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Thermal neutron background measurement in CJPL

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ABSTRACT

This paper describes the measurement of thermal neutron flux in the CJPL underground laboratory in the proximity of the CDEX experiment. A low background thermal neutron detection system is designed which applies a combination of a ^{3}He proportional tube and a ^{4}He proportional tube as the detector. Thermal neutrons can be captured by the ^{3}He proportional tube while the ^{4}He proportional tube is for the purpose of background measurement. The tube wall is made up of oxygen-free copper to reduce the background due to radioactivity of the wall material. The electronics readout system has been developed to store triggered events' waveforms so as to get the amplitude spectrum and monitor the data quality. We observed an average thermal neutron flux of $\Phi = 4.00 \pm 0.08 \times 10^{-6}/\mathrm{cm}^2$ s in the CJPL experiment hall in the proximity of CDEX experiment and the neutron and background events both distribute uniformly along the tube.

1. Introduction

China Jinping Underground Laboratory (CJPL) is the deepest underground laboratory in the world which is located in the Jinping tunnel in Sichuan Province of China. It has an average rock overburden of 2.4 km which makes the cosmic rays flux to a very low level less than 100 counts per square meter per year [1]. The principal source of the background radiation of underground laboratories is the rock's natural radioactivity. The content of several typical radioactive nuclides of the rock sample of CJPL is much lower than the normal level [2]. All of these make CJPL an ideal place for experiments requiring extremely low background radiation level and the China Dark Matter Experiment (CDEX) is one of them. Thermal neutron is an annoying component in many underground experiments for its ability of nuclide activation which will increase the instruments' background level and deteriorate the performance of the experiment system. The main neutron source of the underground laboratory is from the natural radioactivity of the rock via spontaneous fission and (α, n) reactions [3,4]. A detailed understanding of the thermal neutron flux is helpful to the interpretation of CDEX results. CDEX instruments are placed in a small room wrapped up by a thick layer of polyethylene. The measurement of thermal neutron flux is taken place in the hall outside the PE room, and the solid angle covered by the CDEX shield from the view of the neutron detector is 0.29.

In this paper we present the design and implementation of the low background thermal neutron detector and its electronic readout system. The performance of the detection system is fully tested and the measurement results in CJPL experiment hall are discussed.

2. The design of thermal neutron detection system

Detector: A proportional counter tube filled with ^{3}He is used to detect thermal neutrons via the reaction $\mathrm{n} + {}^{3}\mathrm{He} \longrightarrow \mathrm{T} + \mathrm{p}$ ($Q = 0.764$ MeV). The cross-section of this reaction for thermal neutrons is $5333 \pm 7b$ [5]. A photo-neutron source was utilized to generate the thermal neutron field needed for testing. X-ray generated by a 9 MeV electron accelerator reacts with heavy water to produce neutrons via the reaction $\gamma + \mathrm{D} \longrightarrow \mathrm{p} + \mathrm{n}$. The generated fast neutrons are injected into a graphite house and 1–30 ms after each X-ray pulse there exists a thermal neutron field in the graphite house. The readout system only counts between this time interval to ensure the detector is working in thermal neutron field. The amplitude spectrum of the ^{3}He proportional counter tube in this thermal neutron field is shown in Fig. 1. Thermal neutron events are mainly registered in the energy region around $Q = 764$ keV and the plateau to the left side of the peak is due to capture near the wall in which case one of the two reaction products is absorbed by the wall which is known as the wall effect [6].

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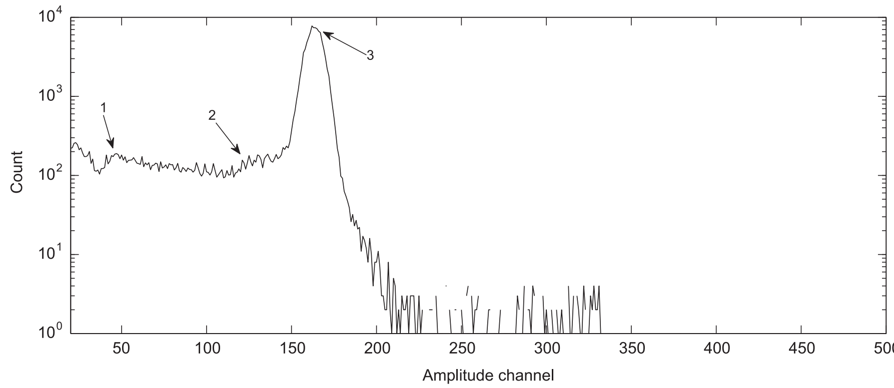

Fig. 1. Thermal neutron amplitude spectrum for the ^{3}He proportional tube: (1) E_t=191 keV; (2) E_p=573 keV; (3) E_{p+t} = 764 keV.

