Colloque GANIL 2023

lundi 25 septembre 2023 - vendredi 29 septembre 2023

Soustons

Recueil des résumés

Contents

Fission / 9

Shell effects in fission and quasifission

Auteur: Cedric Simenel[1]

Co-auteurs: Kyle Godbey [2]; Patrick McGlynn [1]; A. Sait Umar [3]

[1] *Australian National University*

[2] *Michigan State University*

[3] *Vanderbilt University*

Auteur correspondant cedric.simenel@anu.edu.au

Fission of atomic nuclei is often affected by quantum effects leading to asymmetric mass splits. These shell effects can be investigated at the mean-field level with single particles level densities, indicating that several proton and neutron shell effects are usually at play prior to scission [1]. In addition to shell effects in the compound nucleus, quantum shells stabilising fission fragments with octupole shapes have been invoked as a factor determining the distribution of nucleons between the fragments at scission, explaining the fact that the centroid of the heavy fragment charge distribution is found around Z ⊠ 54 in actinide fission [2].
Shell effects have also been identified in the quasifission process [3]. Quasifission occurs in fully damped heavy-ion collisions following a significant mass transfer from the heavy to the light fragment, without formation of a compound nucleus. Microscopic calculations recently showed that similar shell effects were to be expected in both fission and quasi-fission [4,5].
Here, we use static and time-dependent mean-field approaches to investigate and compare the shell effects affecting fragment formation in both fission and quasifission. In particular, we discuss the possibility to use quasifission to obtain some information on fission modes in superheavy nuclei, which would benefit from the fact that quasifission cross-sections are much larger than for fusion-fission.

[1] R.N. Bernard, C. Simenel, G. Blanchon, EPJA 59, 51 (2023)
[2] G. Scamps, C. Simenel, Nature 564, 382 (2018)
[3] M. Morjean, D.J. Hinde, C. Simenel et al., Phys. Rev. Lett. 119, 222502 (2017)
[4] C. Simenel, P. McGlynn, A. S. Umar, K. Godbey, Phys. Lett. B 822, 136648 (2021)
[5] P. McGlynn and C. Simenel, arXiv2302.06938

Spectroscopy of heavy and superheavy elements / 10

Optimization of in-gas jet laser spectroscopy for S3-LEB

Auteur: Anjali Ajayakumar[1]

[1] *GANIL*

Auteur correspondant anjali.ajayakumar@ganil.fr

The Super Separator Spectrometer-Low Energy Branch (S^3-LEB) is a low-energy radioactive ion beam experiment under commissioning as part of the GANIL-SPIRAL2 facility [1-3]. It will be used for the production and study of exotic nuclei by in-gas laser ionization and spectroscopy (IGLIS), decay spectroscopy, and mass spectrometry.
Development work has been ongoing at the S^3-LEB setup [2-5]. It uses in-gas-jet laser ionization, to resonantly ionize the neutralized atoms, and ion guides to send them to the Piège à Ions Linéaire du GANIL pour la Résolution des Isobares et la mesure de Masse (PILGRIM), a Multi-Reflection Time Of Flight Mass Spectrometer (MR-TOF-MS), or to a decay spectroscopy study station, SEASON. A buffer gas cell with 400 ms extraction time is now coupled to the ion transport ensemble and a de-Laval nozzle of Mach number M ~ 8 (developed at KU Leuven) has been installed at the gas cell aperture, which can create a hypersonic jet of narrow velocity distribution in a reduced collision environment. The hypersonic jet environment reduces the Doppler and pressure broadening by at

least an order of magnitude compared to the gas cell [6,7]. Laser spectroscopy with suitable atomic transition schemes at S3-LEB thus offers improved spectral resolution (≤ 300 MHz) while maintaining high efficiency. It is an efficient technique giving access to isotope shifts and hyperfine constants measurements and thus to nuclear structure such as nuclear spin, moments and difference in nuclear charge radii for the exotic nuclei.
Here, we present ongoing technical developments including development of a continuous wave Ti:sapphire laser system for high resolution laser spectroscopy. The results from the offline commissioning of S3-LEB with first in-gas-jet high-resolution laser spectroscopy results of erbium will be presented. Measurements of the isotope shifts and hyperfine constants in the hypersonic gas jet will be presented and compared with literature and measurements in an Atomic Beam Unit (ABU)[8]. Characterization of the pressure-broadening effects in the gas cell will be reported. Additionally, the first optimization of the overall transport efficiency for the setup with laser-produced ions will be presented.
References:
[1] Grand Accélérateur National d'Ions Lourds, URL: https://www.ganil-spiral2.eu/en/
[2] F. Déchery., et al., Eur. Phys. J. A 51, 66 (2015)
[3] F. Déchery., et.al., NIMS B, 376125 (2016)
[4] J. Romans., et al., Atoms, 10, 21 (2022)
[5] J. Romans., et.al., NIM B, 536, 102 (2023)
[6] R. Ferrer., et.al., NIMS B, 317570 (2013)
[7] R. Ferrer., et.al., Nat. Comm. 8, 14520 (2017)
[8] A.Ajayakumar., et.al.,NIM B, 539, (2023)

Fission / 11

Fission@VAMOS/GANIL: recent results and future

Auteur: christelle schmitt[1]

[1] *IPHC Strasbourg*

Auteur correspondant christelle.schmitt@iphc.cnrs.fr

Fission at low excitation energy has shown over the past decades to be an ideal playground for studying fundamental nuclear properties, in general, and dynamical aspects of nuclear reactions, in particular. While the importance of structural effects in the nascent fragments has been established through numerous studies, the VAMOS campaigns performed during the last few years definitively confirmed the so-far elusive, but clearly dominant, role of specific proton configurations in driving the fission decay of actinides. In addition, the innovative approach implemented at VAMOS made it possible to address the competition between the influence of neutrons and protons with the accurate measurement of elaborate observables such as the fragment N/Z ratio and odd-even effects as a function of excitation energy. Most recently, the enhancement of the set-up permitted to apply the approach to fission of pre-actinides around lead, giving access for the first time in this region to bright new information on fragment isotopic information, N/Z ratio and prompt neutron multiplicity. The unexpected leading role of the proton subsystem with atomic number between the Z=28 and Z=50 characterized by very specific deformations at scission was revealed. Combined with the previously identified stabilizing forces, this finding demonstrates the striking connection between the "old" (actinide) and "new" (pre-actinide) islands of asymmetric fission. This connection is crucial to steer the strive for an unified theory of fission over the nuclear chart.
The recent results obtained at VAMOS are presented, and the "en route"campaigns and projects are discussed. The insight provided by the GANIL approach within the international context of fission studies is finally emphasized.

Applications and Interdisciplinary physics / 12

Ion Collisions with DNA Origami Nanostructures

Auteur: Jaroslav Kočišek[1]

Co-auteurs: Agnes Zerolová [1]; Leo Albert Sala

[1] *J. Heyrovský Institute of Physical Chemistry of the CAS, v. v. i.*

Auteurs correspondants: kocisek@jh-inst.cas.cz, leo.sala@jh-inst.cas.cz

DNA origami nanostructures represent a unique substrate for in singulo experiments with biomolecules, nanotechnology and medicine. In our recent experiments at GANIL, we used these nanostructures as nano-dosimeters to observe damage to DNA. Patterning of the surface deposited DNA origami as well as damage to nanostructures placed in bulk water will be described with focus on physico-chemical effects near the track, which could not be easily studied using other methods.

Shell evolution / 13

Gamma-ray spectroscopy of neutron-rich Niobium isotopes: new insights into the sudden onset of deformation of the A~100 and N=60 region.

Auteur: Mojahed Abushawish[1]

Co-auteurs: Jérémie Dudouet [2]; Olivier Stezowski [2]

[1] *Lyon-IP2I*

[2] *IP2I*

Auteurs correspondants: stezow@ipnl.in2p3.fr, j.dudouet@ip2i.in2p3.fr, m.abushawish@ip2i.in2p3.fr

Exotic nuclei, far from stability, are a perfect laboratory to probe the specific components of the nuclear interaction. The imbalance between the number of protons and neutrons can lead to the appearance of phenomena such as sudden shape transitions and shape coexistence. The nuclei with Z and N around 40 and 60, respectively, show one of the most remarkable examples of sudden nuclear shape transition between spherical and well deformed nuclei.
This work reports on new spectroscopic measurements for the neutron-rich Nb isotopes, produced in transfer and fusion-induced fission reactions at GANIL from two different experiments. The combination of the large acceptance VAMOS++, the new generation gamma tracking array AGATA along with the EXOGAM gamma- ray spectrometer provide a unique opportunity to obtain an event-by-event unambiguous (A, Z) identification of one of the fission fragments, with the prompt and delayed gamma-rays emitted in coincidence with unprecedented resolution.
The level scheme of ^{99,102,104,105,106}Nb have been significantly updated and a level scheme is presented for the first time for the ^{107}Nb nucleus. The analysis of a newly observed spherical/deformed shape coexistence in ^{99}Nb will be presented, as the evolution of the nuclear deformation with the increasing neutron number. These results contribute to a better understanding of the nuclear structure of neutron-rich Niobium isotopes and provide very useful experimental data to constrain nuclear models in this complex island of deformation region.

Heavy ion collisions / 14

Dynamics of cluster production in heavy ion collisions

Auteur: Tom Génard[1]

[1] *GANIL*

Auteur correspondant tom.genard@ganil.fr

Collisions of heavy ions are the best tools at our disposal to probe nuclear matter. It allows us to reach extreme densities, giving us the possibility to constrain transport models. In particular, at

incident energies around 100 MeV/nucleon a participant zone is formed by a part of projectile and target nuclei.

The aim of this work is to characterize the participant zone. We will focus on the characteristics of cluster production (chemical composition, energy, angular distributions, multiplicities, and their correlations). These analyses reveal the neutron richness of the emitted particles, and their yield provides an insight on the mixing of target and projectile contributions. Furthermore, a systematic analysis of the transverse energy of the emitted clusters shows a link between incident energy, compression energy, and density during the reaction.

For this study, INDRA datasets for 124,129Xe+112,124Sn collisions at 100 AMeV have been used to study the effect of neutron richness on the production of light particles. The kinematic study has been done using the datasets for 129Xe+124Sn at 65, 80, 100 and 150 AMeV collisions, and using the 136Xe+124Sn collision dataset for 32 and 45 AMeV.

The results of this analysis were compared to the semi-classical event generator ELIE. This work has been done with the goal of expanding it to a lighter system, 58,64Ni+58,64Ni, measured at 32 and 52 AMeV during the E789 INDRA-FAZIA campaign.

Applications and Interdisciplinary physics / 15

Etched Ion-track grafting for water pollution detection

Auteur: Marie-Claude Clochard[None]

Auteur correspondant marie-claude.clochard@polytechnique.edu

The fabrication of nanoporous PAA-g-PVDF membranes is based on the selective chemical etching of Swift Heavy Ions (SHI) tracks in a polymer thin film followed by AA radiografting inside the etched ion-tracks. PAA functionalized nanopores have demonstrated to efficiently trap and preconcentrate metal ions presents in water at open circuit. This passive metal adsorption at solid-liquid interface at the nanopore walls generally follows a Langmuir law. A Square-Wave Anodic Stripping Voltammetry (SW-ASV) protocol for accurate metal analysis at ppb level is established. After the presorption step, the prototyped probe connecting the nanoporous membrane-electrode is immersed in an appropriate buffer electrolyte for analysis. An accumulation potential (-1.2V / -0.8V for a maximum of 120s without stirring) is then performed to electrodeposit presorbed metal ions trapped inside the polymer porosity. The following stripping step reveals the redox potential of each electrodeposited metals (Ag/AgCl pseudo-reference). Multiple measurements in synthetic waters close to the composition of contaminated natural waters exhibited a decreasing precision with the number of readings R (1.65% (R=2) and 6.56% (R=3)) due to the diminution of trapped metal content in the porosity after each measurement. These membrane-electrodes should be used as disposable (one measurement per membrane). The intra-batch mean precision was 14% (n=3) while inter-batches precision was 20% (n=15). Linear and linear-log calibrations allow exploitation of metal concentrations in industrial wastes ranging from 10 to 500 µg.L-1 and 100 to 1000 µg.L-1 respectively. The LOD depends of the metal ion complexation ability with the functionalized entities grafted inside the nanoporosity. For example, it was found equal to 0.1 µg.L-1 for Hg (II) [1] and 4.2 µg.L-1 (3S/N) for Zn(II) [2].

[1] U. Pinaeva, D. Lairez, O. Oral, A. Faber, M-C. Clochard, T.L. Wade, P. Moreau, J-P. Ghestemc, M. Vivier, S. Ammor, R. Nocua, A. Soulé "Early warning sensors for monitoring mercury in water" Journal of Hazardous Materials 376 (2019) 37–47
[2] M-C. Clochard, O. Oral, O. Cavani, M. Castellino, L. Medina Legiero, T. Elan "Zinc detection in oil-polluted marine environment by stripping voltammetry with mercury-free nanoporous gold electrodes"Scientific Reports (2022) 12:15721 https://doi.org/10.1038/s41598-022-20067-0

Collective modes / 16

Recent results with use of the PARIS array at the Nuball1 and

Nuball2 campaigns in IJCLab

Auteur: Michał Ciemała[1]

[1] *IFJ PAN Kraków, Polska*

Auteur correspondant michal.ciemala@ifj.edu.pl

Since 2016, while PARIS array has been in its initial development phase, one cluster of phoswich detectors has been available for tests and experiments at IJCLab. Hence there has been an excellent synergy between the IJCLab facility and the PARIS detector in its development phase. In 2018, 33 PARIS phoswich detectors (almost 4 clusters) were coupled to the ν−ball1 gamma-ray spectrometer hosted by IJCLab. It was used to study the giant resonance gamma-ray decay in coincidence with low-lying deformed structures. After successful ν−ball1 campaign, in 2022, ν−ball2 started to collect data. PARIS 8 clusters (72 phoswiches) in 'wall'configuration were mounted at IJCLab in October 2022.

In the talk I will present analysis results from the PARIS@ν−ball1 campaign, as well as preliminary results of experiments performed with use of PARIS@ν−ball2 since November 2022 till July 2023.

Nuclei at the drip lines / **17**

Coulomb barrier scattering of the proton halo nucleus 17Ne

Auteur: Ismael Martel[1]

[1] *University of Huelva*

Auteur correspondant imartel@uhu.es

Coulomb barrier scattering of the proton halo nucleus 17Ne

I. Martel(a), J. Díaz-Ovejas(b), D. Dell'Aquila(c,d),L. Acosta(e), J. L. Aguado(a), G. de Angelis(f), M. J. G. Borge(b), J. A. Briz(b), A. Chbihi(g), G. Colucci(h), C. Díaz-Martín(a), P. Figuera(d), D. Galaviz(i), C. García-Ramos(a), J. A. Gómez-Galán(a), C. A. Gonzales(a), N. Goyal(g), N. Keeley(j), K. W. Kemper(k), T. Kurtukian-Nieto(l), D. J. Malenica(m), M. Mazzocco(n,o), D. Nurkic(p), A. K. Orduz(g), A. Ortiz(g), L. Palada(m), C. Parascandolo(q), A. Di Pietro(d), A. M. Rodriguez(a), K. Rusek(h), F. Salguero(a), A. M. Sánchez-Benítez(r), M. Sánchez-Raya(a), J. Sánchez-Segovia(a), N. Soic(m), F. Soramel(n,o), M. Stanoiu(s), O. Tengblad(b), N. Vukman(m), M. Xarepe(i)

(a) Science and Technology Research Centre, University of Huelva, 21071 Huelva, Spain.
(b) Instituto de Estructura de la Materia, CSIC, 28006 Madrid, Spain.
(c) Dipartimento di Chimica e Farmacia, Universitá degli Studi di Sassari, Sassari, Italy .
(d) INFN-Laboratori Nazionali del Sud, 95123 Catania, Italy.
(e) Instituto de Física, UNAM, México.
(f) INFN-National Laboratories of Legnaro, 35020 Legnaro (PD), Italy.
(g) Grand Accélérateur National d'Ions Lourds, BP 55027-14076 Caen, Cedex 05, France.
(h) Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5a, 02-093 Warsaw, Poland.
(i) LIP, Av. Prof. Gama Pinto 2, PT-1649-003, Lisboa, Portugal.
(j) National Centre for Nuclear Research, ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland.
(k) Department of Physics, The Florida State University, Tallahassee, Florida 32306, USA.
(l) Centre d'Etudes Nucléaires de Bordeaux Gradignan, Gradignan F-33175, France.
(m) Rudjer Boskovic Institute, Bijenicka cesta 54, HR-10000 Zagreb, Croatia.
(n) Dipartimento di Fisica e Astronomia, Universitá di Padova, I-35131 Padova, Italy.
(o) INFN-Sezione di Padova, via F. Marzolo 8, I-35131 Padova, Italy.
(p) Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia.
(q) INFN-Naples, Italy.
(r) Centro de Estudios Avanzados en Física, Matemáticas y Computación, University of Huelva, 21071

Huelva, Spain.
(s) IFIN-HH PO-BOX MG-6, 76900 Bucharest Magurele, Romania.

Abstract

17Ne is a proton drip-line nucleus and a candidate for a Borromean two-proton halo with a 15O core. Elastic scattering and the inclusive 15O production on a 208Pb target were measured for the first time at the SPIRAL1 facility at GANIL [1]. The experiment was carried out using the GLORIA detector array [2], a compact DSSSD array able to provide a continuous angular distribution of relevant reaction channels in the angular range from 20° to 120° Lab. The new data reveal the suppression of the Coulomb rainbow peak in 17Ne scattering, a surprising result since the rainbow peak persists in the scattering of the proton-halo 8B [3]. The angular distribution of the cross-section for inclusive 15O production seems compatible with the inelastic excitation of 17Ne. In this contribution the experimental details will be given, and the results discussed in the framework of the Optical Model and Coupled Channel Calculations [4].

References

[1] I. Martel et al., proposal E788S to the GANIL PAC, 2018.
[2] G. Marquínez-Durán, Nucl. Inst. Meth. A755 (2014) 69.
[3] R. Spartá et al., Physics Letters B 820 (2021) 136477.
[4] J. Díaz-Ovejas et al., Physics Letters B (2023), submitted.

Shell evolution / **18**

Shape evolution evidence in the neutron-rich Br isotopes

Auteur: Jérémie Dudouet[1]

Co-auteurs: Giacomo Colombi ; Duy Duc Dao [2]; Caterina Michelagnoli [3]; Frederic NOWACKI [2]; Daniela Reygadas [3]

[1] *IP2I*

[2] *IPHC Strasbourg*

[3] *ILL*

Auteurs correspondants: dreygadas@gmail.com, frederic.nowacki@iphc.cnrs.fr, j.dudouet@ip2i.in2p3.fr, cmichela@ill.fr, colombi@ill.fr, duc.dao@iphc.cnrs.fr

Away from the valley of stability, the imbalance between the number of protons and neutrons serves as a magnifying lens for specific components of the nuclear interaction that cannot be studied otherwise. In such regions of the nuclear chart, new phenomena as appearance or disappearance of magic numbers, shape coexistence or transitions, are examples of the manifestation of the influence of those terms, whose understanding is of fundamental importance. The nuclei in the A~100 region show one of the most remarkable example of sudden nuclear shape transition between spherical and well deformed nuclei, associated with a shape-coexistence phenomenon [1].
This presentation reports on new spectroscopic measurements for the neutron-rich odd-even Br nuclei, lying one proton bellow the low-Z boundary of this island of deformation. The analysis is done from the combination of two experiments : the first one from a transfer- and fusion-induced fission experiment at GANIL using the combination of the large acceptance VAMOS++ spectrometer [2] and the new generation γ-ray tracking array AGATA [3], providing a unique opportunity to obtain an event-by-event unambiguous (A, Z) identification of one of the fission fragments, and the prompt γ-rays emitted in coincidence with unprecedented resolution. The second one is a thermal neutron induced fission experiment at ILL using the FIPPS spectrometer [4], allowing for high gamma fold coincidences measurements.
The level schemes from 87,89Br have been extended, and new level schemes are proposed for the first time for 91,93Br. These new spectroscopic information are compared to state of the art Large Scale Shell Model (LSSM) calculations and the recently developed Discrete Non Orthogonal shell model (DNO-SM) approaches [5]. A very good agreement between experiment and LSSM results is

obtained and the DNO-SM results suggest an unexpected shape evolution in Br isotopes from N=52 to N=58.

[1] Paul E. Garrett, Magda Zielińska, and Emmanuel Clément. Prog. Part. Nucl. Phys., 124 :103931, 2022.
[2] M. Rejmund et al. Nucl. Inst. Methods Phys. Res. A, 646(1) :184–191, aug 2011.
[3] S. Akkoyun et al. Nucl. Inst. Methods Phys. Res. A, 668 :26–58, mar 2012.
[4] Michelagnoli, Caterina et al. EPJ Web Conf., 193 :04009, 2018.
[5] D. D. Dao and F. Nowacki. Phys. Rev. C, 105 :054314, May 2022.

