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Nuclear Instruments and Methods in Physics Research A 478 (2002) 245–249

NUCLEAR
INSTRUMENTS
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RESEARCH
Section A

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A fast triple–GEM detector for high-rate charged-particle triggering

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Abstract

Triple-GEM detectors with pad readout has been tested at the CERN PS T11 Hadron Beam Facility. A time distribution RMS of 6 ns has been obtained with an Ar/CO_2/CF_4 (60/20/20) gas mixture, achieving a substantial improvement with respect to Ar/CO_2 (70/30), where an RMS of 10 ns was obtained. This resulted in an efficiency of about 96% in a 25 ns time-window (and a total efficiency of 99.7%), suggesting that these detectors could be interesting devices for triggering at the typical LHC interaction rate. © 2002 Elsevier Science B.V. All rights reserved.

PACS: 29.40; 29.40.C

Keywords: Gas electron multiplier; GEM; High rate triggering; Tetrafluoromethane

1. Introduction

A gas electron multiplier (GEM) [1] is a thin metal clad Kapton foil perforated with a high density of holes. By applying a suitable voltage difference between the two sides of the GEM, an electric field with an intensity as high as 100 kV/cm is produced inside the holes. By means of an appropriate electric field, electrons produced above the GEM are collected into the holes and are multiplied thanks to the high field. A charged-particle detector can be made by inserting a GEM between a cathode and a board equipped with charge collecting electrodes and by flushing an appropriate gas mixture in this structure. Two or more GEMs can be stacked one above the other, allowing to reach a higher gain and to decrease the spark probability of the structure for a given total gain. In particular triple-GEM structures [2] seem very promising devices to be used at high luminosity colliders.

The distribution of the time response of GEM based detectors working with an Ar/CO_2 (70/30) gas mixture was measured to have an RMS of 10 ns [3] when no electronics slewing corrections are performed. In order to improve the detector time resolution a detailed study on the electric

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fields, detector geometry and gas mixtures has been performed and results are reported in this paper.

2. Detector, electronics and test setup

Three similar detector prototypes (Fig. 1) were built using CERN standard $10 \times 10\,\mathrm{cm}^2$ GEMs [4]. Each GEM has bi-conical holes with 70 μm (50 μm) external (internal) diameter with a pitch of 140 μm. In each detector three GEMs are stacked one above the other at 2 mm distance (the transfer gaps) and positioned 1 mm above the readout pads (the induction gap). On the top of the stack a cathode plane defines a 3 mm-thick ionization gap. The readout board is segmented in $6 \times 16\,\mathrm{mm}^2$ pads. Fifteen pads in each detector are connected to fast preamplifiers having a gain of 10 mV/fC, a peaking time of 5 ns and an electronic noise of about $1300\mathrm{e}^-$ RMS at zero input capacitance.

The test of these detectors was performed during October 2000 at the CERN PS T11 hadron beam facility using charged pions of energy between 2 and 4 GeV at an intensity of about $1\,\mathrm{kHz/cm}^2$. Scintillators equipped with constant fraction discriminators were used to provide a precise common stop signal to the TDCs.

3. Choosing the working conditions

The intrinsic time spread of a GEM-based detector is $\sigma(t) = 1/nv_{\mathrm{drift}}$, where n is the average number of clusters per unit length and v_{drift} is the electron drift velocity in the ionization gap. This arises from the probability distribution $P(x) = n\mathrm{e}^{-nx}$ of the distance of the cluster produced closer to the first GEM, which gives $\sigma(x) = 1/n$.

To achieve a good time resolution, high yield and fast gas mixtures are needed. However, a low efficiency for primary electron detection could worsen this time resolution. To reduce this effect it is important to adjust the electric fields to maximize the detector transparency to electrons and to reach a sufficient electron multiplication in the GEM holes. For each GEM the effective gain depends on [5]:

- the efficiency of collecting primary electrons into the hole, which decreases for high electric field above the GEM because of the defocusing of the field lines (some electrons could hit the GEM upper electrode);

