RESISTIVE PIXELIZED MICROMEGAS: TIME PERFORMANCE STUDIES

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Objectives of the project

They were presented in details during MPGD2022:

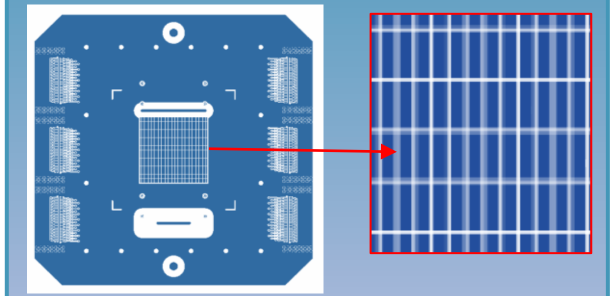
- M. Iodice et al., **«Towards Large Size Pixelized Micromegas for operation beyond 1 MHz/cm^2"**

Briefly, they are:

- Consolidation of resistive Micromegas technology with pad readout for operations at O(10 MHz/cm^2) rate;
- Stability of operation at high gain factors;
- Simplification of construction technique and realization of large area prototypes;

Most of objectives are achieved.
Large detector 20x20 cm^2 built and tested (MPGD2022)
Coming next: very large 50x50 cm^2 prototype – expected in Summer

PIXELATED ANODIC PLANE



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

Time performance studies

We carried out these studies with the aims:

- To measure the overall time resolution of few prototypes;
- To study the dependence of the time resolution as a function of drift velocity;

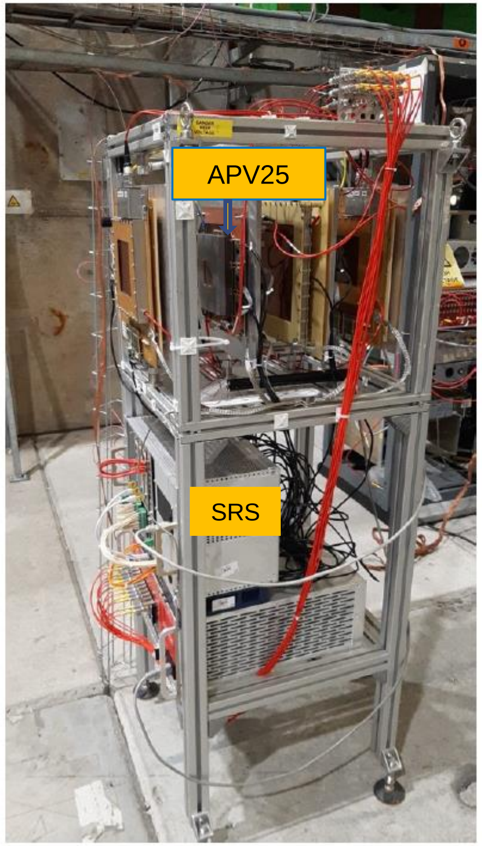
NEXT SLIDES:

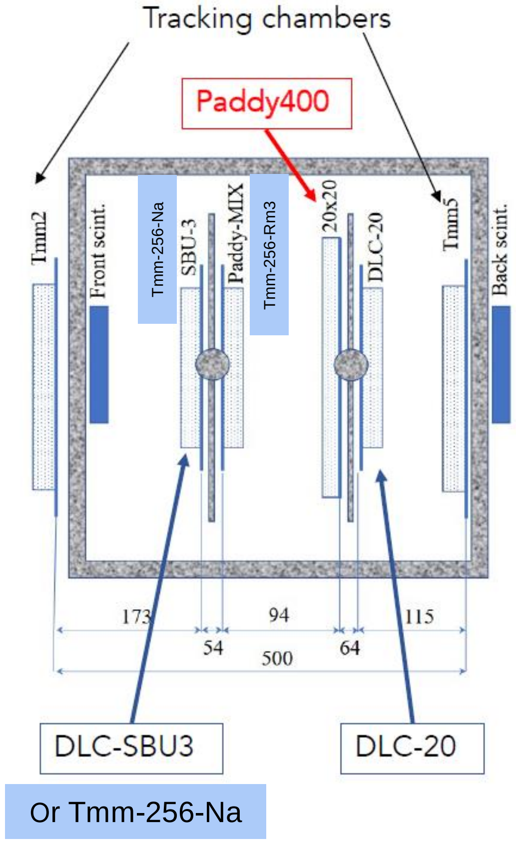
- Description of our experimental setup;
- Methodology of the measurements;
- Comparison with simulations;

Description of experimental setup

150 GeV/c
μ beam

CERN SPS
H4 line





Two plastic (10x10 cm^2) scintillators
→ SRU trigger signal = Vetod Scintillator AND (rate 300 Hz)

Two Resistive Strip bulk-MM (Tmm) chambers as external tracking chambers
(XY readout strips in two different planes, and resistive strips overlapping the X ones)

Two new Tmm-256 chambers
(XY readout strips in two different planes, and a DLC foil as spark protection resistive layer)

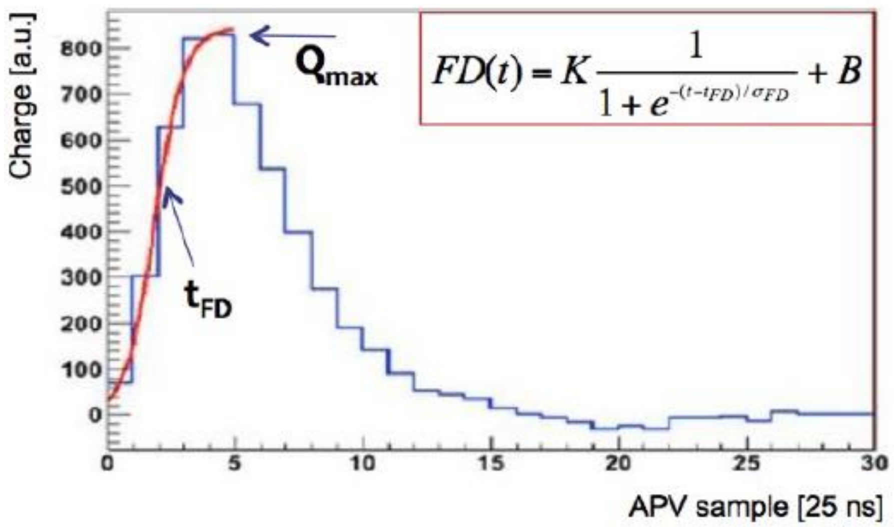
Four resistive pad-mm (SBU3, Paddy-Mix, Paddy400, DLC-20)

FE: 26 hybrid APV25 chips, 2 FECs v6, SRS system.

Two gasesous mixtures: the «standard» $ArCO_2iC_4H_{10}$ (93:5:2) and the «fast» $ArCF_4iC_4H_{10}$ (88:10:2)

Time definitions

For each hit, the associated time is estimated by the fit below



Based on t_{FD}, 3 different time definitions are taken into account at cluster-reconstruction level:

1. **Earliest time among the pad/strips that form a cluster** (E);

2. Mean of times associated to the pad/strips of a cluster (M);
3. Charge-weighted mean of the times associated to the pad/strips of a cluster (wM);

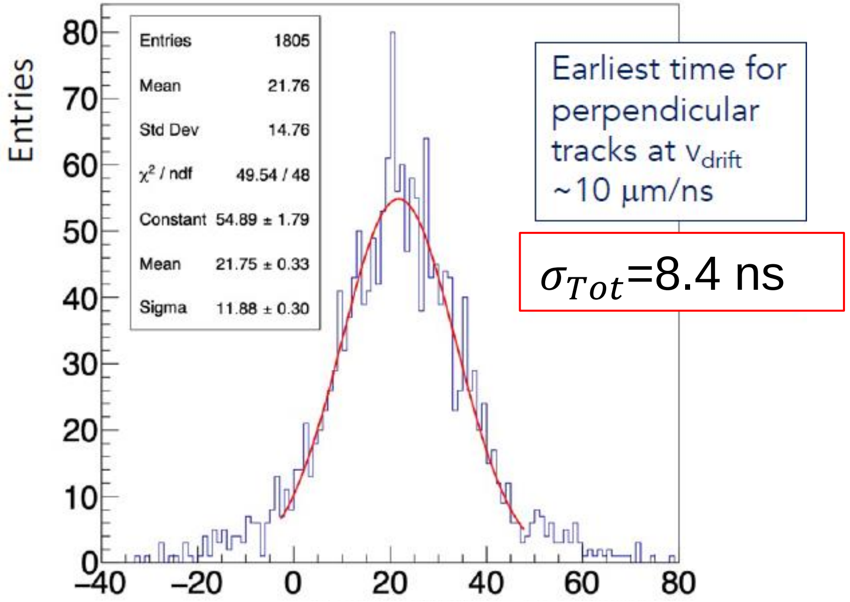
Differently from the definition 1., the 2. and 3. include the effects of signal sharing among readout pads (which is also affected by resistive structures in our prototypes).

