ARISTOTLE UNIVERSITY OF THESSALONIKI

RESEARCH COMMITTEE
ARISTOTLE UNIVERSITY OF THESSALONIKI

PICOSEC Micromegas: Achievements in Precise Timing and Recent Advancements with Large Segmented Prototypes

HEP 2021 – 38th Conference on Recent Developments in High Energy Physics and Cosmology
19 June 2021 – Thessaloniki GREECE

PICOSEC
Micromegas

Christos Lampoudis, School of Physics – Aristotle University of Thessaloniki – GREECE
on behalf of the RD-51 PICOSEC collaboration

Outline

Introduction

- Motivation for the PICOSEC Micromegas detector project
- Detector description

Single anode PICOSEC prototype

- timing performance in laser and particle beams
- simulation and modeling

Multipad PICOSEC prototype: scaling up the detector

- issues related to the 1st mulitpad PICOSEC – performance in timing after corrections

Towards an optimized large PICOSEC detector

- the updated segmented PICOSEC design
- foreseen tests and actions

Concluding remarks

Introduction

Aim for ~ 20 ps timing in particle tracking

Talk by Sebastian White
"Precise Timing in HEP"

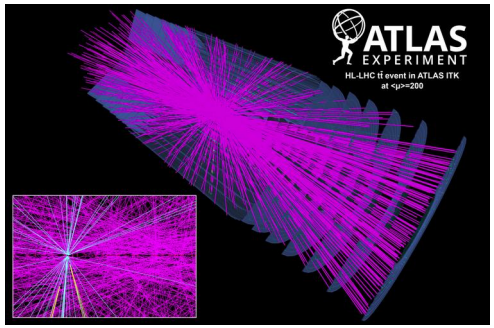
High Luminosity consequences:

High pile-up (up-to 200 events/BC) with large number of tracks

Harsher radiation environment

Requirements:

- Large surface coverage.
- Multi-pad readout for tracking.
- Resistance to aging effects.



Demand for precise timing detectors for physics (Time of Flight, Particle Identification)

Rising needs related to medical and industrial application

PID techniques: Alternatives to RICH methods, J. Va'vra, NIMA 876, 185 – 193, 2017 https://doi.org/10.1016/j.nima.2017.02.075

Available technology:

Solid state detectors

- Avalanche PhotoDiodes: (σ_t ~ 20 ps)
- Low Gain Avalanche Diodes (σ_t ~ 30 ps)
- HV/HR CMOS (σ_t ~ 80 ps)

➔ *Radiation hardness ?*
➔ *Cost*

Gaseous detectors

➢ RPCs: (σ_t ~ 30 ps)
High rate limitation
➢ Micro-Pattern Gaseous Detectors (σ_t ~ 1 ns)

Improve Micromegas performance by **~ 2 orders of magnitude**

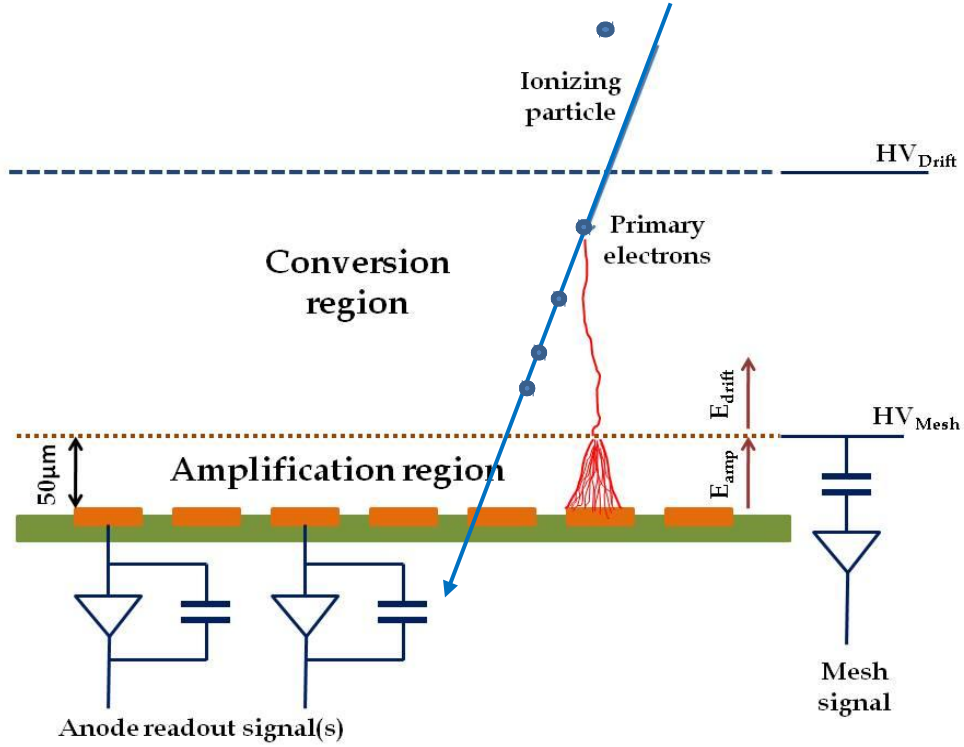
1st step: proof of concept

Next steps: increase area, position-sensitive, radiation hardness

A typical Micromegas

Drift gap/Conversion region
Ionizing particles create electrons, which drift towards readout plane.

Amplification region
Avalanches/amplification, charge movement induces signals.

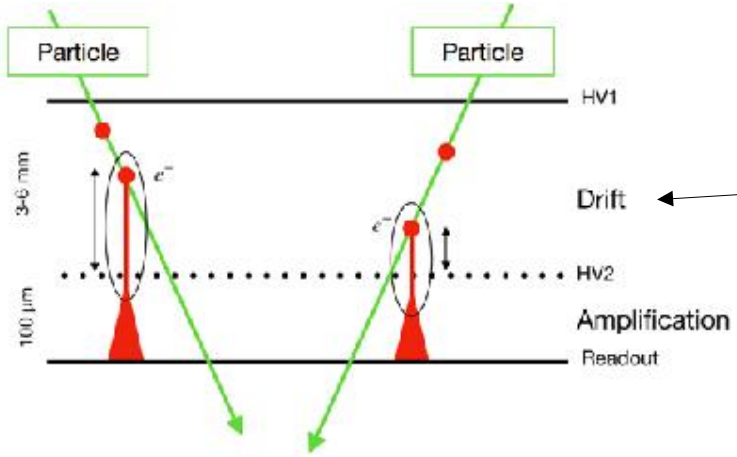


Characteristic advantages of the technology:

Simplicity, Granularity, Homogeneity, Scalability, High rate capabilities, Radiation hardness, Low cost

Y. Giomataris, P. Rebourgeard, J. Robert, G. Charpak, MICROMEGAS: A high granularity position sensitive gaseous detector for high particle flux environments, Nucl. Instrum. Meth. A 376 (1996) 29–35

Timing properties/Limitations



- Ionizations occur in different positions along the particle's trajectory → ~ ns time jitter for a 3-6 mm conversion region
- Diffusion effects

Limitations: reminder

The Physics of Ionization offers the means for precise spatial measurements (high spatial resolution) but inhibits precise timing measurements

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

10.5170/CERN-1977-009

PRINCIPLES OF OPERATION OF MULTIWIRE PROPORTIONAL AND DRIFT CHAMBERS

F. Sauli

Lectures given in the
Academic Training Programme of CERN
1975-1976

GENEVA
1977

which is represented in Fig. 8, for n = 34, as a function of the coordinate across a 10 mm thick detector. If the time of detection is the time of arrival of the closest electron at one end of the gap, as is often the case, the statistics of ion-pair production set an obvious limit to the time resolution of the detector. A scale of time is also given in the figure, for a collection velocity of 5 cm/μsec typical of many gases; the FWHM of the distribution is about 5 nsec. There is no hope of improving this time resolution in a gas counter, unless some averaging over the time of arrival of all electrons is realized.

Limitations: reminder

The Physics of Ionization offers the means for precise spatial measurements (high spatial resolution) but inhibits precise timing measurements

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

10.5170/CERN-1977-009

PRINCIPLES OF OPERATION OF MULTIWIRE PROPORTIONAL AND DRIFT CHAMBERS

F. Sauli

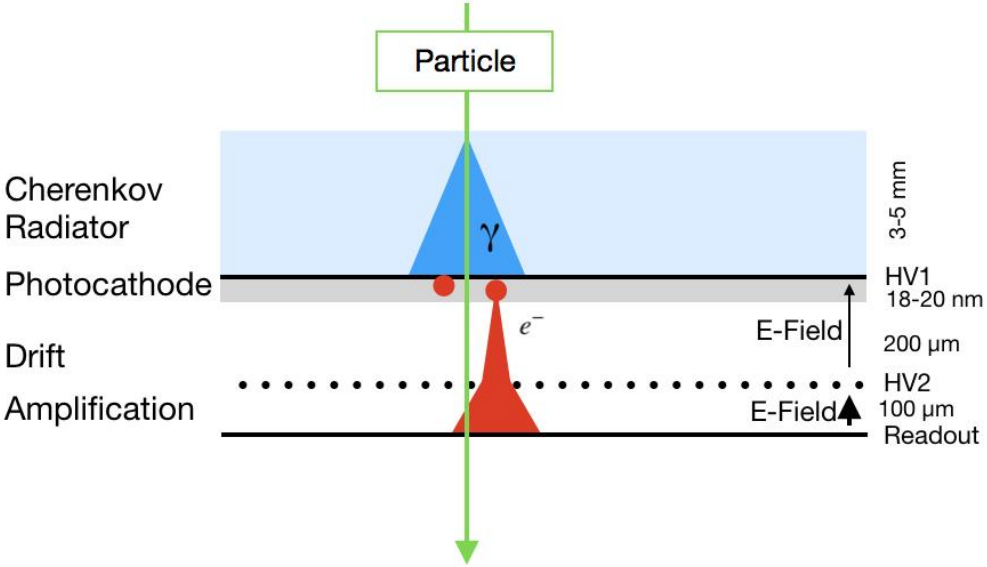
which is represented in Fig. 8, for n = 34, as a function of the coordinate across a 10 mm thick detector. If the time of detection is the time of arrival of the closest electron at one end of the gap, as is often the case, the statistics of ion-pair production set an obvious limit to the time resolution of the detector. A scale of time is also given in the figure, for a collection velocity of 5 cm/μsec typical of many gases; the FWHM of the distribution is about 5 nsec. There is no hope of improving this time resolution in a gas counter, unless some averaging over the time of arrival of all electrons is realized.

Lectures given in the
Academic Training Programme of CERN
1975-1976

What if we could tackle the 'problem' of the **stochastic nature** of the **ionization** by exploiting **other physics phenomena**

Use prompt photons (**Cherenkov radiation**) to extract electrons from the proper material (**Photoelectric effect**).

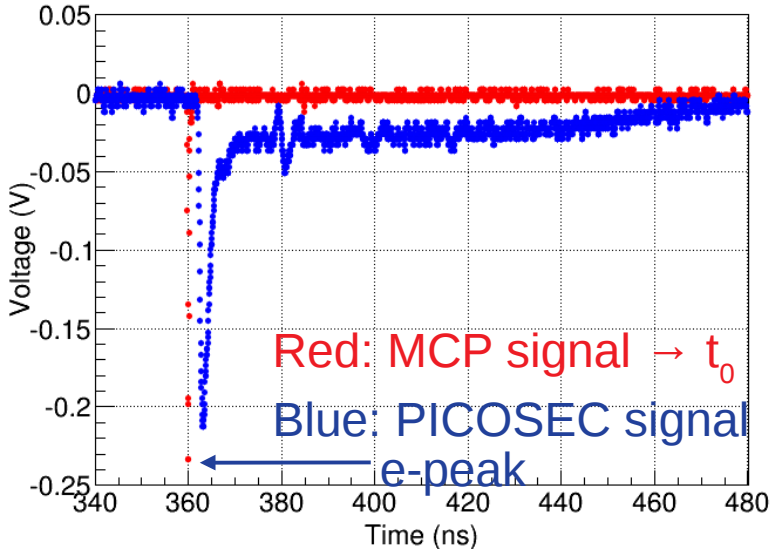
The PICOSEC vs the typical MM



Cherenkov radiator + Photocathode

- ✓ Particle produce Cherenkov light
- ✓ Photo-electrons emerge from photocathode
- ✓ Electrons amplified by a two-stage Micromegas

Signal components: Fast <1ns (electron peak) &
Slow ~100ns (Ion-tail)



Small drift gap (~200 μm) + High E-field:

- ✓ Pre-amplification possible
- ✓ Limited direct ionization
- ✓ Reduced diffusion impact

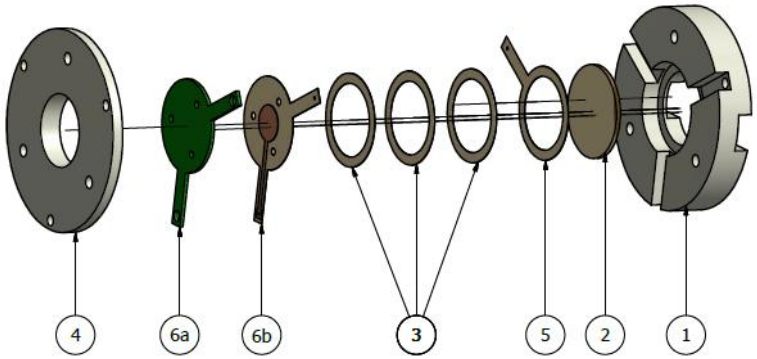
Cherenkov radiator/Photocathode:

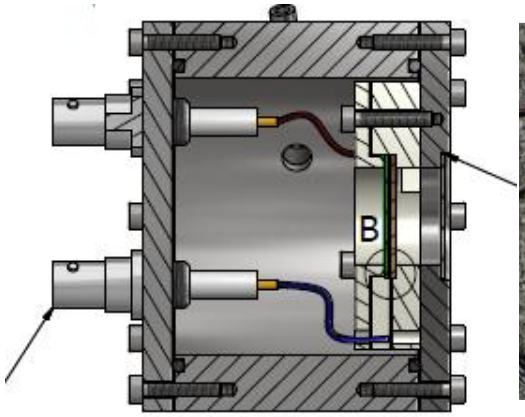
- ✓ Photo-electrons emerging the photocathode simultaneously (fixed distance from the mesh)
- ✓ produce sufficient number of photo-electrons

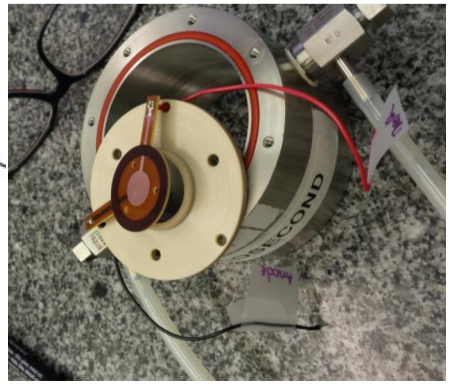
Result: improved timing resolution

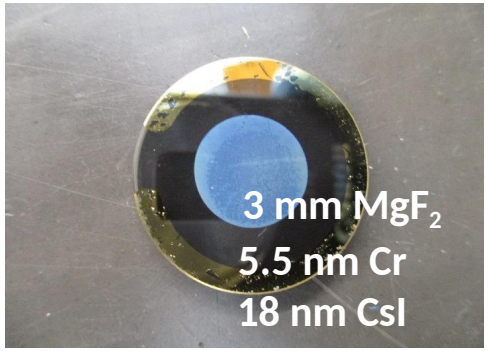
Single anode PICOSEC

The single anode PICOSEC prototypes









Tests with UV lamp / laser → quartz windows

Sensor:

Bulk Micromegas ø 1cm

- Amplification gap 50 μm
- Capacity ~ 35 pF

'Standard' bulk Micromegas ø 1cm

- Capacity ~ 8 pF
- Amplification gap 64 / 128 / 192 μm

Thin-mesh Bulk Micromegas (~5 μm)

- High optical transparency
- Amplification gap 128 μm

50 μm Kapton spacers

- Ensure homogeneous small drift gap & photocathode polarization

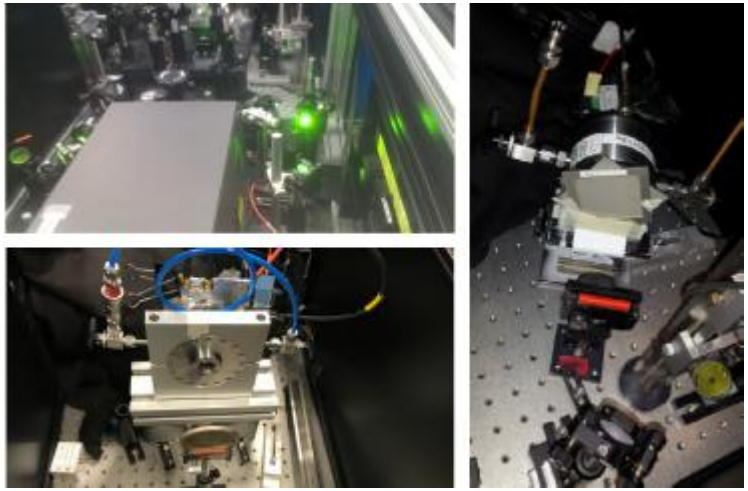
Photocathodes: **MgF_2** crystal (3mm) +

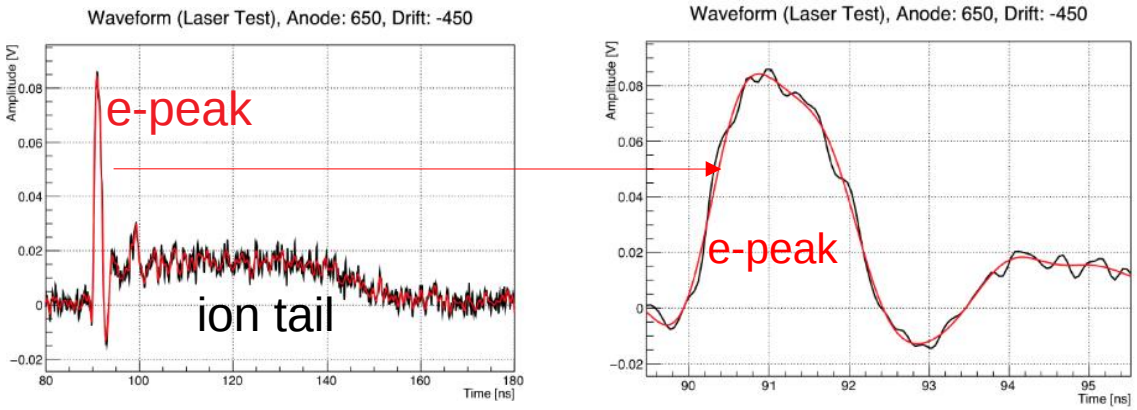
- **CsI** (18nm) on **Cr** (5.5nm metallic subtrate) for muon beam tests
- **Al** (8-10nm) for laser tests

COMPASS gas: (80% Ne + 10% CF_4 + 10% C_2H_6)

Pressure: 1 bar.

Laser tests setup: response to single p.e.

