PICOSEC
Micromegas

The PICOSEC Micromegas Detector on the SPS H4 Beamline: 2023 Status and Future Prospects

RD51 Collaboration Meeting

Thursday, 7th December 2023

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CEA/IRU/Université Paris – Saclay

On behalf of PICOSEC Micromegas Collaboration

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12 institutes from 9 countries

>46 collaborators

What is our motivation?

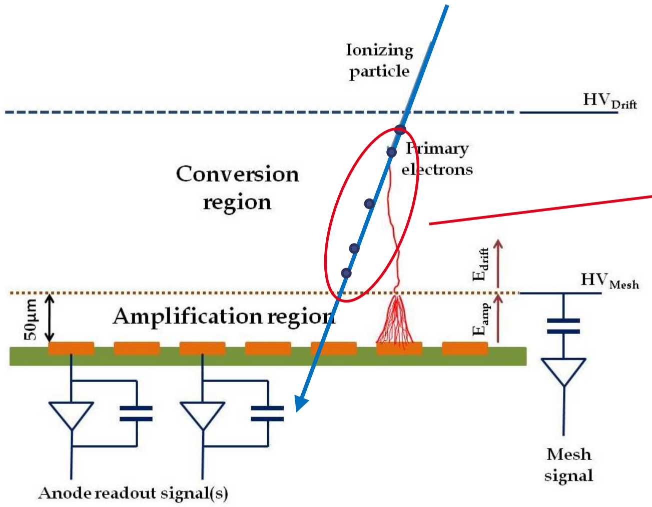
Timing with a few 10's of Picosecond

- **Tracking challenges for HL-LHC**:
  - LHC will go to higher energy & luminosity
    - **5x** nominal instaneous luminosity → Increased particle densities
    - **20x** current integrated luminosity → Increased radiation damage
  - What are the needs:
    - Reduction of mixing different events due to pile-up
    - Track to vertex association → **3D tracking with timing information**
- **Extra detector requirements:**
  - Large area coverage
  - Resistance to aging effects
  - Multi-pad readout tracking
- **Detector Technologies**
  - **Gaseous detectors**
    - Resistive Plate Chambers (RPCs) (σ_t ~ 30 ps)
    - Micro-Pattern Gaseous Detectors (σ_t ~ 1 ns)

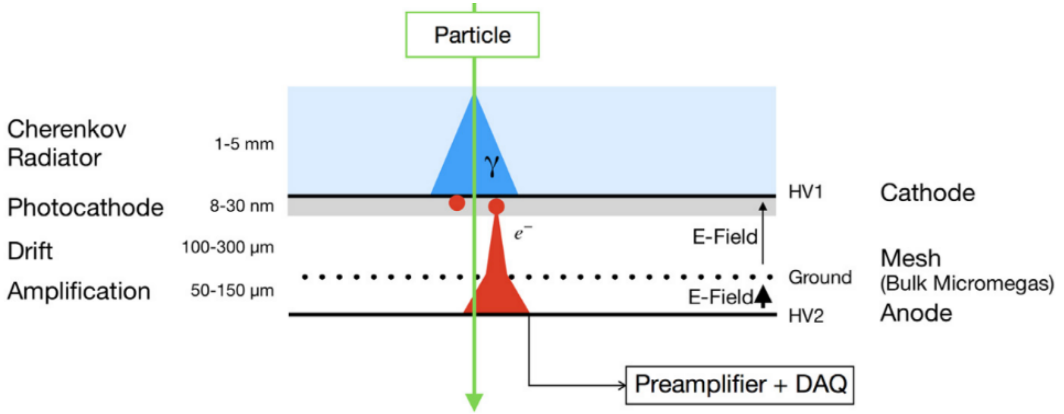
Giant improvement ~
3 orders of magnitude
compared to standard MPGDs

The PICOSEC Micromegas Technology

The PICOSEC Micromegas Technology



Y. Giomataris, P. Rebourgeard, J.P. Robert and G. Charpak, *"Micromegas: A high-granularity position sensitive gaseous detector for high particle-flux environments"*, Nuc. Instrum. Meth. A 376 (1996) 29



J.Bortfeldt, et al., *"PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector"*, https://doi.org/10.1016/j.nima.2018.04.033

- **Limitations of the Micromegas Timing Potential**
  - Stochastic nature of ionization
  - Randomness of last ionization
  - Time jitter of a few ns
- **Modifications in MM Geometry**
  - Smaller Drift Gap
    - Elimination of the stochastic nature of ionization
  - Higher applied Drift Voltage→Pre-avalanche
- **Additional Components**
  - Cherenkov radiator +
  - Solid converter→Photocathode
    Prompt photoelectrons

2023 BeamTime at SPS

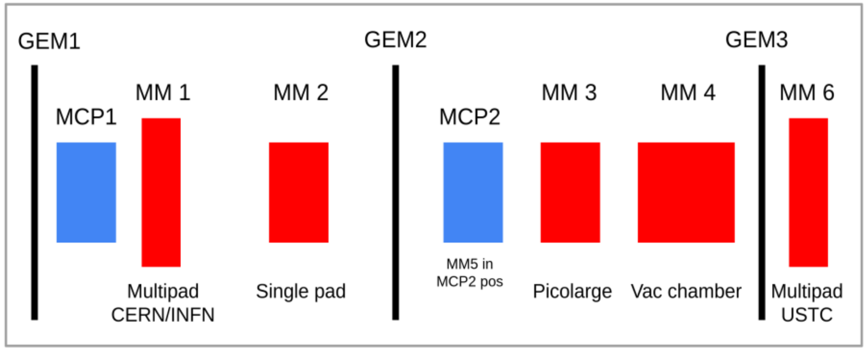
April 2023

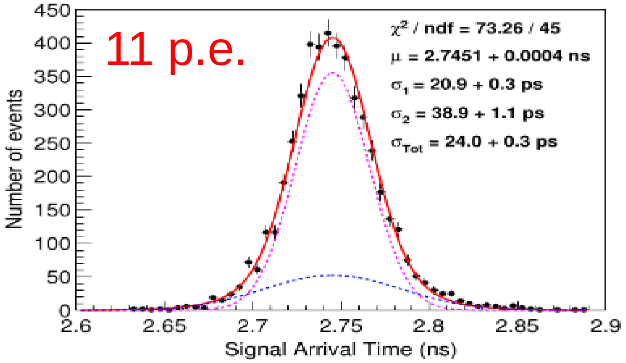
Detector Testing - Particle beams

- Particle Beams @ CERN SPS H4 Beamline
  - Muons (80-150GeV)
    - 8cm diameter of beam
    - 10^5muons/spill (measured rate ~kHz/cm^2)
  - Pions of 80GeV Energy
    - Beam size 2.3x1.6cm
    - Rate ~MH/cm^2

- The Setup
  - Use GEMs for tracking
  - Use MCP PMTs as timing reference devices and for triggering
  - Detectors Under Test
  - Electronics: Commercial/Custom-made preamplifiers
  - Digitizers – Lecroy scopes

- First timing measurement @ Particle Beam (2017)
  - Single Prototype : Thin Gap (200μm) with MgF2 & CsI photocathode





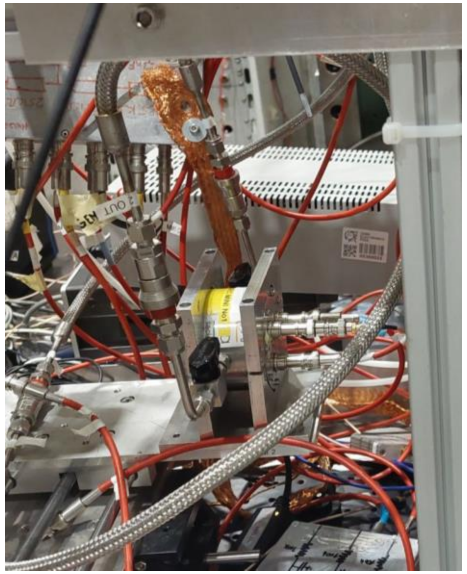
J.Borteldt, et al. *"PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector"*, Nuc. Instrum. Meth. A (2021)https://doi.org/10.1016/j.nima.2018.04.033

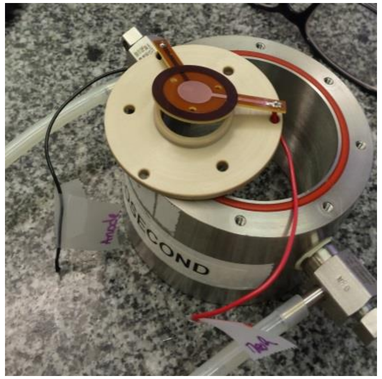
Timing Resolution → RMS of Signal Arrival Time Distribution

Block of Measurements and Detectors Under Test

Alternative Gas Mixtures and Radiation Hardness Tests

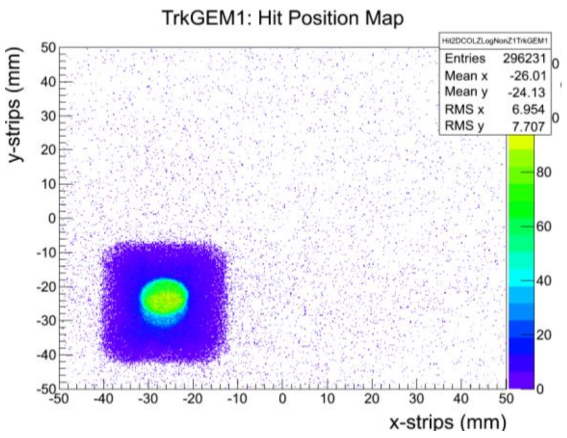
- ✓ Alternative Gas Mixtures → Ne/iC4H10(94/6), ArCO2(93/7), ArCO2iC4H10(93/5/2), comparison with the standard COMPASS Gas
- ✓ Pion runs → *Same time resolution as with muons*

