NN2015

INTERNATIONAL CONFERENCE ON NUCLEUS - NUCLEUS COLLISIONS

CATANIA 21-26 JUNE 2015

BOOK OF ABSTRACTS

AULA MAGNA, MONDAY, 22 June 2015 8.45 – 9.15

KEYNOTE TALK

A. Bracco

INFN Milano and Università di Milano, Italy

Monday 22/06/2015
h. 9.15-11.15

Aula Magna Dipartimento di Fisica ed Astronomia

PLENARY SESSION:

Heavy and Superheavy Elements

Alpha-Photon Decay Spectroscopy of Element 115

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During the past decade, correlated α-decay chains, which all terminate by spontaneous fission, have been observed in several independent experiments using ^{48}Ca-induced fusion-evaporation reactions on actinide targets. These are interpreted to originate from the production of neutron-rich isotopes with proton numbers up to $Z = 118$ (see, for instance, Refs. [1-5] and references therein).

This quest for superheavy elements is related to the fundamental question concerning the properties of the strong nuclear force capable of forming the heaviest atomic nuclei yet known. Therefore, it links directly to the possible existence and location of an 'island of stability' of superheavy nuclei on the nuclidic chart.

Detection technology, data processing and various data analysis tools for superheavy element studies have advanced considerably during recent years. This has allowed for the first multi-coincidence high-resolution spectroscopy experiments along the decay chains of the heaviest man-made isotopes [3,6-8]. Their impact on the search for the island of stability will be highlighted in the presentation, and in particular viewed in conjunction with modern nuclear structure and decay calculations [9,10]. The accessible experimental sample consists of thirty α-decay chains associated with the production of element 115, observed in a spectroscopy experiment conducted with TASISpec at the gas-filled "TransActinde Separator and Chemistry Apparatus" (TASCA) at GSI Darmstadt [3].

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Inverse quasifission phenomena in heavy-ion collisions

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The present work is devoted to the search of new mechanisms of nuclear reactions leading to the formation of heavy and superheavy neutron-rich nuclei in heavy-ion-induced reactions at energies around the Coulomb barrier. At these energies the influence of shell effects on the formation of the reaction products is significant.

It was found that at the transition from Ca to Ni projectiles the contribution of quasifission process rises sharply. The estimated value of formation probability of compound nucleus formed in the reaction ^{64}Ni+^{238}U drops three orders of magnitude with respect to the ^{48}Ca+^{238}U reaction [1, 2]. An alternative way for further progress in superheavy nuclei can be achieved using the deep-inelastic or quasifission reactions.

Several years ago, on the basis of a multidimensional model, it was proposed to use multinucleon transfer reactions to produce new neutron-rich heavy and superheavy nuclei at bombarding energies close to the Coulomb barrier [3]. In this theoretical study it is proposed that proton and neutron (independent) flows strongly depend on the shell structure of the multidimensional potential energy surface and the values of fundamental parameters which guide the nuclear dynamics, such as nuclear viscosity. One of the successes of this model is the prediction of an increased yield of targetlike fragments in the lead region formed in the reaction ^{160}Gd+^{186}W due to the influence of closed shells at N=82 in light fragment and Z=82, N=126 in heavy fragment.

To explore the role of shell effects in the formation of neutron-rich binary fragments in damped collision, we have investigated experimentally binary reaction channels in the reactions ^{88}Sr+^{176}Yb [4], ^{156,160}Gd+^{186}W at the Coulomb barrier energy. To form the fragment with mass around 208 u (double magic lead) projectile nucleus has to transfer about 22 nucleons to the target (the so-called "inverse" quasifission process). The main task of the present work is to test if shell closures are still effective on the primary fragment production even for such a large mass transfer and its dependence on the neutron excess of dinuclear systems.

In present work the experimental mass-energy and angular distributions of binary fragments formed in the reactions ^{24}Mg+^{248}Cm, ^{36}S+^{238}U, ^{48}Ca+^{144,154}Sm, ^{208}Pb, ^{238}U, ^{244}Pu, ^{248}Cm, ^{58}Fe+^{208}Pb, ^{244}Pu, ^{248}Cm, ^{64}Ni+^{186}W, ^{238}U, ^{88}Sr+^{176}Yb, ^{136}Xe+^{208}Pb, ^{156,160}Gd+^{186}W are presented. The experimental data were obtained using the double arm time-of-flight spectrometer CORSET [5].

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Nuclear Structure Studies of the Heaviest Elements by High-Precision Mass Measurements

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High-precision mass measurements are a well-established method to investigate the nuclear structure evolution in exotic nuclides. Binding energies and indicators such as nucleon separation energies that can be derived from masses reveal nuclear structure features such as shell closures or the onset of deformation. Recent advances in slowing down high-energy beams from different nuclear reactions in buffer gas cells have opened the door to extend precision measurements in ion traps to essentially all elements. Mass measurements with Penning traps provide masses with supreme accuracy reaching a level of 10^{-8} or below even for radionuclides. They are now also feasible for the heaviest elements as demonstrated with the first direct mass measurements of nobelium and lawrencium isotopes performed with SHIPTRAP at GSI [1]. From the accurate data the strength of the neutron subshell closure at N=152 has been mapped via the two-neutron shell gap [2]. Another feature of direct mass measurements is to provide firm anchor points pinning down alpha-decay chains in the mass surface. However, such precision measurements are technically very challenging in particular due to extremely low production rates. Advanced ion-manipulation methods and next generation-buffer gas stopping cells will allow us to push towards heavier elements in the future. In this contribution I will discuss the application of high-precision mass measurements for nuclear structure studies and review the recent SHIPTRAP experiments as an example.

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SHE at RIKEN

K. MORITA[1]

[1] *RIKEN, Japan*

Abstract not received

Monday 22/06/2015
h. 11.45-13.45

AULA MAGNA

PLENARY SESSION:

QCD and Hadron Physics

Intermediate Energy Nuclear Reactions

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The interactions between hadrons play a crucial role in shaping our understanding of quantum chromodynamics (QCD) - the theory of strong nuclear force. With the advent of the new accelerator facilities in various laboratories around the World, the study of hadronic interactions is developing into a precision science. One of the most fascinating aspects of this field is that the properties of the basic constituents of the underlying theory can only be indirectly inferred by studying its manifestation in the structure and interactions of the hadrons.

To address these aspects, hadrons are explored experimentally by studying their response to high-precision probes at various energies. Electroweak probes offer versatile and well understood tools to access the internal quark-gluon structure of hadrons. There is also tremendous interest in understanding the interactions among hadrons involving strange and charm quarks. One of the promising ways to pin down such interaction is to produce exotic nuclei where one of the nucleons is replaced by a particle consisting of strange (Λ or Σ hyperon) or charm (Λ_c baryon) quarks. With the PANDA detector at the under-construction FAIR facility in Darmstadt, Germany, there is a plan to produce such nuclei using high quality antiproton beam, which will give tremendous boost to activities in this area. Also a lot of data on the production of hypernuclei will be collected at the J-PARC facility in Japan in the near future.

In this talk we shall present an overview of a fully covariant formulation for describing the production of strangeness -1 and -2 hyperons and hypernuclei [1,2] and H dibaryon state [3] in the K^- induced reactions on proton and nuclear targets. We shall also review the results of our studies on the production of charm baryon (Λ_c^+) [4] and charm mesons ($D^0, D^\pm$) in the antiproton-proton annihilation process at the $\bar{P}ANDA$ energies using a similar approach. This theory is based on an effective Lagrangian picture that retains the full field theoretic structure of the interaction vertices and treats baryons as Dirac particles. The initial state interaction of the incoming projectile with a free or bound target nucleon leads to the excitation of intermediate hadron resonance states, which propagate and subsequently decay into the relevant channels. We shall discuss the specific cases of the production of cascade hypernuclei and charm hypernuclei in K^- and antiproton induced reactions on nuclei, respectively.

This work has been supported by the German Research Foundation (DFG) under Grant No. Le439/8-2 and Helmholtz International Center (HIC) for FAIR and the Council of Scientific and Industrial Research (CSIR), India.

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Experimental Highlights on QCD Medium Properties at RHIC

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Measurements made in heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC) have led to a broad and deep understanding of the properties of hot QCD matter. It has been determined that the quark-gluon plasma (QGP) created in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is a strongly coupled liquid with the lowest value of specific viscosity ever measured. These findings are supported by major empirical observations from both soft and hard probe sectors. However, recent experimental results from RHIC and LHC in small p+A, d+A and 3He+A collision systems provide brand new insight into the role of initial and final state effects. These have proven to be interesting and more surprising than originally anticipated; and could conceivably shed new light in our understanding of collective behavior in heavy-ion physics.

This talk summarizes some of the latest results obtained at RHIC. The significance of these measurements for establishing the properties of hot and dense QCD matter will be discussed. The interpretation of the experimental results in view of the current theoretical understanding will be addressed.

Light Nuclei and Hypernuclei from Lattice QCD

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The only known non-perturbative method that systematically implements Quantum Chromodynamics (QCD) from first principles is its formulation on a discretized space-time, a technique known as Lattice QCD, which consists in a Monte Carlo evaluation of a functional integral. The goal of the NPLQCD Collaboration [1] is to use Lattice QCD to extract information on hadronic interactions relevant to nuclear processes, and specially on those sectors where experiments are difficult to perform. In a recent paper [2] we calculated the binding energies of a range of nuclei and hypernuclei with atomic number A ≤ 4 and strangeness $|s| \leq 2$, including the deuteron, di-neutron, H-dibaryon, ^{3}He, $^3_\Lambda$He, $^4_\Lambda$He, and $^4_{\Lambda\Lambda}$He. These calculations were performed in the limit of flavor-SU(3) symmetry, which corresponds to a pion mass of 800 MeV and to a physical strange quark mass value. The nuclear states were extracted from Lattice QCD calculations performed with $n_f = 3$ dynamical light quarks using an isotropic clover discretization of the quark-action in three lattice volumes of spatial extent $L \sim 3.4$ fm, 4.5 fm and 6.7 fm, with a single lattice spacing $b \sim 0.145$ fm and in the absence of electromagnetic interactions. More recently, we performed exploratory Lattice QCD calculations of the magnetic moments of light nuclear systems [3] (A ≤ 3 and strangeness $s = 0$), also at the SU(3) flavor symmetric point. When presented in terms of the natural nuclear magneton at the corresponding quark masses, the extracted magnetic moments were seen to be in close agreement with those of nature. Additionally, the magnetic moment of 3He was found to be close to that of the neutron, and that of the triton was close to that of the proton, in agreement with the expectations of the phenomenological shell-model, and therefore suggesting that this model structure is a robust feature of nuclei even away from the physical quark masses.

In this talk I will present the goals of our project, the formalism we use and the more recent results relevant to nuclear and hypernuclear physics.

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Chiral nucleon-nucleon forces in nuclear structure calculations

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Realistic nuclear potentials, derived within chiral perturbation theory, are a major breakthrough in modern nuclear structure theory, since they provide a direct link between nuclear physics and its underlying theory, namely the QCD [1]. As a matter of fact, chiral potentials are tailored on the low-energy regime of nuclear structure physics, and chiral perturbation theory provides on the same footing two-nucleon forces as well as many-body ones. This feature fits well with modern advances in ab-initio methods and realistic shell-model. Here, I will review recent nuclear structure calculations, based on realistic chiral potentials, for both finite nuclei [2-5] and infinite nuclear matter [6]. The excellent agreement between experiment and theory paves the way towards an exciting future for the study of the physics of nuclei.

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Monday 22/06/2015
h. 15.15-17.35

Aula 52 INFN-LNS

PARALLEL SESSION:

Heavy and Superheavy Elements

The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

A novel approach to the super-heavy elements search

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It is expected that the cross section for super heavy nuclei production of Z greater than 118 is dropping into the region of tens of femto barns. This creates a serious limitation for the complete fusion technique that is used so far. Moreover, the available combinations of the neutron to proton ratio of a stable projectiles and targets are quite limited and it can be difficult to reach the island of stability of super heavy elements using complete fusion reactions with a stable projectiles. In this context, a new experimental investigation of mechanisms other than complete fusion of heavy nuclei and a novel experimental technique are introduced to our super and hyper nuclei search. This contribution is focused on a novel experimental technique.

Dynamics of fusion, fission, and quasifission*

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We discuss the latest microscopic TDDFT calculations of fusion, fission, and quasifission dynamics. We show recent results and analysis of capture cross-sections and quasifission calculated using the microscopic time-depedent Hartree-Fock theory [1-3]. Studied systems include ^{40,48}Ca+^{238}U and ^{50,54}Cr+^{180,186}W. Results for mass-angle-distributions (MAD) and contact times are presented as a function of orientation of the deformed nuclei with respect to collision axis as well as a function of impact parameter. We compare calculated MAD's to the corresponding experimental distributions. We discuss the dependence of various observables on isospin and elucidate the advantage of using neutron-rich nuclei in fusion experiments leading to superheavy elements. For the first time, we provide a microscopic calculation of fragment excitation energies. We also discuss the calculation of moments of inertia and the possibility of using TDHF to calculate P_{CN} values. With regard to scission dynamics we present results that show the effect of non-adiabaticity in comparison to the adiabatic treatment [4].

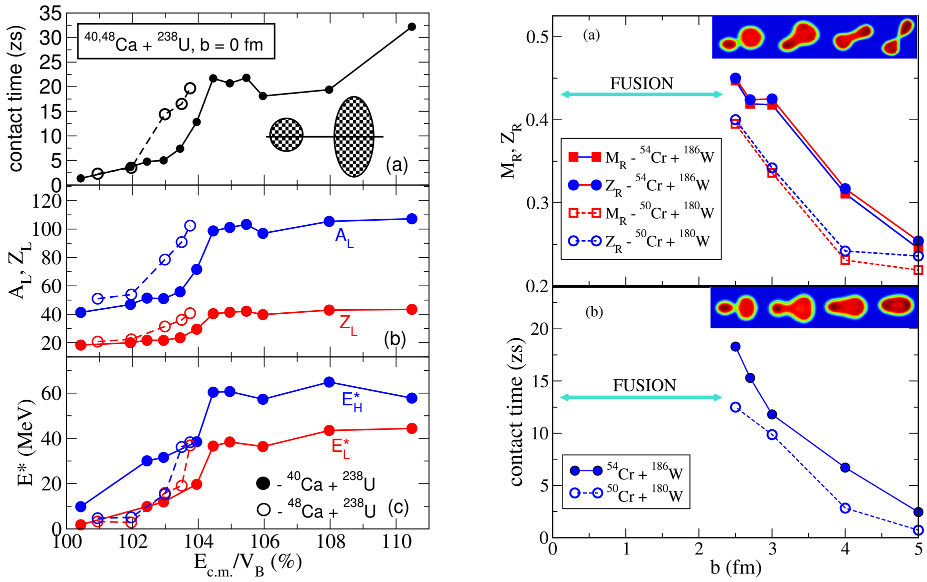

Figure 1: Quasifission results for the ^{40}Ca+^{238}U, ^{50}Cr + ^{180}W, and ^{54}Cr + ^{186}W systems.

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* This work has been supported by the U.S. Department of Energy under grant No. DE-FG02-96ER40975 with Vanderbilt University and by the Australian Research Council Grant No. FT120100760.

Masses, Fission, and β-decay for Astrophysics and SHE

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We have developed a consistent framework for calculating a large number of nuclear-structure and reaction properties. I will briefly outline the main features of this framework. We have used it to calculate the FRDM(2012) "mass-table" (preliminary results are in [1]) a successor to FRDM(1992) [2]. Our by now realistic target date for submitting these results, on which I will provide some highlights, to ADNDT is July 2015. We have used the calculated ground-state single-particle levels and wave functions to calculate Gamow-Teller β transition rates between parent and daughter, the associated decay half-lives and delayed-neutron emission probabilities. The tabulated quantities will be a successor to [3]. Some highlights will be provided. We have completed a large-scale calculation of fission-barrier heights for 5239 heavy nuclides [4]. The computer-readable barrier table is also available at the APS journal web site [5]. I will put the results in perspective with respect to other calculations (and experiments). Currently we focus on developing models for fission fragment-yields see for example Refs. [6, 7]. We show benchmarks of the model. We show some preliminary results from applications to yields in the r-process region and of extension of the model to describe odd-even staggering in the fragment yields. We discuss our proposed method for extending the model to provide yields versus both Z and N with inclusion of odd-even staggering in both variables. We present some results on calculated fission-fragment charge distributions with staggering effects included in the model.

The folded-Yukawa single-particle model (and its implementation in a macroscopic-microscopic framework) has, since more than 40 years, provided very realistic descriptions of nuclear structure in the heavy-element regions. I will conclude by reviewing these results and current status.

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Search for new superheavy elements with Z=119 and Z=120 at the gas-filled recoil separator TASCA at GSI Darmstadt

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In the past 15 years, evidence for new elements with atomic numbers Z=113-118 has been published by collaborations working at Flerov Laboratory for Nuclear Reactions (FLNR) in Dubna, Russia [1]. Some of the results were independently confirmed, and elements Z=114 and 116 were officially recognized by the IUPAC [2], while the others not so far.

To search for yet heavier elements, experiments were performed at GSI and FLNR so far. Element Z=120 was in the center of three of those: the reactions ^{64}Ni + ^{238}U and ^{54}Cr + ^{248}Cm were studied at the velocity filter SHIP at GSI, and upper limits of 90 fb and 560 fb were reached, respectively [3]. The reaction ^{58}Fe + ^{244}Pu was investigated at FLNR and an upper limit of 400 fb was reported [4]. None of these experiments successfully identified element Z=120.

The TASCA collaboration focused on the most asymmetric among all conceivable reactions giving access to element Z=120: ^{50}Ti + ^{249}Cf. While absolute cross sections predicted for Z=120 by different theoretical approaches vary dramatically, all models agree that the ^{50}Ti + ^{249}Cf reaction has the largest cross section, see discussion in [5]. A 39-day experiment on ^{50}Ti + ^{249}Cf was performed, but then interrupted to open the door for a sensitive search for the new element Z=119, which can ideally be produced in the ^{50}Ti + ^{249}Bk reaction. This employs a target isotope that has a half-life below one year, hence needs to run immediately once the target material is available. This was produced and separated at Oak Ridge National Laboratory's HFIR high flux reactor and associated facilities. The Z=119 search lasted more than four months.

I will discuss the preparations for the search for Z=119 and Z=120 at TASCA, including production of ^{249}Bk, the preparation of the targets at the Institute for Nuclear Chemistry at the University of Mainz, the upgrades at TASCA [6], including the installation of a new high-power target station and a digital data acquisition system, before coming to the results of the experiments, which were complemented by experiments on elements 115 [7] and 117 [8]. I will discuss the impact for future studies and close with an outlook for superheavy element research at GSI, which will profit from a dedicated new linac [9].

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Recent experiments in inverse kinematics with the magnetic spectrometer PRISMA

E. Fioretto[1], L. Corradi[1], D. Montanari[2], S. Szilner[3], D. Ackermann[4], D. Bourgin[2], S. Courtin[2], F. Galtarossa[1], A. Goasduff[1], F. Haas[2], T. Mijatović[3], M. Milin[3], G. Montagnoli[5], G. Pollarolo[6], F. Scarlassara[5], N. Soić[3], A.M. Stefanini[1], V. Tokić[3]

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In the last period, two kinds of experiments have been carried out with the large acceptance magnetic spectrometer PRISMA [1], i.e. transfer measurements at sub-barrier energies [2, 3] and direct identification of heavy partner in grazing reactions. Both classes of experiments have been performed in inverse kinematics detecting the light target-like ions with PRISMA at very forward angles in order to have, at the same time, high efficiency and good energy and mass resolutions. Besides the “light” partner products in transfer reactions, the “heavy” partners are presently receiving peculiar attention. In fact, certain regions of the nuclear chart, like that below ^{208}Pb or in the actinides, can be hardly accessed by fragmentation or fission reactions, and multinucleon transfer may be a suitable mechanism to approach the neutron rich areas. It is worthwhile to mention, as an example, that (not yet investigated) nuclear properties of neutron rich nuclei around N=126, relevant for the r-process, play a critical role for theoretical predictions of the synthesis of the heaviest elements [4], for disentangling a variety of astrophysical scenarios [5] and to study the competition between Gamow-Teller and First-Forbidden β transitions.

In this framework, we carried out a test experiment to study the multineutron and multiproton transfer channels populated in the reaction ^{197}Au+^{130}Te at E_{lab}=1070 MeV, using a ^{197}Au beam delivered by the PIAVE+ALPI accelerator complex and detecting both projectile-like and target-like ions. To this end the spectrometer has been equipped with a second arm for the detection of the heavy fragments in kinematic coincidence with the light ones identified in PRISMA. The first physics goal was to get the *A*, *Z* and *Q*-value distributions measuring the "light" reaction products. Since for these rather heavy ions secondary processes should play a non negligible role, it will be interesting to compare final yields (cross sections) with those expected from theoretical models, already successfully applied for lower mass systems. The second goal is to compare the yields of the “light” partner with that of the “heavy” one.

In the following, a discussion of the results obtained in these last experiments as well as the developments carried out around the target area of PRISMA will be presented, with emphasis on the importance for future investigations in the heavy mass regions.

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Exploration of Nuclear Structure and Decay Properties of the Heaviest Elements at SHIP - GSI

F.P. HESSBERGER[1,2]

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[2] *HELMHOLTZ INSTITUT MAINZ MAINZ GERMANY*

To understand the fundamental interactions is a basic topic in natural science. In this quest the limits of nuclear stability are regions of specific relevance. Among them superheavy nuclei particular interest as they owe their existence a delicate interplay of short range nuclear forces acting between the nucleons (protons and neutrons) and long-range Coulomb forces acting solely between charged particles, i.e. the protons. In this sense understanding nuclear stability and its limits at the upper part of the charts of nuclei ($Z > 100$) is essential to understand basic interactions. As the stability of a nucleus is strongly correlated to its decay properties and its structure, understanding of the latter in heaviest nuclei is presently - besides synthesizing new elements - the main challenge of experimental and theoretical investigations concerning the field of superheavy elements (SHE).
At GSI Darmstadt an extensive program on investigating decay properties and nuclear structure investigations by means of studying α – and EC – decay, spontaneous fission as well as α-γ – or α – conversion electron (CE) spectroscopy of nuclei collected in the focal plane of the velocity filter SHIP has been started about one and a half decade ago. The project covered both: systematic investigations of single particle levels populated by α-decay in odd-mass isotopes (see e.g. [1,2,3]) as well as investigation of two- or four-quasi-particle states forming K isomers (see [4,5,6]). In addition, first results on nuclear structure from EC decay of ^{253}No and ^{253}Md using K X-ray – γ – and γ – γ – coincidence measurements [6] and for ^{258}Db by delayed coincidences between K X-rays from EC decay and spontaneous fission of the daughter product ^{258}Rf were obtained [8]. The latter will be discussed as a possibility for an unambiguous Z – identification of superheavy elements.
The studies were supplemented by direct mass measurements at SHIPTRAP [7] and investigation of spontaneous fission properties as fission hindrance of odd-mass nuclei as function of the fissioning nuclear configuration [9] or total energy release in fission (<TKE>) [8].
Results obtained in the element region $Z = 99$ to $Z = 110$ and also their relevance for the spontaneous fission process and expected properties of SHE at $Z > 112$ will be presented and discussed within theoretical frameworks.

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Monday 22/06/2015
h. 15.15-17.25

AULA A

PARALLEL SESSION:

QCD and Hadron Physics

New results in lattice scattering using the adiabatic projection method

D. Lee[1] for the Nuclear Lattice EFT Collaboration

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I discuss the adiabatic projection method, a first principles method for the calculation of scattering and reactions on the lattice. I present *ab initio* lattice results for ^{4}He+^{4}He scattering at next-to-next-to-leading order in chiral effective field theory.

Emission of neutrino-antineutrino pairs by hadronic bremsstrahlung processes

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[2] *Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB, R3T 2N2, Canada*
[3] *TIFR, Homi Bhabha Road, Navy Nagar, Mumbai 400005, India*
[4] *ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[5] *Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany*

We report on recent calculations of neutrino-antineutrino pair production from bremsstrahlung processes in hadronic collisions and consider temperature conditions relevant for core collapse supernovae. Earlier studies on bremsstrahlung from neutron-neutron collisions [1,2] showed that the approximation used in typical supernova simulation to model this process differs by about a factor of 2 from predictions based on chiral effective field theory, where the chiral expansion of two-body forces is considered up to the next-to-next-to-next-to-leading order [3]. When the density of neutrons is large enough this process may compete with other non-hadronic reactions in the production of neutrinos, in particular in the case of μ and τ neutrinos, which are not generated by charged-current reactions. A natural question to ask is then: what is the effect of neutrino pair production from collisions of neutrons with finite nuclei? To tackle this question, we recently have addressed the case of neutron-α collisions [4], given that in the P-wave channels the neutron-α scattering features a resonance near 1 MeV [5]. We find that the resonance leads to an enhanced contribution in the neutron spin structure function at temperatures in the range of $0.1 - 4$ MeV. For significant density fractions of α in this temperature range, this process is competitive with contributions from neutron-neutron scattering.

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PERSPECTIVE STUDY OF EXOTICS AND BARYONS WITH CHARM AND STRANGENESS

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The spectroscopy of exotics states with hidden charm together with the spectroscopy of charmed and strange baryons is discussed. It is a good testing tool for the theories of strong interactions, including: QCD in both the perturbative and non-perturbative regimes, LQCD, potential models and phenomenological models [1, 2, 3]. An understanding of the baryon spectrum is one of the primary goals of non-perturbative QCD. In the nucleon sector, where most of the experimental information is available, the agreement with quark model predictions is astonishingly small, and the situation is even worse in the strange and charmed baryon sector. The experiments with antiproton-proton annihilation and proton-proton collisions are well suited for a comprehensive baryon spectroscopy program, in particular, in the spectroscopy of strange and charmed baryons. Charmed and strange baryons can be produced abundantly in both processes, and their properties can be studied in detail [1, 2, 3]. This gives a possibility to get information about their structure and nucleon-hyperon and hyperon-hyperon interaction.

For this purpose an elaborated analysis of charmed hybrids and tetraquark spectrum together with spectrum of charmed and strange baryons is given. The recent experimental data from different collaborations (BES, BaBar, Belle, LHCb, CDF, D0) are analyzed. The attempts of their possible interpretation are considered [4, 5]. Some of these states can be interpreted as higher-lying charmonium and tetraquarks with a hidden charm. It has been shown that charge/neutral tetraquarks must have their neutral/charged partners with mass values which differ by few MeV. This hypothesis coincides with that proposed by Maiani and Polosa [6]. Many heavy baryons with charm and strangeness are expected to exist. But much more data on different decay modes are needed before firmer conclusions can be made. These data can be derived directly from the experiments using a high quality antiproton beam with momentum up to 15 GeV/*c* planned at FAIR and proton-proton collisions with momentum up to 26 GeV/*c* planned at the superconducting accelerator complex NICA that is being built in Dubna nowadays.

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Elastic nucleon-deuteron scattering and breakup with standard and chiral forces

H. Witała[1], J. Golak[1], R. Skibiński[1], K. Topolnicki[1]

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Comparison of theoretical predictions based on a nucleon-nucleon potential with data for elastic nucleon-deuteron (Nd) scattering and nucleon induced deuteron breakup reveals 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 models of 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, spin correlation and spin transfer coefficients fails to be explained by standard nucleon-nucleon interactions alone or combined with current models of 3NF's [2-3]. Studies of relativistic effects at higher energies have shown that they are negligible practically for all observables in elastic Nd scattering [4].

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^{2}LO) of chiral expansion. The chiral NN potentials have been constructed up to N^{4}LO order of chiral expansion [5]. The N^3LO and N^{4}LO NN forces when used in 3N calculations provide description of NN data of the same quality as standard, realistic NN potentials.

The chiral 3NF at N^{3}LO, derived recently, consists of long range parts with the 2π-exchange, 1π-2π and ring terms [6] and a short-range contributions 2π-contact and relativistic corrections of order 1/m [7]. This is supplemented by 1π- and 3N- contact terms. Preliminary results obtained with chiral forces for elastic Nd scattering and breakup will be presented.

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Hermes results on 3D imaging of the nucleon

L.L. Pappalardo[1] (on behalf of the Hermes Collaboration)

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In the context of rapid theoretical developments in non-perturbative QCD, a formalism of Transverse Momentum Dependent parton distribution functions (TMDs) and of Generalized Parton Distributions (GPDs) was introduced in the last two decades, providing a more comprehensive multi-dimensional description of the nucleon. TMDs and GPDs allow in fact for complementary descriptions of the nucleon in three dimensions (nucleon tomography), spanned by the quarks longitudinal momenta and, respectively, by the their transverse momenta components and transverse spatial coordinates. They thus contribute, with different approaches, to the full phase-space description of the nucleon structure. Furthermore, they provide complementary insights into the yet unmeasured quark orbital angular momentum. Experimentally, TMDs and GPDs can be accessed through the analysis of specific azimuthal asymmetries measured, respectively, in semi-inclusive deep-inelastic scattering and hard exclusive processes, such as hard leptoproduction of real photons or mesons. The HERMES experiment has collected wealth of data on scattering of a longitudinally polarized lepton (electron or positron) beam from HERA off unpolarized, longitudinally and transversely polarized internal gas targets. Collected data allowed to measure a variety of asymmetries with respect to beam charge, beam helicity and target polarization. A selection of HERMES results on observables sensitive to TMDs and GPDs will be presented.

Search for ^{4}He-η bound states in $dd \to {}^3\mathrm{He}p\pi^-$ and $dd \to {}^3\mathrm{He}n\pi^0$ reactions with the WASA-at-COSY facility

Magdalena Skurzok[1], Wojciech Krzemien[1],Pawel Moskal[1,2]

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The existence of η-mesic nuclei in which the η meson is bound in a nucleus by means of the strong interaction was postulated already in 1986 [1] but it has not been yet confirmed experimentally. The discovery of this new kind of an exotic nuclear matter would be very important as it might allow for a better understanding of the η meson structure and its interaction with nucleons [2,3]. The search for η-mesic helium (^{4}He-η) is carried out with high statistics and high acceptance with the WASA detector, installed at the cooler synchrotron COSY of the Research Center Jülich [4].
The search is conducted via the measurement of the excitation function for selected decay channels of the ^{4}He-η system. The kinematics of the reaction is schematically presented in Fig. 1.

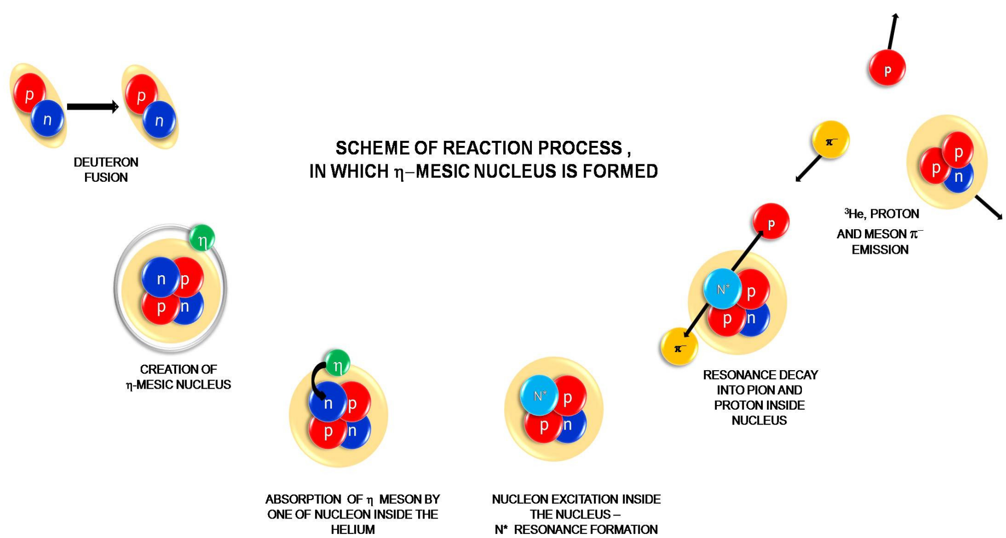

Figure 1: Reaction process of the ^{4}He-η bound state production and decay.

The deuteron beam - deuteron target collision leads to the creation of the ^{4}He nucleus bound with the η meson via strong interaction. The η meson can be absorbed by one of the nucleons inside helium and may propagate in the nucleus via consecutive excitation of nucleons to the N*(1525) state until the resonance decays into the pion-proton pair outgoing from the nucleus [4]. The relative angle between p and π^- is equal to 180° in the N* reference frame and it is smeared by about 30° in the center-of-mass frame due to the Fermi motion of the nucleons inside the helium nucleus.

In the experiment, performed in November 2010, two reactions $dd \to ({}^4\mathrm{He}\text{-}\eta)_{bs} \to {}^3\mathrm{He}p\pi^-$ and $dd \to ({}^4\mathrm{He}\text{-}\eta)_{bs} \to {}^3\mathrm{He}n\pi^0$ were measured with a beam momentum ramped from

2.127GeV/c to 2.422GeV/c. The talk will include description of the experimental method and status of the analysis.

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Monday 22/06/2015
h. 15.15-17.00

Aula F Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Relativistic Heavy-Ion Collisions

(anti)hypernuclei and 3H lifetime puzzle

YU-GANG MA[1]

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The hyperon-nucleon (YN) interaction is of great interest in high energy physics. It will help to understand the structure of nucleus and the NN interaction. At Relativistic Heavy Ion Collider (RHIC), hypernuclei can be generated abundantly. Hypertriton, the lightest hyper nucleus, provides us with a good opportunity to study YN interaction by the lifetime measurement. In this talk, I will present the measurements of hypertriton lifetime through its two body decay channel with the data of Au+Au collisions at sqrt(s_{NN})= 27, 39, 62.4 and 200GeV at STAR. Also, the first measurement for hypertriton via three body decay channel is reported. Physics implication from both measurements is discussed.

Open heavy-flavour measurements with ALICE at the LHC

N. Bastid for the ALICE Collaboration

*Laboratoire de Physique Corpusculaire (LPC), Clermont Université,
Université Blaise Pascal, CNRS-IN2P3, Clermont-Ferrand, France*

The LHC heavy-ion physics program aims at investigating the properties of strongly-interacting matter in extreme conditions of temperature and energy density where the formation of the Quark Gluon Plasma (QGP) is expected. In high-energy heavy-ion collisions, heavy quarks (charm and beauty quarks) are regarded as efficient probes of the properties of the QGP as they are created on a short time scale with respect to that of the QGP. The heavy-ion physics program requires also the study of proton-proton (pp) and proton-nucleus collisions. Besides providing the essential baseline for heavy-flavour measurements in proton-nucleus and nucleus-nucleus collisions, pp collisions are of great interest, also in their own right, since they provide a sensitive test of perturbative quantum chromodynamics. The study of proton-nucleus collisions is used to investigate cold nuclear matter effects such as modifications of the parton distribution functions in the nucleus, gluon saturation, k_{T}-broadening and energy loss, and to validate and quantify hot nuclear matter effects in heavy-ion collisions.

In ALICE, open heavy flavours are studied through the reconstruction of D-meson hadronic decays at mid-rapidity, and via semi-electronic and semi-muonic decays of charm and beauty hadrons at mid-rapidity and forward rapidity, respectively.

A review of the main results on open heavy-flavour measurements with ALICE will be presented. A particular emphasis will be placed on the latest results obtained in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV.

Jet fragmentation study with particle correlation from the ALICE experiment at LHC

D.J Kim[1] for the ALICE collaboration

[1] *University of Jyväskylä & Helsinki Institute of Physics*

In-medium modification of jet fragmentation functions in heavy ion collisions is thought to be a manifestation of the parton energy loss in the medium. Despite of the large energy loss signaled by the large imbalance of jet transverse energies in di-jet events[1] and by the suppression of large transverse momentum hadrons [2], it has been found that jet fragmentation functions in Pb-Pb collisions are very similar to the ones measured in p-p collisions[3]. The ALICE experiment has utilized two-particle correlations to address modification of jet properties in Pb-Pb collisions compared with p+p collisions at the LHC. This might help to quantify medium modifications of the parton shower and the response of the surrounding medium. In this talk, we review the latest results on $\Delta\phi$ and $\Delta\eta$ correlations, as well as jet-fragmentation transverse momentum distributions as a function of centrality and the jet's transverse momentum.

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Recent results from NA61/SHINE

S. Kowalski[1] for NA61/SHINE Collaboration

[1] *Institute of Physics, University of Silesia, Poland*

The main physics goals of the NA61/SHINE programme on strong interactions are the study of the properties of the onset of deconfinement and the search for signatures of the critical point of strongly interacting matter. These goals are pursued by performing an energy (beam momentum $13A$ – $158A$ GeV/c) and system size (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La) scan.

Moreover the experiment provides precision hadron production measurements needed for neutrino beams at J-PARC and Fermilab as well as for air shower simulations of cosmic-ray experiments (Pierre Auger Observatory, KASCADE-Grande and KASCADE).

This talk reviews results and plans of NA61/SHINE. In particular, recent inclusive spectra and new results on fluctuations and correlations of identified hadrons in inelastic p+p and centrality selected Be+Be interactions at the SPS energies will be shown. The energy dependence of quantities inspired by the Statistical Model of Early Stage (kink, horn and step) show interesting behavior in p+p collisions, which is not described by Monte-Carlo models.

Furthermore, the Be+Be data suggest collective flow to develop even in collisions of low mass nuclei.

Quark coalescence from RHIC to LHC

V.Minissale[1,2], F.Scardina[1,2], V.Greco[1,2]

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[2] *INFN-LNS,Laboratori Nazionali del Sud, Via S. Sofia 64,I-95123, Catania, Italy*

We discuss the application of a phase-space coalescence plus fragmentation model for the hadronization of the quark-gluon plasma (QGP) created in ultra-relativistic heavy-ion collisions. Recombination of minijet partons with the partons from the QGP is also included and plays a role at $p_T \sim 2-4$ GeV where the baryon to meson anomaly is observed experimentally.
We show our prediction for light and strange hadrons transverse momentum spectra (π, p, k, Λ, ϕ, Ω) and baryon to meson ratios (p/π, Λ/k, Ω/ϕ) in a wide range of p_T, both for RHIC and LHC energies. The baryon to meson ratio at LHC presents similar features of that at RHIC, but with a shift in the peak of about 0.5 GeV, and this is well predicted by our model.

Monday 22/06/2015
h. 15.15-17.20

AULA MAGNA

PARALLEL SESSION:

Nuclear Structure

Electric Dipole Response of Nuclei and the Symmetry Energy of the Nuclear Equation of State

A. Tamii[1]

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The symmetry energy term of the nuclear equation of state (EOS) is relevant to the size, structure and dynamic properties of a neutron star. Even at and below the saturation density, the symmetry energy parameter is not known well. The first order density dependence of the symmetry energy, called slope parameter, is of particular interest since it is proportional to the baryonic pressure in the neutron star. The symmetry energy and the slope parameter are considered to have a strong correlation to the neutron skin thickness and the electric dipole response of nuclei, especially to the dipole polarizability and the pygmy dipole resonance, of neutron rich nuclei.

The electric dipole (*E1*) response of heavy nuclei has been studied by high-resolution proton inelastic scattering measurements at forward angles including zero degrees [1-4]. The proton scattering at a 295 MeV was used as an electromagnetic probe to extract precisely the distribution of the *E1* reduced transition probability $B(E1)$. Magic and semi-magic stable nuclei of ^{208}Pb, ^{120}Sn, and ^{90}Zr were used as target. The dipole polarizability and pygmy dipole resonance (PDR) strength have been extracted. We will present the experimental results and will discuss the constraints on the neutron skin thickness and the symmetry energy parameters with a help of theoretical model calculations.

References:

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Does monopole pigmy resonance exist in ^{68}Ni ?

H. Sagawa[1,2], I. Hamamoto[1,3]

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[2] *Center for Mathematics and Physics, University of Aizu, Fukushima, Japan*
[3] *Division of Mathematical Physics, Lund Institute of Technology at the University of Lund, Lund, Sweden*

The presence and properties of pigmy resonances are currently of great interest. The observation of a low–energy monopole resonance with a narrow width in the unstable nucleus ^{68}Ni is recently reported in the analysis of inelastic alpha scattering at 50A MeV [1], in agreement with some RPA calculations using the discretized approximation of the continuum. While the centroid of isoscalar giant monopole resonance (ISGMR) is found at 21.1 ± 1.9 MeV, a low energy monopole resonance is reported at 12.9 ± 1.0 MeV. It is an open and interesting question whether this lower peak is the monopole resonance or not. In this contribution we conclude that such a monopole resonance is not expected theoretically.

We study low-energy monopole strength of Ni isotopes using the self-consistent Hartree-Fock calculation and the RPA Green's function method. In order to study the properties of low-energy monopole strength, one must take into account the continuum e ect properly in the theoretical calculations. Because of this reason, we perform the self-consistent HF+RPA calculations with the Skyrme interactions in coordinate system. The strength distributions $S(E)$ are obtained from the imaginary part of the RPA Green function, G_{RPA}, as

$$S(E) = \sum_n |< n \mid Q \mid 0 >|^2 \, \delta(E - E_n) = \frac{1}{\pi} \, Im \, Tr(Q^\dagger(\vec{r}) \, G_{RPA}(\vec{r}; \vec{r'}; E) \, Q(\vec{r'})) \qquad , \qquad (1)$$

where Q expresses the one-body operator

$$Q^{\lambda=0,\,\tau=0} = \frac{1}{\sqrt{4\pi}} \sum_i r_i^2 \qquad (2)$$

for isoscalar monopole strength.

The RPA response function in Fig. 1 is calculated including all strengths due to the coupling between bound and unbound states. Note that the widths of all responses are due to the coupling to the continuum without any smearing factor. It is concluded that sharp monopole peaks with the width of the order of 1 MeV can hardly be expected for ^{68}Ni in the low energy region below 20 MeV in the RPA response. Instead, a broad shoulder of monopole strength consisting of neutron excitations to non-resonant one-particle states (called "threshold strength") with relatively low angular-momenta (ℓ, j) is obtained in the continuum energy region above the particle threshold, which is considerably lower than that of ISGMR. In the monopole excitations of ^{68}Ni there are no unperturbed particle-hole excitations below 20 MeV, in which the particle is placed in either a bound or a resonant state. It is emphasized that a proper treatment of the continuum is extremely important to study the lower excitation energy monopole strength than the ISGMR [2]. If one discretizes the continuum spectra, it is easy to create incorrect response functions.

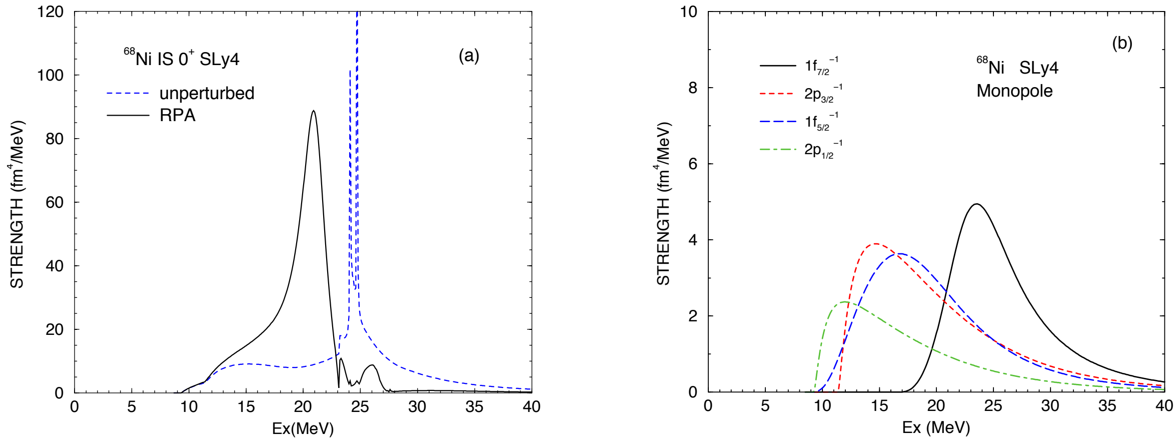

Figure 1: Monopole strength function (1) of ^{68}Ni . (a) Unperturbed monopole strength and isoscalar monopole RPA strength. The RPA strength denoted by the solid curve includes all strengths due to the coupling between bound and unbound states in RPA. In the unperturbed response, the p-h strengths, in which both particle and hole orbits are bound, are not included. The energies of those unperturbed p-h excitations are the $1d_{5/2} \rightarrow 2d_{5/2}$ excitation at 27.60 MeV for neutrons and the excitations of $1p_{3/2} \rightarrow 2p_{3/2}$ at 27.58 MeV and $1p_{1/2} \rightarrow 2p_{1/2}$ at 27.46 MeV for protons. In addition, the proton excitation at 27.3 MeV from the bound $1d_{5/2}$ orbit to the one-particle resonant $2d_{5/2}$ orbit has such a narrow width that the strength is not plotted. The narrow peaks at 24.1 and 24.7 MeV in the unperturbed strength curve are the proton $2s_{1/2} \rightarrow s_{1/2}$ and $1d_{3/2} \rightarrow 2d_{3/2}$ excitations, respectively. (b) Unperturbed neutron threshold strengths, which contribute to the total unperturbed strength below the energy of ISGMR in Fig. 1a, are shown for respective occupied hole orbits.

