Calibration of Precise Large Area Micromegas Detectors Using Cosmic Rays

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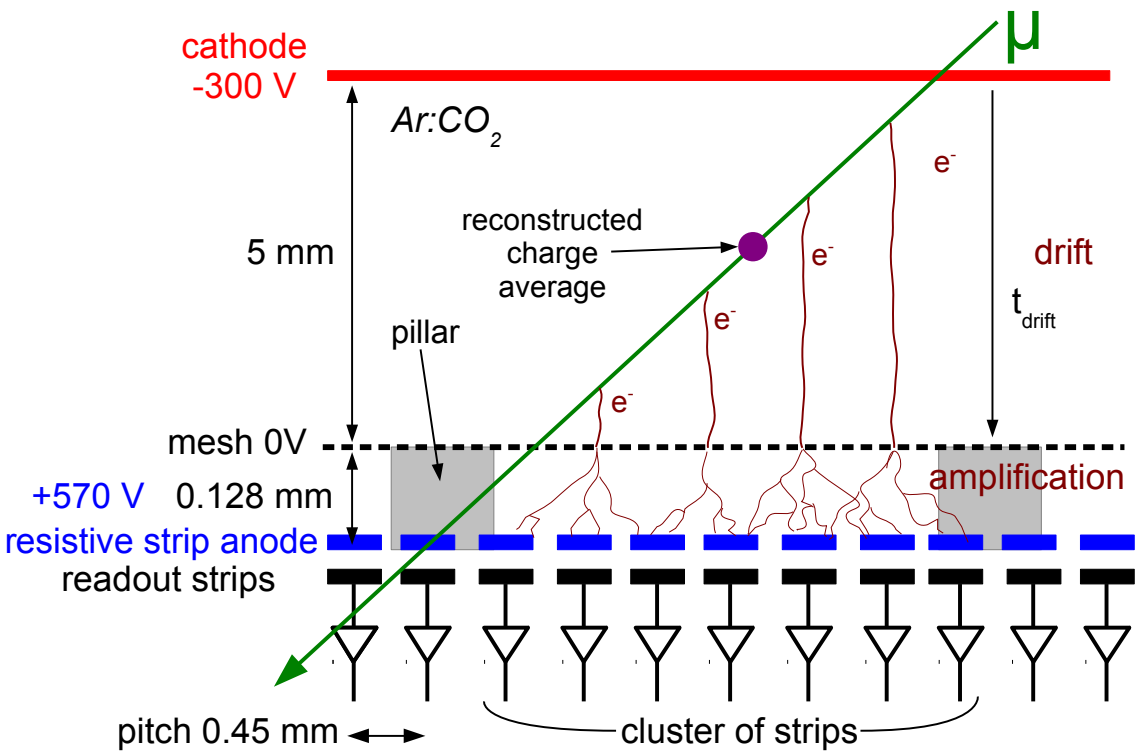
Instrumentation for Colliding Beam Physics

Bundesministerium
für Bildung
und Forschung

Outline

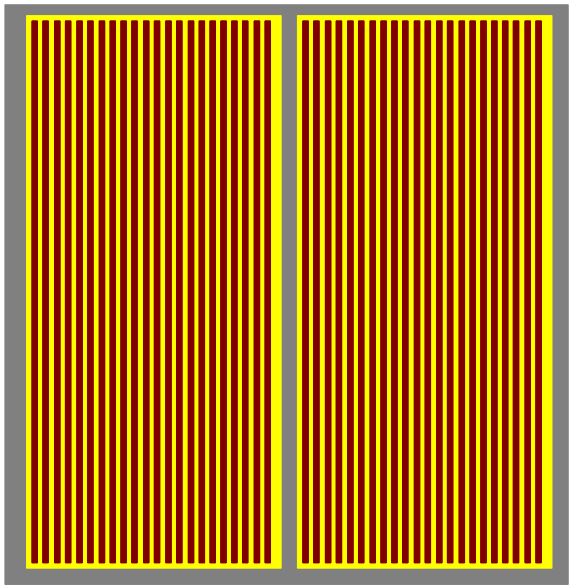
MICROMEsh GAseous Structure



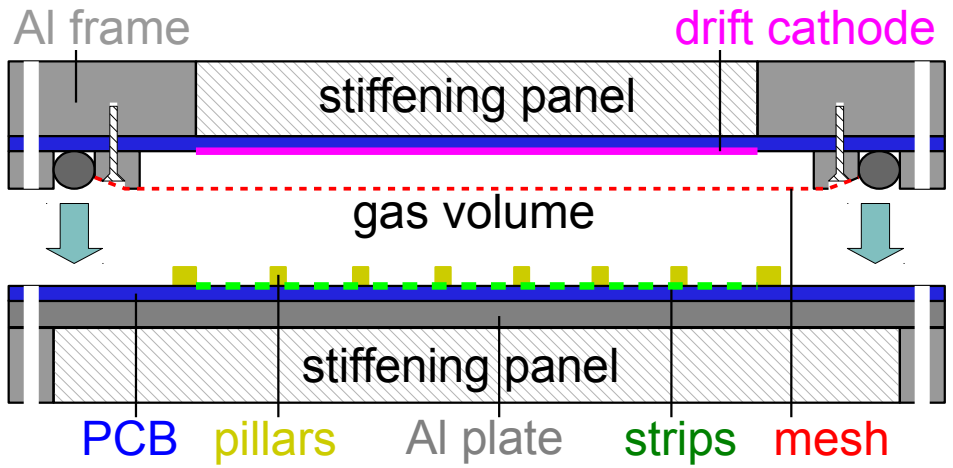
- ionized electrons drift between cathode and grounded mesh
- gas amplification between mesh and anode
- charge collection on resistive strips
- charge detection on readout strips
- positioning of strips with high accuracy mandatory

