High Granularity Resistive Micromegas for Tracking Detectors in Future Experiments

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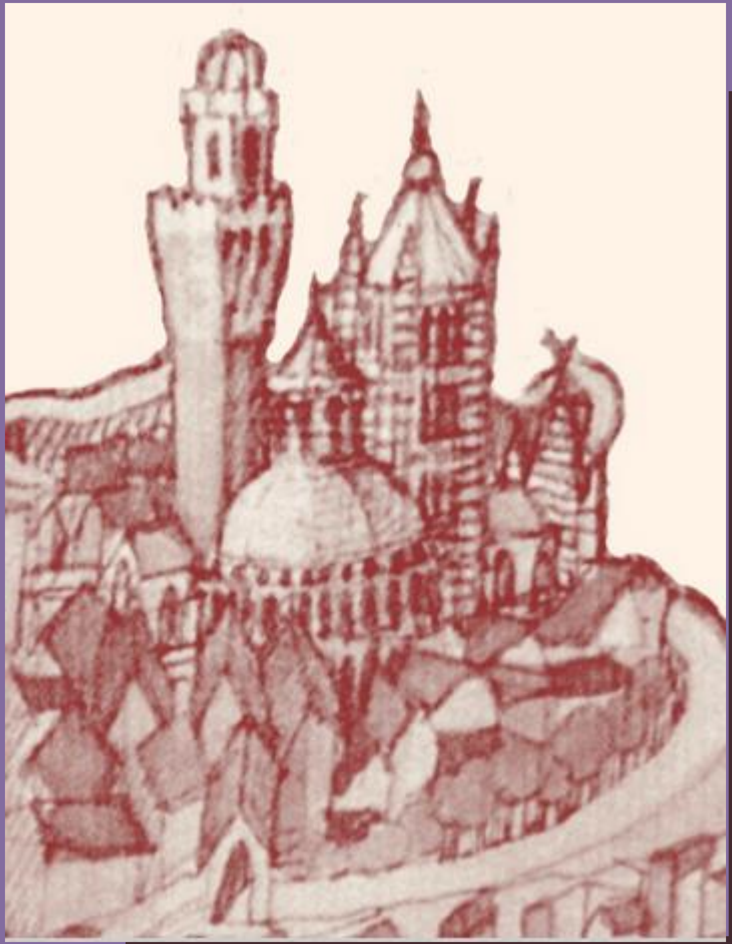
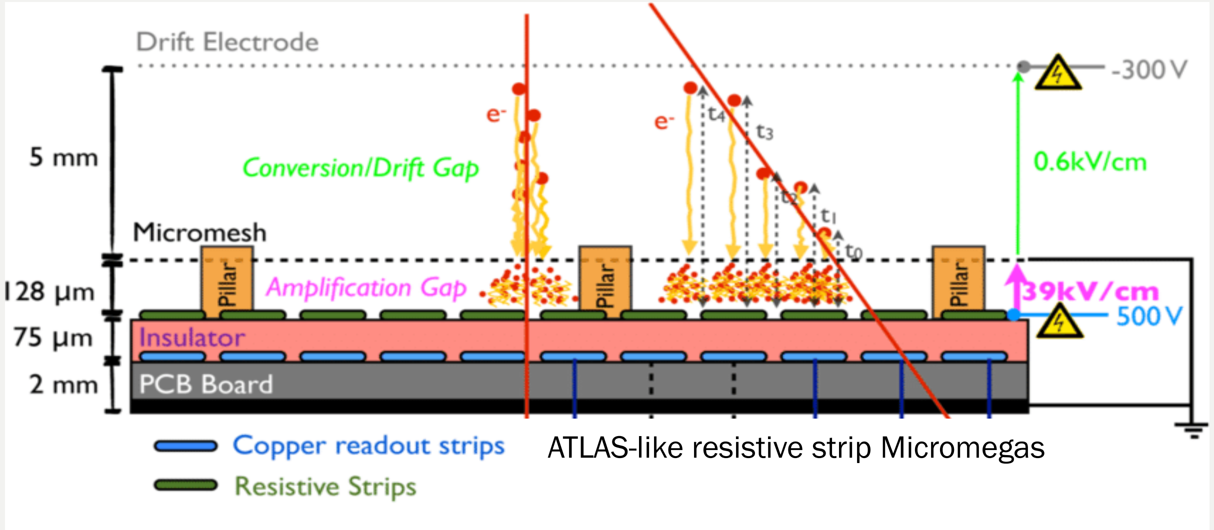


16° Topical Seminar on Innovative Particle and Radiation Detectors (25-29 September 2023)

Contents

- Introduction to RHUM (Resistive High granUlarity Micromegas) R&D
- Description of the latest prototypes
- Characterisation studies in LAB
- Test Beam studies and preliminary results
- Possible tracking application in future particle physics experiments
- Other applications

RHUM R&D objectives

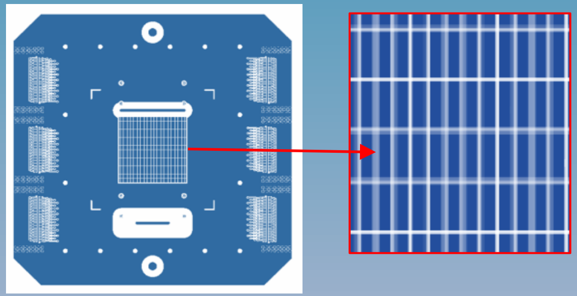


- Consolidation of resistive Micromegas technology with pad readout for operations at O(10 MHz/cm^2) rate;

O(1-10) mm2 rectangular readout pad	⇒	Customised resistive spark protection layout

- Stability of operation at high gain factors;
- Simplification of construction technique and realization of large area prototypes;
- Spatial and time resolutions of < 100 um and O(1-10 ns);

PIXELATED ANODIC PLANE



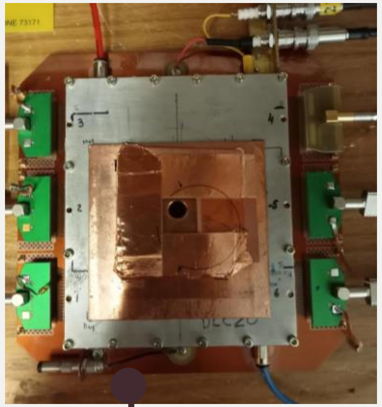
Pixelated readout:
~5x5 cm^2 anodic plane,
pads of **0.8 x 2.8 mm²**

~20x20 cm^2 anodic plane,
pads of **0.8 x 7.8 mm²**

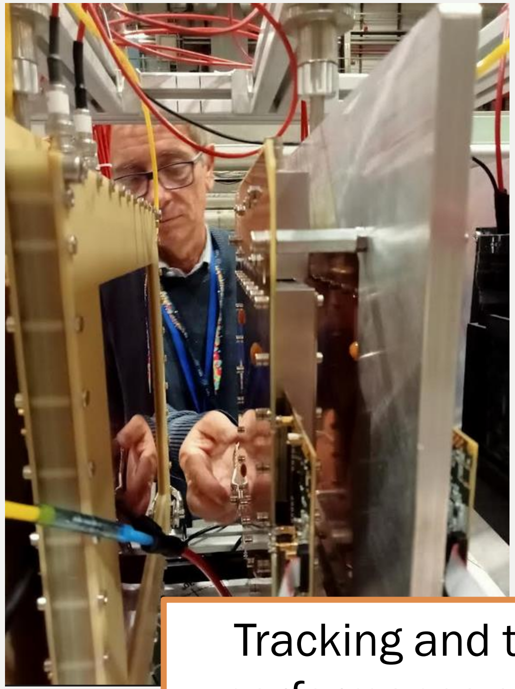
SOON: ~40x48 cm^2 anodic plane with mixed pad granularity

RHUM timeline

Over 10 prototypes were built, each possessing distinct characteristics.

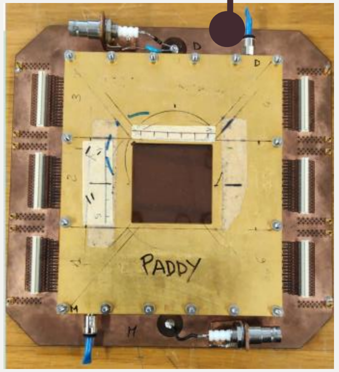


Rate capability, stability studies



Tracking and timing performance studies

2015 | 2017 | 2019 | 2021



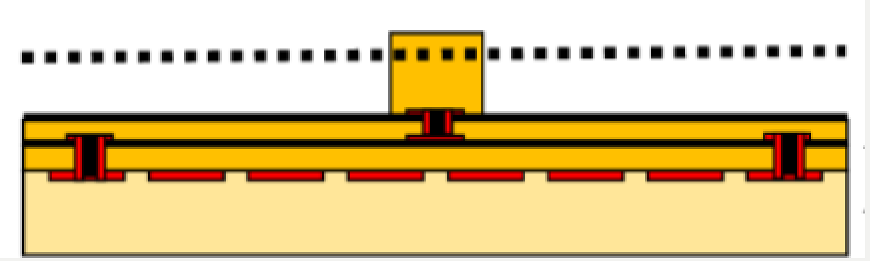
Resistive layer and construction optimisation

In the 1° workshop…
…not only rhum

RHUM latest prototypes

SBU-DLC production technique

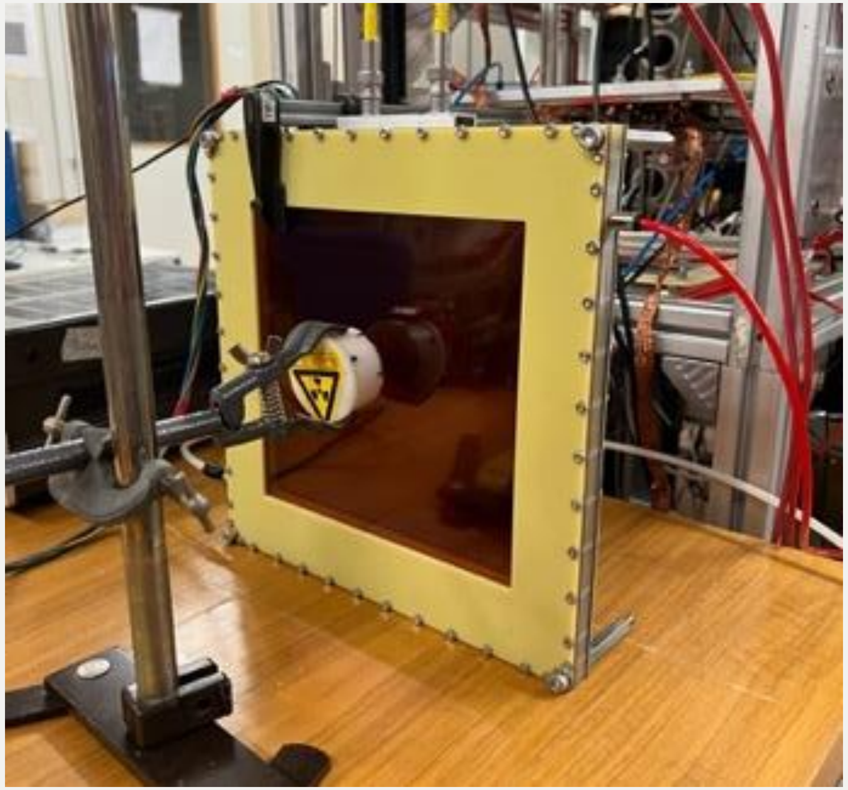
SBU (Sequential build-up) production technique exploits copper clad DLC foils for realizing high-quality vias.



