

Development of a Segmented GEM Readout Detector

15TH PISA MEETING ON ADVANCED DETECTORS

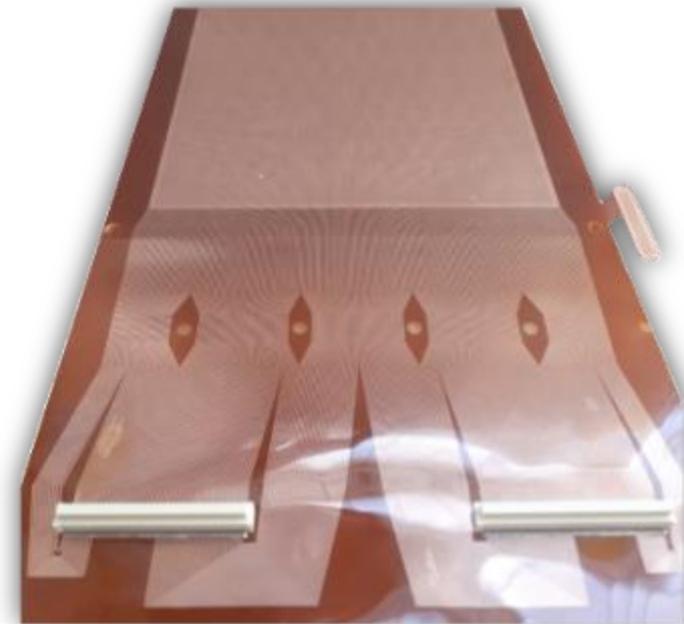
27.05.2022

CHRISTOPH JAGFELD

LMU

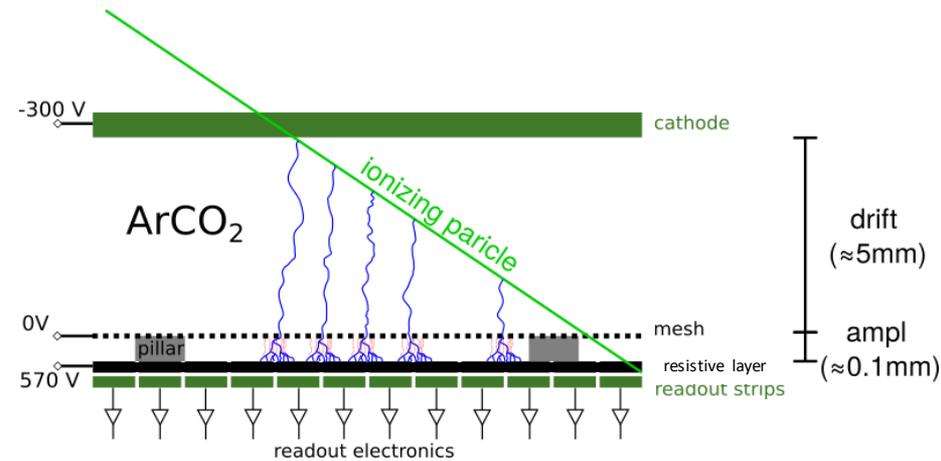


Bundesministerium
für Bildung
und Forschung



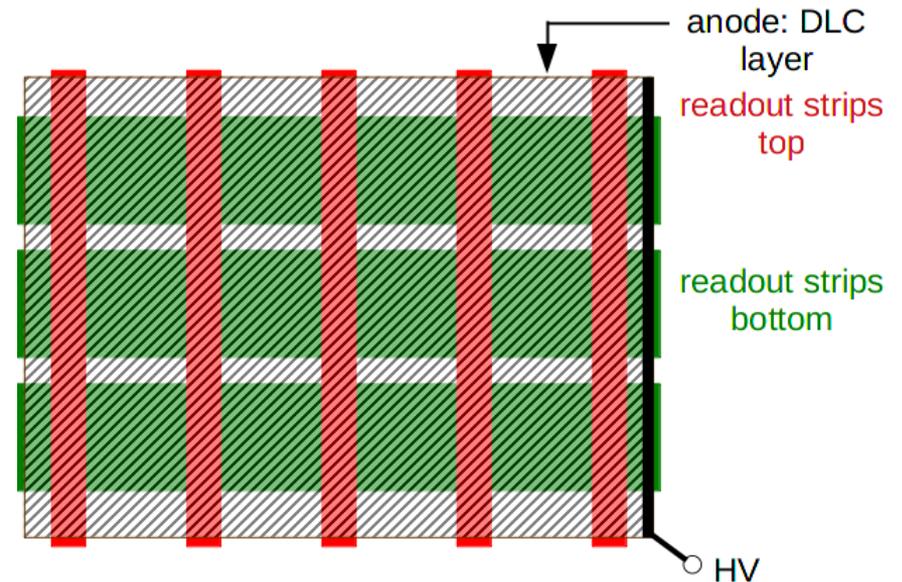
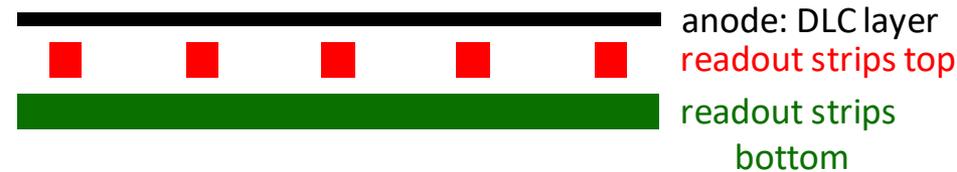
Working Principle of a Micromegas (MM)

- MICROMESH Gaseous Structure detector
- Drift region (≈ 5 mm):
 - Ionization of the gas in the drift region along the particle track
 - Low electric field ($E = 0.6$ kV/cm):
 - \Rightarrow separation of the electrons and ions in the drift region
 - $\Rightarrow V_{\text{drift}} = 45 \mu\text{m/ns}$ (110 ns for 5 mm)
- Amplification region ($\approx 128 \mu\text{m}$):
 - High electric field (≈ 50 kV/cm)
 - \Rightarrow Amplification of the signal by an electron avalanche (Gain ≈ 5000 -10000)
- Resistive anode layer



