A. Austregesilo, F. Haas, B. Ketzer, I. Konorov, M. Krämer, A. Mann, T. Nagel, S. Paul, F. Schneider, S. Uhl

TU München, Physik Department E18

Workshop on GEMs and Micromegas, February 16th 2009

Supported by

Maier-Leibnitz-Labor
Garching bei München
Overview

1. The COMPASS Experiment
2. The PixelGEM Detector
3. GEM Assembly
4. Detector Performance
The COMPASS Experiment

The PixelGEM Detector

GEM Assembly

Detector Performance

The COMPASS Experiment

O: Overview

COMPASS on Muon and Proton Apparatus for Structure and Spectroscopy

Located at the CERN SPS two stage magnetic spectrometer

→ large angular acceptance

data taking since 2002

→ up to 580 TByte/year

Beam Rates (tertiary) Muon:

→ $4 \cdot 10^7$ s$^{-1}$ (secondary) Hadron ($\pi$, K, ...):

→ $5 \cdot 10^6$ s$^{-1}$

Tracking

Si Licons ($\sigma_x \sim 10 \mu m$), SciFis ($\sigma_t \sim 0.4$ ns)

GEMs ($\sigma_x \sim 70 \mu m$), MicroMegas ($\sigma_x \sim 90 \mu m$)

Drift Chambers ($\sigma_x \leq 200 \mu m$)

Florian Haas - TU München Physik Department E18
The COMPASS Experiment

Overview

- **COmmon Muon and Proton Apparatus** for **S**tructure and **S**pectroscopy
  
- located at the CERN SPS
  
- two stage magnetic spectrometer → large angular acceptance
  
- data taking since 2002 → up to 580 TByte/year

---

1 [Nucl. Instr. and Meth. A 577 (2007) 455]
The COMPASS Experiment

Overview

- **Common Muon and Proton Apparatus** for Structure and Spectroscopy
- located at the CERN SPS
- two stage magnetic spectrometer → large angular acceptance
- data taking since 2002 → up to 580 TByte/year

Beam Rates

- (tertiary) Muon: → $4 \cdot 10^7 \text{s}^{-1}$
- (secondary) Hadron ($\pi$, K, ...): → $5 \cdot 10^6 \text{s}^{-1}$

---

1 [Nucl. Instr. and Meth. A 577 (2007) 455]
The COMPASS Experiment

Overview

- **COmmom Muon and Proton Apparatus for Structure and Spectroscopy**
  - located at the CERN SPS
  - two stage magnetic spectrometer
  - large angular acceptance
  - data taking since 2002
  - up to 580 TByte/year

Beam Rates

- (tertiary) Muon: $4 \cdot 10^7 s^{-1}$
- (secondary) Hadron ($\pi, K, ...$): $5 \cdot 10^6 s^{-1}$

Tracking

- Silicons ($\sigma_x \sim 10 \mu m$, SciFis ($\sigma_t \sim 0.4 ns$)
- GEMs ($\sigma_x \sim 70 \mu m$, MicroMegas ($\sigma_x \sim 90 \mu m$)
- Drift Chambers ($\sigma_x \leq 200 \mu m$)

[1][Nucl. Instr. and Meth. A 577 (2007) 455]
GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability

COMPASS requirements:
- beam rates: \( \lesssim 10^5 \text{ mm}^{-2} \text{ s}^{-1} \)

\[1\] [S. Bachmann, A. Bressan, B. Ketzer et al., Nucl. Instr. and Meth. A 470 (2001) 548.]
GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability \( ^1,^2 \)
- COMPASS requirements:
  - beam rates: \( \lesssim 10^5 \text{ mm}^{-2} \text{ s}^{-1} \)
- small material budget \( ^3 \)
  - center: \( x/X_0 = 0.4\% \)

\(^3\) [C. Altunbas et al., Nucl. Instr. and Meth. A 490 (2002) 177]
GEMs for Beam Tracking

Triple-GEM Detectors:
- high rate capability \(^1,2\)
- COMPASS requirements:
  - beam rates: \(\lesssim 10^5 \text{ mm}^{-2} \text{ s}^{-1}\)
  - small material budget\(^3\)
  - center: \(x/X_0 = 0.4\%\)