- <u>DLC-like</u> (Diamond-Like-Carbon)

  micro-mesh (dot line) + pillars (orange)
  DLC foils with 20-50 MΩ/sq (black)
  Polymide insulator (orange);
  6-8 mm vias pitch;
  Copper readout pads (red) on PCB (beige)

PADDY400



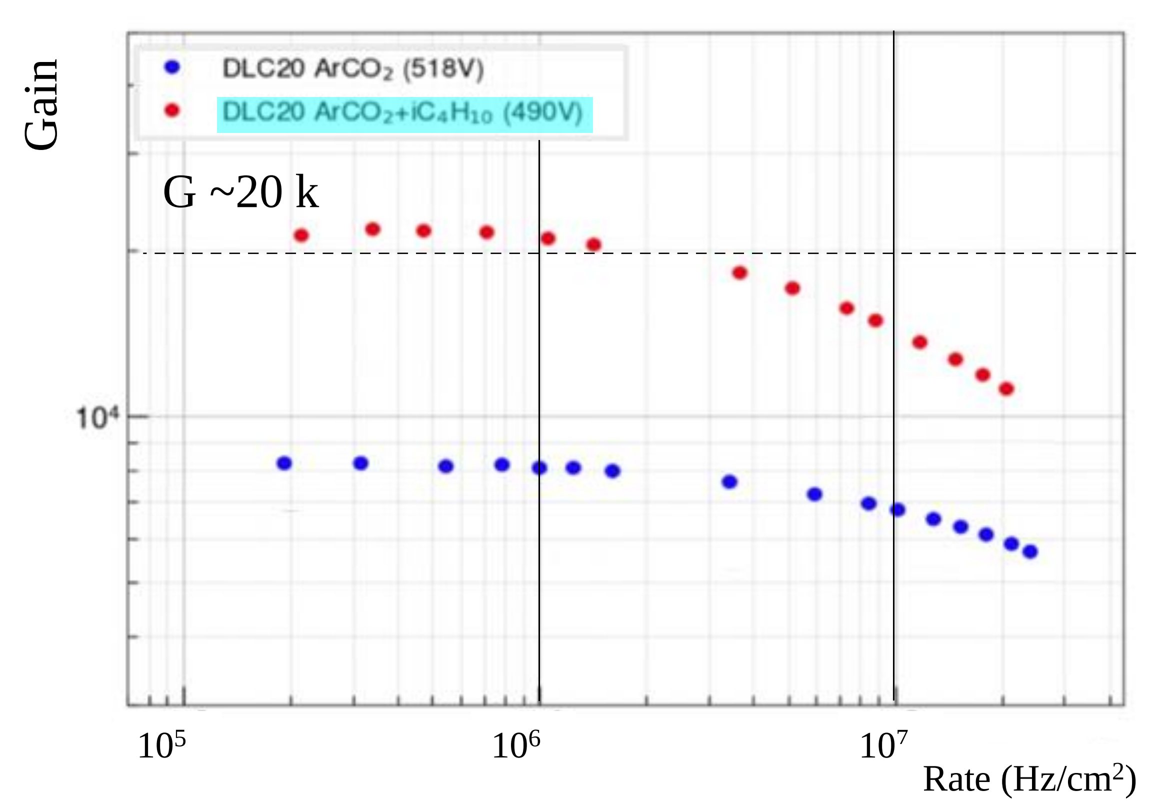
DLC foils with ~30 MΩ/sq
8 mm vias pitch;
~0.8 mm pillar diameter.

Studies of rate capability

DLC-like scheme

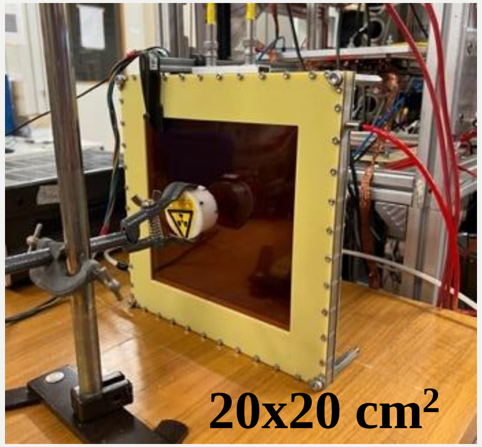
- Negligible charging-up effects.
- Gain stable up to 1-2 MHz/cm^2, and at higher rates, gain drop due to ohmic contribution.
- At 10 MHz/cm^2, gain drop of ~20-25% (can be compensated with ~10 V increase in the Amplification voltage).

w 8 keV X rays, irradiated area 0.79 cm^2



With the two gas mixtures, we observed compatible drops, **$ArCO_2iC_4H_{10}$(93:5:2)%** allows to achieve a **higher gain with an improved spark quenching.**

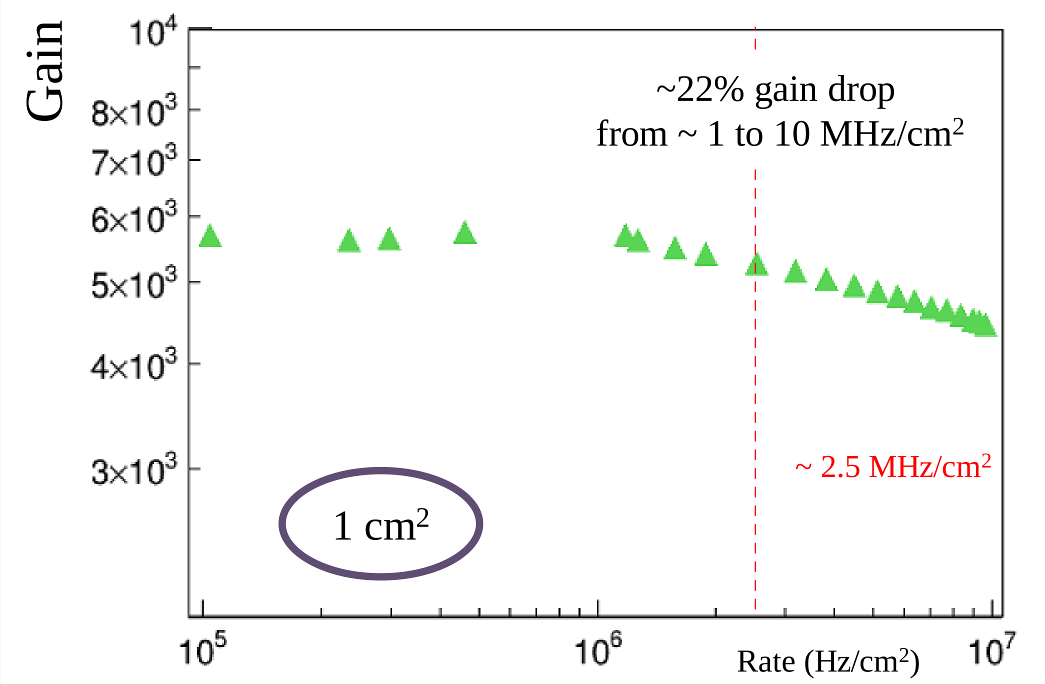
Towards large areas



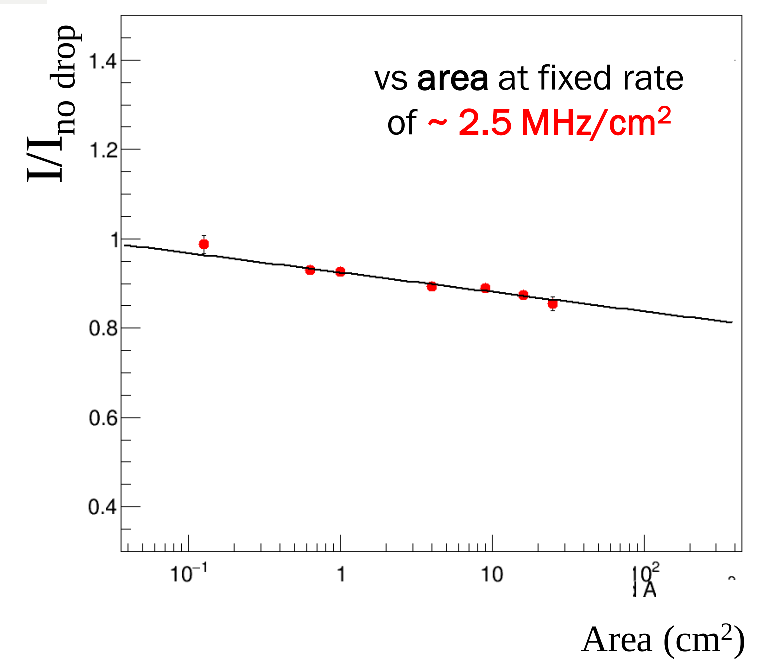
- **Active area ~20x20 cm²**
- **Pad size:** 1x8 mm²
- **Number of Pads:** 4800

PADDY400

Repeated gain/rate capability studies with $ArCO_2$(93:7)%, varying irradiated area up to 25 cm² max area until now.



