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CCD readout of GEM based neutron detectors

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Abstract

We report on the optical readout of the GEM (gas electron multiplier) operated with a gaseous mixture suitable for the detection of thermal neutrons: ^3He-CF_4. A CCD system operating in the 400-1000 nm band was used to collect the light. Spectroscopic data on the visible and NIR scintillation of He-CF_4 are presented. Images of the tracks of the proton and triton recorded with a triple GEM detector are also shown.

Keywords: GEM detectors; CCD; Microstrutures

1. Introduction

Gas detectors filled with ^3He are commonly used for the detection of thermal neutrons mainly because of their high efficiency and low gamma sensitivity. Although the high primary charge (~20000 electrons) and the use of centroid finding method allows for a fast determination of the position of the interaction, the maximum count rates are imposed by pulse counting type detector readout limitations.

The use of the scintillation emitted by the electron avalanches developed in the microstructures has been reported before [1]. We have also presented some previous work on the use of the scintillation of the GEM (gas electron multiplier) avalanches for imaging purposes, both of X-rays and charged particles, using a high-resolution cooled CCD camera [2]. In this last work we anticipated that using appropriate gaseous mixtures and several cascaded GEMs, CCDs could be used to image tracks produced by the products resulting of the interaction between thermal neutrons and the ^3He atom.

In this paper we present data concerning the use of He-CF_4 gaseous mixtures in GEM detectors, a description of a detector that we built to image the tracks of the proton and triton and some sample images obtained with this setup.

2. The experimental set-up

The characteristics of the GEMs currently available were optimized for operation at typical LHC applications using the deeply studied Ar-DME or Ar-CO_2 mixtures [3]. Considering that the operation of GEMs with CF_4 mixtures needs higher magnitude electrical field, as presented in [2], and that we also intent to perform measurements at high pressure, we had some GEMs with double conical holes manufactured [4] with hole dimensions narrower that usual. In this work we used 5×5 cm^2 GEMs having 45, 60 and 80 μm (standard GEM) metal diameter holes with respectively 35 , 50 and 70 μm kapton holes. The kapton thickness was 50 μm and pitch was 140 μm for all GEMs. The GEMs will be referred in this work according to their metal hole diameter.

Considering the high price of ^3He, all the preliminary charge and scintillation measurements were taken using high purity ^4He, as no significant difference is expected in the charge and scintillation properties of these two isotopes when mixed with CF_4. The gases used, all high purity research grade, were supplied to the chamber through stainless steel pipes without any additional purification. The detector was operated in a closed system mode. For these measurements the chamber was irradiated by an X-ray generator with a molybdenium tube. This tube was operated at around 10 kV, the main bremsstrahlung spectrum was peaking around 8 keV.

As the experimental system and detector that were used to obtain these results is similar to the one described in [2], we will only refer the more relevant aspects. The entrance window of the test chamber was carbon fibber with a thickness of 0.5 mm. The GEM front electrode was grounded, the back one was operated at negative voltage. A drift plane was placed 6 mm before the GEM, defining a collection zone. Although an optically transparent collecting grid was placed 2 mm far from the GEM, in these experiments it was ketp at the same voltage as the outer GEM electrode and all the avalanche electrons were collected by this last electrode. The light window, placed behind the GEM, was made of 6mm thick glass with a 5cm effective diameter.

The ratio between the secondary and the primary currents, measured at the GEM back electrode and operating the chamber in ionization mode, respectively, were used to calculate the GEM gains.

A Quantix 1400 camera, manufactured by Photometrics Ltd, was used to readout the light emitted from the GEM. It uses a Peltier cooled, low noise CCD, KAF 1400 from Kodak, with 1317 × 1035 pixels of 6.8 × 6.8 μm^2 and the spectral response goes from 400 to 1000 nm. All the pictures presented in this work were taken with the CCD cooled to -30ºC. A standard 50 mm f:1.8 photographic lens was used and the camera was placed at the minimum allowable focusing distance, about 30 cm away from the chamber glass window.

3. Scintillation and charge data

The data on charge gain He (600mbar) +CF_4 (400mbar) is shown in fig. 1. The drift field was carefully adjusted for maximum GEM transparency. Gain with pure CF_4 at 400 mbar was also measured and, as expected, the addition of 0.6 bar of He is of negligible effect compared to the data represented, independently of the hole diameter. However, it was seen that the addition of 3.6 bar of He shifted the gain curve towards higher voltage of about 30V for the 60 and 45 μm holes, and about 70V for the 80 μm ones.