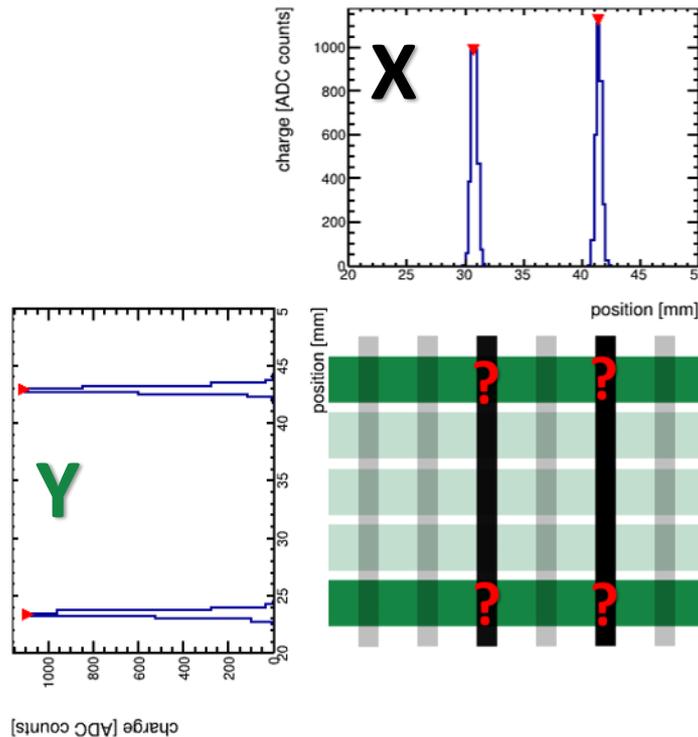
2D Resistive Layer Micromegas (DLC)

- Anode:
 - Resistive layer: Diamond Like Carbon (DLC)
- 2 perpendicular readout strip layers, each with:
 - 360 readout strips
 - 250 μm pitch
- 120 μm high pillar
- Floating mesh (no bulk)
- Ar:CO₂ 93:7



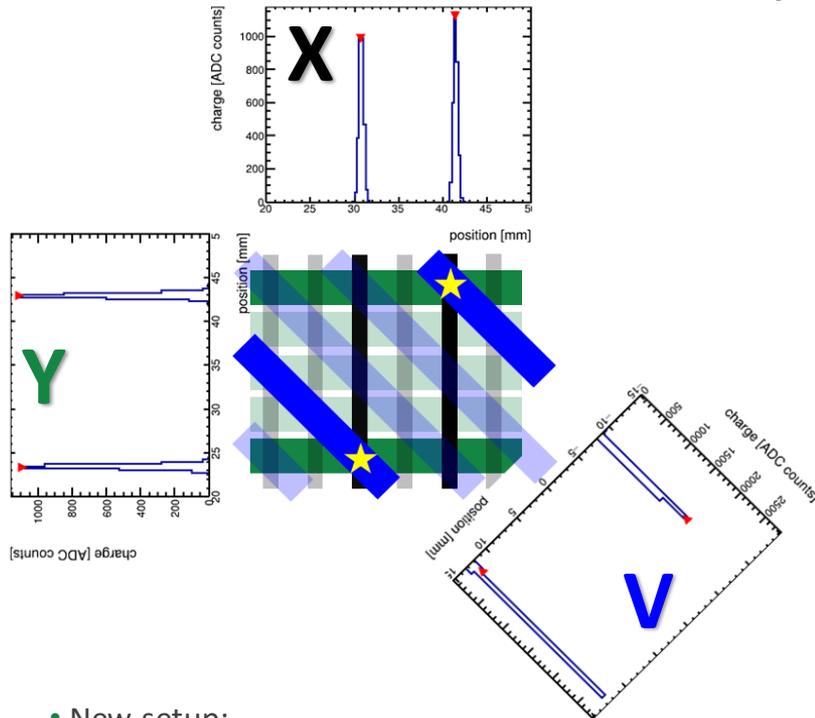
CERN det. Lab: De Oliveira

X/Y Strips : Multiple Particles at Same Time

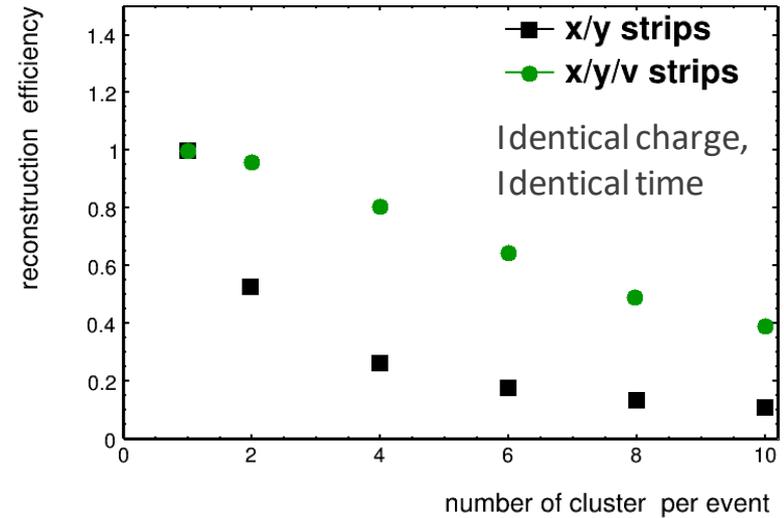


- Two particles at the same time
 - ⇒ Two signatures in each detector layer (**X** / **Y**)
 - ⇒ 1D reconstruction works
 - 2D position reconstruction:
 - Combination of X and Y cluster
 - ⇒ Four different possibilities
 - ⇒ 2D reconstruction problematic
- ⇒ Solution: 3rd layer of readout strips turned by 45 deg

X/Y/V Strips : Multiple Particles



simulation



- New setup:
 - **X/Y** coordinate given by readout strips at the anode
 - **V** coordinate given by readout strips at the mesh location

• Unique 2D cluster combination possible

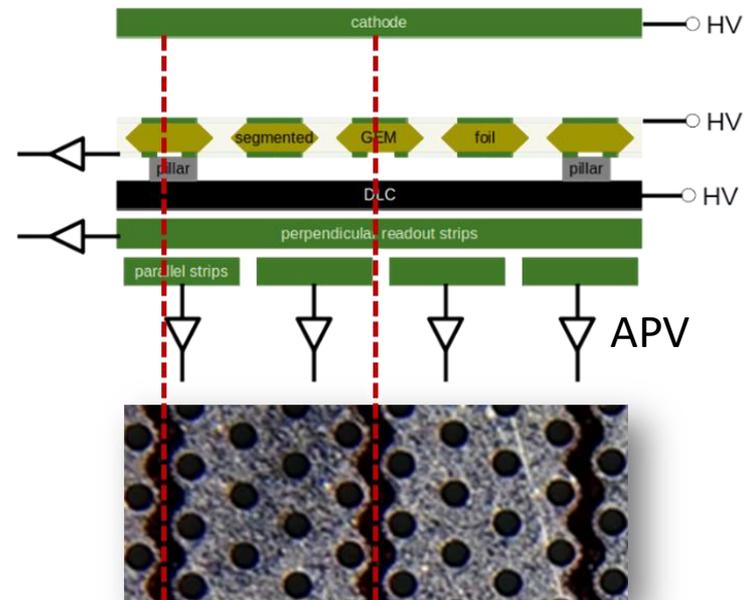
⇒ Reduction of the number of ambiguities by a factor 2-4

