**Low-Energy Nuclear Physics: 6 Core Laboratories, 1 Consortium**

1) NUPECC Flagship Facility: FAIR/GSI (ESFRI facility)

2) NUPECC Flagship Facility: GANIL/SPIRAL2 (ESFRI facility)

3) NUPECC Flagship Facility: ELI-NP Infrastrucure (ESFRI facility)

 There is also a large Hadron Physics group in Bucharest

4) NUPECC Flagship Facility: ISOLDE and NTOF at CERN

5) NUPECC Flagship Facility: SPES-LNL (+ LNS)

 There is also a large ALICE group in LNS and in Padua

6) NUPECC Flagship Facility: JYFL

 There is also a large ALICE group in JYFL

7) CONSORTIUM (ALTO IJCLab + Polish Facilities + CLEAR facilities)

 There is Hadron Physics at ALTO IJClab and in Krakow

**FAIR/GSI**

*NuPECC Flagship facility*

The Facility for Antiproton and Ion Research (FAIR), an ESFRI landmark facility, is under construction as an international facility on the campus of the GSI Helmholtzzentrum for Heavy-Ion Research in Darmstadt, Germany. It will open up unprecedented research opportunities with a focus on hadron and nuclear physics. However, it will also encompass atomic physics and nuclear astrophysics and applied sciences like materials research, plasma physics and radiation biophysics with applications towards novel medical treatments and space science.

The first phase of FAIR is expected to be operational by 2028 and will facilitate experiments with SIS100 using the High-Energy Branch of the Super-FRS, the CBM cave and current GSI facilities. The next steps include the APPA cave and the Low-Energy Branch of the Super-FRS. The CR and HESR storage rings will be unique tools for precision measurements for atomic, nuclear and hadron physics.

Long-duty-cycle and continuous-wave beams for the low-energy programme will be provided by HELIAC.

The completion of the full FAIR facility is the declared goal of all FAIR shareholders and should be vigorously pursued, as it will provide European science with world-class facilities for many decades.

**ISOLDE and NTOF (CERN)**

*NuPECC Flagship facility*

ISOLDE is a world-class ISOL facility at CERN, providing radioactive ions with high intensity and excellent emittance over a wide range of energies. It is unique worldwide in using 1.4-GeV protons on thick targets, resulting in the widest range of isotopes (>1300) and elements (>75) from He to Pu, either at low energy (30-60 keV) or as post-accelerated radioactive

beams up to 10 MeV/u. A series of detectors and beam-line installations is maintained by users, exploiting radioisotope ions for a wide range of science. There is a focus on nuclear physics with precision measurements of nuclear properties (masses, moments, radii and spins), radioactive decay and reaction studies. These include nuclear astrophysics measurements and searches for physics beyond the Standard Model. Hyperfine effects are used to address aspects of atomic and molecular physics. Radioactive ions are also used as probes of the environment within hard, soft and biological materials, addressing aspects of condensed-matter physics and life sciences. The MEDICIS Facility has provided mass-separated radioisotopes for medical R&D projects since 2018 and developed its first therapeutic clinical translation medical project in 2023.

The n\_TOF facility is a world-wide unique installation which offers a pulsed neutron beam with an extremely wide energy spectrum covering the thermal region (sub-meV) up to the fast region with neutrons up to GeV energies. Very high resolution in low-background conditions in both experimental areas are characteristics of the facility, which coupled to the low duty-cycle/high-intensity characteristics of the driver accelerator makes n\_TOF a unique neutron source for nuclear physics experiments.

Experiments focus on measuring neutron-induced reaction cross sections for stellar nucleosynthesis, nuclear fission and fusion technology, dosimetry, medical applications, and in general for nuclear data.

**GANIL/SPIRAL2 (France)**

*NuPECC Flagship facility*

GANIL-SPIRAL2 is one of the major nuclear physics facilities in the world with SPIRAL2 selected at the ESFRI

roadmap. The accelerator complex delivers three different beams for users: high-intensity stable beams, from

Carbon up to Uranium between ~ 1 MeV to 95 MeV/nucleon; very high-intensity light beams such as p, d, Helium; wide range of high-intensity exotic beams produced either in flight with the LISE and S3

fragment separators or with the ISOL method at the SPIRAL1 facility; and neutron beams with Neutron

For Science (NFS) since 2020.

