

A fast Tracker for COMPASS based on the GEM

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The small area tracking system of COMPASS, a new high-luminosity fixed target experiment at CERN's SPS accelerator, comprises 20 large-size triple GEM (Gas Electron Multiplier) detectors. It was completed and fully operational for the first time for the 2002 muon run. We report on the performance of these chambers in the high-intensity beam and give first results on efficiencies as well as spatial and time resolutions measured for the full set of detectors under various beam conditions.

1. THE COMPASS EXPERIMENT

COMPASS (Common Muon and Proton Apparatus for Structure and Spectroscopy), a fixed target experiment at the Super-Proton-Synchrotron at CERN, came into operation in 2001. It is designed to investigate the structure and excitations of hadrons, both the domain of non-perturbative QCD, using muon and hadron beams of 100 – 200 GeV/ c and intensities up to 10^8 particles per second.

A key feature of the experiment is the detection of a high-statistics sample of particles containing charm quarks. As a first goal, the cross section asymmetry for the production of open charm will be measured by scattering polarized muons from a polarized Li⁶D target [1]. In leading order, charmed D^0 , \bar{D}^0 , and D^* mesons are produced in a process called photon-gluon-fusion, in which a polarized virtual photon from a beam muon interacts with a gluon via the exchange of a charm quark. This process is known to be particularly sensitive to the spin of the gluon, thereby probing the gluon contribution to the nucleon spin, possibly answering the long-standing question of the origin of the spin of nucleons. Using pion and kaon beams, we will study doubly-charmed baryons, first evidence of which has been recently reported [2], as well as semi-leptonic decays of

charmed baryons.

Additional topics with hadron beams include the measurement of pion and kaon polarizabilities using Primakoff scattering [3], and the study of exotic hadrons, which are predicted by QCD but have not been firmly established until now.

All these measurements require the use of very intense beams to obtain high integrated luminosities, and, consequently, the use of tracking detectors with very high rate and multi-track resolution capabilities, combined with fast, fully pipelined readout electronics, capable of digesting trigger rates up to 100 kHz for certain measurements of the hadron program.

The current setup of the COMPASS detector is shown in Fig. 1. It is a two-stage magnetic spectrometer, optimized for acceptance and mass resolution. The first stage utilizes a magnet with a field integral of 1 Tm (SM1 in Fig. 1) to detect secondary particles with momenta down to 0.5 GeV/ c , while the second stage is equipped with a magnet of 4 Tm to deflect particles with momenta above 10 GeV/ c . A ring imaging Čerenkov counter (RICH) for $\pi/K/p$ discrimination is essential for identification of charmed mesons. Each of the stages is equipped with electromagnetic and hadronic calorimetry (ECAL, HCAL) and muon identification. Tracking is done in so-called tracking stations, each consisting of a

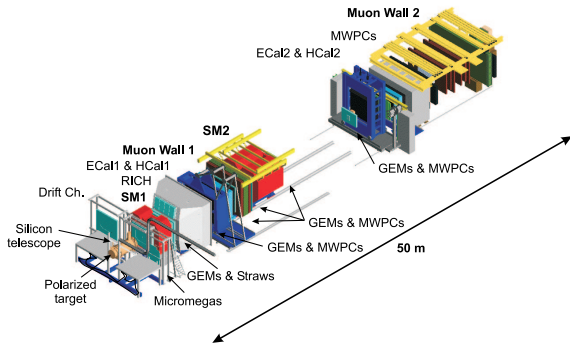


Figure 1. Schematic view of the COMPASS spectrometer in its present stage.

nested set of different types of position sensitive detectors with granularity and rate capability increasing towards the beam axis. While large-size drift chambers/tubes and multi-wire proportional counters are used for the outer regions, micropattern gaseous detectors are mounted to cover the near-beam region [4], where they have to cope with particle rates higher than 1 MHz/cm^2 . In particular, 20 GEM detectors arranged pairwise in 10 stations perform the tracking downstream of the first spectrometer magnet. Here, a mass resolution of $10 \text{ MeV}/c^2$, as envisaged for D^0 mesons, requires that the GEM detectors expose as little material as possible to the tracks in order to minimize multiple scattering. After a brief overview of the principle of the GEM and the design adopted for COMPASS to allow a safe operation of these devices in a high-rate environment, we will focus in this paper on first results on the performance of the full set of detectors in the 2002 COMPASS beam.

