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nGEM fast neutron detectors for beam diagnostics

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ABSTRACT

Fast neutron detectors with a sub-millimetric space resolution are required in order to qualify neutron beams in applications related to magnetically-controlled nuclear fusion plasmas and to spallation sources. A nGEM detector has been developed for the CNESM diagnostic system of the SPIDER NBI prototype for ITER and as beam monitor for fast neutrons lines at spallation sources. The nGEM is a triple GEM gaseous detector equipped with polypropylene and polyethylene layers used to convert fast neutrons into recoil protons through the elastic scattering process. This paper describes the results obtained by testing a nGEM detector at the ISIS spallation source on the VESUVIO beam line. Beam profiles ($\sigma_x = 14.35$ mm, $\sigma_y = 15.75$ mm), nGEM counting efficiency (around 10^{-4} for 3 MeV $< E_n <$ 15 MeV), detector stability ($\approx 4.5\%$) and the effect of filtering the beam with different type of materials were successfully measured. The x beam profile was compared to the one measured by a single crystal diamond detector. Finally, the efficiency of the detector was simulated exploiting the GEANT4 tool.

1. Introduction

Applications related to nuclear fusion and spallation sources will need sub-millimetric fast neutrons beam monitors. Two of such applications are the construction of the CNESM diagnostic system of the SPIDER NBI prototype for ITER in Italy [1] and the construction of the CHIPir beam line at ISIS-RAL in UK for single event effects studies [2,3]. Examples of detectors that own such a space resolution to be used as beam monitors are single crystal diamond detectors [2] and Gas Electron Multipliers (GEM) based detectors. GEM [4,14,15,16] based detectors were invented at CERN as charged particle tracking detectors [5] but, if properly adapted, these can be also used as neutral particle detectors [6,17,18,19]. This paper describes the construction and test of a GEM detector prototype especially developed for fast neutron detection. All the tests were performed at the ISIS-RAL (UK) VESUVIO electron volt neutron beam line.

2. Experimental setup

2.1. ISIS VESUVIO Facility

The measurements were performed with nGEM and diamond detectors placed in the neutron beam of the VESUVIO [7] beam line at a flight distance of about $L = 12.5$ m from the neutron source. At ISIS, neutrons are produced by a 800 MeV proton beam with a double bunch fine structure and a repetition frequency of 50 Hz. The two proton bunches are about 70 ns wide (FWHM) and 322 ns apart. The proton beam delivers an average current of 180 Ah on a Ta–W target yielding about 30 neutrons per incident proton. In the energy range $E_n > 1$ MeV the neutron spectrum has approximately $1/E_n$ behavior.

2.2. nGEM detector

A nGEM detector is a triple GEM chamber equipped with a solid-state fast neutrons converter cathode, similarly to what is done for detection of 14 MeV neutrons from fusion plasmas [8]. The cathode of a nGEM detector is composed of two layers: one polyethylene (CH_2) film 60 μm thick and one aluminum layer 40 μm thick. In addition another polyethylene (CH_3) layer, 400 μm thick has been

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Fig. 1. Front view of the nGEM detector installed on the Vesuvio beam line.

added on top of the cathode, out of the gas tight zone, in order to increase conversion efficiency. Incident neutrons are converted into protons by elastic recoil in the thin polythene (CH_2) film or in the external polypropylene (CH_3) sheet. Protons leaving the conversion layers with enough energy can cross the Al foil and reach the gas, thus ionizing it. Since the drift gap thickness (3 mm wide) is narrower than the proton range, only a fraction of the proton energy is deposited in the gas and detected. Ionization electrons liberated by protons energy release drift towards the GEM foils where they are multiplied [5]. The signal generated by electron cascade is induced on a padded anode (total of 128 pads, $12 \times 6\ mm^2$ area) that is connected to the front end electronics. The front-end chip used to readout all the pads are the CARIOCA-GEM digital chips [9]. All the CARIOCAs are then connected to a custom made FPGA mother board [11] that analyzes the LVDS signal coming from the chips.

The detector active area was $10 \times 10\ cm^2$, the gap geometry is the same as LHCb detectors [10] and the gas mixture employed in all the measurements is Ar/CO_2 70%/30%. Photos (rear and front views) of the detector installed in the VESUVIO beam line are shown in Figs. 1 and 2. The high voltage configuration was generated using the HVGEM [11] NIM module and the potentials were applied to each electrode by means of passive resistive–capacitive filters properly designed for a triple GEM detector.