Spectroscopy of heavy and superheavy elements / 19

Decay spectroscopy of 225Pa: Study of octupole deformation in the neutron-deficient actinides

Auteur: Emmanuel Rey-herme[1]

Co-auteurs: Iain Moore [2]; Ilkka Pohjalainen [2]; Andrea Raggio [2]; Jan Sarén [2]; Damien Thisse [3]; Marine Vandebrouck [3]

[1] *CEA-Saclay*

[2] *Accelerator Laboratory, Department of Physics, University of Jyväskylä, Finland*

[3] *CEA/Irfu/DPhN, Université Paris-Saclay, France*

Auteurs correspondants: iain.d.moore@jyu.fi, emmanuel.rey-herme@cea.fr, andrea.a.raggio@jyu.fi, damien.thisse@cea.fr, marine.vandebrouck@cea.fr, jan.saren@jyu.fi, ilkka.pohjalainen@jyu.fi

The study of the structure of neutron-deficient actinides is of particular interest since several theoretical calculations predict strong octupole deformations in this region of the nuclear chart [1, 2, 3]. However experimental data are scarce due to very low production rates.

There is an ongoing program at the IGISOL (Ion Guide Isotope Separation On-Line) facility, University of Jyväskylä, to study actinide isotopes, including the decay spectroscopy of neutron-deficient actinides produced through proton-induced fusion-evaporation reactions on a ^{232}Th target. A successful experiment was performed in July 2020 where short-lived actinide isotopes were produced, mass separated and guided to a decay spectroscopy station. Using an experimental setup composed of Ge, Si and Si(Li) detectors, α, γ and electron decay spectroscopy of the selected nuclei was performed to reconstruct the decay schemes that are missing or incomplete in this region of the nuclear chart. In this presentation, I will show results focusing on ^{225}Pa, for which very little decay information was available before this experiment, as well as its daughter nucleus ^{221}Ac. Reconstruction of the decay scheme and measurement of α hindrance factors indicates a static quadrupole-octupole deformation in ^{221}Ac. In particular the level scheme of ^{221}Ac is interpreted in terms of parity-doublet bands arising from this octupole deformation.

The second goal of this experiment was to measure production yields in order to consider a laser spectroscopy program in the future. Indeed laser ionisation spectroscopy is well established as a powerful tool in nuclear structure studies [4]. It allows the measurement of spins, magnetic dipole moments, electric quadrupole moments and changes in the mean-square charge radii independently of nuclear models.
\newline

In the near future, the possibility to perform laser ionisation spectroscopy of neutron-deficient actinides at S^3-LEB will allow to continue this program towards nuclei further from stability. In particular the SEASON (Spectroscopy Electron Alpha in Silicon bOx couNter) detector will enable the coupling of two approaches : laser ionisation spectroscopy and decay spectroscopy.
I will conclude my talk discussing perspectives for the study of octupole deformations in the neutron-deficient actinides, in particular those offered by SEASON at S^3-LEB.

[1] S.E. Agbemava, A.V. Afanasjev, Phys. Rev. C 96, 024301 (2017).
[2] S.E. Agbemava, A.V. Afanasjev and P. Ring, Phys. Rev. C 93, 044304 (2016).

[3] L.M. Robledo and R.R. Rodr´ıguez-Guzm´an, J. Phys. G: Nucl. Part. Phys. 39, 105103 (2012).
[4] P. Campbell, I.D. Moore and M.R. Pearson, Prog. Part. Nucl. Phys. 86, 127-180 (2016).

Poster session - with cocktail and buffet / 20

PVDF nanostructuration, piezocomposites synthesis and modeling piezoelectric behaviors

Auteur: Marie Sigallon[1]

[1] *LSI Polytechnique*

Auteur correspondant marie.sigallon@polytechnique.edu

Flexibility and strong polarization of its beta crystalline phase has made the homopolymer PVDF (Polyvinylidene Fluoride) a worldwide studied piezomaterial in the development of piezogenerators and the domain of energy harvesting. The race to achieve the best piezoperformances with this material is on. The actual research trend is focused on developing flexible composite piezomaterials with the aim of increasing notably the piezoelectric constant d33.
SHI irradiations and track-etching on thin piezoPVDF membranes (dozens of microns) enable us to work on the nanostructuration of PVDF and on the elaboration of new composites. From these highly porous PVDF matrices (fluencies of 108-109 cm-2), it is possible to embed inorganic nanowires or MOF (Metal Organic Framework) inside PVDF nanoporosity.
In addition, to better describe the piezoelectric behavior of PVDF we have developed an experimental set-up that stresses the membrane by a sinusoidal strain. The direct sinusoidal piezoresponse of the material is real-time monitored for different frequencies of strains and different load resistances in the electric circuit. Resulted quantitative analysis of datasets enables us to verify our mathematical model derivatized from Curies'constitutive equations. The challenge is to define a figure of merit that can be applied to any piezocomposite.
Preliminary results have shown that a scaling law exists between the output voltage and the product of the load resistance by the mechanical solicitation frequency.

Shell evolution / 21

Investigating shape transition in neutron-rich nuclei in the region of A = 100 through conversion electron spectroscopy at ALTO

Auteur: Guillem Tocabens[None]

Co-auteurs: The BEDO collaboration ; Clément DELAFOSSE [1]; David Verney [2]

[1] *IJCLab*

[2] *IPN Orsay*

Auteurs correspondants: guillem.tocabens@cea.fr, clement.delafosse@ijclab.in2p3.fr, verney@ipno.in2p3.fr

The region of neutron-rich nuclei around $N = 60$ has attracted interest in the late eighties, and even until now, its unique features continue to be of great importance in our understanding of shape evolution far from stability. First indirect evidence of shape coexistence in the region comes from a substantial increase in the two-neutron separation energy together with the difference in mean-square charge radius in nuclei from rubidium to zirconium at $N = 60$ [1], [2]. The observation of low-lying 0^+ states in even-even strontium and zirconium isotopes and the inversion between the spherical and intruder configuration at $N = 60$ and above supports the shape transition hypothesis. Such an inversion can be explained by a polarization mechanism introduced by P. Federman and S. Pittel [3], in which the addition of neutrons to the $g_{7/2}$ orbital can cause the promotion of protons in its spin-orbit partner orbital, $g_{9/2}$, which in turn can cause the promotion of more neutrons to $g_{9/2}$. Correlations between neutrons in $g_{9/2}$ and protons in $g_{7/2}$ lead to deformation and the mutual polarization causes the $Z = 40$ gap to be reduced, and the lowering of the energy of the 0^+ intruder configurations towards $N = 60$. The most direct way to study these low-lying 0^+ states in even-even nuclei is via conversion electron spectroscopy, to observe electric monopole transition to the ground state.

An experiment was conducted in October 2022 at ALTO, to investigate neutron-rich strontium and zirconium isotopes up to mass 100 through β decay of a rubidium ISOL beam. The beam was then collected in the newly developed COeCO [4] decay station to measure the E0 decay strength in ^{98}Sr and both ^{98}Zr and ^{100}Zr but also to look for a low-lying 0^+ state, predicted but not yet discovered, in ^{100}Sr. I will present the results of this experiment, which led to several re-measurements of half-lives of states in ^{96,97,100}Zr, ^{97}Sr as well as a new value for the half-life of the first 0^+ excited state in ^{98}Zr. This new half-life value allows to determine the strength of the E0 transition, which in turn gives a value of the difference in mean-square charge radius between the ground state and the first excited 0^+ state. These results expand on our knowledge of shape transition in the region and open up new perspectives for conversion electron studies in neutron-rich nuclei produced at ALTO.

[1] U. Hager et al., Phys. Rev. Lett. 96, 042504 (2006)
[2] P. Campbell et al., Phys. Rev. Lett. 89, 082501 (2002)
[3] P. Federman and S. Pittel, Phys. Rev. C 20, (1979)
[4] G. Tocabens, PhD thesis, defended December 2022

Spectroscopy of heavy and superheavy elements / **22**

Status of the SIRIUS detector array*

Auteur: Rikel Chakma[1]

[1] *GANIL*

Auteur correspondant rikel.chakma@ganil.fr

The superconducting LINAC (LINear ACcelerator) of SPIRAL2-GANIL will deliver very intense heavy-ion beams up to uranium by virtue of the additional NEWGAIN (NEW GAnil Injector) with mass to charge ratio (A/Q = 7)[1]. The S^3 (Super Separator Spectrometer) of SPIRAL2 was designed to have high transmission, high beam rejection and high mass resolving power capabilities to study rare isotopes like superheavy and exotic nuclei far from the stability with very low production cross-sections[2]. At the focal plane of S^3, a state-of-art detector array called SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3)[3] will be installed to perform decay spectroscopic studies in the region of the very heavy and superheavy nuclei where very little spectroscopic data[4] is available. SIRIUS will be capable of detecting heavy ions and their subsequent decay products: alpha particles, beta particles, internal-conversion electrons, gamma rays, X rays and fission fragments. It is composed of an ion tracker to track the ERs (Evaporation Residues) passing through it and also to measure their time of flights, a DSSD (Double-Sided-Silicon-Strip Detector) for implanting the ERs and to establish their spatial and temporal correlations with their successive decays, four stripy pad silicon detectors in a tunnel configuration placed upstream to the DSSD to detect the escaping charged particles from the DSSD thus allowing performance of internal-conversion-electron spectroscopy, five clover detectors placed in a close geometry around the silicon detectors to carry out detailed gamma spectroscopy. Currently, we are commissioning the setup using sources and beam. In this conference, I will present the current status of the SIRIUS project.

References

[1] D. Ackermann et al., NEWGAN White Book (2021) 1-39.
[2] F. Déchery et al., Eur. Phys. J. A 51 (2015) 66.
[3] N. Karkour et al., IEEE Nuclear Science Symposium 51 (2016) 1-6.
[4] Ch. Theisen et al., Nucl. Phys. A 944 (2015) 333-375.

*S^3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de

Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and by the E.C.FP7-INFRASTRUCTURES 2007, SPIRAL2 Preparatory Phase, Grant agreement No.: 212692.
SIRIUS has been funded by the CPIER (Contrat Plan Etat Inter Régional) and the Région Normandie \& the European Union through the RIN-Tremplin Grant SoSIRIUS.

Nuclei at the drip lines / 23

(d, 3He) transfer reactions with Be-Li isotopes near the drip-line

Auteurs: Lynda Achouri[1]; Marlène Assié[2]; Beyhan BASTIN[3]; Didier Beaumel[4]; Yorick Blumenfeld[2]; Wilton Catford[5]; ANNA CORSI[6]; François de Oliveira[3]; Nicolas de Séréville[4]; Benoit Delaunay[7]; Franck Delaunay[1]; Beatriz Fernandez Dominguez[8]; Freddy FLAVIGNY[1]; serge franchoo[9]; Anastasia Georgiadou[10]; Julien Gibelin[11]; Valérian Girard-Alcindor[3]; Faïrouz Hammache[12]; bertrand Jacquot[13]; O Kamalou[3]; Shumpei KOYAMA[14]; Valérie Lapoux[15]; Antoine LEMASSON[3]; Juan Lois-Fuentes[16]; Gavin Lotay[None]; Miguel Lozano González[17]; Miguel Marques[18]; Adrien MATTA[19]; Anne Meyer[20]; Nigel Orr[18]; Maurycy Rejmund[3]; Maurycy Rejmund[3]; Thomas ROGER[3]; Olivier Sorlin[3]; Iulian stefan[10]; Christelle STODEL[3]; Daisuke Suzuki[21]; Jean-Charles THOMAS[22]; Natalia Timofeyuk[None]; Marine Vandebrouck[15]

[1] *LPC Caen*

[2] *IPNO*

[3] *GANIL*

[4] *IPN Orsay*

[5] *University of Surrey*

[6] *CEA Saclay*

[7] *CC-IN2P3/CNRS*

[8] *USC*

[9] *ipn*

[10] *IJCLab*

[11] *LPC CAEN/Université de Caen*

[12] *IPN-Orsay*

[13] *CNRS*

[14] *the University of Tokyo*

[15] *CEA Saclay DPhN*

[16] *IGFAE/USC*

[17] *IGFAE-USC*

[18] *LPC-Caen*

[19] *LPC Caen, CNRS-IN2P3*

[20] *Université Paris-Saclay - IJCLab*

[21] *RIKEN Nishina Center*

[22] *Grand Accélérateur National d'Ions Lourds*

Auteurs correspondants: miguellozano.gonzalez@usc.es, mrejmund@ganil.fr, thomasjc@ganil.fr, girardalcindor@ganil.fr, bastin@ganil.fr, valerie.lapoux@cea.fr, beaumel@ipno.in2p3.fr, matta@lpccaen.in2p3.fr, marques@lpccaen.in2p3.fr, oliveira@ganil.fr, w.catford@surrey.ac.uk, bertrand.jacquot@ganil.fr, koyama@nucl.phys.s.u-tokyo.ac.jp, hammache@ipno.in2p3.fr, yorick@ipno.in2p3.fr, g.lotay@surrey.ac.uk, juan.lois.fuentes@usc.es, n.timofeyuk@surrey.ac.uk, gibelin@lpccaen.in2p3.fr, stodel@ganil.fr, delaunay@in2p3.fr, orr@lpccaen.in2p3.fr, marine.vandebrouck@cea.fr, delaunay@lpccaen.in2p3.fr, beatriz.fernandez.dominguez@usc.es, flavigny@lpccaen.in2p3.fr, deserevi@ipno.in2p3.fr, roger@ganil.fr, acorsi@cea.fr, franchoo@ipno.in2p3.fr, assie@ipno.in2p3.fr, achouri@lpccaen.in2p3.fr, stefan@ipno.in2p3.fr, daisuke.suzuki@ribf.riken.jp, lemasson@ganil.fr

Proton-removal reactions along the Be-Li chain close to the drip-line have been investigated with the aim of establishing the role of the Geometrical Mismatch Factor (GMF) and NN effects [1] in lowering the cross sections, as observed previously in He-Li nuclei [2].

The experiment was performed at GANIL using 10Be and 12Be beams at 30 AMeV impinging a CD2 target, with an intensity of $3 \cdot 10^5$ pps and $2 \cdot 10^4$ pps respectively. The angle and energy of the light recoil were detected by using 8 MUST2 telescopes [3], and a zero-degree detector consisting of an ionization chamber and a plastic scintillator that permitted the identification of the heavy recoil.

The missing-mass technique was used to reconstruct the excitation energy spectrum, from which cross sections can be extracted. Particular attention has been paid to the 12Be(d, 3He)11Li transfer reaction, but also to the 12Be(d, t)11Be channel as it enables a further constrain to the GMF of 12Be [4].

Preliminary results of the excitation energy for 11Li and 11Be will be presented and an overview of the status of the analysis for 10Be reactions will be depicted

References
[1] N. K. Timofeyuk, J. Phys. G Nucl. Partic. 41, 094008 (2014).
[2] A. Matta et al., Phys. Rev. C 92, 041302 (2015).
[3] E. Pollacco et al., Eur. Phys. J. A 25, 287–288 (2005).
[4] F. Nunes et al., Nucl. Phys. A 609, 43–73 (1996)

Nuclei at the drip lines / **24**

Missing mass spectroscopy of light proton unbound nuclei

Auteur: Shumpei Koyama[1]

[1] *GANIL*

Auteur correspondant shumpei.koyama@ganil.fr

Light proton-unbound nuclei, ^{8}C, ^{7}B, ^{6}Be and ^{5}Li, were investigated by the missing mass method. By using this method, we can measure resonances independently of their decay channels. This is efficient especially for the four-proton unbound nucleus ^{8}C. Decay channels can be also investigated by the coincidence detection.
We performed the experiment with an N=3 isotone secondary beam containing ^{9}C, ^{8}B, ^{7}Be and ^{6}Li produced by the LISE spectrometer. The beam was bombarded on a liquid hydrogen target of 1.5 mm in thickness. Resonances in proton-unbound N=2 isotones were systematically populated via the one-neutron transfer (p, d) reaction. An array of MUST2 telescopes was used to detect recoil deuterons from the target and decay fragments. We will report on the experimental results on newly observed resonances.

Poster session - with cocktail and buffet / **25**

$^{77-89}Zr proton rich isotopes nuclear structure investigation

Auteur: Nadjet Laouet[1]

Co-auteur: Fatima Benrachi [1]

[1] *LPMPS Laboratory, Frères Mentouri Constantine-1 University, 25017 Constantine (Algeria)*

Auteurs correspondants: nadjet.laouet@umc.edu.dz, fatima.benrachi@umc.edu.dz

Systems far from β stability are good candidates for solving nuclear structure anomalies in such exotic regions and for the improvement of our knowledge about NN interaction. Odd zirconium isotopes, lay from proton drip-line to neutron one, provide encouraging opportunities to progress nuclear model development. This work aims to investigate the odd $^{77-89}Zr$ isotopes in ^{78}Ni mass region. The calculations were performed in the framework of the nuclear shell model by means of $NuShellX@MSU$ code.
By applying calculated single particle energies, we have introduced some modifications on the original effective interaction, basing on monopole effect. The elaborated interaction is used to calculate some nuclear properties of the studied isotopes. The results are then compared to the available experimental data.

Nuclei at the drip lines / 26

Study of the tensor force contribution in the N isotopic chain using QFS reactions

Auteurs: Antoine Barrière[1]; Olivier Sorlin[1]; Nikhil Mozumdar[2]; R³B Collaboration[None]

[1] *Grand Accélérateur National d'Ions Lourds (GANIL)*

[2] *Technische Universit ̈at Darmstadt*

Auteurs correspondants: olivier.sorlin@ganil.fr, antoine.barriere@ganil.fr

In the shell model framework, the two-body nuclear force can be divided into a central, spin-orbit (SO) and tensor parts. The vast majority of studies performed so far in the chart of nuclides shows that the amplitude of the SO splitting scales with the function presented by G.Mairle [1], from systematics of nuclei studied so far in the valley of stability. Two exceptions to this trend have been found so far for the ^{133}Sn [2,3] and ^{35}Si [4] nuclei. As for the first, deviation to the trend has been attributed to the effect of the continuum, while the second to the effect of the central proton depletion that induces a strong reduction of the SO splitting of orbits probing the interior of the nucleus [5,6]. There is not so far striking evidence of the effect of the tensor force that should induce a change in the SO splittings that depends on its strength.

An experiment has been recently performed using the R³B setup at GSI, within the FAIR Phase-0 program. One of the scientific goals of is to study the role of the tensor force when approaching the neutron drip-line. During this experiment a "cocktail"of nuclei, among which ^{22}O and ^{21}N, was sent on a 5 cm LH2 target surrounded by tracking detectors and the CALIFA calorimeter [7]. This calorimeter allows to detect γ-rays and light particles from the QFS reactions in inverse kinematics. To study the spectroscopy of unbound states with an unprecedented energy resolution, this new setup includes the high resolution and granularity neutron detector NeuLAND [8].

In this work, the ^{22}O($p, 2p$) and ^{21}N(p, pn) QFS knockout reactions provide us information on the tensor force contribution to the $0p_{1/2}$-$0p_{3/2}$ SO splitting in the N isotope chain, from N=8 to N=14 shell closure, when the neutron $0d_{5/2}$ orbital is filled. The first reaction gives access to the $1/2^-$ and $3/2^-$ states in ^{21}N, and the second allows to check that 6 neutrons are indeed populating the $0d_{5/2}$ orbital in ^{21}N.

Preliminary results from this study will be presented.

[1] G. Mairle, Phys. Lett. B **304**, (1993) 39.
[2] K. L. Jones et al., Nature **465**, (2010) 454.
[3] R. Orlandi et al., Phys. Lett. B **785**, (2018) 615.
[4] G. Burgunder et al., Phys. Rev. Lett. **112**, (2014) 042502.
[5] O. Sorlin et al., Phys. Lett. B **809**, (2020) 135740.
[6] A. Mutschler et al. Nature Phys. **13**, (2017) 152.
[7] A. Knyazev et al., Nucl. Instr. and Meth. A **940**, (2019) 393-404.
[8] K. Boretzky et al., Nucl. Instr. and Meth. A **1014**, (2021) 165701.

Shell evolution / 27

Evolution of the N=50 shell gap: new insights from spectroscopic data on 82Ge

Auteur: Damien THISSE[1]

Co-auteurs: Matthieu Lebois [2]; David Verney [3]; Jonathan Wilson [4]

[1] *CEA*

[2] *Institut de Physique Nucléaire d'Orsay*

[3] *IPN Orsay*

[4] *IJC Lab, Orsay, France*

Auteurs correspondants: damien.thisse@cea.fr, jonathan.wilson@ijclab.in2p3.fr, lebois@ipno.in2p3.fr, verney@ipno.in2p3.fr

The evolution of the N = 50 single-particle gap size from β stability towards the exotic 78Ni, at the origin of the magic nature of the N = 50 isotones, is still poorly understood. Experimental data indicate that the size of the effective N = 50 gap continuously decreases from stability down to Z = 32 [1]. This reduction must certainly be followed by a stabilization around Z = 30, a phenomenon that has still not received any theoretical explanation.

