PICOSEC
charged particle timing to 24 ps with Micromegas

F.J. Iguaz

On behalf of PICOSEC collaboration

Seminaire d'Instrumentation, 7th November 2017

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The Picosec collaboration

- **CEA-Saclay:** T. Papaevangelou, I. Giomataris, M. Kebbiri, T. Gustavsson, D. Desforge, M. Pomorski, P. Legou, O. Maillard, C. Guyot, P. Schwemling, F.J. Iguaz.
- **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, R. Veenhof, S. White[1].
- **NCSR Demokritos:** G. Fanourakis.
- **USTC (China):** Y. Zhou, Z. Zhang, J. Liu, B. Qi, X. Wang.
- **Univ. Thessaloniki:** I. Manthos, V. Niaouris, K. Paraschou, D. Sampsonidis, S.E. Tzamarias,.
- **NTUA:** Y. Tsipolitis.
- **LIPP:** M. Gallinaro.

[1] Also University of Virginia.

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- The Picosec detection concept.
- Timing measurements:
- On going R&D and future plans.
- Summary

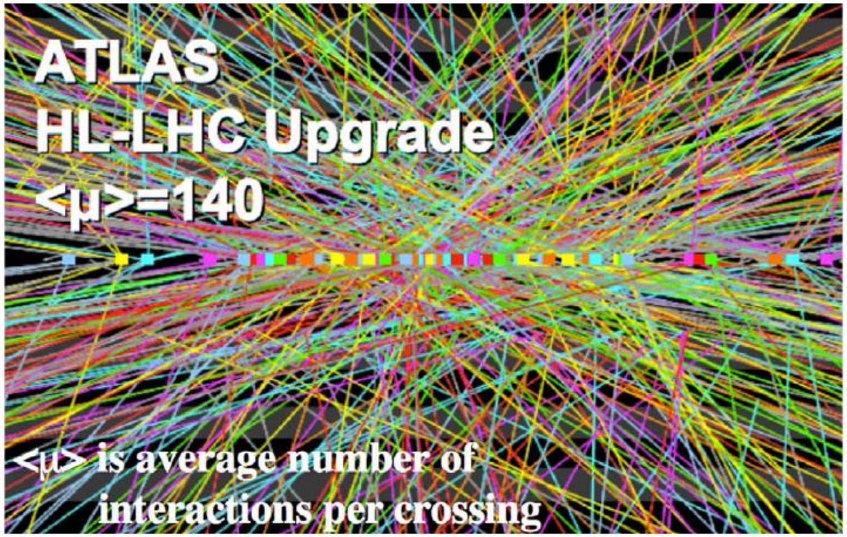
Motivation: why ~10 ps are interesting?

High Luminosity Upgrade of LHC:

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

Extra detector requirements:

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



PID techniques: Alternatives to RICH methods, J. Va'vra, accepted in NIMA, https://dx.doi.org/10.1016/j.nima.2017.02.075

State-of-art precision timing

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 ?*

Gaseous detectors

- RPCs: (σ_t ~ 30 ps)

➔ *High rate limitation*

- MPGDs ($\underline{\sigma_t \sim 1\ ns}$)

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Question:

Can a *Micromegas detector* reach a timing resolution of the order of *few tens of picoseconds?*

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➔ ***YES, for a proof of concept (the aim of this talk)***

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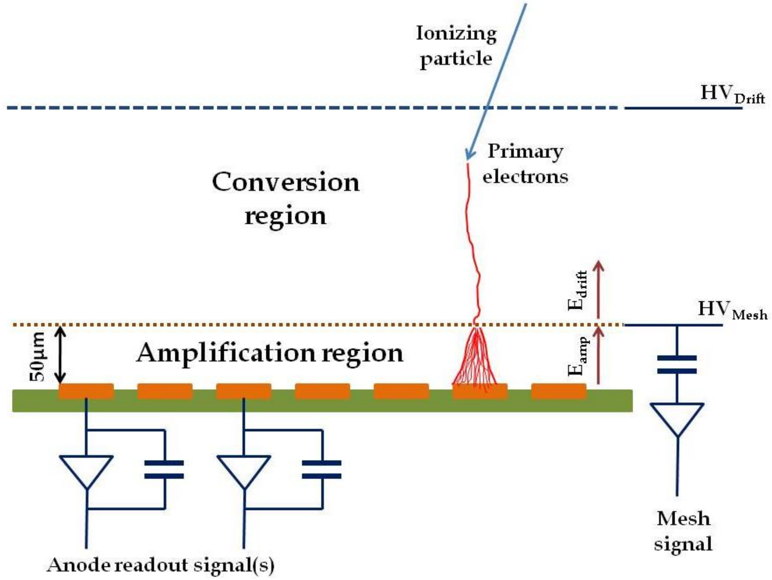
➔ ***YES, for a proof of concept (the aim of this talk)***

➔ ***Pending: Large-area, position-sensitive, radiation hardness***

A Micromegas detector



Conversion region
Radiation create electrons, which drift to the readout plane.

Amplification region
Electrons are amplified & the charge movement induces signals.

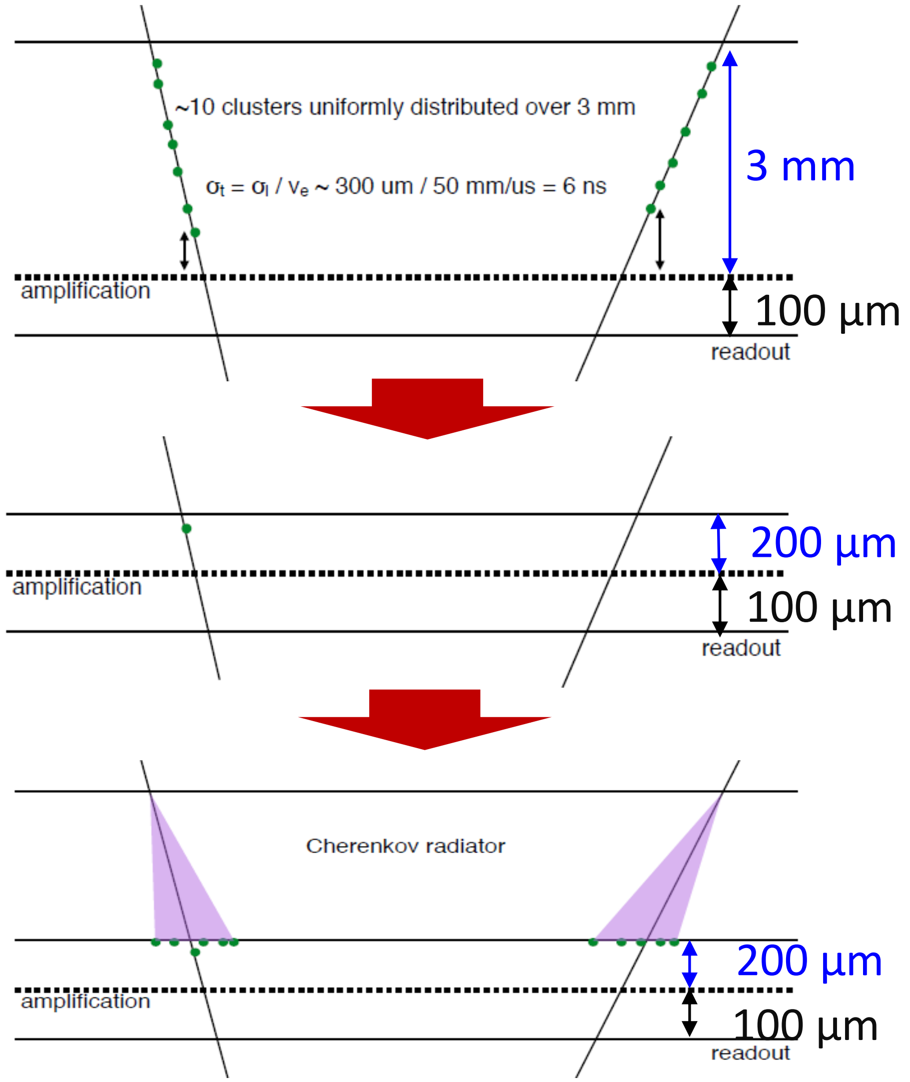
Interesting features for many applications:

Simplicity	Granularity	Homogeneity	Scalability

Timing limitation factors:

- **Large conversion region:** charges created in different positions.
- **Diffusion effects:** ~0.3 mm/cm$^{0.5}$ -> **~6 ns for 3 mm drift distance!**

Improving the Micromegas timing



Standard MPGD detector:

- **Large ionization volume.**
- **Big diffusion (~ns).**

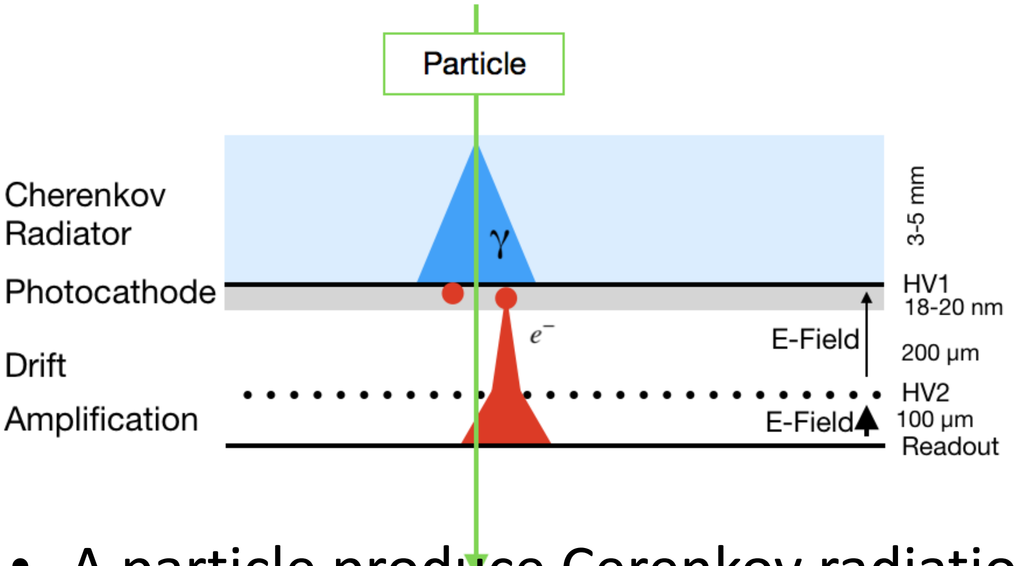
Drift gap is reduced:

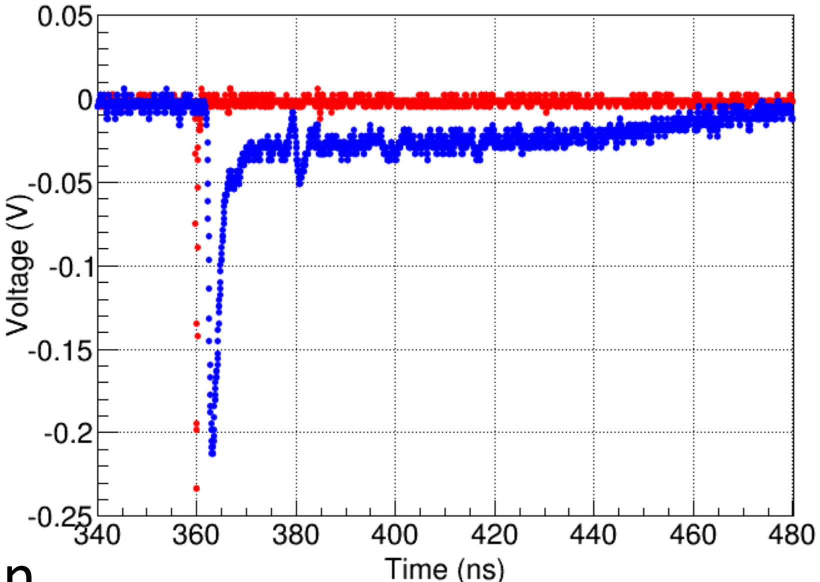
- **Diffusion limited.**
- **Preamplification.**

Cerenkov radiator:

- **Primary electrons localized in time & space.**

The Picosec detector





- A particle produce Cerenkov radiation.
- Photons produce electrons in the photocathode.
- Electrons are amplified by a two stage Micromegas detector.
- Two signal components:
  - Fast: ***electron peak*** (~1 ns). -> Timing features.
  - Slow: ***ion tail*** (~100 ns).

