DE LA RECHERCHE À L'INDUSTRIE

Silicon detectors hate him !

See how this gaseous boy can provide good time resolution in a high flux environment

@

PHENIICS Fest 2019

Lukas SOHL
28.05.2019

UNIVERSITÉ PARIS SUD
Comprendre le monde, construire l'avenir
université PARIS-SACLAY

École Doctorale PHENIICS Doctoral School

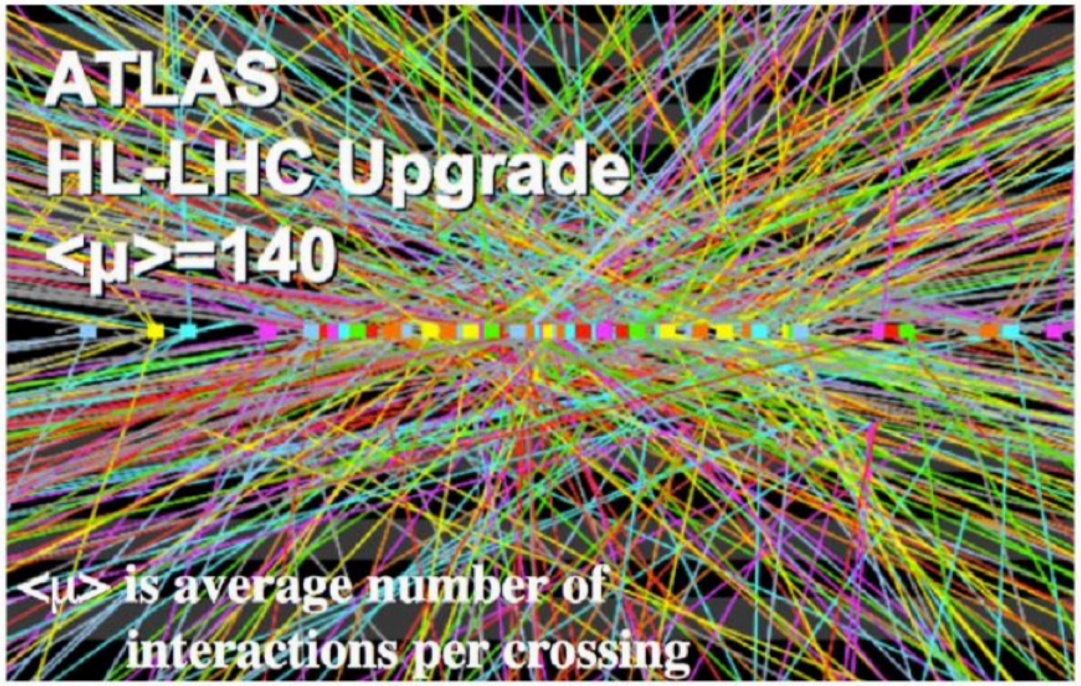
We need robust timing detectors !

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.
- Segmented anodes for tracking.
- Resistance to aging effects.



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

PICOSEC-Micromegas

PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector, Nucl. Instrum. Meth. A903 (2018) 317-325. doi:10.1016/j.nima.2018.04.033.

is brought to you by:

- **CEA Saclay (France):** D. Desforge, I. Giomataris, T. Gustavsson, C. Guyot, F.J. Iguaz[1], M. Kebbiri, P. Legou, T. Papaevangelou, M. Pomorski, P. Schwemling, E. Scorsone, L. Sohl.
- **CERN (Switzerland):** 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, R. Veenhof[2], S. White[3].
- **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 (Greece):** G. Fanourakis.
- **NTUA (Greece):** Y. Tsipolitis.
- **LIP (Portugal):** M. Gallinaro.
- **HIP (Finland):** F. García.
- **IGFAE (Spain):** D. González-Díaz.

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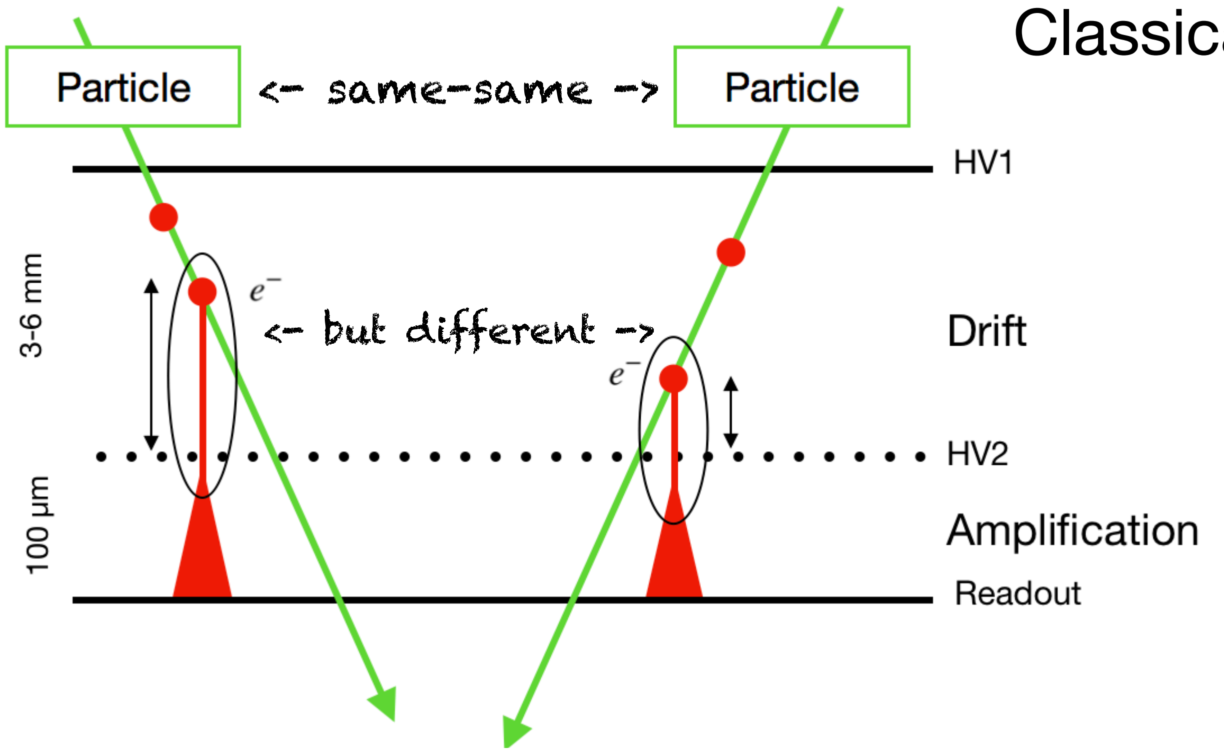
[2] Also MEPhI & Uludag University.
[3] Also University of Virginia.

Reaching sub ns time resolution with Micromegas

Classical MM

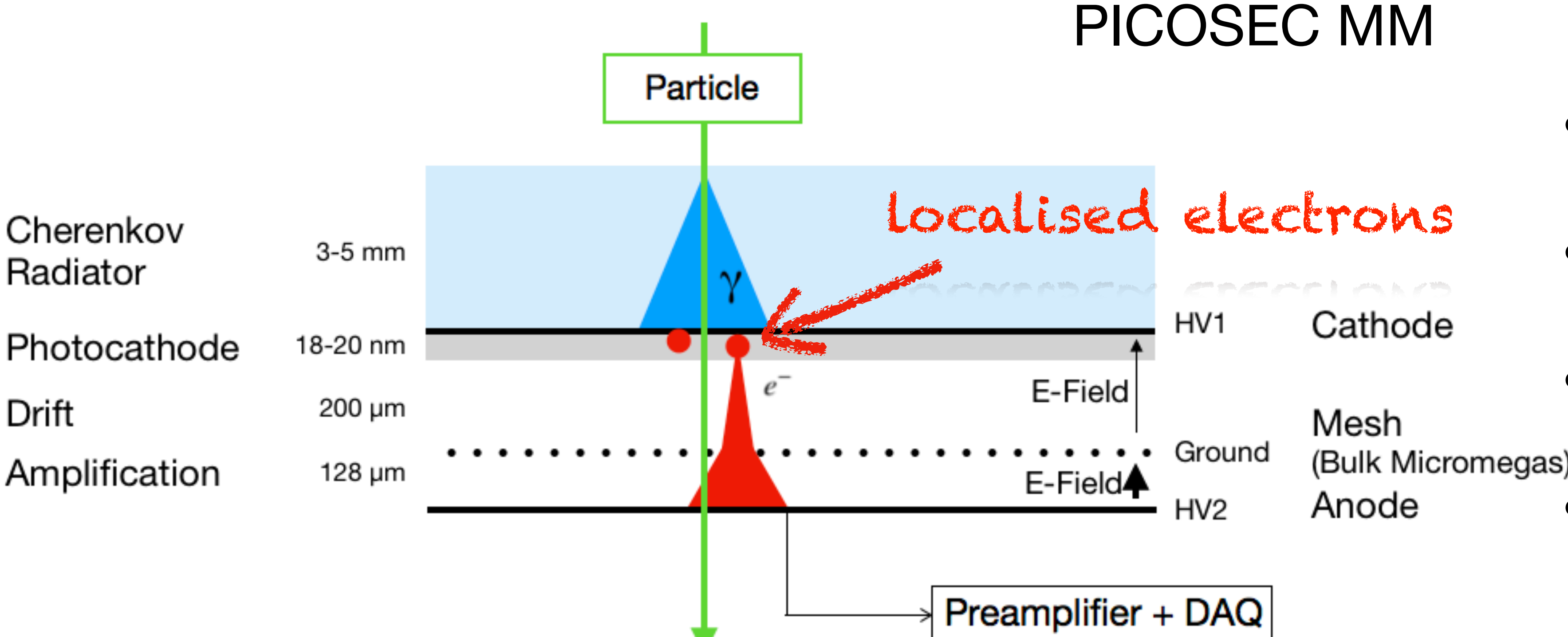


- Different position of ionisation clusters at direct gas ionisation
- Inevitable signal arrival time jitter due to drift velocity and average ionisation lenght

$$\sigma_t = \frac{\sigma_I}{v_d} = \frac{355\,\mu m}{84\,\frac{\mu m}{ns}} \approx 4\,ns$$ bad :(

