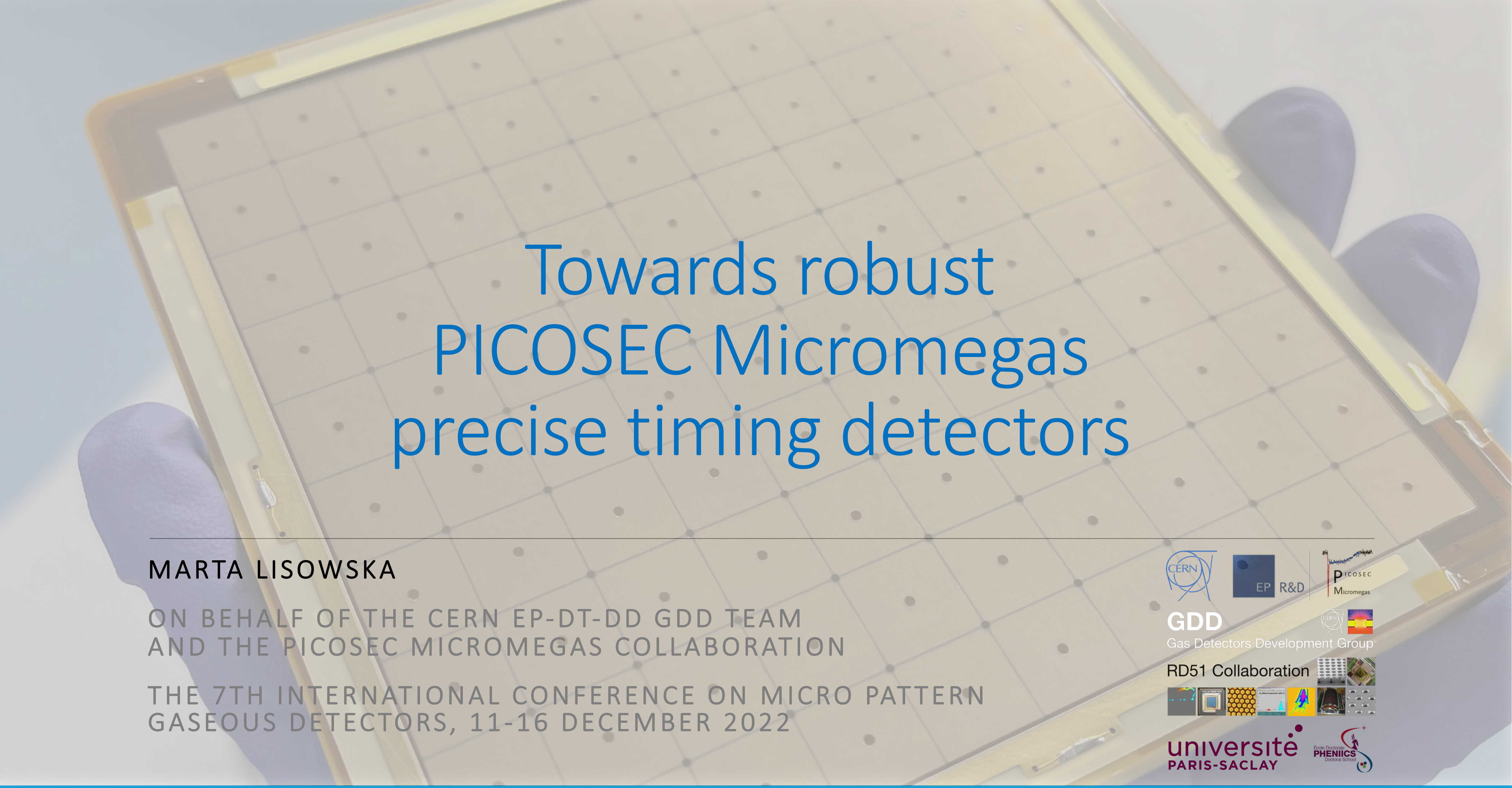


Towards robust PICOSEC Micromegas precise timing detectors

MARTA LISOWSKA

ON BEHALF OF THE CERN EP-DT-DD GDD TEAM
AND THE PICOSEC MICROMEGAS COLLABORATION

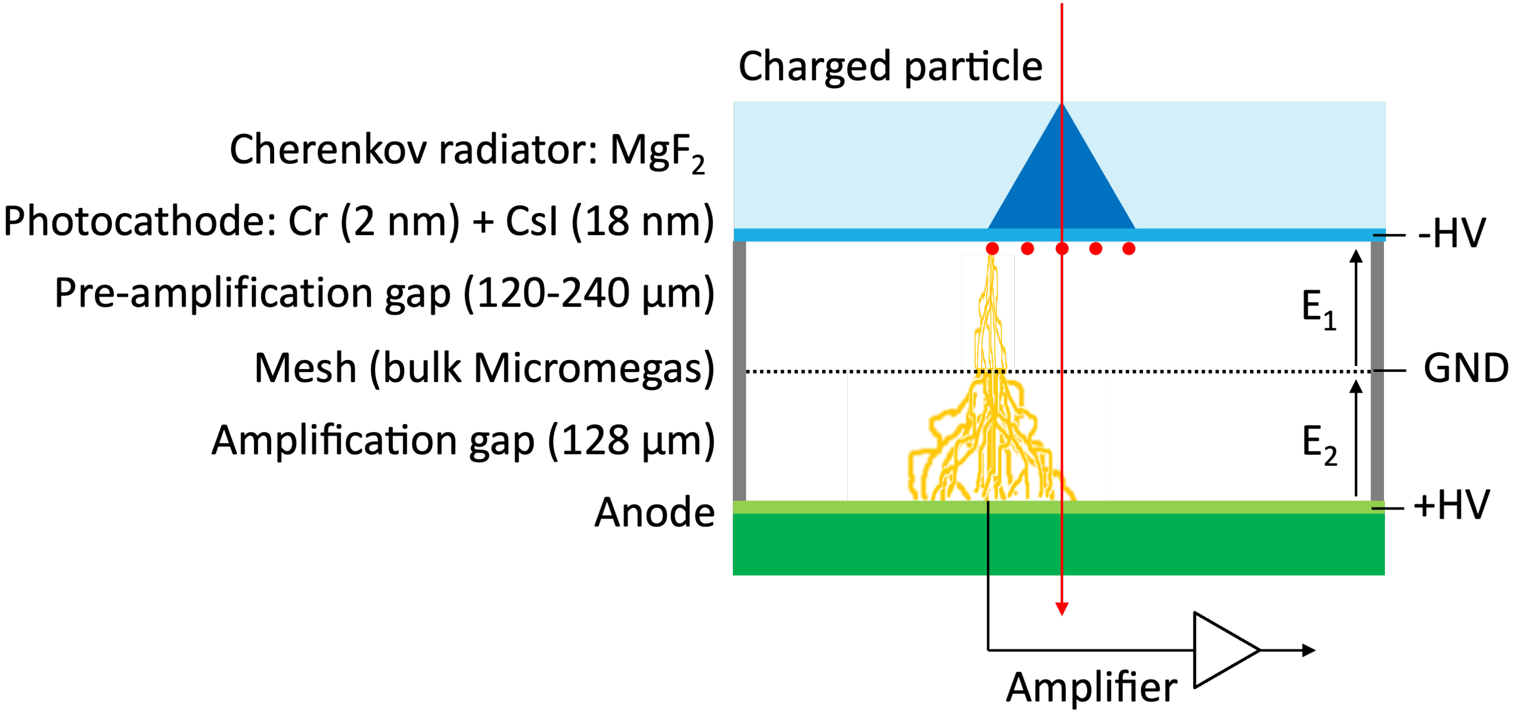
THE 7TH INTERNATIONAL CONFERENCE ON MICRO PATTERN GASEOUS DETECTORS, 11-16 DECEMBER 2022

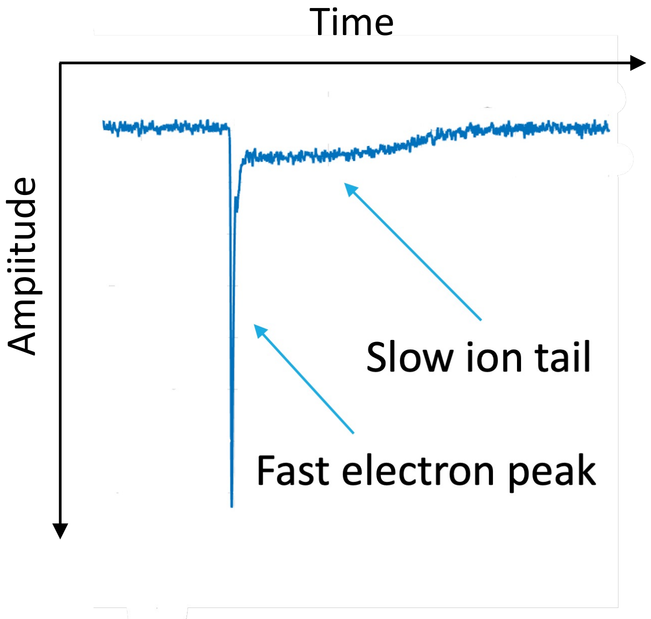
CERN
EP R&D
PICOSEC Micromegas
GDD
Gas Detectors Development Group
RD51 Collaboration
université PARIS-SACLAY
Ecole Doctorale PHENIICS Doctoral School

PICOSEC Micromegas

Detector concept

- **PICOSEC Micromegas collaboration:** gaseous detector that aims at reaching a time resolution of tens of picoseconds





- First single-pad prototype with $\sigma < 25$ ps → Now we want to make the concept appropriate to physics applications

PICOSEC Micromegas

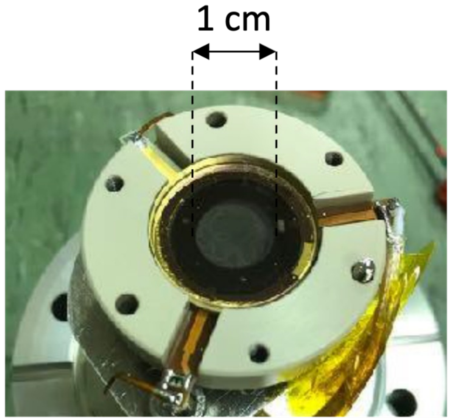
Developments towards applicable detector

- **Objective:** Robust tileable multi-channel detector modules for large area coverage

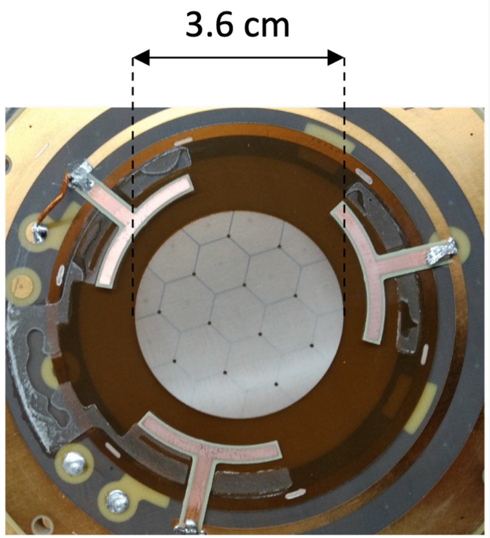
- **Preamplification gap:**
  - → uniform thickness
  - → reduced thickness

- **Robustness:**
  - → resistive Micromegas
  - → robust photocathodes

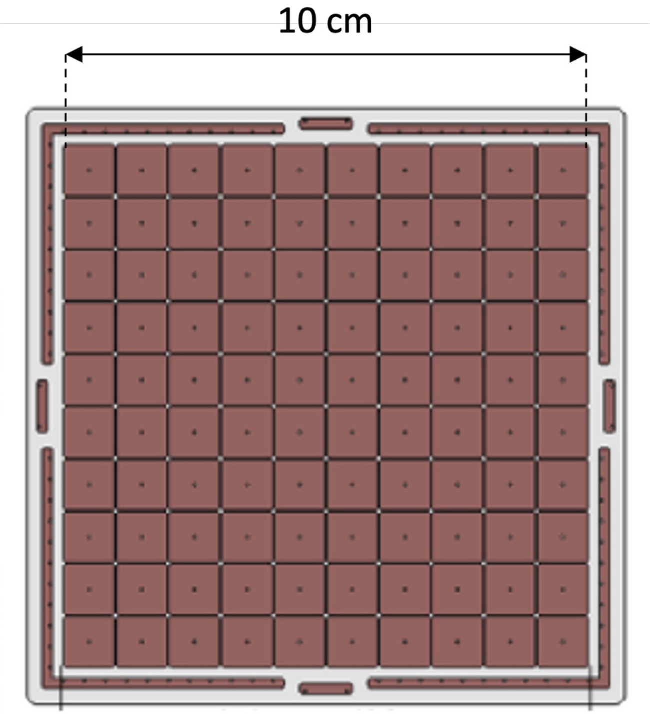
- **Electronics:**
  - → dedicated amplifiers
  - → multi-channel digitisers



Single pad (2016)
⌀1 cm



Multi pad (2017)
⬡ 1 cm



10x10 module
□ 1 cm

More information about the 100-channel detector and dedicated amplifiers in the previous presentation by Antonija Utrobicic

Resistive Micromegas

Advantages and requirements

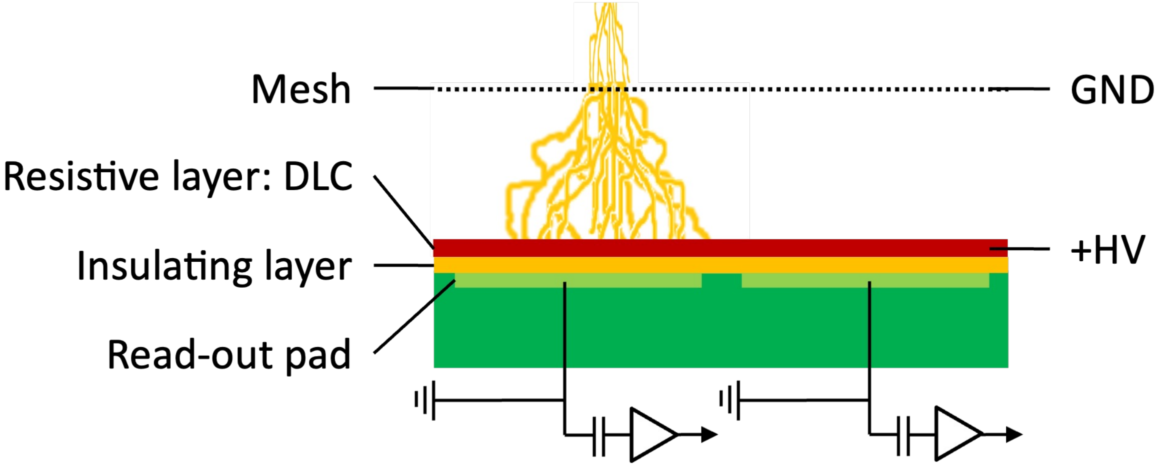
- **Advantages of resistive Micromegas:**

  + limitation of the destructive effect of discharges

  + stable operation in intense pion beams

  + better position reconstruction, signal sharing

- **Objective:** profit from the advantages of the resistive Micromegas while maintaining good time resolution



Requirements for choosing the resistivity:

low enough to:

→ minimise the voltage drop during high rate beam

→ improve the position reconstruction

high enough to:

→ ensure stable operation

→ not affect the rising edge of the signal

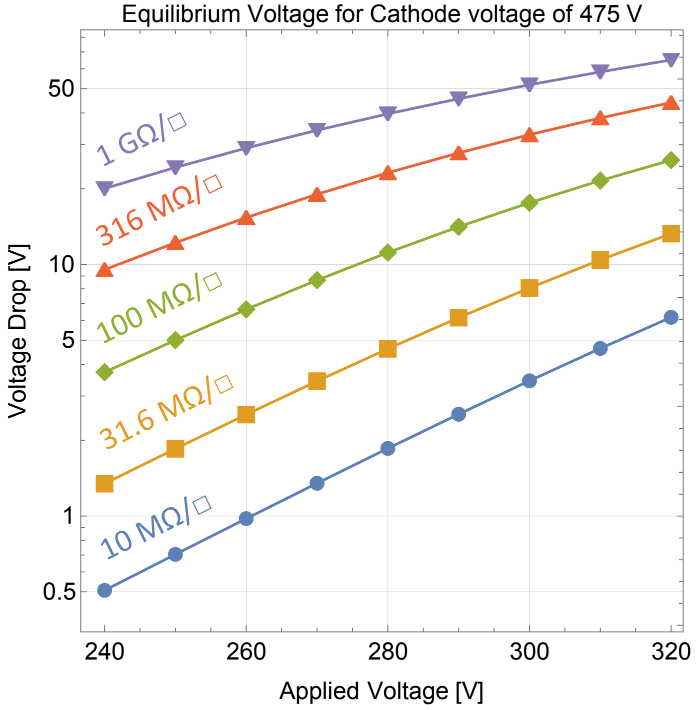
Resistive Micromegas

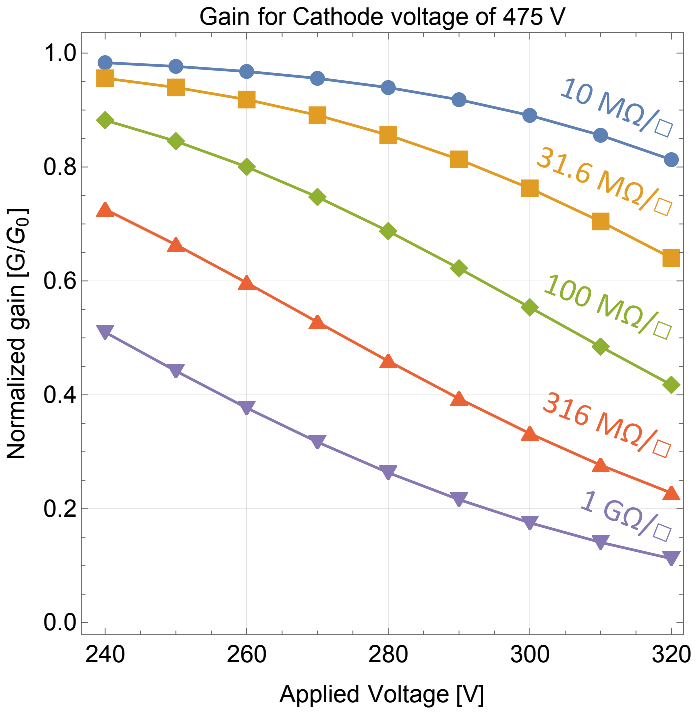
Rate capability

SIMULATIONS

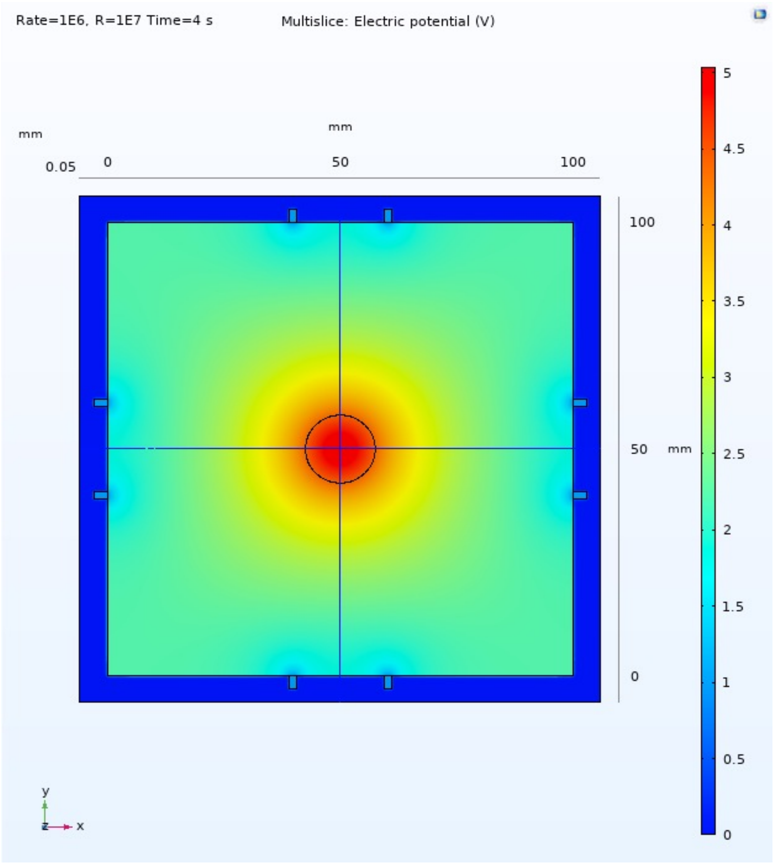
for a pion beam of 1.5 cm dia. and 1.9 MHz

Simulated voltage and gain drop vs applied voltage for different resistivities





Simulated voltage drop across the area



The minimum resistivity that ensures a detector’s stable operation is 10 MΩ/□

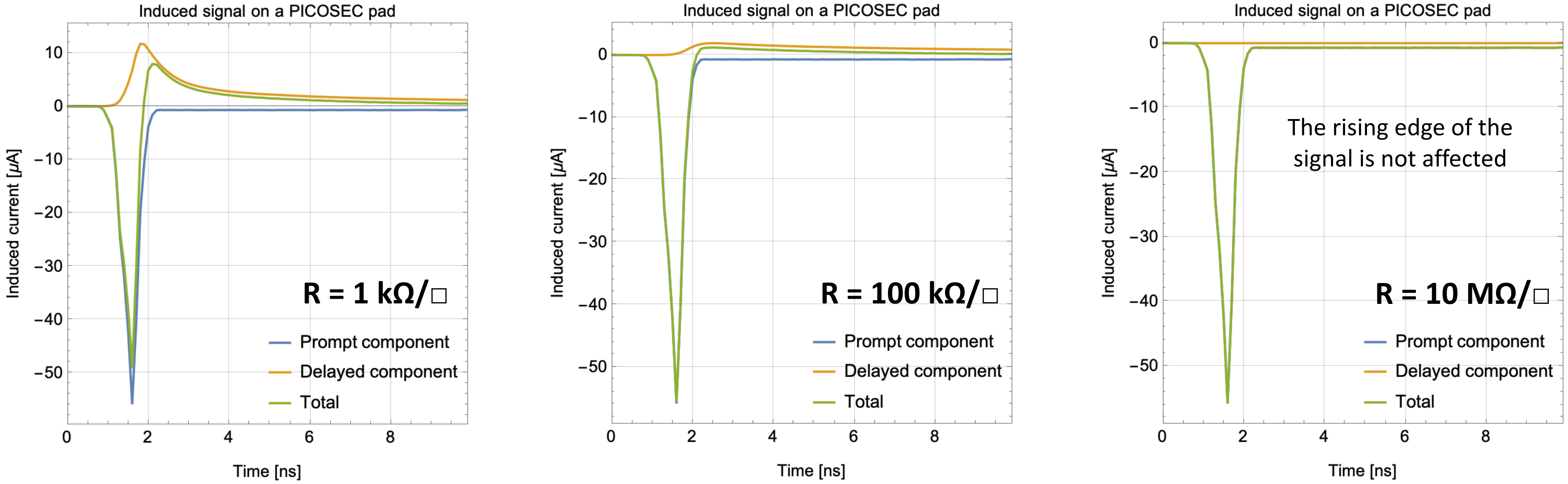
All simulations by Djunes Janssens

Resistive Micromegas

SIMULATIONS

Dependence on the rising edge of the signal

Simulated shape of the induced signal for different resistivities



The rising edge of the signal is not affected

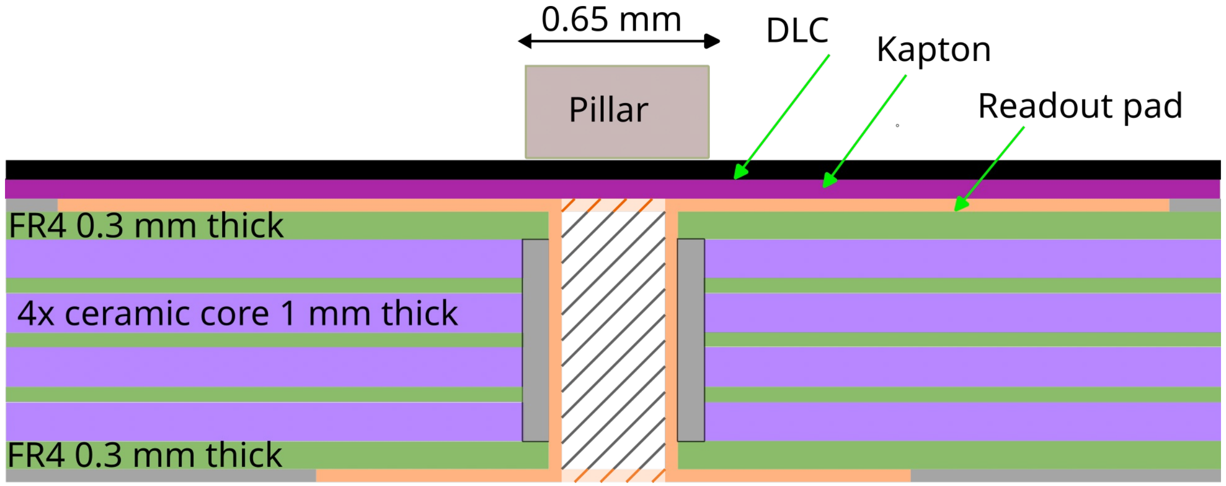
Resistivity chosen for the 10x10 cm^2 area PICOSEC MM detector: **20 MΩ/□**

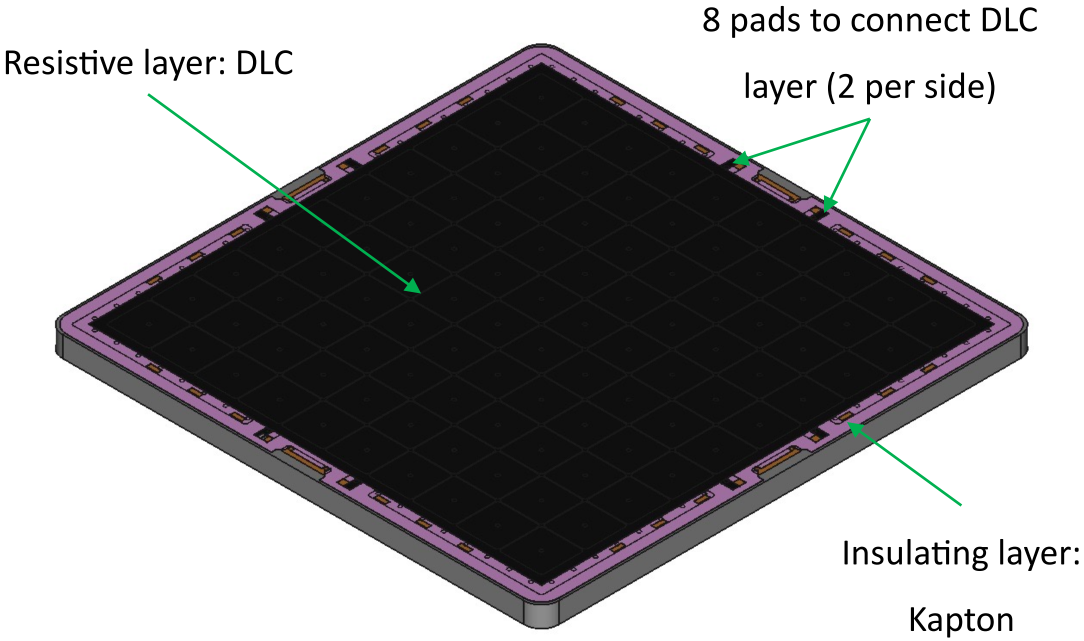
All simulations by Djunes Janssens

Resistive Micromegas

Multipad: 100-channel PICOSEC MM detector

- **Multipad:** 100-channel detector with a 10x10 cm^2 area **resistive MM** with anode surface resistivity of **20 MΩ/□**
- Production procedure as for a non-resistive Multipad with an additional production step to add a resistive layer

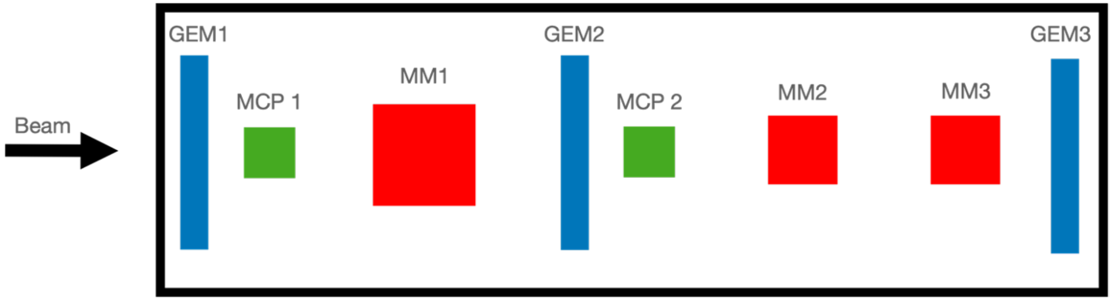




More information about the design and production procedures of the Multipad in the presentations by Antonija Utrobicic

Resistive Micromegas

RD51 test beam campaign

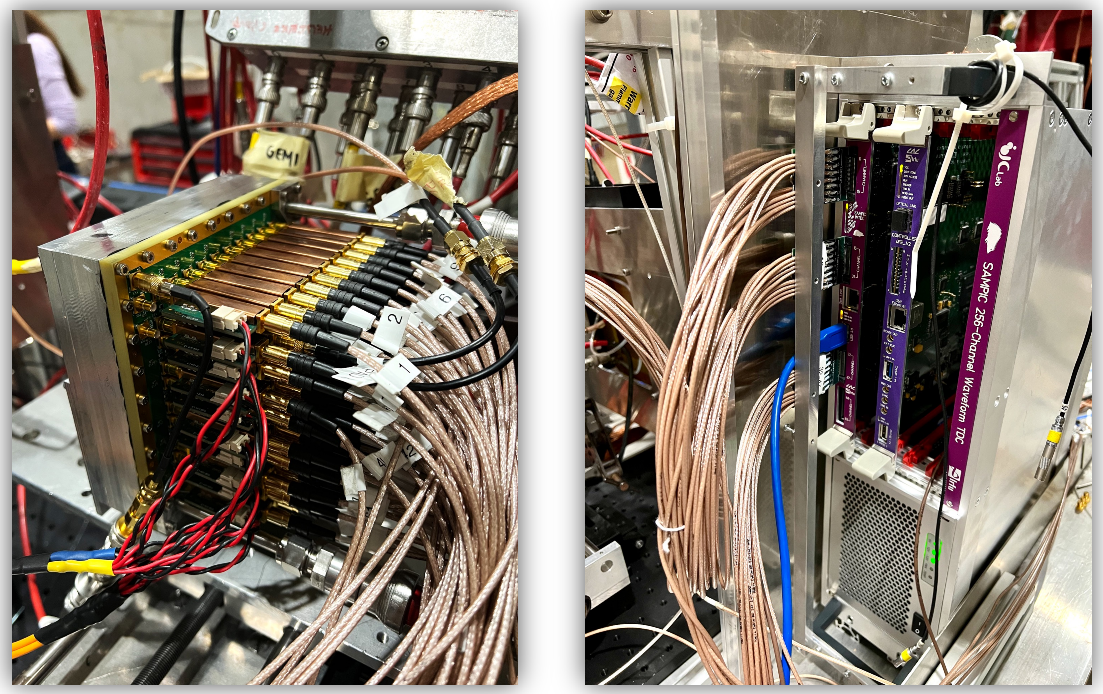


- **Beam type:** CERN SPS H4 beam line, 150 GeV/c muons

- **Experimental setup:**
  - → **tracking**/**timing**/**triggering** telescope: **GEMs** + **MCP PMTs**
  - → **PICOSEC Micromegas (MM) detectors**
  - → flammable gas mixture: $Ne:CF_4:C_2H_6$ (80:10:10)

- **Previously used electronics:** Cividec + Oscilloscope
  - → both not scalable to multiple channels detector

- **New electronics dedicated for Multipad:**
  - → Custom-made RF pulse amplifier cards optimised for PICOSEC
  - → 128-channel SAMPIC digitizer



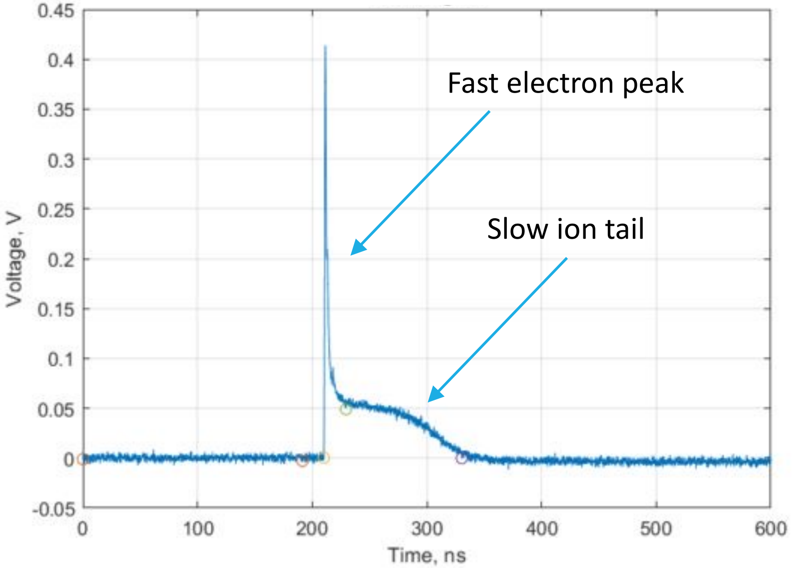
Resistive Micromegas

PRELIMINARY

Test beam measurements - oscilloscope

- **Multipad** with a **resistive MM 20 MΩ/□,** a CsI photocathode and RF pulse amplifiers measured with an oscilloscope

