PICOSEC

Charged particle timing at sub-25 ps precision with a Micromegas based detector

F.J. Iguaz

On behalf of PICOSEC collaboration

6th Beam Telescope Workshop, ETHZ, 17th January 2018

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The PICOSEC collaboration

- **IRFU/Saclay (France):** D. Desforge, I. Giomataris, T. Gustavsson, C. Guyot, F.J. Iguaz, M. Kebbiri, P. Legou, O. Maillard, T. Papaevangelou, M. Pomorski, P. Schwemling.
- **CERN:** J. Bortfeldt, F. Brunbauer, C. David, J. Frachi, M. Lupberger, H. Müller, E. Oliveri, F. Resnati, L. Ropelewski, T. Schneider, L. Sohl, P. Thuiner, M. van Stenis, P. Thuiner, R. Veenhof, S. White[1].
- **USTC (China):** J. Liu, B. Qi, X. Wang, Z. Zhang, Y. Zhou.
- **AUTH (Greece):** I. Manthos, V. Niaouris, K. Paraschou, D. Sampsonidis, S.E. Tzamarias,.
- **NCSR:** G. Fanourakis.
- **NTUA:** Y. Tsipolitis.
- **LIP:** M. Gallinaro.
- **IGFAE**: D. González-Díaz.

[1] Also University of Virginia.

Outline

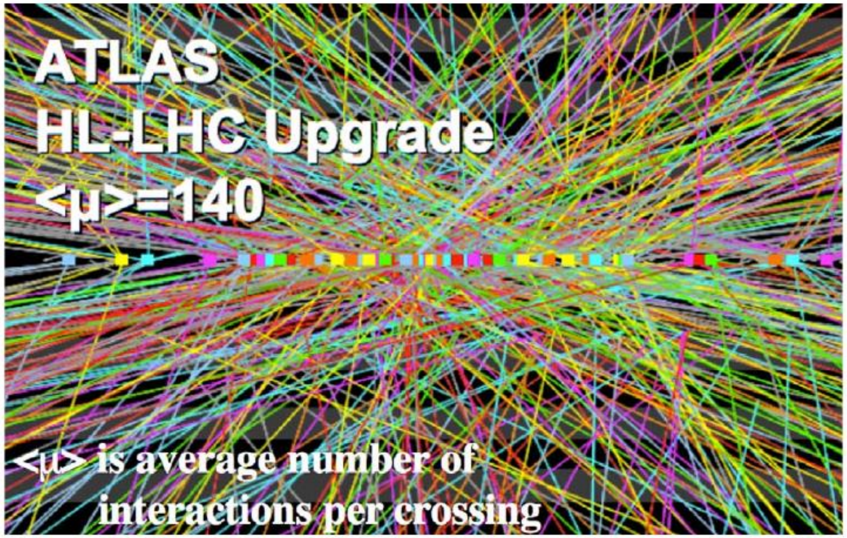
- The Picosec detection concept.
- Beam tests at CERN SPS H4.
- On going R&Ds for a demonstrator.
- Summary.

First article submitted to NIMA:
J. Bortfeldt *et al.*, *"PICOSEC: Charged particle timing at sub-25 picosecond precisión with a Micromegas based detector"*, **arXiv:1712.05256**

Motivation: why ~10 ps are interesting?

High Luminosity Upgrade of LHC:

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

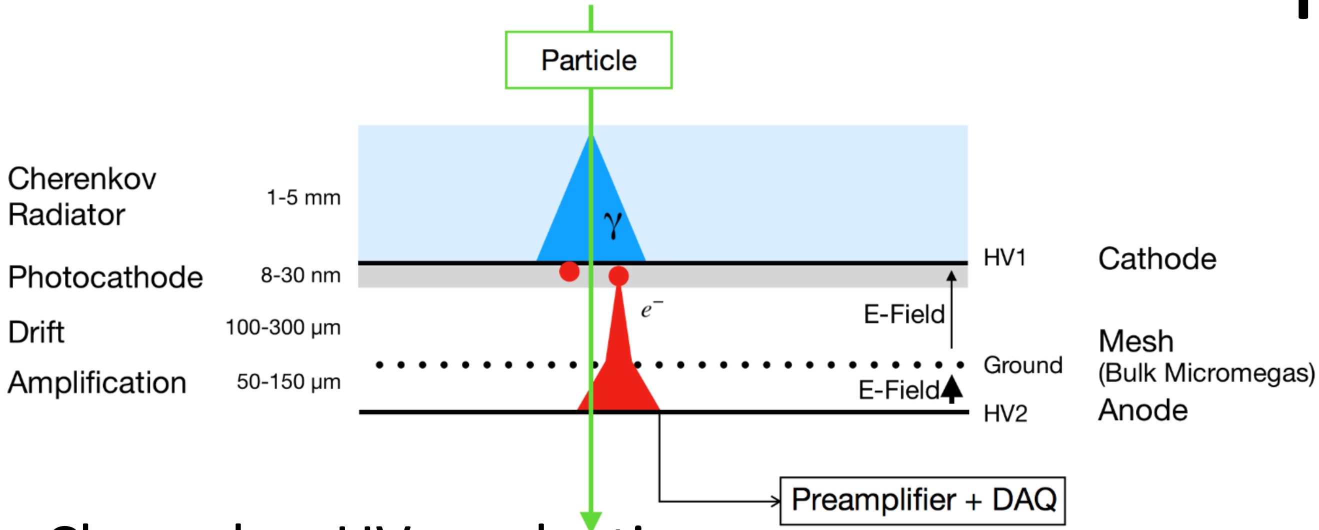


PID techniques: Alternatives to RICH methods, J. Va'vra, NIMA **876** (2017) 185-193, https://dx.doi.org/10.1016/j.nima.2017.02.075

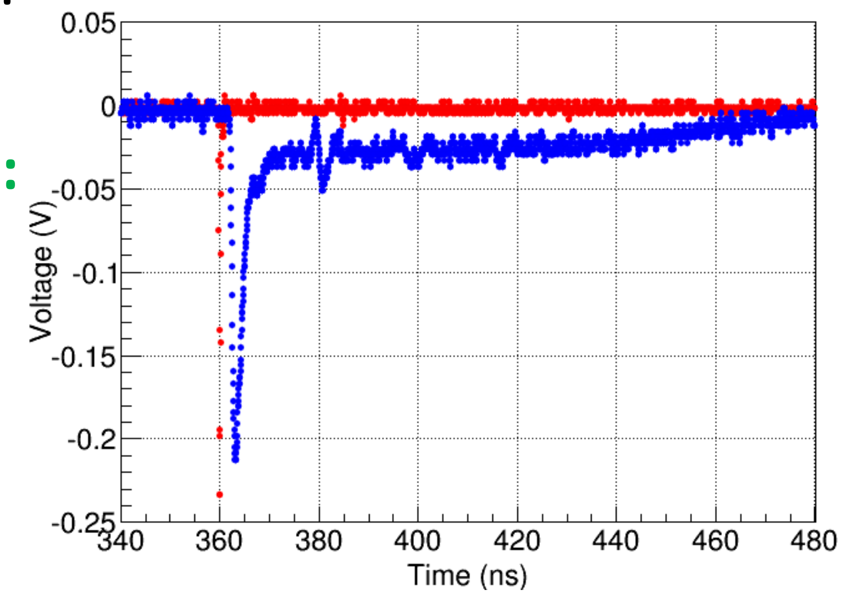
Extra detector requirements:

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

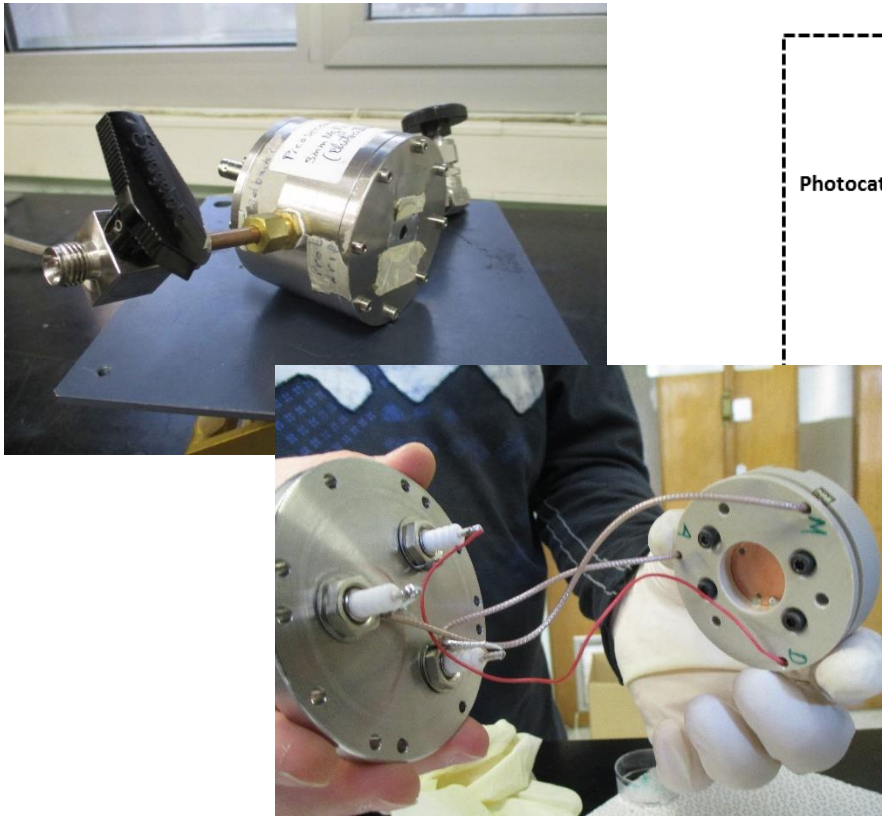
The PICOSEC detection concept

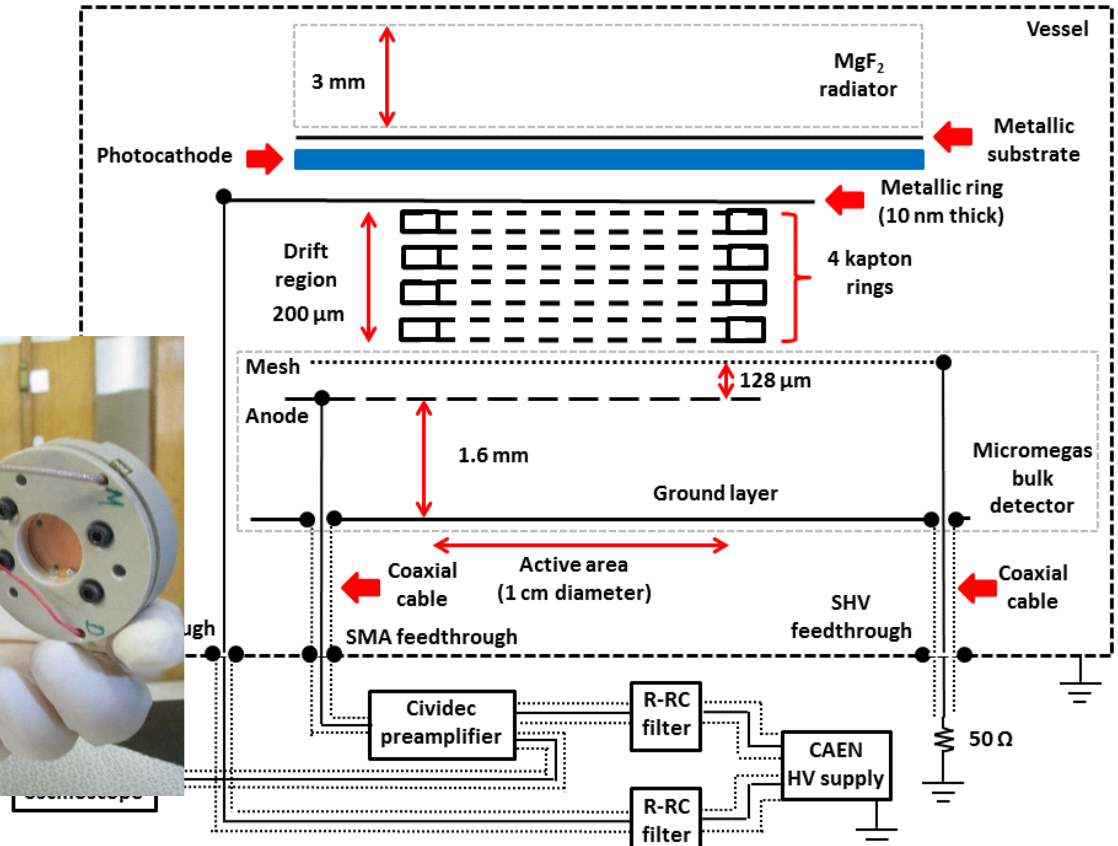


- **Radiator:** Cherenkov UV production.
- **Photocathode:** UV -> electrons.
- **Two-stage Micromegas (drift+amp):** electrons are amplified.
- Two signal components:
  - Fast: ***electron peak*** (~0.5 ns).
  - Slow: ***ion tail*** (~100 ns).



