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Construction and calibration of the multi-neutron correlation spectrometer at Peking University

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ABSTRACT

A Multi-Neutron Correlation Spectrometer (MuNCoS) composed of 80 detector modules was constructed at Peking University. A position resolution of less than 3 cm (FWHM) for a typical long scintillation module was obtained based on cosmic ray tests. A calibration method using an unstable nucleus beam of ^{11}Be, together with the fragment identification by using a zero degree telescope, has been successfully developed. Neutron detection efficiencies of 15(1)% and 17(2)% were achieved for neutron energy intervals of 30–40 MeV and 40–60 MeV, respectively, and at a signal charge threshold of 4 MeVee. The experimentally determined neutron detection efficiencies agree well with the simulation based on the GEANT4 code.

1. Introduction

Since the discovery of two neutron halo nuclei such as ^{6}He, ^{11}Li, ^{14}Be and some others, much effort has been devoted to investigate their structures based on the cluster models which treat them as an inert core plus a few valence neutrons [1]. The correlation between the valence neutrons is one of the key problems in this kind of description and has been studied intensively in the literature [2–8]. On the experimental side large size neutron detector arrays [9–12] with high detection efficiency, good position resolution and adequate cross-talk discrimination capability are mandatory in these studies [13]. In order to increase the cross-talk rejection rate while retaining the normal neutron detection performances, we have proposed a new array called the Multi-Neutron Correlation Spectrometer (MuNCoS) at Peking University (see Fig. 1a). The design goal is to have a single neutron detection efficiency of approximately 20% for neutron energies between 10 and 100 MeV, a position resolution of less than 6 cm, and a cross-talk rejection rate of 90% while retaining about 80% of the detected two-neutron events. In this article we report on the design, construction and experimental tests of the spectrometer. Due to the complexity of the cross-talk treatment [14,15], we concentrate here only on the normal properties of the spectrometer while leaving the cross-talk analysis to another report.

2. Design of the MuNCoS

The MuNCoS is composed of 80 plastic scintillator modules (BC-408). Each module has a size of $200 \times 6 \times 5$ cm^3 (Fig. 1b) and is coupled to two fast Photon-Multiplier Tubes (PMT, Hamamatsu R1828-01) at both ends by silicone optical grease (Fig.1b). The scintillator is wrapped with aluminized Mylar for the internal light reflection and black plastic tape to shield it from outside light. The PMT is optimized for timing measurement, and is assembled with a high voltage divider base. The tube and the base are enclosed in a magnetic shielding case.

In order to discriminate the charged particles that enter the neutron detectors, some thin and large size veto detectors were prepared and might be placed in front of any neutron detection layer. Each veto module has a size of $210 \times 35 \times 1$ cm^3 and is also wrapped with aluminized Mylar and black tape. Each module is coupled to two Hamamatsu R1828-01 PMTs via specially shaped light guides. Three veto modules form one veto layer to cover the whole active area of a neutron detector layer. In Fig. 1 a, these thin veto layers (green color) can be seen in front of every two neuron detector layers.

The whole MuNCoS array can be mounted in different configurations with a specially designed support framework in order to

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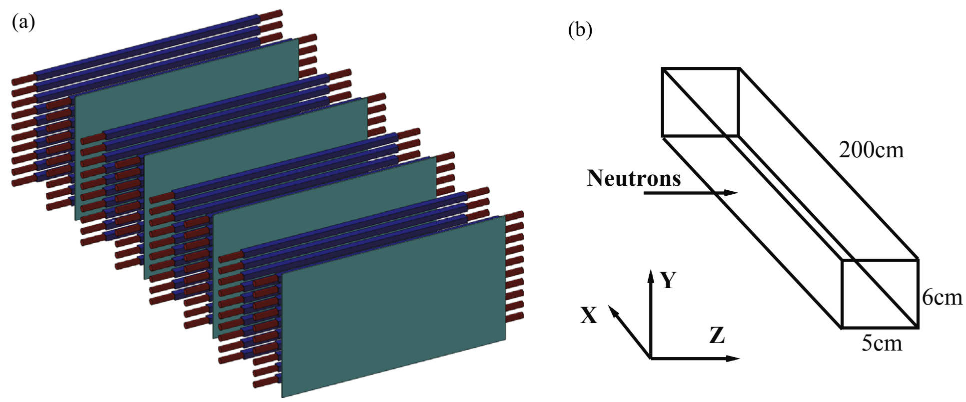

Fig. 1. (a) Schematic view of the MuNCoS (see the text for details); (b) one module of the MuNCoS.

meet various application goals. Its standard configuration is shown in Fig. 1a, including 8 neutron detection layers, each being composed of 10 scintillation modules. There is a gap of about 5 cm between the adjacent two modules in one layer, while the distance between the adjacent two layers is about 50 cm. This scattered configuration is in favor of the cross-talk rejection as demonstrated by the DEMON array [16]. In total four veto layers can be installed in front of some of the neutron detection layers, in order to discriminate the charged particles.

