

**OPTIMIZATION OF OPERATION AND TEST OF LARGE SIZE GEM
DETECTORS**

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ABSTRACT

We describe basic development work aimed at the realization of large (~ 1000 cm² active) detectors for the COMPASS experiment, based on the gas electron multiplier technology. Essentially a high-rate forward spectrometer, the experiment requires high accuracy tracking of scattered particles and light detectors, in order not to degrade mass resolution and particle identification. The choice of a double GEM structure with two-coordinate read-out fulfils the above requirements. Systematic studies confirm the required performances, with good safety margins for an operation in harsh environments. We discuss the design problems encountered in the construction of the large devices and the solutions adopted, together with preliminary results obtained with prototypes in the laboratory and in a high intensity beam.

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1. INTRODUCTION

The COMPASS experiment [1], in construction at CERN, will investigate the internal structure and spectroscopy of hadrons. Two magnetic spectrometers, one for detecting hadrons at large angles (>30 mrad) and/or low momenta, and the second for angles below 30 mrad and large momenta are used. The more stringent requirements to the detectors are imposed by the intensity of the muon beam (100 MHz), and by the large interaction rate of the hadron beam (1 MHz). Charged tracks close to the beam are detected in ten stations, making use both of silicon microstrips and gaseous micro-pattern devices. For the regions located within a $15 \div 20$ cm radius from the beam, twenty large area detectors based on the gas electron multiplier (GEM) technology will be built, each with two-dimensional projective readout capability, reduced mass, and the possibility to inhibit detection of the main beam in the central region. High rate capability, robustness and excellent single- and multi-track resolution are mandatory for the detectors.

2. GEM OPERATION AND PERFORMANCES

The basic element in GEM detectors is a thin polymer foil, metal-clad on both sides, pierced by a high density of holes [2]. On application of a difference of potential between the two electrodes, electrons released by radiation in a gas on one side of the structure are drifted into the holes, multiplied and released on the other side. The multiplier is a detector on its own; installed however as pre-amplifying element in front of another micro-pattern device, it permits to sustain larger overall gains in harsh radiation environments [3-5]. With two GEM in cascade, the electron charge can directly be detected on a segmented printed circuit [6]. With a new conception of the pick-up board, one can accomplish two-coordinate projective read-out, with both electrodes kept at ground potential, a considerable practical advantage [7].

Performances of double-GEM detectors have been extensively studied both in the laboratory and in test beams. The most relevant are a position resolution for minimum ionizing tracks, perpendicular to the detector, of 40 μm rms, and a time resolution of 18 ns fwhm. The achievable gain at moderate radiation fluxes is as large as 10^5 , whilst it still exceeds 10^4 at high rates, above $10^5 \text{ mm}^{-2}\text{s}^{-1}$. This holds also when exposing the detector to strongly ionizing particles [8]. Given the value of gain, a few thousand, needed for efficient detection of fast particles with existing electronics, a sufficient margin for proper operation is obtained, ensuring a comfortable efficiency plateau for minimum ionizing particles in presence of highly ionizing background.

GEM devices operate effectively in a wide choice of gases; a mixture of argon and CO_2 in the volume proportion 70-30 % has been preferred for the present work. Although not the best for obtaining the highest gain, it has several advantages, namely to be not flammable, chemically stable and with a fast electron drift velocity. A stable gain under high rate, long-term exposure to radiation has been demonstrated with a double-GEM detector operated with this gas mixture [9], even using a conventional fiberglass-epoxy assembly technology, banned for the more susceptible gas micro-strip chambers.