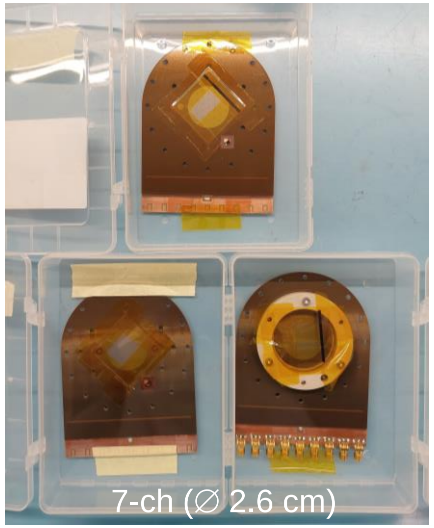




Robust & Efficient prototypes

- ✓ Resistive prototypes ~ 10MO, 200kO
- ✓ Comparison of Different Geometries on Resistive Layer (capacitive sharing and normal resistive sharing)
- ✓ Timing runs on individual pads
- ✓ Long scan for uniformity map on amplitude and timing
- ✓ Signal Sharing

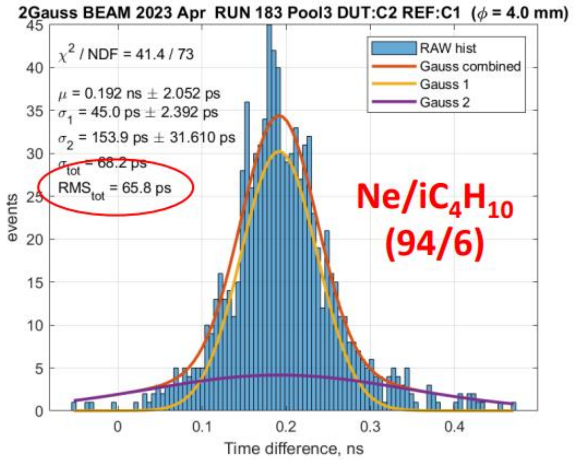




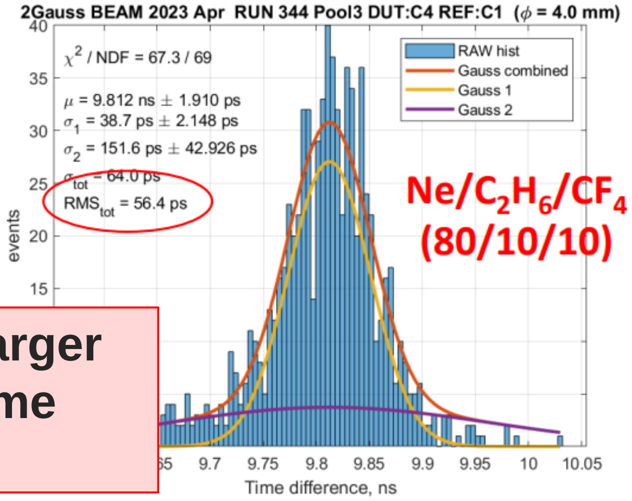
Highlight Preliminary Results

Alternative Gas Mixtures and Radiation Hardness Tests

- Photocathode used was **B4C 6nm** (<u>3 PE/MIP</u>)
  - Photoelectron yield is around Lower time resolution wrt CsI is expected (**with CsI ≈25ps**)
- The two distributions are measured at **similar gains** for the two mixture
- The impact of CF_4 in timing is **visible but not drastic (≈15%)**
- Still, the 3-component gas mixture has a wider operational range because it is more quenched



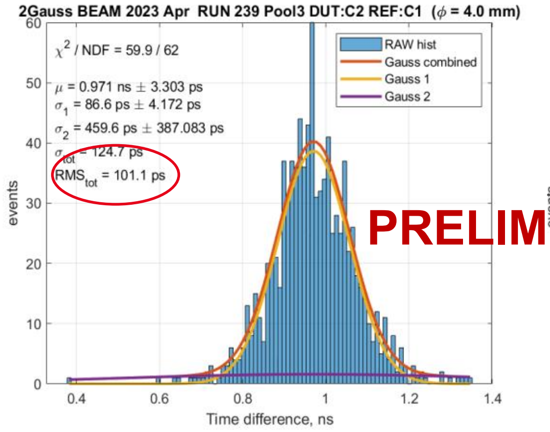
PRELIMINARY



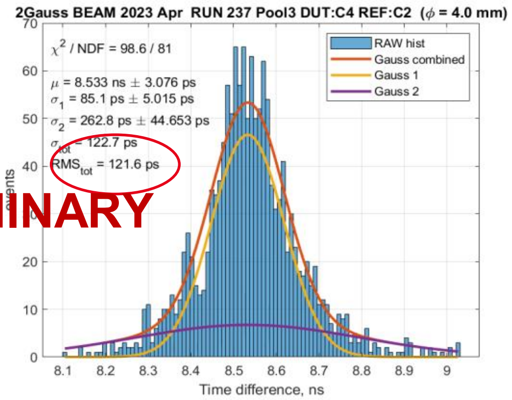
Ne/iso 94/6 may achieve larger gain maintaining the same time resolution

- Single pad non resistive - 1 cm - 7nm B4C
- Single pad 82MO/□ resistive - 6nm B4C photocathode

Using MCP reference
DUT @ 275/430V



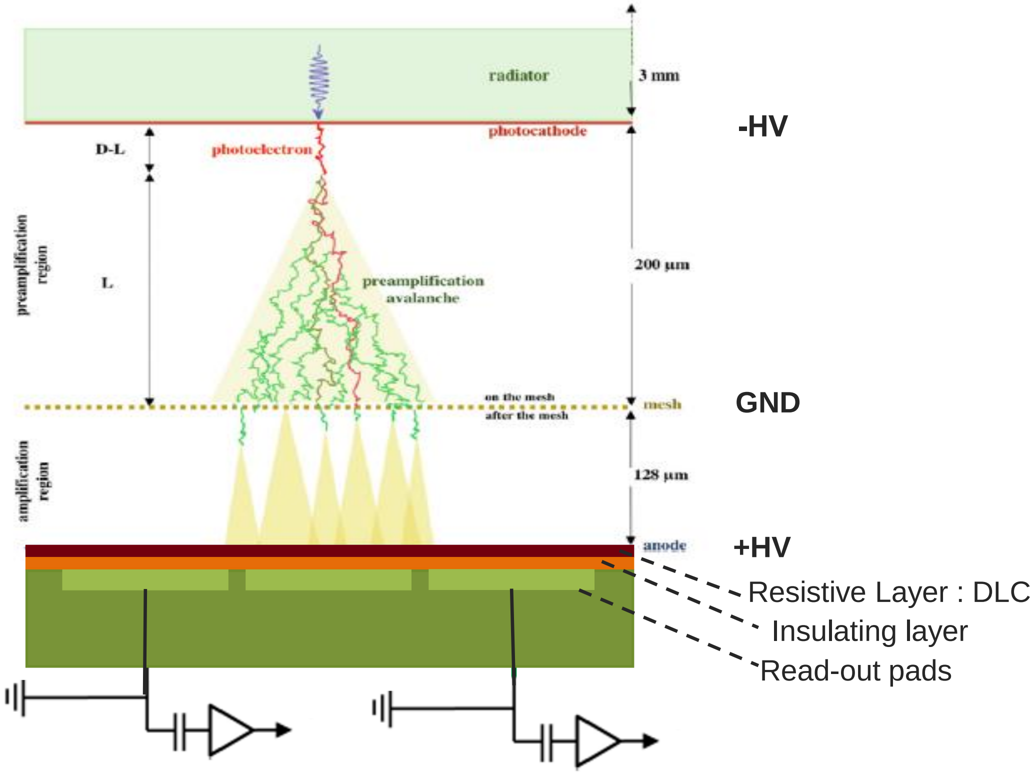
Using picosec as reference
DUT @ 300/420V



PRELIMINARY

More info on the <u>presentation</u> of D. Fiorina – Fast Workshop 2023

Robustness & Efficiency ≡ Resistive prototypes



The goal is to profit from those advantages while maintaining a good timing resolution

More info on the presentation of A. Kallitsopoulou – RD51 Collaboration meeting – June 2023

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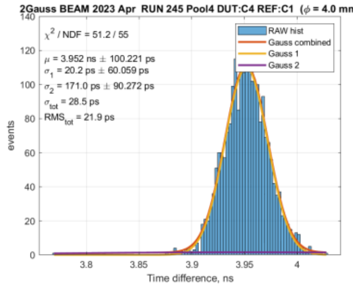
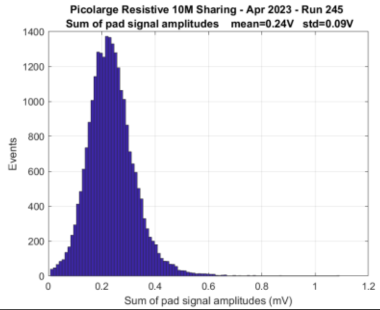
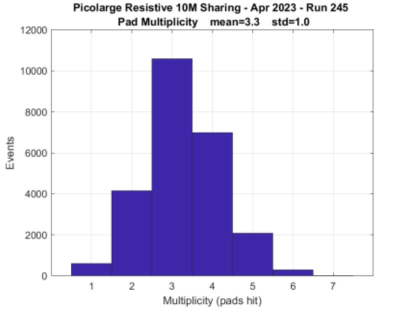
7-pad 10MΩ - resistive sharing - 550/275

RMS→20ps central region

Mean active pads = 3



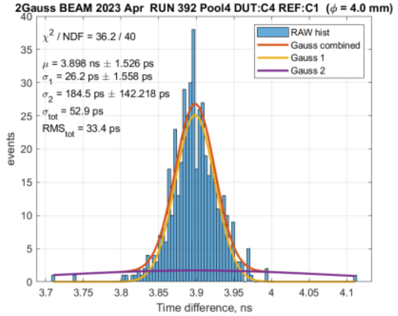


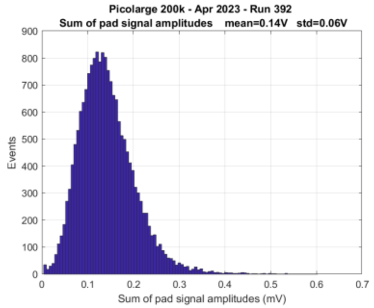


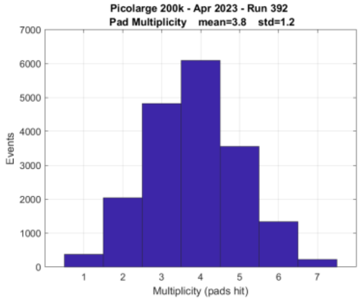
7-pad 200kΩ - resistive sharing - 550/275

