PICOSEC
Micromegas

12th International Conference on
POSITION SENSITIVE
DETECTORS

Precise timing and recent advancements with segmented anode PICOSEC Micromegas prototypes

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on behalf of the RD51 PICOSEC-Micromegas Collaboration

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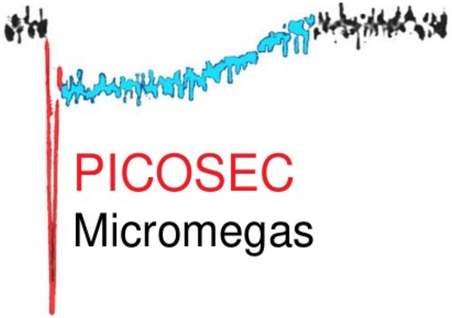
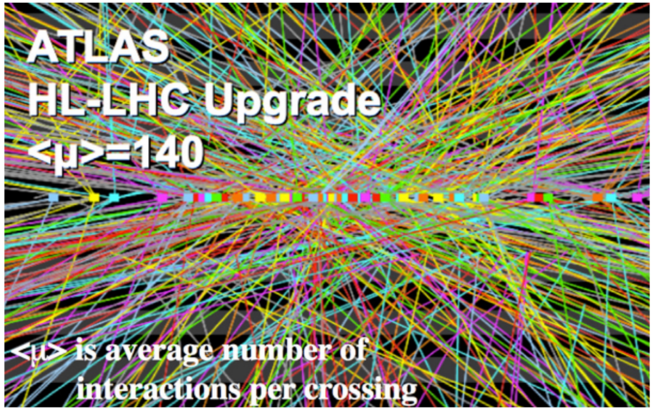
Need for ~ 20 ps timing in particle tracking



- **High Luminosity LHC:**
  - More than 140 “**pile-up**” proton-proton interactions (“vertices”) will happen in the same LHC clock, in close space (Gaussian ± 45mm). 3D tracking of charged particles is not enough to associate them to the correct vertex . Including precise timing **(20-30 ps)** offers an extra dimension of separation.
  - Identification of collision point would reduce pile-up background. Precise timing **(∼10 ps)** would locate z_{vertex} to σ∼2 mm equivalent to ∼20x background rejection



- Precise **Time-of-Flight (ToF)** measurements for Particle Identification (PID) at level of **≈20 ps/MIP** can offer Pion/Kaon and Kaon/Proton separation for a wide momentum range
- **Tagged neutrino beam** (time and flavour of tagging) for event-by-event decay measurements (ENUBET)

RD51 PICOSEC-MicroMegas Collaboration

- **CEA Saclay (France):** S.Aune, D. Desforge, I. Giomataris, T. Gustavsson, F.J. Iguaz[1], M. Kebbiri, P. Legou, O. Maillard, T. Papaevangelou, M. Pomorski, L.Sohl
- **CERN (Switzerland):** J. Bortfeldt[2], F. Brunbauer, C. David, M. Lisowska, M. Lupberger[3], H. Müller, E. Oliveri, F. Resnati, L. Ropelewski, L. Scharenberg, T. Schneider, M. van Stenis, A. Utrobicic, R. Veenhof[4], S.White[5]
- **USTC (China):** J. Liu, B. Qi, X. Wang, Z. Zhang, Y. Zhou
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- **NCSR (Greece):** G. Fanourakis
- **NTUA (Greece):** Y. Tsipolitis
- **LIP (Portugal):** M. Gallinaro
- **HIP (Finland):** F. García

PICOSEC
Micromegas

1) Now at Synchrotron Soleil, 91192 Gif-sur-Yvette, France
2) Now at LMU, Munich, Germany
3) Now at University of Bonn, Germany
4) Also MEPhI & Uludag University.
5) Also University of Virginia.
6) Now at University of Birmingham, UK

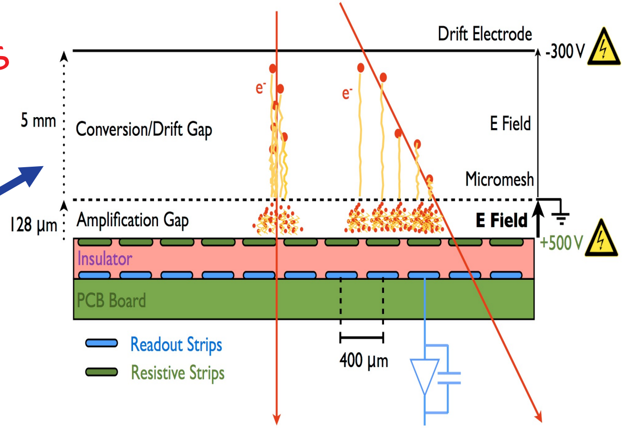
PICOSEC-Micromegas detector concept

- **Classic Micromegas**

  Giomataris Y. et al., NIMA 376(1996) 29

- Multiple electrons produced at different points along particle's path in the ~3-6mm drift region → <u>Time jitter order: **few ns**</u>

MicroMegas

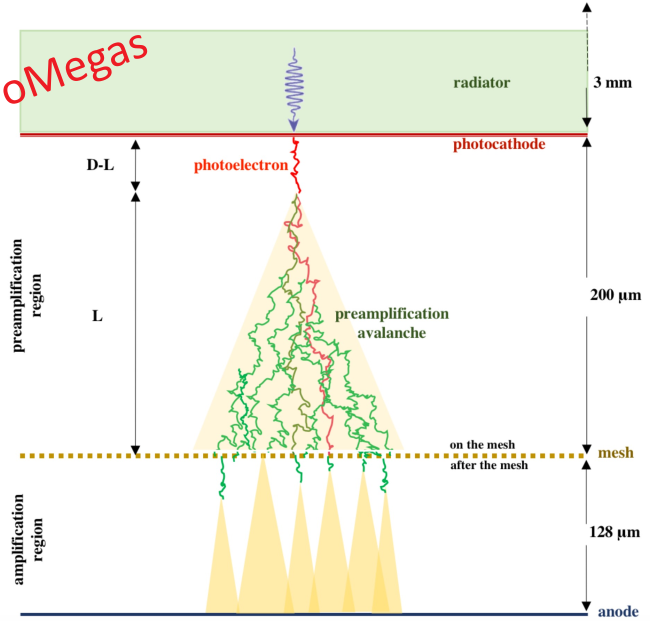


Needed to get enough original electrons

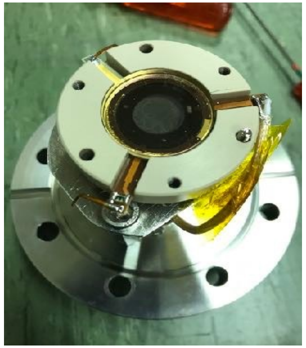
- **Micromegas + Cherenkov radiator + photocathode** ⟶ synchronous photo-electrons enter Micromegas

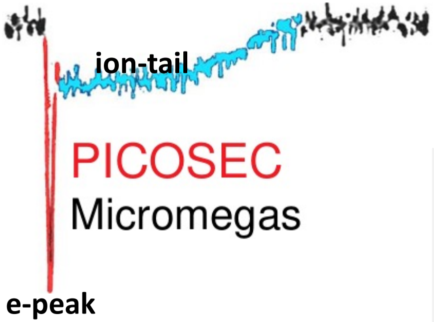
- **Small drift gap** & high field → avalanches start as early as possible with minimal time jitter → <u>Timing resolution a **few tens of ps**</u>

