Istituto Nazionale di Fisica Nucleare

Pixelised Resistive Micromegas for Tracking Detectors in Future Particle Physics Experiments

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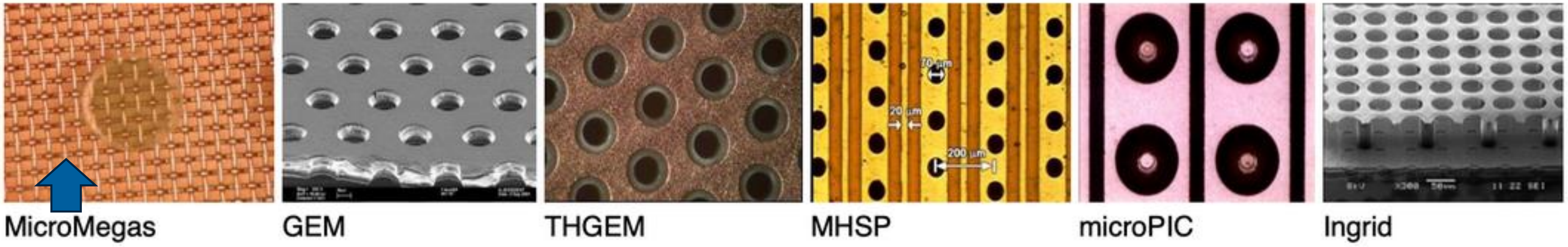
Contents

- Introduction of MPGD and 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

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

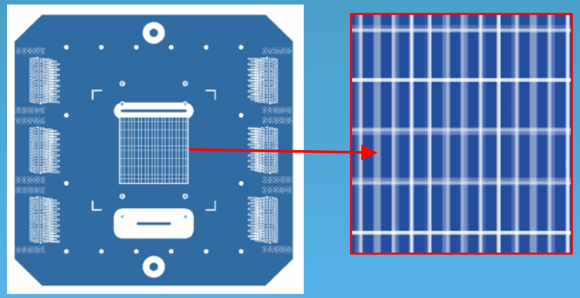
RHUM R&D objectives

- 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 (next slide)

- 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



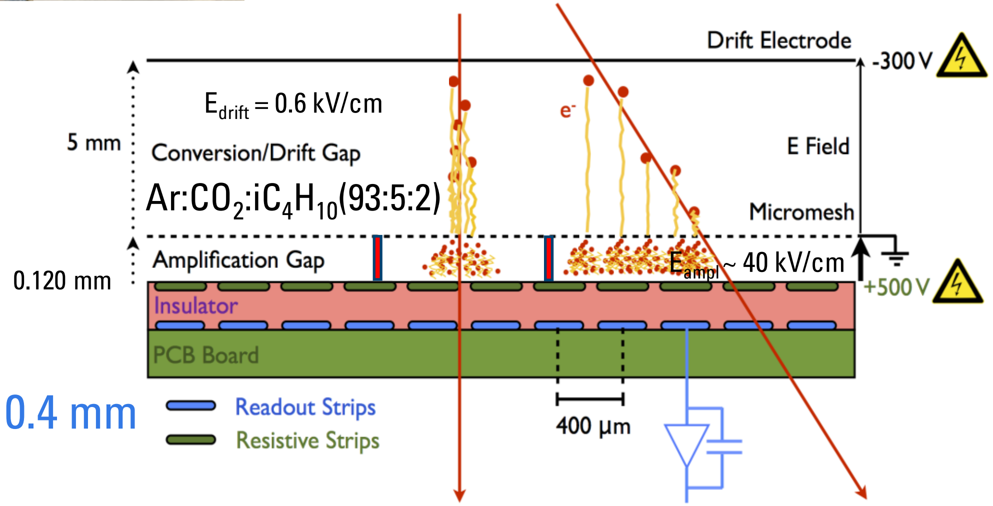
Pixelated readout:
~5x5 cm^2 anodic plane,
pads of **0.8 x 2.8 mm^2**

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

SOON: ~50x50 cm^2 anodic plane
with mixed pad granularity

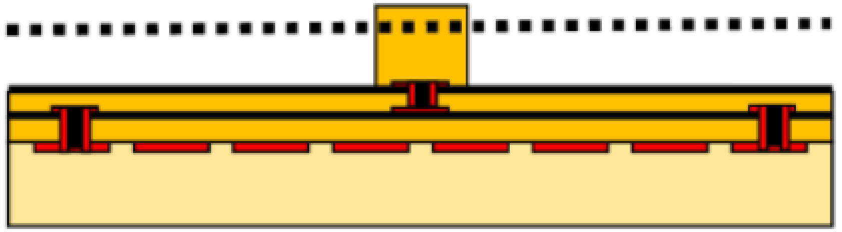
RHUM latest prototypes

ATLAS-like resistive strip layout



min strip area:

SBU-DLC technique



- **DLC-like** (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 side;
  Copper readout pads (red) on PCB (beige)

