Nuclear Instruments and Methods in Physics Research A 806 (2016) 14–20

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Neutron beam monitoring for time-of-flight facilities with gaseous detectors

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ARTICLE INFO

Article history:
Received 4 September 2015
Accepted 16 September 2015
Available online 9 October 2015

Keywords:
Neutron beam monitor
Gaseous Detector
Time-of-flight method
Beam profile

ABSTRACT

Triple Gas Electron Multipliers (GEM) for slow and fast neutrons were employed at the n_TOF facility at CERN as online beam imaging monitors and for energy spectra measurements via the time-of-flight technique. The detectors were exposed to the neutron spectrum ranging from thermal to 1 GeV, produced by spallation of 20 GeV/c protons in a lead target with a maximum intensity of $7 \cdot 10^{12}$ protons per pulse. The spectrum and the 2D count distribution of the neutron beam were measured and compared at two distances from the target, 185 m and 200 m. The detectors showed radiation hardness, linear response and the ability to monitor the beam profile online with high spatial resolution.

1. Introduction

Neutron time-of-flight facilities such as n_TOF [1] at CERN and LANSCE [2] at LANL are commonly employed for studying neutron induced reactions for nuclear structure and reaction physics [3], astrophysics [4], nuclear technology [5] and detector characterization [6]. These facilities typically feature white neutron sources produced by spallation through protons impinging on heavy targets. The neutron energy is determined by measuring the time-of-flight over a known path. The neutron beam characteristics need to be continuously monitored in terms of spot dimensions and energy spectrum at the experimental areas.

In this study the triple Gas Electron Multiplier (GEM) [7] is investigated as a neutron beam monitor, able to measure the energy spectrum via the time-of-flight technique and monitor online the 2D count distribution of the neutron beam spot. Detectors for slow and fast neutrons were tested at the n_TOF facility at CERN; this facility features a neutron source produced by spallation on a lead target by 20 GeV/c protons from the Proton Synchrotron (PS) with a maximum intensity of $7 \cdot 10^{12}$ protons per pulse, with typically a few pulses per minute. The neutrons so produced travel inside a large beam pipe and arrive at two experimental areas, called EAR1 and EAR2, located at 185 m and 20 m from the target, respectively. Measurements can also be performed right before the EAR1 beam dump, located 200 m from the target. Due to the long flight path and short proton pulse, the time-of-flight defines the neutron kinetic energy; the spectrum produced ranges from 10^{-3} eV to 1 GeV (see Fig. 1). The spectrum shows an intense evaporation peak at 1 MeV, a high energy peak at 100 MeV and a thermal peak with lower intensity.

2. Experimental set-up

The triple GEM consists of three insulating kapton foils, clad on both sides with thin metal layers and sandwiched between two electrodes, a cathode and an anode, creating four regions inside the detector: a drift region, two transfer regions and an induction region. The foils are perforated with a large number of holes, acting as multiplication channels for electrons released by ionizing radiation in the gas mixture. If a suitable voltage is applied to the foils, a strong electric field is generated inside the holes, so that electrons can acquire enough energy to develop an avalanche. The signal generated by the electron cascade is induced on a padded anode.

Three triple GEM detectors were tested for slow and fast neutrons. The first one for slow neutrons, named GEM ^{10}B and described in detail in [8,9], has an active area of 5×5 cm^2 and glass sheets coated with a thickness of 300 nm of ^{10}B on both sides. The second detector for slow and fast neutrons has an active area of 10×10 cm^2 and a 1 μm B_4C cathode [10]. The fast neutron detector [11], equipped with 60 mm polyethylene (PE) and 40 mm aluminium, has an active area of 10×10 cm^2. The voltage is applied by a HVGEM NIM module [12]; the values of fields, high

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http://dx.doi.org/10.1016/j.nima.2015.09.054
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voltages and currents are instantaneously monitored by nanoammeters integrated in the HVGEM. A set of eight CARIOCA-GEM CHIPs [13] shape and digitize the signals induced on 128 pads. An FPGA motherboard collects the signals and counts them in several time windows without any dead time. More information about the acquisition system can be found in [14]. The detectors were filled with a gas mixture of Ar/CO_2 (70/30) and their characteristics and measurement positions are summarized in Table 1.

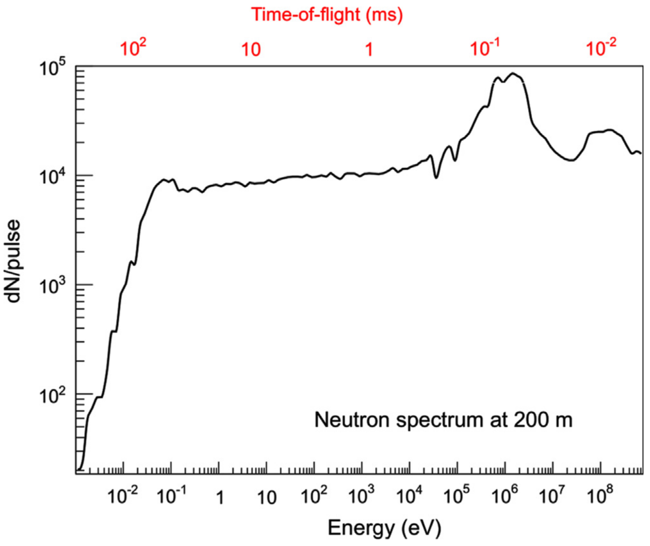

Fig. 1. n_TOF neutron spectrum at the EAR1 beam dump 200 m from the target, taken from [1].