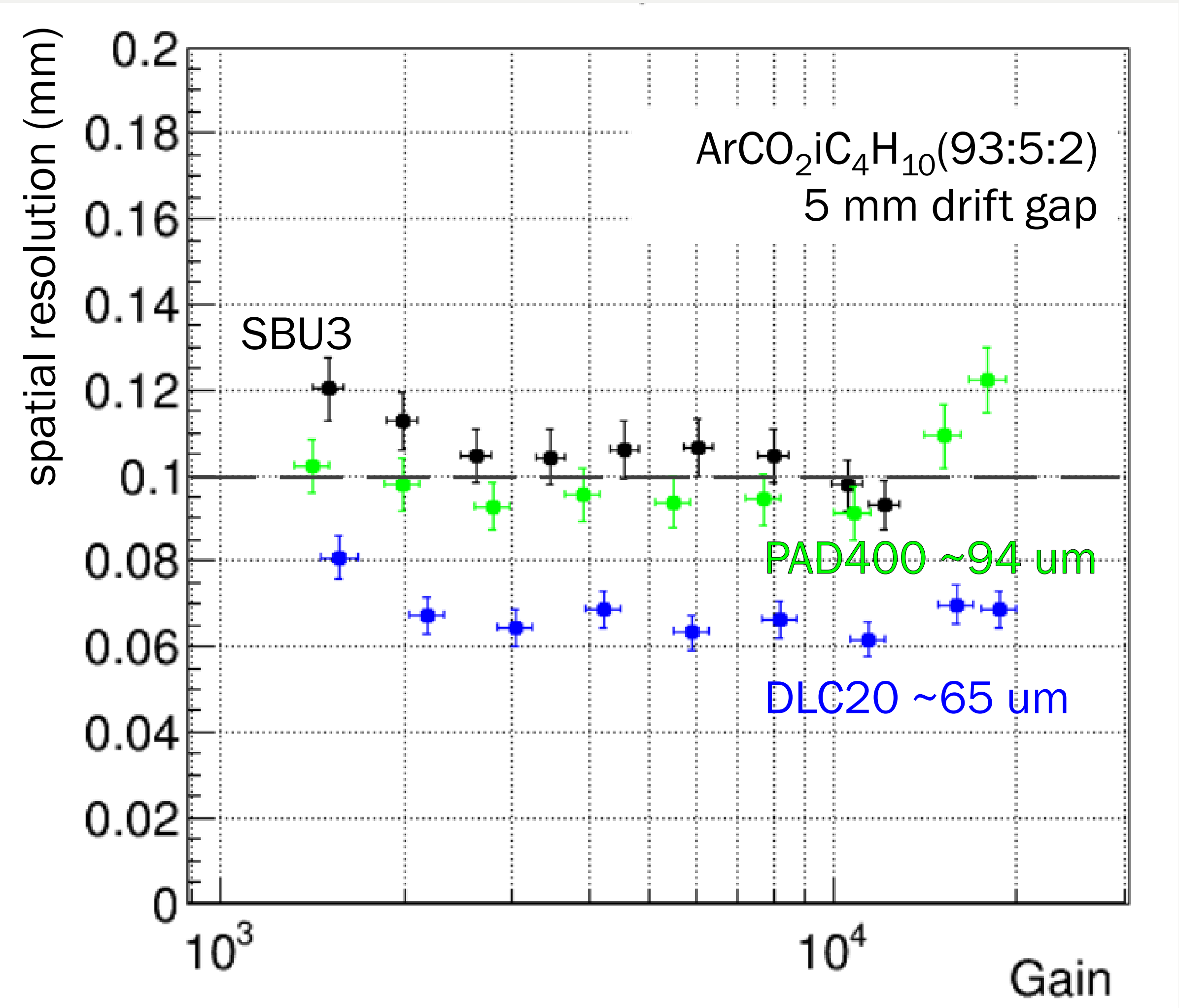
Area dependence fit a log function,



Previous study of area dependance for smaller areas: https://indico.cern.ch/event/868940/contributions/3813865

Spatial resolution

CERN SPS H4 Line (150 GeV/c muons), Gas Mixture $ArCO_2iC_4H_{10}$(93:5:2), drift voltage 300V, centroid method

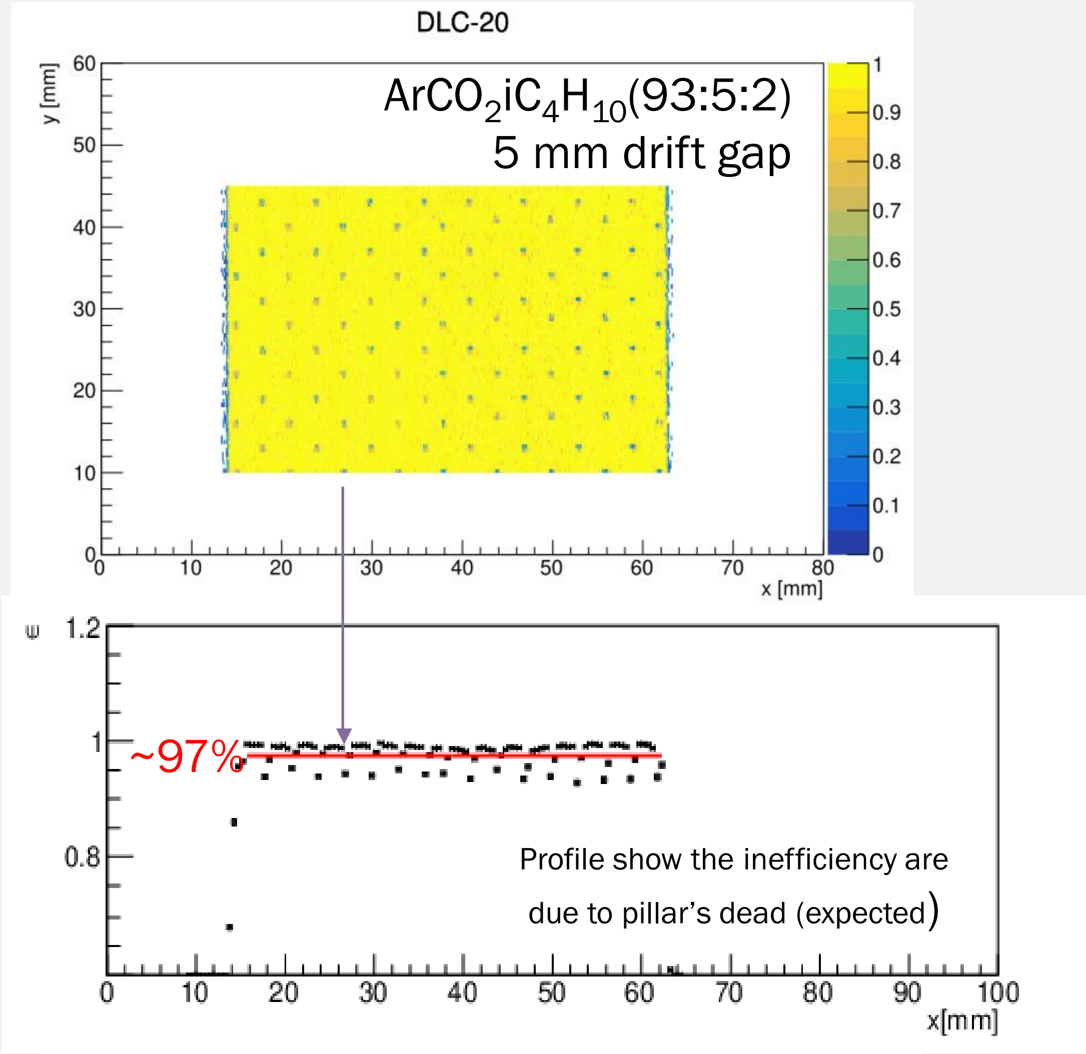


- FE saturation worsen the spatial resolution at high V_{ampl}
- Second coordinate is limited by pad side (3-8 mm)
- Ongoing investigation how to optimise the position reconstruction

< 100 um Spatial resolution along the precision coordinate in a tracking 2D-plane

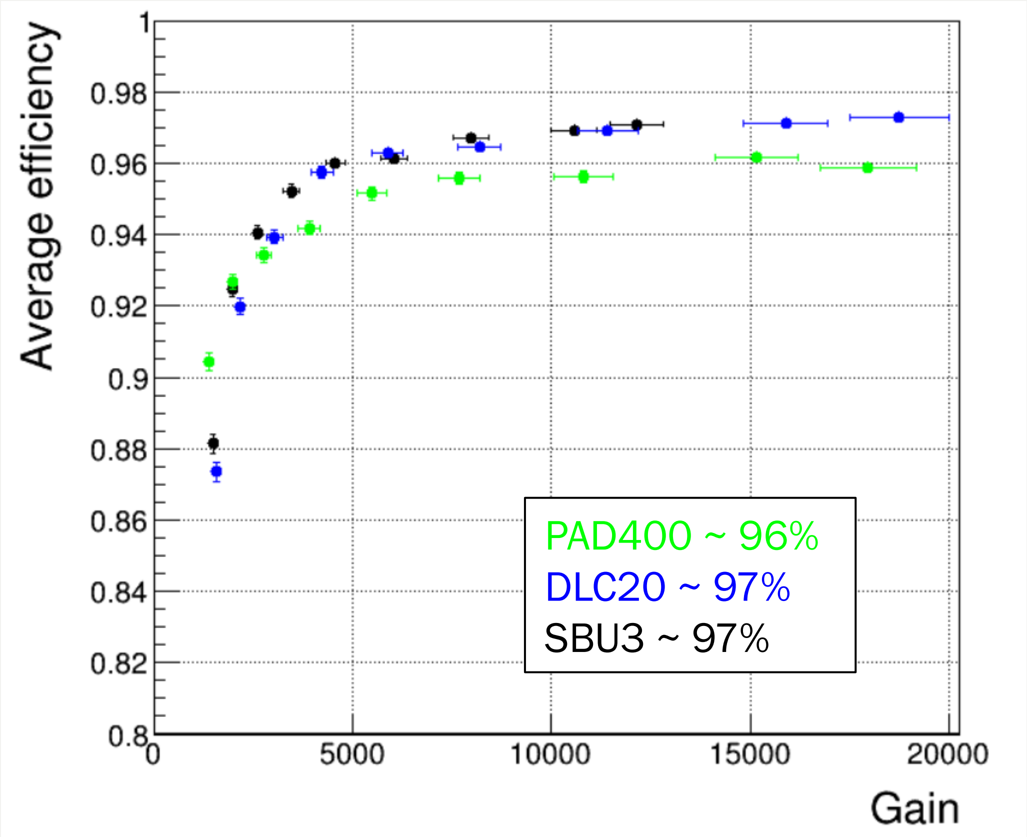
- Centroid optimisation that considers the specifics of each detector, i.e. its resistive spark protection structure (ongoing)

