X,Y,U,V Four Layer MM-GEM Hybrid Detector Using Segmented GEM Foils

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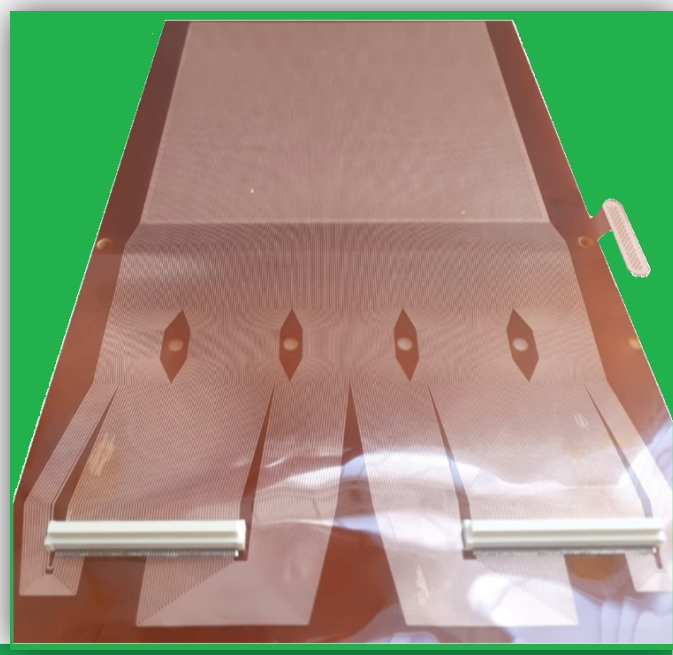
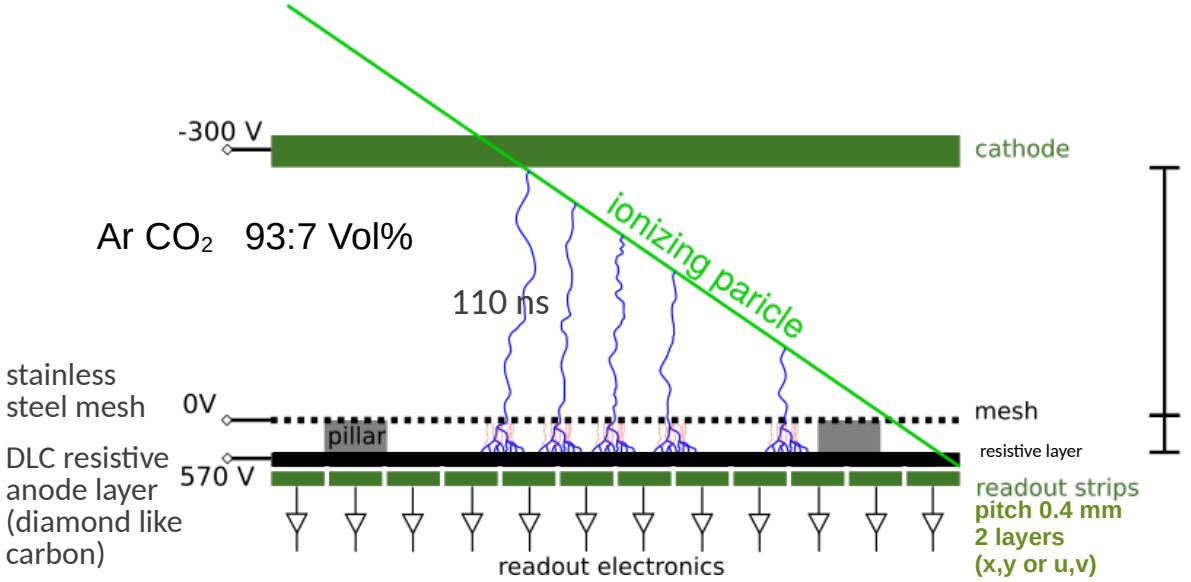


Micromegas (MM)

(micromesh gaseous structure)



position determination: X,Y layers

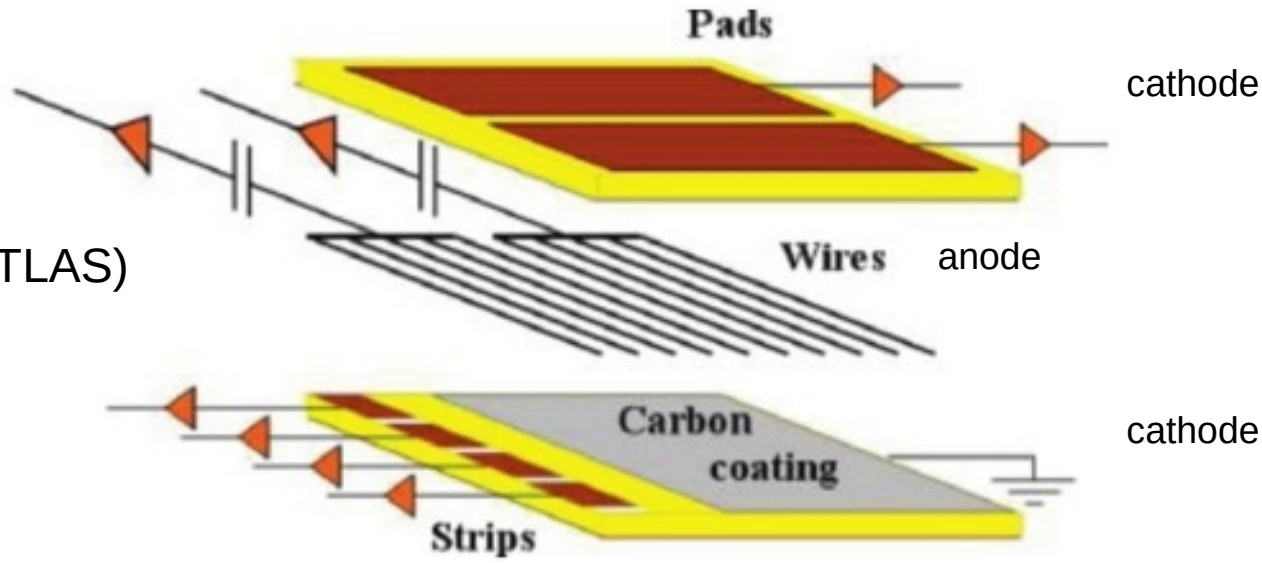
$$x_{centroid} = \frac{\sum_{n=1}^{N} x_i \cdot q_i}{\sum_{n=1}^{N} q_i}$$

$$\mu TPC : angle = slope \frac{t_{drift} \cdot v_{drift}}{i_{strip} \cdot pitch}$$

Wire Chamber Readout: Wires, Cathode Strips, Cathode Pads …

the combination of anode + cathode information improves detector performance

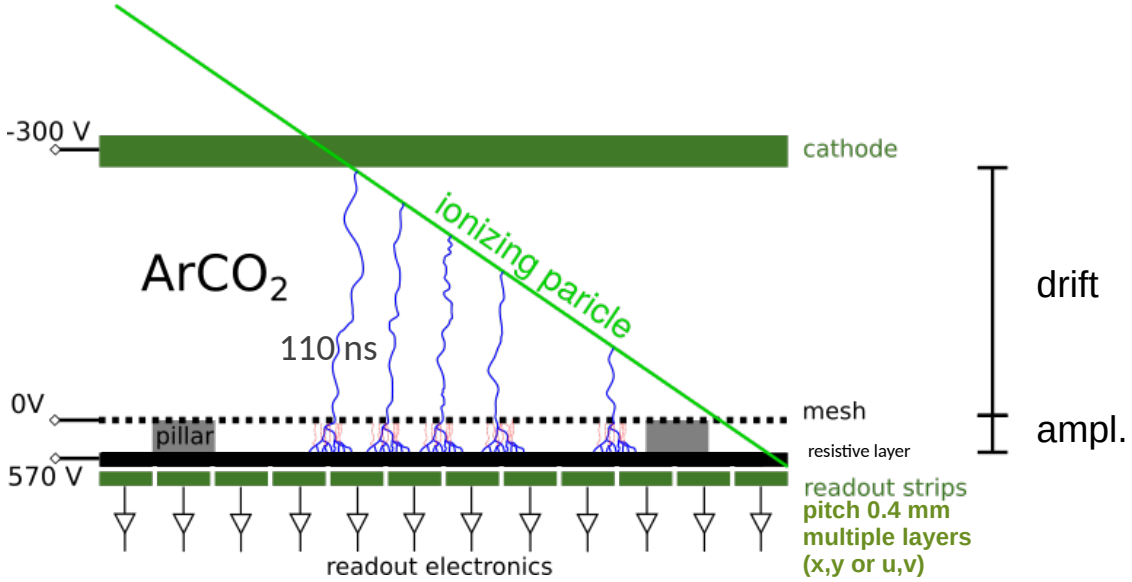
sTGC (ATLAS)



position: wires + cathode strips (2nd coordinate)
trigger: cathode pads

Micromegas (MM)

(micromesh gaseous structure)