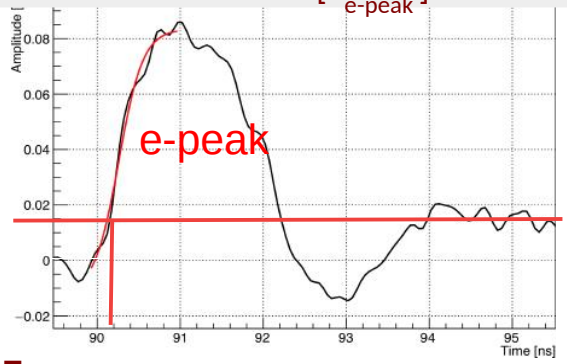




Signal from Laser runs (right is zoom in e-peak)

$T_{e\text{-}peak}$ = Signal Arrival Time (SAT)

* SAT of a sample of events = $\langle T_{e\text{-}peak} \rangle$
* Time Resolution = RMS[$T_{e\text{-}peak}$]



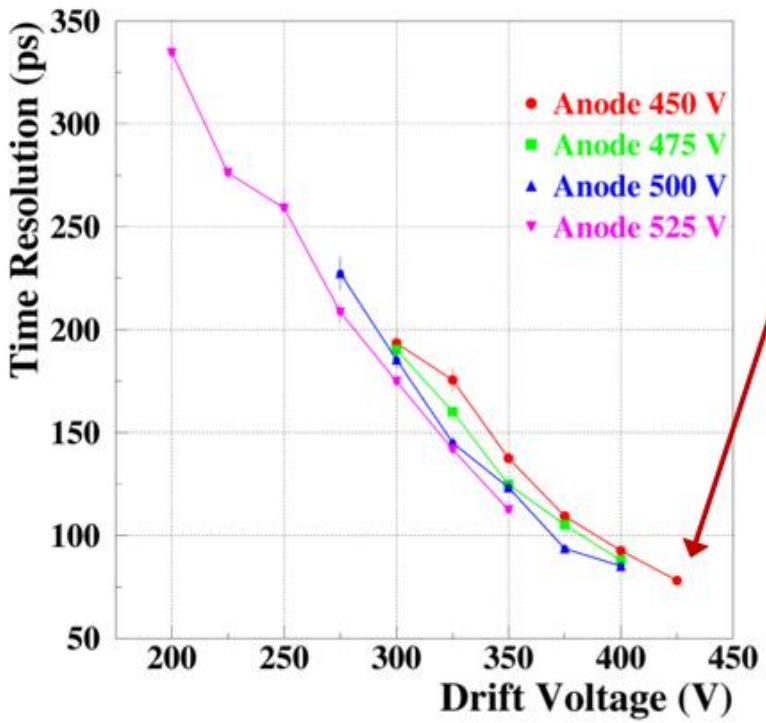
$T_{e\text{-}peak}$ Time (ns)

J.Bortfeldt et. al. (RD51-PICOSEC collaboration),"PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector", Nuclear. Inst. & Methods A 903 (2018) 317-325

Time the signal arrival with Constant Fraction Discrimination (CFD) on the fitted e-peak
(CFD @ 20% of the e-peak amplitude)

Talk by I. Manthos, "Signal processing techniques for precise timing with novel gaseous detectors"

Laser tests: time resolution for single p.e.



Best time resolution for **1 photo-electron**:
76.0 ± 0.4 ps @ Vd/Va = -425V / +450V

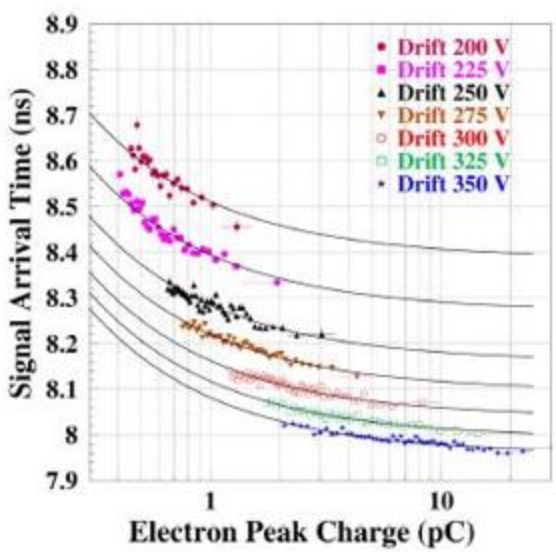
improves strongly with higher drift field, less with anode field

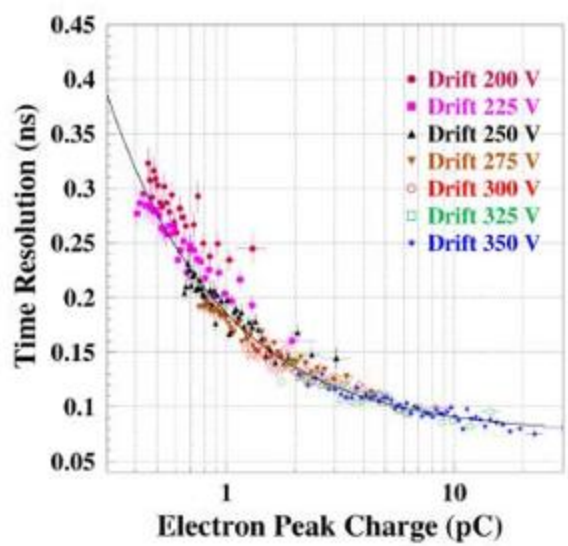
The Signal Arrival Time (SAT) depends on the e-peak charge:

- bigger pulses ➔ smaller SAT
- higher drift field ➔smaller SAT

Shape of pulse is identical in all cases ➔ timing with CFD method does not introduce dependence on pulse size

Responsible for this "slewing" of SAT: **physics of the detector**





Beam tests: muons @ CERN SPS

Beam tests with 150 GeV muons @ CERN SPS H4:

- ✓ timing measurements
- ✓ **photocathode quantum efficiency**

(number of photoelectrons per muon)

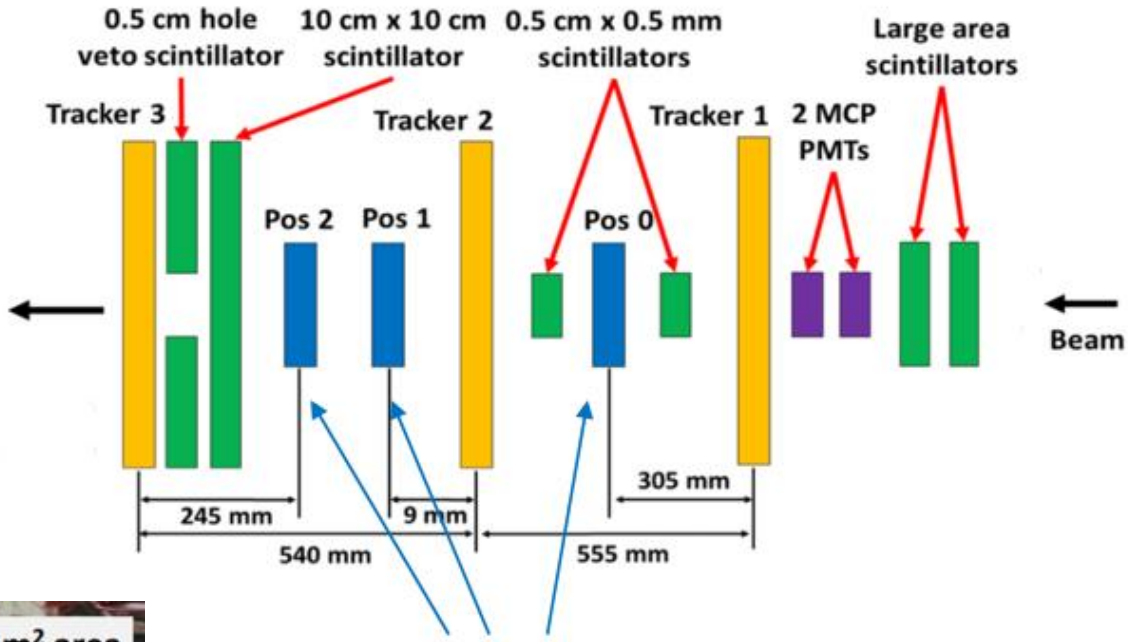
3 beam periods per year (2016 - 2018)

No beam for 2019/2020 !

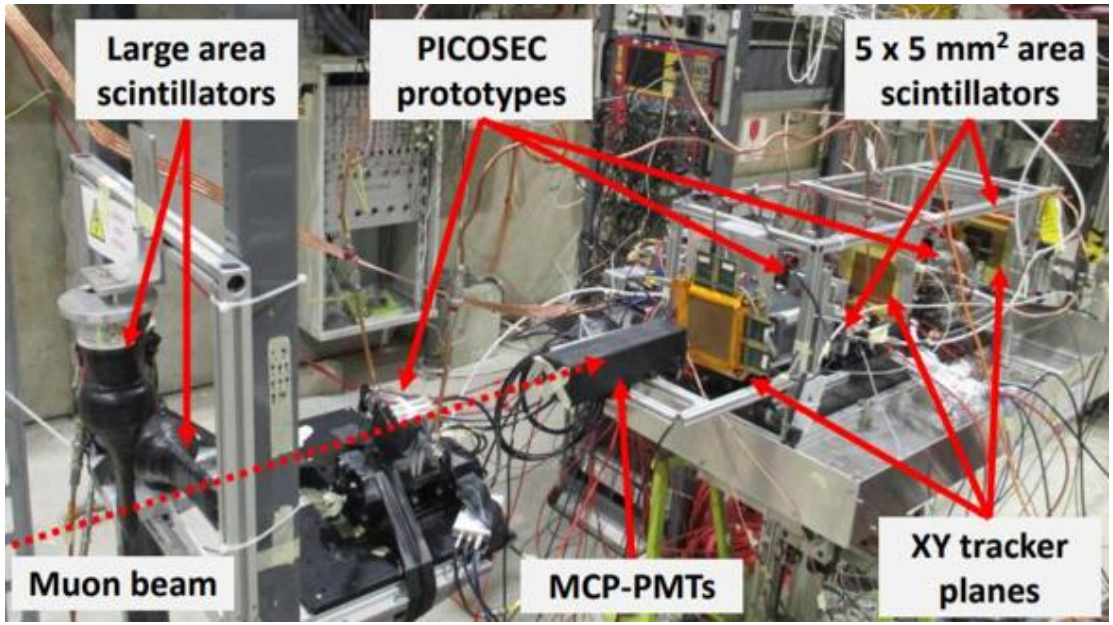
alternatives:

➔ *DESY, Frascati, PSI…*

➔ *Laboratory measurements: monochromators, UV lamps, cosmic bench*



PICOSEC Prototypes



Time reference: two MCP-PMTs (**<5 ps** resolution).

Scintillators: used to select tracks & to avoid showers.

Tracking system: 3 triple-GEMs (**40 μm** precision).

Electronics: CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

Beam tests: time resolution for MIPs

Same detector as for Laser tests:

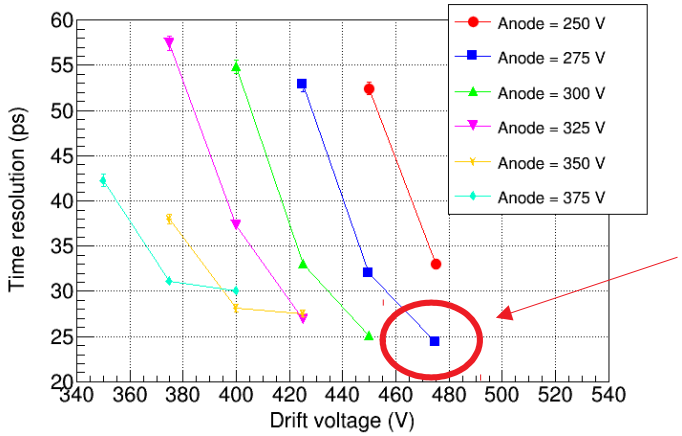
- MgF_2 radiator 3 mm thick
- 18 nm CsI on 5.5 nm Cr
- Bulk MicroMegas
- "COMPASS gas"

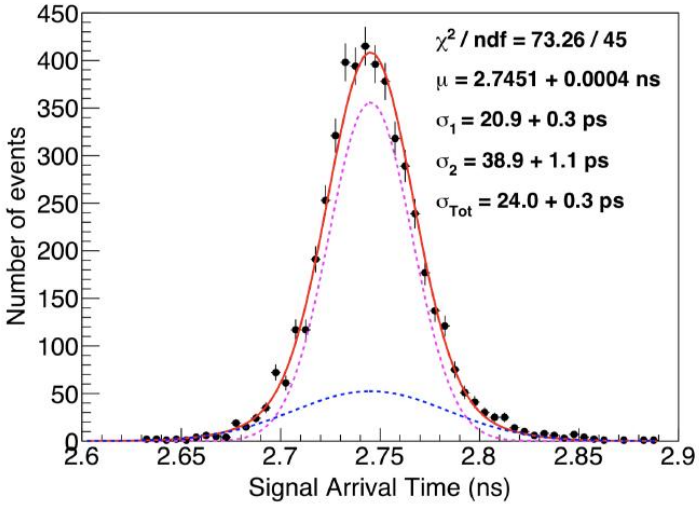
Optimum operation point: V_{drift}/V_{anode}: **-475V/+275V**

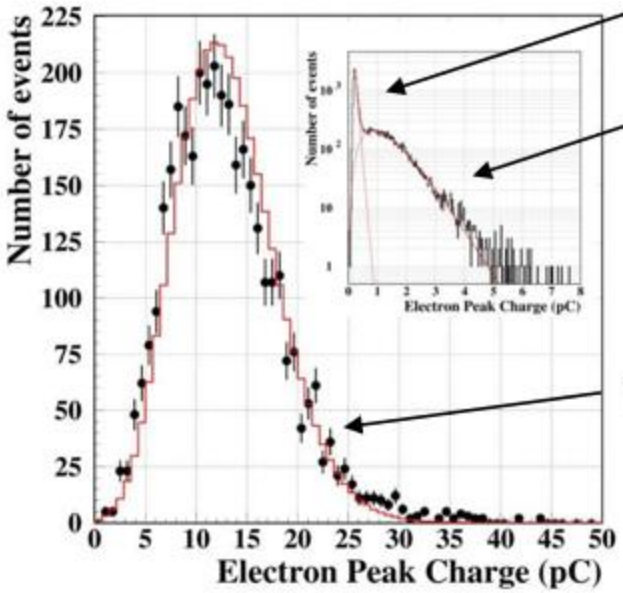
Best result: **24 ± 0.3 ps**

$N_{p.e.}$ = **10.1 ± 0.7**

Mean number of p.e. per muon produced in the CsI photocathode





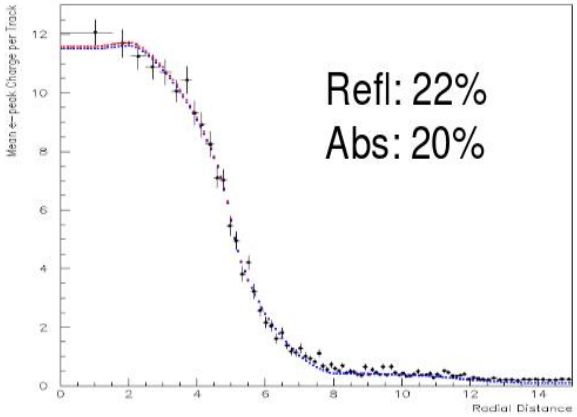


Noise component

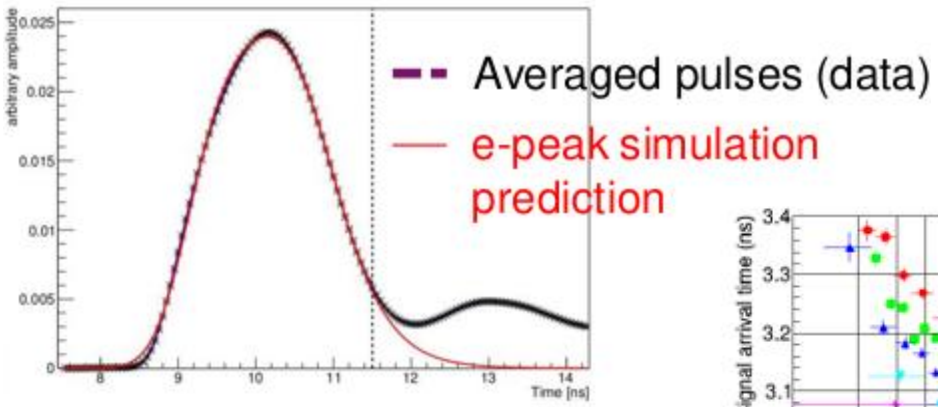
Signal for single p.e from UV-lamp tests: "Polya" (Gamma distribution)

Signal of MIPs

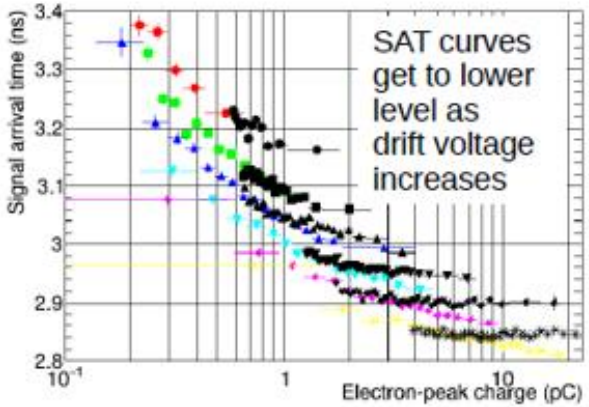
Convolution of Poisson, geometrical acceptance function and single p.e. response (Polya)

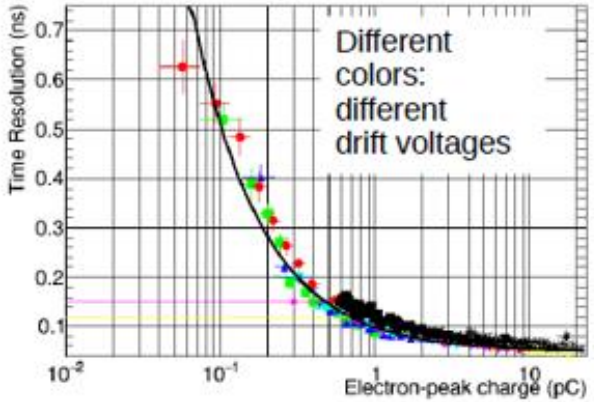


Modeling & simulation: thorough understanding of the detector



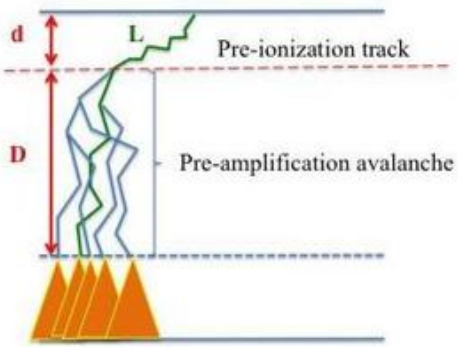
Detailed Garfield++ simulations reveal the same behaviors as seen in single p.e. laser data! (slide 14)



