Development of a Segmented GEM Readout Detector

JOINT PARTICLE PHYSICS GROUP SEMINAR

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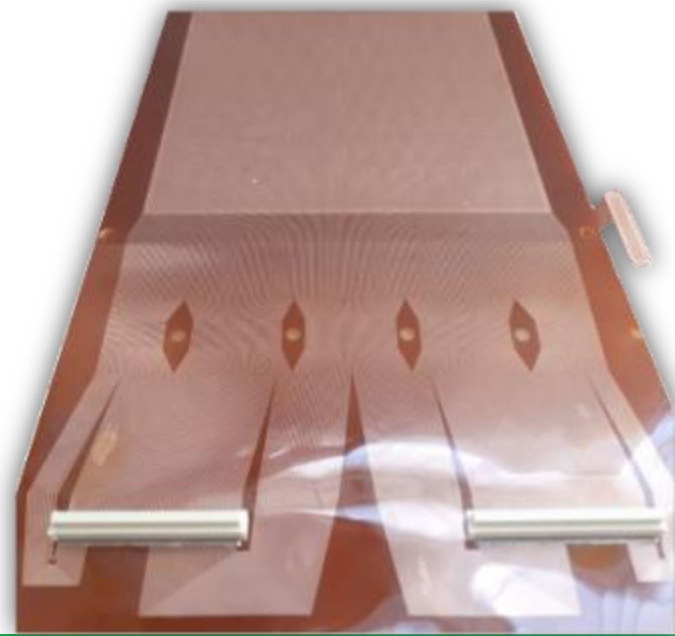


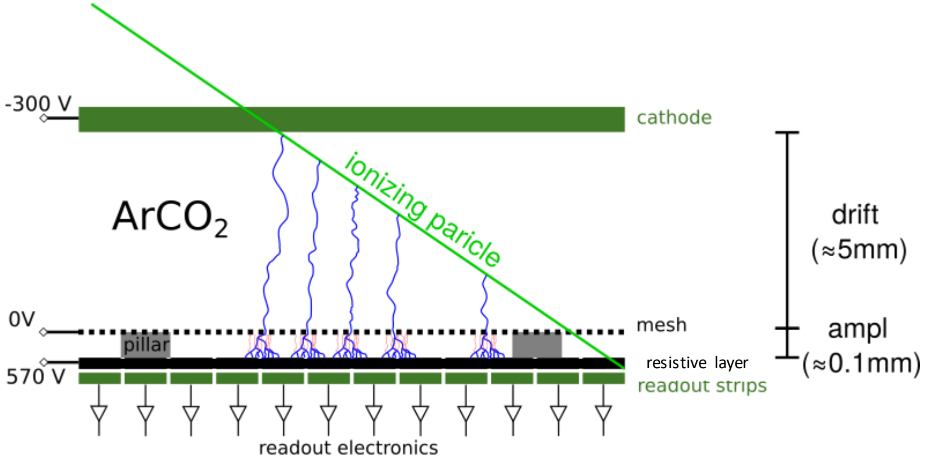
Working Principle of a Micromegas (MM)

- 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):

  ⇒ separation of the electrons and ions in the drift region

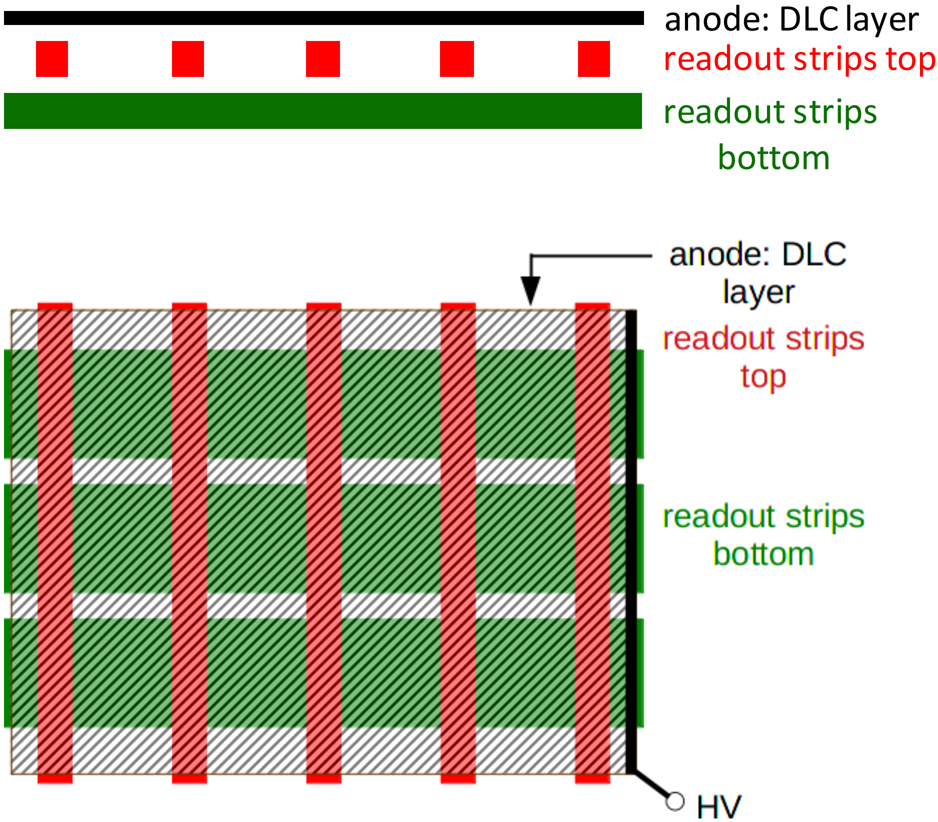
  ⇒ V_{drift} = 45 μm/ns (110 ns for 5 mm)
- Amplification region (≈ 128 μm):
  - High electric field (≈50 kV/cm)

  ⇒ Amplification of the signal by an electron avalanche (Gain ≈ 5000-10000)
- Resistive anode layer



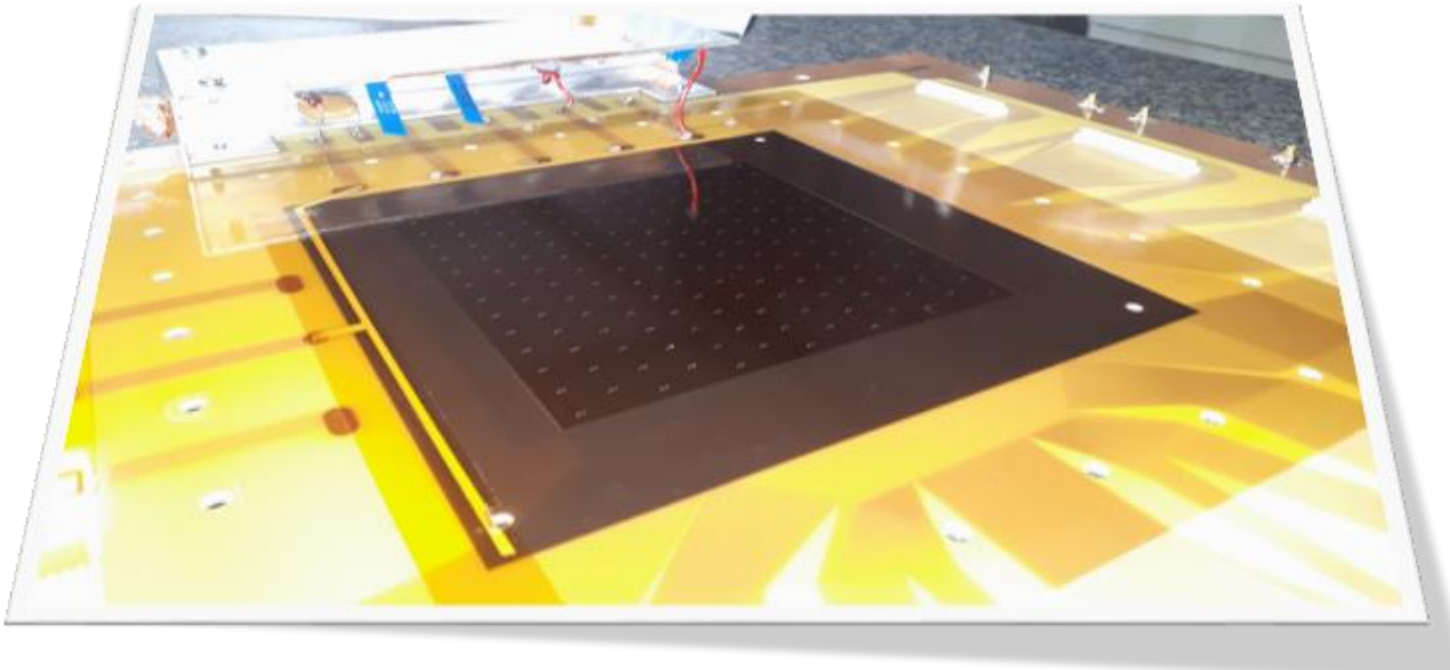
2D Resistive Layer Micromegas (DLC)

