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Progress with the Gas Electron Multiplier

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Abstract

Offering position accuracies of few tens of microns and rate capabilities close to a MHz mm-^{2}, detectors using the Gas Electron Multiplier (GEM) as amplifying element are attractive whenever a precise knowledge of the energy loss topology is required. Moreover, they are robust and easy to manufacture. Cascading two or more GEM foils permits to achieve larger gains and reliable operation in harsh operating conditions. We discuss the operating principles and the major performances of the new devices, particularly in view of their possible use for particle identification in Transition Radiation and Cherenkov Ring Imaging detectors.

Keywords: Gas Electron Multiplier; GEM; high rate gas detectors; micro-pattern detectors.
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A variety of performing gaseous devices, named micro-pattern detectors (MPD), has been developed in the recent years. Providing good detection efficiency and localization accuracy at high rates, they are potentially very powerful for use in high energy physics experiments and other applied fields [1]. Experience has shown, however, that MPDs have a tendency to discharge when exposed to high rates or to highly ionizing particles. With the exception of the delicate Micro-Strip Gas Chambers, the new devices are generally sturdy enough to withstand discharges without damage. This may not be the case, however, for the sensitive readout electronics; moreover, the recovery time after a breakdown can seriously affect the detector efficiency. The recently introduced Gas Electron Multiplier (GEM) [2] offers a way to improve on this crucial point [3]. The basic component of the device is a metal-coated thin insulating foil, chemically pierced with a high density of holes, typically 50 to 100 per square millimeter. On application of a suitable potential difference, each hole acts as an independent proportional counter; electrons released in the gas layer above the foil drift into the holes and multiply in the high field within the channels (Fig. 1). Most of the avalanche electrons proceed into the lower gap, and can be collected on a passive electrode. Cascading several multiplying elements, one can reach much higher gains before discharges than in a single stage device, as shown in Fig. 2. Fig. 3 gives an example of response in the

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detection of soft (5.9 keV) X-rays; the energy resolution (around 20% FWHM), although not record-breaking, is generally sufficient for most applications. High rate capability (approaching a MHz mm^{-2}) and radiation tolerance have been demonstrated [4-7].

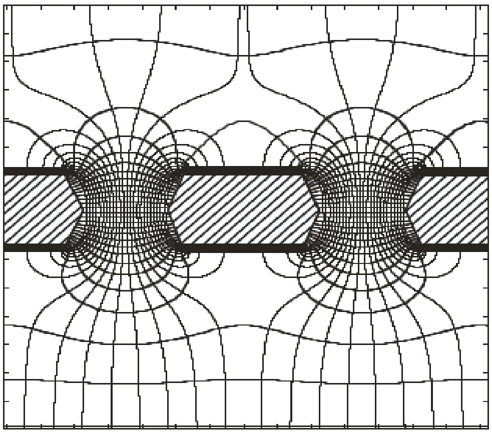

Fig. 1. Schematics and fields in the Gas Electron Multiplier.

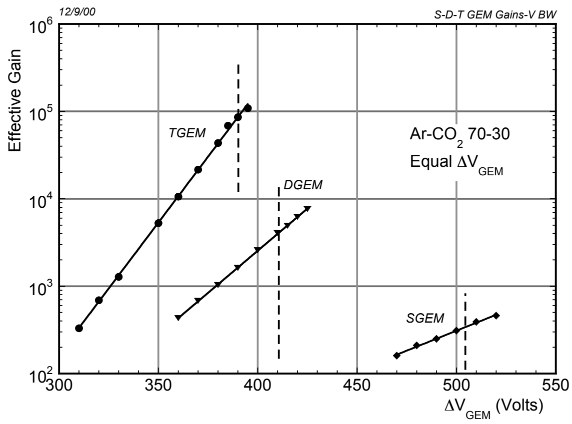

Fig. 2. Gain (full curves) and discharge limits on exposure to alpha particles (dashed lines) of multiple GEM detectors.

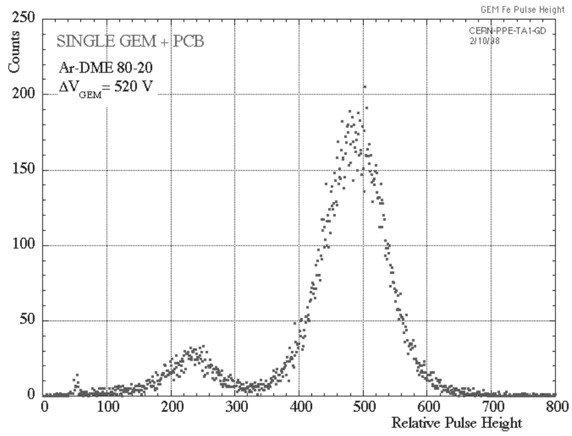

Fig. 3. Energy resolution of a double GEM for 5.9 keV x-rays.