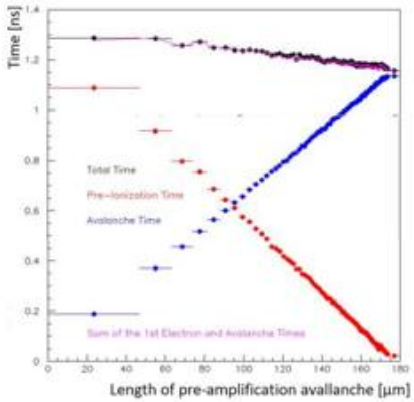


Phenomenological model describing stochastically the dynamics of the signal formation

https://arxiv.org/pdf/1901.10779.pdf

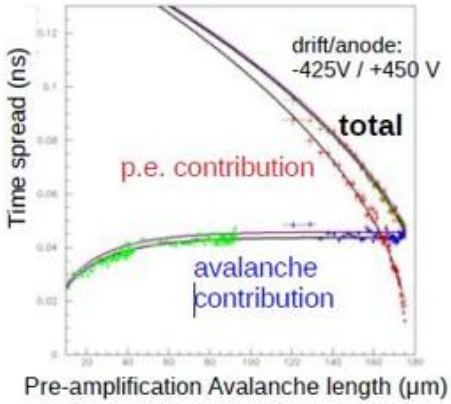


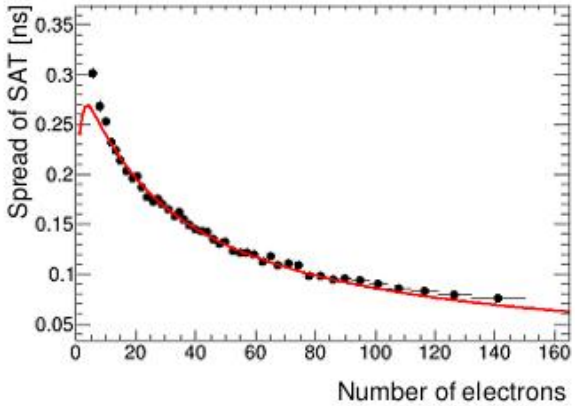
The model describes **SAT** and **Resolution** vs. **avalanche length** & vs. **number of electrons** in avalanche (i.e, e-peak charge)



Avalanche speed = 154 µm/ns

Electron speed = 134 µm/ns

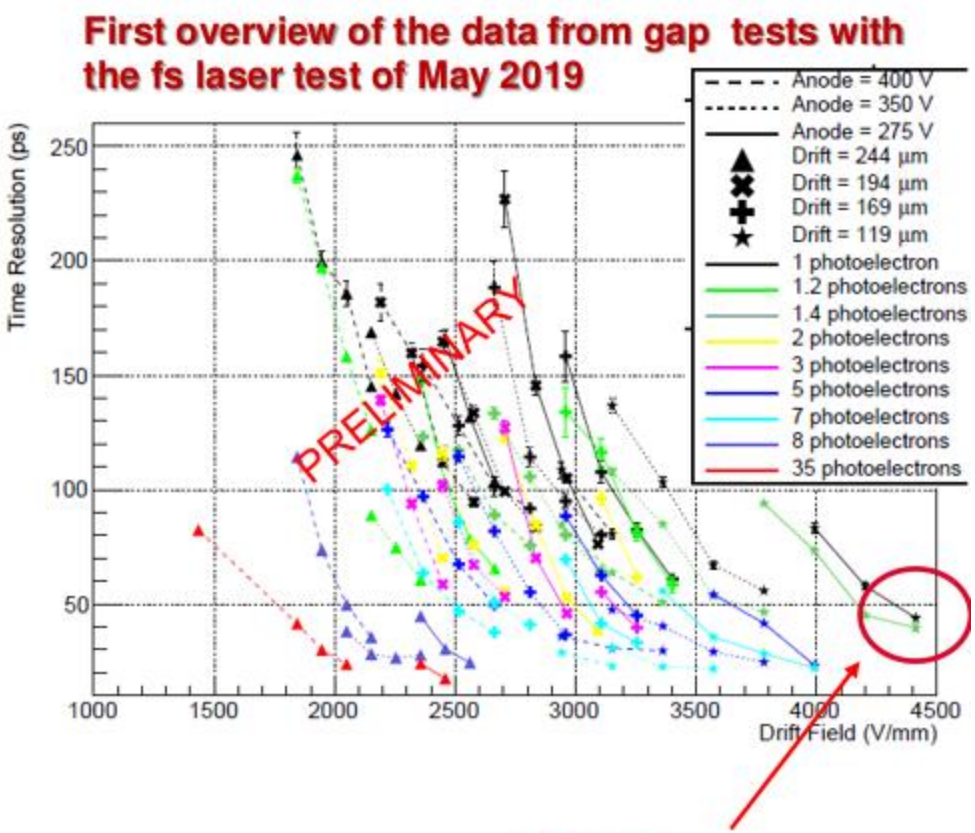




Time spread of SAT defined by the avalanche length = avalanche size

J. Bortfeldt et al., "*Modeling the Timing Characteristics of the PICOSEC Micromegas Detector*", NIM-A, https://doi.org/10.1016/j.nima.2021.165049

Model driven optimization of the detector



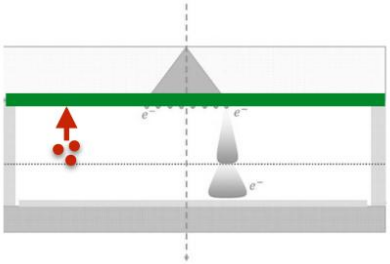
Time resolution < 50 ps is observed for single photoelectrons !!!

- **Drift gap:** The majority of the tests was done with **200 µm** gap. Reducing it is expected to **improve avalanche size and stability**. *Tests were performed in May 2019 at the fs laser* for gaps of **120**, **170** , **195** and **245 µm**
- **Gas composition**. CF_4 is increasing drift velocity, however is decreasing the maximum gain. **Ne or He mixtures with only C_2H_6 as quencher** are expected to increase maximum gain
- Gas pressure: decreasing pressure is equivalent with decreasing the amplification gaps.

CsI photocathode: performance and limitations

Best time resolution with CsI, although it is sensitive to humidity, can be damaged from sparks and high ion backflow (>25% for high drift fields)

Ongoing R&D in two directions:



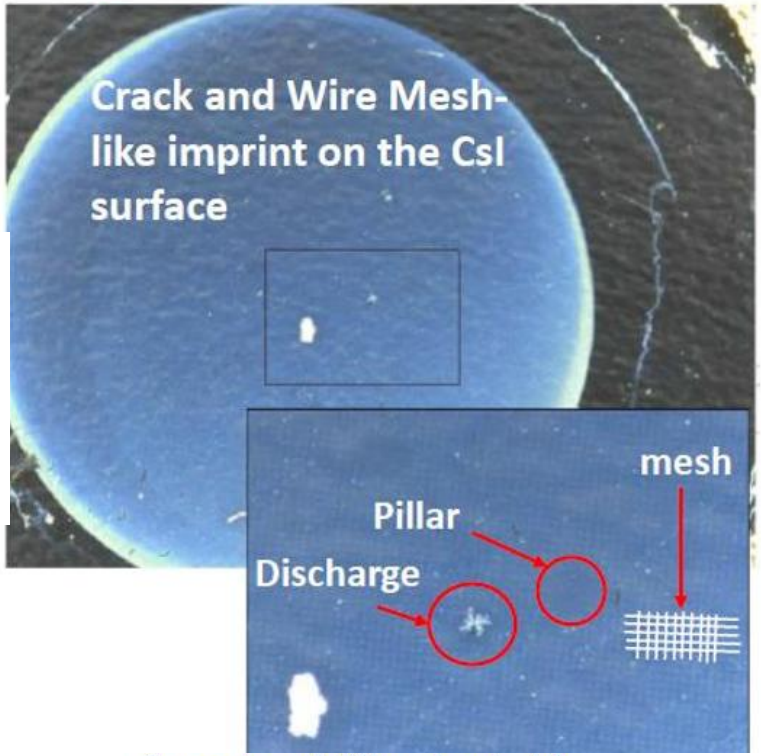
Use protective coatings:

- Protection layers (LiF, MgF_2,...)
- New detector design (e.g. double mesh Micromegas)

Investigate alternative photocathodes and/or combination of material/thickness (evaluate QE vs robustness):

- pure metallic (Cr, Al, ..)
- DLC (Diamond Like Carbon)
- B_4C (Boron Carbide)

A typical CsI photocathode used in a test beam

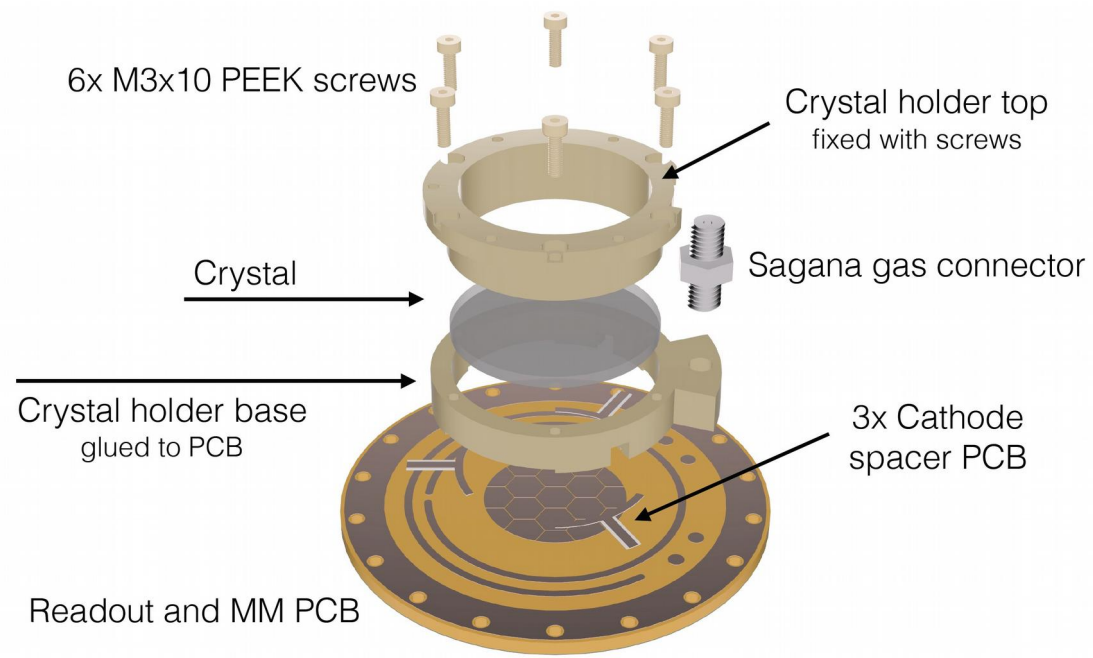


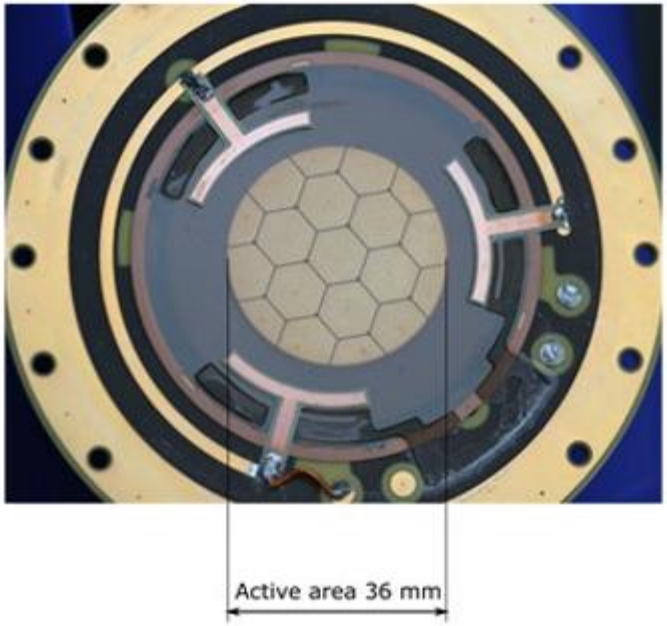
Comparison of different materials

MgF_2	Substrate	Nphe	Res (ps)	Opt. A/D
3 mm	5.5 nm Cr +18 nm CsI	10.4 ± 0.4	24.0 ± 0.3	+275/-475
3 mm	20 nm Cr	0.66 ± 0.13	189.4 ± 5.3	+425/-425
3 mm	6 nm Al	1.69 ± 0.01	71.4 ± 1.8	+275/-525
5 mm	10 nm Al	2.20 ± 0.05	57.6 ± 0.6	+275/-600

First Multipad PICOSEC prototype

The first multipad PICOSEC

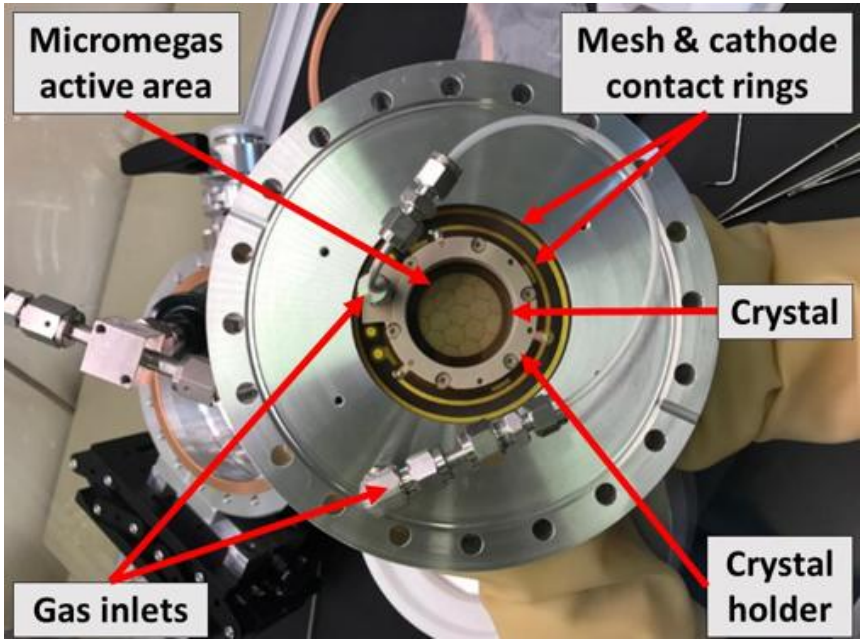




Similar detector configuration as for single pad:

- MgF_2 radiator 3 mm thick,
- 18 nm CsI on 5 nm Cr
- Bulk MicroMegas
- "COMPASS gas"
- 200 μm drift gap

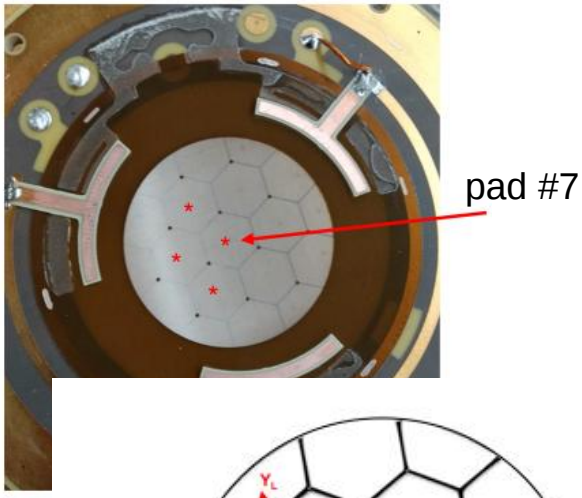
Optimum operation point: V_{drift}/V_{anode}: **-475V/+275V**

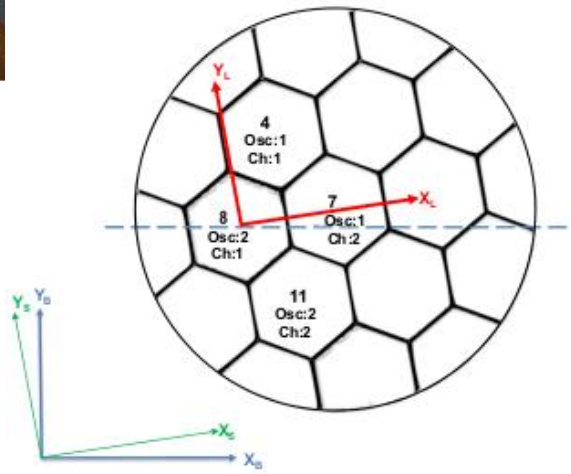


Individual pad response vs distance R

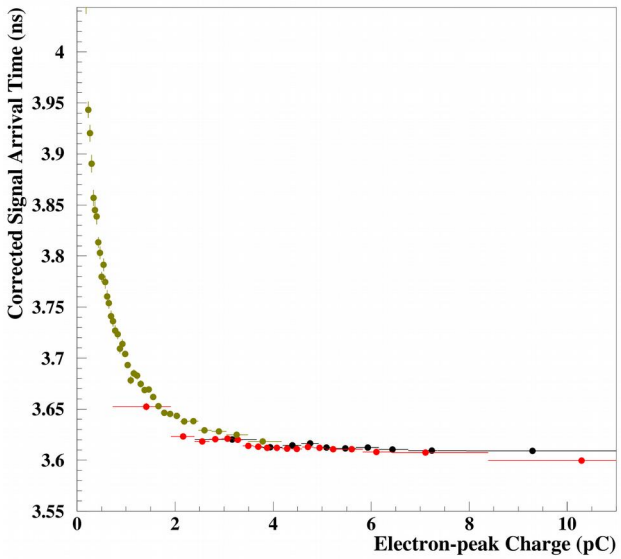
timing resolution for pad #7

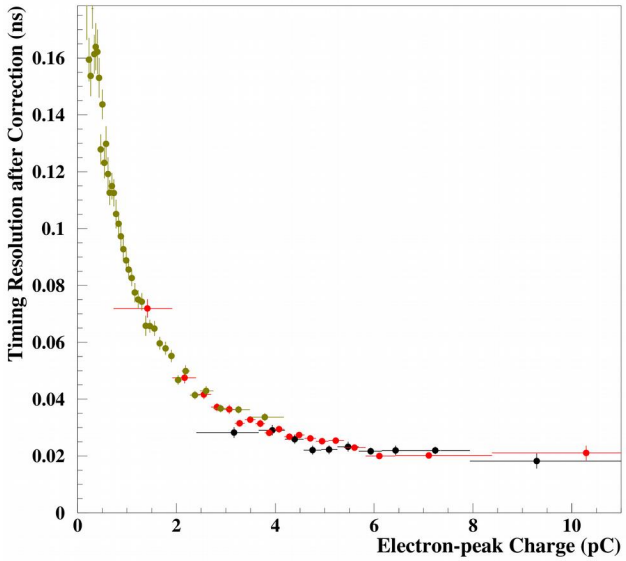
19 hexagonal pads 5mm side





SAT for pad #7





R: distance from pad center.

0 < R < 2mm: full Cherenkov cone (3mm) inside a single pad surface

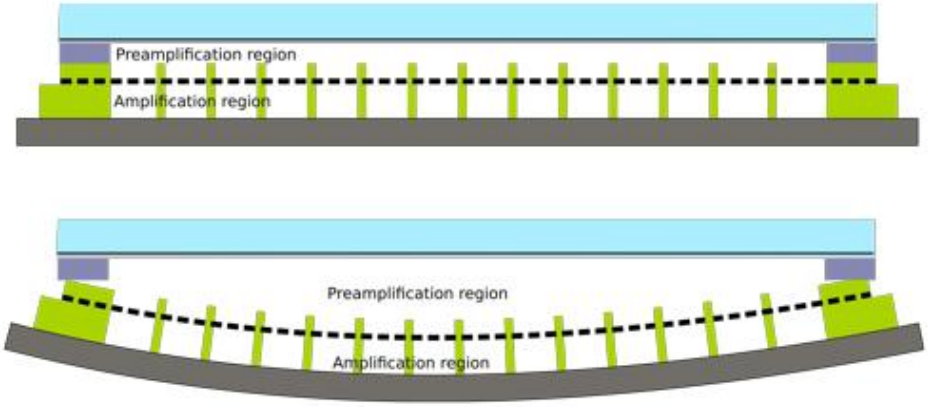
2 mm < R < 4.33 mm

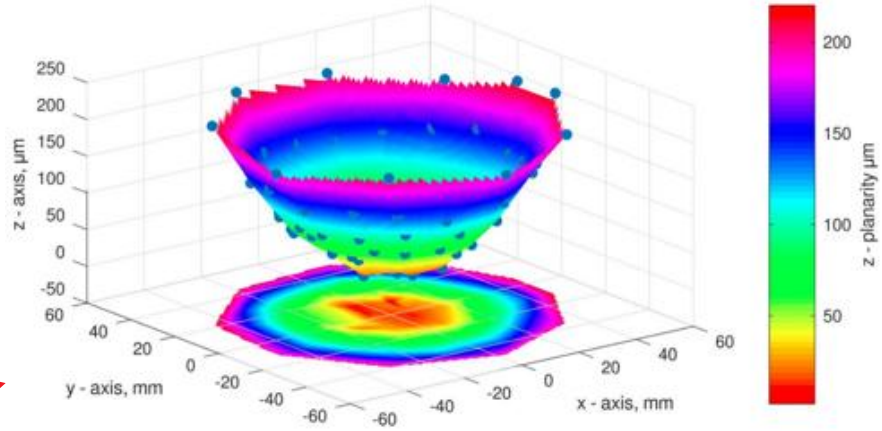
4.33 mm < R < 7.5mm: full Cherenkov cone (3mm) mostly outside a single pad

Time resolution for each individual pad worsens as R increases!

