Progress on fine granularity resistive Micromegas and preliminary results of the capacitive sharing technique

M. Alviggi[1,2], M. Biglietti[3], M. T. Camerlingo[5], K. Chmiel[3,4], M. Della Pietra[1,2], C. Di Donato[1,6], R. Di Nardo[3,4], P. Iengo[2], M. Iodice[3], R. Orlandini[3,4], S. Perna[1,2], F. Petrucci [3,4], G. Sekhniaidze[2], M. Sessa[7]

[1] INFN Napoli, [2] Universita` di Napoli "Federico II", [3] INFN Roma Tre, [4] Università di Roma Tre, [5] INFN Bari, [6] Universita` di Napoli "Parthenope", [7] INFN Roma 2

The RHUM* (Dream) Team

*Resistive High granUlarity Micromegas for Future Detectors

Goals

- Consolidation of resistive pixelised Micromegas, for measurements at high rates - order of 10 MHz/cm^2
  - High-granularity/low occupancy readout on pads of the order of mm^2
- Robustness and stable operation at high gains
- Performance
  - efficiencies close to 100%
  - spatial resolution below 100 μm
  - time resolution below 10 ns
- Demonstration of the scalability of detectors on large surfaces
- Medium/Low-rate Version – Capacitive Sharing
  - K. Gnanvo et al., Nucl. Instrum. Meth. A 1047 (2023) 167782

new

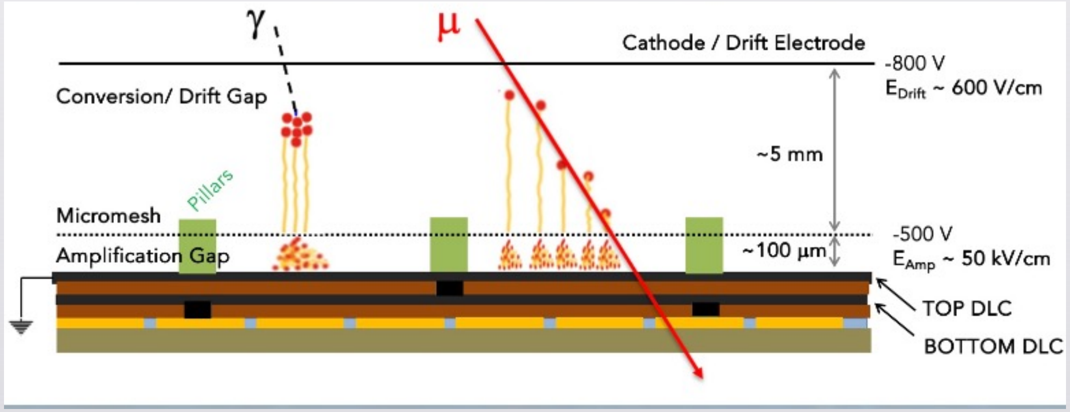
Double DLC layer Micromegas Concept

initial goal was to optimize the structure and to explore the complementarity among different configurations → studies conducted on small-scale prototypes

Final configuration: use of resistive foils based on Diamond Like Carbon structures (DLC).

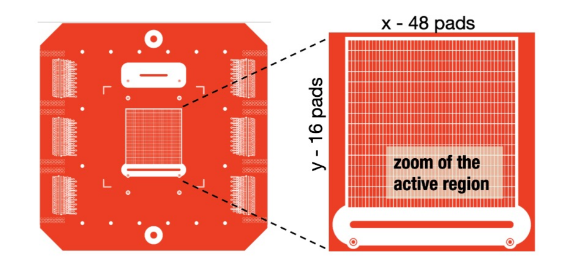
Readout pads are covered by a double layer of DLC with a grid of staggered interconnecting vias for rapid charge evacuation

Typical (optimal) DLC resistivity: 20 – 40 Mohm/sq



Towards Large Size Pixelised Micromegas

small size prototypes

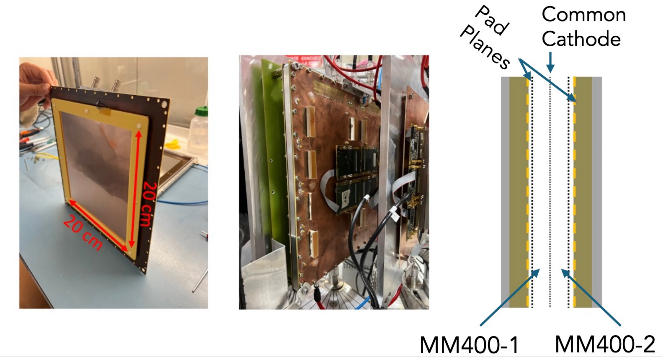


active area : 4.8cm x 4.8 cm

segmented in
48 x16 readout pads

pad size: 1 x 3 mm^2

medium size prototypes



Two detectors Paddy400-1 and Paddy400-2

active area : 20 cm x 20 cm (40% readout in central part)