- Anode:
  - Resistive layer: Diamond Like Carbon (DLC)
- Micro pattern readout:
  - Charge signal couples to readout strips
  - 2 perpendicular readout strip layers, each with:
    360 readout strips / 250 μm pitch
  - Readout strips are read out by frontend electronics (APV25)
- 120 μm high pillar
- Floating mesh (no bulk)
- Ar:CO_2 93:7



CERN det. Lab: De Oliveira

Micromegas Readout Structure (DLC)



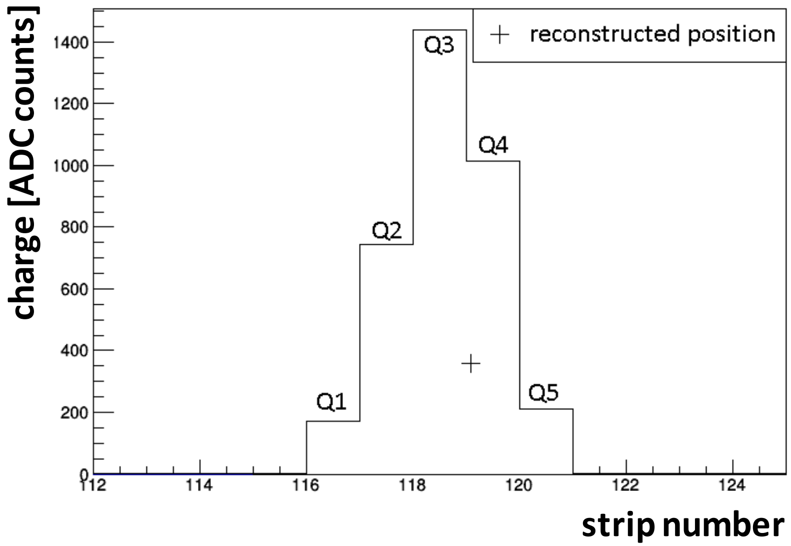
Particle Reconstruction

- Pulse height:

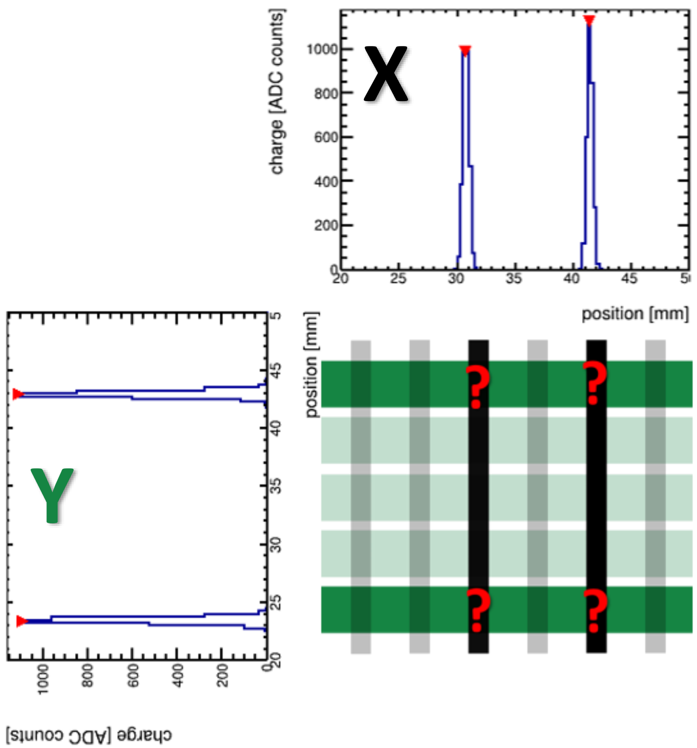
$$Pulse\ height = \sum_{strips} Q_{strip}$$

- Position (charge weighted mean):
  - ⇒Weighting of each strip with its maximum charge

$$x_{measured} = \frac{\sum_{strips} X_{strip} * Q_{strip}}{\sum_{strips} Q_{strip}}$$



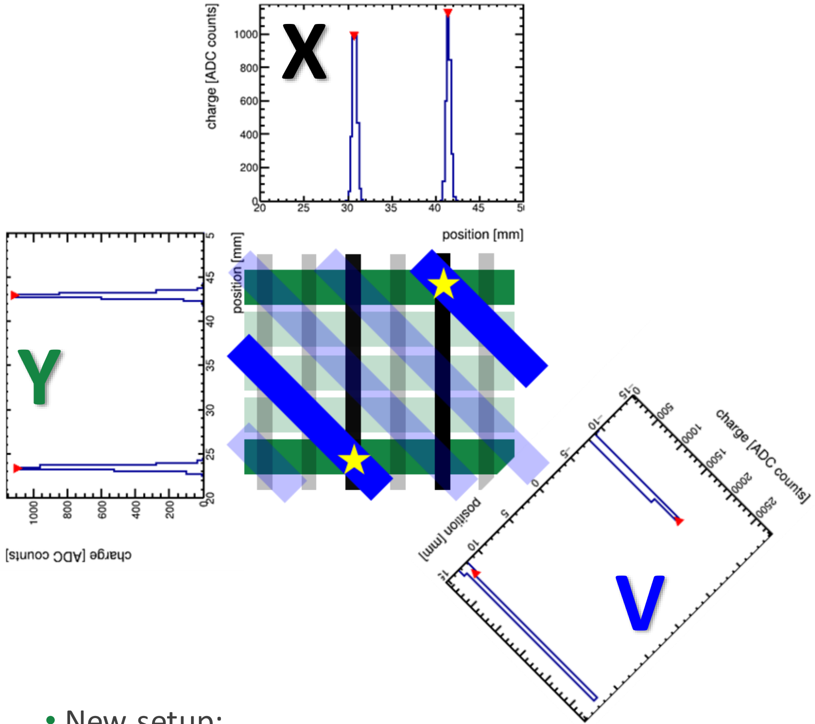
X/Y Strips : Multiple Particles at Same Time