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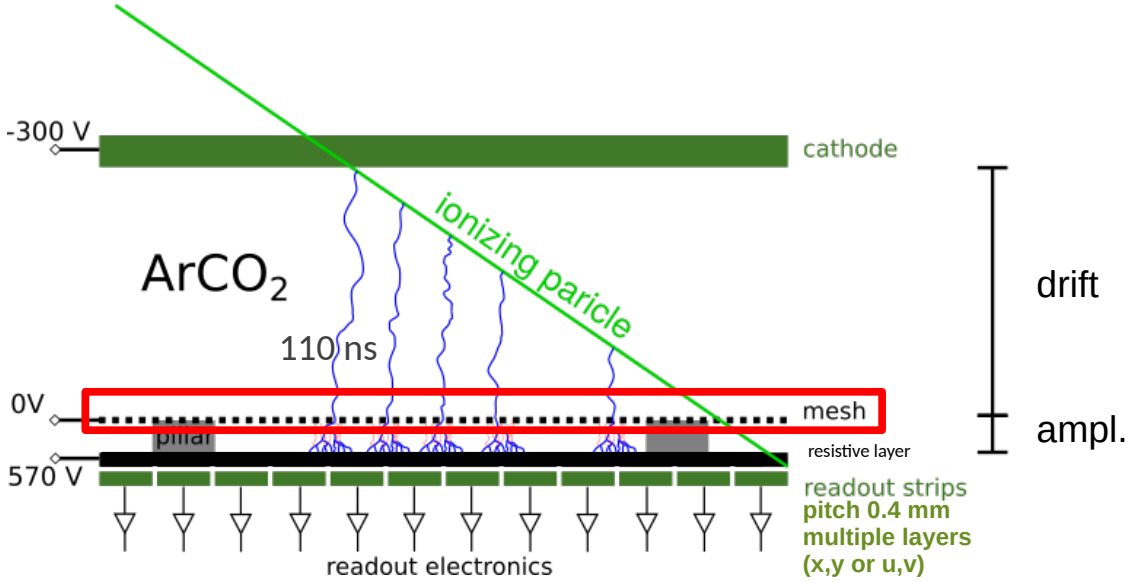
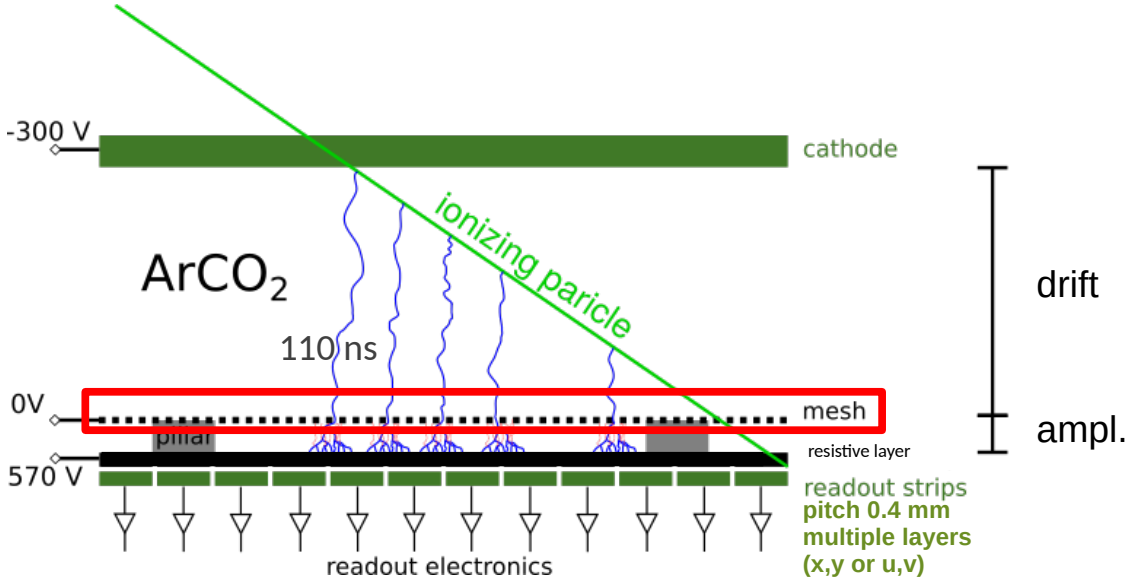


replace MESH by GEM foil

Micromegas (MM)

(micromesh gaseous structure)

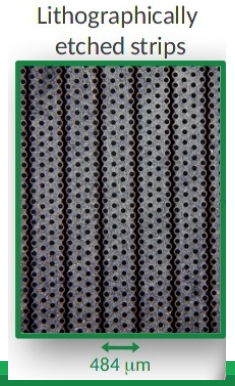


replace MESH by GEM foil

=> no “standard” MM-GEM hybrid

$U_{anode} = f(U_{GEM})$
$U_{GEM} = f(U_{anode})$

GEM foil with etched strips



CERN det. Lab:
R. de Oliveira

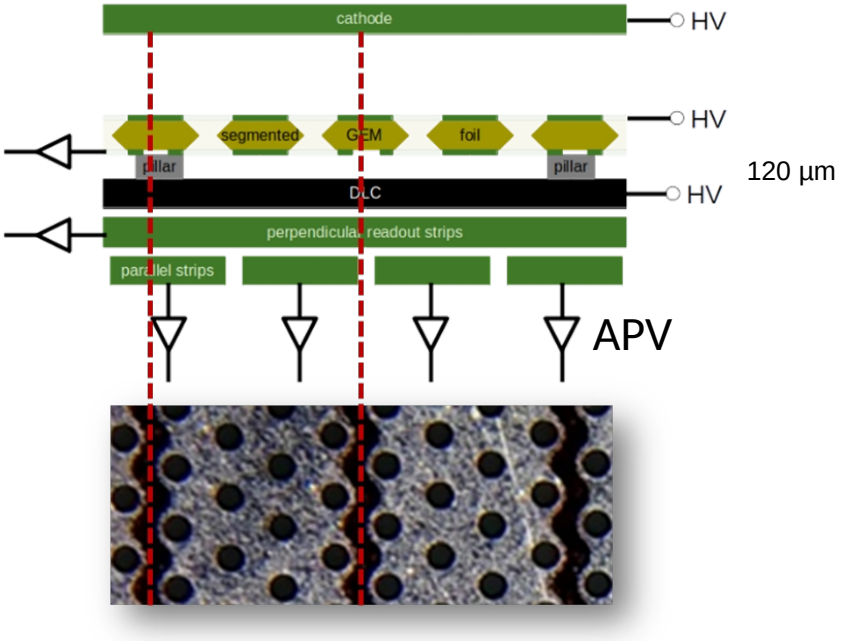
GEM Strip-Readout (at the Mesh Location)

- use of a segmented GEM foil instead of the mesh
  - **here: strips on lower side of the foil**

- the segmented GEM foil is mounted on top of the pillars (120 µm)

- **two amplification steps**:
  both: GEM + ANODE
  can be opeated at relatively low voltages

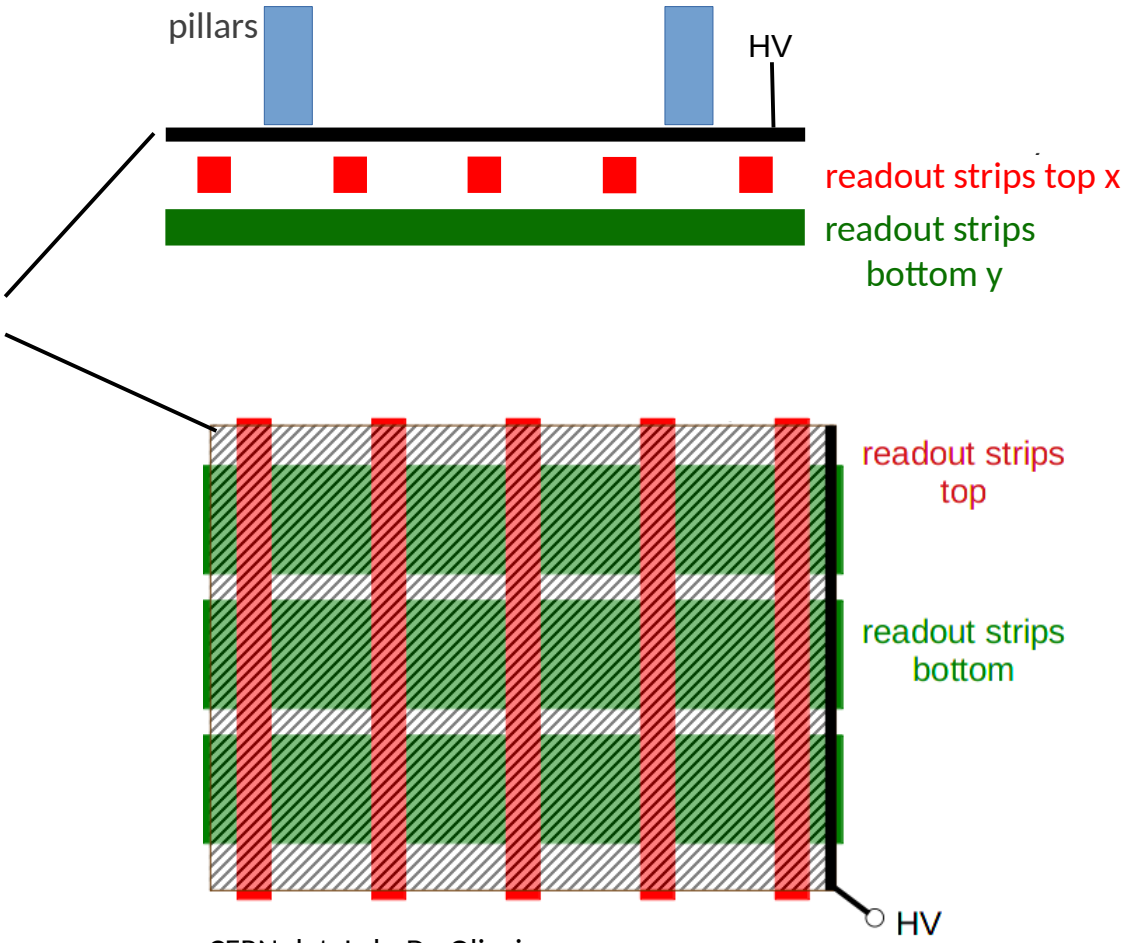
- readout using **APV**s:
  on GEM strips and ANODE strips



2D DLC Micromegas Anode
(DLC v1: 10 x 10 cm²)

- **Resistive Anode Layer:**
  diamond like carbon (**DLC**)
  120 µm pillars on top

- **2** perpendicular
  readout strip layers:
  - 360 readout strips
  - 250 µm pitch
    each