The first Picosec prototype



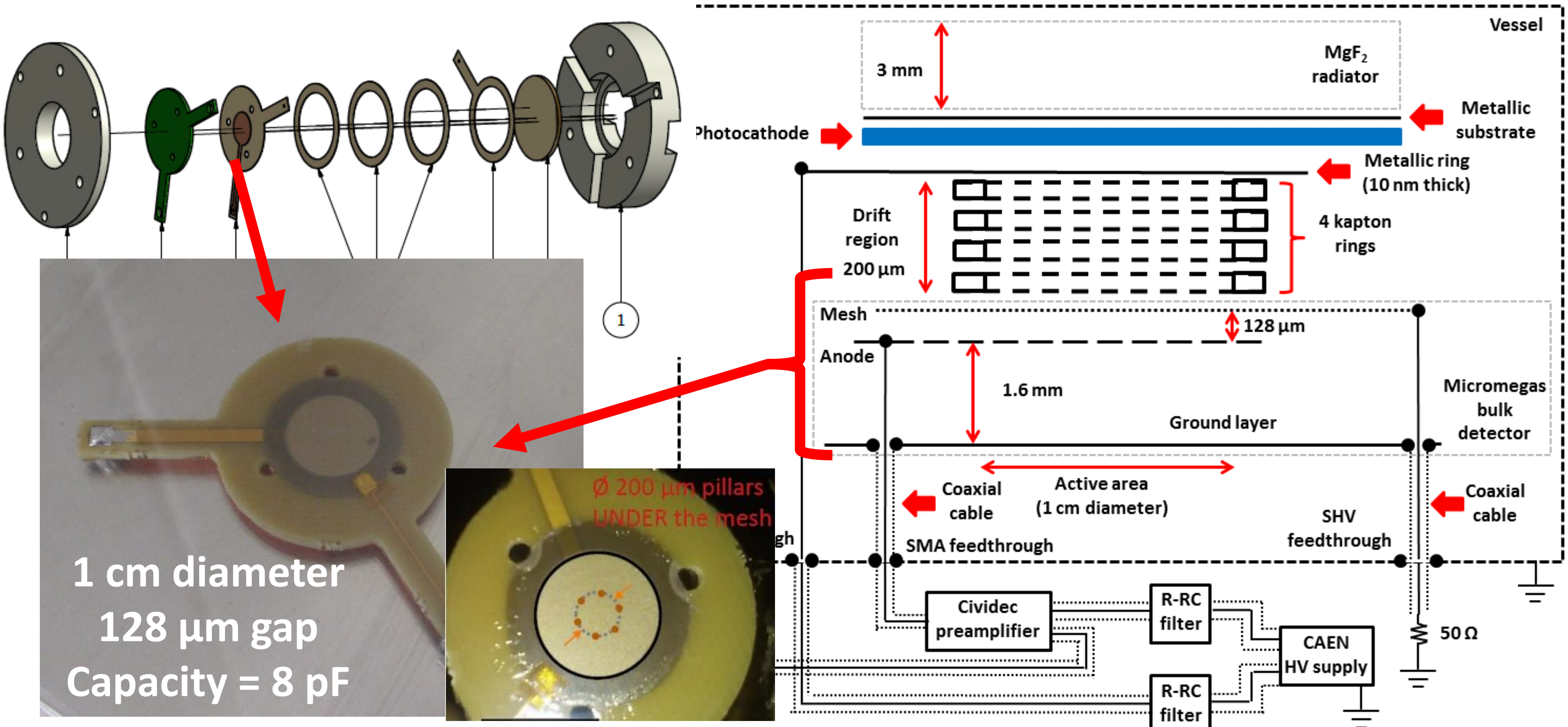


1 cm diameter active area

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

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

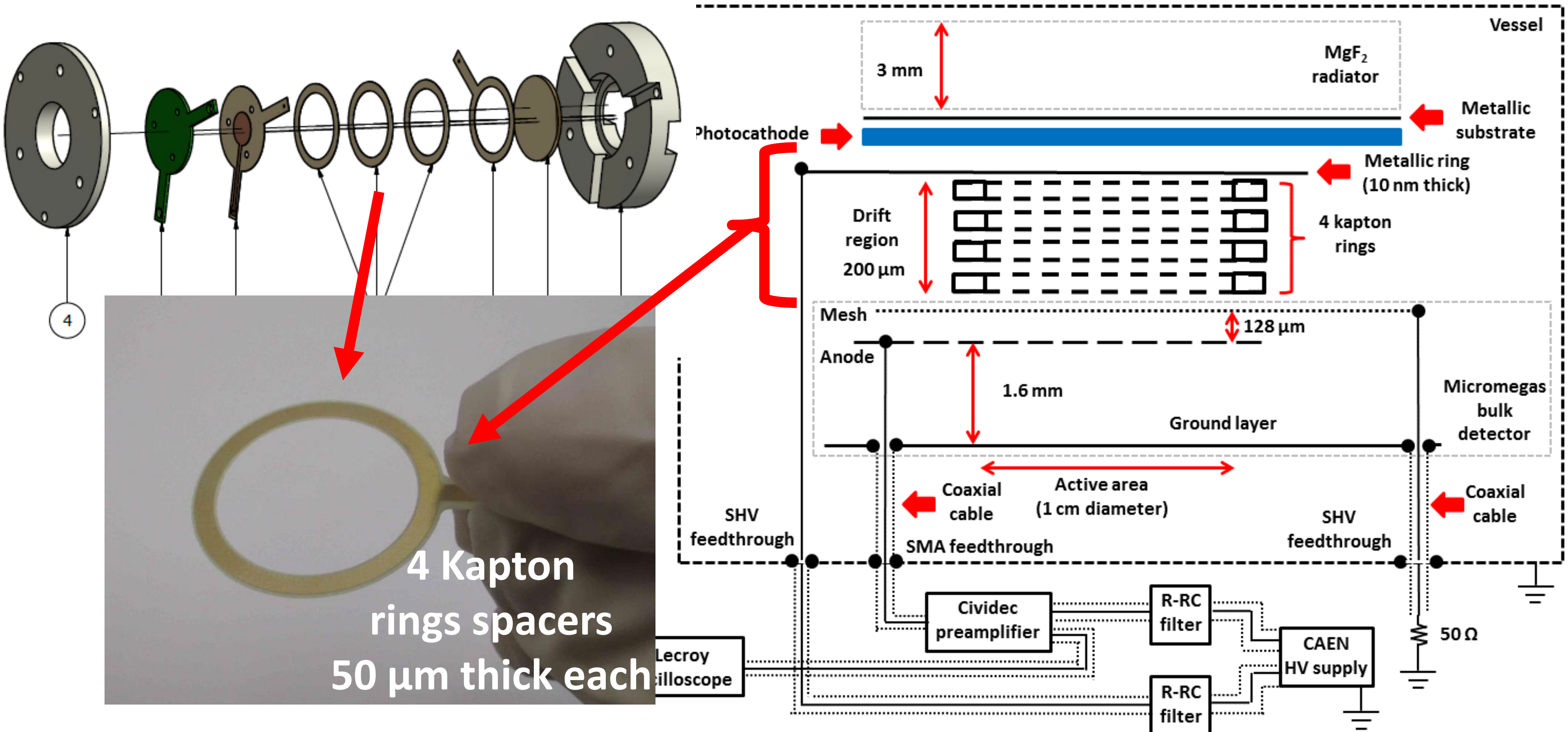
The first Picosec prototype



Main elements:

- Bulk MM readout (6 pillars).
- 4 kapton rings spacers -> 200 µm drift.
- Radiator + photocathode.

The first Picosec prototype



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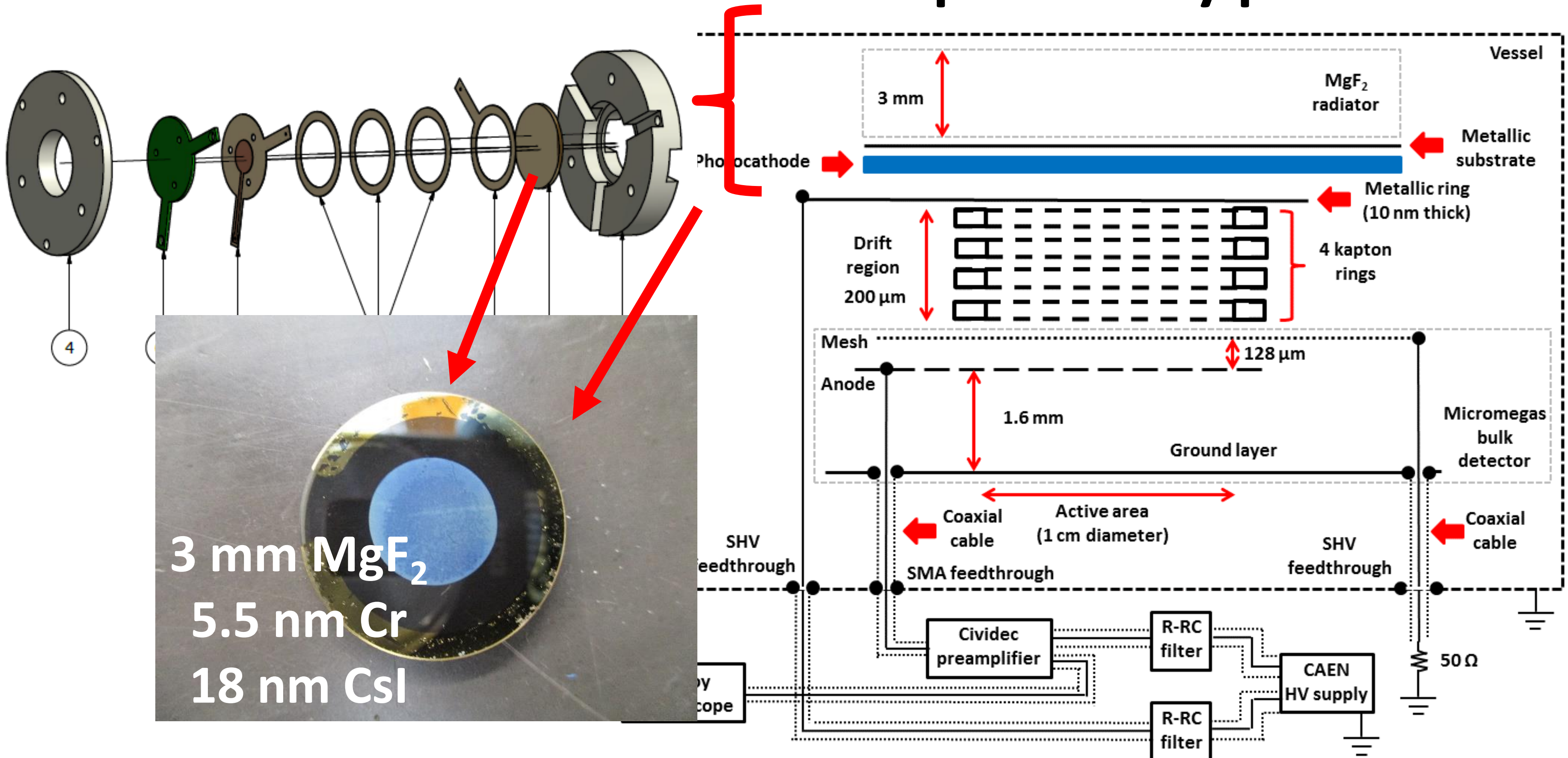

Main elements:

- Bulk MM readout (6 pillars).
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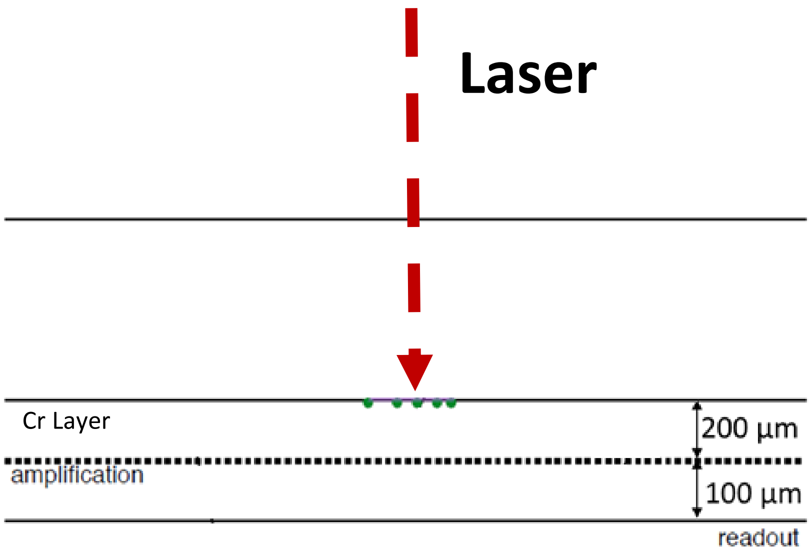
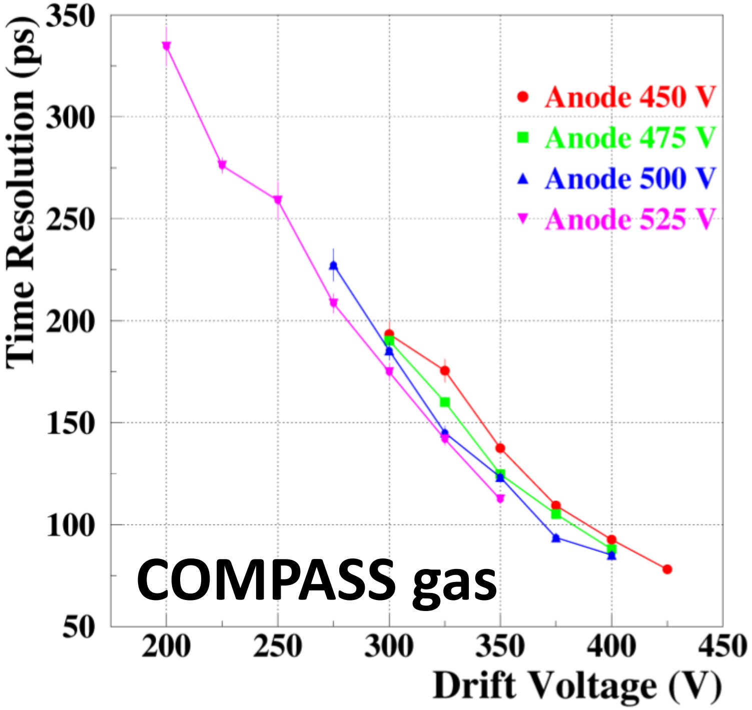
Timing for single-photoelectrons





- Pulsed laser at IRAMIS facility: **<u>267-288 nm wavelength</u>**.
- Split in two parts: fast photodiode (13 ps) & PICOSEC.
- Laser intensity reduced by electroformed nickel meshes.
- Time resolution for single photoelectrons: **76.0 ± 0.4 ps**
- Further improvement expected for higher drift fields.

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

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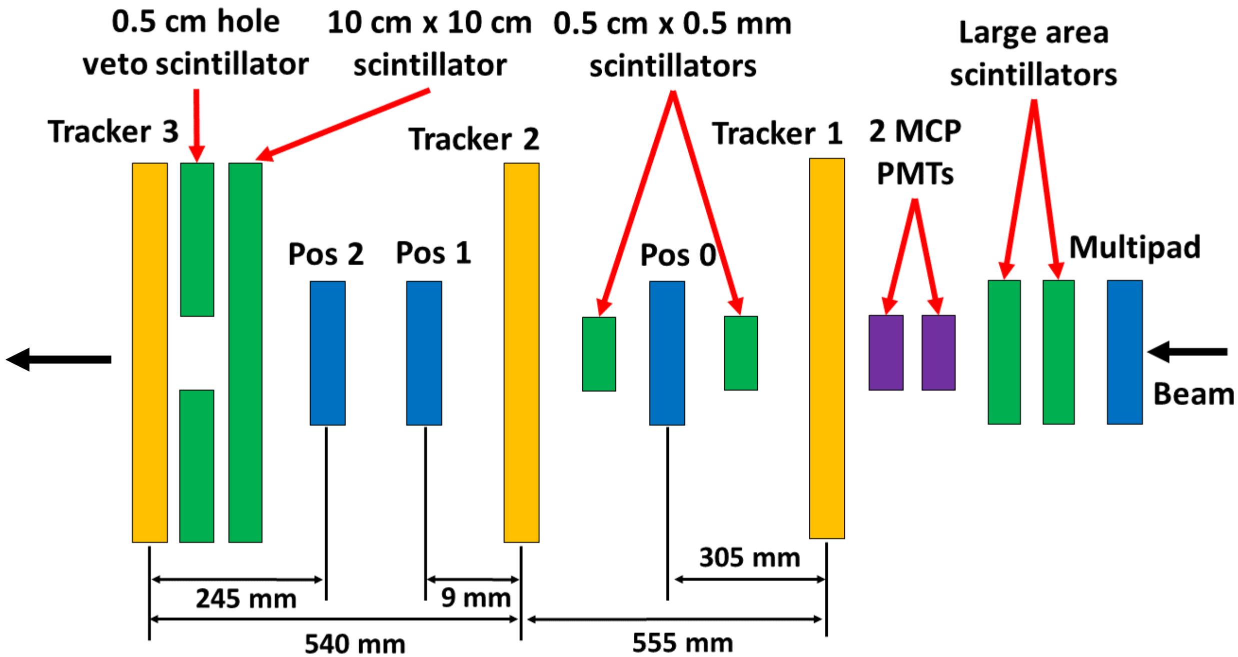
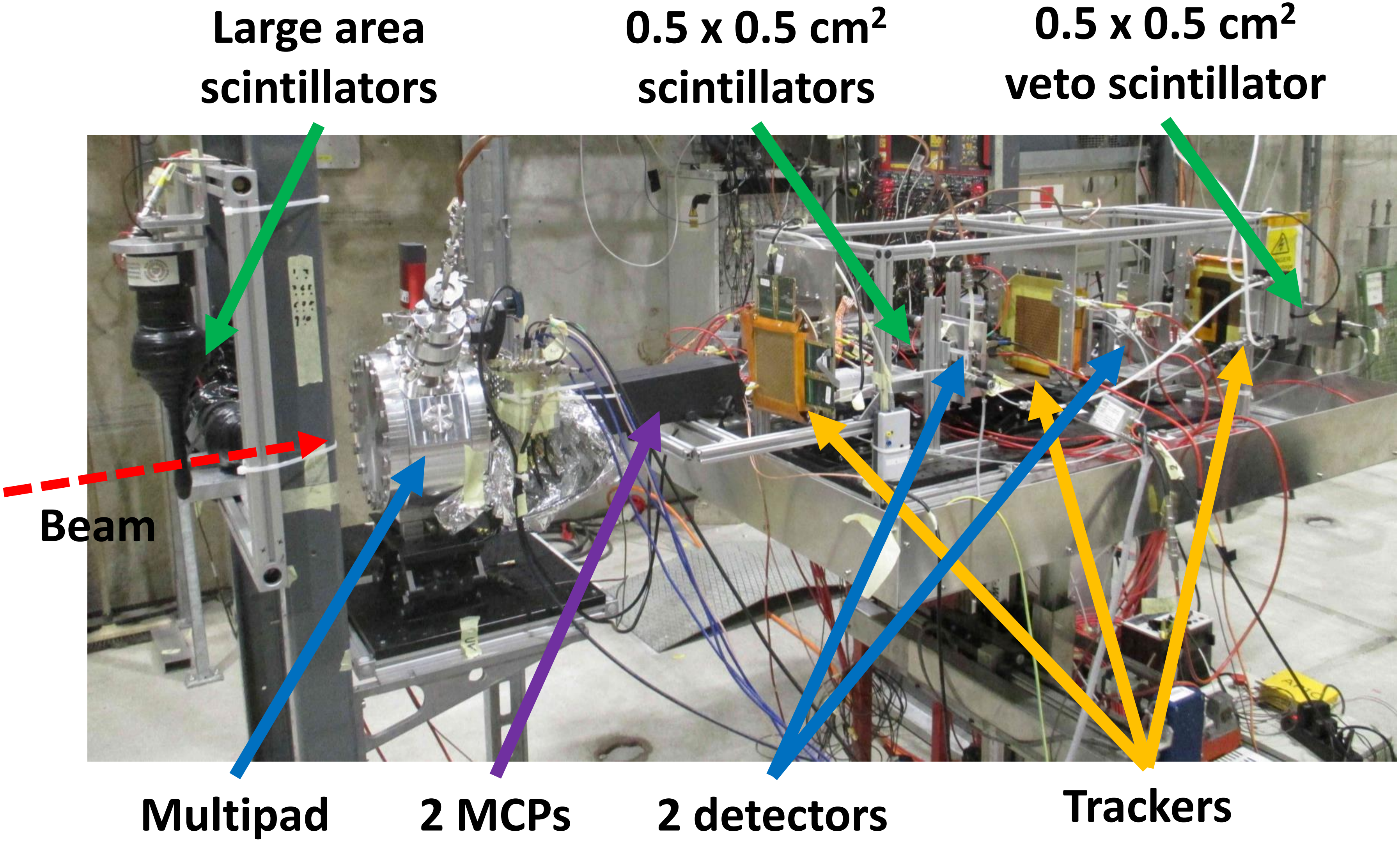
Beam tests at CERN SPS H4: setup