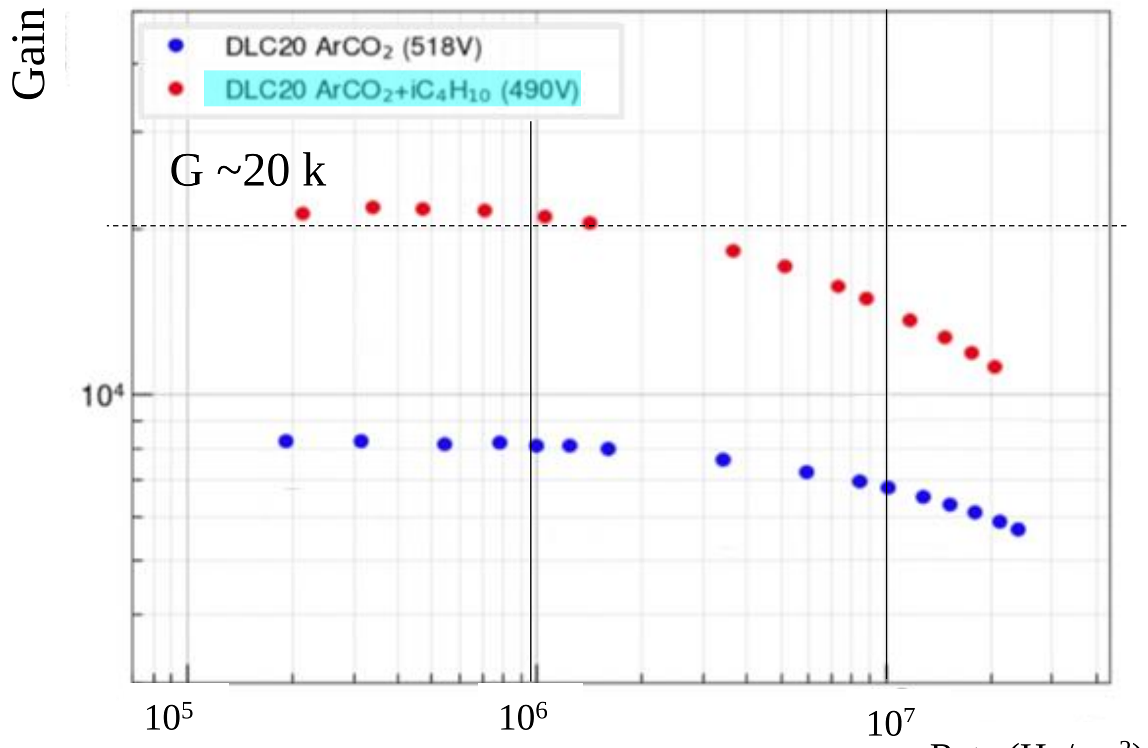
Within the RHUM project, over 10 prototypes were built, each possessing distinct characteristics.

Studies of rate capability

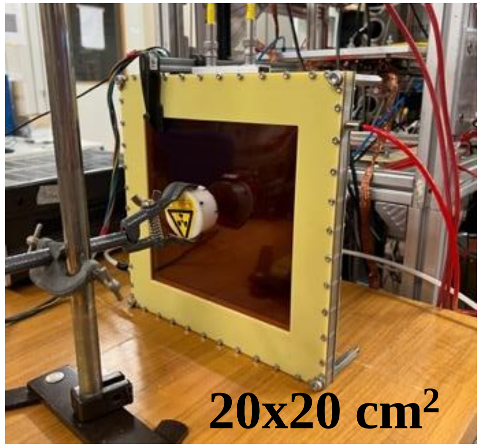
<u>DLC-like scheme</u>

- Negligible charging-up effects.
- Gain stable up to 1-2 MHz/cm², and at higher rates, gain drop due to ohmic contribution.
- At 10 MHz/cm², 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.**

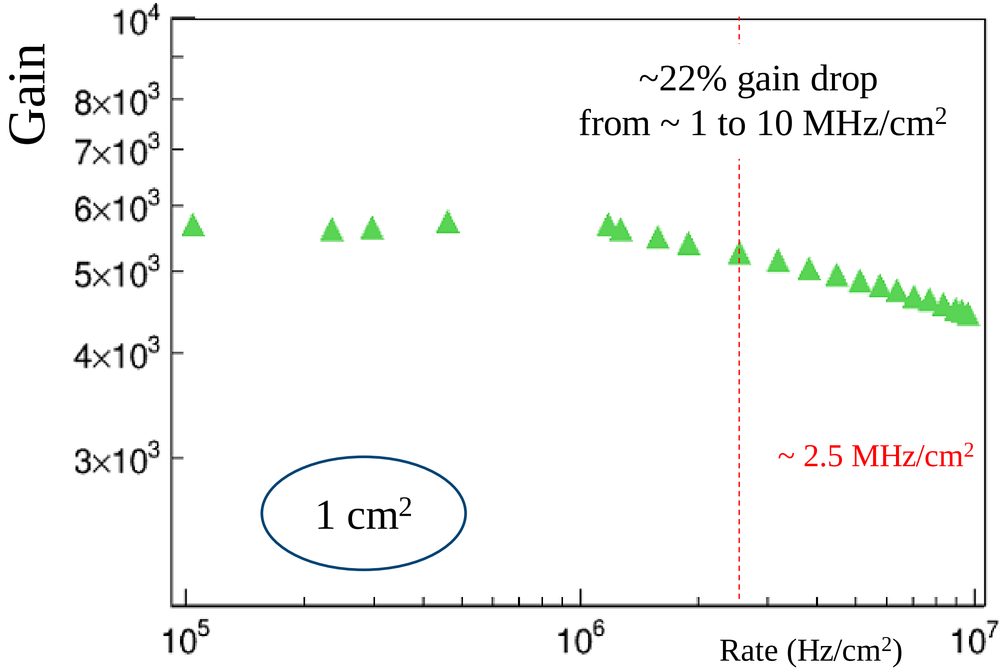


Towards large areas

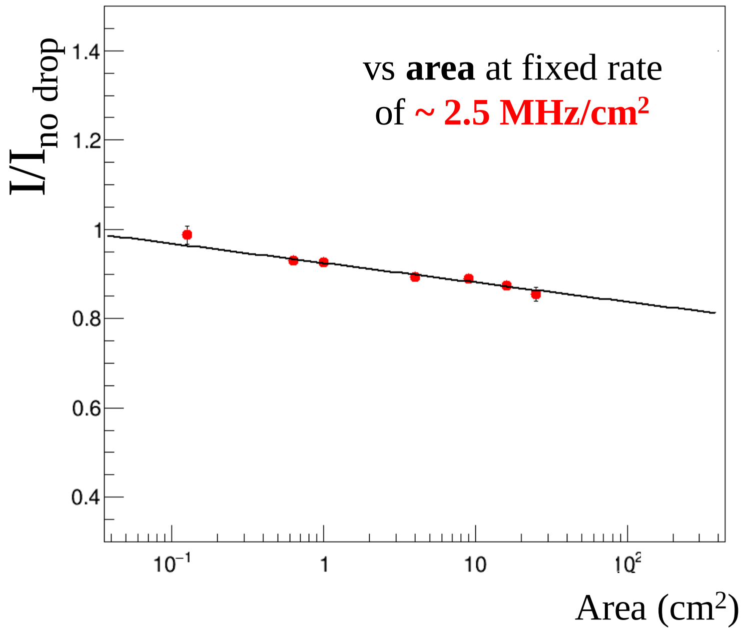
PADDY400

- **Active area ~20x20 cm^2**
- **Pad size:** 1x8 mm^2
- **Number of Pads:** 4800

Repeated gain/rate capability studies with $ArCO_2$(93:7)%, varying irradiated area up to 25 cm^2 max area until now.



