Resistive High granUlarity Micromegas (RHUM) Status and Perspectives

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On behalf of the RHUM R&D group

(INFN - Italy)

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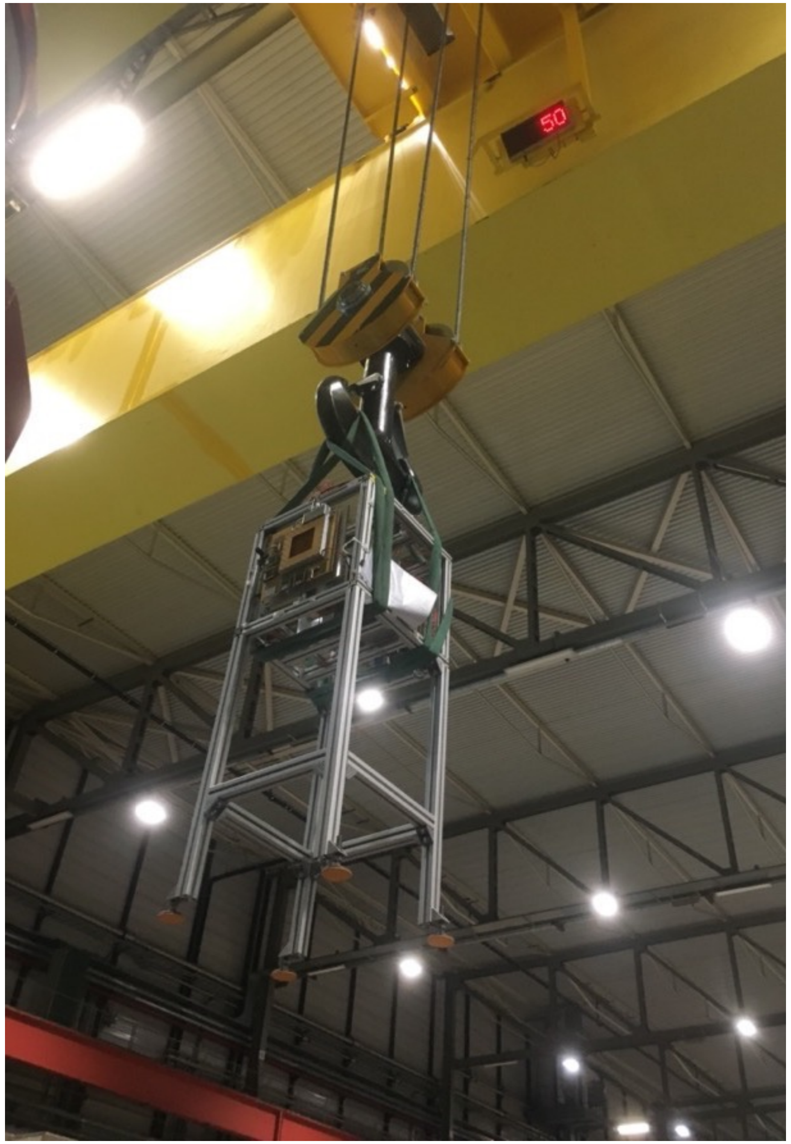
(last 😥) RD51 Collaboration Meeting

4 December 2023

CERN



Outline of the talk – Wrap up of the RHUM R&D

- An R&D on Resistive Micromegas – short history/overview
- Small size pixelised detectors
  - State of the art
    capability, spatial resolution, efficiency)
  - Recent studies (time resolution, thin drift gap, …)
- Ongoing work:
  - Larger area detectors
  - New objectives and short-term perspectives
- Summary on Present Status and Future Prospects

RHUM

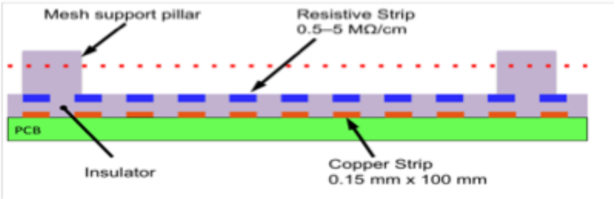
Resistive High granUlarity Micromegas

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)

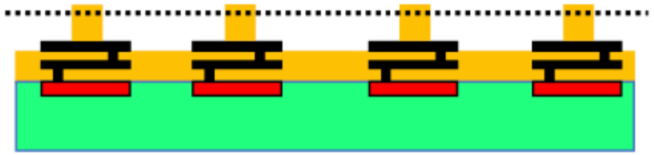
2013

or

1 full DLC layer

2015

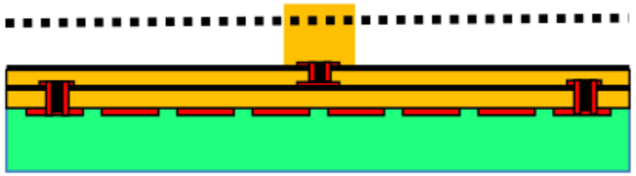
High-rate detectors 10Mhz/cm2
Charge evacuation inside active area



2 layers with screen printed pads

2015

or



2 DLC layers without patterns

2020

Recent developments on resistive Micromegas

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All Resistive MM structures

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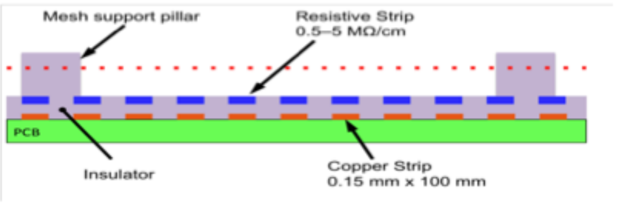

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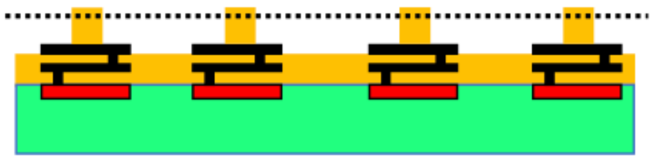

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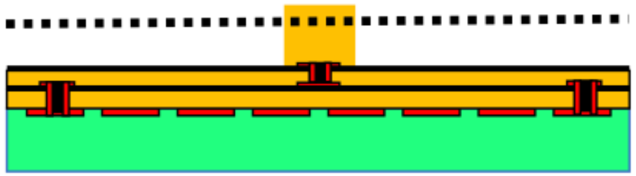
2015

or



2 DLC layers without patterns

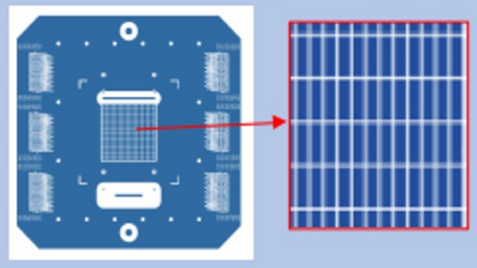
2020

This is the journey of the RHUM project

The start (2015): Resistive Pad-Patterned Micromegas

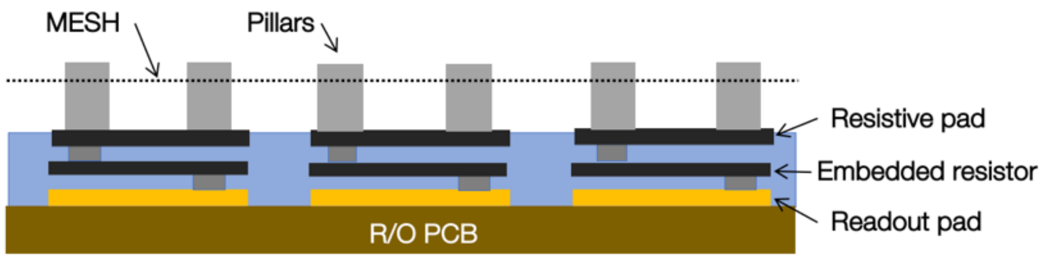
- Configuration inspired by (1 cm^2 pad resistive MM) by M. Chefdeville and co-authors [1], [2], and by (non-resistive GEM + MM hybrid) detector in COMPASS [D. Neyret, et al.]
- Push the technology to high rates - Main changes/improvements:
  - Combine a resistive scheme to a high granularity readout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

Readout PAD anodic plane (common to all prototypes)



4.8 x 4.8 cm^2 active region
768 pads, 0.8 x 2.8 mm^2 each
48 pads – 1 mm pitch ("x")
16 pads – 3 mm pitch ("y")

