity measurement.

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Presence of Kramers predicted dissipation strength in heavy-ion induced reactions is well established from the study of different probes like pre-fission neutrons, gamma ray multiplicities from the compound nucleus giant dipole resonance (GDR), light charged particles and evaporation residues etc [1]. Nowadays the research is going on to establish the behavior of nuclear dissipation under various observables such as isospin, excitation energy, shell effect etc. The study of shell effect on nuclear dissipation is important for the production of super heavy elements (SHE), as SHE are mainly produced by cold fusion process, where the maximum excitation energy can be 30-40 MeV, where shell effect can play an important role. Present work mainly deals with the study of effect of shell closure in compound nucleus (CN) on nuclear dissipation using neutron multiplicity as a probe. A series of experiments were carried out at Inter University Accelerator Center (IUAC), New Delhi using Pelletron and LINAC beam. Three isotopes of Fr (^{213,215,217}Fr) are populated by fusion of ^{19}F+^{194,196,198}Pt in the excitation energy range of 46.6–91.8 MeV [1]. Out of these ^{213}Fr is shell closed CN (N = 126) and other two are away from shell closure (N = 128, 130). Experimentally obtained neutron multiplicities for different CN are compared with statistical model predictions with and without inclusion of shell corrections using both Bohr-Wheeler and Kramers modified fission widths. It is observed that the statistical model calculations using Bohr-Wheeler predictions under-predicts the experimental neutron multiplicity except at the lowest energy, which clearly indicate the presence of dissipation effects. During the statistical model calculation using Kramer fission width without shell correction, it is observed that excitation energy dependent dissipation strength is required to explain the experimental neutron multiplicity and strength of dissipation required from ^{213}Fr (N = 126) shell closed CN is quite less as compared to other two CN and this lowering is visible up to 91.8 MeV. Later, to understand the lowering of dissipation due to shell closure more clearly, the shell effects are included in nuclear mass and fission barrier [2]. It is observed that again the excitation energy dependent dissipation strength is required to fit the experimental neutron multiplicity and comparison of dissipation strengths for different CN shows that the all the three CN behave similarly above 60 MeV excitation energy, whereas a suppression in dissipation strength for shell closed CN (^{213}Fr) is observed below 60 MeV. From the present study, it can be concluded that the shell closure in CN results in the lowering of nuclear dissipation strength at low excitation energy. Hence the increase in the survival probability of SHE due to shell closed CN can be offset by some extent by the lowering of dissipation strength.

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Nucleon mean-free path in the medium

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We provide first-principle calculations of the nucleon mean-free path in the medium by extending the many-body Green's functions formalism to the complex energy domain. Using self-consistent ladder self-energies, we find the spectra and lifetimes of quasi-particles in nuclear and neutron matter. With a consistent choice of the group velocity, the nucleon mean-free path can be computed. Our results indicate that, for energies above 50 MeV at densities close to saturation, a nucleon has a mean-free path of 4 to 5 femtometers. This paves the way toward an ab initio description of transport properties of dense matter.

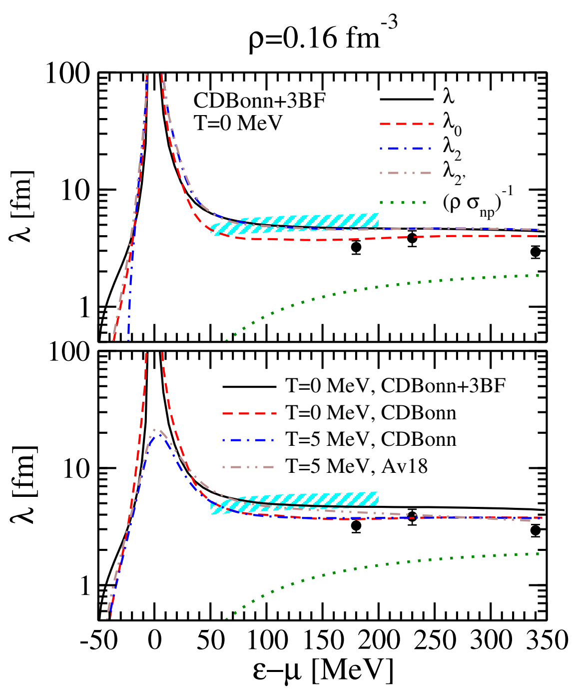

Figure 1: *Mean-free path of a nucleon in nuclear matter as a function of energy. Upper panel: results obtained with a CDBonn+3BF self-energy at $T = 0$ MeV for different approximation schemes. Lower panel: mean-free path from the fully dressed pole for different NN forces and two different temperatures.*

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Oscillations in the fusion excitation function of ^{28}Si + ^{28}Si above the barrier

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The fusion excitation functions of light heavy-ion systems like ^{12}C,^{16}O + ^{12}C,^{16}O show oscillatory structures above the Coulomb barrier, sometimes caused by resonances. They may also be due to the penetration of successive centrifugal barriers well separated in energy. Those structures are best revealed by plotting the derivative of the excitation function [1]. CC calculations based on a shallow potential in the entrance channel reproduce nicely the oscillations. This implies some consistency with fusion hindrance at far sub-barrier energies, because the ion-ion potential directly influences both effects.

In heavier systems, the amplitude of oscillations decreases and the peaks get nearer to each other. This makes the measurements very challenging. We have performed a first experiment for ^{28}Si + ^{28}Si, by measuring fusion cross sections in an energy range of $\simeq$15 MeV above the barrier, with 0.5 MeV lab-energy steps. Previous data marginally suggest the presence of oscillations in this system [2]. The beam was accelerated by the XTU Tandem of the LNL onto 50 μg/cm^2 targets, and fusion-evaporation residues were detected near 0^o. Preliminary results are shown in the figure.

It is remarkable to note that three regular oscillations are clearly observed. The predicted oscillatory structure of Ref.[1] (full line in the figure) is in good agreement with the observations. The final result of the experiment, together with our recent data down to far sub-barrier energies, will be analyzed within the CC model, and will provide a stringent test for the calculations, in particular for the choice of the ion-ion potential, and for the possible relation of the observed structures with resonances.

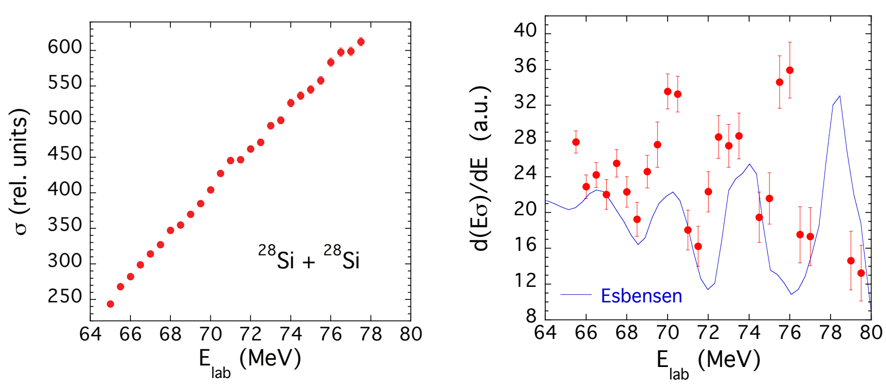

Figure 1: *(left) Fusion cross sections of ^{28}Si + ^{28}Si; statistical uncertainties are close to 1% for all points. (right) Energy-weighted derivative of the excitation function, compared to the prediction of Ref.[1].*

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Studies of interactions in three-nucleon systems via measurement of vector and tensor analyzing powers

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Understanding the interaction between nucleons is fundamental for nuclear physics and a starting point for describing properties of nuclei and reactions involving nucleons. Observables for three-nucleon (3N) systems constitute an important basis for testing modern theories of these interactions. Polarization observables can be sensitive to smaller and different dynamical ingredients as compared to cross section, therefore they are necessary for comprehensive understanding of the system.

High precision data for vector and tensor analyzing powers of the ^{1}H($\vec{d}$,d)p elastics scattering and ^{1}H($\vec{d}$,pp)n breakup reaction at 130 and 100 MeV deuteron beam energies have been measured at KVI in a large fraction of the phase space [1,2,3]. They are compared to the theoretical predictions based on various approaches to describe the three nucleon (3N) system dynamics. Theoretical predictions describe very well the vector analyzing power data for both studied processes, with no need to include any three-nucleon force. Tensor analyzing powers can be also very well reproduced by calculations in most of the studied region, but locally certain discrepancies are observed. In the case of breakup process at 130 MeV, the discrepancies appear for A_{xy} when model 3N forces are included. Predicted effects of 3NFs are much lower at 100 MeV. At this energy equally good consistency between the data and the calculations, with or without 3NFs, is obtained. On the other hand, Coulomb interaction starts to play the role and has to be included into calculations in order to reproduce experimental data. Conclusions following from that analysis will be confronted with the data obtained at other beam energies.