The first Picosec prototype

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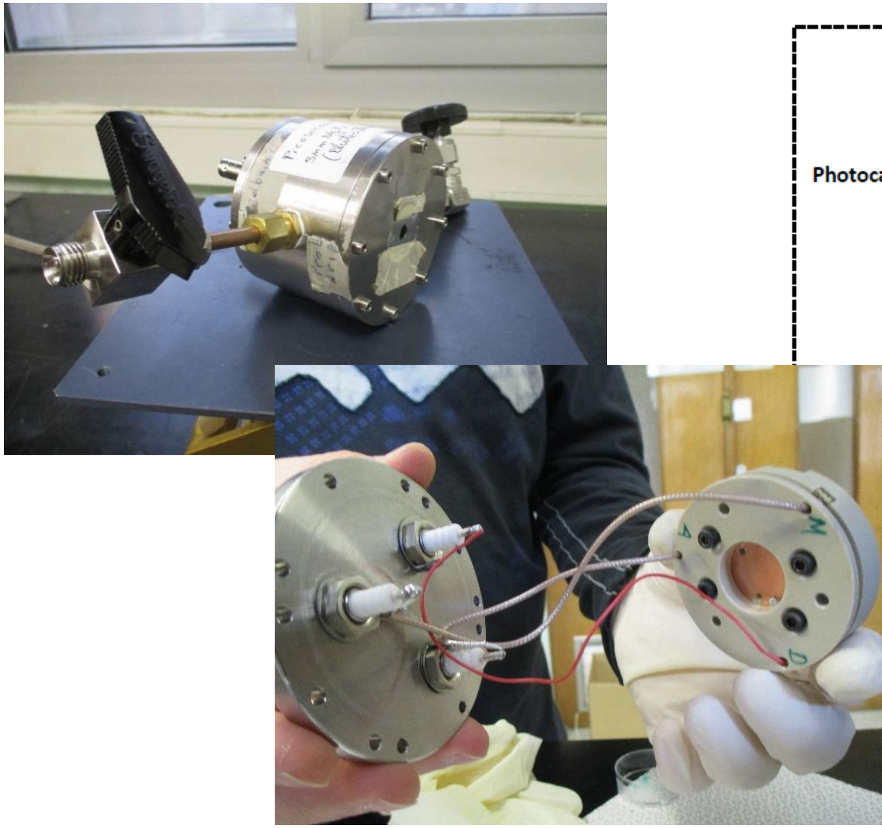
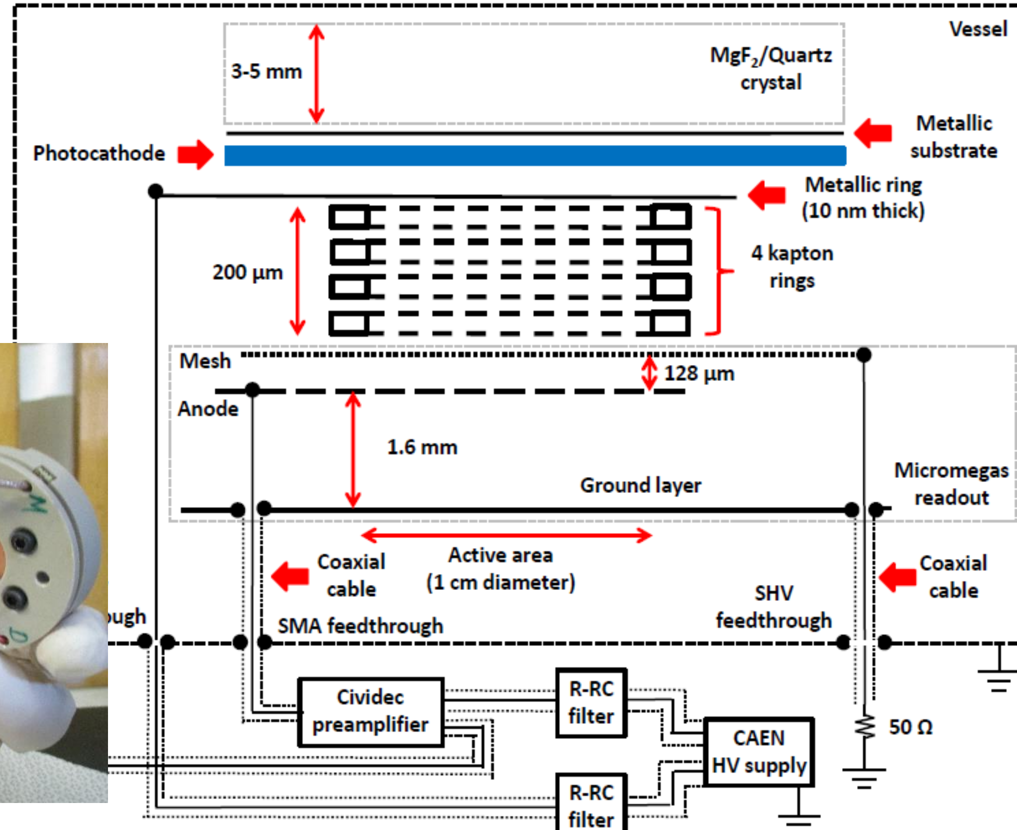
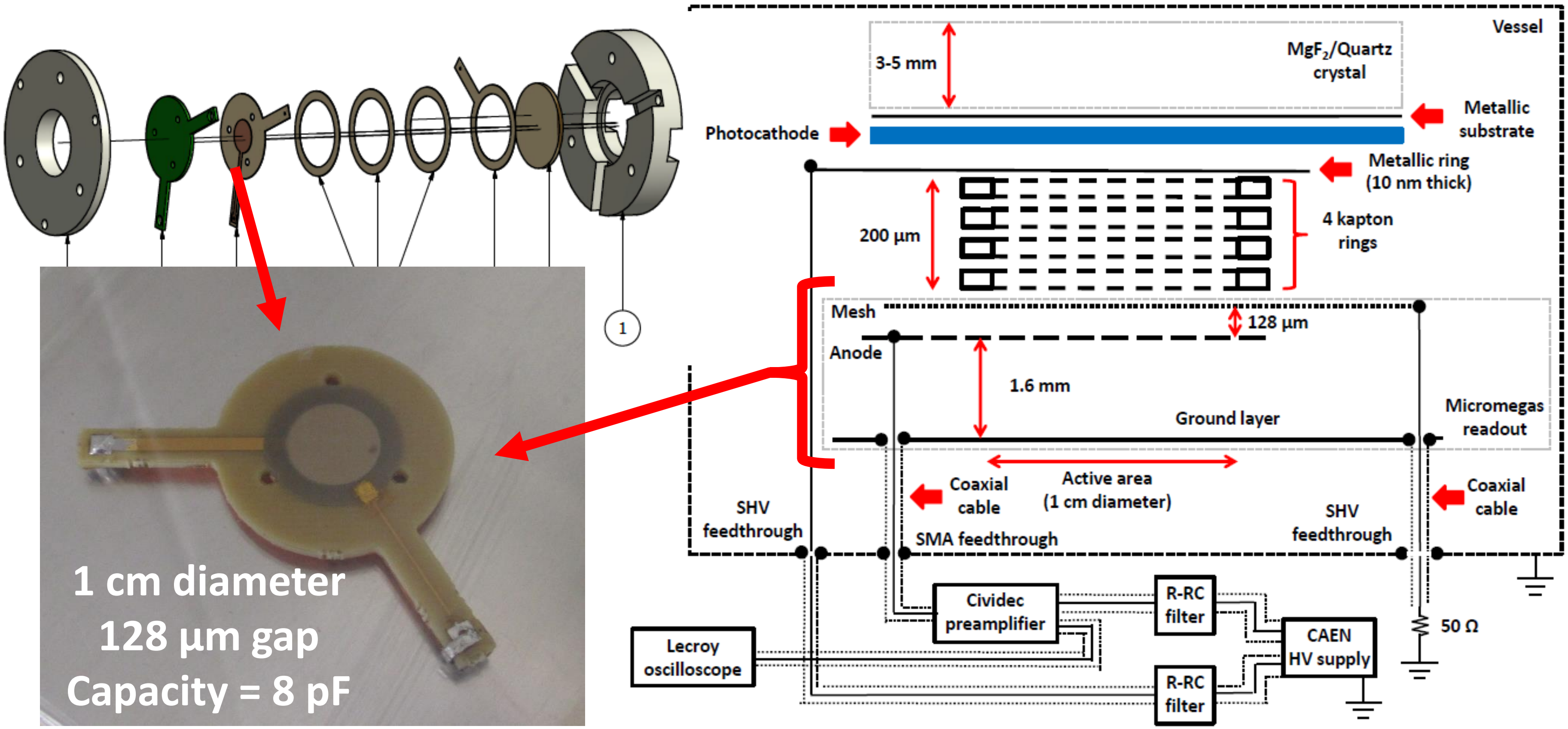




1 cm diameter active area

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

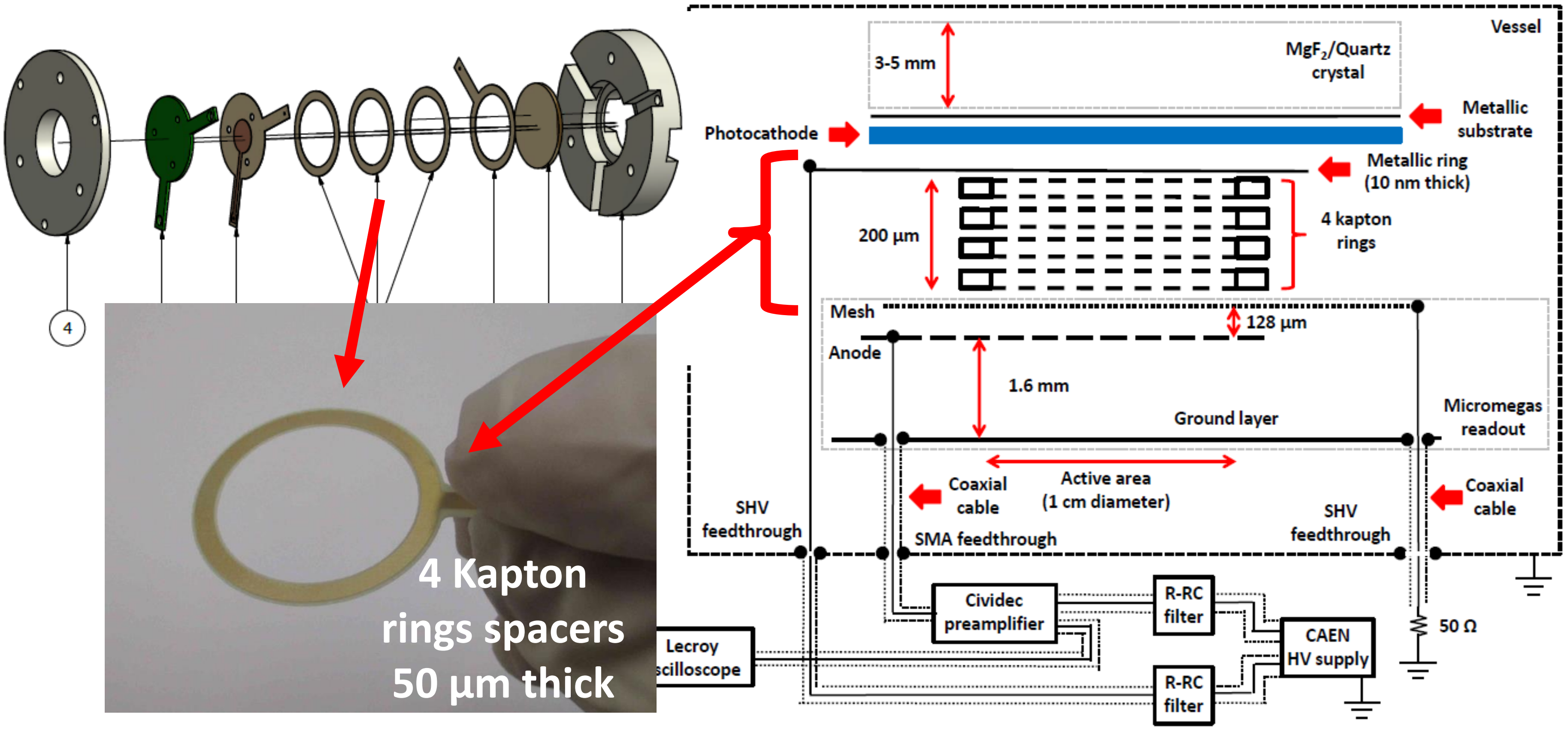
The first Picosec prototype



Main elements:

- Bulk MM readout.
- 3 kapton rings spacers to define the drift.
- A crystal + photocathode.

The first Picosec prototype



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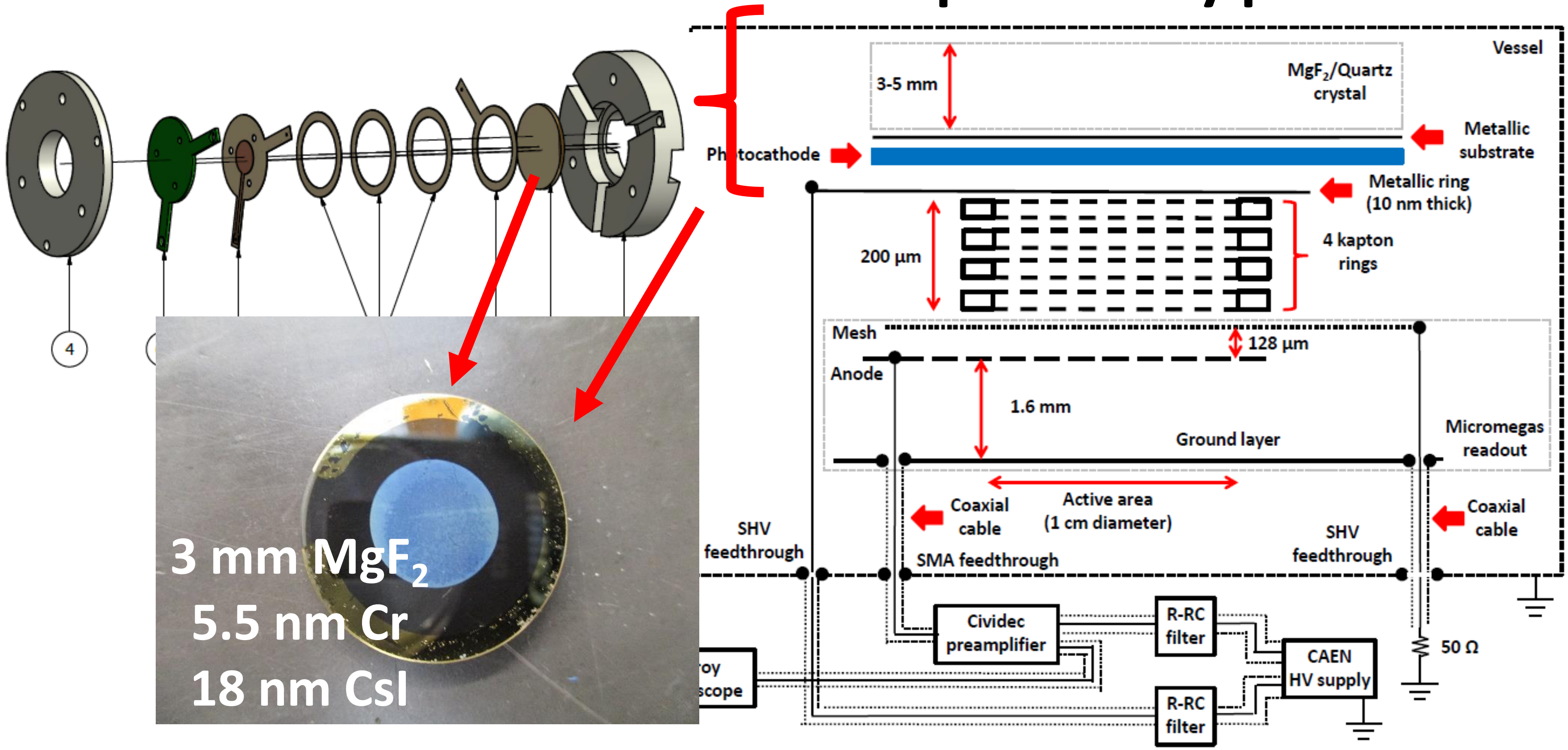

