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Book of Abstracts

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Measurements of prompt-fission neutrons in ^{235}U(n$_{th}$,f) and ^{252}Cf(sf)

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Prompt fission neutrons carry valuable information on how excitation energy is shared between fragments in nuclear fission. Precise measurements on the neutron multiplicity are needed both as a function of fragment mass and excitation energy, as data are rather scarce. In this work we present two complementary experimental setups to measure prompt fission-neutrons, at different excitation energies; namely the 2E and the 2E-2v techniques.

The 2E-2v method is a state-of-the-art technique to determine the masses of pre- and post neutron emission yields. Several competing setups world-wide aim at using the 2E-2v method to suppress uncertainties in fission yields. The VERDI (VElocity foR Direct particle Identification) spectrometer is one such setup, developed at JRC-GEEL. VERDI has two Time-Of-Flight (TOF) sections and 16 silicon detectors in the end of each section. The fission fragment energies are measured in the silicons whereas the fragment velocity is obtained by means of its TOF. Electrons ejected from the target itself are deflected and detected in a MCP (Micro-Channel Plate) to provide a start trigger. The fragments entering the silicon detector provide the stop signal.

From VERDI we present results on the spontaneous fission of ^{252}Cf(sf). A superior mass resolution was observed as compared to conventional techniques. Some main challenges associated with the instrument as well as the method itself will be subject of a detailed discussion.

In the second part, we present our experiments using the 2E technique by utilizing a Frisch-Grid Ionization Chamber (FGIC) together with two liquid-scintillator detectors. By means of a coincidence measurement we derive the average prompt fission neutron multiplicity, $\overline{\nu}(A)$, in ^{252}Cf(sf) and ^{235}U(n$_{th}$,f). Results on $\overline{\nu}(A)$ and $\overline{\nu}(TKE)$ agree well with recent measurements from JRC-GEEL; however, both data-sets disagree with older reference data.

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Charged-particle decay studies in the ^{100}Sn region

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The region of α decaying nuclei close to ^{100}Sn offers a unique opportunity to study α decays, where the valence nucleons occupy the same orbitals. This might give a rise to exceptionally high α-particle preformation factor, leading to very fast α decay. This kind of enhanced α decay was suggested already in 1965 [1], however, to date there is no confirmation for the existence of this so called superallowed α decay. The most enhanced known α emitter is ^{212}Po, however, this case is lacking the $N = Z$ symmetry. The α decays of ^{112}Ba, ^{108}Xe, and ^{104}Te are expected to compete for the fastest known α decay [2].

The astrophysical rp-process has been proposed to terminate with rapid α decays of proton rich tellurium isotopes. The details of the termination depends on the single proton separation energies of antimony isotopes [3]. These energies can be probed indirectly by measuring the proton and α-decay energies in this region.

In this presentation, preliminary results of an experiment performed at ATLAS, Argonne National Laboratory, using the Fragment Mass Analyzer (FMA) to study charged-particle decays in the ^{100}Sn region will be presented.

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New capabilities of the ATLAS facility at Argonne

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The ATLAS facility has recently seen a number of upgrades, both in terms of the accelerator and the associated instrumentation. The Argonne Gas-Filled Separator, AGFA, represents a new design for such separators that consists of only two magnetic elements allowing for a short ion trajectory from target to focal plane. It can be operated in stand-alone mode or in conjunction with Gammasphere to study prompt gamma radiation emitted from products subsequently registered at the focal plane allowing for efficient study of the structure of trans-fermium nuclei. The AGFA separator is presently being commissioned and will soon be available for use in the research program. The Argonne In-Flight Radioactive Ion Separator, AIRIS, is a magnetic chicane that can separate in-flight produced radioactive beams from the primary beam and other reaction products. Since AIRIS is installed in the ATLAS, these radioactive beams can be transported to all downstream target stations. The commissioning of AIRIS is scheduled for the early summer 2018.
In this talk, I will review the anticipated physics impact and the status of these separators.
This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

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Summary talk

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The FOOT 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 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 concerns 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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Effect of angular momentum selectivity of the beta-Oslo method

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Accurate predictive models of neutron capture cross sections are key to understanding cosmogenic nucleosynthesis, fundamental nuclear physics, and nuclear stockpile security. For several decades, the "Oslo Method" has been used to determine gamma-ray strength functions and nuclear level

densities, important input parameters to such models. This method has traditionally been limited to the study of nuclei close to stability that can be created in charged-particle collisions with stable targets. More recently, the "beta-Oslo Method" was developed, a new application of the Oslo Method to nuclei formed by beta decay, allowing strength function and level density measurements in more neutron-rich nuclei. However, the range of angular momenta of nuclear states populated by beta decay, within $1\hbar$ of the ground state of the decaying nucleus, are much more limited than by charged particle reactions and in the natural distribution available.

To investigate the effect on the Oslo Method of this angular momentum selectivity, artificial nuclear level schemes for a range of neutron-rich strontium isotopes were generated by the Monte Carlo code DICEBOX. Gamma ray cascades were simulated from distributions of states with angular momentum that can be populated by beta decay, assumed to be measured with 100% lossless efficiency, and analyzed with the Oslo Method. The strength functions and nuclear level densities extracted were then compared to both the known models used to generate the DICEBOX cascades and those parameters extracted from a broader initial angular momentum distribution. Furthermore, the sensitivity of the method to certain subject user-defined inputs, such as the determination of unknown normalization parameters and gamma-ray matrix resolution, was noted.

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Mass measurements in the vicinity of ^{78}Ni at JYFLTRAP

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The double Penning-trap mass spectrometer JYFLTRAP [1] at IGISOL [2] has been recently used to measure the masses of neutron-rich Fe, Co, Ni, Cu, and Zn isotopes. The masses of these nuclei close to the Z=28 and N=50 closed shells are relevant for understanding the nuclear structure far from stability but also for the studies of core-collapse supernovae. Electron captures play a key role during the collapse stage of supernovae [3] as they reduce the electron gas pressure, cool the core via neutrino emission and drive matter to more neutron-rich nuclei. To calculate the composition of matter in a core-collapse supernova, extended Nuclear Statistical Equilibrium (NSE) models can be used. One of the key parameters for the NSE calculations is the nuclear binding energy [4]. According to recent studies, the binding energies and electron capture rates on nuclei situated in the vicinity of the N=50 shell closure have a high impact on core-collapse simulations [5]. Data for the isotopes located close to Z=28 and N=50 are also important for understanding the nuclear structure close to ^{78}Ni [6].

The ions of interest were produced by 35 MeV proton-induced fission on a uranium target at IGISOL. Over the 11 nuclides measured during the one week of experiment, five were measured for the first time. The measurements were mainly done using the time-of-flight ion-cyclotron resonance technique (TOF-ICR) [7]. In addition, the novel PI-ICR technique [8] was used for some cases to identify long-living isomeric states. In this contribution, I will describe the experimental method and preliminary results from the experiment.

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The ESSnuSB conceptual design study

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The goal of ESSnuSB project is to discover and measure neutrino CP violation using a long-baseline oscillation experiment taking advantage of two recent opportunities. The first is the construction of the European Spallation Source, ESS, in Lund, which is planned to be the world's most intense proton source.The second is the recently measured large value of the oscillation mixing angle θ13. A consequence of this measurement is that placing the neutrino detector at the second neutrino oscillation maximum, instead of at the first, which primarily is the case for other proposed expriments, will lead to higher sensitivity in the measurement. The aim of the recently approved ESSνSB H2020 Design Study is to provide the means for European physicists and accelerator engineers to perform a Conceptual Design Report for the ESSnuSB project, i.e. to investigate how investements already being made in the ESS research infrastructure can be used to further neutrino physics in Europe. An ogoing COST Action, CA15139, "Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery", recognizes the importance to have future neutrino facilities in Europe as well. In Sweden the Garpenberg mine is situated at a distance from ESS that corresponds to the second oscillation maximum and is thus proposed to be the location of the detector. In this presentation I will discuss the ideas behind the ESSnuSB project as well as the work that is planned to lead to the conceptual design report.

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Lifetimes of nuclear states in proton-emitting nuclei from Differential Plunger measurements.

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Over the last few years, a programme of research performed at the University of Jyvaskyla, Finland has established the first measurements of the nuclear state lifetimes built above proton emitting states [1-5]. Lifetimes have been deduced in several nuclei; 109I [1], 151Lu [2,3] and 113Cs [4] for the first time using a specially constructed Differential Plunger for Unbound Nuclear States (DPUNS) plunger [5]. The new experimental results have led to the development of a non-adiabatic quasi-particle code which has been required to explain proton emission based on the experimentally deduced deformations extracted from the lifetime measurements. This talk will show how the new lifetime values for the ground- and isomeric-state proton decays in 151Lu are best interpreted by a mildly oblate deformation, settling a long-standing theoretical debate about the shape of 151Lu. The more recent lifetime results for the deformed proton emitter 113Cs will also be discussed. In this case the wavefunctions extracted from the non-adiabatic quasi-particle code were used separately

to evaluate both proton emission and gamma-ray transition rates as a function of deformation. In this study, a consistent quadrupole deformation was found to match both the experimental proton emission half-life and the lifetime of the electromagnetic state in 113Cs. This deformation is in agreement with the earlier proton emission studies, but is now more firmly supported based on the measured electromagnetic transition rates. The perspectives for future lifetime measurements using MARA will also be discussed along with the development of a new differential plunger involving two degrader foils.