PAD-Patterned



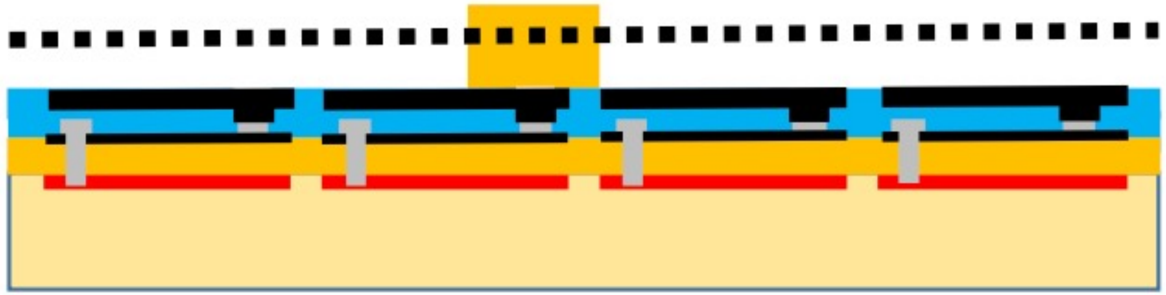
Readout pads 0.8x2.8 mm^2

PAD-P

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

The Resistive Pad-P Micromegas - manufacturing

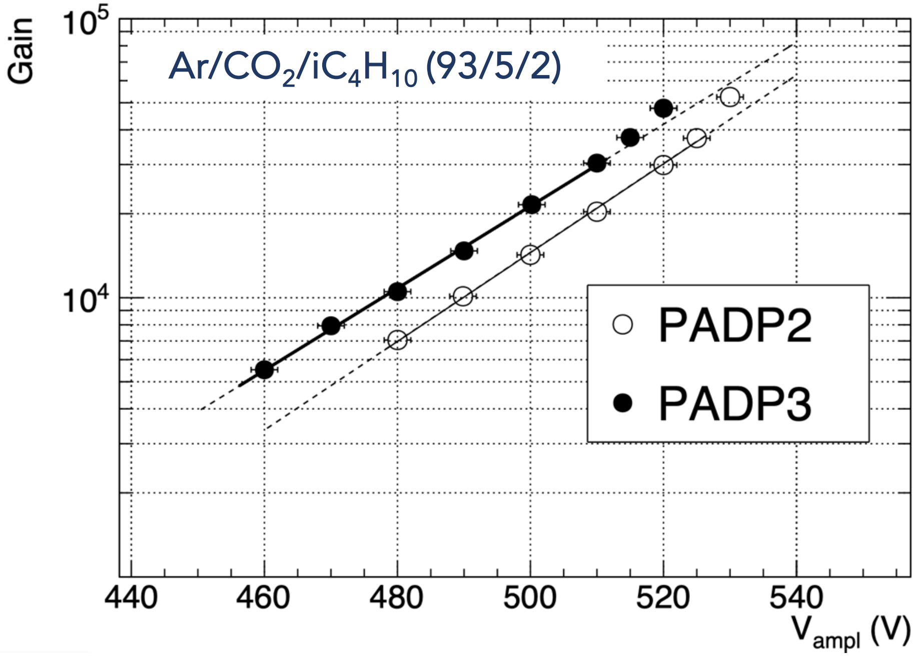
- First Prototype: Full screen-printing (including the insulation layer)
  → failed due to sparks caused by (unavoidable?) micro-holes in the insulation layer;
- Second generation: 2 layers screen printed resistors on Kapton → Successful
- Third Generation: Patterned DLC for the embedded resistors and 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)

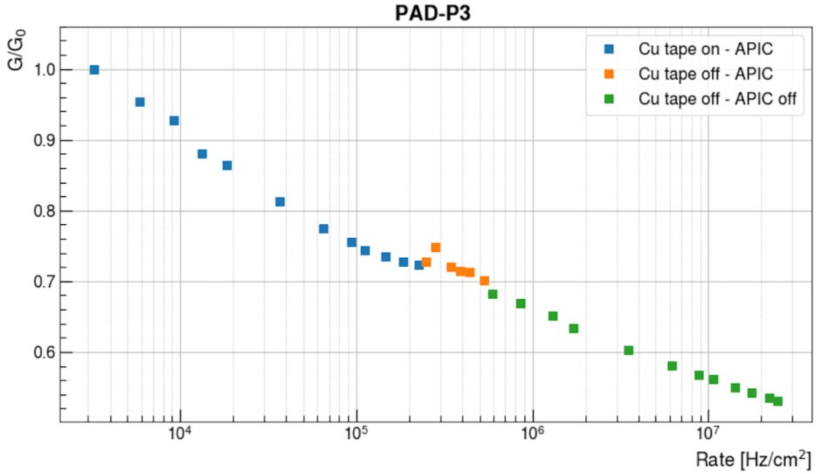


- MIX "DLC" and screen printed

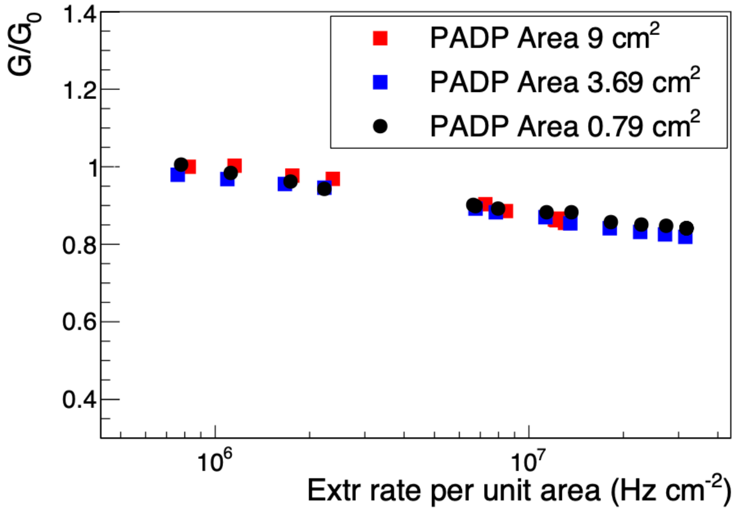
The Resistive Pad-P Micromegas - Performance

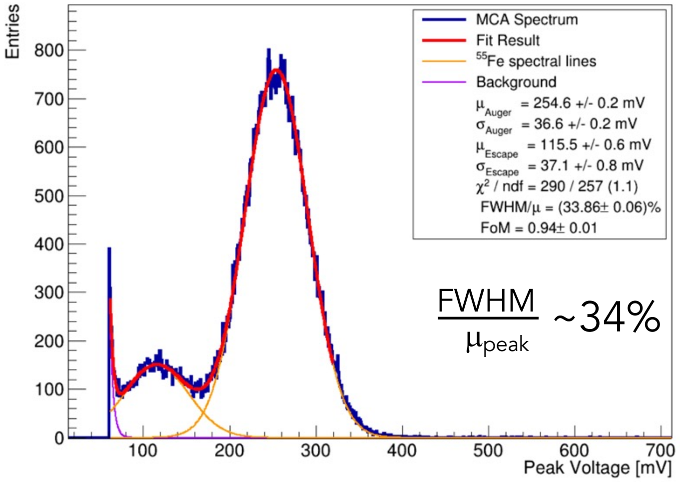
- Good stability up to a gain of 50k ☺
- Significant charging-up – it also severely affects the linearity with rates ☹
- Independence of the rate capability on the irradiated surface ☺
- Moderate energy resolution and spatial resolution (non-uniformity of gain – edge effects for each pad) ☹





Drop at low rates dominated by charging-up

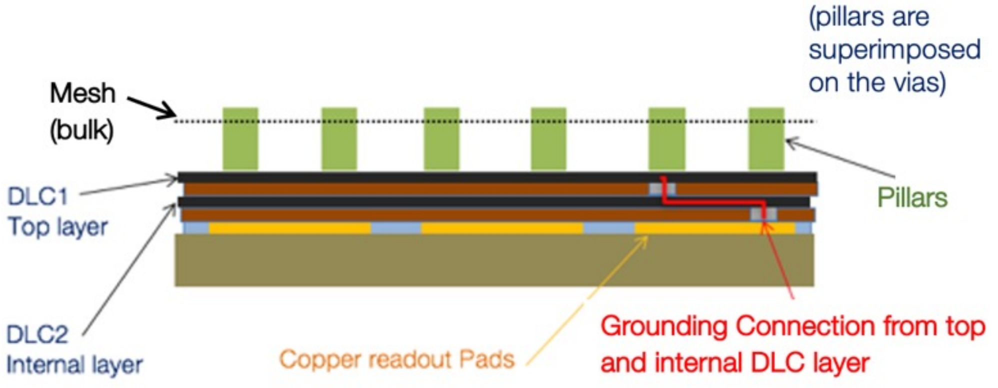




The Double DLC layer resistive configuration

- 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



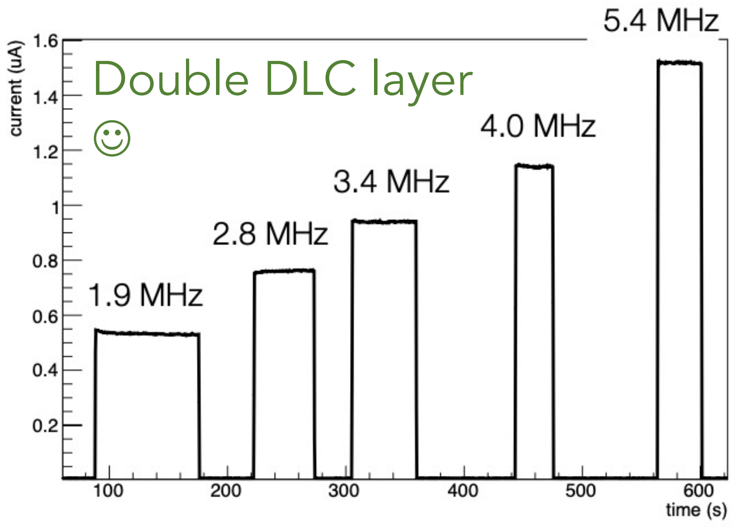
DLC20 (20 MΩ/sq)

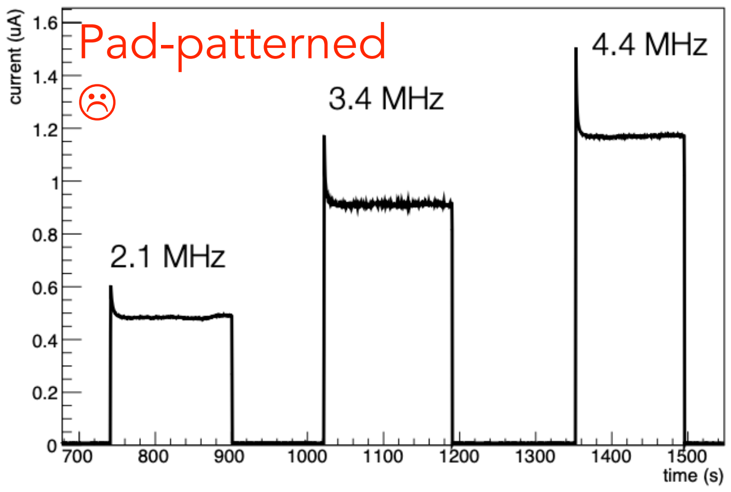
DLC-SBU (30 – 50 MΩ/sq)

