International Conference on High Energy Physics 2018

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

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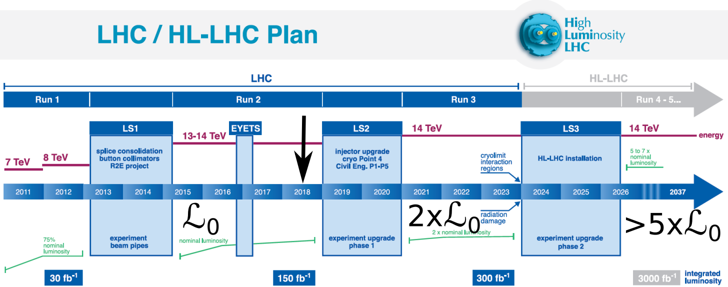
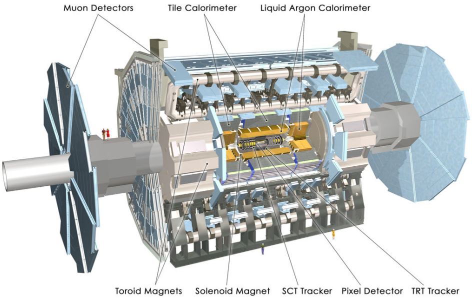
on behalf of the ATLAS muon collaboration

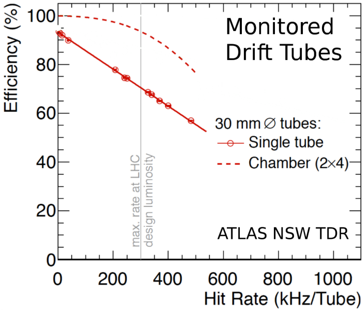
Ludwig-Maximilians-Universität München - Lehrstuhl Schaile

05.07.2018, Seoul

LHC Upgrade Status







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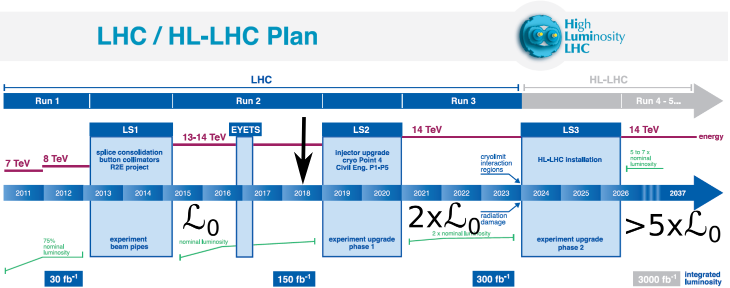
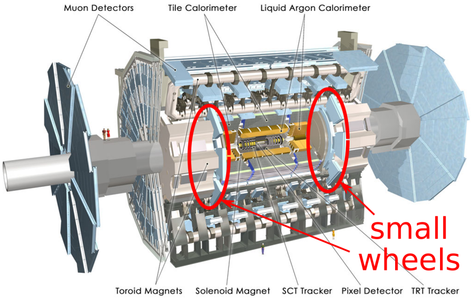
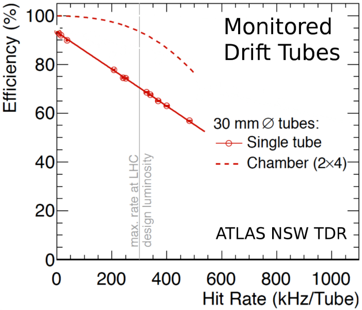


