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Book of Abstracts

Contents

9

Angular correlations and direct linear polarisation masurements with FIPPS instrument

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Angular correlation measurements and direct linear polarization measurements are powerful tools for identifying the spins and parities of excited nuclear states involved in a γ-ray cascade, and for measuring the multipole orders and mixing ratios of transitions. Though the physical angular correlations are fully calculable from first principles, experimental effects can make the extraction of coefficients and thus conclusions about spins and mixing ratios difficult. I will present data analysis techniques developed for the clover detectors of the FIPPS spectrometer at ILL Grenoble.

7

Complementary study of double-octupole states in 150Sm

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We present preliminary results from a recent investigation performed at ILL to study the presence of the negative-parity components in the structure of positive-parity states in atomic nuclei. In order to identify the candidates for such states one has to investigate the excited states in medium mass nuclei around N=88 using various probes. The first experiment was performed in Munich and was a two-neutron transfer reaction in order to find the correct energy of various levels and their total angular momentum. The second investigation was a beta-decay study to populate the low-spin states in 150Sm and to determine their gamma decay pattern. Therefore, the experiment performed at ILL using the 149Sm(n,g) reaction was concentrated on determining the decay pattern of the medium-spin levels and therefore, completes a series of experimental investigations on 150Sm. Gamma rays were detected using the FIPPS array composed of 16 clover detectors, eight of them being supplied by IFIN-HH. The reaction has populated a large number of states up to about 8 MeV with spin numbers typically around J= 4. Key information will be extracted from the decay of these states and their angular correlation measurements.

3

Development of Gas Filled Magnet for FIPPS phase2

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The future upgrade of the FIPPS [1] (FIPPS phase2) aims to i) explore the exotic neutron-rich nuclei region of the nuclear chart with higher selectivity ii) explore the dynamics of the fission process such as generation of spin in fission. To achieve this goal, detection and identification of the fragments produced after neutron induced fission is necessary independent from multiple gamma-ray coincidences.
Thus a new ancillary detector is required to detect the mass of the fission fragments with good resolution (δA< 4 amu at A = 150), while maintaining a large geometrical and momentum acceptance (> 50 msr and ∆P/P > 10%).
The Gas-Filled-Magnet (GFM) technique has been proposed based on experiment at LOHENGRIN [2], to obtain a good mass resolution (< 4 amu at A=150) and a large geometrical and momentum acceptance (> 50 msr and ∆ P/P > 10%). An innovative design consisting of a 1/r magnetic field index and Thales circle-shaped entrance and exit magnet edges is proposed which reduces the need for complicated tracking detectors. Current stage feasibility study of realistic magnet design and optimization of the fission fragment separation, magnet size and weight are being carried out. The characteristic of the magnet will be presented using realistic magnetic field calculations using and GEANT4 Monte-Carlo simulations.

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A. Chebboubi, et al., Nucl. Instr. Meth. B 376 (2016) 120

6

Digital coincidence study with SiPM for nuclear structure studies

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The evolution of shell structure far from the β stability line is one of the great challenges over the past two decades. Neutron rich nuclei near magic numbers show modifications in their properties as expected by shell model calculations that uses traditional shell closures. For the study of these nuclei, the ADT (Advanced Delayed Technique) βγγ(t) technique is used. This technique was developed by Henry Mack [1,2] and combines gamma spectroscopy and fast-timing coincidences to measure half-lives of excited states. The knowledge of the level scheme and the half-lives allows to extract transition probabilities that make the comparison with theoretical calculations possible. For the construction of the level scheme HPGe detectors are used, due to their good energy resolution, using gamma-gamma coincidences. For the measurement of the half-lives fast scintillators as LaBr3(Ce) crystals are commonly used. This scintillator combines a fast response with a high detection efficiency and a good photon yield, allowing the measurements of lifetimes down to the ps range by coincidences method. Nowadays, lifetimes down to the range of the 10ths of ps have been studied by coupling LaBr3 scintillator crystals to photomultiplier tubes.

