International Conference on High Energy Physics 2018

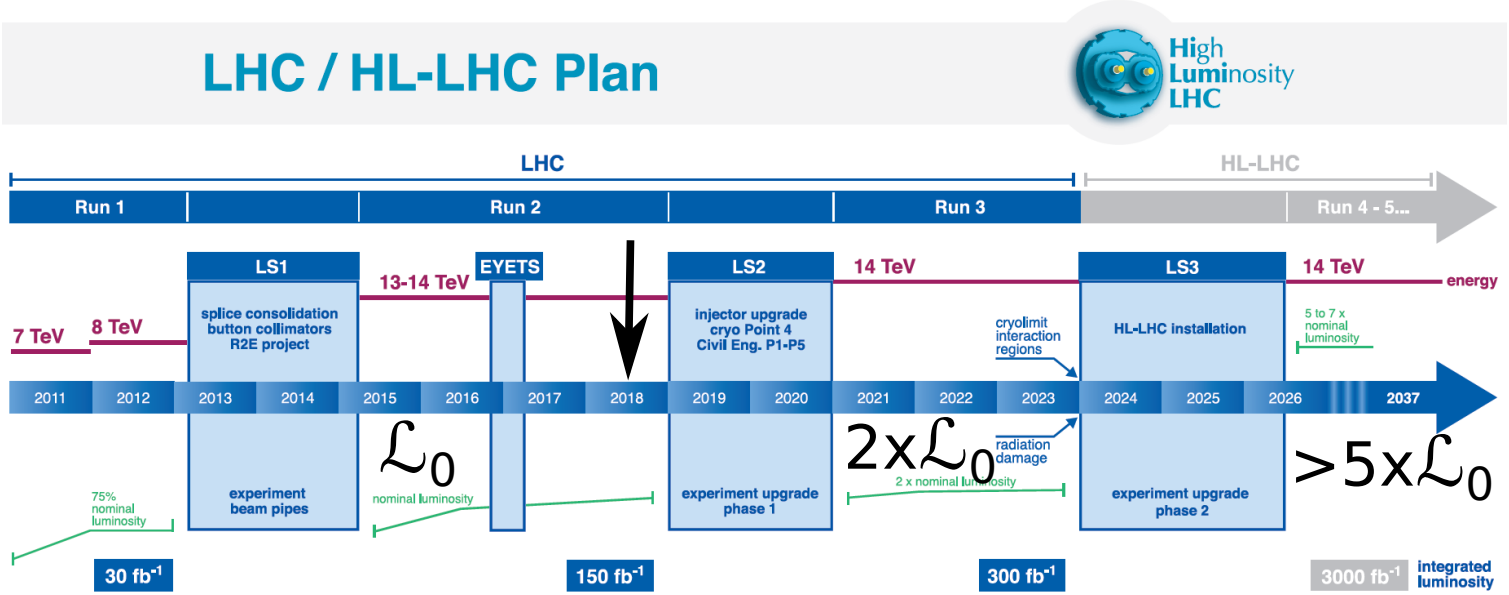
Performance and Calibration of 2 m^2-size 4-layered Micromegas Detectors for the ATLAS Upgrade

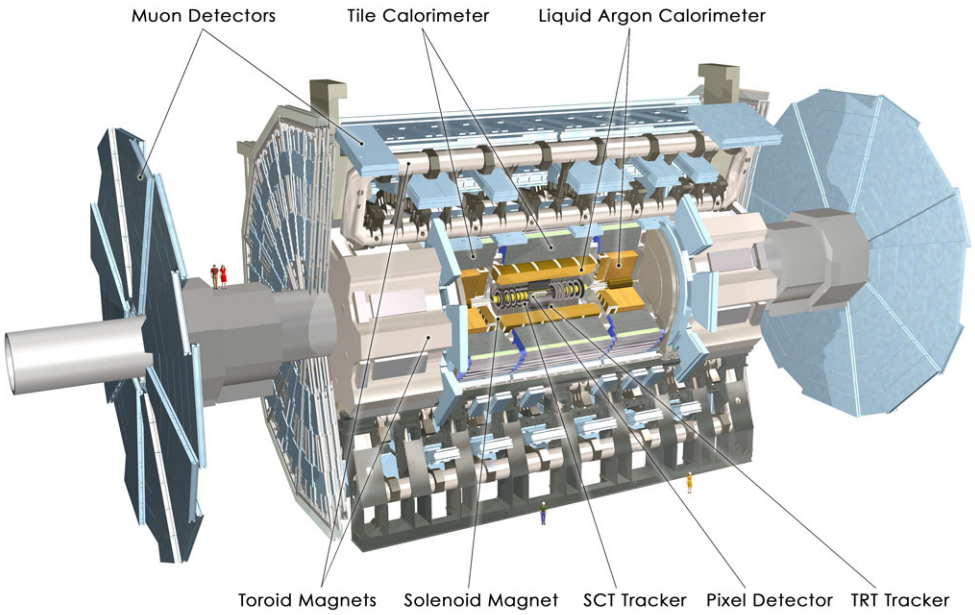
Maximilian Herrmann,
on behalf of the ATLAS muon collaboration

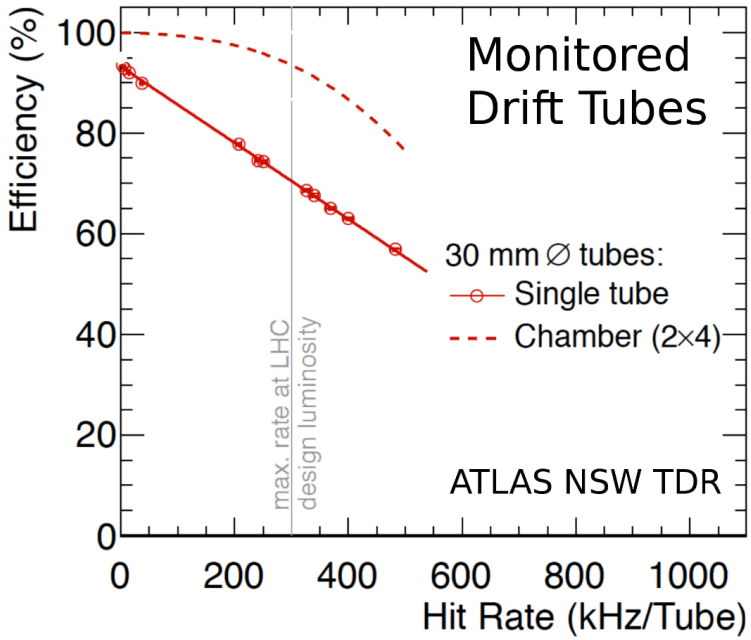
Ludwig-Maximilians-Universität München - Lehrstuhl Schaile