Main elements:

- Bulk MM readout.
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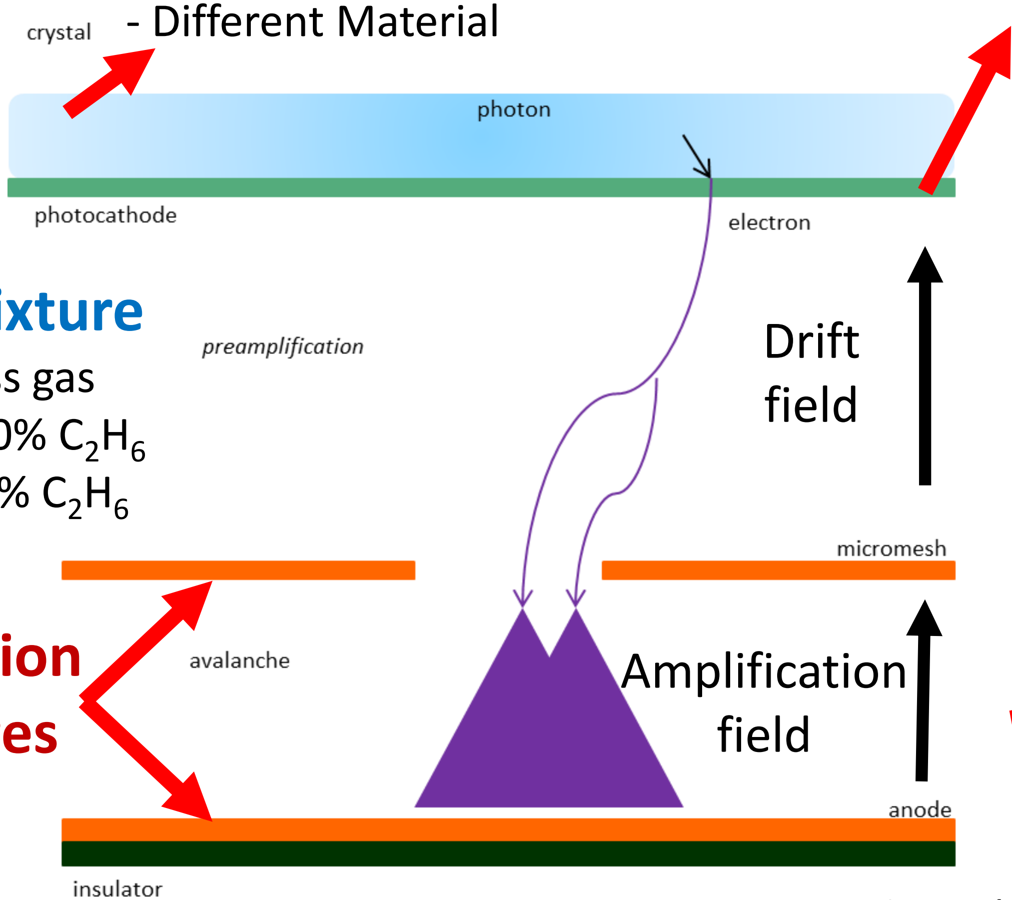
Optimization parameters

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



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

Operation voltages

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

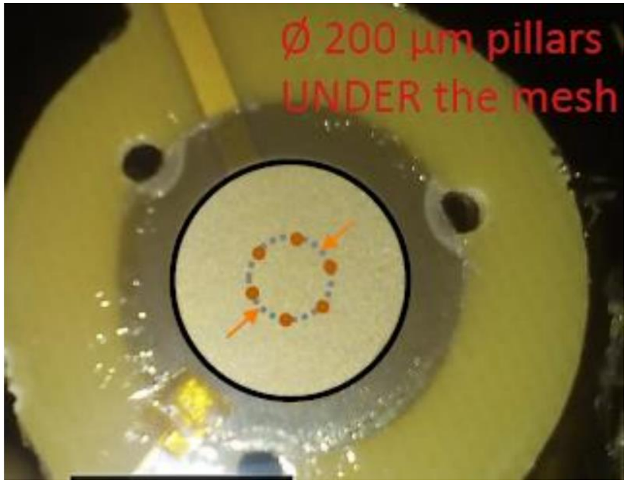
Micromegas:
- standard bulk
- bulk with 6 pillars
- thin mesh bulk
- Resistive (different values)

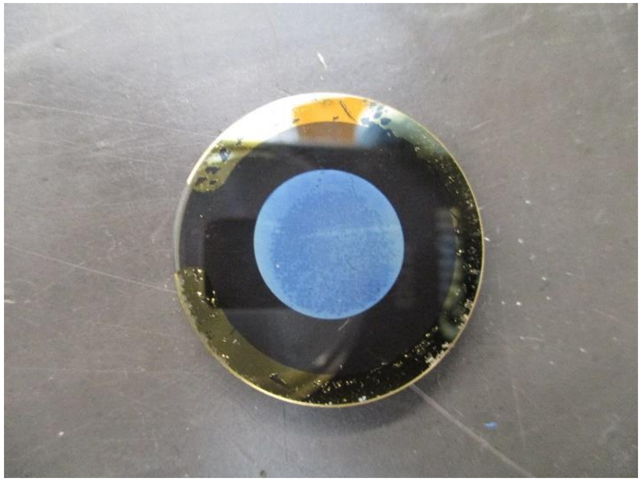
E. Oliveri (CERN)

Timing measurements

Timing measurements

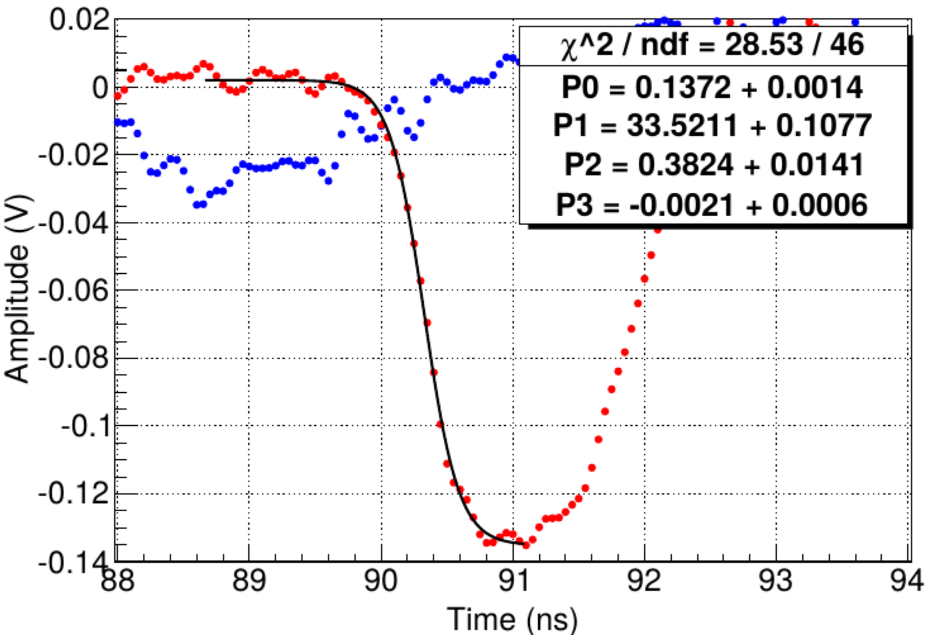
- Standard Picosec detector:
  - **Bulk** Micromegas with 6 pillars.
  - Photocathode: **3 mm MgF2 + 5.5 nm Cr + 18 nm CsI**.
  - Gas: **Compass gas** (Ne + 10% C_2H_6 +10% CF_4).





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.



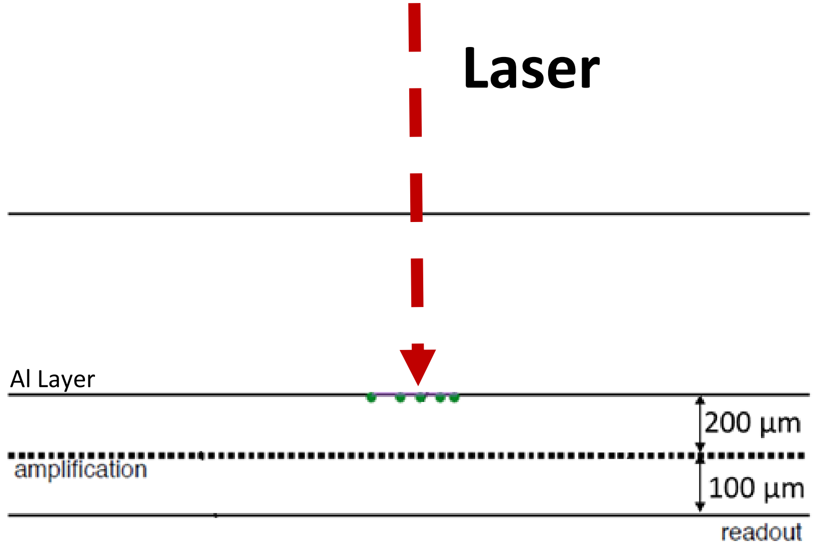
$$V(t) = \frac{P_0}{1 + e^{-P_2 \times (t - P_1)}} + P_3$$

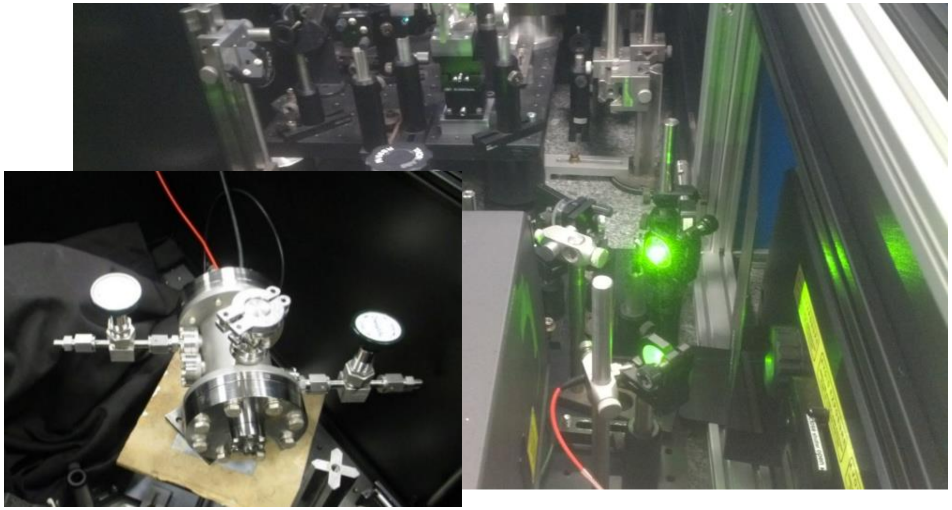
$$t_z = P_1 - \frac{1}{P_2} \, log \left[\frac{P_0}{y_0 - P_3} - 1 \right]$$

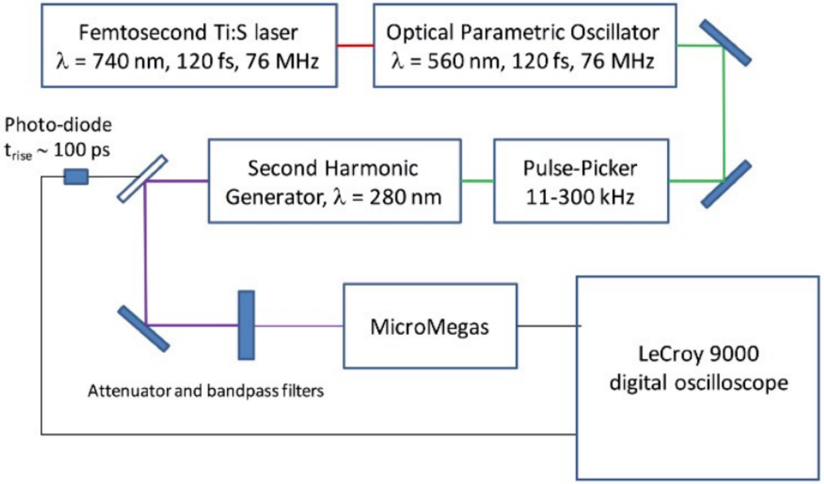
Timing measurements: single photo-electron (laser tests)

Timing measurements: laser tests.

