Towards Large Size Pixelized Micromegas for operation beyond 1 MHz/cm2

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

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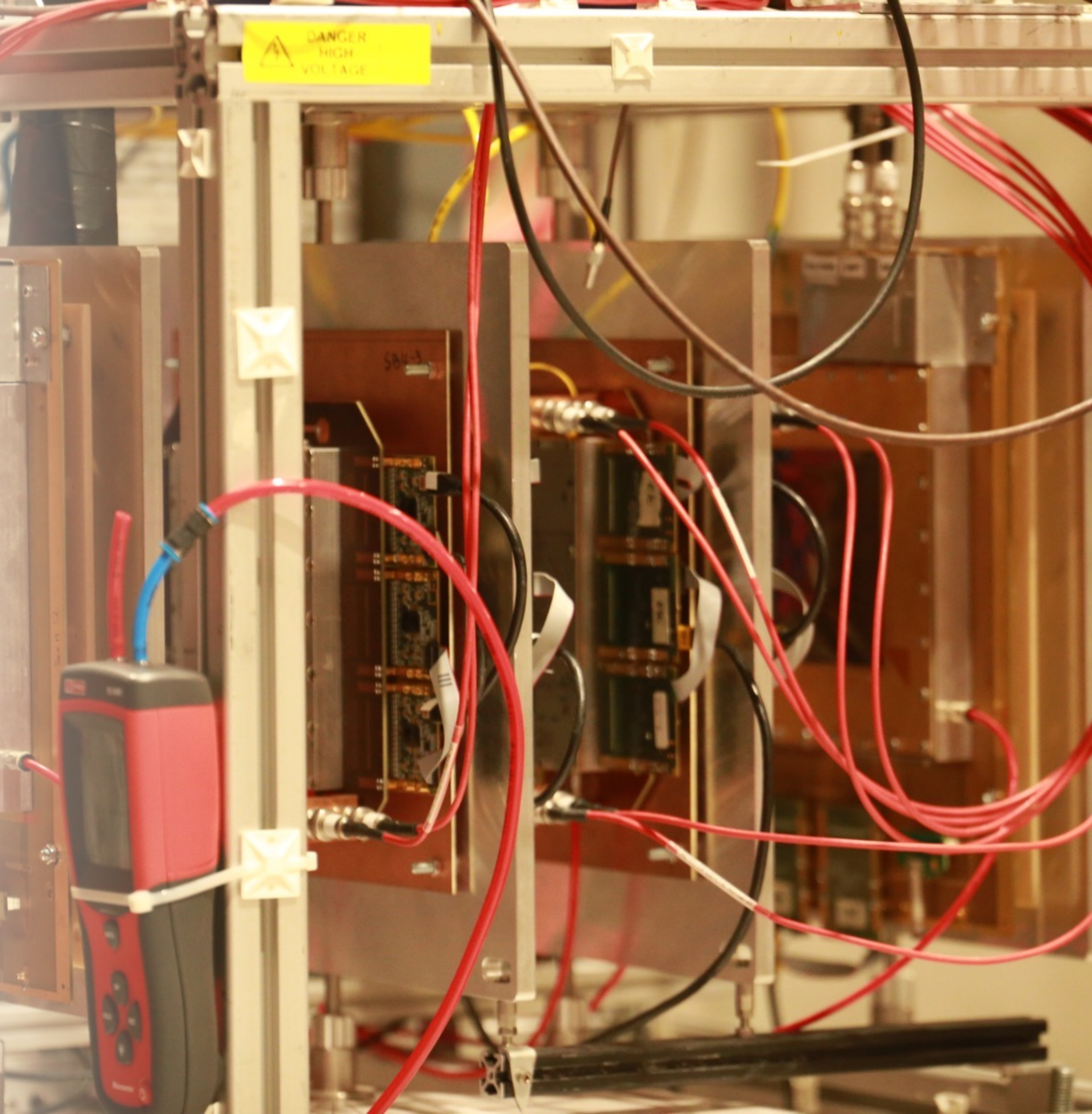
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

The 7th International Conference on
Micro Pattern Gaseous Detectors 2022
December 11-16, 2022
Weizmann Institute of Science, Rehovot, Israel



Main Purpose of the project

- Consolidation of resistive Micromegas, for measurements at rates of the order of 10 MHz/cm^2
- 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

RHUM

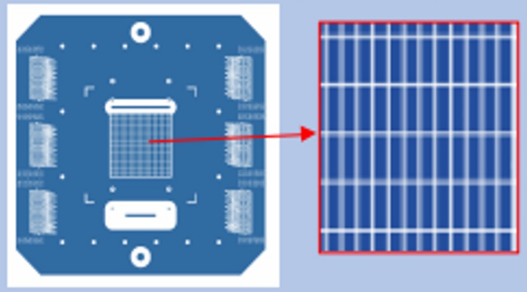
Resistive
High
gran**U**larity
Micromegas

- Detector concept and prototypes description
- Small size small Pad Detectors – State of the art
- Ongoing work:
  - Larger area detector → preliminary tests
  - Latest test-beam → Time resolution
- Summary and Outlook

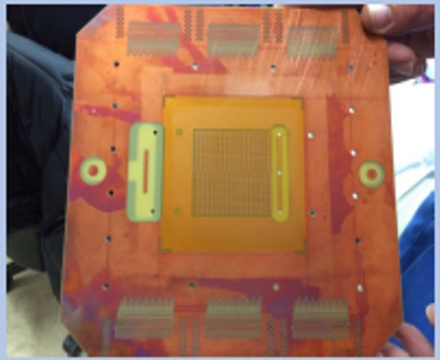
The Small Size Prototypes

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

Readout PAD anodic plane (common to all prototypes)



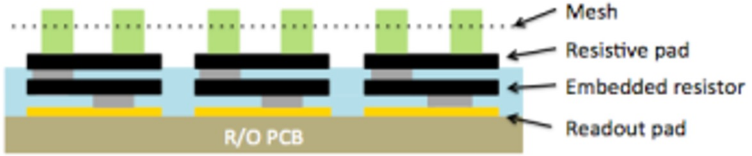
4.8 x 4.8 cm² active region
768 pads, 0.8 x 2.8 mm² each
48 pads – 1 mm pitch (“x”)
16 pads – 3 mm pitch (“y”)



Signals routed to six Panasonic connectors

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

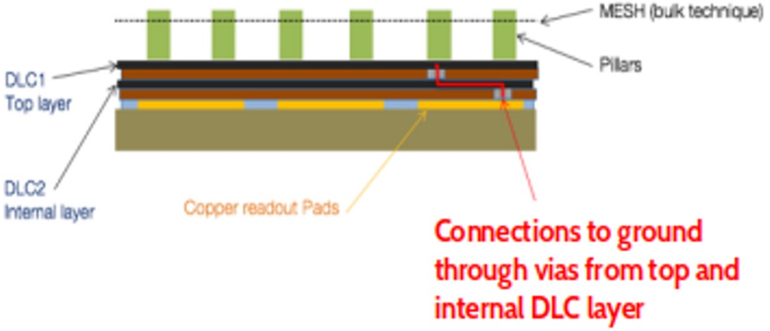
PAD-Patterned



PAD-P3

- EMBEDDED RESISTORS between resistive and readout copper pads
- Each pad completely independent form neighbors
- Resistance between top and copper pad ~7 MΩ

Uniform Double DLC



DLC20 (20 MΩ/sq)

DLC-SBU (30 – 50 MΩ/sq)

