Development of the ELISSA array: prototype testing at Laboratori Nazionali del Sud

G. L. Guardo[1,2,⋆], *A.* Anzalone[2], *D.* Balabanski[1], *S.* Chesnevskaya[1], *W.* Crucillá[2], *D.* Filipescu[1], *M.* Gulino[2,3], *M.* La Cognata[2], *D.* Lattuada[1], *C.* Matei[1], *R. G.* Pizzone[2], *G. G.* Rapisarda[2], *S.* Romano[2,4], *C.* Spitaleri[2,4], *A.* Taffara[2], *A.* Tumino[2,3], and *Y.* Xu[2]

[1] *ELI-NP/ IFIN-HH, Magurele, Romania*
[2] *INFN, Laboratori Nazionali del Sud, Catania, Italy*
[3] *Facoltá di Ingegneria e Architettura, Universitá Kore, Enna, Italy*
[4] *Dipartimento di Fisica e Astronomia, Universitá degli Studi, Catania, Italy*

Abstract. The Extreme Light Infrastructure-Nuclear Physics (ELI-NP) facility, under construction in Magurele near Bucharest in Romania, will provide high-intensity and high-resolution gamma ray beams that can be used to address hotly debated problems in nuclear astrophysics, such as the accurate measurements of the cross sections of the ^{24}Mg(γ,α)^{20}Ne reaction
For this purpose, a silicon strip detector array (named ELISSA) will be realized in a common effort by ELI-NP and Laboratori Nazionali del Sud (INFN-LNS), in order to measure excitation functions and angular distributions over a wide energy and angular range. A prototype of ELISSA was built and tested at INFN-LNS in Catania (Italy) with the support of ELI-NP. In this occasion, we have carried out experiments with alpha sources and with a 11 MeV ^{7}Li beam that show up a very good energy resolution (better than 1%) and very good position resolution, of the order of 1 mm. Moreover, a threshold of 150 keV can be easily achieved with no cooling.

1 Introduction

The upcoming ELI-NP facility consists of two major components: the High Power Laser System and the Gamma Beam System (GBS). ELI-NP will allow either combined or stand-alone experiments using the high-power laser and the gamma beam [1]. The ELI-NP GBS will provide, for the first time, pencil size gamma beams in the range between 200 keV and 19.5 MeV with a bandwidth better than 0.5%, spectral density of about 10^4 photons/s/eV and linear polarization higher than 95% [2].
Such a facility will open new experimental perspectives for studies in the field of photonuclear physics. Moreover, thanks to these excellent features, the ELI-NP GBS will provides unique opportunities to respond to the need of Nuclear Astrophysics to perform accurate measurements of small cross sections (order of μb or even less) of nuclear reactions of the hydrogen and helium burning processes and hence of the astrophysical S-factors that are essential for stellar evolution modeling. As an example, a direct ^{24}Mg photodissociation measurement using gamma beams of energies 10-12 MeV will allow us to

⋆e-mail: luca.guardo@eli-np.ro

determine a much more accurate cross section to be used in nuclear reaction network calculations to improve the knowledge of the pre-supernova chemical composition.
Indeed, silicon burning sets the chemical composition of the star right before the core collapse and the subsequent supernova explosion, thus constituting a key process for the understanding of core-collapse supernovae [3]. In this framework, the ^{24}Mg(γ,α)^{20}Ne reaction governs the downward flow from ^{24}Mg to ^{4}He, thus determining the effective rate of ^{28}Si destruction, making its reaction rate critically important to stellar models [3]. At present, the ^{24}Mg(γ,α)^{20}Ne reaction rate has been calculated from the ^{20}Ne(α,γ)^{24}Mg rate. In the temperature range of interest, around $3.9\cdot10^{9}$ K, the ^{20}Ne(α,γ)^{24}Mg reaction rate may be subject to systematic errors of the order of a factor of 2, as can be seen from the different results reported in [4]. For those reasons, a new measurement using the gamma radiation beam with unique characteristics at ELI-NP may allow us to resolve conflicting data.