calibration $\Rightarrow$ determine position of strips using cosmic muons

Construction of a 1 m^2 Prototype Micromegas



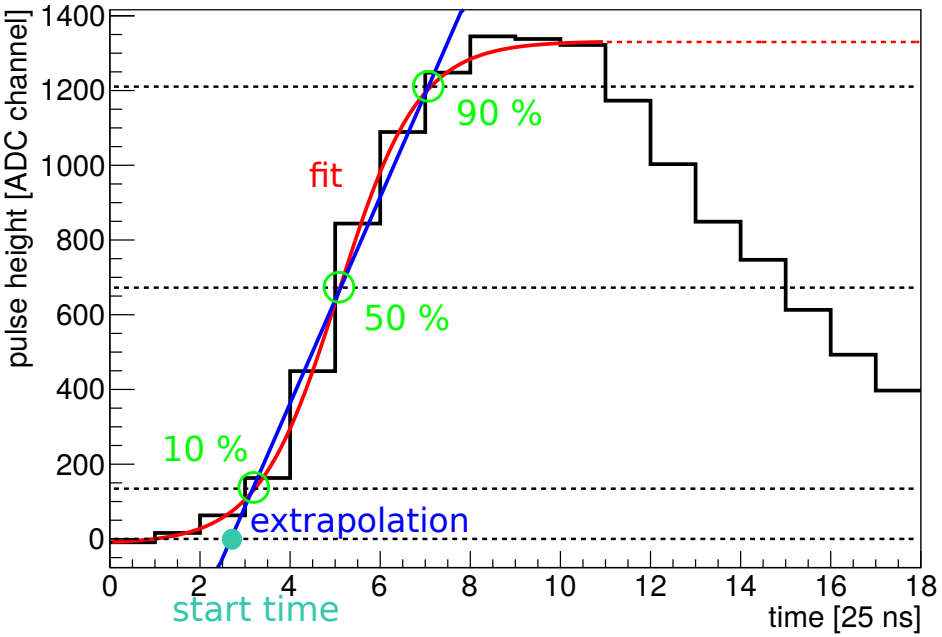
- two readout anode boards (due to photolithographic limitations)
- no alignment tooling used during gluing on Al plate
- active area: $0.92 \times 1.02\,\mathrm{m}^2$



- stiffening panels as support structure for anode and cathode
- mesh mounted on drift panel
- gas volume enclosed by anode and cathode
- potential deformation due to overpressure of Ar:CO_2

Time Evolution of the Signal on a Single Strip

beginning of the signal : fit by an inverse Fermi function

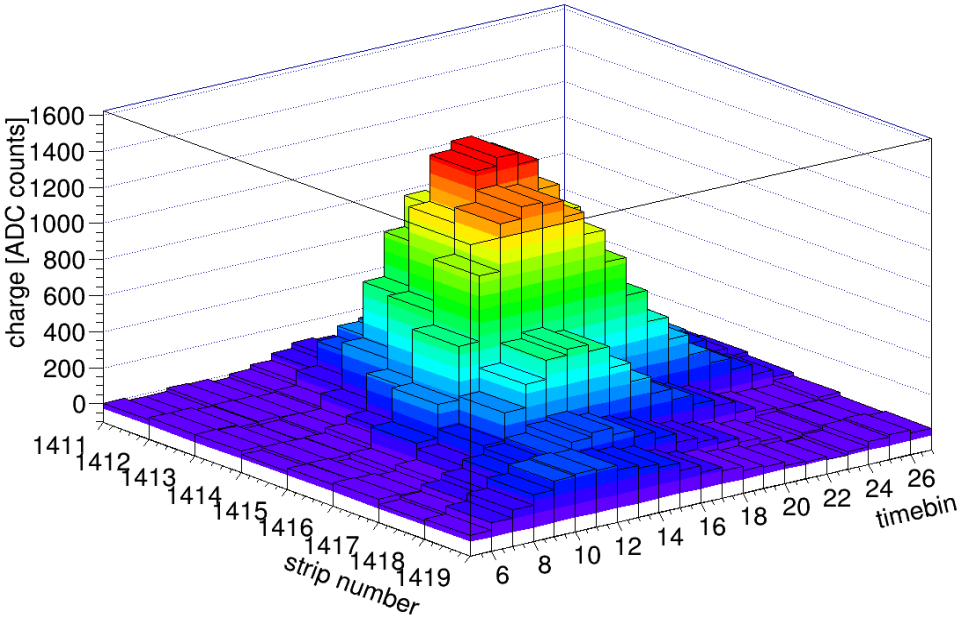


$$f_{\mathrm{Fermi}} = \frac{p_0}{1 + \exp[(p_1 - x)/p_2]} + p_3$$

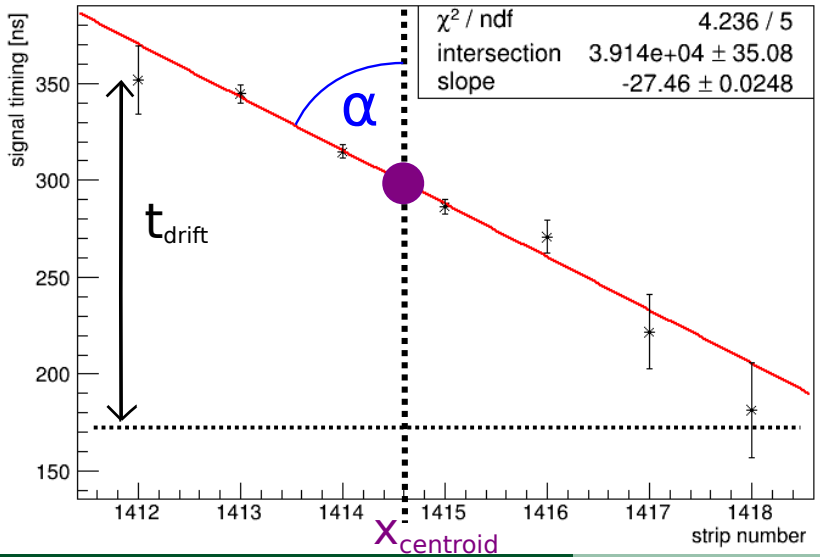
- p_0 : maximal pulse height
  $\Rightarrow$ charge of signal
- p_1 : time of 50% maximal pulse height
- p_2 : $\propto$ rise time
- p_3 : pedestal

$\Rightarrow$ 3 values of f_{Fermi} at 10% , 50% and 90% define start time of signal by extrapolation

