Precision Calibration of Large Area Micromegas Detectors Using Cosmic Muons

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Origin and Structure of the Universe
The Cluster of Excellence for Fundamental Physics

Outline

Motivation: Excellent Spatial Resolution

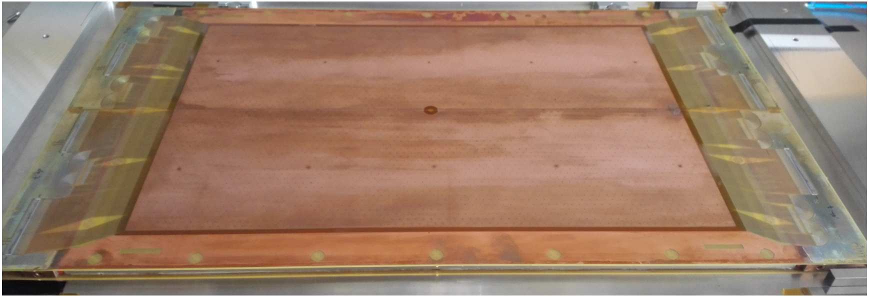
small Micromegas:

- simple construction
- accurate realization
- well understood

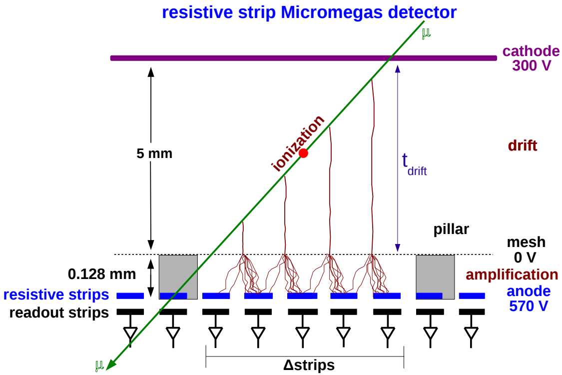
large Micromegas (request):

- accuracy conservation at large scale
- more than one PCB:
  - precise assembly needed

$\Longrightarrow$ calibration needed



Working Principle of Micromegas



- MICROMEsh GAseous Structure (Micromegas)
- electron drift region
- amplification region
- charge collection on resistive strips
- charge detection on readout strips by capacitive coupling

- centroid method:

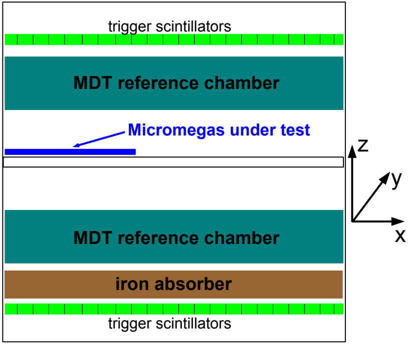
$$x_{\text{cen}} = \frac{\sum\limits_{\text{strips}} x_{\text{strip}} \cdot q_{\text{strip}}}{\sum\limits_{\text{strips}} q_{\text{strip}}}$$

- μTPC method: angle reconstruction

$$\Rightarrow \Theta = \arctan\left(\frac{1}{slope_{fit}} \times \frac{pitch}{v_{drift}}\right)$$

