LMU test beam performance of capacitive sharing Micromegas

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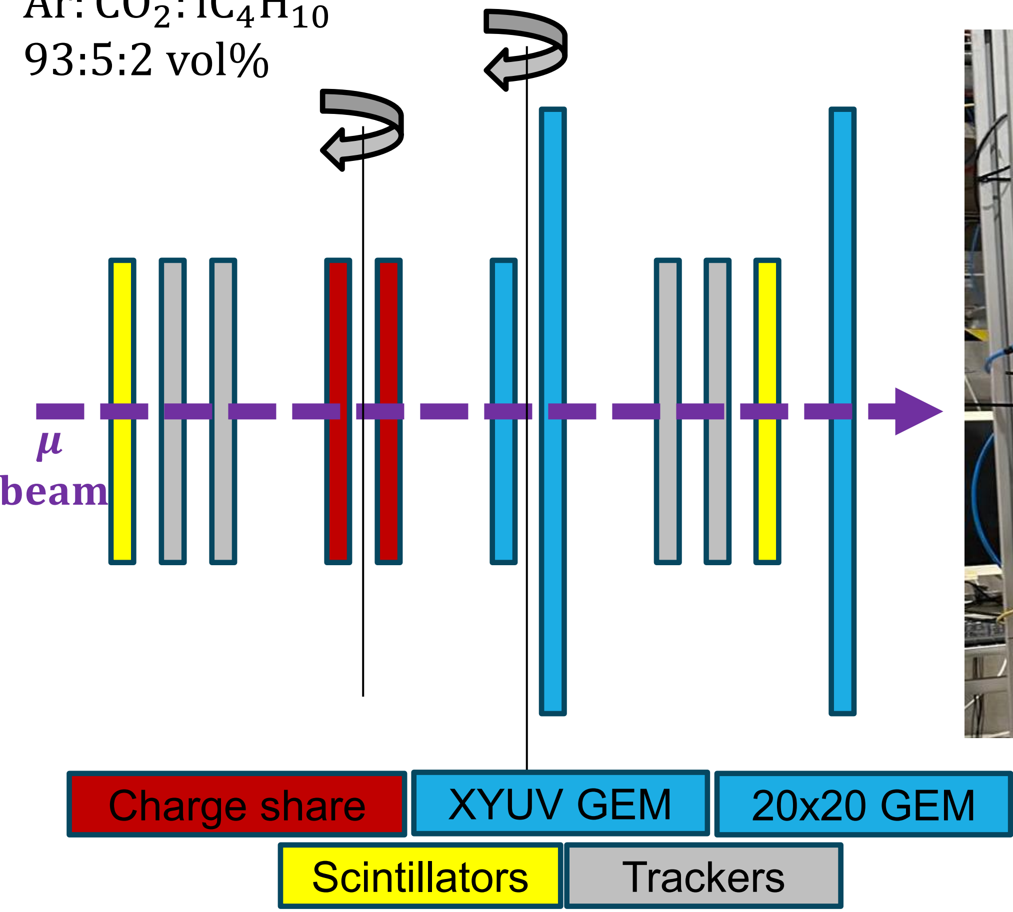
9TH OCTOBER 2025

