Developments of Resistive Micromegas with Capacitive Sharing for Low/Medium Rates Applications

6th DRD1- Collaboration Meeting

Warsaw,

Astronomical Centre

of the Polish Academy of Sciences

6 October 2025

M. ALVIGGI, M. BIGLIETTI, M.T. CAMERLINGO, K. CHMIEL, M. DELLA PIETRA, C. DI DONATO, R. DI NARDO, A. FARILLA, P. IENGO, M. IODICE, R. ORLANDINI, G. SEKHNIAIDZE, M. SESSA

Outline

- From the established achievements for high-rates applications to medium/low rates for FCCee:
  - o The first resistive micromegas implementing the capacitive sharing concept
    - Recap on established results (new analyses)

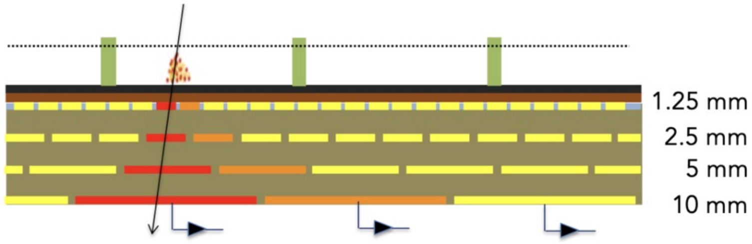
WHAT's NEXT:

- New Large-size Micromegas Prototype 50x40 cm^2, double DLC, fine granularity and capacitive sharing
- The new medium-size prototypes with capacitive-sharing and hexagonal pads
  - o First test at the July Test-Beam with VMM

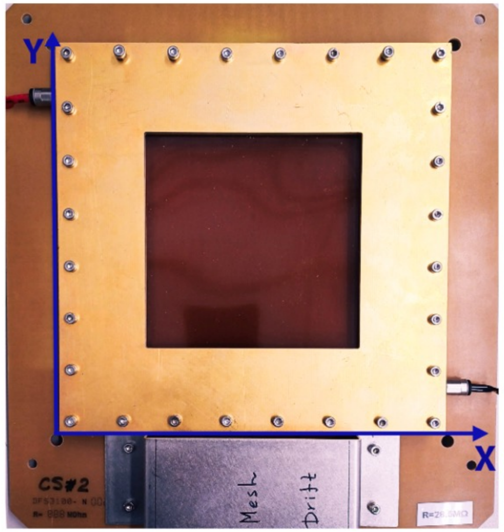
Resistive Micromegas implementing the capacitive sharing concept

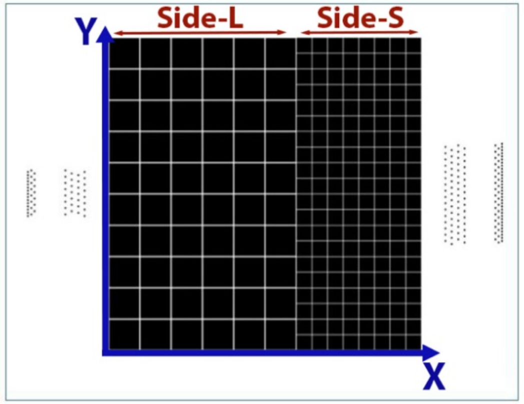
- In 2024 the first resistive Micromegas implementing the capacitive sharing concept [1] was produced
- Preliminary results reported by K. Chmiel at the 4th DRD1 Coll. Meeting
- Here a quick recap and final results.

[1] Concept from R. De Oliveira and K. Gnanvo et al., NIMA 1047 (2023) 167782)



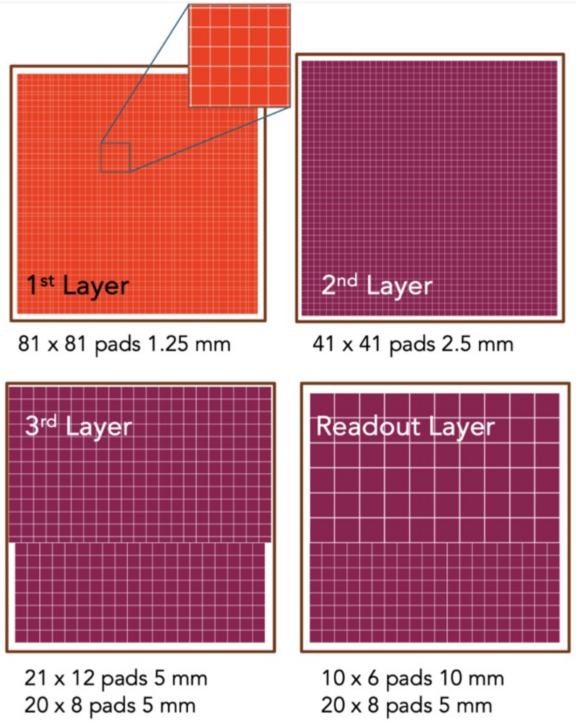
PADDY-CS





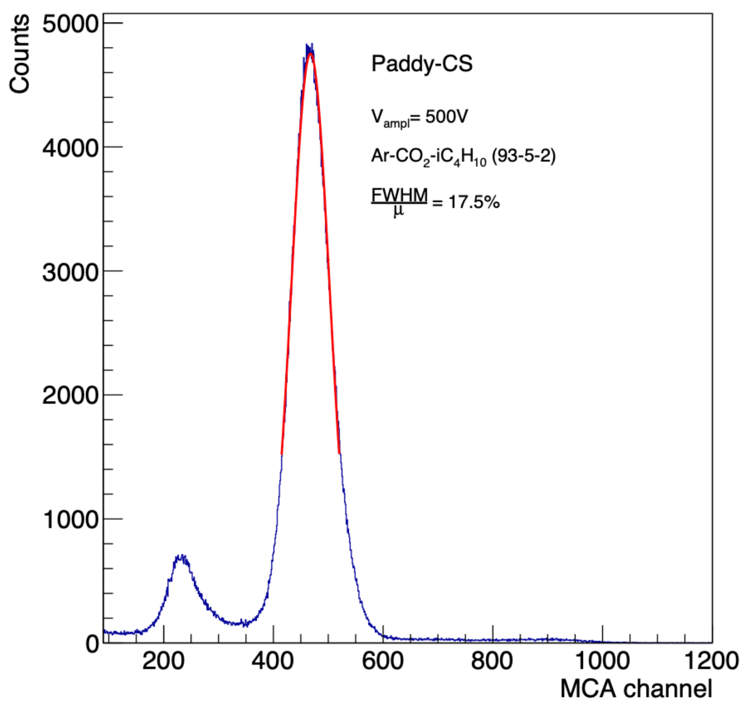
- Single DLC resistive layer ~30 MΩ/sq
- Pad size of "top-layer" (signal induction): 1.25x1.25 mm2
- **Side-L**: Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2
- **Side-S**: Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 (replicated twice)

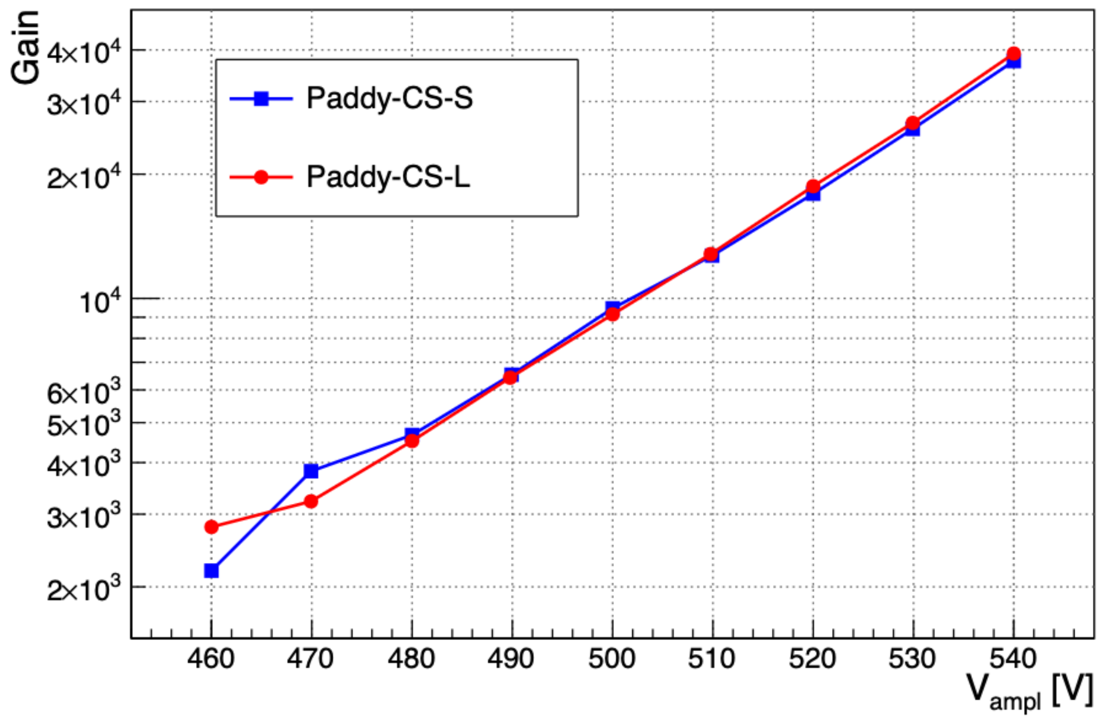
Layout of the three internal layers and the readout layer



Paddy-CS - characterization studies

Gas Mixture: Ar-CO2-iC4H10 (93-5-2)

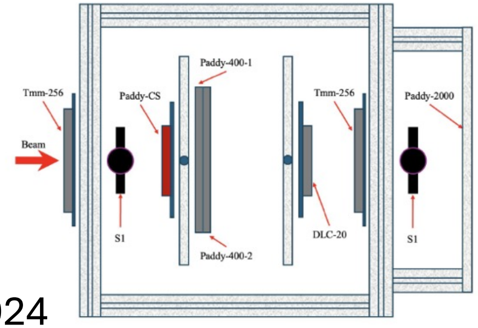


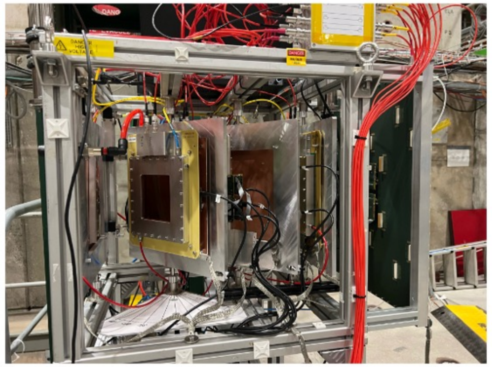


Energy resolution at 5.8 keV is ~17.5%

Stable operation up to a gain of approximately 4×10^4 for both Large and Small sections