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^{25}Na and ^{25}Mg fragmentation on ^{12}C at 9.23 MeV per nucleon at TRIUMF and AMD calculations

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Accelerated beams of short-lived radioactive nuclei have been available for a few years from different facilities around the world. Heavy-ion collisions using radioactive ion beams (RIB) gives the possibility to study the equation of state of nuclear matter with different neutron-to-proton (N/Z) ratios. RIB are available with energies up to 15 MeV per nucleon at TRIUMF from the ISAC II superconducting linear accelerator [1]. The HERACLES multidetector is used to study heavy-ion collisions at TRIUMF, with ion beams with an energy range between 8 to 15 MeV per nucleon [2]. Seventy-eight detectors are axially distributed around the beam axis in 6 rings allowing detection of multiple charged fragments from nuclear reactions. Experimental data was collected by HERACLES from a radioactive ^{25}Na beam and a stable ^{25}Mg beam at 9.23 MeV per nucleon on a carbon target. For analysis, we compare energy spectra and isotopic ratios from both projectiles with an hybrid code. Antisymmetrized Molecular Dynamics (AMD) [3] is used to treat the dynamics of colliding systems and GEMINI [4] for the statistical deexcitation of fragments.

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Neutron-deuteron scattering observables at E_{lab} =14.1 MeV within differential equations Faddeev formalism

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We study the inelastic neutron-deuteron scattering on the basis of the configuration-space Faddeev-Noyes equations [1]. The Merkuriev-Gignoux-Laverne approach [2] is generalized for arbitrary nucleon-nucleon potentials and with an arbitrary number of partial waves.

A new computational method for solving the nucleon-deuteron breakup scattering problem is proposed. This method is based on the spline-decomposition in the angular variable and on a generalization of the Numerov method for the hyperradius (see Ref. [3]).

Neutron-deuteron observables are calculated using the Argonne AV14 nucleon-nucleon potential at the incident nucleon energy 14.1 MeV. Convergence of numerical results with respect to maximum value of the three-body angular momentum M is studied. Accuracy of elastic amplitudes computed is checked by using more detail grids in the angular variable. These amplitudes are applied for calculations of the elastic differential cross-section, and the nucleon A_y and deuteron iT_{11} analyzing power. The breakup amplitudes have been calculated under FSI configuration. To calculate elastic and breakup amplitudes, we take into account all orbital angular momenta of subsystems ℓ and $\lambda \leq 4$, the total angular momentum of a pair nucleons $j \leq 3$, and the total three-body angular momentum M up to 13/2. For the elastic observables we have obtained a good agreement with theoretical predictions of the Bochum [4] and Grenoble [5] group. All predictions for analyzing powers have considerable discrepancies with the experimental data [6,7].

For the nd breakup scattering at E_{lab} =14.1 MeV the angular distribution and nucleon analyzing power A_y have been calculated. In this case agreement with the experimental data [8] and the prediction of the Bochum group [9] for the nucleon analyzing power A_y have only qualitative character. These preliminary results are currently under study.

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Measurements of interaction cross sections for $^{22\text{-}35}$Na isotopes

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Interaction cross sections (σ_I) for Na isotopes from stability line to the vicinity of the neutron drip line have been measured at around 240*A* MeV. The σ_I for $^{33\text{-}35}$Na have been measured for the first time. The experiment was carried out by using BigRIPS at RIBF.

The halo and skin structures at the nuclear surface have attracted much interest. These exotic structures were discovered by measurements of interaction cross sections[1,2]. In this work, we measured σ_I for Na isotopes including the nuclei that are located in or near the so-called "island of inversion". Figure 1 shows the mass number dependence of σ_I for $^{22\text{-}35}$Na isotopes on C targets. Starting at mass number 28, the present data deviate from systematics for stable nuclei with increasing mass number. The tendency of σ_I for $^{22\text{-}31}$Na isotopes corresponds with that of nuclear deformation parameter β_2. From the present data, the root mean square nuclear matter radii $\langle r_m^2\rangle^{1/2}$ were determined by using Glauber-type calculation. These $\langle r_m^2\rangle^{1/2}$ are almost in agreement with theoretical calculation by relativistic mean field model (RMF) [3]. A monotonic growth of the neutron skin thickness has been observed as the neutron number increases in Na isotopes. This results are consistent with results in ref. 2. Moreover, the shell structures of neutron excess Na isotopes will be discussed.

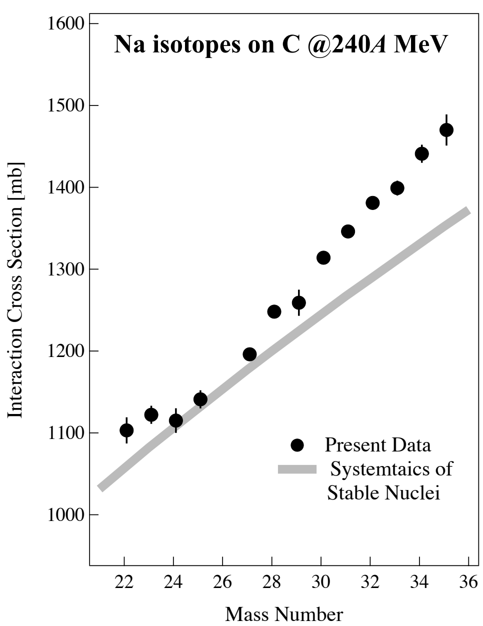

Figure 1: The observed mass number dependence of interaction cross sections for Na isotopes on C targets.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Ultraperipheral production of very small number of particles in ultrarelativistic heavy ion collisions

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We shortly review physics related to the production of particles in peripheral ultrarelativistic heavy ion reactions. Several processes will be discussed such as production of pairs of charged muons, pairs of pions, pairs of charmed quarks, and vector mesons (ρ^0, J/ψ or their radial excitation). The production occurs when heavy nuclei pass each other at impact parameter from $2R_A$ to several thousands of fermis.

Ultrarelativistic heavy ions are a strong source of quasi-real photons. Therefore two competing mechanisms will be considered: photon-photon fusion and high-energy photoproduction on nuclei. The interrelations between these two mechanisms were not studied so far in the literature. Such processes are under current evaluation at RHIC and LHC. Due to large charges of heavy ions the related cross sections are very large. Several processes will be discussed in detail. Some experimental results will be review as well. The photon-photon collisions are interested per se and are related with physics relevant at LEP, BELLE or BABAR. The production of vector mesons is related to physics of gluon saturation studied in electron deep-inelastic scattering off proton and less peripheral heavy-ion collisions.

The presentation will be based mostly on our papers published in recent years.

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Probing nucleon-nucleon correlations via heavy ion transfer reactions

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Transfer reactions play an essential role in the study of collision dynamics and nuclear structure. They have an important impact in the understanding of correlations in the nuclear medium, and play a very important role for the study of the evolution from the quasi-elastic to the deep-inelastic and fusion regime [1]. In the heavy-ion induced transfer reactions, the constituents of the collision may exchange many nucleons, thus providing information on the contribution of single particle and correlated particle transfers, and on the contribution of surface vibrations (bosons) and their coupling with single particles (fermions).

The recent revival of transfer reaction studies greatly benefited from the construction of the new generation large solid angle spectrometers based on trajectory reconstruction that reached an unprecedented efficiency and selectivity. The coupling of these spectrometers with large γ arrays allowed the identification of individual excited states and their population pattern. In this work selected results obtained by using Prisma spectrometer [2] will be presented. Special emphasis will be placed on the major achievements of the last years, as was the extraction of absolute differential cross sections via a careful study the response function of the spectrometer [3,4]. This fact was of crucial value in the extraction of the pair-transfer stregths [5,6,7].

In addition, a new preliminary results of the test of pair-correlation properties in heavy ion induced reactions by populating at once $\pm(nn)$, $\pm(pp)$ and $\pm(np)$ channels will be dicussed [8]. Especially the role played by neutron-proton correlations. Nuclear models point out that such a correlation is expected to be strongest in $N \sim Z$ nuclei, where protons and neutrons occupy the same orbitals.

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Influence of Mass of the Fragmenting System on Projectile Multifragmentation

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We have studied multifragment decays of Mg projectiles after collisions with various emulsion targets at a bombarding energy of 4.5 AGeV. In the study of projectile multifragmentation, the bound charge Z_b , which is the sum of all projectile fragments with charge $Z_{PF} \geq 2$, is considered to be one of the important observables. Correlation between mean number of intermediate mass fragments $<N_{IMF}>$ and Z_b is one of the most interesting aspects of studying projectile multifragmentation. In this report an attempt has been made to study the variation of $<N_{IMF}>$ on the mass of the fragmenting system Z_b [1-2] for Mg-Em interaction at 4.5 AGeV and compare the result with the results reported by ALADIN and KLMM [1-4]. A rise and fall pattern in $<N_{IMF}>$ vs Z_b plot with the maximum value of $<N_{IMF}>$ corresponding to the value of Z_b = 6-7 could be observed for our Mg-Em system. The value of bound charge corresponding to the maximum value of average number of intermediate mass fragments is found to be consistent with the results reported by other workers. The variation of $<N_{IMF}>$ on Z_b normalized with the projectile charge Z_p indicates a clear size effect for the studied systems.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Scattering of light halo nuclei on heavy target at energies around the Coulomb barrier

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The loosely bound structure of halo nuclei should affect the collisions with heavy targets at energies around the Coulomb barrier. One can thus expect a departure from Rutherford scattering. This deviation shed light on the structure as well as on how the scattering process depends upon the coupling to the continuum.