Methodology

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

$$\sigma_{Tot} = \frac{\sigma_{ch2-ch1}}{\sqrt{2}}$$

Fit function: gaussian

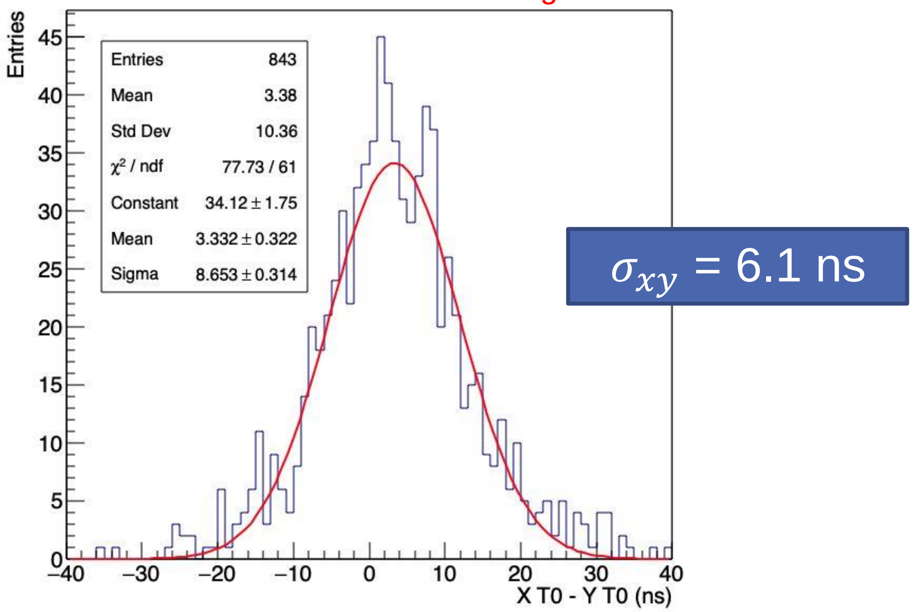


ch2 T0-*ch1* T0

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

$$\sigma_{xy} = \frac{\sigma_{X-Y}}{\sqrt{2}}$$

Fit function: gaussian



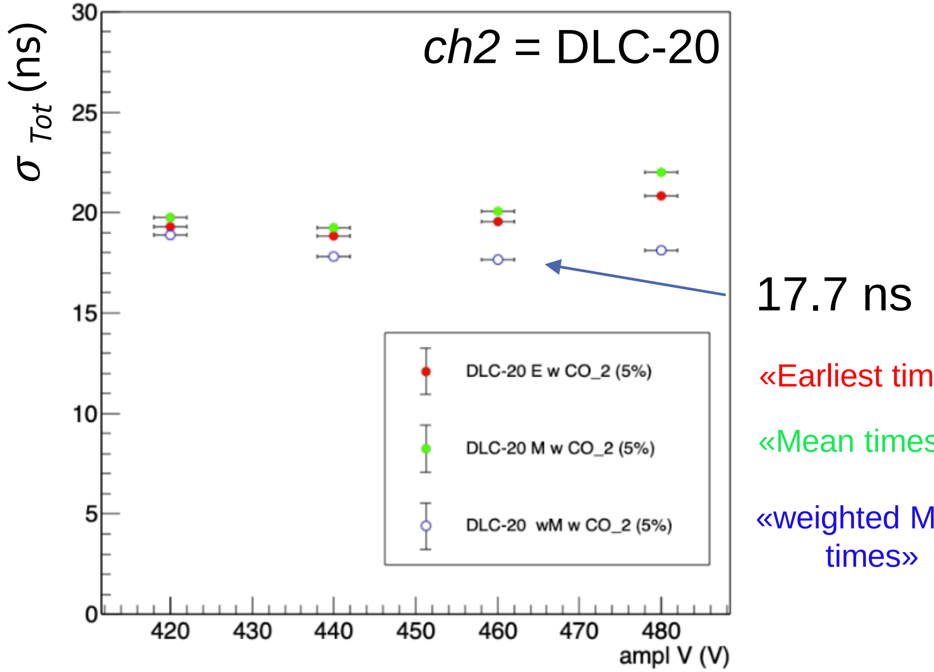
With Resistive Strip bulk-MM, it is possible isolated the contribution σ_{xy} corresponding to the same signal, whose main factors are from electronics and time fit procedure.

ch = chamber

σ_{Tot} vs Amplication voltage (perpedicular tracks)

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

V drift ~ 4.5 cm/us



«Earliest times»

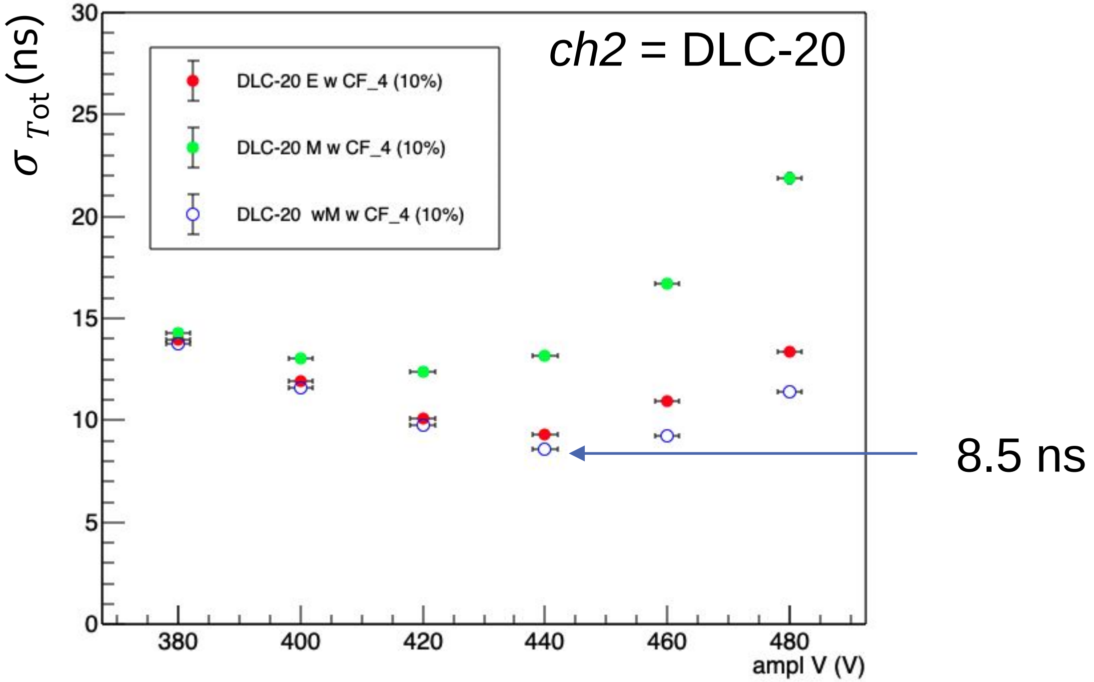
«Mean times»

«weighted Mean times»

with moderately low velocity, the overall time resolution shows a ~ flat behaviour

Mixture $ArCF_4iC_4H_{10}$ (88:10:2)

V drift ~ 10.5 cm/us



at higher velocity (better resolutions), we observe an improvement with gain increase (up to 440 V)

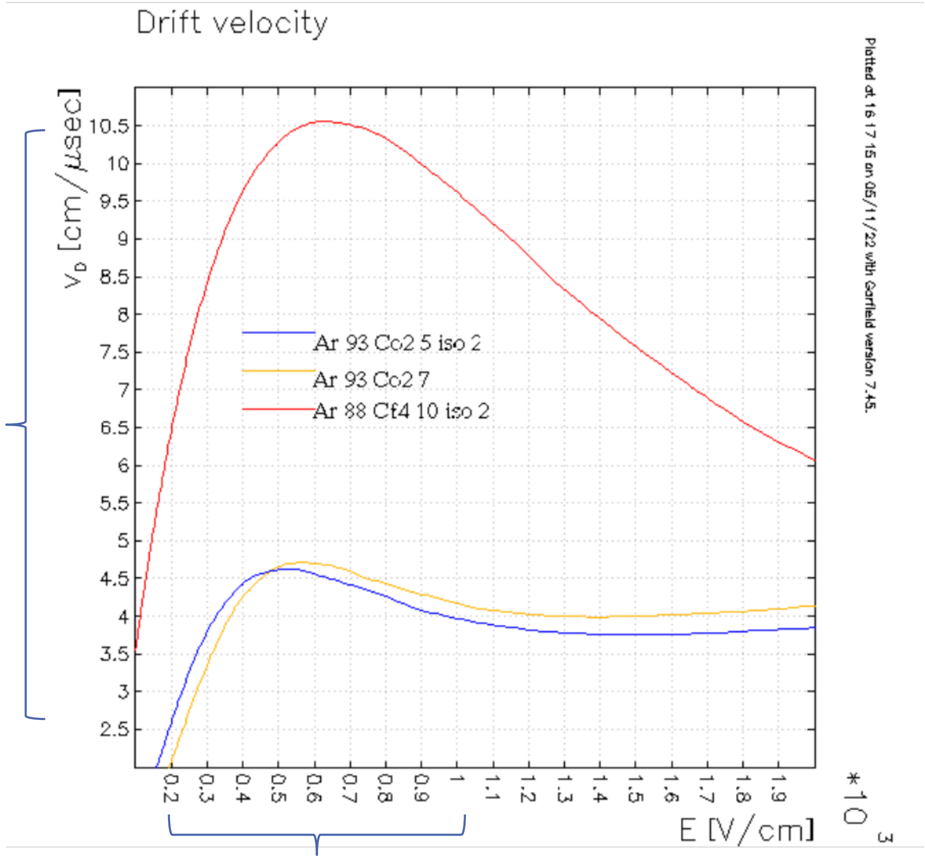
The rise is due to APV channel saturation at high amplification voltages

σ_{Tot} vs drift velocity (perpedicular tracks)

Used the «ATLAS-like» mixture Ar:CO_2:iC_4H_{10}(93:5:2) and the «fast» mixture Ar:CF_4:iC_4H_{10}(88:10:2).

The chambers have 0.5 cm drift gaps, then:

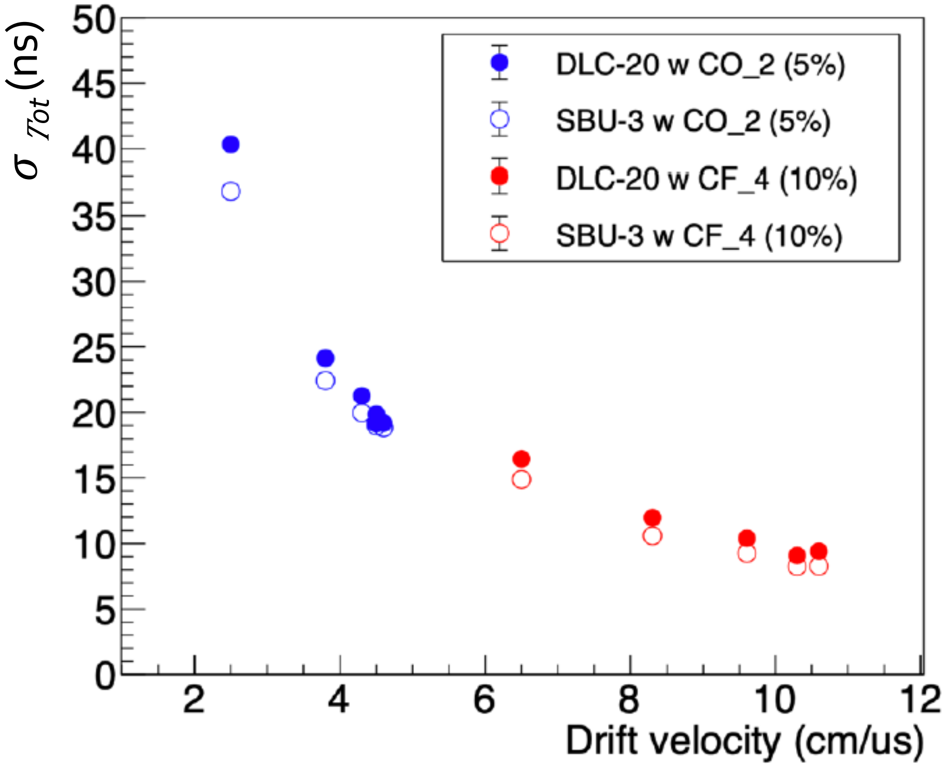
Investigated drift velocity range (from 2.5 to 10.6 cm/us)



Investigated drift field range (corresponding to 100-500 V)