Tracking efficiency



- the average efficiency includes the dead areas due to the pillars

Fiducial interval of 1.5 mm

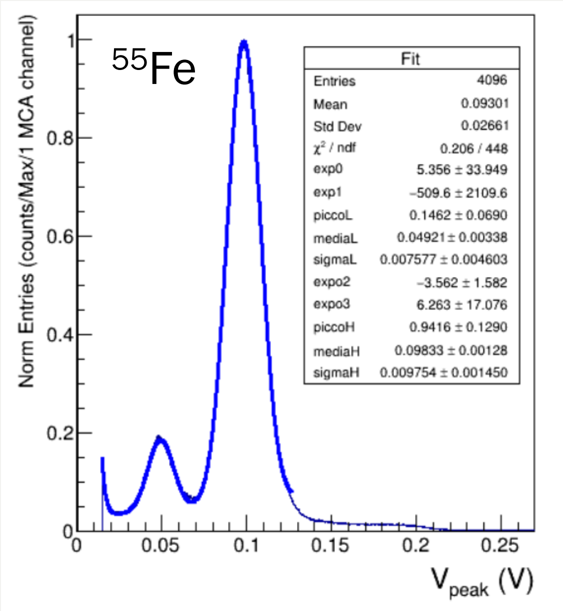


At V_{ampl} > 440 V (G > 4000 and spat res is <= 100 um), average tracking efficiency ≥ 96% (~ 100% far from pillars)

Energy resolution ($ArCO_2iC_4H_{10}$-93:5:2)

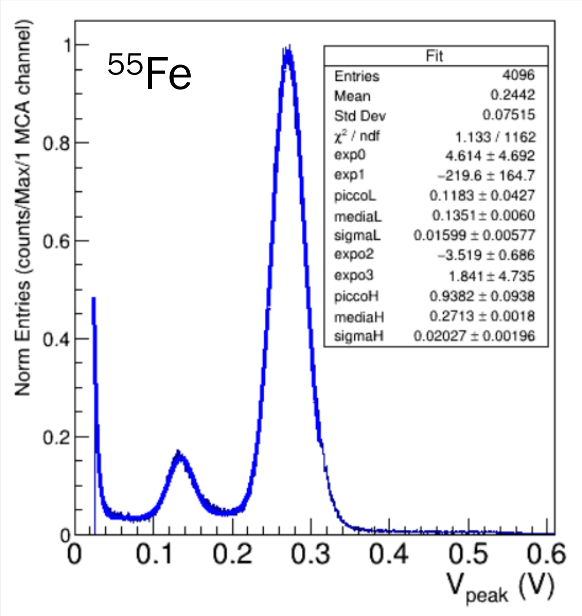
DLC-20 (best case)

$$\frac{\text{FWHM}}{\text{peak pos}} = \sim 23\%$$

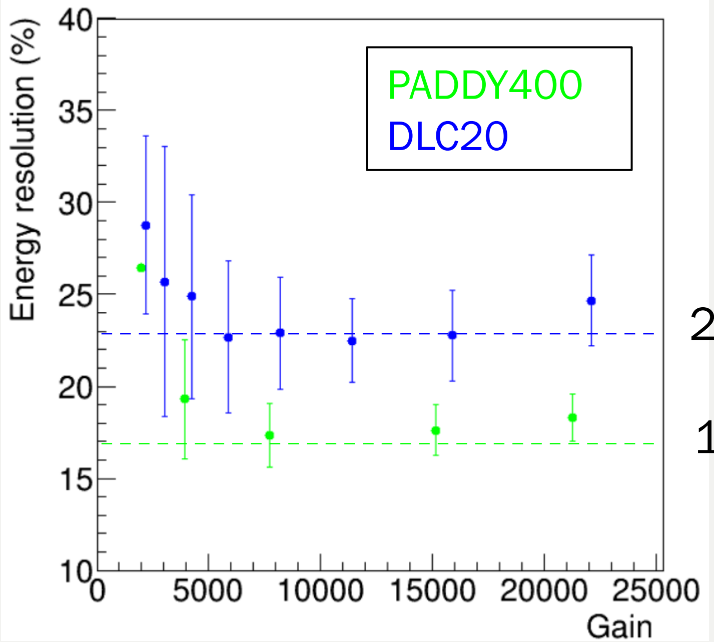


Paddy400 (best case)

$$\frac{\text{FWHM}}{\text{peak pos}} = \sim 17\%$$



Energy resolution at 5.9 keV (^{55}Fe peak)



23%

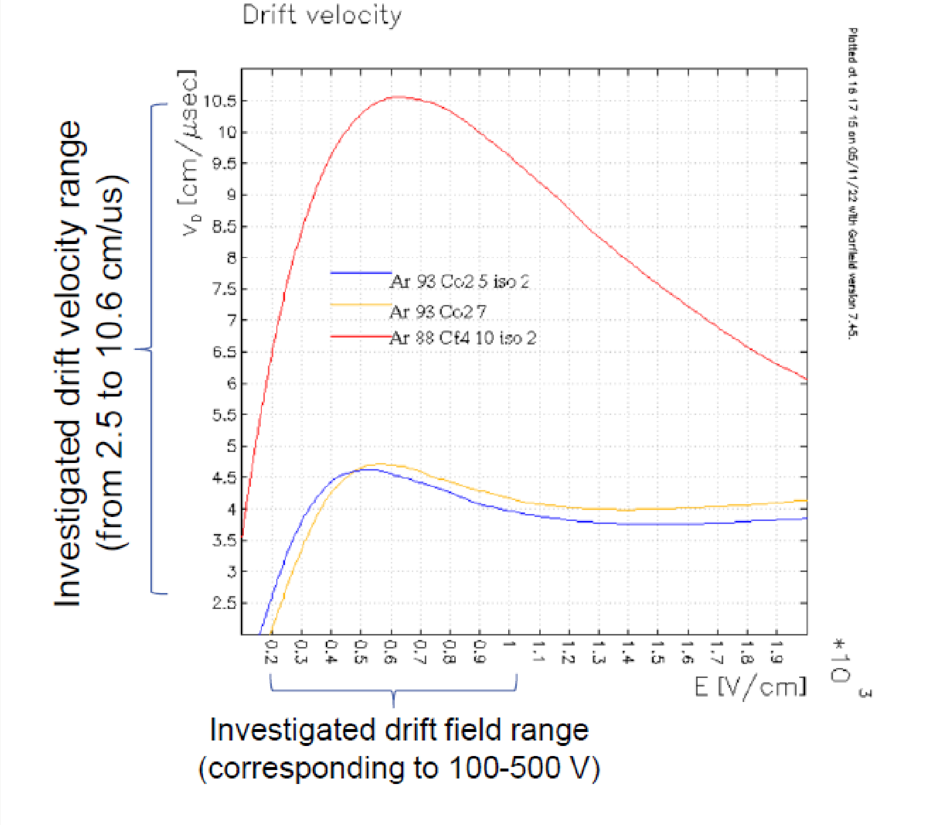
17%

The energy resolution is ~20%. We are currently investigating how the detector design influences the uniformity and its average value.

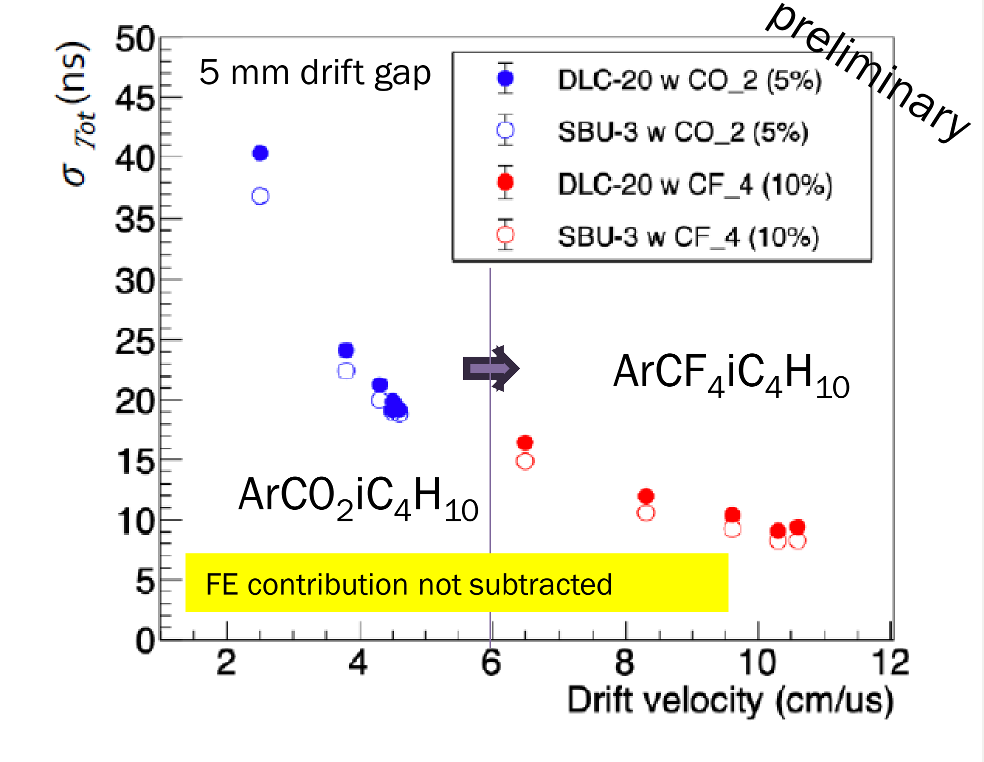
Good energy resolutions: 17-18% is the best observed value up to now.

