Characteristic simulations of stack of four Gas Electron Multipliers (GEMs)

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Advanced Detectors for Nuclear, High Energy and Astroparticle Physics
Bose Institute, Kolkata, India
Outline

• GEM detector and their application
• Garfield++ Simulations
• TUNING DETECTOR
  – Fixing gain and tuning various fields
  – Gains, Transparency, and Ion backflow
• DETECTOR CHARACTERIZATION
  – Induced signals and time resolution
  – Position and energy resolutions
Main objective: Retain physics performance in high rate operation
- continuous read-out of Pb-Pb events at 50 kHz collision rate
- Operation of MWPC without gating grid would lead to massive space-charge distortions due to back-drifting ions
- Instead: Continuous read-out with micro-pattern gaseous detectors
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail

IOP Looking for:
- GEM behavior with gas flow rate
- Long term stability

GEM in large scale experiments
- STAR  forward tracking
- ALICE  TPC readout
- CBM  muon tracker

Standard pitch four layer GEM in IOP Lab

GEM

Standard GEM foil

Table 2

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Primary Electron Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>76.8/74.7</td>
</tr>
<tr>
<td>100</td>
<td>69.6/69.8</td>
</tr>
<tr>
<td>200</td>
<td>62.8/62.7</td>
</tr>
</tbody>
</table>

Fig. 7. Distribution of secondary electron production coordinate (G1).
Simulation Framework

Garfield++

Magboltz: transport properties of electrons in gas mixtures
Heed: ionization pattern produced along the track

webpage http://cern.ch/garfieldpp
Advantage: ROOT framework

ANSYS code: external field solver
Defining: geometry, boundary conditions, initial meshing
--> Produce field maps

loading the mesh (ELIST.lis, NLIST.lis),
the list of nodal solutions (PRNSOL.lis),
and the material properties (MPLIST.lis);

Figure 1.1. Overview of the main classes in Garfield++ and their interplay.
For 4-GEM fabricated in IOP-lab

- Simulation study for the detector
- Tuning fields for proper operation region
Simulations in Garfield++

**Intrinsic gain** = $n/n_1$

**Effective gain** = $n_2/n_1$

**Transparency** = fraction of $n_1$ entering in avalanche zone

**Ion Backflow** = fraction of ions in entering the drift region

**Energy/Position Resolution**

**Induced signal** shapes

Avalanche of electrons in GEM Holes

-- single electron thrown at (0,0,0.7)

-- 4 Layers

-- Ar:CO$_2$ = 70:30
Avalanche And Absorption in GEM

with time

For a particular gas mixture the absorption much depend on field configuration
with z position

- All four layers behaves similar way
- Avalanche grows up with increasing gem layers
Gains for Detector

<table>
<thead>
<tr>
<th>Voltage applied</th>
<th>$\Delta V_{\text{GEM-I}}$</th>
<th>$\Delta V_{\text{GEM-II}}$</th>
<th>$\Delta V_{\text{GEM-III}}$</th>
<th>$\Delta V_{\text{GEM-IV}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>229</td>
<td>239</td>
<td>238</td>
<td>245</td>
</tr>
<tr>
<td>3500</td>
<td>267</td>
<td>279</td>
<td>278</td>
<td>286</td>
</tr>
<tr>
<td>4000</td>
<td>306</td>
<td>319</td>
<td>318</td>
<td>327</td>
</tr>
<tr>
<td>4200</td>
<td>321</td>
<td>334</td>
<td>333</td>
<td>343</td>
</tr>
<tr>
<td>4400</td>
<td>336</td>
<td>350</td>
<td>349</td>
<td>359</td>
</tr>
<tr>
<td>4600</td>
<td>351</td>
<td>366</td>
<td>365</td>
<td>376</td>
</tr>
<tr>
<td>4800</td>
<td>367</td>
<td>382</td>
<td>381</td>
<td>392</td>
</tr>
<tr>
<td>5000</td>
<td>382</td>
<td>398</td>
<td>397</td>
<td>408</td>
</tr>
</tbody>
</table>

We would play with fields:
Induction, Drift and Transfer fields at effective gains ~1800

Fields:
- Drift = 2.08 kV/cm
- Transfer12 = 2.90 kV/cm
- Transfer12 = 2.87 kV/cm
- Transfer12 = 3.12 kV/cm
- Induction = 3.03 kV/cm

deteriorate effective gain
Field Adjustment

- Induction field: high → more transport to electrons at anode
- Transfer fields timing: gains, ion backflow and resolutions of the detector

![Diagram of GEM detector with labels](image)

**Figure 12 (d), gives an additional factor of 2 to the full**
with a component direct charge injection into the readout electrode
Another charge fraction equal to $m$ and moving towards the readout electrode, i.e. from $i$ it is close to 0.1) the induced current component

Since for the drift velocity of a 1 mm gap a full signal width will be about 20 ns induction gap size to the electron drift velocity. For

Note: (a) and (b) are not to the scale.