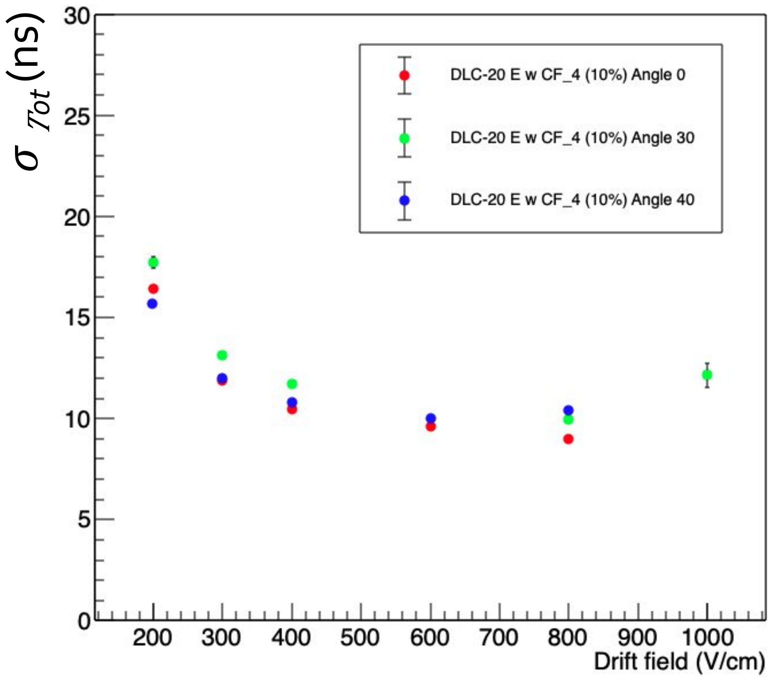
Angle 0°, V_{ampl} 440 V

Based on earliest times

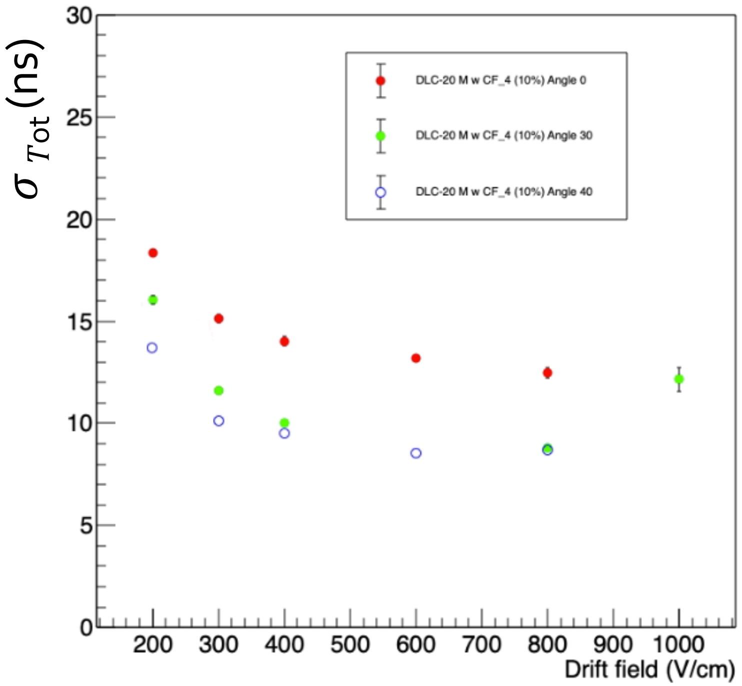


σ_{Tot} vs incident angles (V_{ampl} = 440 V, *ch2* = DLC-20)

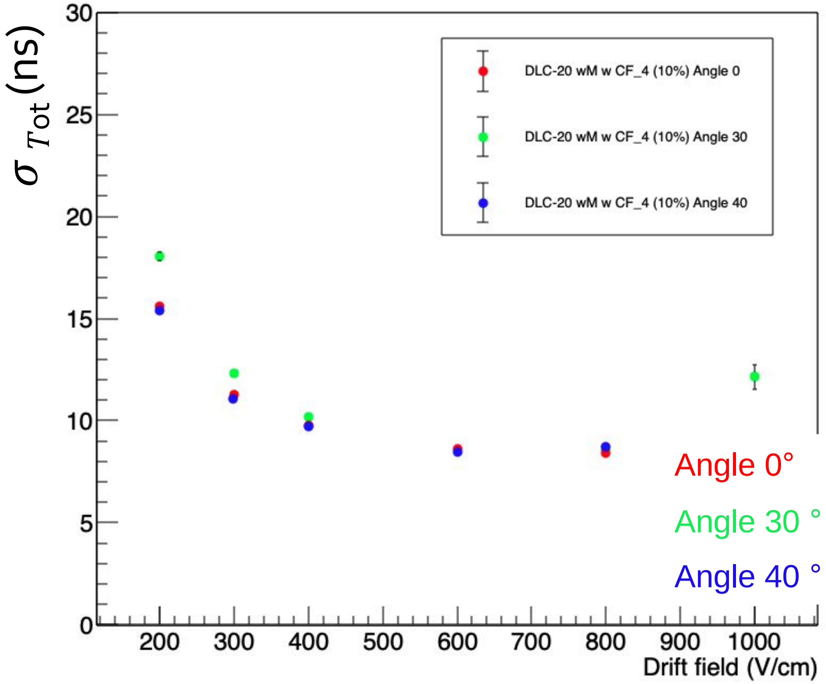
Based on «earliest time»



Based on «mean time»



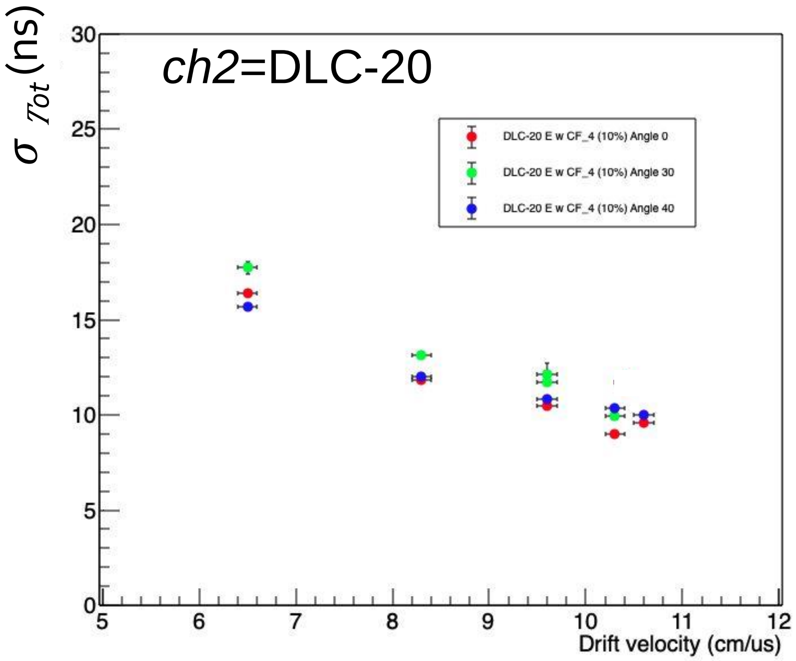
Based on «weighted time»



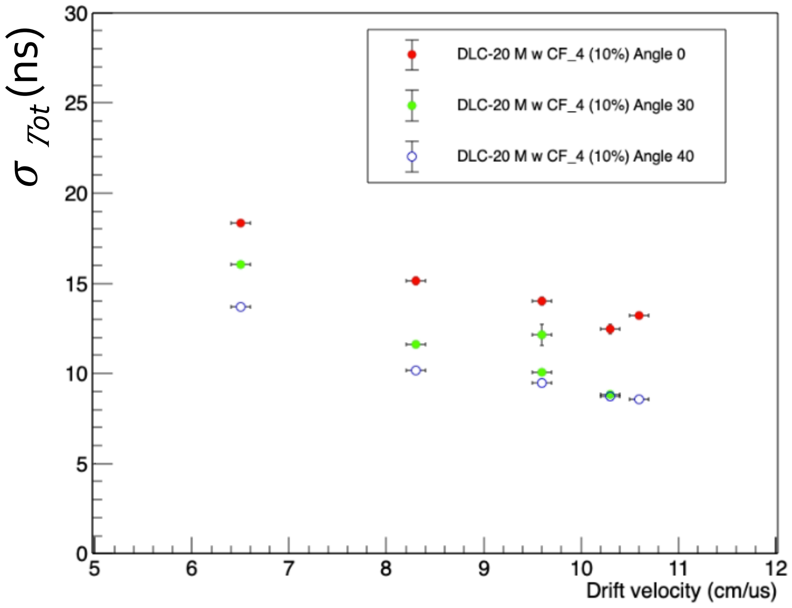
As expected, σ_{Tot} based on «earliest time» or «weighted mean time» definition does not show a clear trend as a function of the angle. While σ_{Tot} based on «mean time» definition improves as the incident angle becomes larger.

σ_{Tot} vs incident angles (V_{ampl} = 440 V) and drift velocity

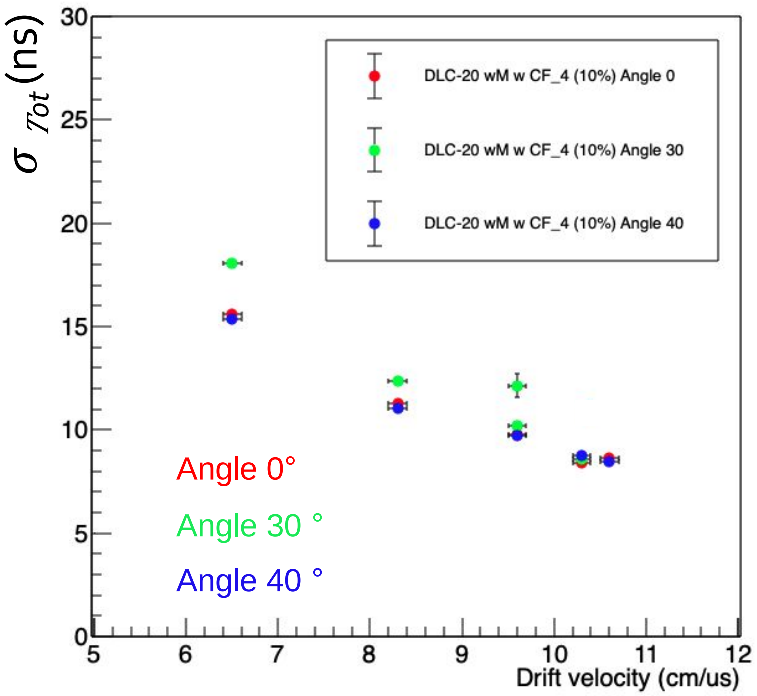
Based on «earliest time»



Based on «mean time»



