IWM-EC 2018

International Workshop on Multi facets of Eos and Clustering

22nd - 25th May 2018
Catania, Italy

BOOK OF ABSTRACTS

Fission in inverse kinematics : recent results and perspectives

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The perspective of applications led to the development of ambitious programs related to the fission process, that also prove extremely fruitful when it comes to understanding the physics of this phenomenon.
The inverse kinematics technique is used by the SOFIA (GSI) and SPIDER (GANIL) collaborations in order to measure simultaneously several observables (isotopic yields, prompt neutron yields, kinetic energies) on a wide range of fissioning systems, including very short-lived ones.
The results of these programs will be presented and the opened questions on the fission mechanism will be discussed in the light of these new experimental information.

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Characterization of the nuclear gas phase produced in HI collisions.

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Heavy ion collisions below 100 MeV/A is a unique tool to produce highly excited nuclear states which has to be experimentally described and characterized in order to progress in the overall theoretical comprehension of nuclear thermodynamics.
The formalism of phase transition in finite system has been widely tested on multifragmentation data and show a good efficiency to describe de-excitation processes in terms of an interplay between liquid and gas phases .
In this work, the focus will be made on the so-called vaporization data and its link with the asymptotic gas phase of the nuclear phase diagram.
After a detailed presentation of the properties of the associated partitions, a comparison with dynamical and statistical will be made to test their present capabilities.
Perspectives will be addressed about the opportunities to study the vaporization process using neutron rich stable beams in the forthcoming INDRA-FAZIA campaign at GANIL.

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Fission in Inverse kinematics: A new window to experimental observables

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Experimentally, the understanding of the complex, long, and intricate process of nuclear fission is approached by collecting as many observables as possible and from all fissioning systems available. The measured properties of the fissioning system and of the fission products, and their correlations, has led to the current picture where, in a very simplified way, the fission proceeds according certain modes or channels centred around fragments with particular numbers of protons and/or neutrons, which emerge with specific deformations that also drive the sharing of part of the available energy.
Most of the information on fission was gathered so far in experiments that use direct kinematics, where the fissioning system can be considered at rest in the laboratory. However, these experiments suffer from two main drawbacks: few observables are measured simultaneously and the fragment atomic number is either absent or poor in resolution. The use of inverse kinematics, where the fissioning system is studied in-flight, opens a possibility to solve those issues and to add new information.
The correlation of the measured observables permits to recover properties such as the total kinetic energy or the neutron multiplicity that can be studied and compared with previous measurements. In addition, the measurement of the atomic number allows us to retrieve quantities such as the neutron-to-proton ratio of the fragments, the total excitation energy, and the elongation of the system can be calculated.
The discussion will mainly focus on the study of transfer- and fusion-induced fission of several systems, produced in inverse kinematics at GANIL (France).

Study of the N=Z fragment production in the $^{40,48}Ca+^{40,48}Ca$ at 35 MeV/u with FAZIA detector

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Experimental data collected with 4 FAZIA blocks for the systems $^{40,48}Ca+^{40,48}Ca$ at 35 MeV/u (FAZIA-SYM experiment) are presented, with a particular focus on the comparison of N=Z fragments in the n-poor and n-rich systems. Preliminary results are shown.

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A study on 4 reactions forming the $^{46}Ti^*$

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The pre-formation of α-clusters in α-conjugate nuclei or their dynamical condensation during nuclear reactions was largely debated. A useful tool to examine cluster emission is the study of pre- equilibrium emitted particles during the dynamical part of the reaction. Indeed, a strong correlation between nuclear structure and reaction dynamics arises when some nucleons or clusters of nucleons are emitted or captured [1]. The NUCL-EX collaboration (INFN, Italy) is carrying out an extensive research campaign on pre-equilibrium emission of light charged particles from hot nuclei with the ultimate goal to study how possible cluster structures affect nuclear reactions [2]. For this purpose, the emission of light charged particles from hot ^{46}Ti nuclei formed in the reactions $^{16}O+^{30}Si$, $^{18}O+^{28}Si$ and $^{19}F+^{27}Al$, was investigated, using the GARFIELD+RCo 4π array, fully equipped with digital electronics [3], at Legnaro National Laboratories. For central impact parameters, the systems form the same compound nucleus, namely $^{46}Ti^*$. Since the bombarding energy per nucleon influences the abundance of pre-equilibrium particles [4], it was kept constant (7 A MeV) for the three reactions ($^{16}O+^{30}Si$, $^{18}O+^{28}Si$, $^{19}F+^{27}Al$). Therefore, the non–equilibrium processes are expected to be almost the same. The reaction $^{16}O+^{30}Si$ has been measured also at a beam energy of 8 AMeV to populate the ^{46}Ti at the same excitation energy as in the case of the $^{18}O+^{28}Si$ at 7 AMeV reaction to obtain the same statistical component.

The experimental data were compared to theoretical predictions where events were generated by numerical codes based on dynamical and/or statistical models and then filtered through a software replica of our apparatus in order to take into account the experimental conditions. Effects related to the entrance channel and to the cluster structure of colliding ions are emphasized through differences among the experimental data and model predictions.

After a general introduction on the experimental campaign, this contribution will focus on the preliminary results obtained so far.

[1] P.E. Hodgson, E. Běták, Phys. Rep. 374 (2003) 1-89.
[2] L. Morelli et al., Journ. of Phys. G 41 (2014) 075107; L. Morelli et al., Journ. of Phys. G 41 (2014) 075108; D. Fabris et al., PoS (X LASNPA), 2013, p. 061.D; V.L. Kravchuk, et al. EPJ WoCs, 2 (2010) 10006; O. V.Fotina et al., Int. Journ. Mod. Phys. E 19 (2010) 1134.
[3] F. Gramegna et al., Proc. of IEEE Nucl. Symposium, 2004, Roma, Italy, 0-7803-8701-5/04/; M. Bruno et al., M. Eur. Phys. Jour. A 49 (2013) 128.
[4] J. Cabrera et al., Phys. Rev. C 68 (2003) 034613.

Results and recent advances with the CHIMERA and FARCOS detectors

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The Chimera detector capabilities are going to be extended with the implementation of a new digital front-end electronics for CsI(Tl) scintillators and the coupling of the Farcos correlators modules. Together with the detection capabilities achieved in the past (pulse-shape detection in Si detectors) and the recent ones, like the improved γ-ray detection in CsI detectors related to the GET digital electronics, the new coupling of CHIMERA and FARCOS arrays is well suited for different and more specific data analysis, in the field of stable and exotic heavy ion beams, e.g., IMF-IMF correlations, pygmy resonances, cluster condensation, nuclear reactions of astrophysical interest and density dependence of the symmetry energy. The obtained results and the expected future performances will be discussed. In particular, emphasis will be given to time scale transition dynamics from neck fragmentation to fusion reactions and multi-fragment emission from fast processes to subsequent long time scale sequential decay.

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Extensions of mean-field descriptions in dynamical processes of nucleonic degrees of freedom

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The description of nucleonic correlations responsible of dissipative processes and thermalization in finite nuclei is a long standing question. The development of models being able to account for these processes in nuclear physics has been a challenge since the last century. Mean-field theories and the corresponding extended versions including two-body collision terms are successful in describing low and intermediate energy collisions, respectively. In this last case with the advent of 4π detectors a huge amount of data revealed the occurence of highly excited states developing processes such as multifragmentation or vaporization, for which mere mean-field approches, even including collision terms, presented serious limitations. These models only provide information about the averaged global behavior of nuclear processes and are not able to reproduce the corresponding multiple exit channels scenarios which have been experimentally evidenced. For this reason stochastic extensions by including a Langevin-type force were explored by different authors [1] in semi-classical descriptions and more recently [2] in quantal grounds. In this work we present different aspects of a perturbative procedure for the progressive inclusion of multiparticle correlations in a semi-quantal dynamical description in order to generate those density fluctuations necessary to describe the expected patterns in exit channels. The positiveness of our model with respect to other descriptions is two folded. It contains quantal ingredients (as shell effects, single particle wave functions) providing a better characterization of nuclear systems at low excitations energies than semi-classical models. On the other side, its compact mathematical formalization allows numerical applications to realistic situations compared with pure quantal pictures, which only have been applied to simplified systems. Our model will be presented and applications to nuclear collisions at incident energies around the Fermi energy will be discussed.

[1] S. Ayik, C. Grégoire, Phys. Lett. B 212 (1988) 269; J. Randrup, G.F. Burgio, P.Chomaz, Nucl. Phys. A 538 (1992) 393; P. Napolitani, M. Colonna, Rhys. Lott. B 726 (2013) 382.
[2] E. Suraud, P.-G. Reinhard, N.J. Phys 16 (2014) 063066.

EXOTIC CLUSTERING INVESTIGATION IN ^{13}B AND ^{14}C NUCLEI.