05.07.2018, Seoul

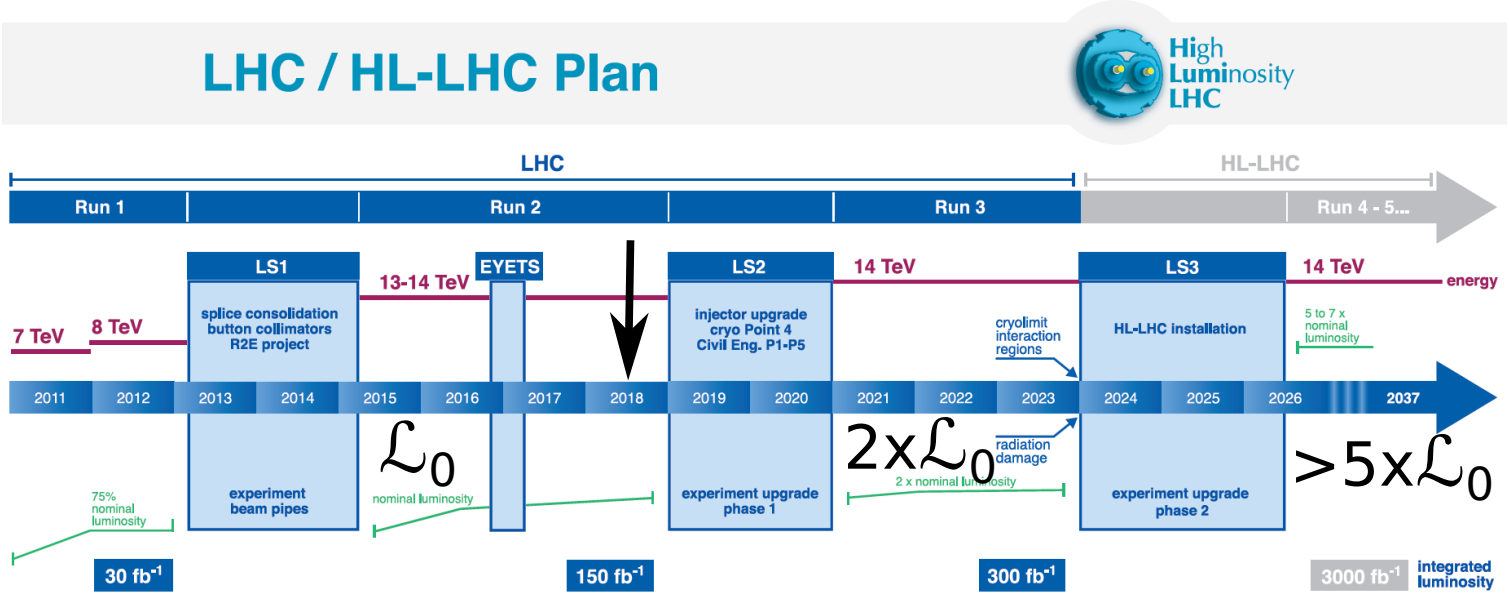
LHC Upgrade Status

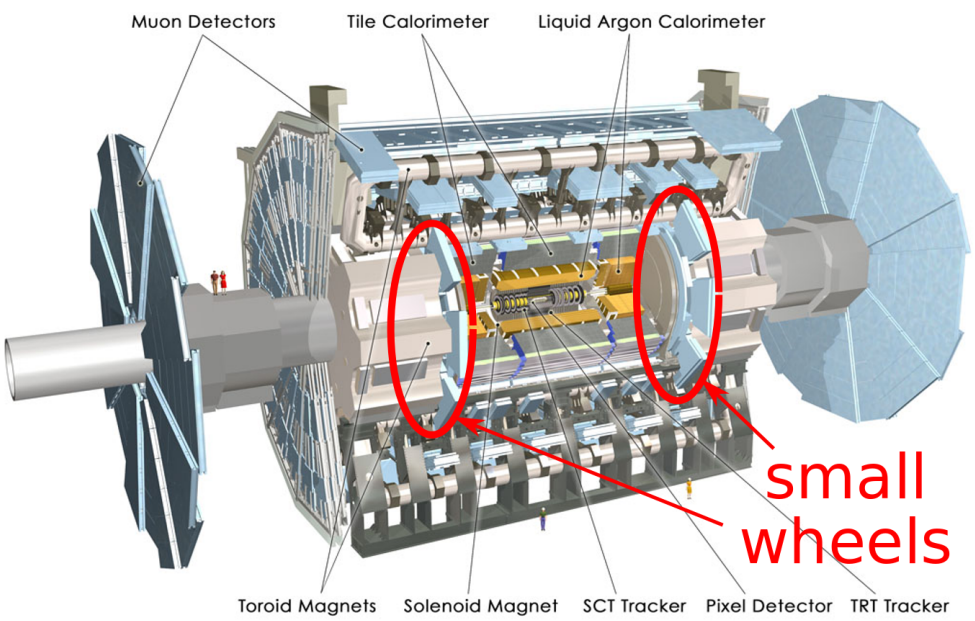


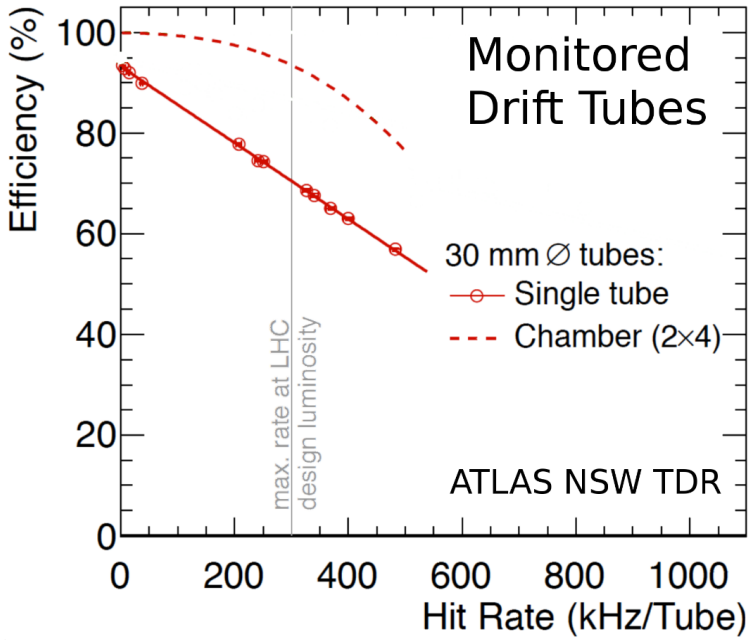




LHC Upgrade Status



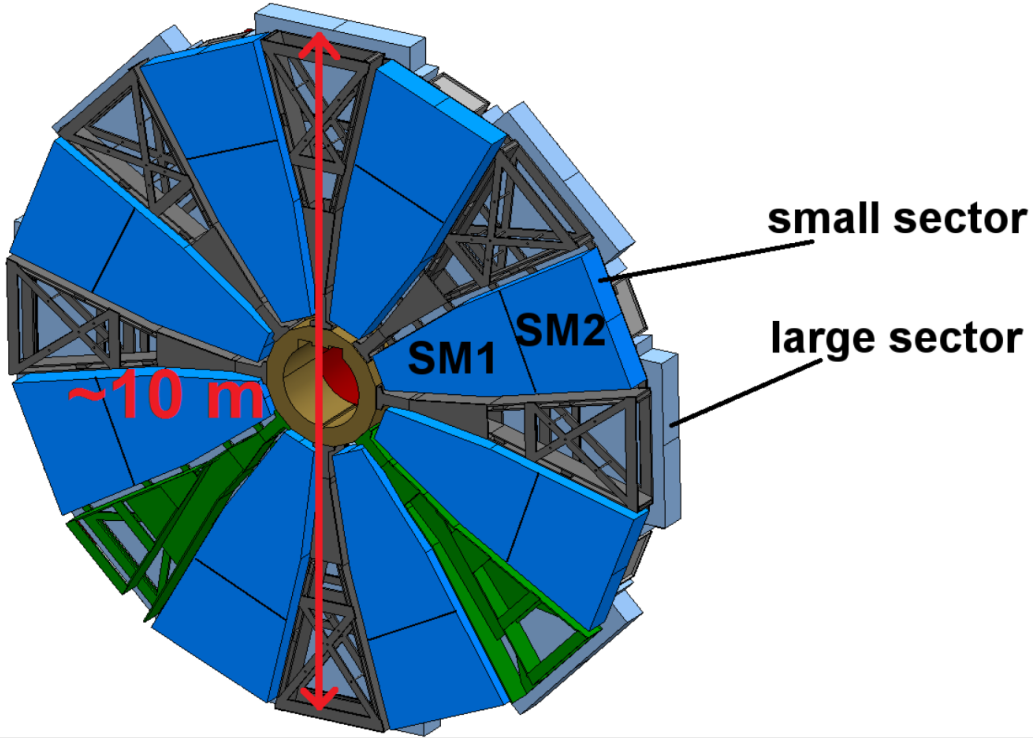




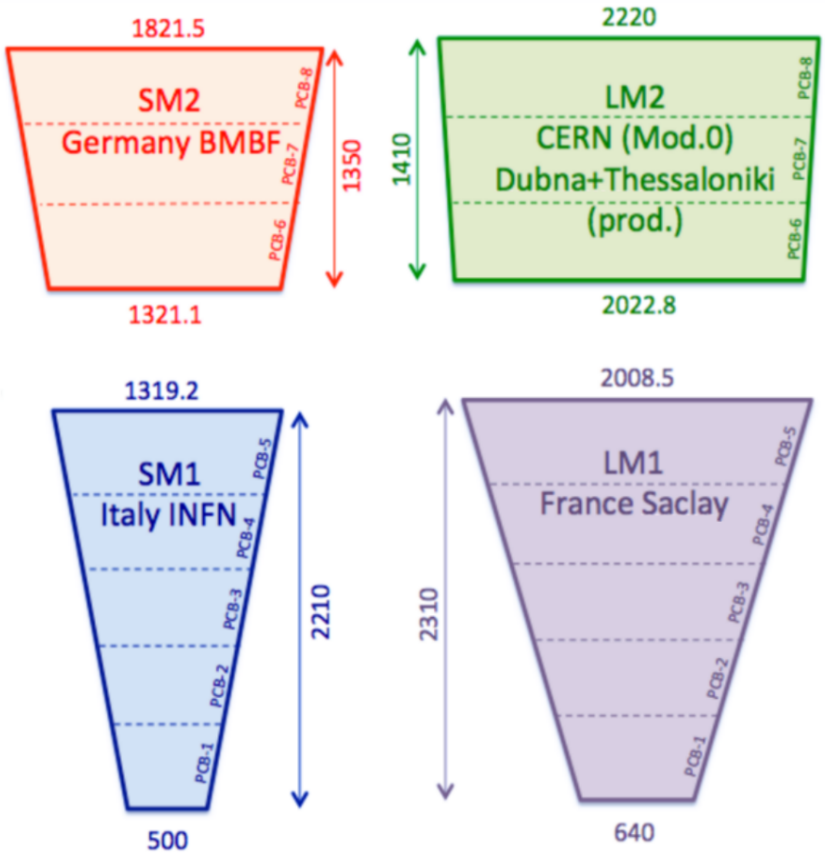
Upgrade of the Muon Small Wheels

replacement of the current end caps of the muon spectrometer by small-strip Thin Gap Chambers (sTGC) and Micromegas quadruplets

New Small Wheel Sectors



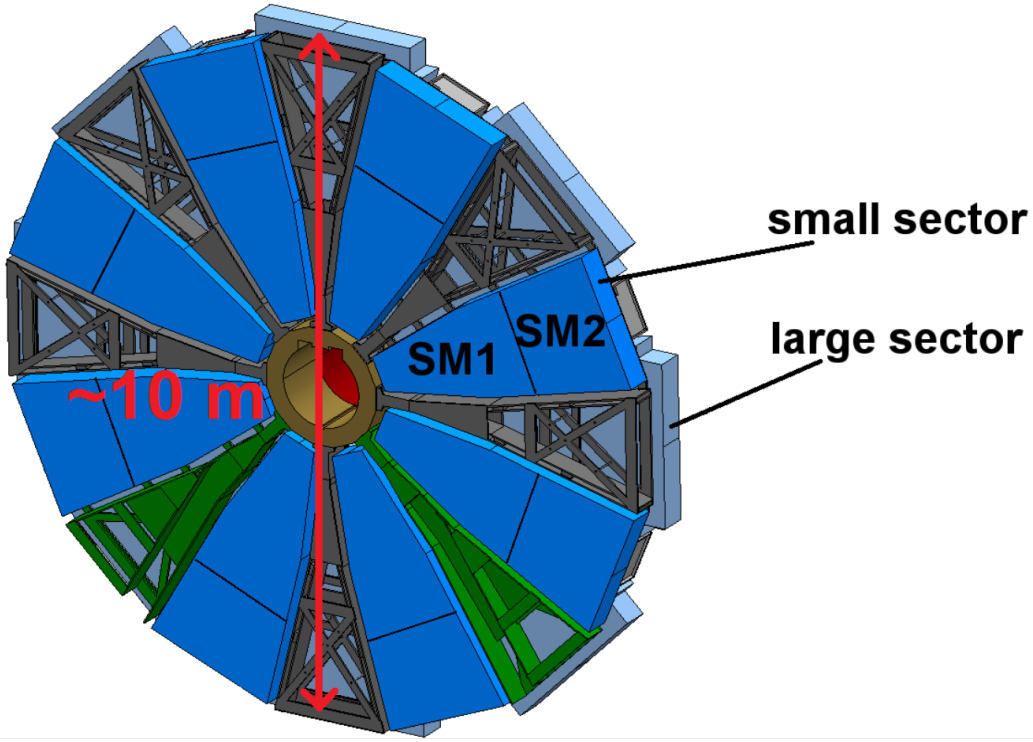
Micromegas quadruplets



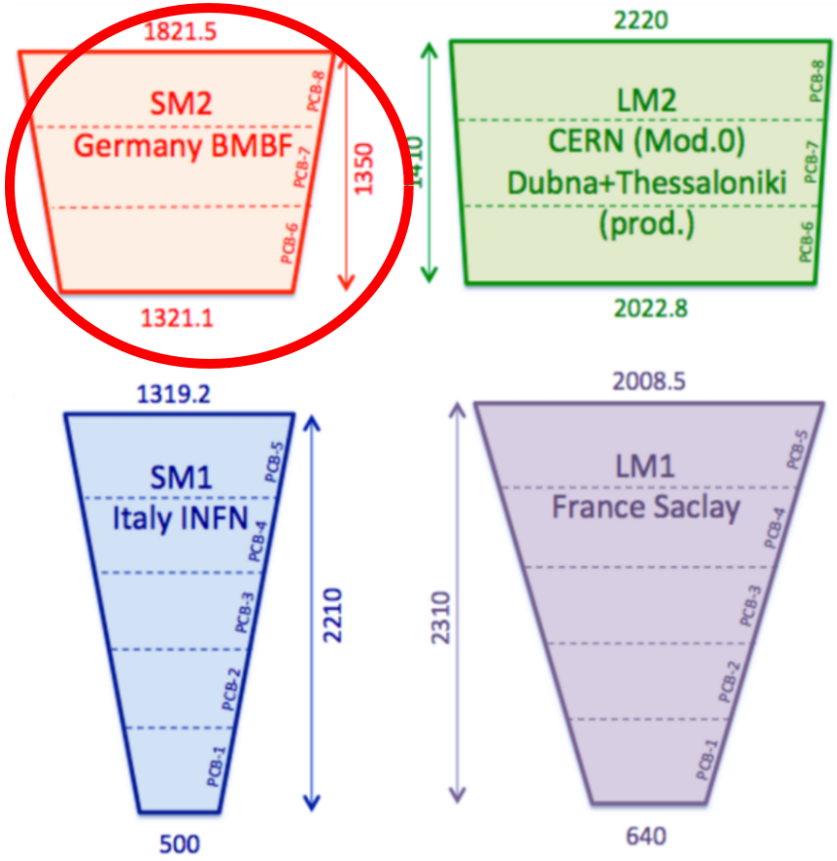
Upgrade of the Muon Small Wheels

replacement of the current end caps of the muon spectrometer by small-strip Thin Gap Chambers (sTGC) and Micromegas quadruplets

