Sensitivity of Triple-GEM Detector for background radiation in CMS Experiment

O. Bouhali¹, A. Castaneda², S. S. Chauhan³, T. Kamon⁴, Y. Kang⁵, S. Kumar³, A. K. Virdi³

¹ Texas A&M University, Qatar
² Universidad de Sonora, Mexico
³ Panjab University, Chandigarh
⁴ Texas A&M University, USA
⁵ University of Seoul, South Korea

For The CMS Collaboration

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Motivation

Main source of radiation background identified in the Muon System:

- From collision and radiation leak from the HCAL gap
  - Mainly Charged Hadrons.
- From the cavern
  - Neutrons produced by the Hadrons interaction with other material i.e. beam pipe or shielding. Secondaries ($\gamma$, $e^\pm$) produced by neutrons.

Signal Produced by these can mimic the muon signal.
**CMS FLUKA Simulation**

**FLUKA:** a fully integrated particle physics Monte Carlo simulation package.
- Suitable for calculating flux maps, particle spectra, energy depositions, dose distributions & ambient dose...

**FLUKA** simulation of **CMS (Compact Muon Solenoid)** is performed for **proton-proton** collision and particle fluxes, differential energy spectrum \((dN/dE)\) and differential angular spectrum \((dN/d\Theta)\) for the
- **Luminosity** \(1.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}\)
- \(120 < R < 260\)
- \(565 < Z < 574\)

are obtained for
- **charged hadrons** \((K^\pm, \pi^\pm, p)\)
- **neutrons** \((n)\)
- **photons** \((\gamma)\)
- **electrons and positrons** \((e^\pm)\)

<table>
<thead>
<tr>
<th>Background Particles</th>
<th>Energy-Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron</td>
<td>(10^{-11} \text{ – } 10^4 \text{ MeV})</td>
</tr>
<tr>
<td>photon</td>
<td>(10^{-3} \text{ – } 10^4 \text{ MeV})</td>
</tr>
<tr>
<td>e^±</td>
<td>(10^{-2} \text{ – } 10^4 \text{ MeV})</td>
</tr>
<tr>
<td>charged hadrons</td>
<td>(10^{-3} \text{ – } 10^4 \text{ MeV})</td>
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</table>
Predictions from FLUKA

At Luminosity $1.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Particle Flux

Energy Spectrum

Angular Spectrum

Differential Energy Spectrum in terms of cm$^{-2}$ for neutrons, photons, $e^\pm$ and charged hadrons.

Differential Angular Spectrum in terms of normalized fraction for neutrons, photons, $e^\pm$ and charged hadrons.

Flux in terms of cm$^{-2}\text{s}^{-1}$ for neutrons, photons, $e^\pm$ and charged hadrons.

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GEANT4 Modelling of Single GEM Detector

Material Budget

<table>
<thead>
<tr>
<th>Layer</th>
<th>Z-Dimensions</th>
<th>Material</th>
</tr>
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<tbody>
<tr>
<td>Drift Board</td>
<td>35 µm / 3.2 mm / 35 µm</td>
<td>Copper / FR4 / Copper</td>
</tr>
<tr>
<td>Drift Gap</td>
<td>3 mm</td>
<td>ArCO2</td>
</tr>
<tr>
<td>GEM 1</td>
<td>5 µm / 50 µm / 5 µm</td>
<td>Copper / Kapton / Copper</td>
</tr>
<tr>
<td>Transfer 1 Gap</td>
<td>1 mm</td>
<td>ArCO2</td>
</tr>
<tr>
<td>GEM 2</td>
<td>5 µm / 50 µm / 5 µm</td>
<td>Copper / Kapton / Copper</td>
</tr>
<tr>
<td>Transfer 1 Gap</td>
<td>2 mm</td>
<td>ArCO2</td>
</tr>
<tr>
<td>GEM 3</td>
<td>5 µm / 50 µm / 5 µm</td>
<td>Copper / Kapton / Copper</td>
</tr>
<tr>
<td>Induction Gap</td>
<td>1 mm</td>
<td>ArCO2</td>
</tr>
<tr>
<td>Readout Board</td>
<td>35 µm / 3.2 mm / 35 µm</td>
<td>Copper / FR4 / Copper</td>
</tr>
</tbody>
</table>