Position and Track Reconstruction



drift time measurement



- centroid method

  $\Rightarrow$ charge average over strips

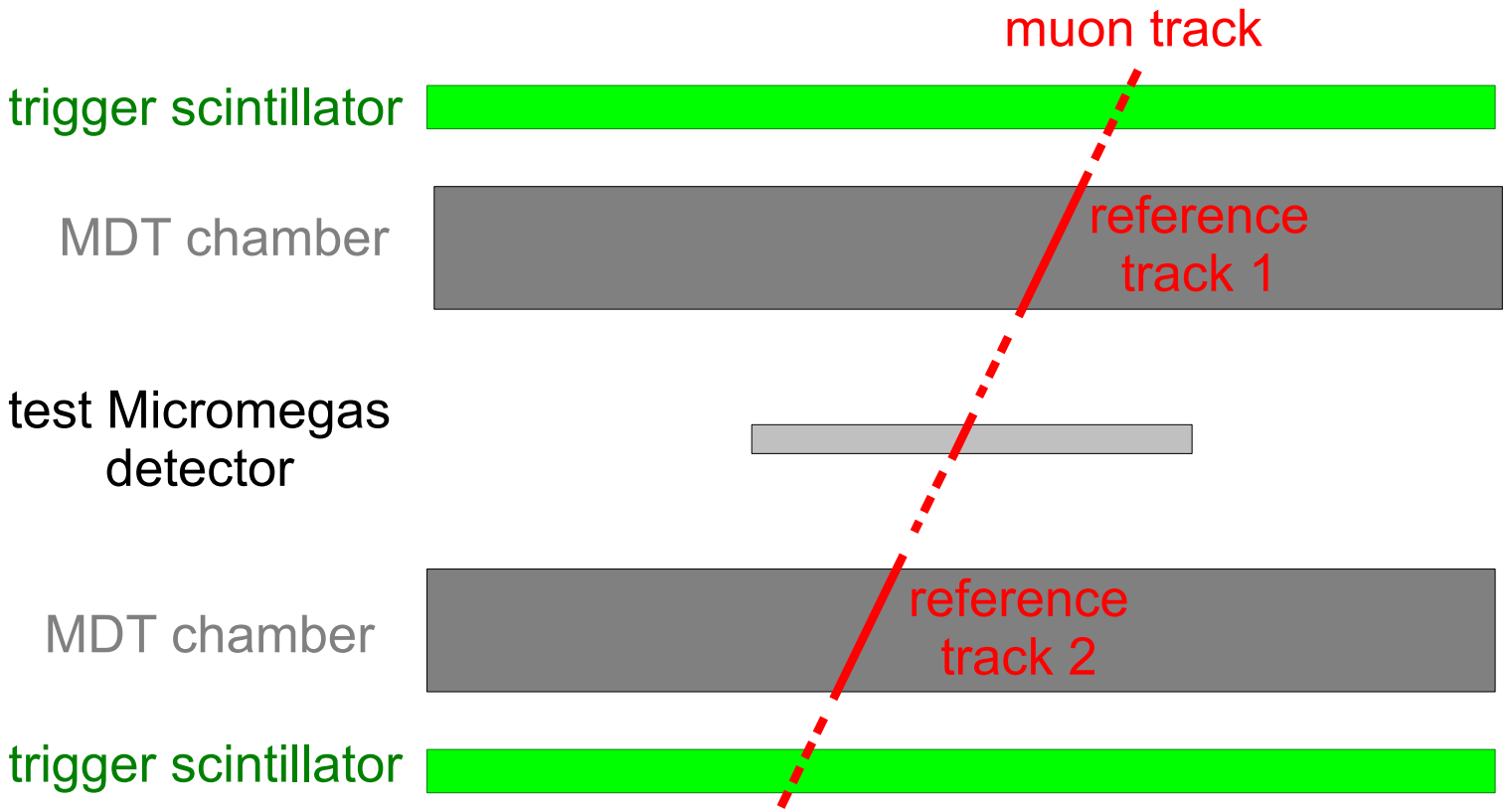
$$x_{\text{centroid}} = \frac{\sum_{\text{strips}} x_{\text{strip}} \cdot q_{\text{strip}}}{\sum_{\text{strips}} q_{\text{strip}}}$$

- TPC-like method

  angle reconstruction by drift time measurement

$$\alpha = \arctan\left(\frac{\text{pitch}}{\text{slope}_{\text{fit}} \cdot v_{\text{drift}}}\right)$$

Cosmic Ray Facility: Calibration



- 2D track reconstruction with two Monitored Drift Tube (MDT) chambers
- trigger via Scintillator hodoscope with coarse resolution ($\approx 10\,\text{cm}$) in orthogonal direction

Cosmic Ray Facility

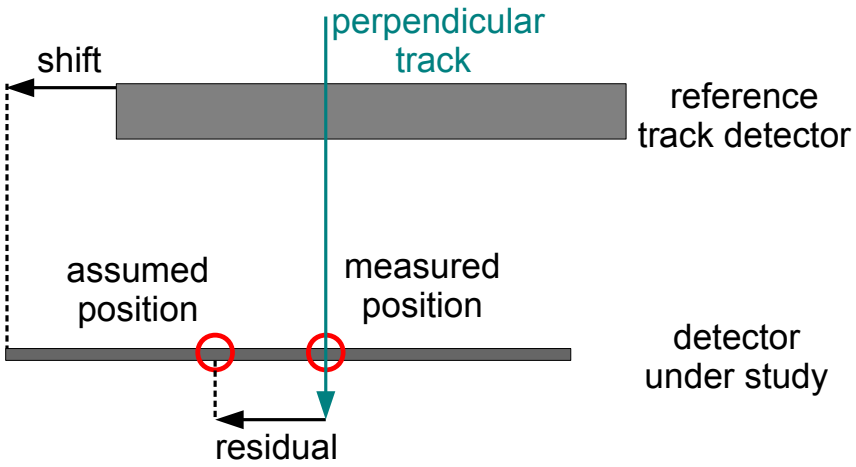
facility to calibrate detectors in Garching near Munich

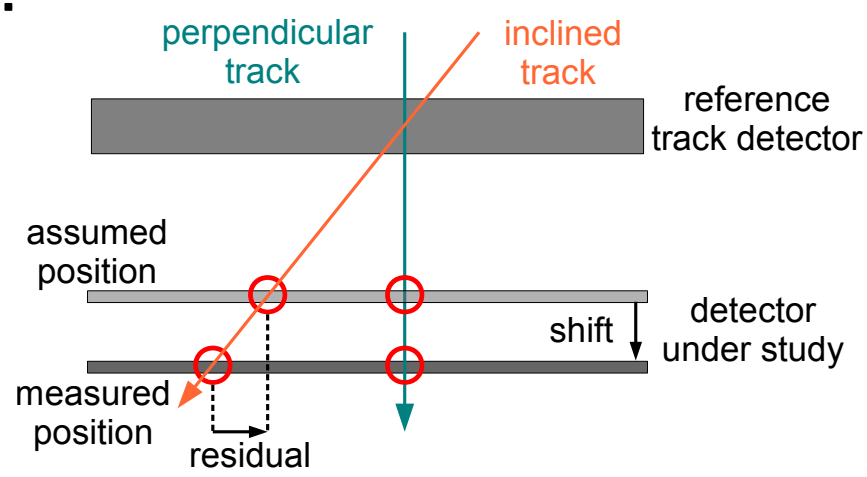
MDT chambers : 2.2 m $\times$ 4 m $\Rightarrow$ active area : 9 m^2