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Nuclei: from Fundamental Interaction to Structure and Stars. Spectroscopy with AGATA and future perspectives with SPES

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The steady progress over the past twenty years in the development of beams of radioactive isotopes has allowed to vastly expand the objectives of experimental nuclear research. It is becoming possible to study in the laboratory a range of nuclear reactions that take place in exploding stars providing crucial information to understand how the chemical elements that we find on Earth were formed. Radioactive nuclei, selectively produced and identified, allow the study of fundamental symmetries in the low energy limit challenging theories developed at the highest energy frontier. These studies are among the objectives of the SPES radioactive ion beam project of INFN, presently in the construction phase at the Legnaro National Laboratories. It will provide high intensity and high-quality beams of neutron-rich nuclei to perform forefront research in nuclear structure, reaction dynamics and interdisciplinary fields like medical, biological and material sciences. SPES is a second generation ISOL radioactive ion beam facility, part of the INFN Road Map for the Nuclear Physics; it is supported by the Italian national laboratories LNL (Legnaro) and LNS (Catania). It is based on the ISOL method with an UCx Direct Target able to sustain a power of 10 kW. The primary proton beam is delivered by a Cyclotron accelerator with an energy of more then 40 MeV and a beam current of 200 μA. Neutron-rich radioactive ions will be produced by Uranium fission at an expected fission rate in the target of the order of 1013 fissions per second. The exotic isotopes will be re-accelerated by the ALPI superconducting LINAC at energies of 10A MeV and higher, for masses in the region of A=130 amu, with an expected rate on the secondary target of 107-109 pps. The status and the perspectives of the project, will be presented together with the scientific program (specially focusing on nuclear spectroscopy) and the related detector developments.

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Recent results from CRIS and new opportunities at IGISOL

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Delta isobars and nuclear saturation

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Despite a century of the finest theoretical and experimental efforts, we still lack a precise, accurate, and systematic description of the strong interaction between protons and neutrons. In this talk I will present some of the recent developments and future perspectives towards a predictive theory for atomic nuclei. I will focus on the effects of including the delta baryon in a chiral effective field theory description of the nuclear force.

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The next order of magnitude in precision and resolution at JYFLTRAP

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JYFLTRAP is a double Penning trap setup in the accelerator laboratory of University of Jyväskylä dedicated primarily for atomic mass measurements of exotic ions and for providing clean samples of ions for decay spectroscopy studies. The setup has been operational for more than a decade utilizing time-of-flight ion-cyclotron resonance (TOF-ICR) technique for atomic mass measurements and various Penning trap cleaning techniques for ion beam cleaning.

Recently we have commissioned the new novel phase-imaging ion-cyclotron (PI-ICR) resonance technique, which has now been used successfully for mass measurements at JYFLTRAP. This technique offers nearly one order of magnitude improvement in obtainable precision. We have demonstrated that this technique is also suitable for separating very low-lying nuclear isomeric states.

We are also constructing a multi-reflection time-of-flight (MR-TOF) separator, which will bring a tenfold enhancement for handling unwanted contaminant ions. In this presentation I will show capabilities of these new techniques and some physics cases measured with the PI-ICR technique.

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Deconvolution of Photon Strenghth and Level Density

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Photonuclear reaction cross sections are well described by the Brink-Axel hypothesis and are widely used to describe the E1 "photon strength" above the neutron separation energy. The Oslo Method has been developed to unfold total "photon strength" below the neutron separation energy. Although both methods are commonly assumed to derive "photon strengths", they actually derive the product of photon strength and level density. Neither quantity is well understood as a function of spin/parity, energy, and multipolarity. In this talk I will demonstrate how to unfold the level density and photon strength from both photonuclear and Oslo reaction data. This results in a continuous, exponentially declining photon strength which when multiplied by the exponentially increasing level density generates the giant dipole resonance. I will show that similarly unfolding the Oslo reaction data provides a better normalization of the "photon strength" data resulting in a nearly constant photon strength for all molybdenum isotopes that is consistent with the comparable photonuclear data. This analysis will also be used to explain thermal neutron capture photon strength where the initial/final state spin dependency must be accounted for.

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Experimental photonuclear cross sections

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Photonuclear cross sections are important to both practical applications and astrophysics in addition to being interesting in their own right from a nuclear structure point of view. Despite this, existing data taken at different laboratories are discrepant and some important cross sections have not been studied at all or are considered unreliable. The Phoenix Collaboration aims at providing new data of (g, n) cross sections for 18 isotopes ranging from 205Tl to 58Ni for generating a reference database for photon strength functions (PSF) within the framework of the IAEA Coordinated Research Project on Photonuclear Data and Photon Strength Functions (F41032). In this talk, the experimental setup for (g,n) cross section measurements at the NewSUBARU storage ring in Japan will be presented. Some key findings from the (g,n) campaigns in the period 2013-2015 will be presented. In addition an update on the analysis of the photonuclear data on 64Zn(g,n),66Zn(g,n), 68Zn(g,n) and the Oslo method analysis of 68Zn(p,p'g) data will be presented.

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First actinide experiment with OSCAR

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New progress on microscopic nuclear inputs for astrophysics applications

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One of the major issues in modern astrophysics concerns the analysis and understanding of the present composition of the Universe and its various constituting
objects. Nucleosynthesis models aim to explain the origin of the different nuclei observed in nature by identifying the possible processes able to synthesize them. Though the origin of most of the nuclides lighter than iron through the various hydrostatic and explosive burning stages in stars is now quite well understood, the synthesis of the heavy elements (i.e. heavier than iron) remains

obscure in many respects. In particular, the rapid neutron-capture process, or r-process, is known to be of fundamental importance for explaining the origin of approximately half
of the A>60 stable nuclei observed in nature. The r-process was believed for long to develop during the explosion of a star as a type II supernova but recent observations tend to favour the merging of two compact objects. The stellar nucleosynthesis requires a detailed knowledge not only of the astrophysical sites and physical conditions in which the processes take place, but also the nuclear structure and interaction properties for all the nuclei involved.

The need for nuclear data far from the valley of stability, for applications such as nucleosynthesis, challenges the robustness as well as the predictive power of present nuclear models. Most of the nuclear predictions are still performed on the basis of phenomenological nuclear models. For the last decades, important progress has been achieved in fundamental nuclear physics, making it now feasible to use more reliable, but also more complex microscopic or semi-microscopic models in the prediction of nuclear data for practical applications. In the present contribution, the reliability and accuracy of recent nuclear theories are detailed and compared for most of the relevant quantities needed to estimate reaction cross sections and beta-decay rates, namely nuclear masses, nuclear level densities, gamma-ray strength, fission properties and beta-strength functions.

Recent efforts to determine ground-state as well as fission properties within the mean-field approach will be described and compared with more traditional phenomenological models. Recent achievements to determine gamma-ray strength functions in deformed QRPA calculations will also be addressed. The impact of such newly-determined microscopic inputs on nuclear reaction cross sections, but also on the r-process nucleosynthesis will be discussed. A special attention will be paid to such new developments in the light of the recent observation of the binary neutron star merger GW170817 and its corresponding optical kilonova counterpart which suggest that neutron star mergers are the dominant source of r-process production in the Universe.

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Super-FRS contributions from Finland

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The Super-FRS separator-spectrometer to be built at FAIR will be able to unambiguously separate and identify all beams from p to U. The identification will be dome using the $\Delta E - B\rho - TOF$ method. Finland will provide detectors that will be used to provide data for beam identification in *event-by-event* mode. The tracking detectors will be constructed to provide the $B\rho$ information at high rate. Energy-loss ΔE detectors, that will provide the Z identification, will also be delivered by Finland. Together with the time-of-flght (TOF) information, the clean selection of rare isotopes can be made. In addition to beam diagnostics, beam profile detectors, detector infrastructure and radiation protection of the target (also contributions from Finland) will be discussed. In addition, preliminary results from latest detector tests will be shown.

Poster session / 3

Probing TeV physics with precision calculations of nucleon Structure using lattice QCD

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This talk will present a number of high precision results on matrix elements of quark bilinear operators between nucleon states using lattice QCD. From these, we extract a number of exciting quantities, at the intersection of nuclear and particle physics. We show that the axial charge g_A, a fundamental parameter encapsulating the weak interaction of nucleons, is calculated with a few percent accuracy. Results for the scalar and tensor charges, g_S and g_T, which combined with precision neutron decay distribution probe novel scalar and tensor interactions at the TeV scale. Vector form factors are probed in electron scattering, while axial vector form factors are used in the calculation of the cross-section of neutrinos on nuclear targets. These energy dependent cross-sections are needed to determine the neutrino flux, an important systematic in neutrino oscillation experiments. Finally we will present results for flavor diagonal charges that provide the contribution of the quark spin to the nucleon spin, the quark EDM to the neutron EDM, and needed to determine the cross-section of dark matter with nuclear targets.

