ANEXA 1.A

Call: ELI-RO/RD/2024 **Project acronym: ELITE**

ELI-NP Thematics: GDE/I.5 Photo-fission studies; GDE/I.7 Techniques and instrumentation for production, transport and diagnostics of radioactive ion beams; GDE/I.11 Development of common data format for VEGA experiments.

Annual Summary Document[1]

Year: 2024

Months: July – December

Project Title: Frontier nuclear fission studies at ELI-NP / ELITE

Project Work Plan

Stage: I.

Activities:

I. 1. Spontaneous fission experiments with a 252Cf source at ELI-NP (part I)

I. 2. In-beam photo-fission experiments (part I)

I. 3. Innovative solutions for FF detectors and RF carpets (part I)

I. 4. Digital pulse processing and automation of fission detectors (part I)

Allocated budget: 1.068.800,00 lei

Realized budget: 1.068.800,00 lei

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

1. Cover Page:
- Group list (physicists, staff, postdocs, students);

The project team is the following:
1. Dimiter L. Balabanski, Project Director, CS I;
2. Alexandru N. State, Activity Responsible, Post-Doctoral Assistant;
3. Adrian I. Rotaru, Activity Responsible, Research Scientist;
4. Sohichiroh Aogaki, Activity Responsible, IDT II;
5. Par-Anders Soderstrom, CS II;
6. Paul Constantin, CS III;
7. Asli Kusoglu, CS III;
8. Deepika Choudhury, CS III;
9. Sangeeta Dhuri, Post-Doctoral Assistant;
10. Teodora Andreea Madgearu (Petruse), PhD Assistant;
11. Rebeca Ban, Enginer, Master Student;
12. Radu Vasile Corbu, Engineer, Master Student;

- Specific scientific focus of group (state physics of subfield of focus and group's role);

The group works in the field of nuclear physics, addressing the emerging field of nuclear photonics. The PI and the members of the team address cutting-edge problems related to fission. The approach is twofold, by performing experimental work and subsequent data analysis and by designing and construction of innovative experimental equipment, implementation of next generation electronics, e.g., FPGA programmable digitizers, and improvement of the digital pulse processing, e.g., upgrades of the existing digital data-acquisition system.

- Summary of accomplishments during the reporting period.

The ELITE project started in the second half of 2024, and work on all activities started with the beginning of the project. In particular, for activity I.1 Spontaneous fission experiments with ^{252}Cf source at ELI-NP, the work on analysis of prompt fission neutron energy-angular correlations (PFN) is in an advance phase, and data taking of fission fragment (FF) – PFN – prompt fission gamma (PFG) FF-PFN-PFG correlations started. For activity I.2 In-beam photo-fission experiments, the data from the 2022-2023 HIγS, Duke U. campaigns is in an advanced stage of analysis. For activity I.3 Innovative solutions for FF detectors and RF carpets, test benches for characterization of THGEM detectors and RF carpets were set up, and the work on design of a FBIG with segmented anode was initiated. For activity I.4 Digital pulse processing and automation of FF detectors, the digital DAQ DELILA has been upgraded for needs of the FF-PFN-PFG energy-angular correlation experiment. The procurement of the foreseen equipment for stage I (2024) has been successfully completed. One paper and two conference proceedings are in preparation. All of them will be submitted in peer-reviewed journals. The work was presented in seven oral presentations at international conferences. A post-doctoral researcher, Dr. Sangeeta Dhuri, has been hired and joined the team, replacing another post-doctoral researcher, Dr. Anamaria Spataru, who left science.

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

Activity I.1 "Spontaneous fission experiments with ^{252}Cf source at ELI-NP": The analysis of prompt fission neutron (PFN) energy-angular correlations is in an advance phase, the data taking of fission fragment (FF) – PFN – prompt fission gamma (PFG) correlations started as well.

Energy-angular neutron correlations measured with stand-alone ELEGANT-GN array: The ELIGANT-GN array consisting of 36 EJ-301 liquid scintillator detectors and 25 ^{6}Li-glass detectors placed in the upper hemisphere and 34 large volume $LaBr_3$:Ce and $CeBr_3$ detectors placed in the lower hemisphere was used for measurements of energy-angular neutron correlations. Two-neutron angular correlations with various energy conditions were studies. Results, compared to FREYA calculations [1], is shown in Fig. 1.

