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NISER, Bhubaneswar
(CMS Collaboration)

Technology and Instrumentation in Particle Physics 2011 (TIPP 2011),
9-14 Jun 2011, Chicago, USA.

On behalf of GEMs for CMS collaboration
LHC currently running at 7 TeV at about $10^{33} \text{ /cm}^2\text{/s}$ luminosity.

Phased Shutdowns planned as Phase I and Phase II

Phase I : (2012-2020), Phase II (>2020)

- Phase I :
  - First shutdown (LS1) (Energy Upgrade): 2012 for 1.5 – 2.0 years ; Commencement : 2014 (Ramp to 14 TeV)
  - Second shutdown (LS2) (Luminosity upgrade): 2017/2018 for ~ 1 yr ; Commencement 2018/2019 : to increase luminosity towards end of this period $10^{34} \text{ /cm}^2\text{/s}$

- Phase II (SLHC):
  - Sometime after 2020, a long shutdown (LS3) - major machince and detector upgrades to achieve integrated luminosity a factor of 10 higher than achieved towards end of Phase I.
The Muon system upgrade

Necessary redundancy needed to reject low pT muons at high luminosities, and maintain trigger efficiency, study QGP, b-tagging, Improvements in Z/W mass resolution.
Forward Muon RPC system equipped with detectors up to $|\eta| < 1.6$. RPC Upscope planned in two phases – A fourth muon station:

RE4/3 ($|\eta| < 1.6$)
R&D for RPC’s designed to handle high rates RE4/2 (1.6 – 2.1)

Other option – MPGD’s instead of RPC’s (1.6 – 2.4), GE1/1 instead of RE1/1
Construction of the first full-size GEM-based prototype for the CMS high-eta muon system, D. Abbaneo et al., arXiv:1012.1524v2 [physics.ins-det]
The Triple GEM-MPGD solves the discharge problem at high gains in MSGC’s by cascading gains over 3 layers – Voltages over 3 layers low enough so as to not exceed Raether limit.

Decoupling of amplification and detection.

High rate capability ($\sim 10^5$/mm$^2$) with high and stable gains.

Good spatial ($\sim 100$ $\mu$m) and timing resolution (4-5 ns) – Use for trigger.
Gas Electron Multiplier (GEM)

Hole diameter = 70 μm, Pitch = 140 μm, size = 10x10 cm²
The Triple-GEM Layout

VOLTAGE AND ELECTRIC FIELDS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VD</td>
<td>-4.4 kV</td>
</tr>
<tr>
<td>ED</td>
<td>2.4 kV/cm</td>
</tr>
<tr>
<td>(\Delta V_{\text{Gem1}})</td>
<td>397 V</td>
</tr>
<tr>
<td>ET1 (Transfer 1)</td>
<td>3.6 kV/cm</td>
</tr>
<tr>
<td>(\Delta V_{\text{Gem2}})</td>
<td>361 V</td>
</tr>
<tr>
<td>ET2 (Transfer 2)</td>
<td>3.6 kV/cm</td>
</tr>
<tr>
<td>(\Delta V_{\text{Gem3}})</td>
<td>315.5 V</td>
</tr>
<tr>
<td>EI (Induction)</td>
<td>3.6 kV/cm</td>
</tr>
</tbody>
</table>

Incident Particle

V cathode = -4.4 kV

3 mm

ED  DRIFT

2 mm

ET1  TRANSFER 1

2 mm

ET2  TRANSFER 2

2 mm

EI  INDUCTION

V Readout anode = 0 kV

2 mm

3 mm
Previous simulations have been done in MAXWELL – Bonivento et. al., IEEE Transactions on nuclear science, Vol. 49, No. 4, Aug 2002.

This simulation uses ANSYS. ANSYS improves on Maxwell in the meshing methods provided: Free and Mapped. We use Free with no restrictions on element size.

Model generation can be accomplished in two ways: direct and solid.