The interplay of two effects will occur: Firstly, the Coulomb break-up reduces the elastic cross section. Secondly, the distortion of the wave function, generated by the displacement of the charged core with respect to the centre of mass of the nucleus, reduces the Coulomb repulsion, and thus the elastic cross sections.

We report here on a series of experiments performed at different facilities to study the behaviour of the scattering of the light halo nuclei 6He, 11Li and 11Be on lead. The results are interpreted in the framework of 4-body Continuum-Discretized Coupled-Channel calculations. The departure from Rutherford scattering at energies below the barrier is well beyond the expected behaviour. Furthermore, the breakup probability data shed light on the effective breakup energy as well as on the slope of the B(E1) distribution.

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First results from a quasifree scattering experiment with light neutron-rich nuclei at and beyond the dripline at LAND/R^{3}B

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Nuclear structure is known to change dramatically close to the driplines (e.g. halo-structure, clustering). At large isospin, the varying influence of components of the nuclear interaction, such as the tensor, the 3-body and the spin-orbit part, leads to modifications of the traditional shell structure, see e.g. [1] for a recent review. The resulting changes of the nuclear structure make nuclei at and beyond the neutron dripline an interesting target for experimental studies.
The S393 experiment, performed at the LAND/R^{3}B (Reactions with Relativistic Radioactive Beams) setup at GSI, aims at studying a large number of light nuclei near the neutron dripline in complete kinematics. In particular the experiment provides data for studying the cluster structure of Beryllium isotopes, extracting (n,γ) rates for r-process nucleosynthesis, deriving single-particle spectroscopic factors, and studying the shell structure of nuclei near and beyond the neutron dripline. Radioactive beams with of nuclei in the range from $Z = 4$ to $Z = 10$ with kinetic energies around 490 AMeV were provided by the GSI fragment separator FRS.
The LAND/R^{3}B setup (shown in Fig. 1), being the precursor and transitional setup to R^{3}B at FAIR, allows for experiments in complete kinematics. This is facilitated by the high kinetic energies of the secondary beams available at GSI, which lead to relativistically forward-focused reaction products. This provides optimal conditions to study quasifree scattering [2], specifically (p,2p) and (p,pn) reactions, which are important in order to create and study unbound nuclei. For example the latter are created when a nucleus at the neutron dripline undergoes a (p,2p) reaction with the target. Detecting the two protons from the reaction plus the products of the resulting break-up, one is able to tag the reaction mechanism exclusively.
Measuring the momentum distributions of the outgoing particles allows to study single particle states and offers a second method to reconstruct the recoil momentum, apart from measuring it directly.
The data analysis is ongoing. Identified reaction channels and the current status of the analysis, which focuses on quasifree knockout reactions and unbound neutron rich nuclei, will be presented.

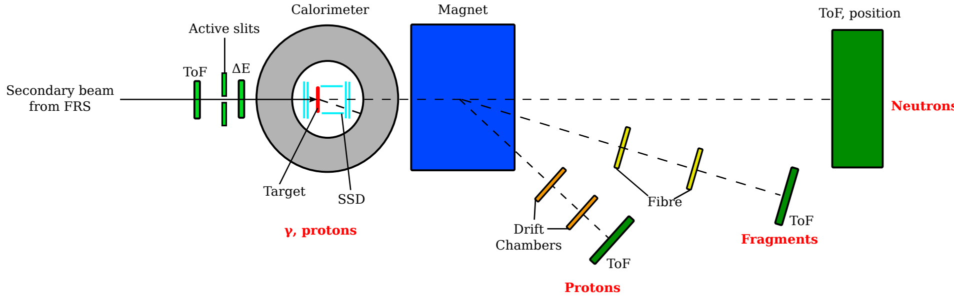

Figure 1: *A schematic drawing of the LAND/R^{3}B setup used during the S393 experiment. Not to scale.*

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Non-locality in the adiabatic model of (d,p) reactions

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It is long known that the experimental cross sections of (d,p) reactions are best reproduced by theoretical calculations if deuteron breakup is accounted for. Such calculations, performed usually in the adiabatic model, use local neutron and proton optical potentials taken at half the deuteron energy in order to calculate the distortion in the incident channel. However, it is also known that nucleon optical potentials are non-local due to the complex nature of the target. What has been an open question until now is how the adiabatic model should be modified to include these non-localities. We propose a model in which all the complexity of the continuum n + p + A effects and the non-localities in the p-A and n-A interactions is reduced to a simple two-body equation with an effective deuteron potential which is easy to construct. Such a potential can be read in by existing transfer reaction codes thus giving our approach the opportunity to being widely used. We demonstrate that in our new approach the effective deuteron potential is reduced with respect to the traditional adiabatic potential and quantify the influence of this effect on (d,p) cross sections.

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Elastic scattering of ^{17}O ions from ^{58}Ni and ^{208}Pb at near-barrier energies

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Elastic scattering experiments provide a first information on the overall reactivity of an exotic projectile. We have recently undertaken a research program aimed at measuring the ^{17}O elastic scattering process from medium and heavy targets, being ^{17}O (S_n = 4.143 MeV) a good reference case for its mirror nucleus: the weakly-bound and radioactive ^{17}F (S_p = 0.600 MeV).

The experiment was performed at the Laboratori Nazionali di Legnaro with an ^{17}O beam impinging on a ^{58}Ni (150 μg/cm^2) target from 42.5 to 55 MeV in 2.5 MeV steps and on a ^{208}Pb (200 μg/cm^2) target at 5 energies in the interval 78-87 MeV. We used three modules of the EXPADES detector array (whose commissioning is reported in another contribution to this conference). Two 300 μm thick Double Sided silicon Strip Detectors (DSSSDs) were placed symmetrically to the beam axis to cover the angular range θ_{lab} = [36°-74°]. A DSSSD telescope (40+300 μm) was placed at backward angles to cover the range θ_{lab} = [95°-125°]. Left and right panels of Fig. 1 show the ^{17}O elastic scattering angular distributions on ^{58}Ni and ^{208}Pb, respectively.

The results were analyzed within the framework of the optical model to extract the reaction cross sections (shown in the insets), which, after being scaled for the different projectile atomic numbers, result to be larger for the stable well-bound ^{17}O rather than for the weakly-bound radioactive ^{17}F. This outcome suggests, that for the pair ^{17}O-^{17}F nuclear structure effects are more relevant than the projectile binding energy in the reaction dynamics at Coulomb barrier energies.

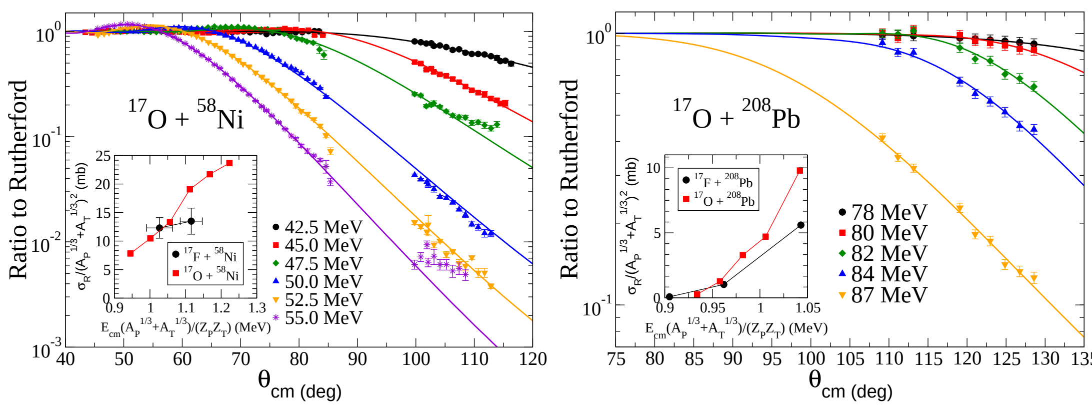

Figure 1: *^{17}O angular distribution for the systems ^{17}O+^{58}Ni (left) ^{17}O+^{208}Pb (right). Continuous lines are the results of optical model best-fits of the collected data. The insets show the reduced reaction cross sections for the systems ^{17}O,^{17}F+^{58}Ni (left) and ^{17}O,^{17}F+^{208}Pb (right).*

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Measurement of the ^{240,242}Pu(n,f) cross section at the CERN n_TOF facility

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The sustainable use of nuclear energy as a means of reducing reliance on fossil-fuel for energy production has motivated the development of nuclear systems characterised by a more efficient use of nuclear fuels, a lower production of nuclear waste, economic viability and competitiveness and minimal risk of proliferation of nuclear material and is being pursued by international collaborations [1]. The accurate knowledge of relevant nuclear data is crucial for feasibility and performance studies of advanced nuclear systems, including Accelerator Driven Systems (ADS) and Generation IV reactors. These data include neutron cross sections of a variety of plutonium isotopes and other minor actinides, such as neptunium, americium and curium.