Estimated time jitter for COMPASS Micromegas

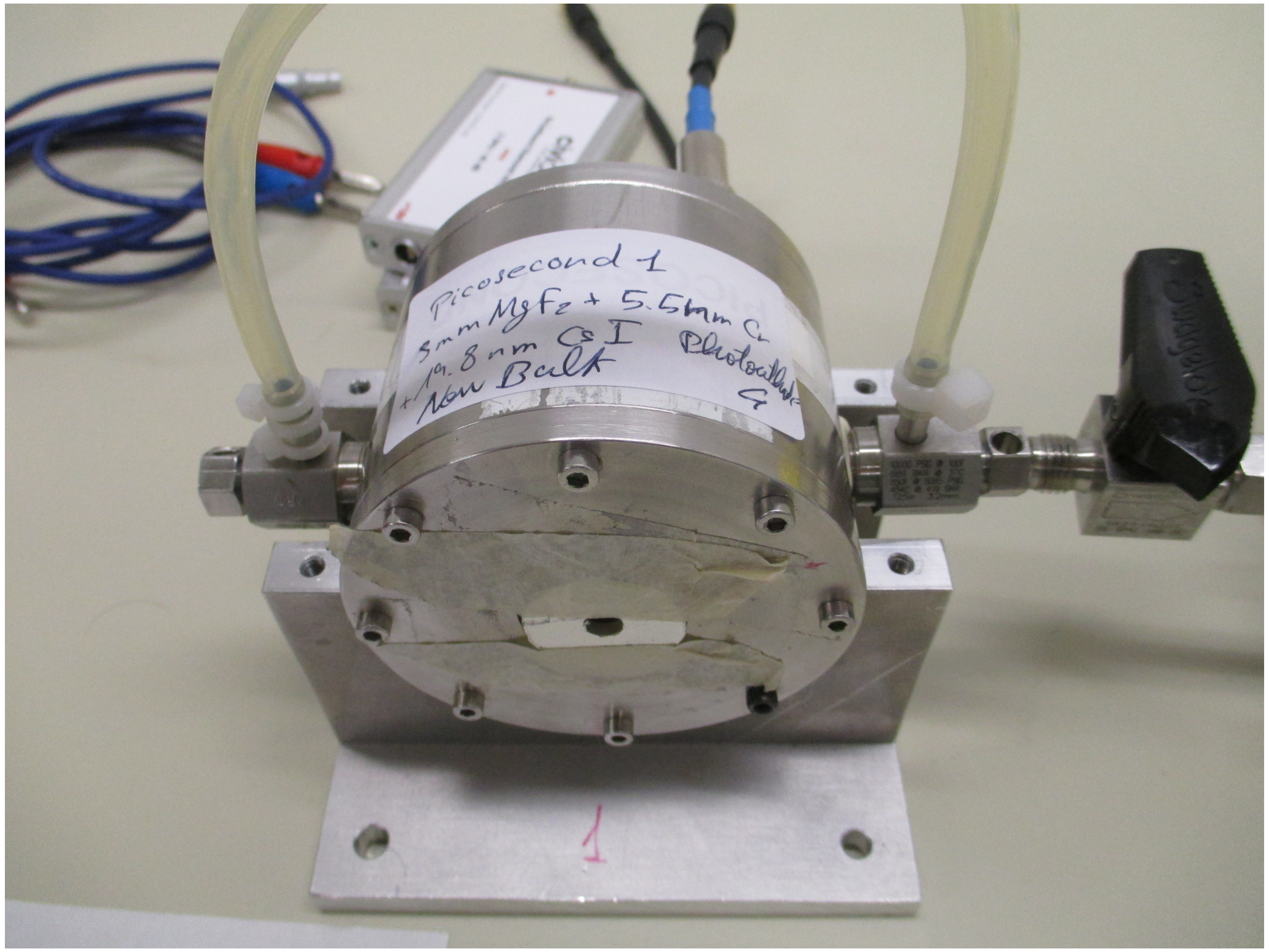
PICOSEC MM

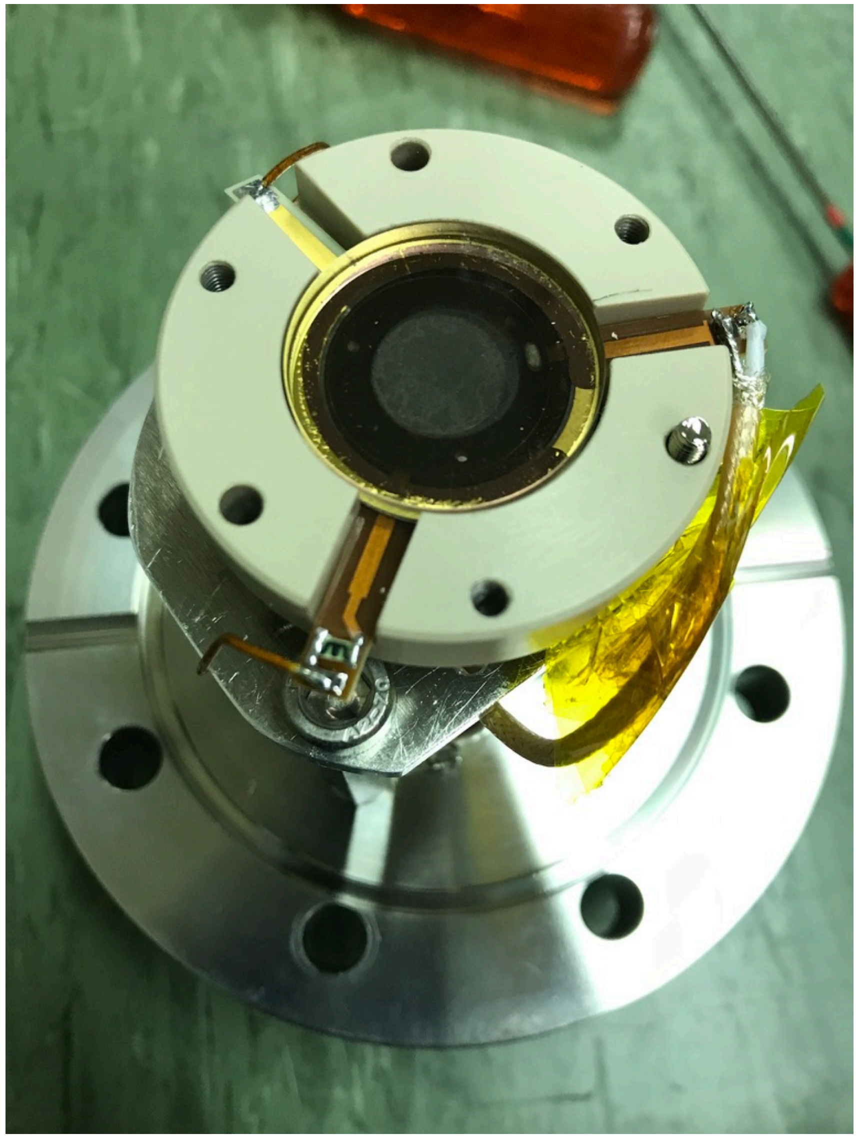


- Particle produce Cherenkov radiation
- Electrons are emitted by the radiation in a photocathode
- All primary ionised electrons are localised on the photocathode
- Due to high electric field, time jitter before first amplification minimised

The first Prototypes

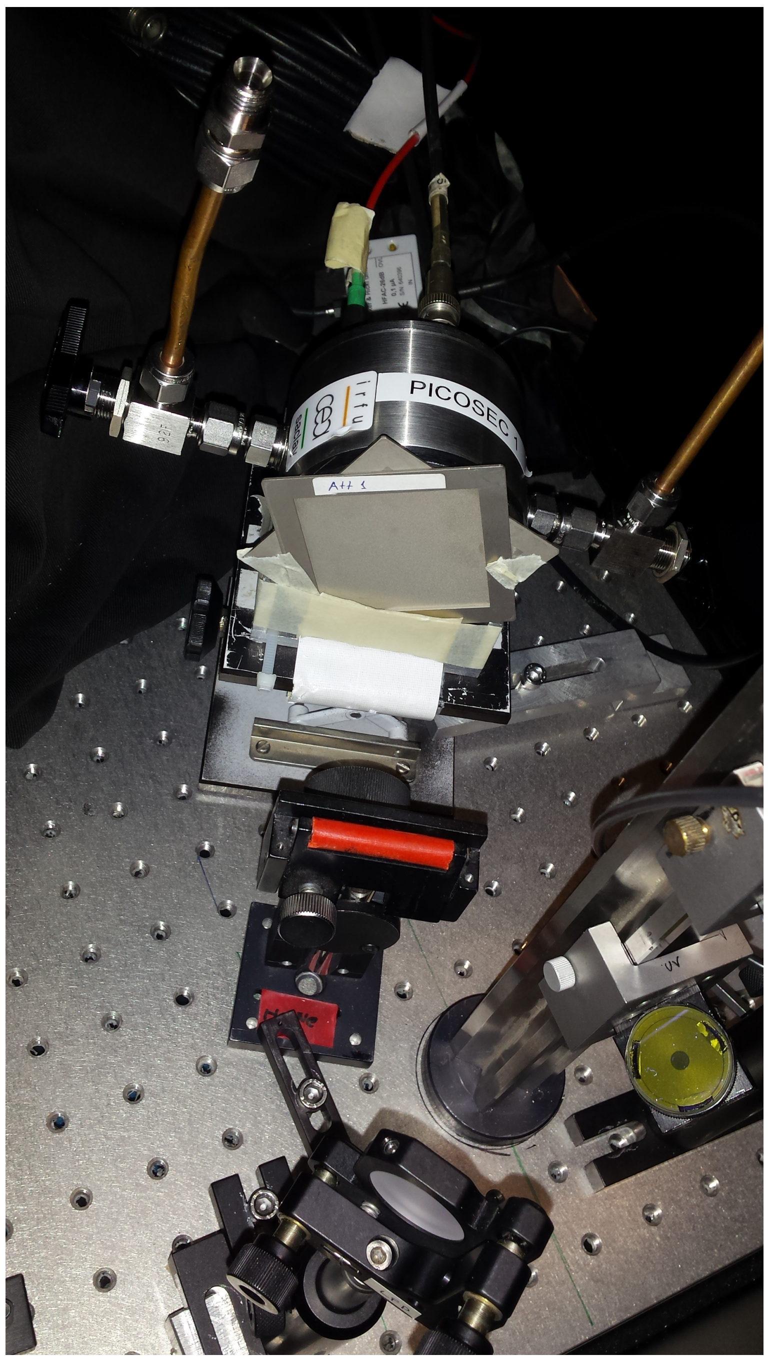
Single pad prototypes (1 cm diameter active area) are tested since 2016
Different Micromegas like Bulk, Thinmesh and Microbulk are studied

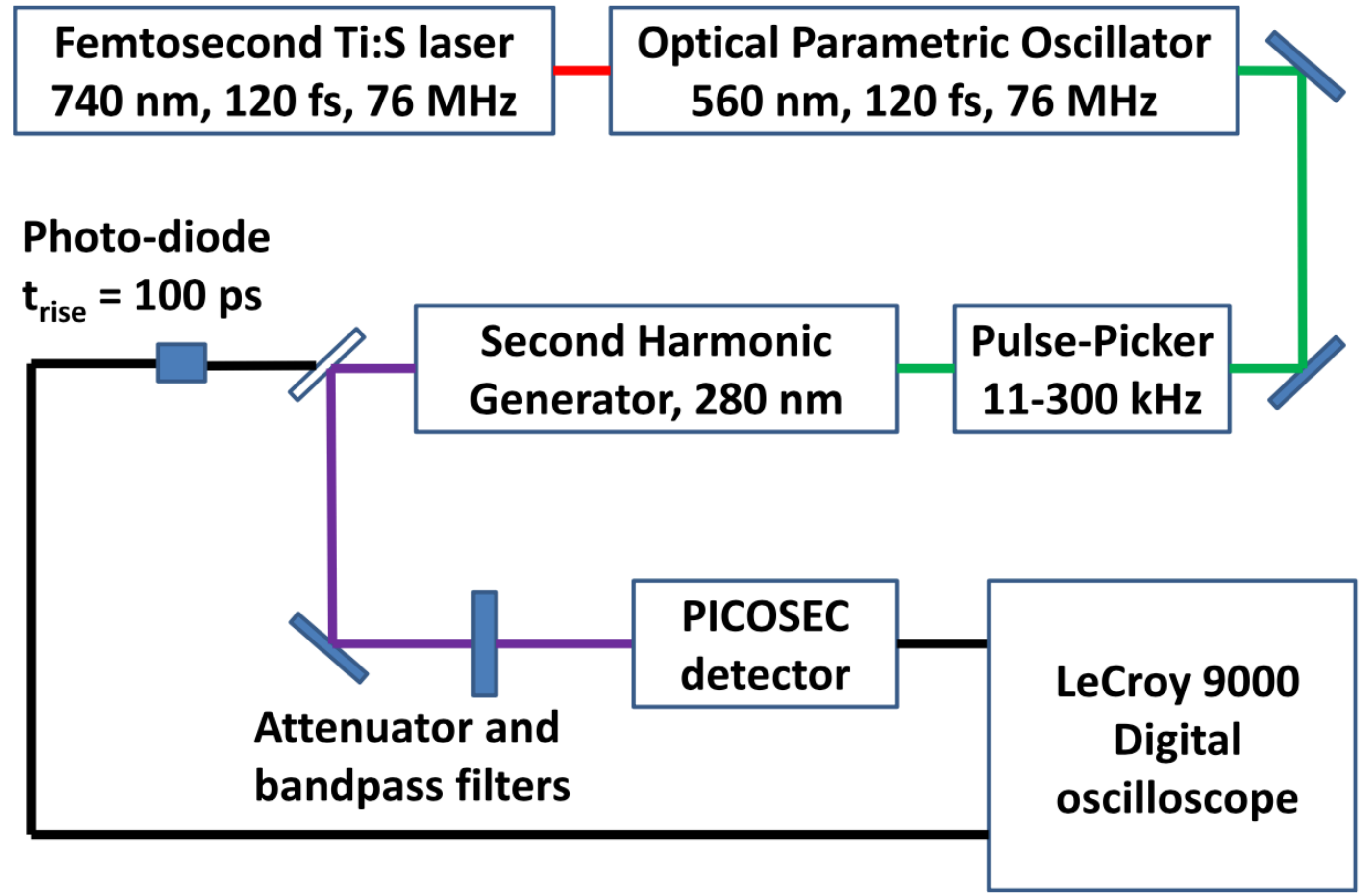




Laser Test

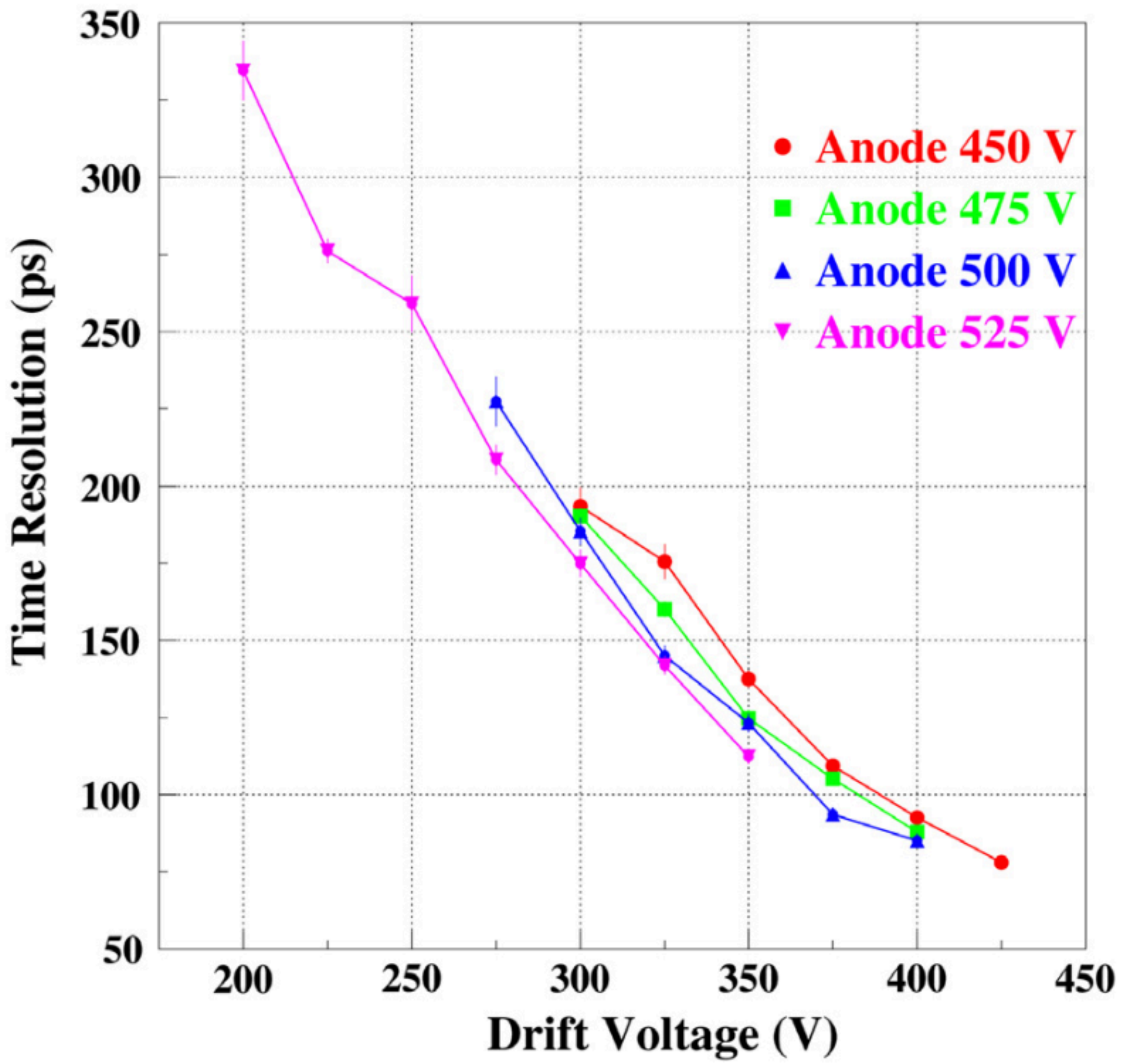
to measure the performance in a clean environment





