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A GEM detector for the COMPASS experiment

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A 31×31 cm^2 GEM based prototype for the Small Area Trackers (SAT) of the COMPASS experiment is under development at CERN. The experiment requires for the SAT stations almost massless tracking detectors, in order not to spoil the mass resolution of the spectrometer, and the tracking of the scattered muon down to the beam. Good space resolution and rate performances are mandatory in this region. The choice of a double GEM structure with two-coordinate read-out fulfils the above requirements and guarantees a good margin in the detector operation.

A review of the design problems and solutions which have been adopted together with first measurements in the laboratory is presented.

1. INTRODUCTION

The COMPASS experiment at CERN [1] will investigate both the internal structure and spectroscopy of hadrons. The two programs requires as a key features the detections of high statistic samples of charmed particles. The measurement of the cross-section asymmetry from open charm production in photon-gluon fusion process $\gamma^{*}\mathrm{g} \rightarrow \mathrm{c}\bar{\mathrm{c}}$ of polarised muons impinging on a polarised nucleons allows to determine the gluon polarisation ΔG. On the other end semi-leptonic decays of charmed and double-charmed baryons are accessed using hadron beams. The more stringent requirements for the detectors are coming from the intensity of the muon beam (100 MHz) and the large interaction rate in the hadron beam (1 MHz). The initial set-up of the experiment for the ΔG measurement is shown in figure 1; two magnetic spectrometers, the first detecting hadrons at large angles (>30 mrad), and/or low momenta and the second hadrons with angles below 30 mrad and large momenta are used. Key points of the first spectrometer is the hadron identifications done by a fast RICH detector, which allows to identify the products of the D^0 decays [2]. Ten tracking stations are foreseen; relevant to micro-pattern detectors is the Small Area Tracker (SAT) where silicon and micro-pattern gas detectors are used. The silicon detectors cover the beam spot (about 5 cm $\oslash$), while three micromegas [3] and twenty GEM detectors [4] are foreseen for the region within a $15 \div 20$ cm radius from the beam. Micromegas are only placed between the target and the first spectrometer magnet SM1, while GEM detectors are used for all the other tracking stations.

A closer view of the position of the first three GEM stations placed between SM1 and the RICH is shown in fig. 2; as visible from the picture, the detector GEM1 is placed just at the end of SM1, and will be operated in a magnetic field of the order of 0.2 T. All the other chambers will work in regions with a limited or even zero magnetic field.

2. GEM PERFORMANCES, A SUMMARY

Performances of single- and double-GEM detectors have been carefully checked both in the laboratory and in test beams at CERN. For all the tests a convenient gas mixture of argon-$\mathrm{CO_2}$ in the volume proportion 70-30% have been used; although if this mixture is not optimised for very high gas gain, it has some advantages, namely it's a not flammable and relatively fast mixture that doesn't need a particular choice in the components of the chamber and of the gas system (like for instance DME based mixtures). The main results for the Double-GEM detectors are summarised hereafter [5–7]:

- position resolution $\sigma = 40\mu$m;
- time resolution FWHM = 18ns;
- plateau length in presence of MIPs from S/N=20 up to S/N 10^3, i.e. a 150V plateau;
- maximum gain for 5.9 keV Fe X-rays $\sim 10^5$;
- maximum gain for 6.4 MeV α particles above 10^4 without detector breakdown;
- maximum gain for a rate of 5×10^5 5.9 keV X-rays converted /mm^2 above 5×10^4;
- no aging up tp 12 mC/mm^2.

It appears that the main limitation to the detector performances comes from the maximum gain achievable in presence of heavily ionising particles HIPs (in this case 6.4 MeV α's) but this limit is a factor of five to ten higher than almost all the other single micro pattern structures [6] and higher by the same order of magnitude than the threshold for full efficiency detection of MIPs (~ 2000) using highly integrated fast electronics [8,9]. Moreover GEM based detectors are the only that allow to use a two coordinate read-out with both the coordinate at ground potential [10,11].

3. THE COMPASS PROTOTYPE

The results listed above make this new technology very interesting for application in high rate experiments like COMPASS. The guide lines for designing

