INPC 2013

INTERNATIONAL
NUCLEAR
PHYSICS
CONFERENCE

FIRENZE, ITALY 2-7 JUNE 2013

Book of Abstracts

01 – Plenary Talks

Foreword

In the present booklet we have collected the one-page abstracts of all the

Plenary Talks

presented at the International Nuclear Physics Conference (INPC2013) in Firenze. This is the first of eleven PDF-files/booklets containing all contributions accepted at the Conference. They are listed below, divided according to the various topics:

01 - Plenary Talks (PL)
02 - Nuclear Structure (NS)
03 - Nuclear Reactions (NR)
04 - Hot and Dense Nuclear Matter (HD)
05 - Fundamental Symmetries and Interactions in Nuclei (SY)
06 - Hadron Structure (HS)
07 - Nuclear Astrophysics (NA)
08 - Neutrinos and Nuclei (NN)
09 - Hadrons in nuclei (HN)
10 - Nuclear Physics Based Applications (AP)
11 - New Facilities and Instrumentation (NF)

Within each topic, the abstracts are numbered and arranged alphabetically according to the name of the first author. Each abstract is uniquely identified by its topics acronym and number. In the parallel and poster sessions of the Conference each contribution will be marked by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

Plenary Talks (PL)

PL 001.	Structure and spin of the nucleon *H. Avakian* Contact email: *avakian@jlab.org*
PL 002.	Electromagnetic reactions and few-nucleon dynamics *S. Bacca* Contact email: *bacca@triumf.ca*
PL 003.	Nuclear Structure with Gamma-ray Tracking Arrays *Dino Bazzacco* Contact email: *dino.bazzacco@pd.infn.it*
PL 004.	Imaging devices for medicine and security *A. J. Boston* Contact email: *A.J.Boston@liverpool.ac.uk*
PL 005.	Many-Body Quantum Reaction Dynamics near the Fusion Barrier *M. Dasgupta* Contact email: *Mahananda.Dasgupta@anu.edu.au*
PL 006.	Hadron physics from Lattice QCD *C. T. H. Davies* Contact email: *christine.davies@glasgow.ac.uk*
PL 007.	Meson Spectroscopy in the Light Quark Sector *R. De Vita* Contact email: *devita@ge.infn.it*
PL 008.	Kaon-Nucleon interaction: what can we learn from experiments? *L. Fabbietti* Contact email: *laura.fabbietti@ph.tum.de*
PL 009.	Exploring nuclear structure with deep-inelastic heavy-ion collisions *B. Fornal* Contact email: *Bogdan.Fornal@ifj.edu.pl*

PL 010.	Recent results from FRS experiments with exotic nuclei produced with uranium projectiles and perspectives with the super-FRS *H. Geissel* Contact email: *H.Geissel@gsi.de*
PL 011.	Recent results from heavy-ions collisions at CERN *P. Giubellino* Contact email: *paolo.giubellino@cern.ch*
PL 012.	Probing Sea Quarks and Gluons: The Electron-Ion Collider Project *T. Horn* Contact email: *hornt@cua.edu*
PL 013.	Recent Developments in the Understanding of Explosive H-Burning and the rp-Process Path: Classical Novae and Type I X-Ray Bursts *J. José* Contact email: *jordi.jose@upc.edu*
PL 014.	Three-nucleon forces and their importance in three-nucleon systems and heavier nuclei *Nasser Kalantar-Nayestanaki* Contact email: *nasser@kvi.nl*
PL 015.	Cluster formation and breaking, and cluster excitation in light nuclei *Yoshiko Kanada-En'yo* Contact email: *yenyo@yukawa.kyoto-u.ac.jp*
PL 016.	Lattice QCD and the phase diagram of strong interaction matter *Frithjof Karsch* Contact email: *karsch@bnl.gov*
PL 017.	Recent progress in EDF-based methods applied to nuclear properties *E. Khan* Contact email: *khan@ipno.in2p3.fr*
PL 018.	A Precise Measurement of Neutrino Mixing Angle ϑ_{13} at RENO *Soo-Bong Kim* Contact email: *sbk@snu.ac.kr*

PL 019.	Nuclear Physics and the development of new systems for energy production and waste transmutation *S. Leray* Contact email: *sylvie.leray@cea.fr*
PL 020.	Chiral Effective Field Theory for Nuclear Forces: Achievements and Challenges *R. Machleidt* Contact email: *machleid@uidaho.edu*
PL 021.	Nuclear Physics from Lattice Simulations *Ulf-G. Meißner* Contact email: *meissner@hiskp.uni-bonn.de*
PL 022.	World new facilities for radioactive ion beams *T. Motobayashi* Contact email: *motobaya@riken.jp*
PL 023.	Strange light nuclei *S.N. Nakamura* Contact email: *nue@lambda.phys.tohoku.ac.jp*
PL 024.	Direct Reactions with Exotic Nuclei *A. Obertelli* Contact email: *alexandre.obertelli@cea.fr*
PL 025.	New Horizons in Ab Initio Nuclear Structure Theory *Robert Roth* Contact email: *robert.roth@physik.tu-darmstadt.de*
PL 026.	Neutron Beta Decay as a Probe of Weak Interactions *A. Saunders* Contact email: *asaunders@lanl.gov*
PL 027.	Nuclear astrophysics of stellar explosions and neutron stars, and new opportunities at FRIB@MSU *H. Schatz* Contact email: *schatz@nscl.msu.edu*

PL 028.	Searching for new physics in beta-neutrino correlations *N. Severijns* Contact email: *nathal.severijns@fys.kuleuven.be*
PL 029.	Shell evolution and nuclear forces *O. Sorlin* Contact email: *sorlin@ganil.fr*
PL 030.	Neutron Star Masses, Radii, and the Equation of State of Dense Matter *A.W. Steiner* Contact email: *steiner3@uw.edu*
PL 031.	Recent results from heavy-ion collisions at RHIC *Thomas Ullrich* Contact email: *thomas.ullrich@bnl.gov*
PL 032.	Probing the nuclear Equation-of-State and the Symmetry Energy with heavy-ion collisions *G. Verde* Contact email: *giuseppe.verde@ct.infn.it*
PL 033.	Ultrarelativistic heavy-ion collisions: a theoretical review *Xin-Nian Wang* Contact email: *xnwang@lbl.gov*

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Structure and spin of the nucleon

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Four decades of lepton-nucleon scattering experiments revealed several intriguing aspects of nucleon structure. One of the most surprising results is the unexpectedly small fraction of the proton's spin that is due to the contribution from quarks and antiquarks. Studies of orbital motion of partons attracted a huge amount of theoretical and experimental interest. In recent years parton distributions, describing longitudinal momentum, helicity and transversity distributions of quarks and gluons, have been generalized to account also for transverse degrees of freedom. Two new sets of more general distributions, Transverse Momentum Distributions (TMDs) and Generalized Parton Distributions (GPDs) were introduced to describe transverse momentum and space distributions of partons.

