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Photonuclear spectroscopy with the ELIADE array at ELI-NP

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Summary. — The Extreme Light Infrastructure – Nuclear Physics in Bucharest-Măgurele, Romania, is a major European undertaking with the aim of constructing a facility that can produce the worlds highest intensity laser beams as well as unique high-brilliance, narrow-bandwidth gamma-ray beams using laser-based inverse Compton scattering. One of the main instruments being constructed for the nuclear physics and applications with high-brilliance gamma-beams research activity is the ELIADE detector array of eight segmented HPGe clover detectors. Using the nuclear resonance fluorescence technique this setup will provide us with access to several nuclear observables like spins, parities, level widths, and branching ratios in the decay. From these observables we expect to draw conclusions about, for example, nuclear dipole response, properties of pygmy resonance and collective scissors mode excitations, parity violation in nuclear excitations, and matrix elements for neutrinoless double-beta decay, among other topics. The uniqueness of the environment in which ELIADE will operate presents several challenges in the design and construction of the array. In this contribution we will present some of these challenges and how these challenges are overcome.

1. – Introduction

One of the most important inventions in recent years regarding the field of high-power laser systems is the chirped pulse amplification for lasers [1]. Using this technique it is possible to create ultra-short laser pulses that can provide pulses of power well up in the PW regime. This concept is currently being realised within a new infrastructure in Europe called the Extreme Light Infrastructure (ELI) that will become the most intense laser beam-line system world wide. ELI is divided into four pillars consisting of three specialized facilities: ELI Beamlines, Dolní Břežany, Prague, Czech Republic, that focuses on short-pulse secondary sources of radiation and particles; ELI Attosecond Light Pulse Source, Szeged, Hungary that focuses on ultrashort pulses with high repetition rate; and ELI Nuclear Physics (ELI-NP), Măgurele, Romania, that focuses on nuclear

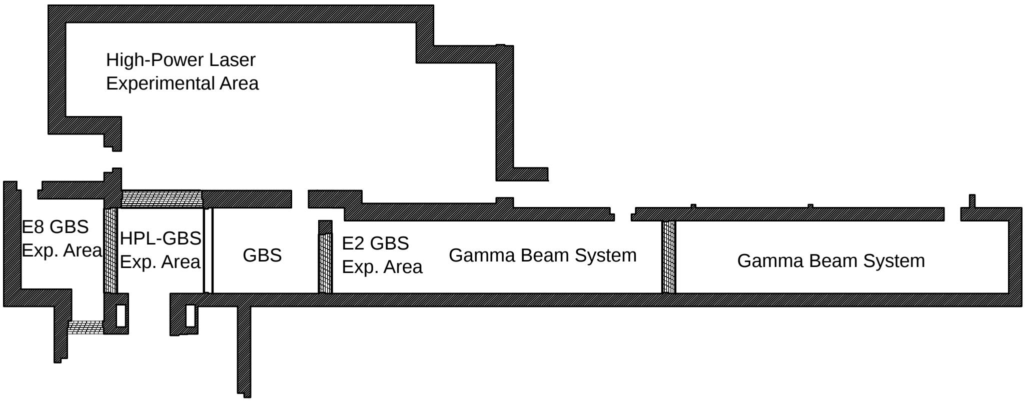

Fig. 1. – Drawing of the experimental areas at ELI-NP and their layout with respect to the gamma-beam system.

physics based on a combination of high-power lasers and a high-brilliance gamma-beam system (GBS). The location of a fourth, future, pillar that is projected to reach up to 100 PW power is still to be determined.

The GBS is the part of ELI-NP projected to provide the highest brilliance beam of γ rays in the world and outperform existing facilities with an order of magnitude both with respect to intensity as well as bandwidth. The approach to generate the beam as proposed in the technical design report [2] is to use the Compton backscattering technique. The main principle behind this technique is to have an electron beam collide with an optical energy laser, where a part of the electron momentum will be transfered to the photon creating high-energy γ-rays. Since the energy of these γ rays depends on the Compton scattering angle, the energy of the transmitted beam can be precisely selected using a collimator at an appropriate angle relative to the electron-laser interaction. Within the ELI-NP project, the electron accelerator is proposed to be a warm LINAC with an energy of the electron beam up to 720 MeV, which will give the possibility to produce γ rays up to 19.5 MeV. It is foreseen that this system will be able to provide a beam intensity higher than $5 \cdot 10^8$ γ/s with a bandwidth of $\leq 0.5\%$ [3]. Using the GBS at ELI-NP, a setup to perform Nuclear Resonance Fluorescence (NRF) [4, 5] measurements is under implementation both for basic research and for applications related to industry, non-proliferation, and cultural heritage studies [6]. A drawing of the ELI-NP facility is shown in fig. 1 where the primary GBS up to the low-energy (E2) experimental area will provide a beam with energies up to 3.5 MeV, followed by a second stage of the GBS that will be able to deliver a beam with an energy up to 19.5 MeV to the joint high-power laser-system and GBS interaction area, and up to the high-energy experimental area (E8).

