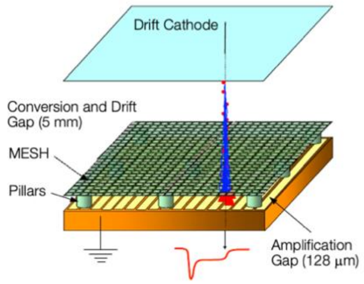
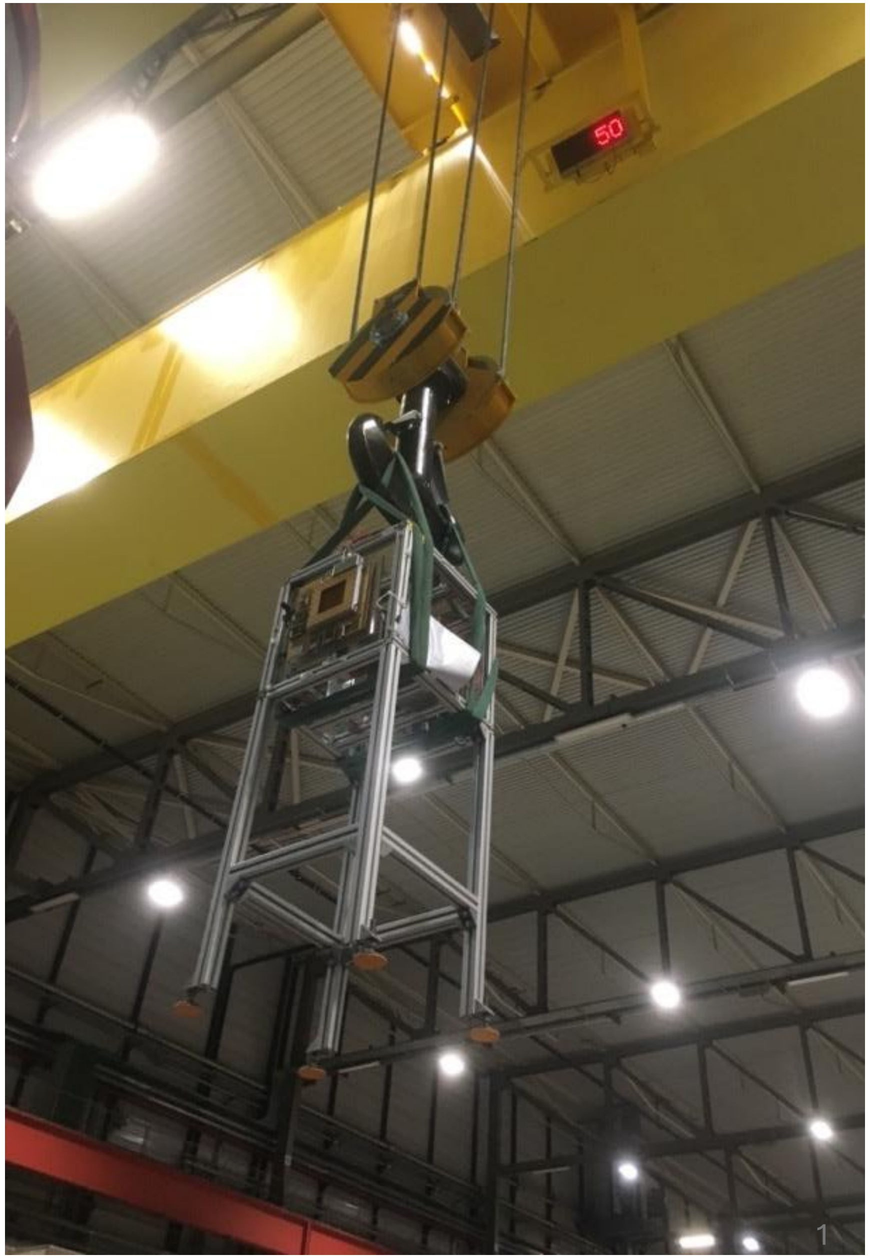


New Generation Resistive Micromegas for FCCee Muon systems



Napoli (expression of interest):

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

Roma3 (expression of interest):

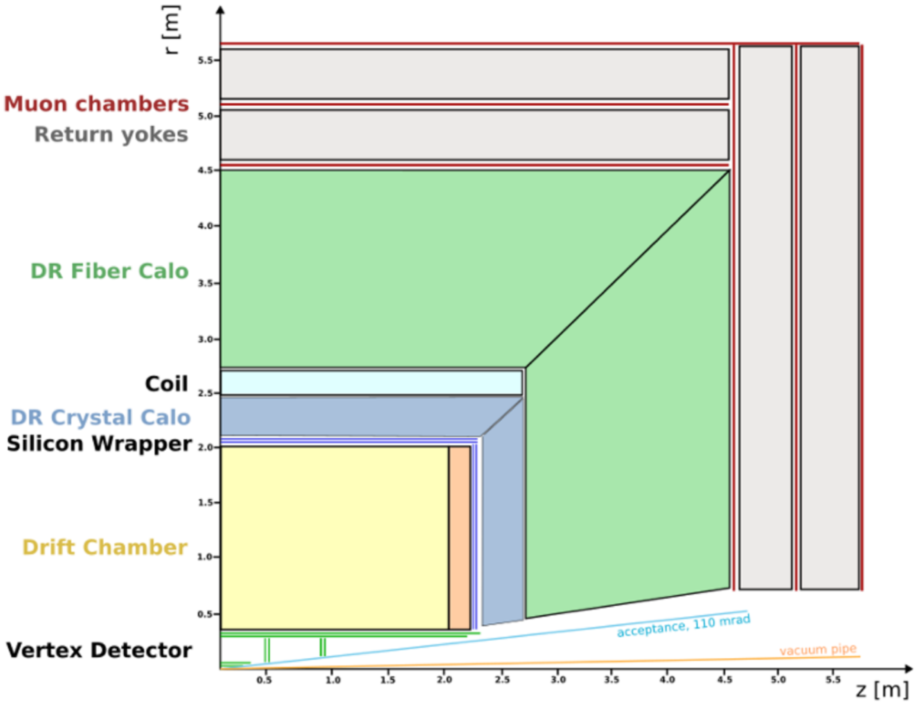
M. Biglietti, B. Di Micco, R. Di Nardo, M. Iodice, F. Petrucci

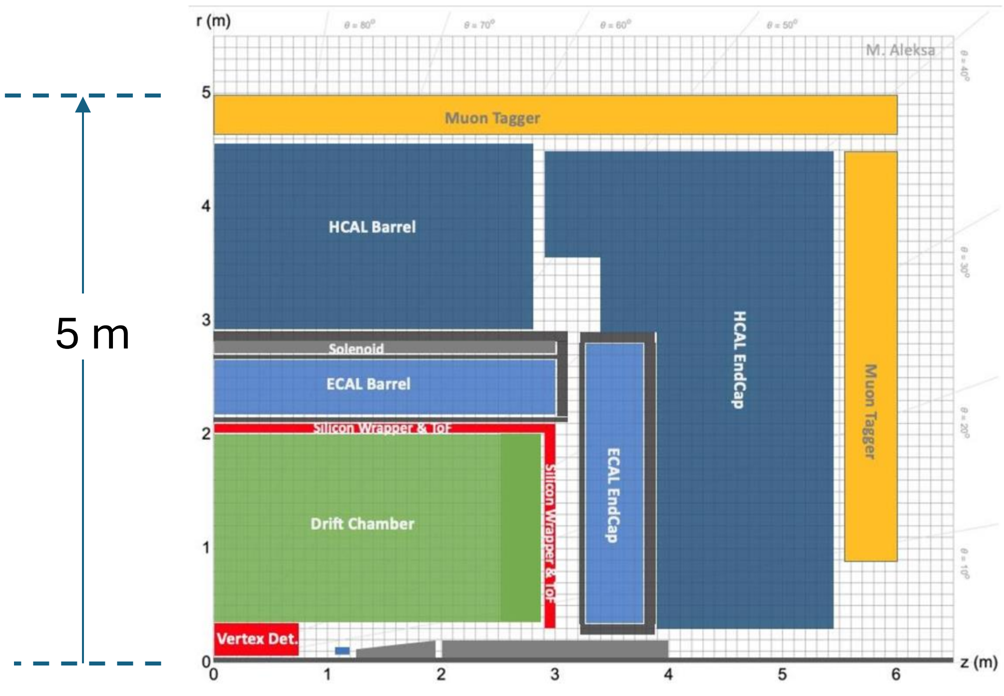
Detector Concepts Meeting

09/12/2024

Dimensions/coverage of the Muon systems at FCCee

IDEA





ALLEGRO

Similar dimensions for the Muon detectors for ALLEGRO and IDEA:

- Total surface Barrel: ~315 m^2
- Total surface Both endcaps: ~2x75 m^2 = 150 m^2
- Tot surface: ~500 m^2
- x 3/4 layers for 100% efficiency / redundancy and tracking → 1500 / 2000 m^2

Facilitate production by combining different technologies (e.g., Barrel/Endcap)

Requirements

Still to be studied in detail.