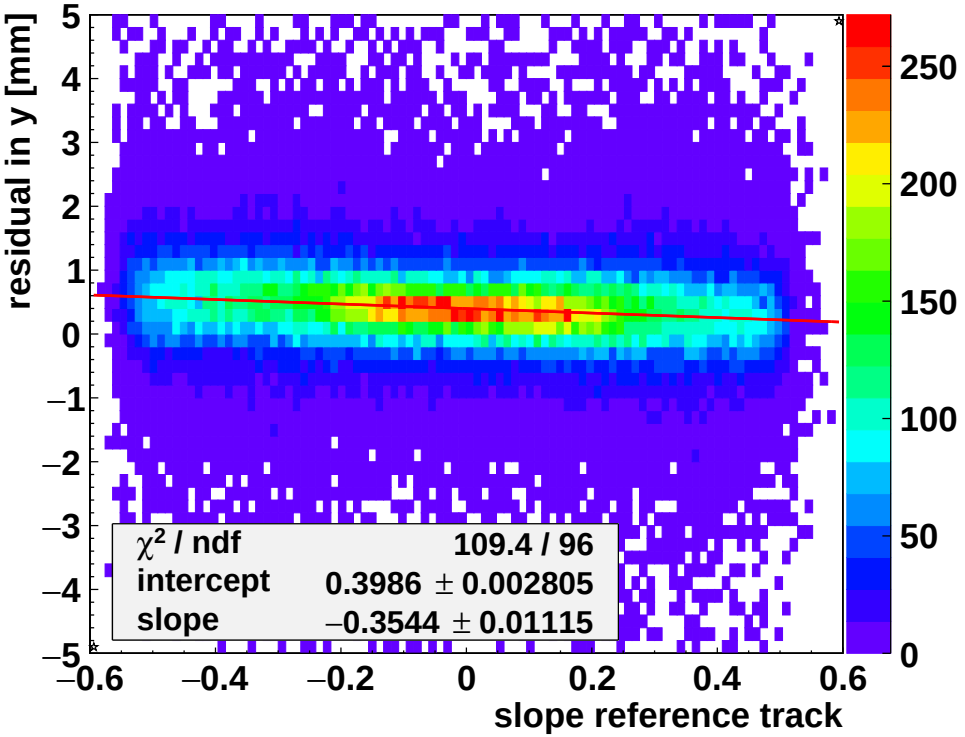
angular acceptance : $\pm 30^\circ$

Alignment by Use of Reference Tracks

Idea:



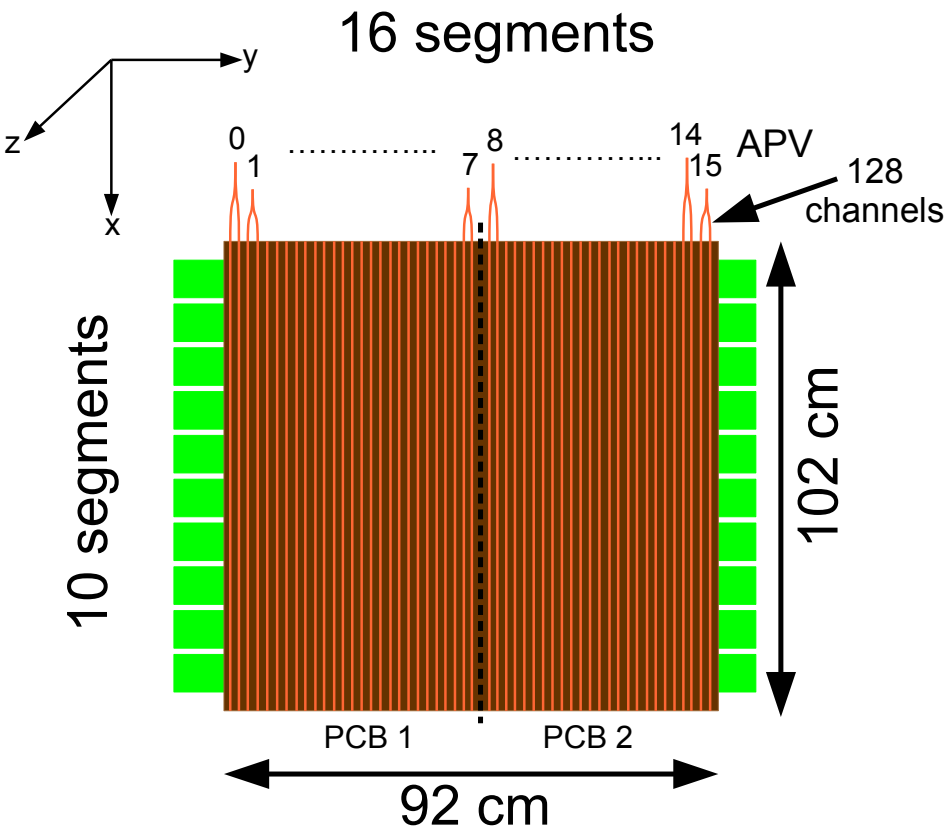




Implementation:

- **residual** = $\mathrm{pos}_{\mathrm{measured}} - \mathrm{pos}_{\mathrm{reference}}$
- residual vs. slope of reference track
  $\Rightarrow$ linear fit
- $\mathrm{shift}_{\mathrm{horizontal}} = \mathrm{intercept}_{\mathrm{fit}}$
- $\mathrm{shift}_{\mathrm{vertical}} = \mathrm{slope}_{\mathrm{fit}}$

