SM2 Micromegas Modules (M0,M1,M3) in the LMU Cosmic Ray Facility

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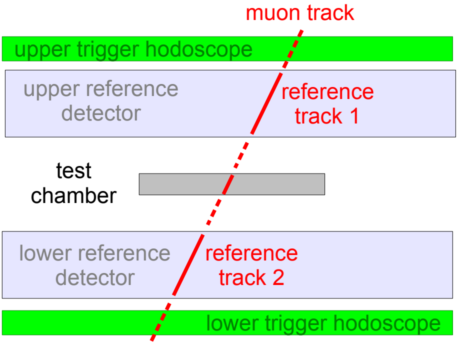
Ludwig-Maximilians-Universität München - Lehrstuhl Schaile

Muon Week 25.10.2018

Outline

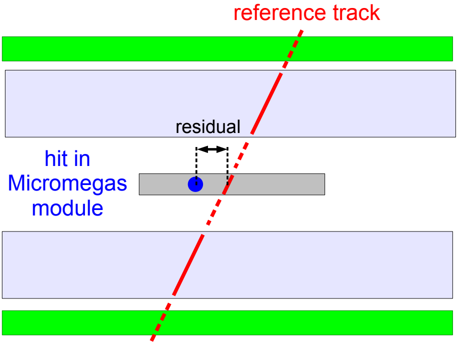
1. Cosmic Ray Facility
2. Pulse Height and Efficiency
3. Reconstruction of Readout Board Alignment
4. Track Reconstruction with Micromegas
   - Charge Weighted Position
   - Drift Time Measurement

Cosmic Ray Facility



track reconstruction	2 $\times$ Monitored Drift Tube chambers (MDTs)
trigger	scintillator hodoscope
active area	2.2 m $\times$ 4 m
angular acceptance	$\pm$ 30°
readout	12288 channels
	$\rightarrow$ 96 APVs (frontend electronics)
	$\rightarrow$ 6 FECs (scalable readout system)
readout rate	130 Hz (full muon rate)

Cosmic Ray Facility

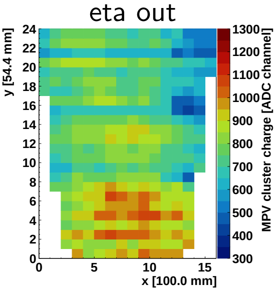


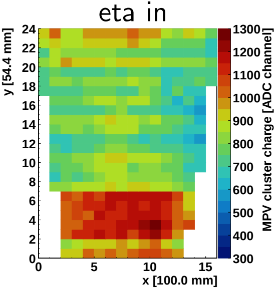
$$\text{residual} = \textcolor{blue}{\text{measured}} - \textcolor{red}{\text{reference}}$$

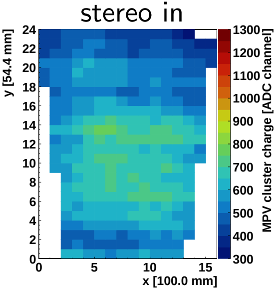
$$= \text{centroid} \times \text{pitch} - \text{track}_{\mathrm{MDTs}}(\ \text{height}_{\mathrm{MM}}\ )$$

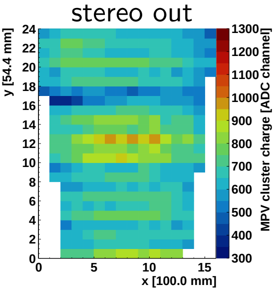
Pulse Height and Efficiency

M3 Pulse Height Map at $U_{\mathrm{amp}} = 560$ V, Ar:CO_2 93:7, 1800 ppm H_2O









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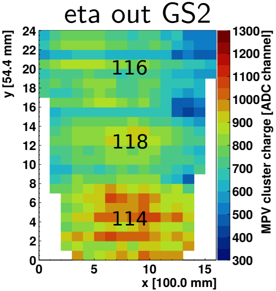
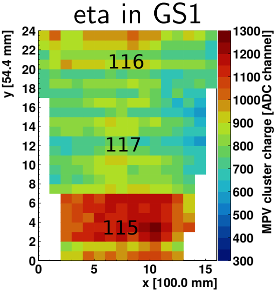
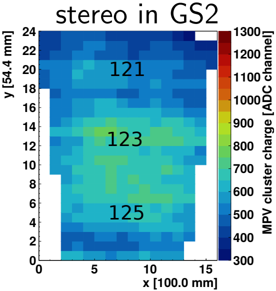
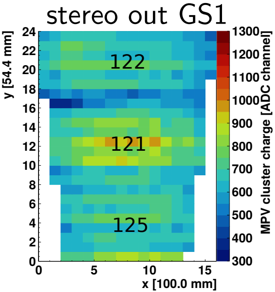
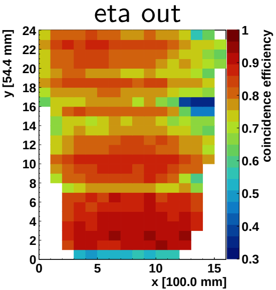


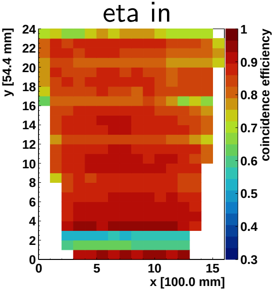






M3 Efficiency Map at $U_{\mathrm{amp}} = 560$ V, Ar:CO_2 93:7, 1800 ppm H_2O



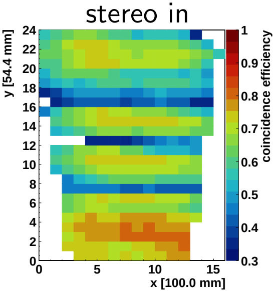


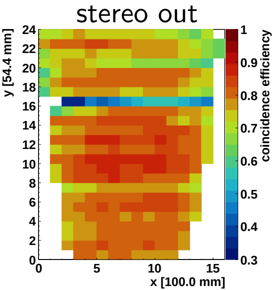
cluster

≥ 2 strips

strip risetime

> 2.5 ns

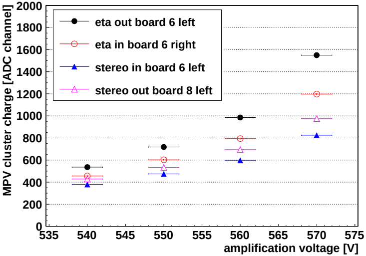




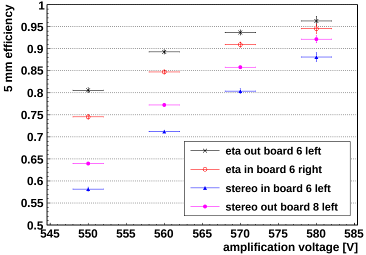
Amplification Scan for Ar:CO_2 93:7

Module 1

cluster charge

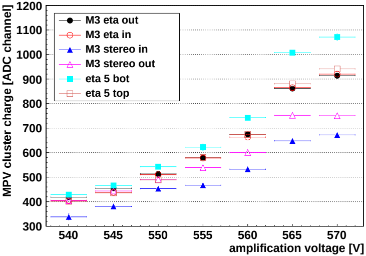


efficiency

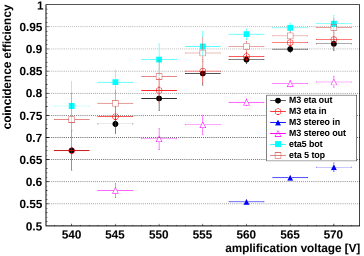


Module 3 & Eta 5 (board 8 left)

cluster charge



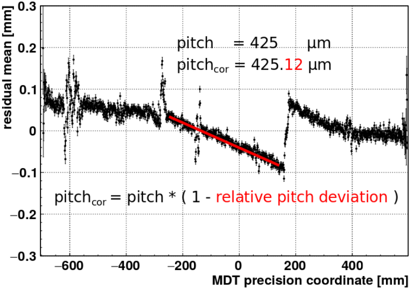
efficiency



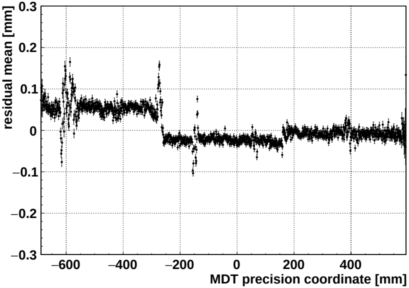
Reconstruction of Readout Board Alignment