At the moment, only educated guess for Muon detection with tagging/tracking capabilities

- Spatial resolution: 300 - 500 μm in both coordinates(*)
- Time resolution: few - 10 ns
- Efficiency: close to 100%
- Sustainable gas mixture

(*) or asymmetric (~ 0.2 mm / 1mm) for LLP tracking ?

Resistive Micromegas for FCCee

- For applications in future e+e− colliders, the use of large area gaseous detectors, optimized for medium/low rates, proves to be an optimal solution for muon detection.
- MPGD detectors have established themselves as a technology with high performance and great scalability, certainly suited for the ALLEGRO or IDEA detector concepts
- For many years, our groups have been conducting R&D on high performance resistive Micromegas with the following main objectives:
  - Consolidation of resistive Micromegas, for measurements at future colliders, also aiming at very HIGH rates, of the order of **10 MHz/cm^2**
  - Optimization of the spark protection resistive scheme to achieve **stable operation at high rate/gain**
  - Demonstration of the **scalability** of detectors on large surfaces
  - **Exploitation of the robustness and stability of configurations achieved at high rates to redirect R&D efforts towards a simplified and optimized version for operation at low/medium rates.**
  - Industrialisation/production at industries (ongoing with ELTOS in Italy)

In this context, our interest lies in promoting resistive Micromegas for muon detection at FCCee

Background – the Napoli and Roma3 groups and recent R&Ds

- Both INFN Napoli and Roma3 ATLAS detector groups, have longstanding experience in gaseous detector construction (RPC, MDT, Micromegas). with essential contributions for large experiments (at LEP and LHC)
- Considering the recent story, Napoli and Roma3 have both essentially contributed (with major roles) to all the phases of the ATLAS NSW project, in particular in the Micromegas system, in the R&D, design, construction, integration, commissioning, operation.

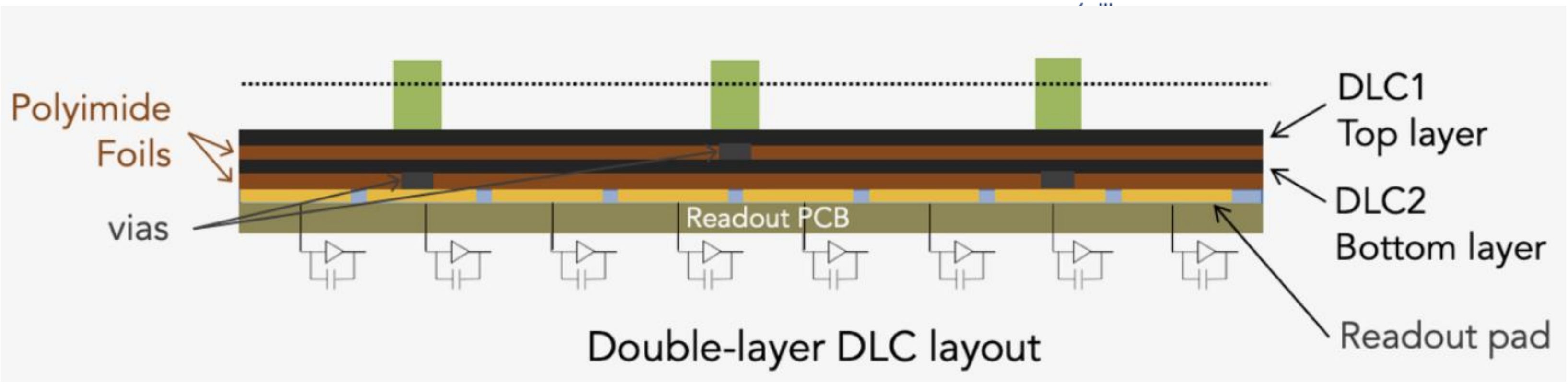
- Started in 2015 the R&D on High Performance Resistive Micromegas has achieved all the project goals and is **fully aligned with the ECFA Roadmap implemented in DRD1**
  - Stable and reliable operation has been demonstrated, at the optimal operating point, with a large margin before instability. Rate Capability > 1-10 MHz/cm2
  - Very good results on spatial (<100 um) and time resolution (~5 ns)
  - Low/Medium rate applications: R&D with readout capacitive sharing for reducing the number of elx channels
  - The construction of large-sized high-granularity detectors (50x40 cm^2) has demonstrated scalability up to modules with dimensions large enough to cover large apparatuses

- This R&D is progressing within the strategic themes for future experiments of the DRD1 Collaboration

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



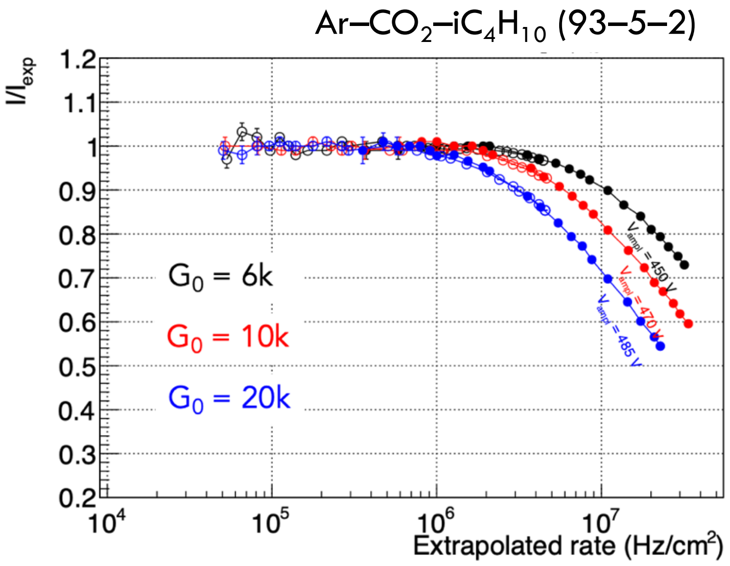
DLC20 (20 MΩ/sq)