2. – ELIADE

For performing experiments with the GBS, several instruments are under development at ELI-NP. These include the ELIGANT setup for photonuclear reactions above neutron-threshold [7], ELI-BIC and ELITHGEM for photo-fission studies [8], and ELISSA and ELI-eTPC for nuclear astrophysics experiments [9]. The main focus in these proceedings,

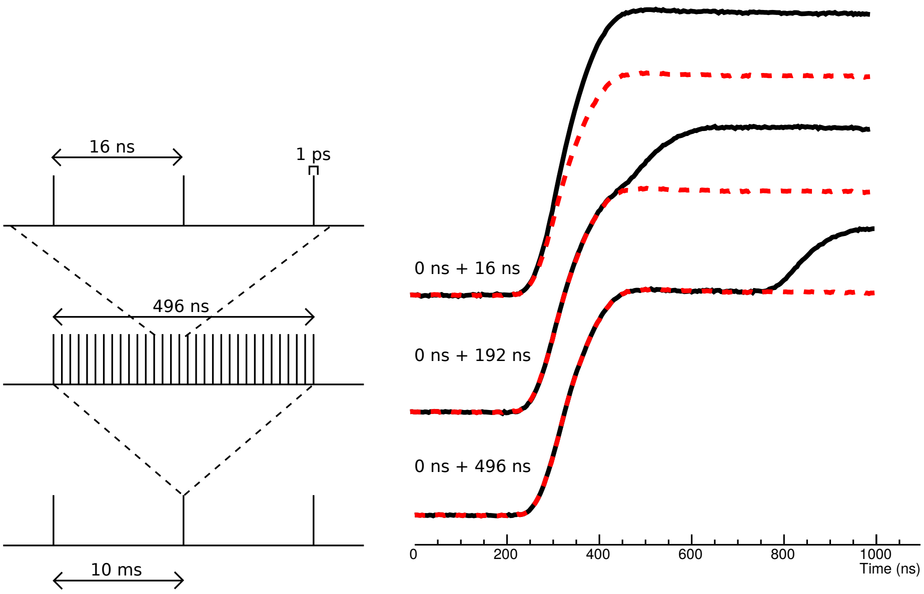

Fig. 2. – (Left) Time structure of the beam from the gamma-beam system proposed in the technical design report. A macro-pulse featuring a 100 MHz frequency is composed of 32 micro-pulses 1 ps wide each, and separated by 16 ns. (Right) Illustration of the expected pile-up atificially generated by superimposed waveforms (black) of measured single γ events (red) within the CAEN v1725 digitizer time range. The waveforms were collected during measurements with one ELIADE segmented Clover detector.

however, is the segmented high-purity germanium (HPGe) array ELIADE (ELI Array of DEtectors) [4] that will be used as a high-resolution γ-ray spectrometer for NRF.

For the design and operation of a high-resolution γ-ray spectrometer at ELI-NP there are two main aspects that need to be taken into account: sensitivity to the physics observables that are to be studied and robustness of operation within the rather harsh conditions that will be present in the environment of a high-brilliance GBS. As one of these key physics observables is the angular distributions of the decay from transitions populated in resonant photon scattering. ELIADE will consist of eight detectors, four located in a central ring at 90° with two detectors horizontal and two detectors vertical to the beam axis, and a second ring of four detectors at 135°. With this configuration will maximize the sensitivity to the angular distributions of dipole transitions and also be able to distinguish dipole and quadrupole transitions from the detectors in the backward angles.

The choice of HPGe detectors for high-resolution γ-ray spectroscopy, however, comes with a price. In this case the price is the rather low time-resolution that is especially critical in the ELI-NP environment. In fig. 2, the typical time structure of the GBS is shown, where the photons arrive in 496 ns wide macro-pulses separated by 10 ms. These macro-bunches are further divided into micro-pulses that are $\sim$ 1 ps wide and separated by 16 ns each. Due to the high intensity of the beam, ELIADE will operate in a very large γ-ray background with this time structure. Since the photons are not evenly distributed in time, but each micro-pulse will contain approximately 10^5 photons, pile-up of signals is one of the major concerns, see fig. 2. This kind of time structure is not possible to resolve with traditional HPGe detectors and analysis techniques.

As the majority of the background consist of low-energy γ-rays from electron-positron annihilation and Compton scattering of the beam in the target, one brute force way of reducing the background count rate the detectors can be shielded with thick lead and/or copper attenuators. While this will efficiently shield from low-energy γ-rays it will also shield γ rays of interest, thus the method is only feasible up to a certain degree, which, for foreseen physics cases, will not be enough to get the counting rate within specifications [4]. However, the usage of segmented Clover detectors and storing the leading 1 μs of the traces recorded by the CAEN v1725 digitizers, both the hit patterns and pulse-shape analysis of the first part of the digitized voltage pulses from the detector can be used to disentangle pile-up events.

3. – Conclusions: Present status of ELIADE

As of the time of writing, all the HPGe detectors have been delivered to ELI-NP and the first characterization tests have been performed. The data acquisition system to read out the detectors based on the CAEN v1725 14 bit and 250 MS/s digitizers is available and to be used with the MIDAS data acquisition software. A dedicated signal transport system from the detectors to the data acquisition has been developed by the Institut für Kernphysik at the University of Cologne and is under delivery. A CAEN SY4527 high-voltage system is also available and in working condition and a prototype liquid nitrogen cooling system controlled by a dedicated LabVIEW program running on a National Instruments compact RIO computer is available with a full scale version of this system under development. Necessary detector mechanical components like reaction chambers [10, 11] and a final detector support structure are under construction and delivery is expected during the end of 2018 and beginning of 2019. The ELIADE array is presently being moved moved from the ELI-NP detector laboratoty to the experimental area for installation in the experimental area E8 (see fig. 1).

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