Pixelised Resistive Micromegas for high rates environment

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On behalf of the RHUM R&D group
(INFN - Italy)

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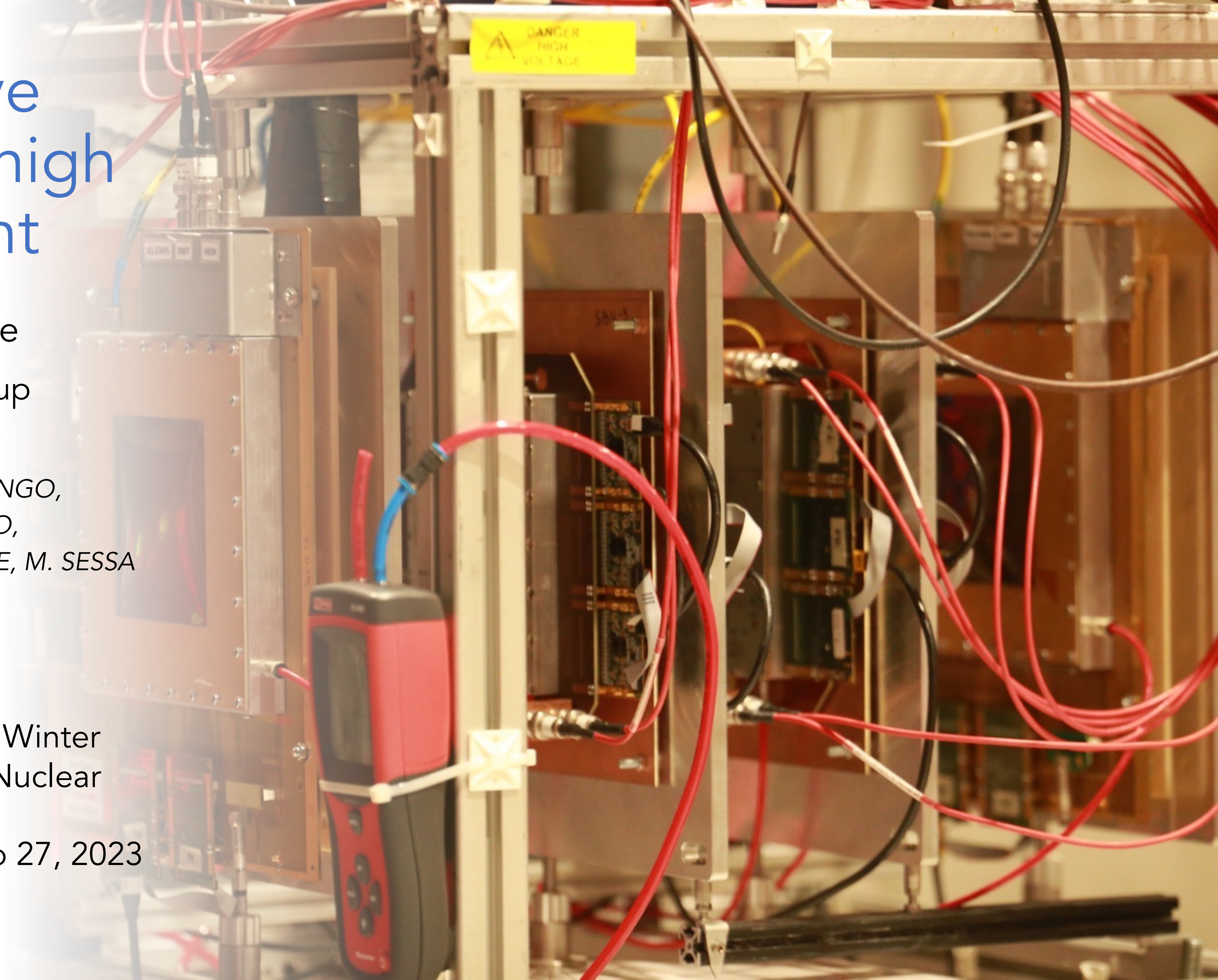

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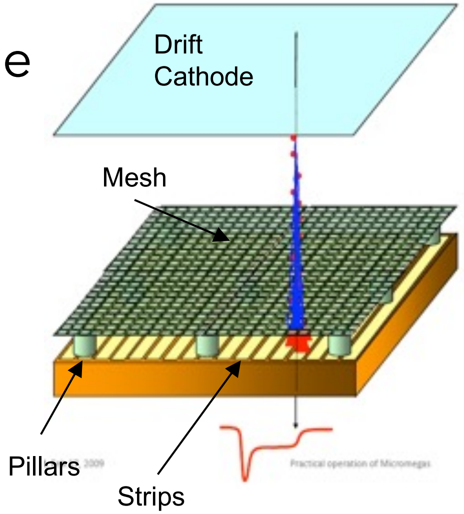
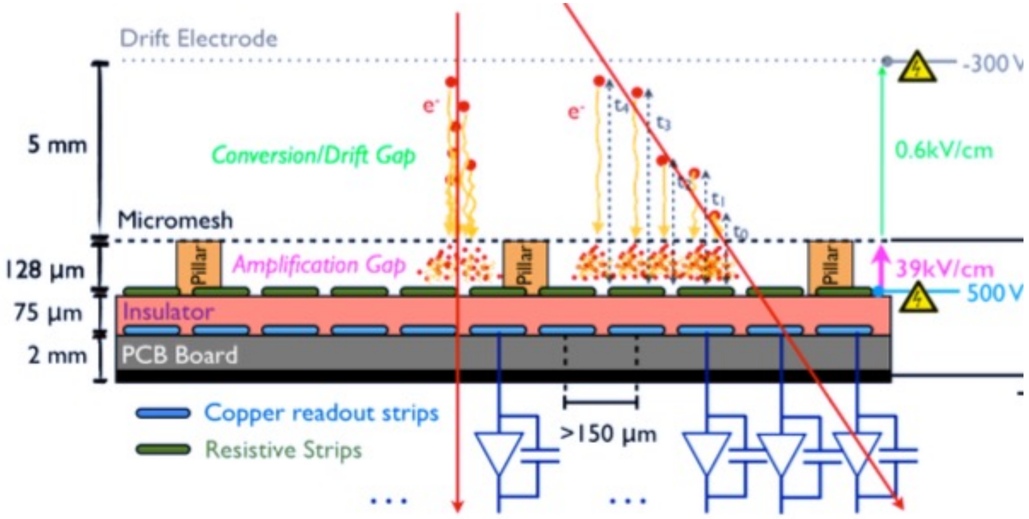
Resistive Micromegas (a Micro Pattern Gaseous Detector)

Short Intro

- A breakthrough in the Micromegas technology was the implementation of a resistive layout to suppress discharges intensity *(a dedicated R&D for ATLAS)*
- ATLAS New Small Wheel endcap MUON detector implements Micromegas with resistive strips:
  - resistive anode strips on the top of the readout strips (with insulator in between)
  - The signal is capacitively induced to the readout strips



- A metallic micro mesh separates the drift volume (~5 mm) from the amplification volume (~100 μm);
- electrons and ions produced in the amplification volume are collected in 1 ns and ~100 ns respectively;



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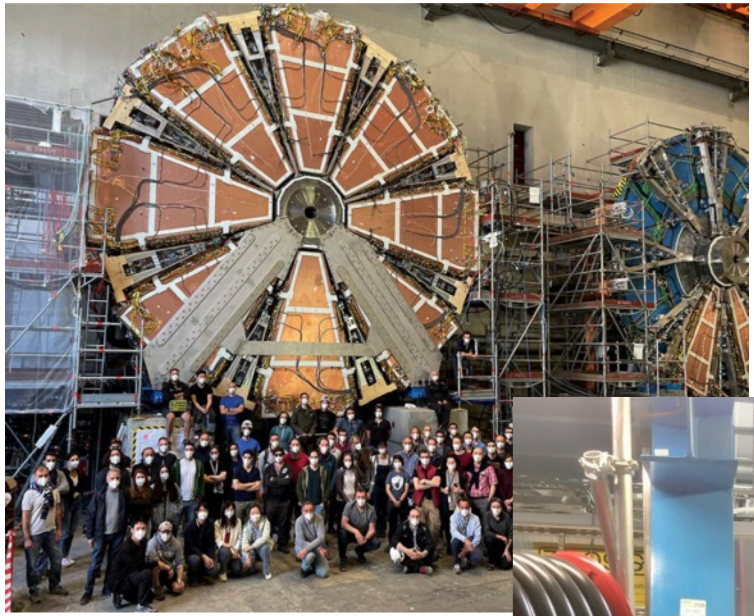
    - The signal is capacitively induced to the readout strips
    - NOW the NSW is in operation in ATLAS
    - Large area: total surface of ~1200 m^2 of Micromegas active area
    - Will operate at moderate hit rate up to ~15 kHz/cm^2 during the phase of High-Luminosity-LHC

