

INTRODUCTION

Ultra-intense laser fields, reaching up to 10^{22} W/cm², are now able to produce typical radiation formerly used in nuclear facilities, as demonstrated in laboratories across the globe. The emerging laser-driven technologies are very promising in terms of cost, size and available parameter range. However, the vast majority of experiments were performed in laboratories where the operation of the laser system did not reach the reliability of the nuclear facilities counterparts. Crossing the gap from lab-based experiment to facility-based experiment was identified in Europe as a major step forward. As a consequence, the construction of a laser-centred, distributed pan-European research infrastructure, involving ultra-short and ultra-intense laser technologies at the state of the art and beyond, was triggered through the Extreme Light Infrastructure (ELI) project. The European Strategic Forum for Research Infrastructures (ESFRI) has selected in 2006 a proposal based on ultra-intense laser fields with intensities reaching up to 10^{22} – 10^{23} W/cm² called “ELI”, for Extreme Light Infrastructure. The construction of a large-scale laser-centred, distributed pan-European research infrastructure, involving beyond the state-of-the-art ultra-short and ultra-intense laser technologies, received the approval for funding in 2011–2012.

The three pillars of the ELI facility are built in The Czech Republic, Hungary, and Romania [1]. The Romanian pillar is ELI-Nuclear Physics (ELI-NP) [2]. The scientific research at ELI-NP involves two domains where only very few experimental results were reported until now. The first one is laser-driven experiments related to nuclear physics, strong-field quantum electrodynamics and associated vacuum effects. The second domain is that of experiments based on a Compton back-scattering high-brilliance and intense low-energy (less than 20 MeV) gamma beam, a combination of laser and accelerator technology at the frontier of knowledge.

The ELI-NP research centre will be located in Magurele, near Bucharest, Romania. The new facility is intended to serve a broad national, European and International science community. In addition to fundamental themes, a large number of applications with significant societal impact are being developed. These applications extend from the nuclear power plant waste management to new radio-isotopes for medicine and cancer therapy, and from space science to materials science and nanoscience using new powerful probes such as, for example, a brilliant positron beam.

During the last three years, a significant fraction of the international scientific community contributed to the shaping of the ELI-NP facility science program through a series of international workshops. As a result, these scientific

meetings lead to the definition of about ten new development directions for the experiments to be carried out at the future facility. For each of them, writing of Technical Design Reports (TDRs) by specialized working groups of international scientists and coordinated by ELI-NP physics team, was triggered and further developed during the workshops. A concluding international meeting, attended by more than 150 scientists from four continents was held from February 18th to 20th, 2015 at Magurele. Final versions of the TDRs were presented and discussed by the ELI-NP International Scientific Advisory Board (ISAB) in June 2015. ISAB final priority recommendations endorsed the science plan and the TDRs, allowing ELI-NP project to proceed towards the implementation phase.

In the following, as an introduction to the present volumes, consisting of 15 articles, a short description of the 15 TDRs will be presented, as well as the scientific and technical links between them, leading to a coherent, innovative and exciting future scientific program for the ELI-NP facility.

The first article, *Laser beam delivery at ELI-NP*, describes the Laser Beam Delivery (LBD) system, which covers the interface between the High Power Laser System (HPLS) and the experiments. The main infrastructure consists of the following components: the beam transport lines for the six main outputs of HPLS and the synchronization beam line providing the timing of the laser pulses with the Gamma Beam Source (GBS) and the experiments on a fs timescale.

The three following articles, namely *Laser-driven nuclear physics at ELI-NP*, *High field physics and QED experiments at ELI-NP*, and *Combined laser and gamma experiments at ELI-NP*, encompass the new science domains opened by ELI-NP, where high power lasers will reach for the first time ultra-high power and intensities: 10 PW and more than 10^{23} W/cm². The scientific program that will benefit from High Power Laser System (HPLS) pulses will focus on *Laser Driven Nuclear Physics* (LDNP), associated to the E1 experimental area, *High Field Physics and QED*, associated to the E6 area, and fundamental research opened by the unique combination of the two 10 PW laser pulses with a gamma beam provided by the Gamma Beam System, which is associated to E7 area.

The scientific case of the LDNP TDR encompasses studies of laser induced nuclear reactions, aiming for a better understanding of nuclear properties and of nuclear reaction rates in laser-plasmas, for producing neutron rich nuclei, which are highly relevant for astrophysics, as well as for the development of radiation source characterization methods based on nuclear techniques.

The ELI-NP facility will enable focused laser intensities above 10^{21} W/cm², reaching for the first time 10^{22} – 10^{23} W/cm². We propose to use this capability to investigate new physical phenomena at the interfaces of plasma, nuclear and particle physics at ELI-NP. The article on *High field physics and QED experiments at ELI-NP* proposes a comprehensive experimental area (E6) at ELI-NP for investigating High Field Physics and Quantum Electrodynamics and the resulting production of electron-positron pairs and of energetic γ -rays. The

proposals are classified according to the science areas investigated: Radiation Reaction Physics, Compton and Thomson Scattering Physics, QED in Vacuum, and Atoms in Extreme Fields.

