GEM Detectors – Development, Application and Current Status of Indian Efforts

Md. Naimuddin
University of Delhi

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Outline

- The GEM Detectors – Underlying principle
- The current developments in GEM technology
- The GEMs and Experiments
- GEM detector activity in India
- Development of GEM foils and related infrastructure
- Large size GEM foils production
- Application of GEM technology for Imaging
- Summary
GEM Working Principle

GEM: A new concept for electron amplification in gas detectors

F. Sauli
CERN, CH-1211 Genève, Switzerland

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Abstract
We introduce the gas electron multiplier (GEM), a composite grid consisting of two metal layers separated by an insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable differer potential, inserted in a gas detector on the path of drifting electrons, allows to pre-amplify the charge drifting through the channels. Coupled to other devices, multiwire or microstrip chambers, it permits to obtain higher gains, or to operate in critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.

MWPC / Drift Chamber

Rate Capability Comparison for MWPC and MSGC
• High Rate Capability
• High Gas Gain
• Good Space, Time and Energy Resolution
• Good Ageing Properties
• Ion Backflow and Photon Feedback Reduction
• Large Size
• Low Cost

Triple GEM technology is the most common scheme compromise between assembly complexities and discharge issues

• Single-chamber efficiency > 98 % for mips
Technology Development Highlights

CMS high eta upgrade triple GEM

- Standard double mask method limits max. size of the detector (30x30 cm²)
- Single mask technique reduces costs and production time
- Performance comparison (max. gain, stability, rate capability..) shows no difference
Polyurethane Treatment

Non-treated THGEM suffers from: limited max. gain, response non-uniformity and time instabilities

Thick GEM

Polishing and Cleaning

COMPASS RICH photodetector upgrade prototype
New Developments

Light (0.4% $X_0$) 2D GEM detector for low energy antiproton beam monitoring

Glass GEM for sealed photon large area detector

Piggy Back – a novel method of the readout of the MPGD detectors using pixel chips; Electronics is completely separated from the detector volume
GEMs and Experiments

- **COMPASS**
  - GEM a Pixel
  - 33 x 33 cm²

- **LHCb**
  - Time resolution: 4.5 ns rms

- **BESIII**, second cyclindric GEM

- **KLOE2**: Cylindric triple GEM
  - 60 cm

- **TOTEM**
  - JLab Hall A
  - 40 x 50 cm²

- **PRad**
  - 105 cm
GEMs and Experiments

Star - Forward GEM Tracker

CMS forward muon spectrometer: tracking & trigger

CMS GEM:
Trapezoidal GEM Prototype (99 x 45-22 cm²)

Super BigBite spectrometer

R-O TPC

BoNuS

ALICE

S-PHENIX

Quad-GEM Gain Stage
Operated @ low IBF
Indian GEM Efforts

• GEM is the new age of the detector for nuclear and particle physics experiments, which was first developed at CERN.

• From that point onwards, only CERN has been the sole provider of the foils which makes it difficult to cope up with increasing demand of the GEM foils. So, there is a need for commercially available GEM foils to help fulfill the surge in demand.

• Along these lines an India based company Micropack Pvt. Ltd. acquired a license from CERN under ToT to produce GEM foils.

• It’s a long process to validate the foils delivered by these companies to claim that the GEM detectors made from these foils are compatible with high scientific standards.

• Many Indian institutions and industries are involved in the GEM R&D, application and manufacturing.

• There are groups involved in the GEM detector activity as part of scientific collaborations.

• There is an effort ongoing to utilize GEM technology for the societal applications like medical imaging, cargo imaging, etc.
Some India-CMS institutions along with Micropack started work to establish a consistent manufacturing procedure for GEM foils.

The primary focus of producing these foils to use them for the GE2/1 and ME0 upgrades of the CMS-GEM muon upgrade.

After many iterations, Micropack successfully manufactured the 10cm x 10cm, 30cm x 30cm and 60cm x 40cm GEM foils using both double and single mask technique.

The GEM foils are now commercially fabricated in the Micropack and they are becoming suppliers of GEM foils.
Test & QC of Indian GEMs

Inner Dia
49.9+-1.6 um

Outer Dia
70.01+-1.6 um

Kapton & Copper Defects

QC2 Long

Observed discharge

Leakage Current (nA)

0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

0 500 1000 1500 2000 2500 3000 3500 4000

Time (s)

450V 500V 550V 600V 0V

Kapton & Copper Defects

Number of Defects

GEM Back GEM Front

0 10 20 30 40 50 60 70 80 90 100

Type of Defects

Un-etched Under-size hole Over-size

Without-hole Excess etching Burnt
After a lot of efforts and many iteration, GEM foils of Scientific Quality that matches with the CERN foils quality were produced at Micropack Pvt. Ltd., Bengaluru in 2017. Since then quite a few orders including from CERN have been received by the Micropack Pvt. Ltd. for the supply of 10cmX10cm GEM foils.
A triple-GEM detector using Micropack produced foils was built using the same gap configuration used by CMS i.e. Drift/transfer1/transfer2/induction gap of 3mm/1mm/2mm/1mm.