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Clustering phenomena are well known in nuclear physics. Indeed, some properties of nuclei can be simply described by assuming a nuclear structure made of a few weakly interacting clusters. In n-rich nuclei, the α-α cluster structure as a core may persist, it is the exchange of neutrons between the α-particle cores which binds the system; thus molecular-like structures may show-up. In addition, in n-rich light nuclei, it is predicted the existence of cluster configurations where at least one of the clusters is unbound or weakly bound, and it is predicted to become more and more favored when nuclei approach the drip-line. Antisymmetrized Molecular Dynamics (AMD) [1] calculations indicate the possible existence of exotic clustering in neutron-rich isotopes of various elements as for example Beryllium, Boron, Carbon etc. In order to investigate upon the existence of molecular and/or exotic cluster configurations in Boron and Carbon n-rich isotopes we undertook two experiments: the first experimental study of exotic ^{9}Li+α cluster states of ^{13}B using the Thick Target Inverse Kinematics (TTIK) method at TRIUMF (Canada), and, with the same technique, the measurement of ^{10}Be+α scattering at LNS in Catania, where the ^{10}Be radioactive beam was produced in batch mode. The beams were stopped in a Helium- flooded chamber. The elastically scattered (recoil) alpha particles were detected by Si DE-E telescopes placed around 0° in the laboratory system corresponding to 180° in the center of mass. Detectors were placed also off 0° in order to have information on the angular dependence of the cross-section. In the case of ^{13}B the excitation function shows the presence of various peaks in an excitation energy region never explored before. In the case of ^{14}C, our exclusive measurement of elastic scattering data with, for the first time, a high intensity beam, sheds some light on the contradictory previously published results [2, 3]. In this contribution the results of these experiments will be discussed.

1. Y. Kanada-Enyo and H. Horiuchi Prog. Theor. Phys. **142**, 205 (2001)
2. H. Yamaguchi *et al.* Phys. Lett. B **766**, 11 (2017).
3. A. Fritsch *et al.* Phys. Rev. C **93**, 014321 (2016).

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ELIE; a phenomenological model for nuclear reactions at intermediate energies

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In this talk, I will present a phenomenological model (ELIE) dedicated to the description of nuclear collisions in the intermediate energy range.

The model allows for a complete event-by-event comparison with experimental data. The model is based on well defined assumptions which will be described. The main parameters of the model are the nuclear temperature, the density reached in central collisions, the in-medium nucleon-nucleon cross-section and the nuclear compressibility modulus. These quantities are obtained by a detailed comparison with a large set of experimental data obtained by the INDRA/FAZIA collaboration from incident energies between 25 and 100 MeV/u. Conclusions on the fragmentation mechanism at Fermi energies as well as the influence of the isospîn degree of freedom will be drawn.

Isospin influence on the Intermediate Mass Fragments dynamical emission at Fermi energy and at low energy

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A study of the damped reactions with Projectile-Like break-up following a Deep Inelastic Collision, is presented, by analysing the reactions ^{78,86}Kr+^{40,48}Ca at 10 AMeV.
The isospin is expected to play a crucial role in this reaction mechanism, in fact previous studies on the competition between the dynamical and statistical IMF production in the Projectile-Like fragmentation in the reactions ^{124}Xe+^{64}Ni,^{64}Zn, ^{112}Sn+^{58}Ni and ^{124}Sn+^{64}Ni at 35 AMeV have shown a dependence of the dynamical emission from the neutron enrichment of the system.
Because in the Fermi energy domain the binary step preceding the PLF break-up shows similarities to the strongly damped reactions present in the low-energy regime, an attempt of a comparison between these damped reactions in these two energy domains is also presented.

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Status of the SPES project @ LNL and its scientific and technological challenges.

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Several technological innovations and challenges are foreseen for SPES (Selective Production of Exotic Species), the INFN project for a Nuclear Physics facility with Radioactive Ion Beams (RIBs). The project is in advanced construction in Legnaro and the installation phase has begun. SPES will provide mostly neutron-rich exotic beams, derived by the fission fragments (10**13 fiss/s) produced in the interaction of an intense proton beam (200 microA) on a direct UCx target. The expected beam intensities, their quality and, eventually, their maximum energies (up to 11 MeV/A for A=130) will permit to perform forefront research in nuclear structure and nuclear dynamics, studying a region of the nuclear chart far from stability. By coordinating the developments on the accelerator complex and those of the experimental equipments a successful program is foreseen. The Linac ALPI post-accelerator is under a strong upgrading. For what it concerns the instrumentation, some equipments are already installed at the Legnaro National Laboratory and they are regularly upgraded. Moreover, newly developed instruments are under study and construction, which are very innovative and challenging and well inserted within international collaborations.

Several Letter of Intents have been presented to the Scientific Advisory Panel during the 3rd SPES International Workshop in October 2016. The presented themes represent a quite large and up-to-date scientific program to be discussed and studied in the forthcoming years.

New trends in mass identification with telescope detectors

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Most open questions in nuclear structure and dynamics require to measure not only the charge but also the mass of reaction products. It is, for example, mandatory in order to constrain the equation of state of asymmetric nuclear matter and its clustering properties at low density, but also to study exotic cluster states in nuclei. In this contribution, I will report on recent improvements in isotopic identification with telescope detectors. It will cover efforts made by different collaborations around the world to improve detector quality, electronic chains and signal processing. New identification techniques such as Pulse Shape Analysis identification or relative time of flight identification, as well as their performances, will also be discussed

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Versatile multichannel CMOS front-end with selectable full-scale dynamics from 90 MeV up to 2 GeV for the readout of detector's signals in nuclear physics experiments

C. Guazzoni on behalf of the FARCOS collaboration
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We developed a versatile multichannel CMOS front-end with selectable full-scale dynamics from 90 MeV up to 2 GeV for the readout of detector's signals in nuclear physics experiments. The core of the frontend electronics is a custom designed CMOS charge preamplifier able to guarantee an energy resolution of the order of 10 keV FWHM with a power budget of about 10 mW/channel (ASIC only). 16- channel charge preamplifiers are integrated in a single chip in ams [1] 0.35µm C35B4C3 technology together with the CsI(Tl) frontend and few additional slow control services as shown in Fig. 1. A dedicated 8 layer frontend board – see Fig. 2 – houses 2 ASICs and the line-drivers needed to provide a differential output and to drive the several-meter long connections. High-density right-angle open-pin- field connectors interconnect the motherboards and the patch-panel. 4 of these boards are needed for each telescope and they form also the mechanical walls of the telescope.
The first application of the developed frontend is to instrument the FARCOS (Femtoscope ARray for Correlation and Spectroscopy) [2] detection system, a novel detector featuring high angular and energy resolution able to reconstruct the particle's momentum at high precision and capable of performing correlation measurements of LCPs and of LCPs and IMFs. The designed frontend is extremely versatile, being suitable to be coupled to different detector topologies and signal polarities with capacitances ranging from about 10 pF up to about 200 pF.
Fig. 3 shows the measured energy spectrum with the frontend coupled with a 300 µm thick DSSSD of the FARCOS telescope illuminated with a mixed-nuclei α source during tests at the DEFEL beamline of LABEC (INFN, Firenze). The measured energy resolution (resistive feedback and 90 MeV dynamic range) is excellent. Fig. 4 shows an example of the ΔE-E identification plot (one strip of the 300 µm DSSSD and one strip of the 1500 µm thick DSSSD) in the case of a ^{16}O beam impinging on a LiF target at 88 MeV (Tandem, LNS, INFN, Italy). Protons, deuterons, tritons and α nicely gather as expected and the punching through is clearly visible. The presentation will focus on the designed frontend system and on the results of its qualification, together with the design of the final version of the frontend equipping the FARCOS telescopes.
This work has been supported by INFN in the framework of the NEWCHIM experiment.

[1] ams AG, Tobelbader Strasse 30, A-8141 Premstaetten, Austria.
[2] FARCOS TDR, available at https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view

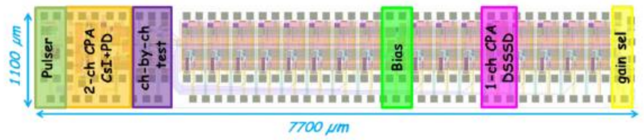

Fig. 1. Layout of the 16 channel FARCOS ASIC.

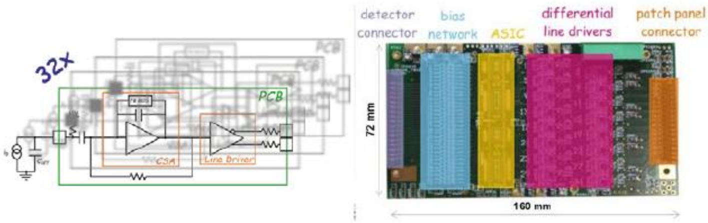

Fig. 2. Scheme of principle and photograph of the first release of the FARCOS motherboard: a custom designed 8-layer PCB housing ASICs & differential line drivers. High-density right-angle open-pin-field interconnection between motherboard and patch-panel.