Higher working gas pressure and addition of a heavier gas will help to reduce the range of the daughter products in the gas volume to reduce the wall effect. A combination of 4 atm of ^{3}He and 5 atm of Ar is applied as the working gas of the proportional counter tube. A narrow region from 150 mV to 180 mV in the amplitude spectrum is selected as the region of interest (ROI) in the thermal neutron detection and the main background in this energy range is considered to arise from α decay of products of U and Th disintegration in the wall material of the detector [7,8]. The wall of the tube is made up of oxygen-free copper to reduce background arising from radioactivity of the wall material.

High-voltage applied has significant effect on the FWHM resolution of the full energy peak of the amplitude spectrum. The relation between the FWHM resolution and the hight-voltage applied has been measured and the result is shown in Fig. 2. The best performance is achieved while the high-voltage is 1420 V. Fig. 3 validates the proportional tube is working at proportional working stage at 1420 V. Thus 1420 V is selected as the working high-voltage for the best resolution performance.

An additional ^{4}He tube which shares exactly the same mechanical size with the ^{3}He proportional tube is applied to get a detailed understanding of the background of the ^{3}He tube. ^{4}He and ^{3}He share the same characteristics on γ absorbing and charged particles' energy deposition process while the cross-section for thermal neutron capture of ^{4}He is negligible with respect to that of ^{3}He. So the amplitude spectrum of ^{4}He tube is approximately equal to the background amplitude spectrum of ^{3}He tube whatever the background may arise from.

Resistive anode wire is applied to make the detector position sensitive which not only makes it possible to get the position information of thermal neutron and background events but also facilitates monitoring if the tube registers occasional spark signals caused by the high-voltage cables and connectors. Table 1 shows the detailed parameters of the designed detector.

Readout electronics: We designed the readout system for the two-tube detector including the front-end electronics, digital data acquisition board and PC DAQ software. Fig. 4 shows the block diagram of the readout system. The Pre-AMP in Fig. 4 stands for a charge sensitive pre-amplifier followed by a shaping amplifier. Design details of the Pre-AMP are determined based on the study in a previous article [9]. The 4 analog outputs of the Pre-AMPs are digitalized by two dual-channel 80 MHz 14 bit ADC chips. The digital data acquisition system and the PC DAQ software work together to record both the left and the right waveform of the tube if any triggered event occurs on that tube. The occurring time, amplitude and position can be calculated from the data stored and storing the entire waveform will help to discriminate interference signals.

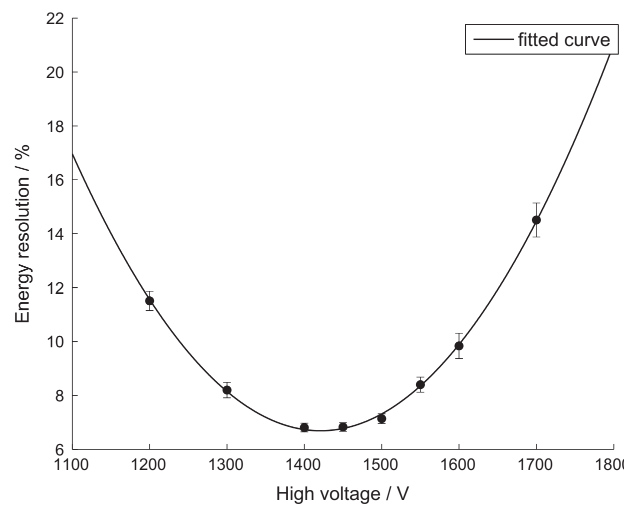

Fig. 2. Relation between energy resolution of ^{3}He tube and the high-voltage applied.

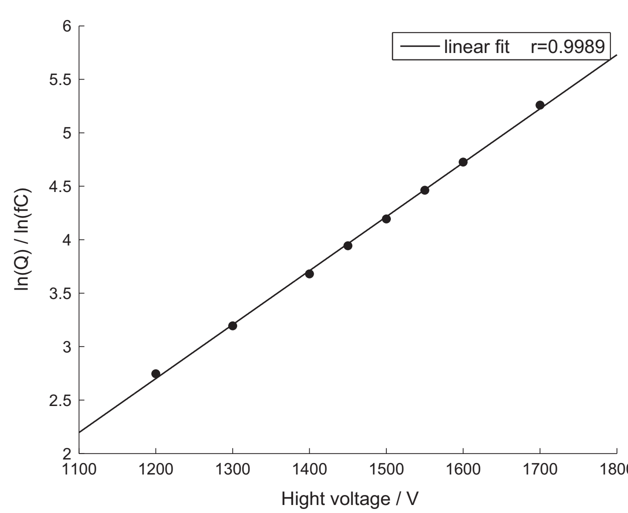

Fig. 3. Relation between high-voltage and the natural logarithm value of Charge output.

3. Detector system performance

Position resolution: The measurement of position resolution was carried out on the photo-neutron source. As the photo-neutron source produces an isotropic thermal neutron field, a neutron collimator was designed. A smaller box with one side open was placed in a larger one and 1 cm thick B_4C powder was filled