Paddy-CS – Test-Beam Results



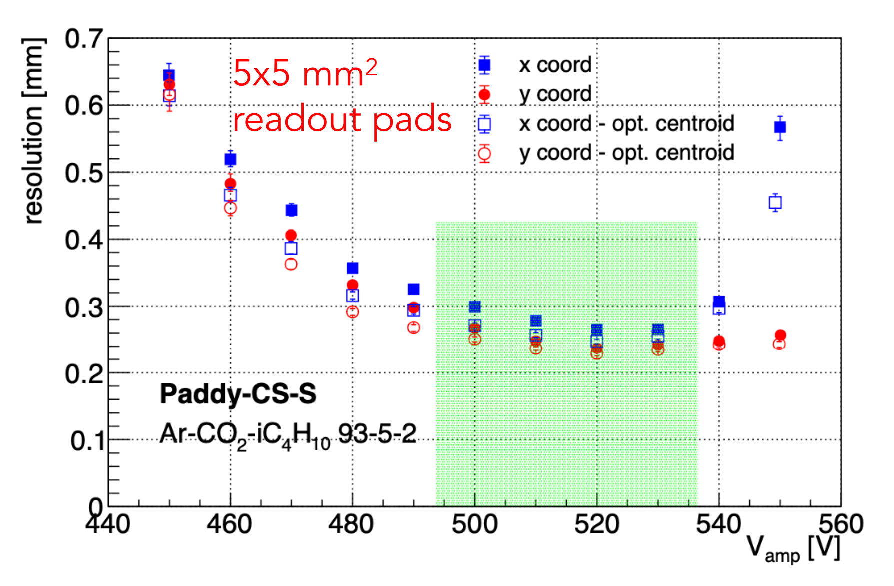


April 2024
150 GeV muon beams in the H4 SPS test beam area at CERN

Cluster position evaluated with an extended definition of the charge weighted centroid:

$$x_c = \frac{\sum x_i q_i^p}{\sum q_i^p}$$

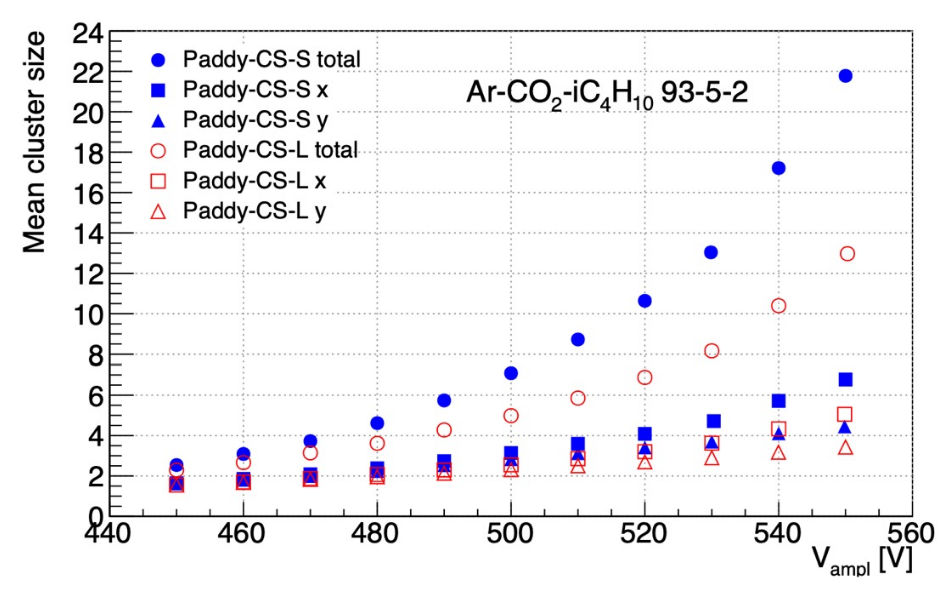
Results for p=1 and optimal p=1.2

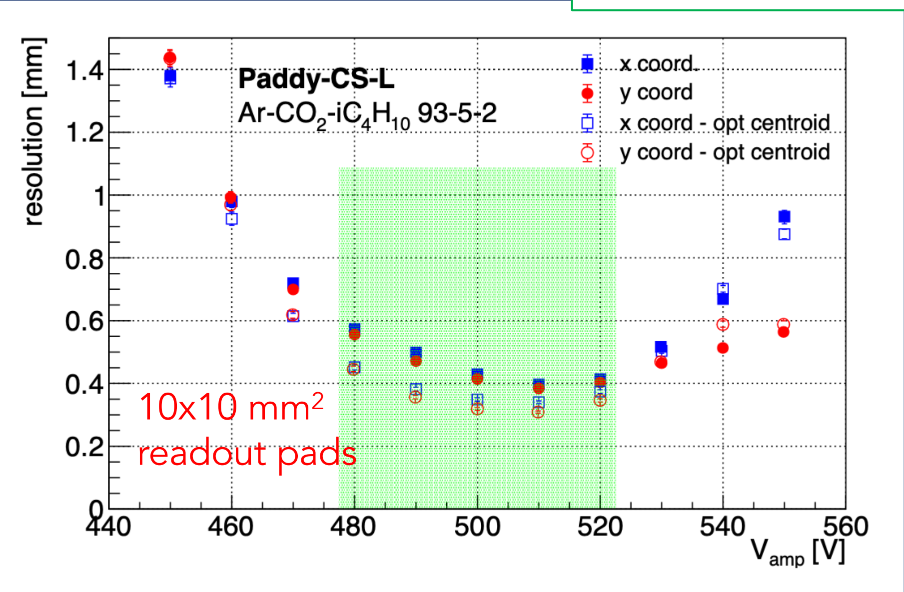


Key results:

- Cluster-size and Spatial Resolutions (For perpendicular tracks)

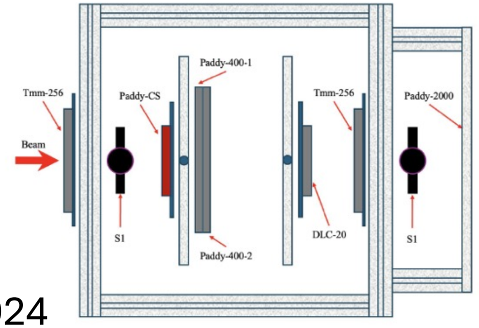
σ ~ 220 μm
with 5x5 mm2 pads
1/23 of the pad-size

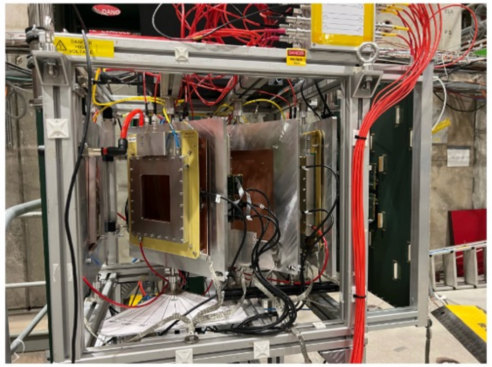




σ ~ 310 μm
with 10x10 mm2 pads
1/30 of the pad-size

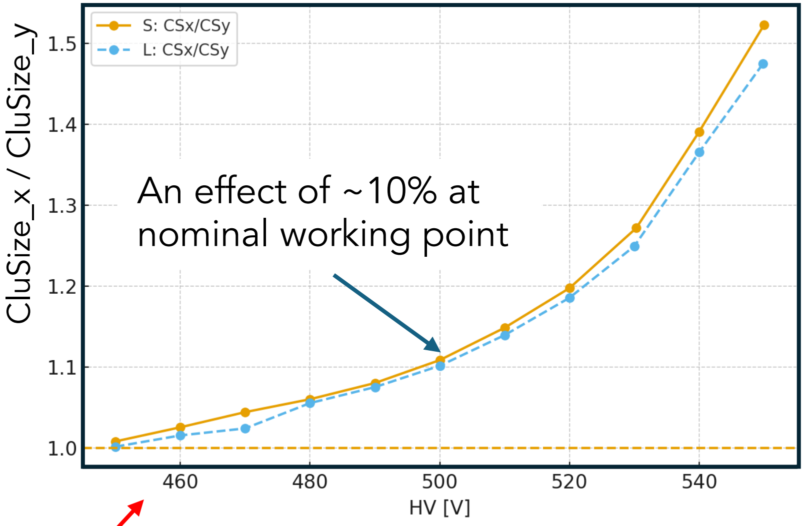
Paddy-CS – Test-Beam Results

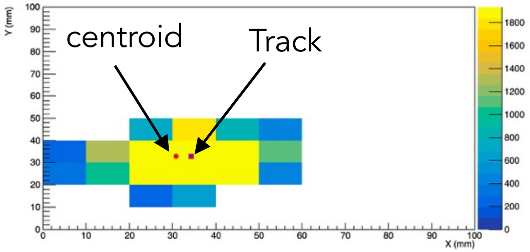




April 2024
150 GeV muon beams in the H4 SPS test beam area at CERN

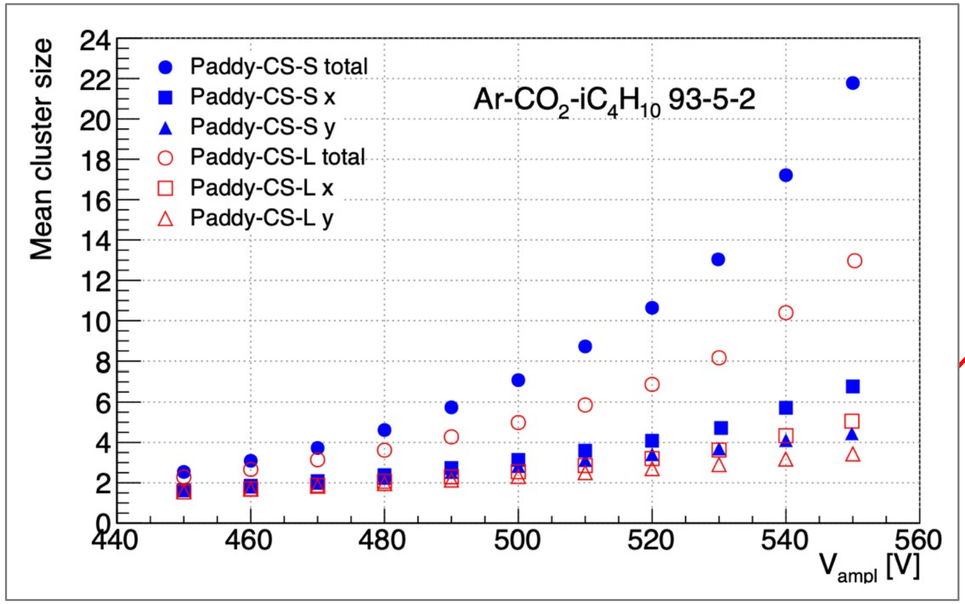
Ratio CluSize_x / CluSize_y Vs HV (Small and Large)