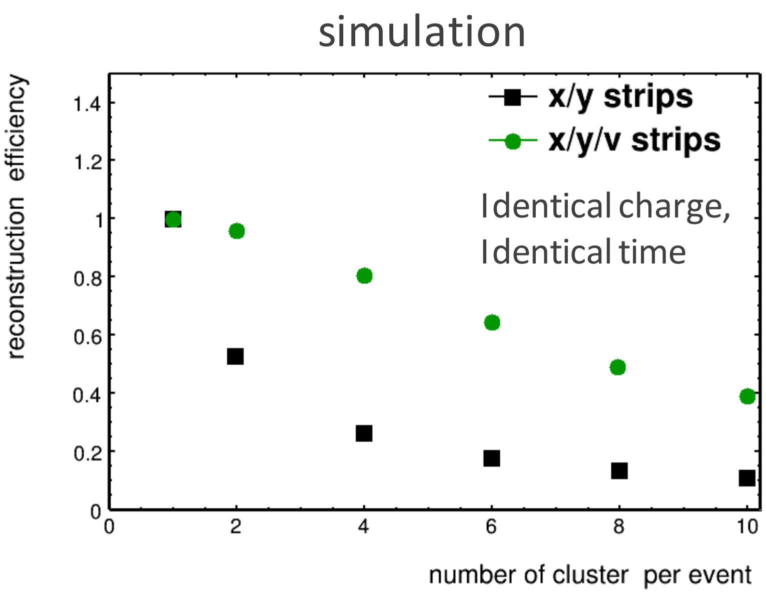


- Two particles at the same time
  - ⇒Two signatures in each detector layer (**X** / **Y**)
  - ⇒ 1D reconstruction works
- 2D position reconstruction:
  - Combination of X and Y cluster
  - ⇒Four different possibilities
  - ⇒2D reconstruction problematic

⇒Solution: 3rd layer of readout strips turned by 45 deg

X/Y/V Strips : Multiple Particles





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

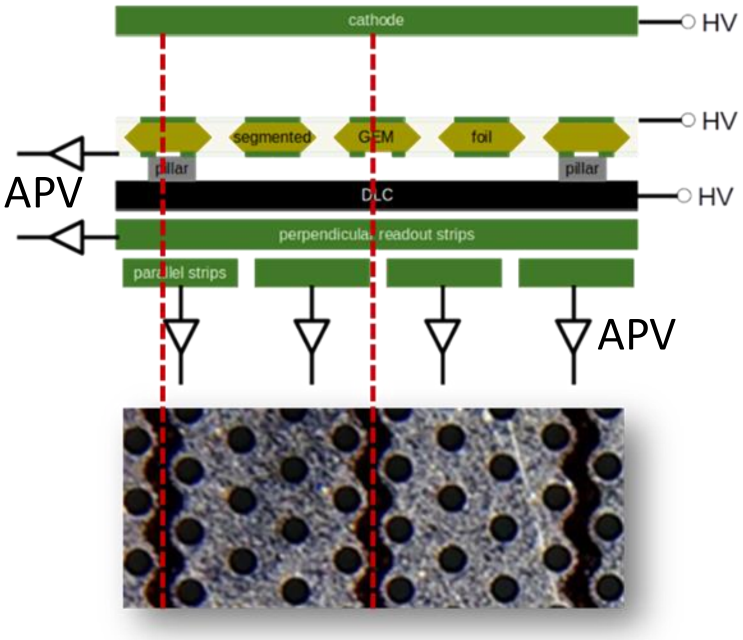
- New setup:
  - **X** / **Y** coordinate given by readout strips at the anode
  - **V** coordinate given by readout strips at the mesh location
- Unique 2D cluster combination possible

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

⇒Further improvement by using charge and time information

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



Working Principle of the GEM foil

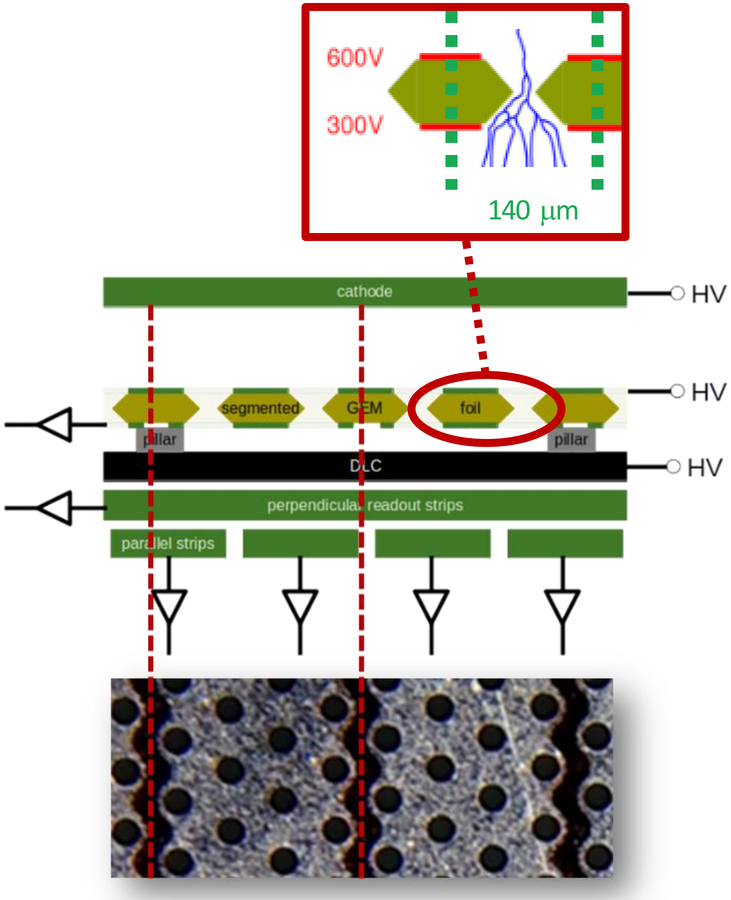
- GEM foil:
  - 2 layers of copper

    ⇒ separated by 50µm kapton (isolating)
  - Circular holes
    - Diameter holes: 70 µm
    - Periodicity 140 µm
  - Very high electric field between copper layers (≈50 kV/cm)

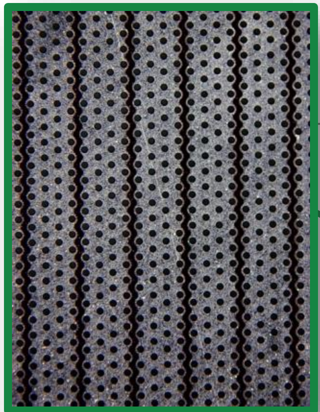
⇒Amplification of the signal by an electron avalanche inside the holes

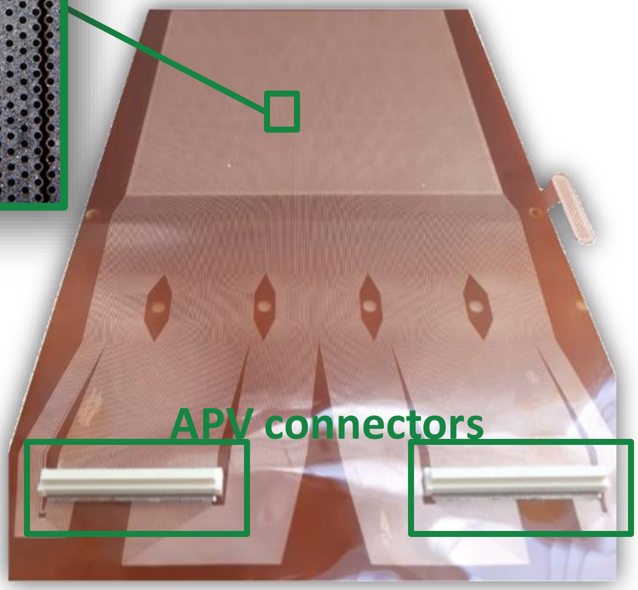
⇒Two amplification steps for the SGR Detector

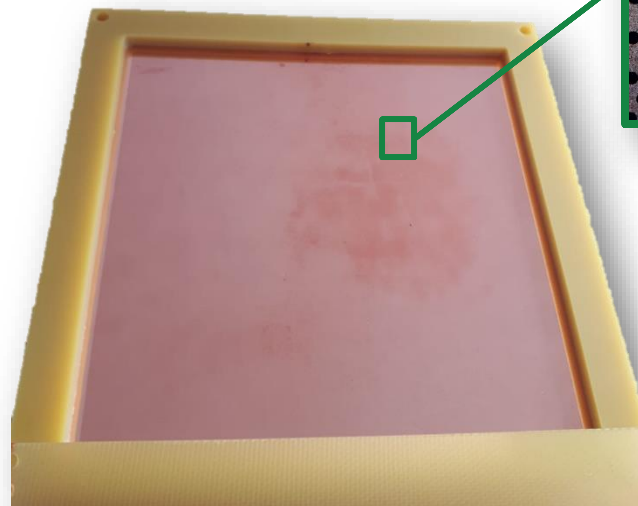
- Inside GEM foil
- Inside amplification region of the MM structure