A unique feature of GEM detectors is that proportional multiplication and charge detection are performed on separate electrodes; the propagation of accidental discharges to the sensitive electronics can be prevented with proper choice of the operating conditions. Signals induced on the readout board are purely due to electrons, without tails due to a slow ion component, as in other gas detectors, and are therefore very fast. Using thin multi-layer boards, one can achieve two-dimensional projective readout with all readout electrodes kept at ground potential, resulting in a considerable simplification in the read-out electronics. Exploiting charge sharing, and computing the center of gravity of the detected signals, typical position accuracies around 40 µm can be obtained for charged particles and soft X-rays [8].

A system of large size (31x31 cm^2 active) triple-GEM detectors has been built at CERN for the COMPASS spectrometer, and operates successfully in the high rate and background environment of the experiment [9]. To satisfy the low material budget requirements, detectors are manufactured gluing the various foils on thin frames over light honeycomb supporting plates; each chamber has an average thickness on the active area of 7‰ X_0. Fig. 4 shows one detector installed in the experiment, fully equipped with the analogue readout electronics. On occurrence of a first level trigger, the complete induced charge profile is recorded in orthogonal directions on two sets of readout strips at 400 µm pitch. Calculation of the centre of gravity of the recorded charge profiles provides the two coordinates, with a position accuracy for minimum ionizing particles perpendicular to the chamber around 70 μm rms (Fig. 5). The very good correlation between the two projected charge measurements offers a powerful tool to find the correct pairs in case of multiple tracks. The chambers have detection efficiency close to 100%, even for large multiplicities (Fig. 6) [10].

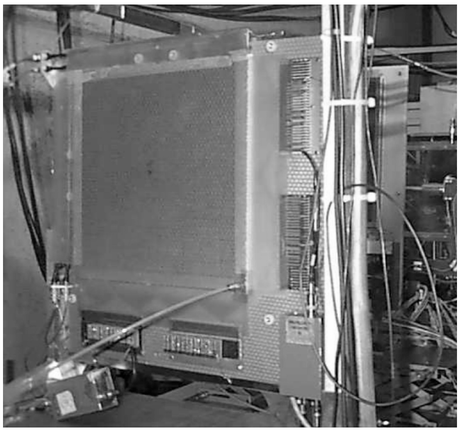

Fig. 4. A triple-GEM detector in the COMPASS experiment.

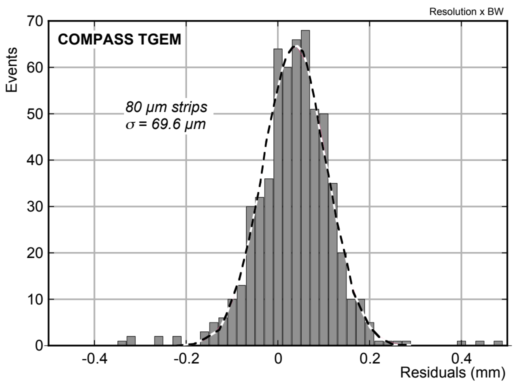

Fig. 5. Position accuracy for minimum ionizing particles.

By proper choice of the applied potentials, one can achieve full electron collection from the sensitive volume, whilst strongly reducing the positive ion re-injection in the drift volume; an ion feedback of a few percent was demonstrated by early studies [11]. This has motivated the development of GEM detectors for the end-cap read-out of high multiplicity Time Projection Chambers (TPC), where the accumulation of ions in the drift volume can cause serious distortions [12].

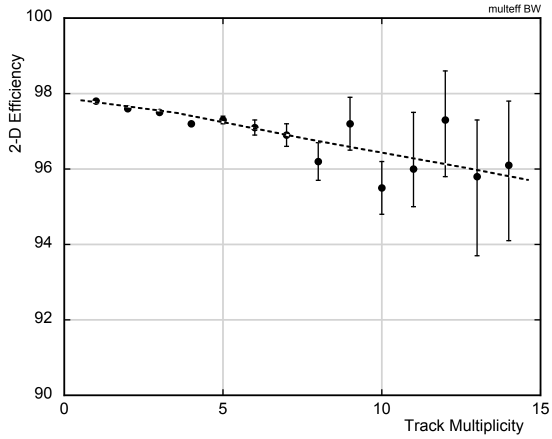

Fig. 6. Two-dimensional reconstruction efficiency as a function of track multiplicity.