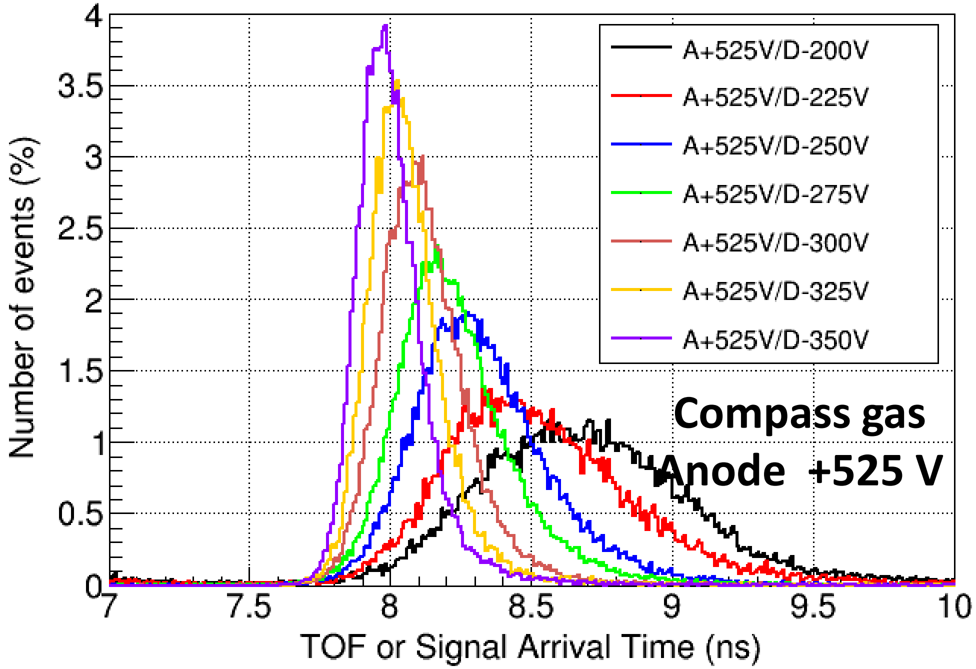
- IRAMIS facility @ CEA Saclay.
- Wavelength: **280 nm**.
- Light attenuators.
- Trigger from fast PD.
- Cividec 2 GHz, 40 db preamplifier.
- DAQ: 2.5 GHz LeCroy scope.
- Data in **Compass gas** & CF_4+20%C_2H_6.







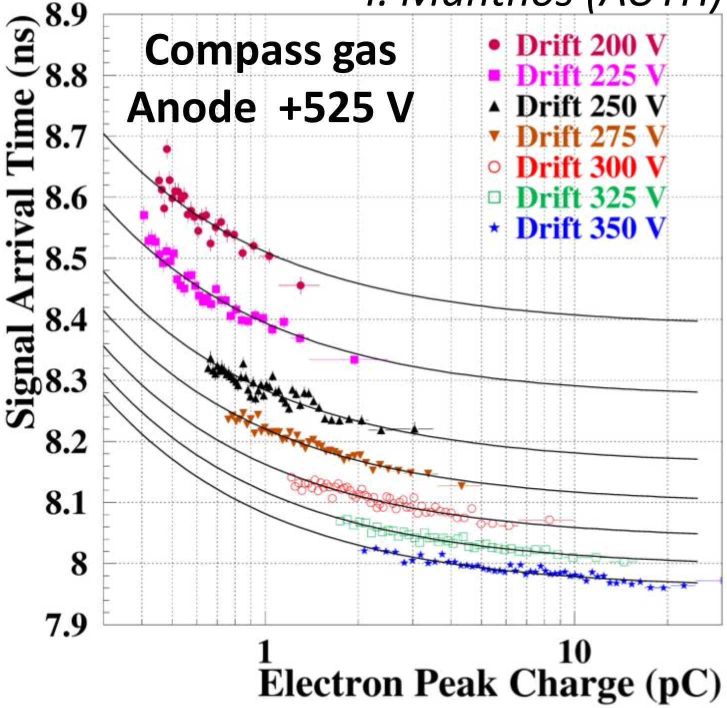
Results of laser tests: SAT vs amplitude

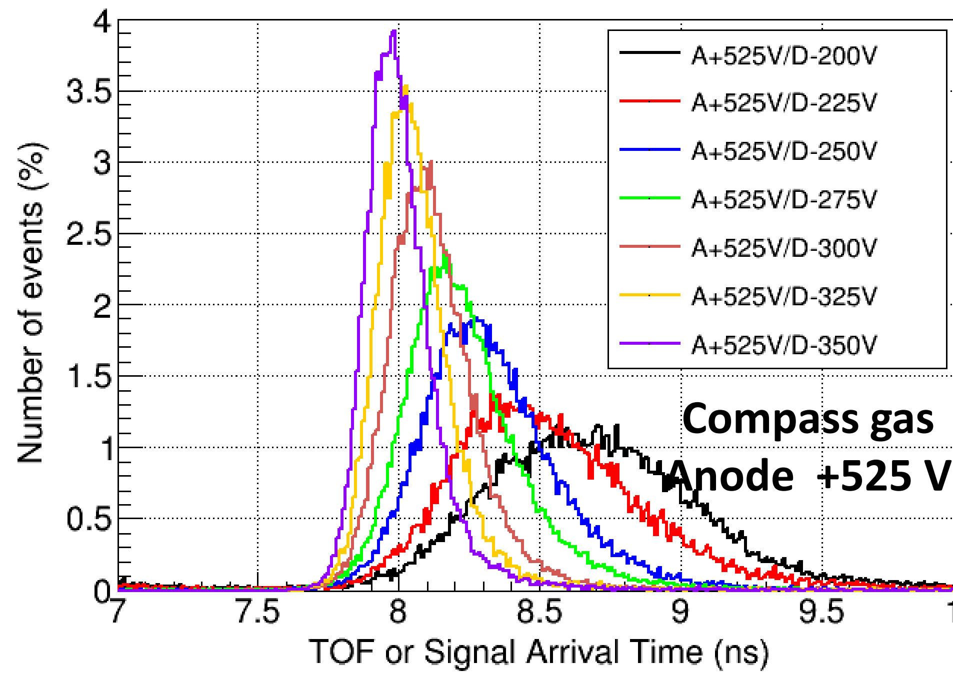


- TOF (Signal Arrival Time) distribution shows a tail at high values.

Results of laser tests: SAT vs amplitude

I. Manthos (AUTH)





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- This tail is a result of the correlation btw TOF & pulse amplitude.

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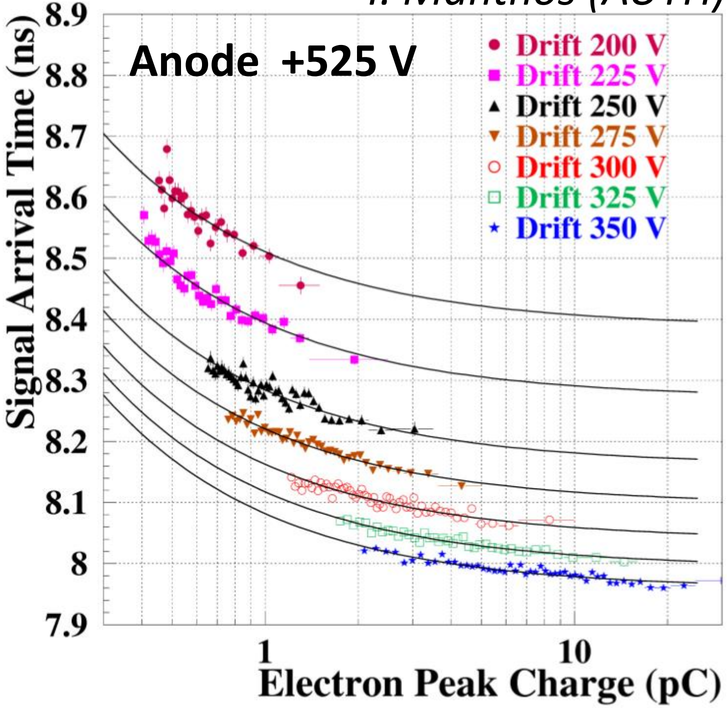

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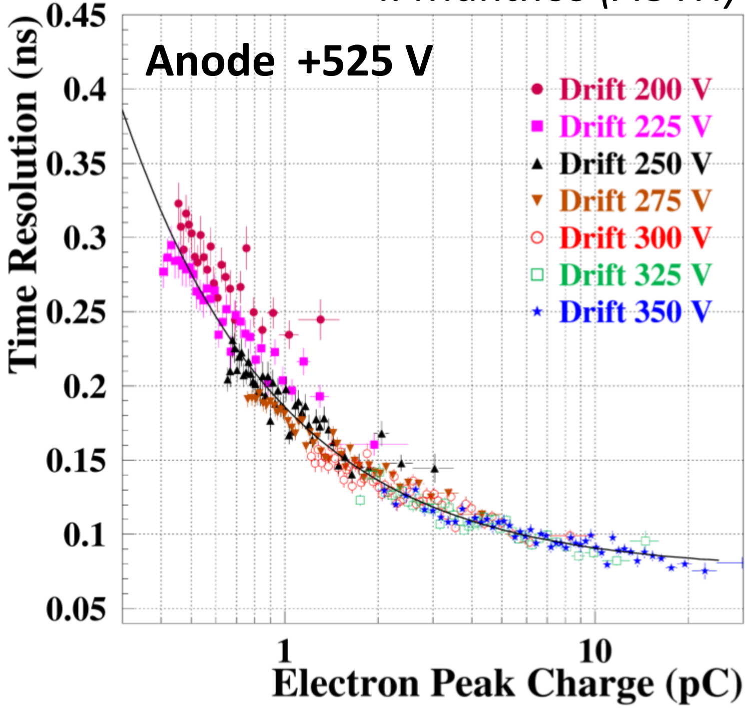

- TOF (Signal Arrival Time) distribution shows a tail at high values.
- This tail is a result of the correlation btw TOF & pulse amplitude.
- And a correlation btw the time resolution & pulse amplitude.

Results of laser tests: SAT vs amplitude

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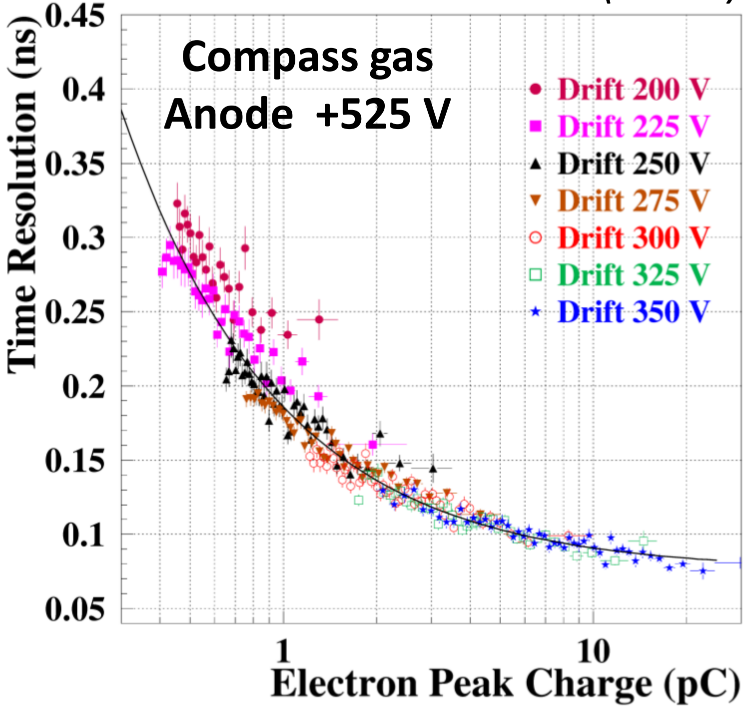

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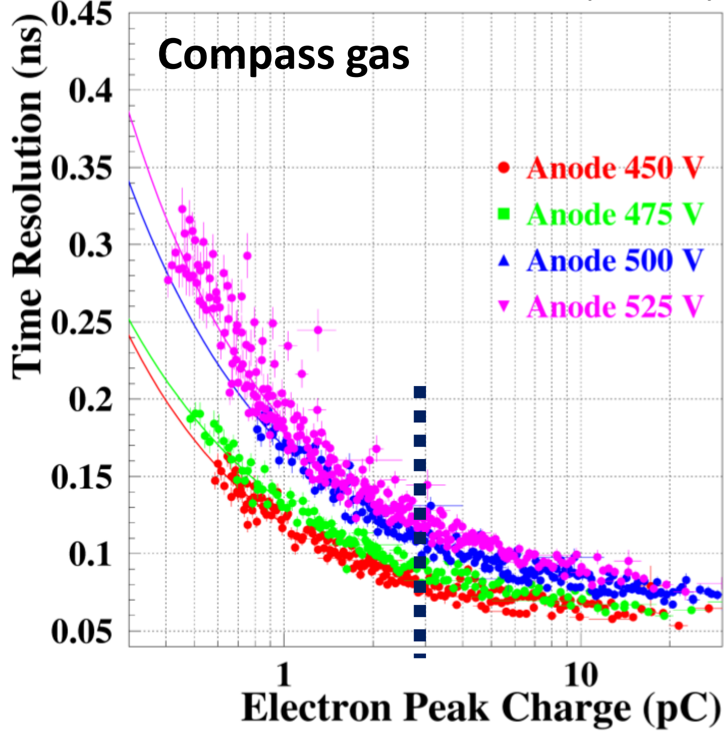
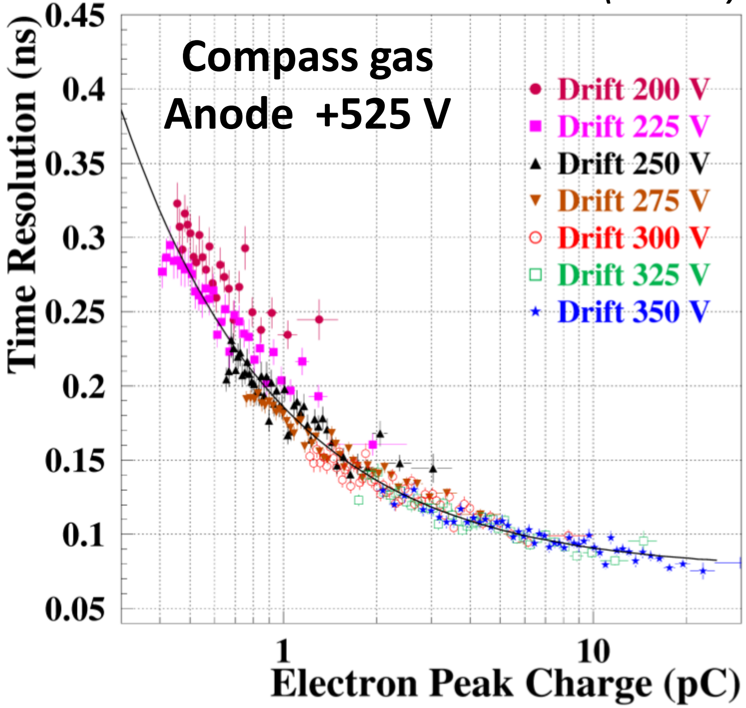