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

State of the art - High-Rate Capability

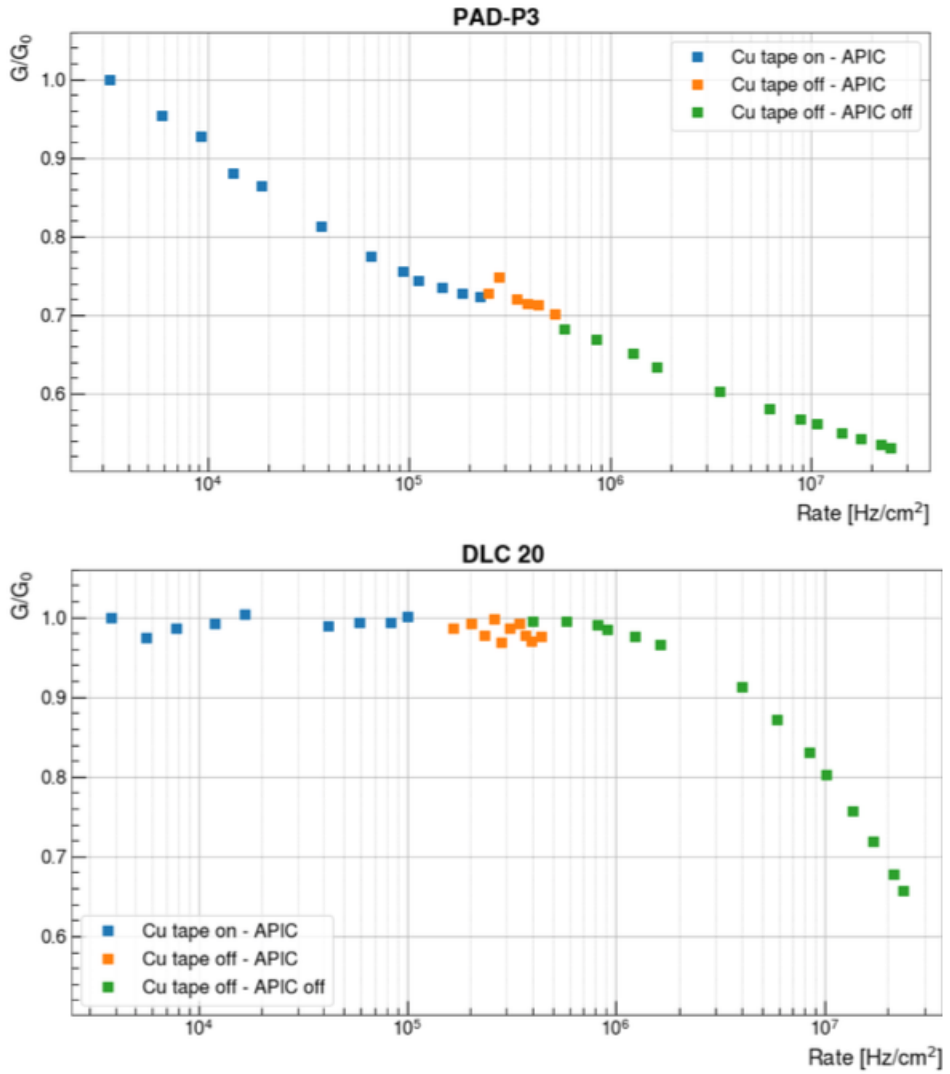
- Measured using 8 keV X-rays peak from a Cu target with different intensities (~4 order of magnitude) @ CERN GDD lab

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

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



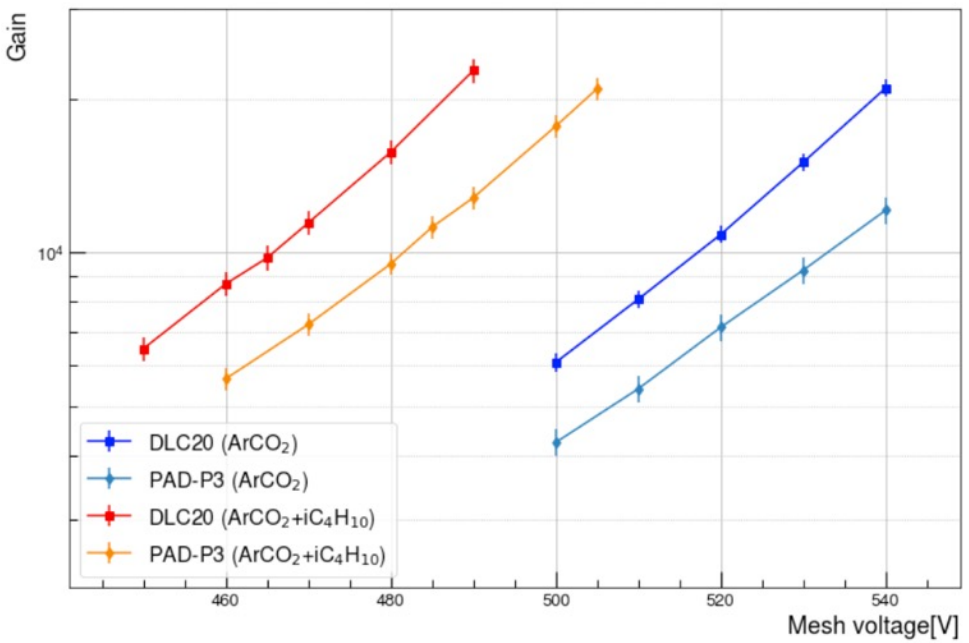
High-Rate Capability and Gas Optimisation

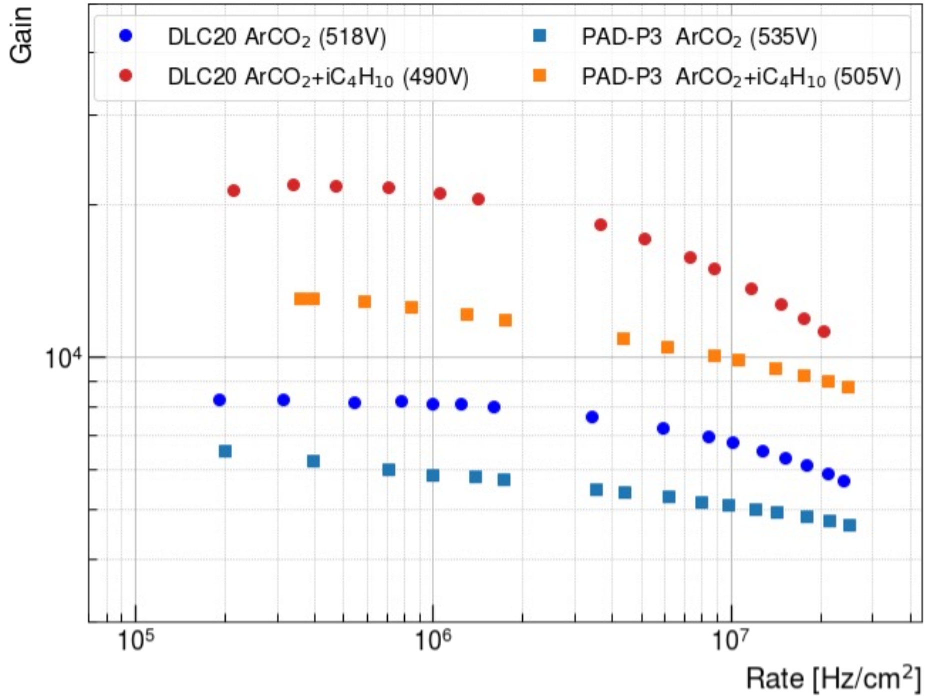
Started using $Ar:CO_2$ 93:7 → added 2% isobutane $Ar:CO_2:iC_4H_{10}$ 93:5:2 to improve the stability and extend the dynamic range

Gain >2x10^4 reached at very high rates (>10 MHz/cm^2) in stable conditions → remarkable results!