In this context, the ^{240,242}Pu(n,f) cross sections were measured relative to the well-known ^{235}U(n,f) cross section. These isotopes are included in the Nuclear Energy Agency (NEA) High Priority List [2] and the NEA WPEC Subgroup 26 Report on the accuracy of nuclear data for advanced reactor design [3]. The measurements were performed at the CERN n_TOF facility [4], taking advantage of the wide energy range (from thermal to GeV) and the high instantaneous flux of the n_TOF neutron beam.

The measurements were carried out with the innovative Micromegas (Micro-MEsh GAseous Structure) gas detector [5]. The gas volume of the Micromegas is separated into a charge collection region (several mm) and an amplification region (tens of μm) by a thin “micromesh” with 35 μm diameter holes on its surface. The amplification that takes place in the amplification region significantly improves the signal-to-noise ratio of the detector. A chamber capable of holding up to 10 sample-detector modules was constructed and used to house the plutonium samples ($4\times^{240}PuO_2$, $4\times^{242}PuO_2$, with a total mass of 3.1 and 3.6 mg respectively for each isotope) and a reference ^{235}U sample (3.3 mg). The detector was operated with an Ar:CF_4:isoC_4H_{10} gas mixture. The behaviour of the detectors was studied in detail by means of Monte Carlo simulations performed with the FLUKA code [6], focusing particularly on the reproduction of the pulse height spectra for α-particles and fission fragments for the evaluation of the detector efficiency and the quality of the peak-search routine.

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Sub-barrier fission cross-section resonances of ^{232}Th(n,f), ^{234,238}U(n,f) with effects on fission fragment and prompt neutron emission data

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The correlation between the sub-barrier resonant behaviour of fission cross-section of non-fissile actinides characterizing the pre-scission stage and the non-statistical fluctuations of their fission fragment and prompt neutron data (characterizing the post-scission stage) around the incident energies of resonances is outlined and supported by quantitative results for three fertile actinides ^{238}U(n,f), ^{234}U(n,f) and ^{232}Th(n,f).

The pre-scission stage (when only one nucleus is involved with the evolution on the fission path) includes the calculation of neutron-induced cross-sections, focusing on the fission cross-section. The calculation is done in the frame of the refined statistical model for fission with sub-barrier effects included in the STATIS code (for details see for instance Ref.[1] and references therein) and also implemented in the code EMPIRE (details can be found for instance in Ref.[2] and references therein).

The post-scission stage (involving many nuclei, the fission fragments, emitting prompt neutrons and gammas according to their structure properties and excitation energy partition) is treated in the frame of the Point-by-Point (PbP) model (for details see the appendix of Ref.[3] and references therein). Total average quantities, characterizing both fission fragments and prompt neutron emission, as a function of incident neutron energy (obtained by averaging the PbP results as a function of fragment over the fission fragment distributions) reveal variations around the energies of sub-barrier resonances in the fission cross-section. This correlated behaviour making the link between the pre-and post scission stages.

In the pre-scission stage, the sub-barrier resonances of experimental fission cross-section data are very well described by our model calculations performed for ^{234,238}U and ^{232}Th. The neutron-induced cross-sections of competitive processes (elastic and inelastic scattering and gamma-capture) are also obtained in good agreement with existing experimental data.

In the post-scission stage, the primary results of the PbP model, consisting in the so-called multi-parametric matrices of quantities characterizing both fission fragments and prompt neutron emission (such as level density parameter a(Z,A,TKE), prompt neutron multiplicity ν(Z,A,TKE)) are averaged over experimental fragment distributions. The resulted total average quantities, such as energy release <Er>, level density parameter <a>, average neutron separation energy from fragments <Sn>, prompt neutron multiplicity <ν> as a function incident energy (En), exhibit visible non-statistical fluctuations around En of sub-barrier fission cross-section resonances. In the case of ^{238}U(n,f) more details about can be found in Ref.[4].

For the first time prompt emission quantities (such as prompt neutron multiplicity and spectra, prompt gamma-ray energy and so on) are calculated for ^{234}U(n,f) and ^{232}Th(n,f) at many En and are obtained in very good agreement with existing experimental data. Average prompt emission quantities as a function of TKE, such as <ν>(TKE), <ε>(TKE), (obtained by averaging the corresponding PbP multi-parametric matrices over the double distributions Y(A,TKE) as described in Ref.[3]) are calculated at many En revealing interesting behaviours: the slope dTKE/dν practically does not vary with En and the flattening of <ν> at low TKE values is more pronounced at low En.

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Wobbling motions of nuclear molecule $^{28}\text{Si} - {}^{28}\text{Si}$

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High-spin resonances well above the Coulomb barrier in $^{28}\text{Si}+^{28}\text{Si}$ system exhibit a number of sharp peaks correlated among the elastic and inelastic channels. In their angle-averaged excitation functions, bumps are seen corresponding to the grazing angular momenta, and several sharp peaks are found on each bump [1]. Angular correlation measurements for $^{28}\text{Si} + {}^{28}\text{Si}$ at $E_{\text{cm}} = 55.8\text{MeV}$ show characteristic features [2]. We analyzed the correlations by using normal modes of the equilibrium configuration of interacting two oblate nuclei, and found that the molecular ground state reproduces those characteristic features of the angular correlations very well [3].

We expect that some of those sharp peaks on the bump correspond to wobbling excited states, and thus we have analyzed their angular correlations. In the high spin limit ($|K|/J \sim 0$), we obtain analytical wobbling (K-mixing) solutions as $F_n(K) = H_n(K/b)\exp(-K^2/2b^2)$, with Hermite polynomials H_n for n-th excited states, which provides a good perspective [4]. Oscillating behaviors of the coefficients of the K-substates give rise to wobbling excitations. For numerical calculations, we have exactly diagonalized hamiltonian of a triaxial rotator, and have used the solutions.

The fragment-fragment-γ angular correlations in the mutual 2^+ channel decays are displayed in fig. 1, which are classified for three quantization z-axes: (a) beam direction, (b) normal to the plane and (c) fragment direction taken perpendicular to the axes (a) and (b). Solid lines show theoretical results of the molecular ground state with $J = 38$, which have dominant $m = 0$ (disalignment) in (b). It is found that the molecular ground state reproduces the measured correlations very well [2, 3]. Furthermore predictions are given for the first and second excited states of the wobbling motion. Apparently the excited states exhibit different characteristics from those of the molecular ground state. For the first excited state (dashed lines), with a dominant $m = 2$ pattern in (b), a strong alignment is indicated. The second excited state (dotted lines) gives dominant $m = 2$ pattern in (a), due to high K-rotation. (The fragment spins are parallel to the molecular z'-axis, which is seen commonly in the twisting motion.) Decay properties have been also investigated; due to the alignment, the wobbling excited states show strong suppression in the elastic channel, which is consistent with the data around $E_{\text{cm}} = 57\text{MeV}$ [1].

Finally, the molecular ground state with $J = 38$ is a good candidate for the resonance at $E_{\text{cm}} = 55.8\text{MeV}$. In addition, we have predicted angular correlations for the wobbling excited states. Experiments on the nearby resonances are strongly called for, which will unveil the long-standing mystery of the high-spin resonances in heavy-ion collisions.

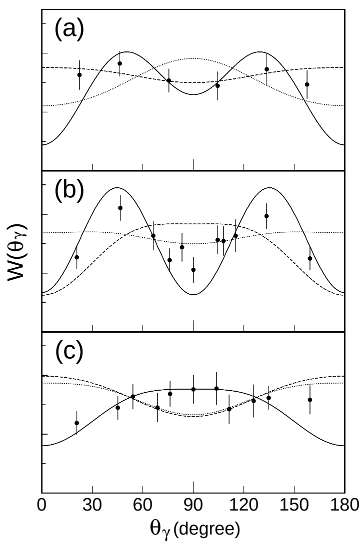

Figure 1: *Angular correlations of $^{28}Si + {}^{28}Si$ decays at $E_{cm} = 55.8MeV$*

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^{28}Si $-$ ^{28}Si dinucleus configuration and disalignments of angular momenta

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High-spin resonances well above the Coulomb barrier in the ^{28}Si $+$ ^{28}Si system exhibit a number of narrow and prominent peaks correlated among the elastic and inelastic channels, which suggest rather long-lived compound system [1,2]. Disalignments between the orbital angular momentum and the fragment spins at $E_{\rm cm} = 55.8$MeV have been indicated by the angular distributions in the inelastic channels that show dominance of a single orbital angular momentum $L = J = 38$ [3].

