The 8th International Conference on MPGDs

Robust photocathodes and spatial resolution studies of resistive PICOSEC Micromegas precise-timing detectors

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On behalf of the PICOSEC Micromegas Collaboration

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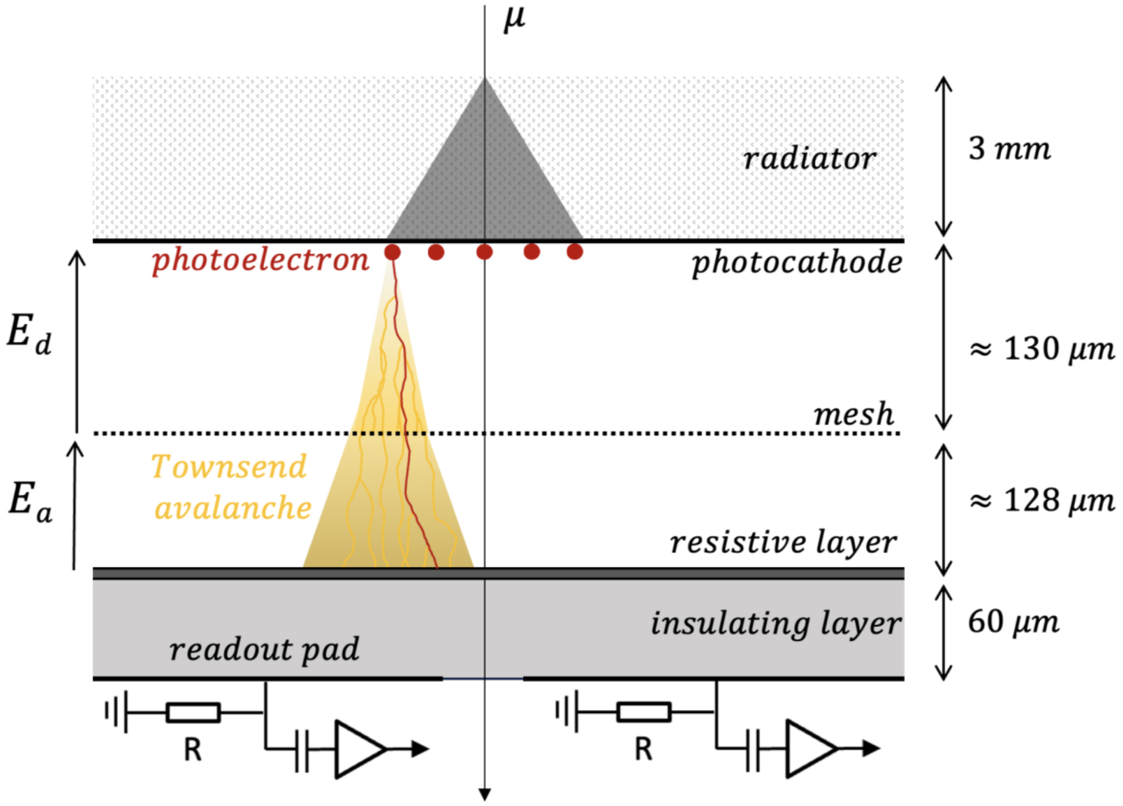
Introduction

To enable the sub-25 ps PICOSEC Micromegas precise-timing detector to perform effectively under the demanding conditions of physics experiments, we are adapting its design to improve robustness.

Outline:

- Resistive Plane PICOSEC Micromegas
  - Single-Channel Prototype
  - Increased Readout Granularity for Spatial Resolution
  - Multi-Pad Prototype with Vertical Charge Evacuation
- Robust Photocathodes
  - DLC
  - B4C
  - Graphene
- Towards an Applicable Detector
- Conclusion



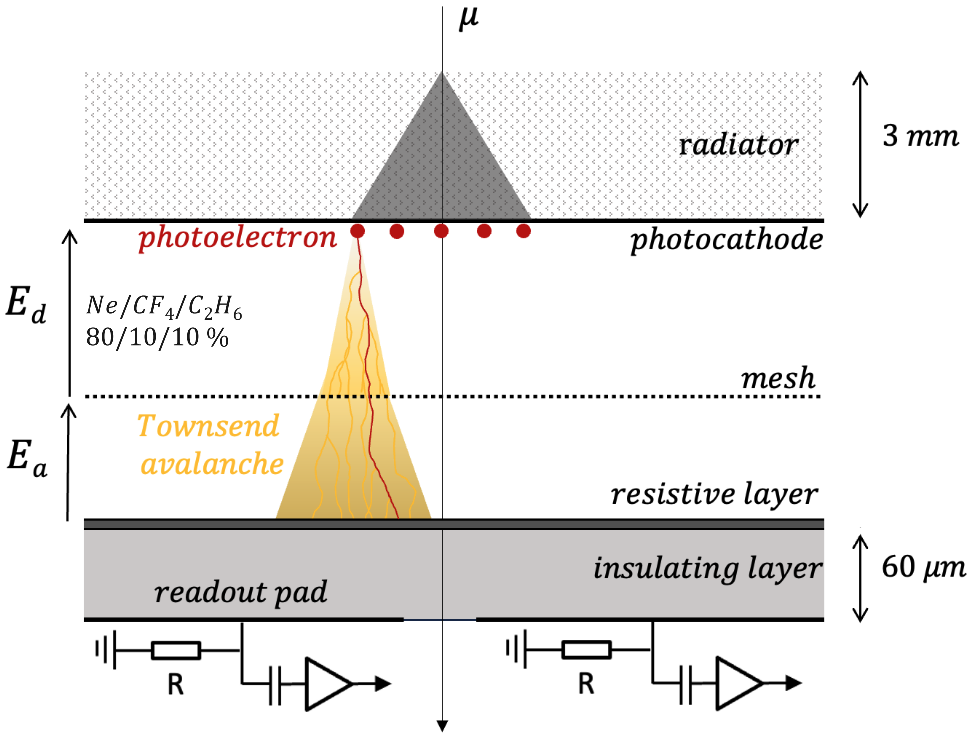
The general progress overview can be found in Yue Meng's presentation of this morning.

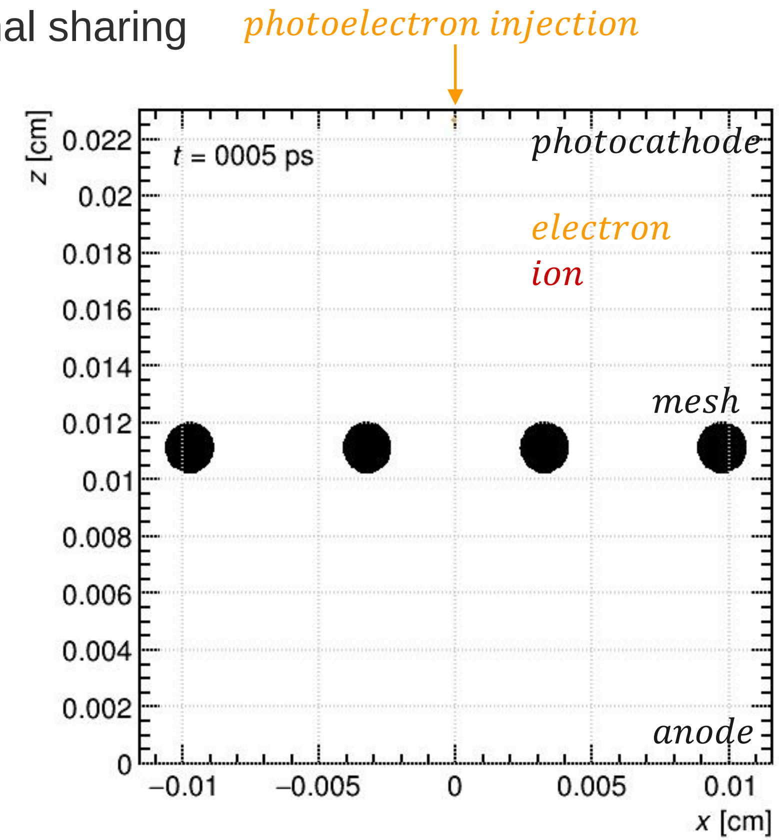
Resistive plane PICOSEC Micromegas

Resistive PICOSEC Micromegas

A resistive layer is introduced in both single- and 100-channel readout structures to enhance the detector's robustness while maintaining a timing resolution of under 25 ps. These slightly conductive materials offer:

- More stable operation by quenching discharges
- Potentially improved position reconstruction through increased signal sharing





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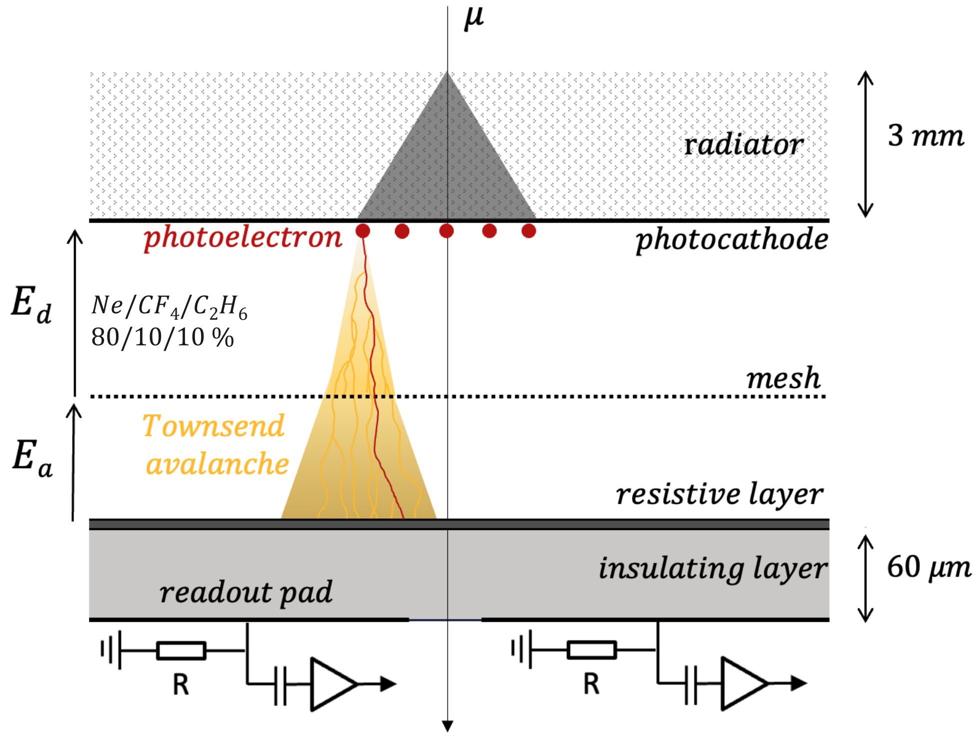
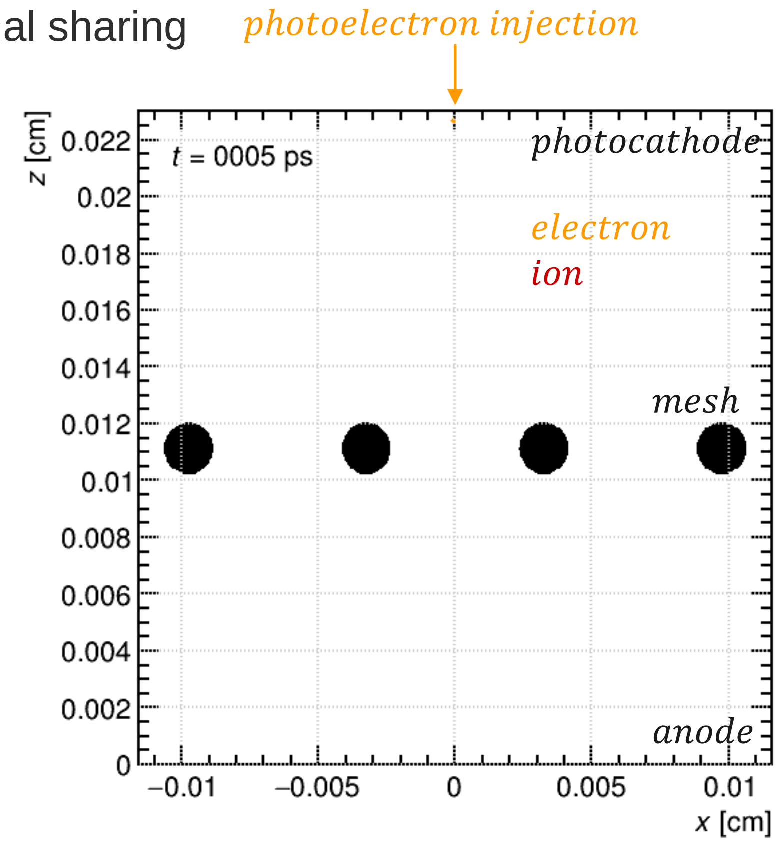


