Development and applications of gas electron multiplier detectors

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Abstract

Recent developments of the Gas Electron Multiplier (GEM) are described, as well as its applications as fast, position-sensitive detector in particle physics, medicine, neutron spectrometry and astrophysics.

Keywords: Gas Electron Multiplier; GEM; Fast gas detectors; GEM applications

The Gas Electron Multiplier (GEM) [1] consists of a thin metal-clad insulating foil with a high density of holes, typically 50–100/mm² (Fig. 1). On application of a voltage between the two sides, electrons released in the upper gas volume drift into the holes, multiply and transfer to the other side where they can be collected or further amplified. Proportional gains of several thousand can be obtained in a wide range of operating gases and conditions [2]. A unique feature of the device is that the multiplication element is electrically separated from the readout plane; this offers a wide freedom in the choice of the readout pattern, which can be realized using strips or pads, all at ground potential [3]. As only the electron charge component of the avalanche is detected, the signal is very fast. Several GEM foils can be cascaded, permitting to sustain large gains even in presence of heavily ionising particles, prone to induce discharges in most counters. Fig. 2 shows for multiple GEM detectors, the total gain and the discharge probability on exposure to 6 MeV α-particles, emitted by $^{220}$Rn [4] carried with the gas. The horizontal scale is the voltage applied to each foil, progressively reduced in multiple structures for a given total gain. For the triple GEM detector, at a nominal gain around $10^4$, comfortable for detection of minimum ionising particles, the discharge probability is barely measurable. This has motivated the adoption of multi-GEM devices by several experiments operating in harsh radiation environments.

A system of 20 large size triple-GEM detectors has been built for high rate tracking in the COMPASS experiment at CERN [5]. Each chamber has a $31 \times 31$ cm$^2$ active area and two-dimensional projective readout on strips at a 400 μm pitch. Manufactured with thin frames on light honeycomb supporting plates, the detectors have an average thickness corresponding to 7% of a radiation length on the active area, to satisfy the low material budget imperatives of the experiment. The picture in Fig. 3 shows a completed detector before installation in the beam. On each trigger, charge is recorded on $\sim$700 readout strips at

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400 μm pitch in two orthogonal directions. The good correlation between the two charge measurements (Fig. 4) offers a powerful tool to find the correct pairs in case of multiple tracks.

Another feature of the detector is the possibility to remotely control the gain in a region corresponding to the size of the primary beam, achieved by patterning the GEM electrodes with a central disk, 5 cm in diameter, independently powered. Applying a potential 150 V lower than nominal, the gain is locally reduced preventing detection in the central area. Full efficiency can be restored remotely over the full area for calibration and alignment.

The two-dimensional localization characteristics of the detector can be exploited for medical imaging with good position accuracy over large areas. In the detection of neutral radiation, a fast signal can be extracted on the lower GEM electrode for triggering and energy discrimination purposes. The X-ray absorption radiography of a small mammal, shown in Fig. 5, has been recorded with a small size two-dimensional GEM detector [6].
By proper choice of the applied potentials, one can achieve full electron collection from the sensitive volume, whilst strongly reducing the positive ion reinjection in the drift volume; an ion feedback of a few percent was demonstrated by early studies [7]. This has motivated the development of the technology for the end-cap read-out of Time Projection Chambers (TPC), where at high rates the accumulation of ions in the drift volume can cause serious problems. 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. Several groups are investigating the technology in the framework of the TESLA detector project [8].

The excellent performances and robustness of detectors based on the GEM technology have encouraged many groups to envisage 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 [9]; photoelectron tracks, individually recorded, show a clear asymmetry indicating the degree of polarization of the source.

Using a similar detector with very fast recording of charge on small pads, the authors of Ref. [10] have recorded the X-ray activity around at the ENEA Tokamak fusion machine in Frascati, and more recently at the Princeton Plasma Physics Laboratory. Fig. 6 shows one frame of energy-discriminated plasma emission distribution recorded at a sampling rate of 10 kHz [11]. The measurement has permitted for the first time to confirm a rotation of the plasma within the observation time, theoretically foreseen but not experimentally verified so far.

A very interesting direction of research concerns the use of multi-GEM devices for the detection and localization of single electrons emitted by an internal photo-cathode. It was found some time ago that the large ion- and photon-feedback suppression of GEM structures allows to attain very large gains in pure noble gases and their mixtures, considered friendly for conventional photo-cathodes [12]. Recent works have confirmed this observation, and demonstrated that large gain and high quantum efficiency can be obtained with triple GEM devices having a CsI photo-cathode [13]. Particularly suitable for efficient photoelectron extraction are CH₄ and CF₄ fillings, as shown in Fig. 7 providing the fraction of electron current obtained in the gas as compared to vacuum, for constant illumination [14]. Recently, the same authors have succeeded making a small size sealed GEM detector, first attempt in the direction of manufacturing a gas device capable of detecting and localizing photons in the visible range [15]. Detailed studies on the medium-term survivability of photo-cathodes are on the way.

Electronic recording of the amplified charge is not the only method of readout for GEM devices. Exploiting the scintillation light emitted in the avalanches, the authors of Ref. [16] have demonstrated the excellent imaging capability of the detector; coupled to a low-noise CCD camera, the
device has been used to record various types of events, from X-ray absorption radiography to neutron conversions. Fig. 8 shows tracks generated by protons–triton produced by neutrons in $^3$He [17].

High-pressure operation of GEM detectors is needed in applications requiring high conversion efficiency for neutral radiation, hard X-rays or neutrons. Early measurements, however, found that the maximum attainable gain in most gases decreases rapidly with the increase in pressure [18]. This might be a consequence of the use of a GEM geometry optimized for operation at atmospheric pressures, and further work in this direction is needed. Recently, however, it has been found that the trend is different in light noble gases; for helium, in particular, high gains can be obtained up to 15 atm (Fig. 9), a very promising result in view of the use for neutron detection [19].

References