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THE PROPERTIES OF THE LOW ENERGY NEUTRON ARRAY AND LABR$_3$ DETECTORS IN THE S408 EXPERIMENT AT GSI

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Abstract

An array consisting of 15 scintillator bars has been constructed and used in coincidence with state of the art LaBr$_3$ detectors for studying charge-exchange reactions in inverse kinematics. Details of the design (wrapping procedure) and test results about cross scattering effects, time and position resolution and light collection of a Low Energy Neutron Array (LENA) will be presented together with γ-ray energy. The neutron energy is determined by the time-of-flight technique, while the position of interaction is deduced from the time difference information from photomultipliers attached to both ends of each bars.

I. Introduction

Charge-exchange (CE) reactions at intermediate energies have been used extensively in nuclear structure studies as a sensitive probe of the spin-isospin response of nuclei. Experimental investigations have mostly been limited to stable targets.

The charge exchange reactions in inverse kinematics are efficient tools for studying collective phenomena, like neutron-skin of exotic nuclei. Using (p,n) reaction in inverse kinematics the kinetic energy of the neutrons is relatively low and short flight path is sufficient for the time-of-flight measurements.

Recently we have performed an experiment (S408) at the GSI, Darmstadt for studying the absolute, model independent neutron-skin thicknesses of the ^{124}Sn isotope [1].

The aim of the experiment was to investigate the strength of the isovector giant dipole resonance (IVGDR), using (p,n) reaction in inverse kinematics, in order to constrain the symmetry energy of the Equation of State (EoS).

Low-energy neutrons (1 to 4 MeV) were observed by LENA. The array was mounted at a distance of 1 m and 65°< Θ_{lab} <75°. The neutrons were measured in coincidence with γ-rays coming from the de-excitation of the IVGDR, using six very large (3.5"x 8") $LaBr_3$ spectrometers. A few important detectors of the LAND group were also used: the POS detector for providing a start signal to the ToF measurement with the LENA neutron detector, and the ROLU unit for beam tracking.

II. The LENA

The aim of the construction of LENA was to study (p,n) type reactions in inverse kinematics using unstable beams [2].

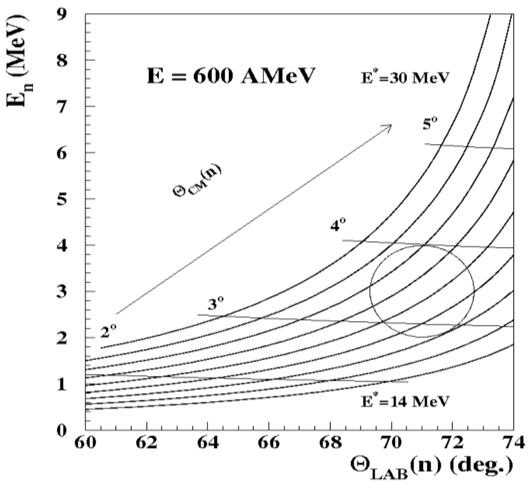

Figure 1: The neutron energy as a function of the laboratory scattering angle

The array was designed to measure neutron energies by the time-of-flight technique and angles with high resolution, and at the same time having high detection efficiencies.

The angular resolution plays an important role in these measurements, since the neutron energy depends strongly on the laboratory angle: $\Delta\theta = 1°$ means $\Delta E^* = 1$MeV as shown in Fig.1.

The following technical requirements were taken into account in the course of designing: To avoid neutron scattering requires less material in the holder structures and environment. The position of detector frames should be adjustable in the range of laboratory angle $40° < \Theta_{lab} < 80°$.

Sharp TOF-start signal and low cross-scattering of neutrons are needed. Good light collection mode was necessary. In order to increase light collection, good reflectors surrounding the optical system (wrapping) were required, which are efficient in a wide range of wavelength and incidence angle.

LENA is an array consisting of 15 single detectors. There are 3 modules each of them contains 5 paddles as it is shown in figure 2. Each detector consists of plastic scintillator material with a size of $10 \times 45 \times 1000$ mm^3. The type of the plastics is: UPS89 (NE102A). Light output Percent Anthracene: 65 %, and the wavelength of maximal emission is 423 nm.

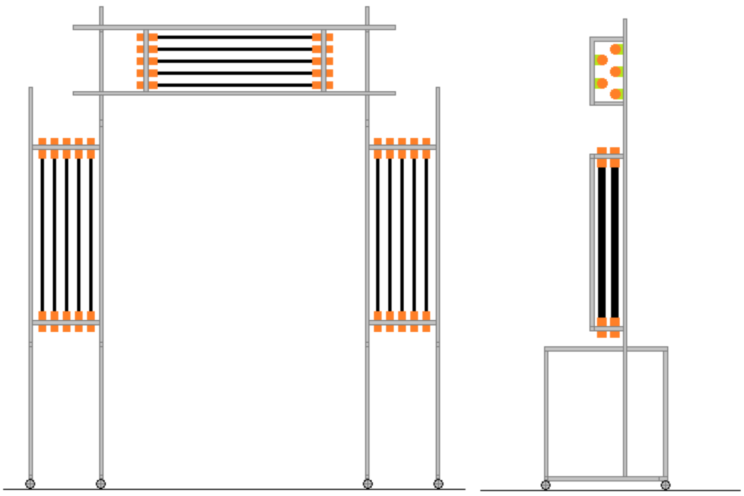

Figure 2: The schematic layout of the LENA.