- The direct method defines the nodes and elements of a model directly. The volume of data to be entered for the direct method would be about ten times that of the solid generation. We have used solid modelling.
- Material definition and properties: Air, copper, and kapton. The common property to be defined is the permittivity of the materials. Assign material properties to the various volumes created from the boolean operations in the first step (Solid Volumes)
- Assign loads to the geometry - DOF (Degrees of Freedom) of the various solid materials. In the detector case it is the voltage configuration which is the load.

Solve the problem and generate the electric field, and potential field maps which are input to GARFIELD.
A single GEM cell, showing one hole and quarter of a hole on the corners.
Basic triple GEM cell
High electric fields are seen inside the GEM hole and very low elsewhere.
The electric field map files generated by ANSYS is read correctly by GARFIELD as can be seen by the high electric fields generated at the holes. The X-Y and X-Z view of one layer of the detector as seen in GARFIELD. The GEM cell can be replicated in GARFIELD. Only the Kapton is seen as the conductor layers are removed.
Avalanche formation by single electron

Electron drift lines from a track of Pion (E = 1 GeV) as calculated in HEED.
The simulation studies two gas mixtures which have been found suitable by test beam results.

- \( \text{Ar/CO}_2/\text{CF}_4 \rightarrow 45/15/40 \)
- \( \text{Ar/CO}_2 \rightarrow 70/30 \)

Calculations are done for \( B=3T \) in MAGBOLTZ within GARFIELD.

- Diffusion coefficient
- Drift velocity
- Lorentz angle
- Townsend coefficient.

Timing resolution from Prototype I tests:

- Timing Resolution from Prototype I tests:
- June 13, 2011
- TIPP, 9-14 Jun 2011, Chicago, IL, USA.
- June 13, 2011

Choice of \( \text{CF}_4 \):
- Non-flammable
- Fast drift velocity
- Very small diffusion
At 2.4 kV/cm, $D_L \sim 15 \text{ } \mu m/mm$ = 45$\mu$m for 3 mm drift gap

At 2.4 kV/cm, $D_L \sim 8 \text{ } \mu m/mm$ = 24$\mu$m for 3 mm drift gap
Diffusion Coefficient

Diffusion coefficient for $B=0\,T$ & $B=3\,T$

![Graphs showing diffusion coefficients for different fields.](image-url)
Lorentz Angle $\theta(E,B) = 8^\circ/90^\circ$

- Ar/Co2
- Ar/Co2/CF4

Angle ~ 49-50 deg at 2.4 kV/cm

Angle ~ 5.5 – 6.0 deg at 2.4 kV/cm
Drift Velocity for $\theta(E,B)=90^\circ$

\[ v_D = \frac{\mu}{1 + \mu^2 B^2}(E + \mu E \times B + \mu^2 B(E \cdot B)) \]

\[ v = \frac{-\mu E}{1 + \mu^2 B^2} \left( \begin{array}{c} \mu^2 B^2 \cos \theta \sin \theta \\ -\mu B \sin \theta \\ 1 + \mu^2 B^2 \cos^2 \theta \end{array} \right) \]
Comparison of drift velocity for $\theta \ (E,B) = 8^\circ$ and $\theta \ (E,B) = 90^\circ$. As expected, the x component is negative for $\theta \ (E,B) = 8^\circ$ and for the lower angle, the z component along the E field is dominant.
We compare the drift velocity obtained in the simulation with the experimental result obtained by the LHCb muon station for various gases.

Alfonsi et al., NIM A 518 (2004)
Signal induced on the readout anode due to electron motion in induction gap.

Current flow given by Ramo’s theorem:

\[ I_k = -q v(x) \frac{E_k(x)}{V_k} \text{ where } k=\text{kth electrode, } E_k \text{ is weighting field } (V_k = 1) \]
6 layer CSC for each endcap muon station.

Radial strips – wires perpendicular to strips.

A *Local Charged Track* (LCT) is formed when coincidence of at least 4 hit strips in different layers occurs.

Strips must belong to a predefined road (LUT).

Signals can be spread as much as the maximum drift time (40-50 ns) and therefore the bunch crossing is assumed to be defined by the second hit in time.
Muon Trigger studies

- CSC reconstructs tracks and measures momentum.
- $L_1$ rates and Trigger turn-on curves for CSC for different $p_T$ thresholds.
- Some preliminary plans to include MPGD with CSC.