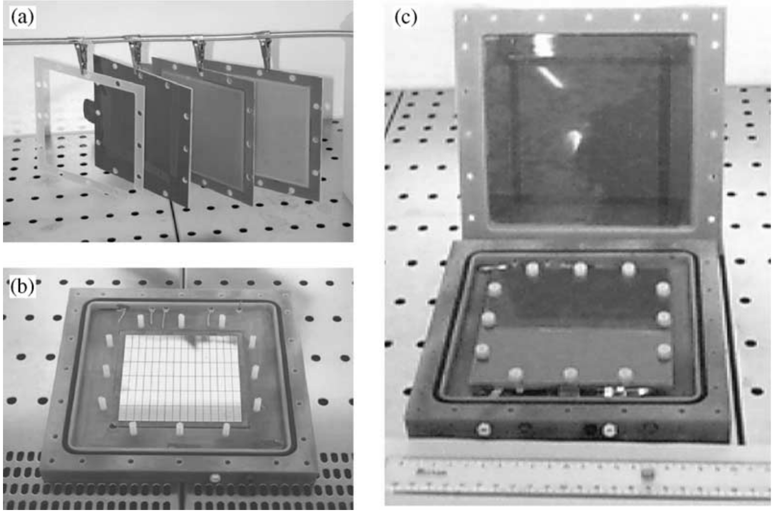

Fig. 1. (a) The three GEMs glued on the G10 frames of different thickness. (b) Readout pads mounted on the gas-tight G10 box. (c) The three GEMs stacked in the box.

- the capability of extracting secondary electrons from the holes, which increases while increasing the intensity of the electric field below the GEM;
- the electron multiplication into the holes, which increases exponentially with the voltage applied to the GEM electrodes.

Two different gas mixtures were tested, Ar/CO_2 (70/30) and $Ar/CO_2/CF_4$ (60/20/20). The electron drift velocity for both mixtures is reported in Fig. 2.

4. Detector performances

4.1. Transparency optimization

Scans in the drift (E_d) and in the transfer fields ($E_t = E_{t1} = E_{t2}$) were performed with the purpose of maximizing the detector efficiency in a 25 ns window.[2]

At low E_d the efficiency decreases due to the small drift velocity and the electron diffusion in the gas. At high E_d efficiency losses are due to the field-lines defocusing effect (see Fig. 3a).

For the transfer fields it was observed that at low E_t the efficiency decreases due to the poor electron extraction capability from the lower side of the GEM. At high E_t the extraction efficiency saturates but the defocusing effect on the GEM below starts to appear (see Fig. 3b).

The optimal working point was found at $E_d = 3\,kV/cm$, $E_t = 4\,kV/cm$ and $E_i = 5\,kV/cm$, where a total efficiency of 96% was reached. The value chosen for E_i is a compromise between a good electron extraction capability from the last GEM and a low sparking probability in the induction gap.

It should be noted however that in this case the GEMs gain were kept at moderate values, with only 390 V on each GEM, and in these conditions the detector is not at full efficiency.

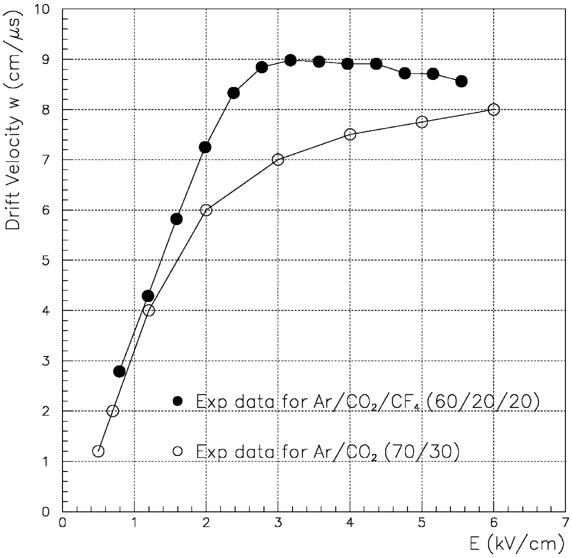

Fig. 2. Measured electron drift velocity for Ar/CO_2 (70/30) [6] and $Ar/CO_2/CF_4$ (60/20/20) [7].

4.2. Total gain optimization

In order to increase the first cluster detection probability, it is important to have a high detector total gain and a high electron transparency on the first GEM. A scan on the voltage of the first GEM (V_{gem}) was performed while keeping the other two GEMs supplies at moderate values (390 V). This was done to avoid possible discharges on the last GEM due to the high total charge and to reduce the amplification of the ionization created between the first and the second GEMs, which could generate hits early in time.

Efficiency in a 25 ns time window increases with the voltage supply of the first GEM and seems to saturate to a value close to 90% for Ar/CO_2 (70/30) and to 96% for $Ar/CO_2/CF_4$ (60/20/20) (Fig. 4).

