ANEXA 1.A

Call: PN-IV-P5.9/Subprogramul 5.9.1 **Project acronym: CIPHERS**

ELI-NP Thematics: ……

GDE/1.1 Nuclear Resonance Fluorescence Experiments

GDE/I.2 Gamma-ray studies above the neutron threshold

Annual Summary Document[1]

Year: 2024

Months: July - December (1-7)

Project Title: Complementary Investigations for Photon beams - High-Energy nuclear Resonant States with charged particle probes

Project Work Plan (according to the contract)

Stage: I.

Activities: Technical developments

I. 1. PAC proposals - statistical states, discrete states

I. 2. Plastic scintillator

I. 3. Analysis preparatory experiments

Allocated budget: 1.078.800,00 lei

Realized budget: 1.078.800,00 lei

[1] Please fill in all the required items and do not alter the template

1. Cover Page (1 page):
- Group list (physicists, staff, postdocs, students);
- Specific scientific focus of group (state physics of subfield of focus and group's role);
- Summary of accomplishments during the reporting period.

Staff:
Pär-Anders Söderström, Sohichiroh Aogaki, Dimiter Loukanov Balabanski,, Ruxandra Borcea, Cristian Costache, Nicoleta Florea, Asli Kusoglu, Constantin Mihai, Razvan Lica, Catalin Neacsu, Dmitry Testov, Andrei Turturica, Gabriel Valter Turturica

Postdocs:
Anamaria Spataru

Students:
Sara Rebeca Ban, Maria Brezeanu, Andreea Ghitiu (Gavrilescu), Raj Alexandru Gutoiu, Teodora Andreea Madgearu (Petruse), Alexandru Gabriel Stoica, Sorin Ujeniuc

Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Involved in the interpretation and analysis of the experimental data from the preparatory experiments, detector development, and discussion and preparation for coming experiments

Specific scientific focus of group: Experimental studies of nuclear structure using charged particle and photon beams with multi-element detector arrays. The role of the group has been to develop the software and hardware, perform the experiments, analyse the experimental data, and disseminate the experimental data at conferences and in form of publications.

2. Scientific accomplishments (max. 3 pages) – Results obtained during the reporting period.

2.1 Experimental proposals

One submitted proposal is to do a precision measurement of the double-gamma decay in ^{72}Ge in order to determine the nuclear matrix elements governing the decay. The branching ratio for the double-gamma decay has been recently determined at GSI to be $2x10^{-5}$. The isomer will be populated in a (p,p') reaction and p-γγ coincidences will be measured to determine the angular distribution of the g rays, which is sensitive to the relative importance of double E1 and M1 decays.

Another proposal submitted is the continuation of the measurements of the nuclear level densities and photon strength functions in the nucleus ^{140}Ce has been submitted to the IFIN-HH PAC. This proposal follows an experiment performed in November 2024 at HIγS aiming to study relative self-absorption experiments with ^{140}Ce to study the nuclear level density of dipole-excited states in the excitation energies below the neutron separation threshold using gamma-ray beams. These two experiments together will provide valuable information, not only about the statistical model parametrizations and microscopic approach to nuclear level densities, but also serve as a benchmark for charged-particle reactions and gamma-ray beam reactions that will be used at ELI-NP. The HIγS experimental technique is based on a series of self-absorption measurements with absorbers of different thickness, while the ELI-NP/IFIN-HH experimental technique will be based on the Oslo method with proton beams.

2.2 Plastic scintillator

Fast-timing methods are well-established methods that have been used extensively at IFIN-HH with coincidence techniques for nanosecond and sub-nanosecond lifetimes of excited nuclear states. For this to work, two signals are needed: one used as a start, givenand one as a stop. The time difference between these two signals gives the lifetime of the measured excited nuclear state. Typically, this has been done using fast scintillating detectors such as $LaBr_3$(Ce) to obtain the timing of gamma photons. In the case of transfer reactions, when the level of interest is directly populated from the nuclear reaction, there is no gamma photon that can be used as a start. In this scenario, the residual charged particles can be used with a fast charged-particle timing detector. Such a detector has been developed that can operate in vacuum conditions within the ROSPHERE reaction chamberbased on a BC400 plastic scintillator connected to a SiPM readout and secured by a 3D-printed holder inside the reaction chamber. This detector is shown in Figure 1.