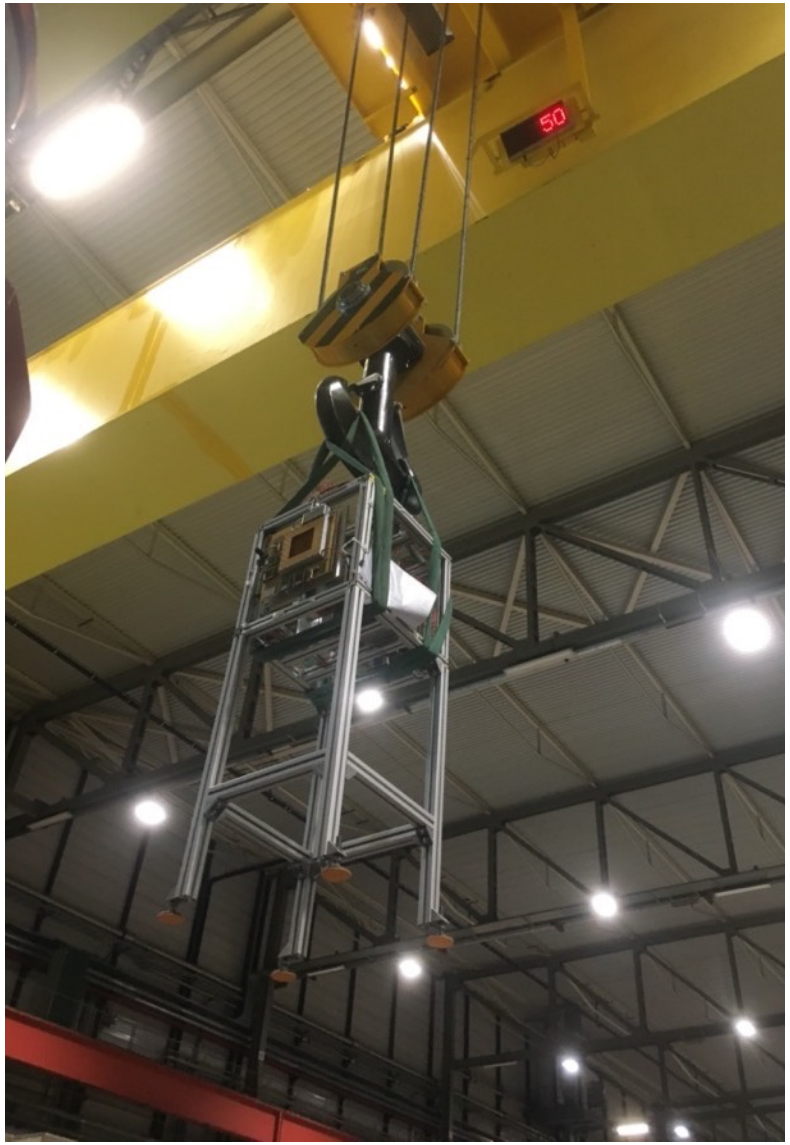


It's a mature technology for HEP experiments

New R&D to improve Micromegas performance

Main Purpose of the project

- Consolidation of resistive Micromegas, for measurements at rates of the order of 10 MHz/cm^2
  (3 orders of magnitude higher than in ATLAS NSW)
- High-granularity low occupancy readout on pads of the order of mm^2, capable of withstanding high radiation.
- Demonstration of the scalability of detectors on large surfaces
- Stability of operation at high gains
- simplification of the construction technique for industrial production



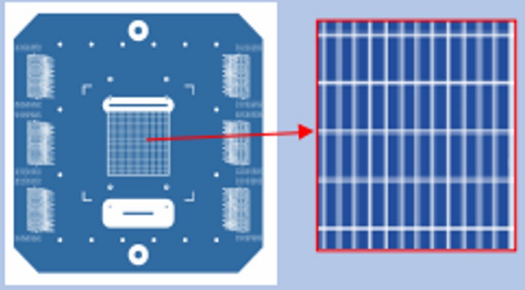
Outline of the talk

- Detector concept and prototypes description
- Small size pixelised detectors
    - State of the art
      (rate capability, spatial resolution, efficiency)
    - New studies on time resolution
- Ongoing work:
    - Larger area detector → preliminary tests
- Summary and Outlook

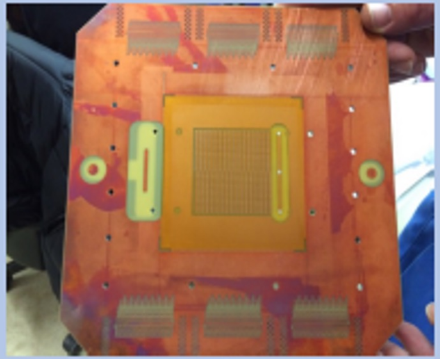
The Small Size Prototypes

Several Prototypes built and tested with a common readout layout but different spark protection systems

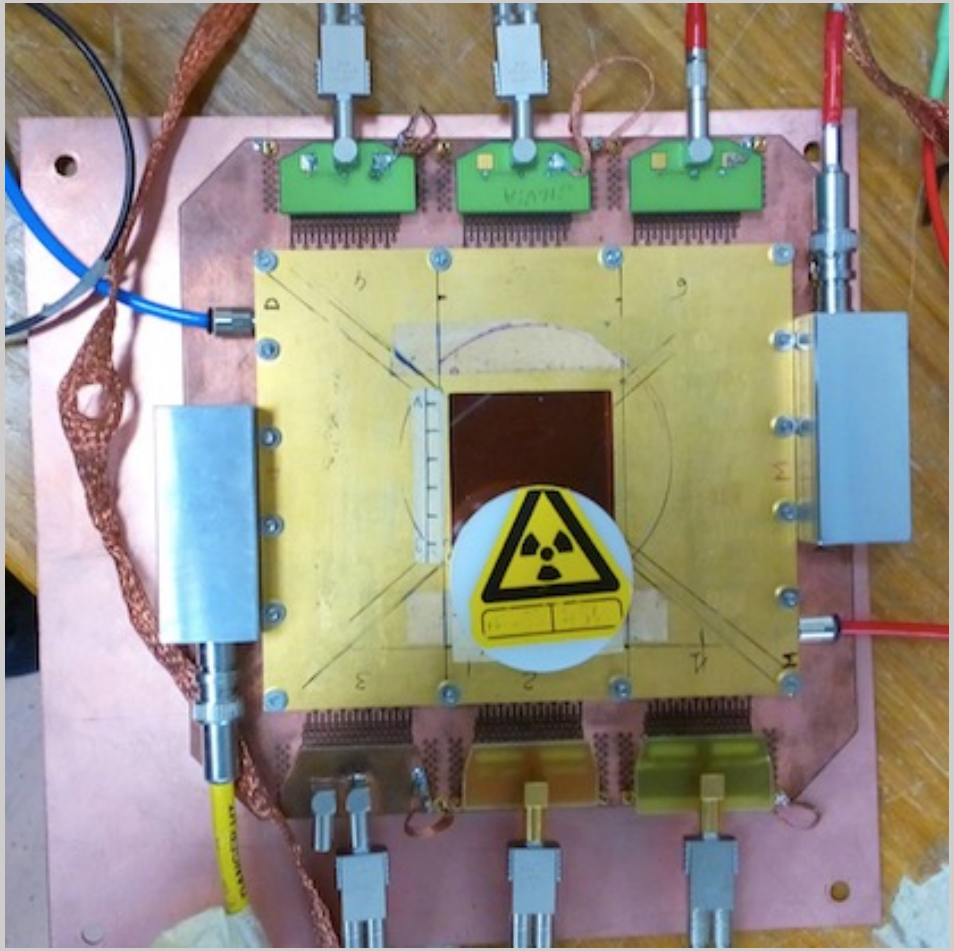
Readout PAD anodic plane (common to all prototypes)



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")



Signals routed to six Panasonic connectors



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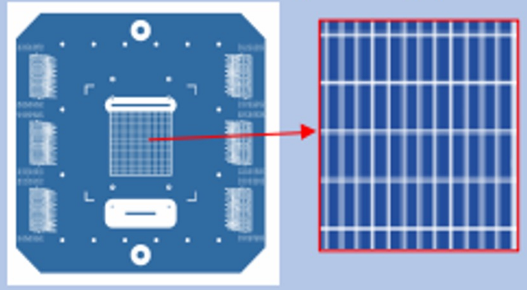

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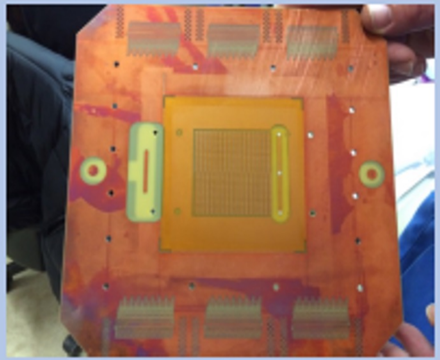

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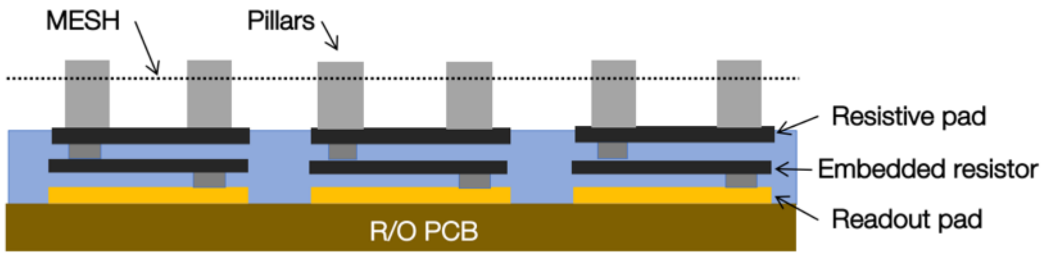
CONFIGURATIONS of the resistive layers
two main categories: Pad-patterned and uniform DLC layers(*)

PAD-Patterned



PAD-P

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

(*) **D**iamond **L**ike **C**arbon coating on Kapton (by sputtering)

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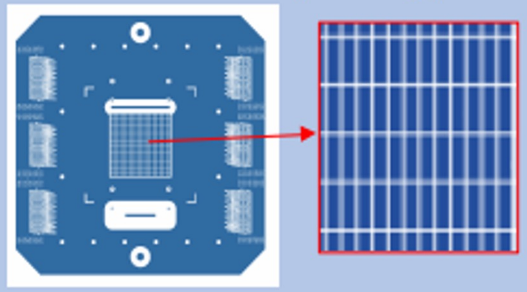

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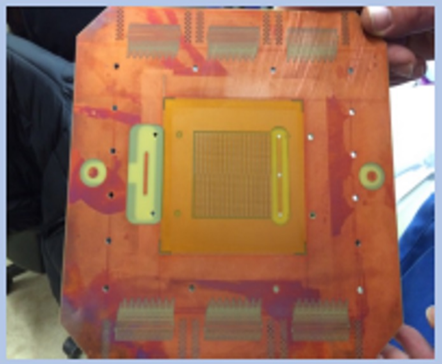