Anode plane pad size: 1x 8 mm^2

also tested in sandwich config sharing the same cathode

large size prototype

“The Big one”
Paddy-2000: 50 x 40 cm^2

Readout central region 6.4x6.4 cm^2 with1x8 mm^2 pads

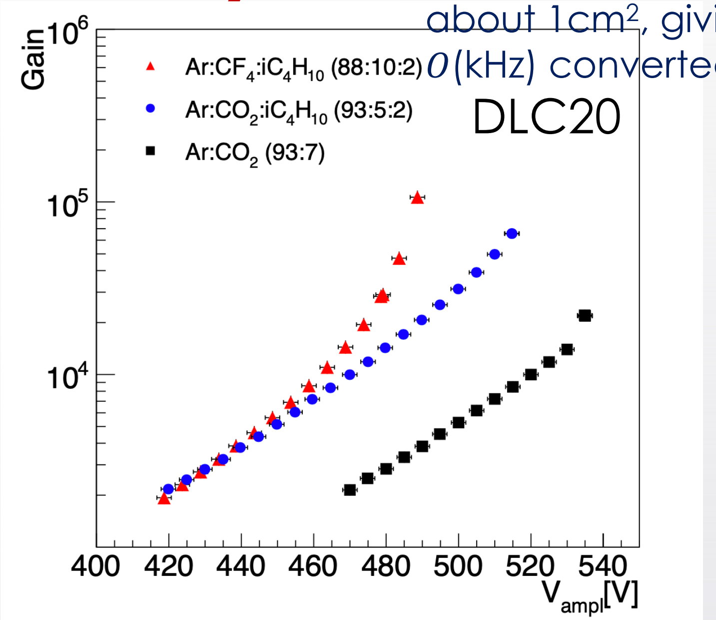
Surrounding area – 2048 pads, 10x10 mm^2

Gain and Rate Capability

Addition of 2% of isobutane significantly extends the stability range up to 7×10^4 and 10^5 with $Ar:CO_2:iC_4H_{10}$ (93:5:2) and $Ar:CF_4:iC_4H_{10}$ (88:10:2)

guarantee a working point with enough margin

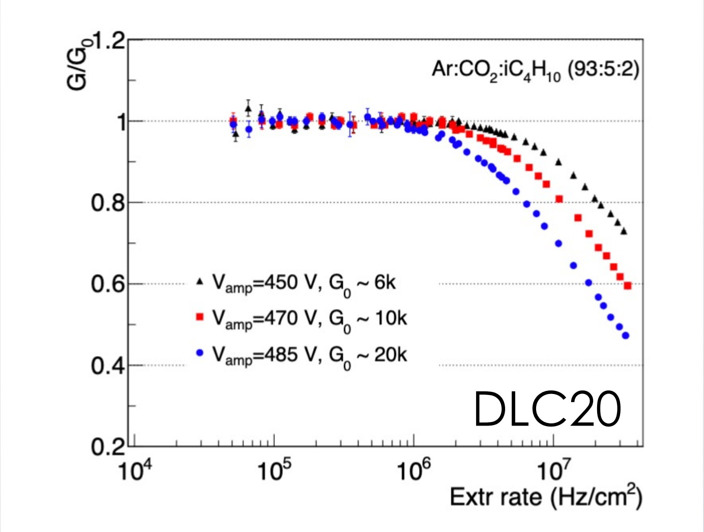
^{55}Fe source on spots of about $1 cm^2$, giving a rate $\mathcal{O}$(kHz) converted X-rays



Rate capability Vs X-rays from the copper anode X–Ray gun.

Gain drops at 10 MHz/cm^2 are limited to 10% at G_0 = 6000

8 keV photons ionization ~5 higher than MIP particles → rate capability of order 10 MHz/cm^2 at a gain of 20k !

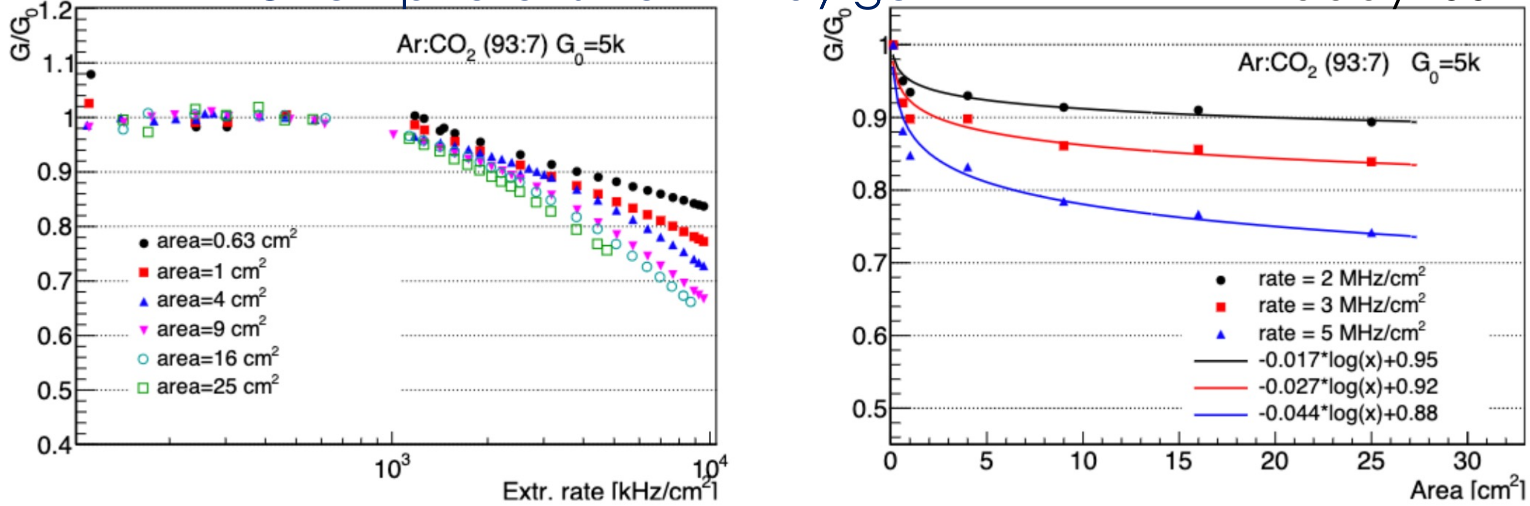


Gain dependence on the irradiated area

- stable behaviour is measured up to about 1 MHz/cm²
- empirical logarithmic dependence
- behaviour similar to small DLC prototypes