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

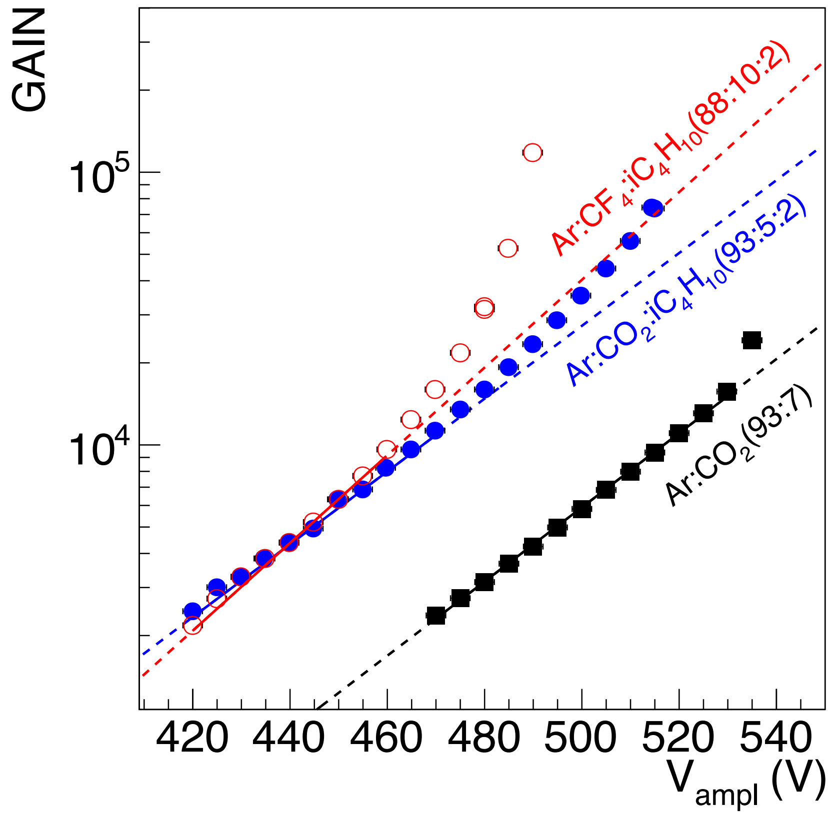
DLC resistive Micromegas – Performance - overview

- Negligible charging up effects

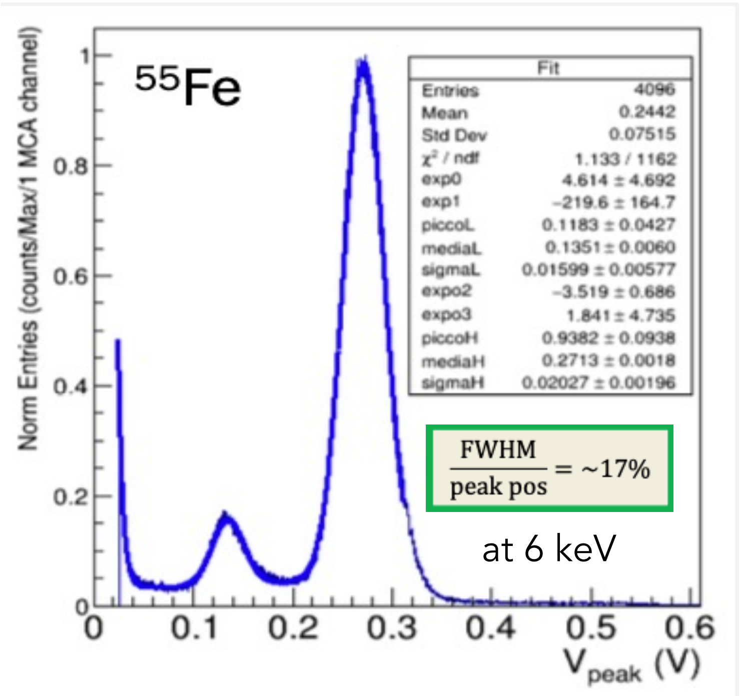




- Good stability
- High Gain with 2% of iC_4H_{10}

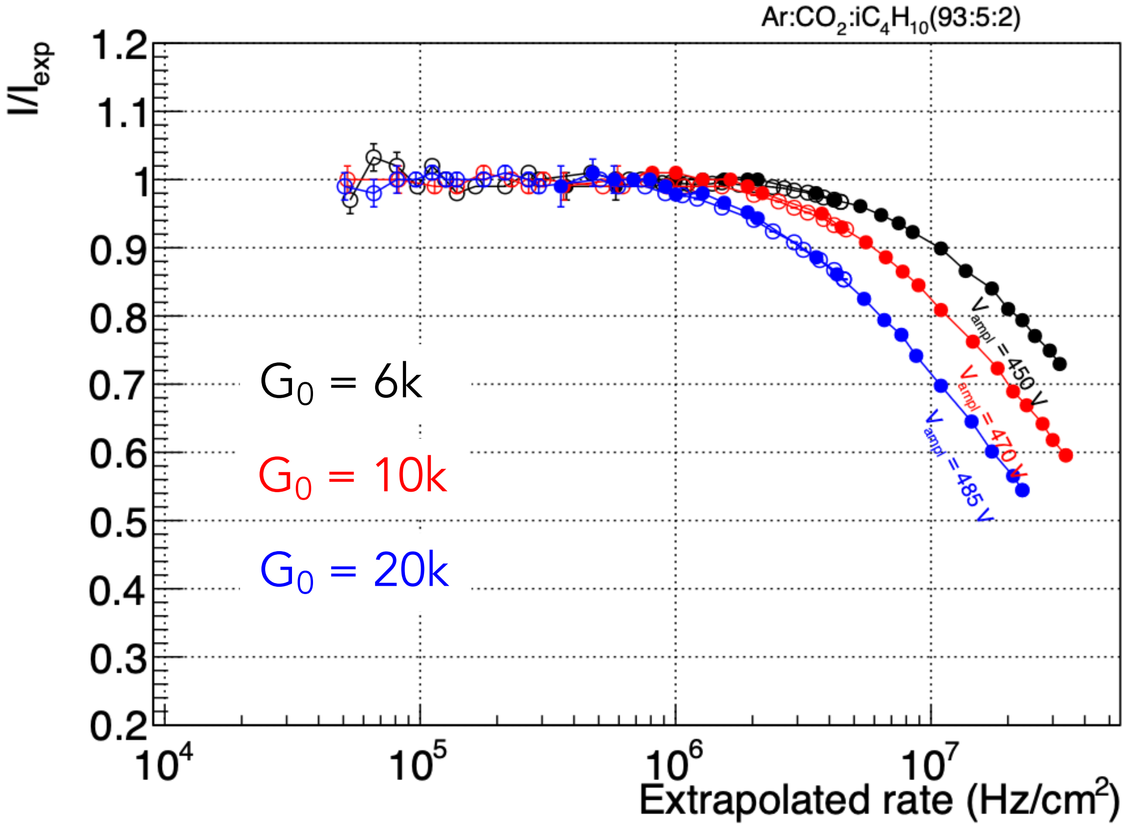


- Good energy resolution
~17% at 6 keV



DLC MM – Rate Capability and Ion Backflow

Can achieve high-rate capability (limited gain drop up to 10 MHz/cm²) with ~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)
(ionisation n_0>250 e^-, Vs n_0~50 for MIP in 5 mm)