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The β-Oslo Method

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Neutron-capture reactions on very neutron-rich nuclei are essential for heavy-element nucleosynthesis through the rapid neutron-capture process, now shown to take place in neutron-star merger events. For these exotic nuclei, radiative neutron capture is sensitive to their γ-emission probability at low γ energies.

In this talk, we present measurements of the γ-decay strength for neutron-rich systems applying the β-Oslo method. The experiments were conducted at the National Superconducting Cyclotron Laboratory, Michigan State University, using the Summed NaI (SuN) total absorption spectrometer. Results on ^{78}Ge, ^{70}Ni and ^{51}Ti are shown.

The β-Oslo method relies on measuring γ-decay spectra at well-defined excitation energies. The unfolding technique for obtaining reliable excitation energies is discussed.

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Interplay between single-particle and collective degrees of freedom in heavy nuclei

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The interplay between single-particle and collective degrees of freedom in ^{251}Fm was investigated using combined internal conversion electron (ICE) and γ-ray spectroscopy. Excited states in ^{251}Fm were populated via the α-decay of ^{255}No produced in the fusion-evaporation reactions: ^{208}Pb(^{48}Ca, 1n)^{255}No and ^{209}Bi(^{48}Ca, 2n)^{255}Lr. The intense beams were delivered by the U-400 cyclotron at the FLNR, JINR, Dubna. The separators VASSILISSA [1] and SHELS [2] were used to select the fusion evaporation residues. At the focal planes of these separators the GABRIELA [3] spectrometer was used to perform a time and position correlated measurement of the characteristic decay properties to further isolate the nuclei of interest. ICE spectroscopy of ^{251}Fm was performed for the first time [4]. These measurements allowed the multipolarities of several transitions in ^{251}Fm to be established, and, the M2/E3 mixing ratio in the decay of the low-lying 5/2+ isomer to be determined. The extracted B(E3) value will be compared to those found in other members of the N=151 isotonic chain and to theoretical calculations.

Time permiting, recent results from on-going measurements will also be presented. In particular, "pxn cross-sections"and the implications of accessing nuclei closer to the "island of stability". Upgrades to the detection system and electronics of GABRIELA can also be mentioned.

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DISCOVERY OF THE NEW ISOTOPES ^{169}Au, ^{170}Hg AND ^{165}Pt AND A NEW ISOMER OF ^{165}Ir USING THE MARA MASS SEPARATOR IN ITS FIRST TRAILBLAZING EXPERIMENT

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Measurements of proton decay from nuclei near or beyond the proton dripline have been widely used in recent works to shed light on otherwise inaccessible nuclear structure information, such as mother and daughter state spin assignments. There is a high sensitivity relationship between the proton decay energy (Q_P) and the partial proton decay half-life, and measurements of these quantities in potentially observable candidates can be used to determine spectroscopic factors, which allow testing of theoretical models. As such, many exotic proton emitters need to be measured. Using the new vacuum mode mass separator MARA in its maiden experiment, a 378MeV ^{78}Kr beam was incident on ^{92}Mo and ^{96}Ru targets. This produced compound nuclei $^{170}Pt and ^{174}Hg$ and MARA was tuned to collect mass 165 and 169 (as well as neighbours) respectively. Using the BB17 DSSD as part of the MARA-FP system, recoil decay tagging and a new novel trace readout analysis technique were used to identify fusion evaporated recoils and subsequent decays. Proton emission was observed from the new isotope ^{169}Au and from the ground state of ^{165}Ir, as well as alpha emission from the new isotopes ^{165}Pt and ^{170}Hg. Decay particle energies and half-lives were measured, and spectroscopic factor and hindrance factor calculations allowed assignment of spin among other interesting quantities.

Poster session / 44

Optical potential and knockout reactions

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This presentation will show results of nucleon scattering and knockout reactions on medium-mass nuclei making use of optical potentials derived consistently from ab-initio Self Consistent Green Function (SCGF) with saturating Chiral Effective Field Theory (χ-EFT) interaction.

The properties of this self-energy will be discussed in the context of elastic scattering on Ni, Ca and O isotopes, and comparing the low-energy scattering experimental cross sections and angular distributions. It will be shown that it is possible to reproduce key low energy scattering observables in medium mass nuclei from "first principles"consistently.

Possible expansion of this approach to effective density functionals and heavy nuclei will be discussed.

session 10 / 67

The Inverse-Oslo method

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The recent measurement of the Neutron Star Merger event by LIGO [1] and subsequent optical measurements have revealed that Neutron star mergers are probably one of the primary sites for the r-process of nucleosynthesis [2]. An important source of uncertainty in the r-process models is the nuclear data input [3], especially important is the neutron capture cross-section which is directly observable for only a handful of nuclei close to stability.

The Oslo Method provides an alternative, indirect route to constrain the neutron capture cross-sections by providing the nuclear level density (NLD) and γ-ray strength function (γSF) which are important in Hauser-Feshbach calculations. The method requires experiments where the γ-ray distribution is measured as a function of excitation energy. This has been achieved for several years with transfer reactions with light ion beams, eg. p,d,^{3}He,α, at the Oslo Cyclotron Laboratory and more recently in β-decay experiments [4]. A new class of experiments have recently joined the 'Oslo Method family', namely the inverse kinematics experiment. The NLD and γSF of ^{87}Kr was successfully extracted from a experiment with a ^{86}Kr beam hitting a deuterated polyethylene target at iThemba LABS in early 2015. With the addition of inverse kinematics we are now able to probe the NLD and γSF of virtually any nuclei that can be accelerated in the lab. The γSF and NLD of ^{87}Kr will be presented together with Hauser-Feshbach calculations of the neutron capture cross-section of ^{86}Kr.

New developments are also happening at the Oslo Cyclotron Laboratory with the implementation of the Oslo SCintillator ARray (OSCAR), consisting of 30 large volume $LaBr_3$(Ce) detectors (3.5x8"). OSCAR is a substantial upgrade from the old CACTUS array (NaI-detectors) both in terms of improved energy and time resolution and efficiency. To compliment the new array, we have replaced the old analog data acquisition system to a new state-of-the-art digital system consisting of seven Pixie-16 digitizers (2 x 500 MHz, 5 x 250 MHz), allowing for much higher throughput. The new array will allow for new innovations in experimental techniques that could allow for extraction of NLD & γSF above the neutron separation energy and discrimination between neutron and γ-rays.

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Session 9 / 11

ISOL-BASED EXOTIC NUCLIDES IN POROUS SILICON FOR SIMULTANEOUS DIAGNOSTICS AND RADIOTHERAPY

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The study of targeted porous nanoparticles as drug carriers is a growing field in cancer-therapy research. The porosity of the particle enables anticancer drugs to be loaded inside the particle and its surface can be modified to include tumour targeting properties. The nanoparticles are then injected into the blood stream and through the properties of the carrier nanoparticles the anticancer drugs can be targeted to the tumour cells. Alongside anticancer drugs, the particles can also be loaded with radionuclides for diagnostics and radiotherapy. The implanted nuclides can, moreover, be chosen so that the specific radiative properties allow for both imaging and therapy at the same time. The resulting carrier particle is a theranostic (therapeutic and diagnostic) system that provides local radiotherapy, which can be observed on-line throughout the treatment by PET or SPECT imaging.

Recently, interest has been shown in theranostic nuclides or matched isotopic multiplets. In a matched multiplet one element includes chemically identical isotopes with different medically relevant radiative properties. One example is the theranostic quadruplet of terbium, where two isotopes are suitable for tomography (¹⁵²Tb for PET and ¹⁵⁵Tb for SPECT) and two isotopes have therapeutic properties (¹⁴⁹Tb alpha emission, ¹⁶¹Tb electron emission) [1]. These novel radionuclides are to date only available in suitable quantities and purities at large-scale radioactive ion beam facilities or nuclear reactors.

We use porous silicon (PSi) particles as carrier nanoparticles which are biocompatible, can be made biodegradable and are thus suitable for use in a living body [2-8]. To load the radioactivity into the PSi particles, we implanted ¹⁵⁵Dy into thin PSi foils at the ISOLDE facility. The nuclides were produced through proton-induced spallation in a tantalum target. The ions were thermally released, ionized, and accelerated to an energy of 50 keV. The extracted ions were mass-separated in the general-purpose separator and implanted into the PSi foils in a collection chamber. The final radionuclide of interest, ¹⁵⁵Tb, was obtained through the beta decay of ¹⁵⁵Dy that was available at high yield through resonant laser ionization. To characterise the implantation process, the implantation depth of ¹⁵⁵Dy in the PSi structure was studied through successive ion-beam etching of an implanted foil and by analysing the resulting radioactivity profile. The foils were then post-processed into particles through milling. The resulting particles were incubated in vitro in biocompatible fluids jto assess the stability of the radioactive PSi system over an observation period of 21 days.