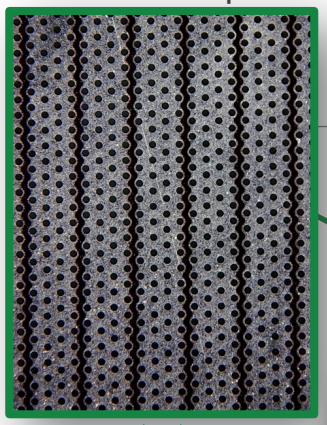


CERN det. Lab: De Oliveira

Segmented GEM Foil 1

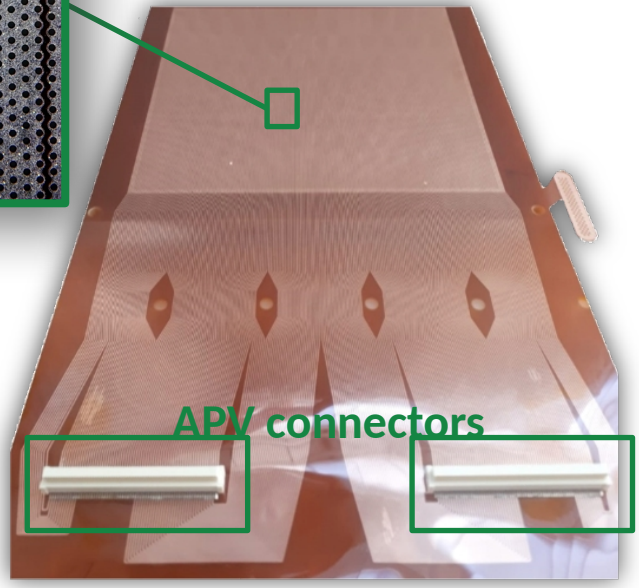
bottom: strips top: one area

Lithographically etched strips

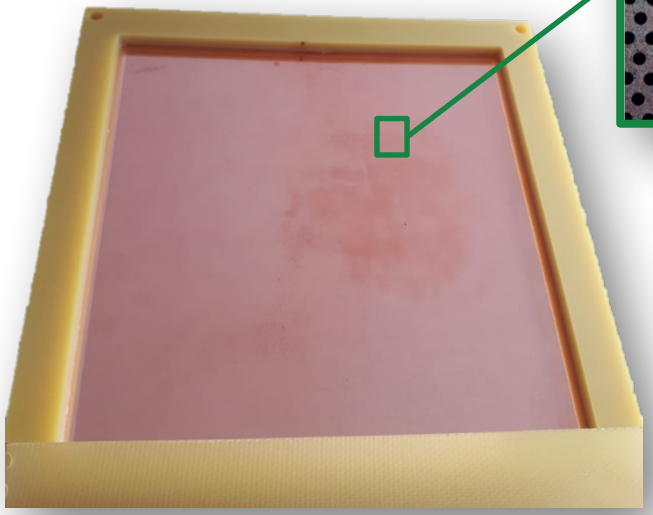


484 μm

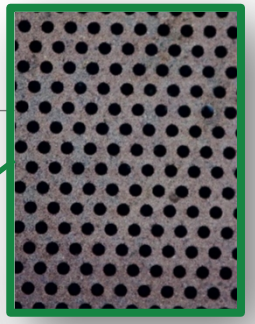
Bottom side (segmented)



Top side (not segmented)



1 area



70 μm holes
140 μm pitch

- Bottom side [segmented]:
  - 212 readout strips
  - Strip pitch: 4 GEM holes ≙ 484 μm
- Top side [not segmented]:
  - standard GEM foil: 10 cm x 10 cm
  - 4 mm thick frame (only on top side)

inverse layout exists: strips on top side, bottom side not segmented
=> works similarly well

MM-GEM

Prototype 1

- Anode DLC:
  - strips top layer: **X**: 0.25 mm pitch
  - strips bottom layer: **Y**: 0.25 mm pitch
- GEM Foil with strips:
  - one side segmented

    Y: 0.484 mm pitch
- idea: **compare performance of y-layers**

  1 detector: GEM strips top
  1 detector: GEM strips bottom

Prototype 2

- Anode DLC:
  - strips top layer: **U**: 0.40 mm pitch +45 deg.
  - strips bottom layer: **V**: 0.40 mm pitch -45 deg.
- GEM Foil with strips:
  - both sides segmented (top and bottom)

    X: 0.484 mm pitch 0 deg.
    Y: 0.484 mm pitch 90 deg.
- **full 4 layer layout**

  1 detector

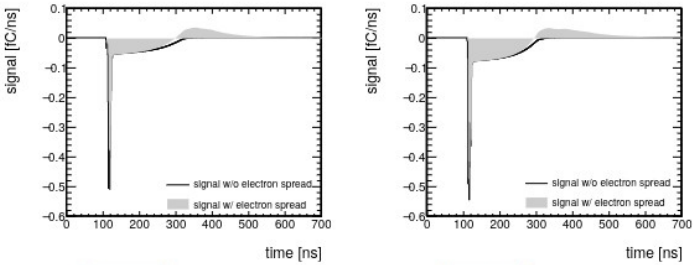
  multiplicities up to 10 clusters / event resolvable

Simulated Signal Creation

SG strips bottom | SG strips top

SG: segmented GEM

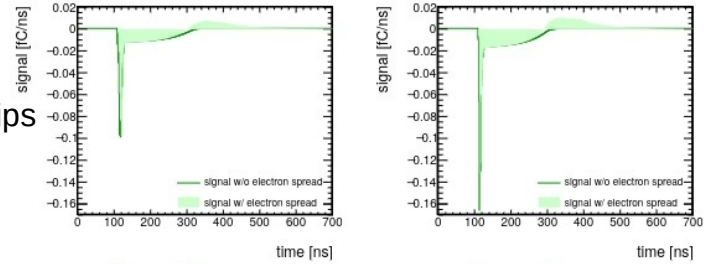
MM top strips



(a) Top Micromegas readout strip. SGR foil segmented on the bottom side.

(b) Top Micromegas readout strip. SGR foil segmented on the top side.

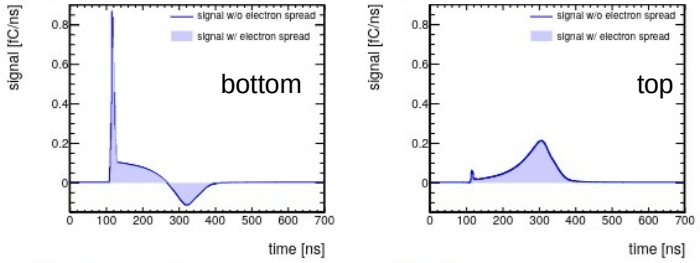
MM bottom strips



(c) Bottom Micromegas readout strip. SGR foil segmented on the bottom side.

(d) Bottom Micromegas readout strip. SGR foil segmented on the top side.

GEM strips



(e) GEM strip on the bottom side. SGR foil segmented on the bottom side.

(f) GEM strip on the top side. SGR foil segmented on the top side.

simulated signals:

weighting fields: ANSYS

Shockley-Ramo-theorem

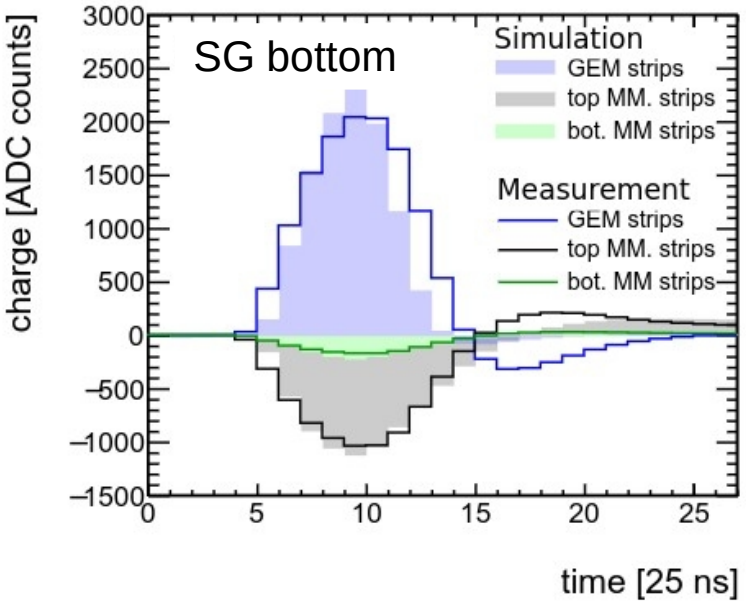
+ charge movement on the resistive anode

bipolar or late signal from ion movement through GEM holes

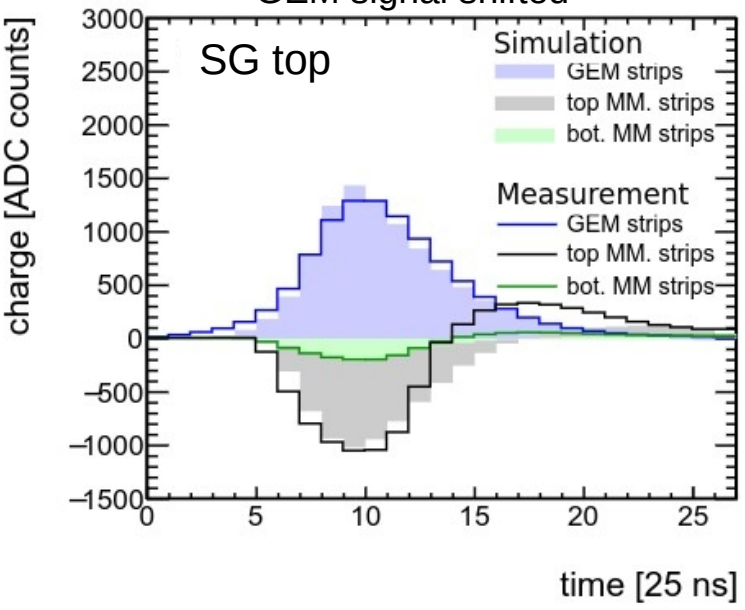
Signal Creation: Comparison Measurement - Simulation