Waveform



Resistive Micromegas

PRELIMINARY

Test beam measurements - oscilloscope

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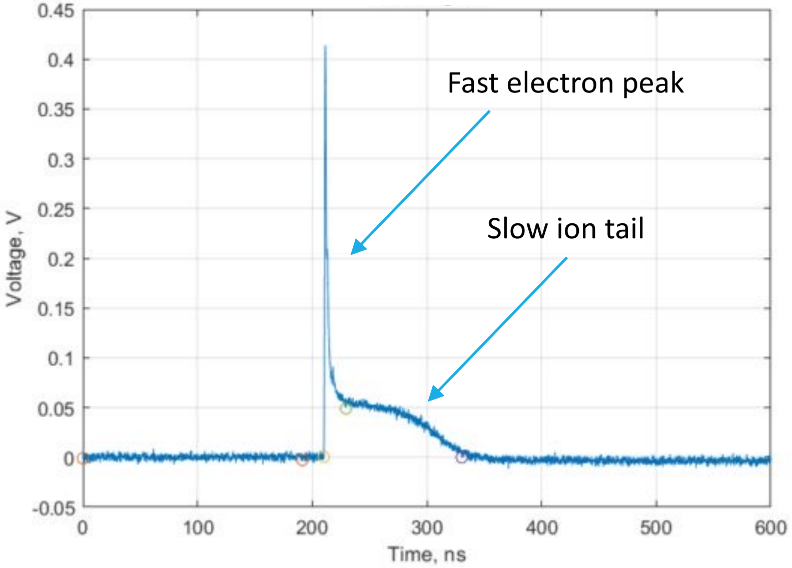
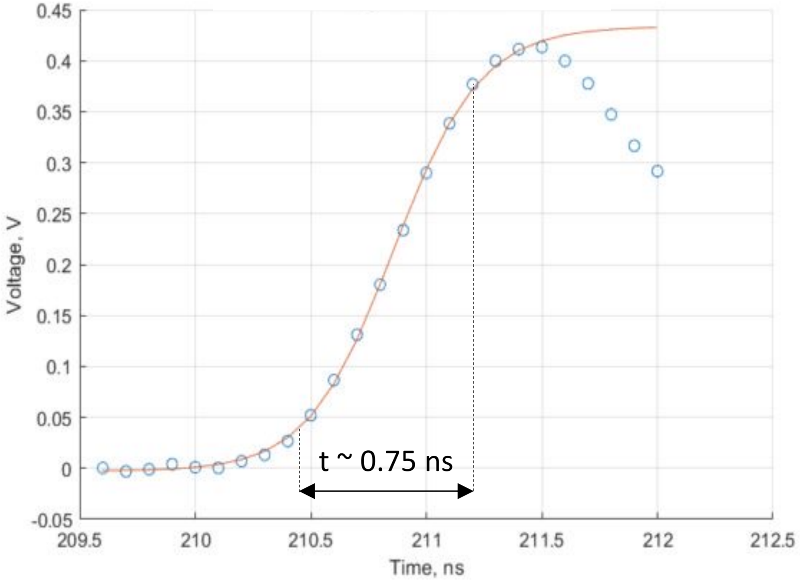
Waveform



Rise time

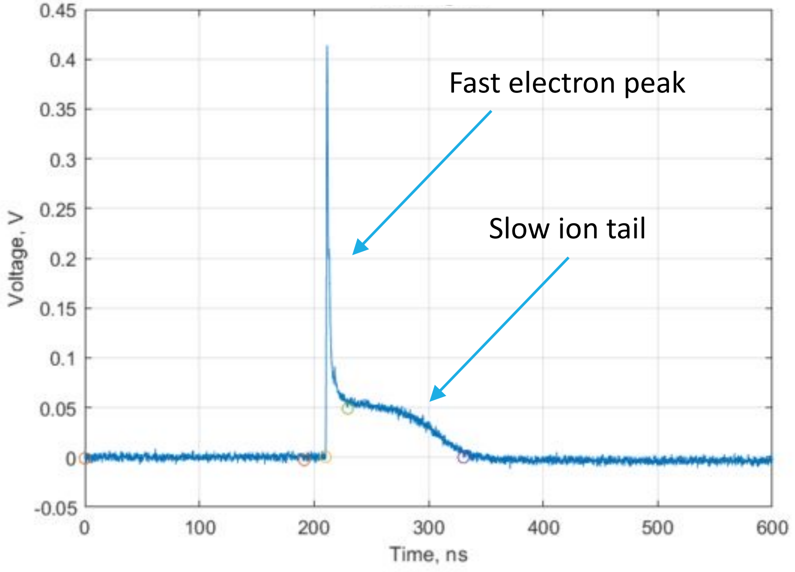


Resistive Micromegas

PRELIMINARY

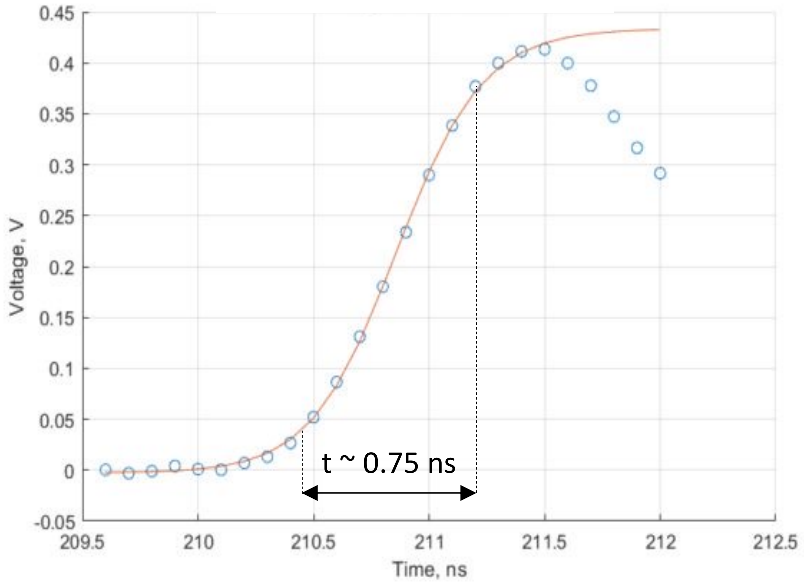
Test beam measurements - oscilloscope

- **Multipad** with a **resistive MM 20 MΩ/□,** a CsI photocathode and RF pulse amplifiers measured with an oscilloscope

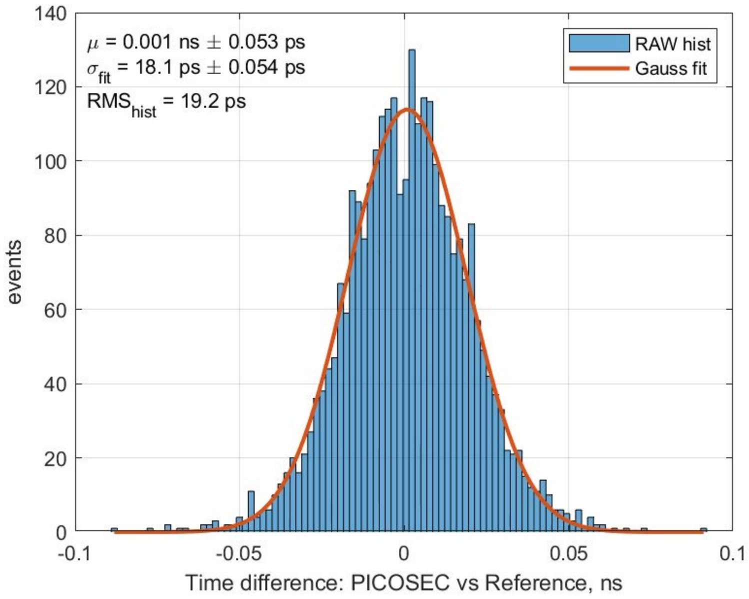

Waveform

Fast electron peak

Slow ion tail


Rise time

t ~ 0.75 ns


Time resolution

μ = 0.001 ns ± 0.053 ps

σ_{fit} = 18.1 ps ± 0.054 ps

$\mathrm{RMS}_{\mathrm{hist}}$ = 19.2 ps

- Preliminary results for 10x10 cm^2 **resistive MM 20 MΩ/□** showed a **time resolution below 20 ps** for an individual pad!

Resistive Micromegas

New digitiser dedicated for 100-channel detector

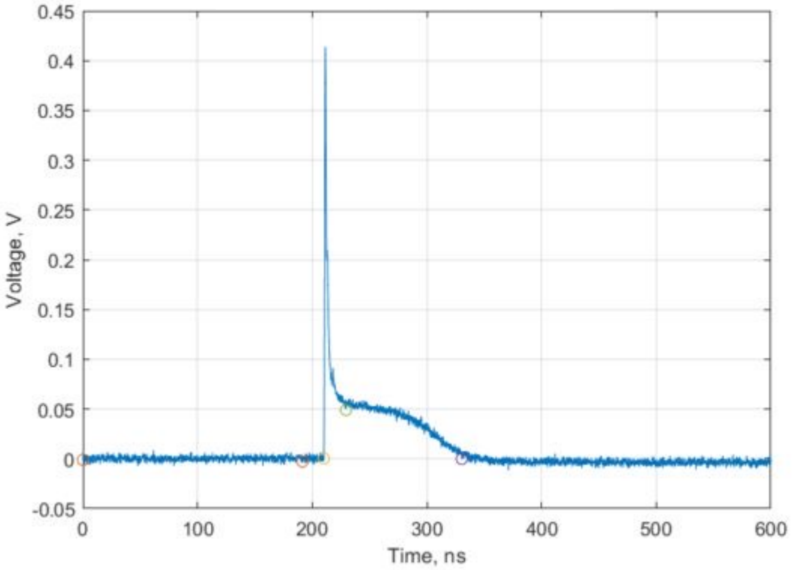
- **SAMPIC Waveform TDC**

  → 128-channel digitiser under test (instead of a 4-channel oscilloscope) – possibility to read out full Multipad

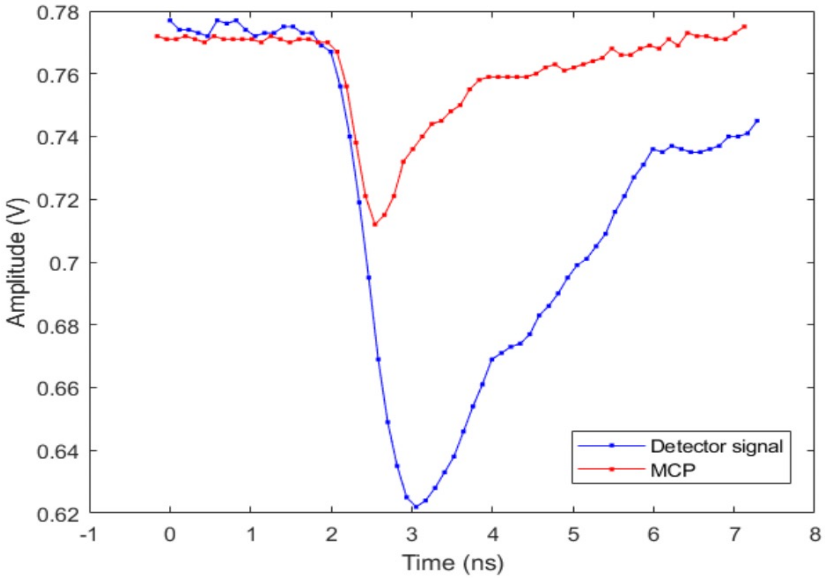
  → 8.5 GS/s sampling frequency (instead of 10 GS/s with oscilloscope) – test of achievable timing precision

  → 64 samples maximum digitalisation – ion tail is not fully included in the signal

Waveform from oscilloscope



Waveform from SAMPIC



SAMPIC digitiser developed by Jihane Maalmi, Dominique Breton et al., CEA Saclay

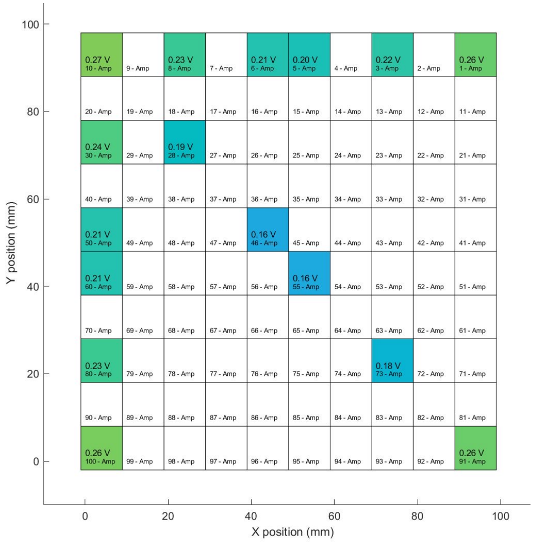
Resistive Micromegas

PRELIMINARY

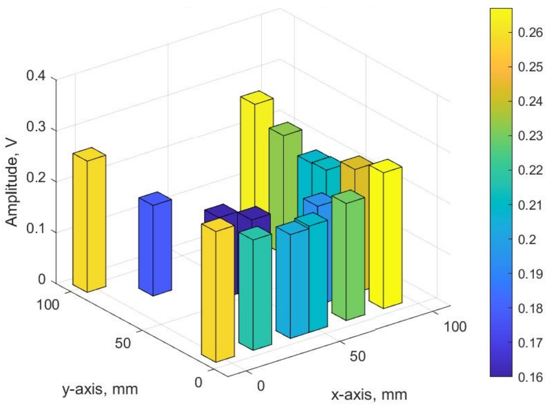
Test beam measurements – SAMPIC (1)

- **SAMPIC readout** of a 100-channel PICOSEC detector equipped with a resistive MM 20 MΩ/□ and a CsI photocathode
- **Signal amplitude** results achieved with single p.e. (LED measurement) and with multiple p.e. (beam measurement)

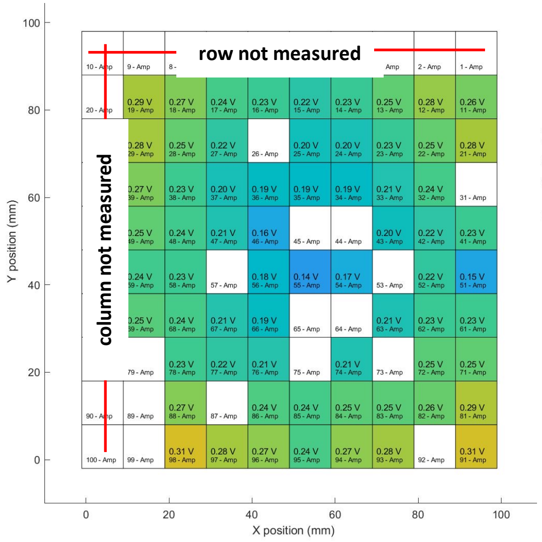
Signal amplitude for **single p.e.** measurements



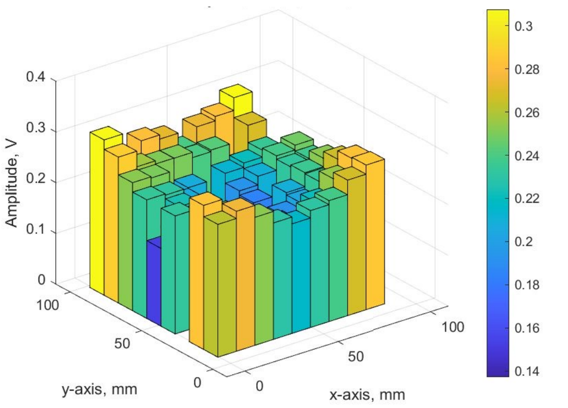
0.27 V 10 - Amp	9 - Amp	0.23 V 8 - Amp	7 - Amp	0.21 V 6 - Amp	0.20 V 5 - Amp	4 - Amp	0.22 V 3 - Amp	2 - Amp	0.26 V 1 - Amp
20 - Amp	19 - Amp	18 - Amp	17 - Amp	16 - Amp	15 - Amp	14 - Amp	13 - Amp	12 - Amp	11 - Amp
0.24 V 30 - Amp	29 - Amp	0.19 V 28 - Amp	27 - Amp	26 - Amp	25 - Amp	24 - Amp	23 - Amp	22 - Amp	21 - Amp
40 - Amp	39 - Amp	38 - Amp	37 - Amp	36 - Amp	35 - Amp	34 - Amp	33 - Amp	32 - Amp	31 - Amp
0.21 V 50 - Amp	49 - Amp	48 - Amp	47 - Amp	0.16 V 46 - Amp	45 - Amp	44 - Amp	43 - Amp	42 - Amp	41 - Amp
0.21 V 60 - Amp	59 - Amp	58 - Amp	57 - Amp	56 - Amp	0.16 V 55 - Amp	54 - Amp	53 - Amp	52 - Amp	51 - Amp
70 - Amp	69 - Amp	68 - Amp	67 - Amp	66 - Amp	65 - Amp	64 - Amp	63 - Amp	62 - Amp	61 - Amp
0.23 V 80 - Amp	79 - Amp	78 - Amp	77 - Amp	76 - Amp	75 - Amp	74 - Amp	0.18 V 73 - Amp	72 - Amp	71 - Amp
90 - Amp	89 - Amp	88 - Amp	87 - Amp	86 - Amp	85 - Amp	84 - Amp	83 - Amp	82 - Amp	81 - Amp
0.26 V 100 - Amp	99 - Amp	98 - Amp	97 - Amp	96 - Amp	95 - Amp	94 - Amp	93 - Amp	92 - Amp	0.26 V 91 - Amp



