High granularity small-pad resistive Micromegas for high-rate environment

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on behalf of the RHUM collaboration:

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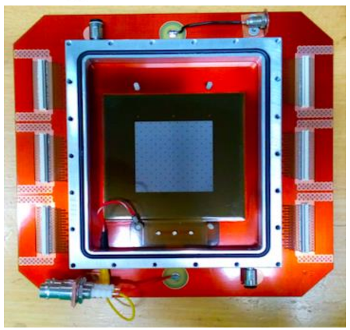
XLII International Conference on High Energy Physics
July 18th - 24th 2024 Prague (Czech Republic)

The RHUM project

RHUM

Resistive High granUlarity Micromegas



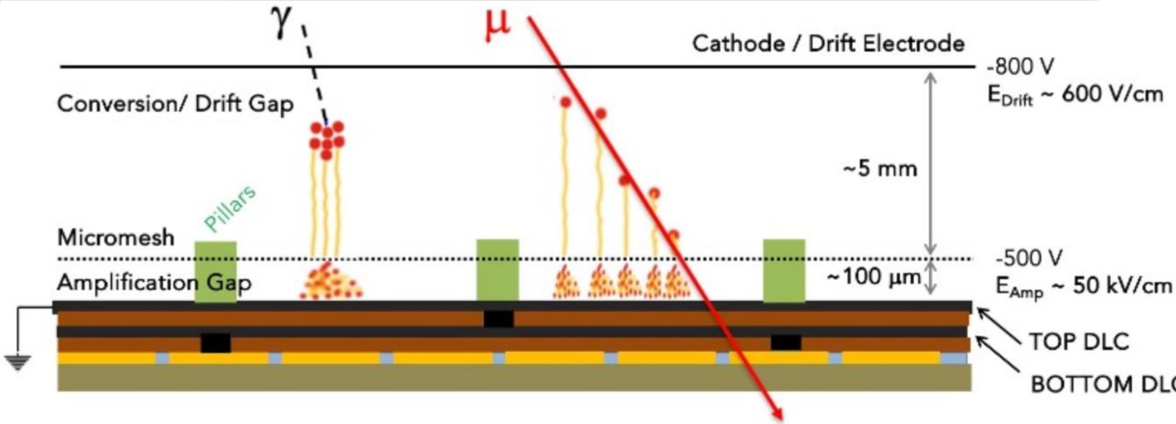
- Develop a **M**icro**P**attern**G**aseous**D**etector detector, based on the Micromegas technology, able to work efficiently at particle rates up to several MHz/cm^2
- Implement a small pad readout to reduce the occupancy
  - O(mm^2) for high-rate capability and good spatial resolution in both coordinates
- Optimize the spark protection resistive scheme to achieve stable operation at high rate/gain
- Demonstrate the detector scalability to large surfaces
- Simplify the construction techniques for industrial production
- R&D started in 2015 (INFN and University of Napoli and Roma Tre) in collaboration with CERN and with the CERN PCB Workshop (Rui De Olivera) for prototype construction.

Possible applications in HEP

- Very fwd muon tracking extension in existing experiments
- Muon detector/TPC @ future accelerators
- Readout for sampling calorimeter

  see L.Longo's talk on Saturday!
- ...

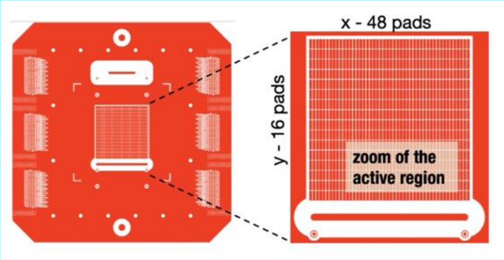
Micromegas technology



- Resistive Micromegas technology → cover readout copper strip/pad with a resistive insulator to suppress discharges
- Drift region of ~5 mm width (→ E~60 V/mm) and Amplification region of ~100 μm (E~5 kV/mm) separated by a metallic micro-mesh, supported by 0.8 mm diameter pillars
- Geometrical and electrical configuration to guarantee a fast charge evacuation
  - fundamental for high-rate applications
- Extensively studied different solutions for the resistive layout on small prototypes
  - Optimal configuration: Double layer of resistive foils based on Diamon Like Carbon (DLC) structures connected through conducting vias – DLC foil resistivity of 20-40 MΩ/□
- Demonstrated to be a solid detector technology for HEP experiments

