A Triple-GEM Detector with Pixel Readout for High-Rate Beam Tracking in COMPASS

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TU München, Physik Dep. E18

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Outline

1. COMPASS-Experiment

2. PixelGEM Detector

3. Characterisation

4. Conclusion
The COMPASS-Experiment

Overview

COMPASS Muon and Proton Apparatus for Structure and Spectroscopy located at CERN's SPS two-stage magnetic spectrometer taking data since 2002

2 types of beam muons: $4 \times 10^7$ s$^{-1}$

hadrons: $2 \times 10^7$ s$^{-1}$

energies: 160-190 GeV

Physics Goals

- nucleon spin-structure
- hadron spectroscopy

Tracking

- Silicons, Scint. Fibres
- GEMs, MicroMegas
- MWPCs, Drift Chambers
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Hadron Beam 2008

- intensity up to $2 \cdot 10^7 \text{s}^{-1}$
- flux density $> 10^5 \text{mm}^{-2}\text{s}^{-1}$
- SciFi act as secondary target: $x/X_0 = 1.8 - 2.6\%$
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**COMPASS GEMs**
- $x/X_0 = 0.4\%$
- no gain drop due to space charge $\Rightarrow$ high inherent rate capability
- strip readout $\Rightarrow$ occupancy too high $\Rightarrow$ centres deactivated
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**Solution:** GEM with pixel read-out
Gas Electron Multiplier: avalanche amplification in holes

3-fold staggered design to increase gain and avoid discharges
Read-out Circuit
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Read-out: $450 \times 450 \text{ mm}^2$

- 3 conducting layers
  Cu $5 \mu\text{m}$
- 2 intermediate layers
  Kapton $50 \mu\text{m}$
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Centre: $32 \times 32 \text{ mm}^2$
- $32 \times 32$ Pixels
- pitch: 1 mm
## Read-out Circuit

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### Centre: \(32 \times 32\, \text{mm}^2\)
- \(32 \times 32\) Pixels
- pitch: 1 mm

### Periphery: \(100 \times 100\, \text{mm}^2\)
- 512 crossed (2D) strips
- equal charge-sharing
- pitch: \(400\, \mu\text{m}\)
GEM Foil

- GEM Foil
  - Foil: 330 x 330 mm
  - Kapton 50 µm
  - Cu cladding: 5 µm or 1 µm
  - Gas circulation holes: diameter 0.5 mm
  - Active Area: 100 x 100 mm²
  - Segmented amplification region
  - Double-conical holes
  - GEM hole diameter: 70 µm
  - Pitch: 140 µm
GEM Foil

**Foil:** $330 \times 330 \text{ mm}^2$

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- gas circulation holes: diameter $0.5 \text{ mm}$

Active Area: $100 \times 100 \text{ mm}^2$
- segmented amplification region
- double-conical holes
- GEM hole diameter: $70 \mu\text{m}$
- pitch: $140 \mu\text{m}$
Front-End Electronics

APV card

- analogue APV25 S1 ASIC\(^1\)
- 38.88 MHz sampling frequency
- 128 channels
- 160 samples pipeline:
  up to \(\sim 4 \mu s\) trigger latency

Front-End Electronics

**APV card**
- analogue APV25 S1 ASIC\(^1\)
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- 160 samples pipeline: up to $\sim 4 \mu s$ trigger latency

**Read-out Scheme**
- 16 APV cards per detector
- bus card to 12 bit ADC
- total equiv. noise charge: 1300-1500 electrons

---
The fully assembled Detector
Material Thickness in $\%_0$ of radiation length $X_0$

<table>
<thead>
<tr>
<th></th>
<th>centre $[X_0/1000]$</th>
<th>periphery $[X_0/1000]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeycomb Support</td>
<td>0.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Drift Foil</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3 GEM Foils</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Readout Circuit</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Shielding</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Gas</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total Thickness</strong></td>
<td><strong>3.8</strong></td>
<td><strong>7.1</strong></td>
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centre: $r < 15$ mm, periphery: $r > 15$ mm

Cu layer thickness 5 $\mu$m
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Cu layer thickness $5 \mu m / 1 \mu m$
## Material Thickness in % of interaction length $\lambda_I$

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<td>3 GEM Foils</td>
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Cu layer thickness 5 $\mu$m / 1 $\mu$m
Gain-Voltage-Dependency

measured with $^{55}$Fe source for 5 $\mu$m Cu GEM

selected 3900 V for a gain of $\sim 7500$
Setup in COMPASS
Beams from SPS

**SPS Tunnel**

**Occupyancy [%]**

**Low Intensity $\mu^-$ Beam**
- total flux: $1.1 \cdot 10^6 \text{ s}^{-1}$
- max. density: $2.5 \cdot 10^3 \text{ mm}^{-2} \text{s}^{-1}$