⇒ Further improvement by using charge and time information

$$efficiency = \frac{\# particles_{correct\ reco}}{\# particles_{all}}$$

Signal Readout at the Mesh Location

- Segmented mesh difficult to realize
 - Use of a segmented GEM foil instead of the mesh
 - Segmentation into strips on one side of the foil
 - Produced at detector lab at CERN
 - The segmented GEM foil is mounted on top of the pillars
 - Readout of the GEM strips using APVs
- ⇒ Two amplification steps
- Inside GEM foil
 - Inside amplification region of the MM structure



Lithographically
etched strips

Segmented GEM Foil

1 piece

Bottom side (segmented)

Top side (not segmented)

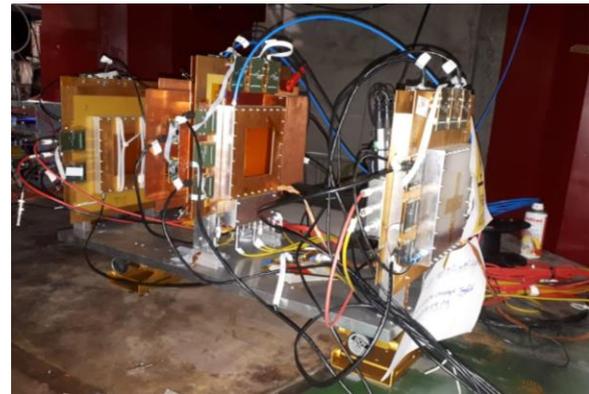
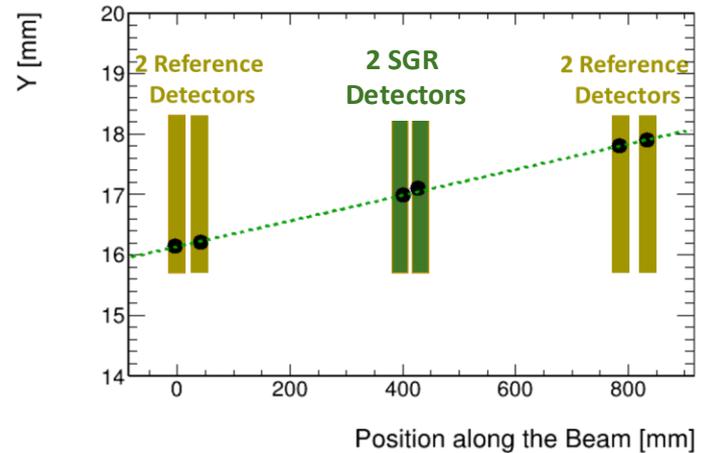
484 μm

APV connectors

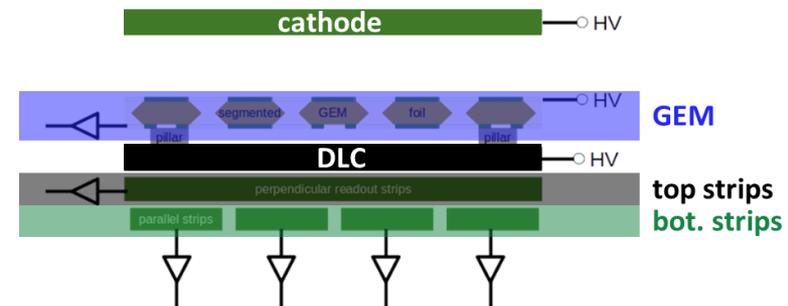
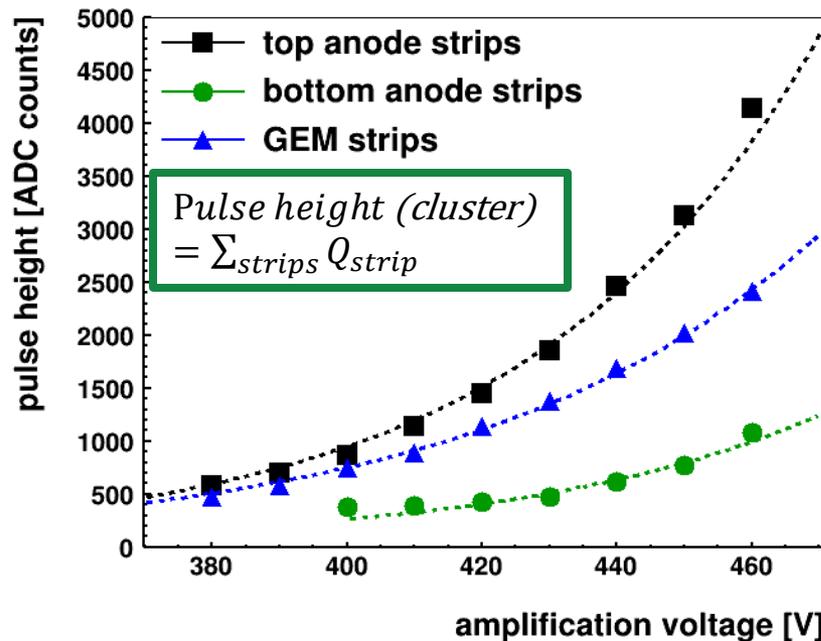
- Bottom side [segmented]:
 - 212 readout strips, connected to APVs via Panasonic connectors
 - Strip pitch: 4 GEM holes \cong 484 μm
- Top side [not segmented]:
 - standard GEM foil, 10 cm x 10 cm, 70 μm holes, 140 μm hole periodicity
 - 4 mm thick frame (only on top side)
- Inverse layout exists: strips on top side, bottom side not segmented => works similarly well

Beam Time H4 October / November 2021

- Four resistive strip Micromegas for precision reference tracking (3x2D & 1x1D)
- Investigated detectors:
 - Segmented GEM MM Hybrid with strips on **top side** of GEM
 - Segmented GEM MM Hybrid with strips on **bottom side** of GEM
- Determination of detector efficiency and resolution and pulse height for:
 - different voltage combinations
 - different inclination angles