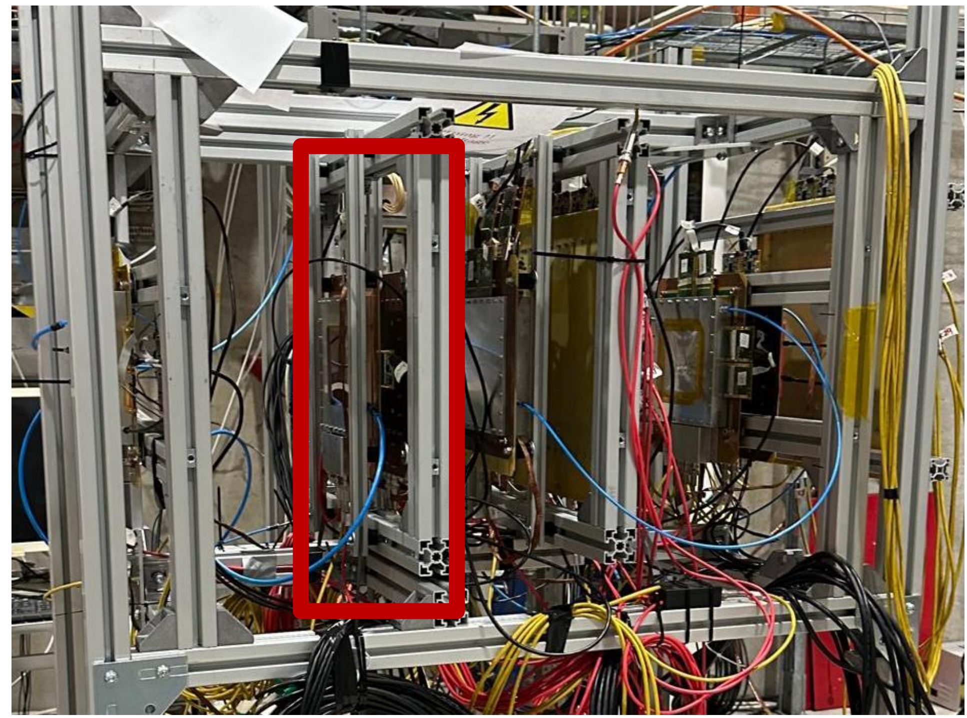
DRD1 COLLABORATION MEETING

Test-beam 2025 setup

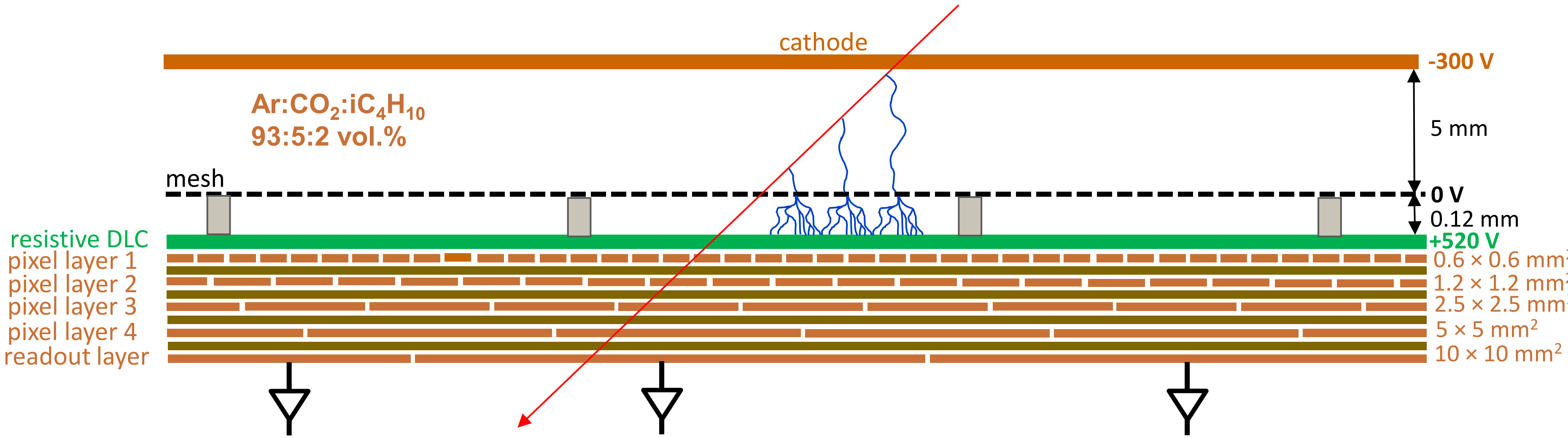
$Ar:CO_2:iC_4H_{10}$
93:5:2 vol%



120 GeV muons from CERN SPS



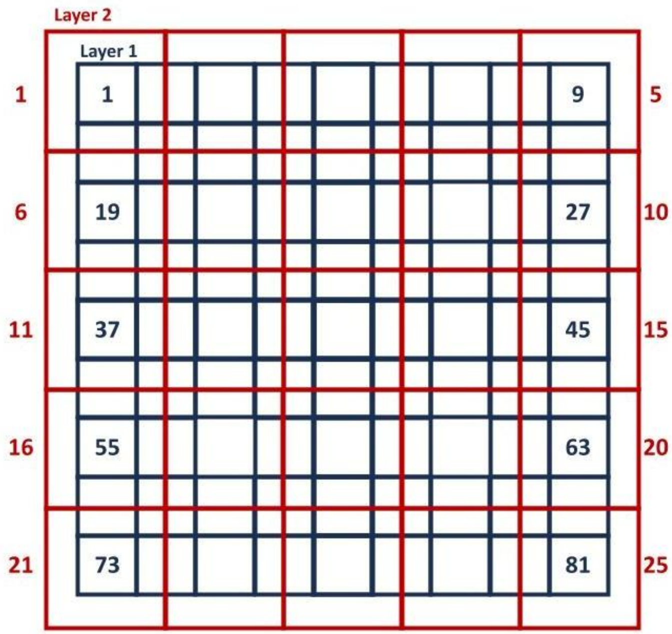
5 Layer Charge Spreading Anode

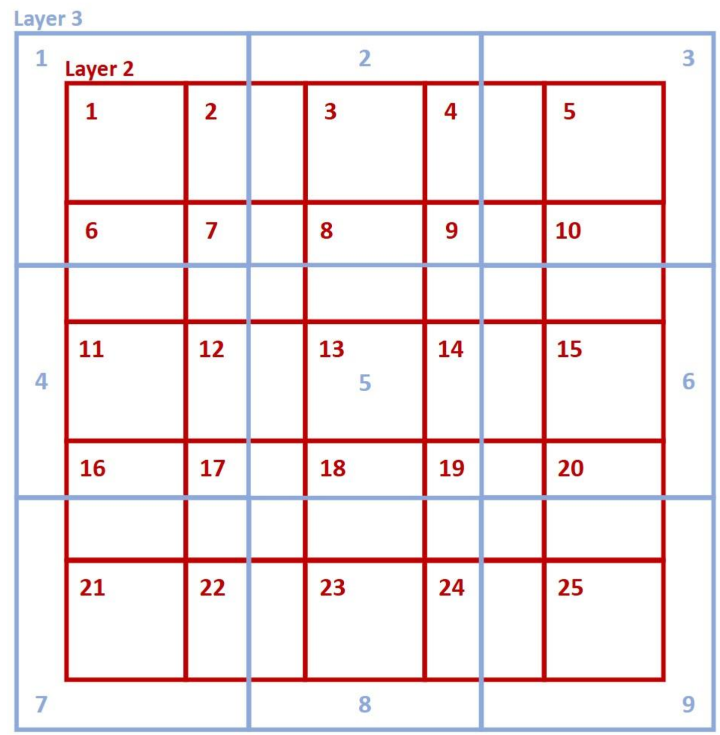


Basic Idea:

- Prototype 1: Reduce the number of readout channels strongly via charge sharing on several stacked readout layers (developed by Rui in 2022)
- Prototype 2: Reduce it further by a pixel-strip hybrid readout structure (developed by Rui in 2024)

Charge Sharing Concept: Prototype 1





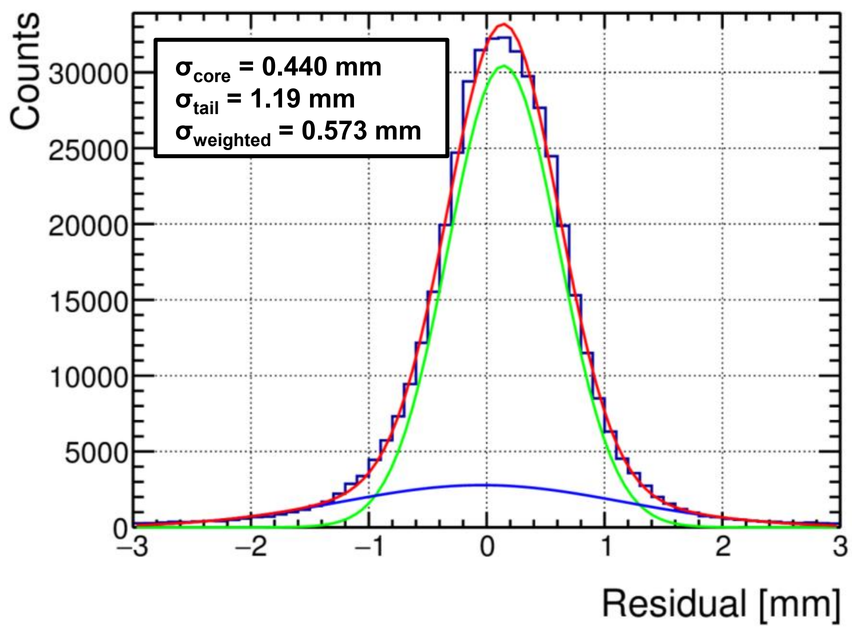
Concept:

- Pixels of layer n are double in length and width to the pixels in layer n - 1
- Pixels of layer n start in the center of the pixels in layer n - 1
- Position is contained in the pulse height distribution of the neighbouring pixels

5 layer PAD detector (PAD5): Spatial Resolution

- Five stacked layers with pixel pitch increasing from 0.625 mm, 1.25 mm, 2.5 mm, 5 mm to 10 mm
- Total readout channels reduced from 25 k to just 100 channels; 1 APV25 hybrid used to read the complete detector
- Residual = $pos_{track} - pos_{pixel\_det}$
- Resolution ($\sigma_{weighted}$) determined by a double Gaussian fit:

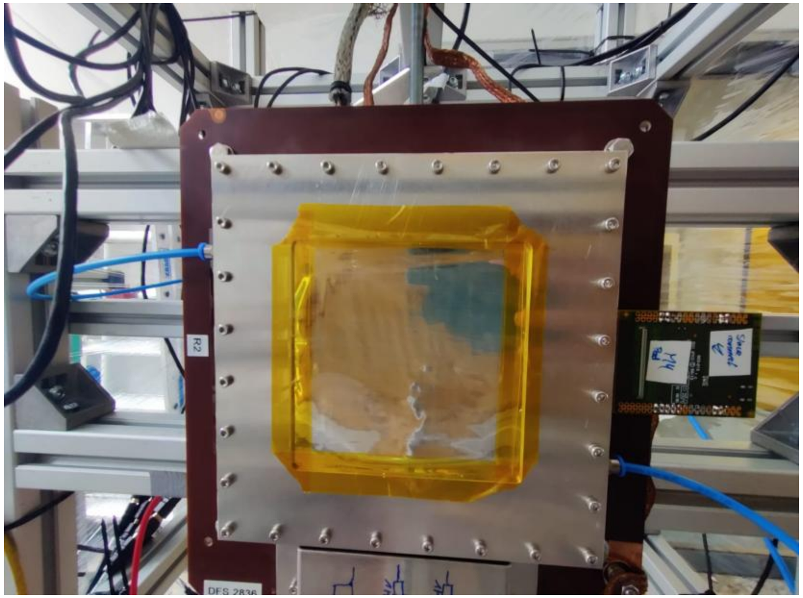
$$\sigma_{weighted} = \frac{\sigma_{core} \times a \int e^{\frac{(x-b)^2}{2\sigma_{core}^2}} + \sigma_{tail} \times c \int e^{\frac{(x-d)^2}{2\sigma_{tail}^2}}}{a \int e^{\frac{(x-b)^2}{2\sigma_{core}^2}} + c \int e^{\frac{(x-d)^2}{2\sigma_{tail}^2}}}$$

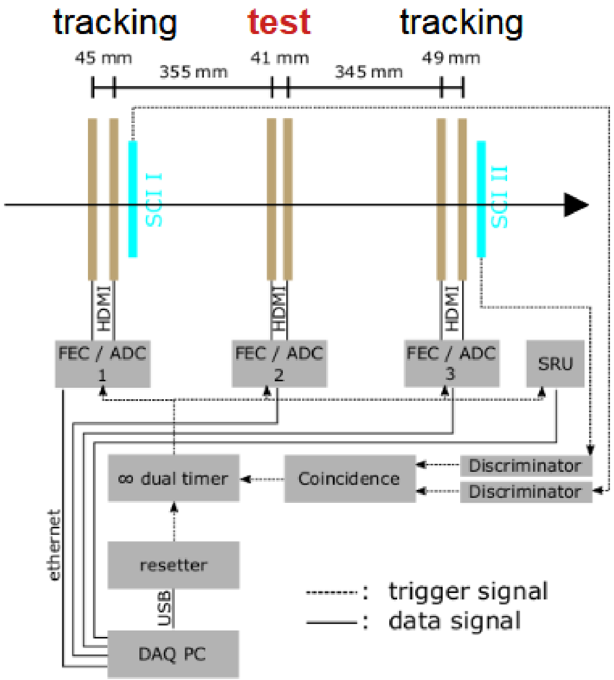


Accounting for track error σ_{track} O(30 μm) $\approx 0.439\ mm$

Resolution much better than $\frac{10\ mm}{\sqrt{12}} \approx 2.89\ mm$, but long tails observed