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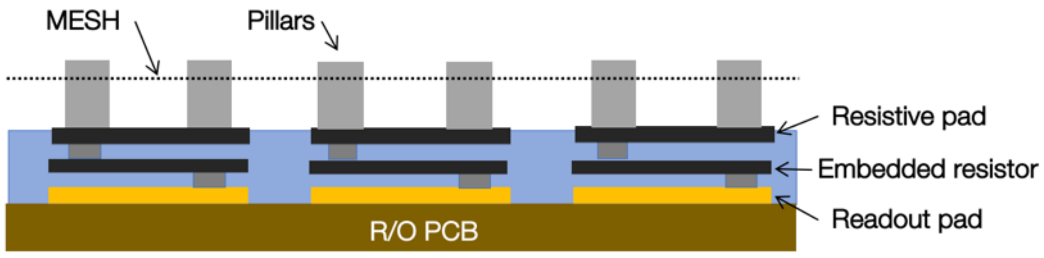

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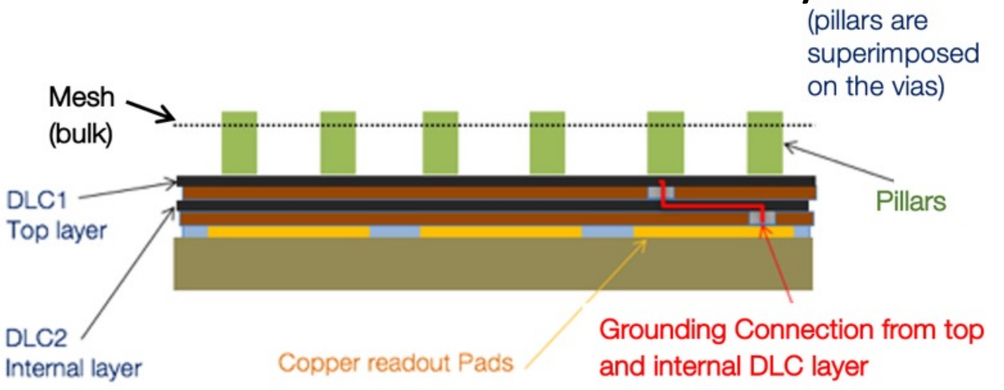
Double DLC(*) Uniform resistive layer



DLC20 (20 MΩ/sq)

DLC-SBU (30 – 50 MΩ/sq)

- Uniform double DLC layers with DOT grounding connections (every ~8 mm)
- Sequential Build-Up technique (based on copper-clad DLC) implemented in recent years

(*) **D**iamond **L**ike **C**arbon coating on Kapton (by sputtering)

State of the art - High-Rate Capability (relative GAIN Vs rate)

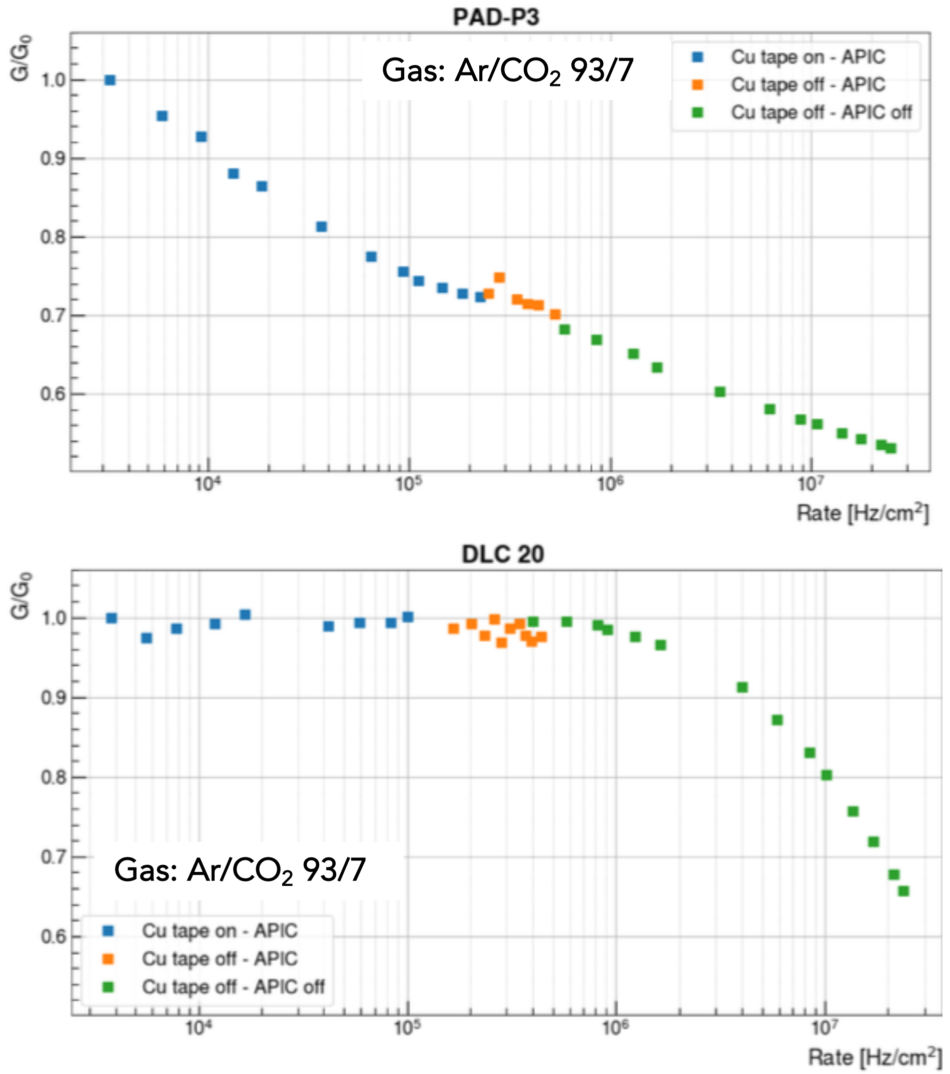
- Measured using 8 keV X-rays peak from a Cu target with different intensities (~4 order of magnitude) @ CERN GDD lab

PAD-P resistive scheme

- Relatively fast gain loss for rates < 0.1MHz/cm^2 due to charging-up effect
- Slower ohmic voltage drop through the individual pads at higher rates (Resistive-to-copper pad R ~10 MΩ)

DLC and SBU prototypes

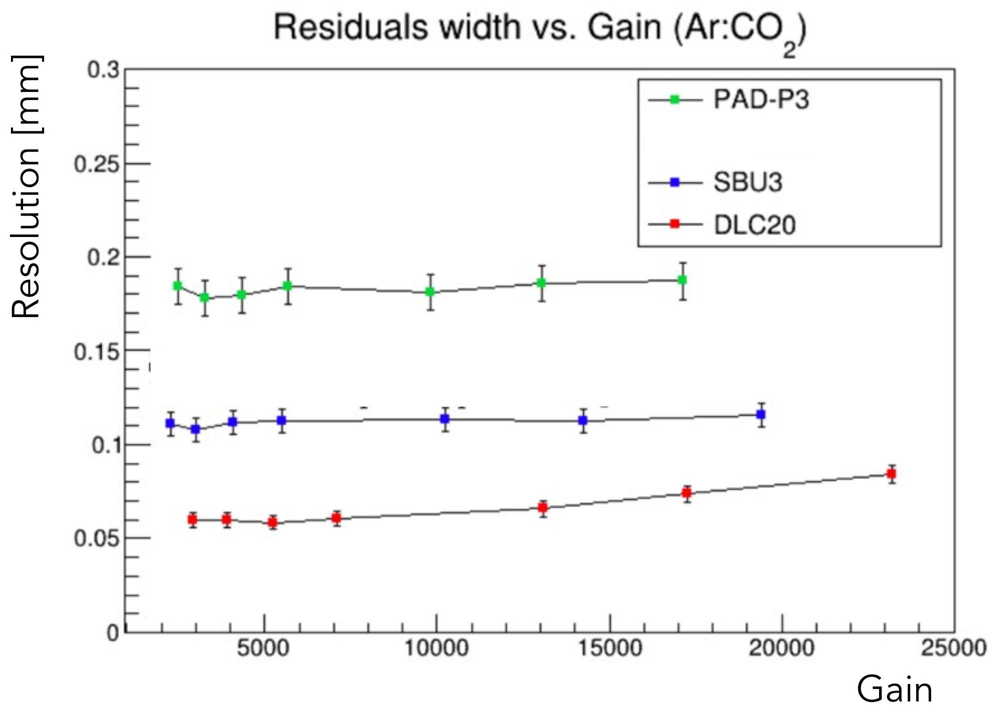
- Gain essentially stable up to ~1-2 MHz /cm^2
- At higher rates gain loss is fully accounted by ohmic gain drop
- At 10 MHz /cm^2 ~20% Gain drop



Performance at Test-Beams – Spatial resolution

Position resolution:

- Cluster residual from position extrapolated from external tracking chambers.
- 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 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