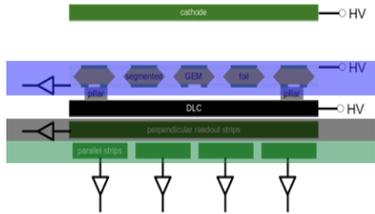
Muons: Pulse Height Comparison GEM-MM



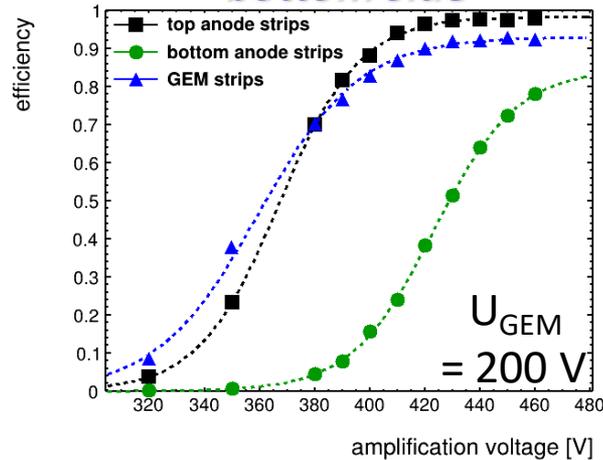
- Approx. same pulse height for **top readout** strips and **GEM strips**
 - Pulse height_{top} \approx 1.5 pulse height_{GEM}
- Optimized anode design exists with strip pitch 0.4 mm (not shown here)
 - Pulse height_{top} \approx pulse height_{bot}

⇒ 2D particle reconstruction possible

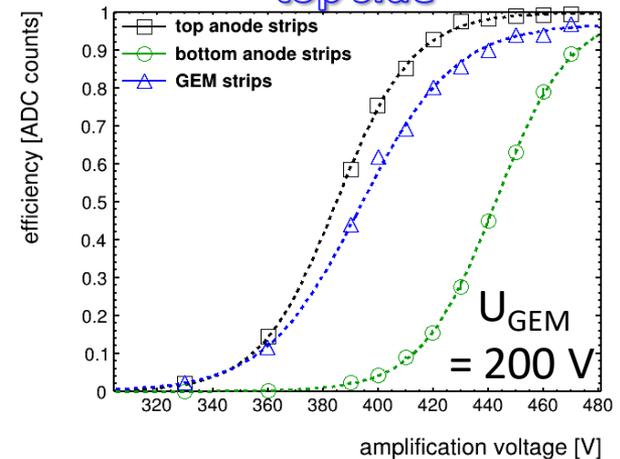
Efficiency Determination (perpendicular μ -track)



Det1: GEM strips on bottom side



Det2: GEM strips on top side



- Efficient event: $x_{track} - x_{measured} \leq \pm 1mm$

$$efficiency = \frac{\# \text{ efficient events}}{\# \text{ reference tracks}}$$

⇒ Approx. same efficiency for top and GEM readout strips
 Voltage offset: 20 V for all readout planes at detector with GEM strips on the top side (assembly of the detector)

⇒ Efficiency > 90% for GEM readout strips and top readout strips

Spatial Resolution Determination

- Residual:

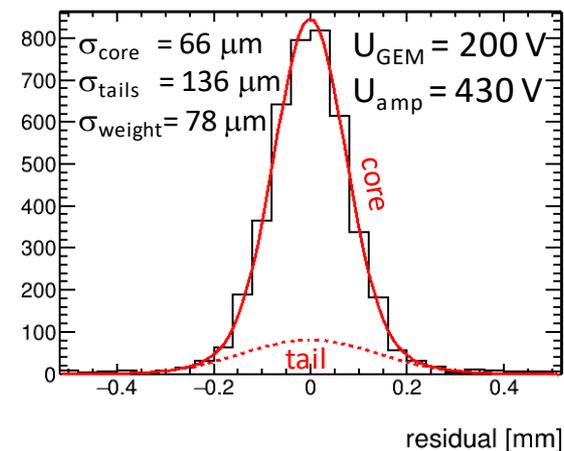
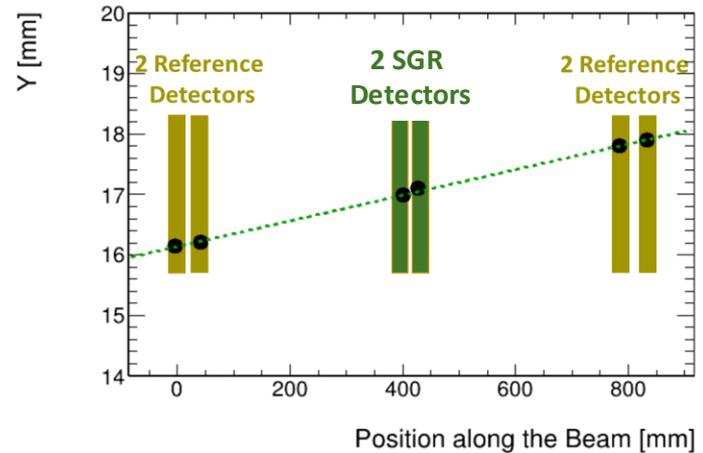
$$residual = x_{track} - x_{measured}$$

- Resolution determination via a double gaussian fit:

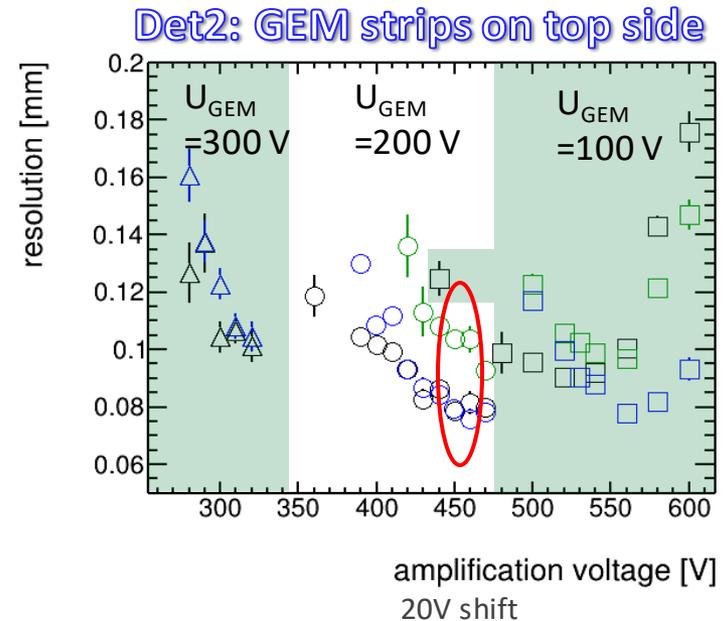
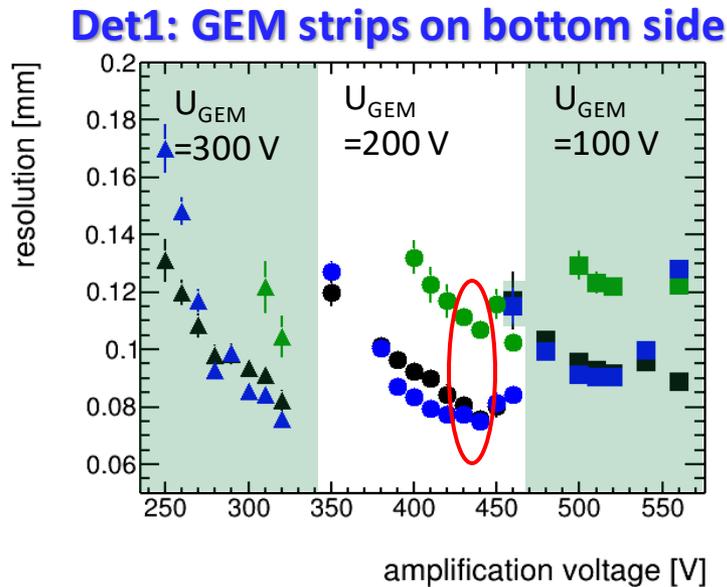
$$\sigma_{1/2} = \sqrt{\sigma_{core/tails}^2 - \sigma_{track}^2}$$

$$\sigma = \frac{\sigma_1 \times \int gauss_1 + \sigma_2 \times \int gauss_2}{\int gauss_1 + \int gauss_2}$$