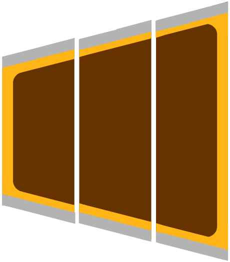
Reconstruction of Readout Board Alignment (Single Layer, example M0 - eta in)

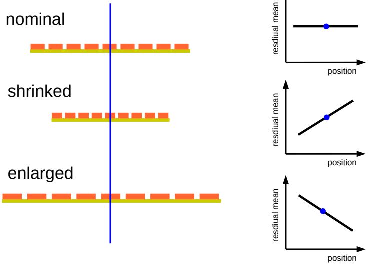
without correction



pitch deviation considered







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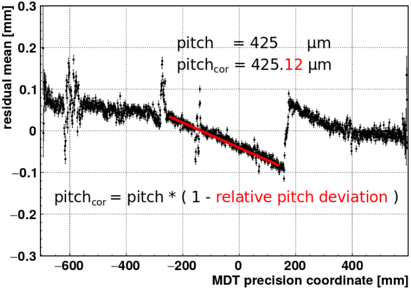

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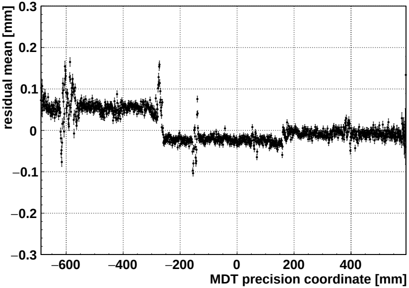

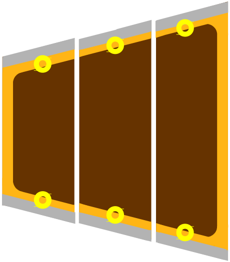

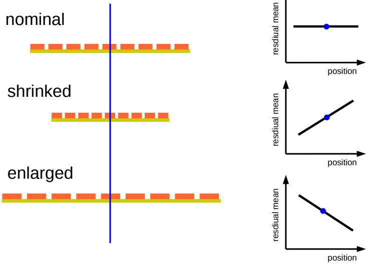

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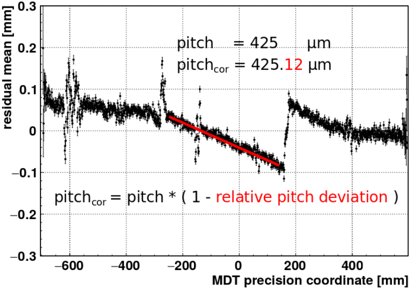

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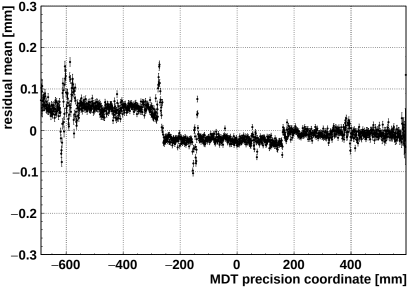

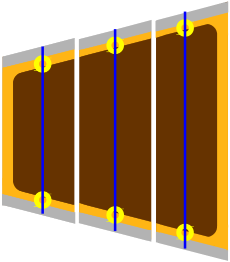

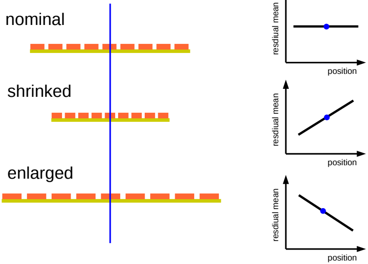

Reconstruction of Readout Board Alignment (Single Layer, example M0 - eta in)

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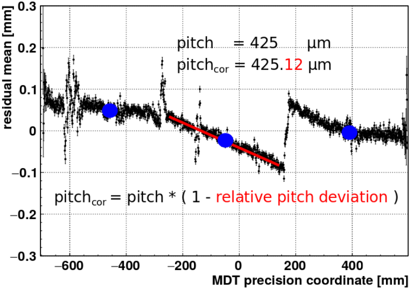

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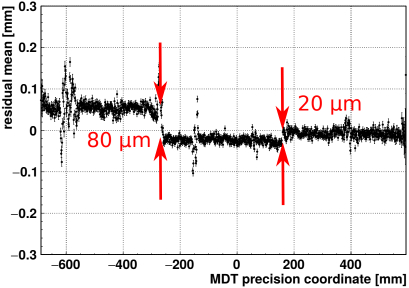
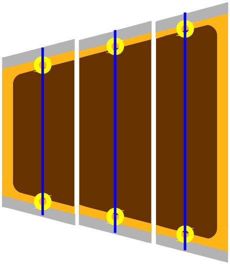
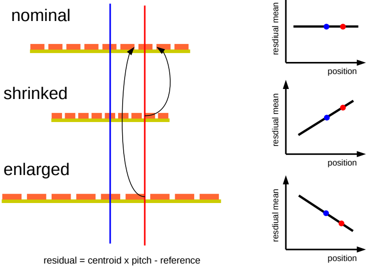
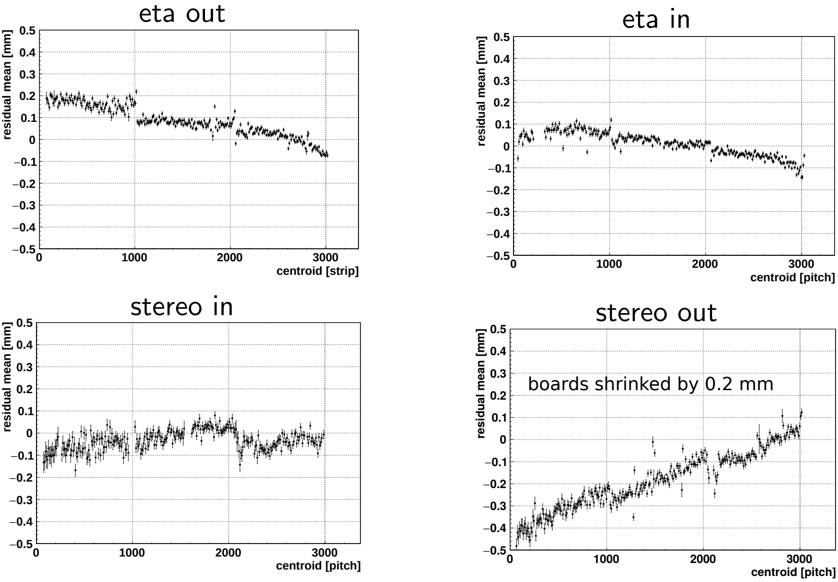
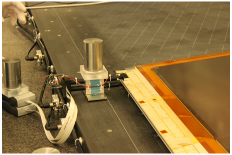




