Charged particle timing at sub-25 ps precision: the PICOSEC detection concept

F.J. Iguaz

On behalf of PICOSEC collaboration

PM2018, 28th May 2018

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PICOSEC collaboration

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- **CERN:** J. Bortfeldt, F. Brunbauer, C. David, J. Frachi, M. Lupberger, H. Müller, E. Oliveri, F. Resnati, L. Ropelewski, T. Schneider, P. Thuiner, M. van Stenis, P. Thuiner, R. Veenhof[1], S. White[2].
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[1] Also MEPhI & Uludag University.

[2] Also University of Virginia.

Outline

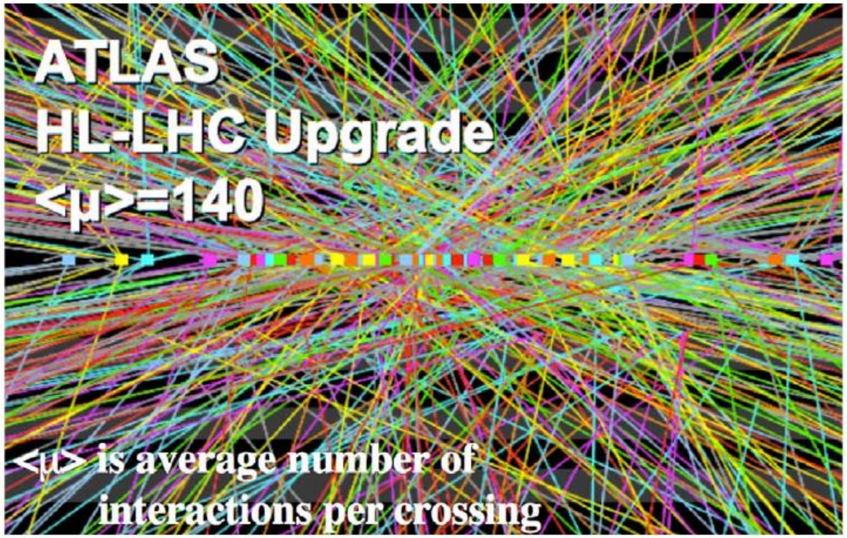
- The PICOSEC detection concept
- Timing results
- R&Ds for a demonstrator
- Summary

Poster on "**Spatial time resolution of MCP–PMTs**"
by **<u>Lukas Sohl</u>** (**<u>TODAY</u>**, PhotoDetectors and PID session)

Motivation for picosecond timing

High Luminosity Upgrade of LHC:

- To mitigate pile-up background.
- ATLAS/CMS simulations: ~150 vertexes/crossing (RMS 170 ps).
- ~10 ps timing + tracking info.

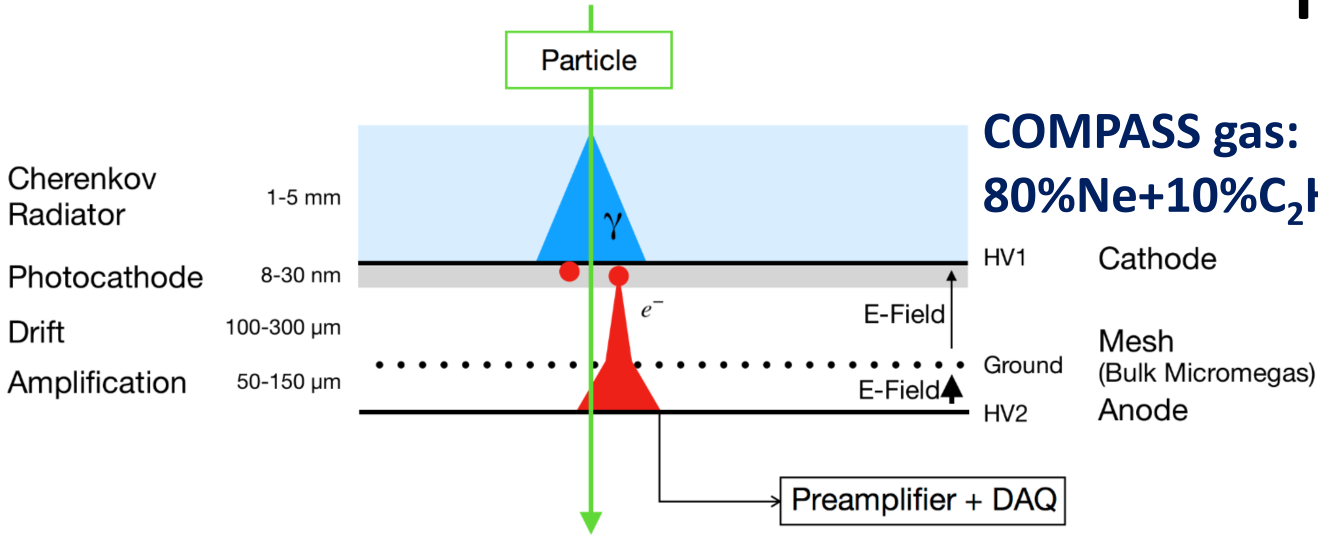


PID techniques: Alternatives to RICH methods, J. Va'vra, NIMA **876** (2017) 185-193, https://dx.doi.org/10.1016/j.nima.2017.02.075

Extra detector requirements:

- Large surface coverage.
- Segmented anodes for tracking.
- Resistance to aging effects.

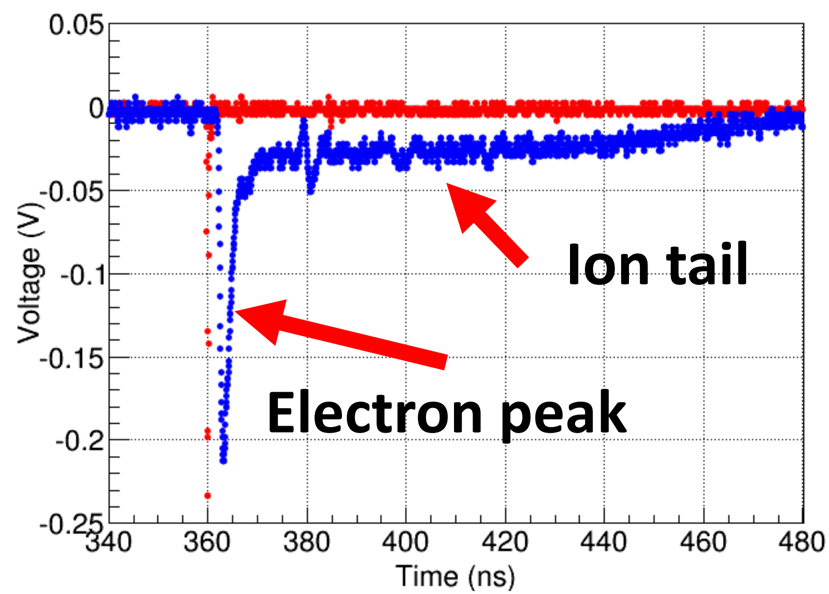
The PICOSEC detection concept



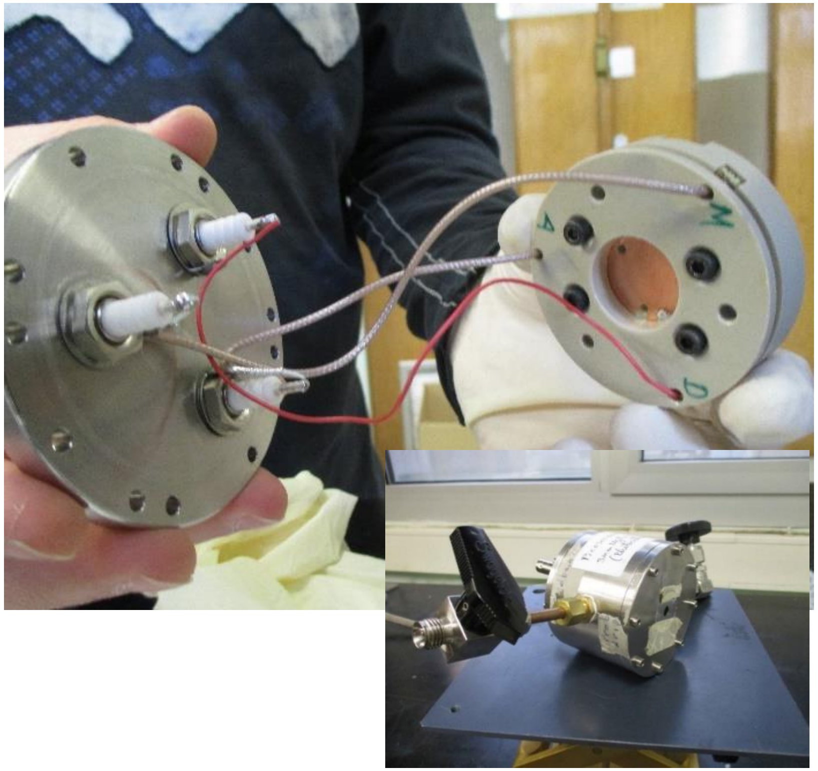
COMPASS gas: 80%Ne+10%C_2H_6+10%CF_4

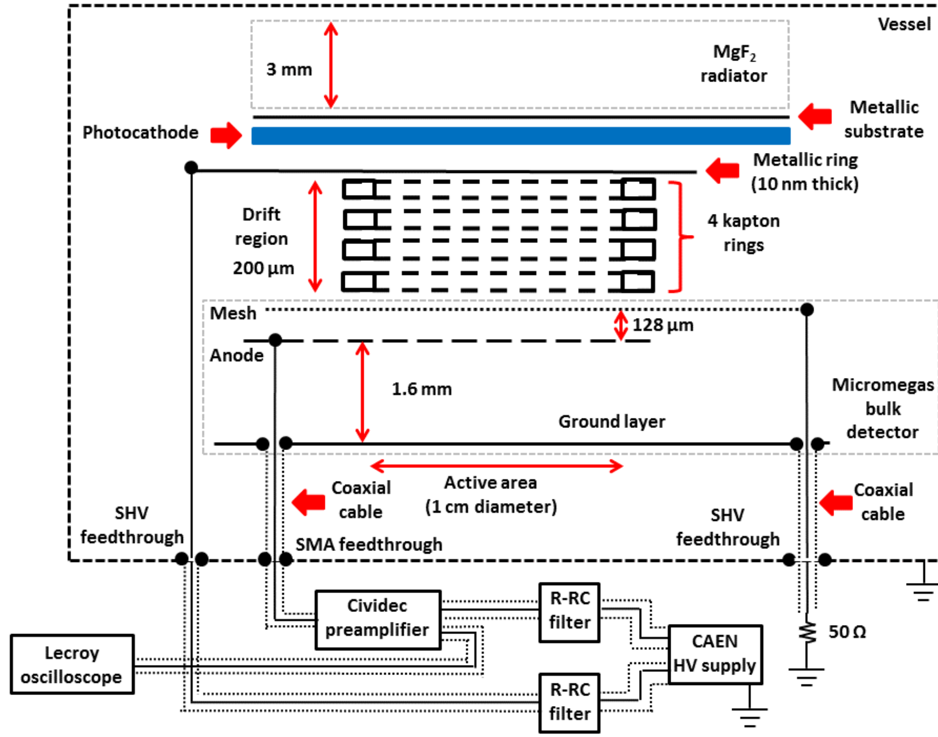
- **Radiator:** Cherenkov UV production.
- **Photocathode:** UV -> electrons.
- **Two-stage Micromegas:** drift (pre-amplification) + amplification gaps.

J. Bortfeldt *et al., accepted in NIMA,*
arXiv:1712.05256
https://doi.org/10.1016/j.nima.2018.04.033



The first PICOSEC prototype

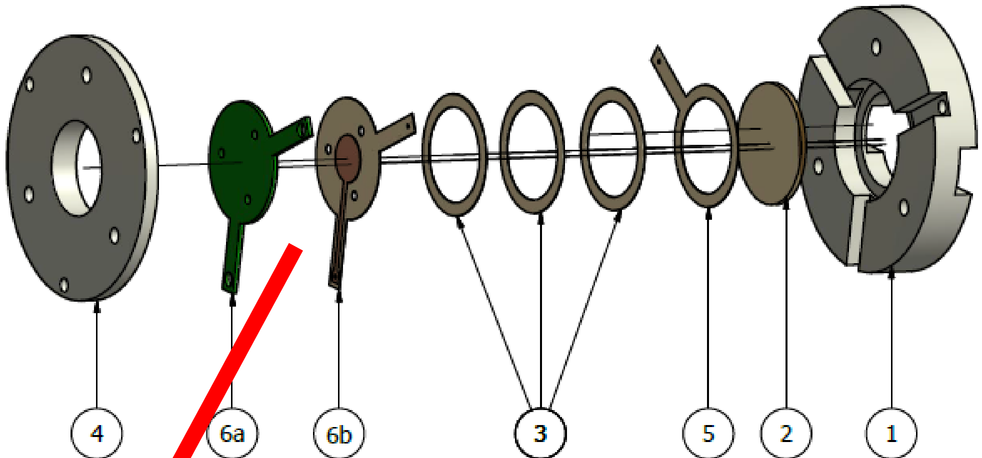


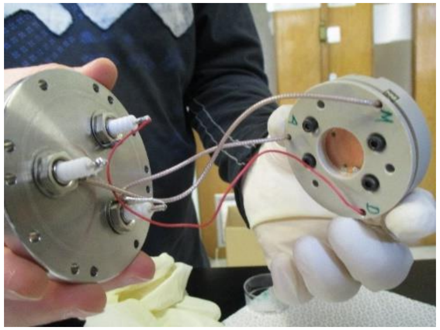


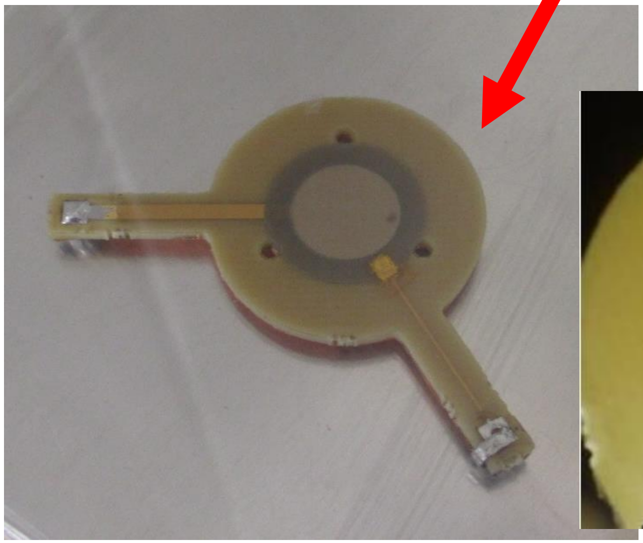
1 cm diameter active area prototype

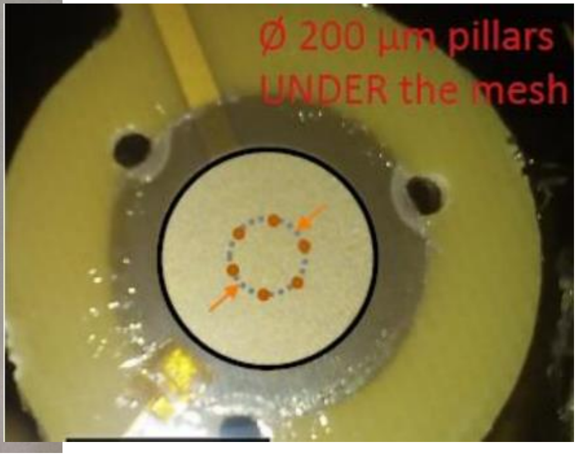
- A small prototype.
- As a single pad, it is pretty large.

