Investigation of the SM2 Module 0 at H8C Testbeam and in the Cosmic Ray Test Facility

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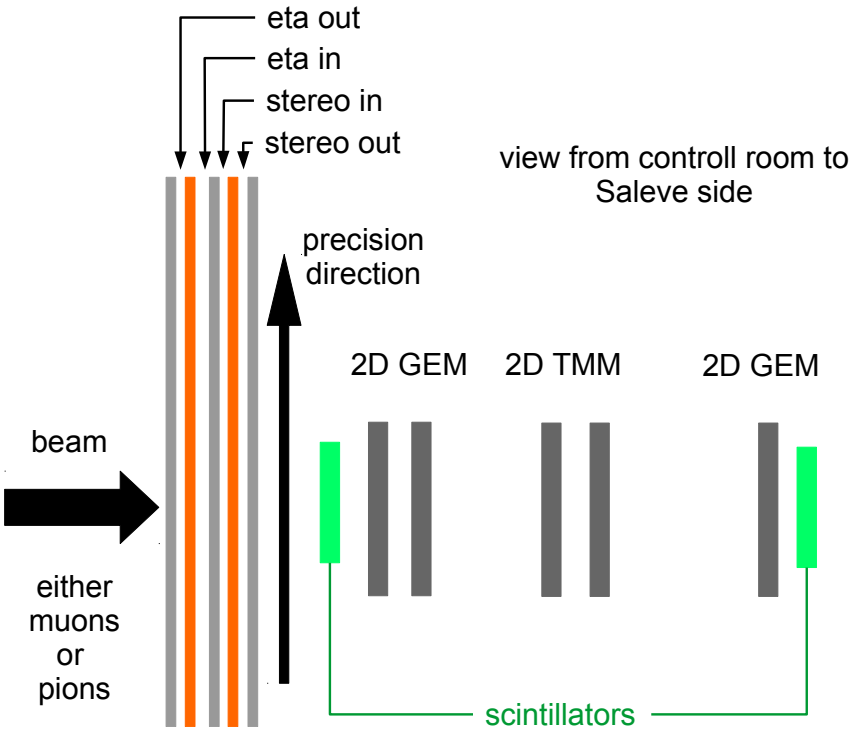
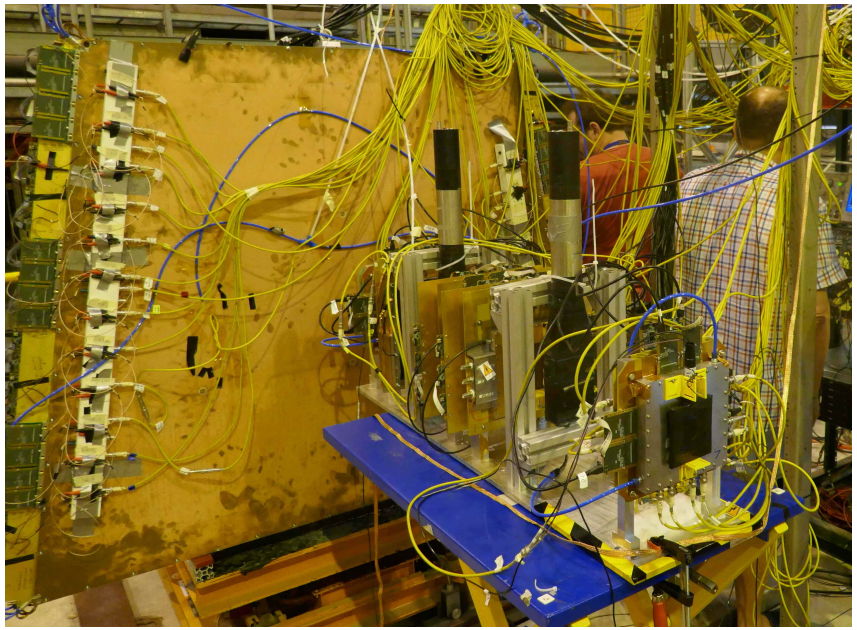
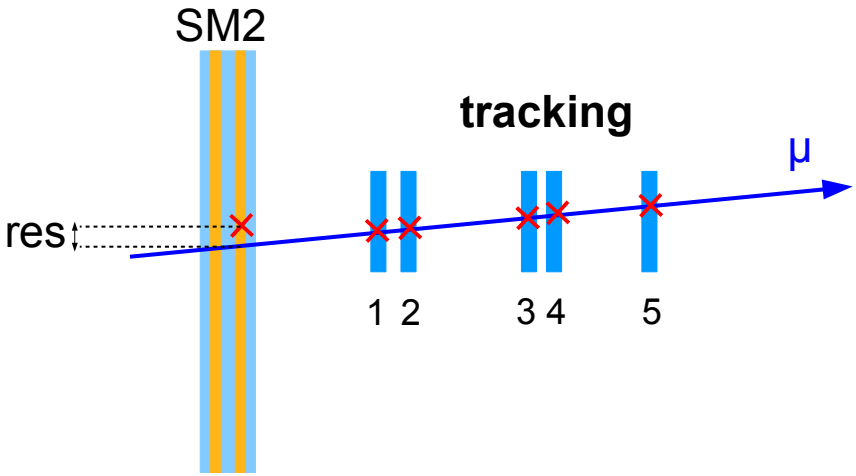
H8 Testbeam Setup for Tracking

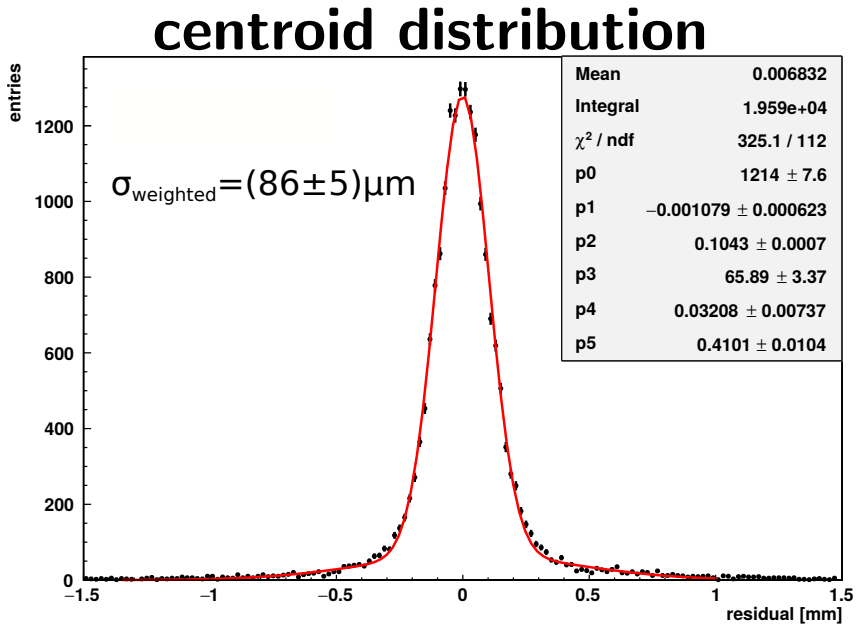




- module fully equipped with 96 APVs
- 1024 strips for each layer were read out by two FEC cards
- two further FEC cards for 28 APVs of tracking telescope:
  3 twodimensional GEMs and 2 twodimensional TMMs
  $\Rightarrow$ 4 FECs read out @ 220 Hz
- acquisition of 25 ns time jitter via TDC (VME)