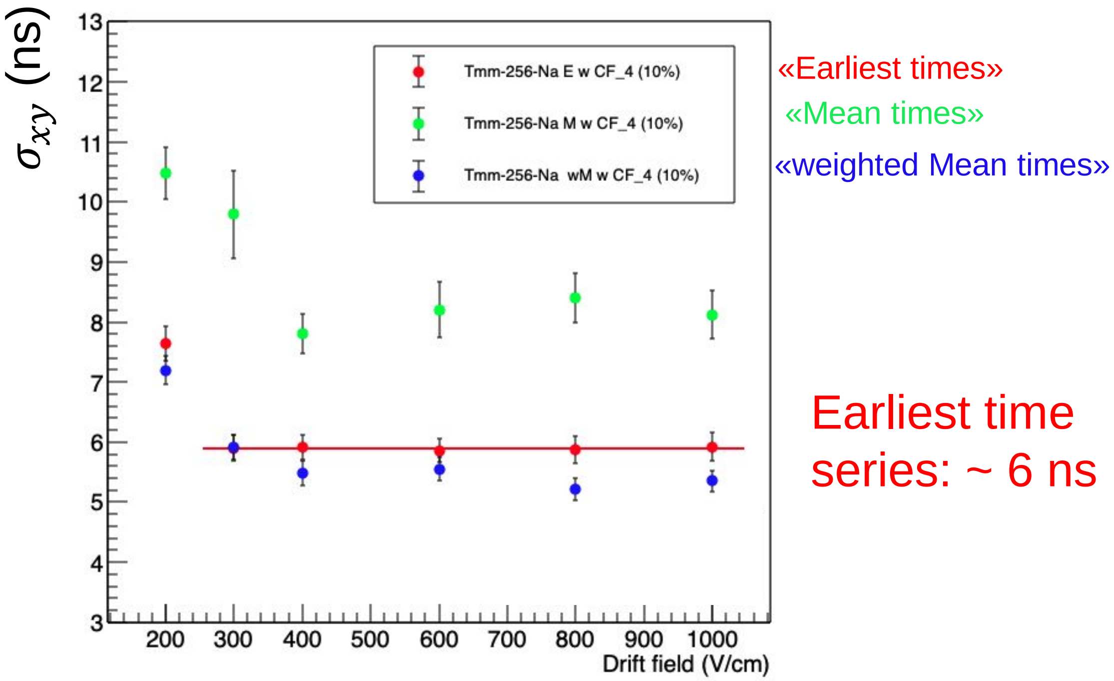
Based on <<weighted time»



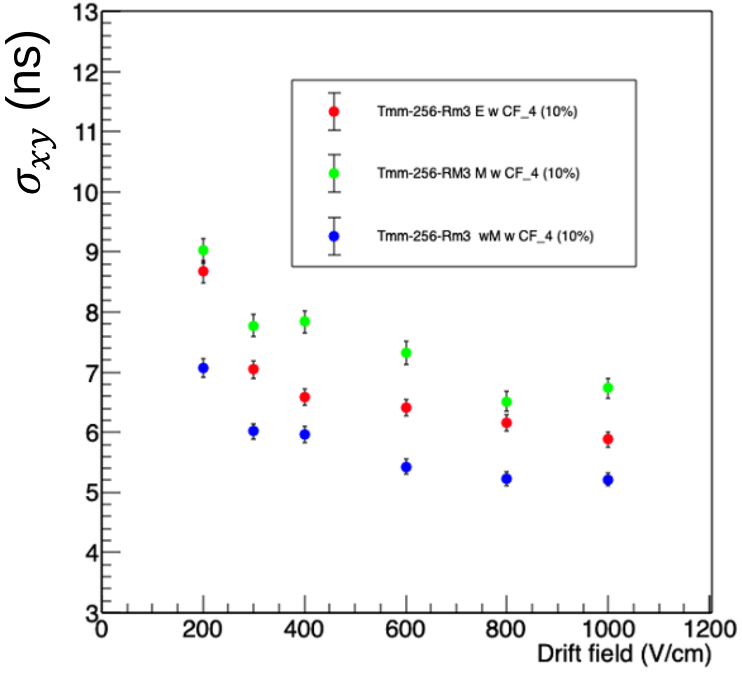
Similar comments as slide before, ongoing deeper investigations at V_{ampl} 460 V

Estimates of σ_{xy} in Tmm-256 chambers

σ_{xy} **vs drift field in Tmm-256-Na (**V ampl **450 V**, angle 0°, mixture $ArCF_4iC_4H_{10}$, DLC resisitivity around 10 MΩ/square**)**



σ_{xy} **vs drift field in Tmm-256-Rm3 (**V ampl **470** V, angle 0°, mixture $ArCF_4iC_4H_{10}$, DLC resisitivity around 40 MΩ/square**)**

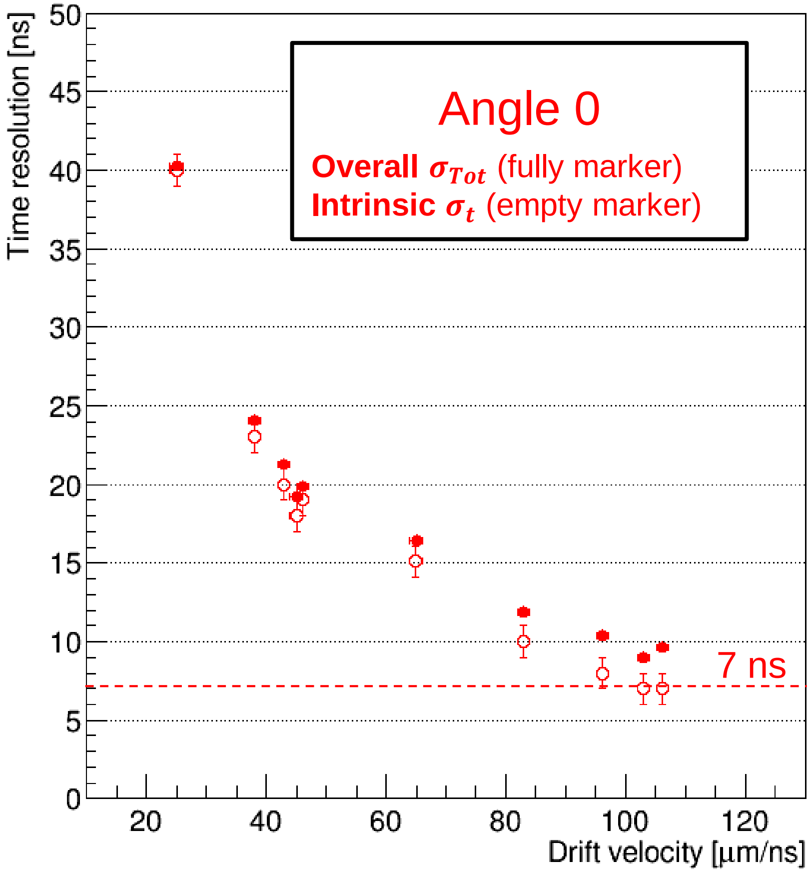


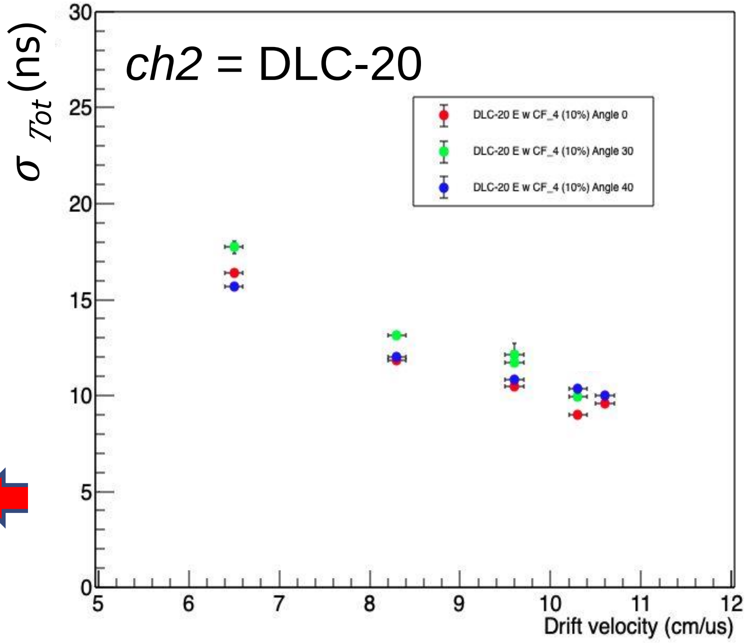
Dependance on the time definition and on the low values of Drift field. The last one becomes more severe in the case of Tmm-256-Rm3.

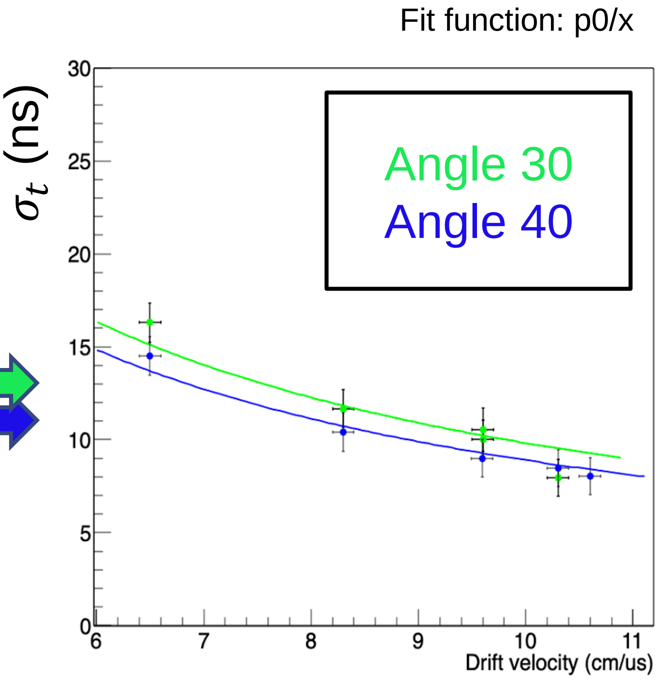
Not found a unique contribution to apply on all the investigated cases. Just applied in NEXT SLIDE

First attempt of σ_t estimate

The contribution from electronics and time fit method (σ_{xy} in previous slide) is squared subtracted from σ_{Tot} in the case of earliest times,







In the case of *ch2*=Paddy400 (slide 6), the best intrinsic time resolution $\sigma_t < 6$ ns, too.