The first PICOSEC prototype



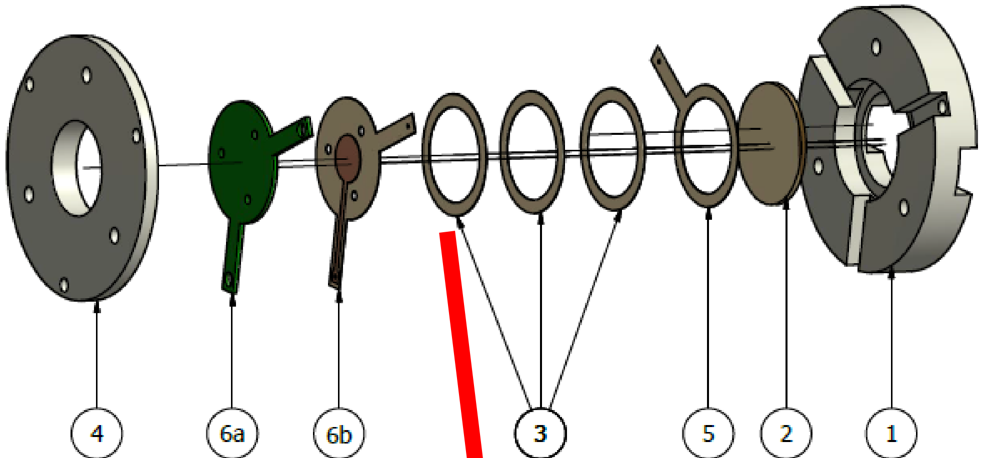


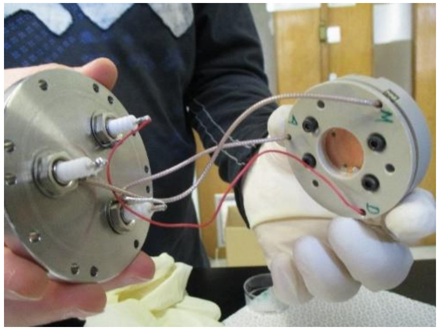


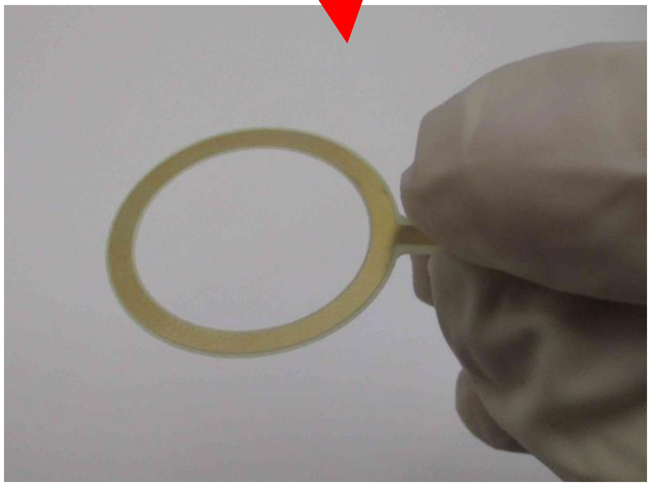


Bulk Micromegas
1 cm diameter
128 µm gap
Only 6 pillars
Capacity = 8 pF

The first PICOSEC prototype

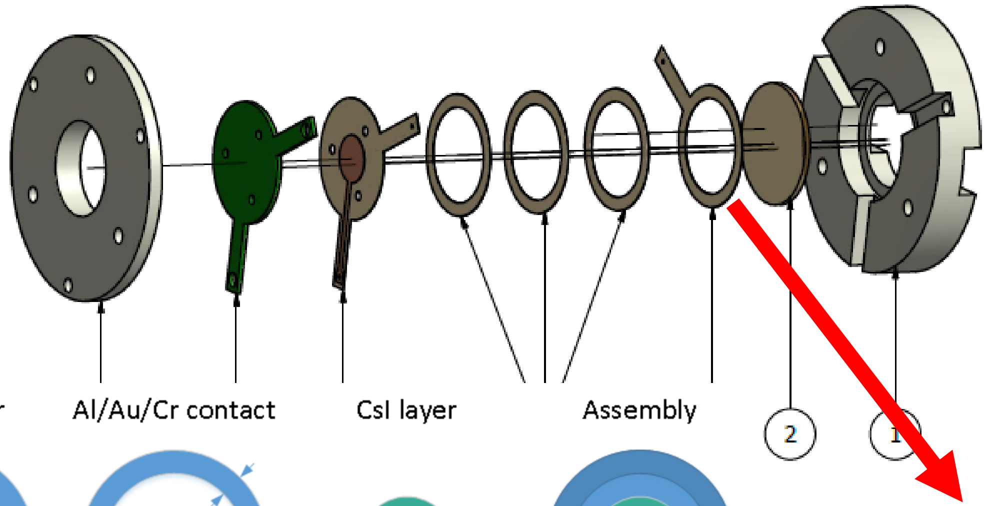


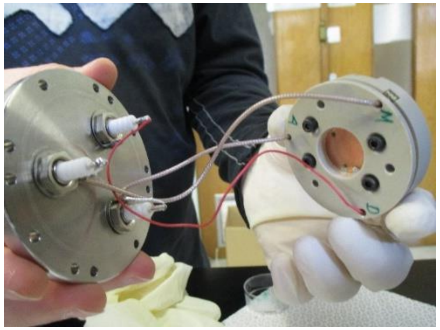


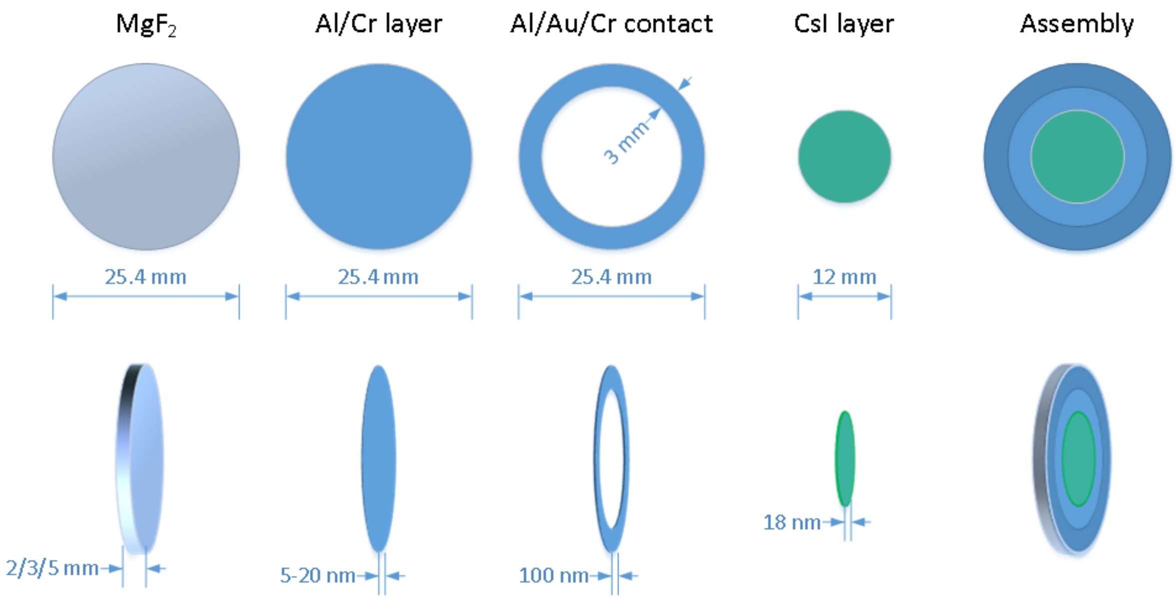


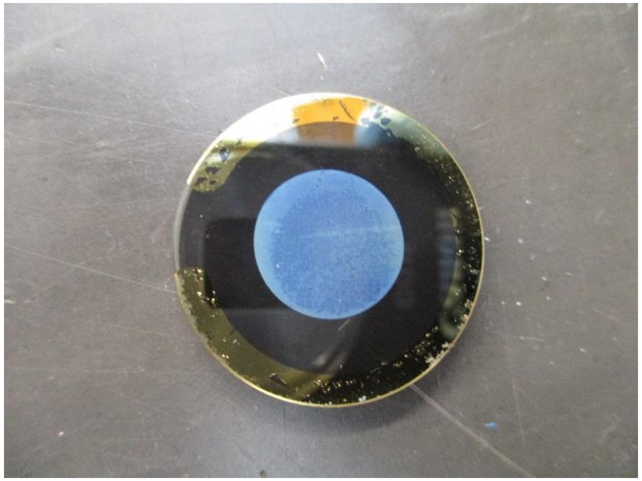
4 Kapton rings spacers
Drift = 200 µm

The first PICOSEC prototype



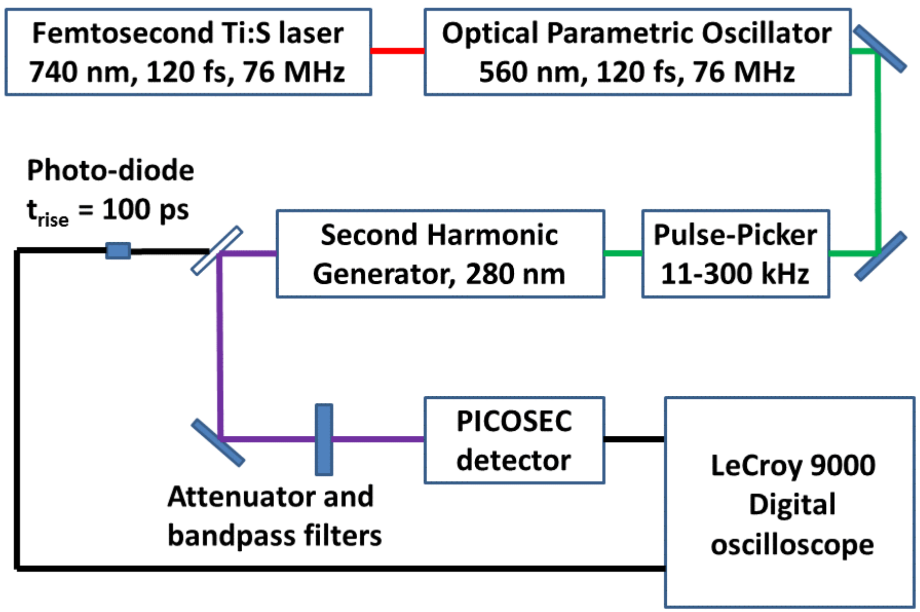


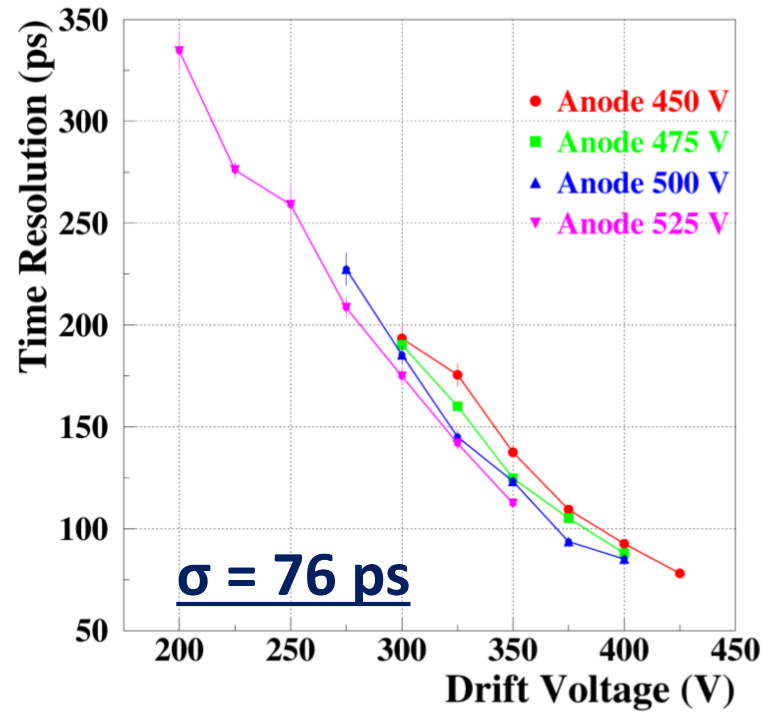




3 mm MgF$_2$ + 5.5 nm Cr + 18 nm CsI

Single photoelectron timing

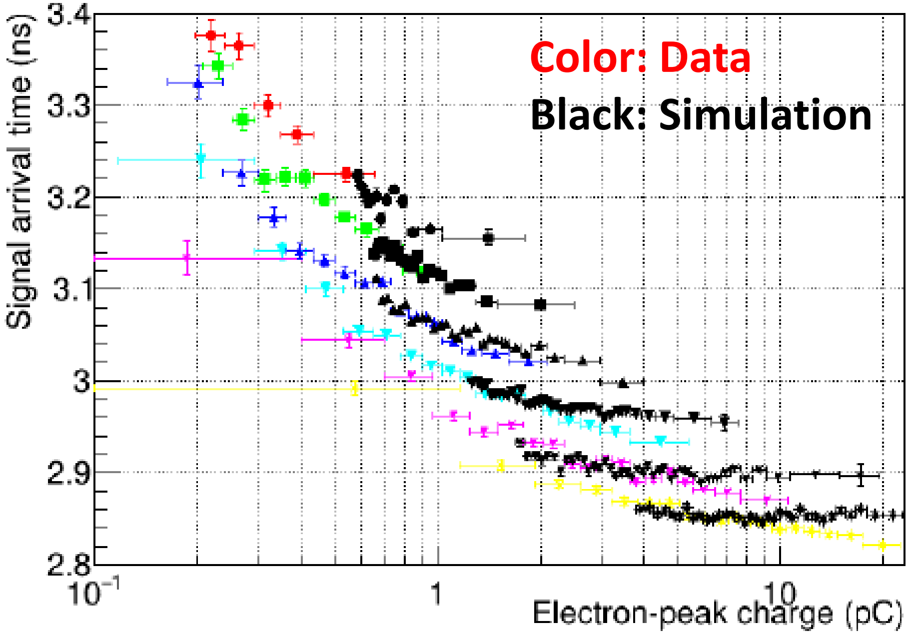


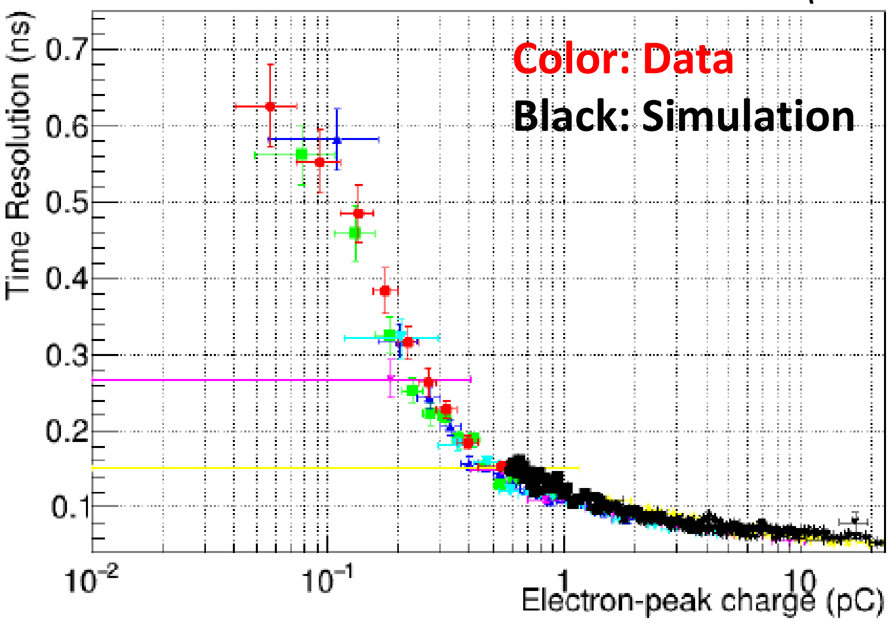


- Pulsed laser at IRAMIS facility: **267-288 nm wavelength**.
- Splited in two: fast photodiode (**13 ps res**) & PICOSEC.
- Laser intensity reduced by electroformed nickel meshes.
- Time resolution for single photoelectrons: **76.0 ± 0.4 ps**