SPS Test Beam 2023 Setup

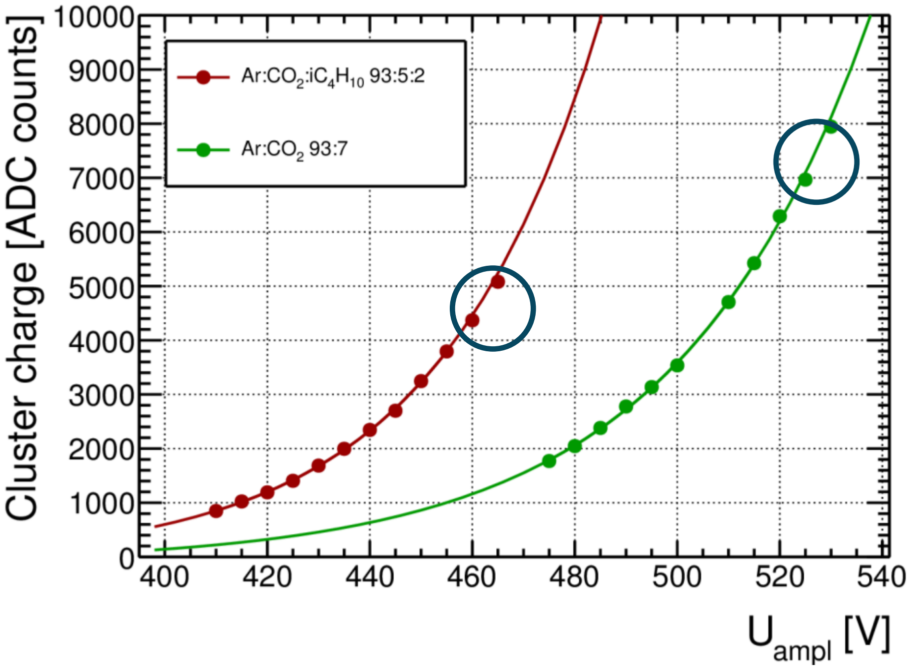


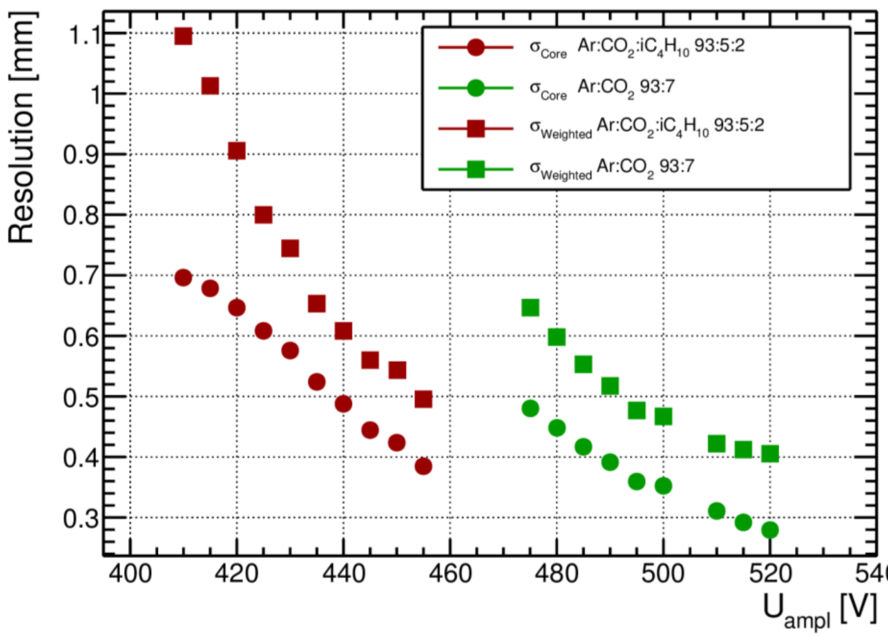


120 GeV muons
H4 beamline
Cern SPS

- Gas used: Ar:CO_2 in 93:7 vol%
- 120 GeV muons from the H4 beamline from SPS 2023
- 4 reference Micromegas detectors used to build tracks
- Scintillators in coincidence used for triggering events

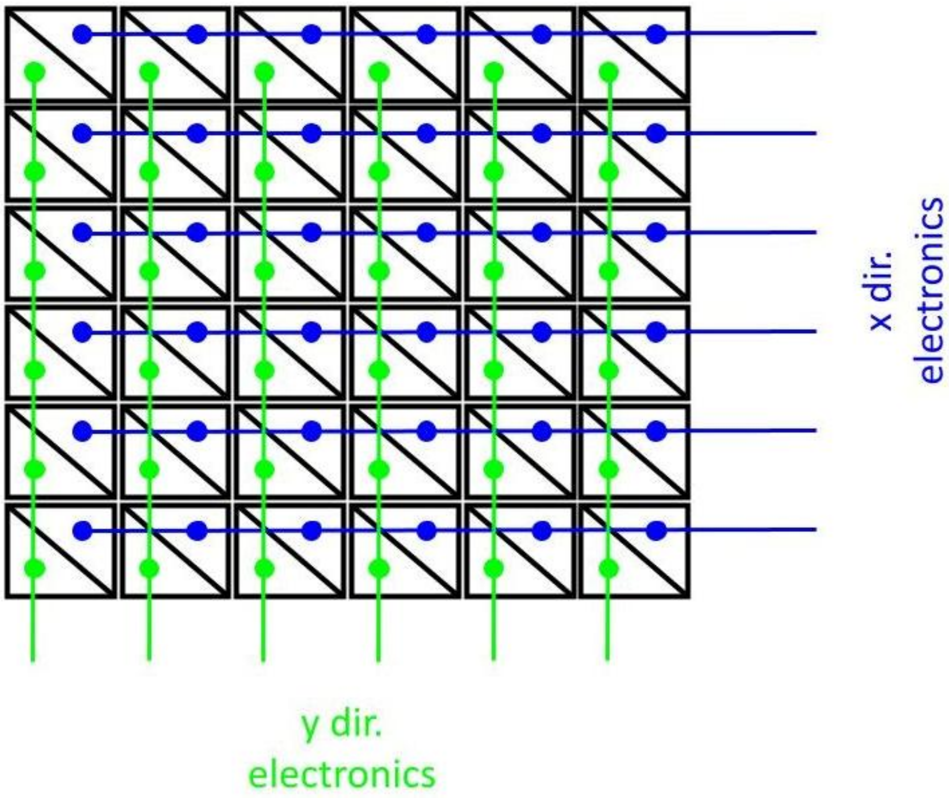
5 layer PAD detector: Gas studies





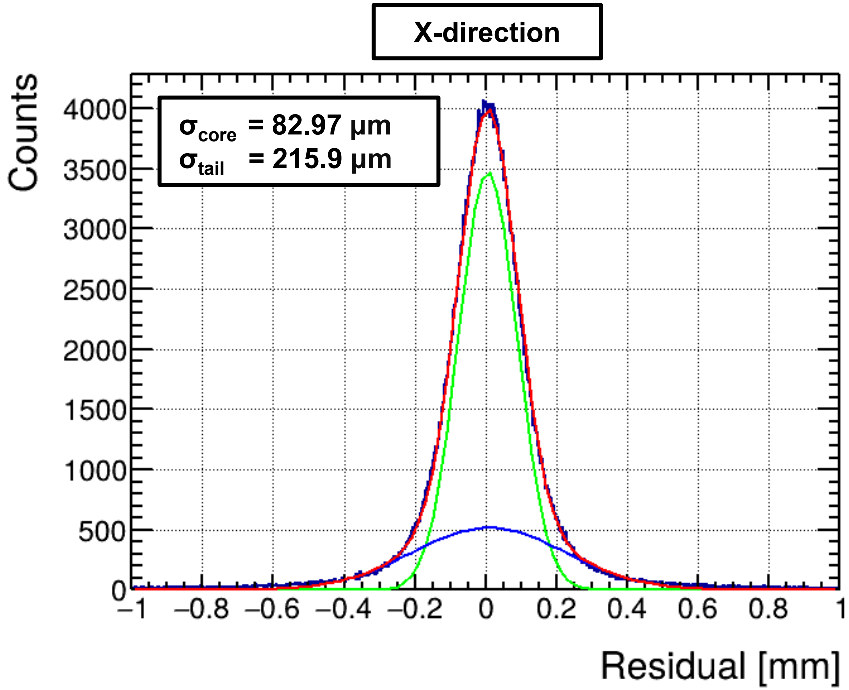
- Comparison of the testbeam 2023 and testbeam 2025 with different gas mixtures
- Double exponential behaviour seen for both gas mixtures
- Ar:CO_2:iC_4H_{10} already heavily saturating due to electronics at 460 V
- Ar:CO_2 sees better resolutions at the same cluster charges (under investigation)