PICOSEC-MicroMegas



First prototype





PICOSEC Micromegas timing performance

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

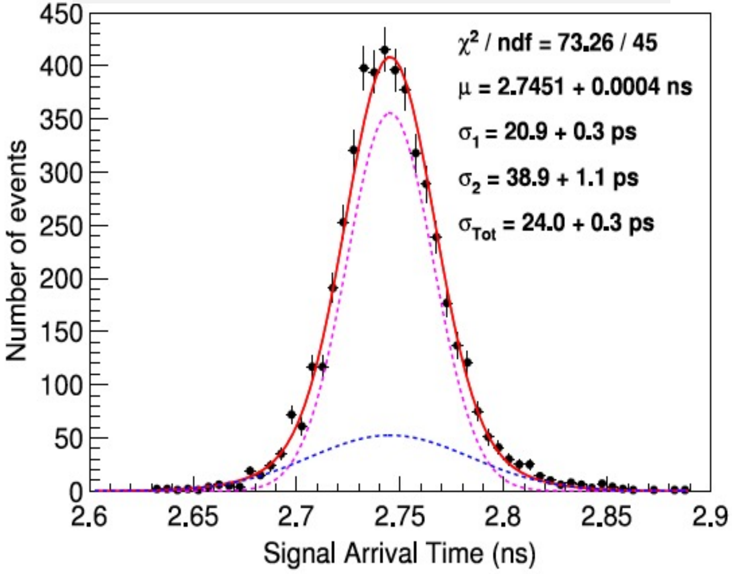
SAT of a sample of events = $<T_{e\text{-peak}}>$

Time Resolution = RMS[$T_{e\text{-peak}}$]

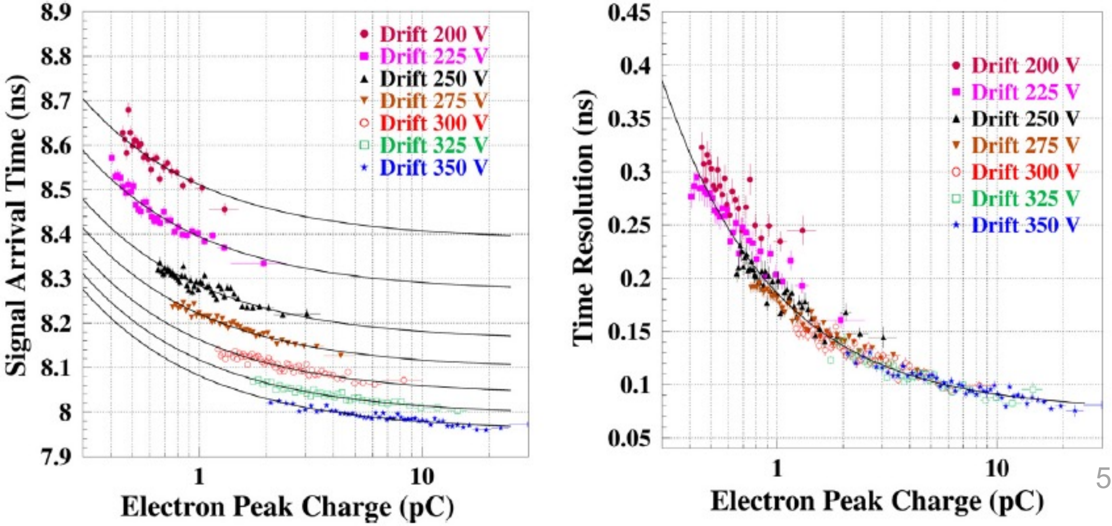
The Signal Arrival Time (SAT) depends non-trivially on the e-peak charge:
- bigger pulses → smaller SAT
- higher drift field → smaller SAT

* Shape of pulse is identical in all cases → timing with CFD method does not introduce dependence on pulse size
* Responsible for this “time-walk” of the SAT: **physics of the detector**

Timing MIP with 24ps resolution

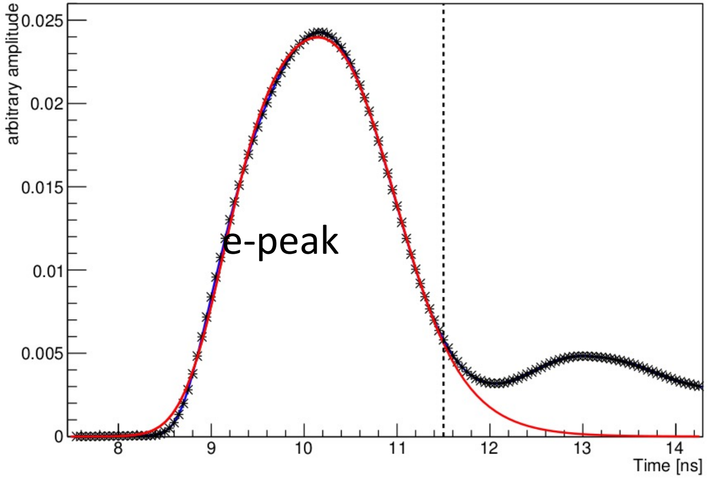


Timing single photoelectrons resolution with 76.0 ± 0.4 ps achieved



J Bortfeldt et al. for the PICOSEC Collaboration
NIM-A 903(2018) 317-325

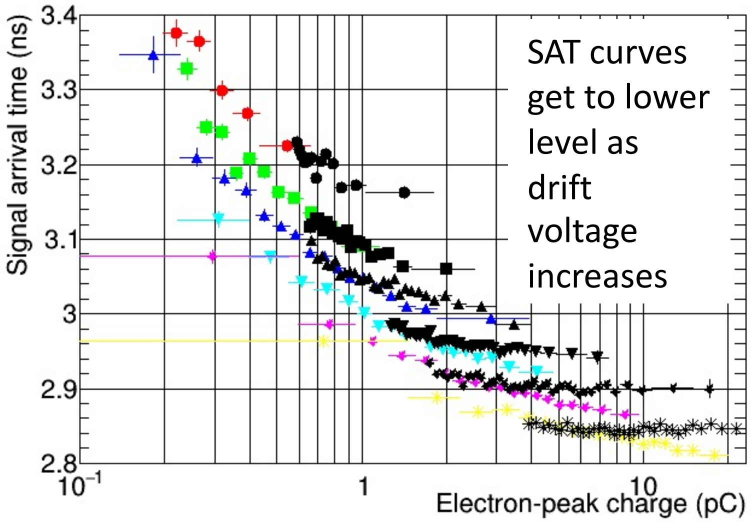
Detailed simulation with Garfield++



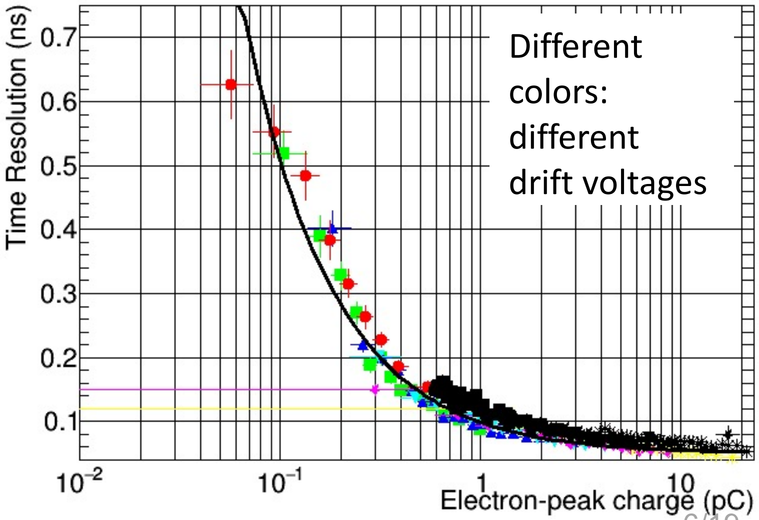
Black: Averaged PICOSEC waveforms in a certain e-peak charge region

Red: e-peak Simulation Prediction (Garfield++ and Electronics Response)

All behaviors seen in single p.e. laser data are also seen in these detailed Garfield++ simulations!!!