Great progress has been made since then in measurements of different Single Spin Asymmetries (SSAs) in semi-inclusive and hard exclusive processes providing access to TMDs and GPDs respectively. Facilities world-wide involved in studies of the 3D structure of nucleon in electroproduction include HERMES at HERA, CLAS and Hall-A at JLab and COMPASS at CERN. TMD studies in Drell-Yan process are also becoming an important part of the program of hadron scattering experiments. Studies of GPDs and TMDs are also among the main driving forces of the JLab 12 GeV upgrade project and future facilities, such as GSI and EIC.

In this talk we present an overview of the latest developments in studies of TMDs and GPDs and discuss newly released results, ongoing activities, as well as some future measurements.

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Electromagnetic reactions and few-nucleon dynamics

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The interaction among nucleons is governed by quantum chromodynamics (QCD). In the low energy regime relevant to nuclear physics, QCD is not perturbative and thus difficult to solve. A series of potentials have been devised in the literature to describe nuclear forces in terms of effective degrees of freedom: protons and neutrons. For the determination of realistic nuclear Hamiltonians and to discriminate among different potentials, a variety of observables have to be investigated. The study of electromagnetic reactions is fundamental to understand the nuclear dynamics, because a clear comparison between theory and experiment is facilitated by the perturbative nature of the electromagnetic probe. By concentrating our analysis on light-nuclei, where ab-initio approaches are applicable, we can study the sensitivity of electromagnetic reactions to different Hamiltonians, the only ingredients of theoretical calculations.

The difficulty in calculating electromagnetic cross sections is that excited states in the continuum are involved, where the nucleus is broken up in several pieces. Their complicated calculation can be avoided by using the Lorentz Integral Transform (LIT) method [1], where the problem is reduced to a bound state Schrödinger-like equation. Recent results obtained from the application of this method to the calculation of electromagnetic reactions will be showcased. An example is the monopole transition form factor $F_{\mathcal{M}}(q)$ in ^{4}He [2], shown in Figure 1. We observe that $F_{\mathcal{M}}$ exhibits a strong potential model dependence, and can serve as a kind of prism to distinguish among different potentials and shed more light on few-nucleon dynamics. We will also discuss how we extend these calculations to medium mass nuclei, to describe the giant dipole resonance of ^{16}O from first principles [3]. By merging the LIT with coupled cluster theory [4] we open up the exciting possibility to investigate inelastic reactions for medium-mass stable and possibly unstable nuclei with ab-initio methods.

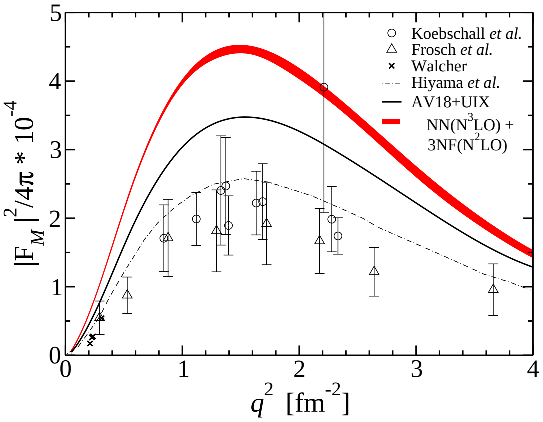

Figure 1: *Monopole transition form factor to the first* 0^+ *excited state of* ^{4}*He: calculations with different three-body Hamiltonians in comparison to experimental data.*

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Nuclear Structure with Gamma-ray Tracking Arrays

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In the past decades, a great amount of Nuclear Structure information has been obtained with γ spectroscopy techniques based on the use of arrays of Compton-suppressed high-purity germanium (HPGe) detectors. With about one hundred detector modules, the largest set-ups of this type, EUROBALL and GAMMASPHERE, could reach full-peak efficiencies of 10%, working ideally in experiments with heavy ion stable beams producing nuclei with moderate recoil velocities.

The present trend towards experiments with radioactive ion beams is, however, very challenging for these detection systems. First of all it is clear that quite larger full peak efficiencies are needed to cope with the much lower beam intensities. Furthermore, when produced at high energy fragmentation facilities, the nuclei of interest move with relativistic velocities, resulting in severe Doppler broadening of the γ-ray spectra due to the large detector opening-angles needed to achieve sufficient efficiency. In this situation, the conclusion was soon reached that conventional techniques cannot achieve the required levels of efficiency and selectivity.

The gamma-ray spectroscopy community decided to embark on the search for a new detection paradigm and, after a decade of development, the first modules based on the new concept of γ-ray tracking have eventually started operating in real experiments.

Tracking of gamma rays is based on the capability to determine both energy and position of the individual interactions by which gamma rays are absorbed inside the large-volume high-purity germanium crystals used in gamma ray spectroscopy. If these quantities are known with sufficient precision, the gamma rays of the detected event can be reconstructed (tracked) and characterized in details. The required position sensitivity inside the germanium crystals is achieved by the combination of electrical segmentation of the outer electrode, fully-digital data acquisition techniques and detailed analysis of the signals induced on the segments by the charge collection process. The development of this technology has been pushed by the AGATA and GRETA projects, both aiming at the ultimate 4π germanium-only detector.

These two instruments are expected to play a major role in the future nuclear structure studies at the very limits of nuclear stability.

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Imaging devices for medicine and security

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Studying the structure of the nucleus at the frontiers of nuclear stability presents a number of difficult challenges. The advent of radioactive ion-beam facilities has required a step change in the sensitivity of the nuclear instrumentation required to study the expected new and exciting nuclear phenomena. The detection of gamma radiation is at the heart of nuclear structure physics experiments and is key to the success of many industrial and medical applications involving gamma ray imaging. Projects such as the Advanced Gamma Tracking Array (AGATA) in Europe and the Gamma-ray Energy Tracking Array (GRETA) in the United States have pushed the technical boundaries needed to realise spectrometers capable of measuring nuclei far from stability.