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

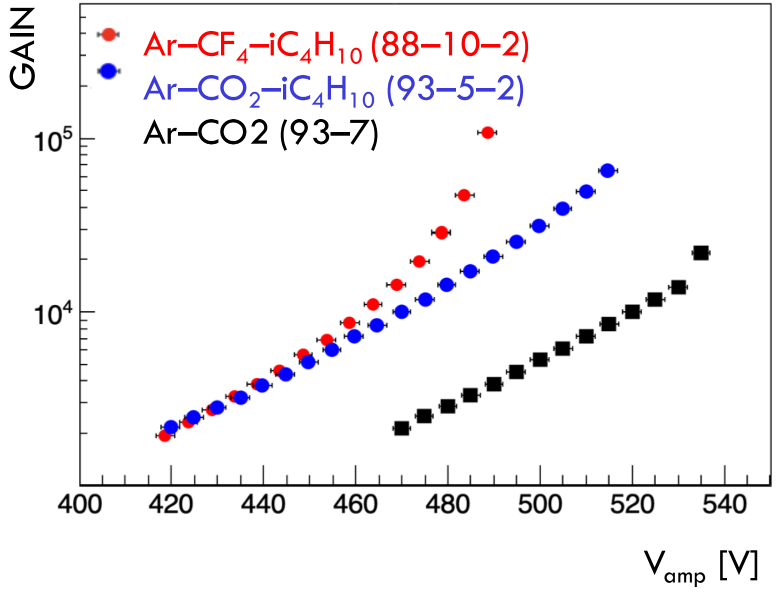
Rate capability Vs X-rays



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

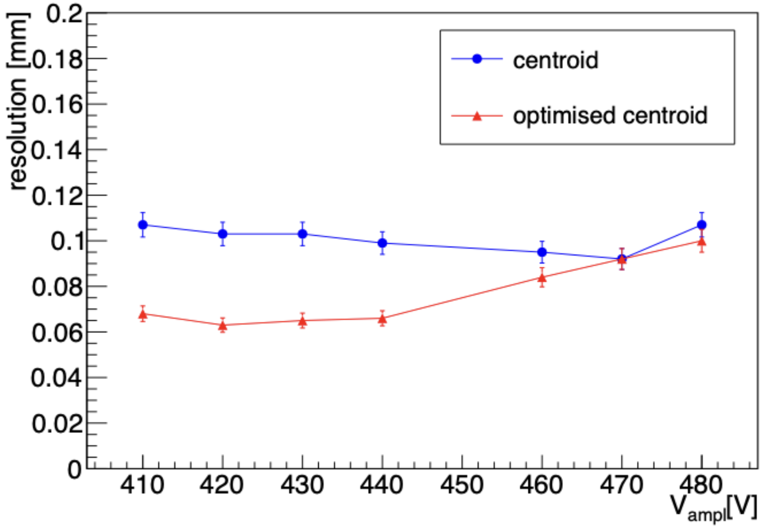
GAIN Vs HV - different Gas Mixtures



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

Above 5 x 10⁴

Test-Beam: Spatial Resolution

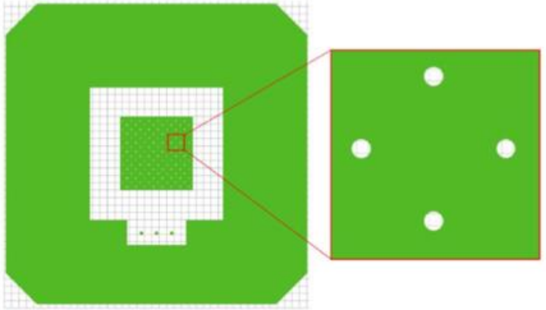


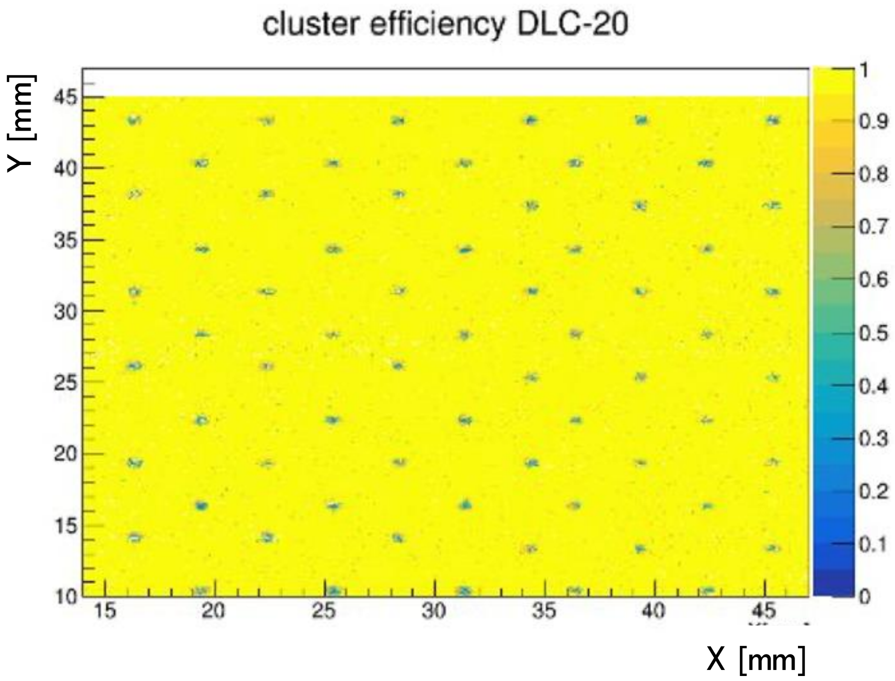
Optimised : **~65 µm with 1mm pad**

Achieved Performance - Efficiency

LOCAL INEFFICIENCIES from Circular pillars:

- 0.3 mm for DLC20

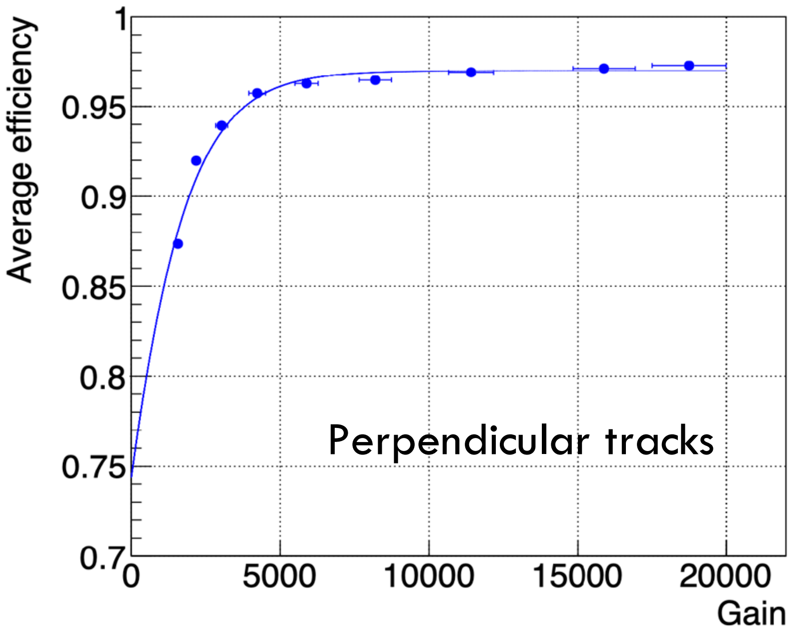




Efficiency >99%
Outside the pillars region

Tracking efficiency:

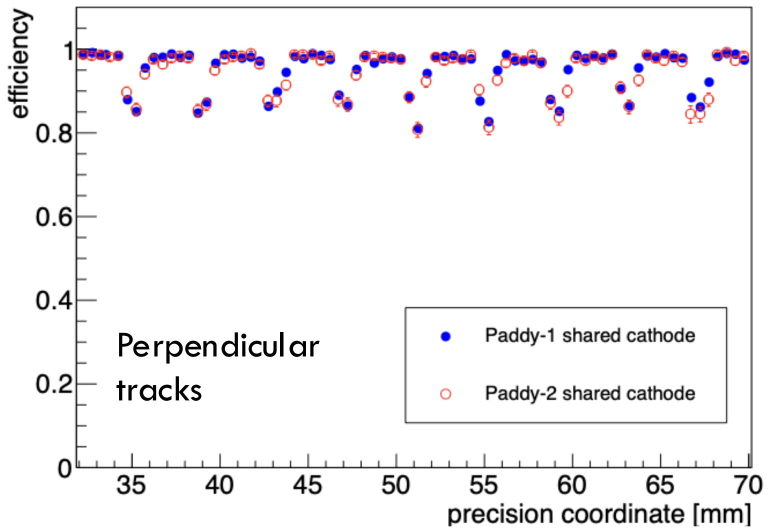
1.5 mm fiducial range wrt extrapolated position from external tracking chambers

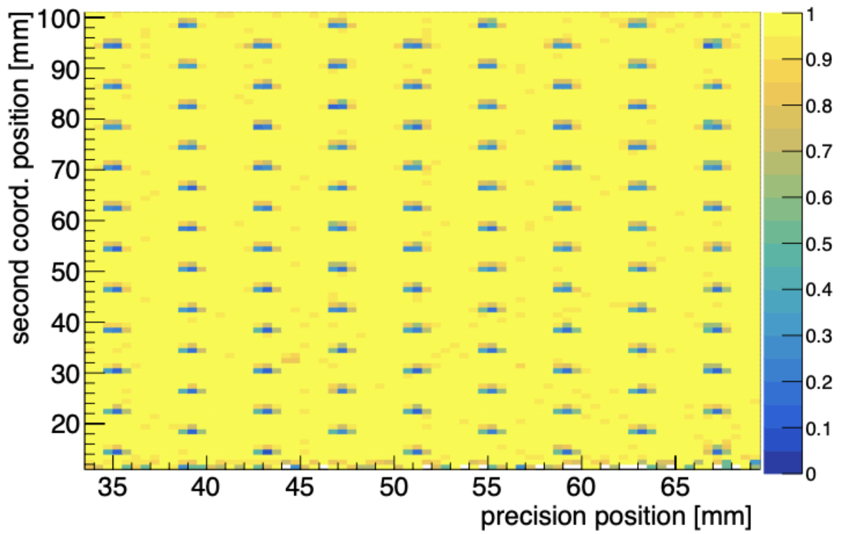


Average tracking efficiency at plateau ~97%
It includes inefficient areas on the pillars
The effect is very much reduced for inclined tracks