8 keV photons from X-ray gun

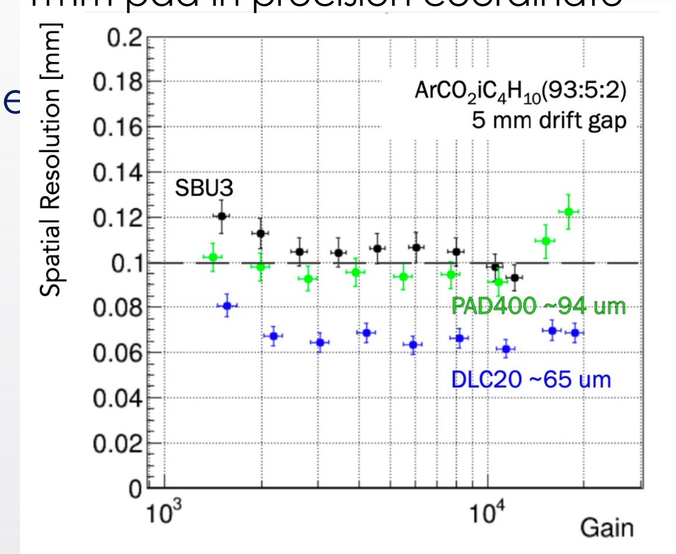
Paddy400



Spatial Resolution

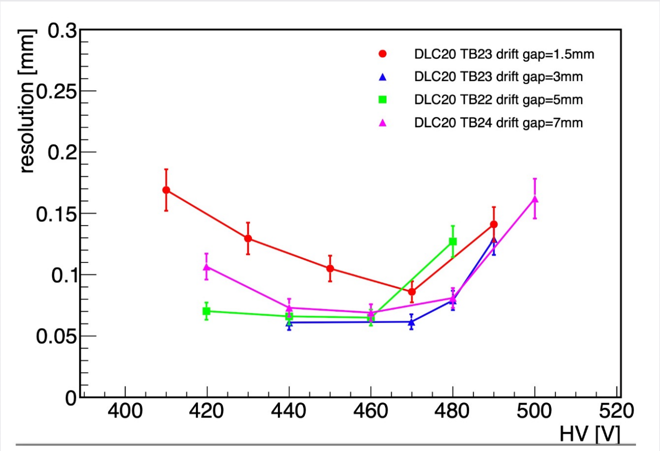
- Unbiased cluster residual wrt extrapolated position from e
  tracking chambers
  - position from charge weighted cluster centroid
- Extrapolation error is subtracted (about 50 μm).
- Statistical uncertainty is negligible
- Systematic uncertainty (fit procedure) ~5%

1mm pad in precision coordinate

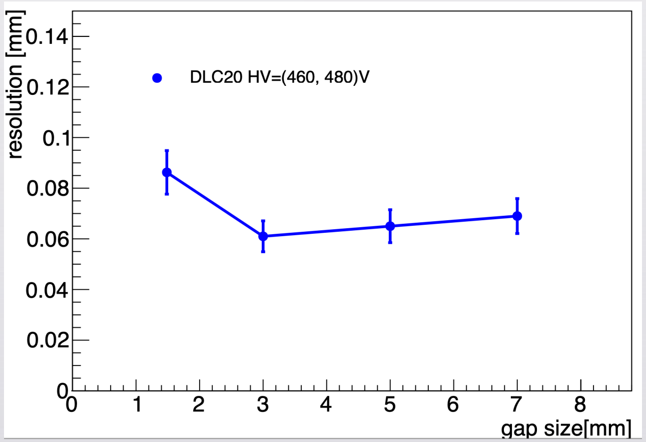


Study of the spatial resolution
as a function of the drift gap size
shows small dependency

deterioration only for very small drift gap (~1.5mm)



for perpendicular tracks



Spatial resolution- Centroid Optimisation

new

The cluster position is evaluated with an extended definition of the charge weighted centroid:

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

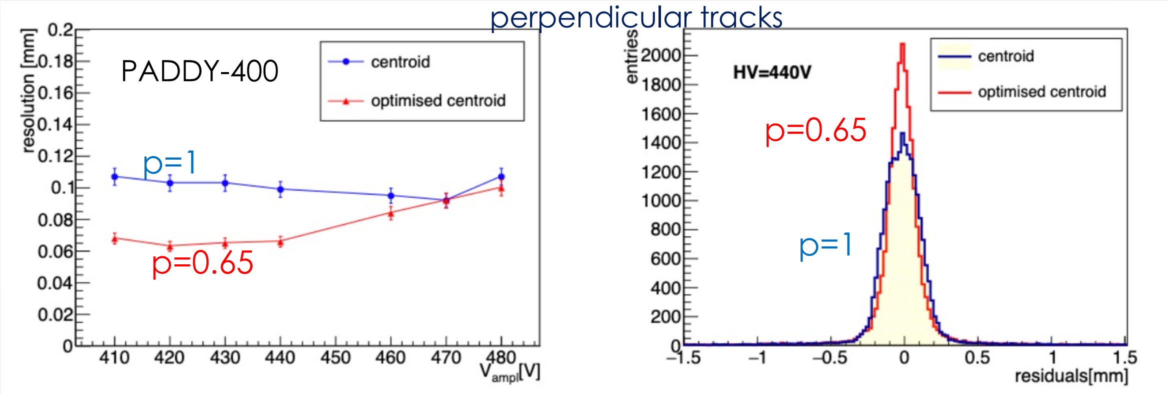
optimal parameter "p" found trought a minimisation of residuals