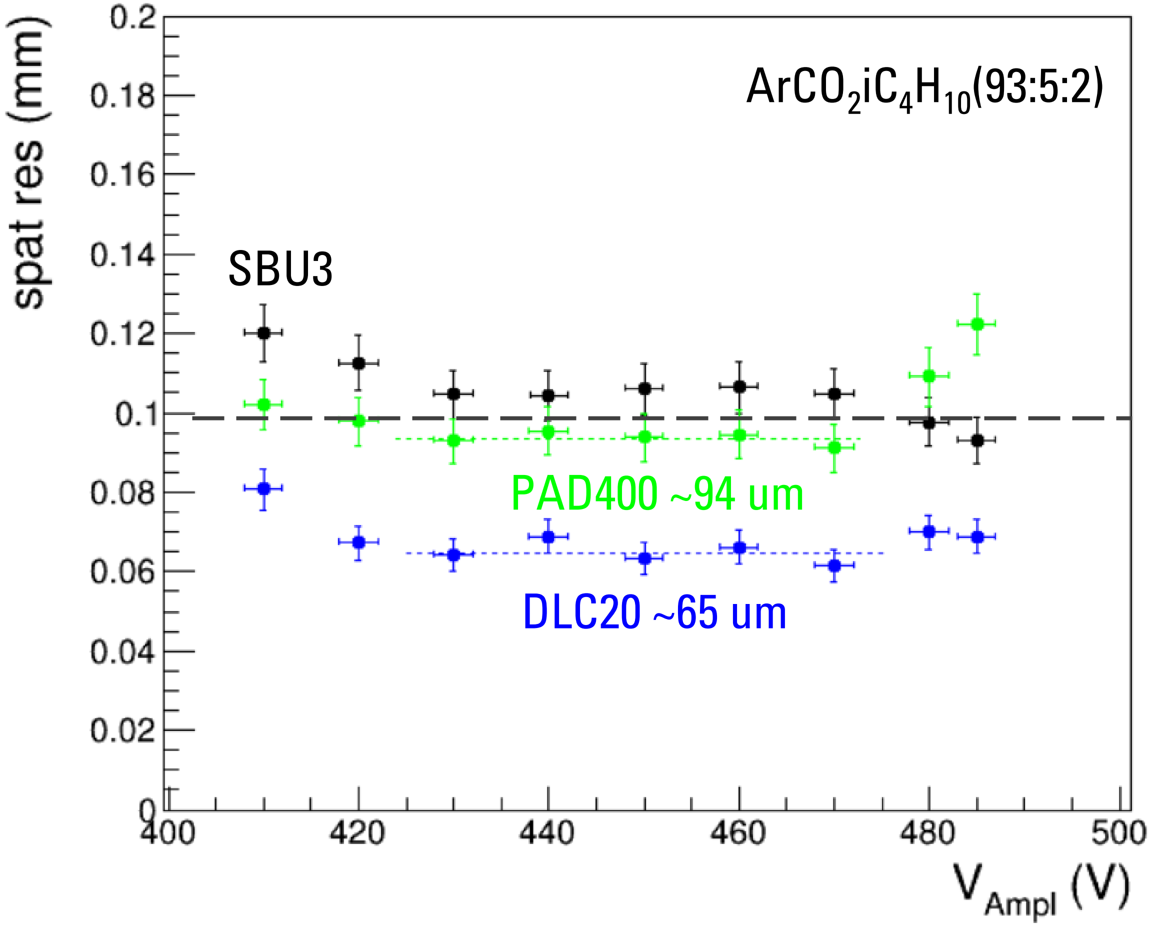
Area dependence fit a log function,



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

Spatial resolution

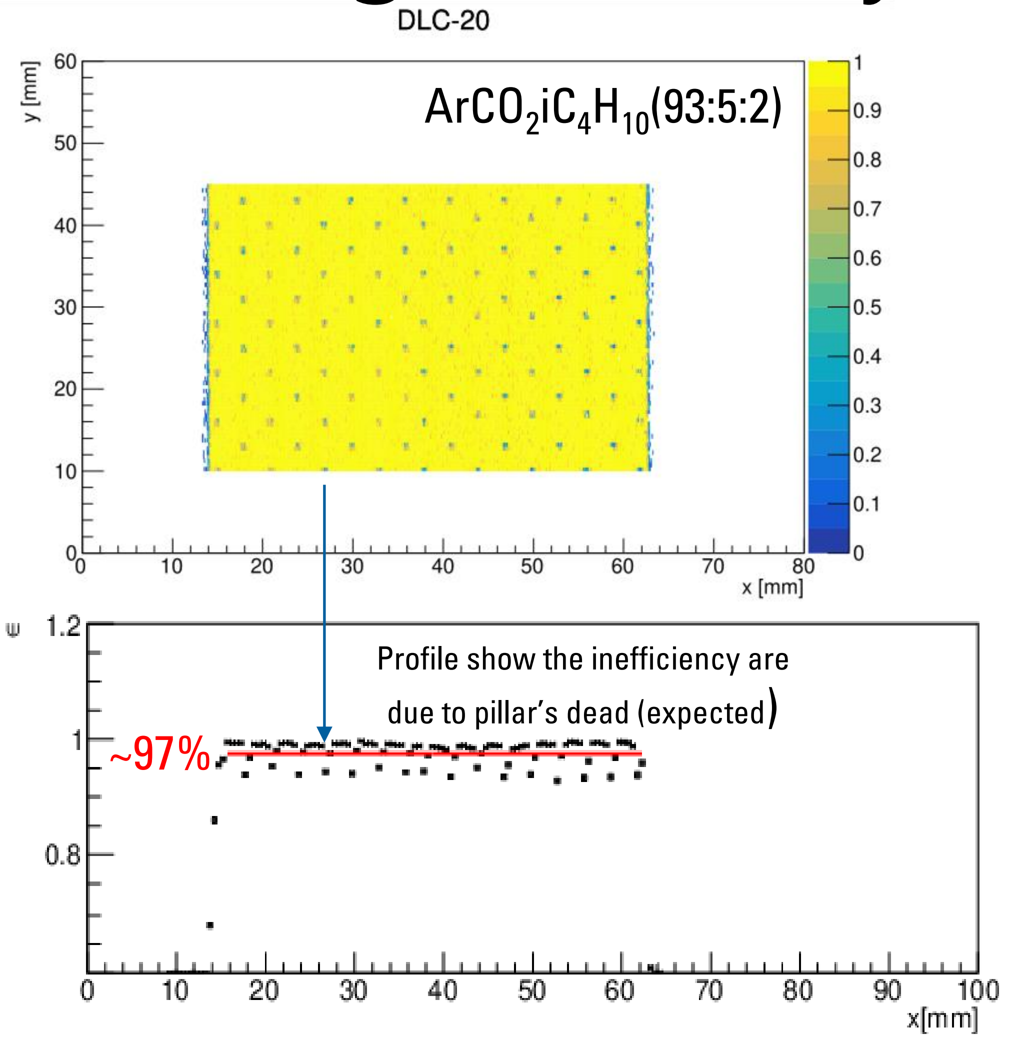
CERN SPS H4 Line (150 GeV/c muons), Gas Mixture $ArCO_2iC_4H_{10}$(93:5:2), drift