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: 2025

Months: January - December (1-12)

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

Project Work Plan (according to the contract)

Stage: II.

Activities:

II. 1. Geant4 simulations

II. 2. DAQ system

II. 3. Silicon detectors

II. 4. PAC proposals - complementary

II. 5. Experiments - statistical states

Allocated budget: 1.676.400,00 lei

Realized budget: 1.676.400,00 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, Sorin Pascu, Dmitry Testov, Andrei Turturica, Gabriel Valter Turturica

Postdocs:
Hafez Aslani, Teodora Andreea Madgearu (Petruse), Anamaria Spataru

Students:
Sara Rebeca Ban, Maria Brezeanu, Andreea Ghitiu (Gavrilescu), Raj Alexandru Gutoiu, 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 Geant4 simulations

The first task for 2025 focuses on the Geant4 simulation of the experimental setup for high-energy γ-ray spectroscopy using large-volume $LaBr_3$:Ce and $CeBr_3$ detectors within the ELIFANT array at IFIN-HH. The simulations were performed using the Geant4 toolkit and the GROOT simulation package with the geometries imported from CAD files. The simulated setup includes the detector array, BGO shields, and mechanical structures, with the possibility to include up to 24 detectors across the five rings and the dedicated reaction chamber developed for the charged-particle experiments. From these simulations we calculate the full-energy peak efficiency and peak-to-total ratio for several different cases, to build a total response matrix for the array that will be used for the interpretation of the experimental data. This response includes the stationary emission of γ rays as well as Doppler shifted and Doppler corrected response. In Figure 1, such a response matrix is shown following the emission of γ rays from a nucleus traveling at a velocity of 0.09339 relative to the speed of light, both with and without the anti-Compton rejection shields activated. In general, the comparisons of these simulations to the experimental data show that we are well in control of the experimental setup and that we understand the setup from a simulation point of view, something that will be used for the interpretation of the results.

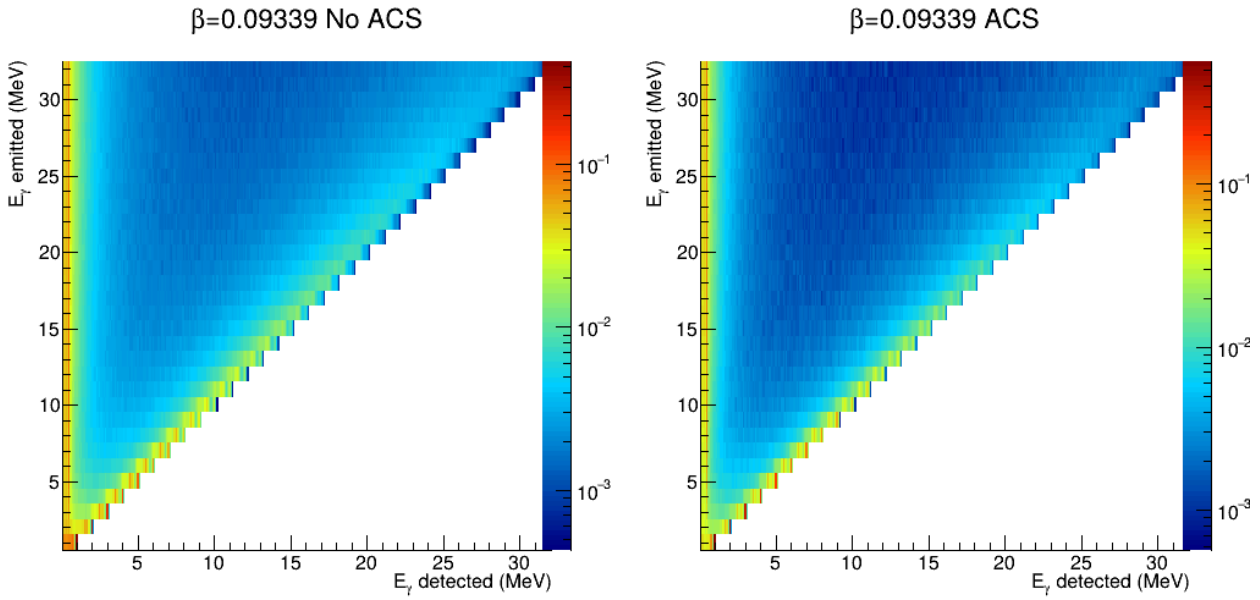

Figure 1: Simulated response matrix including Doppler shift and Doppler correction without (left) and with (right) ACS shields activated.

