Nuclear Inst. and Methods in Physics Research, A 888 (2018) 235–239

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Experimental study of boron-coated straws with a neutron source

Zhaoyang Xie [a,b,c], Jianrong Zhou [b,c,d,1], Yushou Song [a,*], Jeffrey L. Lacy [e], Liang Sun [e], Zhijia Sun [b,c,**], Bitao Hu [d], Yuanbo Chen [b,c]

[a] Key Discipline Laboratory of Nuclear Safety and Simulation Technology, Harbin Engineering University, Harbin 150001, China
[b] Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing 100049, China
[c] Dongguan Neutron Science Center, Dongguan 523803, China
[d] School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China
[e] Proportional Technologies Inc., 12233 Robin Blvd., Houston, TX 77045, USA

ARTICLE INFO

Keywords:
Boron-coated straw
n-gamma discrimination
Longitudinal resolution
Three-dimensional positioning
Neutron scattering instrument

ABSTRACT

Multiple types of high quality neutron detectors are proposed for the first phase of the China Spallation Neutron Source (CSNS), which will be commissioned in 2018. Considering the shortage of ^{3}He supply, a detector module composed of 49 boron-coated straws (BCS) was developed by Proportional Technologies Inc. (PTI). Each straw has a length of 1000 mm and a diameter of 7.5 mm. Seven straws are tightly packed in a tube, and seven tubes are organized in a row to form a detector module. The charge division method is used for longitudinal positioning. A specific readout system was utilized to output the signal and simultaneously encode each straw. The performance of this detector module was studied using a moderated ^{252}Cf source at the Institute of High Energy Physics (IHEP). The signal amplitude spectrum indicates its n-gamma discrimination capability. Despite the complex readout method, a longitudinal resolution of FWHM = 6.1 ± 0.5 mm was obtained. The three-dimensional positioning ability qualifies this BCS detector module as a promising detector for small angle neutron scattering.

1. Introduction

Small angle neutron scattering (SANS) [1] is an effective method of observing the microstructures of materials and biological molecules. The China Spallation Neutron Source (CSNS) being constructed in Dongguan will provide high quality neutron beams for such applications. In addition to the neutron source, a SANS instrument including a large area position-sensitive neutron detector is an essential component [2,3]. Existing SANS instruments use different kinds of detectors, including multi-wire proportional chambers (^{3}He) [4], scintillators [5] and ^{3}He linear position sensitive detectors (LPSD) [6]. Among these detectors, ^{3}He-based LPSDs were used most widely due to their outstanding performance. For example, the original MWPCs in SANS2d were replaced by ^{3}He LPSDs in 2014. As a result, efficiency improved by 30%–40%, and a higher counting rate capability was achieved [7].

On the other hand, the issue of increased demand and limited supply of ^{3}He [8] has caused a serious shortage of this rare gas. Multiple ^{3}He-replacement neutron detection technologies have been established in recent years. The boron coated straw (BCS) technology is a promising candidate that can be manufactured easily and economically for large area applications. It shows many advantages including high count rate capability and n-gamma discrimination ability. Furthermore, the BCS is a gas detector working in proportional mode just like a ^{3}He-based LPSD, and it shares many features in common with the LPSD. The existing maintenance techniques and readout system for the LPSD can be conveniently transferred to the BCS.

For neutron imaging purposes used in homeland security, BCSs with a diameter of 4 mm were developed and studied by Proportional Technologies Inc. (PTI) [9–16]. In this report, straws with a diameter of 7.5 mm were developed by PTI to maintain geometric compatibility with the ^{3}He LPSDs used in existing SANS instruments such as SANS2d [7] and BIO-SANS [17]. Seven straws were sealed in a tube, and seven tubes were packed in a row to form an scalable detector module. The performance of this module was studied by a moderated ^{252}Cf neutron source at the Institute of High Energy Physics (IHEP). To improve the signal processing quality and reduce the number of readout channels, the multiplex readout method was used [18].

In Section 2, the experimental setup is described in detail. In Section 3, the n-gamma discriminating and positioning abilities are discussed along with the experimental results. Lastly, a summary is given in Section 4.

* Corresponding author.
** Corresponding author at: Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing 100049, China.
E-mail addresses: songyushou80@163.com (Y. Song), sunzj@ihep.ac.cn (Z. Sun).
1 Joint first author.

https://doi.org/10.1016/j.nima.2018.01.090
Received 29 December 2016; Received in revised form 17 January 2018; Accepted 25 January 2018
Available online 1 February 2018
0168-9002/