Each signal from a PMT is split into one timing signal and one charge signal, with the former being fed into a Constant Fraction Discriminator (CFD) followed by a Time-to-Digital Converter (TDC), and the latter directly into a Charge-to-Digital Convertor (QDC). The neutron time of flight (ToF) between the reaction target and the detector is determined by:

$$t_{\rm ToF} = \frac{t_L + t_R}{2} + t_0 \tag{1}$$

where $t_{\rm L}$ and $t_{\rm R}$ are timing signals from both ends of the module, relative to the common starting time provided by a beam detector, and t_0 the offset time to be determined by an absolute time calibration. The hit position of the neutron along the module is derived from the difference of the two timing signals:

$$x = c\frac{t_{\rm L} - t_{\rm R}}{2} + x_0 \tag{2}$$

where c (the effective speed of light) and x_0 (the position offset) can be calibrated in a cosmic ray test. The position independent geometric mean charge Q is given by the two charge signals of a module:

$$Q = \sqrt{Q_{\rm L} Q_{\rm R}} \tag{3}$$

Q is proportional to the electron equivalent deposited energy E (in MeVee) [17]:

$$Q = aE + b \tag{4}$$

where a and b are also parameters to be calibrated (see Section 3 below).

3. Module performance test with cosmic rays

A cosmic ray test was carried out at Peking University to study the performance of the scintillation modules. As shown in Fig. 2, the test setup is composed of four modules in one layer with a vertical spacing of 17 cm to each other. A passing-through muon fired the modules, and the signals $t_{\rm L}$, $t_{\rm R}$, $Q_{\rm L}$ and $Q_{\rm R}$ were recorded for each module. As shown in Fig. 3, the time difference spectrum has two sharp edges, corresponding to the geometrical ends of the module. These edges can be used to make the above defined

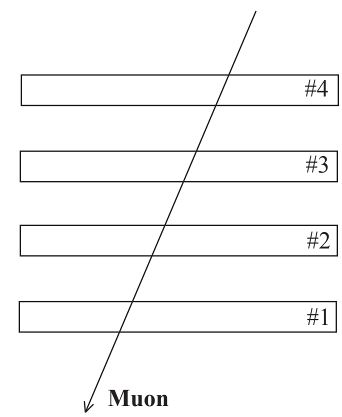

Fig. 2. Setup for the cosmic ray test.

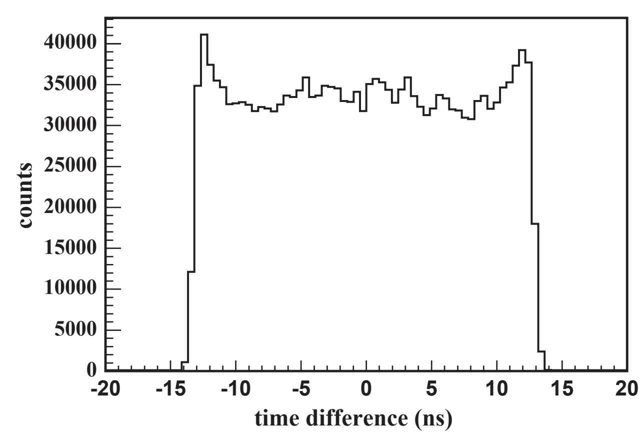

Fig. 3. Time difference spectrum for the scintillation module #2.

(Eq. (2)) position calibration. This calibration was verified by locating a γ-ray source at various positions along the module [18]. From this calibration, an effective speed of light along the scintillation module was determined to be 15.6 cm/ns.

The usual way to determine the position resolution relies on using a particle beam with very small spot size but sufficient intensity to hit the detector. The spectrum of the difference between the measured position and the real hitting position gives the uncertainty (resolution) of the position measurement. In the reality, the fine reference beam is often defined by small collimation holes [19,20] or by some small trigger detectors [21]. But this method is inefficient and even impossible in case of very low beam intensity, such as cosmic rays, and for a large detector array composed of many units. We adopted here an alternative