Centroid Spatial Resolution for Perpendicular Incident





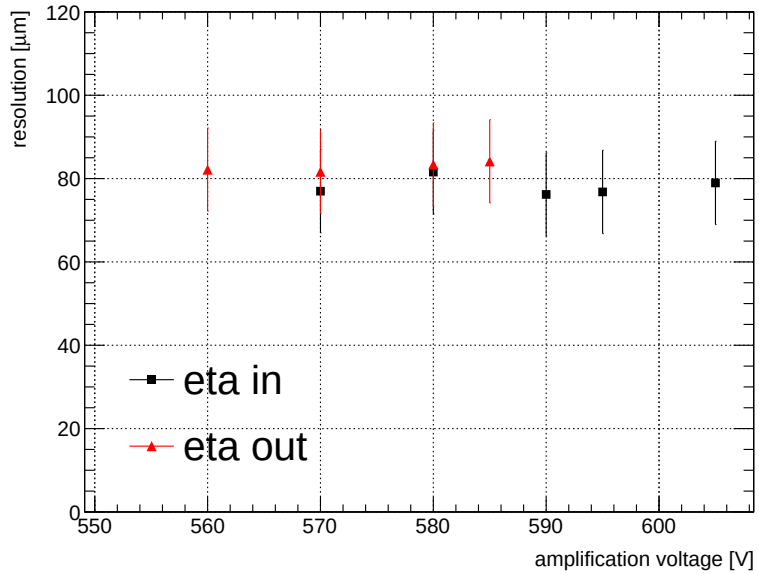
- 5 reference detectors: $\sigma_{\text{track}} = 70\,\mu\text{m}$ track uncertainty @ SM2
- residual distribution fitted by double Gaussian
  - each Gaussian corrected by the track uncertainty
  - sigmas weighted by integral of the respective Gaussian (I_i)

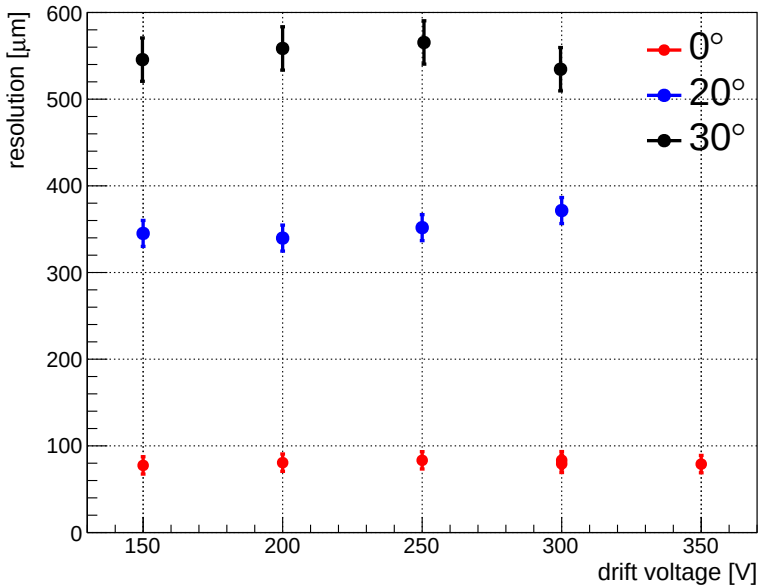
$$\sigma_{\text{centroid}} = \frac{I_1 \cdot \sqrt{\sigma_1^2 - \sigma_{\text{track}}^2} + I_2 \cdot \sqrt{\sigma_2^2 - \sigma_{\text{track}}^2}}{I_1 + I_2}$$

- resolution : **86**$\pm 5\,\mu$m for eta out @
  $U_{\text{amplification}} = 580\,\text{V}$
  $U_{\text{drift}} = -300\,\text{V}$

conclusion : tracking works

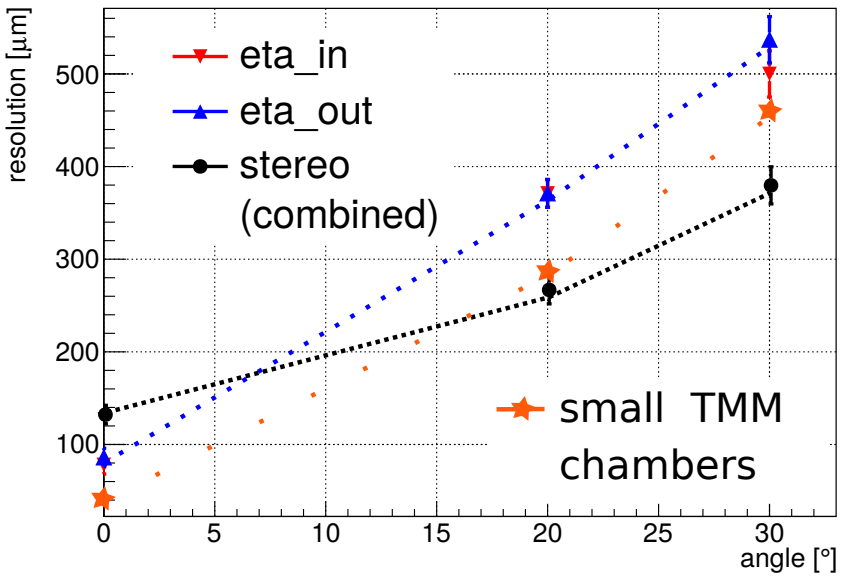
Investigation of Centroid Resolution





- for both eta layers the same resolution is achieved

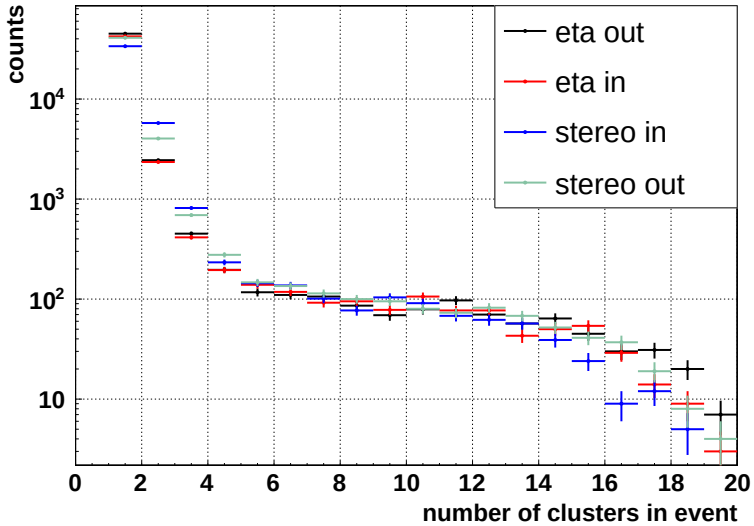
  $\Rightarrow$ below 90 µm
- resolution independent of amplification voltage
- resolution independent of drift voltage
- angular dependence very similar to K.Ntekas (10×10 cm^2 chambers)