Signal amplitude for **multiple p.e.** measurements



10 - Amp	9 - Amp	8 -					Amp	2 - Amp	1 - Amp
20 - Amp	0.29 V 19 - Amp	0.27 V 18 - Amp	0.24 V 17 - Amp	0.23 V 16 - Amp	0.22 V 15 - Amp	0.23 V 14 - Amp	0.25 V 13 - Amp	0.28 V 12 - Amp	0.26 V 11 - Amp
	.28 V 29 - Amp	0.25 V 28 - Amp	0.22 V 27 - Amp	26 - Amp	0.20 V 25 - Amp	0.20 V 24 - Amp	0.23 V 23 - Amp	0.25 V 22 - Amp	0.28 V 21 - Amp
	.27 V 39 - Amp	0.23 V 38 - Amp	0.20 V 37 - Amp	0.19 V 36 - Amp	0.19 V 35 - Amp	0.19 V 34 - Amp	0.21 V 33 - Amp	0.24 V 32 - Amp	31 - Amp
	.25 V 49 - Amp	0.24 V 48 - Amp	0.21 V 47 - Amp	0.16 V 46 - Amp	45 - Amp	44 - Amp	0.20 V 43 - Amp	0.22 V 42 - Amp	0.23 V 41 - Amp
	.24 V 59 - Amp	0.23 V 58 - Amp	57 - Amp	0.18 V 56 - Amp	0.14 V 55 - Amp	0.17 V 54 - Amp	53 - Amp	0.22 V 52 - Amp	0.15 V 51 - Amp
	.25 V 69 - Amp	0.24 V 68 - Amp	0.21 V 67 - Amp	0.19 V 66 - Amp	65 - Amp	64 - Amp	0.21 V 63 - Amp	0.23 V 62 - Amp	0.23 V 61 - Amp
	79 - Amp	0.23 V 78 - Amp	0.22 V 77 - Amp	0.21 V 76 - Amp	75 - Amp	0.21 V 74 - Amp	73 - Amp	0.25 V 72 - Amp	0.25 V 71 - Amp
90 - Amp	89 - Amp	0.27 V 88 - Amp	87 - Amp	0.24 V 86 - Amp	0.24 V 85 - Amp	0.25 V 84 - Amp	0.25 V 83 - Amp	0.26 V 82 - Amp	0.29 V 81 - Amp
100 - Amp	99 - Amp	0.31 V 98 - Amp	0.28 V 97 - Amp	0.27 V 96 - Amp	0.24 V 95 - Amp	0.27 V 94 - Amp	0.28 V 93 - Amp	92 - Amp	0.31 V 91 - Amp



Missing pads under investigation

(dead pads, bad connection…)

- Non-uniform response of the signal across the area: amplitude decrease towards the center of the detector
- Possible reason: variation in the resistive MM board planarity of 30 μm → Investigation of the production procedure

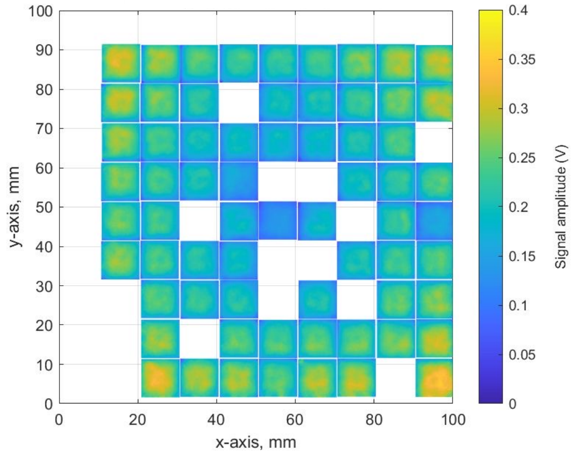
Resistive Micromegas

PRELIMINARY

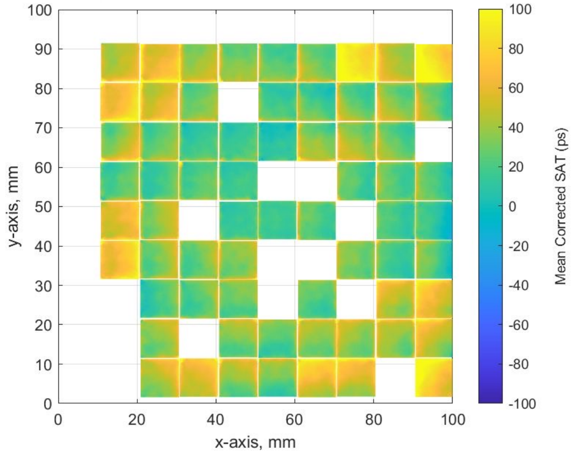
Test beam measurements – SAMPIC (2)

- **SAMPIC readout** of a 100-channel PICOSEC detector equipped with a resistive MM 20 MΩ/□ and a CsI photocathode

Signal amplitude



Signal arrival time



- Non-uniform response of the signal within the pads

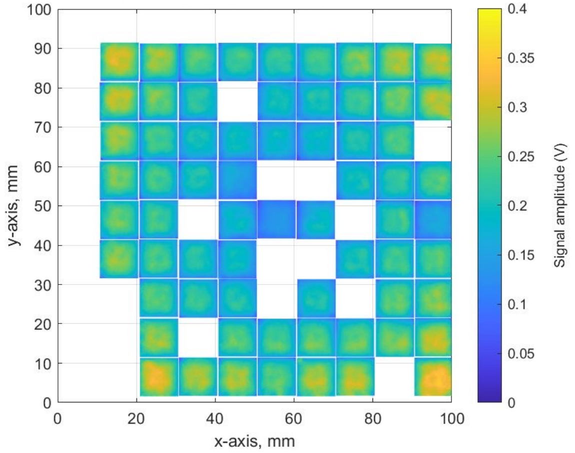
Resistive Micromegas

PRELIMINARY

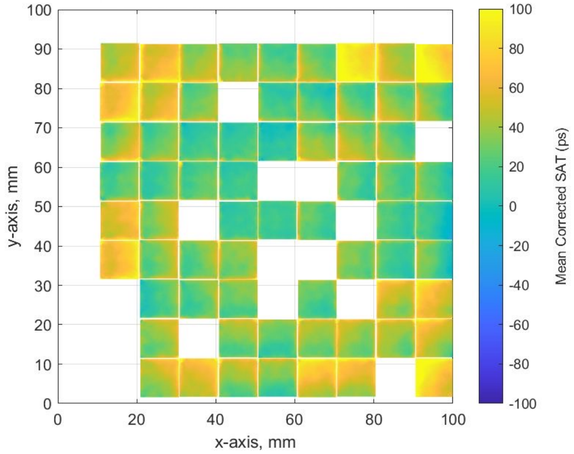
Test beam measurements – SAMPIC (2)

- **SAMPIC readout** of a 100-channel PICOSEC detector equipped with a resistive MM 20 MΩ/□ and a CsI photocathode

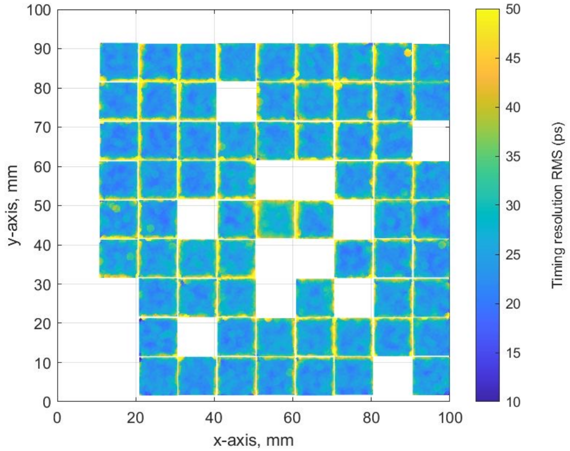
Signal amplitude

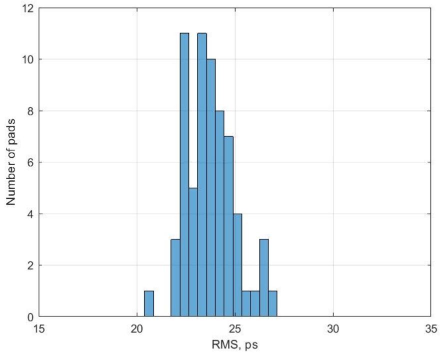


Signal arrival time

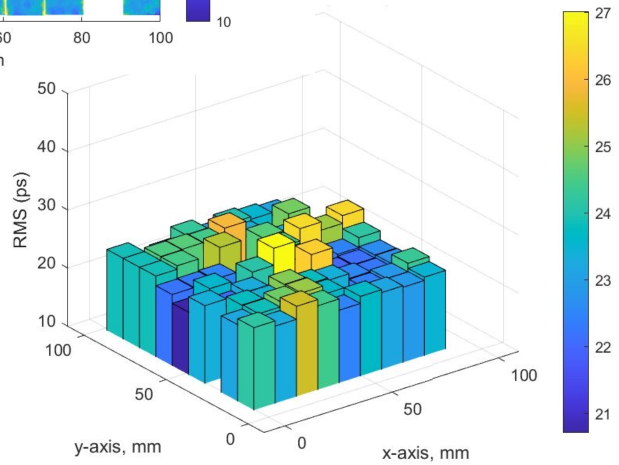


Time resolution





- Non-uniform response of the signal within the pads
- Uniform time resolution within the pads
- Narrow distribution of the time resolution across the area
- **Tool to study the response of 100-channel PICOSEC detector**



Robust photocathodes

Problem with CsI and alternatives

QE AND AGEING STUDIES PERFORMED USING UV LIGHT

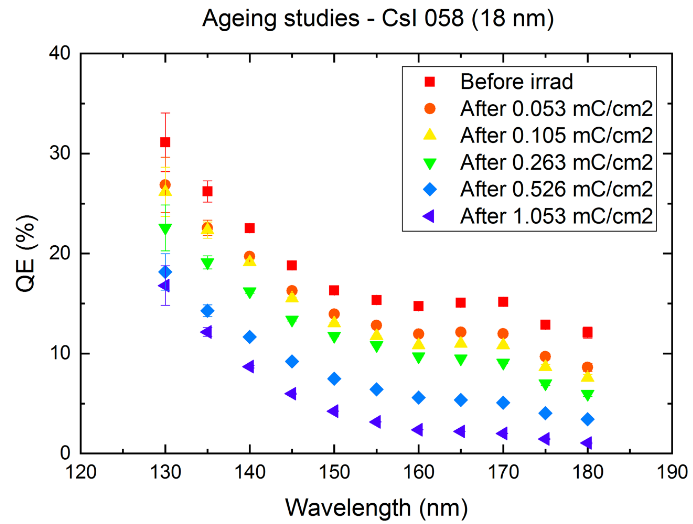
- **First single-pad prototype:** CsI photocathode

  + high quantum efficiency in comparison to other materials: ~10 p.e. / MIP

  with 3 mm MgF_2 radiator + 3 nm Cr layer + 18 nm CsI photocathode

  - can be damaged by ion back flow, sparks, discharges

  - sensitive to humidity (assembly)



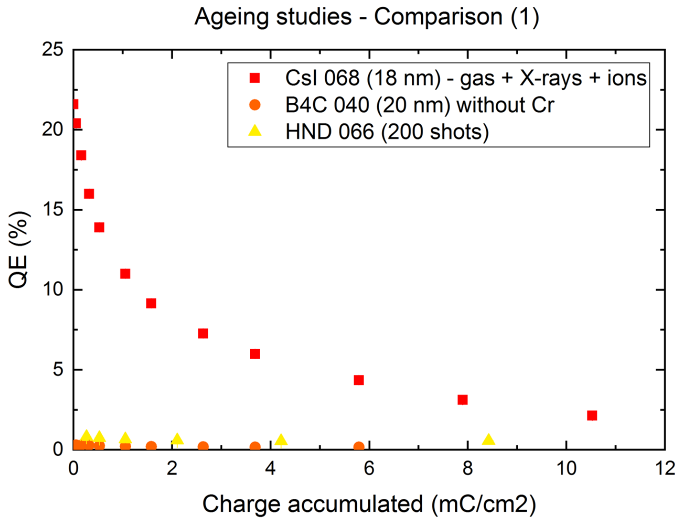
- Need to search for **alternative photocathode materials**:

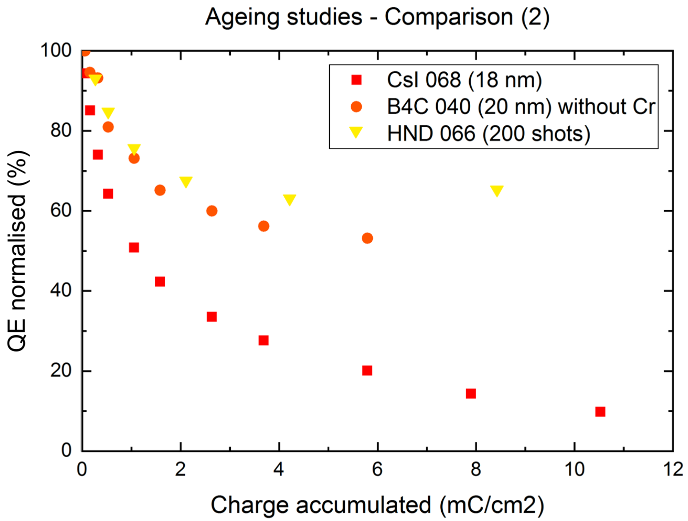
  → Diamond Like Carbon (DLC)

  → Boron Carbide (B_4C)

  → Nanodiamonds

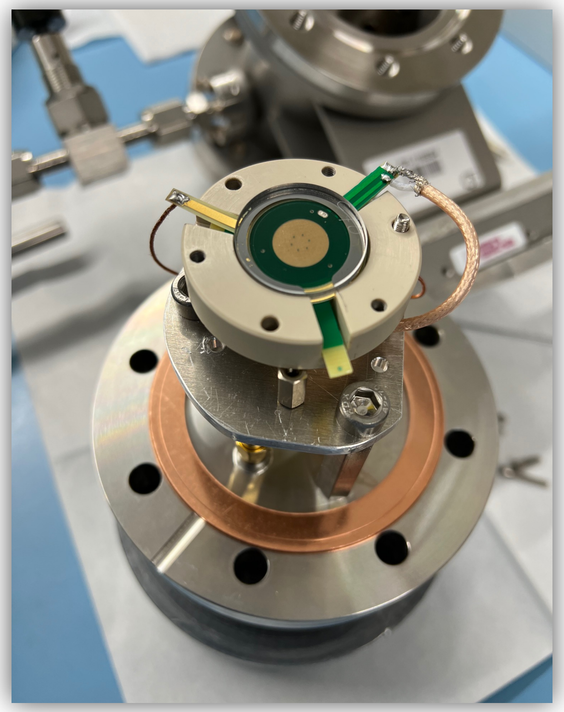
  → …





Robust photocathodes

Test beam measurements – B_4C photocathodes



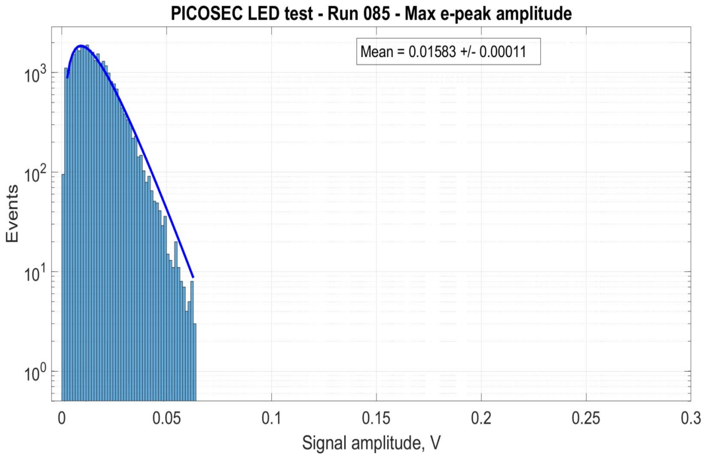
- **Prototype #1**: Single channel non-resistive MM, pre-amplification gap 170 µm
- **Photocathodes**: B_4C of different thicknesses*

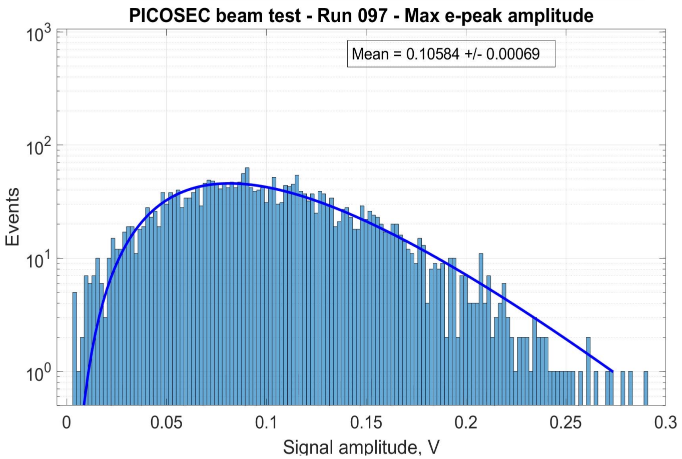
- **Measurements procedure**:

  1. Single PE measurement with LED → 2. Beam measurement → 3. Timing measurement

- **#PE analysis procedure****:

  1. Find maximum amplitude for each waveform
  2. Plot a histogram of all maximum amplitudes
  3. Fit with Polya and calculate the mean value
  4. Divide beam mean amplitude by LED mean amplitude to obtain #PE for each photocathode





* B_4C photocathodes deposited by M. Pomorski (CEA Saclay)

** PE analysis thanks to help of S. Tzamarias (AUTH), D. Janssens (CERN) and M. Robert (Queen's University)

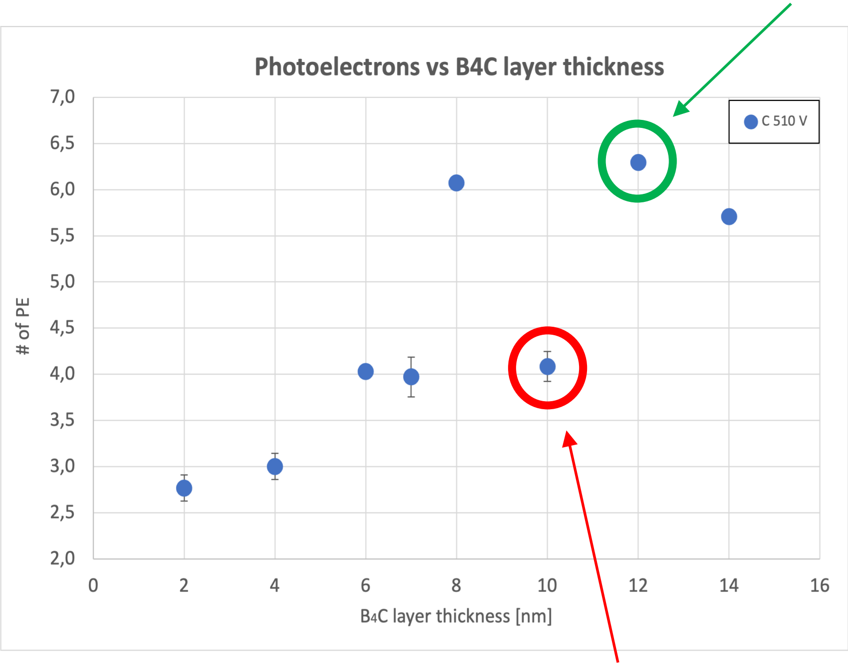
Robust photocathodes

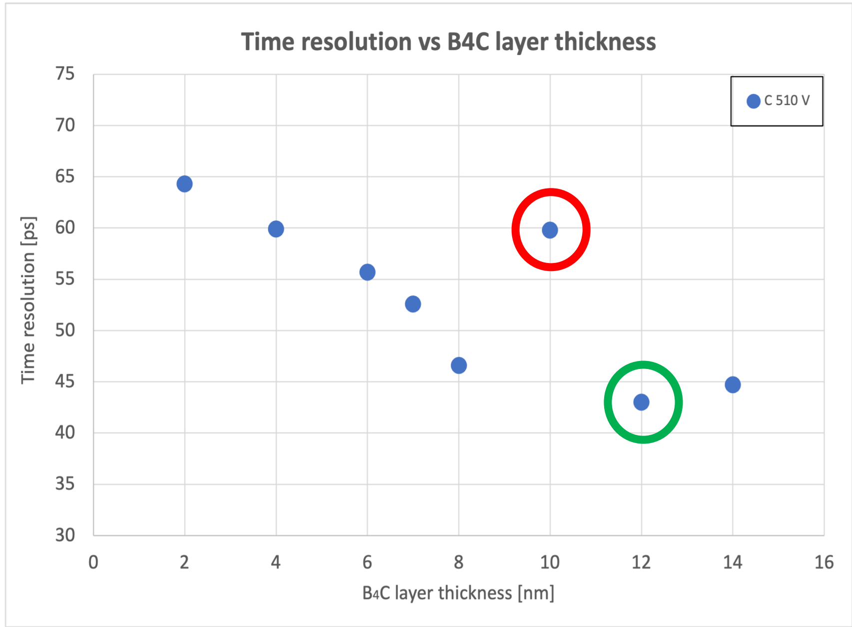
PRELIMINARY

Results for B_4C of different thicknesses

- **Prototype #1**: Single channel non-resistive MM*, pre-amplification gap 170 µm

The best sample





Does not follow the trend.
Different thickness? Problem with the deposition?

*Produced at CERN MPT workshop

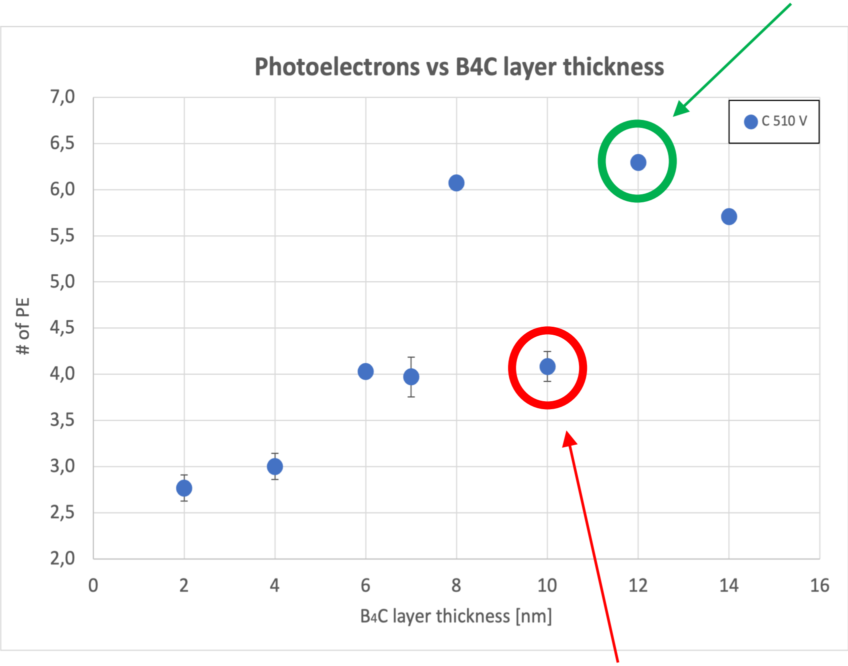
Robust photocathodes

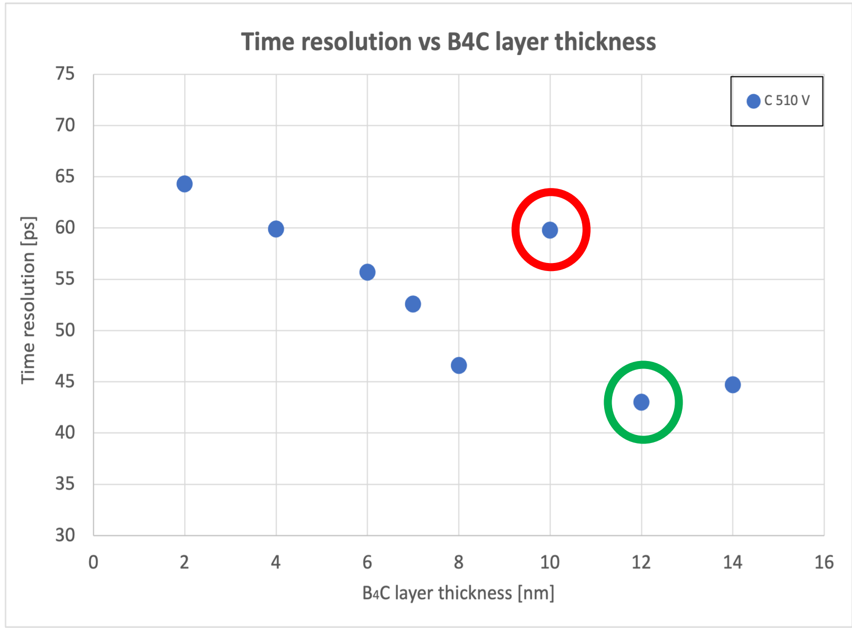
PRELIMINARY

Results for B_4C of different thicknesses

- **Prototype #1**: Single channel non-resistive MM*, pre-amplification gap 170 µm

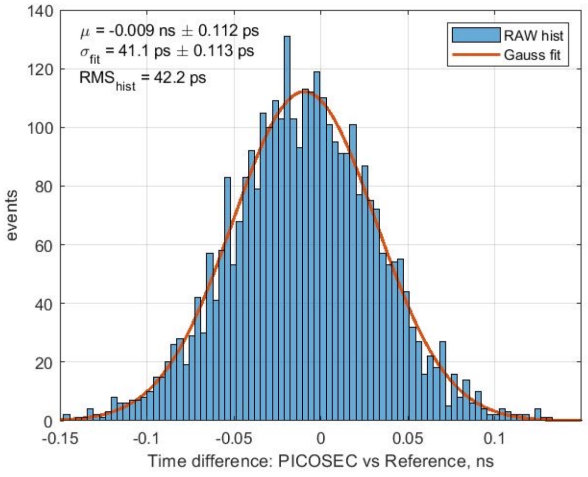
The best sample





Does not follow the trend.
Different thickness? Problem with the deposition?

Time resolution with
CsI photocathode



Problem with the MM detector:
Time resolution with CsI > 40 ps!

*Produced at CERN MPT workshop

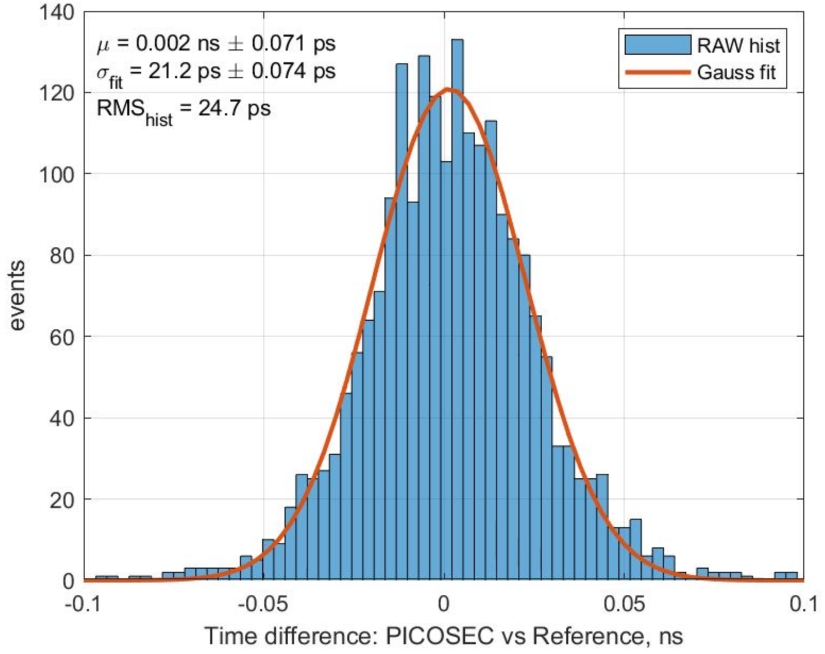
Robust photocathodes

PRELIMINARY

Results for 12 nm B_4C with different prototype

- **Prototype #2**: Single channel non-resistive MM*, pre-amplification gap 120 µm, detector confirmed to work properly

CsI photocathode



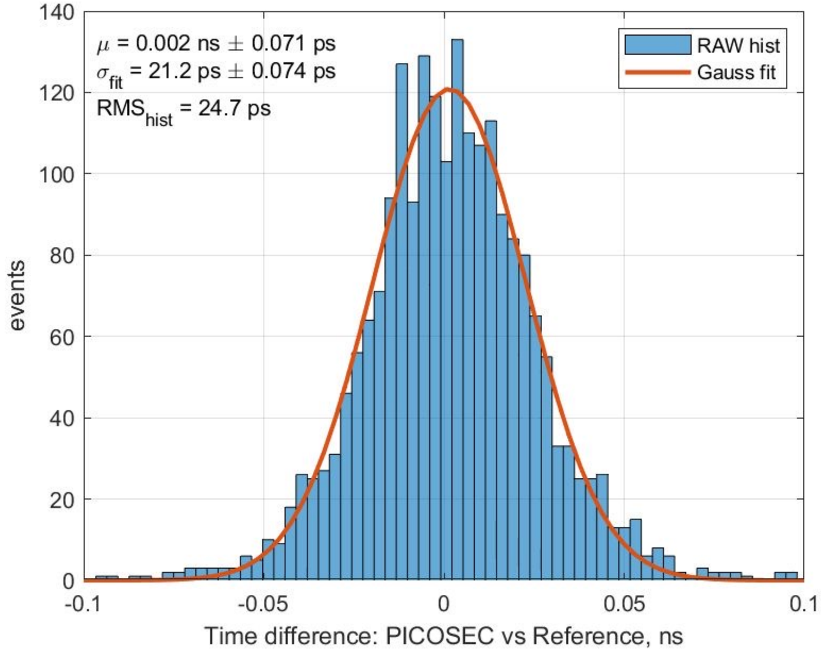
*Produced at CEA Saclay

Robust photocathodes

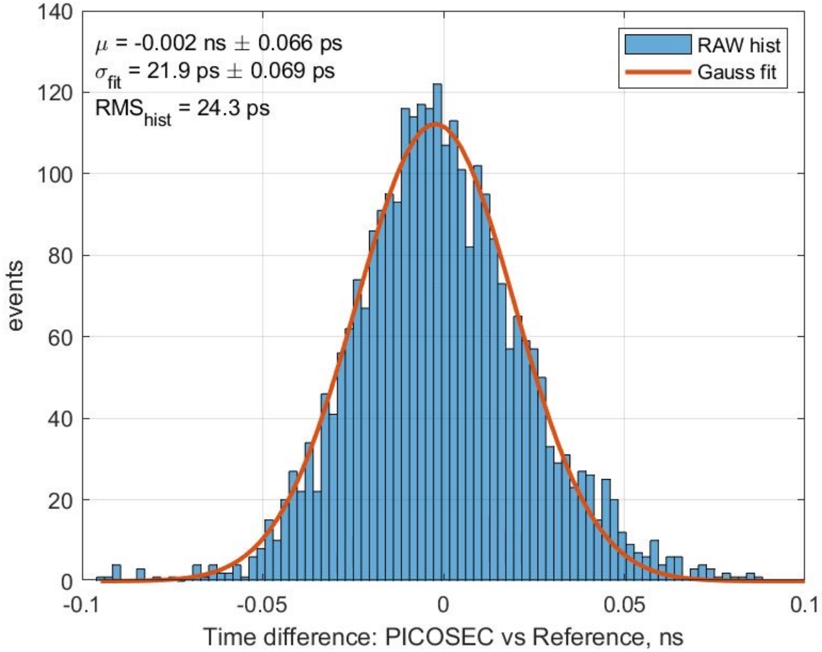
PRELIMINARY

Results for 12 nm B_4C with different prototype

- **Prototype #2**: Single channel non-resistive MM*, pre-amplification gap 120 µm, detector confirmed to work properly



CsI photocathode



B_4C 12 nm photocathode

- Single-pad prototype equipped with a **12 nm thick B_4C photocathode** showed a **time resolution below 25 ps!**