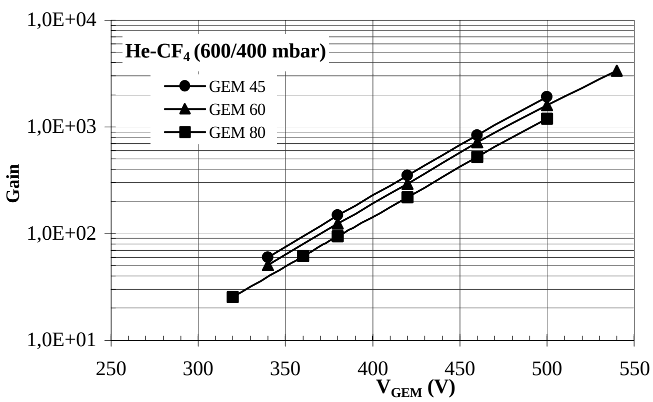

Fig. 1 GEM gains measured in He (600mbar)-CF_4 (400mbar) as a function of V_{GEM} for GEMs with 45, 60 and 80 μm hole diameter.

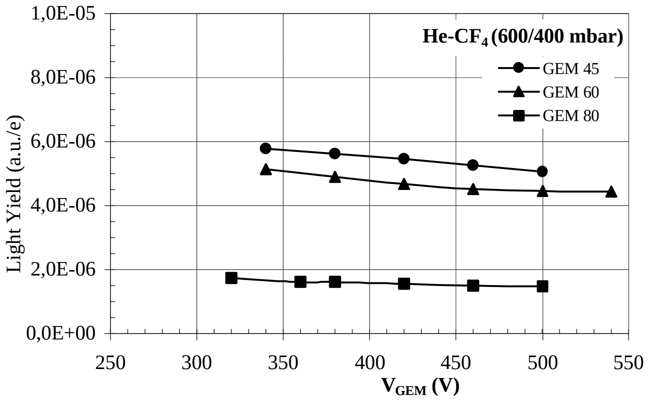

Fig. 2 Ratio of emitted light over secondary electron current versus V_{GEM} measured in He (600mbar) +CF_4 (400mbar) for GEMs with 45, 60 and 80 μm hole diameter.

Measurements taken on the collection and the transparency of these GEMs also suggested that the pitch of the GEMs should be changed in future designs to improve electron transfer between GEMs.

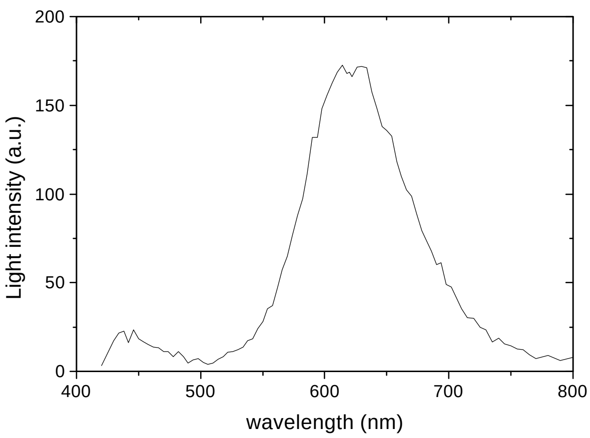

Fig. 3 Emission spectrum in He (600mbar) +CF_4 (400mbar) gas mixture measured at charge gain of 190 ($\Delta\lambda$=5 nm).

Fig. 2 Shows the data on scintillation measured in the same conditions as in the previous figure. The GEMs with 45 μm holes have higher light emission than the other GEMs. The measured emission spectrum of the He-CF_4 mixture is shown in Fig. 3. The used CCD has a mean quantum efficiency of 35% at the light peak.

The ^{3}He-CF_4 mixture is commonly used in gaseous neutron detectors. The ^{3}He is used for neutron conversion ($^3He + n \Rightarrow p + {}^3H + 764$ keV) and the CF_4 is needed to decrease the range of the proton and the triton. Fig. 4 shows the energy deposition along the straight track in 1 bar CF_4 [5]. The centroid of the distribution has an offset of approximately 40% of the proton track, limiting the position resolution of this type of detectors. As our purpose was to obtain images of tracks about 1 cm long we decided to operate the detector with a CF_4 partial pressure of 400 mbar.