$$slope_{fit} = \frac{t_{drift}}{\Delta strip}$$

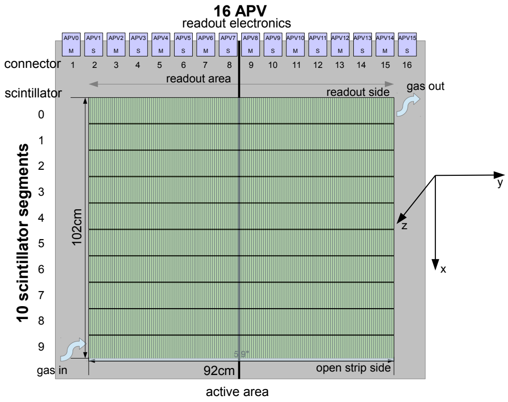
Cosmic Ray Facility, LMU Munich



- two Monitored Drift Tube (MDT) reference chambers
  $\Longrightarrow$ two reference tracks
- two trigger scintillator hodoscopes
  $\Longrightarrow$ second coordinate
  $\Longrightarrow$ segmentation of test Micromegas in 10 cm wide segments
- 34 cm iron absorber $\Longrightarrow E_\mu > 600\,\mathrm{MeV}$
- active area $9\,\mathrm{m}^2$, $\Theta \in [-30^\circ, 30^\circ]$

$\Longrightarrow$ investigation of the whole active area of 2-3 m^2 large Micromegas

$1\,\mathrm{m}^2$ Micromegas Chamber (L1)



- resistive strip technology
- **active area**: $0.92 \times 1.02\,\mathrm{m}^2$
- two readout boards with in total **2048 strips**
- **pitch**: $0.45\,\mathrm{mm}$
- Ar:CO_2 93:7 vol% @ atmospheric pressure

- **16 APV25 front-end** boards 57.6 mm wide (y - coordinate)
- **10 scintillator segments** 100 mm wide (x - coordinate)

$\Longrightarrow$ subdivision of detector in 16 APV $\times$ 10 scintillators = 160 partitions

$\Longrightarrow$ **calibration and alignment for each of the 160 partitions**

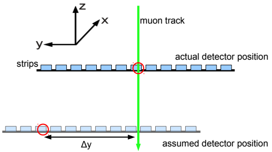
Alignment - Using Reference Tracks (160 partitions)

- measurement of y position
  (**perpendicular tracks**):
  residual via centroid method:
  $\text{res} = y_{\text{measured}} - y_{\text{predicted}}$
  $\Delta y = \text{res}$

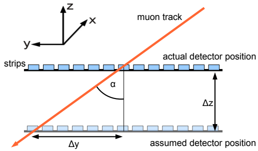
- measurement of z position
  (**inclined tracks**):
  $\Delta z = \frac{\text{res}}{\tan \alpha}$
  $\text{res} = m_{\text{y}} \cdot \Delta z$
  with $m_{\text{y}} = \tan \alpha$

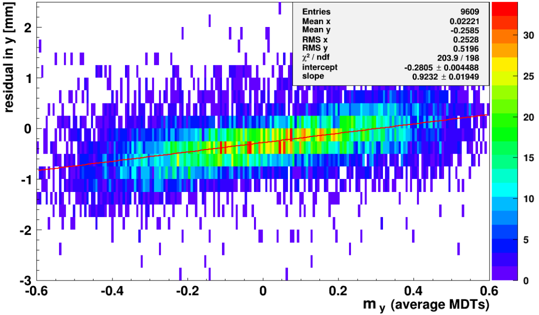
- fit with a straight line
  $\Rightarrow \Delta z = \text{slope}$
  $\Delta y = \text{intercept}$

measurement of y position



measurement of z position





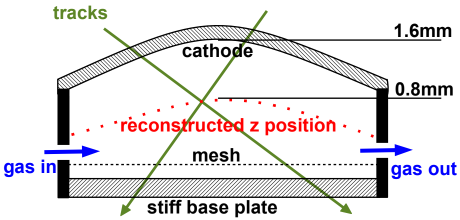
Deformation of Drift Region

inclined muon tracks:

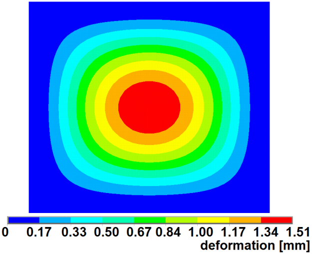
- drift gap deformation due to small overpressure (10 mbar)
- maximum deviation from plane measured ≈ 0.8 mm