voltage 300V, centroid method



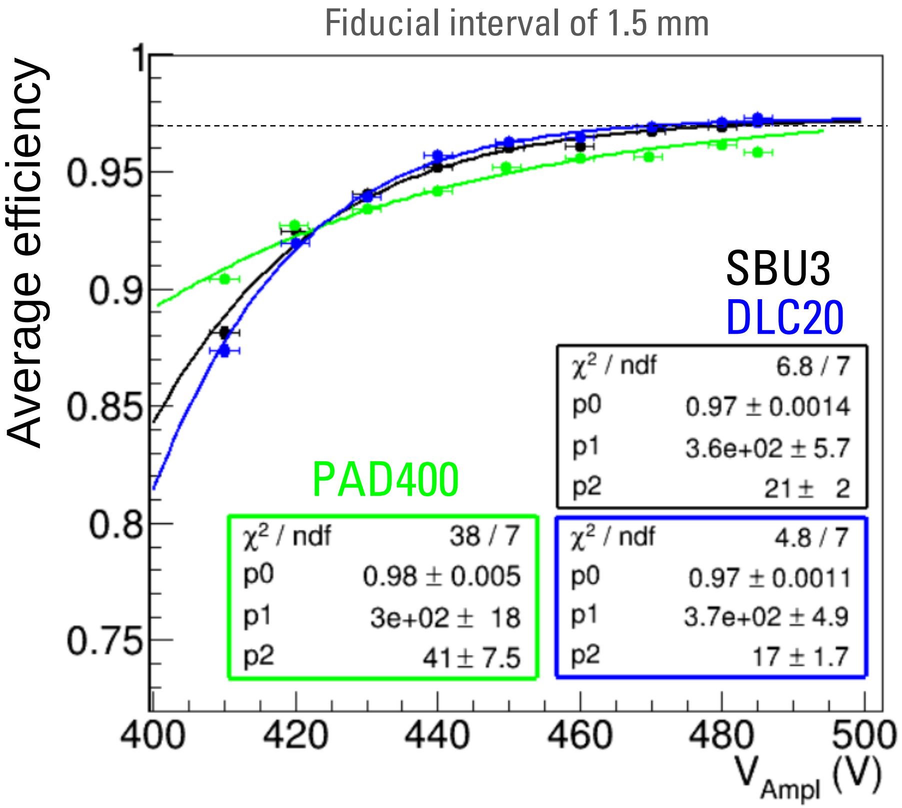
- FE saturation worsen the spatial resolution at high V_{ampl}
- Second coordinate is limited by pad side (3-8 mm)
- Ongoing investigation how to optimise the position reconstruction

