Current status of PICOSEC Micromegas precise timing detectors and future prospect

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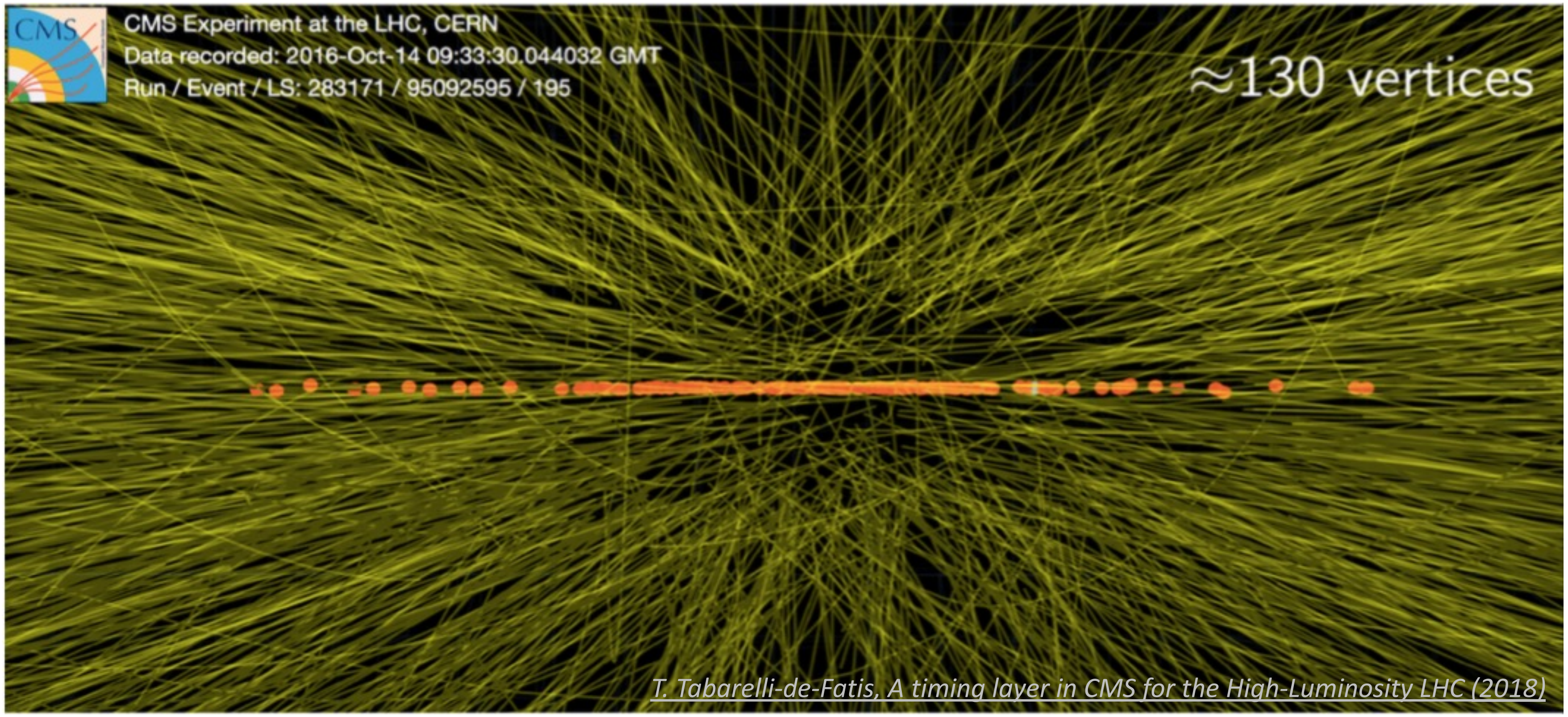
ON BEHALF OF THE CERN EP-DT-DD GDD TEAM
AND THE PICOSEC MICROMEGAS COLLABORATION

RD51 MINI WEEK, 27-28 FEBRUARY 2023

Precise timing detectors

Motivation

- **Challenges of future HEP experiments:** high pile-up environments, connecting tracks with primary vertices, …



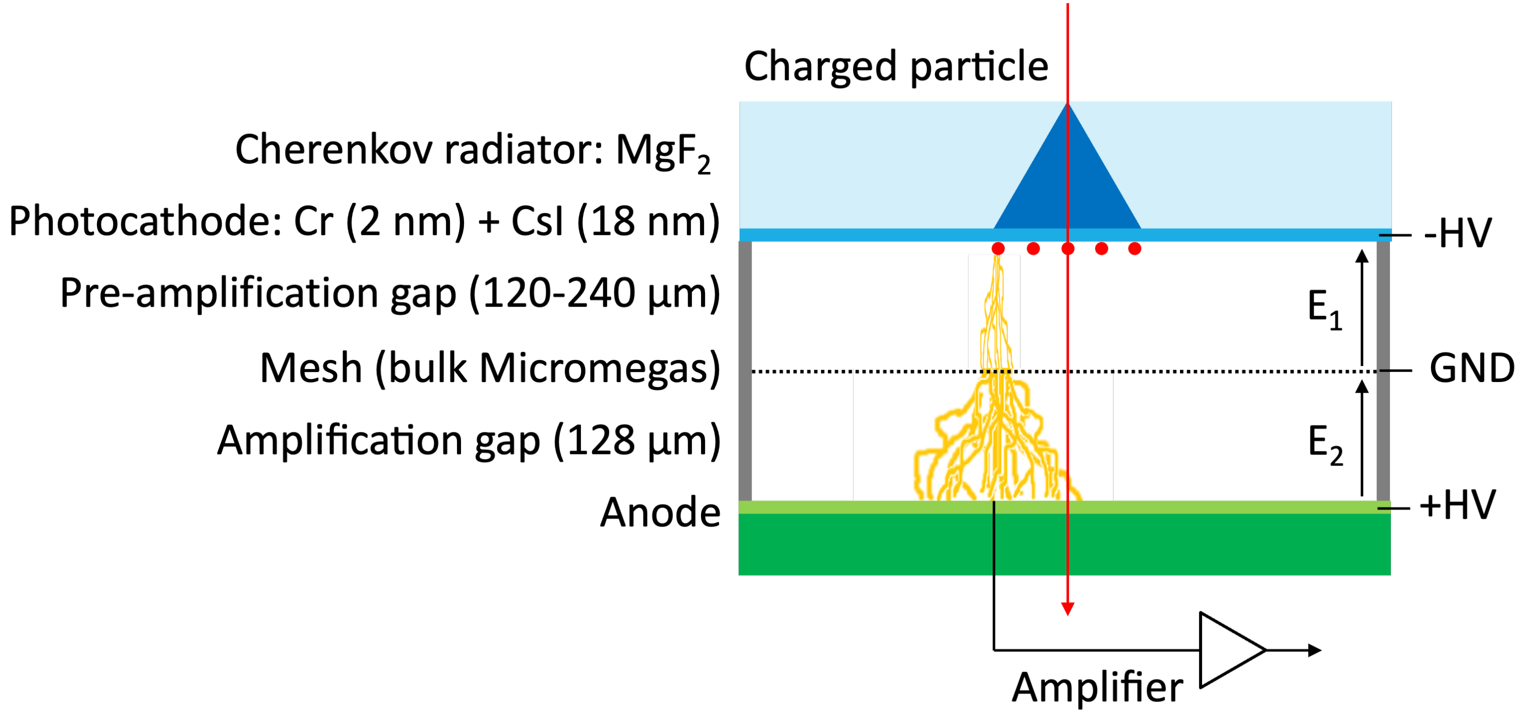
T. Tabarelli-de-Fatis, A timing layer in CMS for the High-Luminosity LHC (2018)

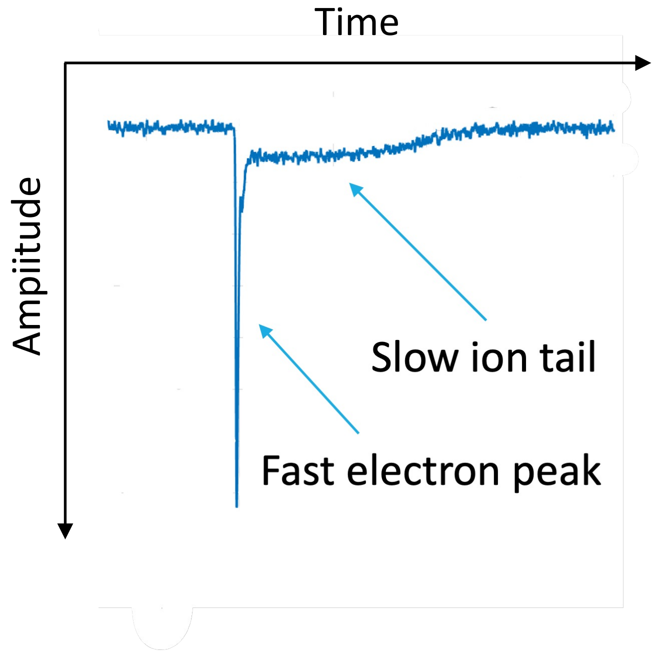
- **Detectors requirements:** time resolution of tens of picoseconds, stable long-term operation, large area coverage, …

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

- **Large area coverage:**

  100-channel prototypes, tileable modules

- **Detector optimalisation:**

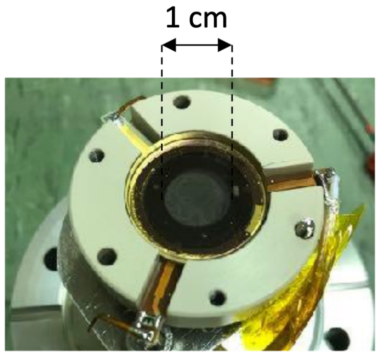
  gaps thickness, fields settings, operating gas

- **Robustness:**

  resistive Micromegas, robust photocathodes

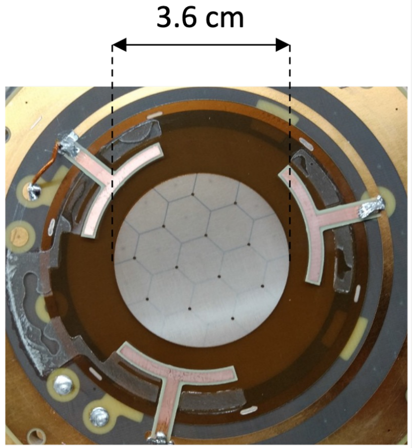
- **Electronics:**

  scalable amplifiers, multi-channel digitiser



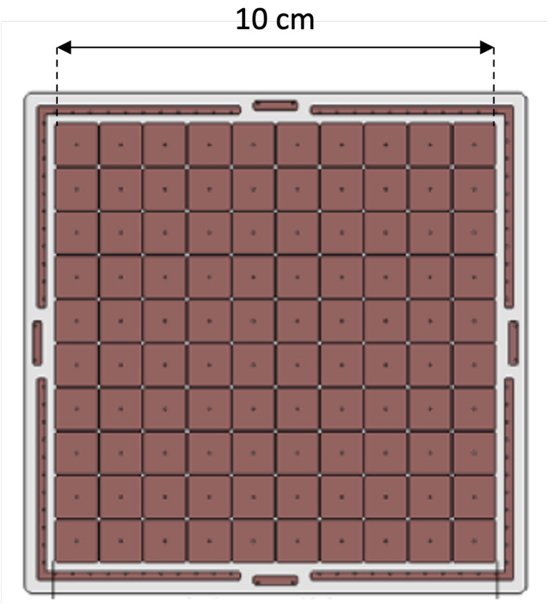
Single pad (2016)

⌀1 cm



Multi pad (2017)