$N_{primaries}$ ~300
→ $N_{electrons}$ ~6x10^6 close to the Raether limit

~50 V difference between the two mixtures

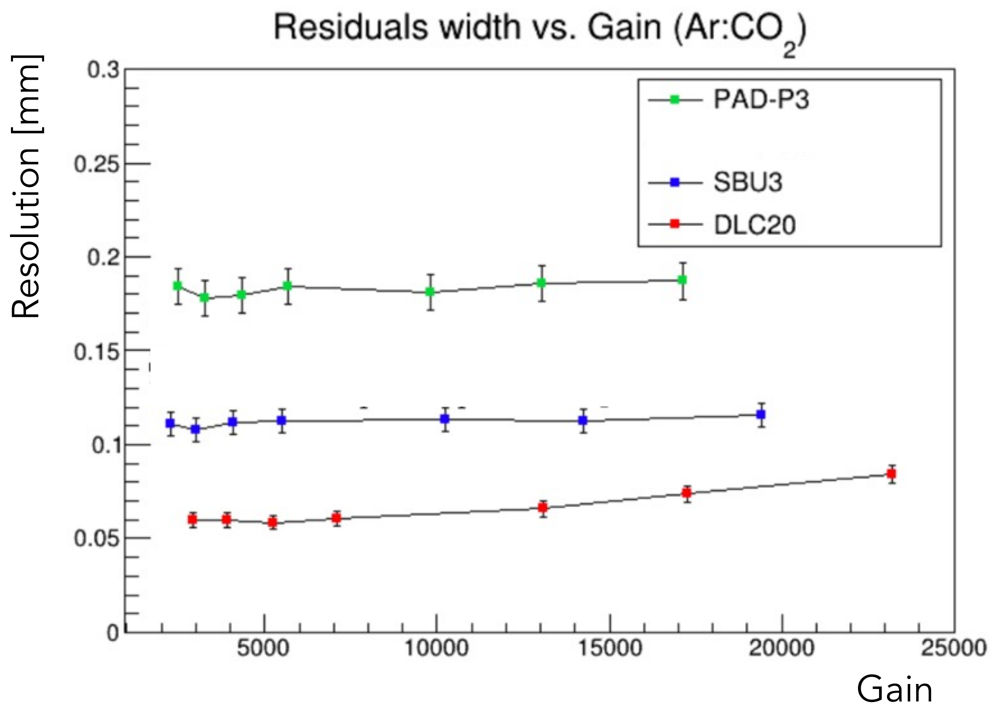




Performance at Test-Beams – Spatial resolution

Position 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%



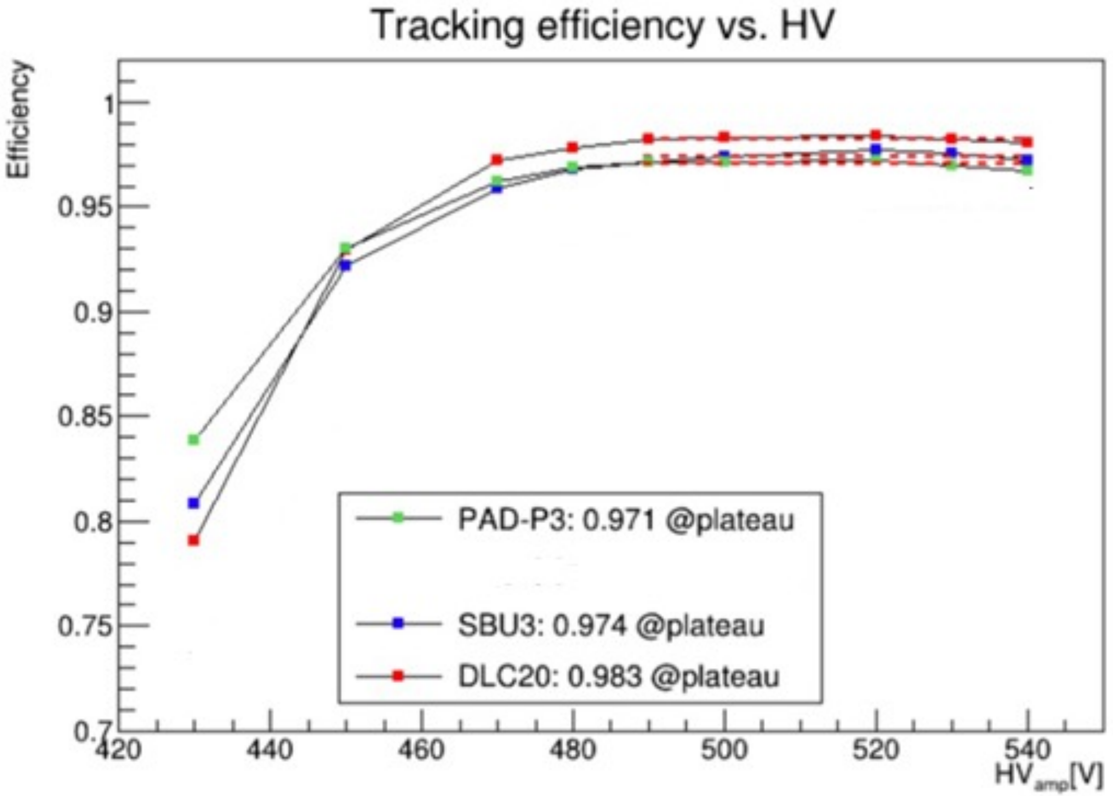
- Different resolutions measured for chambers with very similar layout, gain and cluster size, BUT with different RC
- Investigate the impact of the different contributions to the cluster size: direct induction, capacitive coupling AND resistive charge spread (dependent on RC)

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

Performance at Test-Beams - Efficiency

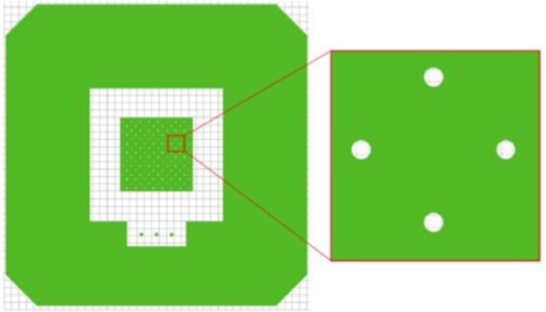
Tracking efficiency:

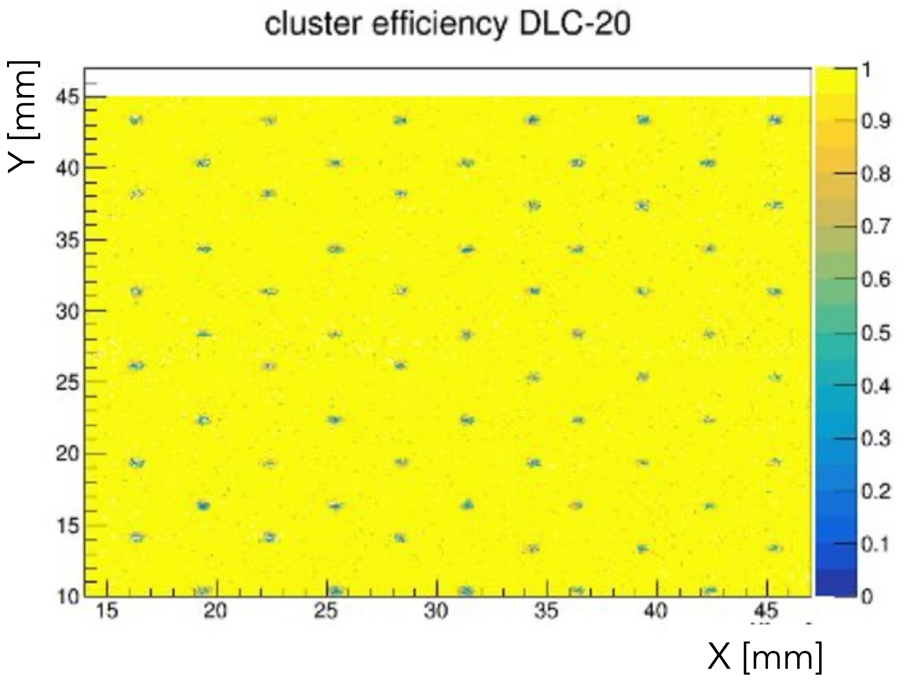
1.5 mm fiducial range wrt extrapolated position from external tracking chambers



LOCAL INEFFICIENCIES from Circular pillars:

- 0.3 mm for DLC20
- 0.7 mm for SBU3





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:

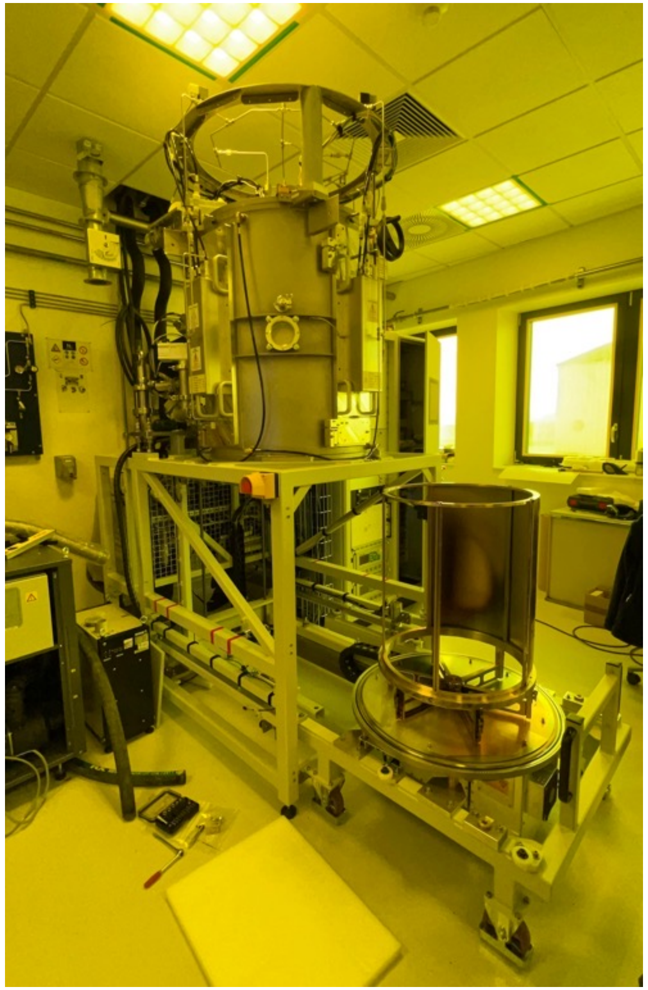
- stable operation up to 20 MHz/cm2 with gain >10k;
- detector efficiency >98 % ; position resolution < 100 μm.

