The 8th International Conference on Micro-Pattern Gaseous Detectors

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USTC HEFEI 2024

Resistive High Granularity Micromegas for Future Detectors. Status and Perspectives

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[6] INFN Bari, [7] Univ. di Napoli Parthenope

The R&D on Resistive High granUlarity Micromegas

- Consolidation of resistive Micromegas, for measurements at rates of the order of **10 MHz/cm²**
- Implement a small pad readout to reduce the occupancy
  - O(mm²) for high-rate capability and good spatial resolution
- Optimize the spark protection resistive scheme to achieve stable operation at high rate/gain
- Demonstration of the **scalability** of detectors on large surfaces

Possible applications in HEP

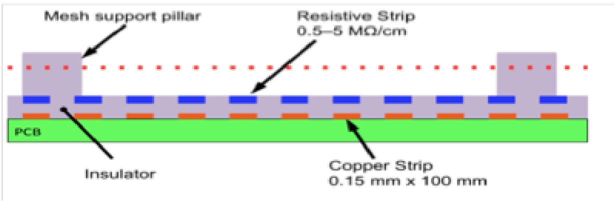
- Very fwd muon tracking extension in existing experiments
- Muon detector/TPC @ future accelerators
- Readout for sampling calorimeter (see A. Stamerra talk on Monday)
- Proton structure – QCD physics (AMBER) (see M. Alexeev talk)

Recent developments on resistive Micromegas

A one-slide summary from Rui (Rui De Oliveira, RD51 MPGD School)

All Resistive MM structures

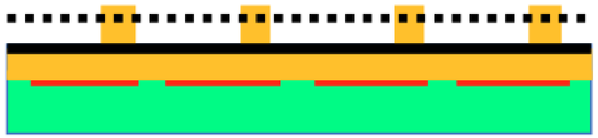
Medium-rate detectors 100kHz/cm2
Side evacuation of the charges



Screen printed resistive strips (ATLAS NSW)

2013

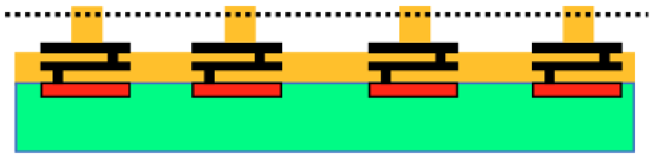
or



1 full DLC layer

2015

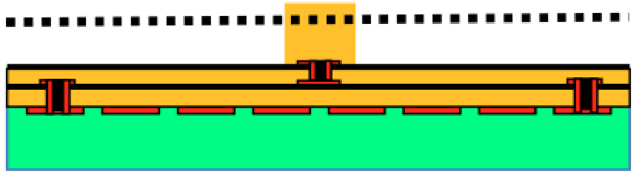
High-rate detectors 10Mhz/cm2
Charge evacuation inside active area



2 layers with screen printed pads

2015

or



2 DLC layers without patterns

2020

Recent developments on resistive Micromegas

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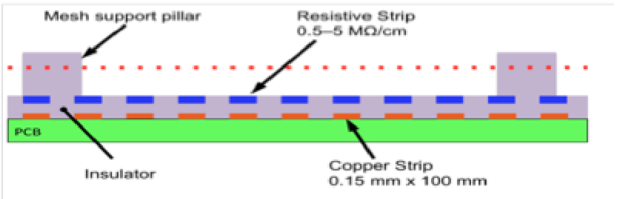

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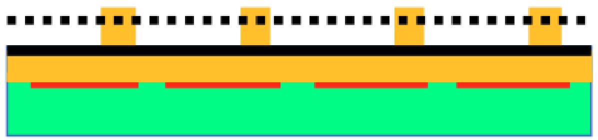

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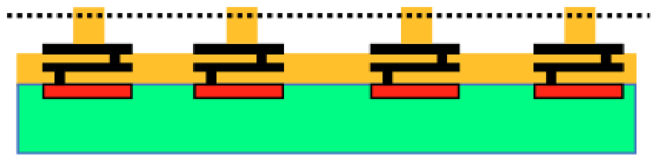
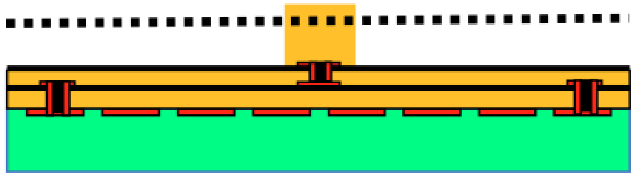


2 layers with screen printed pads

2015

or



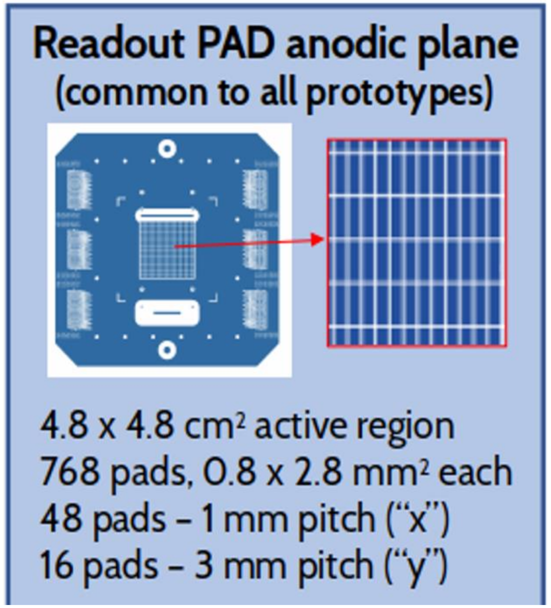
2 DLC layers without patterns

2020

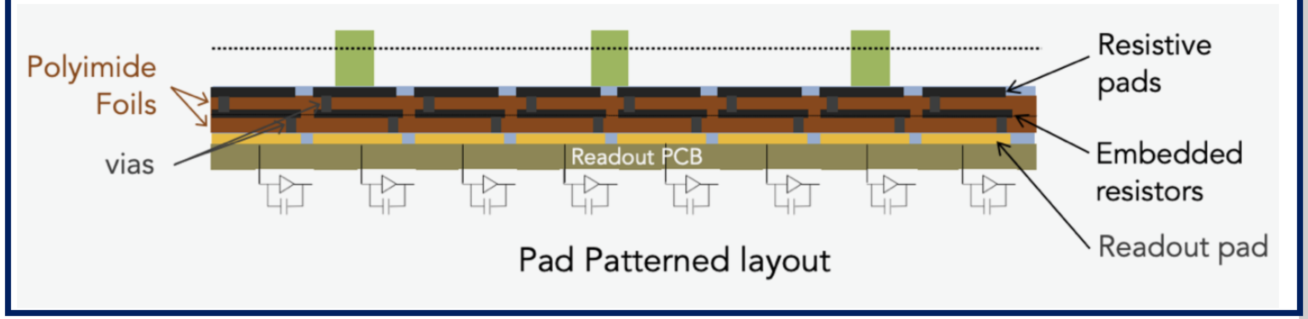
This is the work carried out within the RHUM project

The start (2015): Resistive Pad-Patterned Micromegas

- Configuration inspired by (1 cm^2 pad resistive MM) by M. Chefdeville and co-authors [1], [2], and by (non-resistive MM + GEM hybrid) detector in COMPASS [D. Neyret, et al.]
- Push the technology to high rates - Main changes/improvements:
  - Combine a resistive scheme to a high granularity readout for stable operation at high gain (G~10^4 and beyond) and high rates (up to 10 MHz/cm^2)
  - Improve and ease the production technique



PAD-Patterned



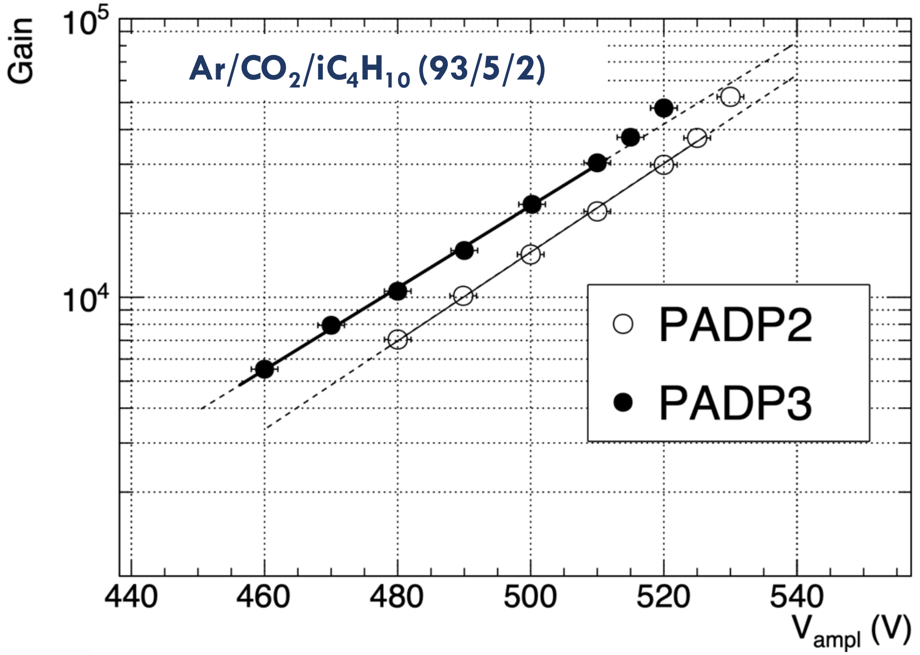
Readout pads 0.8x2.8 mm^2

PAD-Patterned

- EMBEDDED RESISTORS between resistive and readout copper pads
- Each pad completely independent from neighbours

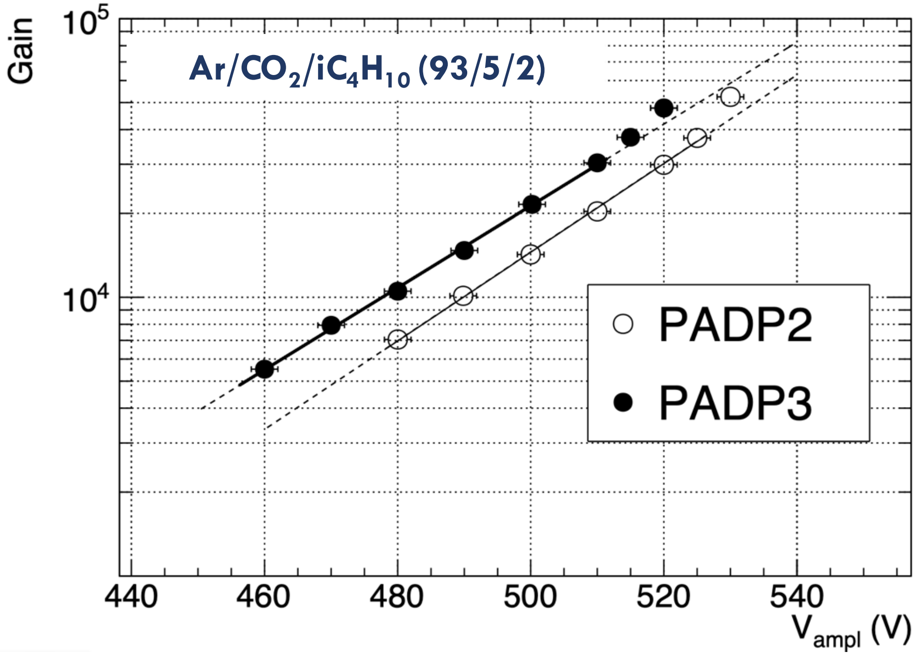
The Resistive Pad-P Micromegas - Performance

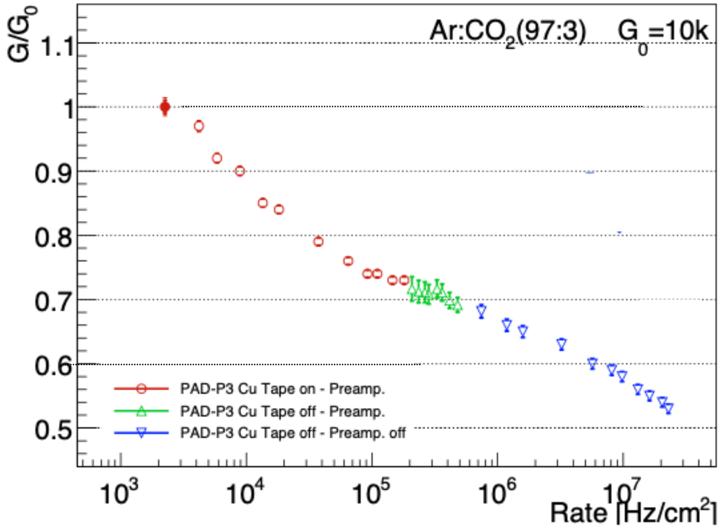
- Good stability up to a gain of 50k ☺



The Resistive Pad-P Micromegas - Performance

- Good stability up to a gain of 50k ☺
- Significant charging-up – it also severely affects the linearity with rates ☹

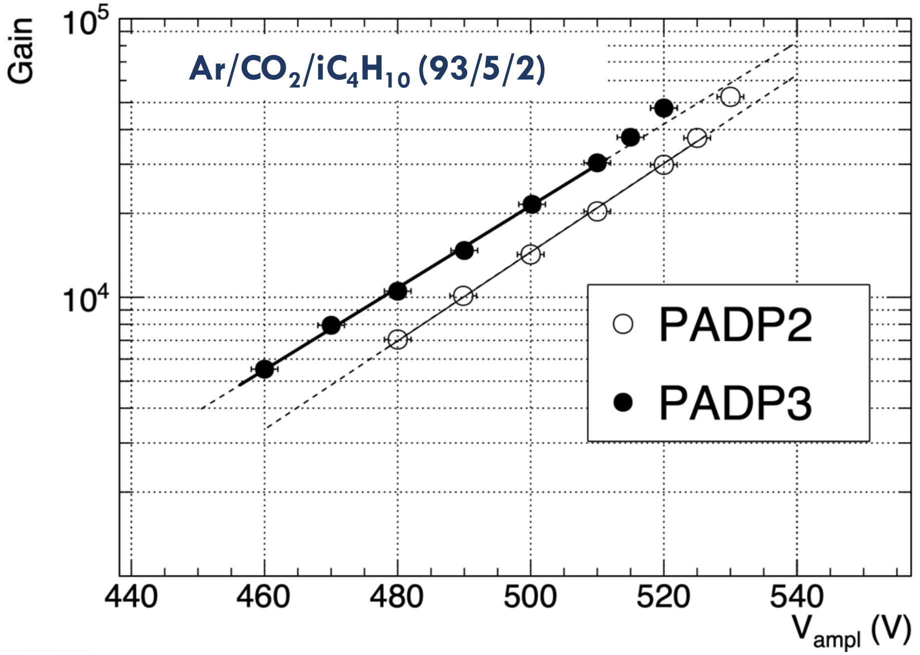


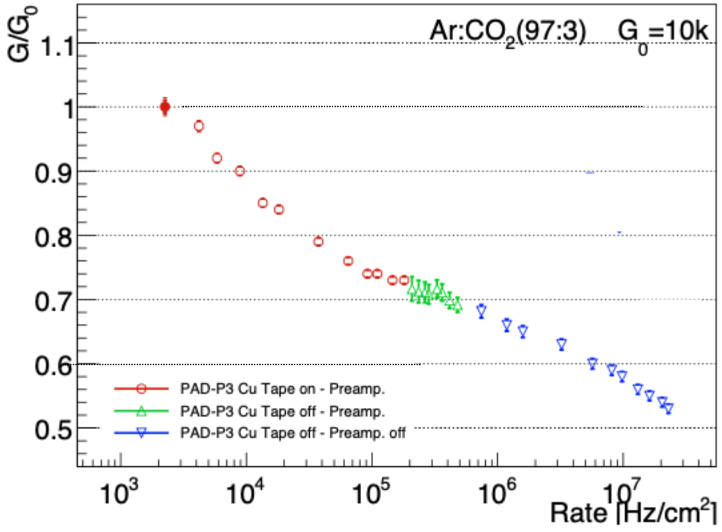


Drop at low rates dominated by charging-up

The Resistive Pad-P Micromegas - Performance

- Good stability up to a gain of 50k ☺
- Significant charging-up – it also severely affects the linearity with rates ☹
- Independence of the rate capability on the irradiated surface (due to independent "cells") ☺