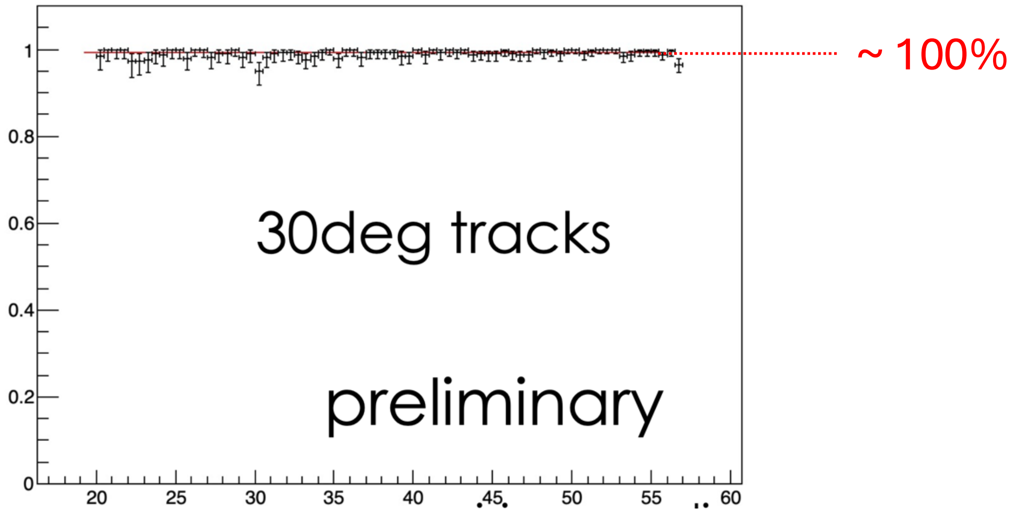
Achieved Performance - Efficiency

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

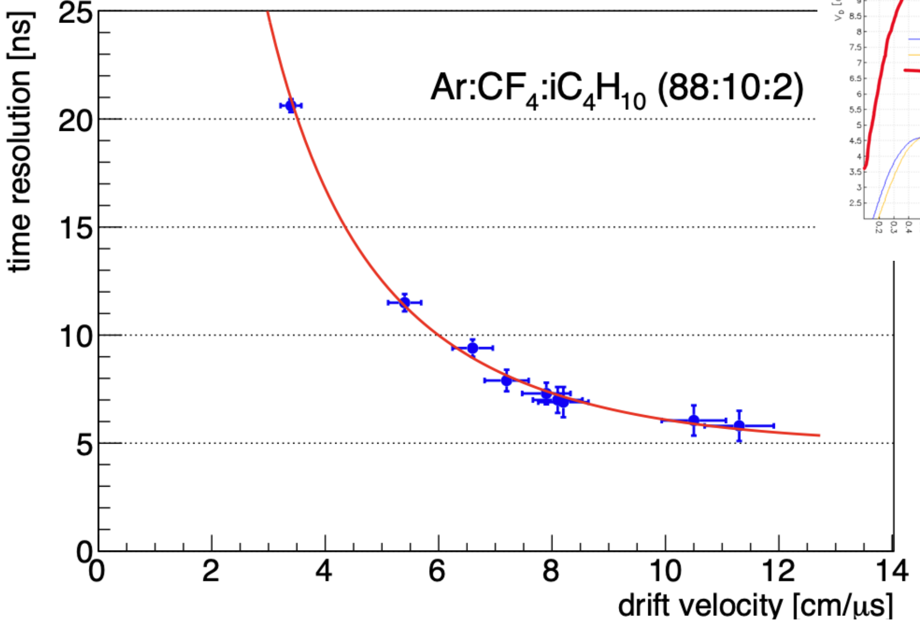


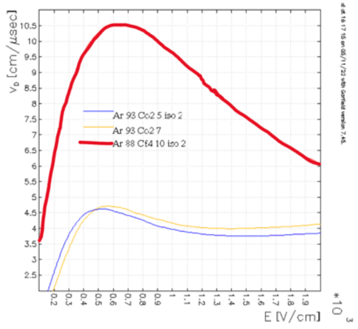


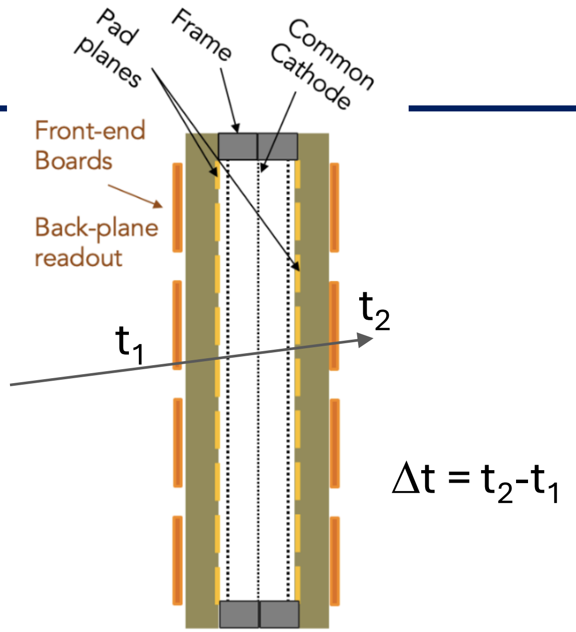
The pillars effect disappears for inclined tracks



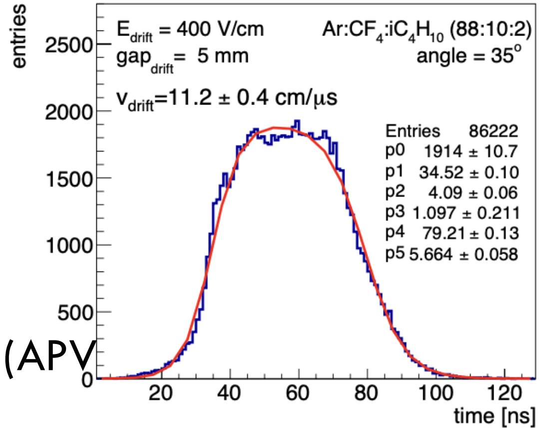
Time Resolution



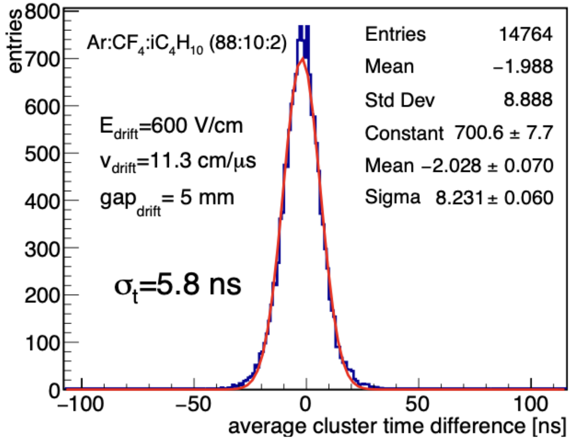




t₁ (or t₂) distribution



Δt distribution



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

σ_{time} ~ 5.8 ns at v_{drift} ~ 11 cm/μs

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

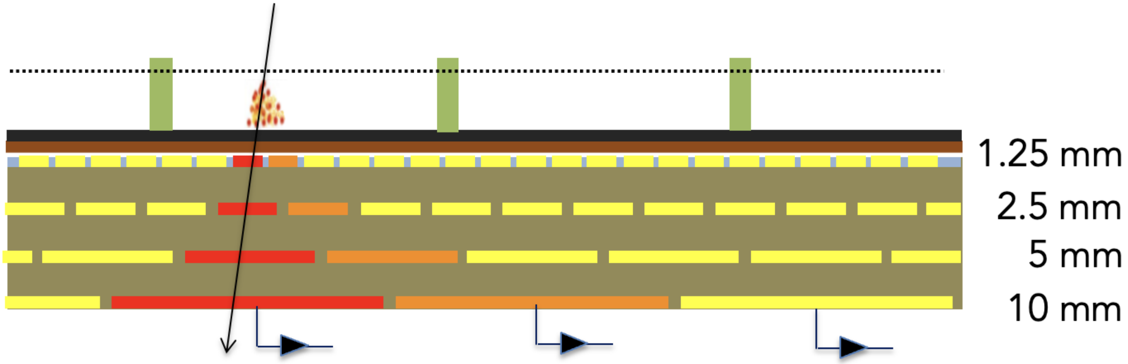
FE (APV

→ Detector σ_t ~ 4.2 ns

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.