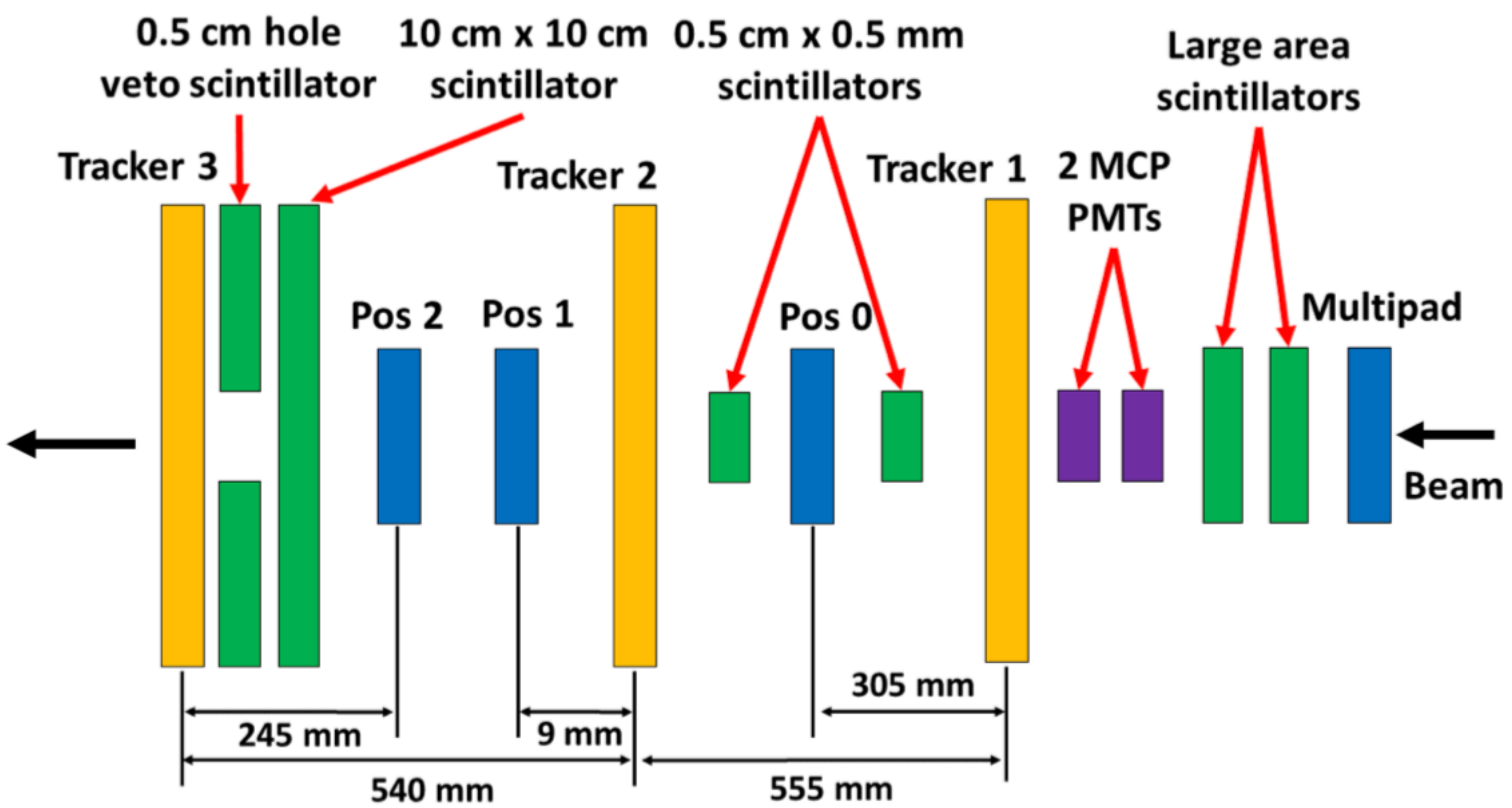
- **Pulsed laser at IRAMIS Facility (CEA Saclay)**
- **267 - 288 nm Wavelengths**
- **Repitition rate up to 500 kHz**
- **Laser intensity attenuated to study single photoelectron emission**

Reaching less than 1 ns with a single photoelectron



- **Fast photodiode (13 ps res) used as a t0 reference**
- **Detector response at different field settings has been measured**
- **Time resolution of up to 76.0 ± 0.4 ps**

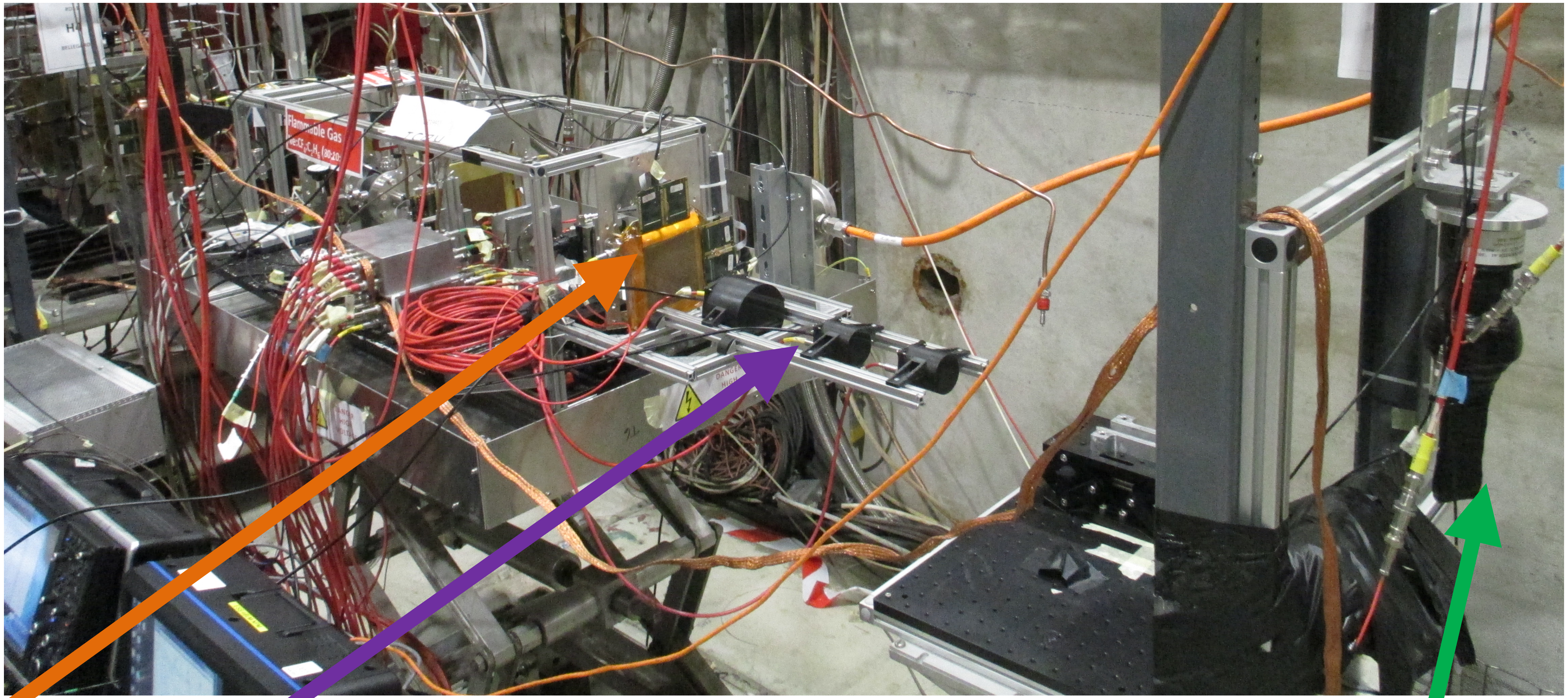
The real deal: Running in a particle beam



150 GeV muons or pions

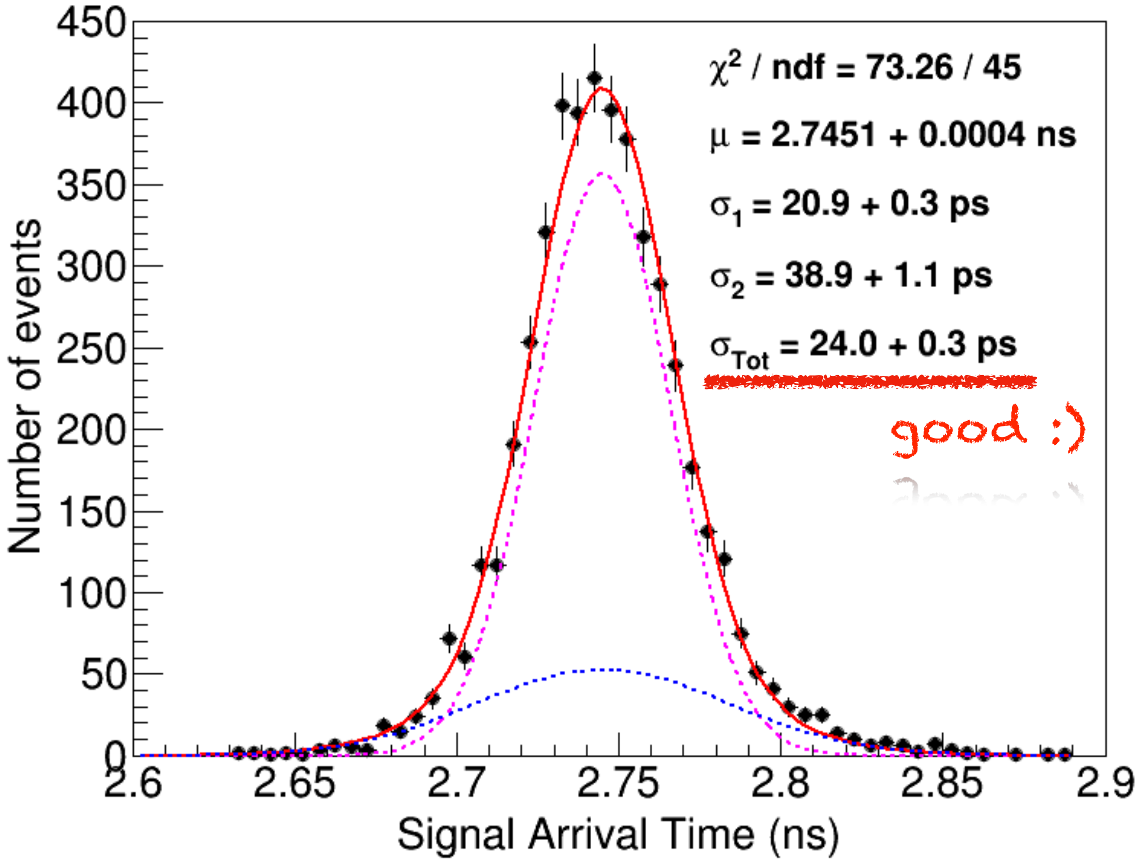
- **Time reference:** two MCP-PMTs (**<u><5 ps</u>** resolution).
- **Scintillators**: used to select tracks & to avoid showers.
- **Tracking system:** 3 triple-GEMs (**<u>40 µm</u>** precision).
- **Electronics:** CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