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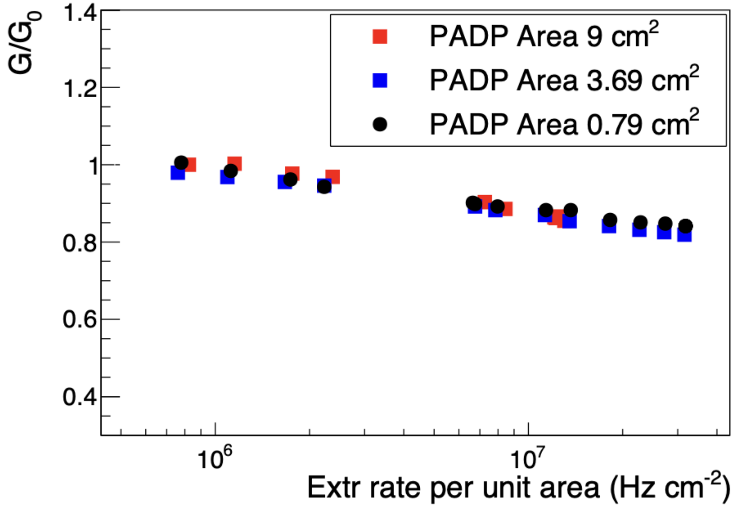
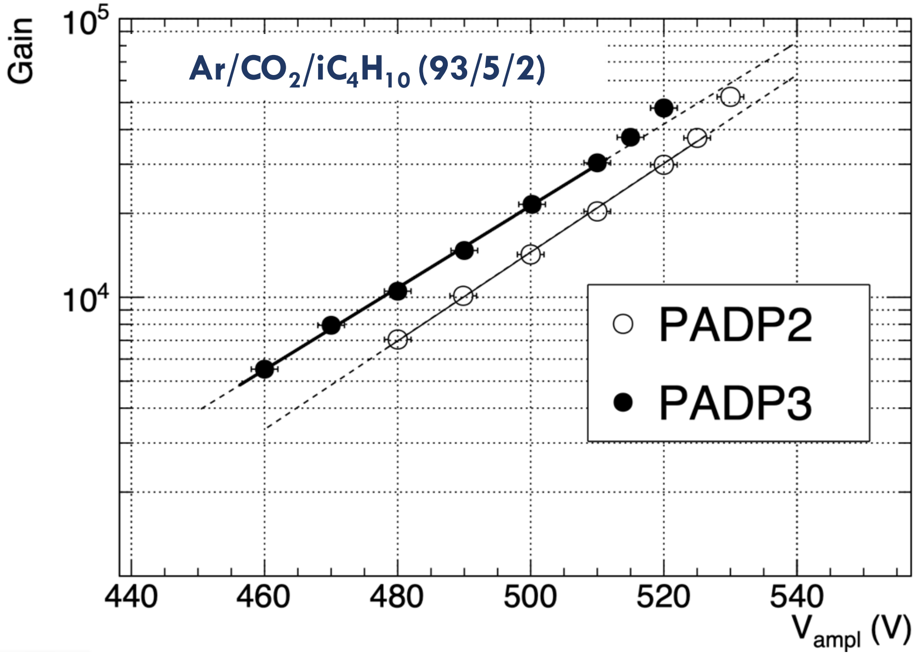
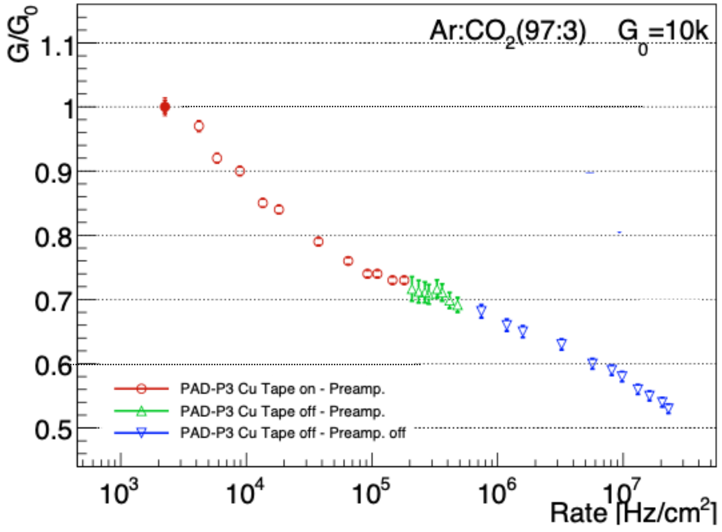


The Resistive Pad-P Micromegas - Performance

- Good stability up to a gain of 50k ☺
- Significant charging-up – it also severely affects the linearity with rates ☹
- Independence of the rate capability on the irradiated surface (due to independent "cells") ☺
- Moderate energy resolution and spatial resolution (non-uniformity of gain – edge effects for each pad) ☹





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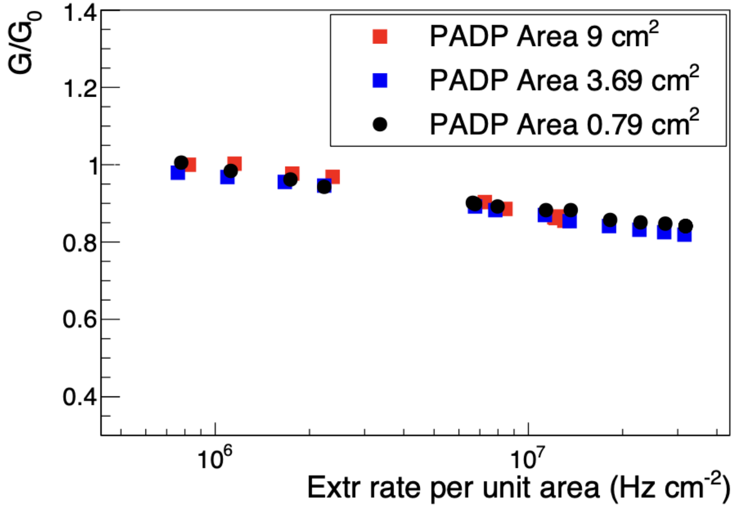
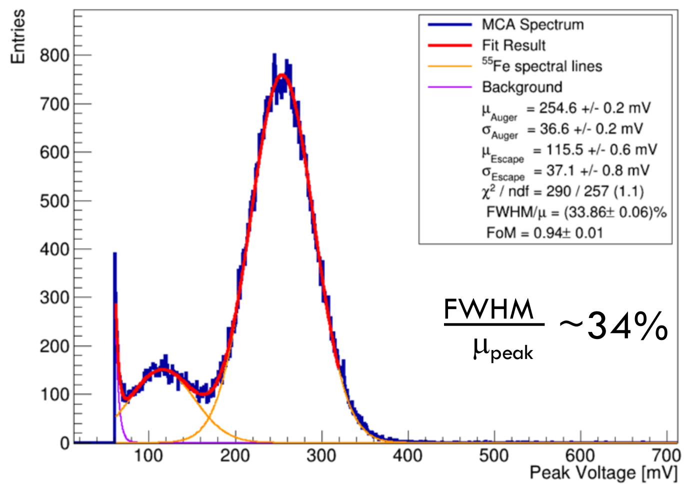
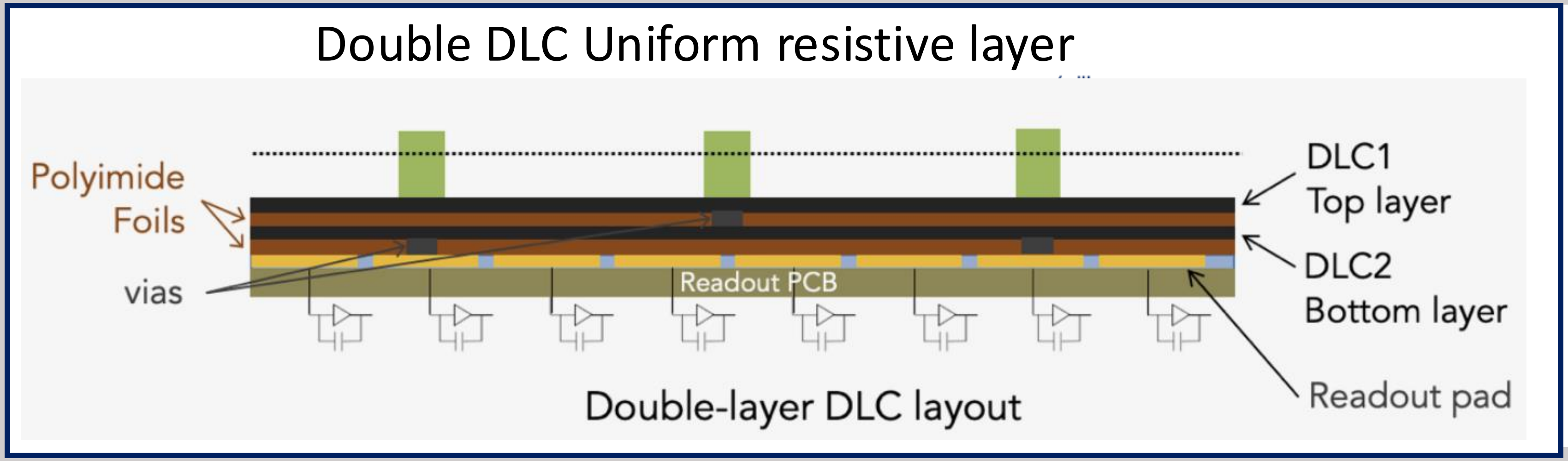




The Double DLC layer resistive configuration

- 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)



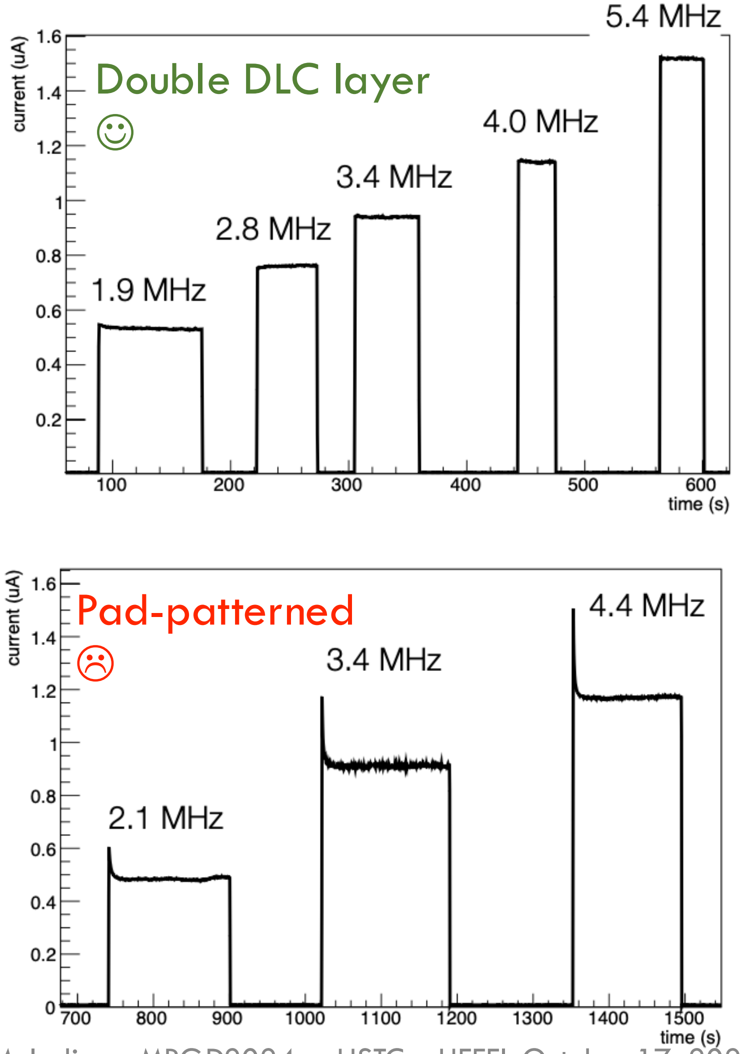
DLC20 (20 MΩ/sq)

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

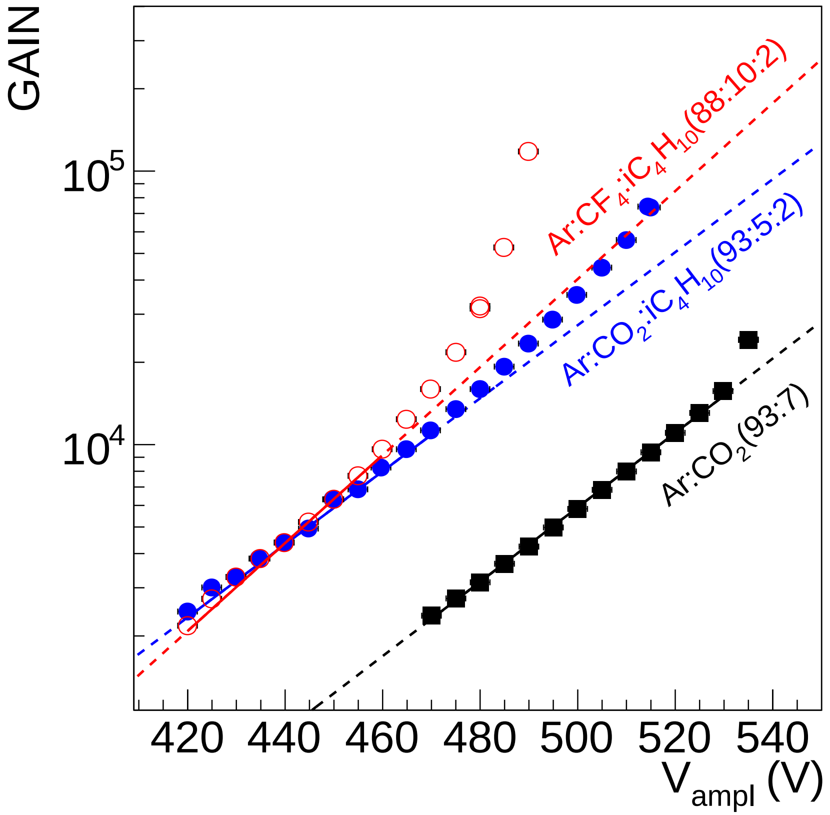
DLC resistive Micromegas – Performance - overview