High-performance arrays are thus under development. One of these arrays is the Fission Product Prompt gamma-ray Spectrometer (FIPPS) at Institut Laue-Langevin (ILL), Grenoble (France). This array is nowadays consisting of HPGe clovers for high precision gamma-ray spectroscopy. A fast-scintillation array for lifetime measurements can also be used as ancillary device. The traditional

choice of photomultiplier tubes is compromised by the eventual coupling of the gamma spectrometer with a magnetic device (as foreseen in the future for the identification of fission fragments). A good alternative to these sensors is silicon photomultipliers (SiPM). Among their numerous properties [3], SiPM are insensitive to magnetic fields up to 10T and have a quantum detection efficiency comparable to the one of the photomultiplier tubes. Their mayor drawbacks are the temperature dependence and after-pulsing, due to the silicon characteristics and the impurities on the material. Silicon sensors are known to have a timing resolution of 100ps, really close to the photomultiplier tube resolution. A digital acquisition system has been developed using CAEN digitizer cards with a high sampling rate for proper timing determination and high throughput to treat the amount of data generated. Currently the digital processing systems have energy and timing performances very close to the analog systems, also allowing online processing.
The final goal of the project is to develop a SiPM-based system for fast scintillator detectors, hosting not only the electronics needed to drive the SiPM but also the digital conversion and processing stage. Once this is achieved, we will implement the SiPM-based detector for nuclear structure experiments to measure half-lives of excited states populated in fission experiments at FIPPS.

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15

ELIADE : A state-of-the-art facility for NRF studies

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The upcoming high brilliance gamma beam facility at ELI-NP (Extreme Light Infrastructure – Nuclear Physics) will open up a new horizon on nuclear physics research by photo-induced nuclear reaction mechanisms. One of the processes, Nuclear Resonance Fluorescence (NRF), is a very effective way to measure and study basic nuclear properties. The NRF process is highly important as both the excitations and de-excitations of nuclear states are carried out by electromagnetic interaction, which is the best understood interaction in nature.

The gamma-rays will be detected by the state-of-the-art multi-detector array ELIADE (ELI-NP Array of DEtectors) comprising of segmented HPGe clover detectors and large volume CeBr3 detectors. The design of the array is highly flexible so that it can be easily transported between the high- and low-enregy gamma beam areas inside ELI-NP lab according to the requirement of the experiments. Digital sampling data acquisition systems with a global clock synchronization for all
digitizers will be utilized for the data handling. Two type of digitizers [V1725 (type α) and V1730 (type β)] from CAEN will be used for different detectors. The type α digitizers (16 channel/module) have a resolution of 14 bit with sampling rate of 250 MS/s and will be used for Clover detectors, whereas the type β (8 channel/module) will be used for CeBr3 and have 12 bit resolution with a sampling rate of 500 MS/s. Data acquisition control will be carried out by MIDAS Software (Developed at STFC, Daresbury, UK). For minimization of EMI/EMC effect on the signal transmissions, the single-differential-single transmission system will be utilized for all the signals from the detectors end to the front-end electronics.

The combination of a high brilliance gamma beam and an advanced detection system will make it possible to explore new and exciting phenomena in nuclear physics. Status of the different aspects associated with the ELIADE set-up are reported during the presentation. This work is partially supported by the BMBF (05P18PKEN9).

14

Exotic structure and dynamics in neutron-rich A~100 nuclei

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Neutron-rich A~100 nuclei relevant for the astrophysical r-process and nuclear reactor related issues manifest sudden variations of particular nuclear properties in some isotopic chains, a more smooth transition in some others, and exotic shape isomers induced by triple shape coexistence in some nuclei. Our recent investigations represent an attempt to a comprehensive understanding of shape coexistence phenomena suggested by the experimental data at low spins and the richness of various structural effects at intermediate spins within the beyond-mean-field complex Excited Vampir variational model with symmetry projection before variation using a realistic effective interaction obtained from a nuclear matter G-matrix based on the charge-dependent Bonn CD potential and a large model space.
Results will be presented concerning effects of shape coexistence and mixing on structure and electromagnetic properties as well as b−decay properties around the neutron number N=58.

