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Tracking system based on GEM chambers

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Summary. — GEM chambers are becoming one of the best technology for charge particle tracking fulfilling the challenging requirements of modern experiment at intermediate and high energy, including Parity Violation Electron Scattering experiments. GEM tracker combines high spatial resolution, large active area and pretty good tolerance to high particle flux, at reasonable cost. GEM technology is shortly presented and a specific application for the high luminosity experiments in Hall A at JLab is discussed. Some alternatives to the GEM are also addressed.

PACS 29.40.Cs – Gas-filled counters.
PACS 29.40.Gx – Tracking and position-sensitive detectors.

1. – Introduction

Several factors contribute to the optimal choice of the technology of a charged particle tracking system; some of the most relevant parameters are presented in table I. Silicon trackers and Micro Pattern Gaseous Detector (MPGD) are by no mean the elected choices in experiments running at large luminosity (such as in parity violation electron scattering at low energies); however, unless extreme spatial resolution is required, the MPGD's largely prevail in terms of lower costs.

Among the MPGD's [1], Gas Electron Multiplier (GEM) [2] and Micro-Mesh Gas (MicroMeGas) [3] chambers currently attract the large attention of the developers and users of experimental equipments. The two technologies present similar features and the choice between them is sometime a question of scientific background and experience; technical differences can be found in spark rate (generally higher in MicroMeGas), higher flexibility in GEM readout geometry, simpler high voltage distribution but more demanding mechanical accuracy in MicroMeGas.

TABLE I. – *Relevant parameters and achievable values for common tracking system technologies; cost estimation does not include electronics, manpower and high voltage system. MWDC = Multi Wire Drift Chamber, MPGD = Micro Pattern Gaseous Detector, SiD = Silicon Detector, RPC = Resistive Plate Chamber.*

		Tracking Technology				
Parameter	Unit	MWDC	MPGD	SiD	Straw	RPC
Rate Capability	MHz/cm^2	0.02	> 50	20	5	0.001
Spatial Resolution	μm	50	40	< 10	100	< 10
Time resolution	ns	1	< 5	< 10	0.4	0.1-1
Cost (main material)	€/cm^2	0.2	1-5	> 20	0.2	0.5
Material Budget (X/X_0)	%	< 0.5	0.6	0.3	0.2	1.5

In the next two sections the status of the GEM technology is described in some details, with a working example; in the last section recent interesting developments of the MicroMeGas are presented.

2. – Status of the GEM technology

A typical GEM chamber generally consists of 3 cascaded GEM foils sandwiched between the cathode foil (drift) and the anode plane (readout) as schematically shown in fig. 1. The GEM foil is made of a 50 μm Kapton® substrate with few μm copper layers on both sides and periodic holes of 70 μm diameter and 140 μm pitch between their centers. A voltage difference of $\sim$ 350–400 V is applied to the 2 sides of the foil creating a strong electrostatic field in the holes.

A charge particle (see fig. 1) traveling across the chamber, ionizes the gas that fill the chamber; the ionized electrons drift toward the readout plane, and passing into the GEM holes, they are multiplied with a typical gain of 20 on each GEM foil. Electrons that pass through the 3 GEMs, produce, on average, an avalanche with about 8000 electrons; this avalanche is collected on the readout plane, producing a detectable electronics signal.

GEM can sustain large hit rate, without gain degradation, up to 50 MHz/cm^2, at least, compatible with the requirements of the demanding PVDIS-Solid experiment at JLab [4]. Moreover GEM aging, as other gas detectors, depends on gas composition and flux rate. Excellent stability has been measured above 1 C/cm^2 (*e.g.*, in [5]) of accumulated charge per unit area.

A recent major development, prompted by the requirement of large active area (an important requirement in many modern experiments), is the new single mask production photo-lithographic method [6], which overtakes the intrinsic limitation (in size) of the original double mask alignment procedure; this progress permits the realization of GEM foils of virtually any size (currently up to about 100×40 cm^2). The latest single mask large foil production has performances similar to the double mask foils: gain [7] and leakage current [8] are rather comparable between the two methods, and further improvement of the single mask is expected in the coming months; costs of the single mask method is lower and production is faster than the original double mask.