The detector bars are wrapped with a special VM2000 multilayer reflector foil, which has recently been issued by 3M. It is a multi-layer reflective foil based on a novel technology [3].

This foil has a reflection coefficient of $R > 97\%$ for $\lambda \geq 400$ nm, and $R = (98.5 \pm 0.3)$ % at 430 nm wavelength of light [4].

The response of the plastic scintillator is bad for low energy protons, which are created by the elastic scattering of the neutrons. A very good light collection is necessary to pick up the small signals, so proper wrapping material, and perfect fitting of the foil onto the plastic were important criteria.

Fast PM-tubes with active dividers were attached at both ends of the detector bars. We used high viscosity silicon grease for the light coupling (type: EJ-560 Optical Interface sheet). Two different PM-tubes were tested in order to reach the lowest possible detection threshold: Hamatsu R2059 and Photonis XP2262. There was not significant difference between the two tubes. Hence we decided for Photonis XP2262. The schematic layout of the detector-system and one module from side-view is shown in Fig. 2. Similar neutron spectrometers have recently been built also by Beyer et al. [5] and by Perdikakis et al. [6].

In order to avoid the neutron scattering, the construction of the holder was very important. It should contain as small amount of material as possible, but it also should be stable. We used ITEM Profil “6” 30x30 (0.0.419.01) as holder material.

II.1. The wrapping procedure

The following procedure was used for the optimal wrapping. In the first step we prepared a special wrapping mold. The size of the mold was half-half mm smaller then the original plastic bars, like $(1000\times44{,}5\times9{,}5)$ mm^3. The baking form was made of aluminum and its surface was perfectly flat. A slice of VM2000 foil was cleaned with ethanol and layed between the mold. This should be a very precise process, any stretch, stress or shrink the reflective film can compromise the optical properties of the foil.

When the aluminium baking form was perfectly covered with foil the construction was fixed using external handcuffs. The covering procedure was carried out with the help of an exterior aluminium mold fixture. The distance between the handcuffs was 10 cm.

The wrapping mold with the foil was put into an electric oven and it was baked during 2 hours at 115 °C. The mold was removed from the oven after 2 hours baking and it was cooled during 24 hours.

After removing the foil from the mold, we let it relax for one week before wrapping the plastic into the foil.

The optical parameters of the foil did not change after such a procedure.

II.2. Test of the wrapping

Using the $^{7}Li(p,n)^{8}Be$ reaction at different proton energies mono-energetic neutrons were created and the effect of the wrapping on the light collection were studied by measuring the detection efficiency of the detectors.

The experiment was performed at PTB, in Braunschweig. The distance of the detectors from the target was about 5 m, and the neutron energy range was varied between 0.2 and 2 MeV.

Three types of wrapping were studied. We compared the efficiency of bars, wrapped by Teflon (+ black plastic) and by specially treated VM2000 foil (+ black plastic) to bars which wrapped by VM2000 foil, without baking (+ black plastic).

The values were normalized to data of the simple VM2000 foil.

Wrapping	**Energy of the neutrons**		
	210 keV	**471 keV**	**1,04 MeV**
Teflon tape	95%	96%	96%
VM200	*100%*	*100%*	*100%*
VM200 (treated)	115%	115%	119%

Table 1. Efficiency of the covered detector bars at the given energyes

We can conclude that about 15-20% increasing in neutron detection efficiency was achieved using the special treated VM2000 foils.

II.3 Investigation of the cross scattering effects

The intended applications of the LENA are sensitive for the exact place of the events, so the scattering, “crosstalk” between detectors can be a serious problem. In deriving the experimental data we required firing the first scintillator in the first raw. The scattering probabilities from that scintillator are shown in Fig. 2. The cross talk at two different energy values was studied.

One is at 471 keV neutron energy (which is indicated by red numbers in Fig.3) and the other one is at 1040 keV neutron energy (which is indicated by *black* numbers in Fig.2).

We have also performed Monte-Carlo simulations for the crosstalks. These results are in good agreement with our experimental results.

