

GEM detectors activity at the Laboratori Nazionali di Frascati of INFN

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After ten years of development for high energy physics experiments, GEM detectors demonstrated great robustness, long-term stability of operation, remarkable flexibility and capability to accomplish different tasks in harsh environments.

This technology has entered the field of triggering devices with its application in the innermost region of the upstream Muon station of the LHCb experiment. Such application has required for an R&D on fast and high yield CF₄-based gas mixtures, performed by our group in Frascati in collaboration with the INFN of Cagliari, leading to an improvement in the time resolution of a factor of three (down to 3 ns r.m.s.).

Exploiting our established experience, we are starting an R&D on large-size GEM detectors. In the framework of the KLOE experiment upgrade, we are developing a completely new and competitive category of ultra-light, full sensitive vertex detector for high energy experiments, based on a fully cylindrical GEM detector. Moreover several GEM detectors have been realized for photon beam diagnostic and more recently a luminometer is under construction for accelerator machine studies.

Keywords: GEM, CGEM, tracking

1. Overview of the main activities

The first application of detectors based on Gas Electron Multiplier (GEM) technology [1] is the COMPASS experiment [2], where they operate as tracking device exploiting the excellent spatial resolution and high rate capability of this kind of detector, but little interest has been devoted to the time performance.

An intense R&D on this aspect has been performed by our group in collab-

oration with the INFN of Cagliari ^a, during the development of a detector for the harsh region around the beam pipe of the upstream muon station of LHCb experiment.

Section 2 describes the study of new fast CF₄-based gas mixtures that allowed us to achieve such result.

The LHCb experience has been a precious background for new R&D on this technology: large size GEM detector can find important applications in the upgrade of LHCb apparatus as well as in other experiments.

In particular, in the framework of the KLOE experiment upgrade, we are developing a completely new and competitive category of ultra-light, full sensitive vertex detector, based on a fully cylindrical GEM detector.

This is reported in section 3.

Finally, minor activities include the study of GEM detectors as imaging devices for medical application and beam diagnostic. A luminometer based on GEM technology is under construction. This will be installed in DAFNE accelerator in Frascati for machine studies during the incoming upgrade, where the *crab waist* beam crossing technique can open the way for high luminosity kaon and beauty factories.

2. LHCb GEM detectors

LHCb GEM detectors instrument the high-irradiated region around the beam pipe of the upstream muon station [3,4].

Two layers of triple-GEM detector with pad readout are foreseen in this region (12 stations, 24 chambers), with the digital information coming from corresponding pads in each layer logical OR-ed through the front-end electronics. The total area is less than 1 m², but about the 20% of the total triggered muon will come from this device. In fact the response of this detector contribute in the first level trigger decision of the experiment, so a critical issue is a high efficiency in bunch crossing identification.

The requirements of the double layer are a rate capability better than 0.5 MHz/cm², an efficiency in 20ns time window greater than 96%, a cluster size lower than 1.2 pads per crossing particle, and the capability of sustain 10 year of operation in LHCb environment without damage or loss of performance.

To fulfill the demanding time resolution that comes from the 20ns time window requirement, a specific study of new fast (high drift velocity, high ionization yield) gas mixtures based on CF₄ has been performed with small

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size prototypes [5]. The choice of the Ar/CO₂/CF₄ (45/15/40) gas mixture, together with an optimization of the geometry of the final detector, allowed us to achieve time resolution better than 3ns r.m.s. (Fig. 1), to be compared to the 10ns r.m.s. time resolution of standard Ar/CO₂ gas mixtures, and to fulfill all the experiment requirements.

Accurate aging and robustness measurements were successfully performed with a high intensity X-ray beam in our laboratory and with the high rate hadronic beam (low momenta pions with a proton contamination) of the Paul Scherrer Institute (PSI) in Zurich. Moreover a global irradiation test of the final LHCb chambers has been performed at the irradiation facility of the ENEA-Casaccia with a ⁶⁰Co source, in order to test compatibility of the gas mixture with the construction materials. Performance of irradiated chambers, measured afterwards on a beam test at CERN, shows no significant losses after an integrated charge of about 2.2 C/cm², equivalent to about 12 years of operation at LHCb environment [6].

The production and the quality controls of the 24 chambers were completed at the end of 2006 and the installation is foreseen by the end of this year [7]. In Fig. 2 the efficiency of one of the twelve stations is shown, as measured, with the official LHCb DAQ electronics, on a test on SPS beam configured with a 25ns bunch crossing time structure, to simulate LHCb running condition.