*Produced at CEA Saclay

Summary

- Excellent timing performance of the new 100-channel PICOSEC MM prototype

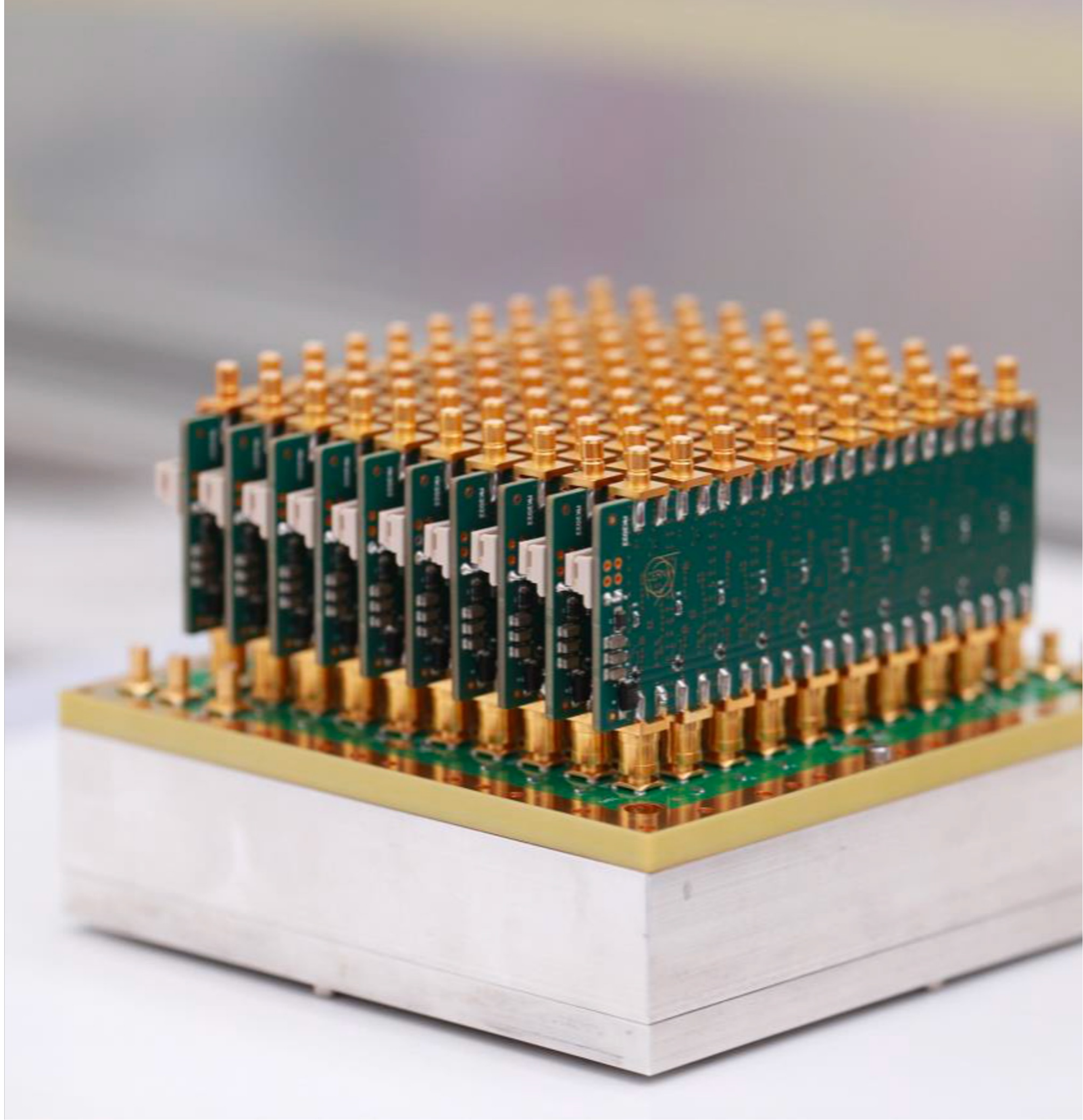
  → **Multipad with a resistive MM with a time resolution < 20 ps** for an individual pad

- Measurements with a complete readout chain

  → **Successful readout of multiple channels**

- Developments towards robust photocathodes

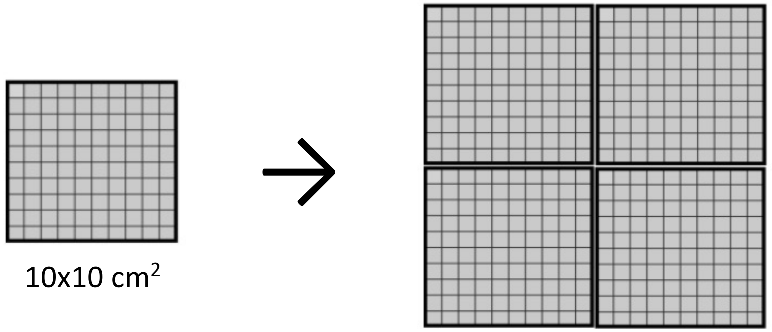
  → Preliminary results of a single-pad prototype equipped with a **12 nm thick B_4C photocathode** showed a **time resolution < 25 ps**



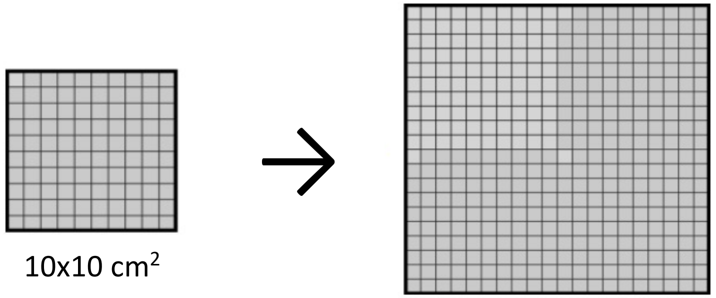
Future perspectives

Developments

- **Stability** → Stable operation in intense pion beams with resistive MM Multipad
- **Robustness** → PICOSEC MM detector with a 10x10 cm^2 area B_4C and DLC photocathode
- **Electronics** → Complete readout of all 100 channels, exploring alternative electronics
- **Integration** → Sealed detectors (clean, hermetically closed devices with high gas quality)
- **Scaling to larger area** → Tiling 10x10 cm^2 modules, development of 20x20 cm^2 prototype



Tiling: 4 x 10x10 cm^2



20x20 cm^2

PICOSEC Micromegas Collaboration

M. Lisowska[1,2,*], Y. Angelis[3], J. Bortfeldt[4], F. Brunbauer[1], E. Chatzianagnostou[3], K. Dehmelt[5], G. Fanourakis[6], K. J. Floethner[1,7], M. Gallinaro[8], F. Garcia[9], P. Garg[5], I. Giomataris[10], K. Gnanvo[11], T. Gustavsson[12], F.J. Iguaz[10], D. Janssens[1,13,14], A. Kallitsopoulou[10], M. Kovacic[15], P. Legou[10], J. Liu[16], M. Lupberger[7,17], S. Malace[11], I. Maniatis[1,3], Y. Meng[16], H. Muller[1,17], E. Oliveri[1], G. Orlandini[1,18], T. Papaevangelou[10], M. Pomorski[19], L. Ropelewski[1], D. Sampsonidis[3,20], L. Scharenberg[1,17], T. Schneider[1], L. Sohl[10], M. van Stenis[1], Y. Tsipolitis[21], S.E. Tzamarias[3,20], A. Utrobicic[22], R. Veenhof[1,23], X. Wang[16], S. White[1,24], Z. Zhang[16], and Y. Zhou[16]

[1] European Organization for Nuclear Research (CERN), CH-1211, Geneve 23, Switzerland
[2] Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[3] Department of Physics, Aristotle University of Thessaloniki, University Campus, GR-54124, Thessaloniki, Greece
[4] Department for Medical Physics, Ludwig Maximilian University of Munich, Am Coulombwall 1, 85748 Garching, Germany
[5] Stony Brook University, Dept. of Physics and Astronomy, Stony Brook, NY 11794-3800, USA
[6] Institute of Nuclear and Particle Physics, NCSR Demokritos, GR-15341 Agia Paraskevi, Attiki, Greece
[7] Helmholtz-Institut für Strahlen- und Kernphysik, University of Bonn, Nußallee 14–16, 53115 Bonn, Germany
[8] Laboratório de Instrumentacão e Física Experimental de Partículas, Lisbon, Portugal
[9] Helsinki Institute of Physics, University of Helsinki, FI-00014 Helsinki, Finland
[10] IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[11] Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, USA
[12] LIDYL, CEA, CNRS, Universit Paris-Saclay, F-91191 Gif-sur-Yvette, France
[13] Inter-University Institute for High Energies (IIHE), Belgium
[14] Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
[15] Faculty of Electrical Engineering and Computing, University of Zagreb, 10000 Zagreb, Croatia
[16] State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China
[17] Physikalisches Institut, University of Bonn, Nußallee 12, 53115 Bonn, Germany
[18] Friedrich-Alexander-Universität Erlangen-Nürnberg, Schloßplatz 4, 91054 Erlangen, Germany
[19] CEA-LIST, Diamond Sensors Laboratory, CEA Saclay, F-91191 Gif-sur-Yvette, France
[20] Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki 57001, Greece
[21] National Technical University of Athens, Athens, Greece
[22] Institute Ruder Bosković Institute, Bijenička cesta 54, 10000, Zagreb, Croatia
[23] Bursa Uludağ University, Görükle Kampusu, 16059 Niufer/Bursa, Turkey
[24] University of Virginia, USA

PICOSEC
Micromegas

Thank you for your attention!

CONTACT: MARTA.LISOWSKA@CERN.CH

Back up slides

Classical vs PICOSEC Micromegas

Signal arrival time jitter

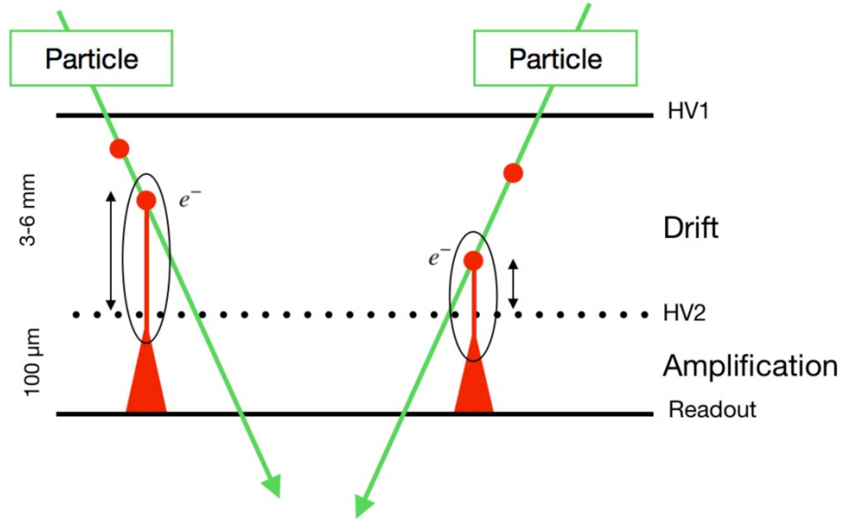
- **Classical Micromegas:**

  → different position of ionisation clusters at direct gas ionisation

  → signal arrival time jitter due to drift velocity and average ionisation length

$$\sigma_t = \frac{\sigma_I}{v_d} = \frac{355\,\mu m}{84\,\frac{\mu m}{ns}} \approx 4\,ns$$

Estimated time jitter for COMPASS Micromegas



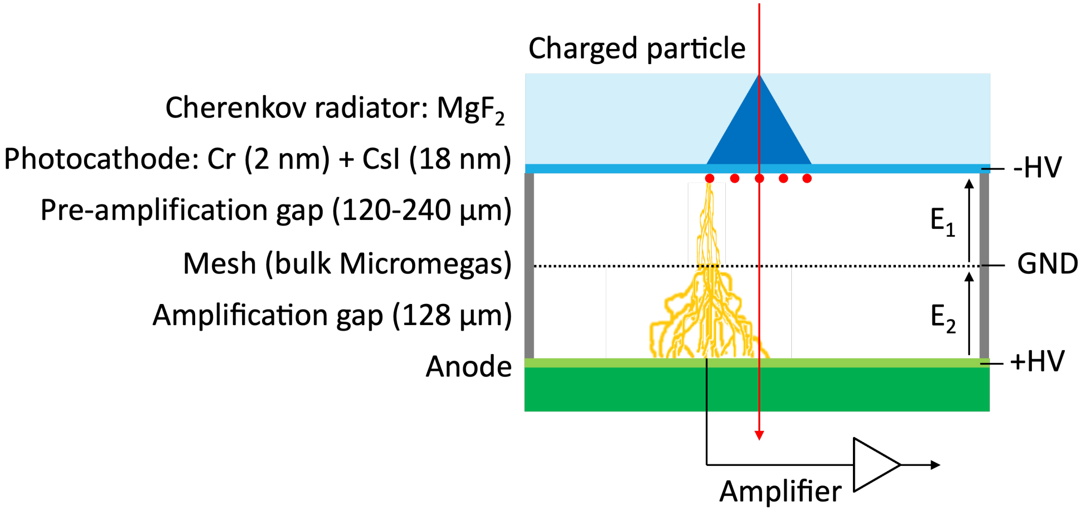
- **PICOSEC Micromegas:**

  → particles produce Cherenkov radiation

  → electrons are emitted by the radiation in a photocathode

  → all primary ionised electrons are localised on the photocathode

  → due to high electric field, time jitter before first amplification minimised



L. Sohl, RD51 Miniweek (2020), link

PICOSEC Micromegas

Signal arrival time

- **Signal arrival time (SAT) = <$T_{e\text{-peak}}$>**

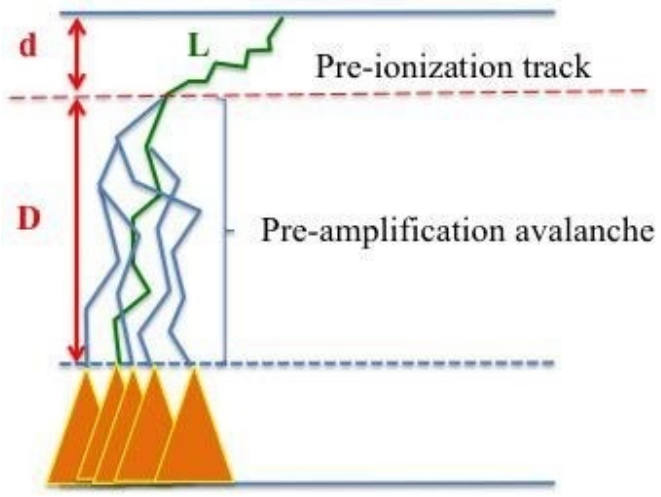
  → SAT depends on e-peak charge

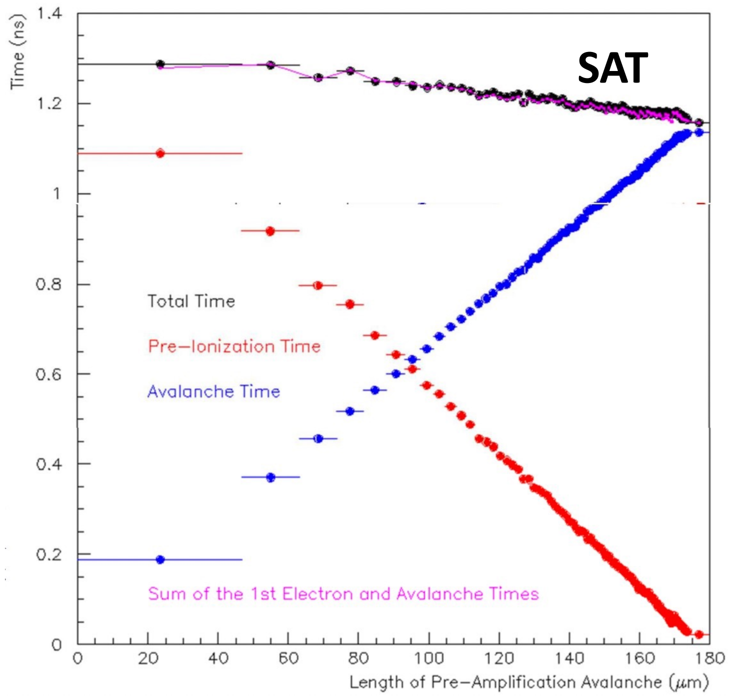
  → SAT can be reduced by higher drift field and bigger pulses

- **Location of first ionisation determines length of avalanche**

  → longer avalanches result in bigger e-peak charge

  → bigger e-peak charge reduces SAT



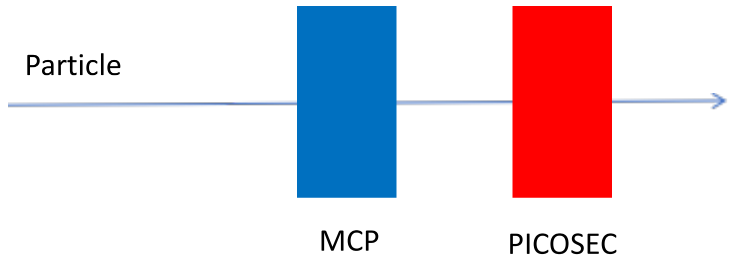


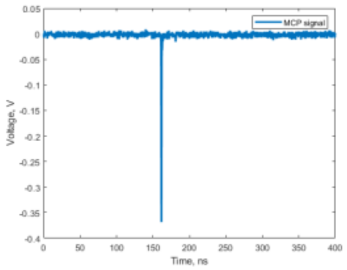
K. Kordas, VCI 2019 conference, link

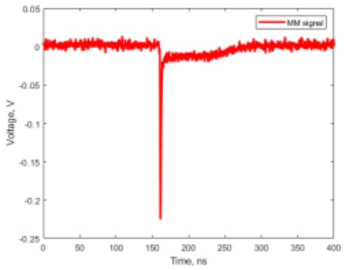
PICOSEC Micromegas

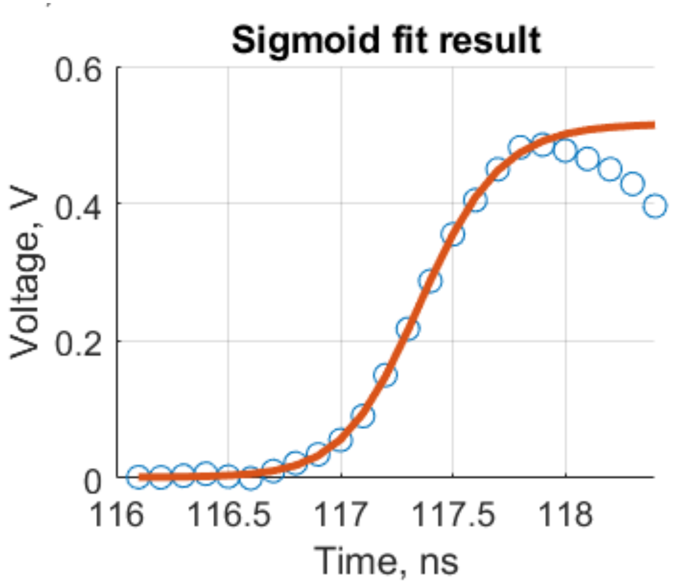
Timing properties

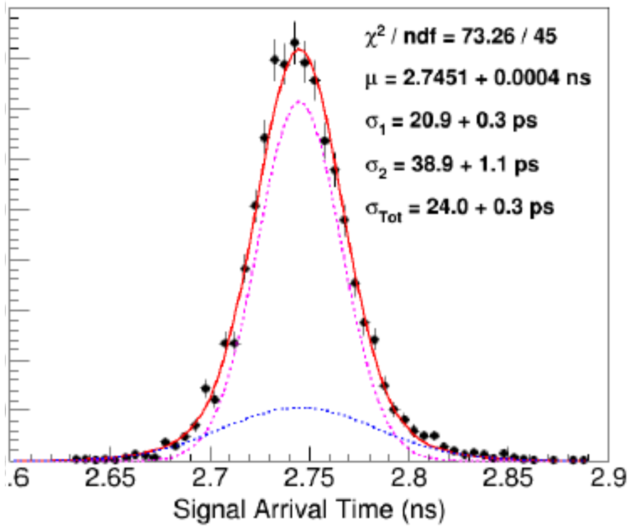
- Reference device with better timing precision than the PICOSEC is needed to quantify the timing precision of PICOSEC.
- Sigmoid function is fitted to the leading edge of the electron peak. Position of the signal is calculated at 20% Constant Fraction (CF).
- Signal arrival time (SAT): the difference between PICOSEC and reference detector timing marks.
- Time resolution of the detector is defined as standard deviation of SAT distribution.