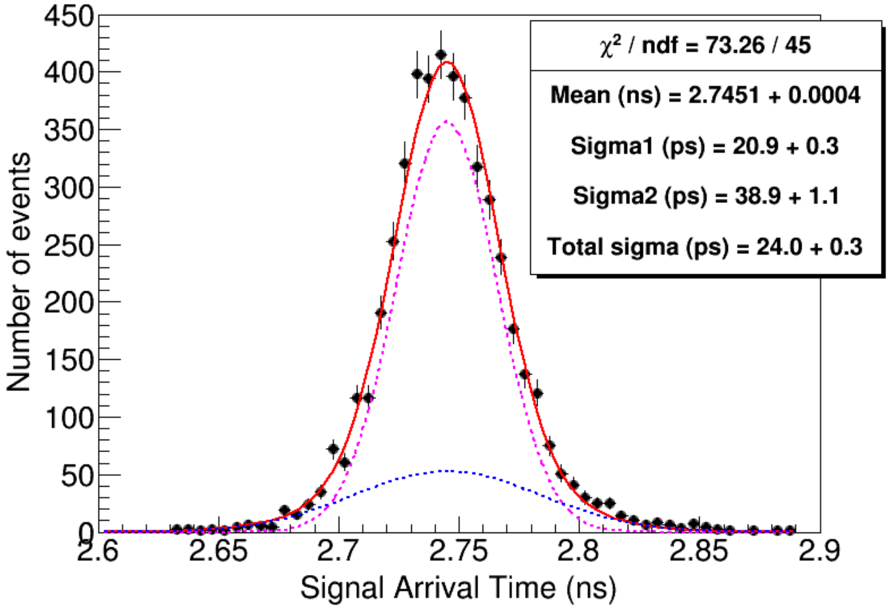
150 GeV muons or pions

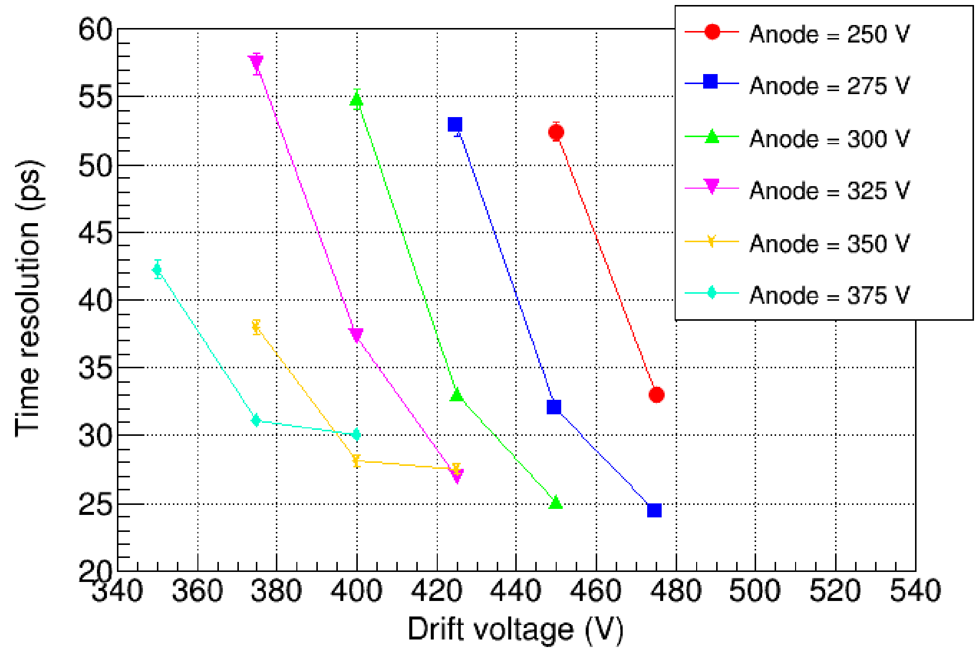
- **Time reference:** two MCP-PMTs (<**5 ps** resolution).
- **Scintillators:** coincidence of 3 scintillators + veto to avoid showers.
- **Tracker:** 3 GEMs to measure the impact point with 50 µm precision.
- **Electronics:** CIVIDEC preamplifiers + 1-4 2.5 GHz LeCroy scopes.
- **Nphe:** calibrations of SPE by UV lamps remotely controlled.

Beam tests at CERN SPS H4: setup



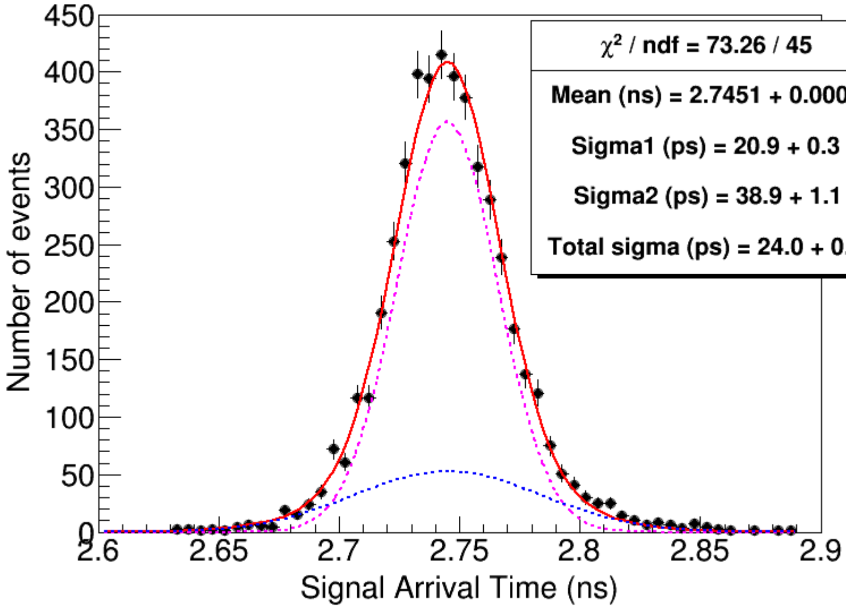
Beam tests at CERN SPS H4: results

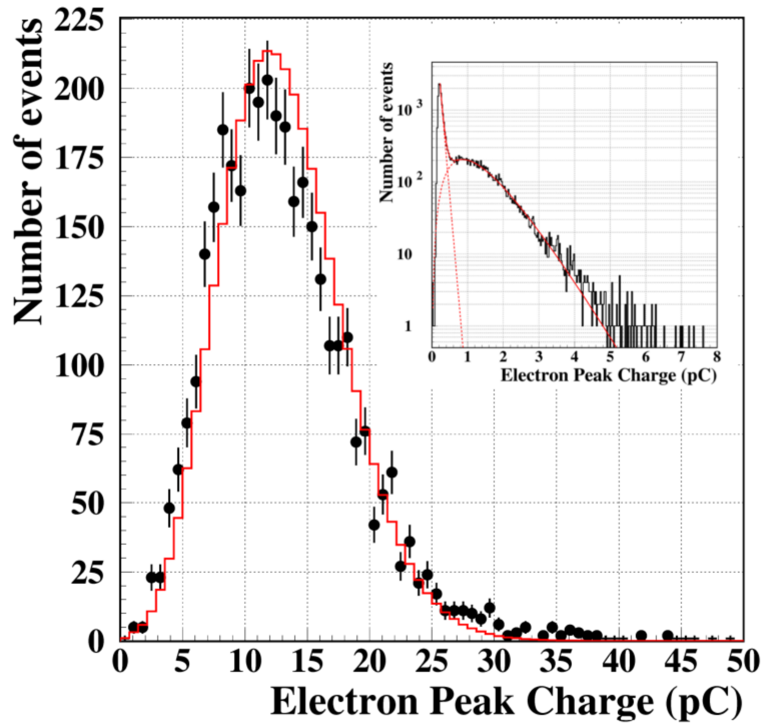




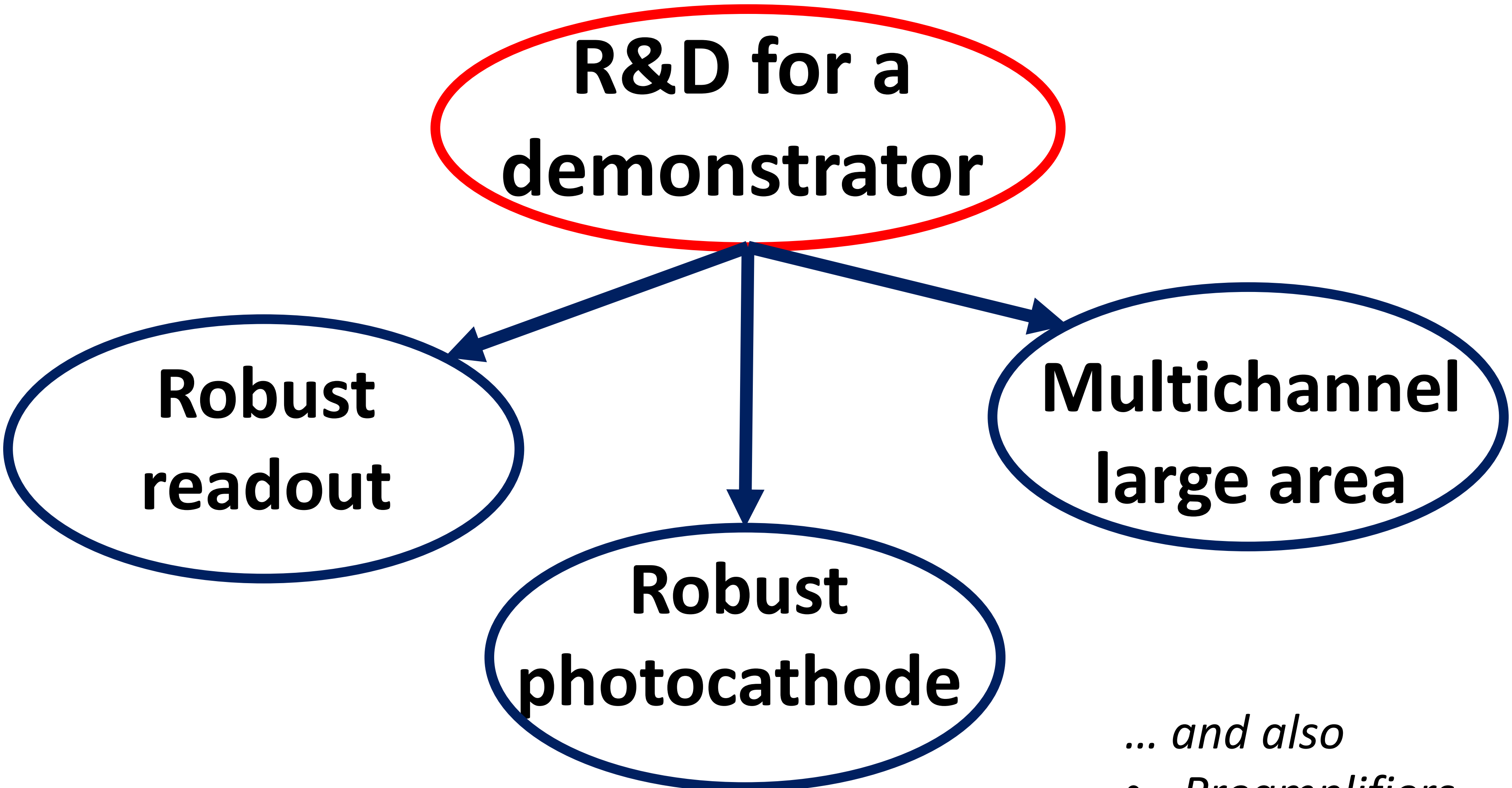
- Time resolution for 150 GeV muons: **24 ps**
- Optimum operation point: Anode +275V / Drift – 475V.
- Mean number of photoelectrons per muon = **10.4 ± 0.4**
- Results repeated in two different beam campaigns.

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.