In the GANIL experimental halls, a variety of experimental infrastructures is fully available to all users with local technical support, including the VAMOS large acceptance spectrometer used for direct, fusion-evaporation reactions and deepinelastic reactions for spectroscopy studies of exotic nuclei, and the LISE III spectrometer, which separates, focuses and unambiguously identifies projectile-like fragments using several types of detectors. LISE is also used for atomic physics experiments.

The European gamma spectrometer AGATA is planned to move to GANIL in 2028, for a 2 years campaign exploiting intense stable beams and radioactive beams from SPIRAL1.

Three beam lines with dedicated equipment are also available for atomic and condensed matter physics,

at low energy (around 1 MeV/nucleon), at medium energy and at high energy (95 MeV/nucleon).

Another beam line is devoted to industrial applications, and to biological research. In total, between 50 and 60% of GANIL beam time is allocated to interdisciplinary and applied research to tackle major societal challenges including cancer therapies, medical radioisotopes and energy.

**LNL-SPES/LNS (Italy)**

*NuPECC Flagship facility*

LNL and LNS are property of the Istituto Nazionale di Fisica Nucleare (INFN) and are devoted to Fundamental

and Applied Nuclear Physics Research. Their activities are complementary and strictly coordinated.

The LNL-LNS laboratories offer access to stable-ion beams, radio-active ion beams and also

to neutron beams, delivered by the BELINA facility at LNL. The LNL and LNS laboratories have different accelerator complexes providing light and heavy ion beams up to 80 MeV/u.

The main research programmes at Legnaro centre on nuclear structure, reactions and astrophysics, and are carried out with the Tandem-ALPI-PIAVE accelerator complex (TAP), providing stable ion beams from p to Pb at energies up to approximately 10 MeV/u. Interdisciplinary activities are also performed using the two Van de Graaff accelerators, with a strong focus on the development and characterization of targets for novel radioisotopes for medicine and applications, elemental microanalysis for material, earth and environmental sciences and cultural heritage. In the field of accelerator technologies, the main developments are for the European Spallation Source and for the IFMIF RFQ.

At Legnaro, the SPES (Selective Production of Exotic Species) project is constructing Europe’s first dedicated radioactive ion beam facility for fission fragments based on the fission of a UCx target induced by a primary proton beam delivered by the high intensity cyclotron. High-intensity proton beams will be also exploited for the production of radioisotopes for applications. The construction of the new complex is very advanced and the facility will come into operation during the period of the access offered by the EU program.

Among the powerful detector systems available for the scientific programme, the large acceptance magnetic spectrometer PRISMA for heavy ions is used with different gamma-ray arrays, such as AGATA, which is hosted at LNL until 2028. Other set-ups include the GALILEO γ-ray spectrometer composed of 55 Compton-suppressed HPGe detectors, the GARFIELD large solid- angle multi-detector array for light charged particles and fragment identification for reaction studies, and an active target system.

Laboratori Nazionali del Sud hosts a Tandem and a Superconducting Cyclotron delivering light and heavy-ion beams at low and medium energy. The LNS scientific mission is mainly the study of nuclear reactions at low and intermediate energies, with a focus on the equation of state of nuclear matter, charge-exchange reactions to determine the NME of the double beta decay, and the study of light nuclei also in connection with stellar and primordial nucleosynthesis. The LNS Superconducting Cyclotron is being equipped with a second beam extraction system to improve the intensity of stable beams, and should become operational in 2027. This will allow the use of the new FRAgment Ion Separator (FRAISE) for exotic beams production via projectile fragmentation.

Among the several state-of-the-art detection systems available at LNS: the large acceptance heavy-ion magnetic spectrometer MAGNEX and the charged particle array detector CHIMERA for the study of the dynamics and thermodynamics of nuclear reactions.

Research activity using a superconducting plasma trap PANDORA is also planned for the experimental study of transmutations in plasma, to constrain β-decay rates in highly ionised systems, of astrophysical interest.

**ELI-NP-I (Romania)**

*NuPECC Flagship facility*

The ELI Nuclear Physics Infrastructure (ELI-NP-I) is a facility in Magurele, Romania, comprising the ELI-NP site of the ELI ESFRI distributed facility based on high-power lasers, the IFIN-HH accelerator complex, and the Department of Hadron Physics with research programs and R&D activities at CBM and ALICE.