Signals of a given amplitude:

- 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

I. Manthos (AUTH)



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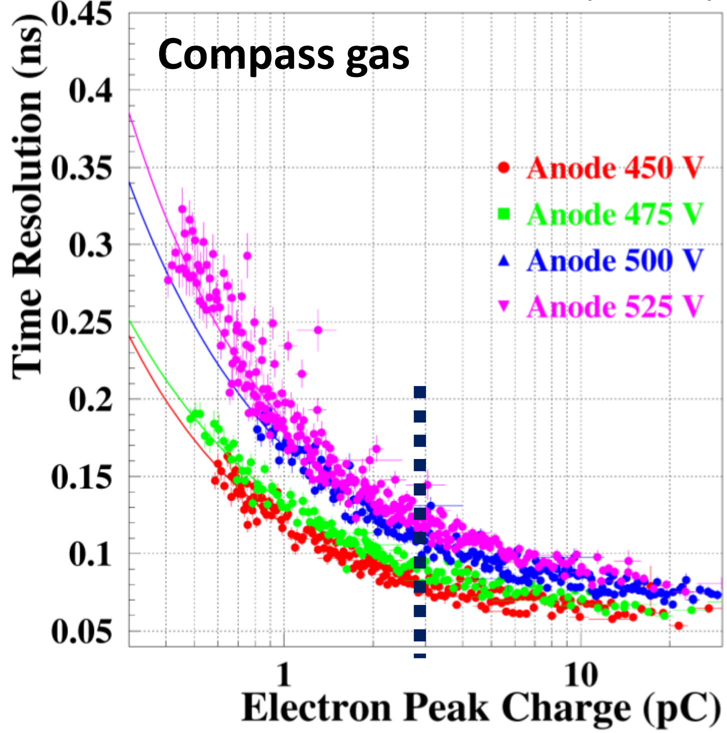
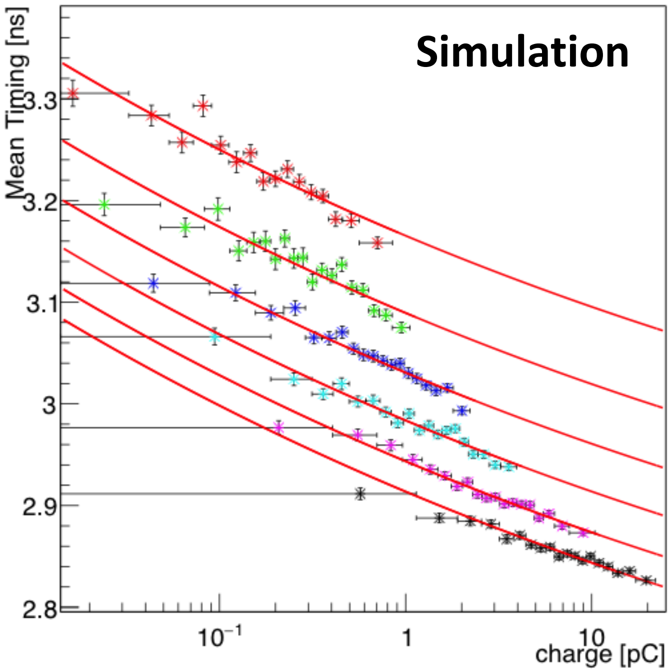
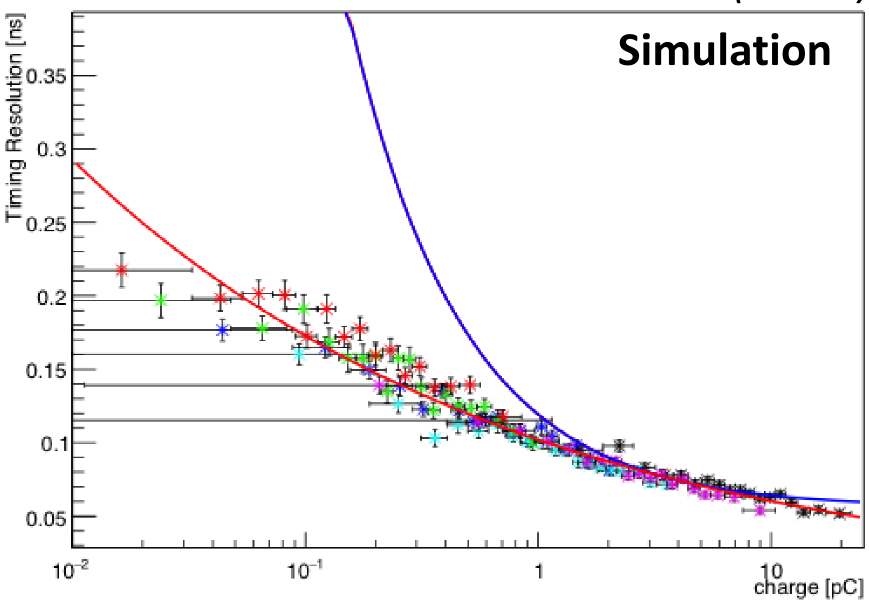


Timing properties are mainly determined by the pre-amplification stage.

Simulation of the detector response



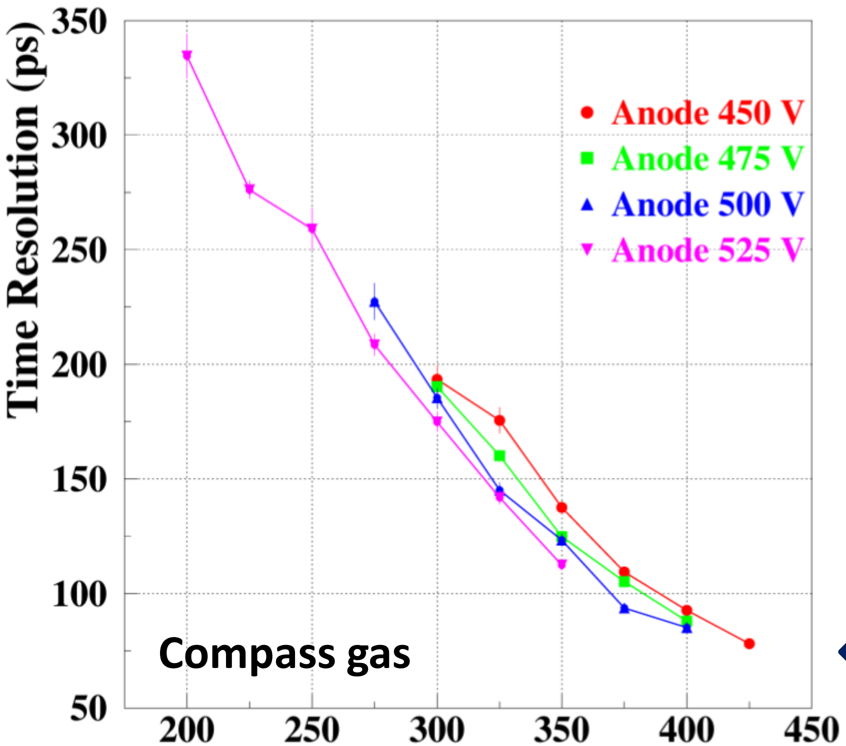
K. Paraschou & S.E. Tzamarias (AUTH)



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

Further details: "Progress report on the modelling of slewing & resolution effects in Picosec detector" by K. Paraschou (RD51-WG4 group, 25th Sep).
https://indico.cern.ch/event/667256/contributions/2732572/attachments/1529392/2393101/KostasPresentation.pdf

Results of laser tests: summary



I. Manthos (AUTH)

Correction applied:

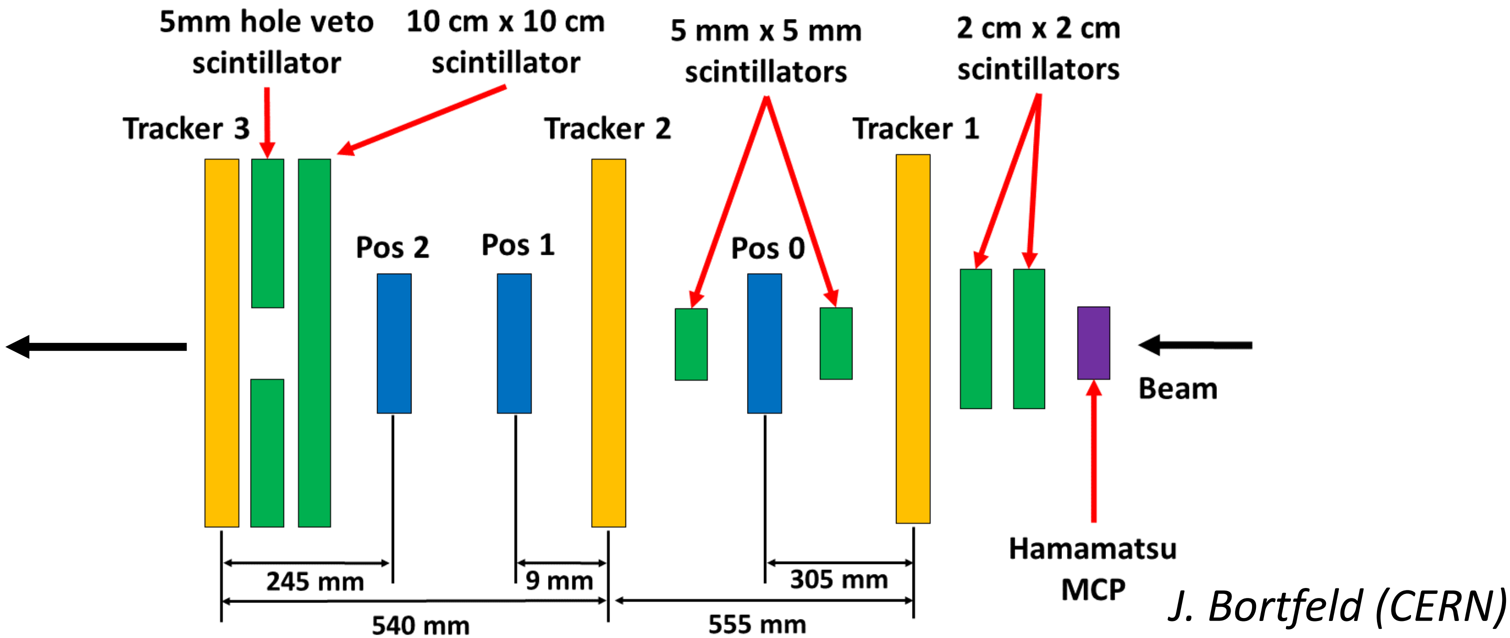
1) **SAT dependence.**
2) **DAQ threshold.**

- Time resolution for 1 photo-electron: **76.0 ± 0.4 ps.**
- Further improvement expected for higher drift fields.

Timing measurements:
150 GeV muons
(beam tests)