Strip Readout
- strip occupancy too high
- no sufficient beam tracking with strip readout
GEMs for Beam Tracking

Triple-GEM Detectors:
- high rate capability \(^{1,2}\)
  - COMPASS requirements:
    - beam rates: \(\lesssim 10^5\) mm\(^{-2}\) s\(^{-1}\)
  - small material budget\(^3\)
    - center: \(x/X_0 = 0.4\ %\)

Strip Readout
- strip occupancy too high
- no sufficient beam tracking with strip readout

GEM detector with combined pixel/strip readout
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 µm
The combined Pixel-Strip-Readout

- 3-layer foil (base material: Kapton)
- thickness: 100 $\mu$m
- 32 x 32 pixels
- pitch: 1 mm
The combined Pixel-Strip-Readout

- 3-layer foil  
  (base material: Kapton)
- thickness: 100 µm
- 32 x 32 pixels
- pitch: 1 mm
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 $\mu$m
- 32 x 32 pixels
- pitch: 1 mm
- 1024 strip channels
  (512 x, 512 y)
- pitch: 400 $\mu$m
- equal charge sharing
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 \( \mu m \)
- 32 x 32 pixels
- pitch: 1 mm
- 1024 strip channels
  (512 x, 512 y)
- pitch: 400 \( \mu m \)
- equal charge sharing
The combined Pixel-Strip-Readout
The combined Pixel-Strip-Readout

Dimensions

- pixel area: $32 \times 32 \text{ mm}^2$
The combined Pixel-Strip-Readout

Dimensions
- pixel area: 32 x 32 mm$^2$
- active area: 100 x 100 mm$^2$
GEM Geometries and Settings
GEM Geometries and Settings

GEM Parameters
- double-conical etched holes
- 140 \( \mu m \) pitch
- 70 \( \mu m \) outer hole diameter
GEM Geometries and Settings

GEM Parameters
- double-conical etched holes
- 140 µm pitch
- 70 µm outer hole diameter

GEM Characteristics
- segmented foils
- triple amplification
- asymmetric gain sharing
GEM Geometries and Settings

**GEM Parameters**
- double-conical etched holes
- 140 $\mu$m pitch
- 70 $\mu$m outer hole diameter

**GEM Characteristics**
- segmented foils
- triple amplification
- asymmetric gain sharing

**Foil Properties**
- foil size: 330 x 330 mm$^2$
- no gas amplification in outer region
- big holes (Ø 0.5 mm) only for gas exchange
The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

GEM Geometries and Settings

**GEM Parameters**
- double-conical etched holes
- 140 $\mu$m pitch
- 70 $\mu$m outer hole diameter

**GEM Characteristics**
- segmented foils
- triple amplification
- asymmetric gain sharing

**Foil Properties**
- foil size: 330 x 330 mm$^2$
- no gas amplification in outer region
- big holes ($\varnothing$ 0.5 mm) only for gas exchange


Florian Haas - TU München Physik Department E18
COMPASS PixelGEM Production
Assembly
The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

- All constructional drawings done at TU Munich (with advice of CERN engineers)
- The same for the layout of the foils (Gerber files)
- Foils and support structures manufactured at CERN
- Testing, assembly and commissioning done at TU Munich
Infrastructure

The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

Production
class 100

Oven
Clothes
Entrance Area

UltraSonic Bath
Gas Line (nitrogen)

Test Area
Test Box

PC

Dry Box

Testing
class 1000

Microscope
Light Table

Florian Haas - TU München Physik Department E18
COMPASS PixelGEM Production
Preparation

- Sanding of all support frames to remove grouts (danger of shortcuts in the detector)
- Cleaning of components with Isopropanol and demineralized water in ultrasonic bath
- Storage of foils in nitrogen atmosphere to avoid oxidation

**After preparation touch components only with gloves**
(fingerprint on foils can cause 1 mA leakage current!)
Quality Assurance I - Optical Inspection
Quality Assurance I - Optical Inspection
Quality Assurance I - Optical Inspection
Quality Assurance I - Optical Inspection
Quality Assurance I - HV Tests