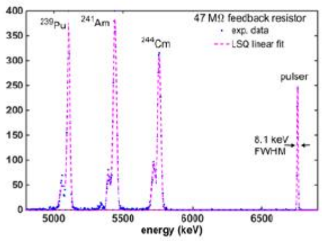

Fig. 3. measured energy spectrum (300 μm thick DSSSD, illuminated with a mixed-nuclei α source at the DEFEL beamline of LABEC (INFN, Firenze).

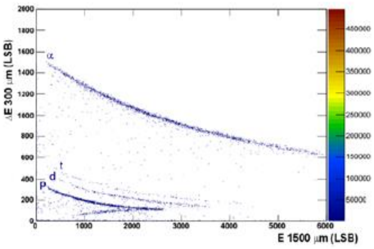

Fig. 4. ΔE-E identification plot (one strip of the 300 μm DSSSD and one strip of the 1500 μm thick DSSSD) in the case of a ^{16}O beam impinging on a LiF target at 88 MeV (Tandem, LNS, INFN, Italy).

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Transport properties in the Fermi energy domain

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The study of transport properties is a key point to determine energy dissipation and isospin diffusion for heavy ion induced collisions in the Fermi energy domain. This can be achieved by measuring the nuclear stopping linked to the in - medium mean free path λ_{NN}^{nm} of nucleons in nuclear matter [1, 2]. The determination of this latter and the corresponding nucleon – nucleon cross - section σ_{NN}^{nm} is indeed connected to the determination of the nuclear equation of state and its density and isospin dependence. The transport properties and moreover the transport quantities (λ_{NN}^{nm}, σ_{NN}^{nm}, μ_{NN}^{nm}) are also a good probe to constrain the phenomenological and theoretical models of the nucleon - nucleon interaction in the nuclear matter [3, 4].
In this talk, we will present new simulations on light charged particles and light clusters (d, t, ^{3}He) compared to experimental data on a large - scale analysis, coming from the INDRA 4π array. By looking at the isotropy ratio of the protons [1, 2] and the rapidity distributions of the light clusters, we will demonstrate that we are able to get consistent information concerning the transport properties of nucleons in nuclear matter. We will present also some comparisons with microscopic models (AMD, HIPSE) including the in - medium dependence for the nucleon - nucleon cross - section determined so far, specifically by looking at kinematical observables (isotropy ratio, rapidity) for light charged particles and clusters.

[1] G. Lehaut, et al., Physical Review Letters 104(23) (2010).
[2] O. Lopez, et al., Physical Review C 90(6) (2014).
[3] D. Coupland, et al., Physical Review C 84(5) (2011).
[4] A. Rios, et al., Physical Review Letters 108(1) (2012).

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The SπRIT and pion detectors in RIKEN for the experimental study of symmetry energy with heavy ion collisions

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For the experimental study of density dependent symmetry energy, there are several experimental devices for heavy ion collision experiments in Japan. The SπRIT Time Projection Chamber (TPC) was designed and constructed at the National Superconducting Cyclotron Laboratory, Texas A&M University, RIKEN and Kyoto University. It was used in a campaign of experiments at the Radioactive Isotope Beam Factory at RIKEN, intended to constrain the symmetry term of the Nuclear Equation of State at around twice saturation density. The commissioning of the SπRIT system including SπRIT TPC was completed in spring 2016, with the experimental campaign also performed in 2016. The experiment is designed especially to compare the ratio of negative and positive pions produced in asymmetric collisions. I will present overview of SπRIT experimental device and preliminary results from the experiments in addition to the overview of Kyoto pion range counter which was built for the basic study of pion production in heavy ion collisions as the pilot experiment of SπRIT project.

SπRIT project is supported by the U.S. DOE under Grant Nos. DE-SC0014530, DENA0002923, US NSF Grant No. PHY-1565546, and the Japanese MEXT KAKENHI grant No. 24105004.

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Current trends in the microscopic description of fission

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The description of fission in atomic nuclei challenges most advances many-body microscopic non-equilibrium theories. In the absence of superfluidity, it is not possible to describe the dissociation of a heavy Fermi liquid into two equals (symmetric fission) and/or unequals (asymmetric fission) smaller systems. This has been recently clearly pointed out using most advanced quantum transport theories where pairing correlations has been explicitly treated. These progresses in theory provides unique tools to understand specific aspects of fission: fission time-scales that have been found to be anomalously large, energy sharing between internal excitation and collective motion, pre- and post-scission neutron emission. These aspects will be reviewed during the talk. While already rather costly numerically, mean-field dynamics including or not pairing cannot describe fully the fission process. This stems from the intrinsic classical nature of a mean-field theory in collective space. Accordingly, such theory cannot describe quantum tunneling through the fission barrier and/or interferences between different classical paths. Several approaches have been proposed to overcome these difficulties, like the time-dependent generator coordinate method (TDGCM) or the stochastic mean-field (SMF) theory. Recent successes of these theory will be reviewed.

[1] G. Scamps, C. Simenel, and D. Lacroix, Phys. Rev. C 92, 011602(R) (2015).
[2] Y. Tanimura, D. Lacroix, and G. Scamps, Phys. Rev. C 92, 034601 (2015).
[3] A. Bulgac, P. Magierski, K. J. Roche, and I. Stetcu, Phys. Rev. Lett. 116, 122504 (2016).
[4] D. Regnier, N. Dubray, N. Schunck, and M. Verrière, Phys. Rev. C 93, 054611 (2016).
[5] Y. Tanimura, D. Lacroix and S. Ayik, Phys. Rev. Lett. 118, 152501 (2017).
[6] G. Scamps and C. Simenel, arxiV:1804.03337.

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Hot news from INDRA and the next scientific INDRA+FAZIA program at GANIL

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In this talk, I will present the recent results obtained by the INDRA collaboration concerning the study of nuclear dynamics and the equation of state. More specifically, I will discuss the issue of equilibration in heavy-ions induced reactions in the Fermi energy domain and the experimental constraints put on transport models concerning energy dissipation and isospin transfer. A special emphasis will also be made on the new experimental program planned at GANIL in the forthcoming years using stable beams around the Fermi energy. This latter consists on the coupling of INDRA 4π array and the new FAZIA demonstrator. By the combination of high-quality isotopic identification, excellent energy and angular resolution achieved by FAZIA at forward angles and the full 4π coverage, very good elemental identification given by INDRA at backward angles, we will be able to deeply investigate the isovector part of the EOS – the symmetry energy - and study its density dependence by looking at exclusive events obtained with differents reaction mechanisms such as deep-inelastic reactions, neck events or central collisions.

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On the Origin of the Elliptic Flow and its Dependence on the Equation of State in Heavy Ion Reactions at Intermediate Energies

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Recently it has been discovered that the elliptic flow, v_2, of composite charged particles emitted at midrapidity in Heavy-Ion collisions at intermediate energies shows the strongest sensitivity to the Nuclear Equation of State (EoS) which has been observed up to now within a microscopic model. This dependence on the nuclear EoS is predicted by Quantum Molecular Dynamics (QMD) calculations which show as well that the absorption or rescattering of in-plane emitted particles by the spectator matter is not the main reason for the EoS dependence of the elliptic flow at mid-rapidity but different density gradients (and therefore different forces) in the direction of the impact parameter (x-direction) as compared to the direction perpendicular to the reaction plan (y-direction), caused by the presence of the spectator matter. The stronger density gradient in y-direction accelerates the particles more and creates therefore a negative v_2. When using a soft momentum dependent EoS, the QMD calculations reproduce the experimental results.

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Constraints on the density dependence of the symmetry energy

J.Lukasik
IFJ PAN, Krakow, Poland

An overview of the recent and future experimental approaches to constrain the high density behavior of the symmetry energy will be presented. A special emphasis will be put on the results obtained from the ASY-EOS experiment with the use of the KRATTA detector.

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Active Targets and Time Projection chambers as new tools for probing EoS and clustering

T. Marchi for the NUCLEX and ACTAR TPC collaborations
INFN Laboratori Nazionali di Legnaro, Italy

There is increasing interest in the use of Time Projection Chambers (TPCs) for low and intermediate energy Nuclear Physics experiments. This is related to the capabilities offered by incoming and outgoing particle tracking, provided that dedicated technology has been developed to handle many electronic channels and large dynamic ranges in a cost effective-way.
In this contribution I will review the status of the main TPC and Active Target projects worldwide, selecting those that are (or will be soon) studying the topics of interest for the conference, namely the Nuclear Equation of State and Clustering effects in nuclei.
I will show the common methodology that connects the different projects, even at very different energy regimes. I will then focus on the capabilities offered by Active Target detectors when dealing with very low intensity beams like those produced at the forthcoming Radioactive Ion Beams facilities. When it comes to low intensity beams of rare nuclei, indeed, the use of TPCs as Active Target detectors allows to improve the luminosity of the setup and to perform experiments in regions of the Nuclear Chart under extreme isospin conditions.