- Negligible charging up effects

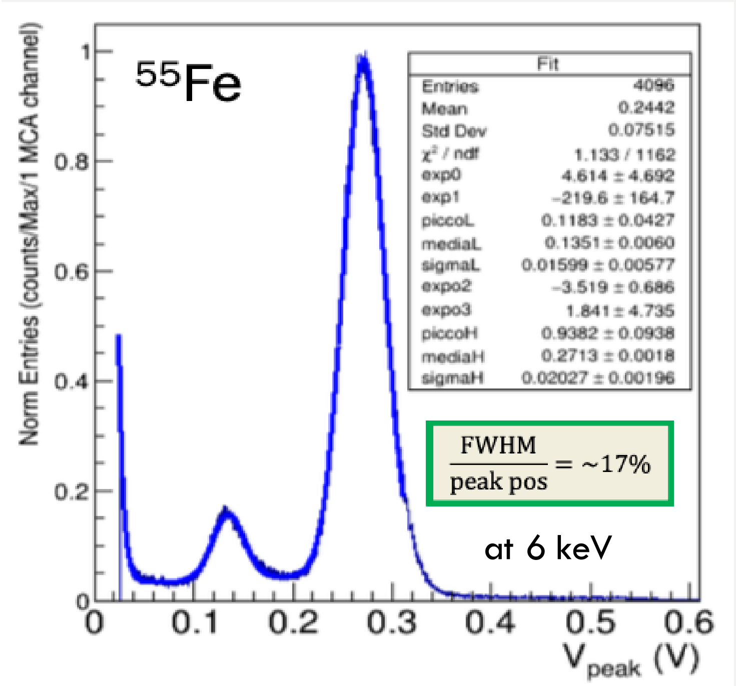


- Good stability
- High Gain with 2% of iC_4H_{10}

Above 5 x 10^4

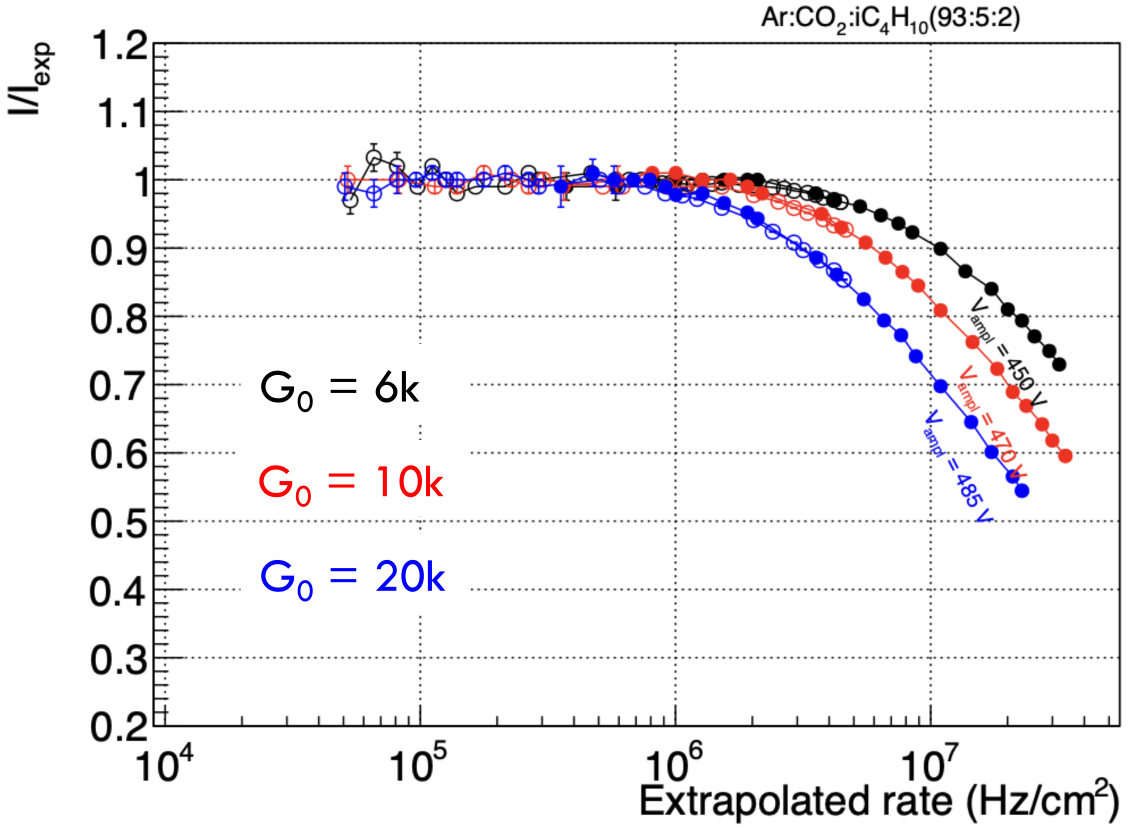


- Good energy resolution
  ~17% at 5.9 keV (Fe55)



DLC MM – Rate Capability

Can achieve high-rate capability (limited gain drop up to 10 MHz/cm^2) with DLC ~20-30 MOhm/sq



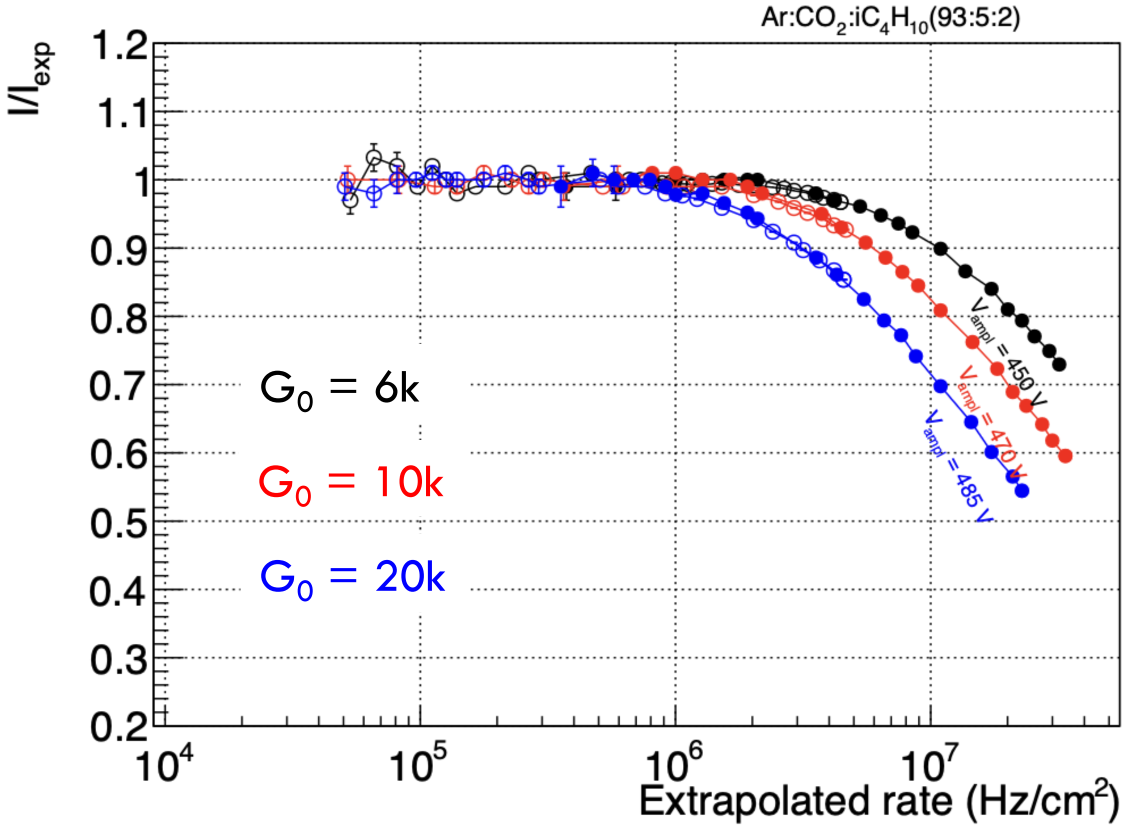
Here, the rate capability is reported for **gains of 6, 10, 20 k**

For X-rays irradiations from Cu – X-ray gun (~8 keV) on a circular spot 1cm diam.

(ionisation n_0>250 e$^-$, Vs n_0~50 for MIP in 5 mm)

DLC MM – Rate Capability and Ion Backflow

Can achieve high-rate capability (limited gain drop up to 10 MHz/cm^2) with DLC ~20-30 MOhm/sq



Here, the rate capability is reported for **gains of 6, 10, 20 k**
For X-rays irradiations from Cu – X-ray gun (~8 keV) on a **circular spot 1cm diam.**
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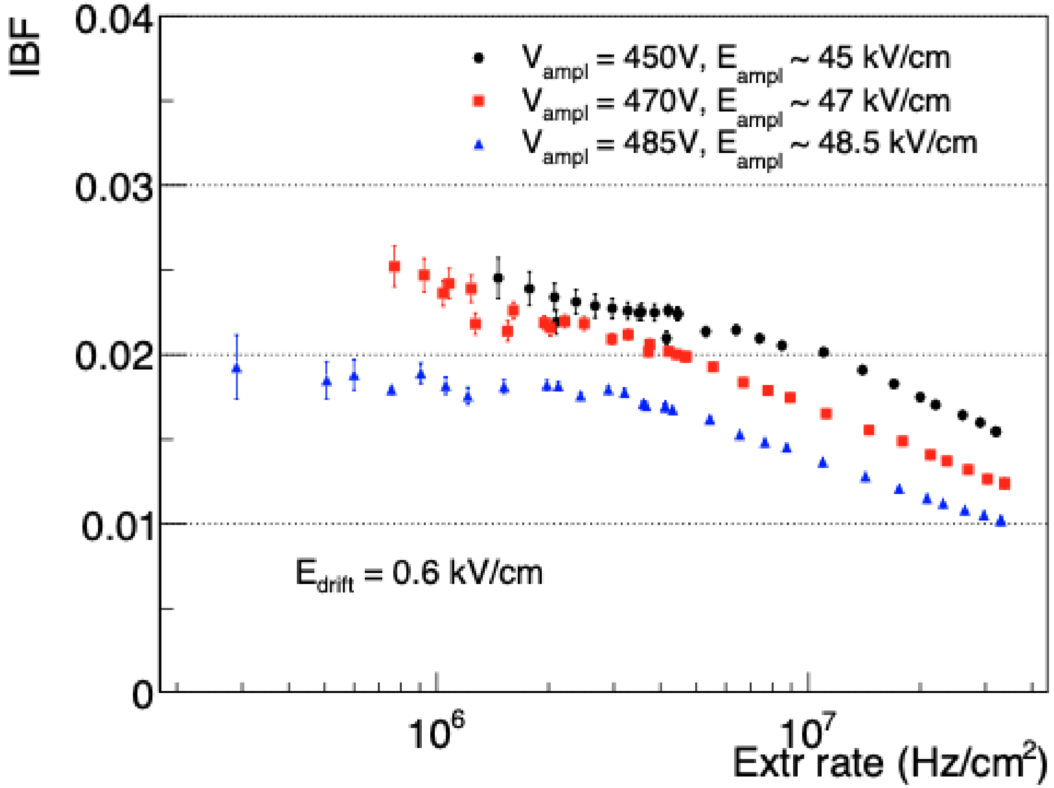
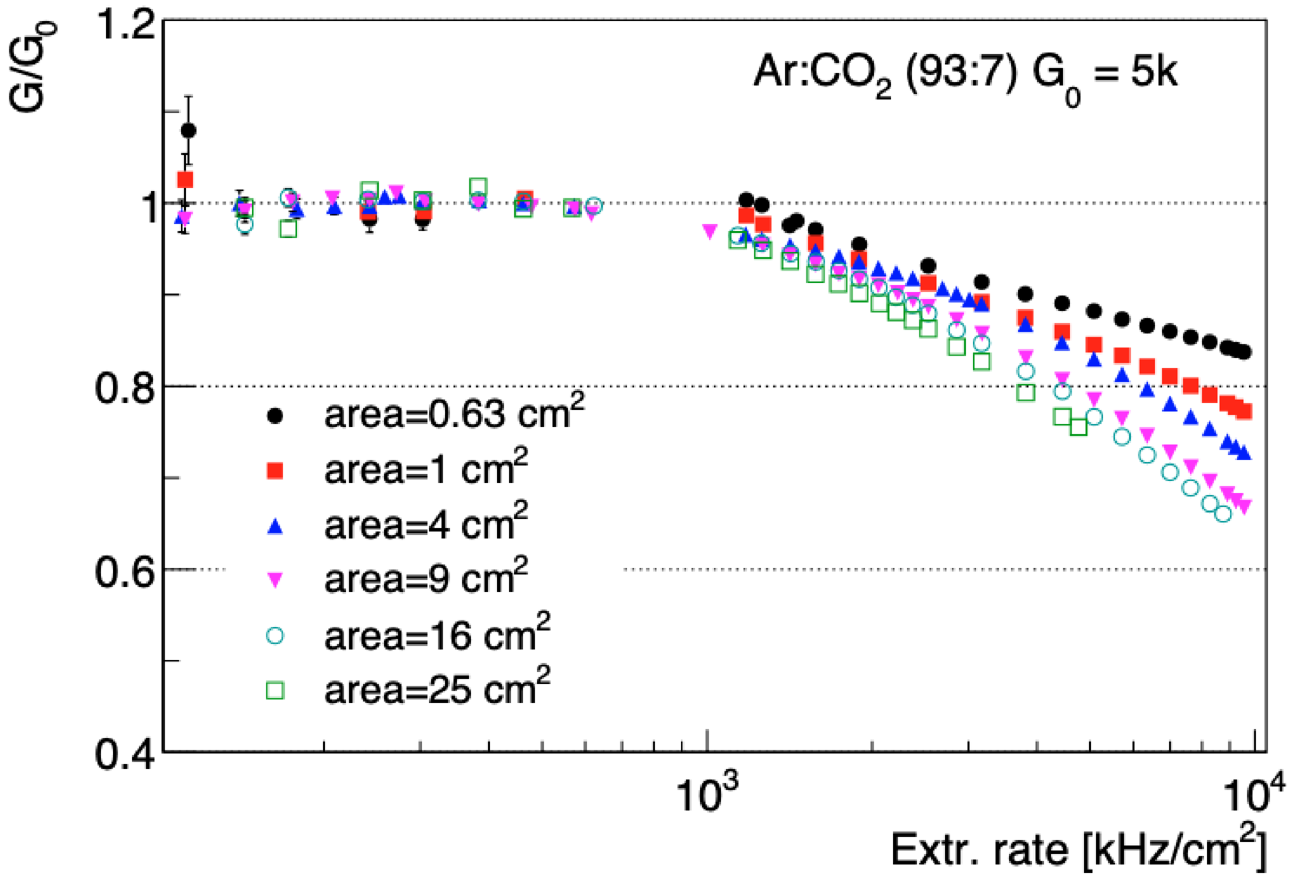
Ion Backflow



Ion BF within 1-3% and decreasing with rates and Vamp (inverse dependence on Eamp/Edrift - see P. Colas et al.)

