Testing of the NE213 and ^{6}Li glass detectors for the ELIGANT-GN array at ELI-NP

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Summary

We propose use ^{7}Li(p,n)^{7}Be reaction as a source of monochromatic neutrons in order to study the NE213 and ^{6}Li-glass detectors response which are components of ELIGANT-GN array being developed at ELI-NP.

Introduction

The ELI-NP facility will provide a high-brilliance gamma beam of the energy up to 19.5 MeV. This range is well-suited to study high-energy collective excitations up to around two neutron threshold energy. The "Gamma above Neutron Threshold" Working Group at ELI-NP proposes to study the gamma and neutron decay of the Giant/Pygmy Dipole Resonances. The dedicated ELIGANT-GN array was designed, consisting of 34 $LaBr_3$:Ce/$CeBr_3$ scintillators for gamma detection as well as 32 NE213-type liquid scintillator and 32 ^{6}Li-glass detectors for fast-neutrons measurement. The first type is best suited for neutron energies higher than 1 MeV, while the later for the low energy region. The proposed experimental setup was simulated using the GEANT4 code. The simulations were based on light output curves from literature and the obtained detector efficiencies were checked against similar existing detection systems. However, ^{6}Li-glass detectors are not yet implemented in the code, and there is an urgent need for reliable test experimental data.

We propose to utilize the facilities available at IFIN-HH to develop, test and characterize the detectors for ELIGANT-GN detection system designed for ELI-NP experiments. The proposal is the continuation of the tests that have already been started at IFIN-HH but this time we would like to extend the number of detectors and measured energy points as well as integrate the current which would allow to measure the cross sections.

Experiment description

The energy of neutrons will be estimated using the time-of-flight (ToF) method. We proposed to use mechanical frame of two walls each with 12 spots for NE213 or ^{6}Li-glass detectors. We would also like to use $LaBr_3$:Ce detectors to measure the gamma-rays. This would give very precise time reference for the ToF but also would allow to test a gamma-neutron coincidence measurement which is planned for future ELIGANT-GN array.

The calibration and resolution estimation for NE213-type neutron detectors can be done using gamma-rays as the light yield of the recoiling atomic electrons is linear above about 100 keV [1, 2]. However, the low Z value typical of liquid scintillators means that gamma-ray interactions are dominated by Compton scattering at energies of a few MeV. Thus, resolution-broadened Compton edges must be carefully interpreted in order to calibrate the detector. Two different prescriptions to extract the Compton edge from a resolution-smeared distribution have been reported by Flynn et al. [3] and Knox and Miller [1]. General agreement between these two was achieved using Monte Carlo simulations [8]. We can use similar approach: measure the detector response spectrum with gamma-ray sources, simulate the theoretical Compton spectrum using GEANT4, and use a best-fit to fold the Compton spectrum with a Gaussian resolution function.

The discrimination between gamma ray and neutron with NE213 can be achieved by pulse-shape discrimination (PSD). The simplest and most popular method for PSD is the charge integration method, where the slow component of the pulse charge is compared with the total pulse charge or the fast component.

The procedure to characterize ^{6}Li-glass detectors is not well established yet. Detector responses have been measured with Cf-252 time-tagged ionization chambers and validation of MCNP has been achieved [5]. Similar procedure has been applied with mono-energetic neutrons [6]. We propose to measure the detector response and test the use of GEANT4 simulations.

In order to implement correctly our detectors in the Geant4 simulations, the light output curves are very important. We will construct the light output curves using the detector response functions at various neutron energies.

We plan also to ***measure proton beam current***. For this, a Faraday cup (with guard ring at ~-300V to repel the delta electrons) will be prepared and the stack of targets on cup end will be placed and followed by graphite coin. From this cup a current integrator will be fed and we will acquire its output in a DAQ during irradiation. This will allow to estimate the ^{7}Li(p,n)^{7}Be cross sections.

ELI-NP will provide the entire data acquisition chain and the NE213-type liquid scintillators and ^{6}Li-glass detectors as well as the mechanical frame for the detector walls.

