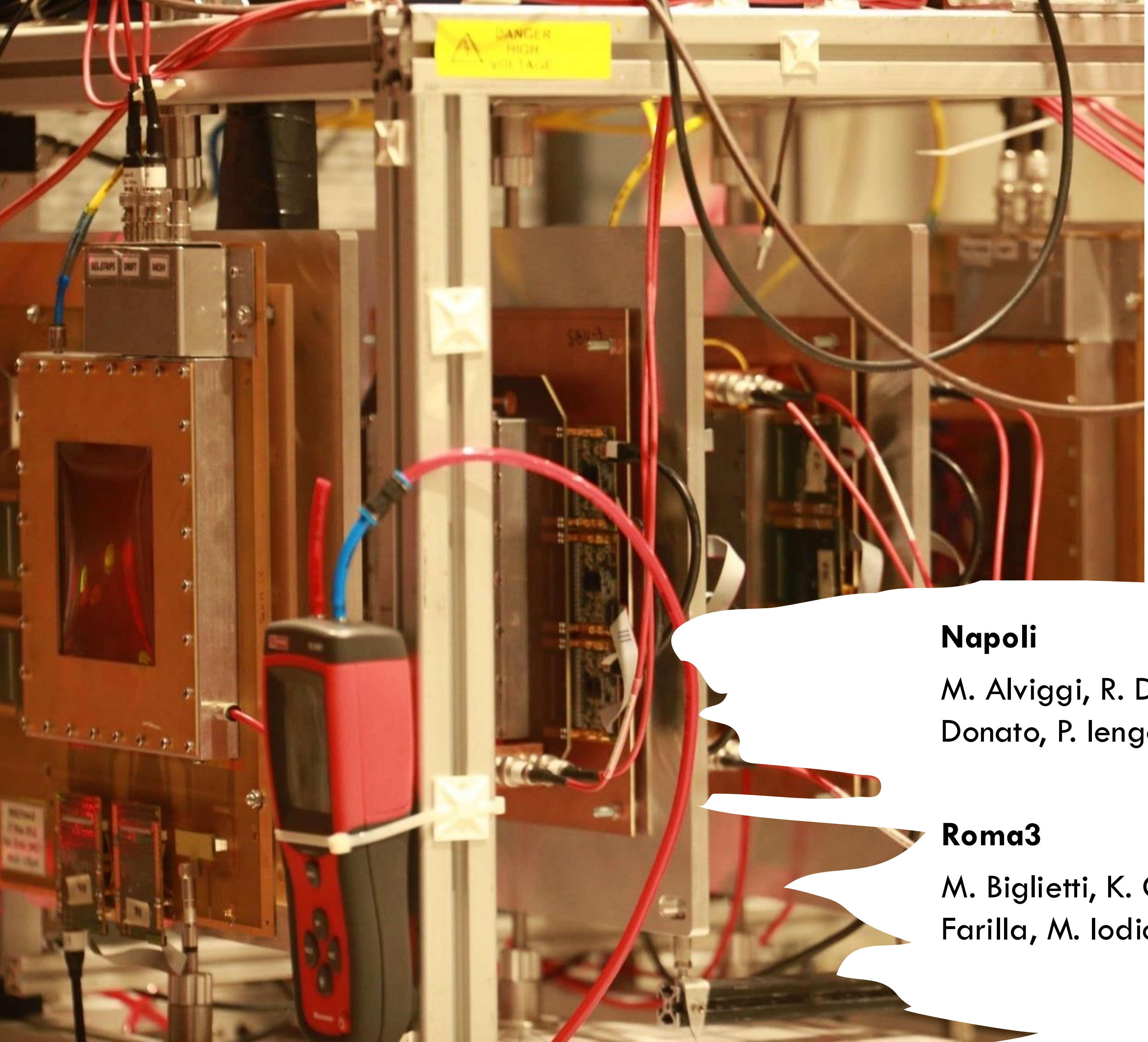


R&D plans for the Micromegas detectors in 2025

IDEA Study Group

22/04/2025

Napoli

M. Alviggi, R. De Asmundis, M. Della Pietra, C. Di Donato, P. Iengo, S. Perna, G. Sekhniaidze

Roma3

M. Biglietti, K. Chmiel, B. Di Micco, R. Di Nardo, A. Farilla, M. Iodice, R. Orlandini, F. Petrucci

INTRODUCTION – Micromegas for FCCee Muon Systems

- Started in 2015 the R&D on High Performance Resistive Micromegas has achieved all the project goals and is **fully aligned with the ECFA Roadmap implemented in DRD1**
    - Excellent results achieved with resistive Micromegas for high-rates configuration implementing DLC resistive foils (double layer for high-rate applications)
    - Stable operation with Eco-friendly, non flammable, cheap gas mixture Ar-CO_2(5%)-Isobutane(2%) at atmospheric pressure
    - Stable operation up to very high gain, > 5 x 10^4

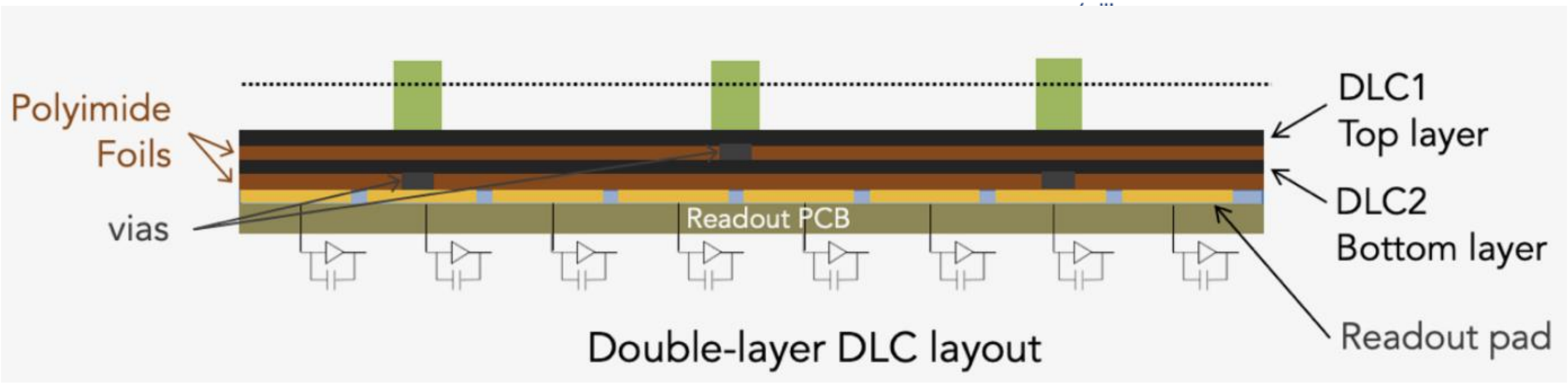
      → Large margin at the optimal Working Point before instability
    - Rate Capability > 1-10 MHz/cm2 @ gain > 10^4
    - Very good results on spatial and time resolution (<100 um and ~5 ns, respectively)
    - Construction of large-sized high-granularity detectors (50x40 cm^2) demonstrating scalability up to modules with dimensions large enough to cover large apparatuses

- This R&D is progressing towards LARGE AREA, STABLE AND SIMPLIFIED STRUCTURES for Low/Medium rate applications: R&D with readout capacitive sharing for reducing the number of elx channels

State of the art - The Double DLC layer resistive configuration

- Configuration inspired by G. Bencivenni and co-authors (applied to uRWell) (see e.g. JINST_10_P02008)
- Charge evacuation inside the active area, through “vertical dots”
- First Prototype: Grounding connection vias “filled manually”
- Second generation: the sequential build up technique (SBU) was implemented exploiting copper-clad DLC foils. It allows best alignment of vias and connections by plating techniques (Rui De Oliveira at INSTR 2020)

Double DLC Uniform resistive layer



DLC20 (20 MΩ/sq)

DLC-SBU (30 – 50 MΩ/sq)

- Uniform double DLC layer with DOT grounding connections (every ~8 mm)
- Sequential Build-Up technique implemented in recent years

Achieved performance

- Gain and maximum stability point for different gas mixtures
- Charging-up
- Energy resolution
- Rate capability and ion backflow
- Rate capability and dependence on the irradiated area
- Test-Beam:
    - Spatial Resolution
    - Efficiency
    - Time Resolution

Can be found in a recently published paper:

M. Alviggi et al.
"Resistive fine granularity Micromegas: characterization and performance for different spark protection resistive schemes"
2025 JINST 20 P01012