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Probing the Structure of the Unbound Nuclei ^{9}He and ^{10}N Through Proton Elastic Scattering

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The study of light nuclei at the drip lines offers a unique opportunity to test our ab-initio understanding of nuclear structure in the case of extreme proton to neutron ratios. With the advent of high-quality radioactive beams, these nuclei can now be accessed through transfer, charge exchange, or elastic scattering experiments in inverse kinematics. The very neutron-rich ^{9}He nucleus has been a subject of active research over the past decade, and many peculiarities in its structure have been claimed. We have recently performed a measurement of proton elastic scattering from ^{8}He to study the T=5/2 isobaric analog states of ^{9}He at energies near the T=2 neutron decay threshold. The quality and intensity of the ^{8}He beam at TRIUMF allowed for a high-resolution experiment with excellent statistical uncertainty, and the results of our study will be presented. At the other extreme, we have also recently performed a proton elastic scattering experiment on ^{9}C at Texas A&M University to directly probe the structure of the proton-unbound nucleus ^{10}N. Preliminary results of this experiment will be discussed as well.

Collectivity beyond N=40 in neutron-rich Cr and Fe isotopes.

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After the discovery of an enhanced collectivity in the N=40 Cr and Fe isotopes below Z=28, the evolution of collectivity beyond N=40 and the position of the collectivity maximum is still an open question. The first campaign of the Shell Evolution And Search for Two plus Energies At the RIBF (SEASTAR) scientific program took place in Spring 2014 at the Radioactive Isotope Beam Factory. It focused on the spectroscopy of the more neutron-rich attainable nuclei such as Cr and Fe N¿40 isotopes via proton knockout reactions with the unique combination of the DALI2 gamma array [1] with the MINOS device [2]. MINOS is a new device composed of a thick liquid hydrogen target and a Time Projection Chamber (TPC). The charged particles produced by knockout reactions are detected in the TPC and enable the reconstruction of the reaction vertex with the use of a tracking algorithm, thus ensuring an optimal Doppler correction for the measured gamma rays. The first analysis results of the SEASTAR campaign will be presented with the first spectroscopy of 66Cr and 70,72Fe. The performances of the MINOS TPC will also be detailed.

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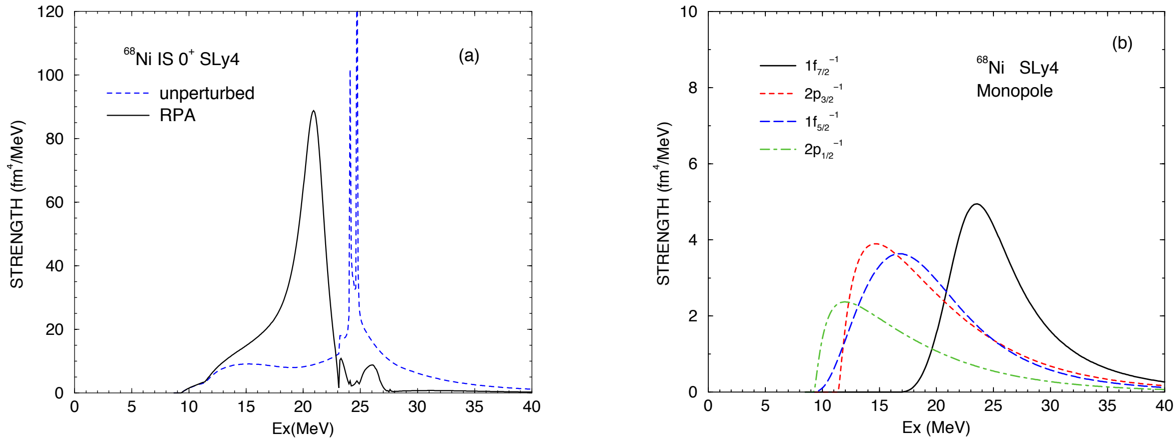

Figure 1: Monopole strength function (1) of ^{68}Ni . (a) Unperturbed monopole strength and isoscalar monopole RPA strength. The RPA strength denoted by the solid curve includes all strengths due to the coupling between bound and unbound states in RPA. In the unperturbed response, the p-h strengths, in which both particle and hole orbits are bound, are not included. The energies of those unperturbed p-h excitations are the $1d_{5/2} \to 2d_{5/2}$ excitation at 27.60 MeV for neutrons and the excitations of $1p_{3/2} \to 2p_{3/2}$ at 27.58 MeV and $1p_{1/2} \to 2p_{1/2}$ at 27.46 MeV for protons. In addition, the proton excitation at 27.3 MeV from the bound $1d_{5/2}$ orbit to the one-particle resonant $2d_{5/2}$ orbit has such a narrow width that the strength is not plotted. The narrow peaks at 24.1 and 24.7 MeV in the unperturbed strength curve are the proton $2s_{1/2} \to s_{1/2}$ and $1d_{3/2} \to 2d_{3/2}$ excitations, respectively. (b) Unperturbed neutron threshold strengths, which contribute to the total unperturbed strength below the energy of ISGMR in Fig. 1a, are shown for respective occupied hole orbits.

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Interplay between proton-neutron pairing and deformation in N=Z medium mass nuclei

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The effect of pairing correlation between nucleons of different spin and isospin is expected to be more pronounced in self-conjugate nuclei. From an experimental point of view, high intensity radioactive beams will offer new possibilities to study the importance of isoscalar and isovector pairing interaction between protons and neutrons along the N = Z line. From a theoretical point of view, in order to incorporate proton-neutron pairing correlations in microscopic models, one needs usually to go beyond the standard independent quasi-particle picture, obtained for example in the BCS or HFB approximations. In this work, we employ a model combining self-consistent mean-field and shell-model (SM) techniques to study the competition between particle like and proton-neutron pairing correlations in fp-shell even-even self-conjugate nuclei. The self-consistent mean-field calculations provide the main ingredients, single-particle shells and residual two-body matrix elements, that are used in the subsequent SM calculations. In such a way, deformation effects are realistically and microscopically described. The resulting approach can give a precise description of pairing correlations and eventually treat the coexistence of different condensate formed of pairs with different spin/isospin. The standard BCS calculations are systematically compared with more refined approaches including correlation effects beyond the independent quasi-particle approach. The competition between proton-neutron correlations in the isoscalar and isovector channels is also analyzed, as well as their dependence on the deformation properties. Besides the expected role of the spin-orbit interaction and particle number conservation, it is shown that deformation leads to a reduction of the pairing correlations. The competition between isoscalar and isovector pairing in the deuteron transfer is finally addressed [1].

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First experimental indication of the Giant Pairing Vibration in the ^{14}C and ^{15}C nuclei

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The elementary excitation mode known as Giant Pairing Vibration (GPV) was predicted by the theory in the 70's [1], in analogy with the Giant Resonances (GR) observed in almost all nuclei. The link between GPV and GR is the symmetry between particles and holes single particle states. Both of them are collective states, manifestation of a coherence mechanism of the particle-hole (GR) or particle-particle/hole-hole (GPV) excitations connecting major shell of the harmonic-oscillator-like mean field. The excitation of the GPV should be induced by two-nucleon transfer reactions with $L = 0$ angular momentum transfer. Despite the strong theoretical indications in favour of the existence of the GPV and many experimental attempts, a clear signature of it has been achieved only recently [2].
In this context, an experimental campaign was pursued at the Catania INFN-LNS laboratory by the (^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV on different targets (^{12}C,^{13}C,^{9}Be,^{11}B,^{16}O), using the MAGNEX spectrometer to detect the ejectiles. Thanks to its high resolution and large acceptance, high quality inclusive spectra were obtained, even in the region above the two-neutron emission threshold in the residual nucleus [3]. New phenomena appeared, such as the dominance of the direct one-step transfer of the two neutrons [4] and the presence of broad resonances at high excitation energy in the ^{14}C and ^{15}C spectra. The latter are associated with the first experimental indication of the GPV [2]. In the ^{14}C nucleus it is identified at an excitation energy of 19.9 MeV with respect to the target ground state and in the ^{15}C one at 20.4 MeV, values compatible with the GPV theoretical predictions by state-of-the-art cQRPA calculations on light nuclei [5]. The $L = 0$ nature of the transition to these resonances is suggested by model independent analysis of the measured cross section angular distributions by CRC calculations. The complete analysis of the properties of these resonances will be presented at the Conference.

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Monday 22/06/2015
h. 15.15-17.25

AULA AZZURRA LNS

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

Probing nucleon-nucleon correlations in heavy ion transfer reactions

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Transfer reactions play an essential role in the understanding of collision dynamics and nuclear structure [1]. The recent revival of transfer reaction studies greatly benefited from the construction of the new generation instrumentations that reached an unprecedented efficiency and selectivity [2].

Grazing collisions produce a wealth of nuclei in a wide energy and angular range and with cross sections spanning several orders of magnitude. Due to the complexity in their analysis and interpretation, it is essential to assess quantitative probes of the nucleon-nucleon correlations.

One of the major achievements of the last years was the extraction of absolute differential cross sections via a careful study of the response function of the spectrometer. This was of crucial value in the extraction of the pair-transfer strengths. It was also very important to study the structure of the states dominantly populated by the transfer mechanism [3,4], as the final reaction products reflects a strong interplay between single-particle and collective degrees of freedom and the reaction dynamics.

Significant progress has been recently achieved by performing studies far below the Coulomb barrier with the PRISMA spectrometer. Transfer cross sections obtained from excitation functions for the closed shell ^{40}Ca+^{96}Zr [5] and superfluid ^{60}Ni+^{116}Sn [6] systems have been measured from the Coulomb barrier energy to energies corresponding to very large distances of closest approach where the nuclear absorption is negligible. The transfer probabilities have been compared with microscopic calculations that incorporate nucleon-nucleon correlations, essential for the population pattern of the single particle levels around the Fermi energy. These calculations very well reproduce the experimental data in the whole energy range, in particular, the transfer probability for two neutrons is very well reproduced, in magnitude and slope.

The talk will focus on the main outcome of these recent studies, critically addressing the new achievements, the present problems and new challenges, especially in view of forthcoming experiments to be performed with exotic beams at the radioactive beam facilities.

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Evidence for a four-body state in ^{9}Be through the $^8\mathrm{Li}(p,d)^7$Li reaction

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We report on a simultaneous study of the (p,p), (p,α) and (p,d) reactions on ^{8}Li at low energies [1]. The experiment was performed using a thick hydrogen target and a radioactive ^{8}Li beam available at the RIBRAS facility of São Paulo [2]. This experiment represents an upgrade of a previous experiment [3], where only the $^8\mathrm{Li}(p,\alpha)^5$He cross section was measured. A comparison with previous direct $^7\mathrm{Li}(d,p)^8$Li data suggests a newly observed ^{9}Be resonance around $E_x = 18.67$ MeV with a large $^7\mathrm{Li}^\star + d$ component. The properties of this resonance are determined by a R-matrix analysis [4], which provides evidence for a significant clustering. As the $^7\mathrm{Li}^\star$ nucleus and the deuteron present a strong deformation, this ^{9}Be state can be interpreted as a four-body resonance. We suggest that it could be also observed in $^7\mathrm{Li}(d,d')^7\mathrm{Li}^*$ inelastic scattering.

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Effects of coupling to breakup channels in reactions induced by weakly bound and halo nuclei.

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Reactions induced by weakly bound and halo nuclei have been intensively studied in the last years [1-7]. The low breakup threshold and the cluster or halo structure of the ground state can affect the dynamics of the reaction at energies around the Coulomb barrier, producing a significant reduction of the elastic scattering cross section with respect to the Rutherford prediction. This effect can be associated with couplings to breakup channels, since the continuum of such nuclei is close to the ground state. One method to obtain a complete theoretical description of such collisions is the Continuum Discretized Coupled Channels (CDCC) formalism, where the breakup process is considered as an inelastic excitation of the projectile in the continuum.

To investigate the effects of the coupling to breakup channels, elastic scattering angular distributions for the collisions induced by ^{6,7}Li and ^{6}He on a ^{64}Zn target have been measured by our group at several energies around the Coulomb barrier [8,9]. For the ^{6,7}Li induced collisions quasi elastic barrier distribution have also been measured [9]. Experimental data have been compared with CDCC calculations, considering a two-body model of the projectile, α+d(t) for ^{6,7}Li and α+2n for ^{6}He, respectively.

In the case of stable weakly bound nuclei ^{6,7}Li, due to the difference between the breakup threshold of ^{6}Li (1.47 MeV) and ^{7}Li (2.47 MeV), the couplings to the continuum states have been found more important for the first one than for the latter.

The effects of such couplings are expected to be more significant in the case of the halo nucleus ^{6}He, where the breakup threshold is 0.97 MeV. New experimental elastic scattering angular distributions for the system ^{6}He+^{64}Zn and those of Ref. [6] are compared with optical model (OM) and CDCC calculations. The results show a strong coupling to the breakup channels, even larger than for the stable lithium isotopes. The comparison with the OM, where an analytical Coulomb dipole polarization potential [10] was included, suggests that the effects of the dipole polarization are minor. This result differs from the effects observed in reactions induced by ^{6}He on the heavy target ^{208}Pb Ref.[7], where dipole Coulomb couplings play an important role.

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First observation of β-delayed γ-proton decay in ^{56}Zn

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We report the observation of a very exotic decay mode at the proton drip-line, the beta-delayed gamma-proton decay, clearly seen in the beta decay of the T_z = -2 nucleus ^{56}Zn [1]. Here this decay mode, already observed once in the *sd*-shell [2], is seen for the first time in the *fp*-shell.

The experiment was performed at the LISE3 facility of GANIL, using a $^{58}Ni^{26+}$ primary beam with an average intensity of 3.7 *e*μA, accelerated to 74.5 MeV/nucleon and fragmented on a 200 μm thick natural Ni target. The fragments were selected by the LISE3 separator and implanted into a Double-Sided Silicon Strip Detector 300 μm thick, surrounded by four EXOGAM Ge clovers for gamma detection.

The proton decay of the ^{56}Zn Isobaric Analogue State is normally expected to be isospin forbidden, however competition between beta-delayed protons and beta-delayed gamma rays has been observed. Similar cases have been seen before. The particularity here is that the states populated in the gamma de-excitation are also proton-unbound, consequently the rare and exotic beta-delayed gamma-proton decay has been observed. In particular, three gamma-proton sequences have been seen after the beta decay [1]. This observation is very important because it does affect the conventional way to determine the Gamow-Teller (GT) transition strength B(GT) near the proton drip-line, where the general opinion until now was that the B(GT) is simply deduced from the intensity of the proton peaks. On the contrary, the observed proton intensities are due to both direct feeding and indirect feeding coming from the gamma de-excitation. Thus both gamma and proton decays have been taken into account in the estimation of the Fermi and GT strengths. Evidence for fragmentation of the Fermi strength due to strong isospin mixing is found. The results are compared with the mirror process, the ^{56}Fe(^{3}He,*t*)^{56}Co reaction [3].

The beta-delayed gamma-proton decay may become a common decay mode in heavier, more exotic systems with $T_z \leq -3/2$, which will be studied this year at the Radioactive Ion Beam Factory at RIKEN during the EUroball RIken Cluster Array (EURICA) campaign.

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$G^{(I)}(E)$ is the perturbed Green's function, while $G_0(^{(I)}E)$ is the unperturbed Green's function given by,

$$G_0^{(I)}(E) = \sum_{1,2} \frac{|(j_1 j_2)^{(I^+)}\rangle\langle(j_1 j_2)^{(I^+)}|}{e_1 + e_2 - E - i\eta}, \tag{6}$$

where the sum includes all independent two-particle states coupled to the total angular momentum of I with the positive parity, described by the three-body Hamiltonian for ^{24}O$+n+n$.

The correlated decay energy spectrum obtained with Eq. (4) takes into account fully the final state nn interaction and will be largely different from the result without the final state nn interaction. The latter corresponds to the first term in Eq. (5). Without the final state nn interaction, the two valence neutrons in ^{26}O occupy the s.p. resonance state of $1d_{3/2}$ at 770 keV, and the peak in the decay energy spectrum appears at twice this energy.

With the contact final state nn interaction, we discuss the ground I=0^+ state and also the excited I=2^+ state of ^{26}O using the same three-body model of ^{24}O+n+n system with full account of the continuum. The correlated decay spectrum shows that the peak energies are shifted towards lower energies. The energy shift ΔE is larger in $I = 0$ than in $I = 2$, i.e., the peaks in the spectrum appear at $E = 0.148$ MeV ($\Delta E = -1.392$ MeV) for $I = 0$ and at $E = 1.354$ MeV ($\Delta E = -0.186$ MeV) for $I = 2$. Notice that the energy shift for the $I \neq 0$ states from the unperturbed energy is much smaller than the energy shift for the 0^+ state which is a typical spectrum governed by a strong pairing correlation between two valence neutrons [4]. The calculated energies are consistent with the observed energy spectra in ^{26}O in refs. [1, 5] .

References

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Production cross section measurement and identification of new isotopes in the vicinity of ^{100}Sn

I. Čeliković[1,2], M. Lewitowicz[1], R. Gernhäuser[3], R. Krücken[4], S. Nishimura[5], H. Sakurai[5,6], H. Baba[5], B. Blank[7], A. Blazhev[8], P. Boutachkov[9], F. Browne[10], G. de France[1], P. Doornenbal[5], T. Faestermann[3], Y. Fang[11], J. Giovinazzo[7], N. Goel[9], M. Gorska[9], S. Ilieva[12], T. Isobe[5], A. Jungclaus[13], G. D. Kim[14], Y.-K. Kim[14], I. Kojouharov[9], N. Kurz[9], G. Lorusso[5], D. Lubos[3], K. Moschner[8], I. Nishizuka[15], J. Park[4], Z. Patel[16], M. Rajabali[4], S. Rice[16], H. Schaffner[9], L. Sinclair[17], P. A. Söderström[5], K. Steiger[3], T. Sumikama[15], Z. Wang[4], H. Watanabe[18], J. Wu[5,19] and Z. Xu[5,6]

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In this contribution we report on the measured production cross sections of neutron deficient isotopes around ^{100}Sn, produced at BigRIPS fragment separator at RIKEN Nishina Center, by fragmentation of a 345 MeV/nucleon ^{124}Xe beam impinging on a 4 mm Be target. Production cross sections, deduced for nuclei with transmission larger than 1% are compared with several fragmentation experiments and EPAX empirical cross section formulae. In the estimation of the experimental production cross sections, a special attention was paid to contributions from secondary reactions in the primary target. Production cross sections measured in experiments with different target thicknesses corrected for the contributions of secondary reactions show a good overall agreement between different experiments.

In the the same experiment, several new isotopes: ^{96}In, ^{94}Cd, ^{92}Ag, ^{90}Pd have been identified. The observation of new isotopes is confronted with the proton drip-lines predicted by various mass models. Based on the systematics of the production yields of ^{93}Ag and neighbouring nuclei it was demonstrated that ^{93}Ag is a new proton emitter with a half-life comparable to the time of flight through the BigRIPS fragment separator. The estimated lifetime of ^{93}Ag is compared to predictions of simple model of the proton emission using various mass models.

Three-body model study of unbound nucleus ^{26}O

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We study the two-neutron decay and the first excited 2^+ state of an unbound nucleus ^{26}O with a three-body model assuming an inert ^{24}O core and two valence neutrons. In order to describe the decay properties of neutron unbound nucleus, we take into account the couplings to the continuum by the Green's function technique.

In the experiment of Ref. [1], the ^{26}O nucleus was produced in the single proton-knockout reaction from a secondary ^{27}F beam. We therefore first construct the ground state of ^{27}F with a three-body model, assuming the ^{25}F+n+n structure. We then assume a sudden proton removal, that is, the ^{25}F core changes to ^{24}O keeping the configuration for the n+n subsystem of ^{26}O to be the same as that in the ground state of ^{27}F. This initial state, $\Psi_i^{(I)}$, is then evolved with the Hamiltonian for the three-body ^{24}O+n+n system for the two-neutron decay.

We consider two three-body Hamiltonians, one for the initial state ^{25}F+n+n and the other for the final state ^{24}O+n+n. For both cases, we use Hamiltonian

$$H = \hat{h}_{nC}(1) + \hat{h}_{nC}(2) + v(1,2) + \frac{\vec{p}_1 \cdot \vec{p}_2}{A_c m}, \tag{1}$$

where A_c is the mass number of the core nucleus, m is the nucleon mass, and $\hat{h}_{nC}$ is the single-particle (s.p.) Hamiltonian for a valence neutron interacting with the core. We use a contact interaction between the valence neutrons. See ref. [2] for details of the parameters of Eq. (1) and the contact interaction between the neutrons.

With the initial wave function $\Psi_i^{(I)}$ calculated by the three-body model, the decay energy spectrum for a given angular momentum I can be computed as [3],

$$\frac{dP_I}{dE} = \sum_k |\langle \Psi_k^{(I)} | \Phi_i^{(I)} \rangle|^2 \, \delta(E - E_k), \tag{2}$$

where $\Psi_k^{(I)}$ is a solution of the three-body model Hamiltonian with the angular momentum I with the energy E_k. Notice that Eq. (2) can be expressed as

$$\frac{dP_I}{dE} = -\frac{1}{\pi}\Im \sum_k \langle \Phi_i^{(I)} | \Psi_k^{(I)} \rangle \, \frac{1}{E_k - E - i\eta} \, \langle \Psi_k^{(I)} | \Phi_i^{(I)} \rangle, \tag{3}$$

$$= -\frac{1}{\pi}\Im \langle \Phi_{\rm ref}^{(I)} | G^{(I)}(E) | \Phi_i^{(I)} \rangle, \tag{4}$$

where $\Im$ denotes the imaginary part and η is an infinitesimal number and

$$G^{(I)}(E) = G_0^{(I)}(E) - G_0^{(I)}(E) v (1 + G_0^{(I)}(E) v)^{-1} G_0^{(I)}(E). \tag{5}$$

$G^{(I)}(E)$ is the perturbed Green's function, while $G_0(^{(I)}E)$ is the unperturbed Green's function given by,

$$G_0^{(I)}(E) = \sum_{1,2} \frac{|(j_1j_2)^{(I^+)}\rangle\langle(j_1j_2)^{(I^+)}|}{e_1 + e_2 - E - i\eta}, \tag{6}$$

where the sum includes all independent two-particle states coupled to the total angular momentum of I with the positive parity, described by the three-body Hamiltonian for ^{24}O$+n+n$.

The correlated decay energy spectrum obtained with Eq. (4) takes into account fully the final state nn interaction and will be largely different from the result without the final state nn interaction. The latter corresponds to the first term in Eq. (5). Without the final state nn interaction, the two valence neutrons in ^{26}O occupy the s.p. resonance state of $1d_{3/2}$ at 770 keV, and the peak in the decay energy spectrum appears at twice this energy.

With the contact final state nn interaction, we discuss the ground I=0^+ state and also the excited I=2^+ state of ^{26}O using the same three-body model of ^{24}O+n+n system with full account of the continuum. The correlated decay spectrum shows that the peak energies are shifted towards lower energies. The energy shift ΔE is larger in $I = 0$ than in $I = 2$, i.e., the peaks in the spectrum appear at $E = 0.148$ MeV ($\Delta E = -1.392$ MeV) for $I = 0$ and at $E = 1.354$ MeV ($\Delta E = -0.186$ MeV) for $I = 2$. Notice that the energy shift for the $I \neq 0$ states from the unperturbed energy is much smaller than the energy shift for the 0^+ state which is a typical spectrum governed by a strong pairing correlation between two valence neutrons [4]. The calculated energies are consistent with the observed energy spectra in ^{26}O in refs. [1, 5] .

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[1] E.Lunderberg *et al.*,Phys.Rev.Lett.**108**,142503 (21012).

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Monday 22/06/2015
h. 15.15-17.05

Sala Conferenze LNS

PARALLEL SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

Excited nuclear matter at Fermi energies : from transport properties to the equation of state

O. Lopez
(INDRA-FAZIA collaboration)

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Properties of excited nuclear matter are one of the main subject of investigation in Nuclear Physics. Indeed, the response of nuclear matter under extreme conditions encountered in heavy-ion induced reactions (large compression, thermal and collective excitations, isopin) around the Fermi energy is mandatory when studying the nuclear equation of state and the underlying in-medium properties concerning the nuclear interaction [1]. In this contribution, I will present some experimental results concerning the transport properties of nuclear matter, focusing specifically on the determination of in-medium quantities such as mean free pathes and nucleon-nucleon cross sections around the Fermi energy [2]. We will see that, in this specific energy range, energy and isospin dissipations exhibit very peculiar features, such as the crossover between 1-body to 2-body dissipation regimes corresponding to the transition between the nuclear response from Mean-Field to the nucleonic response through the appearance of nucleon-nucleon collisions. As a perspective, I will also discuss some new experimental probes concerning the study of the isospin degree of freedom for the equation of state (symmetry energy) that can be investigated along forthcoming radioactive beam facilities in the next years [3].

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The role of the symmetry energy on Pygmy Dipole Resonance dynamics: from schematic models to transport approaches

Virgil V. Baran[1], M. Colonna[2], M. Di Toro[3], I. D. Palade[1], A. Croitoru[1]

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[2] *INFN-LNS, Catania, Italy*
[3] *University of Catania, Italy*

By considering different parameterizations with density of the symmetry energy is investigated theoretically the emergence and the nature of the low energy dipole response evidenced experimentally for various systems. We analyze the consistency of the predictions provided by a generalization of the Brown-Bolsterli schematic model with a density dependent particle-hole residual interaction and those based on self-consistent microscopic transport approaches using the Vlasov equation. In both cases an additional collective mode is signaled whose energy centroid is closer to the distance between two major shells and exhaust few percentages of Energy Weighted Sum Rule. From the sensitivity of EWSR to the density dependence of the symmetry energy is concluded that precise experimental determination of the PDR properties can settle important constraints on the behavior of the symmetry energy well below saturation.

Alpha-particle clustering in excited expanding self-conjugate nuclei

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[2] *National Institute for Physics and Nuclear Engineering, Bucharest-Magurele, Romania*

Clustering is a generic phenomenon which can appear in homogeneous matter when density decreases; the formation of galaxies as well as the disintegration of hot dilute heavy nuclei into lighter nuclei are extreme examples occuring in nature. As far as nuclear physics is concerned, the nucleus viewed as a collection of α-particles was very early discussed [1] and in the last forty years both theoretical and experimental efforts were devoted to clustering phenomena in nuclei. Very recently the formation of α-particle clustering from excited expanding self-conjugate nuclei was revealed in two different constrained self consistent mean field calculations [2] [3].

The contribution will report on an experiment performed with the CHIMERA multi-detector for the reaction ^{40}Ca+^{12}C at 25 MeV/nucleon bombarding energy, which was used to produce and carefully select minor classes of events from which excited $N\alpha$ sources can be unambiguously identified. Their excitation energy distributions are derived with mean values around 3-4 MeV per nucleon, which indicates that mean densities about 0.4-0.3 the normal density have been reached. Their energetic emission properties were compared with two simulations, one involving sequential decays and a second for simultaneous decays. For excited expanding $N\alpha$ sources composed of 4, 5 and 6 α-particles, for which statistics is good enough for conclusives comparisons with simulations, evidence in favour of simultaneous emission (α-particle clustering) is reported.

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In-medium and isospin effects of strange particles in heavy-ion

Z. Q. Feng

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Dynamics of strange particles produced in proton induced nuclear reactions and in heavy-ion collisions near threshold energies has been investigated within the Lanzhou quantum molecular dynamics (LQMD) transport model[1]. The in-medium modifications on particle production in dense nuclear matter are considered through corrections on the elementary cross sections via the effective mass and the mean-field potentials. A repulsive kaon-nucleon potential is implemented in the model through fitting the flow data and inclusive spectra in heavy-ion collisions, which enhances the energetic kaon emission squeezed out in the reaction zone and leads to a variation of the high-momentum spectrum of the K0/K+ yields. It is found that the stiffness of nuclear symmetry energy plays a significant role on the isospin ratio with decreasing the incident energy and a hard symmetry energy has a larger value of the K0/K+ ratio in the domain of subthreshold energies. The attractive antikaon-nucleon potential enhances the subthreshold K production and also influences the structure of inclusive spectra. The strangeness production is strongly suppressed in proton induced reactions in comparison to heavy-ion collisions. The kaon-nucleon and antikaon-nucleon potentials change the structures of rapidity and transverse momentum distributions, and also the inclusive spectra[2]. The measured data from KaoS collaboration have been well explained with inclusion of the in-medium potentials.

[1] Z. Q. Feng, Phys. Rev. C 83, 067604 (2011); 84, 024610 (2011); 85, 014604 (2012); Nucl. Phys. A 878, 3 (2012); Phys. Lett. B 707, 83 (2012).
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Influence of Skyrme-type Momentum Dependent Interaction on HICs Observables

Y. Zhang[1], M.B. Tsang[2], Z. Li[1]

1) China Institute of Atomic Energy, Beijing, China
2) Michigan State University (MSU), USA

A new version of the improved quantum molecular dynamics model has been developed by including Skyrme type momentum dependent interaction. Four Skyrme parameter sets, SLy4, SkI2, SkM*, Gs, and 12 kinds of MSL (K_0, S_0, L, m_s^*, m_v^*) parameter sets are adopted in the transport model code to calculate the isospin diffusion, single and double ratios of transverse emitted nucleons, neutron proton isoscaling ratios. The calculations evidence that isospin diffusion observable at lower beam energy is sensitive to the slope of symmetry energy. The high energy neutrons and protons and their ratios from reactions at different incident energies provide a robust observable to study the momentum dependence of symmetry potential, which is related to the nucleon effective mass splitting, at higher beam energy. Furthermore, the covariance analysis are performed to quantify the correlation between the interaction parameters in a transport model and the HIC observables commonly used to extract information of Equation of State in asymmetric nuclear matter.

Tuesday 23/06/2015
h. 8.30-10.30

Aula Magna Dipartimento di Fisica ed Astronomia

PLENARY SESSION:

Relativistic Heavy-Ion Collisions

Studying the Quark-Gluon Plasma in Nuclear Collisions at the LHC

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[1] *Physikalisches Institut, Universität Heidelberg, D 69120 Heidelberg*

The theory of strong interaction, quantum-chromo-dynamics, predicts for high temperature and density a new state of matter in which the confinement of quarks and gluons is lifted. This state, the quark-gluon-plasma, existed in the early universe after the electro-weak phase transition up to about 10 microseconds. In the past 25 years accelerator-based experiments have been conducted in order to recreate this state of matter for a short time. The ideal tool are collisions of heavy nuclei at energies as high as possible. Now with the Large Hadron Collider (LHC) at CERN an entirely new energy regime is accessible.

Two aspects of the data will be explored: (i) Experimental knowledge about the phase bounary between ordinary hadronic matter and the quark-gluon plasma. This is based on the measured yields of various hadronic species. Here a direct link can be made the the full statistical operator of QCD including it's fluctuations. (ii) Evidence for deconfinement. This comes from the production of charmonia as a function of center of mass energy and centrality of the collision. Data on quarkonium production as well as on open heavy flavor will be discussed. The LHC data will be put into perspective vis-a-vis the results from lower energies.

Collective dynamics, fluctuations and instabilities in Relativistic Heavy Ion collisions

László P. Csernai

Department of Physics and Technology, University of Bergen, Norway

Fluid dynamical processes became a dominant direction of research in high energy heavy ion reactions. The QuarkGluon plasma formed in these reactions has low viscosity [1], which leads to significant fluctuations and turbulent instabilities [2]. One has to study and separate these two effects [3], but this is not done yet in experiments. When such separation is performed, both fluctuations and new collective effects, like rotation and turbulence and the arising polarization [4] and two particle correlations [5] can be studied. The polarization arises from the shear flow based on the equipartition principle between local flow vorticity [6] and particle spin. Vorticity increases with beam energy in peripheral collisions, while higher temperatures counteract spin alignment. Due to these two effects polarization is expected to be observable at lower energies also [6].

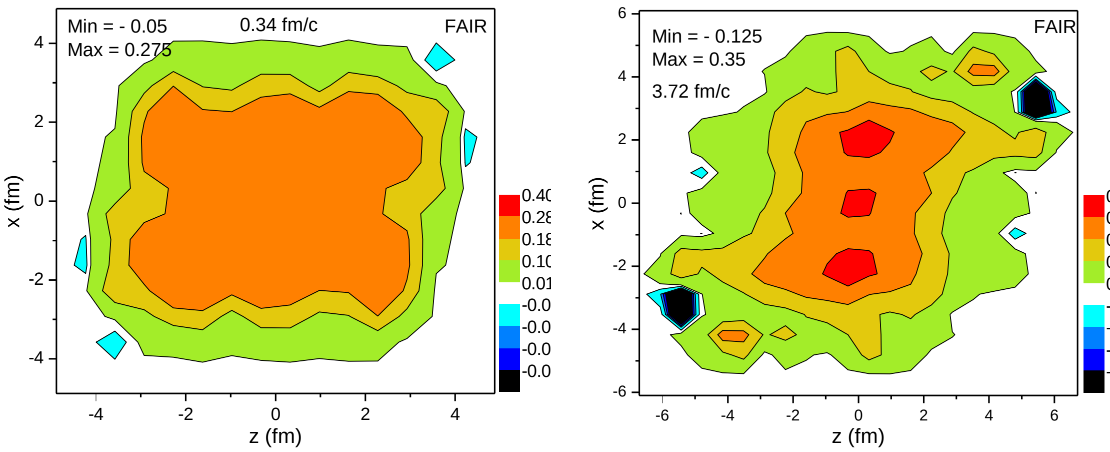

FIG. 1. (Color online) The relativistic weighted thermal vorticity Ω_{zx}, calculated in the reaction [x-z] plane at t=0.34 fm/c and at t=3.72 fm/c. The energy of the U+U collision is $\sqrt{s_{NN}} = 4.0 + 4.0$ GeV, $b = 0.5 b_{max}$, and the cell size is $dx = dy = dz = 0.610$ fm. The average, energy weighted vorticity, Ω_{zx} is 0.0856 / 0.0658 for the two selected times. From ref. [6].

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[4] F. Becattini, L.P. Csernai and D.J. Wang, Phys. Rev. C **88**, 034905 (2013)
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Understanding properties of the Quark Gluon Plasma (QGP) on the basis of correlation and fluctuation measurements at RHIC and the LHC

Rene Bellwied[1]

[1] *University of Houston, Physics Department, Houston, TX 77204, USA*

The measurement of identified particle correlations and fluctuations in the aftermath of the phase transition from a deconfined quark-gluon state of matter to a hadron gas enables us to not only determine unique properties of the QGP state, such as the initial conditions and the viscosity over entropy ratio, but also shed light on the non-perturbative processes at the phase boundary. Based on data from the ALICE experiment at the LHC and the STAR experiment at RHIC I will focus on the system size and energy dependence of plasma properties and the fascinating process of hadronic matter formation during the phase transition.

Hadron formation in relativistic nuclear collisions and the QCD phase diagram

F. Becattini[1]

[1] *Department of Physics, University of Florence, Italy*

We review recent advances in the subject of hadron production in relativistic heavy ion collisions. We focus on the issues of chemical freeze-out, chemical equilibration and the role of post-hadronization inelastic collisions. From the observations collected in elementary and heavy ion collisions, a picture emerges in which hadrons are born in a chemically equilibrated distribution at hadronization, which is thereafter slightly distorted by rescattering effects. The reconstructed hadronization line in T-muB plane nicely matches the shape of the extrapolated pseudo-critical band from lattice QCD calculation.

Tuesday 23/06/2015
h. 11.00-13.00

AULA MAGNA

PLENARY SESSION:

Nuclear Structure

Shape phase transitions far from stability

D. Vretenar[1]

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The rich variety of nuclear shapes is governed by the evolution of shell structure of single-nucleon orbitals. Far from β-stability the energy spacings between single-nucleon levels change considerably with the number of neutrons and/or protons. The reduction of spherical shell closure is associated with the occurrence of deformed ground states and, in a number of cases, with the phenomenon of coexistence of different shapes in a single nucleus.

In most cases the transition between different shapes in isotopic or isotonic sequences is gradual, and reflects the underlying modification of shell-structure. In a number of examples, however, with the addition or subtraction of only few nucleons one finds signatures of abrupt changes in observables that characterize ground-state nuclear shapes. A quantitative analysis of the evolution of nuclear shapes and shape phase transitions, including regions of short-lived exotic nuclei that are becoming accessible in experiments at radioactive-beam facilities, necessitate accurate modeling of the underlying microscopic nucleonic dynamics. Important advances in nuclear theory have recently been made in studies of complex shapes and the corresponding excitation spectra and electromagnetic decay patterns, especially in the "beyond mean-field" framework based on nuclear density functionals. Particularly interesting applications include studies of triaxial deformations at low energy, and the occurrence of simultaneous quadrupole and octupole shape phase transition [1-5].

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Time-dependent Hartree-Fock calculations for multinucleon transfer and quasi-fission processes

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We report our recent results on time-dependent Hartree-Fock (TDHF) calculations for nucleus-nucleus collisions at around the Coulomb barrier producing two fragment nuclei. The TDHF theory has been quite successful in describing nuclear excitations in the linear response theory and low-energy heavy ion collisions as nonlinear and nonperturbative quantum dynamics of many nucleons. One of recent directions is a description of nuclear collisions involving exchanges of a number of nucleons.

We have recently carried out calculations for multinucleon transfer (MNT) processes in low-energy heavy ion reactions [1]. Employing the particle-number projection method [2], we may evaluate cross sections which can be compared directly with measurements. We find the MNT processes proceed in two distinct stages depending on the distance of two nuclei. At sufficiently long distance in which surfaces of two nuclei do not touch, exchanges of nucleons proceed as a succession of single-nucleon transfer processes. When the surfaces of two nuclei touch, a neck is formed. The MNT after the neck formation takes place as a result of neck breaking. Since the neck is composed of both protons and neutrons, they move coherently in this process. To compare with measured cross sections, we need to evaluate nucleon evaporations which take place in much longer time scale. We have invented a method to evaluate excitation energies of fragment nuclei [3] and have estimated the number of nucleons emitted in longer time scale [4].

When two heavy nuclei collide, fusion process is suppressed by a large charge number of the unified system, giving rise to so-called quasi-fission processes. In recent TDHF calculations, it has been clarified that the quasi-fission processes may be described reasonably [5,6]. We have carried out systematic TDHF calculations for quasi-fission processes of various projectile-target pairs, changing incident energies and impact parameters. A few intriguing aspects have been found: In quasi-fission processes involving deformed nuclei, neck development depends strongly on the nuclear orientation relative to the incident direction. It has also been found that inverse quasi-fission processes (nucleons exchanged toward directions increasing mass asymmetry) occur systematically when the incident energy increases [7]. We will discuss possible origins of this observation such as nuclear shell effects and density fluctuations in the neck region.

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Interplay between collective and single particle excitations around neutron-rich doubly-magic nuclei

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Università degli Studi e INFN sezione di Milano, Milano, Italy

In doubly-magic nuclei, in general, the lowest excited states exhibit a high degree of collectivity. This characteristics is related to the fact that, due to the large energy gaps for both neutrons and protons, simple particle-hole core-excited states are located at rather high energies, while the energy of excitations arising from very complex configurations (phonons) is lowered significantly.
In consequence, in nuclei with one or two particles outside of a doubly-closed core the lowest structure should be dominated by the couplings between phonon excitations and valence particles, giving rise to series of multiplets. The identification of these multiplets can provide precise, quantitative information on the phonon-particle couplings. In fact, the energy and transition probability for states belonging to phonon-particle multiplets can be calculated within mean-field based models and comparisons with experiment can provide a unique test of various theoretical approaches.
From a broader perspective, understanding the coupling of a single particle to vibrational motion in nuclei is of primary importance, as this coupling is responsible for the quenching of spectroscopic factors [1] and it is also the key process at the origin of the damping of giant resonances [2].

This talk will present the situation in nuclei lying in close proximity of doubly-magic systems, such as ^{47,49}Ca [3,4], ^{133}Sb and ^{210}Bi. Various types of reactions will be discussed: from multinucleon transfer with heavy ions, to cold neutron capture (n,γ) and neutron induced fission on ^{235}U and ^{241}Pu targets. The results of measurements performed at Legnaro National Laboratory and ILL (Grenoble), using complex detection systems based on HPGe arrays coupled to magnetic spectrometers (PRISMA) or fast $LaBr_3$ scintillator detector arrays for lifetime measurements will be presented. Data on ^{61,65,67}Cu [5,6], obtained at NIPNE (Bucharest), will also be briefly discussed in terms of couplings with the 3^- octupole phonon of the semi-magic ^{60,64,66}Ni cores. Experimental data will be compared with theoretical calculations either based on a particle-phonon coupling approach or on a shell model employing realistic effective nucleon-nucleon interactions.
Perspectives for studies with cluster transfer reactions employing radioactive beams from ISOLDE and SPES will be finally given.

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Heavy ion charge exchange reactions

T. Uesaka

RIKEN Nishina Center, Saitama, Japan

Abstract not received

Tuesday 23/06/2015
h. 14.30-16.40

Aula F Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Relativistic Heavy-Ion Collisions

J/ψ production in heavy-ion collisions and related aspects

R. Arnaldi[1]

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Charmonium production in heavy-ion collisions is considered one of the main signatures for the formation of a plasma of quarks and gluons (QGP). The binding of the c and $\bar{c}$ is, in fact, expected to be screened in a very hot environement, leading to the melting of the charmonium states. In parallel to this suppression mechanism, in high energy collisions, charmonium production is expected to be affected by (re)combination of the c and $\bar{c}$ quarks either in the quark gluon plasma or at the hadronization phase. Furthermore, cold nuclear matter effects, as shadowing or energy loss, have also been verified to influence the charmonium yields. Results obtained in proton-nucleus collisions, where the hot medium is not expected to be formed, are, therefore, essential to calibrate these cold matter effects and to allow a quantitative determination of the QGP-related suppression in nucleus-nucleus interactions.

In the last thirty years charmonium production has been extensively investigated both in nucleus-nucleus and in proton-nucleus collisions. Results from SPS and RHIC will be discussed together with the most recent findings from the high energy LHC experiments and the role played by the aforementioned hot and cold matter effects, at the various collision energies, will also be addressed.

Anisotropic flows and the shear viscosity of the QGP within an event by event transport approach

S. PLUMARI[1], G.L. GUARDO[1], F. SCARDINA[1], V. GRECO[1]

[1] *INFN-LNS, CATANIA, ITALY*

We study the build up of elliptic flow v_2 and high order harmonics v_3, v_4 and v_5 for a fluid at fixed η/s by mean of an event-by-event transport approach. We study the effect of the η/s ratio on the build up of the $v_n(p_T)$. In particular we study the effect of a temperature dependent η/s for two different beam energies: RHIC for Au+Au at $\sqrt{s} = 200\,GeV$ and LHC for $Pb+Pb$ at $\sqrt{s} = 2.76\,TeV$. We find that for the two different beam energies considered the suppression of the $v_n(p_T)$ due to the viscosity of the medium have different contributions coming from the cross over or QGP phase. In ultra-central collisions the $v_n(p_T)$ show a strong sensitivity to the η/s ratio in the QGP phase and this sensitivity increase with the increase of the order of the harmonic. Moreover, we discuss the correlation between the initial spatial anisotropies ϵ_n and flow coefficients v_n. We find that at LHC energies the v_n are more correlated to the initial ϵ_n respect to RHIC energies. We find that the elliptic flow v_2 is strongly correlated with initial eccentricity ϵ_2. While higher harmonics v_3, v_4 and v_5 are weakly correlated to their asymmetry measure in coordinate space ϵ_3, ϵ_4 and ϵ_5. The degree of correlation increase with the impact parameter. At LHC energies and in ultra-central collisions we find that the linear correlation coefficent $C(n, n) \approx 1$ for $n = 2, 3, 4$ and 5.