This presentation will focus on how the technology designed for Nuclear Physics experiments has found application in areas outside of the core physics programme. Sensors developed for Medical, Security, Environmental and Nuclear imaging systems will be presented and discussed. The prospects for multi-modality imaging systems will be highlighted and opportunities for future research and development identified.

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Many-Body Quantum Reaction Dynamics near the Fusion Barrier

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Understanding the interactions of weakly bound nuclei and heavy nuclei at energies close to the fusion barrier is a challenging problem, as outcomes are sensitively dependent on the quantum nature of the colliding nuclei. Coupling-enhanced tunneling can result in orders of magnitude enhancement in cross-sections at energies below the average barrier – however, inhibition of fusion is also observed, which is not yet quantitatively understood. The latter may be related to the onset of irreversibility, which can reduce the effects of quantum superposition at energies well-below the barrier. Indeed, nuclear collisions may be a unique probe of the quantum dynamics of many-body systems as they are isolated from external environments. Experiments and theoretical developments in these areas have progressed hand-in-hand, as improved experimental techniques have revealed new facets of reaction dynamics. I will discuss recent experiments which highlight the role of time-scales of processes that are fast enough to compete with fusion.

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Hadron physics from Lattice QCD

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I will describe recent calculations using lattice Quantum Chromodynamics to determine hadron masses and hadronic decay rates that probe internal structure. Current calculations allow percent level tests of QCD when compared to experiment and enable the parameters of QCD, quark masses and the strong coupling constant, to be accurately determined. The figure below shows, as an example, the status of the ‘gold-plated’ mesons from lattice QCD calculations.

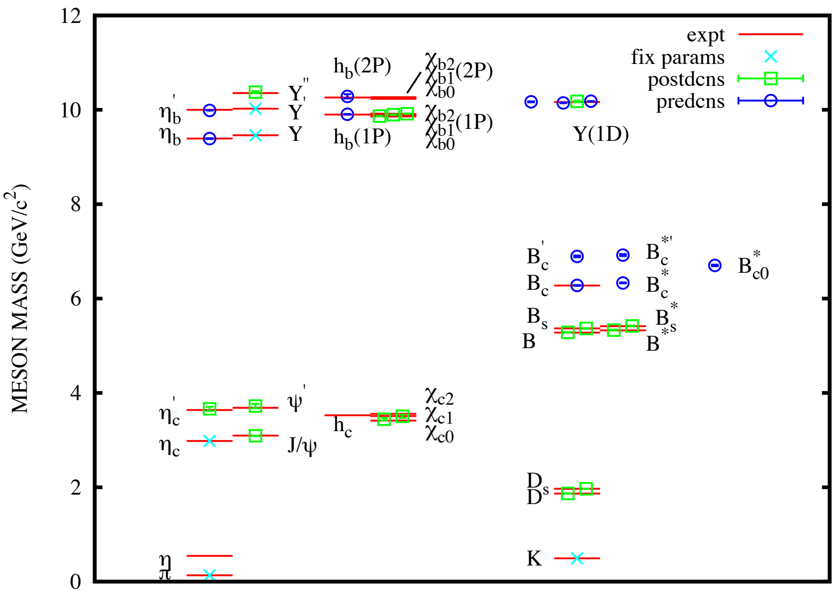

Figure 1: *The spectrum of ‘gold-plated’ mesons from lattice QCD compared to experiment.*

I will also describe prospects for the future now that lattice QCD calculations are able to work at physical values of the up/down quark masses on large volumes.

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Meson Spectroscopy in the Light Quark Sector

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Understanding the hadron spectrum is one of the fundamental issues in modern particle physics. We know that existing hadron configurations include baryons, made of three quarks, and mesons, made of quark-antiquark pairs. However most of the mass of the hadrons is not due to the mass of these elementary constituents but to the force that binds them. Studying the hadron spectrum is therefore a tool to explore one of the fundamental forces in nature, the strong force, and Quantum Chromo Dynamics (QCD), the theory that describes it. This investigation can provide an answer to fundamental questions as what is the origin of the mass of hadrons, what is the origin of quark confinement, what are the relevant degrees of freedom to describe these complex systems and how the transition between the elementary constituents, quarks and gluons, and baryons and mesons occurs.

In this field a key tool is given by meson spectroscopy. Mesons, being made by a quark and an anti-quark, are the simplest quark bound system and therefore the ideal benchmark to study the interaction between quarks and understand what the role of gluons is. In this investigation, it is fundamental to precisely determine the spectrum and properties of mesons but also to search for possible unconventional states beyond the $q\bar{q}$ configuration as tetraquarks ($qqqq$), hybrids (qqg) and glueballs. These unusual states can be distinguished unambiguously from regular mesons when they have exotic quantum numbers, i.e. combinations of total angular momentum, spin and parity that are not allowed for $q\bar{q}$ states. These are called *exotic* quantum numbers and the corresponding states are referred to as *exotics*.

The study of the meson spectrum and the search for exotics is among the goals of several experiments in the world that exploit different reaction processes, as e^+e^- annihilation, $p\bar{p}$ annihilation, pion scattering, proton-proton scattering and photoproduction, to produce meson states. This intense effort is leading to a very rich phenomenology in this sector and, together with recent theoretical progresses achieved with lattice QCD calculations, is providing crucial information to reach a deeper understanding of strong interaction.

In this talk I will review the present status of meson spectroscopy in the light quark sector and the plans and perspectives for future experiments.

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Kaon-Nucleon interaction: what can we learn from experiments?

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The study of hadron properties within nuclear matter, at a finite temperature and density, have been addressed from theory and experiments with the main aim to connect those to possible signatures of the of chiral symmetry restoration.

In particular, hadrons containing strangeness have been measured in heavy ion collisions and proton induced reaction at intermediate energies (1-2 AGeV) and the study of their kinematic variables has allowed to determine the in-medium modified mass for K^+ and K^0_S, while this search is still on going for K^-. In general, an attractive potential is predicted among K^- (Lambda) and nucleons, while a repulsive effect has been measured for K^+ and K^0_S. To this end, the interpretation of the collected data is rather model dependent and makes use of the prediction by transport models. On the other hand, the issue of the K^- Nucleon interaction is addressed by forming kaonic atoms in high precision experiments which are directly comparable to effective unitarized chiral theories and by studying the properties of the Lambda(1405) resonance, which is described by theory as a molecular stare either a K^- - proton or a pi - Sigma states. Indeed, the presence of the Lambda(1405) resonance, close to the K^- - Proton threshold, influences greatly the kaon spectral function in matter and it is hence linked to the studies of Kaon-Nucleus interaction.