DLC MM – Rate Capability and Ion Backflow

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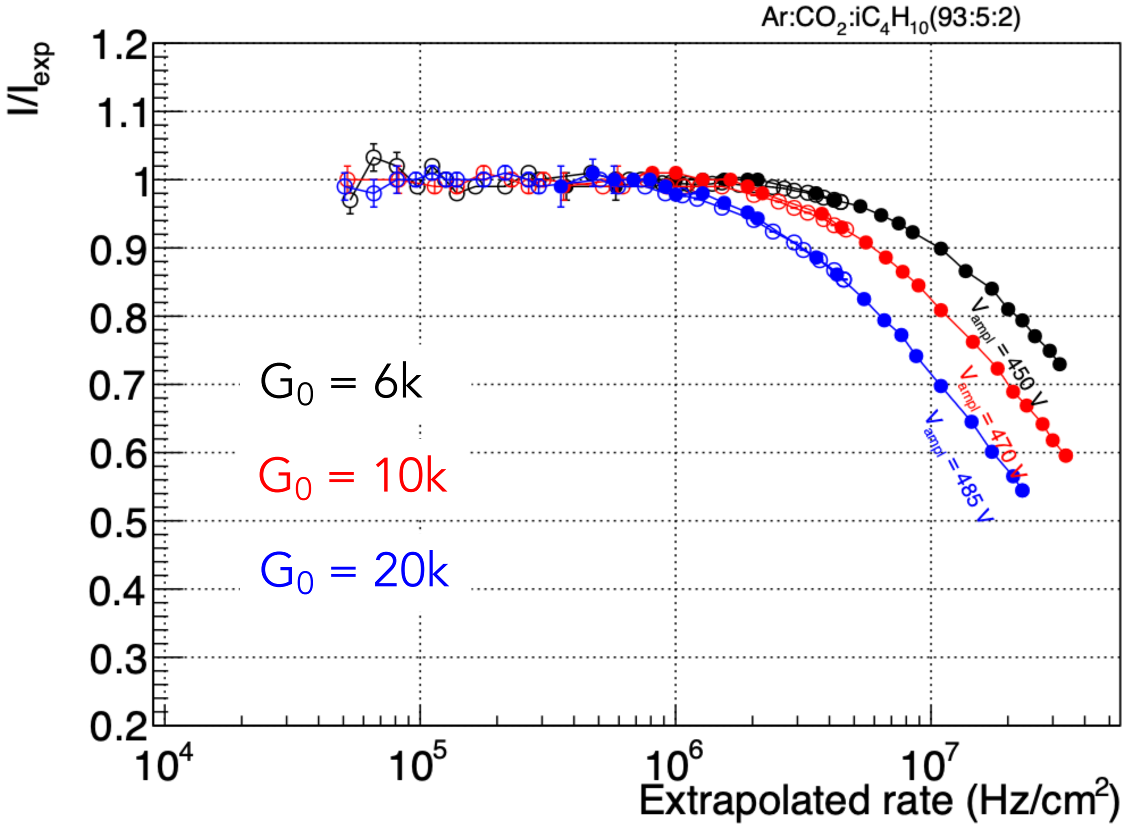
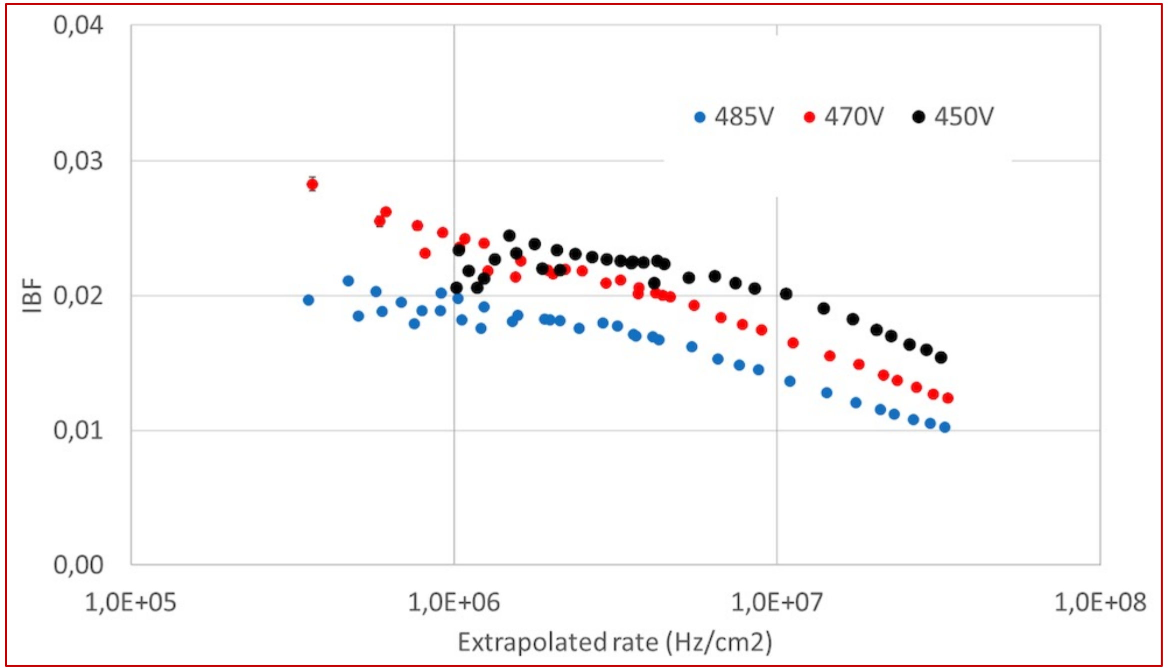


Here, the rate capability is reported for gains of 6, 10, 20 k
For X-rays irradiations from Cu – X-ray gun (~8 keV)
(ionisation n_0>200 e^-, Vs n_0~50 for MIP in 5 mm)

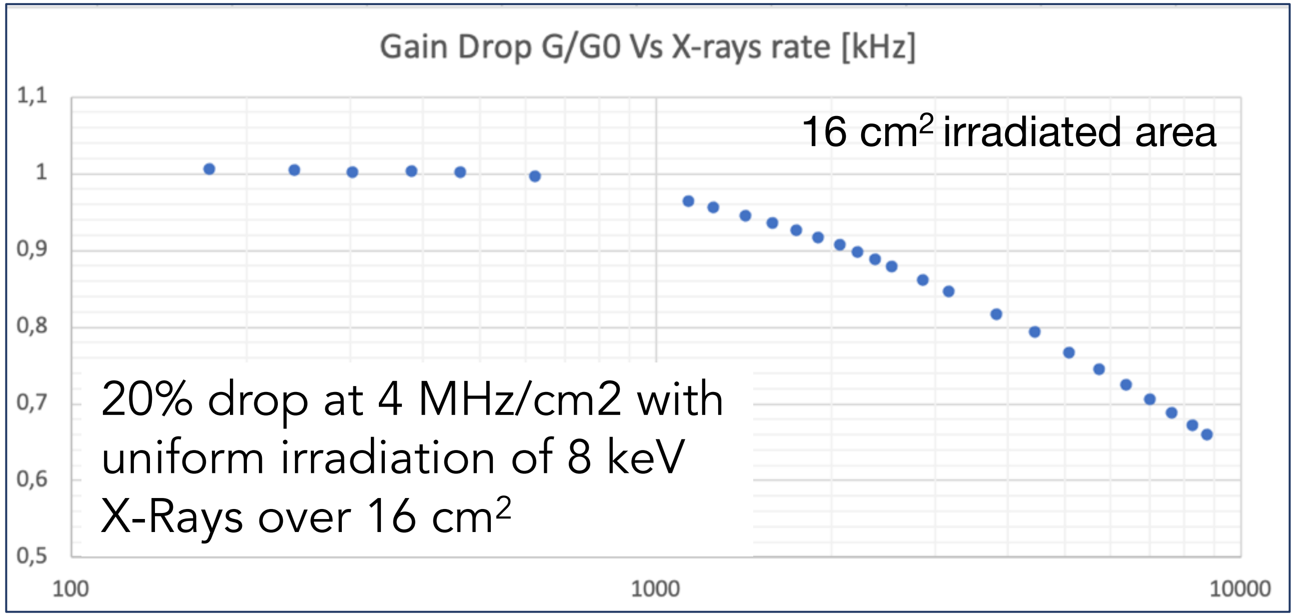
Ion Backflow



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

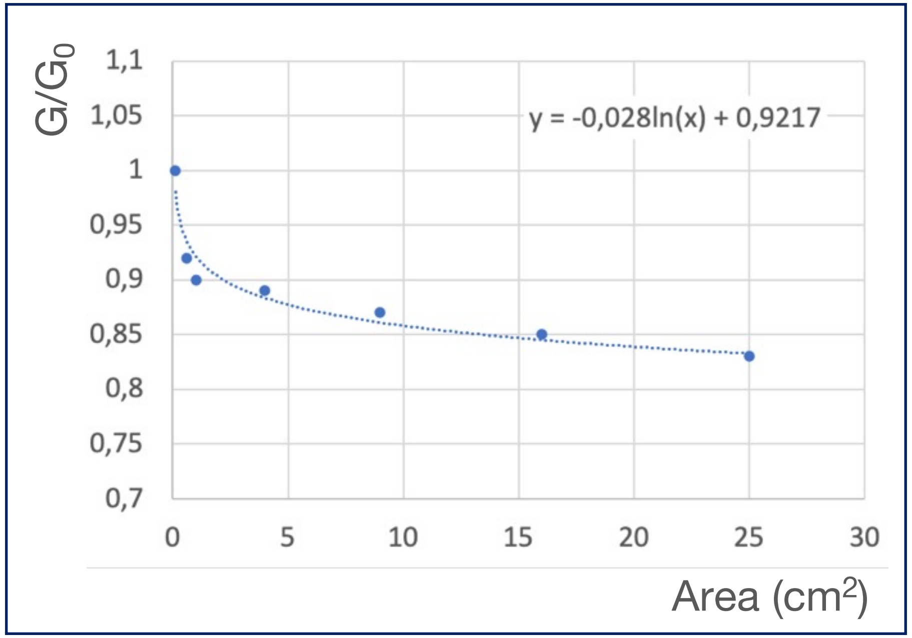
- Can reach high-rate capability well above 1 MHz/cm^2 with ~20-30 MOhm/sq and grounding connection dot vias every 6-10 mm
- Limited dependence of the rate capability from the irradiated surface



Dependence on the irradiated area

Fixed 8 keV X-rays rate: 3 MHz/cm^2

(Equivalent to > 10 MHz/cm2 for MIPs)

