The Gas Electron Multiplier, a Hall-B Region-1 Tracking Upgrade

Howard Fenker, Jefferson Lab

Abstract

The Gas Electron Multiplier (GEM) is a novel device which provides gas avalanche multiplication without a reliance on precision mechanical structures or microfabricated surfaces. It is not difficult to imagine using it to build a drift chamber, a cathode strip chamber, or a combination of the two in geometries which would be challenging for more conventional wire chamber techniques. This report provides a description of the device, a draft implementation of a GEM for a Region-1 tracking upgrade in CLAS, and a summary of the properties of such a system.

Description and Principle of Operation

Over the last eighteen months, Sauli and co-workers[1,2,3] have developed and demonstrated a new type of gas avalanche multiplication structure with very promising features. The Gas Electron Multiplier (GEM), shown in Fig. 1, is composed of an insulating film with conductive surfaces, with the entire thickness perforated by tiny holes. By applying an appropriate voltage between the surfaces, an electric field is established through the holes with sufficient magnitude to cause avalanche multiplication in typical wire-chamber gas mixtures. A *drift electrode* some several millimeters away from one surface of the GEM can be biased in such a way that electrons produced by ionizing radiation in this drift region have a high probability of drifting into a hole and initiating an avalanche. A large fraction of the electrons resulting from the avalanche then follow field lines out of the holes and move towards the *cathode plane,* thus generating a detectable signal on this electrode. The cathode plane can be formed of electrodes patterned in whatever way is appropriate for the particular application. Pixels, strips, or a continuous resistive medium can form the cathode or *readout plane*, thus allowing simple hodoscopic readout (as in a proportional wire chamber), or charge division readout for high precision position measurements. Measurement of the drift time, in combination with the hit position on the readout plane, can yield true three-dimensional measurement of the space point where primary ionization occurred. This concept is presented in Fig. 2.

It is worth stressing that the GEM and the associated drift and readout electrodes need not be constrained to be flat. Cylindrical surfaces or any similar shapes with curvature along only one axis are straightforward to fabricate. More complicated shapes, such as spherical surfaces, could likely be developed with some extra effort in the fabrication process.

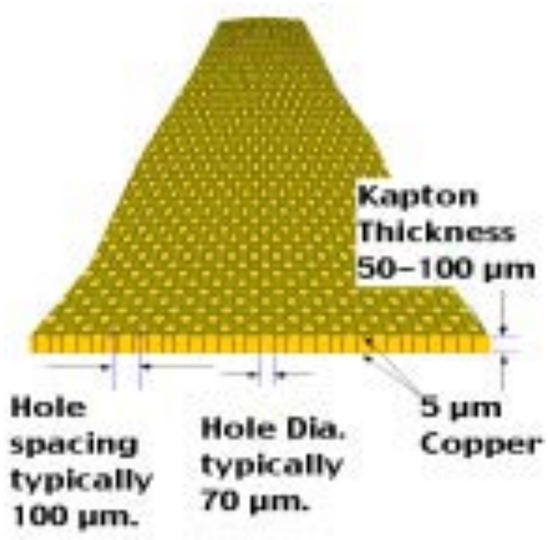

Figure 1. Schematic of a GEM Foil.

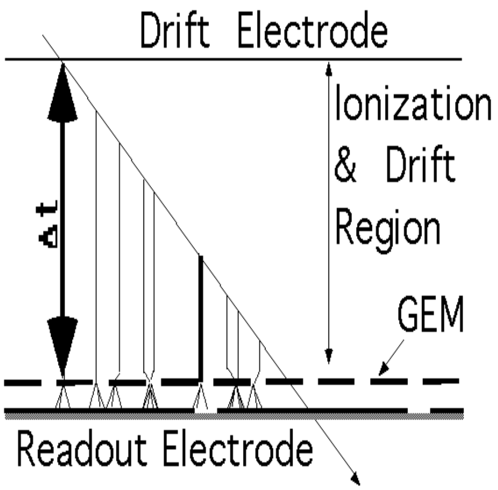

Figure 2. Cross Section of a GEM-Based Detector, showing electron trajectories.

Characteristics of the GEM in Operation

In initial tests GEM structures were placed just above conventional PWC structures or microstrip gas chamber planes. This allowed study of the GEM gain and electron transparency even at low GEM gains. More recently[2] GEMs have been operated at higher gains so that bare copper electrodes could be used for readout (the so-called *ionization mode*). This is made possible by running the GEM with effective gain (Amplification • Electron Efficiency) as high as about 20,000 in Ar-DME. Gains approaching 10,000 have been demonstrated in Ar-CO_2. The rise time of signals in this case is the drift time of electrons across the last gap (30ns). In combination with a Micro-Strip Gas Chamber (MSGC), time and position resolutions of 5ns and 40 µm, respectively, have been achieved.