The testing of this new detector was achieved via in-beam tests comparing the detector's performance to that of a 1.5 × 1.5 × 1 inch conical LaBr3(Ce) crystal, which was coupled to an R9779 Hamamatsu PMT readout. The LaBr3(Ce) conical crystal was chosen for its good time resolution, of 130 ps. We chose a transfer reaction induced by a beam of ^{11}B on a ^{181}Ta target, at incident energy (47 MeV) below the Coulomb barrier. This is a well known reaction, previously used at the ROSPHERE array. The new plastic detector was placed in the reaction chamber in front of the target with respect to the beam direction, while the $LaBr_3$(Ce) detector was placed outside the reaction chamber as close as possible to the target position. We achieved a time resolution of 896(5) ps, and we showed that this can be greatly improved by adding more SiPM cells to enhance photon collection. We showed that the detector can distinguish between charged particles and photons, and, if necessary, to further decrease photon efficiency we can reduce the plastic thickness to 1 mm. By utilizing a fully covered SiPM readout, we can take advantage of its granularity to add positioning sensitivity capabilities, enabling angular measurements.

2.3 Analysis of preparatory experiments

For measuring γ-ray strength functions and nuclear level densities below the neutron separation threshold, the Oslo method has been used extensively over the years. With the projected photon beams at the ELI-NP, which is expected to provide users with narrow bandwidth photon beams for photoexcitation and decay studies, there will be new opportunities to measure the γ-ray strength functions directly. In 2023, an experiment was performed to apply the Oslo method at the 9MV facilities at IFIN-HH for the first time. The choice of targets for this experiment was ^{112}Sn, due to it recently being measured at the Oslo Cyclotron Laboratory for verification of the results, and ^{114}Sn, as this was not previously measured.

The experiment was performed using the 21 ELIGANT-GN large-volume $LaBr_3$:Ce, and $CeBr_3$ detectors mounted in the ROSPHERE structure at the 9MV Tandem accelerator at IFIN-HH, see Ref- erence for an overview of this setup. In addition to the γ-ray detectors, the setup included a $\Delta E - E$ telescope consisting of two annular DSSSD in the backward direction for scattered charged particles.

Here we will discuss the measured γ-ray strength functions for ^{112}Sn and ^{114}Sn. While we extract these at low energy, up toaround 8 MeV, we can compare the results with the high-energy total excitation strength obtained from high-energy (p, p′) scattering at very forward angles performed at the RCNP, Osaka University. In Figure 2, we show the agreement both in absolute values for ^{112}Sn and ^{114}Sn between our data sets and the RCNP data sets. Furthermore, for ^{112}Sn, our data, the Oslo data, and the RCNP data agree very well, suggesting that the experimental procedures are sound. For comparison, we also include a comparison to some of the frequently used global parametrizations of the γ-ray strength functions, especially for systematic astrophysical rate calculations and similar, as implemented in the TALYS code. While several different γ-ray strength functions models exist in this code, we have limited the comparison to some recommended models.