It was also found that in the configuration where the electric fields increase progressively by 30% from gap to gap (the so-called "Field Scaling" configuration) a 94% efficiency is obtained at low values of V_{gem} (390 V) (Fig. 4b), indicating that it might be possible to have an efficient detector working in safer conditions for what concerns the spark probability.

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[2] Only the scans performed with $Ar/CO_2/CF_4$ (60/20/20) are described here since no dependence on the gas mixture has been found.

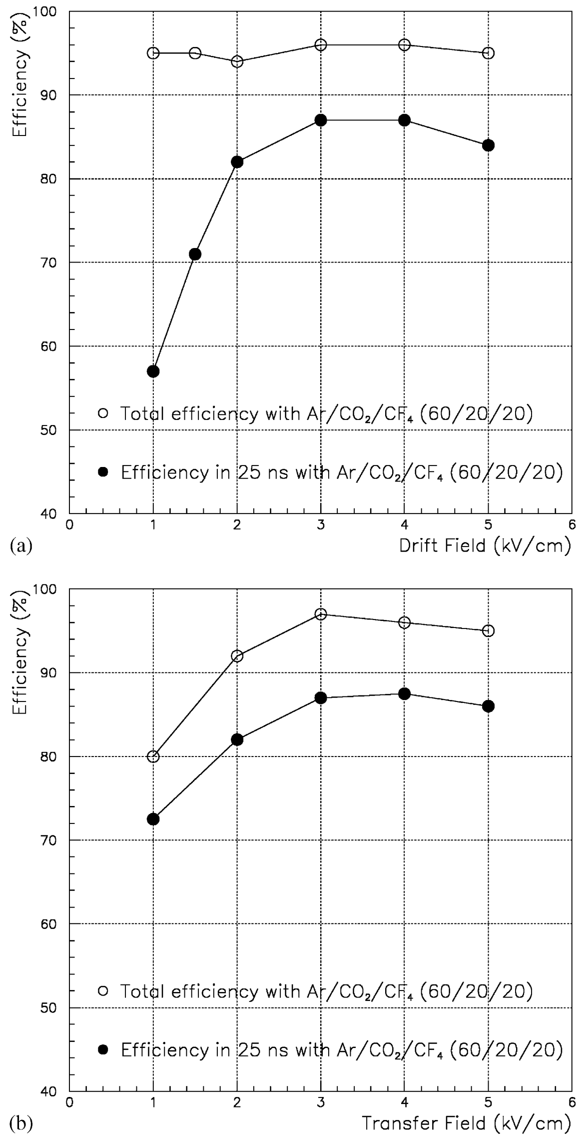

Fig. 3. Efficiency (total and in a 25 ns window) as a function of the intensity of (a) the drift field E_d (for $E_\mathrm{t} = 2.2\,\mathrm{kV/cm}$) and of (b) the transfer fields E_t (for $E_d = 3$ kV/cm).

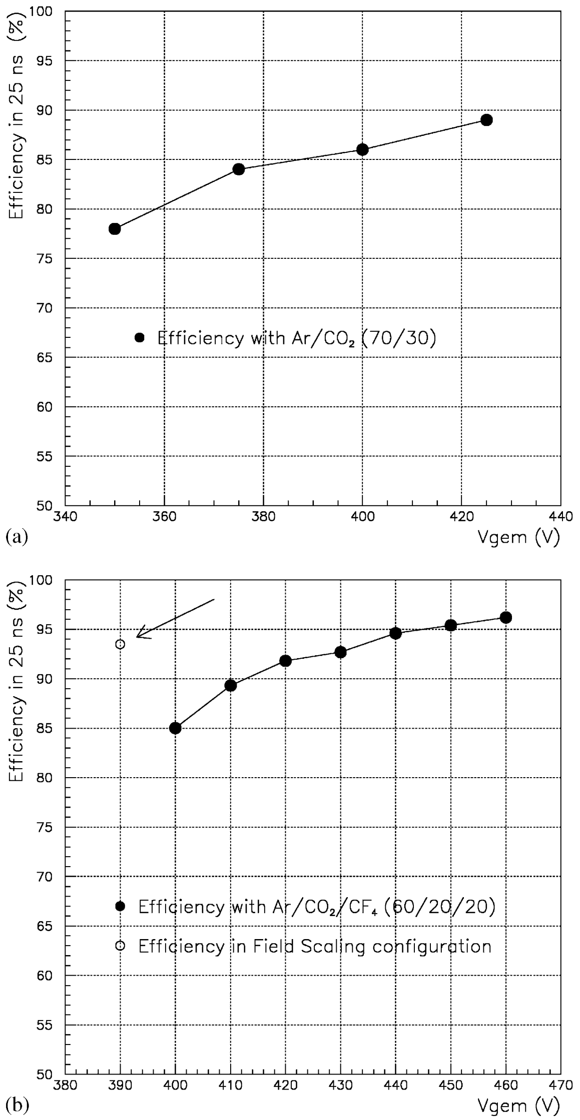

Fig. 4. Efficiency in a 25 ns window as a function of V_gem, using $\mathrm{Ar/CO_2}$ (70/30) (a) and $\mathrm{Ar/CO_2/CF_4}$ (60/20/20) (b). The efficiency measured in the "Field Scaling" configuration is also reported.