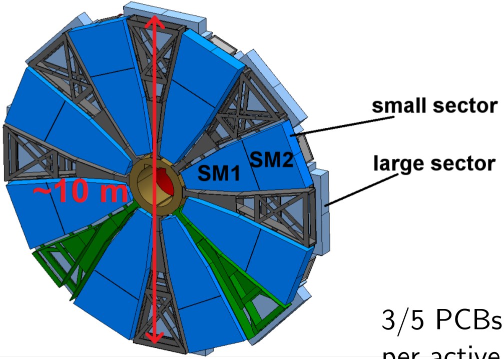




Upgrade of the Muon Small Wheels

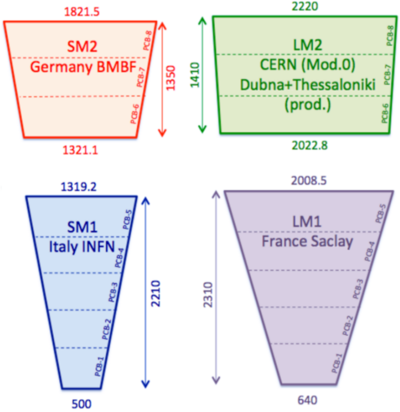
replacement of the current end caps of the muon spectrometer by small-strip Thin Gap Chambers (sTGC) and Micromegas quadruplets

New Small Wheel Sectors



3/5 PCBs per active layer

Micromegas quadruplets



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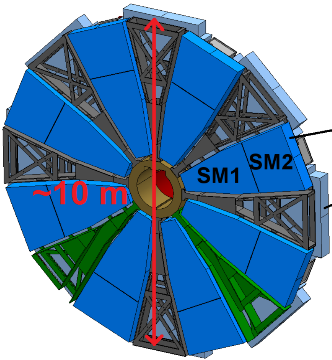
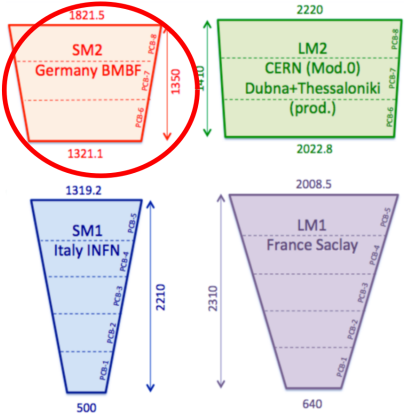


small sector

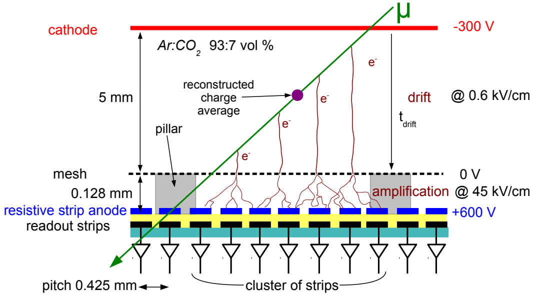
large sector

3/5 PCBs per active layer

Micromegas quadruplets



MICROMEGAS - MICROMEesh GAseous Structure



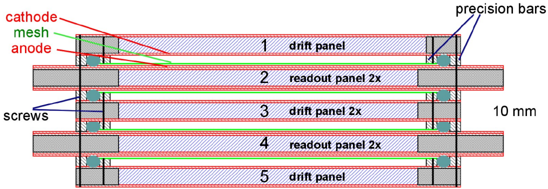
$$\text{centroid} = \frac{\sum_{\text{strips}} \text{strip} \cdot q_{\text{strip}}}{\sum_{\text{strips}} q_{\text{strip}}}$$

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

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

$\Rightarrow$ incident angle reconstruction

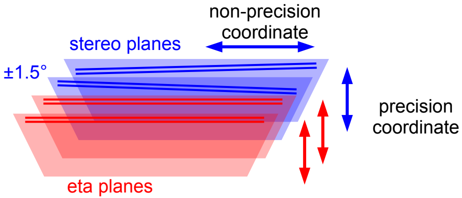
Micromegas Quadruplet



4 active layers of Micromegas

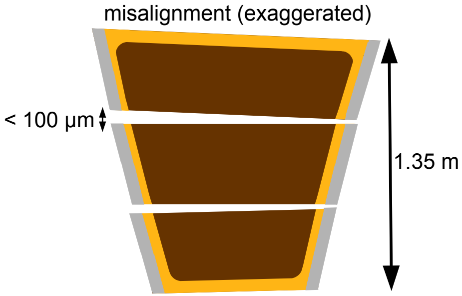
$\Rightarrow$ 2 $\times$ back-to-back

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

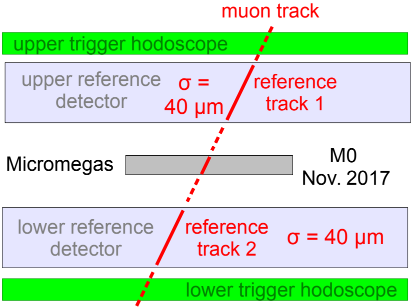
$\Rightarrow$ reconstruction and calibration of alignment errors (during production) required