DLC MM – rate capability and dependence on the irradiated area

- Can reach high-rate capability well above 1 MHz/cm^2 with ~20-30 MOhm/sq and grounding connection dot vias every 6-10 mm
- Limited dependence from the irradiated surface



20% drop at 4 MHz/cm^2 with uniform irradiation of 8 keV X-Rays over 25 cm^2

DLC MM – rate capability and dependence on the irradiated area

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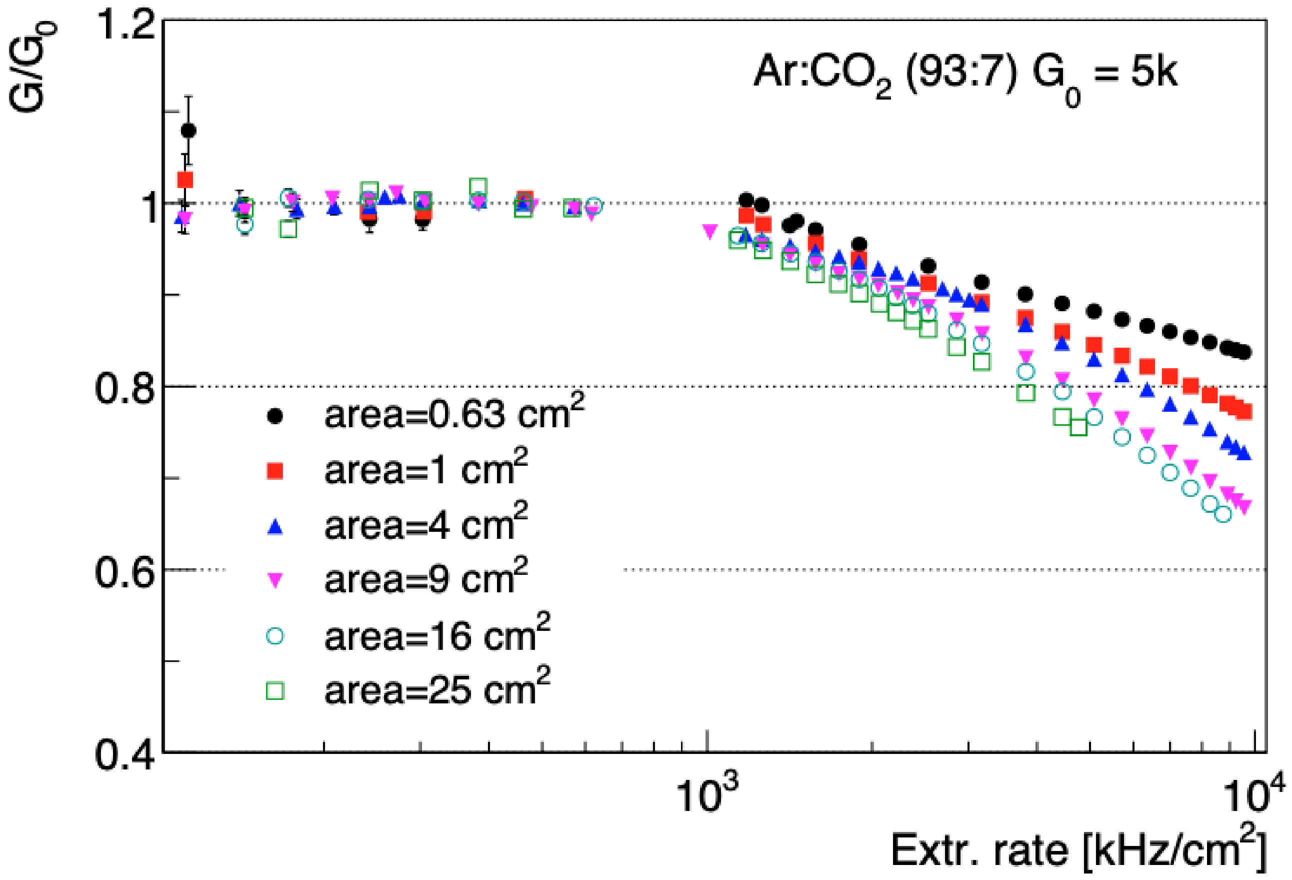
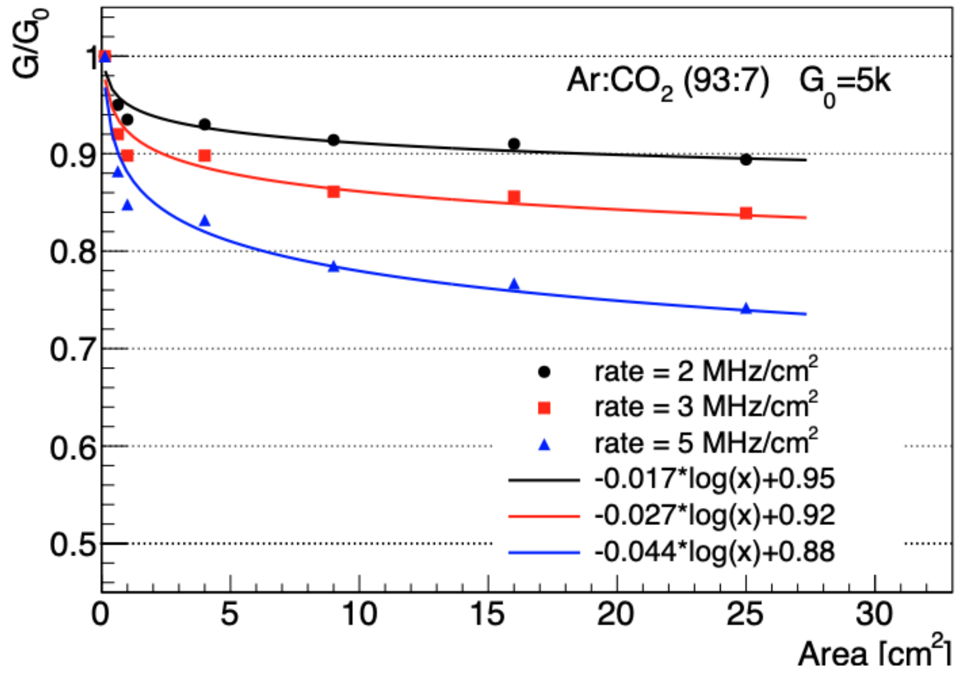


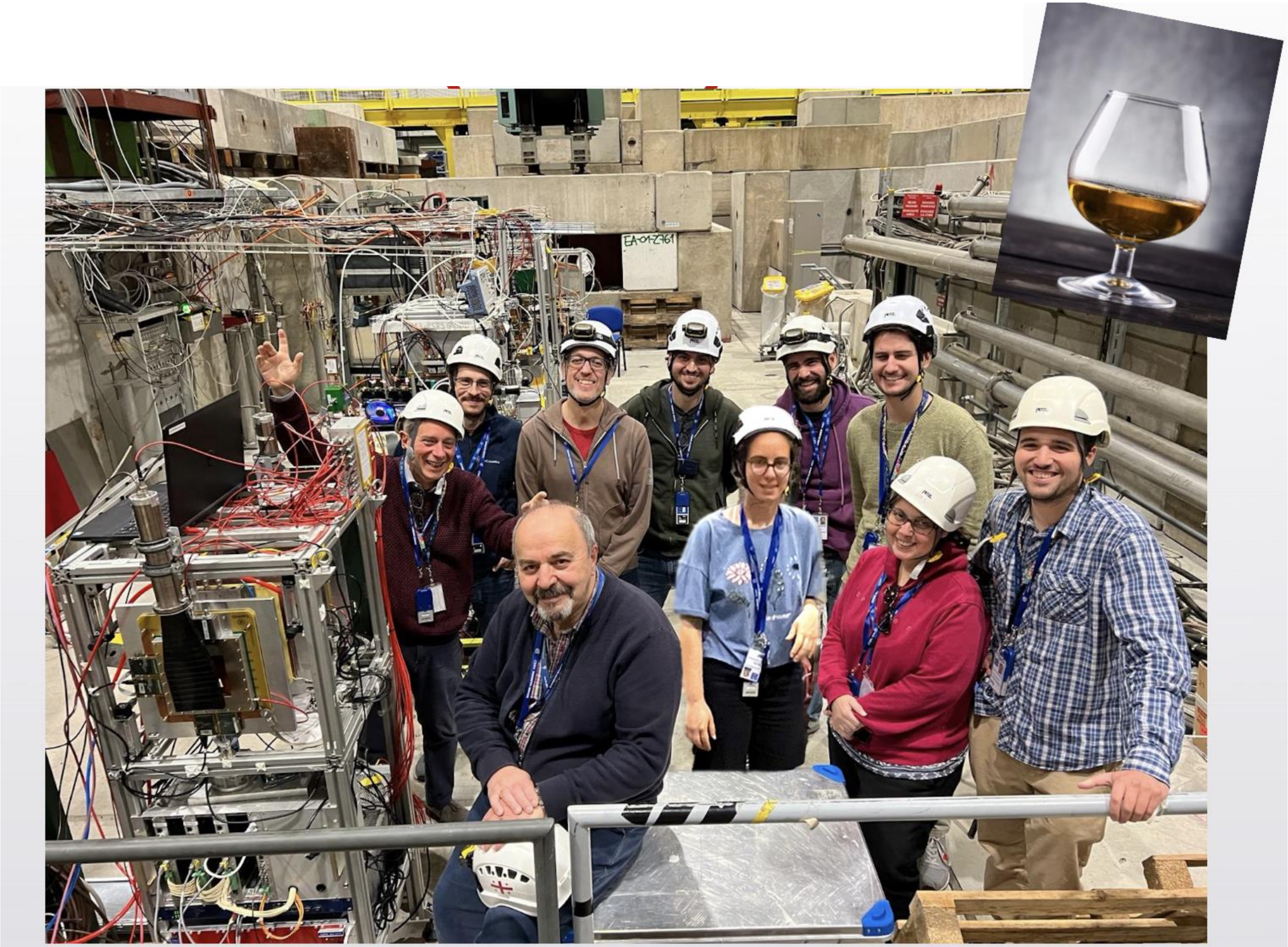
Dependence on the irradiated area

At fixed 8 keV X-rays rate: 2, 3, 5 MHz/cm^2



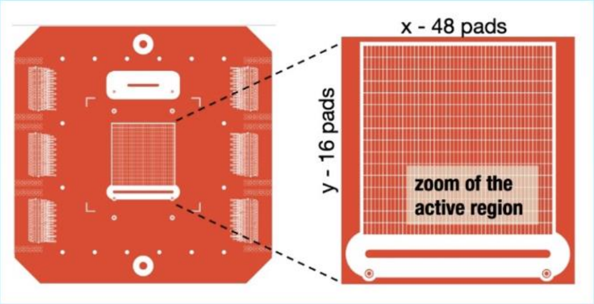
- Observed a logarithmic dependence
- G/G0 ~72% extrapolated to 40x40 cm^2 with 3 MHz/cm2 (>10 MHz/cm^2 equivalent MIPs)
  - Can be compensated with +10 V

TEST-BEAM Results



Prototypes under Test and Their Size Evolution

Small size prototypes

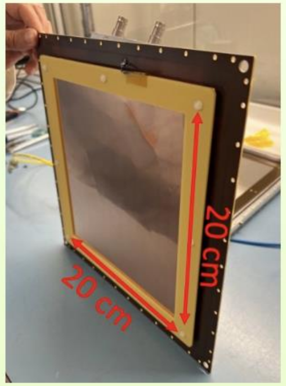


Several resistive layout tested

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

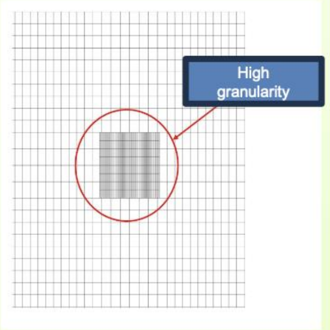


Two detectors:
Paddy400-1 & Paddy400-2

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

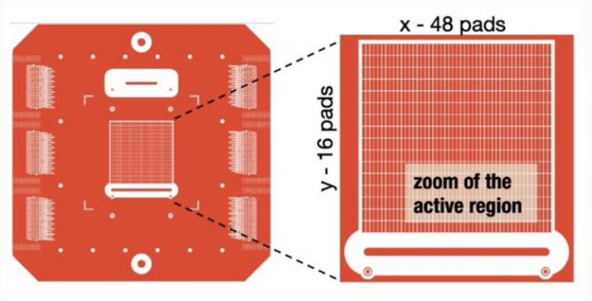


Paddy-2000 - “The Big one”

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

Prototypes under Test and Their Size Evolution

Small size prototypes



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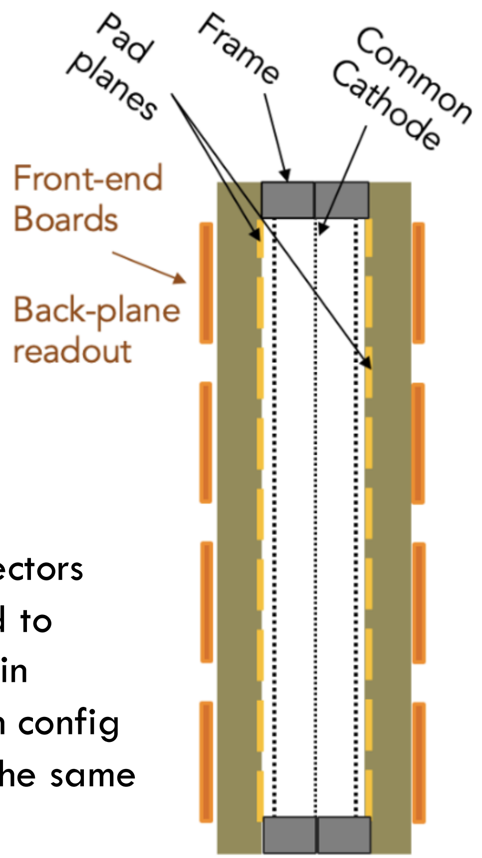
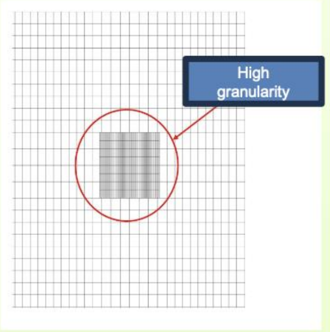