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

Tracking efficiency



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

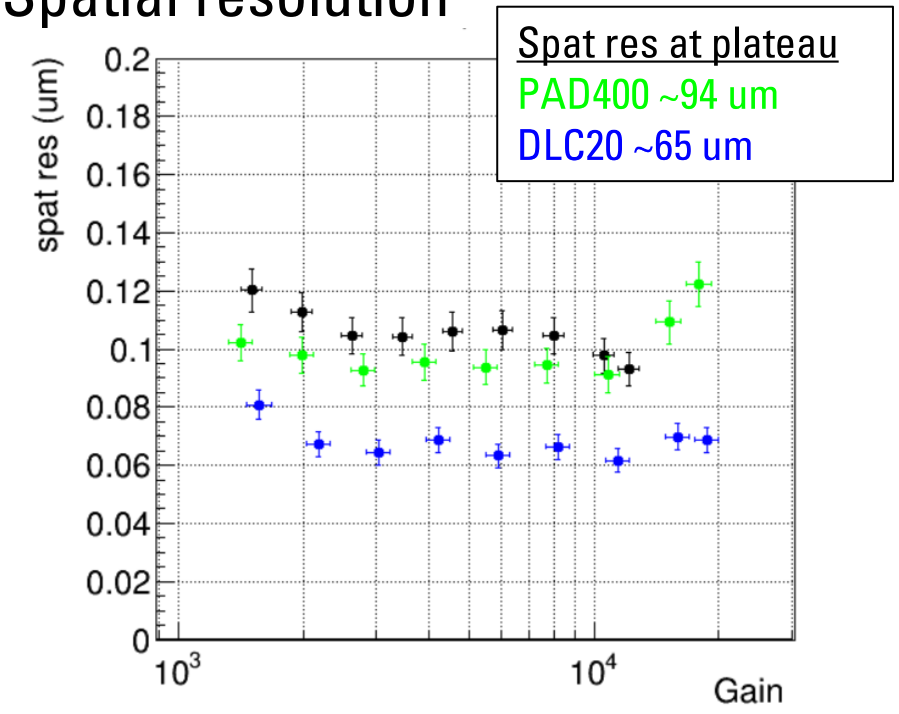


At V_{ampl} > 440 V (G > 4000 and spat res is <= 100 um), average tracking efficiency ≥ 96% (~ 100% far from pillars)

vs GAIN

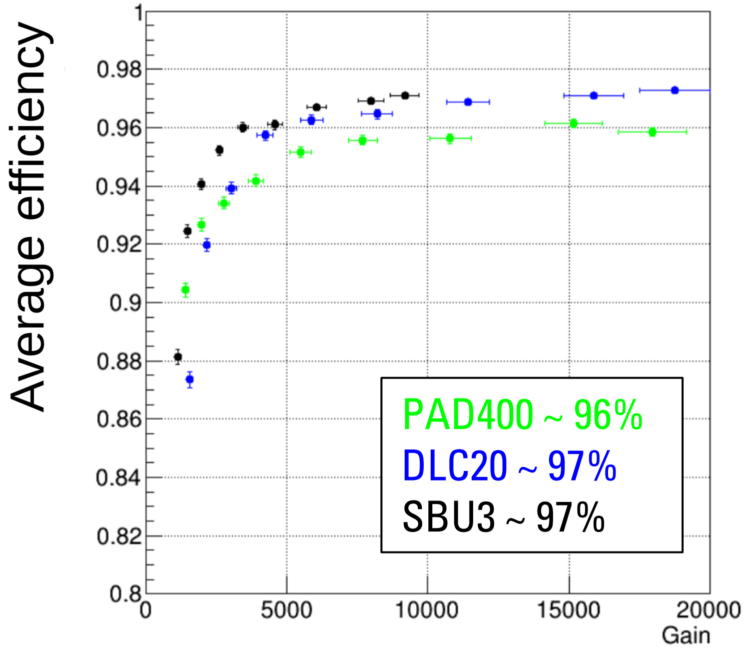
$ArCO_2iC_4H_{10}$(93:5:2)

Spatial resolution



$ArCO_2iC_4H_{10}$(93:5:2)

Efficiency (1.5 mm fiducial interval)

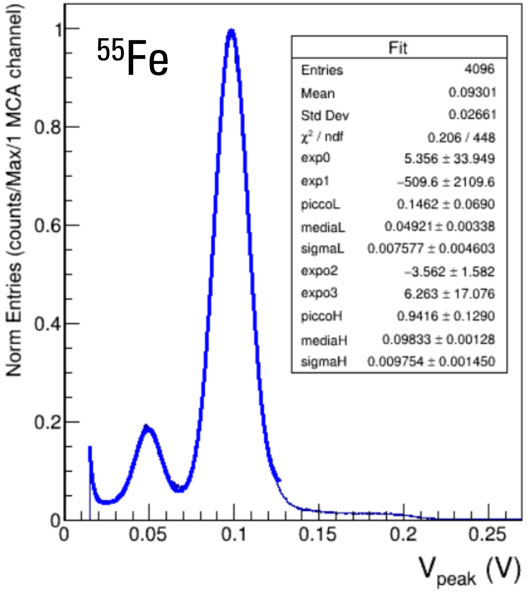


- Centroid optimisation that considers the specifics of each detector, i.e. its resistive spark protection structure (ongoing)

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

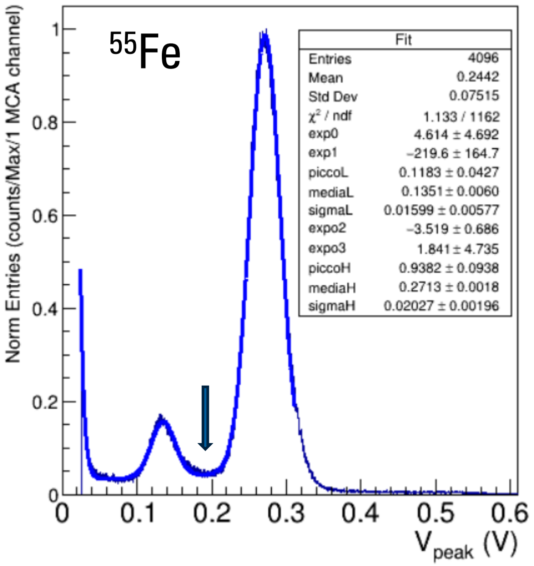
DLC-20 (best case)