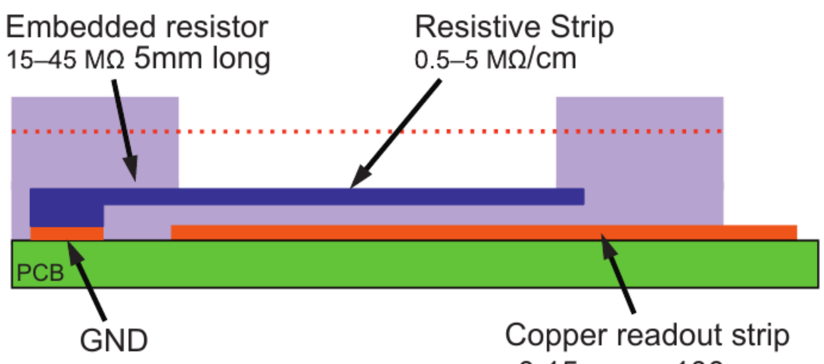


... and also

- *Preamplifiers*
- *Digitizers*

Robust readout: resistive Micromegas

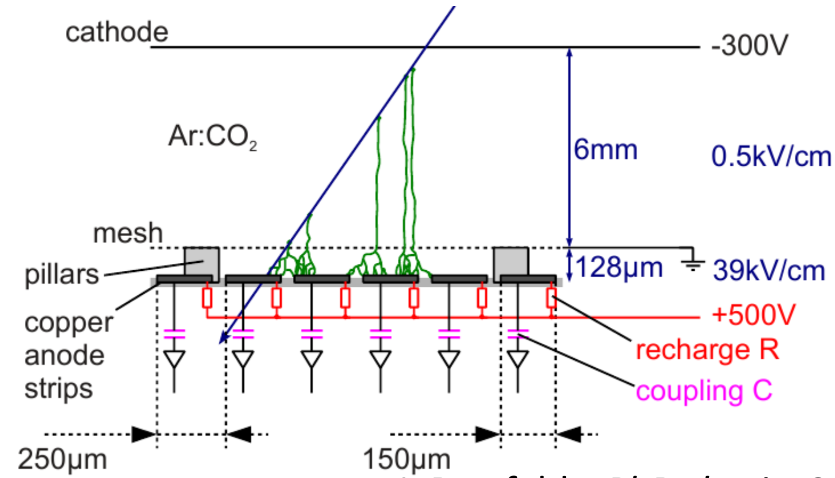
Resistive strips (MAMMA)



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

Resistive strips over signal strips & grounded at one side.

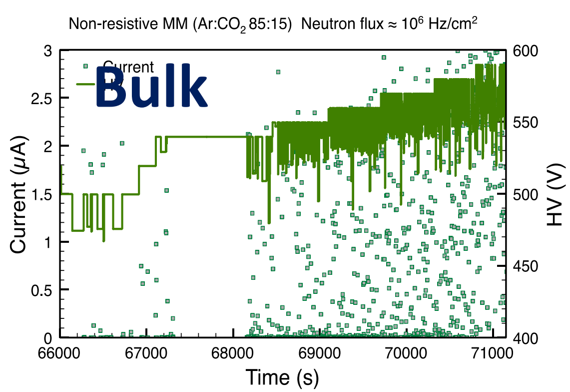
Discrete resistors (COMPASS)

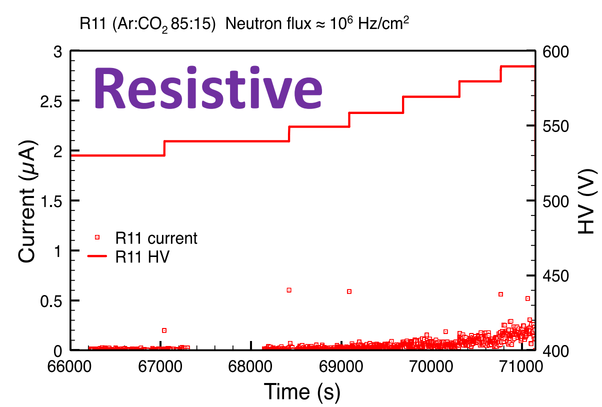


J. Bortfeldt, *PhD thesis, 2014.*

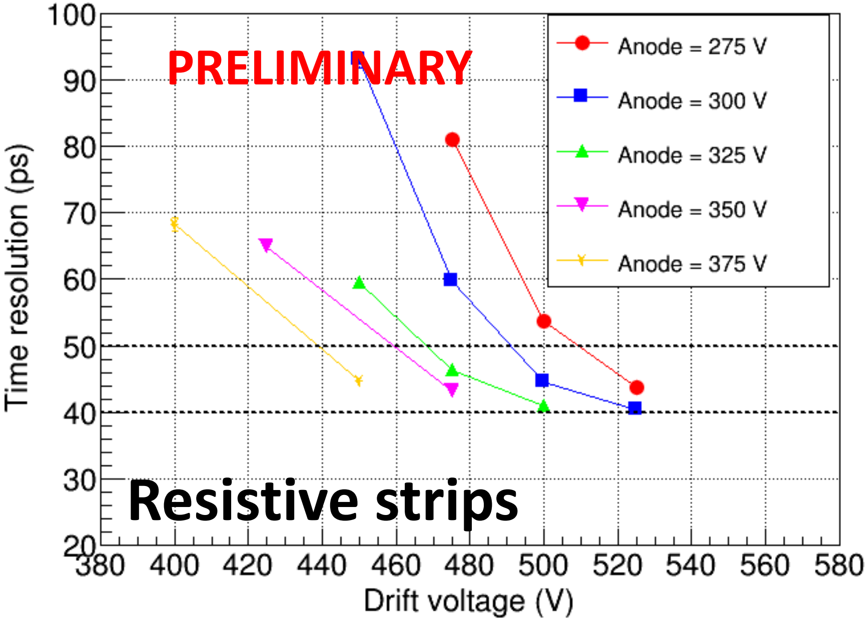
Anode strips individually connected to HV via resistors.

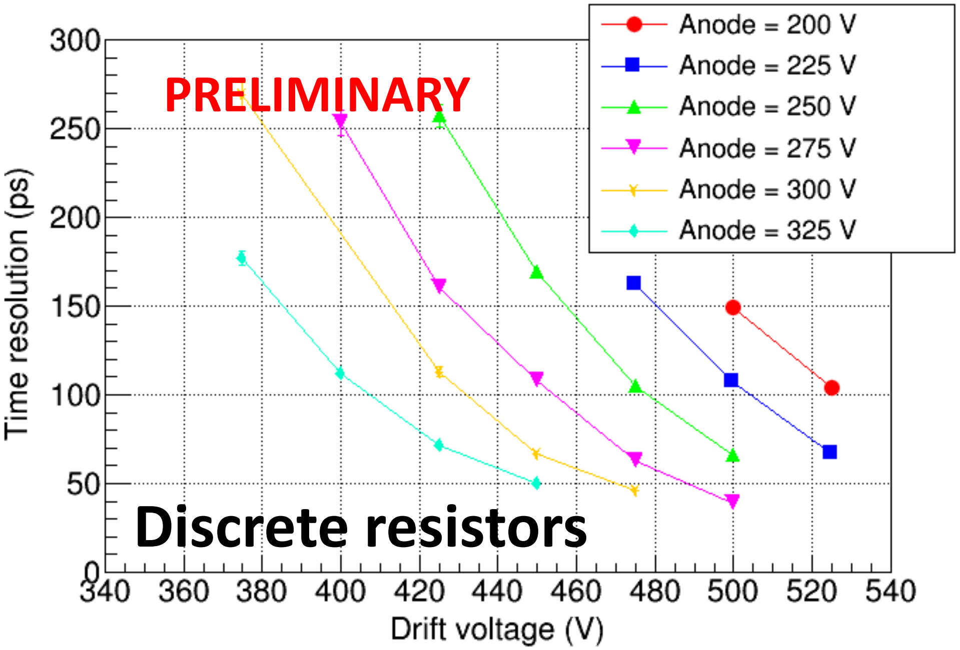
Resistive readouts operate stably at high gain in neutron fluxes of 10^6 Hz/cm^2.





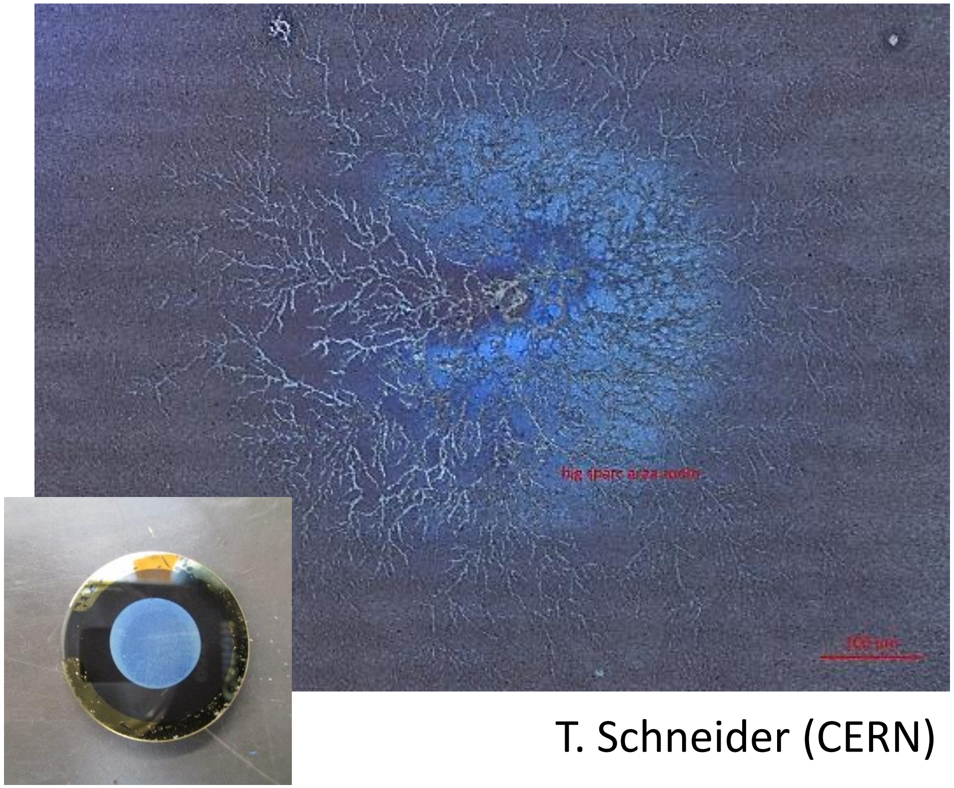
Robust readout: first results





- Values not far from the standard PICOSEC detector.
  - Resistive strips type: **40 ps** (10 MΩ/☐), **35 ps** (300 kΩ/☐).
  - Discrete resistors type: **40 ps** (25 MΩ).
- Resistive readouts worked for hours in intense pions beam.

Robust photocathode: several options



T. Schneider (CERN)

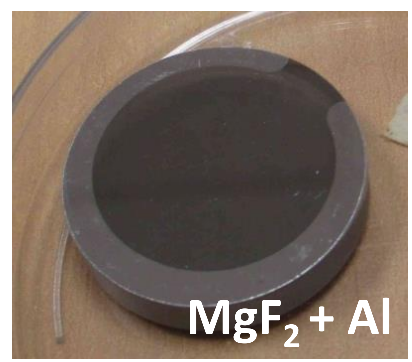
Pure metallic:

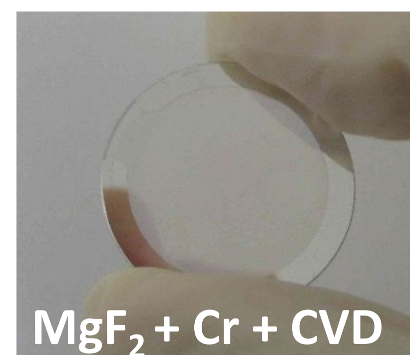
- Chromium, Aluminum.
- Some samples tested in beam.

Diamond or secondary emitter

CsI protection layers:

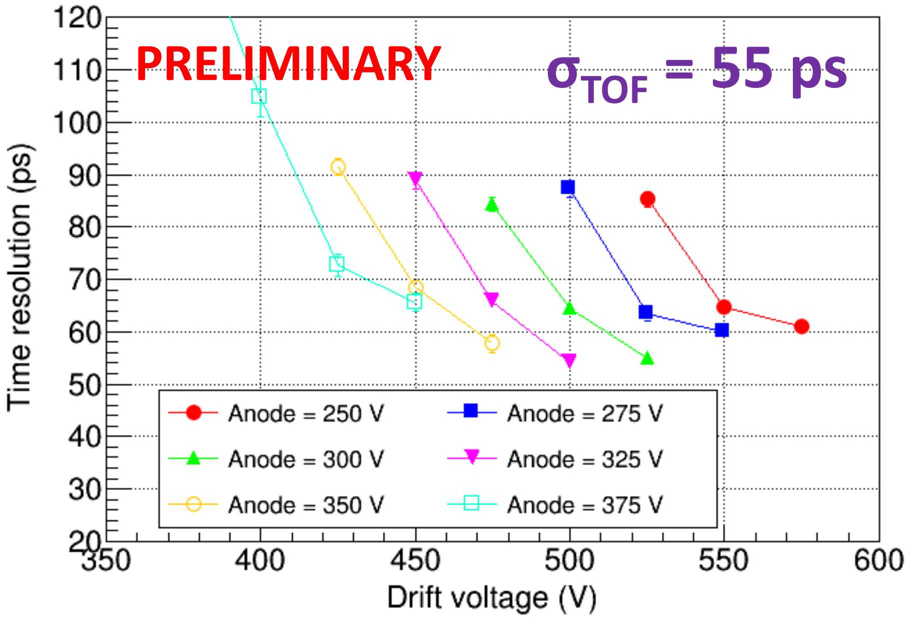
- Graphene shield.
- PC coating.





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

Robust photocathode: several options



Pure metallic:

- Chromium, Aluminum.
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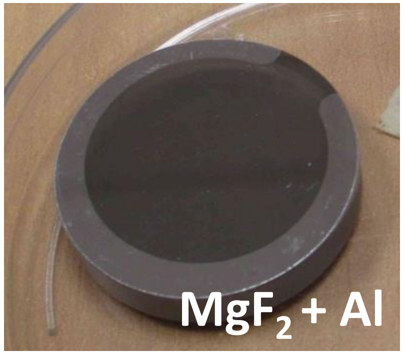
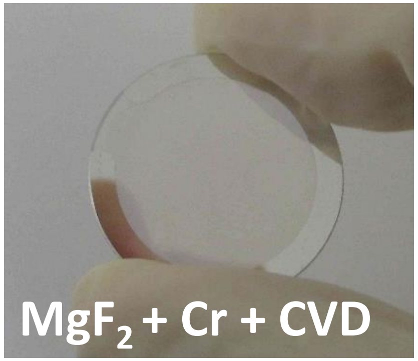
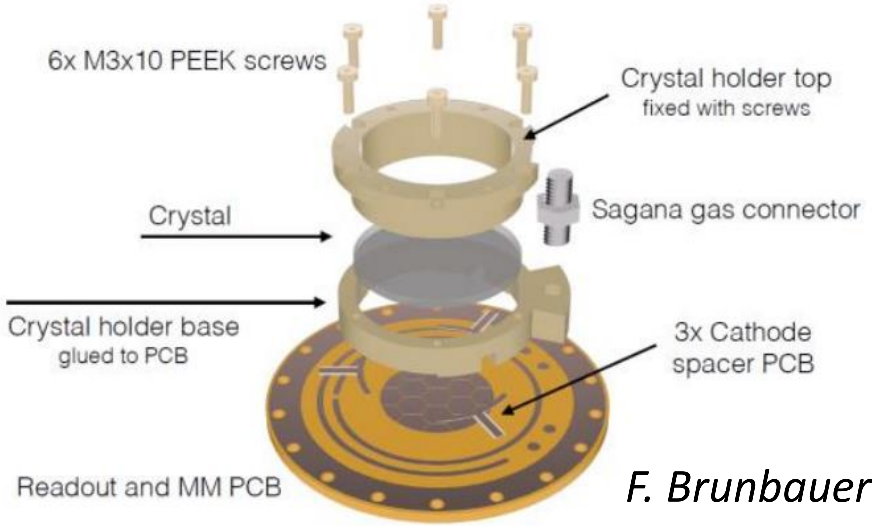
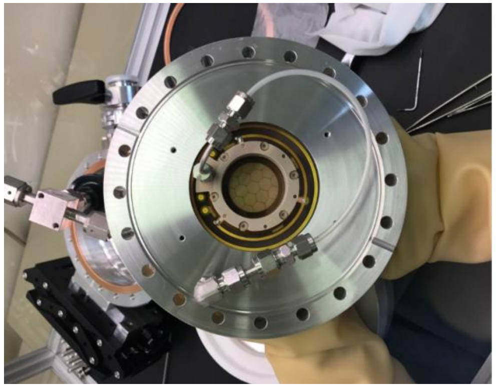
A 5 mm MgF2 + 10 nm Al photocathode showed in last beam a time resolution of **55 ps** and **~2.6 phe/muon**.