Example of an "asymmetric" cluster with a displaced position in x (and well reconstructed in y)

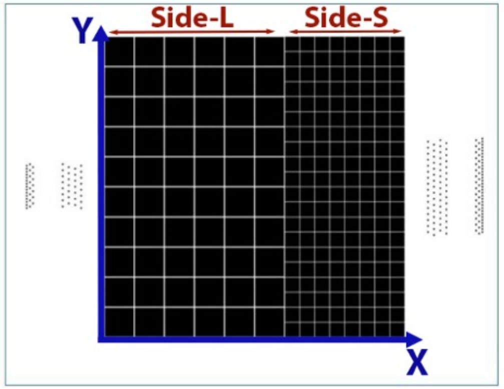
- Cluster-size
  (For perpendicular tracks)



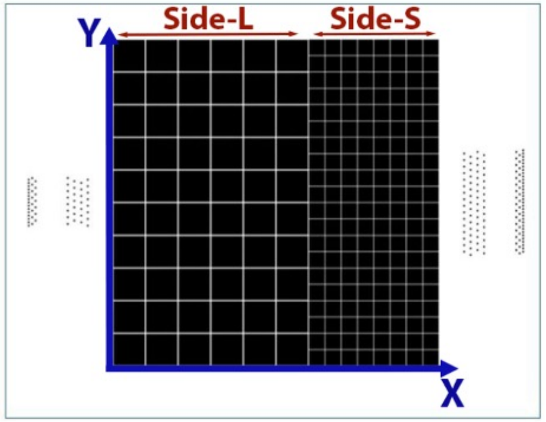
We observe a systematic asymmetry of the cluster size CluSize_x > CluSize_y

Moreover, the spatial resolution in x is lightly worst than in y !

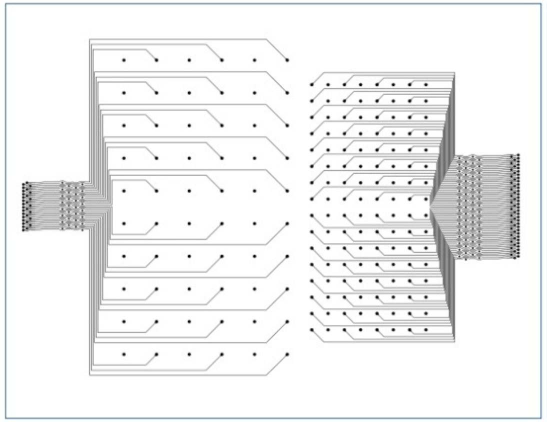
…and border effects should favour larger cluster in y !



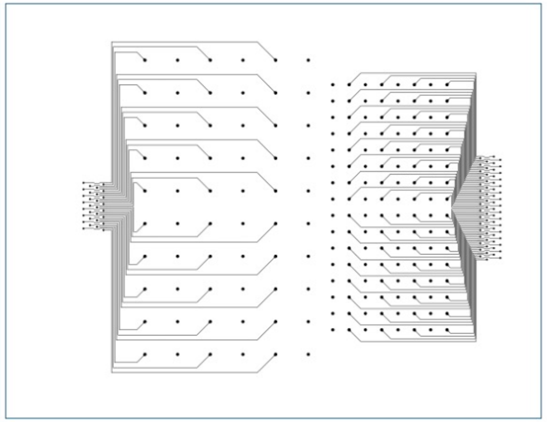
A cross-talk issue



Readout PAD
Layer 4

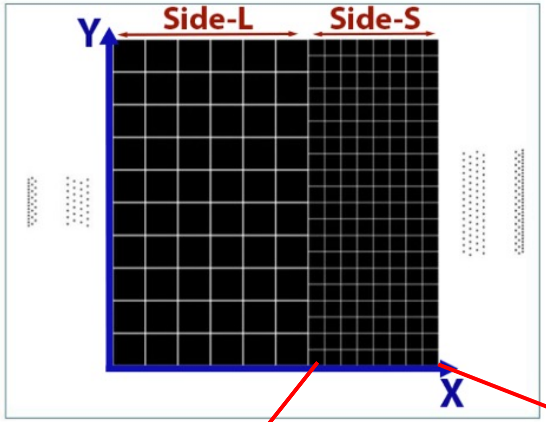


Routing to connectors
Layer 5

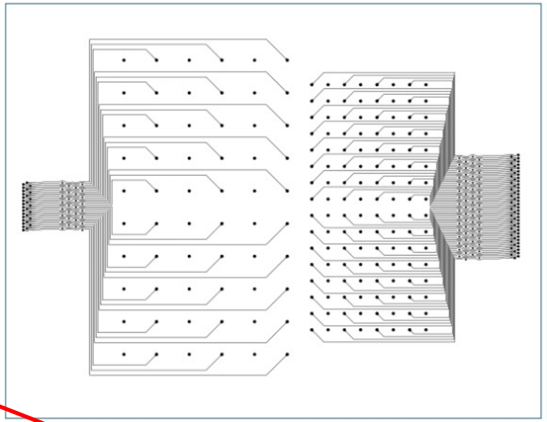


Routing to connectors
Layer 6

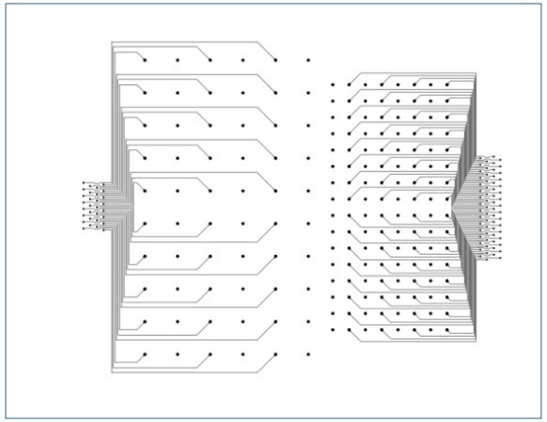
A cross-talk issue



Readout PAD
Layer 4

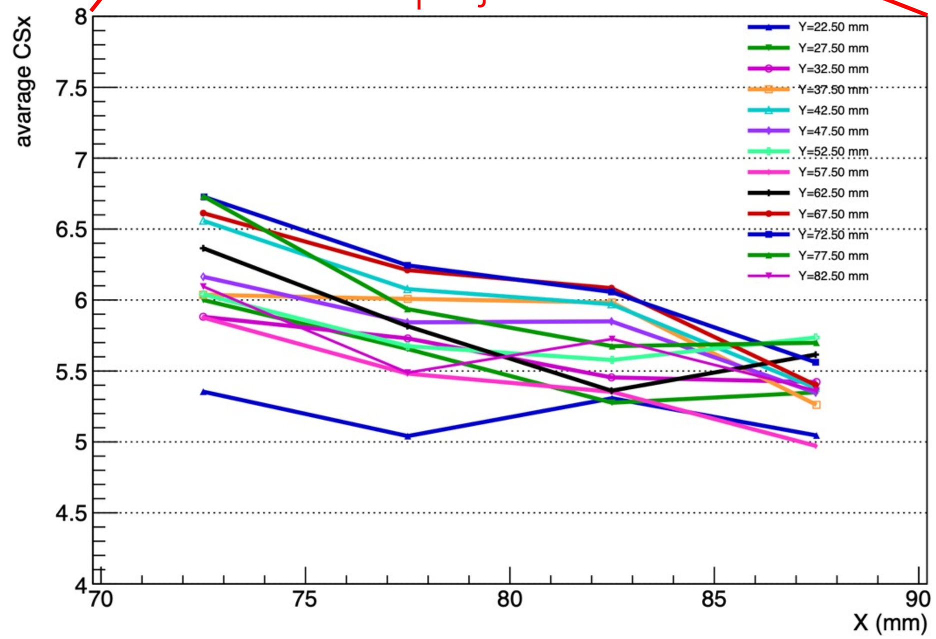


Routing to connectors
Layer 5



Routing to connectors
Layer 6

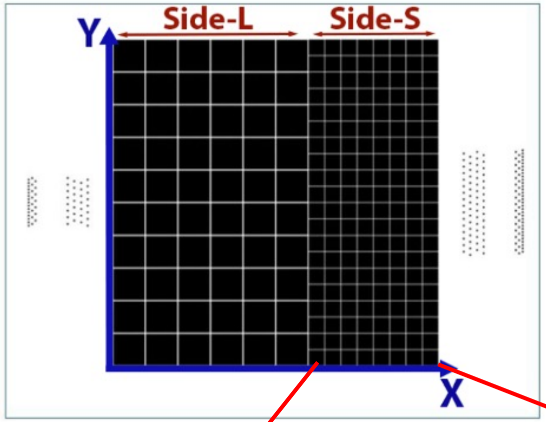
Cluster-size projected in x Vs x



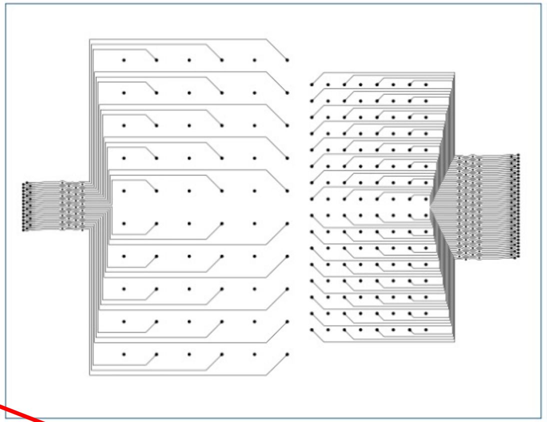
Each line runs along the routing strips

Decreasing for the pads closest to the readout (smaller routing length)