**High Intensity $\mu^-$ Beam**
- total flux: $4.8 \cdot 10^7 \text{ s}^{-1}$
- max. density: $1.2 \cdot 10^5 \text{ mm}^{-2} \text{s}^{-1}$
Crosstalk Suppression

beamspot with crosstalk
Crosstalk Suppression

tag channels with high-amplitude neighbours
after clustering: remove clusters containing mostly tagged pixels
Crosstalk Suppression

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Efficiency Scan

**Low Intensity**: $\sim 2 \cdot 10^{3} \text{ mm}^{-2} \text{s}^{-1}$

- Efficiency plateau: $\sim 98.5 \%$
- bg prob. per pixel: $\sim 0.1 \%$
- roadwidth used: 0.6 mm

**High Intensity**: $\sim 1 \cdot 10^{5} \text{ mm}^{-2} \text{s}^{-1}$

- Efficiency plateau: $\sim 95.5 \%$
- bg prob. per pixel: $\sim 2 \%$
- roadwidth used: 1 mm
**Efficiency Map**

**Low Intensity:** $\sim 2 \cdot 10^3 \text{ mm}^{-2}\text{s}^{-1}$

Average efficiency: $\sim 98.5\%$

**High Intensity:** $\sim 1 \cdot 10^5 \text{ mm}^{-2}\text{s}^{-1}$

Average efficiency: $\sim 95.5\%$
Spatial Residuals

**Low Intensity:** $\sim 2 \cdot 10^3 \text{ mm}^{-2}\text{s}^{-1}$

- Weighted mean: $\sigma_x = 90 \mu m$

**High Intensity:** $\sim 1 \cdot 10^5 \text{ mm}^{-2}\text{s}^{-1}$

- Weighted mean: $\sigma_x = 135 \mu m$

Black/blue: with/without clustering,  Green: Gaussian components
Temporal Residual

**Low Intensity:** $\sim 2 \cdot 10^3 \text{ mm}^{-2} \text{s}^{-1}$

$$\text{rms} = 9.9 \text{ ns}$$
Conclusion and Outlook

GEM with pixel read-out
radiation-hard in-beam tracker
stable operation in muon beams up to $1.2 \cdot 10^5$ mm$^{-2}$s$^{-1}$

extremely thin: $x/X_0 = 0.2\%$ and $\lambda/\lambda_I = 0.07\%$

Outlook
ongoing work on analysis/reconstruction
deployment of 5 PixelGEM detectors in COMPASS in 2007/2008

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**Efficiency: Roadwidth Scan**

**Low Intensity:** $\sim 5 \cdot 10^3 \text{ mm}^{-2}\text{s}^{-1}$

**High Intensity:** $\sim 2 \cdot 10^5 \text{ mm}^{-2}\text{s}^{-1}$
Crosstalk: Design of Read-out Circuit

first version
Crosstalk: Design of Read-out Circuit

first version

improved layout
Readout Chain
Production: Gluing GEM foil onto Spacer Grid
Spatial/Temporal Resolution Strip-GEMs

**Spatial resolution**
- Test beam/low intensity:
  \[ \langle \sigma_x \rangle \approx 50 \mu m \]
- Standard physics run: \( 4 \times 10^7 \mu^+ / s \):
  \[ \langle \sigma_x \rangle \approx 70 \mu m \]

**Time resolution**
- 3 analog samples per trigger
- Rising edge of signal
- Reconstruct \( t_0 \) from known pulse shape

\[ \langle \sigma_t \rangle \approx 12 \text{ns} \]

[B. Ketzer et al., NIM A535, 314 (2004)]
Efficencies Strip-GEMs

**Low intensity beam:** \(5 \cdot 10^6 \mu^+/s\)
- All detectors reach plateau (\(\varepsilon > 98\%\))
- Gain \(\sim 8000\)
- SNR \(\sim 18\)
- Losses due to spacer grid: 1.2-1.5%

**Standard physics beam:** \(4 \cdot 10^7 \mu^+/s\)
- Background correction
  \[\varepsilon_{\text{app}} = \varepsilon + (1 - \varepsilon) \cdot b\]
- Single plane: \(\langle \varepsilon_{1D} \rangle = 97.2\%\)
- 2D (space point): \(\langle \varepsilon_{2D} \rangle = 95.6\%\)

[B. Ketzer et al., Nucl. Phys. B 125C, 368 (2003)]

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