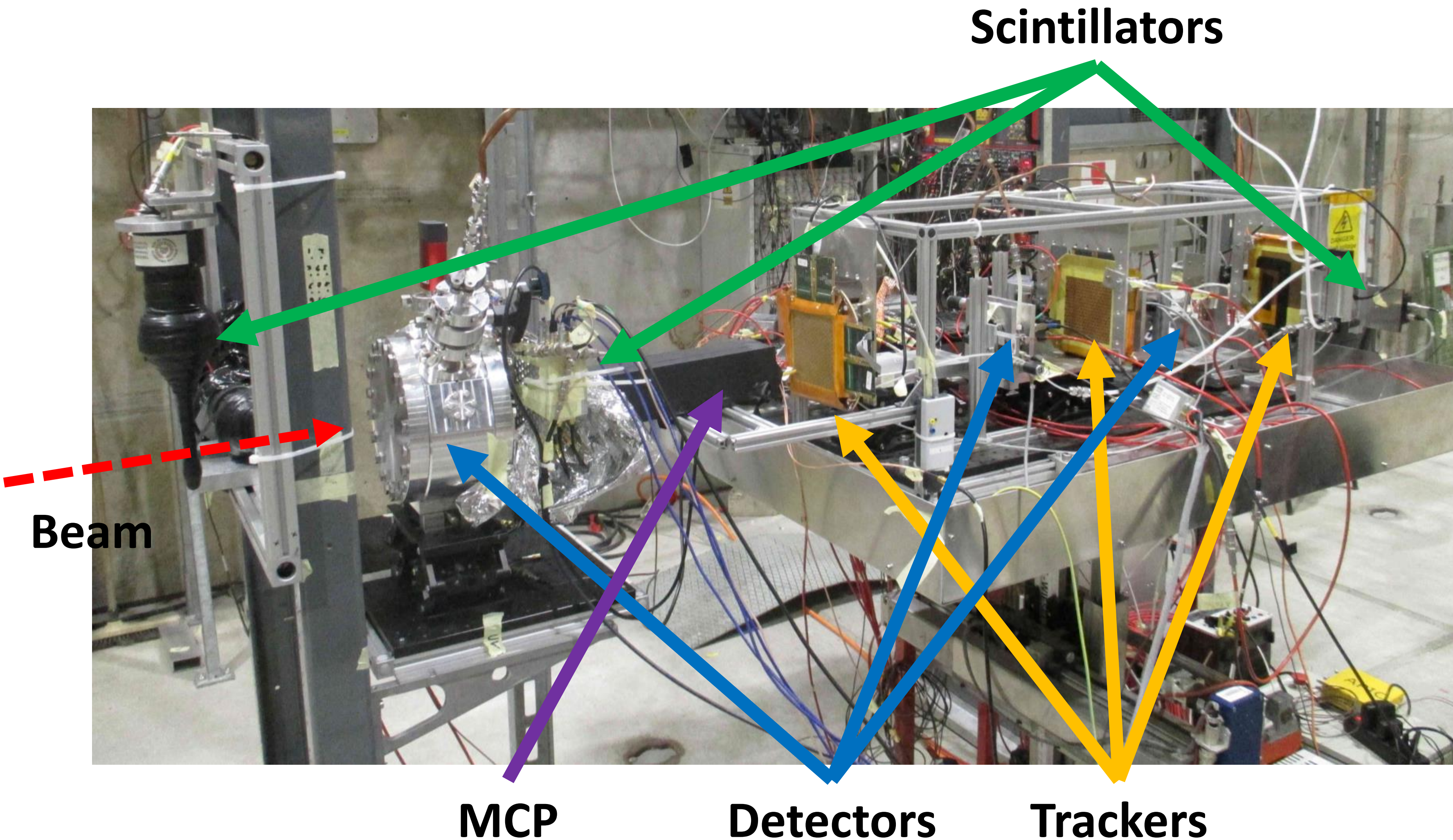
CERN-H4 north area SPS Extraction line

The setup during beam tests

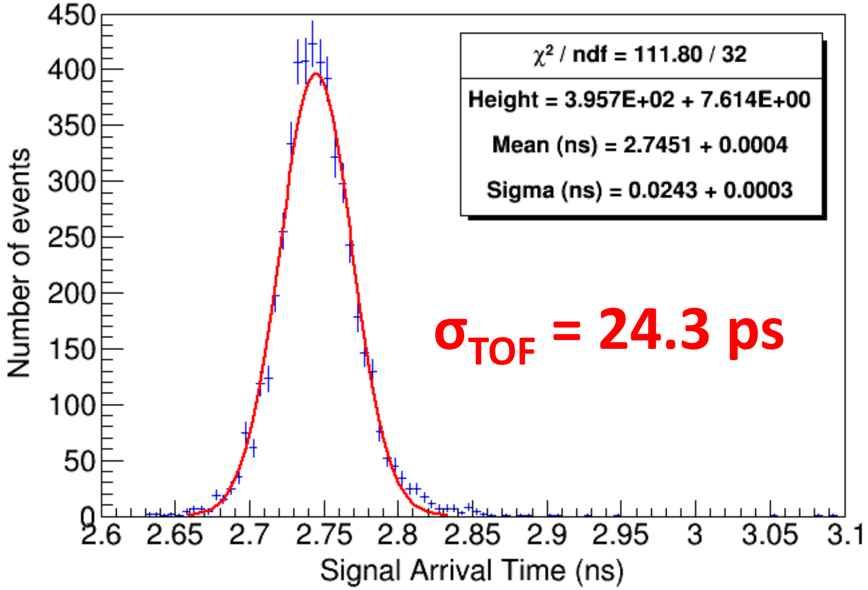


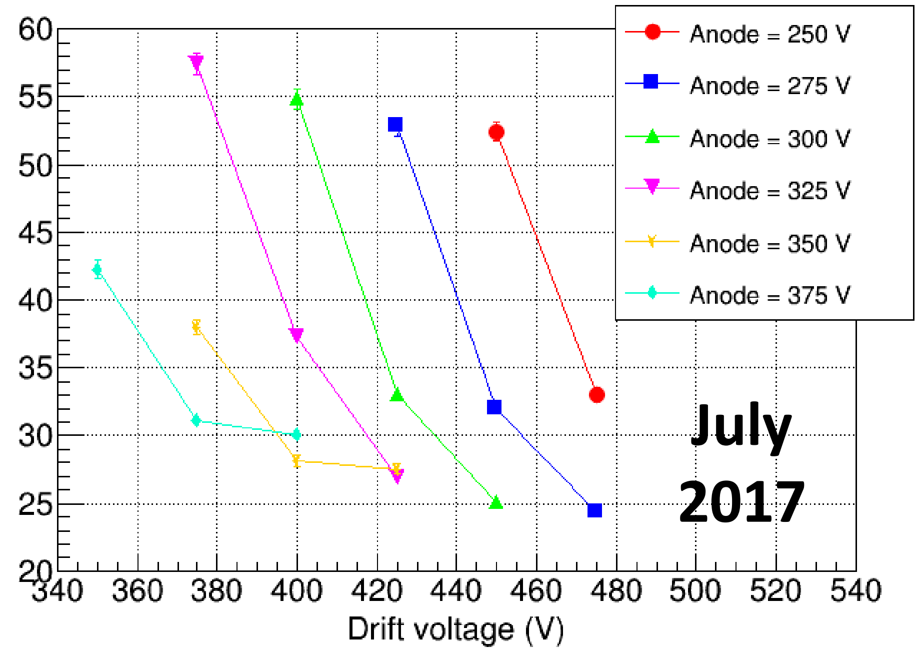
- **Time reference:** one Hamamatsu MCP-PMT (**5.5 ps** time resolution).
- **Scintillators:** coincidence of two 5x5 mm^2 and a veto to avoid showers.
- **Tracker:** 3 GEMs to measure the impact point in each detector.
- **Electronics:** CIVIDEC C2 preamplifiers + 1-4 2.5 GHz LeCroy scopes.
- **Nphe:** calibrations of SPE by UV lamps remotely controlled.

The setup during beam tests



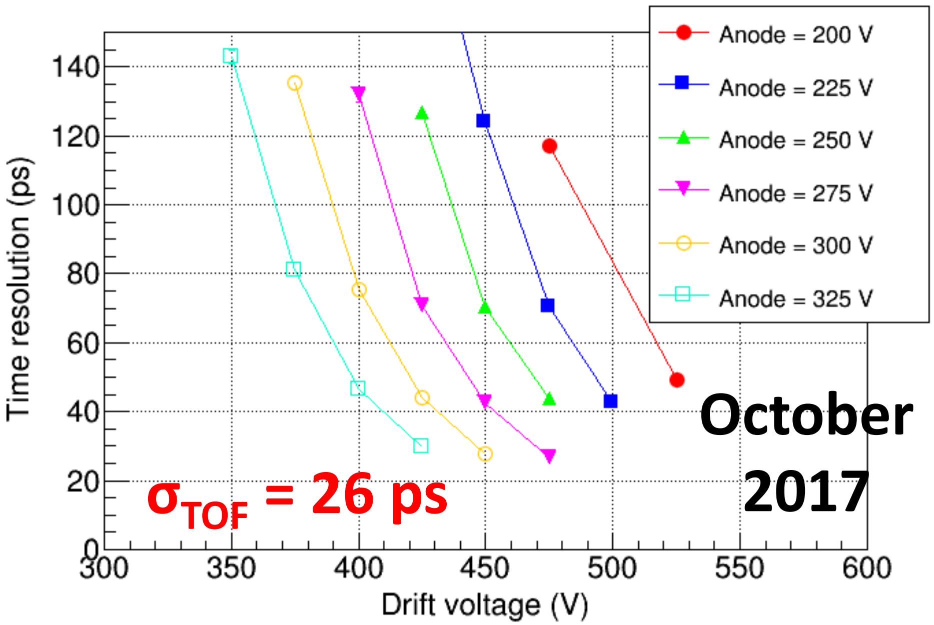
Results of beam tests: 24 ps for bulk

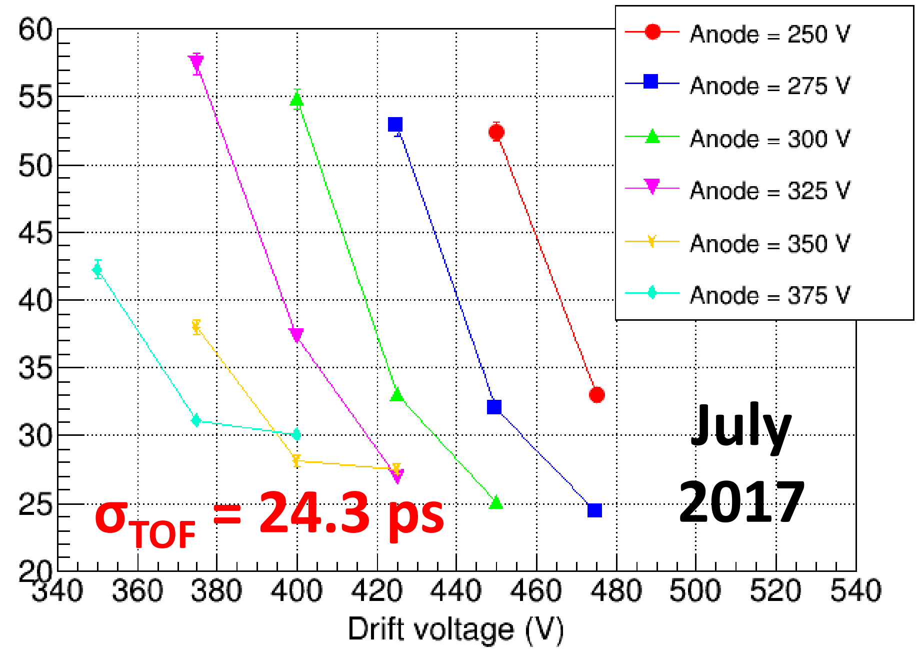




- Best result: **24 ps** (bulk MM + Cr/CsI photocathode).
- Optimum operation point: Anode +275V / Drift – 475V.
- Nphe = **10.1 ± 0.7**
- Result repeated in two different beam campaigns.

Results of beam tests: 24 ps for bulk



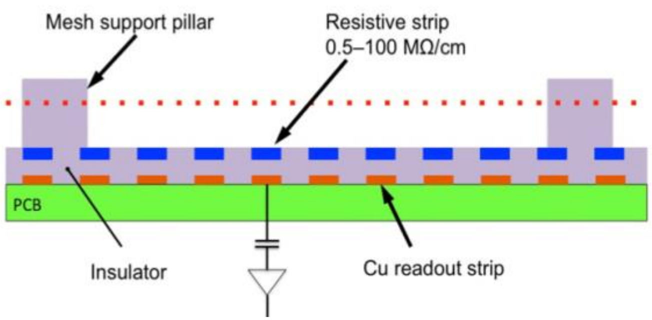


- Best result: **24 ps** (bulk + Cr/CsI photocathode).
- Optimum operation point: Anode +275V / Drift – 475V.
- Nphe = **10.1 ± 0.7**
- Result repeated in two different beam campaigns.

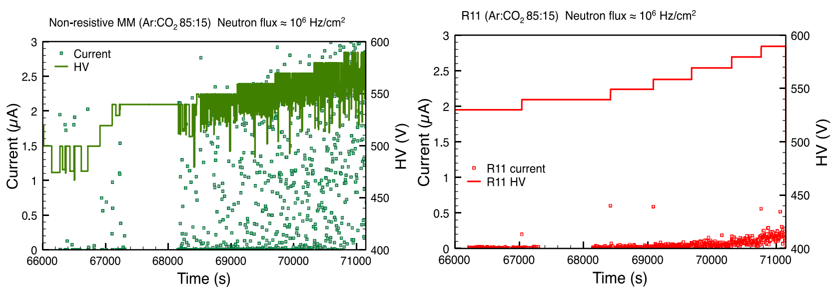
On going R&D
and future plans

Robust readout: resistive MM

ATLAS New Small Wheel - MicroMegas (J. Wotschack et al.)



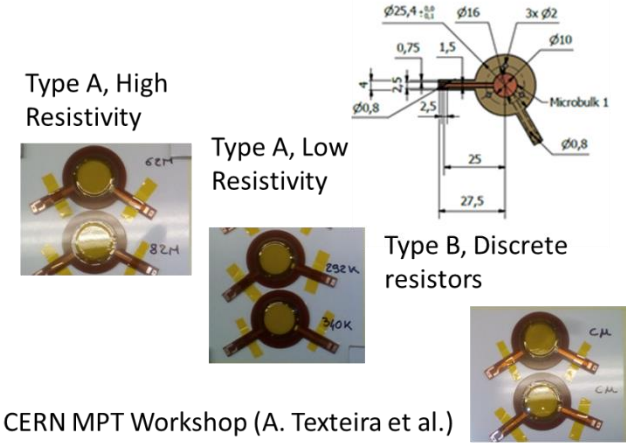
G. Iakovidis, arXiv:1310.0734v1 [physics.ins-det] 2 Oct 2013



Nuclear Instruments and Methods in Physics Research A 640 (2011) 110–118

A spark-resistant bulk-micromegas chamber for high-rate applications

T. Alexopoulos [a], J. Burnens [b], R. de Oliveira [b], G. Glonti [b], O. Pizzirusso [b], V. Polychronakos [c], G. Sekhniaidze [d], G. Tsipolitis [a], J. Wotschack [b,*]



CERN MPT Workshop (A. Texteira et al.)