Partitioning of the Detector Area

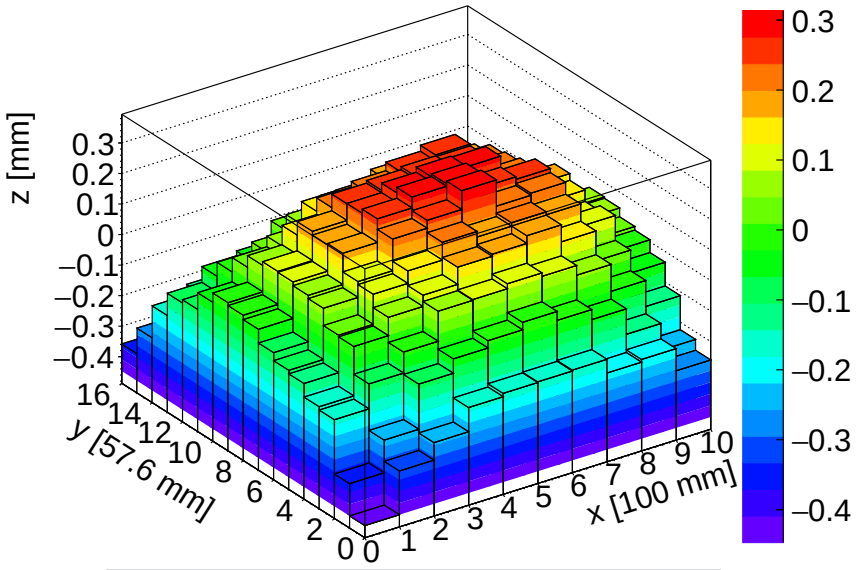


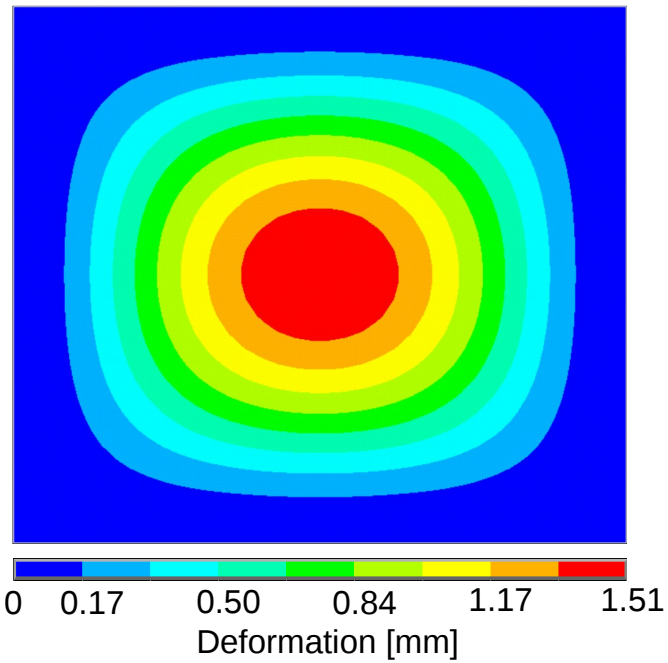
- two readout boards
  with in 2048 strips
- 16 APV25 frontend boards
  $\Rightarrow$ 16 segments in y direction
- 10 cm resolution of scintillator hodoscope
  $\Rightarrow$ 10 segments in x direction

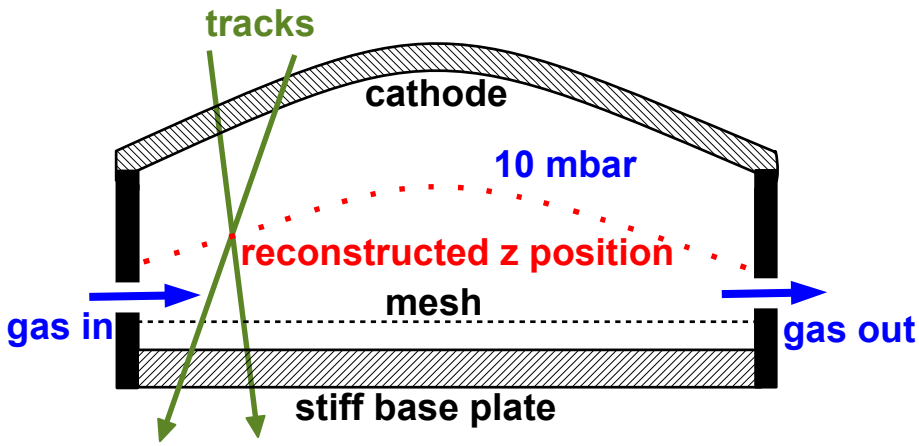
$\Rightarrow$ 160 partitions
à $100 \times 57.6\,\mathrm{mm}^2$

$\Rightarrow$ calibration and alignment for each of the 160 partitions individually