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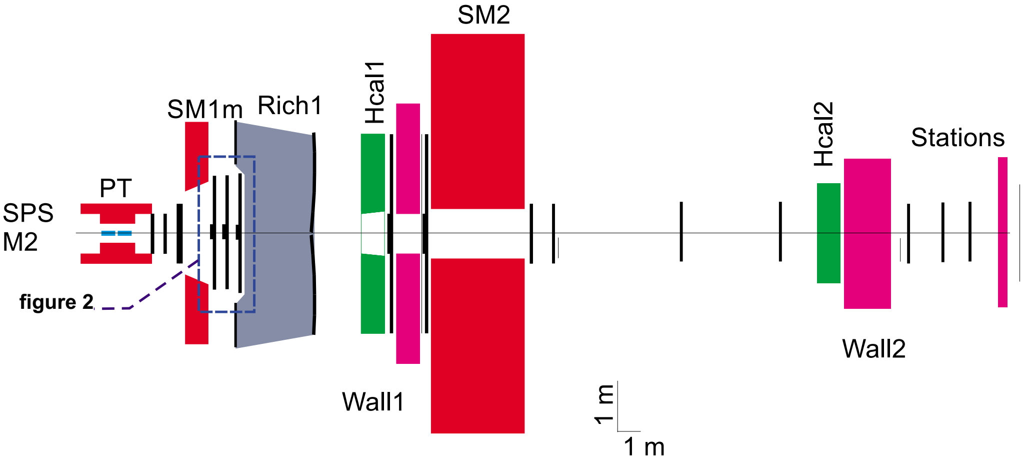

Figure 1. Initial layout of the COMPASS experiment for the ΔG measurement.

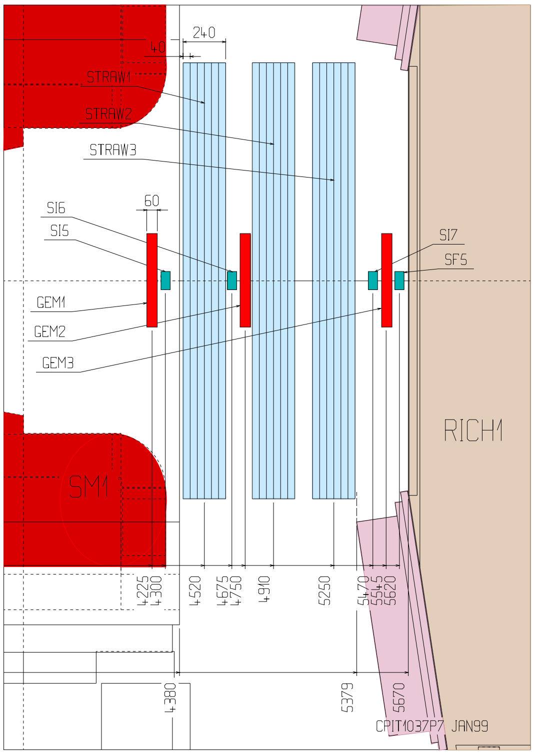

Figure 2. Position of the GEM detectors after the magnet SM1 of the first spectrometer.

the COMPASS SAT detectors are essentially the following:

- a low mass and compact structure;
- the largest possible active surface (starting from the original $43 \times 43\,\mathrm{cm}^2$ copper clad Kapton foils);
- a two-dimensional read out to reduce the number of detectors (i.e. mass) needed for a space point;
- a dead area of the size of the beam spot to limit occupancy problems.
- APV-M chips as front-end electronics [2]

The resulting design is shown in figure 3 (top and side views). Basic elements of the detector are two identical GEMs with an active surface of $31 \times 31\,\mathrm{cm}^2$ and the two-coordinate read-out printed circuit board (PCB); both GEMs and the PCB are made using 50μm thick Kapton clad on both sides with a 5μm copper layer[3]. The GEMs holes have the 'standard' high gain design with 140μm pitch and a inner/outer diameter of $50/70\mu$m respectively. The PCB has 780 31 cm long strips with a 400μm pitch on both the coordinates; in order to have a equal sharing of the signal the upper strips have a width of only 80μm, while the lower are 350μm wide. The inter-strip capacitance is $\sim$ 20 pF (0.6 pF/cm) between upper and lower strips.

In order to keep the mass of the detector at the minimum, both in the active area than outside, we have used two 3 mm thick honeycomb plates as supporting structures and very thin (5 mm wide) frames.

The upper electrode of the GEMs is segmented into four elements connected to the common high voltage line via individual protection resistors to decrease the total charge available in case of discharge. Moreover, an inner disk of 5cm diameter (fig. 4) is power independently through a 150μm wide strip running in the GEM; decreasing of the voltage (i.e. gain) between the two electrodes in this central region allows to suppress detection of the beam. The distance between the four elements of the detector (drift electrode, GEM1, GEM2 and PCB) is 3/1/1 mm respectively (fig. 3). A 3 mm gap as a primary ionization volume is a typical choice for micro-pattern detector in order to minimise the collection time (i.e. the memory of the detector) without loss of efficiency due to statistical fluctuation in the primary ionization; the 1 mm gaps between

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[2] The use of existing electronics is mandatory giving the time schedule of the experiment and the resources available. Due to the large (40MHz) clock frequency the APV-M chip is suitable for our fixed target application without large loss of the signal.