11

Fast-timing experiments using the FIPPS spectrometer

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In early 2018, fast-timing experiments were performed using the FIPPS spectrometer. The setup consisted of eight HPGe clover detectors and was equipped with 16 ancillary ultra fast $LaBr_3$(Ce) timing detectors. This contribution discusses the assembly and properties of the mounted fast-timing setup while giving insight into problems and their respective solutions. The principle of lifetime measurement is demonstrated using the newly introduced time-symmetrisation method and including examples of the ^{115}Sn(n,γ)^{116}Sn experiment. The half-life of the 4_2^+ state was determined for the first time demonstrating the feasibility of probing non-yrast states and measuring their lifetimes using (n,γ) reactions.

2

First active target fission campaign at FIPPS

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Prompt gamma-ray spectroscopy of fission fragments allows to study neutron rich nuclei in the mass range around 80 < A < 160. One limitation of this type of studies is the intrinsic gamma-ray background originating from beta decays of instable fission fragments. In order to reduce this background an active fission target was developed for FIPPS, designed to distinguish between fission events and beta-decays. To achieve this, the actinide of interest is dissolved in a deuterated liquid scintillator and placed within a thin target cell directly in the collimated thermal neutron beam of FIPPS. The scintillation light signal allows to identify fission events with a very high efficiency (>95%). A first U-235 fission campaign with active target took place at FIPPS in autumn 2018, taking data for 36 days. Gamma-ray spectroscopy was performed with the eight FIPPS clover detectors and the eight IFIN-HH clover detectors with anti-Compton shields. In this talk the concept and design of the active target as well as its performance during the first fission campaign will be presented. The

impact on the data quality/analysis will be demonstrated. Further developments to be used for the next fission campaign will be introduced.

12

Fission studies with EXILL and FIPPS. Coupling FIPPS to one arm of the fission fragment spectrometer FALSTAFF.

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Nuclear fission is a complex process, for which an microscopic description is challenging. Most of the energy of the process is transferred into kinetic energy : fragments are repulsed by Coulomb force according to their shape evolution after the scission point. How exactly the remaining energy is shared between the two fragments is one of the open questions on the fission process. Another one is how the angular momentum is generated at scission and what is its distribution. In the last decade, large efforts were made in the fission community to improve the modeling of the fission process and of the de-excitation of the fission fragments. Here we would like to present our results with EXILL data, our short-term plan with FIPPS data and our perspectives with FIPPS.

The EXILL experiment campaign conducted in 2012-2013 at ILL with a 235U target allows us to study the de-excitation of the fission fragments with large statistics. We extracted the intensities of the main discrete gamma-ray transitions for a set of fission fragments and we compared our results to the ones predicted by the FIFRELIN simulation code. Different models were tested (e.g. spin distribution of the fragments at scission) and these first results are encouraging.

The recent FIPPS campaign with a 235U active target brings new opportunities. At first, the expected reduction of background will allows us to explore a larger set of fission fragments. Next, this experiment with a fission trigger makes possible the extraction of fission yields Y(A,Z). It should permit to complete the yields measured at Lohengrin and access the ones that are difficult or impossible to be measured at Lohengrin. Finally, we plan to explore the population of shapes in the region of nuclei with shape coexistence.

In order to improve the experimental sensitivity, we consider bringing one arm of the FALSTAFF fission fragment spectrometer to ILL and coupling it to FIPPS. FALSTAFF is developed at IRFU for NFS (GANIL/Spiral2). The arm consists of a pair of secondary electron detectors (SED) and an axial ionization chamber. SEDs measure the fragment time of flight (and thus its speed). The ionization chamber measures the fragment energy. The combination of both measurements provides the mass of the fragment after neutron evaporation. The goal is to reach a resolution (sigma) of about 2 uma.

8

GRIDSA: Femtosecond Lifetime Measurements with Germanium Detector Arrays

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Lifetime measurements allow extraction of fundamental information on the nature of the excited states of a nuclear system. Since nuclear lifetimes cover many orders of magnitude, a number of experimental techniques and detection setups have been developed depending on the range of the lifetime of interest. The Gamma-ray Induced Doppler Shift Attenuation (GRIDSA) Method presented here is applied to the measurement of very short lifetimes, in the femtosecond range. It allows determining the nuclear lifetime by measuring the Doppler shift of a gamma ray emitted from the state of interest, in different directions with respect to a coincident preceding gamma ray, populating the same state and inducing a recoil of the nucleus in the target material with velocities of the order of 104-105 m/s. We realized an experiment in order to test the GRIDSA technique for the measurement of fs lifetimes after (n,gamma) reactions. The measurement was performed at the Institut Laue-Langevin (ILL) with 8 Ge-clover detectors of the FIPPS array. Preliminary results are discussed.