⬡ 1 cm



10x10 module

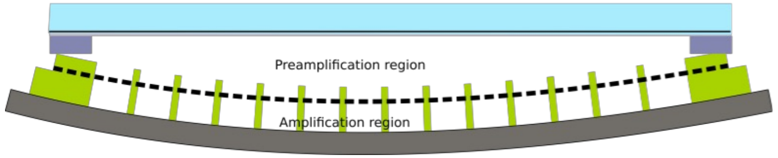
□ 1 cm

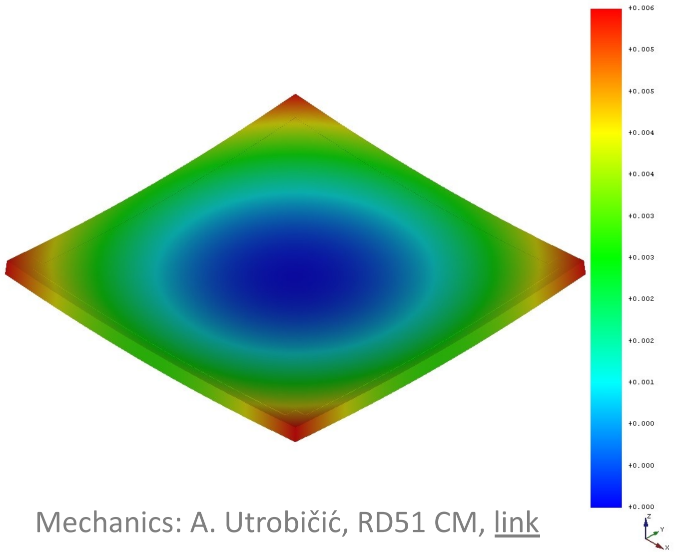
PICOSEC Micromegas

100-channel detector for large-area coverage

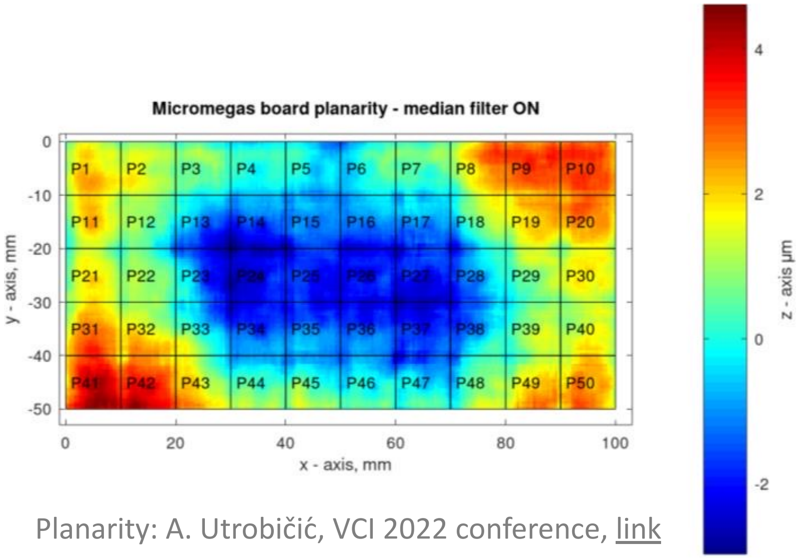
- **Problem:** first 19-channel PICOSEC Micromegas prototype

  → 3.6 cm dia. area, 30 µm deformations, non-uniform timing response
- **Intensive R&D activities:** From simulations and design, through production and assembly to measurements and analysis (details: A. Utrobičić, MPGD2022, link)
- **Current status: 100-channel PICOSEC Micromegas detector with uniform thickness (< 10 µm) of the preamplification gap**

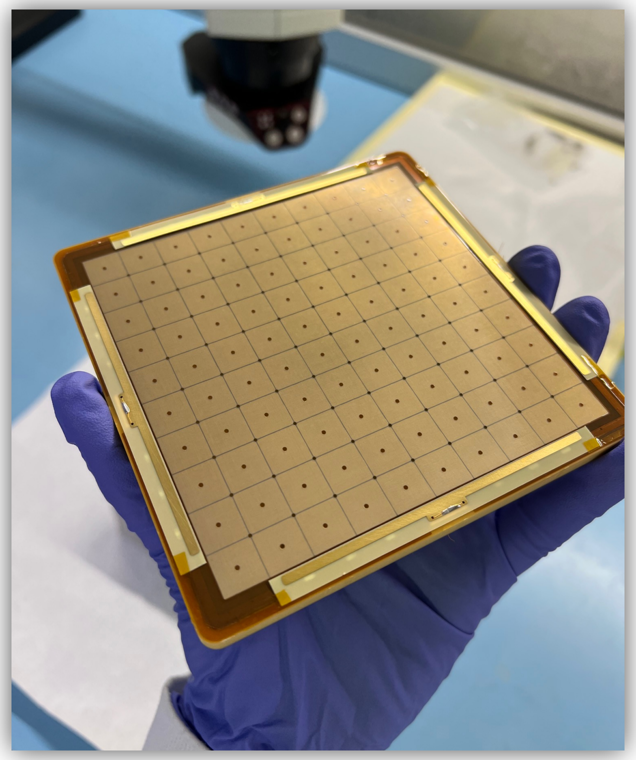




Mechanics: A. Utrobičić, RD51 CM, link



Planarity: A. Utrobičić, VCI 2022 conference, link



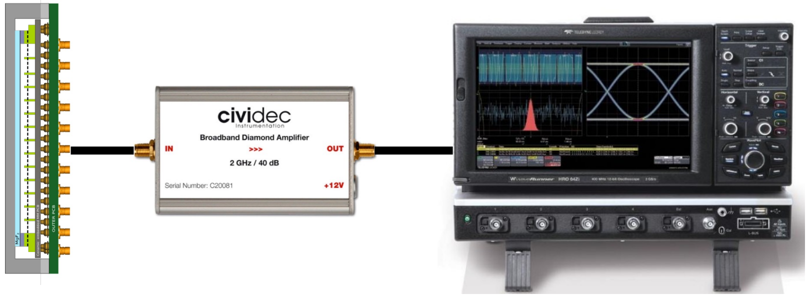
PICOSEC Micromegas

Electronics dedicated for multi-channel detector

- **Previously used electronics:**

  Cividec as an amplifier + Oscilloscope as a digitiser

  → both not scalable to multi-channel detector



- **New electronics dedicated for multi-channel detector:**

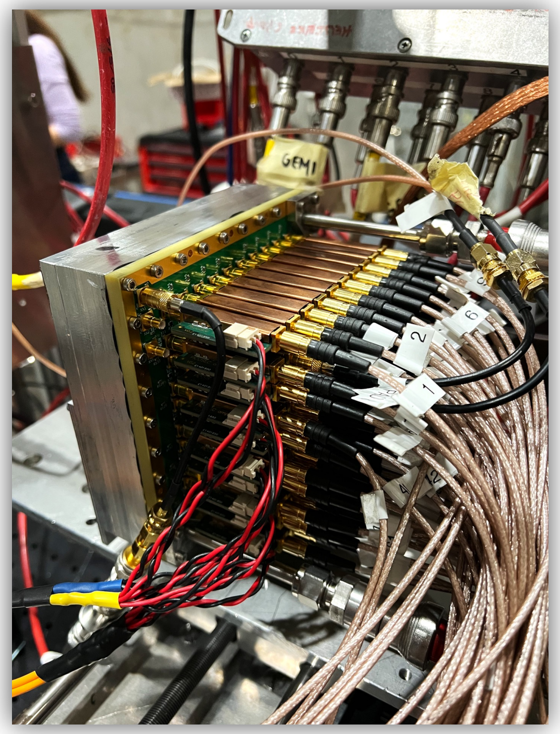
  → Custom-made RF pulse amplifier cards optimised for PICOSEC

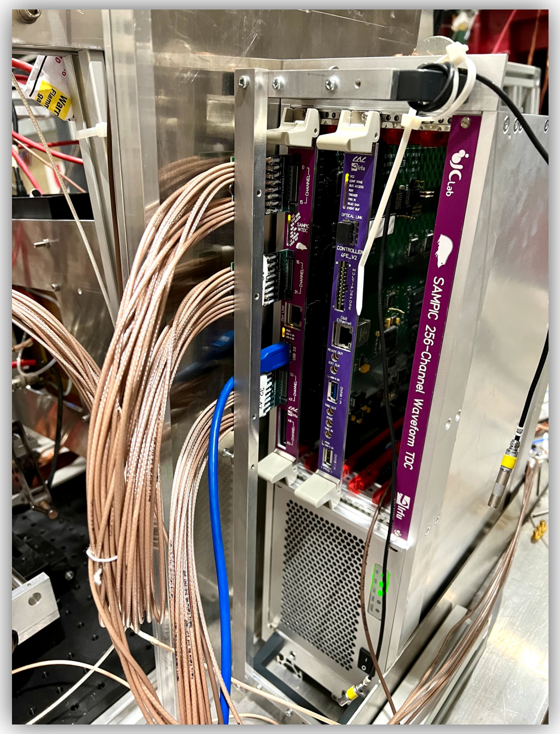
  Spark protection up to 350 V, bandwidth 650 MHz, gain 38 dB,

  power consumption 75 mW (idea: C. Hoarau et al., link; optimized by GDD and M. Kovacic, details: A. Utrobičić, MPGD2022, link)

  → 128-channel SAMPIC Waveform TDC digitizer

  Sampling frequency 8.5 GS/s





PICOSEC Micromegas

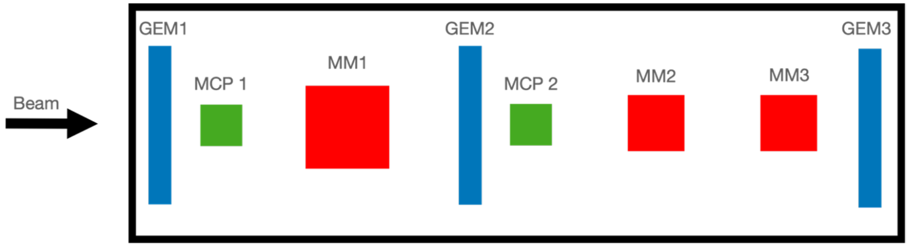
RD51 test beam campaign measurements

- **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)



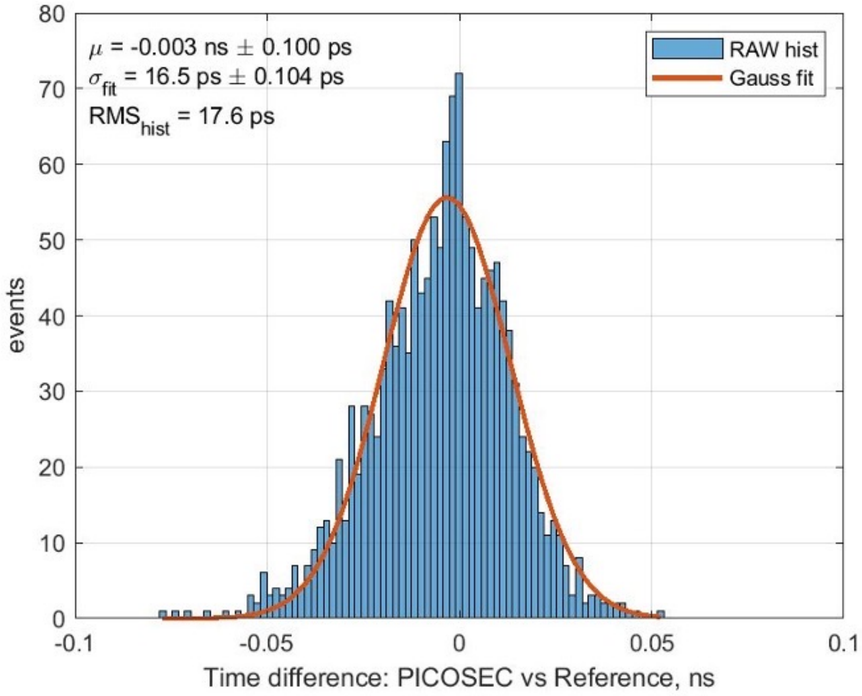
- **Characterisation of the 100-channel PICOSEC Micromegas detector (2021, 2022):**

  → Excellent timing performance of the single-channel proof of concept transferred to the new 100-channel prototype giving uniform time resolution < 25 ps for all measured pads

  → **Improvement of the time resolution to < 18 ps** by detector optimalisation

  (details: A. Utrobičić, MPGD2022, link)