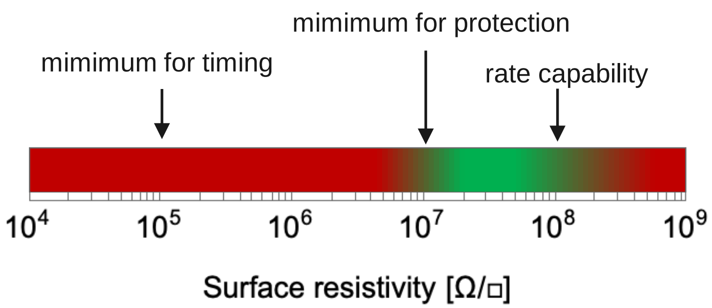


J. Bortfeldt et al., NIM A 903 (2018) 317
A. Utrobicic, RD51 Collaboration meeting (14-06-2022)
A. Utrobicic et al., JINST 18 (2023) C07012 [2304.00056].
M. Lisowska et al., JINST 18 (2023) C07018 [2303.18141].

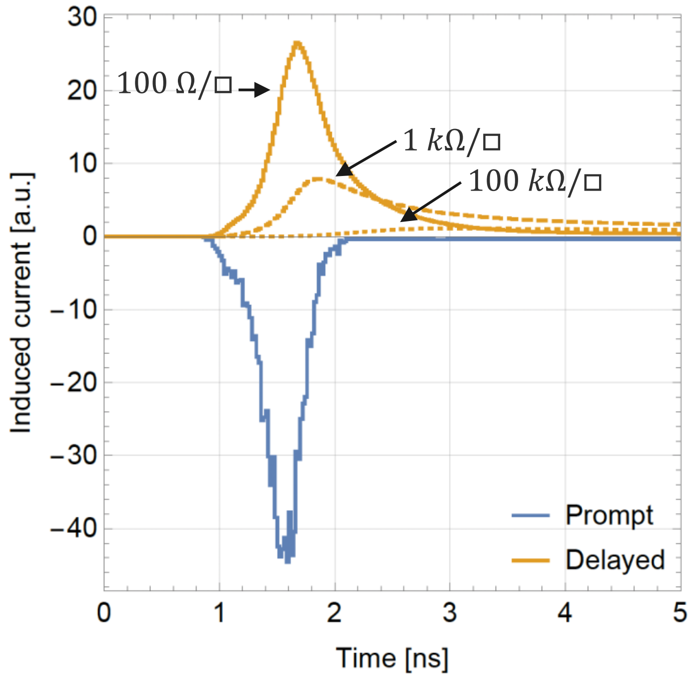
Resistive PICOSEC Micromegas

A surface resistivity of 20 MΩ/□ was chosen to ensure that:

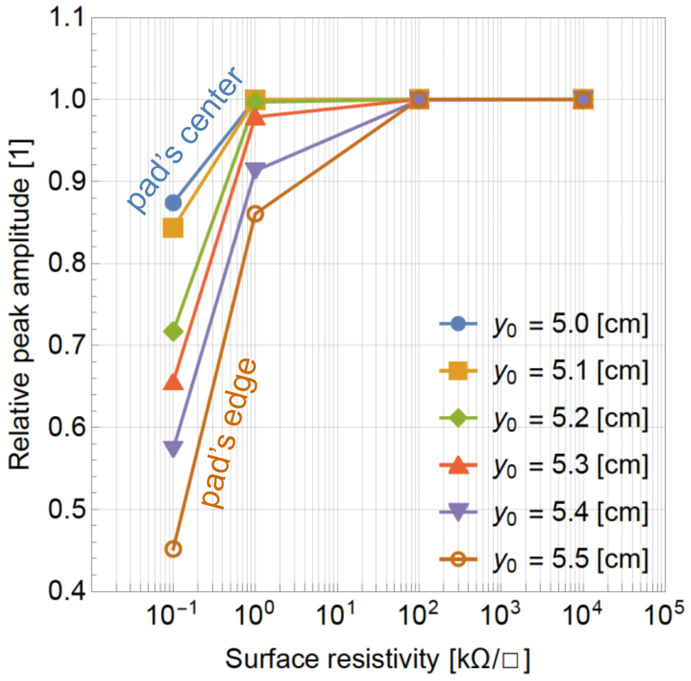
- **the leading edge of the signal is minimally affected by the delayed component**,
- the rate capability estimation,
- the protection against discharges.



Induced signal on the edge of a 1 x 1 cm^2 pad



Relative signal amplitude reduction



Minimum surface resistivity for timing: D. Janssens' presentation of yesterday

D. Janssens, PhD dissertation, https://cds.cern.ch/record/2890572

Resistive PICOSEC Micromegas

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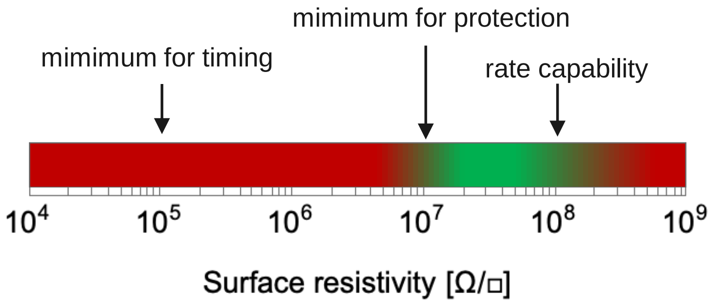
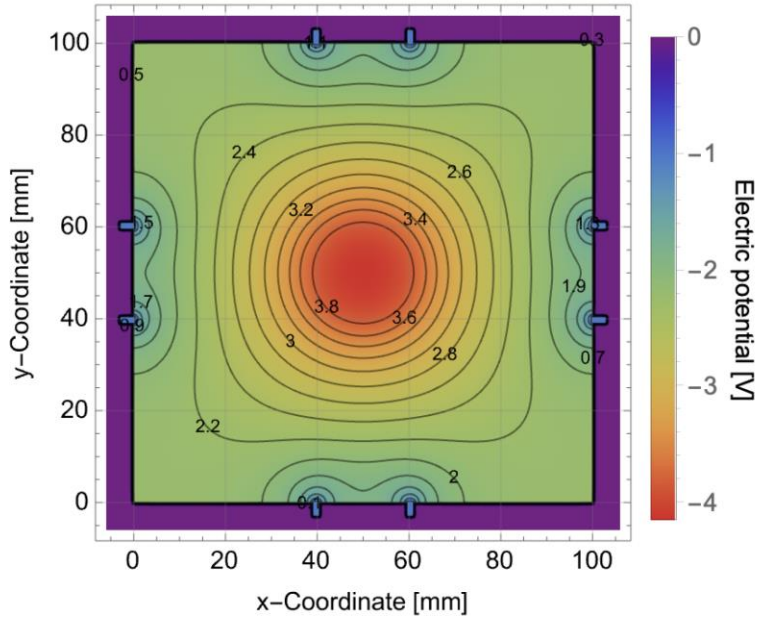
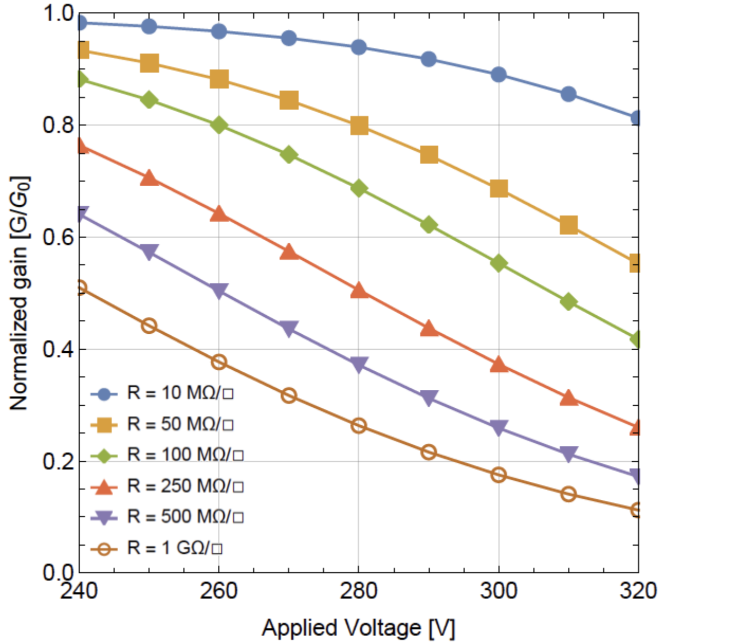