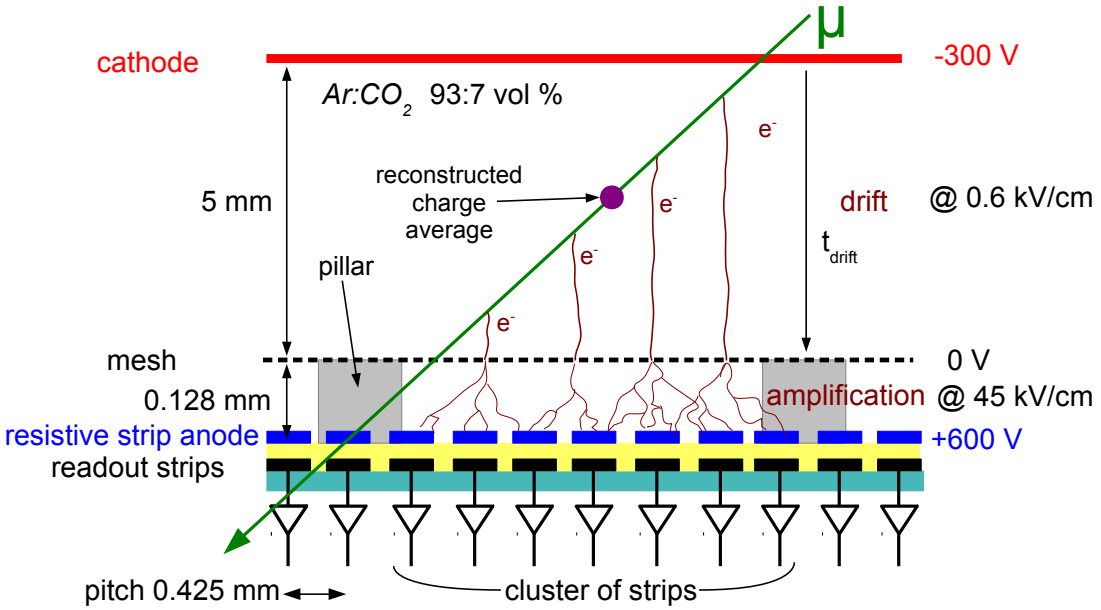
New Small Wheel Sectors



Micromegas quadruplets



MICROMEGAS - MICROMEesh GAseous Structure



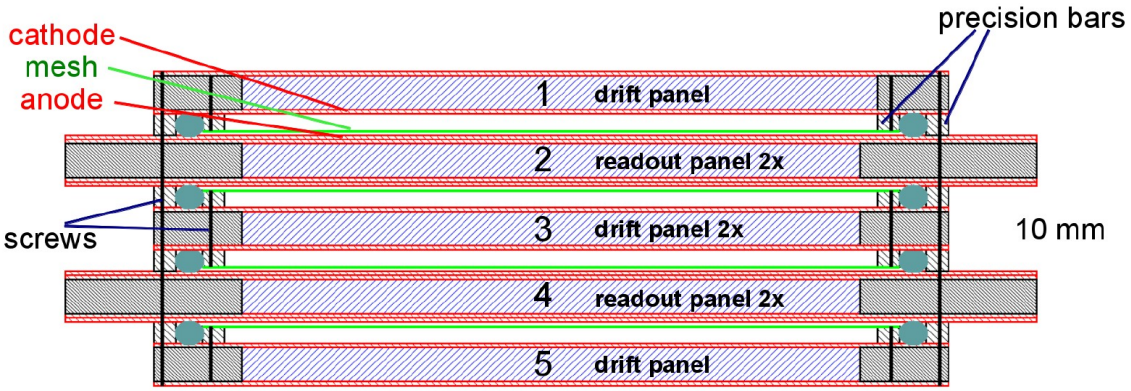
$$\text{centroid} = \frac{\sum_{\text{strips}} \text{strip} \cdot q_{\text{strip}}}{\sum_{\text{strips}} q_{\text{strip}}}$$

$\Rightarrow$ position $=$ centroid $\times$ pitch

$t_{\text{drift}} = f(\text{strip})$

$\Rightarrow$ incident angle reconstruction

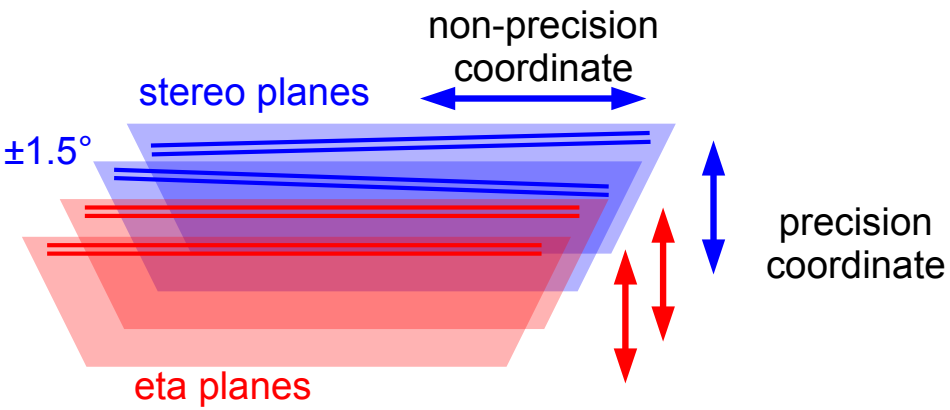
Micromegas Quadruplet



4 active layers of Micromegas

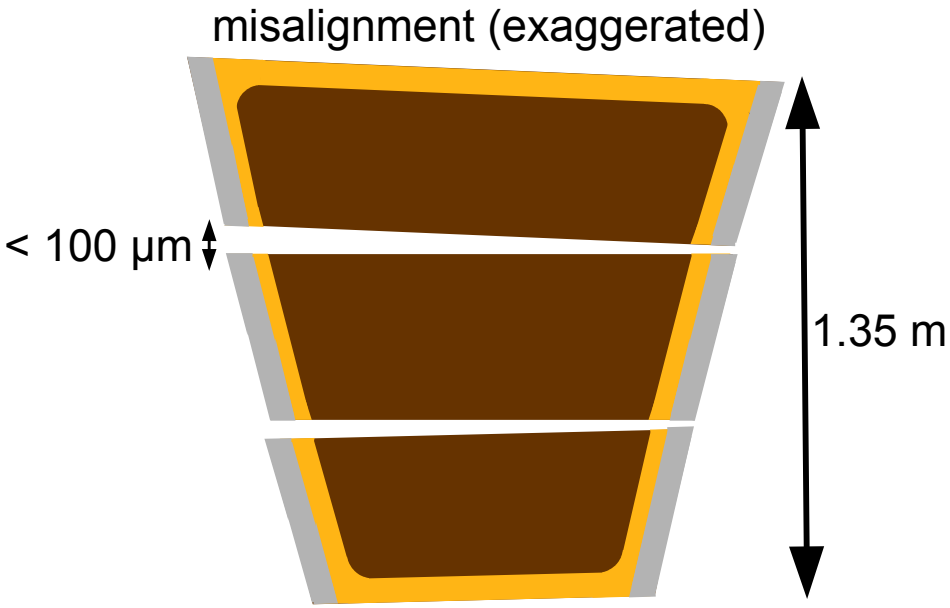
$\Rightarrow$ 2 $\times$ back-to-back

Design of Readout Anodes



- eta planes for precision reconstruction in pseudorapidity direction perpendicular to anode strips
- stereo planes for additional coarse position information along the anode strips

SM2 anode



technical limitations
micropattern readout anode: width $\leq$ 50 cm

$\Rightarrow$ 3(/5) printed circuit boards (PCB) per active layer

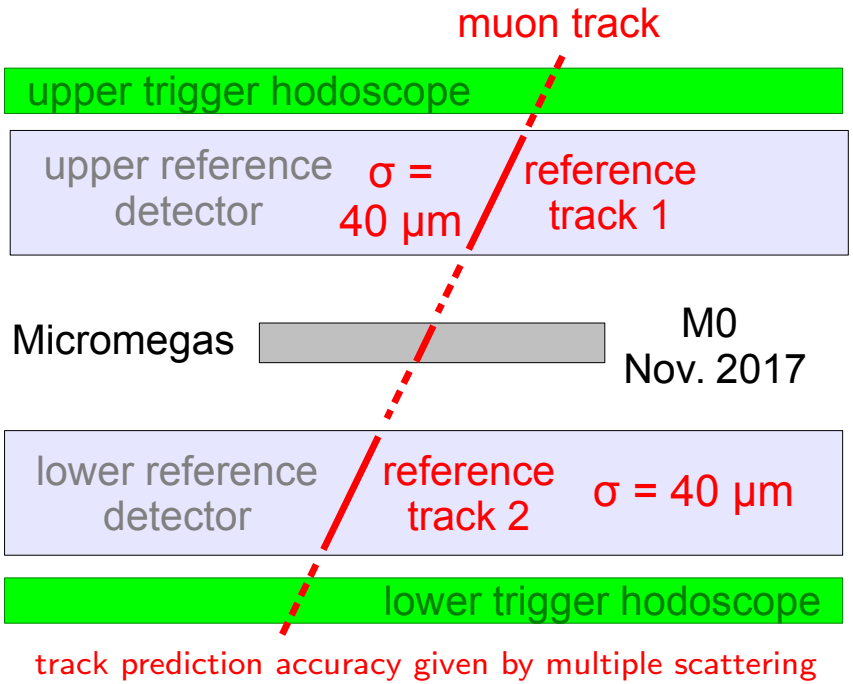
$\Rightarrow$ reconstruction and calibration of alignment errors (during production) required