SG: segmented GEM

GEM signal shifted



(c) U_{drift} = 420 V, U_{GEM} = 200 V, U_{ampl} = 400 V



(d) U_{drift} = 420 V, U_{GEM} = 200 V, U_{ampl} = 430 V

measured signal shape and simulation are in good agreement

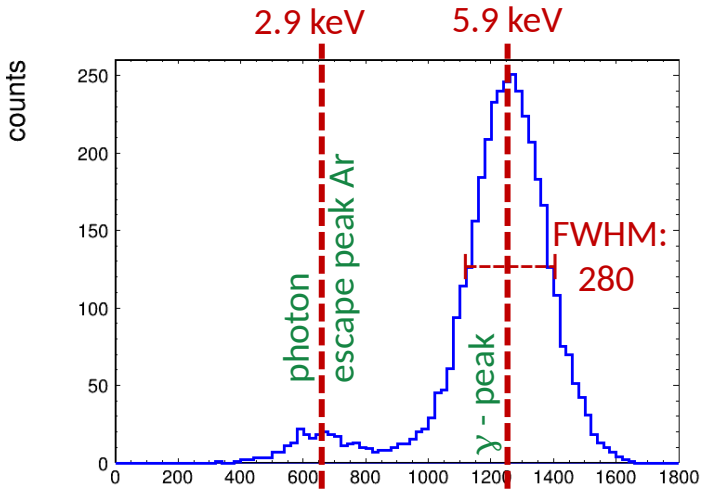
FE55: Energy Resolution

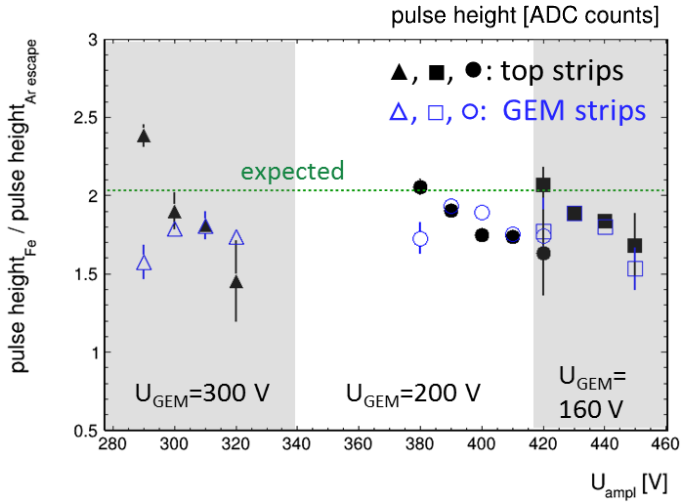
- investigation of the pulse height using Fe55
- two peaks:
  - peak at 5.9 keV: γ of Fe55
  - peak at 2.9 keV: K_α photon (Ar)

  $\Rightarrow$ expected ratio: $\frac{5.9\ keV}{2.9\ keV} = 2.03$
- reconstructed ratio close to 2.03
  (top – , and GEM – readout strips)

$$\frac{\Delta E}{E}(Fe\,55) = 22.2\,\%(FWHM)$$

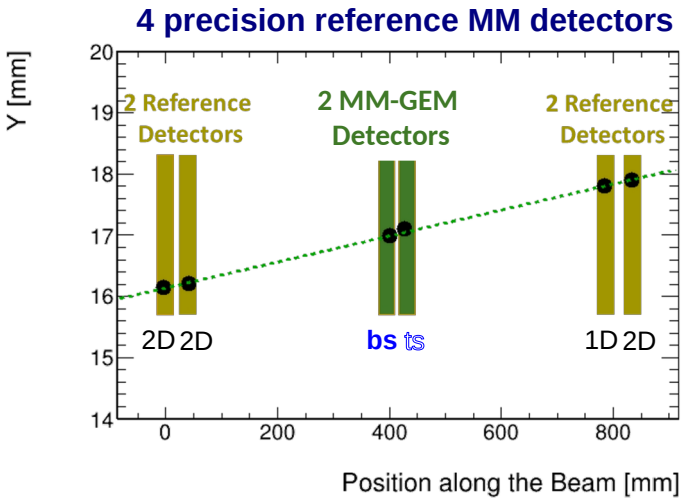
Good energy resolution: 22%



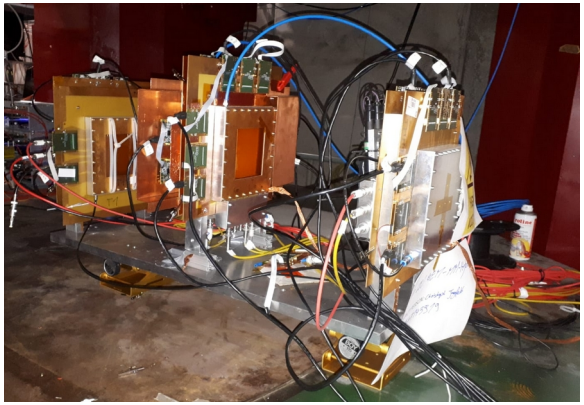


Beam Times: H4 October / November 2021 PT1
H4 September 2023 PT2

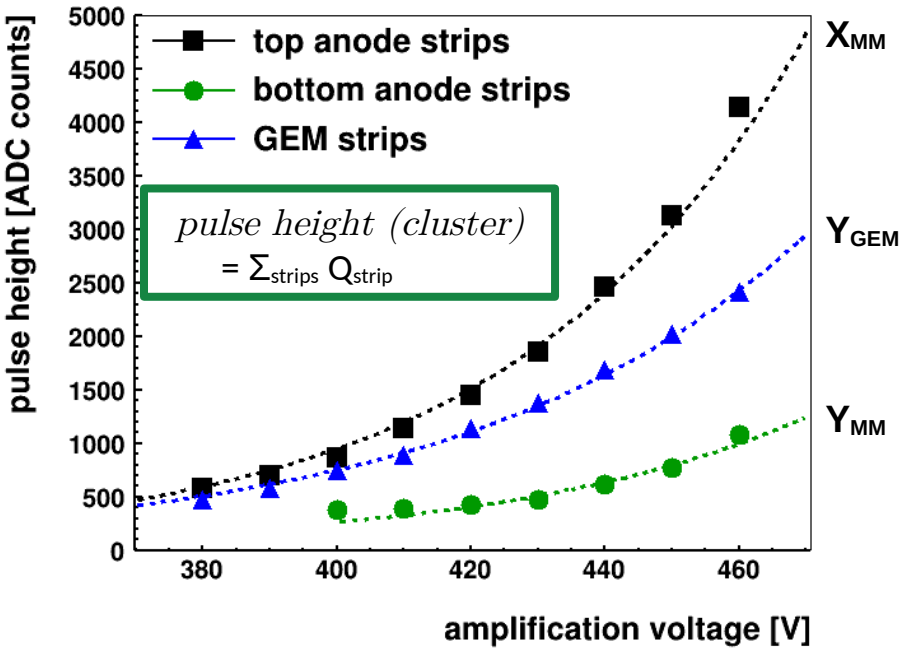
- investigated MM_GEM hybrids:
  - 1. GEM strips on **bottom side**
  - 2. GEM strips on top side

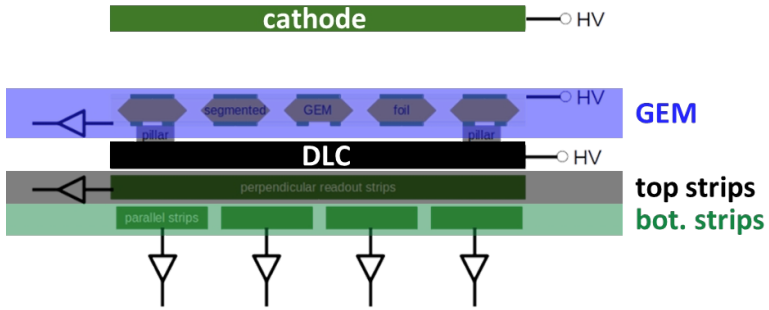


- determination of **detector efficiency** and **resolution** and **pulse height** for:
  - different voltage combinations
  - different inclination angles



Muons: Pulse Height Comparison GEM-MM

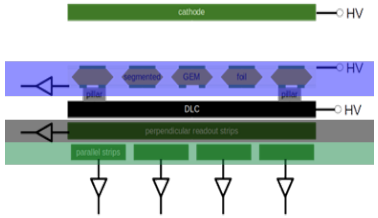




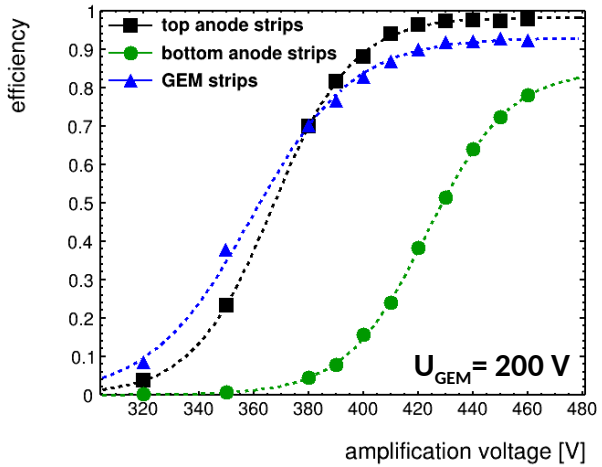
- similar pulse height for **top readout** strips and **GEM strips**
  - Pulse height $_{top}$ ≈ 1.5 pulse height $_{GEM}$
- Pulse height $_{top}$ ≈ 4-5 pulse height $_{bot}$
  (Optimized anode design exists with strip pitch 0.4 mm, not shown here)

⇒ **2D particle reconstruction is well possible**

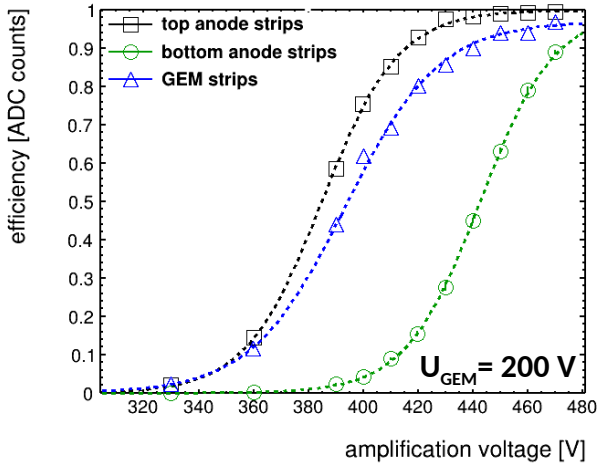
Efficiency Determination (perpendicular µ-track)