"How nuclear jets form and disintegrate into clusters in heavy-ion collisions"

P. Napolitani[1] *and M.Colonna*[2]
1. *IPN-Orsay, Orasy, France*
2. *INFN-LNS, Catania, Italy*

The most extreme deformations that can be explored in heavy-ion collisions at Fermi-energies are collimated flows of nuclear matter which recall jet dynamics. From microphysics to the cosmological scale, jets are rather common topologies.
In nuclear physics, pioneering works focused on the breakup of these structures, resulting into early nuclear-fission models in analogy to the droplet formation in viscous liquids; such view became emblematic to explain surface-energy effects and surface instability by analogy with the Rayleigh instability.
Through a dynamical approach based on the Boltzmann-Langevin equation, well adapted to out-of-equilibrium conditions, we explored the possibility that nuclear jets could arise in heavy-ion collisions from different conditions than those leading to fission or neck fragmentation, and that they can breakup from mechanisms that are mostly unrelated to cohesive properties.

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The NArCos Project

Emanuele V. Pagano for NewChim Collaboration
INFN-LNS, Catania, Italy

With the advent of the new facility for radioactive ion beams, in particular for the neutron rich ones to the respect of the stable beams, it is necessary to develop neutron detection systems integrated with the charged particle ones. The integration of neutron signal, using neutron rich beams, became an important tool in order to study the property of the nuclear matter in extreme conditions. For this reason new detectors using new materials have to be build. In this contribution, it will be presented the NArCoS (Neutron Array for Correlation Studies) project having the purpose to construct a new detector for neutrons. In the presentation, the first tests, efficiency and resolution estimations will be presented.

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Recent results of the ISOFAZIA experiment

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INFN – Sezione di Firenze, Sesto Fiorentino (Firenze), Italy

Recent results concerning isospin transport phenomena on the system $^{80}Kr+^{40,48}Ca$ at 35AMeV are presented. An investigation of the isospin content of both fission fragments coming from the QuasiProjectile is also shown. Data were collected with four FAZIA complete blocks (ISOFAZIA experiment). An accurate comparison with the prediction of transport models is also shown.

Decay of ^{12}C excited states produced in Heavy Ion Collisions at intermediate energies

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The decay of ^{12}C excited states has been explored in $^{12}C + ^{24}Mg$ at 35 AMeV and $^{48}Ca + ^{27}Al$ at 40 AMeV reactions studied at Laboratori Nazionali del Sud of Catania using CHIMERA 4π multi-detector. In the first analyzed system, $^{12}C + ^{24}Mg$, a signature of direct processes in the decay of ^{12}C resonances has been observed while in $^{48}Ca + ^{27}Al$ reaction these states seem to decay through purely sequential mechanisms. In the following we present results of dedicate analysis and simulations performed in order to investigate on the reasons of such discrepancies and their possible connection with the different reaction mechanisms and /or structural differences of the reaction partners.

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Equilibration Chronometry and Reaction Dynamics

Alis Rodriguez-Manso & A.B. McIntosh
Texas A&M University

Heavy ion collisions exhibit a complex and beautiful variety of behavior which arrises from the dynamic interplay of competing forces. The nuclear equation of state governs this behavior, and by studying this behavior we have formed an understanding of the equation of state. The low-density neck which is very pronounced in heavy ion collisions below the balance energy play many roles. The neck acts as a sink for neutrons, but also acts as a bridge to allow neutron-proton equilibration and mass exchange between the reaction partners. The material in the neck can be released as free nucleons, or can aggregate into clusters. The neck will rupture at least once as the reaction partners re-separate, but can rupture in multiple places with measurable delay between the ruptures.

We have recently characterized neutron-proton equilibration in heavy ion reactions in an unprecedented level of detail. We examine the measured composition of the remnant of the projectile and the largest remnant of the neck. These compositions both show a clear dependence with rotation angle, and as the heavy fragment becomes more neutron rich the light fragment becomes less neutron rich. The rotation angle is interpreted as a measure of the duration of contact; not only is a timescale extracted for neutron-proton equilibration but it is seen that the composition changes exponentially in time, consistent with a process following first-order kinetics. The results are robust with respect to the impacts of secondary decay, the background of statistical decay, and choice of alignment angle definition. The equilibration is seen for a broad range of final states, and for beam and target combinations with varying initial neutron richness.

We explore how these measurements compare to dynamical transport model calculations. If we wish to trust constraints on the nuclear equation of state, it is crucial to test and expand our understanding of the mechanics and dynamics of heavy-ion collisions through comparison to dynamical transport calculations.

Few-nucleon correlations in nuclei and nuclear matter

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Few-nucleon correlations (A ≤ 4) are considered in nuclear matter at subsaturation densities, finite temperature, and arbitrary asymmetry. In particular, the formation of light elements (^{2}H, ^{3}H, ^{3}He, ^{4}He) are of relevance for the nuclear matter equation of state for special parameter values. Starting from an in-medium Schrödinger equation, a quasi-particle approach is used including self-energy and Pauli-blocking effects. Results for the composition and the thermodynamic potentials are shown. A quartetting wave-function approach is discussed to explain α-like clustering in nuclei.

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Upgrade of experimental facilities @ LNS

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The Laboratori Nazionali del Sud (LNS) in Catania are equipped with a superconducting solenoid, called SOLE, coupled to MEDEA multidetector, which, up to now, has been used in the study of the Giant Dipole Resonances as a forward collector of the evaporation residues on the focal plane detector MACISTE. SOLE characteristics in terms of size and magnetic field intensity make it an appealing instrument to build an helical orbit spectrometer at the LNS, like HELIOS in ARGONNE, which could be used to study direct nuclear reactions with radioactive beams once the cyclotron will be upgraded.
A feasibility study of an helical orbit spectrometer which uses SOLE magnetic field has been undertaken in the last years. Some preliminary results and possible applications will be presented.

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Temperature and density of hot decaying ^{40}Ca and ^{28}Si

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Bose-Einstein Condensation (BEC) is known to occur in weakly and strongly interacting systems such as dilute atomic gases and liquid ^{4}He [1]. During the last decade it was theoretically shown that dilute symmetric nuclear matter may also experience Bose particle condensation [2]. This possible new phase of nuclear matter may have its analog in low-density states of α-conjugate lighter nuclei. In the cooperation with the group from the Cyclotron Institute at Texas A&M University we have initiated a search for evidence of Bose Condensates. Our experiments employed 10, 25, 35 MeV/u beams of ^{40}Ca and ^{28}Si incident on ^{40}Ca, ^{28}Si and ^{12}C, both the projectile and target were α-conjugate nuclei. By means of quantum-fluctuation analysis techniques, we obtained temperatures and densities of the decaying hot ^{40}Ca and ^{28}Si projectile-like sources produced in reactions ^{40}Ca + ^{40}Ca, ^{40}Ca + ^{12}C and ^{28}Si + ^{12}C at 35MeV/A. The method allows to trace important quantum effects such as fermion quenching or Bose - Einstein Condensation in nuclei [3-7]. The preliminary results will be presented.

[1] Pitaevski L P and Stringari S, (2003) Bose-Einstein Condensation, Clarendon Press, Oxford.
[2] Roepke G et al (1998) Phys. Rev. Lett. 80 3177; Beyer M et al (2000) Phys. Lett. B 448 247; Sogo T et al (2009) Phys. Rev. C 79 051301.
[3] Hua Zheng and Aldo Bonasera, Physics Letters B 696 (2011) 178 – 181.
[4] Hua Zheng, Gianluca Giuliani, Aldo Bonasera, Nuclear Physics A 892 (2012) 43 – 57. [5] Zheng H., Giuliani G., Bonasera A. Nuclear Science and Techniques 24 (2013) 050512.
[6] Zheng H., Giuliani G., Bonasera A. Phys Rev C 88 (2013) 024607.
[7] Zheng H. and Bonasera A. Phys Rev C 86 (2012) 027602.

Alpha clustering and condensation in nuclear systems-- A nuclear Quantum Phase Transition

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Alpha-particle clustering and condensation is considered in nuclear mat- ter and finite nuclei. Pair and quartet condensation are contrasted. It is pointed out that, contrary to pairing, quartetting should be qualified as a Quantum Phase Transition (QPT). That is alpha condensation, at zero tem- perature, exists only below a critical density and, thus, the density is the control parameter. This fact will be highlighted for the example of alpha cluster states in ^{12}C with the Hoyle state as its most prominent member. However, other alpha cluster states above the Hoyle state will also be dis- cussed. The present situation of alpha clustering in ^{16}O will be considered. Going to heavier self-conjugate nuclei, the Coulomb explosion of ^{40}Ca into ten alphas becomes possible because the Coulomb barrier has faded away for such high numbers of alphas. Alpha-clustering on top of doubly magic nuclei like ^{20}Ne or ^{212}Po can be another subject to be considered if time permits.