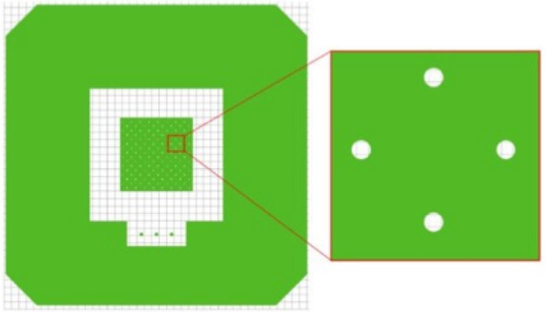
Performance at Test-Beams - Efficiency

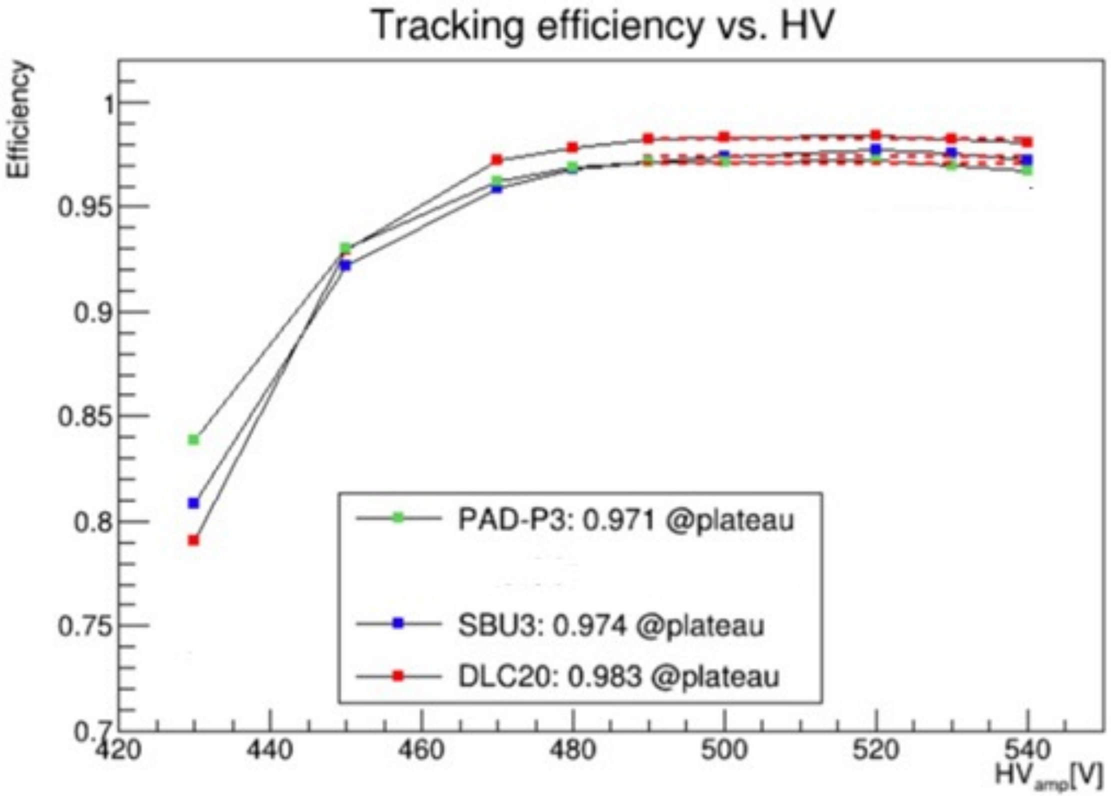
Tracking efficiency:

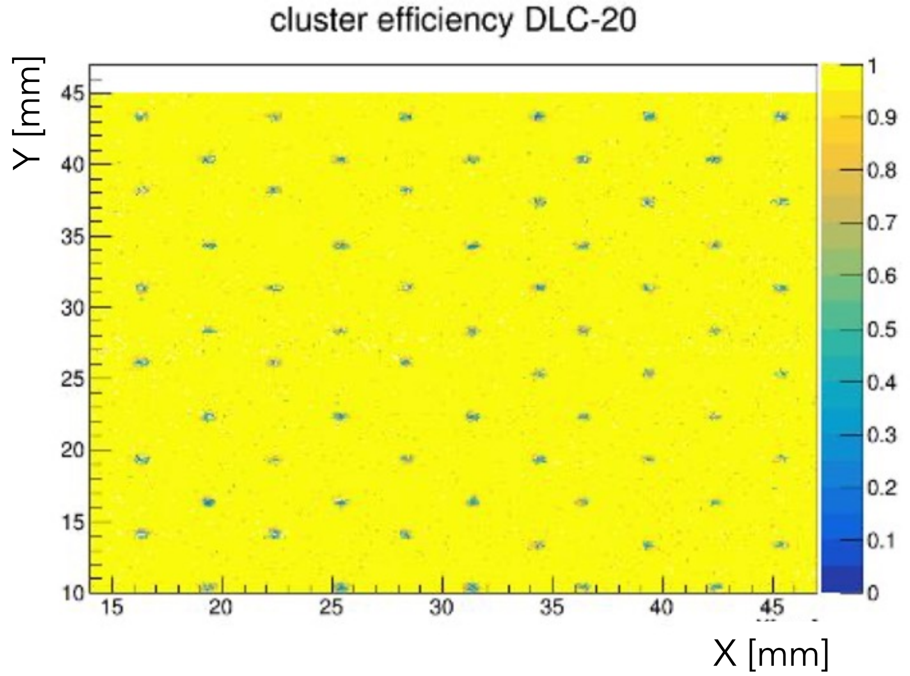
1.5 mm fiducial range wrt extrapolated position from external tracking chambers

LOCAL INEFFICIENCIES from Circular pillars:

- 0.3 mm for DLC20
- 0.7 mm for SBU3







Efficiency >99%
Outside the pillars region

Timing studies

GOAL: Measurement of the time resolution as a function of the drift velocity (of e^- in the drift gap)

We used 2 different gas mixtures, varying the Drift Voltage:

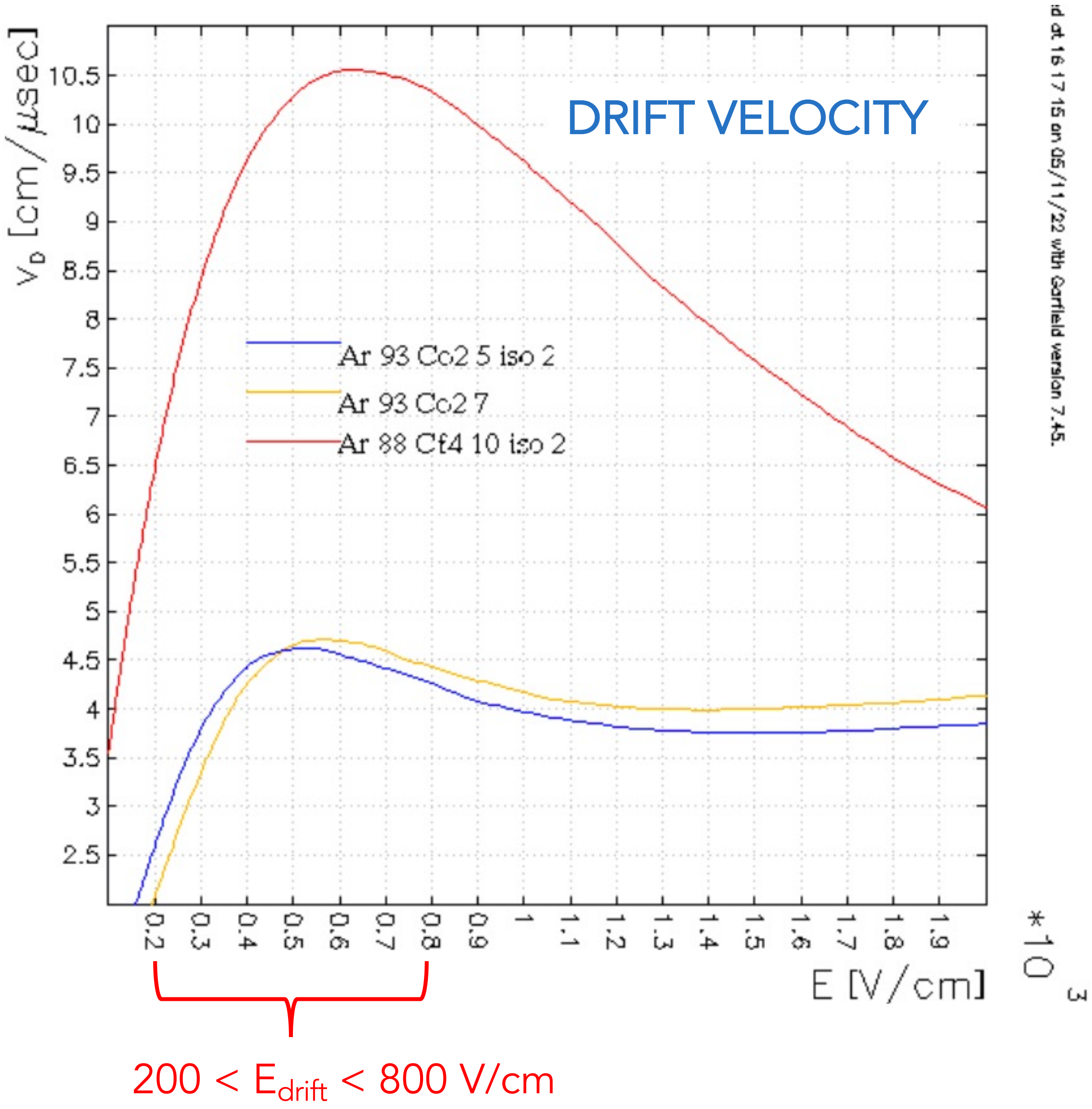
Scan in E_{drift}: [200: 800] V/cm

- With $Ar/CO_2/iC_4H_{10}$ (93/5/2)