Simulated voltage drop for $\Phi = 6 \cdot 10^5\ cm^{-2}s^{-1}$ pion beam



Simulated amplification drop from $\Phi = 6 \cdot 10^5\ cm^{-2}s^{-1}$ pion beam



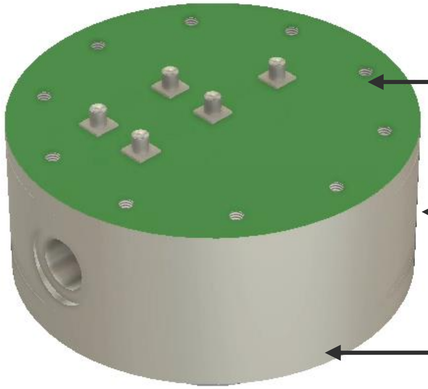
Minimum surface resistivity for timing: D. Janssens' presentation of yesterday

D. Janssens, PhD dissertation, https://cds.cern.ch/record/2890572

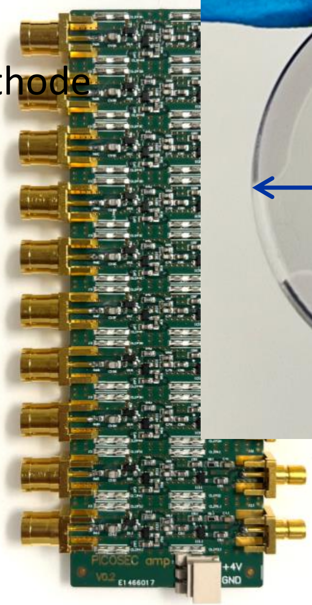
Single channel resistive PICOSEC Micromegas

After production, the timing performance of the resistive single-pad detector for fully contained events was measured using custom-built current amplifiers and a 10 GS/s sampling oscilloscope.

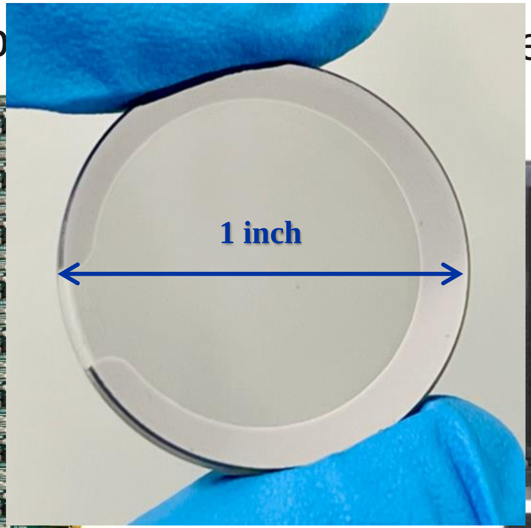
Single-pad prototype design



RF current amp

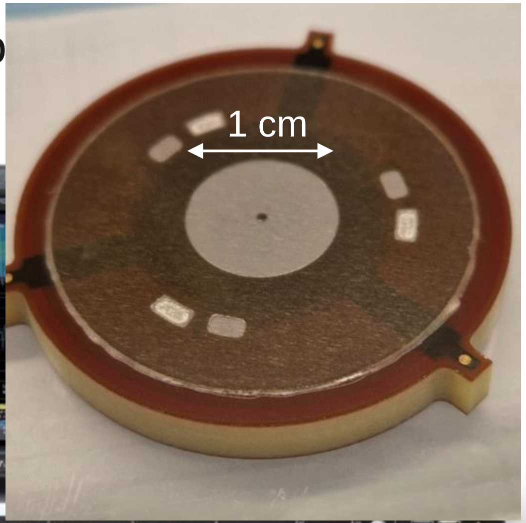


radiator with a photocathode



eCro

Micromegas board

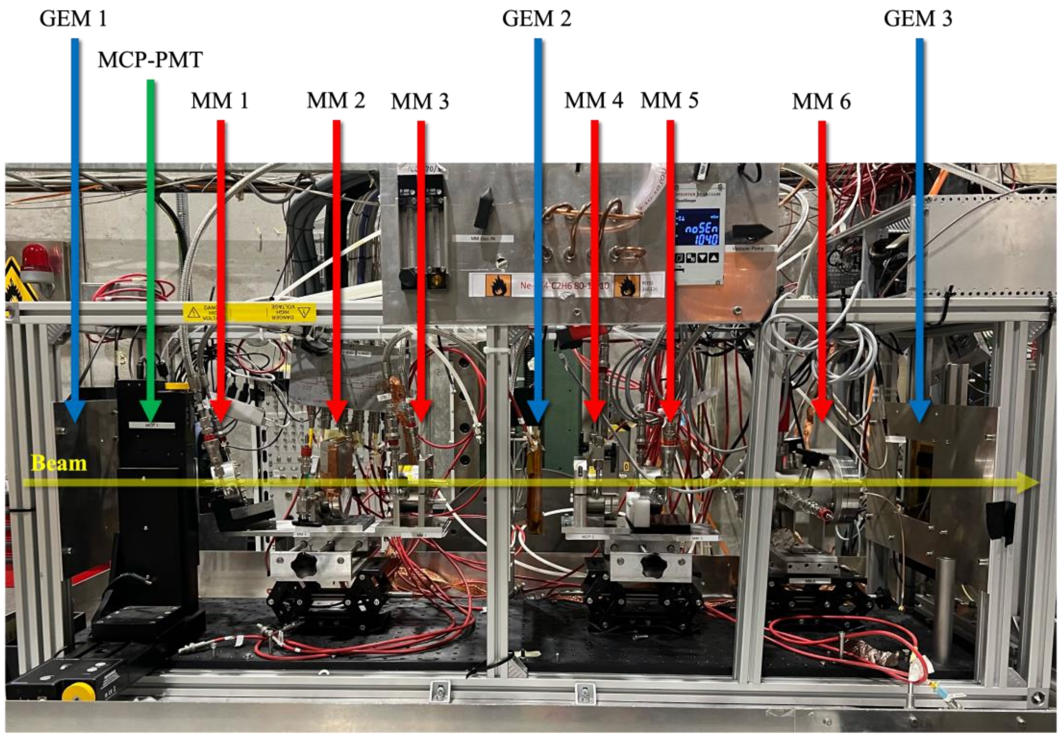


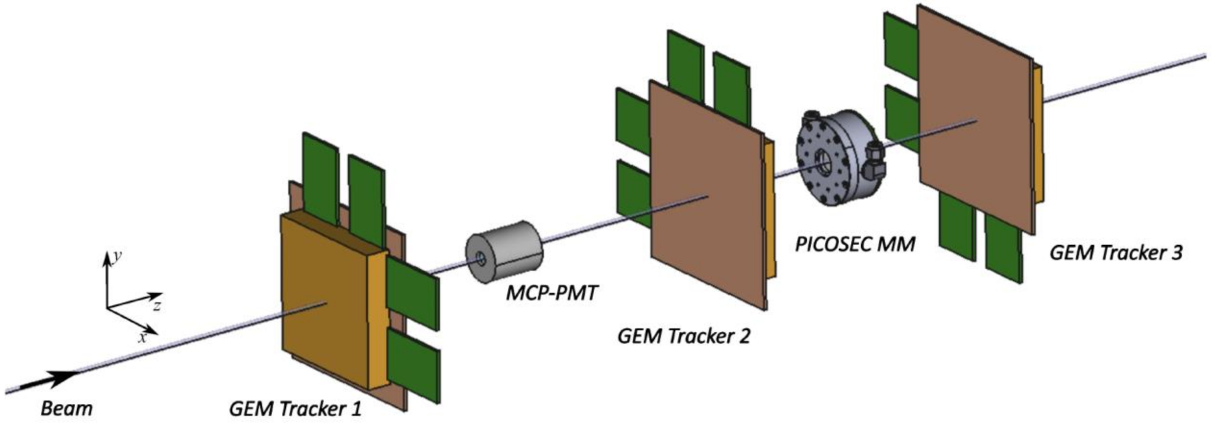
PICOSEC amplifier design: A. Utrobičić, et al., JINST 18 (2023) C07012
Based on the RF pulse amplifier: C. Hoarau, et al., JINST 16 (2021) T04005
Chamber and Micromegas board design: A. Utrobičić, et al., arXiv:2406.05657 [physics.ins-det]

Single channel resistive PICOSEC Micromegas

This prototype, along with several others, was tested in both the lab and the CERN SPS H4 beamline using 150 GeV/c muons.

By utilizing tracking information from GEMs and timing information from MCP-PMTs, the timing performance could be measured.