By using a molecular model the authors found the equilibrium configuration of interacting two oblate nuclei to be the *equator-equator* (E-E) one as displayed in fig. 1 [4]. The axis of the largest moment of inertia is normal to the plane defined by the two pancake-like ^{28}Si nuclei, which is assigned approximately to be the reaction plane of the molecular ground-state resonance of a high-spin state, as explained later. The spins of the ^{28}Si fragments are in this plane, not normal to the plane, since no rotation can occur about the symmetry axes of ^{28}Si. Thus, the spins of ^{28}Si are disaligned with the orbital angular momentum, which naturally explains the experimental observation.

In order to study distribution of the spin orientations in the dinuclear molecule, we further investigate the rotational state of the total system [4]. Since the E-E configuration is *triaxial*, rotations of the total system induce mixing of K-quantum numbers. At a given angular momentum J, the triaxial configuration rotates preferentially about the axis corresponding to the largest moment of inertia in the state with the lowest energy, which is called *wobbling*. In the high spin limit ($|K|/J \sim 0$), the analytical wobbling (K-mixing) weights are given by a gaussian distribution, and we have the wave function for the wobbling ground state as $\Psi_\lambda^{JM} \sim \sum_K \exp(-K^2/2b^2) D^J_{MK}(\theta_i)\chi_K(R, \alpha, \beta_1, \beta_2)$, where χ_K describe the motions of the internal degrees of freedom, which are in the zero-point vibrations at the equilibrium configuration illustrated in fig. 1. As a matter of course, the K-mixing given above provides a quantitative description of the fragment spin distribution [5], which has turned out to clarify that the angular correlation measurements for ^{28}Si $+$ ^{28}Si made with 4π gamma detectors have provided crucially important information on resonances [3].

In conclusion, study of the ^{28}Si $+$ ^{28}Si system by the dinuclear molecular model gives variety of molecular states. In them the molecular ground state with $J = 38$ is a candidate responsible for the resonance at $E_{\rm cm} = 55.8$MeV[4,5]. For systematic study for excitations of the molecular modes, the same kind of information on the other nearby resonances of ^{28}Si $+$ ^{28}Si is strongly called for.

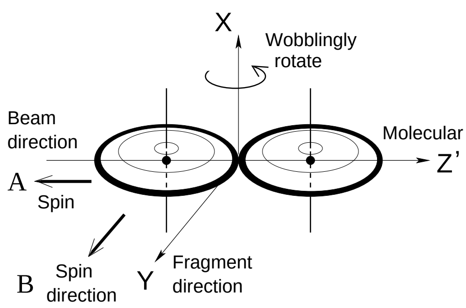

Figure 1: *$^{28}Si - ^{28}Si$ molecular ground-state configuration and spin directions.*

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Measurement of light charged particles in the decay channels of medium-mass excited compound nuclei

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The ^{48}Ti on ^{40}Ca reactions have been studied at 300 and 600 MeV using the Tandem-ALPI accelerator complex at Laboratori Nazionali di Legnaro. The reactions have been analyzed focusing on the fusion-evaporation (FE) and fusion-fission (FF) exit channels, which dominates in symmetric entrance channel collision at moderate bombarding energies. In particular, the energy spectra, angular distributions, and multiplicities of the emitted light charged particles in the two reaction channels FE and FF will be discussed. An estimation of the absolute cross sections for both channels will be also given. The experimental results will be then compared to Monte Carlo simulations based on the statistical model. The comparison between the results obtained from the same system populated at two excitation energies is important to evidence the possible growing of non-equilibrium effects. At the lower energy complete fusion is expected to exhaust almost the whole central collision cross section, with a consequent negligible non-equilibrium emission. This reaction may therefore be used to keep under control the statistical code parameters. Results on the comparison between the two reactions energies will be discussed.

Indeed, very few data exist in literature which are coming from coincidence measurements between evaporation residues and light charged particles for compound nuclei with mass $A < 150$. That is why statistical model parameters are not completely tested in this mass region. The present work, which deals with the de-excitation of ^{88}Mo, is therefore very interesting because experimental results will help in refining the statistical description of the decay of hot and rotating nuclei with moderate size.

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Differential Cross Sections for Neutron Elastic and Inelastic Scattering on Sodium-23

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Measurements of neutron elastic and inelastic scattering on ^{23}Na have been performed for sixteen incident neutron energies above 1.5 MeV with the 7-MV CN Van de Graaff at the University of Kentucky Accelerator Laboratory using the ^{3}H(p,n) reaction as the neutron source. These measurements were supplemented with γ-ray excitation functions using the (n,n'γ) reaction. The time-of-flight technique is employed for background reduction in both neutron and γ-ray measurements as a means to determine the energy of the scattered neutrons. Cross section measurements at the laboratory support fuel cycle and structural materials research and development.

Previous reaction model evaluations [1] relied primarily on total cross sections and four (n,n_0) and (n,n_1) angular distributions in the E_n = 5 to 9 MeV range. The inclusion of more inelastic channels provides additional information on direct couplings as a function of angular momentum transfer. Model calculations examining collective and compound properties will be presented.

Research at the University of Kentucky Accelerator Laboratory is supported by grants from the U.S. Department of Energy-Nuclear Energy Universities Program, the U.S. National Science Foundation, the USMA Nuclear Science and Engineering Research Center, the USNA James Kinnear Fellowship, and the Cowan Physics Fund at the University of Dallas.

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Dynamics of the collinear ternary fission decay

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We have performed systematic work on the search for true ternary fission, with three fragments of comparable masses, e.g. in ^{252}Cf(sf,fff) and ^{235}U(n,fff). From numerous studies in the last decades (see Pyatkov et al.[1] and refs.) we have learnt, that for intermediate mass ternary fragments such decay will be collinear and special experimental techniques (missing mass), are needed to study these. The signature is obtained in binary TOF (based on gas detectors [1]) coincidences between two fragmrnts (θ_{rel} = 180°), with a dispersive medium in one of the detector arms and a support grid of the foils at the entrance of the ionisation chambers. With two fragments which are originally collinear, they are separated by a small angle, 2°, which allows the blocking of one of the lighter fragments leading to $missing\ mass$ events. The process was named "collinear cluster tri-partition", CCT. The relatively high yield of the CCT-effect (more than 10^{-3} per binary fission) in the channels like, ^{132}Sn + ^{50}Ca + ^{72}Ni, are explained. For the dynamics of the process we have calculated within the fragmentation valley the opening angle for fragments in the collinear decay, see Fig.1. For the process to be considered sequential, the kinetic energies [2] of the fragments are obtained. The third fragments have very low kinetic energies (below 20 MeV), but span a large phase space due to the favourable Q-values, which contains about 25 mass-combinations of nuclei with their excited states, and spins. This explains the large overall yield compared to previous work on $ternary\ fission$, where a light fragment in the decay is assumed to produce a triangle for the three vectors of the fragments in the detectors.

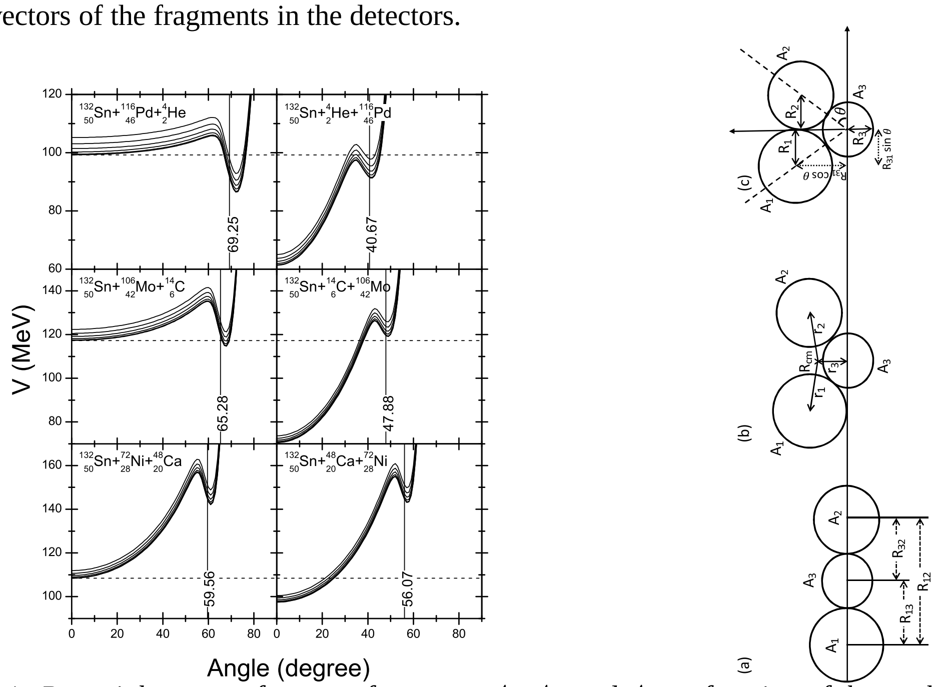

Figure 1: *Potential energy of ternary fragments A_1,A_2 and A_3 as function of the angles between them. Right: The relative angles of the three fragments in ternary (CCT) fission decay for ^{252}Cf (sf).*

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A New Interpretation of Cluster Radioactivity Mechanism

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The discovery of nuclear molecules [1], double nuclear system and deep inelastic transfer reactions [2, 3] allow a new interpretation to be proposed for the cluster formation mechanism.