Simulation of detector response

K. Paraschou & S.E. Tzamarias (AUTH)

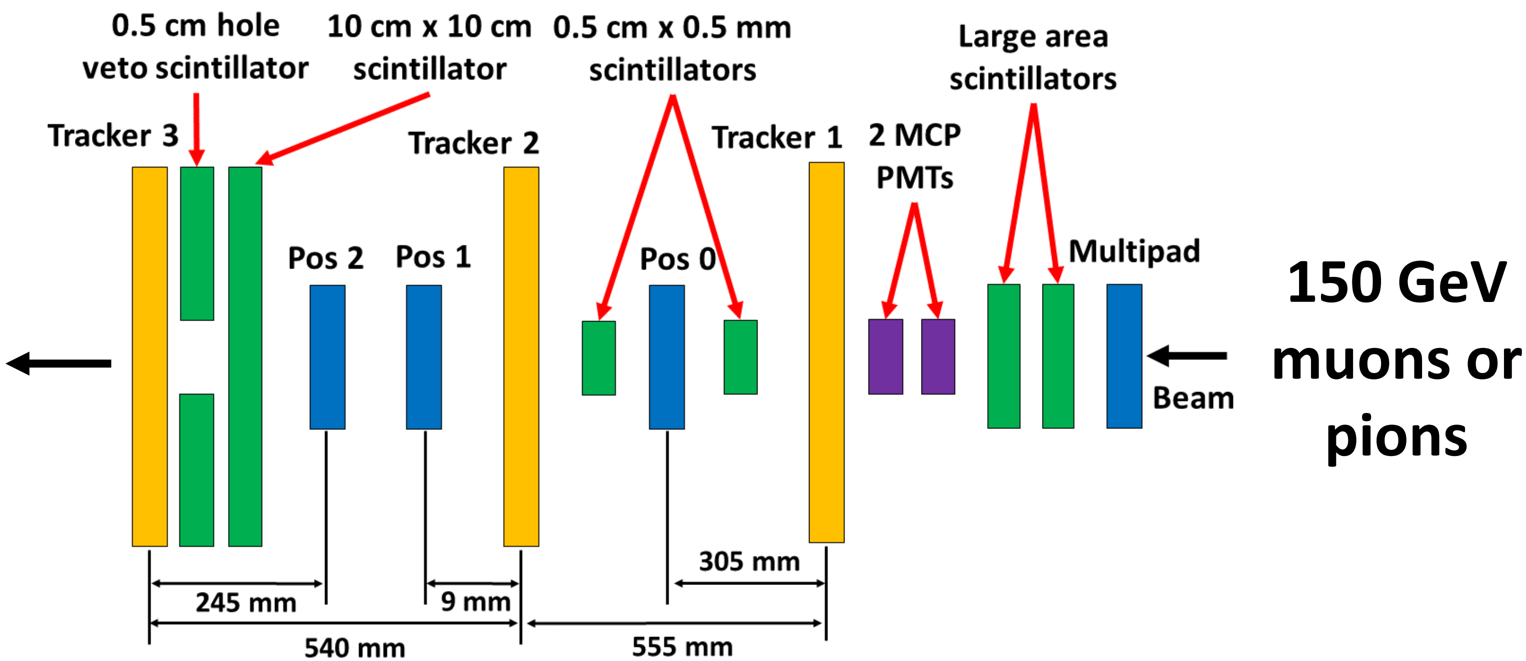




- Detector timing is mainly defined by the pre-amplification stage.
- Qualitatively description by a simulation based on Garfield++.

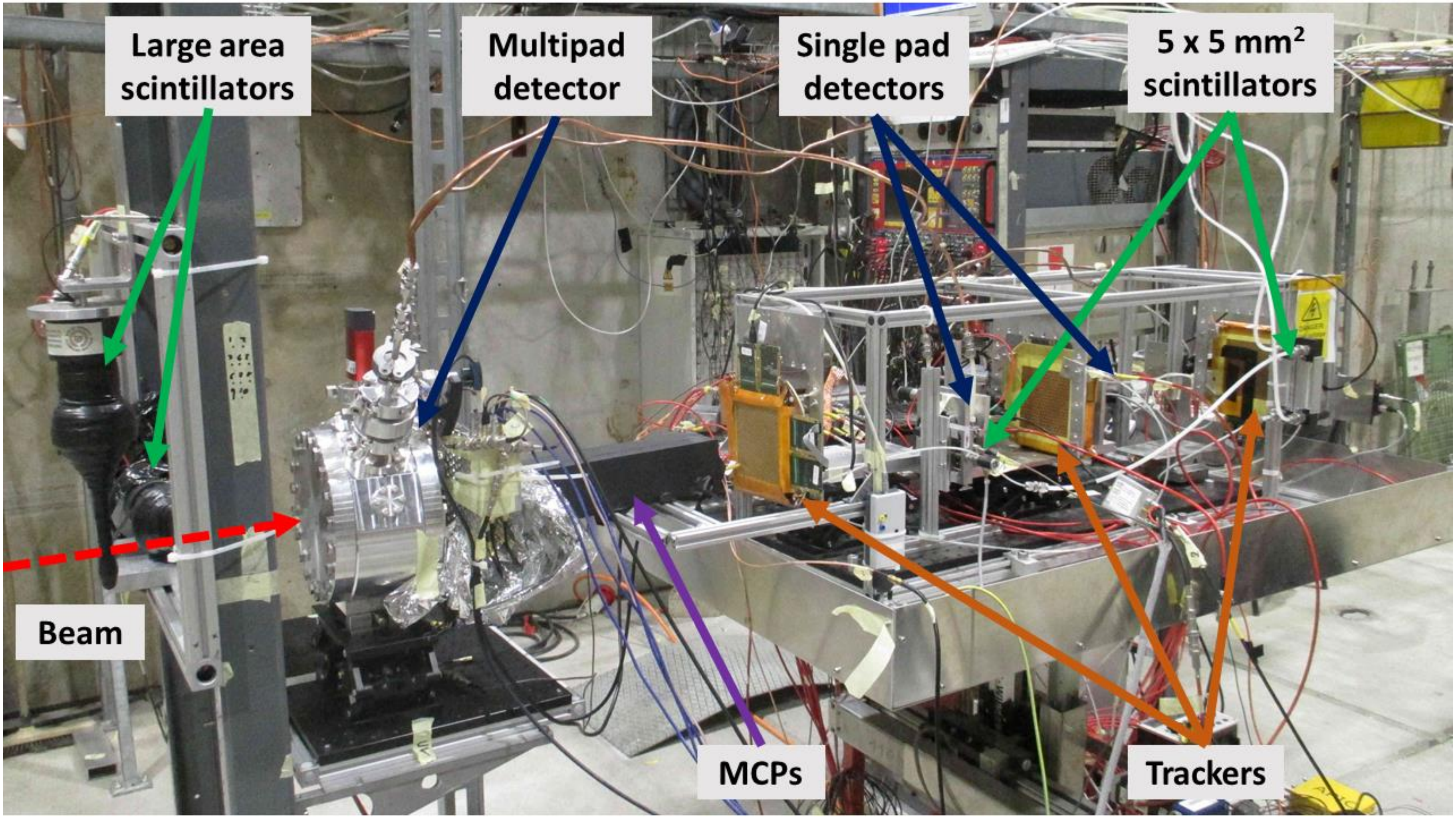
More details: "A data driven simulation study of the timing effects observed with the PICOSEC MicroMegas Detector" by K. Paraschou (RD51-WG4 group, 13th Dec).
https://indico.cern.ch/event/676702/contributions/2809871/attachments/1574857/2486512/Konstantinos_RD51_miniweek.pdf

Beam tests at CERN SPS H4: setup

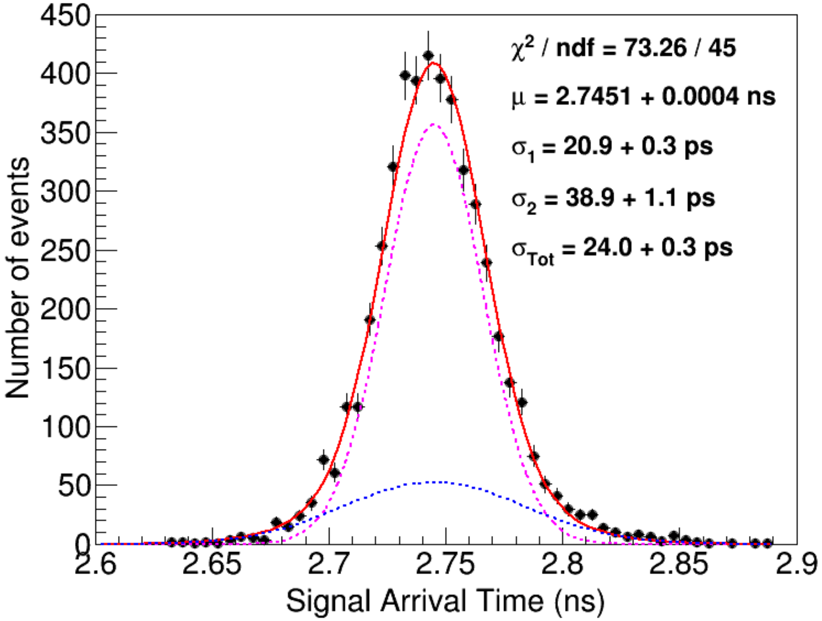


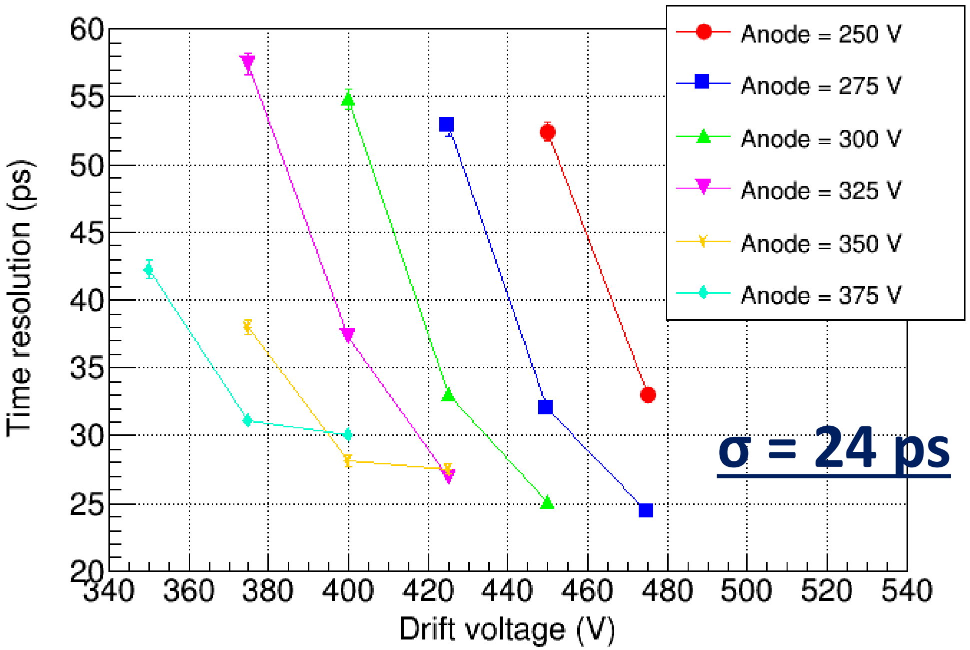
- **Time reference:** two MCP-PMTs (**<u><5 ps</u>** resolution).
- **Scintillators**: used to select tracks & to avoid showers.
- **Tracking system:** 3 triple-GEMs (**<u>40 µm</u>** precision).
- **Electronics:** CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

Beam tests at CERN SPS H4: setup



Beam tests at CERN SPS H4: results





- Time resolution for 150 GeV muons: **24 ps**
- Optimum operation point: Anode +275V / Drift – 475V.
- Mean number of photoelectrons per muon = **10.4 ± 0.4**
- Results repeated in two different beam campaigns.

R&D for a demonstrator

Robust readout

Robust photocathode

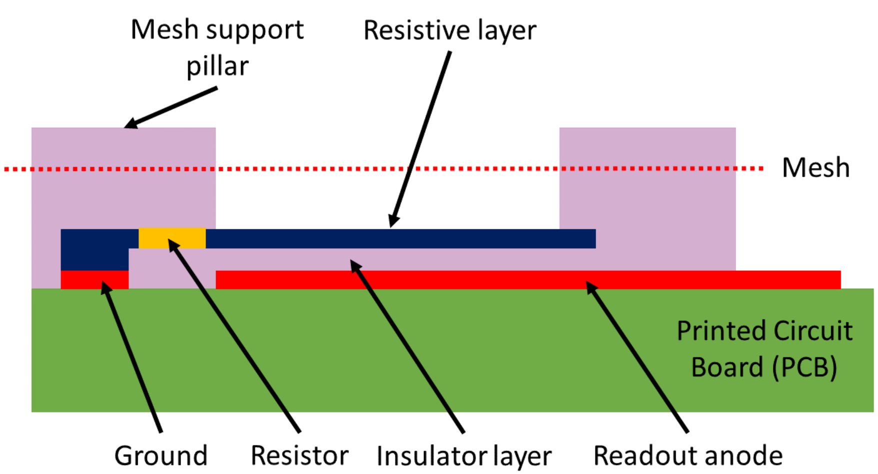
Multichannel large area

... and also

- *Preamplifiers*
- *Digitizers*

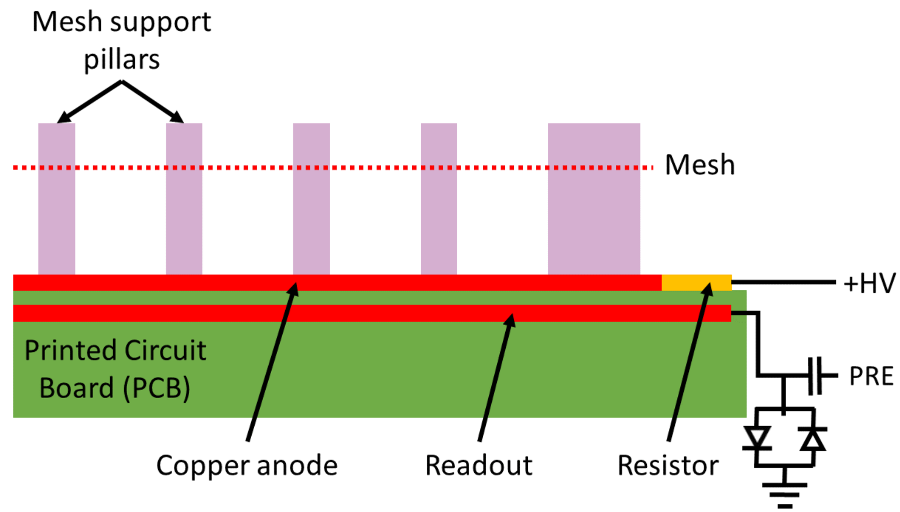
Robust readout: resistive Micromegas

Resistive strips (MAMMA)



Resistive strip grounded

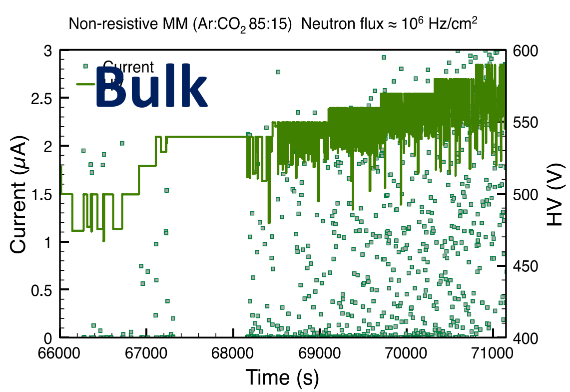
Floating strips (COMPASS)