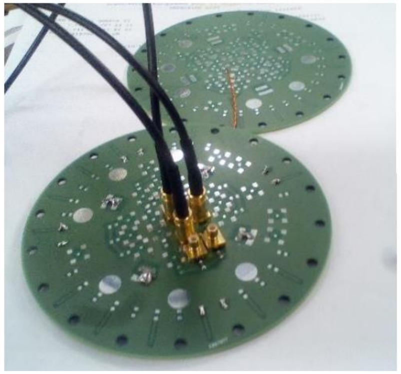




Scaling up: the Multipad detector

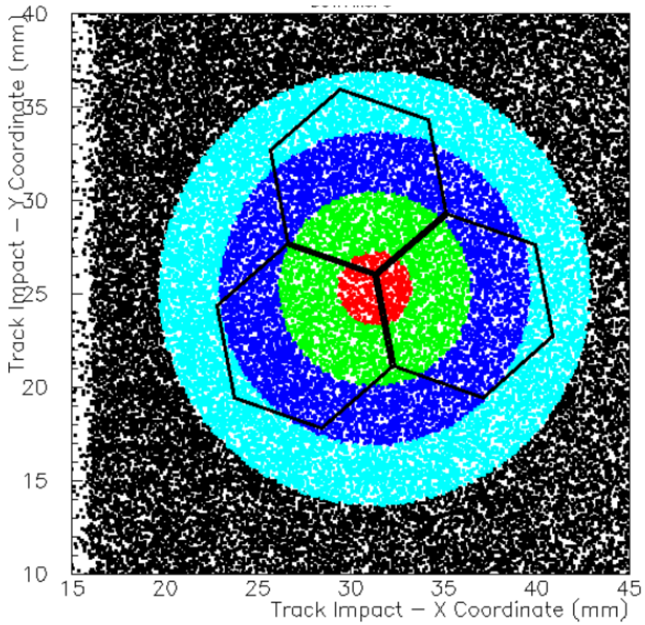






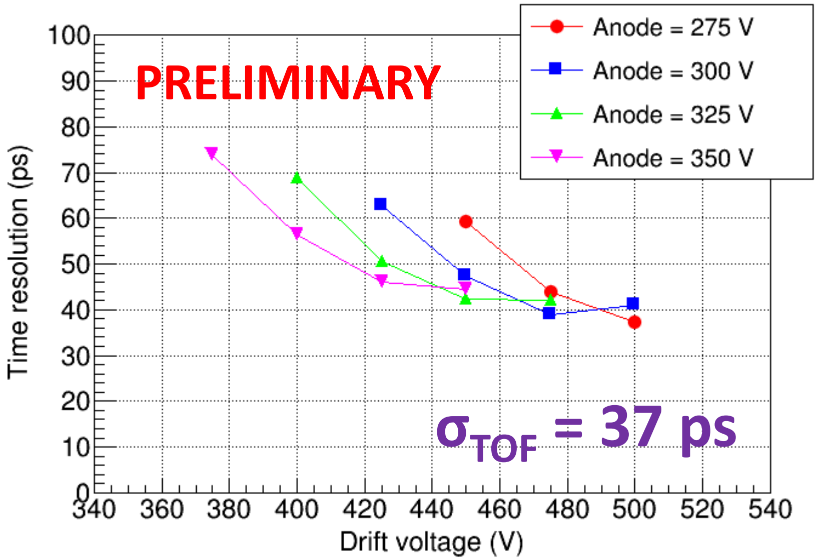
F. Brunbauer (CERN)

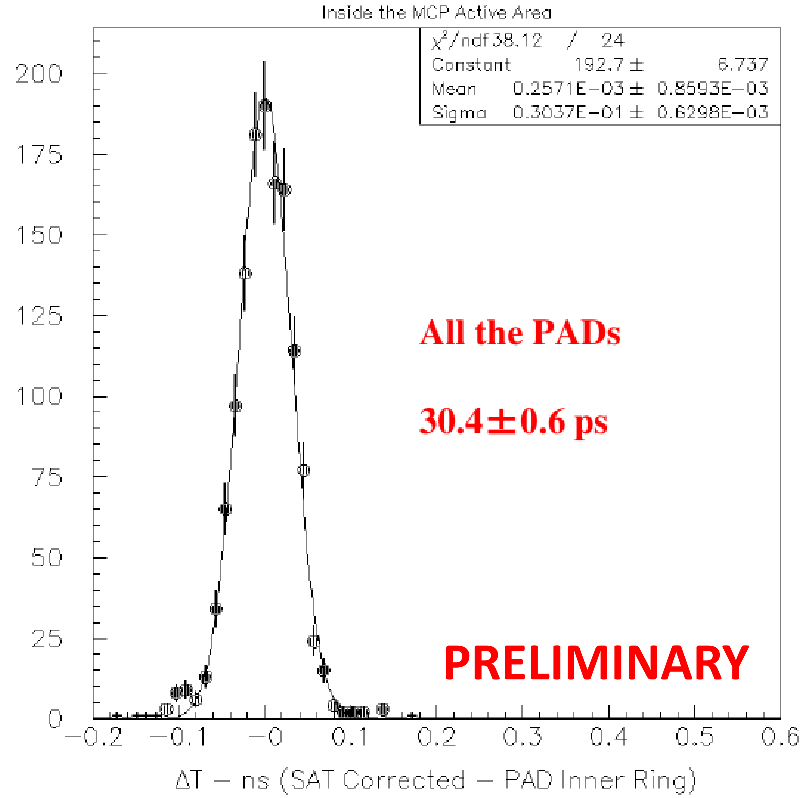
- 35 mm diameter area, 19 pads.
- Tested during Oct 2017 test beam.
  - One pad: **37 ps**.
  - MCP centered btw 3 PADs to study the charge/timing share btw them. Preliminary result: **30 ps**.



S. E. Tzamarias (AUTH)

Scaling up: the Multipad detector





S. E. Tzamarias (AUTH)

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- Tested during Oct 2017 test beam.
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Summary

PICOSEC: "a two-stage Micromegas detector coupled to a Cherenkov radiator and equipped with a photocathode."

Timing performance:

- Single photo-electrons: **76 ps**.
- 150 GeV μ's: Bulk readout (**24 ps**), resistive (**35 ps**). Nphe = **10.4**.
- Pions: First long runs with resistive detectors.
- Metallic (Al): **55 ps** (**2.6 phe**). Multipad: **30 ps**.

R&D for a demonstrator:

- **Readout:** Resistive Micromegas.
- **Photocathode:** metallic, CVD, secondary emitter, protection layer.
- **Scaling-up**: large area, multi-channels & electronics integrated.

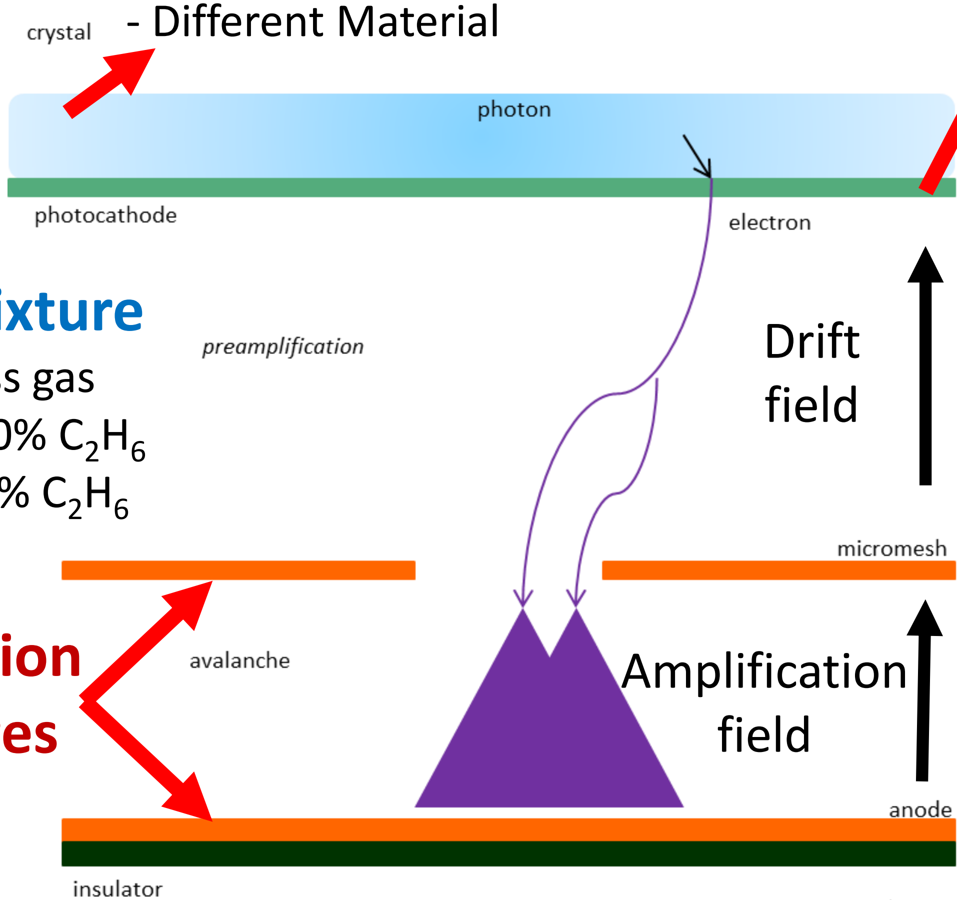
Back-up slides

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

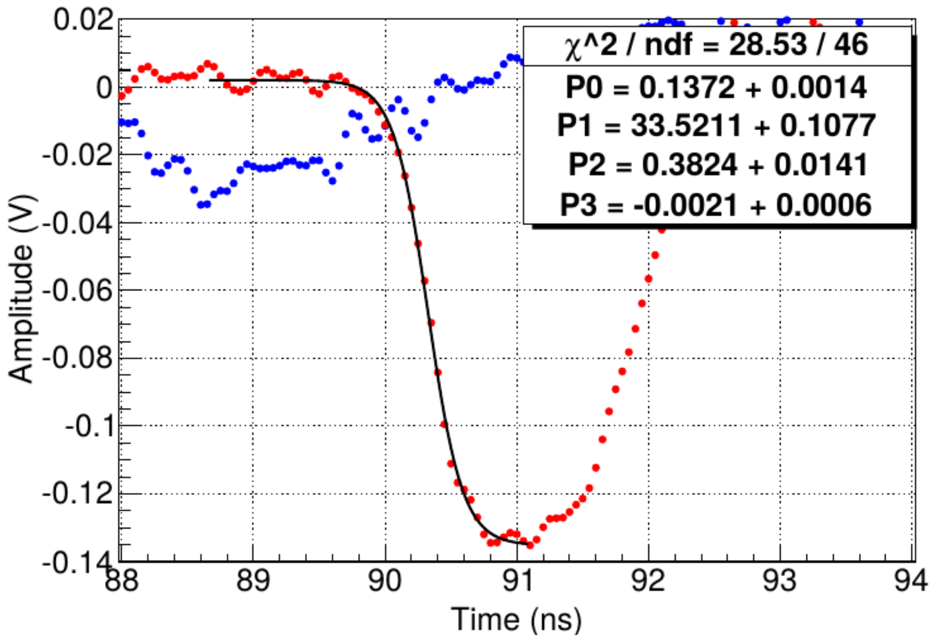
Operation voltages

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

E. Oliveri (CERN)

Timing measurements

- 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.

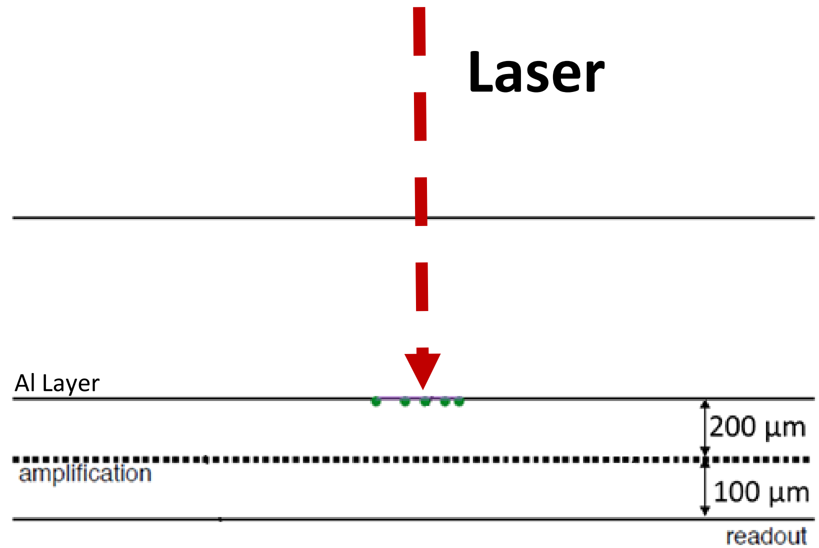


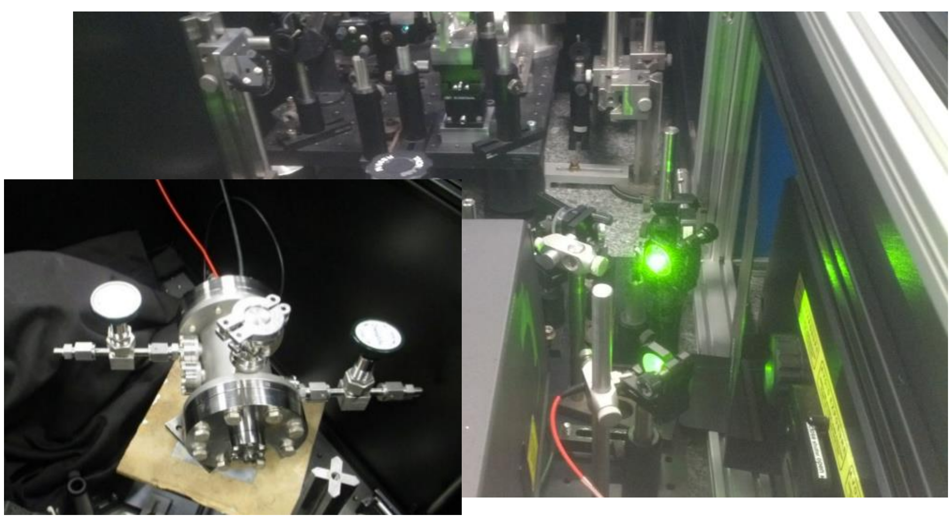
$$V(t) = \frac{P_0}{1 + e^{-P_2 \times (t - P_1)}} + P_3$$

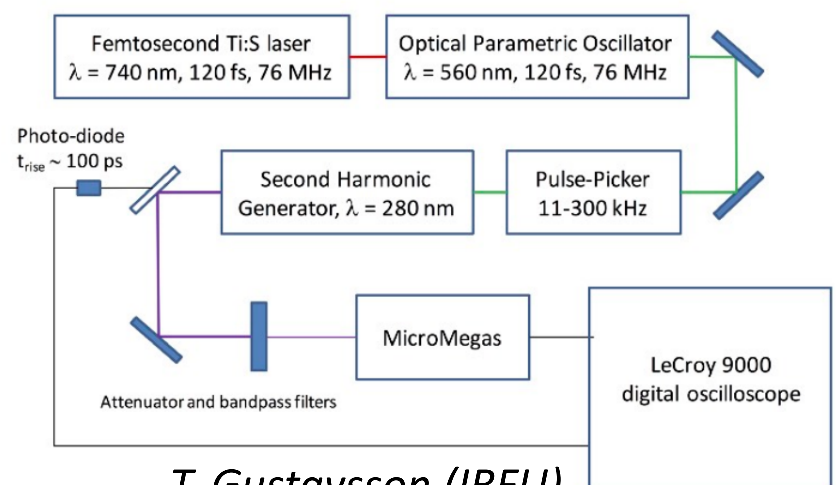
$$t_z = P_1 - \frac{1}{P_2} \, log \left[\frac{P_0}{y_0 - P_3} - 1 \right]$$

Timing measurements: laser tests.