3. Measurements

3.1. nGEM detector counting efficiency

The nGEM detector efficiency to different kinds of particles was measured as a function of the effective gain by varying the sum of potential difference over the three GEM foils ($\sum \Delta V_{GEM} = V_{GEM}$). Two different measurements were performed: V_{GEM} scans when the neutron beam was on and off. The former is a measurement of the neutron detection efficiency while the latter gives a result in term of detection efficiency for particles nontimely connected with the neutron beam, that is mainly photons coming from surrounding materials activation. Fig. 3 shows the result of the measurements. The counting rate of the detector is an increasing function of V_{GEM} but when the beam is off there is a threshold value under which the chamber does not detect any particles: by applying a $V_{GEM} < 900$ V the photons background is completely rejected. Therefore the measurement when the beam is on can be split into two different components: up to $V_{GEM} = 900$ V only neutrons are detected while for higher values the counting rate is due to both neutrons and photons. Results obtained here are compatible with [12].

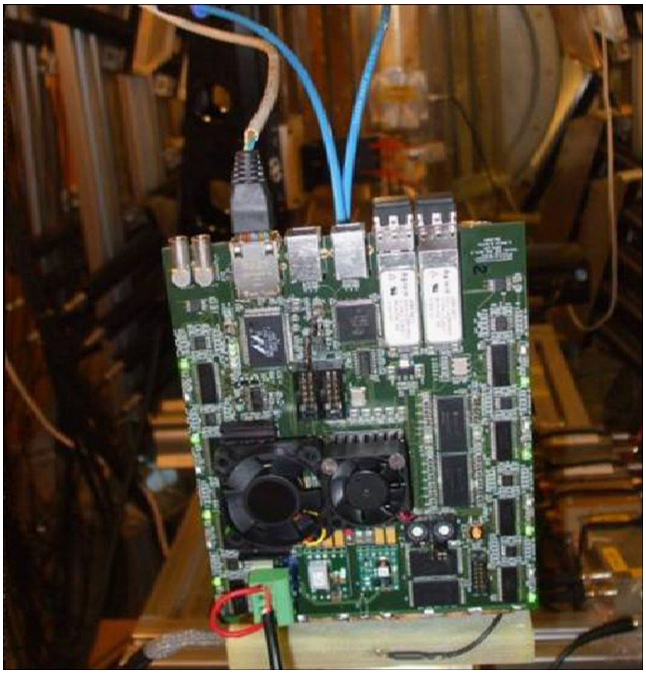

Fig. 2. Rear view of the nGEM detector installed on the Vesuvio beam line.

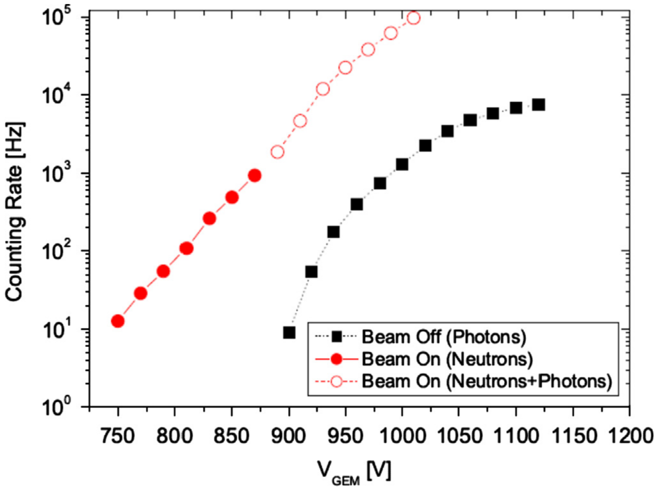

Fig. 3. nGEM counting rate as a function of V_{GEM} when the beam was on (neutrons + photons) and off (photons); E_d (Drift Field) = E_{T1} (Transfer 1 Field) = E_{T2} (Transfer 2 Field) = 3 kV/cm, E_{Ind} (Induction Field) = 5 kV/cm.

3.2. Vesuvio beam profile measurements

A bi-dimensional Vesuvio beam profile reconstruction has been obtained by exposing the detector to the neutron beam for about 2 min. In order to be able to detect neutrons and to be insensitive to photons, the following electrical configuration was applied to the device: E_d (Drift Field) = E_{T1} (Transfer 1 Field) = E_{T2}