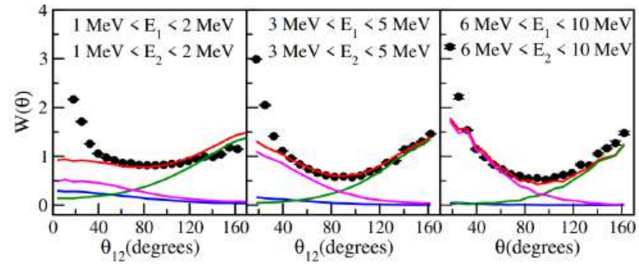

Fig.1. Two-neutron angular correlations with energy conditions: (left) the energies both neutrons are between 1 MeV and 2 MeV; (middle) the energies are between 3 MeV and 5 MeV; (right) the energies are between 6 MeV and 10 MeV. FREYA calculations considering emission by all fragments are in red, by two heavy fragments – in blue, by two light fragments – in pink and by a heavy and a light fragment – in green.

Three-neutron angular correlations were also analysed by setting different energy and angular conditions. Sample results are presented in Fig. 2. The data analysis is finalized, the results were presented at an international conference and a paper is under preparation [2].

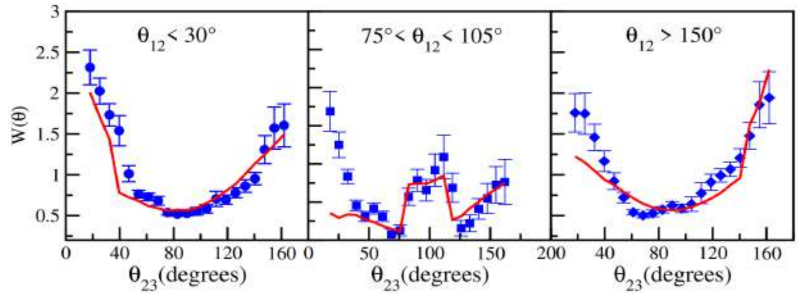

Fig.2. Three-neutron angular correlations with various neutron energies: (left) Two neutrons are emitted within 30°; (middle) Two neutrons are emitted perpendicular to each other; (right) Two neutrons are emitted in opposite directions. The neutron yield *vs* the emission angle of the third neutron is compared with FREYA calculations in red.

Measurement of FF-PFN-PFG correlations with the ELIGANT-GN array coupled to a FF trigger: A Si DSSD detector was integrated with the ELIGANT-GN array for measurements of the vector of the fission fragment. The data taking started in September 2024 and will continue six months. The digital DAQ, DELILA, which was developed in-house is used in the experiments. DELILA was upgraded to integrate the FF Si DSSD detector.

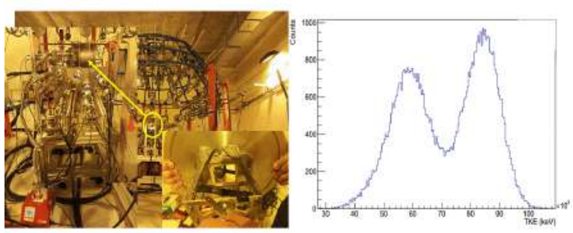

Fig.3. (Left) The ELIGANT-GN + FF trigger setup at ELI-NP. The FF Si DSSD detector is placed in a chamber in the centre of the array, which indicated with an arrow in the left-hand side insert in the figure. In the right-hand side insert is shown the assembly inside the chamber with the holder for the ^{252}Cf

source and mounted Si DSSD detector. (Right) TKE spectrum of the fission fragments measured with the ^{252}Cf source.

The experimental setup is shown in left-hand side of Fig. 3. A vacuum chamber, in which the Si DSSD detector is placed in the centre of the ELIGANT-GN array. The ^{252}Cf is mounted in the camber, in the geometrical centre of the array. In Fig. 3 (right) is demonstrated that the Si DSSD detector allows to distinguish between light and heavy fragments.

Activity I.2 "In-beam photo-fission experiments": The ELI-NP team was involved in photo-fission experiments at the HIγS free-electron laser facility, Duke University. The measurements were carried out in 2022-2023. In the experiments, three fission chambers were placed one after the other downstream the γ beam, as shown in the left-hand side of Fig. 4. Two of them were position sensitive Frisch-gridded Bragg ionization chambers (FGIC), having ^{234}U and ^{238}U targets, respectively, the third one was a dual fission chamber and was used for flux monitoring. The ^{238}U chamber was surrounded by 12 neutron and 12 γ-ray detectors for measurements of PFN and PFG. The beam parameters are listed in the figure. The data was recorded with a digital DAQ using SIS3316 digitizers read out with a custom software (see the middle part of Fig. 4). Signals were taken from the cathode, Frisch grid, left and right cage planes, and the left and right anode plane, which allows identification of the fragment and its vector. Preliminary results for the ^{238}U photo-fission mass distribution are shown in the right-hand side of Fig. 4. The responsibility for the data analysis, which is in its final stage, was taken by the LLNL group for ^{238}U, and the TU Darmstadt group for ^{234}U.