2. THE GEM DETECTORS

The GEM (Gas Electron Multiplier) [5] is a metal-coated insulator foil, perforated by typically 10^4 holes per cm^2 of $70 \mu\text{m}$ diameter, rendering it optically semi-transparent. In a GEM-based detector the foil is inserted into a gas volume between a drift cathode and a readout anode,

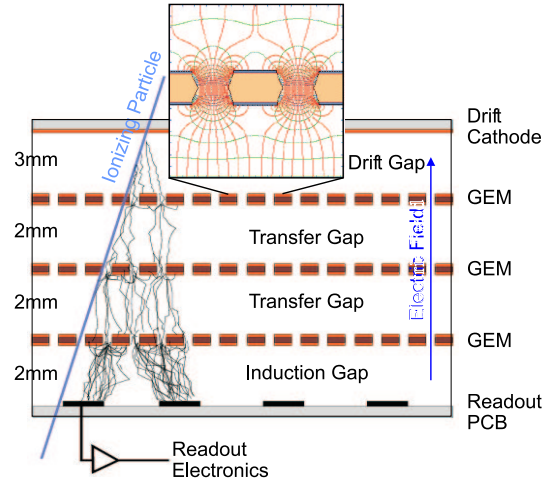


Figure 2. Schematic cross section of a COMPASS triple GEM detector.

and a potential of $\sim 400 \text{ V}$ is applied between the two sides of the foil. Primary electrons created in the volume above the foil are guided by the electric field lines into the holes, where the electric field is high enough ($\sim 50 \text{ kV/cm}$) to induce gas amplification. The resulting charge cloud is then extracted on the other side of the foil and can be detected or transferred to another amplification stage, as shown in Fig. 2. Ions are created inside the holes only, and are to a very large extent neutralized on the top side of the GEM foil. This intrinsic suppression of ion-feedback makes the device very interesting for application in a Time Projection Chamber, and is currently under investigation by several groups [6,7].

The possibility to cascade several amplification stages, unique to this type of detector, allows to tune the gain to the requirements of the specific application, and, at the same time, strongly reduces the probability for gas discharges due to heavily ionizing tracks entering the detector volume [8]. For COMPASS, a triple-GEM configuration as shown in Fig. 2 was chosen, with a gap between the drift cathode and the first GEM of 3 mm , and gaps between GEM foils and to the readout anode of 2 mm , respectively, the dis-

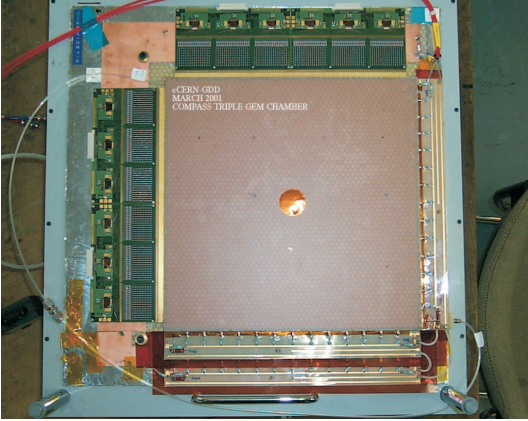


Figure 3. Photograph of a COMPASS GEM detector. The active area of $31 \times 31 \text{ cm}^2$ is covered by a honeycomb plate, the central hole indicating the position of the beam killer. The high voltage is supplied to all electrodes through a resistor chain on thin printed circuit boards (PCBs) on the right and bottom sides of the active part. The strips of the 2-D readout anode PCB are wire-bonded to the front-end cards on the left and top sides.

tances between electrodes being guaranteed by thin spacer grids made of fiber glass [9]. Further optimization steps to completely prevent discharges include an asymmetric sharing of the total gain between the three foils, gradually decreasing by $\sim 10\%$ at each amplification step, and segmentation of the GEM foils on one side, decreasing the energy stored in each sector [10].

The active area of the detector, limited by the current technique used to manufacture the GEM foils, is $31 \times 31 \text{ cm}^2$ (Fig. 3). The central region of the detector of 5 cm diameter, inactive during normal operation in the high-intensity beam, can be activated for alignment purposes in a low-intensity beam by an external switch. For reasons of operational safety, the high-voltage is supplied to all electrodes by a single source through a resistive divider, shown on the left and bottom side of the active area in Fig. 3.

The clear separation of amplification and read-

out stages intrinsic to GEM-based detectors, allows the use of sophisticated readout structures, in the case of COMPASS two orthogonal sets of 768 strips on top of each other, insulated by $50 \mu\text{m}$ thick ridges of Kapton, equally sharing the total charge from an ionizing track.

The front-end electronics makes use of the APV25 chip, which continuously shapes, preamplifies and samples the signals from 128 readout strips at a frequency of 38.8 MHz, and stores the sampled amplitudes in an analogue pipeline, awaiting an external trigger decision with a maximum latency of $4 \mu\text{s}$. Upon reception of a trigger signal, the amplitudes of three consecutive samples of each channel, corresponding to the traversal time of the triggering particle, are multiplexed and digitized by an analog-to-digital converter, custom-made to perform common-mode correction and suppression of empty channels.