Deformation of the Drift Region due to Overpressure

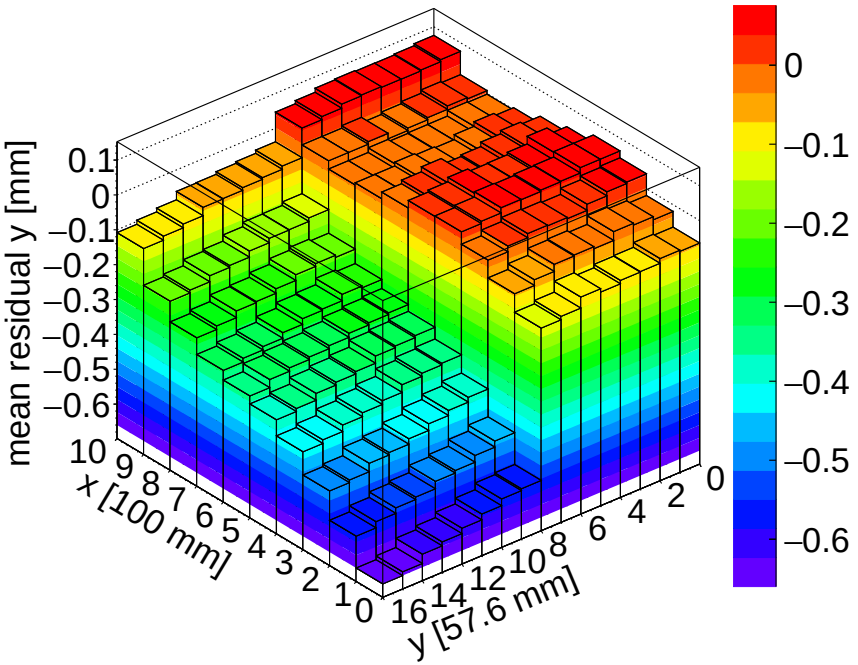


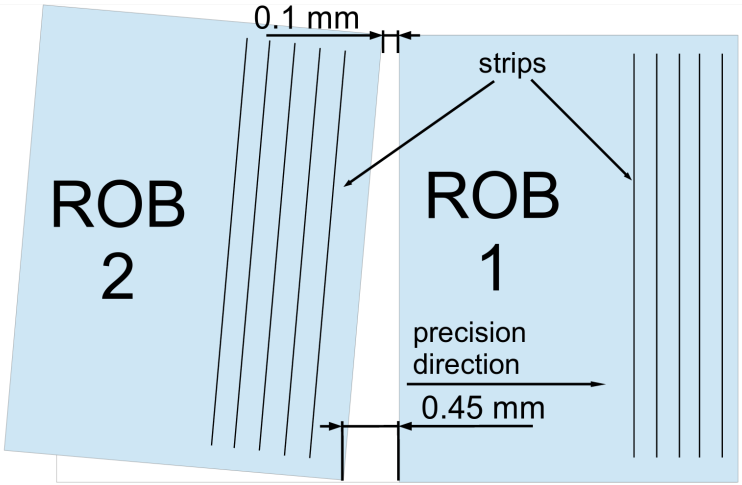




- drift gap deformation due to small overpressure
- maximum deviation of 0.8 mm from central plane
  $\Rightarrow$ 1.6 mm at cathode
  (stiff base plate support)
- deformation in agreement with finite element simulation (ANSYS)

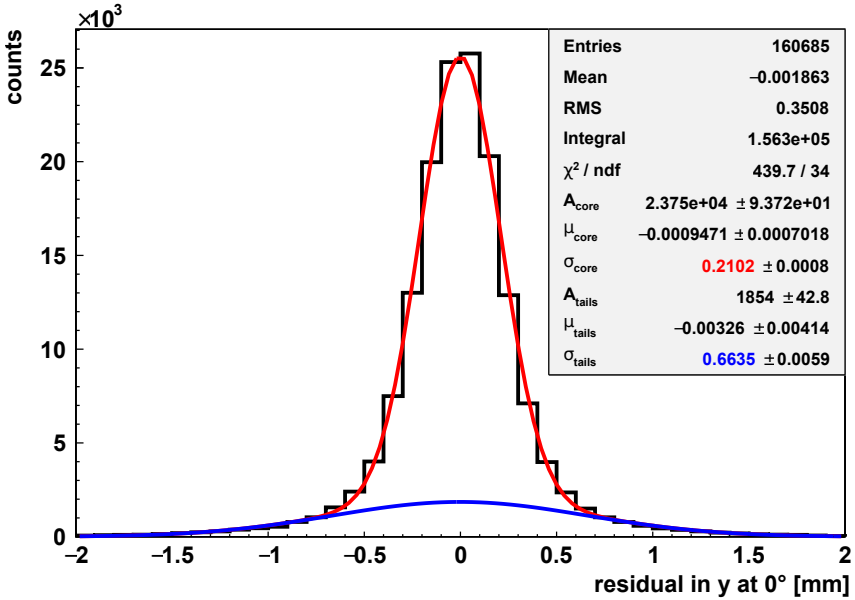
Result of Calibration: Shift and Rotation between Readout Boards

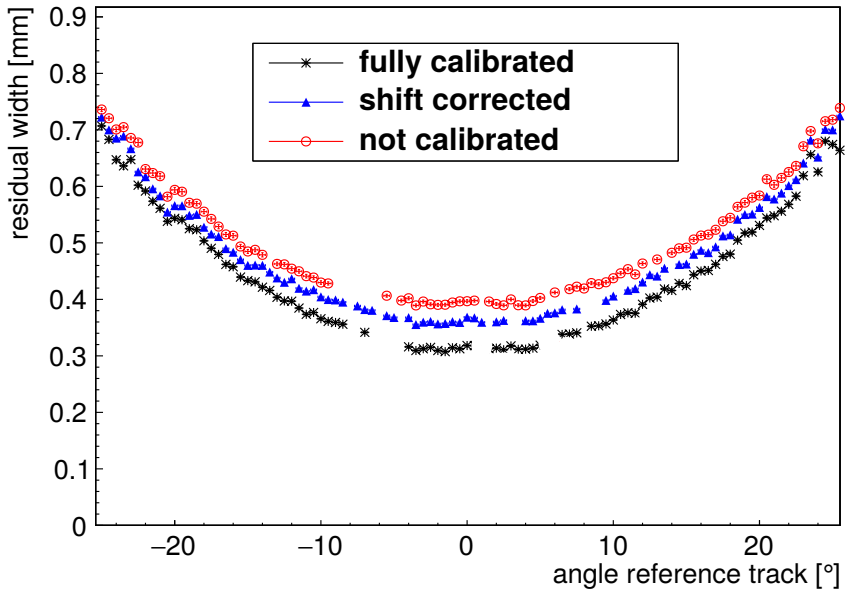




- analysis of all 160 partitions individually
- alignment of the right half of the detector
  $\Rightarrow$ misalignment between PCBs becomes visible
- **shift :** 0.1 mm
- **rotation :** 0.35 mm/m
- 50 µm effects are clearly observable