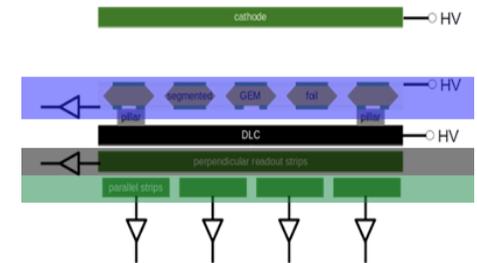
- Track accuracy $< \sigma_{det}$



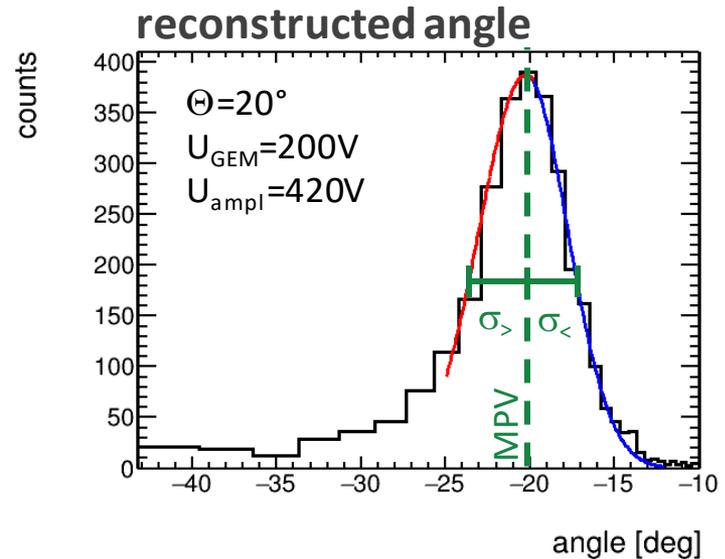
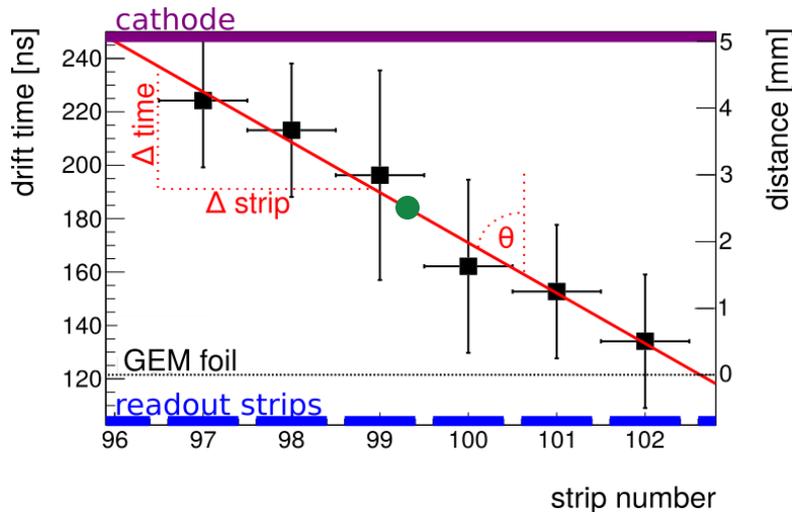
Spatial Resolution (perpendicular μ -track)



- $U_{anode} = f(U_{GEM})$
- Best resolution for $U_{GEM} = 200\text{ V}$, $U_{anode} = 440\text{ V}$
 - **Res_{GEM} $\approx 80\ \mu\text{m}$**
 - **Res_{anode top} $\approx 80\ \mu\text{m}$**
 - **Res_{anode bot} $\approx 100\ \mu\text{m}$**
- Discrepancy in the resolution between **top anode strips** and **GEM strips** (charge movement on the DLC layer)
 - \Rightarrow Can be improved



μ TPC: Principle (20°)



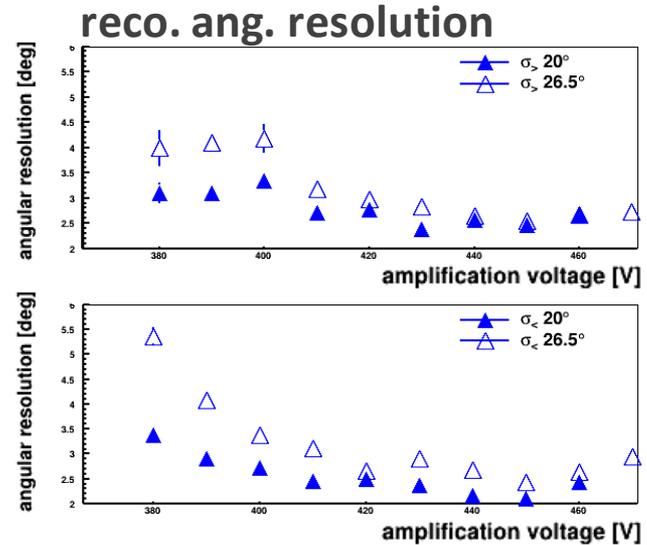
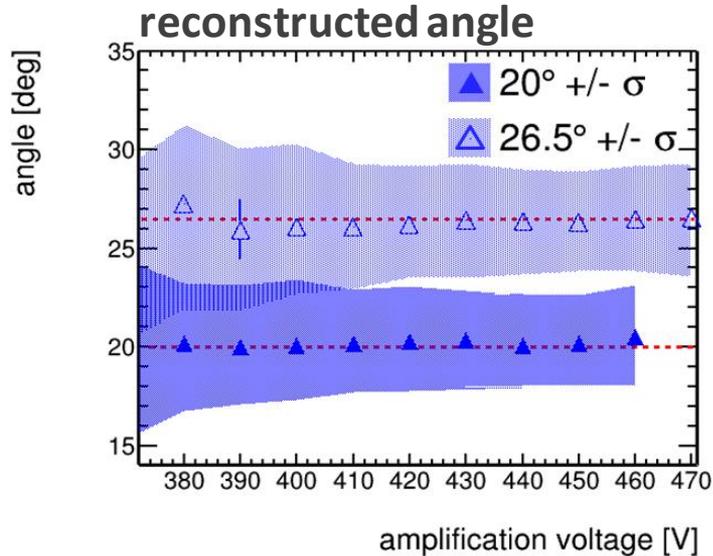
- Determination of the angle and position via the strip times

$$\Rightarrow \text{angle} = 90^\circ - \text{atan} \left(\frac{t * v_{\text{drift}}}{\text{strips} * \text{pitch}} \right)$$