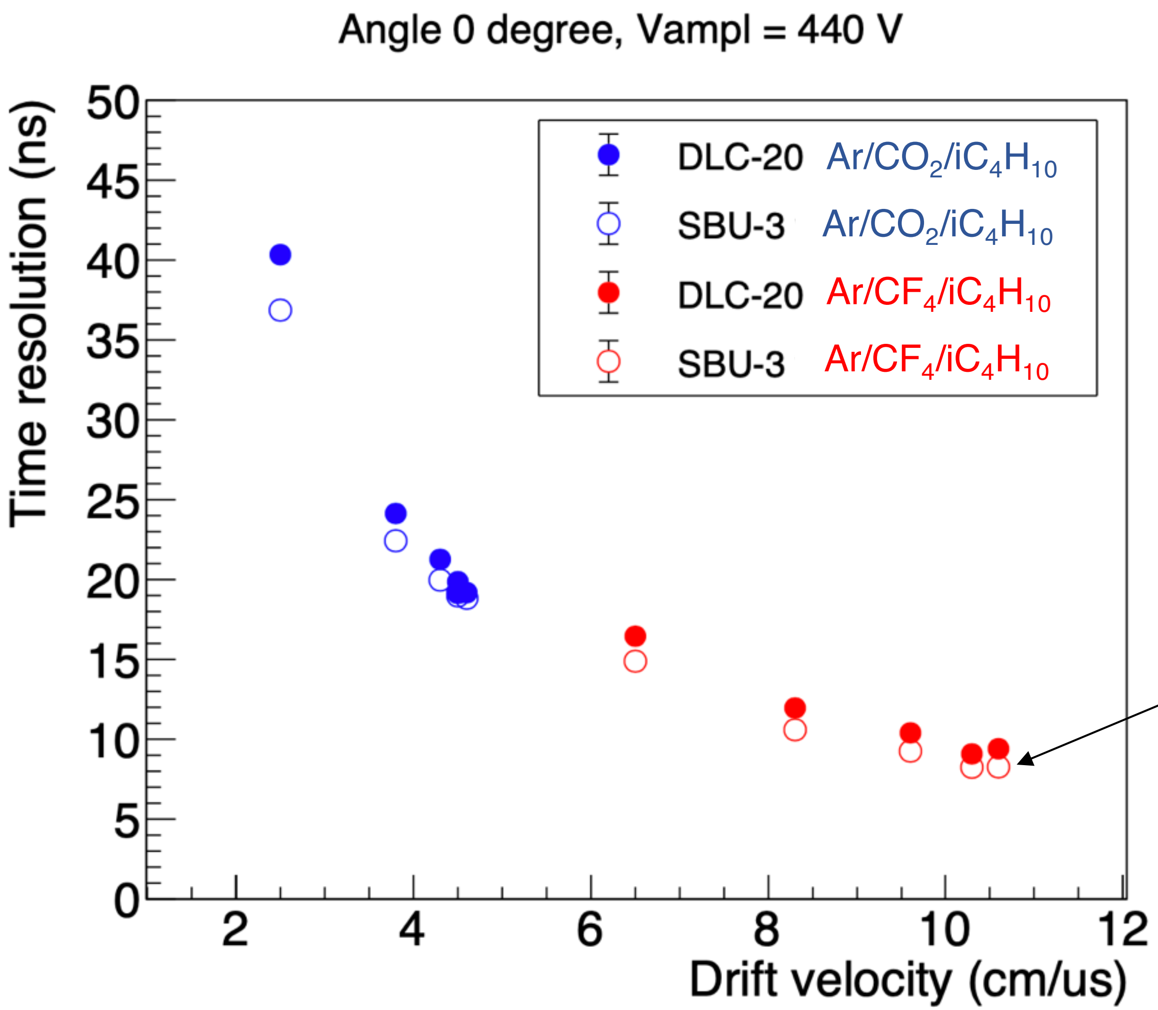
  range in drift velocity: v_{drift}: 2 – 4.5 cm/μs

- With $Ar/CF_4/iC_4H_{10}$ (88/10/2)

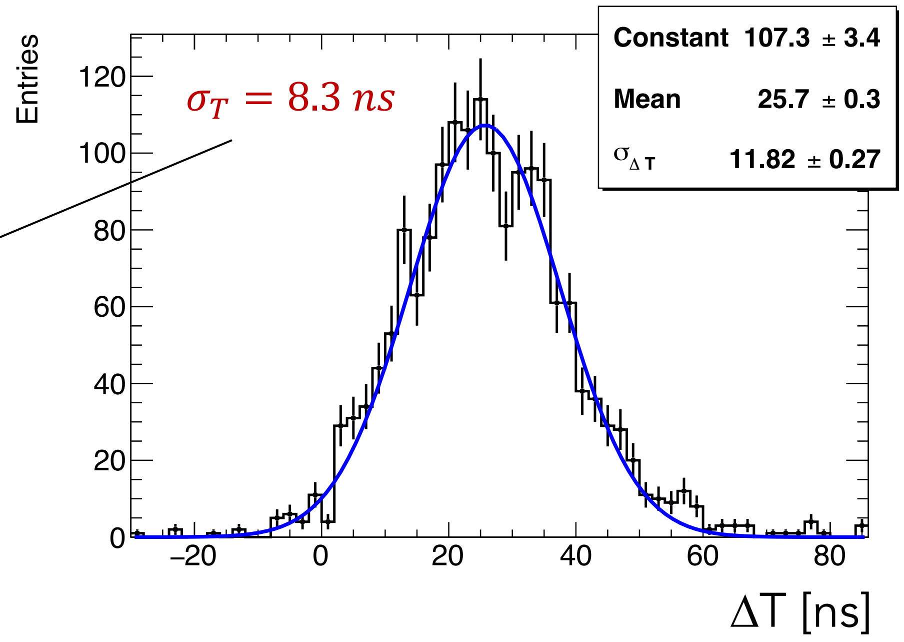
  range in drift velocity: v_{drift}: 3.5 – 10.5 cm/μs



Time Resolution – dependence on the drift velocity



- Cluster time: charge weighted mean time of all the pads in the cluster
- ΔT: Difference of the cluster time in two different chambers
- Time resolution: $\sigma_T = \sigma_{\Delta T}/\sqrt{2}$



R&D: achievements and ongoing work

In the last years different spark protection resistive layouts have been implemented on several Small Pads Micromegas prototypes.

From tests and comparison among them we reached:

- stable operation up to 20 MHz/cm2 with gain >10k;
- detector efficiency >98 % ; position resolution < 100 μm.
- Time resolution ~8 ns (ongoing effort to achieve 5 ns)

DLC (SBU) (double layer) detectors resulted in:

- better energy and spatial resolutions;
- negligible charging up effects;

It fits in the new stream of resistive MPGD production exploiting DLC and new sputtering facilities

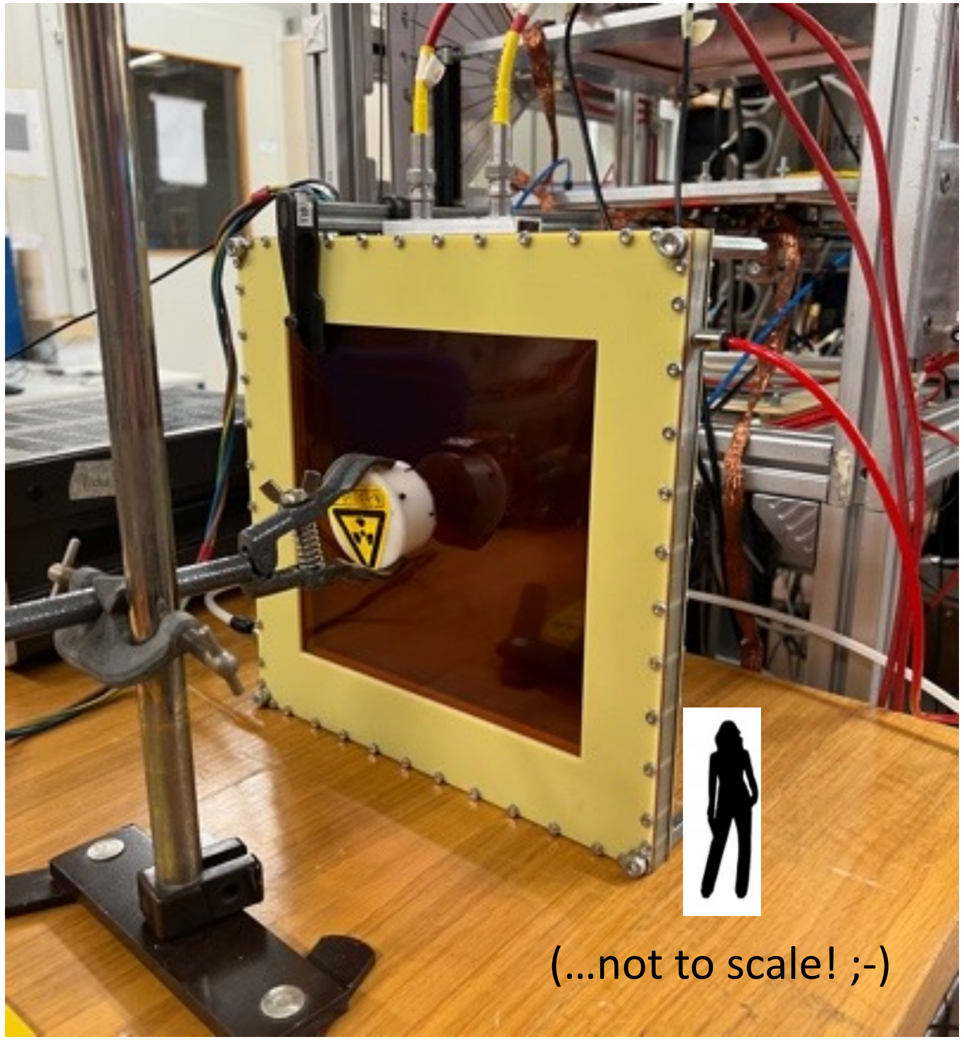
A new sputtering facility is now available at CERN →