3. THE COMPASS PROTOTYPE

The major requirements for the COMPASS tracking detectors are a compact structure with low mass, and the largest possible ratio of active to total surface. Two-dimensional read-out obviously helps reducing the number of detectors and their mass. A dead area the size of the beam spot in the center of the detectors is needed to avoid occupancy problems in the high intensity runs. The design adopted is shown schematically in Fig. 1. The main components of the detector are two identical GEMs with an active surface of $31 \times 31 \text{ cm}^2$, a projective two-coordinate read-out printed circuit board (PCB), and a drift electrode delimiting the sensitive volume. Both GEMs and PCB are manufactured on $50 \text{ }\mu\text{m}$ thick kapton, clad on both sides with a $5 \text{ }\mu\text{m}$ copper layer, with technologies developed in the CERN workshops¹. For the GEMs, we have adopted a standard high gain design, with regularly spaced $70 \text{ }\mu\text{m}$ holes in hexagonal patterns at a $140 \text{ }\mu\text{m}$ pitch [10]. In order to keep the overall mass of the detector at minimum inside and outside the active area, we have used two light honeycomb plates, 3 mm thick, as supporting structures, and very thin (5 mm wide) frames for the detector assembly. The resulting thickness in the active area is below 3‰ of a radiation length for each pair of coordinates. To decrease the total energy in case of discharges, one electrode in each GEM is segmented into four sectors connected to the common high voltage line via individual protection resistors. An inner disk, 5 cm in diameter, is independently powered through a thin insulated line running along the center of the electrode (Fig. 2). Decreasing the voltage difference in this region prevents detection of the beam; the region can be however activated in low intensity runs, to ease the alignment procedures. Narrow gaps between segments, $\sim 200 \text{ }\mu\text{m}$, minimize efficiency losses but are wide enough to sustain the potential difference necessary to inhibit operation in each sector (around 400 V).

The readout board consists of two insulated perpendicular sets of 780 read-out strips each, 31 cm long, with $400 \text{ }\mu\text{m}$ pitch, separated by $50 \text{ }\mu\text{m}$ thick kapton ridges; Fig. 3 is a close view of the readout pattern. In order to achieve uniform sharing of the signals in the two projections, the upper strips have a width of $80 \text{ }\mu\text{m}$, while the lower ones are $350 \text{ }\mu\text{m}$ wide. High-density, fast amplifiers cards followed by charge-encoding electronics are wire-bonded on each strip to record the pulse profiles. A three mm thick primary ionization volume has been adopted, a common choice for fast micro-pattern detectors in order to minimize the collection time without loss of efficiency. The one mm gaps between the two GEMs, and between the second GEM and PCB are a compromise between the minimum distance required to effectively separate the two amplification structures, and a reduction of electron diffusion during the drift between elements². Since the field in the GEM holes dominantly determines the gain, the tolerance in the distance between the different elements of the chamber is not a critical parameter. It affects however the charge transfer efficiency: a 10% variation in the gap results roughly in the same variation in the signal, acceptable for tracking applications. Although the honeycomb support increases the rigidity of the thin frames, high mechanical

¹ Developed by A. Gandi and R. De Oliveira, EST-MT

² Further studies, not completed at the time of the design, suggest that a wider transfer gap (2 mm) is more effective to prevent the propagation of accidental discharges.

stress could not be put on the structure without introducing deformations. The use of spacers appeared therefore mandatory in our structures. Several alternatives have been tested in the laboratory on smaller prototypes, before implementation in the larger devices. Between them, thin kapton strips, one mm high, glued to the electrodes in a spiral shape (Fig. 4), one-mm diameter acetate spheres, and epoxy-glass grids with a pitch of several cm and a wall width of $\sim 400 \mu\text{m}$ [11]. To fix the kapton strip and the acetate sphere on the electrodes, we have used two-component epoxy certified to have good insulating properties³. For the grid, a thin layer of glue⁴ has been deposited on the plate before machining the grid, and the adhesion was obtained by lamination at high temperature¹. No degradation in the detector performances due to the spacers has been observed in all three cases, and the only effect is a small inefficient region around the spacer itself. The expected integral efficiency loss induced by the kapton strip and the spheres is very small (0.1 %), while it is larger but still tolerable (1%) for a grid having a pitch of 8 cm. The kapton spiral spacer has been adopted for the first COMPASS detectors; although rather laborious to install, it proved very effective in preventing deformation of the gaps, as demonstrated by the good measured uniformity of gain.