$$x_{trk} - \frac{\sum x_i q_i^p}{\sum q_i^p}$$

improvement of ~35%

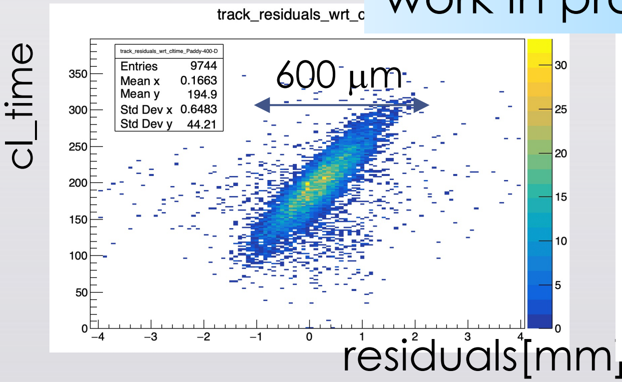
at high gain the resolution is limited by poor charge measurements in APV due to saturation

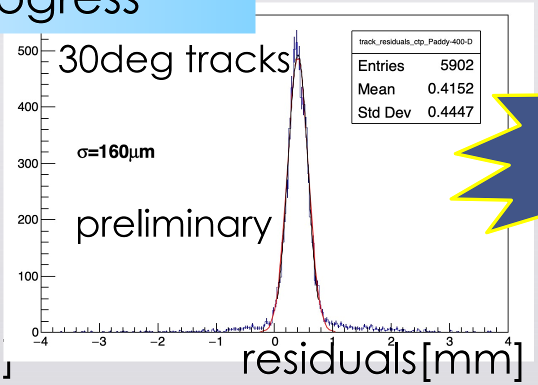
perpendicular tracks



work in progress

Under development : exploit timing information for inclined tracks → cluster time projection method

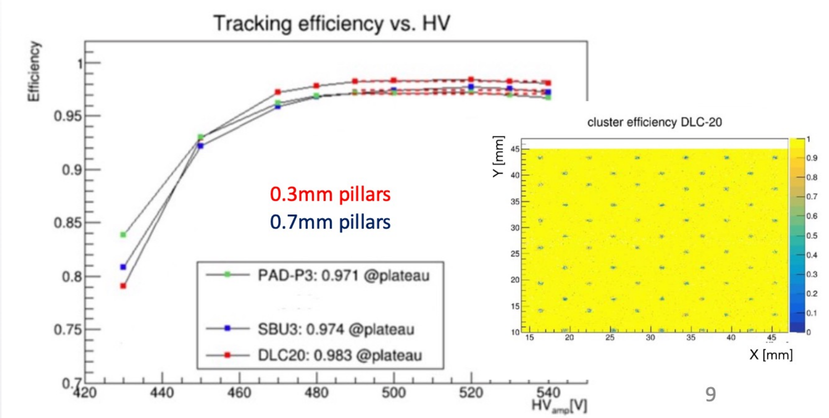




new

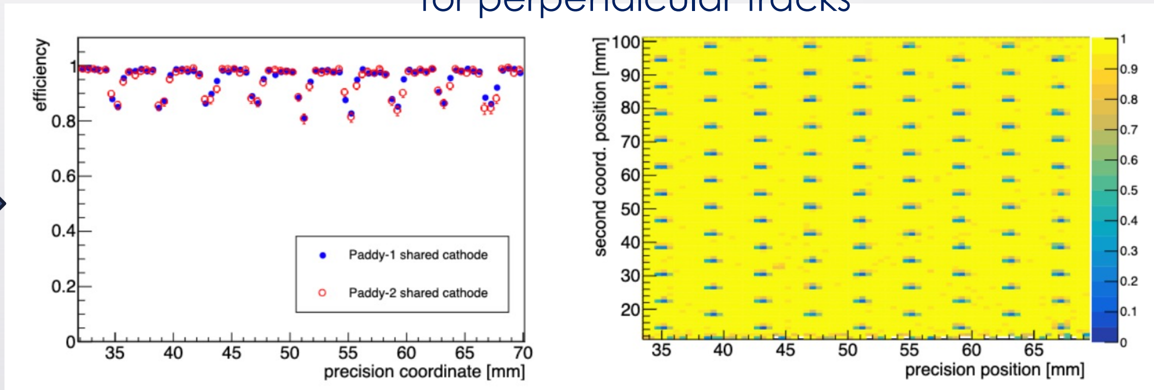
Efficiencies

- 1.5 mm (on precision coordinate) fiducial cut wrt extrapolated position from external tracking chambers
- Efficiency for perpendicular tracks is nearly 100% except at pillar positions