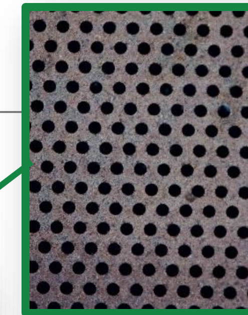


Segmented GEM Foil





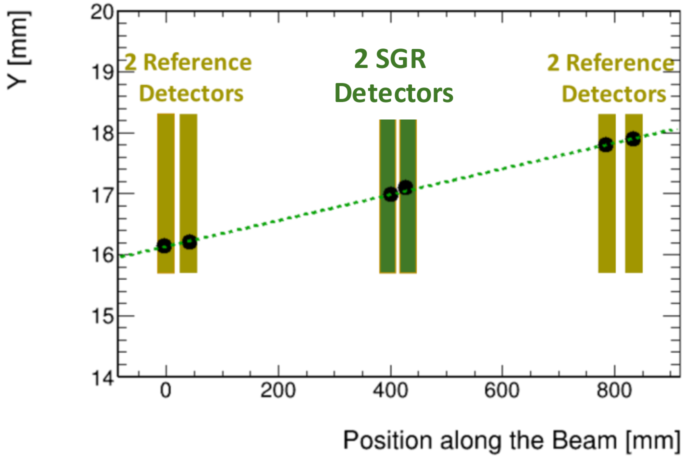


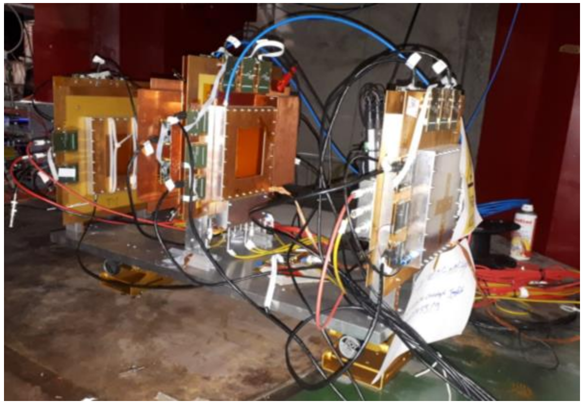


- Bottom side [segmented]:
  - 212 readout strips, connected to APVs via Panasonic connectors
  - Strip pitch: 4 GEM holes ≙ 484 μm
- Top side [not segmented]:
  - standard GEM foil, 10 cm x 10 cm, 70 μm holes, 140 μm hole periodicity
  - 4 mm thick frame (only on top side)
- Inverse layout exists: strips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

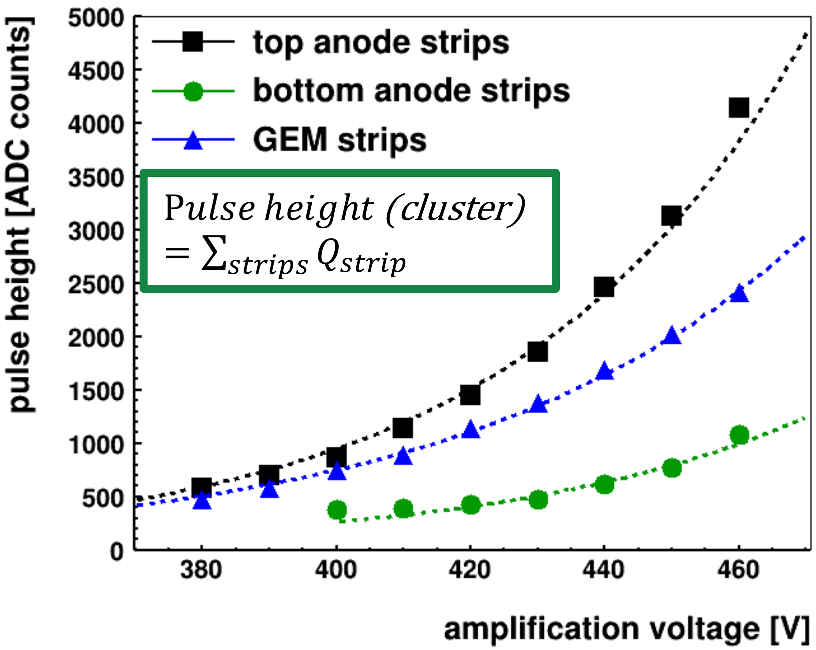
Beam Time H4 October / November 2021

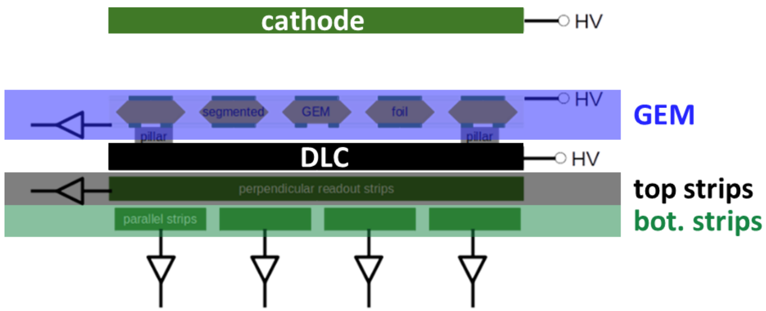
- Four resistive strip Micromegas for precision reference tracking (3x2D & 1x1D)
- Investigated detectors:
  - Segmented GEM MM Hybrid with strips on top side of GEM
  - Segmented GEM MM Hybrid with strips on **bottom side** of GEM
- Determination of detector efficiency and resolution and pulse height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





Muons: Pulse Height Comparison GEM-MM

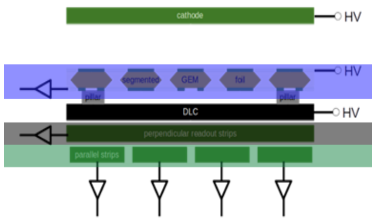




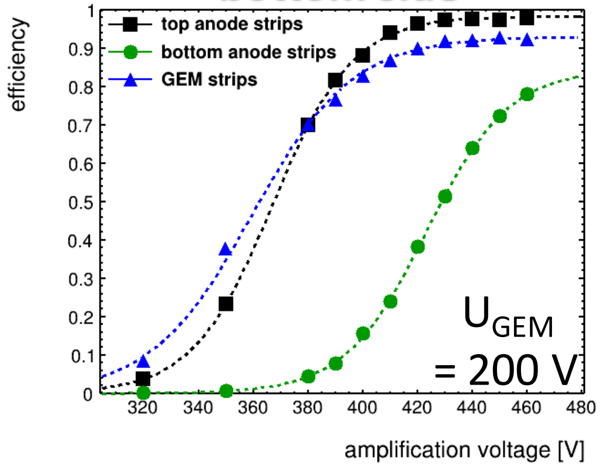
- Approx. same pulse height for **top readout** strips and **GEM strips**
  - Pulse height$_{top}$ ≈ 1.5 pulse height$_{GEM}$
- Optimized anode design exists with strip pitch 0.4 mm (not shown here)
  - Pulse height$_{top}$ ≈ pulse height$_{bot}$