- IRAMIS facility @ CEA Saclay.
- Wavelength: **280 nm**.
- Light attenuators.
- Trigger from fast PD.
- Cividec 2 GHz, 40 db preamplifier.
- DAQ: 2.5 GHz LeCroy scope.
- Data in **Compass gas** & CF_4+20%C_2H_6.



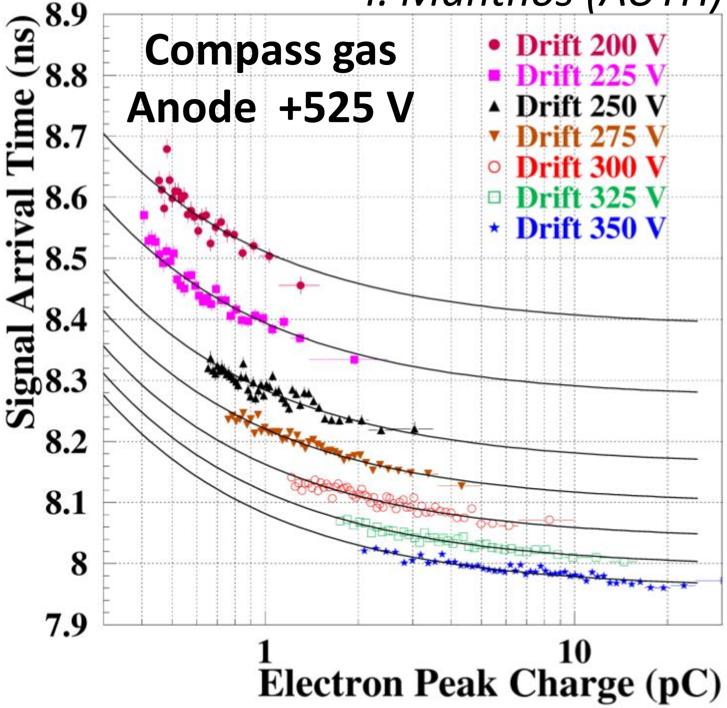


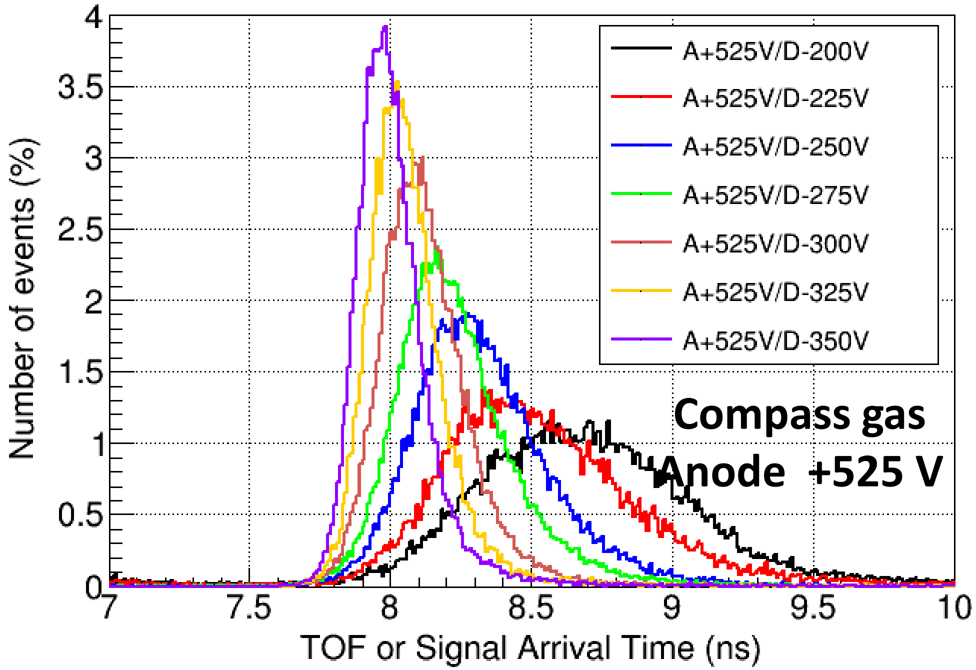


T. Gustavsson (IRFU)

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

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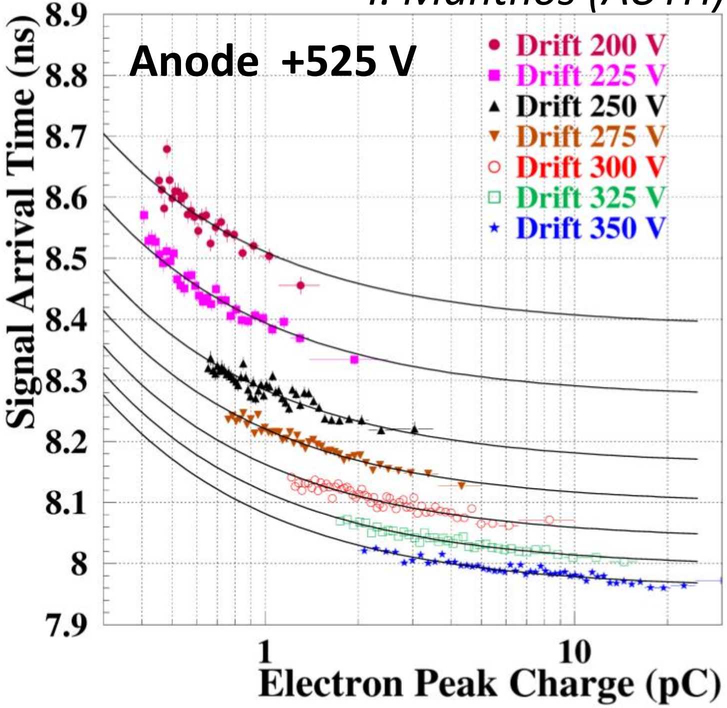

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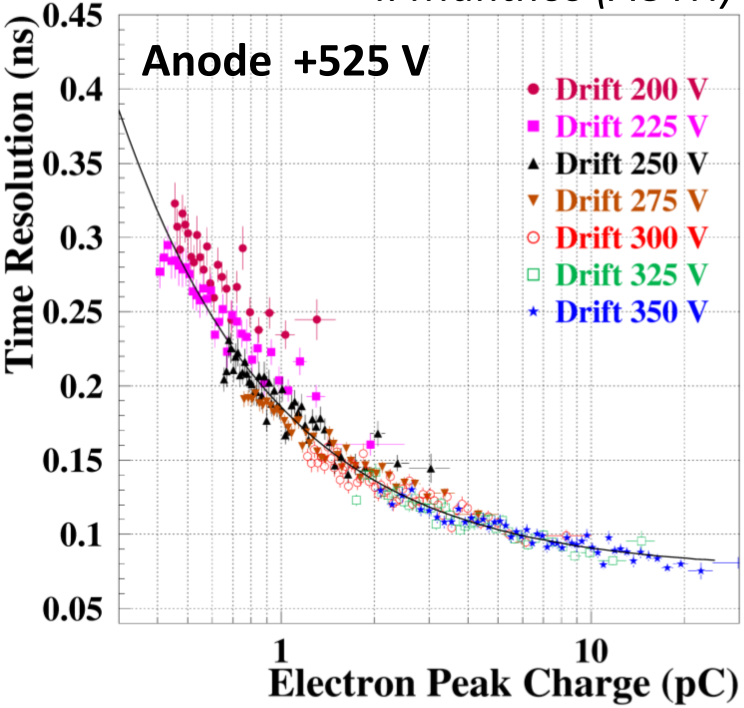
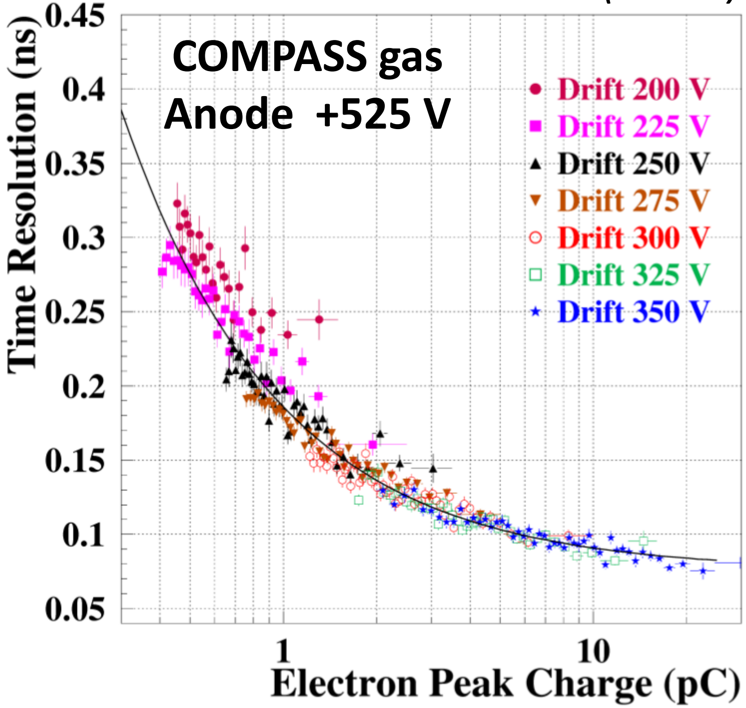


- TOF (Signal Arrival Time) distribution shows a tail at high values.
- This tail is a result of the correlation btw TOF & pulse amplitude.
- And a correlation btw the time resolution & pulse amplitude.

Results of laser tests: SAT vs amplitude

I. Manthos (AUTH)



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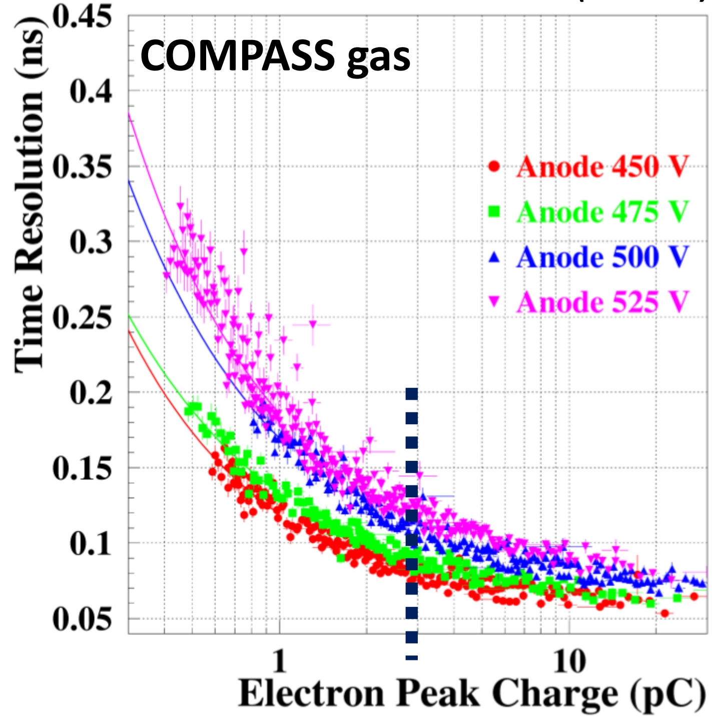
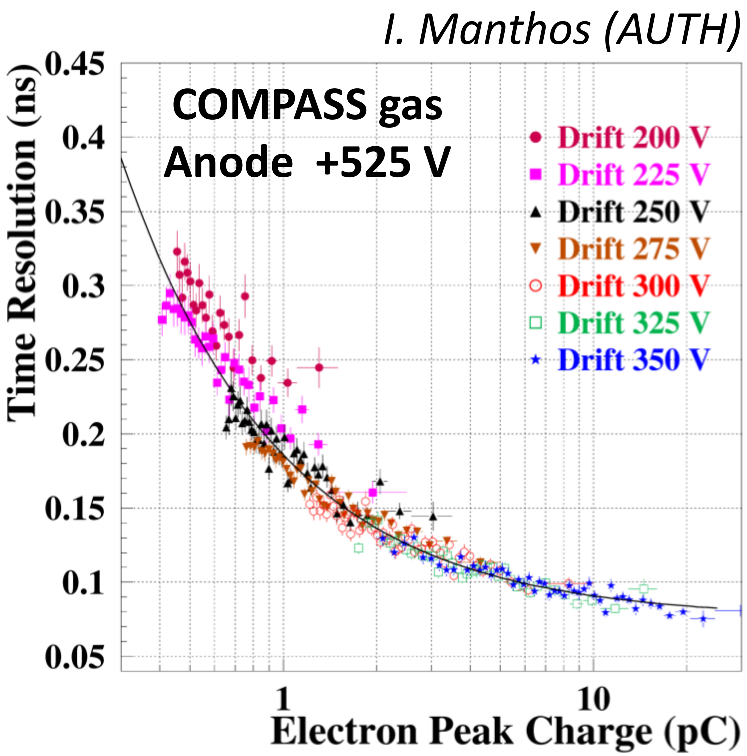
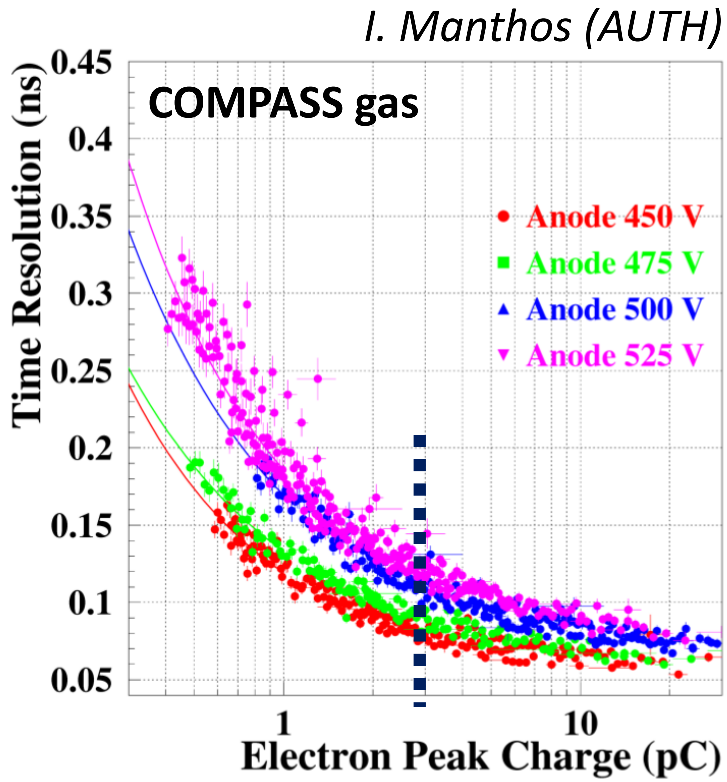