Time resolution of a 100-channel PICOSEC



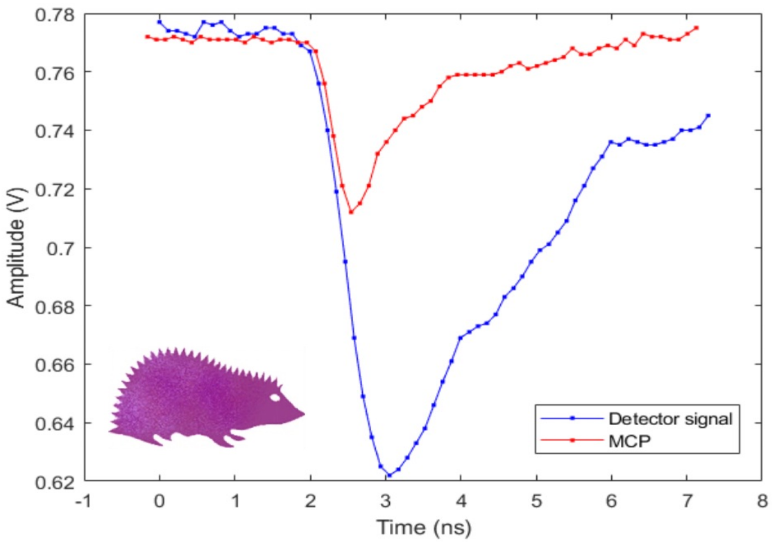
SAMPIC digitiser

PRELIMINARY

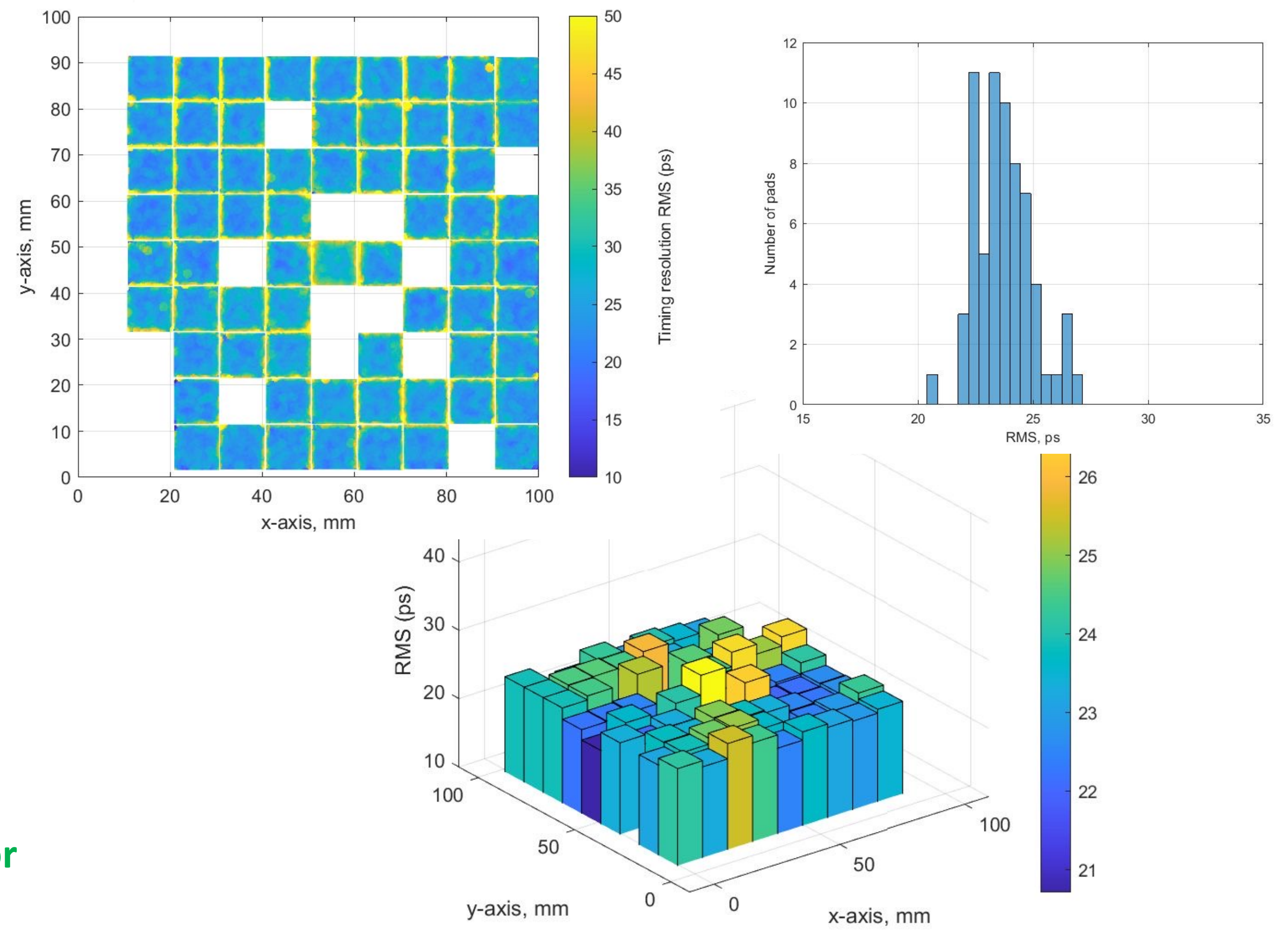
Readout of a multi-channel detector

- **SAMPIC readout** of a 10x10 cm^2 area 100-channel PICOSEC detector

Waveform from SAMPIC



Time resolution



- 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**

(details: M. Lisowska, MPGD2022: link)

Resistive Micromegas

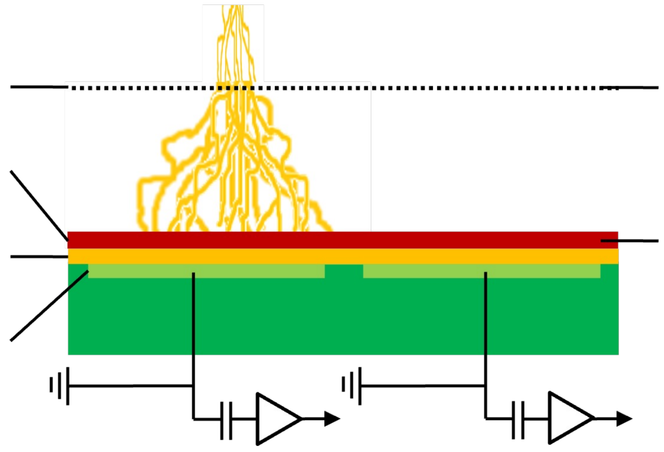
Advantages and requirements

- **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:

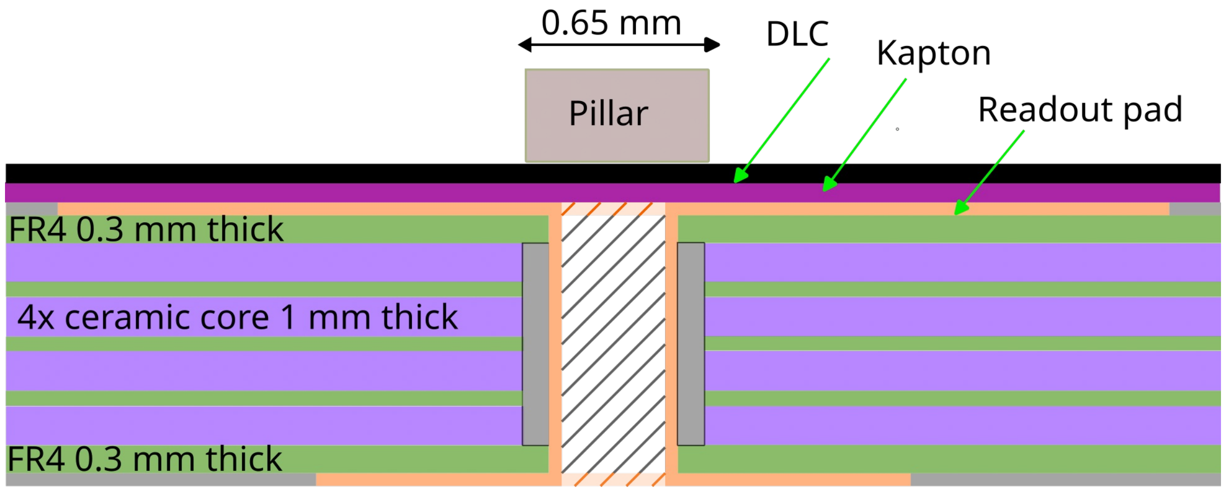
→ ensure stable operation

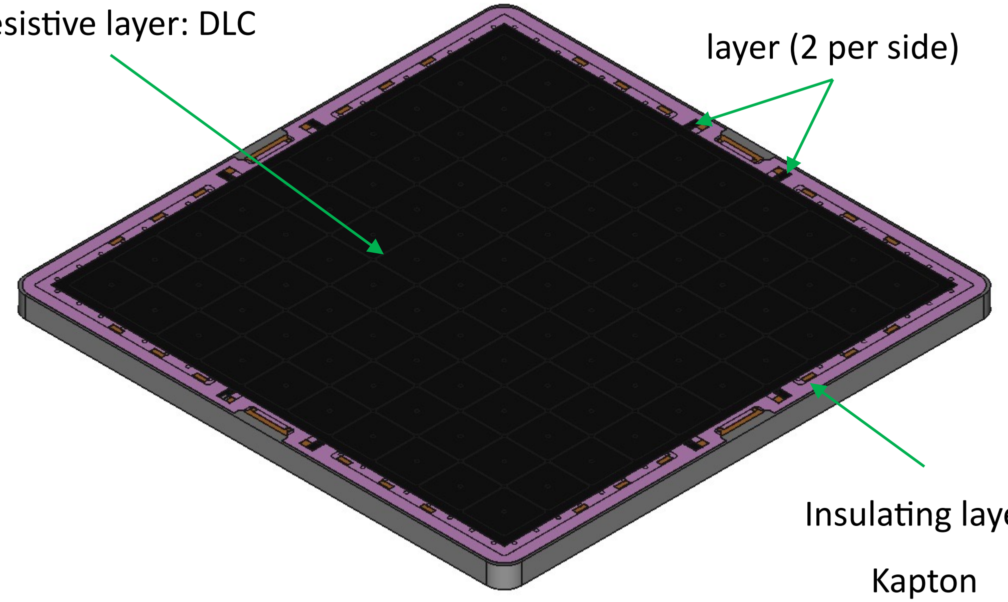
→ not affect the rising edge of the signal

Resistive Micromegas

Simulations and production of a 100-channel resistive PICOSEC MM detector

- Simulations* of rate capability and signal rising edge dependence to select the resistivity for a PICOSEC prototype
- Production of a 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





*All simulations by D. Janssens | **Details: A. Utrobičić, Multipad design and production