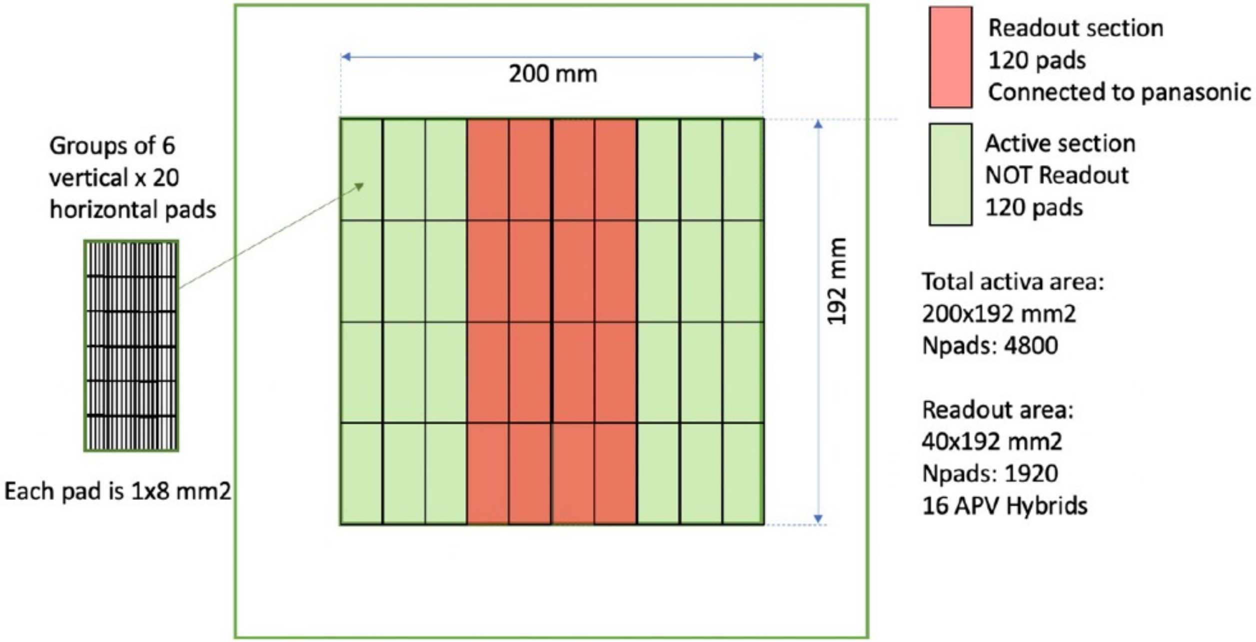
(co-funded CERN-INFN)

NOW, moving towards LARGER AREA DETECTORS…

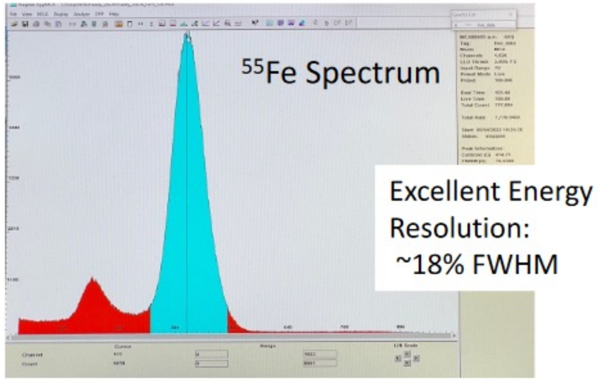
Towards Large Area – PADDY400 the 20x20 cm^2 Prototype

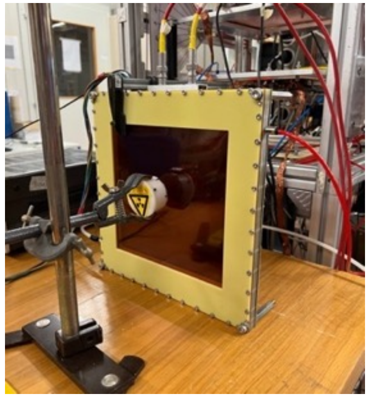
- Active area: 200x192 mm^2
- Pads 1x8 mm^2 - Total Number of Pads: 4800
- Double DLC layer (30-40 MOhm/sq) with grounding vias every 8 mm
- Panasonic connectors on the back of the detector
- Partially readout: 1920/4800 connected pads

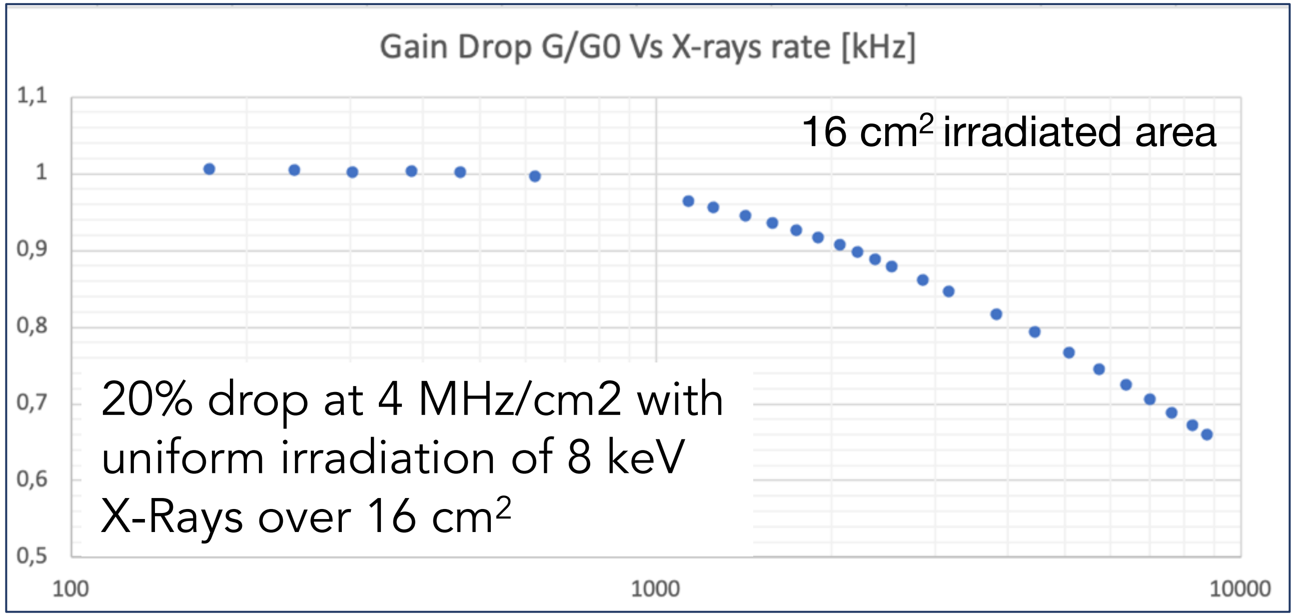




Paddy400 – rate capability and dependence on the irradiated area



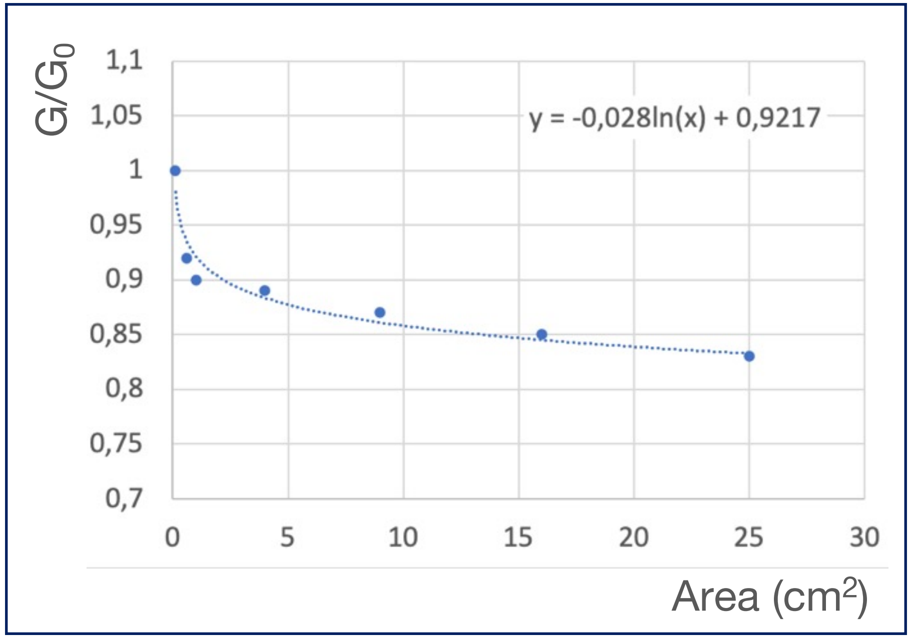




Dependence on the irradiated area

Fixed 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

APPLICATIONS of large area pixelized MM for high rates

- Potential candidate for upgrades for very forward muon detection at LHC (e.g. ATLAS Large Eta Muon tagger)
- Sampling Hadron Calorimetry for the Muon Collider (dedicated ongoing R&D)
- Currently under consideration:
  - Muon Veto for SHADOWS (proposal for proton dump physics at CERN)
  - Replacement of Muon detectors for AMBER (successor of Compass)

- Detectors for high energy (tens/hundreds TeV scale) and very high intensity new particle accelerators (FCC-ee/hh) or for the **Electron-Ion-Collider (EIC)**
- Readout layer of a Time Projection Chamber
- More "exotic" applications, e.g. detection of External Neutral Atoms (ENA) in Space Weather research program

Summary and Outlook

- Several Small Pad Micromegas prototypes were built using different resistive layout solutions: based on embedded resistors or using uniform DLC resistive foils
- Performance achieved:
  - stable operation up to 20 MHz/cm^2 with gain $>10^4$
  - detector efficiency > 98%
  - position resolution < 100 μm
- New large(r) area prototype built
  - Preliminary results very promising
  - Rate capability well beyond 1 MHz/cm2 with large area irradiation
  - Energy Resolution <20% at 5.9 keV
- With the construction of even larger small-pad detectors THIS year, our R&D is reaching the goal of establishing the technology for future use under hard environment and high-rate in particle physics and other applications.