Signals of a given amplitude:

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

Results of laser tests: SAT vs amplitude

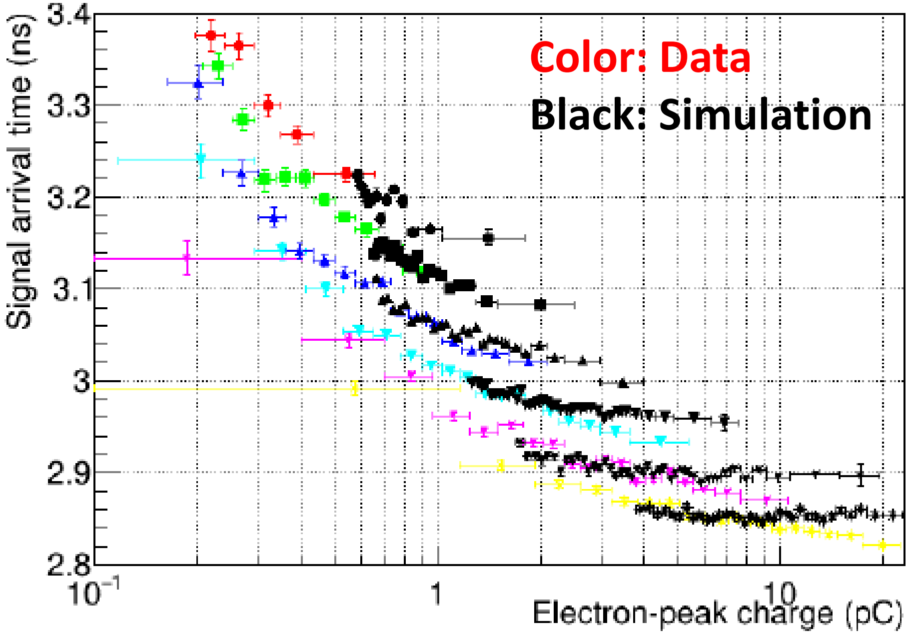


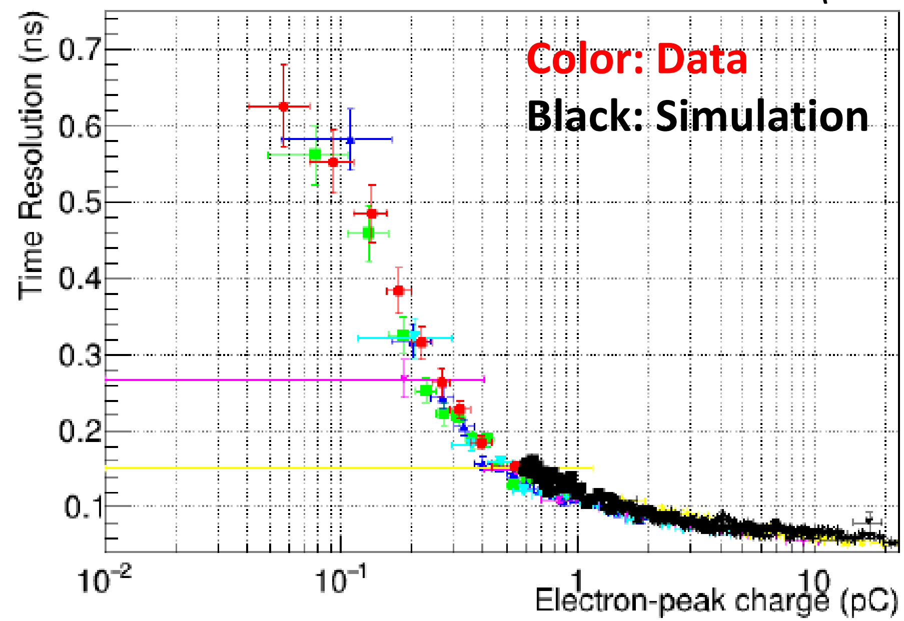


Timing properties are mainly determined by the pre-amplification stage.

Simulation of the detector response

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

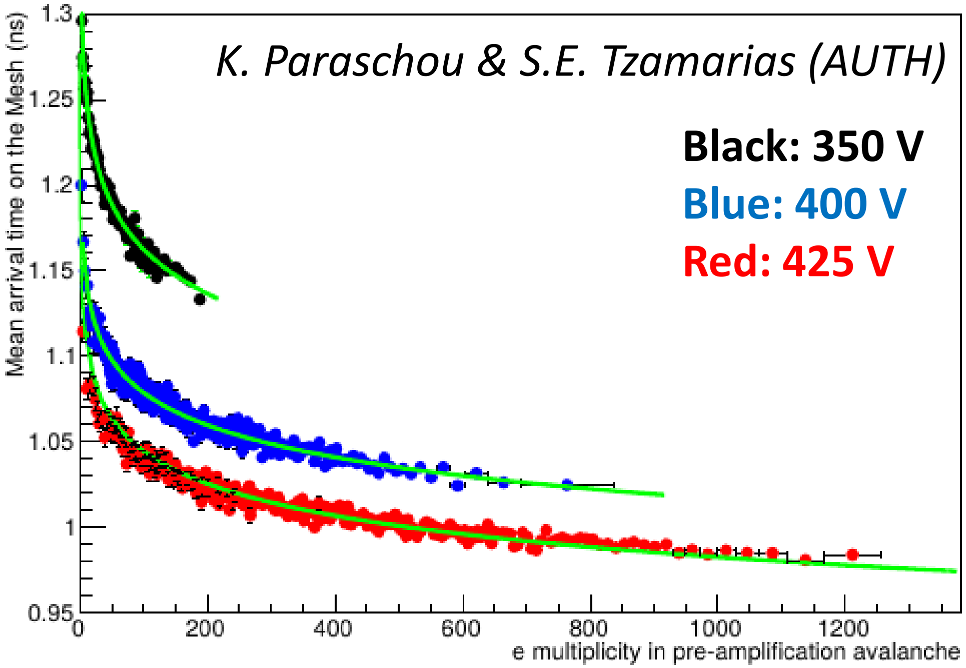


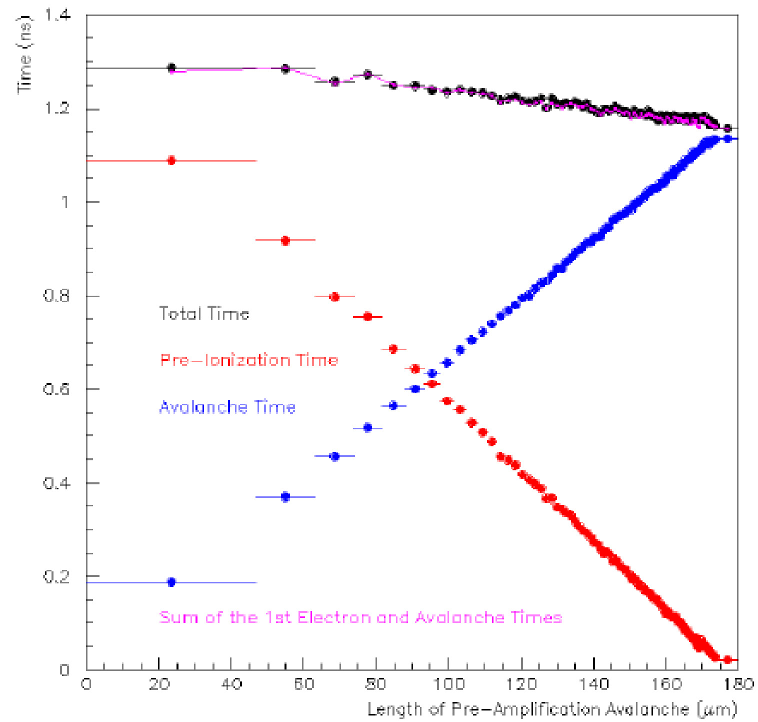


- It qualitatively describes the observed dependences.
- Timing is mainly defined by the pre-amplification stage.

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

Simulation of the detector response

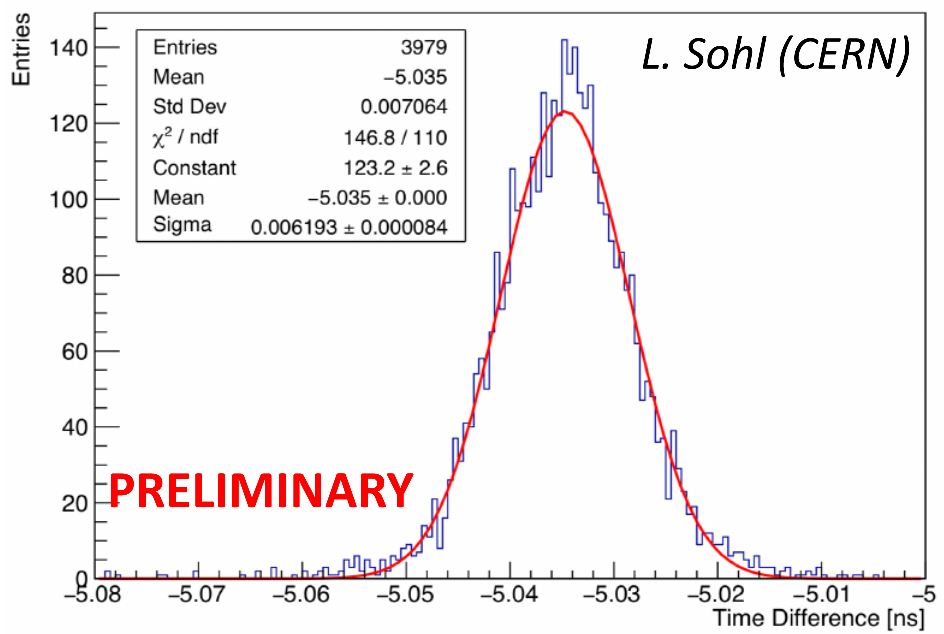




- The observed effects are due to the dependence of the effective drift velocity of primary photoelectrons with the distance at which the first ionization happens.

The timing reference during beam tests

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



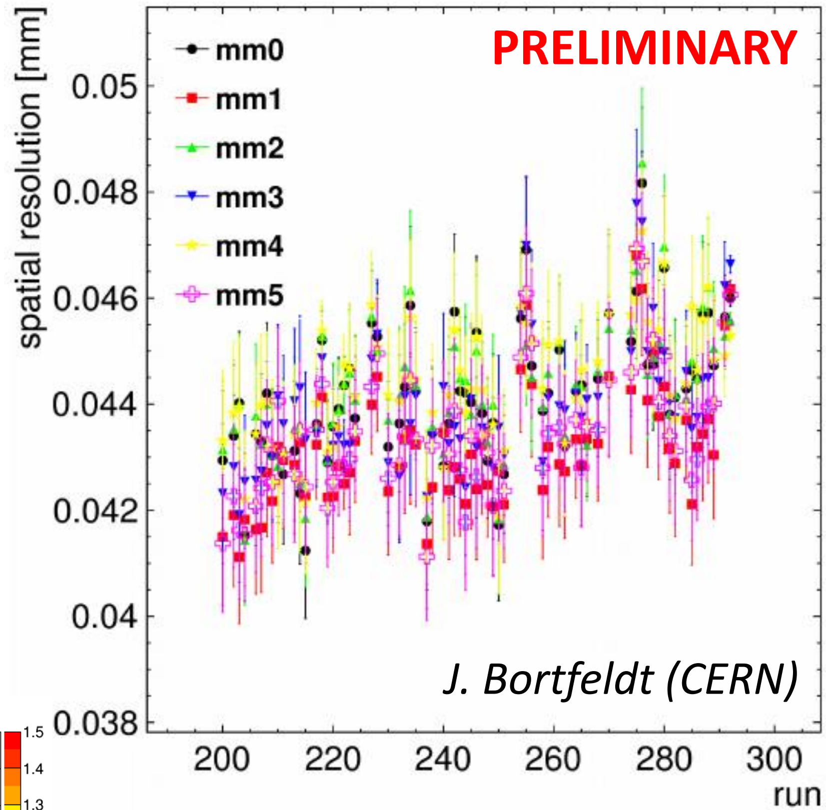
σ_{TOF} = 6.19 ± 0.08 ps

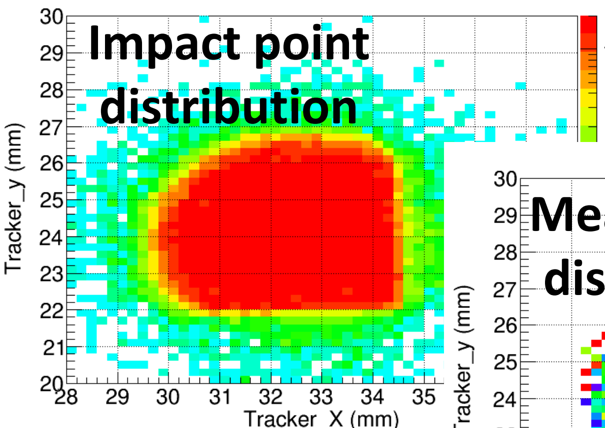
σ_{MCP} = 4.38 ± 0.06 ps

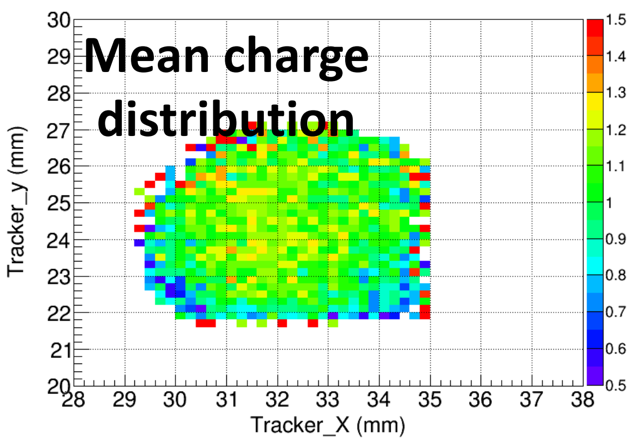
July 2017 Beam tests
MCP1 & MCP2 coincidence

The tracker system

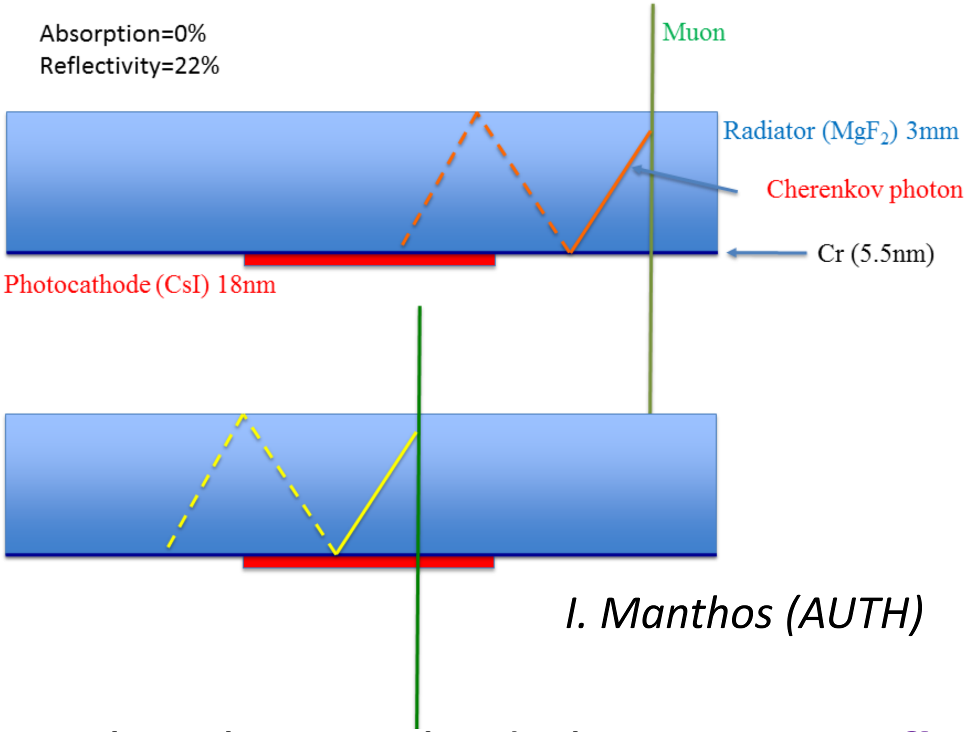
- Three x-y GEMs detectors.
- Combinatorial Kalman filter based tracking algorithm to reconstruct track.
- Spatial resolution < 50 µm.
- Detector alignement study.