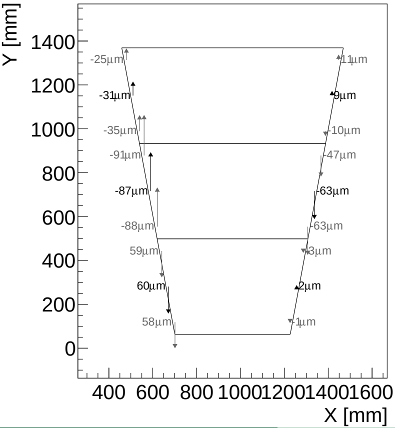


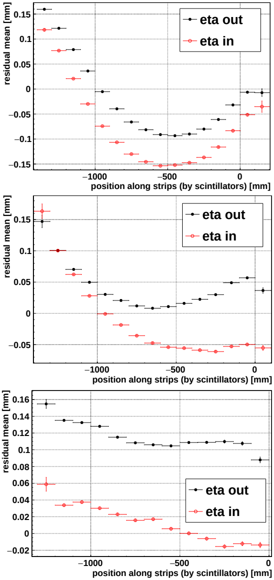
M3 Alignment Single Layer



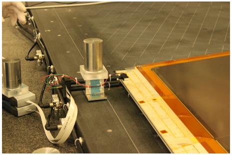


Rasfork: RS2E00003 (top side: GS1)





Reconstruction of Readout Board Alignment (Layer to Layer, Eta3 in M3)



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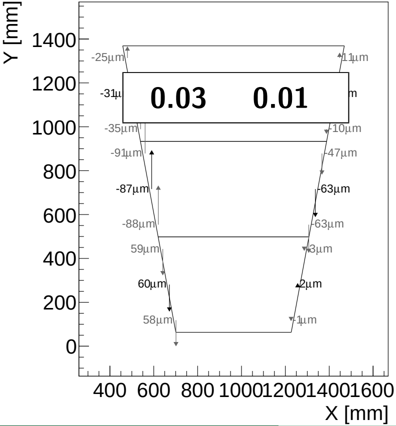
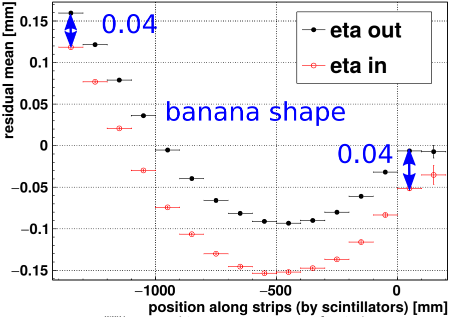
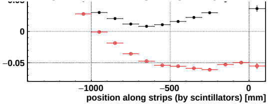
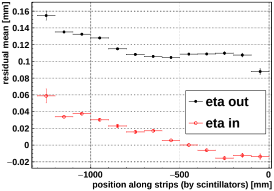
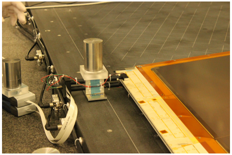








Reconstruction of Readout Board Alignment (Layer to Layer, Eta3 in M3)



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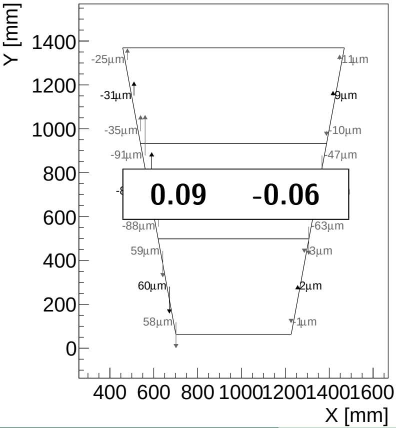

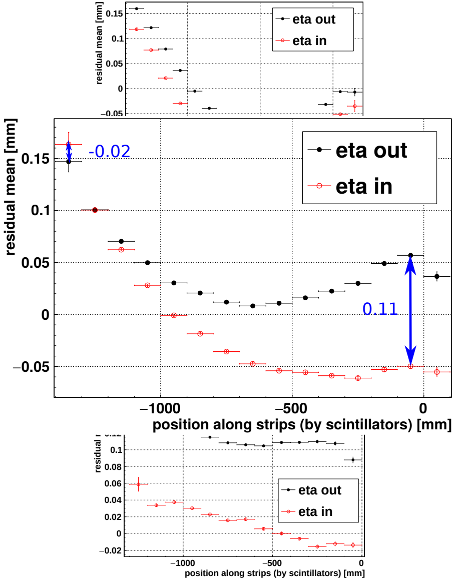

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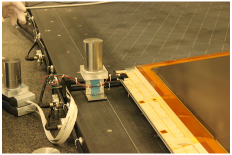

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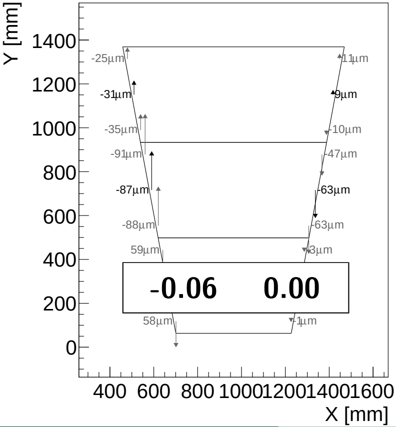
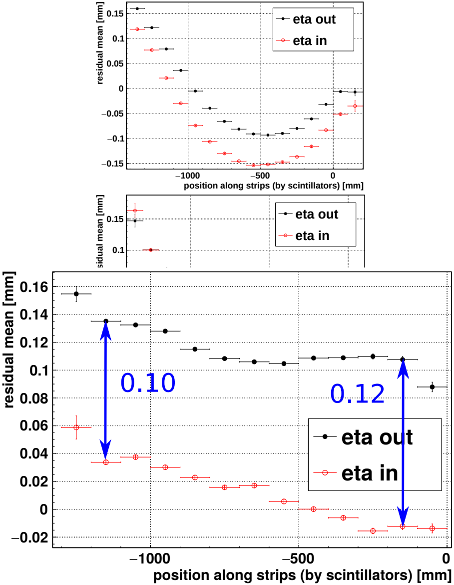
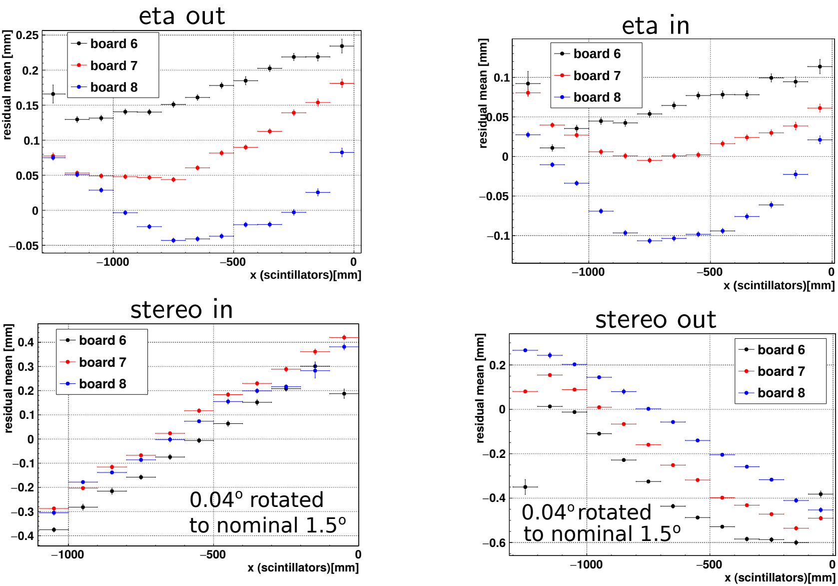