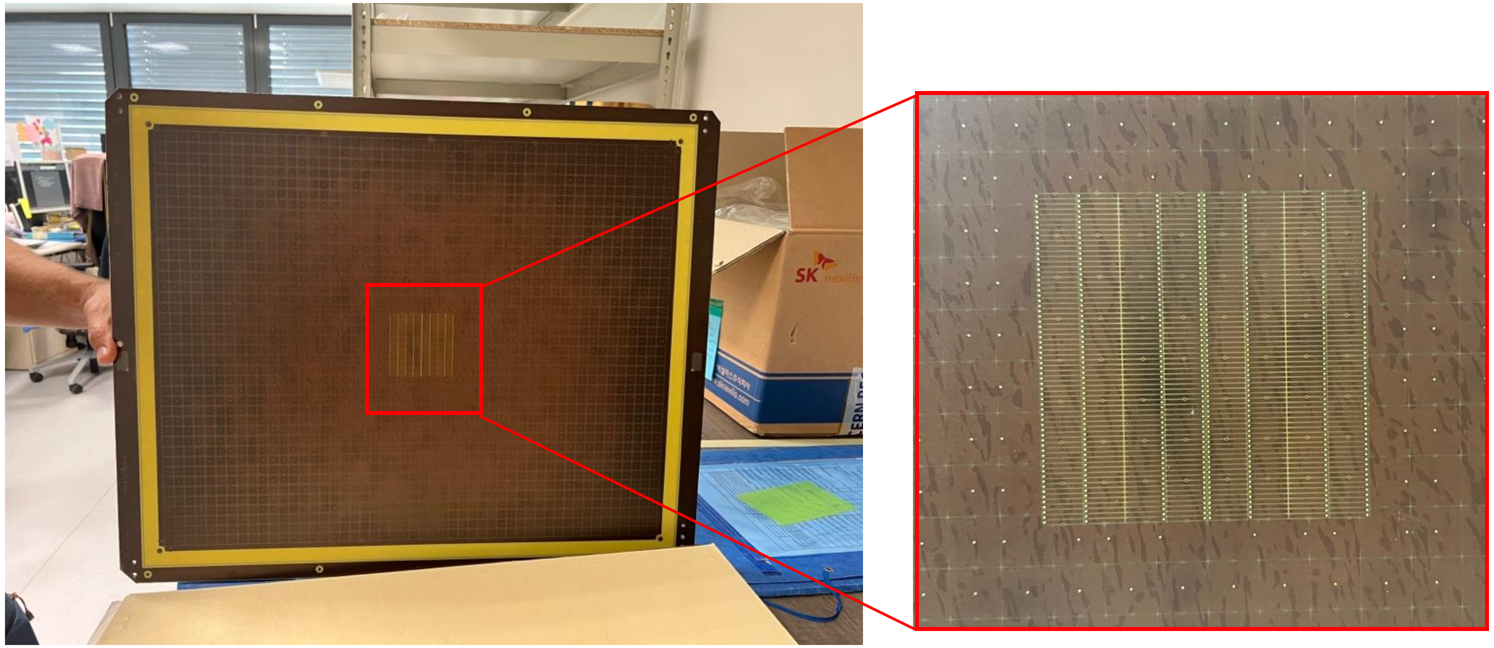
and some results in Backup Slides

These Performance studies refer to small (5x5, 10x10 cm^2) and medium size 20x20 cm^2) Micromegas prototypes

…more recent developments toward LARGE size detectors…

Towards Large Area

$50x40\ cm^2$ Double DLC layer



High-rate configuration
DOUBLE DLC LAYER

Fine granularity readout in the centre, $1\ cm^2$ pads elsewhere (for practical reasons – number of channels)

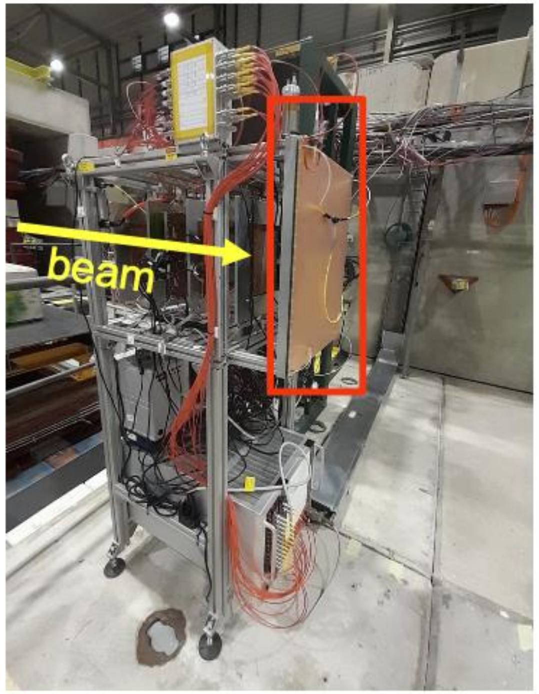
Central region
$6.4x6.4\ cm^2$
with $1\ x8\ mm^2$ pads

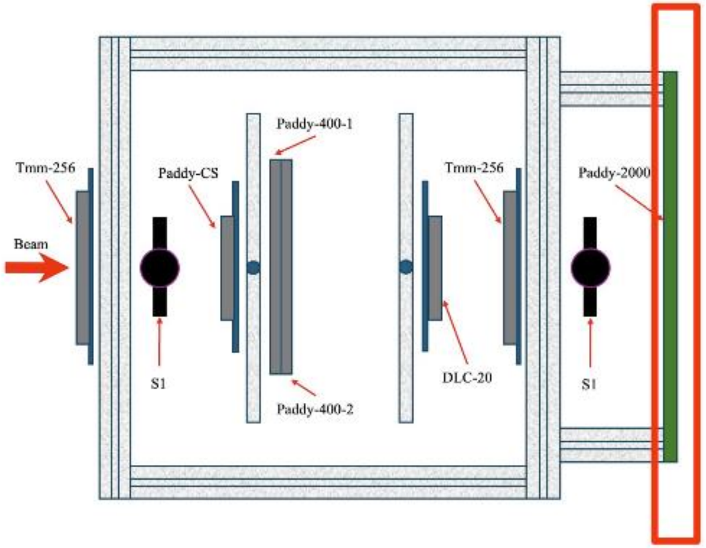
Hirose connectors on the back
Central region readout through 4 connectors
Full detector readout out by 20 hybrids

Results of the 50x40 cm^2 Micromegas

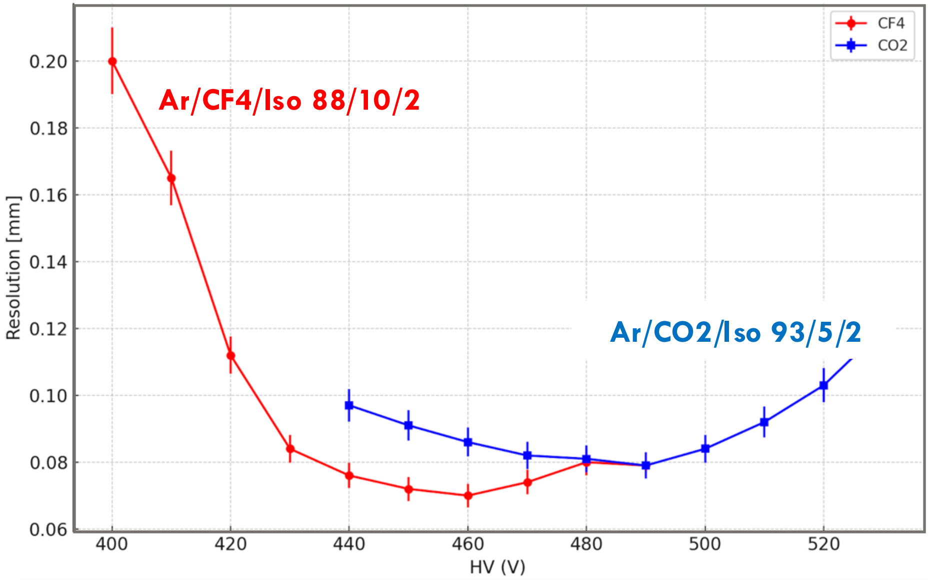
Chamber tested for the first time during a test beam in 2024 at CERN H4

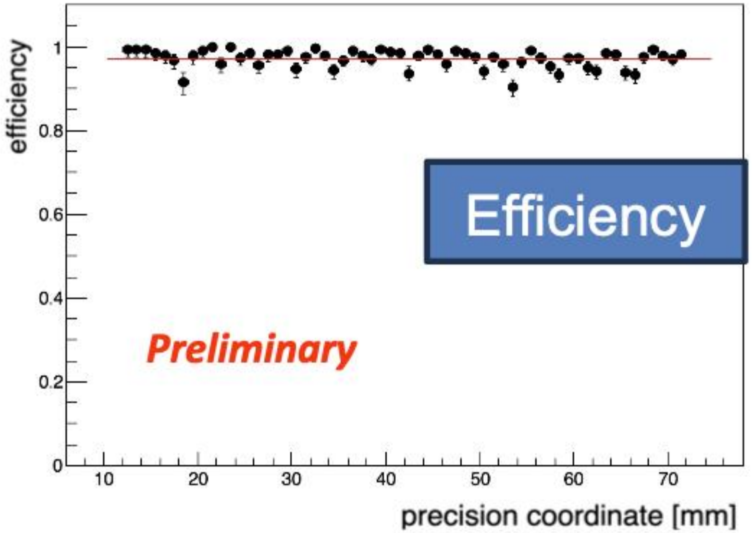
- Similar performances achieved as smaller prototypes
- The full analysis of the collected data is in progress





Spatial Resolution Vs HV





Activity in 2024 – 2025

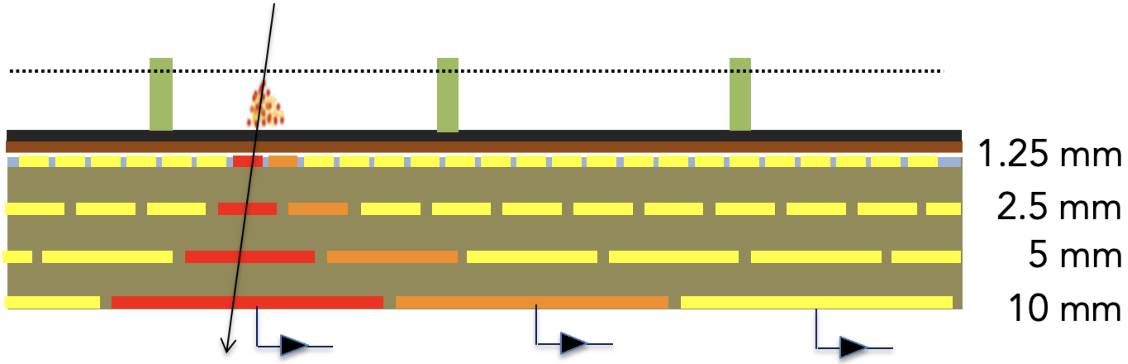
Progressing towards LARGE AREA, STABLE AND SIMPLIFIED STRUCTURES for
Low/Medium rate applications

R&D with readout capacitive sharing

Medium/Low-rate Version – Capacitive Sharing

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

SINGLE LAYER DLC Layout implementing the "capacitive sharing" concept, aiming at preserving good spatial resolution with a reduced number of readout channels: Charge shared in large readout pads through the capacitive coupling between stack of layers of pads.

