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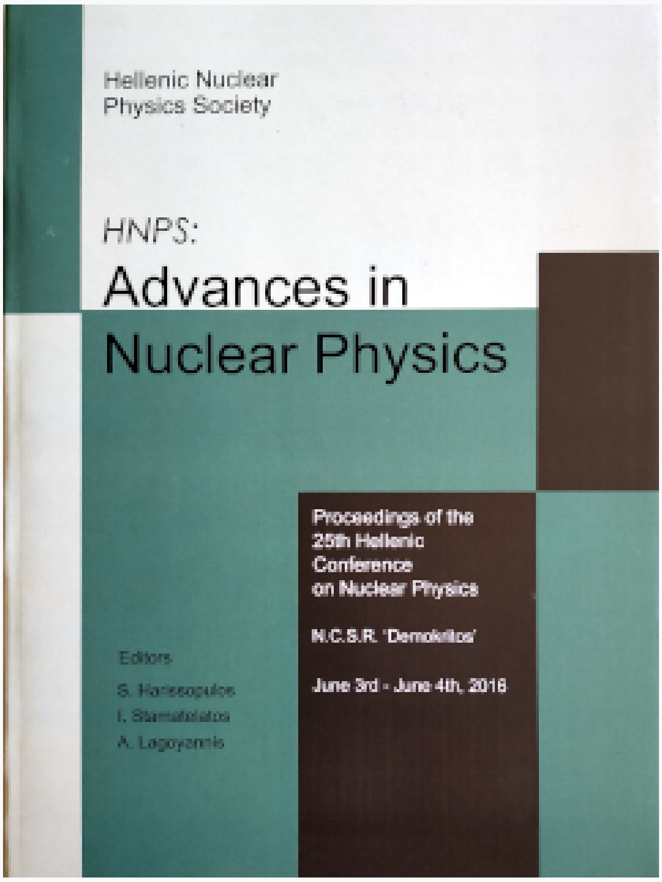

Installation of NEOPTOLEMOS, the new sum spectrometer for cross section measurements of capture reactions at the TANDEM Accelerator Laboratory of NCSR “Demokritos”

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Installation of NEOPTOLEMOS, the new sum spectrometer for cross section measurements of capture reactions at the TANDEM Accelerator Laboratory of NCSR “Demokritos”

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Abstract

Cross-section measurements of capture reactions are of key importance in understanding the contribution of the uncertainties of nuclear properties, such as the nucleon-nucleus potential and the nuclear level densities, entering in astrophysics abundance calculations. During the recent years, the Nuclear Astrophysics group of NCSR “Demokritos” has been conducting angle-integrated cross-section measurements using a large-volume NaI(Tl) detector installed at the Dynamitron Tandem Laboratory of the University of Bochum in Germany. Thanks to LIBRA funds a brand new cylindrically shaped NaI(Tl) detector, coined NEOPTOLEMOS, was acquired that is axially segmented in two, covering a solid angle of almost 4π for γ rays emitted at its center.

Keywords NaI(Tl), 4π detector, segmented, cross-section

THE 4π SUMMING NaI DETECTOR

Various experimental techniques and setups have been used, so far, for cross-section measurements of capture reactions. Up to now, the detectors most commonly used in these setups are HPGe detectors. For the determination of cross sections with this type of detectors, it is required to analyze all the γ transitions that lead to the ground state (transitions γ_1 and γ_5 in Fig. 1(a)) from spectra collected at several detection angles.