First multipad PICOSEC: unforeseen deformation

A. Utrobicic

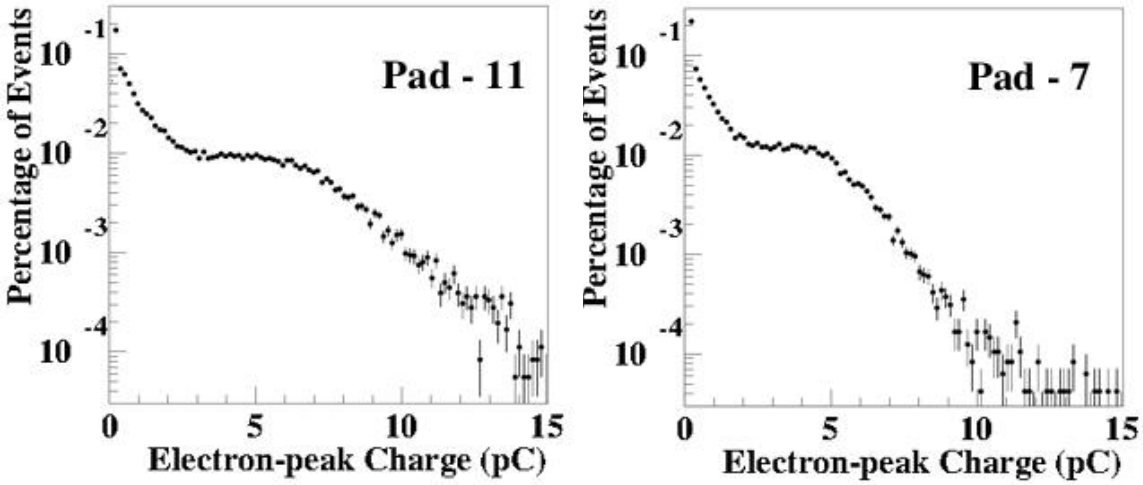




ZEISS O-INSPECT 863 – CERN Metrology service

- Timing performance revealed anode deformation (confirmed later by an optical device measurement)
- Drift gap non uniformity → spatial variation of the detector gain
- Direct impact on the timing performance between pads
- Corrections applied, restored a uniform timing response over all detector active area

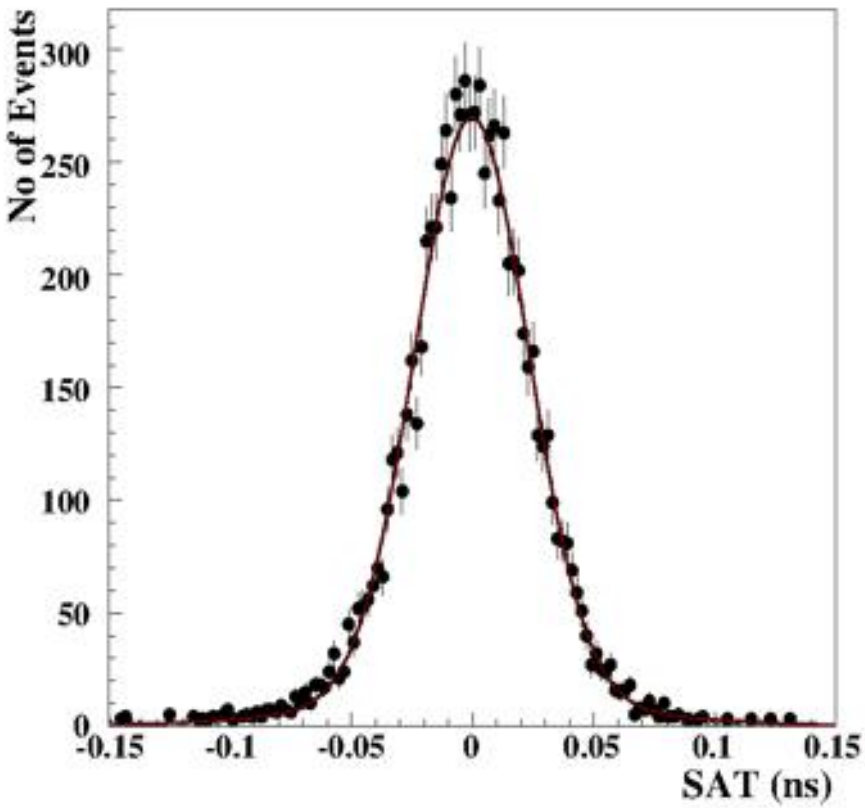
evident lower gain

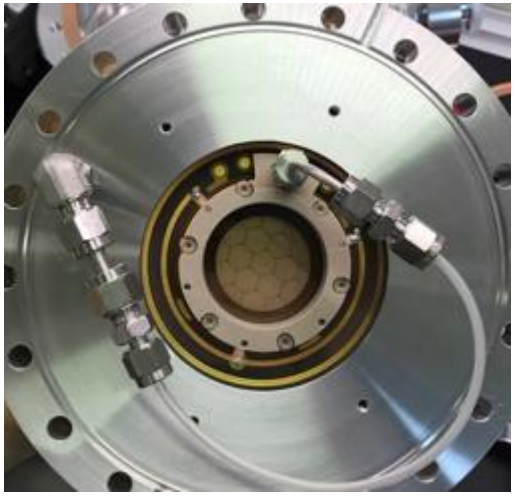


Timing performance of a multi-pad PICOSEC-Micromegas detector prototype, NIM A 933 – 2021

Global time resolution

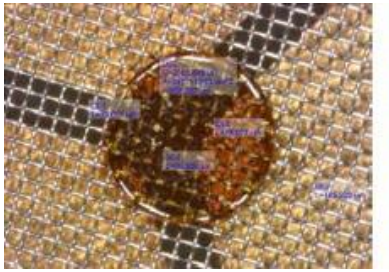
Distribution of fully corrected arrival time measurements of all pad signals induced by MIPs passing within 2 mm from the respective pad center.

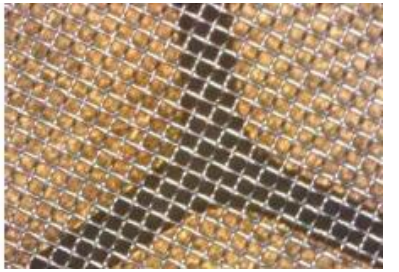




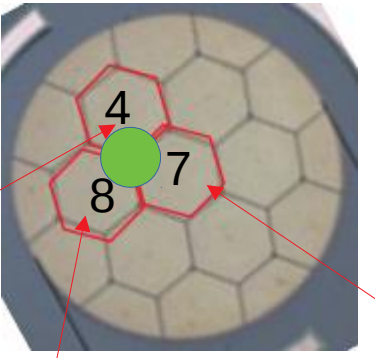
The solid line represent a double Gaussian fit to the data points with an RMS of ***25.8 ± 0.6 ps****.*

Combined pads timing resolution (I)

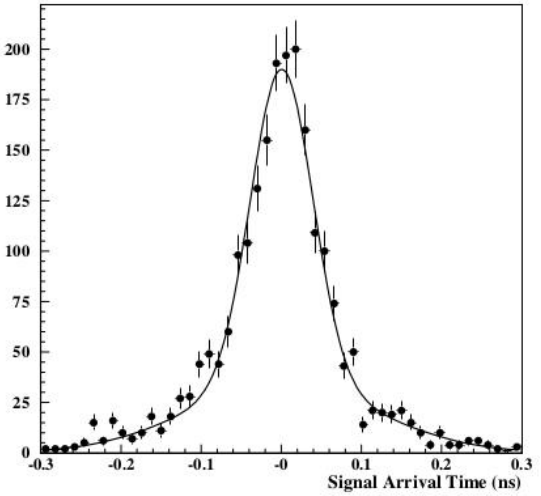




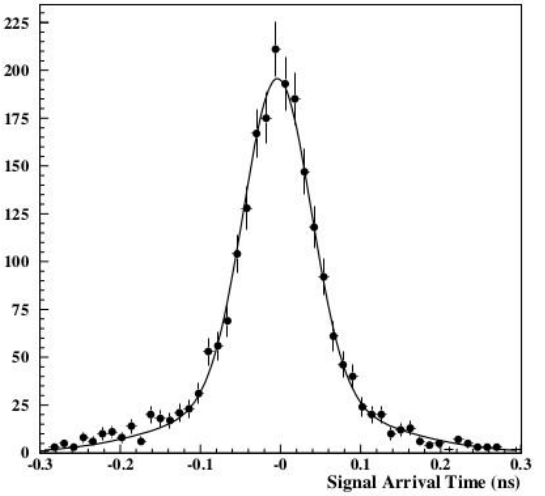
MIPs producing Cherenkov ring **equally** shared among neighboring pads!



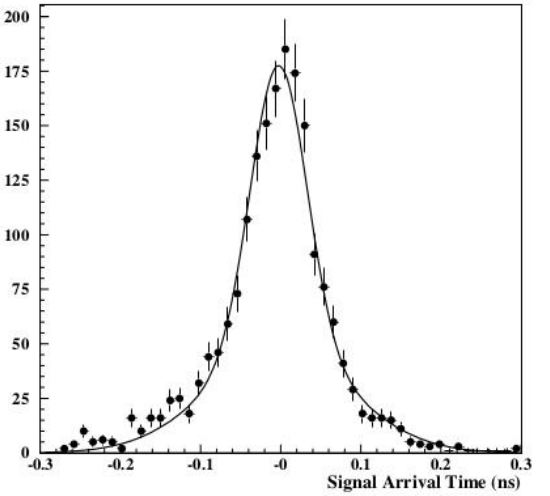
pad #4: 71.3±2.5 ps



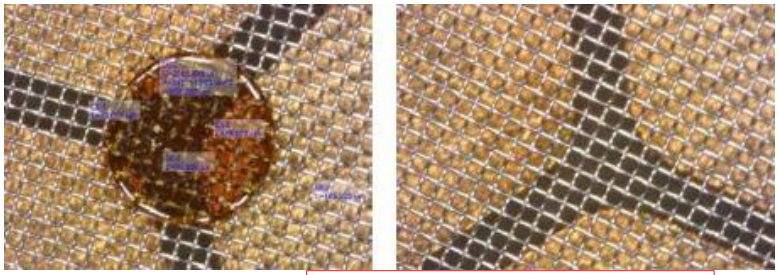
pad #8: 68.0±2.5 ps



pad #7: 66.2±2.5 ps

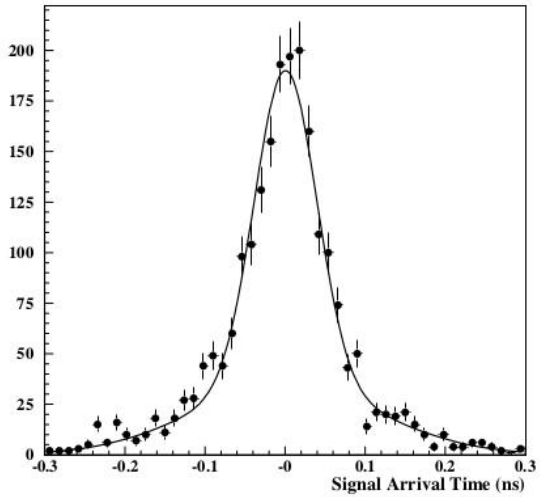


Combined pads timing resolution (II)

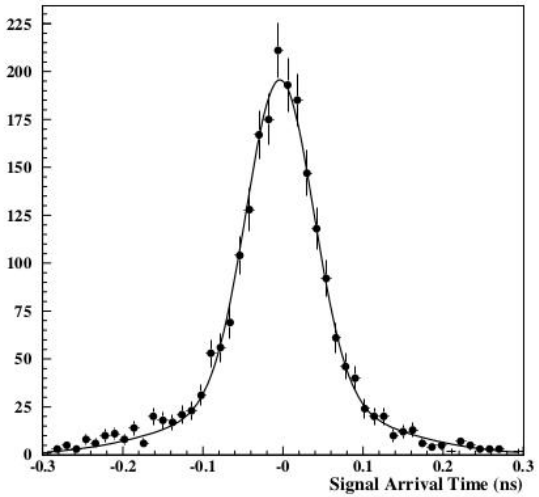


MIPs producing Cherenkov ring **equally** shared among neighboring pads!

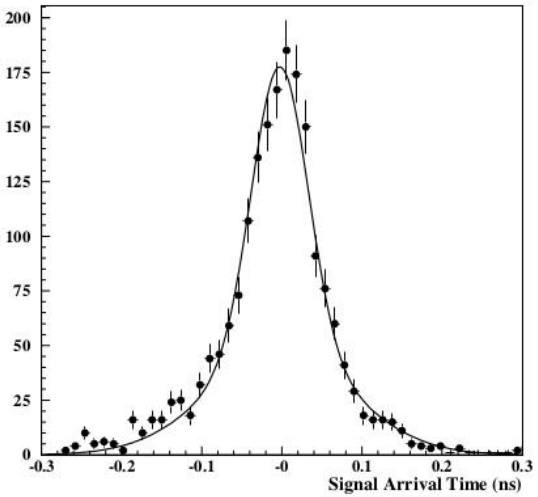
pad #4: 71.3±2.5 ps



pad #7: 66.5±2.5 ps



pad #8: 68.0±2.5 ps



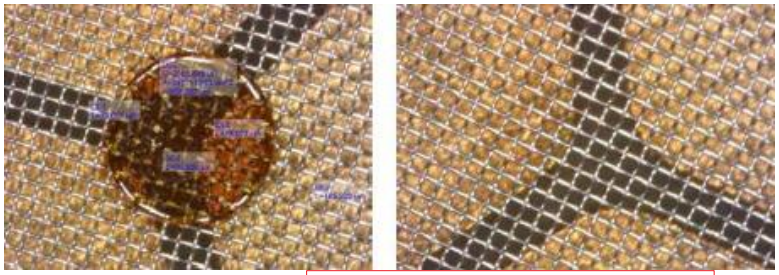
SAT and time resolution dependence known via $\tau(Q_e^m)$ and $\sigma(Q_e^m)$

$$\chi^2 = \sum_{m=1,M} \frac{\left(T_{comb.} - \left[T^m_{f-corr.} - \tau\left(Q^m_e\right)\right]\right)^2}{\sigma^2\left(Q^m_e\right)}$$

$$\hat{T}_{comb.} = \frac{\sum_{m=1,M} \frac{\left(T^m_{f-corr.} - \tau\left(Q^m_e\right)\right)^2}{\sigma^2\left(Q^m_e\right)}}{\sum_{m=1,M} \frac{1}{\sigma^2\left(Q^m_e\right)}}$$

...obtain an estimation of the MIP arrival time

Combined pads timing resolution (II)

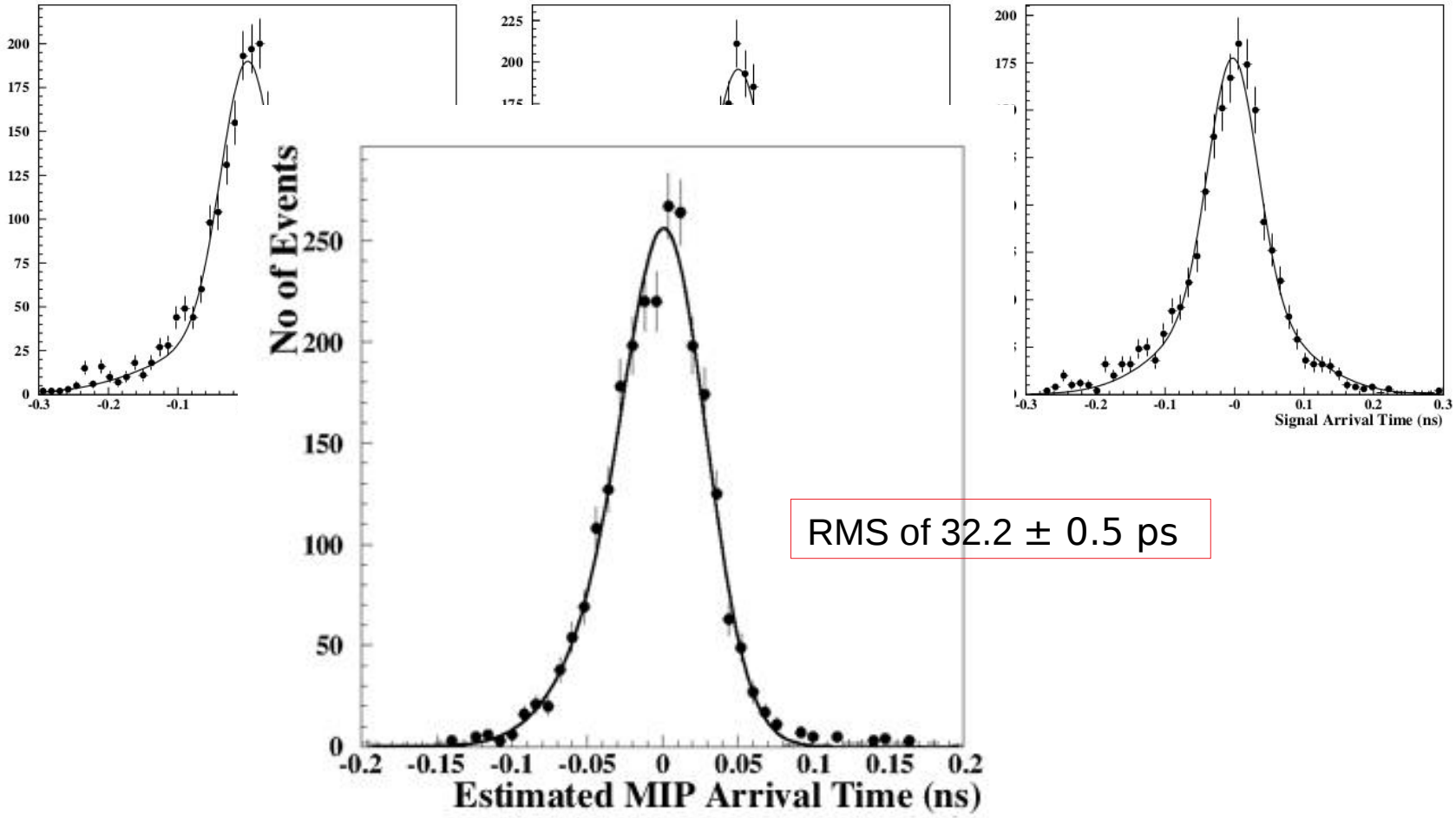


MIPs producing Cherenkov ring **equally** shared among neighboring pads!