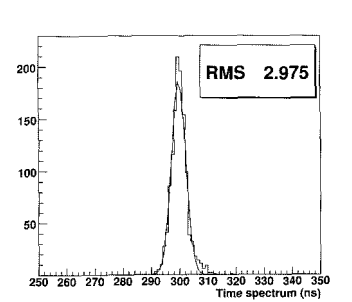


Fig. 1. The best time resolution obtained with LHCb GEM detectors

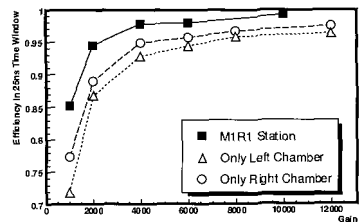


Fig. 2. Efficiency as a function of gain, measured in the last test on SPS beam

3. Cylindrical GEM detectors for KLOE upgrade

In the framework of the upgrade of the KLOE experiment in Frascati we are developing a novel idea for an ultra-light cylindrical triple-GEM (C-GEM)

detector [8], for vertex and inner tracking purposes.

The proposed detector will play a crucial role in the study of the K_S rare decays and the measurement of the neutral kaon interferometry.

The main requirements are a moderate detector spatial resolutions, $\sigma_{r\phi} \sim 200\mu\text{m}$ and $\sigma_z \sim 500\mu\text{m}$, but a very low material budget inside the active area, 1.5% of X_0 for the whole sub-detector.

The inner tracker will be composed by five C-GEM layers. Each C-GEM is realized inserting one into the other the required five cylindrical structures made of thin ($50\div 100\mu\text{m}$) polyimide foils: the cathode, the three GEMs and the anode readout.

The first small-size prototype (~ 90 mm diameter and ~ 250 mm active length) has been built using LHCb GEM foils and a $50\mu\text{m}$ thick Kapton foil, with a $5\mu\text{m}$ thick copper deposition, as anode and cathode electrodes. Such cylindrical electrodes are obtained gluing, inside a vacuum bag, the polyimide circuits rolled up on machined PTFE cylinders that act as moulds. Then cylindrical electrodes are inserted one into the other and glued to fiberglass flanges, used as mechanical support. After the assembly, the C-GEM prototype has been installed in a stretching system equipped with a gauge meter allowing the monitoring and control of the applied mechanical tension.

The C-GEM prototype, operated with an $\text{Ar}/\text{CO}_2 = 70/30$ gas mixture, has been characterized with an X-ray gun (~ 6 keV) measuring the current on the anode. Neither dark current nor sparks up to a gain of 10^4 have been observed (Fig. 3), in a wide range of stretching tension, that resulted to be not a critical parameter.

The construction procedure of cylindrical GEM electrodes implies the presence of a singularity along the gluing junction line (3 mm wide), made of bare Kapton with neither copper nor holes. The effect of this singularity is to create distortions of the transfer field lines above and below the singularity itself, but without generating dead zones.

A preliminary simulation study shows (Fig. 4) that electrons, generated in the conversion gap by a track, are still efficiently driven in the multiplication holes of the GEM. The track detection efficiency for MIP, practically 100% all over the GEM foil, slightly drops to $\sim 98\%$ for the pessimistic case of tracks crossing perpendicularly in the middle of the junction line [9].

The next prototype under construction, with a strip readout and equipped with front-end electronics, will allow us to understand the effective relevance of this issue. In fact the success of the small size C-GEM has opened the way for the construction of a full scale prototype of the first layer of

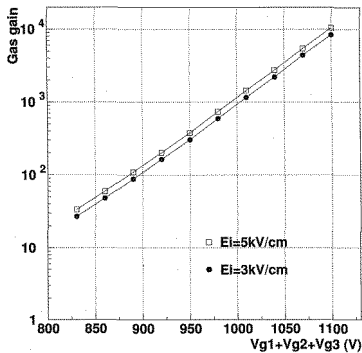


Fig. 3. Gain vs. gem voltages measured on C-GEM prototype with an X-ray tube

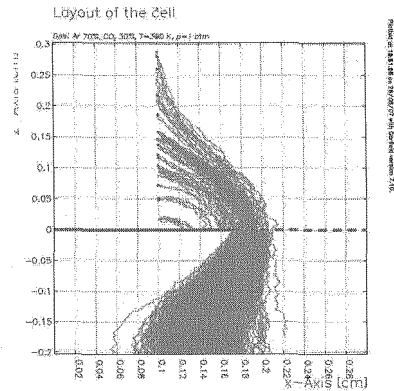


Fig. 4. Simulation studies of the gluing junction line

the inner tracker.

4. Conclusions

Laboratori Nazionali di Frascati has developed an established experience in the Gas Electron Multiplier technology, contributing with two major projects, the LHCb GEM detectors and the KLOE cylindrical GEM vertex tracker, investigating new aspects and introducing innovative applications.

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