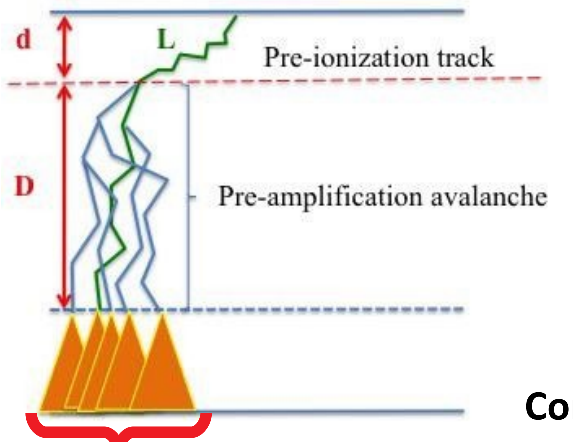
SAT curves get to lower level as drift voltage increases



Different colors: different drift voltages

Color: Simulation – Black: Data

Detailed simulations: under the hood



Gives e-peak pulse

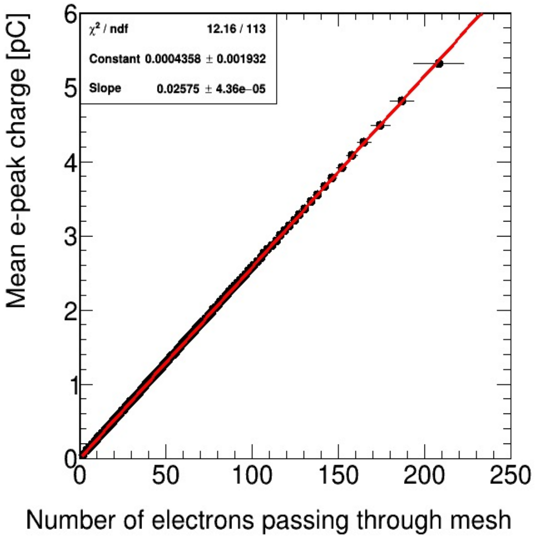
Microscopic equivalent to e-peak's SAT = Mean Time (T) of all electron arrival times on the mesh

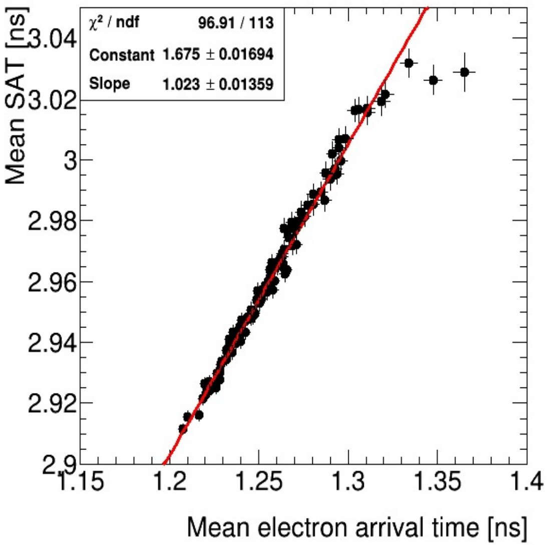
*** <SAT> linear with <T>**

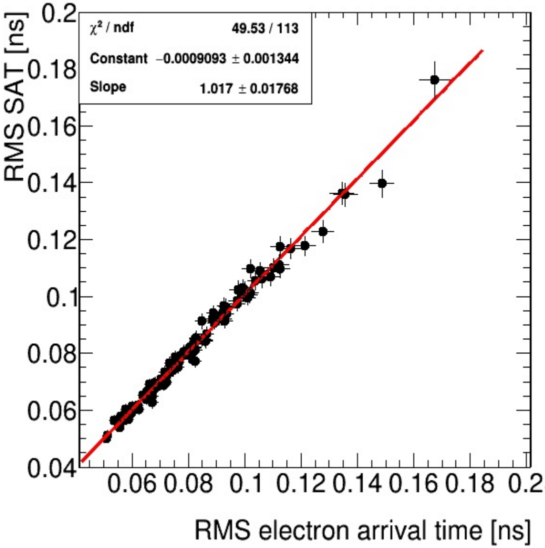
*** RMS(SAT) linear with RMS(T)**

Correspondence of experimental Observables to Relevant Microscopic Variables

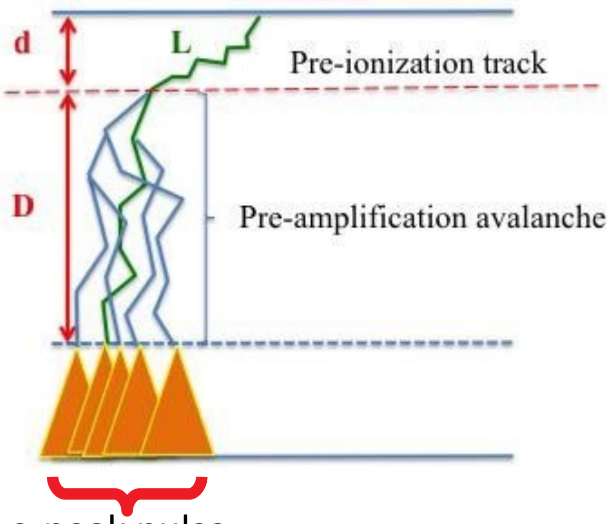
Sets of avalanches of a certain e-peak charge





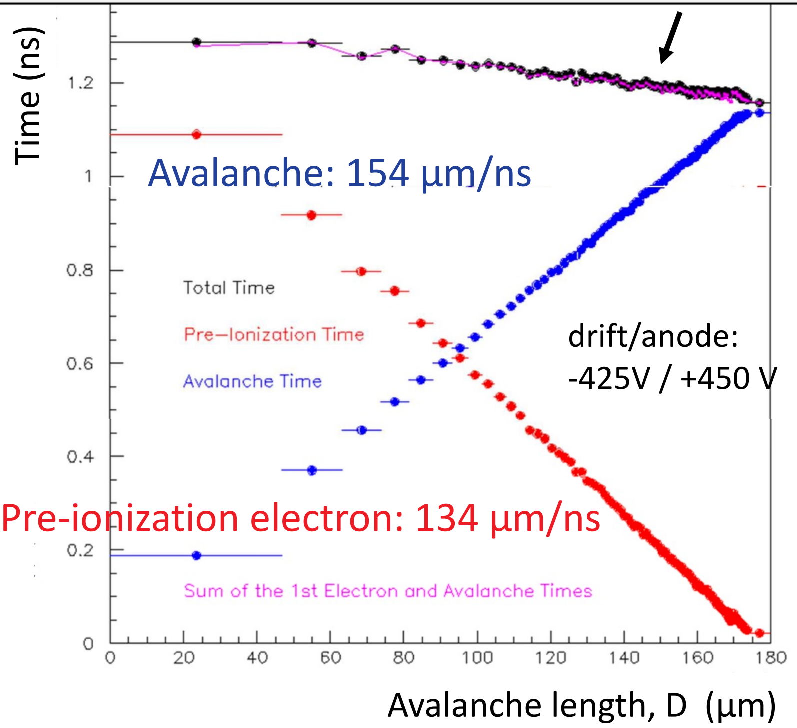


Detailed simulations: under the hood



e-peak pulse

Total arrival time reduces with avalanche length



Avalanche: 154 μm/ns

Pre-ionization electron: 134 μm/ns

drift/anode:
-425V / +450 V

!