The time spectra recorded with the two gas mixtures, for the two runs with the highest efficiencies, are shown in Fig. 5. A substantial improvement in the spread of the distribution was obtained using the $\mathrm{CF_4}$-based gas mixture, reducing the RMS from 10 to 6 ns.

5. Conclusions

Three-GEM detectors prototypes equipped with pad readout and supplied with a mixture of $\mathrm{Ar/CO_2/CF_4}$ (60/20/20) at STP have shown very good time performances, resulting in a time distribution

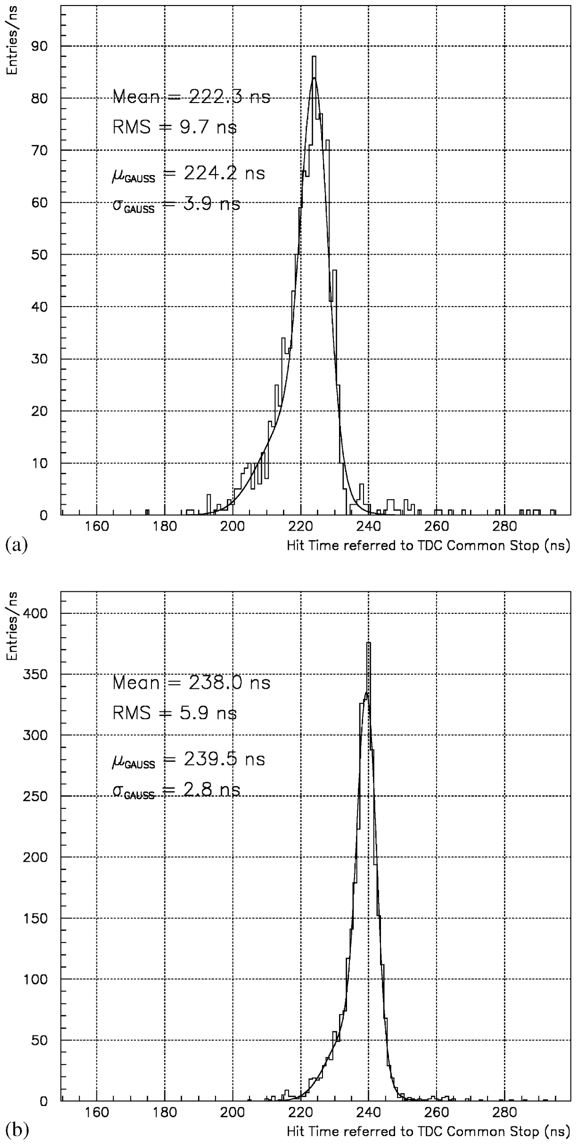

Fig. 5. Time distribution of triple-GEM detectors using Ar/CO_2 (70/30) (a) and Ar/CO_2/CF_4 (60/20/20) (b). μ_{GAUSS} and σ_{GAUSS} are respectively the mean and the standard deviation of the gaussian fit of the peak.

RMS of 6 ns and an efficiency of 96% in a 25 ns time window. Studies aiming to investigate the stability of these detectors under high charged-particle rate and their ageing properties are in progress. A fine tuning of gas mixture, electric field configuration and detector geometry might allow additional improvements on the time resolution.

Acknowledgements

The authors would like to thank F. Sauli for useful discussions. This work would not have been possible without the support of the technical staff both at INFN Cagliari and at LNF, and in particular of: M. Arba and M. Tuveri (INFN Cagliari) for the realization of the mechanics of the Cagliari prototype; D. Marras (INFN Cagliari) for the design and the assembly of the front-end electronics of the Cagliari prototype; B. Ortenzi (LNF) for the design of the detector box of the Frascati prototypes; E. Iacuessa and S. Valeri for the realization of the mechanics of the Frascati prototypes; the LNF Electronics Pool for the realization of the front-end electronics of the Frascati prototypes.

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