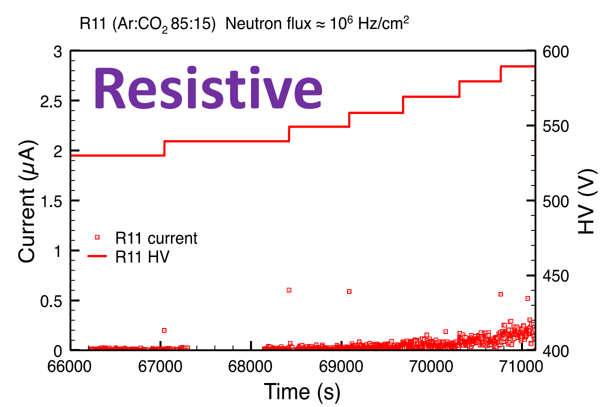


Copper layer to HV via resistor

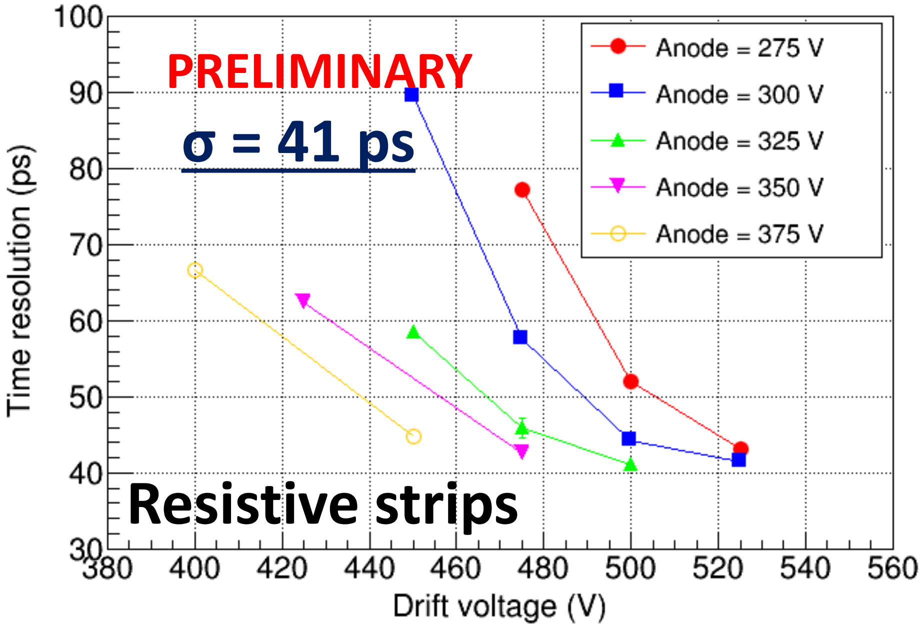
Resistive readouts operate stably at high gain in neutron fluxes of 10^6 Hz/cm^2.

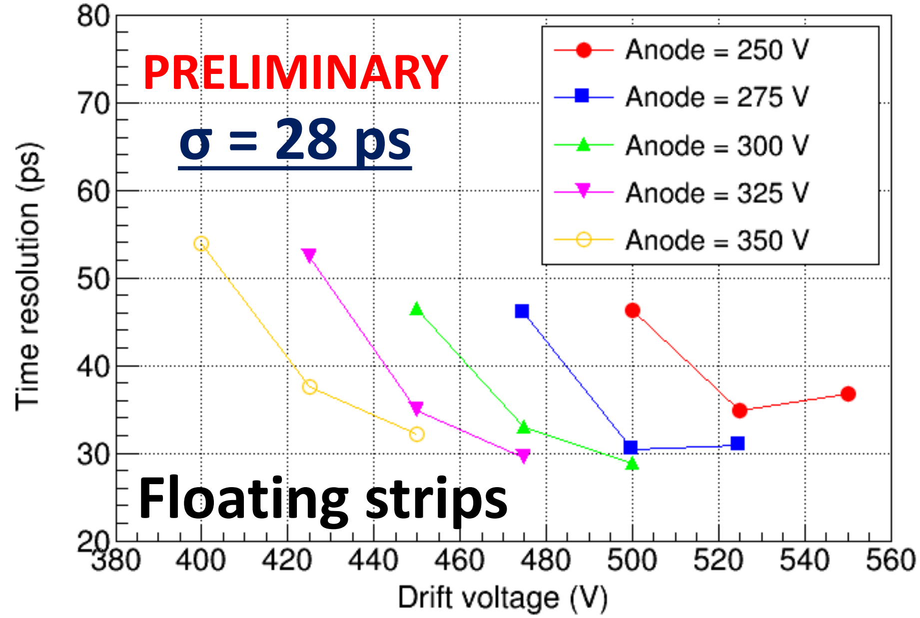
T. Alexopoulos *et al.*, *NIMA* **640** (2011) 110-118.





Robust readout: first results





- Values not far from the PICOSEC bulk readout.
  - **Resistive strips**: **41 ps** (10 MΩ/☐), **35 ps** (300 kΩ/☐).
  - **Floating strips**: **28 ps** (25 MΩ).
- Resistive readouts worked during hours in intense pion beam.

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Institut de recherche sur les lois fondamentales de l'Univers

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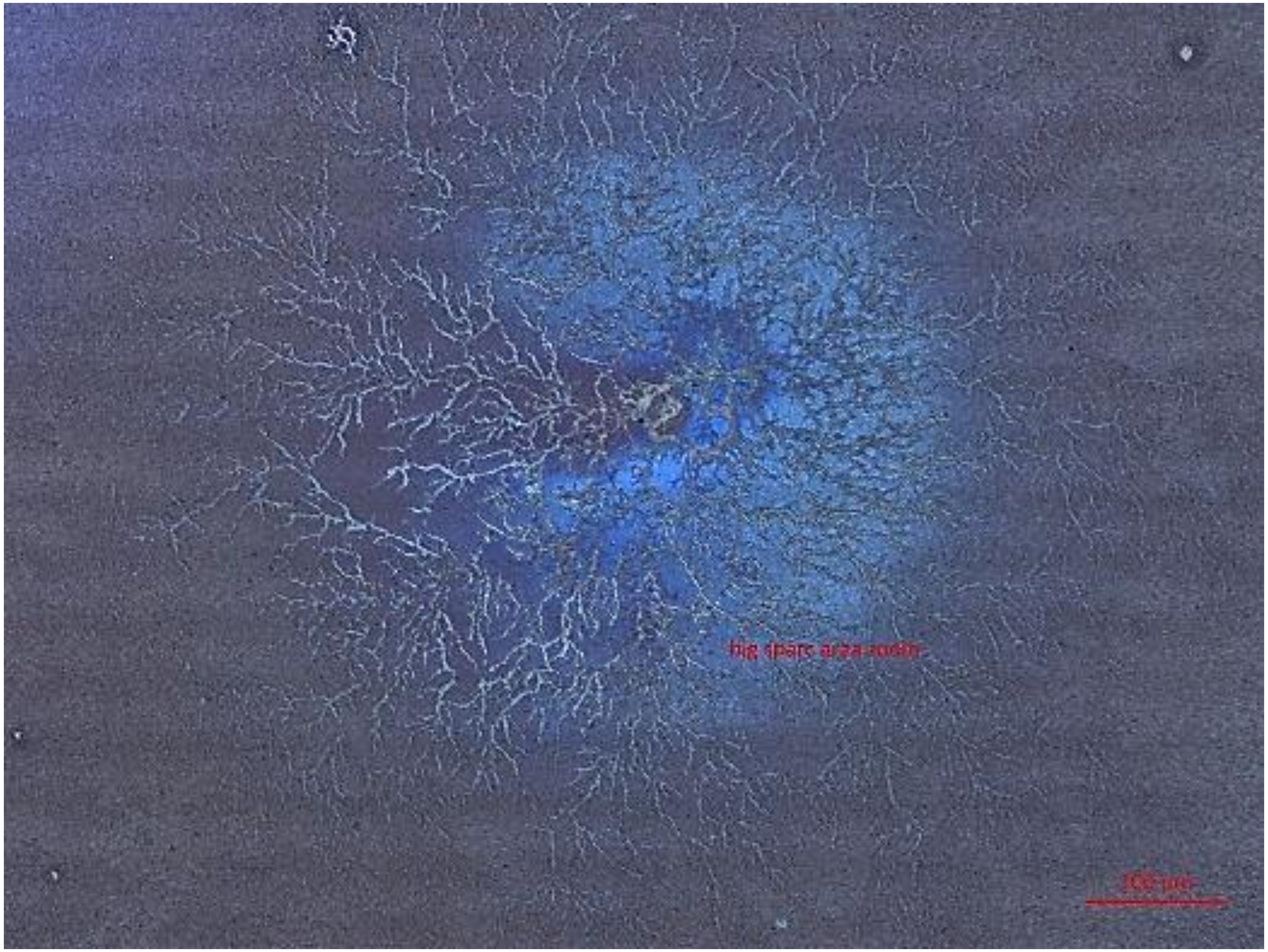
Robust photocathode



Standard photocathode after beam-test

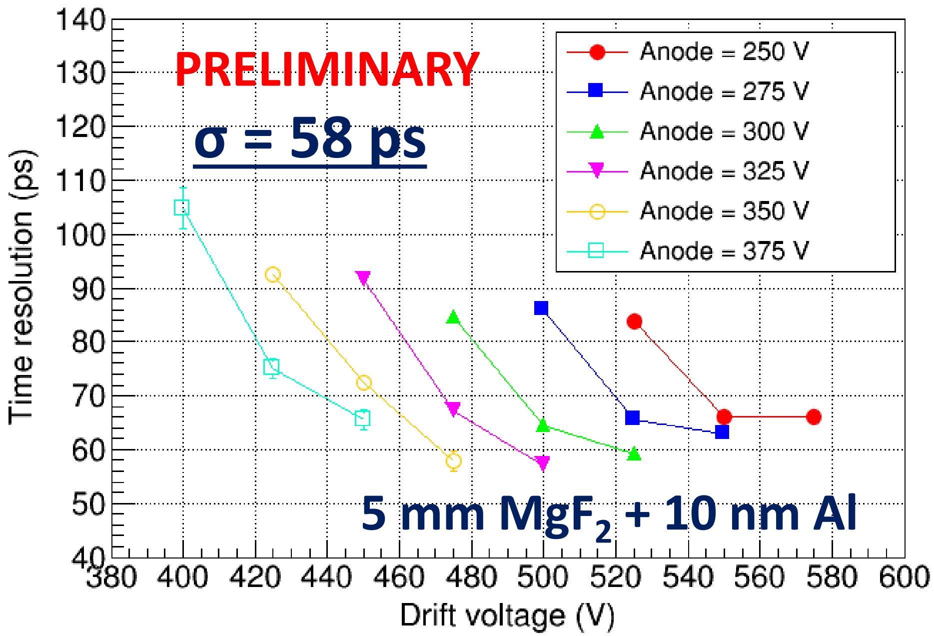
T. Schneider (CERN)

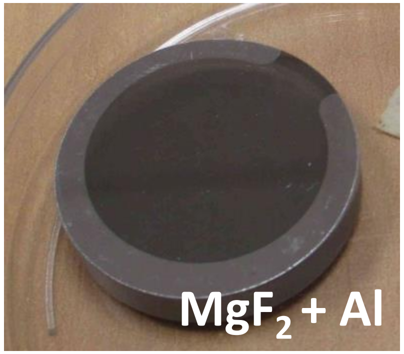
An efficient & robust photocathode against sparks & ion back-flow.

Robust photocathode: first results

Explored options:

- **Pure metallic (Cr/Al)**
- **CsI + protection layer**
- **CVD or secondary emitter**
- **DLC**





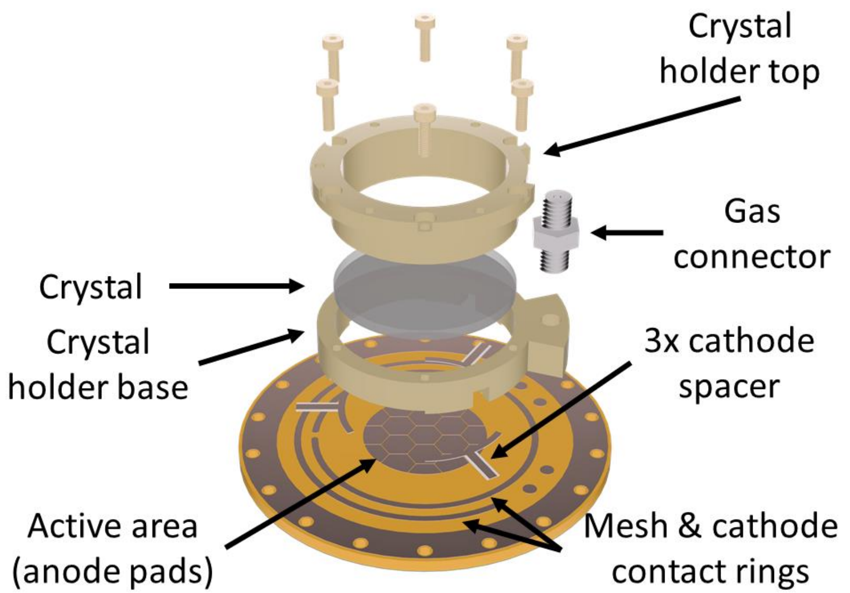
M. Kebbiri (CEA)

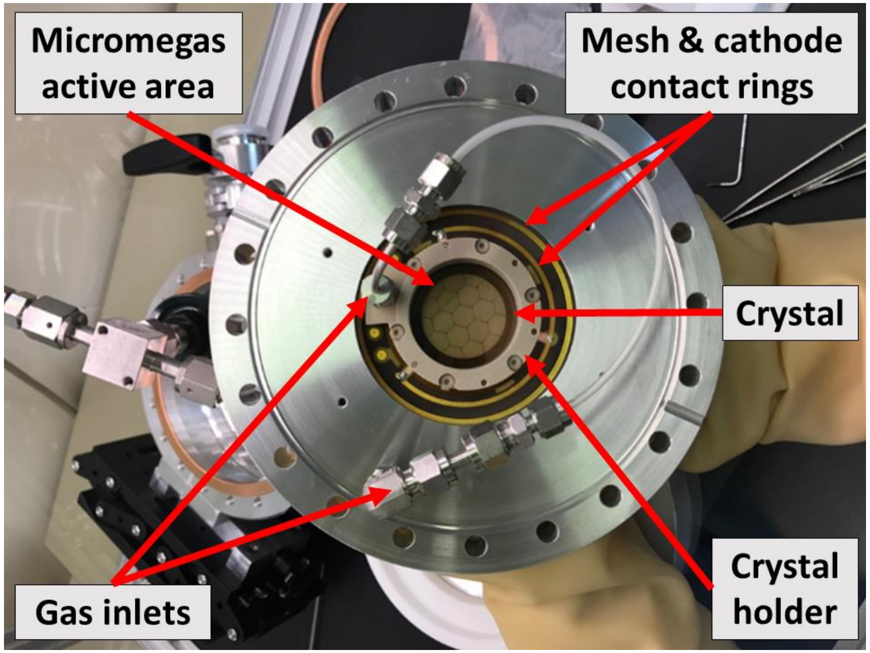
Y. Zhou (USTC)

First results:

- **Metallic**: **58 ps** & **2.2 phe/μ**
- **DLC** (preliminary, May 2018): **65 ps** & **2.4 phe/μ**