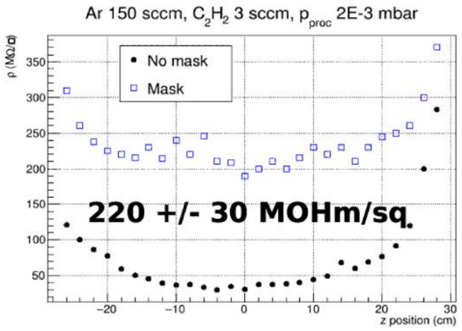


The production is greatly simplified:

- 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

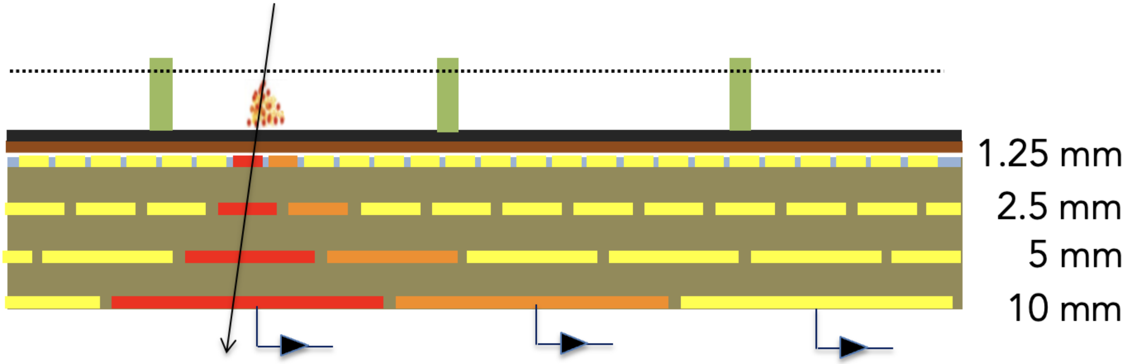
Production of DLC foils now feasible at CERN with the CERN-INFN Sputtering Machine

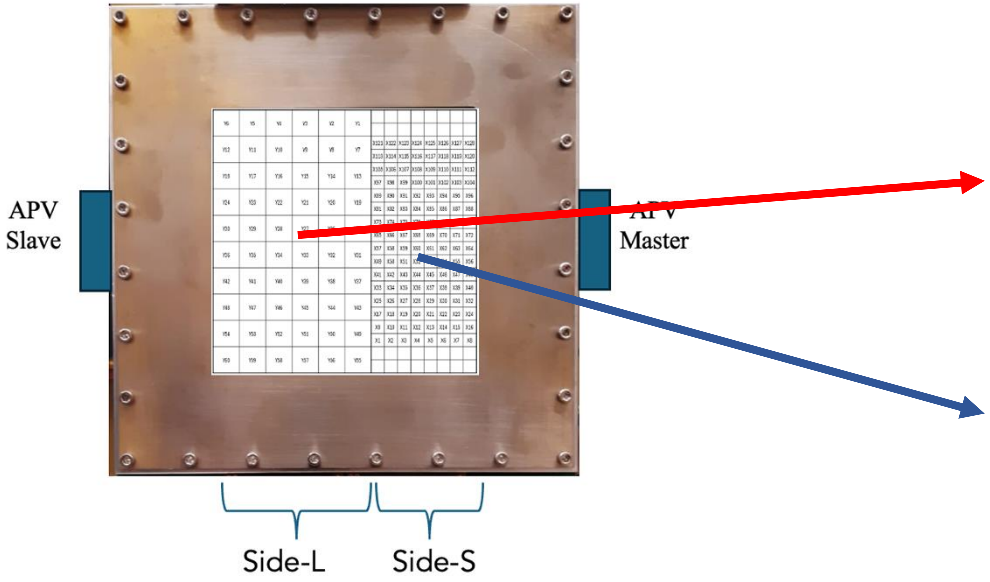


Medium/Low-rate Version – Capacitive Sharing

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



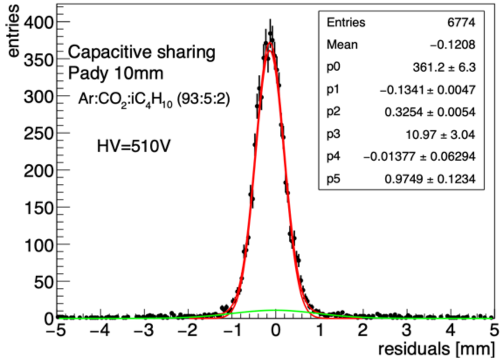


- Pad size of "top-layer" (signal induction): 1.25x1.25 mm2
- **Side-L**: Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2
- **Side-S**: three layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2