Time information: ongoing studies

Key factors: **drift velocity** (i.e. gas mixture and drift electric field), FE electronics



$$\sigma_{Tot} = \frac{\sigma_{earl\ time\ chamb2-chamb1}}{\sqrt{2}}$$

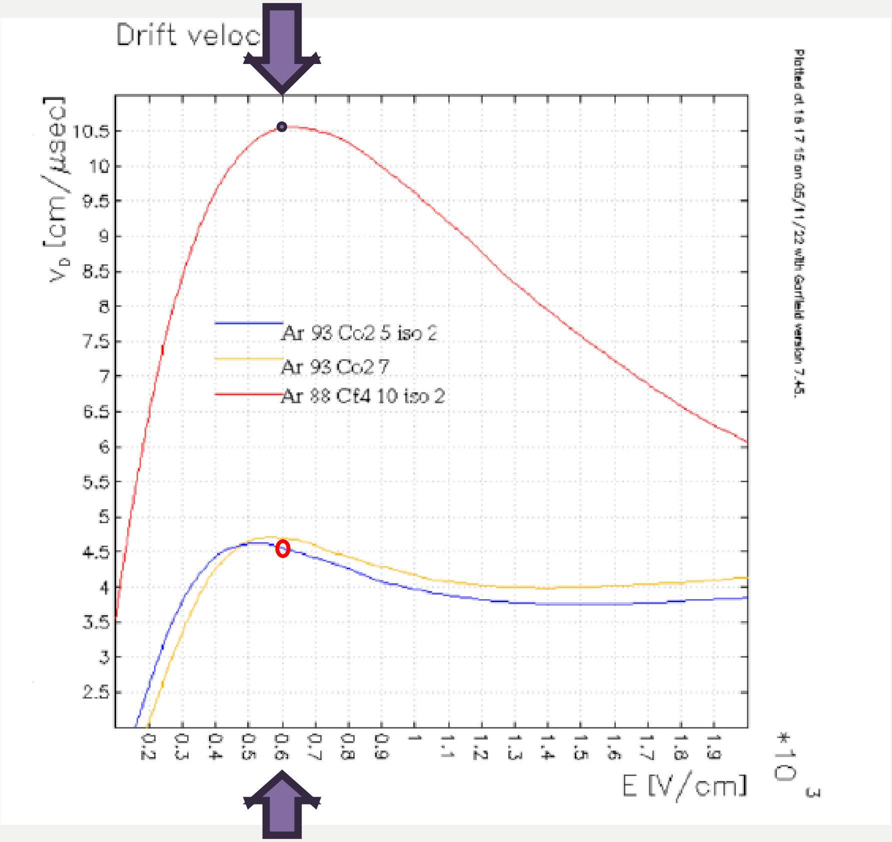


Contributions from the electronics and signal fit to extract the time is estimated to be around 4 ns from preliminary studies

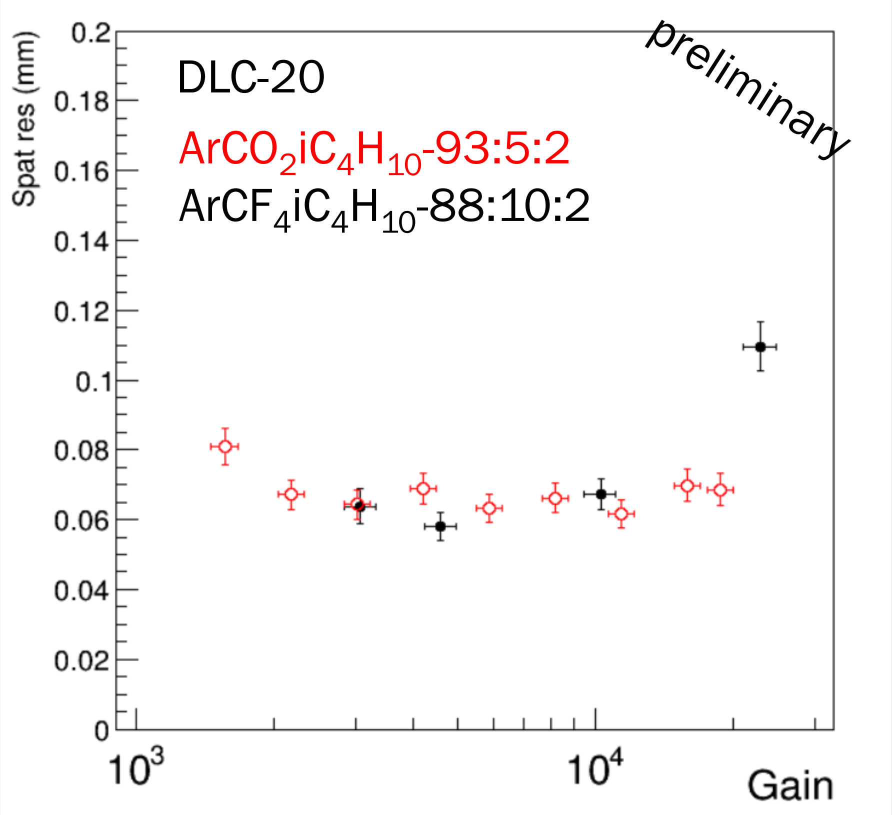
➢ Using a «faster» gas mixture (and same FE), the time resolution improves

Spatial resolution comparison

After fixed the drift electric field

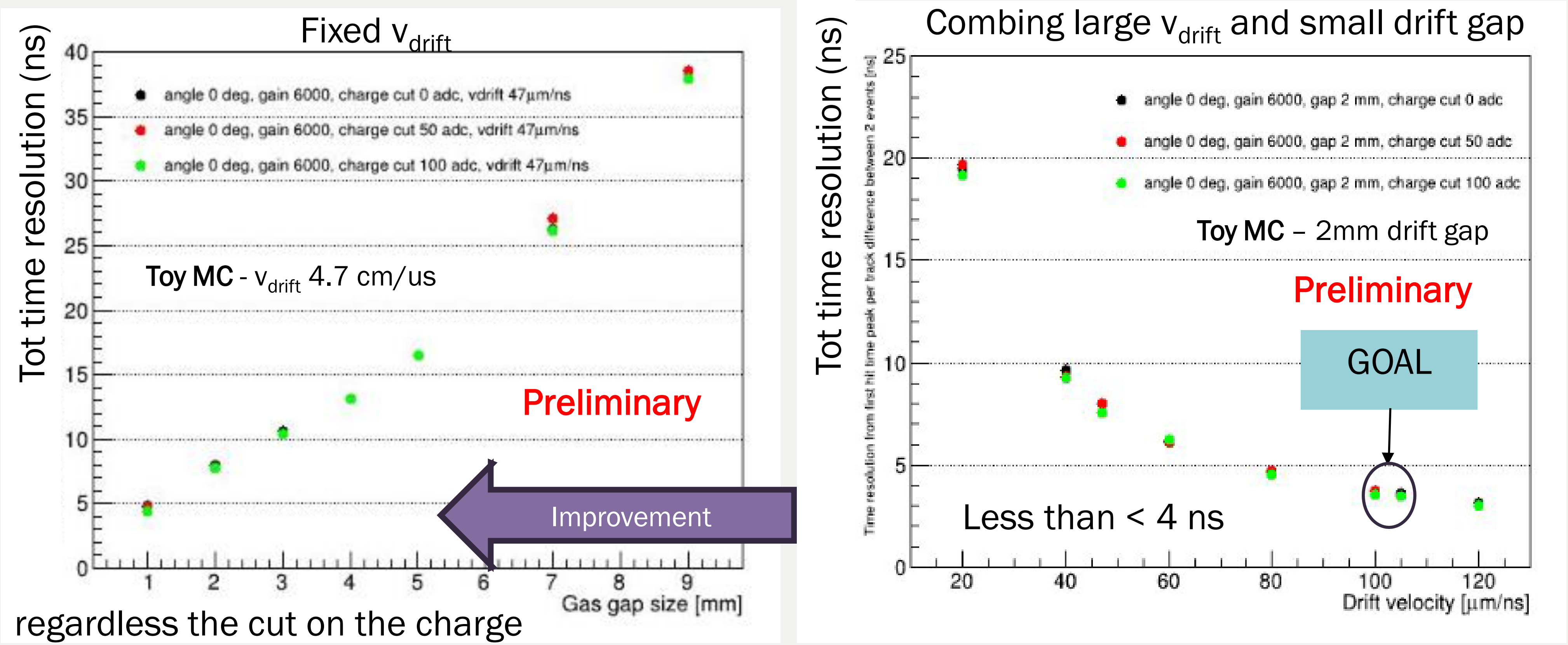


Different gaseous mixture (5 mm gap)



- ➢ Drift velocity does not affect spatial resolution.