Avalanche runs with higher drift velocity than **pre-ionization electron**

So, SAT "slewing" seen in single p.e data is explained:

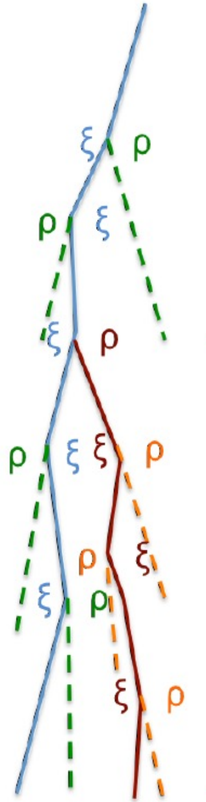
SAT reduces with avalanche length
Long avalanches → big e-peak charge } **SAT reduces with e-peak charge**

!

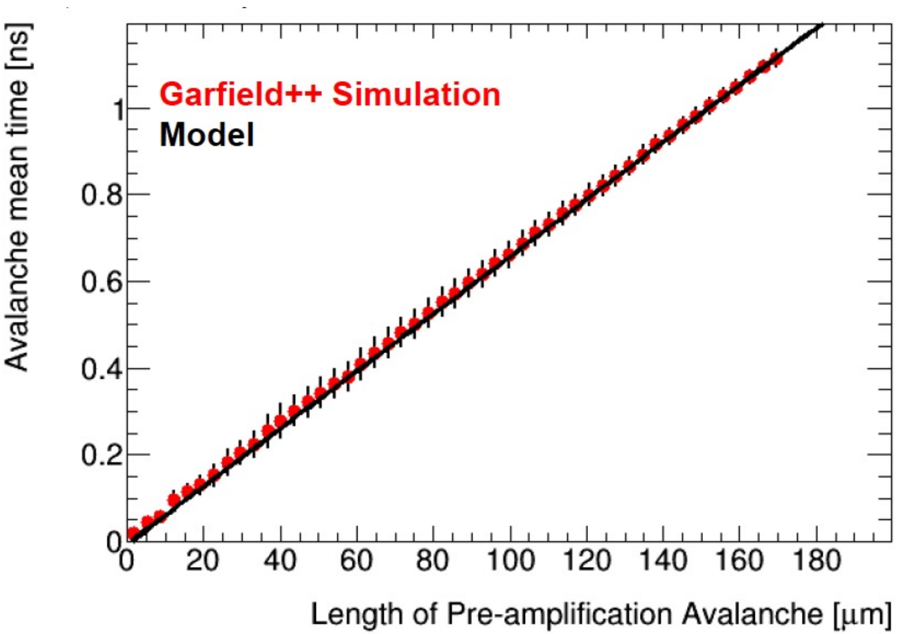
Phenomenological model: A deeper looking under the hood

- An ionizing electron in the avalanche, every time it ionizes, will gain a time **ξ** relative to an electron that undergoes elastic scatterings only.
- A new produced electron by ionization starts with low energy, suffers less delay due to elastic backscattering compared to its parent. Relative to its parent it will have a time-gain **ρ**
- Parameters **ξ** and **ρ** should follow a joint probability distribution determined by the physical process of ionization and the respective properties of interacting molecules

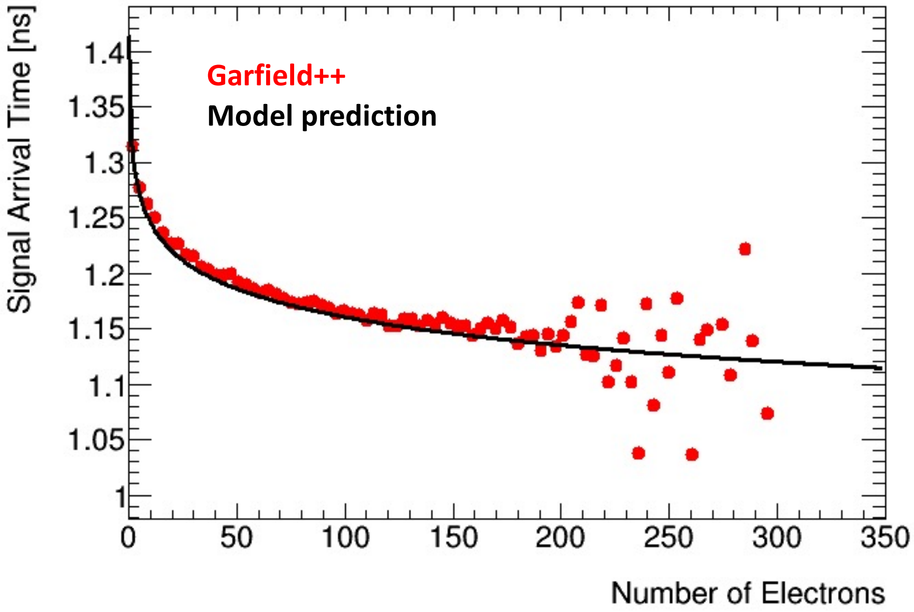
J. Bortfeldt et al. for the PICOSEC Collaboration, NIM-A, Vol. 993, (2021), 165049 - arXiv:1901.10779