In 2018, the ν-Ball campaign took place at the ALTO facility of Orsay [2]. The γ-spectrometer was made of 34 HPGe detectors to perform high resolution γ-spectroscopy, coupled to 20 LaBr3 scintillators enabling the realization of fast-timing measurements. During this campaign, medium-spin yrast and near-yrast states of neutron-rich nuclei were successfully populated in the fission of a 232Th target exposed to the quasi-mono-energetic fast-neutron flux generated by LICORNE. Among all the reaction products, the N = 50 nucleus 82Ge have been identified. In this presentation, I will show results focusing on the new spectroscopic data obtained for the nucleus 82Ge [3]. Indeed, using double and triple γ coincidences in the HPGe of ν-Ball, we were able to add two new transitions and one excited state in its level scheme. The latter is interpreted as the 7+ state originating from the N = 50 core-breaking configuration $\nu(1g_{9/2})^{-1}\nu(2d_{5/2})^{1}$, and we discuss the relationship between its observed excitation energy and the effective N = 50 shell gap amplitude at Z = 32. This new information is used to quantify the evolution of the N = 50 gap from Z = 38 down to Z = 32. According to our analysis, the gap slope is almost three times as high as the one obtained in Ref. [1]. We propose for the first time to explain this
evolution by the effect of the isospin asymmetry of the pseudo-spin symmetry in this region [4].

In the future, at GANIL, there will be the opportunity to study N = 50 isotones on the neutron deficient side at the DESIR facility. The possibility to study nuclei close the N = Z line, near the doubly magic 100Sn nucleus, will allow to further study the role of the isospin asymmetry of the pseudo-spin symmetry in the evolution of the nuclear orbitals.

Références

[1] M.-G. Porquet and O. Sorlin, Evolution of the N = 50 gap from Z = 30 to Z = 38 and extrapolation toward 78Ni., Phys. Rev. C **85**, 014307 (2012)
[2] M. Lebois et al., *The ν-ball γ- spectrometer*, NIM A **960**, 163580 (2020)
[3] D. Thisse et al., *Article submitted to EPJ A in January 2023*
[4] H. Liang et al., *Hidden pseudospin and spin symmetries and their origins in atomic nuclei*, Phys. Rep. **570**, 1-84 (2015)

Fundamental interactions and symmetries / 28

b-STILED: Search for Tensor Interactions in nucLear bEta Decay

Auteur: Mohamad Kanafani[None]

Co-auteurs: Xavier Flechard [1]; Sylvain Leblond [2]; Etienne Liénard [1]; Xavier Mougeot [3]; Oscar Naviliat-Cuncic [4]; Gilles Quemener [5]; Jean-Charles THOMAS [6]

[1] *LPC Caen*

[2] *LNE/LNHB*

[3] *CEA / LIST / LNHB*

[4] *Laboratoire de Physique Corpusculaire de Caen*

[5] *CNRS/IN2P3 - LPC Caen*

[6] *Grand Accélérateur National d'Ions Lourds*

Auteurs correspondants: quemener@lpccaen.in2p3.fr, xavier.mougeot@cea.fr, naviliat@lpccaen.in2p3.fr, flechard@lpccaen.in2p3.fr, sylvain.leblond@cea.fr, thomasjc@ganil.fr, kanafani@lpccaen.in2p3.fr, lienard@lpccaen.in2p3.fr

Precision measurements in beta decay play an essential role in the search for new physics beyond the standard model (SM), by probing "exotic"phenomena such as scalar and tensor interactions. The existence of such interactions induces deviations on certain observables away from their SM predictions. The study of the full beta energy spectrum offers a sensitive property to probe these interactions.

The goal of this work is to perform the most precise measurement of the β-energy spectrum in ^{6}He decay, in order to extract the Fierz interference term b with a precision in the order of $4 \cdot 10^{-3}$. This term depends linearly on exotic coupling constants, allowing to search for or to constrain the presence of tensor interactions in nuclear beta decay.

The main instrumental effect observed in previous measurements of the beta energy spectrum resides in the energy loss due to electrons backscattering outside the detector volume. A new technique is used to overcome this effect. It consists of using a very low energy beam of $^{6}He^{+}$ ions (25 keV) deposited between two scintillation detectors forming a 4π calorimeter. The use of this technique ensures the deposition of the entire energy of the detected beta particles. An experiment with this setup was performed at the Grand Accélérateur National d'Ions Lourds (GANIL) in 2021.

This contribution will introduce the general context of the project, describe the experimental setup, report the status of the data analysis and present the preliminary results

Heavy ion collisions / **29**

Study of the isospin transport phenomena in the 58Ni+58Ni reaction at 32, 52 and 74 AMeV with the FAZIA-INDRA apparatus.

Auteur: Lucia Baldesi[1]

[1] *Dipartimento di Fisica e Astronomia Università di Firenze , INFN Sezione di Firenze*

Auteur correspondant lucia.baldesi@fi.infn.it

Heavy-ion collisions at Fermi energies allow to investigate various phenomena, such as the isospin transport phenomena. These can be interpreted in the framework of the Nuclear Equation of State (NEoS), which describes the properties of nuclear matter in terms of thermodynamic variables.
In this talk we will show the preliminary results of the study of the ^{58}Ni+^{58}Ni reaction at three different energies 32, 52 and 74 AMeV. These reactions were measured during the E789 and E818 experiments performed with FAZIA-INDRA apparatus [1,2] at GANIL (Caen, France). The large angular coverage of the coupled detectors (2°-176°) allows the characterization of events. Moreover FAZIA, covering the forward polar angles (1.5°-14°), provides an optimal charge and mass identification of the fragments (up to Z=25) [3].
The ^{58}Ni+^{58}Ni reaction was measured at 32 and 52 AMeV in 2019 and partially already analysed [4], while the set of measurements was completed during the E818 experiment (May 2022) with the same reaction at 74 AMeV. These measurements are particularly interesting because they offer the

possibility to investigate the isospin transport phenomena [5] in a wide energy range. Moreover, the measure at 74 AMeV allows to study how the cross section of the reaction channels changes at high energy where the vaporization channel could be important.

References
[1] R. Bougault et al., Eur. Phys. J. A 50, 47 (2014)
[2] J. Pouthas et al., Nucl. Instr. and Meth. in Phys. Res. A 357, 418 (1995)
[3] N. Le Neindre et al., Nucl. Instr. Meth. A 701, 145–152 (2013)
[4] C. Ciampi et al., Phys. Rev. C 106, 024603 (2022)
[5] S. Piantelli et al., Phys. Rev. C 103, 014603 (2021)

Shell evolution / 30

Ab initio density distributions in the Sn sector

Auteur: Pierre Arthuis[1]

[1] *Technische Universität Darmstadt*

Auteur correspondant pierre.arthuis@tu-darmstadt.de

Nuclear radii and densities are key quantities that naturally bridge nuclear structure and reactions and open a window towards a detailed understanding of the nuclear interaction within a given theoretical framework. Long restricted to light systems due to model-space convergence limitations as well as interactions deficiencies, recent progress on both accounts now allow for accurate ab initio description of those quantities up to and above the tin isotopic chain.

I will present ab initio radii and density distributions for Sn and Xe isotopes and show how they can be compared with past experimental results such as SCRIT in RIKEN, as well as inform current experimental endeavours, e.g. aimed at constraining the nuclear symmetry energy slope parameter at GSI/R3B. This paves the way for fruitful collaboration between experiment and theory in the context of upcoming programs at SPIRAL2 and beyond.

Nuclei at the drip lines / 31

Proton hole states in ^{19}N from the d(^{20}O, ^{3}He): Study of the Z=6 shell gap

Auteur: Juan Lois-Fuentes[1]

Co-auteurs: Beatriz Fernández-Domínguez [1]; Thomas ROGER [2]

[1] *IGFAE/USC*

[2] *GANIL*

Auteur correspondant juan.lois.fuentes@usc.es

The Z=6 shell gap in neutron-rich carbon isotopes has been a subject of debate, with recent studies claiming its prevalence in this region of the nuclear chart [1], in contradiction with recent measurements [2] and shell model predictions [3].
In order to shed more light into this subject, the structure of ^{19}N was investigated through the proton-removal d(^{20}O, ^{3}He) reaction using the active target ACTAR TPC [4].

In 2022, the GANIL facility provided a pure ^{20}O beam which was selected by the LISE3 spectrometer at 35A MeV with an intensity of $2{\cdot}10^4$ pps. The beam was delivered to the ACTAR TPC setup, filled with a 90/10 mixture of D_2 and C_4H_{10} at 1 bar. The energy of the particles leaving the volume was measured in the Si pad detectors while the angle was obtained from the reconstruction of the tracks in the gas. The E_x spectrum was built with the missing mass technique. The obtained results demonstrate the potential of the ACTAR TPC setup for future transfer reaction experiments.

The low-lying structure of ^{19}N revealed multiple p-hole states with l=1 determined from the differential cross section. The location of the states that carry the largest $0p_{1/2}$ and $0p_{3/2}$ strength allowed for the determination of the ($\pi 0p_{1/2}$-$\pi 0p_{3/2}$) spin-orbit splitting in ^{20}O. Our results support a reduction of the Z=6 shell gap due to the tensor force in agreement with theoretical predictions from [3] using state-of-the art interactions in this region such as YSOX and SFO-tls.

References:

[1] D.T. Tran et al., Nature Communications, 9, (2018),1594.
[2] I. Syndikus et al., Physics Letters B, 809, (2020), 135748.
[3] T. Otsuka et al. Phys. Rev. lett. 95, (2005), 232502
[4] B. Maus et al. Nucl. Instrum. Meth. Phys. Res. A 940, (2019), 01689002.

Applications and Interdisciplinary physics / 32

Hadrontherapy for glioblastoma: impact on tumor cells and on the healthy tissue

Auteur: Samuel Valable[1]

Co-auteurs: Juliette Aury-Landas [1]; Nolwenn Pasquet [1]; Charly Hélaine [1]; Jérôme Toutain [1]; Edwige PETIT [1]; Myriam Bernaudin [1]; Elodie Peres [1]

[1] *ISTCT UMR 6030*

Auteur correspondant samuel.valable@cnrs.fr

Glioblastoma (GBM) are brain tumors resistant to conventional therapies, in particular to radiotherapy based on X-rays. Therefore, the use of hadrontherapy appears as very appealing strategy thanks to their finite dose deposition to spare normal brain tissue but also to their greater biological efficacy toward radioresistant tumor cells and their low sensitivity to hypoxia, a well know factor of radioresistance.
Here, we evaluated in vitro the effects of high-LET particles, especially carbon ions on hypoxia induced radioresistance. Hypoxia-induced radioresistance was studied in two human GBM cells (U251, GL15) exposed to X-rays or to carbon ion beams with various LET (28, 50, 100 keV/µm). Cell survival, radiobiological parameters and cell cycle, were assessed under those conditions. These results demonstrate that, although CIRT is more efficient than X-rays in GBM cells, hypoxia can limit CIRT efficacy in a cell-type manner that may involve cell-specific pathways. These results also confirm that other mechanisms in parallel to hypoxia are involved in radioresistance.
Glioma stem cells (GSC) are suspected to be the most radioresistant cells due to their quiescent state and high efficacy in DNA repair pathways. The number of GSC increases after radiotherapy and is associated with the risk of recurrence. This increase in GSC could result from dedifferentiation of tumor cells after X-ray irradiation. The impact of hadrontherapy on tumor cell dedifferentiation is less documented. We therefore studied the effect of different radiation modalities on this dedifferentiation capacity in human GBM cells (U87-MG). Interestingly, our results show that protons and in a less manner carbon ions decrease the formation of sphere contrary to X-rays. We are now conducting experiments to test whether the combination of radiation and hypoxia targeting agents could improve the effects of radiation alone.
Lastly, while hadrons appear of main interest to spare normal tissue due to ballistic properties, the effects on non-tumor tissues remain to be determined. It is important to question the potential effects of these new treatment modalities on cerebral cells. Preliminary results on various cells derived from normal brain will also be presented.

In conclusion, our study shows while targeting HIF pathways could rather be interesting in presence of X-rays. The use of hadrons limits the dedifferentiation ability of GBM. Thus, hadrontherapy seems to be a promising therapy to limit resistance and thus target the recurrence of GBM.

Poster session - with cocktail and buffet / 33

PISTA, a new detection system for fission studies in inverse kinematics at VAMOS

Auteur: Lucas Bégué–Guillou[1]

[1] *Ganil*

Auteur correspondant lucas.begue@ganil.fr

More than 80 years after its discovery, a complete description of the fission process remains a challenge. It is a many-body dynamic problem involving both microscopic and macroscopic aspects of nuclear matter. Technological breakthroughs such as the development of Gen-IV reactors and various fundamental aspirations bring motivation for the scientific community to have a better understanding of this mechanism. Moreover, new experimental data on exotic fissioning systems that cannot be probed using direct neutron induced fission are needed to further understand the fission process.

At GANIL, fission studies using the VAMOS++ large acceptance spectrometer combined with ^{238}U beams at energies around the Coulomb barrier allow to populate such exotic fissioning systems. Also, fission induced by transfer or fusion reaction in inverse kinematics allows us to obtain isotopic identification (in mass and charge) of fission fragments. As well, the detection and identification of the target-like residue provide the characterization of the fissioning systems. Such a combination has been shown to be a powerful tool to extract post-evaporation isotopic yields and neutron content (N/Z) that hold the signature of the shell effects at play in the process [1].

Recently, an upgrade of the target-like residue detection systems has been initiated. For this, the new PISTA (Particle Identification Silicon Telescope Array) detector has been developed, this last will be located 10 cm away from the target and will cover angles between 30° and 60°. Allowing one of the fragments to enter VAMOS++ where it will be isotopically identified. PISTA is an array of eight trapezoidal silicon telescope detectors assembled as in a corolla. Each telescope is composed of two single sided silicon detectors, 100 µm and 1000 µm thick. The thickness was chosen to identify light ions up to Oxygen. Target-like nuclei will be identified using (ΔE, E) technique up to Oxygen isotopes, resulting in the characterisation of the fissioning system. The high angular granularity of the detector will allow the reconstruction of the reaction kinematics, thus allowing the reconstruction of the Excitation energy of the fissioning system. An experiment using ^{238}U beam at 6 A MeV impinging on a 100 µm thick ^{12}C target is schedule in June.Thanks to this new detector, isotopic fission yields with high statistics per energy bin of about 1 MeV in excitation energy from 6 up to 20 MeV is expected. In this poster, the different features of this new detection system will be presented. In addition, preliminary results from the experiment scheduled in June will be presented.

Shell evolution / 34

New results from in-beam and decay spectroscopy in the region around doubly-magic 132Sn performed at the Radioactive Isotope Beam Facility

Auteur: Andrea Jungclaus[1]

[1] *IEM-CSIC*

Auteur correspondant andrea.jungclaus@csic.es

In the last decade, a considerable progress in the understanding of the structure of nuclei in the vicinity of 132Sn, the heaviest doubly-magic nucleus far-off stability accessible for experimental studies, was achieved. The vast amount of results obtained in several experimental campaigns performed at the Radioactive Isotope Beam Facility (RIBF) in Japan, in combination with state-of-the-art theoretical investigations, contributed in a significant way to this progress. In the present contribution, we will discuss unpublished results from several different experiments. We will start with new (and maybe last?) results from an experiment which was dedicated to decay spectroscopy in the 132Sn region and performed during the EURICA campaign in 2014. This experiment already delivered a lot of very valuable information giving rise to the publication of numerous articles over the last years. Some examples are the first observation of the decay of the isomeric 6+ states in 136,138Sn or the identification of the p3/2 proton single-hole state in131In. Regarding in-beam g-ray spectroscopy, exciting new results from various experiments performed with the DALI2+ spectrometer consisting of NaI scintillator detectors as well as with the HiCARI array, which is based on both segmented and unsegmented Ge detectors, will be discussed. The talk will close with a glance at the exciting future perspectives in the region around 132Sn.

Beta decay / 35

Technological developments for the NUMEN experiment

Auteurs: Daniela Calvo[1]; Diego Sartirana[2]

Co-auteurs: Clementina Agodi [3]; Francesco Cappuzzello [4]; Diana Carbone [3]; Manuela Cavallaro [3]; Carlo De Benedictis [5]; Carlo Ferraresi [5]

[1] *INFN-Sezione di Torino (IT)*

[2] *INFN - Sezione di Torino (IT)*

[3] *INFN - LNS, Catania (IT)*

[4] *Universita' di Catania - Dipartimento di Fisica e Astronomia and INFN - LNS, Catania (IT)*

[5] *DIMEAS, Politecnico di Torino and INFN - Sezione di Torino (IT)*

Auteurs correspondants: manuela.cavallaro@lns.infn.it, agodi@lns.infn.it, carlo.debenedictis@polito.it, diego.sartirana@to.infn.it, daniela.calvo@to.infn.it, francesco.cappuzzello@lns.infn.it, carboned@lns.infn.it, carlo.ferraresi@polito.it

NUMEN proposes to measure the absolute cross section of Double Charge Exchange reactions in nuclei of interest for the $0\nu\beta\beta$ decay since the two processes present important similarities even if they are mediated by different interactions. The existing large acceptance spectrometer MAGNEX has been used for pilot runs with ^{20}Ne and ^{18}O beams provided from the existing cyclotron at INFN-LNS. Nevertheless the tiny values of the DCE cross sections to measure and the upper limit of the existing ion beam intensity pushed towards a refurbishment of the superconducting cyclotron with a beam intensity up to 10^{13} ions/s and a ion energy range of 15-60 MeV/u.
Since this corresponds to a beam power on target about three order of magnitude larger than in present conditions, the upgrade of MAGNEX became mandatory [1]. A new requirement is also to transport the non-interacting beam ions through MAGNEX up to the beam dump.
Technological developments mainly involve the scattering chamber with the target inside and the Focal Plane Detectors (FPD). Indeed a new cooling technique is applied to the target to dissipate the large amount of heat generated from the beam interaction. It is based on Highly Oriented Pyrolitic Graphite which acts as substrate and backing for the isotopes and drain the heat to a cryo-cooler. The ejectiles are utmost emitted in the forward direction, they enter in the magnetic spectrometer to be detected in the FPD. The expected high rate suggested a time projection chamber with electron amplification based on three THGEM layers for ion tracking. A PID wall based on SiC and CsI (Tl) telescopes provide the measurements of the energy loss of ions and their residual energy respectively. An additional γ-ray spectrometer based on 110 $LaBr_3$(Ce) detectors will be installed around the spherical scattering chamber, the detectors will be installed as quarters and octants sectors , their handling is obtained with automatic systems. The design of the integration is now in the final phase. However, the integration of all these components also offers challenging aspects. An automatic manipulator to handle remotely the target is now integrated to the scattering chamber and under test at INFN-Torino. The setup includes also the cryogenic system and specific tests heating the target are underway.

[1] Finocchiaro et al. For the NUMEN Collaboration, The NUMEN heavy ion multidetector for a complementary approach to the neutrinoless double beta decay, 2020, Universe 6 (9) 129

Fundamental interactions and symmetries / 36

MORA, First Data Analysis

Auteur: Luis Miguel Motilla Martinez[1]

[1] *University of Caen, GANIL, University of Jyvaskyla*

Auteur correspondant luis-miguel.motilla-martinez@unicaen.fr

Around us we see an universe filled with galaxies, stars and planets like ours. But when we look back to the Big Bang and the processes that created the matter in it, at first we observe that there should have been created the same amount of matter and antimatter, thus the universe would be empty or different than it is. Sakharov proposed several mechanisms to explain the matter-antimatter asymmetry, one of them being the violation of the CP symmetry.

In the MORA experiment, we aim to measure the D correlation, which is non zero for violation of T symmetry in polarized nuclei, thus it can be related to CPV. For this we use a detector setup made of MCP's, Phoswiches and Si detectors, to measure coincidences between beta emissions and recoil ions, product of the beta decay of trapped Mg23 ions.

Here I will present an introduction to D correlation, how we acquired the previous data in Jyvaskyla in November 2022, how we analyzed it and the results we got concerning the calibration of detectors and polarization measurement.

Applications and Interdisciplinary physics / 37

First Astatine-211 production at SPIRAL-2: contaminants cross-section measurements

Auteur: Saba Ansari-Chauveau[1]

Co-auteurs: Gilles De France [1]; Anne-Marie Frelin [1]; Arnaud Guertin [2]; Ferid Haddad [3]; Xavier Ledoux [1]; Jaromír Mrázek [4]; Eva Šimečková [4]

[1] *GANIL, CEA/DSM-CNRS/IN2P3, Caen, France.*

[2] *SUBATECH, Universite de Nantes, Ecole des Mines de Nantes, Nantes Cedex, France.*

[3] *SUBATECH, Universite de Nantes, Ecole des Mines de Nantes, Nantes Cedex, France. & GIP ARRONAX, Saint-Herblain, France*

[4] *NPI, Nuclear Physics Institute of CAS, 25068 Rez, Czech Republic*

Auteur correspondant ansari-chauveau@ganil.fr

Targeted Alpha Therapy (TAT) offers a promising approach to treat cancer, particularly micrometastases, by utilizing the short range of alpha particles and their high linear energy transfer. Astatine-211, which belongs to the halogen family also shares chemical properties with Iodine, a radioisotope commonly used for imaging and also widely used to treat thyroid cancer. This similarity enables the use of Iodine as an analogue for biodistribution and dosimetry studies while using ^{211}At for treatment. For these reasons, the production of ^{211}At and the characterization of the contaminants must be studied and optimized.