Toy-MC in a nutshell

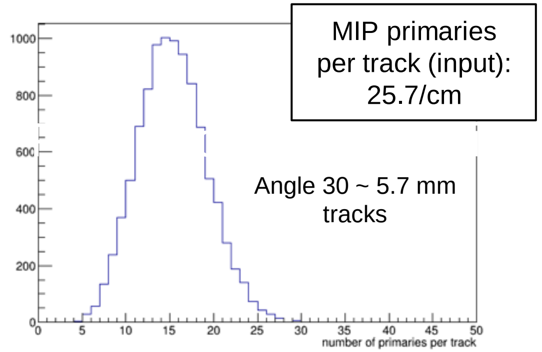
Recently developed a toy-MC to have an easy and flexible software for Micromegas time resolution studies

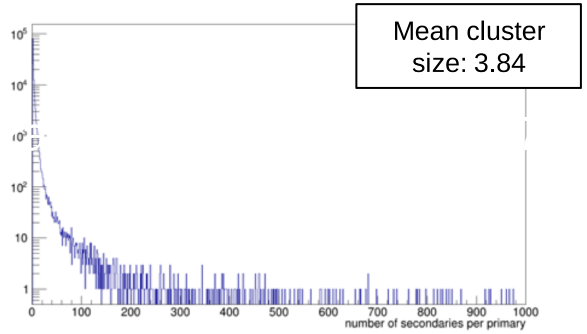
It is based on/it includes:

- Poissonian pdf (for primary ionizations) and Ref 1 (for secondary ionizations in Back-up slide 21);
- Polya pdf for Amplification gain (set G = 6000);
- APV25 shaper transfer function

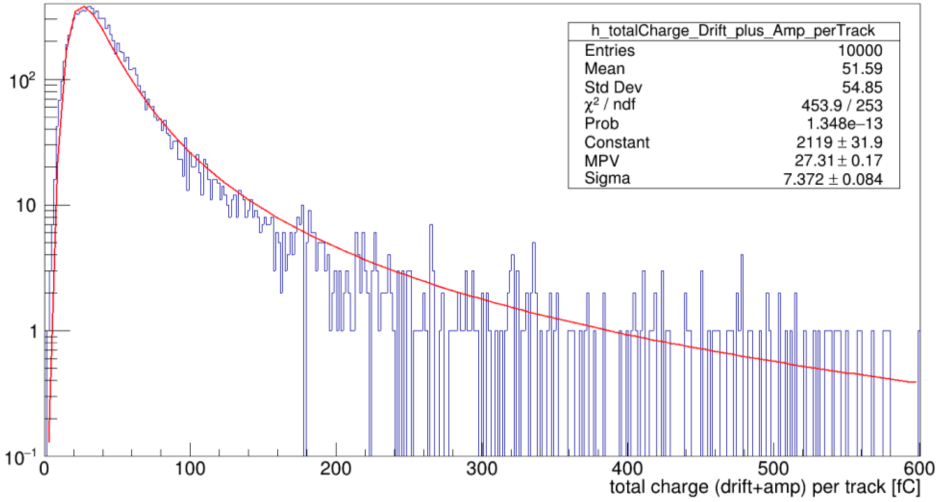
Not included electric fields and resistive spark protection layer

Primary and secondary ionizations (case Ar:CO2 93:7)

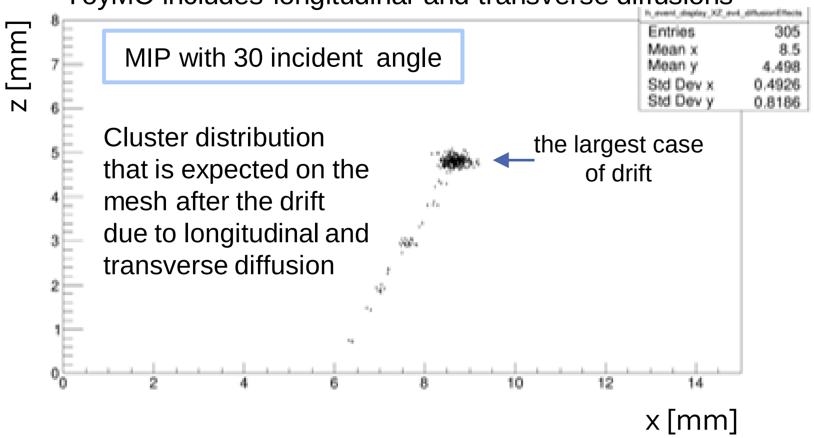




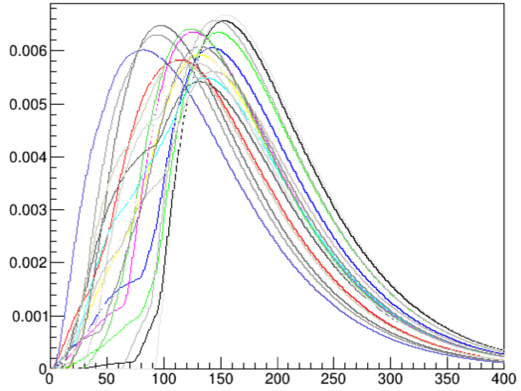
Total charge in the amplification gap with Landau fit



ToyMC includes longitudinal and transverse diffusions

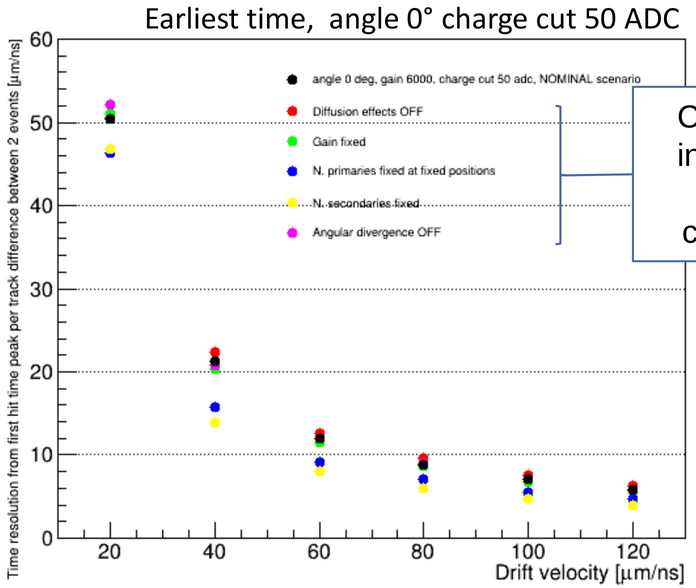


Signal on each pad using APV25 shaper transfer function



Simulated trends: «very» preliminary comparison

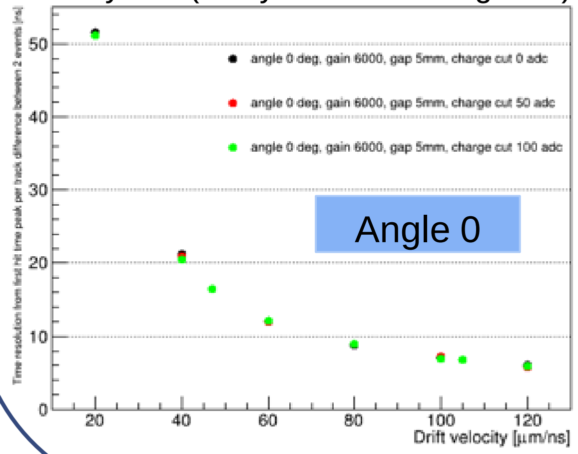
Only Toy-MC



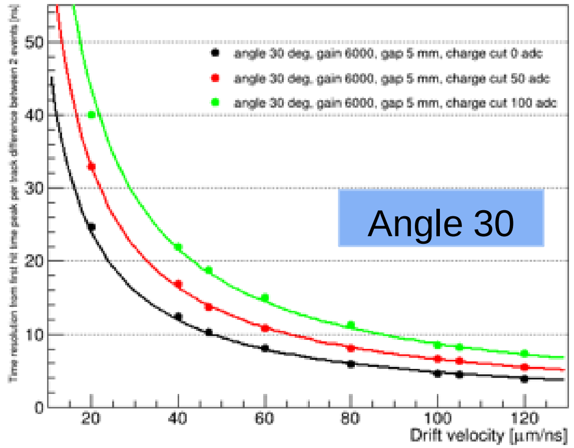
Curves where one of the input parameters is fixed (with electronics contribution always ON)

Comparing **black** (cumulative) and **blue** or **yellow**, resolutions are dominated by statistical fluctuation of **primary** and **secondary** ionizations with electronics contribution ON

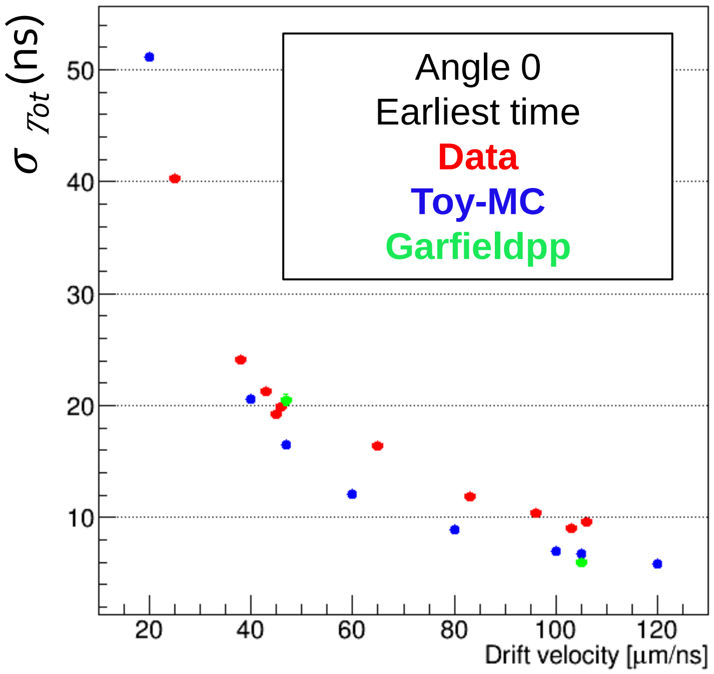
Only MC (study w.r.t. the charge cut)



Only MC (study w.r.t. the charge cut)



Fit function P0/x



This comparison is still very preliminary, because:

- Few differences btw Toy-MC and data are still present (for example time sampling, time fit procedure),
- Validation of the Toy-MC with Garfield++ (ongoing)

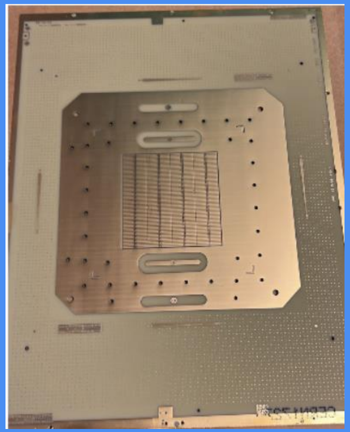
On the other hand, it shows that the Toy-MC is already in quite advanced stage.