New 2-dimensional readout pattern has been developed for the KLOE cylindrical GEM [7], with interleaved x strips (vertical) and u pads (at 40° degree) with pass-through vias, the latter being connected through strips on the opposite side of the read-out foil; large area are achieved with pitch of 650 μm. For smaller pitch, the original

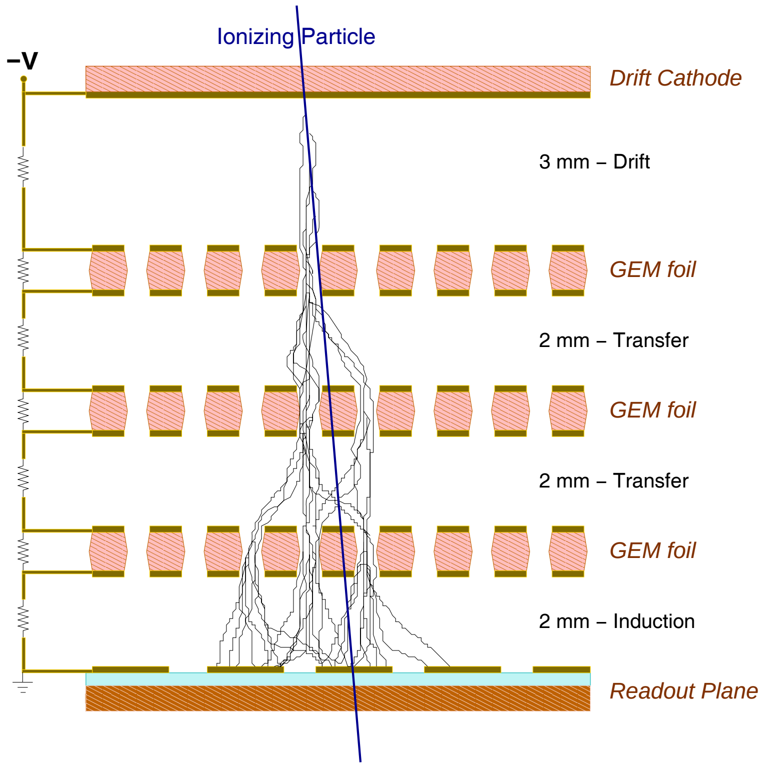


Fig. 1. – Schematic cross section of a 3 cascaded GEM chamber; distance between foils is typically in the range of few mm; values depend on the specific application.

2 layers 2-dimensional COMPASS solution [9] is still more affordable in terms of price and production quality([1]).

Several front-end ASICS are under development for the readout of GEM and similar detectors. The APV25 [10] originally developed for the CMS Silicon tracker still represents one of the most consolidated, analog readout solution, with high integration (128 channel/chip) and radiation hardness characteristics. On the other hand, the VFAT chip [11] is a sort of digital alternative to the APV25, with the same channel integration. Evolution of some existing chips is underway: important progress is expected in the short terms (3–5 years) for a new generation, MPGD dedicated, architecture (Saltro/GdSP [12]) that hosts ADC and rather complex digital signal processing features as well as a fast optical link.

3. – A practical example, the GEM Tracker for the JLab HallA equipment in the 12 GeV era

A new tracking system (the SBS front tracker [13], also part of the RD51 activities) largely based on GEM chambers is under development for high luminosity experiments

([1]) The COMPASS readout consists of two strip layers on 50 μm Kapton® substrate; strip pitch is 0.40 mm on both layers; the lower layer is made of 0.34 wide strips while the upper layer has strips of 0.080 mm width.