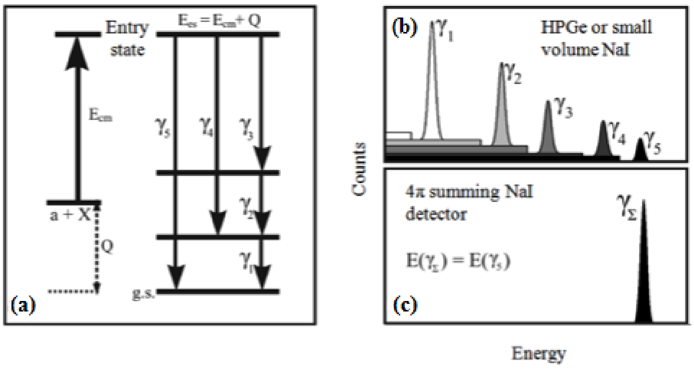

Fig. 1. Typical spectra (b) from HPGe or small volume NaI detector and (c) from a large-volume 4π summing NaI detector for the de-excitation of a compound nucleus (a) [1].

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This method is time consuming regarding both the measurement and the analysis process. The former results from the relatively small efficiencies of the HPGe detectors while the latter is related with the number of the γ peaks and spectra that need to be analyzed. Taking into account that at least 5 different detection angles are required and there can be up to 20 γ transitions feeding the ground state, it is obvious that the analysis procedure in this kind of measurements is not a trivial task. A sketch of a typical γ spectrum measured with a HPGe detector for the de-excitation of a compound nucleus is shown in Fig. 1(b).

All these disadvantages can be overcome by using a large-volume NaI detector covering a solid angle of almost 4π for photons emitted at its center. The large volume of the crystal enables the full absorption of a photon with high efficiency, while, because of its long decay time (250 ns), the photons emitted by the same γ cascade are detected as one with energy equal to the sum of the energies of the individual photons. This results to the formation of a single peak in the γ spectrum (Fig. 1(c)).

Therefore, by using a 4π summing NaI detector for the determination of the cross section of a capture reaction, the analysis procedure is considerably faster since, ideally, only one γ peak needs to be analyzed in every beam energy. In addition, the high efficiency of a NaI crystal results in relatively short measurement times. The Nuclear Astrophysics group of NCSR "Demokritos" has conducted several measurements by employing a large-volume eightfold segmented NaI(Tl) crystal previously installed at the Tandem Laboratory of NCSR "Demokritos" and a 12″x12″ summing NaI detector installed at the Dynamitron Tandem Laboratory (DTL) of the University of Bochum. From these measurements, a new method, the so-called "4π γ-summing method" was developed. This method takes advantage of the aforementioned characteristics of a large-volume NaI detector and enables fast and reliable cross-section measurements of capture reactions. In order to further employ the 4π γ-summing method, a new large-volume NaI detector was acquired and is already installed at the Tandem Laboratory of NCSR "Demokritos".

THE NEW 4π NaI DETECTOR AT THE TANDEM LABORATORY

The new summing NaI detector of the Tandem Laboratory is a 14″x14″ NaI crystal, axially segmented in two, as it is illustrated in Fig. 2(a). In order to choose the appropriate geometry of the new detector, Monte Carlo simulations with Geant4 code were performed for a well-studied reaction and the summing efficiencies of NaI crystals of various dimensions were calculated.

The new detector was installed in a stainless-steel frame consisting of two pieces which have the ability to move up and down mechanically. Also the small base, on which the frame of the detector is mounted, can move forward and backward along the beam axis.

This new detector outclasses the one installed previously at the Laboratory as well as the one installed at the University of Bochum, since its volume results in 25% to 50% (depending on the average multiplicity of the cascade) higher summing efficiencies.