In this talk, the current status of the studies of strange hadron production in heavy ion collisions at intermediate energies, the latest findings on the properties of the Lambda1405 and its connection to the precision measurement of kaonic hydrogen will be presented. Future measurements exploiting pion beams will be discussed as fundamental to unravel some basic properties and the impact of these kind of results for models for neutron stars will be addressed.

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Exploring nuclear structure with deep-inelastic heavy-ion collisions

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Deep-inelastic processes between complex nuclei were first observed in the sixties [1], but it was not until the early 1970s that the importance of the new damped-reaction mechanism was recognized by experimental groups and that theoretical concepts were developed (e.g., [2]). A specific goal early on was to discover the collective phenomena and relaxation processes occurring within a small quantum system that is initially far from equilibrium. The usefulness of deep-inelastic reactions for discrete gamma-ray spectroscopic studies came into focus only in 1990's, when it was demonstrated that they are amenable to populating excited structures at relatively high spin in nuclei far off the valley of beta stability [3]. This initial work triggered a series of experimental investigations aimed at exploring high-spin structures in neutron-rich nuclei hard to reach by other methods. The technique relies on using processes which occur at incident energies roughly 20% above the Coulomb barrier where the production of neutron-rich species results from a tendency towards N/Z equilibration of the di-nuclear system formed during the collisions. Characteristic gamma rays from those products can in principle be measured, but, since the total reaction yield is spread over many nuclei, the spectra are quite challenging. The development of efficient Compton-suppressed germanium arrays (GASP, GAMMASPHERE, EUROBALL) enabled fruitful studies of discrete gamma rays from those reaction products, especially in measurements carried out with a thick target. Here, the presence of known gamma rays is combined with the gamma-gamma coincidence technique to provide an accurate identification of the product nuclei. In thin target experiments, on the other hand, the gamma rays need to be detected in coincidence with reaction products identified, for example, in a magnetic spectrometer (CLARA+PRISMA, EXOGAM+VAMOS), as this is the only way to properly correct for Doppler effects while simultaneously providing the identification of the fragments.

By using both thick and thin targets with deep-inelastic collisions, yrast and near-yrast structures have been located in many nuclei that were previously inaccessible. The results include: the discovery of the doubly-magic character of ^{68}Ni [4], the identification of a sub-shell closure at N=32 in neutron-rich nuclei [5], the location of high-spin yrast isomers in neutron-rich nuclei in the neighborhood of the doubly- magic ^{208}Pb (e.g., [6]), etc.

With the advent of high-intensity, neutron-rich radioactive beams at energies close to the Coulomb barrier, there is much optimism about the potential of deep-inelastic processes as a unique tool to access yrast structures in exotic nuclei located close to the radioactive projectile.

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RECENT RESULTS FROM FRS EXPERIMENTS WITH EXOTIC NUCLEI PRODUCED WITH URANIUM PROJECTILES AND PERSPECTIVES WITH THE SUPER-FRS

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FOR THE FRS- AND FRS-ESR COLLABORATIONS,
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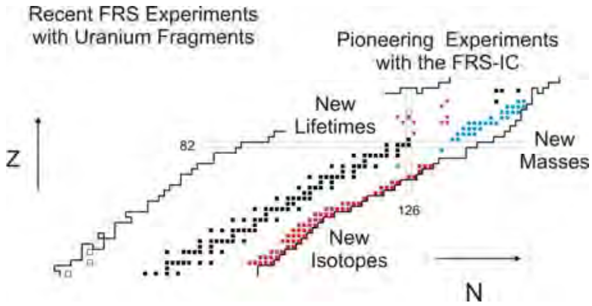
Relativistic exotic nuclei have been produced via uranium projectile fragmentation and fission and investigated with the in-flight separator FRS [1] directly, or in combination with either the storage-cooler ring ESR or the FRS Ion Catcher. The primary uranium beam, accelerated by the heavy-ion synchrotron SIS-18, impinged on the production target with a kinetic energy of up to 1000 A·MeV.

60 neutron-rich isotopes have been discovered in the element range from Nd to Pt and their production cross sections have been measured [2]. Fission is the dominant reaction process contributing to the production of the new neutron-rich isotopes of the lighter elements in this experiment.

In another experimental campaign the fragments were separated in flight and injected into the storage-cooler ring ESR for accurate mass and lifetime measurements. In this experiment we have obtained accurate new mass values of 33 neutron-rich nuclei in the element range from platinum to uranium [3]. In total more than 150 nuclides including references with well-known masses have been covered in this large-area mass measurement. A novel data analysis has been applied which reduces the systematic errors to about 10 keV by taking into account the velocity profile of the cooler electrons and the residual ion-optical dispersion in this part of the storage ring.

Pioneering experiments have been carried out with the FRS Ion Catcher (IC) [4,5,6]. The FRS IC consists of three experimental components, the dispersive magnetic system of the FRS with a monoenergetic degrader, a cryogenic stopping cell filled with pure helium and a multiple-reflection time-of flight mass separator. The FRS IC enables high precision spectroscopy experiments with keV exotic nuclides.

Results from these different FRS experiments will be presented in this overview together with perspectives for the next-generation facility Super-FRS [7]. The novel features of the Super-FRS compared to the present FRS and other facilities in the world will be discussed in addition.



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Recent results from heavy-ions collisions at CERN

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Nuclear collisions at the LHC have allowed experimenters to study strongly interacting matter in unprecedented conditions of temperature and density and with a much enhance range of probes. The dedicated Heavy-Ion experiment, ALICE, and the two multipurpose experiments, ATLAS and CMS, have proven to be extraordinary and complementary instruments for the study of these collisions, unveiling new features of the quark-gluon plasma in these extreme conditions. Based on what has been learned from the first years of data taking, the LHC HI community has developed a coherent plan for the future of the field, including a major upgrade of ALICE and operation of all experiments at much higher luminosity of PbPb collisions. In the presentation, an overview of what has been learnt from the first two runs with lead ions and a first look at the results from the recent proton-lead run will be given, together with a glimpse at the long-term view of the prospects of experimentation with Heavy Ions at the LHC.