The prototypes size evolution

Small size prototypes

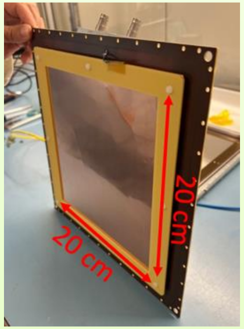


Several resistive layout tested

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

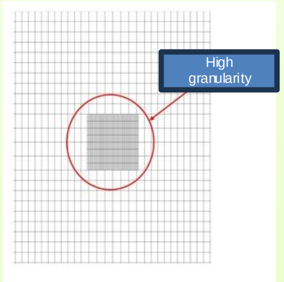


Two detectors:
Paddy400-1 & Paddy400-2

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

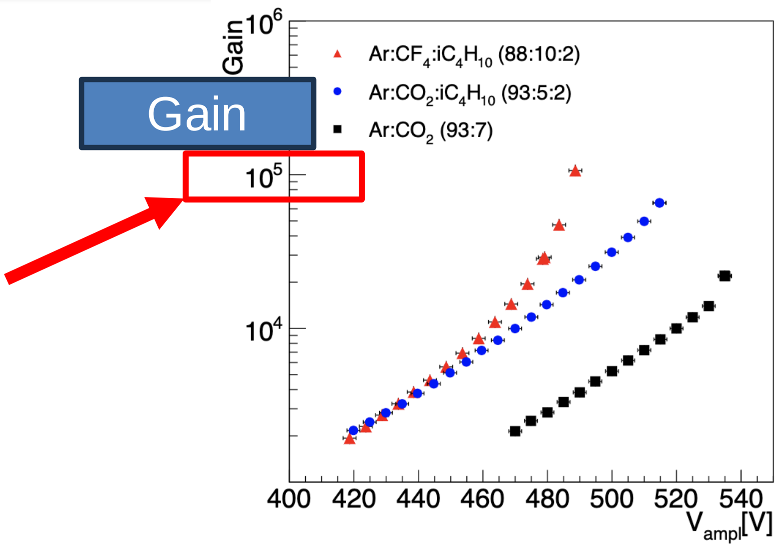


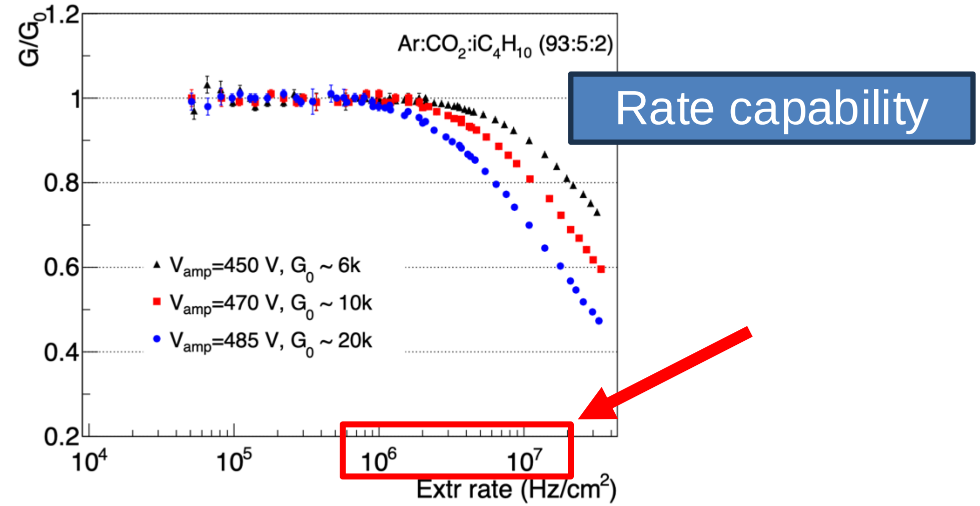
Paddy-2000 - "The Big one"

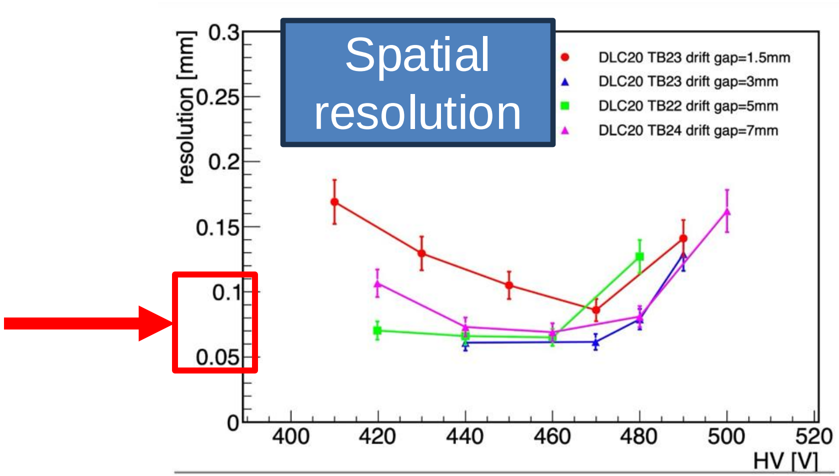
Active area : 50 cm x 40 cm
Anode plane pad size:
Central part
1x8mm^2 → 512 pads
Surrounding area
10x10mm^2 → 2048 pads

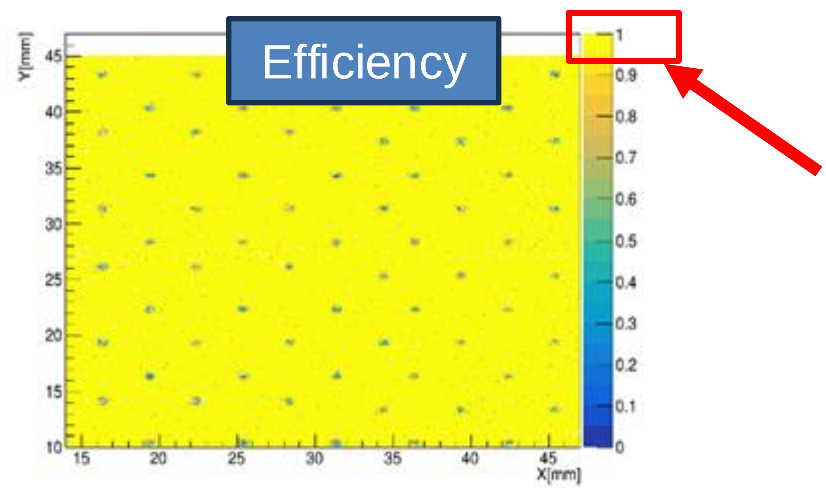
- I will mainly focus on the results obtained for the medium and large prototypes