BACKUP

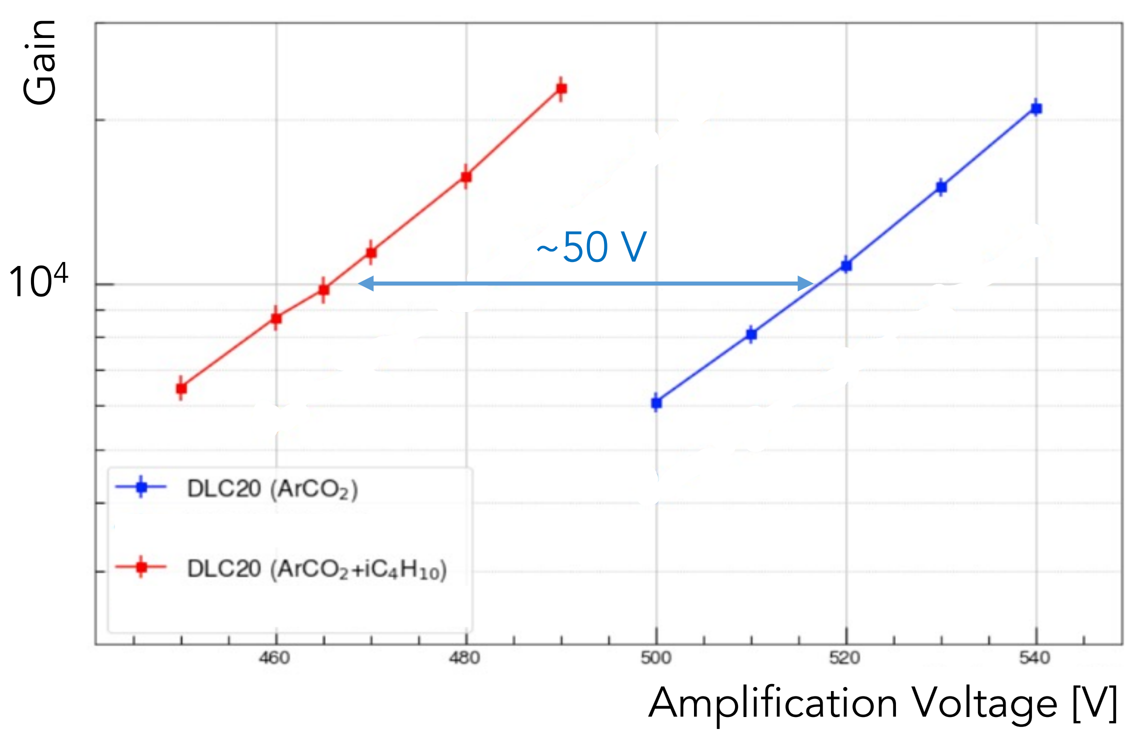
High-Rate Capability and Gas Optimisation

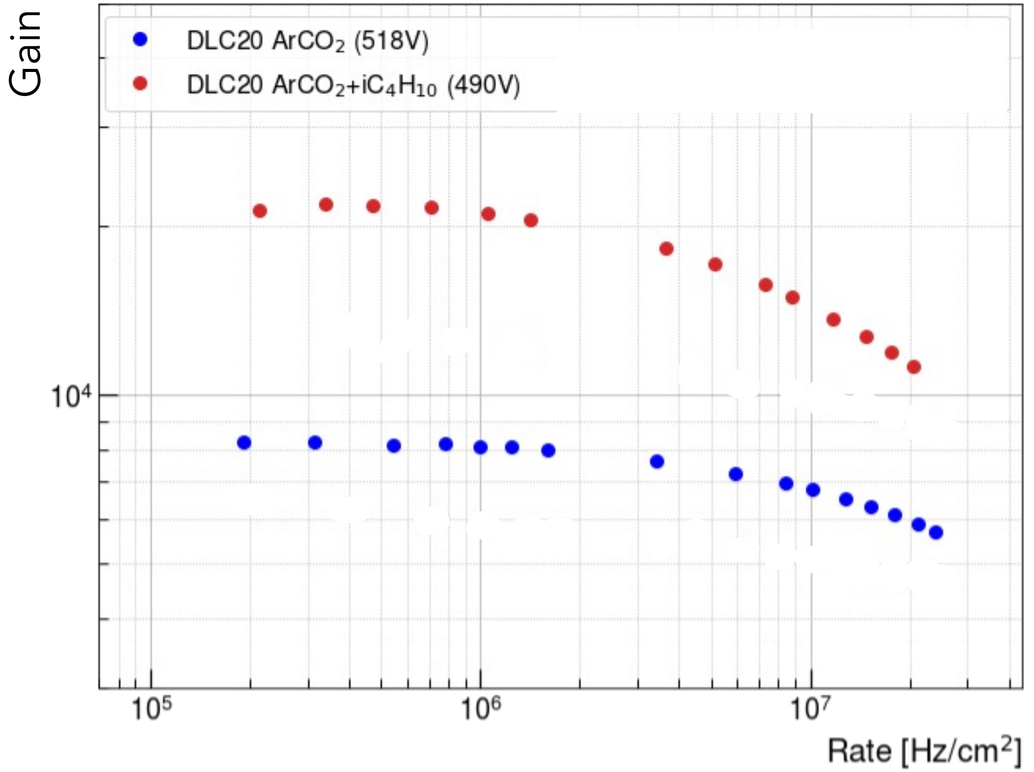
Started using Ar:CO_2 93:7 → added 2% isobutane Ar:CO_2:iC_4H_{10} 93:5:2 to improve the stability and extend the dynamic range

Gain >2×10^4 reached at very high rates (>10 MHz/cm^2) in stable conditions → remarkable results!

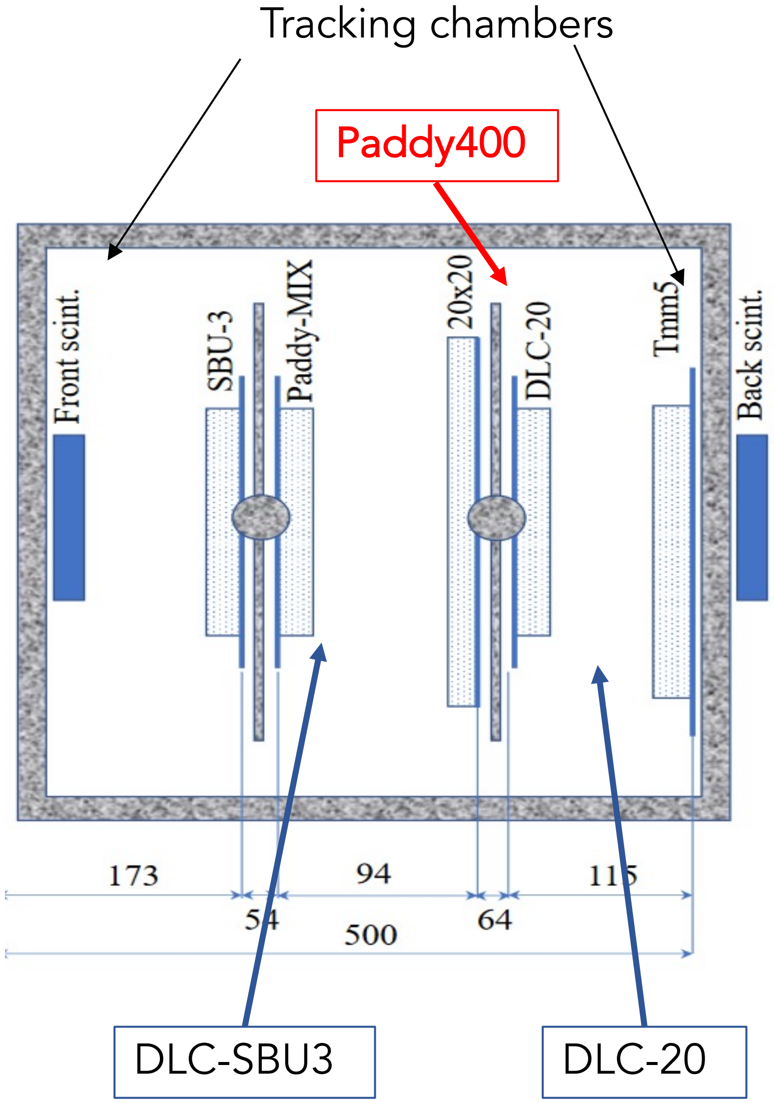
$N_{primaries}$ ~300
→ $N_{electrons}$ ~6×10^6 close to the Raether limit

~50 V difference between the two mixtures





Latest Test Beam Measurements (October 2022)



Test Beam at CERN (H4) with high energy muons and pions.