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Probing Sea Quarks and Gluons: The Electron-Ion Collider Project

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The 21st century holds great promise for reaching a new era for unlocking the mysteries of the structure of the atomic nucleus and the nucleons inside it governed by the theory of strong interactions (QCD). In particular, much remains to be learned about the dynamical basis of the structure of hadrons and nuclei in terms of the fundamental quarks and gluons. One of the main goals of existing and nearly completed facilities is to map out the spin flavor structure of the nucleons in the valence region. A future Electron-Ion Collider (EIC) would be the world's first polarized electron-proton collider, and the world's first e-A collider, and would seek the QCD foundation of nucleons and nuclei in terms of the sea quarks and gluons, matching to these valence quark studies. The EIC will provide a versatile range of kinematics and beam polarization, as well as beam species, to allow for mapping the spin and spatial structure of the quark sea and gluons, to discover the collective effects of gluons in atomic nuclei, and to understand the emergence of hadronic matter from color charge. I will summarize the physics goals and present an overview of the proposed EIC.

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Recent Developments in the Understanding of Explosive H-Burning and the rp-Process Path: Classical Novae and Type I X-Ray Bursts

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Many stars form binary or multiple systems, with a fraction hosting one or two degenerate objects (white dwarfs and/or neutron stars) in short-period orbits, such that mass transfer episodes (accretion) onto the degenerate component ensue. This scenario is the framework for a suite of violent stellar events, such as *classical novae*, *type I X-ray bursts*, type Ia supernovae, or eventually, *stellar mergers*. The expected nucleosynthesis accompanying these cataclysmic events is very rich. Here, we will focus on the explosive H-burning regimes that caharacterize Classical Novae and some X-ray bursting systems.

Extensive numerical simulations of nova outbursts have shown that the accreted envelopes attain peak temperatures ranging between 10^8 and 4×10^8 K, for about several hundred seconds, and therefore, their ejecta is expected to show signatures of a significant nuclear activity, which is driven by proton-capture reactions in competition with β+-decays, proceeding close to the valley of stability, up to Ca. It has been claimed that novae can play a certain role in the enrichment of the interstellar medium in a number of intermediate-mass elements. This includes ^{17}O, ^{15}N, and ^{13}C, systematically overproduced in huge amounts with respect to solar abundances, with a lower contribution in a number of other species with $A < 40$, such as ^{7}Li, ^{19}F, or ^{26}Al. Some of the radioactive species synthesized drive characteristic gamma-ray signals that may be detected by current (and future) space observatories.

X-ray bursts, in turn, constitute the most frequent source of stellar explosions in the Galaxy (and the third most energetic events after supernovae and nova outbursts). They take place in the H/He-rich envelopes accreted onto neutron stars in binary systems. They are powered by a suite of nuclear processes, including the *rp-process* (rapid p-captures and β^+-decays), the 3α-reaction, and the *αp-process* (a sequence of (α,p) and (p,γ) reactions); here, the nuclear flow proceeds far away from the valley of stability, merging with the proton drip-line beyond $A = 38$, and reaching eventually the SnSbTe-mass region, or beyond.

This review will address recent advances in the modeling of such stellar explosions, with emphasis on state-of-the-art, hydrodynamic simulations (1-, 2- and 3-D), on their gross observational properties and on their associated nucleosynthesis. The impact of current nuclear uncertainties on the final nucleosynthetic yields will be discussed in detail for both astrophysical scenarios.

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Three-nucleon forces and their importance in three-nucleon systems and heavier nuclei

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Three-body systems have been studied in detail at KVI and other laboratories around the world in the last few years. Even though a relatively good understanding of most phenomena in nuclear physics at intermediate energies has been arrived at by only considering two-nucleon forces, high precision three-nucleon data and nuclear structure studies in light nuclei have revealed the shortcomings of these forces. Hadronic reactions in three-body systems give a handle on effects such as those from three-body forces. In the last few decades, the two-nucleon system has been thoroughly investigated both experimentally and theoretically. These studies have resulted in modern potentials which describe the bulk of the data in a large range of energy. This knowledge can be employed in a Faddeev-like framework to calculate scattering observables in three-body systems. In regions and for the reactions in which the effects of Coulomb force are expected to be small or can be calculated accurately, and energies are low enough to avoid sizable relativistic effects, deviations from experimental data are a signature of three-body force effects.

At KVI, various combinations of high-precision cross sections, analyzing powers and spin-transfer coefficients have been measured at different incident proton or deuteron beam energies between 100 and 200 MeV for a large range of scattering angles and for the reactions mentioned above. Calculations based on two-body forces only do not describe the data sufficiently. The inclusion of three-body forces improves the discrepancies with data significantly. However, there are still clear deficiencies in the calculations. A selection of data will be presented and compared with the state-of-the-art calculations.

Cluster formation and breaking, and cluster excitation in light nuclei

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In the recent progress of experimental and theoretical studies of unstable nuclei, it was revealed that cluster aspect is one of the essential features in light unstable nuclei as well as stable nuclei. For instance, a variety of cluster states have been suggested in neutron-rich Be, where the 2α core and surrounding excess neutrons play important roles (for example, Refs. [1,2] and references therein). In addition to such two-center cluster structures suggested in Be and Ne isotopes, three-center cluster structures have been attracting a great interest. A 3α cluster gas state suggested in the excited ^{12}C is one of the recent hot topics and often discussed in relation with alpha condensation in dilute nuclear matter [3,4,5]. In excited states of neutron-rich C, further rich cluster phenomena are expected due to the 3α core formation and valence neutrons.

These facts indicate that various kinds of cluster structure emerge depending on the excitation energy and also depending on the number and the kind of core clusters as well as the number of excess neutrons. In low-lying states, clusters are tightly bound in general and the cluster feature is characterized by spatial many-body correlation or cluster formation at the surface. On the other hand, in highly excited states, one may often see remarkable cluster structures where clusters weakly couple to each other. Another cluster aspect peculiar to neutron-rich nuclei is the molecular orbital structure where clusters are bonded by excess neutrons in molecular orbitals.

In this work, we focus on the cluster aspects of light nuclei such as Be and C isotopes and discuss the cluster formation/breaking and the cluster excitation in nuclear many-body systems. Based on the calculations of antisymmetrized molecular dynamics (AMD) [2,6], which is a microscopic model for study of nuclear structure and does not rely on any assumption of clusters, we will show how the cluster formation and the cluster excitation occur in dynamics of many-nucleon systems as a function of the proton and neutron numbers and the excitation energy (or density).

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

Lattice QCD and the phase diagram of strong interaction matter

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In the chiral limit strong interaction matter undergoes a phase transition from a low temperature, chiral symmetry broken phase to a chirally symmetric high temperature phase - the quark gluon plasma. Although there seems to be compelling evidence from lattice QCD calculations that this transition is second order, it is a theoretical issue that still is not settled unambiguously. Similarly it is an open question whether at physical values of the light and strange quark masses the pseudo-critical (crossover) transition at vanishing baryon number density turns into a true second order phase transition at non-zero baryon number density. Finding evidence for or against the existence of this QCD critical point is one of the most challenging problems in current theoretical and experimental studies of the QCD phase diagram.