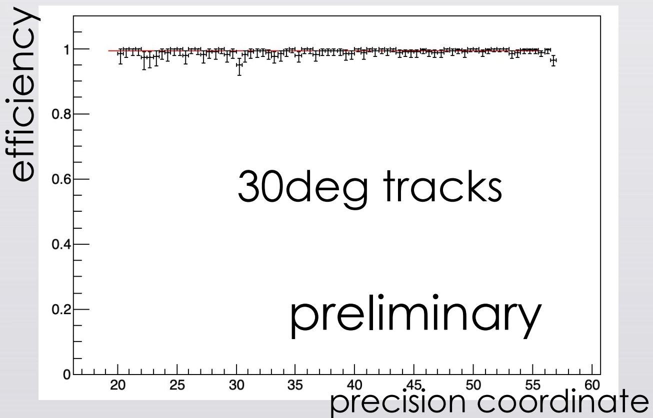


for perpendicular tracks

efficiencies for Paddy400
with shared cathode



pillars disappear with inclined tracks



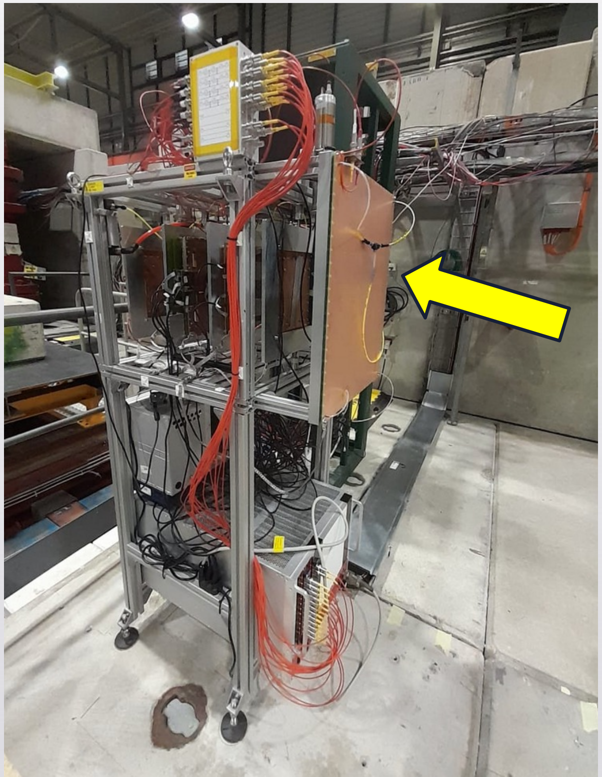
Paddy-2000 – the "Big One"

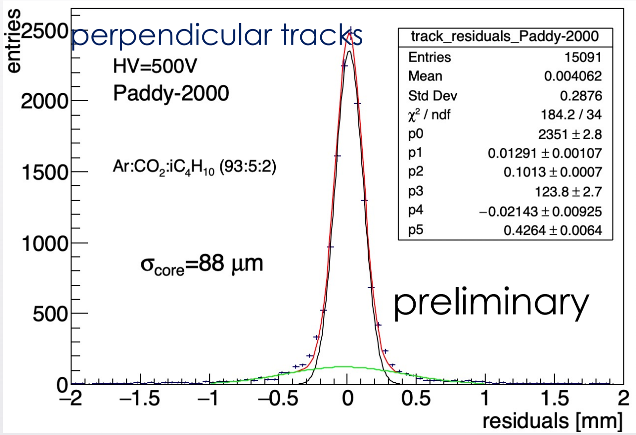
new

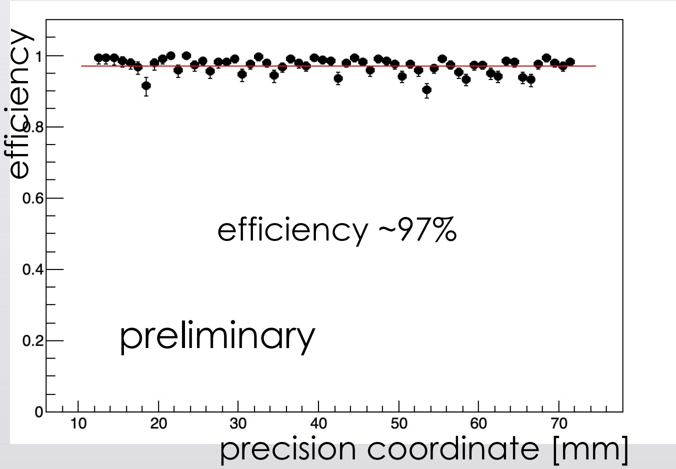
tested for the first time in 2024 Test Beam in April