3. COMMISSIONING

A total of 20 large-size GEM detectors have been installed for the 2002 muon run of COMPASS, thus completing the setup as initially planned. Before its installation in the spectrometer, each detector is tested in the laboratory using a collimated source of 8.9 keV X-rays and a ^{90}Sr beta source. To ensure a uniform response over the whole detector surface, the relative gain and energy resolution is mapped on a matrix of 16 points on the detector surface. Gain variations of the order of $\sim 8\%$ RMS are attributed to local variations of the GEM hole diameter, and are accepted. The effective gain, determined by the current into a group of readout strips at a known rate of incoming X-rays, is then measured at the points with minimum and maximum gain, as shown in Fig. 4 for one particular detector.

4. BEAM PERFORMANCE

In the experiment, all detectors were initially set to voltages corresponding to a minimum gain of 8000, which had been found in various test beams to be necessary for full detection efficiency ($> 98\%$) of minimum ionizing particles on both readout coordinates. Using a low-intensity beam

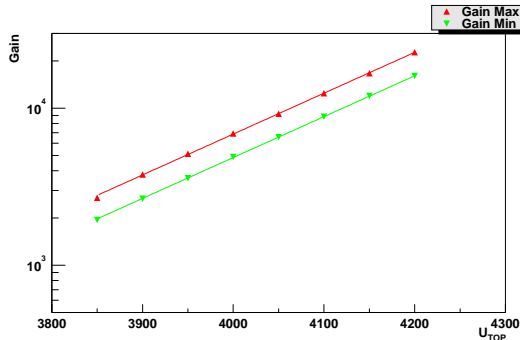


Figure 4. Effective minimum and maximum gain curves for one particular COMPASS GEM detector.

with both spectrometer magnets switched off, an efficiency scan for each detector was then performed by varying the voltage applied to the resistive divider in steps of 50 V around the nominal value. Tracks were identified by the official COMPASS track reconstruction program using the information from all other detectors, and then interpolated to the position of the GEM detector under investigation. A hit in this detector was considered valid in terms of 2-D efficiency, if both coordinates had seen a signal with amplitude higher than five times the average noise of a single strip, within a spatial window of five times the detector resolution, measured in test beams to be $50 \mu\text{m}$ [10]. Fig. 5 shows efficiency curves for the detectors with maximum and minimum efficiency, and for the average of all 20 chambers as a function of the difference to the individual nominal values of U_0 . The curve with the lowest efficiency was measured for the most downstream GEM detector in the spectrometer, with a corresponding track extrapolation over several meters, and is therefore attributed due to a larger track uncertainty rather than a true deficiency of the detector. The average value for the 2-D efficiencies of all detectors at their nominal high voltage settings is $(98.8 \pm 0.1)\%$, not taking into account inefficient regions obstructed by spacer grids, which correspond to $\sim 1.8\%$ of the total

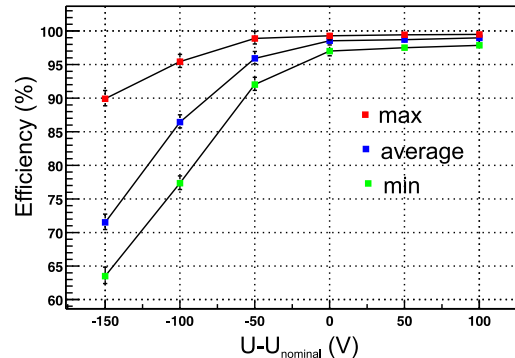


Figure 5. Efficiency curves versus voltage difference from the nominal setting for two detectors, and for the average of all 20 chambers.

area of each detector.

Fig. 6 shows 2-D efficiency maps for some detectors, this time measured in the high-intensity muon beam of $2 \times 10^8 \mu/\text{spill}^1$ in a standard physics run. The 2-D efficiency averaged over all detectors at these conditions is $(97.3 \pm 0.1)\%$, not including spacer grids. The loss of $\sim 1\%$ with respect to the low-intensity beam is tentatively attributed to space charge effects in regions very close to the inactive central part of the detector, where occupancies of $> 20\%$ had been observed due to a slight misalignment of the beam with respect to the detector center.

For the measurement of the spatial resolution of all detectors, again a low-intensity beam was chosen in order to get a very clean track sample. In addition, only GEM detectors (assumed to have equal spatial resolution) were used to define a track, so that the track error was precisely known. Only tracks segments longer than 15 m were considered, with the additional requirement that the detector next to the one under investigation has seen a hit corresponding to the track in order to keep the error due to multiple scat-

¹One spill corresponds to a period of 5 s, during which particles are extracted from the SPS and delivered to the experiment.