Two detectors designed to operate in sandwich config sharing the same cathode

Large size prototypes



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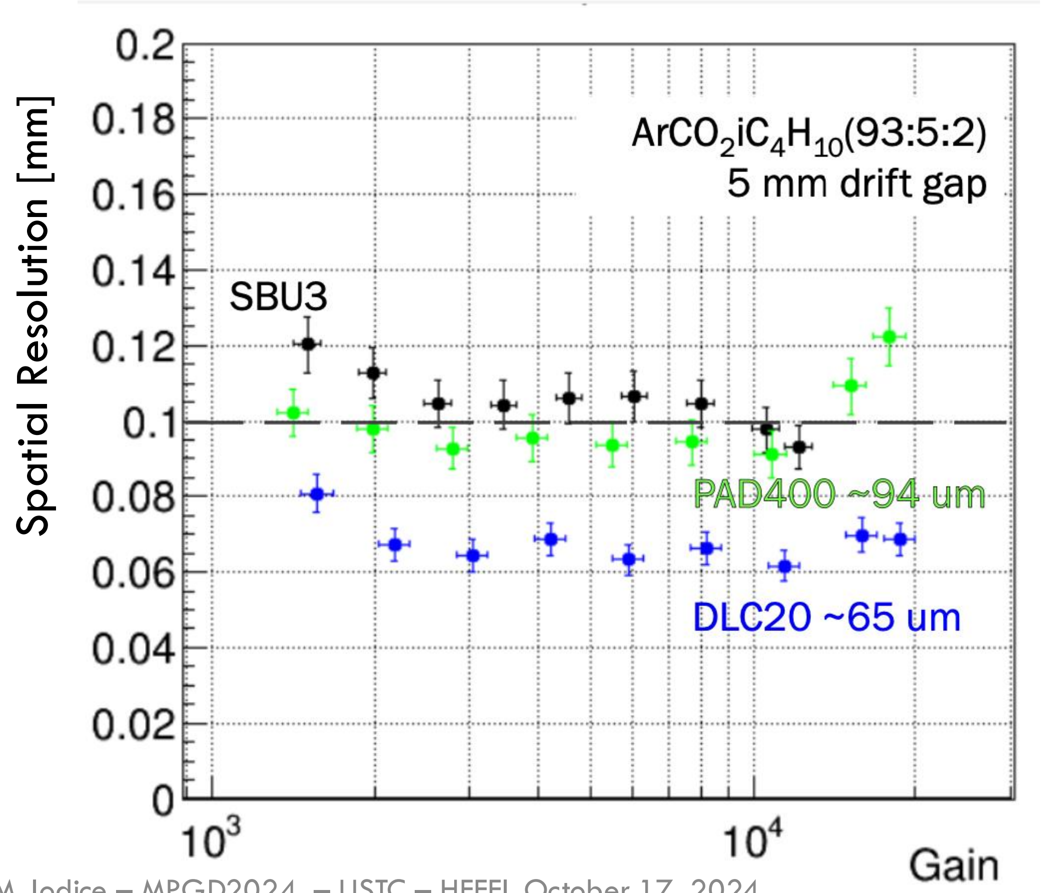
Active area : 50 cm x 40 cm
Anode plane pad size:
Central part
1x8mm^2 → 512 pads
Surrounding area
10x10mm^2 → 2048 pads

Spatial Resolution

Excellent spatial resolution: ~65 µm for perpendicular tracks with a pad size of 1 mm !



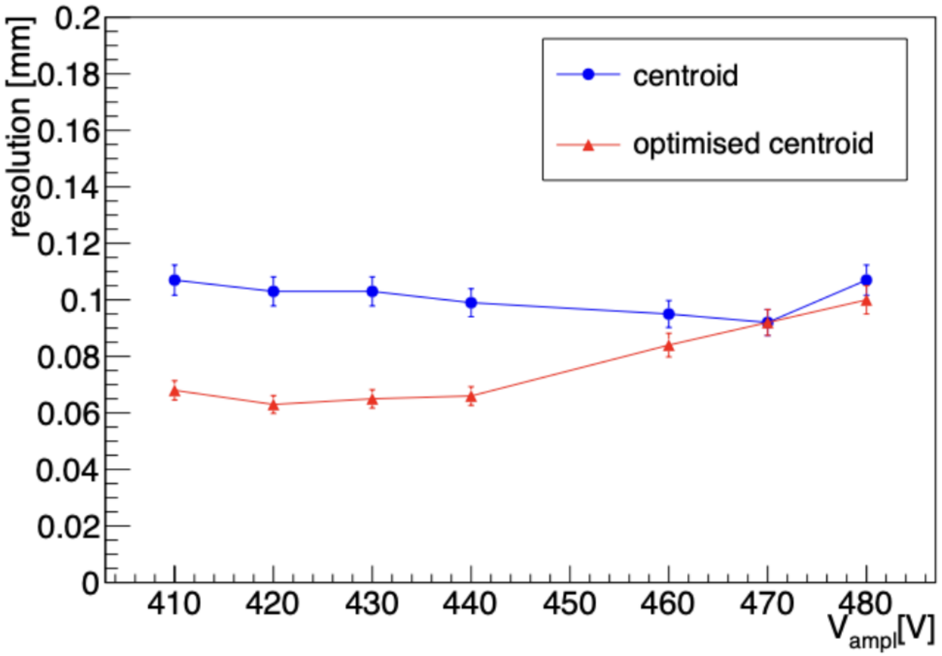
METHOD

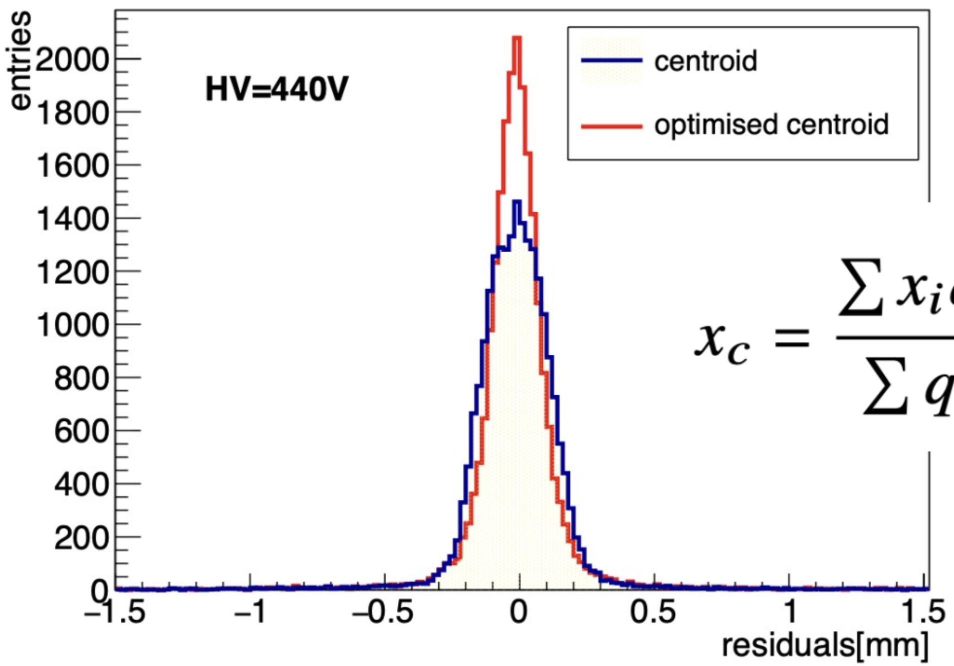
- Unbiased cluster residuals wrt extrapolated position from tracking chambers
  - Position from charge weighted centroid
- Extrapolation error (~50 µm) subtracted
- Statistical uncertainty is negligible
- Systematic uncertainty (fit procedure) ~5%

- Different resolutions measured for chambers with very similar layout, gain and cluster size, BUT with different RC
- Investigate the impact of the different contributions from: direct induction, capacitive coupling AND resistive charge spread

However, similar resolutions with optimized cluster position reconstruction → See next slide…

Spatial Resolution – optimization of the cluster position reconstruction





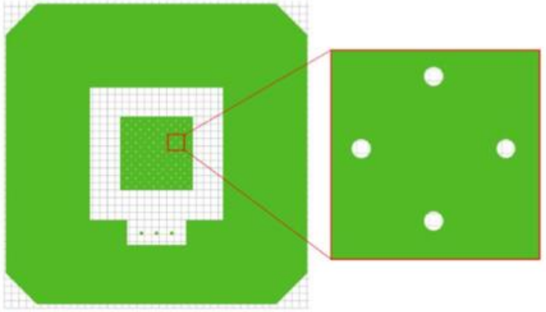
$$x_c = \frac{\sum x_i q_i^p}{\sum q_i^p}$$

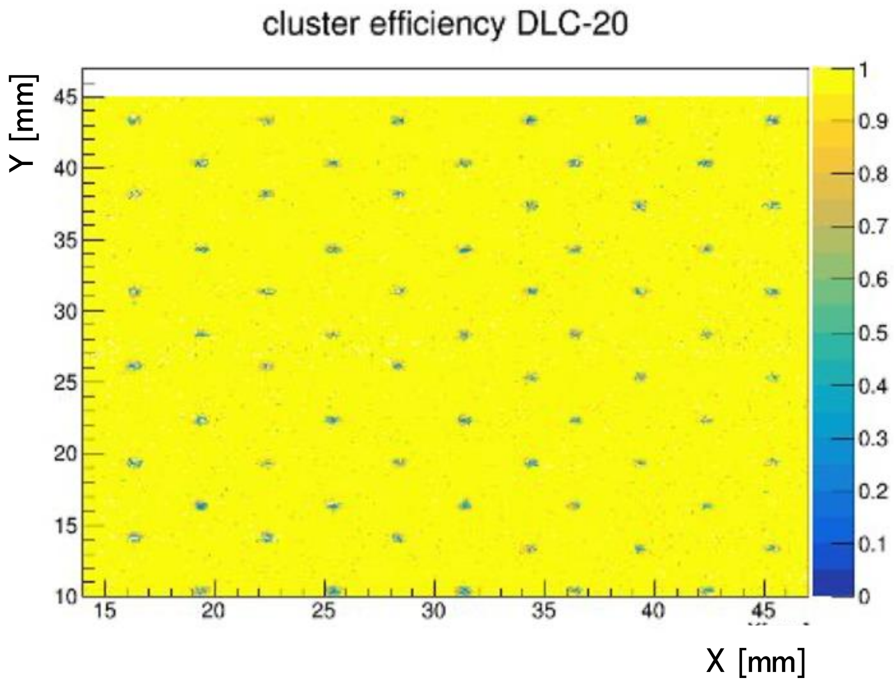
- Cluster position evaluated with an extended definition of the charge weighted centroid (p=0.65)
- Position resolution obtained fitting the residual distribution in the precision coordinate w.r.t. the reconstructed muon track
  - Extrapolation uncertainty~50μm (subtracted in quad) , systematic uncertainty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

Efficiency

LOCAL INEFFICIENCIES from Circular pillars:

- 0.3 mm for DLC20

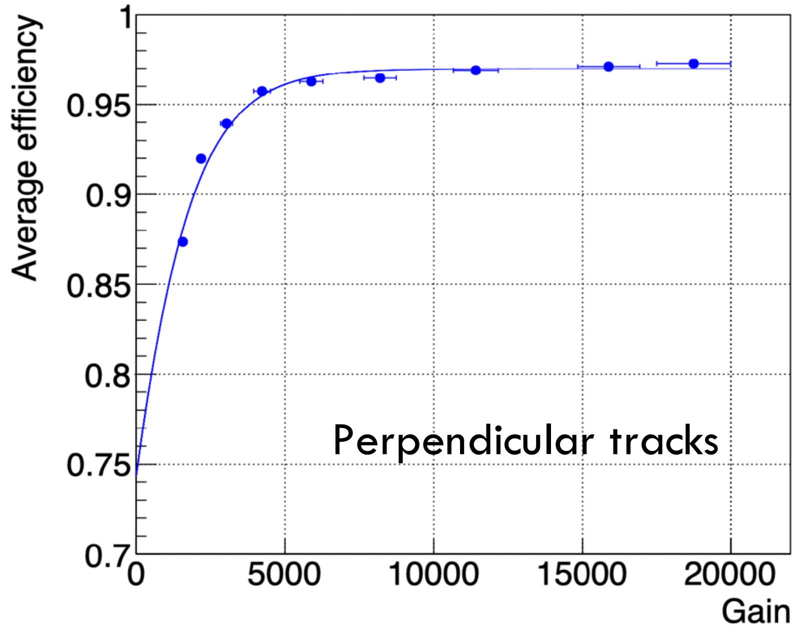




Efficiency >99%
Outside the pillars region

Tracking efficiency:

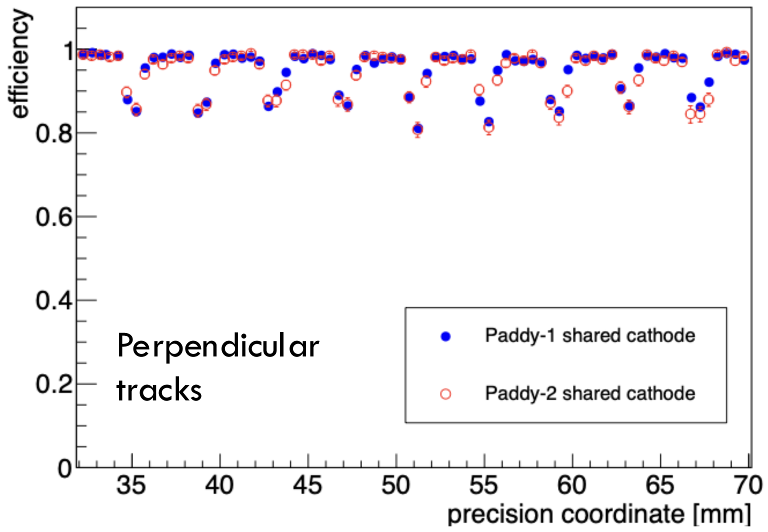
1.5 mm fiducial range wrt extrapolated position from external tracking chambers