[3] Manufactured at CERN-EST-MT

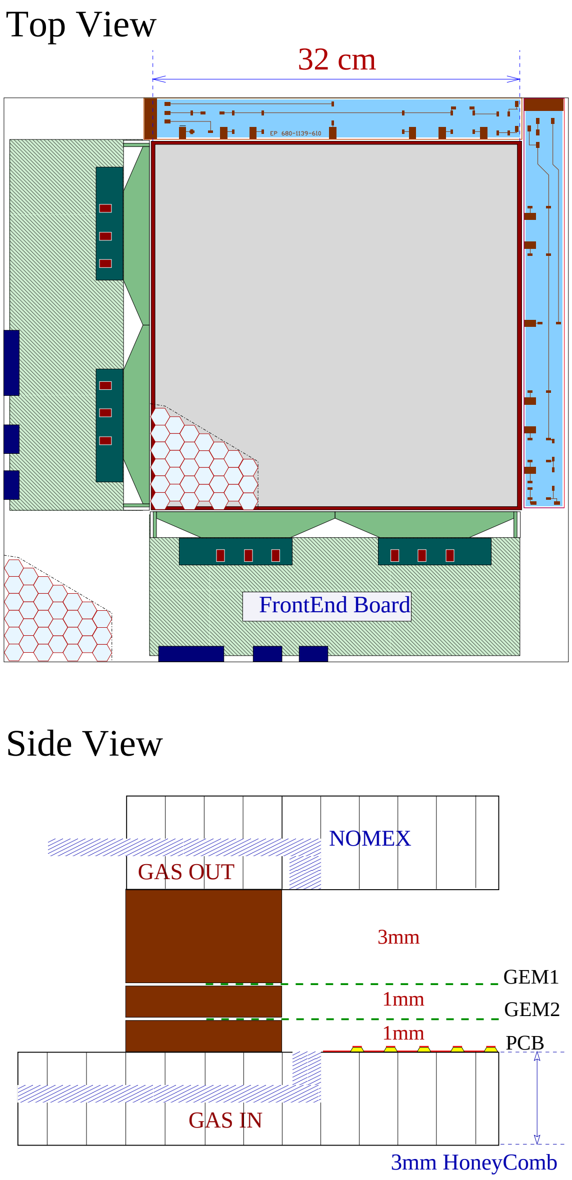

Figure 3. Top and side view of the GEM detector prototype. The two honeycomb supporting structures, the front end boards and high-voltage distribution system are visible in the upper picture. In the lower a blow-up of the side view close to the frame shows the internal structure of the chamber and the gas inlet and outlet

GEMs and GEM-PCB is an optimisation between the minimum allowed distance needed to effectively separate the two amplification structures, and reduction of charge diffusion. Besides a small distances as the advantage of a lower working voltage for the drift electrode, which with this scheme is around 3000V.

3.1. Spacers

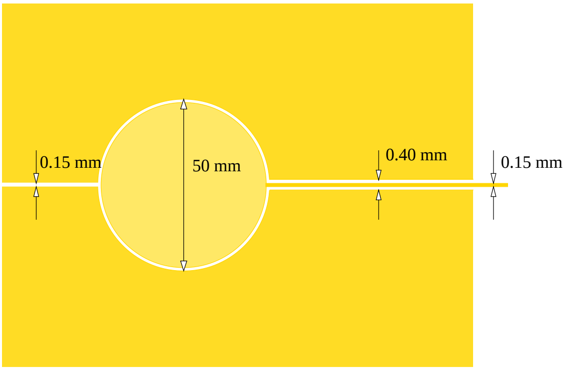

Figure 4. Detail of the central area of the upper GEM electrode. A 5 cm diameter disk is powered independently through a 150μm dedicated line. By a suitable choice of the applied potential the detection of particles can be activated and deactivated at wish

Although the honeycomb support increases the rigidity of the thin frames, high mechanical stress cannot be put on the structure without introducing deformations; this means that the use of spacers is almost mandatory in our structure in order to keep the distances between GEMs or GEM and PCB. The distance between the different elements of the chamber is not a critical parameter of the detector (see [12,13] for details), since a 10% variation in the distance roughly correspond to the same variation in the signal, which is acceptable for the tracking application of the device. Three 1mm high spacers glued directly on 10 × 10 cm^2 GEMs have been tested in so far: a thin (50μm thick) Kapton strip (top picture in fig 5); a 1mm diameter acetate sphere (middle) and finally an epoxy-glass grid[4] with pitch form 1 to 10 cm and a wall width of 400μm (bottom). For the Kapton strip and for the acetate sphere Araldite AY 103 glue has been used. For the grid a thin layer of No Flue Arlon 47N1080 has been deposited on the plate before machining the grid. No degradation of the detector performances due to the spacers have been observed for all three cases, and the only visible effect is an inefficient region around the spacer itself (see figure 6). The percentage efficiency loss given by both the Kapton strip and the sphere is small ($\sim .1\%$) with respect of the grid (1% for a grid pitch of about 8cm) but the gluing procedure is more delicate.