MAIN Goals:

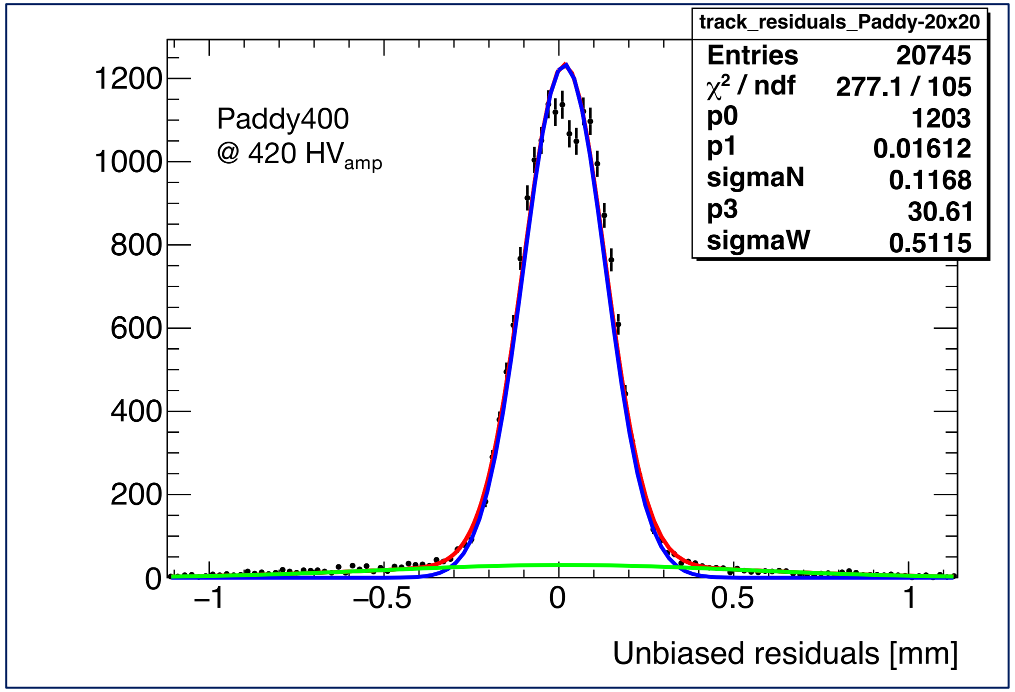
- Spatial resolution and efficiency of new detectors
  → Focus on PADDY400
- Timing resolution, also exploiting faster gas mixture
- Pion and multi-tracking

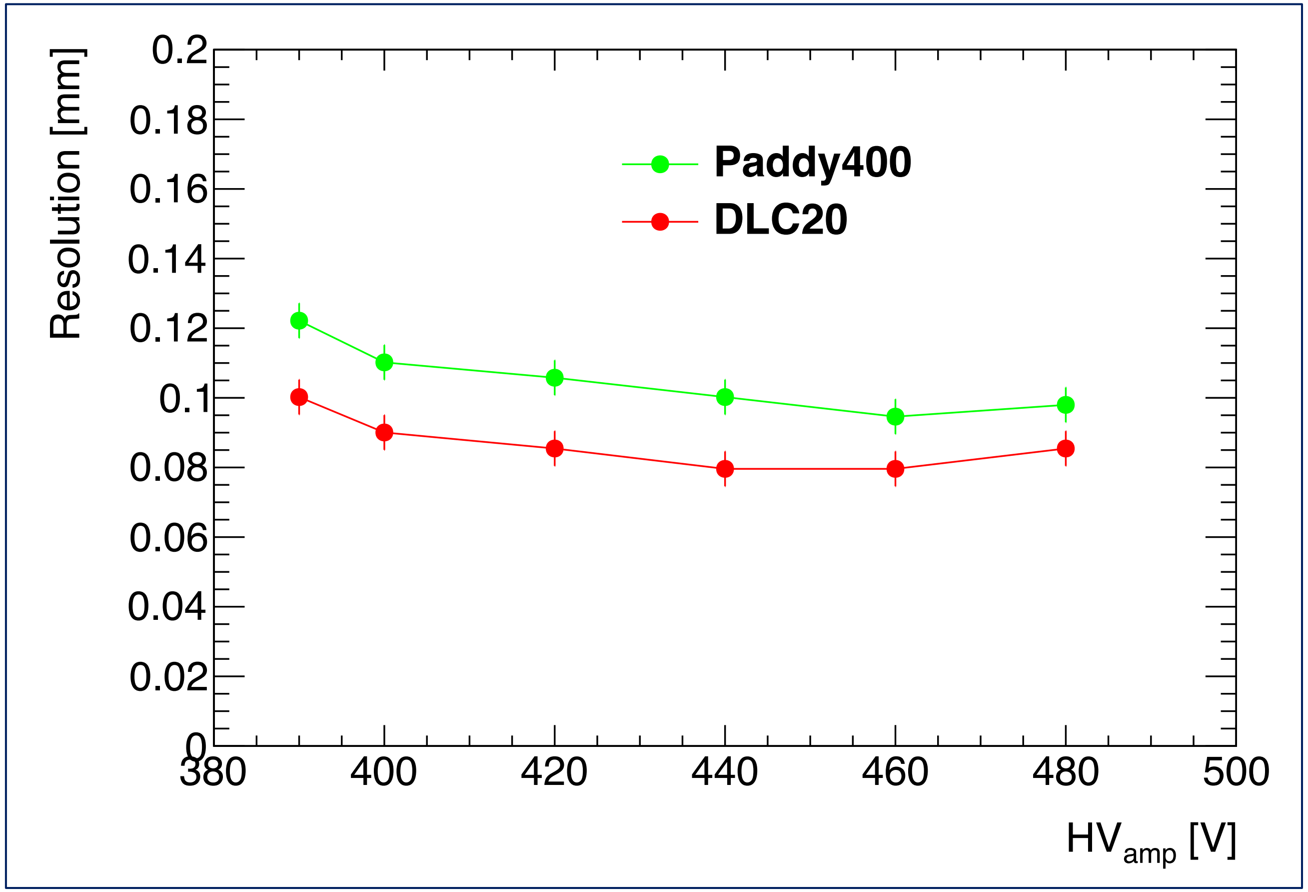
Spatial Resolution

- Cluster residual wrt extrapolated position from external tracking chambers.
- Extrapolation error is subtracted (50 μm).
- Statistical uncertainty is negligible
- Systematic uncertainty (fit procedure) ~5%

$Ar:CO_2:iC_4H_{10}$ 93:5:2 gas mixture

1 mm pitch - precision coordinate





Efficiency

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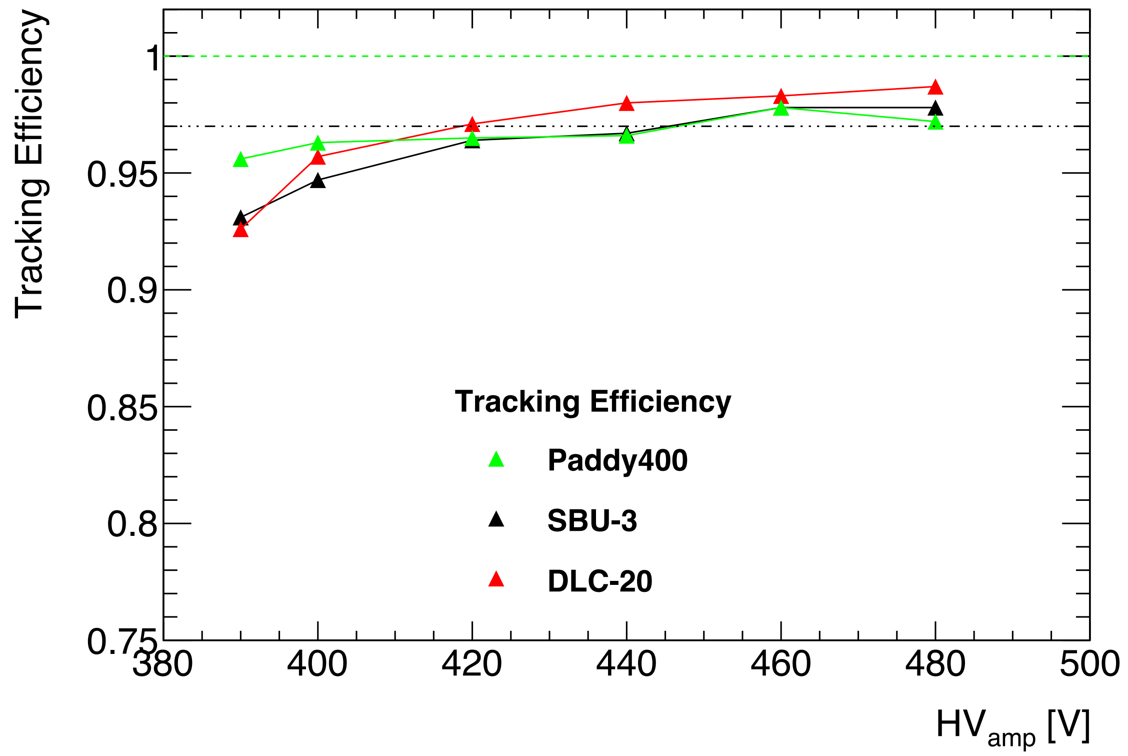

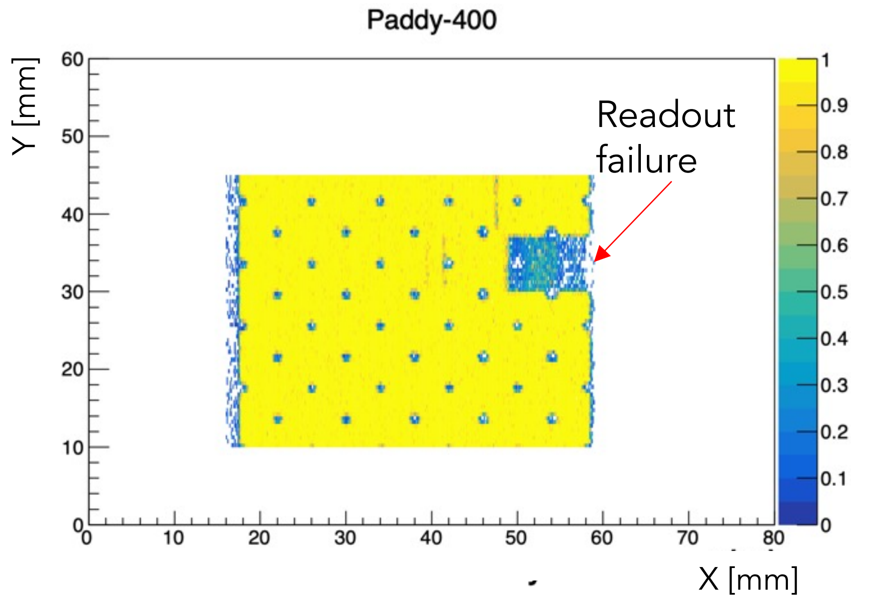

0.7 mm diameter pillars