conclusion : centroid resolution is excellent and behaves as expected

Cluster Reconstruction

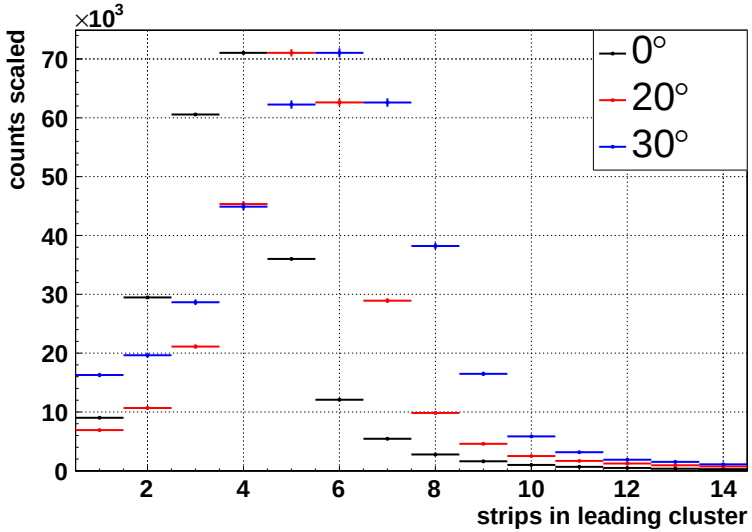
number of clusters



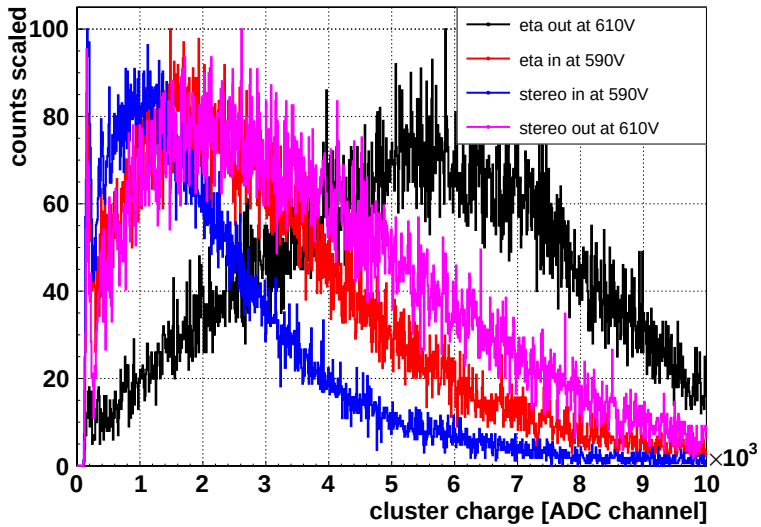
- only the cluster with the highest charge is considered (leading cluster, 90% single cluster events)

  clusters created by noise are avoided
- number of strips in leading cluster increases with angle as expected
- readout PCB differences of Module 0 boards influence heavily the amplification, but not the resolution

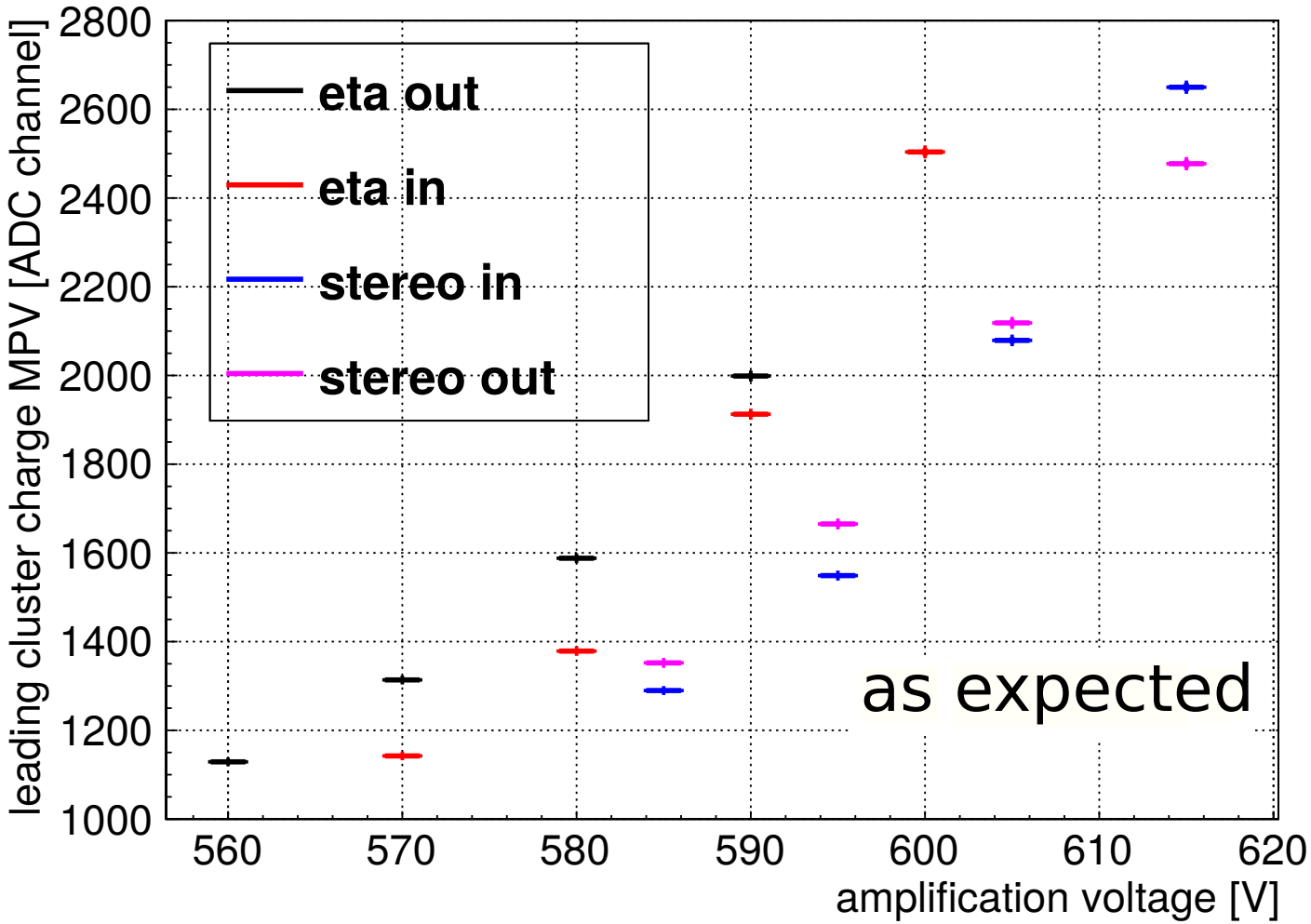
number of strips in leading cluster



charge of leading cluster



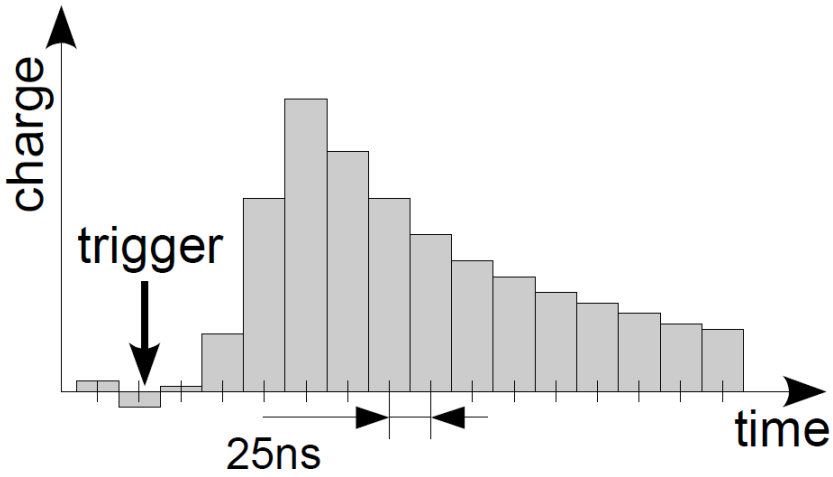
Pulse Height



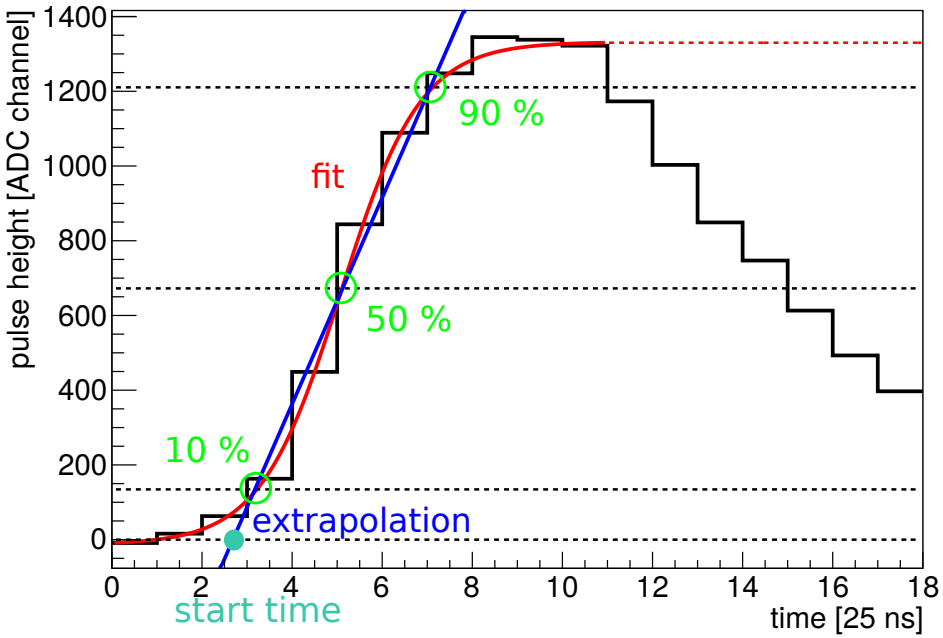
- gas amplification depended on layer
- gas amplification for stereo layers lower