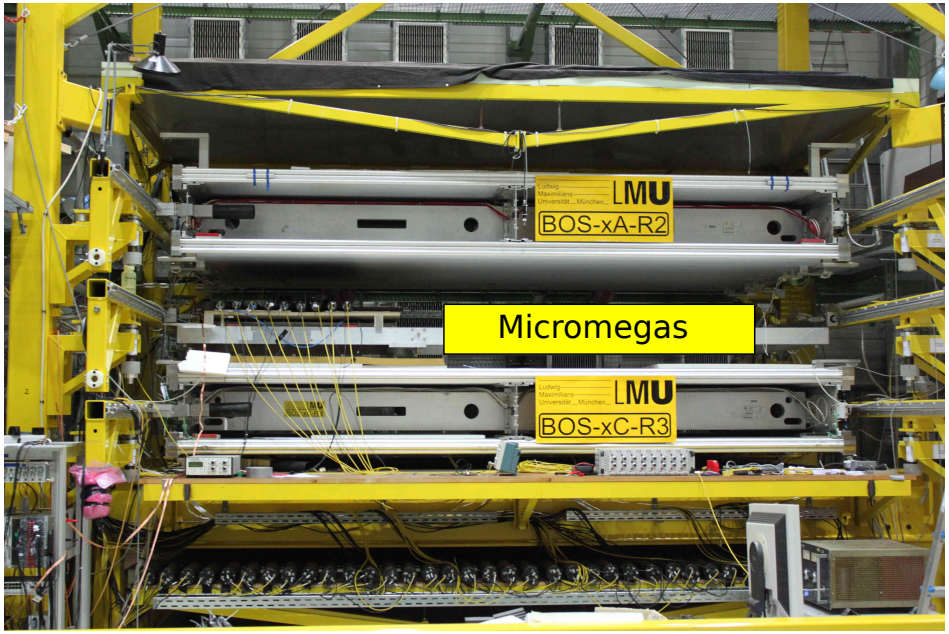
SM2 Prototype - M0

Measurement Campaign

- Cosmic Ray Facility in Munich
- testbeam at H8 beamline at the SPS

Cosmic Ray Facility LMU Munich

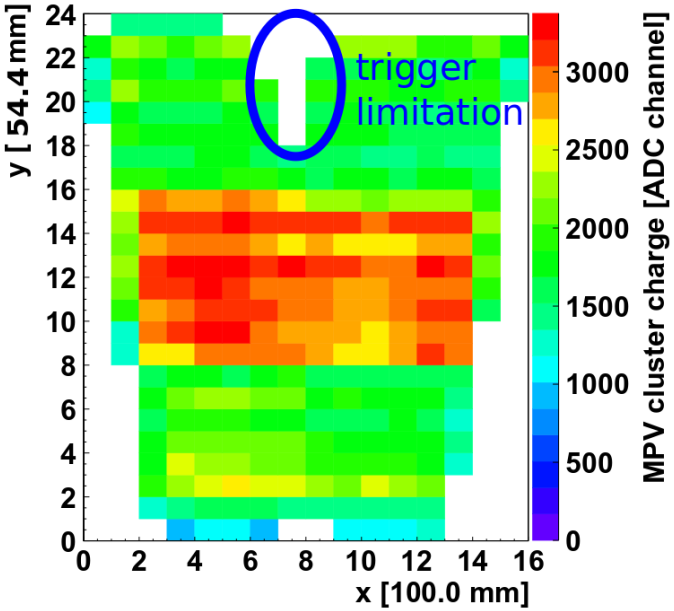




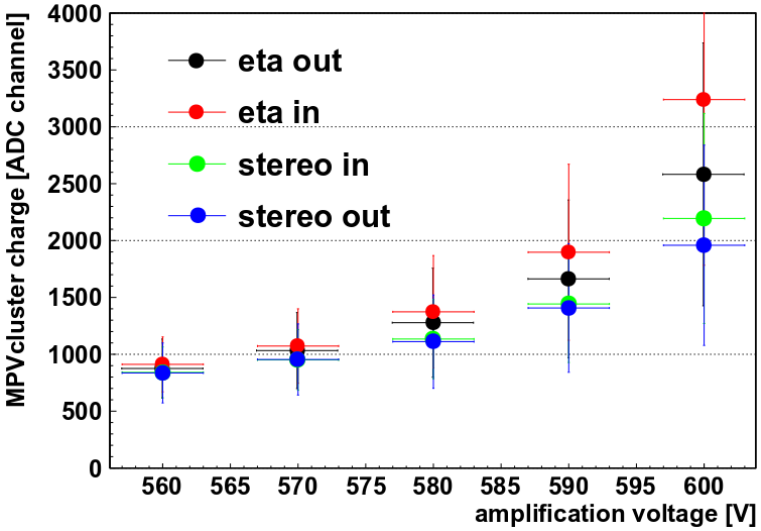
track reconstruction	2 × Monitored Drift Tube chambers (MDTs)
trigger	scintillator hodoscope
active area	2.2 m × 4 m
angular acceptance	± 30°
readout	12288 channels
	→ 96 APVs (frontend electronics)
	→ 6 FECs (scalable readout system)
readout rate	130 Hz (full muon rate)
measurement period	17.10. - 06.12. 2017

M0 : Full Area Pulse Height

eta in: cluster charge



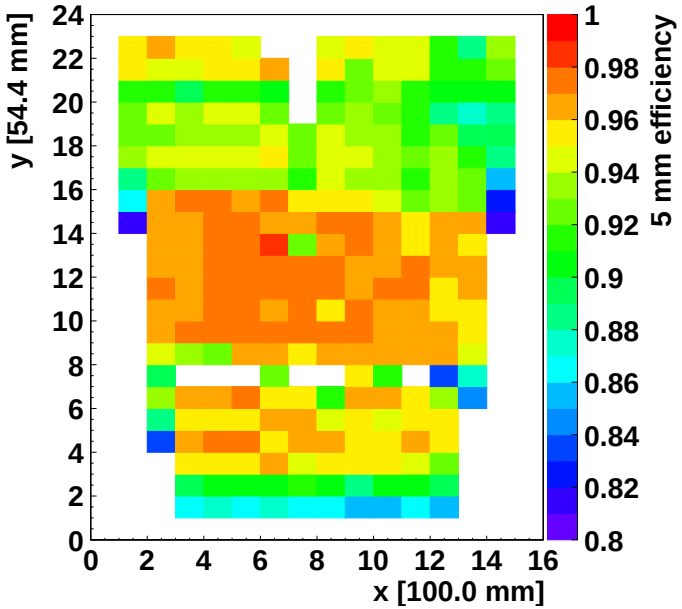
amplification scan



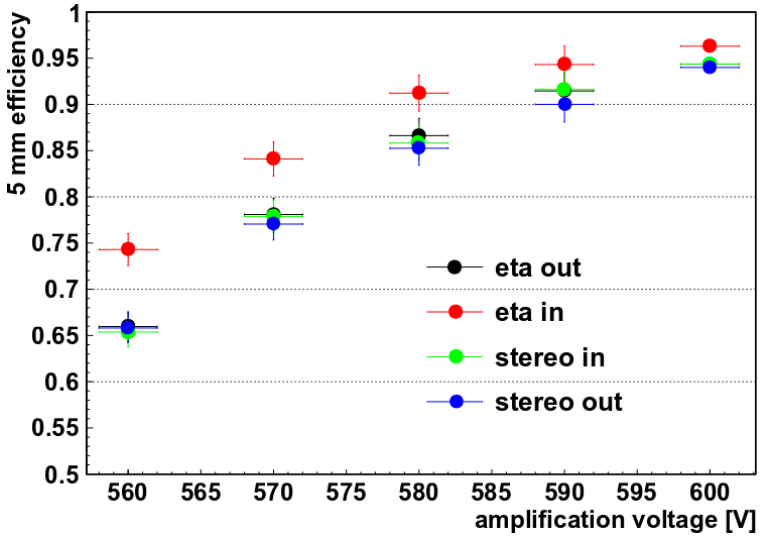
- $U_{\mathrm{amp}} = 600\,\mathrm{V}$
  $U_{\mathrm{drift}} = -300\,\mathrm{V}$
  Ar:CO_2 93:7 vol%
- for each bin (54.4 mm×100 mm):
  cluster charge distribution fitted with Landau
  ⇒ Most Probable Value (MPV)
- differences between
  readout boards clearly visible
  ⇒ higher amplification for central board
  ⇒ homogeneity spoiled by
  prototype PCB quality
- smaller features due to trigger acceptance
- exponential rise as function of the amplification voltage (Townsend)
- differences between readout layers
  due to variation in prototype PCB quality

M0 : Full Area Efficiency

eta in: 5 mm efficiency



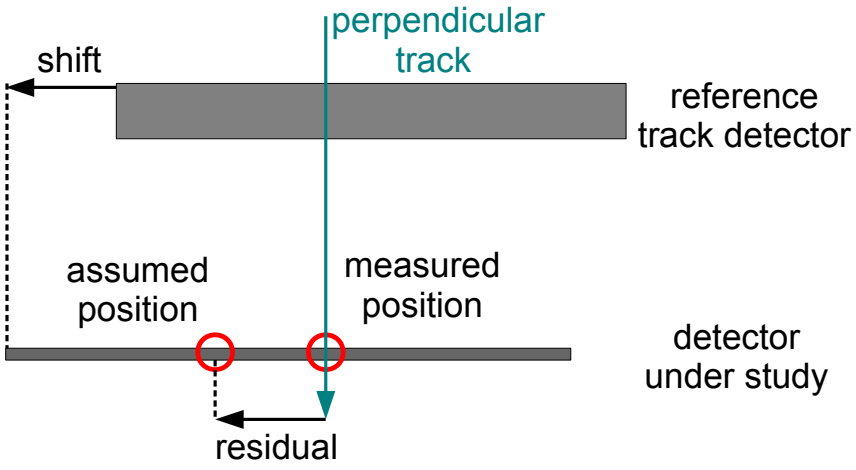
efficiency turn on curve

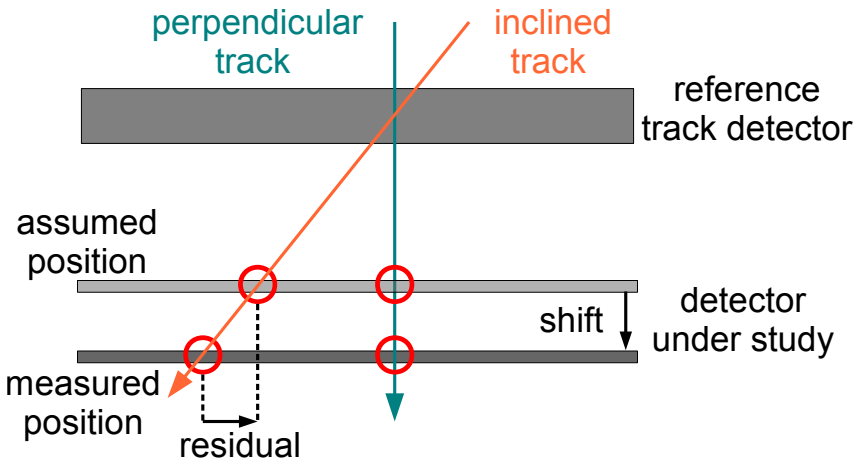


- $U_{\mathrm{amp}} = 600\,\mathrm{V}$
  $U_{\mathrm{drift}} = -300\,\mathrm{V}$
  Ar:CO_2 93:7 vol%
- 5 mm efficiency:
  number of cluster found within $\pm$ 5 mm to reference track
  divided by
  number all tracks going through partition
  $\Rightarrow$ calculated for each bin separately
- higher amplification of central board leads to higher efficiency
- efficiency at boarders spoiled due to tapered edges (rectangular partitions)
- efficiency turn on curve reaches more than 90% at 590 V for all layer
- differences between layer due to problematic prototype PCB material

Alignment using Reference Tracks

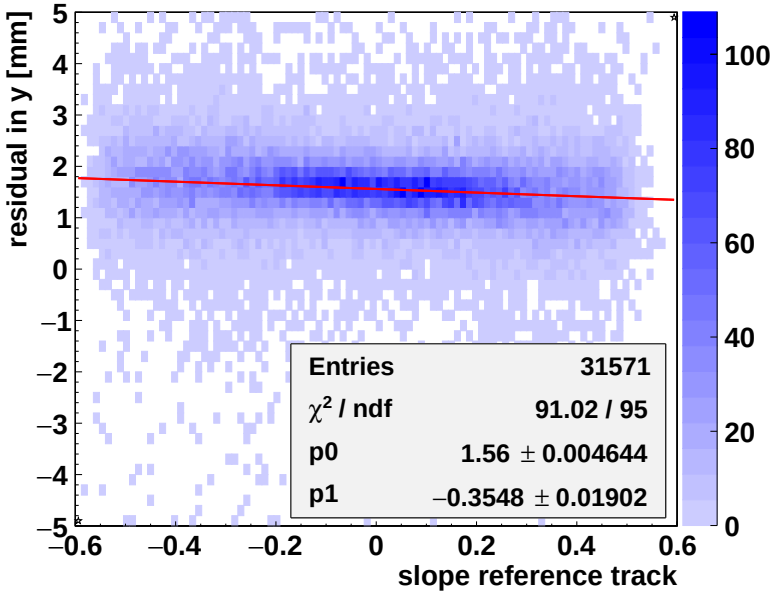
Concept:





Implementation:

before alignment



residual = $pos_{measured}$ - $pos_{reference}$

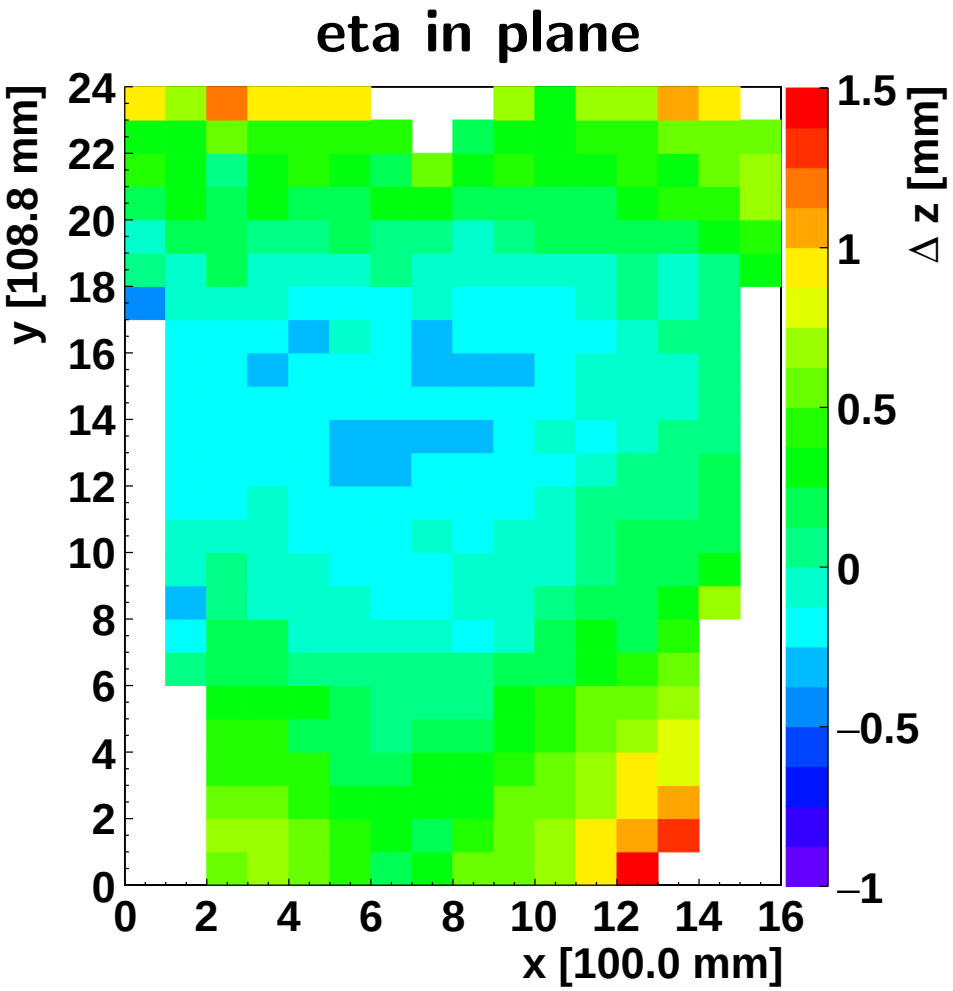
⇒ residual vs. slope (reference track)