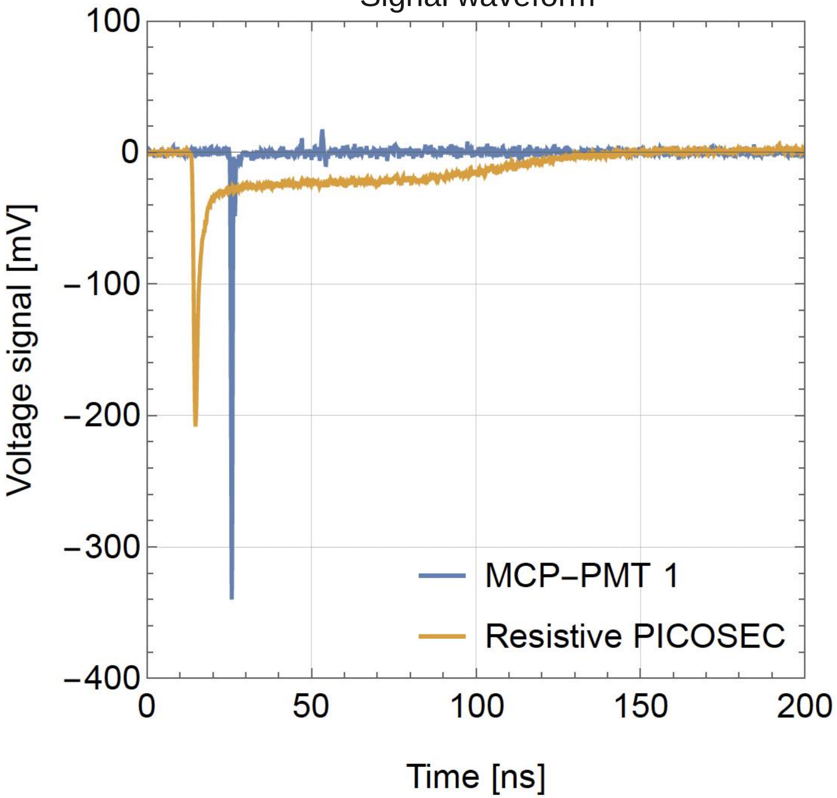




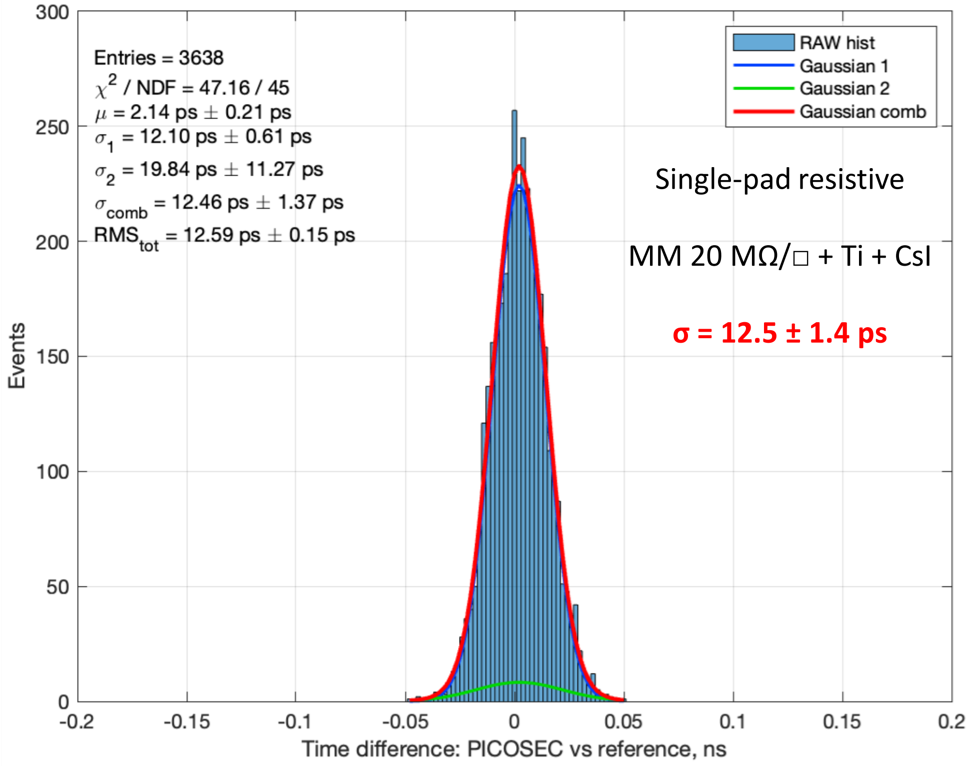
Single channel resistive PICOSEC Micromegas

The detector with 10 mm ϕ active area demonstrated equivalent performance compared to a non-resistive prototype, achieving a time resolution of σ = 12.5 ± 1.4 ps.

Signal waveform



Time difference distribution

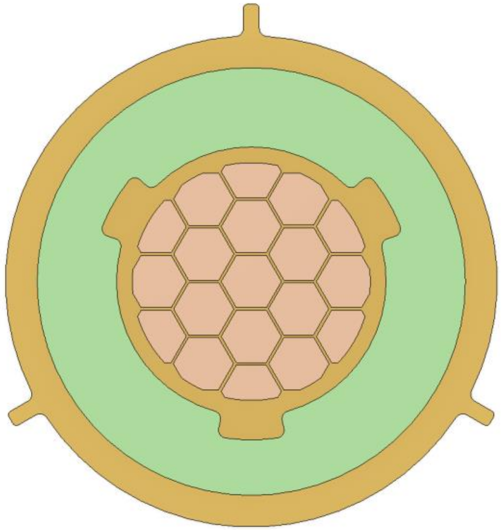


M. Lisowska, PhD dissertation, (available soon).
D. Janssens, PhD dissertation, https://cds.cern.ch/record/2890572

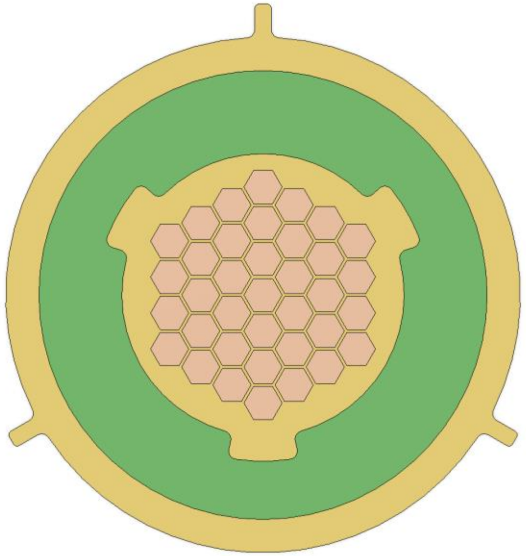
Increase readout granularity for spatial resolution

To investigate potential improvements in spatial resolution, two sets of resistive PICOSEC Micromegas prototypes with increased granularity and a 15 mm active area were produced and tested.

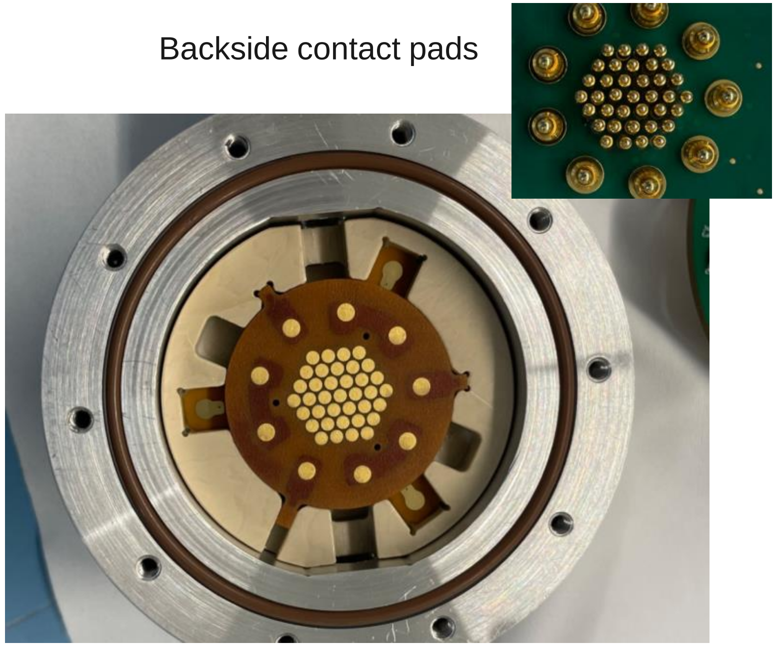
19 pads with 3.5 mm pitch



37 pads with 2.2 mm pitch



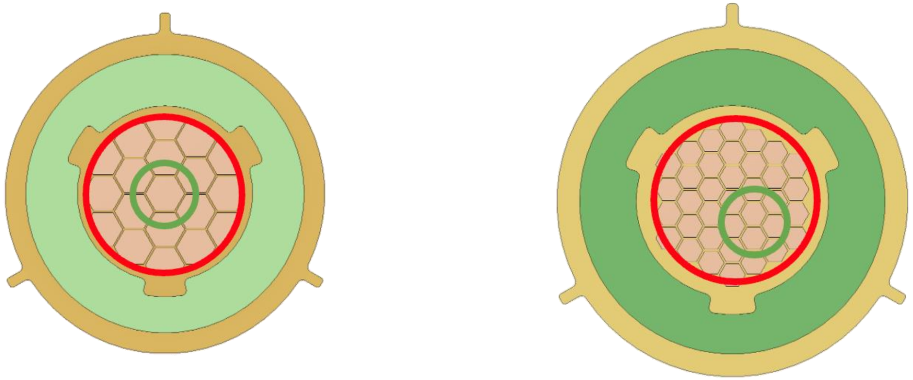
Backside contact pads

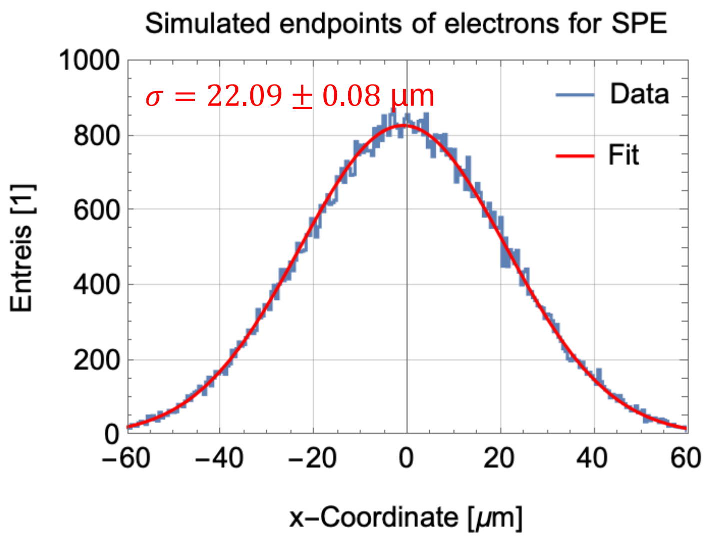


The pads were read out using a SAMPIC waveform TDC, while an MCP-PMT (timing reference) scanned across the active area (self-triggered in coincidence with the reference).

Increase readout granularity for spatial resolution

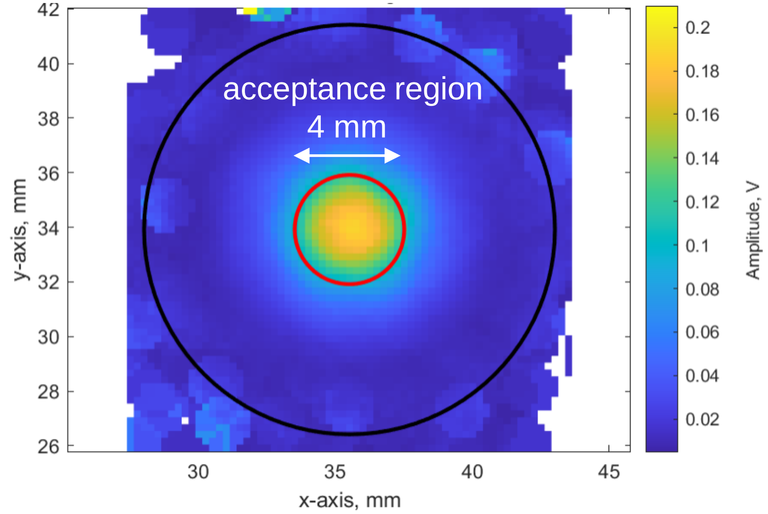
For the 3.5 mm readout pad pitch, comparable timing performance was observed on the central pad, despite only having partially contained events, with most charge centered around the particle trajectory.