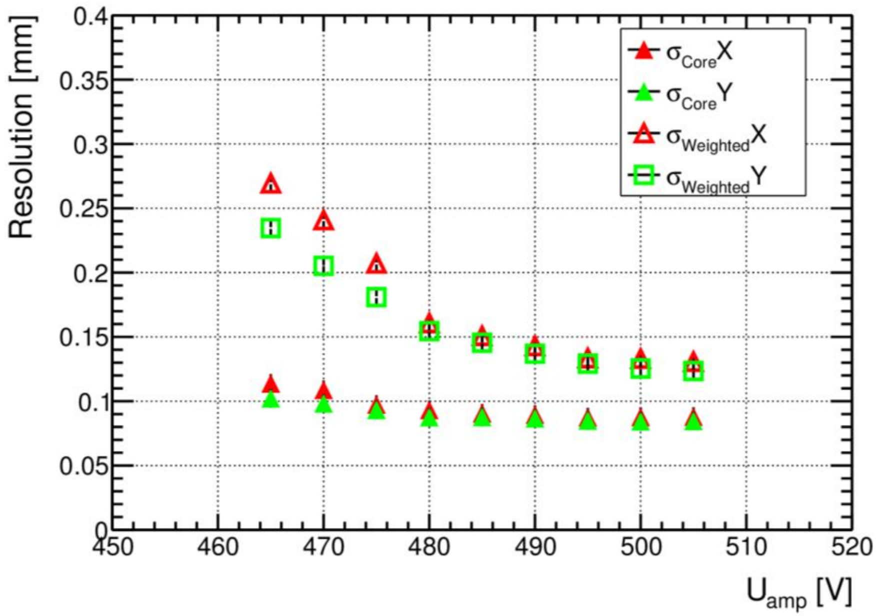
3 layer Charge Spreading Anode with Strip-like Readout (PADH)



- 3 layer pixel detector with 0.3 mm, 0.6 mm and 1.2 mm pixel pitch
- readout layer **pixels subdivided into 2 halves with interconnected rows and columns** readout by a single channel
- For standard pixels of 1.2 mm pitch, total number of readout channels = 85 × 85 = **7225 channels**
- For strip-like readout, total number of readout channels = 85 + 85 = **170 channels**

PADH: Spatial Resolution

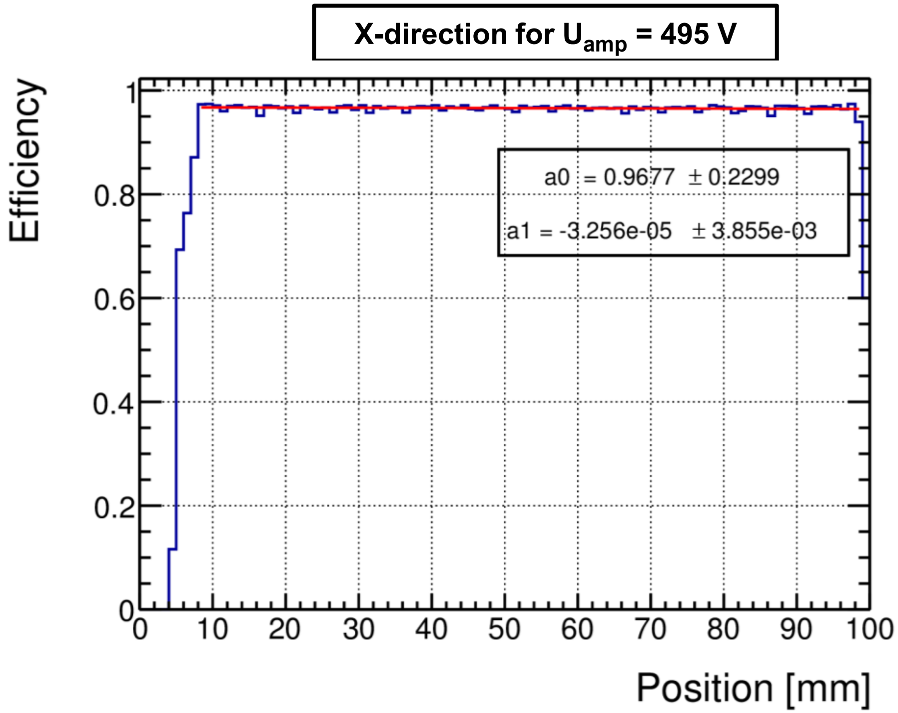


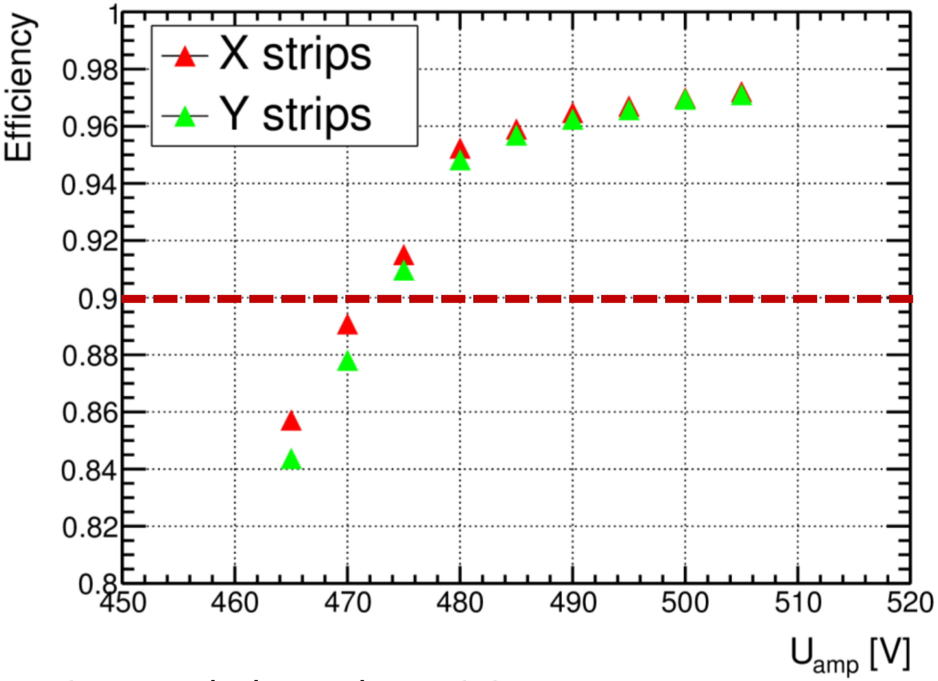


Resolution (with track error σ_{track} O(30 µm)): $\sqrt{\sigma_{core}{}^2 - \sigma_{track}{}^2}$

Resolution achieved ≈ 77 µm

PADH: Efficiencies



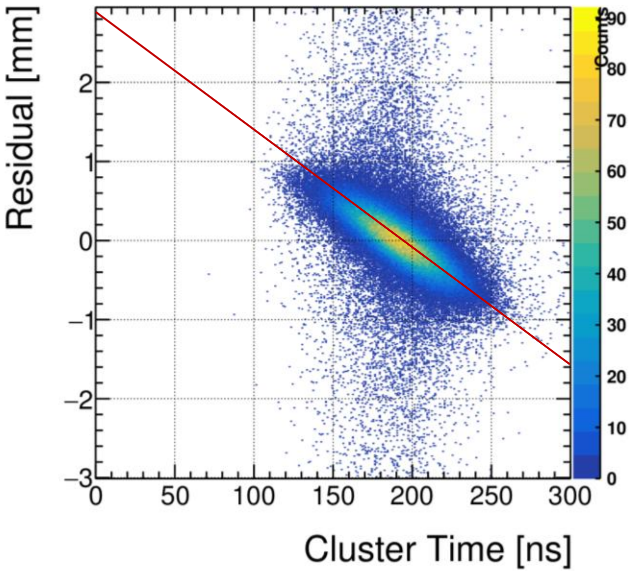


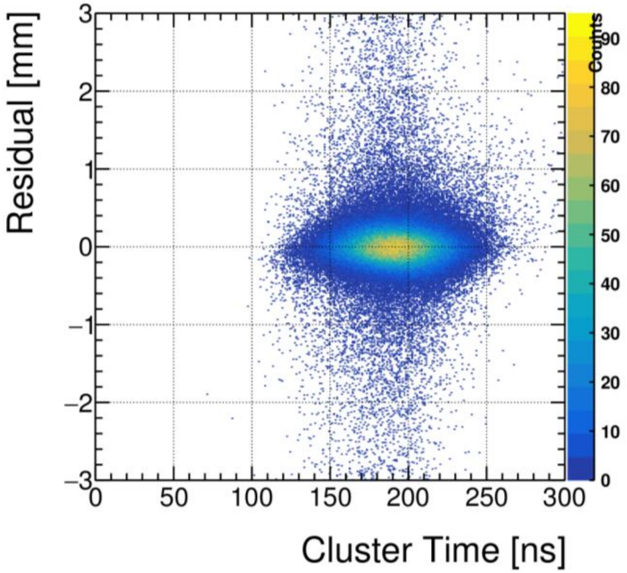
$$\text{Efficiency} = \frac{\#\ of\ reconstructed\ events\ in\ investigated\ det.}{Total\ \#\ of\ reconstructed\ tracks}$$