Our results using ¹⁵⁵Tb will be presented with our recent activities in nuclear applications studying other rare-earth nuclides in a PSi carrier system for nuclear medicine.

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session 2 / 6

Reactions with 9Li beams at HIE-ISOLDE

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The recent upgrade to the ISOLDE radioactive beam facility, the HIE-ISOLDE project, opens new possibilities for studies of exotic nuclei. At the current stage HIE-ISOLDE can provide up to 8MeV/A post-accelerated radioactive beam, and will reach 10MeV/A in the summer of 2018. Combined with ISOLDE's high purity and intensity beams, we can take on the challenge of studying light nuclei near the driplines, where unbound states are known to play an important role. Experimental data is still lacking to make detailed theoretical descriptions of such systems.

In particular we want to study neutron rich Li isotopes with neutron transfer reactions using an accelerated ⁹Li beam. Bombarding either deuterons or tritons, we can reach final ⁸Li-¹¹Li states as well as many other. We are particularly interested in the reactions leading to ¹⁰Li and ¹¹Li, in which the finer structure is still highly debated.

I shall report from two recent experiments carried out at HIE-ISOLDE, one with a deuterated plastic target and one with a titanium backed triton target. Both experiments were performed in the Scattering Experiments Chamber (SEC). I will furthermore compare the results with two older experiments, carried out with the old REX-ISOLDE post-acceleration stage.

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Light radioactive ion beam program at ACCULINNA-2 at FLNR

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An significant the upgrade of the Dubna Radiactive Ion Beams facility is the replacement of the ACCULINNA fragment separator with a new high acceptance device - the ACCULINNA-2. The project of a new in-flight facility for low energy $30-60$ AMeV primary beams with $3\ Z\ 36$ has been started in 2011. The new device is destined to add considerably to the studies of drip-line nuclei performed with the use of variety of direct reactions known to be distinctive to the 10–50 AMeV exotic secondary RIBs. An overview of the design, construction and commissioning studies of the ACCULINNA-2 device will be presented.
Recently, secondary beam profiles as well as RIBs production rates were measured for ^{15}N (49.7 AMeV) primary beam and Be target. Example dE-ToF identification spectra and calculated beam purity for selected isotopes will be demonstrated. Measured isotope yields agrees with LISE++ simulations. The ^{6}He + d experiment, aimed for the study of elastic and inelastic scattering in a wide angular range, was chosen for the first run. Preliminary results of the measurement will be presented.

Future upgrades of ACCULINNA 2 setup (zero degree spectrometer, RF-kicker) and prospects of new experiments achievable with light radioactive ion beams in next years will be discussed.

Session 5 / 12

Recent mass measurements for nuclear structure and astrophysics at JYFLTRAP

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JYFLTRAP is a cylindrical double Penning trap mass spectrometer [1] located at the Ion Guide Isotope Separator On-Line (IGISOL) [2] facility in Jyväskylä. In total, over 330 atomic masses for nuclear structure, fundamental physics and nuclear astrophysics have been measured with JYFLTRAP. In this contribution, I will discuss our recent results for nuclear structure and astrophysics.

On the neutron-deficient side, the measurements of ^{31}Cl ($T_{1/2}$=190 ms) [3] and ^{52}Co ($T_{1/2}$=104 ms) [4] are among the most exotic nuclei ever studied at JYFLTRAP. Their masses are important for testing the isobaric multiplet mass equation as well as for the rapid proton capture (rp) process occurring e.g. in type I X-ray bursts. The new, more precise proton separation energy for ^{31}Cl helps to constrain astrophysical conditions where ^{30}S can act as a waiting point in the rp process. Also new heavier isotopes in the A=80 region have recently been measured using ^{36}Ar+^{nat}Ni fusion-evaporation reactions at the HIGISOL heavy ion guide. On the neutron-rich side, we have extended our studies to heavier fission-fragment region relevant for understanding the formation of the rare-earth peak in the astrophysical r process [5].

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session 10 / 69

Observation of the ground state transition in the beta decay of ^{20}F

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We report the first detection of the second-forbidden, non-unique, $2^+ \to 0^+$, ground-state transition in the beta decay of ^{20}F. A low-energy, mass-separated ^{20}F beam produced at the IGISOL facility in Jyväskylä, Finland, was implanted in a thin carbon foil and the beta spectrum measured using a magnetic transporter and a plastic-scintillator detector. The log-ft value inferred from the observed beta yield is remarkably large, making this the strongest second-forbidden, non-unique transition ever measured. The result is supported by shell-model calculations and has important implications for the final evolution of Super-AGB stars.

Session 5 / 25

Finite amplitude method applied to calculation of nuclear photo absorption cross section and rotational moment of inertia

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The response of the atomic nucleus to external stimulation provides crucial information about its structure and the complex forces acting between constituent nucleons. To access these excited modes, within the framework of superfluid nuclear density functional theory, linear response theory, that is, the quasiparticle random-phase-approximation, (QRPA) is one of the commonly used method. Traditionally, the QRPA has been formulated in its matrix form (MQRPA). The disadvantage of the MQRPA formulation is the fact that dimension of the QRPA matrix becomes large, in particularly when spherical symmetry is broken, preventing fully self-consistent calculations. To circumvent the large computational cost of MQRPA, the finite-amplitude-method (FAM) solves the linear response problem by iterative means.

As a first application of the FAM-QRPA, we have done a systematic computation of the nuclear photo absorption cross sections for the heavy rare-earth nuclei [1]. For most of the calculated cases, where experimental data existed, we could reproduce measured photo absorption cross section well, although with heavier rare earth isotopes some deficiency was seen. A simple modification of the Thomas-Reiche-Kuhn sum rule enhancement factor cannot cure this deficiency.

For a second application, we investigated Nambu-Goldstone (NG) mode connected to spontaneous symmetry breaking of rotational symmetry, caused by nuclear deformation. The NG mode represents a special case of collective motion and allows access to corresponding Thouless-Valatin inertia parameter. With FAM-QRPA we have calculated the moment of inertia for low-lying rotational states in several rare-earth and actinide isotopes [2], obtaining a good correspondence with experimental values. Computationally, FAM-QRPA is less demanding compared to cranked HFB calculation.

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The Orsay Universal Plunger System - past, present, and feature

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In a collabortation between Centre de Sciences Nucléaires et de Sciences de la Matière (CSNSM) and Institut de physique nucléaire d'orsay (IPNO) a so-called Plunger device used for Recoil Distance Doppler Shift measurements and Time Differential Recoil-in-Vacuum measurements for g-factor measurements has been developed.

I will present the device, in the forefront of the transition from two motor technology to that of using a single Piezo electric step motor. This will be followed by the presentation of the major experimental campaigns in which the OUPS has been used:

1 - Campaign at the ALTO facility using the ORGAM HPGe detector array.
2 - Campaign at the ALTO facility using the MINORCA detector array.
3 - Campaign at the GANIL facility using the AGATA HPGe detector array combined with the VAMOS spectrometer.

The physics addressed is varied ranging from shape coexistence in the neutron deficient Osmium isotopes to lifetime measurements close to ^{208}Pb passing by shell evolution for neutron rich nuclei close to N=40 and N=50. Both published and not published result will be presented.

I will end with a few words about the immediate future of the use of version of the OUPS to be used at AGATA together with the NEDA neutron detector and DIAMANT charged particle detector and possible prospects for lifetime measurements for very heavy nuclei with the AGATA+VAMOS gas filled combination at GANIL.

Poster session / **42**

Improvements to Fission Modeling and Evaluations Using Delayed Gamma Ray Modeling with FIER

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Several recent forums have highlighted the need for a new fission product yield (FPY) evaluation for a wide variety of applied nuclear science and engineering applications. However, since most measurements of FPYs are made through the observation of decay radiations, any new FPY evaluation requires an integral validation which convolves both FPY and the relevant decay data. FIER is a software package that was recently developed to analytically predict delayed gamma-ray spectra following neutron-induced fission with propagated uncertainties. In previous work, FIER was used to assess the accuracy of nuclear data listed in the Evaluated Nuclear Data File (ENDF) through comparison to experimentally measured delayed gamma ray spectra following 235U(n,f) using the GODIVA critical assembly. Using a minimization routine, fission yields were varied until the discrepancy was resolved, highlighting the utility of FIER as an integral validation for both fission product yields and decay data. Additionally, current work on developing FIER's delayed neutron prediction capabilities is presented. This work will extend FIER's application space and enhance FIER's potential utility for validating a new FPY evaluation.