shows similar performance as small prototypes

full analysis of TB data in progress





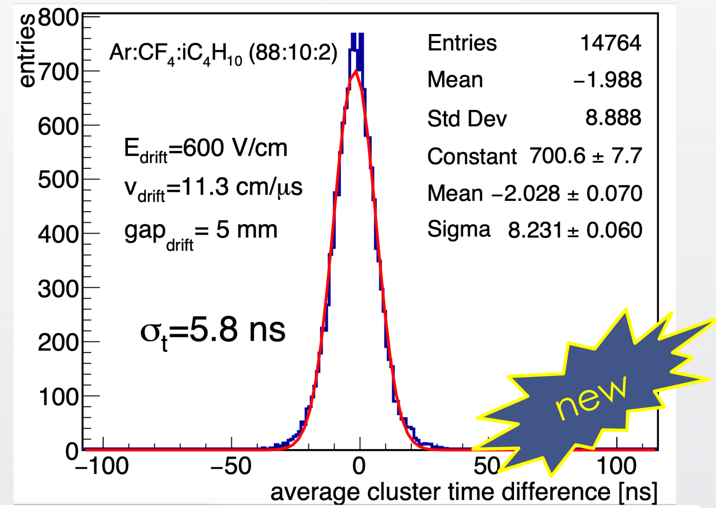


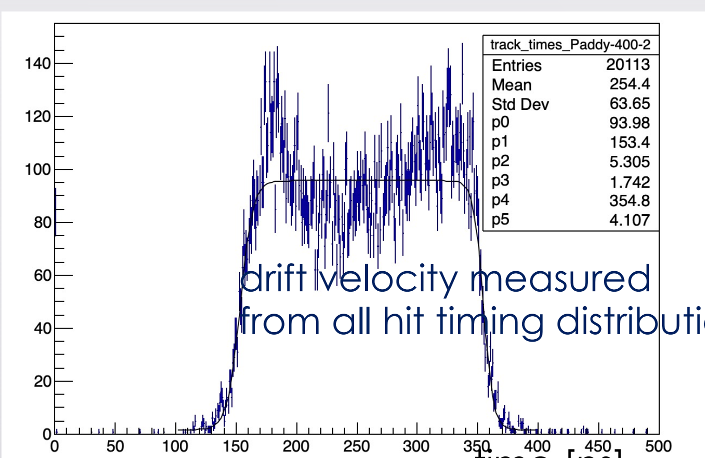
Time resolution

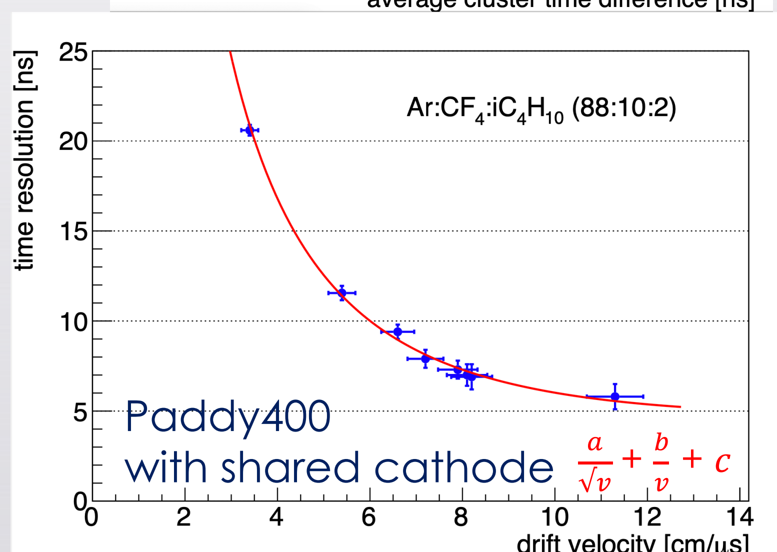
Method: compute the time difference between on-track clusters in two different chambers

Gaussian fit performed to each time difference distribution, time resolution evaluated as sigma/sqrt(2)

Improved analysis (mainly better definition of detector fiducial region) → Paddy400 time resolution ~ 6 ns at v_{drift} ~11cm/us [fast gas mixture, includes effects from electronics/APV q(t) distribution fit]

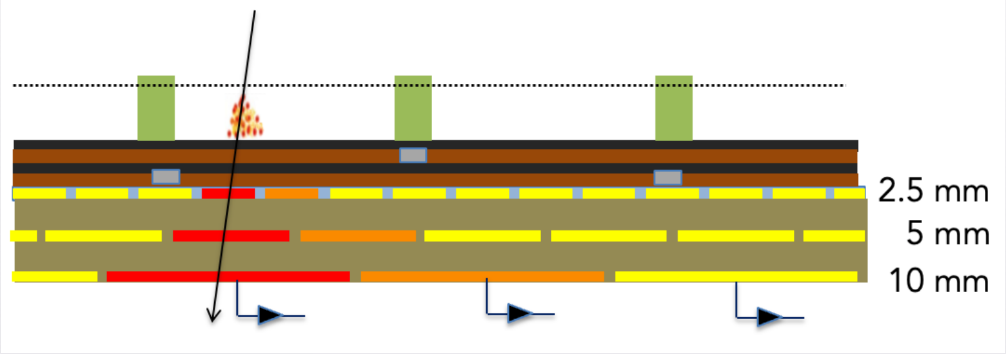


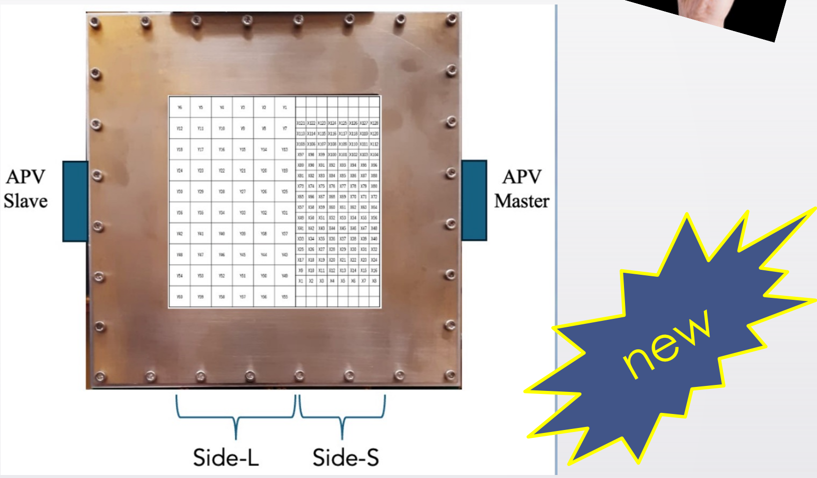




Capacitive Sharing Chamber

charge shared in large readout pads using capacitive coupling between stack of layers of pads → spatial resolution and reduction of readout channels