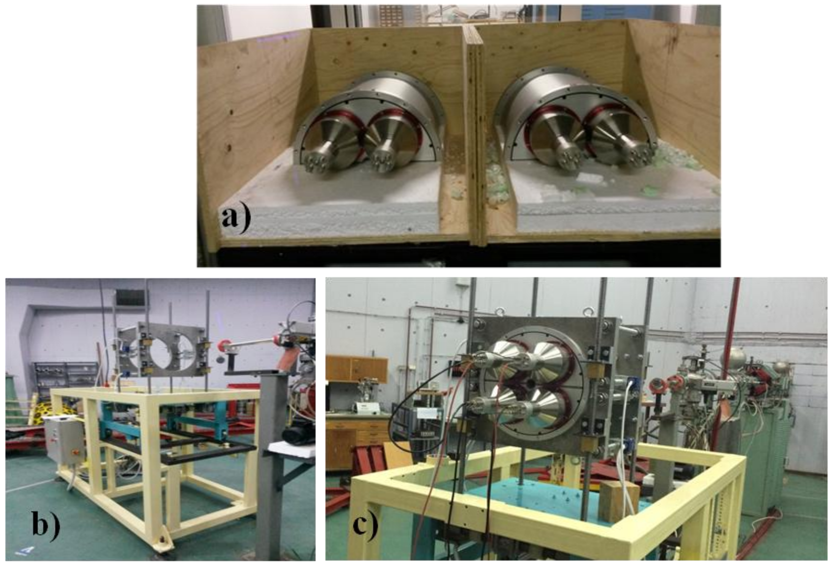

Fig. 2. a) The new 14″x14″, axially segmented in two NaI spectrometer,
b) the base and the frame of the detector and c) the detector in the laboratory today.

SUMMING EFFICIENCY DETERMINATION

After the installation of the new sum spectrometer, it is essential to determine its characteristics. One of the most important quantities that has to be studied is the summing efficiency of the detector.

The Nuclear Astrophysics group of the Tandem Laboratory developed a method for the determination of the summing efficiency of a 4π NaI detector [1]. In the case of the Bochum detector, two measurements in each beam energy are needed for the determination of the summing efficiency, one measurement with the target placed at the center of the crystal and one with the target placed at its edge. From the ratio R of the intensities of the sum peaks in the spectra collected from the two aforementioned measurements, one can deduce the average multiplicity <M> of the involved cascades taking part at the studied de-excitation from the equation

(1)

Subsequently, from the deduced average multiplicity and the energy of the sum peak, the summing efficiency is determined by the graph presented in Fig.3 [1].

In the case of the newly acquired detector, similar studies need to be conducted in order to deduce the empirical relation between the average multiplicity <M> and the ratio

(2)

where $I_{4\pi}$ is the intensity of the sum peak when the signal from the whole crystal is taken into account and $I_{\text{Top or Bottom}}$ is the sum-peak intensity when the signal of only one of the segments

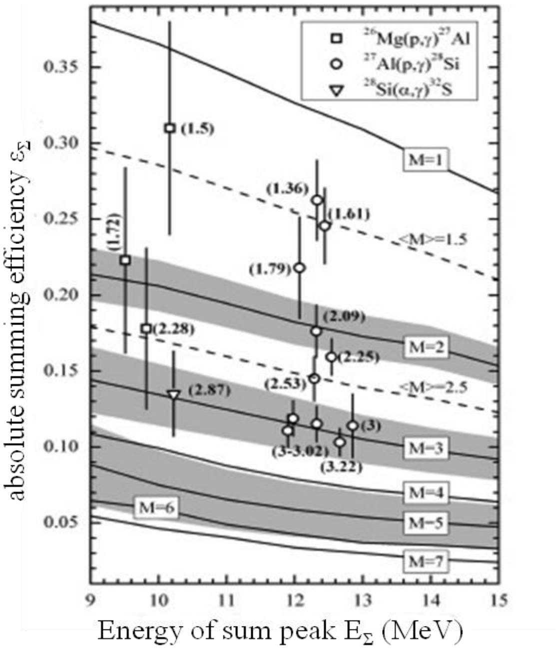

Fig. 3. The absolute summing efficiency diagram from experimental data and Geant4 simulations for the 4π NaI detector of Bochum [1].

is considered. It is worth noting that with the new NaI detector only one measurement is needed at each beam energy for the determination of the ratio R and consequently the summing efficiency. In addition, experimental studies of resonant reactions and GEANT4 calculations are scheduled to be performed for the correlation of the summing efficiency with the average multiplicity <M> and the energy of the sum peak.