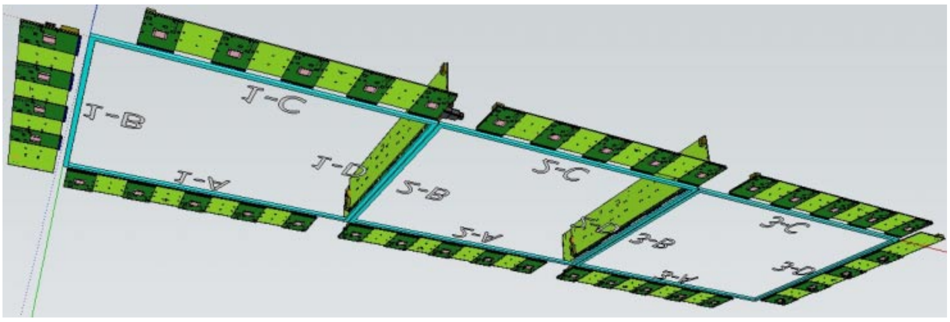


Fig. 2. – Electronics layout of a GEM chamber of the SBS tracker; light green represents the backplane; dark green the front-end cards, with the small APV25 in light pink.

that are planned to take data in Hall A at JLab after the 12 GeV CEBAF upgrade. The tracker is designed to be able to operate in high background environment (up to $\sim 250\,\mathrm{MHz/cm^2}$ photon flux and $\sim 0.2\,\mathrm{MHz/cm^2}$ charge particle flux); it is expected to provide a transverse active area of $40 \times 150\,\mathrm{cm^2}$, with a single hit resolution of $\sim 70\,\mu\mathrm{m}$.

The tracker will be made of 6 chambers, each chamber will be composed of 3 independent GEM modules of $40 \times 50\,\mathrm{cm^2}$ active area. The single module, has 3 GEM foils and 2-dimensional x/y readout ([9], mentioned above) with a strip pitch of 0.4 mm. The total radiation length X/X_0 is 0.54%. In order to minimize the dead area, the width of the mechanical frames, where the foils are glued, is only 8 mm thick.

The size of the module has been chosen taking into account the maximum GEM foil size available in 2009 (when the single mask method were not consolidated enough) and the maximum tolerable strip length. In fact, the length of the strip impacts on the electronic noise(^{2}) and on the rate of pile up on a single event (due to the high background). At a first approximation, the latter may compromise the tracking reconstruction while the former degrade the spatial resolution.

The total 40500 strips of the tracker will be readout by the APV25 chips located on small front-end cards connected to the readout plane of the GEM module by flexible terminals plugged into tiny ZIF connectors. The cards are mechanically supported by 4 backplanes which are distributed along the sides of the module on the same plane or at 90 degree, as shown by the 3D drawing of fig. 2, to minimize the dead area between adjacent modules.

Up to 16 APV25 front end cards are configured, controlled and readout by a specifically designed VME64x module called Multi Purpose Digitizer (MPD), managed by a powerful FPGA supported by 128 MByte SDRAM and 12 bits fast ADC. In addition to the VME64x interface (backward compatible), optical link, Ethernet and USB ports are also available.

The first full scale prototype of the base module, shown in fig. 3, has been assembled in October 2010, equipped with the dedicated APV25 readout electronics and firstly tested at the DESY test beam, with partial support of the EUDET European program.

(^{2}) The noise of the strip depends, to a large extend, to the capacitance C_s between a single strip and the strips of the other layer (which can be considered a single uniform plane). C_s is proportional to the length of the strip; for 50 cm long, 80 μm wide strip, $C_s \sim 30\,\mathrm{pF}$.