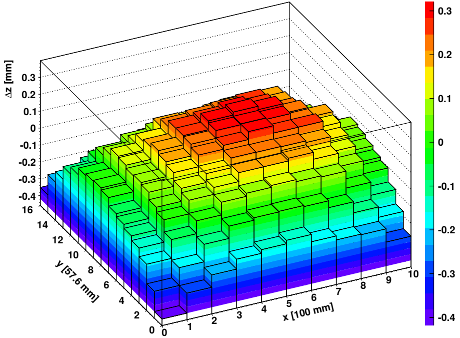
$\Longrightarrow$ 1.6 mm at cathode (stiff base plate support)

- resolution < 0.1 mm



finite element simulation (ANSYS)



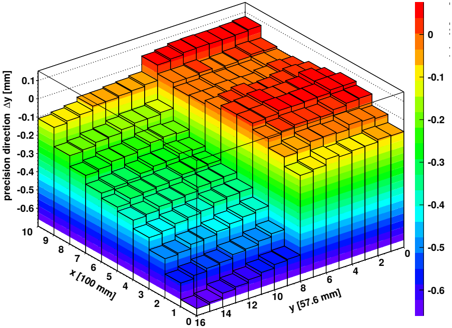


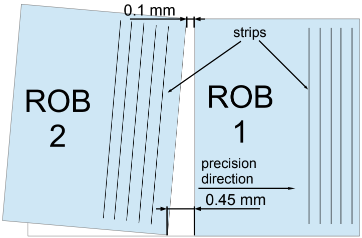
Strips Calibration – Shift between Readout Boards

- 2 readout boards
- no alignment tool used

perpendicular muon tracks:

- variation of gap size between PCB plates due to gluing
- **shift:** 100 µm
- **rotation:** 350 µm/m
- determination of strip position within 15 µm





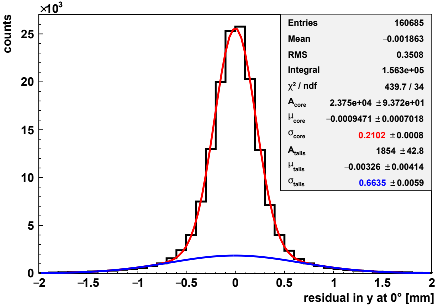
Spatial Resolution – CRF

determination of spatial resolution:

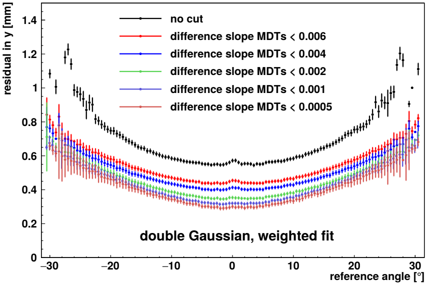
- residual with centroid method
- fitted with double Gaussian function
- sigmas weighted by integral

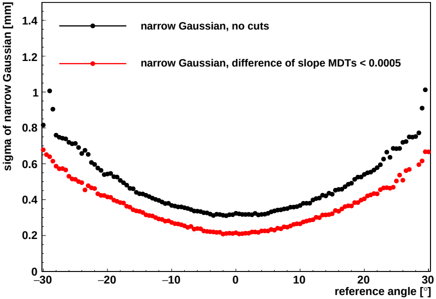
spatial resolution limited by:

- multiple scattering
- extrapolated tracks from MDTs



cut on slope of reference detectors

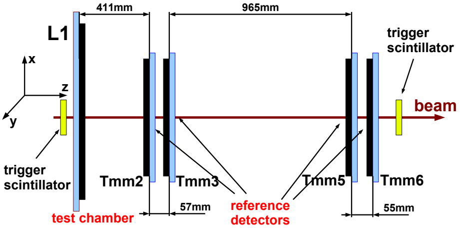


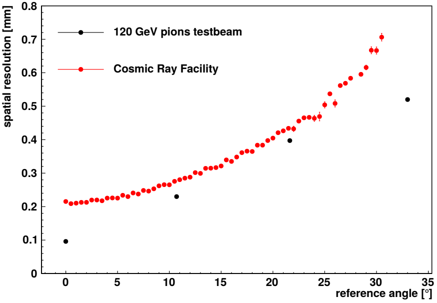


Spatial Resolution – Comparison to Testbeam Data

120 GeV pions testbeam (H6 @ SPS/CERN):

- centroid method
- spatial resolution at 0°: $\approx 100\ \mu m$
- angular dependent



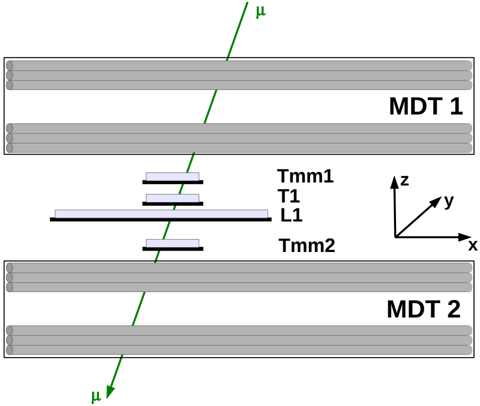


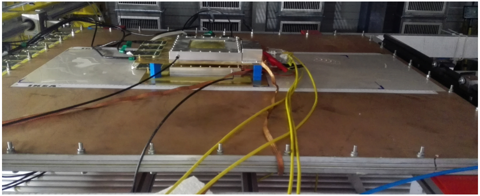
Micromegas Telescope in the CRF

- comparison of large and small Micromegas
- investigation of spatial resolution

telescope consisting of:

- $2 \times (9 \times 9)\,\text{cm}^2$ (Tmm1 + Tmm2)
  - 2D readout
  - $250\,\mu\text{m}$ pitch
  - $\sigma < 60\,\mu\text{m}$
- $1 \times (10 \times 10)\,\text{cm}^2$ (T1)
  - 1D readout
  - $400\,\mu\text{m}$ pitch
  - $\sigma < 80\,\mu\text{m}$
- $1 \times (102 \times 92)\,\text{cm}^2$ (L1)
  - 1D readout
  - $450\,\mu\text{m}$ pitch
  - $\sigma < 100\,\mu\text{m}$





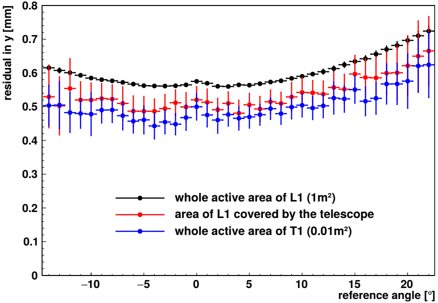
Analysis of Telescope Data

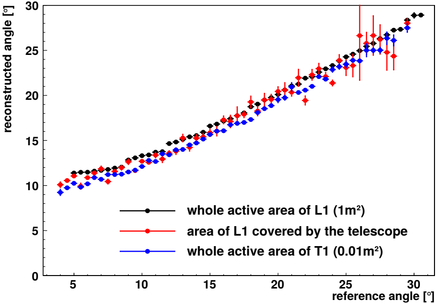
spatial resolution (centroid method):

- same reconstruction method as before, MDTs as reference, no cuts applied
- L1 restricted to size of T1
- large error bars due to low statistics for the broad Gaussian

angle reconstruction:

- same quality





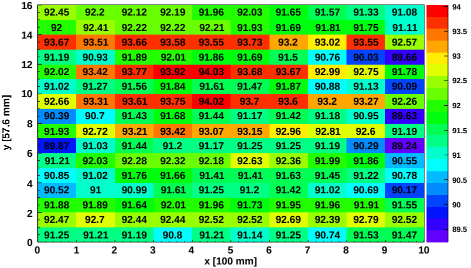
Efficiency

3σ tracking efficiency:

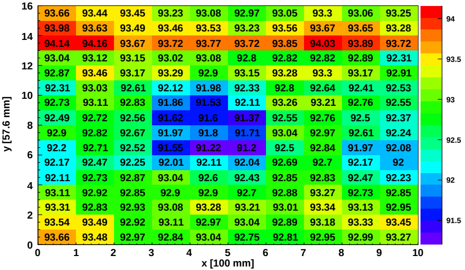
- homogeneous 3σ tracking efficiency over whole active area within 1 %
- limited by multiple scattering
- regions with lower efficiency due to edge effects

reduced efficiency due to increased multiple scattering in telescope detectors

3σ efficiency $(92 \pm 1)\%$



3σ efficiency [%] with telescope installed



Summary

- calibration of the whole active area of large Micromegas in Cosmic Ray Facility with accuracy $< 30\,\mu\text{m}$
- measurement includes:
  - homogeneity of efficiency and charge distribution
  - determination of z position with resolution $< 0.1\,\text{mm}$
  - calibration of readout strip position every 10 cm with an accuracy of $15\,\mu\text{m}$
- L1 Micromegas ($1\,\text{m}^2$):
  - shift and rotation between readout boards calibrated
  - 1.6 mm deformation of the drift gap due to 10 mbar overpressure
  - spatial resolution limited by multiple scattering, also in MDTs
- measurements with a Micromegas telescope in CRF:
  - spatial resolution better for part of L1 covered by telescope
  - angle reconstruction similar for L1 and small detector
  - no drift gap deformation for small Micromegas
- uniformity of efficiency and pulse height at $1\,\text{m}^2$

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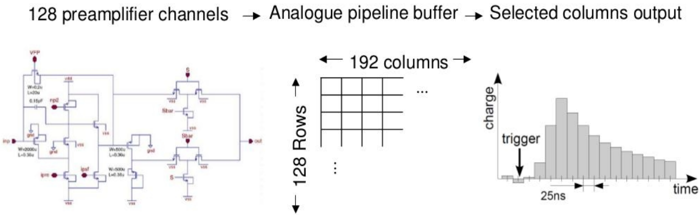
THANK YOU

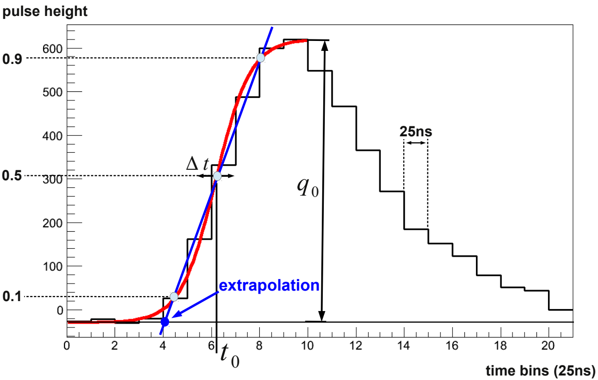
Backup

Readout with APV25



- 128 charge sensitive amplifier channels
- pipeline buffer of 192 cells depth for each input channel
- filled consecutively with every clock cycle
- blocks of one or more pipeline columns can be read out for each trigger

Start of Signal: Fit Using Inverse Fermi Function



- signal-rise fitted with $q(t) = \frac{q_0}{1+\exp\left(\frac{t_0 - t}{\Delta t}\right)} \implies t_0$
- extrapolate starting point:
  - straight line through: **0.1**×Max, **0.5**×Max and **0.9**×Max of inv. Fermi function (Max $\hat{=}$ maximum of pulse height)
  - extrapolate to t_s = t(q = pedestal)

$$\implies \text{starting point: } t_s = t_0 - \frac{\ln(81)}{1.6}\Delta t$$