2.2 DAQ system

The DAQ software DELILA was further developed to implement and combine the newly purchased V2730 digitiser into a complete setup. During the ELIFANT campaign at the 9MV facility at IFIN-HH, Romania, several experiments were carried out with this configuration, in particular the measurement of the nuclear level density of ^{140}Ce that is one of the key measurements for this project. In this experiment, DELILA was implemented to record data from several different detectors with very different characteristics and different readout firmware. More precisely, in this experiment, a 14 MeV proton beam from the Tandem accelerator bombarded a thin target of ^{140}Ce, and the resulting nuclear reaction products and gamma radiation were detected 4 HPGe detectors, 20+24 scintillation detectors ($CeBr_3$ and $LaBr_3$, both with anti-Compton shields), and two annular silicon strip detectors (122 total channels) applying the ΔE-E technique for particle identification.

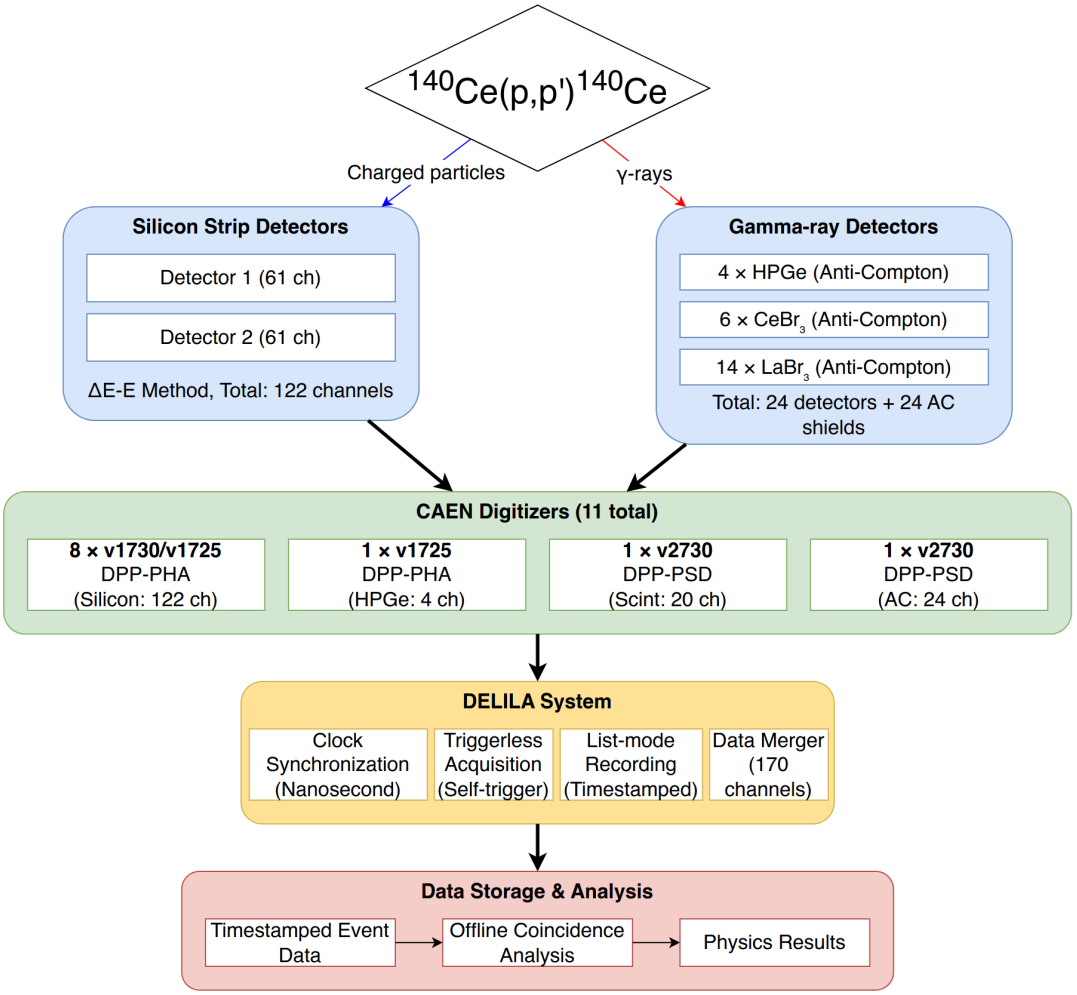

Figure 2: DAQ structure of DELILA during the ^{140}Ce experiment

In these measurements, DELILA's software managed up to 170 acquisition channels across 11 CAEN digitizers, each configured with optimally selected firmware for the corresponding detector type (DPP-PHA for HPGe and silicon, DPP-PSD for scintillators). The clock synchronization between silicon and scintillator signals showed a time-resolution of about 5 ns FWHM and with good stability over extended runs, even after hardware resets. Minor timing shifts (about 8 ns) between digitizer models were observed, due to the different sampling frequencies, cable delays and internal delays. The general DAQ structure is shown in Figure 2.

The data analysis procedure developed within the DELILA framework involved three main steps: calibration with standardised radioactive sources, L1 coincidence event selection, and L2 user-defined logic for event filtering. The eventbuilder that was developed for this analyser was based on the ROOT framework and could efficiently process several hours of data within minutes. Operationally, the system was shown to have a high reliability with up to 11 days of continuous use in the case of the longest beam time.

2.3 Silicon detectors