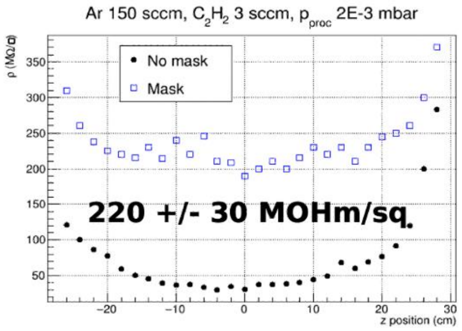


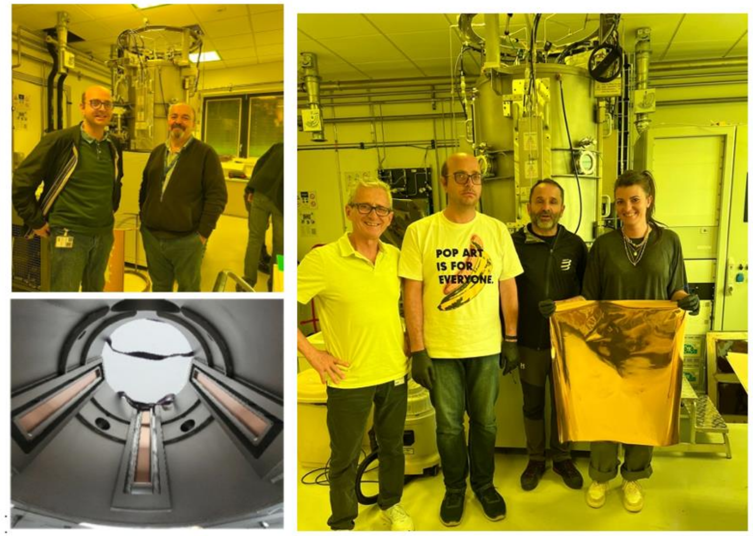
The production is greatly simplified:

- Capacitive sharing implemented in multilayer PCB
- SINGLE LAYER DLC, without grounding vias in the active area.

Moreover, now the production of DLC foils can be done in house, at CERN

Production of DLC foils now feasible at CERN with the CERN-INFN Sputtering Machine

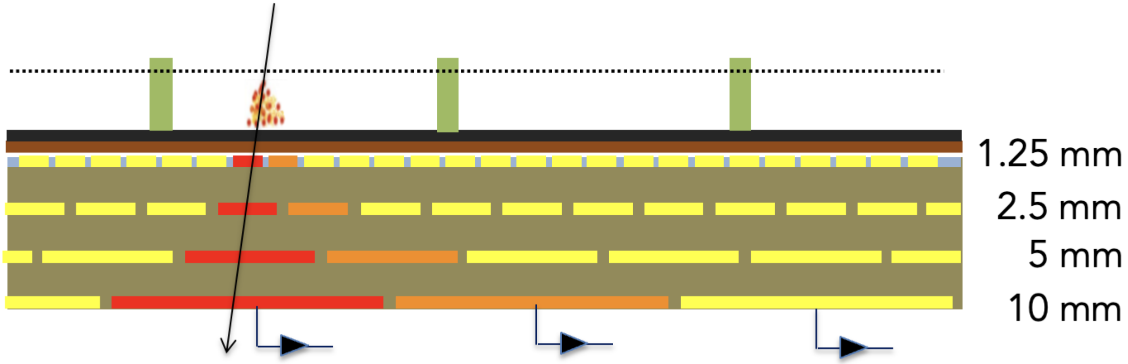


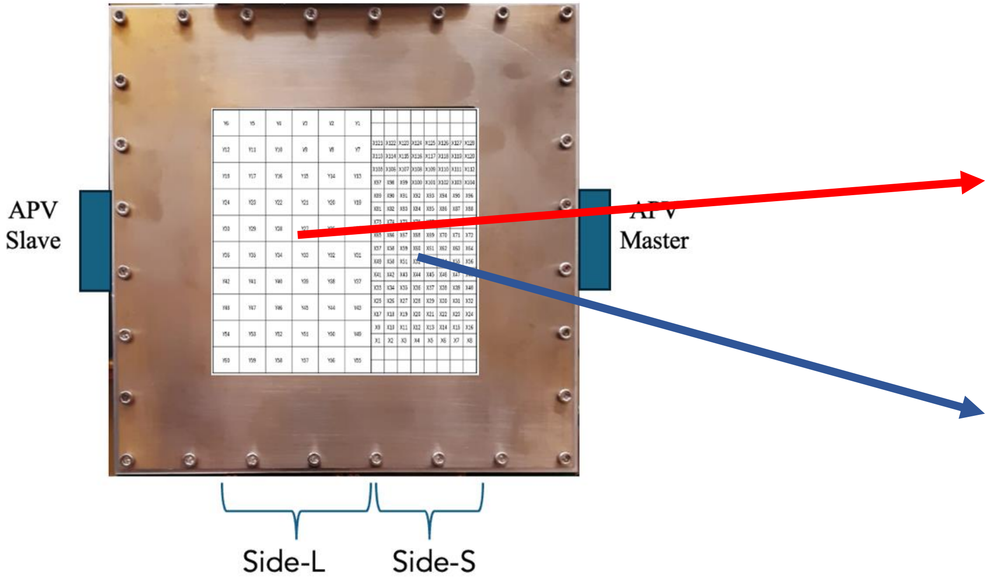


Medium/Low-rate Version – Capacitive Sharing

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

We built a small size prototype, with two sections, to explore capacitive sharing over three and four layers, with readout of 5x5 and 10x10 mm^2 size pads, respectively



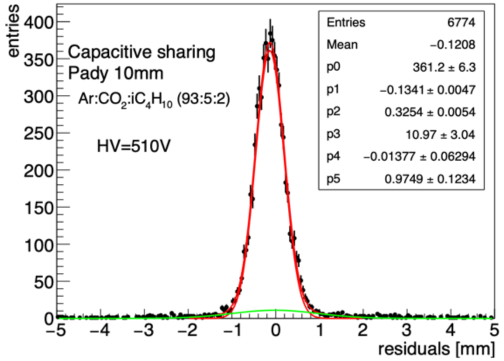


- Pad size of "top-layer" (signal induction): 1.25x1.25 mm2
- **Side-L**: Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2
- **Side-S**: three layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2