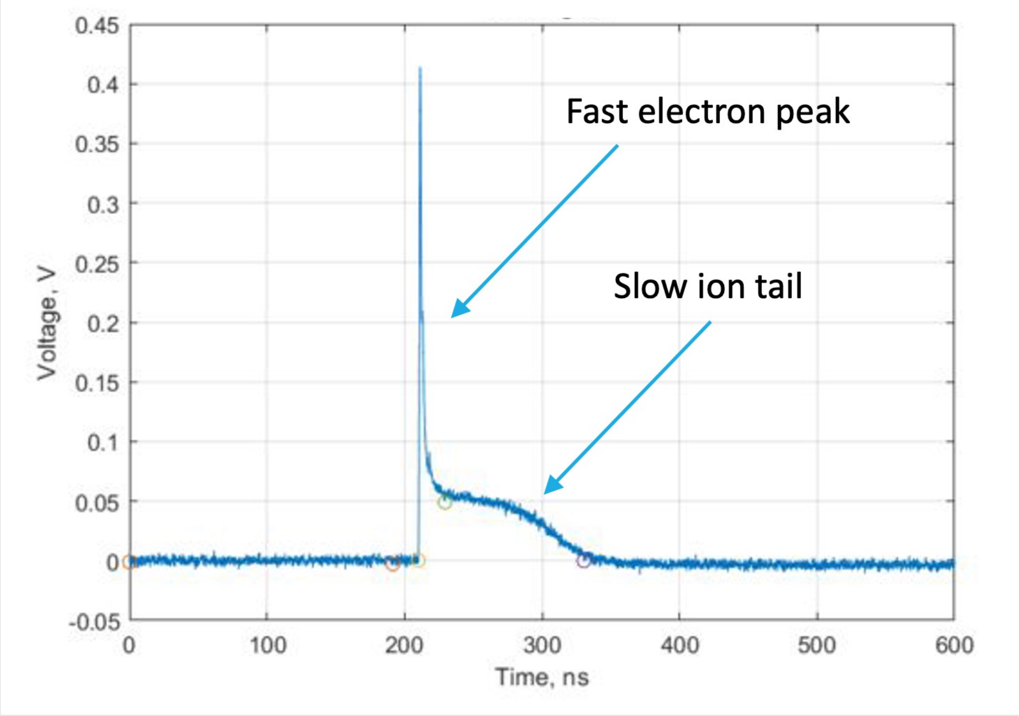
Resistive Micromegas

PRELIMINARY

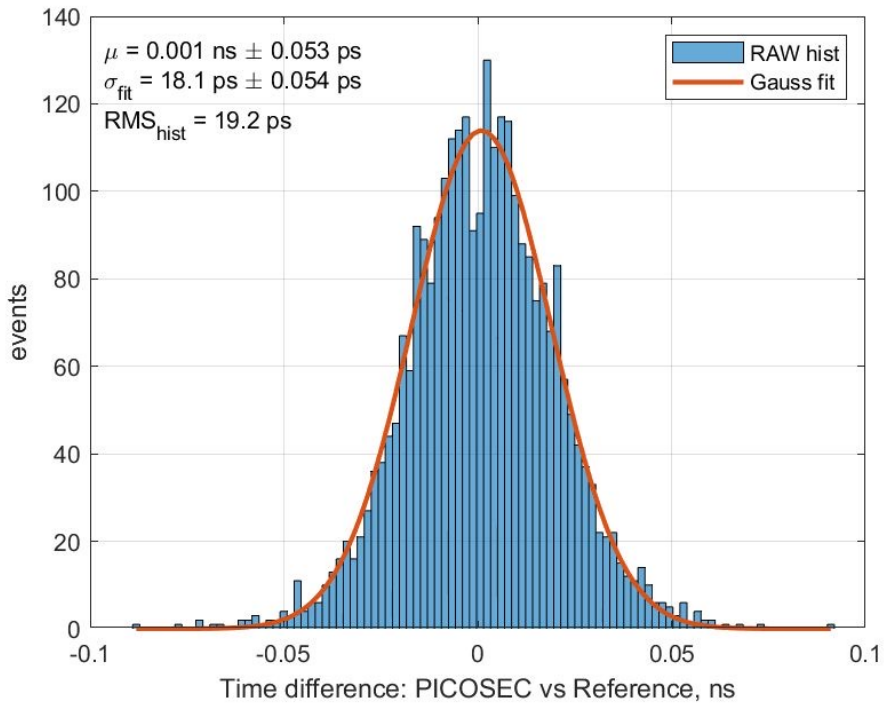
RD51 test beam campaign measurements

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

Waveform



Time resolution



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

(details: M. Lisowska, MPGD2022: link)

Robust photocathodes

CsI and alternative materials

- CsI photocathode:

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

  - can be damaged by ion back flow, sparks, discharges; sensitive to humidity (assembly)

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

  → Diamond-Like Carbon DLC (USTC)

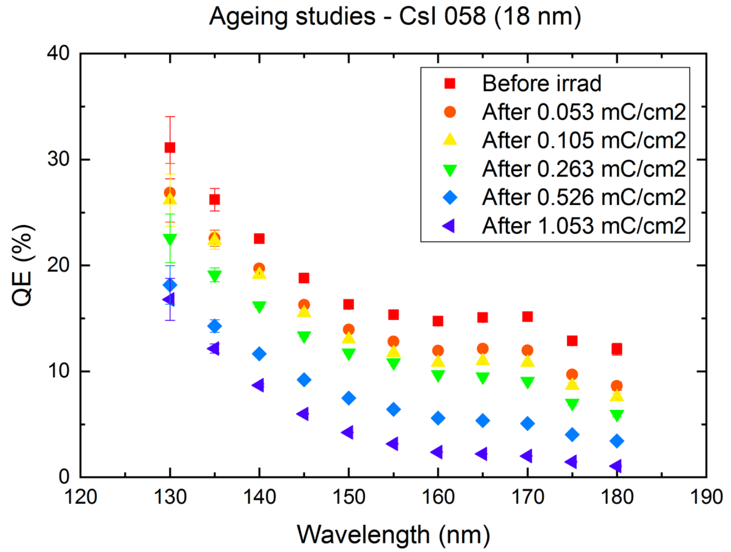
  → Boron Carbide B_4C (CEA, USTC)

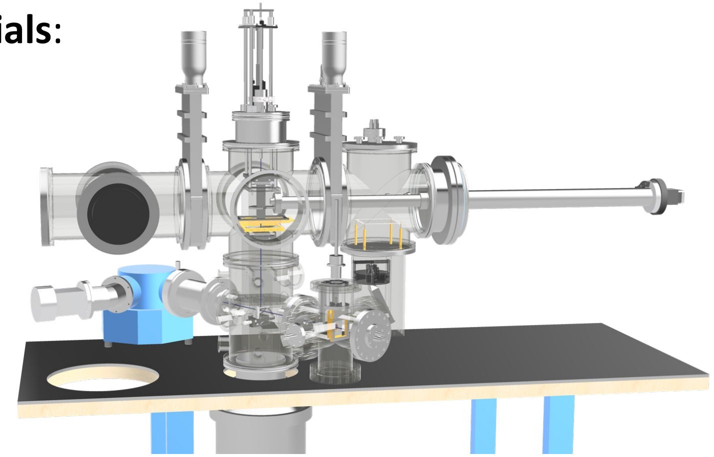
  → Nanodiamonds (INFN)

- **ASSET** – Photocathode characterisation setup

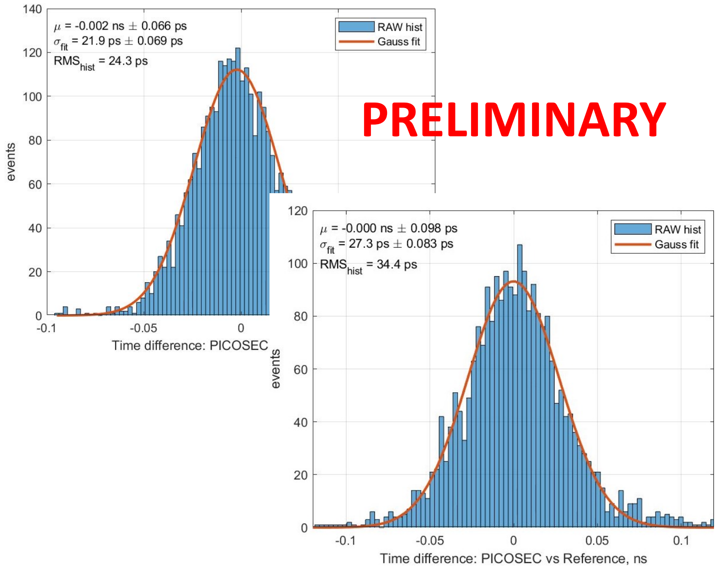
  (details: M. Lisowska, RD51 MW, link)

- **Preliminary results:** Single-pad prototype equipped with a **12 nm thick B_4C photocathode** showed a **time resolution of 25/35 ps** (details: M. Lisowska, MPGD2022, link)





Time resolution of a 12 nm thick B_4C



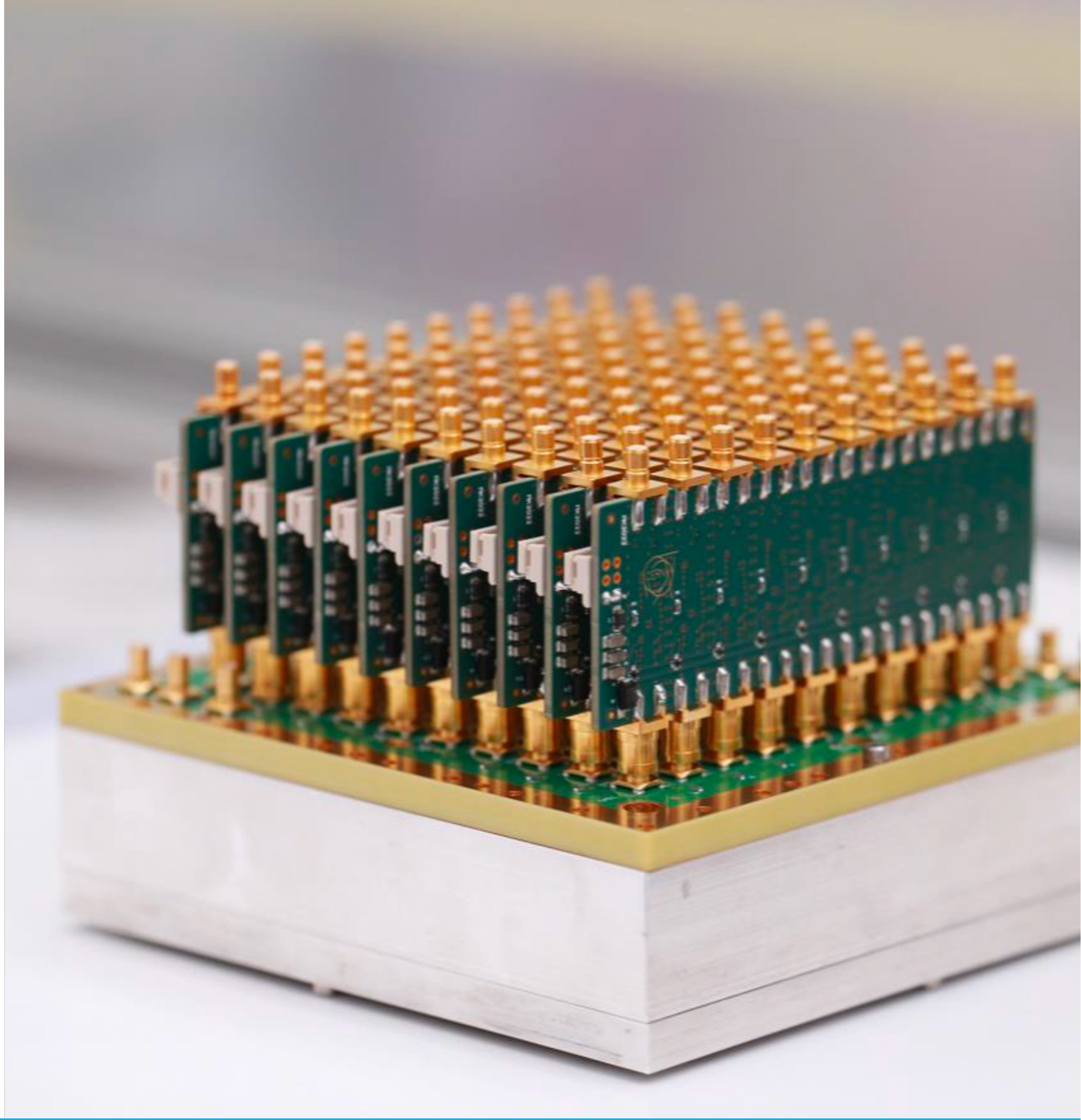
Summary

- Excellent timing performance of the **100-channel PICOSEC MM prototype** → **Multipad with a time resolution < 18 ps** for an individual pad

- Measurements with a **complete readout chain** → **Successful readout of multiple channels**

- **Resistive Micromegas** → Preliminary results of a 10x10 cm^2 **resistive MM 20 MΩ/□** showed a **time resolution < 20 ps** for an individual pad

- **Robust photocathodes** → Preliminary results of a single-pad prototype equipped with a **12 nm thick B_4C photocathode** showed a **time resolution < 35 ps**