One of the goals for this year was to test the performance of a silicon detector setup for measurements in the GDR and PDR regions. For this purpose we purchased a set of dedicated silicon detectors of CD shape of NTD type to be used in the ΔE−E particle telescope. A dedicated beam-time at the 3MV Tandem was carried out partially using the V2730 digitizer acquired within the scope of this project to test the pulse-shape identification algorithms for particle identification in the NTD type detectors. In addition to

this, a dedicated beam-time at the Research Center for Nuclear Physics at Osaka University was carried out aiming at the GDR photoescitation cross-section of several light isotopes (^{12}C, ^{16}O, ^{26}Mg, ^{27}Al, ^{56}Fe). In this setup, a lampshade style detector, as described in this project proposal, consisting of NTD silicon was installed for charged-particle identification and charged-particle branching ratios. This setup included both digitizers and standard analogue electronics to make use of both digital pulse-shape identification techniques and ΔE−E methods and will serve as a critical data set for comparison of the performance of these detector setups.

2.4 PAC proposals - complementary

As a follow-up to the ^{140}Ce low-energy NLD measurements, an experimental proposal to measure the NLD of ^{140}Ce above the neutron separation energy has been prepared. The motivation for this complementary proposal is the importance of high-energy NLDs in certain applications that can not necessarily be extrapolated from the low-energy data. The Oslo method, widely used for NLD extraction below the neutron threshold relies on γ-ray spectroscopy and can not, thus, be used near or above the neutron separation threshold due to model dependencies and the need for extrapolation of the data.

To complement these challenges we proposed an experiment using particle evaporation spectra instead of γ-ray spectra. Specifically, the reaction channel of interest was the neutron emission following the ^{139}La(^{6}Li,αn)^{140}Ce reaction. This method makes it possible to measure NLDs above the neutron threshold by reconstructing excitation energy using detected alpha particles and correlating them with the associated neutron spectra. The planned setup features 24 ELIGANT-GN liquid scintillator detectors arranged in a Neutron Wall geometry, silicon detectors for ΔE−E particle identification, and large-volume $CeBr_3$ and $LaBr_3$ detectors for complementary data. The ^{6}Li beam will be pulsed and the target a thin ^{139}La foil.