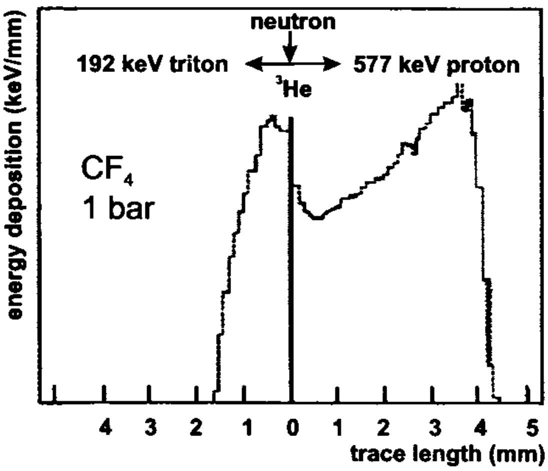

Fig. 4 The energy deposition along the proton and triton track in 1 bar CF_4.

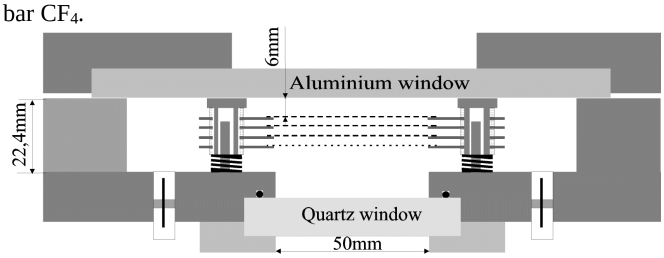

Fig. 5 Schematic cross-section of the detector. The CCD (not shown) was placed 30 cm away from the glass window.

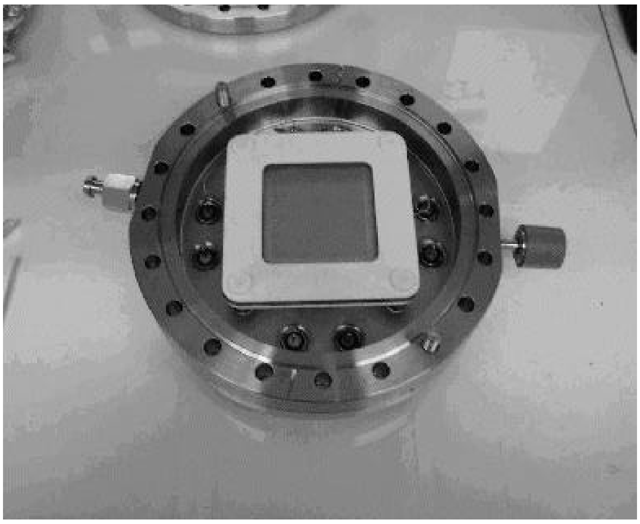

Fig. 6 Photograph of the detector with the entrance aluminium window removed, showing the stacked GEM assembly and transparent grid electrode.

For the neutron measurements the radiation entrance of the detector was replaced with a 6 mm thick aluminium window. Fig. 5 shows a diagram of the detector and a view of the open box is shown in Fig. 6. In order to have a high sensitivity a cascaded triple GEM was used. GEMs with 80 μm holes were used for the entrance and intermediate positions and a 60 μm one was used as outer GEM. Considering the measurements presented in the previous section this is not the optimum choice of GEM geometry, but the configuration was conditioned by the availability of GEMs at the time of the experiment.

The voltages were applied to the GEMs electrodes using a resistive voltage divider. The aluminium entrance window was grounded and the absorption zone was 6 mm deep. The distance between the GEMs was 2mm.

An AmBe source neutron source with Polyethylene shielding was used for the data taking, carried out at the ILL Grenoble. Fig. 7 shows some images of the projections of the proton and triton tracks, taken with the CCD camera using a 7 x 7 binning and an exposition time of 10 ms with a 1 bar ^3He- 400 mbar CF_4 filling. The co-linear structure of the tracks is clearly seen in most events, although a few angled tracks, corresponding to higher energy neutrons were also recorded. The track with the shorter length, shown in the bottom-right CCD image corresponds to a more inclined track or to wall effects.

Fig. 8 shows in more detail two images of tracks and the respective distribution of the scintillation light along the longitudinal CCD pixels of the track projection. The energy depositions curves of the proton and the triton are easily identified and should be compared with Fig. 4.

Some superimposed tracks, obtained with a longer exposition time (1s) and slightly higher CF_4 partial pressure, implying shorter tracks, are shown in Fig. 9. Some interactions due to the gamma background are also seen.