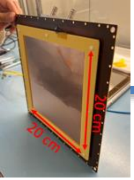
Performances for small size prototypes





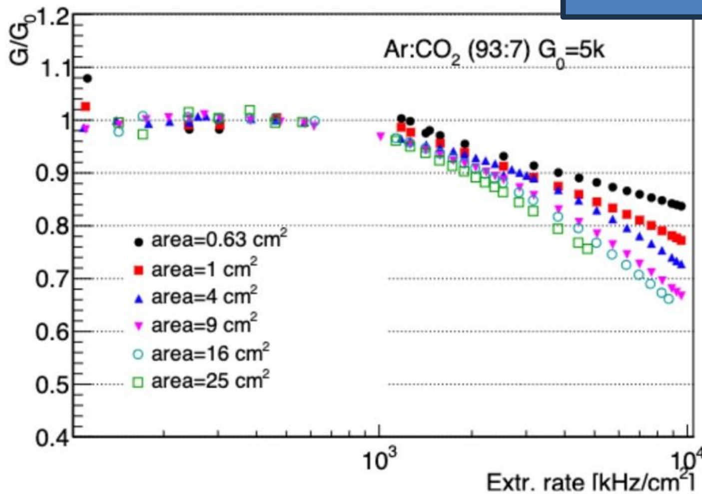


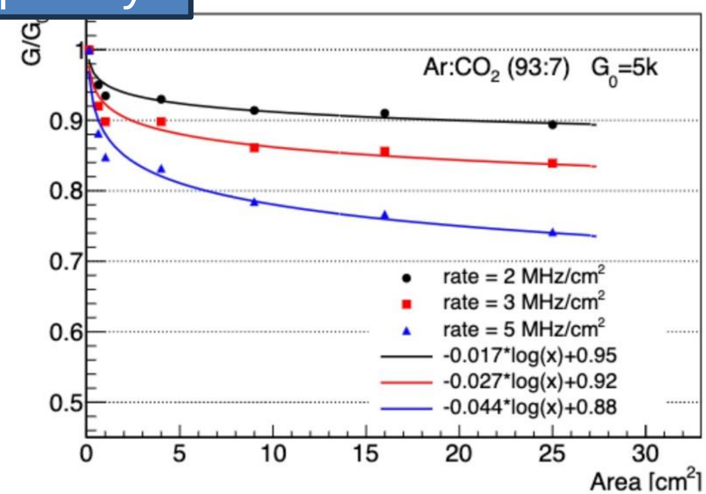




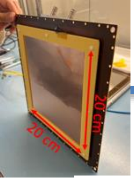
Performances of the mid-size prototypes

Rate capability



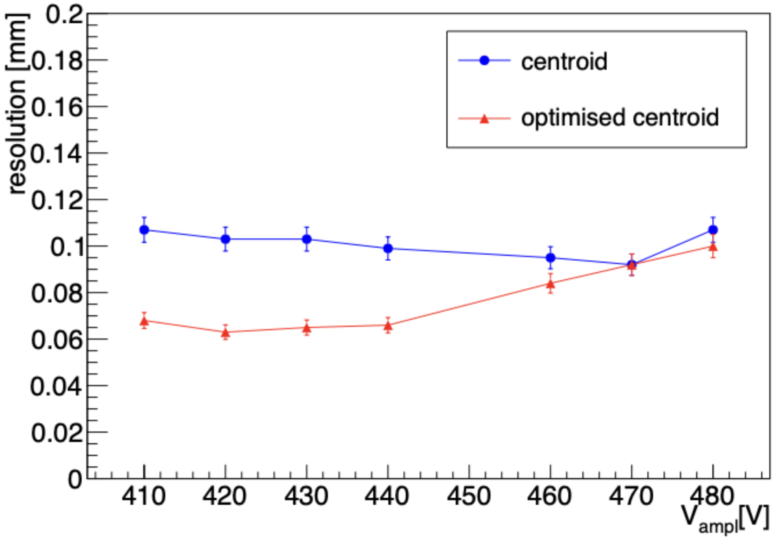


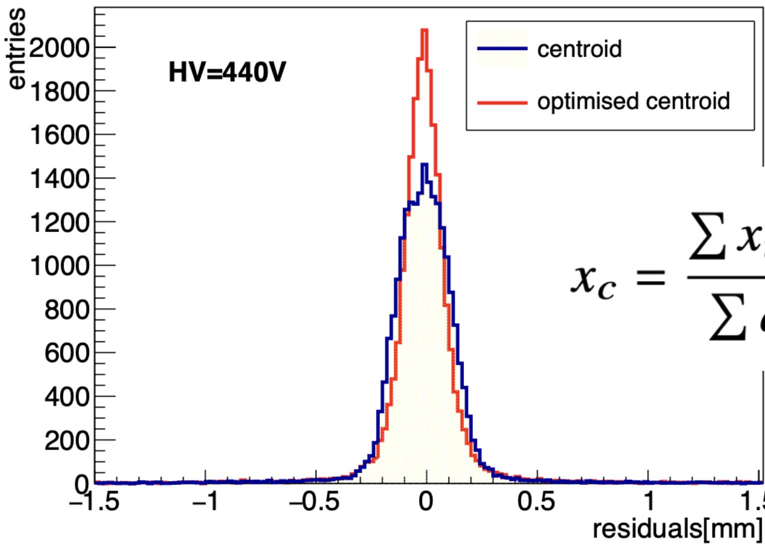
- Rate capability measured with X-rays for the 20x20 cm^2 detector
- Detector stable with almost no gain loss up to 1MHz/cm^2
  - In general performance similar to the small prototypes
- Gain dependence on the irradiated area studied
  - Residual effect of charging spread on the resistive layer → increasing gain drop with larger surfaces
  - Logarithmic dependence, effect sizable only at very high rate on very large surfaces