The chiral phase transition at vanishing values of the light quark masses as well as the elusive critical point at non-zero net baryon number density can be studied in lattice QCD simulations through the analysis of net baryon number, electric charge and strangeness fluctuations as well as correlations among these conserved quantum numbers. We will present recent progress made in the calculation of these observables, compare these calculations with measurements of proton and electric charge fluctuations in heavy ion collision experiments and discuss consequences for the QCD phase diagram at vanishing and non-vanishing net baryon number densities.

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

Recent progress in EDF-based methods applied to nuclear properties

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Energy density functional-based methods aim to provide an accurate and universal description of the various nuclear phenomena, opening the possibility to encompass the nuclear chart in an unified approach. Recent advances in this field will be reviewed focusing on nuclear properties, namely the various nuclear structure states offered by the nature:

- Nuclear matter: links with neutron stars, constraints from nuclear observables on the equation of state (symmetry energy, incompressibility) and clusterisation.
- Quantum liquid states: mean free path of nucleons, latest description of nuclear shapes, superheavy elements, driplines predictions, and haloes in medium-mass nuclei.
- Cluster states: conditions of occurrence, prediction of exotic states (linear chain, rings).

Dynamical aspects such as exotic nuclear excitations and radioactive decays shall also be addressed.

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A Precise Measurement of Neutrino Mixing Angle θ_{13} at RENO

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The Reactor Experiment for Neutrino Oscillation (RENO) started data-taking from August, 2011 and has observed the disappearance of reactor electron antineutrinos, consistent with neutrino oscillations. The experiment has made unprecedentedly accurate measurement of reactor neutrino flux, and performed a definitive measurement of the smallest neutrino mixing angle theta_13 based on the disappearance. Antineutrinos from six reactors at Yonggwang Nuclear Power Plant in Korea, are detected and compared by two identical detectors located at 294 m and 1383 m, respectively, from the reactor array center. In this talk, a new result from RENO will be presented based on the further reduction of backgrounds and a spectral shape analysis. A precise measurement of reactor neutrino flux and spectrum will be also presented in comparison with expectations.

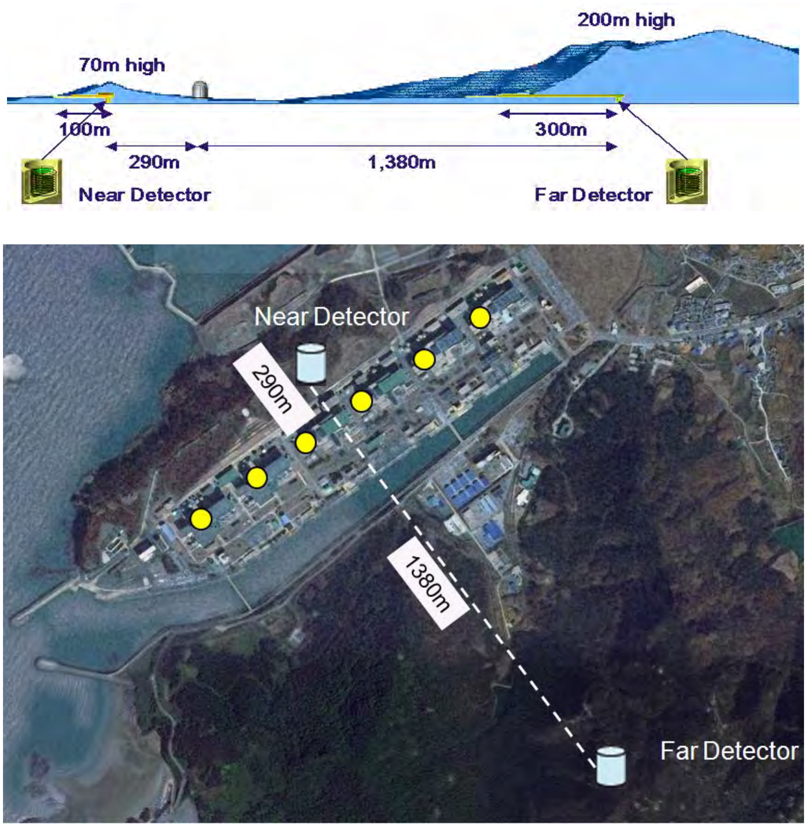

Figure 1: *A schematic setup of the RENO experiment.*

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

Nuclear Physics and the development of new systems for energy production and waste transmutation

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During the last decade, nuclear physicists have demonstrated a growing interest for applications, in particular in the domain of nuclear energy. This interest was driven initially by the possibility to transmute nuclear waste in accelerator-driven sub-critical reactors and then by the studies for the development of a new generation of nuclear reactors. Nowadays, safety considerations are becoming an important driving force and related requests for nuclear data are arising.

In this talk, the new needs will be discussed. A review of recent achievements in nuclear physics for nuclear energy will be presented. The emphasis will be put on applications in which the role of fundamental nuclear physics is important: either by the development of original experimental techniques or by the search for a deeper understanding of reaction mechanisms. Opportunities offered by the availability of new facilities will also be discussed.

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Chiral Effective Field Theory for Nuclear Forces: Achievements and Challenges

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The problem of a proper derivation of nuclear forces is as old as nuclear physics itself, namely, about 80 years. Since the nuclear force is a manifestation of strong interactions, the modern view is that any serious derivation has to start from quantum chromodynamics (QCD). However, the well-known problem with QCD is that it is non-perturbative in the low-energy regime characteristic for nuclear physics. For many years this fact was perceived as the great obstacle for a derivation of nuclear forces from QCD—impossible to overcome except by lattice QCD. The effective field theory (EFT) concept has shown the way out of this dilemma. To ensure that the EFT in not just another phenomenology, it must have a firm link with QCD. The link is established by having the EFT observe all relevant symmetries, particularly, the (broken) chiral symmetry of low-energy QCD. During the past two decades, it has been demonstrated that chiral EFT represents a powerful tool to deal with nuclear forces in a systematic and model-independent way [1]. Two-, three-, and four-nucleon forces have been derived up to next-to-next-to-next-to-leading order (N^3LO) and (partially) applied in nuclear few- and many-body systems—with, in general, a good deal of success. This may suggest that the 80-year old nuclear force problem has finally been cracked. Not so! Some basic issues have been swept under rug for years and now need our full attention, like the proper renormalization of the two-nucleon potential. Moreover, the order-by-order convergence of the many-body force contributions is still obscure at this time.