4. FIRST RESULTS OF PROTOTYPE TESTING

Two full size prototypes as described have been completed and partly tested so far; the picture in Fig. 5 shows a completed detector. The larger honeycomb plate on the back serves both the purpose of preserving planarity, and of supporting the readout electronics and ancillary connections. The high voltage to each electrode is supplied to the sectors through individual protection resistors, mounted on distribution boards (top and left in the picture); on each GEM, the central area (beam killer) is connected to a separate power supply to control the local efficiency. For the initial tests, due to restricted availability, we have only equipped 128 adjacent strips in each plane with fast analogue readout electronics⁵; all the strips are however connected to ground, making the whole area of the detector active.

Both prototypes behaved satisfactorily in the laboratory, although in the first, mainly intended for mechanical studies, two GEMs of known poor quality were mounted. Fig. 6 shows the uniformity of gain across the sensitive area, recorded in the first prototype on a group of 16 adjacent strips, using a charge amplifier and a 6 keV X-ray source, at a gain of a few thousand. The second prototype, made with better quality GEMs, could hold safely the nominal voltage required to reach the middle of the efficiency plateau for minimum ionizing particles (420 V on each GEM). Installed in a high intensity beam at CERN, it is at present undergoing systematic tests of reliability and performances. Fig. 7 show preliminary data on integral pulse height spectra (or cluster charge) recorded on one of the read-out planes; the small peak on the left represents the electronics noise. Fig. 8 is a scatter plot of the charge recorded on one coordinate as a function of the other, showing the excellent correlation between the two projections. This will greatly help finding the correct pairs in multi-prong events.

³ Araldite AY 103.

⁴ No-Flue Arlon 47N1080.

⁵ PRESHAPE 32, with 45 ns shaping times.

REFERENCES

- [1] G. Baum et al., Proposal for a Common Muon and Proton Apparatus for Structure and Spectroscopy, CERN/SPLSC 96-14 (1996).
- [2] F. Sauli, Nucl. Instrum. and Meth. A386 (1997) 531.
- [3] R. Bouclier et al., Nucl. Instrum. and Meth. A396 (1997) 50.
- [4] B. Schmidt, Nucl. Instrum. and Meth. A419 (1998) 230.
- [5] W. Beaumont et al., Nucl. Instrum. and Meth. A419 (1998) 394.
- [6] A. Bressan et al., Nucl. Instrum. and Meth. A425 (1999) 262.
- [7] A. Bressan et al., Nucl. Instrum. and Meth. A425 (1999) 254.
- [8] A. Bressan et al., Nucl. Instrum. and Meth. A424 (1998) 321.
- [9] S. Bachmann et al., Limitations of Gas Electron Multipliers, Proc. Micro-Pattern Gas Detectors Workshop, Orsay June 28-30, 1999.
- [10] J. Benlloch et al., Nucl. Instrum. and Meth. A 419 (1998) 410.
- [11] S. Bachmann et al., A GEM Detector for the COMPASS experiment, Proc. Micro-Pattern Gas Detectors Workshop, Orsay June 28-30, 1999.