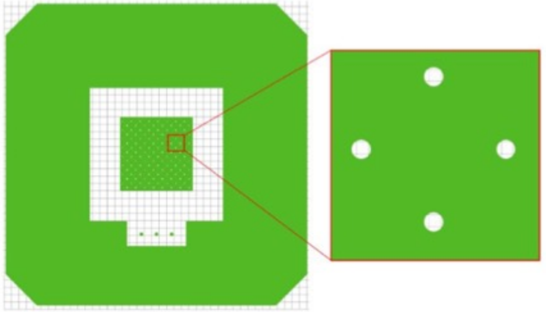


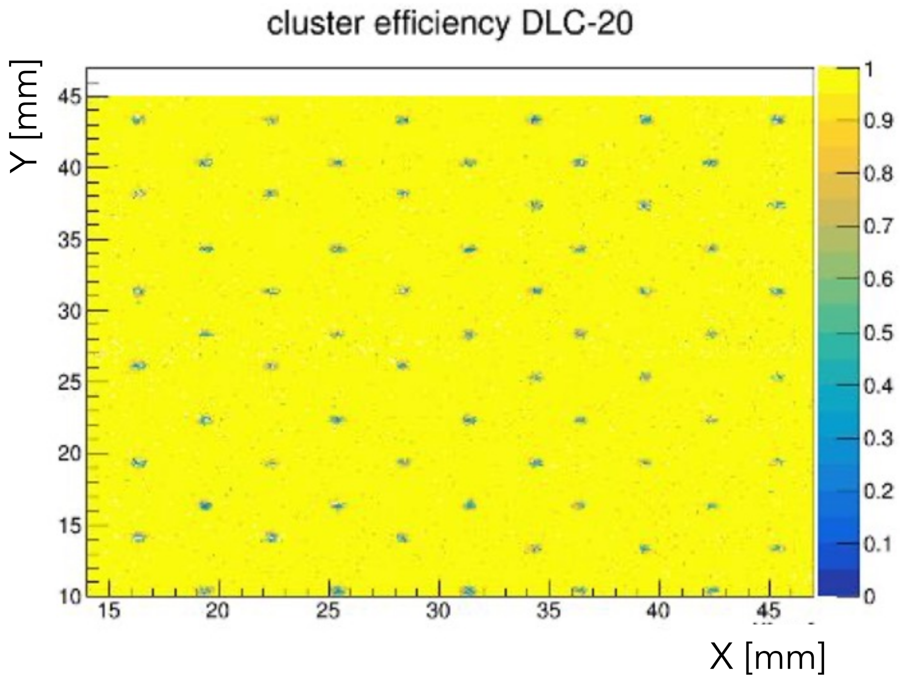
- Logarithmic dependence
- G/G0 ~72% extrapolated to 40x40 cm^2 with >10 MHz/cm^2 MIPs
  - Can be compensated with +10 V

Performance at Test-Beams - Efficiency

LOCAL INEFFICIENCIES
from Circular pillars:

- 0.3 mm for DLC20

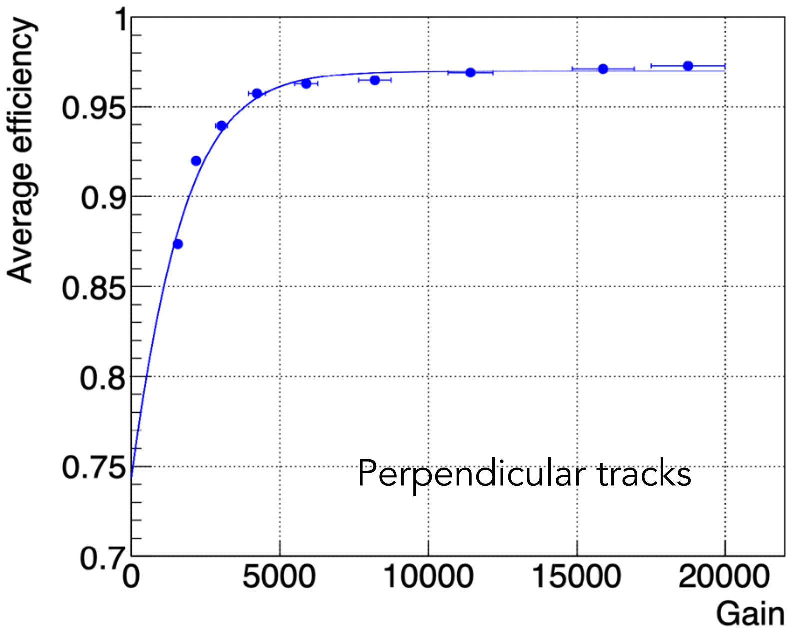




Efficiency >99%
Outside the pillars region

Tracking efficiency:

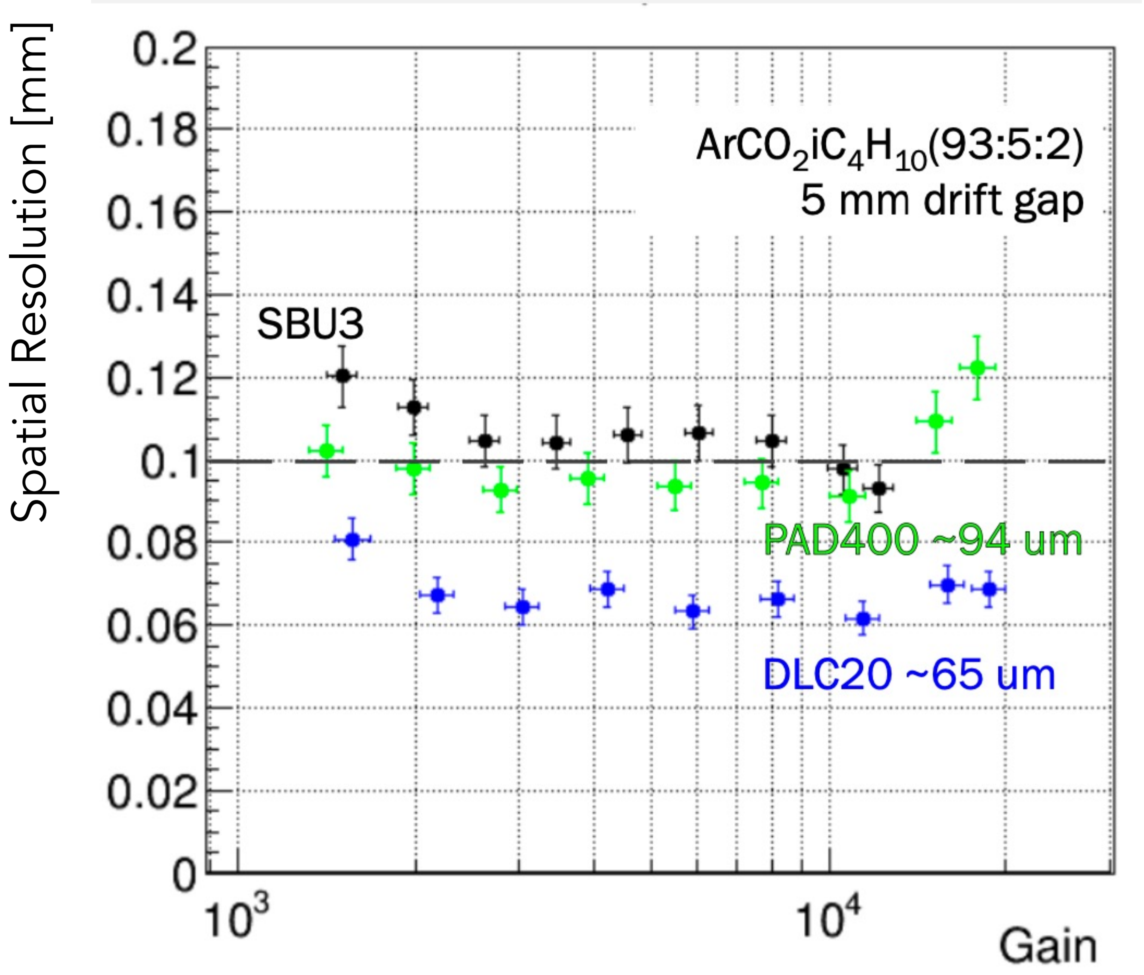
1.5 mm fiducial range wrt extrapolated position from external tracking chambers



Average tracking efficiency at plateau ~97%
It includes inefficient areas on the pillars
The effect is expected to be mitigated for inclined tracks (under study)

Spatial Resolution

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



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

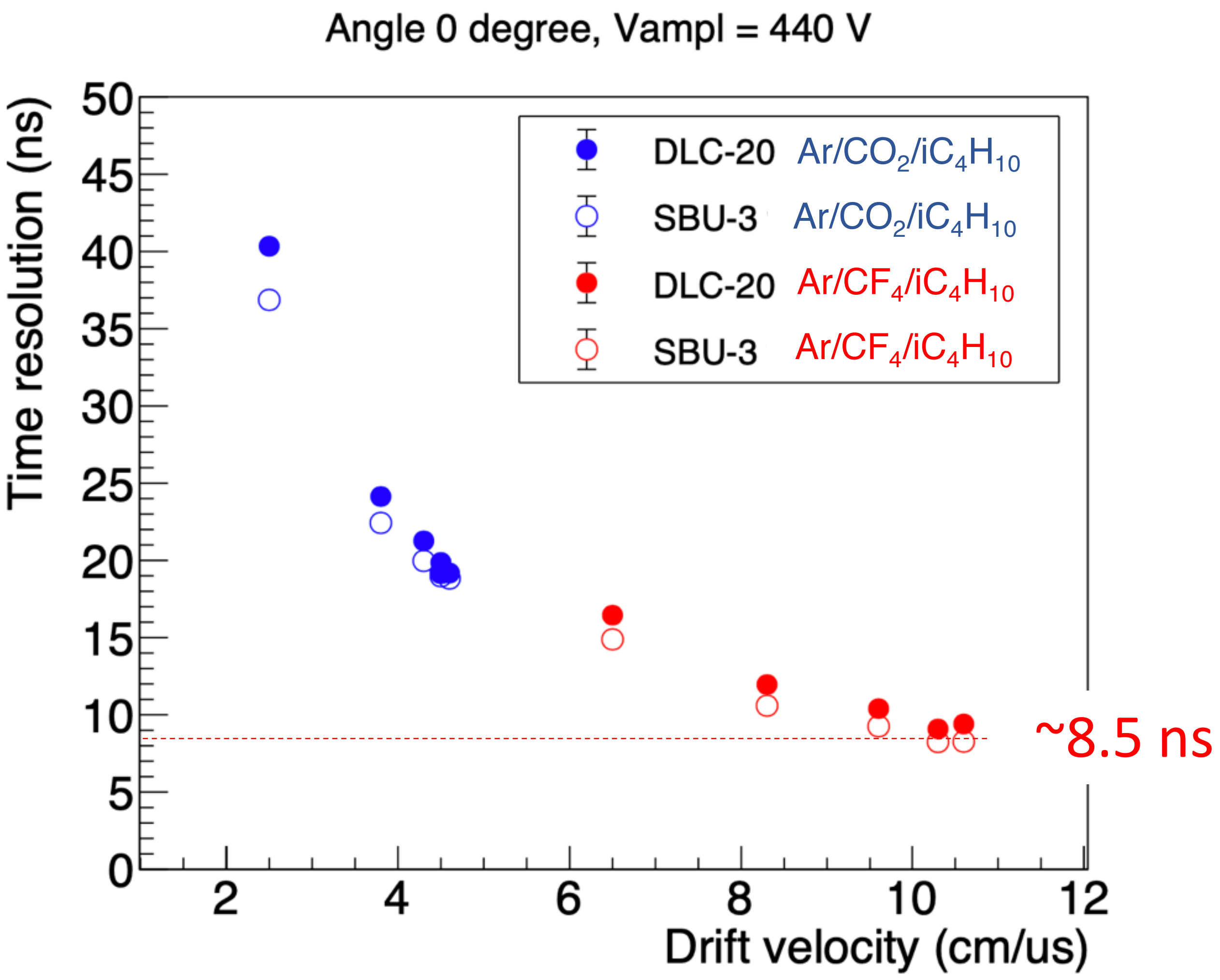
→ Under investigation and ongoing work for the optimization of the charge centroid algorithms