⇒ linear fit

$shift_{horizontal} = intercept_{fit}$

$shift_{vertical} = slope_{fit}$

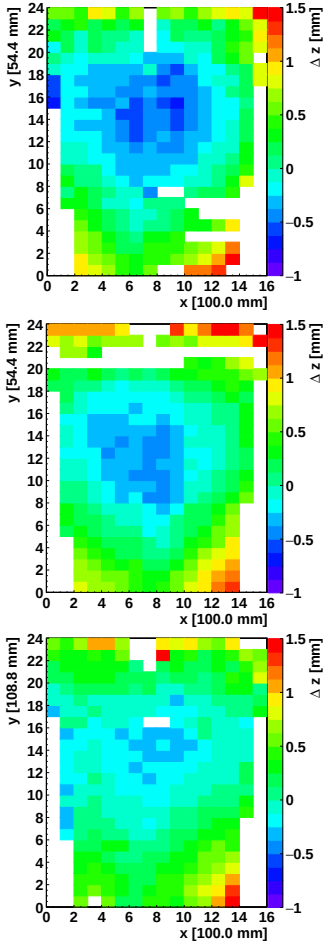
Reconstruction of the Gravitational Sag of M0



stereo in

stereo out

eta out



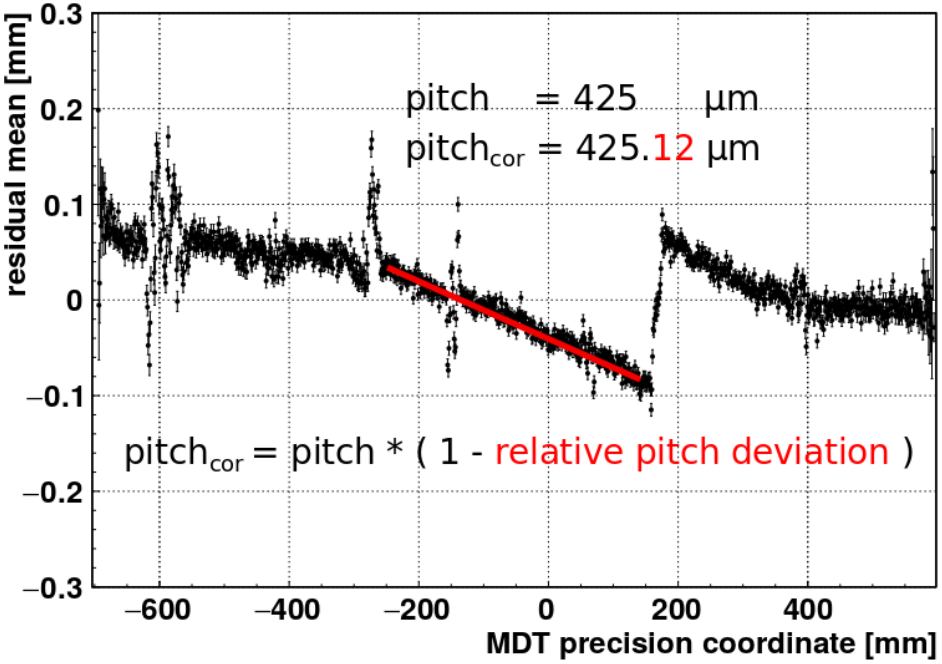
⇒ all layers show gravitational sag

⇒ irrelevant for ATLAS, as detectors will be used vertically in NSW

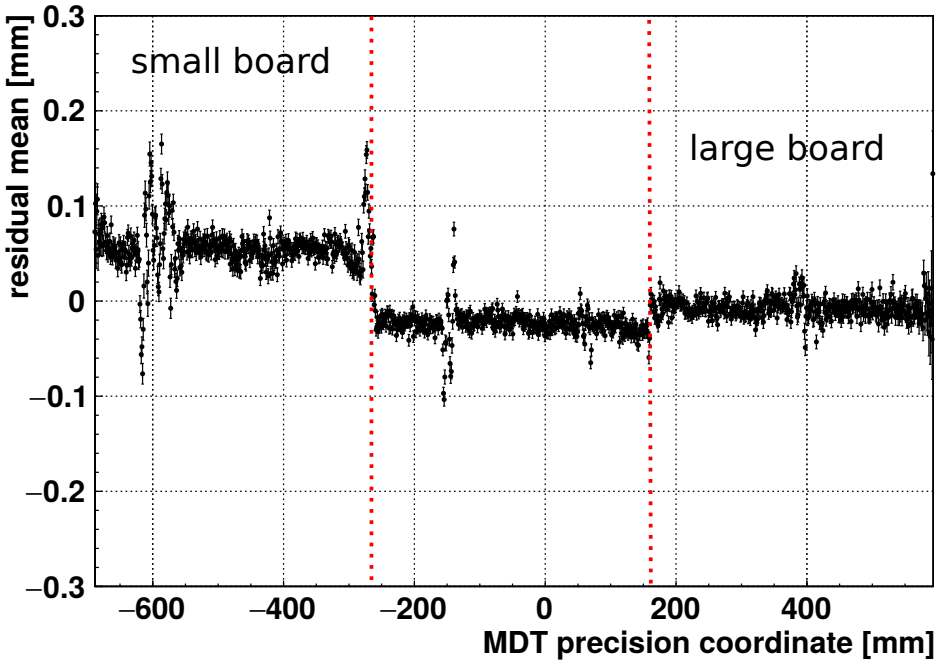
M0 : Board Alignment and Reconstructed Pitch Deviation

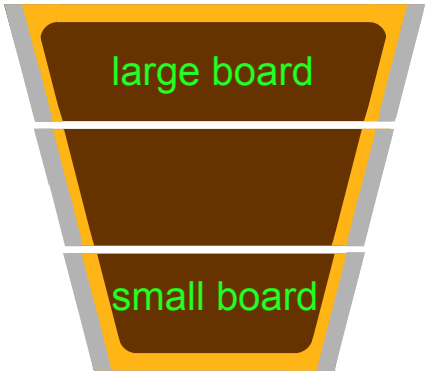
$$\text{position} = \text{centroid} \times \text{pitch}$$