APV Readout and Signal Reconstruction for µTPC Analysis

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
- ionization time in drift region corresponds to start time of signal

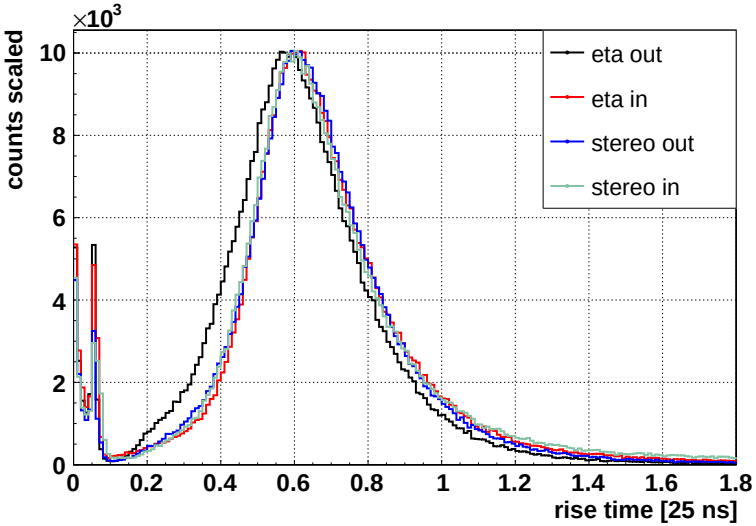
  $\Rightarrow$ fit with inverse Fermi function:

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

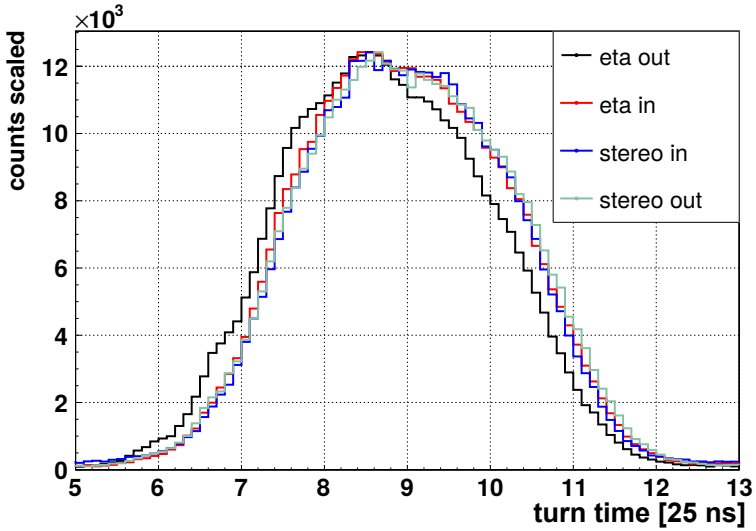
  - p_0 : maximum charge
  - p_1 : turn time ($\hat{=}$ 50%)
  - p_2 : rise time
  - p_3 : offset (≈ 0)
- 25 ns time jitter due to 40 MHz sampling recorded via TDC

Single Channel Signal Properties @ 20° , 300 V U_{drift}

rise time

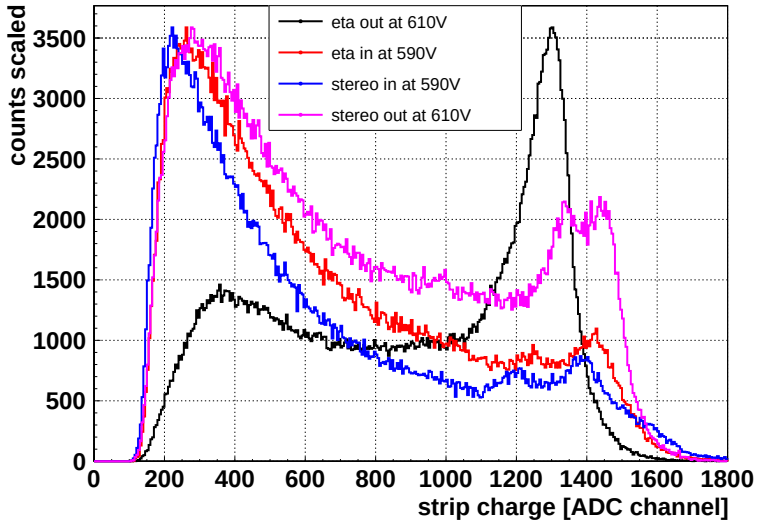


turn time

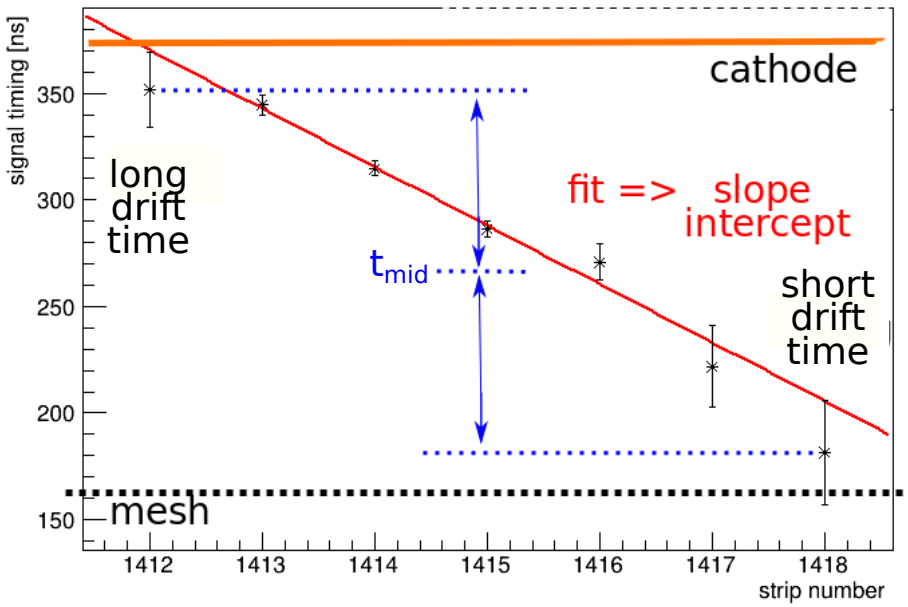


- noise signals:
  rise times smaller than 2.5 ns
- very similar signal shapes for all layers
- adjust amplification voltage to avoid saturation of readout channels
- cluster reconstruction:
  combine neighboring strips with at max 2 missing strips

maximum charge



µTPC Analysis



linear fit:

signal time $= m_{\text{fit}} \cdot$ strip number $+ t_{\text{fit}}$

- angle reconstruction:

  m_{fit} : slope µTPC fit

  $\theta = \arctan\left(\frac{\text{pitch}}{m_{\text{fit}} \cdot v_{\text{drift}}}\right)$