RMS → 27ps central region

Mean active pads =4



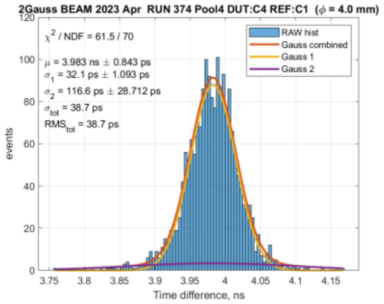


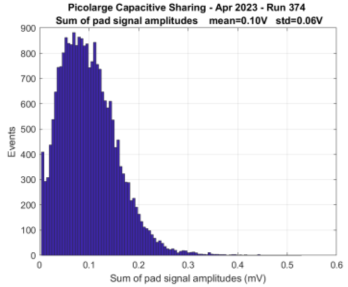


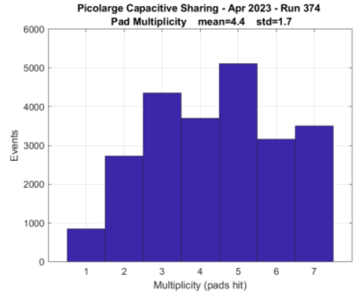
7-pad 10MΩ - capacitive sharing - 570/275

RMS → 33ps central region

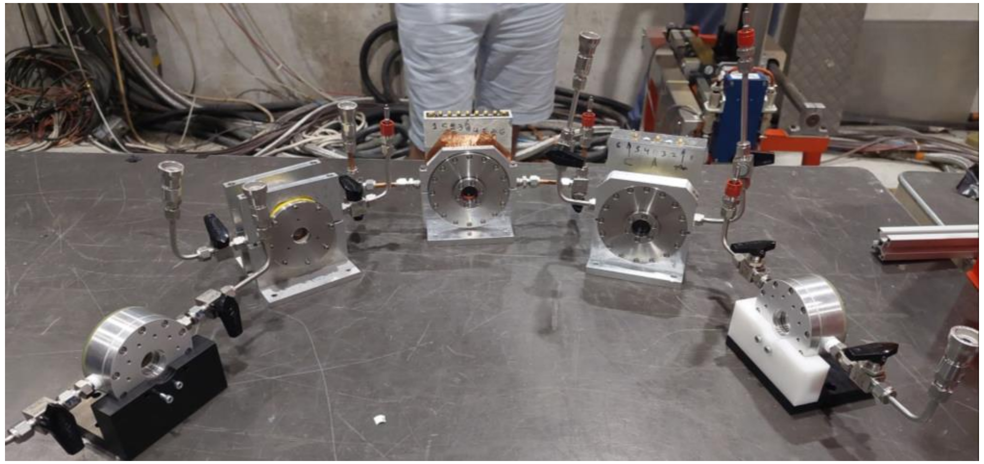
Mean active pads =5







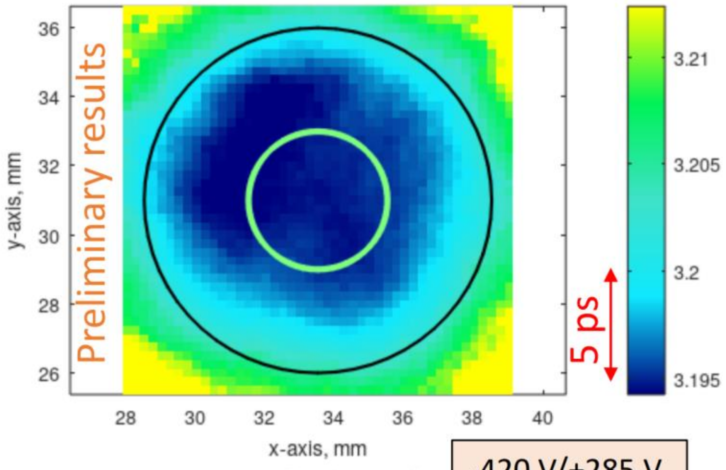
July 2023



Scan measurements for single ch. PICOSEC (Φ10 mm, Φ13 mm and Φ15 mm active area)

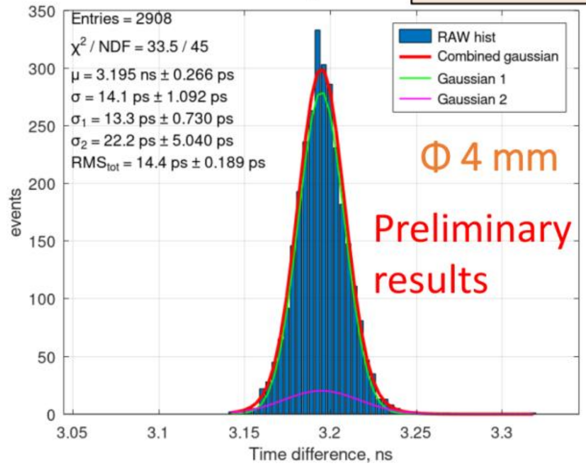
- Measurements with MCP mounted on a movable stage and scanning the entire pad area.
- Very uniform time response over the entire detector area for all three prototypes. Mean SAT well below 5 ps in the central region.