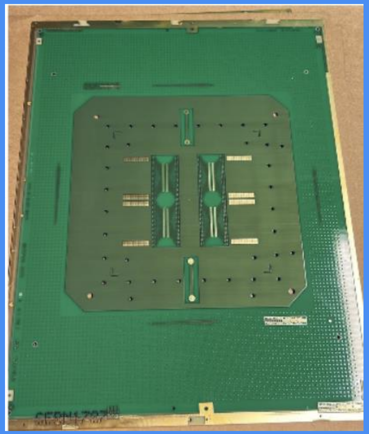
Our project in the DRD1 framework

At the moment

<u>Resistive pixelized Micromegas:</u>

- Members: 11 (title slide)
- R&D;
- Performance characterisation;
- Technological transfer (w ELTOS company);





- Application in experiment;

RD51 MPGD
&
INFN gr5

<u>Towards DRD1</u>:

- As INFN members and associates, we are involved into an internal discussion;
- Our experience now lasting for many years as members of the RD51 network is extremely positive:
  - RD51 offered us the possibility to grow our experience and skills in detector RD;
  - We could profit by the support (both knowledge and financial and inclusive approach) of common projects and common tools

The new DRD1 structure can be a good opportunity to strengthen and extend communities that carry out R&D projects

- we aim at a bottom-up approach along the lines of RD51, with a light structure (and MoU)
- the specificities and main goals of DRD1 should be taken into account

Our group is already involved in the preparation of the DRD1 proposal and is ready to support the proposed structure and the future implementation, while continuing to actively participate in the internal discussion inside INFN

Conclusions

A dedicated study of time performance of resistive Micromegas with pad readout was presented as function of Vampl, drift velocity, and incident angle:

- Different time definitions were taken into account to estimate the overall time resolution:
  - at 0 incident angle and as function of Vampl: at a moderate drift velocity, a smoother trend is observed than the one at an higher velocity. In both the cases, local minima were observed, the rise at high amplification voltage is reasonable due to the APV channel saturation;
  - As a function of incident angles:
    - Due to the pad size, the estimate method is no sensitive to incident angle < 20° (from previous studies)
    - Investigated 30°, 40° angles: clear trend in the case of mean time definition.

Overall time resolutions < 10 ns using the «fast» $ArCF_4iC_4H_{10}$ (88:10:2) mixture. In the first attempt to remove the contribution from electronics and analysis, we found time resolutions < 6 ns.

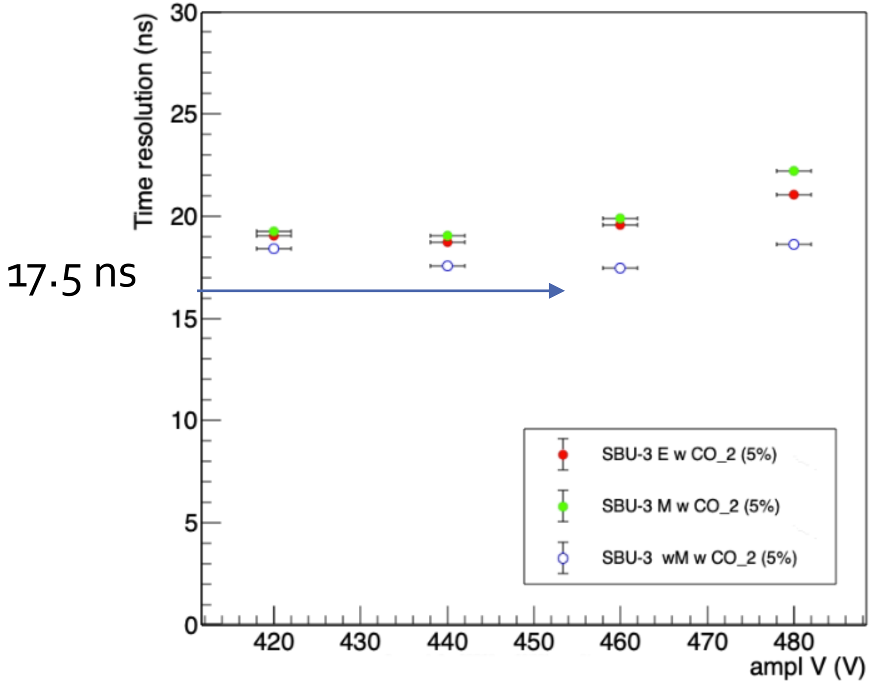
The study includes a comparison with toy-MC simulations (still ongoing):

- It is ready to be validated with Garfield++.
- With the previously reported caveats, the very preliminary comparison btw ToyMC and data already shows that the proposed ToyMC could be a proficient tool to complete the study of time performance

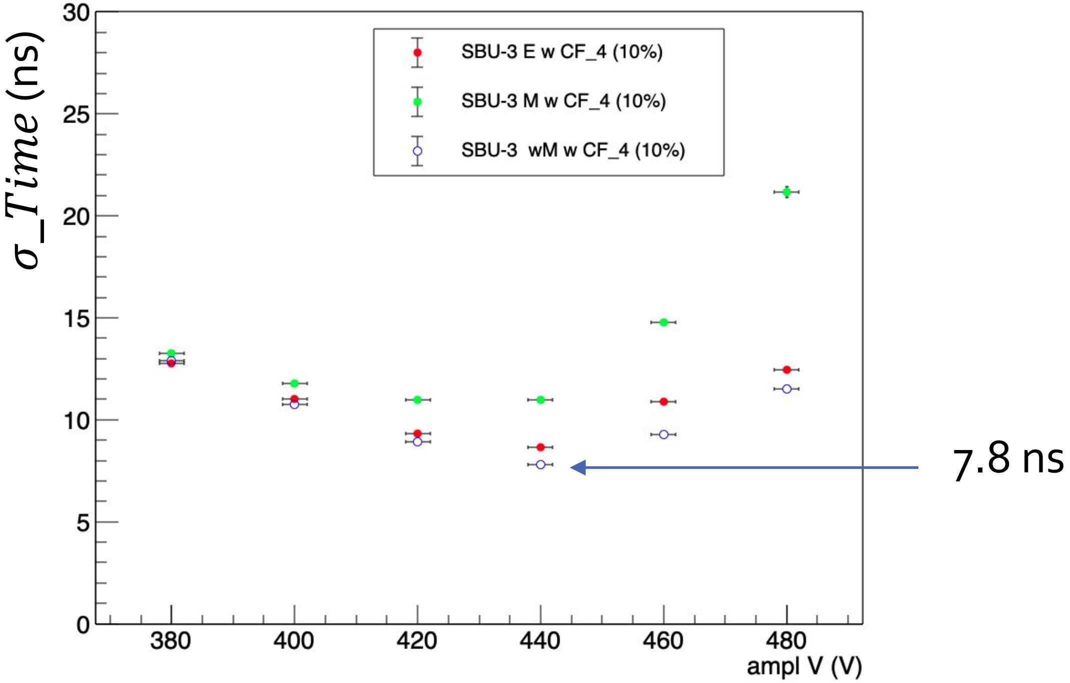
BACK-UP

Vs Amplication field (SBU-3, 0 incident angle)

Mixture ArCO2iC4H10



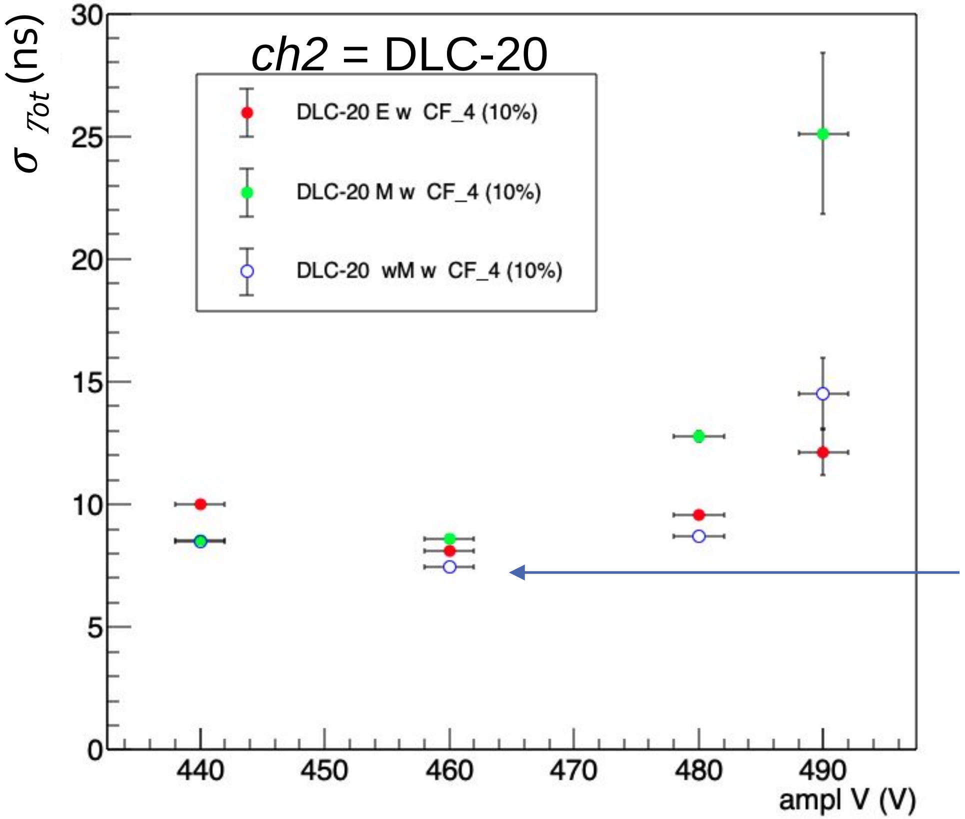
Mixture ArCF4iC4H10



σ_{Tot} vs Amplication voltage (40° incident angle)

Mixture $ArCF_4iC_4H_{10}$ (88:10:2)

V drift ~ 10.6 cm/us



7.4 ns

At 40° incident angle, the best values seems to shift towards higher amplification voltage (+20 V).