…very promising! Results coming soon

Recent developments

- Time resolution studies
- Performance Vs (reduced) drift gap
  - Towards a more compact multilayer structure
  - Improved time resolution?
  - (studies on spatial resolution for inclined tracks)
- Medium-size detctors → Paddy400
- Multi-layer configuration with shared/common cathode

Time resolution



A wide range in drift velocity was explored using different gas mixtures

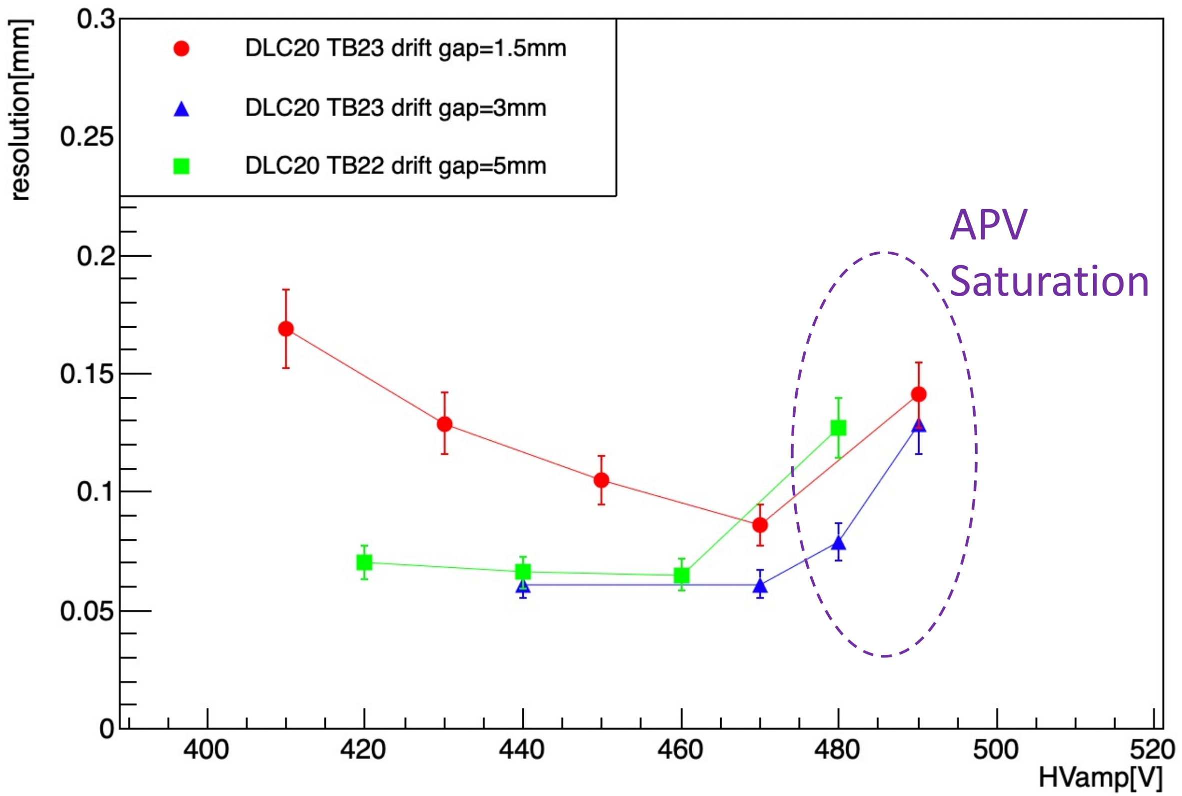
The time resolution improves with the drift velocity (primary ionization fluctuations). Best time resolution achieved ~8.5 ns.

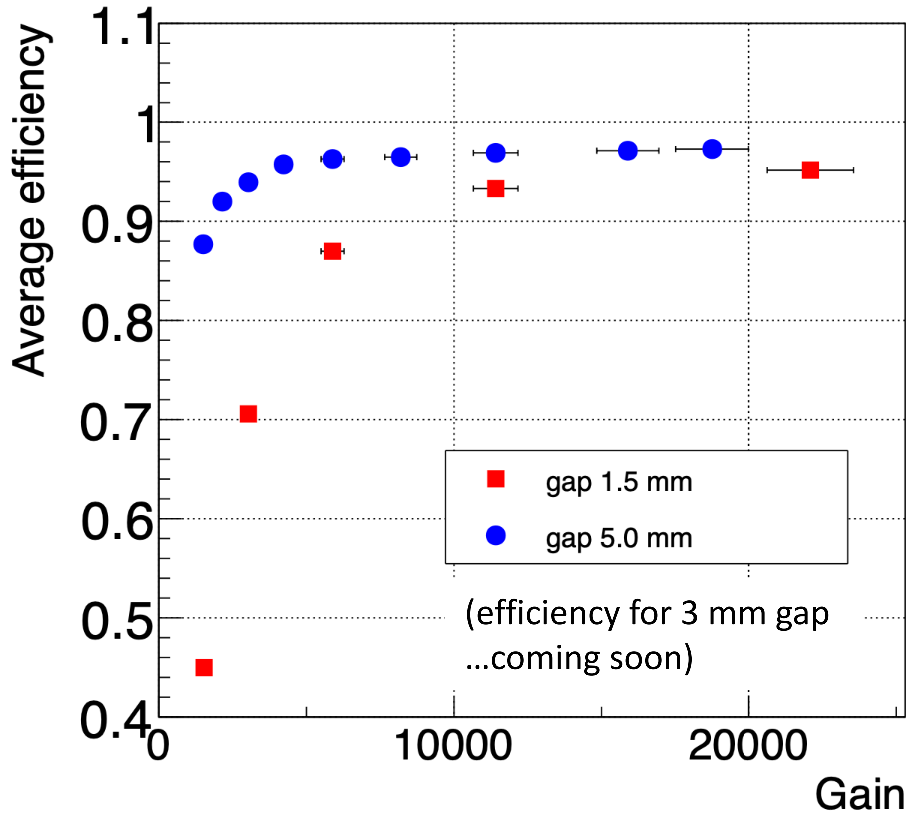
It includes the contribution of signal processing and FE (APV signal fit) time resolution (preliminary estimate is ~4-5 ns → real σ_t ~ 7.5 ns)

From simulations σ_t also improves with a reduced drift gap (reduced pile-up in peak time with charge sensitive preamp)

→ One of the motivations to explore thin drift gaps

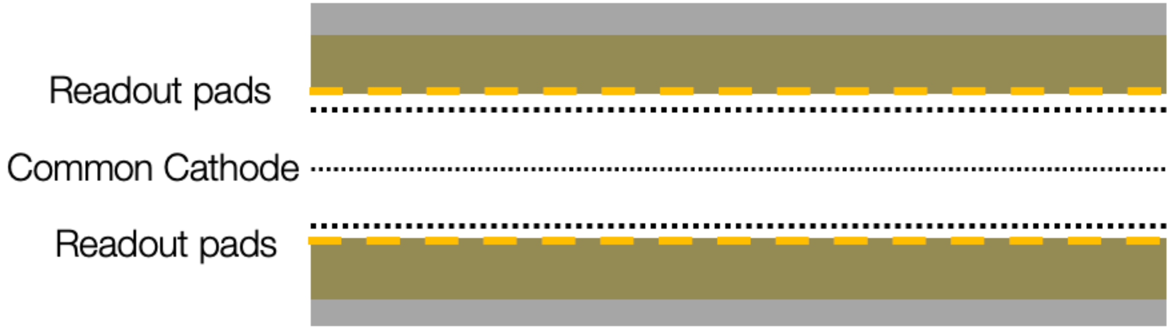
Spatial resolutions and Efficiencies Vs Drift-gap