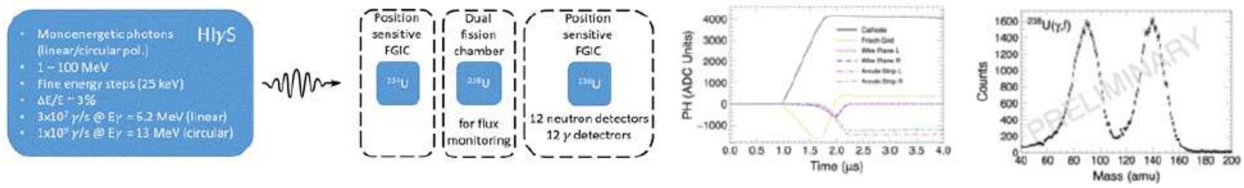

Fig.4. (left) Schematic drawing of the photo-fission setup at the HIγS facility, Duke University, (middle) digital signals from an FBIC, and (right) measured FF mass distribution for ^{238}U.

Activity I.3 "Innovative solutions for FF detectors and RF carpets": Test benches for characterization of THGEM detectors and RF carpets were set up, and the work on design of a FGIC with segmented anode was initiated. Within the project we aim at optimization of the design and the work condition for measurements of FF. A THGEM detector consists of a one or multiple PCBs and a segmented, delay-line readout anode (see Fig. 5). Often, a Frisch grid is added to stabilize the performance. A prototype THGEM with a Frisch grid was assembled, as foreseen in the research plan. In stage I (2024) we have obtained several types of THGEM boards with different thicknesses and began their characterization. ATHGEM PCB is shown in Fig. 5.

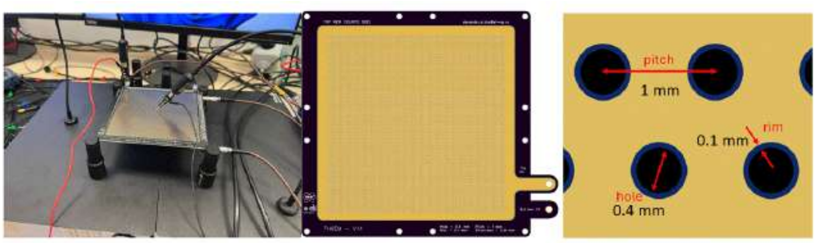

Fig.4. (left) Testing of a readout anode, (middle) typical THGEM PCB, and (right) THGEM structure.

The team is also working on the optimization of the performance of RF carpets. An RF carpet is an ion trap, consisting of a large number of, *e.g.*, concentric electrodes, which keep the fission fragments or the reaction residues above its surface and with a combination DC, RF and AF fields direct them towards a central extraction aperture. RF carpets are used in fission and multi-nucleon transfer (MNT) experiments with Ion Catcher [3] at GSI in which the team is involved. It is of utmost importance for the fast extraction of the fragments to optimize the transport regime of the ions. For this purpose, a test bench was set up at ELI-NP, and characterization of RF carpets with different geometry started.

In the photo-fission experiments at HIγS, Duke University, FGICs with segmented anode were used. A position sensitive anode adds an extra measurement parameter to fission measurements, by also providing azimuthal angle information about the fission fragment trajectory. Such a position sensitive anode can be implemented using a design similar to the one described in Ref. [4] (see Fig. 5). Work on a conceptual design of a FGIC was initiated within the project.

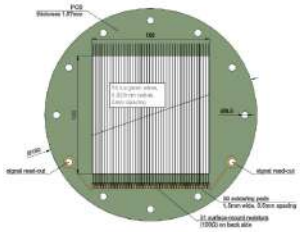

Fig.5. Technical drawing of a position sensitive grid anode [4]. The 100 x 100 mm^2 opening is covered by 50 tungsten wires with diameter 50 μm at a distance of 2 mm from each other. All units are in mm.