SM2 Prototype - M0

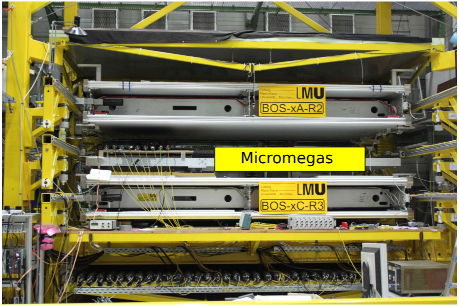
Measurement Campaign

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

Cosmic Ray Facility LMU Munich



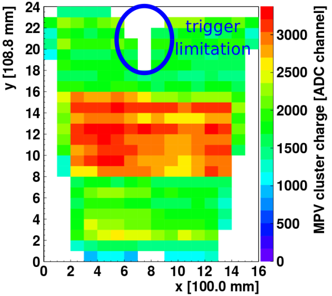
track prediction accuracy given by multiple scattering



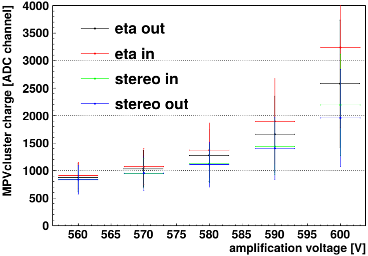
track reconstruction	2 × Monitored Drift Tube chambers (MDTs)
trigger	scintillator hodoscope
active area	2.2 m × 4 m
angular acceptance	± 30°
readout	12288 channels
	→ 96 APVs (frontend electronics)
	→ 6 FECs (scalable readout system)
readout rate	130 Hz (full muon rate)
measurement period	17.10. - 06.12.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

M0 : Full Area Pulse Height

eta in: cluster charge



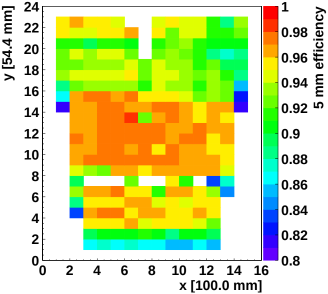
amplification scan



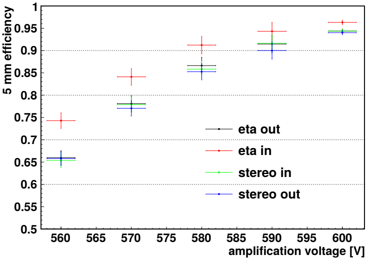
- $U_{\mathrm{amp}} = 600\,\mathrm{V}$
  $U_{\mathrm{drift}} = -300\,\mathrm{V}$
  Ar:CO_2 93:7 vol%
- for each bin ($54.4\,\mathrm{mm} \times 100\,\mathrm{mm}$):
  cluster charge distribution fitted with Landau
  $\Rightarrow$ Most Probable Value (MPV)
- differences between
  readout boards clearly visible
  $\Rightarrow$ higher amplification for central board
  $\Rightarrow$ 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 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

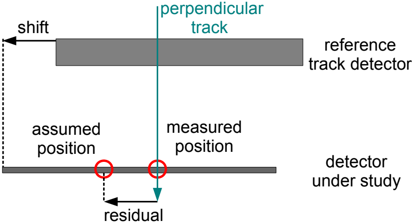
  divided by

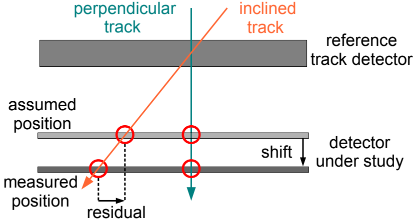
  number all tracks going through partition