⇒2D particle reconstruction possible

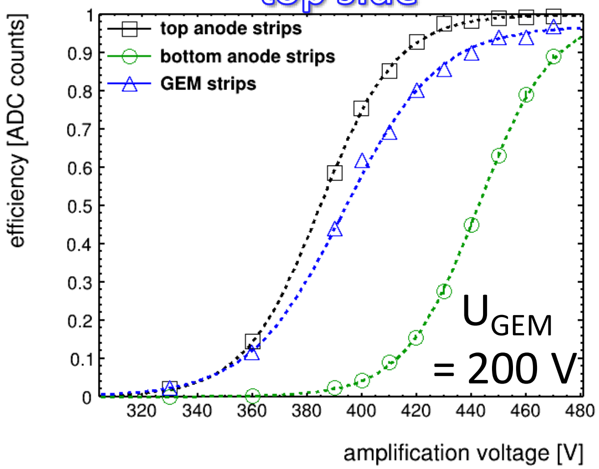
Efficiency Determination (perpendicular µ-track)



Det1: GEM strips on bottom side



Det2: GEM strips on top side



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

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

⇒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:

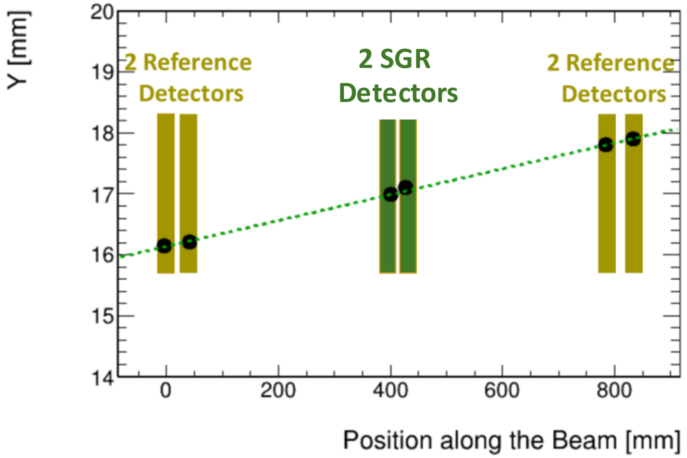
$$residual = x_{track} - x_{measured}$$

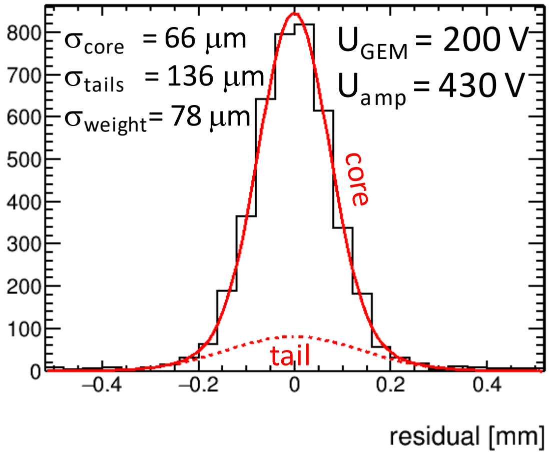
- Resolution determination via a double gaussian fit:

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

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

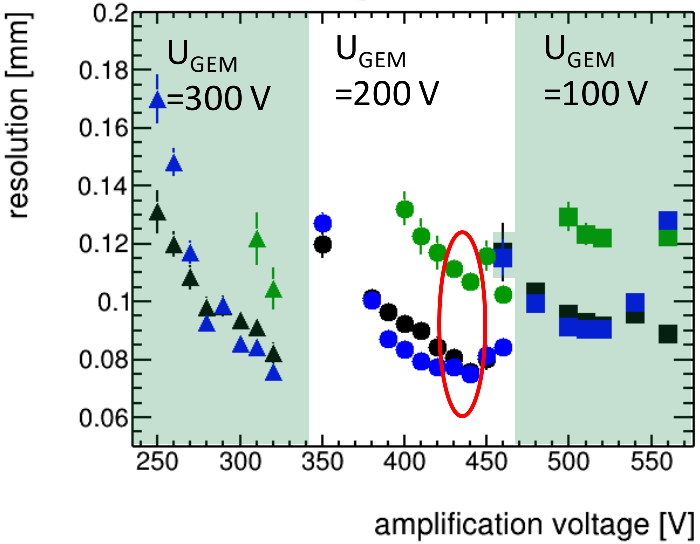
- Track accuracy < σ_{det}



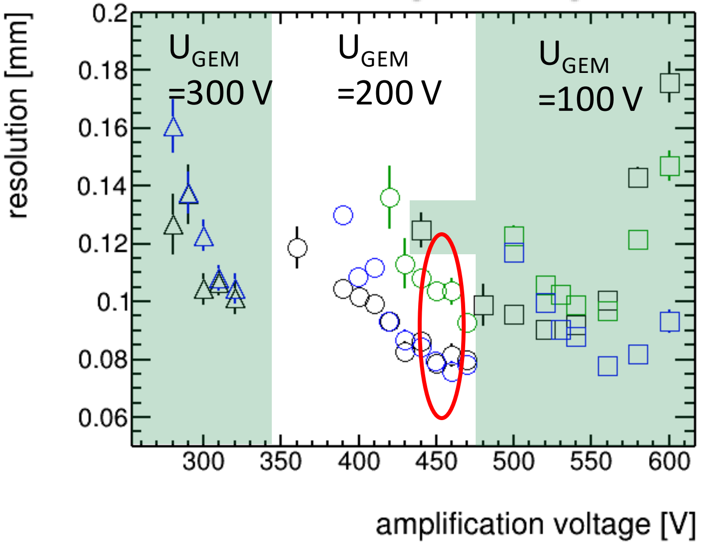


Spatial Resolution (perpendicular μ-track)

Det1: GEM strips on bottom side

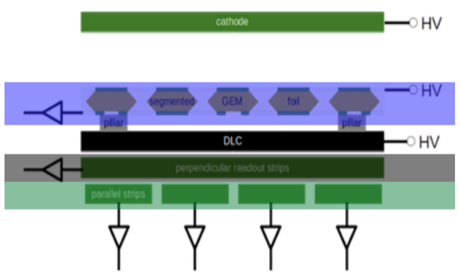


Det2: GEM strips on top side

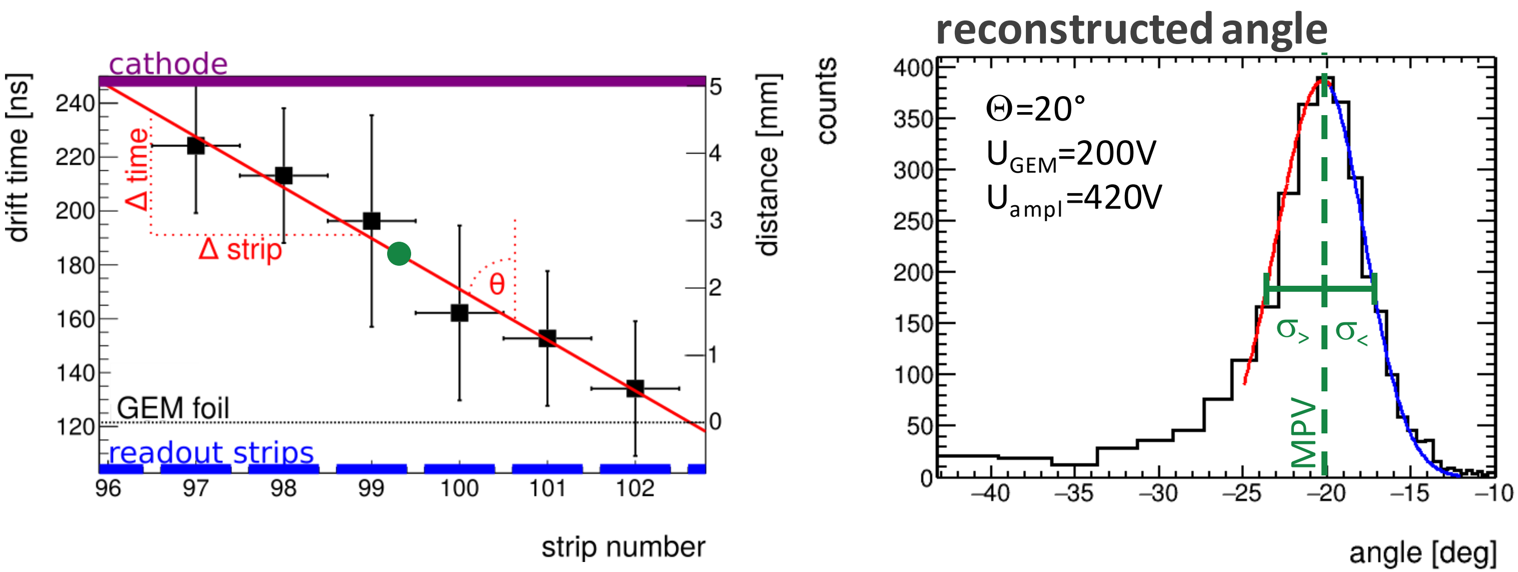


20V shift

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



µTPC: Principle (20°)