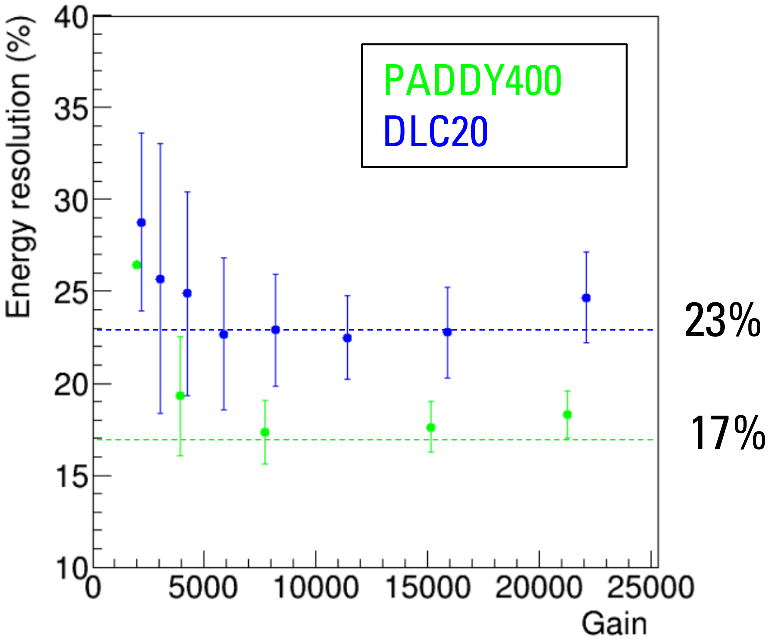
$$\frac{\text{FWHM}}{\text{peak pos}} = \sim 23\%$$



Paddy400 (best case)

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





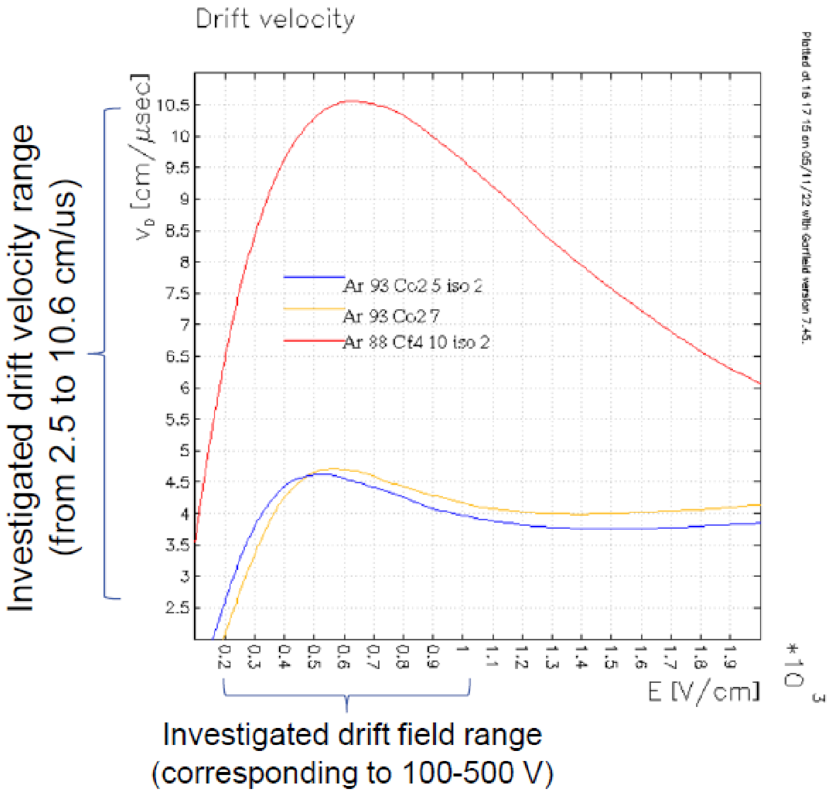
The energy resolution is ~20%. We are currently investigating how the detector design influences the uniformity and its average value.

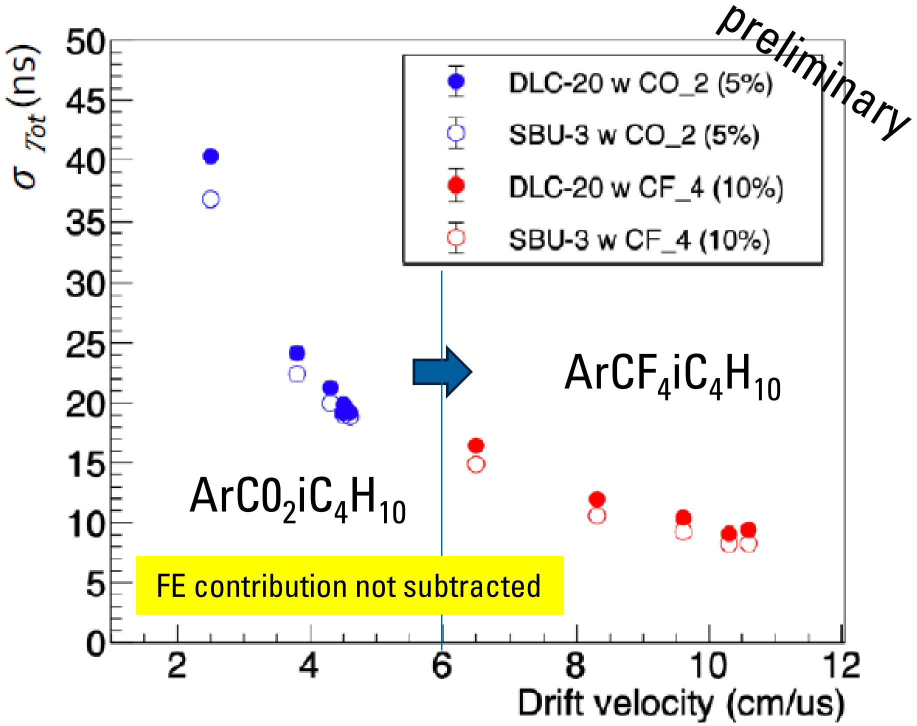
Good energy resolutions: 17-18% is the best observed value up to now.