  $\Rightarrow$ 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

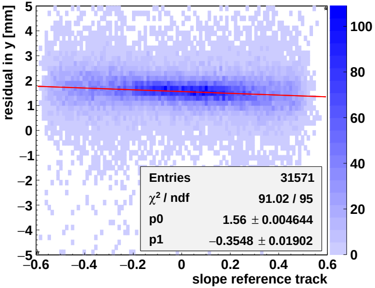
Concept:





Implementation:

before alignment



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

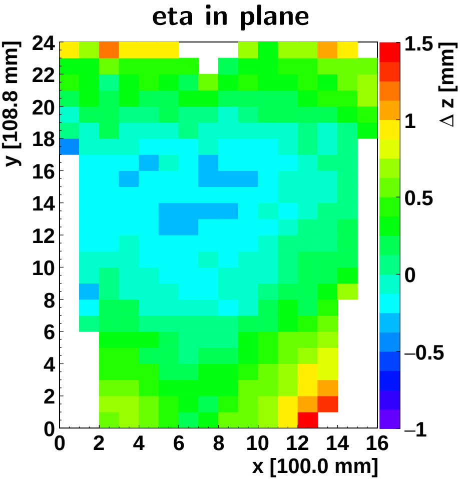
$\Rightarrow$ residual vs. slope (reference track)

$\Rightarrow$ linear fit

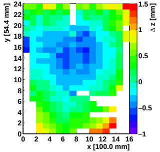
shift$_{\text{horizontal}}$ $=$ intercept$_{\text{fit}}$

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

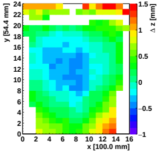
Reconstruction of the Gravitational Sag of M0



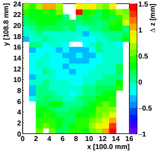
stereo in



stereo out



eta out



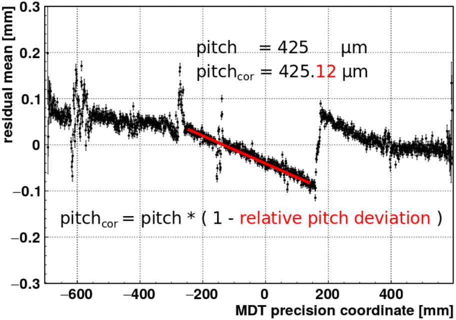
⇒ all layers show gravitational sag

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

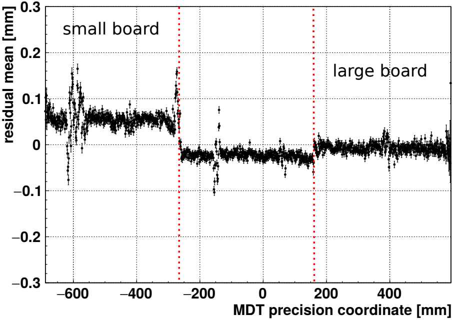
M0 : Board Alignment and Reconstructed Pitch Deviation

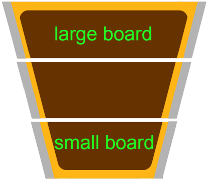
$$\text{position} = \text{centroid} \times \text{pitch}$$