Poster session / **47**

The Multi-Blade ^{10}B-based neutron detector

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The Multi-Blade is a ^{10}B-based gaseous detector conceived to face the neutron-reflectometry challenge to be presented by the European Spallation Source (ESS), where the instantaneous neutron flux on detectors will be without precedent. Reflectometry instruments in particular require high count-rate capability and excellent spatial resolution.
The detector consists of a stack of Multi Wire Proportional Chambers operated at atmospheric pressure with an 80/20 Ar/CO_2 gas mixture. Modularity is achieved using multiple identical units known as cassettes. A cassette consists of a $^{10}B_4C$-coated converter blade instrumented with a two-dimensional readout system in the form of a plane of strips and an orthogonal plane of wires. In order to optimize neutron conversion, improve spatial resolution, and increase count-rate capability, the blades are inclined at 5^o with respect to the direction of the incident neutron beam.
The detector has been characterized for gamma-ray and fast-neutron sensitivity at the Source-Testing Facility of Lund University, Sweden. Moreover, a measurement campaign at the CRISP reflectometry instrument at ISIS in the UK has been successfully conducted, demonstrating the technology to be ready for scientific instruments.
An overview of the detector together with the results of the characterizations will be presented.

session 7 / 33

Intermediate-energy Coulomb excitation of 72Ni

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Transition strengths in the Ni isotopes between N=40 and N=50 have been recently subject of extensive experimental and theoretical investigations [1-6], aiming to understand whether the tensor force acts to reduce the Z=28 shell closure as the neutron g 9/2 orbit is filled towards 78 Ni.
The effect of the Z=28 shell gap quenching and its evolution from 68 Ni towards 78 Ni would be reflected as an enhancement in the quadrupole transition strengths, compared with the seniority scheme predictions for the neutron g 9/2 subshell. In 70 Ni, the large B(E2) value for the first 2 + excited
state obtained by Coulomb excitation [1] was interpreted as an evidence of a large neutron-induced polarization of the proton core [1]. Later, this interpretation was reinforced with an inelastic proton scattering experiment on 74 Ni [2], in which a large deformation parameter was found, pointing to an enhanced quadrupole collectivity.
However, a much lower B(E2) value has been deduced for 74 Ni in a Coulomb excitation experiment [3]. In that work, both experimental and shell-model calculations using the residual LNPS interaction, restore the normal core polarization picture in the neutron rich Ni isotopic chain and suggests that the B(E2) strength predominantly corresponds to neutron excitations.
The known experimental transition strengths by Coulomb excitation are constrained so far to and 74 Ni, while it is still unknown for 72 Ni.
70
Ni
We report on preliminary results from the Coulomb excitation of 72 Ni performed at the Radioactive Isotope Beam Factory at RIKEN. The BigRIPS fragment separator [7] was used to select and purify a secondary beam of 72 Ni at 183 MeV/u. Coulomb excitation of 72 Ni was produced by impinging the beam on a 950 mg/cm 2 Au target. In order to identify the reaction products after the target, the ZeroDegree spectrometer [7] was used, while the gamma rays were detected with the DALI2 array consisted of 186 NaI(TI) detectors around the target position [8]. Detailed analysis and preliminary results will be presented during the talk.

Session 6 / 38

Optical spectroscopy for nuclear and atomic science at JYFL

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High-resolution optical measurements of the atomic level structure readily yield fundamental and model-independent data on nuclear ground and isomeric states, namely changes in the size and shape of the nucleus, as well as the nuclear spin and electromagnetic moments [1]. Laser spectroscopy combined with on-line isotope separators and novel ion manipulation techniques provides the only mechanism for such studies in exotic nuclear systems.

This contribution will provide a status of the different activities connected with optical spectroscopy in Jyväskylä. In recent years an active program on the actinide elements has been initiated in collaboration with the University of Mainz and Vienna. This work has seen the realization of collinear laser spectroscopy of Pu, the heaviest element studied to date with this particular technique [2]. In addition, a multi-pronged approach towards accessing the lowest-lying isomeric state in the nuclear chart, namely ^{229m}Th, forms an active field of current research. Almost 40 years of research has been invested into efforts to observe the isomeric transition which, if found, may be directly accessed by lasers. In 2016, the community was given a tremendous boost with the unambiguous identification of the state by a group in Munich, providing a stepping stone towards a future realization of a "nuclear clock"[3].

The first optical spectroscopy of doubly-charged fission fragments has been performed in yttrium, motivated by access to alkali-like transitions in which the reliability of state-of-the-art atomic calculations can be accessed. This work saw the first use of application of a new off-line ion source, producing stable $^{89}Y^{2+}$, an isotope used as a reference in measurements of more exotic neutron rich isotopes. By merging both the reference beam and the low-energy neutron rich beams from IGISOL, optical isotope shifts have been studied and changes in mean-square charge radii extracted [4]. In 2018 we have started to implement an alkali-vapor charge exchange cell into the collinear beam line for future studies of neutralized atoms.

An exciting new research theme is now underway in collaboration with the University College London. A new atom trap has been installed at JYFL for the purpose of trapping ultra-cold samples of caesium isotopes and isomers. The ultimate goal is to achieve coherent gamma-ray emission via a Bose-Einstein Condensate of ^{135m}Cs isomers produced in fission [5]. The first results from this project will also be presented.

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Poster session / 51

Measuring La(p,x) Cross Sections from 35-60 MeV by Stacked Foil Activation

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In this experiment we use the stacked foil activation technique to measure cross sections for the ^{nat}La(p,x) reaction, with proton energies in the 35-60 MeV range. The primary motivation for this

measurement is to quantify the production of ^{134}Ce, a positron-emitting analogue of the medical isotope ^{225}Ac, which has applications for kinetic bio-distribution assays of new radio-pharmaceuticals. The results of this measurement show significant deviations from the cross sections modeled by the TALYS and EMPIRE nuclear reaction codes using default parameters. There are no previous measurements of this reaction for comparison.

session 10 / 19

Detailed R-matrix analysis of 7Li(p,g)aa at 441keV

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Light nuclei has received new interest with the advent of ab-initio calculations.
In order to test these calculations we need detailed experimental knowledge for comparison.
A prime test candidate is 8Be as it has both a-cluster and single particle states that interfere.

The 8Be system can be populated using the 7Li(p,g)8Be reaction which has a resonance with a branching ration of ˜1‰ at 441keV.
8Be subsequently breaks up into two alpha particles.
This reaction was studied previously using gamma detectors, for the high energy lines to the ground state and first excited state,
and a magnetic spectrometer for the 2+ states at 16.6 and 16.9MeV.
However, these experiments did not take interference into account.

We have measured the 8Be excitation spectrum from 1MeV to 17MeV using a compact silicon array.
Compared to gamma detectors this provides a clean spectrum with high resolution and acceptance.
The extracted excitation spectrum was then analysed with a multi level multi channel R-matrix code giving a complete description of the 8Be spectrum below 17MeV.

Session 9 / 16

Comparison of ease of use of software tools for use in dose rate calculations

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In order to carry out work in the nuclear sector in a cost effective way, while keeping risks ALARA, it is necessary to perform calculations of dose rates in areas where workers will be present, and it is important to choose the right tool for each job. The dependence of this choice upon the type of radiation, material, and geometry is obvious. Of at least equal importance, however, are practical considerations such as the level of accuracy required, the time available to prepare and run the models, the power of available computers, and the expertise level of the analyst.

Individual analysts and organisations are cognizant of these factors and typically make their choices according to their own experiences and working habits. While convenient, selecting methods in this way is susceptible to bias in favour of familiar methods and may result in a superior method being overlooked if it has never come to the attention of the analyst before.

There is a lack of research systematically evaluating available software tools from the point of view of ease of use –i.e. how much time and effort does it take to prepare models, how high are the demands placed on the analyst, and what features are available in different software to partially automate tasks?

Historically, user-friendliness has not been given a high priority in development of radiation transport codes. In the last five to ten years, more and more codes are becoming available with features to improve usability, such as the GUIs of SuperMC [1] and Attila [2], and the unstructured mesh/CAD import feature of MCNP [3]. In the present work, the author presents a survey and comparison of some of the most commonly used tools for dose rate calculation, with particular focus on how difficult it is for a new user to become acquainted with the software and how much skill is required to use it effectively. The methods treated include Monte Carlo codes (MCNP, SuperMC, MCBEND, GEANT4), point kernel codes (Microshield, RadPro, VRdose, RANKERN), discrete ordinates deterministic methods (Attila, ANISN). It is hoped that others who need to calculate dose rates will find this comparison useful and will also follow the example of taking a wide and objective view at available software rather than habitually using the same methods repeatedly.

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Poster session / 50

The study and parametrization of longitudinal profiles of gamma ray showers using simulations for Imaging Atmospheric Cherenkov Telescope array

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Abstract—Gamma-ray astronomy is the study of astronomical objects using the most energetic form of electromagnetic radiation, gamma-rays. Some of the most violent phenomena in the cosmos emit gamma-rays. This study deals with the detection of high-energy gamma-ray showers using ground-based telescopes. These gamma-rays, upon reaching the Earth's atmosphere create a cascade of particles, through various interactions, in the form of atmospheric showers emitting Cherenkov radiation. The images obtained by the Cherenkov telescope arrays can be used for reconstructing the longitudinal profile of the gamma-ray shower. The reconstructed longitudinal profile of gamma-ray showers help in providing information about the initial gamma-rays as well gamma-hadron discrimination.