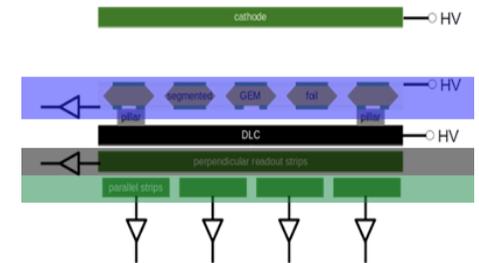
\Rightarrow Position: μ TPC track at $t_{1/2}$

- influenced by 25 ns jitter (muon trigger uncorrelated with 25 ns clock of APVs)

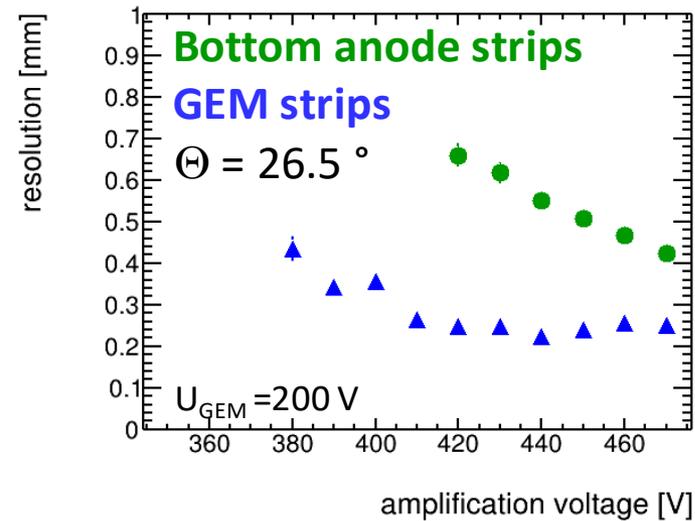
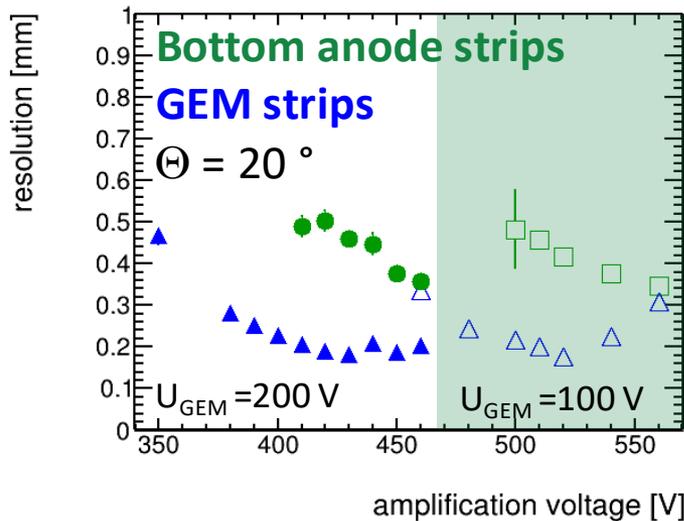
Angular Resolution μ TPC (26.5° and 20°)



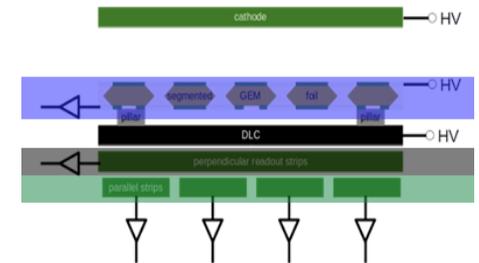
- Incident angle 26.5° and 20°
- Angular resolution:
 - $\approx 2^\circ$ for $\Theta = 20^\circ$
 - $\approx 3^\circ$ for $\Theta = 26.5^\circ$



Spatial Resolution μ TPC (20° and 26.5°)

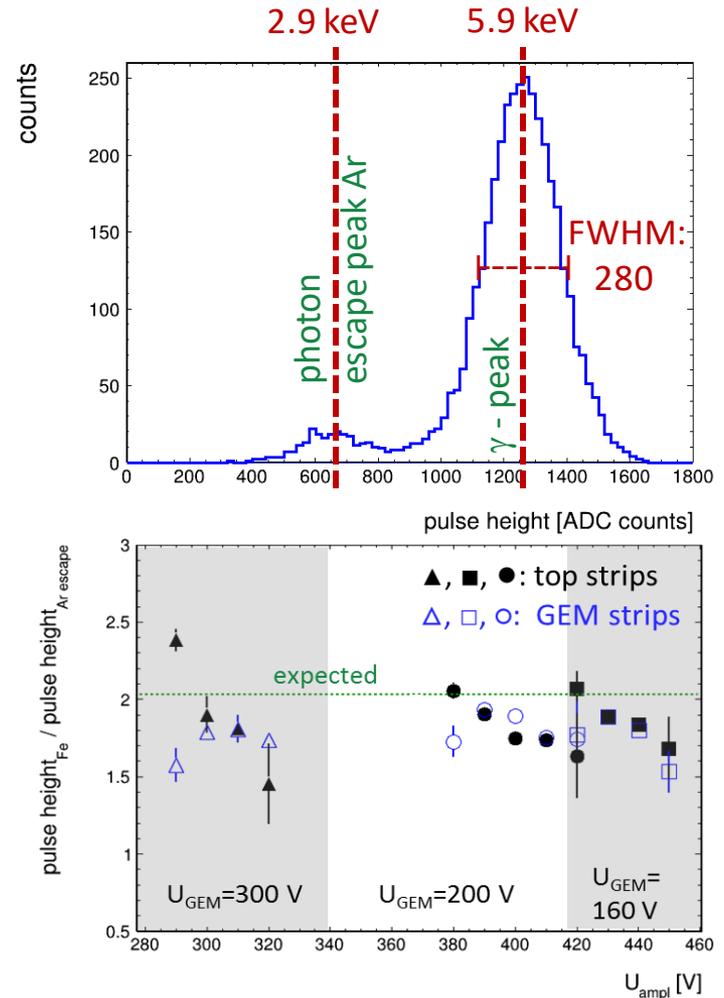


- μ TPC position reconstruction works in principle ✓
 - 1 mm efficiency > 90%
 - Better resolution for GEM strips as for bottom anode strips ☺ (low pulse height on bottom anode strips)
- Charge weighted mean spatial resolution (GEM strips):
 - 20° : resolution $\approx 350 \mu\text{m}$
 - 26° : resolution $\approx 450 \mu\text{m}$
- 25 ns trigger Jitter not corrected ($\pm 12.5 \text{ ns} \triangleq 220 \mu\text{m}$)