The Multipad detector

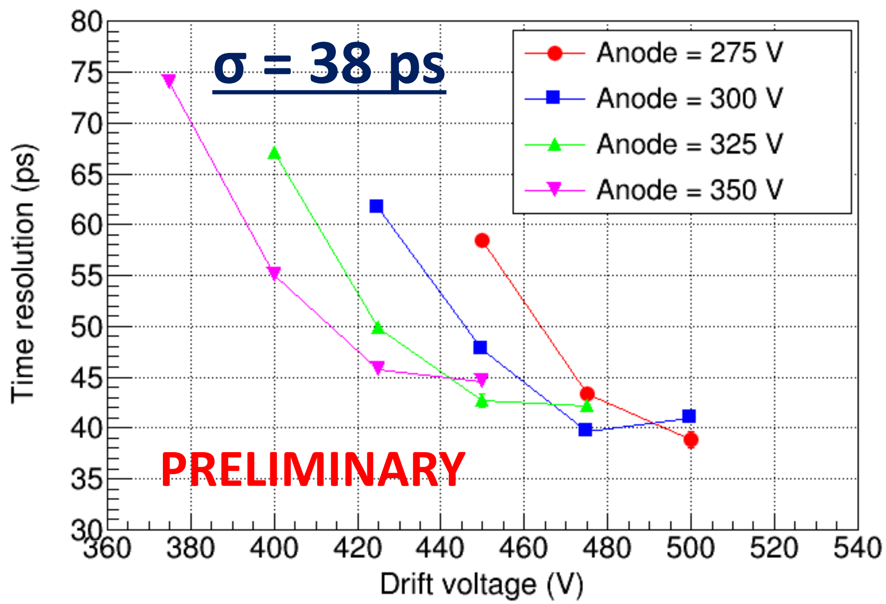


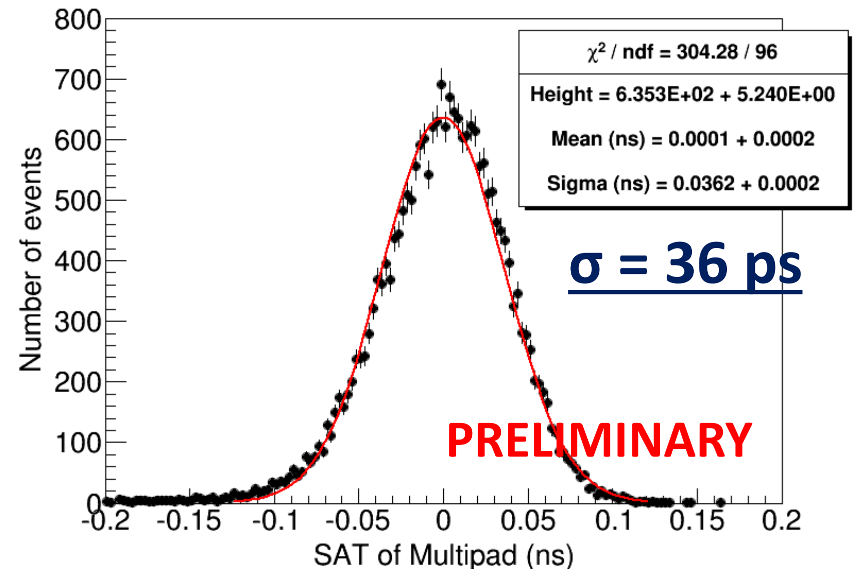


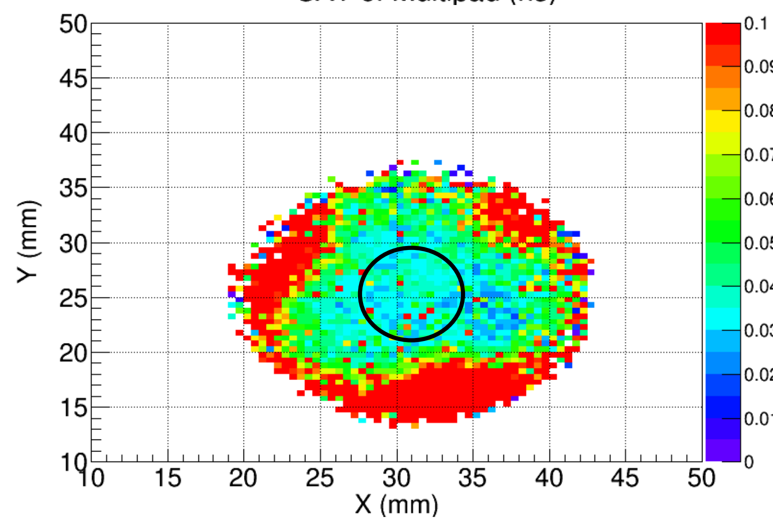
F. Brunbauer (CERN)

- 35 mm diameter area, 19 pads.
- High Voltage & signals extracted from the backside.
- Oct 2017 beam-test: single-pad & MCP centered btw 3 pads.

The Multipad detector: first results

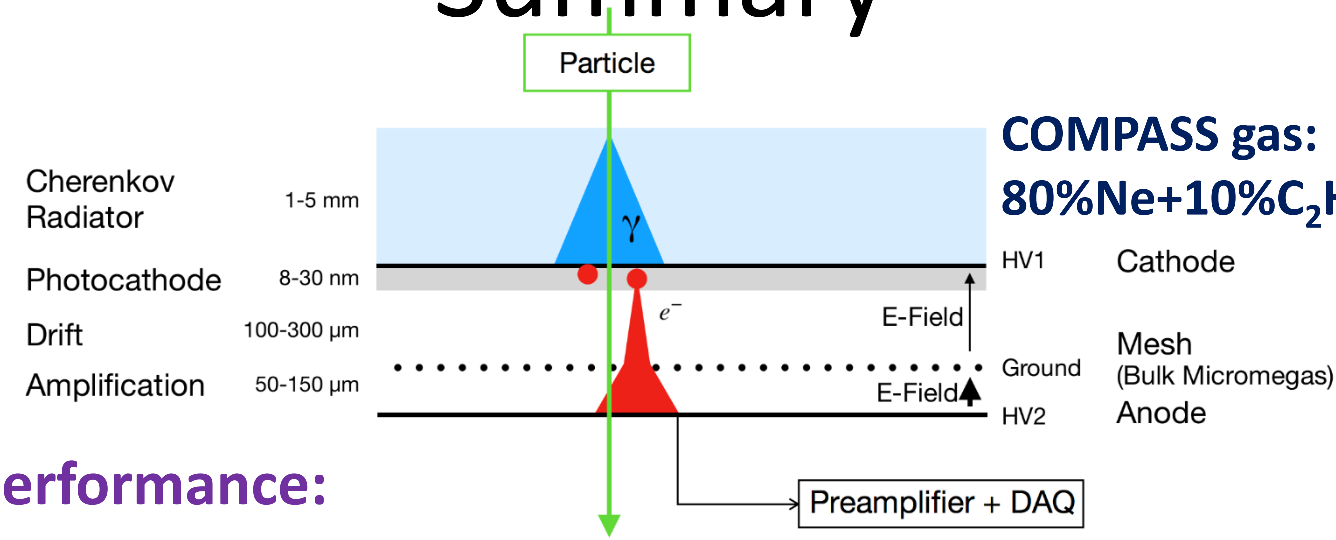






- Single-pad scan: **38 ps**
- Three pad analysis: **36 ps**

Summary



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

Timing performance:

- Single photo-electrons: **76 ps**.
- 150 GeV muons: **24 ps** & **10.4 phe/μ**

R&D to build a demonstrator:

- **Readout:** Resistive Micromegas (**28-41 ps**), long runs with pions.
- **Photocathode:** metallic (**55 ps, 2.2 phe/μ**), DLC (**65 ps**, **2.4 phe/μ**).
- **Scaling-up**: large area & multi-channels with Multipad (**36 ps**).

Back-up slides

Optimization parameters

Crystal:

- Different Thicknesses of MgF2 (2,3,5mm)
- Different Material

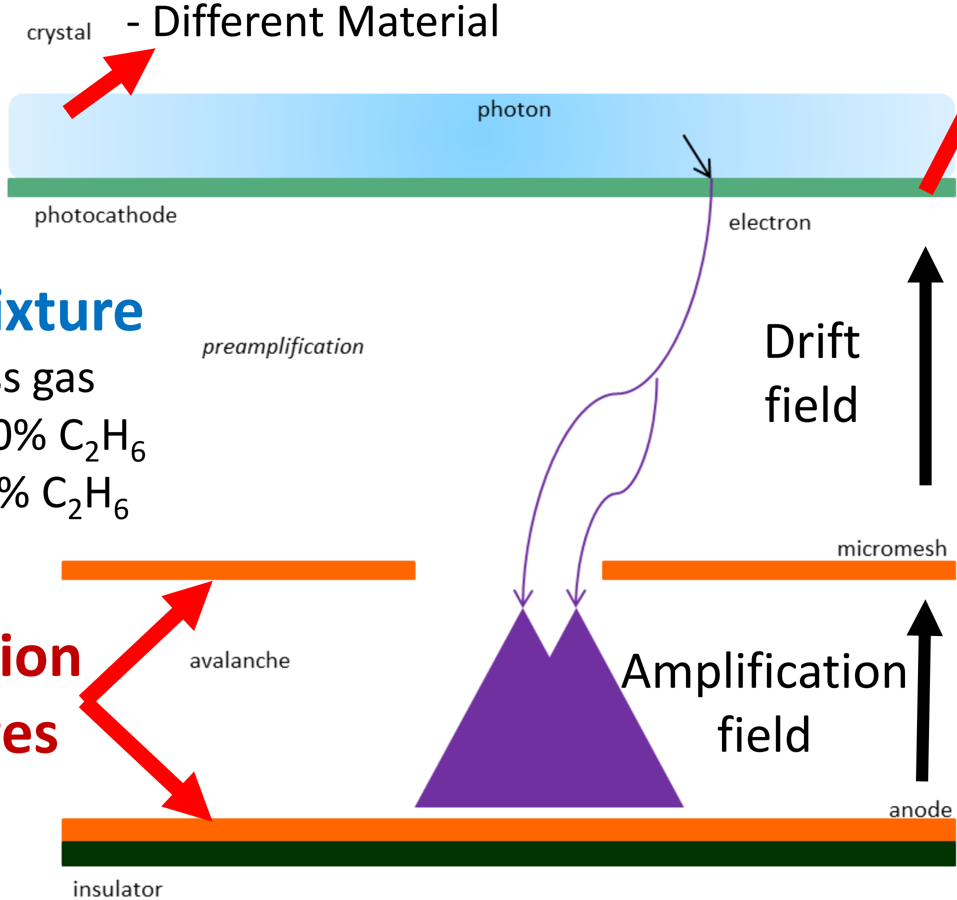
Photocathode:

1) CsI and different:
- producer (CERN, Saclay)
- thicknesses (11, 18, 25, 36nm)
- metallic interface (Al, Cr) & thicknesses (Cr 3, 5.5nm)

2) Pure metallic
- Al(8nm), Cr (10,15,20nm)
- Diamond, B-doped Diamond

Gas Mixture

- Compass gas
- CF4 + 10% C_2H_6
- Ne + 20% C_2H_6



Operation voltages

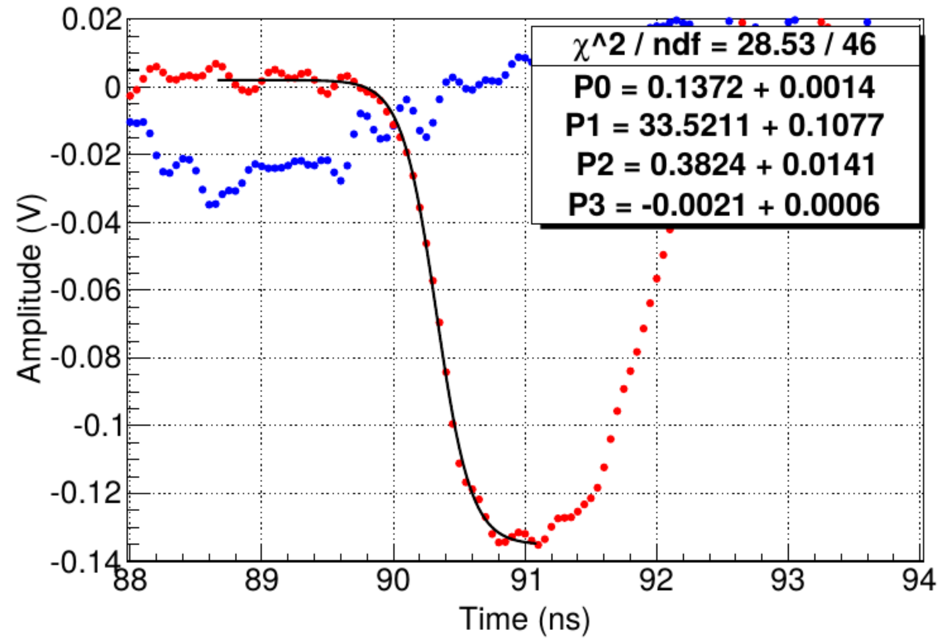
Micromegas:

- standard bulk
- bulk with 6 pillars
- thin mesh bulk
- Resistive (different values)

E. Oliveri (CERN)

Pulse analysis

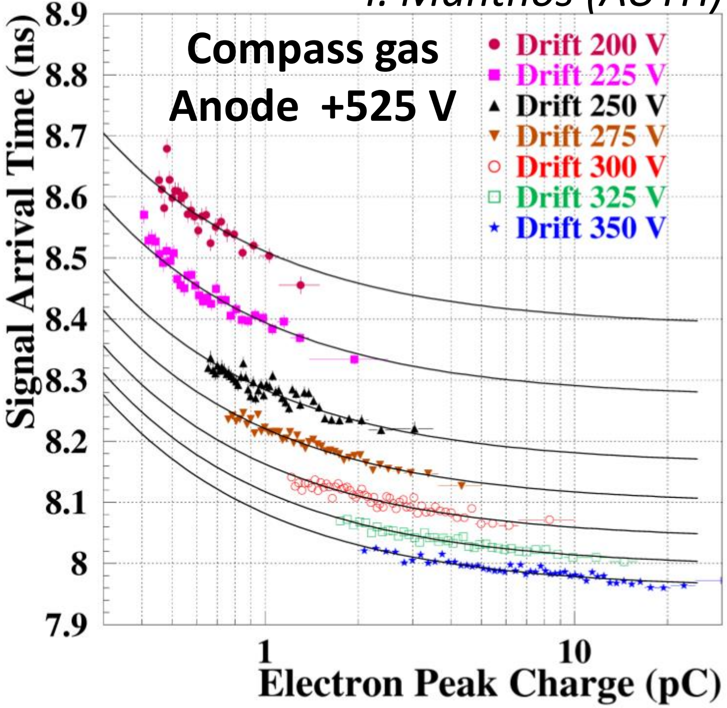
- **Cubic interpolation** (4 points) at a fix value of the leading edge (20%-40% CF).
- Fitting the whole leading edge to a **sigmoid function** & then calculating the time at 20-40% CF.