Understood in terms of phenomenological model



We can predict the effective drift velocity of the avalanche

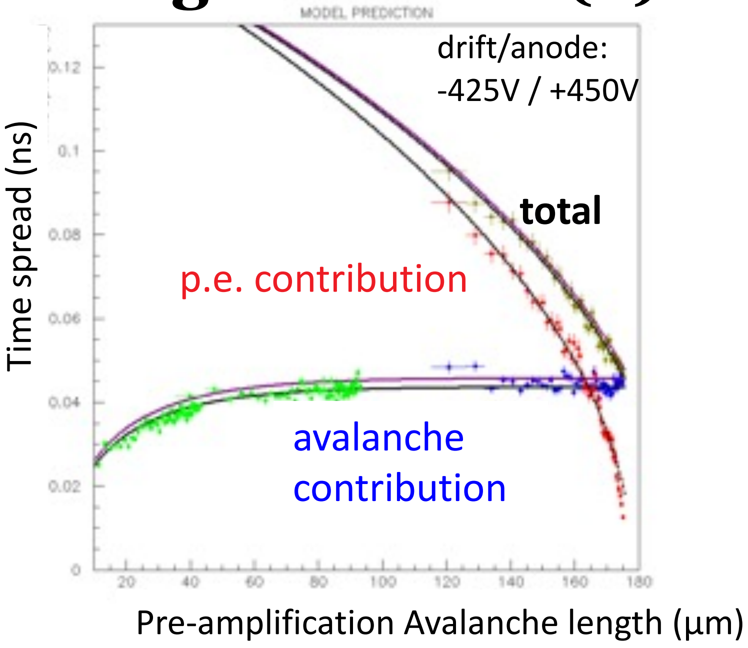


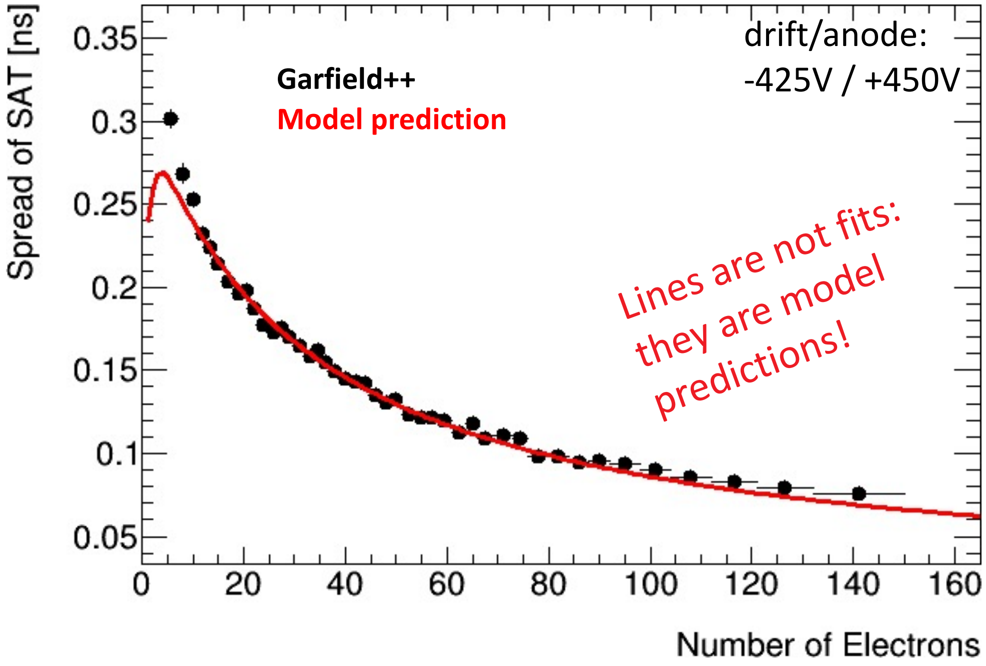
We can describe and explain the SAT dependence on the number of avalanche's electrons (i.e. on the e-peak size)

- The other parameters of the model are: the drift velocity of the photoelectron and the first Townsend coefficient.
- The model treats the number of electrons in an avalanche as continue variable.

Understood in terms of phenomenological model (2)

We can describe and explain the Resolution dependence on the length of the avalanche and on the number of avalanche's electrons (i.e. on the e-peak size)





Lines are not fits: they are model predictions!

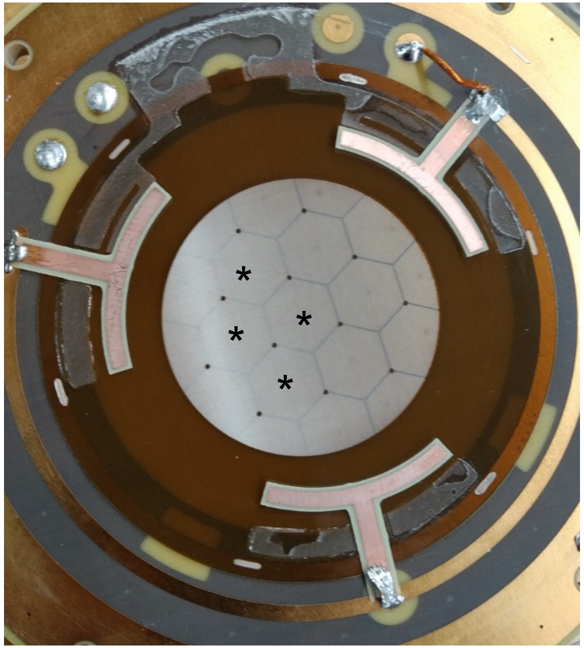
The model describes SAT and Resolution
a) vs. avalanche length &
b) vs. number of electrons in avalanche
(i.e, vs. e-peak charge)

→ Before and after the mesh

Not only averages and RMS, but full distributions, vs. values of operational parameters (e.g., drift voltage)

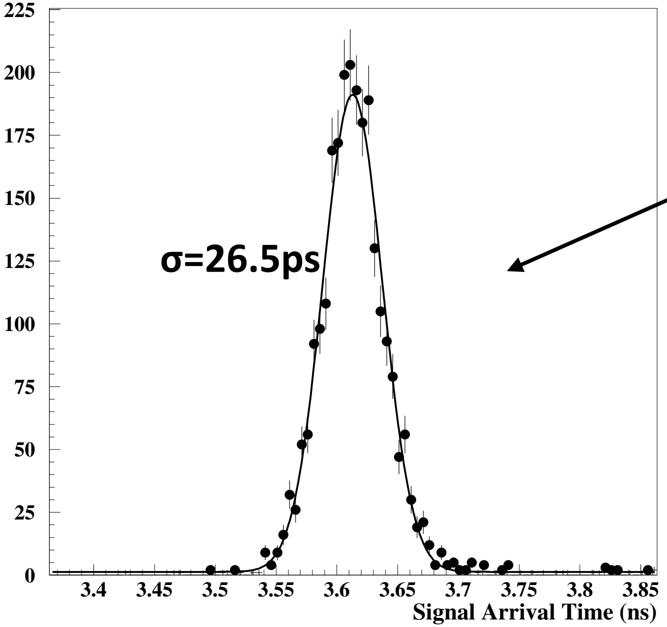
Large-area coverage - Multi-pad PICOSEC

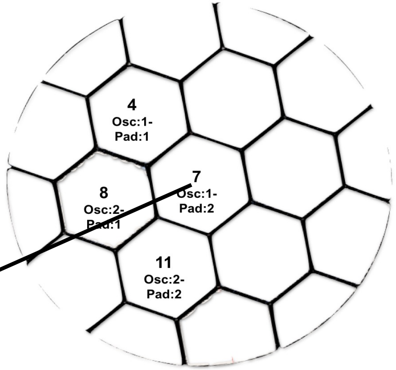
- Like the single-pad (MgF2/CsI/bulkMM/COMPASS gas) PICOSEC which achieved 24ps per MIP
- Hexagonal pads 5mm side
- Readout 4 pads → 2 oscilloscopes



Non perfect planarity

Peripheral pads presented worse timing resolution than central one



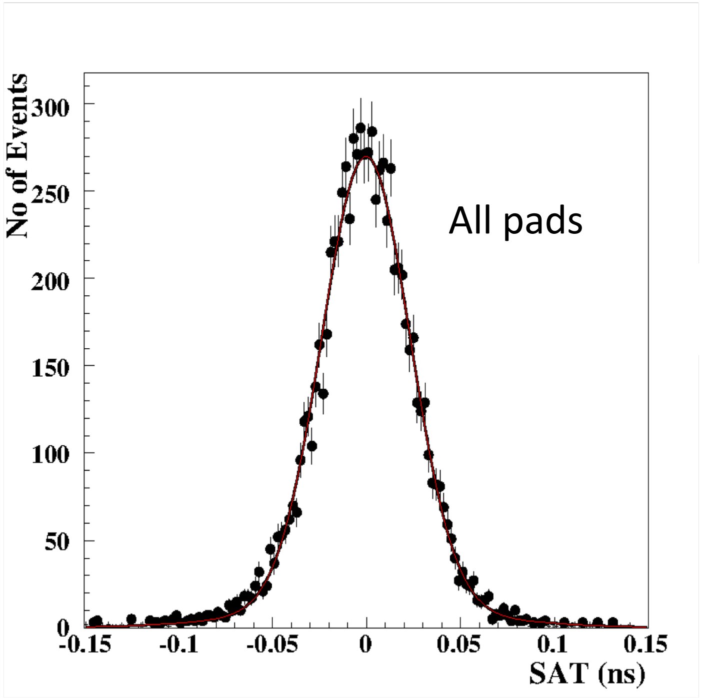


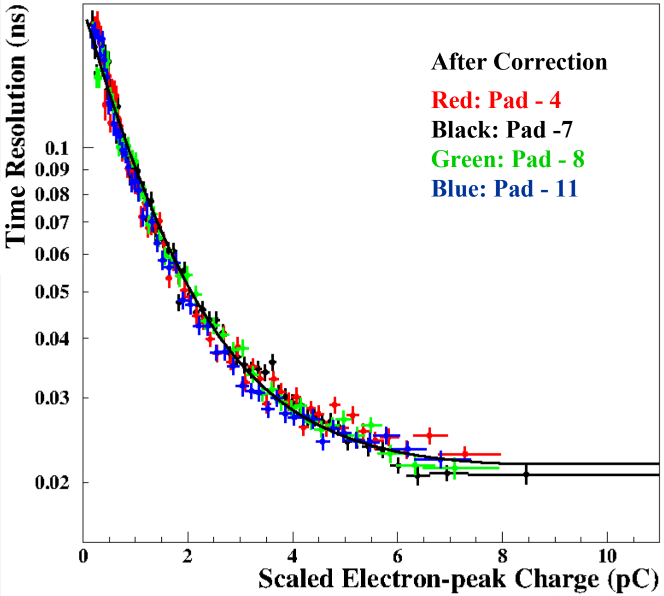
Multi-pad MicroMegas – Individual pad response