Position of Primary Incident Particle = (X_{variable}, Y_{variable}, -3.0 mm) 
Angle Coverage = 0° (with respect to normal to the detector surface)

Primary Particle Distribution at the surface of detector

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Energy-Sensitivity & Angle-Sensitivity

Energy Sensitivity

CMS work in progress

- Basic Single Triple-GEM Sensitivity
- Sensitivity vs Incident Energy [MeV]

Angle Sensitivity

CMS work in progress

- Basic Single Triple-GEM Sensitivity
- Sensitivity vs Incident Angle [Degrees]
Sensitivity in Angle vs Energy Plane

CMS

Neutron

Photon

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Hit Rate Calculation Method

**Hit-Rate (Hz/cm²) = particle flux ⊗ energy ⊗ sensitivity**

Integration of the product will give a number as Average Sensitivity

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**Flux** multiplied by the **Average Sensitivity** is called as **Hit Rate**

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Super-Chamber in The CMS Experiment

### Material Budget

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<td>1 mm</td>
<td>ArCO₂</td>
</tr>
<tr>
<td>Readout Board</td>
<td>35 µm / 3.2 mm / 35 µm</td>
<td>Copper / FR4 / Copper</td>
</tr>
<tr>
<td>GEB</td>
<td>0.105 mm / 0.891 mm</td>
<td>Copper / FR4</td>
</tr>
<tr>
<td>V-Fat &amp; Opto-hybrid</td>
<td>1.00 mm / 1.66 mm</td>
<td>FR4 / FR4</td>
</tr>
<tr>
<td>Cooling Pads</td>
<td>1.00 mm</td>
<td>Copper</td>
</tr>
<tr>
<td>Cooling Pipe</td>
<td>8.0 mm external ⊙, 6.0 mm inner ⊙</td>
<td>Copper (Filled with H2O)</td>
</tr>
<tr>
<td>Cover</td>
<td>1.00 mm</td>
<td>Aluminium</td>
</tr>
</tbody>
</table>

Pull-outs, Spacers, External Frame, Aluminium Zig

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**Position of Primary Incident Particle =**

\[(X_{\text{variable}}, Y_{\text{variable}}, 3.0 \text{ mm above Layer-I})\]

**Angle Coverage =** 90° (with respect to normal to the detector surface)

**Primary Particle Distribution at the surface of detector**

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### Average Sensitivity

#### Super-Chamber Geometry

<table>
<thead>
<tr>
<th>Incident Particle</th>
<th>Layer-I</th>
<th>Layer-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron</td>
<td>0.679 ± 0.013</td>
<td>0.796 ± 0.016</td>
</tr>
<tr>
<td>photon</td>
<td>0.340 ± 0.003</td>
<td>0.239 ± 0.002</td>
</tr>
<tr>
<td>$e^\pm$</td>
<td>1.265 ± 0.037</td>
<td>0.356 ± 0.014</td>
</tr>
<tr>
<td>charged hadrons</td>
<td>19.731 ± 1.321</td>
<td>18.293 ± 1.234</td>
</tr>
</tbody>
</table>

#### Average Sensitivity (%)

- Angular Spectrum is used as an input to GEANT4.
## Systematics on Average Sensitivity