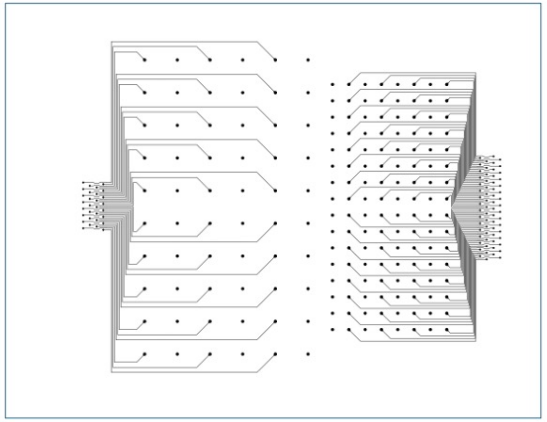
A cross-talk issue



Readout PAD
Layer 4

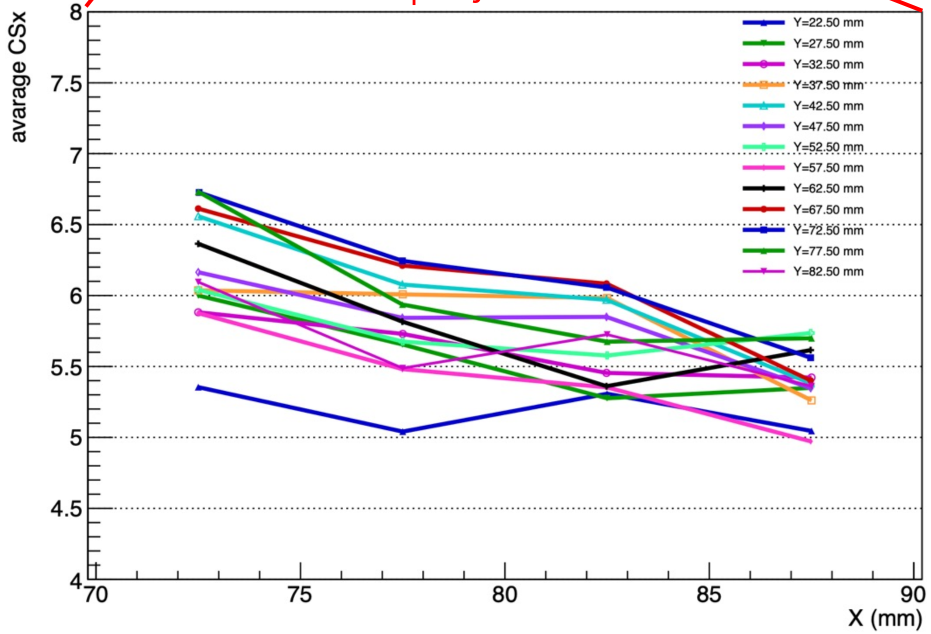


Routing to connectors
Layer 5



Routing to connectors
Layer 6

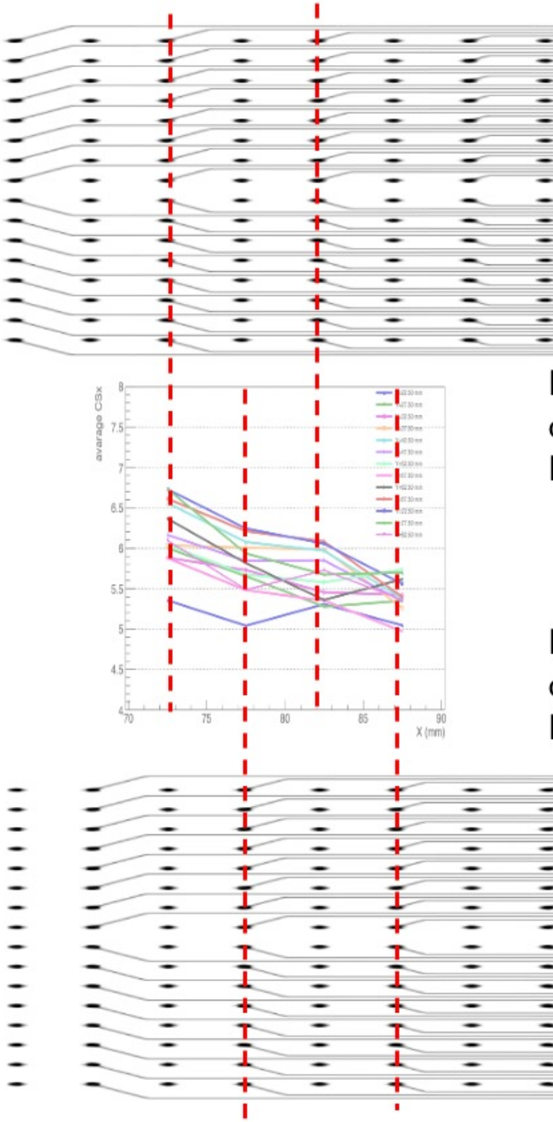
Cluster-size projected in x Vs x



Each line runs along the routing strips

Decreasing for the pads closest to the readout (smaller routing length)

Higher cluster-size for tracks passing through pads whose routing layer is closest to the pad layer

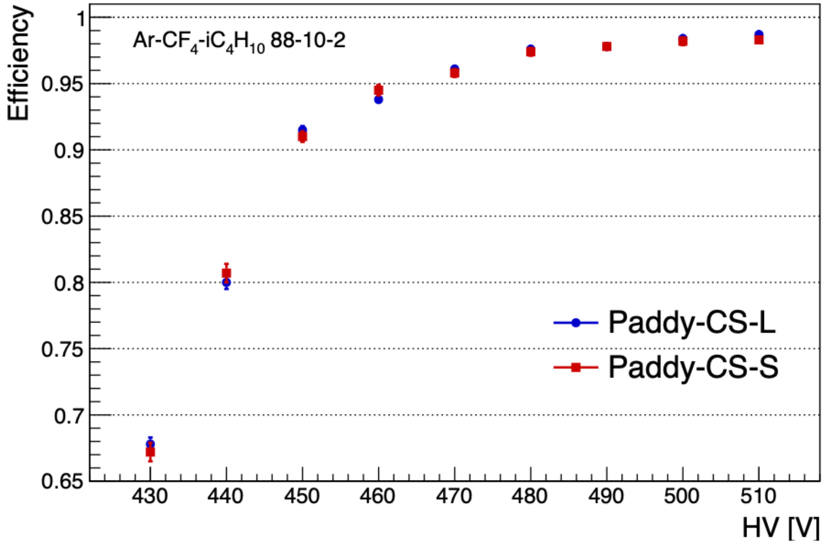


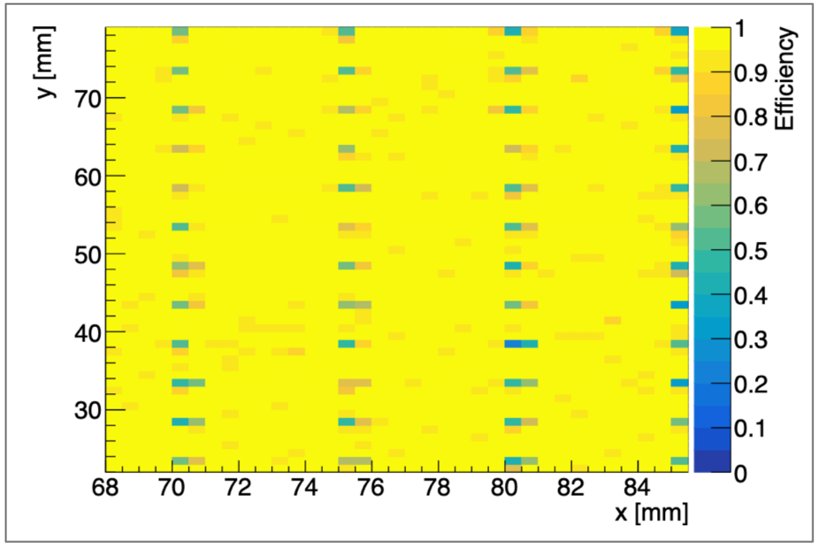
Routing to connectors
Layer 5

Routing to connectors
Layer 5

Paddy-CS - Efficiency

Efficiency:
Defined as the ratio between the number of extrapolated reference tracks whose projected position lies either geometrically inside a reconstructed cluster or within a distance equal to half the readout pad size from it, and the total number of extrapolated tracks.



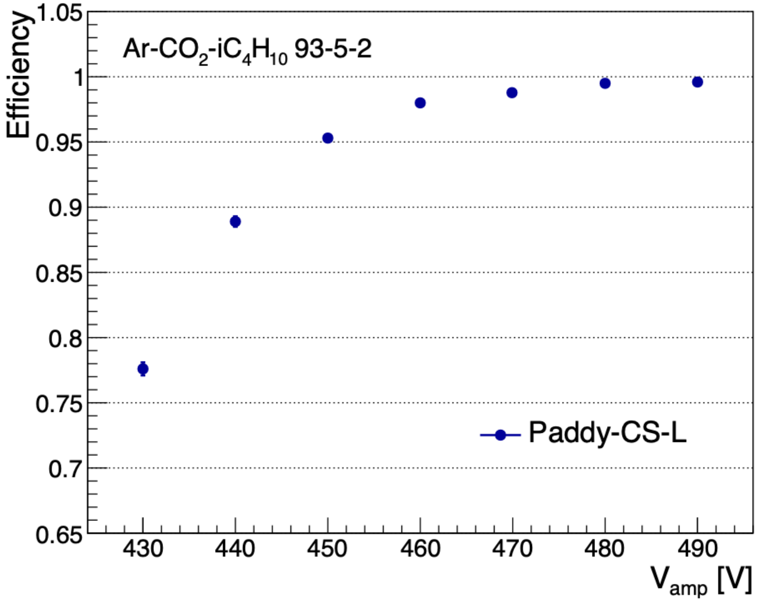


efficiency for perpendicular tracks
Average tracking efficiency at plateau ~98%
It includes inefficient areas on the pillars

The pillar effect is very much reduced for inclined tracks

(38 degrees wrt the perpendicular to the detector plane)

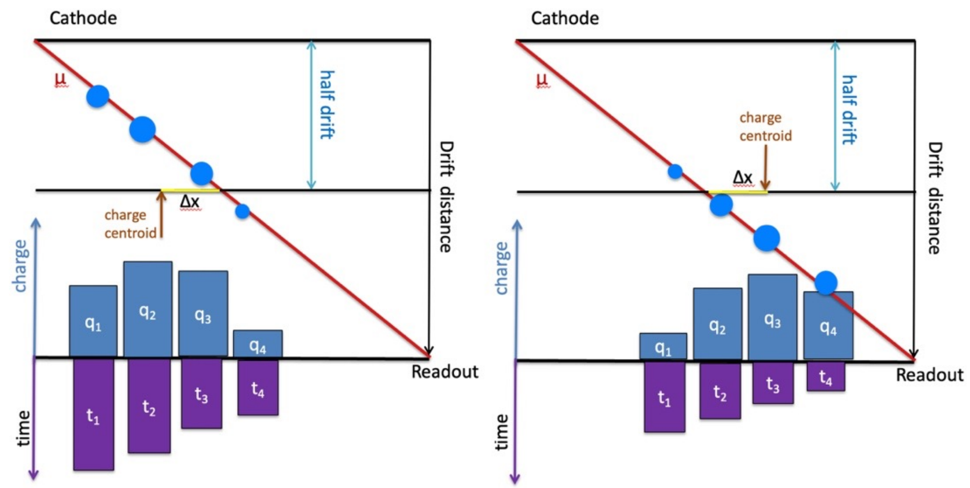
→ efficiency close to 100%



Paddy-CS – Spatial Resolution for Inclined Tracks

- Cluster position reconstruction usually exploit time information in case of inclined tracks – e.g. μTPC
- Inheriting from ATLAS approach, we adopted the "Cluster Time Projection" (CTP method) [1]
    - fluctuation of the cluster time towards earlier (later) values relative to the "central" cluster time is strongly correlated with a positive (negative) position bias of the cluster centroid.
      → Correlation between the cluster average time of the cluster
- Would it work?
- In capacitive sharing detectors the arrival times on neighbouring pads can cross-talk and pile up