10

Gamma spectroscopy of neutron-rich isotopes in the A = 100 region produced in fission induced by cold neutrons with new FIPPS array

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For the neutron number N = 60, a sudden onset of the deformation has been observed in Y isotopes at the ground state, which is manifested by the presence of rotational bands (e.g. [1]). On the other hand, the occurrence of shape coexistence in nuclei with N = 58 and 59, in this region (e.g. [2]), suggests that the evolution of the deformation is a more gradual process. Our goal was to investigate N = 57, 96Y isotope where only a few states were known. Additionally, we decided to investigate whether deformed structures are still present in the 94Y nucleus which lies 5 neutrons away from the N = 60 boundary and in the 97Y with 59 neutrons.
The yttrium isotopes have been produced in the fission of 235U active target induced by cold neutron from the reactor at Institut Laue-Langevin. The level scheme up to excitation energies in excess of 5 MeV has been established based on multi-fold gamma-ray coincidence relationships measured with the new highly efficient HPGe array FIPPS [3] as well as during the EXILL campaign [4]. The experiment has been performed in September 2018 and it was the first fission measurement with FIPPS array. Special emphasis will be placed on comparison of those data with the ones collected during the EXILL campaign.
By exploiting delayed- and cross-coincidence techniques [5], the extensive structure has been delineated. During the analysis, over 50 new gamma transitions, which feed previously known low-spin states as well as the 9.6-s, 8+ isomer in 96Y isotope, have been identified [6, 7]. Moreover, a new isomeric state at 1655-keV excitation energy has been located with a half-life of 201 ns. By using the delayed-coincidence method it was possible to identify above the 201-ns state a few weak transitions, which seem to form a rotational band, in analogy to the structure above the 4- isomer in the 98Y isotope. In the case of 94Y isotope over 11 new gamma transitions have been identified [8] while in the 97Y, 8 new prompt lines can be observed [7]. Angular correlation analysis supported by shell-model consideration allowed to propose spin-parity assignments for most of the new levels.
The existence of the new isomeric state and the possible deformed band built on that isomer in the N = 57, 96Y isotope shed new light on the study of the onset of deformation in neutron-rich nuclei around N = 60. This observation is also in line with the new findings in the 94Y and 97Y isotopes and will be widely discussed.

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5

Neutron and proton inelastic scattering: cross section measurements

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Neutron and proton inelastic cross section measurements were performed at the GELINA neutron source of EC-JRC, Geel, Belgium and at the 9 MV Tandem accelerator of IFIN-HH, Magurele, Romania. The talk will explain the practical importance of these cross sections, will describe the experimental setup and will emphasize the quality of the results.

1

Prompt and delayed spectroscopy of the fission fragments from the 238U(n,f) and 232Th(n,f) reactions with nu-ball/LICORNE

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An experimental campaign to perform prompt and delayed spectroscopy of the fission fragments from the 238U(n,f) and 232Th(n,f) reactions has been recently carried out. The seven-week-long campaign was performed with the nu-ball spectrometer coupled to the LICORNE directional fast neutron source based at the ALTO facility of the IPN Orsay and invloved a large international collaboration. These experiments have clear complimentarities to the recent FIPPS campaign at the ILL, since different fissioning compound nuclei are studied (239U, *233Th* with fast neutrons at nu-ball/LICORNE and 234,236U*and 242Pu* with thermal neutrons at FIPPS). A comparison of the major differences of these two complementary experimental approaches can be made: For example, FIPPS has longer available running times and the ILL provides higher neutron fluxes, with thermal-neutron-induced fission cross sections also much higher than fast-neutron-induced fission cross sections. Hence, to achieve similar fission rates (25 - 100 kHz) with LICORNE requires the use of tens of grams of target material, which can attenuate the lowest energy gamma rays emitted. Nonetheless, the fissioning sytems studied with nu-ball/LICORNE are significantly more neutron-rich than those that can be studied with FIPPS. Furthermore, both experiments have their own unique problems with background from

unwanted reactions and beta decays. These have been solved with a fission tag/active-scintillator target in the case of FIPPS, and neutron-beam pulsation combined with event-calorimetry for nu-ball/LICORNE. Indeed the calorimetry aspects of the nu-ball array give access to some important new fission observables which can be correlated with the detection of individual fragments. Emerging physics results from the first nu-ball campaign will be presented.