Other advantages are the virtual absence of ExB distortions, the narrow cluster size and the absence of a slow ion component in the signal, largely improving the multi-track resolution, that can approach a cubic millimeter, compared to one cubic centimeter typical of conventional TPCs with MWPC readout. Several groups are investigating the technology in the framework of the TESLA detector project; as an example, Fig. 7 shows the efficiency of detection of minimum ionizing tracks measured with a small prototype GEM-TPC device, for two gas choices, and Fig. 8 provides the drift dependence of the localization accuracy [13].

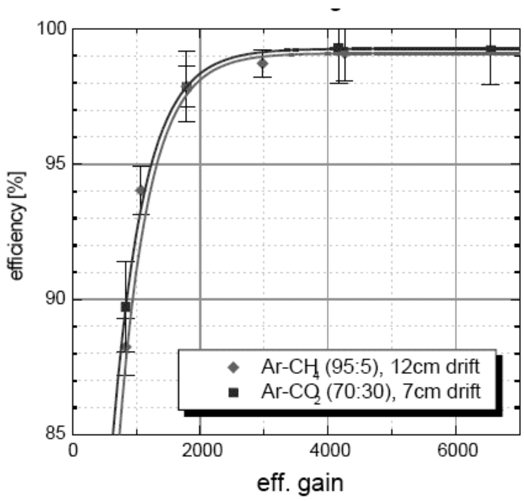

Fig. 7. Single pad row tracking efficiency as a function of gain in a prototype GEM-TPC, for two gas choices.

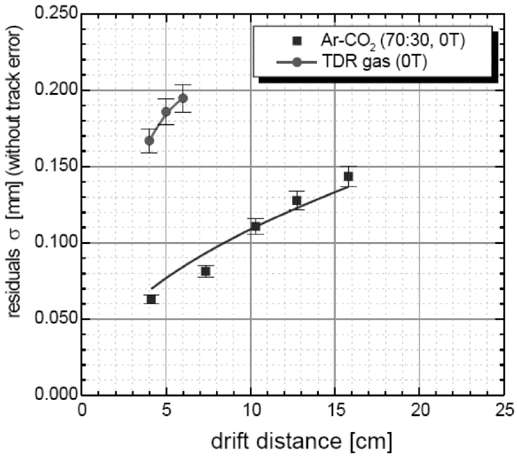

Fig. 8. Position accuracy for a single pad row in the GEM-TPC.

A pixel pattern covering all area is of course the most powerful read-out scheme for these applications, and its implementation is made possible by the freedom of geometry of the charge collecting electrodes. To preserve localization accuracy, the pixel size should not exceed half a millimeter or so, with a consequent inflation in the number of required channels. High-density pixel readout electronics, developed for detectors used in high luminosity experiments or for medical applications, can be used for GEM devices read-out.

An elegant alternative, offering performances between projective strips and pixels, has been developed under the name "hexaboard" [14]; as shown in Fig. 9, it consists in a matrix of charge collecting hexagonal pixels, interconnected on the backside in rows along three directions at 120º to each other. For each event, three independent charge profiles are recorded, providing an ambiguity-free reconstruction for most multiple events. A large hexaboard-based readout scheme, coupled to a double GEM in a TPC device, is under development for the experiment MICE [15].

Recent studies have focused on the optimization of multiple GEM structures for the efficient detection of single photoelectrons. The confinement of avalanches in the holes, with the consequent suppression of photon feedback, explains the exceptionally large gains observed operating the device in pure noble gases and their mixtures, see Fig. 10 [16]. The absence of organic quenchers, often required another structures to achieve high gains,

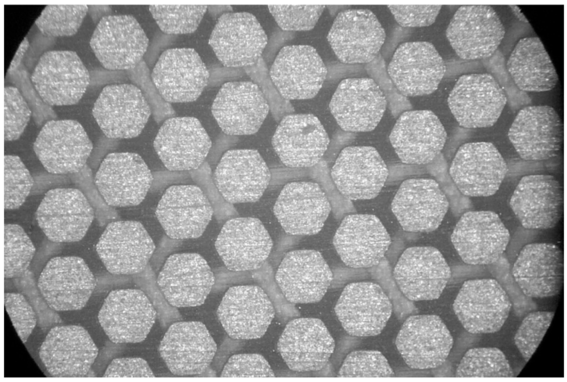

Fig. 9. The hexaboard readout; pads are about 400 µm wide.