Illustration of the Cluster Time Projection



Late average cluster time → negative Δx position bias

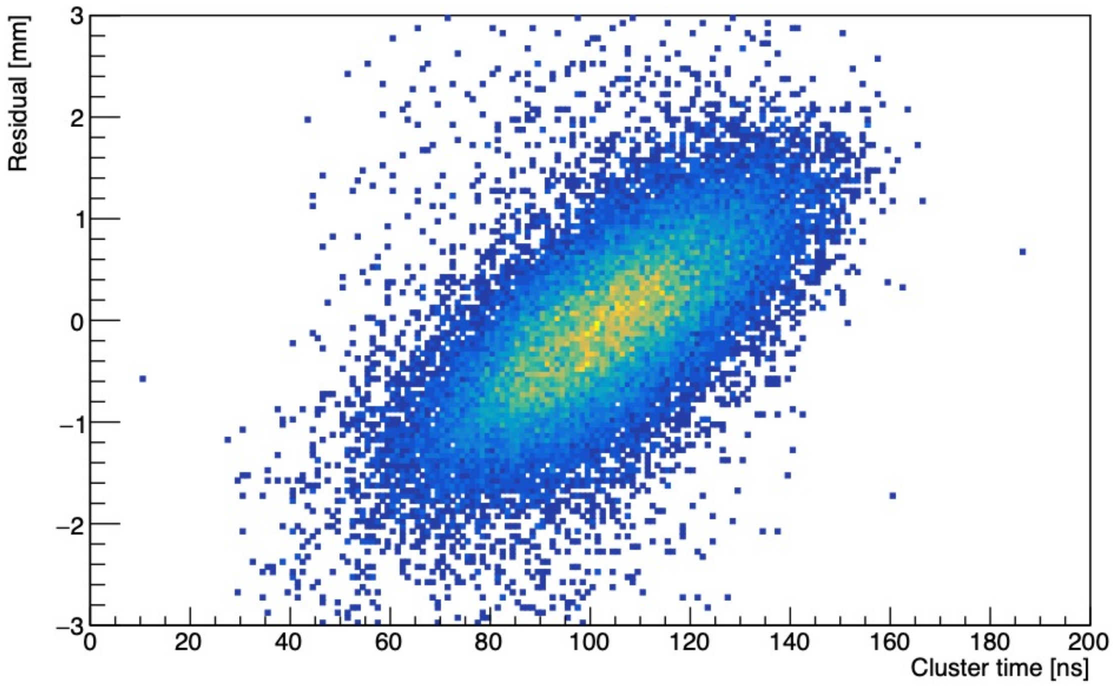
Early average cluster time → positive Δx position bias

[1] B. Flierl, PhD Thesis "Particle tracking with micro-pattern gaseous detectors", April 2018

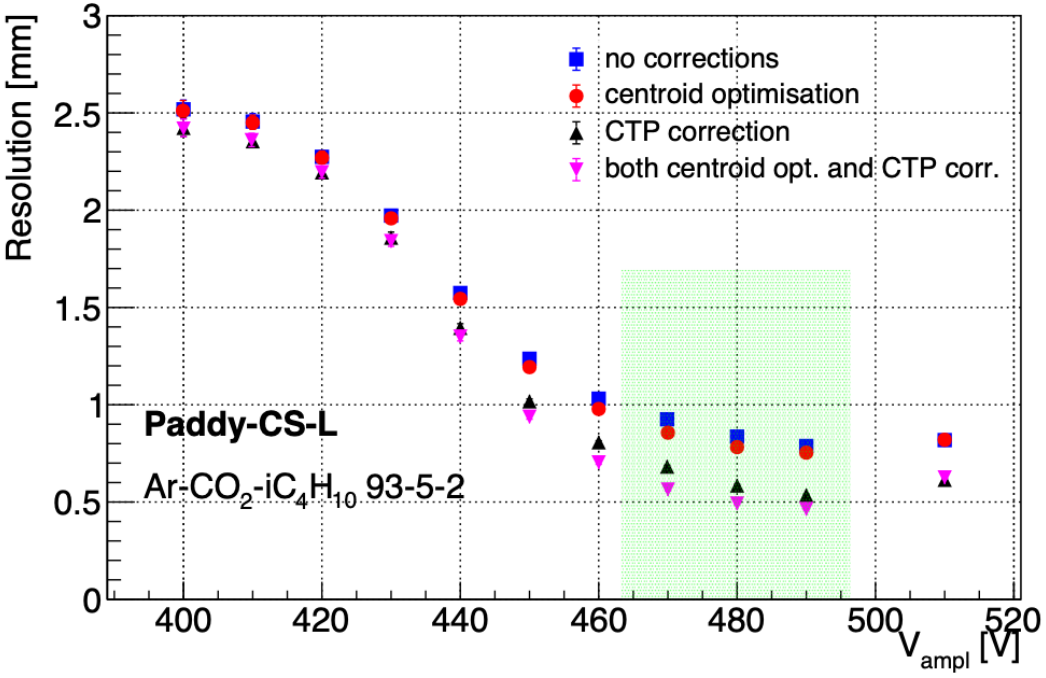
Paddy-CS – Spatial Resolution for Inclined Tracks

- For inclined tracks at 38° a clear correlation is obtained between the residuals and the average cluster time defined as:

$$t_{cl} = \frac{\sum t_i q_i}{\sum q_i}$$



- Spatial Resolution corrected for the residual Vs time correlation (CTP method):



σ ~ 460 μm

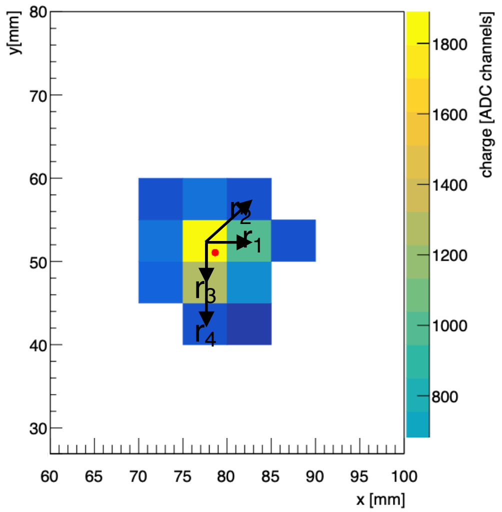
For 10 x10 mm² pads → 1/22 pad size

A remarkable result for inclined tracks!

~ 60-70% improvement with CTP

Paddy-CS – Time Response of neighbour pads (Perp Tracks)

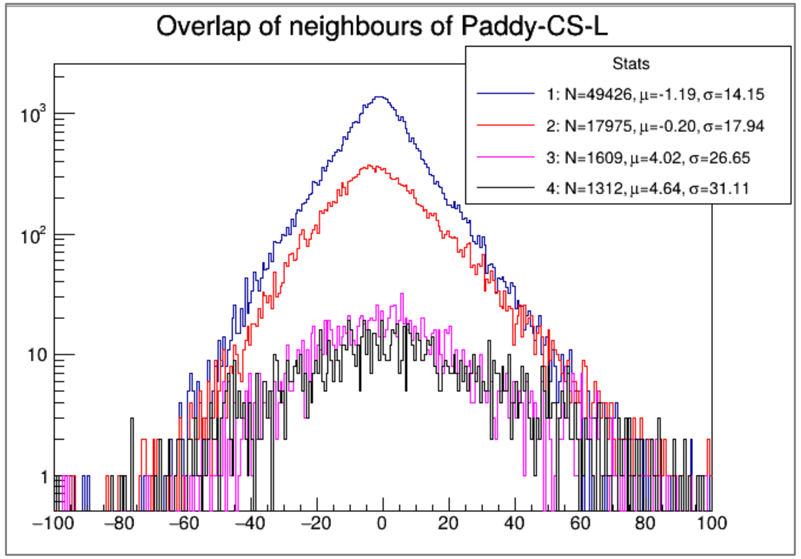
Time Response Analysis FOR PERPENDICULAR TRACKS



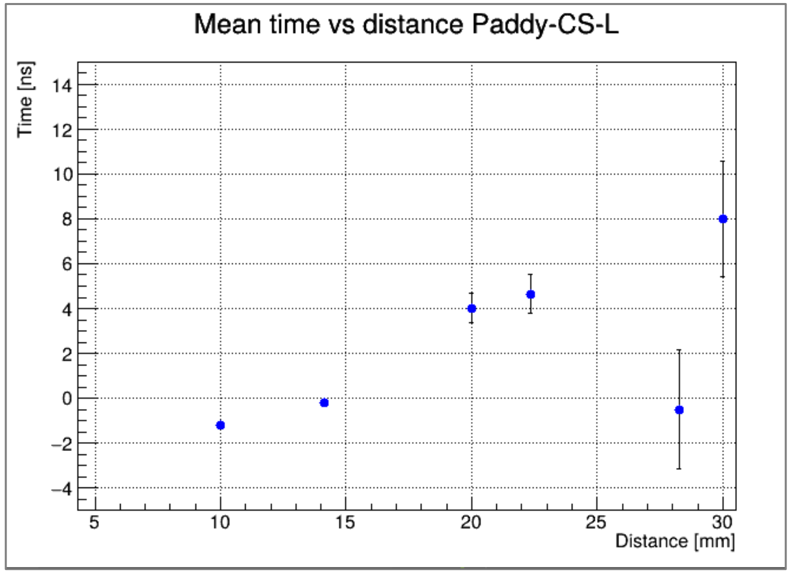
Analysis of pad time response within a cluster

- Goal: verify if cluster formation arises from instantaneous induction on multiple pads (capacitive sharing)
- Check and exclude other possible effects:
  - delayed induction from resistive charge spreading or pile-up

Distributions of relative pad times in clusters for increasing distances from the "central pad"



Mean relative pad times in clusters for increasing distances from the "central pad"