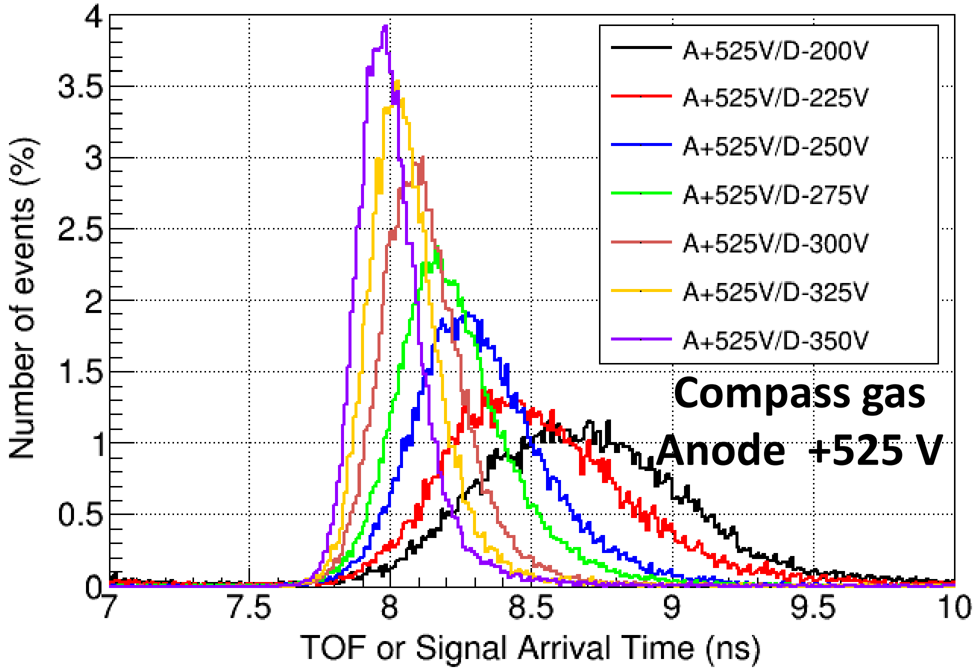


$$V(t) = \frac{P_0}{1 + e^{-P_2 \times (t - P_1)}} + P_3 \qquad t_z = P_1 - \frac{1}{P_2}\, log\left[\frac{P_0}{y_0 - P_3} - 1\right]$$

Results of laser tests: SAT vs amplitude

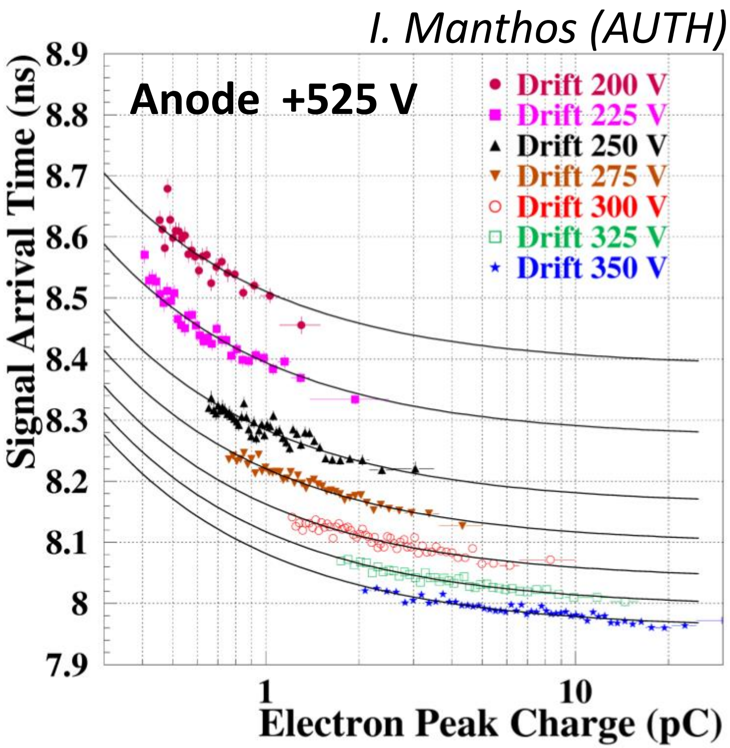
I. Manthos (AUTH)

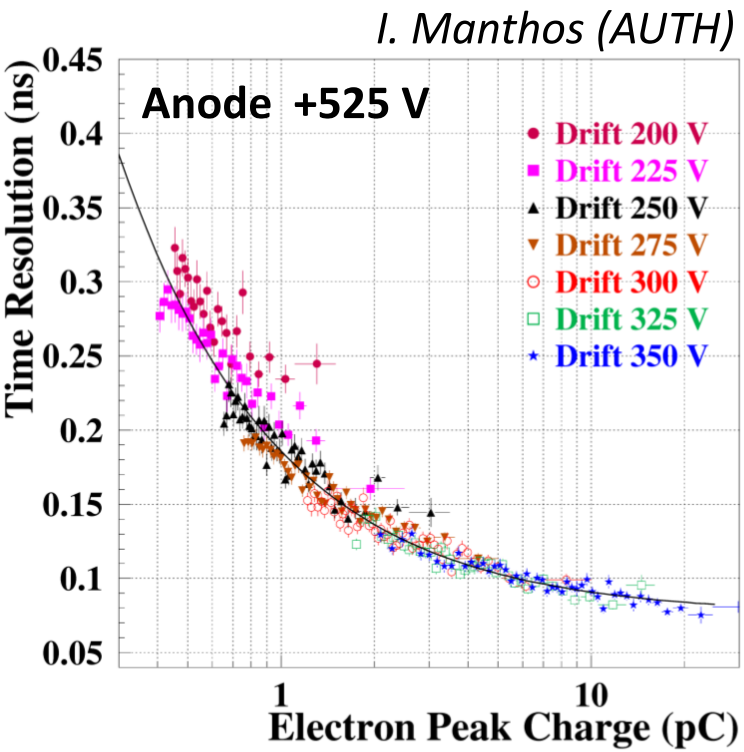




- TOF (Signal Arrival Time) distribution shows a tail at high values.
- This tail is a result of the correlation btw TOF & pulse amplitude.

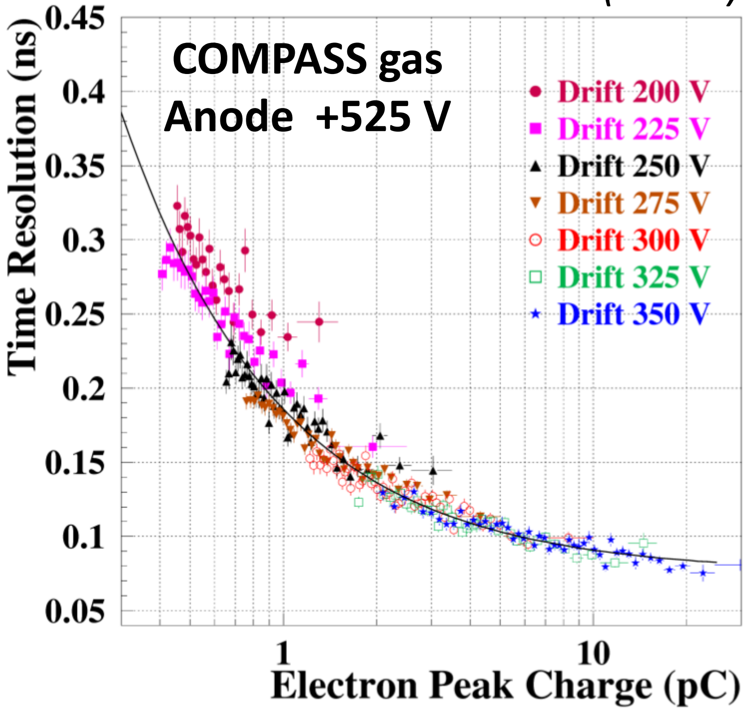
Results of laser tests: SAT vs amplitude

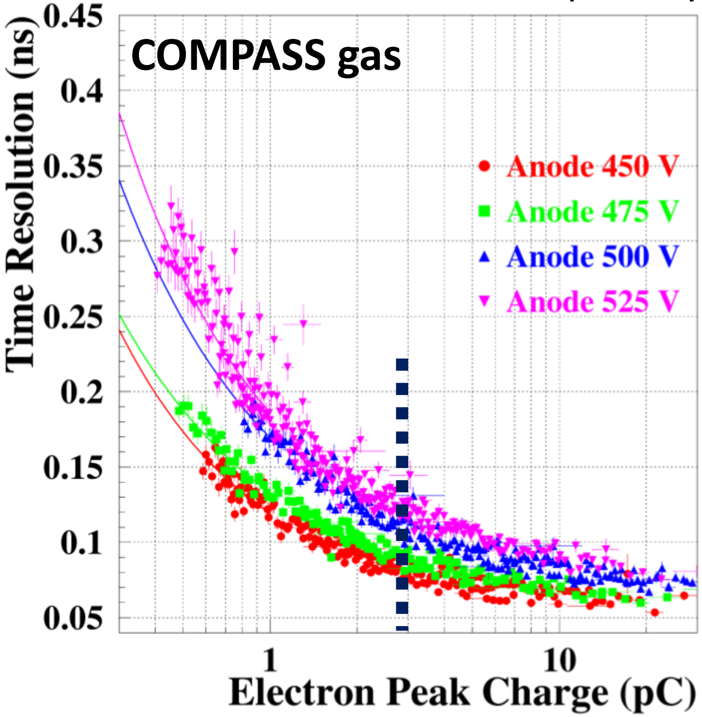




- TOF (Signal Arrival Time) distribution shows a tail at high values.
- This tail is a result of the correlation btw TOF & pulse amplitude.
- And a correlation btw the time resolution & pulse amplitude.

Results of laser tests: SAT vs amplitude

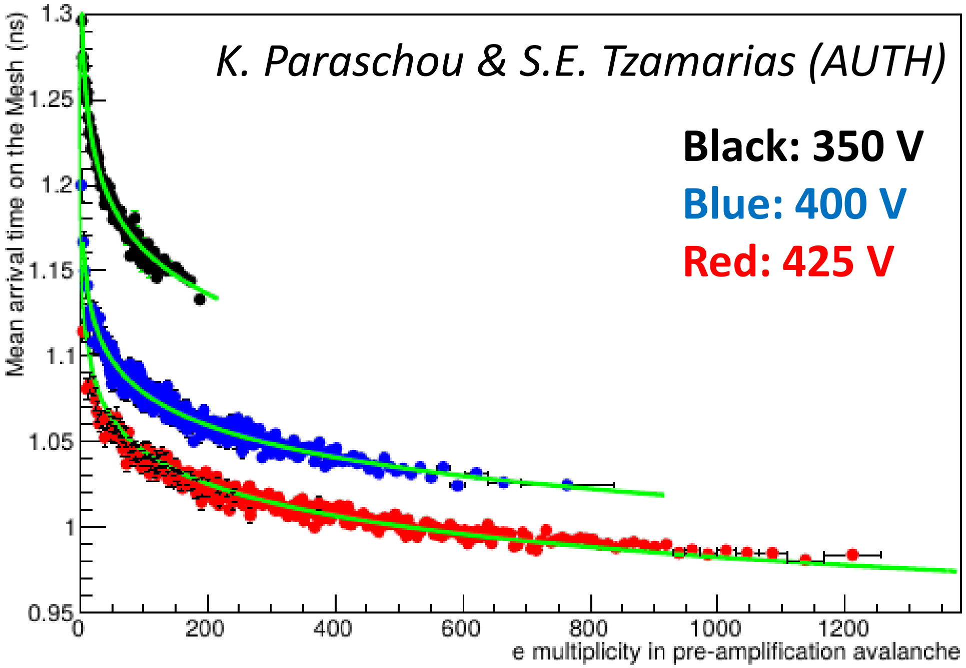


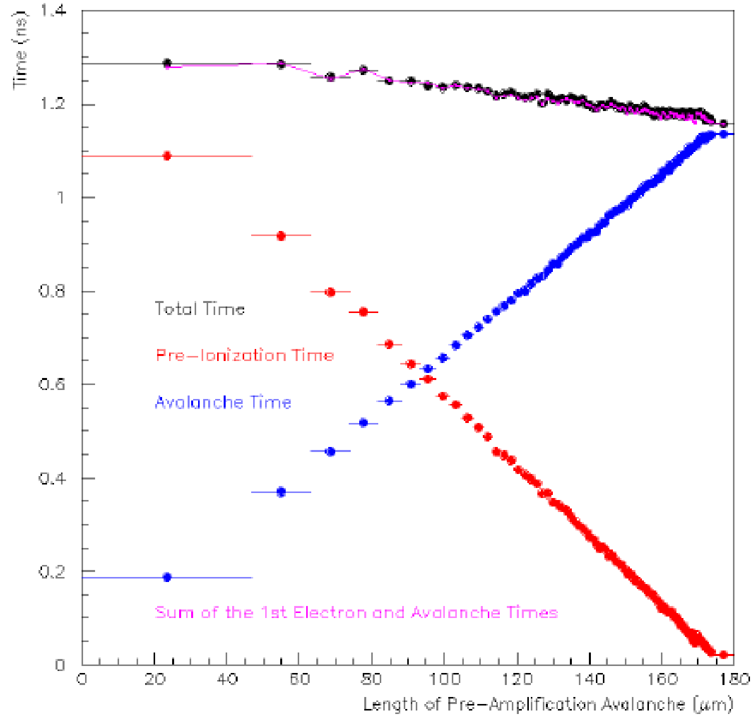


Signals of a given amplitude:

- have **the same** time resolution, even for different drift field.
- show **a better** time resolution, if the anode voltage is lower.

Simulation of the detector response

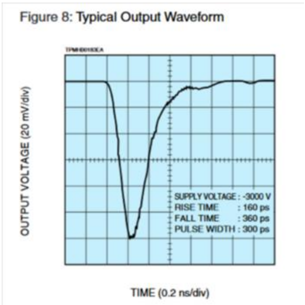


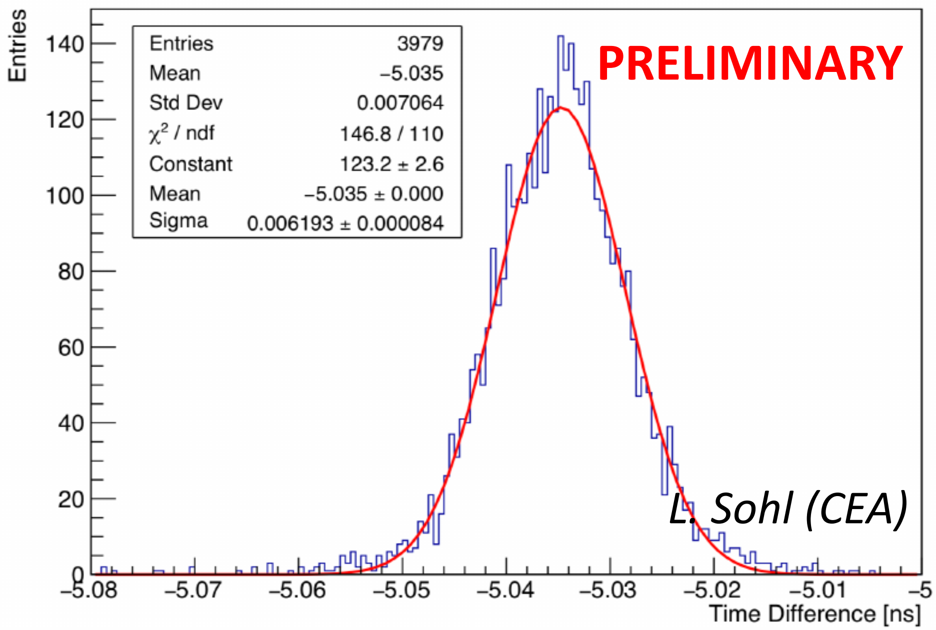


- The observed effects are due to the dependence of the effective drift velocity of primary photoelectrons with the distance at which the first ionization happens.