- Determination of the angle and position via the strip times

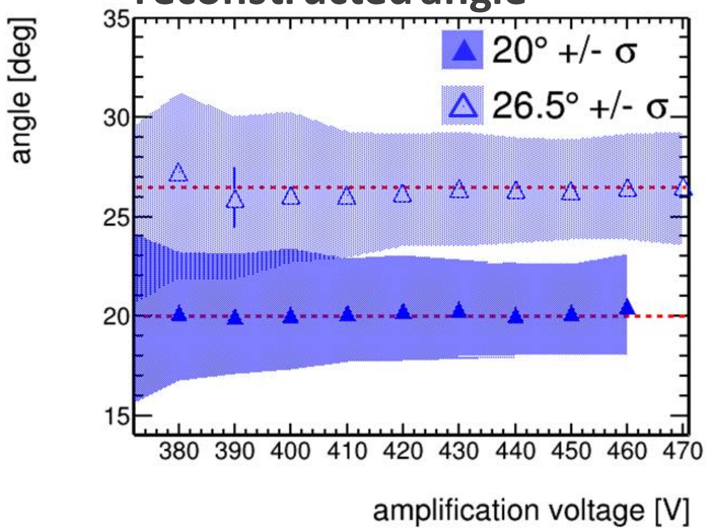
$\Rightarrow angle = 90° - \text{atan}\left(\frac{t * v_{drift}}{strips * pitch}\right)$

$\Rightarrow$Position: µTPC track at $\mathbf{t_{1/2}}$

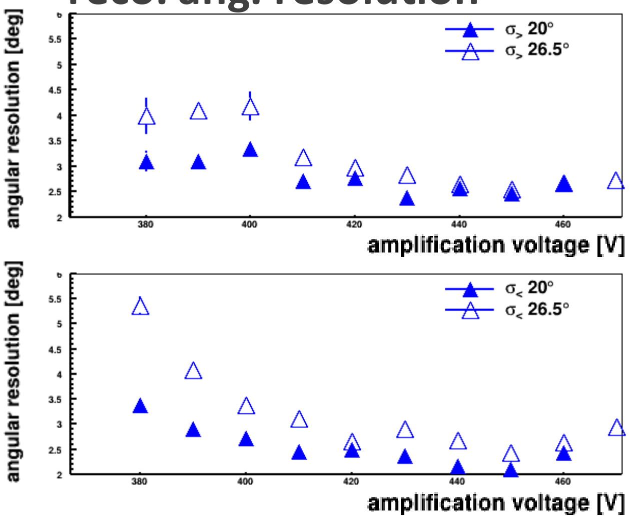
- influenced by 25 ns jitter (muon trigger uncorrelated with 25 ns clock of APVs)

Angular Resolution µTPC (26.5° and 20°)

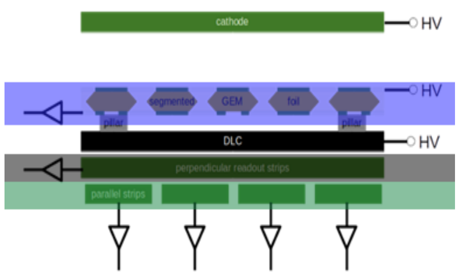
reconstructed angle



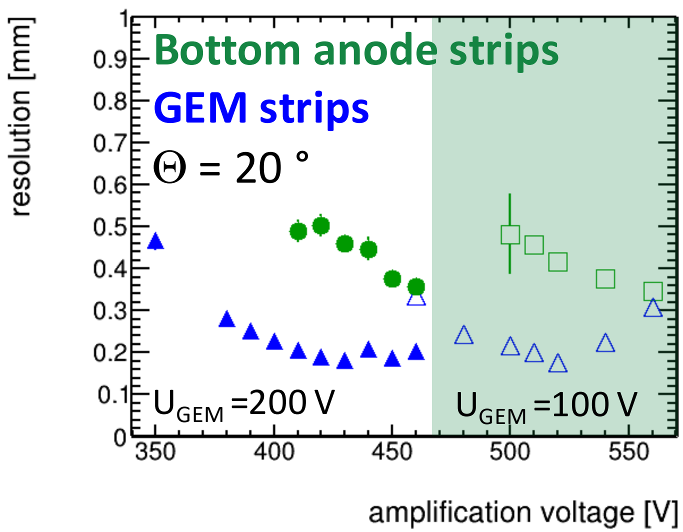
reco. ang. resolution

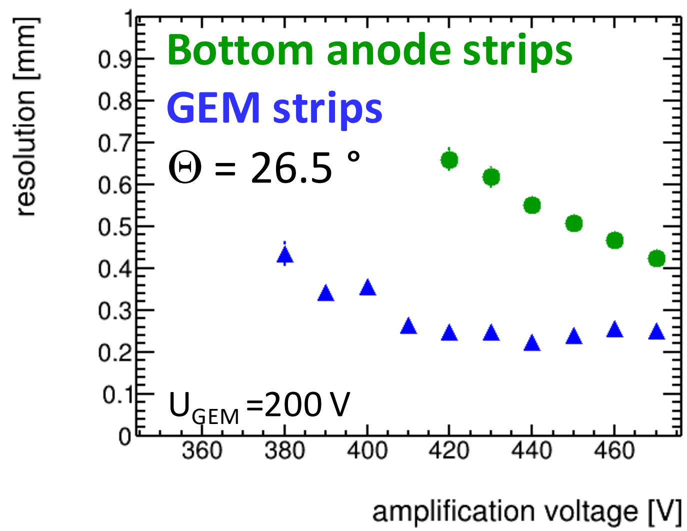


- Incident angle 26.5° and 20°
- Angular resolution:
  - ≈ 2° for Θ = 20°
  - ≈ 3° for Θ = 26.5°

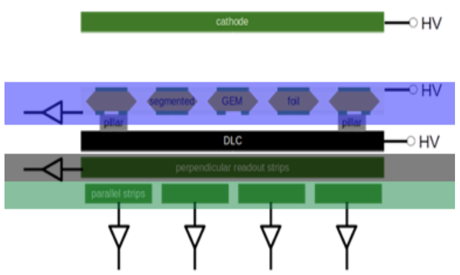


Spatial Resolution µTPC (20° and 26.5°)





- µTPC 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 ≈ 350 µm
  - 26°: resolution ≈ 450 µm
- 25 ns trigger Jitter not corrected (+/- 12.5 ns ≙ 220 µm)