pad #4: 71.3±2.5 ps

pad #7: 66.5±2.5 ps

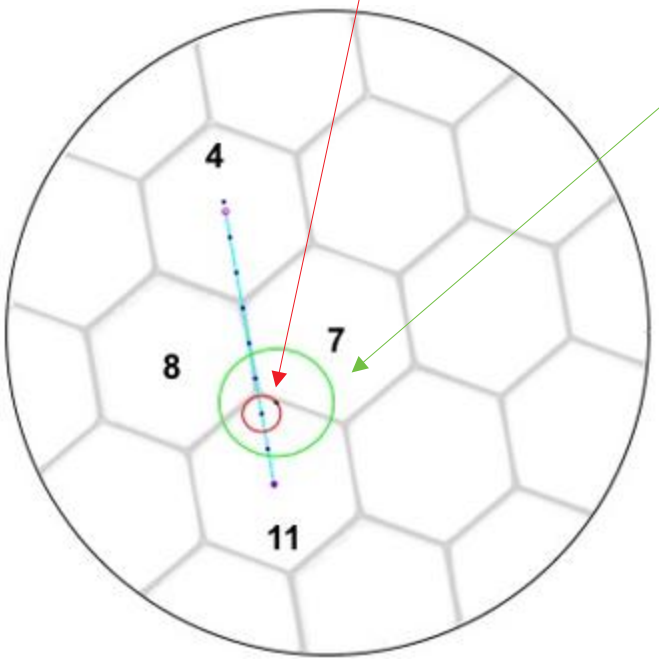
pad #8: 68.0±2.5 ps



RMS of 32.2 ± 0.5 ps

Combined pads timing resolution (III)

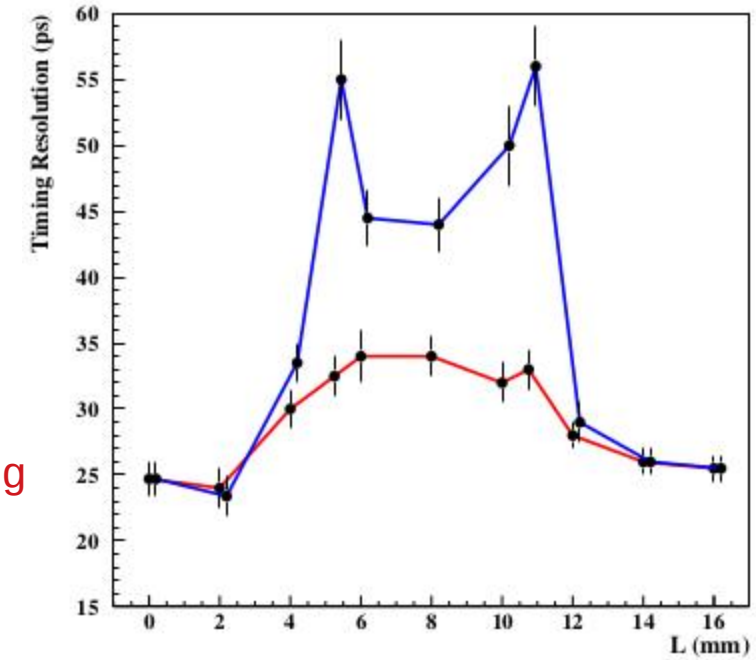
MIPs within a 1 mm radius around sampling points



Cherenkov ring for a MIP passing at the edge of the 1mm sampling point

best single pad timing performance

combined timing resolution



Timing resolution along a ‘path’ from pad #11 towards pad#4

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 993, 21 March 2021, 165076

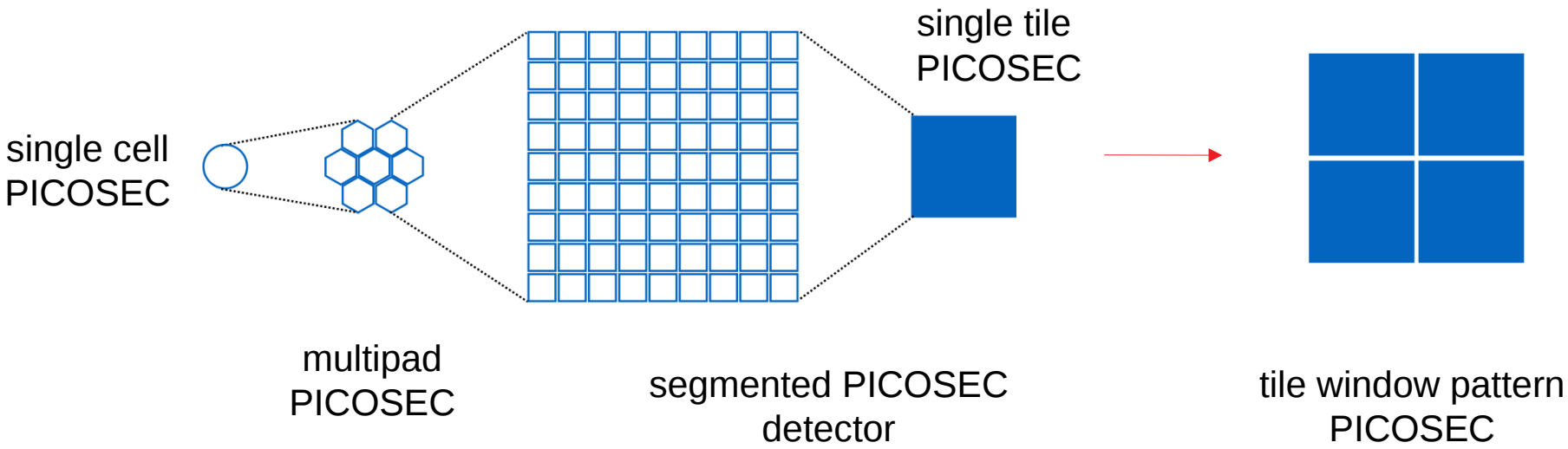
Timing performance of a multi-pad PICOSEC-Micromegas detector prototype

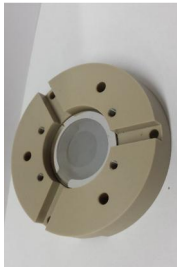
S. Aune [a], J. Bortfeldt [b], F. Brunbauer [b], C. David [b], D. Desforge [a], G. Fanourakis [f], M. Gallinaro [h], F. Garcia [i], I. Giomataris [a], T. Gustavsson [j], F.J. Iguaz [a], M. Kebbiri [a], K. Kordas [d, e], C. Lampoudis [d, e], P. Legou [a], M. Lisowska [b], J. Liu [c], M. Lupberger [b, 1] ... Y. Zhou [c]

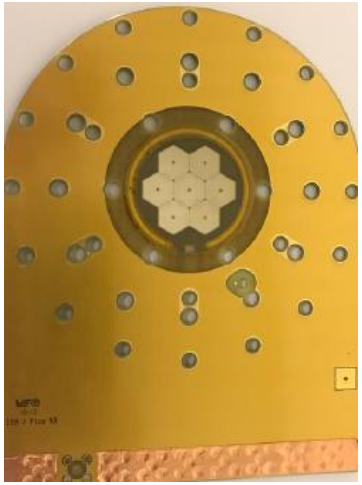
https://doi.org/10.1016/j.nima.2021.165076

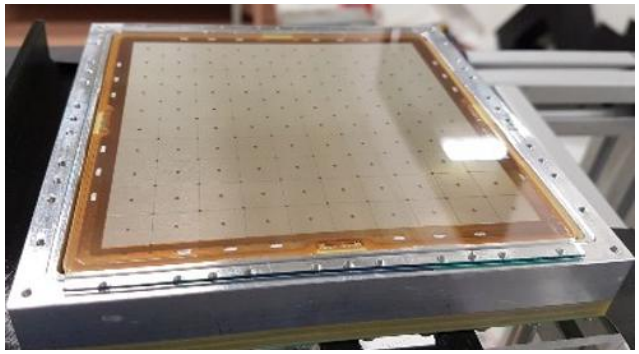
The updated multipad PICOSEC detector

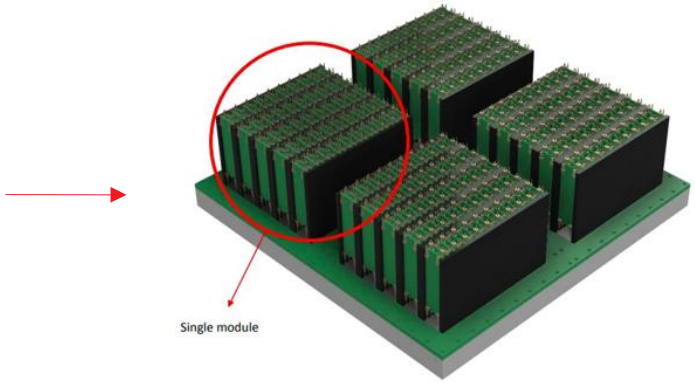
Towards large area coverage: modular design









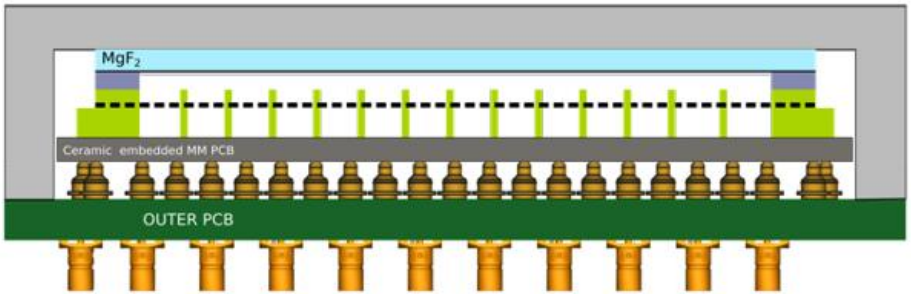


Schematics/photos not to scale

(Florian M. Brunbauer, EP R&D Seminar, May 3, 2021)

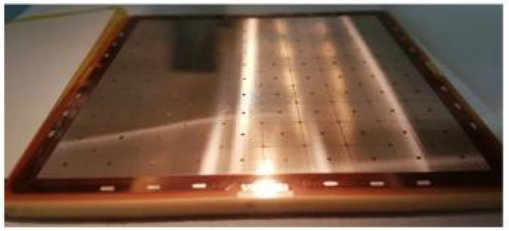
New multipad PICOSEC: realization

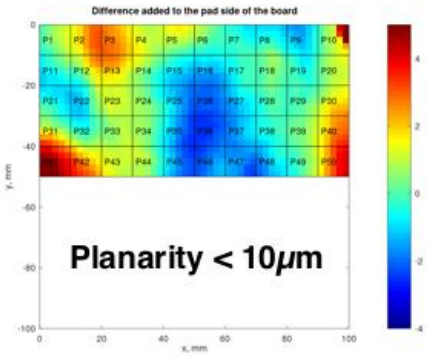
Cross-section



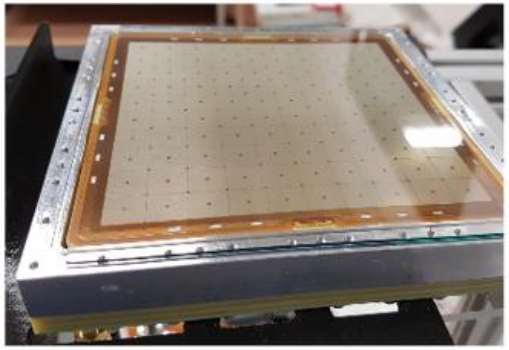
New design:
- larger surface
- mosaic-type of 1 cm side pads
- thick, ceramic PCB for improved rigidity

Bulk Micromegas on ceramic PCB

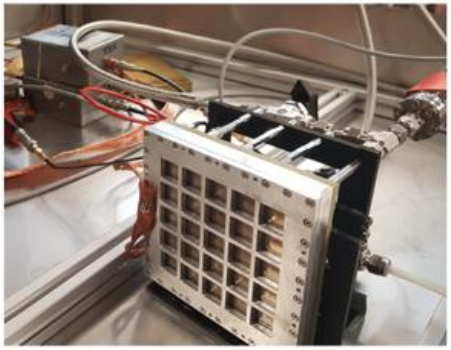




Assembled in housing



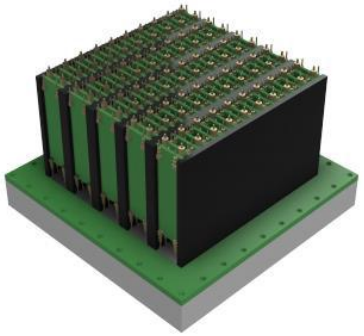
Lab test



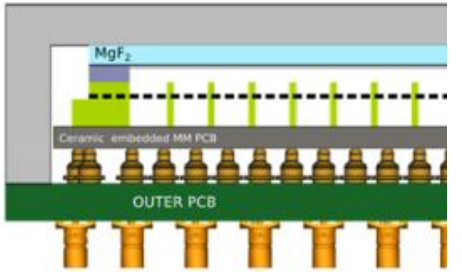
Facts and Considerations
- larger area: demand to maintain a uniform pre-amplification gap (~10μm flatness of anode for a surface of several cm^2)
- Segmented anode (total of 10 x 10 cm^2)
- Mechanical tension due to stretched mesh (~14N/cm), stress caused by mounting the PCB to the detector housing

(Antonija Utrobicic, RD51 Collaboration Meeting, February 16, 2021)

Alternative method for a flat(er) anode

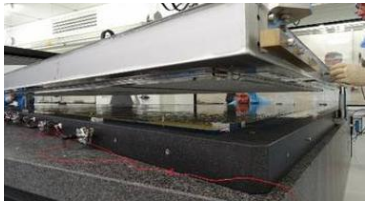


Micromegas made on a hybrid ceramic PCB, completely enclosed in the chamber.
100 channels prototype (10 × 10 cm^2) ready @ CERN

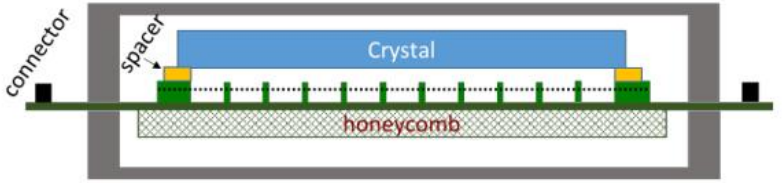


The ATLAS New Small Wheel panel construction principle: bulk Micromegas on a thin PCB, backed on a Alu honeycomb,and glued on super flat surface (vacuum or marble table, with flatness <10 μm)

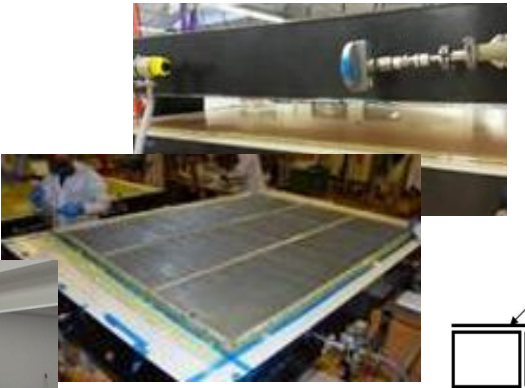
granite table + stiffback technique



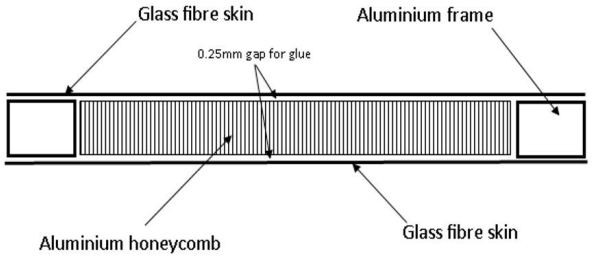
(Thomas Papaevangelou, IRFU - FCC meeting, January 2021)



schematic of the honeycomb-stiffened PICOSEC detector



vacuum table technique



construction principle

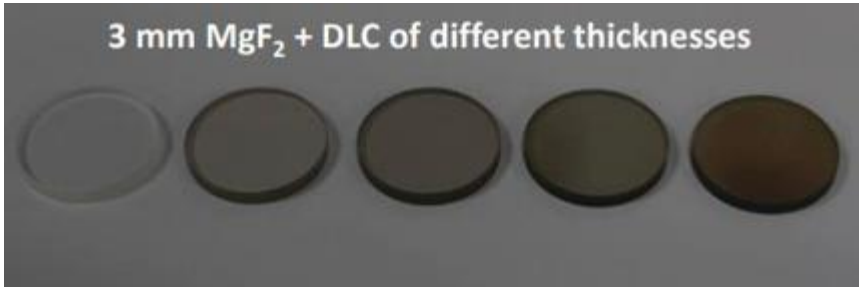
Talk by I. Maniatis, “Construction and operation of large scale Micromegas detectors for the ATLAS Muon upgrade”

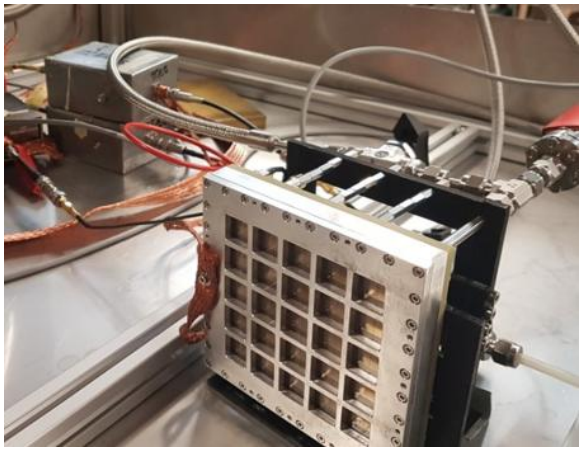
PICOSEC in beam

Test beam period allocated for July and October 2021

Availability: **Muons** (and **electrons** for limited time)

Objective:
- validate the new 100 channel multipad detector and additional PICOSEC prototypes
- test robustness of DLC and B_4C photocathodes candidates
- test of electronics (SAMPIC digitizer, Philippe Legou – CEA Saclay)





(Antonija Utrobicic, RD51 Collaboration Meeting, February 19, 2021)

Conclusions

Summary I

- ✓ Coupling a Micromegas detector with a radiator/photocathode we have <u>surpassed the physical constraints</u> on precise timing with MPGDs, achieving:

  σ_t ~ 76 ps for single p.e. → improved to 44 ps (published)

  σ_t ~ 24 ps for 150 GeV muons (published) (3 mm MgF_2+5.5 nm Cr subtrate+18 nm CsI photochathode), $\langle N_{p.e.} \rangle \simeq 11$

- ✓ Deep understanding of the PICOSEC detector: reproduce results with detailed simulation, apply the phenomenoligal model to explain the observed experimental behavior and use it to optimize parameters

- ✓ Confirmed Multipad PICOSEC timing precision **(published)** brings confidence for modular/large scale installation

- ✓ Critical role of tight mechanical tolerances on the depth of the drift/preamplification stage

Summary II

Status and scheduled actions:

- Commissioning and testing the new segmented PICOSEC (anode on a ceramic PCB)
- Test BLC & B_4C photocathodes on MIP beams to evaluate Q.E. and robustness
- Further optimization is expected to deliver improved precision per MIP

Contributions

The **RD51 – PICOSEC** Collaboration

CEA Saclay (France): S.Aune, D. Desforge, I. Giomataris, T. Gustavsson, C. Guyot, F.J. Iguaz[1], M. Kebbiri, P. Legou, O. Maillard, T. Papaevangelou, M. Pomorski, P. Schwemling, L. Sohl.

CERN (Switzerland): F. Brunbauer, C. David, M. Lisowska, M. Lupberger[(1)], H. Muller[(2)], E. Oliveri, F. Resnati, L. Ropelewski, L. Scharenberg, T. Schneider, M. van Stenis, A. Utrobicic, R. Veenhof[(3)], S. White.

USTC (China): J. Liu, B. Qi, X. Wang, Z. Zhang, Y. Zhou.

AUTH (Greece): G. Angelis, K. Kordas, C. Lampoudis, I. Manthos, K. Paraschou, D. Sampsonidis, a. Tsiamis and S.E. Tzamarias.