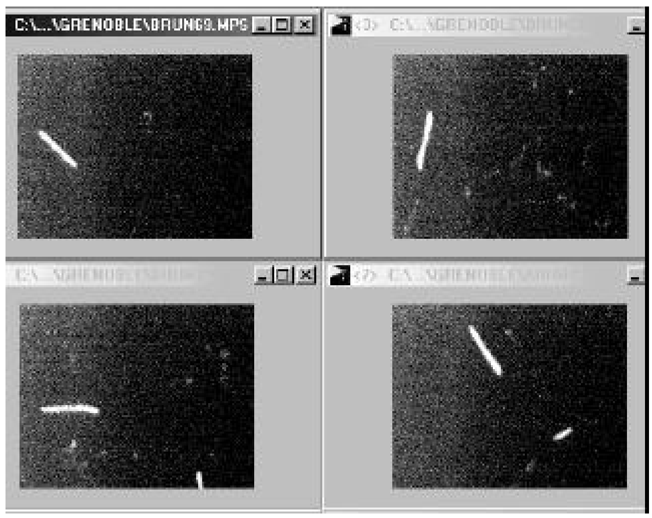

Fig. 7 Images of proton and triton tracks obtained with He(1bar)-CF_4 (400 mbar): V_{GEM1}=V_{GEM2}= V_{GEM3} =400V, E_D= 1kV/cm, E_T= 3 kV/cm, CCD Binning 7×7, Texp.=10ms.

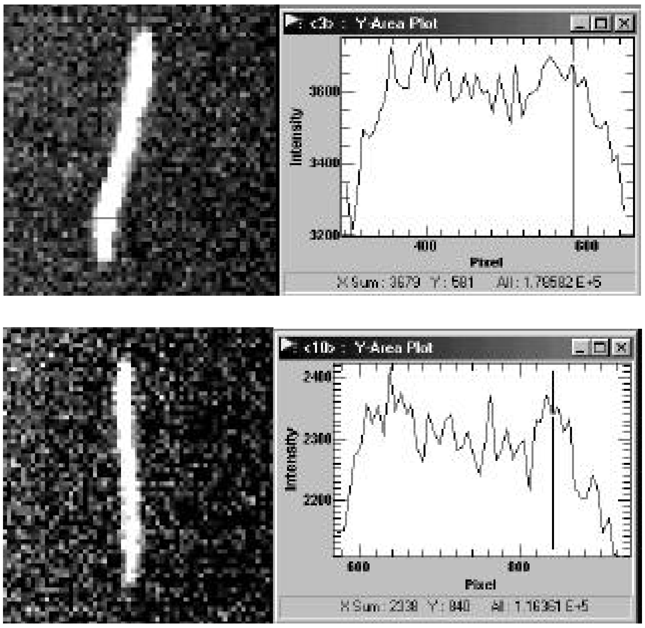

Fig. 8 Distribution of measured scintillation along tracks. The Bragg curves of the proton (left) and triton (right) are revealed.

Fig. 9 Superimposed proton-triton tracks obtained with an exposition time of 1s.

3. Conclusions

A detector with a cascaded triple GEM has been successfully operated with He-CF_4 mixtures and the optical readout of ^{3}He neutron GEM detectors has been done using a simple CCD system. The information about charge deposits along the tracks can be easily extracted from the images and could be useful for avoiding wall effect errors in energy measurements, or for neutron spectroscopy purposes that rely on track angle [6].

The GEM geometry should be optimized for scintillation. Thicker GEMs should have higher light yields, and the performance of our system is being improved using GEMs with narrow holes of smaller pitch.

Applications of the scintillation light emitted by the GEM, using photon counting readouts, are also being considered and data on the operation of GEMs with He-CF_4 mixtures at higher pressures will also be reported soon.

Acknowledgements

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References

[1] F.A.F. Fraga et. al., presented at the Imaging 2000 conference, Stockholm, 28-1 June 2000, submitted to Nucl. Inst. and Meth..

[2] F.A.F. Fraga, L.M.S. Margato, S.T.G. Fetal, R. Ferreira Marques and A.J.P.L Policarpo, presented at the Nuclear Science Symposium and Medical Imaging Conference, Lyon, France, 15-20 October, 2000, accepted for publication in Trans. Nucl. Sci..

[3] J. Benlloch et al., Nucl. Inst. and Meth A419(1998) 410.

[4] CERN Surface Treatment group

[5] F.D. van den Berg, PhD thesis, TUDelft, 2000

[6] U. Titt et. al., Nucl. Instr. and Meth. A416(1998)85