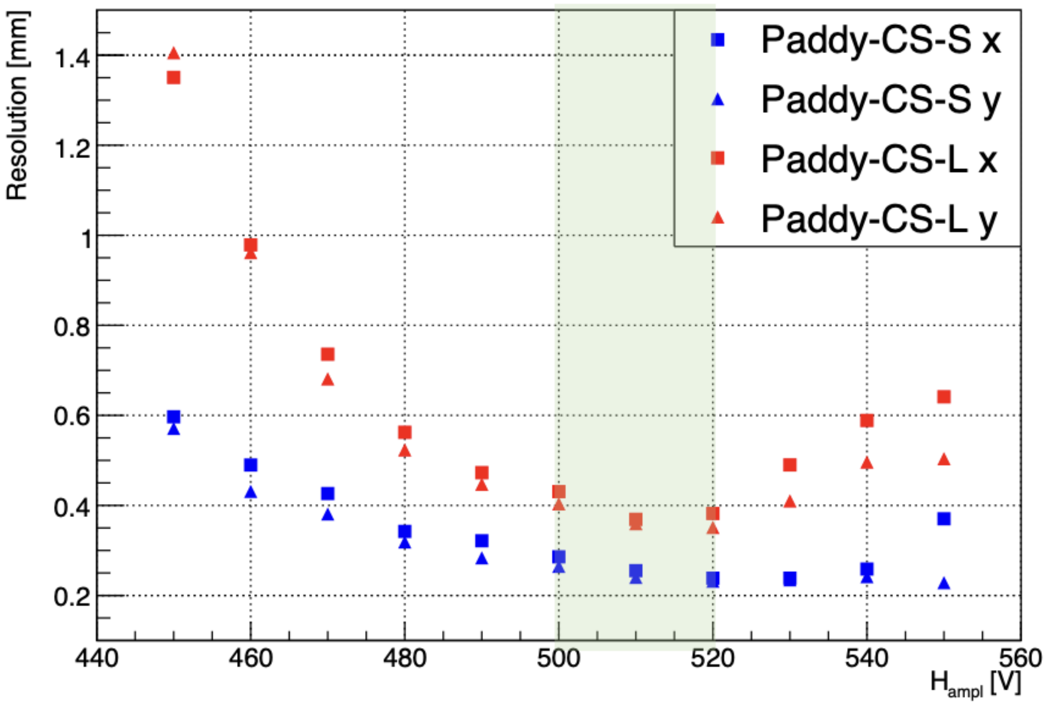
Capacitive Sharing Test-Beam Results

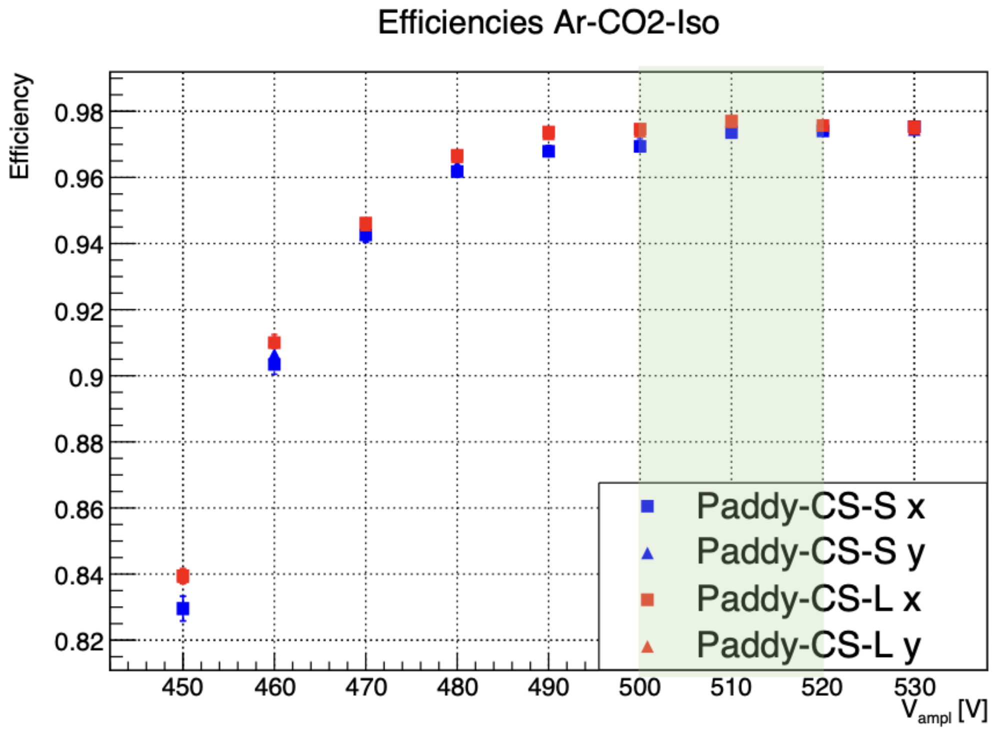
Spatial Resolution and Efficiency

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



Resolution with coverage at 68% Ar-CO$_2$-Iso





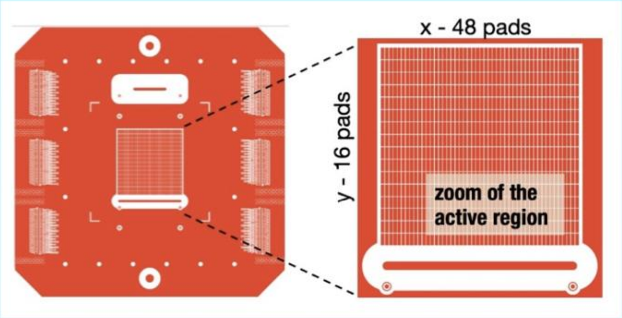
REACH ~380 μm with 10x10 mm^2 pads

→ A factor 1/26 of the pad size

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

From Small to Large Size Prototypes

Small size prototypes

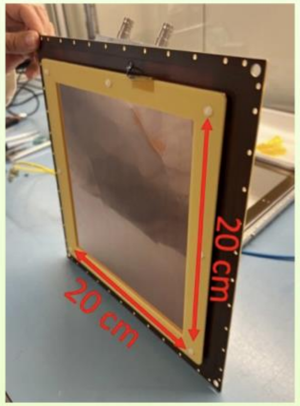


Several resistive layout tested

Active area: 4.8 x 4.8 cm^2 active region
Anode plane pad size: 0.8 x 2.8 mm^2 → 768 pads

48 pads – 1 mm pitch (“x”)
16 pads – 3 mm pitch (“y”)

Medium size prototypes

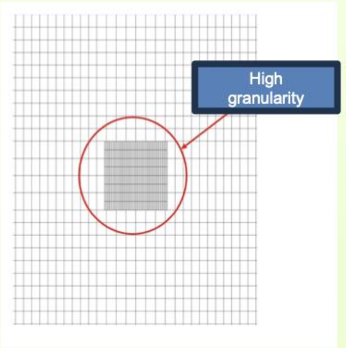


Two detectors:
Paddy400-1 & Paddy400-2

Active area : 20 cm x 20 cm (partial readout in central part, ~40%)
Anode plane pad size: 1x8mm^2 → 4800 pads

- Tests performed also in “common cathode” configuration

Large size prototypes

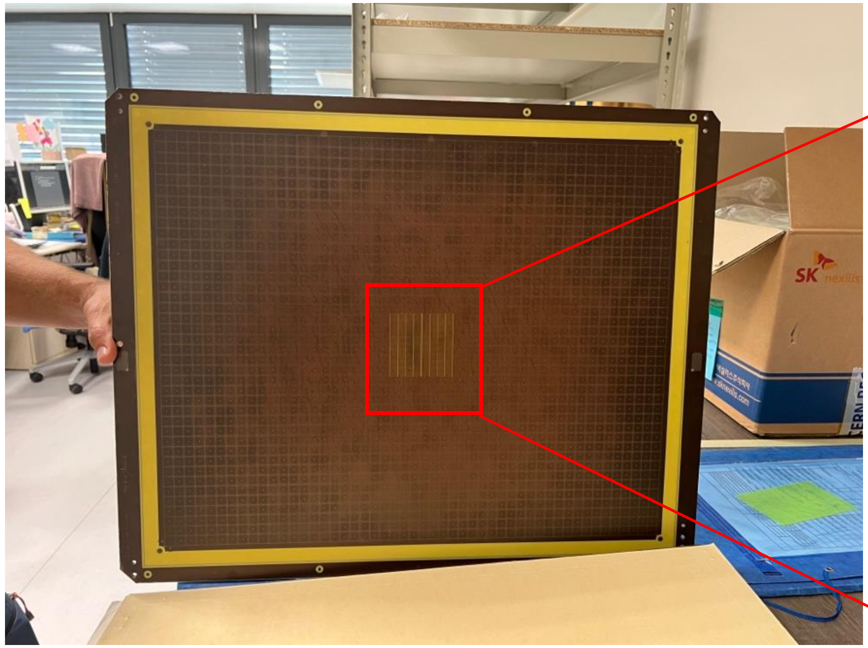


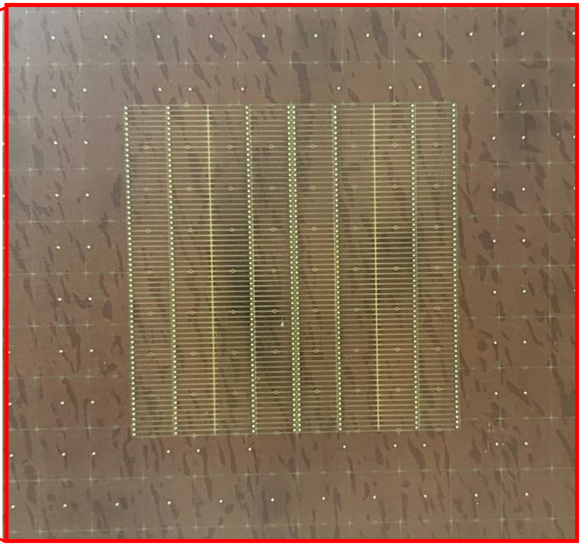
Paddy-2000 - “The Big one”

Active area : 50 cm x 40 cm
Anode plane pad size:
Central part
1x8mm^2 → 512 pads
Surrounding area
10x10mm^2 → 2048 pads

Towards Large Area

Many thanks for all aspects of our R&D to: Rui De Oliveira, B. Mehl, O. Pizzirusso, and all the MPT CERN Workshop





50x40 cm^2 prototype
High-rate configuration
Fine granularity readout in the centre,
1 cm^2 pads elsewhere (for practical reasons – number of channels)