  - At 3MHz/cm^2 on 50x50cm^2 surface expect a modest 30% gain drop → can be compensated easily by 10V increase of the amplification voltage



Performances of the mid-size prototypes

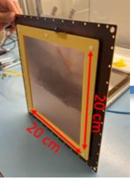
Spatial resolution





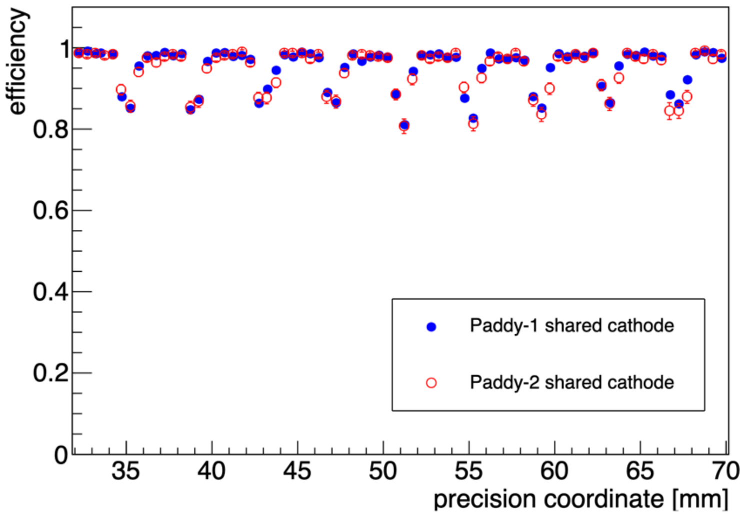
$$x_c = \frac{\sum x_i q_i^p}{\sum q_i^p}$$

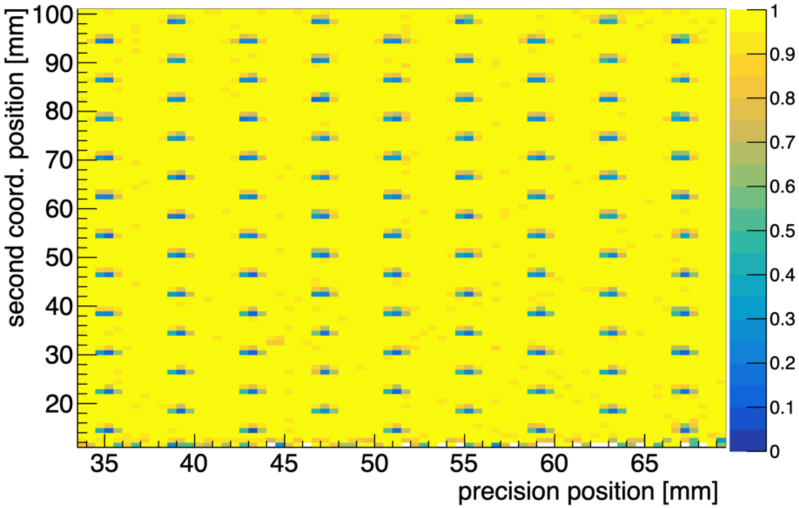
- Cluster position evaluated with an extended definition of the charge weighted centroid (p=0.65)
- Position resolution obtained fitting the residual distribution in the precision coordinate w.r.t. the reconstructed muon track
  - Extrapolation uncertainty~50µm (subtracted in quad) , systematic uncertainty ~5%
- At high gain the resolution is limited by poor charge measurements in APV due to saturation