Keywords—Cherenkov radiation; longitudinal profile; IACT(imaging atmoshperic Cherenkov telescope); reconsturcted source and core; gamma-hadron discrimination

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Relativistic studies of three-body systems within the Bethe-Salpeter approach

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The influence of relativistic effects on the stability of three-body systems is of great interest.
From a general point of view, understanding the interaction in terms of the fundamental degrees of freedom is very important for nuclear and particle non-perturbative physics. Since that is a very difficult problem, simple models are of great value for understanding the crucial qualitative features of the solution with more realistic kernels.
As an attempt towards such studies, we have explored [1] the bound system of three scalar bosons interacting through a zero-range interaction. The binding energies and amplitudes have been computed by solving for the first time the Euclidean Bethe-Salpeter equation for the Faddeev component of the two lowest states.

It is well-known that in the non-relativistic approach the binding energy of this system is not bounded from below, what is known as Thomas collapse. As it was discovered in the light-front dynamics (LFD) [2,3], the relativistic repulsion prevent the Thomas collapse in the non-relativistic sense.

We discuss the impact of higher Fock components on three-body systems, and thus effective three-body forces, by comparing the Euclidean Bethe-Salpeter solutions with the ones computed within LFD. In the present calculations we consider three-body systems in which two of the particles can form a bound state, and in addition, the so-called "Borromean" systems, where no two-body bound state exists. The latter kind of systems were not treated in previous works [2,3] and our results show that these papers were not treating the true ground state. Both of these regimes are discussed in detail. We show that the Thomas collapse is also prevented in the Bethe-Salpeter approach by the relativistic repulsion at small distances. Further counterparts of other well-known phenomena in non-relativistic physics, as the popular Efimov physics, is also briefly discussed.

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In-beam γ-ray measurement of Pb-184

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In-beam γ-ray measurement of Pb-184

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The excited states in Pb-184 were first observed at Accelerator Laboratory of the University of Jyväskylä in in-beam gamma-ray experiment using the recoil-decay tagging technique by Cocks et al. [1]. They assigned transitions belonging to a cascade of E2 transitions and forming a rotational band associated with prolate shape. In order to further probe the structure of the beyond mid-shell nucleus Pb-184, we have conducted a new in-beam study using the JUROGAMII+RITU+GREAT+TDR

[2-4] instrumentation employing reaction 104Pd(83Kr,3n)184Pb with beam energy 354MeV. The improved experimental set-up allowed us to record ˜130 times higher statistics compared to work by Cocks et al. In this presentation, we will show preliminary data that suggest the extension of the yrast band up to spin 14+ and provides evidence for transitions associated with non-yrast structures. Identification of the non-yrast states can provide stringent test for theoretical models in this region and probe the shape coexistence in neutron-deficient Pb isotopes beyond the N=104 mid-shell.

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Poster session / 54

Shell Evolution Towards 78Ni: Spectroscopy of 76Cu

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How well the nuclear shell model fits for very unstable neutron rich nuclei, is an important question which will help us see whether we have fully understood the neutron-proton interactions that happen within the nucleus. One way to investigate this is to carefully study the energy levels and shell gaps in nuclei close to doubly magic 78Ni. The aim of the present work is to contribute to the understanding of the shell structure and thus effects of the nuclear forces through the 76Cu nucleus.

The excited states of 76Cu were accessed via the beta decay of 76Ni for the first time. The experimental study has been performed at RIKEN Nishina Center, Japan. Radioactive isotopes in the 78Ni region were produced via in-flight fission of 238U primary beam with an energy of 345 MeV/nucleon on a thick 9Be target. After being selected and identified in the BigRIPS fragment separator, the 76Ni nuclei were implanted in the WAS3ABi active stopper. The EURICA array with 12 Ge cluster detectors was surrounding the active stopper for the detection of gamma rays emitted from 76Cu nuclei after the β decay of the 76Ni ions. Data from RIKEN has been analyzed to find the gamma energies emitted from 76Cu and with this the energy levels have been found through the gamma coincidence analysis. In this poster, the work done so far on 76Cu will be presented.

session 11 / 36

The African LaBr Array - ALBA

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A project to increase the γ-ray detection efficiency of the iThemba LABS setup was recently funded by the South African National Research Foundation (NRF). This project will result in the acquisition

and installation of the γ-ray detector array ALBA (African LaBr Array), composed of 23 large volume LaBr3:Ce. The array could be used as a stand-alone gamma-ray spectrometer as well as coupled to the K600 spectrometer or to silicon-detector arrays for the particle identification.

This unique experimental setup would allow for new generation of studies where the γ-decay probability has been too low to be investigated with the arrays currently available worldwide. The study of the giant and pygmy resonances as well as the investigation of the nuclear level density and gamma strength function are of particular interest.

The first five detectors of ALBA arrived in December 2018 and they are now being characterised in term of energy/time resolution and efficiency. The project and the preliminary results will be presented.

session 10 / 29

The MONSTER neutron detector array

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The MONSTER (MOdular Neutron SpectromeTER) is a time-of-flight (TOF) spectrometer based on scintillation detectors [1,2]. It is originally intended as a research instrument for DESPEC, in the Low Energy Branch of the Super-FRS recoil separator in FAIR, to be utilized in the beta-delayed neutron emission studies far from the beta stability line. The modularity of the detector array nevertheless allows to use it in various combinations, both as a primary as well as an auxiliary detector system, and provides flexibility to easily move to experiments in other laboratories.

MONSTER will consist of 100 cylindrical modules, each 200 mm in diameter and 50 mm thick. As 2018, more than 60 of these modules are operational. All modules are expected to be ready by 2020. Modules are filled with BC501A organic liquid scintillator with well known pulse shape analysis properties, allowing identification of the neutron events. Each module is connected to 120 mm diameter Hamamatsu R4144 photomultiplier, whose output is digitized with Teledyne fast transient recorder unit.

Several institutes participate to the MONSTER collaboration. The most significant are CIEMAT, Madrid, and University of Valencia, Spain; Variable Energy Cyclotron Centre (VECC), Kolkata, India; and University of Jyvaskyla, Finland.

In the presentation, a technical overview of the MONSTER detector array, an outlook for the intended research program and a summary of the current status of the project will be given. In particular, the presentation will concentrate on the experiments and experimental possibilities at the IGISOL mass separator facility in the JYFL Accelerator Laboratory in the University of Jyvaskyla.

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session 3 / 5

Heavy neutron-rich nuclei

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Studies of close-to-magic nuclei are of fundamental importance for our understanding of nuclear structure. In addition, the properties of N=126 semi-magic nuclei are important in predicting the abundances of elements in the A˜195 r-process peak [1].

Neutron-rich nuclei around ^{208}Pb can be populated in fragmentation and deep-inelastic (multi-nucleon transfer) reactions, with dedicated campaigns being planned at DESPEC (GSI), KISS (RIKEN), AGATA (GANIL), ISOLDE (CERN). Here we report results form a range of recent experiments performed at ISOLDE aimed at this mass region:

(i) ^{208}Tl was populated from the beta decay of ^{208}Hg [2]. This single proton-hole single neutron-particle nucleus provides information on proton-neutron interaction. More importantly, it is a unique testing ground for the study of the competition between allowed and first-forbidden beta decay. Both positive and negative parity states are predicted at low excitation energies in ^{208}Tl. While the population of negative parity states proceeds via first-forbidden beta decay, the population of the positive-parity states is hindered by the very small overlap of the wave-functions (it proceeds via a very small mixing of core-excited configurations).

(ii) information on octupole collectivity was obtained from studies of ^{207}Tl [3] and ^{20}Hg [4]. Several collective octupole states coupled to a proton-hole were observed in ^{207}Tl populated in beta decay. Octupole (and quadrupole) collectivity was studied in ^{206}Hg using Coulomb excitation. Comparison with shell model calculations give a deeper insight into the composition of the octupole phonon, and consequently a better understanding of the nuclear structure in this mass region.

The talk will present recent results obtained on heavy neutron-rich nuclei, together with further plans for measuring the most exotic N=126 nuclei within the DESPEC project at GSI/FAIR, as well as their astrophysical relevance [1].