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**Extrapolation using 2010 data**

$|\eta|<2.4$

Indicative 15kHz limit

<table>
<thead>
<tr>
<th>$L_1$ SineMu rate [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^6$</td>
</tr>
<tr>
<td>$10^5$</td>
</tr>
<tr>
<td>$10^4$</td>
</tr>
<tr>
<td>$10^3$</td>
</tr>
<tr>
<td>$10^2$</td>
</tr>
</tbody>
</table>

$L_1$ pT threshold [GeV]

- $5 \times 10^3$
- $2 \times 10^3$
- $1 \times 10^3$
- $5 \times 10^2$
- $2 \times 10^2$

---

**Threshold Efficiency**

**CMS Preliminary 2010 (7 TeV)**

- CSCTF $P_T \geq 3.0$ GeV/c with 50% at 2.3 GeV/c
- CSCTF $P_T \geq 5.0$ GeV/c with 50% at 3.9 GeV/c
- CSCTF $P_T \geq 7.0$ GeV/c with 50% at 6.1 GeV/c
- CSCTF $P_T \geq 9.0$ GeV/c with 50% at 8.2 GeV/c

$P_T$ of Global Muon, (GeV/c)
Muon Trigger studies

- Single muons ($\theta>1.6$, uniform $\phi$)
- Simulation studies using RPC in the very forward region for different strip configurations (resistive plate chambers)

Spatial resolution

Momentum resolution
Muon trigger studies

Residual distribution is strip dominated.

Improvement in momentum resolution when spatial resolution not dominated by strip width.
Simulation of triple GEM done with ANSYS + Garfield Interface.

- Studied transport parameters for different gas configurations

- Plans to test simulation modelling in other packages like neBEM (near Boundary Element Method) and study further detector characteristics (gain, efficiency, timing resolution etc.)

- Preliminary trigger studies point to need for high eta stations in order to effectively veto low pT muons, or use low pT muons for B physics, improve Z/W mass resolution, QGP, and retain good trigger efficiency.

- Many Thanks to …
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Back-up slides
Compact Muon Solenoid – CMS Detector
### Expected Integrated Luminosities

<table>
<thead>
<tr>
<th>Period (In Years)</th>
<th>Integrated Luminosity (fb-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-2012</td>
<td>~1.0</td>
</tr>
<tr>
<td>2014-2017</td>
<td>~66.0</td>
</tr>
<tr>
<td>2019-2020</td>
<td>~300.0</td>
</tr>
<tr>
<td>2020-2030</td>
<td>~3000.0</td>
</tr>
</tbody>
</table>

**Preliminary Long Term Predictions**

![Graph showing expected integrated luminosity](image)

*June 13, 2011*
Beam Muon = 150 GeV

Can we try to get these plots in simulation as well

TIPP, 9-14 Jun 2011, Chicago, IL, USA. June 13, 2011
Older studies

J. Benlloch et al., IEEE NS45(1998)234
At 2.4 kV/cm, $D_L$ is about 15 $\mu$m/mm = 45 $\mu$m for 3 mm drift gap

At 2.4 kV/cm, $D_L$ is about 8 $\mu$m/mm = 24 $\mu$m for 3 mm drift gap
Testbeam studies – Spatial resolution

Position 1
Run175  
$\varepsilon = 99.11\%$

Position 5
Run631  
$\varepsilon = 98.49\%$

<table>
<thead>
<tr>
<th>Position</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>space resolution (mm)</td>
<td>0.289</td>
<td>0.288</td>
<td>0.316</td>
<td>0.416</td>
</tr>
<tr>
<td>average pitch (mm)</td>
<td>1.06</td>
<td>1.05</td>
<td>1.16</td>
<td>1.49</td>
</tr>
<tr>
<td>average pitch/sqrt(12)</td>
<td>0.305</td>
<td>0.304</td>
<td>0.335</td>
<td>0.430</td>
</tr>
</tbody>
</table>

Resolution $\approx \frac{pitch}{\sqrt{12}}$