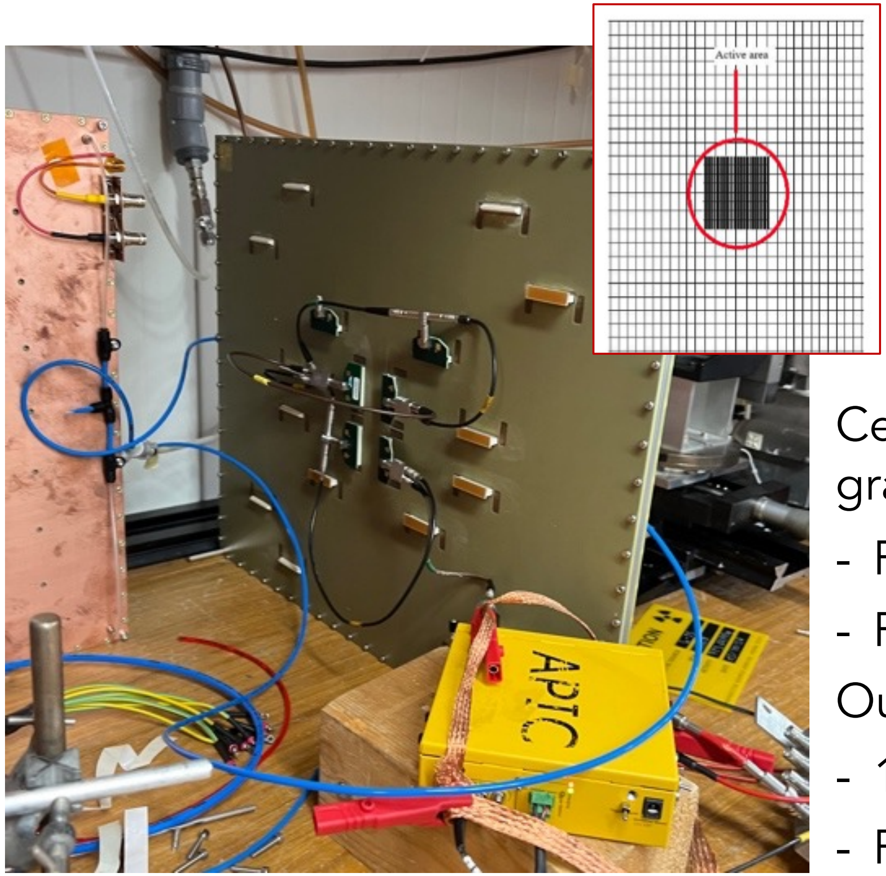


Time of first neighbours very close to main pad
An increase at larger distances is observed

What’s next: 1) Large-size – double DLC - capacitive-sharing

“All-in-one” : integrating the high-rate capability version with the capacitive sharing concept

- Two NEW LARGE-SIZE Resistive Micromegas
  - double layer DLC
  - 3 layers CAPACITIVE SHARING



Active Area
50x40 cm^2

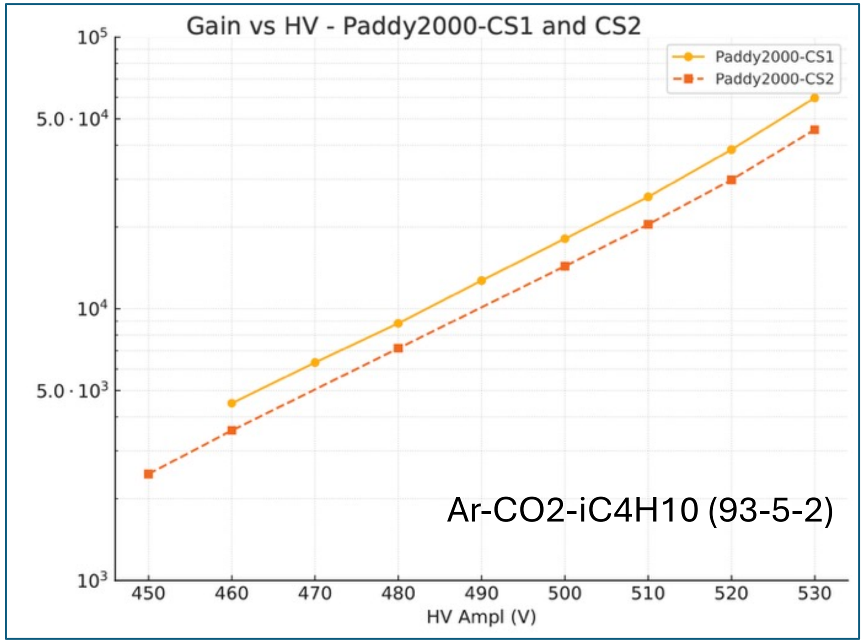
Central area with finer granularity:

- First layer 1x2 mm^2 pads
- Readout layer: 1x8 mm^2

Outer region:

- 1st layer: 2.5 x 2.5 mm^2
- Readout layer: 10 x 10 mm^2

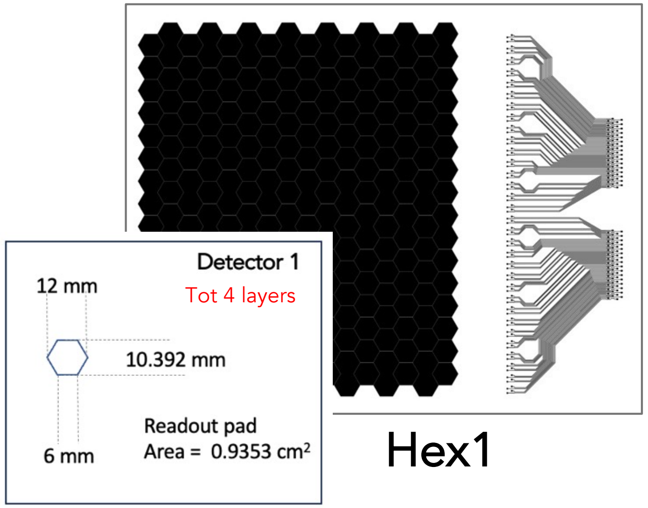
Gain measurements with ^{55}Fe



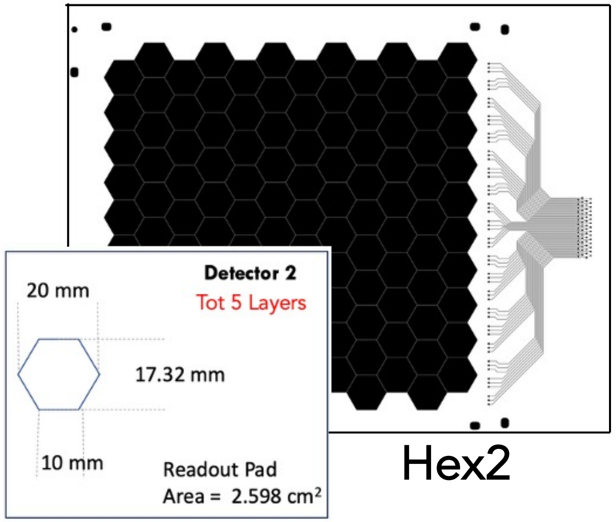
Both detectors are very stable
Reach gain of ~5×10^4
READY TO GO TO THE TEST-BEAM IN NOVEMBER !

What's next: 2) Medium-size capacitive-sharing with hexagonal pads

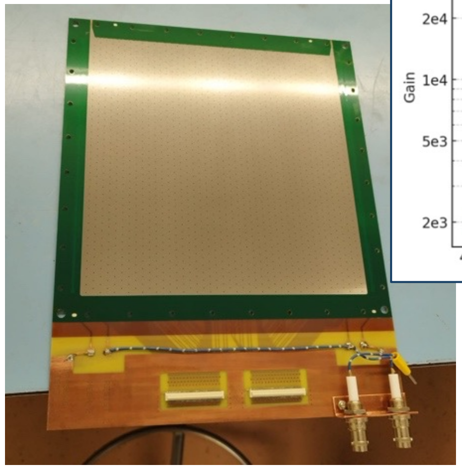
- Two new prototypes with single DLC resistive layer. Active area ~ 20x20 cm^2 with hexagonal pads, implementing 3 and 4 layers of capacitive sharing plus readout pads

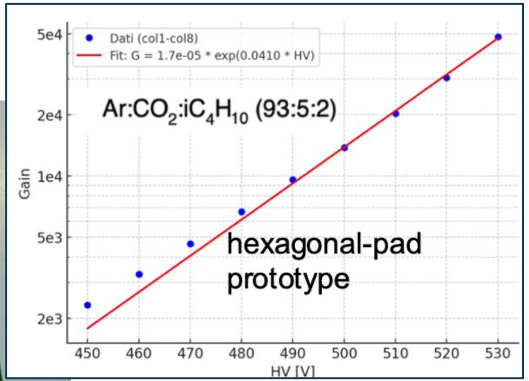


Hex1



Hex2



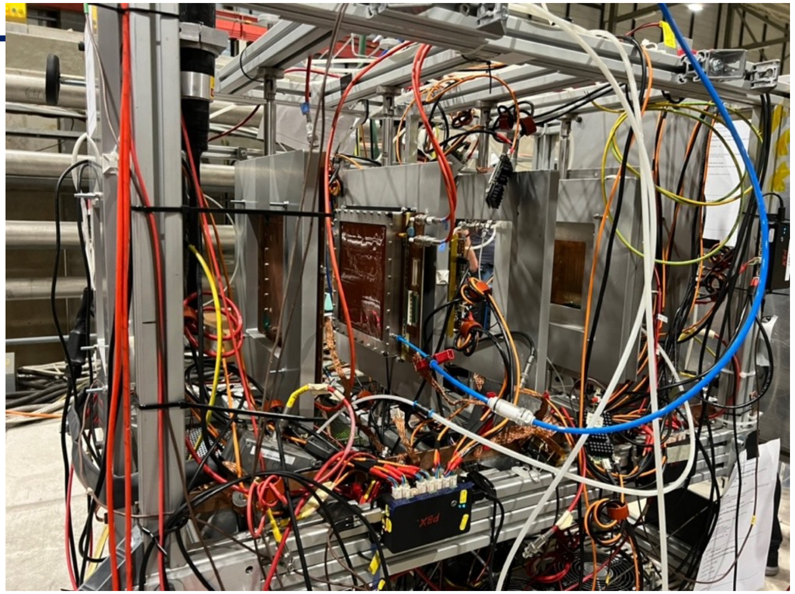


Tot number of pads: 256
Diameter of pads:
- internal layer: 1.5 mm
- Readout layer: 12 mm
- Area readout pad: 0.94 cm^2

Tot number of pads: 120
Diameter of pads:
- internal layer: 1.25 mm
- Readout layer: 20 mm
- Area readout pad: 2.6 cm^2

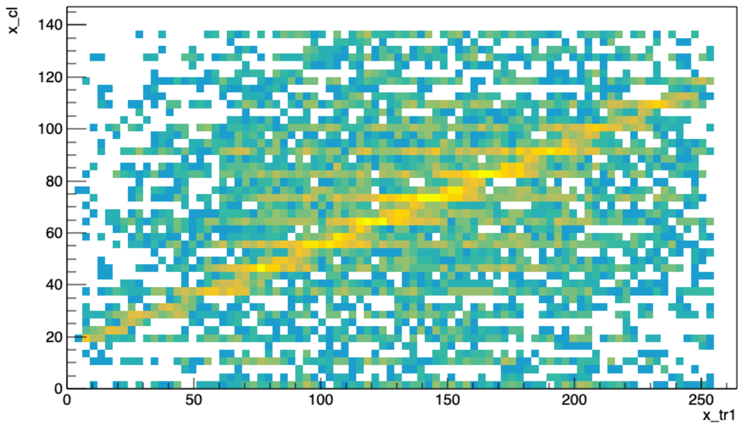
- Production completed in June
- FULL TEST at the November Test-Beam
- First tests done in lab and at the July Test-Beam in the DRD1 MPGD telescope (our first test with VMM) → *next slide*