Towards thinner drift gaps (SIMULATIONS)

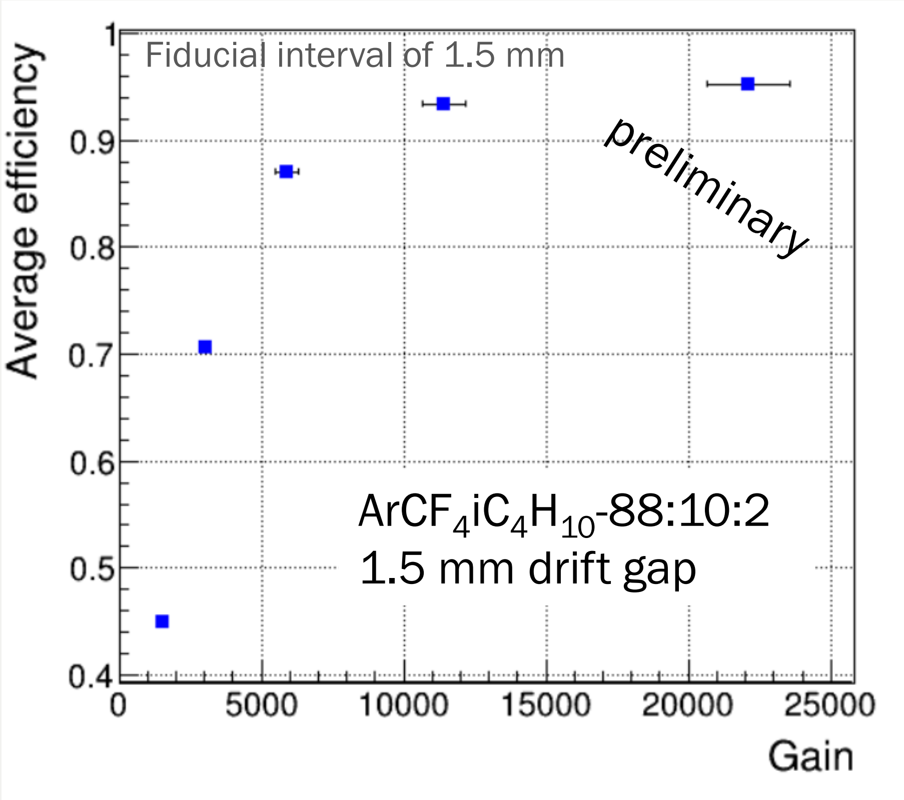


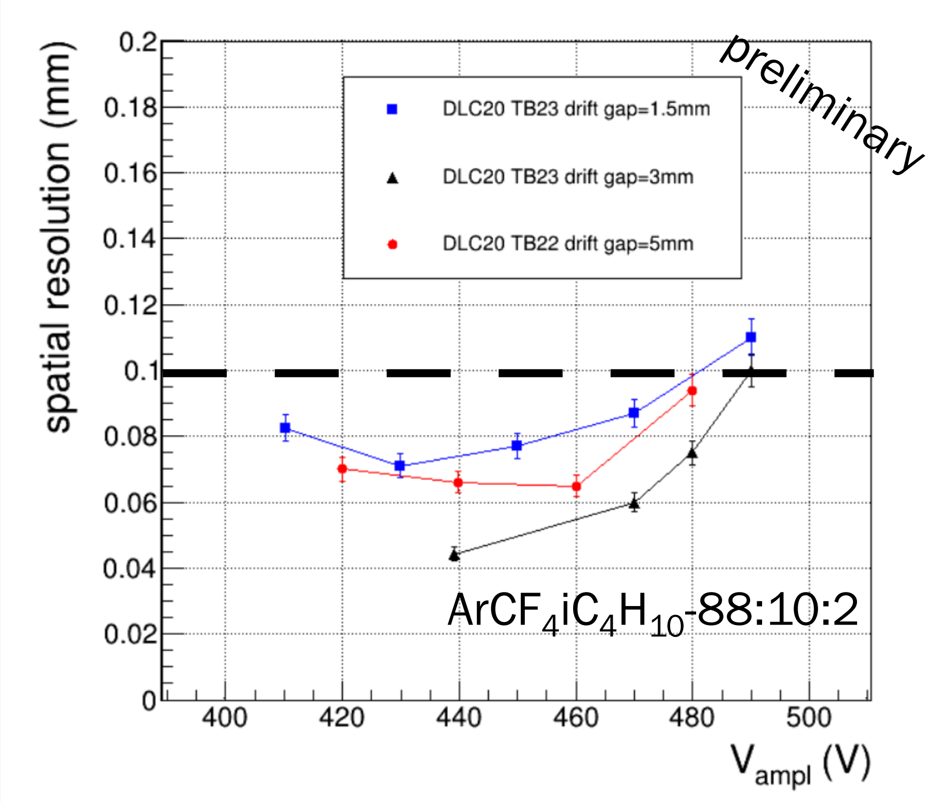
Toy MC includes the electronics contribution using a transfer function (with RC = 50 ns and α = 1.25) and it simulates the **peak time** to consider the FE ASICs use the peak timing mode.

Preliminary since few differences btw Toy-MC and data are still present and its validation with Garfield++ in ongoing.

Preliminary results on 1.5 mm drift gap

- About DATA:
  - ongoing estimation of the transverse diffusion and electronic contributions in the measurements;
  - still ongoing the optimisation of event selection for the cases 1.5 mm drift gap;
  - ongoing analysis of the runs with incident angles > 0 °.





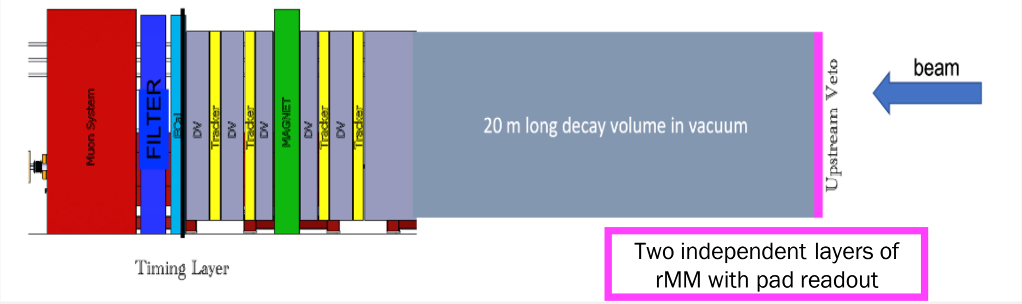
- From this very preliminary analysis, an efficiency of ~95% and a spatial resolution of ~90 um are observed for G > 10k with the thin 1.5 mm drift gap.

On-going proposals

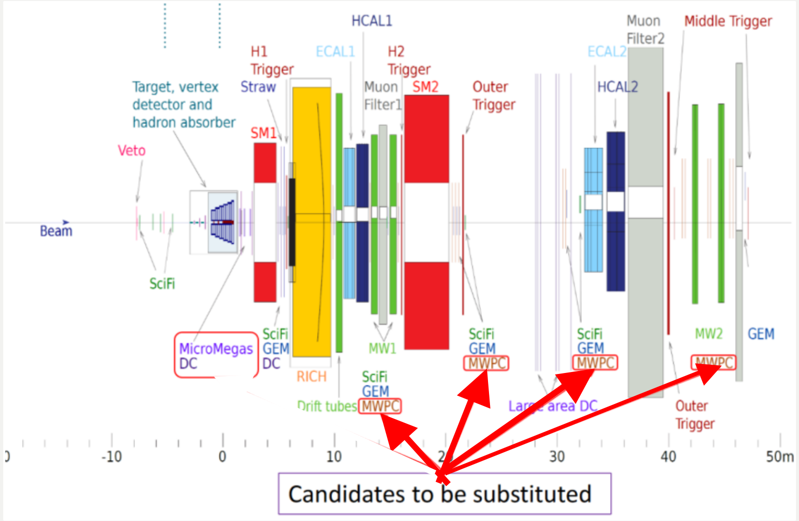
Expanding on the results achieved in the RHUM project, we are exploring potential collaborations for new experimental proposals that could benefit from Micromegas resistive technology (rMM)

- SHADOWS (Search for Hidden And Dark Objects With the SPS) intends to use rMM as Upstream muon Veto (LoI)

Talk on Sep 27, 2023, 3:30 PM in IPRD23 agenda



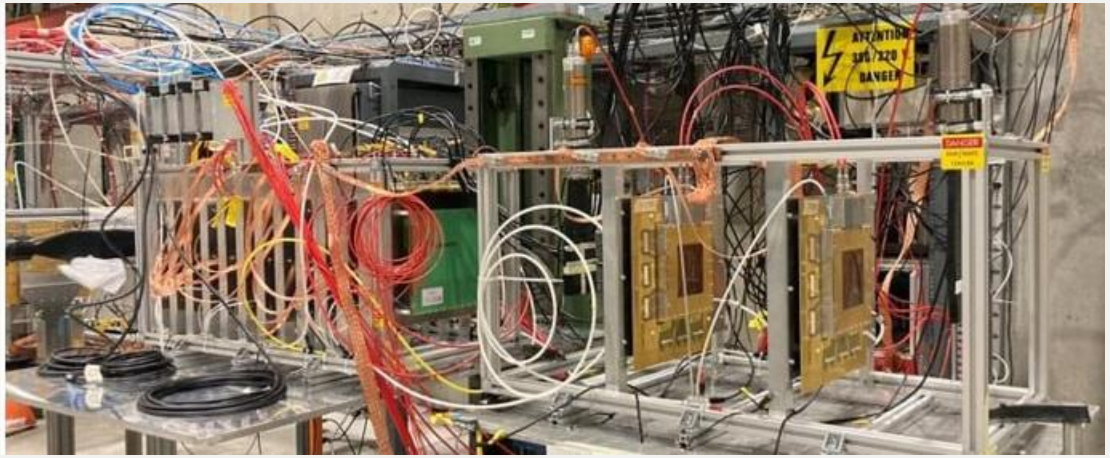
- AMBER (successor of Compass) will possibly upgrade the Muon detectors using rMM in M. Alexeev, "15th Pisa Meeting on Advanced Detectors" (link)

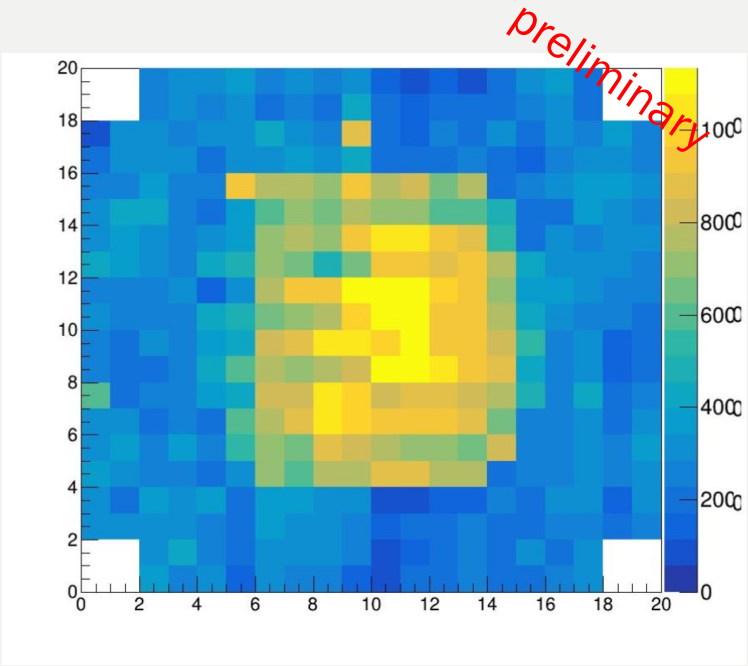


Project for other future rMM applications

- Digital Hadronic Calorimeters (DHCAL using ParticleFlow approach), rMM in the RD51 common project «Development for Resistive MPGD Calorimeter with timing measurement"

