562. A new Triple-GEM Tracking Detector for COMPASS++/AMBER

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COMPASS
COmmon Muon and Proton Apparatus for Structure and Spectroscopy

• Located at CERN
• Two-stage spectrometer
• Will be used for AMBER
  • $\mu - p$ elastic scattering
    ▶ Active target
    ▶ 2MHz with 100 GeV $\mu$-beam

COMPASS GEM DETECTORS - K. J. Flöthner [1]
Motivation for new Detectors

- 22 first large-size GEM detectors in operation since 2001/2002 (Replacement and spares needed until 2021)
- General need to upgrade electronics (e.g. exchange outdated connectors)
- Self triggered readout planned in future (i.e. replace APV25 by e.g. VMM)
GEM
Gas Electron Multiplier

- Invented by F. Sauli 1997
- Belongs to MPGD
- Perforated metal-coated polyimide foil
- Standalone amplification stage
  - Separated readout

[Image of GEM diagram with labels: Drift/Transfer, Amplification, Induction/Extraction]

COMPASS GEM DETECTORS - K. J. Flöthner
GEM
Gas Electron Multiplier

[Image of GEM structure with labels for outer and inner diameters, and a zoom-in on pitch and view.]

[Caption: COMPASS GEM DETECTORS - K. J. Flöthner]
COMPASS GEM Detectors

Content:
- Multi-GEM Detector
- COMPASS GEM Generations
Multi-GEM Detector

- COMPASS setup as example
- Cascade of several GEMs
- Higher gain possible
- Discharge prevention
Multi-GEM Detector

- COMPASS setup as example
- Cascade of several GEMs
- Higher gain possible
- Discharge prevention
1st generation large-size GEM (Compass GEM 1st Generation)

- 30.7 cm x 30.7 cm active area
  - Continuous strips
- 13-fold top-sectored GEM
- Spacer frame with grid
- Gas-inlet via support plate
- Honeycomb plates

[9] COMPASS GEM DETECTORS - K. J. Flöthner
PixelGEM (CG2G)

- 10 cm x 10 cm active area
  - 3.2 cm x 3.2 cm pixel area
- 5-fold top-sectored GEM
- Spacer with grids
- Gas-inlet via support plate
- Honeycomb plates
Ongoing large-size GEM (CG3G)

- 30.7 cm x 30.7 cm active area
  - Strips divided in the centre to reduce occupancy
- 13-fold top-sectored GEM
- Spacer without grids
- Gas-inlet via drift plate
- Honeycomb plates
Insight into the design

Content:
- GEM foils
- Readout foil
- Frames
GEM Foil Design

- Triple GEM stack
- Foils segmented on one side: 12 sectors + centre
- All lines guided through one corner with coverlay protection
- Cu thickness reduced
Readout Plane

- Readout from all sides
- 4x768 strips (cut in middle)
- Hirose FX10 replace older Panasonic P5 series
Frame-Stack for one Detector

- Drift-Frame 3 mm
- GEM-Frames 2 mm
- R/O-Frame 2 mm
Drift Frame of 3 mm

- Gas-out
- Alignment holes
- Gas-in
- Gas distributor slits with increasing size
Electronics

Content:
- APV Front-End
- Supply Card
- HV-Board(s)
APV Frontend

Christian Honisch (honisch@hiskp.uni-bonn.de)

- One Detector:
  - 4x Supply card
    - Each 6x APV Front-End
- Improved input protection
- I²C temperature sensor
- I²C addresses: via detector connection
Supply Card

Christian Honisch (honisch@hiskp.uni-bonn.de)

- Provides Power, Clock, Trigger to APV-FE
- Concentrates analog signals from APV-FE
- **Clock, Trigger, Analog: Matched Lengths**

![Supply Card Diagram]

- Power Input
  - 3.3V, 3A(max)
- GPIO
  - I²C, 16 IO
- Clock / Trigger Fanout
  - Outputs Matched to **150ps**
- Ribbon Cable Connector
  - Analog
  - Clock, Trigger
  - I²C
HV Board(s) SVD

Christian Honisch (honisch@hiskp.uni-bonn.de)

- One Detector:
  - 3+1 HV-Boards
  - Stabilized voltage
  - Switchable configuration
  - Low impact of shorted segments
- Short circuit on segment A -> 15mV drop on segment B (previous: 25V)
- Switch for Central Pad Voltage (GEM<500V)
- Protection for Fault Cases
- Monitoring in preparation

<table>
<thead>
<tr>
<th>Electrode</th>
<th>COMPASS / V</th>
<th>BONN² / V</th>
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<tbody>
<tr>
<td>Drift</td>
<td>-4100</td>
<td>-3255</td>
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<tr>
<td>GEM1 TOP</td>
<td>-3353</td>
<td>-2508</td>
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<tr>
<td>GEM1 BOT</td>
<td>-2943</td>
<td>-2102</td>
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<tr>
<td>GEM2 TOP</td>
<td>-2196</td>
<td>-1751</td>
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<td>GEM2 BOT</td>
<td>-1822</td>
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<td>GEM3 TOP</td>
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<td>-1068</td>
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<td>GEM3 BOT</td>
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<tr>
<td>PCB</td>
<td>(GND) 0</td>
<td>(GND) 0</td>
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</table>
Next Steps

- Commissioning of the new CG3G prototype
- Tests measurements with the new SVD (BONN settings)
- Further production with slight optimizations
- Integration of CG3G detectors in the COMPASS spectrometer
Outlook

- CG3G production
- Further investigations in hybrid readout system
- Prototyping and testing CG4G
- Design for CG5G
- Prototyping and testing CG5G