In this study, we used an alpha beam at SPIRAL2, NFS to produce ^{211}At via the reaction ^{209}Bi(α,2n)^{211}At. The production cross-section of ^{211}At increases with increasing alpha energy up to 31 MeV. However, caution must be exercised as ^{210}At production also occurs via the ^{209}Bi(α,3n)^{210}At reaction above 28.6 MeV. ^{210}At decays to ^{210}Po, an alpha-emitting radionuclide with a half-life of 138.3 days and is highly toxic, if released in tissues.

We irradiated ^{209}Bi target at various alpha beam energies between 28 to 31 MeV to measure ^{210,211}At cross-sections and to determine the ^{210}At/^{211}At ratio. We employed gamma-ray spectroscopy using germanium detectors to evaluate the respective contribution of ^{210,211}At. The incident particle flux was monitored using an instrumented Faraday cup. This flux measurement combined with the number of detected γ-rays allowed to determine the production cross-sections of ^{210,211}At as a function of energy and the results are in good agreement with the literature values. We have also used well-known cross-sections of alpha on Cu from literature to cross-check and improve the accuracy of our flux measurements.

Astatine-211 is a promising radionuclide for TAT and needs careful monitoring of unwanted radionuclides. This study represents the first step in evaluating the cross-section to optimize the alpha beam energy and maximize ^{211}At production while maintaining an acceptable level of ^{210}At contamination. The next step will be ^{211}At production with a high power target for interdisciplinary studies.
This study was financially supported by the REPARE ANR project (Projet-ANR-19-CE31-0013).

Beta decay / **38**

Status of the SPIRAL2-DESIR project

Auteur: Jean-Charles THOMAS[1]

Co-auteurs: Bertram Blank [2]; Franck Varenne [3]

[1] *Grand Accélérateur National d'Ions Lourds*

[2] *CEN Bordeaux-Grradignan*

[3] *GANIL*

Auteurs correspondants: varenne@ganil.fr, blank@cenbg.in2p3.fr, thomasjc@ganil.fr

The DESIR low-energy beam facility is dedicated to nuclear physics, astrophysics, and fundamental interaction studies using exotic nuclei provided by the SPIRAL1 and S3 production sites of GANIL-SPIRAL2. The commissioning of beam preparation devices is ongoing at LP2iB, where a high-resolution mass-separator (HRS-1P) and a double Penning trap (PIPERADE) coupled to a RFQ cooler and buncher (GPIB) are being tested offline. The refurbishment of a high-acceptance RFQ cooler (RFP-1P) will start soon at LPC Caen. Experimental setups are being tested online (MORA@Jyväskylä) or will be soon commissioned offline (MLLTrap@IJCLab). On the infrastructure side, the safety authorization for the construction of the facility has been granted in spring 2023, and the ongoing Public Enquiry (April-May 2023) should allow the Construction Permit to be obtained before the summer. The final delivery of the DESIR buildings is expected by 2025, as well as the installation of the transport beam lines and associated utilities, that should allow to start the operation of the facility by 2026-2027.

Fission / **39**

Energy Dependence of Prompt Fission Neutron Multiplicity in the Reaction

Auteur: Paola Marini[1]

Co-auteurs: J. Taieb ; D. Neudecker ; G. Bélier ; A. Chatillon ; D. Etasse ; B. Laurent ; P. Morfouace ; B. Morillon ; M. Devlin ; J. A. Gomez ; R. C. Haight ; K. J. Kelly ; J. M. O'Donnell

[1] *CENBG/CNRS*

Auteur correspondant marini@cenbg.in2p3.fr

Prompt neutron emission is a challenge in nuclear fission research. Accurate values of the number of prompt fission neutrons emitted in fission reaction and their kinetic energy distributions are essential for fundamental and applied nuclear physics. Indeed, they provide
valuable information on the amount of excitation energy of the heated fissioning system transferred to the primary fragments. Moreover, these data, for the fissile 235 U and 239 Pu isotopes and the fertile 238 U nuclide, are vital inputs to calculate next-generation nuclear reactor
neutronics.
Measuring them to high precision for radioactive fissioning nuclides remains, however, an experimental challenge. We present here a recent and novel measurement of the average prompt-neutron multiplicity from the 239 Pu (n,f) reaction as a function of the incident-neutron
energy, over the range 1-700 MeV. The experiment was carried out at the Los Alamos Neutron Science Center of the Los Alamos National Laboratory. An innovative setup, coupling the Chi-nu liquid scintillator array to a newly developed, high-efficiency, fast fission chamber was used.
The combined setup, the double time-of-flight technique and the high statistics collected allowed to minimize and correct for the main sources of bias and thus achieve unprecedented precision.
Corrections needed to account for neutron angular and energy distributions, as well as detector dead-time and beam characteristics will be discussed in details.
Our data were compared to the most recent ENDF/B-VIII.0 and JEFF3.3 nuclear data evaluations. We will show that, at low energies, our data validate for the first time the ENDF/B-VIII.0 evaluation with an independent measurement and reduce the evaluated uncertainty by up
to 60%. This work opens up the possibility of precisely measuring prompt fission neutron multiplicities on highly radioactive nuclei relevant for an essential component of energy production

Heavy and Superheavy Elements / 40

Isthmus connecting mainland and island of stability of superheavy nuclei

Auteur: Michal Kowal[1]

Co-auteurs: N. V. Antonenko [2]; G. G. Adamian [2]; J. Hong [3]; P. Jachimowicz [4]

[1] *NCBJ*

[2] *Joint Institute for Nuclear Research, Dubna 141980, Russia*

[3] *Department of Physics and Institute of Physics and Applied Physics, Yonsei University, Seoul 03722, Korea*

[4] *Institute of Physics, University of Zielona Góra, Szafrana 4a, 65516 Zielona G\'{o}ra, Poland*

Auteur correspondant m.kowal@ncbj.gov.pl

The excitation functions for producing isotopes of super-heavy nuclei with charge numbers 108-116 are computed and compared to experimental data for ^{48}Ca and Ra/actinide-based complete fusion reactions.
The estimated production cross sections suggest that the Ds nucleus marks the boundary between the island of stability of super-heavy nuclei and the mainland, which contains a relatively large number of neutrons [1].
Comparing the calculated production cross-section of the Cn isotope in the Ca+U hot fusion reaction with the experimental data from the Zn+Pb cold fusion reaction, it is evident that the fusion probability correlates strongly with asymmetry in the entrance reaction channel.
This correlation suggests the possibility of bridging the gap between isotopes of super-heavy nuclei synthesized in opposite (cold and hot) reaction scenarios [2].

REFERENCES

[1] J. Hong, G. G. Adamian, N.V. Antonenko, M. Kowal, P. Jachimowicz,
Physical Review C bf 106 (1), 014614 (2022).

[2] J. Hong, G.G. Adamian, N.V. Antonenko, M. Kowal, P. Jachimowicz,
The European Physical Journal A 58 (9), 180 (2022).

Spectroscopy of heavy and superheavy elements / 41

The LRC approach to unveiling the electronic structure of heavy and superheavy cations

Auteur: Mustapha Laatiaoui[1]

Co-auteurs: EunKang Kim [1]; Biswajit Jana [1]; Michael Block [1]; Harry Ramanantoanina [1]; Sebastian Raeder [2]; Elisabeth Rickert [1]; Elisa Romero Romero [1]

[1] *JGU*

[2] *GSI*

Auteur correspondant mlaatiao@uni-mainz.de

Optical spectroscopy of superheavy elements is an experimental challenge. The production yields of the elements are about one atom per second or even less, the half-lives are extremely short, and the atomic structure is uncharted experimental territory. Conventional spectroscopy techniques based on fluorescence detection are no longer suitable because they lack the sensitivity required to study superheavy elements. Resonance ionization spectroscopy has proven sensitive enough to study the atomic structure of the element nobelium (No, element number 102) [1] and is now being continuously developed to probe the next heavier element, lawrencium (Lr, element number 103).

Recently proposed laser resonance chromatography (LRC) [2] could remedy this situation by providing sufficient sensitivity for the study of superheavy ions and overcoming the difficulties associated with other methods. The novel method combines the element selectivity and spectral precision of laser spectroscopy with the cutting-edge technology of ion mobility spectrometry. Its successful application in the realm of superheavy elements would not only improve our understanding of the existence and functioning of such synthetic and exotic atoms, but also provide valuable data for astronomers searching for possible production sites of such elements in the universe.
In my talk, I will introduce the LRC technique and setup and show initial results from inauguration experiments before presenting prospects for the spectroscopy of Lr+ cations.

This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

References:
[1] M. Laatiaoui et al., Nature 538 (2016) 495.
[2] M. Laatiaoui et al., PRL 125 (2020) 023002.

Heavy and Superheavy Elements / 42

Fusion and competitive fission modes in the cold synthesis of super-heavy nuclei

Auteur: Aleksander Augustyn[1]

Co-auteurs: Michał Kowal [1]; Tomasz Cap [1]

[1] *National Centre for Nuclear Research, Poland (NCBJ)*

Auteurs correspondants: aleksander.augustyn@ncbj.gov.pl, tomasz.cap@ncbj.gov.pl, michal.kowal@ncbj.gov.pl

One of the long-standing topics in nuclear physics is the competition between the symmetric and asymmetric modes of quasi-fission in collisions of heavy and very heavy nuclear systems. The separation of these modes from the excited compound nucleus fission is quite difficult experimentally. Theoretical calculations may give valuable insight into ascertaining contributions from these various processes. And may be used to evaluate fusion probabilities for the synthesis of super-heavy elements.

In this talk, a new method for predicting quasi-fission and fusion-fission yields will be presented. The approach uses a random walk algorithm, in which the shape evolution is governed by the density of states above the multidimensional potential energy surface (PES). The PESs were calculated within the latest version of the Warsaw macroscopic-microscopic model [1], with rotational energy taken into account.

Three cold fusion reactions will be discussed in detail: ^{208}Pb+^{48}Ca, ^{208}Pb+^{50}Ti and ^{208}Pb+^{54}Cr. The influence of angular momentum and excitation energy on ratios of symmetric and asymmetric divisions will be demonstrated. The absorbing nature of the second minimum, leading to a very symmetric mode, will also be shown.

[1] P. Jachimowicz, M. Kowal, and J. Skalski, At. Data. Nucl. Data. Tables. 138, 101393 (2021).

Poster session - with cocktail and buffet / **43**

Study of exotic nuclei interesting for applied and fundamental nuclear physics with Total Absorption Gamma Spectroscopy (TAGS)

Auteur: Julien Pépin[1]

[1] *IFIC-Valencia, Spain and SUBATECH-Nantes, France (co-supervised)*

Auteur correspondant jpepin@subatech.in2p3.fr

Study of exotic nuclei interesting for applied and fundamental nuclear physics with Total Absorption Gamma Spectroscopy (TAGS)

---

*J.Pépin[1) 2)] for the IGISOL I241 collaboration
1) IFIC, CSIC Spain
2) SUBATECH, CNRS/IN2P3, IMT-Atlantique, Nantes Université, France

jpepin@subatech.in2p3.fr

Abstract: Beta decay of neutron rich nuclei is particularly important for many fields in fundamental and applied physics.
In nuclear reactors, the beta decay of fission products is responsible for additional power, the decay heat, and anti-neutrino emission. Decay heat has an important interest in nuclear safety since it represents 7% of the power of a reactor in operation and these decays continue after reactor shutdown. Antineutrino detection is used in fundamental neutrino physics application but it can also be used for non-proliferation purposes since the antineutrino flux reflects the reactor power and the content.
In nuclear astrophysics, the r-process is a process at the origin of the nucleo-synthesis of half of the nuclei heavier than iron. It takes place in hot environments (T~10 9 K) and highly neutron-dense environment. This process is based on the competition between neutron capture (n,γ), photo-dissociation (γ,n) and beta decay reactions. A precise knowledge of the properties of beta decay can constrain the theoretical models used to understand this nucleo-synthesis process.
Some of the nuclei involved in these two fields of nuclear physics are affected by the pandemonium effect: due to the low efficiency f germanium detectors at high gamma energies, some gamma-rays and corresponding high energy levels can be missed in the decay data leading to a distortion of the beta decay feeding.
New measurements of a series of nuclei relevant for the above mentioned opics have been performed

at the IGISOL facility (Jyväskylä, Finland) in September 2022, using Total Absorption Gamma Spectroscopy (TAGS) technique. TAGS is complementary to high resolution gamma-ray spectroscopy and employs a calorimeter to measure the total gamma intensity de-exciting each level of the daughter nucleus providing a direct measurement of the beta feeding. The experimental device used consists of the Rocinante detector, a detector made of 12 barium fluorine (BaF2) crystals and a beta detector acting as a trigger, and a cerium bromine (CeBr3) crystal.
At this conference, the experimental setup will be presented as well as preliminary results of this experiment, especially for nuclei of interest for the r-process such as 84,85As.

Poster session - with cocktail and buffet / 44

Fission Studies with VAMOS and FALSTAFF Spectrometers.

Auteur: Indu Jangid[1]

[1] *GANIL*

Auteur correspondant indu.jangid@ganil.fr

The experimental investigation of fission was focused on neutron-induced fission, in which flux of neutrons is sent to a stable heavy target where the fission process takes place. In the direct kinematics, because of the fission fragments' low velocity, only the full identification of mass distribution of the fragments was possible. In 1994, K.-H. Schmidt, et al.[1] introduced a new technique, inverse kinematics, in which a heavy nuclei beam will be sent to a light target. In this manner, the fission process takes place in flight. In VAMOS (VAriable MOde Spectrometer) at GANIL, the inverse kinematics technique is used to access the nuclear charge information and high-resolution fragment mass. With the VAMOS magnetic spectrometer, only one fission fragment can be identified at a time. In experiment e826 (which took place in March 2022), the FALSTAFF (Four Arm cLover for the Study of Actinide Fission Fragments) spectrometer had used to detect the second fission fragment. The FALSTAFF spectrometer is a new setup based on low-pressure gaseous detectors and offers a new opportunity to identify fission fragments in terms of mass, nuclear charge and velocity vector. With the help of both spectrometers, both fission fragments can be measured simultaneously. In this experiment, a 238U beam was used as a projectile impinging into an Al and a Be target. This poster will present the analysis performed in the VAMOS and FALSTAFF spectrometers in order to determine the full identification of both fission fragments and the resolutions achieved in both cases.

[1] K.-H. Schmidt et al. "Low-energy fission studies of neutron-deficient projectile fragments of 238 U". Phys. Lett. B, 325:313, 1994.

Heavy and Superheavy Elements / 45

Theoretical estimation and reaction mechanism of synthesizing neutron rich nuclei in superheavy mass region

Auteur: Yoshihiro Aritomo[1]

[1] *Kindai University*

Auteur correspondant aritomo@ele.kindai.ac.jp

Research on neutron-rich nuclei in the heavy and superheavy mass region is gaining importance in the fields as the synthesis of new elements [1,2,3], the r-process and multi-nucleon transfer reactions. Furthermore, the use of neutron-rich nuclei is indispensable for reaching the Island of Stability [4] that are predicted to exist in the superheavy element region, and the evaluation of the generation

probability of neutron-rich nuclei is necessary.
To success the synthesis of superheavy elements, we must clarify the fusion-fission mechanism, which is included a role of the nuclear structure of colliding nuclei and the deformation of them in the fusion process. We calculate the probability of forming a compound nucleus using Langevin equation as the dynamical model [5]. We discuss the possibility to synthesize new elements Z ≥ 119. Moreover, to approach to the Island of Stability, we propose the new way using the shell effect during the dynamical process.
To estimate the evaporation residue cross section, we must calculate the survival probability of the excited compound nuclei, in the decay process. At present, the statistical model is used as standard to evaluate the survival probability [6]. When dealing with very small probabilities, and because of the computation time, the use of the statistical mode is suitable.
However, in the neutron-rich nuclei in the superheavy mass region, we find that the inconvenience appears in the calculation of the statistical model code. In the code, we use the mass table by P. Moller [7], and there are cases where the ground state shell-corrected energies in these regions are close to zero or even positive. In the statistical model, the finite height of the fission barrier and the ability to define the saddle point are the basis of the theory construction. In this situation, it may not be applicable to nuclei without a fission barrier. In this research, we discuss based on these analyses, and discuss the introduction of a dynamical model and the modification of the mass table as solutions to the problem.

References
[1] Yu.Ts. Oganessian et.al., Nature 400, 242 (1999); Phys. Rev. Lett. 83, 3154 (1999).
[2] S. Hofmann et.al., Eur. Phys. J. A 31, 251 (2007); L. Stavsetr et.al., Phys. Rev. Lett.103, 132502 (2009); P.A. Ellison et.al., Phys. Rev. Lett. 105, 182701 (2010); Ch.E. Dullmann et.al., Phys. Rev. Lett. 104, 252710 (2010).
[3] K. Morita et.al., J. Phys. Soc. Jpn.73, 2593 (2004); J. Phys. Soc. Jpn. 81, 103201 (2012).
[4] W.D. Myers and W.J. Swiatecki, Nucl. Phys. 81, 1 (1966); A. Sobiczewski, F.A. Gareev, and B.N.Kalinkin, Phys. Lett. 22, 500 (1966).
[5] Y. Aritomo, M. Ohta, Nucl. Phys. A744, 3-14 (2004).
[6] M. Ohta, Proc. of Fusion Dynamics at the Extremes,110 (2001)
[7] P. Moller, J.R. Nix, W.D. Myers, W.J. Swiatecki, Atomic Data and Nuclear Data Tables 59 185-381(1995)

Poster session - with cocktail and buffet / 46

Study of (n,α) reactions of interest for nuclear energy

Auteur: Aurélien Chevalier[1]

Co-auteurs: Roland Beyer [2]; Olivier Bouland [3]; Arnd Junghans [2]; François-René Lecolley [4]; Jean-Luc Lecouey [5]; Xavier Ledoux [6]; Gregory Lehaut [7]; Loredana Manduci [8]; Nathalier Marie [1]; Olivier Sérot [3]

[1] *LPC Caen (ENSICAEN-CNRS/IN2P3-UCN)*

[2] *HZDR*

[3] *CEA/DES/IRESNE Cadarache*

[4] *LPC Caen (ENSICAEN - CNRS/IN2P3 - UCN)*

[5] *ENSICAEN/LPC Caen*

[6] *GANIL, CEA/DSM-CNRS/IN2P3, Caen, France.*

[7] *LPC Caen, CNRS/IN2P3*

[8] *EAMEA*

Auteurs correspondants: arnd.junghans@hzdr.de, manduci@lpccaen.in2p3.fr, fr.lecolley@lpccaen.in2p3.fr, olivier.bouland@cea.fr, marie@lpccaen.in2p3.fr, chevalier@lpccaen.in2p3.fr, roland.beyer@hzdr.de, lecouey@lpccaen.in2p3.fr, olivier.serot@cea.fr, lehaut@lpccaen.in2p3.fr

In reactors, oxygen is present in abundance in the form of water, and/or in the form of oxide in the fuel used (in the case of Pressurised Water Reactors and Fast Reactors). These oxygen nuclei are responsible for 25% of helium formation in nuclear reactors due to the reaction 16O(n,α)13C. However,

this reaction still shows significant discrepancies between experimental and evaluated data that can go up to 30% for some energy ranges. This is why the NEA (Nuclear Energy Agency) has issued several requests included in the HPRL (High Priority Request List)[1] and confirmed by the WPEC 40 (CIELO, 2014)[2] for this reaction in the incident neutron energy range from threshold energy to 20 MeV. Sensitivity analyses conducted by the WPEC 26 (2008)[3] showed that these discrepancies induced significant uncertainties on some nuclear reactors parameters such as helium production (± 7%) and keff (± 100 pcm)[3].
Regarding other (n,α) reactions in light target nuclei, the 19F(n,α)16N cross section is of great interest for the development of the next generation IV reactors that could potentially use molten salt mixtures. Significant differences (up to a factor of 3) have been observed for this nucleus with regards to the (n,α) channel.
In view of improving our knowledge on the (n,α) reactions, the GrACE group (Groupe Aval du Cycle Electronucléaire) of the LPC Caen has developed a new detector named SCALP[4] (Scintillating ionization Chamber for ALPha particle detection in neutron induced reactions). The first two experiments with this new detector carried out at the new NFS facility of GANIL in Caen and at the nELBE facility of HZDR in Dresden were successful.
During this conference, the operational principle of the SCALP detector will be presented and discussed, as well as the experiments that have been conducted using it. Furthermore, insights into the data acquired during this experiment, as well as the ongoing processing and multi-channel analysis of it, will be provided.
[1] E. Dupont et al., HPRL - International cooperation to identify and monitor priority nuclear data needs for nuclear applications, https://arxiv.org/abs/2004.06405
[2] M. B. Chadwick et al., The CIELO collaboration, Nuclear Data Sheets 118 (2014) and M.B Chadwick et al. The CIELO collaboration : Progress, EPJ Web of Conferences 146, 02001 (2017)
[3] M. Salvatores and R. Jacqmin, Uncertainty and Target Accuracy assessment for innovative systems using recent covariance data evaluations (International Evaluation Cooperation, NEA/WPEC-26, 2008) [4] G. Lehaut et al., Nucl. Instrum. Meth. A 797 (2015), 57-63

Poster session - with cocktail and buffet / 47

The synthesis of heavy and superheavy nuclei from the Z = 100 - 106 region in the pxn and axn channels

Auteurs: Tomasz Cap[1]; Michał Kowal[2]; Krystyna Siwek-Wilczyńska[3]; Aleksander Augustyn[2]

[1] *National Centre for Nuclear Research*

[2] *National Centre for Nuclear Research, Poland (NCBJ)*

[3] *Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland*

Auteurs correspondants: aleksander.augustyn@ncbj.gov.pl, michal.kowal@ncbj.gov.pl, siwek@fuw.edu.pl, tomasz.cap@ncbj.gov.pl

The fusion probability for the production of superheavy nuclei (SHN) in cold fusion reactions (1n channel) on ^{208}Pb and ^{209}Bi targets drops by approximately five orders of magnitude, from 10^{-1} to 10^{-6}, with the change of projectile atomic number from 20 (Ca) to 30 (Zn). Recent experimental results for reactions induced on ^{208}Pb target by ^{48}Ca, ^{50}Ti, and ^{54}Cr projectiles show that the probability of compound nucleus formation at energies above the interaction barrier (B_0) can be significantly higher, up to two orders of magnitude, than its value at the peak of the 1n channel and weakly depends on the bombarding energy. As a result, the fusion cross section saturates at higher excitation energies, opening the pathway not only to xn channels but also channels with the emission of charged particles. The channels involving the emission of protons or alpha particles have typically been disregarded in calculations. However, recently revised experimental data indicates that the proton channel could be populated in the ^{50}Ti + ^{209}Bi reaction.