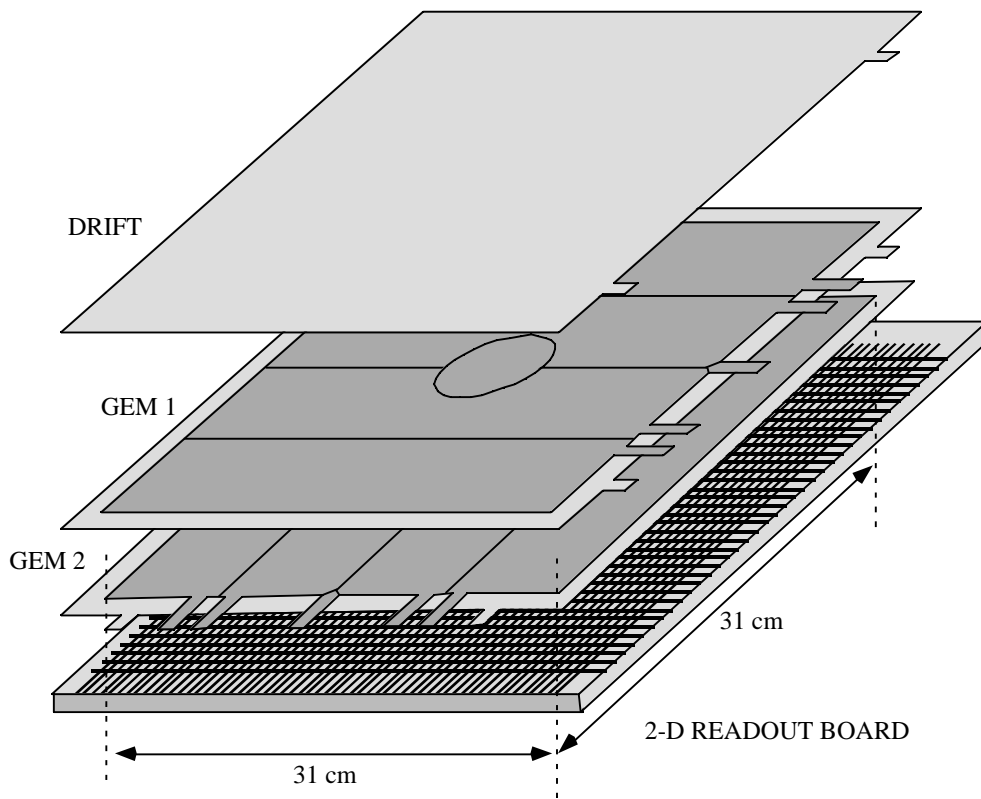


Fig. 1: Schematic view of the double-GEM COMPASS prototype. Both GEMs are segmented, with an independently powered region in the beam area.

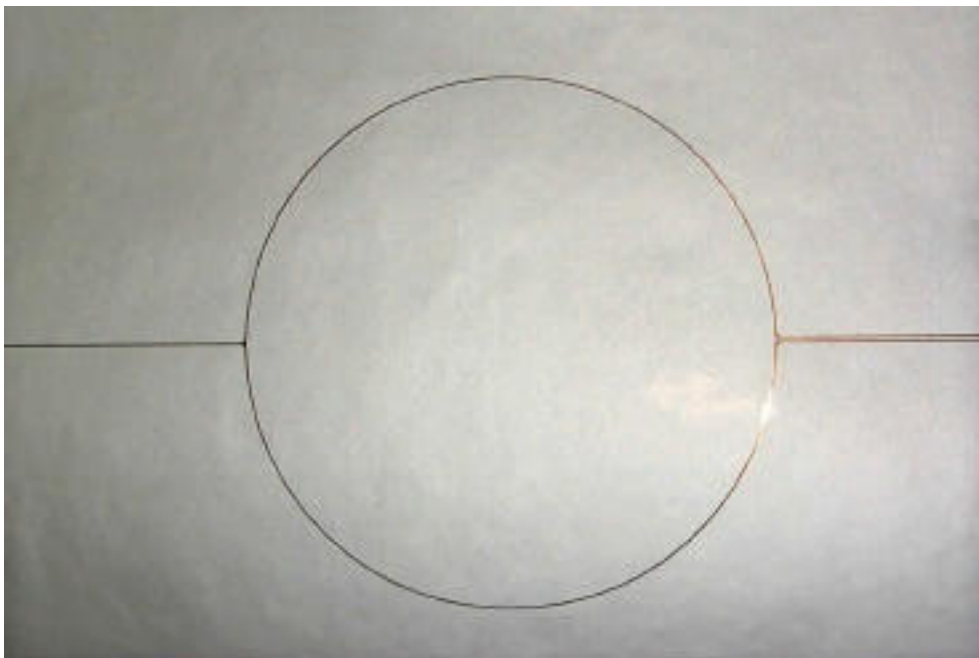


Fig. 2: Close view of the central area of a GEM, 5 cm in diameter, corresponding

to the beam spot, and independently powered through the line on the right.