1° TB at CERN SPS H4 Line (150 GeV/c muons) wo absorbers





Occupancy map (weighted by charge)

- More details in A. Stamerra «24° International Workshop On Radiation Imaging Detectors»
- Talk on Sep 28, 2023, 12:15 PM in IPRD23 agenda

Conclusions

- The results show that pixelised resistive Micromegas:

are **excellent candidates for particle tracking and trigger operation** up to rate O(10 MHz cm^{-2}) with

- **stable HV behaviour,**
- **< 100 um spatial resolution for perpendicular tracks;**
- **Proved < 10 ns time resolution.**

reached a consolidated constructive techniques for large area detectors, to be considered in future experiment proposals

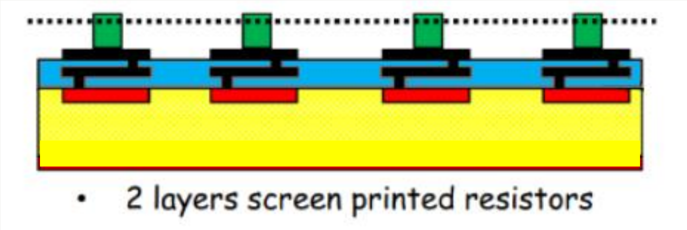
ONGOING studies to push the tracking and timing performances

- setup optimisation to measure resolutions < 4 ns;
- Centroid optimisation that considers the specifics of each prototype.

BACK-UP

Resistive layouts

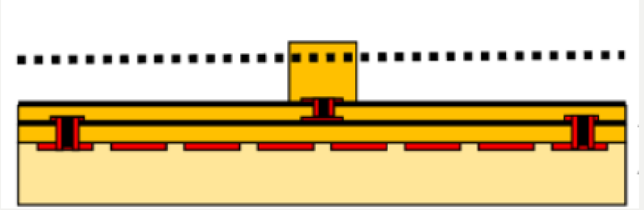
PAD-P embedded resistors



Independent protective resistor (black) for each readout pad (red)

- Ref [1] Construction and test of a small-pad resistive Micromegas prototype (https://iopscience.iop.org/article/10.1088/1748-0221/13/11/P11019)

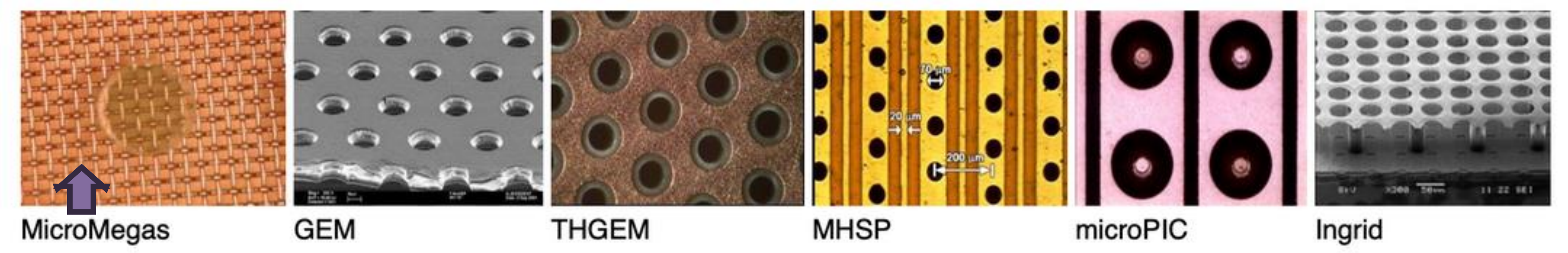
DLC-SBU



DLC foils interconnected by evacuation vias

- Ref. [2] Alviggi et al. - NIM Research Sec. A, Vol. 936, 21 Aug 2019, pp 408-411 (https://doi.org/10.1016/j.nima.2018.10.052)

MPGDs: Micro Pattern Gaseous Detectors



Proposed in several applications for future experiments (from the 2021 ECFA detector R&D roadmap)

Muon systems

Facility	Technologies	Challenges	Most challenging requirements at the experiment
HL-LHC	RPC, Multi-GEM, resistive-GEM, Micromegas, micro-pixel Micromegas, μ-RWELL, μ-PIC	Ageing and radiation hard, large area, rate capability, space and time resolution, miniaturisation of readout, eco-gases, spark-free, low cost	**(LHCb)**: Max. rate: 900 kHz/cm² Spatial resolution: ~ cm Time resolution: O(ns) Radiation hardness: ~ 2 C/cm² (10 years)
Higgs-EW-Top Factories (ee) (ILC/FCC-ee/CepC/SCTF)	GEM, μ-RWELL, Micromegas, RPC	Stability, low cost, space resolution, large area, eco-gases	**(IDEA):** Max. rate: 10 kHz/cm² Spatial resolution: ~60-80 μm Time resolution: O(ns) Radiation hardness: <100 mC/cm²
Muon collider	Triple-GEM, μ-RWELL, Micromegas, RPC, MRPC	High spatial resolution, fast/precise timing, large area, eco-gases, spark-free	Fluxes: > 2 MHz/cm² ($\theta<8^0$) < 2 kHz/cm² (for $\theta>12^0$) Spatial resolution: ~100μm Time resolution: sub-ns Radiation hardness: < C/cm²
Hadron physics (EIC, AMBER, PANDA/CMB@FAIR, NA60+)	Micromegas, GEM, RPC	High rate capability, good spatial resolution, radiation hard, eco-gases, self-triggered front-end electronics	**(CBM@FAIR):** Max rate: <500 kHz/cm² Spatial resolution: < 1 mm Time resolution: ~ 15 ns Radiation hardness: 10^{13} neq/cm²/year
FCC-hh (100 TeV hadron collider)	GEM, THGEM, μ-RWELL, Micromegas, RPC, FTM	Stability, ageing, large area, low cost, space resolution, eco-gases, spark-free, fast/precise timing	Max rate: <500 kHz/cm² Spatial resolution = 50 μm Angular resolution = 70 μrad (η=0) to get $\Delta p/p \leq 10\%$ up to 20 TeV/c

Central/Inner trackers

Facility	Technologies	Challenges	Most challenging requirements at the experiment
HL-LHC	MPGD	High spatial resolution, high rate/occupancy, radiation hardness, low mass	**LHCb option:** replace Scintillating Fibre tracker Spatial resolution:70 μm bending plane
Higgs-EW-Top Factories (ee) (ILC/FCC-ee/CepC/SCTF)	TPC+(multi-GEM, Micromegas, GridPix), Drift Chambers, Cylindrical layers of MPGD	Ultra-lightweight inner or central tracker, high spatial resolution, high rate/occupancy, radiation hardness, low mass, transparency, cluster counting, TPC continuous mode at high rate, (IBF x Gain) ~1	**Inner tracker (SCTF)** Fluxes: ≥10 kHz cm^{-2} s^{-1} Time resolution: 1 ns X/X0 = 1% Spatial resolution: ~100 μm **Central tracker (CepC)** Max. rate: >100 kHz/cm² Spatial resolution: ~100 μm Time resolution: ~ 100 ns dE/dx: <5% Particle separation with cluster counting at 2% level
Rare processes, atomic and nuclear physics (SPS Kaons: K^+ Phase, K-Phase, Mu2eII/COMET-II, ELENA)	TPC, straw tubes	High spatial resolution, occupancy, fast/precise timing, radiation hardness, low mass, Gd-deposited MPGD detectors	Max rate = 500 kHz/straw **(Mu2e II)**: Thinner straw material: 8 μm X/X0 ~ 0.02% per layer, X/X0 ~ 1% total **(COMET+)**: Diameter = 4.8 mm Trailing time resolution = 1 ns per track
Hadron and nuclear physics (EIC, AMBER, PANDA and CMB@FAIR, PRES MAINZ, NA60+	Micromegas, GEM, μ-RWELL, straw tubes	High spatial resolution, good timing, radiation hardness , tolerance to magnetic field	**(EIC)** Max rate = 100 kHz/cm² Spatial resolution ~50 μm X/X0 = 5% dE/dx=12%, continuos running

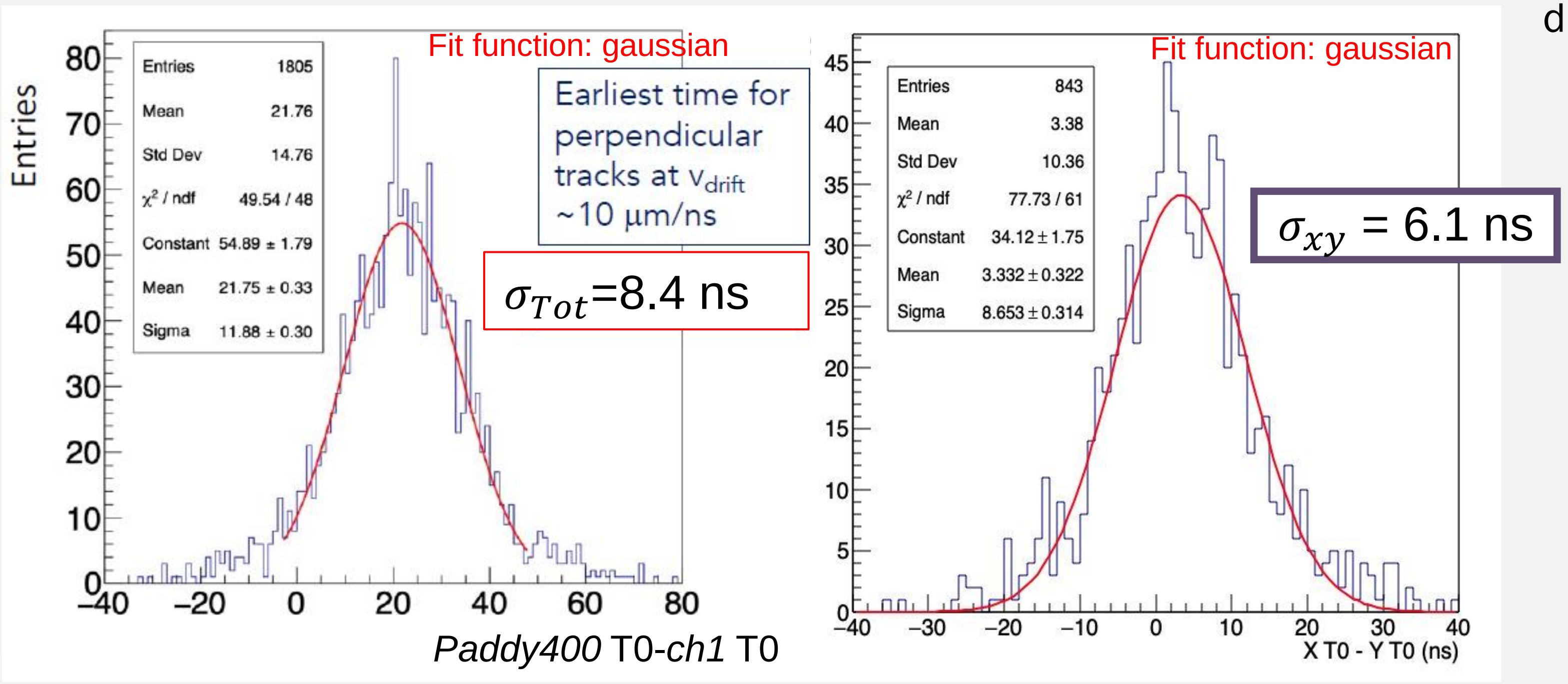
https://cds.cern.ch/record/2784893/files/ECFA%20Detector%20R&D%20Roadmap.pdf