Impact of Calibration on Spatial Resolution





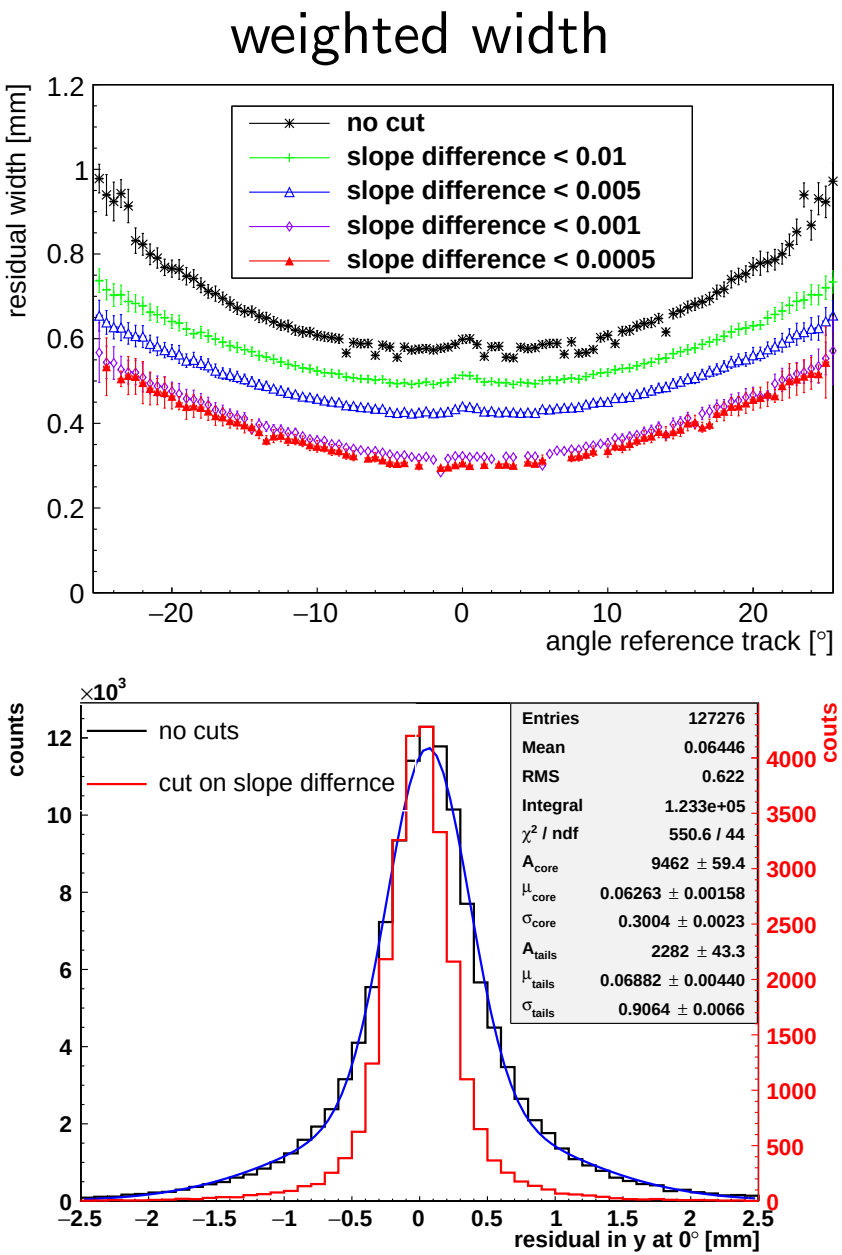
- centroid position reconstruction
- fit residual distribution for each angle with double Gaussian
- plot narrow Gaussian width as function of angle

$\Rightarrow$ calibration improves resolution

improvement @ 0° :

$\approx 100\,\mu m$

Investigation of Multiple Scattering

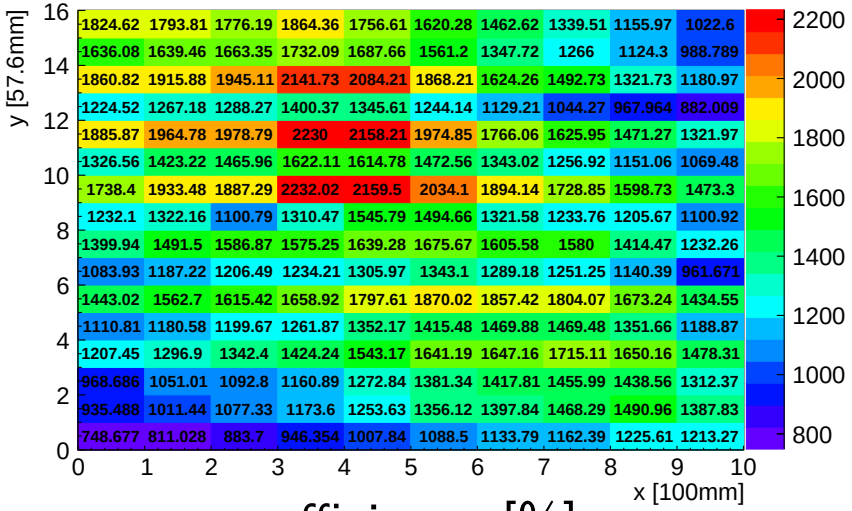


assumption:
multiple scattering of muons
$\Rightarrow$ broadening of residual distributions

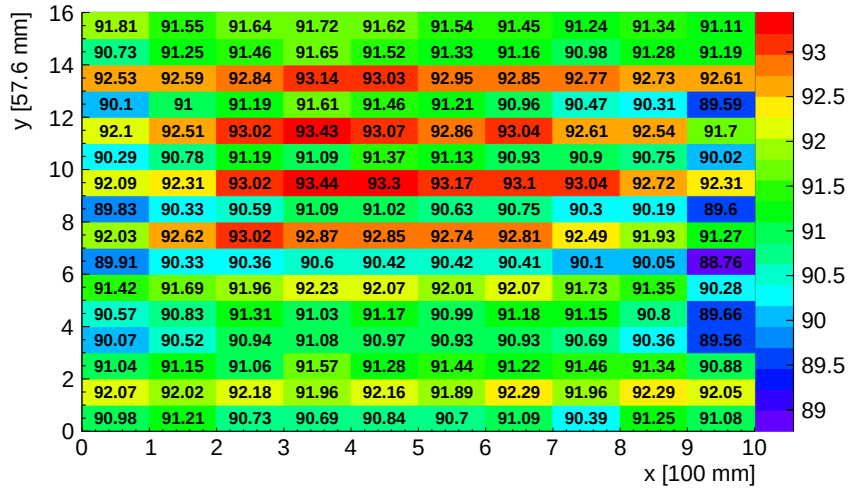
- centroid residual distribution
- fit with double Gaussian
  $\Rightarrow$ weighted sigma
- cut on slope difference of reference tracks decreases residual width by 350 µm

Homogeneity of Pulse Height and Efficiency

MPV of charge distribution [ADC counts]



efficiency [%]