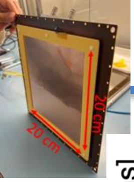
Performances of the mid-size prototypes

Efficiency



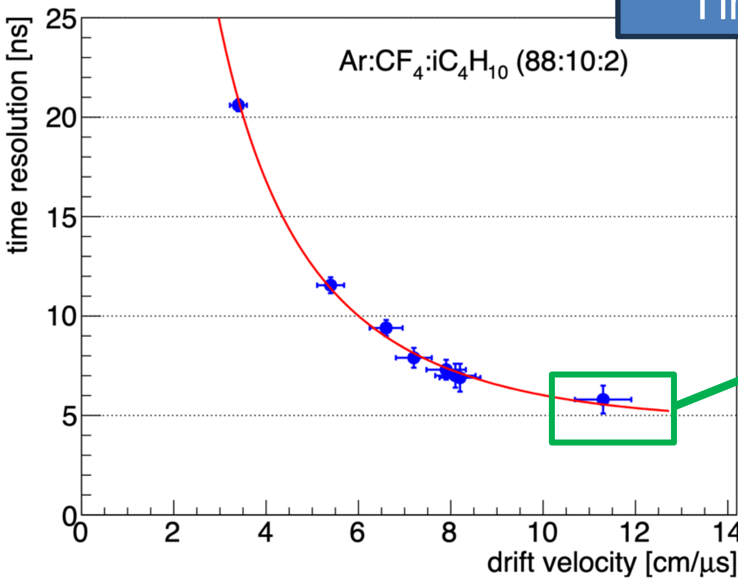


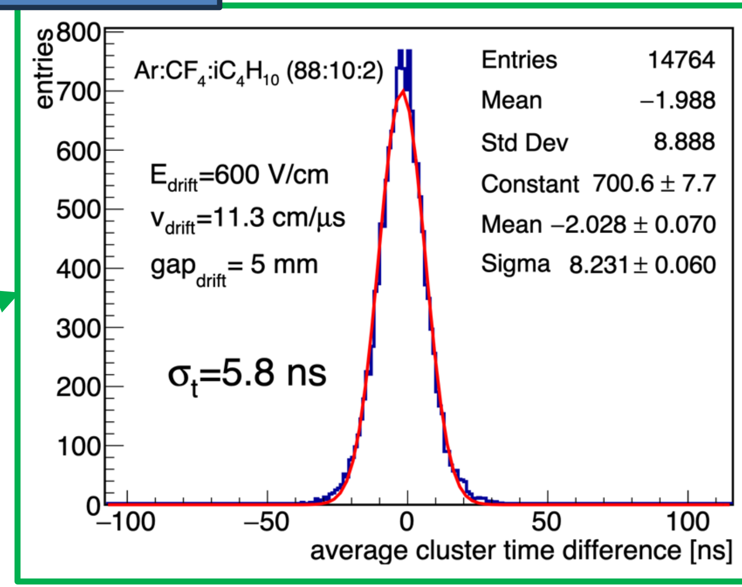
- Results from test beam @ CERN H4 - muon beam
- Fiducial cut at 1.5mm wrt extrapolated position measured with external tracking chambers
- Efficiency @ plateau for perpendicular tracks is nearly 100% except at pillar positions



Performances of the mid-size prototypes

Time resolution



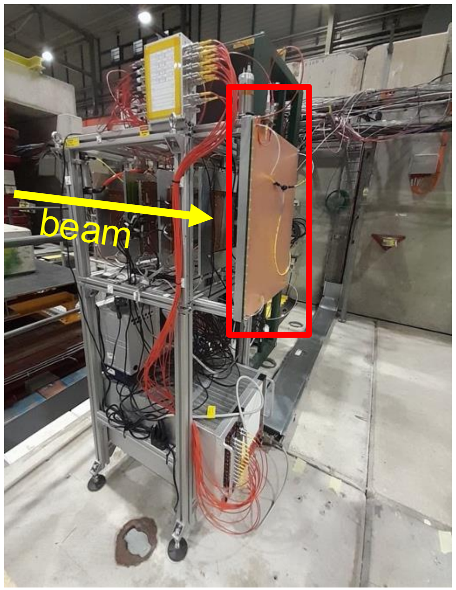


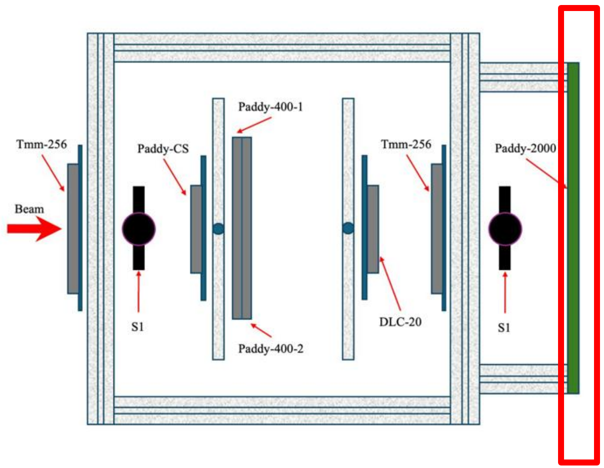
- Evaluated by computing the time difference between on-track clusters in two different chambers
  - Common cathode configuration
- Fast gas mixture **Ar:CF4:iC4H10 (88:10:2)** exploited
- Drift velocities at various E_{drift} measured using the hit time distributions
  - In agreement with simulation
- Measured resolution for the medium size prototype ~6ns at v_{drift} ~11 cm/µs