Taking advantage of the unique configuration and characteristics of the new ELI-NP research infrastructure (10 PW HPLS and GBS) the fourth article (*Combined laser and gamma experiments at ELI-NP*) discusses two main topics in physics with staged developments to gradually tackle them. The first one concerns nuclear reactions, linked to the possibility to reach, at ELI-NP, conditions encountered in the interior of stars – the production and photoexcitation of isomers being proposed. The second topic addresses the probing of the photon-photon interactions below the MeV energy scale that have not been explored thoroughly to date, by utilizing the laser-laser, laser-gamma and gamma-gamma collision systems. By these various combinations of photon beams, we can test sub-eV Dark Matter scenarios as well as nonlinear QED effects both in perturbative and non-perturbative regimes.

So far, with the four first TDRs, mainly fundamental science at reach was introduced. HPLS have also a large potential of application and the fifth article (*Materials in extreme environments for energy, accelerators and space applications at ELI-NP*) will present innovative research in the fields of materials behavior in extreme environments and radiobiology, with applications in the development of accelerator components, new materials for next generation fusion and fission reactors, shielding solutions for equipment and human crew in long term space missions and new biomedical technologies. The specific properties of the laser-driven radiation produced with two lasers of 1 PW at a pulse repetition rate of 1 Hz each are the ultra-short time scale, a relatively broadband spectrum and the possibility to provide simultaneously several types of radiation.

A large-scale complex facility like ELI-NP has to develop a Monitoring and Control System (MCS). Therefore, following the science and applications of HPLS, an MSC TDR has been designed and is presented in the following article. The MCS TDR describes the requirements for the experiments taking place in the experimental areas E1-E8 of the ELI-NP facility, in terms of monitoring and control, specifying input/output signals, estimated data fluxes, data storage needs, synchronization, vacuum control and monitoring, reliability, maintenance, integration with subsystems and other transverse needs. Based on this information, follow the design and implementation details of a modular architecture that will fit the ELI-NP starting needs and will allow for further development.

As stated in the early beginning of this introduction, ELI-NP research facility will offer to the national, European and international users community the possibility to explore **New Frontiers in nuclear physics with Laser Compton Scattering γ -ray beams** – nearly completely polarized and with quasi-monochromatic energy spectrum from 0 to 20 MeV.

Revisiting Nuclear Structure, Nuclear Astrophysics and Nuclear reactions and their applications using this unique and new probe as well as the technical needs related to the accelerator and instruments for these new investigations are the topics of the next 9 articles devoted to the so called Gamma Beam System and experiments.

Gamma beam delivery and diagnostics describes the high brilliance Gamma Beam System at ELI-NP, which is based on the Inverse Compton Scattering of laser light on relativistic electron bunches provided by a warm radio-frequency linear accelerator. The system will deliver quasi-monochromatic gamma-ray beams (bandwidth smaller than 0.5%) with a high spectral density (higher than 10,000 photons/s/eV) and high degree of linear polarization (larger than 99%).

The system will be delivered by the EuroGammaS Association, a European consortium of academic and research institutions and commercial companies with well-established expertise in the field. Optimization and monitoring of the Gamma Beam System requires the proper means for accurately measuring the spatial, spectral and temporal characteristics of the gamma-ray beams. The system will be delivered by the EuroGammaS Association with a set of devices for the optimization of the gamma-ray beam characteristics to be used during the initial phase of setting up the system. The present TDR is also dealing with additional equipment and techniques, complementary to the ones provided by EuroGammaS, required to deliver the gamma-ray beams to the experimental setups and to monitor the characteristics of the beams during the performance of the experiments.

Nuclear photonics is undergoing a revival, the gamma beams with unprecedented features delivered at ELI-NP paving the way for high accuracy studies. In *Nuclear resonance fluorescence at ELI-NP* we discuss the potential of discoveries revisiting nuclear physics studies. The combination of nuclear photonics with the technique of Nuclear Resonance Fluorescence (NRF) allows for the identification of several physical quantities which characterize the excited nuclear states in a completely model-independent way.

The main detection system for the NRF studies is a multi-detector array (*ELIADE* – ELI-NP Array of DEtectors) based on the use of composite high-purity Ge detectors and large volume LaBr₃ scintillator detectors able to detect with high efficiency gamma-rays with energies up to several MeVs in the presence of the high radiation background produced by the gamma beams. Gamma-ray energies and angular distributions will be measured with high accuracy. All physics cases described in the following articles will benefit from the synergic use of each other's instrumentations.