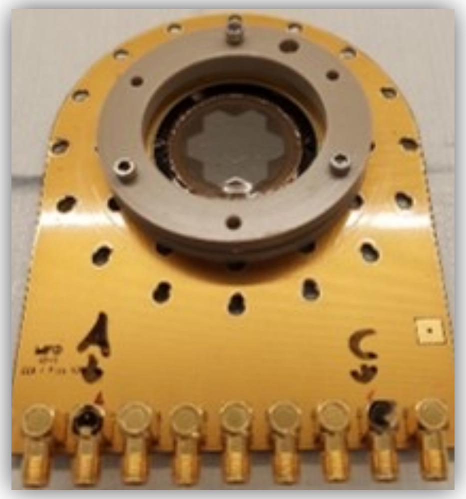
PICOSEC Micromegas

Future prospect

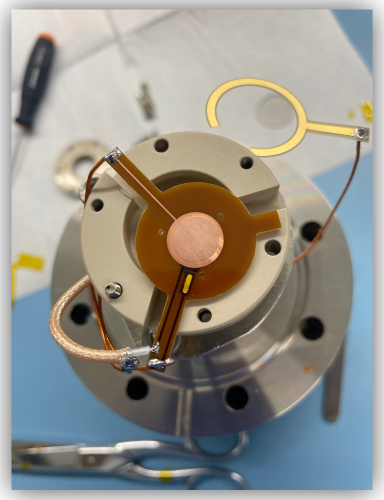
- **Resistive detectors:** Prototypes with different resistivities (200 KΩ/□, 10 MΩ/□, …) (A. Kallitsopoulou, T. Papaevangelou, CEA Saclay); µRWELL PICOSEC (K. Gnanvo)
- **Improving the spatial resolution:** Signal sharing with resistive PICOSEC MM
- **Stability:** High-rate capability studies (D. Fiorina, RD51 MW, link)
- **Robust photocathodes:** 10x10 cm^2 area B_4C and DLC photocathodes
- **Alternative electronics:** ASICs, TDC, threshold based readout
- **Operating gas**: Exploring alternative gas mixtures
- **Material budget:** Alternative ways to preserve detector's planarity; Sealed detectors
- **Scaling up to larger area:** Tiling 10x10 cm^2 modules, development of larger prototypes
- **Photon detection:** PICOSEC Micromegas detector without Cherenkov radiator

- **Detectors with sub-ns time resolution: Tileable multi-channel detector modules for large area coverage fulfilling the requirement of the robustness with "relaxed" timing properties**

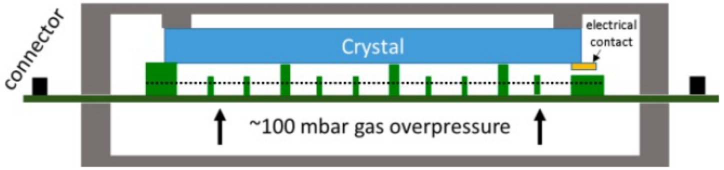
PicoLarge resistive detector



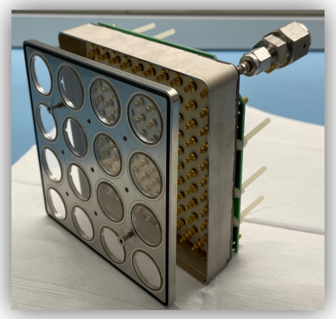
µRWELL PICOSEC



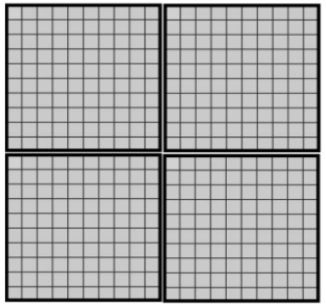
Thin MM PCB with longer pillars



Sealed detector



Tiling: 4 x 10x10 cm^2



PICOSEC Micromegas Collaboration

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Thank you for your attention!

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Back up slides

Classical vs PICOSEC Micromegas

Signal arrival time jitter

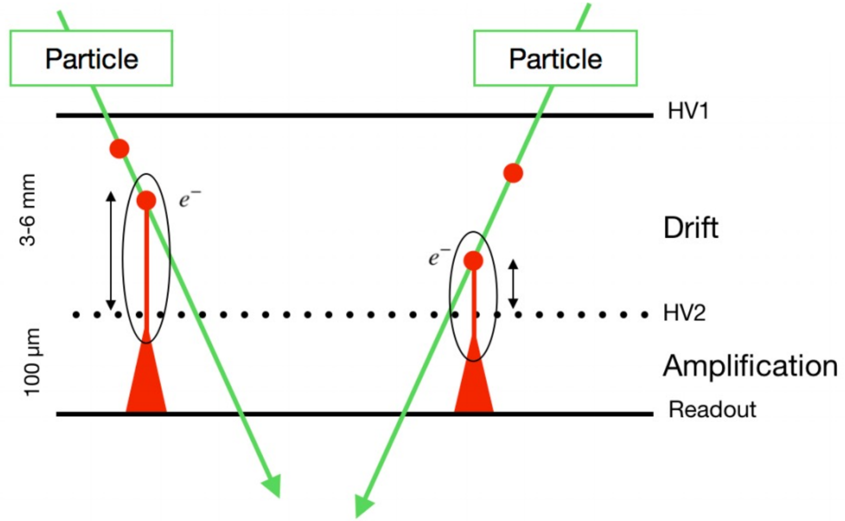
- **Classical Micromegas:**

  → 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



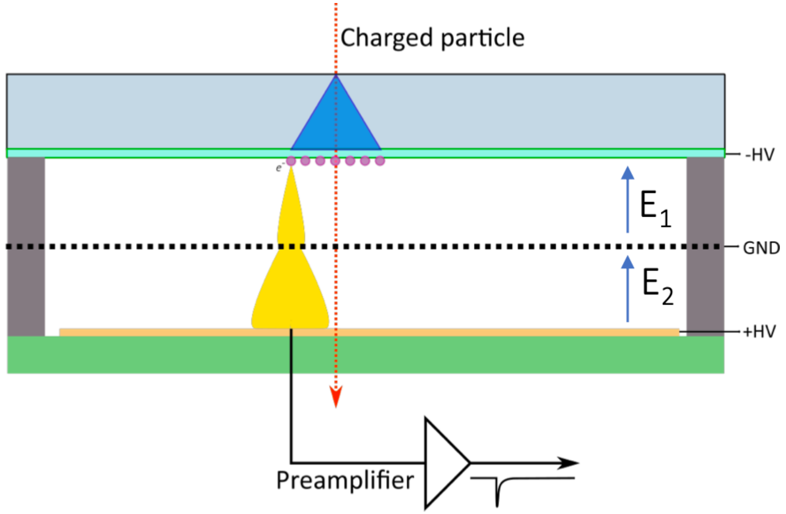
- **PICOSEC Micromegas:**

  → 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) = <$T_{e\text{-peak}}$>**

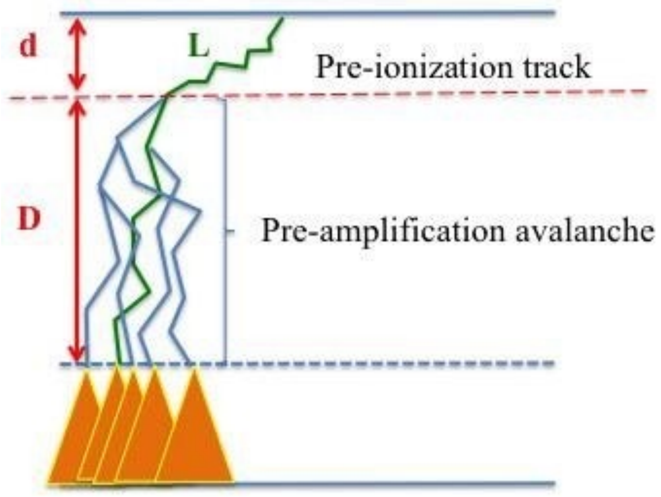
  → SAT depends on e-peak charge

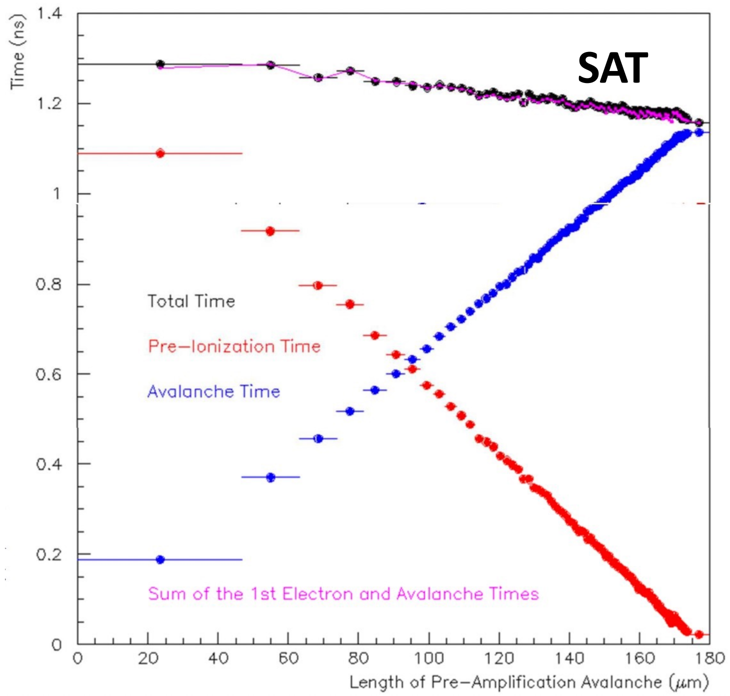
  → SAT can be reduced by higher drift field and bigger pulses