Self triggered readout e.g. with VMM

Updated Large-size

Large-size with Pixel

2021 2022 2023 2024
Thanks
stay healthy
References

Framing: GEM
STRETCHING TOOLS

- Foil stretching by pneumatic DEK (Vectorguard®) frame produced by ASM Assembly.
- Foils equipped in aluminium profiles (Optiguard®) – see “QA of GEM foils”
- Foil in a profile is installed in the DEK frame
- By applying 0.5 MPa pressure DEK claws open allowing foil to be installed
- Releasing pressure closes DEK claws which stretch GEM
- DEK frame stretching force: 10 N/cm
Readout Frame of 2 mm

- Gas-out
- Gas slits with same size
- Alignment/holding framework
GEM Frame of 2 mm

Planned cutting bridges

Gas-out

Glueing rims
Progression
Of Compass Gem Generations

CG1G
Large-size GEM

CG2G
Updated Large-size

CG3G

Updated Pixel GEM

CG4G
Large-size with Pixel

CG5G
Large-size with Pixel

2001 2008 2021 2022 2023 - 2024?

Pixel GEM

Self triggered readout e.g. with VMM

COMPASS GEM DETECTORS - K. J. Flöthner
Standard parameters

- Outer diameter: 70 µm
- Inner diameter: 50 µm
- 50 µm polyimide
- 5 µm copper
- 140 µm pitch
• Standard parameters
  ▶ Outer diameter: 70 µm
  ▶ Inner diameter: 50 µm
  ▶ 50 µm polyimide
  ▶ 5 µm copper
  ▶ 140 µm pitch
GEM Manufacturing

Double Mask
- Polyimide foil between thin copper layers
- Photoresist lamination, masking, exposure and development
- First metal etching
- Polyimide etching
- Second metal etching
- Second masking to define electrodes
- Last metal etching and cleaning

Single Mask

COMPASS GEM DETECTORS - K. J. Flöthner
First Evaluation of Frames

Drift Frame 01
First Evaluation of Frames

Readout Frame 01

Glueing rims
HV Board(s)

- Resistor chain for high voltage distribution
  
  › Remote-controlled switch to activate/de-activate central area  
  (For CG1G with a separate relay near the detector)

![HV Board Diagram]

C. Altunbas et al., NIM A490, 188 (2002)
HV Board(s)

- One PCB for each foil (logic distributed over four identical boards)
- Stabilized Voltage Divider as second Step Project (idea by H. Müller, RD51)
- Switching of center voltage via I^2C

Further Potential

- Large areas covered
  (~ m$^2$, in order to replace MWPC)

- Beam tracking for high-rate > 100MHz / cm$^2$

- Hybrid readout optimized for fixed target geometry

- Radiation hard (small to no aging observed)

- Miniscule material budget in full active area with < 1% $X_0$
Detector Simulator

Christian Honisch (honisch@hiskp.uni-bonn.de)

- Simulates detector capacity
- I²C addresses switchable
- Capacity changeable for first two channels
- Can be used to inject test pulses
APV Test Station

- Space for two FE
- Four monitoring ports
  - Analogue positive/negative
  - Trigger
  - Clock
APV Signal Processing
Pulse Shape Reconstruction

- Prove the functionality of new FE
- Three sample mode used
  - Each with 25 ns delay
- Latency scan performed
  - Systematic shift of $t_0$
- Latency defines at which point the pipeline should be analysed
Pulse Shape Reconstruction

Amplitude vs Latency ID3 channel 42
ENC Observation

• Should give an estimate if the line driver improves the performance

• Realistic test pulse used
  ▶ Corresponds to a MIP
  ▶ 240,000 signal electrons
    - $V_{\text{in}}$ set to 3.2 V

\[
ENC = Q_{\text{Signal}} \frac{\text{Noise}}{\text{Signal}}
\]

\[
Q_{\text{Signal}} = V_{\text{in}} \frac{R_2}{R_1 + R_2} C_P = V_{\text{in}} \frac{10 \Omega}{820 \Omega + 10 \Omega} \frac{1}{1 \text{ pF}}
\]
ENC Comparison

ENC in Number of Electrons vs. Channel

APV25 S0

APV25 S1

closed symbols: peak mode: 270 + 38/pF
open symbols: deconvolution: 430 + 61/pF

With line driver

Without line driver

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Requirements

- High spatial and time resolution for optimized tracking
- High rate capability for stable operation
- Small material budget to reduce interactions with dead material
- Build for long-term operation

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Spatial resolution</td>
<td>$&lt; 100 \mu m$</td>
</tr>
<tr>
<td>Time resolution</td>
<td>$\sim 10 \text{ ns}$</td>
</tr>
<tr>
<td>Rate capability</td>
<td>$&gt; 10^4 \text{ part. mm}^{-2} \text{ s}^{-1}$</td>
</tr>
<tr>
<td>Small material budget</td>
<td>$0.4 % X_0$</td>
</tr>
<tr>
<td>Large active area</td>
<td>$31 \text{ cm} \times 31 \text{ cm}$</td>
</tr>
<tr>
<td>Low aging</td>
<td>up to $7 \text{ mC mm}^{-2}$</td>
</tr>
<tr>
<td>Discharge prevention</td>
<td>prohibit channel loss</td>
</tr>
</tbody>
</table>

[8]
Scope of Cooperation

• Simulations & GEM production optimization
  (J. Ottnads HV-settings & ALICE experience)

• Self triggered readout:
  ‣ VMM
    (M. Lupberger - Bonn, L. Scharenberg - CERN)
  ‣ TIGER (Torino)

• Front-end design (C. Honisch - Bonn)

• Production:
  FTD (Bonn) and/or CERN

• ADCs and DAQ (I. Konorov - TUM)

• (VonRoll for mass production of frames)

• (Piekenbrink Composite GmbH for Honeycomb Plates)