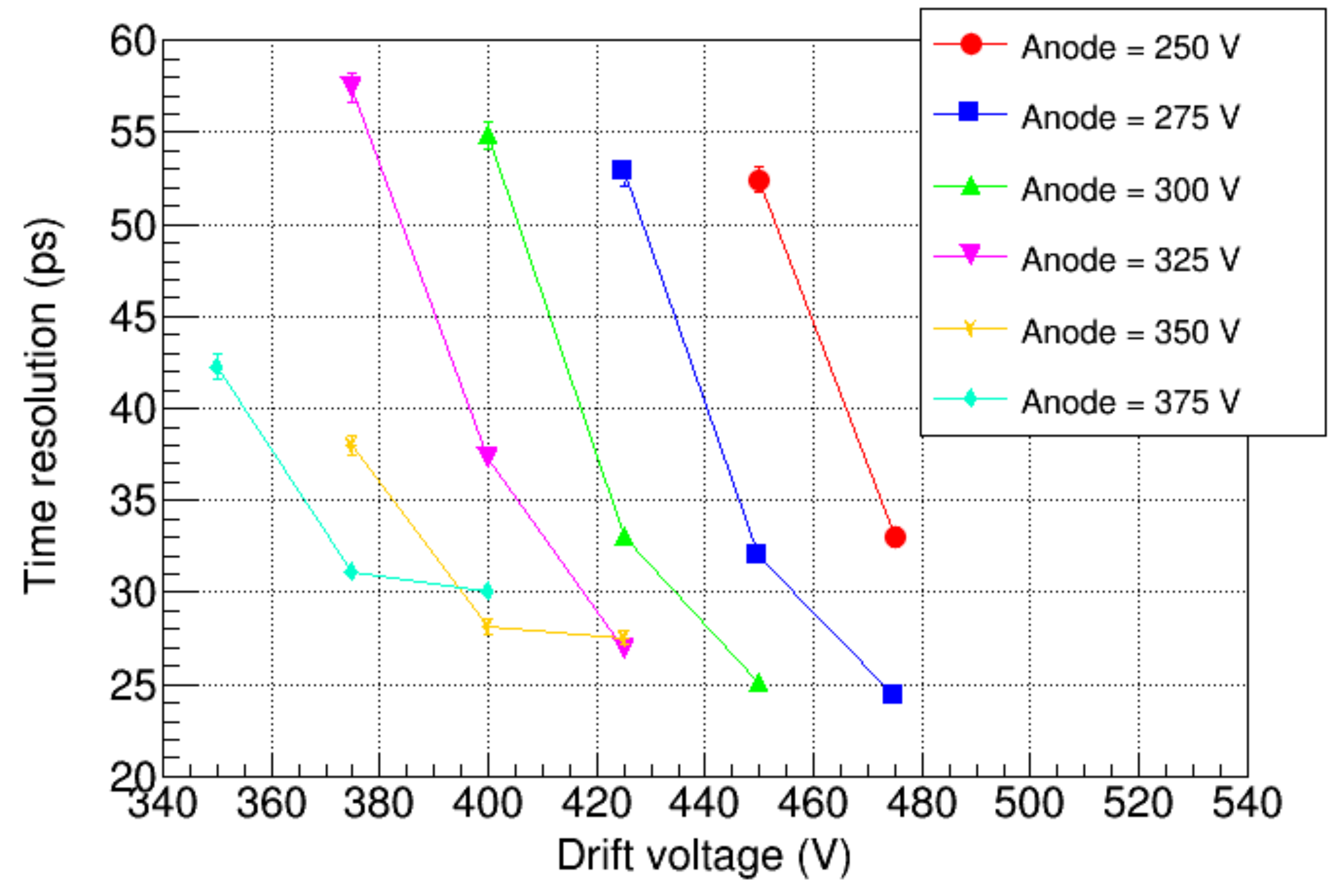
Lots of cables … and stuff



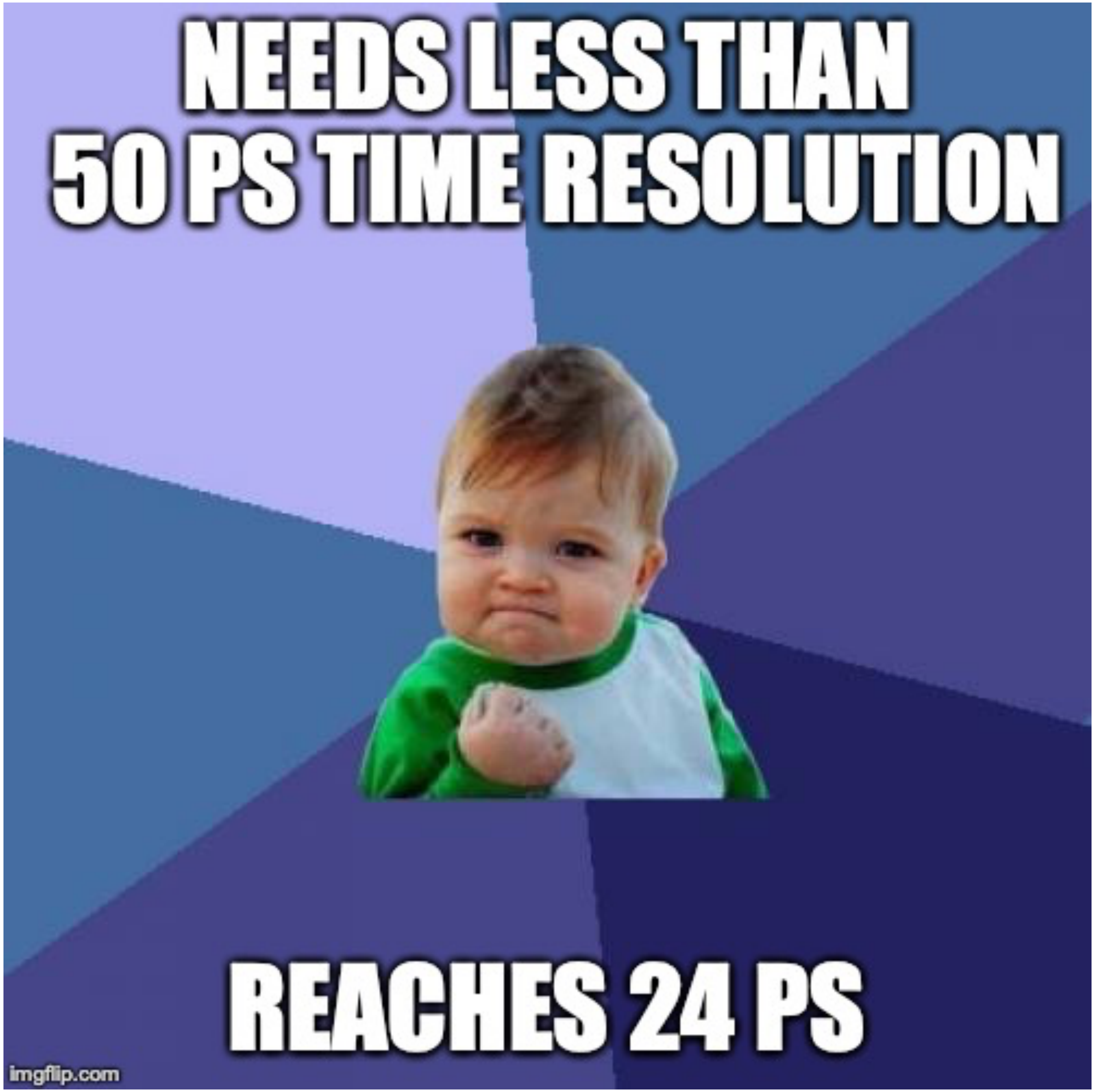
- **Time reference:** two MCP-PMTs (**<u>≤5 ps</u>** resolution).
- **Scintillators:** used to select tracks & to avoid showers.
- **Tracking system:** 3 triple-GEMs (**<u>40 µm</u>** precision).
- **Electronics:** CIVIDEC preamp. + 2.5 GHz LeCroy scopes.

Up to 24 ps time resolution with many photoelectrons

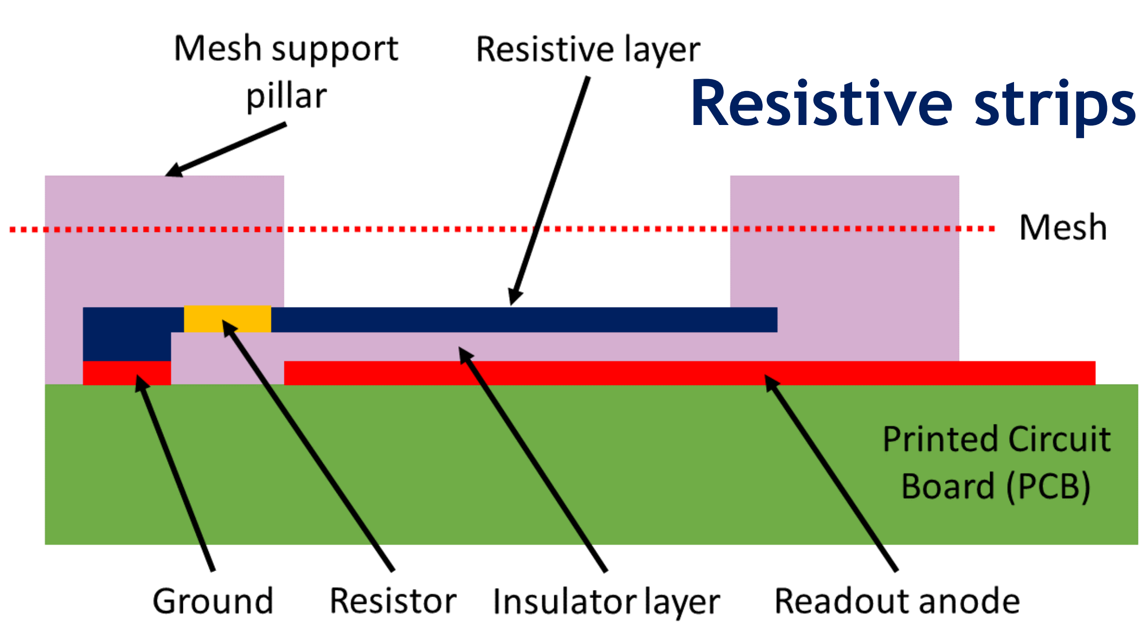




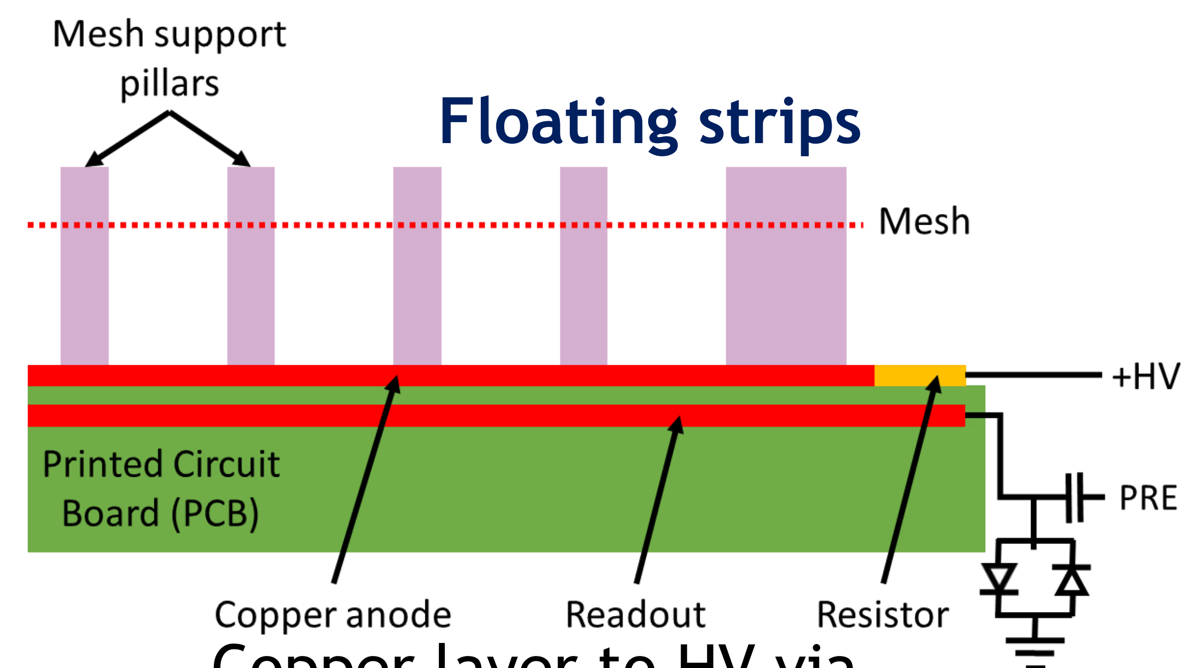
- 3 mm MgF2 window and 5.5 nm Cr + 18 nm CsI Photocathode
- Gas mixture: 80 % Ne + 10 % iC4H10 + 10 % CF4
- Optimal operation point at: Amplification +275 V, Drift -475 V
- Mean number of photoelectrons: 10.4 ± 0.4
- Time resolution for 150 GeV Muons: 24.0 ± 0.3 ps


NEEDS LESS THAN
50 PS TIME RESOLUTION
REACHES 24 PS
imgflip.com

Resistive Micromegas: Facing high flux environments



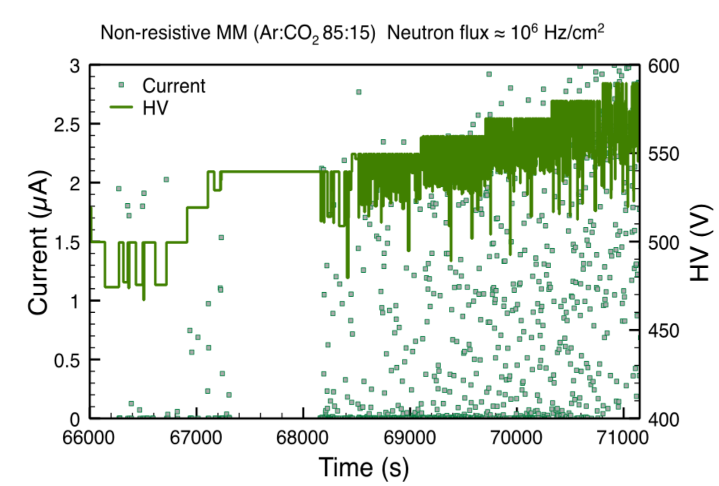
Resistive strip grounded

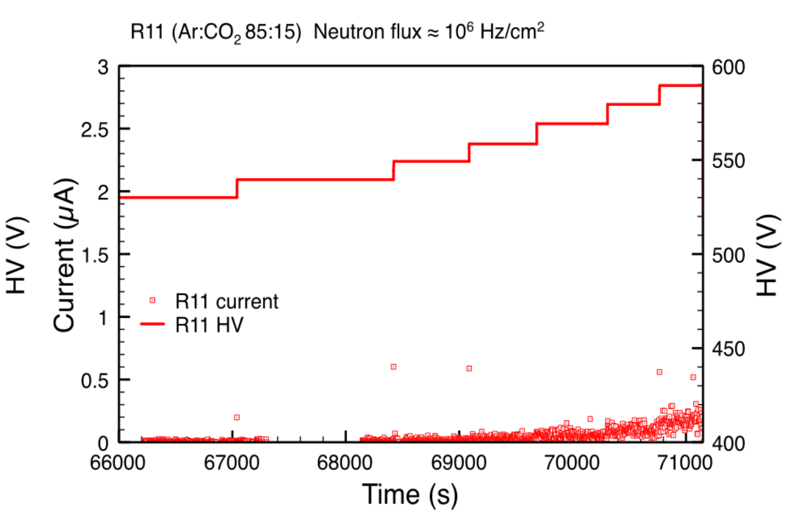


Copper layer to HV via resistor

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.