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

  → longer avalanches result in bigger e-peak charge

  → bigger e-peak charge reduces SAT



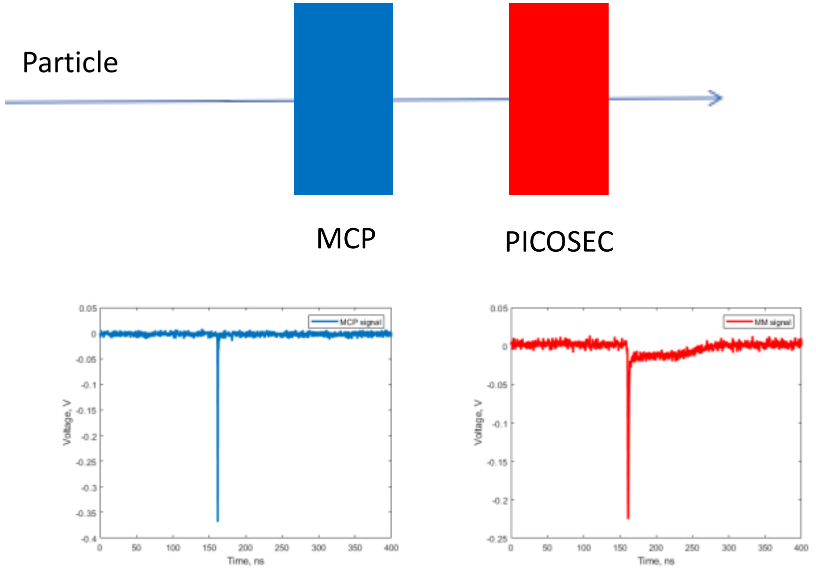


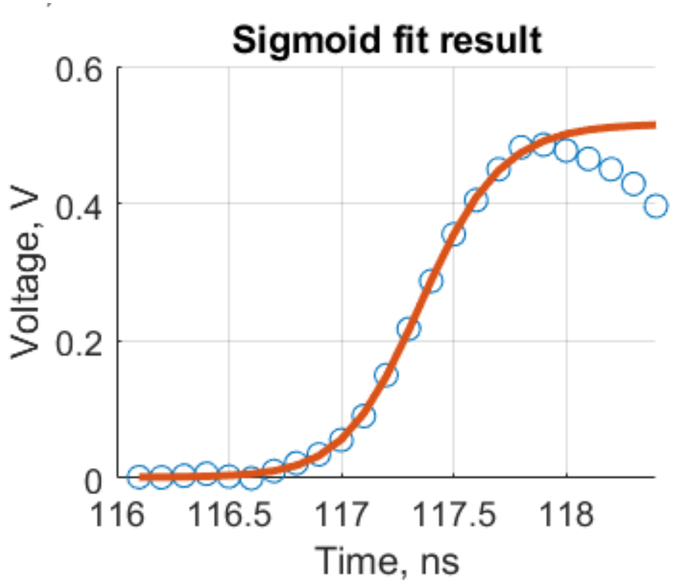
K. Kordas, VCI 2019 conference, link

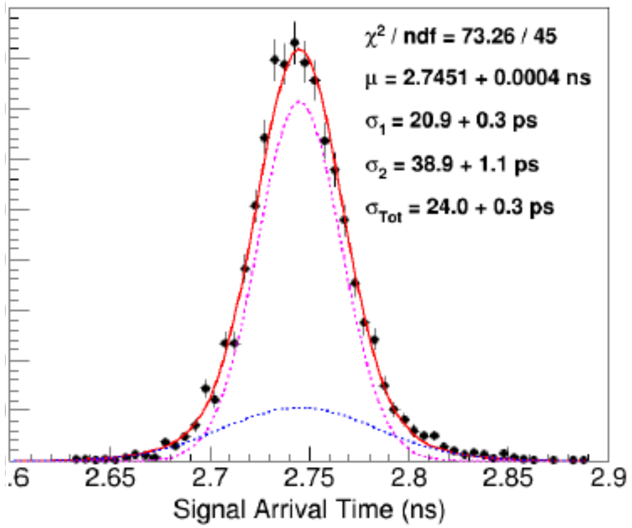
PICOSEC Micromegas

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

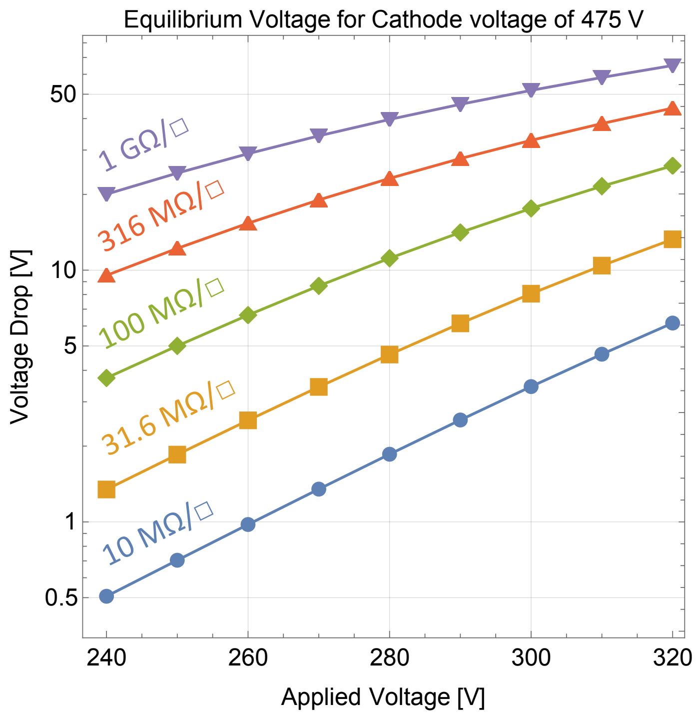
Resistive Micromegas

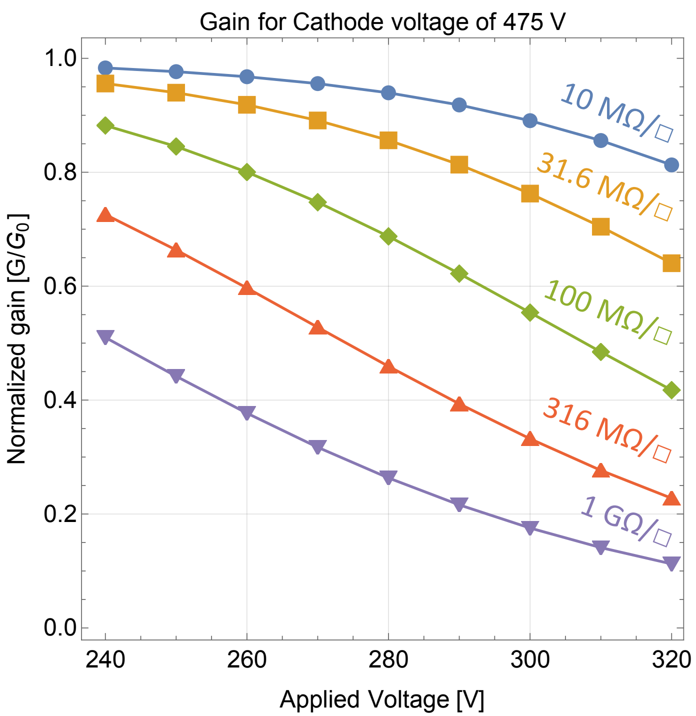
SIMULATIONS

Rate capability

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

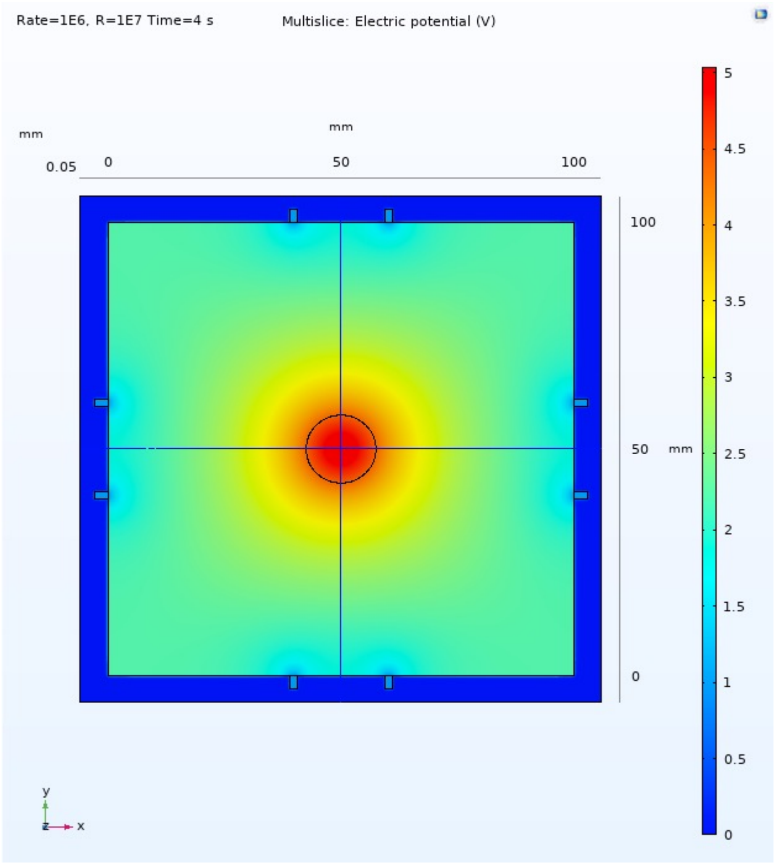
Simulated voltage and gain drop vs applied voltage for different resistivities