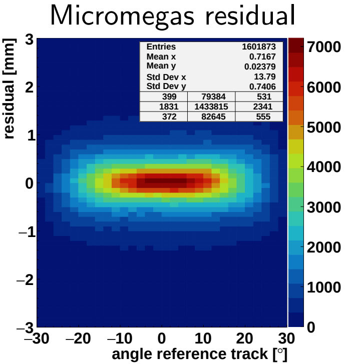


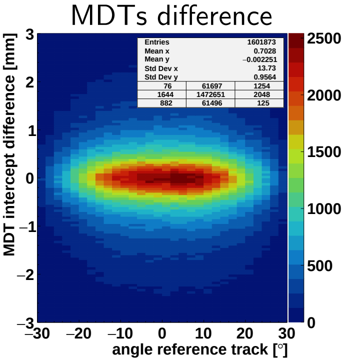
M3 Strip Shape

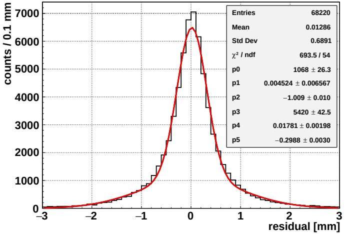


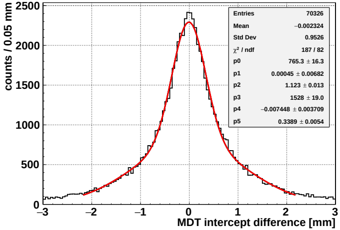
Track Reconstruction with Micromegas

Residual of Charge Weighted Position Reconstruction (M1)









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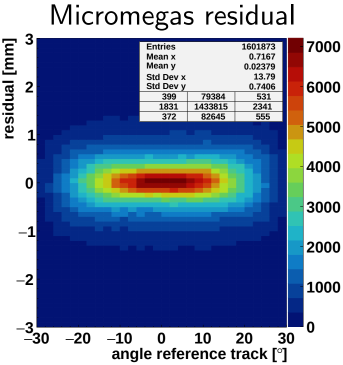
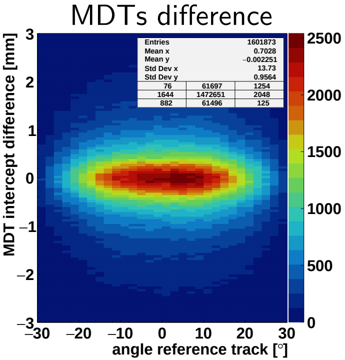
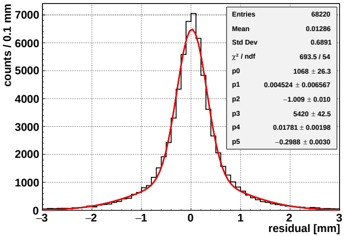
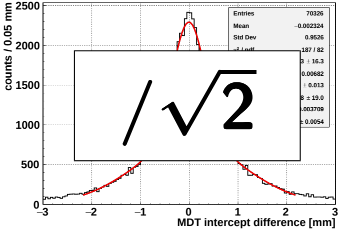
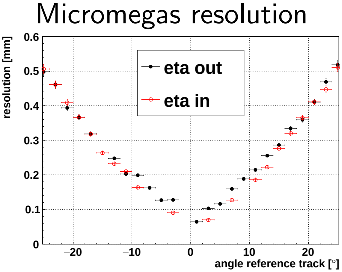
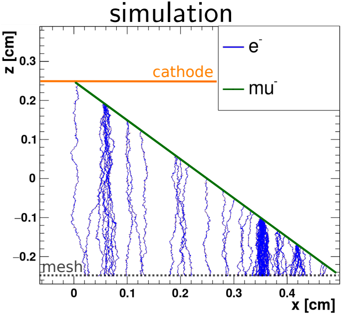












σ of narrow Gaussian $\Rightarrow$

$$\text{resolution} = \sqrt{\sigma_{\mathrm{MM}}^2 - \left(\frac{1}{\sqrt{2}} \cdot \sigma_{\mathrm{MDT}}\right)^2}$$

inhomogeneous ionization
$\Rightarrow$ degrading resolution
for larger angles

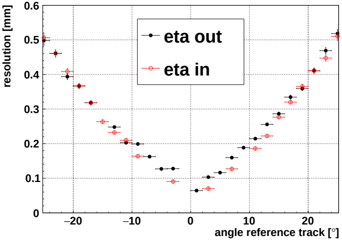
solution: use drift time information
$\Rightarrow$ 2 approaches

(1) Time-Projection-Chamber-like reconstruction (µTPC)

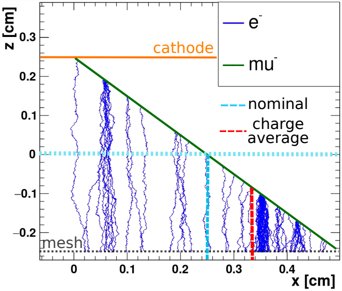
(2) centroid corrected by clustertime

Resolution of Charge Weighted Position Reconstruction (M1)

Micromegas resolution



simulation



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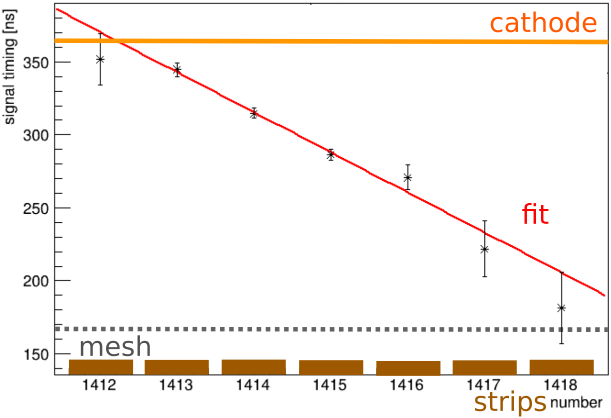
(1) Time-Projection-Chamber-like Reconstruction (μTPC)



- angle reconstruction: $\theta = \arctan\left(\frac{\text{pitch}}{\text{slope} \cdot v_{\text{drift}}}\right)$
- position reconstruction: $\text{pos}_{\mu\text{TPC}} = \frac{t_{\text{mid}} - \text{intercept}}{\text{slope}}$

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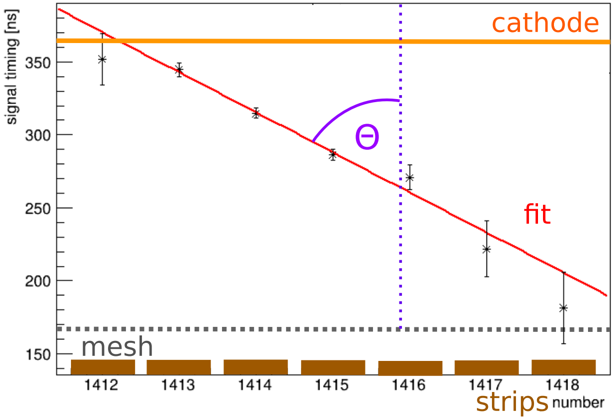