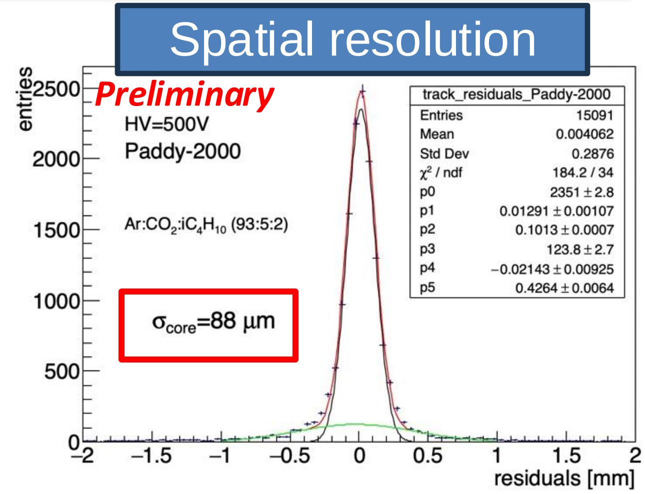
Preliminary results of the 50x40 cm^2 prototype

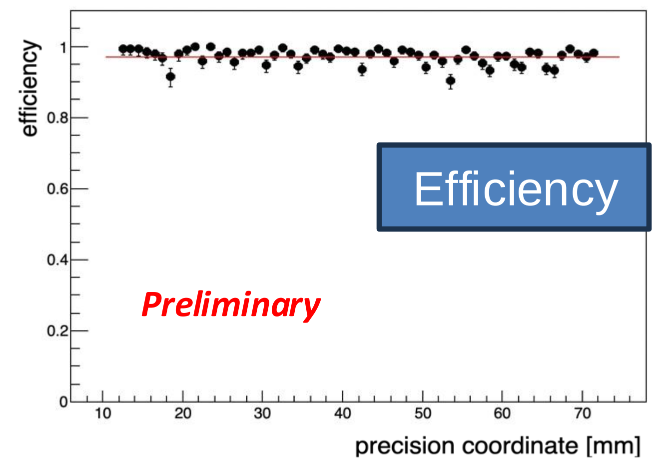
Chamber tested for the first time during a test beam in 2024 at CERN H4

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









Prototype implementing the capacitive sharing

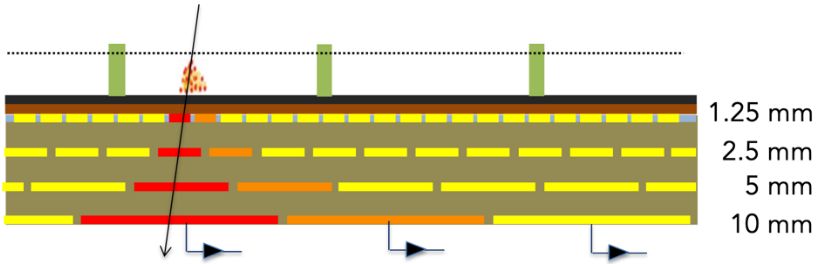
- First implementation of the capacitive sharing principle in a DLC-Double layer resistive Micromegas
- Charge shared in large readout pads through the capacitive coupling between stack of layers of pads.
  - Good spatial resolution and reduction of the readout channels
- Suitable for low- medium- rate applications

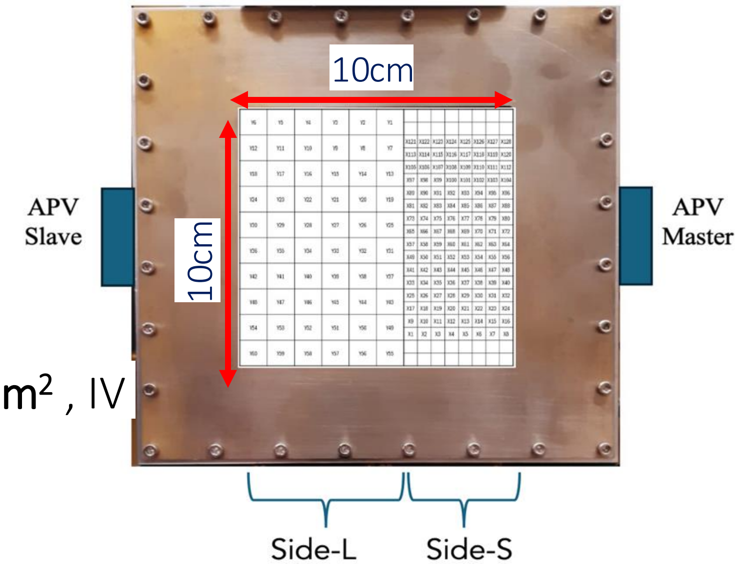
Pad size of "top-layer" (signal induction): 2.5x2.5 mm^2

Side-L: four readout layers capacitive sharing:
I layer **1.25x1.25mm^2**, II layer **2.5x2.5mm ^{2}**, III layer **5x5 mm^2**, IV layer **10x10 mm^2**

Side-S: three readout layers capacitive sharing:
I layer **1.25x1.25mm^2**, II layer **2.5x2.5 mm^2**, III layer **5x5 mm^2**

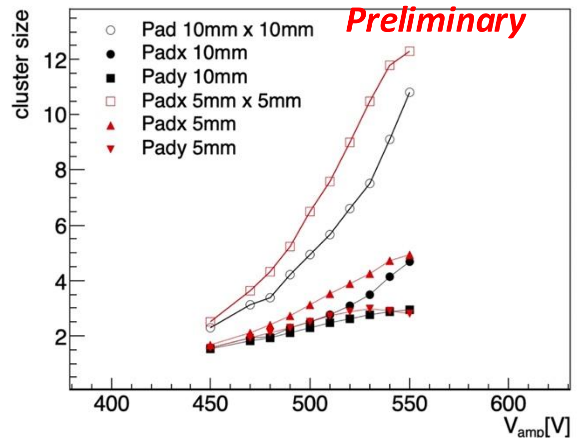
Concept from R. De Oliveira and K. Gnanvo et al., NIMA 1047 (2023) 167782)