NCSR (Greece): G. Fanourakis.

NTUA (Greece): Y. Tsipolitis.

LIP (Portugal): M. Gallinaro.

HIP (Finland): F. García.

IGFAE (Spain): D. González-Díaz.

(1) Now at University of Bonn, D-53115 Bonn, Germany.

(2) Also University of Bonn, D-53115 Bonn, Germany

(3) Also at National Research Nuclear University MEPhI, Kashirskoe Highway 31, Moscow,Russia; and Department of Physics, Uluda University, 16059 Bursa,Turkey

Thank you!

References: publications

- Y. Giomataris, P. Rebourgeard, J. Robert, G. Charpak, MICROMEGAS: A high granularity position sensitive gaseous detector for high particle flux environments, Nucl. Instrum. Meth. A 376 (1996) 29–35

- Y. Giomataris, et al., Micromegas in a bulk, Nucl. Instrum. Meth. A 560 (2006) 405–408.

- J. Bortfeldt, et al. for the RD-51 PICOSEC Collaboration, PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector, Nucl. Instrum. Meth. A 903 (2018) 317–325.

- J. Bortfeldt et al., Modeling the Timing Characteristics of the PICOSEC Micromegas Detector, Nucl. Instrum. Meth. A 933, 2021 (https://doi.org/10.1016/j.nima.2021.165049)

- S. Aune et al., Timing performance of a multi-pad PICOSEC-Micromegas detector prototype, Nucl. Instrum. Meth. A 933, 165076, 2021, (https://doi.org/10.1016/j.nima.2021.165076)

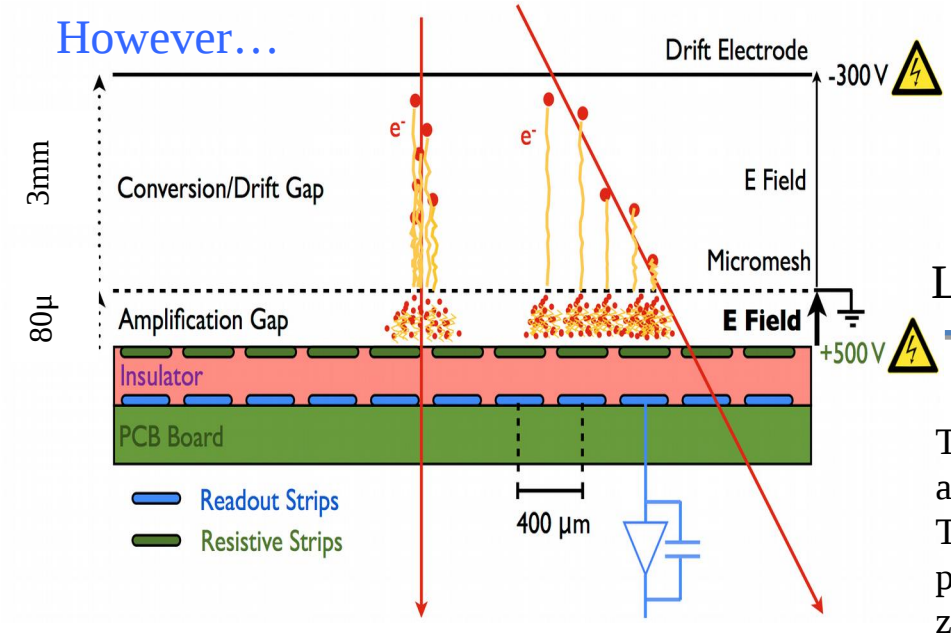
References: selected proceedings and talks

- S.E. Tzamarias, RD51 Open Lectures and Mini Week, 2017, (https://indico.cern.ch/event/676702/timetable/)
- K. Paraschou, Study of the PICOSEC Micromegas Detector with Test Beam Data and Phenomenological Modelling of its Response (2018), arXiv:2010.13535
- The RD51 PICOSEC-Micromegas Collaboration, Letter Of Interest, SnowMass2021 IF5, August 2020
- Manthos I., et al., for the RD-51 PICOSEC Collaboration, Recent developments on precise timing with the picosec micromegas detector, Journal of Physics: Conference Series (2020), Article 012014, 10.1088/1742-6596/1498/1/012014
- A. Utrobicic, Assembly and gain uniformity measurements of a new large area PICOSEC detector, RD51 Collaboration Meeting, February 16, 2021
- Florian M. Brunbauer, Precice timing with gaseous detectors: towards a robust and tileable PICOSEC Micromegas detectors, EP R&D Seminar, May 3, 2021
- Sohl L., Ph.D. thesis, Development of PICOSEC-Micromegas for fast timing in high rate environments, CEA Saclay 17/12/2020, https://lsohl.web.cern.ch/lsohl/

few extras

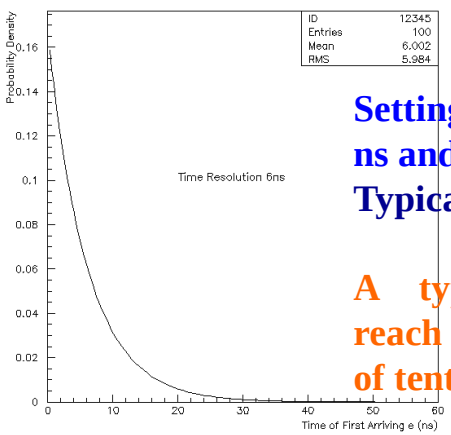
Limitations: reminder

However…



Using the drift velocity (V), we express the probability that the first electrons will reach the anode at ti

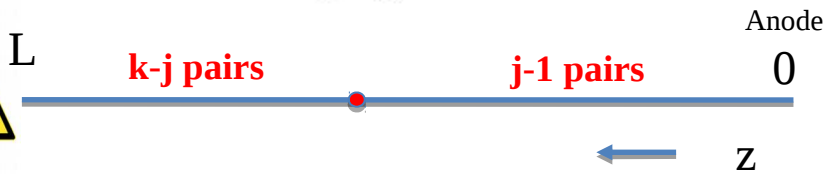
$$A^n_{first}(t) = n(V/L)e^{-nVt/L}$$



Setting typical values, i.e. V=50µm/ns and n=10 we conclude that: Typical Time Resolution ~6ns

A typical MicroMegas cannot reach timing resolution at the level of tenths of ps

$$P^n_k = \frac{n^k}{k!} e^{-n}$$



The probability that an e-ion pair has been produced at Z=z is the same for any value of Z; **p=1/L**

Then, in case that k pairs are produced, the probability that the jth pair has been produced at Z= z is given by the binomial distribution

$$D^k_j(x) = \frac{k!}{(k-j)!(j-1)!}(1-x)^{k-j}x^{j-1}$$

where **x=z/L describes the probability that a pair is produced in the region 0-z**

The probability that the jth pair has been produced at Z= z for any total number of e-ion pair

$$A^n_j(x) = \sum_{k=j}^{\infty} P^n_k D^k_j(x) = \frac{x^{j-1}}{(j-1)!} n^j e^{-nx}$$

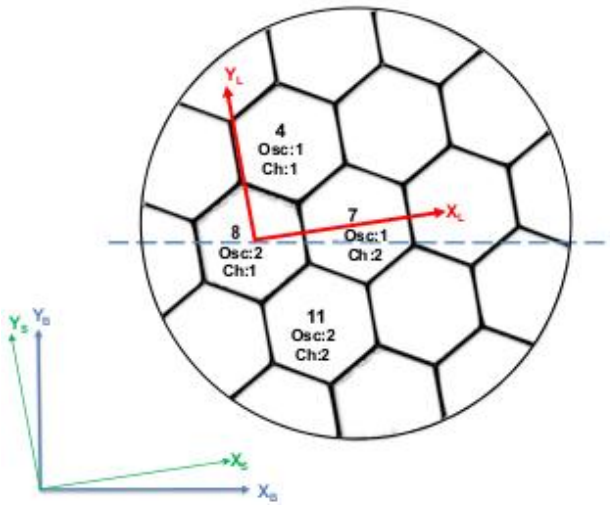
The probability that the last pair (i.e. the closest to the edge 0) has been produced at Z= z is given by (j-1=0):

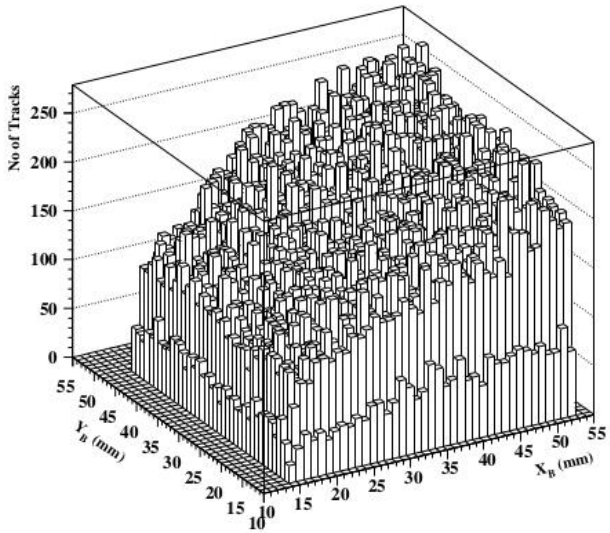
$$A^n_{last}(x) = ne^{-nx}$$

$$A^n_{last}(z) = ne^{-nz/L}$$

Detector alignment: estimating pad centers positions

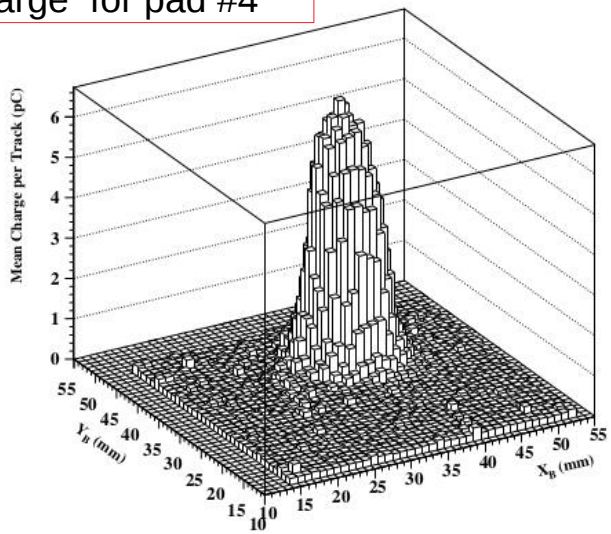
The exact position of each participating pad is needed in order to calculate the combined time resolution



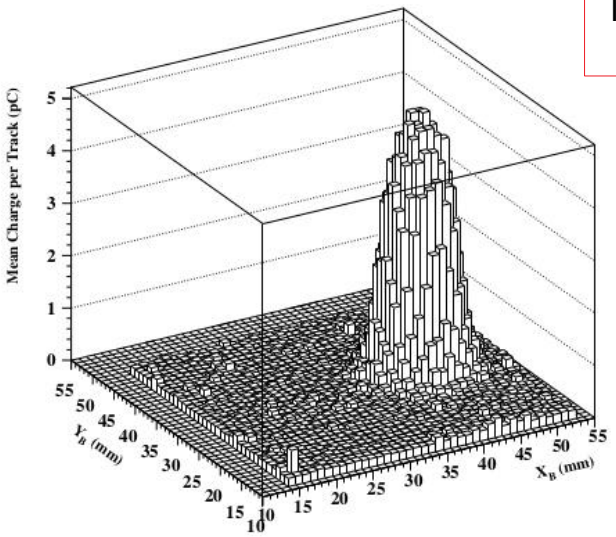


The part of the beam profile that illuminated the area covering all PICOSEC instrumented pads

Mean value of the electron-peak charge for pad #4

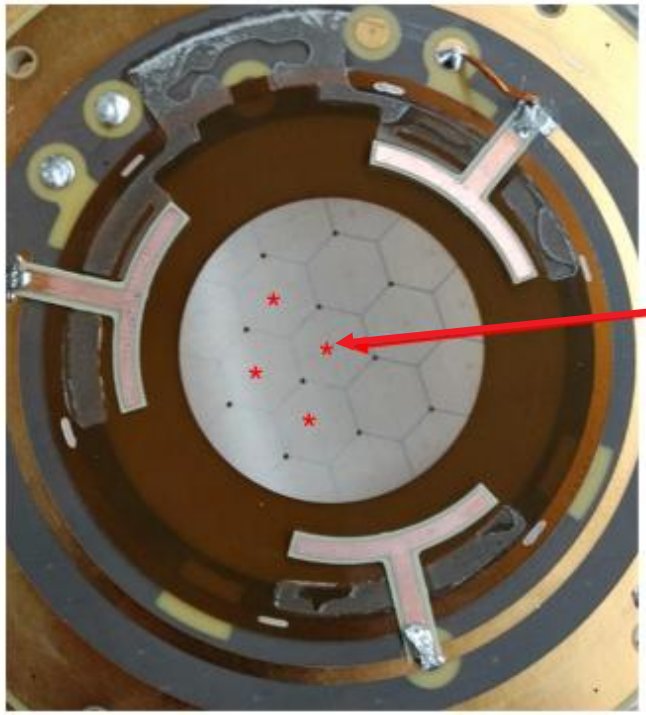


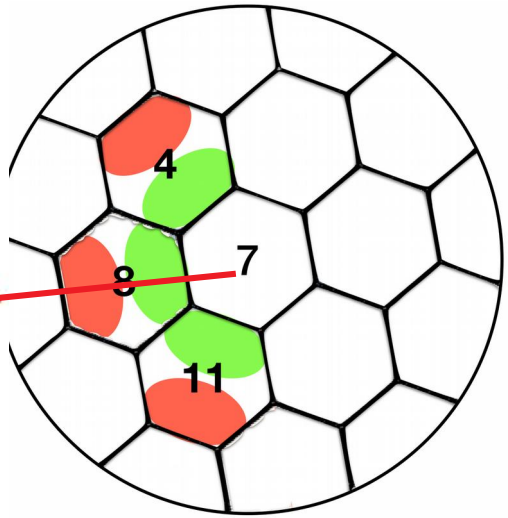
Mean value of the electron-peak charge for pad #7



Individual pad response vs distance R

19 hexagonal pads 5mm side





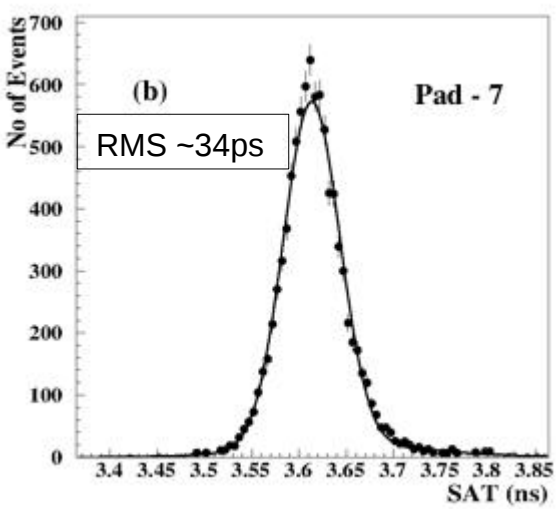
~ 25 ps resolution confirmed for the center of the pads

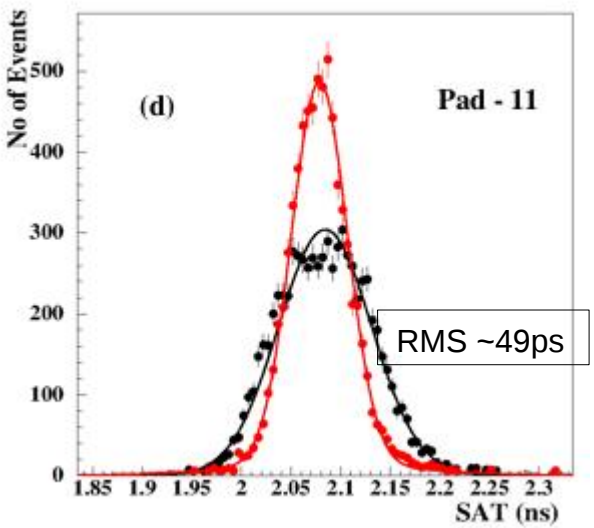
SAT difference between outer vs inner area of the peripheral pads

Gain non-uniformity → worse time resolution

Drift gap distance differences due to the anode deformation

Center of anode curvature located at pad #7

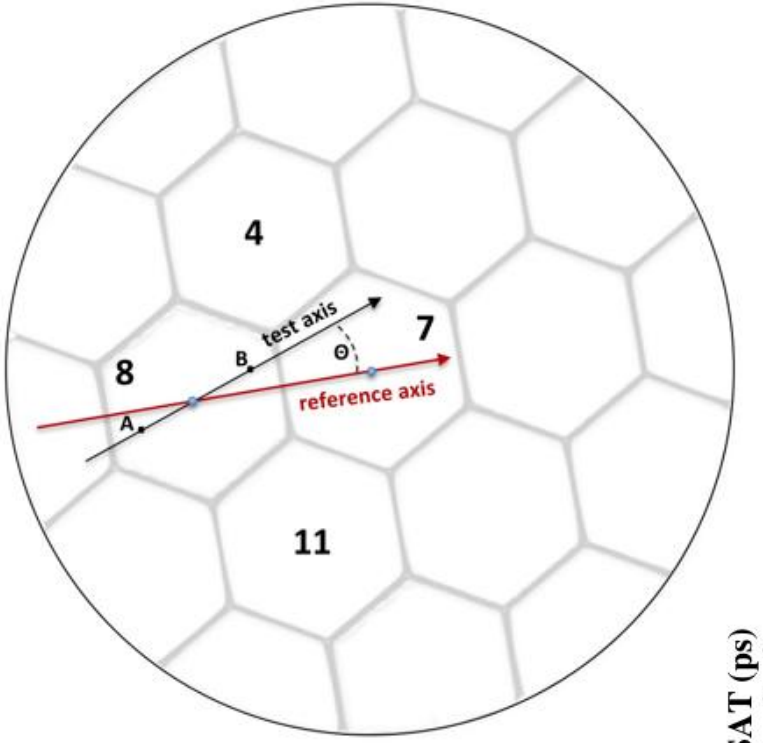




SAT for MIPs passing within **2 mm < R < 4.33 mm** from pad center

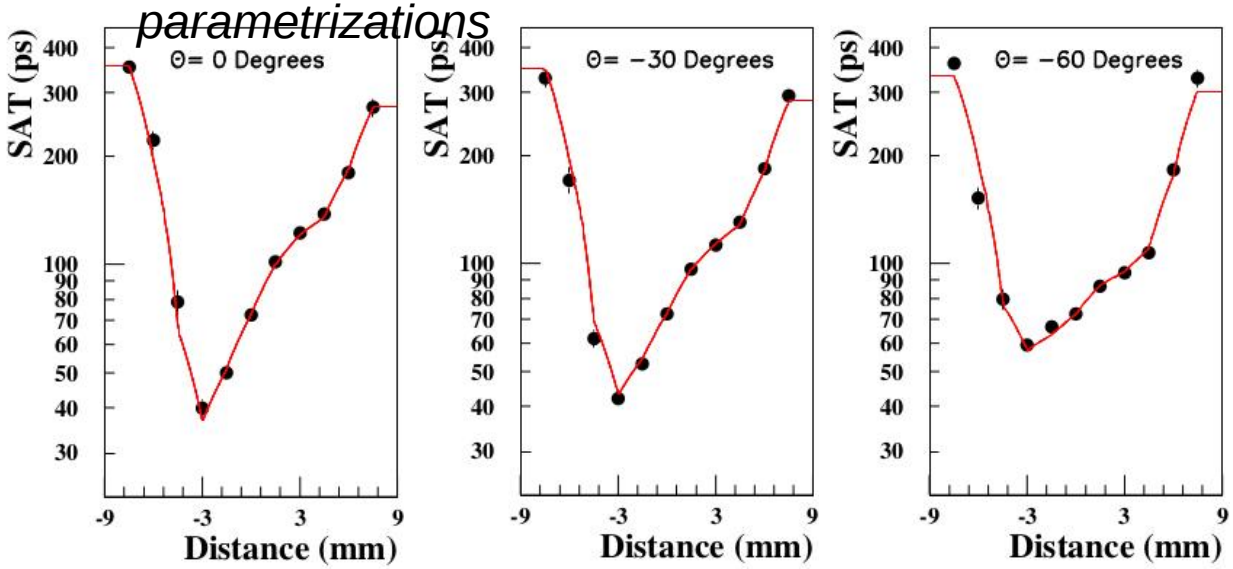
black points: raw SAT measurements
red points: distributions after applying the flatness corrections