It is assumed that nuclei of elements heavier than lead are capable of spontaneously condensing valence nucleons (nucleons above ^{208}Pb) to nuclei of lights elements – clusters. This process results in formation of an asymmetric nuclear molecule, in which both nuclei are in the ground state and interact with each other through the nucleus-nucleus potential. The cluster is formed by successive transfer of valence nucleons to the α-particle, which is formed with a high probability in the surface of the initial nucleus, and further on the light nuclei increasing in mass. Cluster formation is an exoergic process. However, the energy release in this process-Q is below the exit Coulomb barrier and cluster emission (decay of the nuclear molecule) proceeds as a quantum-mechanical process of penetration through the potential barrier.

Realism of the proposed concept of the cluster formation mechanism can be evaluated by considering cluster radioactivity of quite heavy nuclei like $^{251,252}Cf$. Within the adiabatic approach [4] to the mechanism of cluster radioactivity the cluster to emit by these nuclei can be the ^{48}Ca nuclei with experimentally measurable half-life. More than twenty years have passed since these adiabatic calculations but so far nobody in the world has observed cluster radioactivity in the $^{251,252}Cf$ nuclei. Within the proposed approach, emission of the ^{48}Ca cluster from $^{251,252}Cf$ nuclei is impossible because the process of nucleon transfer from heavy nucleus to the light nucleus will continue after the formation of ^{48}Ca, ending in spontaneous fission of the initial nucleus.

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First EXL experiment with radioactive beam: Proton scattering on ^{56}Ni

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EXL (**EX**otic nuclei studied in **L**ight-ion induced reactions at the NESR storage ring) is a project within NUSTAR [1] at FAIR [2]. It aims for the investigation of light-ion induced direct reactions in inverse kinematics with radioactive ions cooled and stored in the future NESR (**N**ew **E**xperimental **S**torage **R**ing). A universal detector system will be built around an internal target of the NESR in order to detect the target-like recoils. One of the key interests of EXL is the investigation of reactions at very low momentum transfers where, for example, the nuclear matter distribution, giant monopole resonances or Gamow-Teller transitions can be studied [3].

The existing ESR (**E**xperimental **S**torage **R**ing) at GSI, together with its internal gas-jet target, provides a unique opportunity to perform this kind of experiments on a smaller scale already today. In the last years we have developed a UHV compatible detector setup mainly based on DSSDs (**D**ouble-sided **S**ilicon-**S**trip **D**etector) for the target-like recoils [4] and an in-ring detection system for the projectile-like heavy ions. With this setup we were able to successfully investigate reactions with a stored radioactive beam for the very first time. As a part of the first EXL campaign we investigated the reaction ^{56}Ni(p,p)^{56}Ni in order to measure the differential cross section for elastic proton scattering and deduce the nuclear matter distribution of ^{56}Ni. The present contribution will present the current status of the project and preliminary results.

This work was supported by BMBF (06DA9040I und 05P12RDFN8) and HIC for FAIR.

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The Structure of the Proton-Dripline Nucleus ^{17}Ne Studied in Knockout Reactions at Relativistic Beam Energies

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^{17}Ne is a proton-dripline nucleus that has raised interest in nuclear-structure physics in recent years. As a (^{15}O+2p) Borromean 3-body system, it is often considered to be a 2-proton-halo nucleus, yet lacking concluding quantification of its structure; this is appearent in the form of different results on the s-/d-wave mixing of the valence-proton pair in the ^{17}Ne ground state in recent years [1-4].
In order to clarify its structure, we have studied breakup reactions of 500 AMeV ^{17}Ne secondary beams in inverse kinematics using the R3B-LAND setup at GSI in 2007. The reactions investigated were Coulomb breakup on a lead target, quasi-free scattering on a proton-rich polyethylene (CH_2) target, and one-proton-knockout reactions on a carbon target.
In this contribution, we focus on knockout and proton-removal reactions on the carbon target: Projectile-like forward protons after one-proton knockout from ^{17}Ne have been measured in coincidence with the ^{15}O residual core, leading to the relative-energy spectrum of the unbound ^{16}F. The selection of the low-energy region in this spectrum enables us to exclusively select events stemming from the knockout of halo (not core) protons.
Monte-Carlo simulations including the detailed geometry of the experimental setup have been carried out, allowing for the determination of the relative-energy-differential acceptance and efficiency for the identification of the various proton-breakup channels leading to ^{15}O in the final state. In consequence, the partial cross sections for 2p-knockout, 1p-knockout, and diffraction (0p-knockout) on ^{17}Ne have been determined, as well as the inclusive 2p-removal cross section. Those, and the also obtained transverse-momentum distributions of residual ^{16}F fragments stemming from 1p knockout on ^{17}Ne, have been interpreted using Glauber-type calculations in terms of a superposition of components of s- or d-proton knockout from the groundstate of ^{17}Ne. In this analysis framework, the relative weights as well as spectroscopic factors for the s- or d-wave valence-proton pair in ^{17}Ne have been determined.
Additionally, the s-/d-weight in the ^{17}Ne ground state has been determined by describing the low-energy region of the ^{16}F relative energy spectrum by a superposition of the four lowest known continuum resonances in ^{16}F, broadened by the experimental resolution determined via the Monte-Carlo simulation. Those two independently obtained results will be compared, and the implications regarding the structure of ^{17}Ne will be discussed.
This work was supported by BMBF (project 05P12RDFN8), by HIC for FAIR, and by GSI.

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New candidate for deformed halo nucleus in Mg isotopes through analysis of reaction cross sections

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The Radioactive Ion Beam Factory (RIBF) at RIKEN has added a new page to the history of unstable nuclei. One of the most attractive region is Island of Inversion ($Z\sim$10-12, $N\sim$20-22), because the nuclei in the region have exotic properties such as large deformation and loss of $N = 20$ magic number. The deformation of $^{28\text{-}32}$Ne has been investigated in Ref. [1]. It is based on the double folding (DF) model with the density calculated by antisymmetrized molecular dynamics (AMD). The AMD-DF model is one of the microscopic approach. The measured reaction cross sections of $^{28\text{-}32}$Ne + ^{12}C at 240 MeV/nucleon have been well reproduced, and the deformation has been determined. In addition, they have concluded ^{31}Ne is a halo nucleus with large deformation.

In this study, we apply the same analysis to Mg isotopes and compare the results with the latest experimental data measured at RIBF. The AMD-DF model well reproduces the experimental data overall. However about ^{37}Mg, the AMD-DF model largely underestimates the experimental data, and this may be because the density given by AMD has improper asymptotic form. ^{37}Mg is the nucleus very near to the drip line and a new candidate for a deformed halo nucleus, so proper asymptotic form is very important to the reaction cross section. As a convenient way of simulating the density calculated directly by AMD, we also propose the double folding model with the density calculated by the deformed Woods-Saxon (DWS) model with the deformation given by the AMD calculation [2]. The DWS-DF model well simulates the reaction cross sections calculated by the AMD-DF model, and it is expected to be a correction for the tail region of AMD density as shown in Fig. 1.

We determine the deformation of Mg isotopes in and near the island-of-inversion region through reaction cross sections, which were very recently measured. Our results suggests that they have large quadrupole deformation and ^{37}Mg expects to be halo structure with deformed core nucleus. In this presentation, we show the results for the reaction cross sections calculated by AMD-DF model, and we then introduce the analysis for ^{37}Mg with DWS-DF model.