A. Utrobičić, VCI 2022 conference, link

Preamplification gap

Uniform thickness

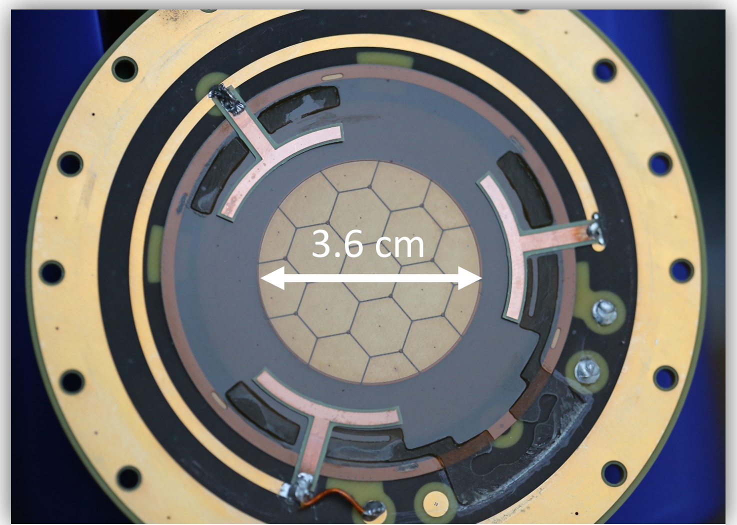
- **Problem:** first 19 channels PICOSEC Micromegas prototype:

  - active area of 3.6 cm in diameter

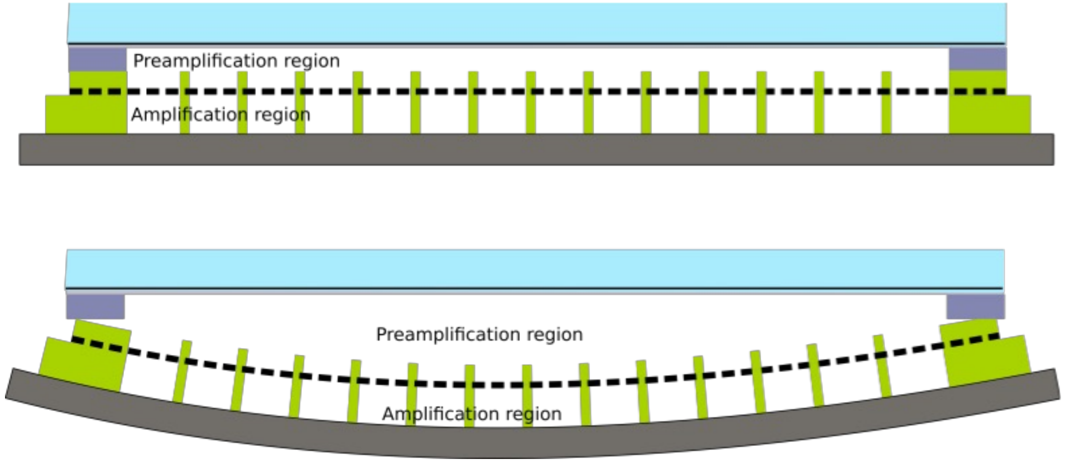
  - deformations in the range of 30 μm in the active area

  - time error and non-uniform response of the detector

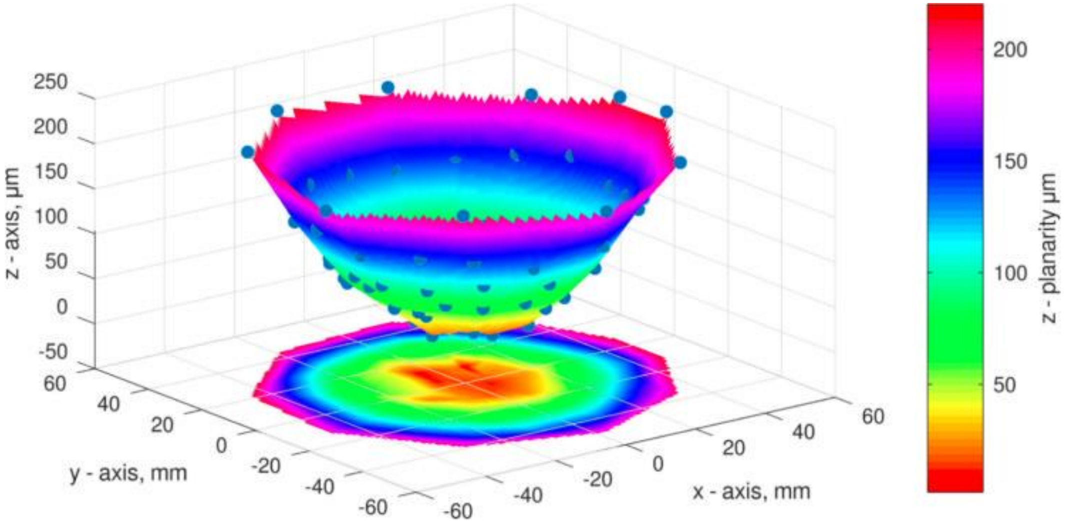
  - problem even more pronounced for larger area prototype



19 channels PICOSEC MM prototype



Problem of non-uniform preamplification gap

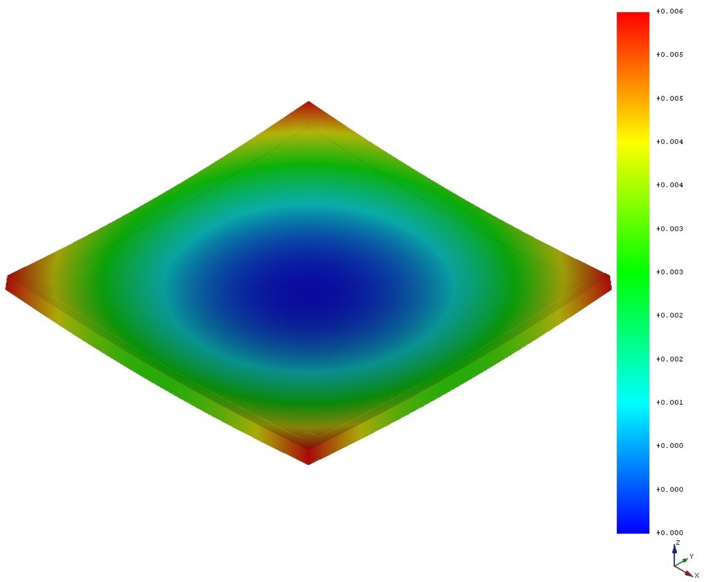


Deformation of 19 channels PICOSEC MM, A. Aune et al., link

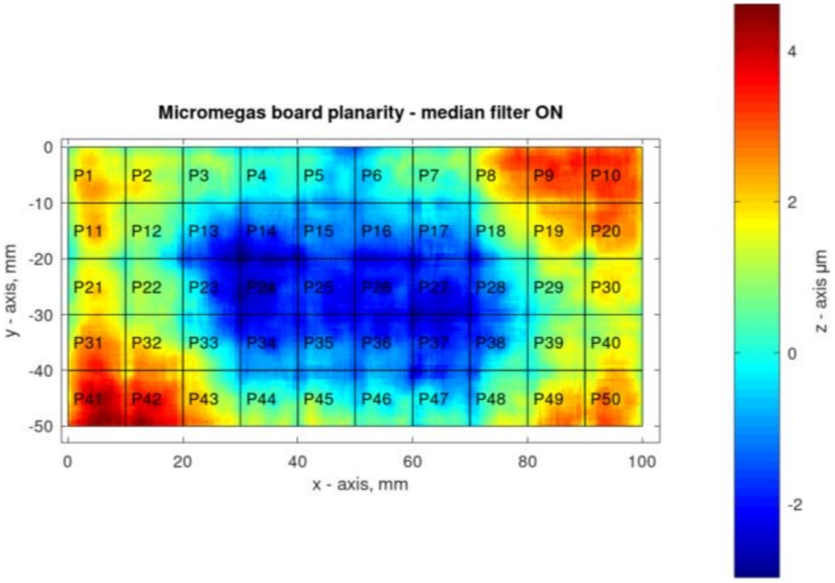
Multipad: 100 channels PICOSEC Micromegas detector

From simulations and design to production, measurements and assembly

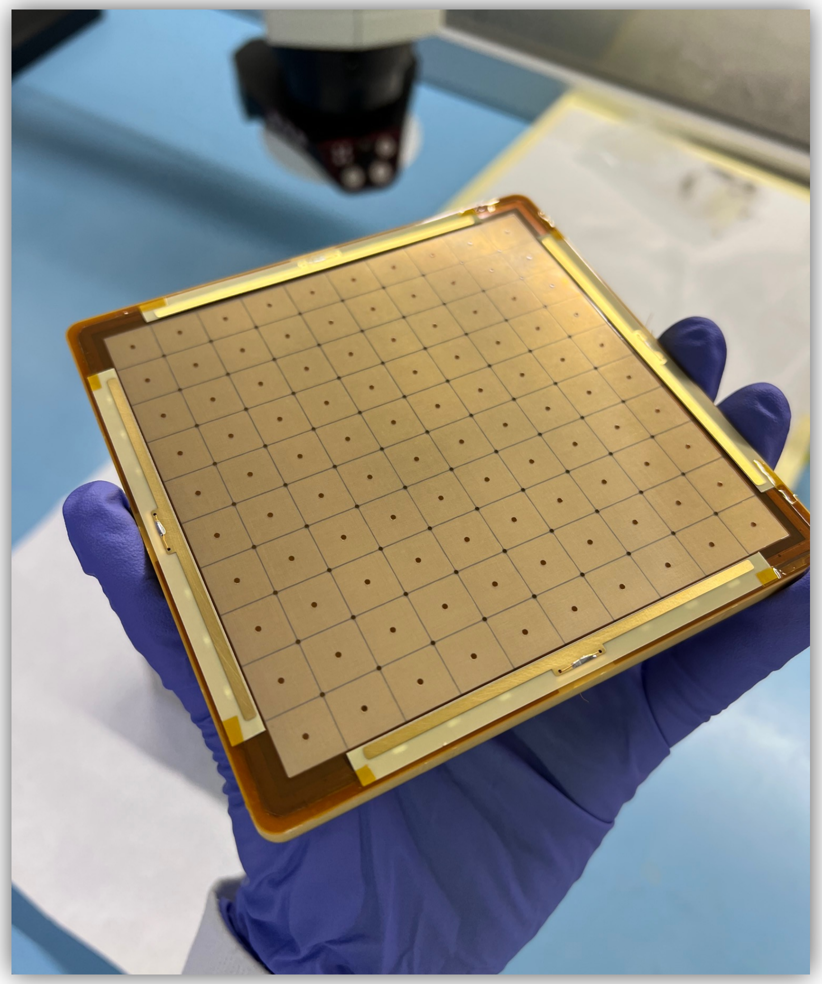
- **Requirement:** Precise mechanics to preserve uniform thickness of the preamplification gap
- **Current status:** 100 channels PICOSEC Micromegas detector with uniform thickness (< 10 µm) of the preamplification gap



Mechanical aspects: A. Utrobičić, RD51 CM, link

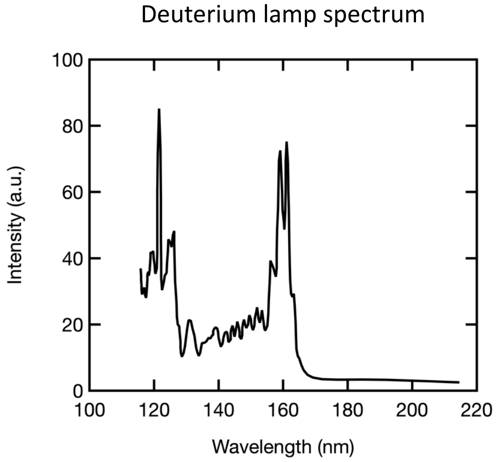


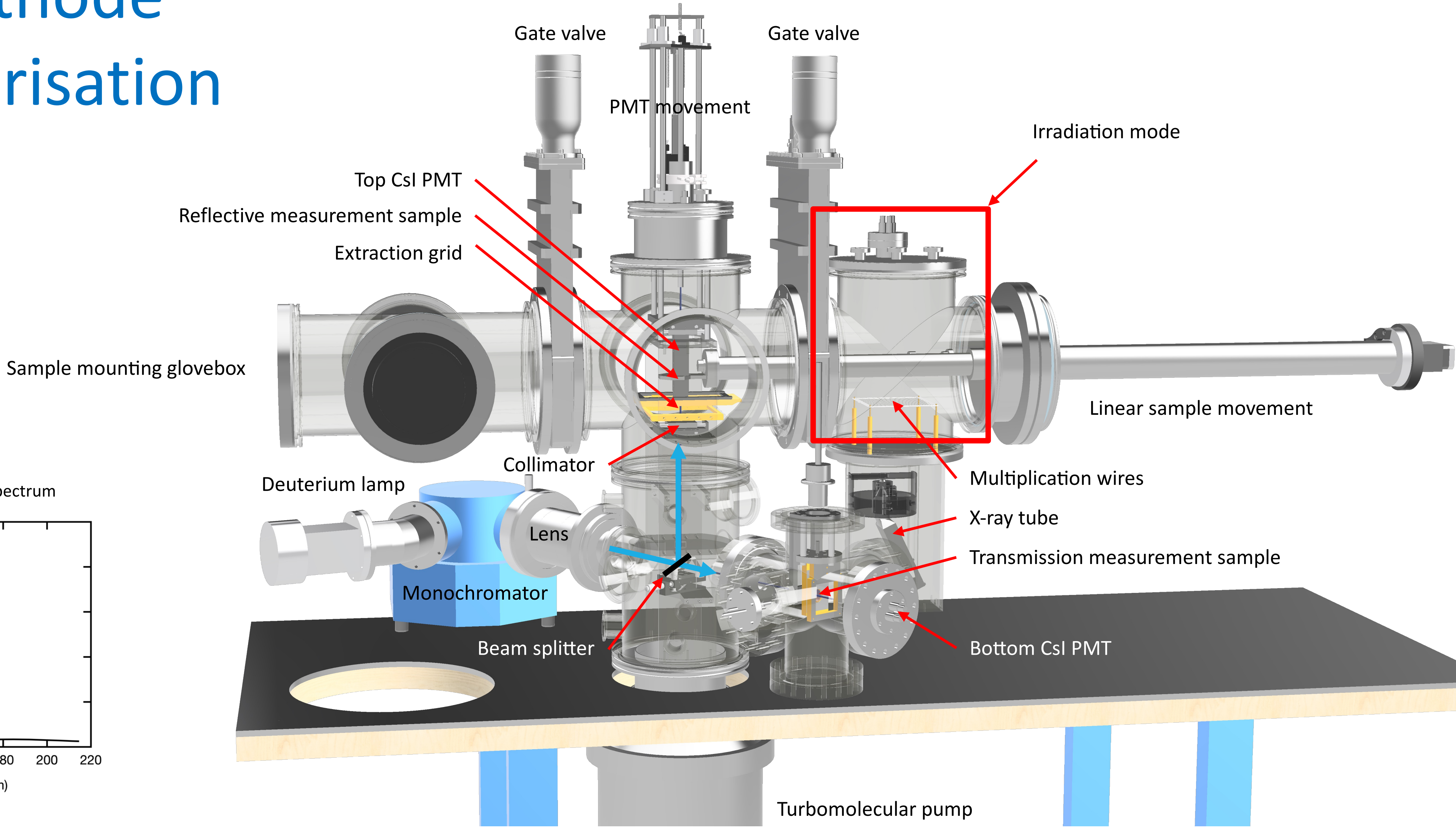
More details: A. Utrobičić, VCI 2022 conference, link