2 The ELISSA detector

Position sensitive silicon strip detectors represent a good solution for detecting charged particles as they provide high position resolution over a large solid angle with a relatively limited channel count. Moreover, a silicon array would make it possible to measure reactions on solid targets with the possibility to measure excitation functions and angular distributions over a wide range allowing for a better understating of reaction mechanism. Resistive strip silicon detector arrays have been successfully designed and commissioned for studies of nuclear astrophysics reactions, e g. ORRUBA (Oak Ridge Rutgers University Barrel Array) or ANASEN (Array for Nuclear Astrophysics Studies with Exotic Nuclei) [5, 6].
In the case of photonuclear reactions of astrophysical relevance, since photodissociations are induced at photon energies slightly larger than particle emission thresholds owing to the typical temperatures in stars, the emitted fragments have low energies, ranging from few hundreds keV to few MeV. Therefore, low-threshold detectors are necessary. Thus, the Extreme Light Infrastructure Silicon Strip Array (ELISSA) is under construction [7]. The performed Monte Carlo simulation using a code based on GEANT4 tracking libraries and the n-body event generator of ROOT, as described in [8], proved that the barrel configuration is particularly suited as it guarantees a very good resolution and granularity, ensuring also a compact detection system (useful as it would allow a simple integration with ancillary detectors, such as neutron arrays) and a limited number of electronics channel [9]. The final setup of the ELISSA array will consist of X3 silicon-strip detectors (manufactured by Micron Semiconductor Ltd.) arranged into a barrel configuration that could be made up of 3 rings of 12 position sensitive detectors, for a total angular coverage of 100° in the laboratory system. The angular coverage is extended by using end cap detectors such as the assembly of four QQQ3 segmented detectors by Micron Semiconductor [10].

3 Test on ELISSA prototype

To test the performance of the X3 detectors and make sure that their energy and angular resolutions are suitable for the realization of the ELISSA detector, a detector prototype has been constructed at INFN-LNS Catania (Italy) in collaboration with the ELI-NP group (Romania). The prototype is made up of a single X3 detector and a single QQQ3 detector, so it replicates in a smaller scale the whole detector, and their readout is performed by means of standard analog electronics. In this occasion, we have carried out experiments with alpha sources and with a 11 MeV ^{7}Li beam at the INFN-LNS tandem. To measure the detection threshold, we have performed a run using a standard 3-peak alpha source and a ^{241}Am source shielded by a 17 μm thick Al foil. This degrader shifted the energy peak

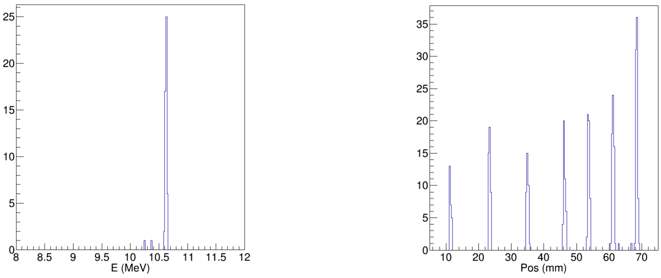

Figure 1. Left panel: Energy spectrum for a fixed position of ^{7}Li scattered off gold. Right panel: Position spectrum for the scattering induced by the ^{7}Li beam on Au target.

to 1 MeV and, due to energy straggling, the energy range spanned reached zero. In this way, we determined the energy threshold under standard conditions (no cooling) to be 150 keV. Energy and position resolutions were measured detecting scattering and reactions induced by the ^{7}Li beam on Au, C and CD_2 targets. In this way, we determined an energy resolution of $\leq$1% for the case of scattering off gold (left panel of figure 1). At energies of about 11 MeV, the position resolution is better than 1 mm (right panel of figure 1) while at lower energies, below about 1 MeV, a position resolution of about 6 mm was found [11]. In this case, the worst position resolution is still good enough for the measurement of angular distribution since it correspond to an angular resolution of about 1.5°.
The good preliminary results of our tests allows us to say that the X3 detectors, as well the standard QQQ3 detectors for which the position resolution is fixed by the strip size and energy resolution is constant to a good approximation, are perfectly suited for nuclear astrophysics studies with ELISSA.

Acknowledgments

This work is supported in part by the Extreme Light Infrastructure Nuclear Physics (ELI-NP) Phase II, a project cofinanced by the Romanian Government and the European Union through the European Regional Development Fund - the Competitiveness Operational Programme (1/07.07.2016, COP, ID 1334).

References

[1] Zamfir N. V., EPJ Web of Conf. **66**, 11043 (2014)
[2] D. L. Balabanski et al., EPL **117**, 28001 (2017)
[3] C. Iliadis, *Nuclear Physics of Stars*, (Weinheim, Wiley-VCH Verlag, 2007)
[4] C. Angulo et al., Nucl. Phys. **A 656**, 3 (1999)
[5] S. D. Pain et al., Nucl. Instr. Meth. Phys. Res. **B 261**, 1122 (2007)
[6] M. Matos et al., PoS **NIC XI**, 226 (2010)
[7] M. La Cognata et al., JINST **12**, C03079, (2017)
[8] D. Lattuada et al. EPJ Web of Conf. **165**, 01034 (2017)
[9] O. Tesileanu et al., Rom. Rep. in Phys. **68**, S699 (2016)
[10] Micron Semiconductor, General cata logue, http://www.micronsemiconductor.co.uk/pdf/cat.pdf
[11] G. L. Guardo et al. EPJ Web of Conf. **165**, 01026 (2017)