Overview of azimuthal correlation measurements from ALICE

You Zhou[1] (for the ALICE Collaboration)

[1] *Niels Bohr Institute, University of Copenhagen,*

Azimuthal correlations are a powerful tool to probe the properties and the evolution of the collision system. In this talk, we will review the recent azimuthal correlation measurements in Pb–Pb, p–Pb and pp collisions from the ALICE detector at the LHC. The comparison of experimental measurements to various theoretical calculations will be discussed. In addition, we will give an outlook to possible future studies of azimuthal correlations for coming LHC running period (Run 2).

MCNP6 Simulation of Light and Medium Nuclei Fragmentation at Intermediate Energies

Stepan G. Mashnik[1] and Leslie M. Kerby[1,2]

[1] *Los Alamos National Laboratory, Los Alamos, NM, USA*
[2] *University of Idaho, Idaho Fall, ID, USA*

Fragmentation reactions induced on light and medium target nuclei by protons and light nuclei of energies around 1 GeV/nucleon and below are studied with the latest Los Alamos Monte Carlo transport code MCNP6 and with its cascade-exciton model (CEM) and Los Alamos version of the quark-gluon string model (LAQGSM) event generators, version 03.03, used as stand-alone codes. Such reactions are involved in different applications, like cosmic-ray-induced single event upsets (SEU's), radiation protection, and cancer therapy with proton and ion beams, to name just a few; therefore, it is important that MCNP6 simulates them as well as possible. CEM and LAQGSM assume that intermediate-energy fragmentation reactions on light nuclei occur generally in two stages. The first stage is the intranuclear cascade (INC), followed by the second, Fermi breakup disintegration of light excited residual nuclei produced after the INC. Both CEM and LAQGSM account also for coalescence of light fragments (complex particles) up to ^{4}He from energetic nucleons emitted during INC. We investigate the validity and performance of MCNP6, CEM, and LAQGSM in simulating fragmentation reactions at intermediate energies and discuss possible ways of further improving these codes.

Thermalization. equilbration and particle production in quark-gluon plasma

M. RUGGIERI[1], A. PUGLISI[2], S. PLUMARI[2], F. SCARDINA[2]

[1] *Università di Catania, Italy*
[2] *INFN-LNS, Catania, Itasly*

We discuss the problems of local thermalization, equilibration and particle productions in quark-gluon plasma produced in ultrarelativistic heavy ion collisions. We implement several kinds of initial conditions, which mimick the initial strong color glasma fields produced by the high energy collision. Once an initial condition for a fireball is specified, we use relativistic transport theory to simulate the dynamical evolution of the fireball, and to study in particular the thermalization and equilibration times, as well as the particle production by means of inelastic QCD processes and decay of the color flux tubes.

Understanding the path length dependence of jet quenching in Heavy Ion Collisions from RHIC to LHC

Myunggeun Song[1], D.J Kim[2]

[1] *Yonsei University, South Korea*
[2] *University of Jyväskylä, Finland*

The centrality dependence of nuclear modification factor(R_{AA}) carries information about path-length dependent partonic energy loss because mean path-length increases as the centrality increases. However, for a given centrality, inclusive R_{AA} emerges by averaging over different path-lengths which depend on the azimuthal angle w.r.t. the reaction plane assuming elliptical shape of overlapping zone of two colliding nuclei in the transverse plane. In this sense, azimuthal dependence of R_{AA} w.r.t. reaction plane offers to get a tighter constraint on the actual path length traversed by the parton in medium. As the azimuthal angle can be converted into the path-length with Glauber simulation[1] of two colliding nuclei, R_{AA} can be represented as a function of not only p_T, but also path-length. By utilizing the existing data from RHIC to LHC[2][3][4], we will show that R_{AA} seems to be aligned with respect to path-length, regardless of centralities in high transverse momentum regions ($p_T > 5GeV/$c) both for RHIC and LHC, and scales like universal function of square of Path-length. These results permit a detailed examination of the influence of geometry in the collision region and of the interplay between collective flow and jet-quenching effects.

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Tuesday 23/06/2015
h. 14.30-16.35

AULA MAGNA

PARALLEL SESSION:

Nuclear Structure

Electromagnetic and neutral-weak response functions of ^{4}He and ^{12}C.

A. Lovato[1], S. Gandolfi[2], J. Carlson[2], Steven[1] C. Pieper, R. Schiavilla[3,4]

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The MiniBooNE collaboration recently reported a measurement of the charged-current quasielastic (CCQE) neutrino-carbon double differential cross section, exhibiting a large excess with respect to the predictions of Monte Carlo simulations carried out within the relativistic Fermi gas model. However, such simulations are based on an oversimplified model of nuclear dynamics and do not take into account reaction mechanisms other than single-nucleon knock out, which are expected to provide a sizable contribution.

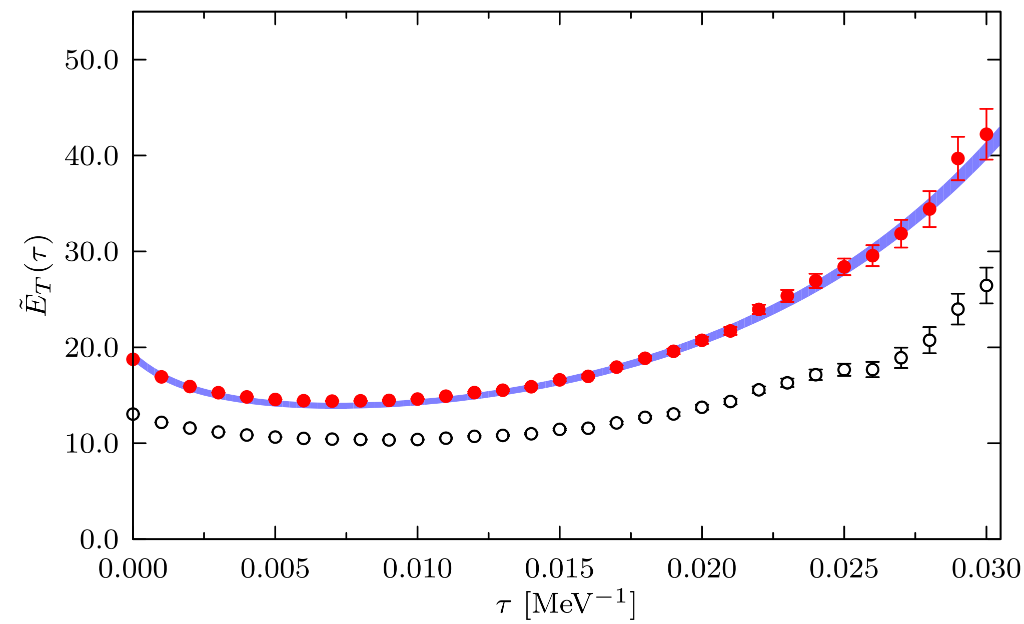

Figure 1: Euclidean electromagnetic transverse response function of ^{12}C at $q = 570$ MeV. The theoretical predictions obtained including only one-body and and both one- and two-body transition operators are represented by open circles and solid circles, respectively. The shaded band refers to the Euclidean response extracted from the world data analysis by Jourdan.

We performed Green's function Monte Carlo (GFMC) calculations of the sum rules of the response functions relevant to neutrino scattering experiments. We use realistic two– and three–nucleon forces; the nucleons interact with external probes via consistent one– and two–body currents. We found that a large fraction ($\simeq 30\%$) of the transverse sum rules of the electromagnetic [1] and neutral current [2] response functions arises from processes involving two-body currents. We have shown that the interference between one-body and two-body currents, which is not consistently included in existing mean-field calculations, plays a major role [3].

While the sum rules allow one to study only integral properties of the response functions, the calculation of the Euclidean response functions allowed us to establish a more direct comparison with experimental data [4]. As shown in Fig. 1, two-body current contributions substantially increase the one-body electromagnetic transverse response function. This enhancement is effective over the whole imaginary-time region we have considered, with the implication that excess transverse strength is generated by two-body currents not only at energies larger than the one corresponding to the quasi-elastic peak, but also in the quasi-elastic and threshold regions. The full predictions for the transverse Euclidean response functions is in excellent agreement with experimental data.

Using Bayesian techniques we were able to invert the Euclidean response of ^{4}He getting the corresponding electromagnetic response functions with unprecedented accuracy for the non-relativistic regime. These results will be used to guide the analyses of quasi-elastic scattering in neutrino experiments.

This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under the NUCLEI SciDAC grant. Computer time was made available by the National Energy Research Scientific Computing Center (NERSC), which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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Theoretical studies of possible toroidal high-spin isomers in the light-mass region

A. Staszczak[1], Cheuk-Yin Wong[2]

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A closed orientable surface has a topological invariant known as the Euler characteristic χ=2 − 2g, where the genus g is the number of holes in the surface. Nuclei as we now know them have the topology of a sphere with χ=2. Wheeler suggested that under appropriate conditions the nuclear fluid may assume a toroidal shape (χ=0). Using the liquid-drop model [1] and the rigid-body moment of inertia [2], it was shown that a toroidal nucleus, endowed with an angular momentum I=I_z aligned about its symmetry z-axis beyond a threshold, is stable against the breathing deformation in which the major radius R contracts and expands. The rotating liquid-drop nuclei can also be stable against sausage instabilities (know also as Plateau-Rayleigh instabilities, in which the torus fissions coplanarly into smaller fragments), when the same mass flow is maintained across the meridian [2].

More realistic calculations with cranked Skyrme-Hartree-Fock approach indicate a possible region of toroidal high-spin isomers in 28≤A≤52 where we find 18 possible N=Z high-spin isomeric states: ^{28}Si(I=44$\hbar$), ^{32}S(I=48, 66$\hbar$), ^{36}Ar(I=56, 72, 92$\hbar$), ^{40}Ca(I=60, 82$\hbar$), ^{44}Ti(I=68, 88, 112$\hbar$), ^{48}Cr(I=72, 98, 120$\hbar$), and ^{52}Fe(I=52, 80, 104, 132$\hbar$) [3]. The systematics of the energies, spins, and the geometries of these toroidal high-spin isomers fall into simple, regular (muti-particle)-(muti-hole) patterns. Furthermore, N≠Z toroidal high-spin isomers may be possible when the single-particle shells for neutrons and protons occur at the same cranked frequency $\hbar\omega$. We have located N≠Z toroidal high-spin isomers in $^{36}_{16}$S$_{20}$(I=74$\hbar$) and $^{40}_{18}$Ar$_{22}$(I=80, 102$\hbar$) whose properties fall into the same systematic patterns, as shown in Fig. 1 [4]. The properties of these toroidal high-spin isomers in the light-mass region will be discussed.

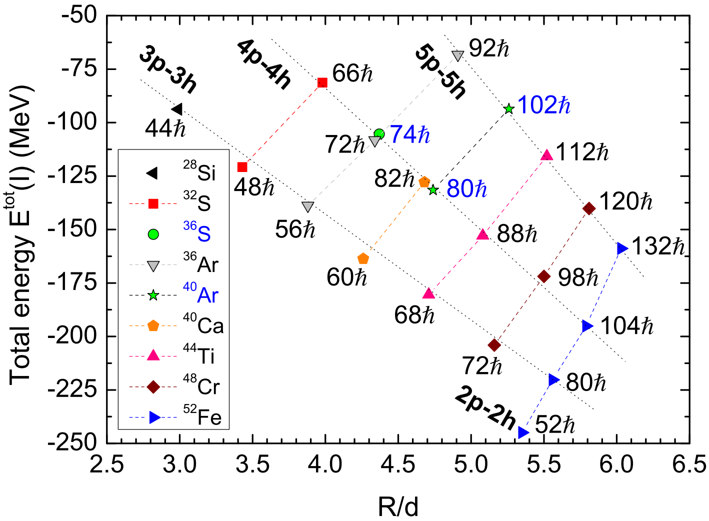

Figure 1: The total energies of the isomeric toroidal states of $^{28}_{14}$Si, $^{32}_{16}$S, $^{36}_{16}$S, $^{36}_{18}$Ar, $^{40}_{18}$Ar, $^{40}_{20}$Ca, $^{44}_{22}$Ti, $^{48}_{24}$Cr, and $^{52}_{26}$Fe and their associated I values, as a function of R/d, where R and d are the major and minor torus radius, respectively. The np-nh configurations relative to the I=0 configuration are also indicated.

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g-factor Measurements for Isomeric States in ^{174}W

M. Rocchini[1], A. Nannini[1], G. Benzoni[2], B. Melon[1], P.R. John[3], M. Ottanelli[1], A. Perego[1], R. Avigo[2], N. Blasi[2], G. Bocchi[2], S. Bottoni[2], A. Bracco[2], F. Camera[2], S. Ceruti[2], F.C.L. Crespi[2], A. Giaz[2], S. Leoni[2], B. Million[2], A.I. Morales[2], L. Pellegri[2], O. Wieland[2], D. Bazzacco[3], R. Menegazzo[3], D. Mengoni[3], C.A. Ur[3], V. Modamio[4], D.R. Napoli[4], J.J. Valiente-Dobon[4], A. Gottardo[5], C. Michelagnoli[6], G. Georgiev[7]

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A lively topic of the nuclear physic investigation concerns the study of high-K isomeric states. These states are useful to understand the nuclear structure and can provide crucial information for testing the theoretical models. Furthermore, the knowledge of the properties of these long-living states may be useful for practical applications in medicine and energy storage methods.

The K quantum number is defined as the projection of the total angular momentum on the symmetry axis of symmetrically deformed nuclei, and the decay among states characterized by different values of K is governed by selection rules. Even if K isomers have been observed in many nuclei, mostly in the A $\sim$ 180 region of the nuclide chart corresponding to well deformed nuclei (like Hf, W and Os isotopes), their decay mechanism is not yet well understood. One hypothesis is the mechanism of K-mixing, in which the mixing of configurations with different K gives the reduced hindrance factor of these states [1]. Another mechanism is the γ-tunneling, in which non-axial fluctuations of the nuclear shape are responsible for the tunneling of the nucleus between configurations with different values of the triaxiality parameter γ. This latter mechanism has proved to well describe the behaviour of K isomers in the A $\sim$ 180 region [2].

In this contribution we report on a recent study of the isomeric states of ^{174}W through the measurement of their giromagnetic factors. This nucleus is of particular interest since the 12^+ isomer shows a decay branch going directly to the ground state band, thus implying a change of 12 units of K. The γ-tunneling mechanism fail to account for the properties of this particular state [3]. In order to analyse this state in term of K-mixing, the knowledge of its multi-quasiparticle configuration is necessary. The nuclear observable connected to the configuration of multi-quasiparticle of the level is the magnetic dipole moment, which can be determined through giromagnetic factor measurements.

The experiment was performed at Legnaro National Laboratory, exploiting the well known TDPAD technique, using the existence GAMIPE apparatus which will be described in detail. The isomeric states were populated using the reaction ^{162}Dy(^{16}O,4n)^{174}W at beam energy of 84 MeV.

The measured value of g-factor has been compared with theoretical estimates for achieved the multi-quasiparticles configuration of the level 12^+. This result will be the starting point for the explanation of the decay mechanism of this level through the K-mixing model.

[1] P.M. Walker *et al.*, Phys. Rev. C **81**, 041304(R) (2010)
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Spatial properties of pairing and quarteting correlations in nuclei

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Interest in the study of the spatial properties of pairing correlations in nuclei has recently been revived [1]. The main interesting physical quantity is the coherence length, defined as the root mean square of the relative distance averaged with the pairing tensor. Intuitively it gives the size of the Cooper pair at a certain point inside the nucleus. We investigate this coherence length as obtained from schematic pairing potentials, like the contact density dependent one and the Gaussian one, and we comment on the results. We then generalize to quarteting correlations by considering the coherence length build out of proton and neutron pairs. We point out the main differences between the pairing and quarteting coherence lengths. Finally we comment on the important role of proton-neutron correlations as they strongly modify the behaviour of the coherence length when taken into account.[2]

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Excited sidebands calculated with Hatree-Fock method with PNC pairing

Wuyang Liang, F. R. Xu

School of Physics, Peking University, Beijing 100871, China

Cranking calculations with phenomenological one-body nuclear potentials (e.g., Nilsson, Woods-Saxon potentials) or with effective two-body interactions (e.g., Skyrme force, relativistic mean field) have been widely successful in the description of nuclear collective rotations. In cranking calculations, the self-consistence in pairing and deformation is important to predict experimental observations. However, the usual Bogoliubov pairing calculation encounters non-convergence problem in the numerical iteration of the cranking Hartree-Fock-Bogoliubov (HFB) differential equations when unpaired particle(s) appears. For a nucleus, sidebands built on broken-pair excited configurations constitute the most part of the spectroscopy of a nucleus, providing rich information about nuclear structure.

The spurious pairing collapse arising from the cranking HFB-type calculations would be related to the violation of the particle-number conservation in the Bogoliubov pairing. To consider the effect from the particle-number fluctuation, one can project the HFB wavefunction onto the good particle number before variation. But it complicates the algorithm. An exact particle-number-conserving (PNC) pairing method was developed and has been successfully applied to cranking calculations. But the original cranking PNC calculations were performed within the Nilsson potential with fixed deformation. The choosing of the deformation parameter relies somewhat on data usually, which limits the predictive power of the model. In our recent work, we have incorporated the PNC pairing into the total-Routhian-surface (TRS) method with Woods-Saxon potential adopted. However, the Hamiltonian constructed with only a one-body potential plus a residual two-body pairing interaction brings a double-counting problem.

We develop a method combining the PNC method with Skyrme two-body nucleon-nucleon interaction in mean-field model for the first time. Starting from the Skyrme force, we can obtain the deformed cranked single-particle energies in the mean-field theory. Based on the cranked basis, pairing correlation is processed by the PNC method which has the regime of the conventional shell model with model space striking smaller. Using our new method, we calculated the yrast bands and K^{π}=6+,K^{π}=8- sidebands for nuclei ^{172,174,176,178}Hf. The four-quasiparticle sideband K^{π}=14- for ^{176}Hf has also been presented. We also give the satisfied results of the transition probability and transition quadrupole moments of the hafnium isotopes.

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High-spin states in $N = 50$ ^{89}Y and ^{91}Nb nuclei: Probing πfp-νdg effective interaction

Purnima Singh[1], R. Palit[1], D. Choudhury[1], S. Biswas[1], S. Saha[1], J. Sethi[1], C. Ghosh[1], H. C. Jain[1], P. C. Srivastava[2], S. Mukhopadhyay[3], D. C. Biswas[3], L. S. Danu[3], A. Asgar[4], G. Mukherjee [4], R. Raut[5], S. S. Ghugre[5], A . K. Sinha[5], S. K. Tandel[6], S. Muralithar[7],

[1]*Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai - 400005, India*
[2]Department of Physics, Indian Institute of Technology, Roorkee-247667, India
[3]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India*
[4]Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata 700064, India
[5]*UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, India*
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In recent years, study of the evolution of nuclear structure in mass regions away from the valley of stability have driven the worlwide efforts in experimental and theoretical research. These studies have revealed a dramatic modifications of the ordering of single-particle orbitals in exotic nuclei as compared to the ones predicted by Mayer, Haxel, Suess and Jensen. The boundary of known nuclei is being pushed continuously due to the advent of radioactive ion beam facilities and highly efficient detection systems across the globe. The experimental information furnished by these state-of-art facilities have served to test the predictive power of theoretical models. However, in several cases the model calculations lack reliable information on some basic inputs, i.e. the single particle energies and the two-body matrix elements. For example, a prediction of the evolution of the $N = 50$ shell gap at very large neutron-to-proton ratios requires a knowledge of the interaction between the fp ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$) protons and the dg ($d_{5/2}$, $g_{7/2}$, $d_{3/2}$) neutrons, which is still not sufficiently understood. High-spin spectroscopic studies of $N = 50$, $Z \sim 40$ nuclei performed in past, have revealed that the low-lying states in these nuclei arise from proton excitations within the $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, and $g_{9/2}$ orbitals. The high angular momentum states were observed to have dominant contribution of $1p - 1h$ configurations involving a single $g_{9/2}$ neutron excitation across the $N = 50$ shell gap into the $d_{5/2}$ orbit [?]. A comprehensive study of multipaticle-multihole ($mp - mh$) excitations in these nuclei may provide necessary data which can lead to the determination of shell model parameters crucial to the understanding of the behaviour of nuclei far from stability. However, these studies are challenging both experimentally and theoretically. The $N = 50$ shell gap is the largest near $Z \sim 40$ [?], making it difficult to populate such states in experiment. Whereas, the exploding dimensions of matrices limit the large-scale shell model calculations incorporating cross-shell excitations. Recently, two experiments were performed at Tata Institute of Fundamental Research using the reaction ^{65}Cu(^{30}Si, 2p2n)^{91}Nb and ^{80}Se(^{13}C, p3n)^{89}Y. The motivation was to investigate the nature of states arising from cross shell excitations in the $N = 50$ isotones ^{89}Y and ^{91}Nb. The γ-ray coincidence events were measured with the Indian National Gamma Array (INGA) spectrometer [?]. High-spin states in both the nuclei were extended up to spin $I \sim 22\hbar$. To understand the structure of observed states, shell model calculations were performed within a model space comprising of four proton orbitals ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$, and $g_{9/2}$) and six neutron orbitals ($p_{1/2}$, $g_{9/2}$, $d_{5/2}$, $g_{7/2}$, $d_{3/2}$, and $s_{1/2}$) relative to an inert ^{66}Ni core. The results of these experimental work and large-scale shell model calculations will be presented.

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Tuesday 23/06/2015
h. 14.30-16.40

AULA AZZURRA LNS

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

TBA

Abstract not received

Scattering process for the system ^{7}Be+^{208}Pb at near-barrier energies

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We investigated for the first time the reaction dynamics induced by the weakly-bound projectile ^{7}Be ($S_\alpha = 1.584$ MeV) on a ^{208}Pb target at three near-barrier energies, namely 37.6, 40.5 and 42.4 MeV. The ^{7}Be Radioactive Ion Beam was produced with an intensity about 2.5×10^5 pps by means of the facility EXOTIC [1] at INFN-LNL (Italy). Charged reaction products were detected in the angular range $\theta_{cm} = [55°,165°]$ with the telescope array EXPADES [2].

Fig. 1 shows the preliminary evaluation of the elastic scattering angular distributions together with the results of the optical model analysis. Fig. 2 presents the reduced reaction cross sections for the systems ^{6,7}Li,^{7}Be + ^{208}Pb [3]. Quite unexpectedly, the ^{7}Be reaction cross section data follow the trend individuated by those measured for the reaction induced by the more tightly-bound mirror nucleus ^{7}Li ($S_\alpha = 2.468$ MeV) rather than those obtained for the similarly weakly-bound projectile ^{6}Li ($S_\alpha = 1.475$ MeV).

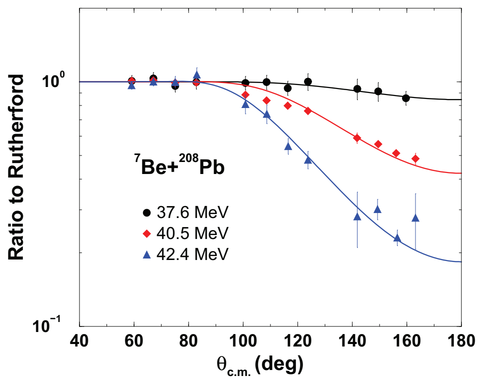

Figure 1: Elastic scattering angular distributions for the system ^{7}Be + ^{208}Pb.

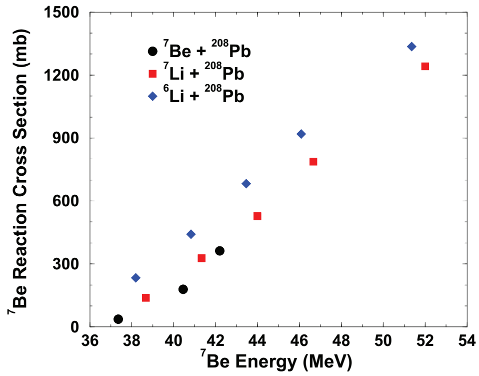

Figure 2: Reduced reaction cross sections for the systems ^{6,7}Li,^{7}Be + ^{208}Pb.

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New evidence of soft dipole resonance in ^{11}Li

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The two-neutron halo nucleus ^{11}Li [1] has an unusual orbital arrangement with parity inversion between the $p_{1/2}$ and $2s_{1/2}$ orbitals breaking the N=8 magic number. The weakly bound halo neutrons and the proximity of opposite parity orbitals open the possibility of the existence of new kind of excitation modes. Shortly after the finding of the halo a low-energy dipole enhancement was suggested due to the long neutron density tail [2]. Following this, a novel phenomenon was proposed where the two halo neutrons (i.e. the halo around the core) could oscillate against the core giving rise to very low-lying soft dipole resonance states [3]. Since then there have been several experiments searching for the existence of such low-lying dipole resonance states [4-9] using different techniques such as pion scattering [4] and pion capture reactions [5], proton inelastic scattering [6], invariant mass spectroscopy [7], Coulomb dissociation [8] and multi-nucleon transfer reaction [9]. Till date however no firm conclusion has been reached.

We will report results from a newly constructed reaction spectroscopy facility, IRIS, at TRIUMF, Canada that utilizes a novel thin solid hydrogen or solid deuteron target for low-energy reactions with radioactive beams [10]. Results from the first measurement of ^{11}Li(d,d') will be presented that show firm evidence for the presence of the a soft dipole resonance state. The reaction being selective to isoscalar dipole excitations only allows a new understanding on the dipole resonance nature in ^{11}Li. Comparison to theoretical predictions will also be discussed.

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Unified studies of structures and reaction in two-center systems

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In light neutron-excess systems, many kinds of molecular structures are discussed from the viewpoint of the clustering phenomena. In particular, much attention has been concentrated on Be isotopes, and their low-lying states are nicely described by the two-center molecular orbit (MO) structure with the ^{8}Be = $\alpha + \alpha$ core. In the MO structure, the excess neutrons perform the single particle motion in the covalent orbit, such as π^- and σ^+, associated with the covalent bonds of atomic molecules [1]. Moreover, in Be isotopes, many resonant states, decaying into the ^{6,8}He fragments, have been observed in unbound states above the α-decay threshold [2]. These resonances are considered to have the atomic structures, which correspond to the binary system of the He isotopes. The two-center picture discussed in Be isotopes has been extended recently to the heavier system [3], and experimental investigation of the highly excited resonances is one of a current issues in the physics of neutron-excess nuclei.

In this report, we will show the systematic analysis of the molecular structures, which are generated by the two-center cores systems. We employ the generalized two-center cluster model GTCM, which is possible to describe the formation of the covalent and atomic structures in general two-center systems [4]. This model is also feasible to handle the reactions problem as well as the structure problem. In a series of the previous studies, we have performed the unified studies of molecular structures and reaction dynamics for ^{10,12}Be, by applying GTCM [4].

We have extended the application of GTCM to even Be isotopes, ^{10,12,14,16}Be ($= \alpha + \alpha + 2, 4, 6, 8N$). In the analysis of Be isotopes, we have found a systematic change of the level scheme, which is induced by the variation of the neutron number. For example, the systematic change of the mysterious 0^+ level, which has the σ^+ orbit configuration, is clearly observed as a function of the neutron number. We have also solved the scattering problem for the respective binary systems, Be = ^{x}He + ^{y}He, by employing the variation method [4]. The scattering matrices are calculated, and we have investigated the resonant structures, appearing in the energy variation of the scattering matrices. The resonant states with a sharp width are generated by the coupling with the neutron transfer channels.

GTCM is also applied to the mirror partners of ^{10,12}Be, such as ^{10}C and ^{12}O ($=\alpha + \alpha + 2, 4P$), and the mirror symmetry in the pair of ^{10}C$-^{10}$Be and ^{12}Be$-^{12}$O is investigated. In these mirror systems, the so-called Thomas-Ehrman shift [5], which means an exceptional suppression of the Couolomb shift for the S-wave configuration, has been confirmed. We have found that a prominent breaking of the mirror symmetry occurs in the monopole transition from the ground 0^+ state to the excited 0^+ states due to the effect of the Thomas-Ehrman shift. Unified studies of structures and reactions in these two-center molecular systems will be presented.

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Evaluation of inelastic breakup in reactions induced by weakly-bound nuclei within a three-body model

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An important mechanism that takes place in nuclear collisions is the dissociation of the projectile into two or more fragments. In many experiments, with both stable and radioactive nuclei, only one of the fragments is detected giving rise to the so-called inclusive breakup. For two-body dissociation, this corresponds to reactions of the form $a(b+x)+A \rightarrow b+$ anything. The theoretical interpretation of these reactions is complicated due to the fact that many processes (compound nucleus, transfer, direct breakup...) can contribute to the production of the b fragment. The total breakup is usually separated into two contributions, namely, the elastic breakup and the inelastic breakup. The former corresponds to processes in which the fragments b and x survive after the collisions and the target remains in its ground state. By contrast, inelastic breakup corresponds to those breakup processes accompanied by the absorption of the unobserved fragment or target excitation. While elastic breakup can be reliably calculated with several reaction models (DWBA, CDCC, Faddeev...), the calculation of inelastic breakup is not so well established. A number of methods were proposed in the 80s by several groups [1-7] to calculate the inelastic breakup contributions but the computed cross sections differ from one method to another. For example, Austern and co-workers [2-4] proposed a post from three-body model (and its DWBA counterpart), whereas Udagawa and Tamura developed a prior form DWBA model [5-7]. Consequently, we have revisited these theories in order to investigate their validity and study their possible applicability to inclusive breakup experiments with exotic nuclei. As a first stage, we have considered the DWBA version of these models, applying it to several inclusive experiments induced by deuterons and other weakly bound nuclei, and comparing with available data. Preliminary results of this comparison will be presented and discussed.

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Measuring fusion excitation functions with RIBsusing the stacked target technique: problems and possible solutions

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In the last decade, fusion reactions induced bylow intensity RIBs have been studied by irradiating stacks of several targets and measuring off-line the radiation emitted in the decay of the evaporation residues [e.g. 1-6].Such a technique offers the considerable advantage that several reaction energies may be simultaneously measured. However, its main drawback is the degradation of the beam quality as it passes through the stack due to statistical nature of energy loss processes and any non-uniformity of the stacked targets.

Indeed, due to the large number of used foils and/or their non-uniformities and/or the quality of RIBs used, in many experiments targets were irradiated by beams having large energy dispersions (e.g. up to ~2 MeV FWHM in [1,2] and up to ~ 6 MeV FWHM in [3,4]). If not taken properly into account, this degradation can lead to ambiguities of associating effective beam energies to reaction product yields in a target within the stack and thus, to a wrong determination of the fusion excitation functions. In general, up to now, for these multiple thick target experiments very limited account has been devoted to the study how these factors could influence the deduced excitation functions. In this contribution the results of a thorough investigation of this problem will be discussed.

In particular, it will be shown that, in general, the traditional way to represent the fusion cross section as function of the energy in the middle of the target, or as a function of an effective energy based on a weighted average which takes into account both the beam energy distribution and the energy dependence of the cross section, lead to a wrong determination of the fusion excitation function. A new method, based on an unfolding procedure of the data, will be proposed.

Considering typical target/degrader combinations different simulations will be presented in order to show the considerable effects of beam degradation on the extraction of the fusion excitation functions. Possible consequences of the discussed effects on existing data will be evaluated.

To properly take into account the discussed effects target surface morphology has to be correctly considered and a method to characterise the target thickness distribution will be presented.

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Monday 24/06/2015
h. 14.30-16.40

SALA CONFERENZE LNS

PARALLEL SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

Dynamical description of heavy-ion collisions at Fermi energies

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Heavy-ion collisions at Fermi energies are open systems which require a non–equilibrium description when the process should be followed from the first instants.

The heated system produced in the collision, can no more be treated within an independent-particle picture and additional correlations should be taken into account: they rely to in-medium dissipation and phase-space fluctuations. Their interplay with the one-body collective behaviour determines the properties (kinematics, fragment production) and the variety of mechanisms (fusion, neck formation, multifragmentation) of the exit channel. Some statistical behaviours which can be postulated for specific equilibrated stages of the process (phase-transition signals) are obtained as a result of the dynamical description.

Starting from fundamental concepts tested on nuclear matter, we build up a microscopic description which addresses finite systems and applies to experimental observables.

Nuclear matter under extreme conditions and finite nuclei with finite range simple effective interaction

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The study of nuclear phenomena from finite nuclei to nuclear matter under extreme conditions in a given model is an area of current nuclear research interest. In the present work we have made such an attempt within the framework of non-relativistic mean field theory using the finite range simple effective interaction (SEI). At difference with other effective interactions of Skyrme and Gogny type, almost all the parameters of the SEI (ten of eleven) are fitted in symmetric nuclear matter and pure neutron matter using informations coming from optical model analysis of scattering data at intermediate energies, transport model analysis of flow data in heavy-ion collisions, thermal evolution of nuclear matter properties and constraints from the neutron star mass measurements and cooling phenomenology [1]. Under this protocol of fixation of parameters, it is possible to vary the density dependence of the equation of state (EOS) of isospin asymmetric nuclear matter (ANM) leaving the momentum dependence of the mean field unchanged. This may provide a theoretical advantage in the analysis of heavy-ion collision data in transport model calculations [2]. The high density behavior of symmetry energy predicted, within this protocol of parameter determination, is neither stiff nor very soft. The mass-radius relation, direct URCA process and crust-core transition density in neutron stars are studied with the SEI. The influence of the presence of hyperons in the core is also examined. Using the SEI and the Extended Thomas-Fermi expansion of the density matrix [3], a local Energy Density Functional is derived to study finite nuclei [4]. This Energy Density Functional has only an additional open parameter, which is fixed from the binding energy of the doubly closed shell magic nucleus ^{40}Ca, plus the strength of the spin-orbit force which is determined from the binding energy of the nucleus ^{208}Pb. With this formalism the binding energies and radii of 161 even-even spherical nuclei reproduced the experimental values with root mean square (rms) deviations 1.5 MeV and 0.015 fm, respectively. These results are of a quality similar to the one found using traditional interactions [5]. This formalism also predicts the kink in ^{208}Pb in the charge radii of lead isotopes. Study of the deformation properties predicted by the SEI in finite nuclei using the Hartree-Fock-Bogoliubov (HFB) formalism are underway and preliminary results obtained are encouraging.

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Sensitivity of N/Z ratio to dynamical fission of quasi-projectile in isobaric systems

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Using the 4π detector CHIMERA, the reactions ^{124}Xe+^{64}Zn and ^{64}Ni at 35 A.MeV (InKiIsSy, Inverse Kinematic Isobaric Systems), have been carried recently at LNS, in order to study the competition between statistical and dynamical fission of projectile-like fragments. For this new experiment, a system that is “isobaric” with respect to the previous studied ^{124}Sn + ^{64}Ni, in both direct and inverse kinematics, has been investigated. In particular in the reactions ^{124}Sn+^{64}Ni and ^{112}Sn+^{58}Ni at 35 A.MeV [1] it has been shown that while the statistical emission assumes the same cross section for the two systems as a function of the IMF charge *Z* of the emitted fragments, the dynamical IMF emission cross section is enhanced for the neutron rich system, pointing to an isospin effects related to the dynamical emission. Preliminary results of the InkiIssy experiment give a first indication of a similar effect when comparing the reactions induced by the Xe beam on two different targets ^{64}Zn and ^{64}Ni with different N/Z ratio. In the INKIISSY experiment, for the first time, a block of four telescopes, DSSSD ΔE-E and CsI(Tl) - prototype of the new FARCOS detector- has been used in coincidence with CHIMERA. Exploring the physics of fast break-up or dynamical fission as a function of the isospin of the entrance channel is also very attractive with new radioactive beams (like ^{132}Sn) that are expected to be available at lower energies of about 15 A.MeV in the next future at SPES [2].

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From Femtonova to Supernova: Heavy Ion Collisions and the Supernova Equation of State

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Central collisions in heavy ion reactions at intermediate energies produce nuclear matter on a microscopic scale that has a wide range of density and temperature. On a macroscopic scale, core collapse supernovae traverse a wide range of density and temperature in their evolution as well. Hot early reaction stage intermediate velocity sources in violent collisions of heavy ion reactions, denoted as femtonovae, are analyzed in the context of a coalescence model. The coalescence analysis yields various quantities that indicate that temperature and density similar to those near the neutrinosphere are achieved. These quantities are analyzed and compared to the results of various supernovae simulations and thus provide insight into the supernova equation of state. Important ingredients in the simulations are identified.

Exploring clustering in alpha-conjugate nuclei using the thick target inverse kinematic technique for multiple alpha emission

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Searching for alpha cluster states analogous to the ^{12}C Hoyle state in heavier alpha-conjugate nuclei can provide tests of the existence of alpha condensates in nuclear matter. Such states are predicted for ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si etc. at excitation energies slightly above the multi-alpha particle decay threshold [1-3].

The Thick Target Inverse Kinematics (TTIK) [4] technique can be successfully used to study the breakup of excited self-conjugate nuclei into many alpha particles. A test run was performed at Cyclotron Institute at Texas A&M University to study the reaction ^{20}Ne+α at 10 AMeV. Here the TTIK method was used to study both single α-particle emission and multiple α-particle decays. Due to the limited statistics, only events with alpha multiplicity up to three were analyzed. The analysis of the three α - particle emission data allowed the identification of the Hoyle state and other ^{12}C excited states decaying into three alpha particles. The results will be shown and compared with other data available in the literature.

In order to increase the statistics for the events with higher alpha particle multiplicity, the experiment has been recently repeated using an improved experimental setup covering a larger solid angle and having a better granularity. The same analysis has been performed on the new data. New results from the events with alpha multiplicity four and possible states in ^{16}O will be shown.

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Neutron rich Λ–hypernuclei study with the FINUDA experiment

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The existence of and the possibility to observe neutron-rich Λ–hypernuclei dates back to 1963 [1]. They are important both for nuclear structure studies, since the addition of a Λ hyperon may stabilize nuclear cores that are otherwise unstable, and for astrophysics, since they may shed light on the stiffness or softness of the equation of state of nuclear matter with hyperons in neutron-star matter.

The most effective nuclear reactions in which they may be obtained are (K^-, π^+) or (π^-, K^+) on light nuclear targets, by detecting the outgoing meson. The expected production rates are lower by about 3 orders of magnitude than those for producing normal Λ–hypernuclei with the same reactions. Few observations of neutron–rich hypernuclei in well-defined final states were reported. In the case of the (K^-, π^+) reaction with K^- at rest, the possible existence of peaks signaling the occurrence of the reaction was hindered by the occurrence of a background due to other reactions.

FINUDA has performed an extensive search for bound neutron–rich Λ-hypernuclear states. In the first data taking (2003-2004), ${}^{6}_{\Lambda}$H , ${}^{7}_{\Lambda}$H and ${}^{12}_{\Lambda}$Be have been investigated by looking at the π^+ from the double charge exchange (K^-_{stop}, π^+) production reaction and upper limits for the production rates were reported [2] .

In the second data taking (2006-2007) a ∼5 times larger statistics has been collected and a new analysis technique has been applied in which we considered not only the π^+ from the formation reaction, but also the π^- from the mesonic decay of the produced neutron–rich Λ–hypernucleus [3]. It is easy to see that, because of the delay due to the hypernucleus's lifetime, the sum of the two kinetic energies is to a first order independent of the mass of the neutron–rich hypernucleus. The method was successful in selecting unambiguously three events related to the production and decay of ${}^{6}_{\Lambda}$H. Its binding energy, evaluated jointly from production of ${}^{6}_{\Lambda}$H in the (K^-_{stop}, π^+) reaction on ^{6}Li targets and its subsequent two-body weak decay to $\pi^- +^{6}\mathrm{He}_{\mathrm{g.s.}}$, is $B_\Lambda = (4.0 \pm 1.1)$ MeV with respect $^{5}\mathrm{H} + \Lambda$. The production rate is evaluated as $(5.9 \pm 4.1) \cdot 10^-6/K^-_{stop}$.

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Tuesday 23/06/2015
h. 14.30-16.35

Aula A Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Fusion and Fission

Low-energy fission and beta-delayed fission with radioactive beams

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In the last decade, through technological, experimental and theoretical advances, the situation in experimental low-energy fission studies has changed dramatically. With the use of advanced production and detection techniques, much more detailed fission information can be obtained for traditional regions of fission research and, very importantly, new regions of nuclei have become accessible for fission studies.

The talk will give a review of recent low-energy fission experiments in very proton-rich nuclei in the lead region, with an emphasis on the exotic phenomenon of beta-delayed fission (βDF). This decay mode, which ideally suits to study low-energy fission, is experimentally accessible only in the well-studied uranium region and in the scarcely-studied (by fission) neutron-deficient lead region. Our pioneering βDF study of ^{180}Tl at ISOLDE(CERN) showed an unexpected asymmetric fission-fragment mass split for ^{180}Hg [1], despite a symmetric split in two semi-magic ^{90}Zr nuclei was expected. This result also identified a new region of asymmetric fission in addition to the well-known asymmetry in trans-uranium nuclei.

More recently, new βDF data on the neutron-deficient nuclides ^{194,196}At and ^{200,202}Fr were obtained at ISOLDE. A mixture of asymmetric and symmetric fission is clearly seen in respective daughter isotopes (after precursor's beta decay) ^{194,196}Po and ^{202}Rn [2]. This establishes a phenomenon of multimodal fission in this region of nuclei. The results will be compared with predictions from several current fission models.

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2. L. Ghys et al., "Evolution of fission-fragment mass distributions in the neutron-deficient lead region", Phys. Rev. C90, 041301(R) (2014)

*On behalf of the IS466/IS534 collaboration: RILIS-ISOLDE(CERN) – University of York (UK) – IKS, KU Leuven (Belgium) – Comenius University, Bratislava (Slovakia), JAEA, Tokai (Japan) – SCK•CEN, Mol (Belgium)

Sub-barrier fusion and transfers in the ^{40}Ca+^{58,64}Ni systems

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Fusion-evaporation is the dominant reaction mechanism in medium-light heavy-ion collisions around the Coulomb barrier (CB). At these energies and at moderate sub-barrier energies, enhancement of the fusion cross-sections was observed whereas hindrance of the fusion cross-section has been identified in many systems at deep sub-barrier 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 and the distributions of barriers have revealed to be a powerful tool to better understand the role of couplings to collective degrees of freedom of the target and projectile. A review on heavy-ion fusion, discussing the low-energy features has been published recently by B. Back et al. [1].

Some of the most striking results on sub-barrier fusion have been obtained in the past in the Ni+Ni [2] systems and recently in the Ca+Ca systems [3]. As regards the Ca+Ca systems, deep sub-barrier fusion cross sections have been measured in the ^{40}Ca+^{40}Ca, ^{40}Ca+^{48}Ca and ^{48}Ca+^{48}Ca systems at the Laboratori Nazionali di Legnaro using the Tandem accelerator Ca beams. All Ca+Ca systems have shown hindrance of the fusion cross section at the lowest energies. For the asymmetric ^{40}Ca+^{48}Ca, hindrance effects show up at lower energies and this was attributed to large effects of positive Qvalue neutron transfers. These results have triggered the present study of the ^{40}Ca+^{58,64}Ni systems. Sub-barrier fusion excitation functions of ^{40}Ca+^{58}Ni and ^{40}Ca+^{64}Ni have been measured at the Laboratori Nazionali di Legnaro using the Tandem accelerator ^{40}Ca beam at laboratory energies ranging from E_{Lab} = 104.75 MeV to 153.5 MeV [4]. Angular distributions have been measured above and below the CB and barrier distributions have been extracted from very accurate data. Coupled channel calculations have been performed with the CCFULL code using the Akyüz and Winther nuclear potential and taking into account the projectile and target inelastic excitations of the 2^+ and 3^- states. Positive Qvalue neutron pair transfer was also included in the calculation for the ^{40}Ca+^{64}Ni system for which this work represents the 1^{st} experimental sub-barrier fusion study. Importance of the transfer channels will be discussed.

A further experimental study to be performed using the Laboratori Nazionali di Legnaro PRISMA spectrometer and aiming at measuring the transfer channels cross sections in these systems will be presented.

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[4] D. Bourgin et al., Phys. Rev. C 90, 044610 (2014).

