Development of High-Resolution Muon Tracking Systems Based on Micropattern Detectors

J. Bortfeldt, O. Biebel, R. Hertenberger, D. Heereman
LS Schaile
Ludwig-Maximilians-University Munich
ANIMMA 2011 Ghent
June 8th 2011

DFG
Introduction and Motivation

- tracking system for 140 GeV muons @ H8-beamline/CERN
- large area detector systems with good spatial resolution $\Delta x \approx 60\mu m$ and high rate capability ($O(m^2)$)
- investigate general behavior of GEM and Micromegas
- investigate spatial resolution of GEM/Micromegas under irradiation with $\gamma$ @ GIF/CERN and $n$ @ MLL tandem accelerator Munich
• MICROMEsh GAS detector
• 360 strips with 150μm width and 250μm pitch → active area: 90mm x 100mm
• 128μm amplification gap
• 5-7mm drift gap
• Ar:CO$_2$ at NTP

• triple GEM detector
• active area: 100 mm x 100 mm
• unsegmented anode or strips with 150μm width and 250μm pitch
• GEM spacing: 2-3mm
• drift gap: 3-4mm
flashADC: Setup & Data Analysis

- 12 bit 1GHz fADC with 2520ns recording time
- trigger: **coincident** or **single**

**Signalshape MICROMEGAS, typical event**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td>69.38 ± 0.1496</td>
</tr>
<tr>
<td>inflect.p.</td>
<td>548.1 ± 0.4151</td>
</tr>
<tr>
<td>sigrise/4.4</td>
<td>34.45 ± 0.3457</td>
</tr>
<tr>
<td>amppoffset</td>
<td>77.32 ± 0.09551</td>
</tr>
</tbody>
</table>

- pulse height, rise time, timing
- cut: mean2-mean1>3σ
Energy Resolution @ 5.9keV X-rays

GEM: \(\frac{dE}{E_{\text{FWHM}}} = 18\%\)

Micromegas: \(\frac{dE}{E_{\text{FWHM}}} = 24\%\)
Micromegas: Signal Formation

- $e^-$ from ionization reach amplification gap: 10-100ns
- gas amplification: <1ns
- total $e^-$-charge on anode, ion cloud induces negative surface charge on anode and mesh
- ions from gas amplification drift towards mesh: 150ns
- observable charge on
  - anode: $q_{a}(t) = q_{e}(t) - q_{ai}(t)$
  - mesh: $q_{m}(t) = q_{i}(t) - q_{mi}(t)$
• overall behavior reproduced by calculation
• charge sensitive preamp not fast enough to resolve steep initial rise (14% of total charge within 1ns → timing)
Micromegas: Capacitance & Pulse Height

- Strong influence of the capacitances in the detector-preamp network onto pulse height
- Agreement between data and calculation
Micromegas: Capacitance & Pulse Height

- signals computable with LTSpice IV

08.06.2011
Jona Bortfeldt (LMU Munich)
GEM: Signal Formation

- signals caused by $e^-$-drift in induction gap: $v_{\text{drift}} \approx \text{const.} \rightarrow t_{\text{rise}} \propto v_{\text{drift}}$
- increase of pulse height with decreasing number of read out strips (not as strongly as in Micromegas)

- $\text{HV}<<0$ cathode
- drift gap
- transfer gap GEM3
- transfer gap GEM2
- induction gap GEM1
- $\text{HV}=0$ anode
Muon Tracking System: Setup

- 4 Micromegas
- 2-dimensional track reconstruction
- readout: 6 Gassiplex FEs per detector, with 64 channels each, 1500 channels in total
- trigger: 6 scintillators (3\textsuperscript{rd} track coordinate) + 1 scintillator ($E_\mu > 600\text{MeV}$)
- irradiation with $^{137}\text{Cs}$ ($\gamma$) and $^{252}\text{Cf}$ ($\gamma + n$)
Micromegas: Efficiency to n and γ & reachable flux

- activity of source and solid angle known → expected rate
- efficiency = \( \frac{\text{rate}_{\text{meas}}}{\text{rate}_{\text{expec}}} \)
- adding 10-50mm lead → discrimination between γ and n

- \(^{137}\text{Cs}\):
  - \( E_{\gamma} = 662\text{keV} \),
  - \( \text{flux rate}_{\gamma} = (1.59\pm0.04)\text{MHz} \),
  - \( \epsilon_{\gamma} = (2.6\pm0.2) \times 10^{-3} \)
  - \( f_{\text{spark}} = (0.24\pm0.01)\text{min}^{-1} \)

- \(^{252}\text{Cf}\):
  - \( E_n \) up to 8MeV, \( E_{\gamma} \approx \text{keV} \ldots 4\text{MeV} \),
  - \( \text{flux rate}_{n} = (9.1\pm0.3)\text{kHz} \),
  - \( \text{flux rate}_{\gamma, \text{fission}} = (16.4\pm1.3)\text{kHz} \),
  - \( \epsilon_{n} < 6.8 \times 10^{-4} \) @95% CL,
  - \( \epsilon_{\gamma} = (1.5\pm0.4) \times 10^{-3} \)
  - \( f_{\text{spark}} = (0.50\pm0.04)\text{min}^{-1} \)
Muon Tracking System: Data Analysis

- hits: center-of-gravity method, regarding only those strips with amplitude > 3\(\sigma\) around the one with maximum amplitude
- track reconstruction: linear fit through all detectors → alignment
- spatial resolution: compare prediction by 2 detectors with measured hit in 3\(^{rd}\) detector:
  \[ \delta = r_3 - r_2 \cdot d_{13}/d_{12} - r_1 \cdot (1 - d_{13}/d_{12}) \]
  \[ \Delta\delta = \Delta\delta(\Delta r_1, \Delta r_2, \Delta r_3) \]
- 4 different triplets of 4 detectors & 4 \(\Delta r_i\) → solveable
Micromegas: $\Delta r$ under Irradiation

<table>
<thead>
<tr>
<th>Micromegas</th>
<th>$\Delta \delta$, no irrad.</th>
<th>$\Delta \delta$, $^{137}$Cs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>105±5 μm</td>
<td>108±5 μm</td>
</tr>
<tr>
<td>2</td>
<td>108±5 μm</td>
<td>108±6 μm</td>
</tr>
<tr>
<td>3</td>
<td>118±7 μm</td>
<td>117±5 μm</td>
</tr>
<tr>
<td>4</td>
<td>122±7 μm</td>
<td>119±5 μm</td>
</tr>
</tbody>
</table>

- no irradiation:
  - $(\Delta r_i)^2 = (\Delta r_{int})^2 + (\Delta r_{ms})^2$
  - $\Delta r_{ms} = 0.13 \text{ μm/mm} \cdot d_{ui}$
  - $\Delta r_{int} \approx 80\text{μm}$

- γ-irradiation: no significant increase

- n-irradiation: no significant increase expected (since pulse height remains unchanged)
• Micromegas and GEM detectors have been investigated, a muon tracking system has been set up
• efficiencies to muons of up to 99% are achieved, the FWHM energy resolution for 5.9keV X-rays is 18% (GEM) and 24% (Micromegas)
• models for signal formation have been presented, quantitative description of data by Micromegas
• single detector spatial resolution of Micromegas around 80μm, no degradation under γ-irradiation, no degradation under n-irradiation expected

Thank you!
• efficiency for muons up to 99% in both detector types
• stable operation $O(\text{week})$
• difference in efficiency $\leftrightarrow$ difference in pulse height