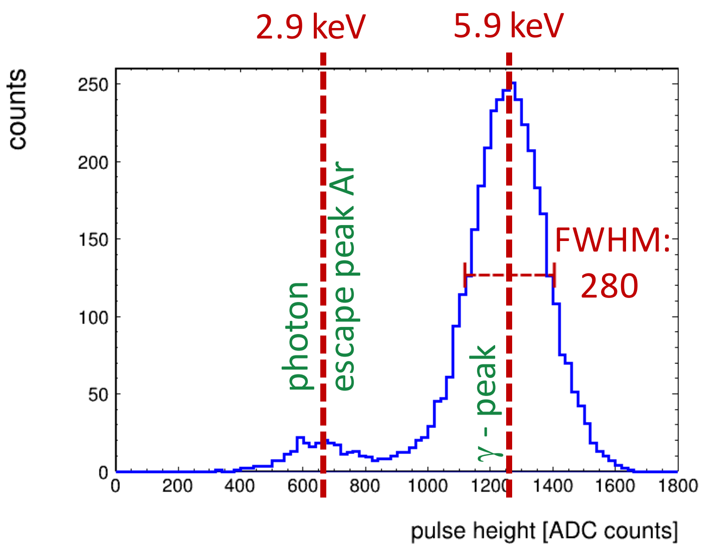


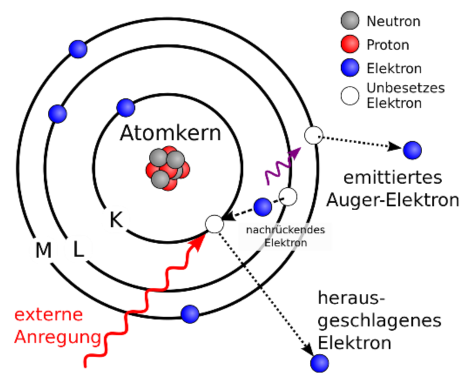
FE55: Ar Escape Peak Analysis

- 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)

  $\Rightarrow$ Expected ratio: $\frac{5.9\ keV}{2.9\ keV} = 2.03$
- Escape Peak:
  - Ionization of the Ar atom (K shell)
  - Higher energetic electron falls down on K shell

  $\Rightarrow$ Emission of a K_α photon, leaving the detector

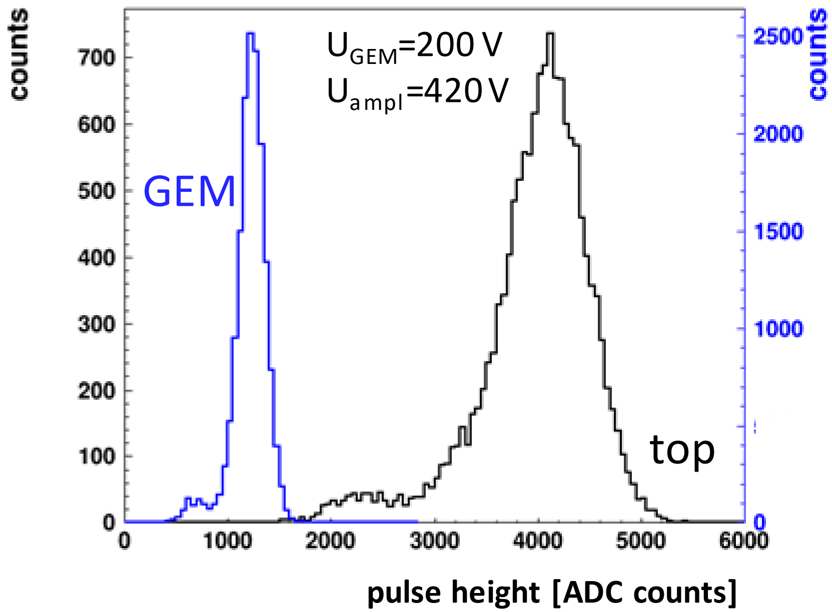


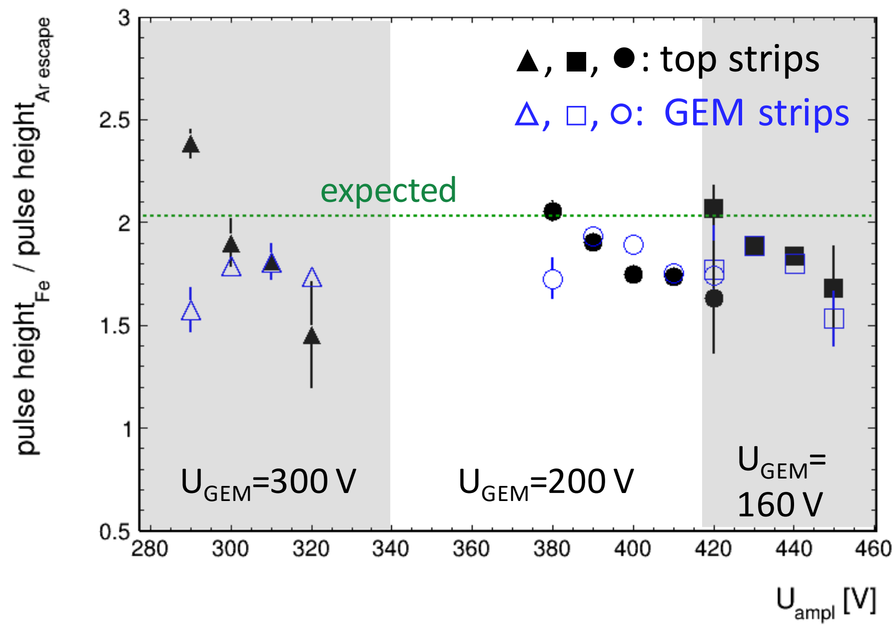


https://de.wikipedia.org/wiki/Auger-Effekt#/media/Datei:Atom_model_for_Auger_process_DE.svg

Is it possible to measure the expected ratio of 2.03?

FE55: Ar Escape Peak Analysis (Segmented GEM)





- $\frac{\Delta E}{E}(Fe55) \approx 20\ \%\ (FWHM)$, (top – , and GEM – readout strips)
- Escape peak visible for all investigated voltages
- Reconstructed ratio close to 2.03 (top – , and GEM – readout strips)