The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

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 dinucleus formed in charge asymmetric heavy-ion collisions [1-4]. The study of its γ decay gives us valuable information on the reaction dynamics and could shed light on the density dependence of the symmetry energy in the nuclear matter Equation of State at sub-saturation densities [5]. Furthermore, being a pre-equilibrium phenomenon, the DD γ decay could be an interesting cooling mechanism of the composite system in the fusion path, to facilitate super-heavy element formation. In this framework, we investigated the DD excitation and subsequent γ decay in the mass region of the ^{192}Pb composite system formed in the fusion-evaporation and fission $^{40}Ca + ^{152}Sm$ and $^{48}Ca + ^{144}Sm$ reactions at E_{lab} = 440 MeV and 485 MeV, respectively. The experiment was performed at Laboratori Nazionali del Sud, Italy. The γ-rays and the light charged particles emitted in the reaction were detected by using the MEDEA apparatus [6] while the heavy reaction fragments were detected by position sensitive Parallel Plate Avalanche Counters placed symmetrically around the beam direction. The analysis of the γ-ray spectra and angular distributions evidenced in a model independent way the DD excitation in such a heavy composite system in both exit channels: fusion-evaporation and fission. The possible implications of observing DD γ radiation in the evaporation channel of a heavy composite system in the super-heavy element quest will be discussed. On the other hand, the observation of DD γ radiation also in the fission exit channel (never observed before) provides inedited information on the DD excitation at higher partial waves, setting thus new severe constraints on theoretical models.

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Microscopic description of fission using dynamical theories.

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Description of fission remains a challenge for nuclear theory. Several ingredients have to be taken into account : tunneling effect, dissipation, non adiabatic process, superfluidity... A theoretical description of fission that take into account simultaneously all of those phenomena is, for now, impossible. In order to simplify the description of the fission process, we divide it into two phases, the first one consists of the crossing of the barrier and the second phase described the descent of the potential towards scission.

To describe the first phase, a method beyond WKB approximation is proposed [1]. The evolution of the wave-function during the tunneling process is obtained using the complex absorption potential method. The resonance states are also calculated allowing long time description of the fission process. The lifetime as well as the fission path is computed and compared to the WKB approximation. This method has been tested in a simple model [1] and is now applied using microscopic collective Hamiltonian [2] or from the GCM theory [3].

The second phase is described with the Time-dependent Hartree-Fock + BCS theory. Starting with a configuration after the barrier, the dynamics take into account the superfluidity, the dissipation and the non-adiabatic effects that are known to play an important role at the scission. The fission modes of the ^{258}Fm nucleus are studied. The resulting fission fragment characteristics show a good agreement with experimental data. Quantum shell effects are shown to play a crucial role in the dynamics and formation of the fragments. The importance of quantum fluctuations beyond the independent particle/quasi-particle picture is underlined and qualitatively studied [4].

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The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

Isospin influence on the decay modes of systems produced in the ^{78,86}Kr+^{40,48}Ca at 10AMeV

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The results of the analysis of the experimental data of the collisions ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca at 10AMeV are presented.
The experiment was performed at the INFN Laboratori Nazionali del Sud (LNS) in Catania with the beams delivered by the Superconductive Cyclotron and the 4π multidetector CHIMERA.
The competition between the various disintegration paths and in particular the isospin effects on the decay modes of the systems produced are investigated.
The neutron richness of the composite nucleus is expected to play a crucial role in the competition between various de-excitation channels, thus providing information about fundamental nuclear quantities such as level density, fission barrier and viscosity.

Different isotopic composition and relative richness were observed between the reaction products of the two systems. An odd-even staggering effect is observed in the charge distributions, in particular for the light fragments produced by the neutron-poor system.

The kinematical characteristics of the IMF seem to indicate an high degree of the relaxation of the formed system. Besides, global feature analysis seems to show some differences in the contribution arising from the various reaction mechanisms for the two reactions.

Dissipative effects in fission investigated with proton-on-lead reactions

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Fission is a clear example of the evolution from a metastable to a quasiequilibrium regime. The dynamics of this process can be described in terms of the potential-energy surface, friction, diffusion and inertia [1,2]. The investigation of different experimental observables has shown evidences that the nuclear friction parameter or viscosity of the medium changes with the deformation, but also with the nuclear temperature [3]. However, these ideas are still under debate because there conclusions could be biased by the experimental conditions. We propose then to investigate these effects with complete kinematic measurements of the fission products at high excitation energy, low angular momentum and small compound nucleus deformation, where dissipative effects in fission should manifest in a clear way [1,4,5].

In this work, we will report recent results obtained at GSI (Darmstadt) for the reaction ^{208}Pb+p at 500A MeV. This reaction fulfills the optimum conditions for the investigation of dissipative effects in fission. Moreover, the new SOFIA setup [6] allowed us to construct observables providing information on the fissioning compound nucleus, and its saddle and scission configurations. In particular, the unambiguous identification in mass and atomic number of both fission fragments, obtained for the first time in this experiment, was a key achievement [6]. Total and partial fission cross sections and the charge distribution of the fission fragments were used to characterize the fission dynamics at small deformation [5,7]. We will present the results concerning the neutron excess and isotopic widths of the fission fragments, their kinematic properties and the average pre- and post-neutron multiplicities, which should help us to investigate the post-saddle dynamics [8].

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Tuesday 23/06/2015
h. 14.30-16.45

AULA 52 LNS

PARALLEL SESSION:

Nuclear Energy and Applications of Nuclear Science and Technologies

The Muon Portal Project: A large area tracking detector for muon tomography

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Each year about 200 million containers transport goods worldwide, crossing the custom borders of many Countries. Many of them are in principle potential sources of small quantities of hidden nuclear material, such as fissile elements. Traditional control systems based on X-ray inspection cannot be easily employed, since the energy or dose required would be too high in order to penetrate big cargos and result in a significant image of the hidden volume.

As an alternative to traditional detection methods, it has been long suggested to employ the scattering process of the secondary cosmic radiation at the sea level (mainly muons), which strongly depends on the atomic number of the traversed material, hence particularly sensitive to high-Z fissile elements. Along this line, several prototype detectors have been proposed over the last years.

The Muon Portal Project is a joint initiative between Italian research and industrial partners [1], aimed at the construction of a real size detector protoype (6 x 3 x 7 m^3) for the inspection of containers by the muon scattering technique, devised to provide a full 3D tomography of the interior of the container in a scanning time of the order of minutes. The muon tracking detector is based on a set of 48 detection modules (size 1 m x 3 m), each built with 100 extruded scintillator strips, so as to provide four X-Y detection planes, two placed above and two below the container to be inspected. Two wavelength shifting (WLS) fibres embedded in each strip convey the emitted photons to Silicon Photomultipliers (SiPM) which act as photosensors. A smart readout strategy allows to reduce by a factor 10 the overall number of 9600 channels.

Detailed GEANT4 simulations have been carried out under different scenarios to investigate the response of the apparatus. The tomographic images are reconstructed by tracking algorithms and suitable imaging software tools. Simulations have demonstrated the possibility to reconstruct a 3D image of the volume to be inspected in a reasonable amount of time, compatible with the requirement of a fast inspection technique [2].

After a research and development phase, which led to the choice and test of the individual components [3,4,5], the construction of the full size detector has already started. This contribution will describe the present status of the Project and preliminary results obtained with the first detection modules.

[1] For further details visit our Web site: *http://muoni.oact.inaf.it*
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A Compton camera prototype for prompt-gamma medical imaging

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In order to be able to fully exploit the beneficial properties of tumour treatment by particle beams (protons, ions), provided by the highly conformal dose deposition within the Bragg peak, precise knowledge of the ion beam stopping range is mandatory. Our approach towards this goal is to detect the prompt photons emitted during nuclear interactions between the hadron beam and the organic target as messengers for the stopping range. The Compton scattering process can be exploited to reconstruct the γ source position from the Compton scattering kinematics of the primary photon.
A Compton camera prototype for a position-sensitive detection of prompt γ rays is being developed in Garching. The detector system is designed to allow also for tracking the Compton-scattered electrons. The camera consists of a monolithic $LaBr_3$(Ce) scintillation absorber crystal (50x50x30 mm^3), read out by a multi-anode PMT (Hamamatsu H9500, 3x3 mm^2 pixel size), preceded by a stacked array of 6 double-sided silicon strip detectors (area: 50x50 mm^2, thickness: 0.5 mm, 128 strips/side) acting as scatterers. From the design simulations, an angular resolution of 2^0 and an image reconstruction efficiency of 10^{-3} - 10^{-5} (E_γ = 2-6 MeV) can be expected. The $LaBr_3$ crystal has been characterized to possess a time resolution of 273 ps (FWHM) and an energy resolution ΔE/E of about 3.8% (FWHM at 662 keV). Using a collimated ^{137}Cs source, the spatial information of the impinging photons extractable from the monolithic crystal was investigated by measuring the light amplitude distributions derived from a 2D grid scan (0.5 mm stepsize). A reference library was created that allows for reconstructing the interaction position of the initial photon using the 'k-Nearest Neighbor' algorithm developed by the Delft group [1]. The status of the detector commissioning and characterization by offline and online measurements will be presented.

This work is supported by the DFG Cluster of Excellence MAP (Munich-Centre for Advanced Photonics).

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Laser-based Acceleration for Nuclear Physics experiments at ELI-NP

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As part of the Extreme Light pan-European research infrastructure, Extreme Light Infrastructure – Nuclear Physics (ELI-NP) in Romania will focus on topics in Nuclear Physics, fundamental Physics and applications, based on very intense photon beams. Laser-based acceleration of electrons, protons and heavy ions is among the top priority research topics, being also a prerequisite for a multitude of laser-driven nuclear physics experiments already proposed by the international research community. A total of six outputs of the dual-amplification chain laser system, two of 100TW, two of 1PW and two of 10PW will be employed in 5 experimental areas, with the possibility to use long and short focal lengths, gas and solid targets, reaching the whole range of laser acceleration processes. We describe the main techniques and expectations regarding the acceleration of electrons, protons and heavy nuclei at ELI-NP, and some physics cases for which these techniques play an important role in the experiments.

Measurements of secondary particle production induced by particle therapy ion beams impinging on a PMMA phantom

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Particle therapy is a technique that uses accelerated charged ions for cancer treatment. The high irradiation precision and conformity achievable with heavy ions enhance the Radio Biological Effectiveness (RBE) of such therapy while helping sparing the surrounding healthy tissues and Organs At Risk (OAR). To fully profit from the improved therapy spatial selectiveness, a novel monitoring technique, capable of providing a high precision "in-treatment" feedback on the dose release position, is required. Since the primary beam is fully stopped inside the patient body, it is necessary to exploit the knowledge on the secondary fragments, that are capable of exiting the body, in order to reconstruct "online" the dose release spot.

In this contribution we will review the results from a campaign of measurements at different beam facilities (LNS - Catania, GSI - Darmstadt, HIT - Heidelberg), aiming for a precise measurement of the fluxes and energy spectra for secondary particles produced by ^{4}He, ^{12}C and ^{16}O ion beams of therapeutic energies impinging on thick PMMA phantoms.
The precise knowledge of the secondary particles production is a key ingredient for both Treatment Planning Software (TPS) development, allowing to improve the MC description of the ion beams interaction with the patient body, and for dose monitoring research and development. In this presentation we present the production of charged and neutral secondary particles, as well as the production of photons that are the result of a beta+ annihilation, for the different energies and experimental setup explored. The fluxes, energy spectra and correlation with the Bragg Peak (BP) position will be shown, together with the expected resolution on the BP position for a typical treatment scenario.

The measurements performed in the different facilities, provided a solid evidence that the rate of produced protons and prompt photons is large enough to supply the particle sample needed for a fast online monitor operating during a typical treatment that will be capable to provide the (millimetric) spatial resolution required by clinical standards.

Study of Spatial Resolution and Muon Tomographic Imaging Properties of Glass RPCs

Qite LI[1,2], Jian GAO[1], Yan JIANG[1], Jing MA[1]

[1] *School of physics, Peking University*
[2] *State Key Labortatory of Nuclear Physics and Technology*

Recent researches show that the high spatial resolution glass Resistive Plate Chambers (RPC) are very promising detectors for Muon Tomography(MT) for discriminating high-Z nuclear materials in containers or vehicles. Prototyping RPCs with LC delay-line readout method were constructed and tested. Detection efficiencies for cosmic rays of about 95% were obtained for both avalanche and streamer modes of operation. A narrow profile for avalanche signal mode is obtained, which lead to an intrinsic spatial resolution less than 1.0 mm FWHM[1]. We meanwhile report imaging results of a Muon Tomography Station prototype based on glass RPCs. Fig 1(a) shows the setup of our MT test station prototype[2]. After 24 hours of exposure, the shapes of two tested bricks ware clear and the difference of mean scattering angle can be observed in Fig. 1(b).

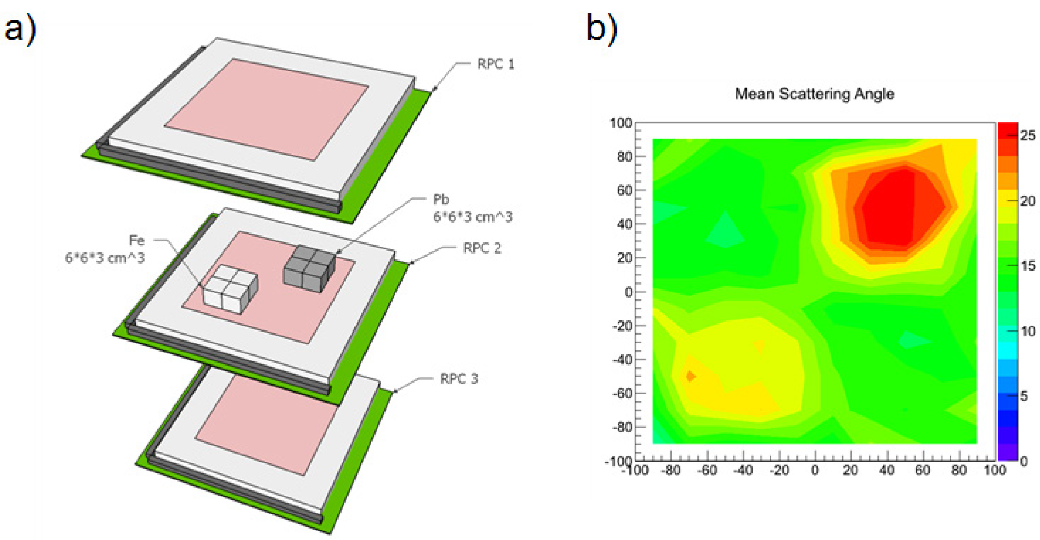

Fig.1 The setup of a minimal MT system using 3 RPCs (a) and the image result of a lead brick and a iron brick (b).

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[2] S. Chen, Q. Li *et al.*, Journal of Instrumentation **9**, C10022 (2014)

NUCLEAR REACTIONS ON COPPER INDUCED BY COSMIC PROTONS

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Copper fragmentation in nuclear reactions under impact of cosmic protons is considered. There is a trend of increase of relative copper concentration in modern integrated circuits (IC) with multilayered 3D architecture, where Cu is used as a main material component of inter-element contact paths, contact pads, etc. In contrast to the original space protons, the nuclear reactions fragments suffer much larger ionization losses, therefore can initiate a charge in a sensitive volume of the ICs exceeding the critical charge for generation of a false signal which can lead to malfunction of spacecraft on-board electronics. In the report the results will be presented of calculations using TALYS code of reactions induced by protons with energies up to 200 MeV, the energy, charge and mass distributions of fragments. As it is the case for the fragmentation of tungsten [1], the obtained results demonstrate that the fragmentation of copper must be taken into account for more accurate prognosis of the possibility of spacecraft on-board electronics upsets.

1. N.G. Chechenin *et al*, Phys. At. Nucl. **78**, 159 (2015).

Tuesday 23/06/2015
h. 17.00-19.10

Aula F Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Relativistic Heavy-Ion Collisions

Upsilon suppression in PbPb collisions beams at the LHC

G. WOLSCHIN[1]

[1] *Heidelberg University, Germany*

Heavy quarkonia and in particular, the Upsilon meson as observed by CMS [1] and ALICE [2] have proven to be a very useful tool to investigate the quark-gluon plasma that is likely created in heavy-ion collisions at RHIC and LHC energies.
Here it is suggested that the combined effect of gluon-induced dissociation, collisional damping, screening, and reduced feed-down explains [3] most of the suppression of Upsilon states that has been observed in PbPb relative to pp collisions at sqrt(s_NN) = 2.76 TeV at the CERN LHC.
The suppression is thus a clear, albeit indirect, indication for the presence of a Quark-Gluon Plasma. A prediction for the centrality-dependent Y(1S) suppression of the forthcoming LHC energy of 5.13 TeV is presented. Regarding the suppression of the Y(2S) state, additional mechanisms have to be considered.

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[2] B. Abelev et al., ALICE Collab., Phys. Lett. B 738, 361 (2014).
[3] F. Nendzig and G. Wolschin, Phys. Rev. C 87, 024911 (2013), and J. Phys. G 41, 095003 (2014).

An Overview of Resonance Measurements at the ALICE Experiment

A. G. Knospe for the ALICE Collaboration

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Resonances play a unique role in the study of ultra-relativistic heavy-ion collisions. Resonance yields, which may be modified by rescattering and regeneration after hadronization, can be used to study the properties of the hadronic phase of the collision. The modification of resonance masses or widths would be a signature of chiral symmetry restoration near the phase transition temperature. The transverse-momentum spectra of the proton and the $\phi(1020)$ can be used to study the mechanisms of particle production. In addition, resonance measurements in pp and p–Pb collisions help to distinguish initial-state effects from the effects of the hot and dense final state. The ALICE Collaboration has studied the $K^{*}(892)^{0}$ and $\phi(1020)$ mesons in pp, p–Pb, and Pb–Pb collisions. Measurements of many resonance properties, including p_{T} spectra, integrated yields, masses, widths, mean p_{T} values, and the nuclear modification factors R_{AA} and R_{pPb}, will be presented and compared to measurements from other experiments, non-resonances, and the predictions of theoretical models.

Shear viscosity η to electric conductivity σ_{el} ratio for the Quark-Gluon Plasma

Armando Puglisi[1], 2, Salvatore Plumari[1,2] and Vincenzo Greco[1,2]

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[2] *Laboratorio Nazionale del Sud, INFN-LNS, Via S. Sofia 63, I-95125 Catania, Italy*

Transport coefficients of strongly interacting matter are currently subject of intense studies due to their relevance for the characterization of the quark-gluon plasma (QGP) produced in ultra-relativistic heavy-ion collisions (uRHIC). We discuss the connection between the shear viscosity to entropy density ratio, η/s, and the electric conductivity, σ_{el}: we find that a minimal eta/s is consistent with a low value of electric conductivity as measured in recent lattice QCD calculations. More generally we show that the ratio of η/s over σ_{el}/T supplies a measure of the quark to gluon scattering rates whose knowledge would allow to significantly advance in the understanding of the QGP phase. We also predict that $(\eta/s)/(\sigma_{el}/T)$, independently on the running coupling $\alpha_s(T)$, should increase up to about ~ 20 for $T \to T_c$, while it goes down to a nearly flat behaviour around $\simeq 4$ for $T \geq 4T_c$.

Analysis of angular distribution of fragments in relativistic heavy-ion collisions by quantum molecular dynamics

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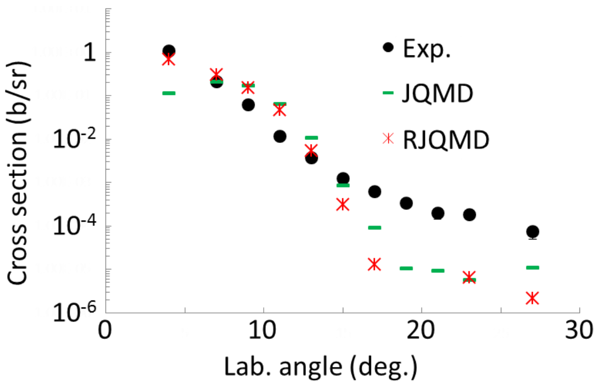
[1] *Japan Atomic Energy Agency, Japan*
[2] *Research Organization for Information Science and Technology, Japan*

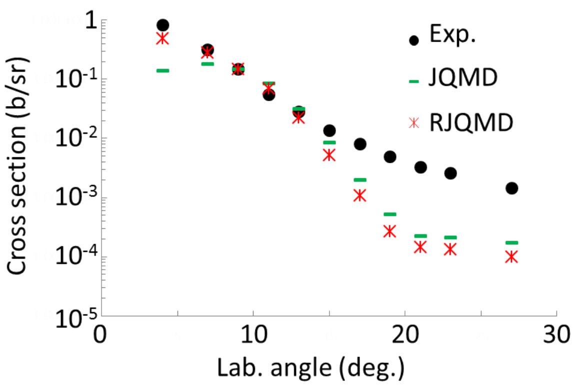
The angular distribution of the fragments produced in heavy-ion collisions is essential for theoretical studies and applications. Among the microscopic reaction models developed to simulate fragment production in nucleus-nucleus reactions, quantum molecular dynamics (QMD) models are generally adopted in radiation transport simulation codes [1] and used in various applications. However, it has been suggested that QMD models tend to overestimate the width of the fragment angular distributions [2]. In this study, we revise JAERI QMD (JQMD) model [3] to simulate the fragment angular distribution by accurate treatment of peripheral collisions.

To reproduce peripheral collisions, the stability of the nuclear ground state was improved by revising the description of nucleon-nucleon interactions. In the previous JQMD model, the description of the interactions between nucleons was not Lorentz covariant; therefore, the ground state configured in the nucleus rest frame was sometimes spuriously excited and disintegrated during its time evolution in the center-of-mass frame. By introducing the Lorentz-covariant Hamiltonian [4], nuclei at their ground states stay stable unless they interact with the reaction partners. Also, the treatment of the in-medium effects on nucleon-nucleon scattering cross sections was revised. In the previous version, the nucleon-nucleon elastic scattering cross sections were always suppressed by the Pauli blocking whereas the new version adopts the cross sections for the free nucleons in peripheral collisions to account for the decline of the Pauli blocking near the nuclear surface. The final clustering scheme was inherited from the previous JQMD model, which binds the nucleons close to each other in phase space after 150 fm/c of time evolution. The momentum, charge, and mass of the fragments were determined by summing their corresponding values of the clustered nucleons.

Fig.1 shows a comparison of the fragment angular distribution measured by Dudouet [5] with those calculated by the previous and revised JQMD (RJQMD) models. The fragment yield measured at the most forward angle was one order of magnitude underestimated by the JMQD model whereas the RJQMD model agrees well with the experimental data.



(a)^{10}B



(b)^{7}Be

Fig. 1 Double-differential cross sections of fragment production in ^{12}C(^{Nat}C,X) reactions

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[2] B.Alpat *et al.*, *IEEE Trans. Nucl. Sci.* **60**, 4673-4682 (2013)
[3] K.Niita *et al.*, *Phys. Rev. C.* **52**, 2620 (1995)
[4] D.Mancusi *et al.*, *Phys. Rev. C.* **79**, 014614 (2009)
[5] J.Dudouet *et al.*, *Phys. Rev. C.* **88**, 024606 (2014)

Overview of jet physics with ALICE at the LHC

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for the ALICE collaboration

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[2] *CCNU WUHAN CHINA*

A cross-over “transition” between ordinary nuclear matter and a state of deconfined quarks and gluons, the Quark Gluon Plasma (QGP), is predicted by lattice QCD calculations at low chemical potential and high temperature in the nuclear phase diagram. Experimentally, ultra-relativistic heavy ion collisions are used to produce and study the hot and dense QGP medium.

Produced in a hard scattering at the early stage of the collision a highly energetic parton is first expected to lose energy in the medium before fragmenting into a hadronic spray of particles called jet. A detailed study of the modification of the jet structure and of its fragmentation pattern in vacuum and in medium should provide us with some insights into the QGP properties.

An overview of recent results on jet physics from the ALICE experiment at the LHC will be presented. After presenting results on jet spectra and nuclear modification factors, we will focus on jet structure and fragmentation observables in different sub-systems p-p, p-Pb and Pb-Pb.

Light flavour hadron production in the ALICE experiment at LHC

A. Badalà [1] for the ALICE Collaboration

[1] *INFN-Sezione di Catania*

The ALICE experiment at CERN has excellent capabilities for the measurement of light-flavour hadrons, thanks to its extensive particle identification and the high-performance tracking. A large number of hadron species from pions to multi-strange baryons and light nuclei have been measured over a large transverse momentum region from ~ 100 MeV/c to ~ 20 GeV/c.

The measurement of these particles is a valuable tool to study the properties of the medium formed in heavy-ion collisions. In particular they give information on the collective phenomena of the fireball, on the parton energy loss in the hot QCD medium and on the hadronization mechanisms such as recombination and statistical hadronization. The measurements in pp and in p-nucleus collisions provide the necessary baseline for heavy-ion data and help to investigate the effects of the ordinary nuclear matter. In this talk a review of the ALICE results on identified light-flavour hadron production in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV and p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV will be presented.

Tuesday 23/06/2015
h. 17.00-19.10

AULA MAGNA

PARALLEL SESSION:

Nuclear Structure

Particle emission at the proton drip-line

M. PFÜTZNER

Faculty of Physics, University of Warsaw, Poland

Nuclei far from stability with a large neutron deficiency exhibit characteristic decay modes which are still far from being fully explored, both experimentally and theoretically [1]. Due to large Q-values for β^+ decay, emission of β-delayed particles becomes an important channel. In addition to single (βp) and double (β2p) delayed protons known since long, the delayed emission of three protons (β3p) was observed only recently. Good understanding of such decays is necessary when the correct knowledge of beta strength distribution is demanded. Beyond the proton drip-line the spontaneous emission of one or two protons from the nuclear ground state becomes possible. The single proton radioactivity is a precious source of structural information for very exotic nuclei. The 2p emission is also believed to carry information about the initial state, in particular about pairing correlations. However, the knowledge on this exotic decay mode is still scarce and the details of its mechanism are not yet clear.

Experimental investigations of exotic and rare decay channels require special instrumentation offering efficiency and sensitivity. An example of such an approach is the Optical Time Projection Chamber (OTPC) developed at the University of Warsaw. Designed with the specific goal to study two-proton radioactivity, it proved to be an excellent tool for investigation of other decay channels accompanied by emission of charged particles. Among the most interesting results obtained with help of the OTPC are the p-p correlations in the decay of ^{45}Fe [2], the discovery of the β3p decay mode [3], and the discovery of the 2p radioactivity of ^{48}Ni [4].

In the talk I will give a short overview of the field of particle spectroscopy at the proton drip-line which will be illustrated with example achievements of the OTPC detector. In more detail I will discuss the most recent applications, including the decay of ^{31}Ar and the study of the most neutron-deficient germanium isotopes. Finally, a general perspective for nuclear spectroscopy beyond the proton drip-line will be sketched [5].

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[2] K. Miernik et al., Phys. Rev. Lett. **99**, 192501 (2007).
[3] K. Miernik et al., Phys. Rev. C **76**, 041304(R) (2007).
[4] M. Pomorski et al., Phys. Rev. C **90**, 014311 (2014).
[5] E. Olsen et al., Phys. Rev. Lett. **110**, 222501 (2013).

Nuclear structure studies of neutron-rich nuclei with large γ-ray spectrometers.

J.J. Valiente-Dobón[1]

[1] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro, Italy.*

Over the last decades nuclear spectroscopy has shown its capabilities to investigate the effective nucleon-nucleon interaction in nuclear matter. Thanks to the methods of γ-ray spectroscopy it has been possible to test such interaction in nuclei at very high spin and with large isospin values (exotic nuclei). The accurate measurement of γ-ray energies, spins, parities and lifetimes of nuclear excited states has allowed to inspect in great detail the various terms of the nuclear hamiltonian. The continuous improvement in germanium γ-array performances and in their associated instrumentation has allowed an enormous increase of the experimental sensitivity. The current forefront Ge γ-array in Europe is AGATA which is based on the new concept of gamma-ray tracking. It is capable of identifying the gamma interaction points (pulse shape analysis) and of reconstructing via software the trajectories of the individual photons (γ-ray tracking). This leads to abandon the Compton suppression concept and to build therefore an array where the full 4π solid angle is covered by germanium detectors, thereby obtaining much larger photopeak efficiency and peak-to-total ratio.

In this presentation a review on the achievements in nuclear structure physics with the CLARA spectrometer [1] and the state-of-the-art γ-ray tracking AGATA array [2] will be discussed, focusing in particular on the properties of neutron-rich nuclei populated via multinucleon transfer or deep inelastic reactions. The experiments spanned from the Si neutron-rich isotopes close to the so called island of inversion up to the heavy shape transitional neutron- rich osmium isotopes. For many of these exotic nuclei, lifetime measurements were possible by using the differential Recoil Distance Doppler Shift method developed for multinucleon-transfer reactions. Some selected results on neutron-rich nuclei together with fort-coming implementation of AGATA at GANIL will be discussed. Finally, the future perspectives with the GALILEO 4π γ-ray array at the Laboratori Nazionali di Legnaro will be shown.

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EXTRACTING THE HEXADECAPOLE PARAMETERS FROM BACKWARD QUASI-ELASTIC SCATTERING

H.Q. Zhang, C.J. Lin, H.M. Jia, F. Yang, X.X. Xu, Z.H. Liu, Z.D. Wu, L. Yang, N.R. Ma, P.F. Bao, and L. J. Sun

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The hexadecapole parameter β_4 is usually difficult to determine experimentally, especially its sign. It is well known that the quasi-elastic (QEL) scattering is sensitive to the coupled-channel effect near the Coulomb barrier. To study the possibility of extracting β_4 from lower-energy backward QEL scattering, the QEL scattering for ^{16}O + ^{152}Sm, ^{170}Er, and ^{174}Yb were measured at a backward angle with small energy intervals. With the help of the coupled-channel calculations [1], the β_4 values for the three target nuclei were extracted with the fixed β_2 values and the obtained values are consistent with the available results. The main result is shown in Fig. 1. This method may be meaningful for the radioactive nuclei with lower beam intensities. More details can be found in Ref. [2]

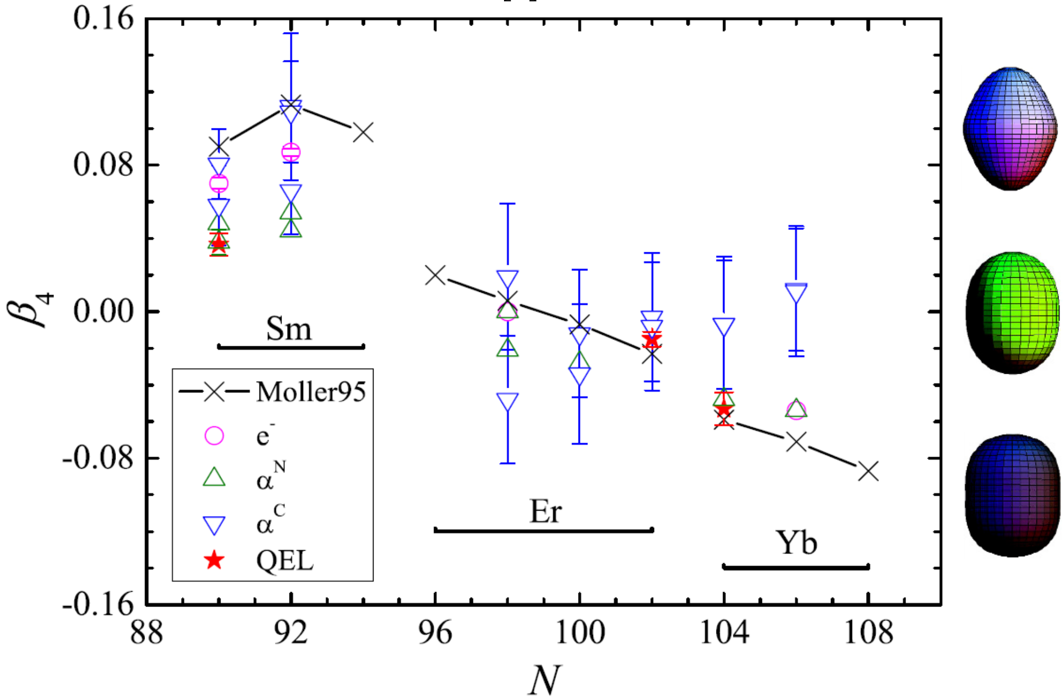

FIG. 1. The variation of β_4 with N for the Sm, Er, andYb isotopes by using different experimental methods and Möller's theoretical prediction. Three schematic forms corresponding to $\beta_4 = -0.1$, 0, and 0.1 with $\beta_2 = 0.3$ are illustrated, respectively.

[1] K. Hagino, N. Rowley, and A. T. Kruppa, Comput. Phys. Commun. **123**, 143 (1999).

[2]H. M. Jia *et al.*, Phys. Rev. C 90, 031601(R) (2014).

Low-lying 1^- and 2^+ states in ^{124}Sn via inelastic scattering of ^{17}O

L. Pellegri[1,2], A. Bracco[3,4], F.C.L. Crespi[3,4] and the AGATA collaboration

[1] *University of the Witwatersrand, Johannesburg, South Africa*
[2] *iThemba LABS, Somerset West, South Africa*
[3] *Dipartimento di Fisica dellUniversitá degli Studi di Milano, Italy*
[4] *INFN, Sezione di Milano, Italy*

The study of the Pygmy Dipole Resonance (PDR), the low energy part of the electric dipole response in nuclei, is particularly relevant to investigate the nuclear structure and also in connection with photo-disintegration reaction rates in astrophysical scenarios. Its description, within the hydrodynamical model, corresponds to a vibration of the neutron skin against a N=Z core. In recent years, the study of the PDR has attracted particular attention since its microscopic structure is presently under discussion. Efforts in the direction of understanding its nature require its excitation using different probes. Indeed, recent works comparing results of photon and α scattering experiments show the presence of a different behaviour in the population of these states [1,2]. While a set of states at lower energy is excited with both types of reactions, the other set at higher energies is not populated by α scattering. This interesting finding has motivated further work based on the use of another probe with strong isoscalar character as ^{17}O.
The experiment was made for the nucleus ^{124}Sn using a set up including the AGATA detector array and a system of Silicon telescopes to measure the scattered particles. With AGATA, the γ decay up to the neutron separation energy was measured with high resolution. The angular distribution was measured both for the γ rays and the scattered ^{17}O ions. The result shows that also in the case of (^{17}O,^{17}O'γ) reaction only the low energy region is populated. The data have been interpreted within the optical model plus DWBA (Distorted Wave Born Approximation) formalism using both the standard collective form factor and a form factor obtained by folding microscopically calculated transition densities. The DWBA calculations give a good description of the elastic scattering and of the inelastic excitation of PDR states. This allowed to extract the isoscalar component of the 1^- states. The investigation of the low-lying 2^+ states will be also presented. The DWBA calculations give a good description also of the 2^+ states.

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^{16}O + ^{16}O molecular structures of positive- and negative-parity superdeformed bands in ^{34}S

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Drastic structure changes caused by excitation are significant characteristics of nuclei, and it is a goal of nuclear physics to clarify the structure changes in a microscopic framework. Clustering and deformation are typical mechanisms of drastic structure changes, and both play important roles in *sd*-shell region.

S isotopes ($Z = 16$) are key nuclei for both of deformation and clustering. The $Z = 16$ is considered as a magic number of superdeformation, and it is expected that superdeformed (SD) bands develop in S isotopes. In a cluster structure picture, S isotopes are analogues of Be isotopes because both can form cluster structures that contain two doubly-closed-shell clusters (α and ^{16}O for Be and S isotopes, respectively) and valence neutrons. In low-lying states of Be isotopes, structures of α + α + valence neutrons in molecular orbitals around α + α are considered to be develop[1]. In ^{32}S, SD states that contain large amount of ^{16}O + ^{16}O cluster structure components have been predicted[2,3], which is an analogue of the ground state of ^{8}Be that have α + α structure. Therefore, it is expected to exist SD states that form ^{16}O + ^{16}O + valence neutrons structures in S isotopes. S isotopes are important to clarify deformed and cluster structures in *sd*-shell region.

Structures of SD states in ^{34}S have been microscopically investigated by using the antisymmetrized molecular dynamics and the generator coordinate method (GCM). GCM basis are calculated by energy variation with a constraint on the quadrupole deformation parameter β. Performing GCM calculation, existence of two positive-parity and one negative-parity SD bands are predicted, and low-lying states and other deformed bands are also obtained.

The three SD bands have structures of ^{16}O + ^{16}O + two valence neutrons in molecular orbitals. Valence neutrons in SD states are in δ^+ and/or π^- orbitals around ^{16}O + ^{16}O. Configurations of valence neutrons in two positive-parity SD bands are $(\delta^+)^2$ and $(\pi^-)^2$, and that of a negative-parity band is $(\delta^+)^1(\pi^-)^1$. The δ^+ and π^- have roles to suppress and develop intercluster distance, respectively, between ^{16}O clusters, which means that δ^+ and π^- orbitals around ^{16}O + ^{16}O have similar roles as π^- and σ^+ orbitals around α + α, respectively, for intercluster distance. In ^{10}Be, configurations of valence neutrons in $J^\pi = 0^+_1$, 0^+_2 and 1^-_2 states are considered to be $(\pi^-)^2$, $(\sigma^+)^2$ and $(\pi^-)^1(\sigma^+)^1$, respectively[1]. SD states in ^{34}S are analogues of low-lying states in ^{10}Be.

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Ab-initio calculation of nuclear structure with many-body perturbation theory

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State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China

Starting from realistic nuclear forces (N^3LO [1] and JISP16 [2]), we perform the Hartree-Fock approximation first. Taking the HF solution as the reference and using many-body perturbation theory (MBPT) [3], we make corrections to the HF calculation, up to the third-order correction in nuclear energy and up to the second order in nuclear radius. As preliminary calculations, we have investigated the closed-shell nuclei, ^{4}He and ^{16}O, obtaining quite good results in both binding energies and radii. Further work is in process.

We thank J. Vary for providing the JISP16 interaction and useful discussions.

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Tuesday 23/06/2015
h. 17.00-19.10

AULA AZZURRA LNS

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

Transfer and knockout with exotic nuclei*

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Orme des Merisiers, F-91191 Gif-sur-Yvette, France

Direct reactions such as transfer and knockout reactions at intermediate energies provide unique final state selectivity and are believed to give essential information on the structure of the populated states. A very significant part of our understanding of nuclear structure is based on single-nucleon transfer reactions and intermediate-energy nucleon removal. On the other hand, the single-particle nature of quantum states is by essence model dependent. Even more difficult is to assess the uncertainty from the reaction model used to analyse direct reaction cross sections.

In this presentation, the difficulty to address the question of nuclear-shell structure from direct reactions will be discuss through recent experimental work at low and intermediate energies. On a second stage, a review of current programs dedicated to these studies will be presented, while future perspectives will be discussed.

*Part of this work was supported by the European Research Council (ERC) through the grant MINOS-258567 and by the Japanese Society for the Promotion of Science (JSPS) through the long-term fellowship L-12520.

Reaction studies with low-energy weakly-bound beams at INFN-LNS

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The study of collisions around the Coulomb barrier induced by halo and/or weakly bound nuclei has been object of many publications. In fact, it has been shown that the peculiar structure of such nuclei, which have very low break-up thresholds and also an extended matter distribution in the case of the nuclear halo, can strongly affect the reaction mechanisms around the Coulomb barrier (see e.g. [1-4] and references therein).

Experimental results on the above topic obtained by our group in Catania concerning the study of fusion, direct processes and elastic scattering using weakly-bound beams will be summarized, discussed and compared with the ones of other authors.

Experimental problems concerning the measurement of fusion cross sections with the stack activation technique and the use of segmented silicon detectors for charged particle angular distributions, will be uderlined and discussed during the presentation.

[1] L.F.Canto et al., Phys. Rep. 424, 1, (2006)

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Study of two and multi particle correlations in $^{12}C+^{24}Mg$ and $^{12}C+^{208}Pb$ reactions at E/A=35 MeV

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Two and multi particle correlations from the decay of sources produced in $^{12}C+^{24}Mg$ and $^{12}C+^{208}Pb$ collisions at E/A=35 MeV have been studied by using the forward part ($1^o < \theta_{lab} < 30^o$) of the CHIMERA multi-detector. Correlations and invariant mass spectroscopy are used to explore simultaneous and sequential decays of resonances in light isotopes with Z∼3-6, produced in peripheral collisions via the break-up of excited quasi-projectiles. Among them we mention ^5Li, ^6Li, ^6Be, ^8Be and the astrophysically important states in ^{12}C decaying into three alpha particles. Exploration of spectroscopy features such as branching ratios with respect to different decay channels (sequential vs simultaneous) as well as thermal features such as internal population of states are expected to provide important information on interplays between reaction mechanism and nuclear structure in a dilute and hot nuclear medium away from saturation. Results and future perspectives at the INFN-LNS will be presented.

Microscopic nuclear form factors for the pygmy dipole resonance

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In the last years special attention has been devoted to the study of the dipole strength at low excitation energy in neutron-rich nuclei: the Pygmy Dipole Resonance (PDR). This mode carries few per cent of the isovector EWSR, and it is present in many isotopes with a consistent neutron excess. It is more pronounced in nuclei far from the stability line but its presence has been established also for stable nuclei like ^{208}Pb. This low lying dipole state (PDR) is a mode whose isoscalar and isovector components are strongly mixed as it is clearly manifested in the corresponding transition densities. This feature allows the possibility to study these PDR states by using an isoscalar probe in addition to the conventional isovector one.

Recently, many experiment have been done using isoscalar probes like α particles[1] or ^{17}O[2]. The traditional way to extract structure information from the data is based on the comparison of the experimental differential cross section with theoretical calculations. The latter rely however strongly on the model used for the construction of the radial form factors which, in the standard codes, are produced according to the collective models prescriptions.

We have compared results of differential cross sections calculations based on three different structure models, in all cases using a the double folding procedure[3] to go from the transition densities to the formfactors. The transition densities used were: the one extracted by a sum rule approach deduced for the high-lying ISGDR[4], the one deduced according to a simple macroscopic model for the PDR and those obtained from a microscopic RPA approach. The comparison among the models has shown a very good agreement with the RPA for the high-lying ISGDR state for both the form factors as well as for the differential cross section. In the case of the PDR state, on the other hand, the weakly-bound nature of the involved orbitals leads to different slopes in the tails of the macroscopic and microscopic transition densities, with consequent differences in the the corresponding formfactors and cross sections.

Therefore, our message is that one has to be careful in using the proper form factor in the experimental analysis of PDR state excitations. Usually a DWBA calculation based on collective models is employed to establish the amount of B(E1) to attribute to the state as well as the percentage of EWSR to be assigned to it. Since we have shown that the use of different form factor may lead to different differential cross section it is of paramount importance the use of the "correct" microscopically-based one. Use of non appropriate form factor has its consequence on the calculated cross section and therefore jeopardizing the extracted physical quantities. The microscopic form factor has the advantage that, by construction, it includes the important property of these states, that is a strong mixing of isoscalar and isovector character.

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Exploring the ^{10}Li structure by the d(^{9}Li,p)^{10}Li transfer reaction

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The study of the unbound system ^{10}Li is of great interest since the knowledge of its structure is a crucial ingredient in the description of the two-neutron halo nucleus ^{11}Li. Despite the significant amount of experimental information gathered during the last years, the properties of the ^{10}Li continuum remains unclear, to the extent that even the energy and the spin-parity of the ground state are still controversial [1,2].

We have investigated the ^{10}Li structure via the ^{9}Li(d,p)^{10}Li transfer reaction in inverse kinematics at TRIUMF. A 100 MeV ^{9}Li beam, produced by the ISAC-II facility, impinged on a CD2 target. The recoiling protons were detected at backward angles by the LEDA array of silicon strip detectors [3], thus allowing the study of the ^{10}Li emitted in the crucial region at forward angles. Protons are detected in coincidence with the ^{9}Li fragments produced from the breakup of the corresponding ^{10}Li. ^{9}Li fragments have been detected and identified by using a ΔE-E telescope of S2 annular DSSD detectors located downstream the target.

The ^{10}Li excitation energy spectrum was reconstructed with significant statistics up to 6 MeV, allowing, for the first time, to explore the completely unknown high excitation energy region. The highly segmented detection system allowed to also measure the angular distributions of the observed resonances at forward angles. The comparison with an extended mean-field approach, where the pairing correlations are introduced [4], allows to disentangle the s, p and d orbital contributions in the different portions of the energy spectrum.