A: Resistive plane a la “mamma”

- Better protection

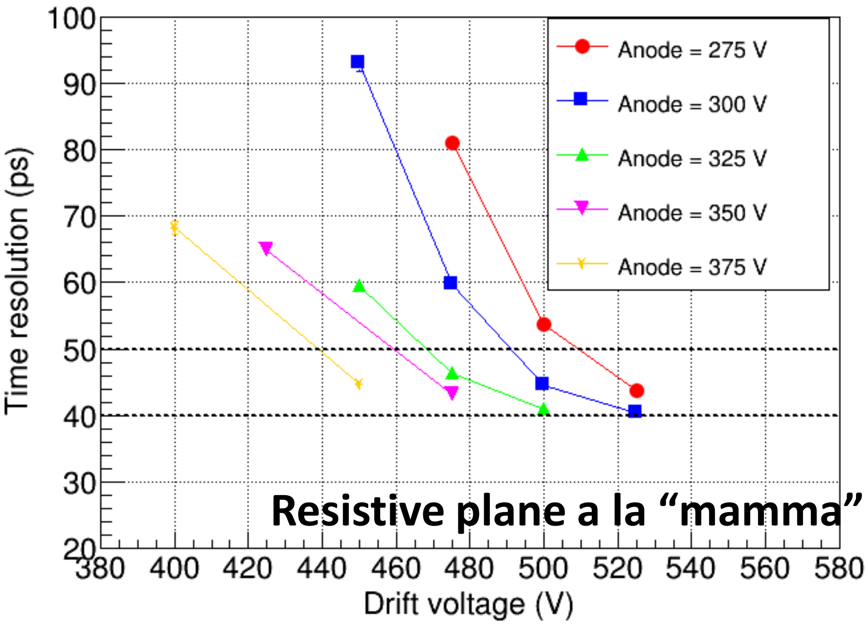
B: Discrete Resistors a la “compass RICH” (Trieste)

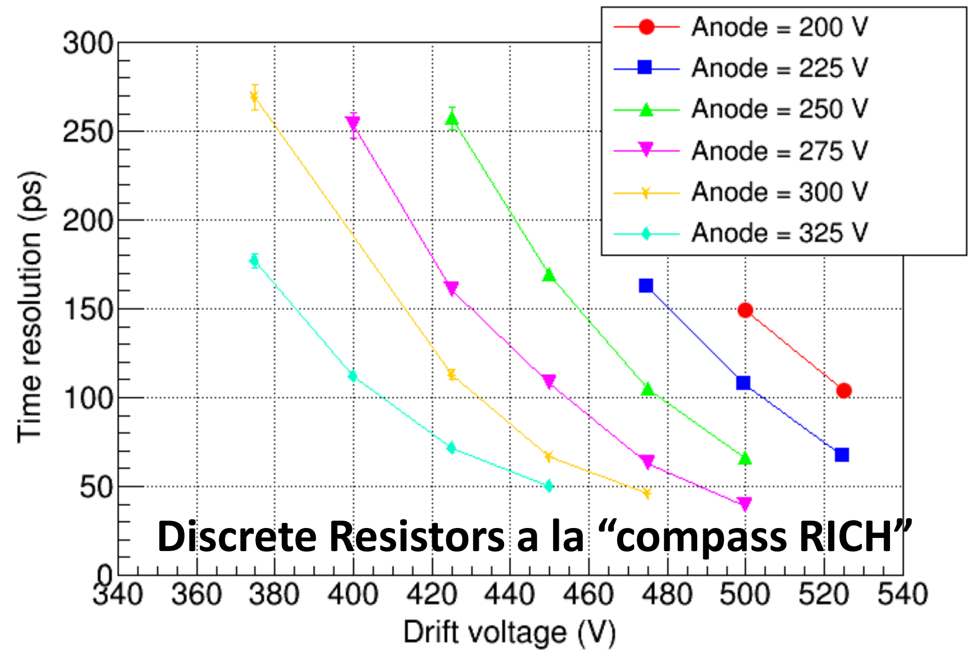
- Larger flexibility on resistor value

C: Embedded Resistors a la “Chefdeville-Geralis-Peskov”

- Tested using low resistivity plane a la “mamma” with discrete resistor a la “compass RICH”

Robust readout: first results



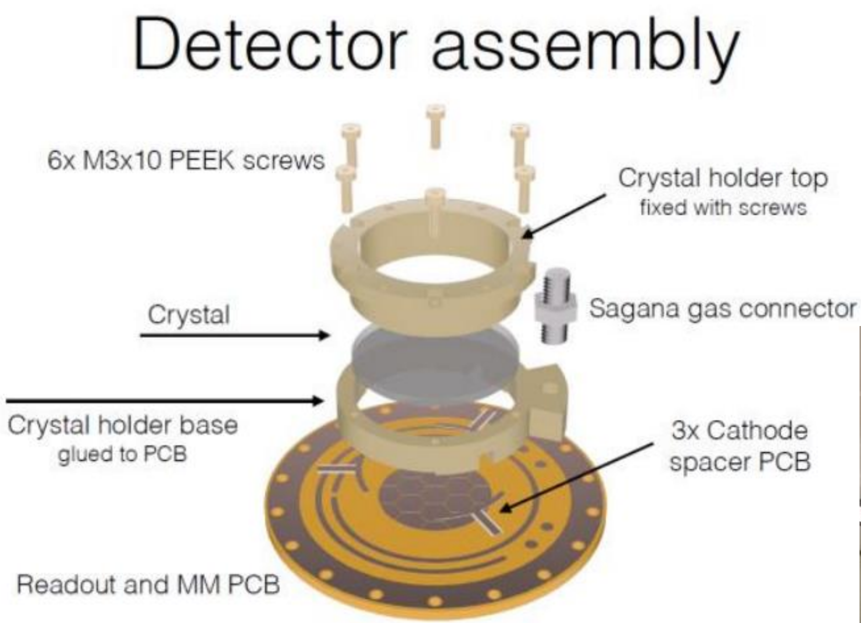


- Values not far from the standard configuration.
  - Type A: **40 ps** (10 MΩ/☐), **35 ps** (300 kΩ/☐).
  - Type B: **40 ps** (25 MΩ).
- Resistive readouts worked during hours in pions beams.

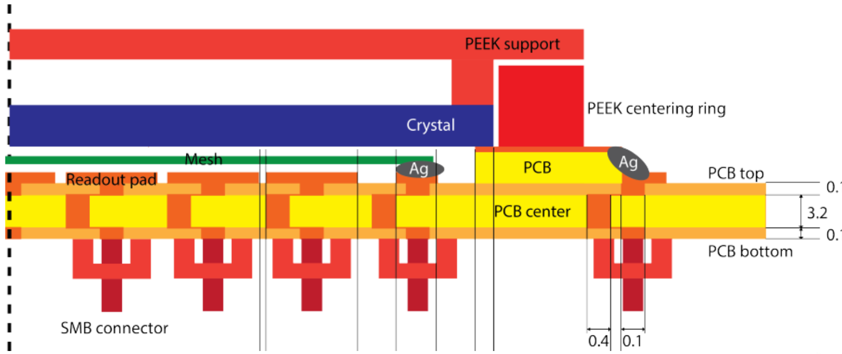
Scaling up

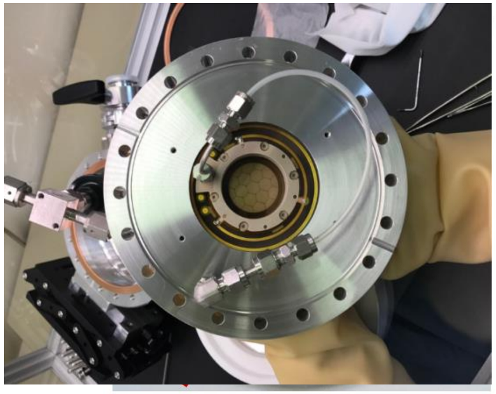
Goals:

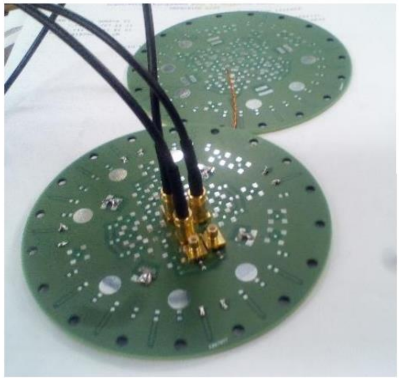
- To preserve the signal integrity with larger mesh & routing/vias.
- To keep an uniform gap on larger surfaces.



F. Brunbauer (CERN)

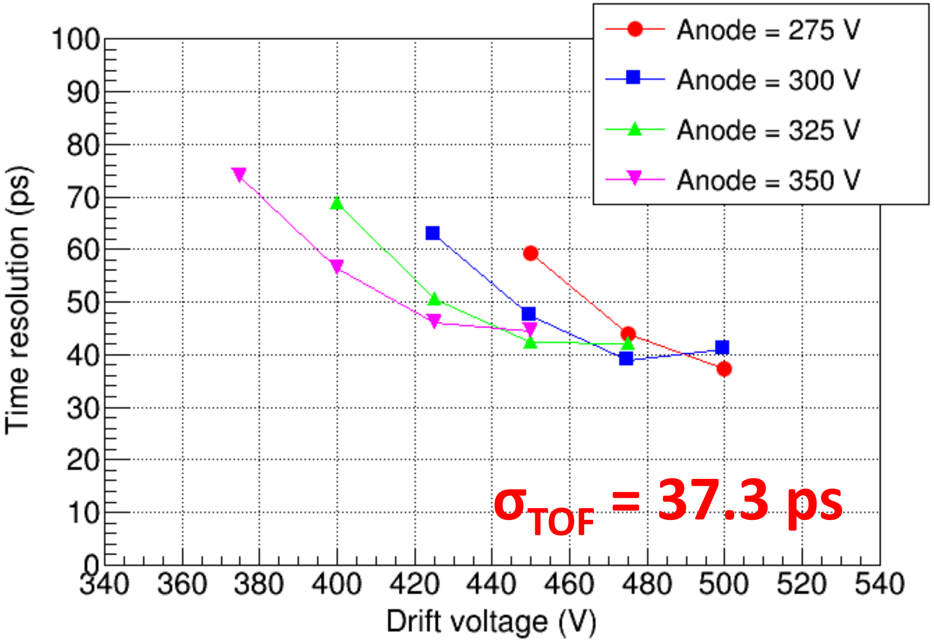


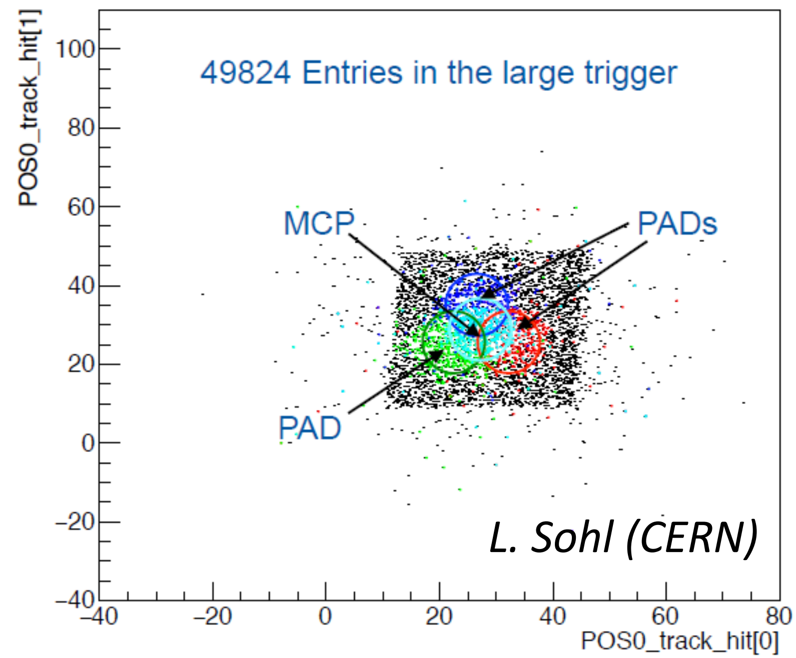




~35mm Active area, 19 pads (7 full size)

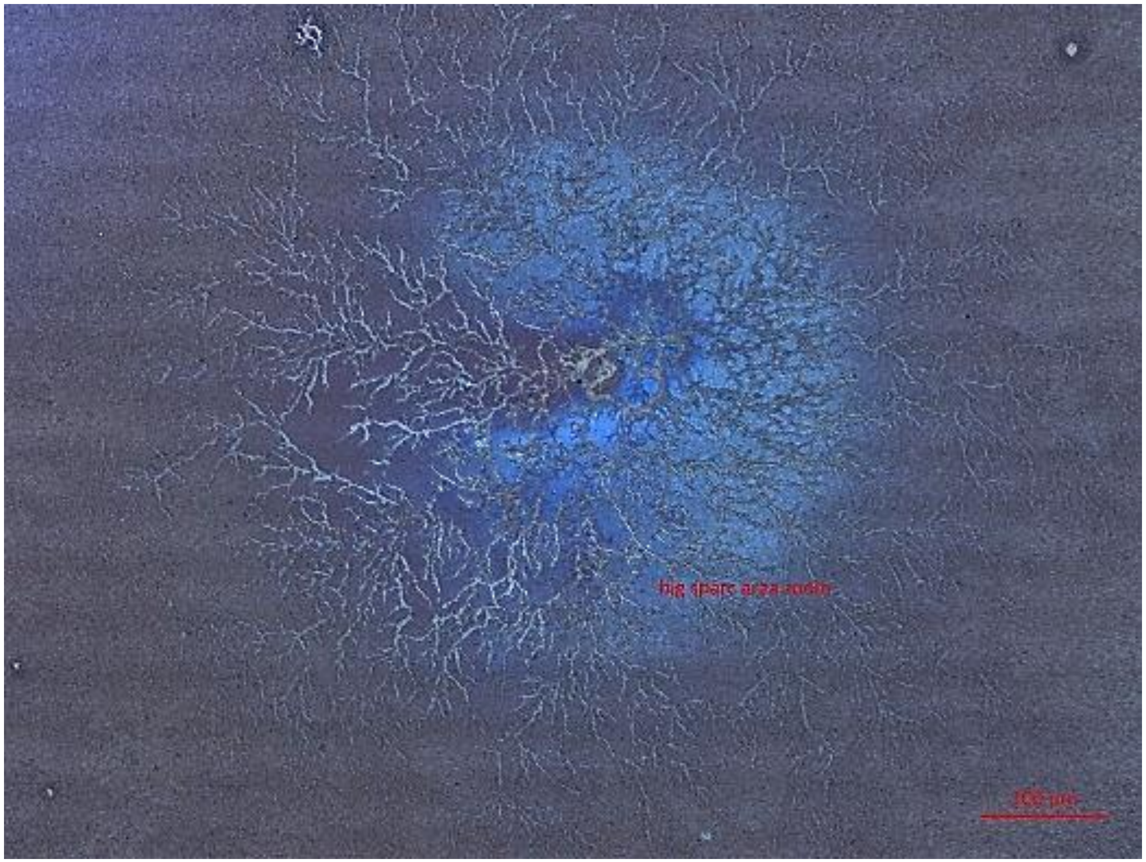
Scaling up: first results





- Field scan centered in one pad: **37 ps**.
- MCP was centered btw 3 PADs -> High statistics (>10^6 events) study of charge/timing sharing btw them.