pitch deviation



corrected pitch

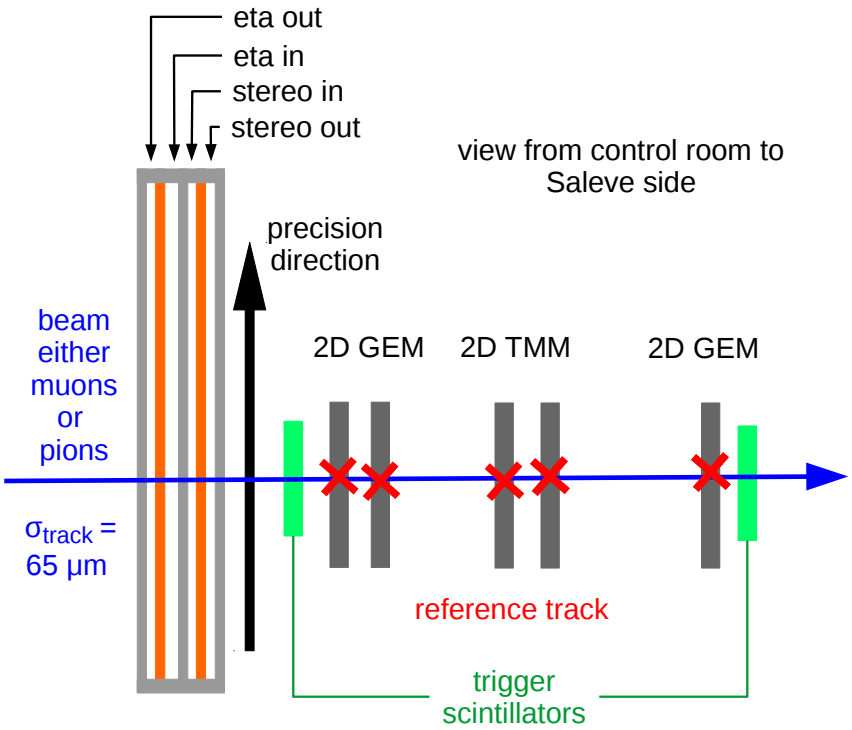


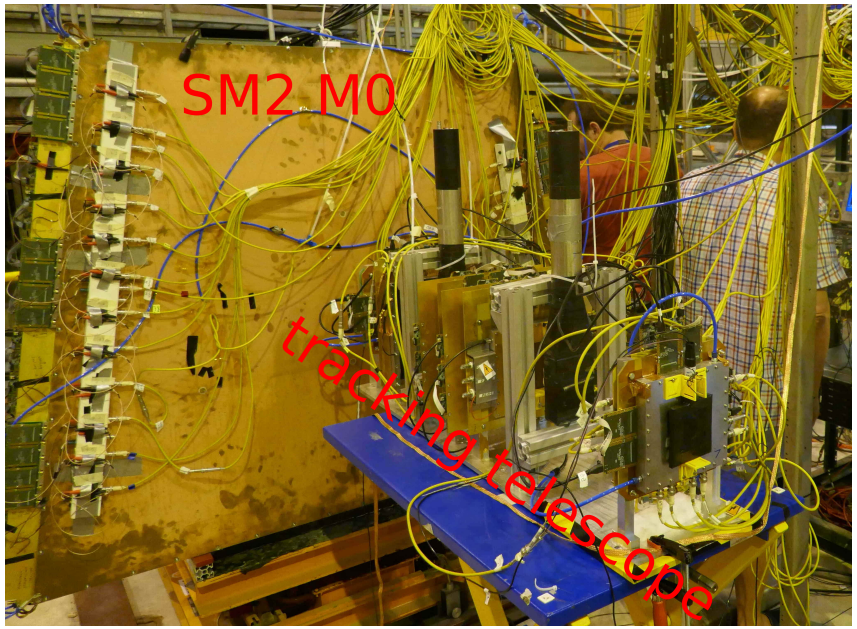


construction equipment optimized
$\Rightarrow$ avoid shifts

humidity control of readout boards
$\Rightarrow$ avoid pitch deviation

H8 Testbeam for SM2 M0 in August 2017

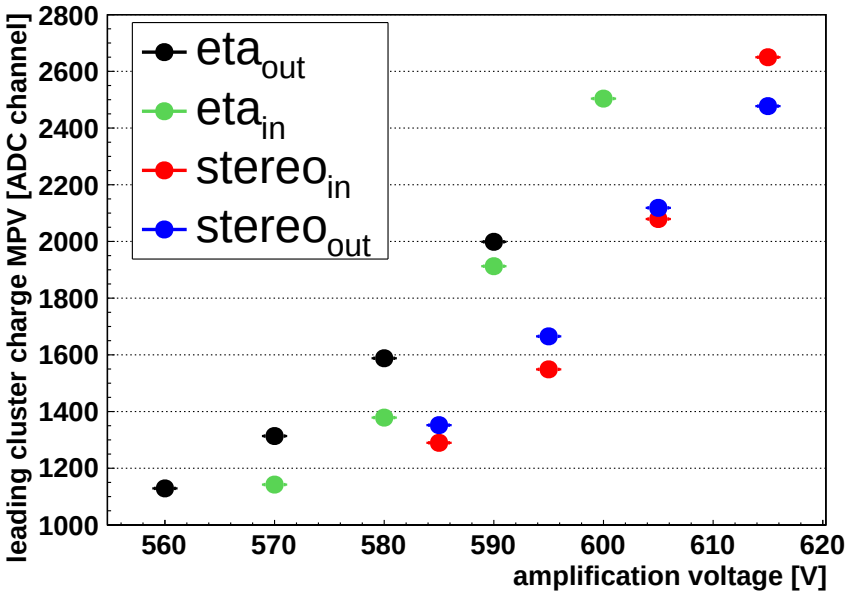


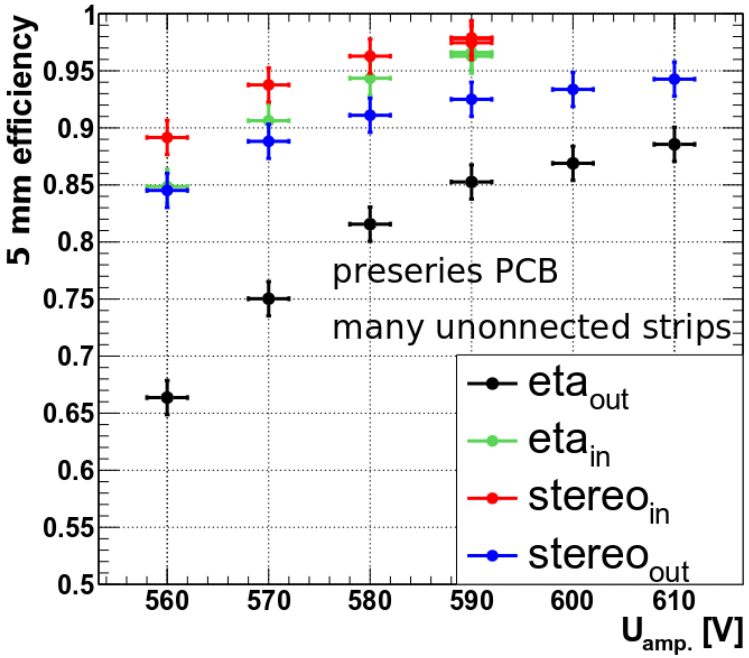


tracking telescope	3 × 2D GEM	
	2 × 2D TMM	
track accuracy	65 µm	(extrapolated at module)
channels	4 × 1024	module
	2976	telescope
readout	32 APVs → 2 FECs	module
	24 APVs → 2 FECs	telescope
trigger rate	∼ 1 kHz (muons)	for 9 cm × 9 cm
readout rate	220 Hz	(limited by bandwidth)

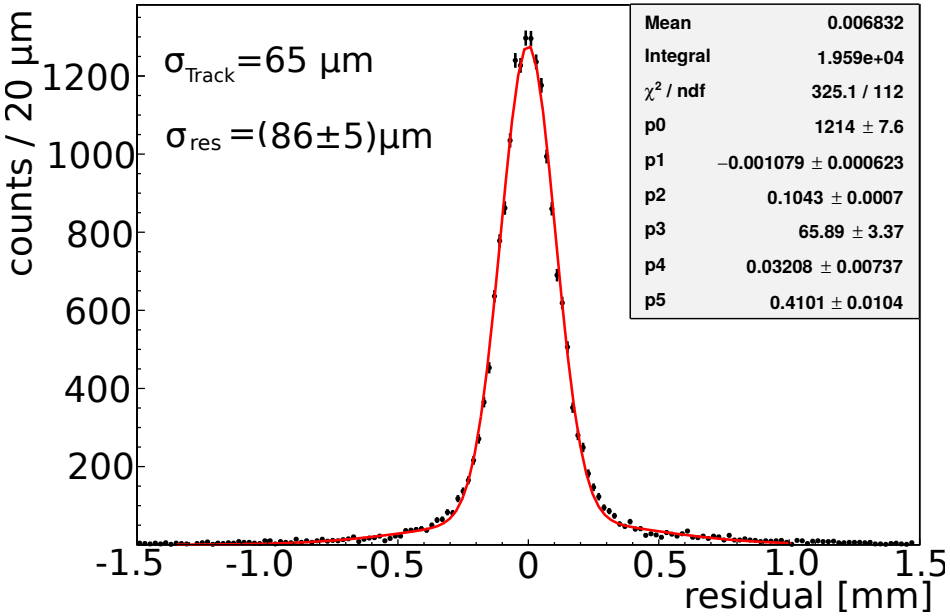
M0 : Behavior of Pulse Height and Efficiency

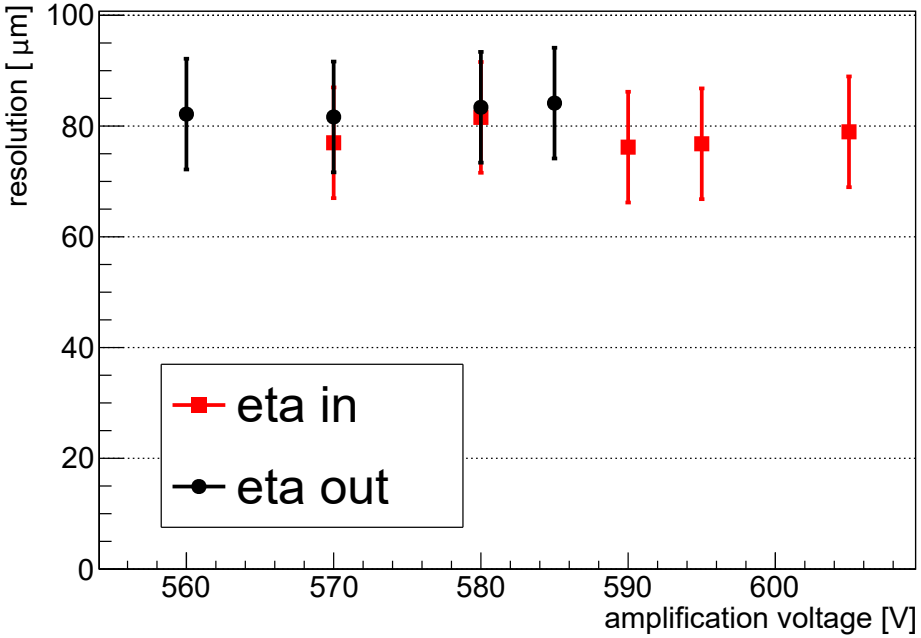
- pulse height:
  exponential rise as function of the amplification voltage (Townsend)
- differences between layers due to variation in prototype PCB quality
- efficiency plateau starting at 590 V
- lower efficiency due to unconnected strips in measurement region (e.g. eta out plane)





M0 : Results for Charge Weighted Position Reconstruction





- residual distribution (difference of measured position and track prediction) fitted with double Gaussian

  ⇒ weighted sigma:

  $$\sigma_{\mathrm{w}} = \frac{I_{\mathrm{narrow}} \cdot \sigma_{\mathrm{narrow}} + I_{\mathrm{broad}} \cdot \sigma_{\mathrm{broad}}}{I_{\mathrm{narrow}} + I_{\mathrm{broad}}}$$

  ⇒ consider track uncertainty:

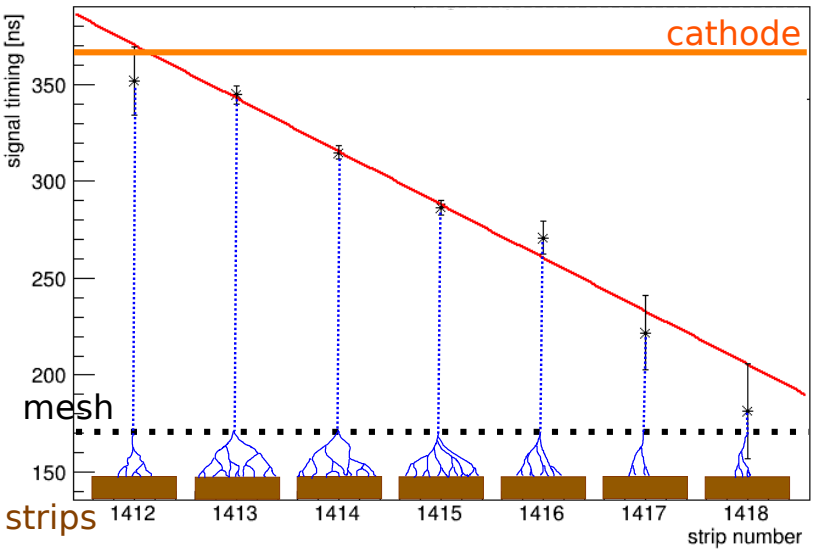
  $$\sigma_{\mathrm{res}} = \sqrt{\sigma_{\mathrm{w}}^2 - \sigma_{\mathrm{Track}}^2}$$

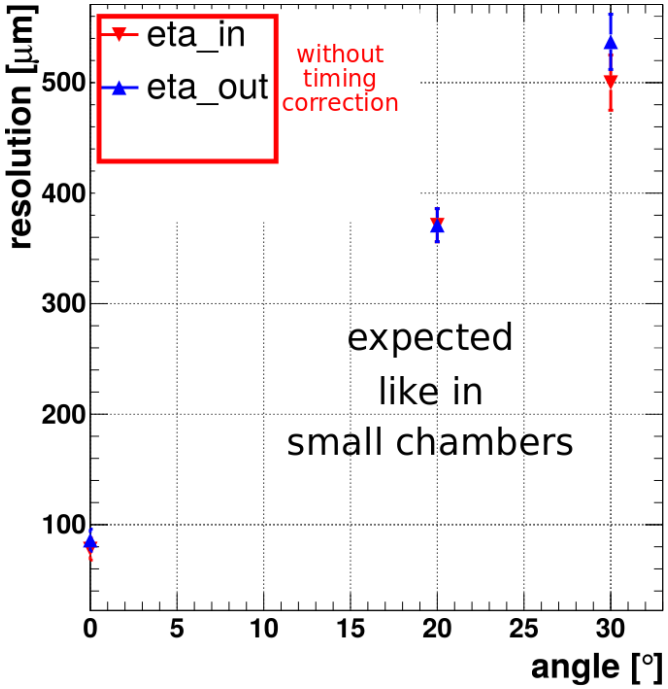
- resolution for perpendicular incident for both eta layers similar

  ⇒ 80 µm

- resolution independent of amplification and drift voltage

M0 : Drift Time Measurement for Track Reconstruction





- drift time measurement enables reconstruction of inclined tracks:

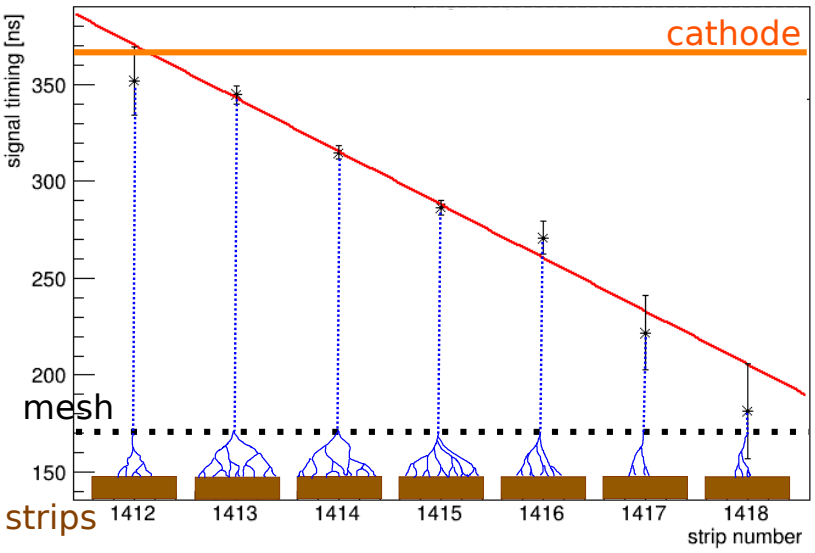
  time-projection-chamber like
- inhomogeneous ionization leads to a timing dependence of the residual
- degrading resolution for inclined incident using charge weighted reconstruction only