Time information: ongoing studies

Dominant contributions (i.e. optimisable factors):
gaseous mixture, FE electronic

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



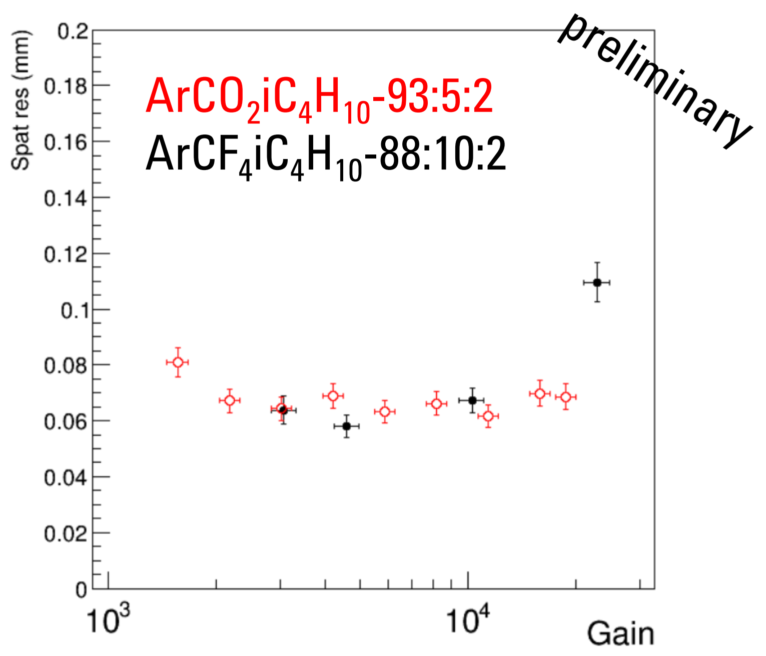


Contributions from the electronics and signal fit to extract the time is estimated to be around 4 ns from preliminary studies

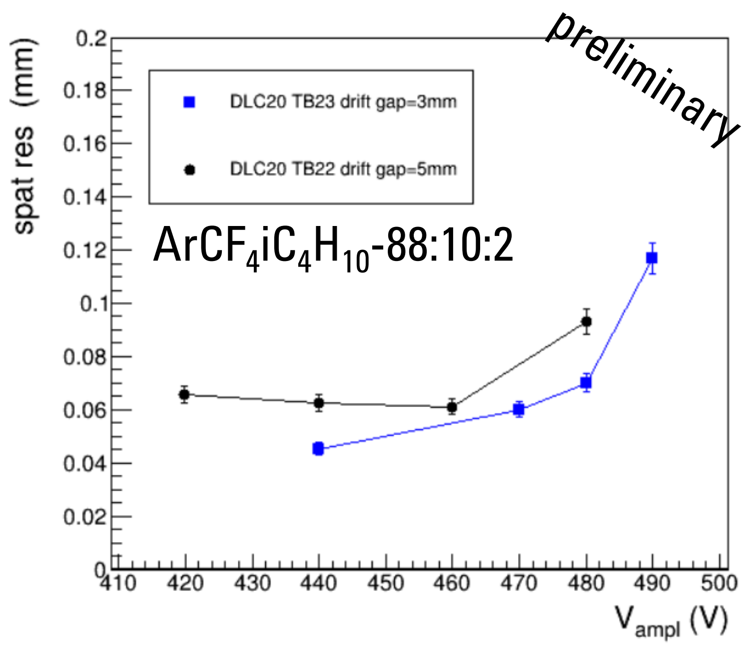
➢ Using a «faster» gas mixture (and same FE), the time resolution improves

Spatial resolution comparison

Different gaseous mixture (5 mm gap)



Different drift gap depth

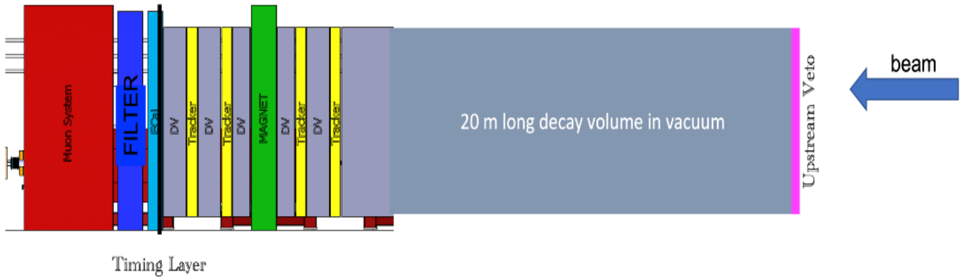


- Drift velocity does not affect spatial resolution.

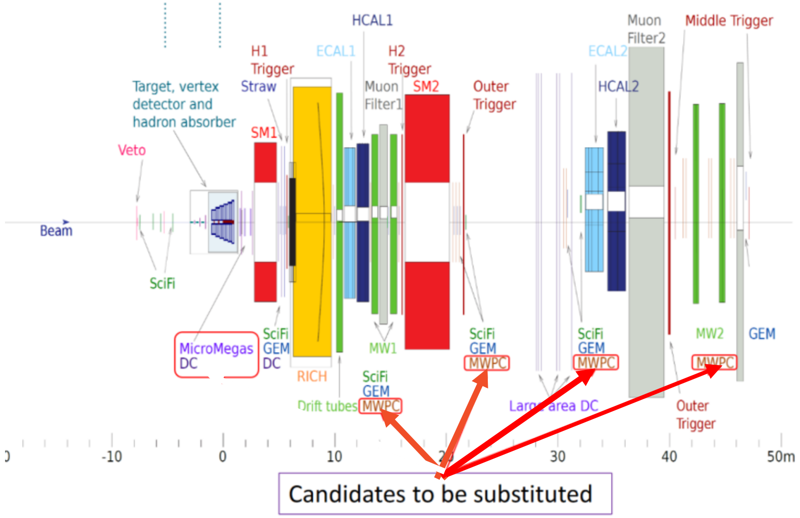
On-going proposals

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)