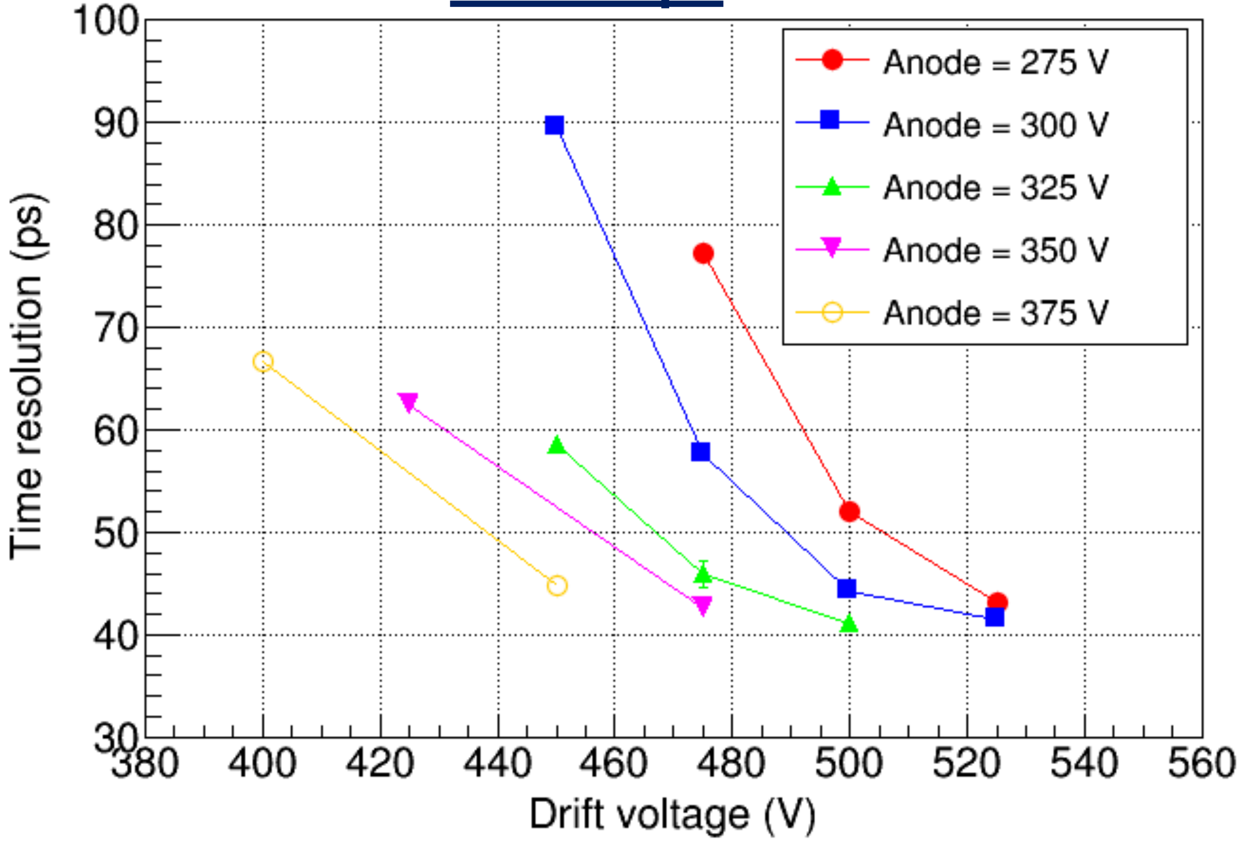


Testing resistive PICOSEC

Time resolution

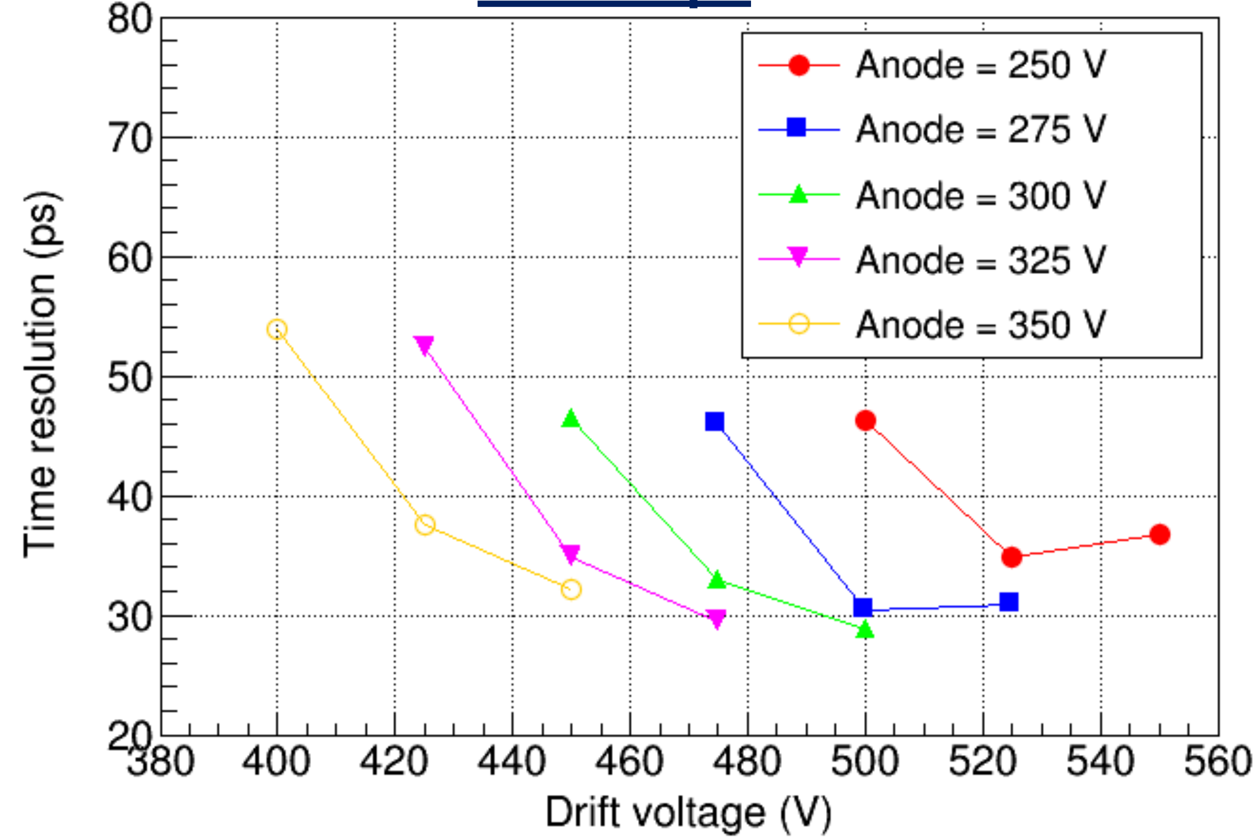
Resistive strips

σ = 41 ps



Floating strips

σ = 28 ps



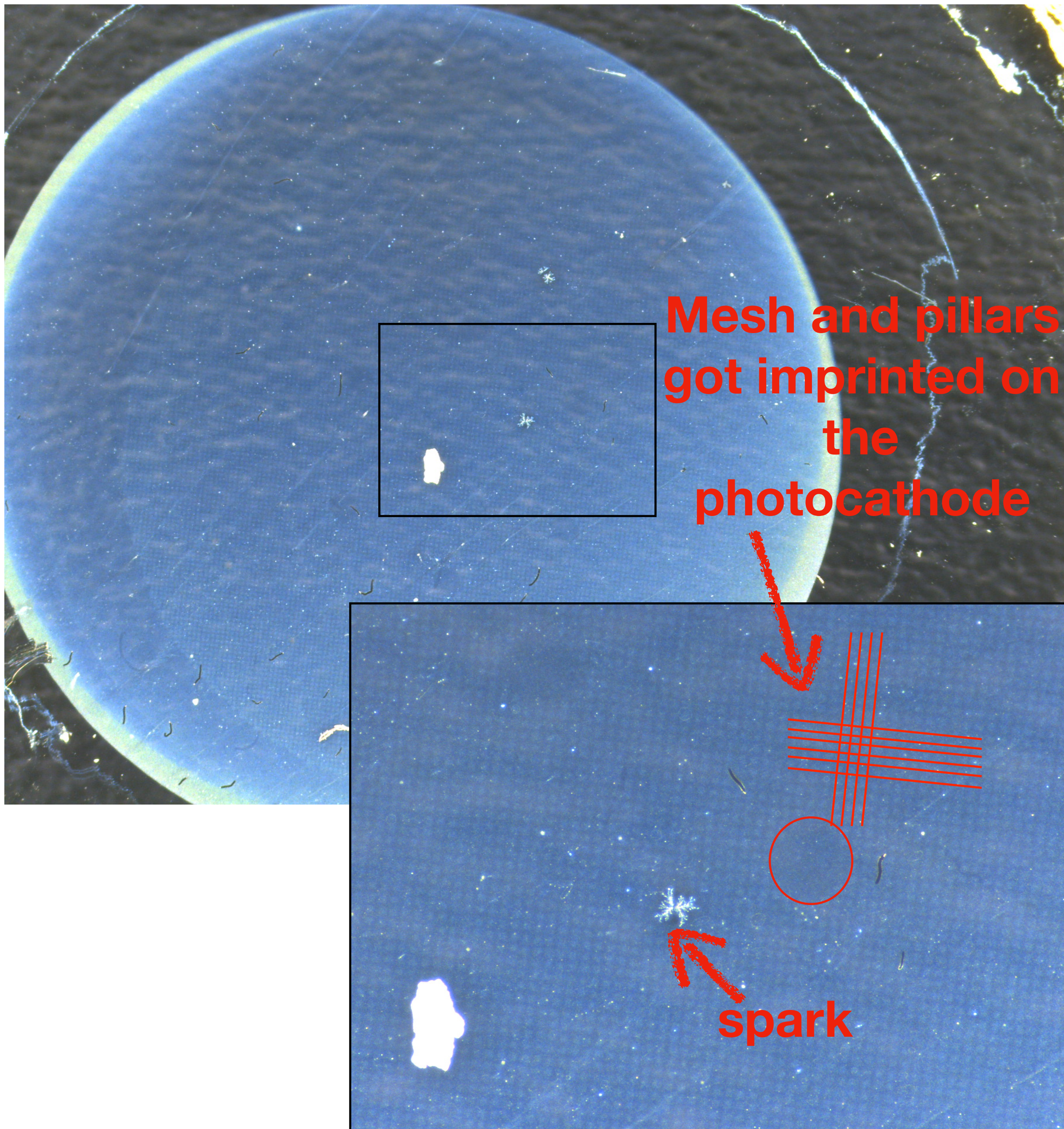
- Values not far from the PICOSEC bulk readout.
  - **Resistive strips:** 41 ps (10 MΩ/□), 35 ps (300 kΩ/□).
  - **Floating strips:** 28 ps (25 MΩ).
- Resistive readouts worked during hours in intense pion beam.

Electron-ion pairs are a thing

Electrons are bombarding the anode

Ions are bombarding the photocathode

Not only the anode can get damage



- **Ion back flow damages CsI photocathode under higher particle flux**
- **Robust photocathodes needed**

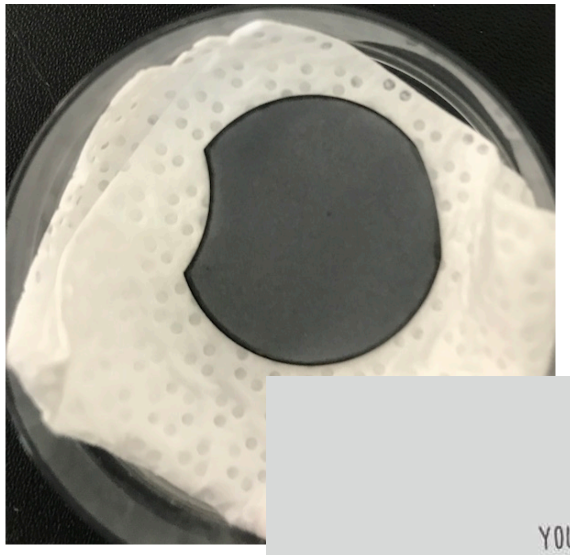
Measurement of the IBF in a pion beam at different field

V_{anode} [V]	V_{drift} [V]	I_{anode} [mA]	I_{drift} [mA]	IBF
+450	-350	98.00	23.40	24
+450	-375	193.85	53.00	28
+450	-325	45.47	10.65	23
+425	-400	193.50	53.10	28
+425	-375	87.30	23.95	27
+425	-350	44.48	10.99	25
+400	-425	178.84	112.39	63
+400	-400	88.55	25.54	28
+400	-375	41.28	11.10	27
+400	-350	20.42	4.44	22

More robust Photocathodes

- **For each photocathode material the working point with the best time resolution has to be determined**
- **The time resolution, quantum efficiency and efficiency are compared**
- **Reference single photon measurements and tracking data are necessary**

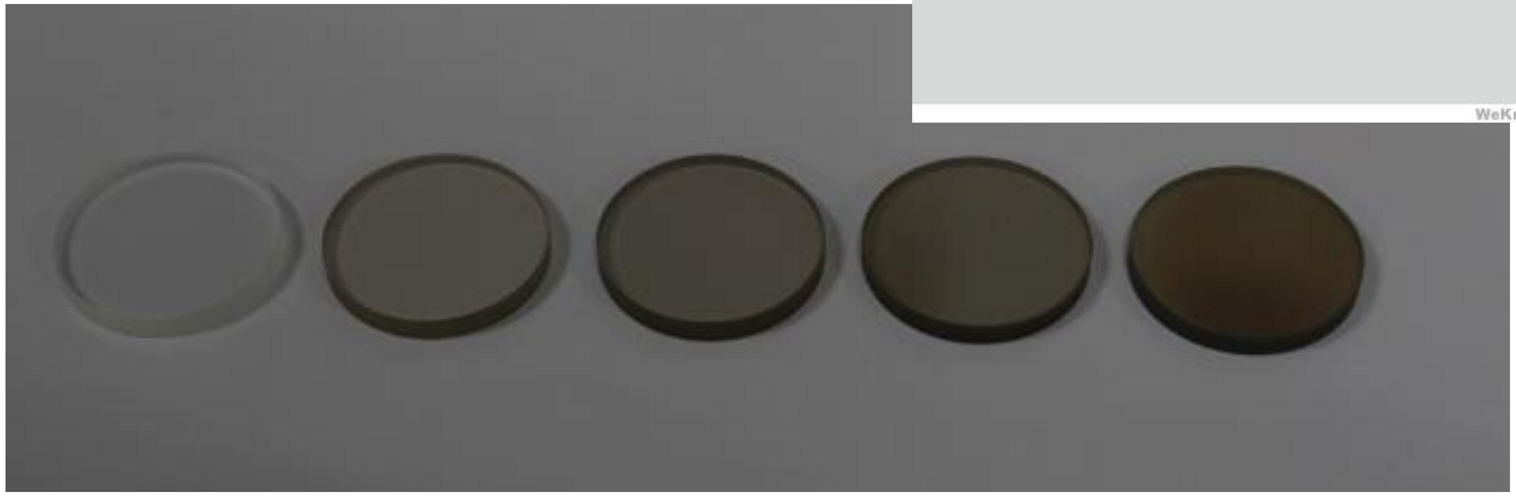
DNCD 5 µm on Si



Different Materials tested like:

- **Metallic Photocathodes**
- **CsI with protection layer**
- **Nano Diamond Seeding**
- **Diamond secondairy emitter**
- **Diamond-like Carbon**