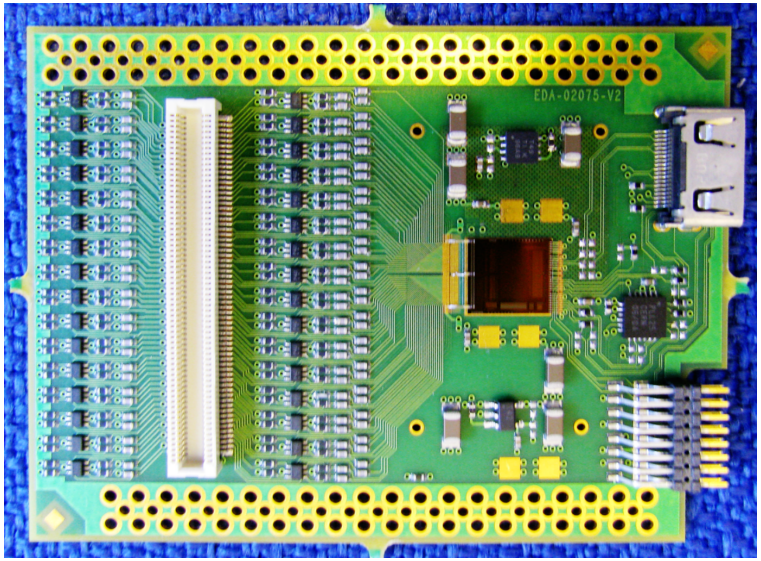
- charge average : 1440 ± 310 ADC channel
- efficiency average : 91.5 ± 0.9 %
- no significant difference between readout boards
- master-slave differences of APV25 frontend boards
- homogeneous 3σ efficiency (deviations due to border effects)
  91.5 % limited by multiple scattering

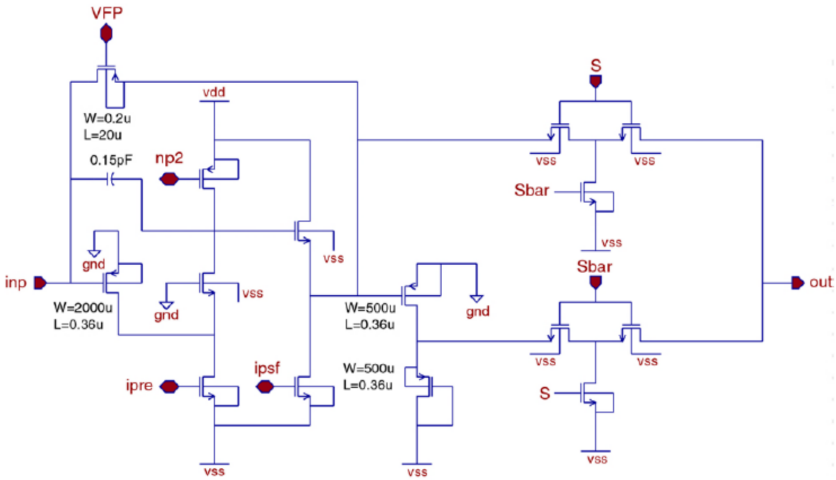
Summary

- Cosmic Ray Facility
- position and track reconstruction
- investigation of $1\,\mathrm{m}^2$ Micromegas detector
  - offline calibration by partitioning of detector plane
  - deformation due to overpressure (1.6 mm @ 10 mbar)
  - misalignment of the readout PCBs during assembly (100 - 450 µm) (no alignment tool available)
  - broadening of the residual distribution due to multiple scattering of muons
  - homogeneous pulse height and high efficiency over large area
- results of calibration:
  - deviation of micro-strips detectable with sensitivity $< 50\,\mu\mathrm{m}$
  - deformations of the active volume perpendicular to the readout area are measurable with sensitivity $< 100\,\mu\mathrm{m}$

Backup

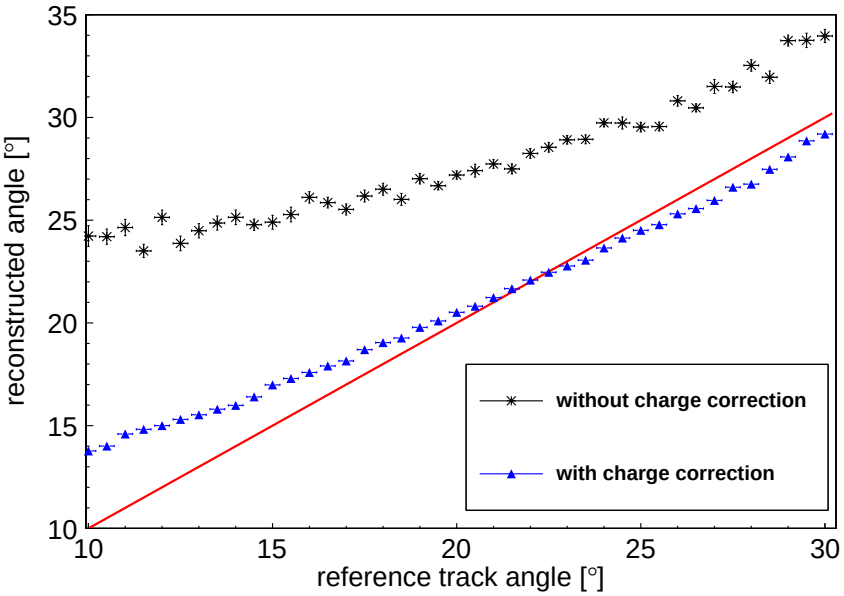
APV25 Frontend Readout Chips

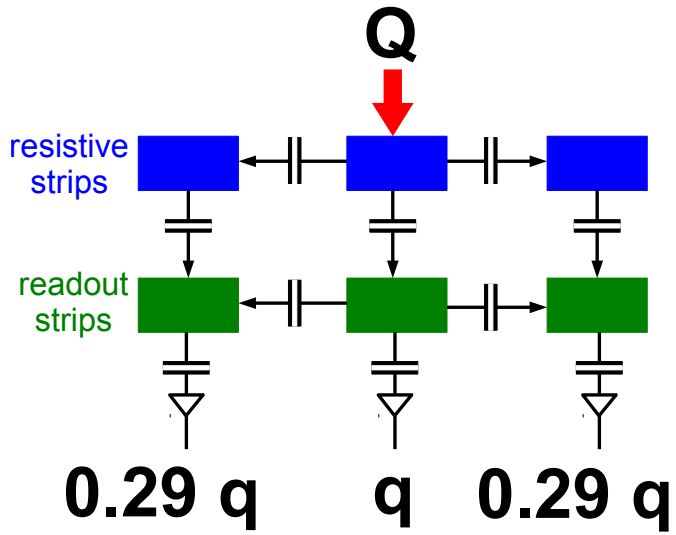




- charge integration over 25 ns
- pairwise connection as master-slave to reduce output channels

Angle Reconstruction by Single Plane TPC Analysis





- angular reconstruction via TPC like method [$t_{\mathrm{Drift}} = \mathrm{f}(\mathrm{strip})$]
- reference track angle by MDT chambers
- larger angles reconstructed due to capacitive coupling between 1 m long strips
- $\Rightarrow$ correction improves angular resolution