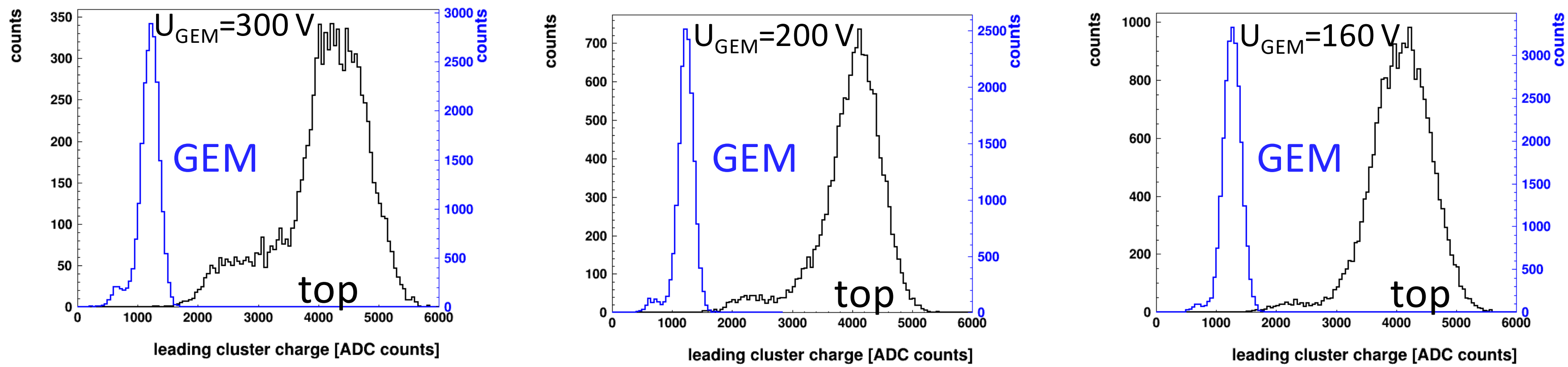
Summary

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

Backup

FE55: Ar Escape Peak Analysis

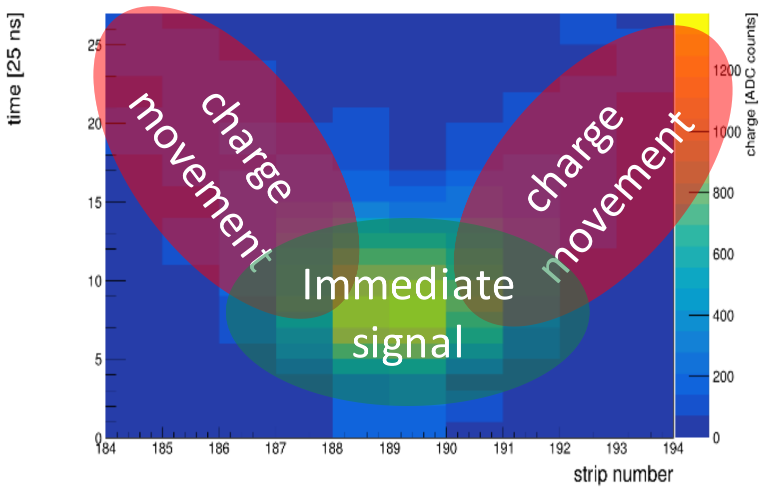
$Ar:CO_2$ 93:7

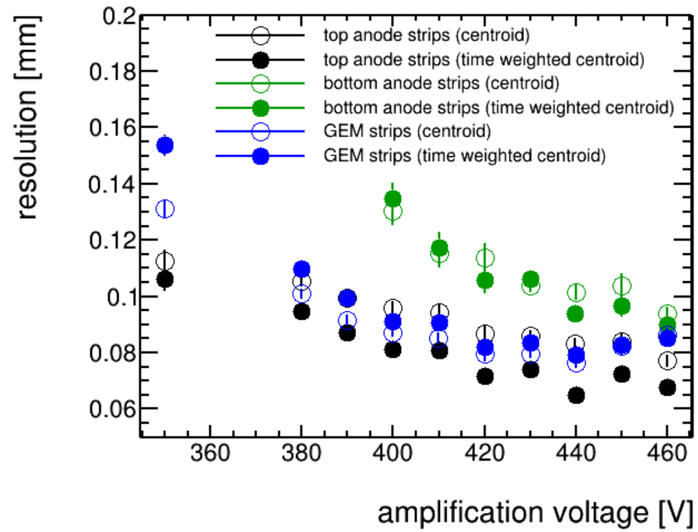


$$Pulse\ height = \sum_{signal\ strips} Q_{strip}$$

- Saturated events are discarded (Q_{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})

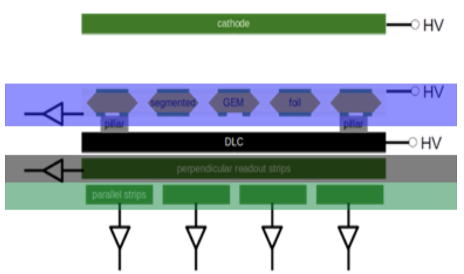
Charge and Time Weighted Mean





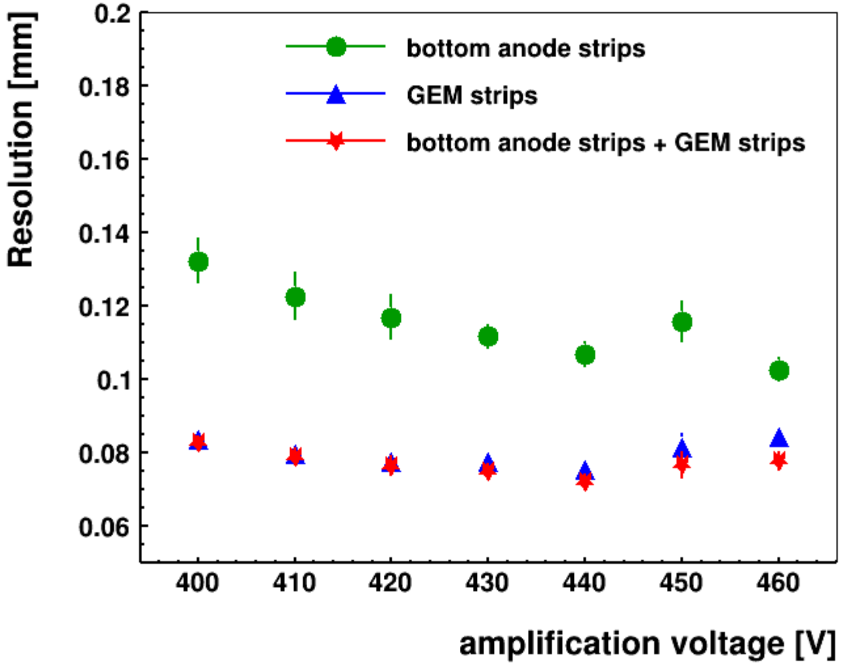
- Higher weight for immediate (fast) signal
- Lower weight for charge movement (later) signal
- Weight signal strip $\propto {}^{1}/_{t^2}$ and $\propto Q$

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



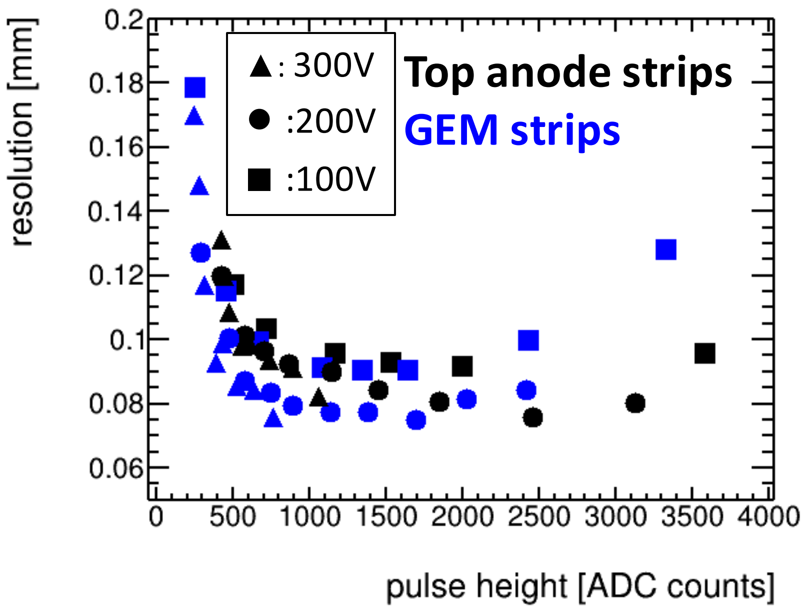
⇒Improvement of the top anode strip resolution

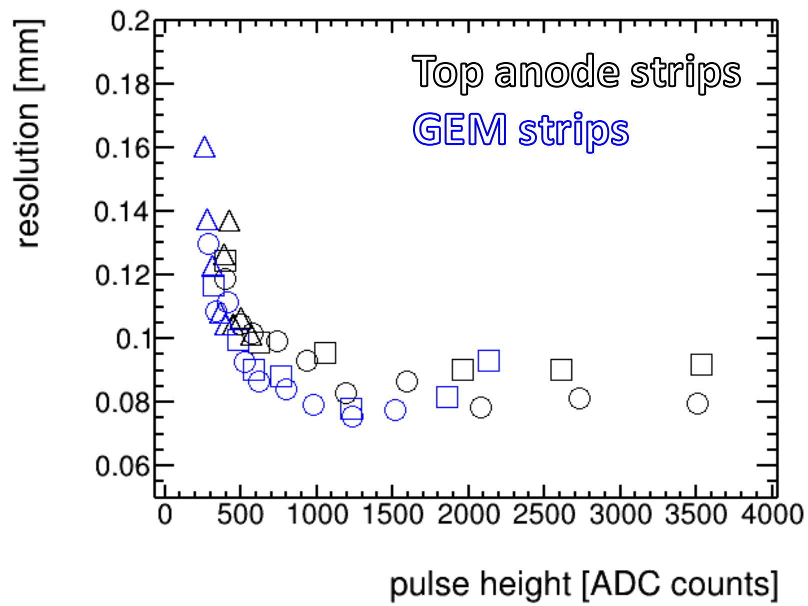
Resolution Determination (Centroid) III



- 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}

⇒Compromise needed

- Better resolution for GEM strips as for anode strips