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

Nuclear Physics from Lattice Simulations

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Nuclear lattice simulations are a new tool to address the nuclear many-body problem. They combine the successfull Effective Field Theory approach to the nuclear force problem with Monte Carlo simulations, thus allowing for *ab initio* calculations of atomic nuclei. I give a short overview of the method and then present recent results on the spectrum of ^{12}C, in particular on the Hoyle state, its structure and its excitations. First results for the spectrum of ^{16}O are also shown. Further, I discuss the formation of carbon and other elements relevant for life on earth as a function the fundamental parameters of QCD and QED, the quantum gauge field theories underlying all of nuclear physics.

World new facilities for radioactive ion beams

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In developing our knowledge on the atomic nuclei, radioactive isotopes (RI) or unstable nuclei have been playing crucial roles. By finding various methods for artificial RI production, nuclear physics research has been extended accordingly. In the mid 80s, the idea to use unstable nuclei in the form of energetic beam was realized for the first time at LBL [1]. The projectile-fragmentation reaction with fast ion beams was used to produce RI's in-flight. The first application of these RI beams was to measure interaction cross sections of light unstable nuclei, and enhancement of matter radius known as neutron halo was observed for some light neutron-rich nuclei. Together with the "ISOL" technique, where RIs are produced by nuclear reactions and re-accelerated by an independent accelerator, and some other methods, radioactive ion beams and related technical developments have enlarged our capability for studying properties of the nuclei and nuclear reactions, and have casted new lights on various problems in nuclear physics .

According to the success and expected fruitfulness of RI beam based studies, "new generation" facilities with drastically enhanced performance in producing beams of nuclei much farther from the stability valley have been and are being planned in the world. In order to cover different energy domains and to meet various scientific demands, their designs are of a wide variety. For example, FAIR in Germany and FRIB in US are based on the fragmentation scheme for beams with a few hundred MeV/nucleon to GeV/nucleon energy, whereas Spiral2 in France and the future facility Eurisol in Europe are on the ISOL method providing lower-energy RI beams. There are a lot more projects including upgrades of existing facilities in the three continents, America, Asia and Europe. Among them, the fragmentation-based facility RIKEN RI Beam Factory in Japan is the accelerator complex in this category that is in operation [2].

The talk will give an overview of such new RIB facilities and their perspectives on nuclear physics research.

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Strange light nuclei

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While normal nuclei consist of up and down quarks, hypernuclei contain strange quark in addition to them. Due to limitation of scattering data between hyperon and nucleon, study of hypernuclear structure has been providing precious information about hyperon-nucleon interaction.

In this decade, precise spectroscopy of Λ hypernuclei by the $(e,e'K^+)$ reaction has established at JLab. Recent measurement of binding energy of ${}^{7}_{\Lambda}\mathrm{He}$ (a neutron halo nucleus ${}^{6}\mathrm{He}$ plus Λ) by the $(e,e'K^+)$ reaction triggered discussion about charge symmetry breaking effect in the ΛN interaction [1].

I will review progresses of the $(e,e'K^+)$ reaction spectroscopy of hypernucleus and future prospect on the study of light hypernuclei.

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Direct Reactions with Exotic Nuclei

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Direct reactions such as nucleon transfer and fast nucleon removal are specific ways to probe the nuclear shell structure. These reactions, first used in stable nuclei studies, have largely contributed for the last 20 years to the investigation of the properties of exotic nuclei.

The application of direct reactions to single-particle spectroscopy and two-body correlations will be presented through recent experimental results. Specificities of direct reactions applied to exotic nuclei– including very weakly bound systems– will be detailed. Limits of the applicability of reaction models to unstable nuclei will be discussed. Finally, future and innovative technical developments dedicated to low-intensity beam studies will be detailed by emphasizing their advantages to existing techniques.

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New Horizons in Ab Initio Nuclear Structure Theory

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Low-energy nuclear theory has entered an era of *ab initio* nuclear structure and reaction calculations based on input from QCD. One of the most promising paths from QCD to nuclear observables employs Hamiltonians constructed within chiral effective field theory as starting point for precise *ab initio* many-body approaches. However, the full inclusion of chiral two- plus three- plus multi-nucleon interactions in exact or approximate many-body calculations poses a formidable challenge. I discuss recent breakthroughs that allow for *ab initio* calculations for ground states and spectra of nuclei throughout the p- and the lower sd-shell with full 3N interactions using consistent Similarity Renormalization Group (SRG) transformations and the Importance-Truncated No-Core Shell Model (IT-NCSM). This framework allows for predictions of nuclear structure phenomena of experimental relevance starting from chiral Hamiltonians rooted in QCD (bottom-up approach) as well as for a validation of the fundamental theoretical ingredients by confrontation with experimental nuclear structure data (top-down approach). I present recent highlights illustrating this two-way link between QCD and nuclear structure. Moreover, I discuss extensions of these *ab initio* calculations to heavy nuclei within coupled-cluster theory and the in-medium SRG, to low-energy reactions of astrophysical relevance, and to p-shell hypernuclei.

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Neutron Beta Decay as a Probe of Weak Interactions

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The beta decay of the free neutron provides a unique low energy probe for the weak nuclear force. Precision measurements of the neutron lifetime and correlations between the neutron spin and its decay products can have a physics reach comparable and complementary to the highest energy particle physics experiments. Experiments using cold and ultra-cold neutrons have measured the parameters of neutron decay, including the lifetime and the correlations between the neutron spin and its decay products. In this talk, I will review the history and status of the world's neutron beta decay programs, with emphasis on the present discrepancies in the values of the neutron lifetime and the axial-vector weak coupling constant and prospects for their resolution in the near future.

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Nuclear astrophysics of stellar explosions and neutron stars, and new opportunities at FRIB@MSU

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The physics of radioactive isotopes plays a key role in the reaction sequences occurring naturally in stellar explosions and accreting neutron stars. It needs to be understood in order to understand the origin of the elements, and to interpret neutron star observations in terms of the properties of dense nuclear matter. Astronomical observations have identified new signatures of the nuclear processes, and in some cases new processes have been discovered. Significant progress has also been made in recent years in identifying the critical elements in these reaction sequences. New experimental devices and techniques have been developed at current radioactive beam accelerator facilities, and some experiments have provided critical data that have improved astrophysical models. I will review some of the recent developments at the intersection of the physics of radioactive nuclei and astrophysics, give some example from recent experiments at the Michigan State University's NSCL, and present an outlook into the future, where new facilities such as FRIB will be able to pin down most of the relevant nuclear physics.