In order to obtain the neutron fields, *w*e propose to use the ^{7}Li(p,n)^{7}Be (Q=-1.6442 MeV) reaction to produce quasi mono-energetic neutron fields. For proposed reaction, the kinematic energy spread is also much smaller than the target-thickness energy spread. The reaction is well studied and used to produce 144, 250, and 565 keV neutron reference fields at National Metrological Institutes. These reference energies are well suited for characterizing the ^{6}Li-glass detectors.

For characterization of liquid scintillators (NE213), the energies above 1 MeV are better suited and can also be accessed with this reaction. However, the cross section for the emission of neutrons has maximum for energy of protons between 2.2-2.4 MeV and drops to its half and stays rather constant for higher energies [7]. For proton energies higher than 2.4 MeV the ^{7}Li(p,n)^{7}Be reaction starts to produce two quasi mono-energetic neutrons As with the IFIN-HH 9 MV cyclotron, the proton beam of energies below 3-3.5 MeV starts to become unstable, therefore, we propose not to go below energy of 3.5 MeV but to use additionally a gold degrader for the low neutron energies generation. Examples of proposed proton energies required at zero degree are shown in Table 1. In cases when degrader is added, the values in brackets indicates the energy than is expected after degrader. We decided to measure more energy point in the region around 1-MeV neutrons to precisely investigate the detection efficiency of both types of detectors. As the energy of neutrons is dependent on the angle, precise estimation of the detectors position is needed.

Table 1. Requested neutron energies and the proton energies to obtain them at zero degree.

Neutron Energy [MeV]	**Proton Energy [MeV]**	**Gold degrader [μm]**
0.144	3.78 (1.94)	25
0.250	3.86 (2.02)	25
0.565	4.03 (2.30)	25
0.650	4.08 (2.37)	25
0.75 and 0.21	4.16 (2.47)	25
0.90 and 0.39	4.27(2.61)	25
1.0 and 0.50	4.34 (2.71)	25
1.2 and 0.72	4.49 (2.90)	25
1.4 and 0.92	4.64 (3.09)	25
2.0 and 1.53	3.68	-
3.0 and 2.54	4.67	-
4.0 and 3.56	5.67	-
5.0 and 4.55	6.66	-
6.0 and 5.56	7.66	-
7.0 and 6.56	8.66	-
8.0 and 7.56	9.66	-

Lithium fluoride targets can be manufactured using standard vapour deposition equipment. Typical evaporated LiF layers are between 50 and 100 $\mu g/cm^2$ on tantalum backing.

Beam time estimation

We can use two approaches:

- Split beam time into two, and use first the full 24 NE213 detectors for higher energies, and then replace some with ^{6}Li glass and use lower energies. This approach might be more efficient for shorter beam time
- Use the same setup all the time (combined NE213 and ^{6}Li glass) for all the proton energies. This would give better characteristic of the detectors (whole energy range) but might require longer beam time due to statistics

The estimation of the expected statistics based on the previous measurement for a liquid scintillator is the following:

- E_p = 5 MeV (no degrader), 12 neutrons/s

- E_p = 4 MeV (no degrader), 3 neutrons/s

- E_p = 4.5 MeV (25 um degrader), 2 neutrons/s

- E_p = 5.7 MeV (50 um degrader), 1.8 neutrons/s

These allow to roughly predict that for measurement with higher energies (E_p > 5 MeV) we may expect ~12 neutrons/s, while for the rest of measurements less 2 neutrons/s are expected. Therefore, we estimate that we would need at least 3 h for each high-energy point (at least 4 measurements), however for each lower-energy point (12 measurements) we should require around 18 h of beam time. This gives a minimum beam time of 8 days. One should consider that longer time might be required for ^{6}Li-glass detectors, especially in case of neutron energies higher than 0.5 MeV. Moreover, taking into account required preparations of the experiment and additional problems that may occur, another 2 days would be required. In case of any spare beam time, a number of measured energy point could be increase which is desired in this kind of test experiments.

Therefore, we ask for a total of 10 days of beam time.

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