The ELI-NP site is dedicated to nuclear photonics, i.e. nuclear physics using extreme photon beams or their secondary radiation. These beams will be used for fundamental research studies as well as for developing high-impact applications. ELI–NP hosts a 2 x 10 PW laser system, the most powerful laser system worldwide, and has been operational at nominal parameters since 2020. High-intensity quasi-monochromatic γ beams up to 19.5 MeV will be provided by a system based on Laser Compton Backscattering (LCB) of laser light from relativistic electrons produced by a linear accelerator. The construction of the γ-beam system is underway and completion is expected in 2026.

The IFIN-HH accelerator complex, consisting of a 9-MV Tandem, a 3-MV Tandetron and a 1-MV Tandetron

Accelerators, offers access to a variety of stable ion beams. In particular, the 9-MV Tandem accelerator is one of the most reliable facilities in Europe providing a wide range of accelerated stable ions, with high intensity and stable operating conditions, attracting a growing international user community. The 3-MV TandetronTM accelerator is mainly dedicated to applied nuclear physics, but it is also used for fundamental research in nuclear astrophysics studies. The 1-MV TandetronTM is a state-of-the-art equipment that plays the key-role in the AMS studies. Equipment available for users include the ROSPHERE array, a state-of-the-art spectrometer housing up to 25 detectors, HPGe or LaBr3(Ce), dedicated mainly to lifetime measurements; a setup dedicated to nuclear reaction and nuclear astrophysics; the neutron array of 81 BC400 plastic scintillators.

**JYFL (Finland)**

*NuPECC Flagship facility*

The Accelerator Laboratory of the University of Jyväskylä (JYFL) (http://www.jyu.fi/accelerator) hosts four accelerators for nuclear physics and applications, delivering a range of stable-ion beams (from protons to Au), electrons and photons, serving an international user community. The main K=130 heavy-ion cyclotron is served by three ECR ion sources and a multi-cusp ion source.

The major instrumentation at the laboratory includes the gas-filled recoil separator RITU, one of the most versatile and efficient systems for in-beam and decay spectroscopy of exotic nuclei in the world, mainly used for studies of proton dripline and superheavy nuclei. The vacuum-mode separator MARA is complementary to RITU, and it is used to probe topics like isospin symmetry and pairing in N=Z nuclei. Coupled with detector arrays at the target area (JUROGAM III Ge detector array) and at their respective focal planes, the two separators form some of the most flexible and efficient systems in the world for such studies.

Exotic beams are also produced at the Ion-Guide Isotope Separation On-Line (IGISOL) facility, for comprehensive studies of nuclear ground (and isomeric) state properties and exotic decay modes, of interest for nuclear structure, astrophysics, as well as neutrino and beyond-standard-model physics.

JYFL is one of the five host laboratories of the European gamma spectrometer AGATA.

For interdisciplinary studies, the RADiation Effects Facility (RADEF) is the most important facility which is specialised in the study of radiation effects in electronics and related materials. RADEF has been one of the three official test sites of ESA since 2005. In addition, a 1.7 MV Pelletron provides MeV ion beams to probe the elemental composition and structural properties of materials with state-of-the-art equipment.

**CONS-LAB (ALTO, NLC, CLEAR)**

**Consortium of laboratories for specialized nuclear and interdiciplinary studies, R&D and detectors testing.**

Within the consortium, innovative research programmes are carried out, including impactful studies of nuclear structure, reaction mechanism, nuclear astrophysics, fundamental interactions and applications of nuclear physics in cross-disciplinary research with high societal value.

The facilities of the consortium offer a variety of state-of-the-art instruments, and are key players focusing on specific scientific and technology topics. The complementarity of the available beams makes the facilities very important in developing experimental techniques or production methods relevant to larger scale infrastructures. The consortium facilities are also particularly adept in education and training.

Activities in hadron physics are also carried out by large groups at IJCLAB (Orsay) and IFJ-PAN (Krakow).

Each of the laboratories has a dedicated Program Advisory Committee, which evaluates the proposals and advises the laboratory management about the priorities.

1. **ALTO at IJCLAB**

The ALTO facility consists of two accelerators: a 15 MV Tandem for stable beams (ions and cluster beams for interdisciplinary physics) and a 50 MeV linear electron accelerator to produce radioactive beams via photofission of a uranium carbide target. In addition, the LICORNE neutron converter is providing intense (up to 108 neutrons/s/str), kinematically focused, quasi-mono-energetic neutron beams with energies between 0.5 and 4 MeV. Research studies focus on nuclear structure and reaction mechanisms, decay heat in reactors and solid-state physics. One beamline is devoted to industrial irradiation.