In this talk, we will explore the potential of utilizing the pxn and axn channels for the successful synthesis of heavy and superheavy nuclei in the Z = 100 - 106 region. We will focus on identifying the reactions that might receive increased attention in the future with the availability of more intense beam currents.

The culations were performed with the latest version of the Fusion-by-Diffusion model [1] assuming that the evaporation residue cross section can be described as a product of three factors: the capture cross section, the fusion probability, and the survival probability. The merging of the colliding projectile and target nuclei was described as a diffusion process. The survival probabilities were obtained using new nuclear data tables for SHN [2], providing a consistent set of masses, deformations, fission barriers, and shell corrections.

REFERENCES

[1] T. Cap, M. Kowal, and K. Siwek-Wilczy\'nska, Eur. Phys. J. A 58, 231 (2022)

[2] P. Jachimowicz, M. Kowal, and J. Skalski, At. Data. Nucl. Data. Tables. 138, 101393 (2021)

Heavy ion collisions / 48

Entrance channel effects in heavy-ion collisions within three-dimensional full dissipative dynamics

Auteurs: Yannen Jaganathen[1]; Michal Kowal[2]

Co-auteur: Krzysztof Pomorski [3]

[1] *National Centre for Nuclear Research, Pasteur 7, Warsaw, Poland*

[2] *NCBJ*

[3] *Maria Curie Sklodowska University*

Auteurs correspondants: m.kowal@ncbj.gov.pl, yannen.jaganathen@ncbj.gov.pl, pomorski@kft.umcs.lublin.pl

We have thoroughly investigated the influence of entrance channel effects on the spin distribution and angular momentum in heavy ion collisions, employing three-dimensional dissipative dynamics. The microscopically derived Langevin equations were numerically solved using the distance, neck, asymmetry and the three angular macroscopic variables, which allow for an adequate description of the fusion process, as it was done in Ref. [1]. Our analysis showed that, unlike what was done in Ref.~[1], a special handling of the boundary conditions is necessary to describe the correct asymptotic shape of the spin distributions. Moreover, by considering the full range of the asymmetry variable, rather than freezing it, we provide a comprehensive understanding of its impact on dissipative dynamics.

Different systems, involving various asymmetry entrance channels were studied using a Yukawa-plus-exponential folding + Coulomb potential, and we will present results for the following heavy-ion reactions: ^{64}Ni+^{92,96}Zr, and the asymmetric systems ^{16}O+^{152}Sm and ^{48}Ca,^{50}Ti,^{54}Cr on ^{208}Pb.

Our analysis considers factors such as friction, mass tensor parameters, diffusion strength, potential energy, and stochasticity in a complete three-dimensional picture. We observe significant variations in the spin distribution by considering various target-projectile combinations with the same excitation energy and compound system. This underscores the crucial role of entrance channel asymmetry in shaping the spin distribution, as it strongly influences the hindrance mechanism and in turn, plays a vital role as a weight for subsequent processes such as splitting.

This investigation enhances our understanding of the intricate relationship between entrance channel effects and the resulting spin distribution, contributing to a broader understanding of dissipative dynamics in heavy ion collisions. Our ultimate aim is the inclusion of shell effects in the potential surface to give a fully microscopic-macroscopic description of the dissipative process.

Beta decay / 49

Developments of the HRS, GPIB and PIPERADE devices for the DESIR facility

Auteur: Mathieu FLAYOL[1]

Co-auteurs: Philippe Alfaurt [1]; Pauline Ascher [2]; Dinko Atanasov [3]; Bertram Blank [4]; Laurent Daudin [5]; Antoine de Roubin [2]; Mathias GERBAUX [6]; Stephane Grevy [2]; Marjut Hukkanen [7]; Audric Husson ; Benoit Lachacinsky [1]

[1] *CNRS-LP2IB-CENBG*

[2] *CENBG*

[3] *LP2iB*

[4] *CEN Bordeaux-Grradignan*

[5] *CNRS/IN2P3/CENBG*

[6] *CENBG - Université de Bordeaux*

[7] *University of Jyväskylä and CENBG*

Auteurs correspondants: atanasov@lp2ib.in2p3.fr, blank@cenbg.in2p3.fr, daudin@cenbg.in2p3.fr, ascher@cenbg.in2p3.fr, grevy@cenbg.in2p3.fr, gerbaux@cenbg.in2p3.fr, deroubin@cenbg.in2p3.fr, marjut.h.hukkanen@student.jyu.fi, flayol@cenbg.in2p3.fr

The DESIR facility at GANIL will receive neutron-deficient ion beams produced by fusion evaporation at S3 (Super Separator Spectrometer) and exotic light nuclei produced by fragmentation at SPIRAL1. DESIR*is an experimental hall dedicated to the study of nuclear structure, astrophysics and weak interaction using beta decay spectroscopy, laser spectroscopy and trap-based experiments at low energy (30-60 keV). Those experiments require highly pure samples of nuclei at odds with the non-selectivity of all the production methods. Therefore, in order to deliver large and very pure samples of exotic nuclei to the different experiments, the LP2iB is currently developing three new devices; a High resolution mass separator (HRS), a radiofrequency quadrupole cooler buncher[1] and a double Penning trap mass spectrometer PIPERADE***[2] that will be placed at the entrance of the DESIR facility. We aim at extracting ion bunches from the GPIB with the best compromise between energy and time dispersion to fit the needs of the downstream experiment using the beam. For now, these bunches are directly sent to PIPERADE. With this device we will be able to perform mass measurements and/or purification at the isomerical level. Indeed Penning traps are designed to reach resolving power of the order of 10^5 to 10^7 depending on the separation techniques. Whether PIPERADE is used to purify or to measure masses, we will have to deal with short-lived nuclei. And since theses techniques are time consuming, one of the challenges is to develop short operating cycles while keeping a high mass resolving power to extract the nuclides of interest from the large amount of isobaric and/or isomeric contaminants. The HRS, the GPIB and PIPERADE are now fully assembled at LP2iB and currently under commissioning before being moved to GANIL when the DESIR hall will be accessible. The latest achievements and the first mass measurements will be presented.

[1] M. Gerbaux, P. Ascher, A. Husson, A. de Roubin, P. Alfaurt, M. Aouadi, B. Blank, L. Daudin, S. E. Abbeir and M. Flayol, et al.
"The General Purpose Ion Buncher: A radiofrequency quadrupole cooler-buncher for DESIR at SPIRAL2",
Nucl. Instrum. Meth. A 1046 (2023), 167631
doi:10.1016/j.nima.2022.167631

[2] P. Ascher, L. Daudin, M. Flayol, M. Gerbaux, S. Grévy, et al.. PIPERADE: A double Penning trap for mass separation and mass spectrometry at DESIR/SPIRAL2. Nucl.Instrum.Meth.A, 2021, 1019, pp.165857. ⟨10.1016/j.nima.2021.165857⟩.

*Désintégration, Excitation et Stockage d'Ions Radioactifs i.e. Decay, Excitation and Storage of Radioactive IonsGPIB –General Purpose Ion Buncher*** PIeges de PEnning pour les RAdionucléides à DEsir i.e. Penning traps for radionuclides at DESIR

Fundamental interactions and symmetries / 50

Is there a dark decay of neutrons in 6He ?

Auteurs: Marius Lejoubioux[1]; Hervé Savajols[2]

[1] *GANIL*

[2] *GANIL/CNRS*

Auteurs correspondants: marius.lejoubioux@ganil.fr, herve.savajols@ganil.fr

The neutron lifetime discrepancy between beam and bottle experiments of 4σ could be interpreted as a possible sign of the neutron decaying into dark particles [1]. If such a decay exists, it could also occur in unstable nuclei with sufficiently low neutron binding energy, a quasi-free neutron decay into a dark matter particle χ; as is the case of 6He with S2n = 975.45keV < mn −mχ [2]. This quasi-free neutron dark decay would be as followed: 6He ⟶4He+n+χ which is the only way to have the emission of a free neutron in the decay of 6He. The SPIRAL1 facility at GANIL was used in June 2021 in order to produce a pure 6He1+ radioactive beam at 25keV to observe an excess of neutrons in the decay of 6He which would be a unique signature for dark matter creation. In this presentation, we report the results of this experiment to set an upper limit for this dark decay mode in 6He.

References
[1] Bartosz Fornal and Benjamin Grinstein. "Dark Matter Interpretation of the Neutron Decay Anomaly"in: Phys. Rev. Lett. 120 (19 May 2018), p. 191801. doi: 10.1103/PhysRevLett.120.191801. url: https://link.aps.org/doi/10.1103/PhysRevLett.120.191801.
[2] M. Pfützner and K. Riisager. "Examining the possibility to observe neutron dark decay in nuclei" in: Phys. Rev. C 97 (4 Apr. 2018), p. 042501. doi: 10.1103/PhysRevC.97.042501. url: https://link.aps.org/doi/10.1103/PhysRevC.97.042501.

Applications and Interdisciplinary physics / 51

Measuring ion-induced electron emission and molecular fragmentation using a Velocity Map Imaging spectrometer

Auteur: Violaine VIZCAINO[None]

Co-auteurs: Jean-Yves Chesnel [1]; Alain MERY [2]; Suvasis Swain [1]

[1] *CIMAP*

[2] *SUBATECH - Université de Nantes*

Auteur correspondant vizcaino@ganil.fr

The study of ion collision with biologically relevant molecules in the gas phase has received increasing interest in recent years in parallel with the development of ion beam therapy. Indeed, these studies help understanding the fundamental mechanisms involved at the molecular level such as fragmentation and electron emission. To study such processes, we have recently built an experimental set-up where the molecular target beam of biomolecules produced with a two-stage effusion cell crosses perpendicularly the projectile ion beam provided by the different GANIL beamlines (ARIBE, IRRSUD or SME). The charged particles (either electrons or fragment cations) emitted in the collision are extracted by a Velocity Map Imaging (VMI) spectrometer and detected with microchannel plates coupled to a phosphor screen. The electrode arrangement of the VMI spectrometer acts as an electrostatic lens focusing particles with the same initial velocity vector into the same position on the detector regardless of their initial position (within the small interaction volume). The 2D image observed on the detector is then processed using an inverse Abel transform algorithm in order to deduce the number of particles (electrons or ionic fragments) emitted as a function of their energy and their emission angle. In this presentation, recent measurements of absolute cross sections for electron emission from the nucleobases uracil and adenine upon collision with carbon ions (0.98MeV/u-C4+ and 13.7MeV/u-C5+) will be presented. Moreover, preliminary data on ion-induced fragmentation processes will be discussed along with the future improvement of the set-up.

Applications and Interdisciplinary physics / 52

Irradiation effects in nuclear materials: case study of nuclear fuels

Auteur: Frederico Garrido[1]

[1] *IJCLab*

Auteur correspondant frederico.garrido@ijclab.in2p3.fr

Nuclear materials define a class of solid of interest for the nuclear industry with the specificity of being submitted to intense irradiation fields. Nuclear fuels and transmutation matrices deserve special attention due to their location at the core of the reactor, and due to the complexity of irradiation sources to which they are subjected, leading to both physical (radiation damage, atomic and electronic displacements, structural transformations) and chemical modifications (incorporation of new elements with their own chemistry in the solid matrix fuel). Ion beams delivered by accelerator facilities are unique tools to simulate the behavior of irradiated solids due to their flexibility: the various relevant parameters can be monitored selectively (e.g., ion, energy, fluence, flux, irradiation temperature) in single or (sometimes) in dual beam conditions. In particular, swift heavy ions delivered by the GANIL facility are unvaluable probes to examine extreme irradiation condition provided by electronic stopping power, giving clues to extrapolate the fuel behavior for future nuclear reactors. Selected examples of irradiation condition for nuclear fuels and transmutation matrices and their consequences for their structural evolution upon ion bombardment will be discussed.

Applications and Interdisciplinary physics / **53**

155Tb production: a proof-of-concept method for an alternative production of medical isotope

Auteur: Charles-Olivier Bacri[1]

[1] *CSNSM*

Auteur correspondant charles-olivier.bacri@csnsm.in2p3.fr

For several years, many radionuclides (RN) are routinely used in nuclear medicine either for imaging (γ and β^+ or positron) or for therapy (α, β^-, Auger electron emitters). They are most-often administered in the form of a radiopharmaceutical, composed of the selected RN and a targeting unit (nanoparticles or biological vectors, like peptides or antibodies) responsible for the specific accumulation of the drug in the diseased tissues. Numerous efforts are still needed to create a "tool box"and expand the catalogue of clinically relevant RN.
In that context, Terbium is an emerging "theranostic" element, which offers four clinically interesting radioisotopes with complementary physical decay characteristics: ^{149}Tb ($T_{1/2}$ = 4.12 h, α therapy), ^{152}Tb ($T_{1/2}$ = 17.5 h, PET imaging), ^{155}Tb ($T_{1/2}$ = 5.32 d, SPECT imaging and Auger therapy), and ^{161}Tb ($T_{1/2}$ = 6.9 d, β^- and possibly Auger therapy). It is a so-called "theranostic"element (contraction of THERApy and diagNOSTIC), since it enables the development of a unique bioconjugate for radiolabelling prior to administration at both the diagnosis and curative stages. Both radiopharmaceuticals have then strictly identical biodistribution and pharmacokinetic properties,enabling a better adaptation of the targeted treatments, paving the way for more personalized medicine.
The major limitation today for the further use of these RNs is their economically sustainable production in sufficiently large quantities with high chemical and isotopic purities. The ongoing TTRIP project (Tools for Tb RadioIsotope Production for nuclear medicine) * aims to face two challenges related to the ^{155}Tb: to develop an alternative method for producing isotopes that are difficult to obtain using conventional methods, and to develop specific chelators for terbium that are compatible with the use of monoclonal antibodies as biological vectors.
These two aspects of our programme will be detailed, with a more specific focus on the ^{155}Tb production part. First results will be presented.
* This project is financed by the contract ANR-21-CE19-0037

Spectroscopy of heavy and superheavy elements / 56

Laser spectroscopy of fermium across the deformed N=152 shell gap

Auteur: Elisabeth Rickert[None]

Co-auteurs: Jessica Warbinek [1]; Sebastian Raeder [2]; Michael Block [3]

[1] *GSI Helmholtz Centre*

[2] *GSI Darmstadt*

[3] *GSI/HIM/JGU*

Auteurs correspondants: s.raeder@gsi.de, j.warbinek@gsi.de, erickert@students.uni-mainz.de, m.block@gsi.de

The existence and stability of heavy nuclei is a forefront topic in physics. Modern laser spectroscopy techniques provide a unique tool to study nuclear shell effects by measuring isotope shifts to infer mean-square charge radii and hence deduce nuclear size and shape. Laser spectroscopy measurements of the isotope shift of an atomic transition of the actinide element fermium (Z=100) have been recently carried out covering isotopes across the N=152 shell gap. On-line and off-line laser spectroscopy experiments with direct and indirect production schemes and offline production methods were combined and methodologically pushed forward to measure isotope shifts in fermium isotopes. Previously non-accessible isotopes, short and long-lived, were covered, enabling experiments at atom-at-a-time quantities through newly developed detection concepts. Changes in the mean-square charge radii were extracted for the longest chain of isotopes investigated in the region of the heavy actinides revealing information on the deformation around the N=152 shell gap.

Nuclei at the drip lines / 57

Overview of the MUGAST silicon array at GANIL

Auteur: Valérian Girard-Alcindor[1]

[1] *IJCLAB*

Auteur correspondant valerian.girard-alcindor@ijclab.in2p3.fr

MUGAST [1] is a state-of-the-art silicon array combining trapezoidal and square shaped double-sided silicon strip detectors (DSSD) to four MUST2 [2] telescopes. Coupled to a gamma-ray spectrometer, the excellent angular coverage and compacity of the MUGAST array make it an ideal tool for the study of transfer reactions. It is a first step toward the development of the new generation of silicon arrays using PSA for particle identification, such as the future GRIT array [3] developped by our collaboration.
In recent years, MUGAST has been widely used at GANIL. First with the AGATA gamma-ray spectrometer and the VAMOS large acceptance spectrometer for the study of ISOL beams from the SPIRAL1 facility. It is now coupled to the EXOGAM gamma-ray spectrometer and to a new zero degree detection system at the end of the LISE fragmentation beamline.
In this talk, a summary of previous results from the 2019-2021 MUGAST-VAMOS- AGATA campaign will be presented, followed by a description of the newly installed experimental setup at LISE, the opportunities it opens up and its performance.

References
[1] M. Assie et al., Nucl.Instrum.Meth.A, 1014, (2021)
[2] Y.Blumenfeld et al., Nucl.Instrum.Meth.A, 421, (1999) [3] M.Assie et al., Eur. Phys. Jour. A51, 11, (2015)

Shell evolution / **58**

Study of proton and neutron excitations along Silicon Isotopes between N=20 and N=28

Auteur: Quentin Délignac[1]

Co-auteur: Stephane Grevy [2]

[1] *LP2I Bordeaux*

[2] *CENBG*

Auteurs correspondants: grevy@cenbg.in2p3.fr, delignac@cenbg.in2p3.fr

The main subject of this study is the experimental investigation of the nuclear structure of exotic neutron-rich nuclei in the vicinity of shell closures in order to constrain the description of the nucleon-nucleon interaction, and in particular its tensor term. Previous studies have shown that a deformation region develops along the N=28 isotonic chain between the doubly magical and spherical ^{48}Ca nucleus (20 protons/28 neutrons) and the ^{42}Si nucleus which is extremely deformed in spite of its semi-magical character (14 protons/28 neutrons). It has been shown that this deformation results from neutron excitations above N=28 and proton excitations above Z=14, both made possible by the reduction of these shell closures under the effect of the tensor component of the nuclear interaction. The goal is now to follow the evolution of the deformation along the Si isotopic chain, between ^{34}Si (N=20) and ^{42}Si (N=28) by measuring for the first time and in a simultaneous way through experiments at GANIL (Grand Accelerator National d'Ions Lourds):

- The contribution of neutrons to the excitation of the 2^+ state of $^{34-36-38}$Si nuclei by inelastic proton scattering.
- The contribution of protons and neutrons to the excitation of the 2^+ state of $^{34-36-38}$Si nuclei by Coulomb excitation on a gold target.

The experiments has been set up during the 2022 campaign of LISE spectrometer (Line d'Ions Super Epluchés) at GANIL. This spectrometer allowed to produce and select ^{34}Si, ^{36}Si and ^{38}Si nuclei. In order to measure the proton and neutron contributions, the experimental setup was composed of two independent experiments on the same beamline with the same radioactive beam.

The first experiment was perfomed with ACTAR-TPC detector (ACtif TARget-Time Projection Chamber). The purpose of this experiment was to measure the inelastic scattering of ^{A}Si(p,p')^{A}Si* reactions, with $(A = 34, 36, 38)$. The analysis of this part is in progress by one of the thesis students of the ACTAR collaboration.

The second experiment was the CoulEx part (Coulomb Excitation). The goal of this experiment was to measure the effective cross section of coulomb excitations. Several types of detectors composed the CoulEx setup. The work of this thesis is mainly based on the analysis of this experiment.

Shell evolution / **59**

Cross-shell interactions at the N=28 shell closure via 47K(d,p) and 47K(d,t) with MUGAST+AGATA+VAMOS

Auteur: Charlie Paxman[1]

[1] *University of Surrey*

Auteur correspondant c.paxman@surrey.ac.uk

Shell evolution in the region around the magic numbers $N = 28$ and $Z = 20$ is of great interest in nuclear structure physics. Moving away from the doubly-magic isotope ^{48}Ca, in the neutron-rich direction there is evidence of an emergent shell gap at $N = 34$ [1], and in the proton-deficient direction, the onset of shape deformation suggests a weakening of the $N = 28$ magic number [2]. The ^{47}K(d,p)^{48}K reaction is uniquely suited to investigating this region, as the ground state configuration of ^{47}K has an exotic proton structure, with an odd proton in the $\pi(1s_{1/2})$ orbital, below a fully occupied $\pi(0d_{3/2})$ orbital [3]. As such, the selective neutron transfer reaction (d,p) will preferentially populate states in ^{48}K arising from $\pi(1s_{1/2}) \otimes \nu(fp)$ cross-shell interactions. The implications of this extend both down the proton-deficient $N = 28$ isotonic chain, where these interactions are expected to dominate the structure of the exotic, short-lived ^{44}P nucleus [4], and across the neutron-rich region, where the relative energies of the $\nu(fp)$ orbitals is the driving force behind shell evolution.