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

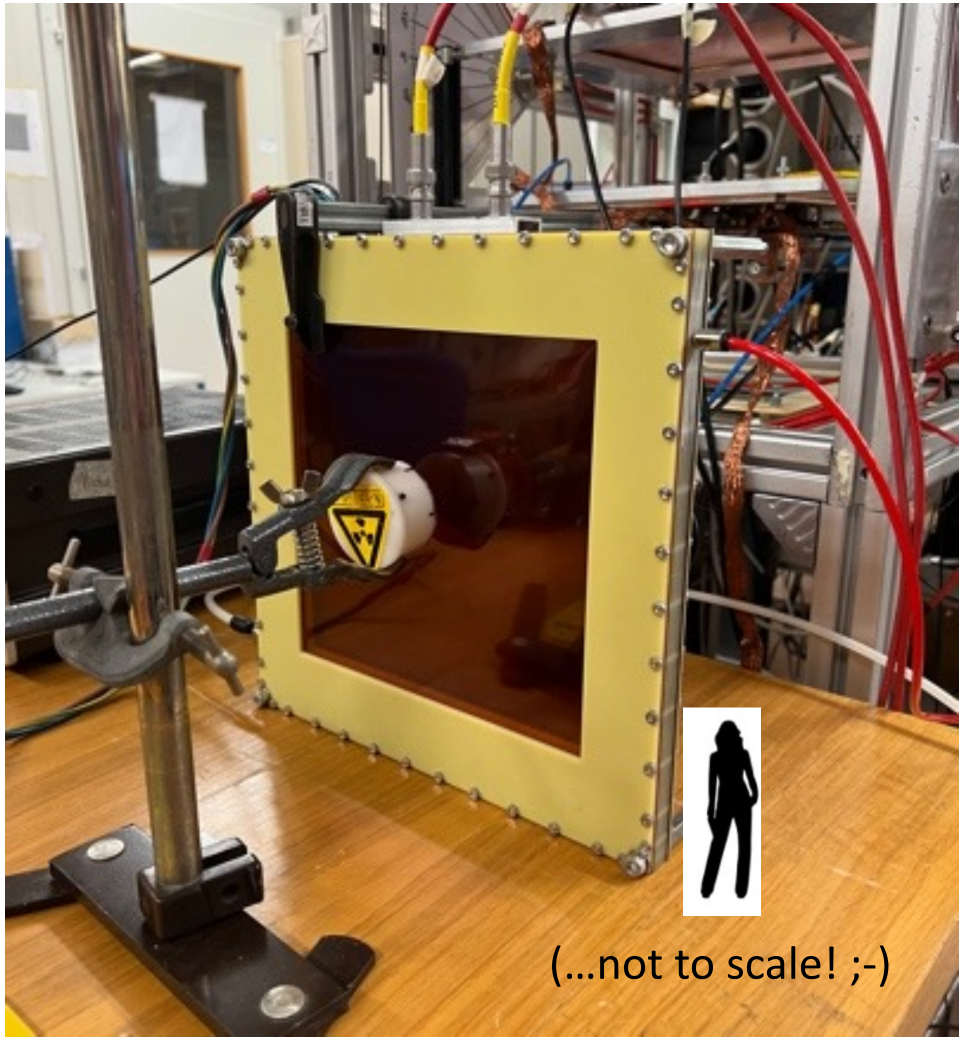
→ CERN-INFN DLC facility at CERN



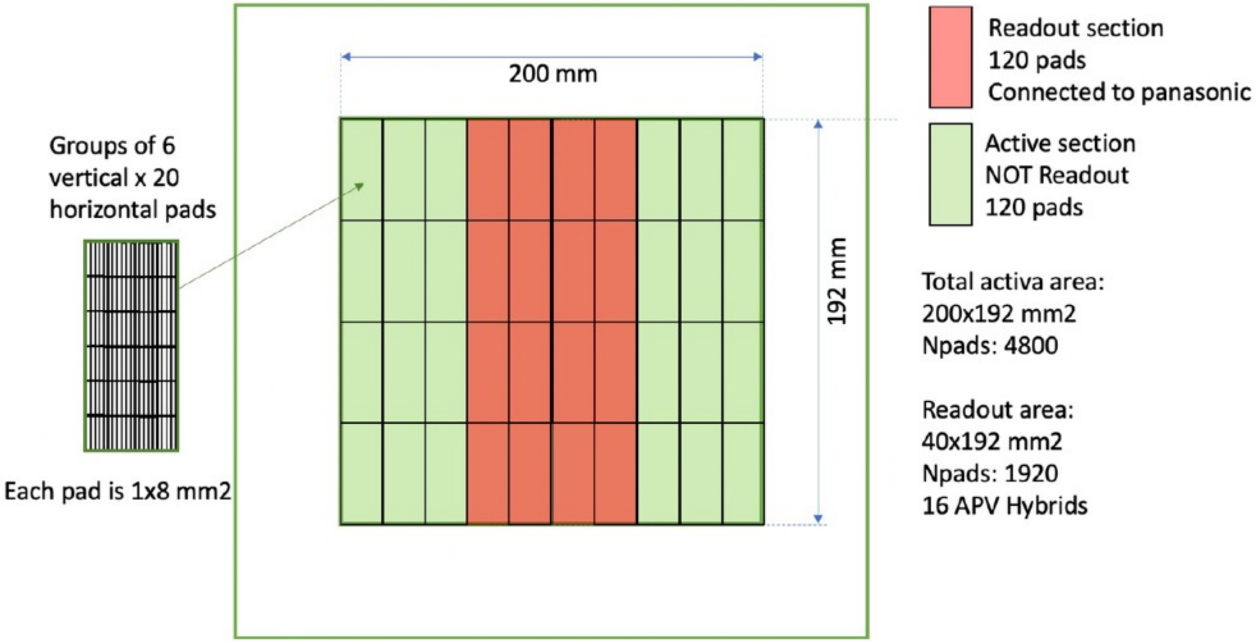
Currently, our R&D project is focusing on:

- Build and characterize a larger area prototype
  - Measure the time resolution
- Investigate different readout electronics

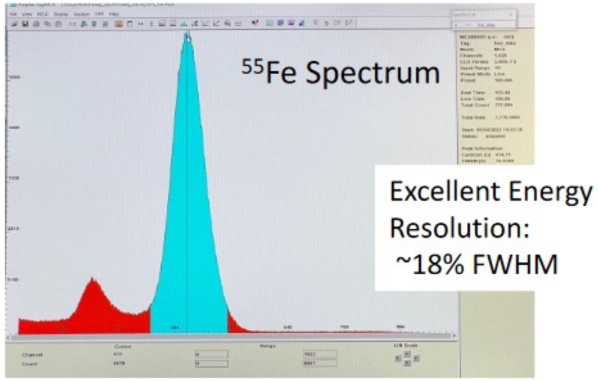
Towards Large Area – PADDY400 the 20x20 cm^2 Prototype