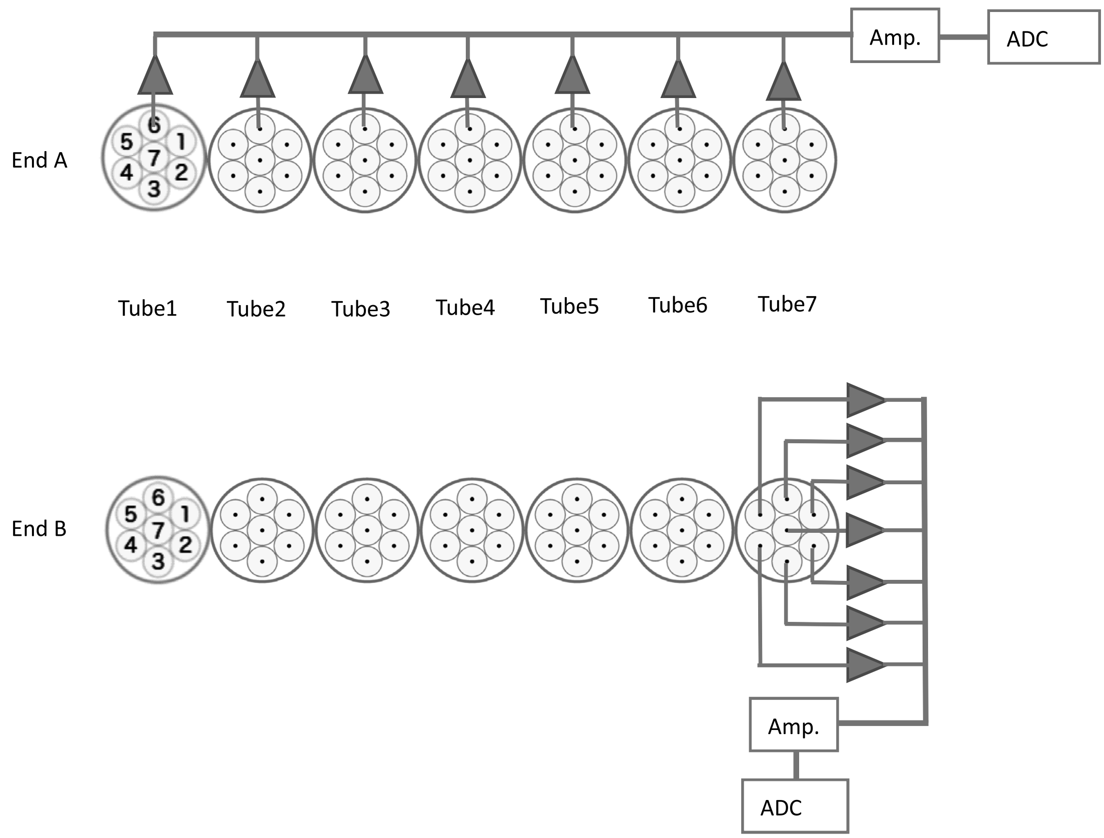

Fig. 1. The schematics of the readout system for this detector module, where the tubes are labeled tube #1 to tube #7, and the straws within a tube are labeled straw #1 to straw #7.

2. Experimental setup

A BCS is 1000 mm long (effective 800 mm) and 7.5 mm in diameter. The wall of the cathode tube is coated with one-micron thick 96% enriched boron carbide (B_4C). A Stablohm wire with a diameter of 20 μm is tensioned in the center of each straw as an anode. A bias voltage of 1051 V is applied between anode wire and cathode tube, which makes the straw work in proportional mode. A mixture of argon and carbon dioxide with a ratio of (90%/10%) is used as the working gas (0.7 atm). Seven BCSs are hexagonally configured in a tube, and seven BCS tubes are grouped to form a detecting module. The seven tubes are labeled tube #1 to tube #7, and the straws within a tube are labeled straw #1 to straw #7, as shown in Fig. 1.

The longitudinal position (along the anode wire direction) is determined by the charge division method. The two ends of each straw are labeled as A and B. To reduce the number of electronic readout channels and identify every straw, a particular readout design is used, as shown in Fig. 1. The end of each straw has an independent preamplifier. At end A of the setup, the signals from straws with the same index across seven tubes go to the same main amplifier and the same ADC. To make the diagram more clear, only the readout of straws labeled as 6 are plotted. At the other end, the signals coming from seven straws in a tube go to the same main amplifier, then to the same ADC. In Fig. 1, only the readout for "Tube 7" is plotted. Thus, fourteen amplifier and ADC channels are sufficient for identifying all the straws in this detector module.

A 6.3×10^5 Bq ^{252}Cf source was used as the neutron source in this experiment (see Fig. 2). The source itself is surrounded by a spherical shield of lead to suppress gamma rays. The neutron moderator is a 35 cm thick layer of paraffin wax. Borax, 11 cm thick, is placed at the outermost layer for absorbing the moderated neutrons. A neutron beam collimator tunnel with a diameter of 10 cm is prepared, starting from the lead sphere and continuing through the neutron moderating and absorbing materials. The BCS detector module was positioned immediately next to the collimator tunnel. Because most neutrons coming through the tunnel are fast, a cylindrical moderator with a thickness of 10 cm is placed in the tunnel to thermalize the neutrons in this experiment. To obtain the longitudinal position resolution of the detector, a collimator made of cadmium with a 1 mm wide slit is attached to the face of the cylindrical moderator nearest the detector.

3. Results and discussion

3.1. Pulse amplitude spectrum and gamma rejection

The pulse amplitude spectrum of a straw with no Cd slit present on the cylindrical moderator is shown in Fig. 3(a). Although most of the gamma rays from the ^{252}Cf source are eliminated by the shields, there always remain some escaping gamma rays captured by the straws. There are also some background gamma rays that enter the spectrum. A gamma peak is hence formed on the left of the spectrum.

To understand the neutron spectrum comprehensively, the following analysis is provided. An incident neutron is captured by the B_4C coated layer through the following reactions [13,19].

$$
\begin{aligned}
&{}^{10}_{5}\mathrm{B} + n \rightarrow {}^{7}_{3}\,\mathrm{Li} + \alpha + Q_1\,(Q_1 = 2.792\ \mathrm{MeV},\ 6\%)\\
&{}^{10}_{5}\mathrm{B} + n \rightarrow {}^{7}_{3}\,\mathrm{Li}^{*} + \alpha + Q_2\,(Q_2 = 2.310\ \mathrm{MeV},\ 94\%).
\end{aligned}
\qquad (1)
$$

The reaction products ^{7}Li and alpha fly back to back as the incident energy is too small in contrast to the reaction energy Q. Due to the geometry of the cathode, only the reaction product escaping from the coated B_4C film and flying into the detector has a chance to ionize the working gas molecules. Different neutron absorption depths in the film and different flying directions make the residual kinetic energy of an escaping particle vary continuously, hence the continuous energy deposition. If the position of neutron absorption is close to the surface