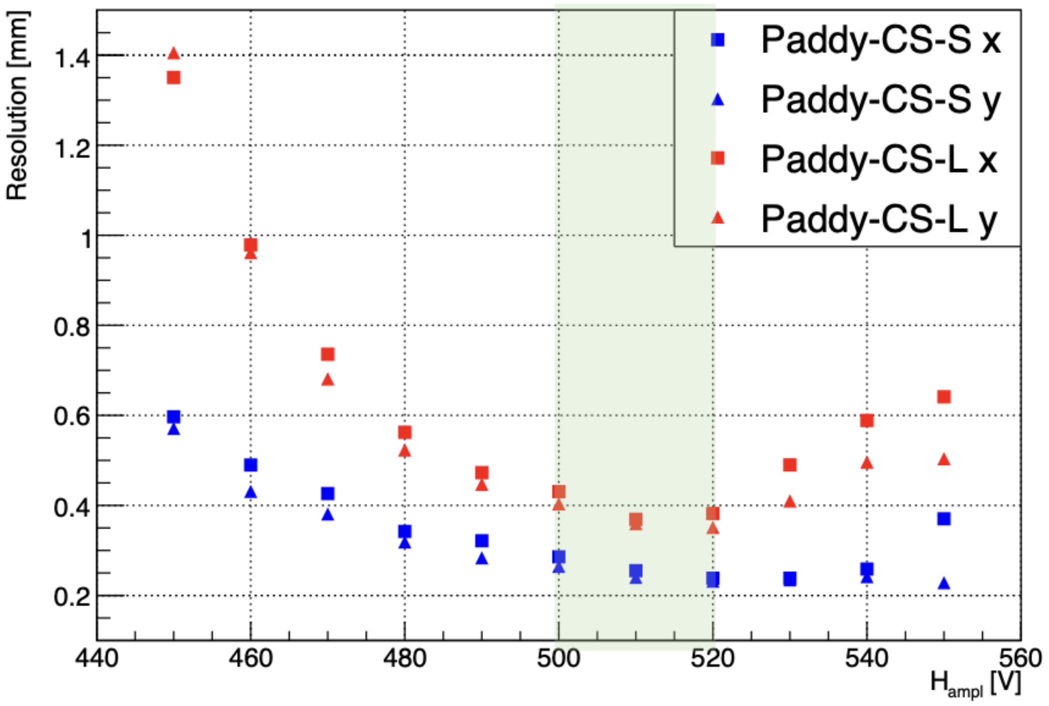
Capacitive Sharing Test-Beam Results

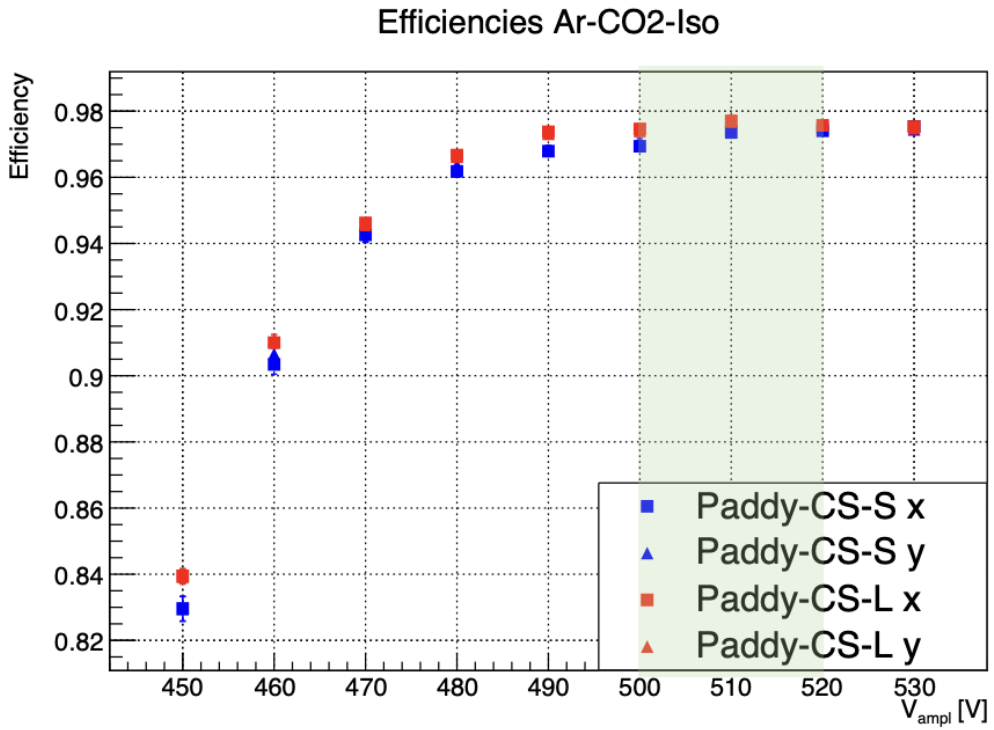
Spatial Resolution and Efficiency

Resolution: half-width of the distribution retaining 68% of the events



Resolution with coverage at 68% Ar-CO_2-Iso





REACH ~380 μm with 10x10 mm^2 pads

(~320 μm with optimised cluster centroid) (NEW)

→ A factor ~1/30 of the pad size

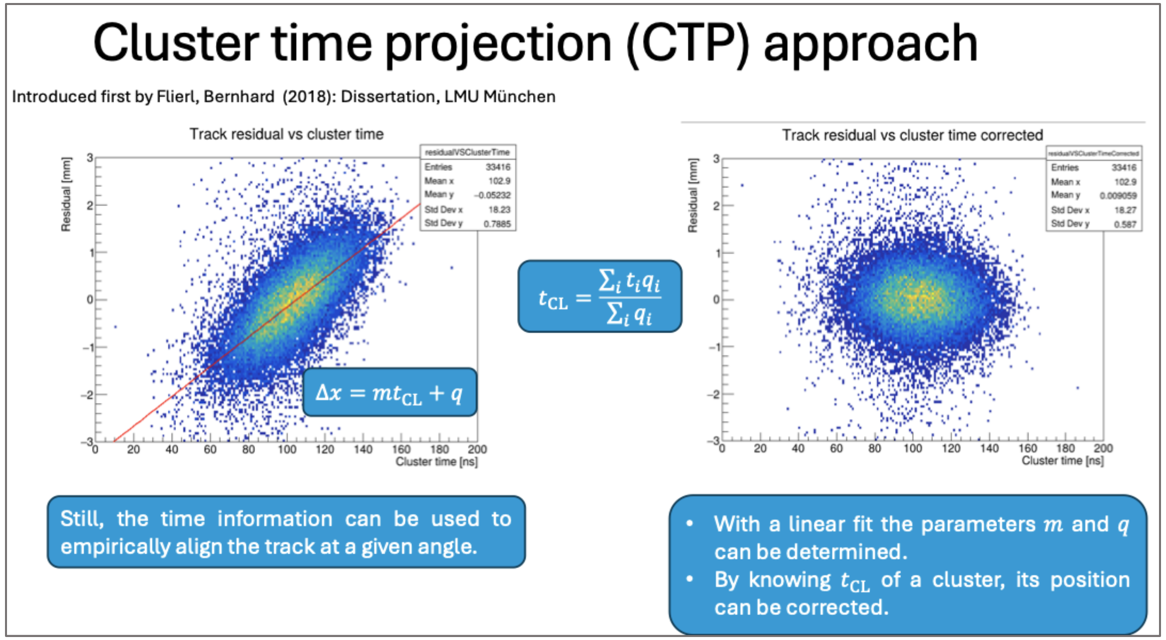
~220 μm with 5x5 mm^2 pads (1/23 of the pad size)

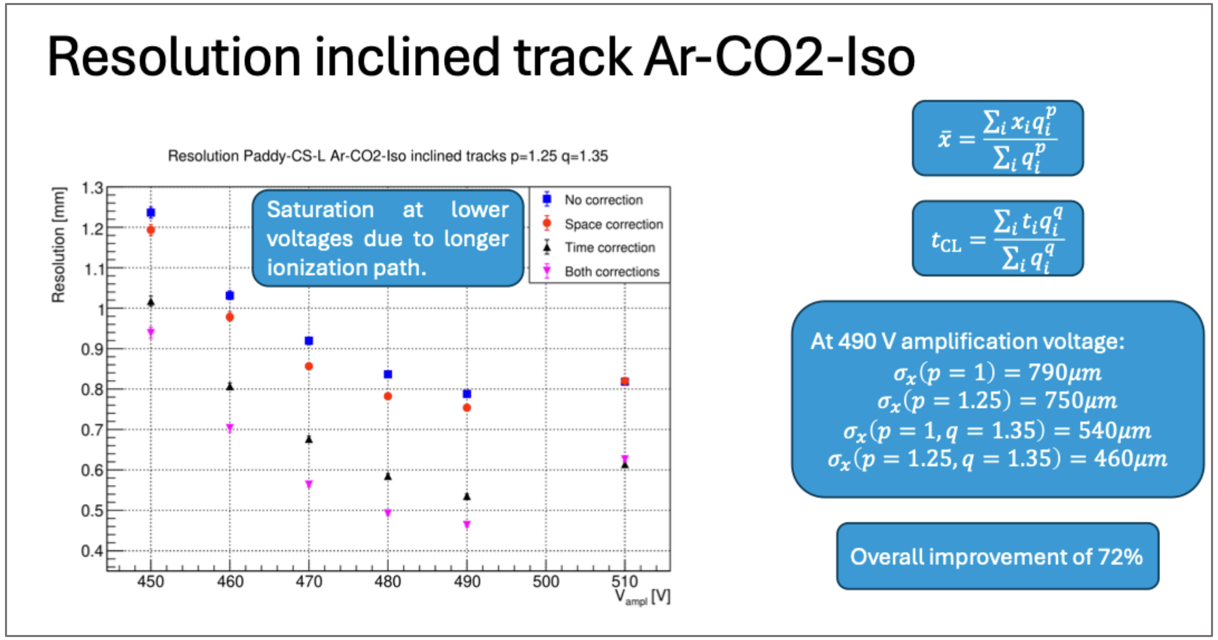
Capacitive Sharing Test-Beam Results

Spatial Resolution FOR INCLINED TRACKS

Exploiting the timing information, implementing the “Cluster Time Projection” method (developed for ATLAS Micromegas) an excellent spatial resolution also for inclined tracks can be obtained

Track angle: 38°



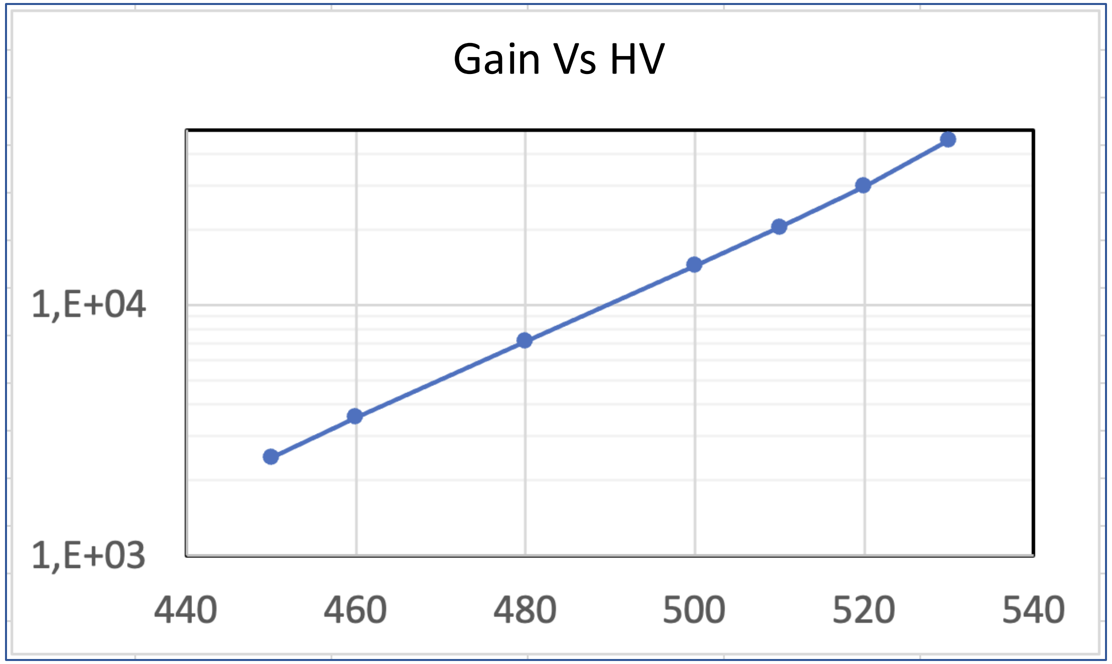


See K. Chmiel DRD1 Coll. Meeting 24–28 Feb 2025

Spatial resolution for inclined tracks at 38° from 10x10 mm2 pads: 460 µm *(work in progress)*

Activity in 2024 – 2025

- Having successfully demonstrated both the scalability to large-size modules and the capacitive sharing concept (on small prototypes), in 2024 we initiated the construction of an ‘all-in-one’ large-size Micromegas detector featuring a high-rate configuration with enhanced stability and capacitive sharing.