	single pad	medium granularity	high granularity
pad pitch [mm]	15.0	3.5	2.2
mean signal ampl. [mV]	193	157.8	62.3
central pad σ_t [ps]	13.9	16.9 ± 0.15	28.3 ± 0.3
cluster size	1	4.0	3.6
x-residuals (full active area) [mm]	/	1.04	1.03
x-residuals (inner 6mm circle) [mm]	/	0.5	0.65

2D signal amplitude map for 3.5 mm pitch

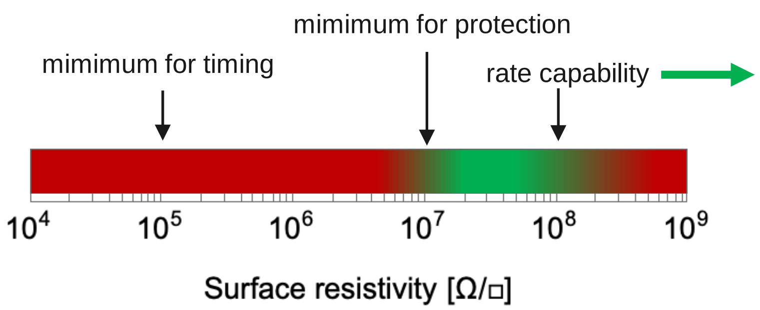


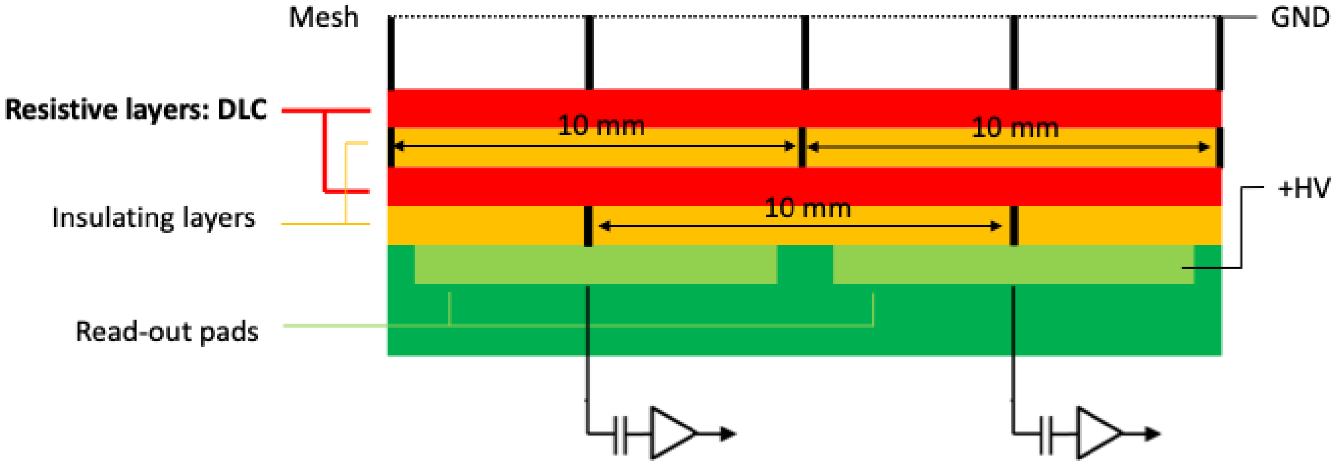
Both timing and spatial resolution are worse for the high granularity readout, most likely due to the smaller signal amplitudes.

Multi-pad prototype with vertical charge evacuation

The rate capability of resistive MPGDs is highly dependent on the charge evacuation scheme used. Various promising 'fast evacuation' configurations can be found within our community.

To enhance the rate capability of the 10 x 10 cm² resistive multi-pad design, a vertical charge evacuation configuration was developed, in contrast to the previous single DLC layer with horizontal evacuation.





G. Bencivenni, et al., JINST 14 (2019) P05014.
M. Iodice et al., Journal of Physics: Conference Series 1498 (2020) 012028.
M. Iodice et al., JINST 15 (2020) C09043.

Multi-pad prototype with vertical charge evacuation

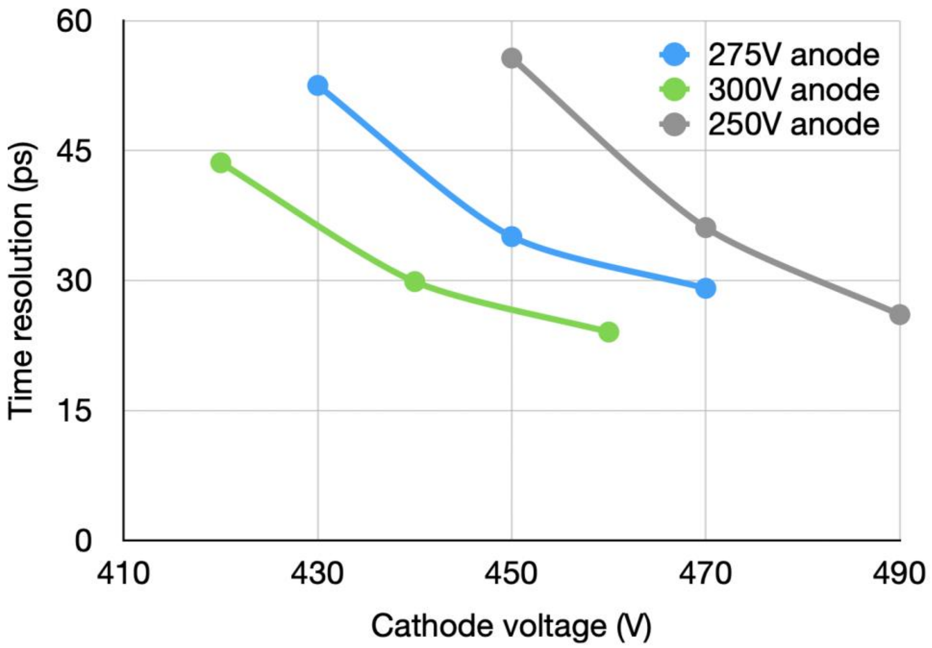
While the observed planarity of the MM board was ~ 15 µm after bulking, thowever, his does not fully explain the magnitude of the non-uniform response observed across the active area.

→ Possibly exacerbated by photocathode degradation!

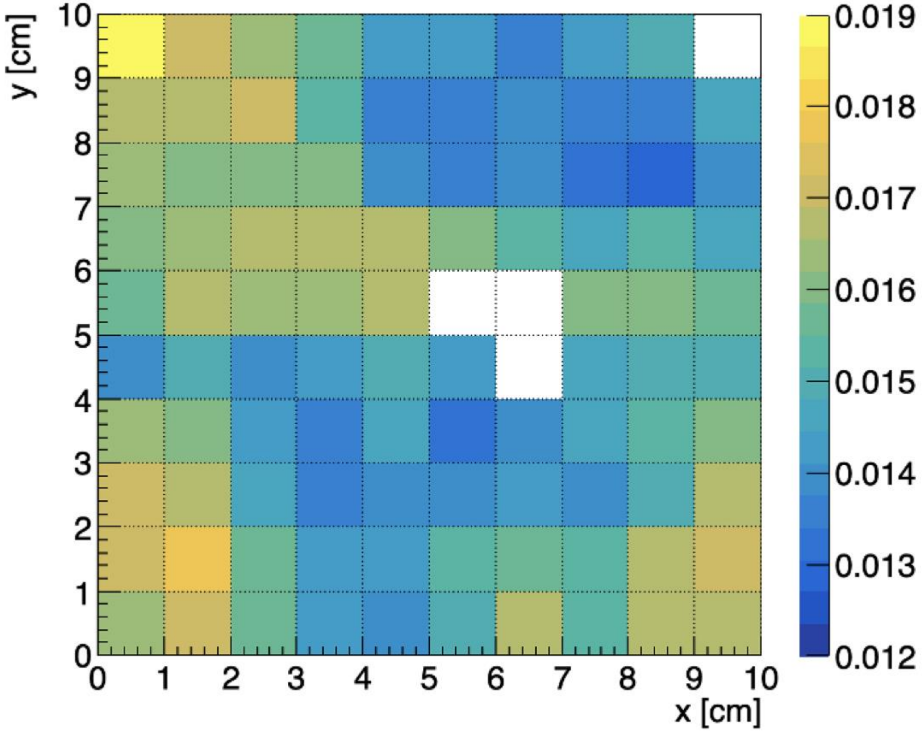
Measured quantities for 150 GeV/c muons

pad 19:	pad 56:	pad 12:
<V> = 91.8 mV, σ_t = 22,1 ps	<V> = 50.6 mV, σ_t = 29.1 ps	<V> = 97.2 mV, σ_t = 21.5 ps
pad 89: <V> = 99.3 mV, σ_t = 19.1 ps		pad 82: <V> = 104.2 mV, σ_t = 19.1 ps

Cathode voltage scan for pad # 56



Mean amplitude for SPE [V]