Hit considered efficient if residual < 1 mm

Efficiencies achieved ≈ 97%

PADH: Inclined Tracks Using Time Corrected Charge Centroid Method





$$t_{cw} = \frac{\sum_{Strips} (q_{strip} \times t_{strip})}{\sum_{Strips} \; q_{strip}}$$

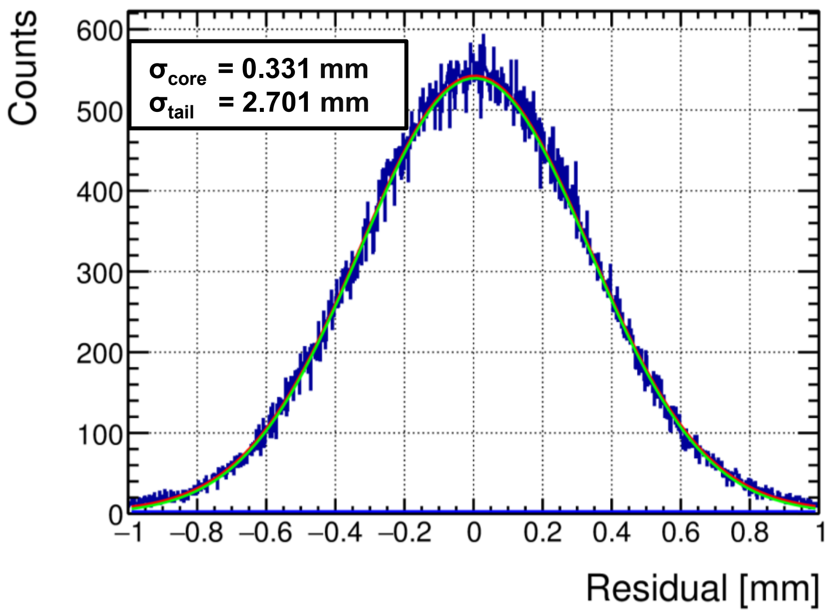
Introduced by B. Flierl
([PhD Thesis, LMU])

$$x_{corr} = x + \; mt + c$$
$$\Delta x \; = x_{true} - x_{corr}$$

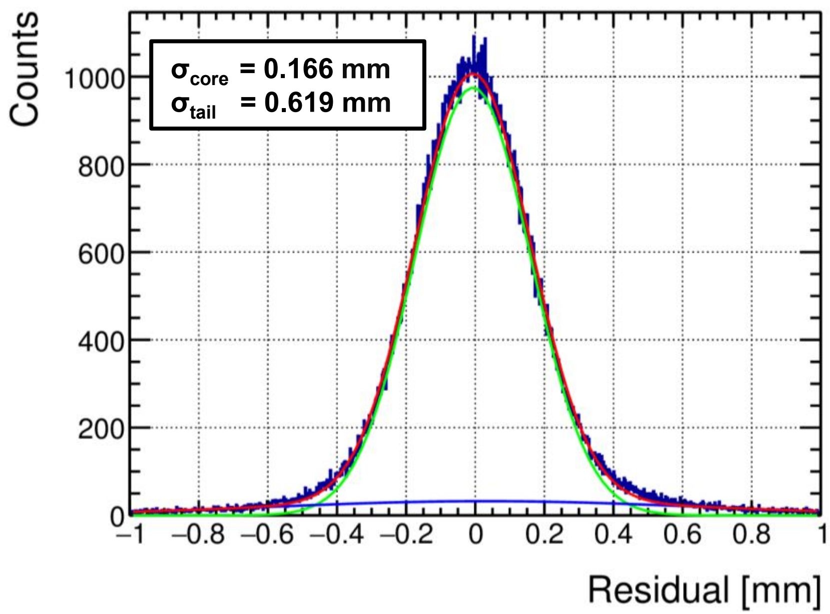
- Detectors tilted by 20º, with the trackers kept perpendicular
- The cluster time information can be used to correct the position information
- A linear fit is used to determine the slope *m* and offset *c* parameters

PADH: Inclined tracks using Time Corrected Charge Centroid method

Charge centroid method



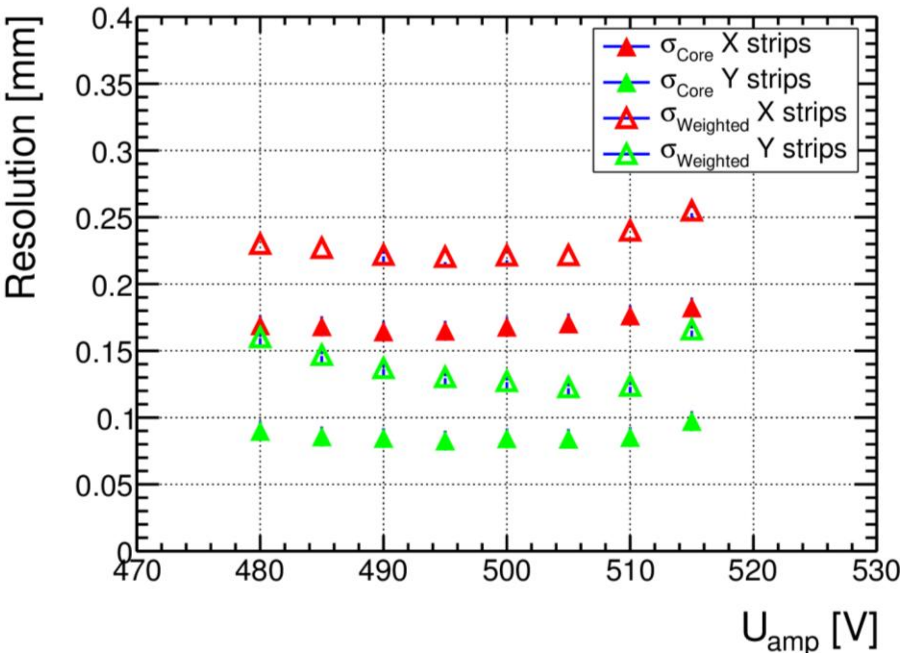
Time corrected charge centroid method

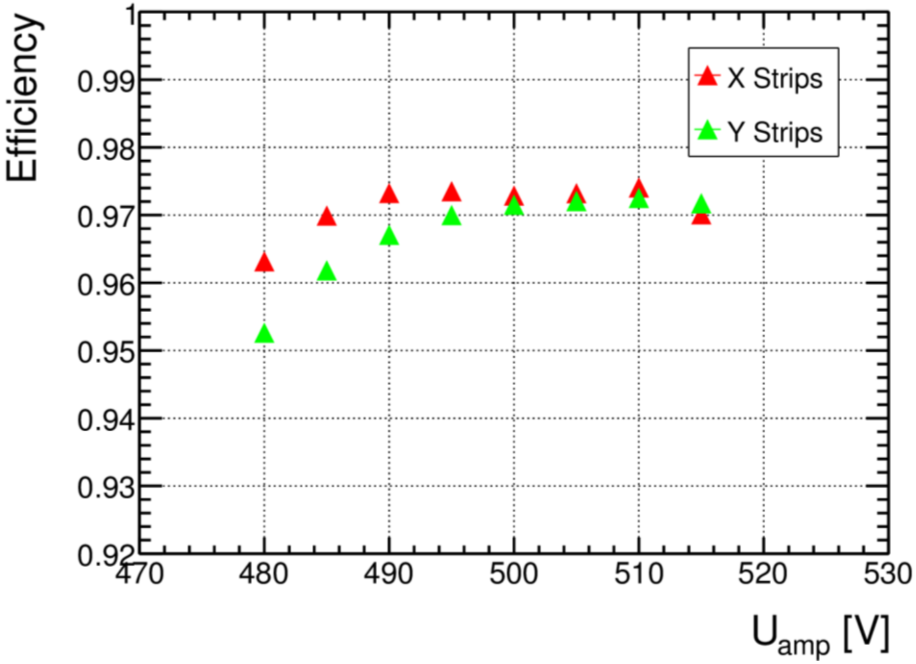


Resolution without time correction ≈ 330 μm

Core resolution achieved with time correction and track error σ_{track} O(30 μm) ≈ 163 μm