Table 1
Summary of detector characteristics and measurement positions.

Detector	Area (cm^2)	Pad size (mm^2)	Position (m)	Energy
GEM ^{10}B	5×5	3×6	185	Slow
GEM B_4C	10×10	8×8	200	Slow, Fast
GEM PE	10×10	8×8	200	Fast

The detectors GEM B_4C and GEM PE were placed at a distance of 200 m from the target, between the end of the beam pipe and the dump (Fig. 2a). They were mounted on a stand and remotely centred by means of a rail, so that the beam impinged vertically to the foils. The FPGA-based motherboard used to analyse the signal coming from the read-out chips was placed off-beam in order to avoid possible interruptions due to the high beam flux, observed in previous measurements [14]. The GEM ^{10}B was tested inside EAR1 at a distance of 185 m (Fig. 2b). Since it is a side-on detector, the beam impinges parallel to the foils through the window.

3. Time of flight measurements

Time-of-flight measurements were performed via the FPGA-based motherboard, externally triggered a few μs before the proton beam hit the target. The beam energy spectrum was measured from the neutron time-of flight, using the classical kinetic energy formula for energy below 1 MeV and the relativistic one above 1 MeV. The time-of-flight ranged from 700 ns for 1 GeV to 150 ms for thermal neutrons, calculated from the following equations:

$$E_n = \frac{1}{2}mv^2, \ E_n < 1 \text{ Mev}$$

$$E_n = mc^2(\gamma - 1), \ \ \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}, \ E_n > 1 \ Mev$$

where c is the velocity of light and v is the neutron velocity ($v = L/t$ with L being the distance from the target and t the time-of-flight).

Two different acquisition methods were employed by means of the FPGA: the multi-slice and the delay scan methods for slow and fast neutrons, respectively. The multi-slice method allowed measuring up to 250 successive time gates of the same width at once, without dead time between them and with a minimum width of 30 μs each. The delay scan method was performed by increasing the acquisition delay with a step equal to the time gate. The minimum gate width is 20 ns.

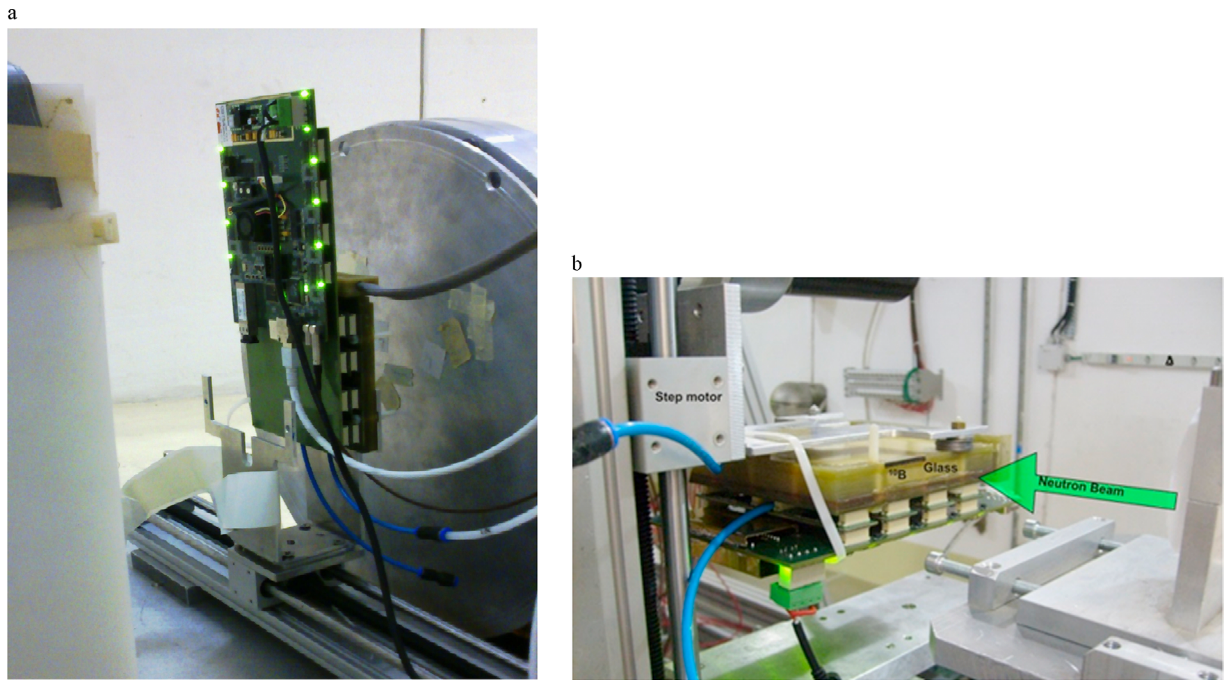

Fig. 2. Experimental set-up at 200 and 185 m respectively. (a) The head-on detectors GEM B_4C and PE were placed at a distance of 200 m, between the end of the beam pipe and the dump. (b) The side-on detector GEM ^{10}B was tested at 185 m, inside the Experimental Area 1 (EAR1).