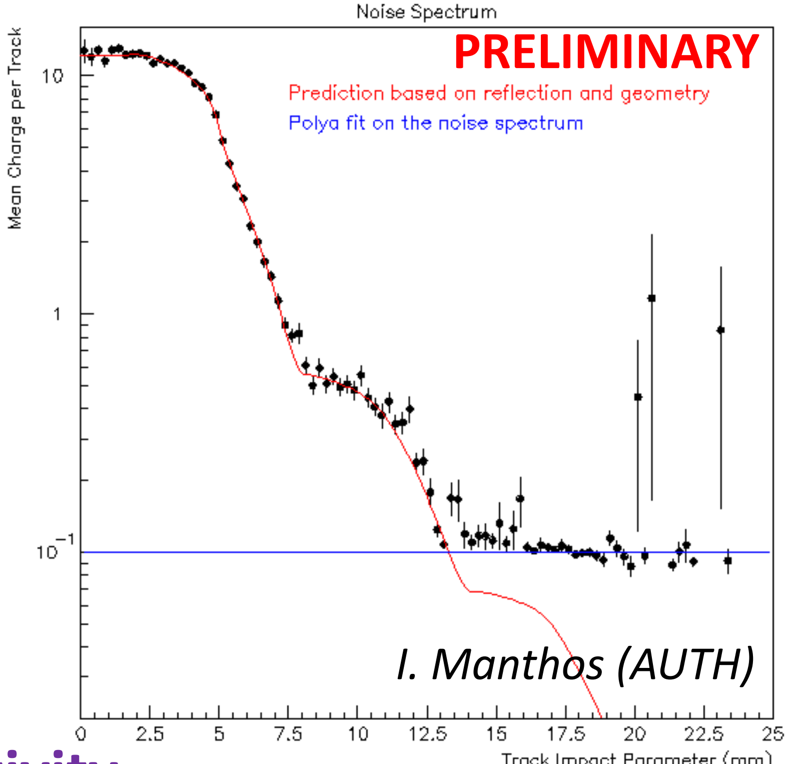




First results of large area trigger runs



I. Manthos (AUTH)



- 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

How the Nphe is calculated?

Polya for multiple photoelectrons charge distribution $P(Q; n, Q_e, rms_e)$

Poisson for the mean number of pes in the Cherenkov cone $f(n;\mu) = \frac{e^{-\mu}\mu^n}{n!}$

Geometrical acceptance $\epsilon = \epsilon(r)$ $r = \sqrt{x^2 + y^2}$

$g(Q) \equiv noise, if\ n = 0$ $G(Q;n) = \begin{cases} P, if\ n > 0 \\ g, if\ n = 0 \end{cases}$

Track displacement $r_i = [(x_i - \delta x)^2 + (y_i - \delta y)^2]$

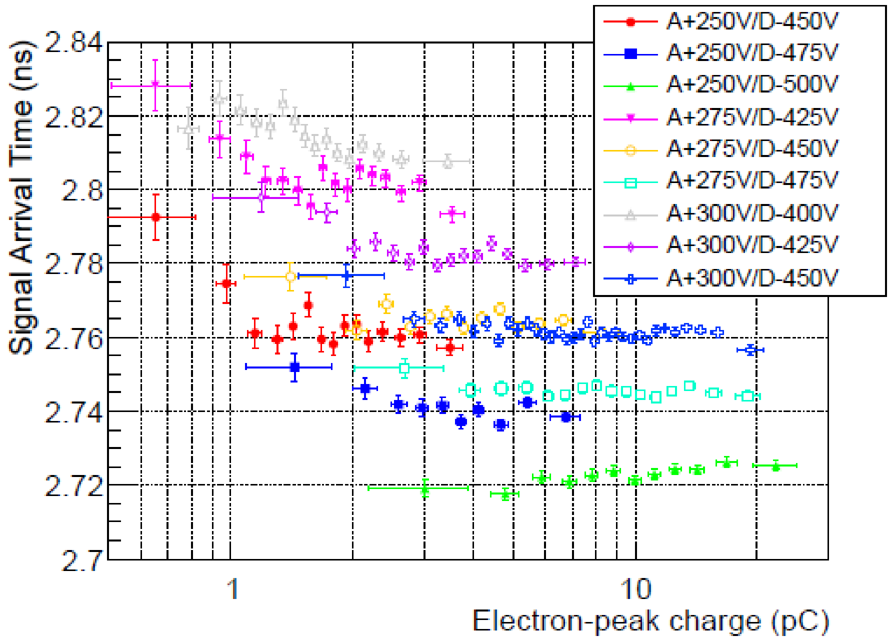
Likelihood minimization to estimate mean number of pes (μ) and true impact parameters (x,y)

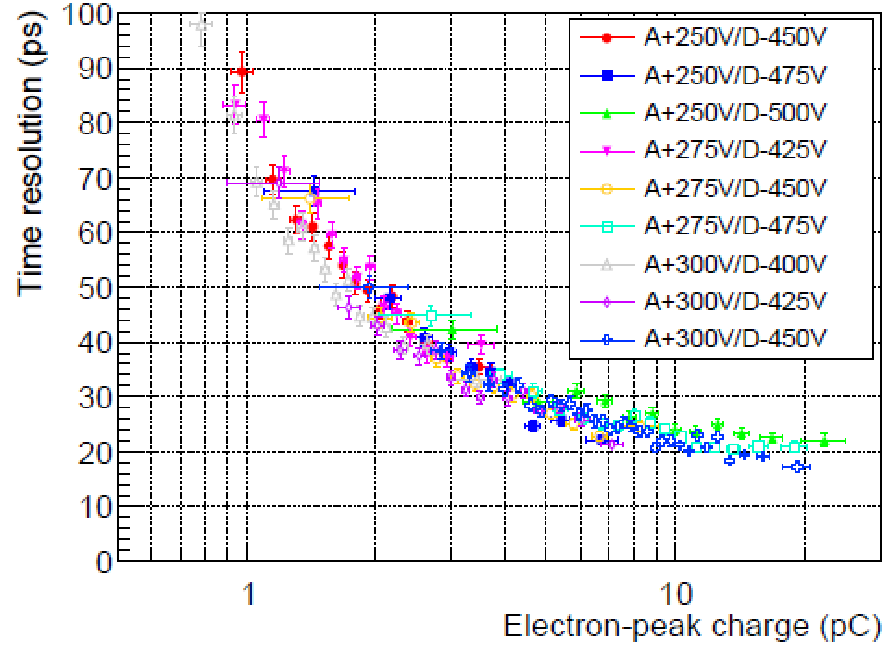
$$L\left(Q_{1,}Q_2 \ldots Q_M, x_{1,}x_2 \ldots x_M, y_{1,}y_2 \ldots y_M; \mu, \delta x, \delta y\right) =$$

$$=\prod_{i=1}^{M} \sum_{n=0}^{\infty} \frac{e^{-\mu\cdot\epsilon(r_i)}.\left(\mu\cdot\varepsilon(r_i)\right)^n}{n!} \cdot G(Q_i; n, Q_e, rms_e)$$

I. Manthos, K. Paraschou & S.E. Tzamarias (AUTH)

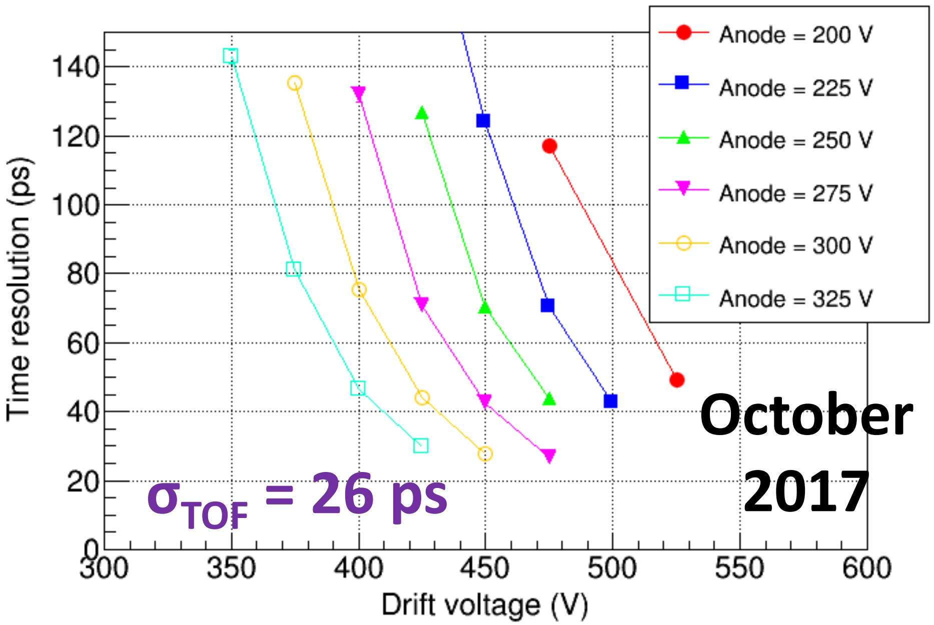
Beam tests at CERN SPS H4: results

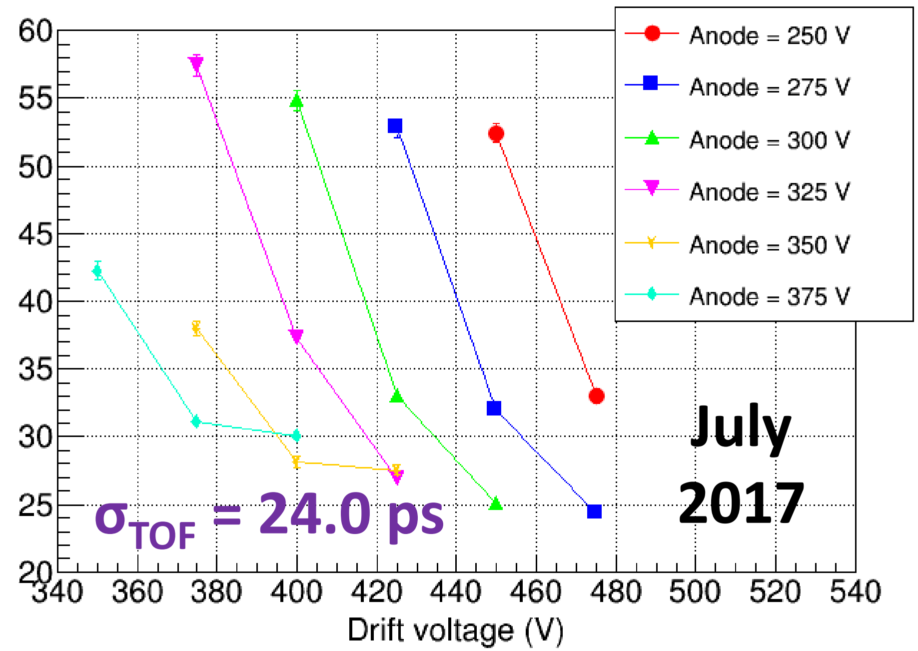




- No dependence btw SAT and electron-peak amplitude.
- The time resolution improves with the amplitude, posibly correlated to the gain in the first amplification stage.
- First approach: one Gaussian fit to SAT distribution.

Beam tests at CERN SPS H4: results



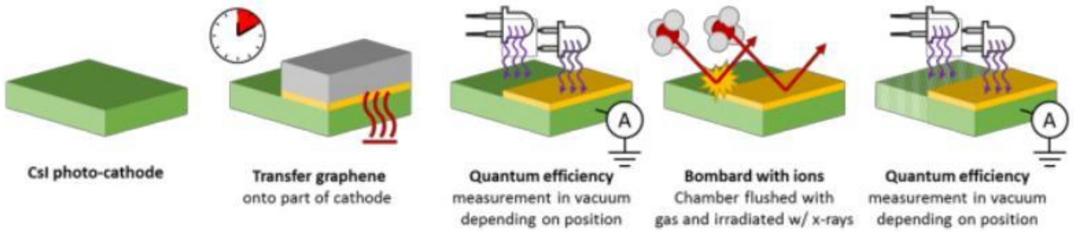


- Time resolution for 150 GeV muons: **24 ps**
- Optimum operation point: Anode +275V / Drift – 475V.
- Mean number of photoelectrons per muon = **10.4 ± 0.4**
- Results repeated in two different beam campaigns.

Robust photocathodes

CsI protection layers:

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

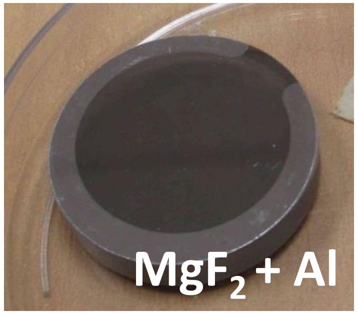


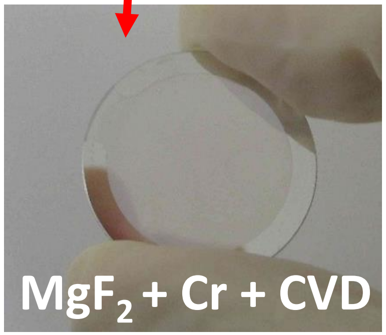
Diamond as photocathode or secondary emitter.

- 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.

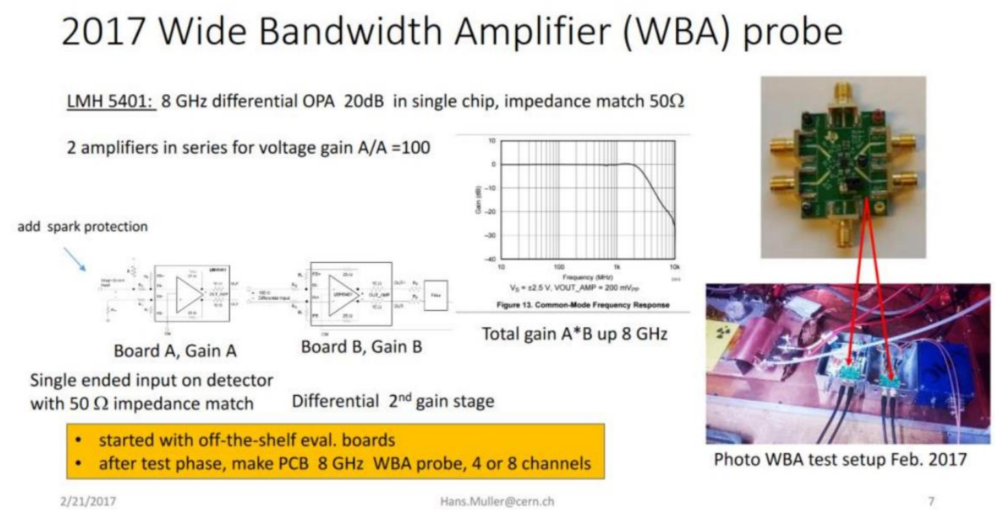




R&D on electronics

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.

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

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