In-depth studies of time performance of the PICOSEC-Micromegas detector concept

@

IPRD19 Siena

Lukas SOHL

15.10.2019

What to expect in the next 15 minutes:

- What is a PICOSEC-Micromegas
  - and why it does have such a good time resolution
- Laser measurement set-up
- Effects of the drift gap on the time resolution
- Pre-studies of gas mixtures
- Outlook on further developments

RD51 R&D Project:

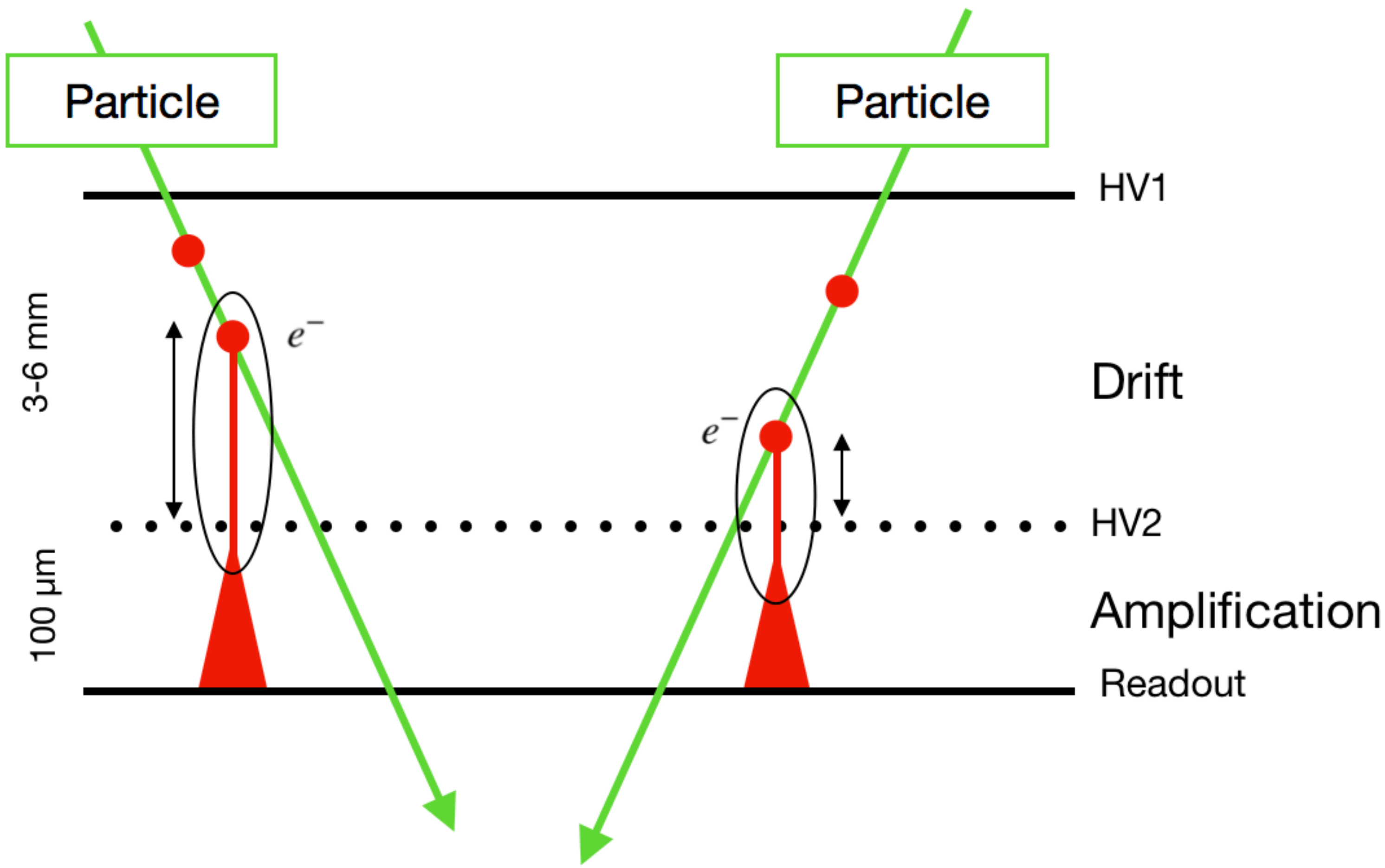
PICOSEC-Micromegas

- **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, 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, Ch. Petridou 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.

[1] Now at Synchrotron Soleil, 91192 Gif-sur-Yvette, France
[2] Also MEPhI & Uludag University.
[3] Also University of Virginia.

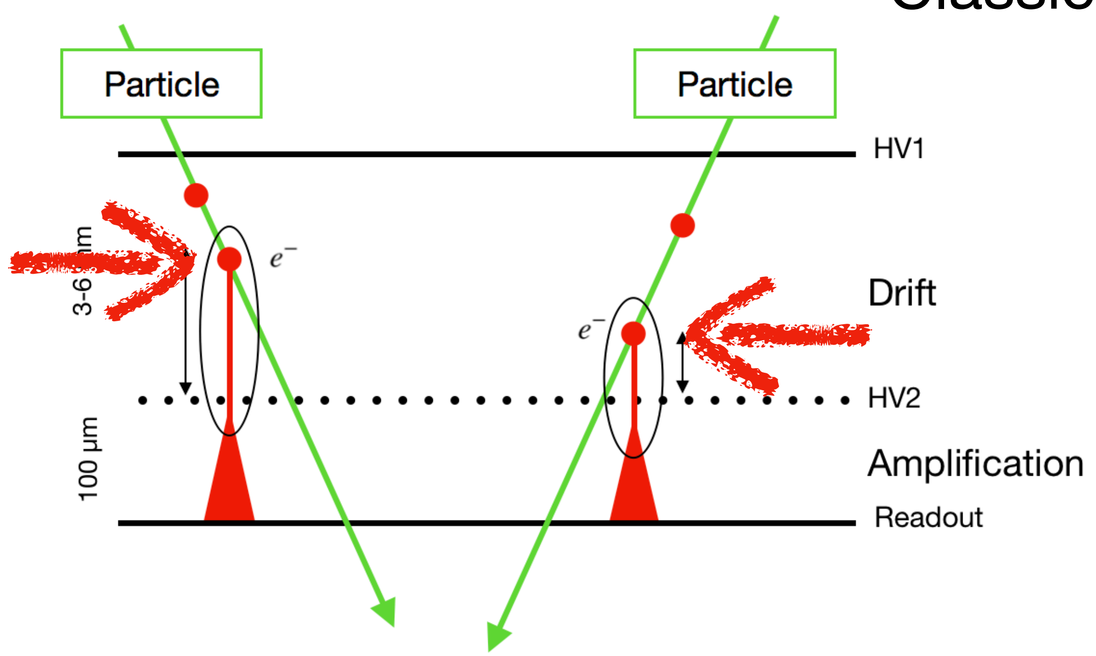
PICOSEC
Micromegas

PICOSEC Micromegas



PICOSEC Micromegas

Classical MM



- Different position of ionisation clusters at direct gas ionisation

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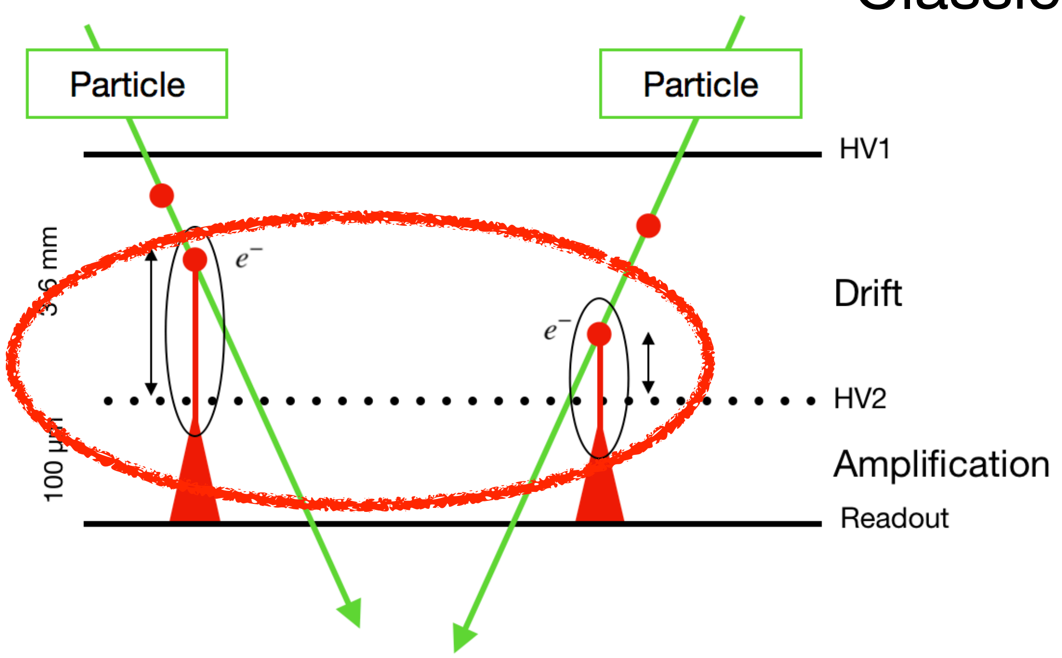

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- Inevitable signal arrival time jitter due to drift velocity and average ionisation lenght

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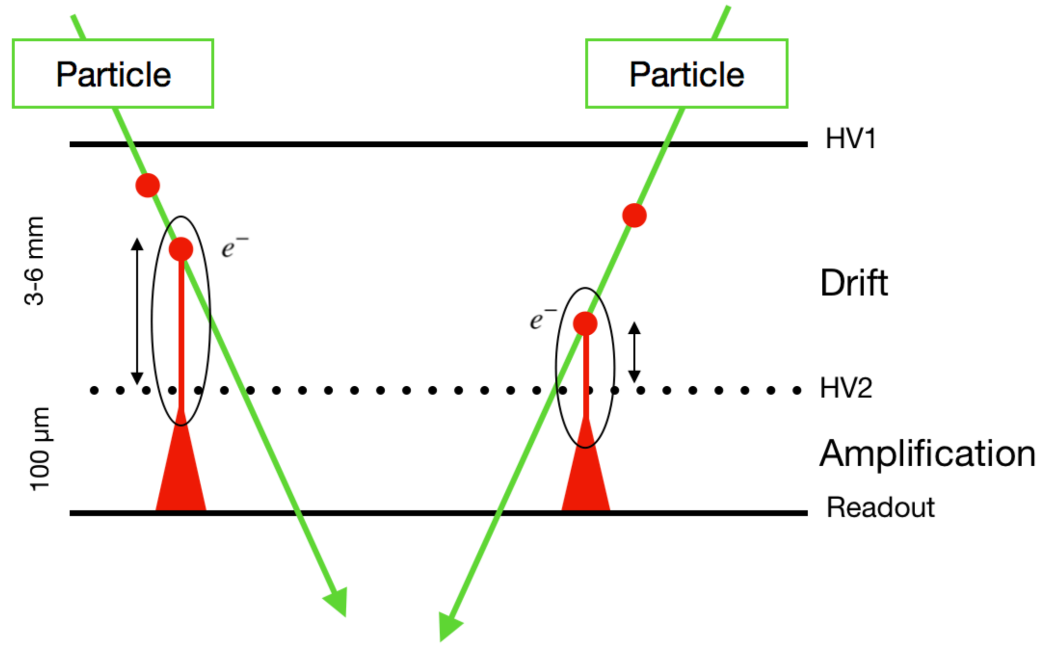

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$$\sigma_t = \frac{\sigma_I}{v_d} = \frac{355\ \mu m}{84\ \frac{\mu m}{ns}} \approx 4\,ns$$

Estimated time jitter for COMPASS Micromegas

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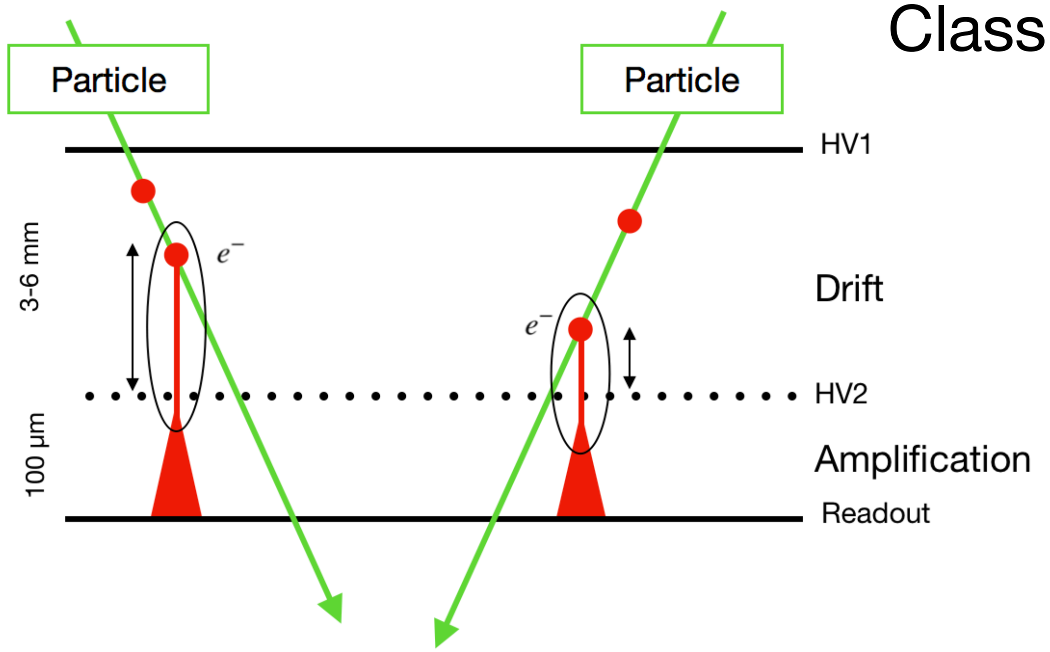

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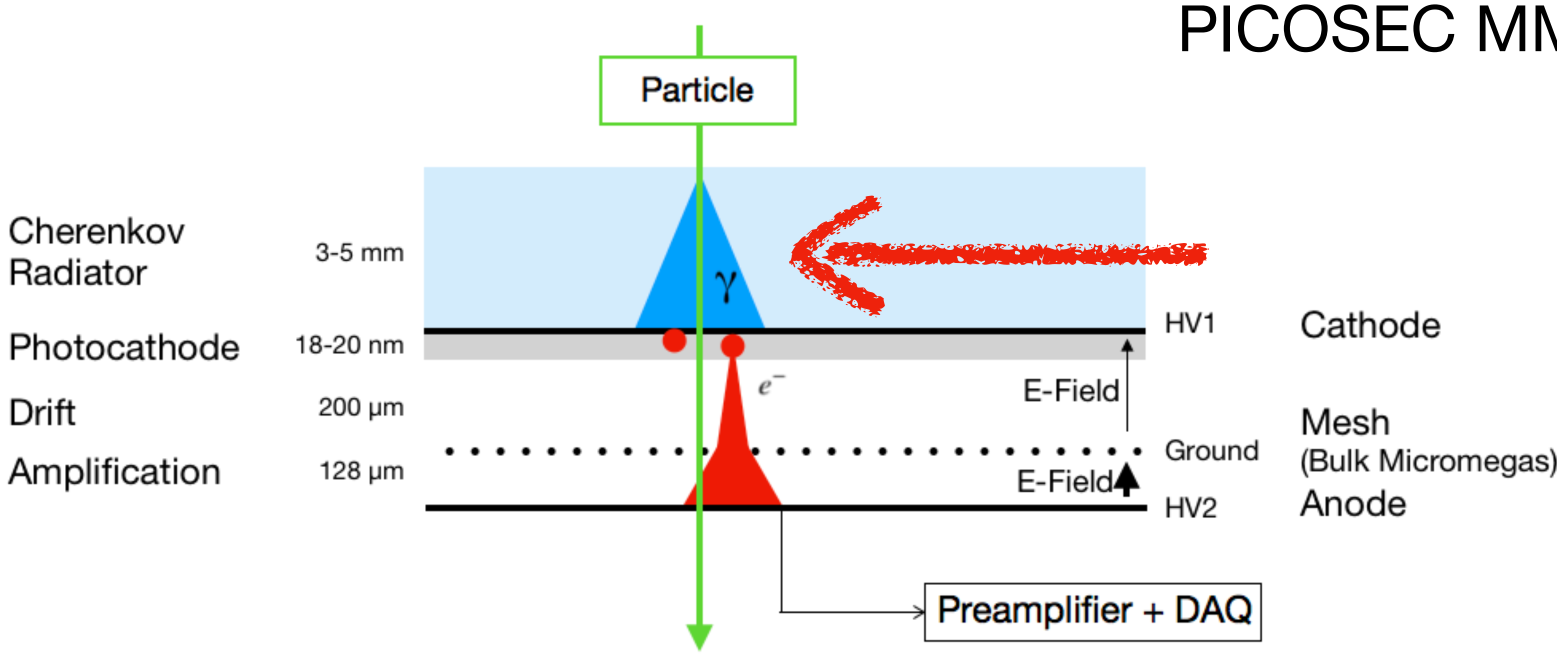

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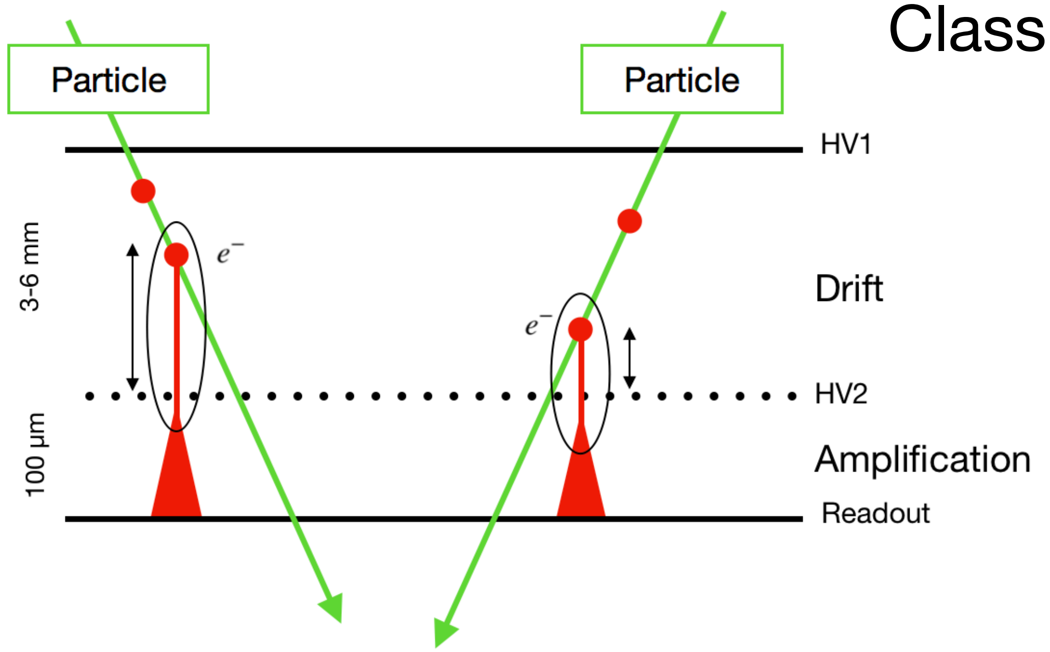

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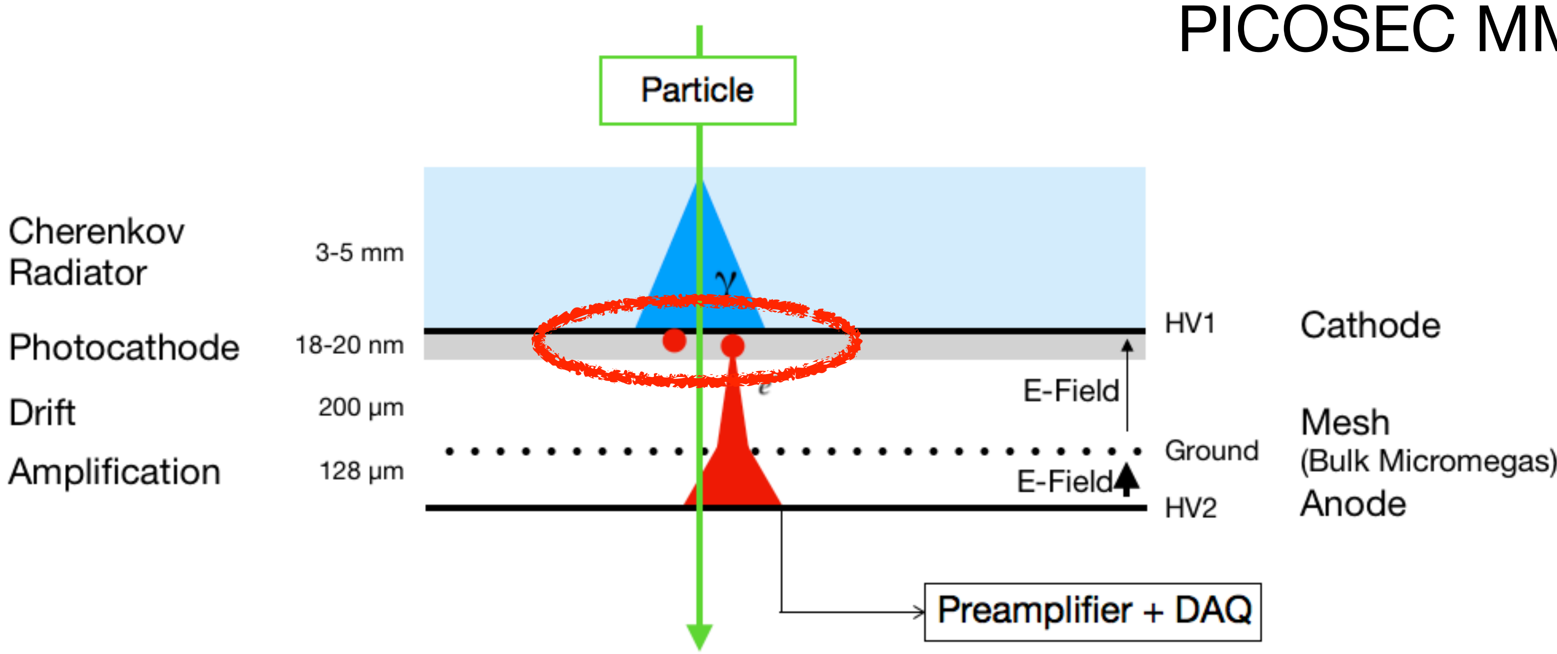

- Particle produce Cherenkov radiation
- Electrons are emitted by the radiation in a photocathode
- All primary ionised electrons are localised on the photocathode

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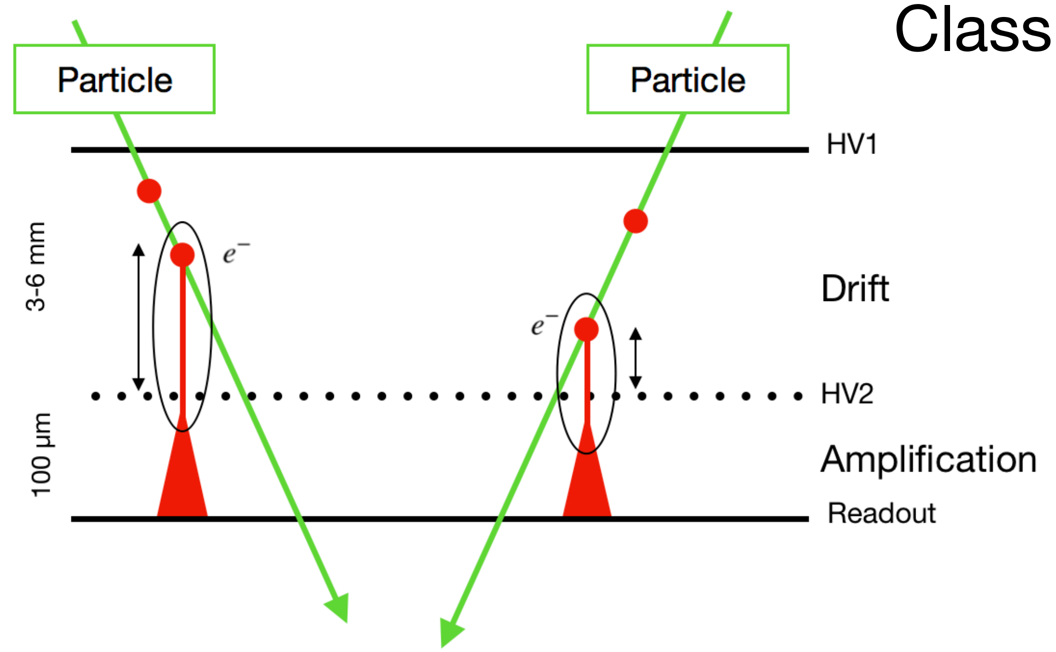

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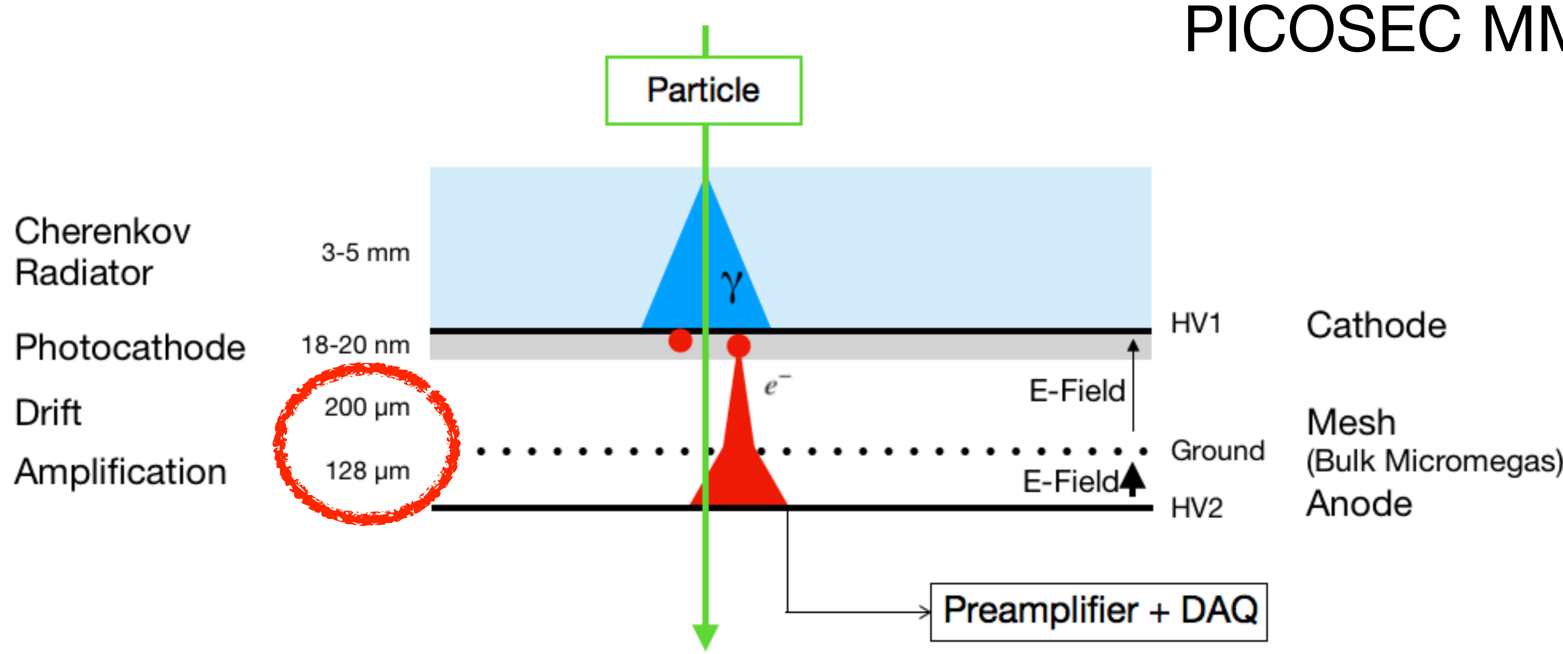
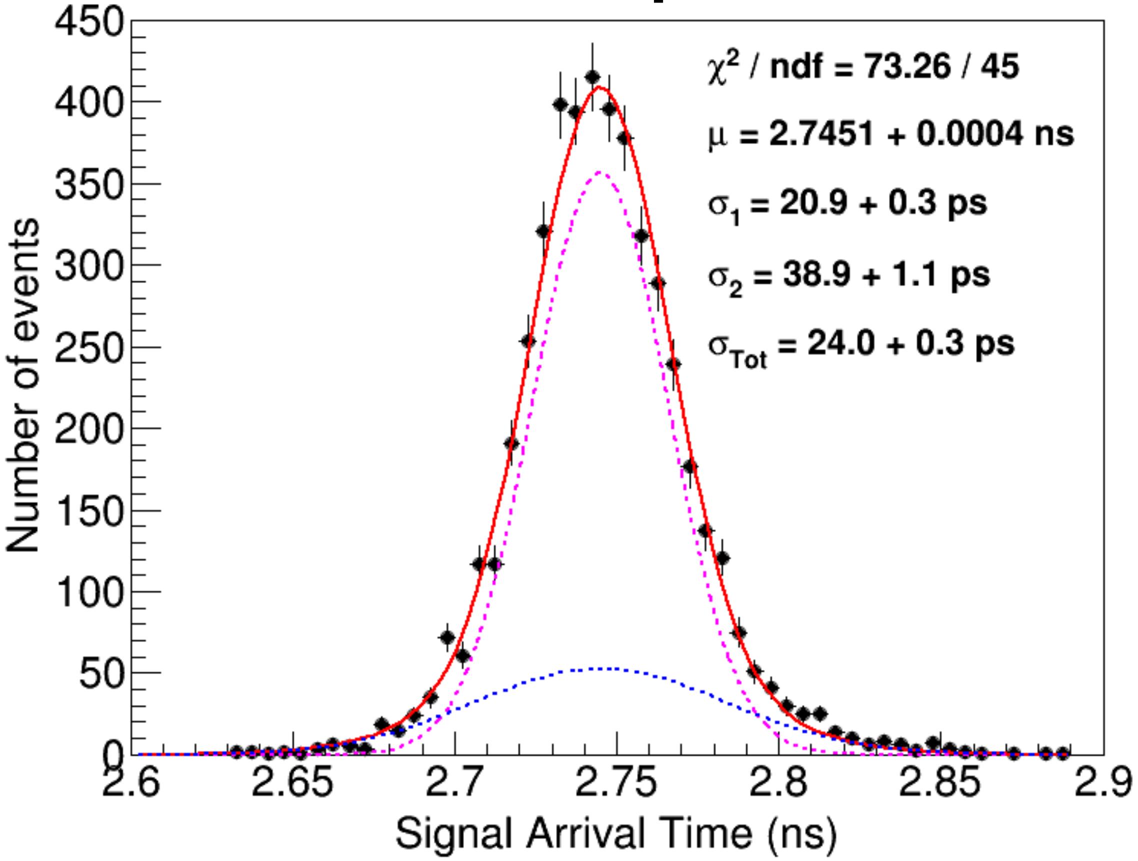


- Particle produce Cherenkov radiation
- Electrons are emitted by the radiation in a photocathode
- All primary ionised electrons are localised on the photocathode
- Due to high electric field, time jitter before first amplification minimised

Previous Development

Time Resolution ~24 ps in muon beam

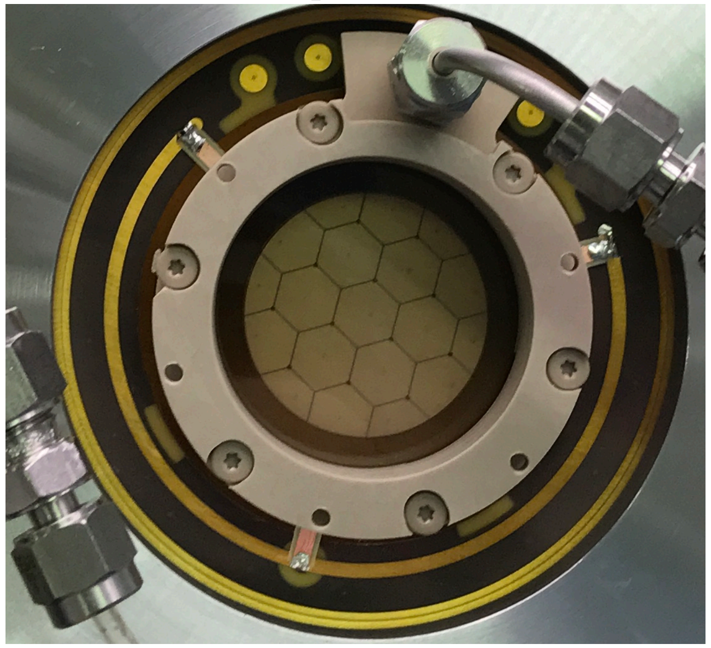


- Fast Timing for High-Rate Environments with Micromegas, EPJ Web of Conferences **174**, 02002 (2018), doi: 10.1051/epjconf/201817402002
- PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector, Nucl. Instrum. Meth. **A903** (2018) 317-325. doi:10.1016/j.nima.2018.04.033.
- Charged particle timing at sub-25 picosecond precision: The PICOSEC detection concept, Nucl. Instrum. Meth. **A936** (2019) 515-518. doi:10.1016/j.nima.2018.08.070.
- Precise charged particle timing with the PICOSEC detector, AIP Conference Proceedings **2075**, 080009 (2019); doi: 10.1063/1.5091210
- PICOSEC-Micromegas: Robustness measurements and study of differentphotocathode materials, J. Phys.: Conf. Ser. **1312** (2019) 012012 ; doi: 10.1088/1742-6596/1312/1/012012

Different photocathode materials tested

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 nm Cr + 18 nm CsI	7.4	100%

First Multipad Detector



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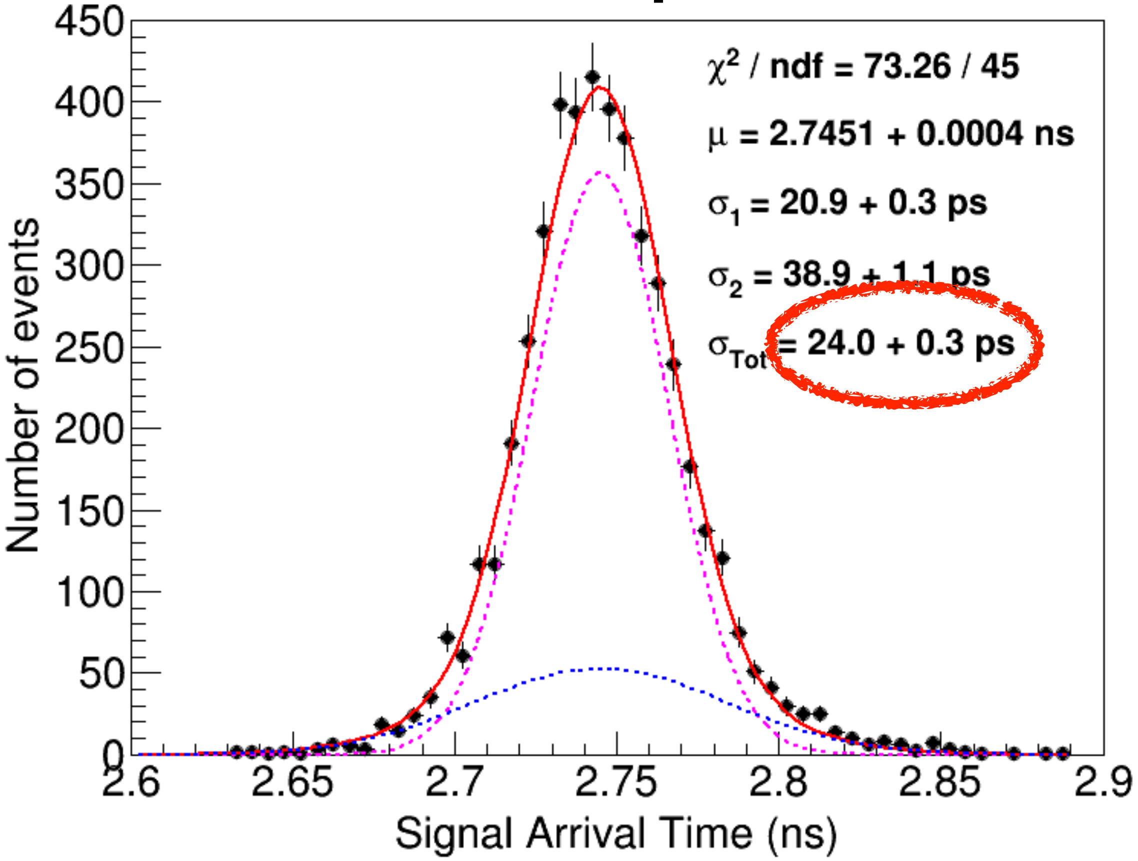

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- Precise charged particle timing with the PICOSEC detector, AIP Conference Proceedings **2075**, 080009 (2019); doi: 10.1063/1.5091210
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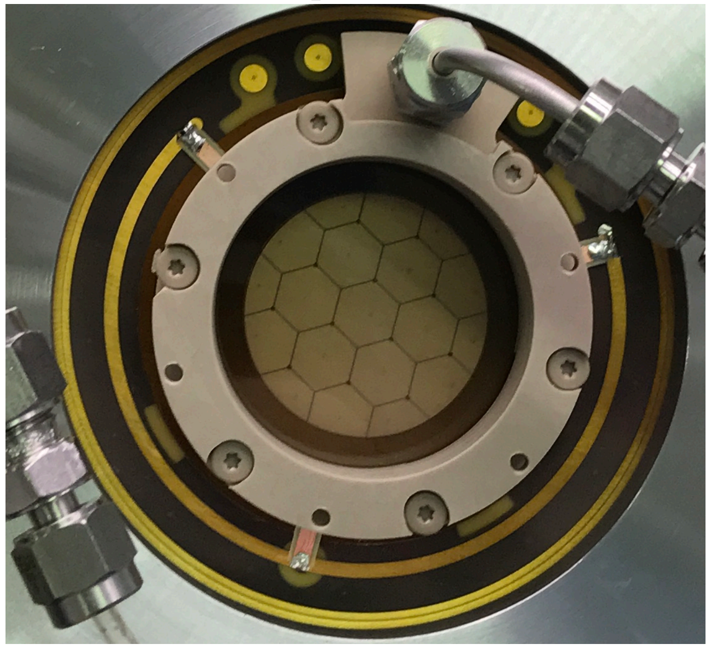

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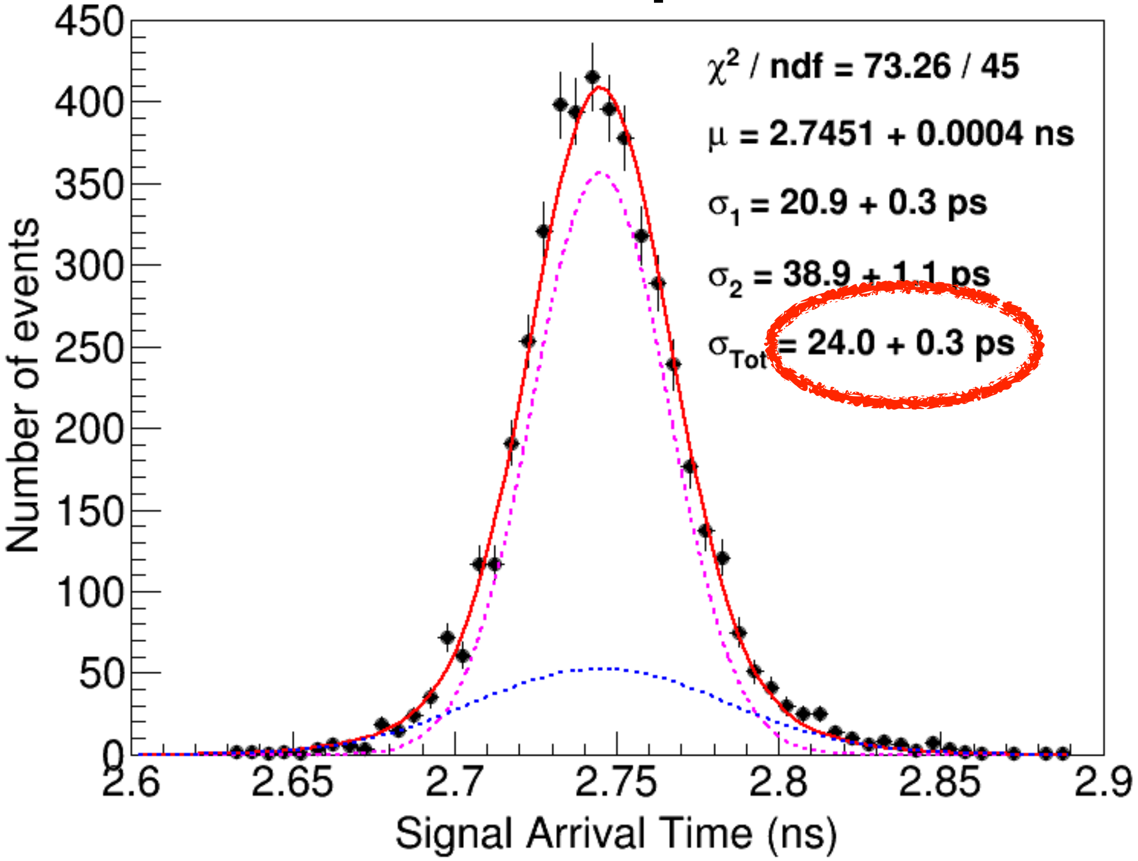

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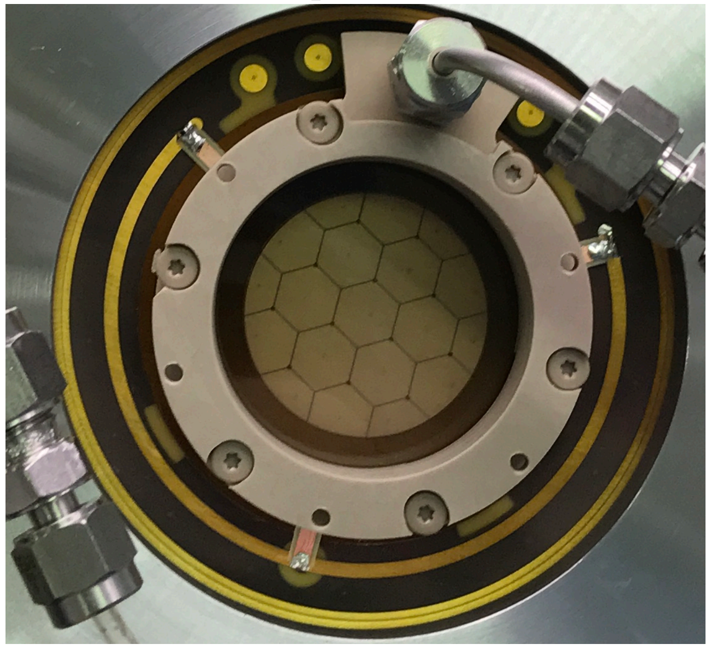

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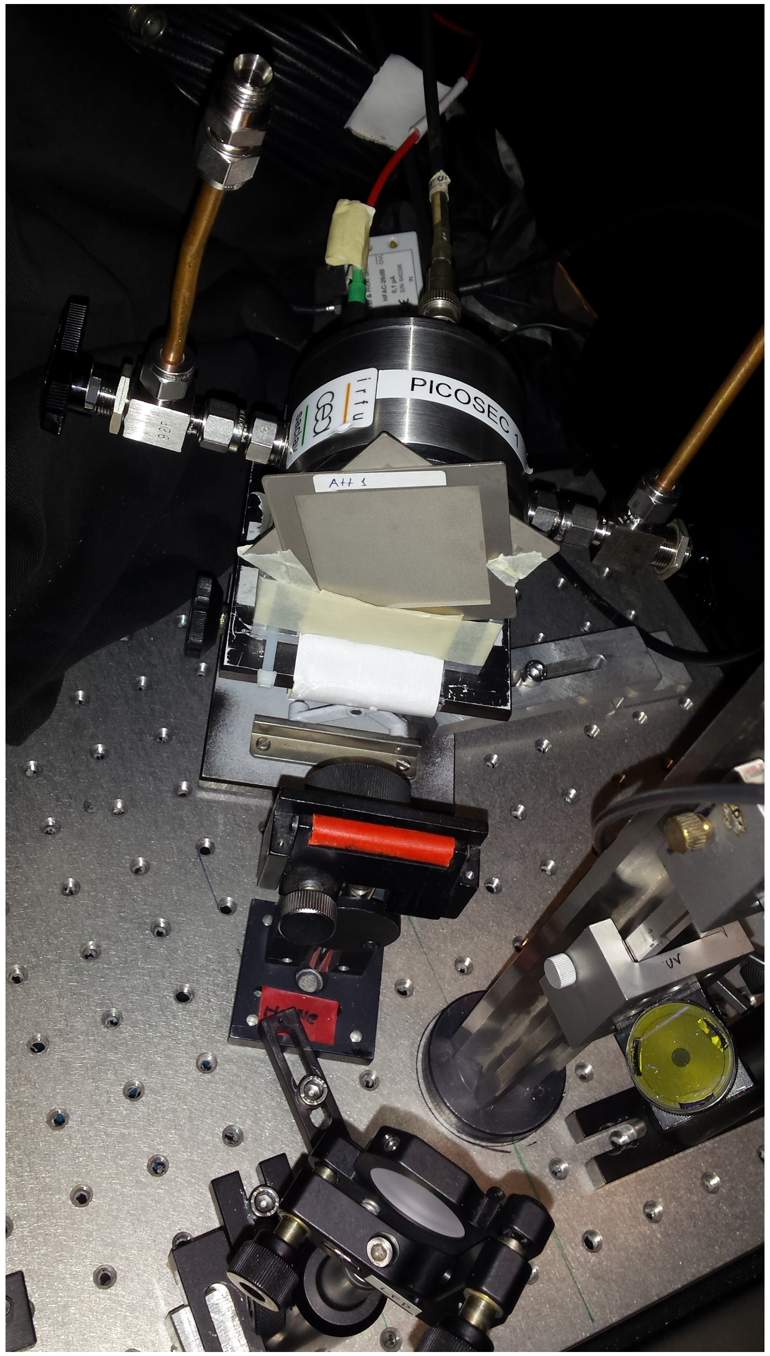
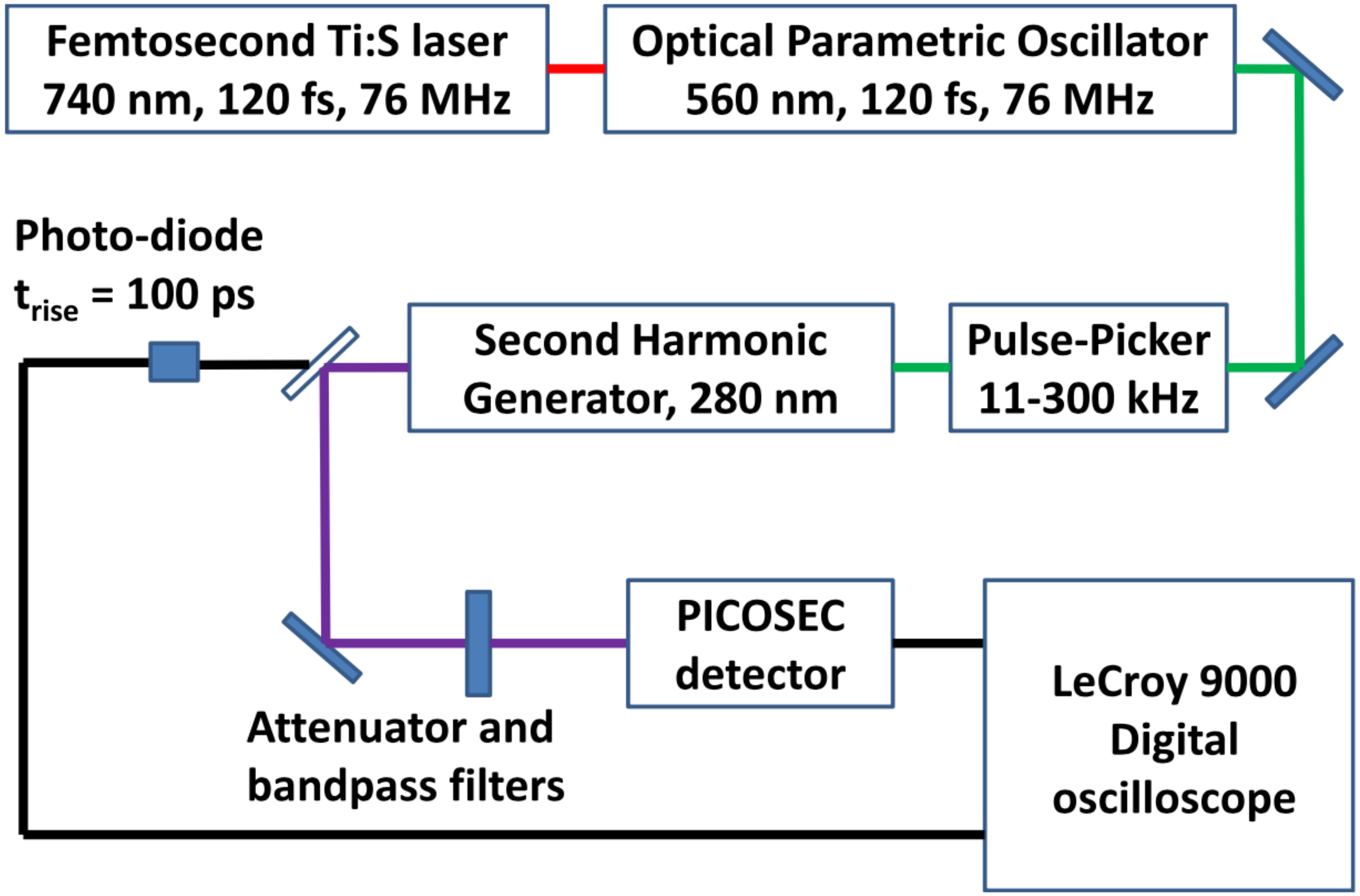
Clean measurements with a Laser





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

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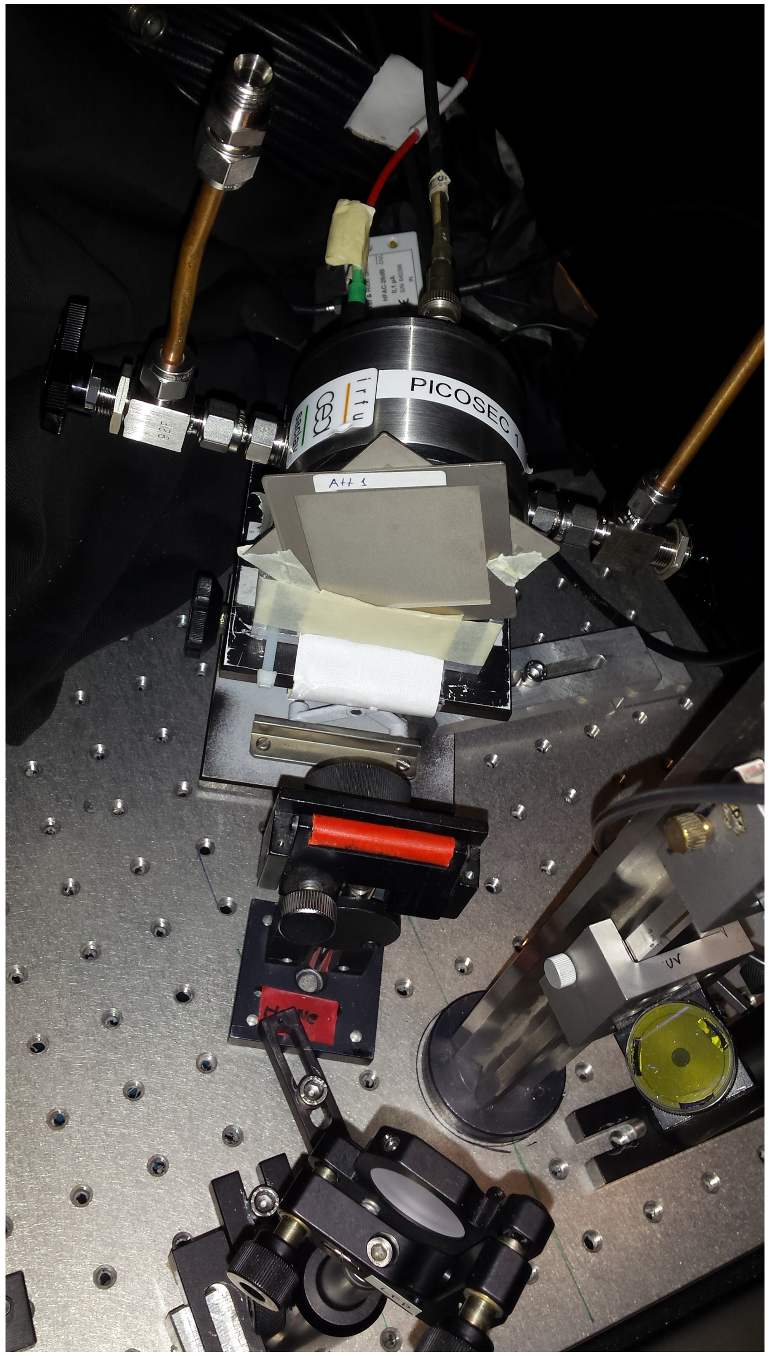

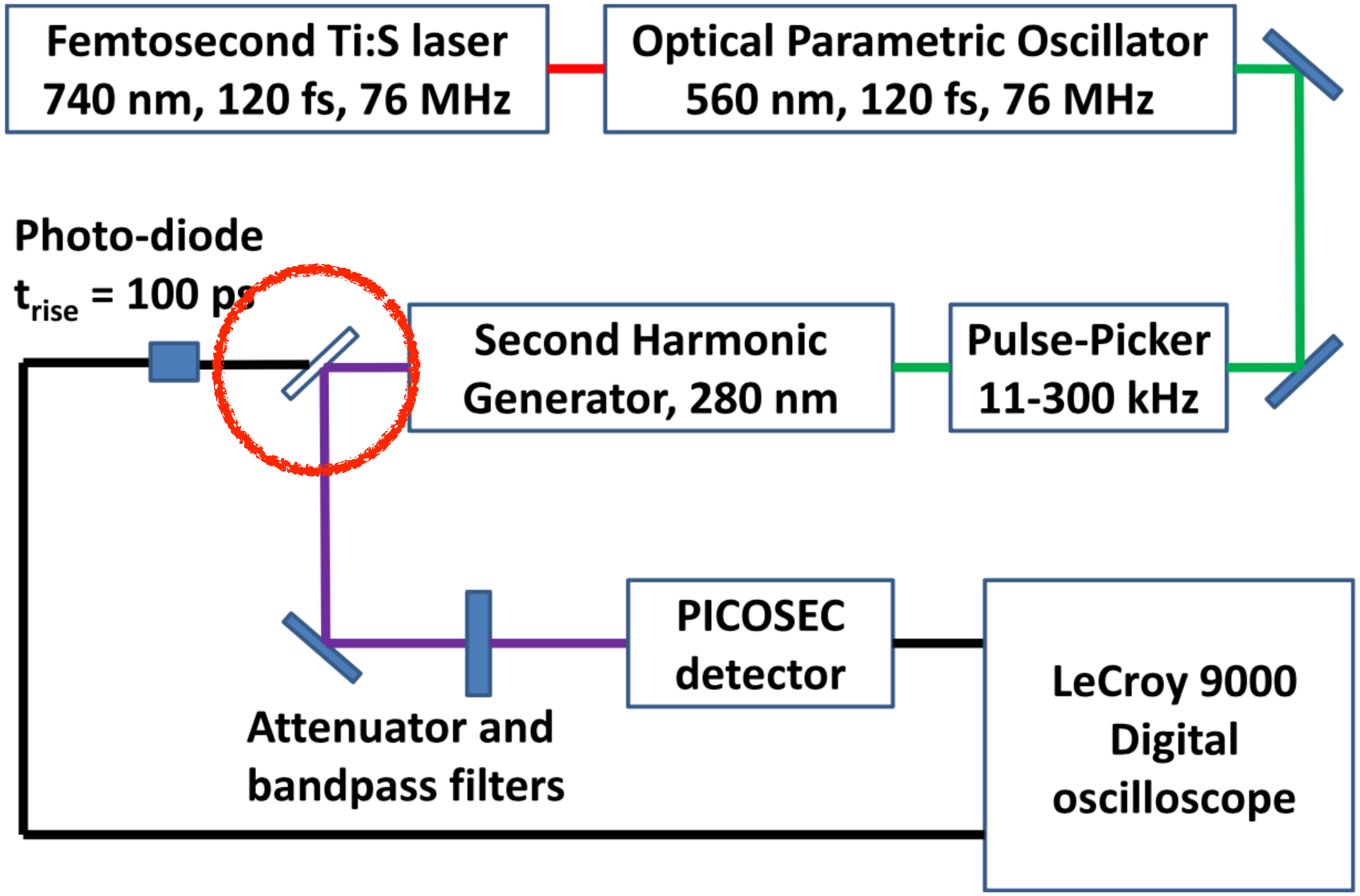

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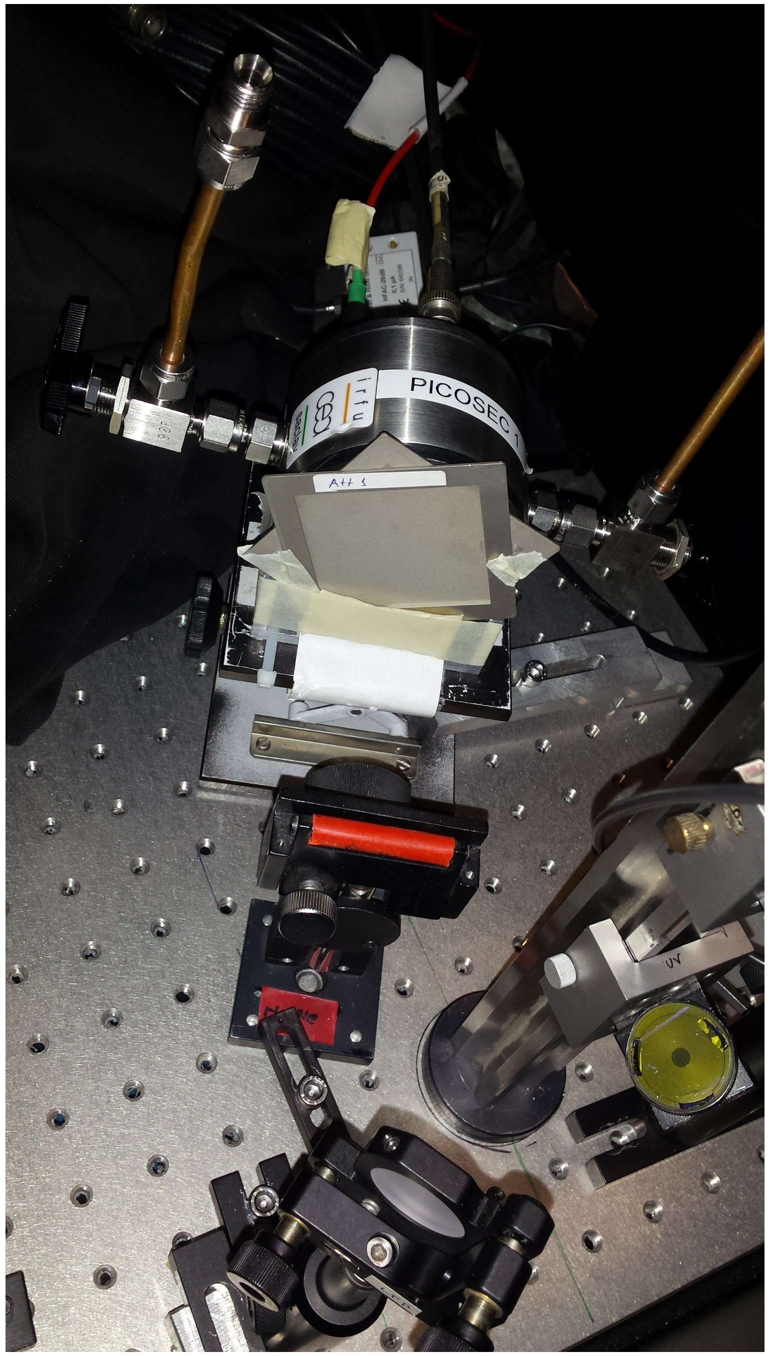

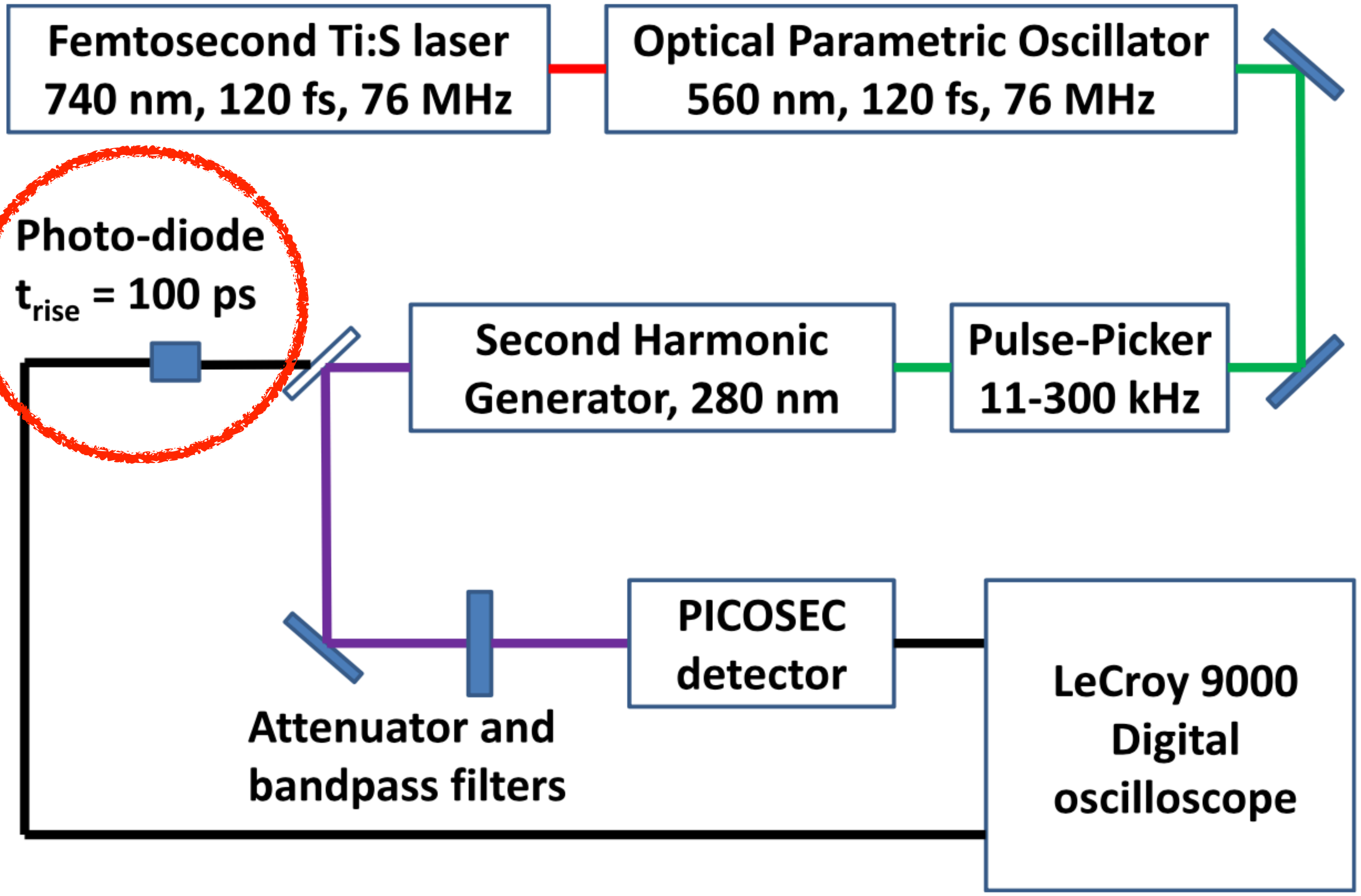

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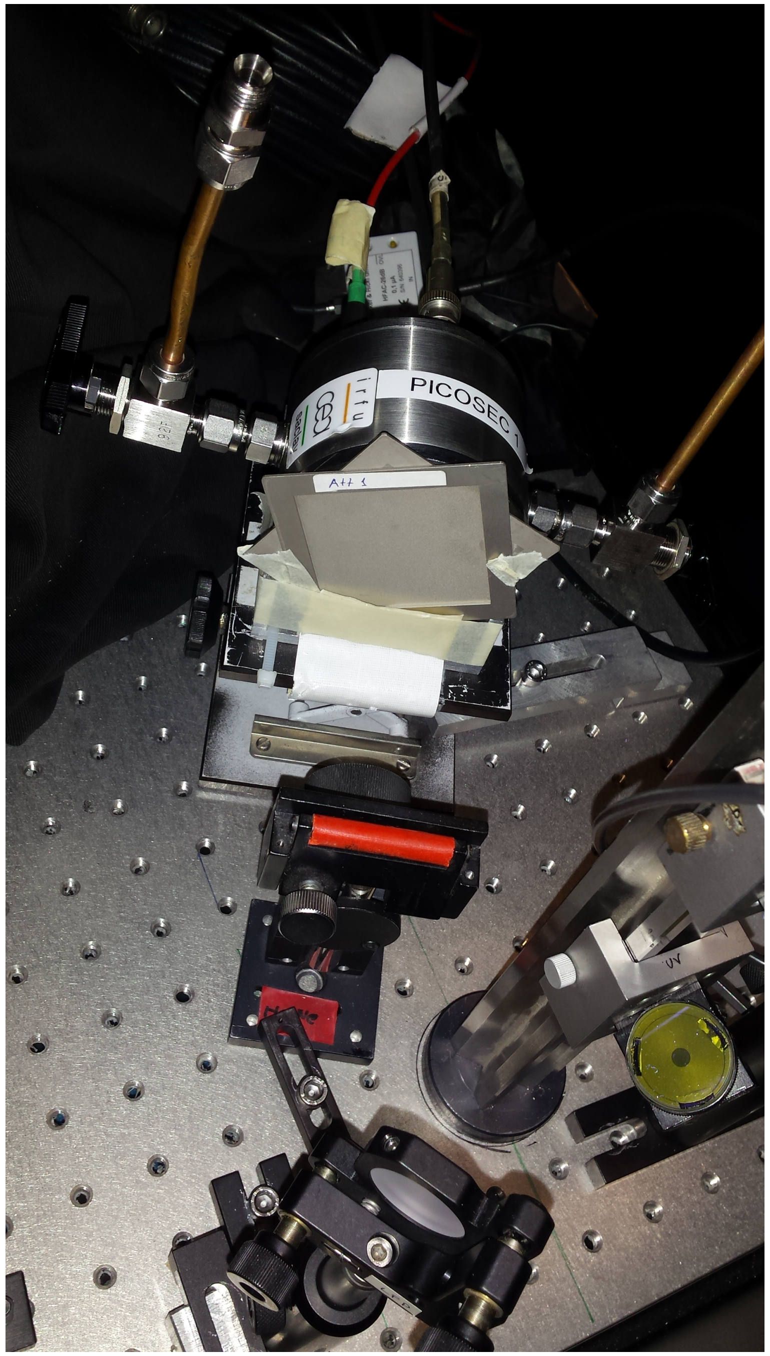

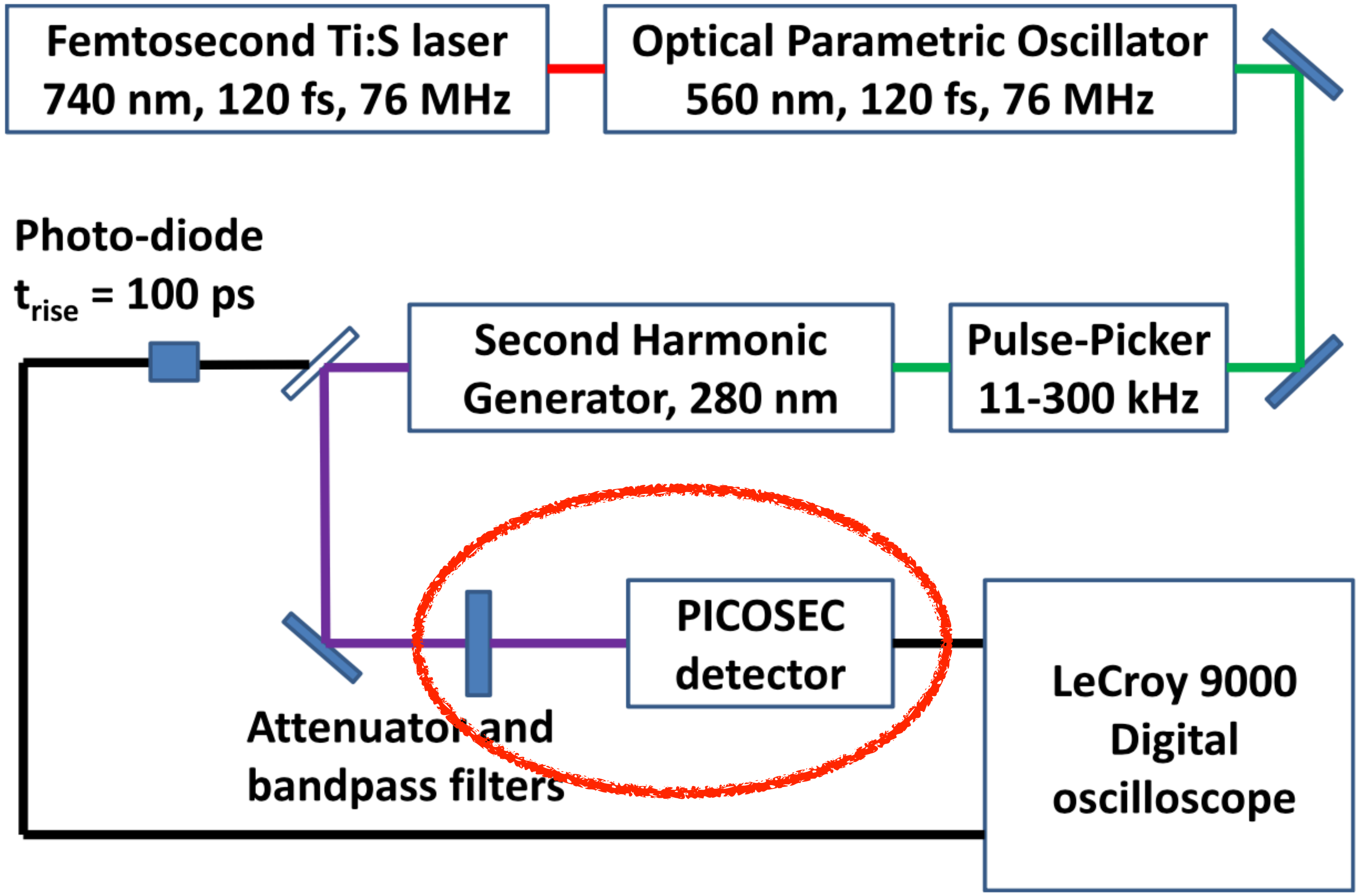

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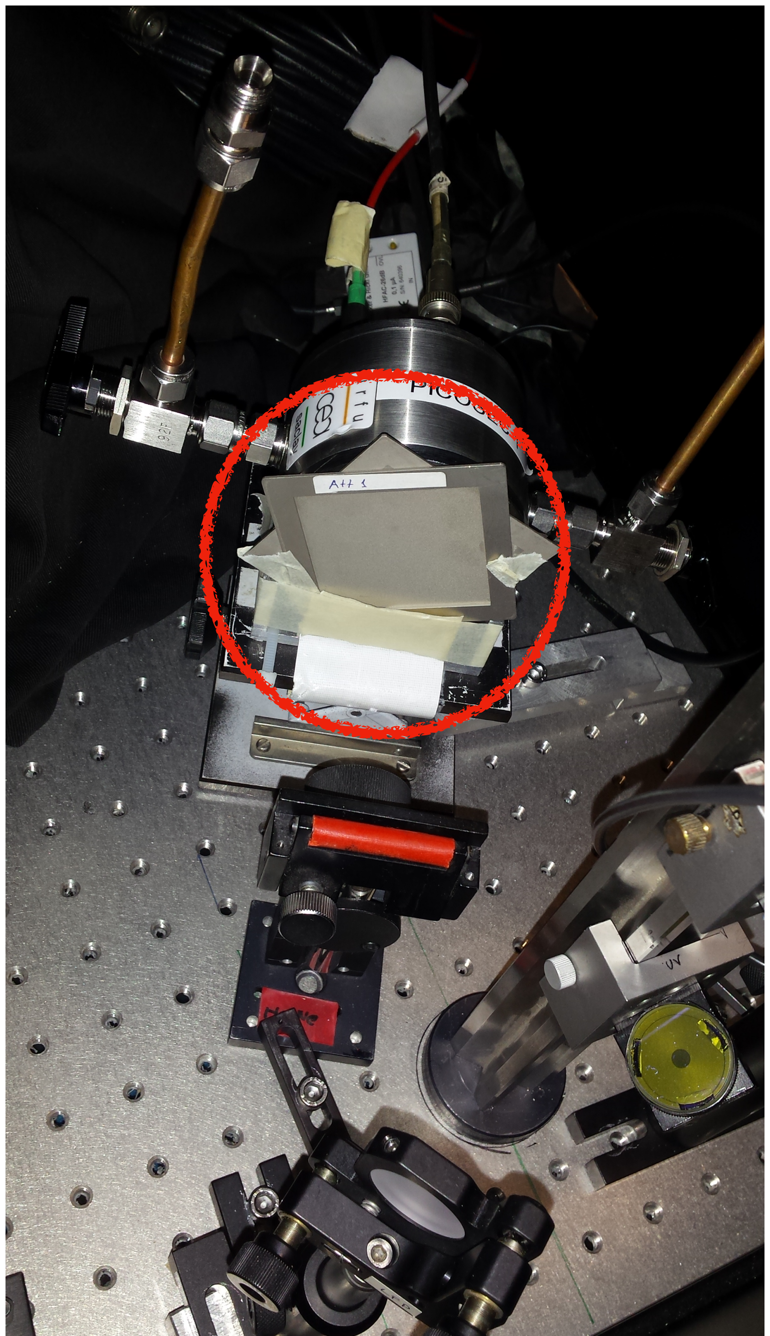
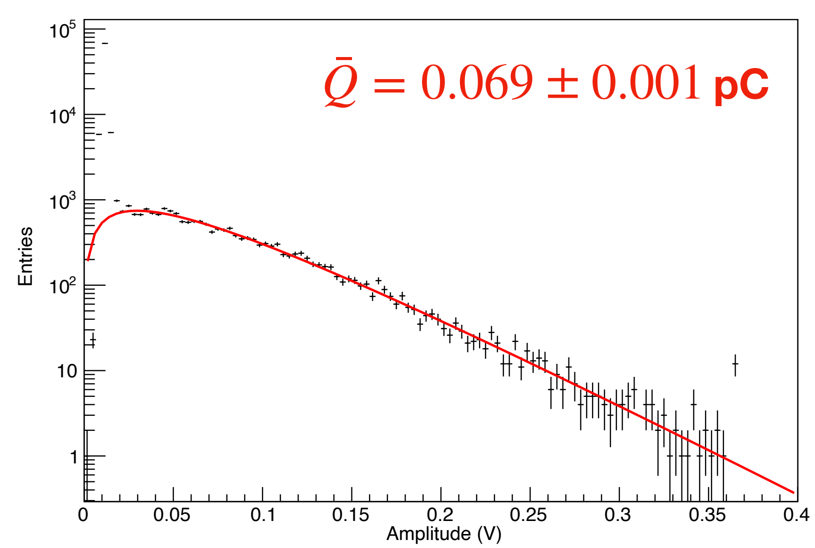
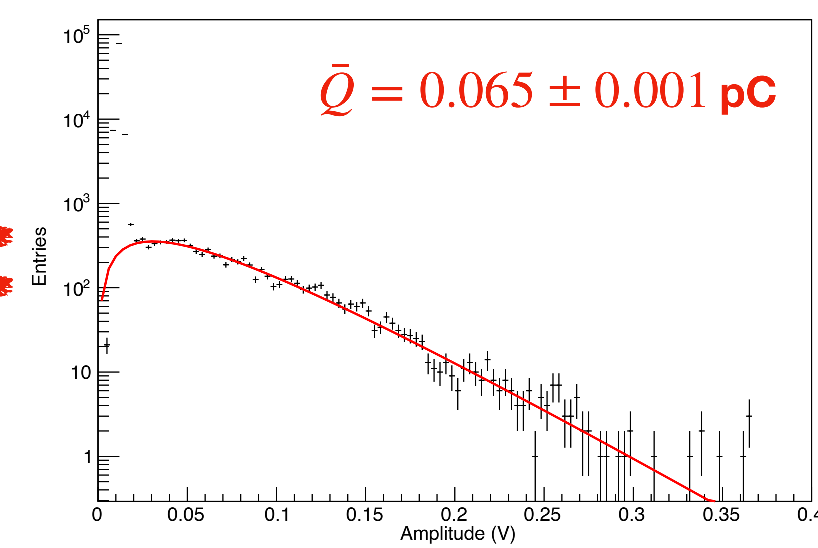
Light attenuation for 1 p.e. measurements with attenuators

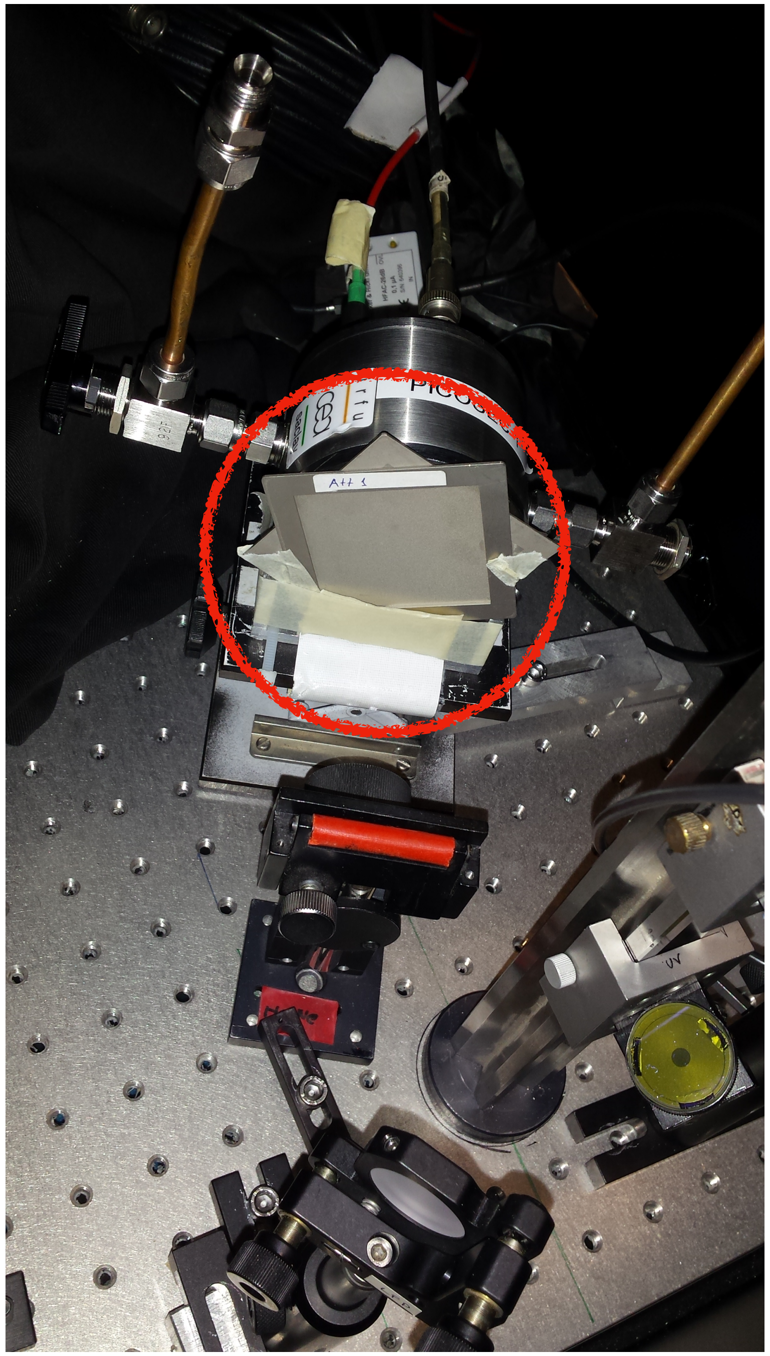


- Mean signal size is determined by a Polya fit
- 1 p.e. condition: additional attenuators are not changing the mean signal size

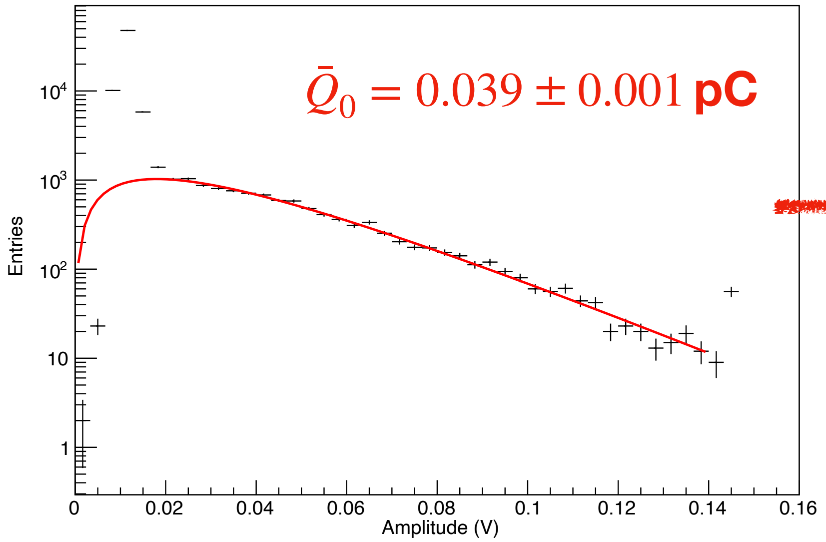


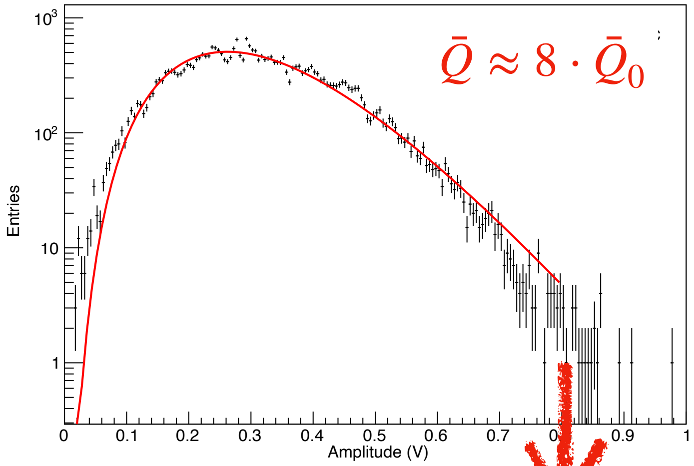


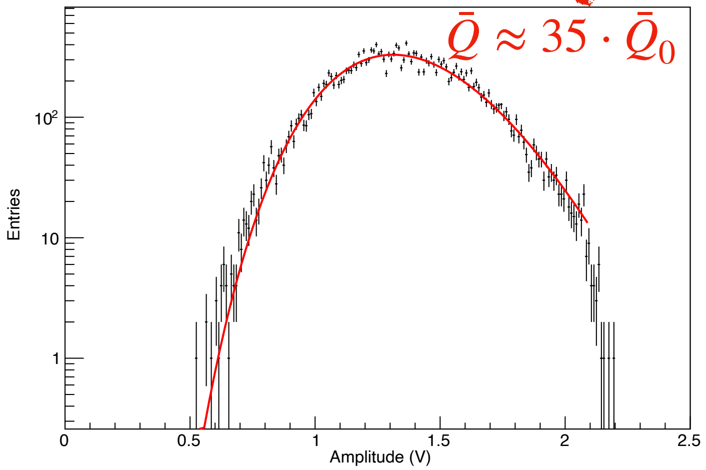
Removing attenuators for n p.e.



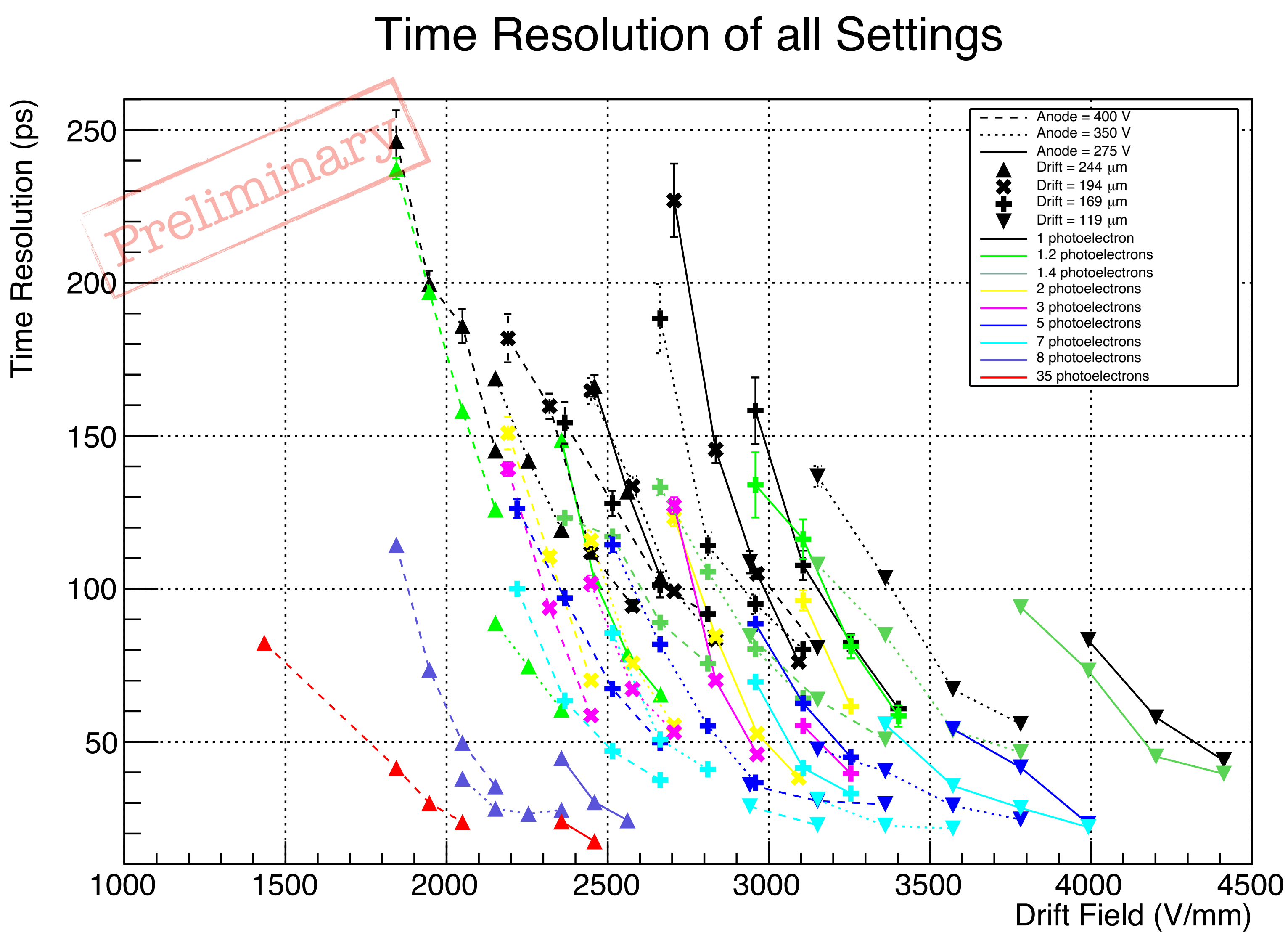
- Mean signal size is determined by a Polya fit
- 1 p.e. condition: additional attenuators are not changing the mean signal size
- Multi p.e. conditions: removing one attenuator after an other resulting in higher mean signal size







Time resolution improves with drift distance and number of p.e.



- Drift field scan performed for several drift distance and p.e. settings

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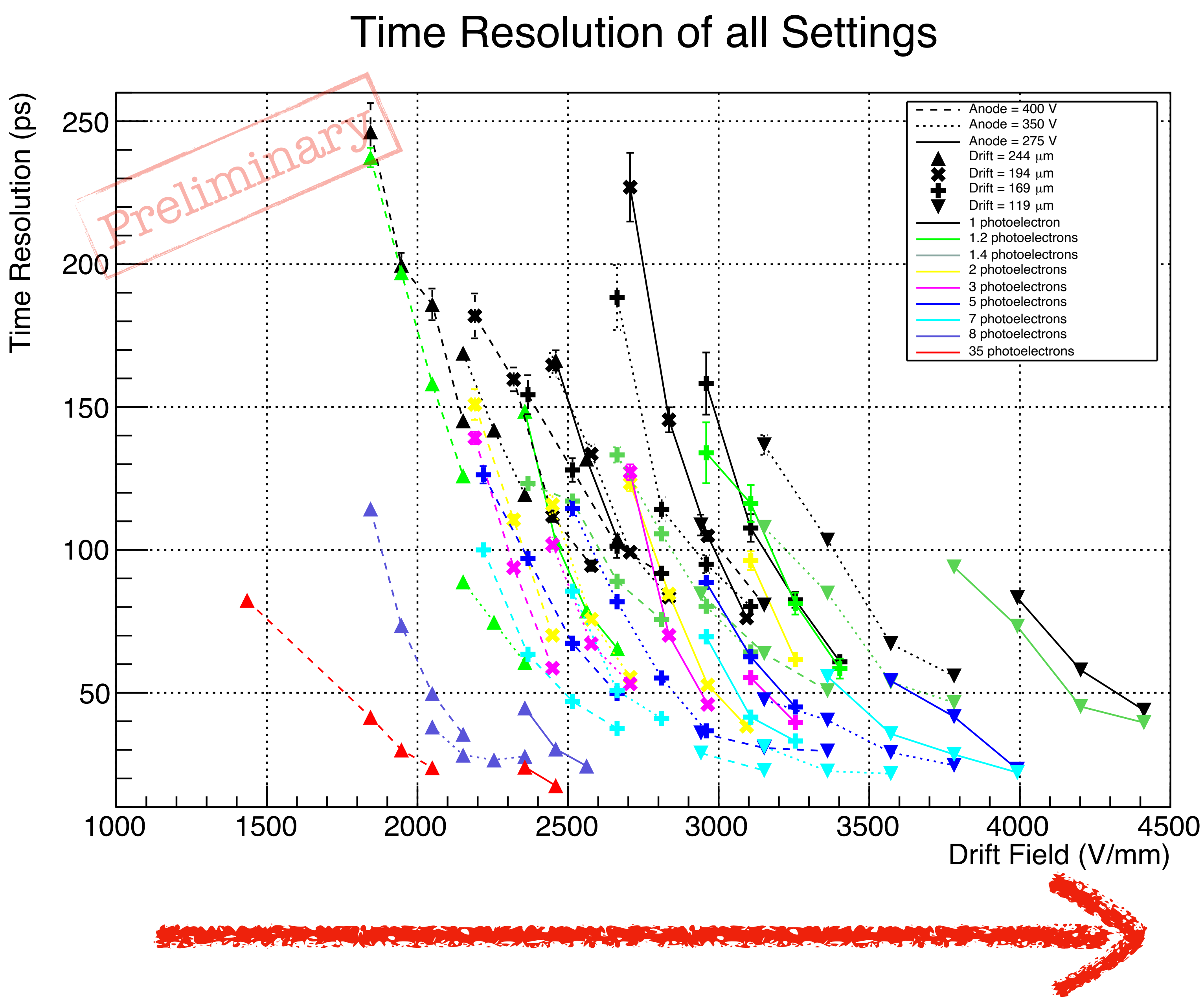

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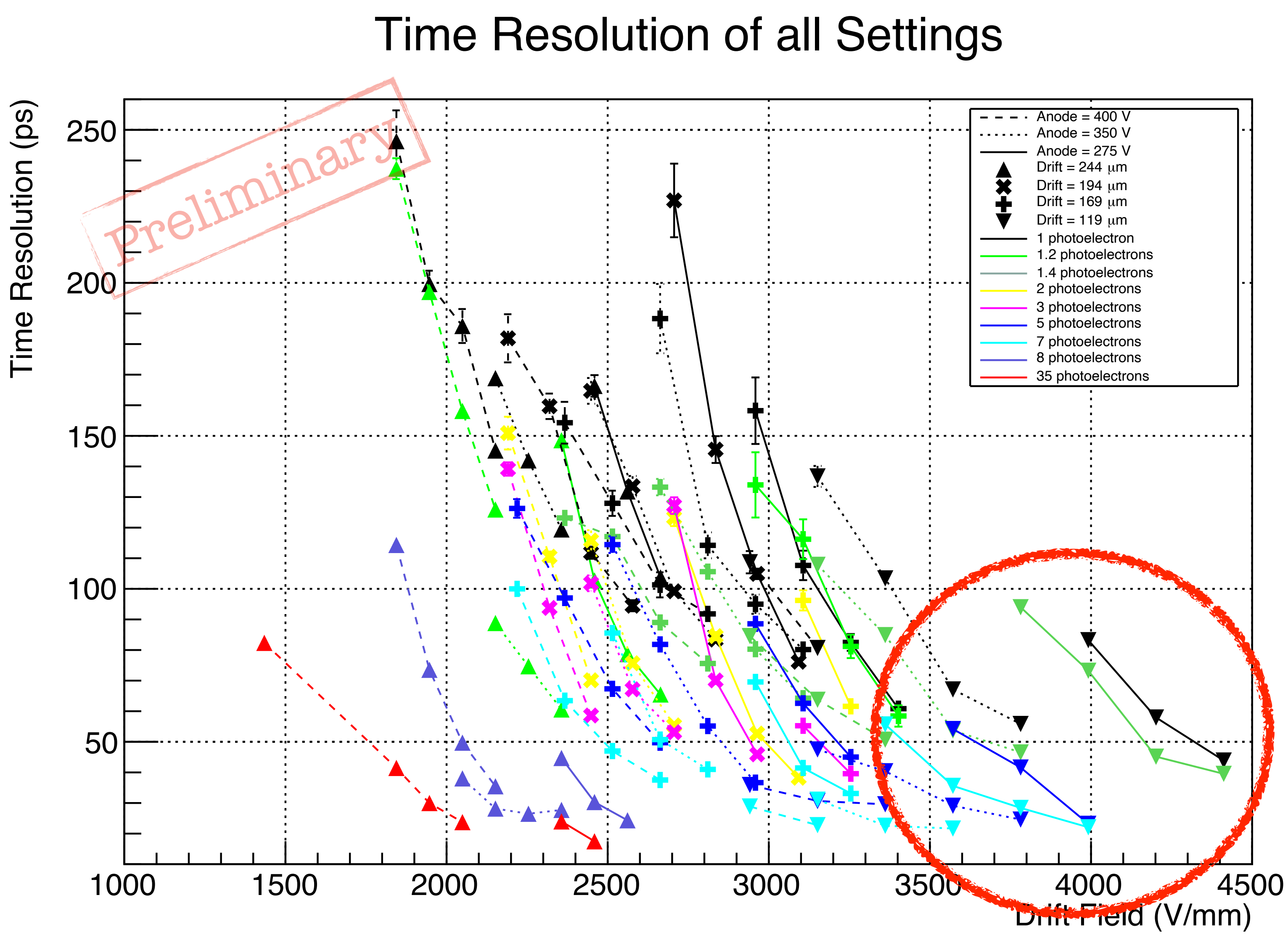