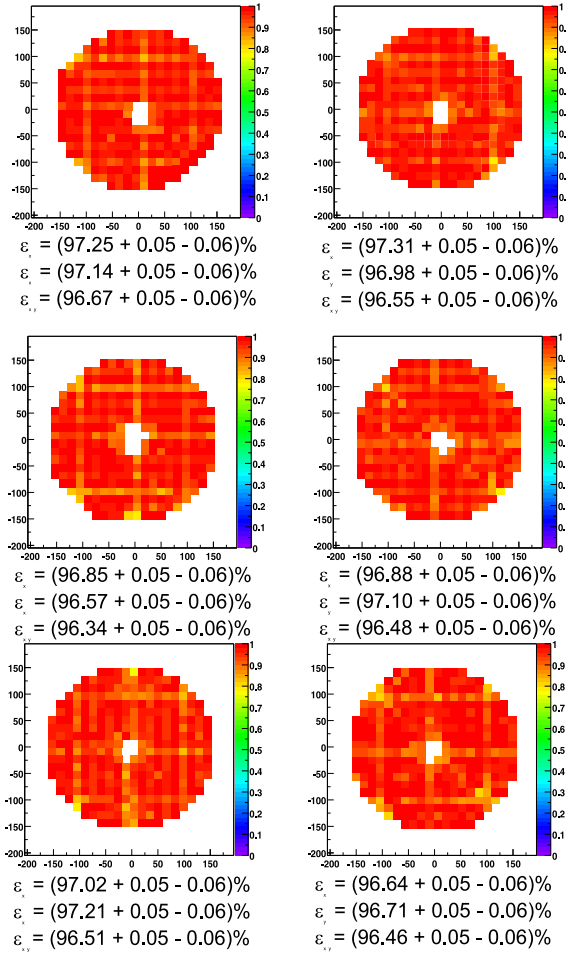


Figure 6. 2-D efficiency maps for some detectors. The numbers quoted underneath each map correspond to the averaged efficiencies for each projection separately, and to the 2-D efficiency, respectively, including inefficiencies due to spacer grids, visible as horizontal and vertical lines.

tering negligible. Fig. 7 shows track residuals for some detectors, including distributions with the smallest $[\sigma = (47.1 \pm 2.5) \mu\text{m}]$ and largest width $[\sigma = (53.7 \pm 5.7) \mu\text{m}]$ of all detectors.

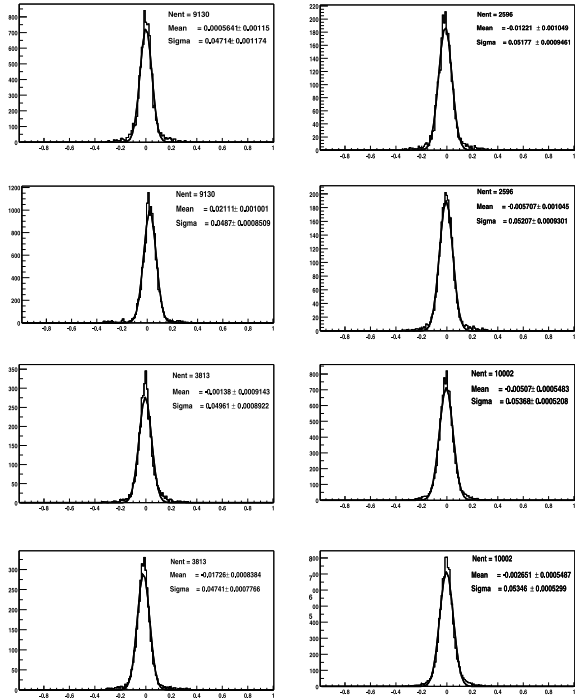


Figure 7. Residuals of measured hit positions versus expected track trajectories for selected chambers.

5. CONCLUSIONS AND OUTLOOK

Large-size triple GEM detectors constitute the backbone of the small area tracking system of the COMPASS experiment at CERN. After a technical run in 2001 with 70% of the system installed, the complete system of 20 chambers has been operational for the first time for the 2002 physics run. After a commissioning phase, all detectors operated stably at their nominal conditions during three months of data taking. The efficiency plateau was reached for all detectors at a gain of 8000, and the spatial resolution was verified in the spectrometer to be $\sim 50 \mu\text{m}$, in very good agreement with our expectation from test beam measurements. No broken strips were identified between the installation of the chambers and the end of the run, also for the ones already installed

in 2001. Further analysis of the detector performance in the high intensity muon beam, concerning efficiencies, spatial resolution, and time resolution, as well as long-term operation, is still in progress.

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