FE55: Ar Escape Peak Analysis

- Investigation of the pulse height using Fe55
- Two peaks:
 - Peak at 5.9 keV: γ of Fe55
 - Peak at 2.9 keV: K_{α} photon (Ar)
- ⇒ Expected ratio: $\frac{5.9 \text{ keV}}{2.9 \text{ keV}} = 2.03$
- Reconstructed ratio close to 2.03 (top – , and GEM – readout strips)
- $\frac{\Delta E}{E} (Fe55) = 22.2\% (FWHM)$
- ⇒ Good energy resolution



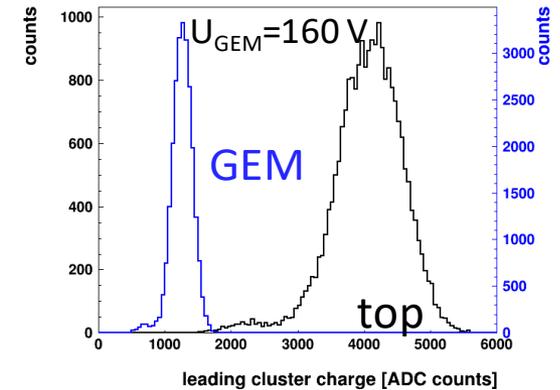
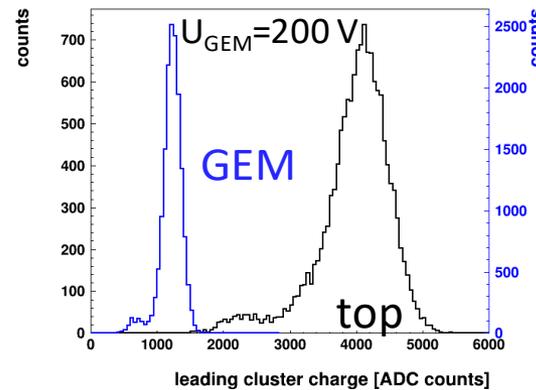
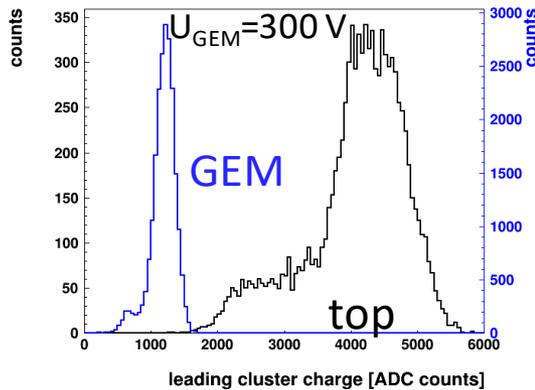
Summary

- Segmented GEM Readout Detector:
 - Y-readout with segmented GEM works (tracking efficiency > 90 %)
 - X-readout by standard resistive Micromegas anode strips (tracking efficiency > 90 %)
 - 2nd Y-readout by standard resistive Micromegas anode strips (off working point => optimized anode design exists)
- Resolution for perpendicular tracks
 - 2D tracking with $\sigma_x = 75 \mu\text{m} = \sigma_{y\text{-GEM}}$ possible
- Resolution for inclined tracks
 - μTPC possible on anode strips and GEM strips
 - Angle reconstruction works: $\sigma_{\text{angle}} = 2^\circ\text{-}3^\circ$
 - Position determination works:
 - 20° : $\sigma_{\text{GEM}} < 180 \mu\text{m}$
 - 26° : $\sigma_{\text{GEM}} < 220 \mu\text{m}$
- Next Step: Build X/Y/V detector for reduction of ambiguities

Backup

FE55: Ar Escape Peak Analysis

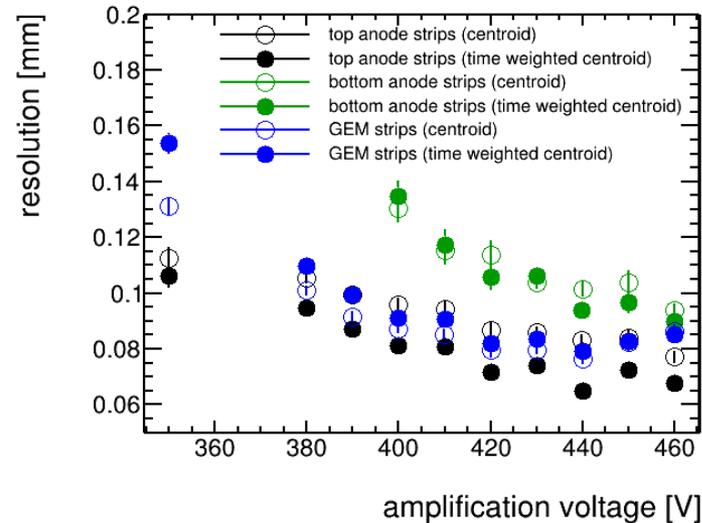
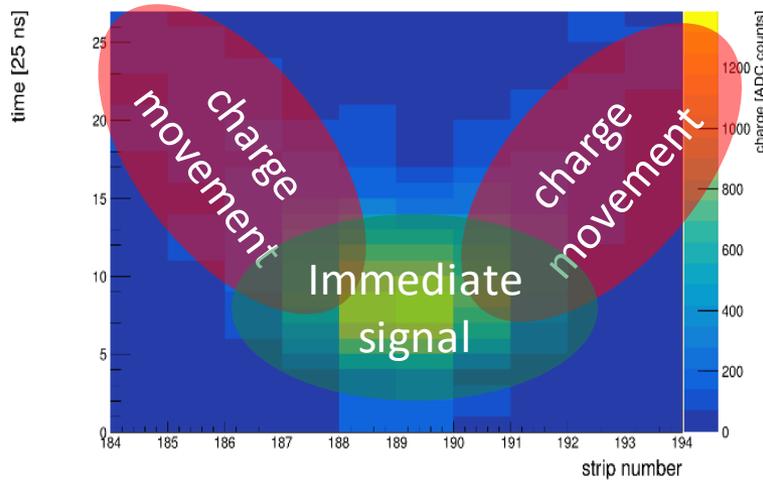
Ar:CO₂ 93:7



$$\text{Pulse height} = \sum_{\text{signal strips}} Q_{\text{strip}}$$

- Saturated events are discarded ($Q_{\text{strip}} > 1500$ ADC counts)
- Highest signals for different U_{GEM} without saturated strips are shown
- Escape peak visible for multiple voltages (U_{ampl} & U_{GEM})