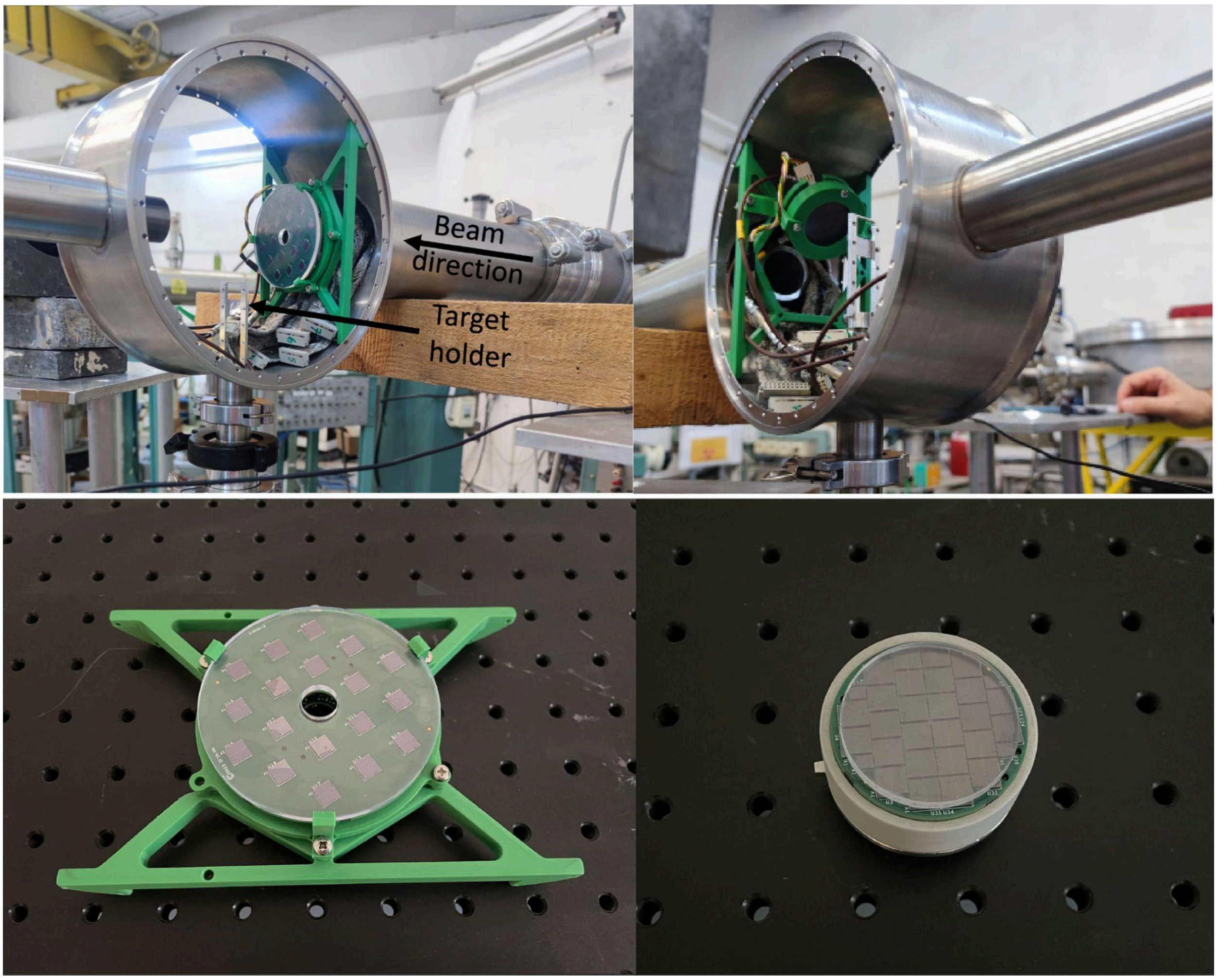

Figure 1: Top panels: the setup used to test the detectors. Bottom panels: zoomed in picture of the detectors. On the left is the sparse SiPM array, and on the right is the full SiPM array placed off-beam at an angle of 45°.

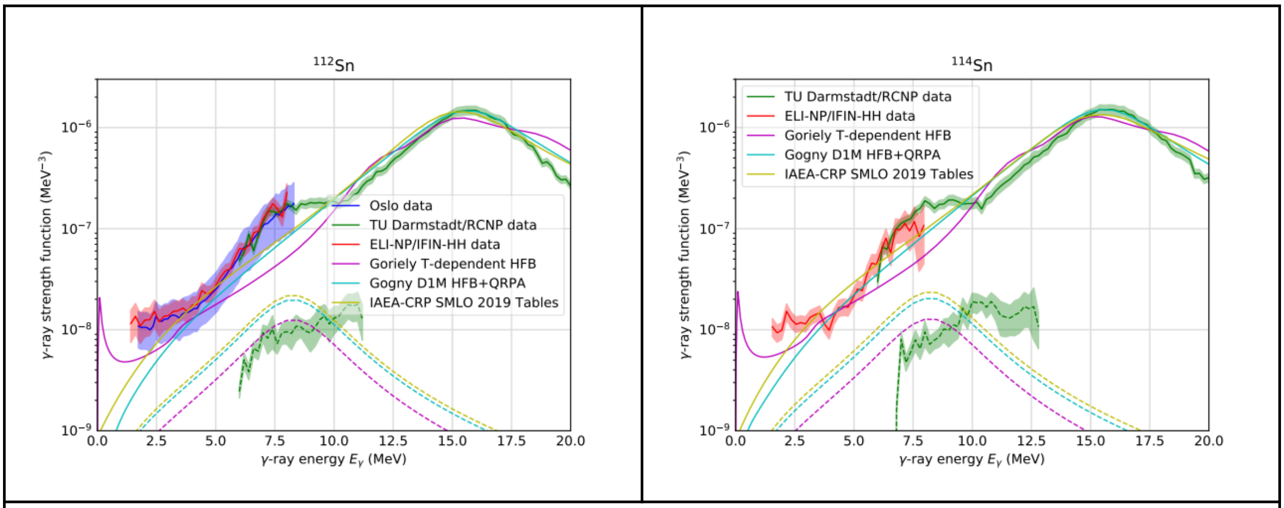

Figure 2: Experimental γ-ray strength funtions of ^{112}Sn and ^{114}Sn

We have shown that using a combination of ELI-NP and IFIN-HH infrastructure, we can extract γ-ray strength functions using methodology developed by Oslo University and the Oslo Cyclotron Laboratory. This type of experiment will serve as a complementary approach to the scientific case of ELI-NP, where this type of observables will be measured using γ-ray beams.

3. Group members (table):

- List each member, his/her role in project and the Full Time Equivalent (FTE) time in project. The FTE formula to be used is: FTE = Total number of worked hours /Total number of hours per reporting period[2];
- List PhD/Master students and current position/job in the institution.