Det1: GEM strips on bottom side



Det2: GEM strips on top side



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

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

⇒ similar 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

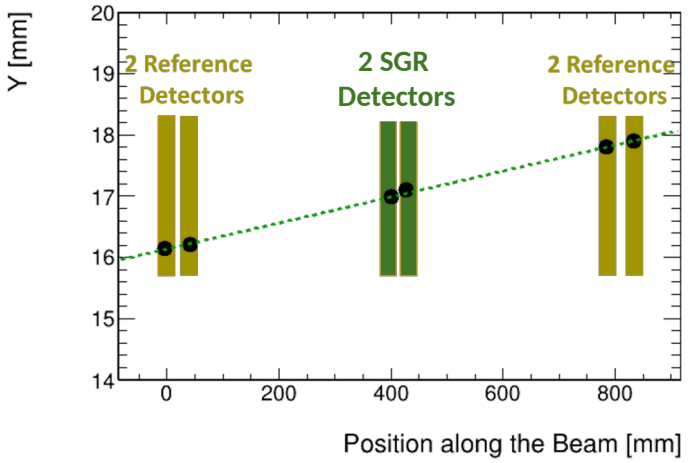
Spatial Resolution Determination

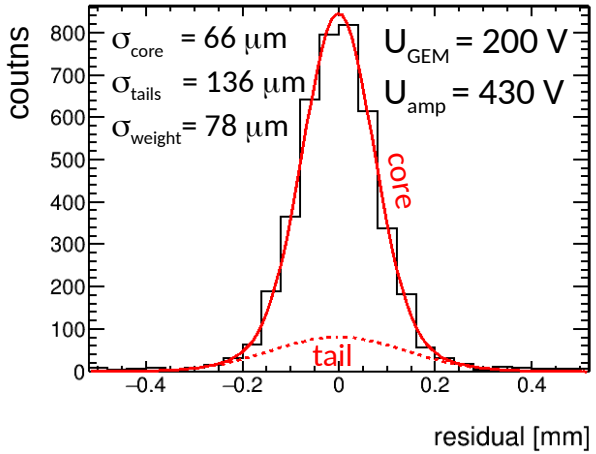
- residual: $\boldsymbol{residual = x_{track} - x_{measured}}$
- resolution determination via double gaussian fit:

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

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

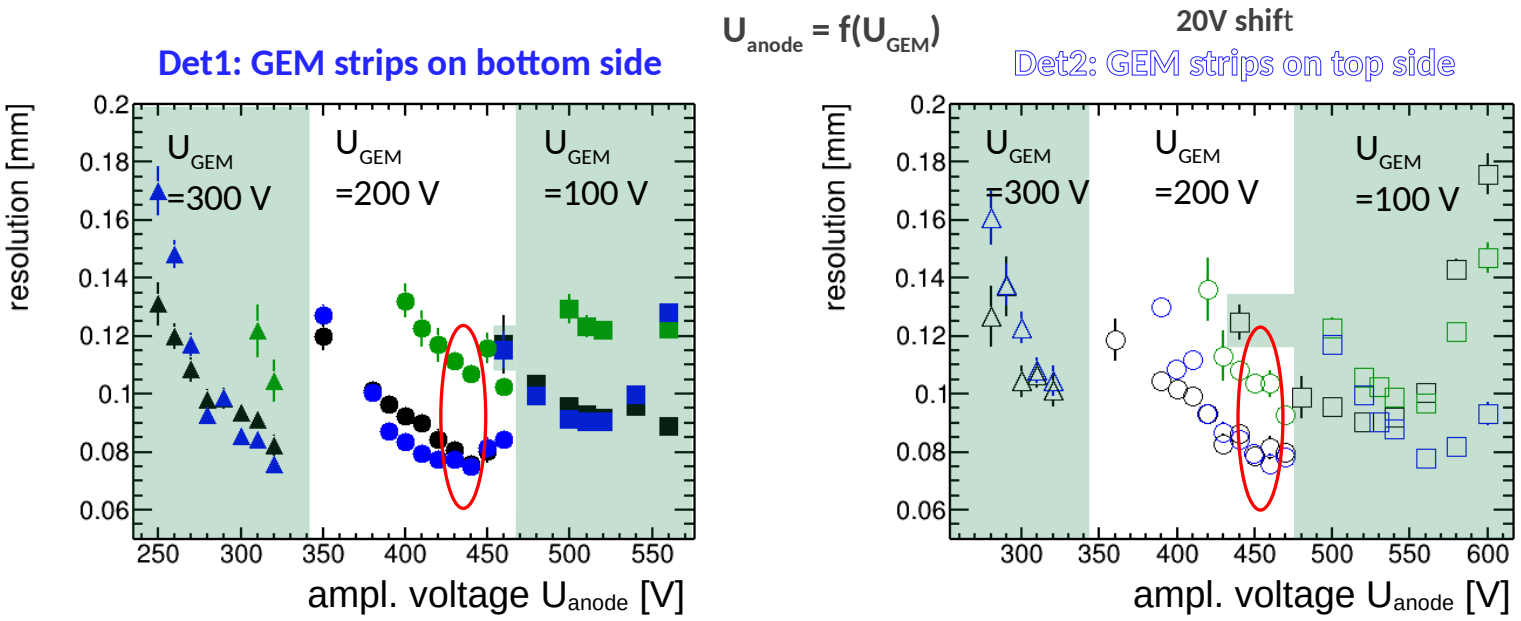
- track accuracy < σ_{det}



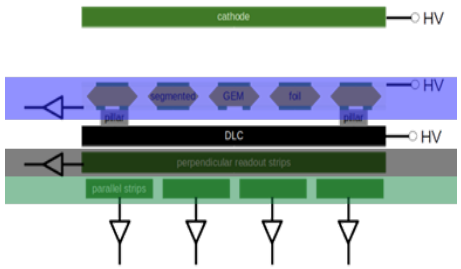


Spatial Resolution (perpendicular µ-track)

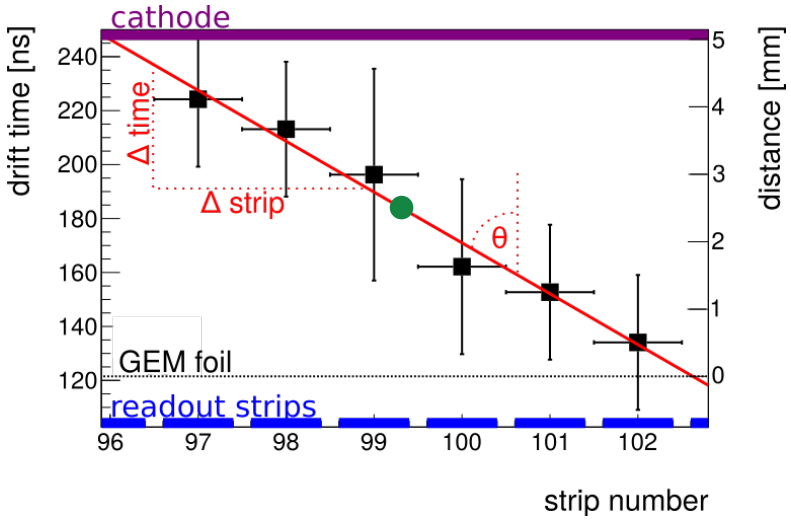
$U_{anode} = f(U_{GEM})$

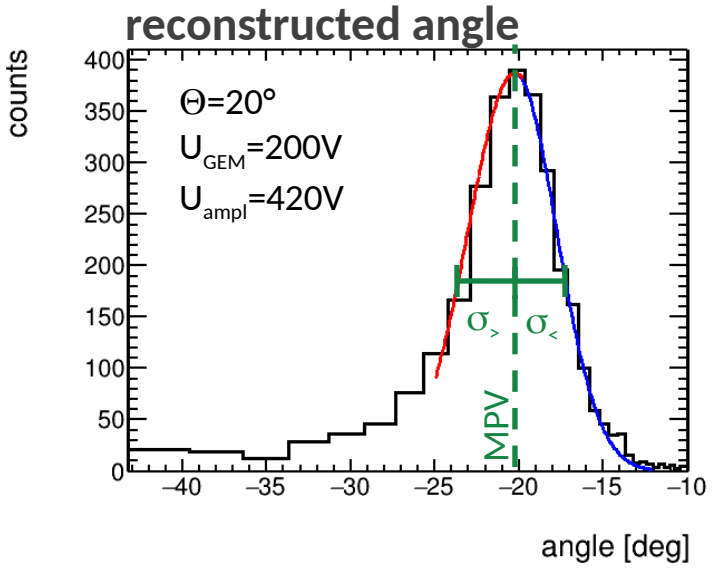


- Best resolution for U_{GEM} = 200 V, U_{anode} = 440 V
  - Res_{GEM} ≈ 80 µm
  - $Res_{anode\ top}$ ≈ 80 µm
  - $Res_{anode\ bot}$ ≈ 100 µm (due to low pulse height)
- Discrepancy in the resolution between **top anode strips** and **GEM strips** (charge movement on the DLC layer)
  - ⇒ improved by new design



µTPC: Principle (20°)





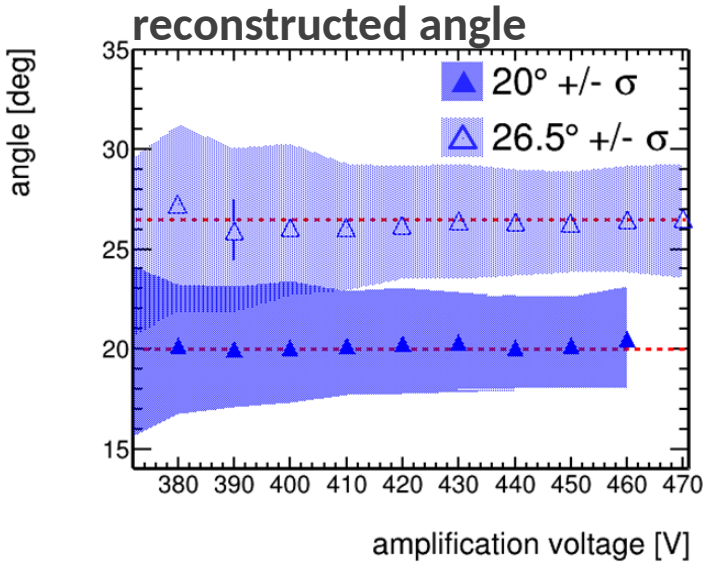
- determination of angle and position using the strip times