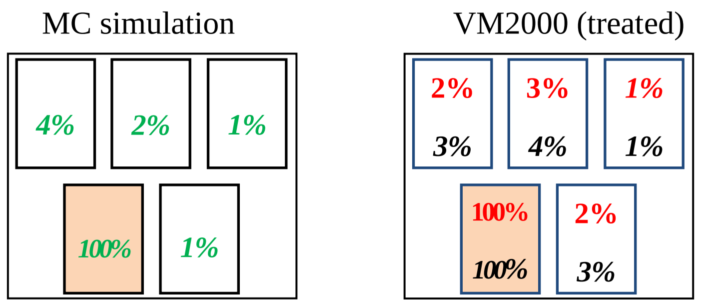

Figure 3. Comparison of the crosstalks obtained by Monte-Carlo simulations and from the experimental data. The first scintillator in the first raw was irradiated by neutrons.

II.3 Investigation of the a position resolution of the LENA

A measurement performed with a ^{90}Sr electron source at GSI, Darmstadt shows a time resolution of 0.9 ns. Hence the position resolution is about 8 cm in the middle region of the detectors, as it is shown in Fig. 4. At the two ends of the detector bars the resolution decreases by 50%.

The positions of the incoming particles along the detector are determined by the time difference between the signals of the two photomultipliers. Events, when both tubes fired were only taking into account in the analysis of the experimental data.

III. The large $LaBr_3$ scintillation detectors

6 large volume (3.5” x 8”) $LaBr_3$ scintillation detectors were used in the

S408 experiment at GSI for detecting the γ–decay of the giant dipole resonance. These scintillators have very good energy and time resolution [7].

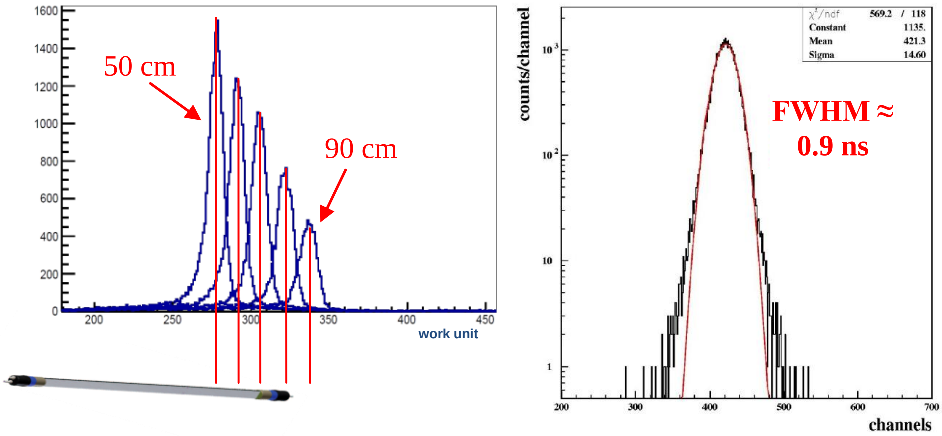

Figure 4. The experimental position resolution and the time resolutions of the LENA

The absolute full-energy peak efficiency of the large $LaBr_3$ detectors were studied following the S408 experiment at the VdG Laboratory in ATOMKI, Debrecen. The conditions were the same as in the S408 experiment. We used 5 mm Pb, 3 mm Cu and 10 mm thick Al absorbers in front of the detectors.

III.1 Study of the efficiency at low and high γ-ray energies

At low energies the efficiency was measured using ^{60}Co and ^{66}Ga gamma-ray emitters, which were placed at 25 cm from the front face of $LaBr_3$ detector. The absolute normalization of the efficiency was carried out using the ^{60}Co source (calibrated by the National Office of Measures of Hungary), which had an activity of 47.52 kBq during the measurement. The full absorption efficiency of the detectors was divided by their solid angle, in order to get the internal efficiency.

At higher energies a version of the point-pair or two-line method combining low-energy radioactive lines with proton resonance capture lines was applied in the efficiency calibrations [8]. This procedure requires two gamma transitions in a cascade.

The efficiency for the high-energy region was obtained by normalizing to the low energy part in the overlapping range around 1.4 MeV which is the internal radiation of the crystal. The target - detector distance was also set to 25 cm in these experiments. The calculated statistical error was less than 1%.

The gamma energies from the following reactions were used: $^{23}Na(p,\gamma)^{24}Mg$, $^{27}Al(p,\gamma)^{28}Si$, $^{39}K(p,\gamma)^{40}Ca$ and $^{11}B(p,\gamma)^{12}C$, $^{7}Li(p,\gamma)^{8}Be$.

All targets were made by evaporation onto thick tantalum backings (0.1 mm) in vacuum.

The measured efficiencies were compared to the calculated ones obtained by a GEANT4 Monte-Carlo simulation code. The simulated efficiency was normalized to the measured values, by the factor of 1.15. The results are in good agreement with the experimental data. The efficiency decreases with the increasing γ-ray energy from 19.7(6) % for 1173.2 keV to 4.5(5) % for 17.6 MeV.

Acknowledgments

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