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Symmetric and asymmetric fragmentation reactions at intermediate energy heavy ion collisions using isospin-dependent quantum molecular dynamics model

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It is well known that the dynamics of asymmetric reactions can be quite different than that of symmetric reactions. This is because of the fact that the excitation energy stored in the later case is in the form of compressional energy whereas, former has significant share in terms of thermal energy. Peaslee *et al*. [1] and later on Donangelo *et al*. [2], to mention a few, reported the failure of quantum molecular dynamics approach (QMD) in reproducing the multiplicities of intermediate mass fragments in asymmetric reactions, though, it works well for symmetric reactions. Therefore, one was interested to check the efficacy of isospin-dependent quantum molecular dynamics (IQMD) approach [3] that has additional refined ingredients in terms of symmetry energy, isospin dependence of nucleon-nucleon cross-section as well as larger Fermi momentum, to mention a few. In this talk, we wish to present our recent analysis of fragmentation and associated phenomenon using IQMD model in symmetric and asymmetric reactions. First of all, we shall present our recent calculations and comparison with experimental data for the production of d_{like}/p_{like} at incident energies up to 1 GeV/nucleon. Then, detailed comparison of our calculations of fragmentation will be made with experimental data involving symmetric as well as asymmetric reactions. We will show that IQMD model works fine for symmetric as well as for asymmetric reactions.

1. G.F. Peaslee, *et al*., Phys. Rev. C **49**, R2271 (1994).
2. R. Donangelo and S.R. Souza, Phys. Rev. C **52**, 326 (1995).
3. C. Hartnack, *et al*., Eur. Phys. J. A **1,** 151 (1998); S. Kaur and R. K. Puri, Phys. Rev. C **89**, 057603 (2014); A. Sharma, A. Bharti, S. Gautam and R. K. Puri, Nucl. Phys. A **945**, 95 (2016).

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Influence of neutron enrichment on de-excitation properties of palladium isotopes

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Heavy-ion collisions at intermediate energies generate emission sources with a large range of excitation energy and N/Z ratio. During the de-excitation phase of the reaction, these sources evaporate light charged particles. This evaporation can be modeled using Weisskopf and Hauser-Feshbach theories. At low excitation energy, experimental results are well reproduced by these theories. In the excitation energy range available with heavy-ion collisions at intermediate energies, models predict that the N/Z of the source could have an influence on the level density parameter, a parameter used in de-excitation models. The INDRA 4π-array was coupled with the mass spectrometer VAMOS to study the de- excitation of palladium isotopes with a large range of N/Z ratio. $^{34,36,40}Ar+^{58,60,64}Ni$ reactions produced compound nuclei with a N/Z range between 1 and 1.26. The beam energies were chosen to produce compound nuclei with 2.9 MeV per nucleon of excitation energy. The coupling of INDRA and VAMOS gives the unique opportunity to detect complete events with light charged particles identified in INDRA and the mass and charge of the compound nucleus residue identified in VAMOS. This exclusive experiment gives the possibility to characterize all the de-excitation chains that leads to a given residue, hence, setting new limits to the isospin dependances on de-excitation properties. The energy spectra of light charged particles detected in coincidence with a residue from all available compound nuclei are also used to evaluate the effect of neutron enrichment on the level density parameter.

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Probing nucleon-nucleon correlations in heavy ion transfer reactions

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The pairing interaction induces particle-particle correlations that are essential in defining the properties of finite quantum many body systems in their ground and neighbouring states. These structure properties may influence in a signi_cant way the evolution of the collision of two nuclei. The search of signatures of pairing has been mainly attempted via the measurement of two-particle transfer channels, in particular, via the extraction of enhancement coefficients, defined as the ratio of the cross section with predictions using uncorrelated states. Recently, pair correlations were probed in heavy ion collisions, where transfers of different nucleon pairs can be studied simultaneously. Grazing collisions produce a wealth of nuclei in a wide energy and angular range and with cross sections spanning several orders of magnitude [1]. Due to the complexity in their analysis and interpretation, it is essential to assess quantitative probes of the nucleon-nucleon correlations.
Significant progress has been achieved by performing studies far below the Coulomb barrier with the PRISMA spectrometer [2]. Transfer cross sections obtained from excitation functions for the closed shell 40Ca+96Zr [3], and superfluid $^{60}Ni+^{116}Sn$ [4,5] 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 extracted from 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 [3,4,5].
Very recently the excitation function in the $^{206}Pb+^{118}Sn$ [6] system was measured in a very challenging experiment, in order to probe whether and to what extent the effect of neutron-neutron correlations in the evolution of the reaction is modified in the presence of high Coulomb fields.
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.

[1] L. Corradi, G. Pollarolo, and S. Szilner, J. of Phys. G 36, 113101 (2009).
[2] S. Szilner et al., Phys. Rev. C 74, 024604 (2007).
[3] L. Corradi et al., Phys. Rev. C 84, 034603 (2011).
[4] D. Montanari et al., Phys. Rev. Lett 113, 052501 (2014).
[5] D. Montanari et al., Phys. Rev. C 93, 054623 (2016).
[6] L. Corradi, S. Szilner, LNL PAC proposal.

Clustering in dilute matter with medium effects

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Strongly interacting matter at subsaturation densities and subcritical temperatures is unstable to density fluctuations and nuclear clusters are formed. This can be described in a statistical approach based on an energy density functional that includes nuclei as explicit degrees of freedom besides nucleons (and leptons in case of compact-star matter). These clusters, however, change their properties in the nuclear medium, in particular their masses, with different contributions originating from the action of the Pauli principle, the interaction with the surrounding medium and the electron screening of the Coulomb potential. The mass shifts lead to a dissolution of the clusters with increasing density. A change of the neutron-proton asymmetry and the density dependence of the symmetry energy also affects the cluster formation.

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Dynamical properties and secondary decay effects of projectile fragmentation in ^{124}Sn,^{107}Sn + ^{120}Sn collisions at 600 MeV/nucleon

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Background: The projectile fragmentation is a well-established technique to produce rare isotope beams but its underlying physical processes are not fully known.
Purpose: We devote ourselves to studying the dynamical properties and secondary decay effects of projectile fragmentation in ^{124}Sn, ^{107}Sn + ^{120}Sn collisions at 600 MeV/nucleon.
Method: The formation of the projectile spectator and the fragmentation process are stud- ied with the isospin-dependent quantum molecular dynamics (IQMD) model. The minimum spanning tree algorithm and the ratio of parallel to transverse kinetic quantities are applied to distinguish the equilibrated projectile spectator during the dynamical evolution. The influence of secondary decay on fragmentation observables is investigated by comparing the calculations with and without the statistical code GEMINI. The validity of the theoretical approach is examined by comparing the calculated product yields with the experimental results of the ALADIN Collaboration for the studied reactions.
Results: The general correlation of an increasing excitation energy with a decreasing mass is found for collisions with impact parameter b = 5-10 fm. The nucleon evaporation of the prefragments reduces the multiplicity of intermediate-mass fragments but does not change their dependence on the isospin of the projectile. The sequential decay also leads to narrower isotope distributions. Switching to GEMINI at a higher excitation energy results in slightly narrower isotope distributions. With the GEMINI code, in which the nuclear masses with shell and pairing corrections are adopted, the calculations can rather generally reproduce the isotope distributions and mean neutron-to-proton ratios of the light fragments.
Conclusion: By permitting only evaporation in GEMINI, the IQMD+GEMINI model is able to reproduce the main features of projectile fragmentation in the studied Sn+Sn reactions.

Equilibration dynamics and isospin effects in nuclear reactions*

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We discuss recent microscopic studies of isospin dynamics in deep-inelastic and fusion reac- tions. For fusion we discuss a new approach to calculate the dependence of fusion barriers and cross-sections on isospin dynamics. The method is based on the time-dependent Hartree-Fock theory and the isoscalar and isovector properties of the energy density functional (EDF). The contribution to the fusion barriers originating from the isoscalar and isovector parts of the EDF is calculated using the DC-TDHF method [1, 2]. It is shown that for non-symmetric systems the isovector dynamics influence the sub-barrier fusion cross-sections. For most systems this results in an enhancement of the sub-barrier cross-sections but for others it can lead to no enhancement or even hindrance. The study of deep-inelastic reactions of nuclei provide a vehicle to explore nuclear transport phenomena for a full range of equilibration dynamics. These investigations provide us the ingredients to model such phenomena and help answer important questions about the nuclear Equation of State (EOS) and its evolution as a function of neutron-to-proton (*N/Z*) ratio [3].