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Effect of breakup channel on other reaction mechanisms of the ^{8}B + ^{208}Pb system at near barrier energies

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In the present work we study the effect of the breakup channel of the proton halo on the other reaction mechanism for the system involving the projectile ^{8}B and a heavy target ^{208}PB. It is found in the literature that the breakup of neutron-halo projectile damp the elastic scattering angular distributions, especially at angles near the Coulomb – nuclear interference peak. Strong damp was found for the ^{11}Li + ^{208}Pb [1] system due to E1 excitation of the projectile to the continuum states. Some damp was also observed for other systems for reactions involving the ^{6}He neutron halo projectile [2 - 4], due to Coulomb-nuclear breakup interference. Recently Y.Y. Yang *et al.* [5] measured the elastic scattering angular distribution for the ^{8}B + ^{208}Pb system at about three times the Coulomb barrier. They found almost no influence of the breakup channel on the elastic scattering at this high energy. Recent work [6] shows that the breakup of the ^{8}B projectile almost does not affect the elastic scattering angular distribution of its interaction with ^{58}Ni. In the present work we show that in the case of the interaction of 8B with heavy target, a damp of the elastic scattering is observed too, mainly dominated by the Coulomb breakup, with a very weak influence of the nuclear breakup. It is observed a contribution of the dipole and quadrupole interactions of the same orders. A strong dependence on the binding energy of ^{8}B is observed in our conclusions. A detail study of the reaction mechanism is performed for the ^{8}B + ^{208}Pb system at near barrier energies.

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Tuesday 23/06/2015
h. 17.00-19.05

SALA CONFERENZE LNS

PARALLEL SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

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 [3]. The flows of neutrons and light charged 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 comparison of elliptic flow ratios with UrQMD calculations for Au+Au system, will be reported.

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Impact of the in-medium conservation of energy on the π^-/π^+ multiplicity ratio

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The π^-/π^+ multiplicity ratio in heavy-ion collisions at a few-hundred MeV/A impact energy has been demonstrated to be a promising observable in the effort of constraining the density dependence of the isovector part of the equation of state of nuclear matter, the symmetry energy, in the supra-saturation region. However, constraints on the stiffness of the symmetry energy extracted using this observable are extremely model dependent [1] and are often in contradiction, for a given model, with those extracted from elliptic flow observables [2,3]. The π^-/π^+ multiplicity ratio is studied using an upgrade of the isospin dependent Tübingen QMD transport model achieved by enforcing the in-medium conservation of energy at local (LEC) or global (GEC) level. This was implemented in collision, decay and absorption processes by including contributions due to the density, isospin asymmetry and momentum dependent baryon [4] and, most recently, pion [5] potential energies which leads to an in-medium modification of particle production thresholds. The LEC scenario is similar to the one recently proposed in Ref. [6]. It is shown that compatible constraints for the symmetry energy stiffness from π^-/π^+ multiplicity ratio and elliptic flow experimental data of Au+Au collisions at 400 MeV/A can be extracted within the GEC scenario only. However, an important dependence of the π^-/π^+ observable on the strength of the isovector part of the $\Delta(1232)$ isobar potential is also demonstrated [4]. The present lack of information on this quantity prevents a precise extraction of the value for the symmetry energy stiffness employing the mentioned observable. A remedy of this situation, possibly achievable trough the study of pion momentum spectra or pion-nucleus collisions, will make future available experimental information on π^-/π^+ multiplicity ratio in heavy-ion collisions close to pion production threshold (SAMURAI Collaboration) [7] extremely valuable.

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Impact of pairing effects on thermodynamical properties and clusteritazion of stellar matter

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We study the influence of pairing effects on several properties of the inner crust of compact stars.

On the one hand, we concentrate on the thermodynamical properties of clustered stellar matter, that is characterized by the simultaneous presence of clusters and homogeneous matter. It is well-known in fact that pairing correlations reduce the crust thermalization time by a large fraction [1]. However, investigations on crust superfluidity carried out so far typically assumed that the cluster component was given by a single representative nucleus and did not consider the fact that at finite temperature a wide distribution of nuclei is expected to be populated at a given crust pressure condition. To do so, we implemente the presence of pairing correlations in the finite temperature Nuclear Statistical Equilibrium (NSE) model [2] for the composition of the crust solving BCS equations with mean field and pairing interaction functionals consistently extracted from a neutron matter BHF calculation [3].

On the other hand, we investigate the influence of pairing correlations on other specific features of the clusterization process which occurs in a stellar matter composed of neutrons, protons and electrons, within the same mean field approach [4]. In particular, we test how pairing correlations may affect the isotopic composition of the clusters which appear in the neutron star crust. As it is currently debated, these structures may moreover influence the neutrino mean free path and star cooling.

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Charge-Changing Cross Section Measurement of Neutron-rich Carbon Isotopes at 50A MeV

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Nuclear matter radii and charge (proton) distribution radii of unstable nuclei have provided important new information on the structure of nuclei far from stability line, and motivated new research direction of nuclear physics. The proton distribution radii for some of the light and stable nuclei have been determined by isotope shift measurements[1,2,3]. However, this method is not applicable to unstable nuclei from B to Ne isotopes due to the uncertainty in atomic physics calculation. The recent progress of Glauber model analysis enable the extraction of the matter distribution radii and proton distribution radii from cross section. Most of the matter radii for p- and p-sd shell nuclei have been determined by interaction- and/or reaction-cross section measurement and Glauber model[4,5]. Using transmission method, we have measured the charge-changing cross section (CCCS) for neutron-rich carbon isotopes using radioisotope beam at $50A\ MeV$ at RCNP, Osaka University, to determine the proton distribution radii. In this talk, the experiment setup and data analysis: process and results are presented and discussed.

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High-spin Molecular Resonances in $^{12}\mathrm{C} + {}^{12}\mathrm{C}$

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Well above the Coulomb barrier of the $^{12}\mathrm{C} + {}^{12}\mathrm{C}$ system, series of resonances have been found with high spins over $10\hbar$, which exhibit prominent peaks in the elastic and inelastic 2^+ channels [1]. Band Crossing Model, based on the double resonance mechanism, has successfully explained resonance mechanism and resonance states with the aligned configurations of the orbital angular momentum and the spins of the excited states of $^{12}\mathrm{C}$ [2]. On the other hand, for high-spin resonances observed in $^{24}\mathrm{Mg}+{}^{24}\mathrm{Mg}$ and $^{28}\mathrm{Si}+{}^{28}\mathrm{Si}$, we have developed a new molecular model [3], in which resonance states are described with a stable geometrical configuration of the constituent nuclei. Recently, we have applied the model to the $^{12}\mathrm{C} + {}^{12}\mathrm{C}$ system, including Coriolis coupling, and have shown how the aligned configuration arises in the resonances [4].

With oblate constituent nuclei, we have found an equilibrium configuration at equator-equator one, which is like two pancakes sitting side-by-side on the plane. As a whole, this *axially asymmetric* shape of the whole composite system allows states with $K = 2n$ (projection of J on z'-axis) in low excitation. With vibrational $1\hbar\omega$ excitation around the equilibrium, the system has also states with $K = 2n + 1$. Coriolis coupling with $\Delta K = 1$ connects those two kind of states, and results in alignments of spins of $^{12}\mathrm{C}$ and the orbital angular momentum in the molecular ground states. The dominant K-rotation of the configuration is $K = 0$ followed with $K = 1$, which appears at $E_{\mathrm{cm}} \sim 14$MeV for the spin $J = 12$ and $E_{\mathrm{cm}} \sim 20$MeV for $J = 14$. Furthermore, several excited configurations have been obtained, such as those with $K = 2$ and $K = 4$ dominance, which are expected to be non-aligned as they have high K-rotations.

Around $E_{\mathrm{cm}} \sim 20$MeV, the molecular ground state with $J = 14$ and excited configurations with $J = 12$ are coexisting. The feature of the resonances appears just to correspond to that obtained by the analysis of the elastic scattering in the same energy region[5]. The reason why we have obtained many narrow resonance states is that the nucleus-nucleus interaction adopted is slightly stronger, compared with BCM one [2], due to the following two points: 1) the interaction between tips of the constituent nuclei is calculated by the double-folding model, which is more realistic than the usual Woods-Saxon optical potential adopted in BCM, 2) the quadrupole deformation of $^{12}\mathrm{C}$ is taken to be large enough ($\beta = -0.86$) to reproduce the experimental $B(E2)$-value.

In conclusion, our molecular model is capable to describe various angular momentum couplings, by the role of the Coriolis coupling. The resultant molecular ground state has its own characteristics as aligned configuration, consistent with BCM, while in the excited states high K-rotational states appear relatively low in energy as non-aligned configurations. Preliminary analysis of partial widths indicates that most of those states are to be observed as intermediate resonances [1, 5]. The results will be reported, which renew the appearance of the molecular resonances in the $^{12}\mathrm{C} + {}^{12}\mathrm{C}$ system.

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Clusters in heavy ion collisions and the symmetry energy

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Clusters of different sizes are copious in the final state of low and intermediate energy heavy ion collisions. The N/Z ratio of clusters and the ratio of isotopic pairs of clusters are a sensitive probe of the nuclear symmetry energy. In this contribution we will review from a theoretical point of view the sensitivity of different observables and the conclusions that have been drawn from this in the work of our group. In particular, we will discuss the information gained from light cluster emission, driven by few-body correlations, and from intermediate mass fragments, subject to isospin transport. From light cluster emission one may learn not only about the density dependence of the symmetry energy but also about the proton/neutron effective mass splitting.

Tuesday 23/06/2015
h. 17.00-19.05

Aula A Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Fusion and Fission

Timelines in Breakup: Sub-zeptosecond processes in near-barrier reaction dynamics

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Understanding the interactions of weakly bound nuclei, and their reaction outcomes, is a key challenge in nuclear reactions research. For well-bound nuclei, collisions near the barrier are well-described by including couplings to quantum states of the approaching nuclei, as modelled in the coupled-channels model. For weakly bound nuclei, reaction dynamics can become more complex due the presence of low-energy resonant states. If the resonant states have lifetimes comparable to the collision timescale, then the reaction outcome depends crucially on whether or not their decay occurs whilst still approaching the target nucleus. For example complete fusion yields should be suppressed if breakup of the projectile-like nucleus (into its cluster constituents) occurs whilst approaching the target. However, complete fusion will hardly be affected if the decay lifetime allows the projectile-like nucleus to pass inside the fusion barrier before disintegrating. By making measurements below the fusion barrier, breakup of the projectile-like nucleus both on the ingoing and outgoing trajectories can be investigated, to understand the situation at above-barrier energies.

This talk will discuss the results of recent experiments at the Australian National University that aim to distinguish breakup of the projectile like-nucleus that occurs when approaching the target from that which occurs when receding from the target. Helped by breakup simulations, observables have been found that exhibit sensitivity to lifetimes even for sub-zeptosecond decays. These results provide insights for understanding reaction dynamics near the barrier.

Breakup of weakly bound nuclei and its influence on fusion

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In this talk it will be discussed some important features of the breakup of weakly bound nuclei, at energies close to the Coulomb barrier, and its effect on the fusion cross section. Contrary to what was assumed for a long time, recently it has been observed experimentally that at sub-barrier energies transfer processes followed by the breakup of stable weakly bound projectile predominates over the direct breakup. It will be shown how important is the interference between the nuclear and Coulomb components of the breakup and how the cross sections of these components increase when the target mass or charge increases. The effects of the breakup on the fusion cross section are of static and dynamical types, which nowadays can be disentangled. Recent systematic results have shown that the dynamics effects due to breakup and transfer processes enhance the complete fusion cross section at sub-barrier energies and suppress it at energies above the barrier for stable and neutron-halo nuclei. Some controversy exists for the fusion of proton-halo nuclei. The presently available results for the suppression factor of the complete fusion, for a given stable weakly bound projectile, seem to be independent of the target. It will be discussed whether this behaviour is due to the predominance of delayed breakup, which can not affect fusion, or simply because this conclusion was obtained from systematic results including only relatively heavy targets, or both of them. Some experimental challenges and the main open aspects in this field will also be discussed.

Effect of breakup and transfer on complete and incomplete fusion in $^{6}Li+^{209}Bi$ reaction in multi-body classical molecular dynamics calculation

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Breakup of stable weakly-bound projectiles results in incomplete fusion (ICF) processes which affect the fusion probabilities [1]. If one of the projectile-fragment is a loosely bound nucleus like deuteron (*d*) then its own breakup in the approach phase is also possible, resulting in nucleon transfer processes. In a recent experiment at sub-barrier energies it is observed that breakup of projectiles like ^{6}Li is predominantly triggered by nucleon transfer such as *n* stripping [2]. Heavy-ion collisions with weakly-bound projectiles have been studied using *CDCC* method [3], a semi-*classical coupled channel approximation* [4] and a *classical trajectory model* [5]. However, none of these models account for CF, ICF and, ICF following nucleon transfer within the same calculation.

We study $^{6}Li+^{209}Bi$ collisions in a multi-body, 3-Stage *Classical Molecular Dynamics* (3S-CMD) *model* [6] in which ^{6}Li is a cluster of α and *d* nuclei held together in a configuration corresponding to the observed breakup energy. The projectile fragments and the target nuclei are first generated with a potential minimization code with an NN potential between all the nucleons approximately reproducing the ground state properties of the nuclei. The projectile and the target nuclei are initially brought along their Rutherford trajectories. The 3-body system is then dynamically evolved using *Classical Rigid Body Dynamics* (CRBD) up to distances close to the Coulomb barrier. This stage is then followed by CMD evolution of the entire many-body system. If one or both the projectile fragments are further constrained to be rigid then these nuclei are dynamically evolved as in the CRBD calculation even in the stage-3.

We have carried out simulations with systematic relaxations of the rigid-body constraints on the target, projectile fragments and the bond between the projectile fragments in the stage-3 of the calculation. We have calculated the relative probabilities [7] of the possible events such as scattering with and without breakup, DCF, SCF, ICF(x) where x is either α or d which is captured. The calculation in which the *d* is also allowed to breakup near the target, x may also be $\alpha+n$, $\alpha+p$, n or p. We find that ICF($\alpha+n$), corresponding to *n* stripping followed by breakup of the resultant ^{5}He to $\alpha+p$ with *p* scattered, contributes significantly in the fusion process. This observation is in agreement with the experimental observation [2] of the importance of direct reaction processes in breakup of weakly bound projectiles.

We have also calculated fusion cross sections, σ_{CF} and $\sigma_{TF} = \sigma_{CF} + \sigma_{ICF}$. The calculated results clearly exhibit the importance of the constituent's excitations and breakup. While as a result of allowing for internal excitations σ_{CF} are comparatively enhanced at all the collision energies, the enhanced breakup of the constituents at higher energies takes away the flux from the CF, resulting in its comparative suppression. The σ_{CF} and σ_{TF} calculations which allows for the breakup of ^{6}Li into α and *d* as well as the breakup of *d* itself, gives reasonable agreement with the experiment [8].

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Fusion reactions of ^{58,64}Ni + ^{124}Sn

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Fusion between Ni and Sn isotopes has been studied for more than thirty years down to cross sections of about 0.1-1 mb [1]. For the recent measurements with secondary beams of ^{132}Sn this cross section limit was caused by the beam intensities available at existing radioactive beam facilities.

Measurements of fusion excitation functions of ^{58}Ni + ^{124}Sn and ^{64}Ni + ^{124}Sn have been extended towards lower energy to cross sections of $\simeq$1 μb. The experiment was performed at the XTU Tandem accelerator of Laboratori Nazionali di Legnaro, using doubly-stripped beams of ^{58,64}Ni on thin ^{124}Sn metallic targets. The evaporation residues were detected with the Legnaro electrostatic separator.

The results, shown in the figure, have been compared to detailed coupled-channels calculations. The calculations show the importance of including transfer reactions in a coupled-channels treatment for such heavy systems. This is different from the conclusion made in a previous paper [2] which claimed that the influence of transfer is not important for fusion reactions of Ni + Sn. In the energy region studied in this experiment no indication of fusion hindrance has been observed which is consistent with a systematic study of this behavior [3]. More details concerning the measurements and the CC analysis will be discussed.

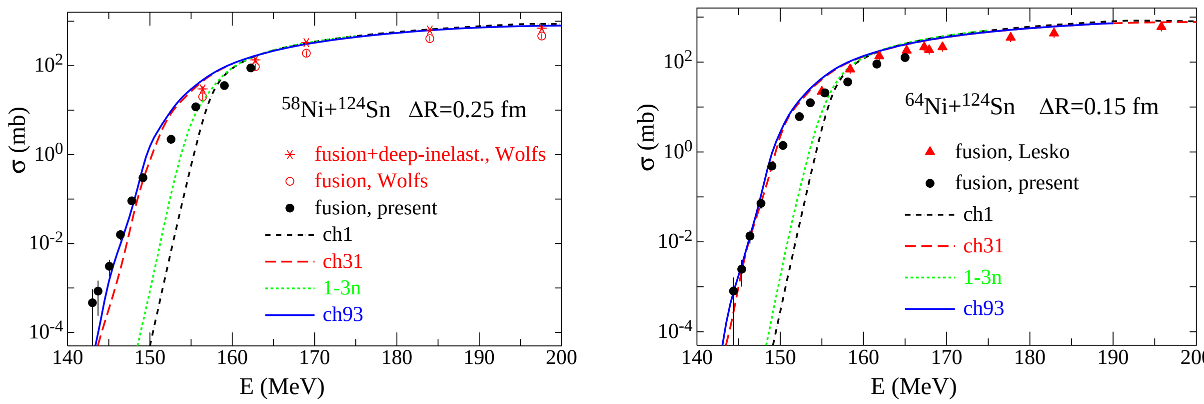

FIG. 1: *Fusion excitation functions measured in this work compared to CC calculations using a Woods-Saxon potential; ch1 is the no-coupling limit, ch31 includes the low-energy 2^+ and 3^- excitations of both nuclei, ch93 includes additionally the 1n and 2n transfer channels.*

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Study of the ^{20,22}Ne + ^{20,22}Ne and ^{10,12,13,14,15}C + ^{12}C fusion reactions with MUSIC

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Fusion cross sections measurements play an important role for both nuclear structure and nuclear astrophysics. For example, fusion reactions between light neutron-rich nuclei have been proposed to be a possible energy source in X-ray superbursts that originate in the crust of an accreting neutron star. Experimental fusion reaction studies are essential to test the predictive power of the theoretical models for the fusion reactions that are included in calculations of superbursts. The development of the MUlti-Sampling Ionization Chamber (MUSIC) detector has opened new possibilities for fusion reaction studies. The high efficiency and flexibility to measure the excitation function of fusion reactions in a large energy range in a single measurement make the MUSIC detector an ideal tool for performing measurements of fusion cross sections with radioactive beams. A systematic study of the excitation function of the ^{20,22}Ne + ^{20,22}Ne and ^{10,12,13,14,15}C + ^{12}C systems using the MUSIC detector has been performed at ATLAS. The experimentally extracted excitation functions and comparison with theoretical predictions will be presented.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

Dissipation strength of the tilting degree of freedom in fusion-fission reactions

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Fission still is one of the most interesting and challenging topics in nuclear physics providing a perfect opportunity to investigate the large scale evolution of initial compound nucleus into fission products. During last decades stochastic approach based on multidimensional Langevin equations 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]. The significance of orientation degree of freedom (K coordinate), which is the projection of the total angular momentum onto the symmetry axis of fissioning nucleus, was demonstrated and an overdamped Langevin equation for K coordinate were introduced [5,6].

In the present study, three collective shape coordinates and the K coordinate were considered dynamically from the ground state deformation to the scission into fission fragments. The resulting four-dimensional Langevin model was applied to calculate a wide set of experimental observables for heavy fissioning compound nuclei. A modified one-body mechanism for nuclear dissipation with a reduction coefficient $k_{\rm s}$ of the contribution from a "wall" formula was used for shapes parameters. The inclusion of the K coordinate in the dynamical consideration and use of the "chaos-weighted wall formula" with a deformation-dependent scaling factor $k_{\rm s}$ lead to fairly good reproduction of different experimental observables for a number of fissioning compound nuclei. Different possibilities of deformation-dependent dissipation coefficient for the tilting coordinate (γ_K) were investigated. Presented results demonstrate that the influence of the $k_{\rm s}$ and γ_K parameters on the calculated quantities can be selectively probed. The nuclear viscosity with respect to the nuclear shape parameters influences the $\langle n_{\rm pre}\rangle$, the fission fragment mass-energy distribution parameters, and the angular distribution of fission fragments. At the same time the viscosity coefficient γ_K affects the angular distribution of fission fragments only. The independence of anisotropy on the fission fragment mass is found at both Langevin calculations performed with deformation-dependent and constant γ_K coefficients. It was found that in the four-dimensional Langevin calculations it is possible to describe experimental data with the deformation-dependent γ_K coefficient. One of the possibility is to use large values of $\gamma_K \simeq 0.2$ (MeV zs)$^{-1/2}$ for compact shapes featuring no neck and small values of $\gamma_K \simeq 0.0077$ (MeV zs)$^{-1/2}$ for elongated shapes. Using such a different value of γ_K for deformations before saddle and along the saddle-to-scission descent tends the dynamics of the K coordinate to the prediction of the transition state model at saddle point.

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Tuesday 23/06/2015
h. 17.00-19.10

AULA 52 LNS

PARALLEL SESSION

Nuclear Astrophysics

Reactions on neutron-deficient nuclei for nuclear astrophysics

J. C. Blackmon[1], L. Afanasieva[1], L. Baby[2], J. Belarge[2], P. D. Cottle[2], C. M. Deibel[1], E. Koshchiy[3], A. N. Kuchera[2,4], J. Lai[1], K. T. Macon[1], M. Matos[1,5], B. C. Rasco[1], G. Rogachev[3], I. Wiedenhöver[2]

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Uncertainties in the rates of many nuclear reactions involving neutron-deficient nuclei persist and hamper our understanding of explosive astrophysical environments like novae, X-ray bursts, and supernovae. Beams of such radioactive nuclei offer new opportunities for direct measurements of cross sections important for astrophysics and for indirect studies of the relevant nuclear structure, but the relatively low intensity of such beams demands the development and application of highly-sensitive experimental approaches. One such approach for charged particle reaction studies is the Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN). ANASEN employs an extended active gas target/detector capability that allows thick gaseous targets to be used with large solid angle coverage while maintaining good center-of-mass energy resolution. One of the goals with ANASEN is to directly measure (α,p) reactions that are important in X-ray bursts using the active target capability with emitted protons detected in arrays of gas proportional counters and silicon strip detectors. ANASEN also allows charged-particle scattering and transfer reaction studies with high efficiency. We will report on results from an initial set of measurements with ANASEN conducted with radioactive ion beams at the Fox Superconducting Accelerator Laboratory at Florida State University (FSU), including reaction studies with beams of ^{6}He, ^{17}F, ^{18}Ne and ^{19}O. The active gas target capability of ANASEN is also now being upgraded to improve the center-of-mass energy resolution for the instrument, and we will report on the progress. We will also compare to some complementary approaches recently developed including one demonstrated by a measurement of the ^{4}He(^{20}Ne,p)^{23}Mg reaction using the HELIcal Orbit Spectrometer (HELIOS) at Argonne National Laboratory that is of interest for understanding Type Ia supernovae. The challenging nature of direct measurements at astrophysical energies with radioactive ions still drives a need for spectroscopic measurements both with stable and radioactive beams. We will report on some recent stable beam studies and on the installation of an Enge splitpole magnetic spectrograph at FSU to enhance such stable beam capabilities. We will survey these technical developments and recent experimental results that are helping improve our understanding of reaction rates that are important in stellar explosions. This work is supported by the U.S. Department of Energy Office of Science, Office of Nuclear Physics under Award Number DE-FG02-96ER40978 and the U.S. National Science Foundation under Grant No. 1064819 and through grants from the Major Research Instrumentation Program that supports the development of ANASEN and implementation of the Enge split pole spectrograph at FSU.

The $^{12}C(^{12}C,\alpha)^{20}Ne$ and $^{12}C(^{12}C,p)^{23}N$ reactions at the Gamow peak via the Trojan Horse Method

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The $^{12}C+^{12}C$ fusion channel in the low energy region is of great interest in astrophysics because of its critical role in studying a wide range of stellar burning scenarios in carbon-rich environments [1-4]. The carbon burning temperature ranges from 0.8 to 1.2 GK, corresponding to center-of-mass energies from 1 to 2 MeV, the so called Gamow peak. A detailed knowledge of the carbon fusion processes is needed at those energies to shed light on all these scenarios and to put constraints on the models. In spite of the considerable efforts devoted to measure the $^{12}C(^{12}C,\alpha)^{20}Ne$ and $^{12}C(^{12}C,p)^{23}N$ cross sections at astrophysical energies, they have been measure only down to 2.14 MeV, still at the beginning of the astrophysical region [5]. As known, direct measurements at lower energies are extremely difficult. Moreover, in the present case the extrapolation procedure from current data to the ultra-low energies is complicated by the presence of possible resonant structures even in the low-energy part of the excitation function. Thus, the Trojan Horse Method [6,7] represents a valid alternative solution for an accurate investigation down to at least 1 MeV. This has been done recently by measuring the $^{12}C(^{14}N,\alpha^{20}Ne)^{2}H$ and $^{12}C(^{14}N,p^{23}Na)^{2}H$ three-body processes at 30 MeV of beam energy in the quasi-free (QF) kinematics regime, where ^{2}H from the ^{14}N Trojan Horse nucleus is spectator to the $^{12}C+^{12}C$ two-body processes. A selective population of resonances associate to ^{24}Mg levels is seen in the Gamow peak. Results will be presented and discussed.

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Asymptotic Normalisation Coefficients from the ^{26}Al(d,p)^{27}Al reaction, mirror nuclei study and application to nuclear astrophysics.

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The observations of the radioactive decay of ^{26}Al by satellites, the first observation of ongoing nucleosynthesis in the galaxy, has triggered an intense need for understanding the mechanism responsible for its production and destruction in galactic phenomena. While the exact provenance is still unresolved, all-sky maps tracking γ-rays associated with its decay have shown that it was produced by several different astrophysical sites such as core collapse supernovae, Wolf-Rayet (WR) stars and novae. A relatively small network of reactions is responsible for the observed ^{26}Al quantities. In hydrogen-burning environment the destruction rate is mainly determined by the ^{26}Al(p,γ)^{27}Si reaction. As a result the occurrence of resonances above the ^{26}Al+p threshold in ^{27}Si has a large impact on the galactic ^{26}Al abundance inherent to each of these astrophysical sites. Recently resonant states have been identified in ^{27}Si by two spectroscopic studies [1,2]. However, the strength of two of those states, at 7532 and 7589 keV (resp. 70 and 127 keV) excitation (resonance) energy, remains mainly unknown. These low energy resonances are currently not reachable via direct measurement as the cross section fall off dramatically with energy. In this study, this obstacle is overpassed via a state of the art spectroscopic study of the mirror nucleus ^{27}Al with the ^{26}Al(d,p)^{27}Al transfer reaction. Such study allows for an indirect measurement of the 127 keV resonance in ^{27}Si. It is currently understood (see, for example, Ref. [1]) that the state in ^{27}Al, equivalent to this resonance, is at 7806 keV. Here the reaction was performed in inverse kinematics at TRIUMF, Canada, using the most intense ^{26}Al beam yet available. We will present results for the measurement of Asymptotic Normalisation Coefficients for (^{26}Al+n)$\equiv^{27}$Al and the implication for the mirror system (^{26}Al+p)$\equiv^{27}$Si focussing on the resonant states.

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AGB star nucleosynthesis: when new data from nuclear physics help to solve puzzles

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Low mass stars contribute to the chemical evolution of the Galaxy as well as more massive supernova progenitors. Indeed the limited amount of processed matter released into the interstellar medium by small objects is compensated by the large number of them. At the late stages of their evolution, stars with mass smaller than 3Mo undergo the Asymptotic Giant Branch (AGB) phase, which has been found to be a unique site for synthesis of some nuclei heavier than Fe trough slow neutron capture reactions. AGB nucleosynthesis is also characterized by H-burning coupled with mixing phenomena, which have been proved to account for anomalies in the Li abundance and C, N and O isotopic ratio observed in stellar spectra and meteorite grains. Nowadays the improvements in stellar spectroscopy and the growing number of geochemical analysis of meteorite grains offer new challenges and stronger constraints for the model of stellar nucleosynthesis and a high precision of the nuclear physics data employed in calculations is required. We present how updated measurements of nuclear cross sections contribute to solve puzzles of oxygen isotopic mix in presolar grains of AGB origins. While despite accurate measurement of the reaction rate the high abundances of 26Al found in the same grains require a specific mixing model to be reproduced, similar to the one needed to trigger the formation of an extended neutron source in low mass AGB stars. Finally, to show the crucial role of a proper estimation of electron density at the nucleus in the stellar plasma we present an evaluation of the complex problem of Li abundances in AGB stars in the light of an ad-hoc estimate of the 7Be time-of-life.

Neutron Star Structure from the Quark-Model Baryon-Baryon Interaction

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One of the most fundamental issues in nuclear physics is the understanding of nuclear many-body systems from realistic nucleon-nucleon (NN) and three-nucleon ($3N$) interactions. It is well-known that $3N$ forces play an essential role in reproducing the energy levels of the light nuclei [1]. Also in nuclear matter, it has been well-established that a $3N$ force is essential to reproduce the experimental saturation point [2]. However, it seems difficult that a $3N$ force describes well few-body systems and nuclear matter at the same time [3].

Quark-model (QM) baryon-baryon (BB) interactions have been modeled to describe the short-range repulsion with the resonating group method by using the constituent quark model [4]. One of the most developed version of the QM BB interactions, i.e. fss2 [5], has been successfully applied to the three-baryon systems (^{3}H, $^3_\Lambda$H [6], and $3N$ scattering [7]) and α particle [8] using the Faddeev or Faddeev-Yakubovsky framework. The model fss2 reproduces the experimental values fairly well without resorting to $3N$ forces, and can give an alternative way to describe nuclear many-body systems, since the role of $3N$ forces may be not so large as usually considered. Therefore it is highly desirable to apply fss2 to the study of nuclear matter and finite nuclei.

Here, we report on the application of fss2 to the equation of state of nuclear matter within the framework of Bethe-Brueckner-Goldstone theory [9]. In Ref. 9, the authors showed that the three hole-line contribution turns out to be non-negligible and to have a substantial saturation effect. The saturation point of nuclear matter, the compressibility, the symmetry energy, and its slope are within the phenomenological constraints. We extend this study to higher density regions and solve the Tolman-Oppenheimer-Volkoff equation for studying the structure of neutron stars, and find that the maximum mass predicted by fss2 is approximately two solar mass, in agreement with observational data.

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Electron screening in laboratory experiments-an unresolved effect

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Energy production, evolution and neutrino emission in stars are governed by fusion reactions. The influence of surrounding electrons that inevitably surround interacting nuclei is very poorly understood in still experimentally unachievable stellar plasmas. Therefore, it is of significant importance to measure the bare cross sections as well as possible. The probability for tunnelling through the Coulomb barrier depends on its height exponentially and even small changes to the barrier caused by electrons surrounding the reactants in laboratory experiments have a significant effect on the fusion cross section. As a result, the measured cross sections are enhanced compared to cross sections for bare nuclei. Experimental studies of various nuclear reactions in metallic environments have shown the expected cross section enhancement at low energies [1-4]. However, the enhancements in metallic targets were significantly larger than expected from the adiabatic limit, which is thought to provide the theoretical maximum for the magnitude of electron screening. The electron screening is an effect far from being understood in the laboratory conditions and consequently it cannot be deduced theoretically. Moreover, its size has to be measured for each metallic environment and each target separately.

Recently, we performed an extensive experimental campaign, with an aim to study the electron screening in the laboratory for various nuclear reactions and involving both low and high Z targets. The ^{1}H(^{7}Li,α)^{4}He fusion reaction was studied for hydrogen implanted Pd, Pt, Zn and Ni targets. Large electron screening, of a few keV was observed in all targets. On the contrary, no large electron screening was observed in the following proton induced reactions: ^{55}Mn(p,γ)^{56}Fe, ^{55}Mn(p,n)^{55}Fe, ^{113}Cd(p,n)^{113}In, ^{115}In(p,n)^{115}Sn, ^{50}V(p,n)^{50}Cr and ^{51}V(p,γ)^{52}Cr. Moreover, no shift in resonance energy for metallic compared to insulator environment was observed for the studied (p,n) and (p,γ) reactions. In a continuation of our experimental campaign, we further investigated the ^{1}H(^{7}Li,α)^{4}He reaction in W, Pd and C environments. In addition, we also focused on studies of electron screening in the ^{1}H(^{19}F,αγ)^{16}O reaction in the same targets (in both normal and inverse kinematics). Preliminary results showed unexpectedly large electron screening values (of the order of 10 keV), pointing to a dependence of the electron screening potential on the position of the target nuclei in metallic lattice as well as to a non-linear scaling (instead of widely accepted linear one) of electron screening potential with the charge number of the target. These hypotheses, if correct, would have a profound effect on the understanding of the "laboratory" electron screening effect and would eventually lead to the more correct bare cross sections extracted from laboratory measurements. Untill plasma experiments become feasible in the laboratory, the study of electron screening in a metal - the plasma of a poor man [2], is the only means of study that will hopefully successfully point towards the correct interpretation of the electron screening and further understanding of immensely important fusion processes in stellar environments. A review of previous results, as well as newly obtained ones will be presented.

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Wednesday 24/06/2015
h. 08.30-10.30

AULA MAGNA

PLENARY SESSION:

Nuclear Energy and Applications of Nuclear Science and Technologies

The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

Recent developments in Nuclear Physics tools and techniques applied to nuclear energy

S. Leray

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Abstract not received

Nuclear Physics and Particle Therapy

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The use of charged particles and nuclei in cancer therapy (hadrontherapy) is one of the most successful cases of application of nuclear physics to medicine. The physical advantages in terms of precision and selectivity, combined with the biological properties of densely ionizing radiation, make the charged particle approach an elective choice in a number of cases. Hadrontherapy is in continuous development and nuclear physicists can give important contributions to this discipline. A recent comprehensive review of the matter is given in ref. [1].
The quality of hadron therapy treatments is closely connected with the ability to predict and achieve a given beam range in the patient. Currently, uncertainties in particle range lead to the employment of safety margins, at the expense of treatment quality. One of the research items in particle therapy is therefore aimed at developing methods to verify the particle range in patients. Non-invasive in-vivo monitoring of the particle range can be performed by detecting secondary radiation, emitted from the patient as a result of nuclear interactions of charged hadrons with tissue, including β^+ emitters, prompt photons, and charged fragments. The exploitation of these processes to verify the correctness of dose delivery requires the comparison of measured and pre-calculated distributions of the secondary particles. The continuous improvement of Monte Carlo models to provide reliable predictions is a key issue. This is a non-trivial task, because there is no rigorous calculable theoretical model for the nuclear interactions involved. In this work some of the most recent results on charged particle therapy will be presented, pointing out the relevant aspects in nuclear physics, with a particular attention to the aspects concerning nucleus-nucleus interactions. The most important directions of research will be summarized.

[1] NuPECC, Nuclear Physics for Medicine (ESF, Strasbourg) 2014 *et al.*, Phys. Rev. Lett. **1**, 1 (2015)

Recent trends in applications of nuclear techniques to Cultural Heritage

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The applications of "nuclear" techniques to problems in the field of Cultural Heritage (CH) are now rather well established and relatively well known to both physicists and scholars, and even to a wider audience.
Radiocarbon dating, which is probably the best known among them, has seen in the recent years some significant trends, both as to technological advancements (use of smaller machines for Accelerator Mass Spectrometry, more effective procedures of contamination removal from the samples to be dated) and as to the areas of application themselves (authentication of contemporary artworks). Another very interesting development, which has been successfully applied for radiocarbon concentration measurements in fields other than CH, is the further reduction of the mass of sample required, to much smaller levels than the typical mg range so far routinely needed: the perspective of a reliable radiocarbon-dating of smaller-mass samples would open the possibility to address new problems also in CH issues.
As to the material analysis through ion beams, the probably most relevant recent trend concerns the more and more general application of scanning techniques leading to the construction of elemental maps, which greatly adds to the significance and representativeness of the obtained result. The same can be said for X Ray Fluorescence (XRF), where highly performing instrumentation is now available - also in compact portable systems for *in-situ* measurements - with mapping capability, in addition to having achieved a detection range extended to lower Z elements down to Na.
The talk will shortly cover these issues, with examples of recent applications to real case studies.

A New Generation of Gamma Ray Sources based on Compton back-scattering: future potentialities for Nuclear Physics and Photonics

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A large effort is being pursued world-wide to advance the performances of Gamma ray photon Sources: the aim is to improve the mono-chromaticity and the spectral density of photon beams in the photon energy range from 1 to 20 MeV, where most of the nuclear photonics and nuclear physics science and applications are performed. The enabling technology under development is based on back-scattering Compton Sources of high power laser beams by high brightness electron beams with energy in the GeV range. Several schemes are being adopted: RF Linacs combined with re-circulated high power laser pulses, storage rings or re-circulated super-conducting Linacs combined to Fabry-Perot optical cavities. After a general introduction on the physics and design criteria of these electron-photon high luminosity colliders, we will describe in more detail the challenges and implementation of the EuroGammaS machine [1], which is in construction for the ELI-NP Romanian pillar as its Gamma Beam System (ELI-NP-GBS), in the frame of the large European initiative called Extreme Light Infrastructure.

[1] O. Adriani et al., http://arxiv.org/abs/1407.3669

Wednesday 24/06/2015
h. 11.00-13.00

AULA MAGNA

PLENARY SESSION:

Reactions and Structure – Unstable nuclei

Reaction theory: status and perspectives

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Ongoing and planned radioactive beam facilities will produce in near future accurate reaction data covering unexplored areas of the nuclear chart. The extraction of meaningful information from these experiments will demand new advances in nuclear structure and reaction theories. Due to the complexity of nuclear reactions, models used to analyse reaction data are usually tailored to specific types of reactions. In particular, for nuclei in the vicinity of the driplines, models must account for the coupling to breakup channels. Moreover, the cluster-like structure commonly exhibited by these nuclei, has emphasized the use of few-body models.

The paradigm is the three-body scattering problem, in which a two-body composite projectile is scattered from a target. As a result, the projectile may scatter elastically, it may excite or break-up, or it may transfer one of the clusters to the target. The exact, rigorous solution of this problem is provided the Faddeev equations. However, the complexity of this method has prevented until very recently its application to realistic cases. Instead, approximate methods have been used, such as coupled-channels (CC) and coupled-reaction channels (CRC) methods, and their extension to the breakup channels, the Continuum-Discretized Coupled-Channels (CDCC) method [1]. When the transition to a particular final state is weak, perturbative versions of these methods, such as the popular Distorted-Wave Born Approximation (DWBA) can be used. These methods have proved be very successful to analyse elastic scattering, inelastic scattering and elastic breakup data in a wide range of energies, from sub-Coulomb scattering to tens of MeV per nucleon. At higher energies, where these methods become computationally demanding, they may be replaced by semiclassical approaches. The latter have also the appealing feature of providing relatively simple closed-form formulae for the calculation of inclusive breakup, including non-elastic breakup contributions, which is essential in the description of fast nucleon removal experiments (i.e. *knockout*) [2].

In this presentation, we review the current status of these reaction models, describe their limitations, and present some recent developments. In particular, we will discuss the inclusion of core excitation, both in the projectile structure as well as in the reaction dynamics [3, 4], and the extension to three-body projectiles [5, 6]. Ongoing work, such as the calculation of inclusive cross sections (including incomplete fusion) or the application to reactions of astrophysical interest, will be also discussed.

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Broad resonances in ^{8}Be, ^{12}C and ^{16}O studied with reactions and beta-decay

H. Fynbo

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We search for and study broad resonances in light nuclei using a combination of capture reactions, transfer reactions and beta-decay. The focus is on resoanances in ^{8}Be, ^{12}C and ^{16}O, which all play important roles in astrophysics, and exibit unusual nuclear structures with both cluster type correlations and mean field type structures.

In this presentation results from new measurements will be presented and compared to theoretical calculations.

Continuum Spectroscopy of Light Nuclei

Robert Charity[1]

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In this talk we will discuss recent results on the continuum spectroscopy of light nuclei measured with the HiRA detector at the National Superconducting Cyclotron Laboratory using the invariant-mass technique. We will look at resonance decays leading to exit channels containing from two to five particles and, in some cases, there are also coincident gamma rays. Of particular interest will be cases of two-proton decay for ground and excited states of isotopes beyond the proton drip line. Two-proton decay is often classified as either prompt or sequential. In the first case, the two protons are emitted at the same time, while the second case, a single proton is emitted forming a long-lived intermediate state which itself eventually decays by proton emission. We will examine the transition from prompt to sequential with increasing excitation energy for ^{16}Ne and ^{6}Be states and show same states which have a strange intermediate behavior. The observed evolution is found consistent with improved calculations with the three-body cluster model of Grigorenko et al. [1]. Finally, for a quantitative understanding of the correlations between the momenta of the three final fragments in ground-state ^{16}Ne decay, the three-body Coulomb force must be considered out to very large separations between these fragments.

[1] Grigorneko et al, Phys. Rev. Lett. 88 (2002) 042502

Nuclear structure and reaction studies with Fermionic Molecular Dynamics

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[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany*

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Cluster structures can be become important for states close to the corresponding thresholds. This is the case for example in halo nuclei, where one- or two-nucleon separation energies are very small and already the ground state clusters in a core and halo nucleon(s). But it can also happen for excited states in well bound nuclei. The text-book example is here the Hoyle state in ^{12}C that sits just above the three-α threshold. Clusters are of course also essential for nuclear reactions where they appear explicitly as degrees of freedom.

Fermionic molecular dynamics (FMD) is a many-body approach that is well suited to treat clustering. It uses Gaussian wave-packets localized in phase-space as single-particle states, many-body basis states are given by Slater determinants projected on parity, angular momentum and total linear momentum. The advantage of the wave-packet basis is that it contains both harmonic oscillator shell model and Brink-type cluster wave functions [1]. The parameters of the single-particle states are obtained by a variation of the energy after projection. Eigenstates of the Hamiltonian are obtained by diagonalization in a set of many-body basis states.

For resonances and scattering states we divide the model space in an internal region that is described by microscopic A-body wave functions and an external region that is described by product states of clusters. This allows us to match the microscopic wave functions with the asymptotic behavior given by Whittaker functions for bound states, purely outgoing Coulomb functions with complex energy for resonances and linear combinations of incoming and outgoing Coulomb functions for scattering states.

Using this approach we were able to describe the ^{3}He(α,γ)^{7}Be capture reaction using a realistic two-body interaction obtained from the Argonne V18 interaction within the unitary correlation operator method (UCOM) [2]. Without adjustable parameters the calculation reproduces both the normalization and the energy dependence of the cross section data. Recently we investigated the continuum states in ^{12}C. Here we include ^{8}Be-α cluster states with several ^{8}Be pseudo-states. Within the restrictions of a microscopic α-cluster model one can qualitatively understand the structure of a band built on the Hoyle state [3]. However one needs to go beyond a pure cluster model to study and understand $M1$, $E1$ and Gamow-Teller transitions that are used to populate states in the ^{12}C continuum.

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Thursday 25/06/2015
h. 8.30-10.30

AULA MAGNA

PLENARY SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

Constraints on the asymmetric equation-of-state from heavy-ion collisions

S.J. Yennello
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The nuclear equation-of-state impacts a number of nuclear properties as well as astrophysical processes. The asymmetric term of the equation-of-state, which describes the behavior away from N=Z, has significant uncertainty. Giant resonances and nuclear masses can elucidate the asymmetry energy for cold normal-density nuclei. Heavy-ion collisions can be used to probe nuclear matter at higher temperatures and densities away from saturation density. Various experiments have placed constraints on the EOS using free neutron-proton ratios, isospin diffusions, neck dynamics, isobaric yield ratios and collective flow. The asymmetry energy is a manifestation of the underlying nuclear interactions. Comparison with theoretical predictions, using different interactions, of multiple observables from a diversity of reactions measured with various experimental aparati will help to further constrain the asymmetry energy of the nuclear equation-of-state and enhance the accuracy of predictions of astrophysical phenomenon.