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session 7 / 10

The SpecMAT active target –transfer reactions and gamma-ray spectroscopy in high-intensity magnetic fields

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Studies of nuclear orbitals migration in exotic isotopes far from stability is a great challenge for modern nuclear physics. Commonly a few experiments are needed to get the necessary information about single-particle states which later can be used for the nuclear orbitals mapping. However, the same information can be collected by performing one experiment where identification of spins and spectroscopic factors of single-particle states will be extracted from transfer reactions in coincidence with high-resolution gamma-ray spectroscopy. SpecMAT is an active target –time projection chamber designed to combine both of these experimental methods. Kinematics of the reaction in SpecMAT can be reconstructed with the resolution of up to 100 keV from the energy of the ejectile charged particles by measuring the curvature of their trajectories in a high-intensity magnetic field. Gamma-ray energy resolution below 4 % at 662 keV gamma-line can be achieved from an array of scintillation detectors. Full information about the reaction and relatively high resolution which

can be reached by the detector in the harsh magnetic environment unfold new horizons on studies isotope in regions close to the driplines.

GEANT4 simulation of the scintillation array, tests of scintillation detectors and acquisition electronics in the 3T magnetic field as well as progress in the design and construction of SpecMAT will be presented.

session 10 / 15

Measurements of isomeric yield ratios in proton-induced fission of $^{\mathrm{nat}}$U by the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique

Authors: Vasileios Rakopoulos[1]; Ali Al-Adili[1]; Laetitia Canete[2]; Tommi Eronen[2]; Ari Jokinen[2]; Anu Kankainen[2]; Mattias Lantz[1]; Andea Mattera[1]; Iain D. Moore[2]; Dmitrii Nesterenko[2]; Heikki Penttilä[2]; Mikael Reponen[2]; Sami Rinta-Antila[2]; Antoine de Roubin[2]; Andreas Solders[1]; Markus Vilen[2]; Juha Äystö[2]; Michael Österlund[1]; Stephan Pomp[1]

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One of the many open questions regarding fission is the origin of the angular momentum of the primary fission fragments. Although it is well established that they carry considerable amount of angular momentum, there are competing theories on how this is generated. It is thus desirable to obtain information on the angular momenta of the fragments as it can provide insights on the properties of the dynamical evolution of the fissioning nucleus from the saddle point until its descent to scission. One of the means to accomplish this is by determining experimentally the isomeric yield ratios.

We report the first measurements of independent isomeric yield ratios, performed at the Ion Guide Isotope Separator On-Line and the JYFLTRAP facilities at the University of Jyväskylä, by employing a novel approach based on the projection of the Penning Trap ion motion onto a position-sensitive detector. The new Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique, recently implemented at JYFLTRAP, provides a superior mass resolving power, where isomers with excitation energies at 50 keV can be readily separated from the ground state. Furthermore, the phase-dependent isomeric cleaning is much faster, facilitating measurements of production ratios of isomers with half-lives at the order of one hundred milliseconds. As with the IGISOL-JYLFTRAP method the ions are estimated by direct ion counting, accurate knowledge of the decay scheme of the products is not required contrary to the measurements performed with γ-spectroscopy.

The isomer yield ratios of ^{119,120,121,122,123,125,127}In, ^{119,121,123,125,127}Cd, ^{81}Ge, ^{129}Sn, ^{129}Sb in the 25 MeV proton-induced fission of $^{\mathrm{nat}}$U were studied. For all odd-A isotopes of In and Cd, the ground state and the metastable state have the same spins [$(\frac{9}{2}^+\frac{1}{2}^-)$ and $(\frac{3}{2}^+\frac{11}{2}^-)$ respectively], with excitation energies from 300 to 450 keV for the former case and 150 to 300 keV for the latter.
Thus, the study of these isotopes can provide important information on the evolution of the initial root-mean-square angular momentum (J_{rms}) of the primary fission fragments with respect to the mass number A and towards the closed neutron shell configuration (N=82). Moreover, the even-A isotopes of In can demonstrate the effect of the odd-Z products on the angular momentum for nuclides with the same neutron number. The case of ^{129}Sn with excitation energy of the metastable state at only 35 keV highlights the superior mass resolving power (MRP) of the new technique. The cases of ^{81}Ge and ^{129}Sb were used as a cross check to older measurements of isomeric yield ratios which were performed at the same facilities by employing only the first trap (purification trap). The 679 keV excitation energy of the metastable state of ^{81}Ge was at the limits of the achievable MRP with the previous technique.

In this work we describe the PI-ICR method which was followed in order to experimentally determine the isomeric yield ratios, and we also report the preliminary results of these measurements.

In addition, from the experimentally determined isomer production ratios the root-mean-square angular momenta (J_{rms}) of the initial fission fragments after scission are estimated using the TALYS code.

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Fission dynamics with microscopic level densities

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Recent studies of shell evolution in the ^{78}Ni region

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Exploring nuclei far away from the valley of stability on the drip lines is one of the main topics at the forefront of current nuclear physics research. Fundamental properties and structure of these so-called neutron-rich, exotic nuclei provide the necessary ingredients to the physics of the unknown "terra incognita"region. Both theoretical and experimental discoveries near the drip lines exhibit that the shell structure in atomic nuclei is not as robust as we thought earlier but a more local concept. New magic numbers appear and some other conventional ones disappear mainly because of the different ordering of the single-particle orbitals. The evolution of nuclear shell structure experimentally, however, becomes rather challenging when more and more neutrons are added to the atomic nucleus. In this respect, the ^{78}Ni region, where Z=28 and N=50 shell gaps are formed, is significantly less known compared to the other doubly-magic regions. The evolution of the proton Z=28 gap at N=50 involves proton SPEs as a function of neutrons from N = 40 to N = 50. In this respect, neutron-rich Cu isotopes, having one proton outside the Z = 28 shell and lying between N=40 and 50 shell gaps, play an important role to inspect the shell structure in the ^{78}Ni region andhave been used as probes by large number of experimental studies so far.

In the present contribution, recent experimental studies performed at RIKEN using β-decay, direct reaction, and Columb excitation measurements will be presented. Neutron-rich nuclein near ^{78}Ni are populated through in-flight fission of ^{238}U on a several mm thick ^{9}Be target in all three experiments.

In the β-decay study, ^{75,77}Ni nuclei are implanted on the WAS3ABi silicon array while the EURICA spectrometer surrounds the active stopper to detect γ rays emitted after the β decay of the implanted ions.

In the (p,2p) knockout reaction, the ^{75,77}Cu nuclei are produced through one-proton knockout of ^{76,78}Zn beam particles at 250 MeV/nucleon impinging on a 10 cm thick active target time projection chamber filled with liquid hydrogen (LH2), called MINOS. The DALI2 NaI array is used to detect de-excitation γ rays measured in coincidence with ^{75,77}Cu nuclei identified in the Zero Degree Spectrometer.

In the third experiment, Coulomb excitation of the ^{77}Cu nucleus is performed on a 900-mg/cm^2 thick ^{197}Au target, mounted in front of the Zero Degree Spectrometer. The DALI2 NaI array is used to detect de-excitation γ ray measured in coincidence with the ^{77}Cu nucleus identified in the Zero Degree Spectrometer. Results will be discussed during the talk.

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New MARA separator status and first results

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Welcome

Session 5 / 8

Relative yields of tin and antimony isotopes in neutron induced fission of ^{nat}U

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Improved independent fission yields will enhance our understandig of the fission process. The mass and charge distribution contain valuable information on the scission configuration and the nuclear potential-energy landscape.

To this end, a Be(p,xn)-neutron converter target and a dedicated ion guide for neutron induced fission reactions has been developed for the IGISOL-4 facility at the University of Jyväskylä, Finland. We present the design, characterisation and performance of the converter together with the first results from a systematic study of neutron induced fission yields using the IGISOL technique.

The reaction products from high-energy neutron-induced fission of ^{nat}U were stopped in a gas cell filled with helium buffer gas, and online-separated using a dipole magnet. The isobars, with mass numbers in the range 128 to 133, were transported to a tape-implantation station and identified through γ-spectroscopy. From this the relative cumulative isotopic yields of tin (Z = 50) and the relative independent isotopic yields of antimony (Z = 51) were deduced. The yields of tin show a staggered behaviour around A = 131, not observed in the ENDF/B-VII.1 evaluation. The yields of antimony also contradict the trend from the evaluation, but are in agreement with a calculation performed using the GEF model that shows the yield increasing with mass in the range A = 128 to A = 133.

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Sandbanks beyond the proton drip-line, x-ray bursts and the rp-process

Authors: Hiroshi Suzuki[1]; Laura Sinclair[2]; Pär-Anders Söderström[3]; Giuseppe Lorusso[4]; Paul Davies[5]; Lidia Ferreira[6]; Enrico Maglione[7]; Bob Wadsworth[2]; Shunji Nishimura[1]; Pieter Doornenbal[1]

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In this contribution we will discuss the observation of the previously unknown isotope ^{72}Rb, with 14 observed events in BigRIPS and the ZeroDegree spectrometer during the EURICA campaign at RIKEN [1]. For context, the role of the neighbouring nuclei ^{72}Kr and ^{73}Rb will be discussed in their role as a waiting point in x-ray burst rp-process scenarios. The nonobservation of the less proton-rich nucleus ^{73}Rb is consistent with the adapted upper limit of 30 ns. For ^{72}Rb, however, we measure a half-life of 103 ns. This observation of a relatively long-lived odd-odd nucleus, ^{72}Rb, with a less exotic odd-even neighbor, ^{73}Rb, being unbound shows the diffuseness of the proton drip line and the possibility of sandbanks to exist beyond it. The ^{72}Rb half-life is consistent with a $5^+ \rightarrow 5/2^-$ proton decay with an energy of 800–900 keV, in agreement with the atomic mass evaluation proton-separation energy.