BEAM 2023 August RUN 283: SAT over the PAD (φ_{avg} = 3.0 mm) Φ10 mm

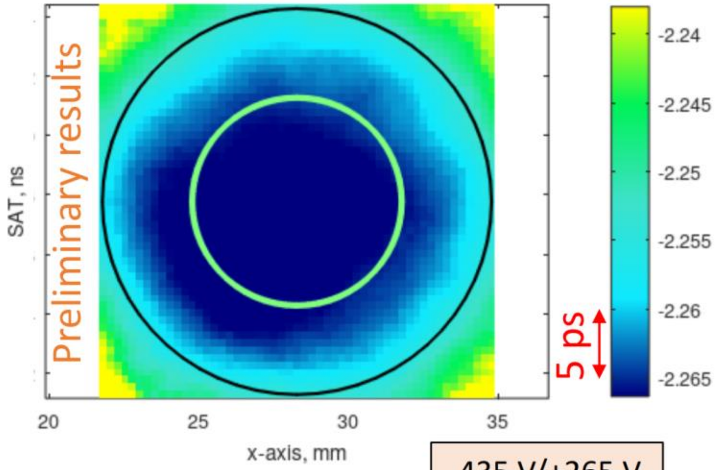


-420 V/+285 V

Double gauss 283

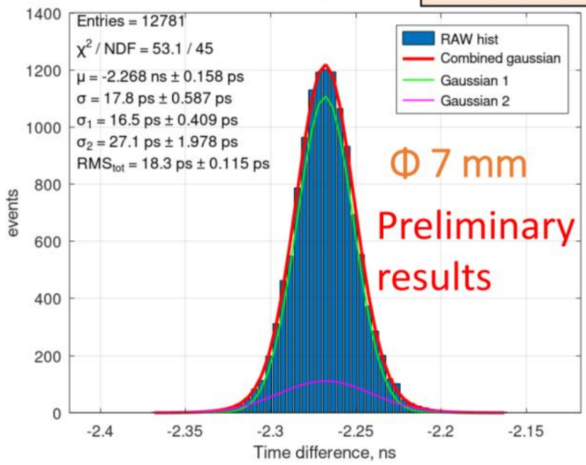


BEAM 2023 July RUN 434: SAT over the PAD (φ_{avg} = 3.0 mm) Φ13 mm

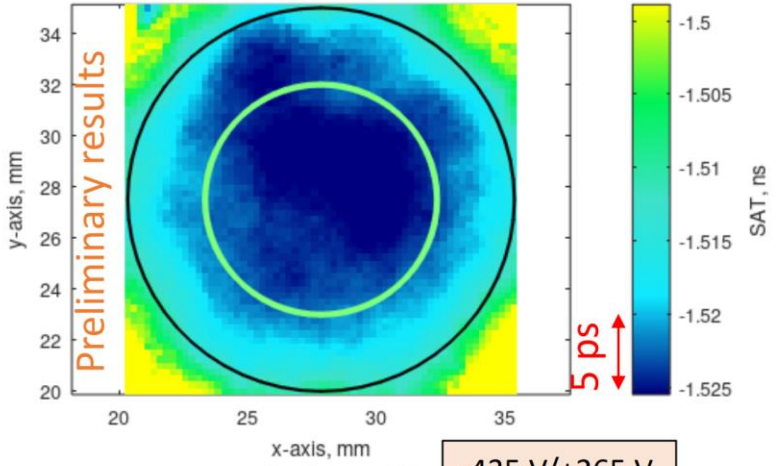


-435 V/+265 V

Double gauss 434

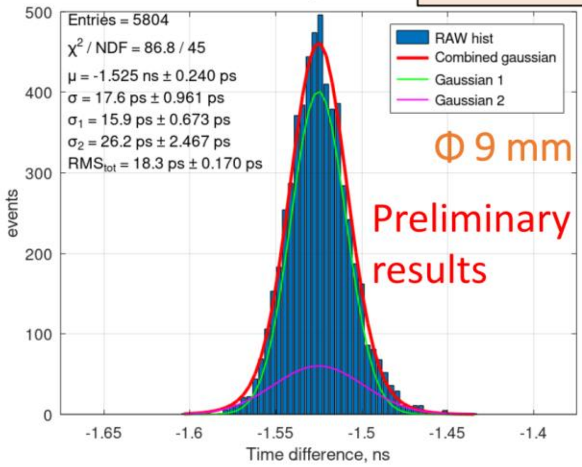


BEAM 2023 July RUN 401: SAT over the PAD (φ_{avg} = 3.0 mm) Φ15 mm



-435 V/+265 V

Double gauss 401



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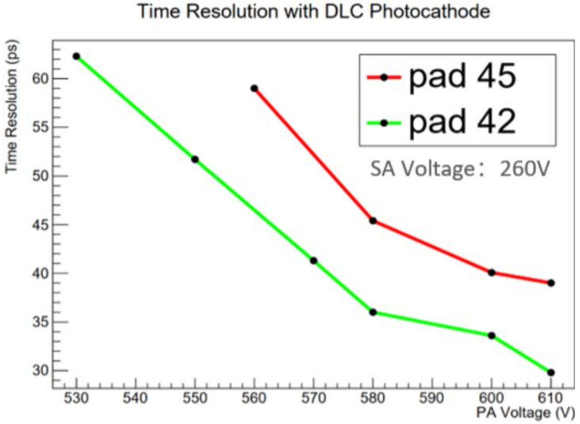
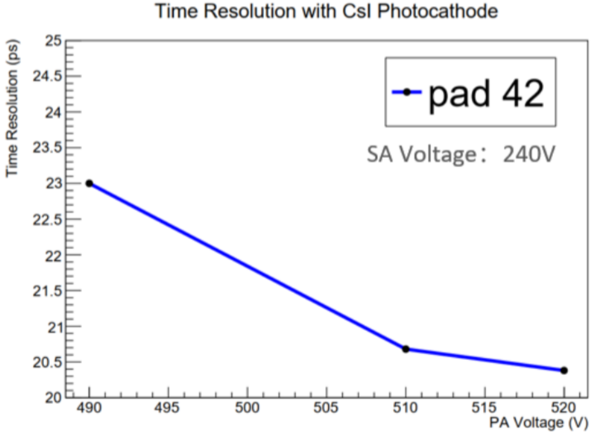
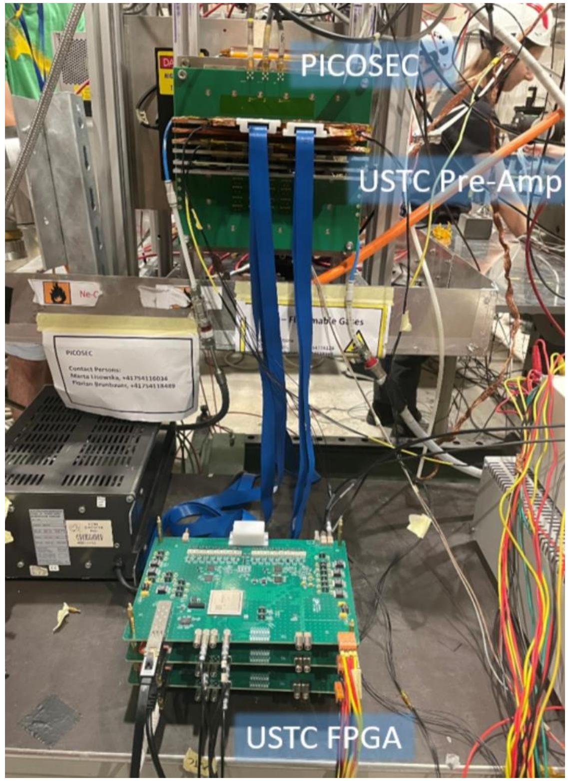
More info on A. Utrobicic's presentation RD51 Collaboration Meeting on Tuesday

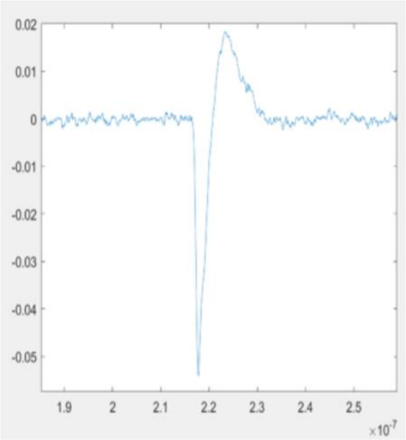
10x10cm2 USTC prototype

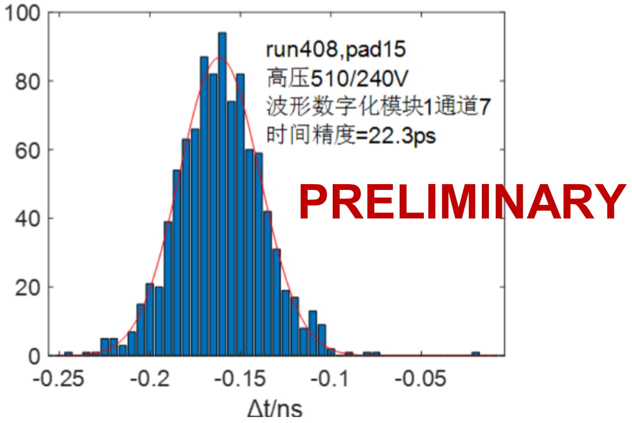
- With DLC photocathode, the time resolution can reach to ~30ps.
- With CSI photocathode, the time resolution can reach to ~20ps



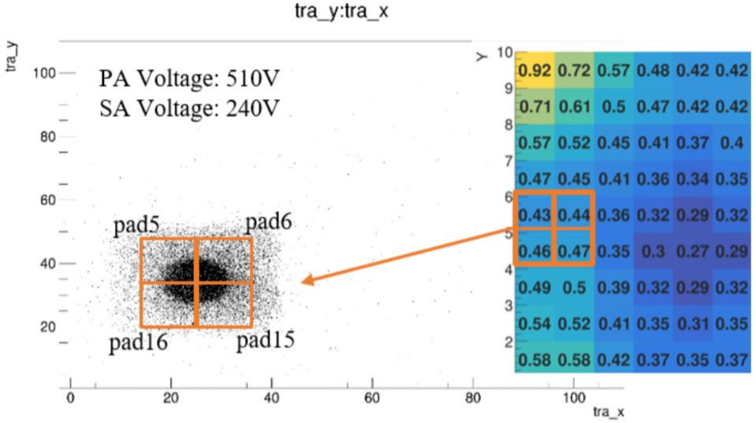


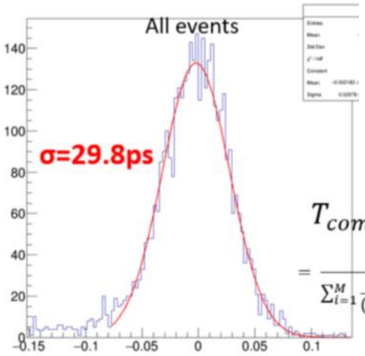






- Recover the timing resolution at ~30ps over signal sharing region



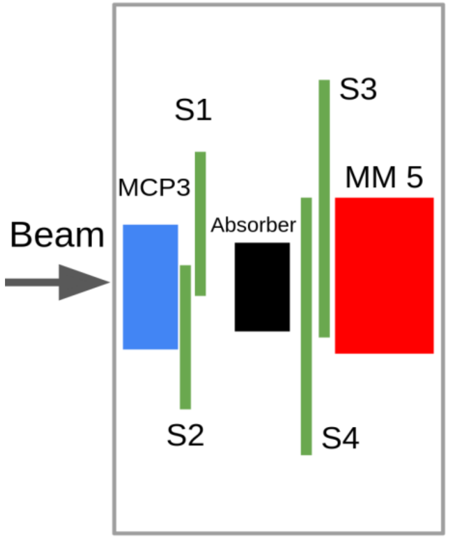


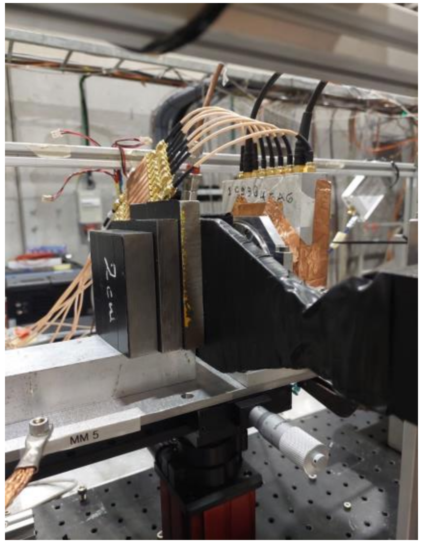
$$T_{combine} = \frac{1}{\sum_{i=1}^{M}\frac{1}{(\delta(signal\ size))^2}} \sum_{i=1}^{M} \frac{SAT^{i}_{true} - SAT^{i}_{corr}(signal\ si}{(\delta(signal\ size))^2}$$

PRELIMINARY

Performance in particle showers

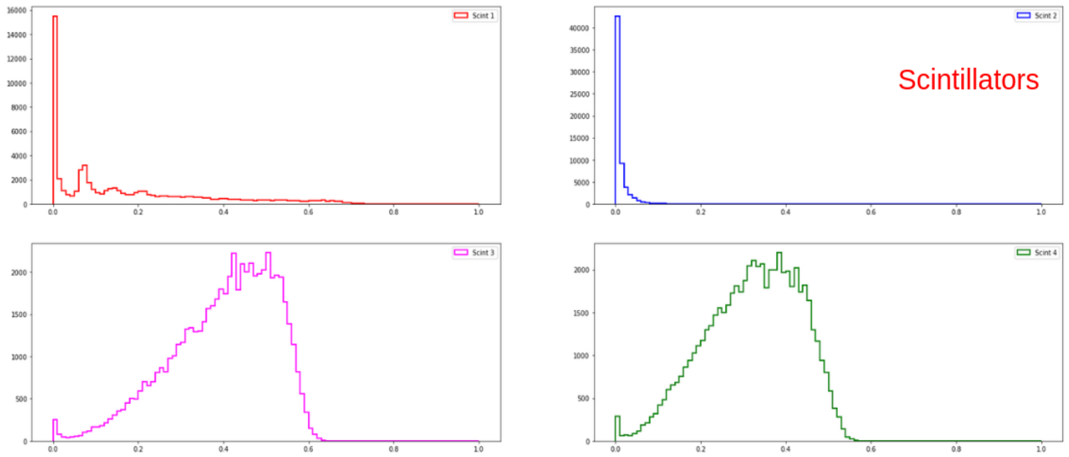
- Particle Beams @ CERN SPS H4 Beamline
  - Electrons 30GeV
  - ~1MH/cm2