- HV tests for Driftplates, Spacergrids and Driftfoils done by ambient atmosphere
- HV tests for GEM foils under nitrogen atmosphere (no oxygen or water allowed)
Quality Assurance I - HV Tests
Gluing

Stretching frame for fixation and flattening of GEM foils during gluing process
Gluing

- Alignment Spacers
- Clamps
- Screws for Stretching

Florian Haas - TU München Physik Department E18
Gluing

- Electrical Tracks
- Gas Hole
Gluing
Gluing

- monitoring of environmental conditions during each production step
- complete polymerization of glue important
  \[\rightarrow\] constant, defined temperature for several hours
Gluing
Quality Assurance II

After each production step the components have to be tested for their stability and functionality.
Assembly

Complete assembly in two steps

- **Step 1:** Gluing the GEM stack, consisting of 3 GEM foils - Spacergrid pairs and Driftfoil glued on Driftplate
- Quality control
- **Step 2:** Gluing tested GEM stack on Readout
Each production step, from the preparation to the last commissioning must be documented.
Each production step, from the preparation to the last commissioning must be documented.

Webbased MySQL database including:
- Photos
- Quality tests
- Production logs
- Environmental data for each production step

For each detector complete summary available (PDF or online)
For detailed procedure steps and further commissioning see production guide\textsuperscript{1} at

\url{www.e18.physik.tu-muenchen.de}

\textsuperscript{1}Construction and Test of PixelGEM Tracking Detectors
Detector Performance
Gain

X-Ray Pixel Measurement: Center(rot), Total(blue)

Center Voltage [V], rest fixed to 3.9kV

Detector Voltage [V]

3650 3700 3750 3800 3850 3900 3950 4000 4050 4100 4150

Gas Gain

960 980 1000 1020 1040 1060

Florian Haas - TU München Physik Department E18

COMPASS PixelGEM Production
Beam Intensities

Estimations of particle flux in the pixel region

**Myon beam**
- $4.8 \times 10^7 / s$
- $\leq 1.2 \times 10^5 / s / mm^2$

**Pion beam**
- $5 \times 10^6 / s$
- $\leq 1.6 \times 10^4 / s / mm^2$
Spatial Resolution

**Low Intensity**: \( \leq 2 \cdot 10^3 / \text{s/mm}^2 \)

\[ \bar{\sigma} = 90 \mu\text{m} \]

**High Intensity**: \( \leq 1 \cdot 10^5 / \text{s/mm}^2 \)

\[ \bar{\sigma} = 135 \mu\text{m} \]

with/without Clustering, green: Gauss fit components
**Time Resolution**

**Low Intensity:** \( \leq 2 \cdot 10^3 \text{s/mm}^2 \)

\[ \begin{align*}
A_{\text{Signal}} & = 4000 \pm 0.2 \\
t_{0,\text{Signal}} & = 0.3386 \pm 0.0163 \\
\sigma_{\text{Signal}} & = 6.918 \pm 0.017 \\
A_{\text{Background}} & = -446.3 \pm 5.3 \\
t_{0,\text{Background}} & = -4.362 \pm 0.079 \\
\sigma_{\text{Background}} & = 19.14 \pm 0.08
\end{align*} \]

\( \sigma_t \leq 7 \text{ns} \)

**High Intensity:** \( \leq 1 \cdot 10^5 \text{s/mm}^2 \)

\[ \begin{align*}
A_{\text{Signal}} & = 5252 \pm 57.8 \\
t_{0,\text{Signal}} & = 2.548 \pm 0.035 \\
\sigma_{\text{Signal}} & = 7.718 \pm 0.073 \\
A_{\text{Background}} & = 9015 \pm 59.2 \\
t_{0,\text{Background}} & = -4.382 \pm 0.117 \\
\sigma_{\text{Background}} & = 27.47 \pm 0.22
\end{align*} \]

\( \sigma_t \leq 8 \text{ns} \)