Activity I.4 "Digital pulse processing and automation of FF detectors": The digital ELI-NP list-mode data acquisition system (DELILA) [5] handles several types of CAEN digitizers. The ELIGANT-GN detectors are connected to VX1730B digitizers, which have a sampling rate of 500 MS/s and are triggered by constant fraction discriminator (CFD). The digitizers use pulse height discrimination (PSD) firmware which allows discrimination by using pulse-shape information. The outputs of Si DSSD detector, are connected to V1725S digitizers, which have a sampling rate of 250 MS/s. The V1725 digitizer calculates the charge using the trapezoid method. The DELILA data-taking architecture for the FF-PFN-PFG correlation experiment is shown in Fig. 6. The digitizer triggerlessly records all hits. An event builder reconstructs the data with a trigger system. In this case, when the DSSD has hit both sides of it, the builder records the other detector's hits in a time window is user defined. Note that particle identification is done using the pulse shape from the DSSD detector instead of a ΔE-E telescope. A Sci-Compiler is used with a visual-oriented FPGA programming software for reduction of the processing time.

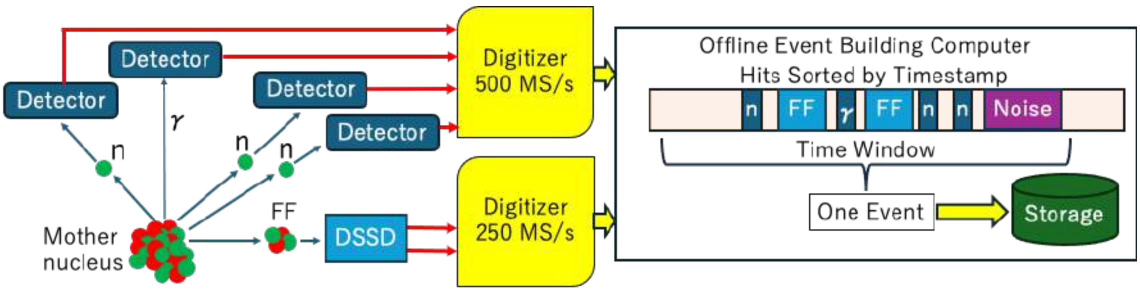

Fig.6. Data flow of the FF-PFN-PFG experiment (left) the hardware architecture, and (right) event builder.

References:

[1] J. M. Verbeke, J. Randrup, R. Vogt, Comp. Phys. Commun. 191, 178 (2015)
[2] D. Choudhury *et al*., Phys. Scr. (2025) in preparation
[3] S. Purushothaman *et al*., Europhys. Lett. **104**, 42001 (2013)
[4] M. Peck, PhD Thesis, TU Darmstadt (2020) doi:10.25534/tuprints-00013374
[5] S. Aogaki et al., IEEE Trans. Nucl. Sci. (2025) in preparation

3. Group members (table):

No.	Name	Academic Degree	Realized FTE 2024 11 July – Dec 2024	PhD/Master students
1	Dimiter L. Balabanski	CS I	0.133	-
2	Alexandru N. State	PostDoc	0.242	-
3	Adrian I. Rotaru	CS	0.239	-
4	Sohichiroh Aogaki	IDT II	0.129	-
5	Par-Anders Soderstrom	CS II	0.184	-
6	Paul Constantin	CS III	0.030	-
7	Asli Kusoglu	CS III	0.184	-
8	Deepika Choudhury	CS III	0	-
9	Sangeeta Dhuri	PostDoc	0.159	-
10	Teodora Andreea Madgearu (Petruse)	PhD Assistant	0.186	PhD student (till Oct. 2024)
11	Rebeca Ban	Engineer	0.169	Student
12	Radu Vasile Corbu	Engineer	0.238	Student

1. Deliverables since the project started: 11 July – Dec 2024

The foreseen deliverables for stage I (Year 2024) are Scientific Reports for Activities I.1 and I.2. A prototype THGEM detector with a Frisch grid was delivered within Activity I.3, and a slow-control system for the THGEM gas chamber was delivered for Activity I.4. The THGEM prototype was not used in experiments so far, since it was decided to use first a Si DSSD detector for the FF-PFN-PFG correlation measurements. In addition, the team members took part in several experiments led by our collaborators, gave eight conference talks, and published one paper and one conference proceeding. The relation of these publication to the project is that an optimized version of DELILA was used in the data taking.