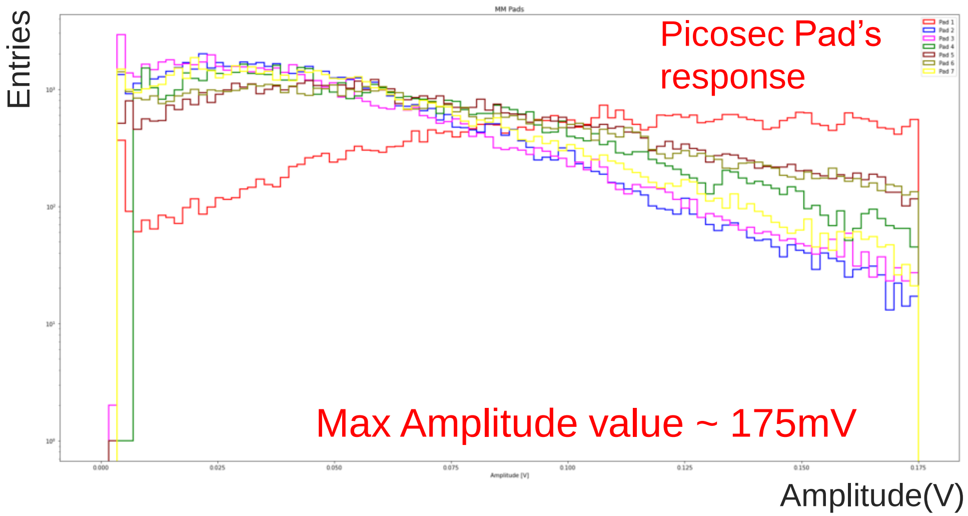




- Multi-Pad Prototype (7-pad)
  - 10MO/☐ Resistive prototype
  - Hexagonal pads ø 1cm
  - MgF2 crystal
  - B4C (12min) photocathode

30GeV electrons with 5cm Fe absorber





Embed a PICOSEC-Micromegas layer inside a calorimeter after a few radiation lengths and/or inside the instrumented hadron damp

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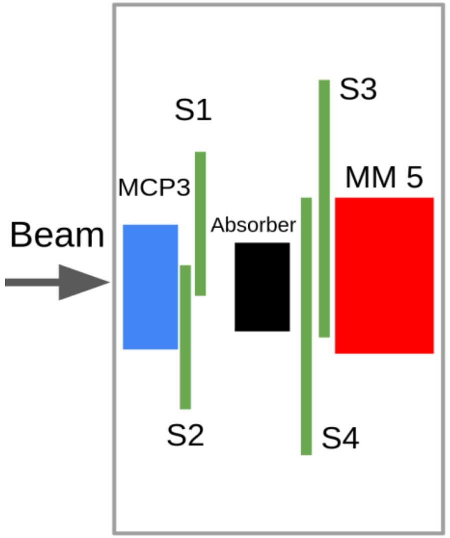
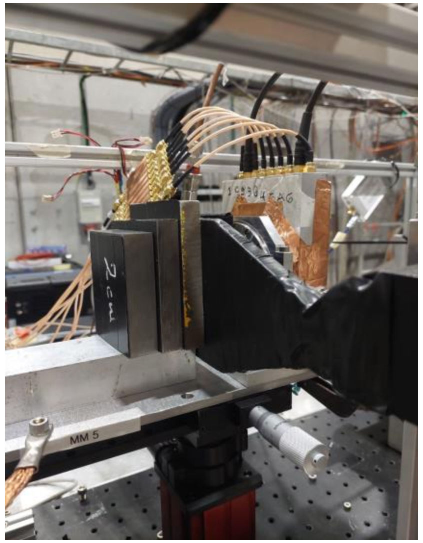
Performance in particle showers

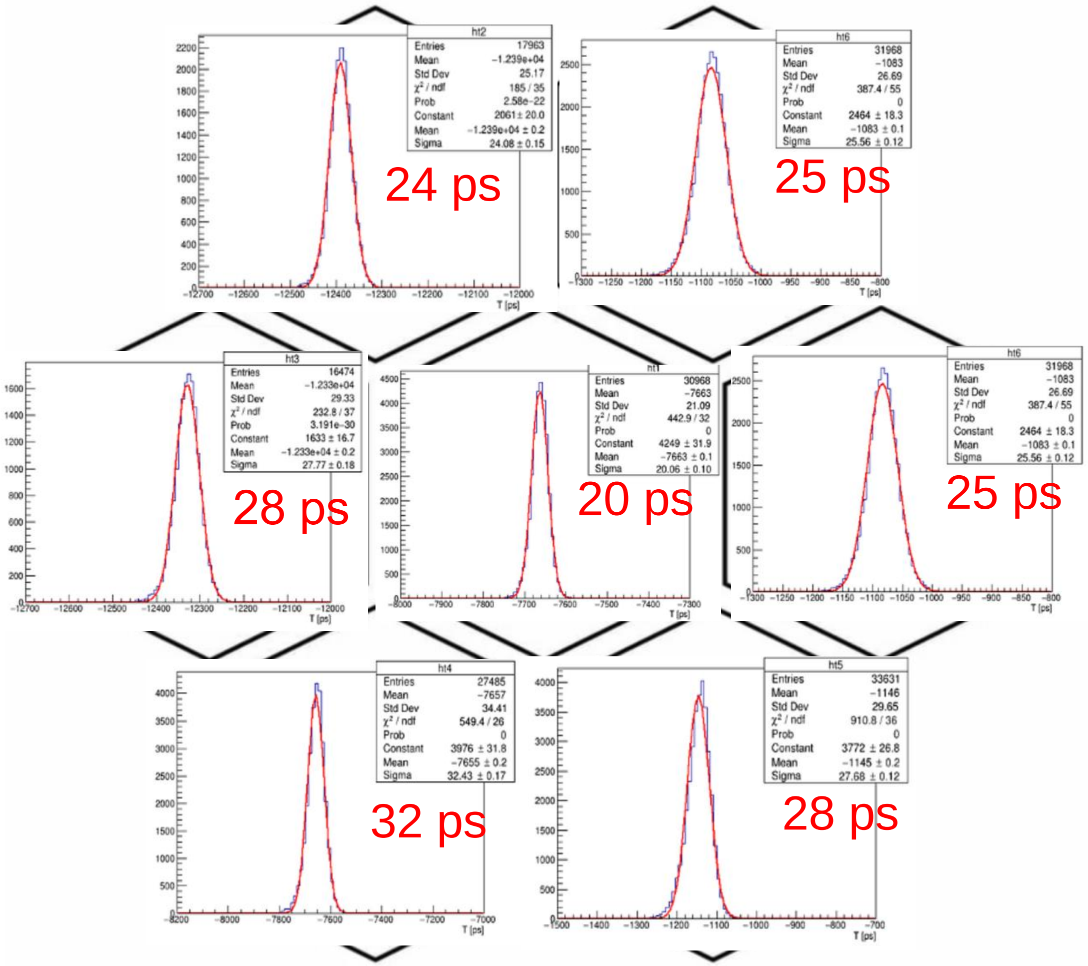
- Particle Beams @ CERN SPS H4 Beamline
  - Electrons 30GeV
  - ~1MH/cm2





- Multi-Pad Prototype (7-pad)
  - 10MO/☐ Resistive prototype
  - Hexagonal pads ø 1cm
  - MgF2 crystal
  - B4C (12min) photocathode