Gain non-uniformity investigation: SAT



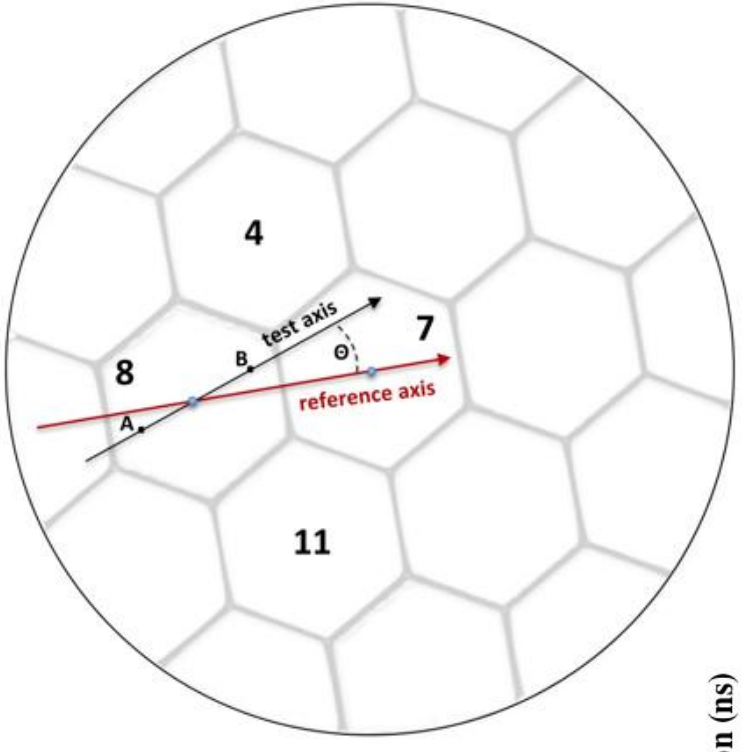
SAT and time resolution of a single pad ideally should obey the symmetry of points A-B regardless of θ.

solid lines represent empirical parametrizations



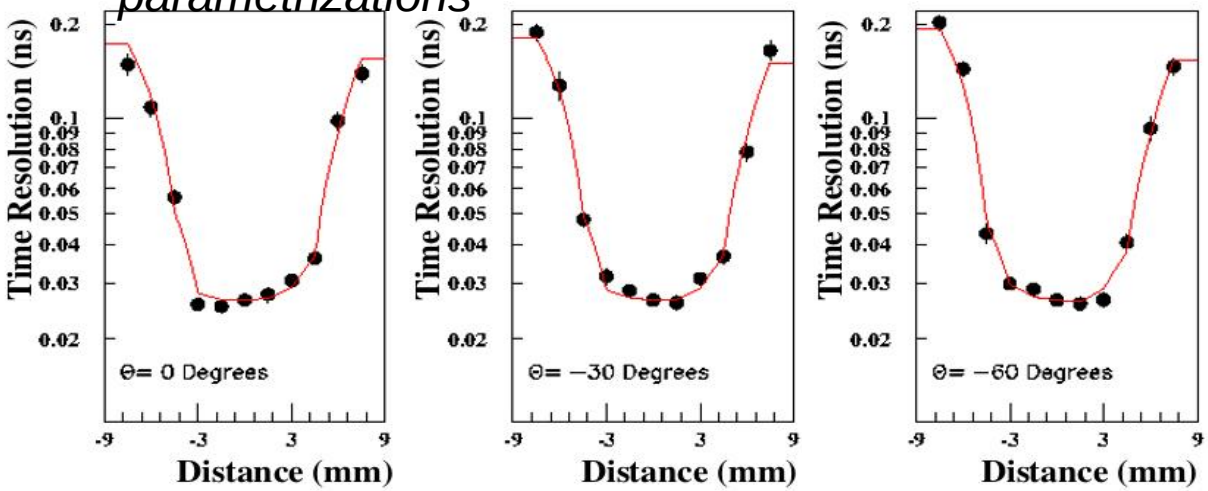
SAT asymmetries reduces for θ approaching 90 deg (absolute value).

Gain non-uniformity investigation: spread of SAT



SAT and time resolution of a single pad ideally should obey the symmetry of points A-B regardless of Θ.

solid lines represent empirical parametrizations



RMS values are approximately symmetric for all Θ.

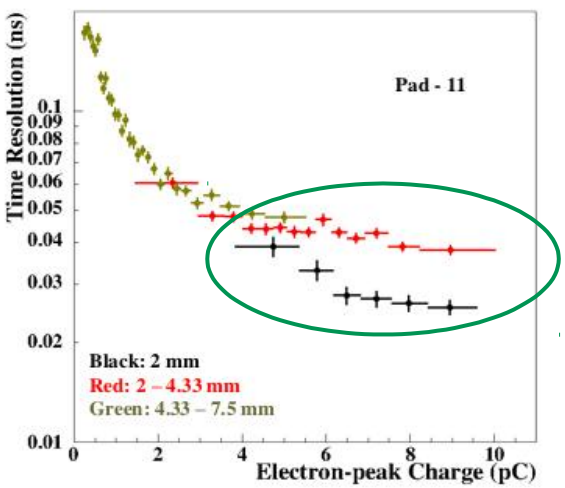
Graph points correspond to tracks passing within 0.5mm around a spot.

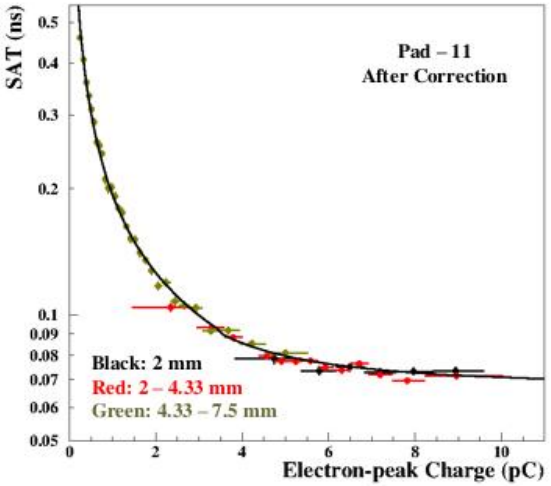
Gain non-uniformity: flatness corrections

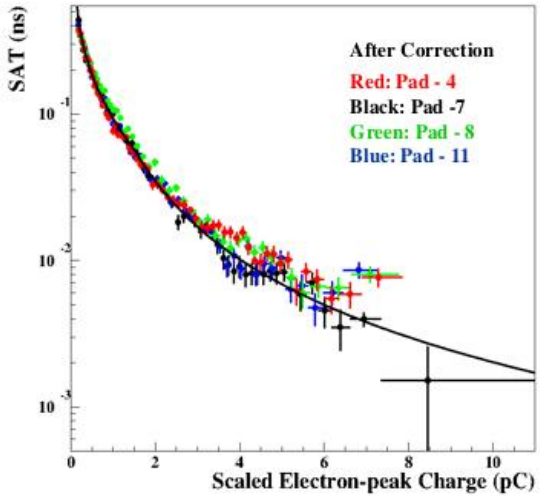
Parametrize mean SAT values as a function of cylindrical coordinates. Apply a flatness correction to the arrival times of all signals of the specific peripheral pad.

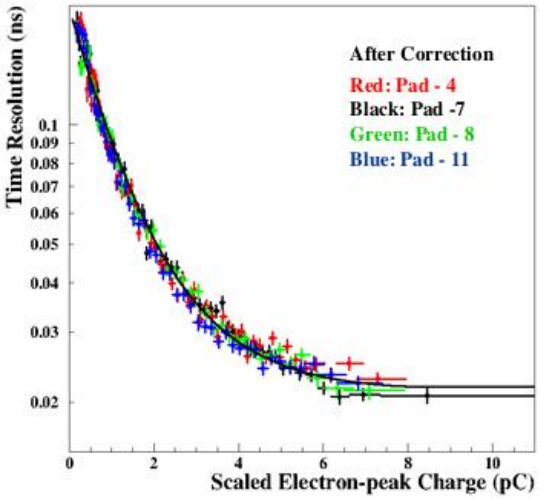
$$T^k_{f-corr.} = T^k_{SAT}(r,\Theta) - \Delta^k(r,\Theta)$$

After corrections the timing properties of the peripheral pads approach those of the central pad #7.
Spread of SAT depends explicitly on e-peak charge regardless of the MIPs impact point









SAT and time resolution after corrections, as compared to the central pad #7 (solid lines are fits of the central pad data).

Readout electronics I

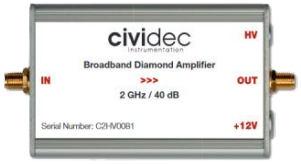
Scheme during first test period (single cell and 1st multipad PICOSEC prototype):

CIVIDEC broadband amplifier, 2 GHz, 40 dB, *(https://cividec.at/electronics-C2-HV.html)*

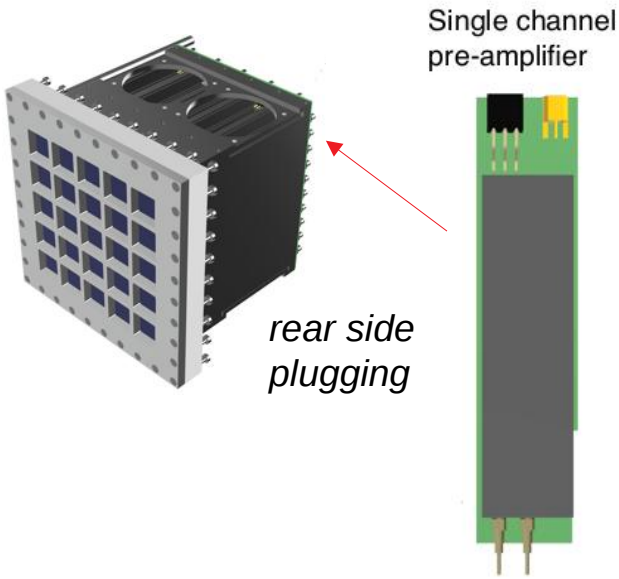
+

LECROY WR8104 oscilloscope, operated at 1.0 GHz analogue bandwidth, sampling rate of 10 Gsamples/s, Waverunner 8000, Teledynelecroy, *(http://cdn.teledynelecroy.com/files/pdf/waverunner8000-datasheet.pdf)*

Costly and not convenient solution for multi-channel application.



Readout electronics II



"Home-made" preamp circuit (Philippe Legou – CEA) tested and proved compatible to PICOSEC timing requirements **+ ASIC**

One card per channel

SAMPIC considered as solution for digitisation with sampling rates ~8GS/s

Test bench for beam time (2021)

- CIVIDEC C2, Ortec 142 IH

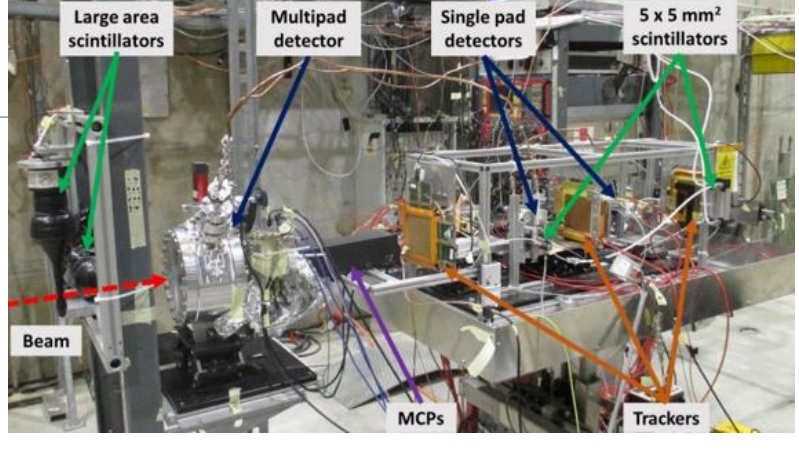
- Oscilloscopes:

- CERN (LeCroy WaveRunner 625Zi, R&S RTO 1044)
- CERN-pool (LeCroy LECROY WR8104 oscilloscopes

- UV led for single p.e spectrum (model:UVTOP240TO18BL)

- Gas: Compass Mixture (Ne:Ethane: CF4 - 80:10:10)

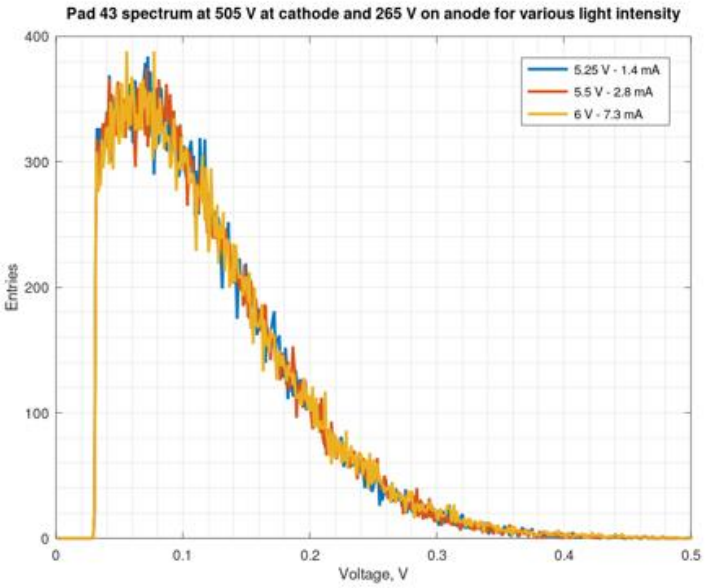
Timing
• MCP-PMT (available 11mm diameter)
• Large area
Triggering
• Scintillators (small area single MIP selection and large area)
Tracking
• Triple GEM detectors, XY readout

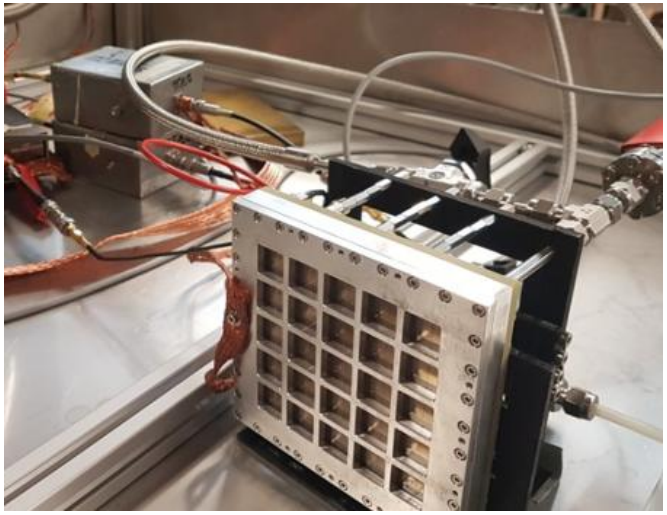


New multipad PICOSEC: first tests

Status

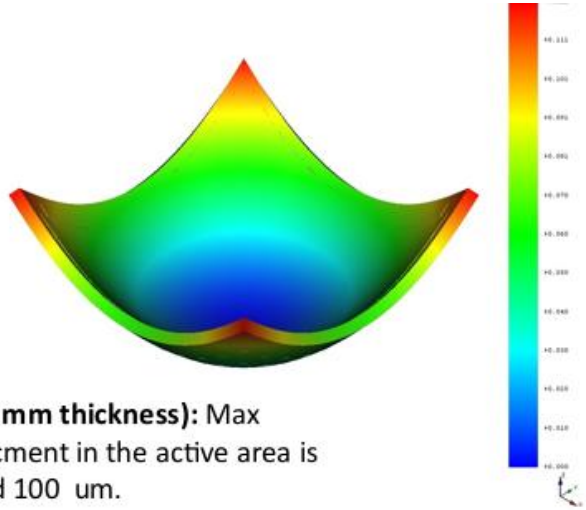
- assembly of the detector is finalized
- first HV test proved a stable operation
- gas tightness measurements performed to determine gas leak rates
- diode light tests done to measure the individual pad response and obtain gain mapping



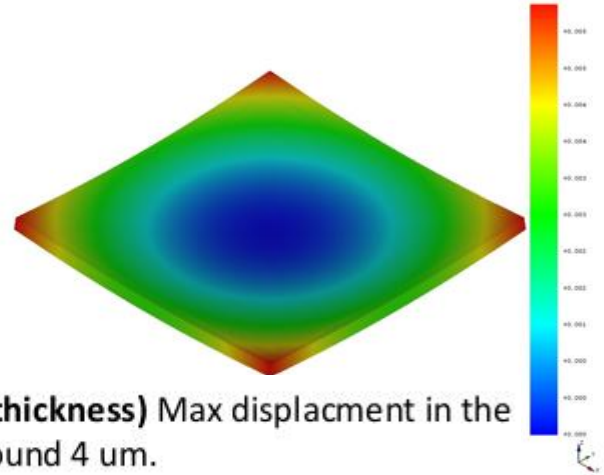


(Antonija Utrobicic, RD51 Collaboration Meeting, February 16, 2021)

New multipad PICOSEC: design requirements



FR4 (3 mm thickness): Max displacment in the active area is around 100 um.

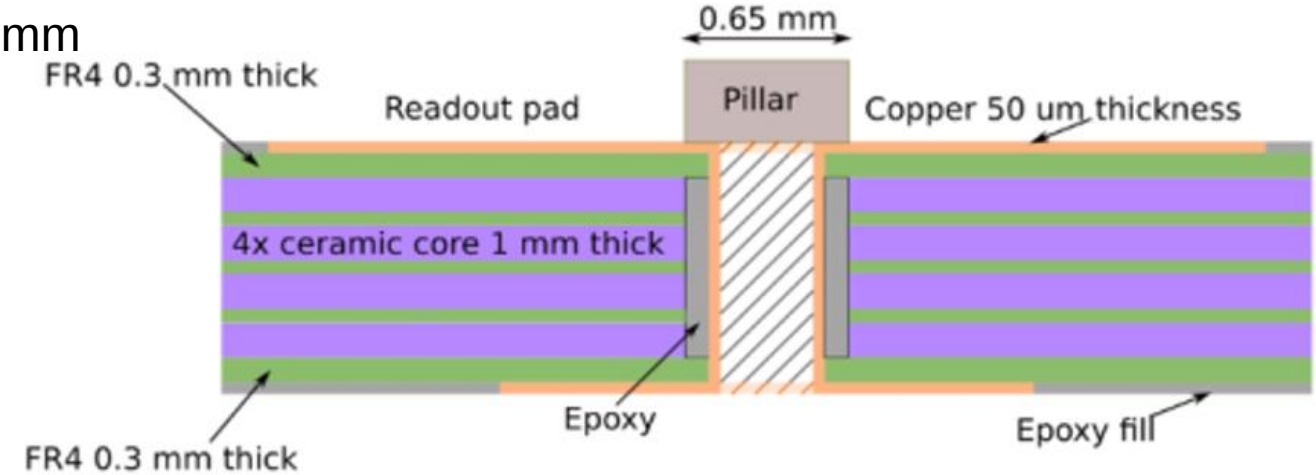


Ceramic (4 mm thickness) Max displacment in the active area is around 4 um.