- position reconstruction:

  t_{fit} : intercept µTPC fit

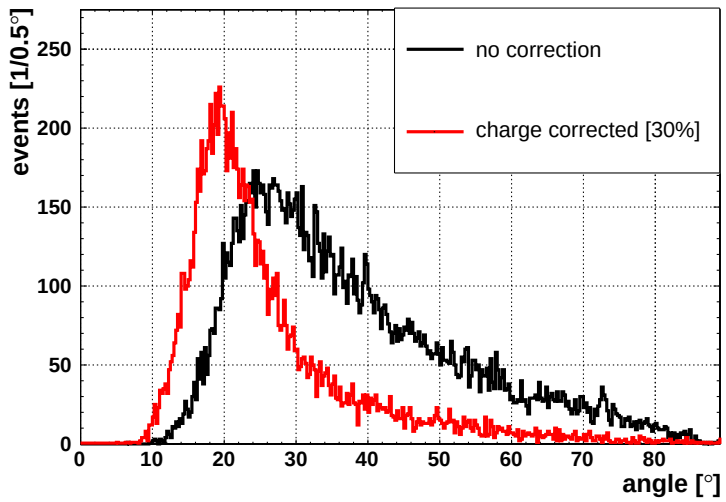
  $t_{\text{mid}} = z_{\text{half}}/v_{\text{drift}} + t_{\text{start}}$

$$\text{pos} = \frac{z_{\text{half}} - v_{\text{drift}} \cdot (t_{\text{fit}} - t_{\text{start}})}{v_{\text{drift}} \cdot m_{\text{fit}}/\text{pitch}} = \frac{t_{\text{mid}} - t_{\text{fit}}}{m_{\text{fit}}} \cdot \text{pitch}$$

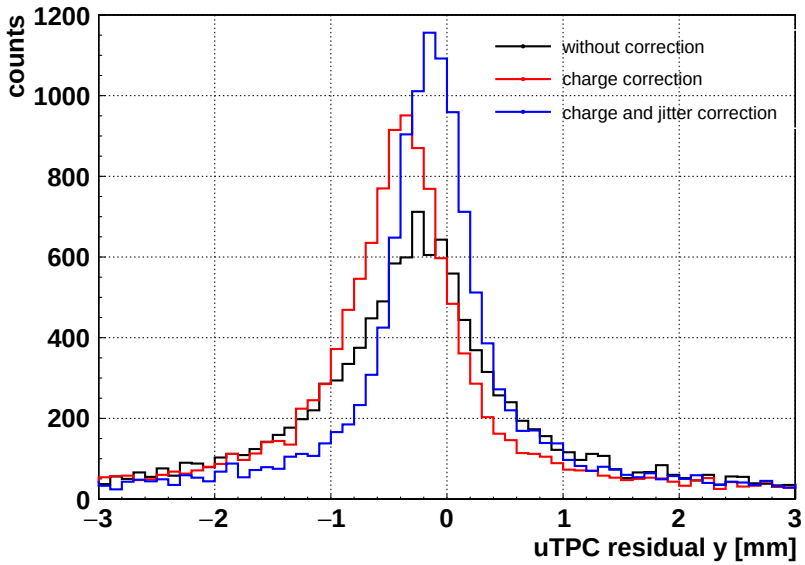
- determination of t_{mid} with new method
- time jitter correction (40 MHz clock of APV/FEC) works ✓
- correction of capacitive coupling between strips $\approx$ 30% ✓
  (LT Spice simulation)

Preliminary µTPC Results at 20°

angle reconstruction



residual distribution

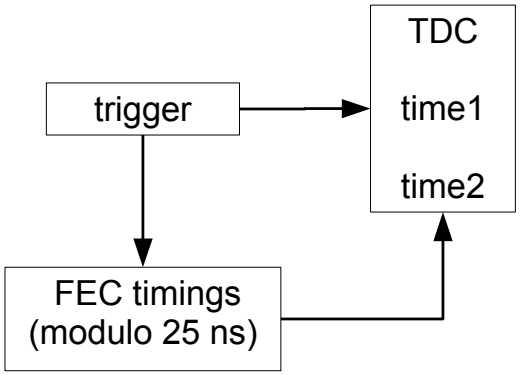


- run parameter:
  - 590 V amplification voltage
  - 300 V drift voltage
  - muons
  - 20° incident angle
- corrections improve angular and residual distributions by decreasing the width

  optimum 30% capacitive coupling
- reconstructed angular distribution peaks at 20° when corrections applied
- very similar results using turn time of Fermi fit, as start time

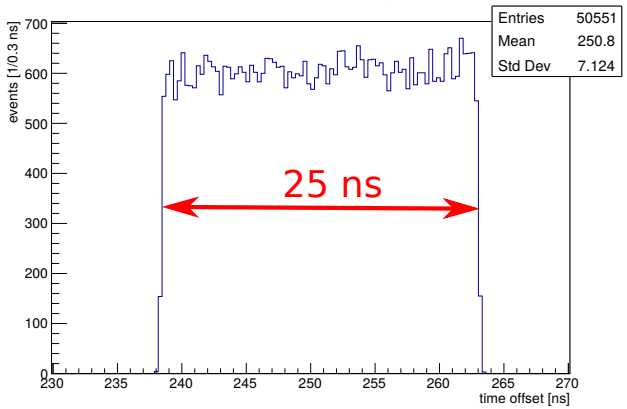
Time Jitter Correction and Signal Time

jitter recording

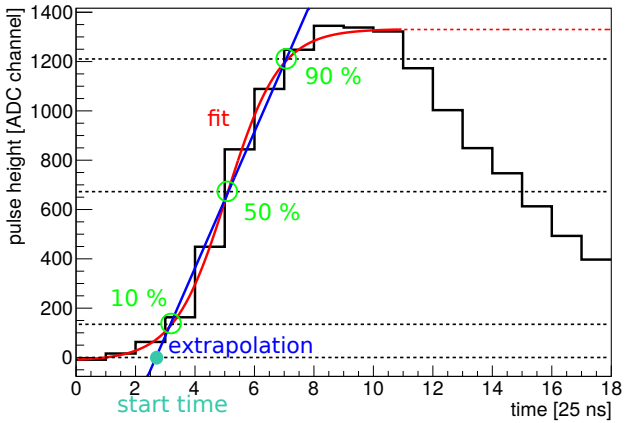


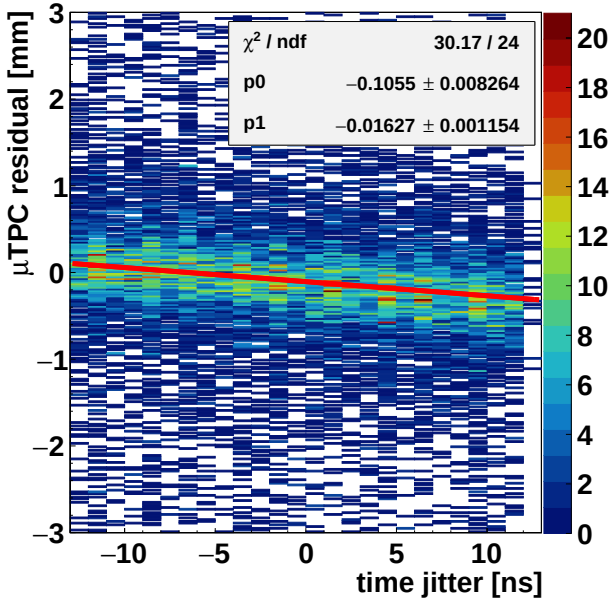
- time jitter due to APV sampling in 25 ns steps
- recorded via TDC
- slope of
  μTPC residual
  VS time jitter
  distribution
  drift time dependent