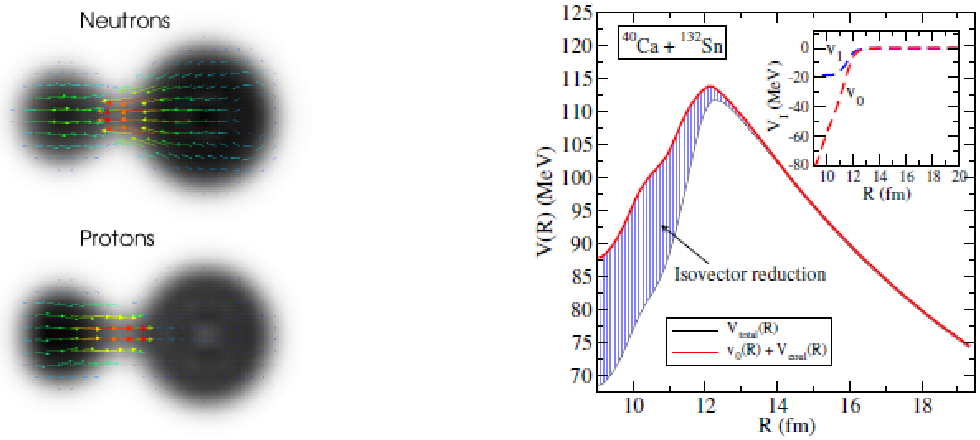

FIG. 1: For the ^{40}Ca+^{132}Sn reaction; neutron and proton current vectors at $R = 11.5$ fm (left). Total and isoscalar DC-TDHF potentials (right). The blue shaded region corresponds to the reduction originating from the isovector contribution.

*This work has been supported by the U.S. DOE under Grant No. DE SC0013847 with Vanderbilt University and by the Australian Research Council Grant Nos. FL110100098, FT120100760, DP160101254.

[1] K. Godbey, A.S. Umar, and C. Simenel, Phys. Rev. C 95, 011601(R) (2017).
[2] C. Simenel, A.S. Umar, K. Godbey, M. Dasgupta, and D. J. Hinde, Phys. Rev. C 95, 031601 (R) (2017).
[3] A.S. Umar, C. Simenel, and W. Ye, Phys. Rev. C 96, 024625 (2017).

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Time of flight identification with FAZIA_

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FAZIA (*Forward A and Z identification Array*) is an array of three-stage Si-Si-CsI(Tl) telescopes. It was designed to operate with beams in the 20–100MeV/u energy range and it provides charge and mass discrimination over a wide range of nuclei and energies. Indeed, in the last few years the FAZIA apparatus proved an excellent identification capability for charged particles emitted in nuclear collisions at Fermi energies. In particular, we achieved charge discrimination through Pulse Shape Analysis (PSA) [1–3] for particles which penetrate at least 30–60 μm (depending on their charge) in the first silicon layer. In the perspective of FAZIA experiments at lower energies (e.g. to be realized at the new ISOL facilities SPES and/or Spiral2), and in general to lower the

identification thresholds, the time of flight (ToF) information could be used. Our collaboration recently renewed important efforts in this direction [4, 5].
Usually, time of flight can be obtained in two ways: either two detectors (start and stop) are used at a certain well measured distance, or the start time mark is given by the accelerator RF signal. Considering the possibility to work also in the absence of pulsed beam, we are studying and implementing a new approach that works for those events where at least one ejectile is properly discriminated in mass. The identified fragments can be used to extract the event start time mark from their energy and mass. This algorithm needs a perfect synchronization among all the ADC clock signals and a precise tuning of all the possible clock skews.
This contribution reports on such recent FAZIA activity, focusing on the basic ideas of the method and on some first results from recent experiments at LNS.

[1] L. Bardelli et al., Nucl. Instrum. Meth. A **654**, 272 (2011).
[2] N. Le Neindre et al., Nucl. Instrum. Meth. A **701**, 145 (2013).
[3] G. Pastore et al., Nucl. Instrum. Meth. A **860**, 42 (2017).
[4] L. Bardelli et al., Nucl. Instrum. Meth. A **521**, 480 (2004).
[5] G. Pastore et al., submitted to Nucl. Instrum. Meth. A (2018).

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FOOT (FragmentatiOn Of Target) Experiment

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Particle therapy uses proton or ^{12}C beams for the treatment of deep-seated solid tumours. Due to the features of energy deposition of charged ^{12}C particles a small amount of dose is released to the healthy tissue in the beam entrance region, while the maximum of the dose is released to the tumour at the end of the beam range, in the Bragg peak region. Dose deposition is dominated by electromagnetic interactions but nuclear interactions between beam and patient tissues inducing fragmentation processes must be carefully taken into account. In proton treatment the target fragmentation produces low energy, short range fragments along all the beam range. In ^{12}C treatments the main concern are long range fragments due to projectile fragmentation that release dose in the healthy tissue after the tumour. The FOOT experiment (FragmentatiOn Of Target) of INFN (Istituto Nazionale di Fisica Nucleare) is a new project designed to study these processes. Target (^{16}O, ^{12}C) fragmentation induced by 150-250 MeV proton beam will be studied via inverse kinematic approach, where ^{16}O and ^{12}C beams, in the 150-200 AMeV energy range, collide on graphite and hydrocarbons target to allow the extraction of the cross section on Hydrogen. This configuration explores also the projectile fragmentation of these beams. The detector includes a magnetic spectrometer based on silicon pixel and strip detectors, a scintillating crystal calorimeter able to stop the heavier fragments produced and to achieve the needed energy resolution, and finally a TOF and ΔE scintillating detector for particle identification. . The experiment is being planned as a 'table-top' experiment in order to cope with the small dimensions of the experimental halls of the CNAO, LNS, GSI and HIT treatment centers, where the data taking is foreseen in the near future (2020). The detector, the performances, the physical program and the timetable of the experiment will be presented.

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The nuclear equation of state: from experiments to astrophysical observations accompained by the hand of theory

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The equation of state (EoS) of isospin asymmetric nuclear matter is a fundamental ingredient in the description of the static and dynamical properties of neutron stars, core-collapse supernova and compact-star mergers. In this talk I will make a review of different experimental and astrophysical observational constraints of the nuclear EoS as well as of several phenomenological models and ab-initio theoretical many-body approches

commonly used in the literature in its description.
I will put a special emphasis on the nuclear symmetry energy whose density dependence is still uncertain in spite of the experimental and theoretical efforts carried out in the last years to study the properties of isospin-asymmetric nuclear systems.

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Comparison of transport codes in box calculations

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Transport descriptions of heavy ion collisions are an important method to extract information on the nuclear equation-of-state and on in-medium properties of hadrons. Different transport model codes have been developed and applied widely. The physical deductions of such analyses should be independent as much as possible of the particular model, or at least, differences should be well understood. However, this has not always been the case in recent analyses, e.g. of pion production.
Therefore a project for a Transport Code Evaluation under controlled conditions has been initiated some time ago, to understand the differences between codes. A first comparison was made for Au+Au collisions at intermediate energies, which showed rather substantial differences. To investigate this further, comparisons were started for calculations in infinite nuclear matter, which can be realized approximately in a box with periodic boundary conditions. In this set-up the different ingredients of a transport calculation can be investigated separately and can be compared against analytical results. We have completed a study of the collision term, and work on the mean field propagation and pion production is in progress. In this talk on behalf of the Transport Code Evaluation project I will report on the status of these comparisons and discuss the implication of the results.

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Isospin effects in nuclear reactions

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The neutron to proton ratio of colliding nuclear systems can affect both the dynamics and thermodynamics that govern the reaction. These effects are a manifestation of the underlying nuclear interaction. Heavy ion collisions can be used to probe nuclear material at finite temperatures and at densities away from saturation density. Comparison of experimental observables, from a diversity of reactions measured with various experimental aparati, with theoretical predictions, using different interactions, can help to constrain the nature of nuclear matter and enhance the accuracy of predictions of astrophysical phenomenon.

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Competition between fusion and quasifission processes in heavy ion collisions close to the Coulomb barrier

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Within the Time Dependent Hartree Fock (TDHF) approach, we investigate the impact of several ingredients of the nuclear effective interaction, such as incompressibility, symmetry energy, effective mass, derivative of the Lane potential and surface terms on the exit channel (fusion vs quasifission) observed in the reaction $^{238}U+^{40}Ca$, close to the Coulomb barrier [1-3]. Our results show that all the ingredients listed above contribute to the competition between fusion and quasifission processes, however the leading role in determining the outcome of the reaction is played by incompressibility, symmetry energy and surface terms. This study unravels the complexity of the fusion and quasifission reaction dynamics and helps to understand the microscopic processes responsible for the final outcome of low energy heavy ion collisions in terms of relevant features of the nuclear effective interaction and Equation of State, such as incompressibility and symmetry energy.