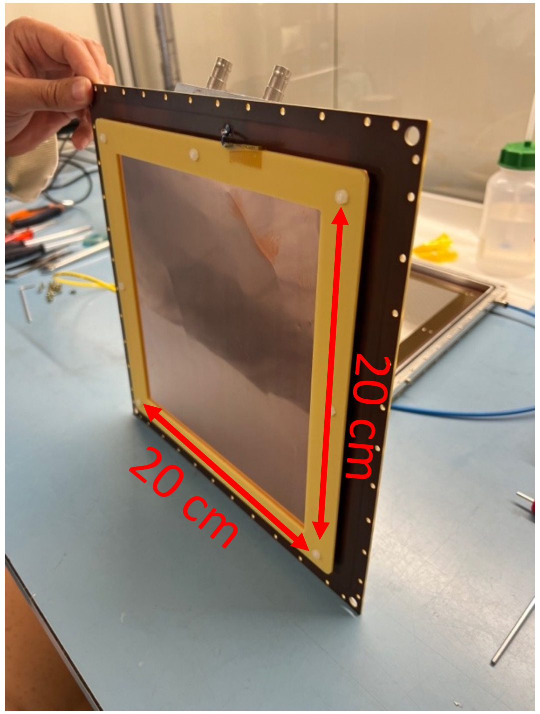


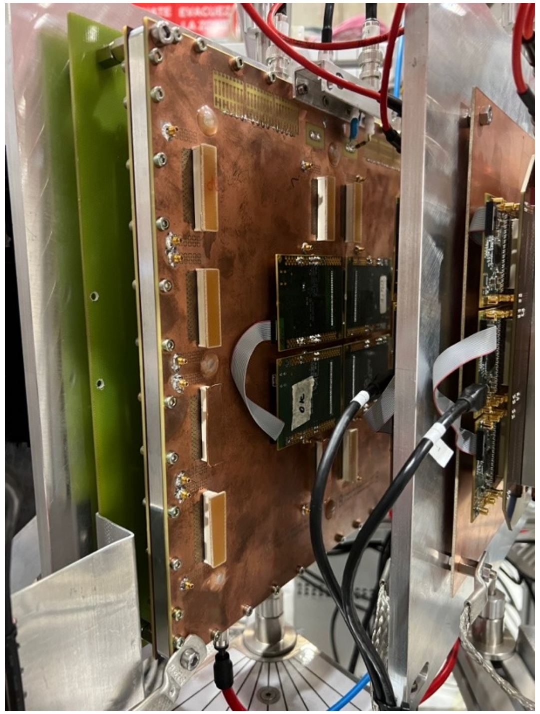
- Similar behaviour for 3 and 5 mm drift gap
- Need high gain, >10 k to reach best performance with 1.5 mm gap (expected)

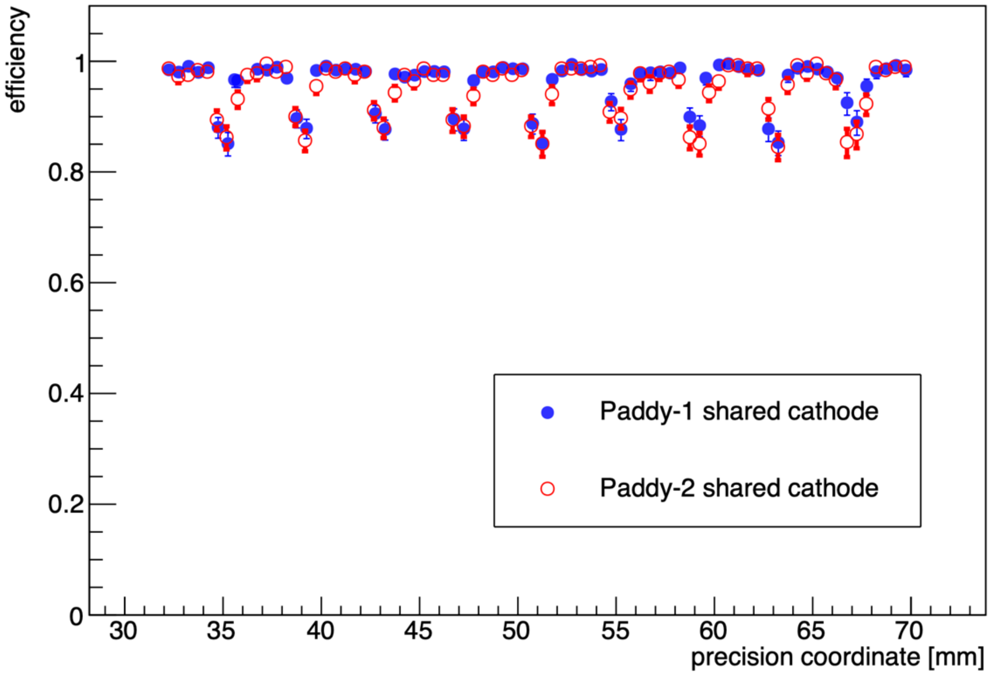
Medium-size (400 cm^2 – Paddy400) common cathode



Compact configuration. Perfectly working, as expected, with no surprises.





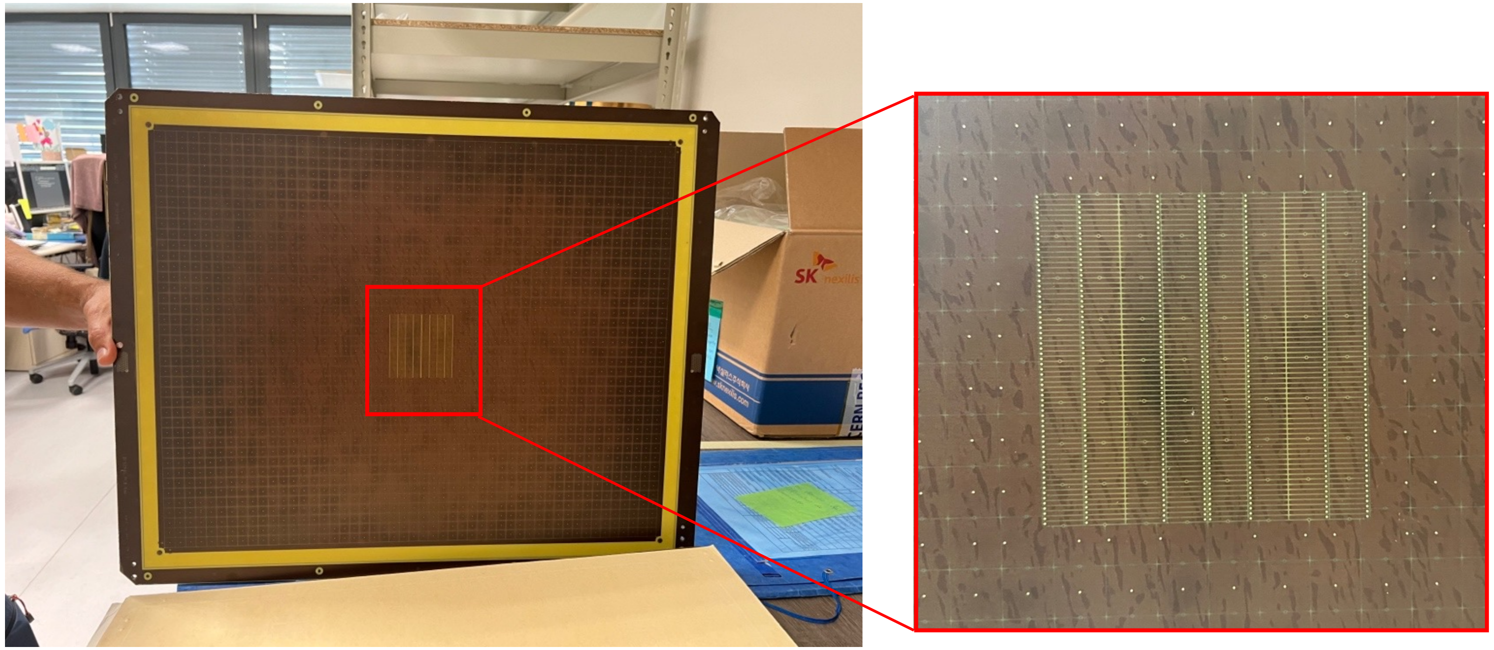


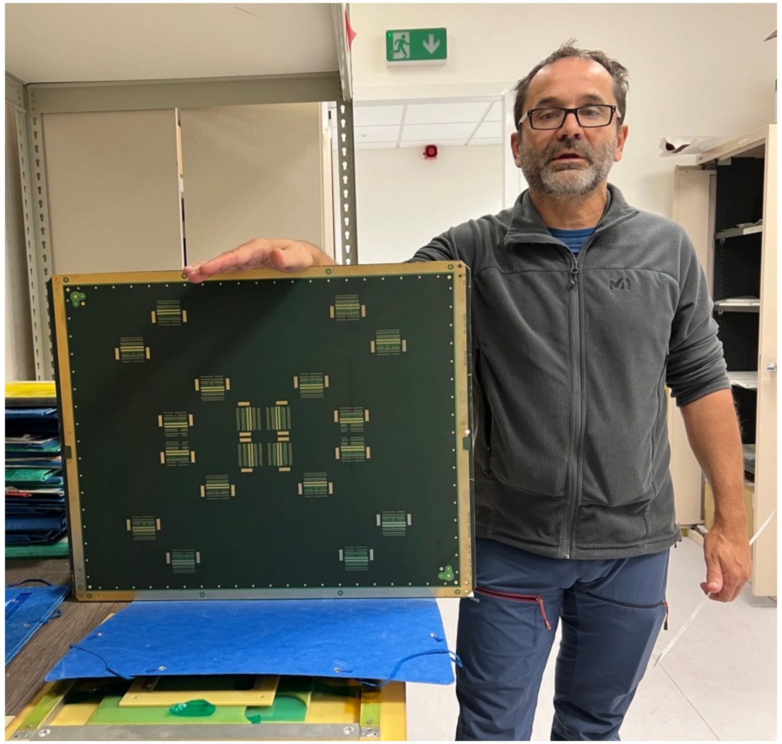
Present status and Future prospects

- Towards large area
- Applications
- Connection with the ECFA Roadmap for Detectors R&D

(we have also recently produced small size prototypes to thoroughly test the Capacitive Sharing concept, to reduce the number of channels – results will come soon !)