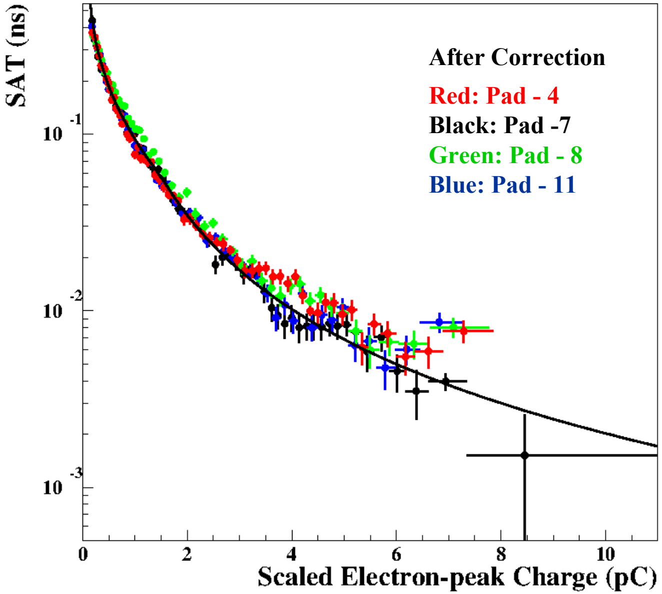
Multi-pad: Same resolution as single-pad

After applying flatness correction:

Timing resolution of **25ps for all pads**



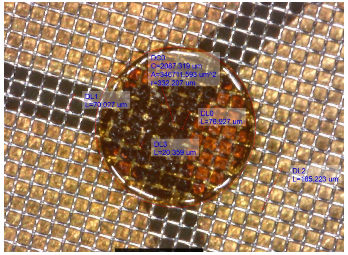


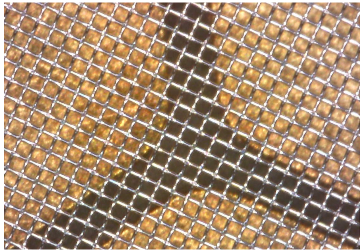


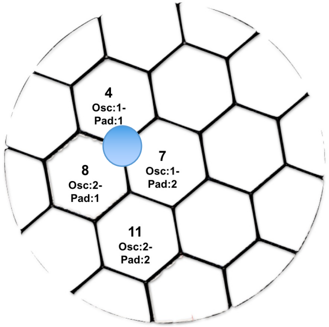
S. Aune et al. for the PICOSEC Collaboration, NIM-A, Vol. 993, (2021), 165076 - arXiv:2012.00545v2