PCB flatness within 10 µm over the active area

Material: hybrid ceramic instead of just FR4

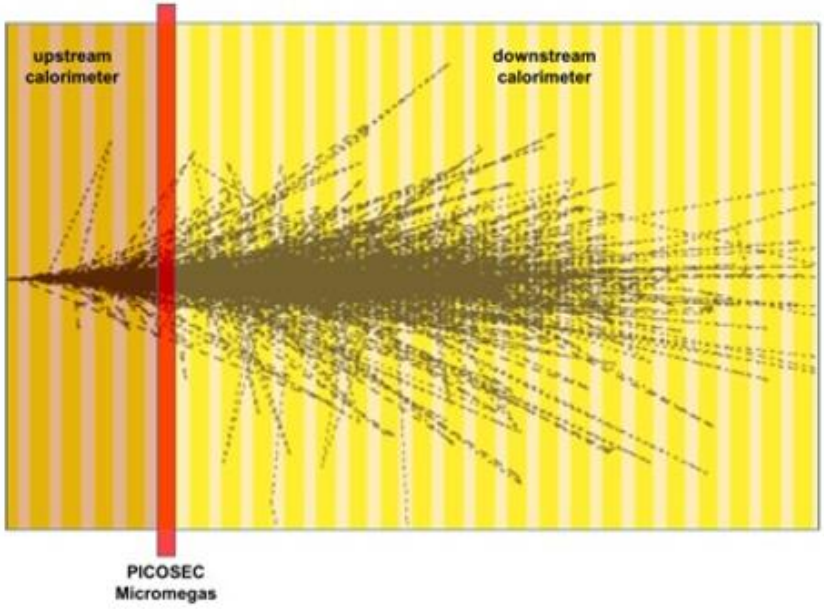
Thickness: 4,85 mm instead of 3 mm



(Antonija Utrobicic, RD51 Collaboration Meeting, February 16, 2021)

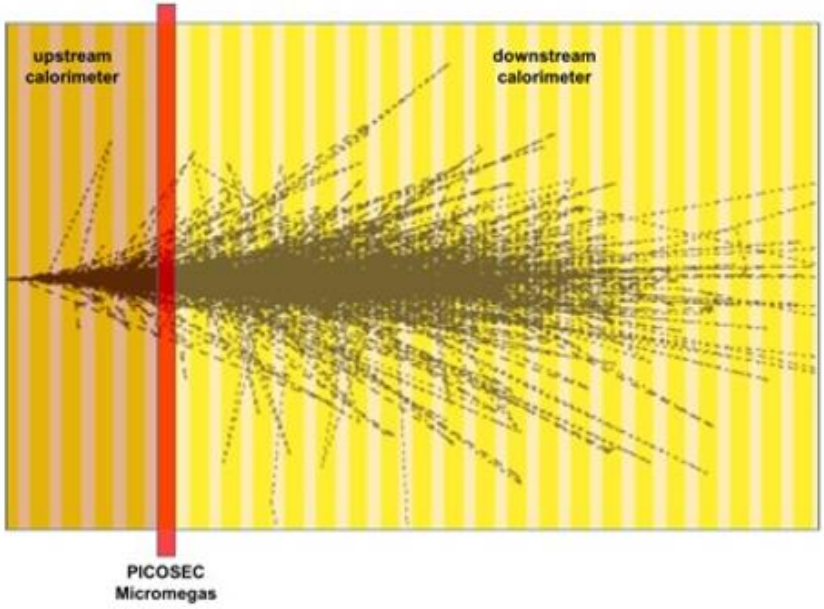
Potential applications

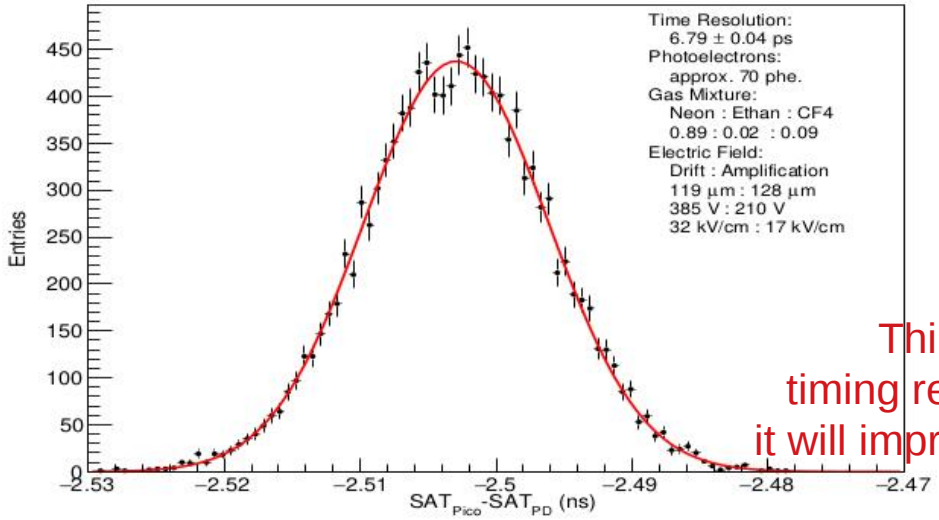
Scenario I: PICOSEC embedded in an EM calorimeter



- Relaxed photocathode – QE requirements (many secondary relativistic electron of the EM shower will produce many Cherenkov photons in the PICOSEC radiator)
- Metallic photocathode (e.g. Cr)
- ~ 240 p.e. after just 2 rad.lengths for a 30 GeV electron shower (2 ps statistical, from simulation)
- ~ 17 p.e. (20 ps) after 2 rad.lengths for a 5 GeV electron shower
- ~ 33 p.e. (14 ps) after 5 rad.lengths for a 5 GeV electron shower

Scenario I: PICOSEC embedded in an EM calorimeter



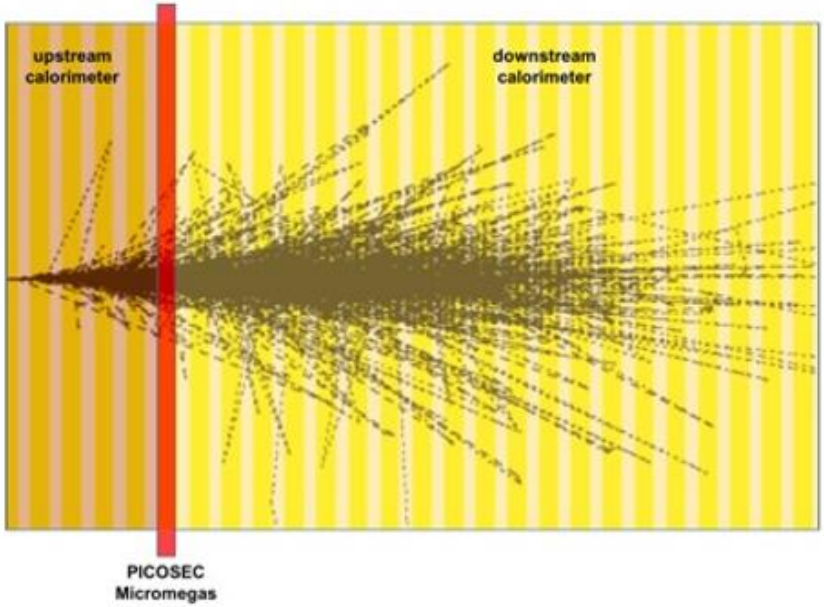


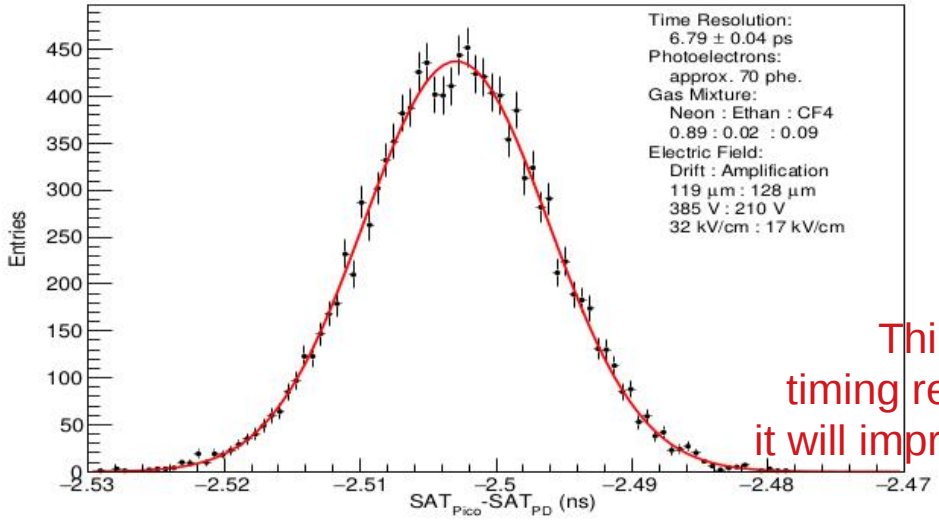
- Relaxed photocathode – QE requirements (many secondary relativistic electron of the EM shower will produce many Cherenkov photons in the PICOSEC radiator)
- Metallic photocathode (e.g. Cr)

- ~ 240 p.e. after just 2 rad.lengths for a 30 GeV electron shower (2 ps statistical, from simulation)
- ~ 17 p.e. (20 ps) after 2 rad.lengths for a 5 GeV electron shower
- ~ 33 p.e. (14 ps) after 5 rad.lengths for a 5 GeV electron shower

Thin gap PICOSEC (119μm Drift gap)
timing resolution of ~ 6.8 ps (for approx.70 p.e.)
it will improve all expected resolution values (x 0.7)

Scenario I: PICOSEC embedded in an EM calorimeter





- Relaxed photocathode – QE requirements (many secondary relativistic electron of the EM shower will produce many Cherenkov photons in the PICOSEC radiator)
- Metallic photocathode (e.g. Cr)
- ~ 240 p.e. after just 2 rad.lengths for a 30 GeV electron shower (2 ps statistical, from simulation)
- ~ 17 p.e. (20 ps) after 2 rad.lengths for a 5 GeV electron shower
- ~ 33 p.e. (14 ps) after 5 rad.lengths for a 5 GeV electron shower

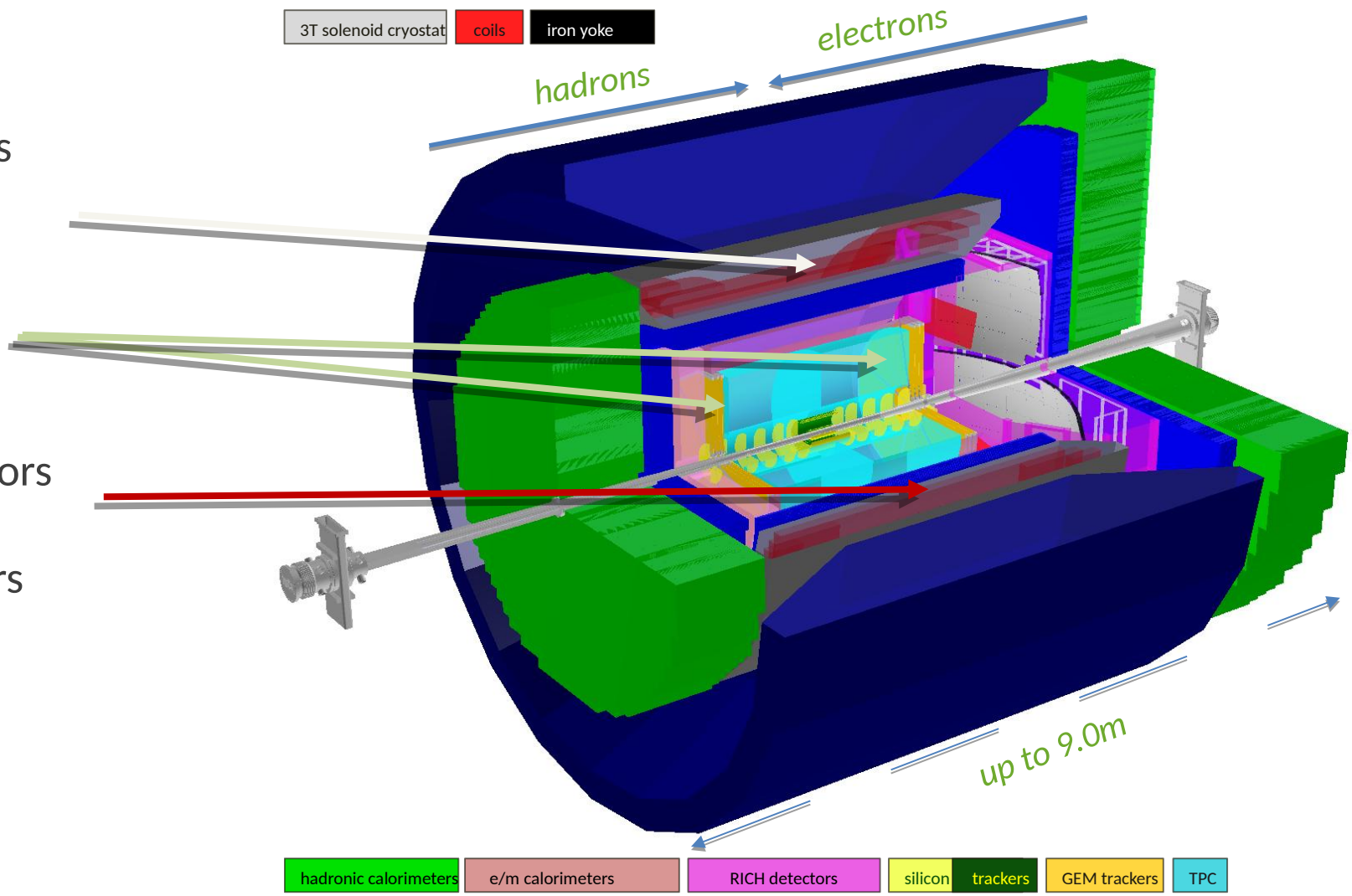
- Potential applications in PID
- e.g. tagging the production time and flavor of neutrino $K^+ \rightarrow \pi^0 e^+ \nu_e$ (ENUBET project)

Thin gap PICOSEC (119μm Drift gap)
timing resolution of ~ 6.8 ps (for approx.70 p.e.)
it will improve all expected resolution values (x 0.7)

Scenario II: timing in Electron Ion Collider

https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements

- Barrel detectors
- TPC Readout
- Forward Detectors
- Timing Detectors



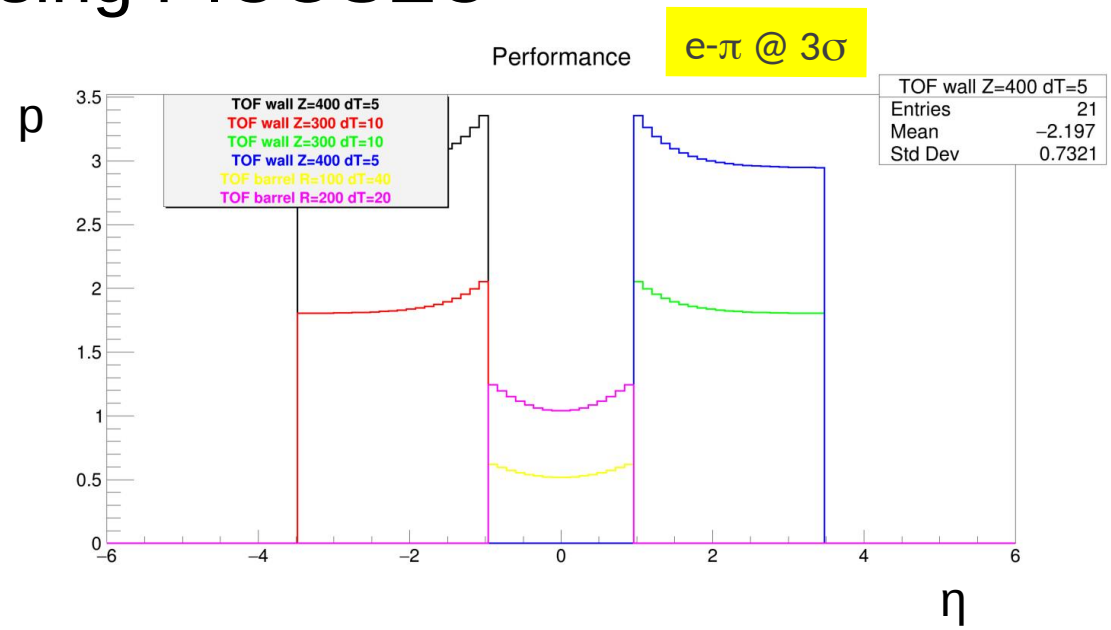
Scenario II: TOF for PID using PICOSEC

Analytical, M. Chiu(eRD14)

TOF PID at RHIC/EIC

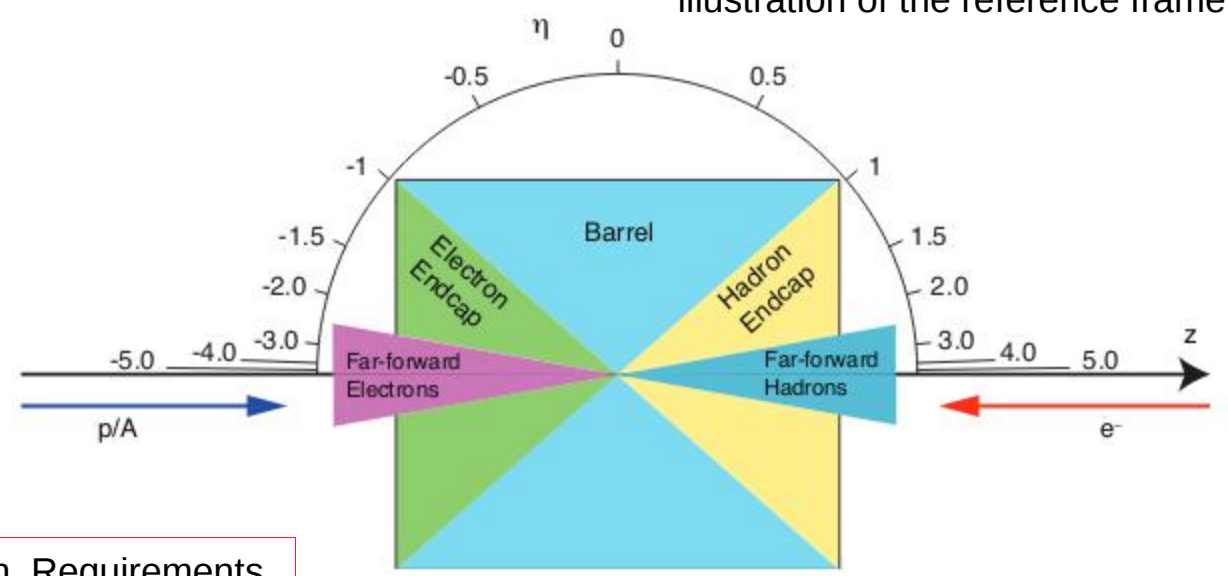
Momentum reach of TOF PID reaches interesting levels if one can achieve ~ 20 ps

Resolution	Distance	Pion-Kaon Separation	Kaon-Proton Separation
σ_{tot}=100 ps	1m		
σ_{tot}=10 ps	1m		
σ_{tot}=20 ps	0.85 m		
σ_{tot}=20 ps	5m		



EIC Detector Requirements and R&D Handbook – January 2019

illustration of the reference frame



- t0 provided by the machine

https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements