Development of a Segmented GEM Readout Detector

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Working Principle of a Micromegas (MM)

- MICROMEsh GAseous Structure detector

- Drift region (≈ 5 mm):
  - Ionization of the gas in the drift region along the particle track
  - Low electric field ($E = 0.6$ kV/cm):
    - Separation of the electrons and ions in the drift region
    - $V_{\text{drift}} = 45 \mu$m/ns (110 ns for 5 mm)

- Amplification region (≈ 128 μm):
  - High electric field (≈50 kV/cm)
  - Amplification of the signal by an electron avalanche (Gain ≈ 5000-10000)

- Resistive anode layer
2D Resistive Layer Micromegas (DLC)

- **Anode:**
  - Resistive layer: Diamond Like Carbon (DLC)
- **2 perpendicular readout strip layers, each with:**
  - 360 readout strips
  - 250 μm pitch
- **120 μm high pillar**
- **Floating mesh (no bulk)**
- **Ar:CO₂ 93:7**
X/Y Strips: Multiple Particles at Same Time

• Two particles at the same time
  ⇒ Two signatures in each detector layer (X / Y)
  ⇒ 1D reconstruction works

• 2D position reconstruction:
  ◦ Combination of X and Y cluster
  ⇒ Four different possibilities
  ⇒ 2D reconstruction problematic

⇒ Solution: 3rd layer of readout strips turned by 45 deg
X/Y/V Strips: Multiple Particles

- New setup:
  - X/Y coordinate given by readout strips at the anode
  - V coordinate given by readout strips at the mesh location
- Unique 2D cluster combination possible
  - Reduction of the number of ambiguities by a factor 2-4
  - Further improvement by using charge and time information

\[ \text{reconstruction efficiency} = \frac{\# \text{particles}_{\text{correct reco}}}{\# \text{particles}_{\text{all}}} \]
Signal Readout at the Mesh Location

• Segmented mesh difficult to realize

• Use of a segmented GEM foil instead of the mesh
  ◦ Segmentation into strips on one side of the foil
  ◦ Produced at detector lab at CERN

• The segmented GEM foil is mounted on top of the pillars

• Readout of the GEM strips using APVs

⇒ Two amplification steps
  ◦ Inside GEM foil
  ◦ Inside amplification region of the MM structure
Segmented GEM Foil

- Bottom side [segmented]:
  - 212 readout strips, connected to APVs via Panasonic connectors
  - Strip pitch: 4 GEM holes $\triangleq 484 \, \mu m$

- Top side [not segmented]:
  - standard GEM foil, 10 cm x 10 cm, 70 $\mu m$ holes, 140 $\mu m$ hole periodicity
  - 4 mm thick frame (only on top side)

- Inverse layout exists: strips on top side, bottom side not segmented => works similarly well
• Four resistive strip Micromegas for precision reference tracking (3x2D & 1x1D)

• Investigated detectors:
  ◦ Segmented GEM MM Hybrid with strips on top side of GEM
  ◦ Segmented GEM MM Hybrid with strips on bottom side of GEM

• Determination of detector efficiency and resolution and pulse height for:
  ◦ different voltage combinations
  ◦ different inclination angles
Muons: Pulse Height Comparison GEM-MM

- Approx. same pulse height for top readout strips and GEM strips
  - Pulse height $_{\text{top}} \approx 1.5$ pulse height $_{\text{GEM}}$

- Optimized anode design exists with strip pitch 0.4 mm (not shown here)
  - Pulse height $_{\text{top}} \approx$ pulse height $_{\text{bot}}$

$\Rightarrow$ 2D particle reconstruction possible
Efficiency Determination (perpendicular μ-track)

**Efficient event:** $x_{\text{track}} - x_{\text{measured}} \leq \pm 1\text{mm}$

Efficiency = \frac{\# \text{ efficient events}}{\# \text{ reference tracks}}

⇒ Approx. same efficiency for top and GEM readout strips
Voltage offset: 20 V for all readout planes at detector with GEM strips on the top side (assembly of the detector)

⇒ Efficiency > 90% for GEM readout strips and top readout strips

**Det1: GEM strips on bottom side**

- Voltage offset: 200 V

**Det2: GEM strips on top side**

- Voltage offset: 200 V
Spatial Resolution Determination

• Residual:
  \[ \text{residual} = x_{\text{track}} - x_{\text{measured}} \]

• Resolution determination via a double gaussian fit:
  \[ \sigma_{1/2} = \sqrt{\sigma_{\text{core/tails}}^2 - \sigma_{\text{track}}^2} \]
  \[ \sigma = \frac{\sigma_1 \times \int \text{gauss}_1 + \sigma_2 \times \int \text{gauss}_2}{\int \text{gauss}_1 + \int \text{gauss}_2} \]

• Track accuracy \(< \sigma_{\text{det}}\)
Spatial Resolution (perpendicular µ-track)

- $U_{\text{anode}} = f(U_{\text{GEM}})$
- Best resolution for $U_{\text{GEM}} = 200\ V$, $U_{\text{anode}} = 440\ V$
  - $Res_{\text{GEM}} \approx 80\ \mu m$
  - $Res_{\text{anode top}} \approx 80\ \mu m$
  - $Res_{\text{anode bot}} \approx 100\ \mu m$

- Discrepancy in the resolution between top anode strips and GEM strips (charge movement on the DLC layer)
  - Can be improved

Det1: GEM strips on bottom side

Det2: GEM strips on top side

Det1: GEM strips on bottom side

Det2: GEM strips on top side
μTPC: Principle (20°)

- Determination of the angle and position via the strip times

\[ \text{angle} = 90° - \arctan \left( \frac{t \cdot v_{\text{drift}}}{\text{strips} \cdot \text{pitch}} \right) \]

- Position: μTPC track at \( t_{1/2} \)
  - influenced by 25 ns jitter (muon trigger uncorrelated with 25 ns clock of APVs)
Angular Resolution $\mu$TPC (26.5° and 20°)

- Incident angle 26.5° and 20°
- Angular resolution:
  - $\approx 2°$ for $\Theta = 20°$
  - $\approx 3°$ for $\Theta = 26.5°$
Spatial Resolution μTPC (20° and 26.5°)

- μTPC position reconstruction works in principle ✓
  - 1 mm efficiency >90%
  - Better resolution for GEM strips as for bottom anode strips ☺ (low pulse height on bottom anode strips)

- Charge weighted mean spatial resolution (GEM strips):
  - θ = 20°: resolution ≈ 350 µm
  - θ = 26.5°: resolution ≈ 450 µm

- 25 ns trigger Jitter not corrected (+/- 12.5 ns ± 220 µm)
FE55: Ar Escape Peak Analysis

- Investigation of the pulse height using Fe55
  - Two peaks:
    - Peak at 5.9 keV: $\gamma$ of Fe55
    - Peak at 2.9 keV: $K_\alpha$ photon (Ar)
  - Expected ratio: $\frac{5.9 \text{ keV}}{2.9 \text{ keV}} = 2.03$

- Reconstructed ratio close to 2.03 (top -, and GEM – readout strips)
  - $\frac{\Delta E}{E} (\text{Fe55}) = 22.2\% \ (FWHM)$
  - Good energy resolution
Summary

• Segmented GEM Readout Detector:
  ◦ Y-readout with segmented GEM works (tracking efficiency > 90 %)
  ◦ X-readout by standard resistive Micromegas anode strips (tracking efficiency > 90 %)
  ◦ 2nd Y-readout by standard resistive Micromegas anode strips
    (off working point => optimized anode design exists)

• Resolution for perpendicular tracks
  ◦ 2D tracking with $\sigma_x = 75 \ \mu m = \sigma_{y-GEM}$ possible

• Resolution for inclined tracks
  ◦ $\mu$TPC possible on anode strips and GEM strips
  ◦ Angle reconstruction works: $\sigma_{angle} = 2^\circ - 3^\circ$
  ◦ Position determination works:
    ◦ 20°: $\sigma_{GEM} < 180 \ \mu m$
    ◦ 26°: $\sigma_{GEM} < 220 \ \mu m$

• Next Step: Build X/Y/V detector for reduction of ambiguities
Backup
FE55: Ar Escape Peak Analysis

Ar:CO₂ 93:7

\[
Pulse \, height = \sum_{signal \, strips} Q_{strip}
\]

- Saturated events are discarded (\(Q_{strip} > 1500\) ADC counts)
- Highest signals for different \(U_{GEM}\) without saturated strips are shown
- Escape peak visible for multiple voltages (\(U_{ampl}\) & \(U_{GEM}\))
Charge and Time Weighted Mean

- Higher weight for immediate (fast) signal
- Lower weight for charge movement (later) signal
- Weight signal strip $\propto \frac{1}{t^2}$ and $\propto Q$

$$x_{time} = \frac{\sum \text{strip} \times \frac{Q}{t^2}}{\sum \frac{Q}{t^2}}$$

$\Rightarrow$ Improvement of the top anode strip resolution
Resolution Determination (Centroid) III

• Combination GEM strips and bottom anode strips
  \[ y_{combined} = \frac{y_{GEM} \times \text{pulse height}_{GEM} + y_{anode} \times \text{pulse height}_{anode}}{\text{pulse height}_{GEM} + \text{pulse height}_{anode}} \]

• Slightly better resolution

• No larger increase due to big difference in resolution
Spatial Resolution (perpendicular µ-track)

- Resolution depending on pulse height (cluster charge)
- Best Resolution at pulse height ≈ 2000 ADC counts (not reachable at $U_{\text{GEM}} = 300\text{V}$)
- Better transparency for GEM foil with higher $U_{\text{GEM}}$
  ⇒ Compromise needed
- Better resolution for GEM strips as for anode strips

![Graph showing resolution vs. pulse height for Top anode strips and GEM strips at different voltages (300V, 200V, 100V).]