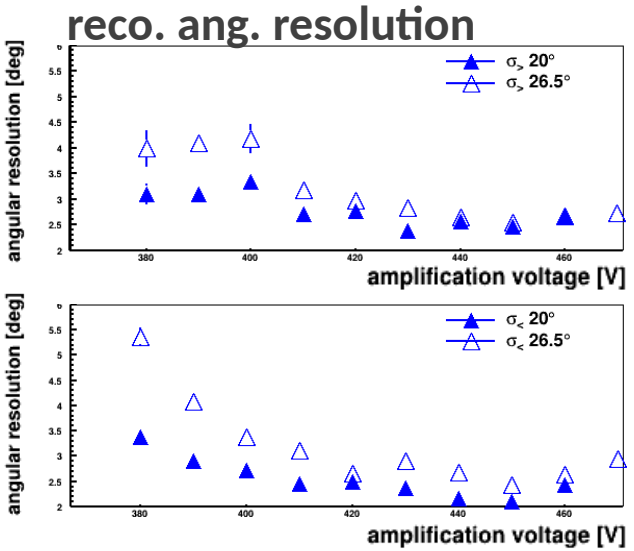
$$angle = 90^0 - atan\left(\frac{t * v_{drift}}{N_{strips} * pitch}\right)$$

(position: µTPC track at $t_{1/2}$)

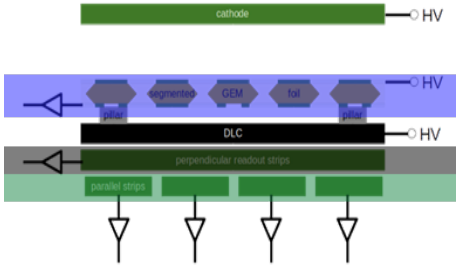
Angular Resolution µTPC (20° and 26.5°)

U_{GEM} = 200V



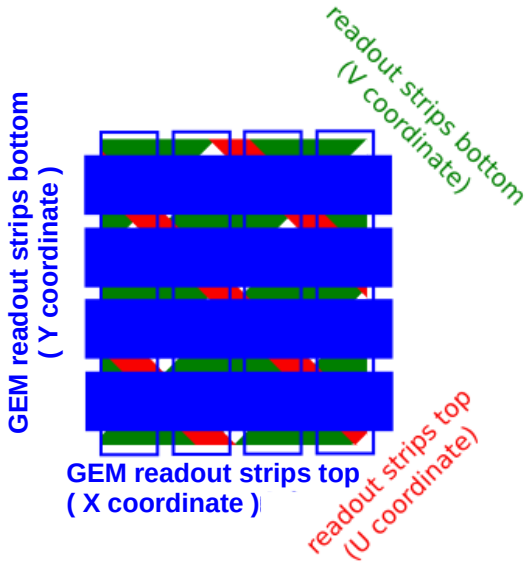


- incident angle 26.5° and 20°
- angular resolution:
  - ≈ 2° for Θ = 20°
  - ≈ 3° for Θ = 26.5°



Prototype 2: X/Y/U/V 4 layer detector

- Anode DLC:
  - U strips: 0.4 mm pitch
  - V strips: 0.4 mm pitch
- GEM Foil:
  - X strips:
    - top side
    - 0.484 mm pitch (nominal)
  - Y strips:
    - bottom side
    - 0.484 mm pitch (nominal)



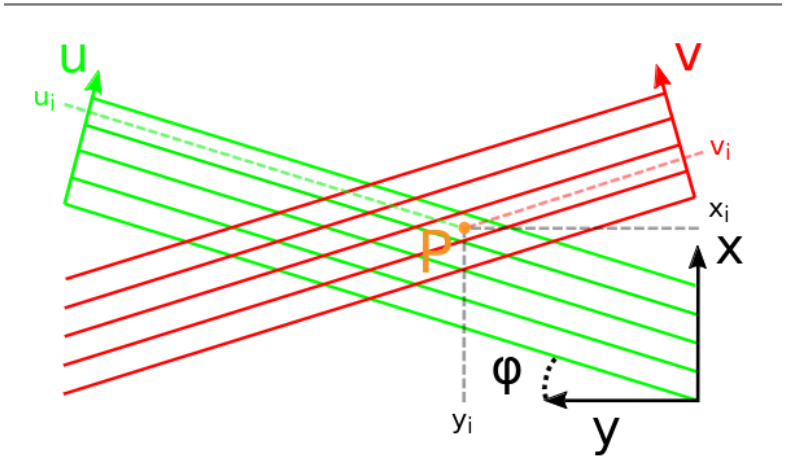
UV strips: position reconstruction

- convert U and V coordinate
  to X and Y position

$$x = \frac{u + v}{2 \cos \varphi}$$

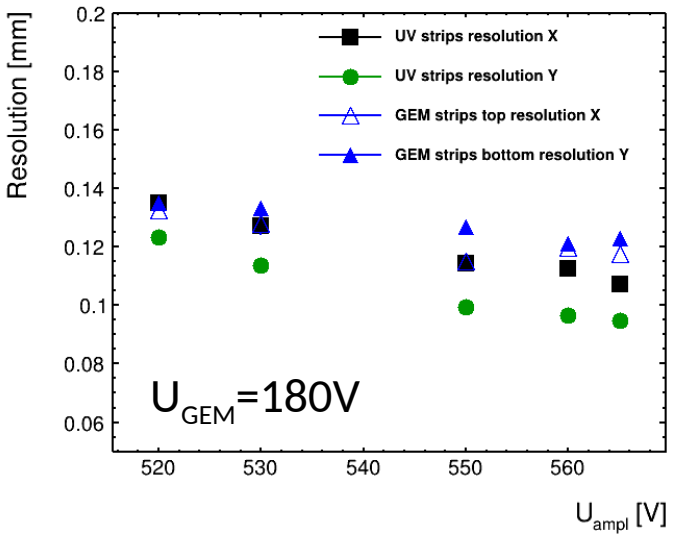
$$y = \frac{u - v}{2 \sin \varphi}$$

with φ = 45°

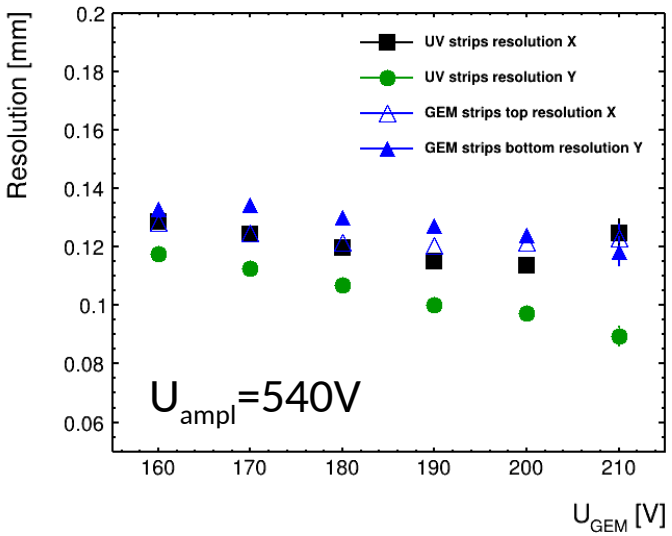


Spatial Resolution (perpendicular µ-track)

Amplification scan

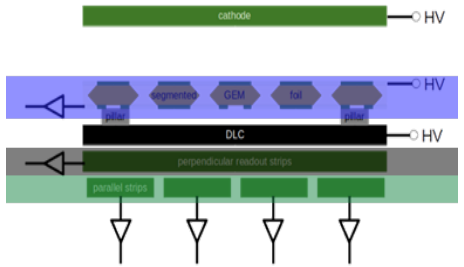


GEM scan

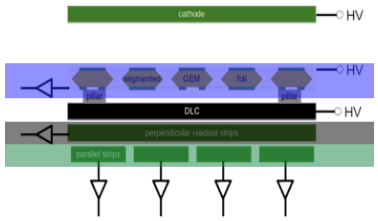


- spatial resolution ≤ 120 µm

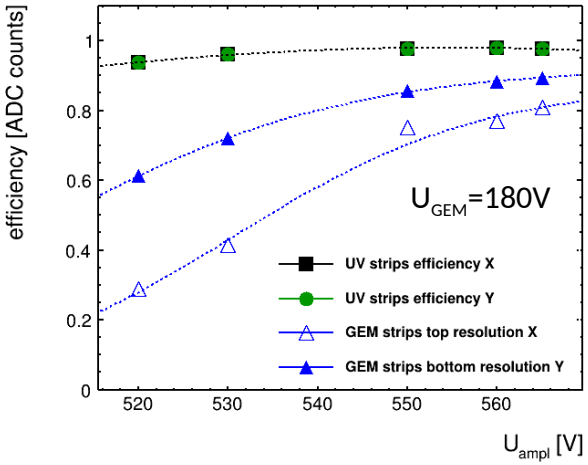
$U_{anode} \Leftrightarrow U_{ampl}$



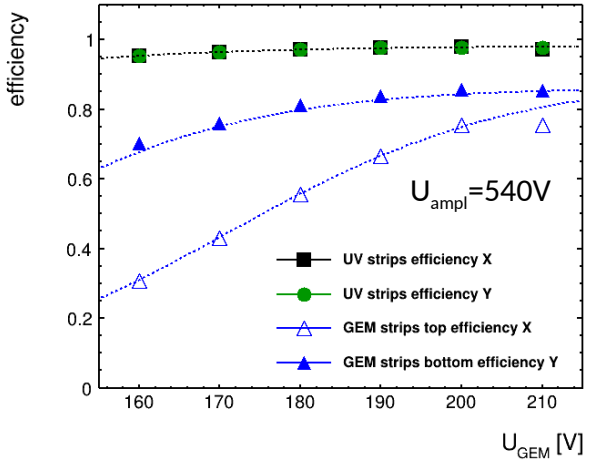
Efficiency Determination (perpendicular µ-track)



Amplification scan



GEM scan



- efficient event:

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

⇒ efficiency > 90% for U/V readout strips => **ok !**

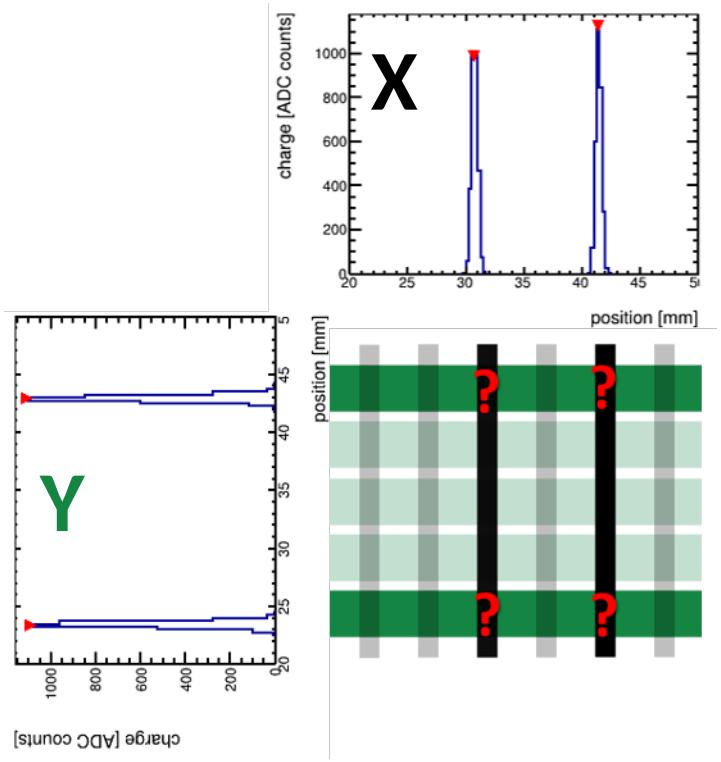
⇒ efficiency < 90% for GEM strips => **detector not yet at the correct working point**

Summary: MM-GEM Prototype 1 + 2

- segmented GEM MM hybrids are working, multiple clusters per event are resolvable
- GEM MM hybrid 1: spatial resolution for perpendicular tracks
  - 2D tracking with $\sigma_x \approx 80\ \mu m = \sigma_{y\text{-}GEM}$ possible
- spatial resolution for inclined tracks
  - μTPC possible on anode strips and GEM strips
  - angle reconstruction : $\sigma_{angle} = 2°\text{-}3°$
- Y_{MM} || Y_{GEM}
  - 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)
- GEM MM hybrid 2: X/Y/U/V detector works, but needs optimization
  - MM: spatial resolution < 100 μm, efficiency > 90 % ok
  - GEM: spatial resolution $\leq$ 120 μm, efficiency < 90% optimization needed

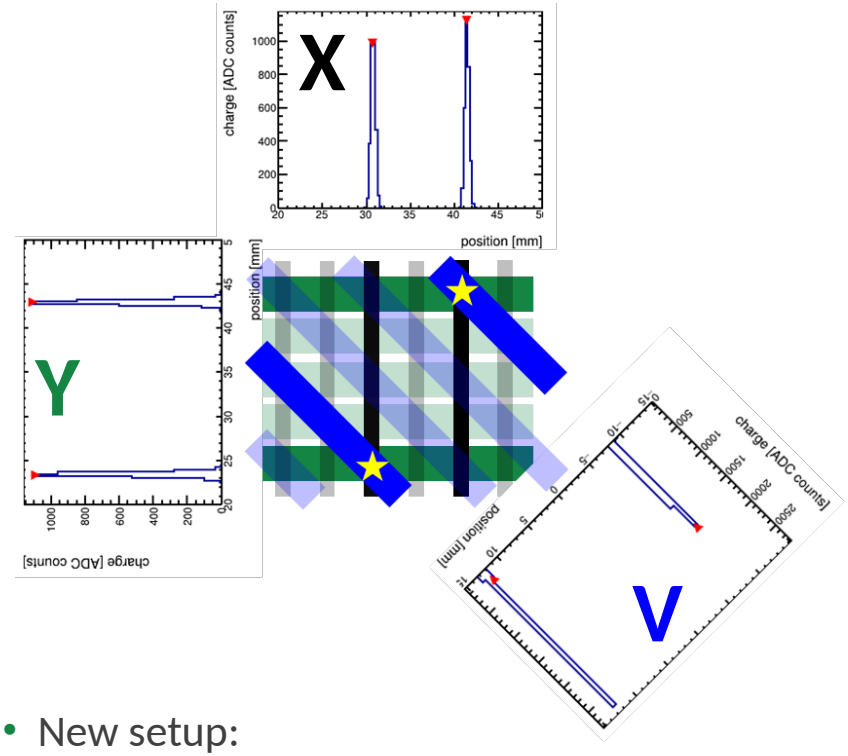
Backup

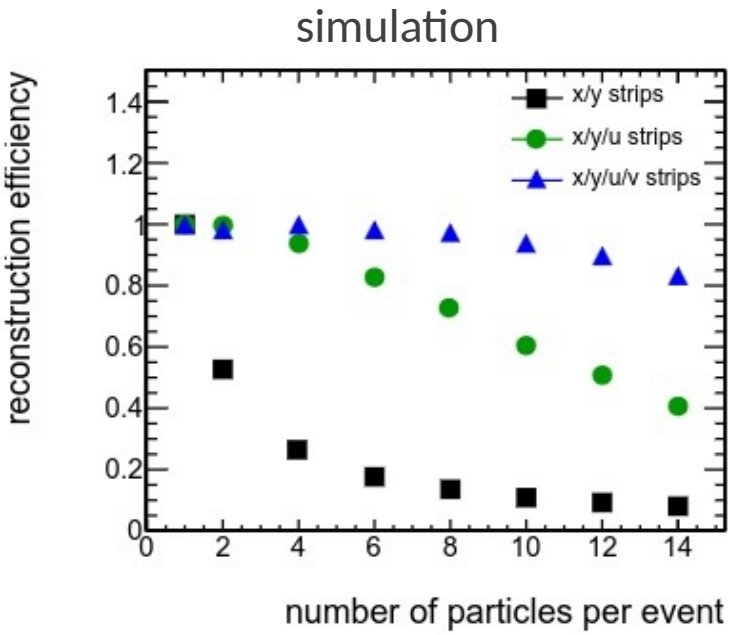
X/Y Strips : Cluster Limitation



- Two particles at the same time
  - ⇒ Two signatures in each detector layer (**X** / **Y**)
  - ⇒ 1D reconstruction works
  - ⇒ 2D reconstruction problematic
- ⇒ Solution: 3rd (and 4th) layer of readout strips turned by ±45 deg

X/Y/V Strips : Multiple Particles



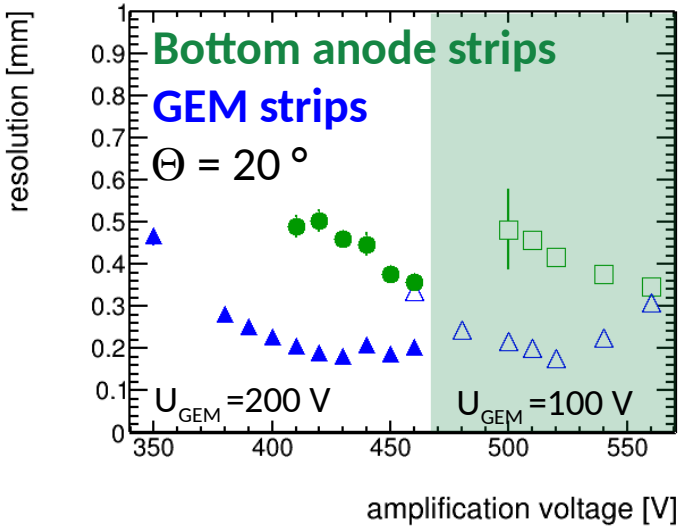


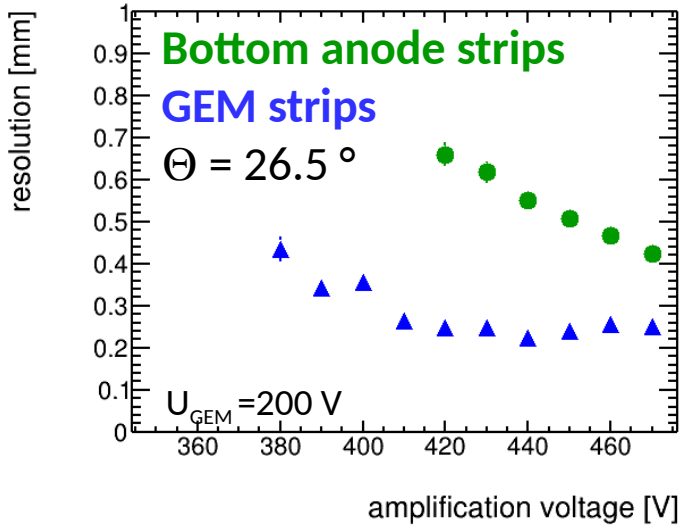
- New setup:
  - **X** / **Y** coordinate given by readout strips at the anode
  - **V** coordinate given by readout strips at the mesh location
- Unique 2D cluster combination possible

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

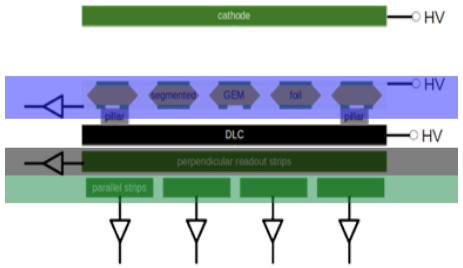
⇒ Further improvement by using charge and time information

Spatial Resolution µTPC (20° and 26.5°)