It would be worth to repeat the studies at higher gains without the issue of electronic channel saturation

Preliminary Data and Toy-MC coarse agreements

In parallel, a Toy MC is implemented to complete the interpretation of the experimental results as function of minimum cut on cluster charge, incident angle and other parameters (drift gap, FE integration time..) :

- For perpendicular tracks, the earliest, mean and weighted mean time show similar performance **(in agreement with data at low gain)**
- In a standard configuration (Ar:CO2, vdrift 47 μm/ns, gain 6000, gap 5 mm, pitch 1 mm) the time resolution is found to be ~16 ns for perpendicular tracks and 8-14 ns at 30°, depending on the charge cut **(in agreement with data)**
- For vdrift ≥ 100 μm/ns, time resolutions of ~6 ns are achieved for 5 mm drift gaps **(the data overall time resolution σ_{Tot} ~7-8 ns)**

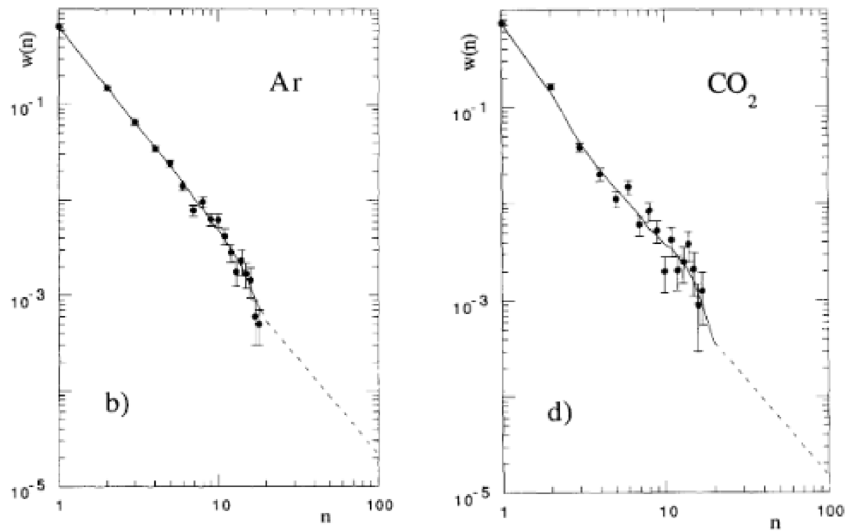
Toy-MC inputs: Ref 1 for secondary ionization

202 Nuclear Instruments and Methods in Physics Research A301 (1991) 202–214
North-Holland

Experimental determination of ionization cluster size distributions in counting gases

Hansjörg Fischle [1], Joachim Heintze and Bernhard Schmidt
Physikalisches Institut der Universität Heidelberg Philosophenweg 12, D-6900 Heidelberg, Germany

Received 15 October 1990



	Ar (%)	CO_2 (%)
k		
1	65.6	72.50
2	15.0	14.00
3	6.4	4.20
4	3.5	2.20
5	2.25	1.40
6	1.55	1.00
7	1.05	0.75
8	0.81	0.55
9	0.61	0.46
10	0.49	0.38
11	0.39	0.34
12	0.30	0.28
13	0.25	0.24
14	0.20	0.20
15	0.16	0.16
16	0.12	0.12
17	0.095	0.09
18	0.075	0.064
19	0.063	0.048
≥20	$21.6/k^2$	$14.9/k^2$

Weighted mean used for Ar:CO2 93:7

APV Shaper transfer function

$$Signal = Q\left(\frac{t}{RC}\right)^{\alpha} e^{-\frac{t}{RC}}$$

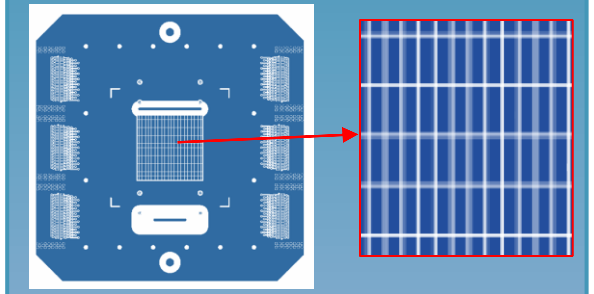
RC = 50 ns, α = 1.25

where '**t**' is the drift time of each electron created in the drift gap (not only primary electrons)
where '**Q**' is the number of electrons created in the avalanche of each electron created in the drift gap (not only primary electrons)

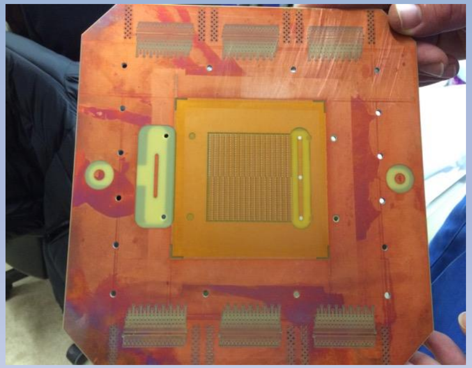
Corrected by a factor 2.65 in order to have at the peak the value of the charge that arrives to the PAD

Small-Pad resistive Micromegas detectors

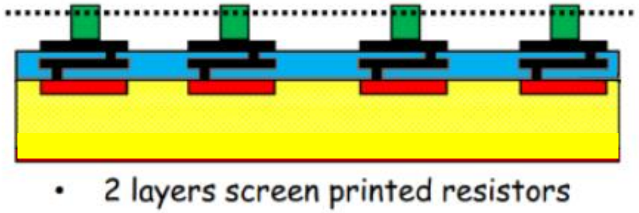
PIXELATED ANODIC PLANE



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

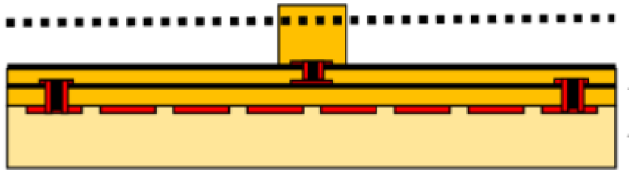


Resistive spark protection schemes



- **PAD-P**:
  micro-mesh (dot line) + pillars (green)
  Embedded pad resistors (black)
  Coverlay insulator (blue)
  Copper readout pads (red) on PCB (yellow)
  O(10) MΩ resistance btw top pad resistor and ground;

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-like** (Diamond-Like-Carbon)
  micro-mesh (dot line) + pillars (orange)
  DLC foils with 20-50 MΩ/sq (black)
  Polymide insulator (orange);
  6-12 mm vias pitch side;
  Copper readout pads (red) on PCB (beige)

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)

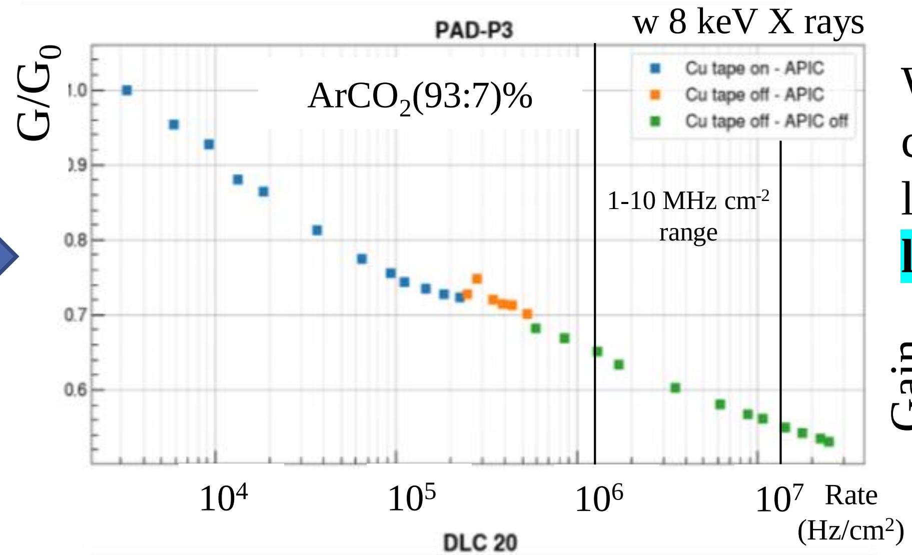
Studies of rate capability

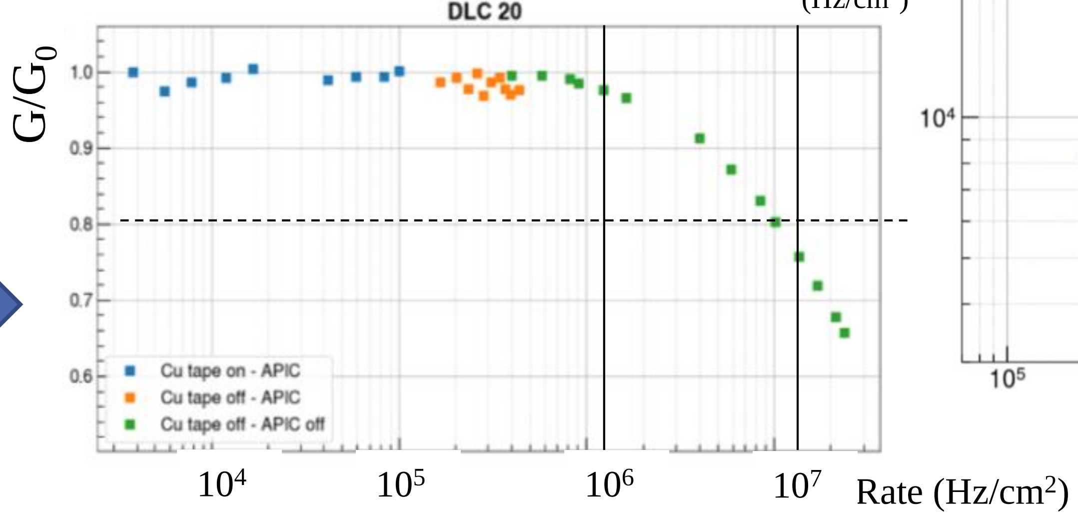
PAD-P scheme

- Relatively fast loss for rate < 0.1 MHz/cm^2 due to charging-up;
- Slower ohmic voltage drop through the individual pads at higher rates;