- 1-D readout board with an active area of 10cm X 10cm used to pick up the signal.
- The Current measurement was performed using a pico-ammeter and pulse measurement was processed using the NIM electronics.
GEM Assembly

Cleaning of GEM Foil
Cutting of HV Pads
QC2 Measurement
Preparation of Stack
Cleaning of Drift Board
Covering Stack
Fixing Stack
Removing Dead Area
Assembly of triple GEM detector with MP foils at DU

10X10 Micropack Foil

Foil withSpacer & Initial Test

Readout Board

Making GEM Stack

Soldering foils on HV Pad

10X10 GEM Detector
Various performance measurements were carried out and compared with the detectors made up using CERN foils.
Performance of the triple GEM detector built using commercially manufactured GEM foils in India

Mohit Gola, Shivali Malhotra*, Aashaq Shah, Asar Ahmed, Ashok Kumar, Md. Naimuddin

Department of Physics & Astrophysics, University of Delhi, Delhi, India

Abstract

The Gas Electron Multiplier (GEM) detectors have been utilized for various applications due to their excellent spatial resolution, high rate capabilities and flexibility in design. The GEM detectors stand as a promising device to be used in nuclear and particle physics experiments. Many future experiments and upgrades are looking forward to use this technology leading to high demand of GEM foils. Until now, CERN is the only reliable manufacturer and distributor of GEM foils, but with technology transfer, few other industries across the globe have started manufacturing these foils employing the same photo-lithographic technique. The Micropack Pvt. Ltd. is one such industry in India which produced first few 10 cm × 10 cm GEM foils, which were then distributed to few collaborating partners for testing reliability and performance of foils before they can be accepted by the scientific community. Characterization of these foils has already been performed by studying their optical and electrical properties. Using these foils a triple GEM detector has been built and various performance characteristics have been measured. In this paper, we specifically report measurements on gain, resolution and response uniformity, by utilizing local quality control set-ups existing at University of Delhi.
The stability of gain is very important for gaseous detector any unwanted variation in gain can cause the loss of efficiency.

Two curves shows the different slopes for ramping up and down and is the clear manifestation of the hysteresis effect.

This can be due to the polarisation within the caption layer.

The stability of gain is mainly affected by two phenomena namely charging up or polarisation.

Charging up effect is due to the trapping of the charge inside the hole, and polarisation is due to the movement of the charge inside the polyamide.

To estimate the variation in gain due to the polarisation a series of measurement performed for several hours and gain amplitude w.r.t time was measured.

The MPGD technology were mainly introduced in response to the limited rate capability of MWPC.

By reducing the size of the amplifying to microscopic scale, the time necessary to evacuate the avalanche ions reduced to sub-microsecond, hence reduced the effect of space-charge and shows the stability in gain.

GEM detectors are known for the stable operation even at very high incoming flux. And three possible regions can be distinguished depending upon the incoming flux.

"Stability test performed on the triple GEM detector built using commercially manufactured GEM foils in India"; 2019 JINST 14 P08004
Large Size: 30cm x 30cm Detector

NS2 TECHNIQUE ASSEMBLY AND TESTING
Even Larger Size: M5 Foils for CMS

Drift Board

GEM foil

Outer foil

Plexi glass & Internal frames

Readout Board

Unetched copper foils
Continuous R&D

12 Strips groups
12 Strips groups
12 Strips groups

GEB 1
GEB 2
GEB 3
GEB 4
GEB 5
OH

M1 and M5
M1
M2
M3
M4

1178 mm
458.5 mm
458.5 mm
458.5 mm
458.5 mm
497 mm
497 mm
497 mm
420 mm
420 mm
420 mm

Int
Ext
The detector used under the operation was built using the Indian made GEM foils.

The detector was operated at a gain of 1000 under Ar/CO2:70/30.
Indian Institutions in collaboration with Micropack Pvt. Ltd. supplied a total of 282 readout + Drift boards to the CMS project.

- Indian collaborators assembled and supplied 16 GE1/1 chambers fully assembled and QC done locally at their institutions.
- Assembled about 10 GE1/1 chambers and standardized the full QC process at CERN.
Summary

✓ GEM detectors reach and applications are now expanding rapidly.

✓ Almost all the major HEP experiments are using or planning to use the GEM technology.

✓ Indian efforts has bore the fruit and GEM foils have successfully being produced in the country now.

✓ Large size GEM foils are being produced and tested at the moment.

✓ There are reasonably good infrastructure and expertise created in the country for GEM R&D and applications.

✓ Efforts to use GEMs to medical imaging and other societal applications are going on in the positive direction.
Thanks
GEM Assembly: Pre-assembly

Preparation of Readout Board
- M3 Tapping
- Fixing Gas Pipe Connector

Preparation of Drift Board
- Fixing Pull-outs on periphery of Drift Board
- Soldering of SMD Components

Gas Pipe Connection
- Soldering of HV Pins

Fixing Brass Inserts in Flanges
- Cleaning of HV Circuit