Overall timing response to showers below 30 ps



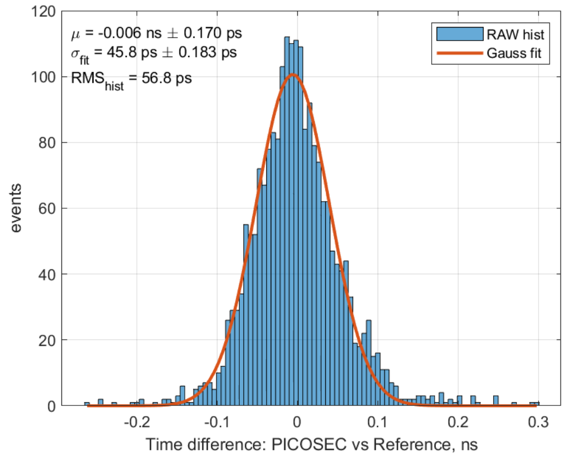
***PRELIMINARY**

August 2023

µRWELL single pad and 7pad 10MΩ

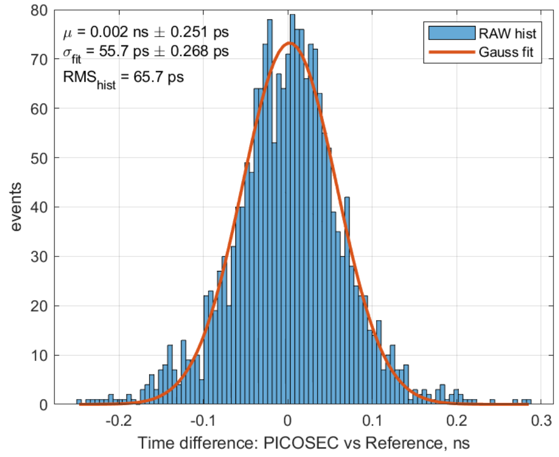
- Muons 150GeV

120µm

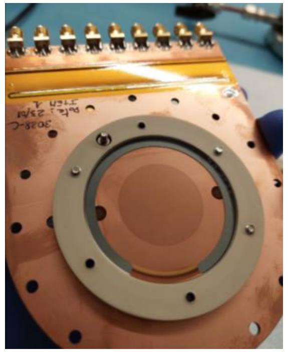


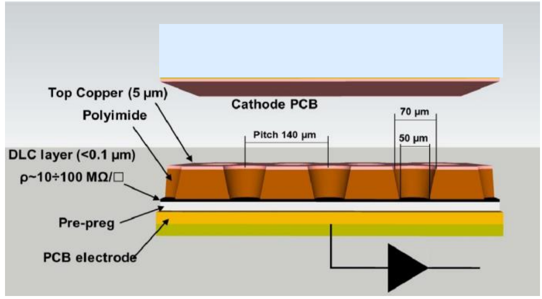
Best point ~ C450/A285
45.8ps

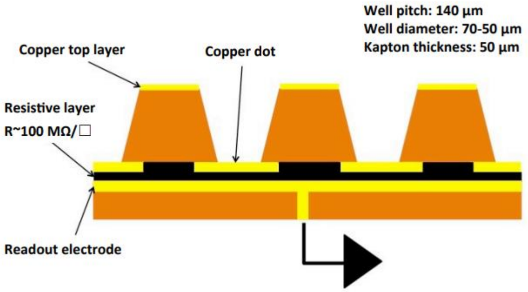
160µm



Best point ~ C570/A250
55.7ps







! µ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB 50µm

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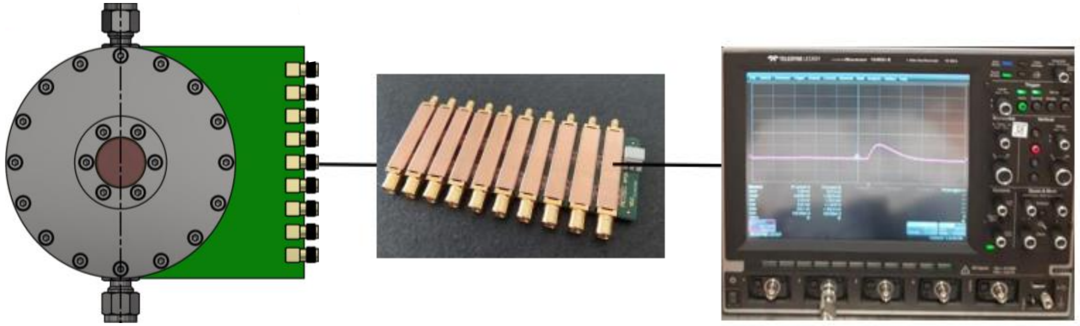
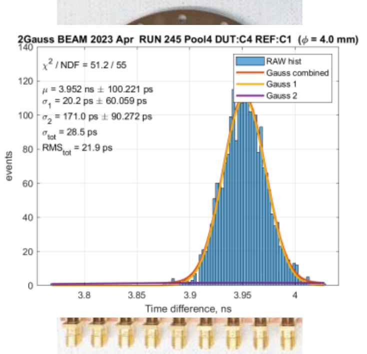
Photocathode - Comparison

- Multi-Pad Prototypes (7-pad)
  - Hexagonal pads ø 1cm
  - MgF2 crystal
  - CsI & B4C photocathodes

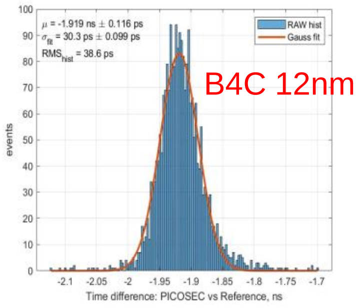


7-pad 10MΩ

RMS→20 ps central region

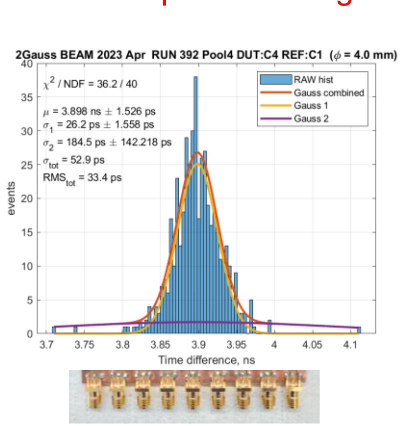


RMS→30 ps central region

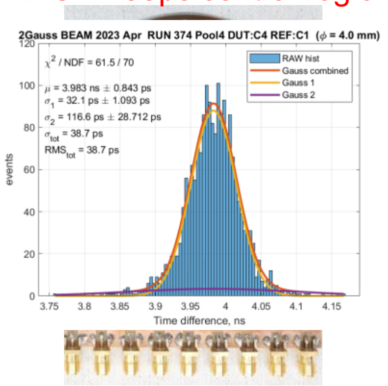


7-pad 200kΩ

RMS → 27 ps central region

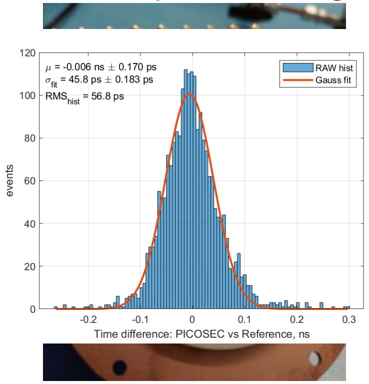


RMS → 33ps central region

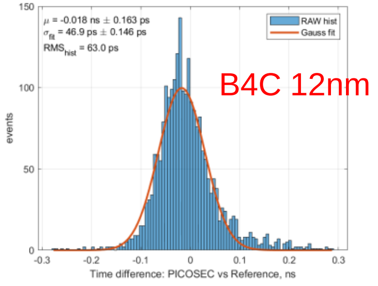


7-pad 10MΩ μRWELL

RMS → 41ps central region

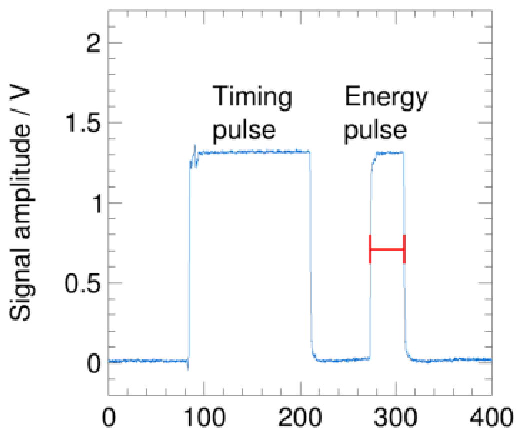


RMS → 42ps central region

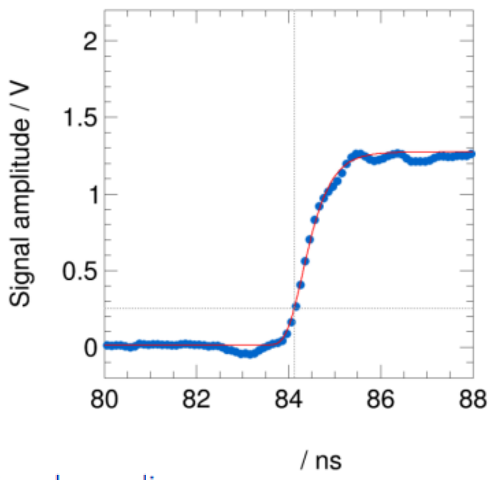


FastIC – Multi-channel Readout

Binary recorded output



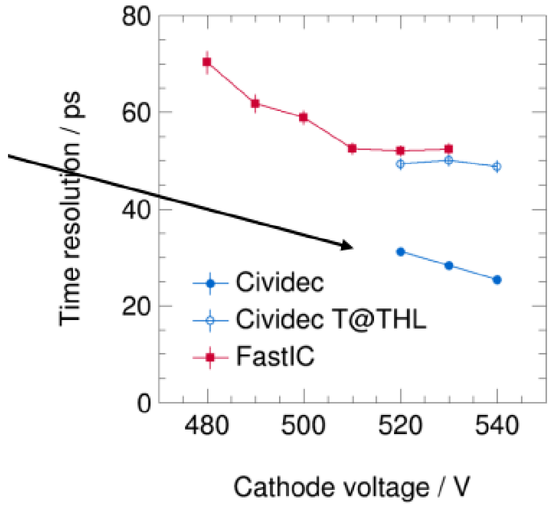
FastIC fit



More info on the presentation of L.Scharenberg RD51 Collaboration Meeting on Wednesday

Timing resolution ~ 50ps can be achieved

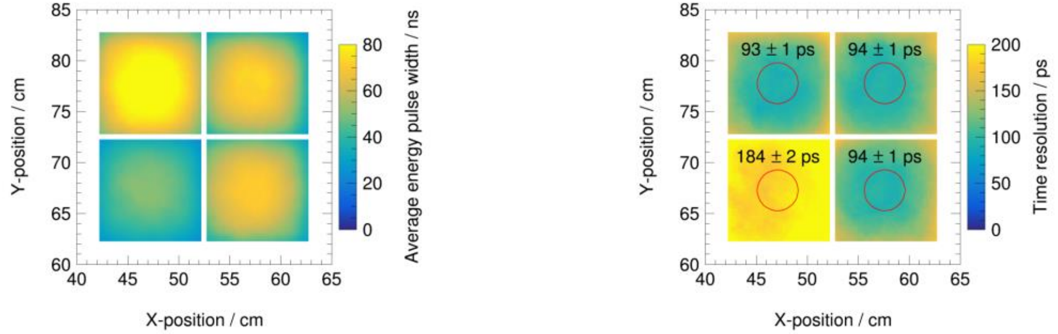
Time resolution depending on pre-amplification voltage



Despite ~1 ns time walk due to T@THL, time resolution of ~50 ps

Results: Multi-channel readout

- Multi-channel readout: pads 15, 16, 25 and 26 of multi-pad detector
- Reconstruct the pads individually
- Just to demonstrate that we can read out multiple channels at once
- Issues in the signal transmission (badly made adapter cables) decreased the time resolution
- Pads 15, 16 and 25 show similar response (<10% variation), as expected from previous studies [Marta's presentation from yesterday]



06 December 2023 L. Scharenberg @ RD51 Collaboration Meeting 12

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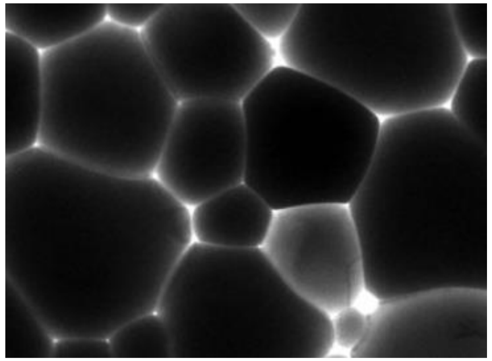
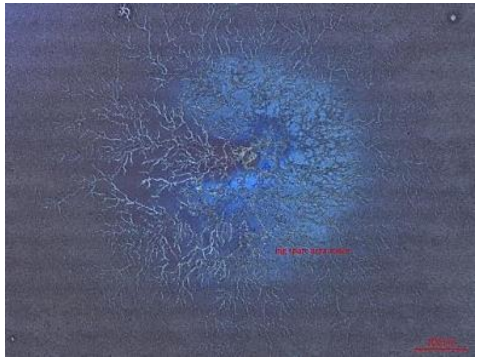
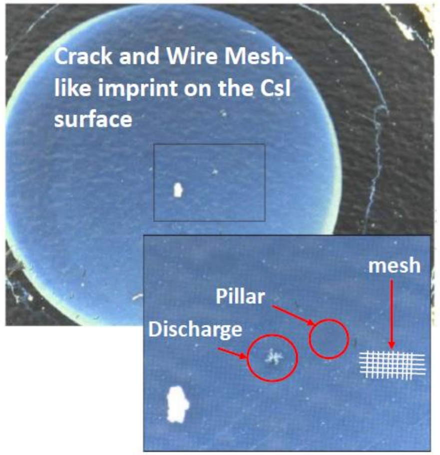
The photocathode issue