Multi-pad MicroMegas – The “3 pads” region

Not the easiest regions

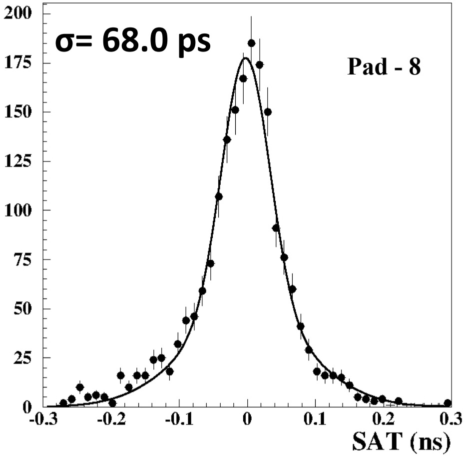

Pillars of ~650µm diameter

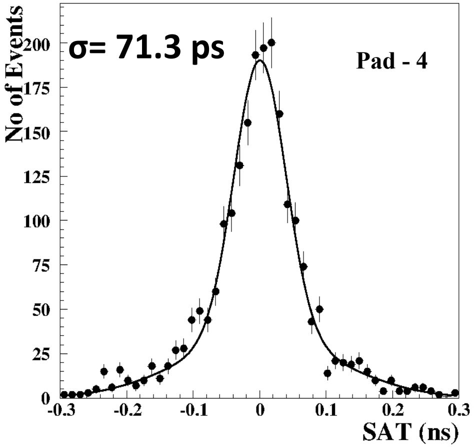

200µm inter-pad space

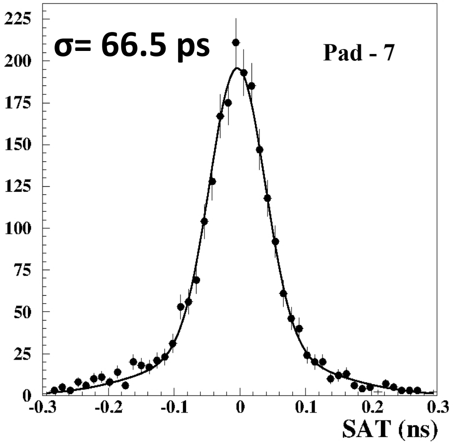


Possible non-uniformities on the field to be studied

Individual pad responses





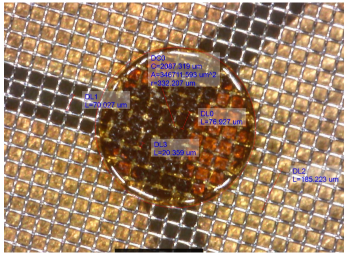


Naive estimation:
<σ>/sqrt(3)≈**40 ps**

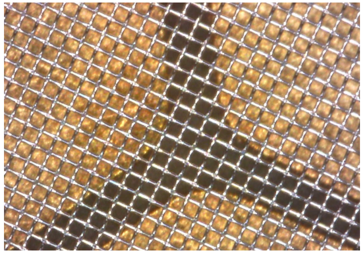
SAT: Signal Arrival Time

Multi-pad MicroMegas – The “3 pads” region

combined pad response



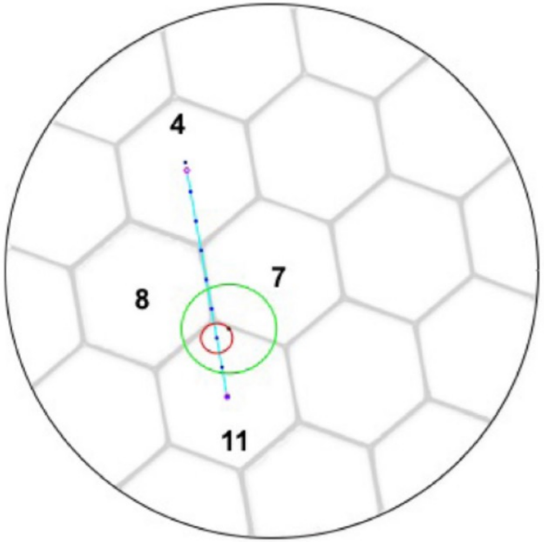
Pillars of ~650µm diameter

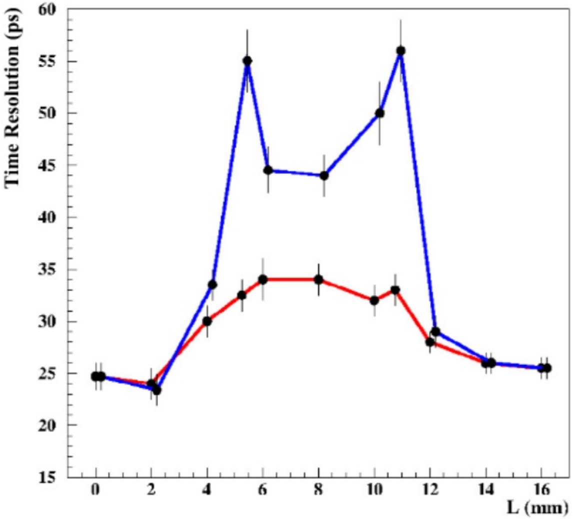


200µm inter-pad space

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

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



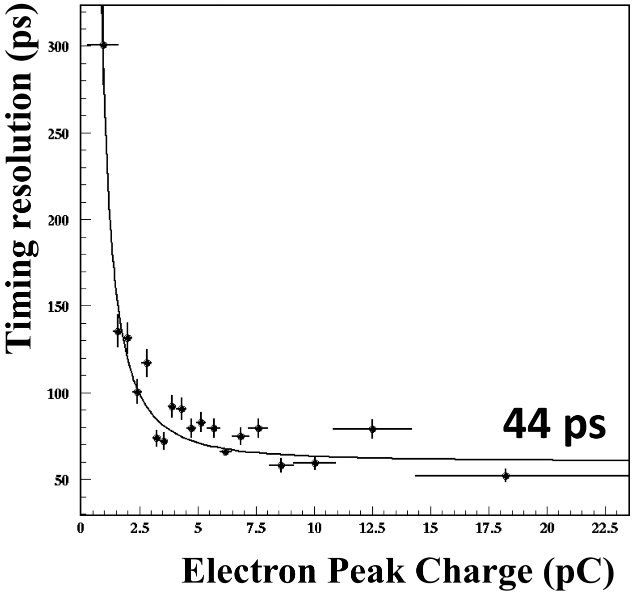


We can do it better!

Reducing drift gap to 119 µm

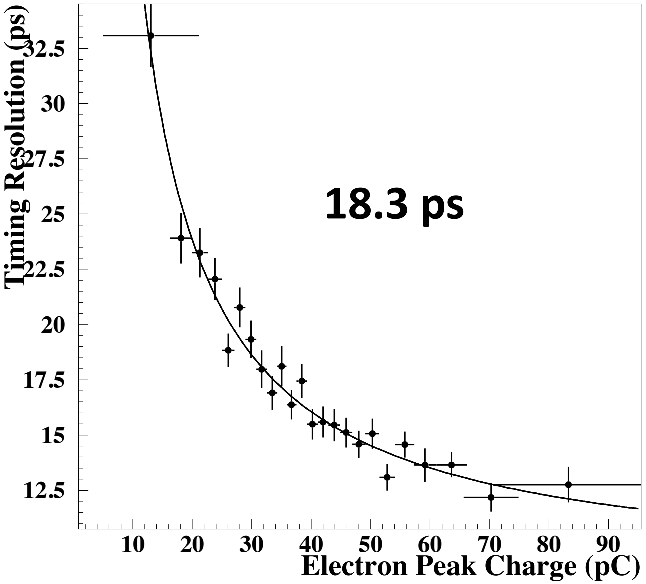
Laser test beam: LYDIL laser laboratory of CEA-IRAMIS (France)

1 photoelectron (pe)