[1] A. Wakhle, C. Simenel, D.J. Hinde et al., Phys. Rev. Lett. 113, 182502 (2014)
[2] A.S. Umar, V.E. Oberacker and C. Simenel, Phys. Rev. C 92, 024621 (2015)
[3] H. Zheng, S. Burrello, M. Colonna and V. Baran, Phys. Lett. B 769, 424 (2017)

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POSTERS

Odd-even effect in the light isotopes yield from the ^{129}Xe + ^{nat}Sn collisions at the energy range 8 to 25 AMeV

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The odd-even effect in the isotopes of the light fragments produced from the reaction ^{129}Xe + ^{nat}Sn at the energy range E = 8 to 25 A MeV is studied. The odd-even effect is clear existence in some of these distributions. At the distributions of the produced isotopes of carbon and oxygen, the ^{13}C and ^{17}O isotopes have the highest and the reasons are open questions. No significant differences between the six bombarding energies are seen in the distribution. The distributions of the produced isotopes for each number of fragments are studied. The yield of these distributions indicates that fission is the dominant decay mode at the bombarding energies (8-20 A MeV). At the bombarding energy 25 A MeV, the two fragments exit channels will be competitive with the three fragments exit channels.

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Role of EOS and scattering cross-section on the dynamics of nuclear reaction at intermediate energies

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The study of heavy-ion collisions is proved to be a useful tool to have a deeper insight of nuclear equation of state (EOS) and in medium nucleon-nucleon (nn) scattering crosssection. The observables such as collective flow, mulifragmentation, nuclear stopping and particle production have been stood significant in understanding the behaviour of EOS and nn scattering cross-section. In this regard, various studies have been done using different theoretical tools by implementing various nuclear compressibilities (i.e., EOS) and binary cross-sections. At the same time, the phenomenona of collective flow, multifragmentation etc. are closely related with the dynamic evolution of the colliding system which is governed by collisions rate and density achieved during the compressional phase of the reaction.
Some of the studies exist in the literature where the role of model ingredients has been investigated on the various observables and non observables that govern reaction dynamics. But none of the study has reported the role of model ingredients such as nuclear compressibility, momentum-dependent interactions and nn scattering cross-section on the nuclear dynamics using IQMD model. With this in mind, we study the role of different equations of state, nucleon-nucleon scattering cross-sections as well as momentumdependent interactions on the collision rate, density and thermalization achieved in the reactions of ^{15}C+^{15}C, ^{48}Ca+^{48}Ca and ^{197}Au+^{197}Au at different incident energies ranging between 50 and 400 MeV/nucleon within the framework of Isospin-dependent Quantum Molecular Dynamics Model (IQMD). Our study reveals the significant sensitivity of nuclear density towards different equations of state and its momentum dependence. Also soft EOS leads to higher compression compared to hard EOS and the role of EOS on nuclear density

increases with energy. Moreover, lighter systems are found to be less sensitive to the choice of EOS compared to heavier systems. On the other hand, nuclear density achieved in a reaction remains unaffected by the choice of nn scattering cross-section. The anisotropy ratio is found to be highly sensitive towards different choices of nn scattering cross-section for central collisions whereas this sensitivity disappears for peripheral collisions.

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Relating infinite nuclear matter characteristics to properties of neutron rich exotic nuclei within relativistic mean field formalisms

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We establish a correlation between the neutron skin thickness and the nuclear symmetry energy for the even-even isotopes of Fe, Ni, Zn, Ge, Se and Kr within the framework of the axially deformed self-consistent relativistic mean field for the non-linear NL3* and density-dependent DD-ME1 interactions. The coherent density functional method is used to formulate the symmetry energy, the neutron pressure and the curvature of finite nuclei as a function of the nuclear radius. We have performed broad studies for the mass dependence on the symmetry energy regarding the neutron-proton asymmetry and found a notable signature of a shell closure at N = 50 in the isotopic chains. The present study reveals an interrelationship between the characteristics of infinite nuclear matter and the neutron skin thickness of finite nuclei.

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Bimodality of largest cluster in nuclear fragmentation: Dynamical and Statistical

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VECC - Kolcata

The origin of bimodal behavior in the residue distribution experimentally measured in heavy ion reactions is revisited using Boltzmann-Uehling-Uhlenbeck simulations. We suggest that, depending on the incident energy and impact parameter of the reaction, both entrance channel and exit channel effects can be at the origin of the observed behavior. Specifically, fluctuations in the reaction mechanism induced by fluctuations in the collision rate, as well as thermal bimodality directly linked to the nuclear liquid-gas phase transition are observed in our simulations. Both phenomenologies were previously proposed in the literature, but presented as incompatible and contradictory interpretations of the experimental measurements. Indeed we have shown that the two bimodality mechanisms are associated in the transport model to different time scales of the reaction, and to different energy regimes. Our results indicate that heavy ion collisions at intermediate energies can be viewed as a powerful tool to study both the reaction mechanism out-of-equilibrium bifurcation due to the non-linearity of the dynamical evolution as well as the thermal bimodality signalling the liquid-gas phase transition.

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Multiplicity and largest cluster size derivative: New signatures of first-order phase transition in intermediate-energy heavy-ion collisions

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Theoretical models on multi-fragmentation of a nuclear system in heavy ion collision at intermediate energy, are known to show the existence of first-order phase transition. Variation of thermodynamic variables like specific heat, entropy, or energy with temperature are the well known signatures. But experimental measurement of these ob- servables is not easy. In multi-fragmentation of a nuclear system, total multiplicity of the fragments, produced in fragmentation is a very basic observable which is measured in most of the experiments. In this work it has been shown that this multiplicity (M) can provide a signature for first-order phase transition. The derivative of M with respect to E^*/A , where E^* is the excitation energy in the center of

mass and A is the total mass of the dissociating system, is expected to go through maximum as a function of E. Theoretical modeling shows that this is the energy where the specific heat Cv maximizes, which typically happens at the first-order phase transition. Since multiplicity can be obtained directly from experiment, experimental detection of the signature from multiplicity is more convenient than that from any other conventional thermodynamic variables like specific heat, entropy. Similarly the derivativeof the the size of the largest cluster(A_{max}) or a_2 (where $a_2 =(A_{max}-A_{max2})/ (A_{max}+A_{max2})$ and A_{max2} is the second largest cluster size) also peaks like specific heat and can be considered as signature of phase transition are are easily accessible to most experiments.
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Effect of Nuclear Pasta on the Nuclear Symmetry Energy

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Using a new parametrization of the CMD model we explore the effect of the presence of Nuclear Pasta on the determination of the value of the symmetry energy term.
We perform this calculation for both Nuclear Matter (no Coulomb term) and Neutron Star Matter (neutral system) as a function of the proton fraction, density and temperature.
Analyzing the Caloric Curve (temperature dependence of the energy of the system) we identify the points at which the topological phase transition sets in and the Temperature of liquid solid phase transition within "Pasta Structures".

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A general ideal multifragmentation kinematics algorithm for nuclear physics, a binary reaction approach

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A simple Kinematical approach to nuclear multifragmentation is studied by means of sequential binary fragmentations. Given a specific reaction tree for the multifragmentation process (specifying the fragments mass and excitation energy at each node) and a set of angles in the laboratory system associated to all but one of the final fragments, the energies of all the particles can be determined as well as the angle of the last particle (at the laboratory and CM frames). A recursive function can be constructed to show this. Using such a function it is shown how it is kinematically possible to distinguish different reaction trees with same final products. Limitations of this approach such as interaction among fragments and relativistic corrections at high energies will be briefly discussed.

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Decay properties of the ^{12}C Hoyle state studied by fragmentation with FAZIA

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The second 0^+ excited state of ^{12}C, also known as the Hoyle state, has a key role in the synthesis of the elements and it is believed to possess a rather unusual structure, where the dominant degrees of freedom are those of α clusters rather than nucleons [1]. Whereas the understanding of the properties of this state has been the focus of a major experimental activity, its 3α-decay mode is still debated (i.e. direct decay into three α particles

or sequential decay with an intermediate ^{8}Be). Experiments performed with inelastic scattering [2] or fusion-evaporation [3] reactions report a very low or even negligible 3α direct decay. On the other hand, Raduta et al. [4] published in 2011 a large value of 17% for 3α direct decay. In this latter case, excited ^{12}C were produced in the ^{40}Ca+^{12}C at 25MeV/A fragmentation reaction.
It has been proposed that this discrepancy is due to the interaction of the excited ^{12}C with the environment. Indeed, fragmentation reactions are characterized by a longer interaction time and by more dissipative processes: decaying ^{12}C are then produced inside a nuclear medium that could modify their intrinsic properties. In order to test this hypothesis, in the framework of the FAZIA collaboration we studied the decay mode of 12C Hoyle state produced in different nuclear media in terms of density and temperature, using the ^{32}S+^{12}C and ^{20}Ne+^{12}C collisions at 25 and 50 MeV/A.
In this poster I will present the FAZIA-COR experiment performed with 4 FAZIA blocks [5] at the LNS (Catania) in March 2017, as well as its first results.