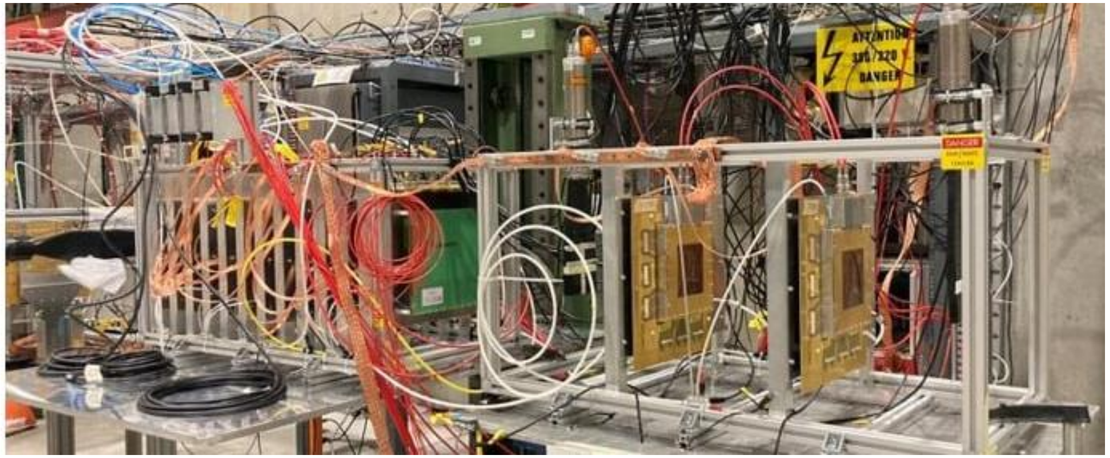
- AMBER (successor of Compass) will possibly upgrade the Muon detectors using rMM in M. Alexeev, “15th Pisa Meeting on Advanced Detectors” (link)

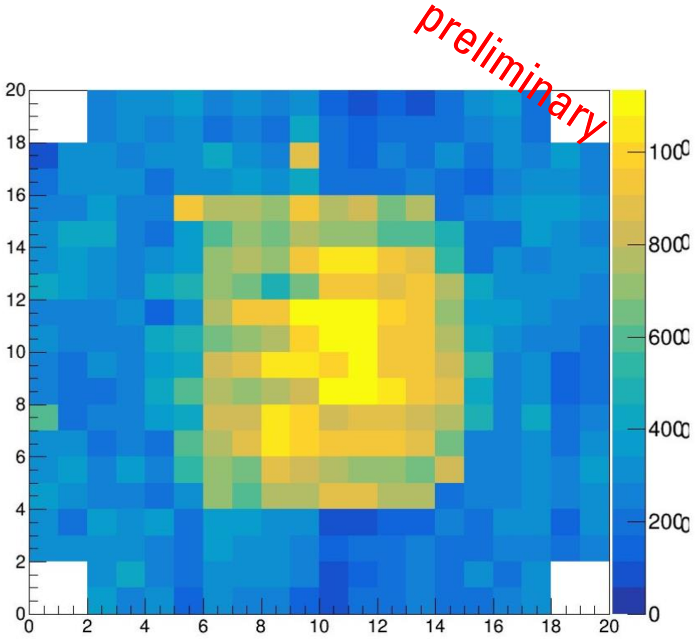


Project for other future rMM applications

- 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»

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

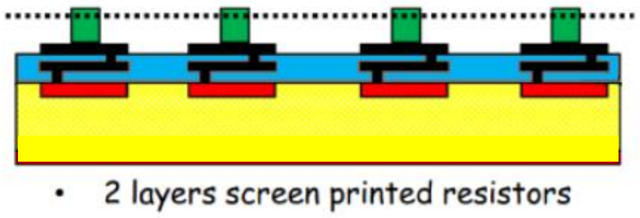
  - **stable HV behaviour,**
  - **< 100 um spatial resolution for perpendicular tracks;**
  - **< 10 ns time resolution;**

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

BACK-UP

Resistive layouts

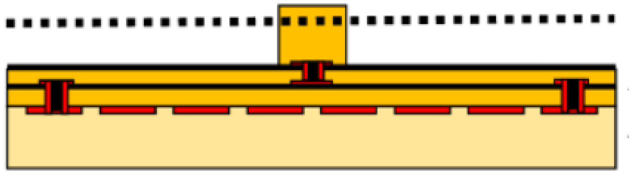
PAD-P embedded resistors



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

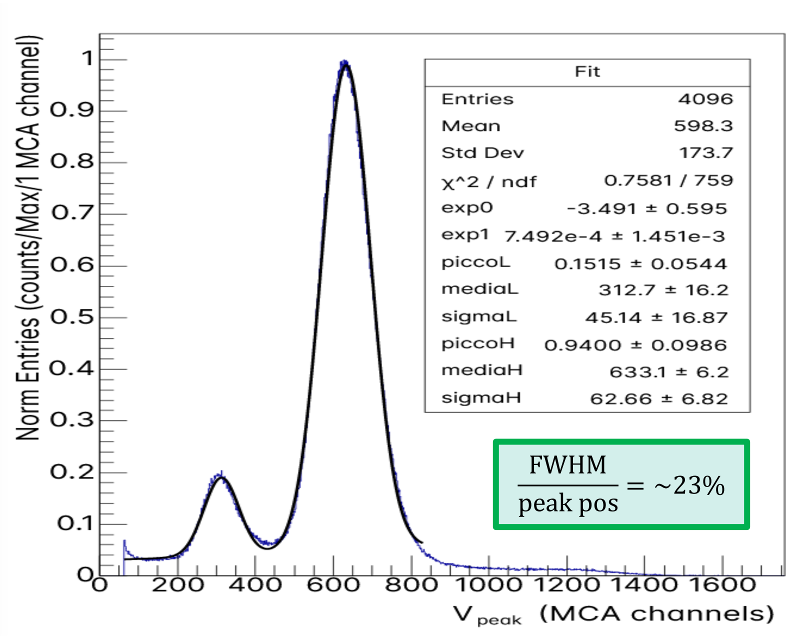


DLC foils interconnected by evacuation vias

- 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)

^{55}Fe spectra

DLC-20 (best case)



Paddy400 (best case)