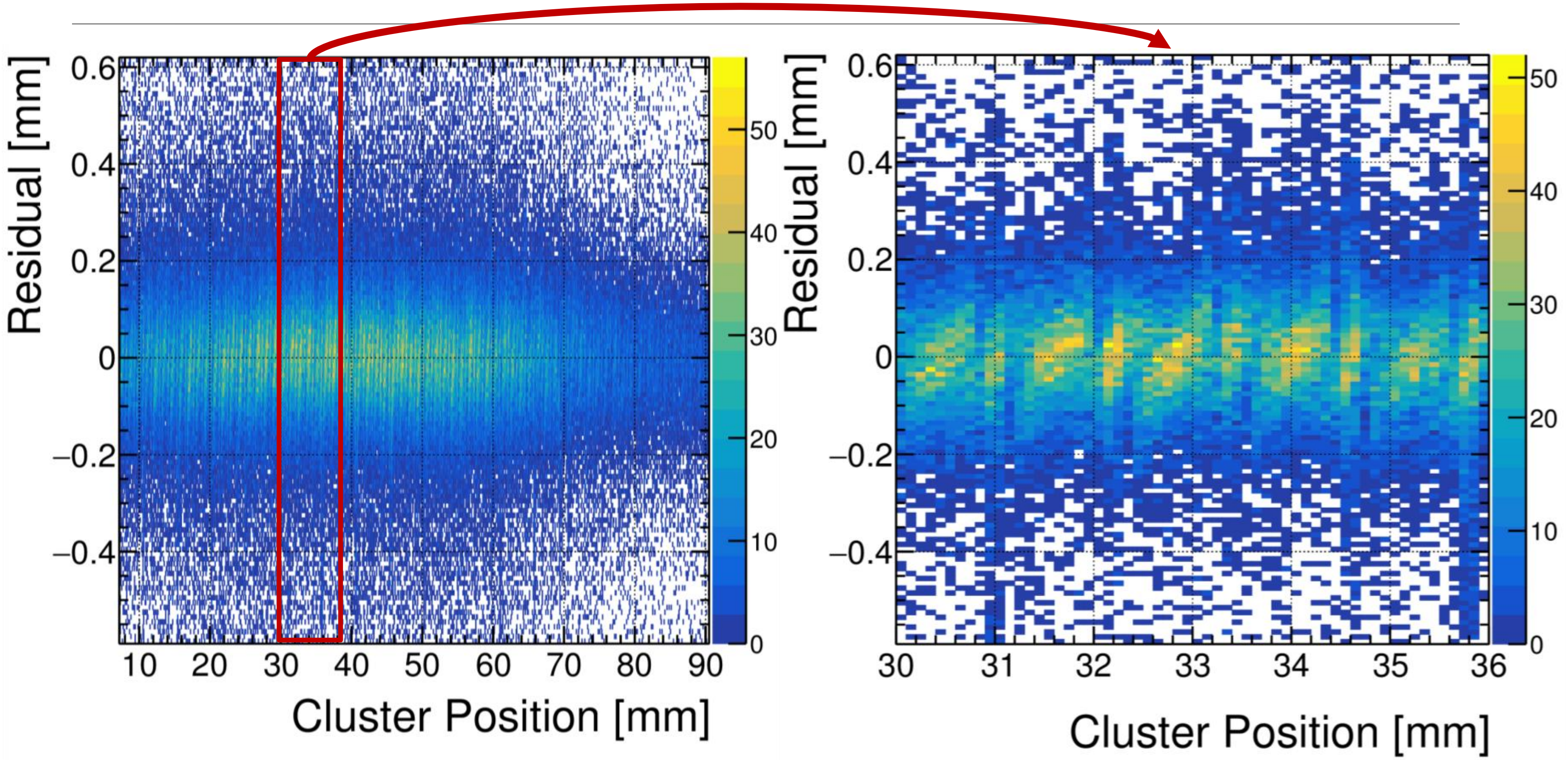
PADH: Inclined tracks analysis





Efficiencies achieved ≈ 97% for voltages > 495 V
Weighted resolution for inclined tracks accounting for track error ≈ 220 µm

Substructures



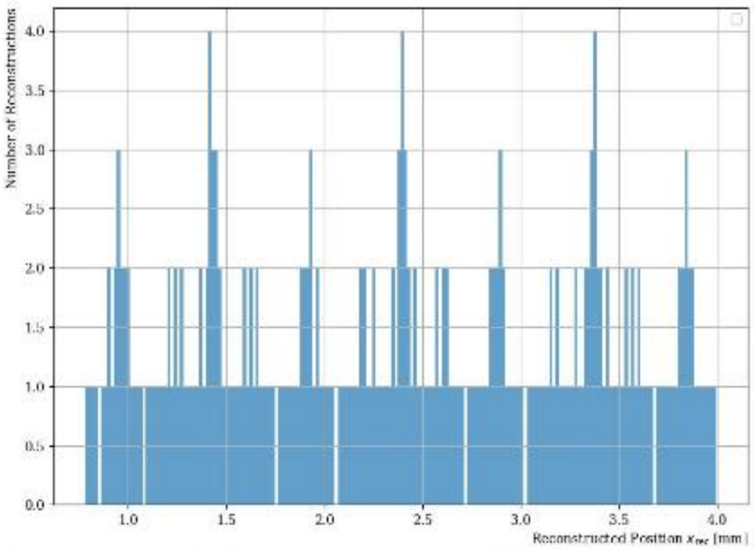
- Substructures observed which occur periodically over the length of the pixel pitch
- Simulation studies performed that expect this behaviour ([Max Menzer's talk on Wed])
- Due to the known dependence on the pitch, these modulations can be corrected (ongoing investigation)

Summary and Outlook

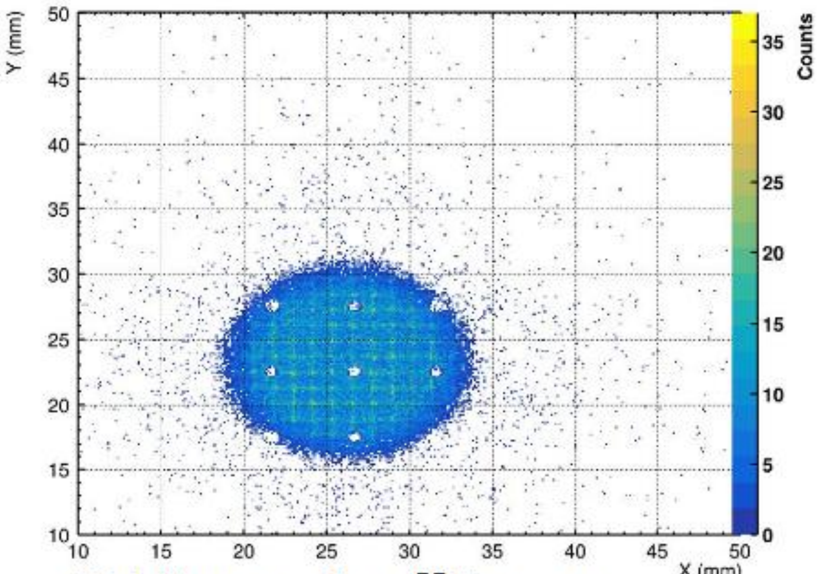
- Micro-pixel detectors with $\sigma < 100$ µm need extremely high number channels, making them cost and power intensive
- Idea: Reduce the number of readout channels strongly via charge sharing on several stacked readout layers and reduce it further by a pixel-strip hybrid readout structure
- The 5 layer detector with 10×10 mm^2 readout pixels achieved core spatial resolutions of $<$ 300 µm but substructures observed
- The 3 layer detector with 1.2×1.2 mm^2 readout pixels sees core spatial resolutions of $<$ 80 µm achieved which also sees the substructures
- Inclined tracks for the 3 layer detector sees resolutions of $<$ 160 µm
- Simulation studies of the charge sharing are ongoing (see Max Menzer's talk on Wed)
- Do other groups working on similar detector concepts also see a similar substructure?