CHARACTERISTICS OF THE NEW SUM SPECTROMETER

The first tests have been carried out with a ^{60}Co γ source placed at the center of the detector. By taking spectra separately from the two segments of the crystal, it was noticed that the gain of the photomultipliers did not match. By changing the photomultiplier gain of the bottom segment we managed to adjust them as it is illustrated in the figures below.

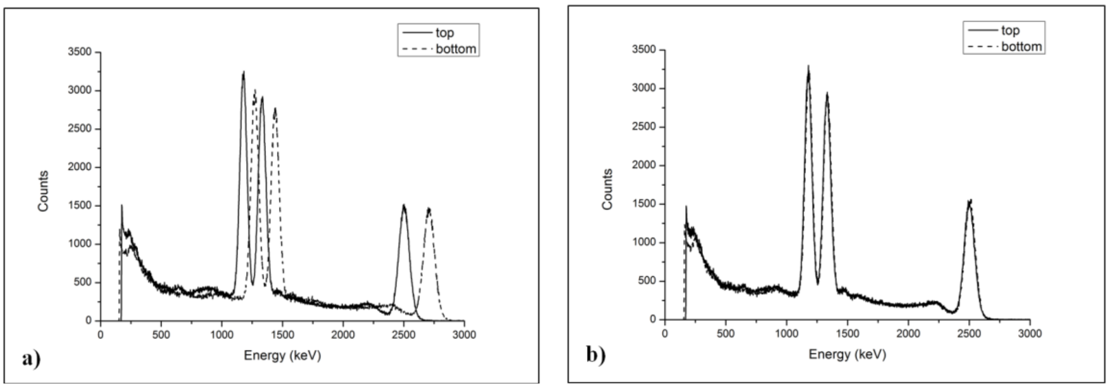

Fig. 4. a) Spectrum from the top and bottom segment of the crystal before the adjustment and b) after the adjustment.

After the adjustment of the gain of the photomultipliers, the peaks in the spectra collected from the two segments and from the whole crystal were analyzed. It was found that the peak at 1333 keV had a resolution of about 5.5% and the sum peak of about 4%. Additionally, the efficiency of the sum peak was estimated to be about 48%.

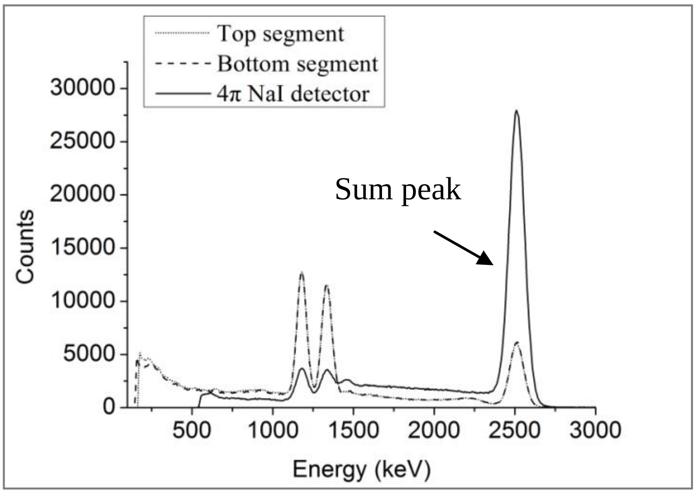

Fig. 5. Spectra from the new 4π detector**.**

CONCLUSIONS

The Tandem Laboratory was equipped with a new sum spectrometer suitable for astrophysical cross-section measurements, enabling the conduction of faster measurements and faster analysis procedure. Our future plans are to perform cross-section measurements of capture reactions which are of great importance in nuclear astrophysics.

References

[1] A. Spyrou et al., Phys. Rev. C 76, 015802 (2007).