pitch deviation



corrected pitch

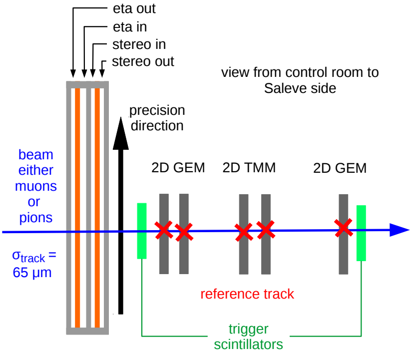


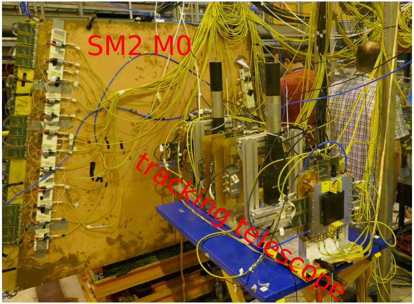


construction equipment optimized
⇒ avoid shifts

humidity control of readout boards
⇒ avoid pitch deviation

H8 Testbeam for SM2 M0 in August 2017

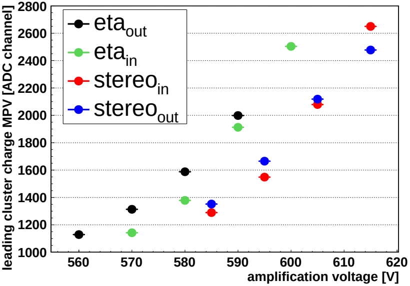


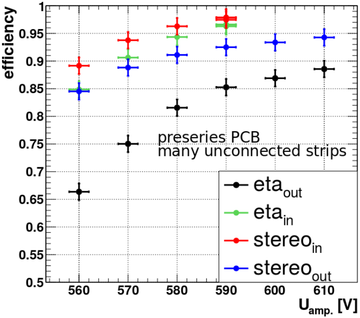


tracking telescope	3 × 2D GEM	
	2 × 2D TMM	
track accuracy	65 μm	(extrapolated at module)
channels	4 × 1024	module
	2976	telescope
readout	32 APVs → 2 FECs	module
	24 APVs → 2 FECs	telescope
trigger rate	∼ 1 kHz (muons)	for 9 cm × 9 cm
readout rate	220 Hz	(limited by bandwidth)

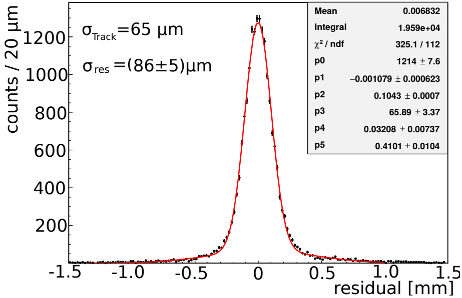
M0 : Behavior of Pulse Height and Efficiency

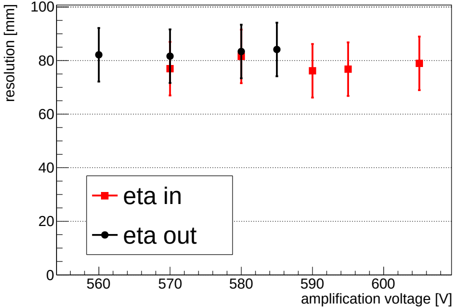
- pulse height:
  exponential rise as function of the amplification voltage (Townsend)
- differences between layers due to variation in prototype PCB quality
- efficiency plateau starting at 590 V
- lower efficiency due to unconnected strips in measurement region (e.g. eta out plane)





M0 : Results for Charge Weighted Position Reconstruction





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

  $\Rightarrow$ weighted sigma:

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

  $\Rightarrow$ consider track uncertainty:

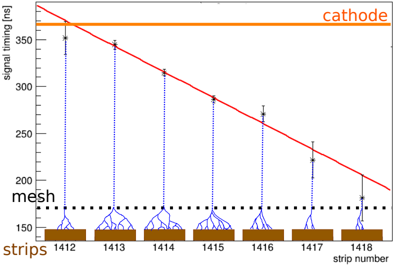
  $$\sigma_{\mathrm{res}} = \sqrt{\sigma_{\mathrm{w}}^2 - \sigma_{\mathrm{Track}}^2}$$

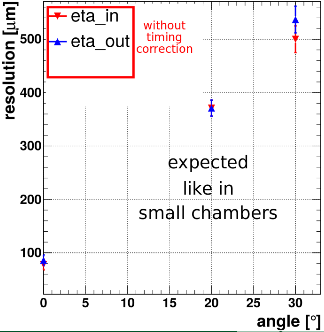
- resolution for perpendicular incident for both eta layers similar

  $\Rightarrow$ 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
- improvement of the position reconstruction using the charge weighted timing
- 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 $\leq 30°$
- resolution limited by signal to noise ratio of APV readout