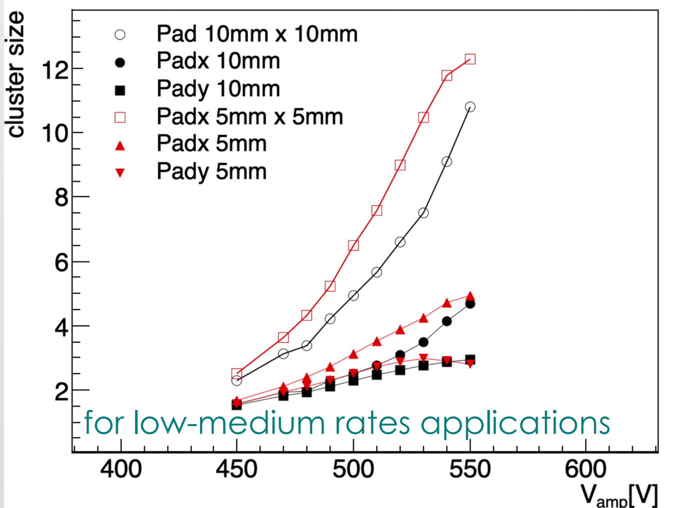




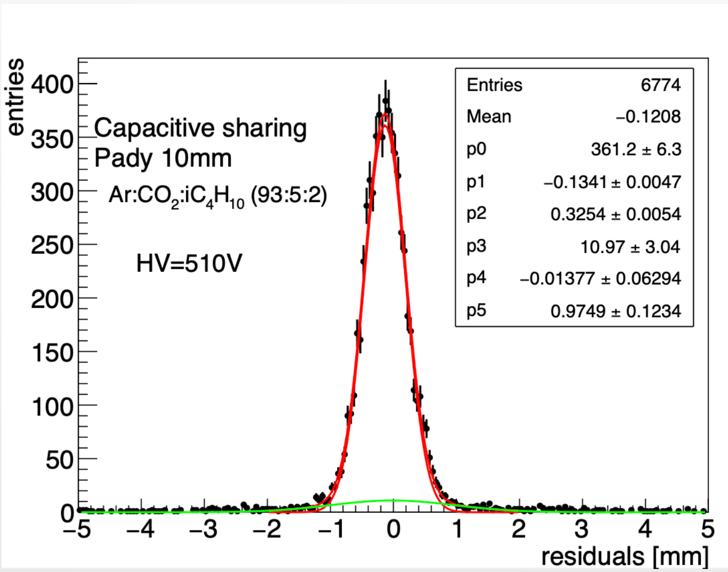
Pad size of "top-layer" (signal induction): 2.5x2.5 mm^2

Side-L: three layers capacitive sharing: 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2

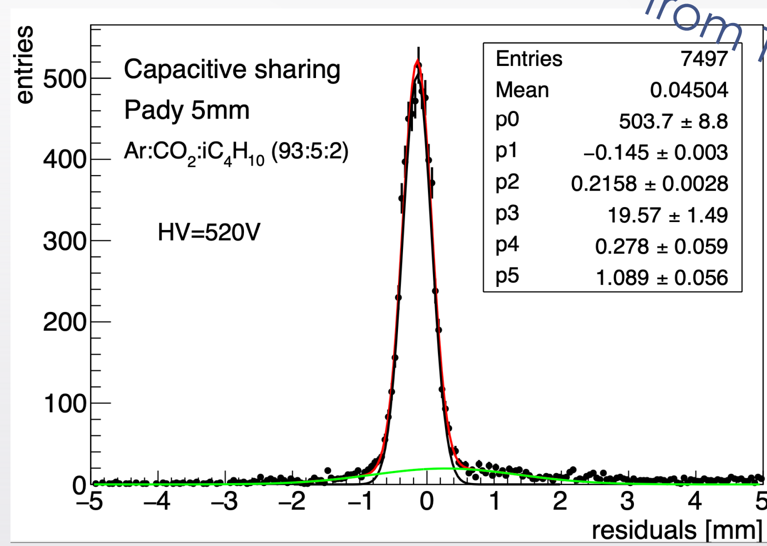
Side-S: two layers capacitive sharing: 2.5x2.5 mm^2 → 5x5 mm^2