[1] M. Freer, et al., Progr. Part. Nucl. Phys. **78** (2014) 1.
[2] M. Itoh, et al., Phys. Rev. Lett. **113** (2014) 102501.
[3] L. Morelli, et al., Journal of Physics G **43** (2016) 4.
[4] Ad.R. Raduta, et al., Phys. Lett. B **705** (2011) 65.
[5] R. Bougault et al., Eur. Phys. J. A **50** (2014) 47.

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New relativistic effective interaction for finite nuclei, infinite nuclear matter and neutron stars

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In this talk, I will describe about are newly generated parameter set for finite, infinite nuclear matter and neutron stars within the effective field theory motivated relativistic mean field (ERMF) formalism. The isovector part of the ERMF model employed in the present study includes the coupling of nucleons with the δ, ω and ρ mesons along with their cross-interactions. The second part comprises the application of the new parameter set for finite and infinite nuclear matter system. The obtained results like binding energy, radii for finite nuclei, and energy and pressure densities for infinite nuclear matter case are compared with the recent experimental data. Finally, I will cover the neutron star properties and the prediction of various tidal deformabilities obtained by this model. In conclusion, I will show that the obtained results are quite comparable with the recent experimental data including tidal deformability with GW170817 observation of the binary neutron stars.

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On the study of identification of fragment structures and correlations among them using quantum molecular dynamics model

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Transport model like quantum molecular dynamics (QMD) model is widely used to describe the multifragmentation phenomenon [1-3]. The phase space of nucleons obtained from the QMD model is injected into secondary clusterization algorithms to obtain information of the fragments. Earlier fragments were identified based on the simple spatial correlations. Later on, algorithms based on energy minimization such as early cluster recognition method (ECRA) [2], as well as simulating annealing clusterization algorithm (SACA) [3] were developed. Over the time, it became clear that the failure of QMD model coupled with spatial correlation method can be overcome by using these advance (but complicated) algorithms. Recently, based on these secondary algorithms, a new algorithm “Fragment recognition in general application (FRIGA)” [4] was proposed that takes care of the reactions involving hyper nuclei. In this talk, we will present our recent in-depth analysis of the fragmentation using QMD+SACA model. In addition, a detailed comparison with experimental data up to incident energy of 1 GeV/nucleon will also be one of the goals of the presentation. We will also put forward the predictive powers of SACA to explain event-by-event correlations among fragments.

1. J. Aichelin, Phys. Rep. 202, 233 (1991).
2. C. Dorso and J. Randrup, Phys. Lett. B 301, 328 (1993).
3. R. K. Puri, Ch. Hartnack, and J. Aichelin, Phys. Rev. C 54, R28 (1996); R. K. Puri and J. Aichelin, J. Comp. Phys. 162, 245 (2000) ; Y. K. Vermani and R. K. Puri, Euro. Phys. Lett. 85, 62001 (2009).
4. A. Le Fevre, Y. Leifels, J. Aichelin, C. Hartnack, V. Kireyev and E. Bratkovskaya, J. Phys. Conf. Ser. 668, 012021 (2016).

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Cluster states in 13C investigated with nuclear reactions induced by α particles on 9Be

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The study of ^{13}C structure allows to understand the effects of clusterization in light non-self- conjugated nuclei. The possible presence of rotational bands built on molecular states has been suggested in several papers [1,2]. Furthermore, in recent times, some theoretical papers [3,4] predicted the possible existence of states corresponding to the coupling of a valence neutrons to the 12C Hoyle state. To shed light on these aspects, we performed a comprehensive R- matrix fit of $\alpha+{}^9$Be elastic (α_0) and inelastic (α_1) scattering data in the energy range E_x-:: 3.5-10 MeV at several angles [5]. To carefully determine the partial decay widths of states above the α decay threshold we included in the fit procedure also $^9Be(\alpha, n_0)^{12}C_{gs}$ and ^{9}Be(α, n_1)$^{12}C_{4.44}$ cross section data taken from [6,7]. This analysis allows to improve the (poorly known) spectroscopy of excited states in ^{13}C in the E_x -::12-17 MeV region [8]. The preliminary results of these studies will be discussed; in particular, we find a possible indication on the existence of the negative-parity molecular band suggested in Refs. [1,2].

[1] M. Milin and W. von Oertzen, Eur. Phys. J. A 14 (2202) 295.
[2] N. Furutachi and M. Kimura, Phys. Rev. C 83 (2011) 021303(R).
[3] T. Yamada and Y. Funaki, Phys. Rev. C 92 (2015) 034326.
[4] Y. Chiba and M. Kimura, J. Phys.: Conf. Ser. 569 (2014) 012047.
[5] I. Lombardo et al., Nucl. Instr. Meth. Phys. Res. B 302 (2013) 19.
[6] L. van der Zwan and K. W. Geiger, Nucl. Phys. A 152 (1970) 481.
[7] R. Kunz et al., Phys. Rev. C 53 (1996) 2486.
[8] M. Freer et al., Phys. Rev. C 84 (2011) 034317.

On the nature of the low-energy E1 strength in the unstable nucleus ^{68}Ni

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The low-energy E1 strength, known as Pygmy Dipole Resonance (PDR) is an excitation mode con- nected to the neutron excess in nuclei. This mode is carrying few per cent of the isovector Energy Weighted Sum Rule (EWSR) and it is predicted to be present in all stable nuclei with neutron ex- cess and in particular for unstable nuclei [1–3]. The study of this mode and the knowledge about the structure are very important also due to the connection with the Equation of state of nuclear matter (EoS), indeed this mode is used as a further tool to constrain it [4, 5]. Moreover, the PDR is connected also to the r- process, responsible for the nucleo-synthesis of the heavy elements [6]. Due to the properties of its transition densities this mode can be populated by both isoscalar and isovector probes [7]. Several experiments, with both the probes, have been performed on stable nuclei [1, 2, 4] and on unstable nuclei by using Coulomb excitation [8]. Despite these different experimental studies the situation regarding the characterization of the PDR is not conclusive. At the LNS-INFN of Catania we have performed an experiment by using the unstable projectile ^{68}Ni impinging on a ^{12}C target, with the aim to study the PDR on the ^{68}Ni by using an isoscalar probe. We produced the ^{68}Ni by exploiting the projectile In Flight Fragmentation method in the dedicated FRIBs transport line. The CHIMERA multidetector [9] and the FARCOS array [10] were used to detect reaction products. We discuss the results about the observation of the Pygmy Dipole Resonance in ^{68}Ni.

References

[1] N. Paar et al., Rep. Prog. Phys. **70**, 691 (2007) and references therein.
[2] D. Savran et al., Prog. Part. Nucl. Phys. **70**, 210 (2013).
[3] A. Bracco et al., Eur. Phys. J. A **51**, (2015).
[4] A. Klimkiewicz et al., Phys. Rev. C **76**, 051603(R) (2007).
[5] J. Piekarewicz et al., Phys. Rev. C **73**, 044325 (2006).
[6] S. Goriely and E. Khan, Nucl. Phys. A **706**, 217 (2002). [7] E. G. Lanza et al., Phys. Rev. C **84**, 064602 (2011).
[8] O. Wieland et al., Phys. Rev. Lett. **102**, 092502 (2009).
[9] A. Pagano et al., Nucl. Phys. A **734**, 504 (2004).
[10] E.V. Pagano et al., EPJ Web of Conf. **117**, 10008 (2016).

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Study of nuclear matter property in heavy-ion fusion reactions

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In this study, using the semiclassical Skyrme energy density formalism, we probe the property of nuclear matter in different heavy-ion fusion reactions. For this purpose, the interaction potentials for the selected systems are calculated by the use of various Skyrme effective forces, which give equations of state (EOS) with a wide range of incompressibility (K) values, in the energy density formalism. Fusion cross sections for the colliding systems are computed from the obtained nucleus-nucleus potentials and compared with the experimental ones. Based on the agreement between the theoretical cross sections and the experimental data, it is found that the Skyrme interactions expressing soft EOS with smaller K values can reproduce the subbarrier fusion data. However, at higher energies, the fusion cross sections can be described by the Skyrme effective forces giving hard EOS with larger K values. The trend observed shows that, the nuclear matter property in the fusion process may change from soft to hard.

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Isospin effects in the decay of hot and rotating compound nuclei

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Opportunities of studying clustering in nuclei with the TTT3 tandem accelerator in Napoli

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In this poster we discuss the opportunities of studying nuclear reactions at low energies by using the beams available at the TTT3 3MV tandem-van der Graaf accelerator in Napoli, Italy. As a first point, a panoramic view of all the species of nuclear beams delivered by the accelerator is given, together with the range of available energies. After, we will show all the beamline and chambers that can be used to arrange several type of detection systems for nuclear reactions studies. Finally, typical examples of investigated reactions induced by proton, alpha and ^{7}Li beams at low energies that are useful to investigate the onset of alpha cluster structure in light nuclei are discussed. Both compound nucleus, resonant elastic scattering and cluster-transfer reactions have been investigated, and the results are sketched. Finally, perspectives for new possible experiments are discussed.