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Searching for new physics in beta-neutrino correlations

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Measurements of the beta-neutrino correlation in nuclear beta decays have historically established the predominant V-A structure of the weak interaction [1]. Still today this type of experiments continue to provide important information on the structure of the weak interaction. In state-of-the-art precision measurements using a variety of techniques, many of which are based on ion and atom traps, a large number of experiments is currently ongoing or being set up at radioactive ion beam facilities worldwide [2]. Comparing experimental results with the standard model expected value for the beta transition investigated, allows probing charged current (scalar or tensor) interactions not included in the standard model.

In this talk an update and overview of this field will be presented. With the precision of these measurements reaching the per mille level small standard model effects now have to be included as well. The most important of these are the so-called recoil effects. These are induced by the strong interaction because the decaying quark is not a free quark but is bound inside a nucleon. Prospects and future of this type of low-energy weak interaction studies in the era of the Large Hadron Collider will be discussed briefly as well.

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Shell evolution and nuclear forces

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Magic nuclei are cornerstones of nuclear structure. Due to the presence of large shell gaps between occupied and valence shells, they are spherical, have large excitation energies and weak excitation probabilities. They are often more abundant than other nuclei in the universe, play key roles in explosive nucleosynthesis, and could bind superheavy nuclei despite the large repulsive coulomb interaction.

Our vision of immutable magic numbers, whatever the proton to neutron ratio, has been drastically changed these last years. In particular it has been demonstrated that the neutron magic numbers 8, 20 and 28 were vanishing far from stability. In parallel new magic numbers appear as N=16.

These discoveries arose with the advent of radioactive ion beam facilities worldwide as well as progresses in detection systems. They pose fundamental questions [1] such as: which parts of the nuclear force drive these modifications of shell closures? Are such effects observed throughout the chart of nuclides, or are they limited to medium mass nuclei? To which extent nuclear forces are changing when approaching the drip line ? What are the consequences of these shell modifications for explosive nucleosynthesis for modeling halo nuclei and for the existence of superheavy nuclei?

Recent experimental studies (transfer, knock-out, beta-decay and isomeric studies) were used to probe the three body force, the spin-orbit interaction and the behavior of nuclear forces at drip line. The impact of such discoveried will be put in perspective with the questions raised above.

[1] O. Sorlin and M.-G. Porquet Phys. Scr. T 152 (2013) 014003

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Neutron Star Masses, Radii, and the Equation of State of Dense Matter

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Neutron stars provide an exciting laboratory for the physics of matter at extreme densities. In particular, neutron star mass and radius measurements are providing a novel constraint on the nuclear symmetry energy, neutron-rich nuclei, the nucleon-nucleon interaction, and the equation of state of dense matter. I will review current and future neutron star mass and radius observations and their potential systematic uncertainties. Then I will show how these observations provide novel constraints on the nature of matter near and above the nuclear saturation density.

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Recent results from heavy-ion collisions at RHIC

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In this talk I will describe the current status of the heavy ion research program at the Relativistic Heavy Ion Collider (RHIC). After the discovery of the strongly coupled quark-gluon plasma (sQGP) the RHIC program is focusing on the quantitative exploration of this new state of matter, i.e., to quantify its properties and to understand precisely how they emerge from the fundamental properties of QCD. This includes the search for the critical endpoint in the QCD phase diagram, a program that consists of a series of low energy runs exploiting the large range of energies accessible at RHIC.

I will report on recent measurements at all energies and their implications for our current understanding of the sQGP, as well as opportunities for future studies with the upgrades to the large experiments, PHENIX and STAR.

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Probing the nuclear Equation-of-State and the Symmetry Energy with heavy-ion collisions

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Heavy-ion collisions provide unique terrestrial means to explore the nuclear equation of state (EoS) under laboratory controlled conditions. The outcome of such studies plays a key role in constraining important properties of stable and exotic nuclear systems as well as those of astrophysical systems and phenomena (such as supernovae explosions and neutron star properties). The study of isospin symmetric nuclear matter has already made significant progress achieving significant constraints. In contrast, the EoS of asymmetric nuclear matter remains still poorly unconstrained both at sub-saturation and supra-saturation densities. Therefore, the last decade has seen an increasing interest towards the isospin degree of freedom in nuclear matter. Several heavy-ion accelerators around the world have delivered beams spanning a wide range of neutron/proton number (N/Z) asymmetries, with the aim of better isolating the effects induced by the symmetry energy on reaction dynamics and studying its density dependence. This research field presently represents a subject of great debate and gathers scientific communities working in different fields (astrophysics, nuclear structure, nuclear dynamics).

In this talk the status on the study of the EoS and the symmetry energy with heavy-ion collision dynamics will be presented. The main experimental observables probing both sub-saturation and supra-saturation density will be discussed. In the sub-saturation domain heavy-ion collisions at intermediate energies (E/A<100 MeV) are studied with measurements of fragmentation observables, isotopic ratios, isoscaling phenomena, isospin diffusion and drift and neutron/proton pre-equilibrium emissions. At supra-saturation densities measurements require studying collisions at energies E/A>400 MeV: sensitive observables include neutron/proton pre-equilibrium emission and elliptic flow, and pion and kaon production and yield ratios.

The results obtained by different groups working in the field, with the present status of our understating on the EoS for asymmetric nuclear matter and views on possible perspectives for future directions will be discussed.

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Ultrarelativistic heavy-ion collisions: a theoretical review

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Experimental data on ultrarelativistic heavy-ion collisions at RHIC and LHC have provided unprecedented evidence for the formation of strongly coupled quark-gluon plasma that manifests a number of remarkable properties. The hot and dense matter exhibits a strong collective behavior during the rapid expansion shortly after its formation. It resembles that for fluid with extremely small shear viscosity that can even preserve the fluctuation in initial energy density. The dense matter is also opaque to energetic partons from initial hard scattering leading to jet quenching phenomena such as suppression of high transverse momentum hadrons and large dijet asymmetry. I will review recent theoretical advances that underpin the physical interpretation of these phenomena and phenomenological efforts to qualitatively extract physical properties of the strongly coupled quark-gluon plasma such as shear viscosity, jet transport coefficient and initial quantum fluctuations.

01 – Plenary Talks