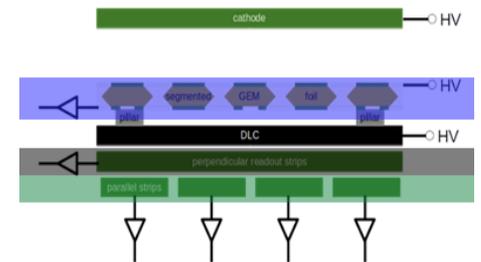
Charge and Time Weighted Mean



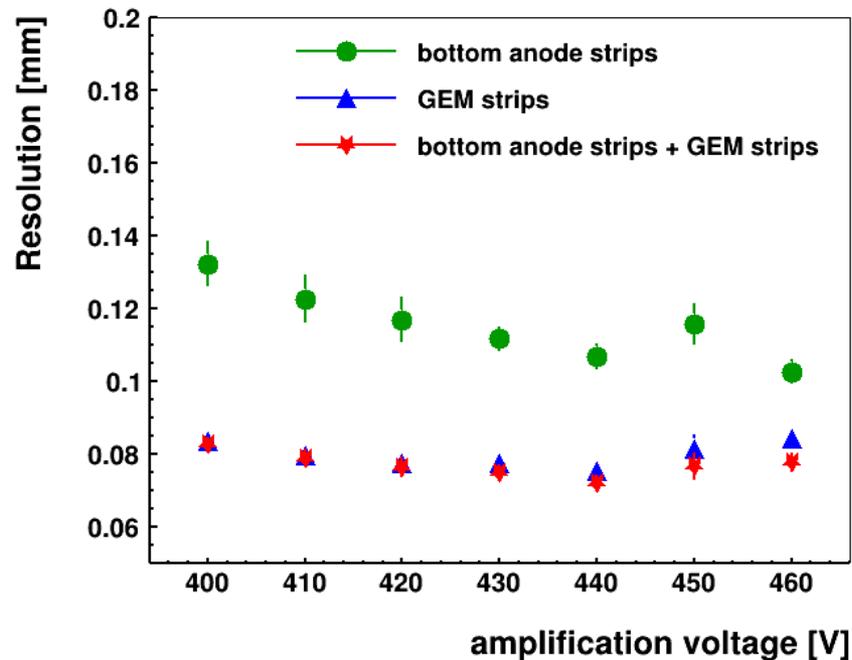
- Higher weight for immediate (fast) signal
- Lower weight for charge movement (later) signal
- Weight signal strip $\propto 1/t^2$ and $\propto Q$

$$x_{time} = \frac{\sum strip * Q/t^2}{\sum Q/t^2}$$

⇒ Improvement of the top anode strip resolution



Resolution Determination (Centroid) III

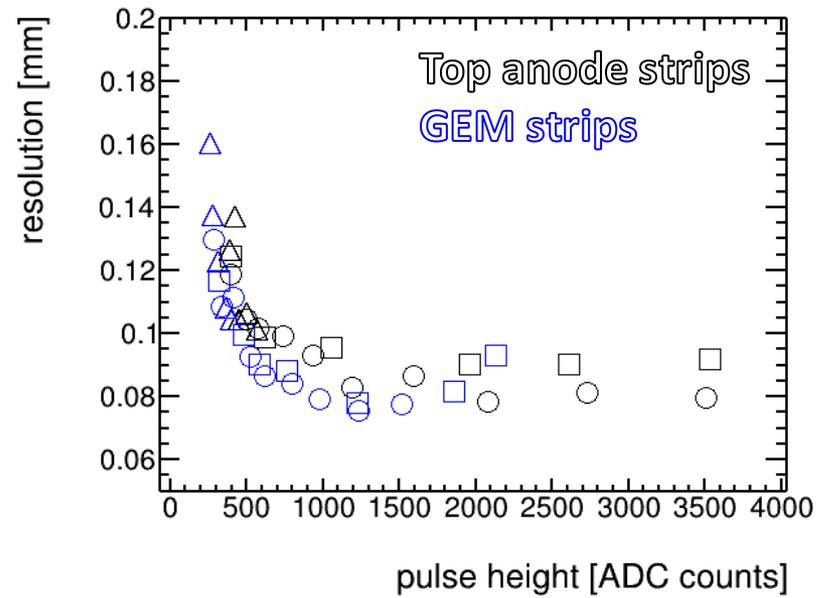
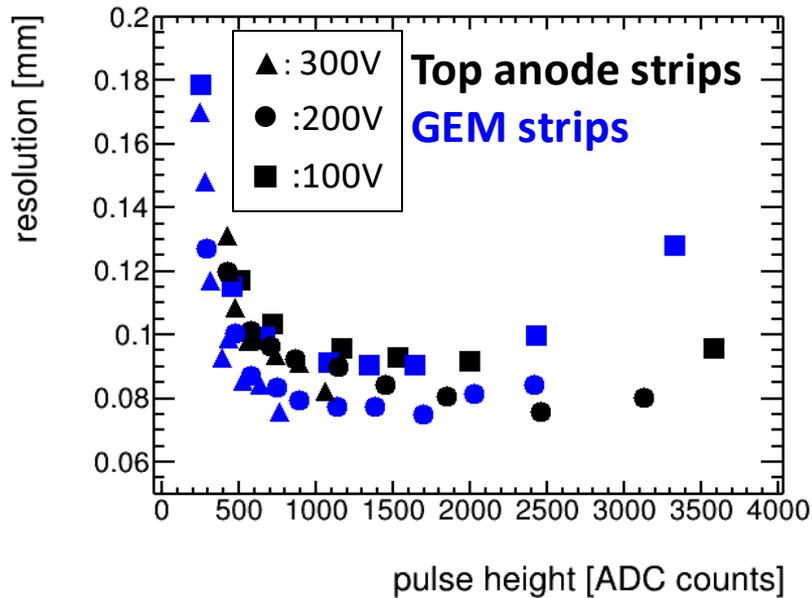


- Combination GEM strips and bottom anode strips

- $$y_{combined} = \frac{y_{GEM} \times pulse\ height_{GEM} + y_{anode} \times pulse\ height_{anode}}{\times pulse\ height_{GEM} + pulse\ height_{anode}}$$

- Slightly better resolution
- No larger increase due to big difference in resolution

Spatial Resolution (perpendicular μ -track)



- Resolution depending on pulse height (cluster charge)
 - Best Resolution at pulse height ≈ 2000 ADC counts (not reachable at $U_{GEM} = 300V$)
 - Better transparency for GEM foil with higher U_{GEM}
- \Rightarrow Compromise needed
- Better resolution for GEM strips as for anode strips