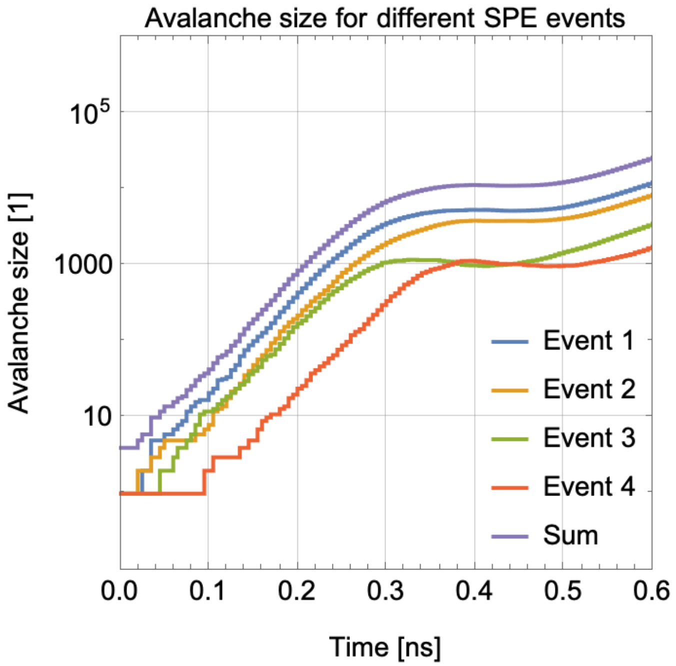
Robust photocathodes

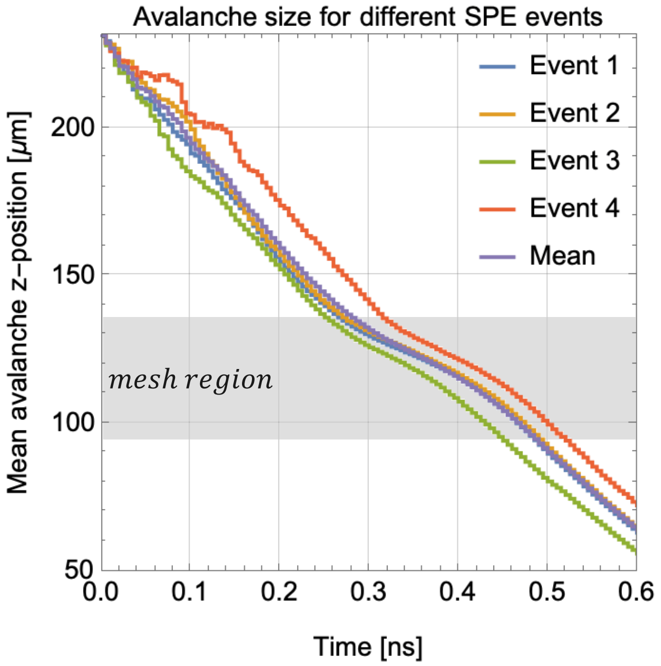
Number of photoelectrons

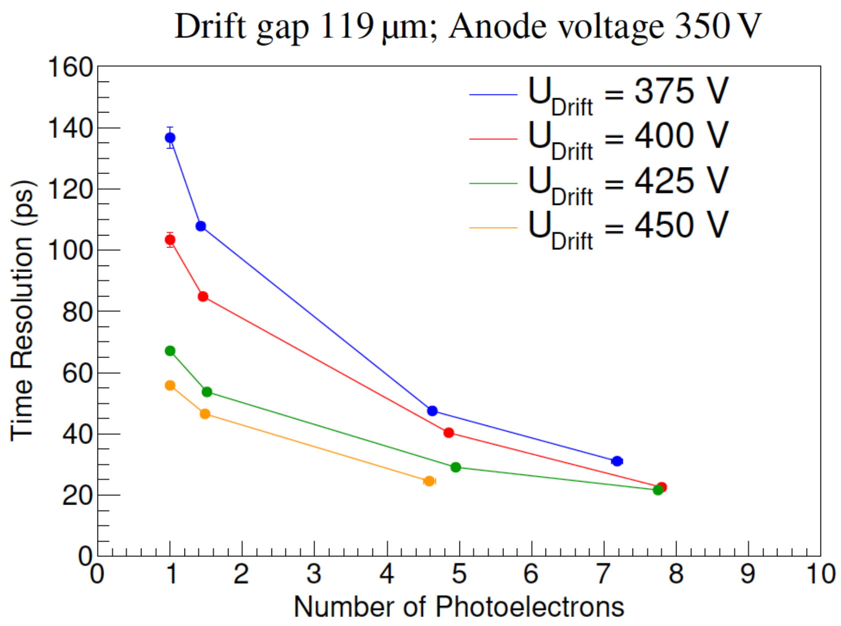
Given a particle crossing the radiator, the choice of photocathode affects the number of photoelectrons (PEs) produced, which is determined by its quantum efficiency. This, in turn, influences the time resolution, which depends on:

$$\sigma \propto \frac{\sigma_{SPE}}{\sqrt{N_{PE}}}$$

timing resolution → σ; σ_{SPE} ← timing resolution for single PE; N_{PE} ← number of PEs



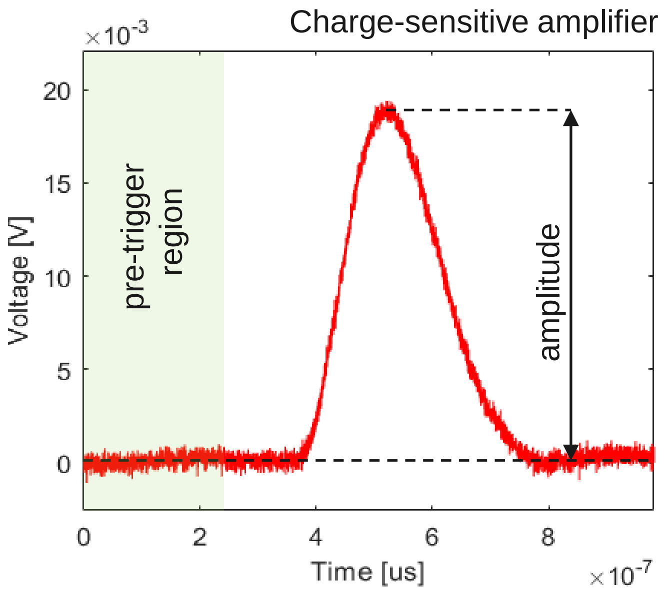


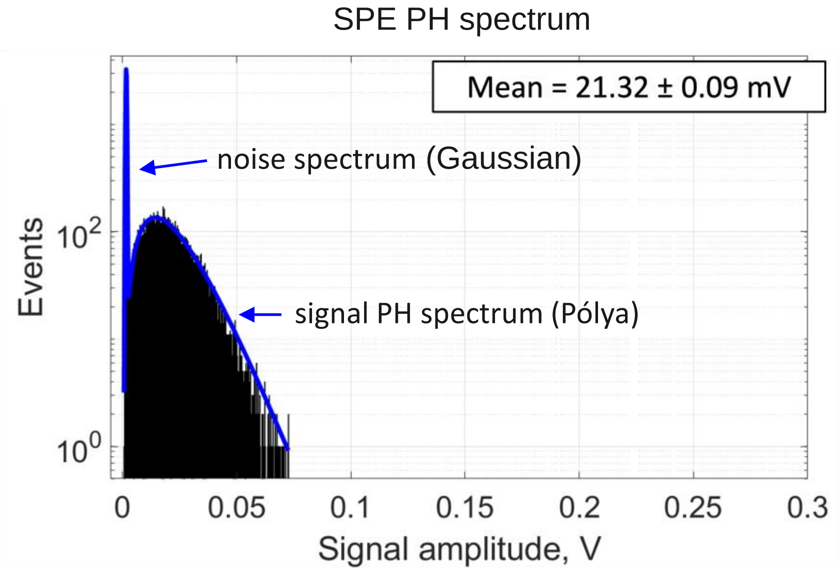


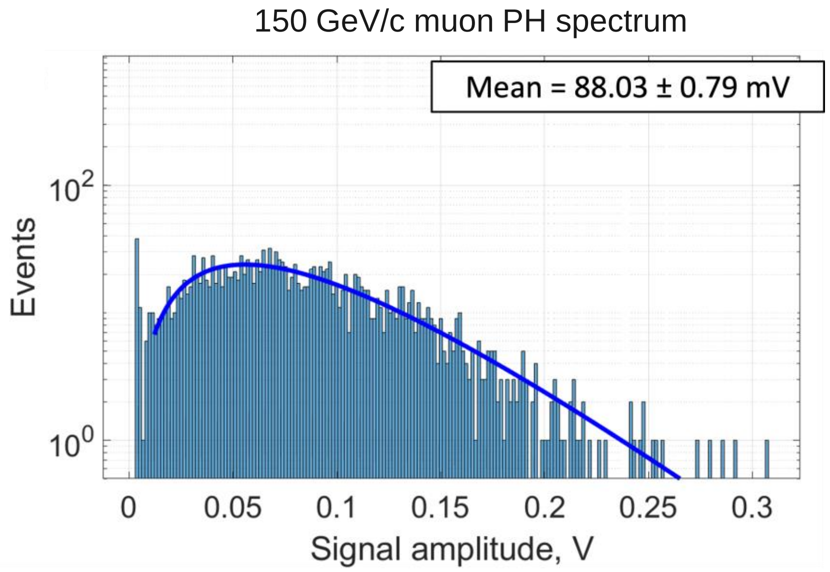
Right plot and equation: L. Sohl, PhD dissertation, https://universite-paris-saclay.hal.science/tel-03167728/.

Number of photoelectrons

The average number of photoelectrons (NPE) is obtained by comparing the pulse heights of single photoelectron (SPE) events, measured with a UV LED, to those from multiple photoelectron measurements using a muon beam.







→ A photocathode with 3 nm Cr and 18 nm CsI produces over 12 photoelectrons per muon when combined with a 3 mm MgF_2 crystal.

L. Sohl, PhD dissertation, https://universite-paris-saclay.hal.science/tel-03167728/.
M. L. V. Fernandez, summer student seminar, https://indi.to/9RPK3.
M. Lisowska, PhD dissertation, (available soon).

Alternative Photocathodes to CsI

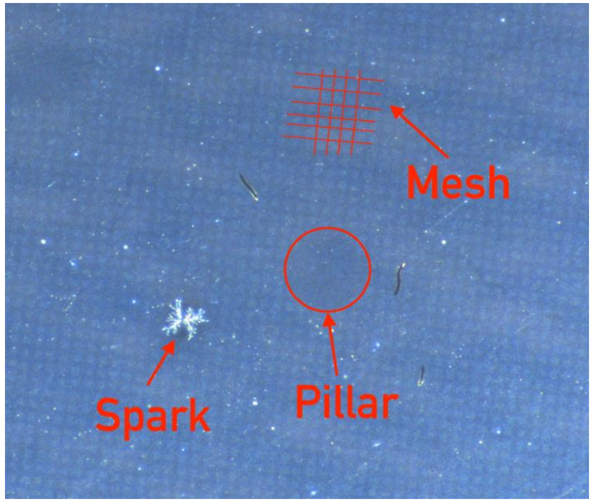
CsI is highly susceptible to degradation from:

- humidity from assembly or possible outgassing of materials, e.g., Kapton
- ion backflow (IBF)
- discharges

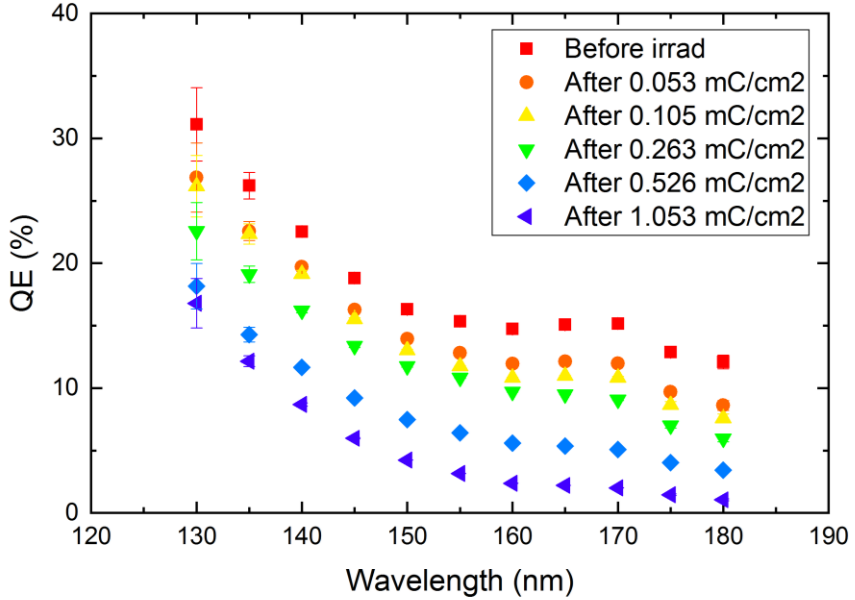
To increase robustness, different alternatives to CsI are being investigated:

- **Diamond-Like Carbon (DLC)**
- **Boron Carbide (B_4C)**
- Nanodiamonds
- Carbon nano-structures
- Graphene

CsI photocathode damaged by IBF



Ageing studies for CsI



CsI photocathode after air exposure

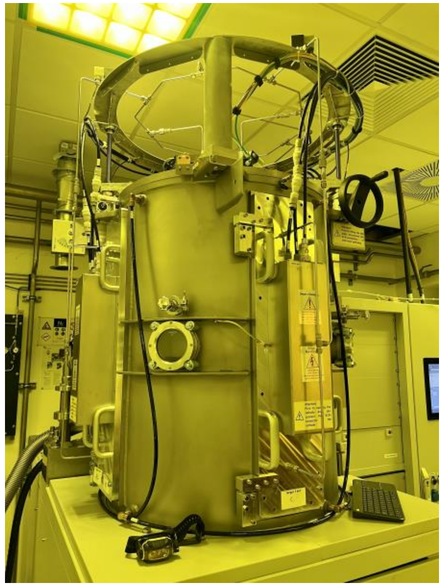
IBF and air exposure observations: L. Sohl, PhD dissertation, https://universite-paris-saclay.hal.science/tel-03167728/.
Air exposure observations: M. Lisowska, PhD dissertation, (available soon).
QE ageing studies: M. Lisowska's master thesis, https://cds.cern.ch/record/2885929.

DLC as Alternative Photocathodes

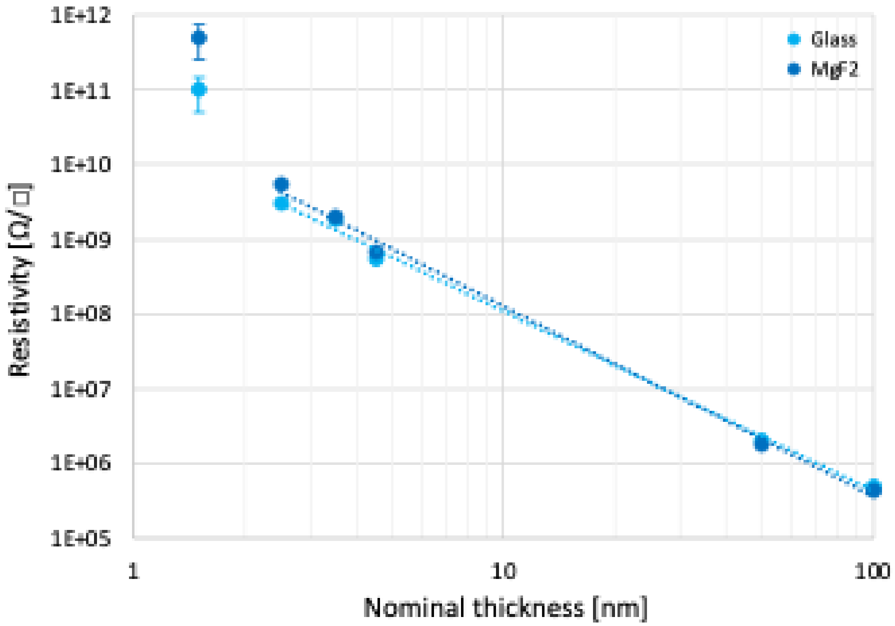
DLC photocathodes, ranging in thickness from 1.5 nm to 3.5 nm, were characterized during the test beam measurements.

The detector with a 1.5 nm DLC layer deposited directly on the radiator exhibited a time resolution of σ = 31.9 ± 1.3 ps, while thicker samples showed approximately 4 ps worse resolution.

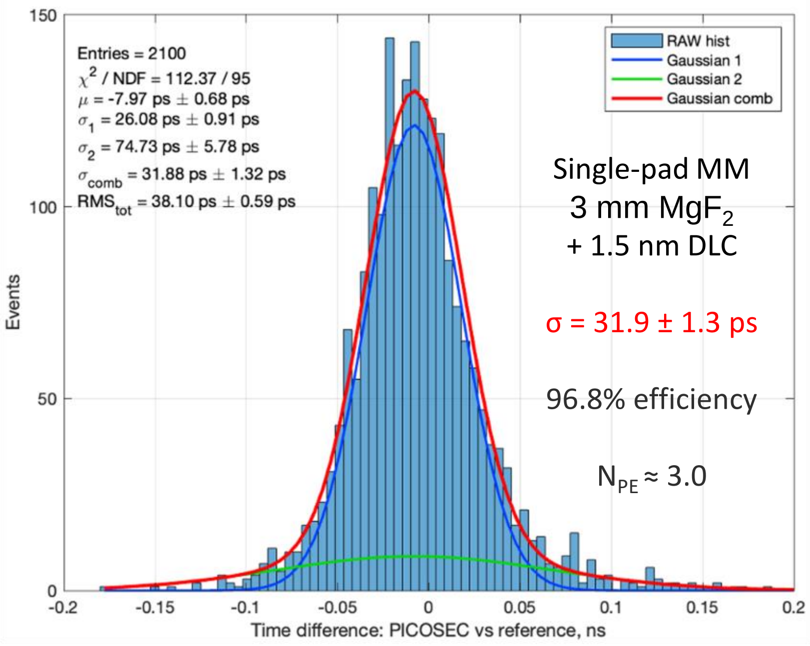
Pulsed DC magnetron vacuum deposition machine



Surface resistivity as a function of layer thickness



Time difference distribution



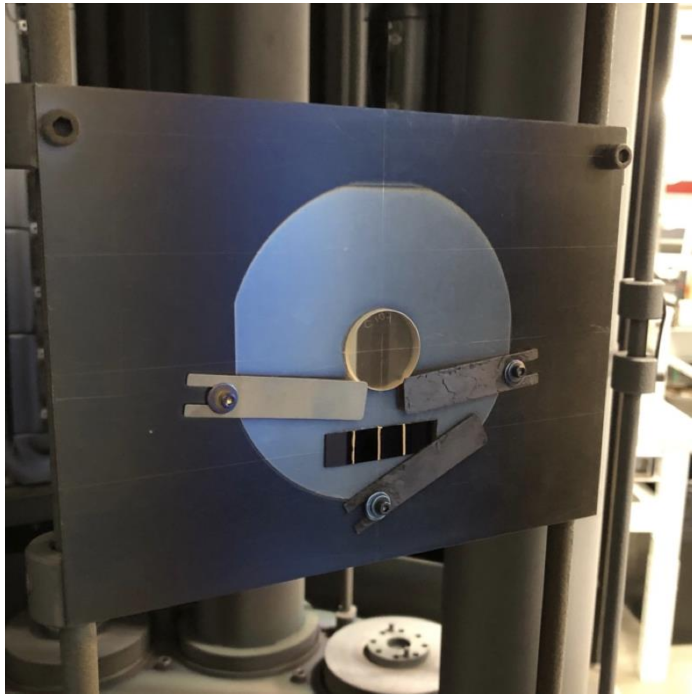
X. Wang, et al., arXiv:2406.08712.
M. Lisowska, et al., arXiv:2407.09953 [physics.ins-det].
M. Lisowska, PhD dissertation, (available soon).

B_4C as Alternative Photocathodes

B4C photocathodes deposited at CEA-Saclay and ESS have demonstrated promising results.

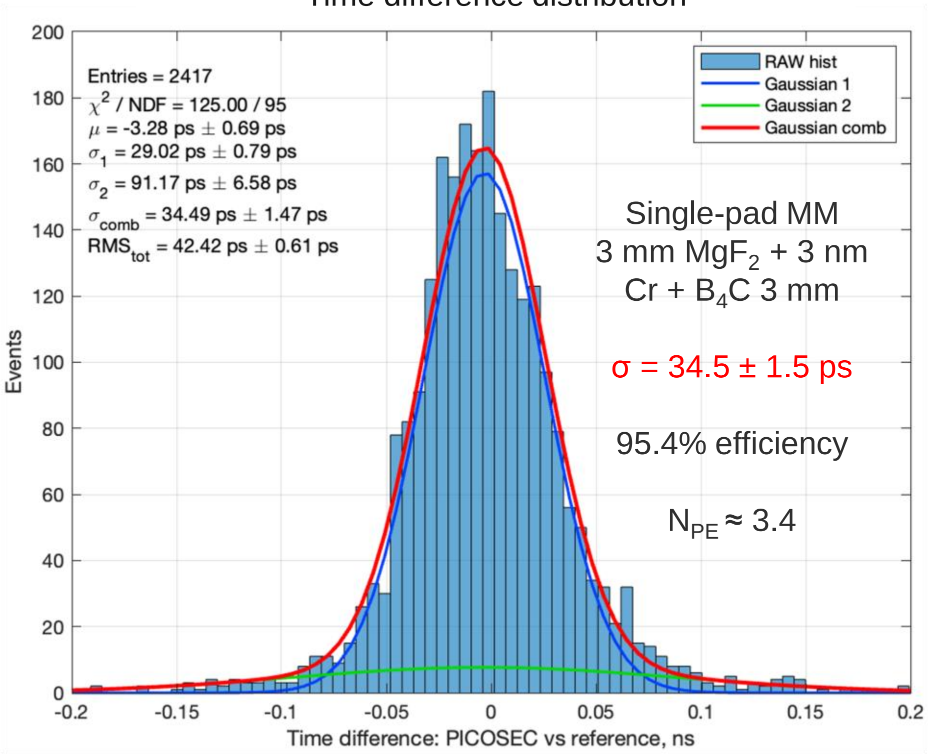
A detector with a 9 nm B4C layer and 3 nm Cr resulted in a time resolution of σ = 34.5 ± 1.5 ps, with thicker samples showing slightly worse resolution by up to ~10 ps.