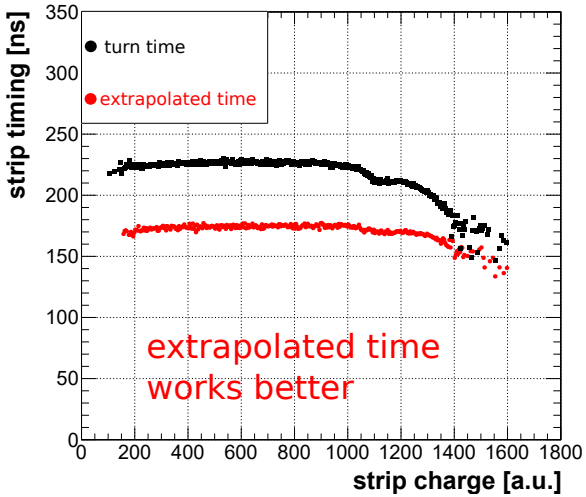
measured jitter



signal fit

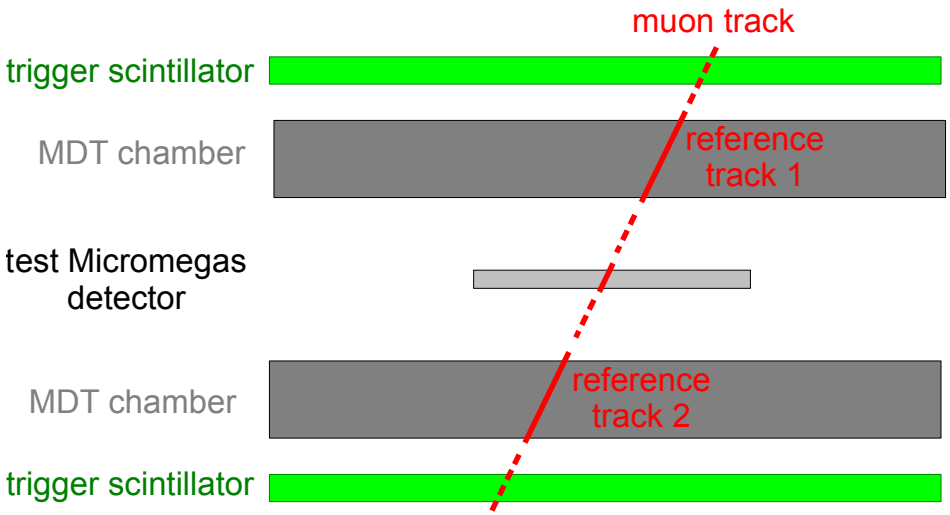






extrapolated time = turn time - log(81)/1.6 · rise time

Cosmic Ray Test Facility for Module Calibration



- 2D track reconstruction with two Monitored Drift Tube (MDT) chambers
- trigger via scintillator hodoscope with $\approx 10\,\text{cm}$ resolution in orthogonal direction
- MDT chambers : $2.2\,\text{m} \times 4\,\text{m}$
  $\Rightarrow$ active area : $9\,\text{m}^2$, angular acceptance : $\pm 30^\circ$
- readout of the full module with six FEC cards @ full 100 Hz µ-rate
  (tested up to 500 Hz with random trigger)

Average Pulse Height Distribution

- MDT chambers

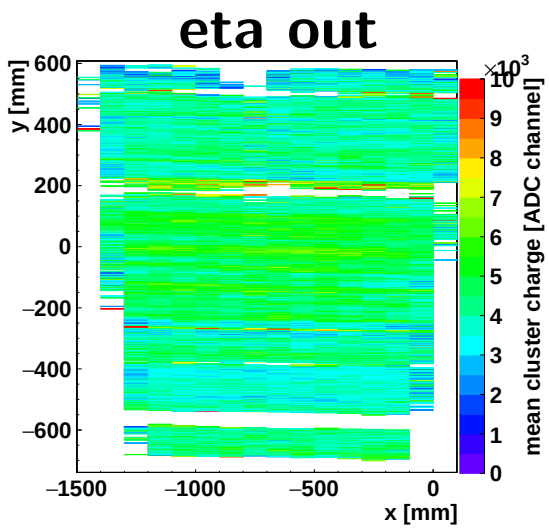
  $\Rightarrow$ **Y** precision coordinate

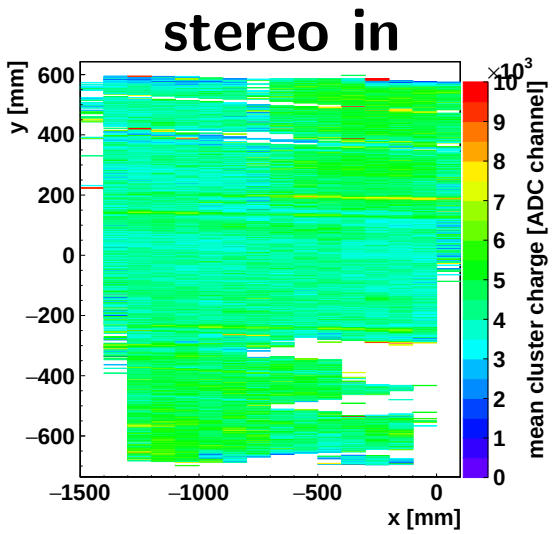
- scintillators

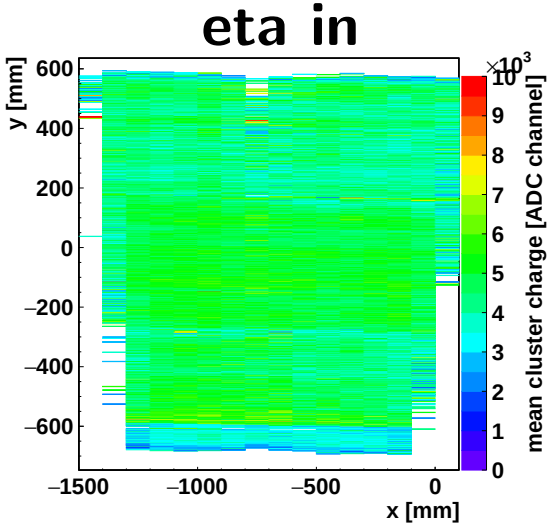
  $\Rightarrow$ **X** coordinate

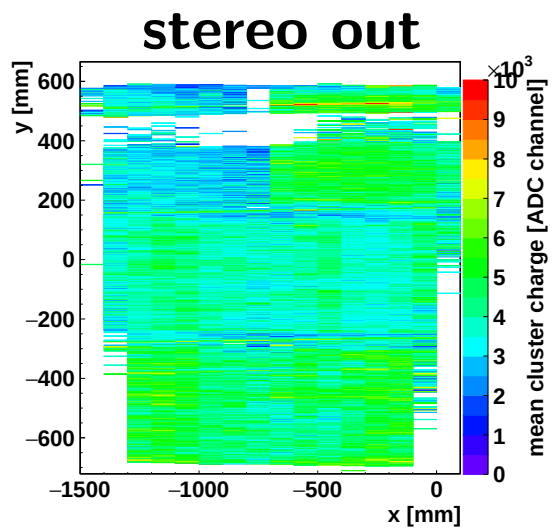
  coarse segmentation

- HV: 600 V, one sector at 560 V (stereo out)
- homogeneous pulse height (some inefficient spots)
- inefficient regions under investigation