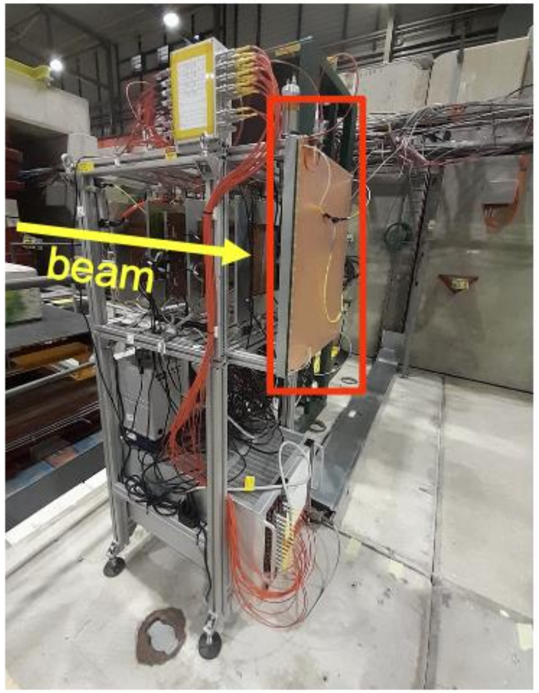
Central region
6.4x6.4 cm^2
with1x8 mm^2 pads

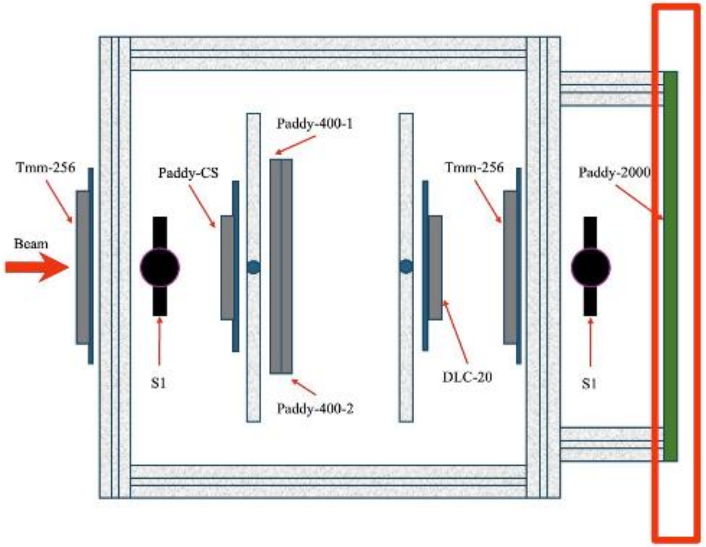
Hirose connectors on the back
Central region readout through 4 connectors
Full detector readout out by 20 hybrids

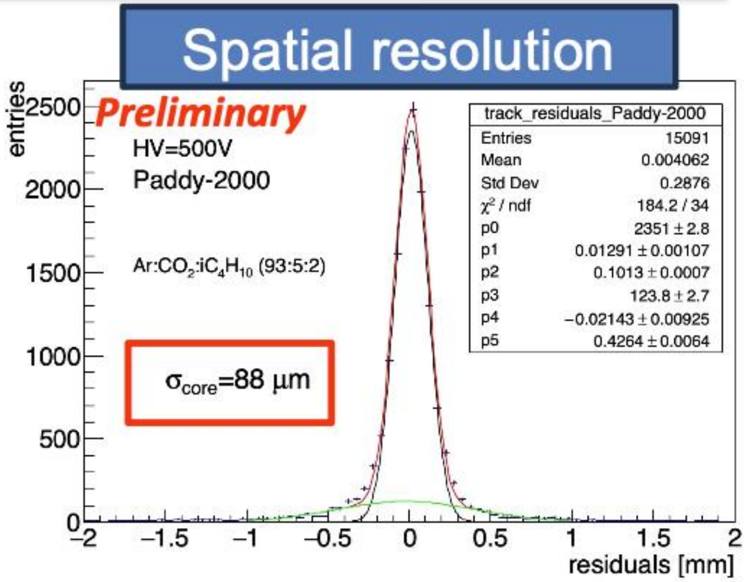
Preliminary Results of the 50x40 cm^2 Micromegas

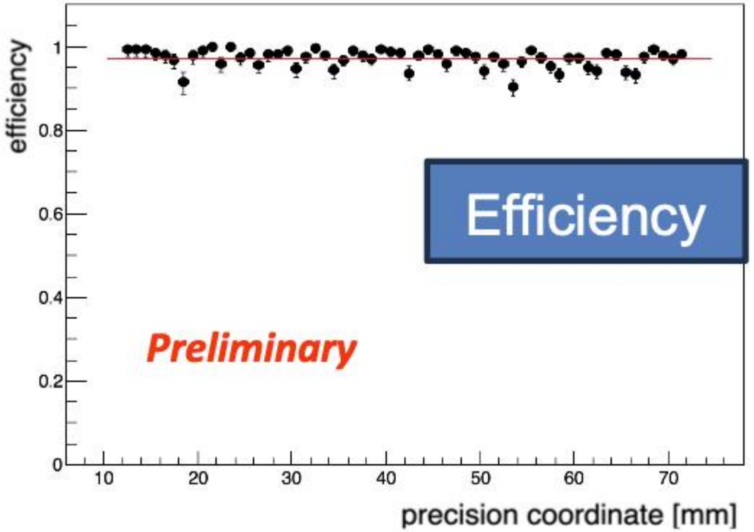
Chamber tested for the first time during a test beam in 2024 at CERN H4