A picture of sparks in a photocathode



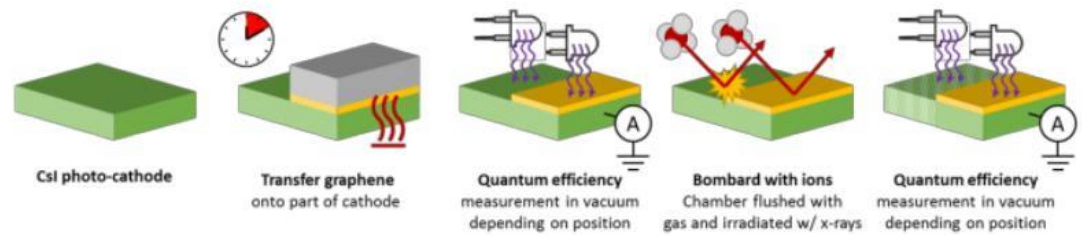
T. Schneider (CERN)

A robust photocathode against sparks & ion feedback is needed.

Robust photocathodes

CsI protection layers:

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

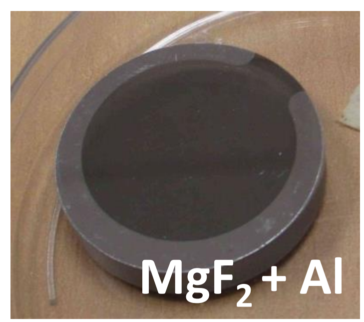


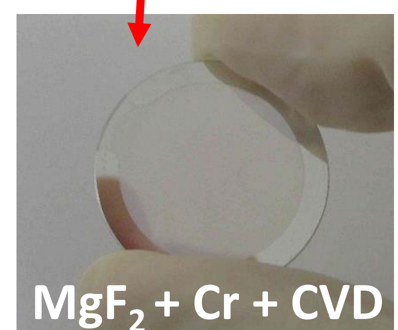
Diamond as photocathode or secondary emitter.

- 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.

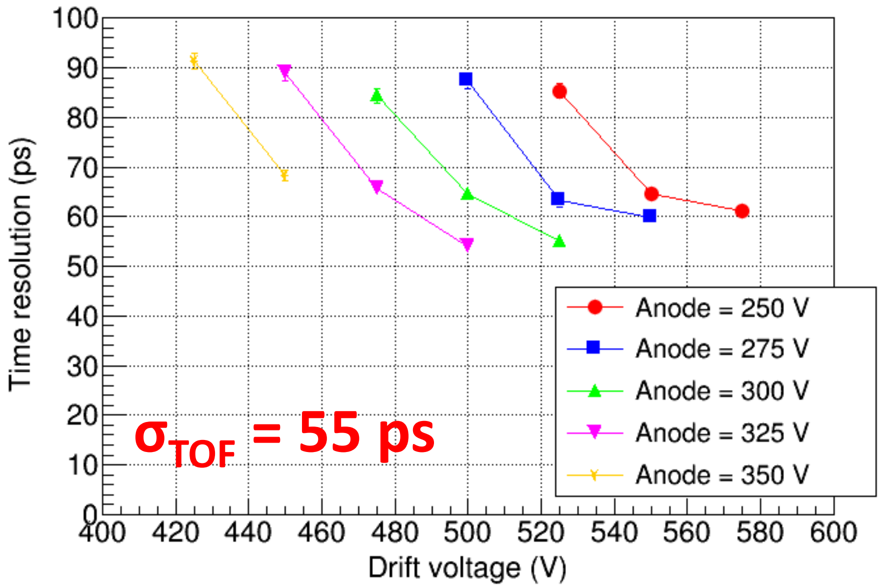
Pure metallic photocathodes:

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





Robust photocathodes: pure metallic

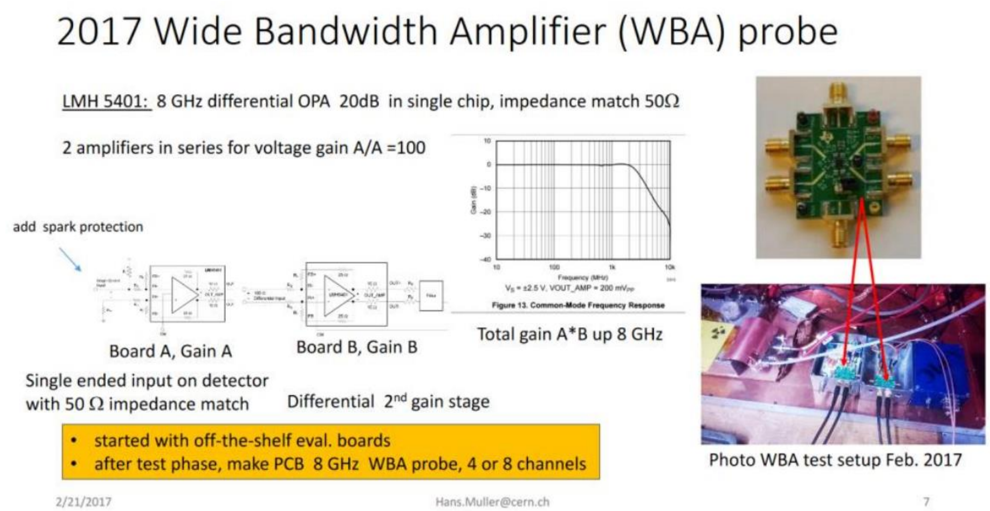


- Previous tests showed modest results:
  - 5 mm MgF2 + 10 nm Cr: ~100 ps, Nphe = 2.2.
  - 5 mm MgF2 + 100 nm CVD: 180 ps, Nphe = ~2
- Pure metallic one (5 mm MgF2 + 20 nm Al): 54 ps!

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

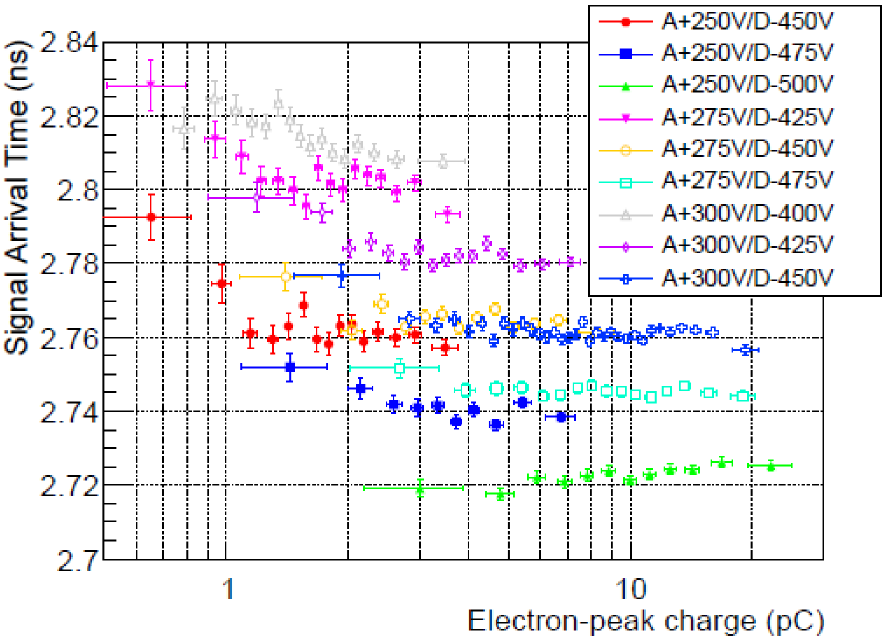
Summary

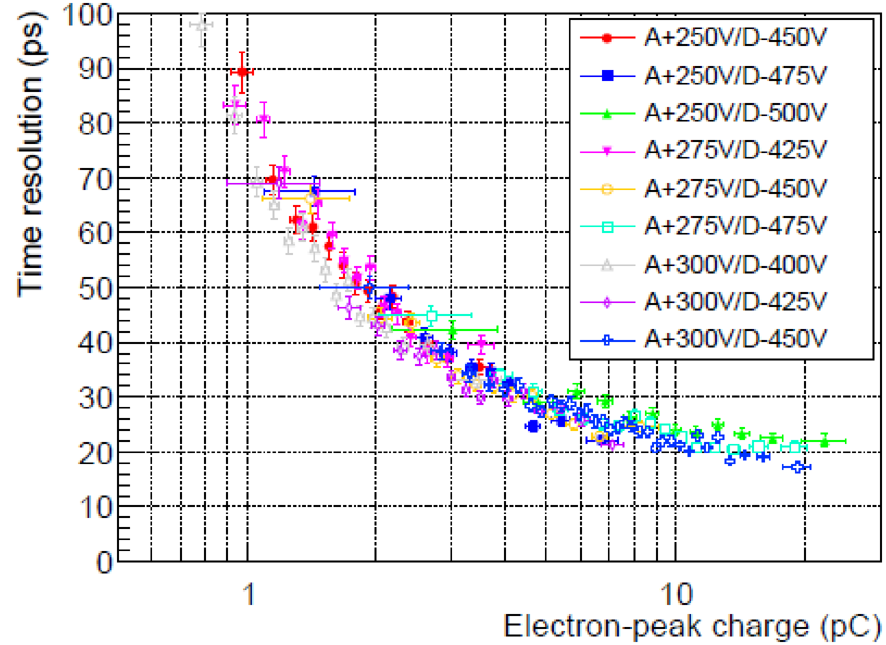
2014	2015	2016	2017
RD51 Proposal submission	First prototype and laser tests	New prototype, better laser results and first beam campaigns	Resistive and multi-channel prototype, photocathode new electronics

- Main results of Picosec:
  - Single photo-electrons: **76 ps**.
  - 150 GeV muons: Bulk readout (**24 ps**), resistive (**35 ps**). Nphe = **~10**.
  - Pions: First long runs with resistive detectors.
  - Multipad: **37 ps** (one pad).
- R&D on going on
  - Detector scaling (large area and multi-channels).
  - New photocathodes, protection layer, secondary emitter.
  - Electronics (amplifiers & digitizers).

Back-up slides

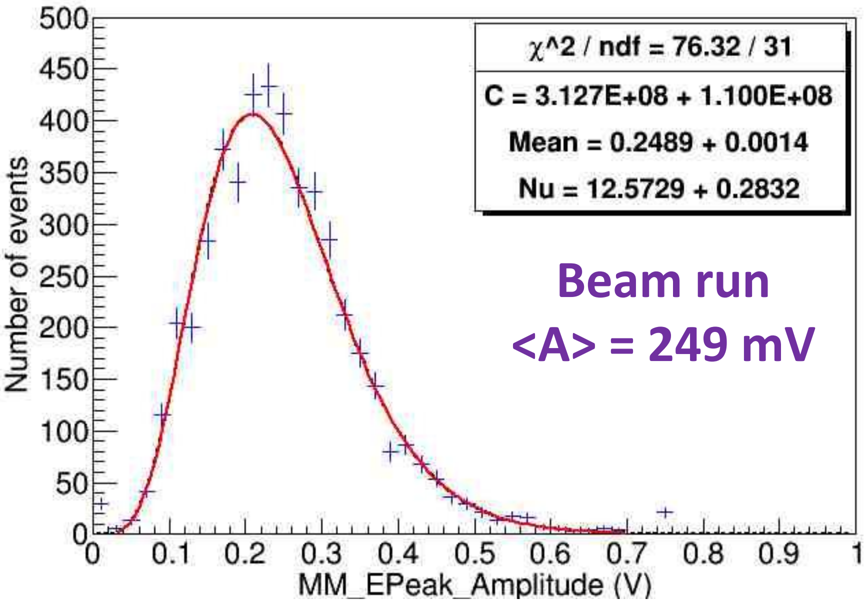
Results of beam tests: SAT vs amplitude

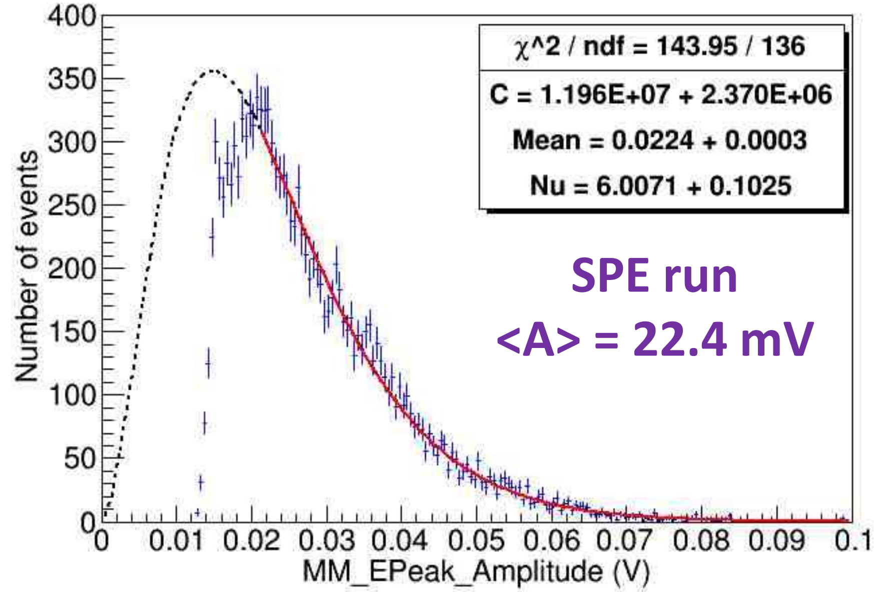




- No dependence btw SAT and electron-peak amplitude.
- The time resolution improves with the amplitude, posibly correlated to the gain in the first amplification stage.
- First approach: one Gaussian fit to SAT distribution.

Number of photoelectrons





Nphe = 249 mV / 22.4 mV = 11.1

- The mean value of amplitude distribution is calculated by a fit to Polya function, for beam runs & SPE run.
- The number of photoelectrons is the ratio of the two values.
- Result of ~10 phe. Systematic errors to be calculated.