Fig. 3: Close view of the read-out board, with two perpendicular sets of strips, separated by 50 μm kapton ridges. The pitch is 400 μm .



Fig. 4: The kapton spiral used as spacer in the one-mm gaps, glued to an electrode.



Fig. 5: A fully assembled COMPASS prototype. 128 strips on each coordinate are equipped with readout electronics, but the whole $31 \times 31 \text{ cm}^2$ area is active.

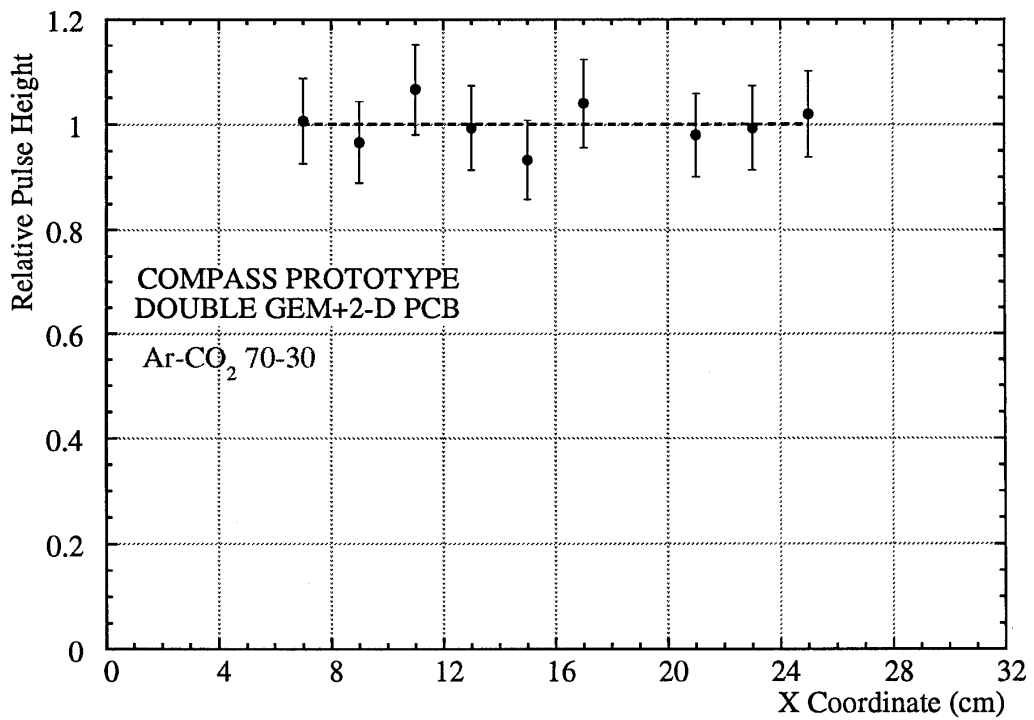


Fig. 6: Gain uniformity along one coordinate, measured on a group of strips.

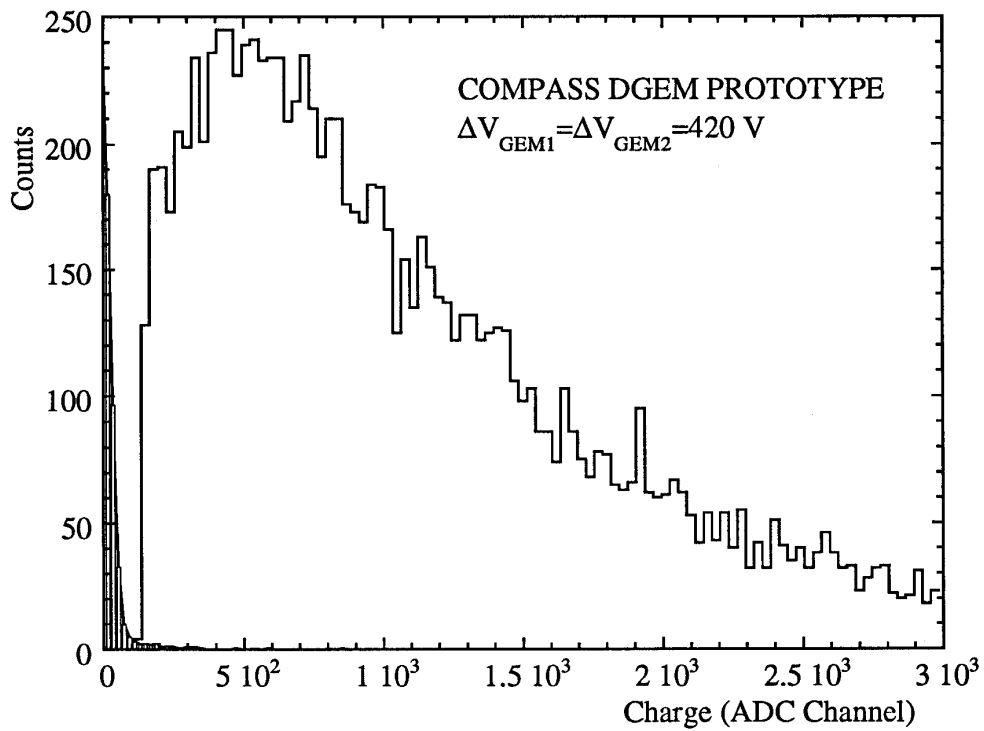


Fig. 7: Cluster charge recorded in a high intensity minimum ionizing particle beam. The average signal over noise (smaller peak at left) is 40 at the nominal operating voltage (420 V on each GEM).

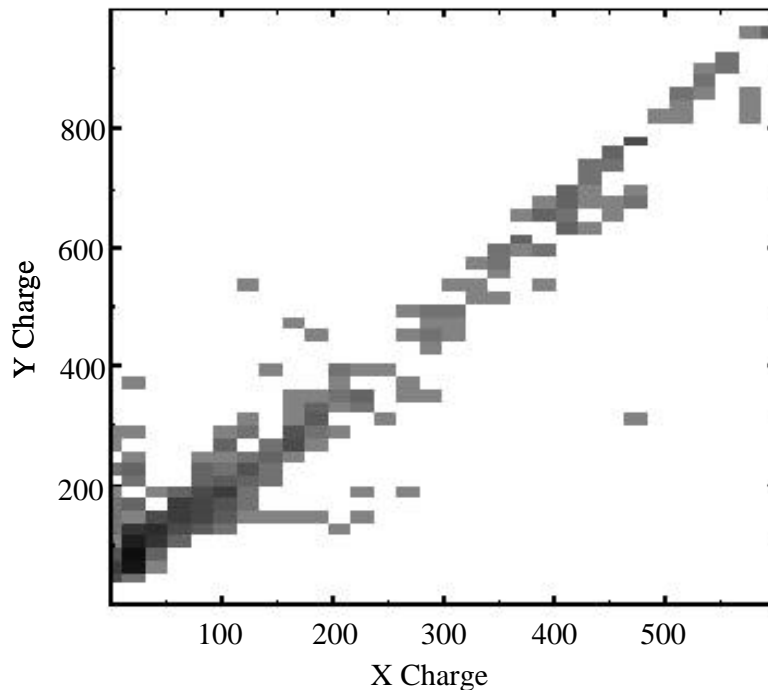


Fig. 8: Cluster charge correlation between the two projective read-out coordinates for a minimum ionizing particles beam.