DLC



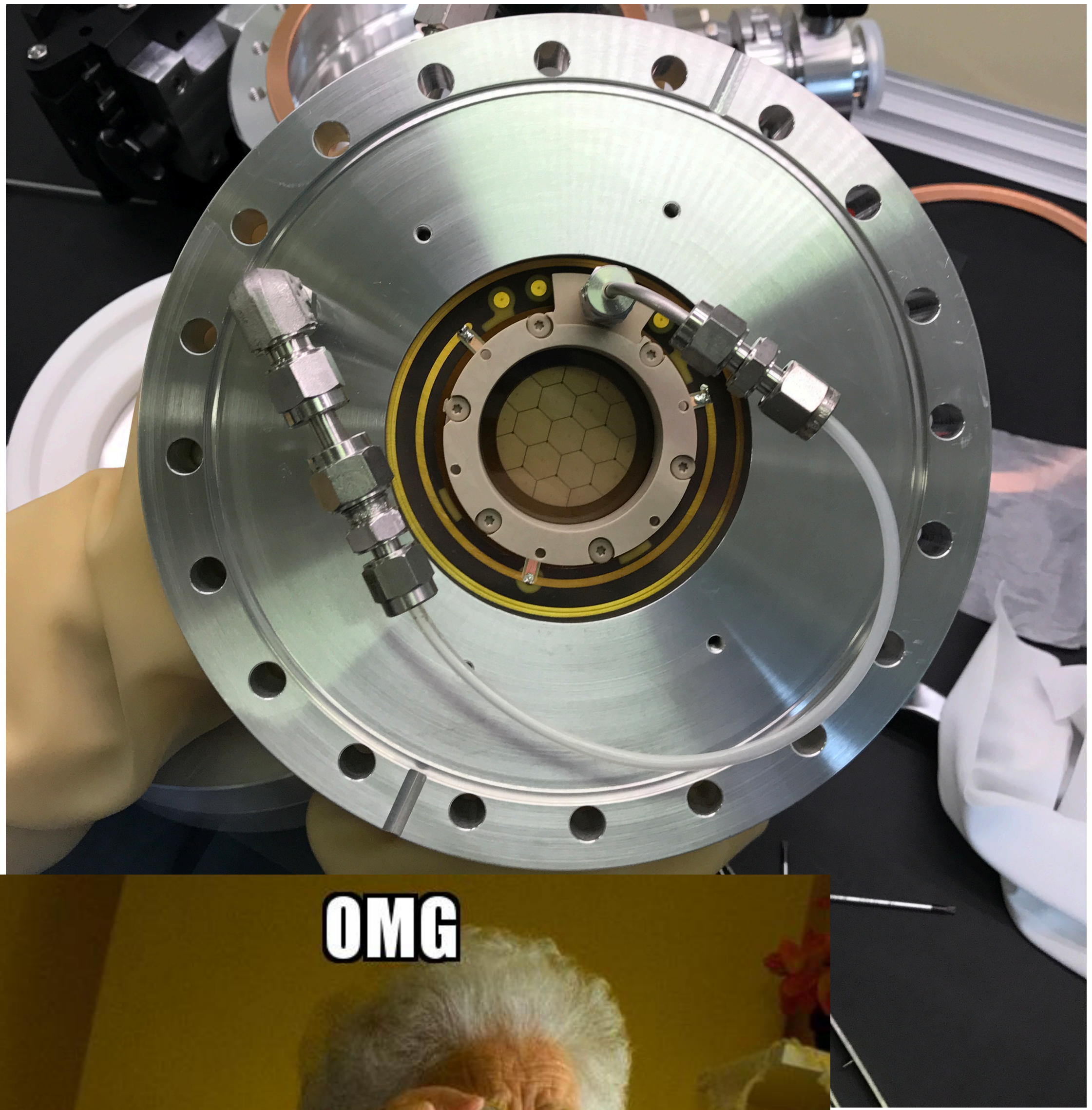
First results:
Come ci, come ça

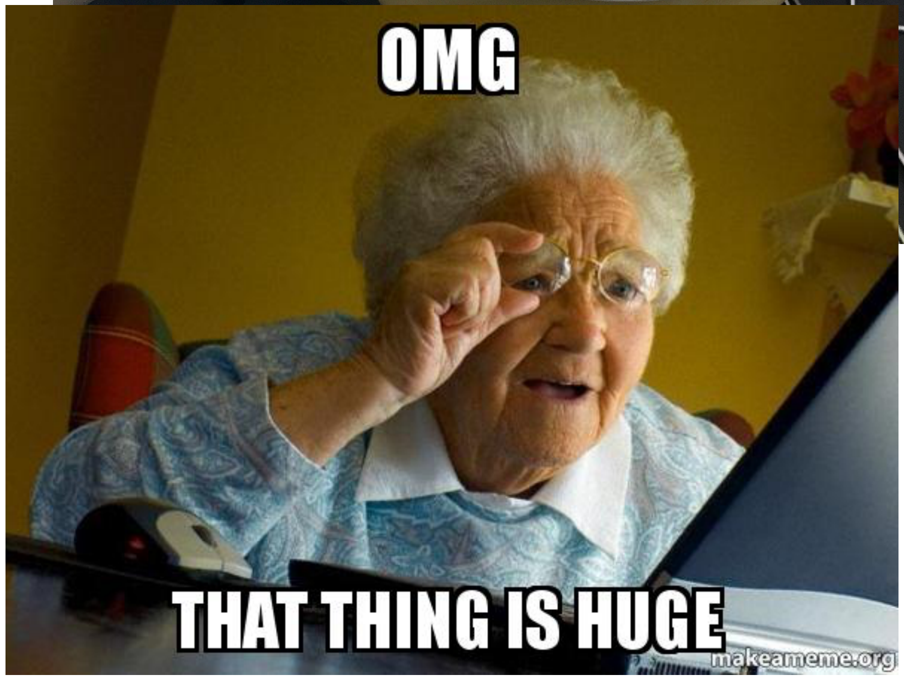
Substrate	Nphe	Res (ps)
5.5 nm Cr +18 nm CsI	10.4 ± 0.4	24.0 ± 0.3
20 nm Cr	0.66 ± 0.13	189.4 ± 5.3
6 nmAl	1.69 ± 0.01	71.4 ± 1.8
18 nm CsI LiF coated	< 1	87.7 ± 3.7
18 nm CsI MgF2 coated	3.55 ± 0.08	45.6 ± 1.5
DLC	2.69 ± 0.11	67.4 ± 1.3

CsI reference

very promising

Growing bigger: Multipad





- Hexagonal segmented readout with a pitch of ~9 mm
- Total active area of 36 mm diameter
- 2 inch Cherenkov window

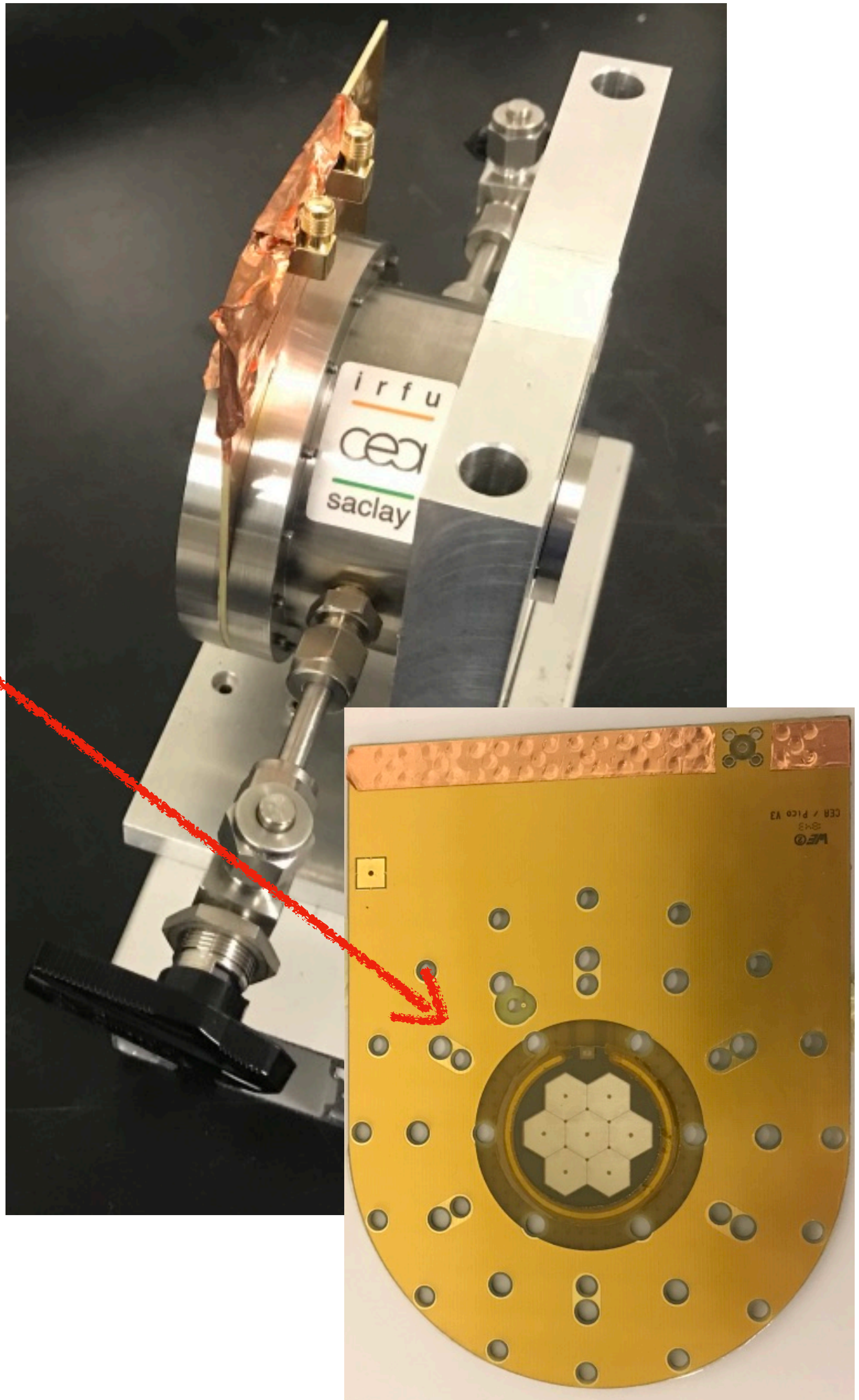
- Each pad is amplified and read out separately
- Read-out is limited by available electronics
- Runs with high statistics have been taken to study the signal behaviour inside and between three pads

What is next …

- **Analysis of larger Multipad datasets with four Pads**
- **Continuing measurements with different photocathode materials**
- **Ageing studies of promising photocathode samples**
- **Development of a resistive multipad Picosec chamber**

- **(Embedded) electronic necessary for segmented readout**

- **Comprehensive simulation and analysis**
- **DLC and Secondary Emitter Production**
- **Measurements at a cosmic muons bench**
- **Additional measurements in the Laser**
- **Participation at particle beam tests all over Europe**



That's all Folks!

Stay Tuned

Backup

MCP-PMT t0-Reference

UV reference measurements performed to complete MCP—PMT t0-reference studies

Photoefficiency of

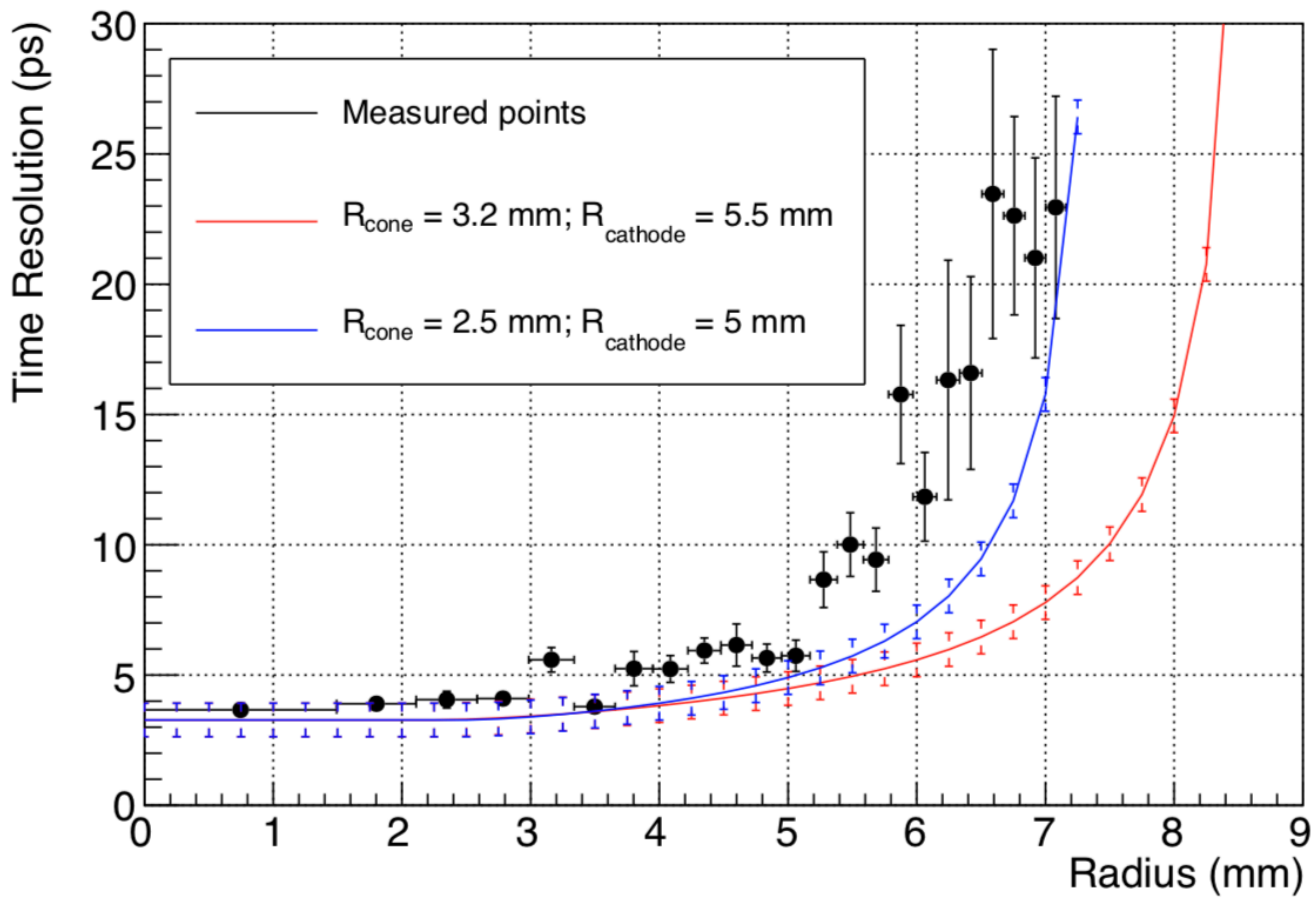
$$N_{\text{p.e.}} = 58.22 \pm 11.45 \, \frac{\text{p.e.}}{\mu}$$

has been measured for a full Cherenkov cone.