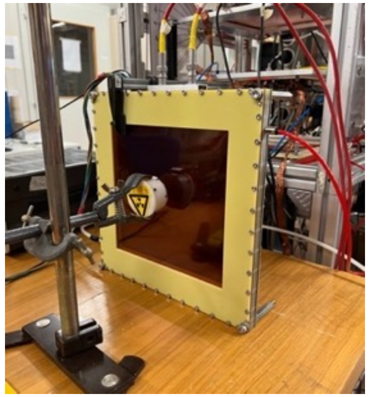


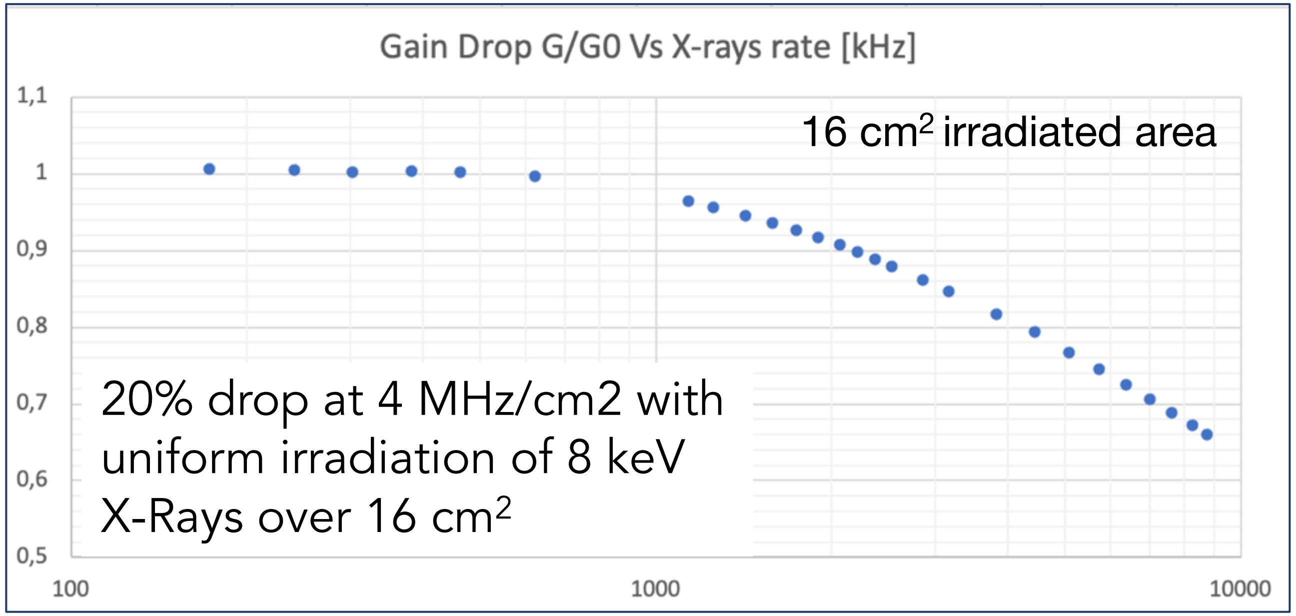
- Active area: 200x192 mm^2
- Pads 1x8 mm^2 - Total Number of Pads: 4800
- Double DLC layer (30-40 Mohm/sq) with grounding vias every 8 mm
- Panasonic connectors on the back of the detector
- Partially readout: 1920/4800 connected pads



Paddy400 – rate capability and dependence on the irradiated area



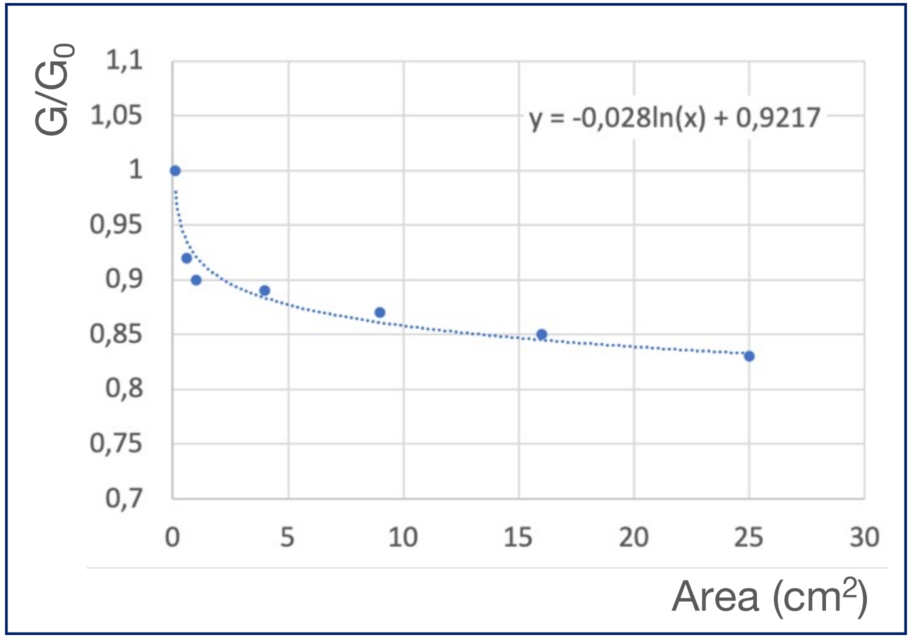




Dependence on the irradiated area

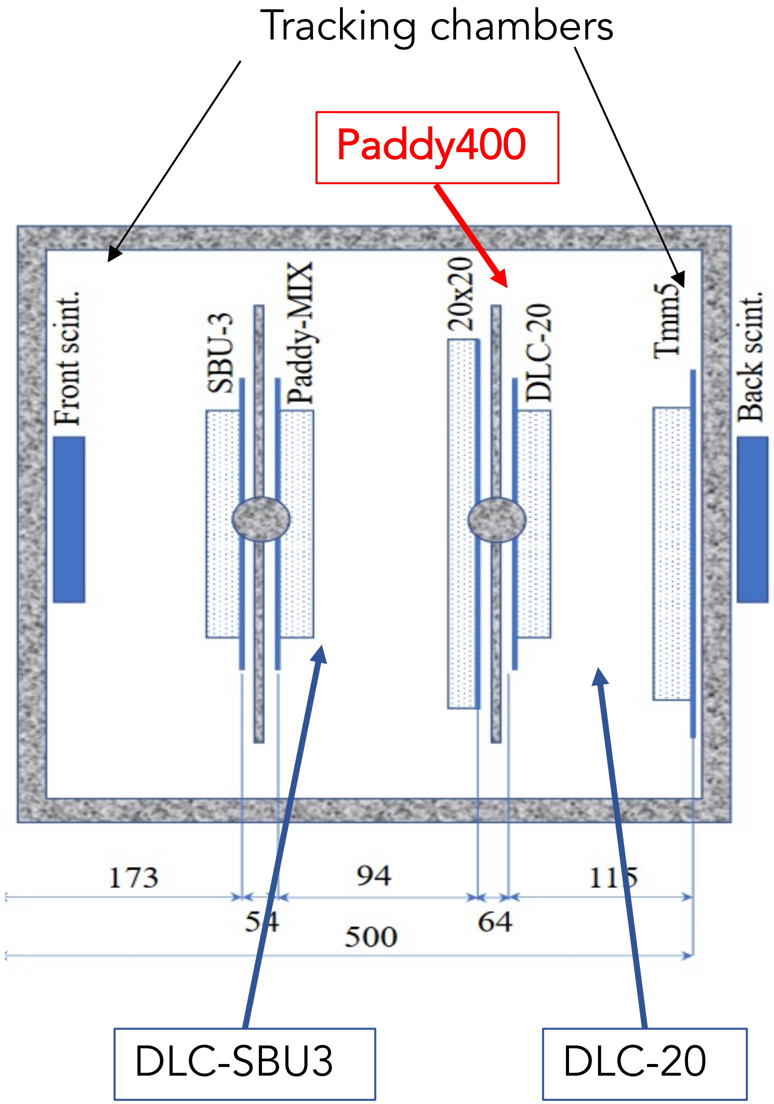
Fixed rate: 3 MHz/cm^2

(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

Latest Test Beam Measurements (October 2022)



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

MAIN Goals:

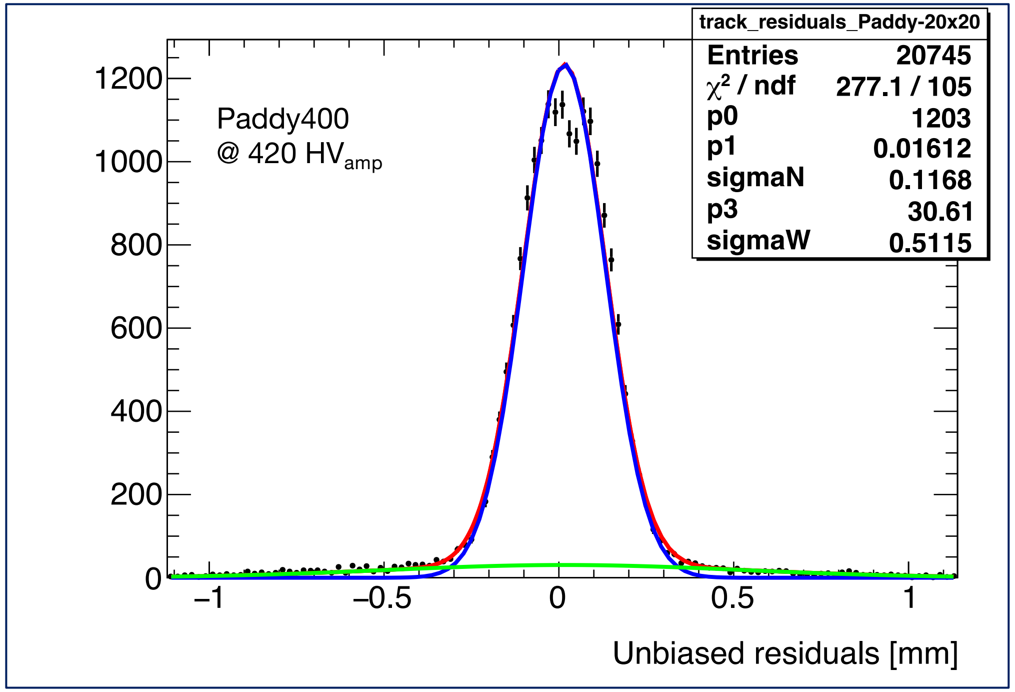
- Spatial resolution and efficiency of new detectors
  → Focus on PADDY400
- Timing resolution, also exploiting faster gas mixture
- Pion and multi-tracking