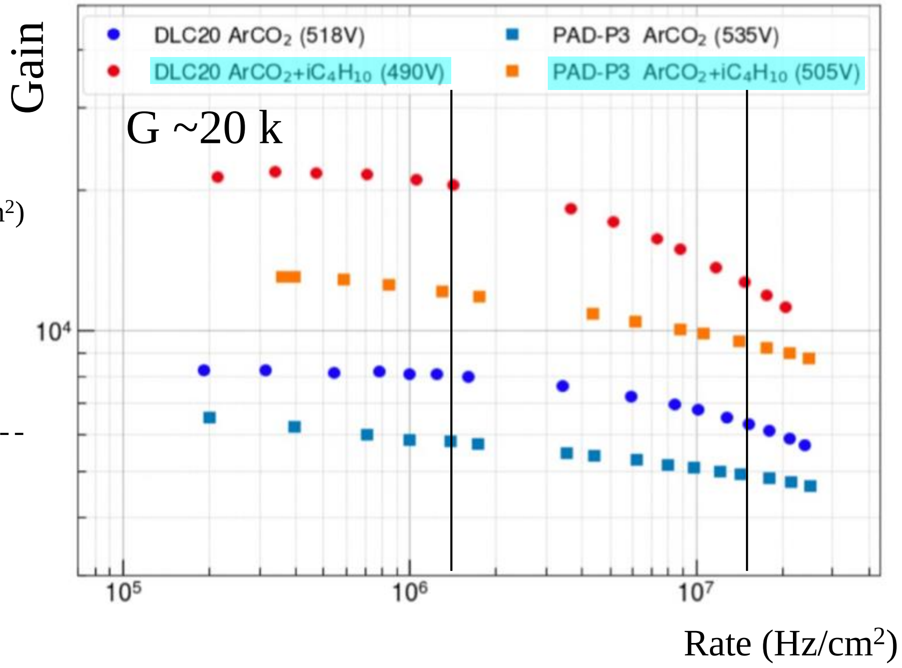
DLC-like scheme

- 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%





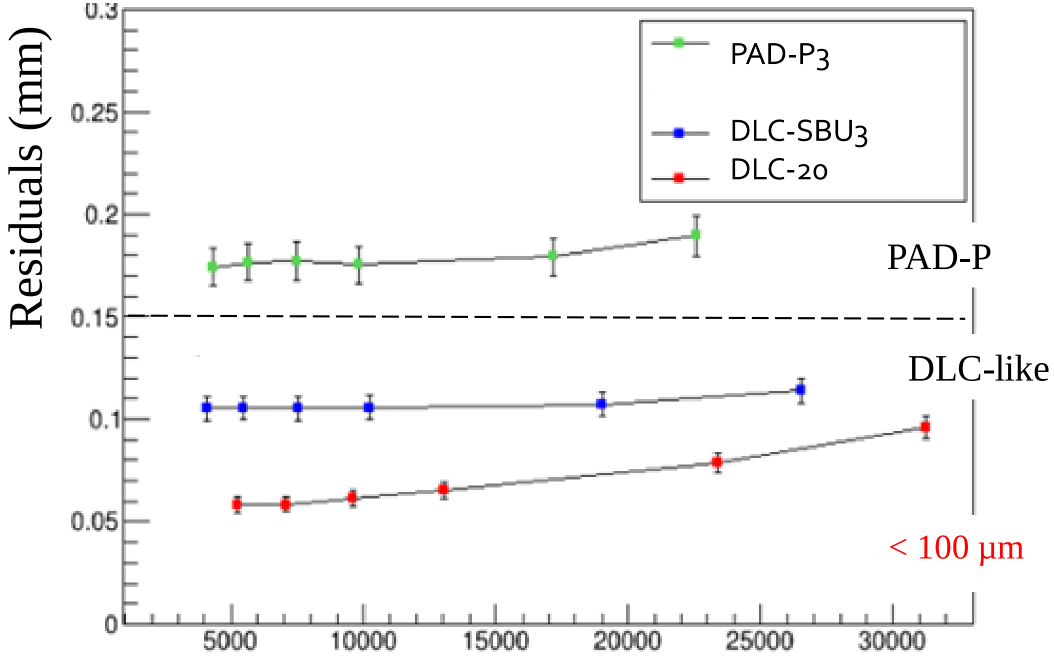
With the two mixtures, we observed compatible drops, **$ArCO_2iC_4H_{10}$(93:5:2)%** lets to work at a **higher gain** and to a **larger spark quenching.**



plots from Master thesis of S. Franchellucci (Univ. Roma Tre)

Studies of tracking performances ($ArCO_2iC_4H_{10}$(93:5:2)%)

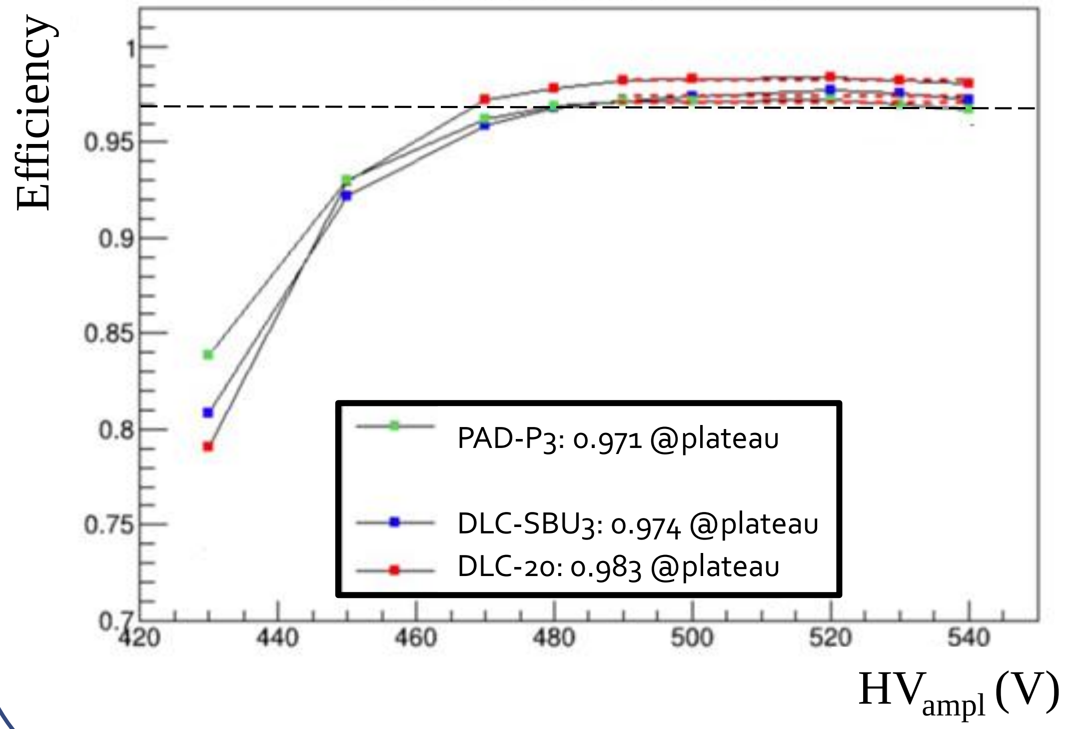
Spatial resolution (along pad short side)



w 80 GeV/c muon beam

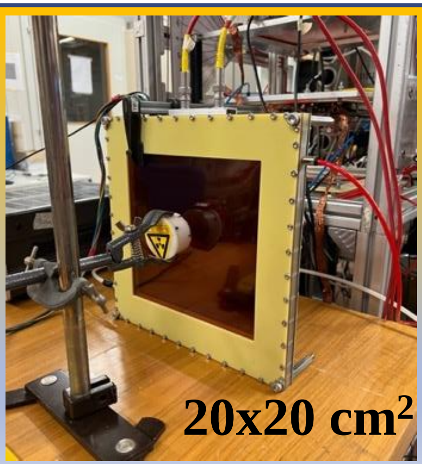
Tracking efficiency

based on cluster search within 1.5 mm fiducial range along the extropated track position in the pad short side

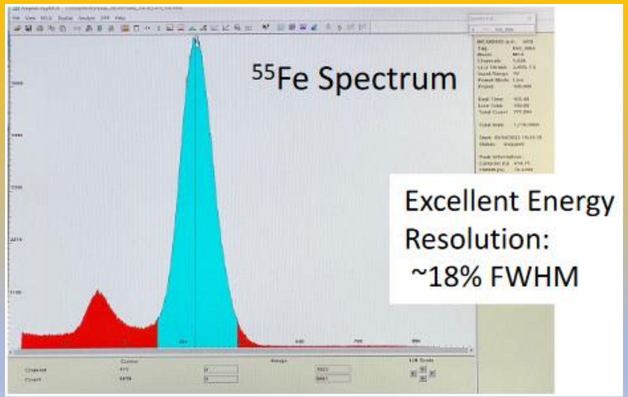


plots from Master thesis of C. Gimmillaro (Univ. Roma Tre)

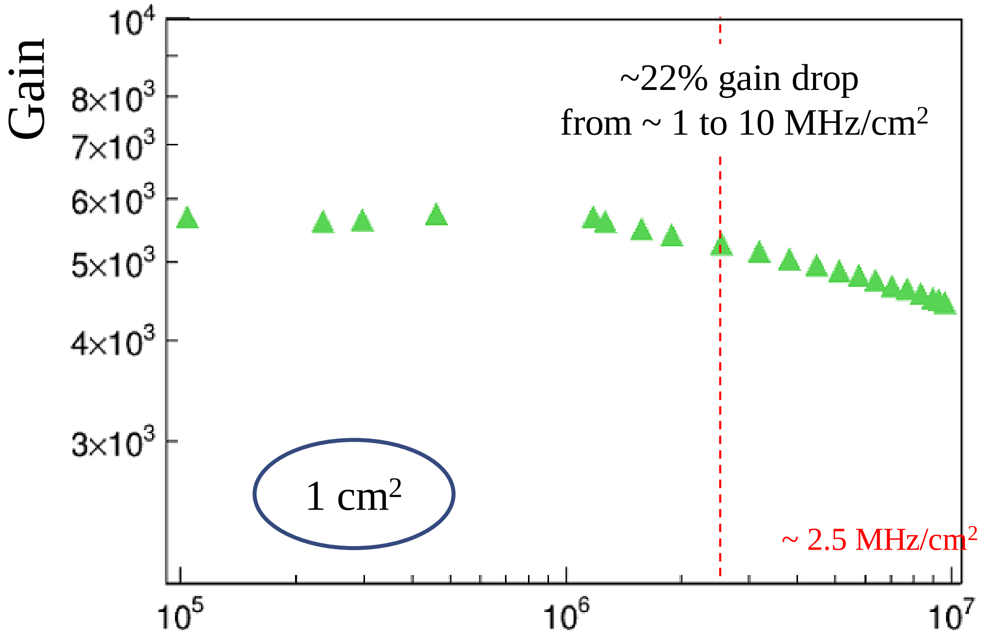
Towards large areas



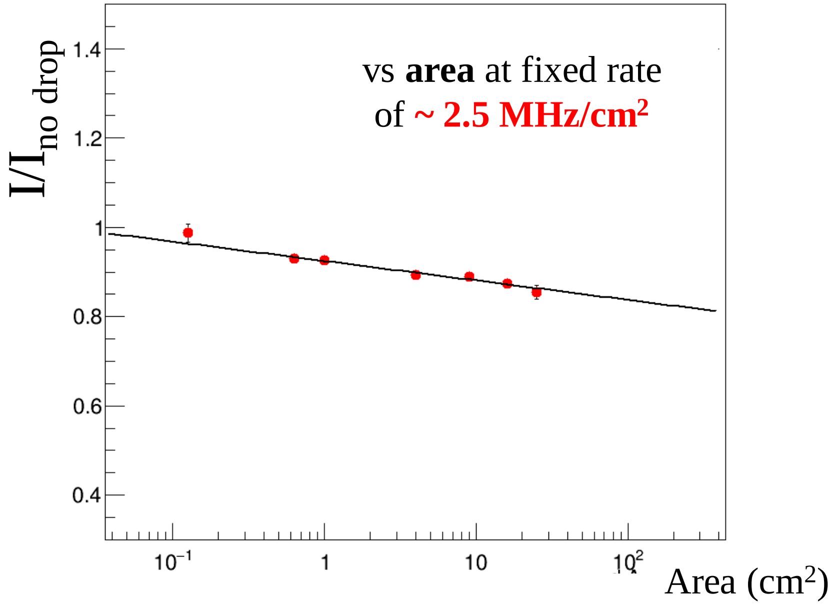
- **Pad size:** 1x8 mm^2
- **Number of Pads:** 4800
- **DLC-like layout** w 8 mm grounding vias pitch
- FE connectors on the back of the detector (partial readout)



Repeated gain/rate capability studies with ArCO$_2$(93:7)%, varying irradiated area up to 25 cm^2 max area until now.



Area dependence tends to saturate,



as already observed for smaller areas in previous study
https://indico.cern.ch/event/868940/contributions/3813865

Tracking efficiency

Tracking efficiency:

1.5 mm fiducial range wrt extrapolated position from external tracking chambers

$Ar:CO_2:iC_4H_{10}$ (93:5:2) gaseous mixture