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

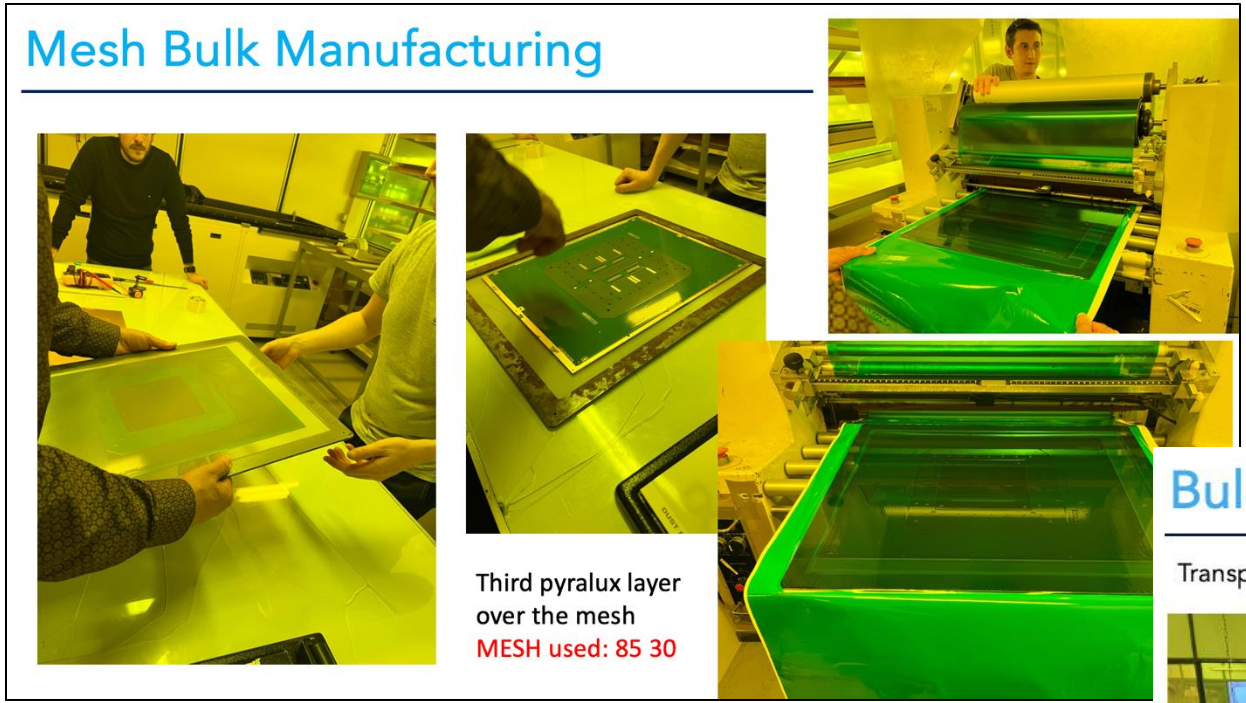








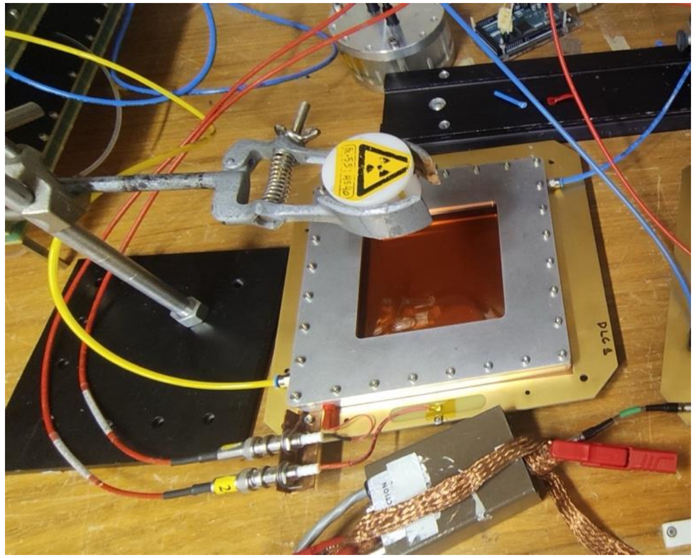
Micromegas Production at ELTOS

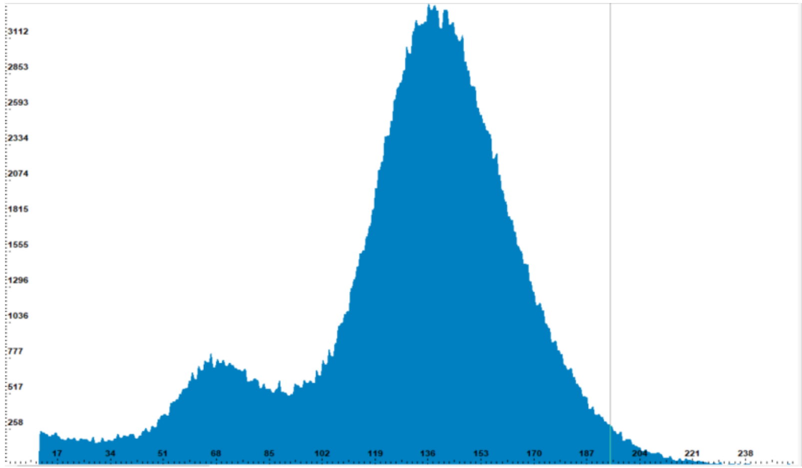


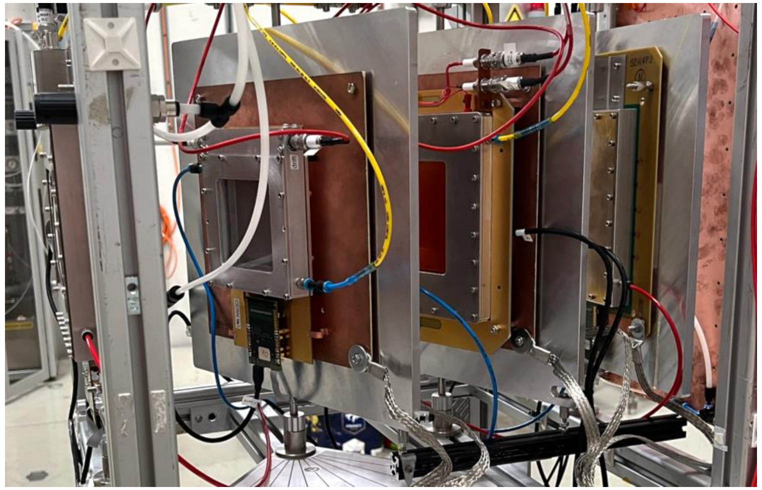
We are currently making efforts to transfer the technology of mesh bulk manufacturing to a PCB company. It's important to note that bulk processing is not a standard practice within the PCB industry.

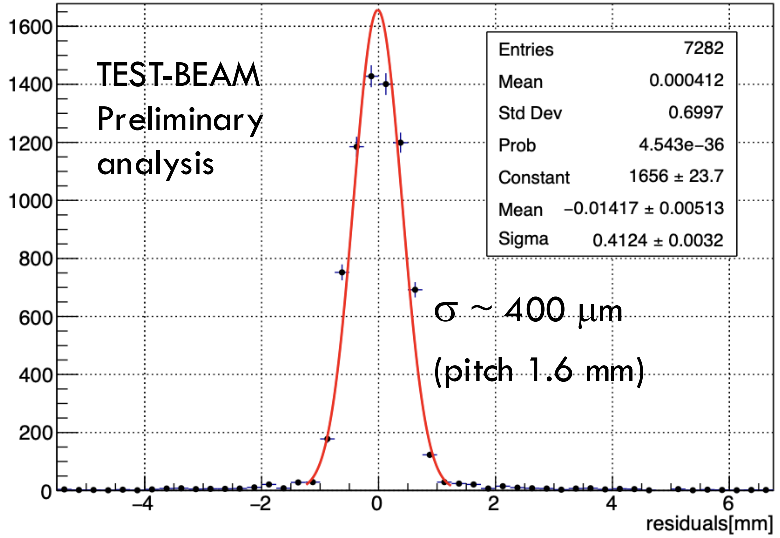
A second production on small-size simplified resistive micromegas (single layer DLC) successfully carried out in June 2024

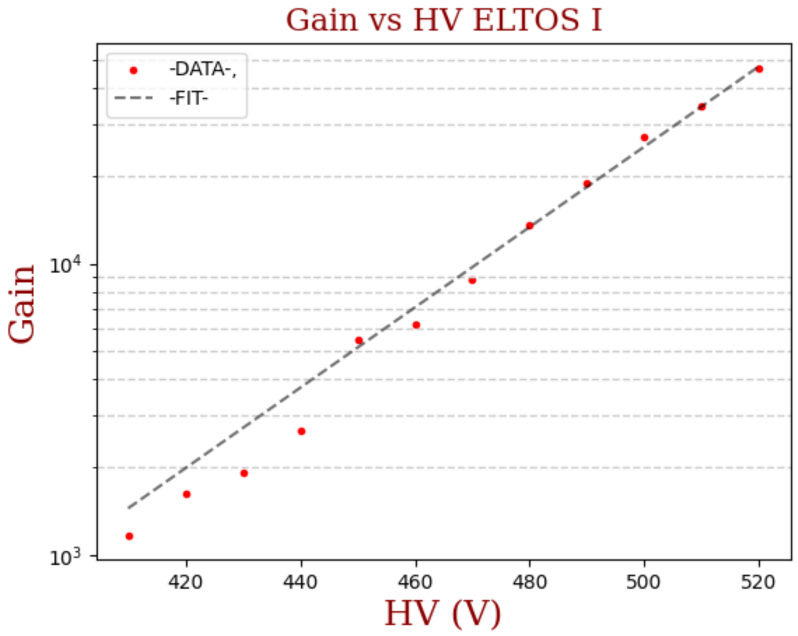
First results of MM produced at ELTOS - very promising











Present status

- Excellent results achieved with resistive Micromegas for high-rates configuration implementing DLC resistive foils
  - **Eco-friendly, non flammable, cheap gas mixture Ar - CO2 - Isobutane (2%) at atmospheric pressure**
  - **Stable operation up to 20 MHz/cm^2 with gain >10^4**
  - **Detector efficiency > 97% (limited by pillars for ⊥ tracks, ~100% otherwise)**
  - **Position resolution < 100 μm**
  - **Time resolution down to <6 ns with fast gas mixture** (@vdrift ~11cm/μs)

- New large area prototypes built and tested up to ~**50x40 cm^2**
  - Very stable working condition even at high rate
  - Comparable performances wrt small prototypes

- Simple and reliable long-term operation:
  - Limited HV required: ~500 V
  - Simple gas system required: no pressurised system, safe/simple gas, no needs of continue calibration
  - High reliability in long-term operations, immune to aging

Present status and Future prospects

- R&D on the **capacitive sharing** concept for **low-medium rate applications ongoing:**
    - **Excellent results with 1 cm^2 Pad dimensions**
    - **Next: study the limits for optimal performance with larger pad dimensions aiming at reducing the number of readout channels**
- Production at industry (design simplification and cost reduction) on the way
- R&D fully aligned to the ECFA Roadmap for Detectors Research and Development
- Ready for new R&D focusing on applications at FCCee for large area muon systems