*blau*: Signal, *magenta*: Underground
**Detector Efficiency**

**Low Intensity**: $\leq 2 \cdot 10^3 / s / \text{mm}^2$

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

Mean Efficiency $\approx 99.3 \%$

Mean Efficiency $\approx 95.5 \%$
Readout Chain

![Diagram of the readout chain](image_url)
Spatial/Time Resolution COMPASS Triple GEM Detectors

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
  \( \langle \sigma_t \rangle \approx 12 \text{ ns} \)

[Florian Haas - TU München Physik Department E18]

[COMPASS PixelGEM Production]
Efficencies COMPASS Triple GEM Detectors

Low intensity beam: $5 \times 10^6 \mu^+$/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: $4 \times 10^7 \mu^+$/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)]

[B. Ketzer et al., NIM A535, 314 (2004)]
The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

Efficiency Plateau

**Low Intensity:** $\leq 2 \cdot 10^3 / s/mm^2$

**High Intensity:** $\leq 1 \cdot 10^5 / s/mm^2$

Efficiency Plateau: 98.5 %

Background per pixel: $\leq 0.1 %$

Efficiency Plateau: 95.5 %

Background per pixel: $\approx 2 %$

Background: probability to find uncorrelated clusters within a certain roadwidth around a track

Florian Haas - TU München Physik Department E18

COMPASS PixelGEM Production
FrontEnd-Electronics

- APV25 S1 ASIC\(^1\)
- 128 channels per APV
- 160 samples pipeline
- 40 MHz sampling frequency
- average noise: 
  \(\sim 1300 - 1500\) electrons
- used for Silicon, GEM and RICH at COMPASS

Front-End Electronics

Readout Scheme
- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information
⇒ clustering
⇒ time reconstruction
Front-End Electronics

Readout Scheme

- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information
⇒ clustering
⇒ time reconstruction
Front-End Electronics

Readout Scheme
- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information
⇒ clustering
⇒ time reconstruction
The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

crosstalk suppression

beamspot with crosstalk
crosstalk suppressed

tag channels with high-amplitude neighbours
after clustering: remove clusters containing mostly tagged pixels
The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

Material Budget

<table>
<thead>
<tr>
<th></th>
<th>Centre [(X_0/1000)]</th>
<th>Periphery [(X_0/1000)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support</td>
<td>0.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Driftfoil</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 Foil</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>Sum</strong></td>
<td><strong>3.9</strong></td>
<td><strong>7.1</strong></td>
</tr>
</tbody>
</table>

Centre: \(r < 15\) mm, Periphery: \(r > 15\) mm

Cu layer 5 \(\mu\)m
## Material Budget

<table>
<thead>
<tr>
<th></th>
<th>Centre</th>
<th>Periphery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>([X_0/1000])</td>
<td>([X_0/1000])</td>
</tr>
<tr>
<td>Support</td>
<td>0.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Driftfoil</td>
<td>0.5 / 0.3</td>
<td>0.5 / 0.3</td>
</tr>
<tr>
<td>3 GEM-Foils</td>
<td>2.1 / 0.8</td>
<td>2.1 / 0.8</td>
</tr>
<tr>
<td>Readout Foil</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>Sum</strong></td>
<td><strong>3.9 / 2.4</strong></td>
<td><strong>7.1 / 5.6</strong></td>
</tr>
</tbody>
</table>

Centre: \(r < 15 \text{ mm}\), Periphery: \(r > 15 \text{ mm}\)

Cu layer 5 \(\mu\text{m} / 1 \mu\text{m}\)
Modifications Prototype - Prototype II
The PixelGEM Project

The COMPASS Experiment
The PixelGEM Detector
GEM Assembly
Detector Performance

The PixelGEM Project

Florian Haas - TU München Physik Department E18

COMPASS PixelGEM Production
The PixelGEM Project

Project Overview

- 2006 Development and first prototype (5 \( \mu \text{m} \)) in the COMPASS spectrometer
- 2007 Improvements in design and electronics, second prototype (1-2 \( \mu \text{m} \)) in the spectrometer
The PixelGEM Project

- 2006 Development and first prototype (5 \(\mu\)m) in the COMPASS spectrometer
- 2007 Improvements in design and electronics, second prototype (1-2 \(\mu\)m) in the spectrometer
- 2008 Five PixelGEMs installed