2.5 Experiments - statistical states

From an experimental working point we have performed the NLD and γ-ray strength function (γSF) measurements outlined in the project proposal, aiming at ^{140}Ce using the Oslo method at the 9MV Tandem at the IFIN-HH institute. The experiment used a 14 MeV proton beam on ^{140}Ce, ^{176}Yb, and ^{110}Pd targets, with 21 ELIGANT-GN large-volume $LaBr_3$:Ce and $CeBr_3$ detectors for gamma-ray detection, and four HPGe detectors for reaction channel identification and spin distribution. The setup also included silicon detectors for charged particle identification and a data acquisition system, based on CAEN digitizers as described above. The beam time performed was for three days of data acquisition on ^{140}Ce, and three days of data acquisition on ^{110}Pd, plus 3 hours of data acquisition on ^{176}Yb as a preliminary study of a highly deformed nucleus with a high level density and possible additional collective structures like a scissors resonance. This data is still under analysis.

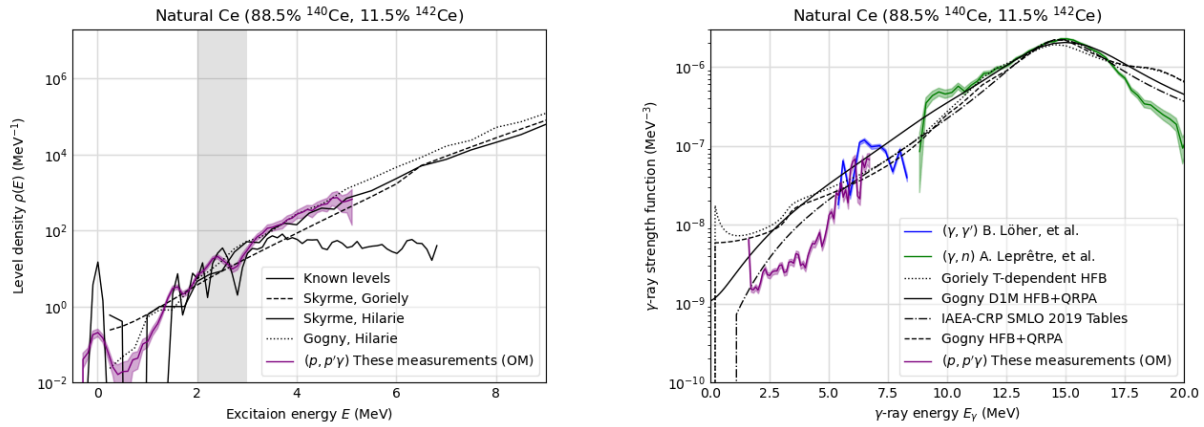

Figure 3: Preliminary results from the ^{140}Ce NLD and γSF experiment

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	0.018
2	ASLANI Hafez		Team member	0.0
3	BALABANSKI Dimiter		Team member	0.0
4	BAN Sara Rebeca		Team member/Master student	0.202
5	BORCEA Ruxandra		Team member	0.0
6	BREZEANU Maria		Team member/Master student	0.117
7	COSTACHE Cristian		Team member	0.146
8	FLOREA Nicoleta Mihaela		Target responsible	0.106
9	GHITIU (GAVRILESCU) Andreea		Team member/PhD student	0.215
10	GUTOIU Raj Alexandru		Team member/Master student	0.0
11	KUSOGLU Asli		Team member	0.413
12	LICA Razvan		Team member	0.028
13	MADGEARU (PETRUSE) Teodora		Team member	0.167
14	MIHAI Constantin		Team member	0.358
15	NEACSU Catalin		Team member	0.115
16	PASCU Sorin		Team member	0.136
17	SÖDERSTRÖM Pär-Anders		Project director	0.523
18	SPATARU Anamaria		Team member	0.0
19	STOICA Alexandru Gabriel		Team member/PhD student	0.113
20	TESTOV Dmitry		Team member	0.036

[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)

21	TURTURICA Andrei Emanuel		Team member	0.216
22	TURTURICA Gabriel		Team member	0.091
23	UJENIUC Sorin		Team member/PhD student	0.020

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, A. Kuşoğlu, *Nuclear level densities and photon strength functions at ELI-NP/IFIN-HH*, submitted to NSP2025 proceedings