Photocathode characterisation

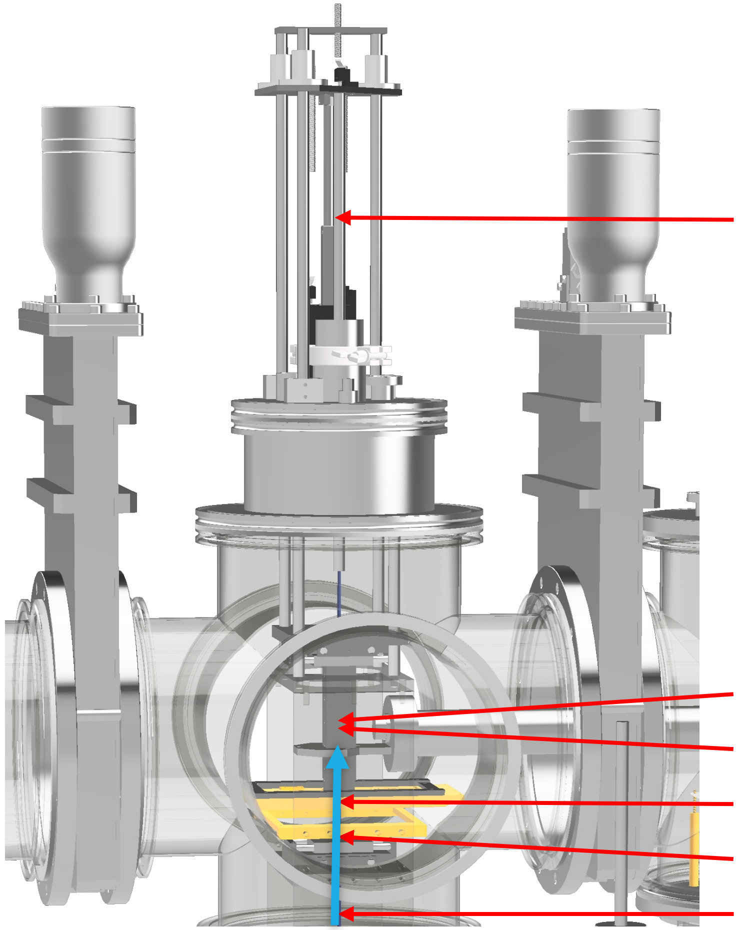
Setup overview





Photocathode characterisation

QE measurements - Reflective mode



PMT movement

CsI PMT meas. position

Sample meas. position

Extraction grid

Collimator

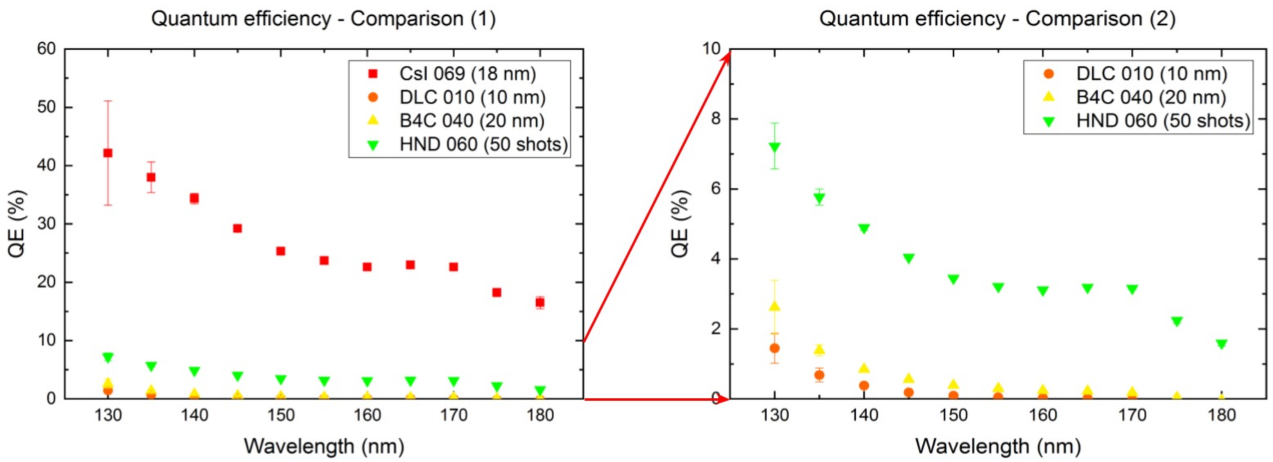
UV beam

Samples: cesium iodide (CsI), diamond-like carbon (DLC), boron carbide (B_4C) and hydrogenated nanodiamonds (HND)

$$\mathrm{QE} = \frac{Electrons_{sample}}{Photons_{PMT}}$$

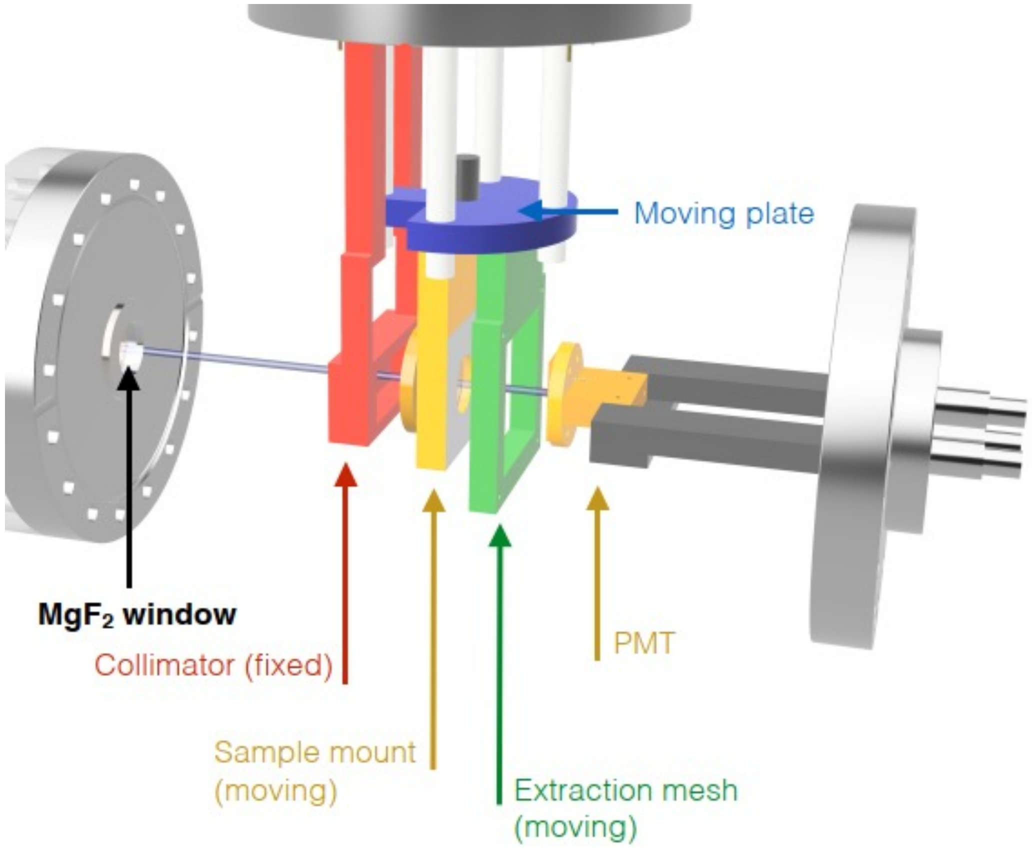
$Electrons_{sample}$ - electrons extracted from the sample

$Photons_{PMT}$ - photons that arrived to the sample



Photocathode characterisation

QE measurements - Transmission mode

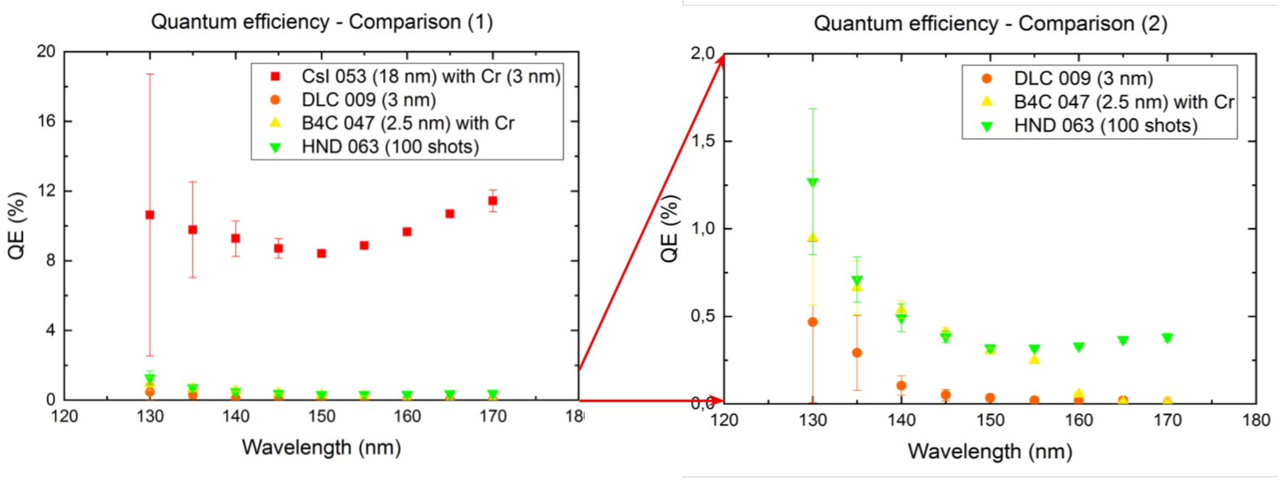


$$\text{Transparency} = \frac{\text{PMT current: sample in}}{\text{PMT current: sample out}}$$

$$\text{QE} = \frac{Electrons_{sample}}{Photons_{PMT}}$$

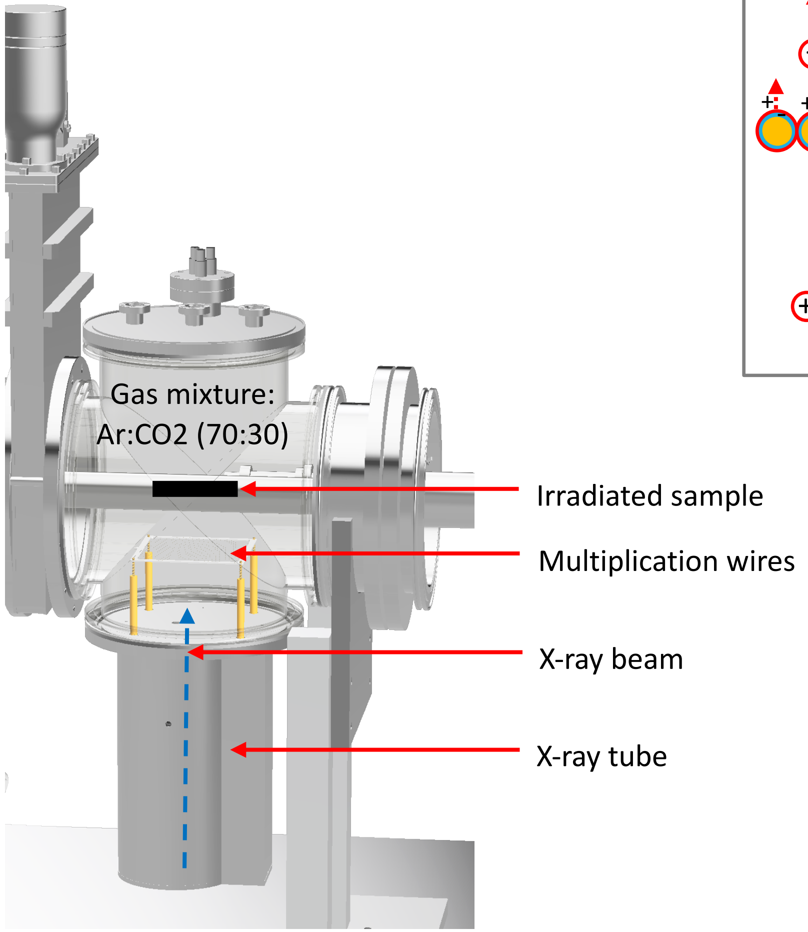
$Electrons_{sample}$ - electrons extracted from the sample

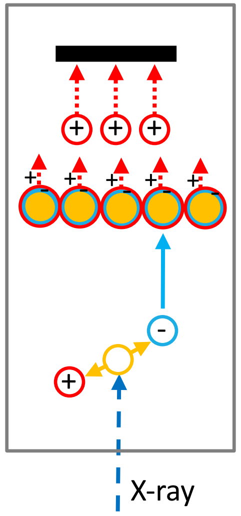
$Photons_{PMT}$ - photons that arrived to the sample



Photocathode characterisation

Ageing studies – Irradiation mode

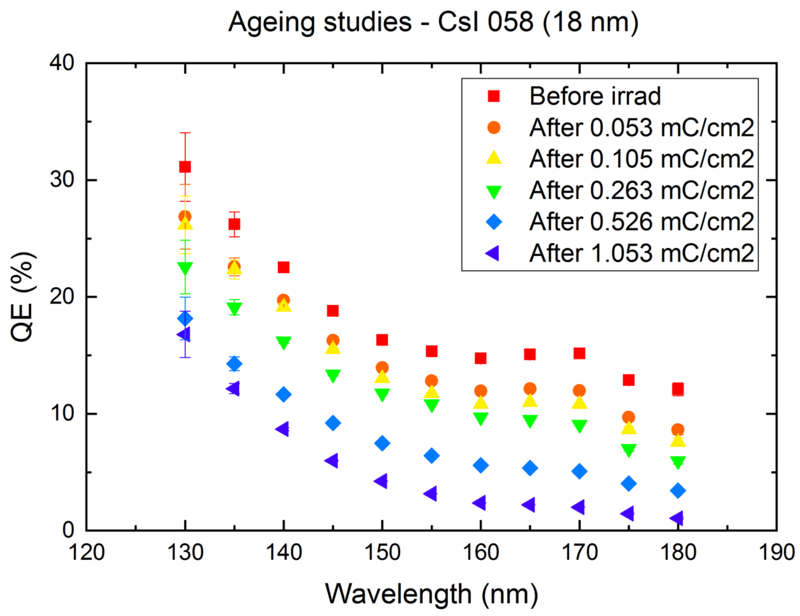


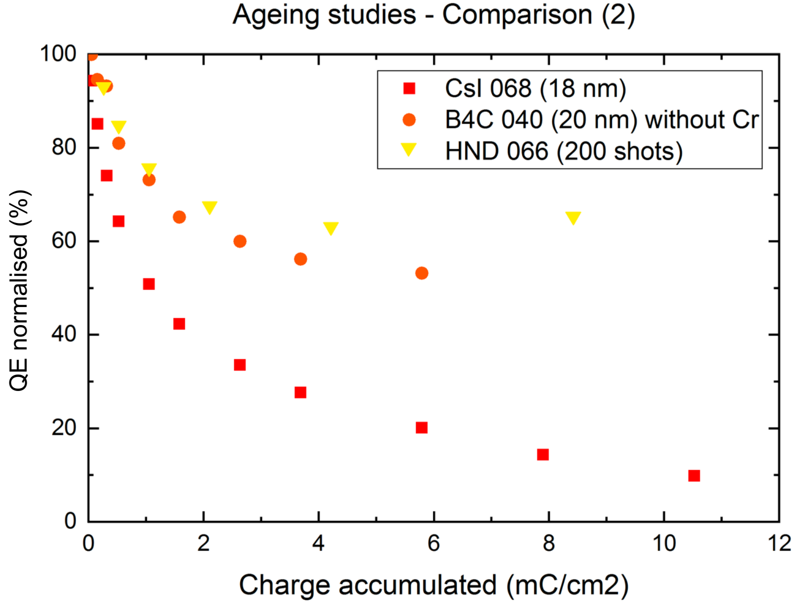


3. Irradiated sample (grounded):
Attraction of ions from avalanche
Accumulation of charge

2. Multiplication wires (positive HV):
Attraction of primary electrons
Avalanche multiplication
Production of electrons and ions

1. X-ray beam in a gas chamber:
Ionization of particles
Creation of primary charge


Ageing studies - CsI 058 (18 nm)


Ageing studies - Comparison (2)

Integration

Sealed detectors

- **Advantages of sealed detectors:**

  + clean, hermetically closed devices with high gas quality

  + high ratio of active area to the size of the device

- **Current status:**

  → one 10x10 cm^2 titanium housing ready to assembly

  → large area robust photocathode (DLC, B_4C) required

  → gas connectors (pinch-off tubes) ready to assembly

  → closing procedure: electron beam welding

  → last step: filling the detector with gas mixture