GEMs have been demonstrated to provide a stable gain at particle rates as high as $2x10^6$ Hz/mm^2 when operated at a gain of about 90. Tests at a gain of 1000 have been successful[4] to at least $2x10^5$ Hz/mm^2. Radiation hardness studies using a high flux of photons shows an initial 5% drop followed by stable gain up to integrated signal currents at least as high as about 750 milli-Coulombs per cm^2 (15 mC/cm per strip using a 200 µm pitch MSGC as the readout electrode).

An important benefit of using a GEM amplifier for a cathode readout chamber is that the sensing electrode is not associated with the high field amplification region. This means that in case of a spark in the high field region there is no discharge current through the sensitive readout electronics. GEMs have been shown to survive repeated sparking with only localized damage to the GEM itself. The bulk of the GEM continues to function as it did before the breakdown.

Application to Hall-B Region-1 Tracking

A possible detector configuration making use of a GEM for Hall-B Region-1 tracking is shown in Fig. 3. Since the GEM and the readout electrodes can be formed on a non-planar surface, the device can be formed of hexagonal segments with curved surfaces to fit within the inner region of CLAS. Either the inner or outer surfaces or both can be used as the readout electrodes. The conductors can be formed as stripes or pads to provide the most natural measurement coordinates for the system. For example both theta and phi coordinates may be readout using charge interpolation across neighboring groups of strips running in orthogonal directions. In this design, one set of stripes may be wider than the other in order to improve the measurement accuracy in that coordinate. This is not necessary, but demonstrates a feature which is available.

Because there are no wires to be held under tension there is no need for relatively massive mechanical supports. A GEM detector module could be fabricated using a thin carbon-epoxy composite material to provide the necessary shape and precision. Readout electronics, shown in Fig. 3 as being in blocks on the outside of the detector unit, could be lumped to coincide with the shadows of the CLAS magnet coils, thus minimizing the scattering of particles passing on to the outer tracking regions.

In Table 1 is a draft list of materials contributing to multiple scattering in a two-GEM detector with readout on both surfaces. Some of the material thicknesses shown are probably larger than necessary, so consider this a worst case estimate of multiple scattering. In particular, note that the mass of the electronics is very rough, and is spread uniformly across the surface of the detector. By putting some effort into reducing the electronics mass, and especially locating it and the cables in the magnet’s shadow, multiple scattering in the detector package can probably be made to be competitive with the existing Region-1 drift chambers.

Track measurement precision of this detector is dependent upon the readout scheme chosen. If simple hit/no-hit readout is used, the position resolution is best for tracks normal to the detector and is equal to the strip pitch divided by $\sqrt{12}$. A significant improvement, easily below 100 µm for normal tracks[5], is obtained by measuring the charge distribution across three neighboring cathode strips nearest the hit position. Finally, to attack the problem of non-normal tracks, one might be able to use the

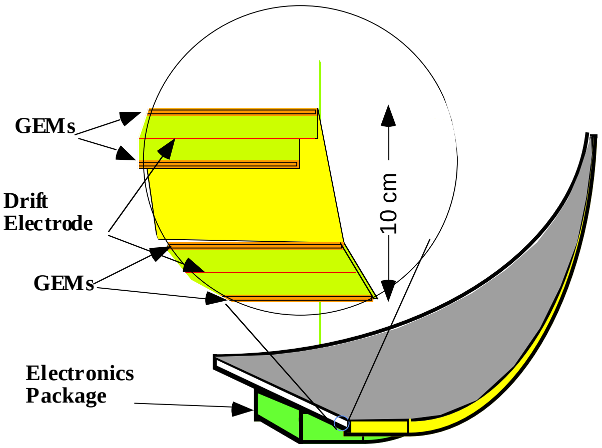

Fig. 3. A detector concept for CLAS with four GEMs to provide four measurements on a track.

Double GEM	material	µm	%Xo
C Fiber Shell	C-Epoxy	800	0.28
Electronics	Poly	4000	0.94
PC Board	G-10	2000	1.03
PC Cladding	Cu	5	0.03
Gas	ArCO2	46000	0.04
GEM Cu	Cu	10	0.07
GEM Kapton	Mylar	140	0.05
Drift Electrode	Cu	10	0.07
Drift Support	Mylar	25	0.01
Total			2.52

Table 1. Double GEM Materials (note:two Double GEMs are shown in Fig. 3)

electron drift time information from individual ionization clusters formed as particles pass through the ionization/drift region (see Fig. 2). This needs further study, and combining drift time with charge division readout may not be simple.

REFERENCES

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[5] H. Fenker, et al., Nucl. Instr. Meth. A 367 (1995) 285-289.