13

Rare targets for FIPPS experiments

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Certain (n,gamma) and (n,fission) experiments with high physics interest have not been performed yet due to non-availability of suitable targets. I will review the availability and possible production of rare isotope targets that would enable such experiments.

4

Search for isovector octupole states in 146Nd

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After the successful observation of an isovector octupole state in $^{144}\mathrm{Nd}$ in the EXILL campain 2013 [1], we performed at FIPPS (phase 1) a coincident $^{145}\mathrm{Nd}(n,\gamma\gamma)$ experiment to study the level structure of $^{146}\mathrm{Nd}$. The $^{145}\mathrm{Nd}(n,\gamma\gamma)$ is well suited to search for isovector octupole states because the neutron capture state of $^{146}\mathrm{Nd}$ has a spin parity J^{π} = 3^- or 4^- and can depopulate via M1 transitions to an isovector octupole state. Two 3^- states are candidates for an isovector octupole state in this nucleus. The transition from an isovector octupole state to the first 3^- is the main fingerprint for such states and for these candidates has not been observed so far [2].
In the offline analysis of the FIPPS data, we saw that in 75% of the neodymium data the declaration of the timestamp worked incorrectly. We have observed random jumps in the timestamps and unreliable lengths of the measurement period in the detectors with the ADC channels 1 to 6. We did not observe this behavior for the detectors with ADC channels 0 and 7 and for all detectors in the data from the energy and efficiency calibration runs. We have recently solved this problem and can restart an analysis with now more than 99% of the data.
In the 25%-dataset we checked our results with earlier measurements and improved the known level structure of $^{146}\mathrm{Nd}$ by adding new 55 transitions and at least two new states [3]. The determination of the searched-for transitions is more difficult than expected and part of the current analysis. For one candidat the desired transition is hidden in the Compton background, for the other candidat the desired transition is located between other strong transitions.

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16

Search for quasiparticle states in 45Ca by neutron-capture reactions and high-resolution, gamma-ray spectroscopy

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The structure of Ca isotopes between N=20 and N=28 is crucial to understand the evolution of single-particle states and collectivity from symmetric to neutron-rich systems. Moreover, new experimental results may serve as a benchmark for the most advanced theoretical models, such as state-of-the-art shell model calculations [1] and ab-initio approaches, employing chiral two- and three-nucleon interactions [2].
The spectroscopic properties of 45Ca were measured in different experiments in the past, yet rather old ones [3-6]. A few states were observed, which were interpreted in terms of simple shell-model calculations and identified with (f7/2)^5 and (f7/2)^-3 neutron configurations, with respect to the 40Ca and 48Ca cores, respectively. However, more complex structures were identified in neighboring nuclei, such as coupled quadrupole-octupole vibrational states below 4.5 MeV in 44Ca [7].
In this context, we intend to search for quasiparticle states coupled to "core" excitations, which could be described by the extension of the Hybrid Configuration Mixing Model [8-9], being developed for open-shell, superfluid systems by the Milano group collaboration [10].
In this workshop, we will be discussing recent results on the structure of the 45Ca nucleus, studied at Institut Laue-Langevin (ILL) by the 44Ca(n,gamma) reaction. Its gamma-ray decay was investigated using the FIPPS HPGe clover array, coupled to LaBr3:Ce fast scintillators designed for lifetime measurements with fast-timing techniques. The preliminary level scheme, built with newly-observed gamma rays, will be presented and the following steps of the analysis will be outlined, along with possible theoretical interpretations.
This work is the continuation of the experimental campaign performed by this collaboration, aimed

at studying the structure of Ca isotopes by neutron-capture reactions and gamma-ray spectroscopy, as already done in the case of the 41-47-49Ca nuclei [11].

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