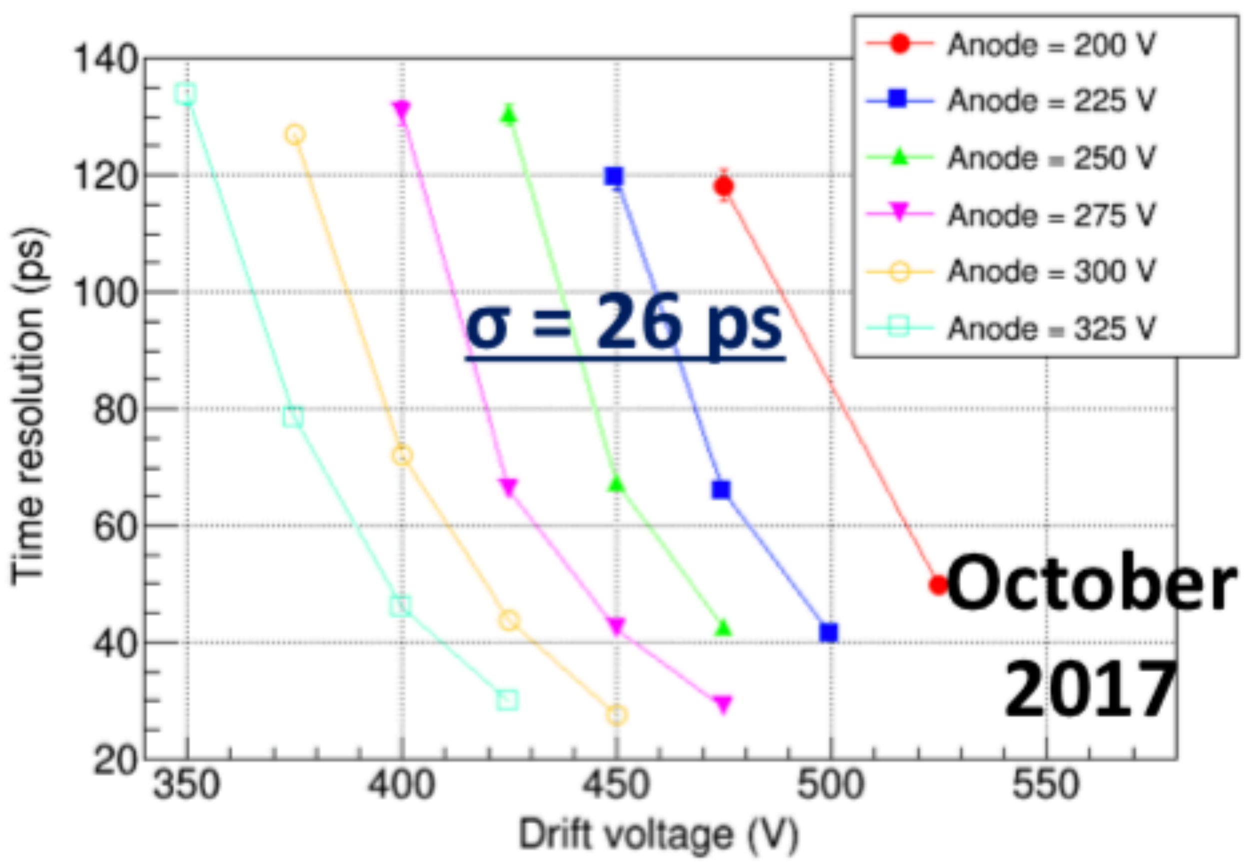
This leads to a time resolution of

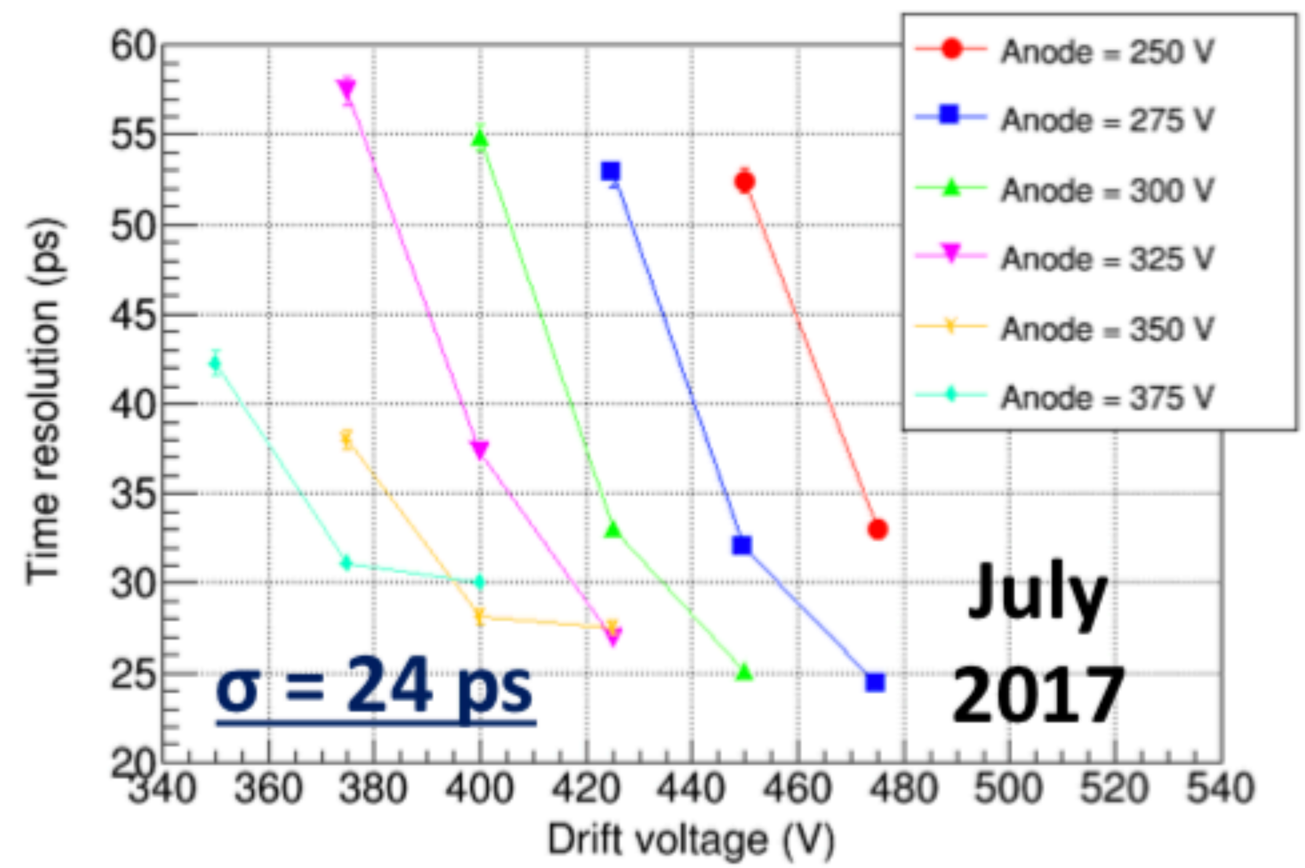
$$\sigma_{\text{MCP}} \approx \frac{\sigma_{\text{TTS}}}{\sqrt{N_{\text{p.e.}}}} \qquad \sigma_{\text{MCP}} = 3.28 \pm 0.64 \, \text{ps}$$

Theoretical spatial distribution can be compared with the measured one.



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.

Diamond-like Carbon

- 2.5 nm DLC time resolution up to 34 ps observed
- Results repeatable in independent samples and Measurements
- Addtitional tests with heating treatment under N2 and H2
- Additional aging tests under pions
- Samples survived rough transport from China

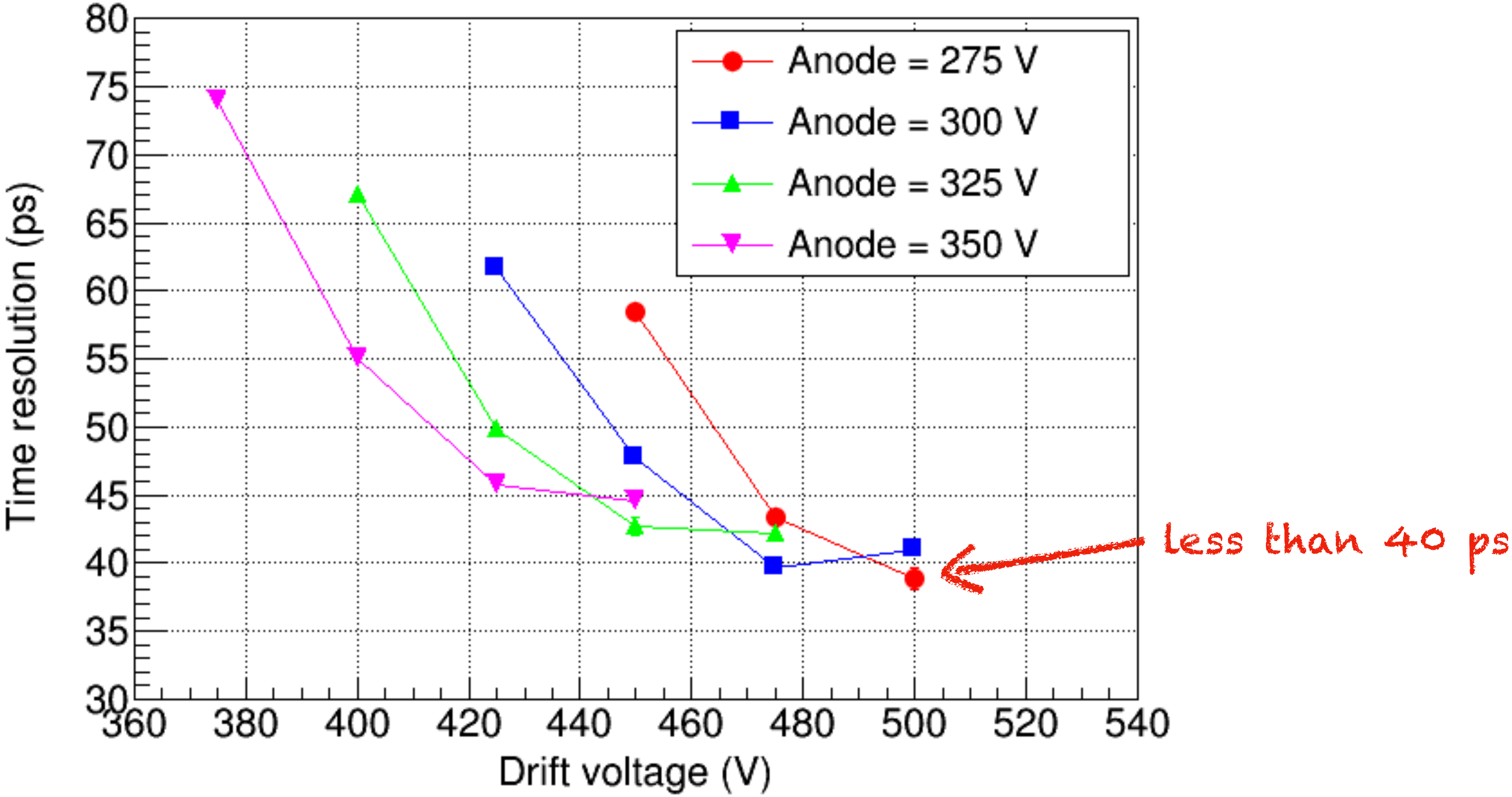
Thickness of DLC film (nm)	Npe/per muon	Detection efficiency for muons
1	Bad	Bad
2.5	3.7	97%
5	3.4	94%
7.5	2.2	70%
10	1.7	68%
5.5 nm Cr + 18 nm CsI	10.4	100%

2.5 nm DLC in Bulk MM

A/D Voltage	Time Res. (ps)
250/550	37
250/575	34
275/525	38
275/550	34
300/500	39
300/525	34

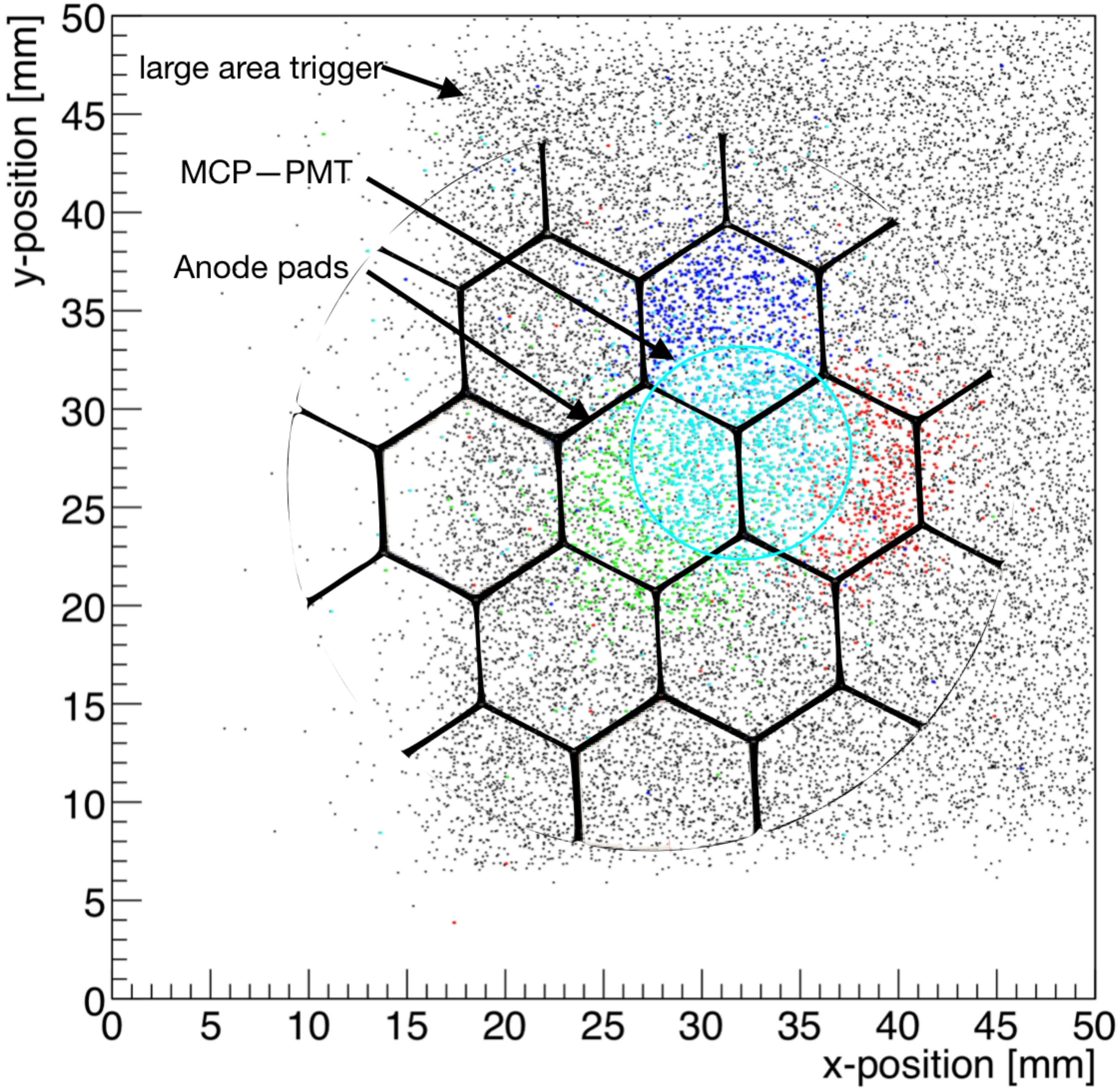
Field scan for one centered pad

Behaviour comparable to single readout detector

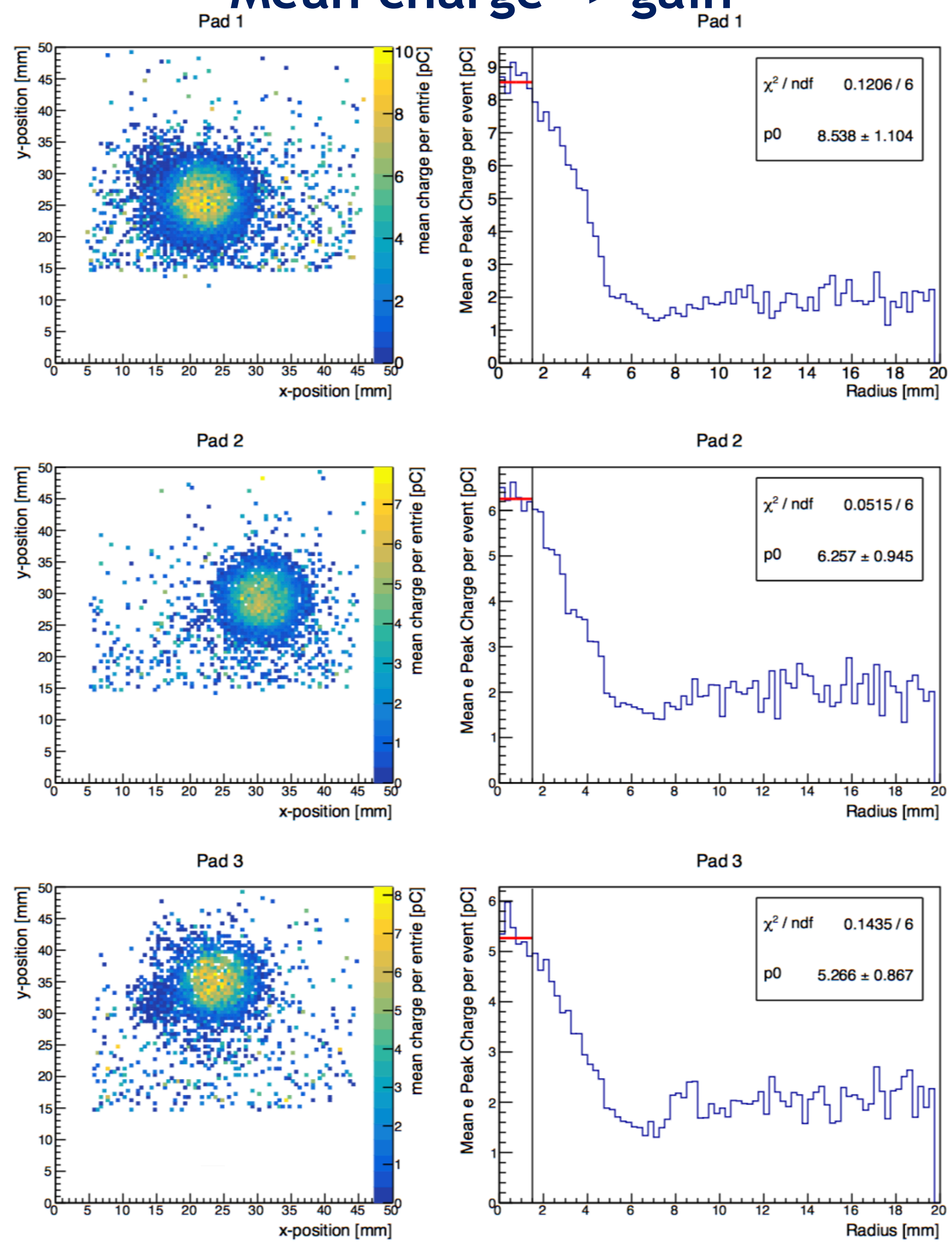


To calculate the combined time resolution of several pads the exact position and gain of each participating pads needs to be evaluated