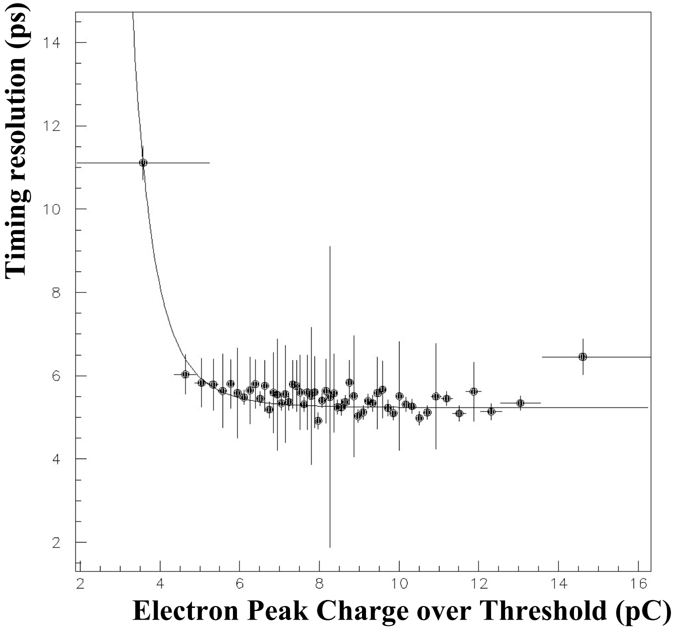
44 ps

7.8 pes



18.3 ps

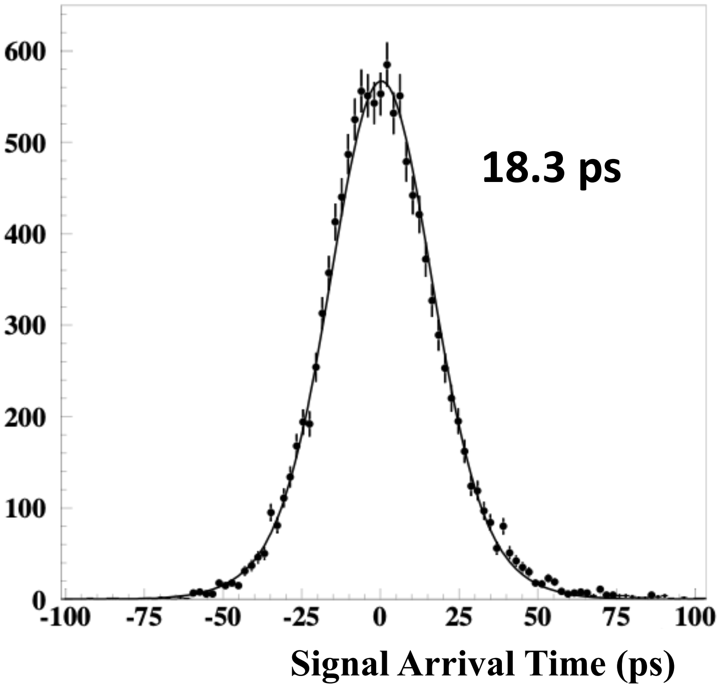
70 pes

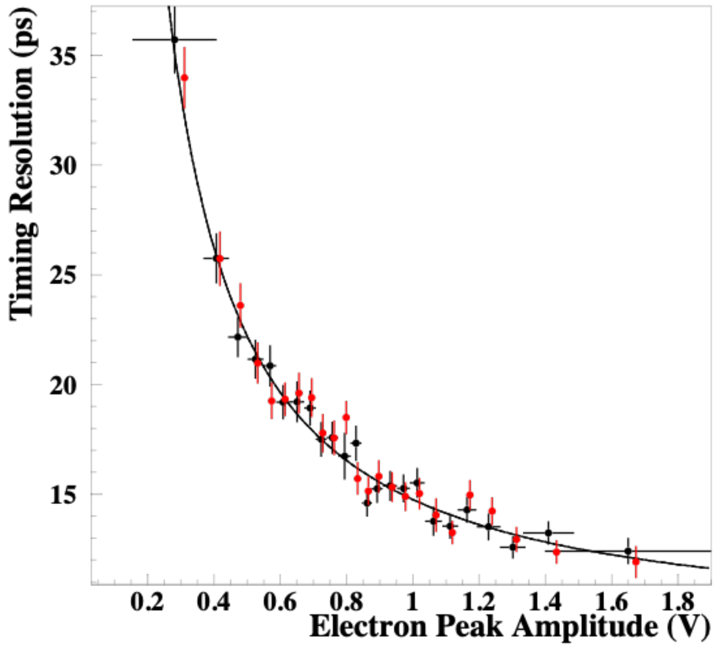


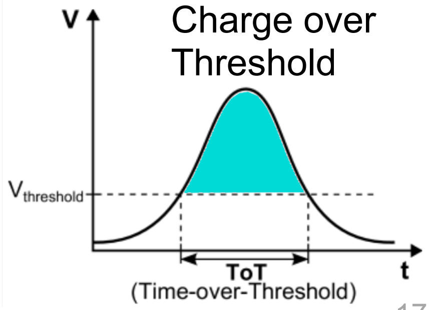
Towards scalable electronics

- Using single threshold electronics (e.g. NINO chip)

Red: Standard offline analysis (CFD@20%)
Black: Single threshold 100 mV, correcting time-walk with the highest available Charge over Threshold (100, 200, 400, 600 mV) – SAT parameterization



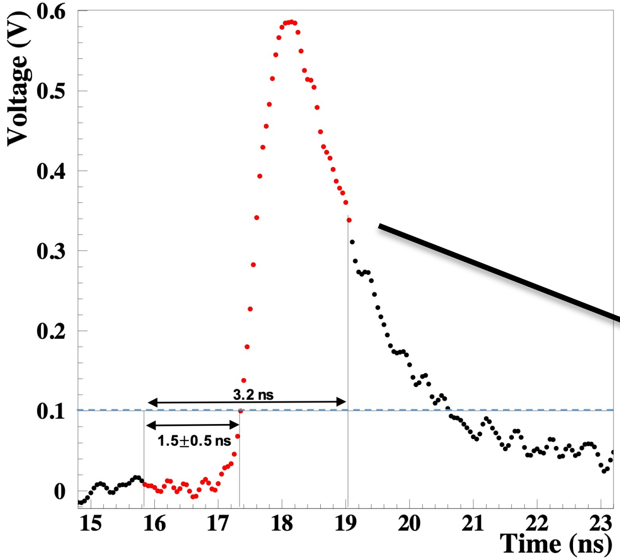




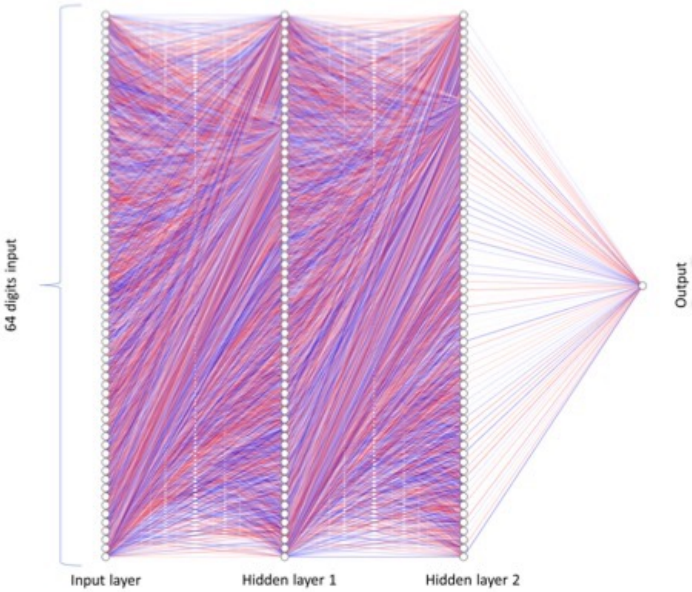
S.E. Tzamarias et al., to be published

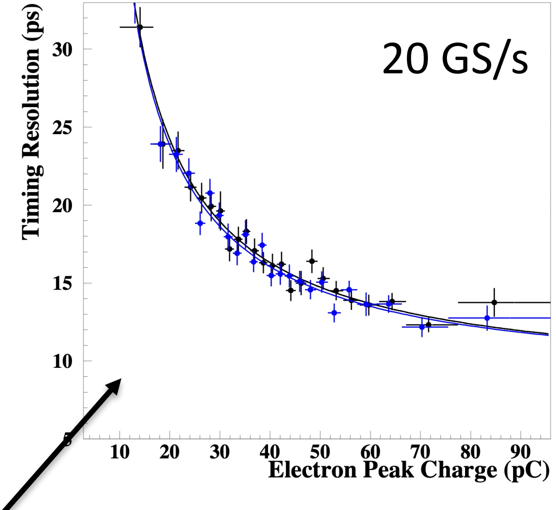
Towards scalable electronics

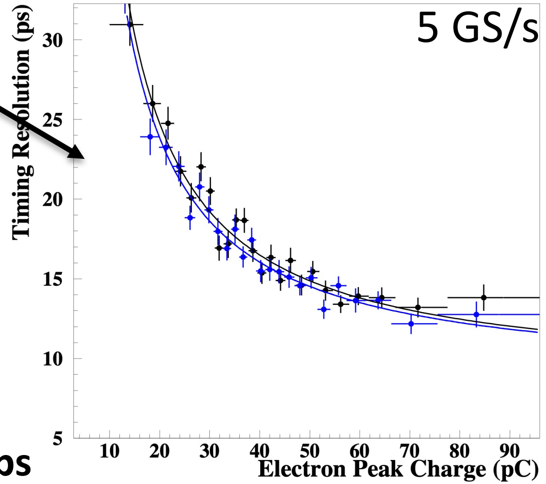
- Digitize only the Leading edge and using artificial Neural Networks (SAMPIC electronics)



Network input: 64 bits (red)





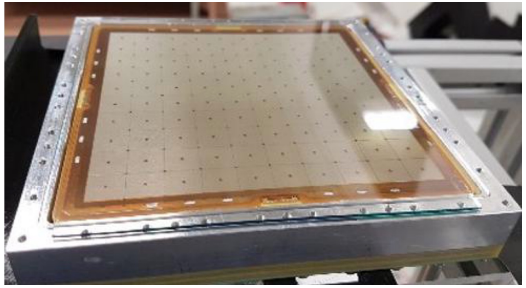


Blue: Offline analysis **18.3ps**

Black: Neural Network **18.3ps** (20GS/s) – **19.2ps** (5Gs/s)

"Timing techniques with picosecond-order accuracy for novel gaseous detectors" A. Tsiamis, poster session 4

Near future work



- New Multipad PICOSEC prototype tested in test beam at CERN in July 2021 with promising results (but with limited statistics)
- Next test beam, October 2021.

- New resistive materials and photocathodes (DLC) will be tested in October 2021 test beam.

- Simulation studies with PICOSEC embedded in an EM calorimeter: a 30 GeV electron produces ~200 pes in MgF_2 radiator with a metallic (Cr) photocathode after 2 radiation lengths
  - Timing resolution <10ps!!
  - No need for: high efficiency photocathode or extremely high electric fields.