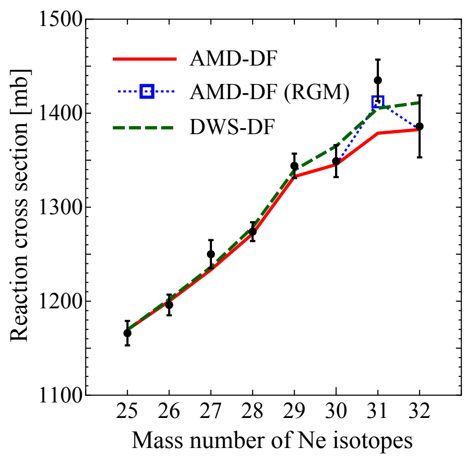

Figure 1: *Reaction cross sections for the scattering of Ne isotopes by ^{12}C. The experimental data are taken from Ref. [3].*

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Recent results on intermediate energy two-proton removal reactions

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The explanation of the magic numbers for nuclei in the valley of stability was one of the milestones in the understanding of nuclear structure. However, in recent years, several theoretical and experimental investigations found evidence that these magic numbers change when going away from stability towards more exotic nuclei. Nucleon knockout reactions using fast rare isotope beams are a well suited tool to study single-particle properties of exotic nuclei and the evolution of nuclear shell structure towards the drip-lines. Recently, a series of experiments has been performed at the National Superconducting Cyclotron Laboratory at Michigan State University in order to study reaction mechanism in nucleon knockout reactions. Such experiments are key for validation of the theoretical description of the reaction mechanism and use for quantitative spectroscopy of very exotic nuclei. In particular the sudden removal of two protons from an intermediate-energy neutron-rich projectile has been shown to proceed as a direct reaction. In addition to giving spectroscopic information, this type of reaction promises a rather unique tool assign spins by measuring the momentum distributions of the heavy reaction residues. First coincidence measurements of the heavy reaction residues and the removed protons enabled the relative cross sections from each elastic and inelastic nucleon removal mechanism to be determined. These more final-state-exclusive measurements are key for further validation of this direct reaction and its use for quantitative spectroscopy of highly neutron-rich nuclei. The kinematic correlations of the removed protons are also analyzed. A Dalitz-plot analysis and comparisons with simulations show that a majority of the triple-coincidence events with two protons display phase-space correlations consistent with the (two-body) kinematics of a spatially correlated pair-removal mechanism. This result promises access to a new, more specific probe of the spin and spatial correlations of valence nucleon pairs in exotic nuclei produced as fast beams.

In this talk I will present recent results from experiments at the interplay of nuclear structure and reactions performed at the NSCL.

Three-nucleon reactions with chiral dynamics

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Comparison of theoretical predictions with data for elastic nucleon-deuteron (Nd) scattering and nucleon induced deuteron breakup clearly shows the importance of the three-nucleon force (3NF). Inclusion of semi-phenomenological 3NF models into calculations in many cases improves the data description. However, some serious discrepancies remain even when 3NF is included.

At low energies the prominent examples were found for the vector analyzing power in elastic Nd scattering and for the neutron-deuteron (nd) breakup cross sections in neutron-neutron (nn) quasi-free-scattering (QFS) and symmetric-space-star (SST) geometries [1]. Since both these configurations depend predominantly on the S-wave nucleon-nucleon (NN) force components, these cross section discrepancies have serious consequences for the nn $^1S_0$ force component. A stronger $^1S_0$ nn force is required to bring theory and nn QFS data to agreement. The increased strength of the $^1S_0$ nn interaction could make the nn system bound. However, even such a drastic modification of the $^1S_0$ nn force does not improve the SST data descritpion.

At energies above ≈ 100 MeV current 3NF's only partially improve the description of data for cross section and spin observables in elastic Nd scattering and breakup. The complex angular and energy behavior of analyzing powers and spin correlation and transfer coefficients fail to be explained by standard nucleon-nucleon interactions alone or combined with current 3NF's [2-3].

One of the reasons for the above disagreements could be a lack of consistency between 2N and 3N phenomenological potentials used or/and omission of important terms in the applied 3NF. The Chiral Effective Field Theory approach provides consistent two- and three-nucleon forces and 3NF occurs for the first time at next-to-next-to leading order (N^2LO) of chiral expansion. This force when used in 3N calculations provides the quality of data description comparable to that with realistic nuclear forces. Recently the chiral 3NF at N^3LO was derived. At this order 3NF consists of long range parts with the 2π-exchange, 1π-2π and ring terms [4] and a short-range contributions 2π-contact and relativistic corrections of order 1/m [5]. This is supplemented by 1π- and 3N- contact terms. Results obtained with these N^3LO forces for elastic Nd scattering and breakup will be presented.

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Symmetry Energy Dependence of Light Fragment Production in Heavy Ion Collisions

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The density dependence of the nuclear symmetry energy is of large actual interest in nuclear physics with important implications in astrophysics, particularly in the properties of neutron stars. It is not well determined in microscopic calculations, and therefore has been investigated in heavy ion collisions. Here also the momentum dependence of the symmetry energy enters, which determines the effective mass difference between protons and neutron. Here we discuss sensitive observables in the region of densities around and below saturation. A promising observable has been the difference in the pre-equilibrium emission of neutrons and protons, which directly depends on the strength of the symmety potential. We extend these studies to the emission of light fragments, in particular to 3He and tritium, which are more easily determined in experiments. We discuss stochastic transport calculations for collisions of different Xe+Sn isotopes in the energy range of 32 to 150 AMeV, varying both the symmetry potential and the effective masses. We find, in particular, that the yield ratios n/p and 3He/t as a function of the emission energy is a promissing observable to disentangle the density and momentum dependence of the symmetry energy. We also compare to preliminary INDRA data.

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Semi-empirical Rules to Extract Fusion Barriers and Penetration Probabilities from Experimental Fusion Cross Section Data

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Fusion barriers E_l and penetration probabilities $P_l(E)$ are important physical quantities in the dynamics of the fusion of two nuclei. Previously, a compact formula for the fusion cross section was presented as a function of energy in terms of the fusion barrier E_0 for the l=0 partial wave and its penetration characteristics [1]. I have recently introduced simple semi-empirical rules to determine the barrier heights E_l and the penetration probability $P_l(E)$ for different l partial waves from experimental fusion cross section, for the collision of identical or non-identical light nuclei [2]. The application of these rules with the illustration of the collisions of ^{12}C+^{13}C and ^{12}C+^{12}C will be presented.

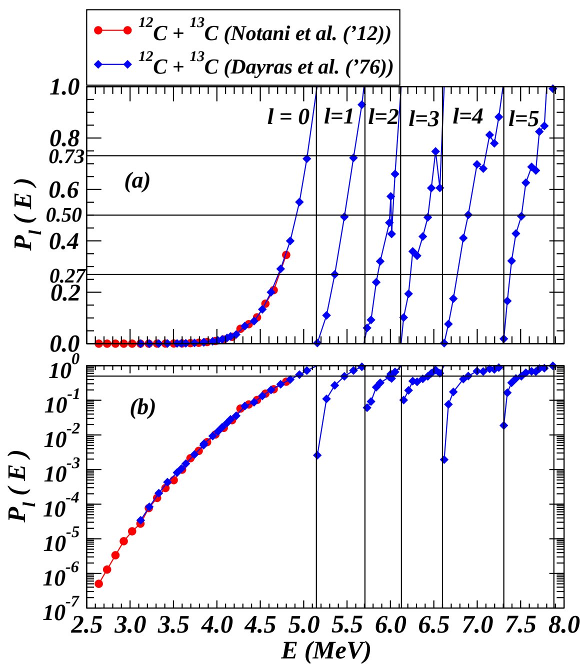

Figure 1: The penetration probability $P_l(E)$ as a function of E on a linear scale (a) and on a logarithmic scale (b) for different partial waves l extracted from the data of Notani $et\ al.$ and Dayras $et\ al.$, for the collision of ^{12}C+ ^{13}C.

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Evolution of Single-Particle Energies for N=9 Nuclei at Large N/Z

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We have studied the ^{13}B(d,p)^{14}B reaction in inverse kinematics to better understand the evolution of the properties of single-neutron states in the *sd* shell for neutron-rich N=9 isotones. We have also obtained data for the ^{15}C($d,^{3}$He)^{14}B reaction to provide additional information on ^{14}B complementary to that obtained with the (d,p) reaction. The nucleus ^{14}B is the most neutron-rich N=9 isotone that is still particle bound in its ground state, and provides an excellent opportunity to explore the effects of the tensor contribution to the evolution of *sd*-shell effective single-particle energies, the properties of loosely-bound or un-bound states, and to test the predictions of shell-model interactions at the boundary of nuclear stability. The inversion of the relative positions of the $1s_{1/2}$ and $0d_{5/2}$ orbitals when moving from ^{17}O to ^{15}C is behavior is driven largely by the changing tensor interaction between the *p*-shell protons and the *sd* shell neutron, however other effects are also likely to be important, such as halo behavior that arises due to the small neutron binding energy. The very weakly bound first-excited state, should its wave function be dominated by a $1s_{1/2}$ neutron configuration, may be the best-known example of a single-neutron-halo state. As the states of interest are either loosely bound, or unbound with respect to neutron decay, they also pose a challenge to the usual reaction models used to analyze transfer-reaction data.