Capacitive Sharing Spatial Resolution



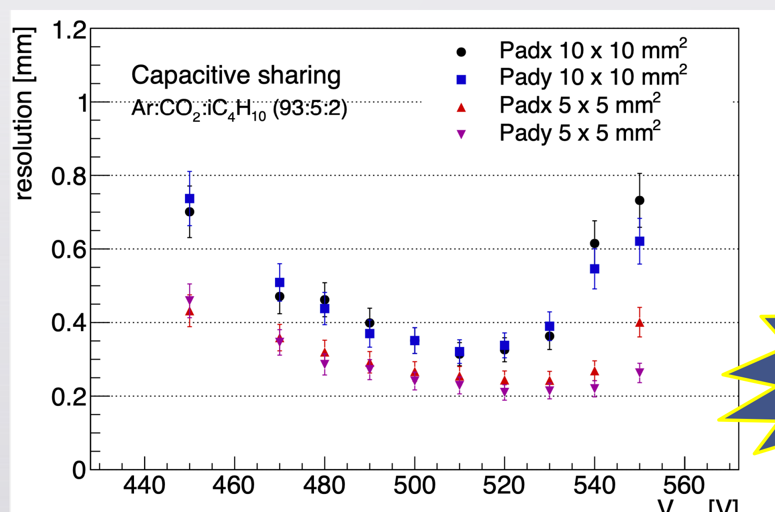
from TB24 in April



large pad resolution ~320 μm
→ factor 1/30 of the pad size

small pad resolution ~200 μm
→ factor 1/20 of the pad size

tipical without capacitive sharing
~1/14 of the pad size

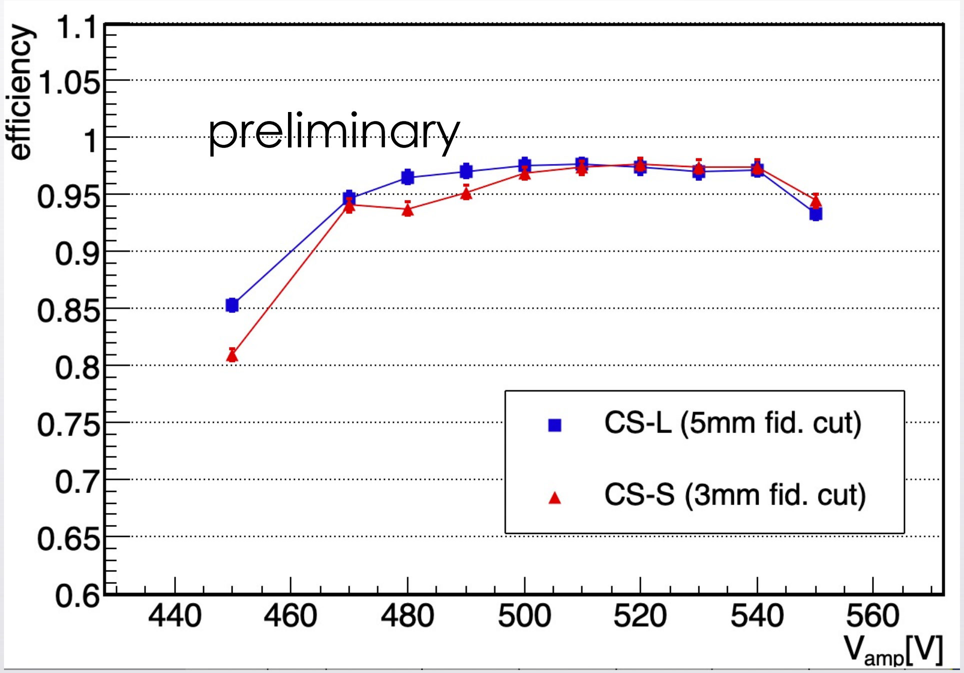


new

Capacitive Sharing Efficiencies

Efficiencies around ~97%

compatible with the “standard” prototypes



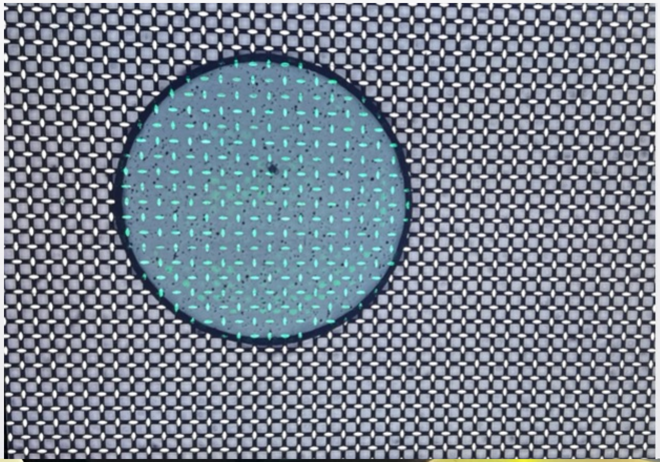
Summary and Outlook

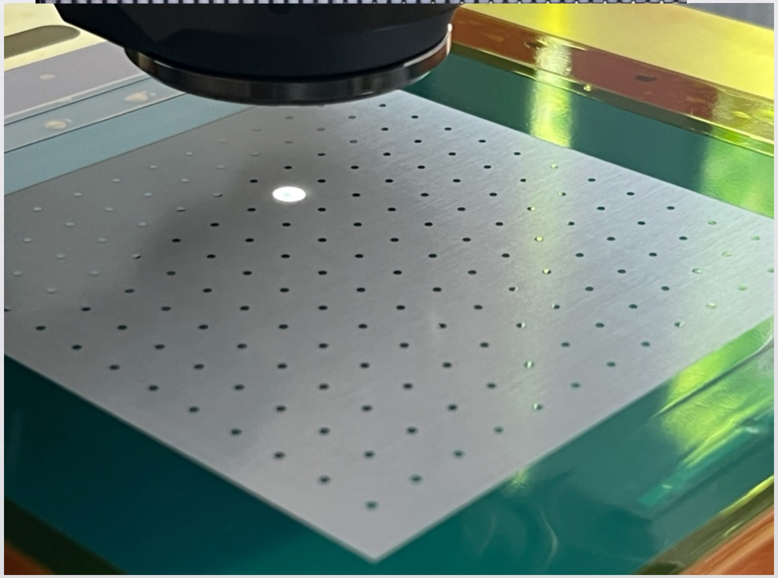
- Started in 2015, the R&D on high performance resistive Micromegas achieved all the objectives of the project and is aligned with the ECFA Roadmap implemented in the DRD1

- The R&D is approaching the strategic themes of DRD1 WP1 for large systems for future experiments, namely (task 2 deliverables):
  - high rate applications : high gain to ensure stability providing a good margins, and rate capability ✓
  - low/medium rate applications : R&D on capacitive sharing started – promising results !
  - space and time resolution ✓
  - scalability for large area apparatuses → construction and test of large size detector (50x40 cm^2) ongoing – promising results!
  - simplifications and cost reduction
    - simplified DLC structures, larger readout elements (exploiting both resistive and capacitive sharing)
    - Production at Industry (ELTOS) is being investigated → last week we have successfully built small size prototypes with DLC and the bulk technique ✓

- Addressing FE electronics and DAQ for high rate operations is crucial → the Topical Workshop on Wednesday will be a good check point

Cheers from Eltos…





first production (2 small prototypes) done

to be tested

next steps : larger size prototypes!