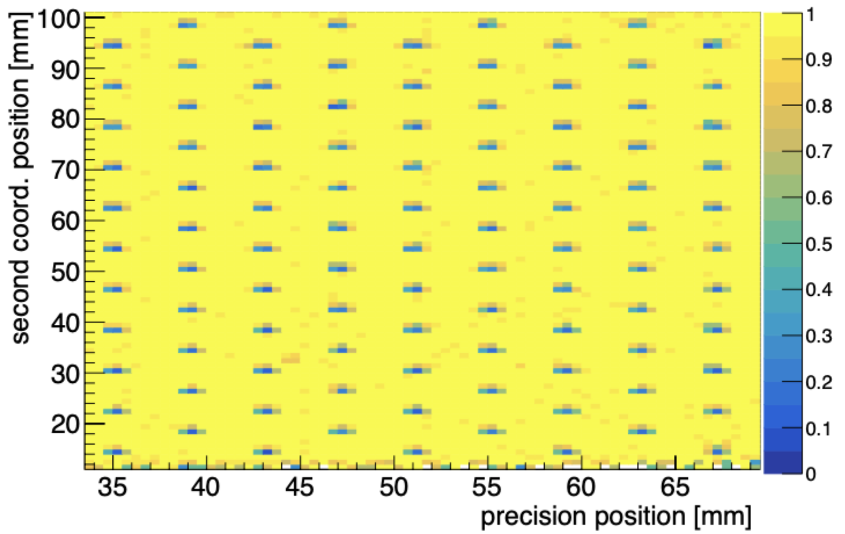


Average tracking efficiency at plateau ~97%
It includes inefficient areas on the pillars
The effect is very much reduced for inclined tracks

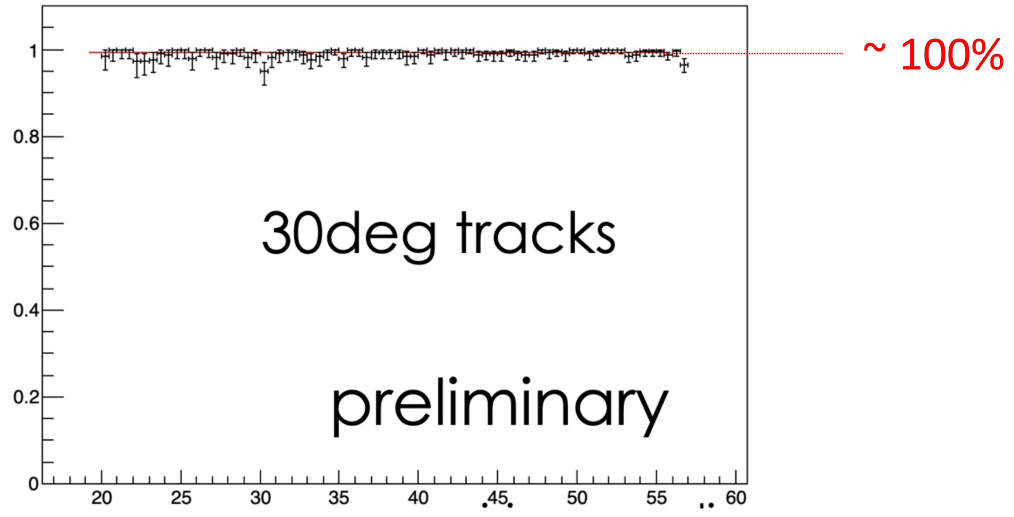
Efficiency

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

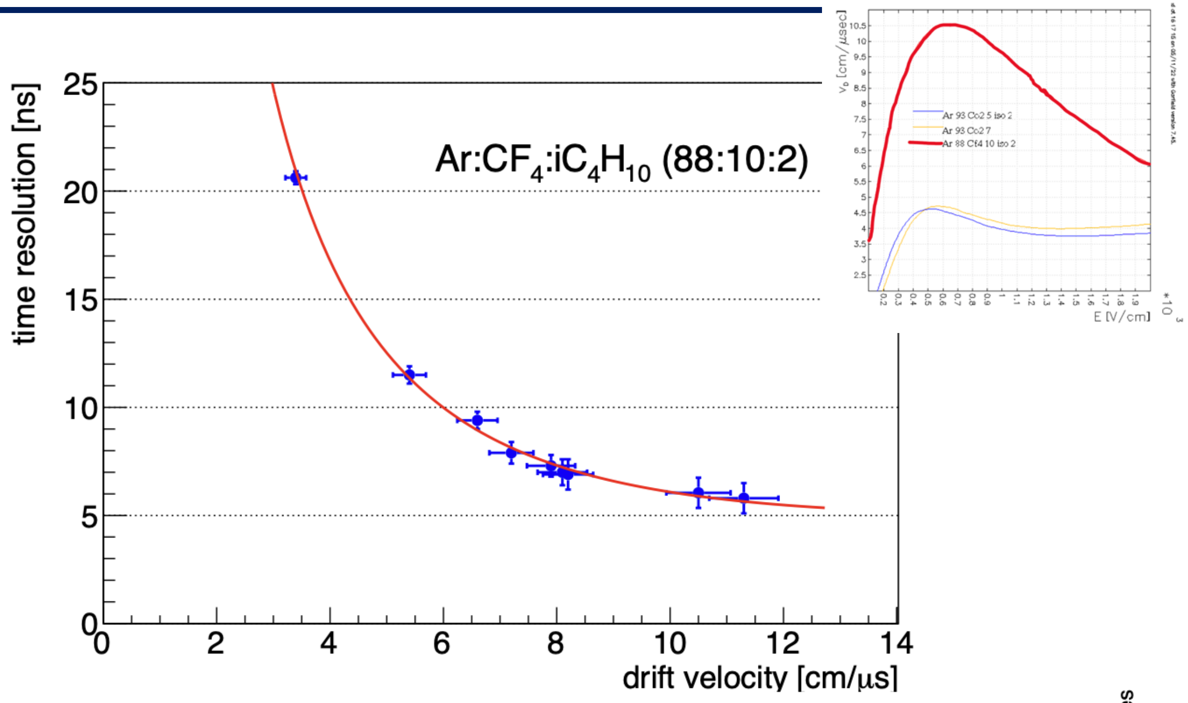


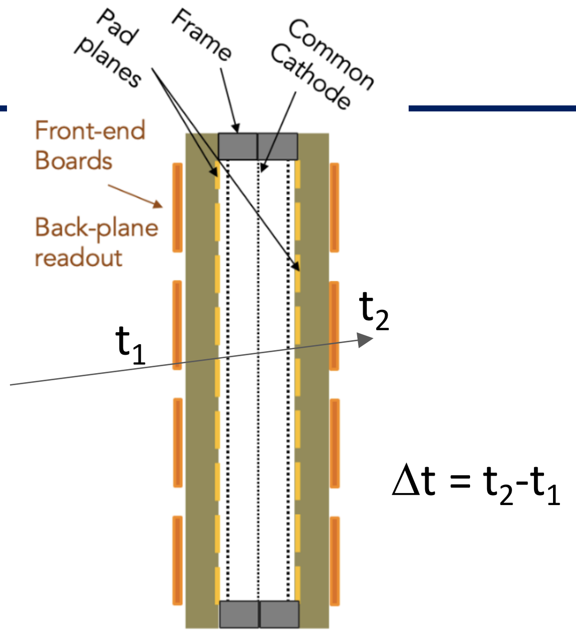


The pillars effect disappears for inclined tracks



Time Resolution





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

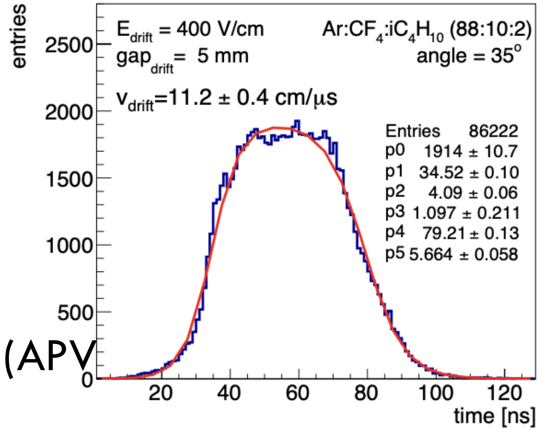
σ_{time} ~ 5.8 ns at v_{drift} ~ 11 cm/µs

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

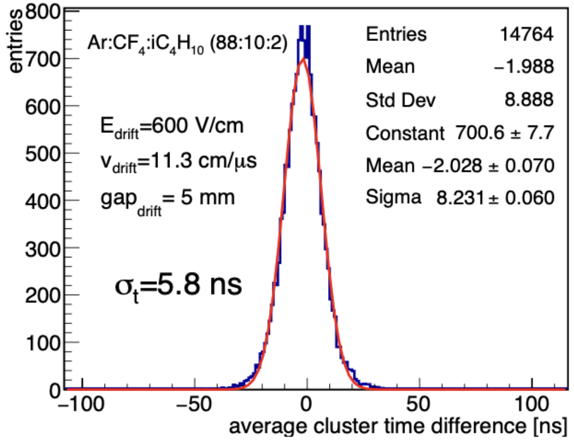
→ Detector σ_t ~ 4.2 ns

t$_1$ (or t$_2$) distribution

FE (APV

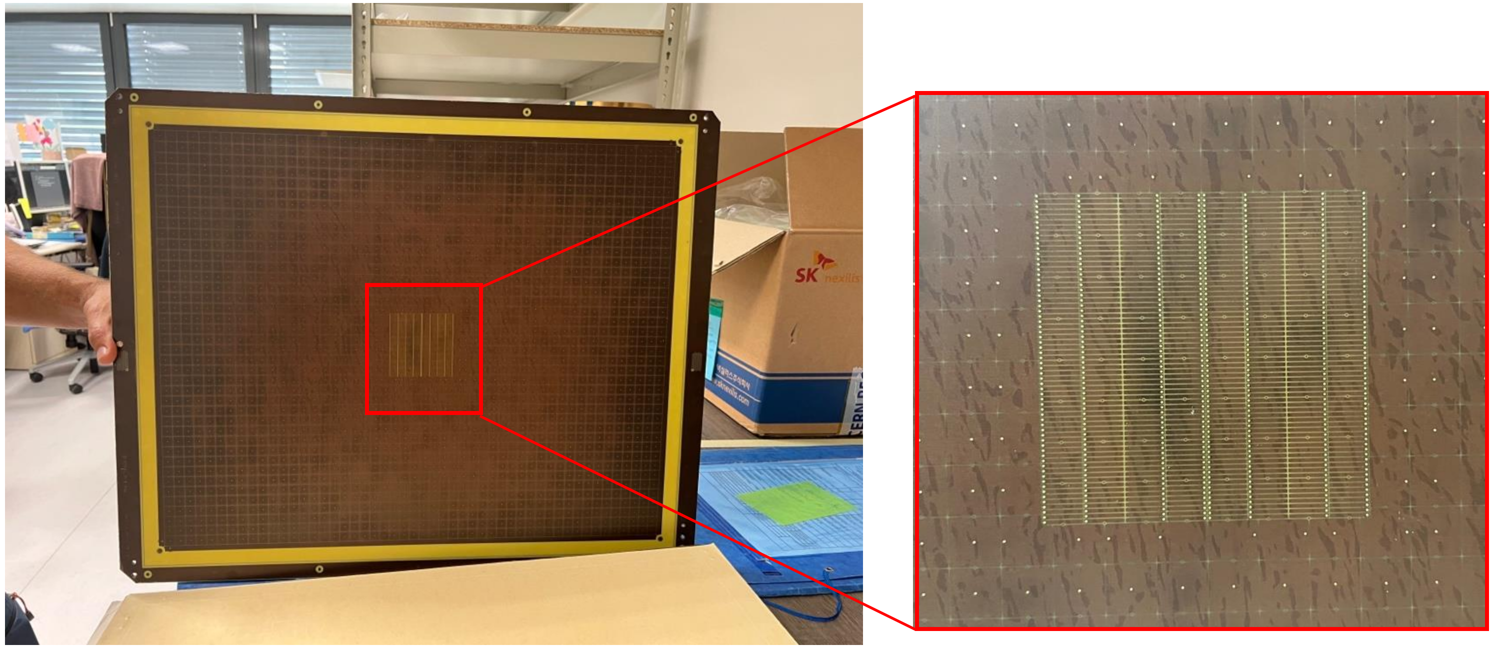


Δt distribution



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



$50x40\ cm^2$ in construction
Fine granularity readout in the centre,
$1\ cm^2$ pads elsewhere (for practical reasons – number of channels)

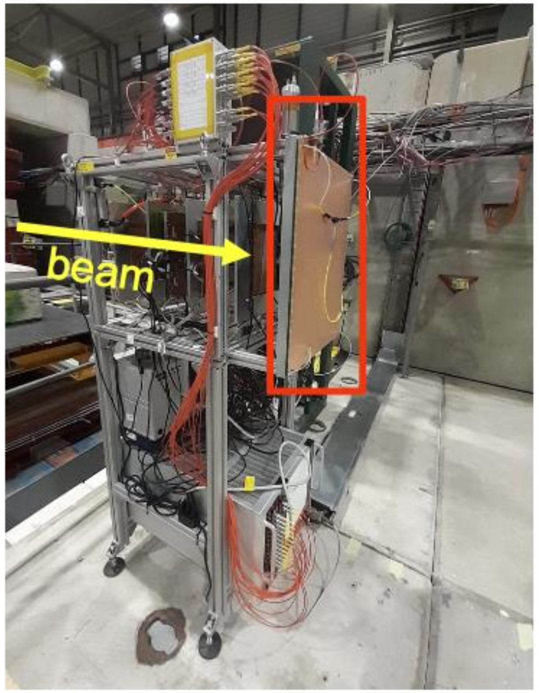
Central region
$6.4x6.4\ cm^2$
with $1x8\ mm^2$ pads

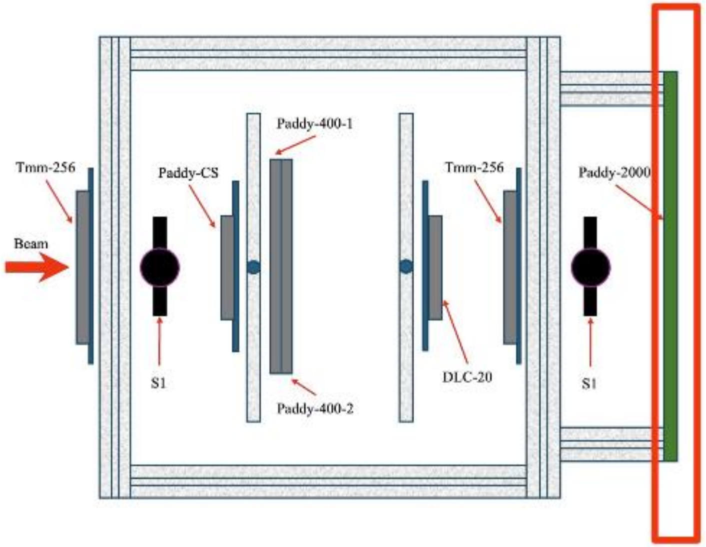
Hirose connectors on the back
Central region readout through 4 connectors
Full detector readout out by 20 hybrids