B_4C sample in the sputtering machine



C.-C. Lai, ESS

Time difference distribution

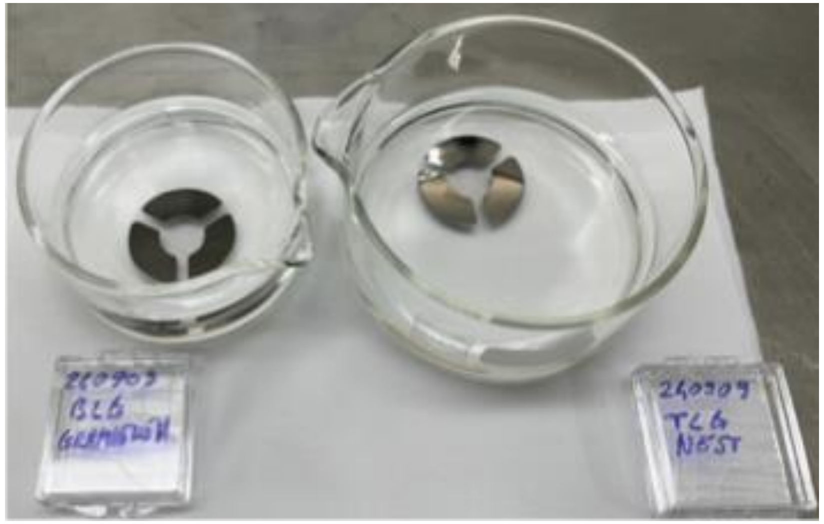


L. Sohl, PhD dissertation, https://universite-paris-saclay.hal.science/tel-03167728/.
M. Lisowska, et al., JINST 18 (2023) C07018.
M. Lisowska, et al., arXiv:2407.09953 [physics.ins-det].
M. Lisowska, PhD dissertation, (available soon).

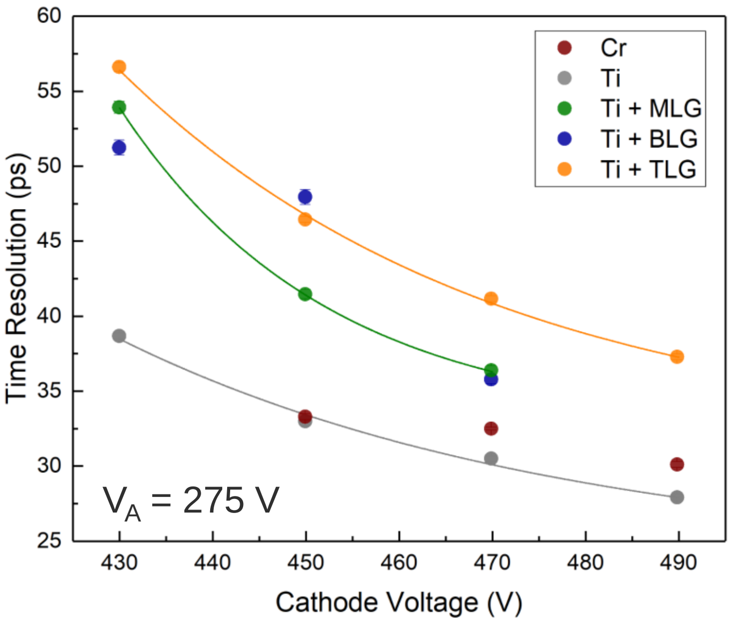
Graphene as Protective Layer

In studies using graphene as a photocathode, a 2.5–3 nm Ti layer produced a surprisingly large number of PEs.

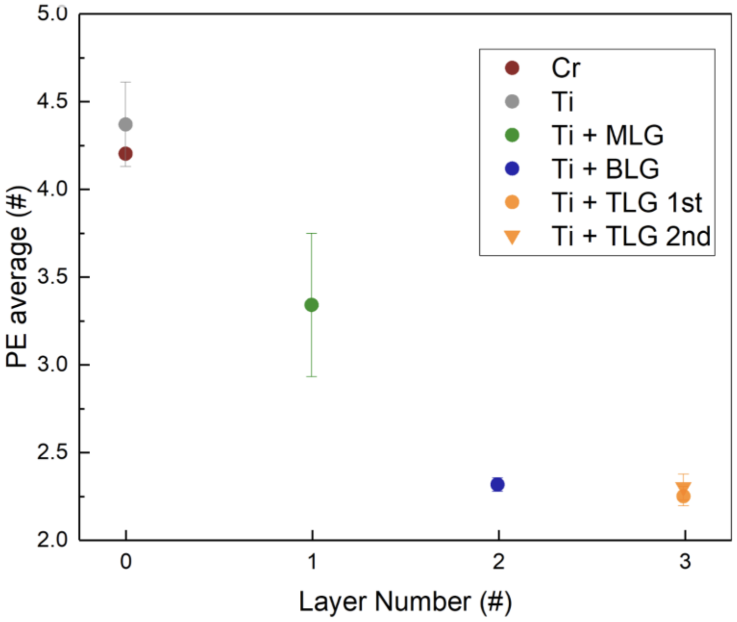
Adding graphene partially screens the photoelectron (PE) emission from the Ti, with the monolayer (ML) screening approximately 30%, and the bilayer (BL) and trilayer (TL) screening about 50% of the PEs.



Cathode voltage scan



Number of photoelectrons per muon crossing



→ Graphene could be considered as a protective layer.

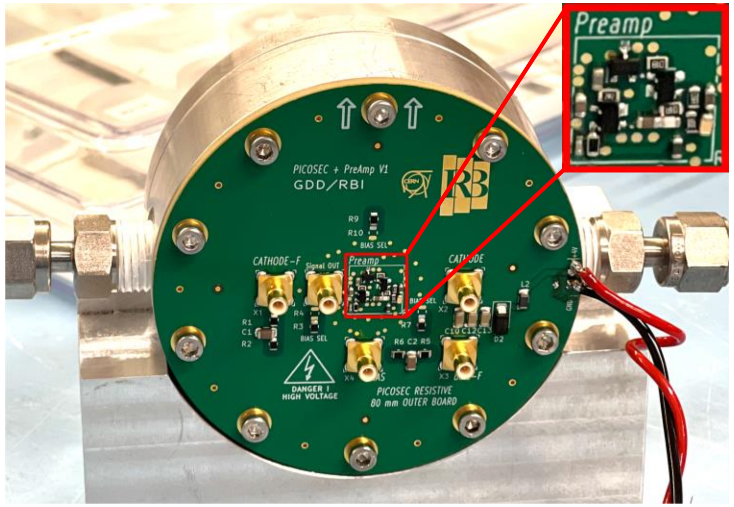
Towards an applicable detector

B_4C as an Alternative Photocathodes

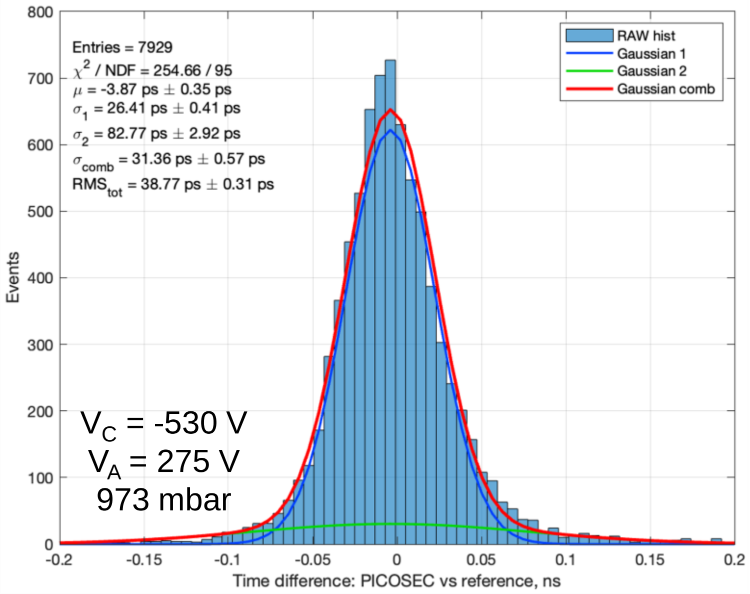
The first measurement combining a single-pad 15 mm ϕ resistive Micromegas + DLC photocathode + embedded amplifier in the outer PCB:

→ showed stable performance and achieved a time resolution of σ = 31.4 ± 0.6 ps for fully contained events.

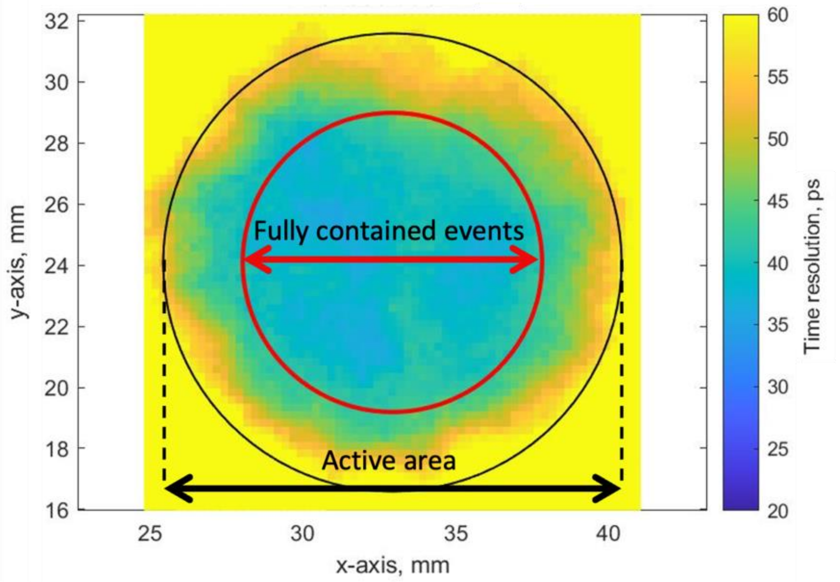
Single-pad detector with the embedded amplifier



Time difference distribution



Time resolution distribution



Summary

To enable the sub-25 ps PICOSEC Micromegas precise-timing detector to perform effectively under the demanding conditions of physics experiments, we are adapting its design to improve robustness.

- **The Resistive Micromegas** with a single-pad and 20 MΩ/□ showed equivalent precision to a non-resistive prototype, with time resolution of σ = 12.5 ± 1.4 ps.
- With **increasing the granularity** of the readout offers the possibility for sub-mm spatial reconstruction, with a pad pitch of 3.5 mm yielding σ = 0.5 mm with minimal timing degradation in the center of the pad.
- **The vertical charge evacuation design**, while promising (< 20 ps), needs further investigation to work out non-uniform response.
- Intensive studies for **alternative photocathodes** resulted in achieving a time resolution of σ = 31.9 ± 1.3 ps for DLC, 34.5 ± 1.5 ps for B_4C, and 36.3 ± 0.3 ps for Ti + a monolayer of graphene.

Outlook:

- **Robust photocathodes:** ageing studies of the DLC and B_4C, response to IBF
- **Rate-capability:** double-layer DLC Micromegas for vertical charge evacuation

PICOSEC Micromegas Collaboration

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Thank you for your attention!