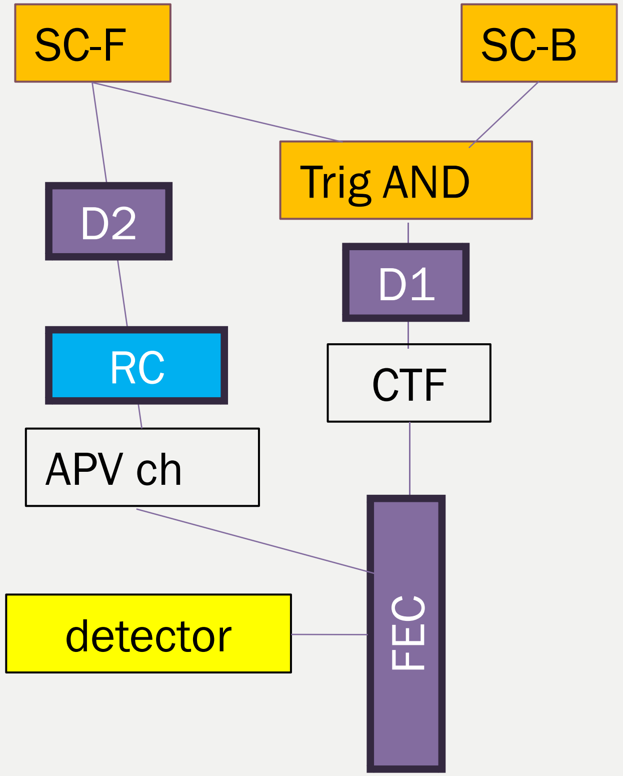
Methodology of the time resolution measurement

When the prototypes are identical, the overall time resolution can be derived by the stdev of time difference distribution between two identical chambers (left), look at the time difference between the X and Y strips of a Tmm that collected the same signal (right), too.

$$\sigma_{Tot} = \frac{\sigma_{ch2-ch1}}{\sqrt{2}} \qquad \sigma_{xy} = \frac{\sigma_{X-Y}}{\sqrt{2}}$$

New: trying w.r.t. trigger signal read by APV after passing through a passive RC differentiator.





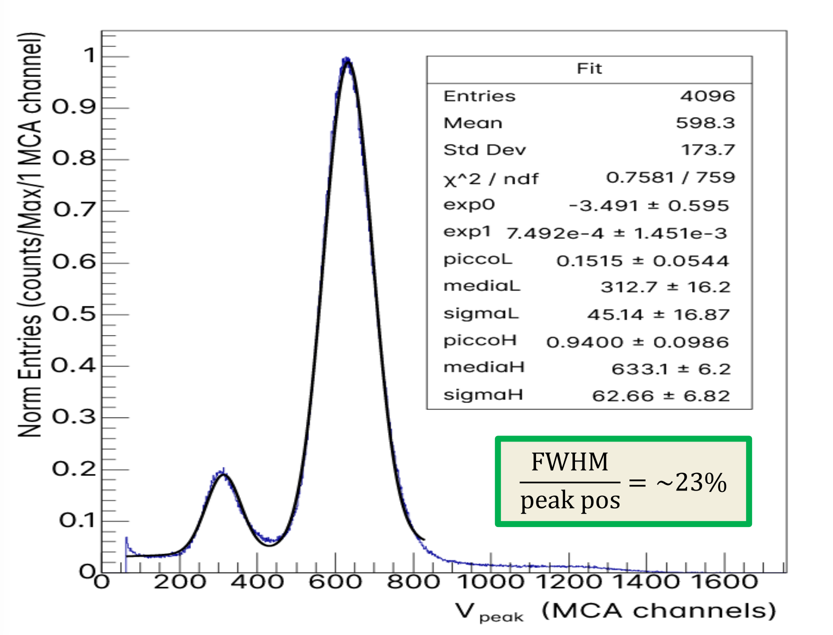
In $\sigma^2_{ch2-ch1}$, the random contributions are canceled, keeping the electronics contribution and possible biases from the analysis.

ch = chamber

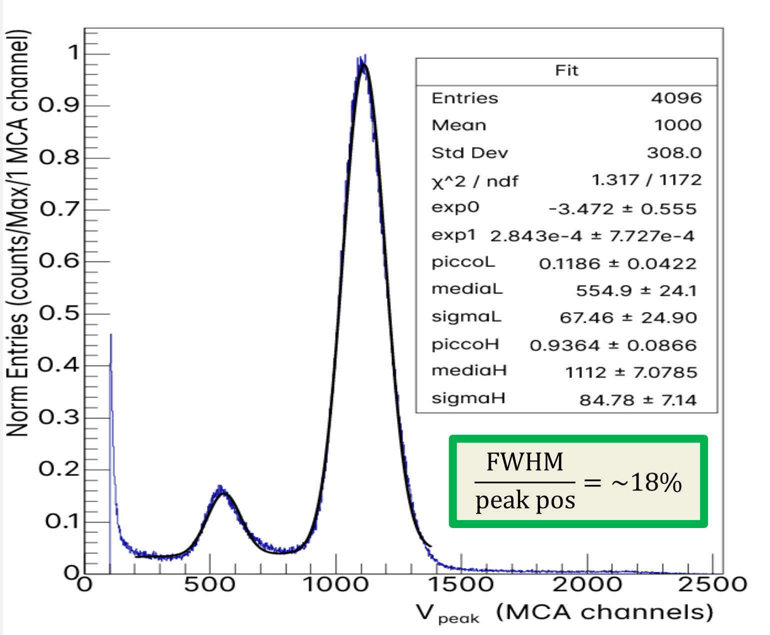
With Resistive Strip bulk-MM, it is possible isolated the contribution σ_{xy} corresponding to the same signal, whose main factors are from electronics and time fit procedure.

^{55}Fe spectra

DLC-20 (best case)



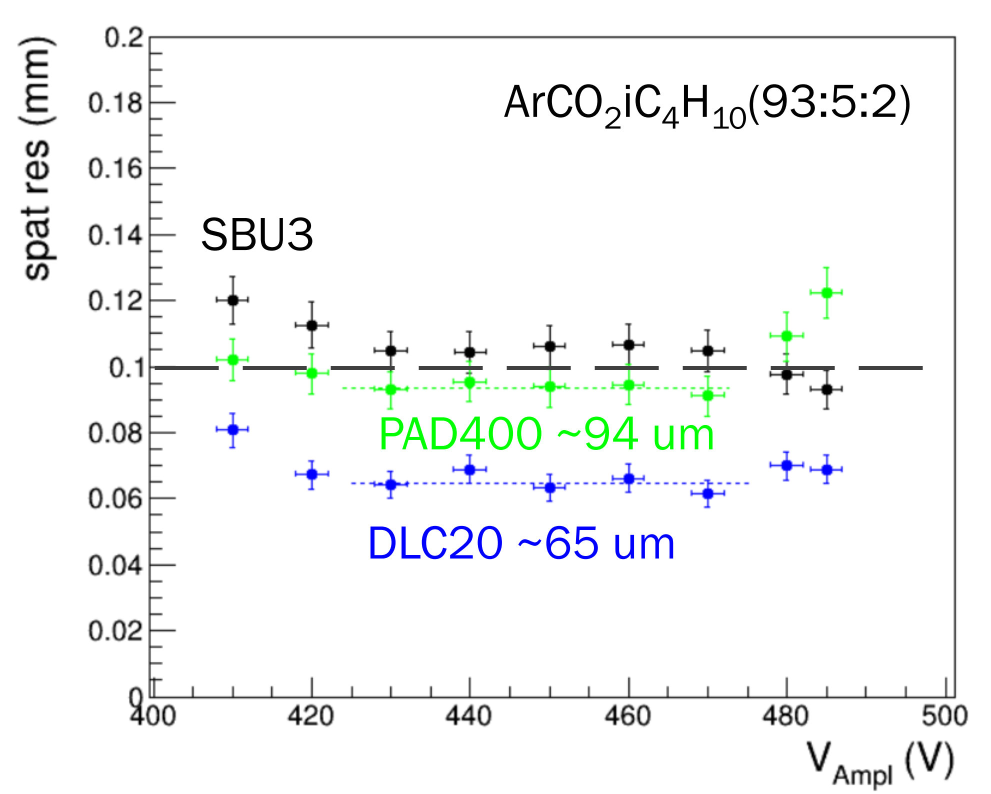
Paddy400 (best case)



As function of amplification voltage

CERN SPS H4 Line (150 GeV/c muons), Gas Mixture $ArCO_2iC_4H_{10}$(93:5:2), drift voltage 300V, centroid method

Spatial resolution



Average efficiency