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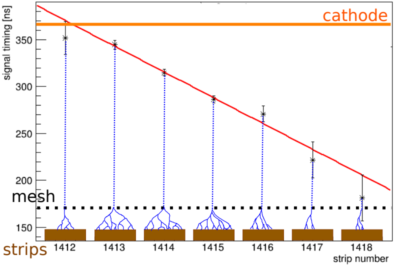

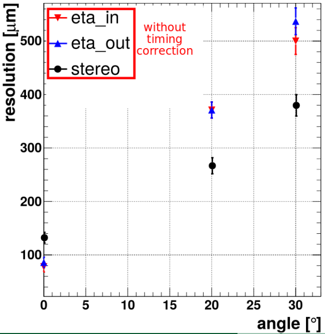

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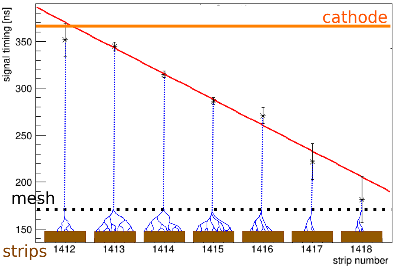

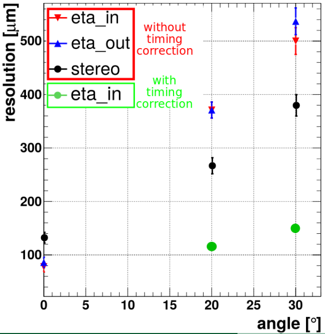

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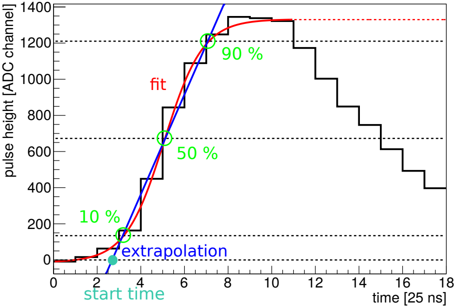
Summary

- 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)

Backup

Time Evolution of the Signal on a Single Strip

beginning of the signal : fit by an inverse Fermi function

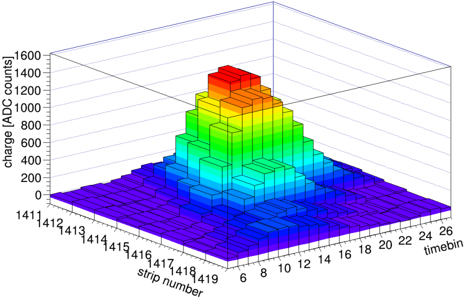


$$f_{\mathrm{Fermi}} = \frac{p_0}{1 + \exp[(p_1 - x)/p_2]} + p_3$$

- 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

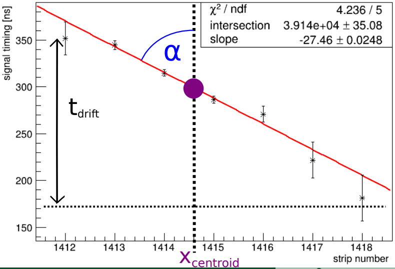


- centroid method

  ⇒ charge average over strips

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

drift time measurement

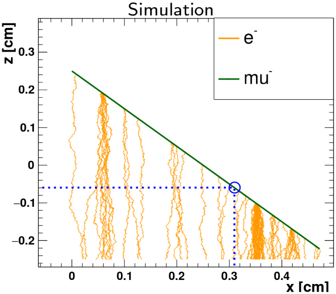


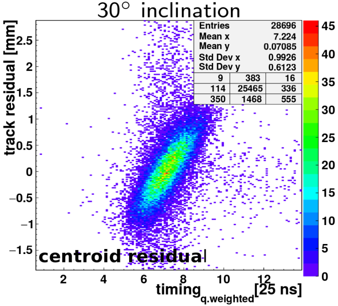
- TPC-like method

  angle reconstruction by drift time measurement

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

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