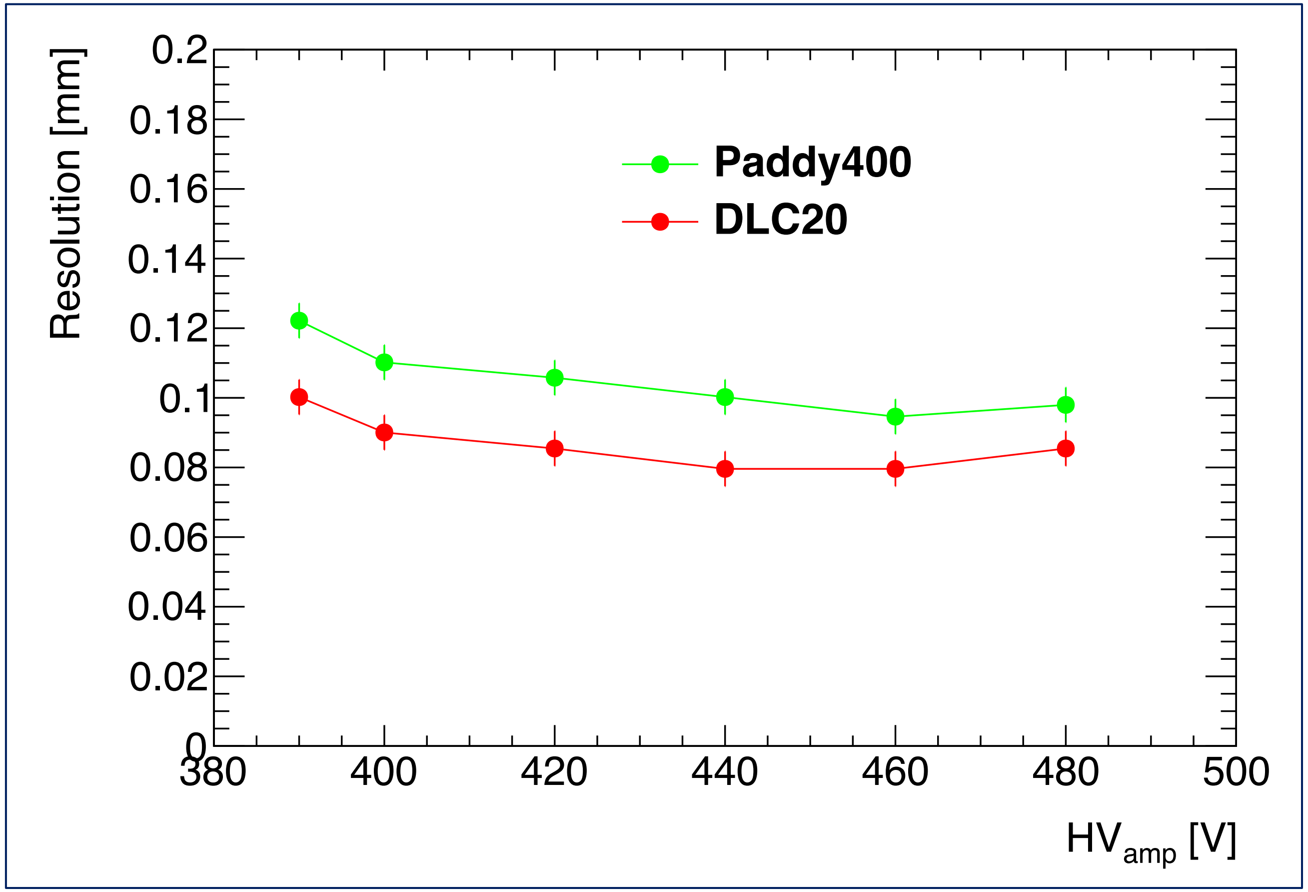
Spatial Resolution

- 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



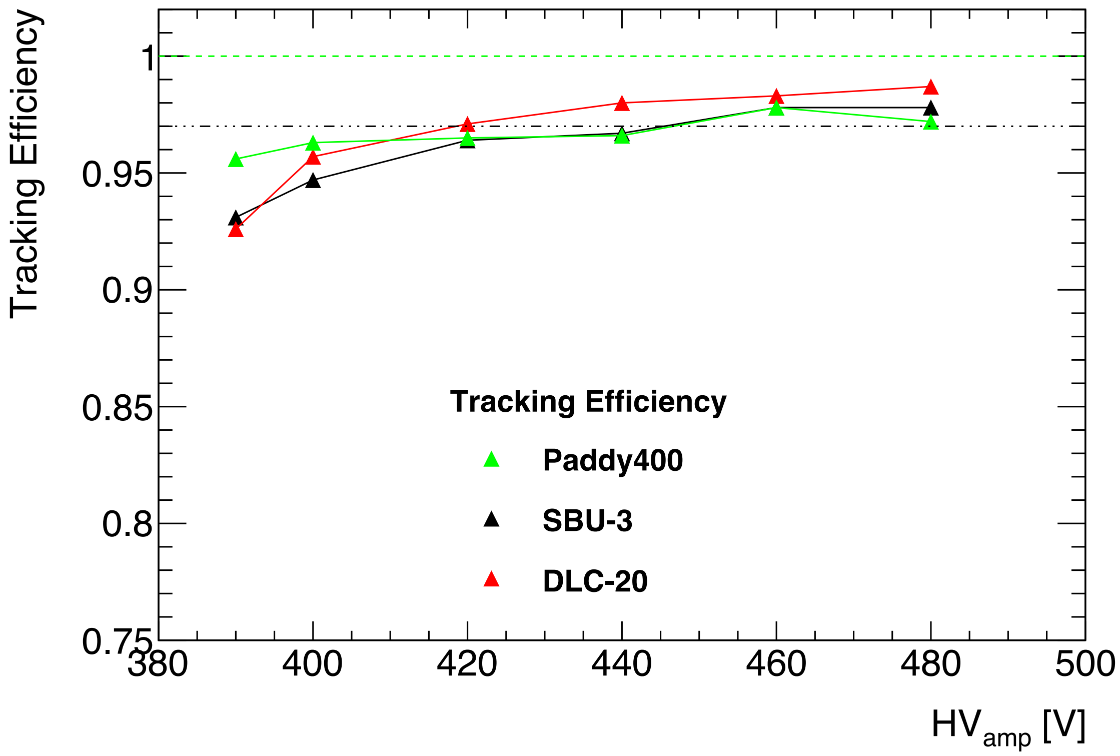


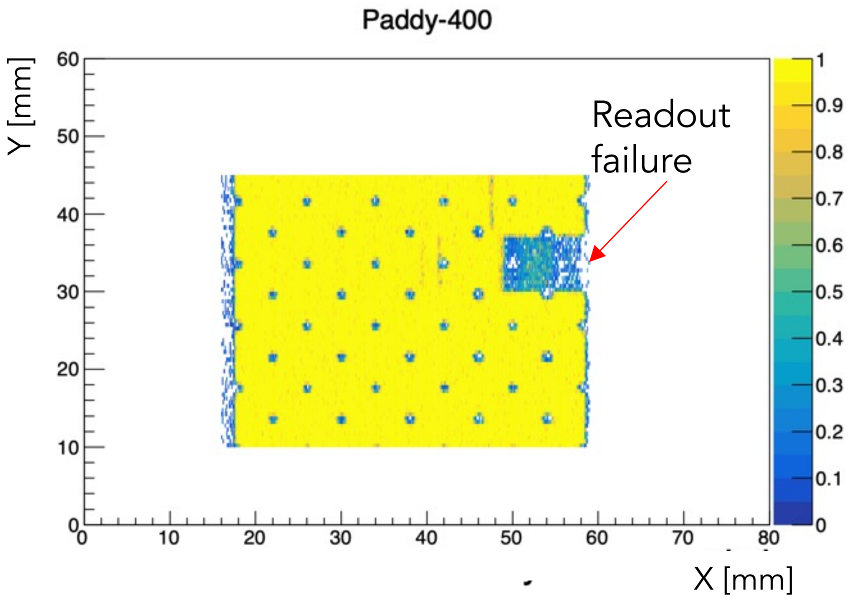
Efficiency

Tracking efficiency:

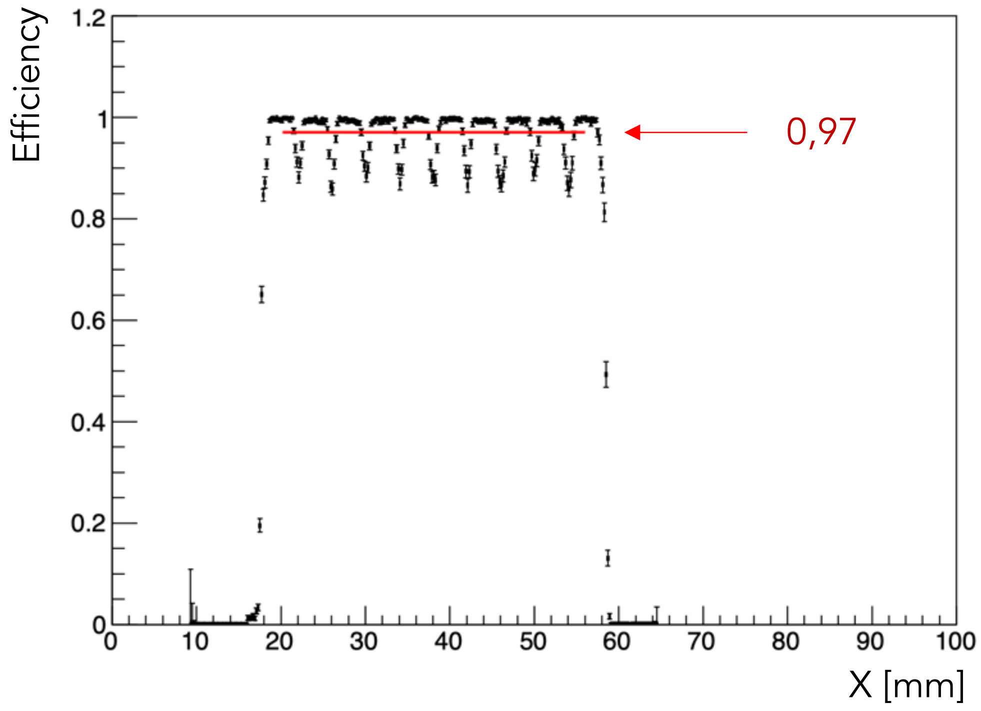
1.5 mm fiducial range wrt extrapolated position from external tracking chambers

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





0.7 mm diameter pillars



Timing studies – the method

- Times from PADs extracted from Fermi-Dirac fit to the signal distribution

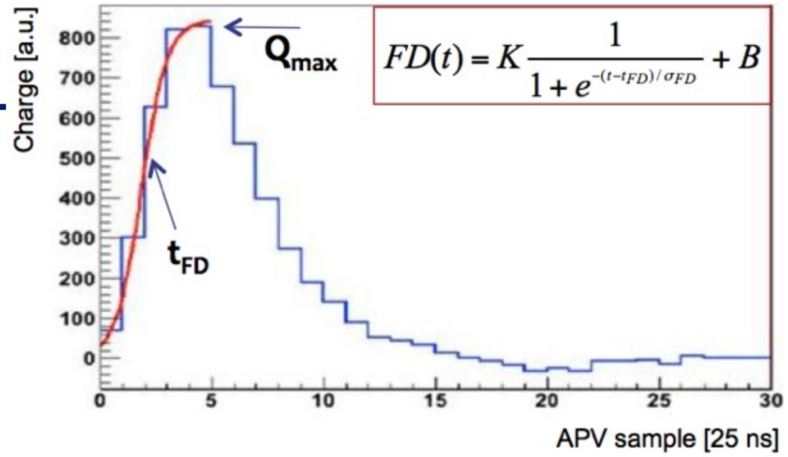
- Four different times computed for a cluster :
  - earliest time of a pad in the cluster
  - time of the pad with max charge
  - arithmetic mean of the pad times
  - charge weighted mean of pad times

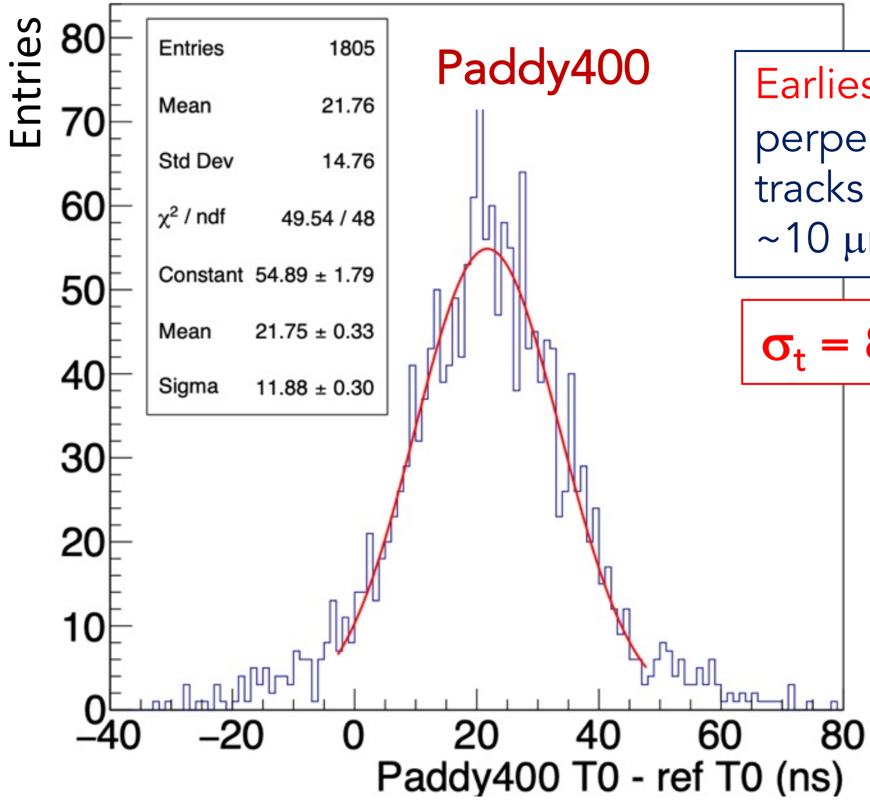
- Time difference between on-track clusters in each pair of chambers

- Gaussian fit and time resolution evaluated as σ/sqrt(2)

- **Paddy400** estimated Time resolution: **8.4 ns** with Ar/CF4/iso at v_{Drift}~10 μm/ns

  (earliest time and charge weighted similar, others worst)
  - electronics and fit uncertainties not subtracted yet





Earliest time for perpendicular tracks at v_{drift} ~10 μm/ns

σ_t = 8.4 ns

Timing studies – exploiting different gas mixtures

DRIFT VELOCITY:

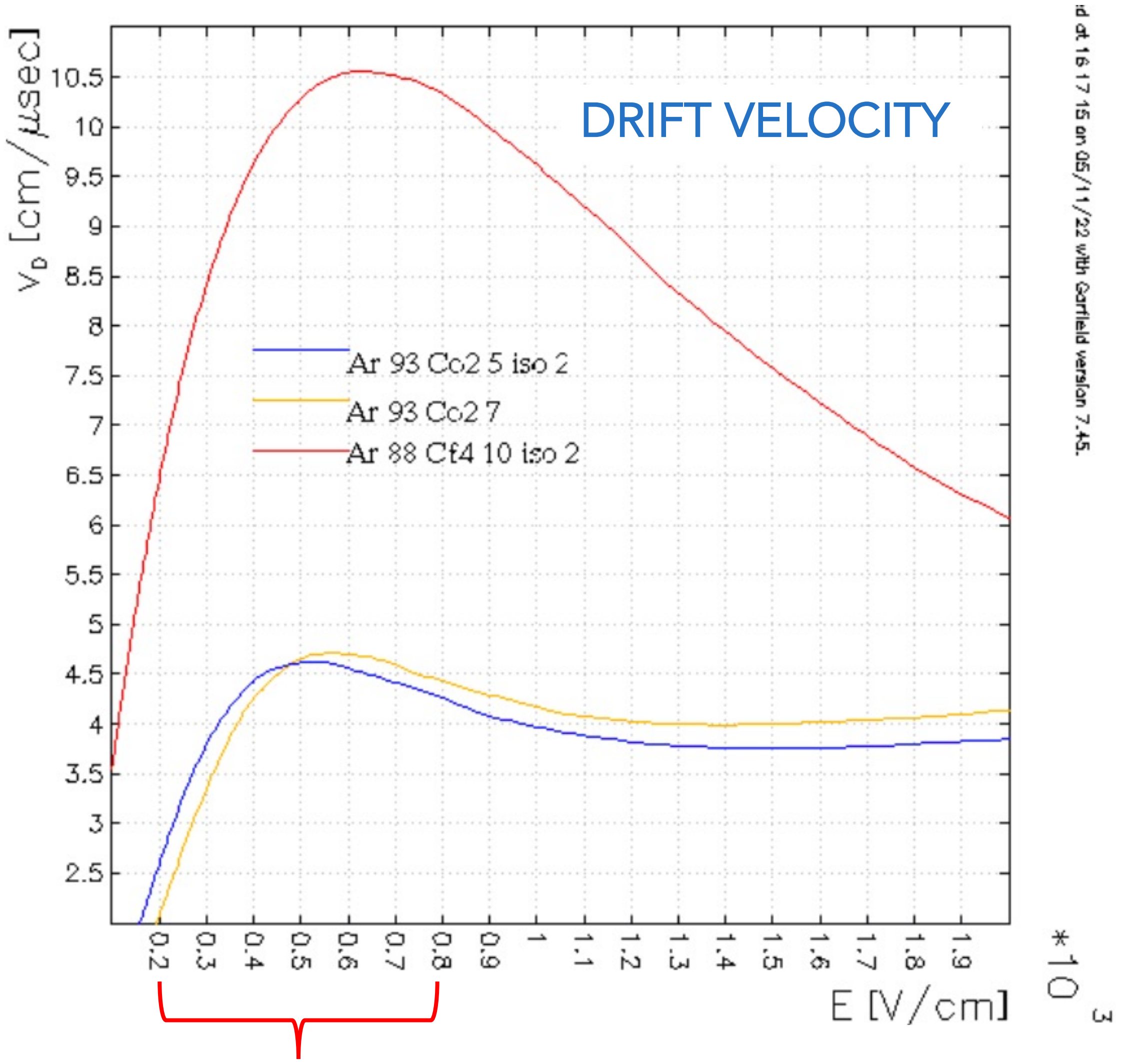
Scan in E_{drift}: [200: 800] V/cm

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

  range in v_{drift}: 20 – 45 um/ns

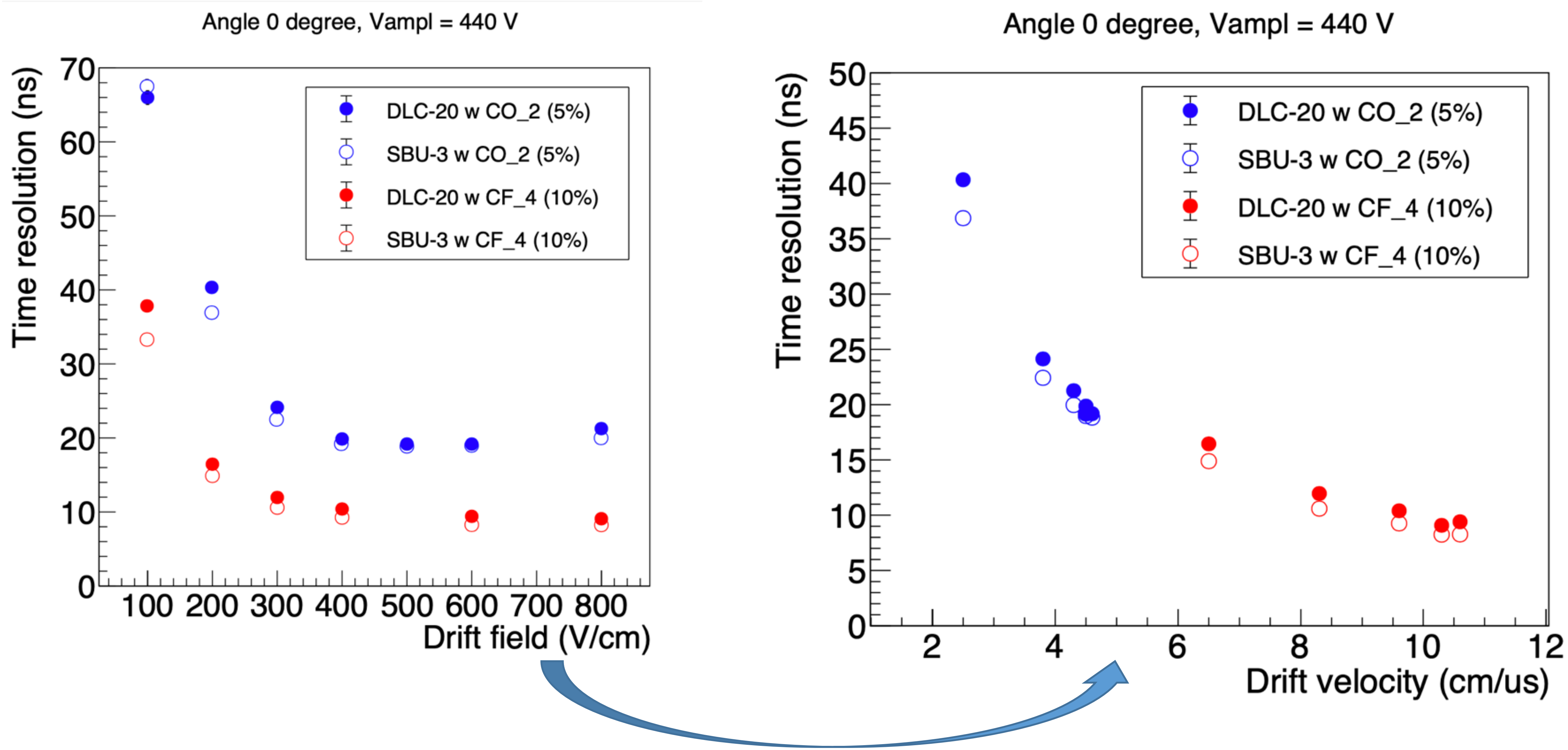
- With $Ar/CF_4/iC_4H_{10}$ (88/10/2)

  range in v_{drift}: 35 – 105 um/ns



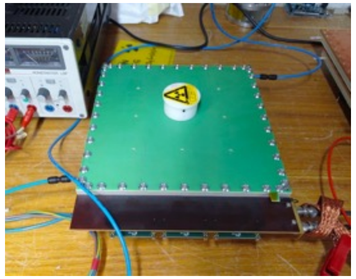
200 < E_{drift} < 800 V/cm

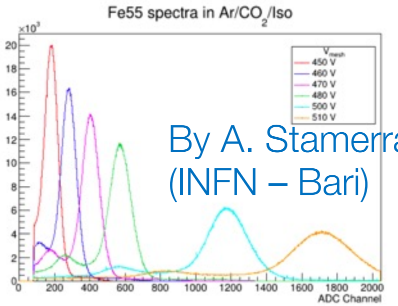
Time Resolution – dependence on the drift velocity



APPLICATIONS

- Resistive High granUlarity Micromegas (RHUM) project for High rates applications like very forward muon detection at LHC (e.g. ATLAS Large Eta Muon tagger → *see Eraldo's talk on Monday)*
- Ongoing R&D for sampling Hadron Calorimetry for the Muon Collider *(RD51 Common Project – contact: P. Verwillingen)* →





By A. Stamerra (INFN – Bari)

- Currently under consideration:
  - Muon Veto for SHADOWS (proposal for proton dump FIPs physics at CERN)
  - Replacement of Muon detectors for AMBER (successor of Compass) *(poster by C. Alice)*
- More "exotic" applications, e.g. detection of External Neutral Atoms (ENA) in Space Weather research program *(SWEATER – talk by T. Tamagawa and R&D on Graphene → talk by A. Apponi on Thursday)*
- 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

Summary and Outlook

- Several Small Pads 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 next 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.**