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Development of PPACs for neutron-induced fission cross-section measurements

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Despite long efforts on experimental and theoretical studies of nuclear reactions, it is still not possible to predict the cross sections of most reactions from the first principles, and therefore accurate measurements are still necessary in order to improve evaluated nuclear data files and to benchmark nuclear model codes. In particular, studies of neutron-induced reactions in medium-energy range are demanded by both fundamental research and applications.

Neutron-induced fission cross sections of ^{235}U and ^{238}U are widely used as standards for monitoring of neutron beams and fields. Nevertheless, there are few measurements above 20 MeV at an absolute scale, i.e., versus the H(n,n) scattering cross section, which is regarded as the primary neutron standard. Taking advantage of the high-intense white neutron beam under construction at the NFS (Neutrons For Science) facility at GANIL, we will measure the ^{235}U and ^{238}U fission cross sections relative to each other and to H(n,n) in a continuous energy range, from 1 to 40 MeV, and in a single measurement, thus canceling out systematic effects due to variations in the beam characteristics. Angular distributions of fission fragments, of interest for studying the states of the fissioning nuclei, will be also measured.

An upgraded version of the Medley setup will be used. It consisted originally of eight ΔE-ΔE-E telescopes, each composed of two Si detectors and one CsI(Tl) crystal, to detect and identify light ions. The new version will also include PPACs (Parallel Plate Avalanche Counter). Each PPAC will produce a fast signal when detecting a fission fragment, before its arrival to a front Si detector in a telescope. The energy of the incident neutron will be measured by the time-of-flight technique.

The first prototypes of the PPACs to be used at NFS have already been built in Uppsala and are being characterized using alpha decay and fission events from a ^{252}Cf sample. During this talk, the status of the whole project will be shown, and the latest available results on PPAC characterization will be discussed.

session 2 / 28

Studies of the atomic nuclei by the MAGISOL collaboration at ISOLDE and HIE-ISOLDE

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In this talk we will discuss Studies of the Atomic Nuclei performed by the Madrid-Arhus-Göteborg (MAGISOL)-collaboration at the CERN-ISOLDE facility.
The MAGISOL installations at the ISOLDE Decay station and at the XT03 beam line of HIE-ISOLDE are described. In continuation a discussion on resent experiments; IS633 on the Electron capture of 8B into highly excited states in 8Be, and IS561 on Transfer reactions at the neutron dripline with triton target, will be made.

Session 9 / 46

Isotope production cross section measurements at the HFNG, LANL-IPF, and LBNL

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The future of nuclear medicine would appear to be the paradigm of personalized medicine —targeted radionuclide therapy to spare healthy tissue, and theranostic medicine, which pairs an imaging isotope with a therapeutic isotope to provide simultaneous, real-time dose delivery and verification, leading to drastic reductions in prescribed patient dose. Candidate isotopes to meet these needs have been identified based on their chemical and radioactive decay properties, and the Bay Area Nuclear Data (BAND) Group is currently leading a series of campaigns to perform targeted, high-priority measurements of thin-target cross sections and thick-target integral yields. These studies will serve to facilitate the production of pre-clinical quantities of radioactivity for emerging and novel medical radionuclides. This talk will focus on the BAND Group's recent efforts to measure production cross sections for emerging medical radionuclides, develop new methods for the monitoring of charged-particle beams, and characterize tunable quasi-monoenergetic neutron sources for high specific activity isotope production. These student-driven projects include a host of recent efforts:

1. Production of the emerging diagnostic radionuclides ^{64}Cu and ^{47}Sc via (n,p) at the UC Berkeley High-Flux Neutron Generator (HFNG), which is being developed as a platform for high-specific activity medical isotope production;
2. Production of the emerging PET tracers ^{51}Mn and ^{52g}Mn via intermediate-energy Fe(p,x) reactions at the Lawrence Berkeley National Laboratory (LBNL) 88-Inch Cyclotron;
3. Production of ^{134}Ce as an in vivo PET diagnostic analogue at the LBNL 88-Inch Cyclotron, to characterize the biological fate and transport of the alpha-emitting therapeutic actinides ^{225}Ac and ^{227}Th;
4. Development of tunable quasi-monoenergetic neutron sources and alternative (n,x) production pathways for ^{225}Ac production at the LBNL 88-Inch Cyclotron;
5. Characterization of Nb(p,4n)^{90}Mo at the Los Alamos National Laboratory Isotope production Facility (LANL-IPF), as a new monitor reaction standard for the in-beam measurement of proton fluence in >40 MeV proton beams;
6. Development of the Fission Induced Electromagnetic Response (FIER) code, to analytically predict delayed γ-ray spectra following fission.

These experiments provide valuable opportunities to measure the distribution of excited nuclear states as a function of angular momentum, through the observation of isomer branching ratios in these energetic (p,x) reactions. In addition, these measurements provide a range of cross section data invaluable to not only the medical isotope production community, but also as new measurements to improve the reliability of the range of modern reaction modeling codes. These also provide valuable insight into the challenges and and unexpected nuances involved in precision cross section data measurements.

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iThemba LABS –opportunities in nuclear science and applications

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Over the last 7 years researchers from the University of Oslo and iThemba LABS have continued to increase collaboration to advance scientific knowledge and student education through cooperation in nuclear physics research. The institutes have effectively utilized the experimental facilities and associated equipment on both sides and have co-ordinated research efforts in experimental nuclear physics as well as student training and education.
During the presentation I will provide an overview of iThemba LABS and focus on our experimental capabilities with special emphasis on the latest developments on the high-energy neutron beam facility, the K600 spectrometer and the ALBA and AFRODITE gamma-ray arrays. Current and future planned measurements using this equipment, in particular in the context of the iThemba LABS – University of Oslo collaboration, will also be discussed.

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Shape coexistence and isospin symmetry along N=Z

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The region of proton-rich nuclei around the N=Z offers a rich testing ground for various nuclear models. Rapid shape changes have been observed between from prolate deformation in 76Kr to an oblate ground state in 72Kr. Based on the comparison with its mirror nucleus 70Se, an oblate shape is expected for 70Kr. Breaking of isospin symmetry as well as the proximity to the proton drip line however, may lead to measurable differences in the excitation energy spectrum as well as the quadrupole collectivity of the A=70 mirror pair 70Kr and 70Se. 70Kr has been studied at the RIBF facility using Coulomb excitation and neutron removal reactions using the BigRIPS fragment separators to select 70-72Kr beams. Reaction products were identified in the ZeroDegree spectrometers, while emitted gamma-rays were detected in the DALI2 array. Detailed spectroscopic information on 70Kr and measurements of the B(E2) value will be presented and discussed in comparison to the mirror nucleus 70Se and theoretical calculations. These results give important insights in the evolution of shape coexistence and isospin symmetry across the N=Z line.

Poster session / 49

Mass shift of charmonium states in $\bar{p}A$ collision

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The masses of the low lying charmonium states, namely, the J/Ψ, $\Psi(3686)$, and $\Psi(3770)$ are shifted downwards due to the second order Stark effect. In $\bar{p}$ + Au collisions at $6-10\tilde{}$GeV we study their in-medium propagation. The time evolution of the spectral functions of these charmonium states is studied with a Boltzmann-Uehling-Uhlenbeck (BUU) type transport model. We show that their in-medium mass shift can be observed in the dilepton spectrum. Therefore, by observing the dileptonic decay channel of these low lying charmonium states, especially for $\Psi(3686)$, we can gain information about the magnitude of the gluon condensate in nuclear matter. This measurement could be performed at the upcoming PANDA experiment at FAIR.

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Particle-core coupling in deformed nuclei: odd-A and doubly even-A identical bands

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Particle-core coupling is an essential concept in the organization of nuclear data.
All odd and odd-odd nuclei demand such a concept, and broken-pair states in all nuclei require it. Models such as the particle-vibrator (weak-coupling) model and the particle-rotor (strong-coupling) model have been the standard workhorses for organizing large amounts of data. It therefore comes as a surprise to discover that an elementary aspect of the particle-rotor model has been overlooked. Specifically the "rotation-particle"(or "Coriolis") term can be shown to give a universal "alignment" contribution to single-particle (Nilsson) configurations. This differs from, but is similar to "alignment"defined in the cranking model. Organizing data using this insight brings into question long-accepted views of the role of pairing in magnitudes of moments of inertia (there is no odd-particle blocking). The basic ideas will be illustrated and consequences for interpretation of nuclear rotational energies will be made, specifically the partitioning of rotational energy into kinetic and potential energy and connection to the symplectic shell model.

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Level densities

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