The first experimental study of states arising from the interaction between $\pi(1s_{1/2})$ and the orbitals $\nu(1p_{3/2})$, $\nu(1p_{1/2})$ and $\nu(0f_{5/2})$ has been conducted, by way of the ^{47}K(d,p) reaction in inverse kinematics. A beam of radioactive ^{47}K ions was delivered by the GANIL-SPIRAL1+ facility, with a beam energy of 7.7 MeV/nucleon. This beam was estimated to be $> 99.99\backslash\%$ pure, with a typical intensity of 5×10^5 pps, and was impinged upon a 0.3 mg/cm^2 CD_2 target. The MUGAST+AGATA+VAMOS detection setup [5] allowed for triple coincidence gating, providing a great amount of selectivity. An analysis based both on excitation and gamma-ray energy measurements has revealed a number of previously unobserved states in ^{48}K, and preliminary differential cross sections for the most strongly populated of these states will be presented. Spectroscopic factors for these states will be discussed in the context of shell model calculations, with regard to the N=28, 32 and 34 shell gaps. Additionally, results for positive and negative parity states in ^{46}K, measured simultaneously via the ^{47}K(d,t) reaction, will also be presented.

[1] D. Steppenbeck et al., Nature 502, 207 (2013).
[2] O. Sorlin and M.-G. Porquet, Prog. Part. Nucl. Phys. 61, 602 (2008).
[3] J. Papuga et al., Phys. Rev. C, 90 034321 (2014).
[4] L. Gaudefroy, Phys. Rev. C, 81, 064329 (2010).
[5] M. Assié et al., Nucl. Instrum. Methods A 1014, 165743 (2021).

Heavy ion collisions / **60**

The INDRA-FAZIA setup: an overview of the most recent results on isospin transport phenomena

Auteur: Caterina Ciampi[1]

[1] *GANIL*

Auteur correspondant ciampi@fi.infn.it

Heavy-ion collisions in the intermediate energy regime (20-100 MeV/nucleon) are a widespread tool to probe the properties of nuclear matter far from equilibrium: among other topics, they allow to investigate isospin transport phenomena, which can be interpreted in the framework of the Nuclear Equation of State (NEoS), i.e. the thermodynamic description of nuclear matter.
The INDRA-FAZIA apparatus, operating in GANIL, is particularly well suited to investigate such kind of phenomena, exploiting the best characteristics of INDRA and FAZIA: twelve FAZIA blocks cover the forward polar angles (from 1.4° to 12.6°) providing good charge and mass identification for the heavy quasi-projectile residue and for most of the reaction products, while twelve INDRA rings provide a large angular coverage (from 14° to 176°). The coupling of the two apparatuses was completed in 2019, and the first experiment was devoted to the study of isospin diffusion in ^{64,58}Ni+^{58,64}Ni at 32 and 52 MeV/nucleon.

In this talk the most recent results from the INDRA-FAZIA apparatus will be presented, focusing on its first experiment. The identification capability of the apparatus allowed us to highlight the isospin transport effects on the neutron content of light and heavy fragments belonging to the QP phase space, obtaining coherent indications of the evolution towards isospin equilibration. Moreover, the high granularity of FAZIA makes it suitable to study the isospin content of the two heavy fragments produced in the quasi-projectile breakup, which in most cases can be simultaneously detected and

mass identified. An in-depth analysis of this exit channel of semiperipheral collisions has been carried out, leading to novel results that add valuable information for a comprehensive view of the process.
The experimental results are also compared to the predictions of the antisymmetrized molecular dynamics (AMD) model, coupled with GEMINI++ as afterburner, in order to validate the event selection procedure and to inspect the dynamical features of the reactions. More specifically, the AMD calculations have been used to extract the information on the relevant timescales of the interaction process, thus helping with the interpretation of experimental observations.

Fission / 61

235U fission fragment study with Falstaff at NFS

Auteur: Diane Dore[1]

[1] *CEA/Saclay, IRFU/Service de Physique Nucléaire*

Auteur correspondant diane.dore@cea.fr

D. Doré1), D. Ramos2), E. Berthoumieux1), J.-E. Ducret2),
X. Ledoux2), P. Marini2,3), S. Oberstedt4), J. Pancin2),
M. Ballu1), P. Herran1), G. Kaur1), A. Letourneau1), T. Materna1), P. Miriot-Jaubert1),
B. Mom1), L. Thulliez1), M. Vandebrouck1), A.-M. Frelin2), P. Sharma2), I. Jangid2),
A. Cheboubbi5), O. Litaize5), O. Serot5), A. Porta6), M. Estienne6), M. Fallot6),
E. Bonnet6), J. Pépin6), L. Matthieu3), T. Kurtukian-Nieto3)

1) DPhN/Irfu, CEA/Saclay, Université Paris-Saclay, 91191 Gif-sur-Yvette, France
2) GANIL, Caen,14000, France
3) Univ. Bordeaux, CNRS, LP2I, UMR 5797, F-33170 Gradignan, France
4) European Commission, Joint Research Centre (JRC), 2440 Geel, Belgium
5) CEA, DES, IRESNE, DER, SPRC, Cadarache, 13108 St. Paul lez Durance, France
6) Laboratoire Subatech, University of Nantes, CNRS/IN2P3, Institut Mines Telecom Atlantique, 44307 Nantes, France

diane.dore@cea.fr

Abstract: Nowadays the fission process still presents a great interest from both theoretical and experimental points of view. New developments on microscopic calculations and expected improvements of nuclear reactors are among the main motivations for new experimental programs devoted to the study of nuclear fission. The FALSTAFF spectrometer aims at providing constraining data that may significantly contribute to an accurate description of the fission process. In its future two-arm configuration, the goal of the FALSTAFF program will be to determine the evolution of prompt neutron multiplicity and the fragment characteristics (mass, charge and kinetic energy) as a function of the compound nucleus excitation energy, by studying neutron-induced fission of specific actinides in the MeV range. Recently FALSTAFF in its one-arm configuration was used in an experiment dedicated to the study of 235U(n,f) at NFS (Neutrons for Science, SPIRAL2/GANIL).

The white energy spectrum of incident neutron beam provided by reactions of deuterons on a thick 9Be production target at NFS allows us to study 235U post-neutron evaporation fission fragments over the incident neutron energy range from 0.5 to 40 MeV. The fragment velocities were measured thanks to two MWPC-SED detectors giving access to the time and position of the fragments crossing an emissive foil while an axial ionization chamber measured the residual energy and the energy loss profile of fragments. LaBr3 detectors were coupled to FALSTAFF to provide an absolute time reference point allowing the determination of the incident neutron energy. The evolution of the fragment characteristics can then be studied as a function of the incident neutron energy.

In this paper, the motivations for the FALSTAFF@NFS experiment will be detailed and the experimental setup will be described. Preliminary results for the fragment velocity, energy, mass and charge distributions will be presented. Foreseen experiments at NFS will be discussed.

Heavy and Superheavy Elements / 62

Nuclear structure and excited states of superheavy nuclei

Auteurs: J. Luis Egido[1]; Andrea Jungclaus[2]

[1] *Universidad Autónoma de Madrid*

[2] *CSIC*

Auteurs correspondants: j.luis.egido@uam.es, andrea.jungclaus@csic.es

We present the first triaxial beyond-mean-field studies of super-heavy nuclei. They include the restoration of the particle-number and angular-momentum symmetries and the mixing of different shapes using the generator coordinate method. The importance of the γ degree of freedom is highlighted by comparing the triaxial to axial-symmetric calculations performed within the same framework. In the calculations, the effective finite-range density-dependent Gogny force is used.

Calculations for the even Flerovium isotopes towards the supposed N=184 neutron shell closure were performed [1] .
For the three even Fl isotopes between the prolate ^{288}Fl and the oblate ^{296}Fl triaxial ground-state shapes are predicted, whereas axial-symmetric calculations suggest a sharp
prolate-oblate shape transition between ^{290}Fl and ^{292}Fl. A novel type of shape coexistence, namely that between two different triaxial shapes, is predicted to occur in ^{290}Fl.
Finally, the existence of a neutron shell closure at N=184 is confirmed, while no evidence is found for Z=114 being a proton magic number.

In the same framework, we present the study of the excitation spectra of super-heavy nuclei. As representative examples, we have chosen the members of the α-decay chains of ^{292}Lv and ^{294}Og [2,3],
the heaviest even-even nuclei which have been synthesized so far using ^{48}Ca-induced fusion-evaporation reactions.
Rapidly varying characteristics are predicted for the members of both decay chains, which are further accentuated when compared to the predictions of simple collective models. The calculations will be compared to the available experimental data [2] and the prospect of observing α-decay fine structures in future experiments discussed. Additionally, the excitation spectra along the α-decay chains of the odd-A nucleus ^{289}Fl is discussed [4]. \\

[1] J. Luis Egido and Andrea Jungclaus, Phys. Rev. Lett. 125, 192504 (2020)

[2] A. S\r{a}mark-Roth, Phys. Rev. Lett. 126, 032503 (2021)

[3] J. Luis Egido and Andrea Jungclaus, Phys. Rev. Lett. 126, 192501 (2021)

[4] D. M. Cox at al, Phys. Rev. C107, L021301(2023)

Shell evolution / 63

Testing ab-initio calculations in light nuclei via high-precision spectroscopy

Auteur: Irene Zanon[1]

[1] *INFN-LNL*

Auteur correspondant irene.zanon@lnl.infn.it

The development and improvement in terms of performances of accelerator facilities and detectors has paved the way for extending the study of nuclear structure towards more exotic nuclei and experimental quantities that have been, until now, less accessible.

In parallel, theoretical methods have advances in precision and prediction capabilities.
In recent years, \textit{ab-initio} calculations in particular have proven to be powerful tools to address open questions in nuclear structure; one example is the role of three-body forces in the evolution of nuclear structure far from stability.
The importance of their contribution is evident in the case of the oxygen isotopic chain.
In fact, only by including these forces in the calculations it is possible to correctly reproduce the neutron dripline in correspondence of ^{24}O, instead of ^{28}O as predicted by standard calculations.
However, in order to quantify the contribution of these forces, spectroscopic information is crucial.

In this context, the ^{20}O nucleus is a perfect playground for these measurements; in fact, the properties of the 2^+_2 and 3^+_1 states of this nucleus are expected to be influenced by three-body forces.
By measuring the spectroscopic properties of these nuclei, such as the excitation energy, the branching ratio and the lifetime, and comparing them to theoretical calculations, it is possible to understand the depth of their influence.

For these reasons, an experiment aimed at studying the ^{20}O was performed in GANIL. The radioactive beam of ^{19}O, provided by the SPIRAL1 complex, impinged on a deuterated target, populating the nucleus of interest by means of a (d, p) reaction.
The target was deposited on a layer of gold in order to measure the lifetime of the states by using the Doppler-Shift Attenuation Method.
The recoils of the binary reaction were detected using the MUGAST array and the VAMOS++ magnetic spectrometer, while the γ rays emitted were detected using AGATA.

The nucleus was first investigated via particle-γ spectroscopy to reconstruct the level scheme and measure the branching ratios.
Then the lifetimes of the 2^+_2 and 3^+_1 states were measured. To do so, the experimental lineshapes were compared to realistic Monte Carlo simulations and the lifetimes were extracted by using the least-χ^2 method.
Finally the reduced transition probabilities, B(E2) and B(M1) deduced from the lifetime measurements, were compared to \textit{ab-initio} calculations.

In this contribution, the results of the particle-γ spectroscopy and the lifetime measurements of the 2^+_2 and 3^+_1 states are reported.
An interpretation of the nature of the excited states of ^{20}O is presented as well as the future perspectives for further investigation in this region.

Applications and Interdisciplinary physics / 64

Design of innovative diamond detectors for beam monitoring in highly radiative environment for applications in nuclear and medical physics.

Auteur: Marie-Laure Gallin-Martel[1]

Co-auteurs: Latifa Abbassi [2]; Jean-François Adam [3]; Adélie André [4]; Yannick Arnoud [5]; Philippe Barberet [6]; Alexandre Bes [4]; Laurent Bonny [4]; Johann Collot [7]; Thierry Crozes [2]; Denis Dauvergne [8]; Rachel Delorme [9]; Francesca Di Franco [4]; Pierre Everaere [4]; Manon Evin [10]; Laurent Gallin-Martel [4]; Arnaud Guertin [11]; Olivier Guillaudin [4]; Ferid Haddad [12]; Christophe Hoarau [13]; Jean Jouve [6]; Charbel Koumeir [14]; Ana Lacoste [4]; Fabien Lafont [4]; Philippe Laniece [15]; Claire Léonhart [4]; Amélia Maia Leite [16]; Sara Marcatili [4]; Marc Marton [4]; Vincent Metivier [17]; Robin Molle [18]; Jean-François Motte [2]; Quentin Mouchard [19]; Jean-Francois Muraz [20]; Freddy Poirier [21]; Nicolas Ponchant [22]; Fatah Ellah Rarbi [23]; Melvyn Reynaud [4]; Olivier Rossetto [24]; Noel Servagent [10]; Stéphanie Sorieul [6]; Jonathan Waquet [25]; Yuwei Zhu [15]

[1] *UMR 58 21*

[2] *Institut Néel*

[3] *STROBE (UGA / INSERM)*

[4] *LPSC*

[5] *LPSC UGA*

[6] *LP2I Bordeaux*

[7] *LPSC - Université Grenoble Alpes - CNRS/IN2P3*

[8] *Laboratoire de Physique Subatomique et de Cosmologie de Grenoble, CNRS/IN2P3*

[9] *Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC-IN2P3, 38000 Grenoble, France*

[10] *SUBATECH*

[11] *CNRS/IN2P3*

[12] *SUBATECH, Universite de Nantes, Ecole des Mines de Nantes, Nantes Cedex, France. & GIP ARRONAX, Saint-Herblain, France*

[13] *LPSC - IN2P3 - CNRS*

[14] *GIP ARRONAX*

[15] *IJClab*

[16] *IJCLab*

[17] *SUBATECH / IMT Atlantique*

[18] *LPSC - CNRS*

[19] *IMT Atlantique - Subatech UMR6457*

[20] *{CNRS}UMR5821*

[21] *CNRS/Arronax*

[22] *LPSC/CNRS*

[23] *LPSC Grenoble*

[24] *LPSC/UGA*

[25] *IN2P3 LPSC*

Auteurs correspondants: leonhart@lpsc.in2p3.fr, latifa.abbassi@neel.cnrs.fr, robin.molle@lpsc.in2p3.fr, christophe.hoarau@lpsc.in2p3.fr, laurent.bonny@lpsc.in2p3.fr, rarbi@lpsc.in2p3.fr, mouchard@subatech.in2p3.fr, ana.lacoste@lpsc.in2p3.fr, collot@in2p3.fr, poirier@arronax-nantes.fr, amelia.leite@ijclab.in2p3.fr, koumeir@arronax-nantes.fr, difranco@lpsc.in2p3.fr, denis.dauvergne@lpsc.in2p3.fr, philippe.laniece@ijclab.in2p3.fr, jonathan.waquet@lpsc.in2p3.fr, m.marton@lpsc.in2p3.fr, lafont.f@gmail.com, andread@lpsc.in2p3.fr, reynaud@lpsc.in2p3.fr, evin@subatech.in2p3.fr, thierry.crozes@neel.cnrs.fr, arnaud.guertin@subatech.in2p3.fr, yuwei.zhu@ijclab.in2p3.fr, olivier.guillaudin@lpsc.in2p3.fr, nicolas.ponchant@lpsc.in2p3.fr, everaere@lpsc.in2p3.fr, vincent.metivier@subatech.in2p3.fr, bes@lpsc.in2p3.fr, sara.marcatili@lpsc.in2p3.fr, barberet@cenbg.in2p3.fr, sorieul@lp2ib.in2p3.fr, rachel.delorme@lpsc.in2p3.fr, noel.servagent@subatech.in2p3.fr, laurent.gallin-martel@lpsc.in2p3.fr, olivier.rossetto@univ-grenoble-alpes.fr, mlgallin@lpsc.in2p3.fr, jean-francois.muraz@lpsc.in2p3.fr, arnoud@lpsc.in2p3.fr, jean-francois.motte@neel.cnrs.fr, jouve@cenbg.in2p3.fr, jean-francois.adam@univ-grenoble-alpes.fr

New accelerators are being developed, either for medical applications (X-ray radiotherapy, hadrontherapy, radiotherapy by synchrotron radiation and "flash" therapies), or for nuclear physics. These developments create the need for very precise beam monitoring with fast counting in a highly radiative environment. An important issue is the adaptation to the temporal beam structures, which vary greatly depending on the type of accelerators (cyclotrons, synchro-cyclotrons or synchrotrons), in terms of duty cycle or peak intensity. A recent tendency to increase the intensity of the beams, for example in a clinical setting, for flash therapy, poses new challenges for the detection of secondary radiation (adapting the counting capacity of the detectors, electronics and data acquisition). The intrinsic qualities of diamond (fast timing, low leakage current, excellent signal-to-noise ratio, radiation hardness, equivalence to human tissue) make this semiconductor a perfect candidate to meet the monitoring requirements of such accelerators and the detection of particles.
The objectives of our multidisciplinary projects are the development of innovative diamond detectors for beam monitoring based either on single or poly-crystalline Chemical Vapor Deposition (CVD) and dedicated front-end electronics readout designed at laboratory. Diamonds are used as solid-state ionization chambers. Their charge collection properties were investigated with various ionizing particles to evaluate the capability of diamond to be a position sensitive detector. Detectors were exposed to 68 MeV proton (ARRONAX) and 95 MeV/u carbon ion beams (GANIL), short-bunched 8.5 keV photons from the European Synchrotron Radiation Facility (ESRF) and 30 keV electron beams at Institut Néel to perform charge collection 2D mapping. Our ultimate scientific objective is to demonstrate that diamond can become a "standard detector"for particle detection, particle counting, time stamps through the design of beam monitors operating with temporal resolutions of 100 ps or less and a high-count rate (from a single particle up to bunches of thousand particles) over a wide dynamic range of beam intensities (fraction of pA up to μA).

Shell evolution / 65

Lifetimes measurements with MNT reactions at the AGATA-VAMOS++ setup: Exploring the seniority conservation in the semimagic $N = 50$ nuclei above $Z = 40$.

Auteur: Andres Gadea[1]

Co-auteur: R.M. Peréz - Vidal [2]

[1] *IFIC CSIC-University of Valencia*

[2] *IFIC, CSIC-University of Valencia*

Auteurs correspondants: rosa.perez@ific.uv.es, andres.gadea@ific.uv.es

Multi-Nucleon Transfer (MNT) reactions is a useful mechanism, to perform nuclear structure studies in nuclei moderately far from stability line. Moreover, MNT allows to directly populate the low lying states in the reaction products.
The development of set-ups involving high acceptance tracking magnetic Spectrometers as VAMOS++ [1], coupled with the Advanced GAmma Tracking Array (AGATA) [2] opened new possibilities, especially if they are used in conjunction with the high-intensity stable beams provided by the GANIL laboratory [3]. With such set-ups it is nowadays possible to have sufficient sensitivity to perform precise lifetime measurements using Doppler-shift-based techniques such as the RDDS method [5], employing the plunger, for lifetimes in the range from few tenths to hundreds of picosecond. This technique rely on a precise Doppler correction that can be provided by the position resolution of the AGATA array coupled to VAMOS++ the latter providing an accurate kinematic reconstruction of the detected ejectile. VAMOS++ do not only allows to identify and select the reaction product of interest but also to perform an event-by-event Doppler correction. Additionally, taking advantage of the Total Kinetic Energy Loss (TKEL) measurement, the contribution from the feeding transitions, a major source of systematic errors, can be controlled.
In a recently published work [6] we have use the set-up and techniques described above to perform accurate lifetime measurements in the $N = 50$ isotones with $Z \geq 40$, i.e. with protons occupying the g9/2 orbital. It is well known that seniority is conserved in orbitals with $j \leq 7/2$ while for orbitals with $j \geq 9/2$, seniority breaking effects may be observed being the eigenstates admixtures of states with different seniorities [7,8].
An extensive study of reduced transition probabilities in ^{90}Zr, ^{92}Mo and ^{94}Ru, together with other known B(E2)'s in the $N = 50$ isotones, has allowed us to conclude that seniority is a good quantum number, i.e. is largely conserved, along the $(g_{9/2})^n$ yrast states at $N = 50$. The experimental evidence of the seniority conservation is a direct evidence of the validity of the short-range pairing interaction, with far-reaching implications for nuclear structure.
The capabilities of the mentioned set-up and the experimental findings will be discussed in this contribution

[1]H. Savajols, and Vamos Collaboration. Nucl. Phys. A 654, 1027c (1999)
M. Rejmund et al., Nucl. Instr. Methods Phys. Res. Sect. A, 646, 184–191 (2011)
[2]S. Akkoyun et al., Nucl. Instr. Methods Phys. Res. Sect. A 668, 26 (2012)
[3]E. Clément et al., Nucl. Instr. Methods Phys. Res. Sect. A, 855, 1 (2017)
[5]A. Dewald, O. Möller, P. Petkov, Prog. Part. Nucl. Phys. 67, 786 (2012)
[6]R.M. Pérez-Vidal et al., Phys. Rev. Lett. 129, 112501 (2022)
[7]P. Van Isacker, Inter. Jour. Mod. Phys. E 20, 191 (2011).
[8]C. Qi, Phys. Lett. B 773, 616 (2017).