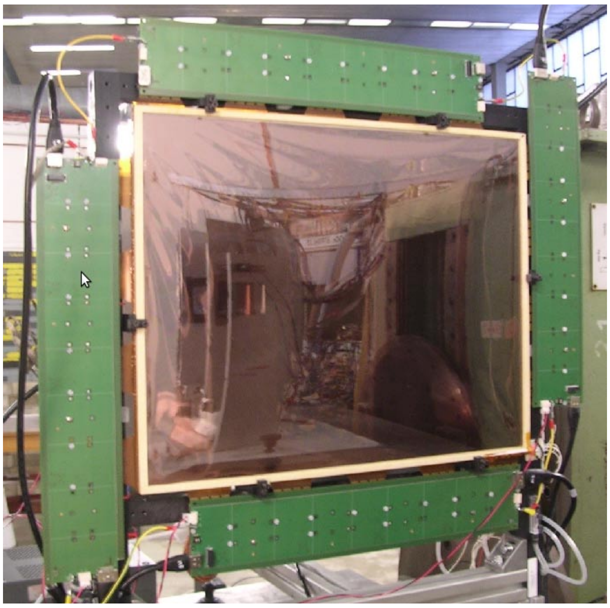
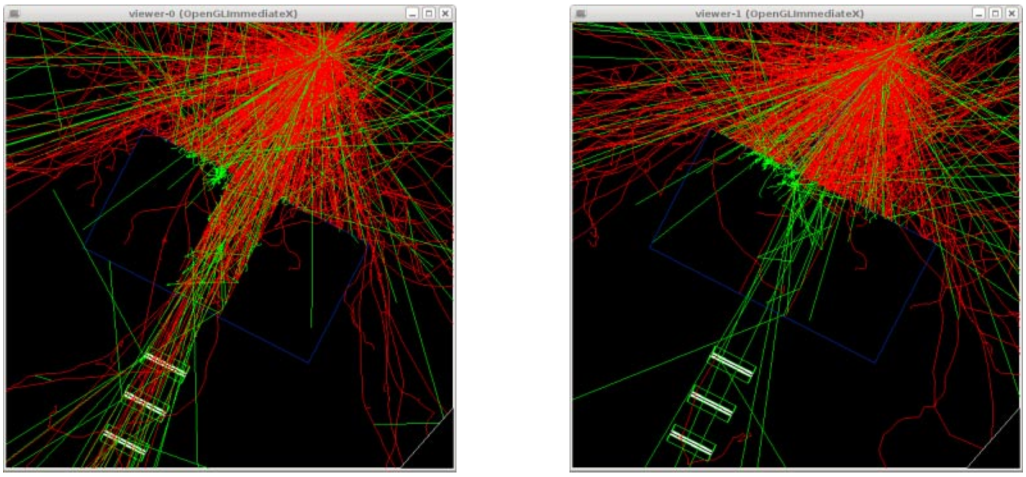


Fig. 3. – First GEM module prototype, from the drift side (protective mylar foil visible). The 18 front-end cards are behind the 4 rectangular backplanes that sit along the 4 sides of the module.

The expected high background hit rate represents a challenge for the track reconstruction efficiency; a GEANT4 based Montecarlo, combined with a realistic GEM digitization algorithm has been developed to study the tracking performances and evaluate different tracking algorithms.



$B = 0$ $B = 1.7$ Tm

Fig. 4. – Example of single GEM Montecarlo event generated by 11 GeV electrons on 40 cm long liquid hydrogen target; GEM are after the SBS dipole magnet. Left: the magnetic field is off. Right: the magnetic field integral is 1.7 Tm.

A typical example of the high background flux of particles investing the GEM chambers is shown in fig. 4 for a single event (with the SBS dipole magnetic field switched on and off). A tree search algorithm has been applied to these simulated data obtaining a tracking efficiency of 85–90% (depending on quality cuts) at the full background conditions quoted above.

4. – GEM alternatives/competitors

MicroMeGas [3] is the best alternative candidate to the GEM, as tracker. Both technologies have started in the second half of the '90; they make intensive use of the most advanced Micro Pattern techniques.

One of the major issue of the MicroMeGas application to high luminosity experiment is the higher probability of discharge (compared to GEM).

In the latest years different approaches have been studied to suppress the spark effects and rates in MicroMeGas. Two of them appear very promising. The first is the use of resistive electrodes which on one side reduces the energy of the sparks and on the other side permits much more flexibility in the design of the readout geometry (*e.g.* use of 2- or 3-dimensional coordinates). The other approach is the use of one (or more) GEM foil before the mesh to provide a first gain and then share the total gain with the amplification section of the MicroMeGas, thus permitting smaller electrostatic field in the mesh-readout $\sim 100\,\mu$m gap. The preliminary results [14] show a clean signal, with excellent spatial resolutions and negligible cross talk. Development on these directions are in progress.

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