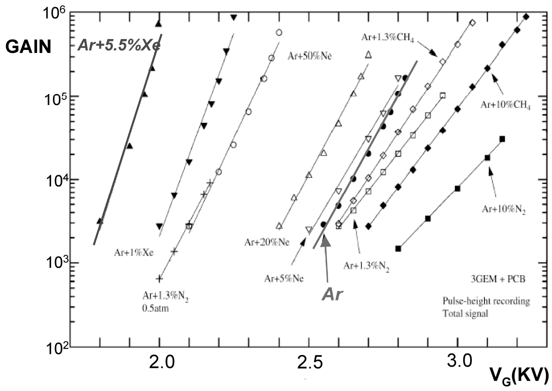

Fig. 10. Gain of a triple-GEM detector in noble gases mixtures.

should permit the use of alkali photocathode materials. The ongoing research in several laboratories may lead to the development of large area, position-sensitive gas photo-multipliers [17-19].

A very attractive approach is to use the upper GEM electrode, facing a transparent window, as reflective photocathode, followed by a transfer of the photoelectrons through the holes to another gas amplifying device [20, 21].The strong suppression of photon and ion feedback in this configuration results in easy single photon detection and extended lifetime of the detector. In view of applications of the technology to Cherenkov Ring Imaging detectors, the CERN group has studied the localization properties of a triple-GEM device having the first multiplier coated with CsI and exposed to a collimated beam of ultra-violet light. As shown in Fig. 11, a single-photon localization accuracy of 60 µm rms has been achieved, together with a linear correlation between the source position and the measured position deduced by a centre of gravity of the collected avalanche charge [22].Exploiting this scheme, a hadron-blind detector is under development for the PHENIX upgrade; electron-positron pairs emit UV photons by Cherenkov effect in a large gas radiator, and the resulting disk is detected by a CsI coated triple GEM device [23]. A mesh placed between the photocathode and the main gas volume, creating a narrow region of inverted field, blocks direct ionization and guarantees that only photons radiated by the electrons and positrons are detected.

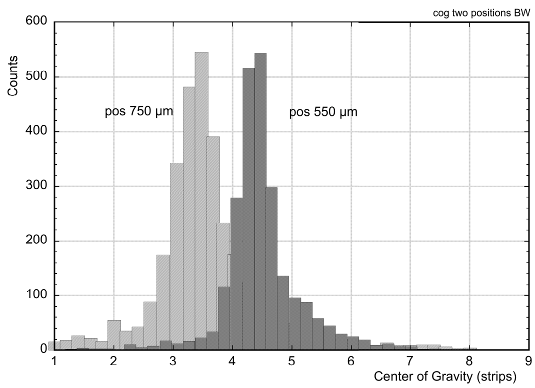

Fig. 11. Position accuracy of a CsI-GEM detector for single photons. Collimated UV source.

The performances and robustness of detectors using the GEM technology have encouraged their use in other applied fields. The excellent resolution that can be obtained recording charge on small individual pads has been exploited for the measurement of polarization of low energy X-rays, in view of applications in astrophysics [24]; photoelectron tracks, individually recorded show a clear asymmetry indicating the degree of polarization of the source. Fig. 12 shows as example the tracks of photoelectrons released in the gas by 20 keV X-ray; pixels on the readout plane are square with 100 μm sides, and the size of the squares in the plot is proportional to the collected charge [25]. For this work, the authors used an innovative readout system consisting of a matrix of thin Film Transistors (TFT) to record the charge. In view of the and commercial availability of large size TFT panels, used in flat screens, the approach seems very far reaching.

Ionization trails can be directly imaged exploiting the gas scintillation properties of the avalanches in a dedicated GEM detector, coupled to a low-noise CCD camera. Despite their obvious limitations in rates, such imaging methods are simple and very powerful; Fig. 13 gives an example of proton and triton tracks, knocked off by neutrons [26]. Integration of the light intensity along the tracks provides the differential energy loss.

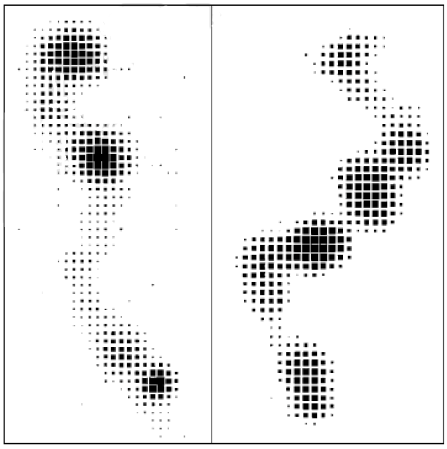

Fig. 12. Photoelectron tarcks produced by 20 keV X-rays. Pixels are 100 μm on the side.

Fig. 13. Proton and triton tracks from neutrons.

The high resolution electronic or optical imaging capability of GEM-based devices, in principle permitting to identify X-ray events from normal ionization losses, may offer a powerful way to improve TRD performances.

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