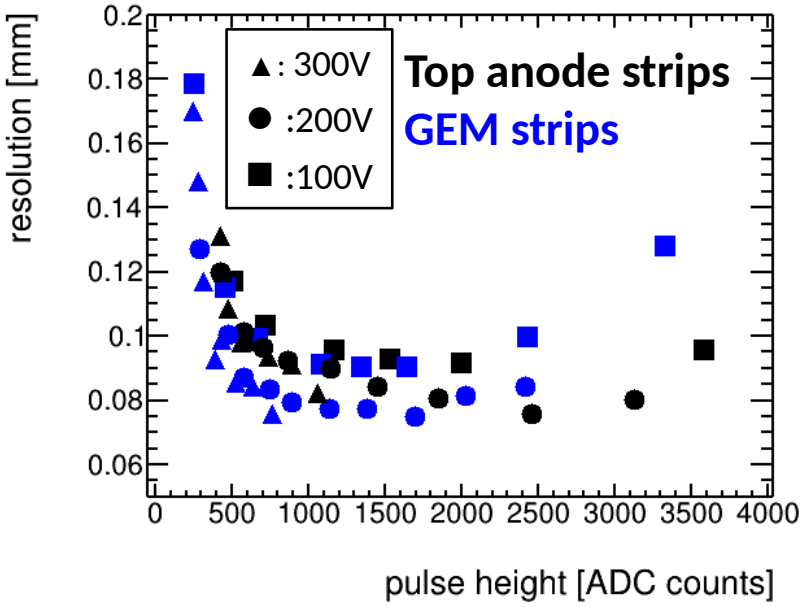


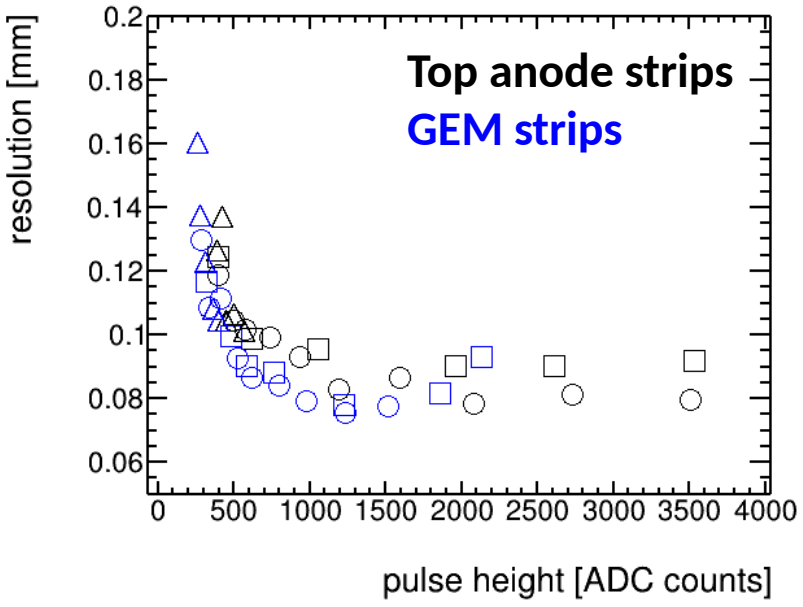


- µTPC position reconstruction works in principle
  - 1 mm efficiency > 90%
  - Better resolution for GEM strips as for bottom anode strips (low pulse height on bottom anode strips)
- charge weighted mean spatial resolution (GEM strips):
  - 20°: resolution ≈ 350 µm
  - 26°: resolution ≈ 450 µm
- 25 ns trigger jitter not corrected (+/- 12.5 ns ≙ 220 µm)



Spatial Resolution (perpendicular µ-track)

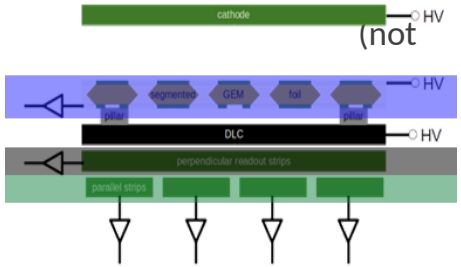




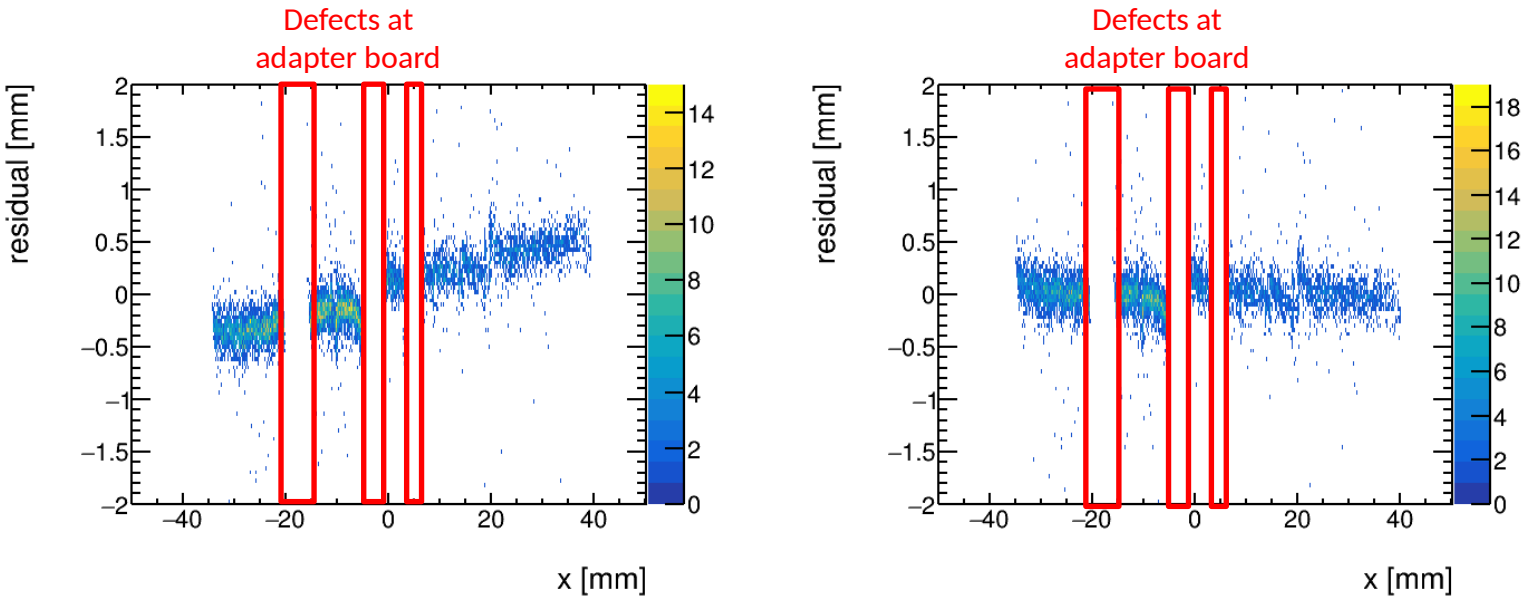
- Resolution depending on pulse height (cluster charge)
- Best Resolution at pulse height ≈ 2000 ADC counts reachable at U_{GEM} = 300V)
- Better transparency for GEM foil with higher U_{GEM}

⇒ Compromise needed

- Better resolution for GEM strips as for anode strips



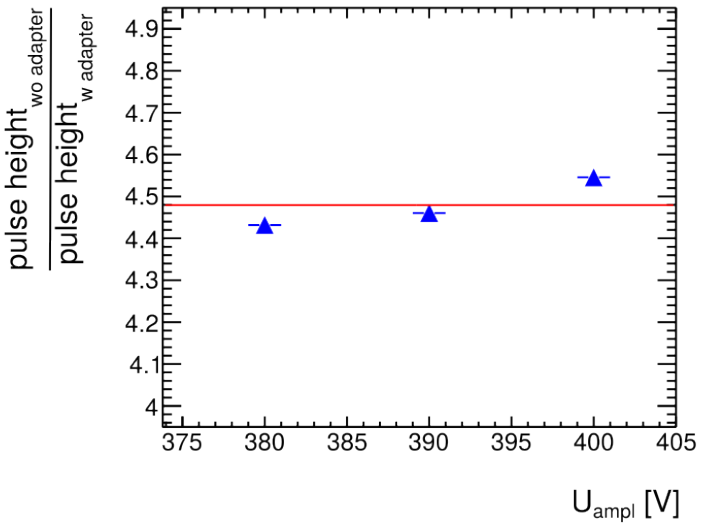
Pitch Reconstruction

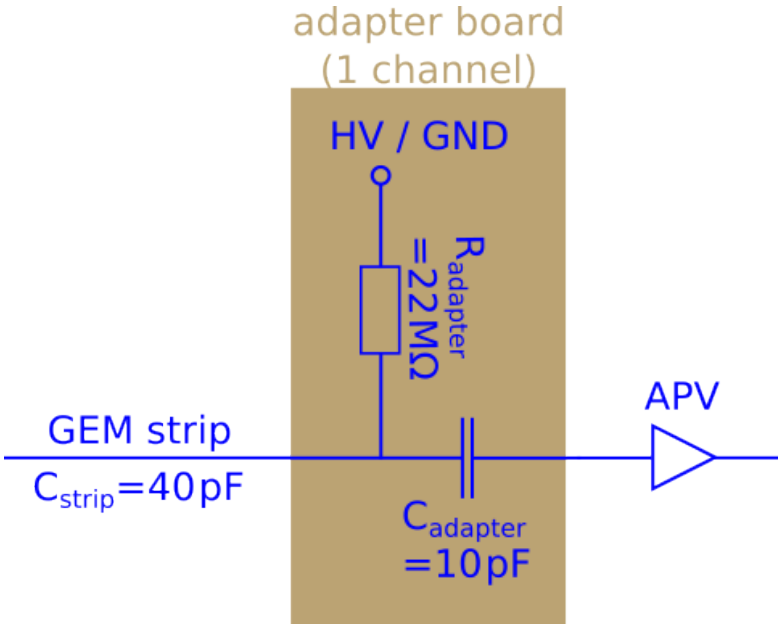


- res x VS x (GEM foil) dependency for nominal pitch 0.484 mm
- correction by pitch adjustment
  - No res x VS x dependency for 0.491 mm pich
  - No res y vs y dependency for 0.486 mm pich

⇒ stretching of the GEM foil enlarges pitch of GEM strips

Adapterboard (GEM foil)





- decoupling of each APV (ground potential) channel via a high pass filter from HV

⇒ pulse height reduction by a factor 4.5