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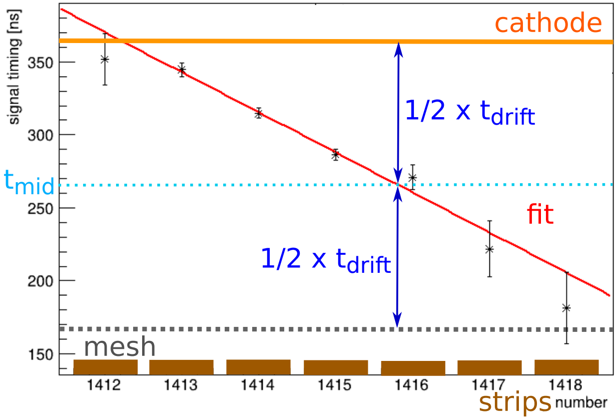

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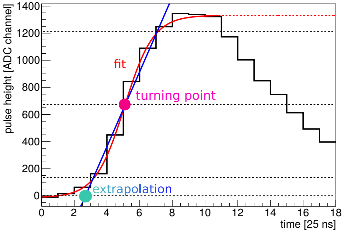
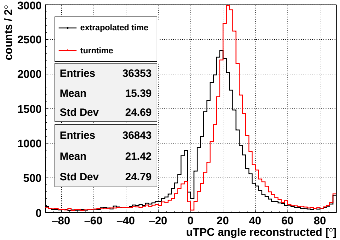
(1) µTPC Angle Reconstruction (M1)

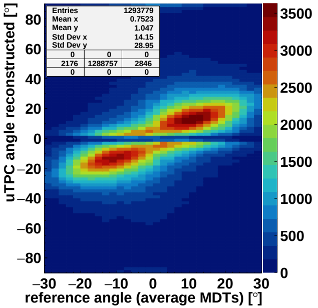
single strip signal



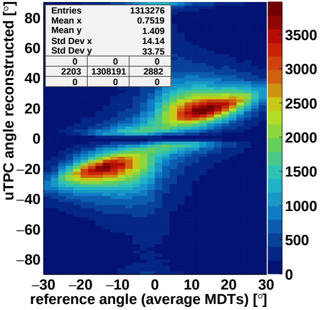
reference angle ∈ [20° , 22°]



extrapolation

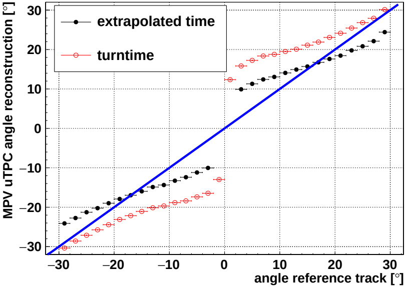


turning point

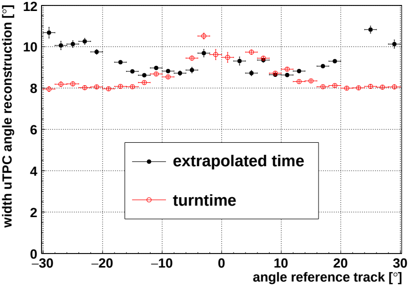


(1) µTPC Angular Resolution (M1)

most probable value reconstructed angle

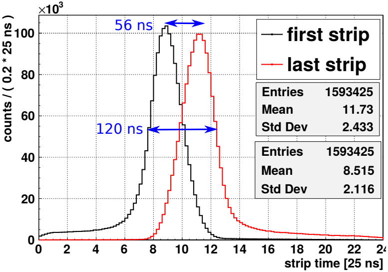


width

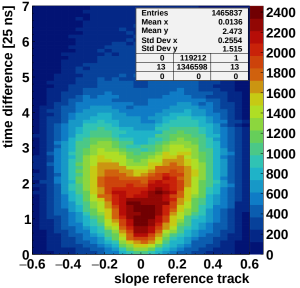


biased, inaccurate reconstruction for small angles

turntime yields better angular estimation and resolution than extrapolation earliest and last signal



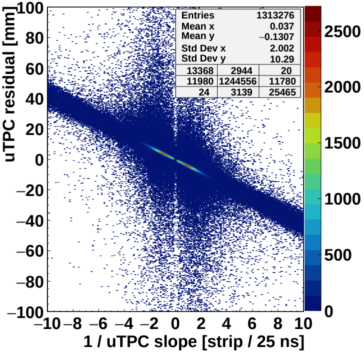
strip time difference per event

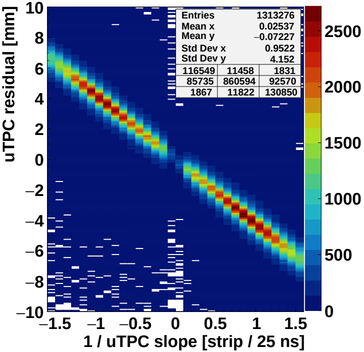


- expected time difference: 106 ns = 5 mm / 47 μm/ns ($\hat{=}$ 4.2 timebins)
- not yet understood differences between timing distributions
- smaller differences per event

(1) Determination of t_{mid} (residual dependence, M1)

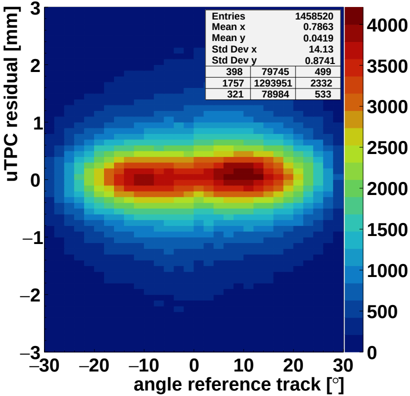
µTPC residual VS 1/ slope ($\propto \tan(\theta)$)

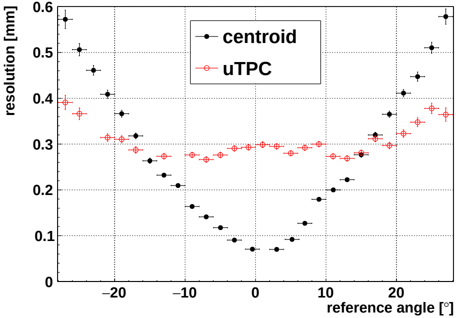




$$\text{residual} = \frac{t_{\mathrm{mid}} - \mathrm{intercept}}{\mathrm{slope}} - \text{reference}$$

(1) µTPC Position Resolution (M1 at $U_{amp} = 570$ V , $U_{drift} = 300$ V)