- List of papers (journal or conference proceeding);
    - **A. Kusoglu, D.L. Balabanski *et al.***, "γ-ray spectroscopic study of self-conjugate ^{10}B nucleus with inelastic proton scattering", EPJ Web of Conferences 311, 00020 (2024);
    - **A. Kusoglu,** "The amazing world of the light nuclei", Science Bulletin, 69, 3303 (2024)

- List of talks of group members (title, conference or meeting, date);
    - **A. N. State**, "Characterization of supersonic helium jets used for heavy ion transport in ion catchers", International Symposium on Nuclear Science (ISNS24), Sep. 9-13, 2024, Sofia, Bulgaria.
    - **A. Rotaru**, "Enhanced Ion Manipulation Using Harmonic Ion Transport System and Spiral RF Carpets", International Symposium on Nuclear Science (ISNS24), Sep. 9-13, 2024, Sofia, Bulgaria.
    - **D. Choudhury,** "Neutron observables in the spontaneous fission of 252Cf", International Symposium on Nuclear Science (ISNS24), Sep. 9-13, 2024, Sofia, Bulgaria.
    - **S. Aogaki,** "Implementation and development of a DAQ system DELILA at ELI-NP", Conference on Computing in High Energy and Nuclear Physics (CHEP2024), Oct. 19-25, 2024, Krakow, Poland.

- List of experiments:

- **D.L. Balabanski, A. Kusoglu,** "E845 –Nuclear moment studies of short-lived excited states using TDRIV on H-like ions. Resolving the ^{22}Ne puzzle on the way to a study of ^{42}Ar and ^{44}Ar", GANIL, Sep. 17-24, 2024, Caen, France.
- **D.L. Balabanski, A. Kusoglu,** "IS748 – A study of seniority-2 configuration on N=126 and 124 isotonic chains", ISOLDE CERN, Sep. 28- Oct. 02, 2024, Geneva, Switzerland.
- **D.L. Balabanski, P.-A. Söderström, A. Kusoglu, S.R. Ban** "Study of M4 stretched configurations decay in ^{12}C", Institute of Nuclear Physics (IFJ), PAN, Oct. 18-21, 2024, Krakow, Poland.
- **D.L. Balabanski, A. Kusoglu,** "Precision measurement of the $1_2^+ \rightarrow 0_1^+$ isovector transition of ^{14}N", Triangle Universities Nuclear Laboratory, Nov. 03-10, 2024, Durham, North Carolina, USA.
- **A. Kusoglu, S.R. Ban** "NP2212-RIBF225-Nuclear moment of short-lived isomeric states using the TDPAC technique", RIKEN Nishina Centre, Nov. 14-24, 2024, Wako, Saitama, Japan.
- **A. Kusoglu, S.R. Ban,** "NP2212-RIBF225-Nuclear moment of short-lived isomeric states using the TDPAC technique", RIKEN Nishina Centre, Nov. 14-24, 2024, Wako, Saitama, Japan.

5. Further group activities (max. 1 page):

Within the project, the team collaborates with a number of research groups from all over the world. First of all, the team is involved in experiments at the HIγS free-electron laser facility, Duke University, gaining experience in experiments with γ beams. These experiments are led by the TU Darmstadt team. Team members were involved in experiments at GANIL, Caen, France, ISOLDE, CERN, the RIKEN Nishina Centre, Japan, and IFJ PAN, Krakow, Poland. These experiments were led by scientists from IJCLab, Orsay, France or IFJ PAN, Krakow, Poland. In all these cases experience related to different novel aspects related to the methodology of the experiment was accumulated by the team. To give one example, the experiments at IFJ PAN at Krakow particle identification was done using pulse shape waveforms from a DSSD detector, a technique which is applied for our in-house FF-PFN-PFG correlation measurements.

For the HIγS photo-fission experiments we collaborate with the group of Prof. Enders from TU Darmstadt, Germany and the group of Dr. Tonchev from LLNL, USA. For the development of the THGEM technology, we collaborate with the group of Dr. Cortesi from FRIB, MSU and the group of Dr. Bressler from the Weizmann Institute in Israel. For the development of the RF-carpet technology we collaborate with the group of Prof. Scheidenberger for GSI Darmstadt and the University of Giessen, Germany. For the construction of the position-sensitive FGIC we collaborate with the group of Prof. Enders from TU Darmstadt, Germany. The group of Prof. Enders is involved in our FF-PFN-PFG correlation measurements, too.