Towards Large Area





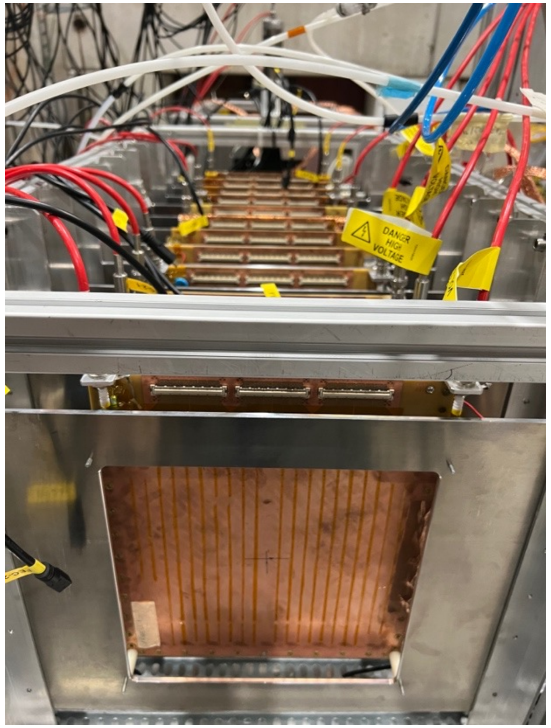
50x40 cm^2 in construction
Fine granularity readout in the centre,
1 cm^2 pads elsewhere (for practical reasons – number of channels)

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

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

Applications

- Digital Hadronic Calorimeters (DHCAL using ParticleFlow approach), rMM in the RD51 common project "Development for Resistive MPGD Calorimeter with timing measurement"
- SHADOWS (Search for Hidden And Dark Objects With the SPS): rMM used for Upstream and Lateral muon Veto



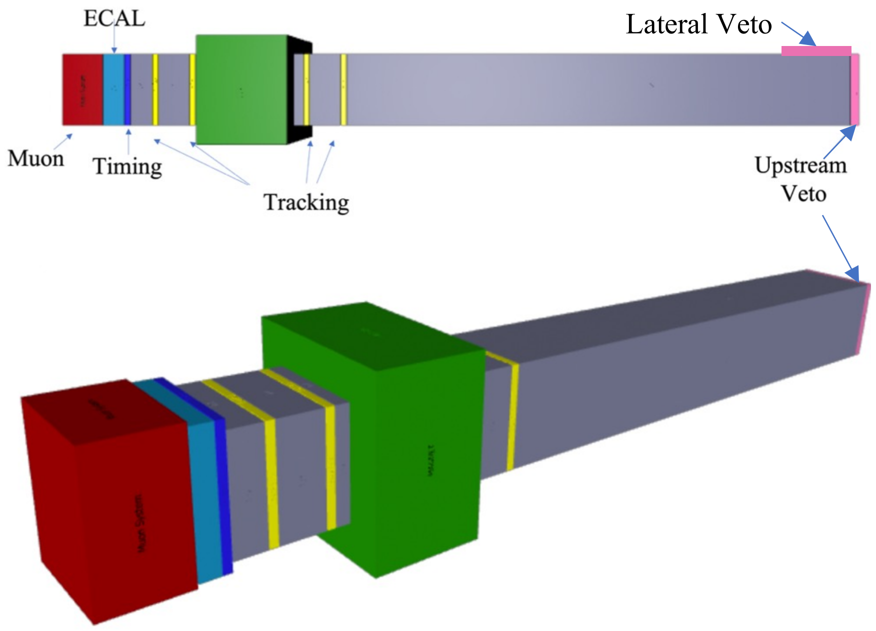
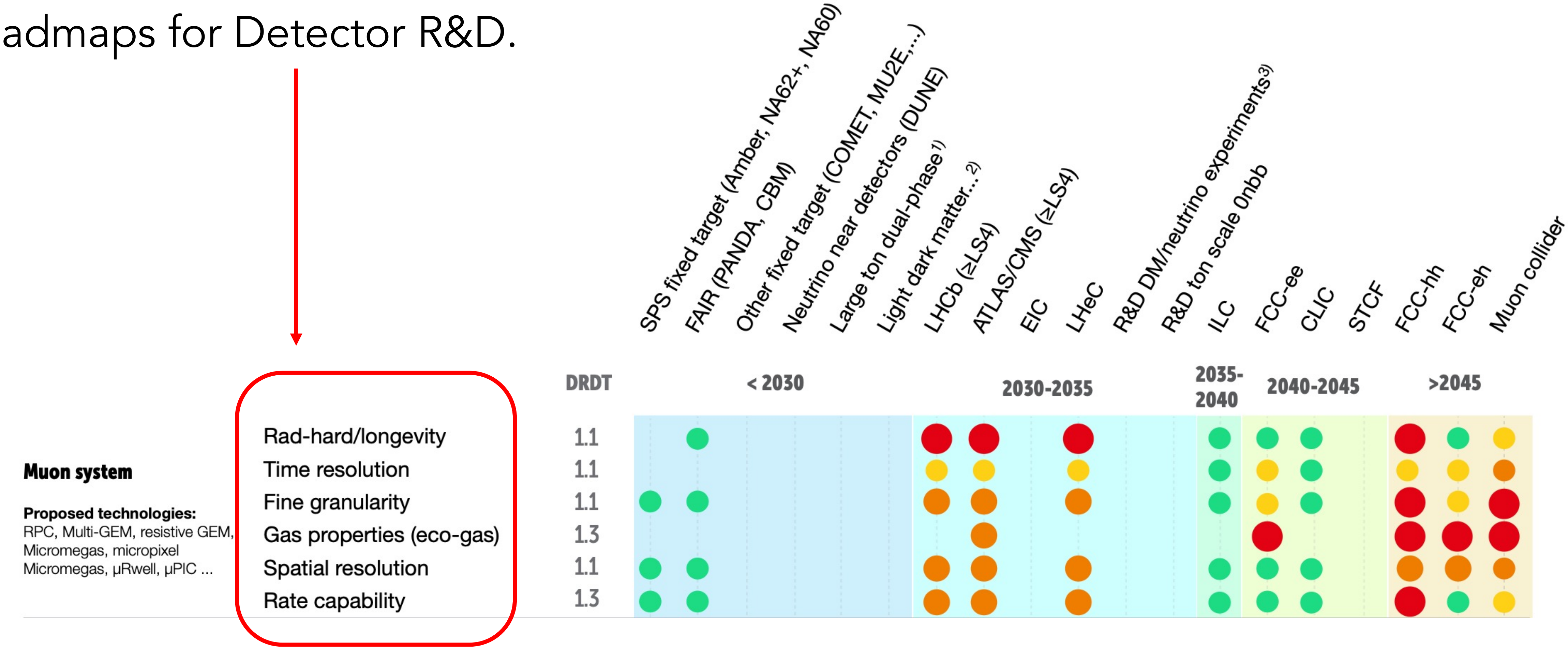


Figure 29. SHADOWS detector layout: lateral view (top) and 3D view (bottom figure).

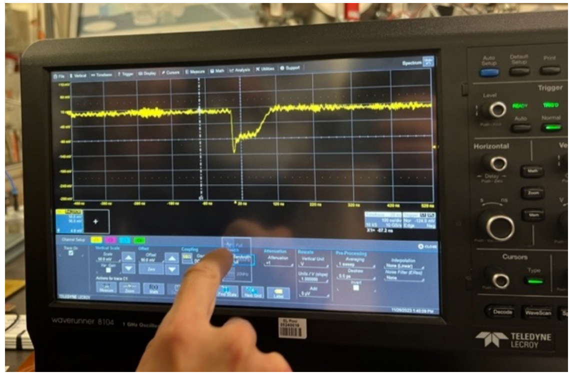
- AMBER (successor of Compass) will possibly upgrade the Muon detectors using rMM with RHUM configuration (M. Alexeev, "15th Pisa Meeting on Advanced Detectors")
- …and, naturally, developing plans to leverage resistive MM a 'la RHUM for upcoming experiments

Connection with the ECFA roadmap

Our efforts align with the primary tasks outlined in the ECFA roadmaps for Detector R&D.

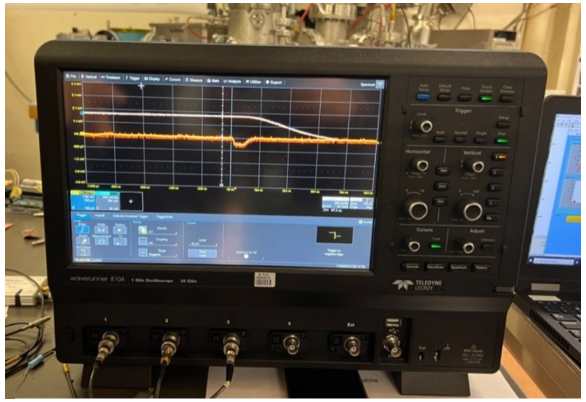


Thank you!



Transimpedance preamp

...and looking forward to meeting you all in the new DRD1 forum! ☺️



Direct – no preamp!