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

Simulated voltage drop across the area

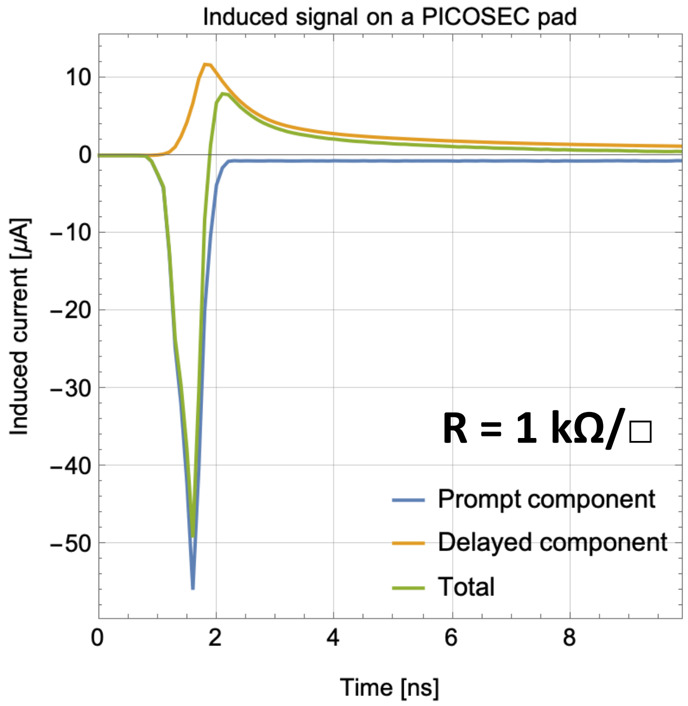


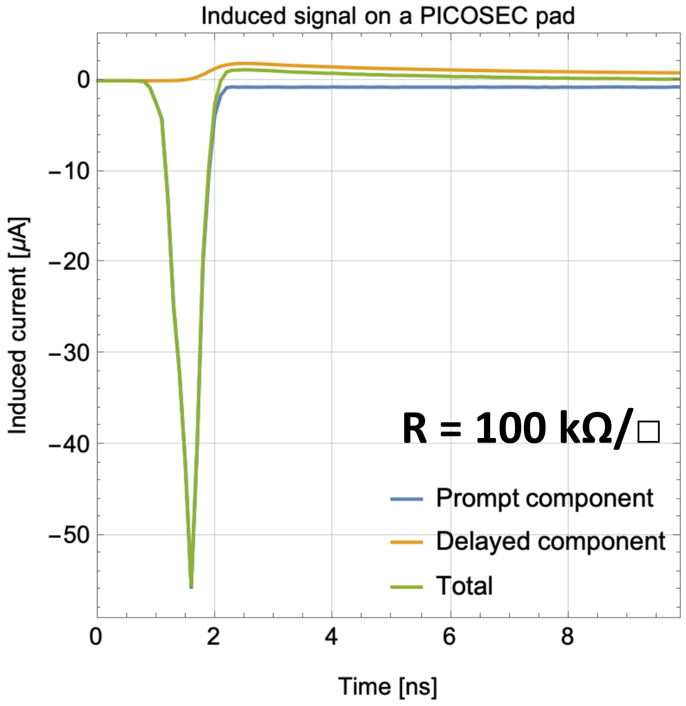
All simulations by Djunes Janssens

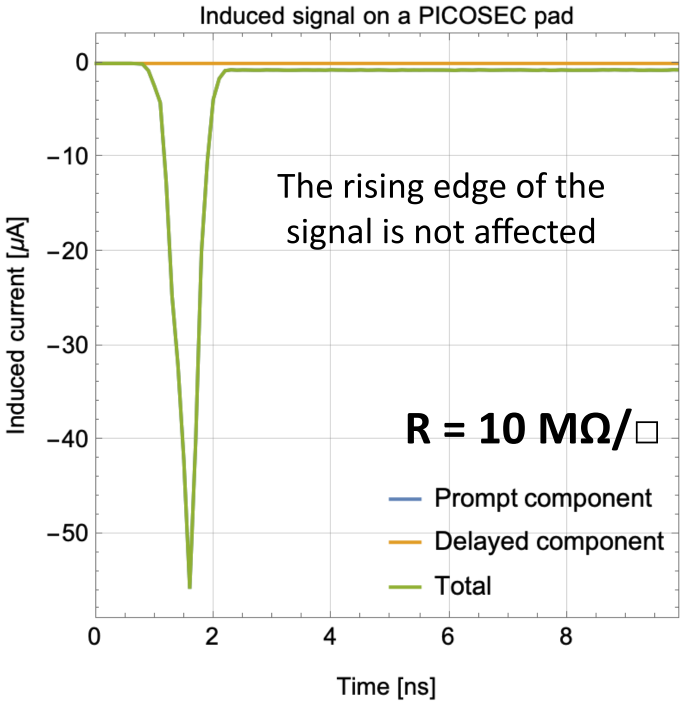
Resistive Micromegas

Dependence on the rising edge of the signal

Simulated shape of the induced signal for different resistivities





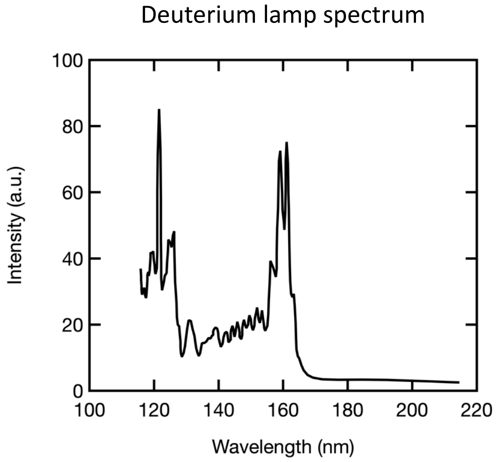


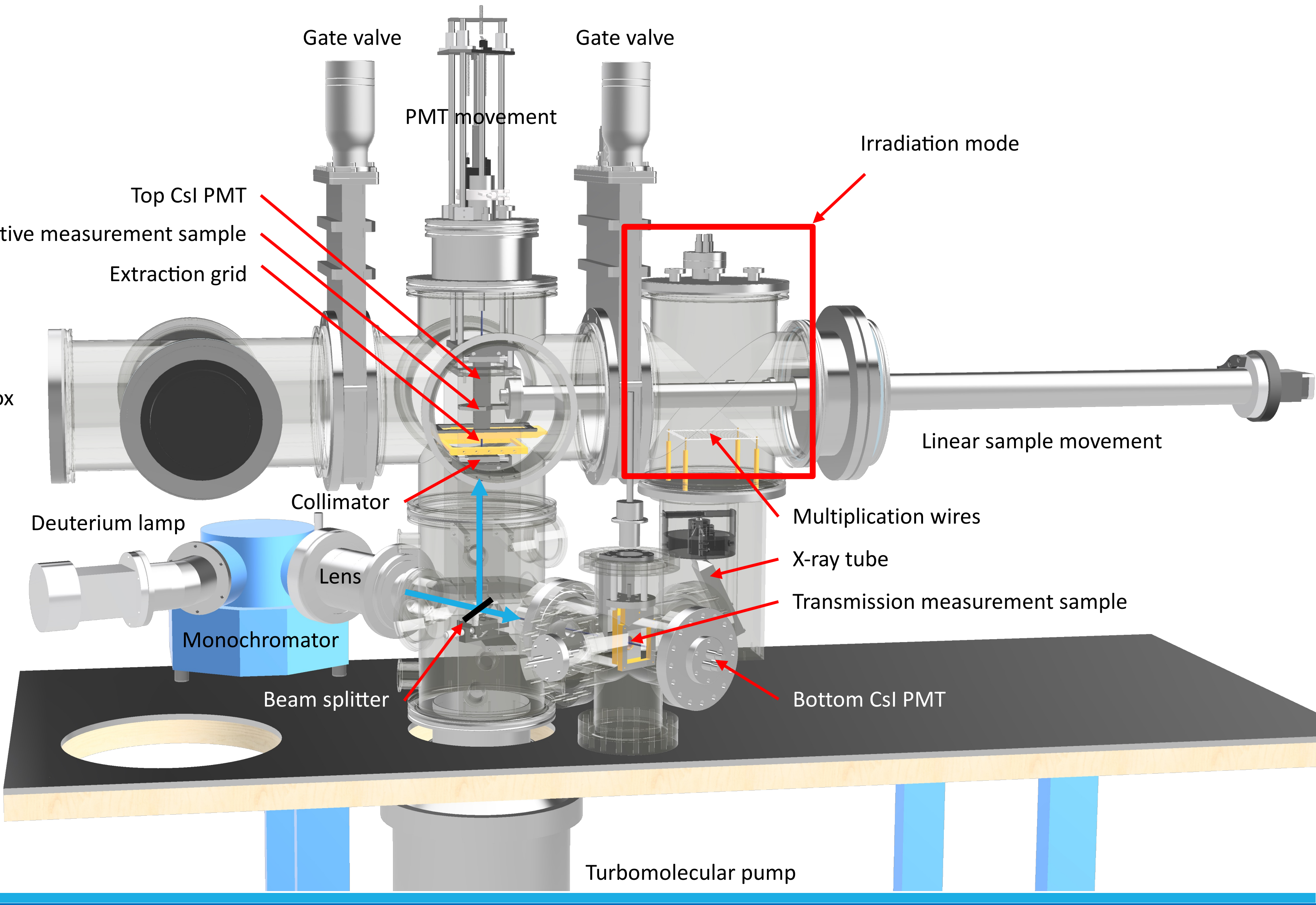
Resistivity chosen for the 10x10 cm^2 area PICOSEC MM detector: **20 MΩ/□**

All simulations by Djunes Janssens

Photocathode characterisation

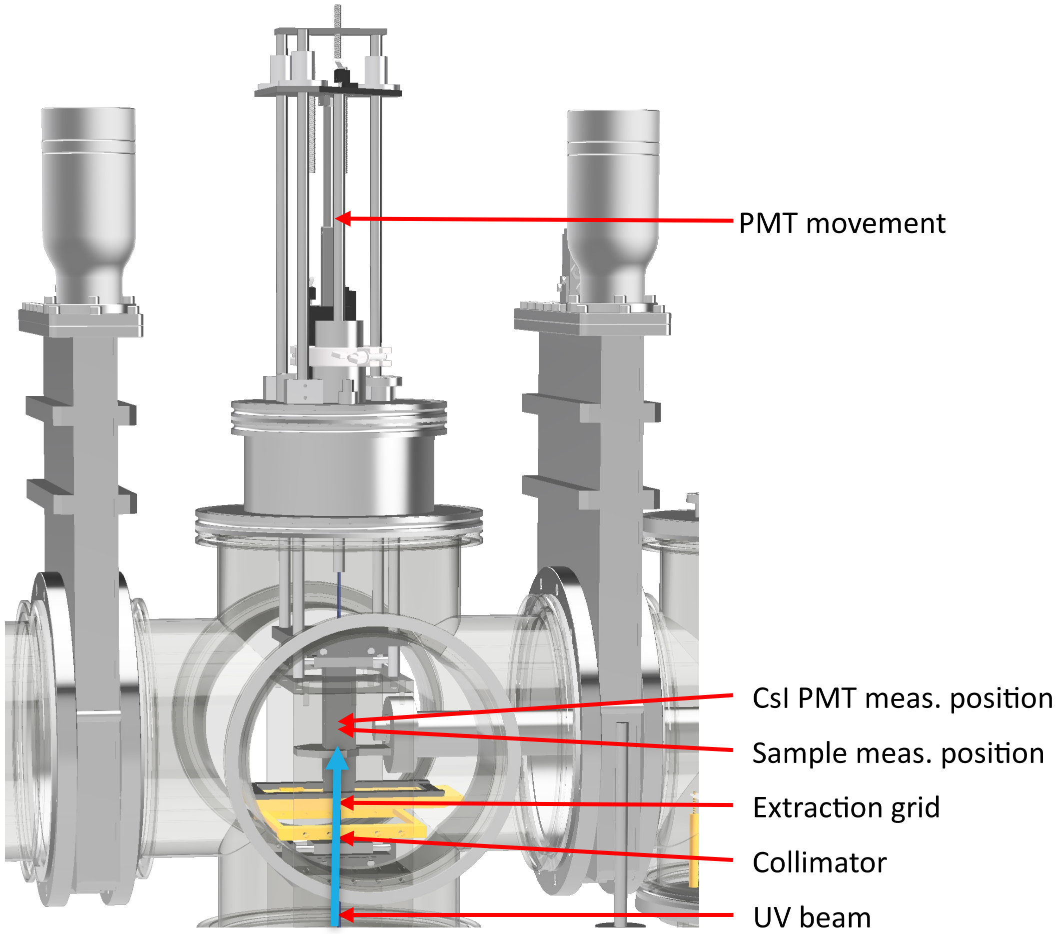
Setup overview





Photocathode characterisation

QE measurements - Reflective mode

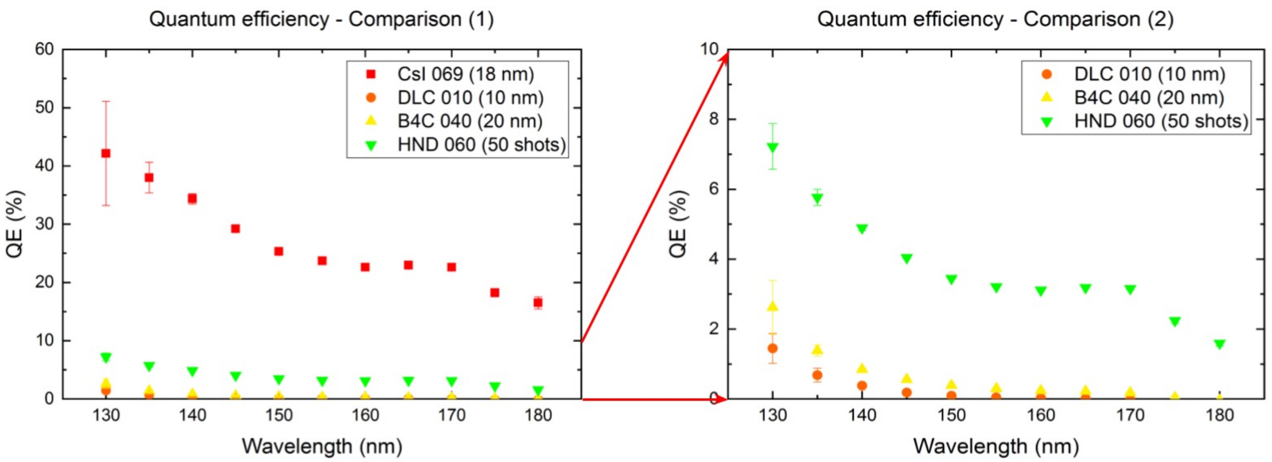


Samples: cesium iodide (CsI), diamond-like carbon (DLC), boron carbide (B_4C) and hydrogenated nanodiamonds (HND)

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

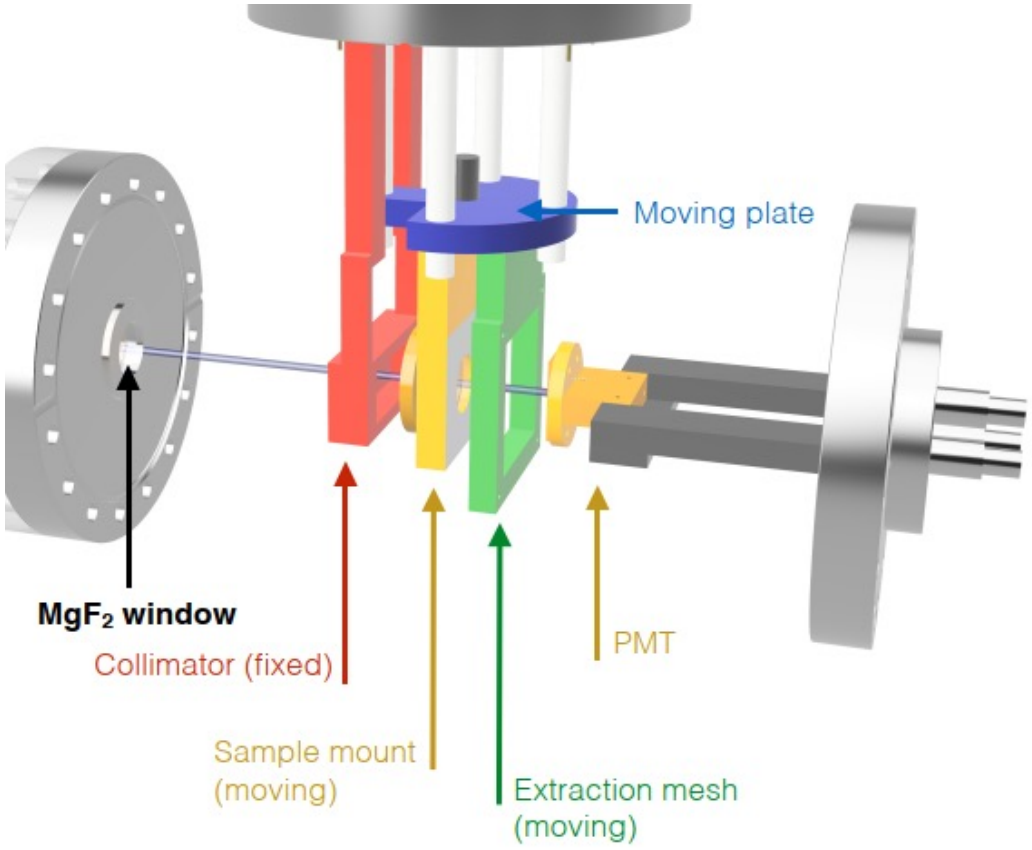
$Electrons_{sample}$ - electrons extracted from the sample