Recent results on light nuclear systems; progress and problems

Martin Freer

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It might feel as though a complete understanding of light nuclei should have been reached by now, and may be it should. However, and on the contrary, these systems have become the testing ground where state-of-the-art theory meets the incredibly rich spectrum of structural possibilities that light nuclei present. Such systems are dominated by correlations which are the finger-print of the strong interaction which generates everything from the collective to single-particle behavior and also examples where these mix. These correlations are manifest is cluster-like states and molecular exchange of neutrons between clusters (mixed bosonic and fermionic modes). This talk will be a review of the recent results of the Birmingham group, where they are helping to improve our understanding of nuclei such as ^{12}C, ^{14}C and ^{12}Be and where open questions remain.

Pairing effect in nuclear reactions

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In recent years, efforts have been made to account for super-fluidity in time-dependent mean-field description of nuclear dynamic [1-3]. Pairing effect is important to achieve a realistic description of static properties of nuclei. In the present talk, I will show that pairing can also affect the nuclear motion. State of the art TDHF approach can describe small amplitude collective motion as well as the collision between nuclei. Very recently, this microscopic approach has been improved to include pairing either in the BCS or HFB framework. Recent applications of the 3D TDHF + BCS (TDHF+BCS) model introduced in [3] will be presented. The role of super-fluidity on one- and two-transfer [4,5], on fusion and on fission [6] will be illustrated.

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[3] I. Stetcu, A. Bulgac, P. Magierski, and K. J. Roche, Phys. Rev. C 84, 051309(R) (2011).
[4] G. Scamps and D. Lacroix, Phys. Rev. C 88, 044310 (2013).
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Cluster production within transport theory

Akira Ono

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It has been known that light clusters, such as α particles and deuterons, are copiously formed in heavy-ion collisions in various conditions. For example, in Au + Au central collisions at several hundred MeV/nucleon, about 80% of protons in the system are bound in clusters and heavier fragments. This fact suggests that cluster correlations may play important roles during the dynamical evolution of heavy-ion collisions. On the other hand, properties of clusters in nuclear medium have been theoretically studied in recent years to obtain the equation of state of low-density matter and to interpret some heavy-ion data. A simple antisymmetrized molecular dynamics (AMD) calculation also shows that nucleons gain binding energy by forming a cluster in a nucleus when the cluster is located near or outside the nuclear surface and/or when the cluster is given a sufficient momentum.

Transport models should be carefully constructed in order to allow the appearance of cluster correlations with the correct probabilities during the time evolution of reactions. In the case of the AMD approach, the two-nucleon collision process has been generalized by allowing one or both of the colliding nucleons N_1 and N_2 to form clusters with surrounding particles as $N_1 + N_2 + B_1 + B_2 \to C_1 + C_2$. We consider clusters ($C_1$ and C_2) up to α particles, and they are represented by placing Gaussian wave packets at the same phase space point. Elastic and inelastic collisions of clusters are naturally introduced by this prescription. We find that this explicit treatment of cluster correlations has a large impact on the collision dynamics and improves the reproduction of multifragmentation data including the yields of protons and α particles. It is, however, important to additionally consider the binding of several clusters.

In this presentation, I will discuss the effects of cluster correlations in heavy-ion collision dynamics. For neutron-rich reaction systems, a typical effect of cluster formation, in particular α-cluster formation, is to enhance the neutron-proton asymmetry of the rest of the system, i.e., $(N - 2n_\alpha)/(Z - 2n_\alpha) > N/Z$ when $N > Z$. This is at least partly responsible for the enhancement of the neutron-proton (or triton-^{3}He) spectrum ratio at low velocities in the center-of-mass frame of expanding and fragmenting neutron-rich systems. Another effect of cluster correlations in expanding systems is that nucleons and clusters cease interacting with each other earlier than in the case without cluster correlations where nucleons continue to interact until a relatively late time. As a consequence, the spectra of emitted particles carry direct information at an earlier time in the case of strong cluster correlations. In central collisions of neutron-rich nuclei at 300 MeV/nucleon, the AMD calculation with cluster correlations shows that the symmetry energy effect on the neutron-proton dynamics at the compression stage is rather directly reflected in the neutron-proton spectra in the final state.

Thursday 25/06/2015
h. 11.00-13.00

Aula Magna Dipartimento di Fisica ed Astronomia

PLENARY SESSION:

Fusion and Fission

Present status of coupled-channels calculations for heavy-ion subbarrier fusion reactions

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Heavy-ion fusion reactions at energies around the Coulomb barrier are strongly influenced by couplings of the relative motion of the colliding nuclei to several nuclear intrinsic motions. It has been well recognized by now that such couplings lead to large enhancement of heavy-ion fusion cross sections at subbarrier energies relative to predictions of a one-dimensional potential model [1-4]. The coupled-channels approach with couplings to low-lying collective motions has been a standard tool to analyze heavy-ion subbarrier fusion reactions [3,5]. It has not only successfully accounted for the subbarrier enhancement of fusion cross sections but also provided a natural explanation for the fusion barrier distribution through the eigen-channel representation [1,3].

In many coupled-channels calculations, one often employs the macroscopic description of nuclear collective motions. That is, a harmonic oscillator and a rigid rotor are assumed for vibrational and rotational motions, respectively. With this approach, the energy and the coupling strength for higher members of excited states are automatically determined once those for the first excited state are specified from the experimental data.

On the other hand, in recent years, the so called beyond mean-field approach has rapidly been developed in nuclear structure physics [6]. While the pure mean-field approximation yields only a single optimized shape, the beyond mean-filed approach takes into account the shape fluctuation effect around the optimized shape with the generator coordinate method (GCM) after the angular momentum and particle number projections are carried out. The anharmonicity of nuclear vibrations as well as a deviation from the rigid rotor due to a coupling between vibrational and rotational degrees of freedom are naturally described with this approach.

In this talk, we will first give an overview of recent theoretical developments of heavy-ion subbarrier fusion reactions, that include the Wong formula for fusion cross sections and its extension, a treatment of non-collective excitations, and fusion cross sections at deep subbarrier energies. We will then present a new approach for coupled-channels calculations, which hybridizes the conventional approach with the microscopic description for low-lying excitations described with GCM. We will apply this approach to subbarrier fusion reactions of ^{58}Ni+^{58}Ni and ^{58}Ni+^{60}Ni and will discuss the role of anharmonicity in subbarrier fusion reactions.

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Sub- and near-barrier fusion reactions: experimental results

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The size and the nuclear structure properties of the reacting nuclei are sensitively probed by fusion reactions near the Coulomb barrier. This is best evidenced by comparing the data for near-by isotopes. Indeed, the fusion of ^{16}O with different samarium isotopes [1] shows the changing structure from spherical vibrational to strongly deformed nuclei. Fusion data for different nickel [2] and calcium isotopes [3] evidently indicate the influence of couplings to nucleon transfer channels. Inelastic and transfer couplings produce fusion barrier distributions, and under the low-energy limit of such distributions the slope of the excitation function keeps increasing in many cases, so that the cross sections are strongly over-predicted by standard coupled-channels (CC) calculations; this was named a hindrance effect [4]. A further point of interest relies in the oscillations that were evidenced a long time ago in the excitation function of light heavy-ion systems in the energy region above the Coulomb barrier.

This talk will review the results of recent experiments on heavy-ion fusion of medium-light systems, and it will focus in particular on fusion of the ^{28,30}Si+^{28,30}Si systems [5], where all phenomena cited above show up to a various extent. We have clear evidence of the consequences produced by the oblate deformation of ^{28}Si, by the vibrational nature of ^{30}Si and by the coupling to neutron transfer channels in ^{28}Si+^{30}Si. Moreover, the hindrance phenomenon is clearly observed in ^{28}Si+^{30}Si while an anomalous trend shows up for ^{28}Si+^{28}Si where the hindrance disappears at the lowest energies, possibly due to the oblate shape of that nucleus. Furthermore, for this system the excitation function has been measured with great detail also above the barrier, and the nature of the regular oscillations that have been revealed, will be discussed.

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Quantifying low-energy fusion dynamics of weakly bound nuclei

Alexis Diaz-Torres[1]

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Low-energy fusion reactions of nuclei far from stability are crucial for forming heavy elements in the universe, which are being intensively investigated in different rare-isotope beam facilities worldwide. The most exotic nuclei are often very weakly bound, and can easily breakup in their reactions with other nuclei. This results in a number of reaction processes, whose unified theoretical description is an outstanding problem. I will introduce both a classical dynamical model and a quantum-mechanical dynamical model of fusion, which seem to provide an unambiguous solution to this problem [1]. These models are a powerful tool for planning and interpreting fusion experiments involving exotic nuclei as well as in applications to gamma ray spectroscopy.

[1] M. Boselli and A. Diaz-Torres, J. Phys. G **41**, 094001 (2014)

Dynamical effects in fission reactions investigated at high excitation energy

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A complete description of the fission process still represents a real challenge despite the recent progress based on microscopic quantum dynamic models [1]. Statistical models, proposed soon after the discovery of fission [2], provide an optimum tool to describe fission probabilities at excitation energies around the fission barrier, for which statistical times dominate over the typical time scales for the coupling between intrinsic and collective degrees of freedom (~ 10^{-21} s^{-1}). At high excitation energies, pre- and post-scission particle emission [3] and fission probabilities [4] indicate that simple statistical approaches are not valid anymore and models describing the dynamics of the process are required. These models are based on transport equations (e.g. Fokker-Planck or Langevin) including dissipative and stochastic terms where the main ingredients are the potential landscape and the friction and inertia tensors [5]. The friction or viscosity parameter is particularly interesting since it quantifies the magnitude of the coupling between collective and intrinsic degrees of freedom in fission.

During the last years several experiments have addressed this topic taking advantage of proton induced reactions at relativistic energies for producing highly-excited fissioning nuclei with low angular momentum [6,7,8]. Under such conditions presaddle dissipative effects clearly manifest. Moreover, the inverse kinematic used in these experiments help in providing accurate measurements of the fission fragments properties. These high-quality measurements have given access to new observables constraining not only the strength of the nuclear dissipation parameter but also other key parameters influencing the theoretical description of the fission process as level densities.

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Thursday 25/06/2015
h. 14.30-16.40

SALA CONFERENZE LNS

PARALLEL SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

Symmetry Energy in Structure and in Central and Direct Reactions

P. Danielewicz

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Abstract not received

Three-body force effect on the properties of neutron-rich nuclear matter

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3) INFN-Pisa and Università di Pisa, Italy

We present an upgraded review of our microscopic investigation on the single-particle properties and the EOS of isospin asymmetric nuclear matter within the framework of the Brueckner theory extended to include a microscopic three-body force. We pay special attention to the discussion of the three-body force effect and the comparison of our results with the predictions by other ab initio approaches. Three-body force is shown to be necessary for reproducing the empirical saturation properties of symmetric nuclear matter within nonrelativistic microscopic frameworks, and also for extending the hole-line expansion to a wide density range. The three-body force effect on nuclear symmetry energy is repulsive, and it leads to a significant stiffening of the density dependence of symmetry energy at supra-saturation densities. Within the Brueckner approach, the three-body force affects the nucleon s.p. potentials primarily via its rearrangement contribution which is strongly repulsive and momentum-dependent at high densities and high momenta. Both the rearrangement contribution induced by the three-body force and the effect of ground state correlations are crucial for predicting reliably the single-particle properties within the Brueckner framework.

Asymmetry Dependence of the Nuclear Caloric Curve

A. McIntosh[1], A. Bonasera[2], P. Cammarata[1], K. Hagel[1], L. Helborn[1,], J. Mabiala[1],
L. May[1], P. Marini[1,], G. Souliotis[3], S. Wuenschel[1], A. Zarrella[1], H. Zheng[2], S. Yennello[1]

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My recent measurements have demonstrated a dependence of the caloric curve on the neutron-proton asymmetry. If confirmed, this represents a new feature of the nuclear equation of state. These results were made possible by the complete isotopic reconstruction of excited quasi-projectiles produced in heavy ion collisions. I will discuss the isotopic reconstruction and multiple probes of the the temperature, which are the strengths of this measurement. I will address the uncertainty which arises from the neutron measurement. I will present the status of an independent experiment designed to measure the caloric curve in a way that completely eliminates the previous uncertainties and will allow us to confirm or deny our initial discovery.

Study of the N/Z dependence of the level density parameter with Ar+Ni reactions

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The nuclear level density is an essential ingredient in calculating the statistical decay of a compound nucleus by particle evaporation, gamma-ray emission or fission. The statistical model has widespread use in nuclear physics and applied research. In all these areas, knowledge of the level density is needed. Ambitious investigations into the N/Z dependence of the level density parameter are conducted by the INDRA collaboration through the study of ^{34,36,40}Ar+^{58,60,64}Ni reactions. Over a large N/Z range, completely exclusive measurements of fusion-evaporation have been obtained by coupling the INDRA 4π multidetector [1] and the VAMOS [2] spectrometer. Preliminary results obtained for the ^{36}Ar+^{58}Ni system at 13.3 A MeV are presented: fusion-evaporation cross sections to deduce angular momentum distribution involved, mass distributions of evaporation residues and weighting of the individual decay channels. The relevant observables for such a promising study are discussed thanks to GEMINI [3] calculations.

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[3] J. Charity *et al.*, Phys. Rev. **C 67** (2003) 044611

Properties of Excited A = 40 Nuclear Systems With Varying Matter Composition

K. Schmidt[1], M. Barbui[2], S. Wuenschel[2], J. B. Natowitz[2], H. Zheng[1,4], N. Blando[2], K. Hagel[2], A. Bonasera[2,6], G. Giuliani[2], M. Rodrigues[3], R. Wada[4], M. Huang[4], C. Botosso[2], G. Liu[2], G. Viesti[2], S. Moretto[2], G. Prete[2], S. Pesente[2], D. Fabris[2], Y. El. Masri[2], T. Keutgen[7], S. Kowalski[1] E. J. Kim[8] and A. Kumar[2]

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When two alpha-conjugate nuclei collide, bosonic properties might control important features of the reaction dynamics and the evolution of the excited system. In an analysis of ^{40}Ca $+^{40}$ Ca reactions at 35MeV/A we selected classes of projectile-like sources with exit channels consisting of only bosons, only fermions, only even-even nuclei, only odd - odd nuclei, only even - odd nuclei and only alpha-conjugate nuclei, respectively and searched for kinematic characteristics of these systems which might differ depending upon the type of matter selected. The distributions of various observables for the different classes of matter and comparisons between them will be presented and discussed.

Effects of symmetry energy and momentum dependent interaction on low-energy reaction mechanisms

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The Stochastic Mean Field model including momentum dependent interaction is developed. We also incorporate the standard Skyrme effective interaction into the model, employing several parameterizations available in the literature. Within the framework of this model, we study the effects of momentum dependent interaction on low-energy reaction mechanisms, which are affected by the properties of nuclear matter at sub-saturation regions. In particular, the effect on collective excitation mechanisms, such as dipole mode excitations, will be investigated. The role of the isovector terms of the nuclear interaction, connected to the symmetry energy of the nuclear EoS, will be discussed. On the other hand, we also investigate the impact of the nuclear symmetry energy on some features of compact stars. We use different EoS to study neutron stars by solving the TOV equations. We demonstrate that different EoS give different mass and radius relation for neutron stars even when they have exactly the same ground state (gs) properties.

Thuerday 25/06/2015
h. 14.30-16.35

AULA AZZURRA LNS

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

Static and dynamics effects in the elastic scattering of light radioactive nuclei elastic: the ^{6}He, ^{8}Li,^{10}Be, ^{8}B and ^{10}C cases

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Correlations of the valence nucleon or nucleons and the strong coupling with the continuum can significantly distort the shell structure as well as the collective properties of the weakly bound exotic nuclei. Effects due to these properties should be expected also in the dynamics of the reactions induced by these nuclei. Elastic scattering, at low energies, is the most important process in terms of cross section and provides information on the nuclear potential, as well as the total reaction cross section. The angular distributions of elastic scattering may contain effects due to the coupling with other reaction channels, providing indirect information about these channels. For exotic nuclei, those processes introduce characteristic dynamic polarizations in the optical potential which are not present in the case of stable projectiles. Effect of cluster configuration of this light nuclei can also be present in the elastic data.

In this talk we will present experimental data related to elastic scattering of exotic projectiles, such as ^{6}He, ^{8}Li, ^{8}B, ^{7,9,10}Be and ^{10}C, on targets with different masses that illustrate these phenomena.

Using CHIMERA detector at LNS for γ-particle coincidences

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[2] INFN - Laboratori Nazionali del Sud, Via S. Sofia, Catania, Italy
[3] Dip. di Fisica e Astronomia, Università di Catania, Via S. Sofia, Catania, Italy
[4] INFN Gruppo collegato di Messina & Dip. di Fisica, Università di Messina, Italy
5 Facoltà di Ingegneria e Architettura, Università Kore, Enna, Italy
[6] INFN Sezione di Napoli & Dipartimento di Fisica, Università Federico II, Napoli, Italy
[7] Politecnico di Milano dipartimento di elettronica informazione e Bioingegneria and INFN Sezione di Milano, Italy
[8] Saha Institute for Nuclear Physics, Kolkata, India
[9] Instituto de Fisica, Universidad Nacional Autonoma de México, México D.F. 0100 Mexico
[+] Deceased

We have recently tested the quality of γ-ray angular distributions that can be extracted in particle-gamma coincidence measurements [1] using the CHIMERA detector [2,3] at LNS. γ-rays are detected by using the CsI(Tl) detectors belonging to the spherical part of the CHIMERA array (from 30° to 176°). Very clean γ-rays angular distributions were extracted in reactions induced by proton and ^{16}O beams on ^{12}C, showing the effect of proton spin flip on the γ-rays angular distributions. γ-particle coincidence measurements were performed also in reactions induced by neutron rich exotic beams (^{6,8}He, ^{8,9}Li, ^{10,11}Be, ^{13}B, ^{16,17}C, ^{68}Ni), produced through in-flight fragmentation at LNS [4]. In most recent experiments also the Farcos array [5] was used to increase both energy and angular resolution measurements of the detected particles. Results obtained with both stable and radioactive beams will be shown.

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α Cluster Structure in Unbound States of ^{19}Ne

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Cluster structures are well known to appear in the excited states of light nuclear systems. A typical example can be seen in ^{20}Ne. The α + ^{16}O cluster model is successful in reproducing the ground and excited rotational band structure in ^{20}Ne [1]. In ^{19}F, which is one proton deficient system of ^{20}Ne, the formation of the α + ^{15}N cluster structures are deeply analyzed [2,3]. On the contrary, the α + ^{15}O cluster structure, corresponding to the neutron deficient system, still remains unclear although the pioneering works can be seen in Refs. [2,3]. The continuum component of this cluster structure is expected to be important in the radiative capture reaction of ^{15}O(α,γ)^{19}Ne, which plays the crucial role in the advanced stage of the Hydrogen burning [4]. In the present study, we investigate the α + ^{15}O structure in the ^{19}Ne nucleus.

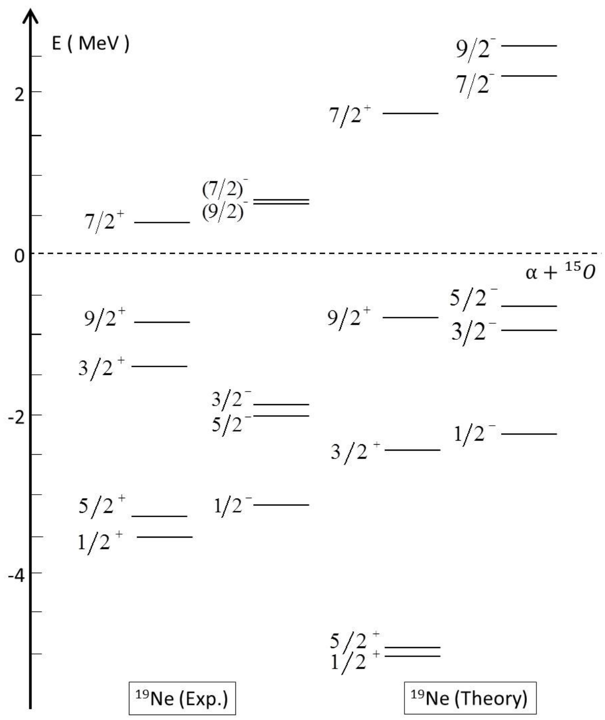

Figure 1: Comparison of the theoretical spectra (right levels) with the experimental data (left levels) in ^{19}Ne. The theoretical levels are obtained from the microscopic cluster model.

We have applied the microscopic cluster model, which is called the Generator Coordinate Method (GCM) [5]. The GCM calculation is based on the nucleon degrees of freedom, and the anti-symmetrization among all nucleons are explicitly considered. The energy levels calculated from GCM is plotted in Fig. 1. The GCM calculation (right levels) nicely reproduce the qualitative feature of the positive parity band ($J^\pi = 1/2^+, ...$) and the negative parity band ($J^\pi = 1/2^-, ...$). We have also applied the potential model, in which the α + ^{15}O potential is determined from the elastic scattering of the α + ^{15}N system. In this potential model, the excitation function of the elastic scattering below $E_{c.m.} \leq 10$ MeV is predicted, which will be measured in future experiments.

In the radiative capture reaction at the astrophysical energy region, the coupling to the five-particle-two-hole ($5p$-$2h$) configuration in ^{19}Ne is expected to be crucial [4]. In the present report, we will also discuss the effect of the $5p$-$2h$ configuration on the α + ^{15}O resonant states.

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BCS description of weakly bound nuclei with a discretized continuum

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Present developments in nuclear facilities allow to study new exotic nuclei, approaching the proton and neutron driplines for both light and medium mass regions of the Segrè Chart. Nuclei close to the dripline are weakly bound and, therefore, affected by the continuum, situations where the last nucleon or nucleons are no longer bound and can explore distances far from the rest of the nucleus.

The effects of the continuum have been traditionally explored for light nuclei where the proximity of the driplines provides a rich variety of weakly bound nuclei and experimental data. In the medium mass region, several attempts for generalizing mean field approaches have been proposed with different results [1,2]. Regarding the Bardeen-Cooper-Schrieffer (BCS) approximation, the single particle continuum is first discretized and then treated normally splitting resonant and background contributions or including a continuum single particle level density [2].

In this contribution we explore the possibility of treating background and resonant parts of the continuum on the same footage. In order to do so, an average constant pairing interaction G cannot be used. General BCS equations are solved for a pairing strength that depends on the single particle wavefunctions of the neutrons forming the Cooper pair. This non-constant G is obtained integrating a residual delta interaction between the different pairs.

This procedure is applied to neutron rich oxygen isotopes. We compare the calculated experimental binding energies and two neutron separation energies with the available experimental data. We also study the spectroscopic factors for two neutron transfer reactions in this isotopic chain. The impact of the different choices for discretizing and including the continuum on these observables is discussed.

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Study on the Neutron-Neutron Correlation in ^{8}He

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In the past decades, many theoretical and experimental studies have been devoted to the neutron-neutron correlation in neutron-rich nuclei. It is of fundamental importance in nuclear physics, but more efforts are still required to reach a full understanding of this phenomenon. ^{8}He, with a well pronounced structure of a core plus several valence neutrons, provides good opportunities to conduct studies directed towards this issue, and strong correlation between the valence neutrons of ^{8}He has been predicted from theoretical calculations in recent years [1, 2].

We have carried out a breakup reaction experiment with ^{8}He beam at 82.3 MeV/nucleon at RIPS beam line in RIKEN, in which the charged fragment ^{6}He and the two neutrons were detected in coincidence [3]. Obvious enhancements at small n-n relative energies and at small n-n c.m.s opening angles were observed, which points to strong correlation between the two emitted neutrons. And strong neutron-neutron correlation in ^{8}He is also revealed from the angular and energy correlation analysis. Some intriguing phenomena concerning the mechanism for the two-neutron emission in 8He were also observed in this work.

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Breakup of ^{22}C in a three-body model

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The breakup of the heaviest Borromean nucleus yet observed ^{22}C [1] is studied by using a four-body coulomb corrected eikonal model [2,3]. The ground and continuum states are constructed with a three-body model in hyperspherical coordinates [4]. The continuum states are computed through a three-body R-matrix method [5]. This is a rigorous method, that calculates the continuum states with the correct asymptotic behavior. As there is no precise experimental information of the ^{21}C virtual state, we construct different ^{20}C-n potentials that provide scattering lengths varying between one order of magnitude, giving different ground state energies and rms radii. A very important property of Borromean nuclei is that they present enhanced dipole strength distributions. This quantity is studied as a function of the ground state energies. We compute breakup cross sections by using different ^{20}C-Target folding potentials to show their sensitivity. The present approach helps to clarify many aspects of the Borromean character of ^{22}C and it is relevant to current and future experimental measurements.

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Thursday 25/06/2015
h. 14.30-16.40

Aula F Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Relativistic Heavy-Ion Collisions

Production and spectroscopy of light hypernuclei with heavy ion induced reactions

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The HypHI project at GSI aims to perform precise hypernuclear spectroscopy with induced reactions of stable heavy ion projectiles and rare-isotope beams on a fixed target. Two experiments have been already performed with stable heavy ion beams in order to prove the experimental principle, Phase 0 and Phase 0.5, respectively with the ^{6}Li+^{12}C and ^{20}Ne+^{12}C reactions at 2 *A* GeV.

The data analysis for the Phase 0 experiment has been already completed, and the results on the invariant mass reconstruction and lifetime values for the observed $^{3}_{\Lambda}$H and $^{3}_{\Lambda}$H hypernuclei as well as the Λ-hyperon have been published [1]. In addition to these known hypernuclei, we have also observed signals in the d+π^- + t+π^- invariant mass distributions, and the lifetime measurements of the state associated with these final states have revealed that it decays with a strangeness-changing weak interaction [2]. Tentatively, we have suggested that these final states may indicate an existence of a strange neutral nucleus $^{3}_{\Lambda}$n [2]. Analyses on the production cross section as well as on the kinematics variables have also been completed [3], and the results will be also discussed. The analysis for the Phase 0.5 experiment are to be completed [4], and preliminary results will be also discussed.

Since the experimental principle has been already proven by the Phase 0 experiment, we plan to extend the project with rare-isotope beams and stable heavy ion beams with FRS at GSI and super-FRS at FAIR. In the proposed experiments, FRS and super-FRS will be employed not only for the production of rare-isotope beams but also as a high resolution forward spectrometer. Details of proposed experiments will be discussed.

In addition, we would like to discuss on the observed lifetime values of $^{3}_{\Lambda}$H, the combined analysis of which has revealed that it is significantly shorter than that of the Λ-hyperon [5], and it should be noted that it has not been understood theoretically even though it is the simplest hypernucleus.

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[4] V. Bozkurt *et al.*, the HypHI collaboration, to be published

[5] C. Rappold *et al.*, Phys. Lett. **B 728**, 543 (2014)

High pt Identified Particle Production in ALICE

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Measurements of the transverse momentum spectra of light flavor particles at intermediate and high pT are an important tool for QCD studies. In pp collisions they provide a baseline for perturbative QCD, while in Pb-Pb they are used to investigate the suppression caused by the surrounding medium. In p-Pb collisions, such measurements provide a reference to disentangle final from initial state effects and thus play an important role in the search for signatures of the formation of a deconfined hot medium. While the comparison of the p-Pb and Pb-Pb data indicates that initial state effects do not play a role in the suppression of hadron production observed in heavy ion collisions, several measurements of particle production in the low and intermediate pT region indicate the presence of collective effects. The evolution of RAA for identified and unindentified particles with centrality and pT will be discussed and compared to theoretical predictions as well as lower energy measurements.

Toward a solution of the R_{AA} and v2 puzzle for heavy quarks

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One of the primary aims of the ongoing nuclear collisions at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) energies is to create a Quark Gluon Plasma (QGP). The heavy quarks, charm and bottom constitutes a unique probe of the QGP properties. Both at RHIC and LHC energies a puzzling relation between the nuclear modification factor $R_{AA}(p_T)$ and the elliptic flow $v_2(p_T)$ related to heavy quark has been observed which challenged all the existing models. We discuss how the temperature dependence of the heavy quark drag coefficient is responsible to address for a large part of such a puzzle. In particular, we have considered four different models to evaluate the temperature dependence of drag and diffusion coefficients propagating through a quark gluon plasma (QGP). All the four different models are set to reproduce the same $R_{AA}(pT)$ observed in experiments at RHIC and LHC energy. We point out that for the same $R_{AA}(pT)$ one can generate 2-3 times more v_2 depending on the temperature dependence of the heavy quark drag coefficient. An increasing drag coefficient as T_c is a major ingredient for a simultaneous description of $R_{AA}(p_T)$ and $v_2(p_T)$ [1]

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Fluctuations of conserved charges and freeze-out conditions in heavy ion collisions

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I will review the recent results on fluctuations of conserved charges obtained on the lattice by the Wuppertal-Budapest collaboration. I will then show a comparison between lattice QCD calculations and experimental data from the RHIC beam energy scan, in order to extract the chemical freeze-out parameters (temperature and baryo-chemical potential) of a heavy-ion collision from first principles. Future perspectives for the measurement of strangeness fluctuations will be discussed.

LIGHT FRAGMENTS FROM (C + Be) INTERACTIONS AT 0.6 GeV/nucleon

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Momentum distributions of hydrogen and helium isotopes from 12C fragmentation on a Be target were measured at 3.5o in the FRAGM experiment [1] at the ITEP TWA heavy ion accelerator. The fragments were selected by correlated time of flight and dE/dx measurements with a magnetic spectrometer with scintillation counters. The main attention was drawn to the high momentum region where the fragment velocity exceeds the velocity of the projectile nucleus. At energy 0.6 GeV/nucleon the momentum spectra of fragments span the region of the fragmentation peak as well as the cumulative region. The differential cross sections cover three-six orders of magnitude depending on the fragment. The shapes of the momentum spectra are compared to the predictions of four ion-ion interaction models: INCL++, LAQGSM03.03, QMD and BC. The kinetic energy spectra of the fragments in the projectile rest frame are fitted with the sum of two exponents with different slope parameters. The temperatures of the source extracted from the slope parameters are 5-8 MeV for a soft component and 15-30 MeV for a hard component. For each fragment the temperatures are compared with the predictions of the above mentioned models as well as with those measured at 1 GeV/nucleon in Au+Au interactions [2]. A dependance of these temperatures on the fragment type is discussed.

[1] B.M.Abramov *et al.*, JETP Lett.**97**,439 (2013); Kulikov *et al.*, POS(Baldin ISHEPP XXII) 079 (2015) [2] T. Odeh *et al.*, Phys. Rev. Lett. **84**, 4557 (2000).

Time evolution of heave quark distribution function in quark gluon plasmas: Laplace transform approach

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Relativistic Heavy-Ion Collider (RHIC) experiments have shown that the state of matter produced after the collision cannot be described by a non interacting quark- gluon gas. Indeed this state of matter consists of a strongly coupled Quark-Gluon Plasma (QGP). Light quarks making up the bulk of the QGP while heavy quarks (HQ), mainly, charm and bottom, act as impurities of the medium. They are not at a fully equilibrated situation with their background, and thus they act as a memory of interaction history during thermalization even at soft momentum scales. In other words, heavy quarks can be considered as valuable probes of the QGP.

The heavy flavor transport in an expanding system of QGP is the main aim of this paper. For this end, we have to find the distribution function of heavy quarks during their thermalization with the medium. Time evolution of heavy quark distribution functions in QGP has been investigated using the Fokker-Plank (FP) equation. The drag and diffusion factors needed for solving the FP equation are derived using the energy loss rate in the QGP due to elastic collisions. The Bjorken method has been used for energy loss with high-momentum transfer. Low-momentum transfer dominated by the interactions with plasma collective modes has been taken into account by hard thermal loop approximation. Energy loss due to gluon emission has also been considered.

The Iterative Laplace Transformation Method (ILTM) is employed to solve the Fokker-Plank equation for such system. This method is more stable in comparison with other presented methods for solving such evolutional equations with non vanishing initial values at the borders. The initial distribution functions of heavy quarks in our calculations are from published data. In order to control the validity of outcomes, we have used evaluated HQ distribution functions to calculate the depletion of high momentum hadrons (D and B mesons) produced in N-N collisions with respect to those produced in p-p collisions expressed through the nuclear modification factor R_{AA}. Our results are in agreement with the experimental data produced by PHENIX for small values of transverse momentum. Therefore it is shown that the ILTM is a reliable technique with suitable stability for solving the Fokker-Plank equation.

Thursday 25/06/2015
h. 14.30-16.40

Aula A Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Fusion and Fission

STUDY OF GDR WIDTHS AT LOW TEMPERATURE AND LAMBDA SPECTROMETER

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Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata- 700 064, India

The study of Giant Dipole Resonance (GDR), even after almost 70 years of its discovery, still remains an intriguing and a very relevant topic of research, particularly in the case of hot and fast rotating nuclei. Many new facets of this giant collective mode of vibration are being brought to light recently owing to the new age powerful detection systems. Even with low energy light-ion and heavy-ion accelerated beams and employing the powerful large volume and modular high energy photon spectrometer LAMBDA at VECC, Kolkata, India, a number of very interesting experimental observations have been made recently, which radically changes the present understanding of GDR vibrations in moderately hot nuclei in general. Particularly the nature of the evolution of the width of GDR at very low temperatures remained a problem both experimentally and theoretically as there were practically no data due to experimental difficulties. Very recently the GDR widths have been measured precisely by the Kolkata group over the entire mass range and observed a hitherto unknown behavior contrary to what the popular models predict. This new behavior has been explained considering the relative dominance of the shape fluctuations due to GDR vibration and the thermal vibrations. On the other hand the microscopic model considers the non-zero pairing fluctuations to describe the behavior at low temperatures.

The LAMBDA spectrometer at Kolkata has been very efficiently being used to study the high energy gamma decays from nuclear reactions to study various structures at high excitations viz., the Jacobi shape transition, isospin mixing in nuclei at various excitations and also for studying some specific reaction mechanisms, like, orbiting.

The availability of higher energy heavy-ion beams from the near ready superconducting cyclotron at VECC will open up many more interesting and challenging prospects with the LAMBDA spectrometer. Exciting challenges and opportunities are also on offer for studying the properties and dynamics of hot exotic nuclei with stable and RI beams through high energy gamma decays from giant resonances.

A few of some very interesting results obtained recently at VECC with the LAMBDA spectrometer and further research possibilities will be discussed during the conference.

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Systematic study of quasifission characteristics and timescales in heavy element formation reactions

D.J. Hinde[1], E. Williams[1], C. Simenel[1], M. Dasgupta[1], A. Wakhle[1,2], I.P. Carter[1], K.J. Cook[1], D.Y. Jeung[1], D.H. Luong[1], G. Mohanto[1], C.S. Palshetkar[1], E. Prasad[1], D.C. Rafferty[1] and R. du Rietz[1,3]

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Quasifission is an important process suppressing fusion when creating superheavy elements in collisions of two heavy nuclei. It results in rapid separation of the dinuclear system formed at contact. Achieving reliable *a priori* prediction of quasifission probabilities is a difficult problem.

Through measurements with projectiles from C to Ni [1], the Australian National University's Heavy Ion Accelerator Facility and CUBE spectrometer have been used to map out mass-angle distributions (MAD) - the fission mass-ratio as a function of centre-of-mass angle. These provide information on quasifission timescales and characteristics in the least model-dependent way.

Mapping mass-angle distribution characteristics against entrance channel and compound nucleus fissilities [1] helps to guide future experiments. Importantly it provides an empirical baseline to better determine important effects of nuclear structure on quasifission in collisions at near- barrier energies. The identification of broad trends, to then allow exploration of finer details, finds an analogy with the liquid drop model of nuclear masses, in which local shell effects can be quantified when the underlying smooth trends are well defined. This principle is exploited in interpreting recent experimental MAD. Corresponding TDHF quasifission calculations [2] will be presented.

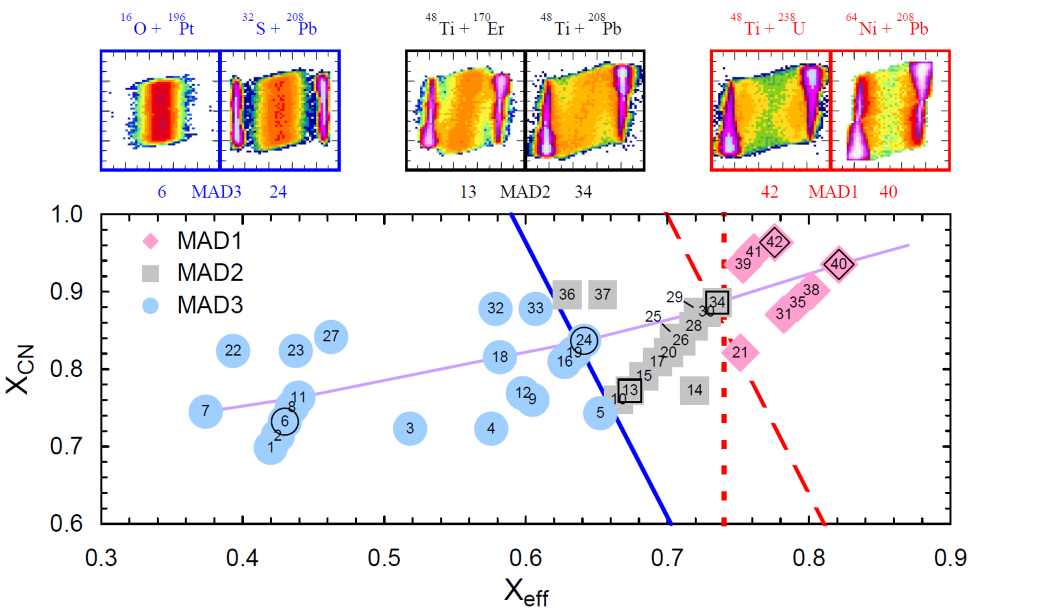

Fig. 1. Main quasifission MAD characteristic plotted against entrance-channel (x_{eff}) and compound nucleus (x_{cn}) fissilities. Symbols are referenced to the reaction numbers of Ref.1, the colour indicating the MAD type (related to the sticking time scale) illustrated by the numbered MAD examples above. The diagonal blue line divides reactions without (left) and with (right) a mass-angle correlation. The dashed red lines indicate boundaries of symmetric-peaked mass distributions (to the left).

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[2] A. Wakhle *et al.*, Phys. Rev. Lett. **113** (2014) 1825

The 12th International Conference on Nucleus-Nucleus Collisions, June 21-26, 2015, Catania, Italy

Fission study by multi-nucleon transfer reaction at JAEA

K. Hirose[1], K. Nishio[1], R. Leguillon[1], J. Smallcombe[1], I. Nishinaka[1], H. Makii[1], R. Orlandi[1], K. Tsukada[1], N. Tamura[1,2], S. Goto[2], S. Chiba[3]

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[2] *Graduate School of Science and Technology, Niigata University, Japan*
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We have developed a measurement system for the multi-nucleon transfer reaction and been studying fission of short-lived minor actinides and neutron-rich nuclides using ^{238}U and ^{232}Th targets. In this experiment, more than ten nuclides were excited up to few tens of MeV including compound nuclei such as ^{240}U, ^{241}Np, ^{243}Pu fission data of which are obtained for the first time.

The experiment was performed at the tandem accelerator facility of Japan Atomic Energy Agency. The target electro-deposited on a nickel backing foil was bombarded with ^{18}O beams. Projectile-like scattered particles after the multi-nucleon transfer reaction were detected and identified using a ΔE-E silicon telescope. The mass distribution was deduced from the time difference between two fission fragments from the compound nucleus which were detected using two pairs of multi-wire proportional counters. Neutrons accompanied by fission were also measured using liquid scintillators placed around the reaction chamber.

In the nucleon transfer reaction, the axis of the angular-momentum transfer can be determined from the direction of the scattered particle. This is one of the most different point from the neutron/ion-induced fusion-fission reaction where only the plane on which the axis lies can be determined. The fission angular distributions with respect to this axis as well as the mass yield, the prompt neutron multiplicity and so on will be presented in the conference, and the data obtained using a ^{248}Cm target will also be available.

Fusion and neutron transfer reactions with weakly bound nuclei within time-dependent and coupled channel approaches

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The numerical solving of the time-dependent Schrödinger equation (TDSE) provides new possibilities for theoretical study of transfer reactions and the first (capture) stage of fusion reactions [1, 2]. In this model the motion of nuclei cores is described on basis of the classical physics. The small typical grid spacing (~ 0.2 fm) of TDSE method leads to correct calculations of the spatial structure of the external (valence) neutron wave function with the formation of two center (molecular) states (Fig. 1a) [3, 4]. The traditional coupled channel approach was combined with the TDSE method [2, 5]. The value of the coupling strength was determined by time-dependent two-center level populations. The coupling matrix elements were determined by the two-center wave functions of the valence neutron. They were calculated within the two-center shell model based on the Bessel series [2]. Results of the cross section calculation for the formation of the ^{198}Au (Fig. 1b) and fusion (Fig. 1c) in the ^{6}He+^{197}Au reaction [6, 7] and for the formation ^{65}Zn isotopes and fusion in ^{6}He+^{64}Zn reaction [8] agree satisfactorily with the experimental data near the barrier. A few additional three-body and two-body quantum models were used for more careful study the processes of neutron transfer, breakup of the weakly bound nucleus ^{6}He and sub-barrier fusion. They are: one and two nuclear cores plus one [1] and two valence neutrons, one and two cores plus a di-neutron.

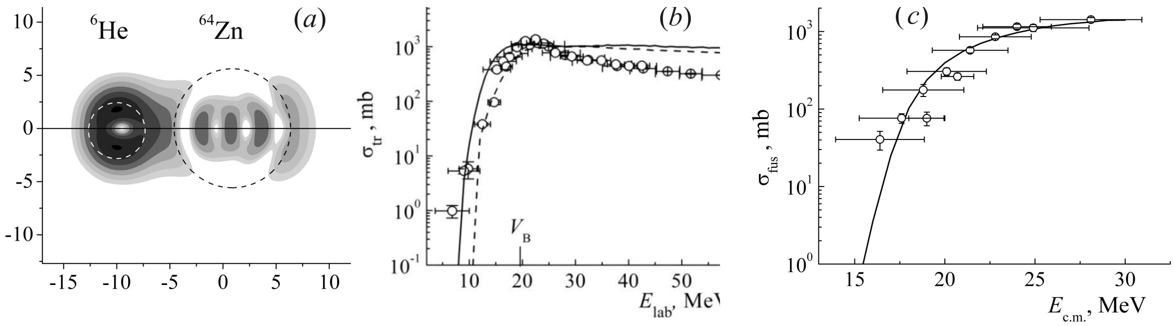

Fig. 1. a) The probability density of the valence neutrons of the ^{6}He nucleus during a frontal collision with the ^{64}Zn at energy in the center of mass system $E_{c.m.} = 8$ MeV, a scale factor is 1 fm, and radii of the circumferences equal to radii of the nuclei. b, c) The excitation functions for the formation of the ^{198}Au isotope (b) and fusion (c) in the reaction ^{6}He+^{197}Au. Experimental data (circles) is from [6, 7]. Theoretical curves were calculated within the coupled channel approach (solid lines) and the TDSE method (dashed line); V_B is the Coulomb barrier.

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[2] V. V. Samarin, Phys. Atom. Nucl. **78**, 128 (2015)
[3] V. V. Samarin, EPJ Web Conf. **66**, 03075 (2014)
[4] V. V. Samarin, EPJ Web Conf. **86**, 00040 (2015)
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[6] Yu. E. Penionzhkevich *et al.*, Eur. Phys. J. A **31**, 185 (2007)
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[8] V. Scuderi *et al.*, Phys. Rev. C. 84, 064604 (2011)

Measurement of fusion excitation function for $^{7}Li+^{64}Ni$ at near the V_B

Md. Moin Shaikh[1], Subinit Roy[1], S. Rajbanshi[1], A. Mukherjee[1], M. K. Pradhan[1], P. Basu[1], V. Nanal[2], S. Pal[2], A. Shrivastava[3], S. Saha[2] and R.G. Pillay[2]

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A recent investigation of $^{6}Li+^{64}Ni$ system [1] has shown that the total fusion (TF) cross section (σ_{TF}), that includes the complete fusion (CF) and non complete fusion cross sections, significantly enhanced below barrier energies. Subsequently CF cross section has been extracted using major *xn* channels coming from pure CF process. The extracted CF cross section show suppression at above barrier energies and enhanced in below barrier energy region compared to the one dimensional barrier penetration model (1DBPM) for that system. The method has been extended to the measurement of fusion of ^{7}Li with ^{64}Ni. The isotope ^{7}Li is more deformed and less weakly bound compared to ^{6}Li. Hence, the comparison of it TF and CF cross section with respect to ^{6}Li is of primary interest [2].

