

High-Resolution Micromegas Based Pion and Muon Telescope

Jona Bortfeldt,

O. Biebel, R. Hertenberger, A. Ruschke, N. Tyler, A. Zibell

LS Schaile

Ludwig-Maximilians-Universität Munich, Germany

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Motivation

- tracking telescope for test beams: high resolution, high efficiency, good double hit resolution, high rate capability
- development & commissioning of muon tracking detectors

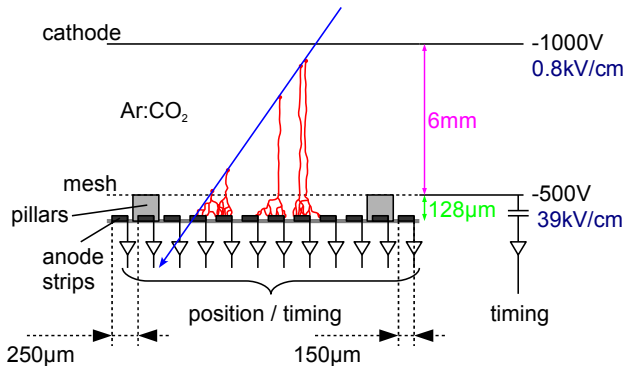
⇒ four $9 \times 10 \text{ cm}^2$ Micromegas with 360 strips (non-resistive)

Calibration Experiments

- H6: 120 GeV - 300 GeV π^-
- H8: \lesssim 160 GeV μ^-
- rates between 1/cm²s and 4.2×10^3 /cm²s
- two Ar:CO₂ gas mixtures **93:7** and **85:15**
- perpendicular tracks and tracks under non-zero angles
- multiple amplification and drift voltages
- statistics: \sim 6M pion and \sim 14M muon tracks

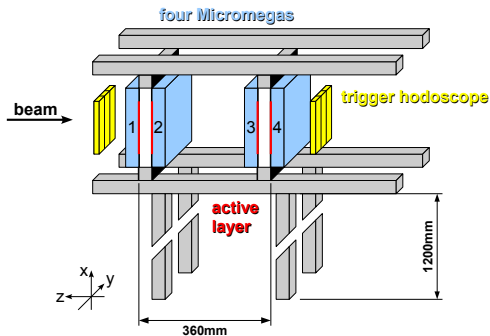
Setup

Micromegas Setup & Functional Principle



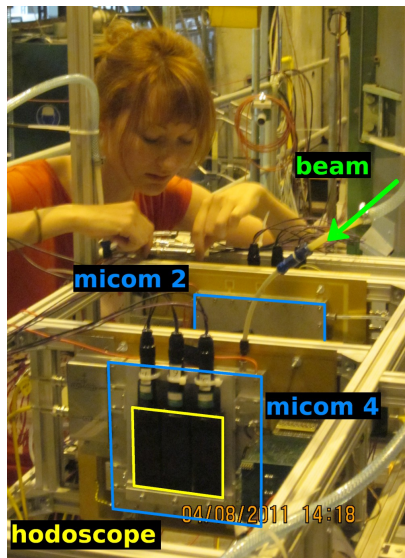
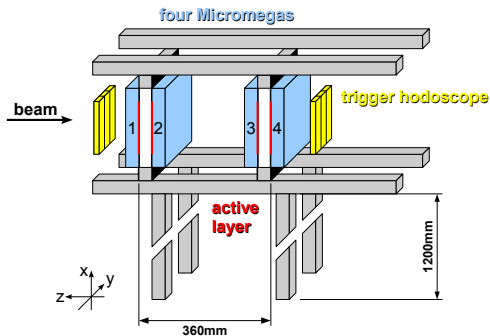
- ionization in 6 mm **drift region**
- gas amplification in 128 µm **amplification region**
- $90 \times 100 \text{ mm}^2$, 360 copper strips (150 µm width and 250 µm pitch)
- gas: Ar:CO₂ 93:7, 85:15 @ NTP

Testbeam Setup



- 4 Micromegas with 360 strips each, all strips parallel
- **trigger:** 2×3 scintillators
→ 3rd coordinate
- readout by Gassiplex frontends, 1500 channels in total
- gas-flux $\sim 1 \text{ ln/h}$ @ 1013 mbar stabilized pressure

Testbeam Setup



Gassiplex Readout Electronics

frontend boards:

- 4×16 analog channels, charge sensitive, multiplexing Gassiplex chips
- A/D conversion

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RIO2: PowerPC for VME

- readout control
- software threshold comparison
- ~ 400 Hz readout frequency
- multi-event buffering (4000 events per SPS spill)
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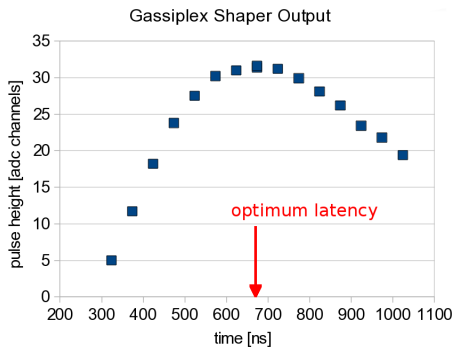
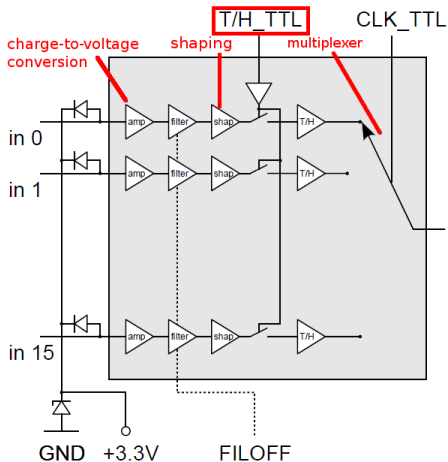
RIO2: PowerPC for VME

- readout control
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DAQ computer:

- ssh interface to RIO2
- data storage
- slow control (HV, flux, pressure, temperature)

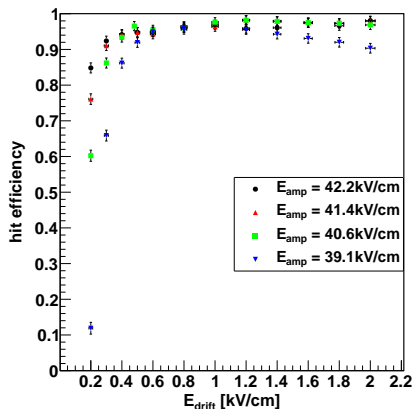
Trigger Latency



Efficiency & Drift Field

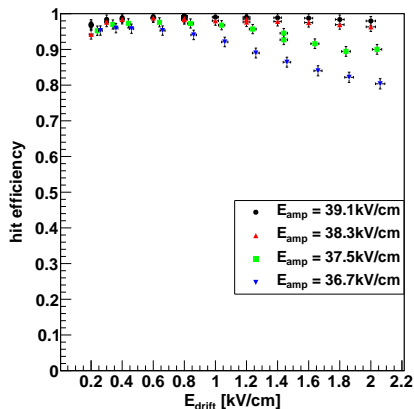
Ar:CO2 85:15

hit efficiency for pions, Ar:CO2 85:15, Micom 1



Ar:CO2 93:7

hit efficiency for muons, Ar:CO2 93:7, Micom 1



$$\epsilon_1 = \frac{\#\text{hit}_{1234}}{\#\text{hit}_{234}}$$

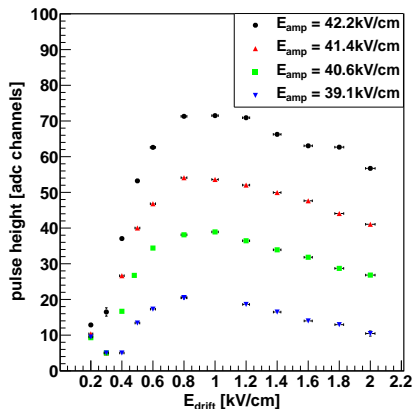
Optimization

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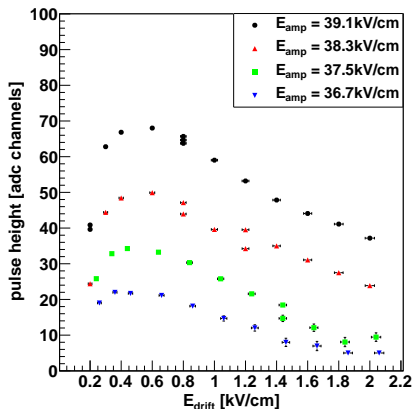
- optimize readout electronics w.r.t. speed, pulse height, stability
- optimize efficiency
- investigate stability (sparking) in high-rate hadron and muon beams
- determine and investigate spatial resolution
- investigate gas properties (drift velocity, diffusion \leftrightarrow spatial resolution)
- optimize reconstruction algorithms

Pulse Height & Drift Field

pulse height for pions, Ar:CO2 85:15, Micom 1



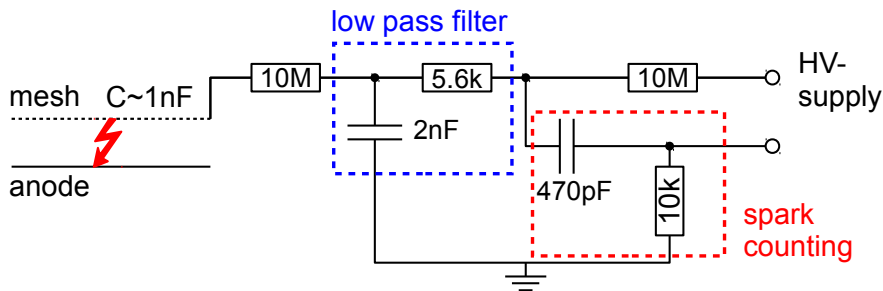
pulse height for muons, Ar:CO2 93:7, Micom 1



- separation of e^- & Ar^+ high $\leftrightarrow E_d$ high
- electric opacity of mesh low $\leftrightarrow E_d$ low

Sparks & Spark Counting

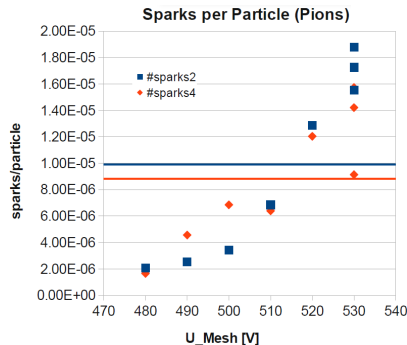
- discharges between mesh (-HV) and anode strips (ground), induced by large ionisation clusters ($> 1000e^-$)
- non destructive, dead time $< 20\text{ms}$
- detect the mesh recharge
- **pions**: spark probability $\sim 10^{-5}$ per particle, similar for all detectors



Sparking in Pion- and Muonbeams

pions:

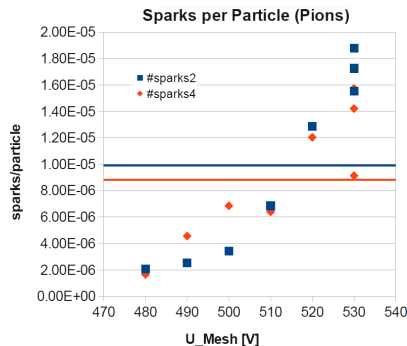
- particle flux $4.2 \times 10^3/\text{cm}^2\text{s}$
- sparking dominated by incident particles
→ similar for all detectors
- sparking probability $\sim 10^{-5}/\text{particle}$
- ~ 2 sparks per SPS spill
→ $< 0.4\%$ deadtime
→ negligible



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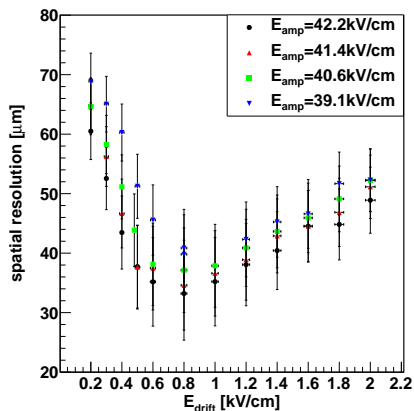


muons:

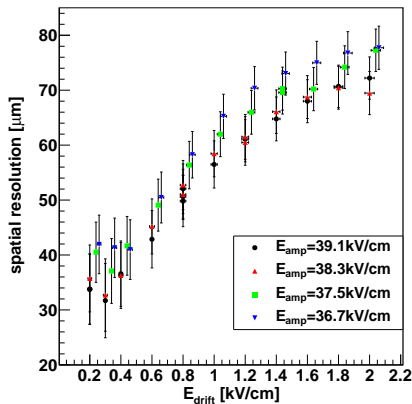
- particle flux $> 4/\text{cm}^2\text{s}$
- sparking dominated by small detector defects, factor 6 difference between detectors
- spark rates 1/30min to 1/5min → $< 0.04\%$ deadtime
→ completely negligible

Spatial Resolution & Drift Field

spatial resolution with pions, Ar:CO2 85:15



spatial resolution with muons, Ar:CO2 93:7



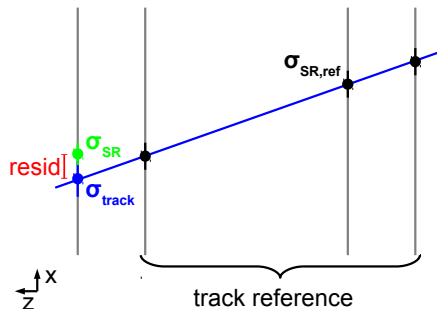
- decrease not only due to rising pulse height
- resolution \leftrightarrow number of electrons, entering the amplification gap

Analysis

Analysis Program

- calibration (every few hours)
 - update offsets for all channels from non-hit strips
- event loop
 - build charge clusters in all detectors, charge mean
 - extract data from the hodoscope
 - build first track by using the leading cluster in all detectors, y-info from hodoscope
 - fit track (90% of all tracks)
 - in case of multiple clusters: use chain algorithm for matching clusters in all detectors to the track (10%)
 - calculate residuals

Single Detector Spatial Resolution I – Track Extrapolation



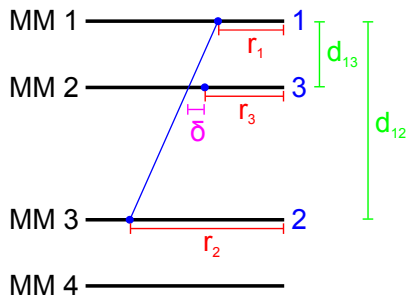
the method:

- extrapolate track from $n - 1$ detectors into the n th
- determine **residual** between measured hit and track prediction
- $\sigma_{\text{resid}}^2 = \sigma_{\text{track},n}^2 + \sigma_{\text{SR}}^2$

details:

- fit line $x(z) = az + b$ to $n - 1$ detectors \leftrightarrow minimize $\chi^2 = \sum_{i=1}^{n-1} \frac{x_i - az_i - b}{\sigma_{\text{SR},i}} \rightarrow a$ and b
- $\sigma_{\text{track}}(z)^2 = \langle (x(z) - \langle x(z) \rangle)^2 \rangle$
 $= \sigma_{\text{track}}(z, \sigma_{\text{SR},i})^2$

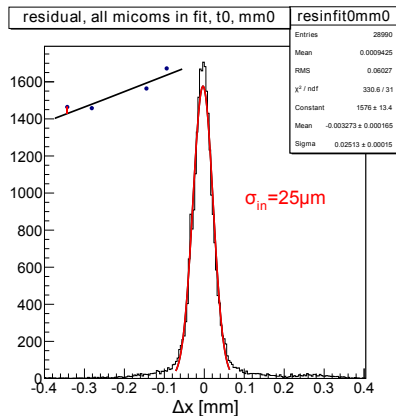
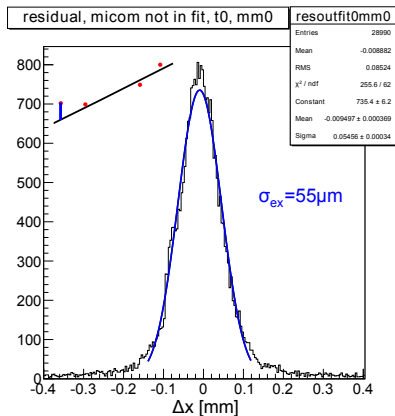
Single Detector Spatial Resolution II – 3 Layer Method



- interpolate **track prediction** by two detectors into 3rd and compare with measured hit in that detector
- $\delta = r_3 - r_2 \frac{d_{13}}{d_{12}} - r_1 \left(1 - \frac{d_{13}}{d_{12}}\right) \rightarrow$
 $(\Delta\delta)^2 = (\Delta r_3)^2 + \left(\frac{d_{13}}{d_{12}} \Delta r_2\right)^2 +$
 $\left[\left(1 - \frac{d_{13}}{d_{12}}\right) \Delta r_1\right]^2$
- 4 Δr_i & 4 different tripllett-equations
 \rightarrow solvable system

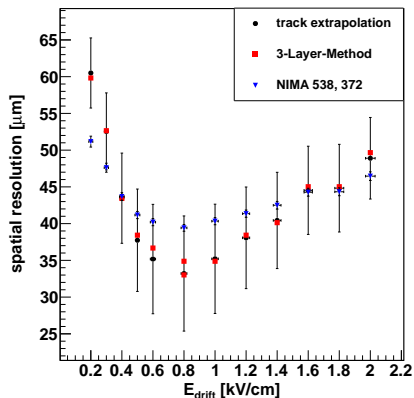
Single Detector Spatial Resolution III – NIMA 538, 372

- determine σ_{in} and σ_{ex} , i.e. the residual for the detector included in the fit and excluded respectively
- Carnegie et al.: spatial resolution $\sigma_{SR} = \sqrt{\sigma_{in} \times \sigma_{ex}}$
- $\sqrt{55 \times 25} \mu m = 37 \mu m$

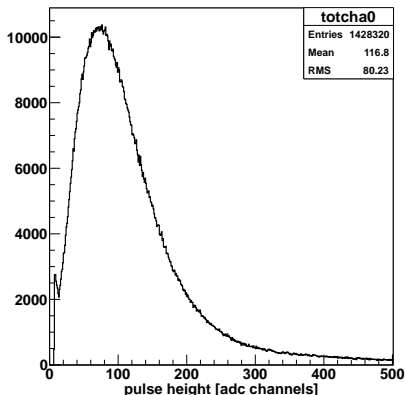


Comparison of the Three Methods

spatial resolution pions, 85:15, $E_{\text{amp}} = 42.2 \text{ kV/cm}$



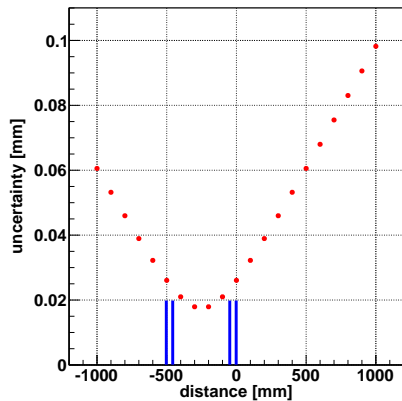
pulse height for 160GeV muons



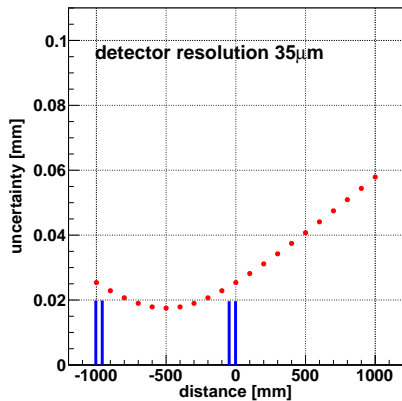
- method I and II equivalent
- method III tends to decrease the difference of spatial resolution for different detectors ($\sigma_{\text{SR,ref}} = 44 \pm 2 \mu\text{m}$)

Tracking Accuracy of the Telescope

track uncertainty for 500mm length



track uncertainty for 1000mm length



Summary & Outlook

- stable operation in pure hadron and muon beam over weeks,
 $p_{\text{spark},\pi} \lesssim 10^{-5}$
- optimization w.r.t. gas gain, drift field, trigger latency, readout configuration
- single detector spatial resolution $\sigma_{\text{opt}} \sim 35\mu\text{m}$
 \Rightarrow overall tracking resolution $\sigma \sim 20\mu\text{m}$
- track merging with additional DAQ systems possible (analog trigger tag)

to do:

- upgrade to 2×4 detectors
- upgrade to RIO3 VME controller $\rightarrow \sim 10$ kHz trigger rate
- merge readout system with MT-Online (spring test beam)
- merge readout system with SRS and $50 \times 50 \text{ cm}^2$ floating strip Micromegas (summer test beam)