The timing reference during beam tests

- Two Hamamatsu MCP PMTs used (Model R3809U-50).
- Time resolution < 5 ps





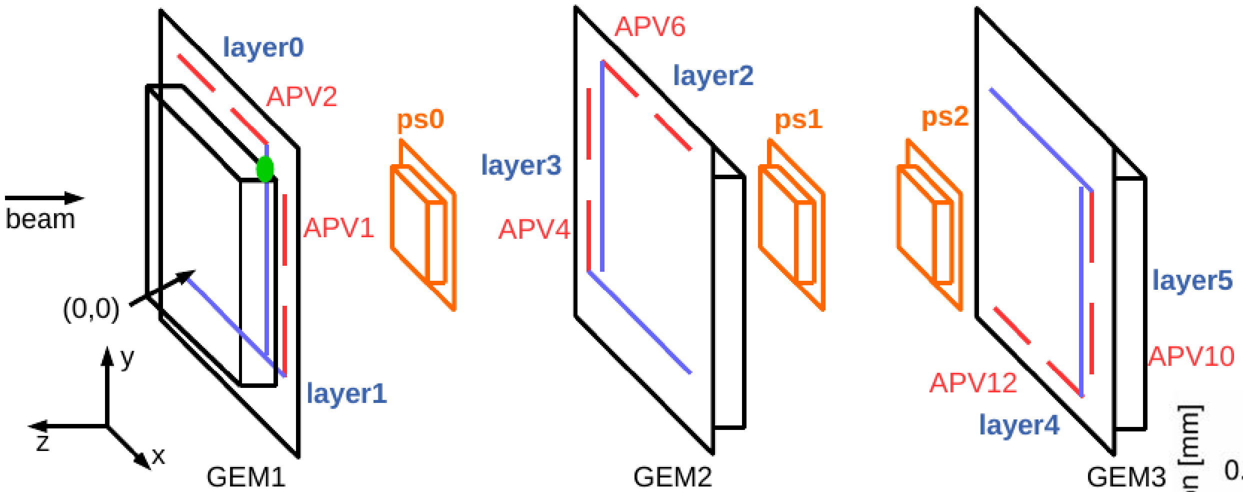
σ_{TOF} = 6.19 ± 0.08 ps

σ_{MCP} = 4.38 ± 0.06 ps

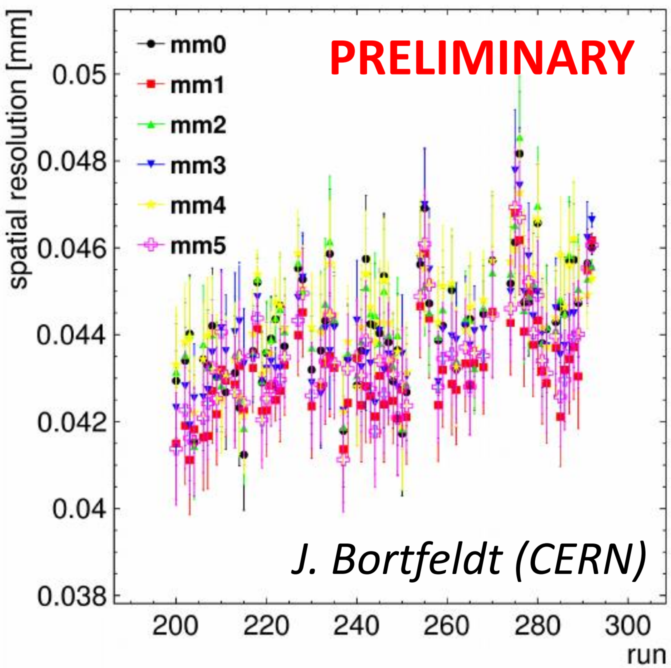
July 2017 Beam tests

MCP_1 & MCP_2 coincidence

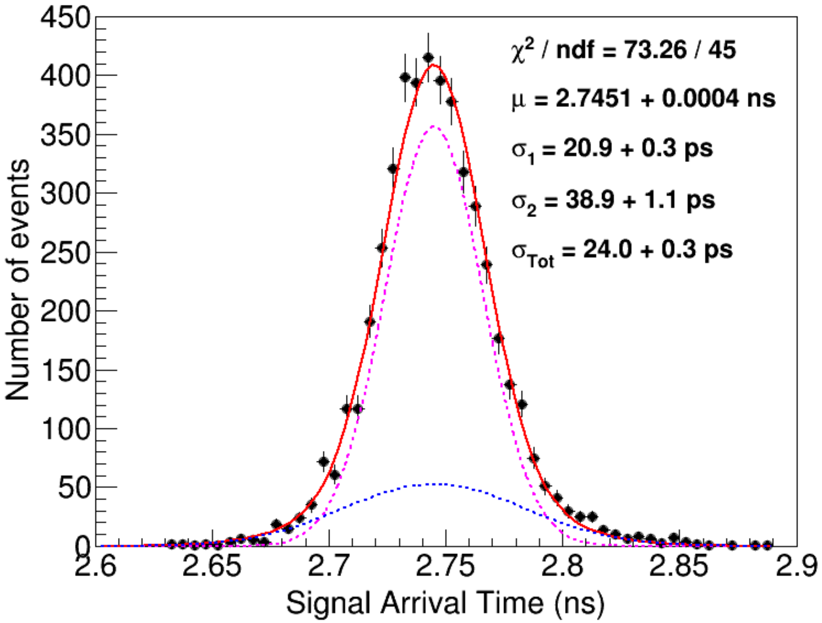
The tracking system

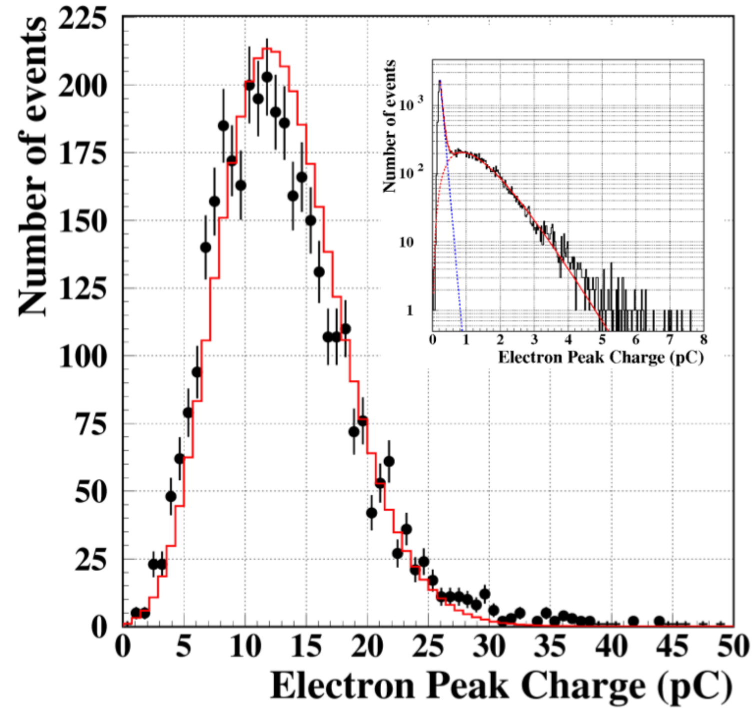


- Three triple-GEMs detectors.
- Combinatorial Kalman filter based tracking algorithm.
- Spatial resolution < 50 µm.



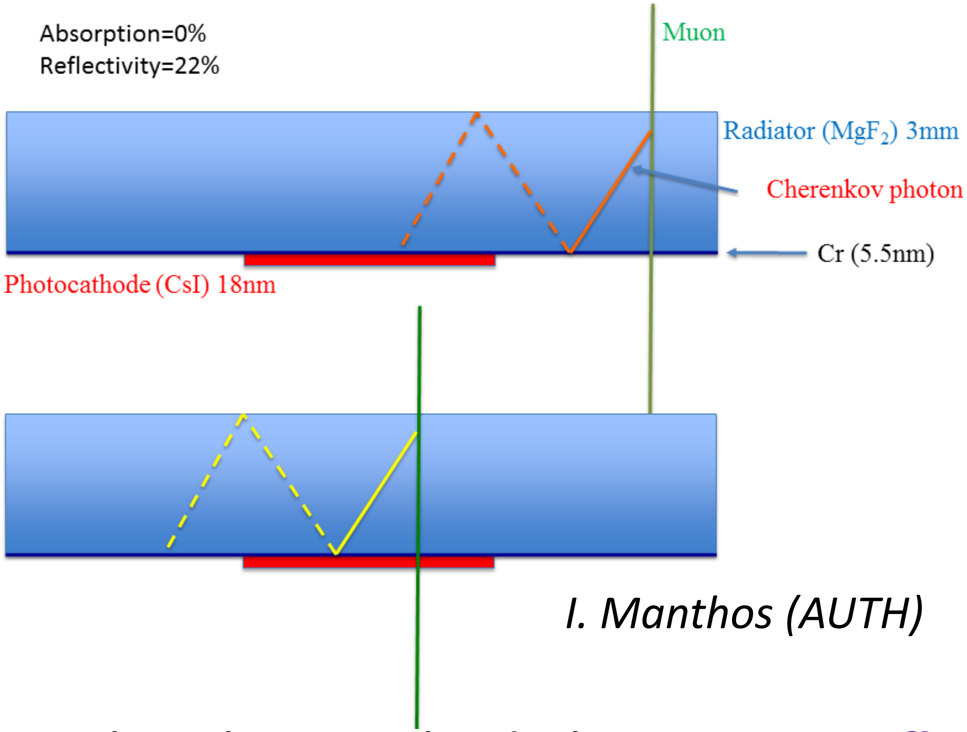
Beam tests at CERN SPS H4: results

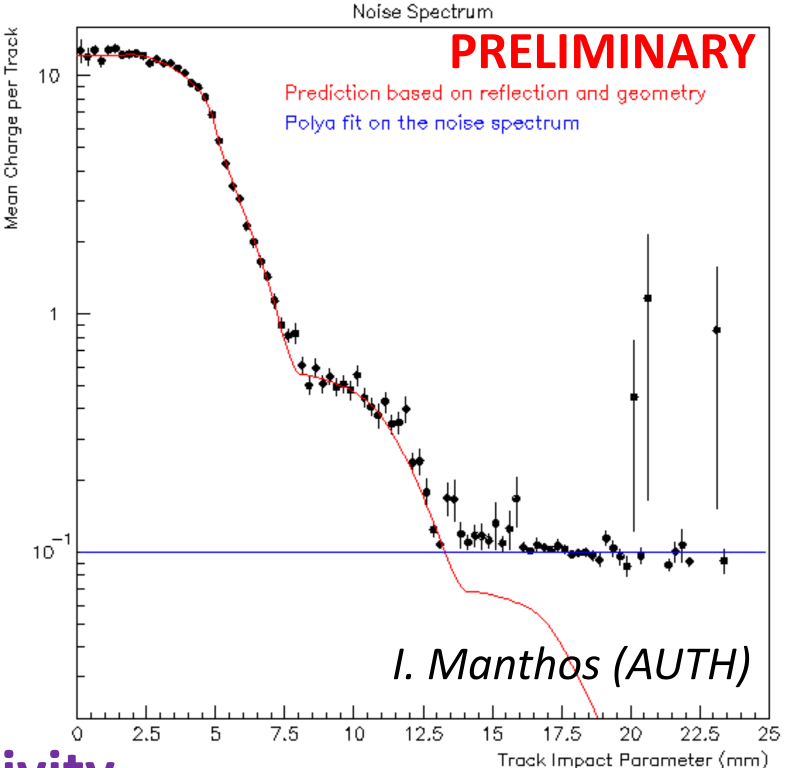




- Time resolution for 150 GeV muons: **24 ps**
- Optimum operation point: Anode +275V / Drift – 475V.
- Mean number of photoelectrons per muon = **10.4 ± 0.4**
- Results repeated in two different beam campaigns.

First results of large area trigger runs

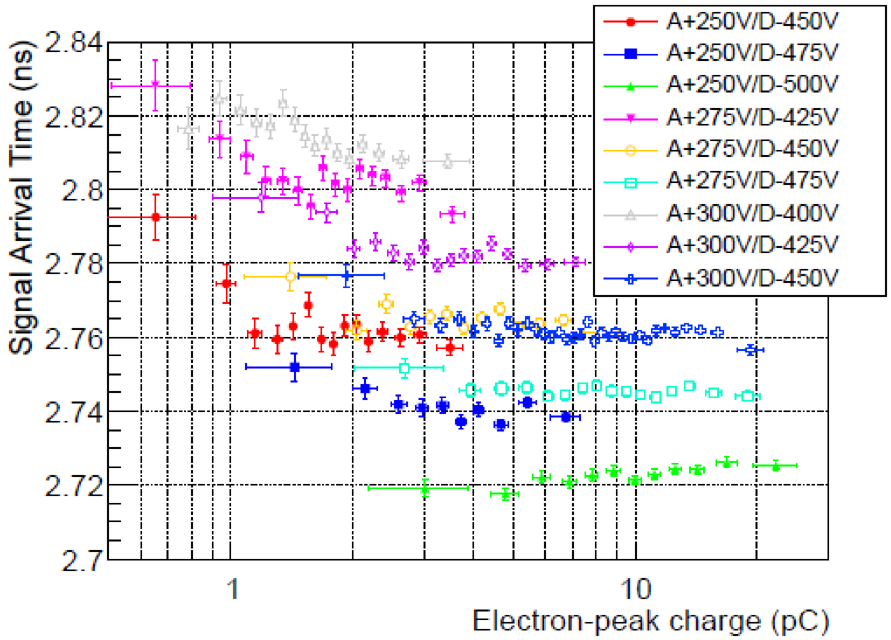


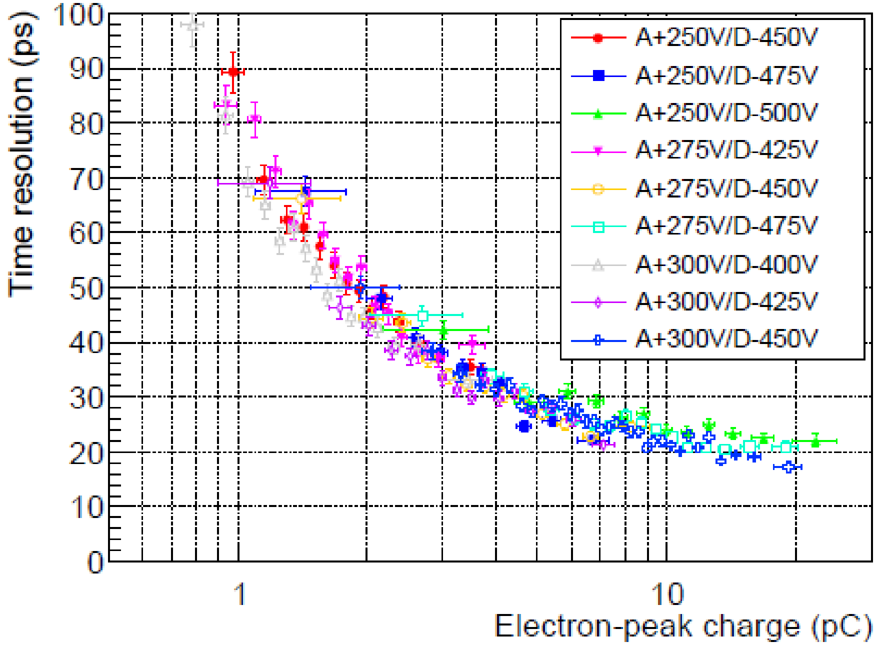


- The photocathode has a **22% reflectivity**.
- UV light from muons outside the active area may be detected.