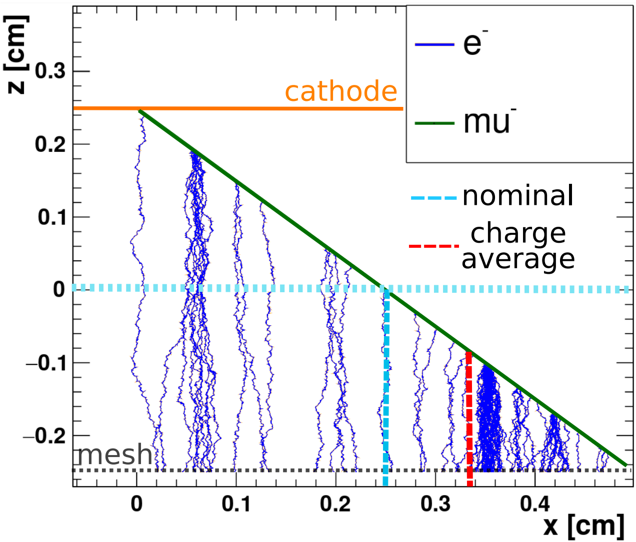




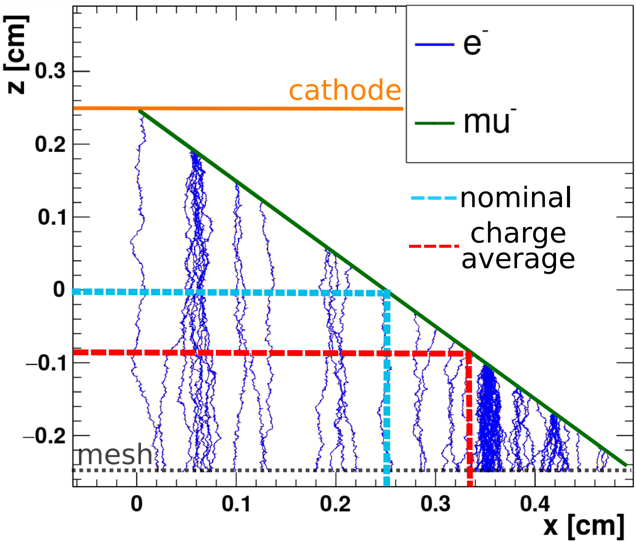
µTPC resolution better than centroid for large angles

but: no improvement of µTPC resolution for increasing incident angle

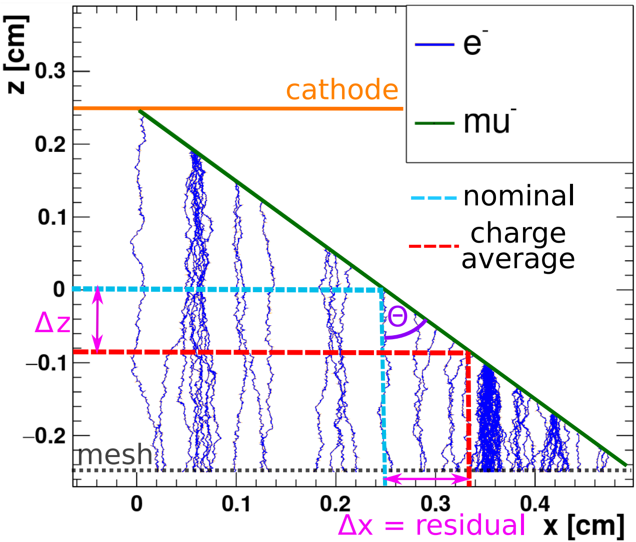
(2) Charge Weighted Timing



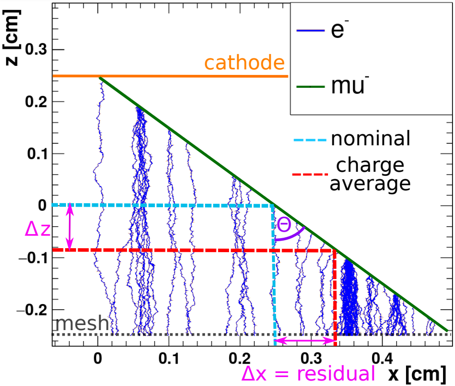
(2) Charge Weighted Timing



(2) Charge Weighted Timing



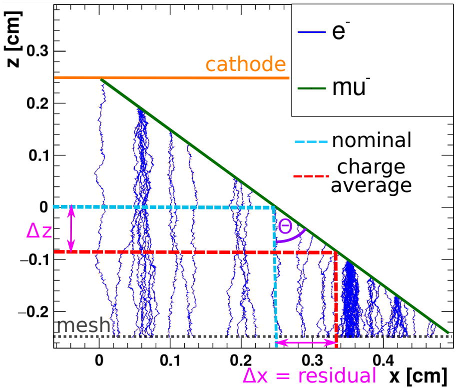
(2) Charge Weighted Timing



$$\triangle x = \triangle z \cdot \tan\theta$$

$$= (t_c - t_{mid}) \cdot v_{drift} \cdot \mathrm{slope}_{ref}$$

(2) Charge Weighted Timing

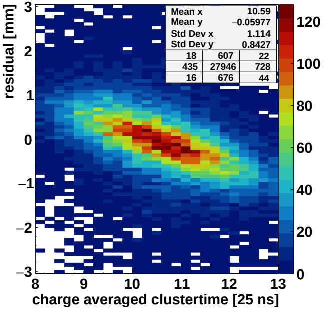


$$\text{centroid} = \sum_{\text{strips}} \text{strip} \cdot q_{\text{strip}} \Big/ \sum_{\text{strips}} q_{\text{strip}}$$

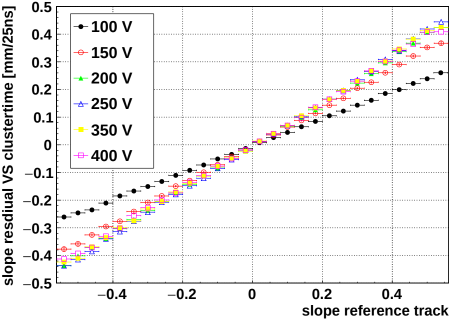
$$t_c = \sum_{\text{strips}} t_{\text{strip}} \cdot q_{\text{strip}} \Big/ \sum_{\text{strips}} q_{\text{strip}}$$

(2) Residual Dependence on Charge Averaged Clustertime (M3)

$$\text{angle}_{\text{ref}} = -26.4°$$
$$\text{slope}_{\text{ref}} = -0.46$$



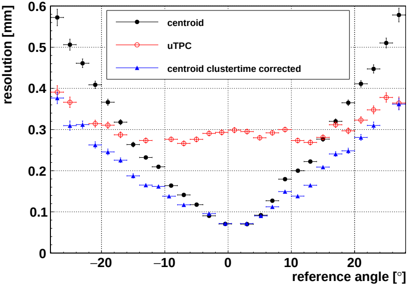
fitted correlation VS $\text{slope}_{\text{ref}}$

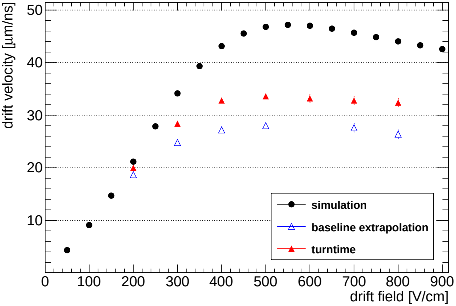


$$\triangle x = (t_{\text{c}} - t_{\text{mid}}) \cdot v_{\text{drift}} \cdot \text{slope}_{\text{ref}}$$

$$\Rightarrow v_{\text{drift}} = \frac{\triangle x}{(t_{\text{c}} - t_{\text{mid}})} \;\; / \;\; \text{slope}_{\text{ref}}$$

(2) Resolution with Charge Averaged Clustertime Correction (M3)





improvement of centroid resolution for large angles
⇒ better resolution expected (see B.Flierl PhD Thesis)

reconstruction of drift velocities fails
⇒ systematics can not yet be excluded

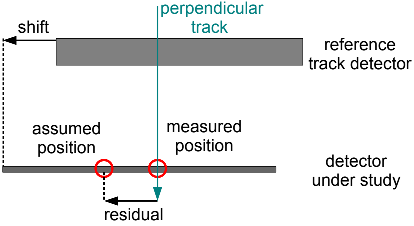
Summary

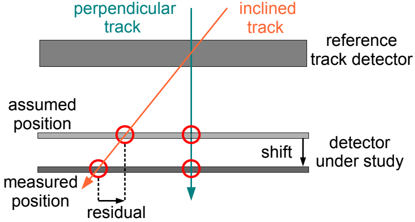
- SM2 - M0 , M1 , M3 - investigation in the Cosmic Ray Facility
- efficiency coupled to pulse height
- reconstruction of the strip alignment
  - pitch deviations ⇒ each board individually (humidity influence)
  - alignment reconstruction ⇒ “banana” shape, shifts, rotations
- track reconstruction with Micromegas
  - resolution depending on incident angle
  - drift time measurement ⇒ resolution improvement for inclined incident

Backup

Alignment using Reference Tracks

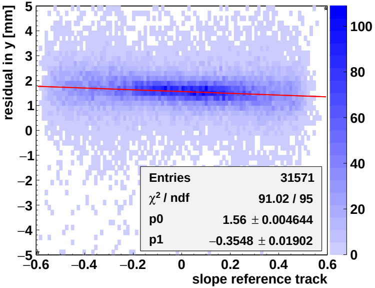
Concept:





Implementation:

before alignment



residual $=$ pos$_{\text{measured}}$ - pos$_{\text{reference}}$

$\Rightarrow$ residual vs. slope (reference track)

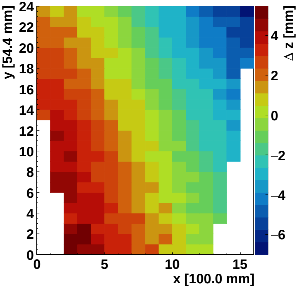
$\Rightarrow$ linear fit

shift$_{\text{horizontal}}$ $=$ intercept$_{\text{fit}}$

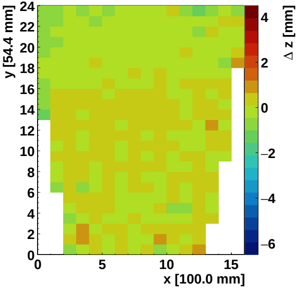
shift$_{\text{vertical}}$ $=$ slope$_{\text{fit}}$

Impact of 3D Alignment

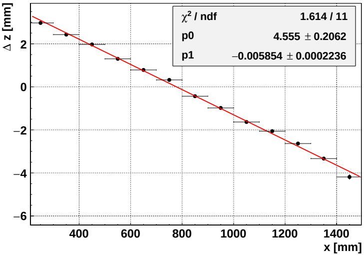
before

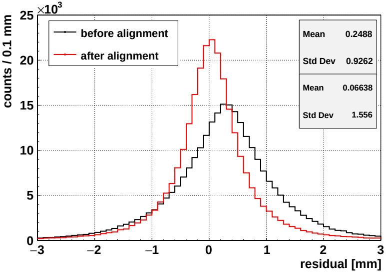


after



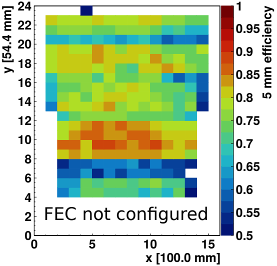
rotation around strips

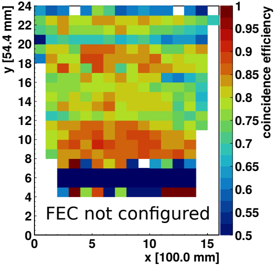




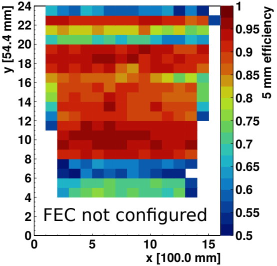
Impact of Zerosuppression and Analysis on Efficiency (M3)

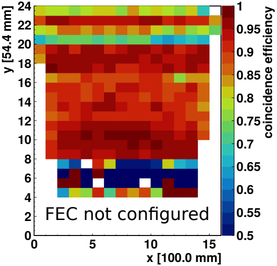
OLD zerosuppression





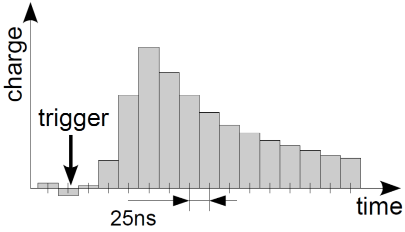
NEW zerosuppression



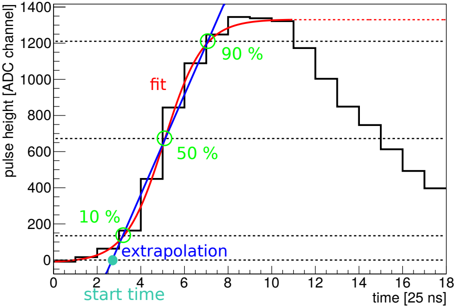


Signal Fit for APV Readout

APV principle



signal fit



- single strip APV readout
- APV is sampling charge in 25 ns steps
- charge on strip corresponds to maximum value of APV signal
- fit signal with inverse Fermi function:

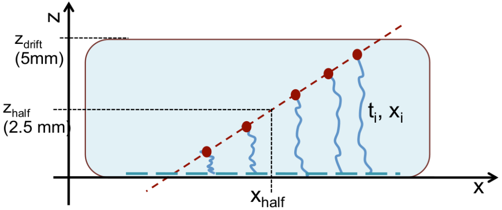
$$q(t) = \frac{p_0}{1 + \exp[(t - p_1)/p_2]} + p_3$$

  - p_0 : maximum charge
  - p_1 : turn time ($\mathrel{\hat{=}}$ 50%)
  - p_2 : rise time
  - p_3 : offset (≈ 0)

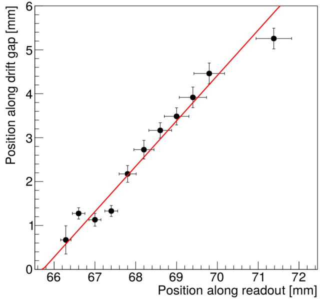
- 25 ns time jitter due to 40 MHz sampling recorded via TDC

µTPC Analysis - Classic Approach

NSW - TDR



CERN-THESIS-2016-019 (K.Ntekas)

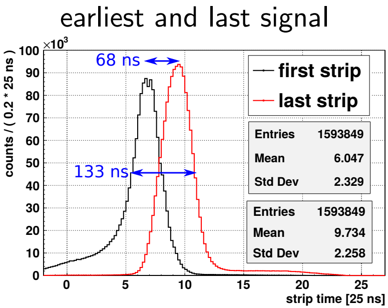


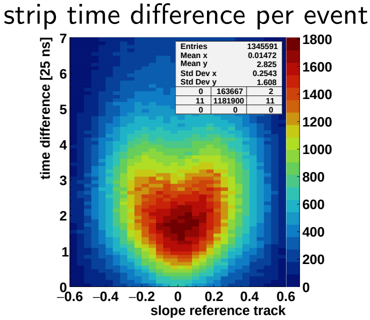
reconstruction of position in drift gap

linear with strip time measurement : $z_s = v_{\mathrm{drift}} \cdot \underbrace{(t_s - t_{\mathrm{offset}})}_{=t_{s,\mathrm{drift}}}$

$\Rightarrow$ biased reconstruction if wrong drift velocity is assumed
(e.g. water, air in gas mixture)

Determination of t_{mid} (extrapolated signal time spectra)

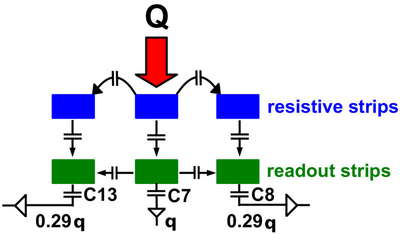




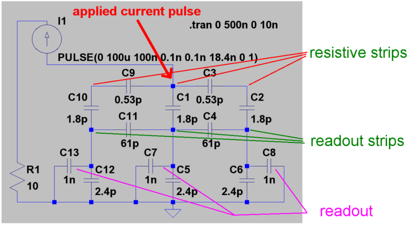
- expected time difference: 106 ns = 5 mm / 47 µm/ns ($\hat{=}$ 4.2 timebins)
- not yet understood differences between timing distributions
- smaller differences per event

charge spread due to capacitive coupling between resistive/readout strips

concept



simulation

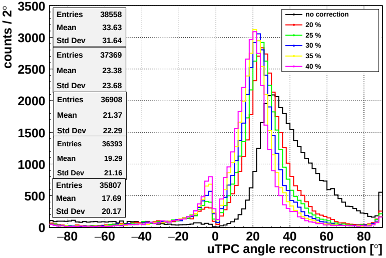


implementation

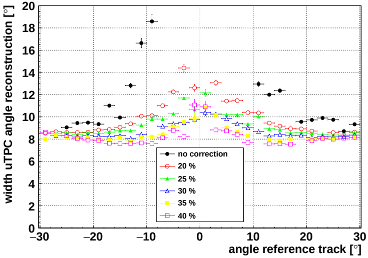
loop strips in cluster
    loop timebins from signalstart to maximum
        loop neighbors from 1 to 3
            neighbor charge - 0.29^n central strip charge
            central strip charge + 0.29^n central strip charge

Impact of Capacitive Coupling Correction

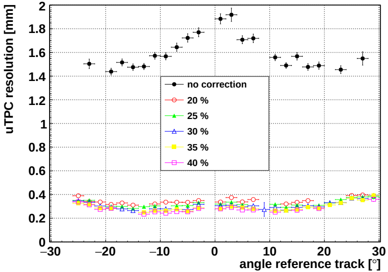
reference angle $\in [20°, 22°]$



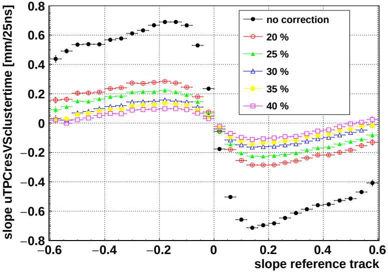
µTPC angular resolution



µTPC position resolution

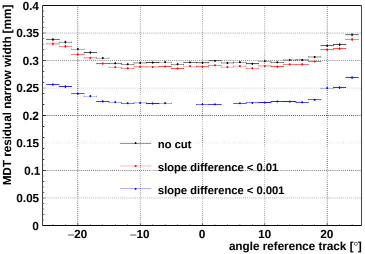


residual dependence on clustertime

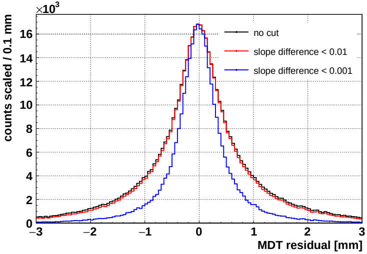


Influence of Multiple Scattering

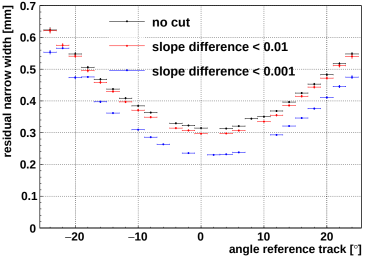
MDT residual width VS angle



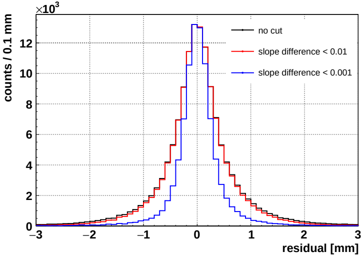
MDT residual perpendicular incident



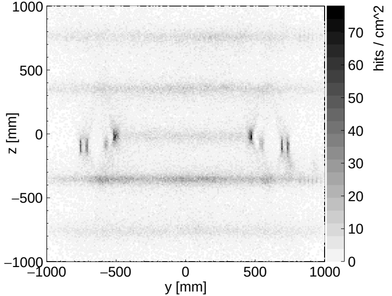
Module 0 residual narrow width VS angle

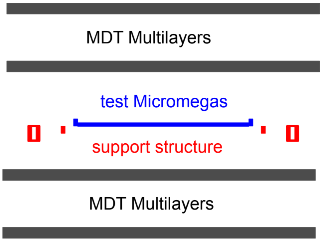


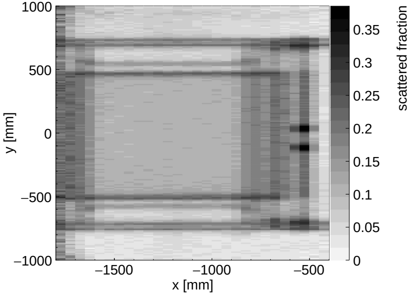
Module 0 residual perpendicular incident

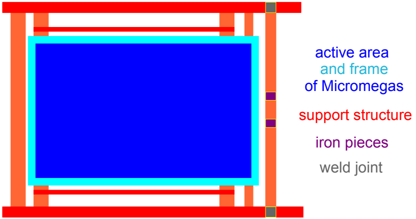


Usage of Multiple Scattering - Muon Tomography (L1)

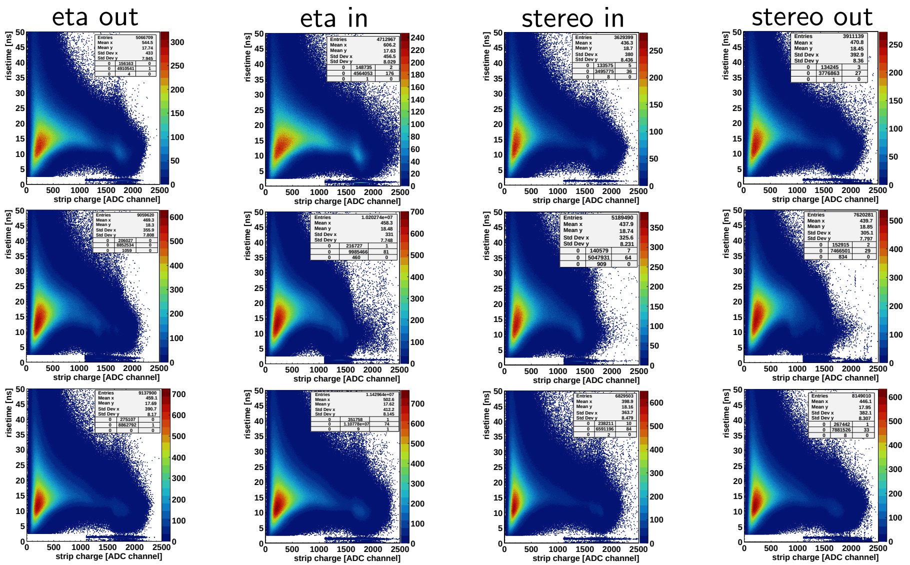








Strip Signal Properties - M3 at $U_{\mathrm{amp}} = 560$ V, Ar:CO_2 93:7



Cluster Properties - M3 at $U_{\mathrm{amp}} = 560$ V, Ar:CO_2 93:7