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



Photocathode characterisation

QE measurements - Transmission mode

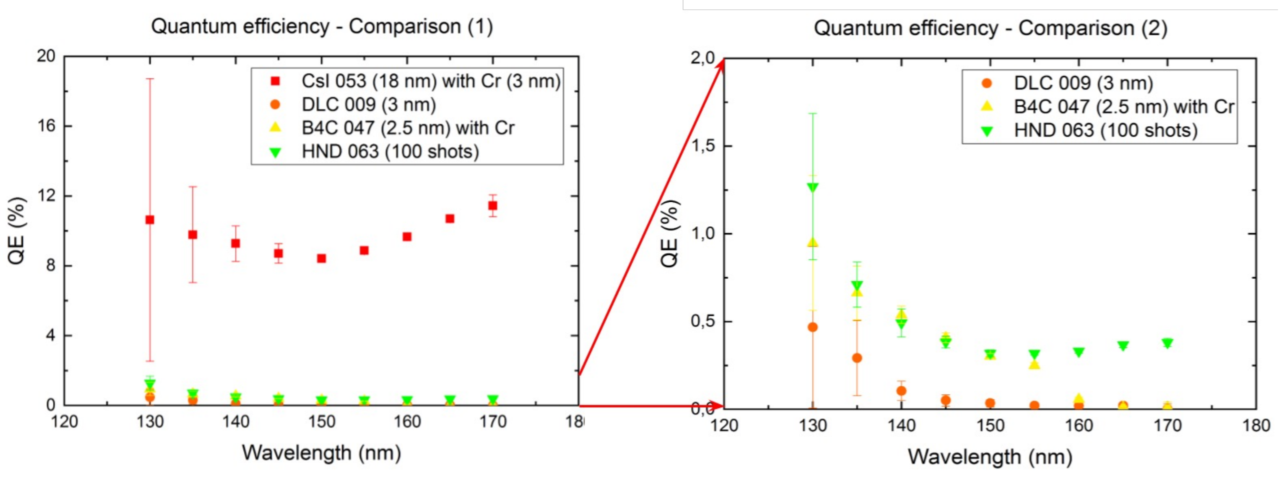


$$\text{Transparency} = \frac{\text{PMT current: sample in}}{\text{PMT current: sample out}}$$

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

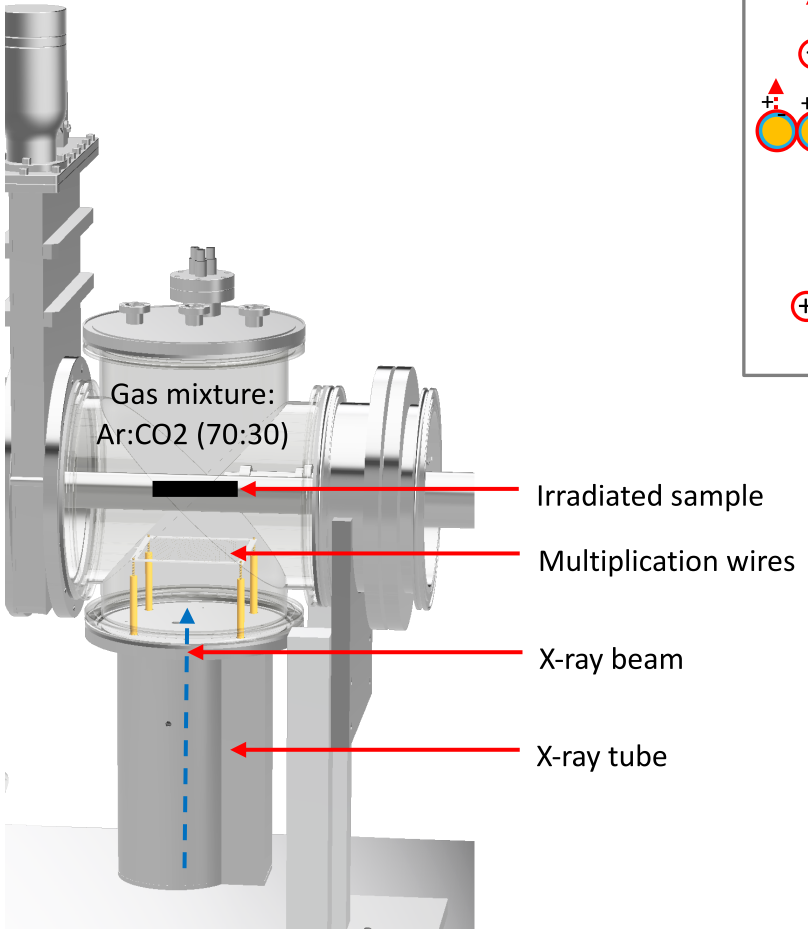
$Electrons_{sample}$ - electrons extracted from the sample

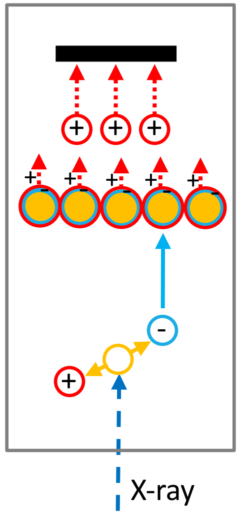
$Photons_{PMT}$ - photons that arrived to the sample



Photocathode characterisation

Ageing studies – Irradiation mode

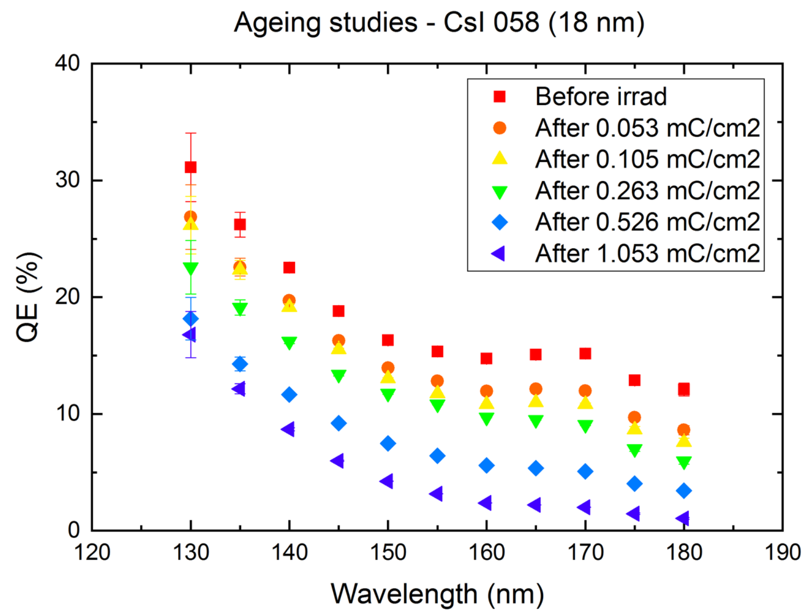


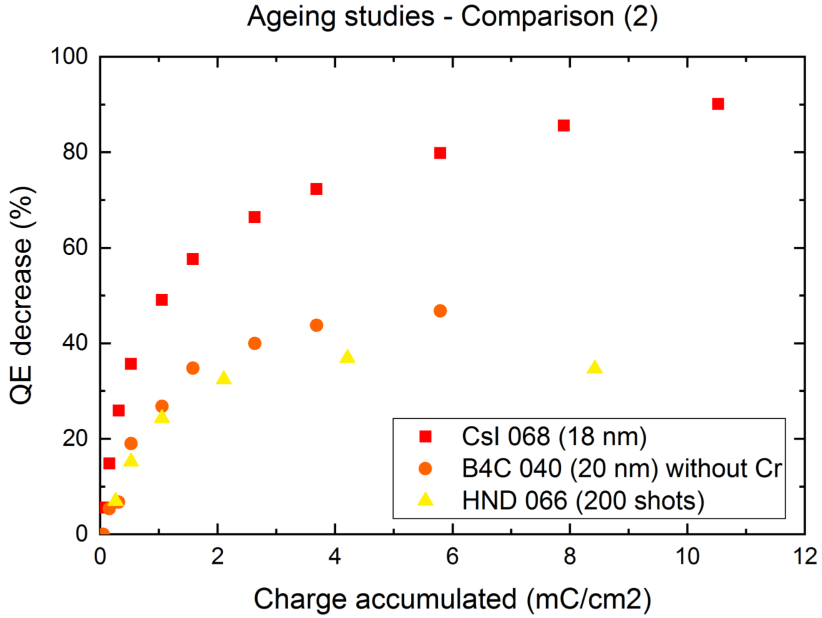


3. Irradiated sample (grounded):
Attraction of ions from avalanche
Accumulation of charge

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





Sealed detector

- **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:**

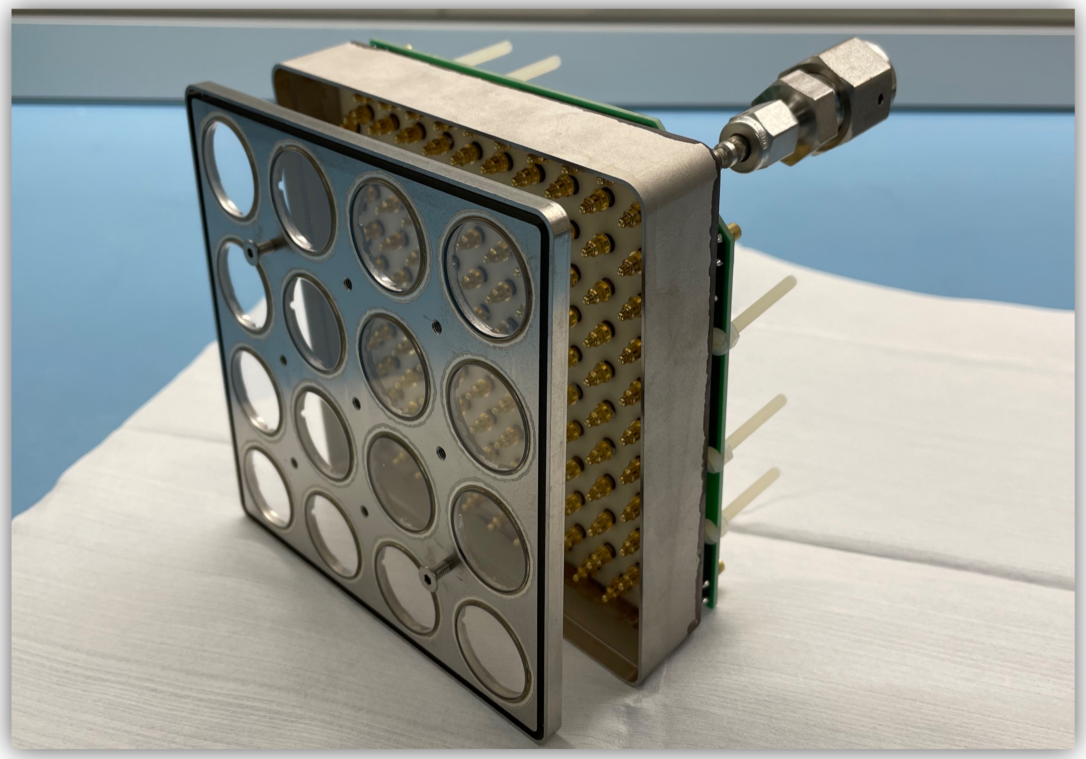
  → one 10x10 cm^2 titanium housing ready to assembly

  → large area robust photocathode (DLC, B_4C) required

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

  → when all components ready – electron beam welding

  → last step – filling the detector with gas mixture



Sealed vessel, M. Lisowska et al., CERN