Extremely high-intensity and monochromatic gamma-ray beams available at the ELI-NP allow us to enter a precision era of investigating electromagnetic responses of atomic nuclei. In *Gamma above the neutron threshold experiments at ELI-NP* the ELIGANT group addresses the four physics cases related to: p-process

nucleosynthesis, nuclear structure of Giant Dipole Resonance (GDR), New Compilation of total and partial photo-neutron cross sections, nuclear structure of Pygmy Dipole Resonance (PDR) and spin-flip Magnetic Dipole Resonance (MDR). This will produce, together with data from nuclear resonance fluorescence (NRF) measurements, a complete study of the PDR and MDR. The PDR study may help to determine the symmetry energy in the equation of state (EOS) for nuclear matter through the neutron skin thickness.

Three photo-fission experimental programs are proposed in the article on *Photofission experiments at ELI-NP* to be carried out with the brilliant gamma beams that will be available at the ELI-NP facility. First, we will measure the absolute photo-fission cross-sections of actinide targets and will study the energy, mass and charge distributions of fission fragments, as well as of ternary fission. One of the goals is to resolve the fine structure of the isomeric shelf and to observe the cluster phenomena in super- and hyper-deformed actinide states. Second, the structure of exotic nuclei produced in photo-fission will be studied, in particular, isotopes of refractory elements, by developing an ISOL-type facility with an ion-guide, a Radio-Frequency Quadrupole (RFQ) ion cooler and a mass separator to separate and transport the isotopes of interest to the measurement stations. Last, we aim at studies of g -factors of short-lived nanosecond isomers since they are difficult to be measured anywhere else.

In the article on *Charged particle detection at ELI-NP* we address central problems in nuclear astrophysics such as the astrophysical cross section factor of the $^{12}\text{C}(\alpha,\gamma)$ reaction and other processes central to stellar evolution. For that purpose we have designed and intend to use a barrel of Silicon Strip Detectors (SSD) and a Time Projection Chamber (e-TPC) detectors. These instruments will be used also to investigate clusters and the many alpha-decay of light nuclei such as ^{12}C and ^{16}O . Last but not least, the unique properties of ELI-NP GBS facility have allowed us to propose innovative applications for the production and use of an intense, polarized positron beam (see *Positron production by gamma beam at ELI-NP*), research towards industrial applications based on NRF and industrial radioscopy and tomography (see *Gamma-beam industrial applications at ELI-NP*), and production of radioisotopes for nuclear medicine (see *Radioisotope production for medical applications at ELI-NP*).

We propose to obtain an intense beam of moderated positrons (e_s^+) with an intensity of the primary positron beam of $1-2 \times 10^6 e_s^+ / \text{s}$ by the (γ, e^+e^-) reaction using an intense γ -beam of $2.4 \times 10^{10} \gamma / \text{s}$ with energies up to 3.5 MeV. Polarized positron beams open up a totally unexplored research area in applied physics studies of Fermi-surfaces, defects, interfaces, etc., where polarized electrons can be studied. The ELI-NP facility will be user-dedicated and unique for positron research in the Eastern Europe.

An ultra-bright, energy tunable and monochromatic gamma-ray source in the range of 0.2–19.5 MeV produced by Laser-Compton Backscattering technique is ideal for nondestructive testing applications. Consequently, this source satisfies the criteria for large-size product investigations with added capabilities like isotope detection through the use of nuclear resonance fluorescence (NRF) technique.

The non-destructive assay based on high-brightness gamma rays can be successfully applied for safeguard applications and management of radioactive wastes. Radioscopy and computed tomography performed at ELI-NP have the potential to achieve high spatial resolution and high contrast sensitivity.

The article on *Radioisotope production for medical applications at ELI-NP* proposes the study of medical radioisotope production using a new route, by γ -induced reaction mechanism where the reaction cross-sections are as low as 0.1 barn. We propose an experimental setup for testing this possibility using the intense gamma-ray beam at ELI-NP facility, with an irradiation area, a target transport system and a test area. An intensity of 10^{11} γ /s for the new gamma beam at ELI-NP will allow in the first stage to obtain radioisotopes in quantities and specific activities (1-2 mCi/g) suitable for medical research.

Last but not least, a final chapter describes ELI-NP technical proposals in the field of Dosimetry and Radiological Protection that are needed to operate the ELI-NP installations, protect all personnel (staff and external users) and public, and ensure monitoring of the environment according to the best national and EU practices.

Benefiting from the support of a growing international community of future users from all over the globe, the ELI-NP facility is therefore on track with the definition of its science program through the completion of the Technical Design Reports presented in these volumes, which allow the construction of the tools needed for Day-One Experiments in late 2018.

Sydney Gales

Scientific Director, Extreme Light – Infrastructure Nuclear Physics

REFERENCES

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