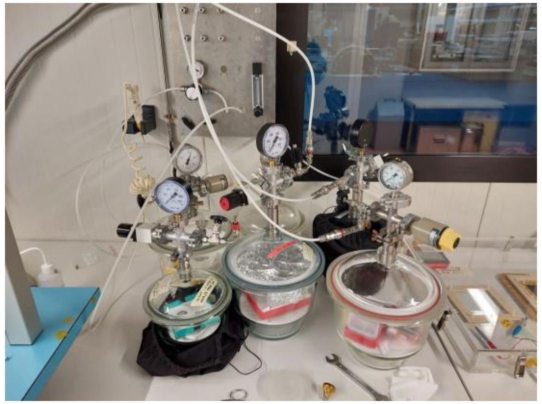
- In the research of photocathode materials
  - Standard photocathode: 18nm CsI +3nm Cr ~ 10pe/MIP
  - CsI sensitive to humidity/ion backflow & sparks
  - Ageing of the material



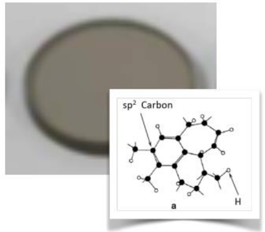


https://doi.org/10.1016/j.nima.2011.10.019

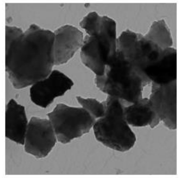




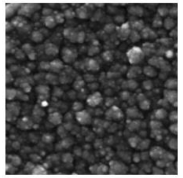
- New materials under test (B4C, DLC, Diamond, Metallic – Al, Cr)



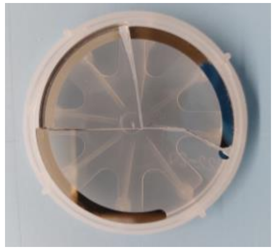
DLC, Y. Zhou et al.

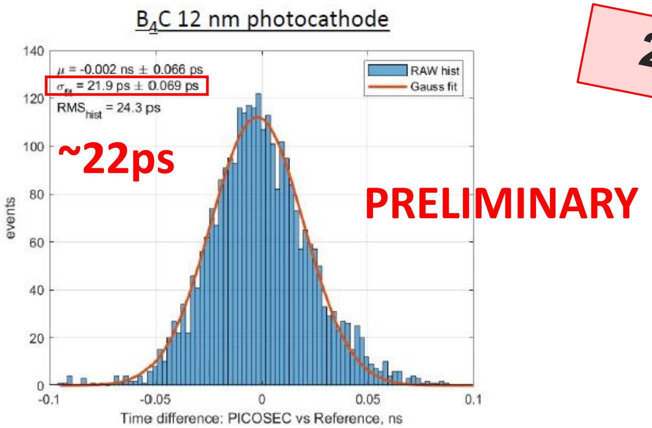


ND, L. Velardi et al.



B_4C, 10.1016/j.jnucmat.2015.01.015





2022

M. Lisowska - Towards robust PICOSEC Micromegas precise timing detectors-MPGD2022
https://indico.cern.ch/event/1219224/contributions/5130512

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More info on the presentation of M. Lisowska at RD51 Collaboration Meeting on Tuesday

Robust photocathodes

Time resolution

New promising results of robust photocathodes from 2023 test beams

- **Prototype**: Single pad non-resistive MM, pre-amplification gap 125/145 µm*
- **Photocathodes**: CsI, DLC, B_4C of different thicknesses from different collaborators**

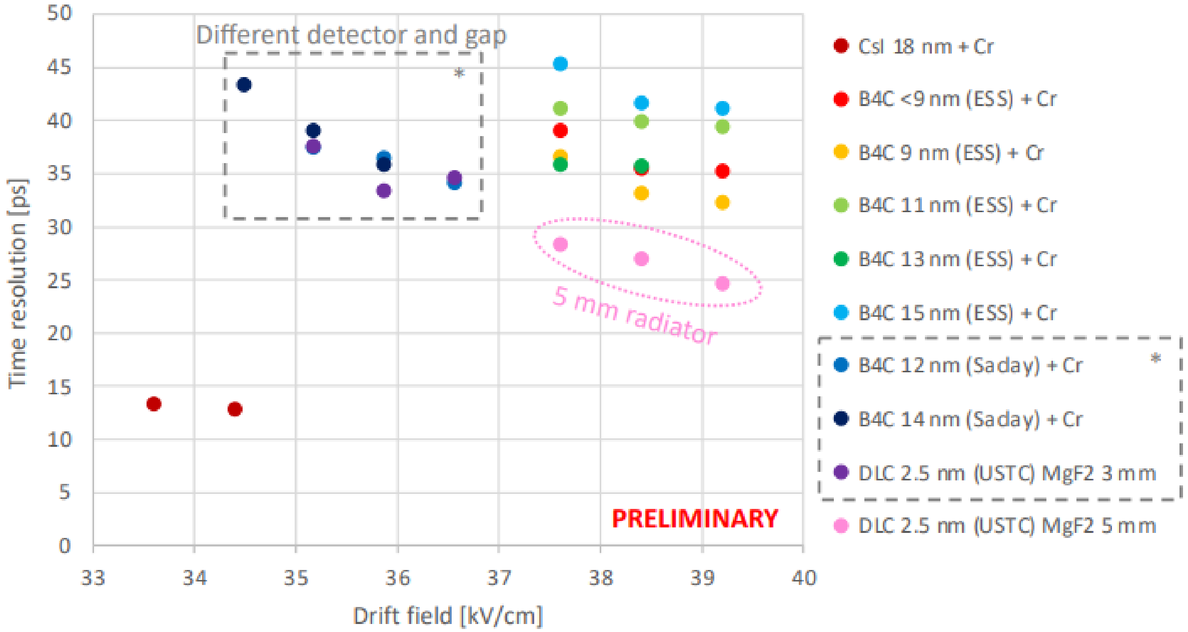
- **Time resolution** after MCP subtracted:

$$\sigma_{PICO} = \sqrt{{\sigma_{combined}}^2 - {\sigma_{MCP}}^2},$$

where MCP double split $\sigma_{MCP} \approx 7.67$ ps

- **Photocathodes** measured in combination with a **new detector with optimized design** were able to **reach higher drift fields** resulting in **better time resolution**

(results at 39.2 kV/cm taken for the further analysis)



*Samples measured in a new detector with 125 µm gap SEALED in August, except for 3 measured with Saclay detector with 145 µm gap FLUSHING in July (marked with a star)

**Depositions: CsI at CERN, DLC at USTC, B_4C at CEA Saclay and ESS

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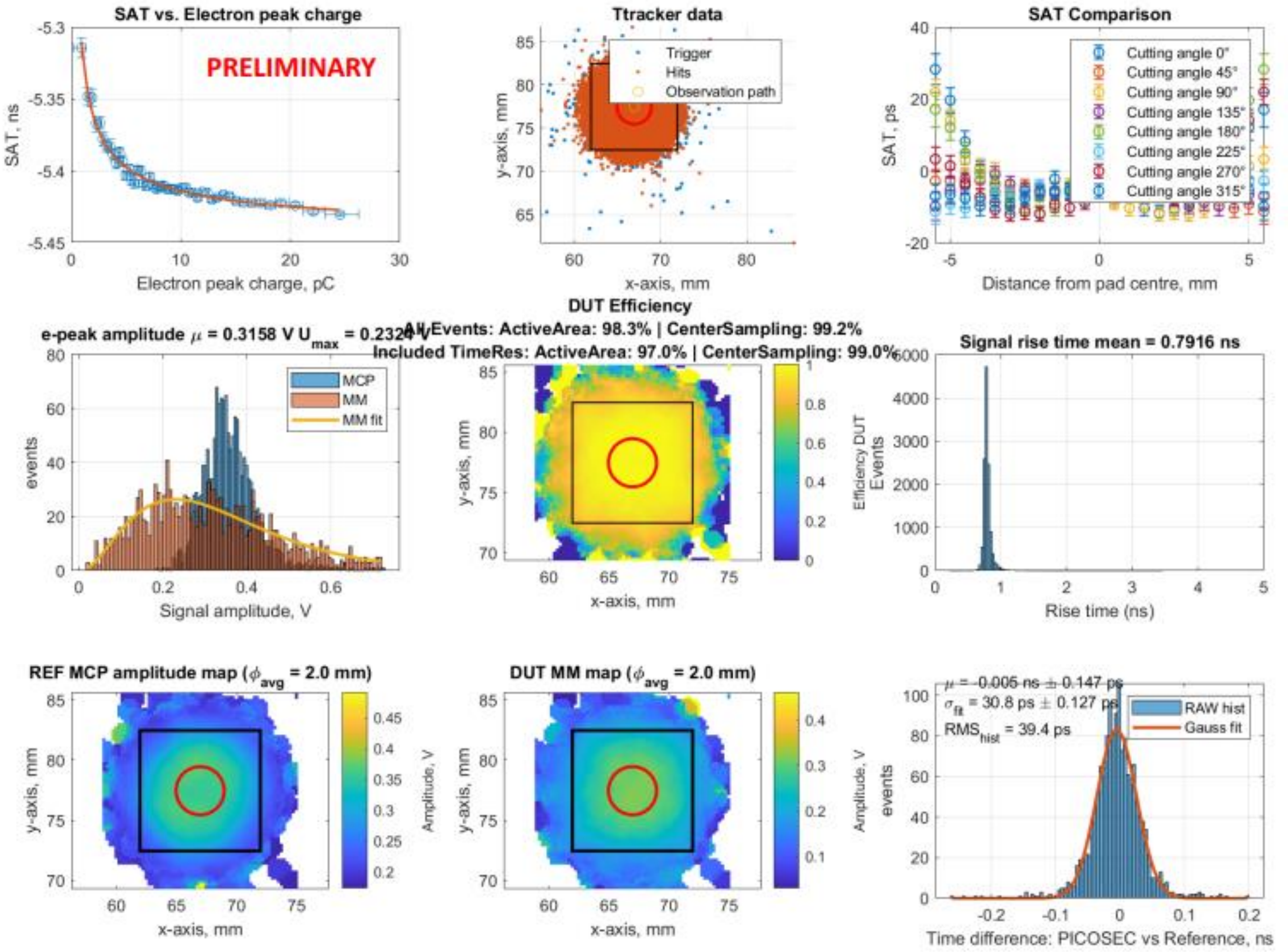
- Measurements of the 100ch Multipad: non-resistive MM, pre-amp gap 180 µm, $10 \times 10\ cm^2$ area 5 mm thick MgF_2 with 2.5 nm thick DLC photocathode