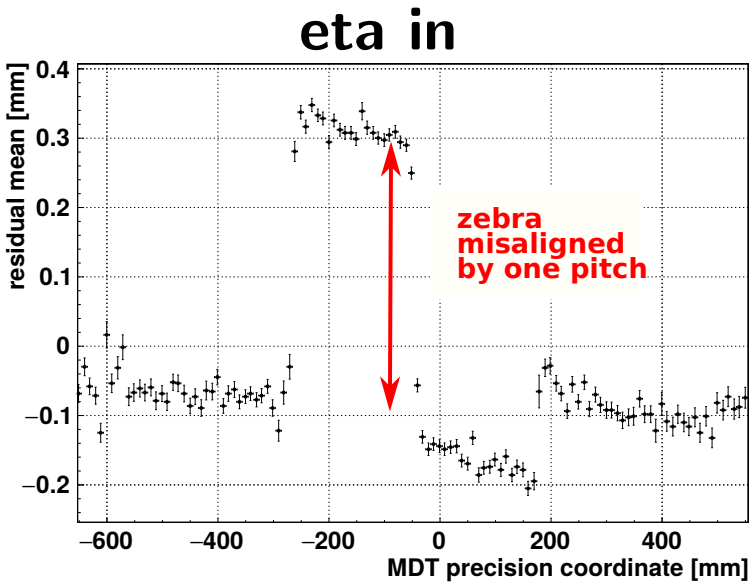


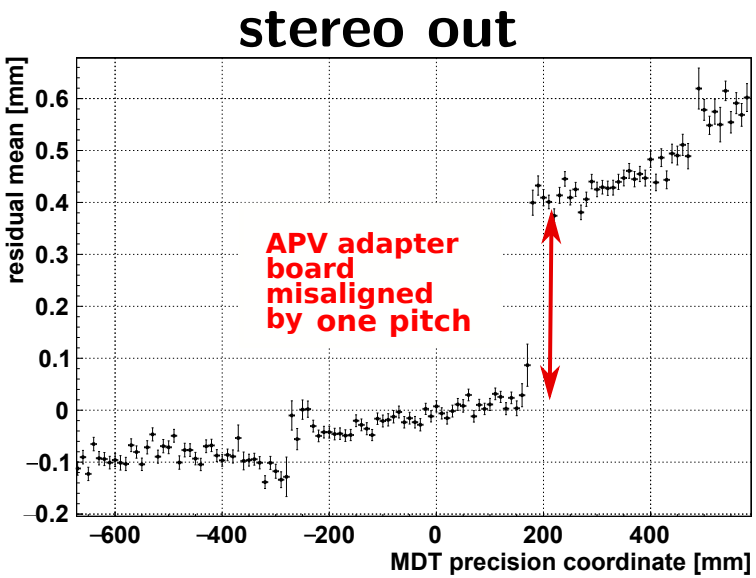






Readout PCB Alignment

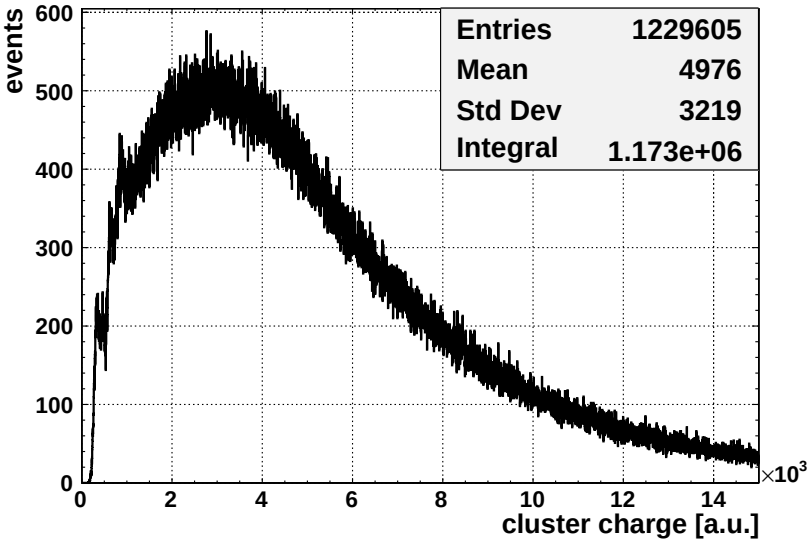




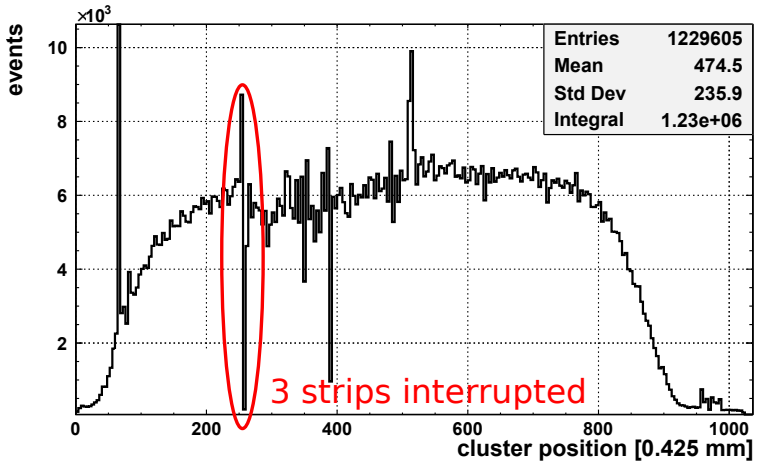
- mean of residual to reconstructed track intersection by MDT as function of precision coordinate of the MDT
- reconstruction of:
  $\Rightarrow$ misalignment of APV adapter boards
  $\Rightarrow$ shift of readout PCB with respect ot each other
  $\Rightarrow$ pitch error $\mathcal{O}(100\,\mathrm{nm})$

First Data of SM2 Module 1

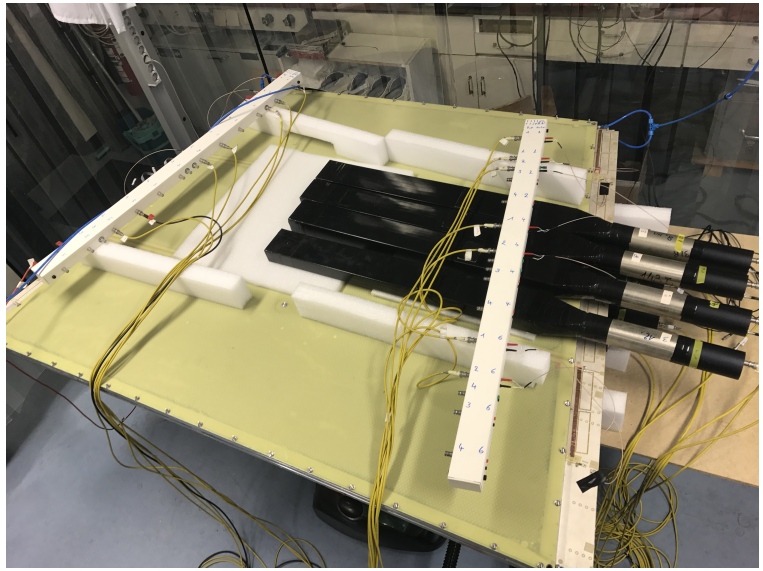
cluster charge



cluster position



setup



- series eta panel 1 doublet
- board 7 of one side read out
- drift voltage : $-300\,\mathrm{V}$
  amplification voltage : $600\,\mathrm{V}$
- coincidence of scintillator trigger from above and below

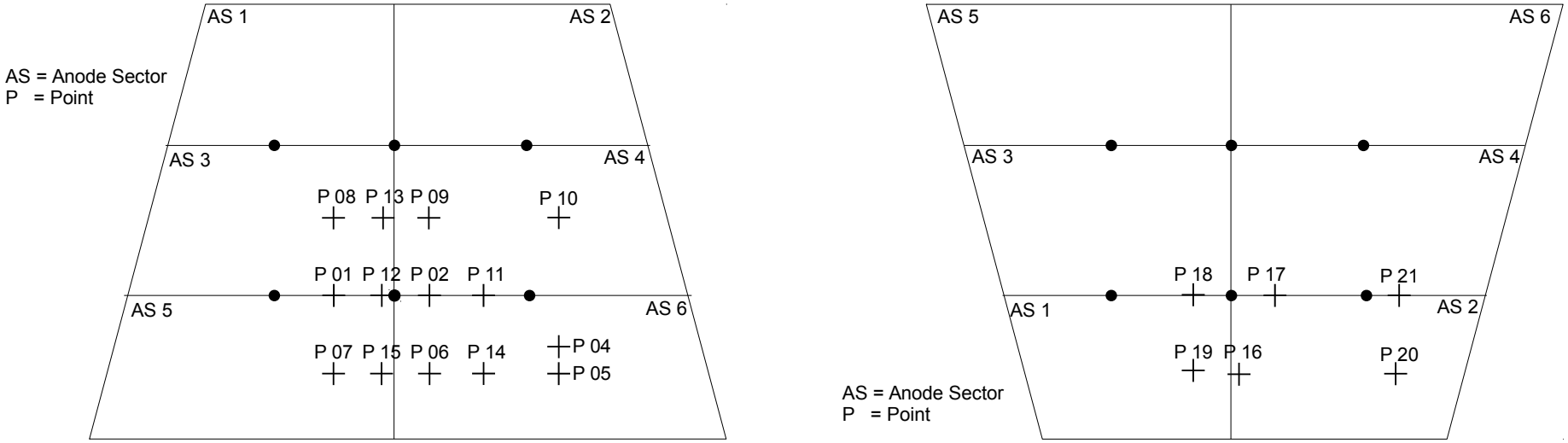
Conclusions

- centroid analysis shows:
  - resolution for perpendicular tracks is below 90 µm ⇒ tracking works ✓
  - resolution behaves as expected ⇒ Module works ✓
- µTPC analysis:
  - signal properties as expected ✓
  - cluster properties as expected ✓
  - corrections (jitter, capacitive coupling) work ✓
  - incident angle is reconstructed correctly ✓
  - resolution will be further investigated
- investigation in the cosmic ray test facility:
  - homogeneous pulse height distribution for the full SM2 Module 0 measured ✓
  - board alignment will be further investigated