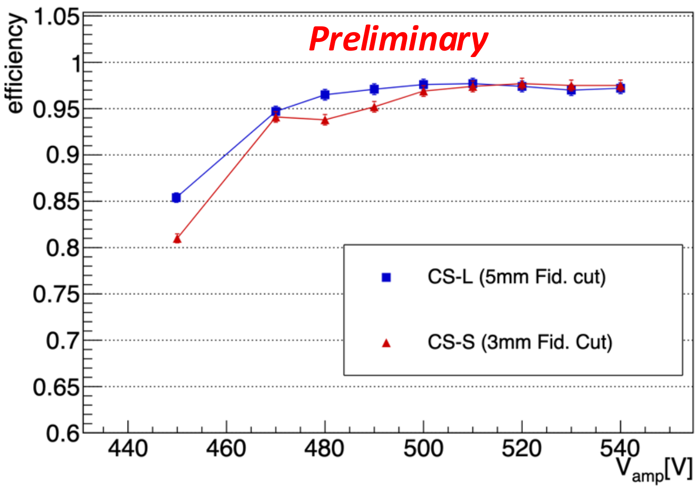


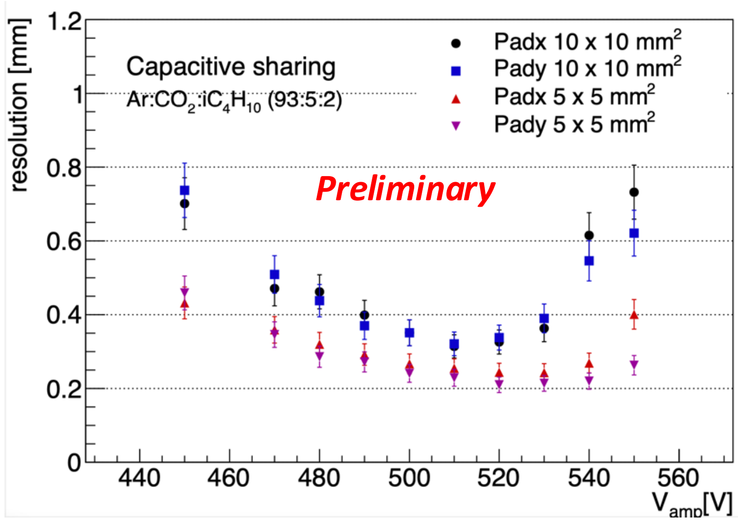


Resolution & efficiency with capacitive sharing

- Resolution measured in the region with large pads (sharing with 4 stacked layers) **~ 320µm**
  – factor ~1/30 of the readout pad size
- Resolution measured in the region with small pads (sharing with 3 stacked layers) **~ 200µm**
  – factor ~1/20 of the readout pad size
- Plateau efficiency at **~97%,** comparable with the prototypes non implementing the capacitive sharing