- Time resolution of the 100ch MM with DLC photocathode **σ ∽30 ps an individual pad**

- Response of full area of 100ch Multipad measured with custom-made amplifiers and SAMPIC digitiser → analysis in progress



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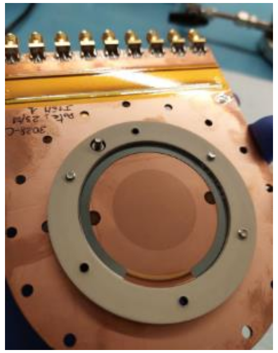
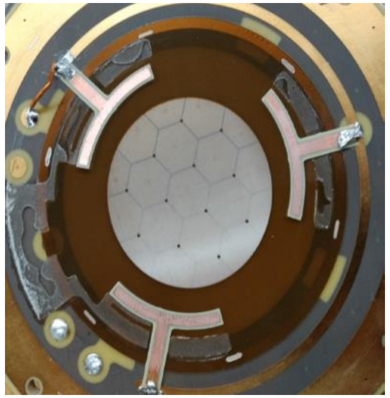
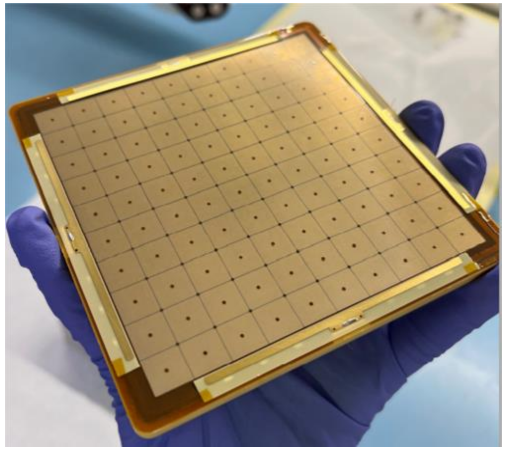
Scalability / Large area Detectors



7 channel anode ⬡ 1 cm



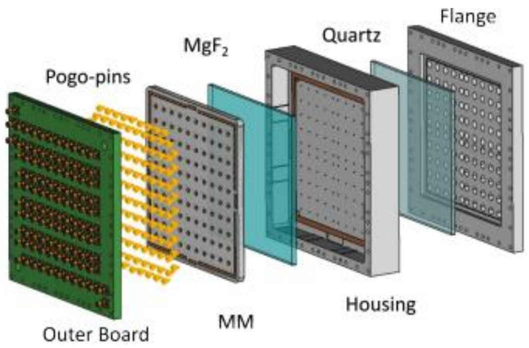
19 channel anode ⬡ 1 cm

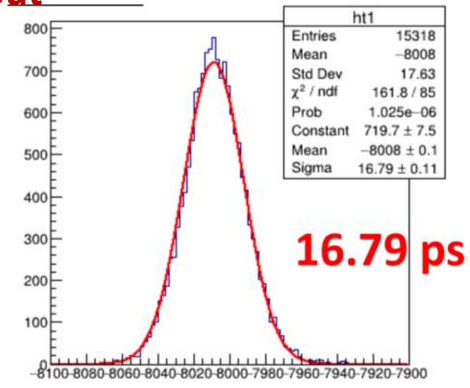


100 channel anode ☐ 1 cm

Ensure the planarity

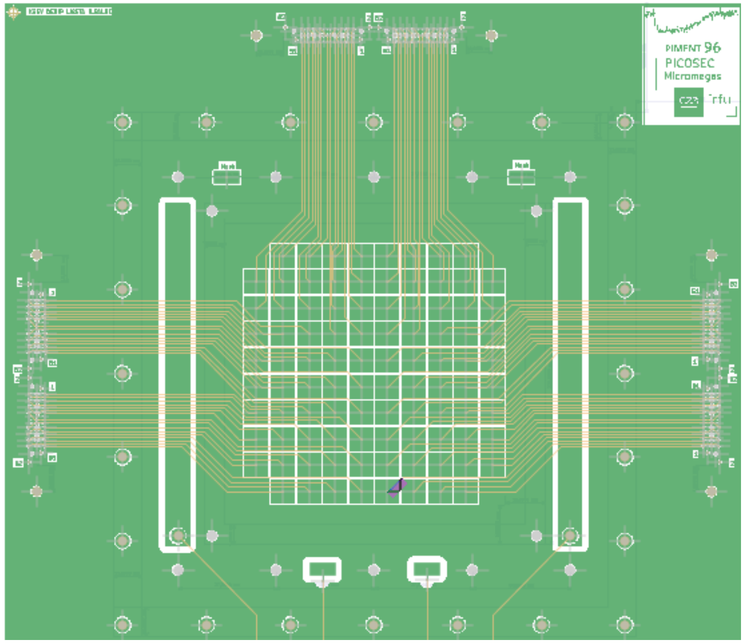
- **Rigid, ceramic-core PCB for the MM readout**





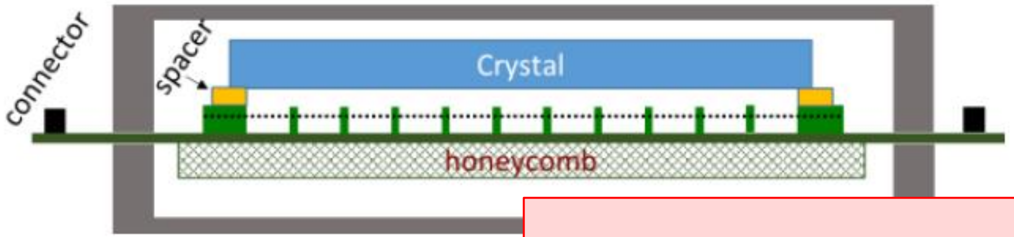
Ready and operational from CERN-GDD Group

NEW design From CEA Saclay



- 96 pad prototype
- Develop custom-made amp. cards in 6 x 16 connector groups compatible for SAMPIC digitization

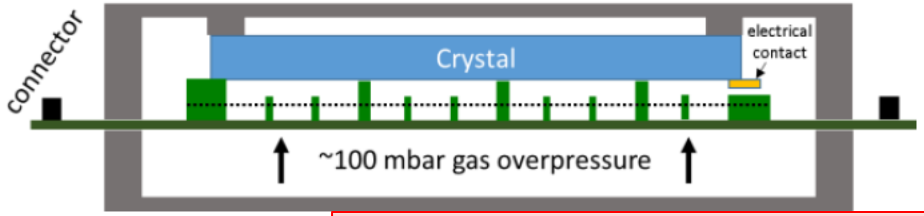
- **The ATLAS NSW Approach**



Risk to damage the bulk MM

- **Advantage:**
  - Low material budget on the detector
  - Allow the fabrication of large flat boards

- **Longer pillars MM module**
  - Pressed against Cherenkov radiator



Risk to damage the photocathode

Conclusions & Future Prospect

Towards an engineered PICOSEC MM module :
multiple directions in detector development

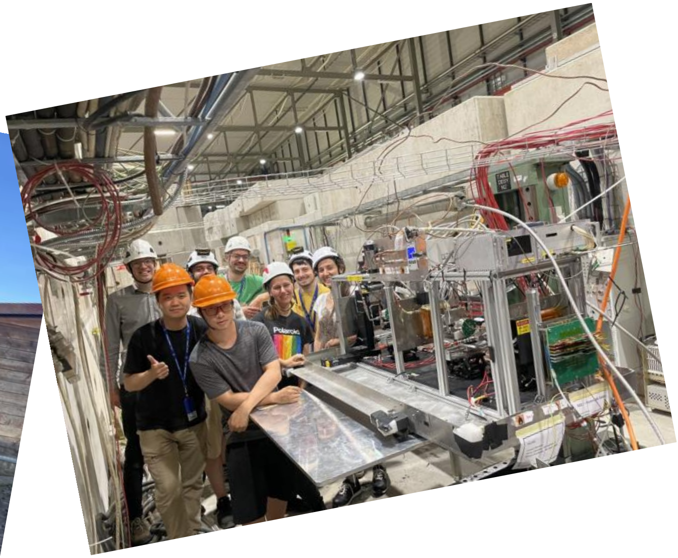
- **Single-channel Prototypes(Un.Zagreb)**
  - Thin gap prototype
    - studies of detector, amplifier and digitizer optimization

- **Robustness & Efficiency (CEA/CERN/USTC/JLab)**
  - Test different photocathode materials
  - Resistive prototypes (µRWELL/ resistive sharing)
  - 20x20cm2 prototype (with different photocathode materials)

- **Pixelated MM Detector (CEA/CERN/ Un. Zagreb/ USTC)**
  - Single channel current amp.
  - Preamp cards + FPGA
  - 16 channel amp cards + SAMPIC
  - FastIC + integrated TDC for fully digital output

- **Possible Applications(CEA)**
  - Common TestBeam with ENUBET collaboration
  - PICOSEC embed in a calorimeter or in a hadron damp

In the end, it's all a matter of timing…



PICOSEC
Micromegas

Thank you for your attention

CEA SACLAY

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