		CO/Partner	Role in project	Full Time Equivalent (FTE)
1	AOGAKI Soichiro	CO IFIN-HH	Team member/Software	0.082
2	BALABANSKI Dimiter		Team member	0.036
3	BAN Sara Rebeca		Team member/Master student	0.072
4	BORCEA Ruxandra		Team member	0.044
5	BREZEANU Maria		Team member/Master student	0.166
6	COSTACHE Cristian		Team member	0.134
7	FLOREA Nicoleta Mihaela		Target responsible	0.058
8	GHITIU (GAVRILESCU) Andreea		Team member/PhD student	0.092
9	GUTOIU Raj Alexandru		Team member/Master student	0.020
10	KUSOGLU Asli		Team member	0.143
11	LICA Razvan		Team member	0.178
12	MADGEARU (PETRUSE) Teodora		Team member	0.041
13	MIHAI Constantin		Team member	0.101
14	NEACSU Catalin		Team member	0.041
15	SÖDERSTRÖM Pär-Anders		Project director	0.143
16	SPATARU Anamaria		Team member	0.020
17	STOICA Alexandru Gabriel		Team member/PhD student	0.036
18	TESTOV Dmitry		Team member	0.041
19	TURTURICA Andrei Emanuel		Team member	0.146
20	TURTURICA Gabriel		Team member	0.149
21	UJENIUC Sorin		Team member/PhD student	0.053

[2] Total number of hours (for a certain period) = 170 average monthly hours x number of months (e.g., for a full year: 170 hours/month x 12 months = 2040 hours)

Name	PhD/Master students	Position in the institution
BAN Sara Rebeca	Master student	AC
BREZEANU Maria	Master student	AC
GHITIU (GAVRILESCU) Andreea	PhD student	AC
GUTOIU Raj Alexandru	Master student	AC
MADGEARU (PETRUSE) Teodora	PhD student	AC
STOICA Alexandru Gabriel	PhD student	AC
UJENIUC Sorin	PhD student	AC

4. Deliverables in the last year related to the project:
- List of papers (journal or conference proceeding);
  - P.-A, Söderström, et al., *Statistical properties and photon strength functions of the ^{112,114}Sn isotopes below the neutron separation threshold*, submitted to Phys. Rev. C
  - P.-A, Söderström, et al., *Neutron and gamma-ray measurements around the particle separation threshold at the Extreme Light Infrastructure - Nuclear Physics*, submitted to Acta Phys. Pol. B

- List of talks of group members (title, conference or meeting, date);
  - A. Kuşoğlu, *Pilot experiments with an array of large volume $LaBr_3$:Ce and $CeBr_3$ scintillators with anti-Compton shields*, (Invited talk) The Turkish Physical Society's 40th International Physics Congress, Bodrum, Turkey, September 2-6, 2024
  - P.-A. Söderström, et al., *Gamma Above Neutron Threshold at ELI-NP: How we got here and where we are going*, (Contributed talk) International Symposium on Nuclear Science, Sofia, Bulgaria, September 9-13, 2024
  - A. Kuşoğlu, *Understanding better the PDR strength through (d,pγ) reactions: N = 28 and 50 nuclei*, (Contributed talk) International Symposium on Nuclear Science, Sofia, Bulgaria, September 9-13, 2024

- Other deliverables (patents, books etc.).
  - P.-A. Söderström, et al., *Study of nuclear level density of ^{140}Ce*, proposal for the IFIN-HH PAC 2024
  - W. Korten, et al., *Precision measurement of the double-gamma decay in ^{72}Ge*, proposal for the IFIN-HH PAC 2024
  - M. Brezeanu, et al., *Influence of different level-density models on the extrapolation in the Oslo method*, submitted to ELI-NP Annual Report 2022-2024
  - P.-A. Söderström, et al., *Photon strength functions of the ^{112,114}Sn isotopes below the neutron separation threshold*, submitted to ELI-NP Annual Report 2022-2024
  - P.-A. Söderström, et al., *Nuclear level density of ^{128}Te with complementary probes and methods*, submitted to ELI-NP Annual Report 2022-2024

5. Further group activities (max. 1 page):
- Within the team activities for 2024 we (P.-A. Söderström, S.R. Ban) have participated in external experiments at the Centrum Cyklotronowe Bronowice, Krakow, “Study of M4 Stretched configuration decay in ^{12}C” as part of the program for external experiments in this project. P.-A. Söderström have also participated in a self-absorption experiment for nuclear level density

measurements using gamma-ray beams at the High Intensity γ-Ray Source (HIγS) at Duke university in the USA, on ^{140}Ce which is one of the key cases in this research project, and a nuclear resonance fluorescence experiment on ^{70}Zn for gamma-strength distribution.