<table>
<thead>
<tr>
<th>Incident Particle</th>
<th>ZPOS</th>
<th>GMP ArCO₂ [60:40]</th>
<th>GMP ArCO₂ [80:20]</th>
<th>DGW 2.7 mm</th>
<th>DGW 3.3 mm</th>
<th>SAR 90 %</th>
<th>SAR 110 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron</td>
<td>+ 1.382</td>
<td>+ 0.251</td>
<td>+ 0.377</td>
<td>+ 1.131</td>
<td>+ 2.010</td>
<td>+ 6.784</td>
<td>+ 0.377</td>
</tr>
<tr>
<td>photon</td>
<td>+ 2.510</td>
<td>+ 0.837</td>
<td>0.0</td>
<td>0.0</td>
<td>+ 1.674</td>
<td>+ 0.837</td>
<td>+ 4.184</td>
</tr>
<tr>
<td>e⁺⁻</td>
<td>- 2.528</td>
<td>+ 1.404</td>
<td>+ 0.562</td>
<td>+ 0.281</td>
<td>+ 0.562</td>
<td>- 0.281</td>
<td>+ 5.618</td>
</tr>
<tr>
<td>charged hadrons</td>
<td>+ 34.636</td>
<td>- 8.189</td>
<td>- 0.279</td>
<td>- 1.121</td>
<td>+ 0.836</td>
<td>+ 1.378</td>
<td>+ 7.790</td>
</tr>
</tbody>
</table>

**Layer-2 Average Sensitivity Variations (%)**

### Systematics FLUKA

- **ZPOS** = Source Normal Position from Detector Surface (Nominal 3.0 mm)
- **GMP** = Gas Mixture proportion (Nominal ArCO₂ [70:30])
- **DGW** = Drift Gap Width (Nominal 3.0 mm)
- **SAR** = Surface Area of Primary over the Detector surface (Nominal 100 % area of Drift Board)

* **% Variation** = \( \left( \frac{\text{Avg. Sensitivity at particular configuration} - \text{nominal Avg. Sensitivity}}{\text{nominal Avg. Sensitivity}} \right) \times 100 \)
Data & Simulation are in agreement within uncertainties

- We can predict the background rates in Run-III also.
- The results can be used for the preselection cut.

*Systematics are added in quadrature.
Back-up
# Average Sensitivity

<table>
<thead>
<tr>
<th>Incident Particle</th>
<th>Layer - 1</th>
<th>Combined</th>
<th>Layer - 2</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>0.680 ± 0.014</td>
<td>0.679 ± 0.013</td>
<td>0.591 ± 0.010</td>
<td>1.001 ± 0.024</td>
</tr>
<tr>
<td>Photon</td>
<td>0.545 ± 0.006</td>
<td>0.134 ± 0.002</td>
<td>0.340 ± 0.003</td>
<td>0.203 ± 0.003</td>
</tr>
<tr>
<td>$e^+$</td>
<td>2.416 ± 0.072</td>
<td>0.113 ± 0.005</td>
<td><strong>1.265 ± 0.037</strong></td>
<td>0.162 ± 0.008</td>
</tr>
</tbody>
</table>

**Average Sensitivity (%)**
Hit Rate Calculation Method

$$\text{Hit-Rate (Hz/cm}^2\rangle = \text{particle flux} \otimes \text{particle energy} \otimes \text{average sensitivity}$$

**Particle-Flux** ➔ CMS simulation using FLUKA Framework

**Average Sensitivity** ➔ Triple-GEM detector simulation using GEANT4 Framework

**Sensitivity** ➔ probability for a particle to interact inside the detector sensitive material and produce a signal event

**Signal** ➔ when the interaction is accompanied by the production of a charged particle in the sensitive volume of the detector

$$\text{Sensitivity} = \frac{\text{Numbers of Detected Events}}{\text{Number of Events fall on the Detector Surface}}$$

*(First 2 gaps are used as sensitive volume)*
Even & Odd Configuration

Even Configuration

Drift Side

Long Chamber in context to CMS

I.P.

Odd Configuration

Read-out Side

Short Chamber in context to CMS

I.P.
Hit rate as a function of the distance from the beam pipe

- Environmental background hit rate of GE 1/1 slice test chamber 28 layer 2 as a function of the distance from the beam pipe to the center of $\eta$ partitions. The value of the data points is measurement in $1.5 \times 10^{34} cm^2 s^{-1}$ obtained by the linear fit to the hit rate versus instantaneous luminosity. Each error bar is obtained from uncertainties in the linear fit. The curve is an exponential function.
Slice Test

27 – Short Chamber
28 – Long Chamber
29 – Short Chamber
30 – Long Chamber