- List of talks of group members (title, conference or meeting, date);
  - A. Kuşoğlu, et al., *Preparatory experiments for the ELI-NP gamma beams at the tandem accelerator of IFIN-HH*, (Contributed) The 8th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX8), Florida State University, Tallahassee, Florida, USA, 15-19 December 2025
  - P.-A. Söderström, et al., *Dipole strength below the neutron threshold from Tandem experiments at ELI-NP/IFIN-HH*, (Contributed) The 8th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX8), Florida State University, Tallahassee, Florida, USA, 15-19 December 2025
  - A. Gavrilescu, et al. *Analysis of High-Energy (p,p') data on ^{10,11}B for the PANDORA Project*, (Poster) The African Nuclear Physics Conference 2025 (ANPC 2025), iThemba LABS, Cape Town, South Africa, 24-28 November 2025
  - A. Kuşoğlu, et al., *Direct Observation of the competing M1 and isospin-forbidden M3 transitions from the decay of the IAS in ^{10}B*, (Contributed talk) International Conference on Nuclear Photonics, Technische Universität Darmstadt, Darmstadt, Germany, 5-10 Oct 2025
  - P.-A. Söderström, et al., *Photon strength functions and nuclear level densities at ELI-NP/IFIN-HH*, (Contributed talk) International Conference on Nuclear Photonics, Technische Universität Darmstadt, Darmstadt, Germany, 5-10 Oct 2025
  - A. Kuşoğlu, et al., *ELIFANT Spectrometer: A State of the Art Instrument for Experiments of High Energy Gamma-Rays*, (Invited talk) Carpathian Summer School of Physics 2025. Exotic Nuclei and Nuclear/Particle Astrophysics (IX). Physics with small accelerators, Sinaia, Romania, 1 Jul 2025
  - P.-A. Söderström, et al., *Nuclear properties around the particle separation threshold using γ-ray and charged particle probes*, (Invited talk) Carpathian Summer School of Physics 2025. Exotic Nuclei and Nuclear/Particle Astrophysics (IX). Physics with small accelerators, Sinaia, Romania, 1 Jul 2025

- A. Kuşoğlu, et al., *ELIFANT: First Results with a New Tool in Nuclear Spectroscopy*, (Invited talk) XVII. International Conference on Nuclear Structure Properties, Sivas Cumhuriyet Üniversitesi, Sivas, Türkiye, 27 Jun 2025
- P.-A. Söderström, et al., *Nuclear level densities and photon strength functions at ELI-NP/IFIN-HH*, (Invited talk) XVII. International Conference on Nuclear Structure Properties, Sivas Cumhuriyet Üniversitesi, Sivas, Türkiye, 27 Jun 2025
- P.-A. Söderström, et al., *Experimental Nuclear Level Densities at ELI-NP and IFIN-HH*, (Workshop) 1st RCM on Updating and Improving Nuclear Level Densities for Applications, International Atomic Energy Agency Headquarters, Vienna, Austria, 26 Mars 2025
- A. Kuşoğlu, *Can we measure g factors of short-lived excited states at GSI/FAIR?*, (Invited talk) Workshop on Nuclear Moments WNM'25, Orsay, France, 12-14 May 2025
- M. Brezeanu, *Influence of different level-density models on the extrapolation in the Oslo method*, (Contributed talk) Young Researchers & Young Engineers Days, ELI-NP, Marurele, Romania, February 25-26, 2025

- Other deliverables (patents, books etc.).
  - P.-A. Söderström, et al., *Experimental feasibility of high-energy nuclear level density measurements by neutron evaporation into the continuum of ^{140}Ce*, proposal for the IFIN-HH PAC 2025