THANKS!

Backup: Reconstruction Error



Histogram of reconstructions from simulation

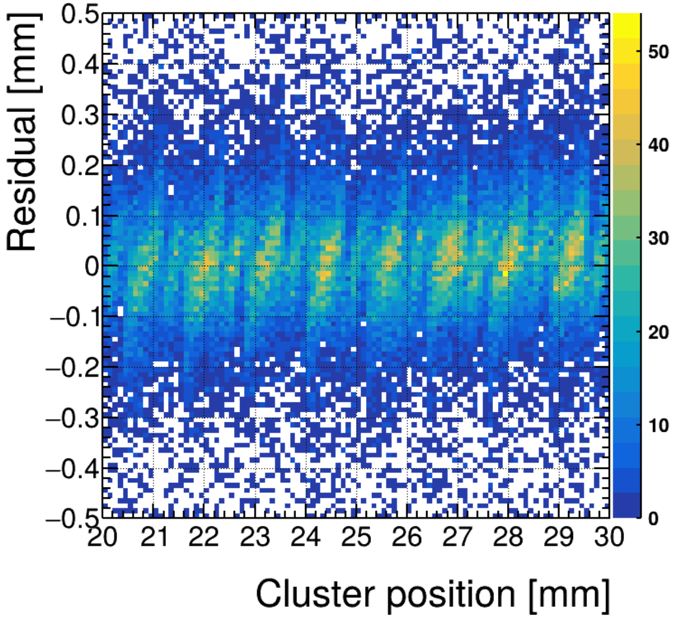


2D hit map of an ^{55}Fe source

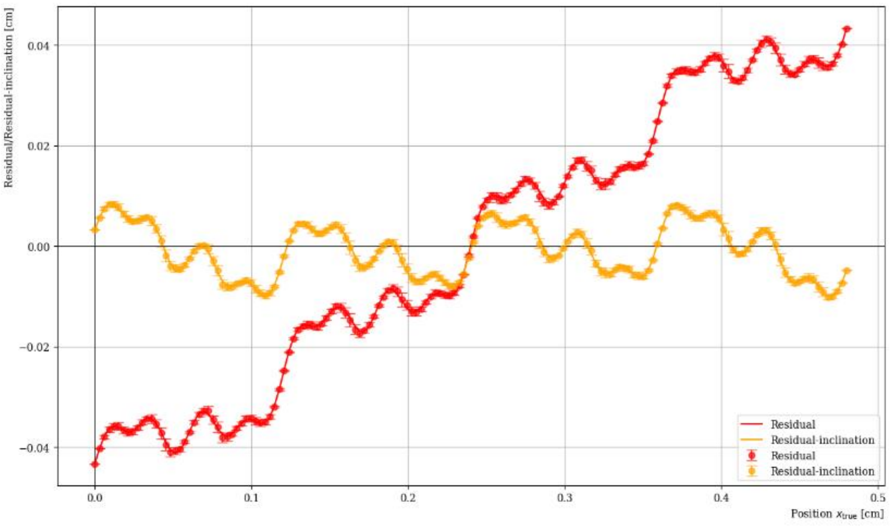
Max Menzer's talk on Wed

PADH: Simulation vs Measurement

Measurement

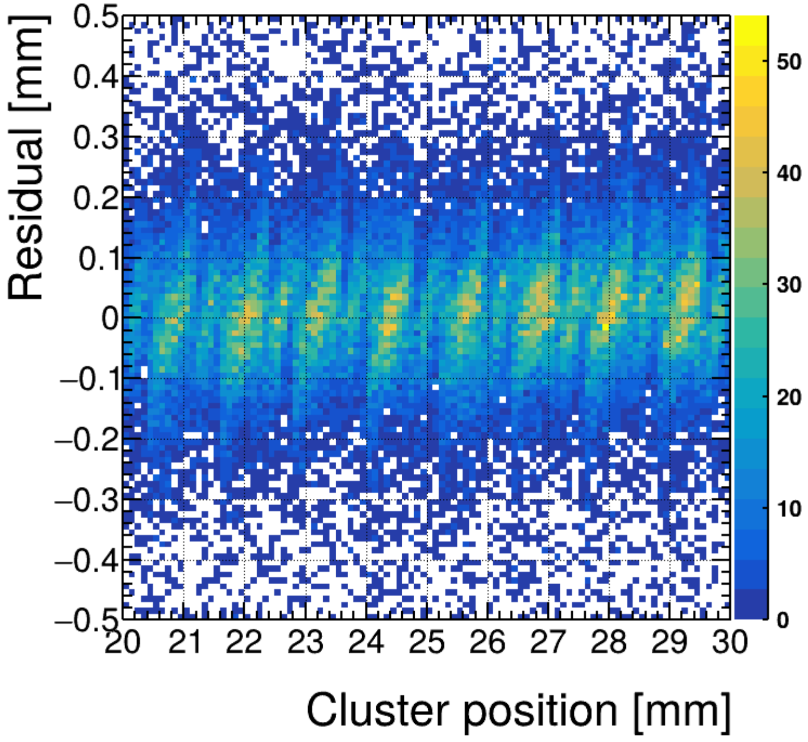


Simulation

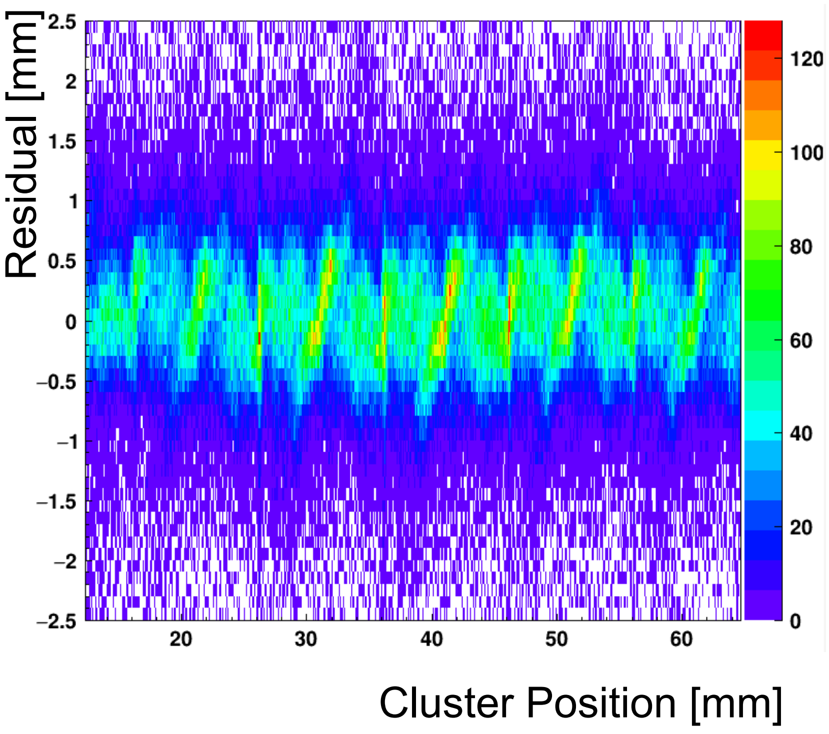


PADH vs PAD5 substructures

PADH

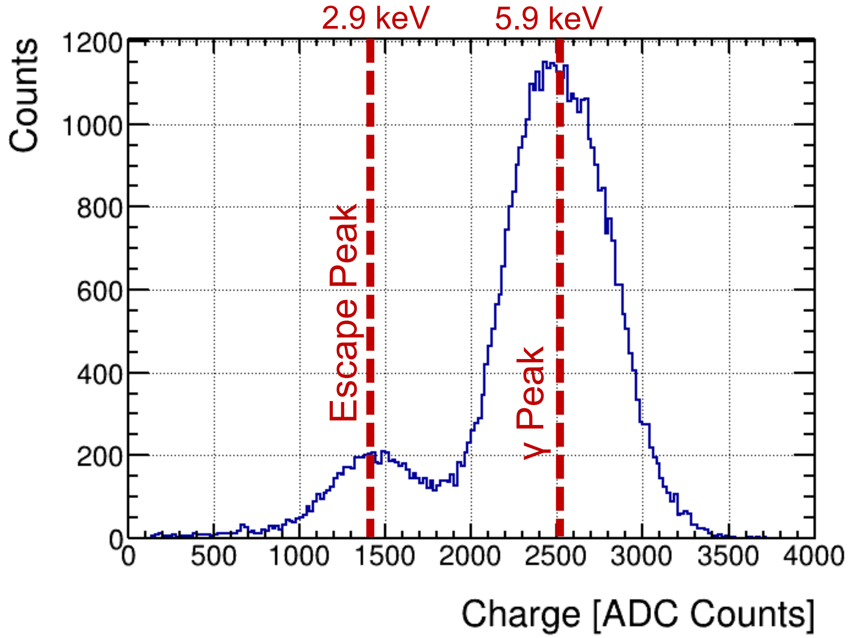


PAD5



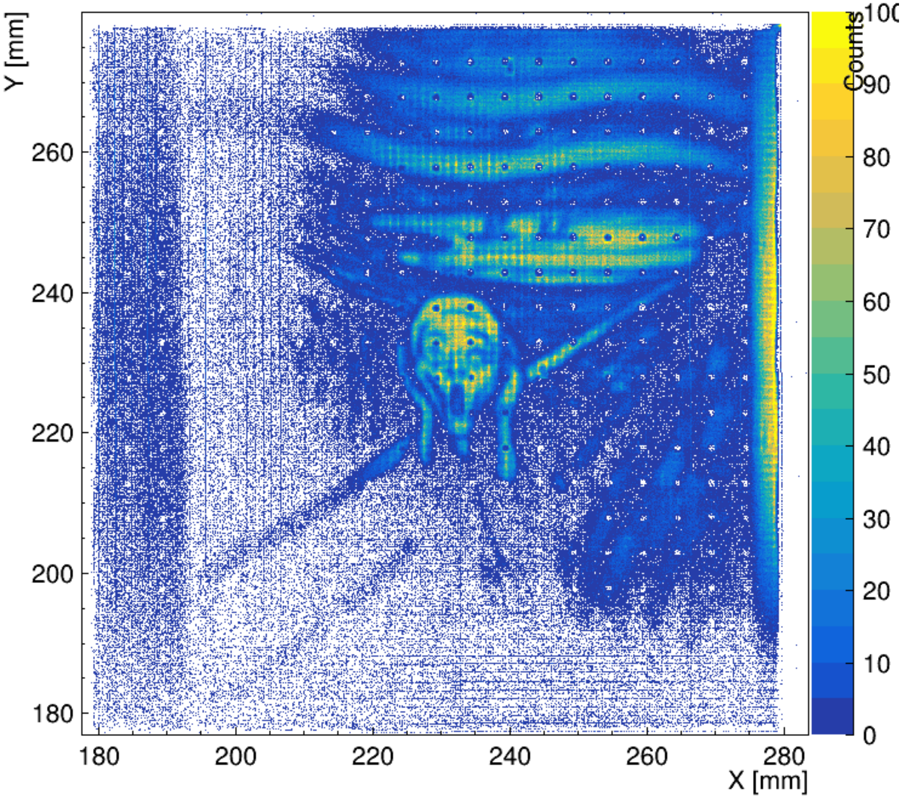
Characterisation using ^{55}Fe source

- Investigation of energy spectrum using an ^{55}Fe source
- Two peaks observed:
  - 5.9 keV γ peak of ^{55}Fe
  - 2.9 keV Argon escape peak
- Expected peak ratio: $\frac{5.9\ keV}{2.9\ keV} = 2.03$
- Reconstructed ratio: 1.8
- Energy resolution: $\frac{\Delta E}{E}$ = 12.27%