More details: "A detailed study of the PICOSEC response to MIPs: number of photoelectorons and timing resolution" by I. Manthos (RD51-WG2 group, 15th Dec).
https://indico.cern.ch/event/676702/contributions/2808894/attachments/1576108/2488913/rd51_manthos_1217.pdf

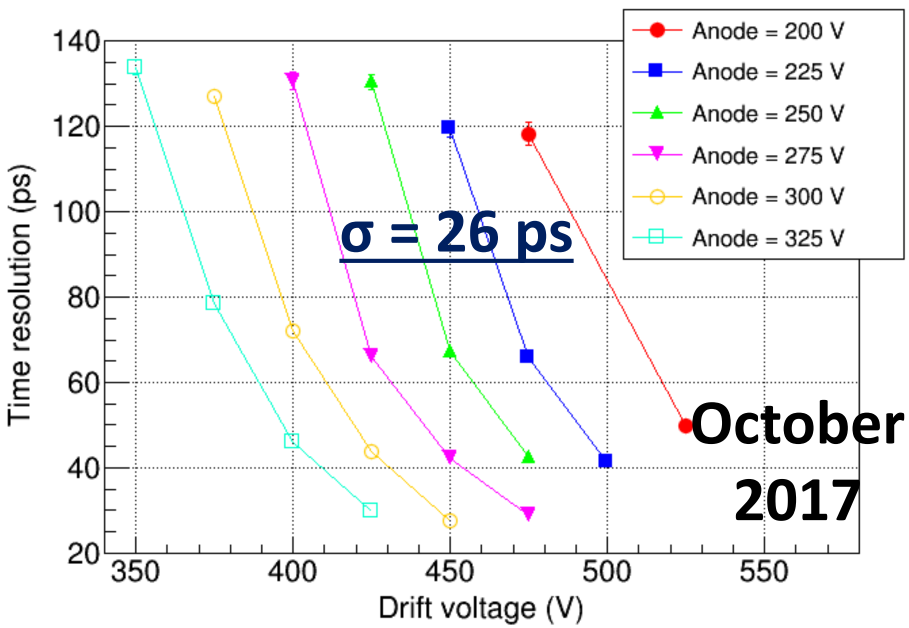
Beam tests at CERN SPS H4: results

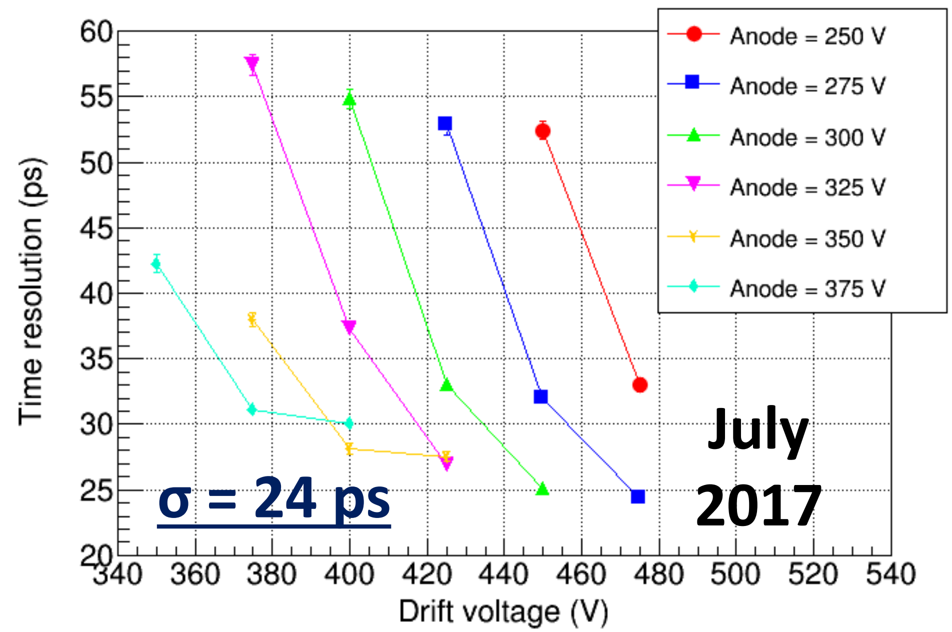




- No dependence btw SAT and electron-peak amplitude.
- The time resolution improves with the amplitude, posibly correlated to the gain in the first amplification stage.

Beam tests at CERN SPS H4: results





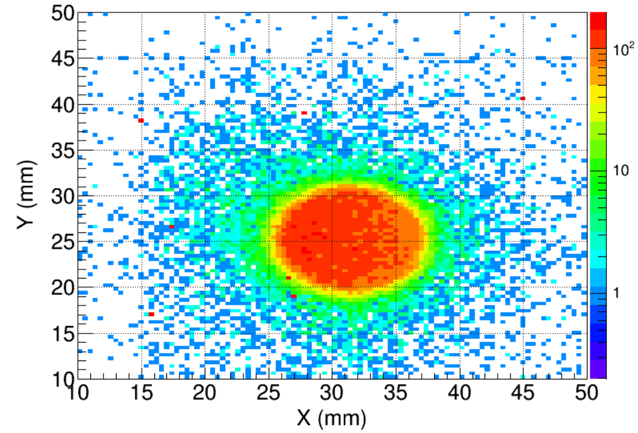
- Time resolution for 150 GeV muons: **24 ps**
- Optimum operation point: Anode +275V / Drift – 475V.
- Mean number of photoelectrons per muon = **10.4 ± 0.4**
- The same result obtained in two different beam campaigns.

Multipad: MCP & Pads

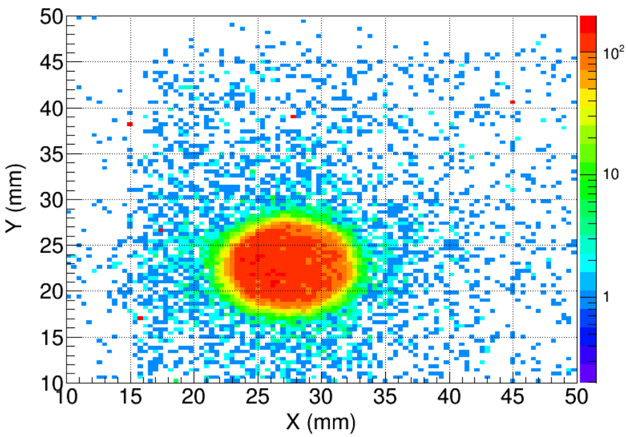
Distribution center for signals > 50 mV (MCP) or >100 mV (Pads).

Element	X (mm)	Y (mm)
MCP	31.16	25.33
Pad 10	27.53	22.73
Pad 9	36.01	23.97
Pad 5	30.14	30.28

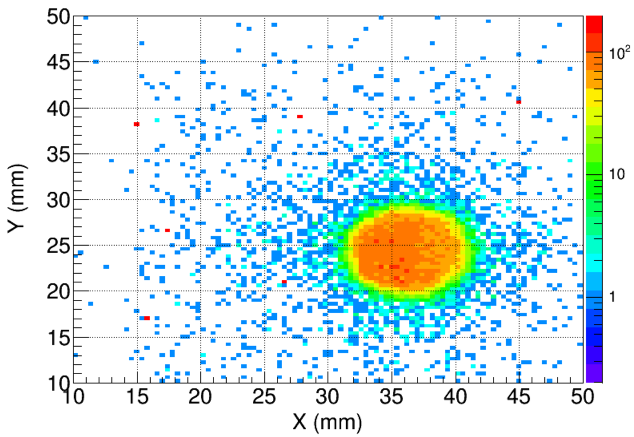
MCP



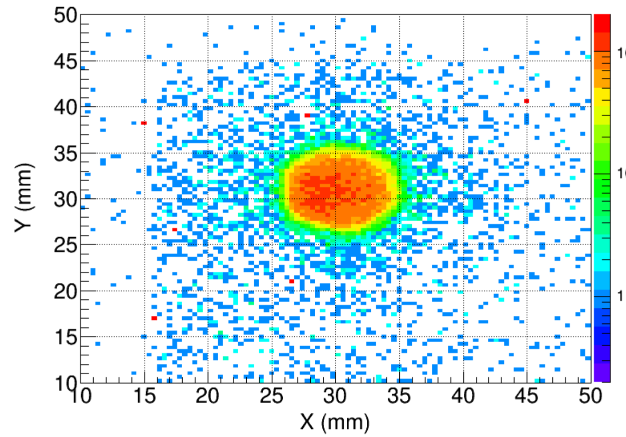
Pad 10



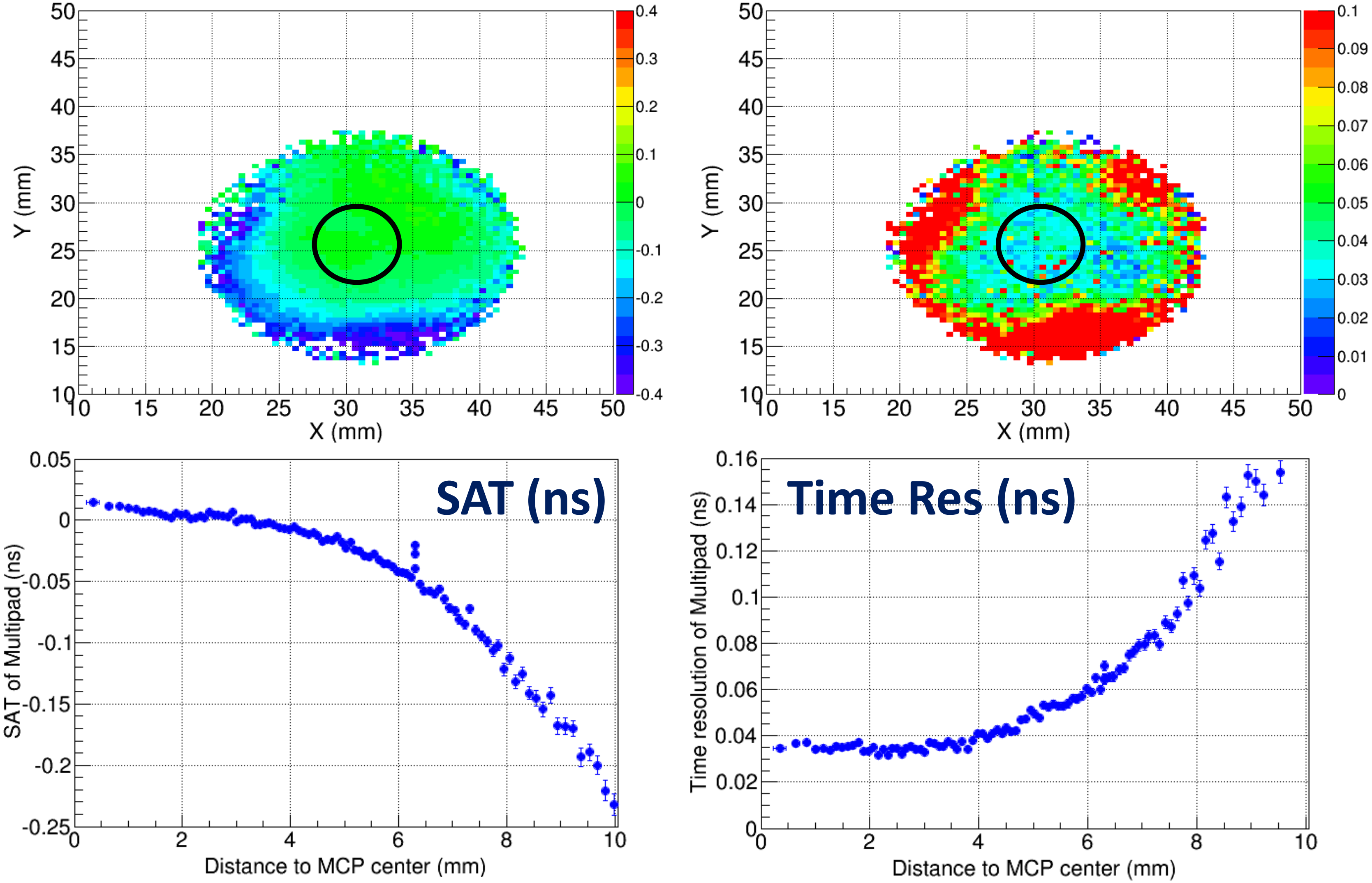
Pad 9



Pad 5



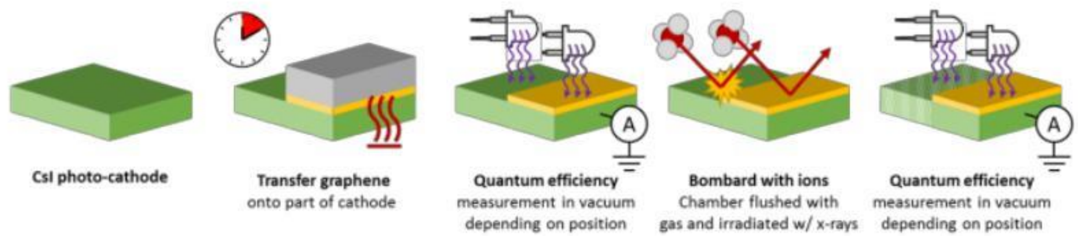
Multipad detector: first results



Robust photocathodes

CsI protection layers:

- PC coating at the Thin Film & Glass Lab at CERN.
- Graphene shield @ CERN (P. Thuiner).

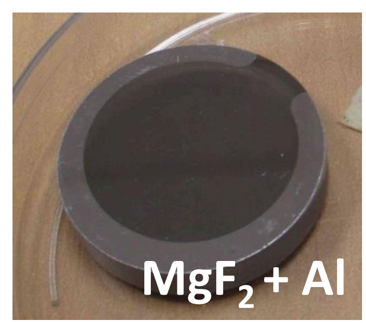


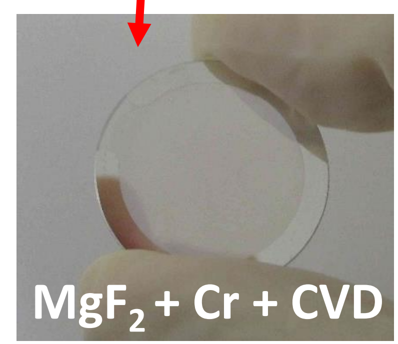
Diamond as photocathode or secondary emitter.

- Photocathodes from Saclay (Pomorski et al.): already tested on beam.
- Photocathodes from Russian Academy of Science (M. Negodaev): pieces production ready to go after specifications defined more precisely.
- Secondary emitter (J. Veloso et al): samples to be tested.

Pure metallic photocathodes:

- Chromium, aluminum.
- First samples already tested on beam.

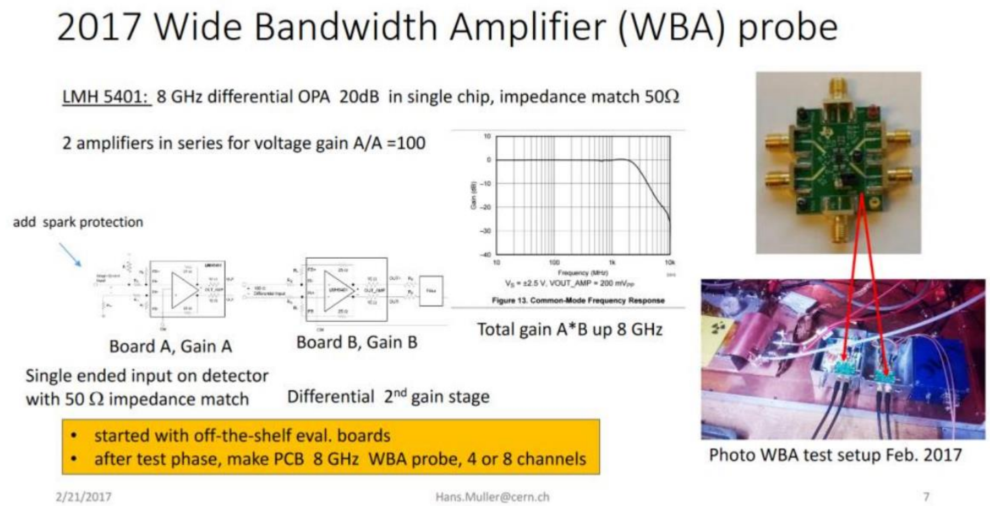




R&D on electronics

Amplifier

- CERN (H. Müller)
- Mini-Circuit
- Saclay (P. Legou)



H. Muller, Precise Timing Workshop, Feb 2017
https://indico.cern.ch/event/607147/contributions/2476905/attachments/1415650/2167318/Plans_fast_electronics_for_MPGD.pdf

Digitizer:

- Oscilloscope.
- SAMPIC.

D. Breton *et al.*,
NIMA **835** (2016) 51-60

SAMPIC: PERFORMANCE SUMMARY

		Unit
Technology	AMS CMOS 0.18μm	
Number of channels	16	
Power consumption (max)	180 (1.8V supply)	mW
Discriminator noise	2	mV rms
SCA depth	64	Cells
Sampling speed	1 to 8.4 (10.2 for 8 channels only)	GSPS
Bandwidth	1.6	GHz
Range (unipolar)	~ 1	V
ADC resolution	7 to 11 (trade-off time/resolution)	bits
SCA noise	< 1	mV rms
Dynamic range	> 10	bits rms
Conversion time	0.1 (7 bits) to 1.6 (11 bits)	μs
Readout time / ch @ 2 Gbit/s (full waveform)	450	ns
Single Pulse Time precision before correction	< 15	ps rms
Single Pulse Time precision after time INL correction	< 3.5	ps rms