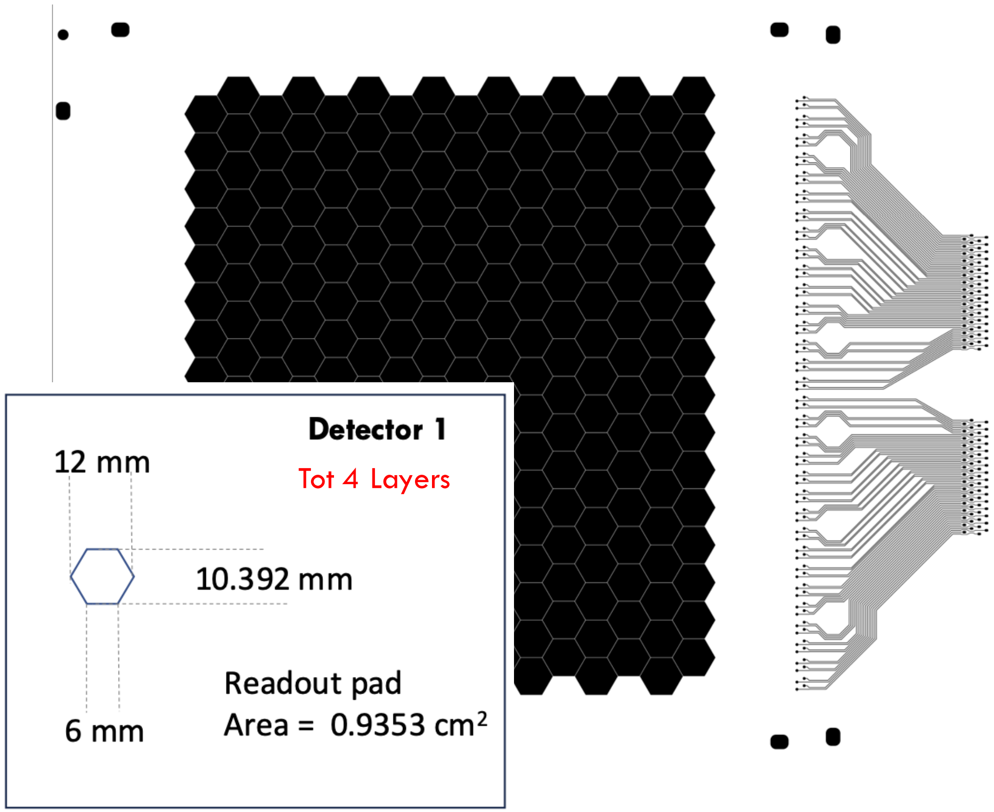


- DELIVERED: end of 2024

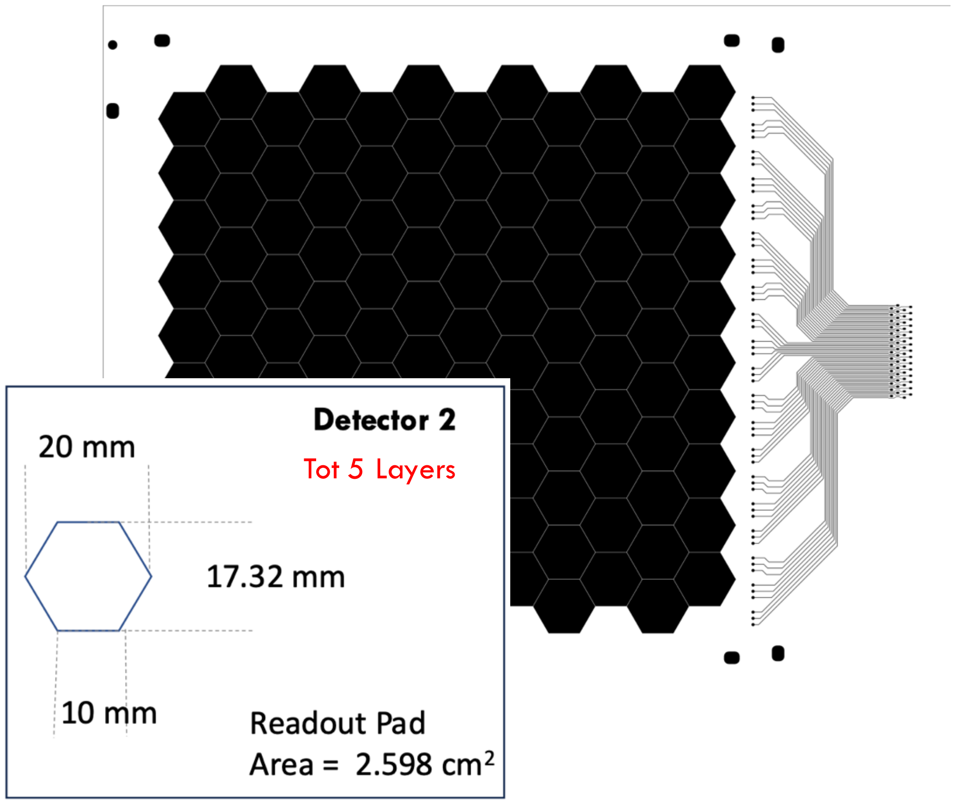
- First tests started beginning of April 2025
- Aiming at Test-Beam in November

Activity in 2024 – 2025

- Aiming to further investigate the potentiality of the capacitive sharing for 2D pad readout we launched the production of two new detectors, with 4 and 5 layers of hexagonal pads



("diameter" internal layer: 1.5 mm)



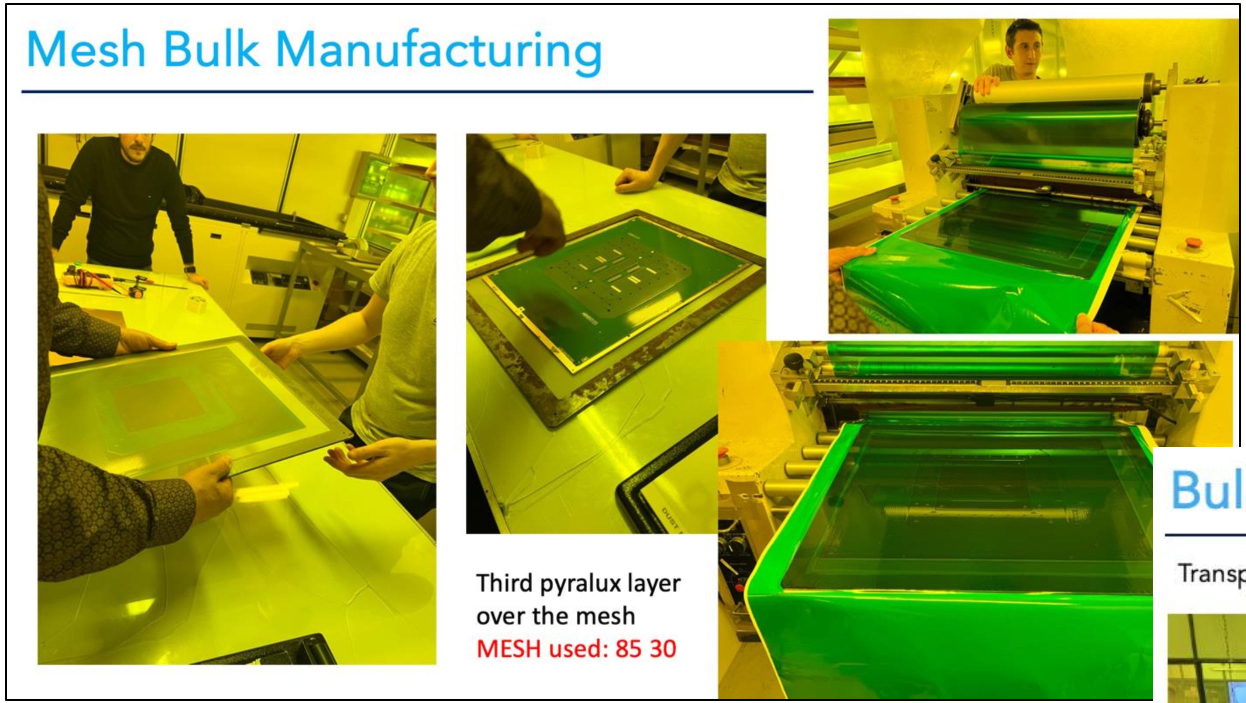
("diameter" internal layer: 1.25 mm)

- Should be delivered in May 2025 – Aiming at full performance studies at the Test-Beam in November 2025

Activity in 2024 – 2025

INDUSTRIALISATION

Activity in 2024 – 2025 - Micromegas Production at ELTOS



In 2024 we continued our efforts to **transfer the technology of mesh bulk manufacturing to a PCB company (ELTOS S.p.A.).**

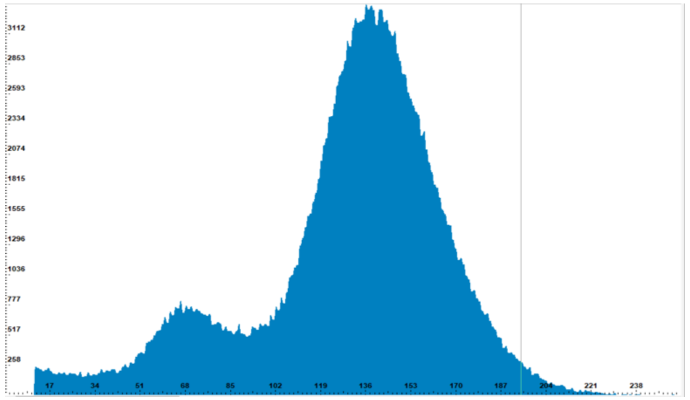
It's important to note that **bulk processing** is not a standard practice within the PCB industry.

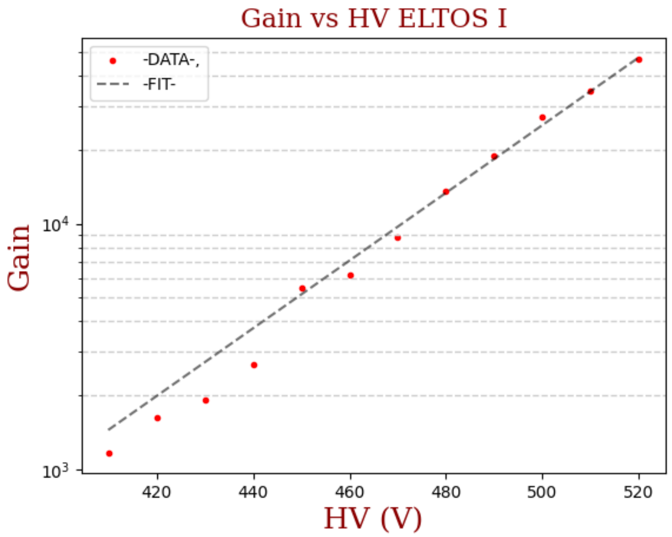
A production on small-size simplified resistive micromegas (single layer DLC) successfully carried out in June 2024

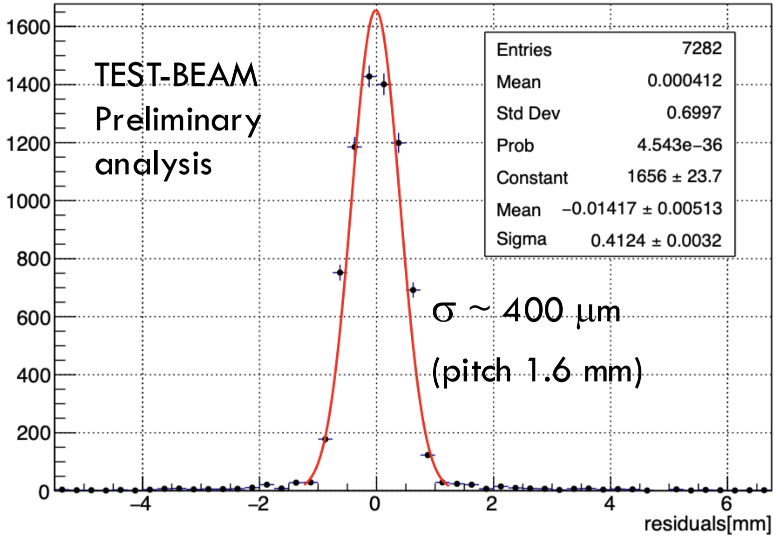
Activity in 2024 – 2025 - Micromegas Production at ELTOS

Initial results from laboratory characterization and test beam data are encouraging, although not yet fully satisfactory.

Performance still affected by instabilities and elevated noise levels.







We are considering a new iteration with ELTOS on medium-size detectors.

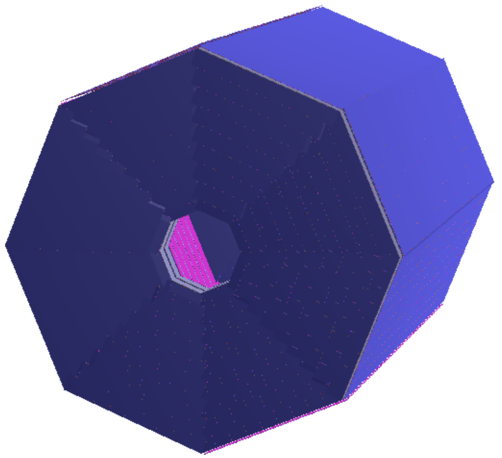
The cost is around 10 k€, but the project is not yet funded.

Received a positive review, but funding has so far only been granted through "DRD1 INFN co-financing"

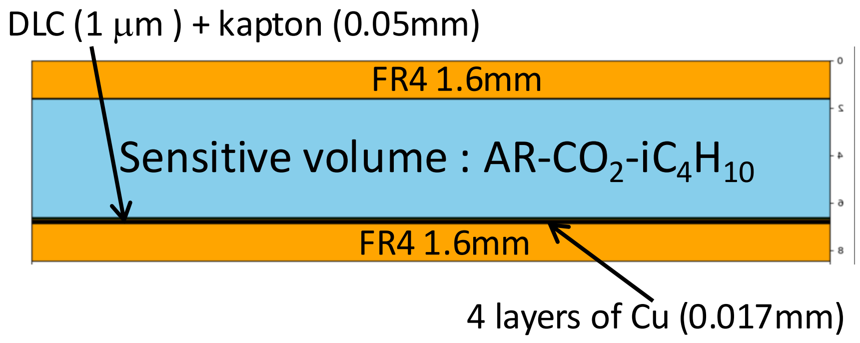
Activity in 2024 – 2025 - Simulation studies

FCC Muon system simulation based on Padded Micromegas

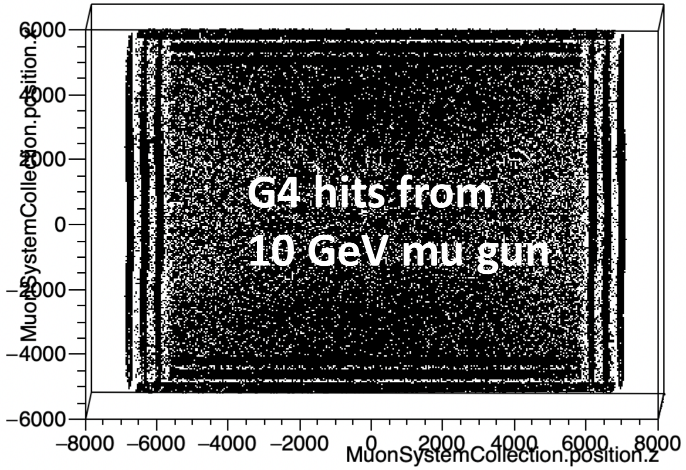
FCC Muon system simulation based on Padded Micromegas



- Work started to implement full-sim using Key4hep/DD4hep
- Based on M. Ali builder (thanks!)
  - https://github.com/key4hep/k4geo/tree/main/detector/muonSystem



- Initially included in ALLEGRO geometry but can be easily adapted into IDEA, allowing comparisons between different solutions
- 3 layers of detector tiles (50x50cm), readout pads of 10mm x 10mm, 2 Yokes (30cm)
- next step: finalize/optimise simulation, start digitization (..and reconstruction)



Planned activities for the next 3 – 5 years

How does the program outlined so far fit into the context of a long-term R&D effort for FCC-ee?

See EoI “Resistive Micromegas detectors for Muon systems at FCCee”
at this *link*

From EoI “Resistive Micromegas detectors for Muon systems at FCCee”

2.2 Planned activities for the next 3-5 years

2025 – 2027

- Develop the concept of capacitive sharing to reduce the number of readout channels while preserving good spatial resolution. Investigate the limits of this technique balancing number of layers/pad-size/signal response
- Optimisation of the resistive protection scheme - Understand the limits of single DLC foil for large size modules (resistivity / detector-size / Voltage drop)
- Advance the technology transfer for construction in the industry (with ELTOS S.p.A., this process has started for resistive Micromegas with bulk mesh).

2026 – 2028

- Optimisation of readout electronics. Comparison of available ASICs and analysis of system scalability $\rightarrow$ Synergies with other MPGD groups
- Enhancement of time resolution while minimizing the use of high-GWP gases.
- Production of a full-size prototype for application at FCCee experiments.