5. Further group activities (max. 1 page):
- Within the team activities for 2025 A. Kuşoğlu participated in CERN/ISOLDE experiment IS673 "*Nuclear moments of excited states in neutron rich Sn isotopes studied by on-line PAC*" 2025-05-01 - 2025-05-05, P.-A. Söderström and A. Kuşoğlu participated in the CCB Krakow experiment *"PDR in ^{64}Ni as systematic sequel of the study in $^{58,62}Ni$ isotopes using the inelastic proton scattering at CCB"* 2025-05-16 - 2025-05-19, P.-A. Söderström, A. Kuşoğlu, and D. Balabanski participated in the University of Jyväskylä experiment *"The g-factor measurement of picosecond states using the Time Dependent Recoil in Vacuum technique on Li-like charge states"* 2025-05-26 - 2025-06-01, P.-A. Söderström, A. Kuşoğlu, T. Madgearu (Petruse), and A. Ghitiu (Gavrilescu) participated in the RCNP/Osaka University experiment *"Photo-nuclear reactions of ^{16}O, ^{26}Mg, ^{40}Ca and ^{56}Fe"* 2025-10-13 - 2025-11-04. P.-A. Söderström and A. Kuşoğlu participated in the CERN/ISOLDE experiment *"Transition probabilities of low-lying excited states in ^{210}Po and ^{210}Pb"* 2025-11-04 - 2025-11-07, P.-A. Söderström, A. Kuşoğlu participated in the HIgS experiments *"Evolution of the internal decay branching ratio of the GDR in the Samarium isotopic chain"* and *"First Study of the Giant Dipole Resonance's γ-decay Behavior Across a Shape-Phase Transition"* 2025-12-01 - 2025-12-14.
- In addition the team has partially contributed resources or manpower to several publications within collaborations
  - A. Gavrilescu, et al. *In-beam commissioning of the Grand Raiden spectrometer coupled with the silicon detector array SAKRA at RCNP*, Phys. Scr., in print.
  - K. Sakanashi, et al. *Precise measurements of the γ-decay probability of the Hoyle state with a new triple coincidence-detection method*, Phys. Lett. B, 870:139893, 2025
  - A. Giaz, et al. *Probing the Isospin Mixing in the ^{72}Kr Compound Nucleus via GDR γ Decays* Phys. Lett. B, 868:139653, 2025.
  - P.-A. Söderström, et al. *Nuclear level density of ^{128}Te from (p,p'γ) scattering and complementary photonuclear data*, Phys. Scr., 100:075301, 2025.
  - S-R. Ban, et al. *Hardware Simulation of Particle Identification Algorithms for Silicon Detectors* UPB Sci. Bull. A, 87(3):165, 2025.
  - P.-A. Söderström, et al., *ELIGANT-TN – ELI Gamma Above Neutron Threshold: The Thermal Neutron setup*, submitted to NIM A
  - S. Aogaki, et al., *DELILA: A Scalable Data Acquisition System for Multi-Detector Nuclear Physics Experiments at ELI-NP*, IEEE Trans. Nucl. Sci. in print

- D. L. Balabanski, A. Kuşoğlu, P.-A. Söderström, *While waiting for γ beams at ELI-NP: First results from ELIGANT and ELIFANT experiments*, EPJ Web Conf., 342:01002, 2025
- C. A. Ur, et al., *Extreme Light Infrastructure - Nuclear Physics: First results*, Eur. Phys. J. A, 61:248, 2025.
- S. Aogaki, and S. Niculae, *Implementation and development of a DAQ system DELILA at ELI-NP*, EPJ Web Conf., 337:01156, 2025
- J.S. Heines et al., *New Lifetime Measurements in the Ruthenium Chain: Investigating the Evolution of Triaxiality*, Acta Phys. Pol. B Proc. Suppl., 18:2-A22, 2025.
- O. Wieland et al., *Search for Extra Yield in Hot Ni Isotopes Below the Giant Dipole Resonance*, Acta Phys. Pol. B Proc. Suppl., 18:2-A33, 2025.

6. Financial Report (budget usage) for the reporting period (see the Annex).

7. Research plan and goals for the next year (max. 1 page).

For the year 2026, according to the Project Work Plan, we intend to focus on performing the remaining experiments on discrete states as well as the complementary experiments that have been discussed here. This will include several experiments at the 9MV Tandem as well as external experiments that have been discussed in this report, the previous year report, and the project proposal. Another task for next year is the analysis of both the discrete state experiments, the statistical state experiments and the complementary experiments that are planned.