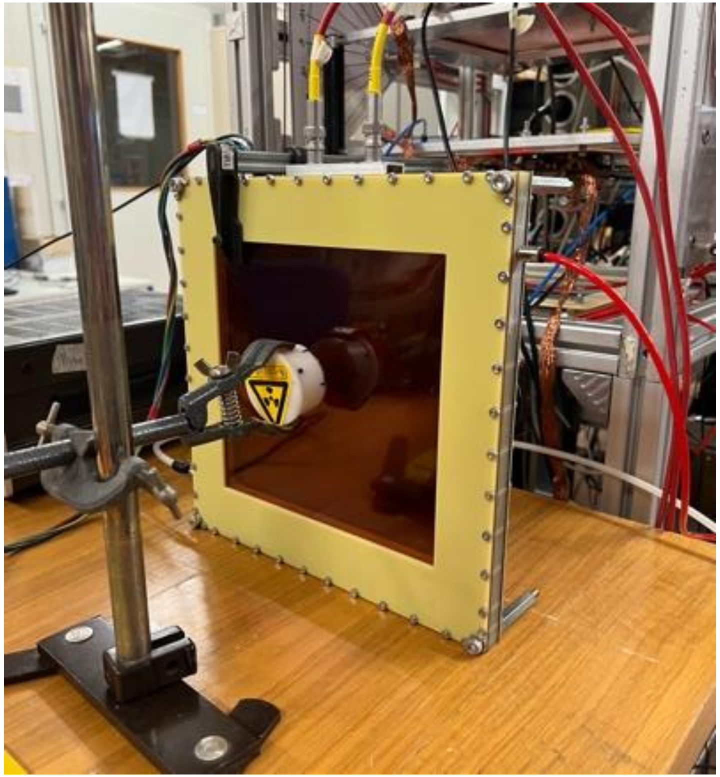
Summary

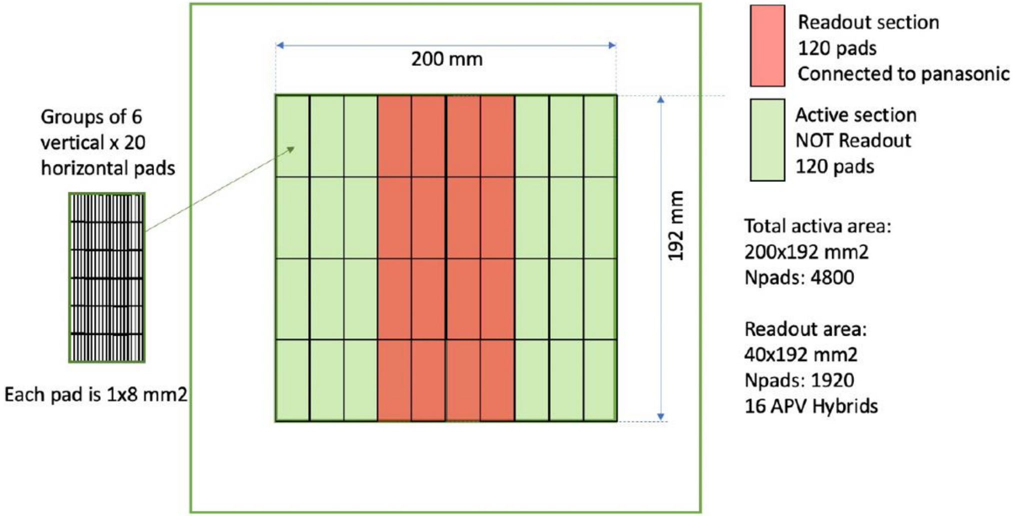
- Several Small Pads Micromegas prototypes have been built employing different solutions for the resistive layout
  - Best performances for high-rate with Diamond-Like Carbon (DLC) resistive foils
- **Performances achieved:**
  - stable operation up to 20 MHz/cm^2 with gain >10^4
  - detector efficiency > 97% (limited by pillars for ⊥ tracks, ~100% otherwise)
  - position resolution < 100 µm
  - Time resolution down to 6ns 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
- R&D started to exploit capacitive sharing concept for low-medium rate applications
- Design simplification and cost reduction on the way
  - Production at industry (ELTOS) is being investigated
- R&D fully aligned to the ECFA Roadmap for Detectors Research and Development
- Ready for new R&D focusing on applications: large area muon systems and sampling calorimetry


Thank you!

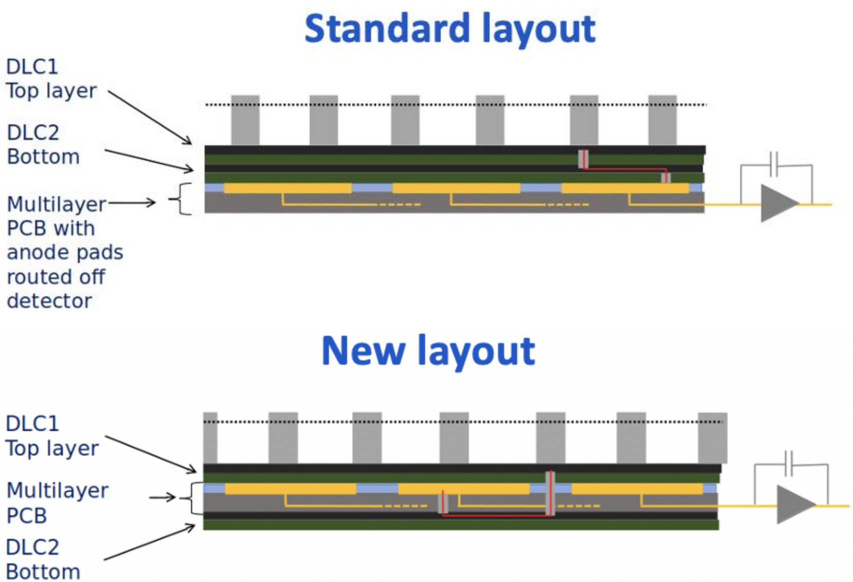
Backup

The 20x20 cm² prototype





- **active area: 200x192 mm^2**
- Pads 1x8 mm^2 - Total Number of Pads: 4800
- Double layer DLC with grounding vias every 8 mm
- Panasonic connectors on the back of the detector
- Partially readout: 1920 connected pads out of 4800 tot pads



Read-out pads (in yellow in the figures), normally placed under the two resistive DLC foils.
In the new layout they are in between them →

- capacitance increase to collect a larger fraction of the signal

Pad-Patterned (PAD-P3)
Resistance from top resistive pad to anode pad:
15-25 MΩ
Independent PADs, limited or negligible charge spread

Standard DLC (DLC20)
Resistivity: Top and Bottom foils ~20 MΩ/□
Grounding vias every 6 mm (12 mm) in the left (right) half of the detector
Read-out pads below the resistive DLC foils

DLC-SBU (SBU3) [Sequential Build-Up technique exploiting copper clad DLC]
Resistivity: Top 22 ± 1 MΩ/□ – Bottom 42 ± 8 MΩ/□
Readout pads between the resistive DLC foils

DLC-SG [Strip Grid grounding scheme]
Resistivity: Top 40 ± 2 MΩ/□ – Bottom 38 ± 6 MΩ/□
Readout pads between the resistive DLC foils
Longer pillars to cover the grounding copper strips