Medium-size capacitive-sharing with hexagonal pads – JULY Test-Beam



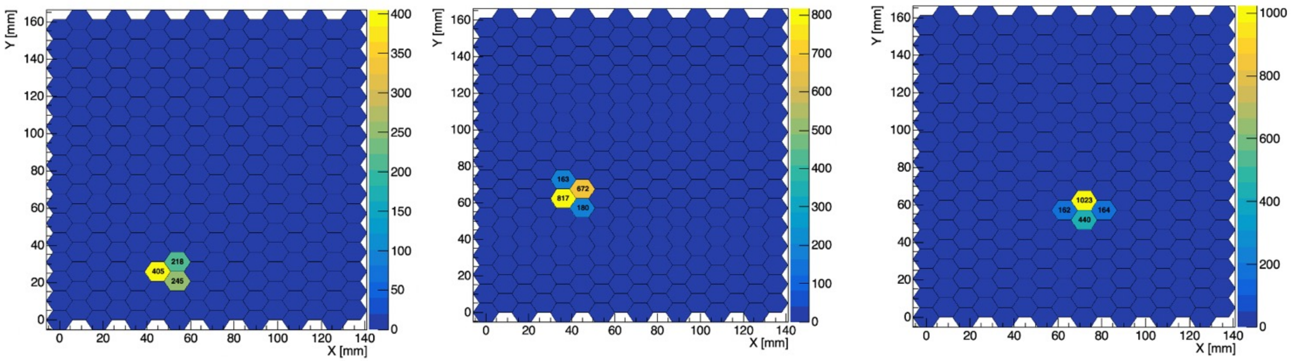
- A first "parasitic" test was done of the hexagonal pad detector 1 (256 pads) in the DRD1-MPGD telescope
- First time we used the VMM (learning it….)
- Struggling with mapping (detector + connector-adapters)
- Adapting our standard reconstruction/analysis software to new event data structure and aiming at a fruitful collaboration to work with Corryvreckan
- All that to say that we are quite behind in the data analysis… HOWEVER, progress is under way.

Hex1_x vs GEM Tracker_x



Good correlation with other detectors

Mapping and clusterisation seems under control (NOW!)

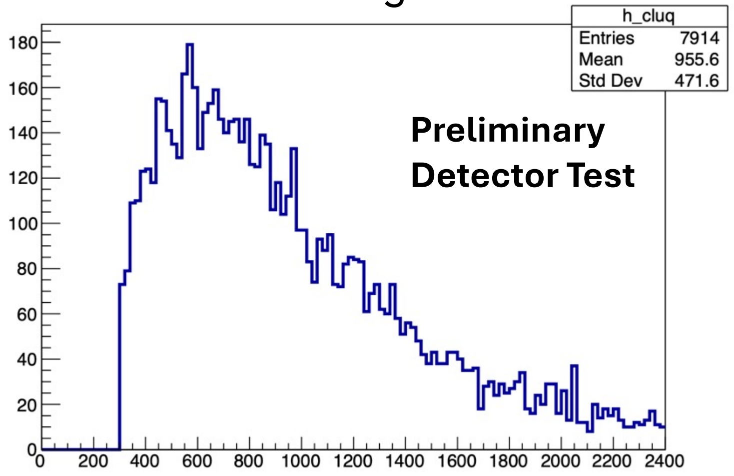


JULY Test-Beam – VERY PRELIMINARY results

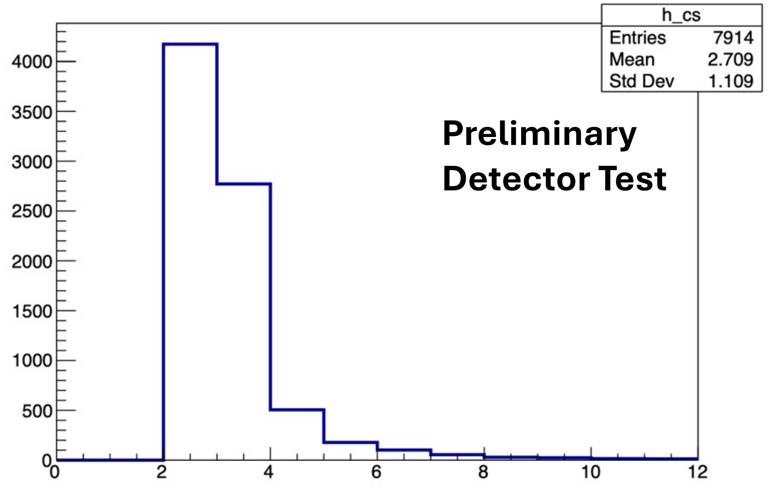
- Preliminary checks to validate the detector's baseline performance
- Fiducial cut and very tight cluster selection cuts have been applied to suppress noisy pads
    - Charge_Adc >150 per pad;
    - Clus_size >1

PROMISING RESULTS
MUCH MORE in a few months from now

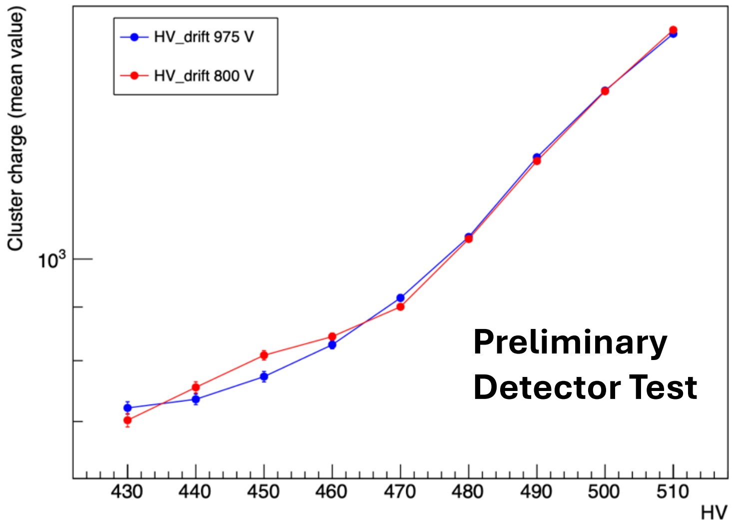
Cluster-charge



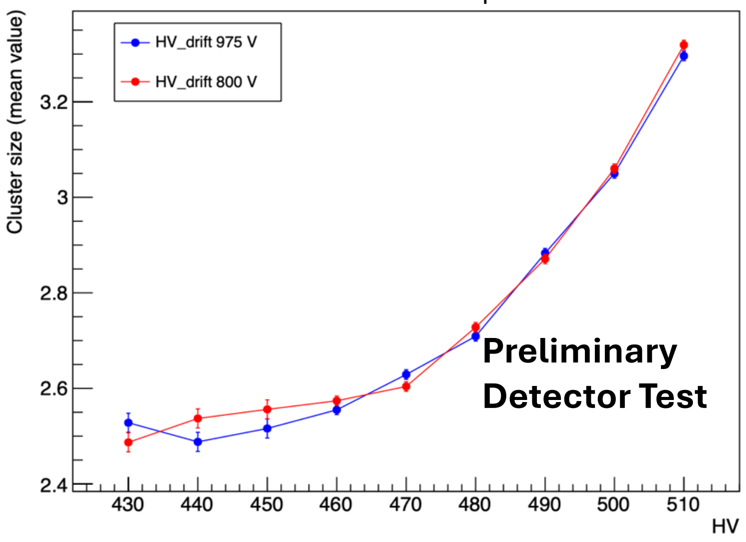
Cluster-size



Cluster-charge Vs HV_{ampl}



Cluster-size Vs HV_{ampl}



Conclusions

- Very good progress so far!
- Promising results with the capacitive sharing concept applied to resistive Micromegas.
- Eagerly looking forward to the next Test-Beam campaign to evaluate the performance of the new prototypes

THANK YOU VERY MUCH!

BACKUP

Towards Application for a Muon System at FCCee

- **EoI ID0084 Resistive Micromegas detectors for Muon systems at FCC-ee**
  - https://indico.cern.ch/event/1529896/contributions/6436845/attachments/3036736/5363065/EOI_Micromegas_FCCee-300125.pdf

- **Resistive Micromegas as an alternative solution for IDEA Muon System and/or ALLEGRO, possibly in conjunction with other technologies**

Resistive Micromegas detectors for Muon systems at FCCee

M. Alviggi[a,b], M. Biglietti[c], M. Della Pietra[a,b], B. Di Micco[c,f], R. Di Nardo[c,f], A. Farilla[c], P. Iengo[a], M. Iodice[c], F. Petrucci[c,f], and G. Sekhniaidze[a]

[a]INFN sezione di Napoli, Napoli, Italy
[b]Università di Napoli Federico II, Napoli, Italy
[c]INFN sezione di Roma Tre, Roma, Italy
[f]Università Roma Tre, Roma, Italy

January 30, 2025

1 Contact persons

Paolo Iengo (paolo.iengo@cern.ch)
Mauro Iodice (mauro.iodice@cern.ch)

2 Scope of planned activities for the next 3–5 years

2.1 Recent developments on resistive Micromegas

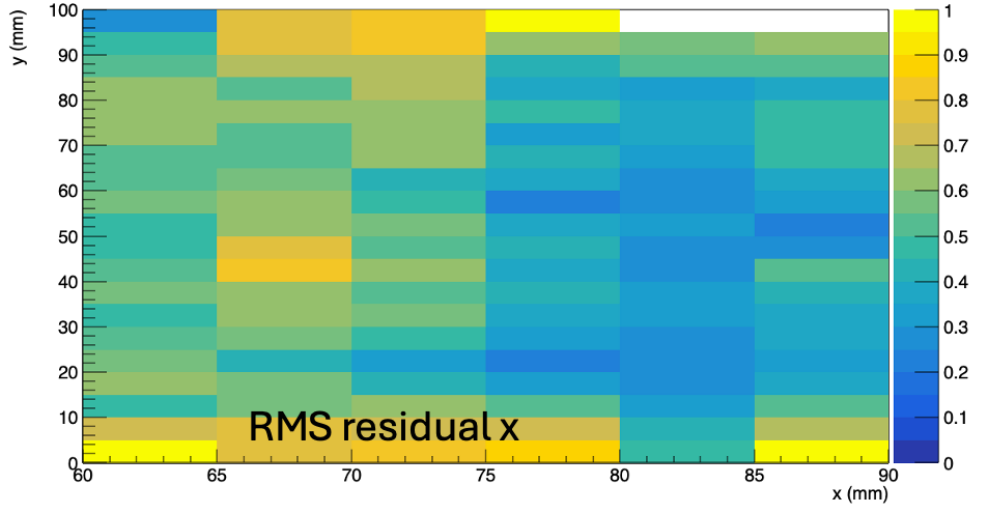
Our research team is conducting since years an R&D activity on high-performance resistive Micromegas detectors. The project is structured in two phases:

R&D Phase 1: Focused on consolidating resistive Micromegas technology for measurements at future colliders, including operation at very high rates (up to 10 MHz/cm^2). A key objective is the optimisation of the spark protection resistive scheme to ensure stable performance at high rates and gain. Additionally, demonstrating the scalability of these detectors for large surfaces is a central goal.