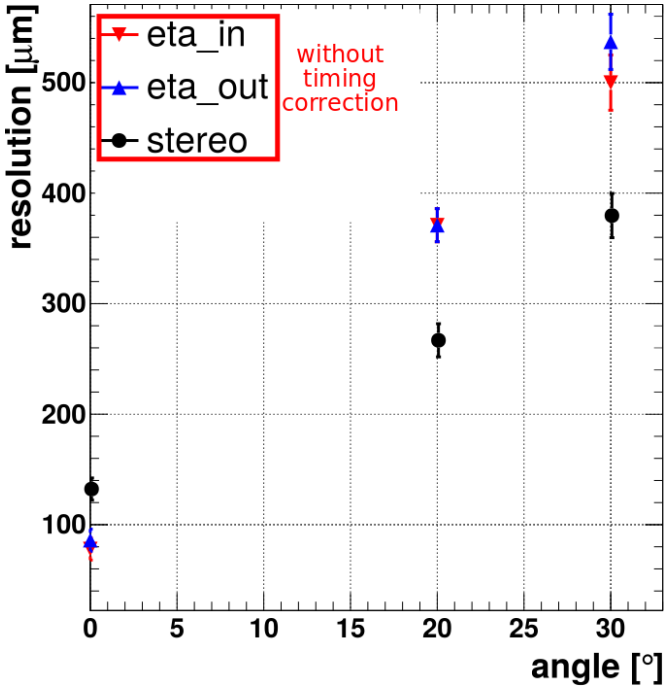
  $\Rightarrow$ similar behavior as

  small size chambers
- charge weighted timing correction improves resolution considerably

  $\Rightarrow$ almost constant for angles $\leq 30^\circ$
- resolution limited by signal to noise ratio of APV readout

M0 : Drift Time Measurement for Track Reconstruction





- drift time measurement enables reconstruction of inclined tracks:

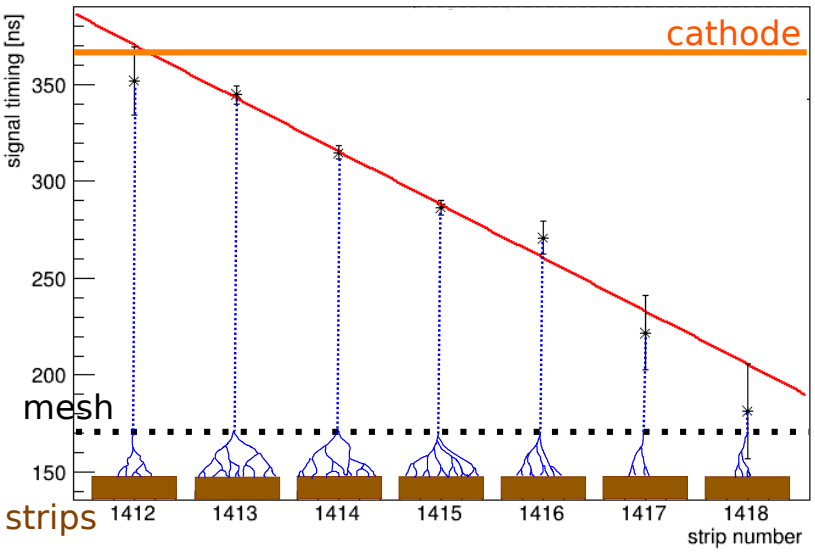
  time-projection-chamber like
- inhomogeneous ionization leads to a timing dependence of the residual
- degrading resolution for inclined incident using charge weighted reconstruction only

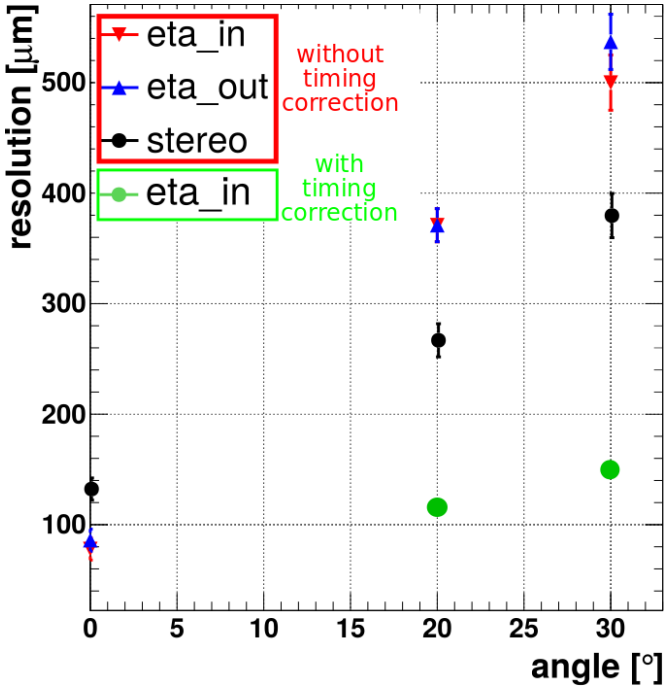
  $\Rightarrow$ similar behavior as

  small size chambers
- charge weighted timing correction improves resolution considerably

  $\Rightarrow$ almost constant for angles $\leq 30^\circ$
- resolution limited by signal to noise ratio of APV readout

M0 : Drift Time Measurement for Track Reconstruction





- drift time measurement enables reconstruction of inclined tracks:

  time-projection-chamber like
- inhomogeneous ionization leads to a timing dependence of the residual
- degrading resolution for inclined incident using charge weighted reconstruction only

  $\Rightarrow$ similar behavior as

  small size chambers
- charge weighted timing correction improves resolution considerably

  $\Rightarrow$ almost constant for angles $\leq 30^\circ$
- resolution limited by signal to noise ratio of APV readout

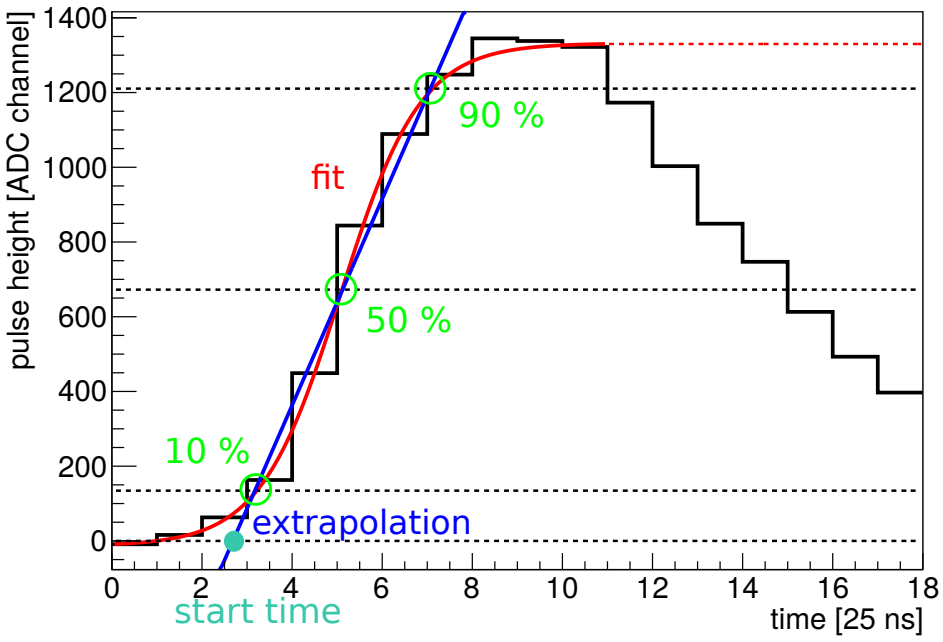
Summary

- upgrade of the ATLAS muon spectrometer inner end cap
  - sTGC and Micromegas quadruplets (16 active layers in total)
  - threepart (/fivepart) readout structure
    $\Rightarrow$ reconstruction and calibration is required after construction
- Investigation of the SM2 Prototype (M0) at the Cosmic Ray Facility in Munich
  - full active area responsive, despite problematic prototype PCB quality
  - calibration of the full active area of SM2 demonstrated
- Measurement at H8 Beamline of the SPS with the SM2 M0
  - reasonable pulse height and efficiency behavior
  - charge weighted position reconstruction for perpendicular tracks
    $\Rightarrow$ 80 µm resolution
    $\Rightarrow$ same for both eta layers
    $\Rightarrow$ independent of drift and amplification voltage
  - drift time measurement for tracks with $\leq 30^\circ$ inclination
    $\Rightarrow$ similar resolution
    $\Rightarrow$ limitation by signal to noise ratio of APV electronics
    (final electronics currently under test with first series SM2 module at H8)

Backup

Time Evolution of the Signal on a Single Strip

beginning of the signal : fit by an inverse Fermi function

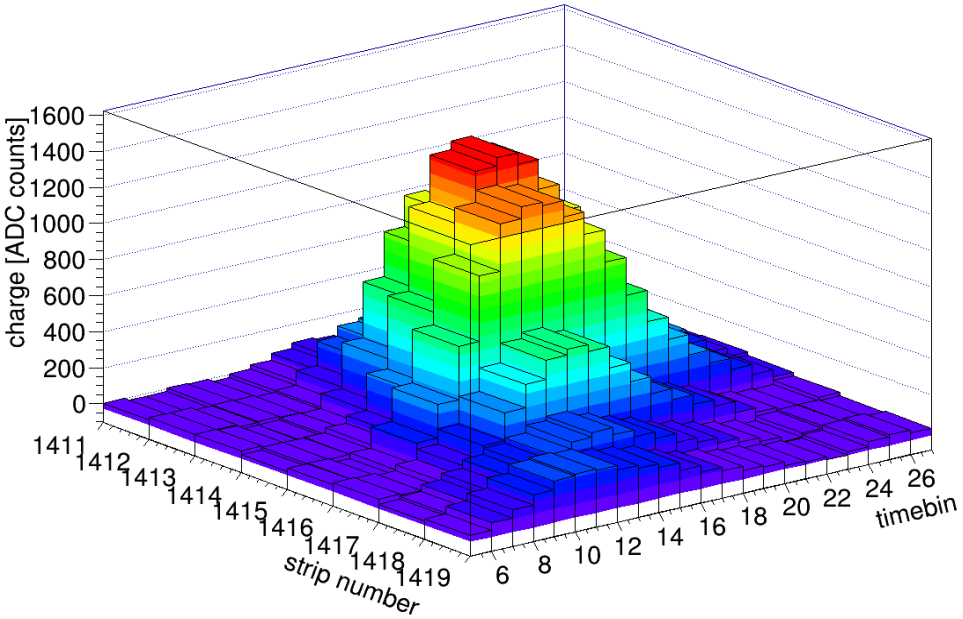


$$\mathrm{f_{Fermi}} = \frac{p_0}{1 + \exp[(p_1 - x)/p_2]} + p_3$$

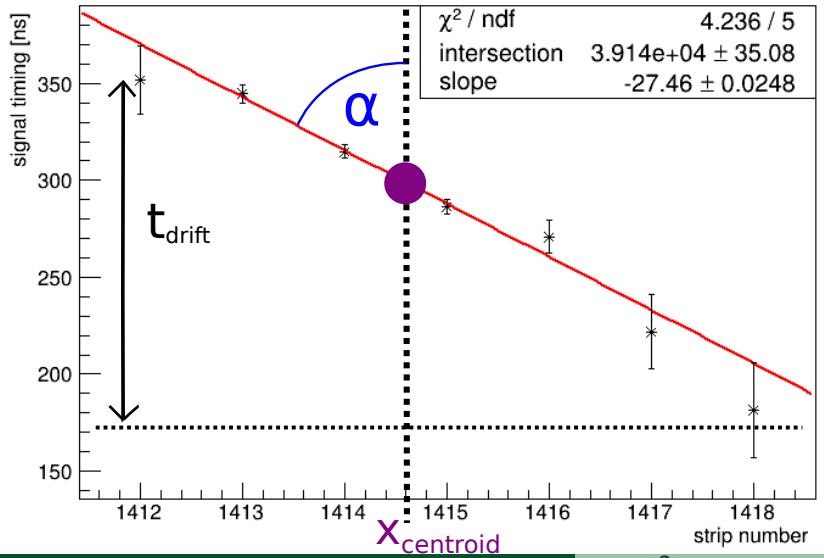
- p_0 : maximal pulse height
  $\Rightarrow$ charge of signal
- p_1 : time of 50% maximal pulse height
- p_2 : $\propto$ rise time
- p_3 : pedestal