Research and development are carried out on target and ion sources for all the future second-generation radioactive ion beam projects (SPIRAL2, EURISOL…). An area is also open to particle physics users with the use of electron beam for tests of small units of particle physics detectors (vertex detectors, several layers of calorimeters w/o absorber etc.) before going to the large facilities such as DESY and CERN.

Main detector setups include: BEDO (a high efficiency gamma setup for decay properties of neutron rich nuclei); TETRA (an 3He neutron detector used to measure neutron emission from neutron rich nuclei); LINO (for collinear laser spectroscopy and laser-induced nuclear orientation); POLAREX (an instrument based on the On-Line Nuclear Orientation method to observe the decay of a spin-oriented ensemble of nuclei); Split-Pole (magnetic spectrometer used for the study of “two-body” reactions with high resolution and for nuclear astrophysical studies); the nu-Ball gamma spectrometer, which consists of a hybrid LaBr3/HPGe array, with possible integration with the PARIS gamma-ray calorimeter; AGAT (a detector for Cluster Physics used for atomic astrophysical studies); and SIHL (an offline separator to test and develop target ion sources).

1. **NLC (SLCJ Warsaw & CCB Krakow) – National Laboratory of Cyclotrons**

NLC is a consortium of the two institutions – Heavy Ion Laboratory of the University of Warsaw (SLCJ) and Cyclotron Center Bronowice (CCB) at Institute of Nuclear Physics Polish Academy of Sciences (IFJ-PAN) in Kraków. It offers access to a wide range of stable ion beams to conduct complementary (by using high energy protons in CCB Krakow and low energy heavy ions in SLCJ Warsaw) research activities, encompassing the fields of nuclear structure, nuclear reactions dynamics, radiochemistry, radiobiology, nano-dosimetry, material sciences, industrial application, medical research and proton therapy.

Accelerator Complex: SLCJ: Isochronous heavy-ion cyclotron (K=160) with two ECR sources, proton/deuteron

GE PETtrace cyclotron (K=16.5); CCB: Medical proton cyclotron PROTEUS-230.

Available Beams: SLCJ: from He up to Ar up to 10 MeV/A, protons/deuterons 16 MeV/A; CCB: protons 70-230

MeV.

Among the main available instrumentation at SLCJ Warsaw: EAGLE (4π gamma-ray array) and associated ancillary detectors, with possible integration with the PARIS gamma-ray calorimeter and the NEDA neutron detector; scattering chambers ICARE and CUDAC for charged particle spectroscopy; irradiation station for radiobiology (with a cells’ laboratory infrastructure) and material interdisciplinary studies;

At CCB Krakow, available instrumentation are BINA (Big Instrument for Nuclear Data Analysis) for in-beam experimental investigations of the dynamics of few-nucleon systems; high-energy gamma-ray detection array HECTOR, which can be complemented with the PARIS array; KRATTA (Kraków Triple Telescope Array- 35 multi-module telescopes for charged-particle detection); large volume LaBr3 detectors and DSSS detectors. Also, there is a test bench for in-beam characterization of new detctors constructed for large scale facilities.

1. **CLEAR (Cluster of Low Energy Accelerators for Research)**

CLEAR is a consortium of three installations: ATOMKI in Debrecen, CNA in Seville and IST in Lisbon, offering access to stable-ion beams and neutron beams. The consortium has a common Program Advisory Committee. The Accelerator Complexes (ATOMKI: 2MV Tandem, 18 MeV Cyclotron; CNA: 3MV tandem, 18 MeV Cyclotron, 1 MV Tandetron for Accelerator Mass Spectrometry (AMS); IST: 2.5 MV van de Graaf) provide beams of protons from 20 keV to 20 MeV, deuterons up to 9 MeV, alphas up to 20 MeV, low energy heavy ions, neutrons up to 3 MeV, electrons 8-12 MeV and photons 4-10 MeV.

Available detectors/spectrometers comprise a split pole magnetic spectrograph (at ATOMKI), La(Br) detectors, Ge, Si detectors, crossed beam reaction chambers, time of flight spectrometers, scintillator detectors.

The three installations (ATOMKI, CNA, IST) are user-oriented facilities, with a long experience on carrying out experiments with international users. They offer access to perform complementary experiments to those of the higher energy facilities and facilitate the access of cross-disciplinary users.