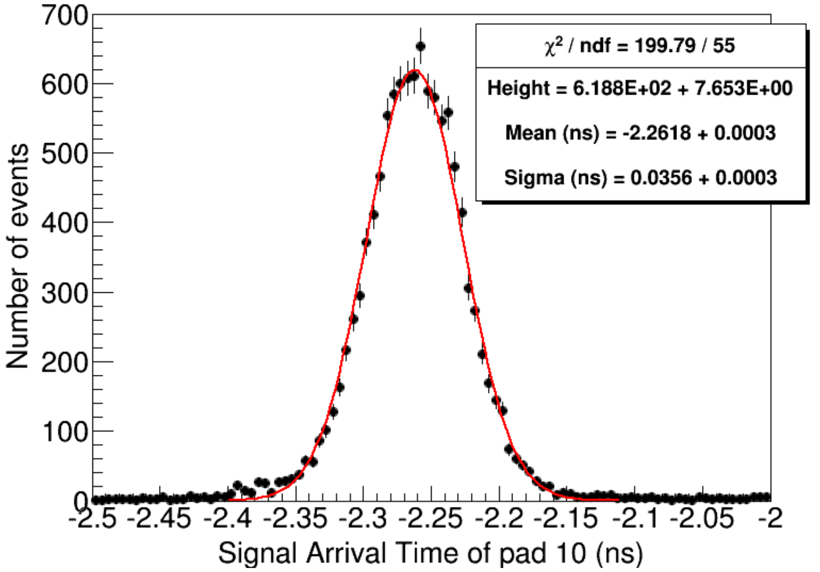
Pad alignment -> position

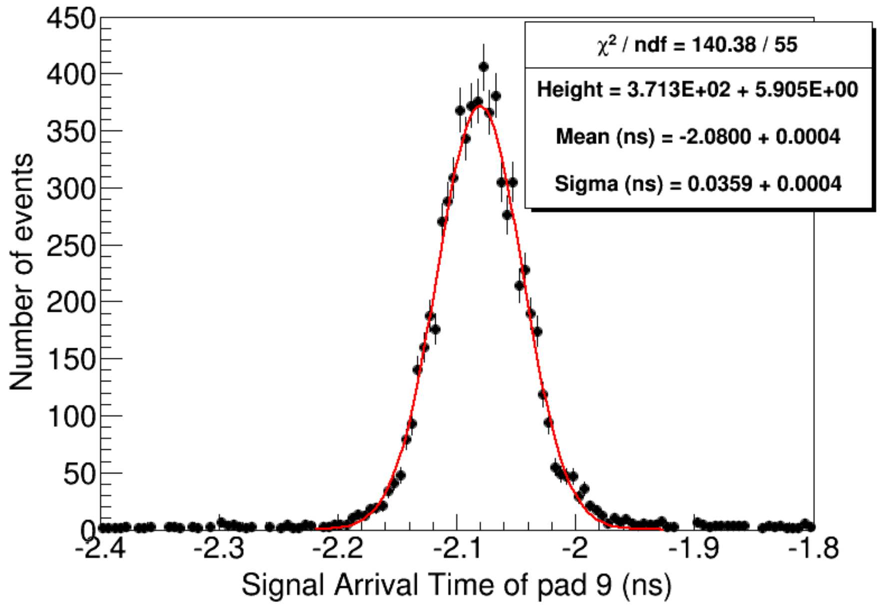


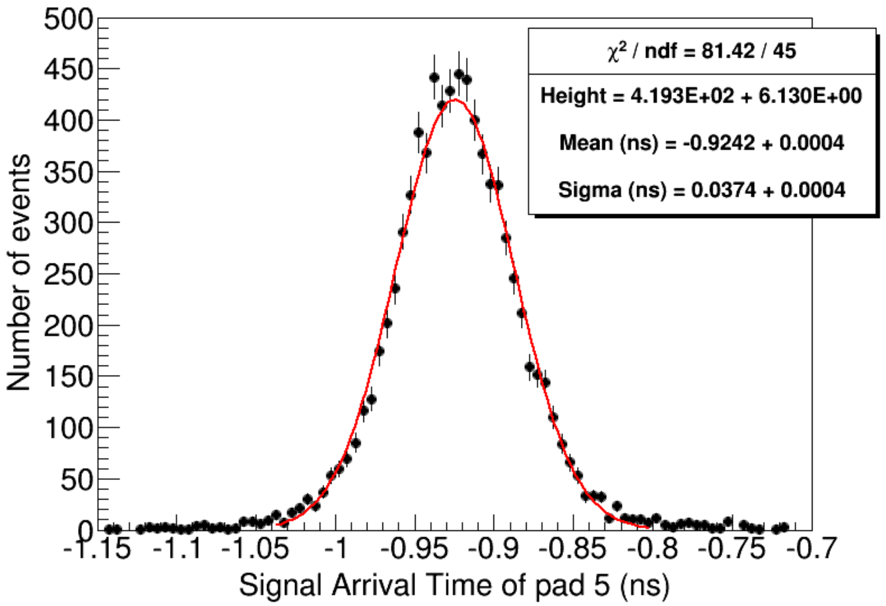
Mean charge -> gain



- Time resolution is **~36 ps** for all Pads
- The time resolution is **compatible** with the value obtained for the small area trigger scans of Pad 9 (**38.8 ps**).

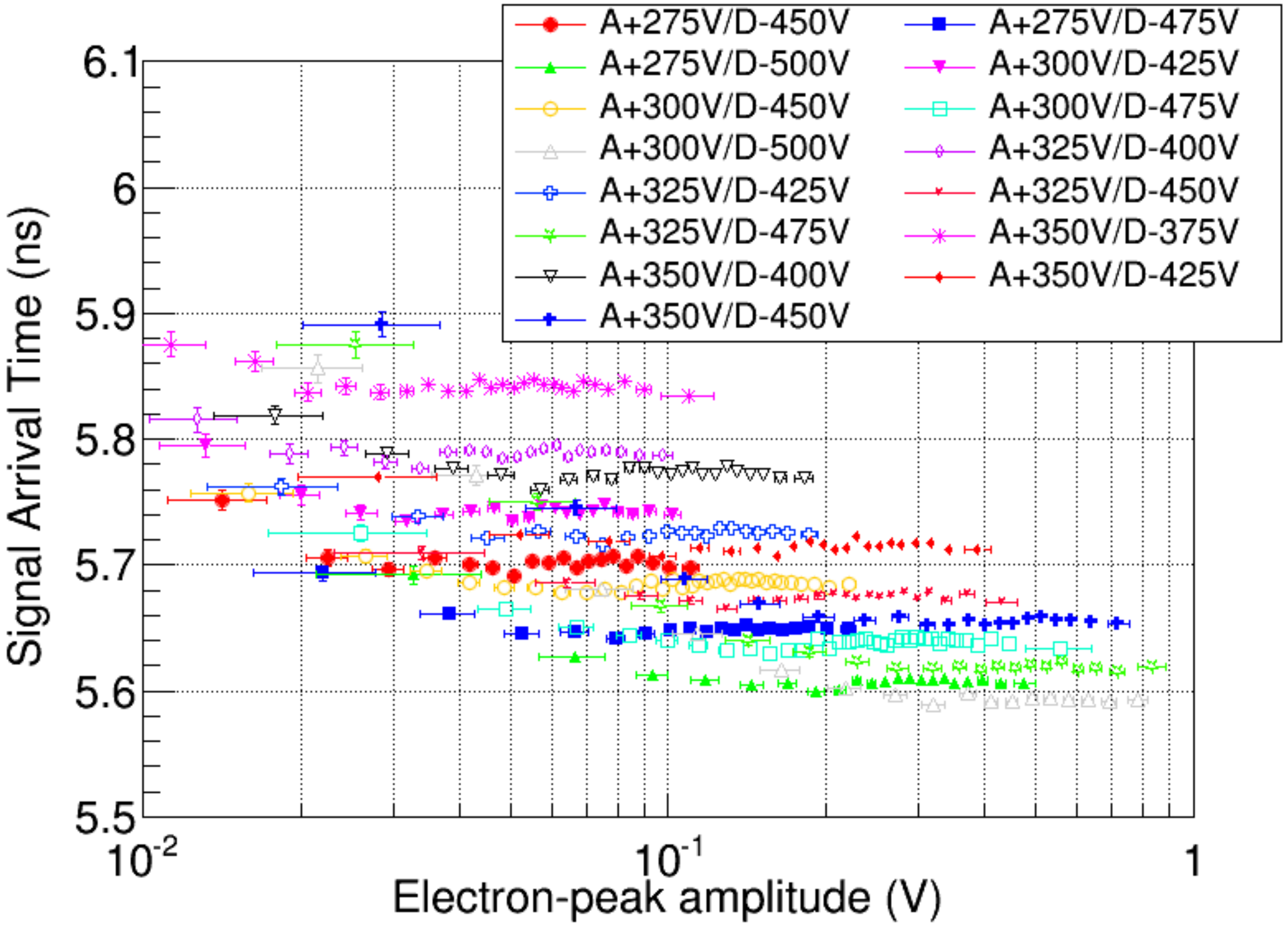


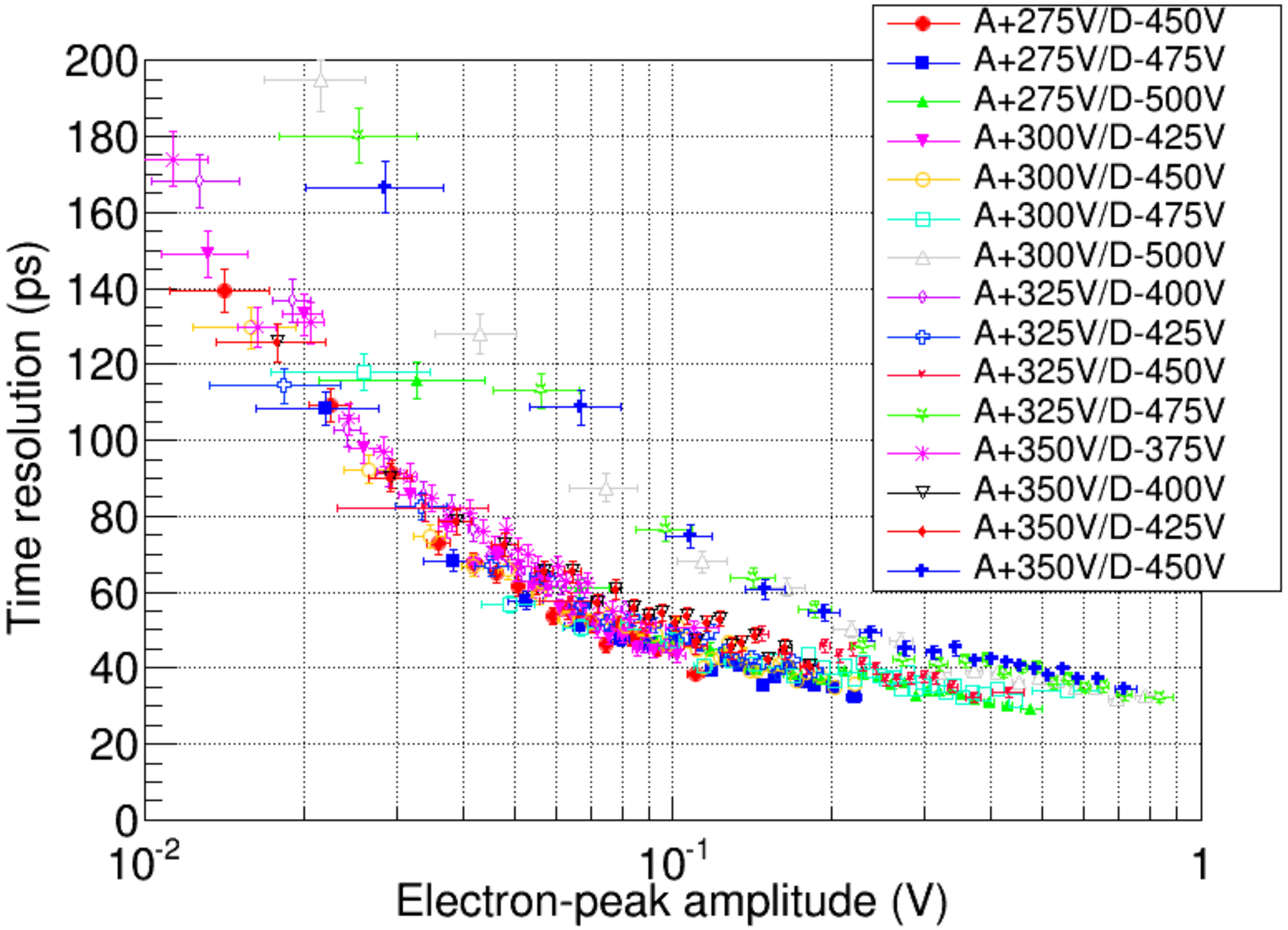




Element	Mean (ns)	Res (ps)
Pad 10	-2.2618	35.6 ± 0.3
Pad 9	-2.0800	35.9 ± 0.4
Pad 5	-0.9242	37.4 ± 0.4

No Slewing in the centre of the Multipad pads





- The Multipad SAT distribution has been calculated by using $W(Q_i)$ & resolution $R(Q_i)$ curves.
- Time resolution is **36 ps**, for a MCP circle of 5 mm.
- Time resolution is constant for impact points in this circle.
- SAT & time resolution still have a surface dependence.