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

Position and Track Reconstruction



drift time measurement



- centroid method

  ⇒ charge average over strips

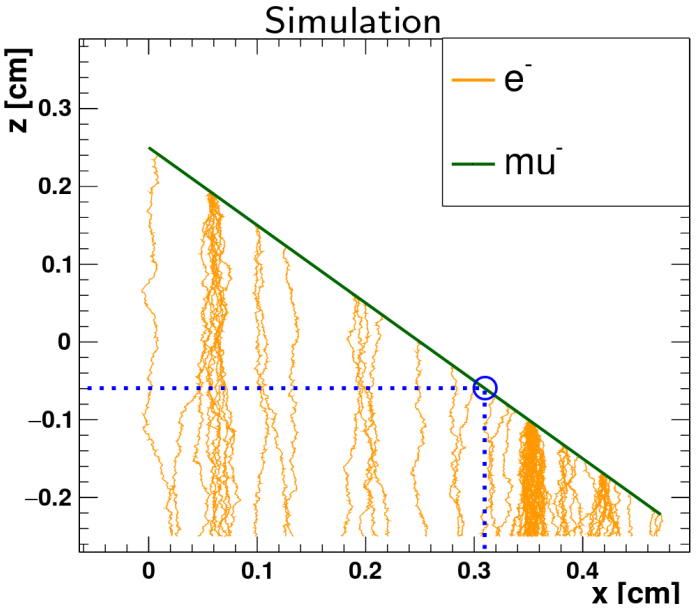
$$\mathbf{x}_{\text{centroid}} = \frac{\sum_{\text{strips}} x_{\text{strip}} \cdot q_{\text{strip}}}{\sum_{\text{strips}} q_{\text{strip}}}$$

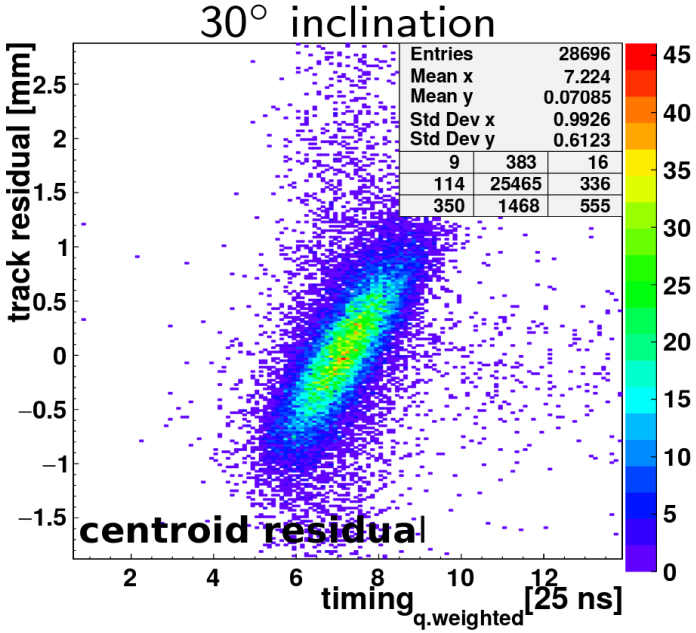
- TPC-like method

  angle reconstruction by drift time measurement

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

Position Reconstruction Using Charge Weighted Clustertime

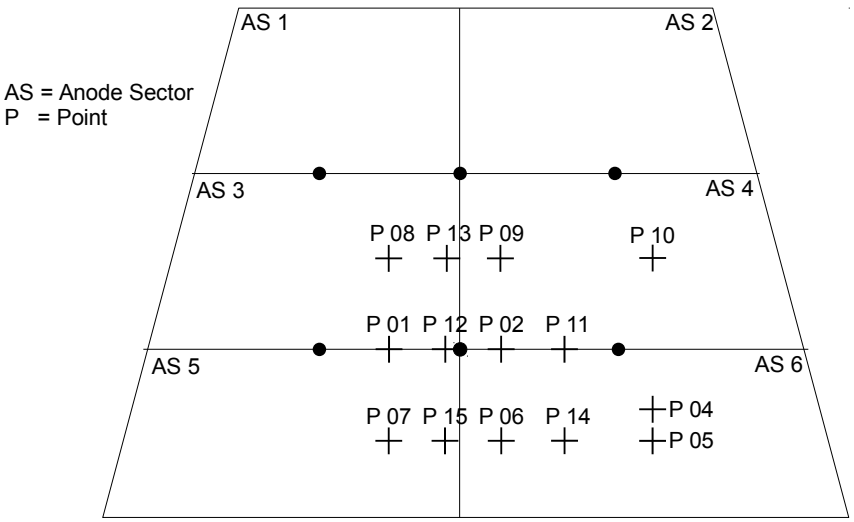


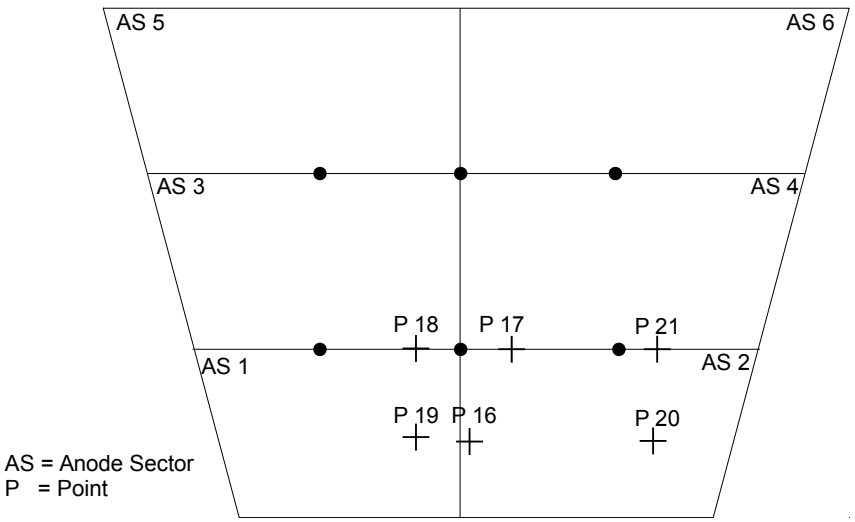


- charge weighted timing:
  $$t_{\mathrm{q}} = \frac{\sum t_{\mathrm{strip}} q_{\mathrm{strip}}}{\sum q_{\mathrm{strip}}}$$
  $\Rightarrow$ vertical position in drift gap
- for inclined incident:
  centroid residual
  VS charge weighted timing
  $\Rightarrow$ linear dependence
- slope given by
  drift time and incident angle
  $\Rightarrow$ drift time is given by gas mixture, cathode voltage and drift gap
  $\Rightarrow$ for NSW Micromegas incident angle is almost fixed
  (direction to interaction point)
- new position is given by:
  $x = x_{\mathrm{cen}} + \triangle t \cdot v_{\mathrm{drift}} \cdot \tan\theta$
  with:

x_{cen}	centroid position
$\triangle t$	$t_q - t_{\mathrm{mean}}$
v_{drift}	drift velocity
θ	incident angle

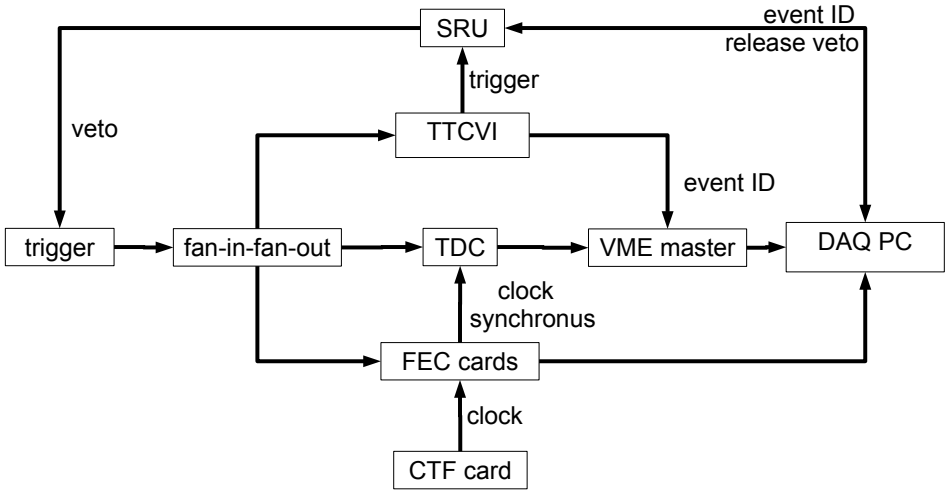
SM2-M0 at H8 Testbeam August 2017 Measurement Overview

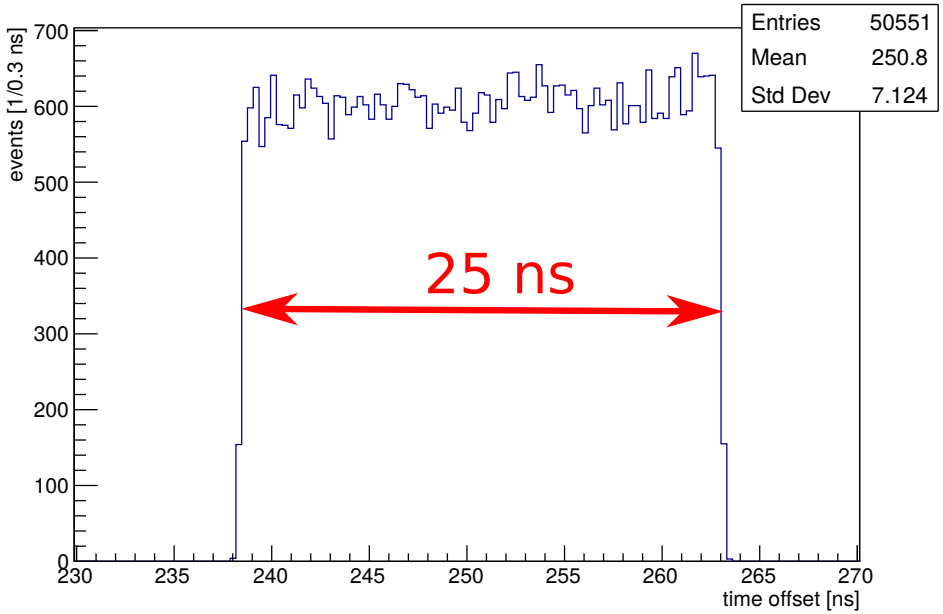




- for second configuration the order of layers was inverted
- at Points 12 and 13 module was tilted for inclined measurements
- several amplification scans made at different Points

Jitter Correction for 40 MHz Readout of APVs





- expected time jitter of signal due to 40 MHz sampling of APVs
- record time difference of trigger signal and FEC cards (connected to APVs) via TDC
- merge at DAQ PC
  $\Rightarrow$ offline offsetcorrection and zerosuppression