Collective modes / 66

Collective modes excited by proton inelastic scattering studied at CCB IFJ PAN

Auteur: Maria Kmiecik[1]

[1] *IFJ PAN Krakow*

Auteur correspondant maria.kmiecik@ifj.edu.pl

An experimental campaign of measurements of the γ decay from states excited in nuclei using proton inelastic scattering reaction have been performed at CCB facility of IFJ PAN. The main goal of the experiments was to study the decay to the ground state of isoscalar giant quadrupole resonance (ISGQR) via γ-ray emission. Previously such phenomenon was observed only once, in 1980s [1].

The experiment was performed at Cyclotron Centre Bronowice (CCB) of IFJ PAN Kraków, Poland, a facility dedicated mainly to the proton radiotherapy. The experimental setup consisted of eight large-volume BaF2 γ -ray detectors of the HECTOR (High Energy deteCTOR) array [2] and 16 triple telescopes of the KRATTA (KRAków Triple Telescope Array) array [3] together with fast plastic scintillators for light charged particle identification and energy measurement. In the experiment the inelastic scattering of 85 MeV proton beam on 208Pb target has been employed and the scattered protons were measured in coincidence with γ transitions.

As a result the measurement of the ISGQR γ-decay has been confirmed and the branching ratio between ISGQR gamma decay to ground state and neutron emission was obtained [4]. During the talk I will present the experimental method, the used equipment as well as the obtained results. In addition, the outlook for the continuation of such studies will be discussed.

[1] J.R. Beene, et al., Phys. Rev. C 39, 1307 (1989);
[2] A. Maj et al., Nucl. Phys. A 571, 185 (1994);
[3] J. Łukasik et al., Nucl. Instrum. Methods Phys. Res., Sect. A709, 120 (2013);
[4] B. Wasilewska et al., Phys. Rev. C 105, 014310 (2022).

Heavy ion collisions / 67

Nuclear symmetry energy and neutron stars

Auteur: Jerome Margueron[1]

[1] *CNRS/IN2P3 - IP2I - Lyon*

Auteur correspondant j.margueron@ip2i.in2p3.fr

The understanding of neutron star properties from fundamental physics is still far from being completed. One of the reasons is that the theory for strong force, QCD, does not apply simply to neutron star matter at a few times the nuclear saturation density. At low density, chiral effective field theory is fixing a limit which can be incorporated in the description of the crust of neutron stars. Above saturation density, the question of phase transition(s) and the onset of new degrees of freedom are extremely important since it impacts the properties of the core of neutron stars. Astrophysical observations (gravitational wave, x-rays, radio) and nuclear physics experiments can be employed to constrain the equation of state for neutron stars, including the symmetry energy. Prospects for future detections will also be discussed.

Spectroscopy of heavy and superheavy elements / 68

Decay-correlated time-of-flight mass spectroscopy by MRTOF-MS

Auteurs: Pierre Brionnet[1]; Yoshikazu Hirayama[2]; Daiya Kaji[1]; Sota Kimura[2]; Kouji Morimoto[1]; Momo Mukai[3]; Toshitaka Niwase[None]; Marco Rosenbusch[4]; Peter Schury[2]; Michiharu Wada[5]; Yutaka Watanabe[2]

[1] *RIKEN Nishina Center*

[2] *KEK Wako Nuclear Science Center*

[3] *Nagoya University*

[4] *WNSC-IPNS-KEK, Tsukuba, Japan*

[5] *KEK*

Auteurs correspondants: michiharu.wada@kek.jp, pierre.brionnet@riken.jp, daiya@riken.jp, yutaka.watanabe@kek.jp, sota.kimura@riken.jp, mukai.momo.c1@f.mail.nagoya-u.ac.jp, morimoto@riken.jp, yoshikazu.hirayama@kek.jp, niwase@phys.kyushu-u.ac.jp, schury@riken.jp, marco.rosenbusch@riken.jp

The mutli-reflection time-of-flight mass spectrograph (MRTOF-MS) has proven to be a valuable tool for online atomic mass measurements. We have shown it to be capable of approaching R_m=10^6 with measurements times $t < 20$ ms, allowing high-precision determinations of the masses of even very short-lived species. The MRTOF-MS has been shown to be a particularly powerful tool for online measurements, as it can simultaneously analyze multiple ion species, maximizing the effective use of limited accelerator time.
By constructing specialized ion detectors that allow for precise determination of ion impact timing and can also detect radioactive decays, we have found that the MRTOF-MS can become an even more effective tool. Using decay-correlations we can perform half-life measurements simultaneous to mass measurements. At the same time, such decay-correlated time-of-flight measurements allows for a strong suppression of stable molecular background ions that are always extracted from even the cleanest gas stopping cell. This allows for high-confidence in measurements of very low yield species such as superheavy nuclides. It can also allow for confirmation the identity of exotic species whose masses have not been previously determined.
I will present recent results for decay-correlated time-of-flight mass spectroscopy measurements performed at WNSC facilities within RIKEN, for alpha- and becay-decaying nuclides. I will also present plans for future studies, including a new configuration that will allow for gamma-ray correlated mass spectroscopy at KISS.

Collective modes / 69

Study of the Pygmy Dipole Resonance using neutron inelastic scattering at GANIL-SPIRAL2/NFS

Auteur: Marine Vandebrouck[1]

[1] *CEA Saclay DPhN*

Auteur correspondant marine.vandebrouck@cea.fr

The pygmy dipole resonance (PDR) is a vibrational mode described as the oscillation of a neutron skin against a core symmetric in number of protons and neutrons. The PDR has been the subject of numerous studies, both experimental and theoretical [1,2,3]. Indeed, the study of the PDR has been and still is of great interest since it allows to constrain the symmetry energy, an important ingredient of the equation of state of nuclear matter that describes the matter within neutron stars [4]. Moreover, the PDR is predicted to play a key role in the r-process via the increase of the neutron capture rate [5]. However, despite numerous experiments dedicated to the study of the PDR, a consistent description is still discussed. In this context, we propose to study the PDR using a new probe: the neutron inelastic scattering reaction (n,n'g).

An experiment to study the pygmy resonance in 140Ce using the (n,n'g) reaction has been carried out in September 2022. This experiment has been made possible thanks to the high-intensity proton beam of the new accelerator SPIRAL2 at GANIL and the NFS (Neutron For Science) facility. The experimental setup consisting of the new generation multi-detectors PARIS [6], for the detection of gammas coming from the de-excitation of the PDR, and MONSTER [7], for the detection of scattered neutrons, was used. In this talk, preliminary results will be presented.

[1] D. Savran, T. Aumann, A. Zilges, Prog. Part. Nucl. Phys. 70, 210-245 (2013)
[2] A. Bracco, E.G. Lanza, A. Tamii, Prog. Part. Nucl. Phys. 106, 360-433 (2019)
[3] E. G. Lanza, L. Pellegri, A. Vitturi, M. V. Andrés, Prog. Part. Nucl. Phys. 129, 104006 (2023)
[4] A. Carbone et al., Phys. Rev. C 81, 041301(R) (2010)
[5] S. Goriely, E. Khan, M. Samyn, Nucl. Phys. A 739, 331-352 (2004)

[6] A. Maj et al., Acta Phys. Pol. B40, 565 (2009)
[7] A. R. Garcia et al., JINST 7, C05012 (2012)

Shell evolution / 70

Shape coexistence studied with Coulomb excitation and AGATA

Auteur: Magda Zielinska[1]

[1] *CEA Saclay*

Auteur correspondant magda.zielinska@cea.fr

The history of Coulomb-excitation measurements with AGATA dates back to the very first physics experiment with this array, which took place in April 2010 and aimed at investigation of a highly-deformed structure in ^{42}Ca [1,2]. The measurement provided magnitudes and relative signs of numerous E2 matrix elements coupling the low-lying states in ^{42}Ca. The shape parameters obtained for the 0^+_2 and 2^+_2 states confirm that the excited structure possesses a strikingly large elongation, similar to that established for superdeformed bands in this mass region, and a slightly non-axial character. In contrast, those for the ground state are consistent with large fluctuations about a spherical shape.

During the AGATA campaign at GANIL, Coulomb-excitation data were collected as a by-product of experiments performed at near-barrier beam energies. Notably, the analysis of slightly "unsafe" Coulomb-excitation data on ^{106}Cd, collected during an experiment aiming at lifetime measurements in ^{106,108}Sn [3], provides information on the collectivity of the presumably oblate structure built on the 0^+_3 state, as well as on the role of octupole correlations in this nucleus [4].

In the recent months, three Coulomb-excitation measurements were performed with AGATA at LNL, aiming at verification of the multiple shape-coexistence scenario in ^{110}Cd and ^{74}Se, and that of the type-II shell evolution in ^{96}Zr. The status of the on-going analysis will be briefly presented.

[1] K. Hadyńska-Klęk *et al.*, Phys. Rev. Lett. 117, 062501 (2016).
[2] K. Hadyńska-Klęk *et al.*, Phys. Rev. C 97, 024326 (2018).
[3] M. Siciliano *et al.*, Phys. Lett. B 806, 135474 (2020).
[4] D. Kalaydjieva, PhD thesis, Université Paris-Saclay, 2023.

Poster session - with cocktail and buffet / 71

Finite temperature effects in electromagnetic transitions of open- and closed-shell nuclei

Auteur: Amandeep Kaur[1]

Co-auteurs: Nils Paar [2]; Esra Yüksel [3]

[1] *Department of Physics, Faculty of Science, University of Zagreb, Bijenička c. 32, 10000 Zagreb, Croatia*

[2] *University of Zagreb*

[3] *University of Surrey*

Auteurs correspondants: akaur.phy@pmf.hr, e.yuksel@surrey.ac.uk, npaar@phy.hr

The electric dipole (E1) and magnetic dipole (M1) excitations of nuclei are excellent probes to study the nuclear structure and dynamics from both experimental and theoretical point of view. Also, the behavior of dipole excitations is known to be highly sensitive to extreme conditions of temperature and neutron excess [1-4]. In this work, the finite temperature relativistic quasiparticle random phase approximation (FT-RQRPA) based on the relativistic nuclear energy density functional (RNEDF) approach is formulated to study the interplay of temperature and pairing effects on electric and magnetic dipole transitions [1]. The properties of open- and closed-shell nuclei are described within the finite temperature Hartree BCS theory (FT-HBCS) using the relativistic density-dependent point coupling DD-PCX interaction [5]. Using this novel approach, the systematic evaluation of isovector E1 and M1 strength distributions is studied for 40-60Ca and 100-140Sn isotopes at temperatures between T=0-2 MeV. It is shown that E1 strength becomes more fragmented, and new excited states emerge in the low-energy region as the neutron number and temperature of Ca and Sn isotopes increase. This happens because of the unblocking of new transitions above the Fermi level due to pairing and thermal unblocking effects. The temperature dependence of the M1 response within FT-RQRPA is also studied for the first time. M1 transitions take place between spin-orbit (SO) partner states. By increasing temperature, the SO gap energies start to decrease, and the M1 response significantly shifts to lower energies. The absolute silent M1 response in 40,60Ca suddenly appeared at higher temperatures due to the thermal unblocking of new transitions between the SO partners. In addition, new low-lying M1 excitation modes are obtained below E<5 MeV in neutron-rich Ca and Sn nuclei.

Fission / 72

Gamma ray spectroscopy of nuclear fission at ALTO and NFS

Auteur: Jonathan Wilson[1]

[1] *IJC Lab, Orsay, France*

Auteur correspondant jonathan.wilson@ijclab.in2p3.fr

Nuclear fission is a complex, dynamical process involving a dramatic re-arrangement of nuclear matter. Even after much experimental and theoretical investigations over many years this fascinating nuclear reaction is stil not fully understood due to the large number of degrees of freedom and final multitude of final states which can be populated. The gamma rays emitted in nuclear fission contain valuable information about both the fission process itself and the structure of exotic neutron-rich nuclei. In this presentation I will address ongoing work to perform gamma-ray spectroscopy of nuclear fission with state-of-the art hybrid deterction systems to learn more about open questions such as excitation energy and angular momentum sharing, high energy gamma-ray emission and barriers in the fission potential energy landscape. The presentation will focus on ongoing and future work at the ALTO and NFS facilties.

Poster session - with cocktail and buffet / 73

Rotation of pear-shaped ^{100}Ru nucleus

Auteurs: Sukalyan Chattopadhyay[1]; Pradip Datta[2]; Anindita karmakar[1]

Co-auteurs: Sajad Ali [3]; Ranabir Banik [4]; Sansaptak Basu [5]; Soumik Bhattacharya [5]; Sarmishtha Bhattacharyya [5]; Shabir Dar [5]; Sneha Das [5]; S.S. Ghugre [6]; Gopal Mukherjee [5]; Soumen Nandi [5]; Satya Samiran Nayak [5]; Haridas Pai [5]; Rajarshi Raut [6]; Wadut Shaikh [7]

[1] *Saha Institute of Nuclear Physics, HBNI*

[2] *Ananda Mohan College, Kolkata*

[3] *Government General Degree College of Pedong, Kalimpong, India.*

[4] *Institute of Engineering & Management, Sector 5, Kolkata, India.*

[5] *Variable Energy Cyclotron Centre*

[6] *UGC-DAE CSR, Kolkata, India*

[7] *Mugberia Gangadhar Mahavidyalaya, Purba Medinipur, India*

Auteur correspondant anindita.karmakar@saha.ac.in

This research is focused on studying nuclear structure in the A ~ 100 region, with a particular emphasis on the N ~ 56 isotone group. The presence of the h11/2 intruder orbital in this group significantly impacts the nuclear shape. The main goal of this study is to investigate the existence of a two-quasi-neutron octupole band within this isotone group.

For this purpose, fusion-evaporation reactions were employed to populate the excited levels of the nucleus of interest, 100Ru. The experimental setup involved gamma-ray detection with an array of 11 hyper-pure Germanium detectors, each equipped with four-fold segmentations. The data acquisition system recorded approximately five billion two-fold coincidence events using the PIXIE-16 digitiser. Six detectors were positioned at a 90° angle to the beam direction to enhance the detection of E1 transitions, while two LEPS detectors were included for efficient detection of low-energy transitions. The remaining five Clover detectors were placed at angles of 125° and 40°.

Analysis of the obtained data was performed using the RADWARE and INGASORT software, which facilitated the examination of the angle-dependant and symmetric γ-γ matrices.

The primary focus was to investigate stable octupole deformation, which exhibited characteristics such as parity doublet bands and relatively fast E1 transitions. To systematically study octupole-deformed nuclei across the periodic table, two variables, Moment of Inertia (J(1)) and a spin-dependent parity splitting index (S(J)), were selected. This systematic analysis helps to provide insights into the underlying physics of the observed level scheme. In this work, 7 new E1 transitions were placed between the assumed octupole bands. The B(E1)/B(E2) ratios for levels of 100Ru were determined using the experimental branching ratios. These values in the spin range $11\hbar < I < 19\hbar$ show a significant enhancement compared to the low spin values of 100Ru. Where all the previous studies on octupole indicate to begin from the ground state band, this study reports the first observed case of an octupole band built on an unpaired configuration.

One limitation of this research is the absence of lifetime analysis due to the thin target experiment conducted.

Poster session - with cocktail and buffet / 76

Study of nuclear fission through Isotopic Yields of Fission Fragments

Auteur: Neeraj Kumar[1]

[1] *Grand Accélérateur National d'Ions Lourds (GANIL)*

Auteur correspondant neeraj.kumar@ganil.fr

The study of nuclear fission [1] plays a crucial role in understanding the fundamental aspects of nuclear physics and holds significant applications across various fields, including power production, space exploration, and the synthesis of radioisotopes for medical applications. In the ongoing fission campaign at the VAMOS++ facility [2], located at GANIL, we investigate the phenomenon of nuclear fission using inverse kinematics [3], which provides a kinematic boost resulting in higher kinetic energies of fission fragments compared to normal kinematics. By utilizing VAMOS++, we have successfully measured and characterized the isotopic distributions of fission fragments resulting from fusion- and transfer-induced fission reactions [4]. In addition to these distributions, the relative isotopic yields of fission fragments [5] provide crucial insights into the dynamics and mechanisms underlying the fission process.

During the AGATA campaign in 2016, we conducted experiments focusing on the fission of 247Cm using the 238U+9Be reaction at an incident energy of 6.2 MeV/A [3]. Additionally, the same reaction was investigated with the PARIS Setup in 2022 at an incident energy of 5.8 MeV/A. These two measurements led to the population of 247Cm at excitation energies of 46.8 and 43.3 MeV, respectively. By extracting isotopic fission yields from these experimental data sets, we aim to obtain valuable information regarding the influence of excitation energy and structural effects on the yields of fission fragments. Furthermore, by comparing these results with the isotopic fission-fragment yields obtained from the 238U+12C (Eb = 6.1 MeV/u) reaction [4], we aim to gain a broader understanding of the intricate details of nuclear fission. The ongoing analysis focused on achieving these objectives, is currently in progress, and we will present the results during the upcoming Colloque GANIL 2023.

References

[1] L. Meitner and O. R. Frisch, Nature (London) 143, 239 (1939).
[2] M. Rejmund et al ., Nucl. Instrum. Methods Phys. Res., Sect. A 646, 184 (2011).
[3] Y. H. Kim et al., Eur. Phys. J. A 53, 162(2017).
[4] D. Ramos et al., Phys. Rev. C 97, 054612 (2018).
[5] D. Ramos et al., Phys. Rev. C 101, 034609 (2020).

Poster session - with cocktail and buffet / 77

Investigating the effect of gas aging on detector performance for the development of a new gas circulation system for ACTAR-TPC at GANIL

Auteur: Rojeeta Devi Kshetrimayum[1]

Co-auteurs: Charly Nicolle [1]; Julien Pancin [1]; Thomas Roger [1]

[1] *GANIL*

Auteurs correspondants: julien.pancin@ganil.fr, charly.nicolle@ganil.fr, thomas.roger@ganil.fr, rojeeta.devi-kshetrimayum@ganil.f

Recent advancements in active target detectors, enabling the detection gas to act as a target for nuclear reactions, have provided a significant boost to the exploration of nuclei near the drip lines and the exotic nuclear phenomena associated with them. ACTAR-TPC at GANIL is a novel detector of such kind that can construct a 3-D mapping of the decay or reaction products from two-dimensional projection of the tracks and electron drift time. In such kind of detection technique which is based on the gas-filled detection chamber, gas purity is a key factor in ensuring optimum detector performance and their lifetime. The recycling of detection gas becomes significantly important to minimize operational costs, in the case of using expensive gases like deuterium (2H), tritium (3H), helium-3 (3He), xenon (Xe), etc. Another significant concern is the use of greenhouse gases (GHG) like CF4, SF6, C3F8, etc in certain experiments to achieve the physics interest of the study. This amplifies the importance of gas recycling considering the environmental consciousness. However, the quality of the recycled gas after cleaning must be satisfactory to achieve the defined optimum performance of the detector. Aiming to the development of an advanced gas regulation system, a comprehensive study is underway to investigate the effect of gas aging on detector performance. Characterization of gas filters was carried out to ensure their efficiency and determine their suitability for adoption in gas recycling. In this presentation, important methodologies employed in the studies will be discussed and the corresponding results will be presented.

Poster session - with cocktail and buffet / 78

Lifetime measurements show high triaxiality in ruthenium.

Auteurs: Andreas Görgen[1]; Johannes Sørby Heines[2]; Wolfram KORTEN[3]; Joa Ljungvall[4]; Victor Modamio[1]; Giorgia Pasqualato[5]

[1] *University of Oslo*

[2] *Université d'Oslo*

[3] *CEA Paris-Saclay*

[4] *IJCLAB/IN2P3/CNRS*

[5] *IJCLab Orsay*

Auteurs correspondants: j.s.heines@fys.uio.no, victor.modamio@fys.uio.no, joa.ljungvall@ijclab.in2p3.fr, giorgia.pasqualato@ijclab.in2p3.fr, andreas.gorgen@fys.uio.no, w.korten@cea.fr

The neutron rich region around A ~ 100 is of special interest in nuclear structure for its many rapid shape transitions. Their exact properties are predicted differently by different nuclear structure models, making this region well suited as a testing ground.
In 2017, experiment E706 populated close to a hundred nuclides in this region using the fusion fission reaction of a 6.2 MeV/u U-238 beam on a Be-9 target, with the aim of investigating lifetimes of excited states with the recoil distance Doppler-shift method. The fission fragments passed through the Orsay Universal Plunger System while the Advanced Gamma Tracking Array (AGATA) measured the emitted gamma-rays. VAMOS++ was used to identify the fission fragments event-by-event.
Results for odd and even ruthenium isotopes will be presented. In Ru-110 and Ru-112, lifetimes in both the ground state band and gamma band have been measured. Comparison with theoretical models and interpretation in terms of deformation parameters yield quantitative information on the evolution of triaxiality in the ruthenium chain. Our results are consistent with ruthenium-110 being a slightly oblate and highly triaxial rotor. Ongoing efforts to extract lifetimes from spectra with many overlapping transitions will also be
presented.