Backup

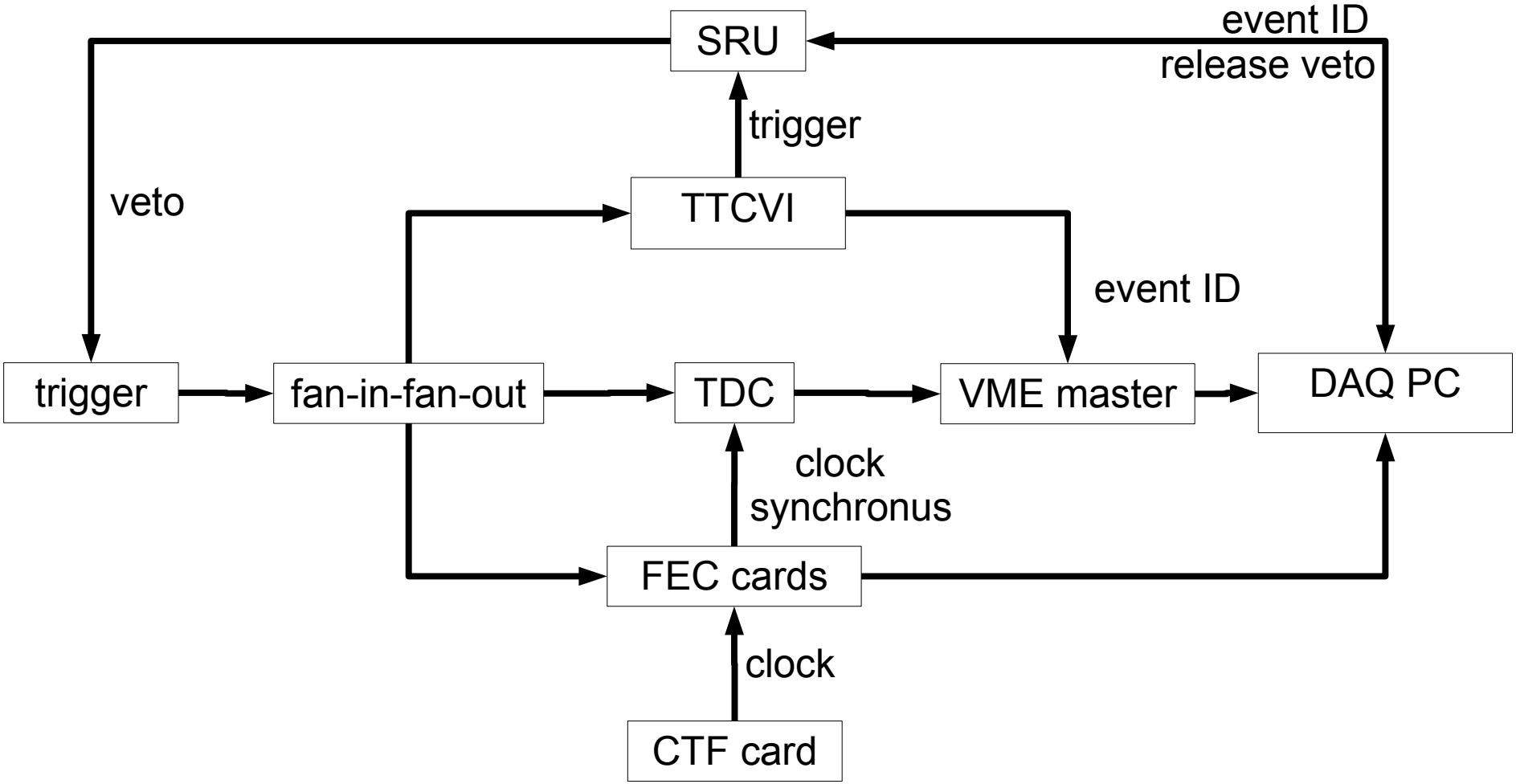
Measurement Program

view from telescope against beam direction



- scan of a large part of the active area to investigate the efficiency
  $\Rightarrow$ dead or noisy areas (for example between the PCBs)
- resolution as function of amplification and drift voltage, as well as incidence angle
- PCB alignment

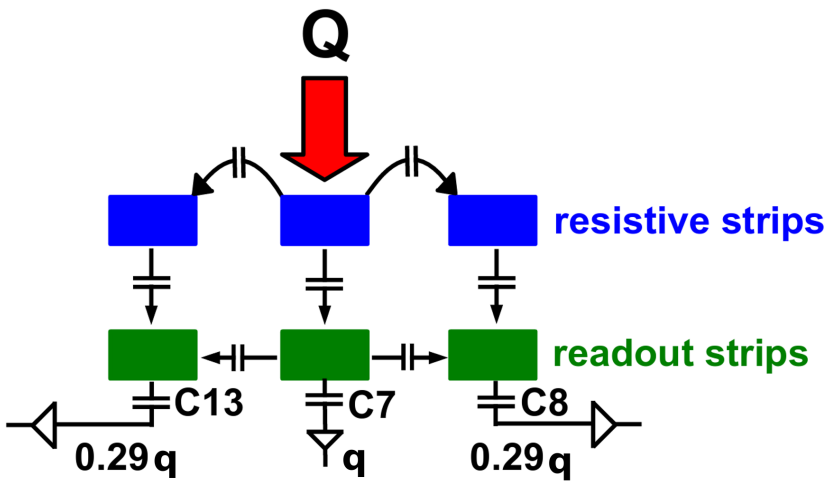
Readout with Jitter Correction Possibility



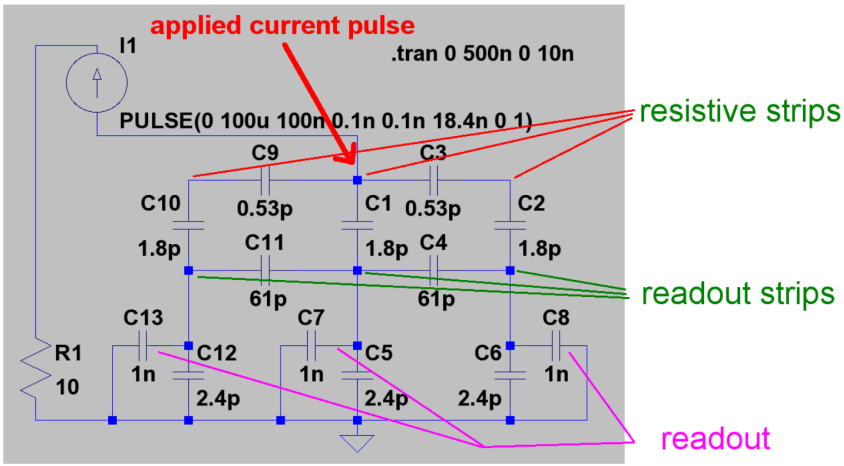
Correction due to Capacitive Coupling of Neighboring Strips

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

Readout PCB Alignment