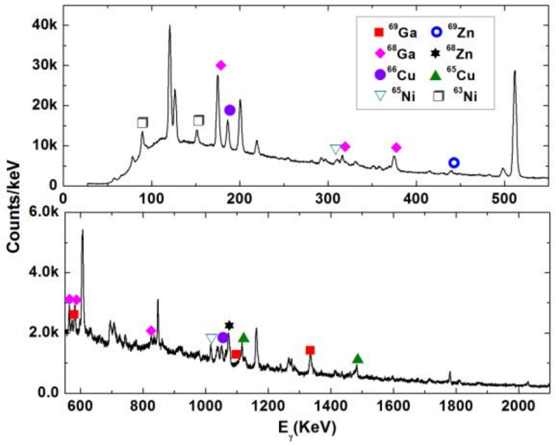

FIG.1 Representative γ spectrum for $^{7}Li+^{64}Ni$ fusion at E_{lab} = 28 MeV.

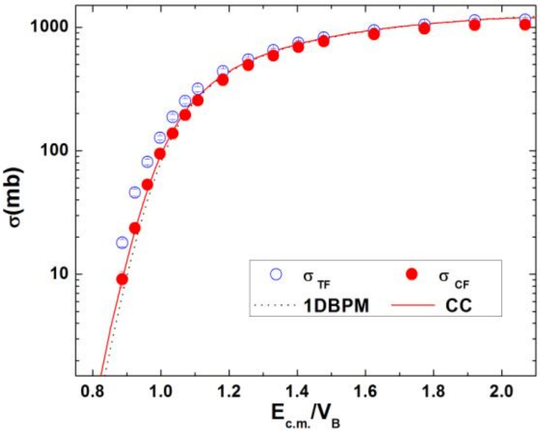

FIG.2 The measured fusion excitation function for $^{7}Li+^{64}Ni$ system with theoretical predictions.

The measurement of $^{7}Li+^{64}Ni$ system fusion was carried out at the Pelletron-Linac facility at Mumbai, India. Online characteristic γ-rays were detected to estimate the cross sections. A Representative spectrum is shown in Fig. 1. The excitation function is measured over energy range 12 to 28 MeV. The excitation function data in comparison with the 1DBPM and coupled channel (CC) predictions from the code CCFULL [3] is shown in Fig. 2. Details of the experiment and the interpretation of the data in reference to the model predictions will be presented in the conference.

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Systematics for low energy incomplete fusion: still a puzzle?

Abhishek Yadav[1], P Kumar[2], Mohd Shuaib[2], Vijay R Sharma[2], Indu Bala[1], D P Singh[3], P P Singh[4], M K Sharma[5], R Kumar[1], R P Singh[1], S Muralithar[1], B P Singh[2], and R Prasad[2]

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During the last couple of decades, with the observation of incomplete fusion (ICF) reactions at energies in the vicinity of Coulomb barrier, considerable efforts are being employed to look for the systematics of ICF reactions at these low energies [1-4]. Complete fusion (CF) is supposed to be the sole contributor to the total fusion cross section at these energies. Since the observation of ICF reactions [5-6], various models were proposed to explain these observables [1-3]. Most of these models are found to fit the experimental data at energies $\geq$ 10 MeV/nucleon to a large extent [3], however, at energies $\approx$ 3-7 MeV/nucleon, the mechanism of incomplete mass transfer is not well understood. It is not out of place to mention that, presently, no theoretical model is available which could reproduce the low energy ICF data satisfactorily [4]. Hence, in recent years, the study of low energy ICF reactions has triggered the resurgent interest to correlate the onset of ICF with entrance channel parameters and to look for the general systematics.

In order to look for the systematics of low energy ICF-reactions, series of experiments has been performed at the Inter-University Accelerator Centre (IUAC), New Delhi. In the present work, the excitation functions (EFs) of ^{18}O+^{159}Tb system and recoil range distribution (RRDs) of ^{12}C+^{159}Tb have been measured & compared with the other nearby systems to understand the ICF reactions. The onset of ICF at slightly above barrier energies has been emphasized in the EFs measurements, however, a clear existence of ICF at low incident energies has been demonstrated by measuring more than one linear momentum transfer components in the measurement of RRDs. In order to have a better insight to the ICF processes, the ICF-fraction have been deduced using the method used in ref. [3]. Morgenstern et al. [7] correlated the ICF fraction with entrance channel mass asymmetry (μ_A), however, Singh et al. [3] introduced the importance of projectile structure in ProMass-systematics. Apart from this, one of our papers shows the dependence of F_{ICF} on the target mass or $Z_P \cdot Z_T$ of interacting partners for a wide range of projectile-target combinations [4]. Further, in one of our recent papers, the projectile structure effect on ICF has been explained by introducing the α-Q-value systematics [4]. As such, the recent experimental results on ICF will be discussed in light of existing systematics during the conference, and an attempt will be made to draw a pathway for some universal systematic for ICF at low energies.

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[4] Abhishek Yadav *et al.*, Phys. Rev C **85**, 034614; *ibid* **85**, 064617; *ibid* **86**, 064603 (2012).
[5] H. C. Britt and A. R. Quinton, Phys. Rev. **124**, 877 (1961).
[6] J. Galin *et al.*, Phys. Rev. C **9**, 1018 (1974).
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Thursday 25/06/2015
h. 14.30-16.20

AULA 52 LNS

PARALLEL SESSION

Nuclear Astrophysics

Indirect techniques for astrophysical reaction rates determinations

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Direct measurements of nuclear reactions of astrophysical interest can be challenging. Alternative experimental techniques such as transfer reactions, inelastic scattering reactions and charge-exchange reactions offer the possibility to study these reactions by using stable beams. In this context, I will present recent results that were obtained in Orsay using these indirect techniques. The examples will concern various astrophysical sites, from the Big-Bang nucleosynthesis to the production of radioisotopes in massive stars.

Studying astrophysical reactions with low-energy RI beams at CRIB

H. Yamaguchi[1], D. Kahl[1], S. Hayakawa[1,2], Y. Sakaguchi[1], Y. Wakabayashi[3,1], T. Hashimoto[4,1], S. Cherubini[2,5], M. Gulino[2,6], C. Spitaleri[2,5], G.G. Rapisarda[2,5], M. La Cognata[2], L. Lamia[5], S. Romano[2,5], S. Kubono[3,1], N. Iwasa[7], T. Teranishi[8], T. Kawabata[9], Y.K. Kwon[4], D.N. Binh[10,1], L.H. Khiem[11], N.N. Duy[12], S. Kato[13], T. Komatsubara[4], A. Coc[14], N. de Sereville[15], F. Hammache[15], G. Kiss[16], S. Bishop[2,17].

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[12] *Dong Nai University, Bui Trong Nghia Street, Dong Nai province, Vietnam.*
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[14] *Centre de Spectrometrie Nucleaire et de Spectrometrie de Masse, Orsay, France.*
[15] *Institut de Physique Nucleaire, Orsay, France.*
[16] *Institute for Nuclear Research (MTA-ATOMKI), Debrecen, Hungary.*
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CRIB (CNS Radio-Isotope Beam separator) is a low-energy RI beam separator of Center for Nuclear Study (CNS), University of Tokyo. Studies on nuclear astrophysics, nuclear structure, and other interests have been performed using the RI beams at CRIB, forming international collaborations. Recent improvements on the beam production at CRIB and experimental studies are discussed, including results and plans for studies on alpha-induced astrophysical reactions, and Trojan-Horse Method (THM) [1,2] measurements using RI beams.

The first THM measurement using an RI beam have recently been performed at CRIB. The measurement was to study the ^{18}F$(p, \alpha)^{15}$O reaction at low energies relevant to astrophysics via the three body reaction ^{2}H(^{18}F, α^{15}O)n. The ^{18}F$(p, \alpha)^{15}$O reaction rate is crucial to understand the nova explosion phenomena, and we successfully evaluated the reaction cross section at novae temperature experimentally for the first time.

Another method extensively used at CRIB is the resonant scattering. An example among the recent measurements is α resonant scattering with ^{7}Li and ^{7}Be beams [3]. This study is related to the astrophysical ^{7}Li/^{7}Be(α,γ) reactions, important at hot p-p chain and νp-process in supernovae. It is also of interest to study exotic cluster structure of ^{11}B/^{11}C nuclei, similar to the one observed at Hoyle state in ^{12}C.

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Fusion measurements of $^{12}C+^{12}C$ at energies of astrophysical interest

D. Santiago-Gonzalez[1,2], C. L. Jiang[2], K. E. Rehm[2], M. Alcorta[3], S. Almaraz-Calderon[2,*], M. L. Avila[2], A. D. Ayangeakaa[2], B. B. Back[2], D. Bourgin[4], B. Bucher[5], M. P. Carpenter[2], S. Courtin[4], H. M. David[2], C. M. Deibel[1], C. Dickerson[2], B. DiGiovine[2], X. Fang[6], J. P. Greene[2], F. Haas[4], D. J. Henderson[2], R. V. F. Janssens[2], D. Jenkins[7], J. Lai[1], T. Lauritsen[2], A. Lefebvre-Schuhl[8], D. Montanari[4], R. C. Pardo[2], M. Paul[9], D. Seweryniak[2], X. D. Tang[10], C. Ugalde[2], S. Zhu[2]

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[9] *Racah Institute of Physics, Hebrew University, Jerusalem 91904, Israel*
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The cross section of the $^{12}C+^{12}C$ fusion reaction at low energies is of paramount importance for models of stellar nucleosynthesis in different astrophysical scenarios, such as Type Ia supernovae and X-ray superbursts, in which this reaction is a primary route for the production of heavier elements. In a series of experiments performed at Argonne National Laboratory using Gammasphere and an array of silicon detectors, measurements of the fusion cross section of $^{12}C+^{12}C$ were successfully carried out in the center-of-mass energy range of 3-5 MeV using the γ and charged-particle coincidence technique. These were the first background-free fusion cross section measurements for $^{12}C+^{12}C$ at low energies. Our results are consistent with previous measurements in the high-energy region; however, our lowest energy measurement indicates a fusion cross section slightly lower than those obtained with other techniques. Results will be presented and the physical implications of extrapolations of the fusion hindrance model and other theoretical calculations will be discussed.

This material is based upon work supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and U.S. Department of Energy grant No. DE-FG02-96ER40978. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

Nuclear magics at explosive magnetization

V.N. Kondratyev[1]

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Nuclear densities exceeding normal values arise at core-collapse supernovae (SNe) events and can be achieved in heavy ion collisions. Accompanying strong magnetization is considered as noticeable pressure component for an explosion. Nuclides produced in such processes contain information on matter structure and explosion mechanisms. In this contribution we analyze possibilities for radionuclides to probe the internal regions of respective sites (cf. [1] and refs.therein): SNe, Transmutation Facilities (e.g., Accelerator-Driven System - ADS). Magnetic modification of nuclear structure is shown to shift the nuclear magic number in the iron region towards smaller mass numbers approaching titanium. Respectively, maximum of nucleosynthesis products is modified with an enhancement of titanium yield. The results are corroborated with an excess of ^{44}Ti revealed from the INTEGRAL mission data for yang supernova remnants at a field strength ranging up to ten teratesla..

[1] V.N. Kondratyev,. Phys.At.Nucl. **75**. 1442 (2012).; EPJ A **50**, 7 (2014)

The Trojan Horse Method as a tool for investigating astrophysically relevant fusion reactions

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In the framework of stellar nucleosynthesis and models, the combined study of the light elements (i.e. lithium, beryllium and boron) abundances in stellar atmospheres gives an unique opportunity for understanding stellar structure because of their different fragility against (p,alpha) reactions. This implies different stellar depths at which they are gradually destroyed, thus the residual atmospheric abundances will reflect the effect of plasma mixing. Being these reactions ignited at temperatures of few millions of Kelvin, experimental nuclear astrophysics has to use often extrapolation procedures to access the relevant Gamow energy peak. Thus, the developments of indirect techniques allowed the experimentalist to by pass such difficulties and, among them, the Trojan Horse Method (THM) has been largely applied for measuring the bare nucleus S(E)-factor for astrophysically relevant reactions, without experiencing both Coulomb penetrability and electron screening effects. THM allows one to extract the bare-nucleus cross-section of a charged-particle induced reaction a(x,c)C at astrophysical energies free of Coulomb suppression, by properly selecting the quasi-free (QF) contribution of an appropriate reaction a(A,cC)s, performed at energies well above the Coulomb barrier. Here, the nucleus A has a dominant x-s cluster configuration, thus representing the so-called "TH-nucleus". Here, in view of the recent TH measurements, the main destruction channel for the two lithium (6Li and 7Li) and boron (11B and 10B) will be discussed, giving large emphasis to their impact on astrophysical scenarios and to their measurement for probing electron screening effects.

Thursday 25/06/2015
h. 14.30-16.20

AULA 52 (LNS)

PARALLEL SESSION:

New Facilities and Detectors

FAZIA applications

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FAZIA Collaboration

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The FAZIA project [1] (present status and perspectives) is presented. The main achievements in terms of identification thresholds and isotopic resolution are discussed, together with the adopted technical solutions. The detector is particularly suited for the investigation of the isospin transport phenomena at intermediate beam energies; perspectives to further reduce the identification thresholds to cope with lower energy ISOL beams are briefly introduced. Some experimental results concerning isospin transport effects [2] obtained with a test telescope are presented. The study of isospin transport phenomena can give information on the symmetry energy term of the nuclear equation of state by means of the comparison of the experimental results on isospin related observables with the predictions of transport codes.

[1] R.Bougault *et al.*, Eur.Phys.J.A, **50**, 47 (2014).

[2] S.Barlini *et al.*, Phys.Rev.C, **87**, 054607 (2013).

High-energy ion beams accelerated by intense lasers

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Over the last 15 years the acceleration of ions with high-power lasers has been object of extensive investigations by many groups worldwide [1]. The main acceleration mechanisms studied in experiments are via electrostatic sheaths set-up at the surface of laser-irradiated foils by relativistic electrons. Beams produced via this process (currently with energies up to ~70 MeV) have very different properties from conventional accelerator beams. Some of these unique characteristics (very low emittance, picosecond emission time, ultralarge current) have already been exploited in a number of innovative applications.

Different mechanisms currently emerging are based on the enormous radiation pressure carried by intense laser pulses, and promise natively narrow band spectra at GeV energies/nucleon with the next generation of high power lasers.

This talk will briefly review the current status and the prospects for near term progress of laser-driven ion acceleration through these mechanisms, with particular reference to recent experimental activities carried out by the A-SAIL consortium [2] at UK (GEMINI, VULCAN) and international facilities. Innovative, compact approaches for beam transport and post-acceleration, which are currently being investigated, will also be illustrated.

One application of laser-driven ion beams which has recently attracted significant attention is the production of MeV-range neutron beams. Beam fusion reactions employing laser-accelerated Deuterons, as well as (p,n) reactions in pitcher-catcher configurations, are explored in current experiments, revealing the production of bright, directional beams of high-energy neutrons.

[1] A.Macchi, M.Borghesi and M. Passoni, Rev. Mod. Phys., **85**, 751 (2013)
[2] S. Kar *et al*, Phys. Rev. Lett., **109**, 185006 (2012)
[2] http://www.qub.ac.uk/A-SAIL

Effects of the interstrip gap on the efficiency and response of Double Sided Silicon Strip Detectors

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Highly segmented double sided silicon detectors (DSSSD) are widely used in nuclear physics to perform accurate measurements of angular distributions, or to study reactions where coincidences of different particles are required to fully characterize the final state of the interaction process. It is well known that when a particle hits the SiO_2 insulating interstrip region, one can observe, in the two adjacent strips, signals with an amplitude which is different than the full energy one including opposite polarity signals [1-5]. For this reason, when analysing data gathered by using DSSSDs, it is very important to reject interstrip events by selecting only the ones producing the correct full energy signals. This results in an efficiency for full energy detection less than 100%.

For the first time, we performed [6] a systematic characterisation of DSSSDs response as function of the incident ion, energy, and polarization voltage, trying to identify an appropriate selection procedure of events which allows to maximize the efficiency for the full energy reconstruction. First tests, using ^{7}Li and ^{16}O beams at different energies, showed that the efficiency for full energy detection depends on the energy of the detected ion and on the applied bias voltage. Moreover, it was observed that the measured efficiency is different than the one extracted by simply considering the geometrical width of the SiO_2 zone. This means that the effective width of the inter-strip region is different than the geometric one declared by the manufacturer. In addition, systematic measurements of the effective width of the inter-strip gap were performed by scanning the front and back inter-strip regions using proton micro-beams at different energies and for different detector bias [7]. Results show that both front and back effective inter-strip width can be much larger than the nominal geometric width of the SiO_2 zone and that both depend on the DSSSD type, and operating conditions. The results were interpreted by a simplified model based on the Shockley-Ramo-Gunn framework, it show that assuming the buildup of positive charge at the SiO_2 interface one can obtain a satisfactory reproduction of all the observed interstrip effects.

In conclusion, the front and back effective interstrip width, which in turn is related to the DSSSD efficiency for full energy detection, depends on the DSSSD type, on its polarization voltage, and on the energy and charge of the detected ions. Therefore for those experiments aiming to measure, for instance, absolute cross-section with high precision, a complete characterization of the used DSSSDs is desirable.

[1] D. Torresi *et al.*, Nucl. Instr. Meth A 713 (2013) 11 and reference therein.
[2] L. Grassi et al. Nucl. Instr. Meth A 767 (2014) 99.

Status and Perspective of the FARCOS detector array

E.V. Pagano[1,2], L. Acosta[4], R. Andolina[1], L. Auditore[5], C. Boiano[6], G. Cardella[3], A. Castoldi[7] DAndrea[3], E. De Filippo[3], S. De Luca[5], D. Dell'Aquila[8], L. Francalanza[8], E. Geraci[1,3], B. Gnoffo[3], C. Guazzoni[6,7], G. Lanzalone[2,9], I. Lombardo[8], N. Martorana[1,2], T. Minniti, S. Norella[5], A. Pagano[3], M. Papa[3], S. Pirrone[3], G. Politi[1,3], F. Porto[1,2], L. Quattrocchi[5], F. Rizzo[1,2], P. Russotto[3], G. Sacca'[3], A. Trifiro'[5], M. Trimarchi[5] , G. Verde[3,10], M. Vigilante[8].

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Nuclear matter under extreme conditions can be studied in the laboratory with heavy- ion (H.I.) collisions. In this case one can indeed vary both the incident energy and mass asymmetry. By exploring different impact parameters and rapidity regions it is possible to access nuclear densities that extends above and below saturation density. Such opportunities allow one to learn more about the nuclear equation of state and its implications in astrophysics phenomena such as supernovae explosions and neutron stars properties. Furthermore, during the dynamical evolution of the studied systems short living exotic states can be produced and their properties can be studied by detecting the final products of resonance decays. All these phenomena involve time scales that need to be accessed with multi- particle correlation measurements. Experimental observables, such as linear momentum and energy, sensitive to both space-time and spectroscopic properties of the nuclear systems produced in the H.I. collisions, need to be measured with both high angle and energy resolution over a large solid angle coverage. In order to address this problem dedicated geometrically flexible correlator arrays are useful tools to be coupled with 4 detectors. One of these arrays is FARCOS, presently under construction at the INFN Sezione di Catania and Laboratori Nazionali del Sud (LNS). The FARCOS (Femtoscope ARray for COrrelations and Spectroscopy) will consist of an array of twenty telescopes, each composed by two Double Sided Silicon Strip Detectors (DSSSD), of thickness 300?m and 1500?m, respectively, followed by four CsI(Tl) crystals read-out by silicon photodiodes. In this contribution a brief report of the present status of FARCOS array and future perspectives will be presented. Particular attention will be devoted to some preliminary results obtained in a recent experiment performed using a prototype of 4 clusters of FARCOS coupled with CHIMERA detector[1].

[1] E.V. Pagano *et al.*, EPJ Web of Conferences (2015) in press.

Progress in MAGNEX focal plane detector

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Ettore Majorana theoretically demonstrated that all results of beta decay theory remain unchanged if the neutrino is its own anti-particle. In double beta decay, two neutrons in the nucleus are converted to protons, and two electrons and two electron antineutrinos are emitted. In the NUMEN (NUclear Matrix Elements of Neutrinoless) project an innovative technique, based on nuclear double charge exchange reactions (DCE), has been proposed in order to access to the nuclear matrix elements, which together with the life time are the two key parameters for access to the neutrino identity (mass, lepton mixing, etc.). The experiments will be performed at LNS-INFN Catania by using beams delivered by superconducting cyclotron accelerator (CS) and the large acceptance MAGNEX spectrometer. The ejectiles produced by DCE will be momentum analysed by the spectrometer and detected by its focal plane and ancillary detectors [1]. Due to the low cross section, the project require the upgrade of the CS accelerator (in order to increase the actual beam intensity of about two order of magnitude up to some pμA) and on MAGNEX detectors (that must be able to run at intensities as high as several MHz). Promising technologies are explored to such purpose, including the use of a highly segmented gas tracker based on GEM multipliers and a wall of about 3 thousand telescopes of SiC + CsI for particles identification. In this contribution we will show the main results of the R&D activities related to this last point.

[1] F.CAPPUZZELLO *et al.*, Nova Publisher Inc., New York, 1-63 (2011)

Thursday 25/06/2015
h. 17.00-18.50

AULA F

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

Systematics of Elastic and Inelastic Deuteron Breakup

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Deuteron-induced reactions are being used to produce medical radioisotopes [1] and as surrogates to other reactions (see review [2] and references therein), among recent applications. Although they have been studied for decades [3-6], the complexity of these reactions continues to make their theoretical description challenging. The direct reaction mechanism is a major contributor to the reaction cross section due to the low binding energy of the deuteron. Competition between elastic breakup, absorption of only a neutron or a proton (stripping and inelastic breakup) and absorption of the deuteron must be taken into account to determine the formation or not of a compound nucleus and its subsequent decay. The inelastic breakup reactions – those in which either only a neutron or a proton is absorbed – are particularly complex, as they form compound nuclei with a wide range of excitation energies and angular momenta. We present the results of a theoretical study of elastic and inelastic deuteron breakup for a large selection of targets at incident deuteron energies below 100 MeV. We use the zero-range post-form DWBA approximation to calculate the elastic breakup cross section [3,4] and its extension to absorption channels to calculate the inelastic breakup cross sections [5,6]. We discuss the regularities and ambiguities in our results, as well as the irregularities in the inelastic breakup energy and angular momentum distributions that complicate their substitution by a smooth distribution obtained from systematics.

References

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Self-consistent description of deformed proton drip-line nuclei

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Covariant density functional theory (CDFT) has provided a framework to develop successful microscopic descriptions of nuclear structure[1]. An important feature of these relativistic mean-field approaches, relies on the fact of requiring only a small number of parameters adjusted to reproduce bulk properties of finite nuclei since they are derived from Lorentz invariant density functionals that consistently connect the spin and spatial degrees of freedom in the nucleus. They are valid over the entire periodic table, and have successfully been able to describe ground state properties in finite spherical and deformed nuclei over the entire nuclear chart, from light nuclei to super-heavy elements, and from the neutron drip line where halo phenomena are observed to the proton drip line. Single particle configurations and spectroscopic factors have also been successfully derived for nuclei at the limits of stability.

Applications to exotic decays have also been presented [2]. Fully self-consistent relativistic description of proton emission from spherical nuclei, based on relativistic density functionals derived from meson exchange and point coupling models, reproduced well the experimental data and could identify the existence of correlations and configuration mixing effects.

We have generalize our model, and performed a fully relativistic self-consistent calculation to describe decay from deformed nuclei. The proton wave function was obtained exactly from the solution of the Dirac equation in a deformed mean field, with outgoing wave boundary condition, therefore, with the correct asymptotic behaviour. The experimental data was reproduced, and the nuclear structure properties of the emitter identified.

In this work, the theoretical procedure will be presented, and the comparison with the data discussed.

1. D. Vretenar, A. V. Afanasjev, G. A. Lalazissis, and P. Ring, Phys. Rep. **409** (2005) 101.
2. L. S. Ferreira, E. Maglione, and P. Ring, Phys. Lett. B **701** (2011) 508.

Elastic, inelastic and breakup cross sections in $^{6}Li+^{112}Sn$ system

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Study of reactions involving weakly bound projectiles is very interesting because of the observation of several unusual features compared to the case of strongly bound projectiles. Suppression of complete fusion, breakup threshold anomaly in optical potential describing elastic scattering and a large production of alpha particles in the reactions are some of those interesting observations [1]. Projectile breakup in the field of a target nucleus is known to play an important role in the manifestation of all the above features. To understand the underlying reaction mechanism, the experimental data on projectile breakup cross section is thus very important to compare with the coupled-channels calculations that include the breakup channels. In order to constrain the values of coupling parameters and the potentials in the coupled-channels calculations it is also important to reproduce simultaneously the experimental data for as many reaction channels as possible for the same target+projectile.

With the above motivation, the elastic, inelastic, transfer and breakup cross sections for $^{6}Li+^{112}Sn$ system have been measured at a bombarding energy of 30 MeV using BARC-TIFR Pelletron facility at Mumbai. Four telescopes of single Si detectors (covering 30 degree) and two telescopes of double sided 16-strip Si detectors (covering 35 degree) were used for the above purpose. Preliminary results obtained from the data of single telescopes and two monitors are shown in Figure 1 below. Differential cross sections for the elastic scattering normalized with the Rutherford cross sections are shown in Fig.1(a). The inelastic cross sections corresponding to $^{112}Sn(2^{+}$,1.25 MeV) and $^{112}Sn(3^{-}$,2.35 MeV) are shown in Fig.1(b) and (c) respectively. The exclusive breakup cross sections corresponding to the 1st resonant state of ^{6}Li (3^{+},2.18 meV) is shown in Fig.1(c). The cross sections for projectile breakup have been extracted following the procedure as described in Ref.[2].

Continuum-discretized-coupled-channels (CDCC) calculations are performed using FRESCO to estimate the projectile breakup cross sections. Breakup channels that are included in the CDCC calculations are similar to the ones in Ref.[2]. Results of the coupled-channels calculations that explain the measured data simultaneously are shown by the solid lines in Fig.1.

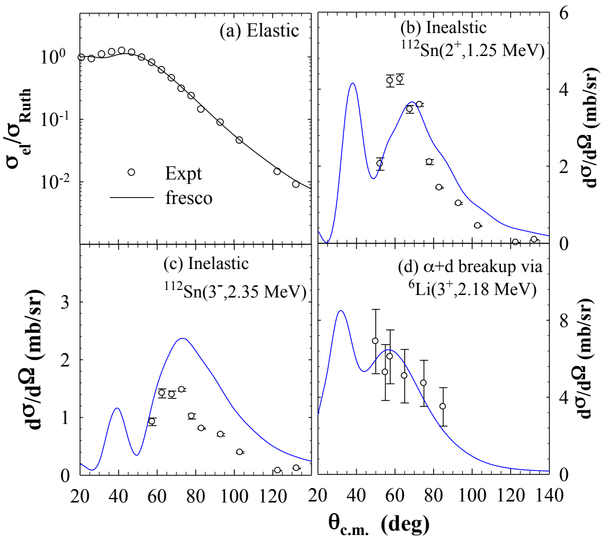

Fig.1.(a) Elastic, (b,c) inelastic and (c) breakup cross sections measured at E_{beam}=30 MeV

[1]S. Santra *et al.*, Phys.Rev.C **90**,064620 (2014), Phys.Rev.C **83**,034616 (2011),), Phys.Rev.C **85**,014612 (2012), and references therein.
[2]S. Santra *et al.*, Phys.Lett.B **677**, 139 (2009).

Some Peculiarities of Interactions of Weakly Bound Lithium Nuclei at Near Barrier Energies

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Experiments on measurement of total reaction cross sections (TCS, σ_R) have become especially important due to the advent of accelerators of radioactive beams of exotic nuclei. However, low intensity and insufficient collimation of beams produced in accelerators do not enable scientists to make measurements of cross sections with the level of precision accessible in the experiments with beams of stable nuclei. For example, it is not possible to measure angular distributions of differential cross sections (DCSAD) of elastic scattering with high angular resolution, to measure DCSAD of inelastic scattering with well-separated excited states, to study of specific reactions, etc. Therefore, the TCS is one of a few important parameters measured for weakly bound nuclei.

Precision measurements of σ_R at low energies are a very important addition to the available data at high energies. Firstly, at low energies σ_R is more sensitive to the distribution of matter on the surface of the nucleus, which is caused by an increase in the cross section of the nucleon-nucleon interaction at low energies [1]. Secondly, at low energies the peculiarities of mutual influence (counteraction) of nuclear and Coulomb effects are especially strongly manifested [2]. Therefore, the data obtained in the experiments on σ_R measurements in the interactions of loosely coupled (exotic and cluster) nuclei at low energies become an important source of information about the mechanism and structure of nuclei.

In [3] we presented a detailed comparative study of the interaction of loosely coupled cluster ^{6,7}Li nuclei. In this paper, we present the results of a joint analysis of all available (our results [4] and literature data) experimental data on DCSAD of elastic scattering and TCS in a wide range of low energies for ^{6,7,8,9}Li and ^{11}Li at energies close to the Coulomb barrier.

Isotopes of ^{6,7,8,9}Li are nuclei with a clearly pronounced cluster structure, and ^{11}Li is an exotic nucleus, the core of which is ^{9}Li. In the process of interaction of weakly bound nuclei with low energy of separation of the valence neutron, different configurations: ^{6,7}Li: {(α + d), (α + t), (^{3}He + t), (^{3}He + ^{4}H)}; ^{8}Li: {(^{7}Li + n); (α + t + n)}; ^{9}Li: {(α + t + 2n)}; ^{11}Li: {(^{9}Li + 2n)} can coexist. These processes may also include mechanisms of cluster exchange. Identification of coexisting configurations requires additional investigations. However, the discrepancy between the theory and the experimental data at near-barrier energies is too high to be explained only by the inaccuracies of the analysis (inaccuracies of wave functions used for lithium nuclei, a possibility of contribution of more complex processes, such as multiple transfer of clusters, etc.).

In our experiments we measured the energy dependence $\sigma_R(E)$ in the interactions of ^{6}He, ^{8,9}Li ions with target nuclei of ^{9}Be, ^{12}C, ^{27}Al, ^{28}Si, ^{59}Co and ^{181}Ta at energies (12,6 – 23,8) MeV/nucleon. We used a new improved method – a combination of full geometry γ- spectrometer and transmission techniques [4].

For comparative analysis, we presented all available (our results and literature data) experimental data for TCS for $^{6-9}$Li and ^{11}Li nuclei for their interactions with the ^{28}Si nucleus. It was found that within the errors all measured TCS values, including our data [4], are in reasonable agreement. It should be noted that σ_R for the exotic nucleus ^{11}Li, the core of which is ^{9}Li, has an anomalous behavior.

In addition, we carried out a joint analysis of the experimental data (DCSAD scattering and TCS) on interactions of ^{8}Li with other nuclei in a wide range of mass numbers at energy 1,75 MeV/nucleon (14 MeV). The experimental energy dependence of σ_R for reactions (^{8}Li + ^{9}Be), (^{8}Li + ^{12}C), (^{8}Li + ^{27}Al) at low energies was obtained. Calculations were made in the framework of the deformed potential of the macroscopic optical model using program SPI-GENOA and semi-microscopic folding model.

In the framework of the joint analysis (DCSAD scattering and TCS) of the total set (our data plus literature data) of the experimental data we studied peculiarities of interactions of weakly bound $^{6-9}$Li and ^{11}Li nuclei and predicted tendencies in σ_R variations at energies near and below the Coulomb barrier.

A detailed review and analysis of research on the interaction (TCS and DCSAD scattering) of weakly bound Lithium nuclei shows a lack of reliable experimental data and the need to:

- Carry out TCS measurements (σ_R) for $^{6,7,8,9,11}Li$ in the energy range from B_c (Coulomb barrier = 3-4 MeV) to 40 MeV/nucleon on ^{9}Be, ^{12}C, ^{27}Al nuclei;
- Carry out TCS measurements for $^{6,7,8,9,11}Li$ in the energy range from B_c (Coulomb barrier = 3-4 MeV) to 10 MeV/nucleon on ^{28}Si nucleus.

In the same energy range it is necessary to measure DCSAD scattering of weakly bound Lithium nuclei on the same target nuclei. This would allow us to identify specific features of interaction mechanisms and to determine corresponding structural characteristics at near barrier energies.

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Mechanism of two-proton emission from ^{23}Al and ^{22}Mg

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The decay of proton-rich nuclei, especially the two-proton ($2p$) radioactivity[1], is an interesting process that may be observed in nuclei beyond or close to the proton dripline[2-3]. One and two-proton emission from ^{23}Al and ^{22}Mg have been measured experimentally by the nuclear reaction method and also the beta-delayed decay method. The energy spectrum for one proton emission and the half-life for beta-decay were obtained. From the spectrum of relative momentum and open angle between two protons, we observed strong component of ^{2}He-like cluster emission from high excitation energy states of ^{22}Mg. While for ^{23}Al, sequential proton decay is dominate.

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Thursday 25/06/2015
h. 17.00-18.50

AULA AZZURRA LNS

PARALLEL SESSION:

Reactions and Structure – Unstable nuclei

Effect of ^{6}Li resonances on near-barrier elastic scattering for reactions with several spherical targets

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Calculations of elastic scattering angular distributions for reactions of the weakly bound projectile ^{6}Li with targets ^{28}Si, ^{58}Ni, ^{144}Sm and ^{208}Pb at energies just above the Coulomb barrier are performed with the continuum-discretized coupled-channel calculation method. Ground, resonant and non-resonant continuum states of ^{6}Li are included in the convergent calculations. The effect of the resonances on elastic scattering angular distributions is studied, in an original procedure, by excluding from the continuum space those states corresponding to the resonances. When the resonances of ^{6}Li are considered, the calculated elastic scattering angular distributions are in good agreement with the measurements. The exclusion of the resonances produces a small effect for the light targets, however the effect increases for the heavier systems. Calculation of the polarization potentials associated with the resonances show that they have a repulsive character at the long range region, where scattering occurs. It is also confirmed that couplings to continuum states of ^{6}Li are essential to achieve agreement with the data.

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Low-energy ^{9}Be+^{208}Pb scattering, breakup and fusion within a four-body model

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We investigate the ^{9}Be+^{208}Pb elastic scattering, breakup and fusion at energies around the Coulomb barrier. The three processes are described simultaneously, with identical conditions of calculations. The ^{9}Be nucleus is defined in an $\alpha+\alpha+n$ three-body model, using the hyperspherical coordinate method. We first analyze spectroscopic properties of ^{9}Be, and show that the model provides a fairly good description of the low-lying states. The scattering with ^{208}Pb is then studied with the Continuum Discretized Coupled Channel (CDCC) method, where the $\alpha+\alpha+n$ continuum is approximated by a discrete number of pseudostates. The use of a three-body model for ^{9}Be improves previous theoretical works, where ^{9}Be is assumed to have a two-body structure ($^{8}\mathrm{Be}+n$ or $^{5}\mathrm{He}+\alpha$), although neither ^{8}Be nor ^{5}He are bound. Optical potentials for the α+^{208}Pb and n+^{208}Pb systems are taken from the literature. We present cross sections at different energies, and investigate the convergence with respect to the truncation of the $\alpha+\alpha+n$ continuum. In general, a good agreement with experiment is obtained, considering that there is no parameter fitting. We show that continuum effects increase at low energies, and confirm that breakup channels enhance the fusion cross sections below the Coulomb barrier.

Coulomb breakup of ^{37}Mg and its ground state structure

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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 [1] and ^{31}Ne[2], especially in and around the so called "island of inversion". 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 new results [3] on the Coulomb breakup of neutron rich ^{37}Mg nucleus on a Pb target at the beam energy of 244 MeV/nucleon within the framework of a finite range distorted wave Born approximation theory that is extended to include the projectile deformation effects. In this theory, the breakup amplitude involves the full wave function of the projectile ground state. Calculations have been carried out for the total one-neutron removal cross section (σ_{-1n}), the neutron-core relative energy spectrum, the parallel momentum distribution of the core fragment, the valence neutron angular, and energy-angular distributions.

The calculated σ_{-1n} has been compared with the recently measured data to put constraints on the spin parity, and the one-neutron separation energy (S_{-1n}) of the ^{37}Mg ground state (^{37}Mg$_{gs}$). The dependence of σ_{-1n} on the deformation of this state has also been investigated. Our study suggests that ^{37}Mg$_{gs}$ is most likely to have a spin parity assignment of $3/2^-$. Using the shell model value for the spectroscopic factor for this configuration and without considering the projectile deformation effects, a S_{-1n} of 0.10 ± 0.02 MeV is extracted. Inclusion of the deformation effects increases the value of the deduced S_{-1n}. The narrow parallel momentum distribution of the core fragment and the strong forward peaking of the valence neutron angular distribution suggest a one-neutron halo configuration in the $2p_{3/2}$ ground state of ^{37}Mg.

We shall also show how our calculated neutron-core relative energy spectrum in the breakup of ^{37}Mg on a Pb target could be used to extract the ^{36}Mg$(n,\gamma)^{37}$Mg radiative capture cross section. To the best of our knowledge this would be the first application of a fully quantum mechanical theory of Coulomb breakup *with deformed projectiles* as an indirect method in nuclear astrophysics. The ^{36}Mg$(n,\gamma)^{37}$Mg reaction is thought to compete with the ^{36}Mg$(\alpha,n)^{39}$Si reaction and could affect a new r-process path proposed in Ref. [4], initiated from light elements.

Our study is thus expected to provide motivation for future experiments on breakup reactions of the neutron rich medium mass nuclei, given that we have identified the observables that are more critically dependent on the ground state structure of the projectile.

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Study of cluster structures in ^{10}Be and ^{16}C neutron-rich nuclei via break-up reactions

D.Dell'Aquila[4,*], L.Acosta[11], F.Amorini[2], R.Andolina[3], L.Auditore[5], I.Berceanu[8], G.Cardella[1], M.B.Chatterjiee[9], E.DeFilippo[1], L.Francalanza[2,3], B.Gnoffo[1], A.Grzeszczuk[10], G.Lanzalone[2,6], I.Lombardo[4], T.Minniti[5], A.Pagano[1], E.V.Pagano[2,3], M.Papa[1], S.Pirrone[1], G.Politi[1,3], A.Pop[8], F.Porto[2], L.Quattrocchi[5], F.Rizzo[2,3], E.Rosato[4,†], P.Russotto[1], A.Trifirò[5], M.Trimarchi[5], G.Verde[1,7], M.Vigilante[4]

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We studied the spectroscopy of ^{10}Be and ^{16}C nuclei by means of projectile sequential break-up reactions. The FRIBs facility at INFN – LNS [1,2] has been used to produce the radioactive beams. Reaction products have been detected by the Chimera 4π array [3]. The good granularity of the Chimera device and the complete azimuthal angle coverage allow to identify and track each break-up fragment of the reactions ^{1,2}H,^{12}C(^{10}Be,^{6}He+^{4}He), ^{1,2}H,^{12}C(^{16}C,^{6}He+^{10}Be), ^{1,2}H,^{12}C(^{16}C,^{6}He+^{6}He+^{4}He). By measuring their energies, masses and flight directions, we reconstructed ^{10}Be and ^{16}C excitation energy spectra. Peaks on these spectra may indicate the presence of excited states characterized by clustering phenomena. The experimental data evidence peaks corresponding to excited states of ^{10}Be known in literature and a new possible state at about 13.5 MeV. From a semi-quantitative study of the corresponding ^{6}He-^{4}He angular correlations we estimated that the 13.5 MeV state could have high spin (possibly 6^+), in agreement recent findings reported in [4]. In this case, it may represent a further member of the ^{10}Be molecular rotational band [5]. Finally, from binary (^{6}He+^{10}Be) and ternary (^{4}He+^{6}He+^{6}He) cluster decompositions of ^{16}C we found, respectively, the indication of possible new states at about 20.6 MeV and 34 MeV. To improve our knowledge on these aspects, a new experiment, with higher angular resolution and better statistics, has been performed recently at LNS by using the Farcos array [6].

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Coupled Rearrangement Channels Calculation of The Three Body System under The Absorbing Boundary Condition

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The absorbing boundary condition (ABC) method, which introduces the imaginary potential outside of a total system, is one of powerful methods to handle the continuum states in three-body systems [1, 2]. In the previous studies, there are several applications of ABC to the three-body problems, but no coordinate rearrangements are taken into account [1]. The inclusion of the rearrangement channels, which means the rearrangement of the Jacobi coordinate among the three particles, is essential to obtain the fast convergence of the total binding energy [3].

In the present study, we apply the ABC method to the three-body calculation, which takes into account the rearrangement channels completely. We handle the identical three-boson system, which interacts by a simple Gaussian potential [1]. The rearrangement channel is explicitly considered by imposing the boson symmetry among the identical three-bosons. The absorbing potential is placed in accordance with the Jacobi coordinate of the individual rearrangement channels.

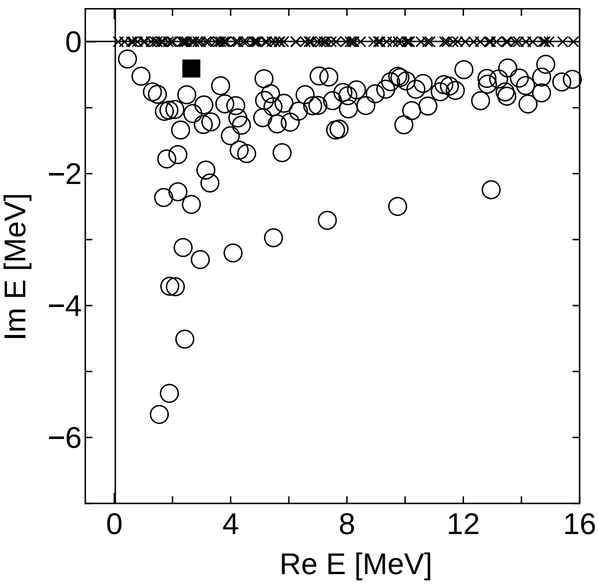

Figure 1: The distribution of the energy eigenvalues plotted in the complex plane.

Figure 1 shows the distribution of the energy eigenvalues obtained by using the ABC method. The eigenvalues appear along the real (horizontal) axis in the case of no absorbing potential, as shown by a series of the crosses, while they are distributed in the complex energy plane if the absorber is switched on. In Fig.1, we can confirm that the resonant state (solid square) is separated from the continuum spectra (open circles). We have also calculated the strength function of the three-body breakup reaction in the ABC framework by applying the extended completeness relation [4]. In the present report, we will demonstrate that the ABC method nicely works in the three-body calculation with the complete rearrangement channels. We will also discuss the general rule of the absorbing boundary condition for the three-body system with the full rearrangement channels.

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Thursday 25/06/2015
h. 17.00-18.55

SALA CONFERENZE LNS

PARALLEL SESSION:

Equation of State of Neutron Rich Matter, Clusters in Nuclei and Nuclear Reactions

Neutron stars: cosmic laboratories for matter under extreme conditions

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[2] *INFN sezione di Pisa*

The true nature and the internal constitution of the compact stars known as neutron stars is one of the most fascinating enigma in modern astrophysics. In this talk, I will analyze the present status of the theoretical calculations for the internal structure of neutron stars and the connection with the properties of ultra dense hadronic matter. In particular, I will discuss the role of strangeness on the equation of state and the implications of the measurement of 2 solar mass neutron stars in PSR J1614-2230 and PSR J0348+0432.

Clusters in neutron rich light nuclei

M. Milin[1], D. Jelavić Malenica[2], A. Di Pietro[3], P. Figuera[3], M. Lattuada[3], Đ. Miljanić[2], A. Musumarra[3], M.G. Pellegriti[3], L. Prepolec[2], V. Scuderi[3], N. Skukan[2], N. Soić[2], D. Torresi[3], M. Uroić[2]

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Due to their high selectivity, transfer and sequential decay reactions are powerful tools for studies of both single particle (nucleon) and cluster states in light nuclei. Their use is particularly simple for investigations of α-particle clustering (because α-particle has J^{π}=0^{+}, which simplifies spin and parity assignments to observed cluster states), but they are also easily applicable to other types of clustering.