Poster session - with cocktail and buffet / 80

A new Gogny parametrization with 3 Gaussians suited for astrophysical applications

Auteur: Lysandra Batail[1]

Co-auteurs: Stéphane Goriely [2]; Stéphane Hilaire [3]; Sophie PERU [4]

[1] *Institut d'Astronomie et d'Astrophysique - Université libre de Bruxelles*

[2] *Université Libre de Bruxelles*

[3] *CEA Bruyères-le-Châtel*

[4] *CEA*

Auteurs correspondants: stephane.hilaire@cea.fr, lysandra.batail@ulb.be, stephane.goriely@ulb.be, sophie.peru-desenfants@cea.fr

Despite major and numerous recent progresses in \textit{ab initio} calculations, it is not yet possible to describe ground state nuclear properties over the whole chart with this approach. Therefore, Energy Density Functionals remain the tool of choice to such end so far. If one wishes then to build a functional with free parameters suited for astrophysical applications, one must \textit{at least} describe nuclear properties, such as masses, as good as possible (\textit{i.e} with a root mean square to measured masses lower or equal to 800 keV), since they are of crucial importance for r-process for example \cite{rpro}, as well as infinite nuclear matter propeties of importance for neutron stars. Only this way, one can hope to extrapolate reliable properties up to the neutron dripline. \\
To this end, several competitive nuclear mass models based on Skyrme interaction within the mean-field framework, and fitted over measured nuclear masses essentially, have appeared over the years. Although they exhibit faithful advantages such as low computational cost, they are also intrinsicly penalized by required energy cut-offs to avoid non physical divergences. Gogny forces, designed mostly to overcome these problems, come then into play to complete the picture. \\
Fitting an interaction is a tedious task and there exist much less Gogny than Skyrme interactions on the market however. Even less are applicable to astrophysics. Most of the forces available have indeed a root mean square over masses enclosed between $2-6$ MeV. \\
Motivated by a relatively recent extension of the Gogny force \cite{does} including a third gaussian in the central term, recents results \cite{D3G3} have lead us to think we could build a parametrization fulfilling previously mentioned requirements. \\

I will present the freshly obtained \cite{D3} Gogny-Hartree-Fock-Bogoliubov nuclear mass model by means of a systematic fitting protocole over infinite nuclear matter and nuclear masses similar to the one adopted for D1M \cite{D1M}, with a rms as low as 800 keV, and show the improvements made compared to other Gogny forces. I will also discuss where we found room for future steps towards fitting procedures as well as what we intend to do next to lower even further the rms.

\bibitem{rpro} M.~Arnould, S.~Goriely, and K.~Takahashi , Phys.\ Rep.\ {\bf450}, 97 (2007).
\bibitem{D1M} S.~Goriely, S.~Hilaire, M.~Girod, S.~Peru, Phys.\ Rev.\ Letters {\bf102}, 242501 (2009).
\bibitem{does} D.~Davesne, P.~Becker {\it et al.}, Acta Physica Polonica B {\bf48}, 3 (2017)
\bibitem{D3G3} L.~Batail, D.~Davesne {\it et al.}, The European Physical Journal A, \textit{accepted} (June 2023)
\bibitem{D3} L.~Batail, S.~Goriely, S.~Peru, S.~Hilaire, \textit{to be submitted}
\bibitem{ame2020} M.~Wang {\it et al.}, Chinese Phys. C {\bf45} 030003 (2021)

Nuclei at the drip lines / 81

On the long-standing quest for the tetra-neutron system: a recent observation of four-neutron correlations and future perspectives

Auteur: Stefanos Paschalis[1]

[1] *University of York*

Auteur correspondant stefanos.paschalis@york.ac.uk

The search for chargeless nuclei consisting only of neutrons has been a long-lasting challenge in nuclear physics, dating more than six decades back (see Ref. [1] for a recent review). The tetraneutron, in particular, has attracted a lot of experimental and theoretical attention. Most models agree that nuclear forces cannot bind four neutrons together without destroying many of the other successful predictions for light nuclei. The theoretical models, however, struggle to provide reliable and consistent predictions regarding the possibility of four neutrons forming a resonance system. On the other hand, no solid experimental information on possible correlations between four neutrons was available until recently as experiments suffered from low statistics and/or large background. The possibility of the tetraneutron forming a resonance state is still an open and fascinating question, which can now be probed theoretically with state-of-the-art ab-initio calculations and studied experimentally by employing new techniques in the upgraded, high-intensity, radioactive-ion beam facilities. In this talk, I will present a brief overview of this long-standing quest and discuss some recent, high-quality results from a novel experiment that was performed at the SAMURAI setup in RIKEN, Japan. This experiment probes the correlation energy between the four remaining neutrons after the quasi-elastic removal of alpha cluster from 8He projectiles and has provided for the first time a notably clean experimental signature. The results have been recently published in Nature [2]. The quest now continues with renewed interest as theoretical models attempt to reproduce the experimental result and new experiments aim to confirm and refine the measurement; hence, this talk will conclude with a brief discussion of these new perspectives.

[1] Marqués, F. M. & Carbonell, J. The quest for light multineutron systems. Eur. Phys. J. A 57, 105 (2021).

[2] Duer, M., Aumann, T., Gernhäuser, R., Panin, V., Paschalis, S., Rossi, D. M., et al. Observation of a correlated free four-neutron system. Nature 606, 678–682 (2022). https://doi.org/10.1038/s41586-022-04827-6

Applications and Interdisciplinary physics / 82

R&D activities on the production of 211At at GANIL

Auteur: Gilles de FRANCE[1]

[1] *GANIL/IN2P3/CNRS*

Auteur correspondant defrance@ganil.fr

The REPARE ANR project aims at developping a high power targetry to optimize the production of the promising alpha emitter ^{211}At in the ^{4}He(^{209}Bi,2n)^{211}At fusion-evaporation reaction. For this, a first task is the precise measurements of several cross-sections to control the production of potential contaminants and to optimize the synthesis of ^{211}At. Several measurements have been performed and will be presented separately at this colloque. A second task is the design of high power target systems. Two options have been investigated : a solid state ^{209}Bi target and a liquid target.
For the first option, the goal is to design, build and use a target station able to sustain 10 kW of beam power. In July 2023, the functionalities of the target station (cooling, current measurements, beam synchronization,⋯) will tested using a ^{20}Ne beam and a dummy target. If the tests are satisfactory, the REPARE irradiation station will be installed in the NFS converter room in September 2023 for a first ^{211}At synthesis run.
For the second option, a milestone is a design study to evaluate the feasibility of a liquid target. Several designs have been evaluated using either pure Bi of a Lead Bismuth Eutectic mixture.
Finally an indirect production route is also under investigation. It consists in the production of ^{211}Rn which beta decays to ^{211}At. This so-called generator technique has several advantages compared to the direct production one.
In this talk the status of these developments will be discussed and presented in a more general perspective.

Fundamental interactions and symmetries / 87

Through the looking glass of the Standard Model with radioactive ion beams

Auteur: Leendert Hayen[1]

[1] *LPC Caen*

Auteur correspondant hayen@lpccaen.in2p3.fr

The use of exotic states of matter allows us to probe the underlying symmetries of the universe to ever greater precision and expose shortcomings of the Standard Model of particle physics (SM), arguably the most successful physical theory created to date. Radioactive ion beams (RIB), in particular, significantly expand the number of available experimental systems to address the SM's lack of sufficient CP-symmetry violation to explain the matter-antimatter asymmetry, the unknown mass mechanism of neutrino's, the nature of dark matter and a host of equally puzzling questions in the weak interaction. In this talk, we will provide an overview of the current landscape and how RIBs intersect with it, and focus on a selection of experiments using novel techniques and systems taking advantage of upgraded facilities worldwide.

Poster session - with cocktail and buffet / 90

Charged particle activation measurements on SPIRAL2/NFS

Auteur: Eva Simeckova[1]

[1] *Nuclear Physics Institute of the CAS*

Auteur correspondant simeckova@ujf.cas.cz

SPIRAL2/NFS is equipped with a the system for irradiation by charged particles and subsequent measurements of activation. The IC (Irradiation Chamber) and PTS (Pneumatic Transfer System) allow for cross-section measurements of short-lived isotopes produced on LINAC charged particle beams. Experiments on proton and deuteron beams were performed with Fe and Mo samples, respectively. Current results of these experiments will be reported.

Poster session - with cocktail and buffet / 91

High precision spectroscopy of fission shape isomers with Nu-Ball2 : Exploring the gamma back-decay

Auteurs: Corentin HIVER[1]; Jonathan Wilson[2]

[1] *IJCLab*

[2] *IJC Lab, Orsay, France*

Auteurs correspondants: jonathan.wilson@ijclab.in2p3.fr, corentin.hiver@ijclab.in2p3.fr

Fission shape isomers (SI) are poorly understood metastable states characterized by a second superdeformed potential energy minimum co-existing with normal deformed states in the low-spin regime [1]. Although many such isomers have been observed in the actinide region, our understanding of the states in the second minimum remains very limited. For most SIs, the only available information is their half life, determined via their exclusive decay mode - delayed fission. However, an interesting possibility of competing γ back-decay branches opens up as the number of protons decreases and fission barriers become harder to penetrate. The nature of this back-decay, however, remains poorly understood, owing to the fact that at the time of their discovery (several decades ago) the techniques of γ ray spectroscopy were not sufficiently well-developed.

In this context, we recently performed high precision γ ray spectroscopy experiments to study ^{236f}U and ^{232f}Th using the Nu-Ball2/PARIS spectrometer. Nu-Ball is a hybrid spectrometer that combines 24 High Purity Germanium (HPGe) Clovers and 64 phoswiches ($LaBr_3$/NaI) of the PARIS collaboration [2], covering more than 90% of the total solid angle. In addition, a Double-sided Stripped Silicon Detector (DSSD) [3] was used to measure the energy of the outgoing light charged particles. Each detector was managed by a state-of-the art fully digital FASTER electronics [4] that allowed for triggerless data acquisition at high data rates. The exceptional selectivity of such a setup comes from a combination of the high resolution of the HPGe detectors, high energy efficiency, charged particle selection, and calorimetry to determine prompt and delayed energy balances.

The full characterisation of these back-decay γ rays enables a unique and precise way to determine the parameters of fission barriers, which play an essential role in the theory of fission. Moreover, spectroscopy in the second well will allow for a better understanding of nuclear structure of these mysterious high-deformation states. Here, the first results of the nu-Ball2/PARIS fission shape isomer experiments will be presented.

[1] P.G. Thirolf, D Habs, Progress in Particle and Nuclear Physics 49 (2002) 325.
[2] F. Camera and A. Maj, The PARIS White Book, ISBN 978-83-63542-22-1 (2021)
[3] https://www.slcj.uw.edu.pl/en/coulomb-excitation-at-the-warsaw-cyclotron/
[4] D. Etasse et al. https://faster.in2p3.fr

Beta decay / 92

The contribution of nuclear physics to reactor antineutrinos

Auteur: Magali ESTIENNE[1]

[1] *Subatech/CNRS/IN2P3*

Auteur correspondant magali.estienne@subatech.in2p3.fr

Reactor antineutrino energy spectra are the subject of active experimental researches nowadays, one of them being dedicated to nuclear physics measurements of the properties of the fission products. Some of these measurements were motivated by two observed anomalies in the antineutrino spectra. The reactor anomaly (RAA), first, was observed in 2011 as a deficit in the reactor antineutrino flux with respect to the conversion model which relies on measurements of integral beta spectra and a conversion approach to predict the antineutrino energy spectra. Then a distortion between 5 and 7 MeV of the measured antineutrino spectra with respect to the conversion model, called the shape anomaly, was observed and still remains unexplained up to now. In 2017, the Daya Bay experiment measured the evolution of the antineutrino flux with the fuel content of the reactor core. The collaboration observed that the deficit of the detected flux compared with the predictions of the conversion model was almost totally explained by the data arising from the fissions of 235U which called into question the measurements of its integral beta spectra.
Summation calculations, based on nuclear data of the fission products, are a unique alternative to the converted spectra. They have the advantage of being predictive for innovative fuels and also of giving access to the main nuclei contributing to the spectra in the various ranges of energy. However some of the beta decay data of interest suffer from the Pandemonium effect, a strong bias which can affect high resolution data coming from experiments with HPGe detectors. The TAGS measurements allow one to overcome this systematic error and thus to correct nuclear data from it as well as the predictions of antineutrino energy spectra. The TAGS collaboration has carried out three experimental campaigns during the last fifteen years at the JYFLTRAP of Jyväskylä (Finland) measuring a large set of data in order to improve the quality of the predictions of our summation method. The impact of these measurements on the predicted antineutrino energy spectrum and flux using our summation calculations will be presented and discussed as well as some on-going activity on studies dedicated to the shape of the antineutrino spectra.

Heavy ion collisions / 93

Equation of State of nuclear matter - the spiRIT perspectives - TBC

Spectroscopy of heavy and superheavy elements / 94

Exploring exotic nuclei by high-precision MRTOF mass measurements: The new ion catcher and mass spectrograph at RIKEN's RIBF facility

Auteur: Marco Rosenbusch[1]

Co-auteurs: S. Chen ; D. Hou ; H. Ishiyama ; Y. Ito ; S. Kimura ; J. Lee ; S. Limura ; J. Liu ; S. Michimasa ; H. Miyatake ; J. Y. Moon ; S. Naimi ; S. Nishimura ; T. Niwase ; P. Schury ; A. Takamine ; M. Wada ; H. Wollnik ; W. Xian ; S. Yan

[1] *WNSC-IPNS-KEK, Tsukuba, Japan*

Auteur correspondant marco.rosenbusch@riken.jp

Exploiting closed-path ion trajectories in an electrostatic ion trap, the multi-reflection time-of-flight mass spectrograph (MRTOF-MS) [1] is one of the most promising techniques for precise mass measurements of short-lived isotopes. Exotic ions produced at radioisotope facilities are stored in an electrostatic trap at kinetic energies on the order of a few keV, reflected back and forth between two electrostatic ion mirrors, and ultimately ejected to a detector for time-of-flight (TOF) determination. By comparison of precise TOF data obtained from ions of well-known mass, the mass of an unknown ion can be calculated with relative uncertainties reaching $\Delta m/m < 5 \cdot 10^{-8}$ using state-of-the-art technology.

At the RIBF/BigRIPS facility of RIKEN (Wako, Japan) the new ZD-MRTOF system [2,3] located downstream of RIBF's ZeroDegree (ZD) spectrometer has been put into operation. The precision mass spectrometer is coupled to a cryogenic helium-gas filled ion catcher [4], where the initially relativistic reaction products are stopped, thermalized, and extracted as ions to be forwarded to the MRTOF-MS.
Since autumn 2020 exotic ion beams are provided to our new setup, and previously unknown radioactive isotope masses, or those with high mass uncertainty, have been determined with high precision and accuracy. This contribution will focus on the success of this setup and the recent achievements for nuclear mass measurements. The physics results and an outlook for the near future program will be presented.
Furthermore, new efforts have been made to improve the wideband mass accuracy of the system, and I will discuss about the presently known causes of uncertainties for wideband mass measurements in MRTOF-MS and our present state of knowledge for possible solutions and technical challenges.

[1] H. Wollnik and M. Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990)
[2] M. Rosenbusch et al., Nucl. Instr. Meth A (under review), arXiv:2110.11507
[3] M. Rosenbusch et al., Nucl. Instr. Meth B 463, 184 (2019)
[4] A. Takamine et al., Acc. Prog. Rep. 52, 139 (2019)

Heavy ion collisions / 95

Experimental study of asymmetric nuclear matter EOS from heavy-ion reactions with RIBF-SPiRIT

Auteur correspondant isobe@riken.jp

Neutron star (NS) is believed to be created as a remnant of supernova explosion. The property of neutron star can be described with the thermodynamical character (Equation of State, EoS) of nuclear matter.
For the determination of outer core NS-EoS, we have performed a series of measurements using heavy ion accelerator of RIKEN Radio Isotope Beam Factory (RIBF).
An international collaboration, named SPiRIT has been formed for the experimental study of the density dependence of symmetry energy term in nuclear EoS. One of the main devices of experimental setup is a Time Projection Chamber (TPC) which will be installed into the SAMURAI dipole magnet at RIBF. The TPC will measure charged pions, protons and light ions simultaneously in heavy RI collisions of neutron rich Sn reactions,
Sn-132 + Sn-124, and neutron deficient Sn reactions, Sn-108 + Sn-112, at Ebeam=270MeV/u.
In this talk, highlights of experimental result will be presented in addition to overview of SPiRIT device.

Introduction / 96

Welcome address - IN2P3

Auteur correspondant marcella.grasso@admin.in2p3.fr

Introduction / 97

Welcome address - CEA

Auteur correspondant franck.sabatie@cea.fr

Introduction / **98**

Welcome address - GANIL (CEA/IN2P3)

Auteur correspondant patricia.roussel-chomaz@cea.fr

99

Study the Neutron Shell Structure of 68Ni via Missing Mass Spectroscopy

Auteur: Ozge Aktas[1]

[1] *GANIL*

Auteur correspondant ozge.aktas@ganil.fr

The structure of atomic nuclei can be described using the single-particle picture, especially for nuclei with magic numbers such as 8, 20, 28, 50, 82, and 126. In these nuclei, there are significant energy gaps between occupied and valence orbitals. However, in reality, the atomic nucleus is a correlated system where nucleons occupy valence orbits, leading to a diffuse Fermi surface. The N=40 shell gap in 68Ni, which is part of the HO-like magic numbers 8 and 20 was studied in terms of this diffuseness which is important for characterizing magicity. The occupancy of fpg neutron orbitals in Stable Ni isotopes (from 58Ni to 64Ni) was investigated and partial filling of g9/2 orbitals starts below N=40 [1]. The shell evolution which is the disappearance of conventional magic numbers, and the appearance of new ones have been observed in the nuclei far from stability. One example of this phenomenon is 78Ni which has conventional magic numbers of Z=28 and N=50.

Recently, measurements of 78Ni have shown that the N=50 magic number state is preserved, but there is evidence of a nearby prolate shape [2]. The energy levels provide information about magicity, but the amplitude of the N=50 shell gap and its evolution by adding neutrons from 68Ni are still unknown. To determine the evolution of the N=50 gap between the d5/2 and g9/2 neutron orbitals, we need to start by determining it in 68Ni at N=40. This can be estimated from the excitation energy of the 5/2+ states in 69Ni, obtained by adding a single neutron to the d5/2 orbital of 68Ni through the (d, p) reaction. Spectroscopic factors can be used to determine the centroid of the 5/2+ states. The hole contribution can be derived from the neutron removal reaction 68Ni(p, d)67Ni. The N=50 gap can then be derived from the difference between the centroids of the d5/2 and g9/2 orbitals. By applying neutron-neutron matrix elements derived in this region, we can infer the size of the N=50 gap in 78Ni and compare it with calculations for 78Ni [3].
In this study, in addition to determining the N=50 shell gap, it is also interesting to study the spin-orbit splitting of the 2p, 1f (hole), and 1g (particle) orbitals in 68Ni. By performing the neutron removal reaction from 68Ni, we can obtain spectroscopic information about the 2p hole states in 68Ni. Also, we can deduce information about the location of the g7/2 particle strength in 69Ni and f7/2 hole strength in 67Ni from the neutron adding and removal reactions, respectively. The neutron spin-orbit splitting between g7/2 and g9/2 and between f5/2 and f7/2 is expected to be around 9 MeV and 7 MeV, respectively, but the strength is likely to be fragmented, especially for the g7/2 orbital.
To summarize, In this study, we present the preliminary results of neutron adding and neutron removal reactions from the 68Ni nucleus to study the neutron Fermi surface at N =40, the g9/2 – d5/2 spacing at N =40, the 2p SO splitting, as well as the 1g and 1f SO splittings.

References:
[1] J.P. Schiffer et al., Phys. Rev. Lett. 108, 022501 (2012).
[2]R. Taniuchi et al., Nature 569, 53–58 (2019).
[3]O. Sorlin and M.G. Porquet, Phys. Scr. T152, 014003 (2013).

Poster and thesis awards / 100

Poster prize

Auteur correspondant indu.jangid@ganil.fr

Poster and thesis awards / 101

Thesis award

Auteurs correspondants: chloe.fougeres@ganil.fr, lukas.madauss@outlook.de

GUEC session / 102

GUEC 1

Auteur correspondant beatriz.fernandez.dominguez@usc.es

GUEC session / 103

Feedback from recent Workshop on Targets & Ion Sources

Auteur: Pierre DELAHAYE[1]

[1] *GANIL*

Auteur correspondant pierre.delahaye@ganil.fr

GUEC session / 104

GUEC 2

Auteur correspondant fanny.farget@ganil.fr