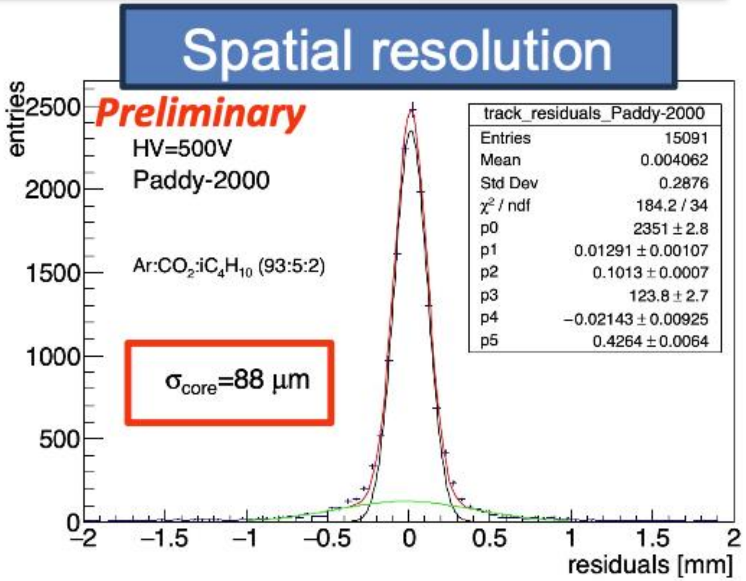
Preliminary Results of the 50x40 cm^2 Micromegas

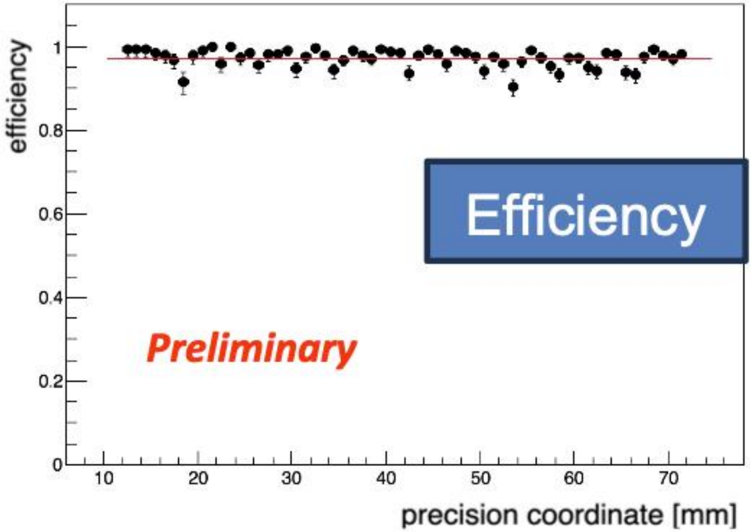
Chamber tested for the first time during a test beam in 2024 at CERN H4

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





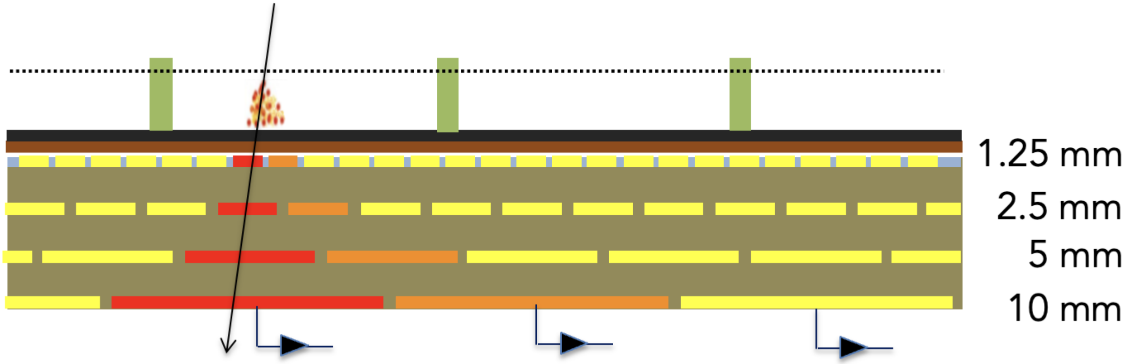


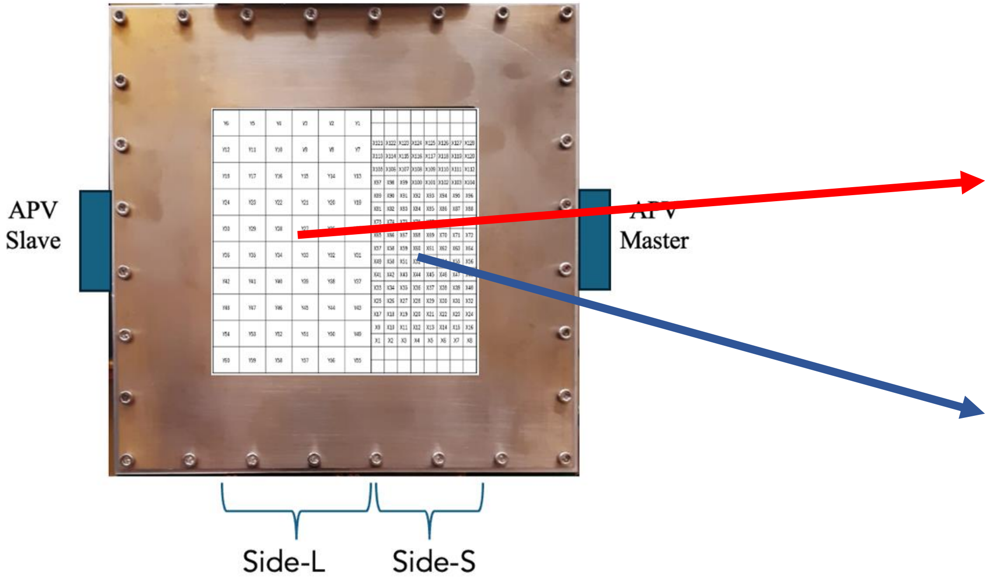


Medium/Low-rate Version – Capacitive Sharing

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

- First implementation of the capacitive sharing principle in a single layer DLC 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

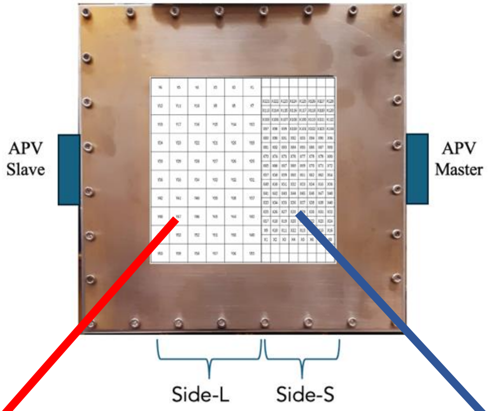




- Pad size of "top-layer" (signal induction): 1.25x1.25 mm2
- **Side-L**: Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2
- **Side-S**: three layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2

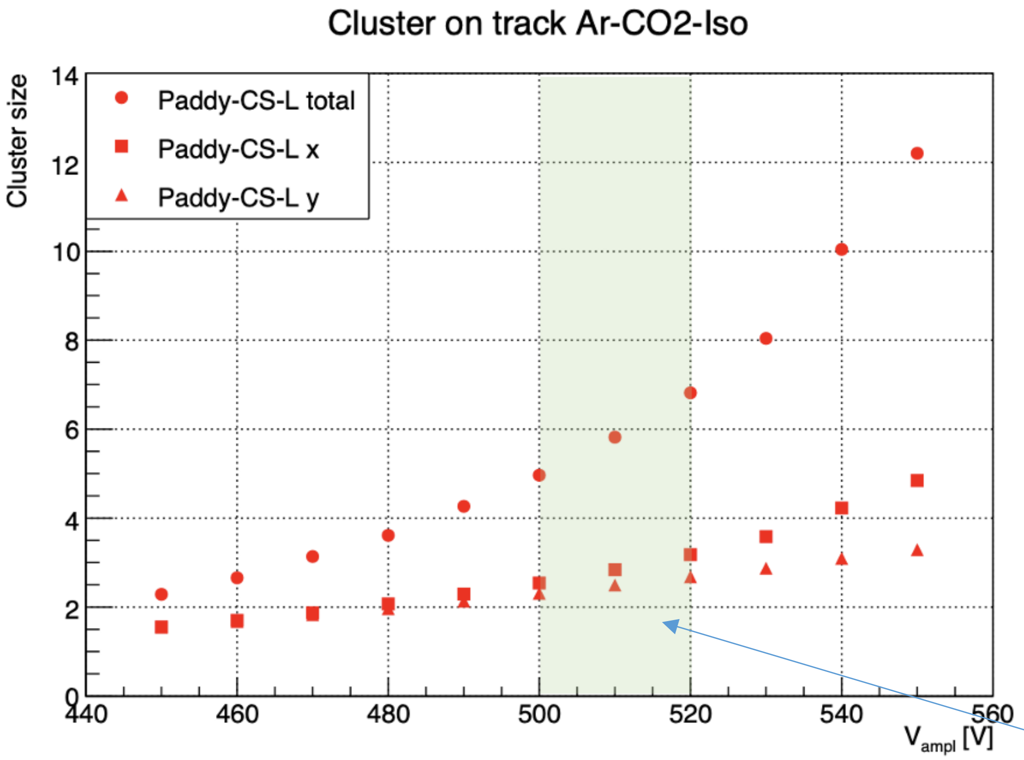
Capacitive Sharing Test-Beam Results

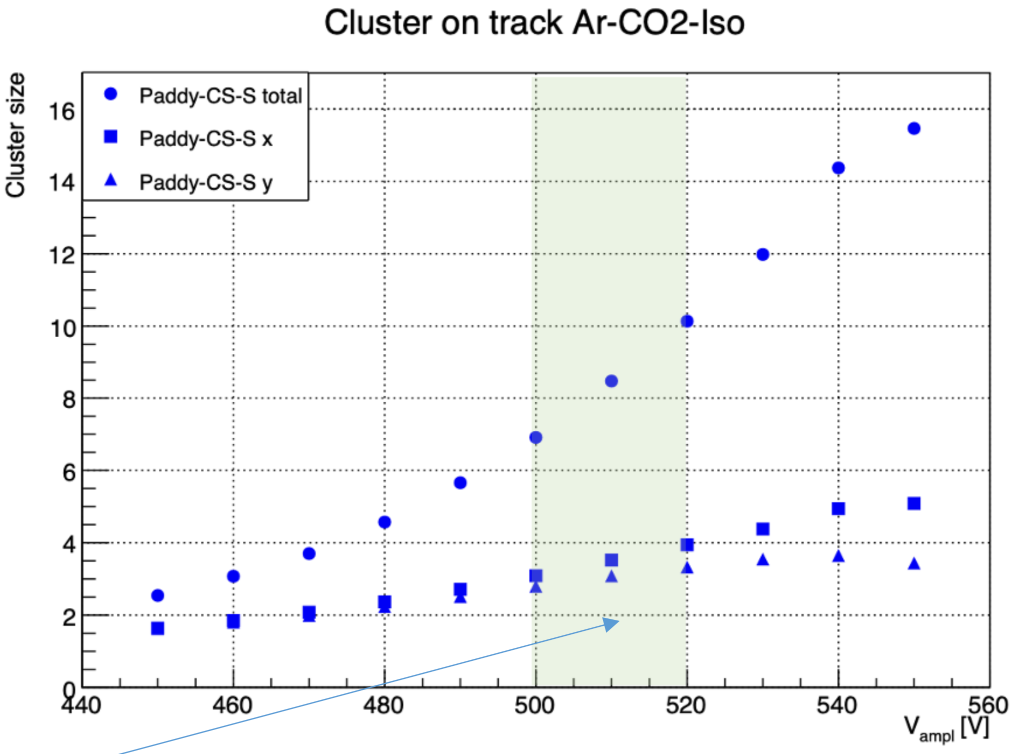
Cluster Size



Readout pads 10x10 mm^2

Readout pads 5x5 mm^2



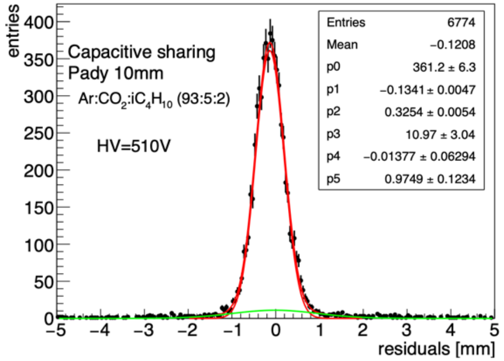


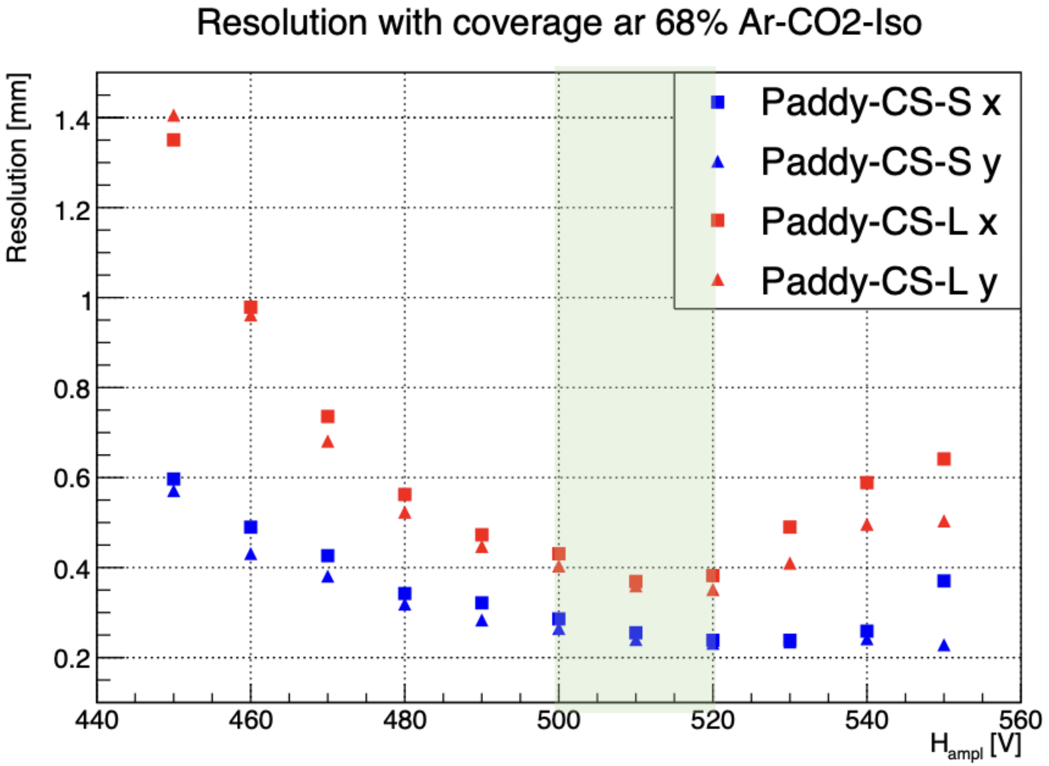
Optimal Working Point (see next slide)

