Multi-layer plastic scintillation detector for high-energy neutrons with n-γ discrimination capability

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High-energy neutron detection is an important tool for experiments using nuclear reactions at intermediate energy. However, considerable γ-ray backgrounds pose a challenge to most neutron detectors. In this study, we propose a novel neutron detector array consisting of multi-layer plastic scintillators with capability to suppress γ-ray background at a low threshold. It is capable of n-γ discrimination by utilizing the range information of secondary particles produced via interactions of neutrons or γ rays in the scintillator material. Compared with the traditional liquid scintillator, the new neutron detector, named stacked detector, is not only competent in a high background environment with faster response, but also cheaper and more flexible.

The stacked detector is composed of sixteen 5-mm-thick plates of plastic scintillator with a total area of 320×160 mm^2. The odd and even layers are connected to photomultipliers by saw-tooth shape light guides separately. Neutrons and γ rays are discriminated by means of the range difference of their secondary particles, namely the numbers of penetrated layers. Given the same energy deposit in the scintillator, the range of a secondary electron ejected by a γ ray is much longer than that of the secondary particle, mainly a proton or a carbon ion, due to a neutron. By reading out both energy deposits in the odd and even layers, one can define a balance ratio as R=(even-odd)/(even+odd). R equals to -1 or 1 if a secondary particle is stopped in the layer of reaction; the R values will be distributed around zero if the secondary particle penetrates several layers, since the deposited energy will now be shared by both odd and even layers. Thus the incoming neutrons and γ rays can be separated by the value of R.

The detector was tested using standard radioactive sources and a series of experiments at RCNP. An ^{241}Am-^{9}Be neutron source, cosmic rays and a proton beam were used to calibrate the light output. Monoenergetic neutrons were generated by the $d(d,^3\mathrm{He})n$ reaction for further investigation of the n-γ discrimination and deduction of the neutron detection efficiency. Neutrons and γ rays can be distinguished clearly, as shown in Fig.1, from the measurements with the ^{241}Am-^{9}Be source, monoenergetic neutrons from the $d(d,^3\mathrm{He})n$ reaction and the prompt γ rays from the $^{12}\mathrm{C}(d,^3\mathrm{He})$ reaction. The typical time width for the prompt γ ray is 350 psec in σ, corresponding to about 8% of reconstructed kinetic energy of neutrons with a flight path of 71 cm. Position resolution obtained from the time difference between two photomultipliers at both ends is around 2.4~3.0 cm in σ.

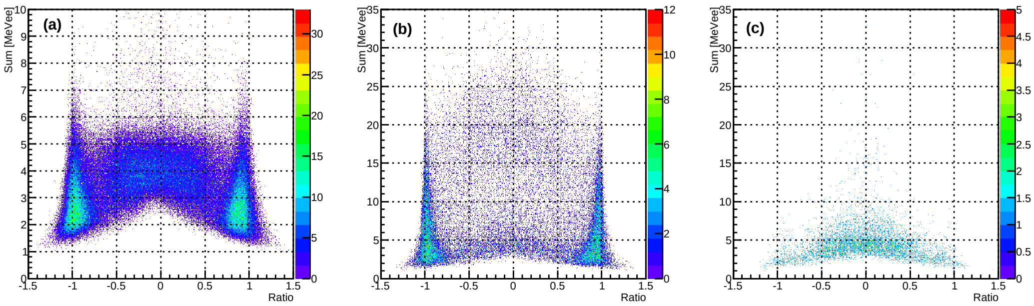

Figure 1: n-γ separation in Sum-Ratio plot from the measurements with (a) the ^{241}Am-^{9}Be source (b) monoenergetic neutrons gated from TOF spectra (c) the prompt γ rays gated from TOF spectra, where Sum=even+odd, Ratio=(even-odd)/(even+odd). See text for details.

The neutron detection efficiency of stacked detector was measured at two different energies using monoenergetic neutron beam produced by the $d(d,^3\mathrm{He})n$ reaction. The CD_2 target with a thickness of 24.3 mg/cm^2 was bombarded by a deuteron beam of 196 MeV with 3-10 nA beam intensity. Scattered ^{3}He was momentum-analyzed by the Grand Raiden spectrometer at 5.5° and 13.5°. Recoiled neutron was detected by stacked detector at central angles of 148° and 112°, respectively. Kinetic energies of neutrons at two angle settings were 16.5±1.1 MeV and 31.2±2.6 MeV, respectively. The number of detected neutrons were determined by subtracting the contribution of accidental γ rays using R information. The measured efficiencies at two energies depending on different thresholds were compared with Monte Carlo simulation by GEANT4 version 10.2 [1] using conventional electromagnetic and hadronic packages. Two physics lists, QGSP_INCLXX_HP and

QGSP_BERT_HP, were tried and compared with experimental data as shown in Fig.2. A good agreement can be achieved between simulation and experiment at 16.5 MeV, while discrepancy at 31.2 MeV depends on different models. The QGSP_INCLXX_HP physics list appears to reproduce the experimental results better.

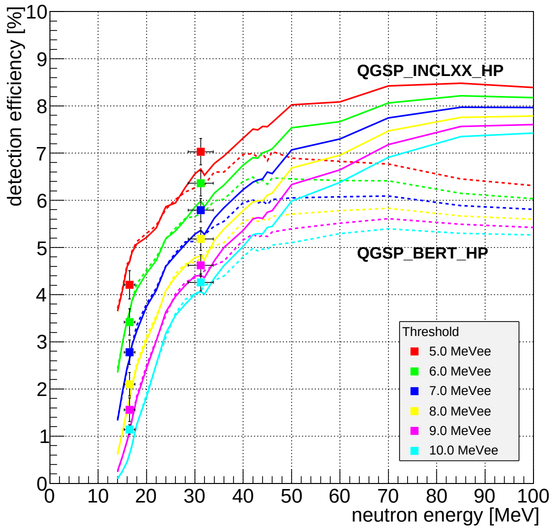

Figure 2: Comparison of measured efficiencies with simulation depending on different thresholds. The solid curves were calculated using the QGSP_INCLXX_HP physics list, while the dashed ones were by the QGSP_BERT_HP physics list.

The n-γ discrimination technique by range makes up for the disadvantage of plastic scintillator, which usually employs a conventional time-of-flight (TOF) method and suffers from accidental (time-uncorrelated) γ rays. By the additional discrimination, accidental γ rays can be efficiently suppressed, thus enabling a lower detection threshold and higher detection efficiency for neutrons. As can be inferred in Fig.1(c), almost 100% of γ rays will be rejected by the value of R at a threshold of 5 MeV_{ee} for layers of 5-mm thickness. With the capability of high rate detection, the stacked detector is proved to be the desired neutron detector especially when neutron events are overwhelmed by huge γ-ray background. Now the detector is ready for use in experiments to measure absolute reaction cross sections involving neutrons, whose detection efficiencies at higher energies can be determined by simulation.

References

[1] S. Agostinelli *et al.*, Nucl. Instrum. Meth. A **506**, 250 (2003), official website: http://geant4.cearn.ch/