Recent results on clustering in neutron-rich isotopes of beryllium, boron and carbon obtained measuring the ^{10}B+^{10}B reactions (at 52 and 70 MeV) will be presented, together with some preliminary results from the ^{7}Li+^{6,7}Li (at 30 and 51 MeV) and ^{7}Be+^{6,7}Li (at 45 MeV) measurements. Highly efficient and segmented detector systems used in experiments (built from 4 or 6 Double Sided Silicon Strip Detectors) allowed studies of double and multiple coincidences and in that way studies of states populated in the transfer reactions, as well as their sequential decay.

Nuclear symmetry energy in density-dependent relativistic Hartree-Fock theory: the role of Fock terms and tensor force

B. Y. Sun[1], W. H. Long[1], L. J. Jiang[1], Q. Zhao[1]

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Nuclear symmetry energy plays an essential role in understanding the isospin-dependent aspects in nuclear physics and the critical issues in astrophysics. With the inclusion of Fock diagrams of the meson-nucleon couplings, the density-dependent relativistic Hartree-Fock (DDRHF) theory has been developed [1] and been utilized to study the symmetry energy and neutron star properties. The inclusion of the Fock terms strongly affects the density-dependent behavior of the symmetry energy at high densities, and in turn the radius and cooling process of neutron stars [2,3,4]. Motivated by recent observational data, the equations of state with the inclusion of hyperons is studied based on the DDRHF theory as well [3]. Because of the extra suppression effect originating from the Fock channel, large reductions on both the neutron-star mass and radius are predicted and a relatively small neutron-star radius could be obtained. In addition, with the possibility to extract the nuclear tensor interaction directly from the Fock diagrams of various meson-nucleon couplings [5], distinct tensor effects is illustrated in the exploration of the isospin properties of nuclear matter and neutron star structures [4]. It is found that the inclusion of the Fock terms in the DDRHF theory reduces the kinetic part of the symmetry energy which could give a negative value at supranuclear density region [6]. Due to the naturally involved tensor force components in the Fock diagrams, the density-dependent behavior of the symmetry energy is fairly softened and consequently it leads neutron stars to be more compact. For the direct Urca process that cools the neutron star rapidly, the threshold density is raised by the nuclear tensor force. Moreover, the isospin coupling-channel decomposition of the symmetry energy is also carried out within the DDRHF theory [6]. The results demonstrate the importance of the Fork diagram, especially from the isoscalar-meson coupling channels, on the isospin properties of the in-medium nuclear force at high densities.

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Excited states of ^{26}Al studied via the reaction ^{27}Al(d , t)

Vishal Srivastava[1], C. Bhattacharya[1], T. K. Rana[1], S. Manna[1], S. Kundu[1], S. Bhattacharya[1], K. Banerjee[1], P. Roy[1], R. Pandey[1], G. Mukherjee[1], T. K. Ghosh[1], J. K. Meena[1], T. Roy[1], A. Chaudhuri[1], M. Sinha[1], A. K. Saha[1], Md. A. Asgar[1], A. Dey[1], Subinit Roy[2], Md. M. Shaikh[2]

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The reaction ^{27}Al(d,t) using 25 MeV deuteron beam has been studied to extract spectroscopic factors for different excited states of the nucleus ^{26}Al. The different excited states of ^{26}Al populated in present experiment have been analysed using zero range as well as finite range distorted wave Born approximation. The calculation using zero range distorted wave Born approximation have been done. The extracted spectroscopic factors have been compared with the previously reported values obtained using one neutron pick up reactions [1 – 3] and have also been compared with those obtained from shell model predictions. From basic nuclear physics as well as nuclear astrophysics point of view the nucleus ^{26}Al has evoked lots of interest [4 – 6]; so the study of the structure of ^{26}Al has been found to be very important. A part of the data have been presented in FUSION14 conference [7].

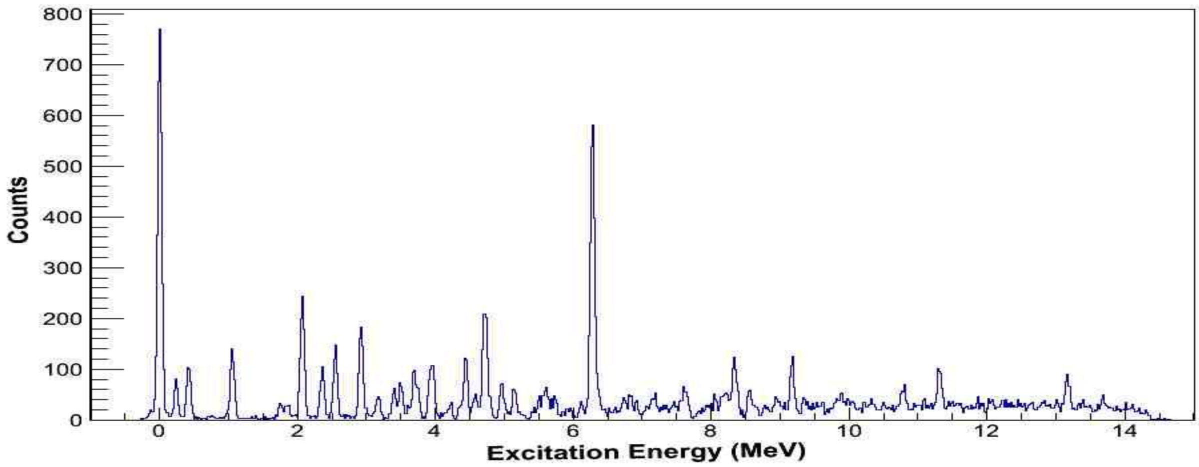

Fig. 1. Typical excitation energy spectrum of ^{26}Al obtained at E_{lab} = 25 MeV and Θ_{lab} = 28°.

Experiment has been performed at the Variable Energy Cyclotron Center, Kolkata using 25 MeV deuteron beam on a self- supporting ^{27}Al target ($\sim 90\ \mu g/cm^2$). Particle identification was done using a three - elements telescope, consisting of a single - sided 55 μm thick Si (ΔE) strip detector, followed by a double - sided 1030 μm Si(E) strip detector backed by two CsI(Tl) detectors (each of thickness 6 cm). Typical excitation energy spectrum for ^{26}Al populated via the reaction channel ^{27}Al(d, t) is shown above in Fig. 1. The Analysis of different excited states of ^{26}Al are in progress and will be presented during the conference.

[1] J. Kroon *et al.,* Nucl. Phys. A 204, 609 (1973).
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The12th International Conference on Nucleus-Nucleus Collisions, June21-26, 2015, Catania, Italy

Influence of various potentials on fragment production in asymmetric collisions

Manpreet Kaur and Varinderjit Kaur

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The knowledge of nuclear interaction potential is a fundamental theoretical tool in the analysis of heavy ion collisions. It is a key ingredient for constructing the nuclear equation of state (NEOS) [1]. The general trend of using the nucleon-nucleon (n-n) interaction potential is to parameterize this potential as a function of density. While parametrizing the potential, one starts with the basic fundamental interaction i.e. Skyrme interaction and then add other components of potential such as Yukawa, Coulomb, momentum dependent interaction and symmetry potential in the study of symmetric as well as asymmetric collisions [2].

In our study, the relative contribution of various components of n-n interaction potential has been investigated by studying the production of various fragments within different rapidity domains for the various asymmetric reactions at b = 0 fm and E_{beam} between 50 and 150 MeV/A by using the isospin-dependent quantum molecular dynamics model [3]. It has been observed that different components of n-n potential play a significant role towards the fragment production in participant region as well as quasi participant rapidity region. The three components namely, Skyrme, Yukawa and Coulomb are sufficient to describe the fragmentation for the central collisions. However, at peripheral colliding geometries, momentum dependent interactions are needed to explain the fragmentation. The competition between different component of potentials show large impact on the production of fragments.

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Thursday 25/06/2015
h. 17.00-18.50

Aula A Dipartimento di Fisica ed Astronomia

PARALLEL SESSION:

Fusion and Fission

Description of the fusion-fission reactions in the framework of dinuclear system conception

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A large number of experimental and theoretical studies devoted to complete fusion and quasifission reactions have been performed in recent years. These studies are aimed to study the properties of nuclear matter and its behavior in different extreme conditions. For example, a number of recent experiments are devoted to study the fusion-fission and complex fragment emission cross sections depending on N/Z, excitation energy, entrance channel asymmetry and etc. [1,2]. The production of new isotopes of nuclei and new superheavy elements in fusion reactions is very active field today. All these experimental investigations require a support from theory. Therefore, developing the appropriate perspective theoretical models are very demanding now. In this contribution, we present the results of our recent theoretical calculations for fusion-fission reactions in the framework of dinuclear system (DNS) conception [3,4]. In particular, the influence of the excitation energy and N/Z of the system on fusion and decay mechanism of compound nucleus formed in the reactions ^{78,82,86}Kr + ^{40,48}Ca, ^{16,18}O + ^{40,48}Ca will be discussed.

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The influence of the 2-neutron elastic transfer on the fusion of ^{42}Ca + ^{40}Ca

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A striking fusion barrier distribution is predicted for strong coupling to a single channel with zero Q-value. Irrespective of the type of coupling (phonon or transfer channel) one should obtain in this case a roughly symmetric distribution possessing two peaks, one on each side of the original uncoupled Coulomb barrier [1]. In practical cases, only coupling to an elastic transfer channel may produce such a distribution which, however, has never been observed sofar, probably because low-lying surface vibrations have a dominant role in most cases, and this may obscure the two-peak structure. The case of ^{42}Ca + ^{40}Ca is particularly attractive, because of the rigid nature of the two nuclei.

We have measured the full excitation function of this system using the ^{42}Ca beam of the XTU Tandem of LNL on a thin ^{40}Ca target enriched to 99.96% in mass 40. The excitation function is shown in the figure (left). The extracted barrier distribution (right) shows clearly two main peaks. We have performed preliminary CC calculations, using the code CCFULL [2], whose results are shown in the figure. The 2^+ coupling strength has been taken from the literature and the schematic 2-neutron (2n) pair transfer form factor [3] has been obtained with a deformation length σ_t= 0.39 fm best fitting the data on ^{40}Ca + ^{48}Ca [4]. No excitation of ^{40}Ca has been considered. The excitation function is quite well reproduced by the calculation including the 2n transfer channel. The two-peak structure of the barrier distribution only shows up when that channel is explicitly taken into account, even if a small energy shift can be noticed. A more detailed CC analysis is in progress and the result will be presented at the Conference.

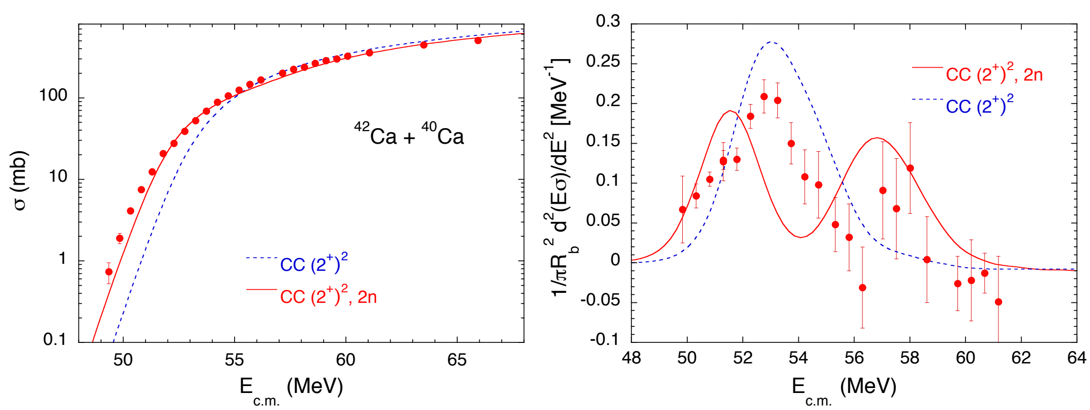

FIG. 1: *Fusion excitation function (left) and barrier distribution (right) of ^{42}Ca + ^{40}Ca (see text). The CC calculations include the excitation of two quadrupole phonons $(2^+)^2$ (blue lines) and, additionally, the 2n transfer channel (red lines).*

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Exploring dissipative processes at high angular momentum

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Current coupled channels (CC) models treat fusion as a coherent quantum-mechanical process, in which coupling between the collective states of the colliding nuclei influences fusion probability in near-barrier reactions. While CC models have been used to successfully describe many experimental barrier distribution (BD) measurements, the CC approach has failed in the notable case of ^{16}O+^{208}Pb [1]. The reason for this is poorly understood; however, it has been postulated that dissipative processes may play a role [2].

Traditional fusion BD experiments can only probe the physics of fusion for collisions at the top of the Coulomb barrier ($L = 0\hbar$). In this work, we will present results using two novel method of probing dissipative processes inside the Coulomb barrier. The first method exploits the predicted sharp onset of fission at $L \sim 60\hbar$ for reactions forming compound nuclei with $A < 160$. The second uses reactions leading to the same compound nucleus with the same excitation energy to produce mass-angle distributions (MADs) for high L collisions.

Using the ANU's 14UD tandem accelerator and CUBE spectrometer, fission outcomes have been measured for the ^{58}Ni+^{60}Ni, ^{50,52,54}Cr+^{208,206,204}Pb, and ^{52,54}Cr+^{198,196}Pt reactions at a range of energies, in order to explore dissipative processes in high angular momentum fusion.

For ^{58}Ni+^{60}Ni, deep inelastic processes have been found to set in before the onset of fusion followed by fission at high angular momentum, based on observations of the evolution of fission fragment mass ratios (M_R) versus total kinetic energy (TKE), shown in Fig. 1. For the Cr+Pb and Cr+Pt data, high L MADs will be presented for the first time. Both results will be discussed in relation to the need [3] for a dynamical model of fusion.

This work was supported by the Australian Research Council, grant numbers DP130101569, DP140101337, FL110100098 and DE140100784.

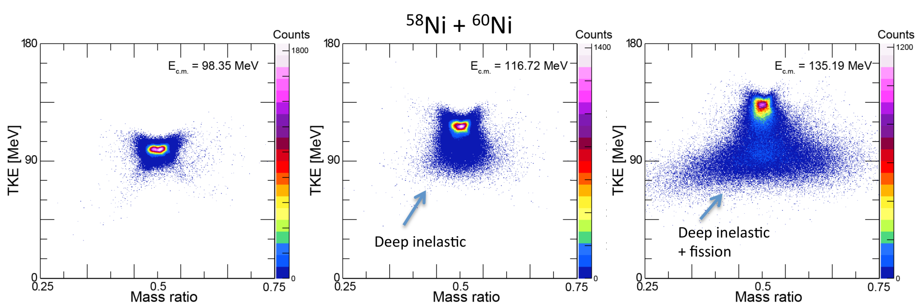

Figure 1: M_R versus TKE for ^{58}Ni+^{60}Ni, $E/V_B \sim 0.97$ to 1.35.

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Nucleus-nucleus potential with shell-correction contribution: barriers and subbarrier fusion

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The full energy of nucleus consists of the sum of macroscopic and microscopic contributions according to the shell-correction method proposed by Strutinsky. The contribution of the shell structure to the nucleus-nucleus potential has been ignored in phenomenological approaches. Therefore, it is desirable to find the improved phenomenological nucleus-nucleus potential which takes into account the contributions of shell-correction energies of the interacting nuclei. Such full potential should take into account both gross and individual properties of the specific nucleus-nucleus system and be more accurate then a global macroscopic potential.

The nuclei strongly interact at small distances between them. This interaction leads to the shift and the splitting of the single-particle levels in both nuclei. Due to this the proton and neutron single-particle spectra in the vicinity of the respective Fermi levels become more homogenous around touching distance. Such behavior of the single-particle levels is clearly demonstrated in the framework of the two-center shell model. According to the shell-correction method, the absolute value of the shell-correction energy is reduced in the case of more homogeneous single-particle spectrum in the vicinity of the Fermi level. The sharp reduction of the contribution of the shell-correction energies of both nuclei to the full potential energy around the touching point of nuclei is obtained in the framework of microscopic two-center shell model calculations.

The phenomenological relaxed-density nucleus-nucleus potential with the shell-correction contribution is discussed in detail [1]. The macroscopic part of the potential is related to a nucleus-nucleus potential obtained in the framework of the extended Thomas-Fermi approach with the Skyrme and Coulomb forces and the relaxed-density ansatz for evaluation of proton and neutron densities of interacting nuclei. The shell-correction energy contribution to the potential is connected to inner structure of nuclei which is disturbed by the nucleon-nucleon interactions of colliding nuclei. A simple approach for the evaluation of the shell correction contribution to the full potential is proposed. The shell-correction contribution shows how the full potential for the specific nucleus-nucleus system deviates from the global macroscopic potential. The shell-correction contribution to the full potential is very important at distances smaller than the barrier radius. The parameters of the shell correction and macroscopic parts of the relaxed-density potential are found by fitting the empirical barrier heights of the 89 systems of spherical or near spherical nuclei as well as the macroscopic potentials evaluated for 1485 nucleus-nucleus systems at 12 distances around touching points. The phenomenological relaxed-density nucleus-nucleus potential with the shell-correction contribution can reproduce the empirical barrier heights with the value of the root mean square error of 0.879 MeV.

It is shown that the deep sub-barrier fusion hindrance takes place for nucleus-nucleus system with the strong negative shell-correction contribution into the full heavy-ion potential, while the strong positive shell-correction contribution into the full potential leads to weak enhancement of the deep sub-barrier fusion cross section [2]. The fusion cross sections for reactions ^{16}O+^{208}Pb, ^{48}Ca+^{48}Ca, and ^{58}Ni+^{54}Fe are well described in the approach [2].

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Fusion of $^{16,18}O$ + ^{58}Ni at energies near the Coulomb barrier

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Dynamical mechanism involving positive *Q*-value of multi-neutron transfers in sub-barrier heavy-ion fusion is a hot topic and is still not clear now.
The system of ^{18}O + ^{58}Ni has a big Q_{-2n}-value and Q_{-2n}/V_B ~ 26%, which is compared to the ^{6}He-induced fusion. It has been measured at energies above the Coulomb barrier [1]. It shows very big fusion enhancement even at near-barrier energies and has been reproduced by Zagrebaev [2].
In order to study further the sub-barrier fusion behavior of this system, recently the fusion excitation functions of $^{16,18}O$ + ^{58}Ni has been measured at energies near- and below-barrier. Preliminary fusion data of ^{16}O + ^{58}Ni is consistent with Keeley's old data [3]. But for ^{18}O + ^{58}Ni, compared with the old data [1], the preliminary new data shows only modest fusion enhancement unexpectedly, which is also lower than Zagrebaev's calculation in Ref. [2]. The residual enhancement caused by the neutron transfers are given based on the coupled-channels calculations by using CCFULL [4]. The fusion barrier distribution shows a different behavior compared with that obtained from quasi-elastic scattering in Ref. [5]. Possible mechanisms are discussed.

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Thursday 25/06/2015
h. 17.00-18.50

AULA 52 LNS

PARALLEL SESSION

Nuclear Astrophysics

Recent results of n_TOF facility at CERN

G. Tagliente and n_TOF collaboration

INFN-Bari, Italy

Astrophysics is approaching a stage where a number of long-standing central questions about our Universe can finally be addressed within a consistent and quantitative way. The so called Standard Model, based on the General theory of Relativity, the Nuclear and the Particle Physics, describes satisfactorily the hot Big Bang cosmology. The currently observed ratio of neutrons and protons (about 13% n and 87% p) was established, when the weak interactions froze out (after 1 s). In this context, the quest for the origin of the chemical elements plays a prominent role: The production of ^{2}H, ^{3}He, ^{4}He and ^{7}Li (after 200 s) in the Big Bang bears important consequences for cosmology and particle physics, whereas the heavy elements beyond Fe witness ongoing neutron capture nucleosynthesis in evolved stars and supernova explosions with immediate constraints for Galactic chemical evolution.

The difficult task is to understand the formation of these heavy elements, where not only the nuclear physics is complicated but also the mechanisms and thermodynamics are not completely understood yet. Advances in our understanding of these processes and of the astrophysical sites where they occur, require advances in laboratory measurements of neutron cross sections.

In this framework the n_TOF collaboration has started a vast program of nuclear capture measurements with the aim of reducing the respective cross section uncertainties below 3%, in order to improve the reliability of astrophysical models.

The innovative feature of the n_TOF facility at CERN, in the two experimental areas, (20 m and 200 m flight paths), i.e. the high instantaneous flux, the high energy resolution and low background, allow for an accurate determination of the neutron capture cross section for radioactive samples or for isotopes with small neutron capture cross section, which are of interest for Nuclear Astrophysics

The n_TOF facility itself, the main results obtained so far, and the implication of the astrophysical program of the n_TOF collaboration will be presented in this talk

Constraining the key α-capture astrophysical reaction rates using the sub-Coulomb α-transfer reactions

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The rate of some α-induced reactions is an important input parameter for the models of stellar evolution and nucleosynthesis. Direct measurements of the corresponding cross sections is often not possible at present due to the small cross sections at the energy of interest caused by the Coulomb barrier. Large uncertainties in extrapolations from direct measurements made at higher energies to lower energies relevant for astrophysics are often caused by the unknown properties (in particular the reduced α width) of near and sub-threshold resonances in the corresponding compound systems. The problem can be mitigated by measuring the α asymptotic normalization coefficients (ANCs) using the (^{6}Li,d) α-transfer reactions. If the reaction is performed at sub-Coulomb energy then the dependence of the result on the model parameters is greatly reduced. This approach was first suggested in Ref. [1] and then applied in [2,3] to constrain the ^{12}C(α,γ), ^{13}C(α,n), ^{14}C(α,γ) reaction rates.

We will discuss the most recent results that were obtained using the sub-Coulomb α-transfer technique. The benchmark ANC measurement of the 5.79 MeV 1^- state in ^{20}Ne that have known partial α-width have been performed to verify the validity of the method [4]. The 0^+ and 3^- cascade transitions of the ^{12}C(α,γ) reaction have been constrained by measuring the corresponding ANCs [5]. The new ANC measurements of the $1/2^+$ state at 6.356 MeV in ^{17}O that plays the crucial role in the ^{13}C(α,n) reaction at energies relevant for the AGB star nucleosynthesis will also be presented [6]. We will discuss how these measurements, combined with the extensive R-matrix analysis, can dramatically reduce the uncertainties of the corresponding reaction rates.

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Insight into the ^{24}Mg excited states located in Gamow window for carbon - carbon burning

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One of the most intriguing questions of nucler physics related to astrophysics is possible resonant contribution in carbon burning process (fusion of two ^{12}C) which may dramatically increase production of heavy nuclei and energy release in many astrophysical sites [1]. Carbon burning strongly influences nucleosynthesis in massive stars, super AGB stars, SN-type Ia and superbursts. The relevant energy range in the ^{12}C + ^{12}C system for super AGB stars and SN-type Ia is E_{cm} = 1.5 to 3.3 MeV, while for the superbursts it extends up to 5.7 MeV. The available experimental data for the ^{12}C+^{12}C fusion cross section cover the energy range down to E_{cm} = 2.14 MeV [2, 3, 4] and show resonant contributions to the process. Since there are numerous resonances observed in the ^{12}C+^{12}C system at energies higher than the Gamow peak, as well as many resonances in the ^{20}Ne + α system in this ^{24}Mg excitation energy range, an extrapolation to the energy range required is very uncertain, calling for the new data. As this region is far below Coulomb barrier, it is extremely difficult to obtain these results.

Attempt to reduce these difficulties using measurement of the $^{12}\text{C} + {}^{16}\text{O} \rightarrow \alpha + {}^{24}\text{Mg}^*$ reaction at E(^{16}O) = 94 MeV and resonant spectroscopy technique will be reported. The interesting ^{24}Mg* decay channels and their threshold energies are ^{20}Ne + α (E_t = 9.31 MeV), ^{23}Na + p (11.69 MeV), ^{12}C + ^{12}C (13.93 MeV) and ^{16}O + ^{8}Be (14.14 MeV). The main idea is to study the resonance structures of ^{24}Mg at excitation energies from 1 up to 6 MeV above the ^{12}C + ^{12}C decay threshold and to determine their parameters by detecting decay fragments and recoil nucleus. Experiment was performed at Tandem accelerator of INFN LNS Catania using experimental setup consisted of 6 silicon detector telescopes, each of them assembled from a thin ΔE detector (thickness of 19 or 20 μm), and a thick Position-Sensitive Silicon Strip Detector (PSSSD) or a Double-Sided Silicon Strip Detector (DSSSD) of thickness 500 or 1000 μm. Experiment was ran for 11 days resulting in high data statistics. The ^{24}Mg excited states have been observed in ^{12}C + ^{12}C, ^{12}C + α, α + α and α + ^{8}Be coincident events. There is a nice correspondence between obtained and existing results. Detailed analysis has been performed to understand origin of structures observed in ^{24}Mg excitation energy spectra between 14 and 20 MeV for the ^{12}C + ^{12}C decay channel.

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Primordial nucleosynthesis revised: the THM contribution

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Big Bang Nucleosynthesis (BBN) nucleosynthesis requires several nuclear physics inputs and, among them, an important role is played by nuclear reaction rates. They are among the most important input for a quantitative description of the early Universe. An up-to-date compilation of direct cross sections of d(d,p)t, d(d,n)^{3}He and ^{3}He(d,p)^{4}He reactions is given, being these ones among the most uncertain bare-nucleus cross sections.

An intense experimental effort has been carried on in the last decade to apply the Trojan Horse Method (THM) to study reactions of relevance for the BBN and measure their astrophysical S(E)-factor. The result of these recent measurements is reviewed and compared with the available direct data. The reaction rates and the relative error for the four reactions of interest are then numerically calculated in the temperature ranges of relevance for BBN ($0.01 < T_9 < 10$) and compared with up-to-date reaction rate compilations. Their value were therefore used as input physics for primordial nucleosynthesis calculations in order to evaluate their impact on the calculated primordial abundances of D, ^{3,4}He and ^{7}Li. These ones were then compared with the observational primordial abundance estimates in different astrophysical sites. A comparison was also performed with calculations using other reaction rates compilations available in literature.

New measurement of the ^{10}B(p,α_0)^{7}Be reaction cross section at low energies and the structure of ^{11}C

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The study of the ^{10}B(p,α)^{7}Be reaction at low energies is important for different reasons. We can analyze the spectroscopy of excited states in the ^{11}C compound nucleus near the α-particle emission threshold [1,2], a region where molecular configurations could be observed. Unfortunately, the spectroscopy of ^{11}C is quite uncertain in the $E_x \approx$ 9.5-10 MeV domain, as reported in [3].

The accurate knowledge of the ^{10}B(p,α)^{7}Be reaction cross section at low energies is important also in the applied physics field. In fact, ^{11}B(p,α)^{8}Be reaction could be used to obtain aneutronic fusion in nuclear reactors [4,5]. Unfortunately, natural boron contains ^{10}B at the 19.9% level, and the proton-induced ^{10}B(p,α)^{7}Be reaction on ^{10}B contaminants leads to the production of radioactive ^{7}Be nuclei, with potential radio-protection issues.

Moreover, a good knowledge of the S-factor of this reaction in the $E_p \approx$ 0.5-1.5 MeV range can be useful for normalization purposes when indirect methods are used to evaluate the S-factor down to astrophysical energies [6,7].

For all these reasons, we performed a new direct experiment at the TTT3 tandem accelerator in Naples. We investigated the ^{10}B(p,α_0)^{7}Be reaction channel in the energy range $E_p \approx$ 0.6-1 MeV. Our main aim was the measurement of absolute reaction cross sections and angular distributions.

Due to the low reaction Q-value (1.15 MeV) and the peculiar reaction kinematics, it is very difficult to isolate the yield of α_0 particles at backward angles simply starting from the ejectile energy spectra. For this reason we placed couples of silicon detectors (symmetrically with respect to the beam axis) at the same backward angles. On the left side the ejectiles were detected by open silicon detectors, while on the right side each silicon detector was preceded by a thin aluminium absorber. High care was devoted to determine the detection geometry and beam alignment. By using this technique, we extracted the α_0 yield by difference.

The obtained experimental angular distributions, excitation functions and the S-factor will be shown and compared with the very few (and partial) data reported in the literature [8,9,10]. Hints on the possible existence of two excited states at 9.34 and 9.49 MeV in ^{11}C will be discussed.

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Thursday 25/06/2015
h. 17.00-18.55

AULA 52 (LNS)

PARALLEL SESSION:

New Facilities and Detectors

Highlights of the ISOLDE Facility and the HIE-ISOLDE Project

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ISOLDE-PH, CERN, 1211-Geneva-23, Switzerland
Instituto de Estructura de la Materia, CSIC, Serrano 113bis, 28006-Madrid, Spain

The ISOLDE Facility at CERN produces radioactive beams through fission, spallation and fragmentation reactions induced by 1.4 GeV protons from the PS booster. The ISOL method involves in this case the bombardment of a thick target with an intense $3x10^3$ proton beam, producing high yields of exotic nuclei with half-lives down to the millisecond range. By a clever combination of target and ion source units including the use of ionization lasers pure beams of 700 different nuclei of 75 elements have been produced and delivered to experiments where properties of the nuclei such as masses, radii, structure and shapes are determined. The high quality of the beams allows high-precision measurements of beta decay and particle correlations including measurement of beta-neutrino correlations in order to prove fundamental interactions in nuclei. Since ten years it offers the largest variety of post-accelerated radioactive beams in the world today. The combination of the Miniball gamma-ray array and T-REX charged particle detection system has been successfully used to study nuclear shapes through Coulomb excitation and transfer reactions up in different region of the nuclear chart. Elastic scattering and transfer in light system has allowed for the study of the interplay between halo structure and reaction mechanism as well to reveal the composition of the few excite states of halo and unbound nuclei.

In order to broaden the scientific opportunities beyond the reach of the present facility, the HIE-ISOLDE (High Intensity & Energy) project will provide major improvements in energy range, beam intensity and beam quality. A major element of the project will be an increase of the final energy of the post-accelerated beams to 10A MeV throughout the periodic table. The first stage will boost the energy of the current REX LINAC to 5 MeV/u where the Coulomb excitation cross sections are strongly increased with respect to the current 3 MeV/u and many transfer reaction channels will be opened.

The first phase of HIE-ISOLDE will start for physics in the autumn of 2015 with an upgrade of energy for all post-accelerated ISOLDE beams up to 5.5 MeV/u. After a submission of thirty-four letters of intend in 2009, twenty-five experiments have been approved for day-one physics with five hundred and eighty shifts. The physics cases approved expand over the wide range of post-accelerated beams available at ISOLDE. A large variety of instrumentation will be implemented. In this presentation HIE-ISOLDE project will be described together with a panorama of the physics cases addressed.

The performance of AGATA: from the LNL Demonstrator to the GANIL setup

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Abstract

The expected experimental conditions at the planned future facilities for radioactive ion beams and for high–intensity stable beams are extremely challenging. Unprecedented levels of efficiency and sensitivity are required for the detection of γ rays, which cannot be obtained with the conventional 4π arrays of Compton–suppressed high–purity germanium detectors. The approach pursued in the past few years implies covering the full 4π solid angle with germanium detectors only, and maximizing the photopeak efficiency and the peak–to–total ratio through the identification of the interaction points of the photons within the germanium crystals and a software reconstruction of their individual trajectories (*Pulse Shape Analysis* and *γ–ray tracking* techniques). The AGATA and GRETA projects, in Europe and USA respectively, aim to the realization of this technology.

This contribution will focus on the Advanced-GAmma-Tracking-Array AGATA. A subset of the array was operational and used for a demonstration phase and physics campaign with stable beams from 2009 to 2012 at the Legnaro National Laboratories, Italy. It has then moved to GSI, Germany, for an experimental campaign at the FRS separator. Since about one year AGATA is installed at GANIL, France, where, configured with 8 triple clusters (24 detectors) it is now running the first experimental campaign coupled to the VAMOS magnetic spectrometer.

The evolution of the performance of the array over the different campaigns will be presented and the Physics opportunities provided by this instrument will be discussed. In particular, the status of AGATA at GANIL will be highlighted, using results from the commissioning runs and from the ongoing experimental campaign.

The nuclear matrix elements of 0νββ decay and the NUMEN project at INFN-LNS

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T. BORELLO[4], M. CUBERO[5], P.R.S. GOMES[6], R. LINARES[6], J. LUBIAN[6], N. MEDINA[4], J.R.B. OLIVEIRA[4], M.R.D. RODRIGUES[4], V.A. ZAGATTO[6]

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The physics case of neutrino-less double beta decay and its tremendous implications on particle physics, cosmology and fundamental physics will be introduced. In particular the crucial aspect of the nuclear matrix elements entering in the expression of the half-life of this process will be deepened.

The novel idea of using heavy-ion induced reactions as tools for the determination of these matrix elements will be then presented. The strengths and the limits of the proposed methodology will be indicated. New data from MAGNEX facility at the INFN-LNS laboratory give first evidences of the possibility to get quantitative results about nuclear matrix elements from experiments. New results will be shown at the Conference regarding the ^{40}Ca(^{18}O,^{18}Ne)^{40}Ar at 270 MeV incident energy.

Finally the NUMEN project of INFN and the proposed strategy to this research will be sketched in the view of the upgrading of the INFN-LNS facilities.

Detector developments for the Super-FRS

C. Nociforo

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To move closer to the extreme limit of stability, the next generation of a large-scale European in-flight facility is presently planned at FAIR [1]. It will provide primary beam intensities up to 4.5×10^{11} ions/spill of ^{238}U at energy of 1.5 GeV/u. Rare isotopes of all elements up to uranium will be produced via fission/fragmentation, spatially separated within a few hundred nanoseconds, and delivered to different experimental branches of the Super-FRS [2].

For radioactive ion beams at velocity $\beta \sim 0.85$ a Time-of-Flight resolution below 50 ps, together with a precise momentum tagging (10^{-4}) and a powerful charge state discrimination will allow to resolve mass number A>150.

In this contribution we will present the technical challenges - high intensity and high resolution - of the detecting system of the in-flight separator Super-FRS and we will discuss some technical solutions, e. g. diamond focal plane detectors [3].

[1] https://www.gsi.de/en/research/fair.htm
[2] M. Winkler *et al*., Nucl. Instr. Meth. B 266 (2008) 4183
[3] C. Nociforo, 2014 JINST 9 C01022

CALIFA: The R3B CALorimeter for In Flight detection of g-rays and high energy charged pArticles

D. Cortina-Gil[1], for the R3B collaboration

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The R3B experiment (Reactions with Relativistic Radioactive Beams) at FAIR (Facility for Antiproton and Ion Research) is a versatile setup dedicated to the study of reactions induced by high-energy radioactive beams. It will provide kinematically complete measurements with high efficiency, for acceptance and resolution, for kinematically complete measurements of reactions with relativistic heavy-ion beams up to 1 AGeV, allowing an intese and broad physics program with rare-isotopes.

One of the key detectors in this experiment, CALIFA (CALorimeter for In-Fligth emitted pArticles), is a complex array of 2560 scintillation crystals, that will surround the target of the R3B experiment. To cope with the requirements of the R3B program, CALIFA combines the detection of low energy g-rays from single-particle excitations and high-energy g-rays associated with different collective modes. Moreover, CALIFA should be capable to detect high energy charged particles emitted from the reaction zone.
The high-energy of the R3B beams determine the conceptual design of the detector that has to accommodate a large Lorentz boost, particularly in the forward region. Therefore, CALIFA consists of two sections, a cylindrical 'Barrel' spanning an angular range from 140 to 40 degrees and an 'Endcap' in forward direction covering the angular range up to 7 degrees. The Barrel is formed by long CsI(Tl), whereas the Endcap combines monolitic CsI(Tl) with phoswich detectors made of LaBr(Ce)/LaCl(Ce), both using PSA techniques to separate punch through protons from stopped protons, and performing a very good background supression. We will underline the main technical caracteristics related with this versatile device, summarised in the corresponding TDR finalised only few months ago.

The experimental program of the R3B includes relevant questions such as the structure of the atomic nucleus at the extreme of nuclear stability (even beyond the neutron drip-line), the multipole response of neutron-rich nuclei, or reactions of astrophysics interest. Special attention will be given to the CALIFA performances in the QFS induced by radioactive beams. The intensities of the Super-FRS beams will allow the study of these reaction even for heavy systems. The improved detection capabilities of CALIFA in conjunction with a liquid hydrogen target will permit using tools such as (p,2p)-, (p,pn)- and (p,pd)-reactions to study deeply bound states in exotic nuclei and clustering short-range and tensor correlations.

Friday 26/06/2015
h. 08.30-10.30

AULA MAGNA

PLENARY SESSION:

Nuclear Astrophysics

Reaction models in nuclear astrophysics

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We present different reaction models commonly used in nuclear astrophysics, in particular for the nucleosynthesis of light elements. Pioneering works were performed within the extranuclear capture model [1] and within the potential model [2], where the internal structure of the colliding nuclei is completely ignored. Significant advances in microscopic cluster models [3] provided the first microscopic description of the $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ reaction more than thirty years ago [4]. In this approach, the calculations are based on an effective nucleon-nucleon interaction, but the cluster approximation should be made to simplify the calculations.

Nowadays, modern microscopic calculations are able to go beyond the cluster approximation, and aim at finding exact solutions of the Schrödinger equation with realistic nucleon-nucleon interactions [5]. These *ab initio* theories, however, are currently limited to low nucleon numbers (typically up to $A \approx 8$). Cluster models, on the other hand, are able to deal with heavier systems (typically $A \approx 40$ for low level densities), but rely on effective interactions. Recent examples are presented and discussed.

[1] R. F. Christy and I. Duck, Nucl. Phys. **24**, 89 (1961)
[2] T. A. Tombrello and P. D. Parker, Phys. Rev. **131**, 2582 (1963)
[3] P. Descouvemont and M. Dufour, in *Clusters in Nuclei*, Ed. C. Beck (Springer, 2012), Vol. 2
[4] Q. K. K. Liu, H. Kanada and Y. C. Tang, Phys. Rev. C **23**, 645 (1981)
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P. Navrtil, R. Roth, and S. Quaglioni, Phys. Rev. C **82**, 034609 (2010)

The 12th International Conference on Nucleus-Nucleus Collisions, June21-26,2015, Catania, Italy

Indirect method in nuclear astrophysics

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Understanding the origin of the elements is one of the key scientific questions facing researchers in nuclear physics and astronomy in the twenty first century. Significant progress in our understanding of the nucleosynthesis is owing to the development of different indirect techniques used to determine the reaction rates and new facilities that are expanding the possibilities for both direct and indirect studies. In this review I address two powerful and now commonly used indirect techniques to obtain the information about astrophysical reactions, the asymptotic normalization coefficient (ANC) method and the Trojan Horse method (THM).
The ANC method focuses on determining the normalization of the tail of the overlap function. The amplitude of this tail determines the overall normalization of the direct capture reaction rate For some reactions, this dominates over resonant capture. In other reactions, direct capture often interferes with resonant capture, which can be very important in determining the overall rate at stellar energies.
The THM provides a way to determine the reaction rate for rearrangement reactions by obtaining the cross section for a binary process through the use of a surrogate 'Trojan Horse' particle.
To demonstrate the power of the ANC method I will compare the astrophysical factors obtained using the ANC indirect method and direct measurements performed by LUNA collaboration for two important astrophysical reactions, ${}^{14}N(p,\gamma)^{15}O$ and ${}^{15}N(p,\gamma)^{16}O$.
Also I compare the most recent LUNA measurements of the primordial astrophysical reaction $\alpha(d,\gamma)^{6}Li$ with the results obtained using the ANC method. I will also mention the recently published constraining the 6.05 MeV and 6.13 MeV cascade transitions in the ${}^{12}C(\alpha,\gamma)^{16}O$ reaction using the ANC method.
To demonstrate the power of the THM I will address the success of this indirect method in the obtaining the reaction rates for the ${}^{2}H(d,p)^{3}H$ and ${}^{2}H(d,n)^{3}He$, for Big Bang nucleosynthesis revisited via THM, measurement of the 10 keV resonance in the ${}^{10}B(p,\alpha_0)^{7}Be$ reaction via the THM and updated THM S factor of the ${}^{19}F(p,\alpha)^{16}O$ reaction.

Where is the site of the r-process?

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The site of the rapid neutron capture process (r-process) is one of the grand challenges in all of physics today. The r-process is thought to be responsible for the creation of more than half of all elements beyond iron. The scientific challenges to understanding the origin of the heavy elements beyond iron lie in both the uncertainties associated with astrophysical conditions that are needed to allow an r-process to occur and a vast lack of knowledge about the properties of nuclei far from stability. One way towards the solution is the disentanglement of the nuclear and astrophysical components of the question. On the astrophysics side, various astrophysical scenarios for the production of the heaviest elements have been proposed but questions remain. On the nuclear physics side, there is great global competition to access and measure the most exotic nuclei that existing facilities can reach. Access to the very rich nuclei far from stability is a worldwide quest. The challenge is to determine via measurements of nuclear properties some distinguishing characteristics of the proposed sites for r-process to take place. Our approach has been to go from what is known in theoretical nuclear physics models to the determination of a set of nuclei that that have the greatest impact on the r-process. While we dont know the properties of specific nuclei far from stability, we do know the nuclear properties that are important for the r-process. These include nuclear masses, -decay rates, n-capture rates, and -delayed neutron emission probabilities. I will present the results of our work exploring the sensitivities of the r-process abundance distributions to specific nuclear physics inputs in various astrophysical scenarios via simulations of the r-process. The efforts include changing a single property and looking at its impact in a given astrophysical environment. Some of our most recent work looks at specific changes of nuclear masses. For example, a single nuclear mass is changed and that change is propagated through all the properties such as capture rates, beta decay rates, etc. of the neighboring nuclei that are affected. The end result is the determination of the most impactful nuclei to the r-process in three different astrophysical scenarios. Surprisingly, all three scenarios point to the same set of nuclei as being most impactful for the r-process.

Nuclear Reaction studies for Explosive Nuclear Astrophysics

P. Woods

Edinburgh University, UK

The talk will explore different experimental approaches being used to address key reactions involving radioactive nuclei required for understanding explosive nuclear astrophysical scenarios, such as novae, X-ray burst and supernovae. New developments including the use of radioactive targets, high resolution transfer reaction studies, and the use of heavy ion storage rings will be discussed.

Friday 26/06/2015
h. 11.00-13.00

AULA MAGNA

PLENARY SESSION:

New Facilities and Detectors

Present and future of RIB facilities in Europe

M. Lewitowicz

GANIL Caen, France

Abstract not received

New Instrumentation for the Equation of State Study at present and future facilities

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To access a wide range of densities, the Symmetry Energy Project, an international collaboration, has been formed to study the equation of state of asymmetric nuclear matter involving doing experiments in different facilities. In order to maximize the science potentials of low intensities rare isotope, we need a new generation of high resolution detectors with high efficiencies. In this talk, I will give a brief overview of the current status of the Equation of State Study in different facilities and our plans to study EOS with new detectors including the recently completed SpiRIT Time Projection Chambers (TPC) for experiments at RIKEN and a proposed solenoidal TPC at NSCL and FRIB.

This material is based on work supported by the DOE under Grant No. DE-SC0004835, NSF under Grant No. PHY-1102511 and the Japanese MEXT Grant-in-Aid for Scientific Research on Innovative Area Grant No. 24105004.

Extreme Light Infrastructure Nuclear Physics (ELI-NP): present status and perspectives

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ABSTRACT

Extreme Light Infrastructure – Nuclear Physics (ELI-NP), a new Research Center under construction, will use extreme electromagnetic fields for nuclear physics research and will be operational in 2018. The status of the Project implementation will be presented. At ELI-NP, a high power laser system together with a very brilliant gamma beam are the two main research tools. Their targeted operational parameters will be described. The related experimental set-ups will be presented, together with the main directions of the research envisioned.

Radioactive Ion Beam Factory at RIKEN

H. En'yo

RIKEN Nishina Center for Accelerator-Based Science

At RIKEN RI Beam Factory (RIBF), having all the experimental facilities in place, the uranium-beam intensity recorded 25pnA in 2014. With use of this powerful beam many experiments are begin performed by variety of researchers from all over the world, producing a lot of new data which were just a dream in several years ago. Recent status of RIKEN RI Beam Factory (RIBF) is presented with comparison with upcoming new facilities all over the world. Discussions will be made how the nuclear physics community can continue firm worldwide competitions and cooperation in the future, while keeping a good balance among domestic, regional (Europe-Africa, Asia-Oceania, and North-South America), and truly international projects.

AULA MAGNA, Friday, 26 June 2015 13.00 – 13.30

SUMMARY TALK

Toru Motobayashi

Riken Nishima Center, Saitama, Japan