4. FIRST RESULTS AND CONCLUSIONS

The first full size prototype have been completed recently. This prototype was meant to develop an assembling procedure and to study possible problems connected with it; as a result the quality of the GEM was reduced during the mounting and the maximum achievable gain was only of the order of few thousands; nevertheless the detector shows a good energy resolution and a good uniformity (see fig. 7) over the whole surface. A second prototype is currently under construction and will be tested by using the COMPASS muon beam at the nominal rate.

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[4] Developed by R. de Oliveira, CERN-EST-MT

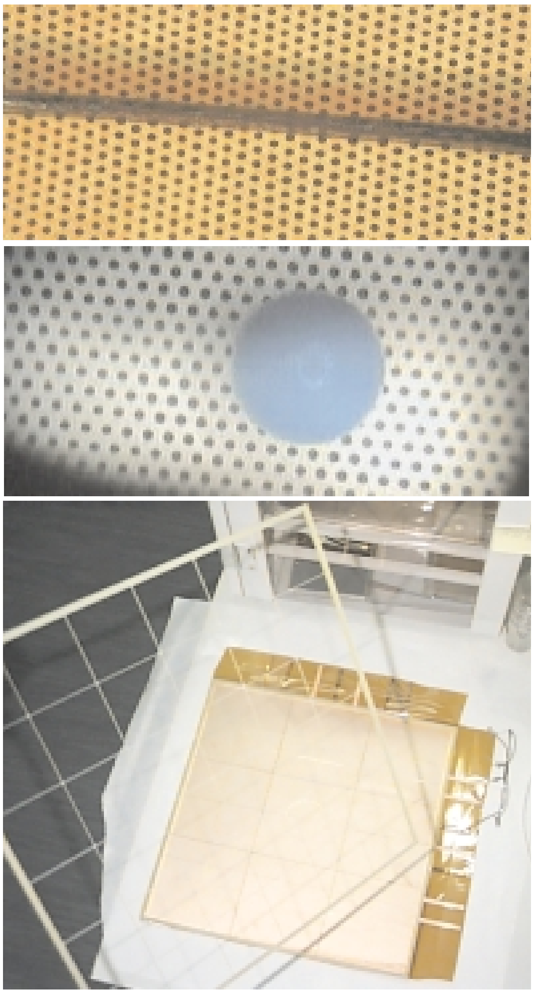

Figure 5. The three spacers that have been tested: a Kapton strip 1mm thick and 50μm (top); a 1mm diameter acetate sphere (middle); and a 400μm thick, 1 mm high epoxy-glass grid (bottom).

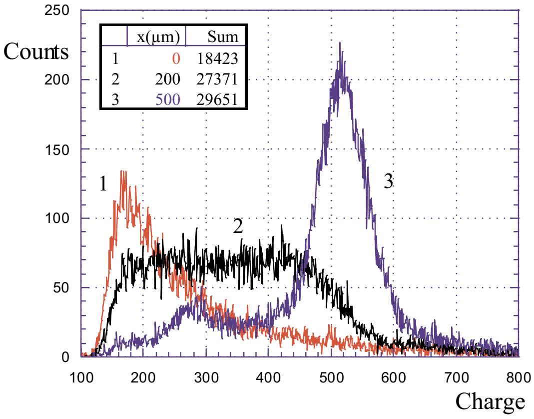

Figure 6. Spectra collected irradiating the chamber at different distances from the Kapton strip with a Fe X-ray source collimated on a 200 $\div$ 300μm $\oslash$ spot.

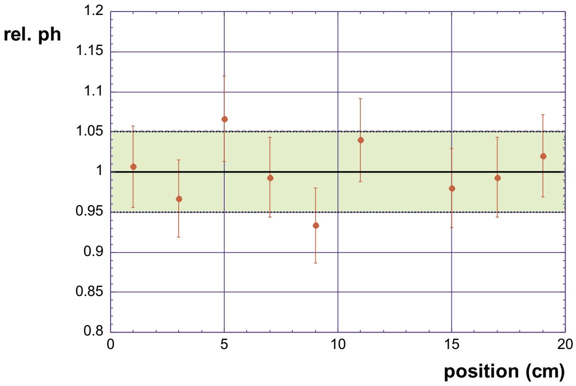

Figure 7. Gain uniformity along the GEM detector showing that the fluctuations are within 5%.

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