We have studied ^{14}B using two reactions: neutron adding with ^{13}B(d,p)^{14}B, and proton removal with ^{15}C($d,^{3}$He)^{14}B. The experiments were conducted in inverse kinematics using radioactive beams produced using the in-flight method via the ^{14}C(^{9}Be,^{10}B)^{13}B and ^{14}C(d,p)^{15}C reactions at the ATLAS facility at Argonne National Laboratory. The proton and ^{3}He reaction products were detected with HELIOS [1] (the HELIcal Orbit Spectrometer), in coincidence with the recoiling residual nuclei. HELIOS exploits a uniform magnetic field to transport light-charged particles from the target to an array of position-sensitive silicon detectors. This method alleviates many difficulties associated with the study of such transfer reactions in inverse kinematics. Similar experiments have been performed to analyze the properties of *sd*-neutron states in ^{13}B[2], ^{16}C[3], and ^{20}O[4]. The neutron-adding reaction yields relative spectroscopic factors that allow us to construct wave functions for the low-lying excitations in ^{14}B which, for 2^- and 1^- levels, are configuration-mixed states that include both $\pi(0p_{3/2})^{-1}\nu(1s_{1/2})$ and $\pi(0p_{3/2})^{-1}\nu(0d_{5/2})$ contributions. The proton-removal data permit a better isolation of the $\pi(0p_{3/2})^{-1}\nu(1s_{1/2})$ components and together, the results provide a determination of the $1s_{1/2}$ and $0d_{5/2}$ effective single-particle energies in this nucleus that can be compared to other similar nuclei in this region. Experimental results and a comparison of the data to shell-model and *ab-initio* No-Core Shell-Model calculations will be presented.

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Charge Changing Interactions Probe Point-Proton Radii of Nuclei

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Neutron skins of exotic nuclei are a key observation to study the equation of state (EOS) of nuclear matter [1]. The density-derivative coefficient in the EOS would be clearly defined by the precise neutron skin thicknesses of extremely neutron-rich nuclei such as ^{78}Ni.

A new approach to probe the point-proton (charge) distributions of exotic nuclei close to the drip line is currently being developed. The charge-changing cross sections σ_{cc} of stable and unstable nuclei ($^{9\text{-}11}$Be, $^{14\text{-}16}$C, $^{16\text{-}18}$O) on a carbon target were investigated at an intermediate energy, 300 MeV/nucleon. A phenomenological Glauber-type model analysis of σ_{cc} for nuclei with known charge radii indicates an approximate, but universal, scaling of σ_{cc} over a wide range of A/Z [2]. This allows the determination of the density distributions of protons bound in the neutron-rich nuclei. An application to the one-neutron halo nucleus ^{15}C and ^{16}C, where laser spectroscopy has technical difficulty, indicates a systematic evolution of proton root-mean-square radii. Combined with the matter radii obtained from the interaction cross sections [3], the present study has revealed for the first time a neutron skin effect in carbon isotopes [2].

As an extension, to examine the applicability of the present method to the whole over the chart of nuclides, the charge-changing cross sections of medium-mass nuclei ranging from $Z = 18$ to 32 (84 nuclides in total) were measured systematically. The results show a significant correlation between the measured cross sections and known charge radii. Being complementary to isotope-shift and electron-scattering experiments, the present study suggests a potential capability to explore the structures of exotic nuclei far from the stability. We will present the methodology developed with the experimental data, the results obtained, and the future physics case of Ni isotopes.

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Study of anti-analog giant dipole resonance in $^{208}\mathrm{Pb}(\vec{p},\vec{n})$ and neutron skin thickness for $^{208}\mathrm{Pb}$

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The neutron density distribution extends somewhat further than the proton one for a nucleus with $N > Z$. The neutron skin thickness ΔR_{pn}, defined as the difference between the neutron and proton root-mean-square radii, depends not only on the neutron excess $(N-Z)$ but also on the symmetry energy term of the nuclear equation of state. Therefore, precise information on ΔR_{pn} has become important to obtain the symmetry energy term. In particular, ΔR_{pn} of $^{208}\mathrm{Pb}$ has been studied by various methods such as dipole polarizability [1], elastic proton scattering, and parity-violating elastic electron scattering.

Recently, Krasznahorkay *et al.* [2] have suggested a new method for determining ΔR_{pn} by using the strong correlation between ΔR_{pn} and the energy ΔE of the anti-analog giant dipole resonance (AGDR) relative to the isobaric analog state (see Fig. 1). This method is very attractive since it can be applied for studying ΔR_{pn} of unstable nuclei [2]. In order to confirm the reliability of this methods, we investigated the strength distribution and the mean energy of the AGDR by multipole decomposition (MD) analysis for the $^{208}\mathrm{Pb}(\vec{p},\vec{n})$ reaction at a bombarding energy of $T_p = 296$ MeV [3]. The polarization transfer observables are very useful to separate the AGDR from the other excitations such as the spin dipole resonance in MD analysis. The ΔE value has been determined to be $\Delta E = 8.67 \pm 0.25(\mathrm{stat.}) \pm 0.23(\mathrm{syst.})$ MeV. By comparing the present ΔE value with the theoretical prediction in the proton-neutron relativistic quasi-particle random phase approximation (pn-RQRPA), we have obtained the ΔR_{pn} value as $\Delta R_{pn} = 0.220 \pm 0.043(\mathrm{exp.}) \pm 0.015(\mathrm{theor.})$ fm, which is consistent with previous results derived by various methods [1]. These findings support that the energy ΔE of the AGDR can be used to deduce the neutron skin thickness ΔR_{pn}.

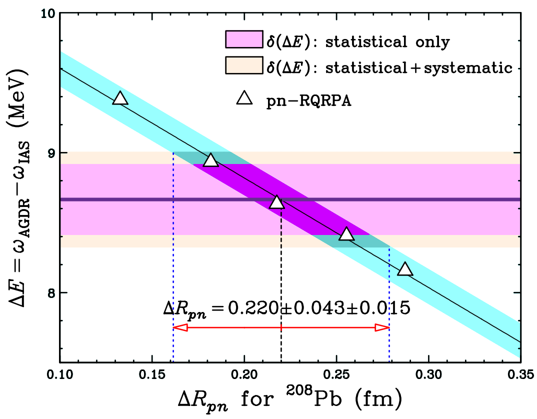

Figure 1 : Extraction of the neutron skin thickness ΔR_{pn} for ^{208}Pb based on the correlation between ΔR_{pn} and the energy ΔE of the AGDR relative to the isobaric analog state.

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N/Z Dependence of the Nuclear Caloric Curve

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Quasi-projectile sources produced in collisions of 70Zn+70Zn, 64Zn+64Zn and 64Ni+64Ni at E/A=35 MeV have been reconstructed using the charged particles and free neutrons measured in the NIMROD-ISiS detector. Equilibrated sources were selected which have a mass A=48-52 and which are on average spherical. Caloric curves for these quasi-projectiles have been extracted with the quadrupole momentum fluctuation thermometer. The caloric curves for the different light charged particle probes show a clear ordering which is consistent with a scenario in which the “expensive” particles are emitted preferentially at early times, when the source is hottest. For all light charged particle probes, the caloric curves show a clear dependence on the composition, (N-Z)/A, of the source. For a given excitation (E*/A), the neutron-poor sources exhibit higher temperatures. A consistent but smaller dependence is observed by selecting on the composition of the initial system rather than the composition of the source. The dependence on source composition is also observed in caloric curves extracted with the Albergo yield-ratio thermometer.

Population of strongly deformed nuclear states

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According to the cluster interpretation, the strongly deformed nuclear state can be treated as the cold rotating dinuclear systems (DNS). The relative distance between the centers of two touching clusters corresponds to the minimum of the pocket of nucleus-nucleus interaction potential. The large overlap of the DNS nuclei is hindered by a repulsive nucleus-nucleus interaction potential at smaller relative distances. The pocket of nucleus-nucleus potential at given angular momentum contains the quasibound states with the energies below the potential barrier and with quite large half-lives. The lowest quasibound state is identical to the superdeformed (hyperdeformed) state in the case of asymmetric (symmetric) DNS configuration. Based on the results of [1], one can be convinced that certain quasimolecular configurations with the dumb-bell shapes have the same quadrupole moments and moments of inertia as those measured for the high- and low-spin superdeformed (SD) states, and low-spin hyperdeformed (HD) isomer states.

Using the cluster and statistical approaches, the population of SD, produced in fusion-evaporation reactions, in the $A \sim 150$ region is described. The calculated characteristics (moments of inertia, quadrupole moment, relative intensities of $E2$-transitions between the rotational states) [2] of SD of ^{152}Dy are close to the experimental values.

The high-spin hyperdeformed (HD) nuclear states are suggested to be directly populated in the capture process either by de-excitation (particle emission) of the initial DNS formed at collision energy above the entrance Coulomb barrier [3] or directly by tunneling through this barrier [4]. The reactions ^{A}Ni+^{A}Ni, ^{A}Ca+^{A}Ca, etc are considered.

The dependence of the calculated results on de-excitaion channel and beam energy is analyzed.

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03 - Nuclear Reactions