**Figure 12. Current and charge induction mechanisms on GEM**

At the signal electrode. In Refs. [2] consider the total charge from the avalanche collected the drift region. Here, we use the same de

**Table 3. Fig. 14 shows the G4 charge fractions**

<table>
<thead>
<tr>
<th>Field</th>
<th>Geometry</th>
<th>Geometry</th>
<th>Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_{\text{in}}$, $q_{\text{ion}}$</td>
<td>$D$</td>
<td>$U$</td>
<td>$L$</td>
</tr>
<tr>
<td>$q_{\text{el}}$, $q_{\text{em}}$</td>
<td>$R$</td>
<td>$i_{\text{d}(t)}$</td>
<td>$i_{\text{d}(t)}$</td>
</tr>
</tbody>
</table>

**Not desirable**

![Graph showing induced signal](image)
Induc*on	filed

Induction Field (keV/cm)

<table>
<thead>
<tr>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
</tr>
<tr>
<td>2000</td>
</tr>
<tr>
<td>3000</td>
</tr>
<tr>
<td>4000</td>
</tr>
<tr>
<td>5000</td>
</tr>
<tr>
<td>6000</td>
</tr>
</tbody>
</table>

Induction field set to 4kV/cm
Drift field set to 0.4kV/cm
Transfer field set to 4.0kV/cm
The value set relatively high transparency

Drift = 0.4 kV/cm
Transfer_{12} = 4.0 kV/cm
Transfer_{23} = 2.90 kV/cm
Transfer_{34} = 2.87 kV/cm
Induction = 4 kV/cm

• Transparency for GEM-I ~1 since electron with a momentum in z-direction left over a hole
• Drift filed is set usually to a low value = 0.4
Gains with T23 and t34

- One need to choose T34 (1-1.5 kV) for higher gain
  BUT – we need to consider ion backflow
Ion Backflow

- Lower T34 significantly reduces ion backflow
- It is far above the acquired ion backflow (e.g. in ALICE)

Our geometry SmP-SmP-SmP-SmP aligned hole geometry
- Large Pitch in between and misalignment can reduce ion backflow in great extent

• Working on various geometry and misalignments

70:30 = Ar:CO₂
Aligned holes
Gain peaks

T34 = 0.2 kV/cm

0.5 kV/cm

1.0 kV/cm

1.5 kV/cm

time in nano sec

micro-coulomb

T23 = 0.2 kV/cm

0.5 kV/cm

1.0 kV/cm

1.5 kV/cm

time in nano sec

micro-coulomb

2/16/17
Induced signal shape

$T_{34} = 0.2 \text{ kV/cm}$

$0.5 \text{ kV/cm}$

$1.0 \text{ kV/cm}$

$1.5 \text{ kV/cm}$

$T_{23} = 0.2 \text{ kV/cm}$

$0.5 \text{ kV/cm}$

$1.0 \text{ kV/cm}$

$1.5 \text{ kV/cm}$

time in nano sec

2/16/17
Induced Signal timing and width

- **Signal Peak time (µ Second):**
  - T23 = 1 kV/cm
  - T23 = 2 kV/cm
  - T23 = 3 kV/cm

- **Signal Width:**
  - T12 = 4 kV/cm, Drift = 0.4 kV/cm, Induction = 4 kV/cm

- **Induced <charge> (µC):**
  - ΔV_{G1} = 336.6 V
  - ΔV_{G2} = 350.9 V
  - ΔV_{G3} = 349.8 V
  - ΔV_{G4} = 359.7 V

- **Transfer Field T34 (kV/cm):**
  - 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2

Graphs showing the relationship between signal parameters and transfer field.
Resolution

Signal spread 200 micron width

Seems to be narrow
• It is single electron multiplication width
• Probably need induced signal analysis
Summary

• GEM simulation in Garfield++ with ANSYS based field calculations is being performed.
• 4-GEM stacks is being tuned and a field configuration is set to work in a preferred gain region
• Ion backflow is in the level of 6-10% and we need misalignment and pitch variation in alternative layers to reduce the value
• Width of the signal at anode plane is about 200 micron and gain width is coming in the range of 1%-2.5%
• Need to work more on induced signals
Backups
Energy peak
The induced current in a readout element:

\[ i = q_{em} \nabla V_w^R \cdot v_e \]

weighting field of the readout electrode \( V_w^R \) with unit potential applied. \( v_e \) is the charge drift.

For a 1 mm gap a full signal width will be about 20 ns for the drift velocity of 5 cm/μs.

Weighting fields and induced currents

Finite Element Field Maps

which contains the nodal solutions for the weighting field configuration.

Fig. 12. Current and charge induction mechanisms on GEM electrodes: (a) drift, (b) upper GEM, (c) lower GEM, (d) readout. Note: (a) and (b) are not to the scale.

Fig. 13. Current components and their measurements.
Induced signals from 4-GEM

A typical signal and induced signal properties in preferable working region of the detector

- From electron collection and ion
  Tracking calculating: Gains, transparency, resolutions and ion backflow, etc

2/16/17
GEM simulations with Garfield++

ANSYS code: external field solver
Defining: geometry, boundary conditions, initial meshing
--> Produce field maps

loading the mesh (ELIST.lis, NLIST.lis),
the list of nodal solutions (PRNSOL.lis),
and the material properties (MPLIST.lis);

Tracking electrons in Garfield++
Using class: ComponentAnsys123

Avalanche of electrons in GEM Holes
-- single electron thrown at (0,0.0.7)
-- 4 Layers
-- Ar:CO₂ = 70:30