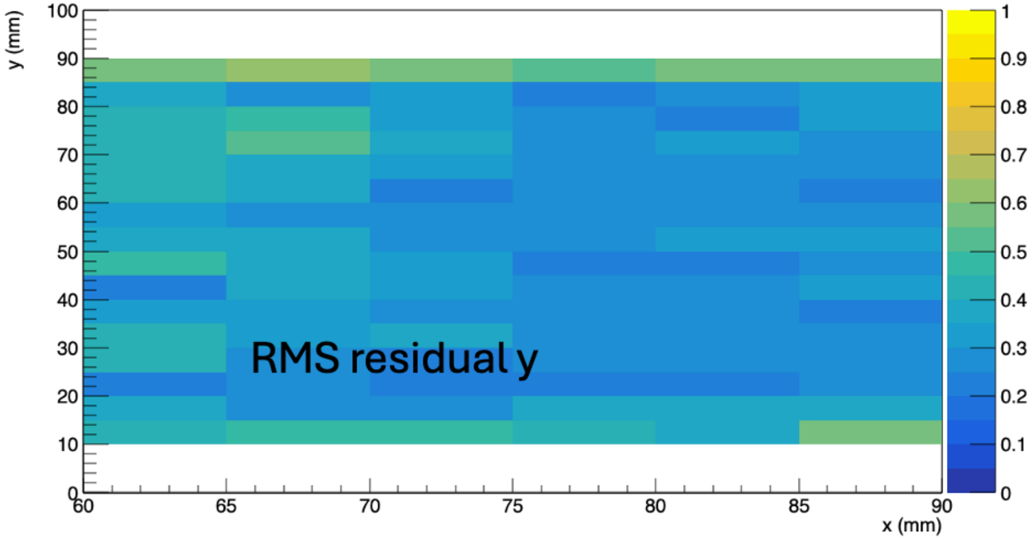
Remarkable results have been achieved, as summarised in [1], with a layout based on a double layer of Diamond Like Carbon structure (DLC) foils and implementing the charge evacuation through a network of dot-connections to ground. Excellent stability was demonstrated for operation under harsh conditions (high rates and high gains), with a large safety margin before the onset of breakdown or instabilities. The targeted objectives were also met in terms of rate capability, spatial resolution (below 100 μm with 1 mm pads), and time resolution (around 5 ns).

R&D Phase 2: Building on the established robustness and stability achieved at high rates, this phase aims to the development of a simplified and optimized version for low to medium rate operations. The key concepts being: high stability; reduced number of readout channels; large area coverage; reliable production and cost reduction; longevity; use of eco-friendly gases; simple operation and maintenance.

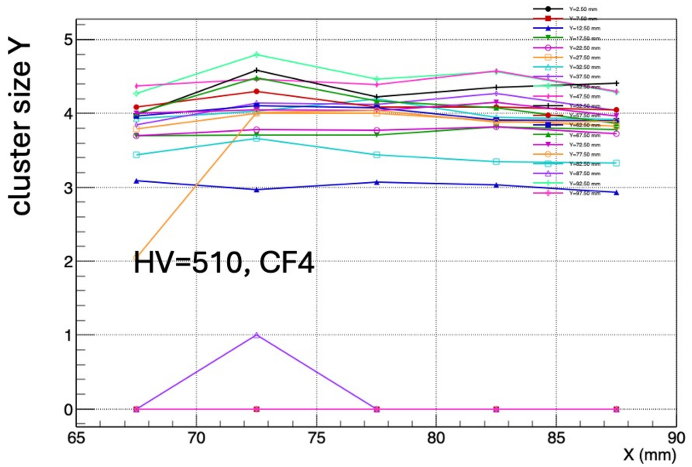
Other convincing plots for cross-talk issue



The RMS residuals in the X-coordinate INCREASE as the distance from the connector grows

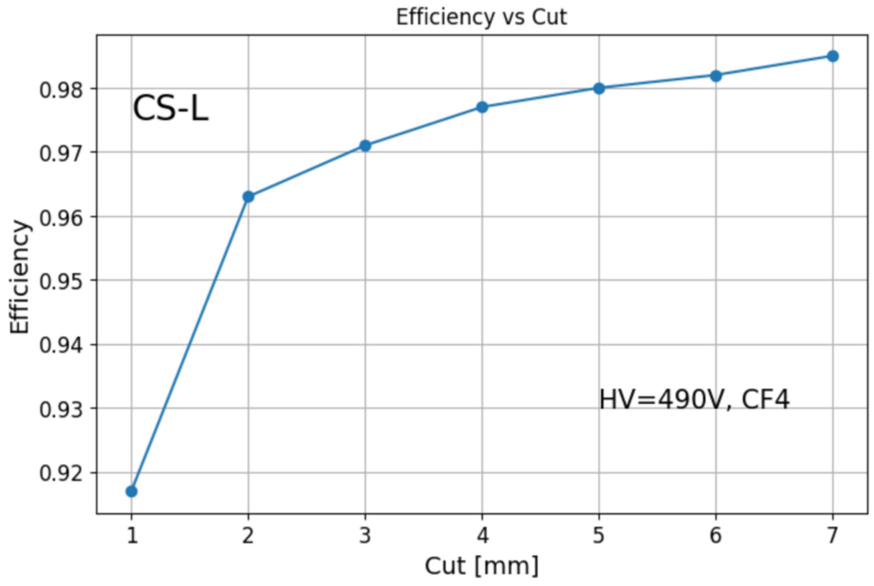


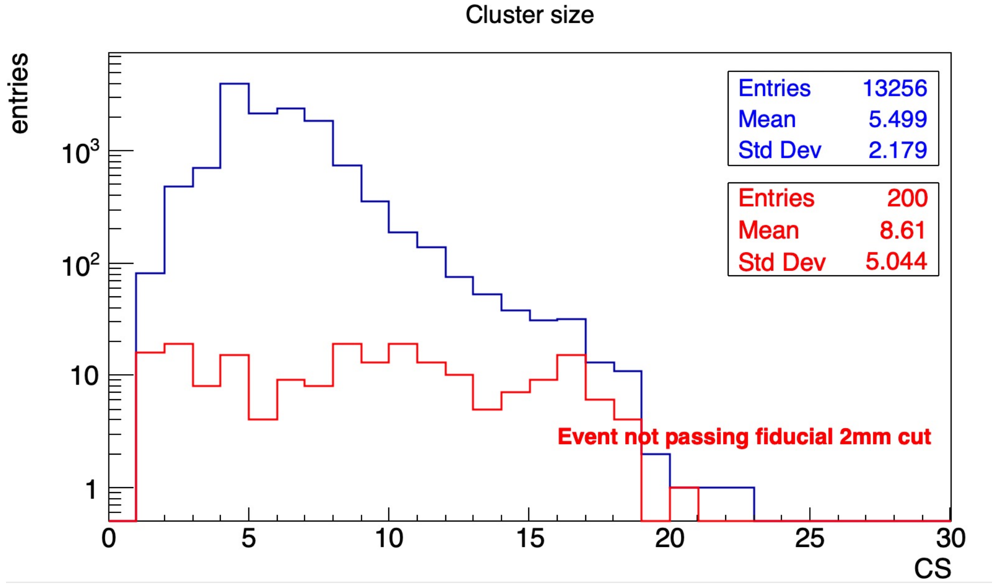
RMS residuals in Y-coordinate is FLAT

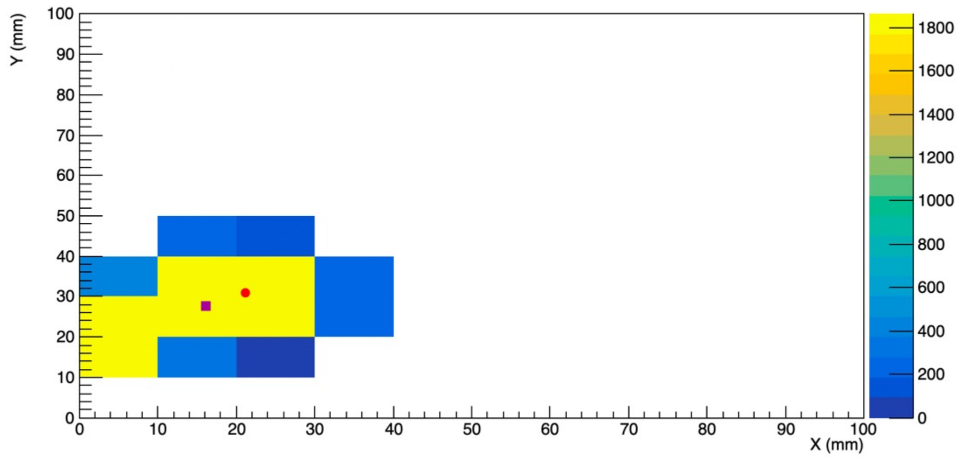


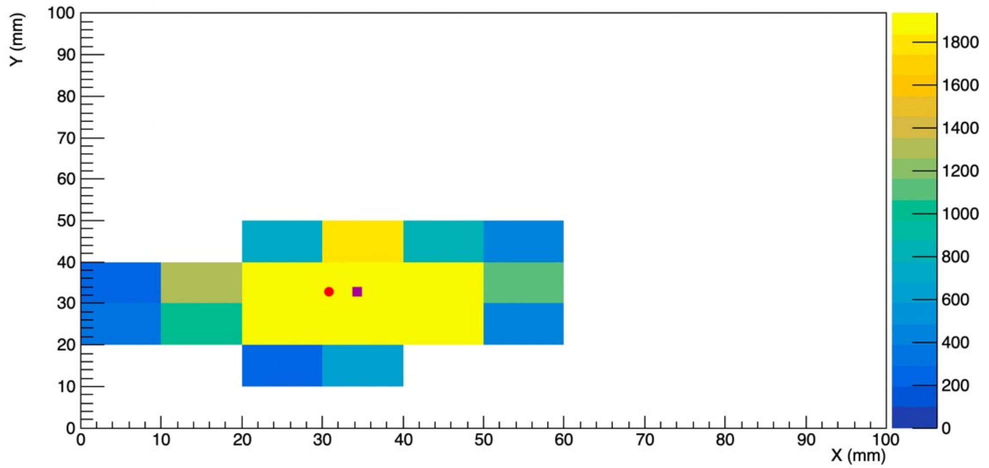
Cluster projection in Y Vs X is flat

Paddy-CS – Efficiency and impact of anomalous clusters









Paddy-CS – Time Response of neighbour pads

Time Response Analysis

For both sections of the detector:
CS-Small and CS-Large