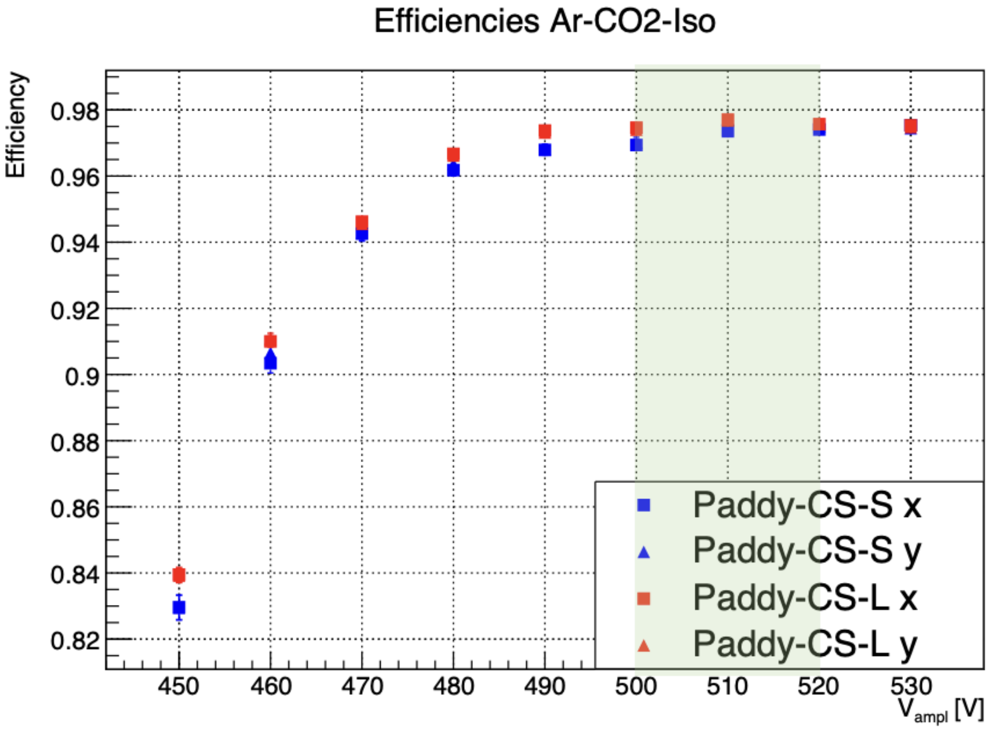
Capacitive Sharing Test-Beam Results

Spatial Resolution and Efficiency

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







REACH ~380 µm with 10x10 mm² pads

→ A factor 1/26 of the pad size

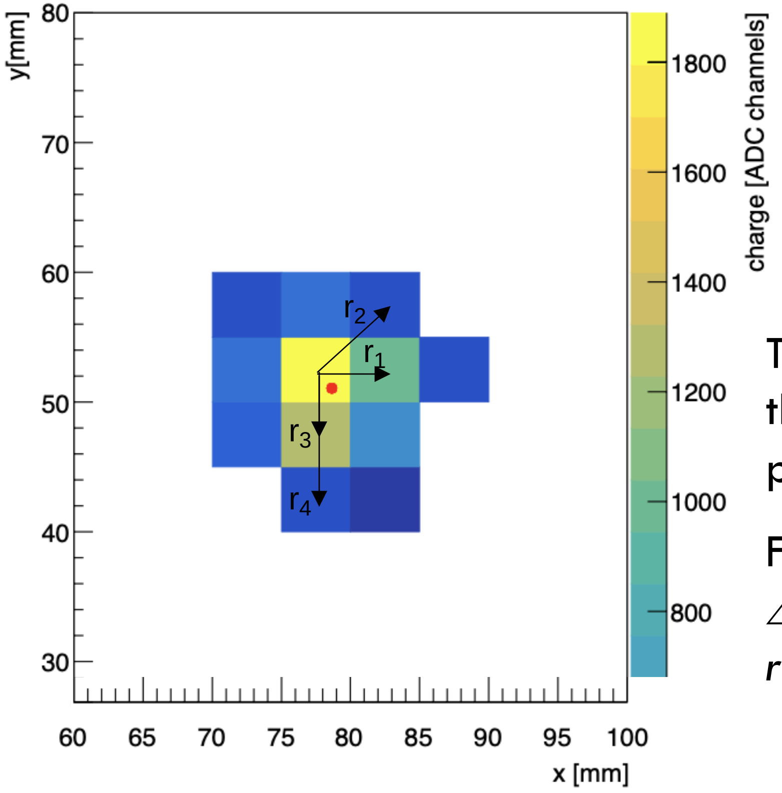
~220 µm with 5x5 mm² pads (1/23 of the pad size)

Capacitive Sharing
Test-Beam Results

Timing

Are all pads in a cluster firing at the same time?

- is there any time dependence Vs distance from the "central" pad ?
- If the the resistive layer "contributes" to the charge sharing, we would expect delayed time for pads at large distance

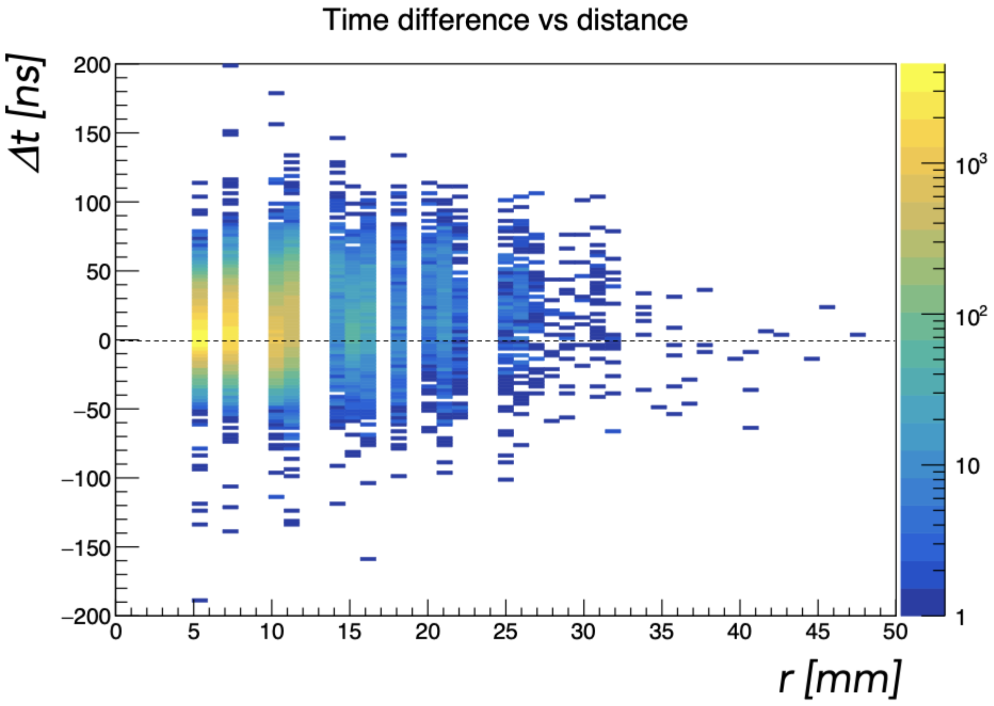


The "central pad" gives the time t_0 and the central position.

For all other pads:

$\Delta t = t_i - t_0$

r_i = *distance from "0"*



For each cluster, plot for all pads Δt vs r_i

No significant trend in time is observed, consistent with an average $\Delta t \sim 0$

For large clusters at large distances, in average a small delayed component is observed

Present status and Future prospects

- 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 <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
- R&D on the **capacitive sharing** concept for low-medium rate applications started → VERY PROMISING
- Production at industry (design simplification and cost reduction) on the way (see M.I. talk tomorrow)

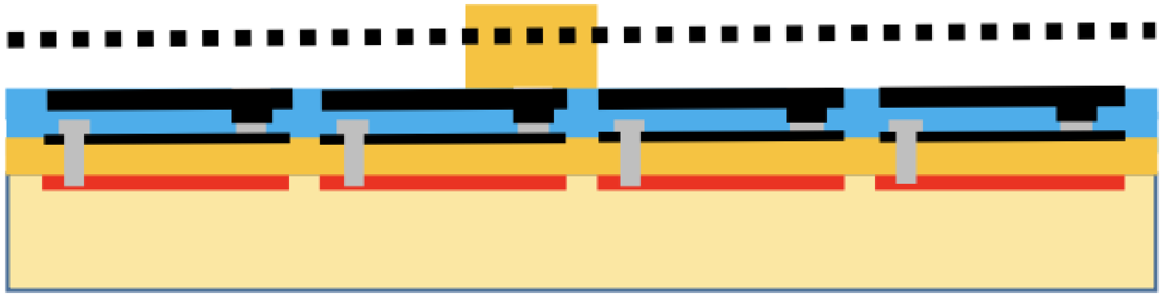
- R&D fully aligned to the ECFA Roadmap for Detectors Research and Development
- Ready for new R&D focusing on applications: large area muon systems and sampling calorimetry

Thank you for your attention

BACKUP

The Resistive Pad-P Micromegas - manufacturing

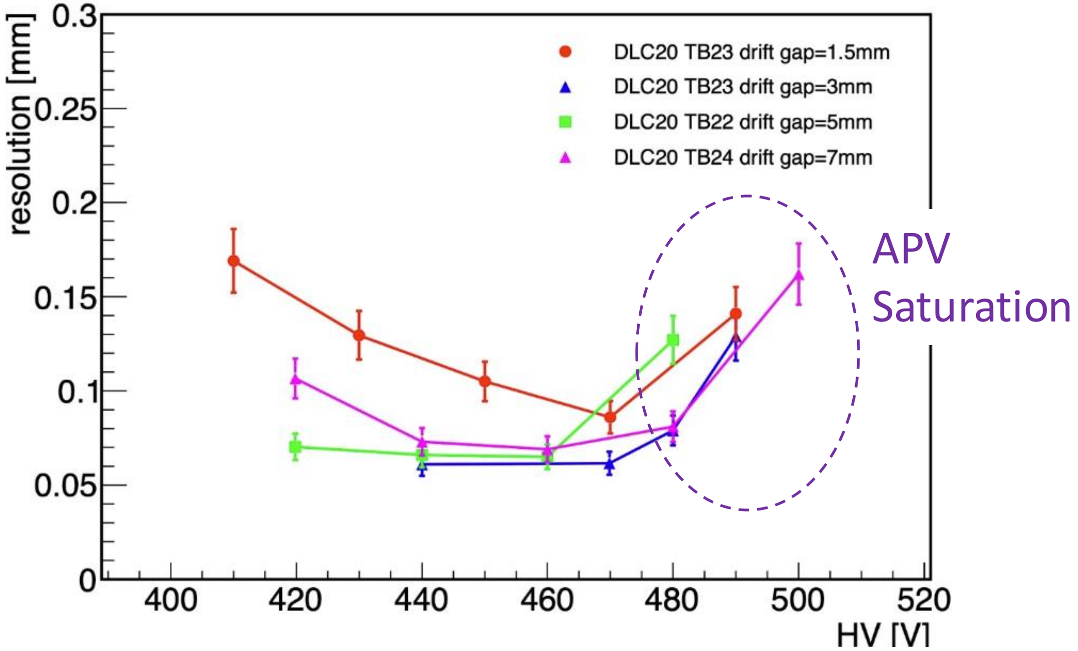
- First Prototype: Full screen-printing (including the insulation layer) → failed due to sparks caused by (unavoidable?) micro-holes in the insulation layer;
- Second generation: 2 layers screen printed resistors on Kapton → Successful
- Third Generation: Patterned DLC for the embedded resistors and shaped coverlay top structure with pad-shaped vessels "filled" with resistive paste (see Rui's talk at INSTR 2020) (PAD-P2 and PAD-P3 in the following plots)



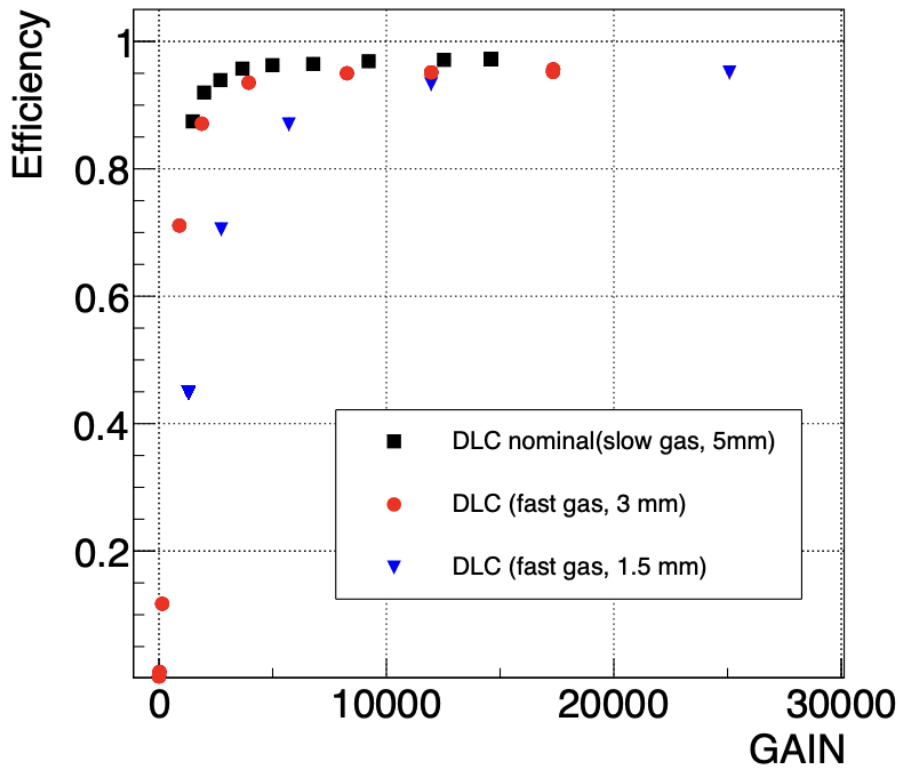
- MIX "DLC" and screen printed

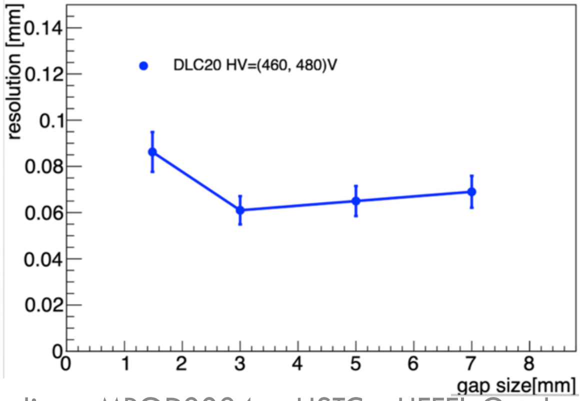
Spatial resolutions and Efficiencies Vs Drift-gap

Spatial Resolution



Efficiency





- Similar behaviour for 3 and 5 mm drift gap
- Need high gain, >10 k to reach best performance with 1.5 mm gap (expected)