^{55}Fe: The Scream

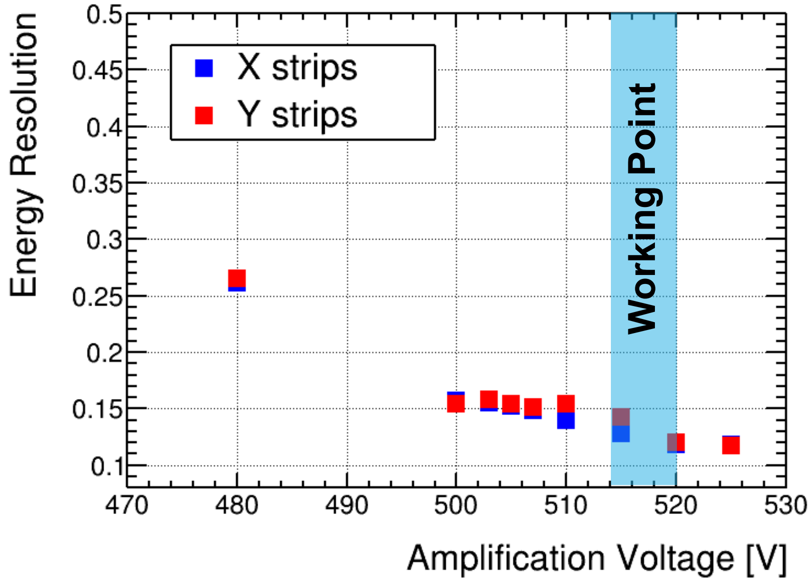
- 3D printed “The Scream” by Edvard Munch placed in between the source and the detector
- Good resolution of the detector can be observed; pillars holding the mesh can also be seen ($A_{pillar} = 1.2 \times 0.2\ mm^2$)

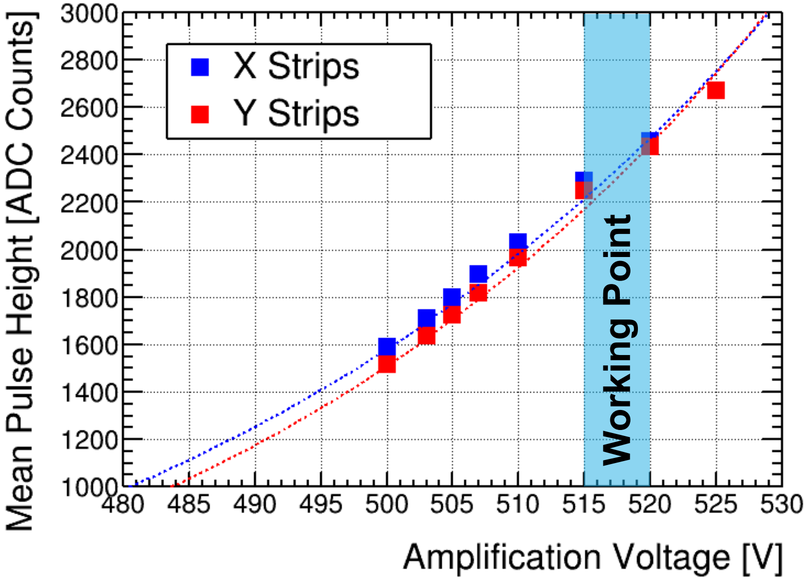


- $V_{drift} = 480$ V; $V_{amp} = 520$ V
- Gas used: Ar:CO_2 in 93:7 vol.%

^{55}Fe: Detector Optimisation

- Determination of pulse height and energy resolutions for different anode voltages
- Pulse height distribution rises exponentially as expected

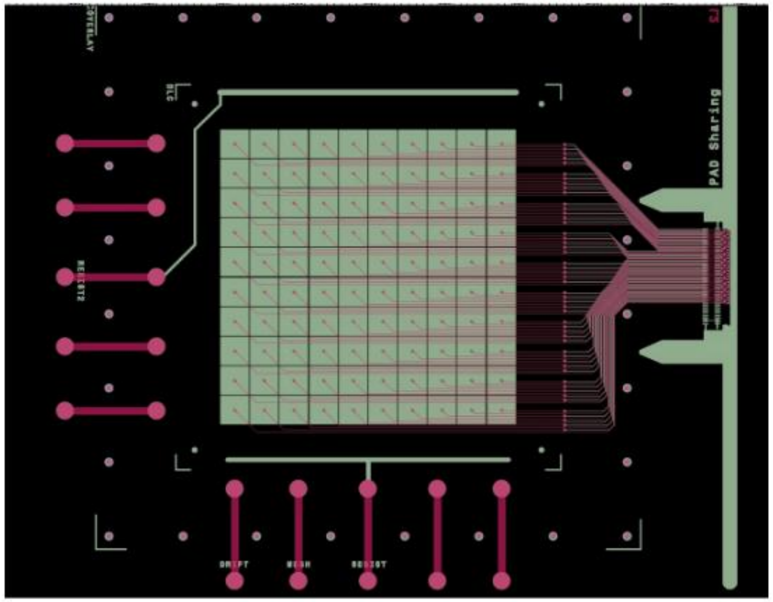




- Current working point for Ar:CO_2: between 515 and 520 V; starting from 525 V readout electronics saturation arises

Backup: Pixel layout

5 layer PAD detector



3 layer PAD detector