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

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

The research plan for stage II (Year 2025) included the following activities:

Activity II.1 "Spontaneous fission experiments with ^{252}Cf source at ELI-NP (part II)": The FF-PFN-PFG correlation measurements with a Si DSSD detector will continue till March 2025. After that the ELIGANT-GN detectors will be needed for an experimental campaign at the 9 MV tandem accelerator of IFIN-HH. They will become available in the fall of 2025 when a setup using a THGEM detector for FF will be assembled.

The goals are to finalize the analysis of the 2024 data, successfully start to accumulated data with the 2025 ELIGANT-GN+THGEM FF trigger array, and publish three peer reviewed papers and one conference proceeding.

Activity II.2 "In-beam photo-fission experiments (part II)": In 2025 we expect that the analysis of the 2022-2023 HIγS photo-fission experiments will be finalized. Members of the project team are in regular contacts with the collaboration related to the data analysis. The PI of the project is member of the PhD committee of Mr. Wende, who is analysing the ^{234}U data. Mr. Wende is in the last year of his PhD, and he reported that the analysis is almost done and he is going to prepare the results for publication. There is further experimental proposal of the TU Darmstadt group, which will be submitted to the HIγS PAC, which aims at photo-fission studies in ^{236}U around the fission barrier, and the project team is part of this proposal. The requirement of the HIγS PAC is that the results from previous experiments should be published/submitted for publication prior application for further beam time.

The data for ^{238}U are analysed by Dr. Malone, who recently got a tenure track position at the US Naval Academy in Annapolis, MD, USA. He is supposed to finalize the analysis of these data and publish them as soon as possible.

The goals are to finalize the analysis of the 2022-2023 data, get an accepted proposal at HIγS, and publish one paper in a peer refereed journal.

Activity II.3 "Innovative solutions for FF detectors and RF carpets (part II)": In 2025 we expect to finalize the optimization of the performance of RF carpets and THGEM assemblies transport and detection of FF and start using them in experiments. The design of a FGIC will be finalized, and fabricate a prototype.

The goals are to understand what are the optimal operational conditions of the RF carpets and THGEM assemblies in different regimes, deliver prototypes of a THGEM assembly, RF carpet and FGIC, publish one paper in a peer refereed journal, and prepare two patent applications.

Activity II.4 "Digital pulse processing and automation of FF detectors (part II)": In 2025 the upgrading of DELILA will continue. The idea is begin the implementation of programmable FPGA digitizers, develop the corresponding firmware, and use them with the ELIGANT-GN array. The firmware will be installed on CAEN VX2730 digitizers. This will allow particle discrimination and, *e.g.*, in experiments with Si DSSD detectors reduce the electronics and detectors. THGEM detectors should be integrated in DELILA, too.

The 2024 prototype of the gas system slow control will be used in experiments. The slow-control system will be upgraded for the gas system of the FGIC, and the FGIC prototype will be tested.

The goals are to upgrade DELILA handle THGEM detectors, to implement FPGA programmable digitizers, to use the slow-control system in experiments, to upgrade it to handle FGICs, and to publish one peer refereed paper and one conference proceeding.

Annex

Financial Report

according to the regulations from H.G. 134/2011

			lei
Type of expenditures		Year 2024	
		Value	
		Planned	Realized
1	**PERSONNEL EXPENDITURES**, from which:	**419.434,00**	**362.378,00**
	1.1. wages and similar income, according to the law	410.204,00	354.406,00
	1.2. contributions related to wages and assimilated incomes	9.230,00	7.972,00
2	**LOGISTICS EXPENDITURES**, from which:	**369.530,00**	**424.043,08**
	2.1. capital expenditures	298.000,00	307.866,57
	2.2. stocks expenditures	70.490,00	115.284,01
	2.3. expenditures on services performed by third parties, including:	1.040,00	892,50
	....		
3	**TRAVEL EXPENDITURES**	**80.000,00**	**85.143,90**
4	**INDIRECT EXPENDITURES – (OVERHEADS) *** ***35% (pt.1+pt.2.2+pt.2.3+pt.3)**	**199.836,00**	**197.235,02**
TOTAL EXPENDITURES *(1+2+3+4)*		**1.068.800,00**	**1.068.800,00**

* Specify the rate (%) and key of distribution (excluding capital expenditures):

35% (pt.1+pt.2.2+pt.2.3+pt.3)

To be filled in for:

- the project leader;
- for each of the partners (if any);
- for the whole projec