2027 – 2029

- Ageing studies, aimed at ensuring the integrity and operational stability of the systems over extremely long data-taking periods.
- Participation in the design, if needed, of new ASICS

Financial aspects

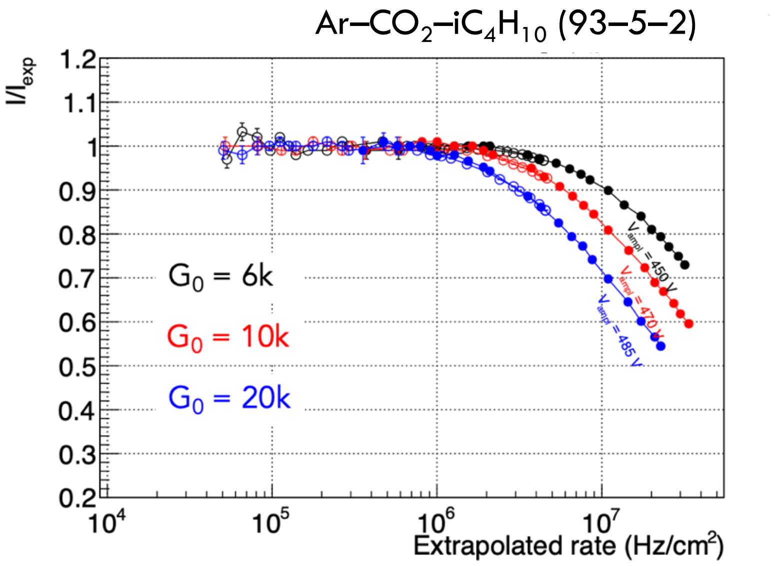
The budget for all the activities reported here was provided by the RHUM project within CSN5, except for the two new capacitive sharing prototypes with hexagonal pads, funded by RD_FCC and currently under construction.

We are considering for 2025 a request for additional fundings AT LEAST to carry on the activity of industrialisation with ELTOS (10 kE) → to be discussed

ADDITIONAL MATERIAL

Achieved performance

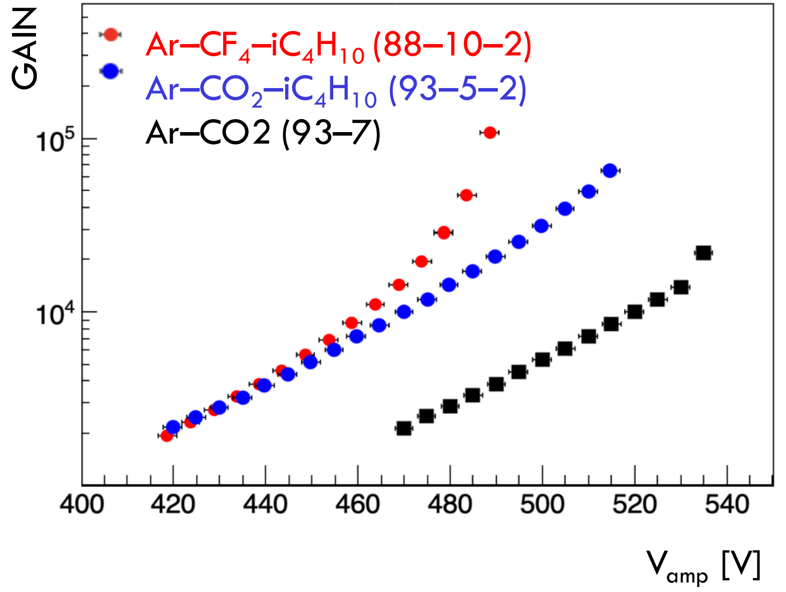
Rate capability Vs X-rays



Here, the rate capability is reported for **gains of 6, 10, 20 k** with X-rays irradiations from X-ray gun (~8 keV)

Gain drops at **10 MHz/cm²** are limited to 20% at G_0 = 10000

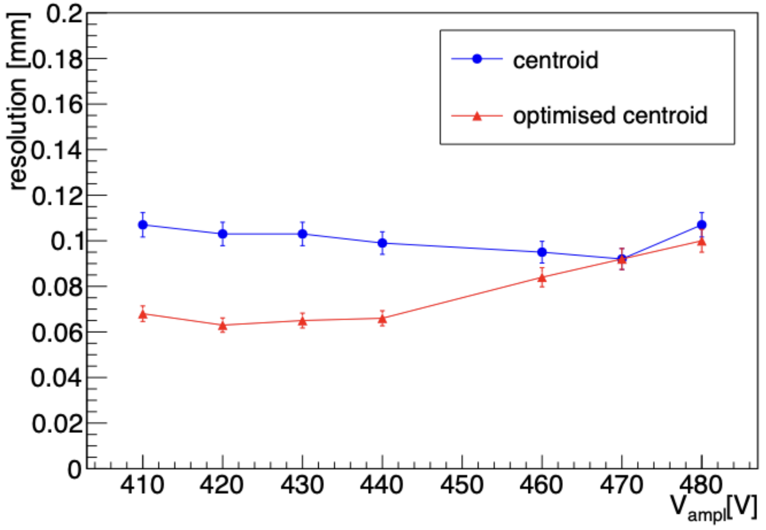
GAIN Vs HV - different Gas Mixtures



- Good stability
- High Gain with 2% of iC_4H_{10}

Above 5 x 10⁴

Test-Beam: Spatial Resolution

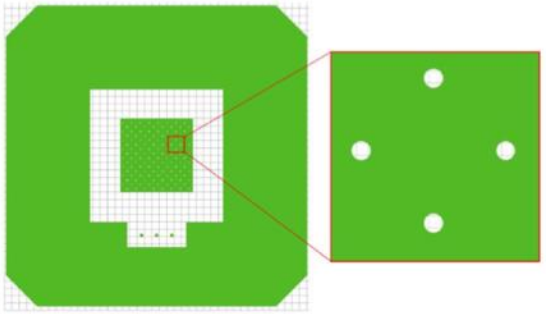


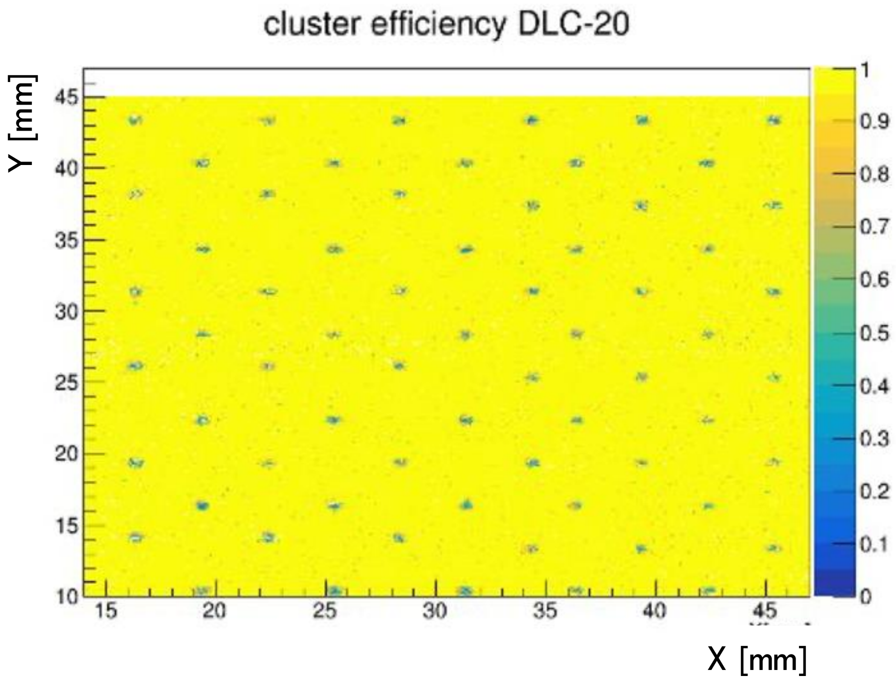
Optimised : **~65 µm with 1mm pad**

Achieved Performance - Efficiency

LOCAL INEFFICIENCIES from Circular pillars:

- 0.3 mm for DLC20

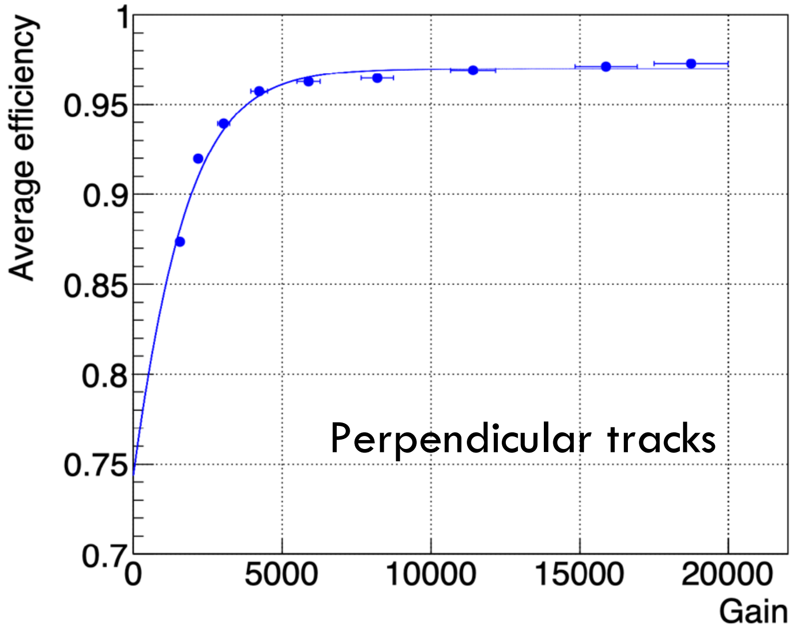




Efficiency >99%
Outside the pillars region

Tracking efficiency:

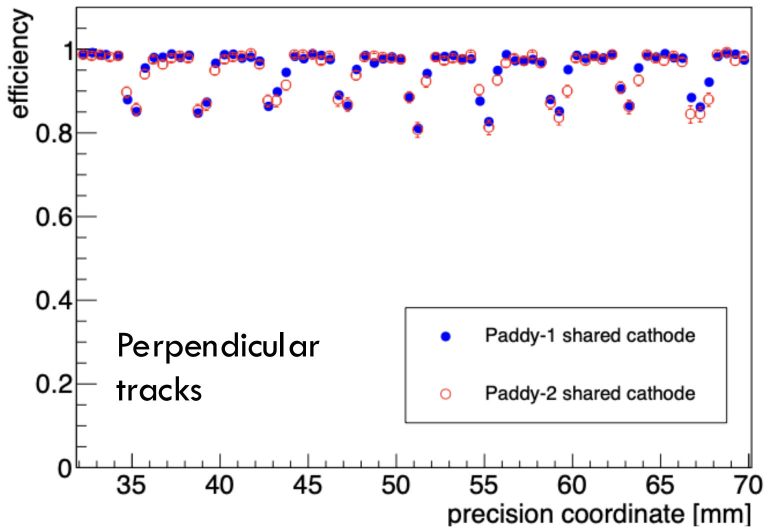
1.5 mm fiducial range wrt extrapolated position from external tracking chambers

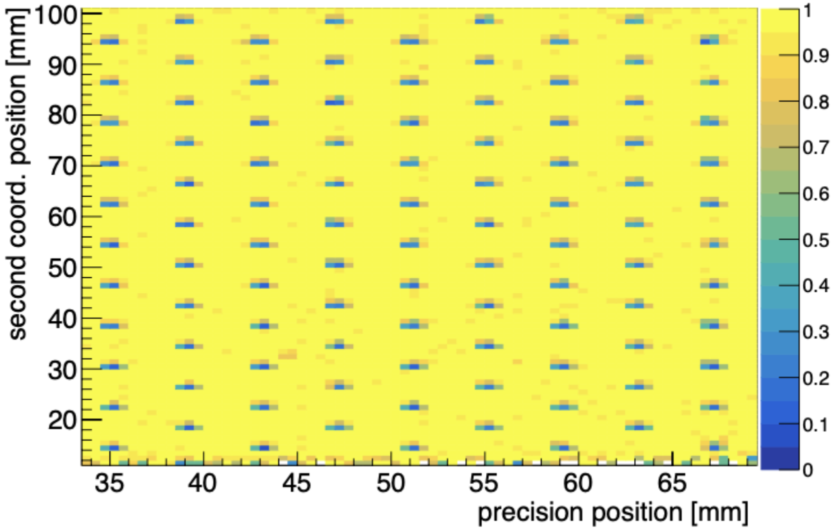


Average tracking efficiency at plateau ~97%
It includes inefficient areas on the pillars
The effect is very much reduced for inclined tracks

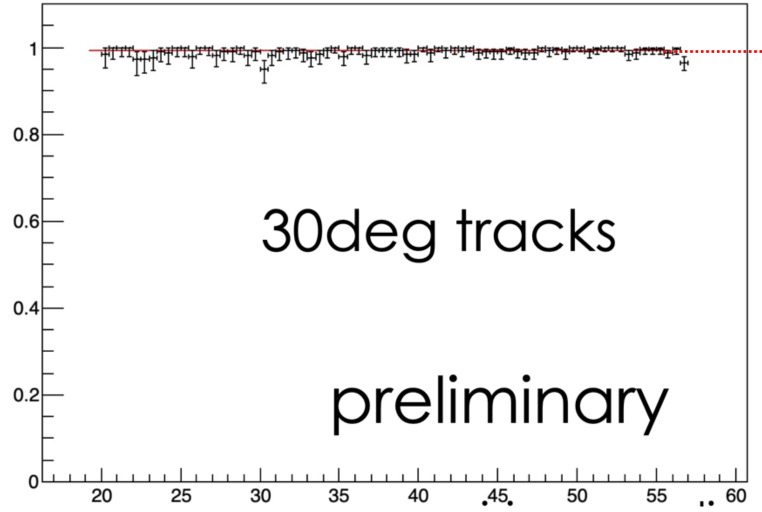
Achieved Performance - Efficiency

Efficiencies for **perpendicular tracks** for Paddy400 with shared cathode



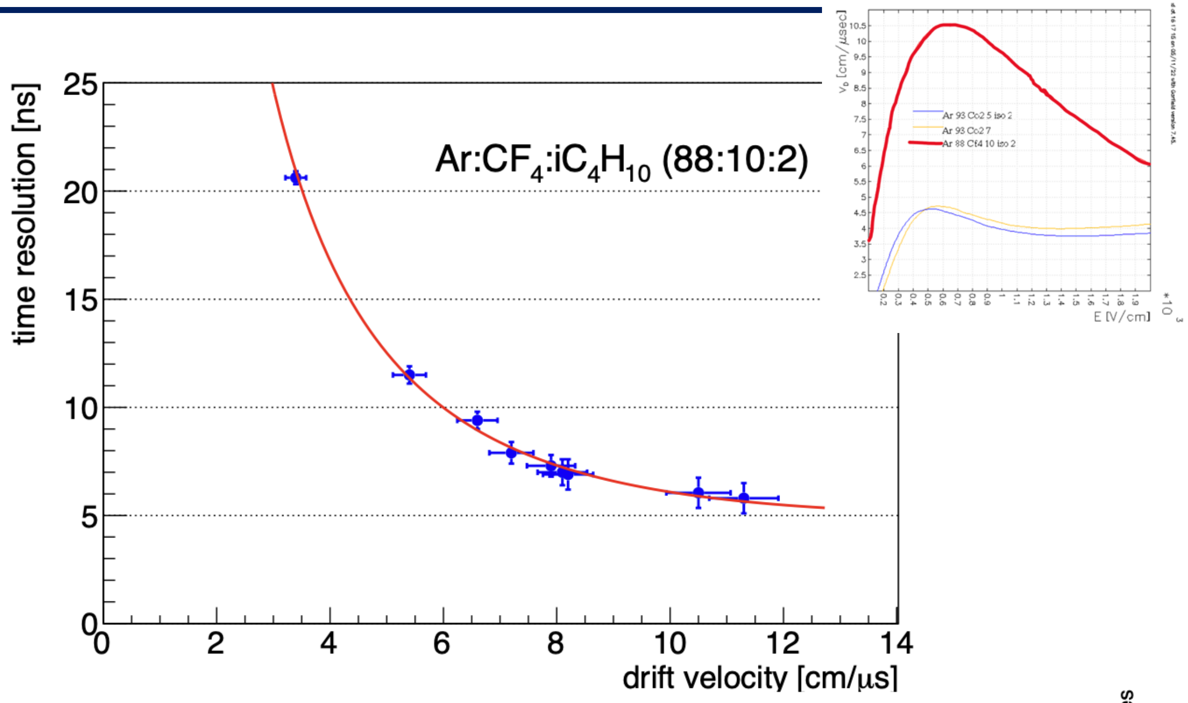


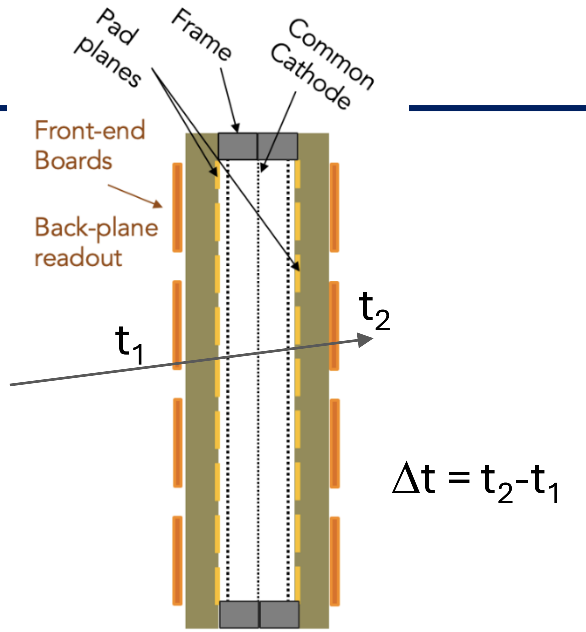
The pillars effect disappears for inclined tracks



~ 100%

Time Resolution





Time resolution from cluster time arrival difference between the two MM:

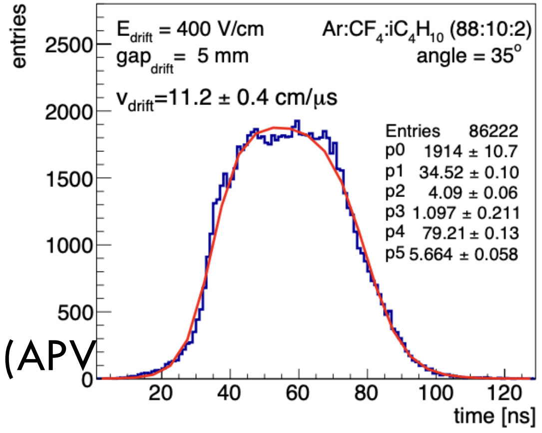
$\sigma_{time} \sim 5.8$ ns at $v_{drift} \sim 11$ cm/μs

Including the contribution of signal processing and signal fit). Preliminary estimate is ~4 ns

→ Detector $\sigma_t \sim 4.2$ ns

t_1 (or t_2) distribution

FE (APV



Δt distribution