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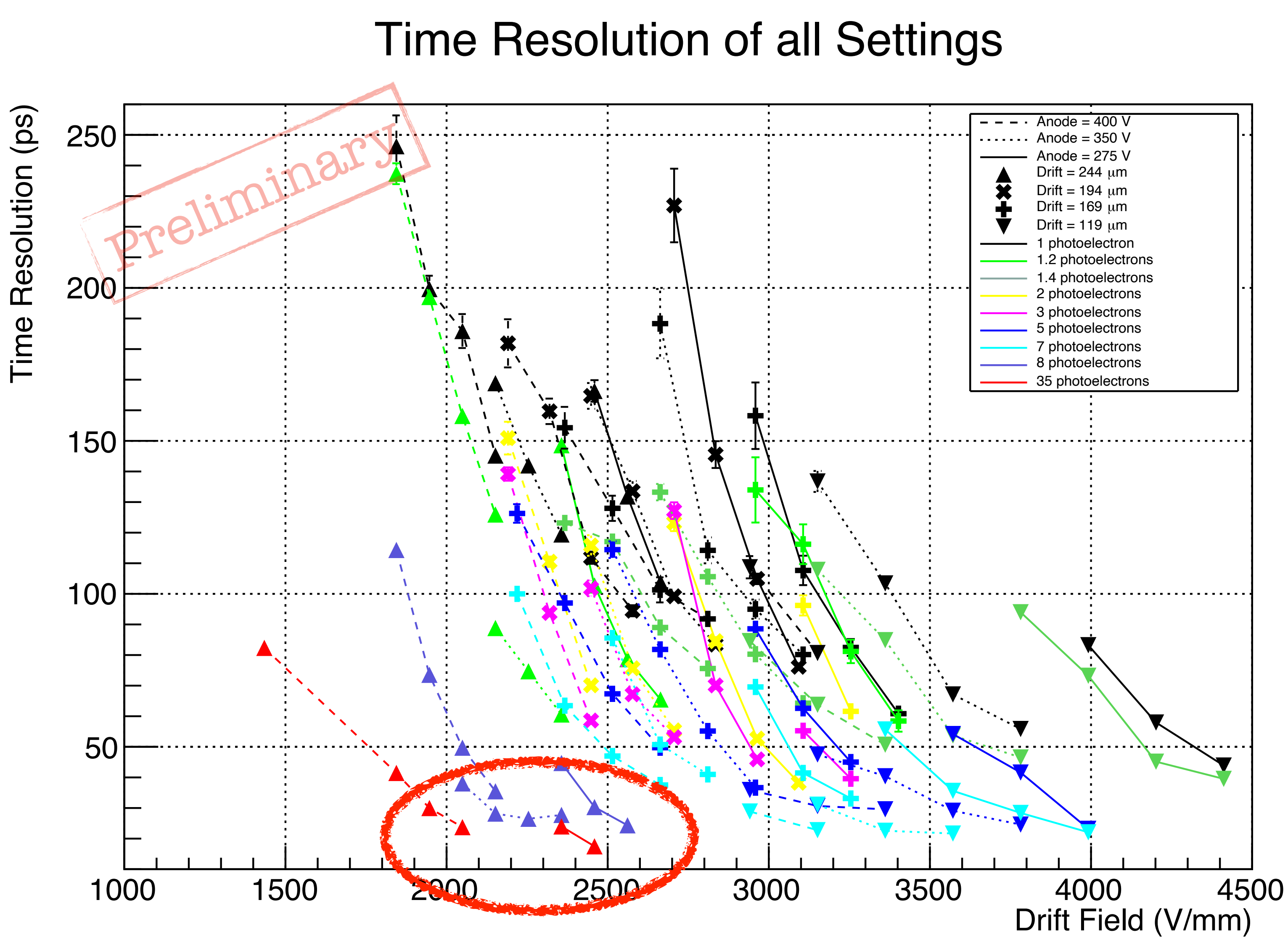

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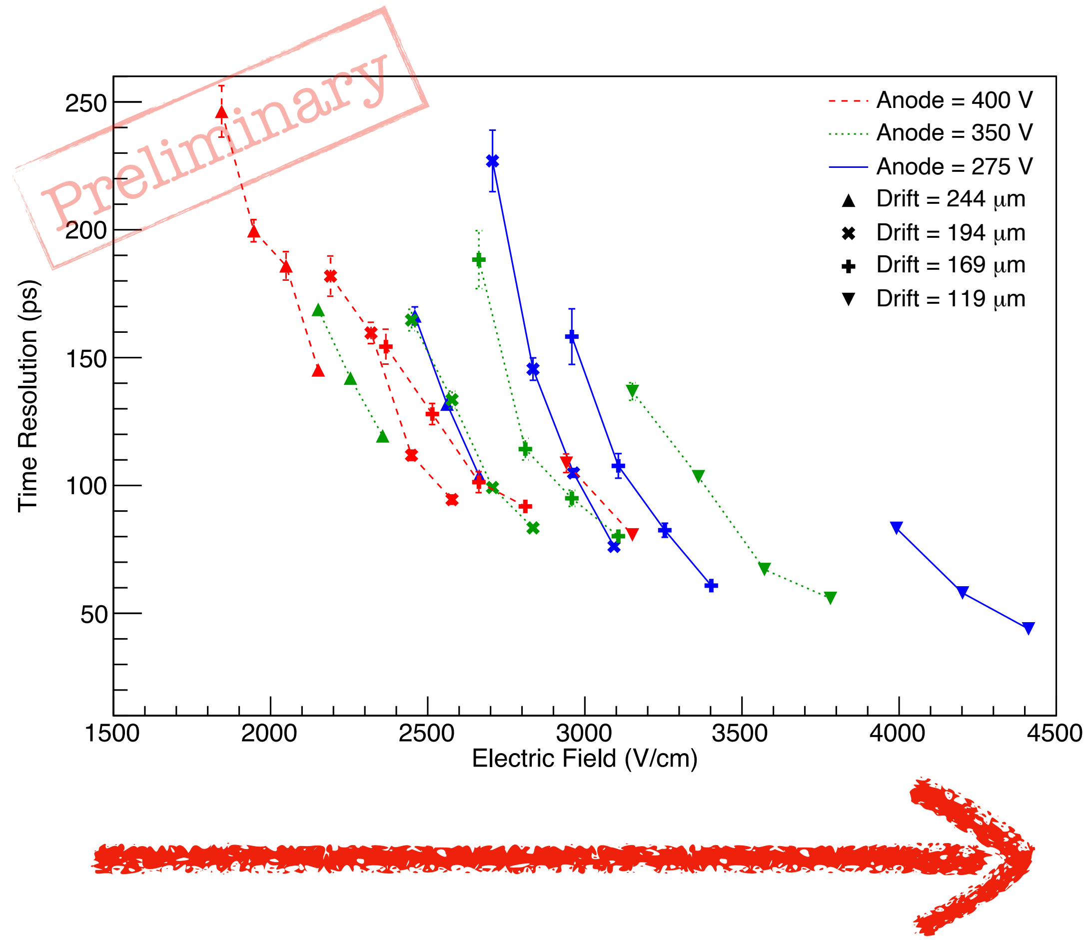
- Smaller drift gaps allow higher electric fields
- Time Resolution up to ~18 ps for many p.e.

Time resolution improves with higher field in a shorter drift gap

1 p.e.; Anode: 128 μm



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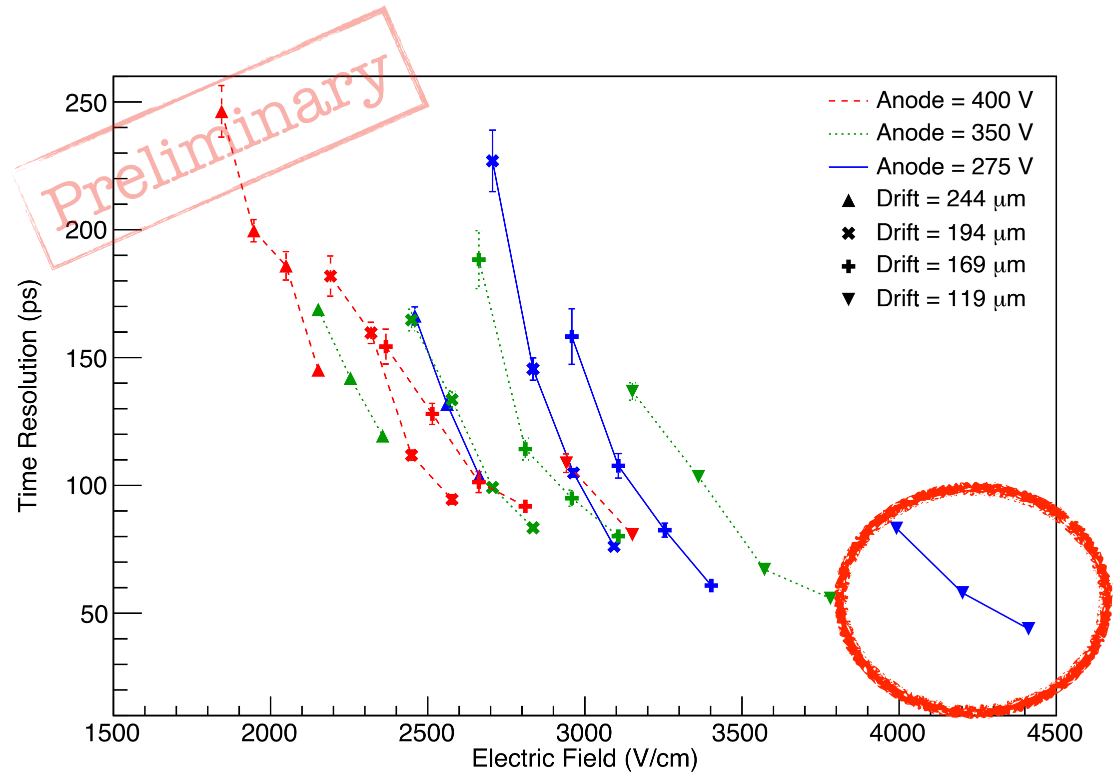

- Time resolution improves with electric field
- Time resolution < 50 ps at 1 p.e. is possible with preamplification larger than amplification

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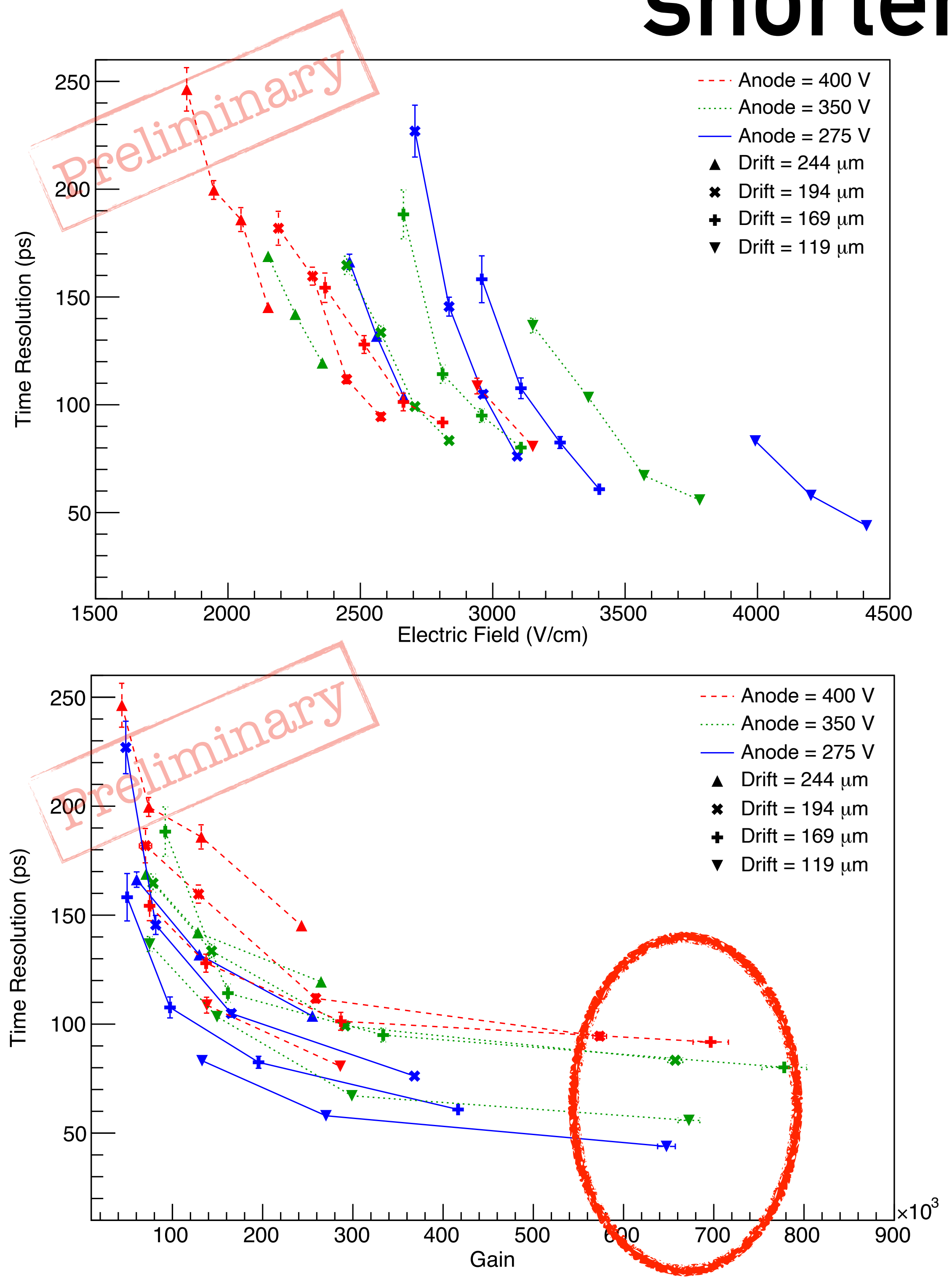

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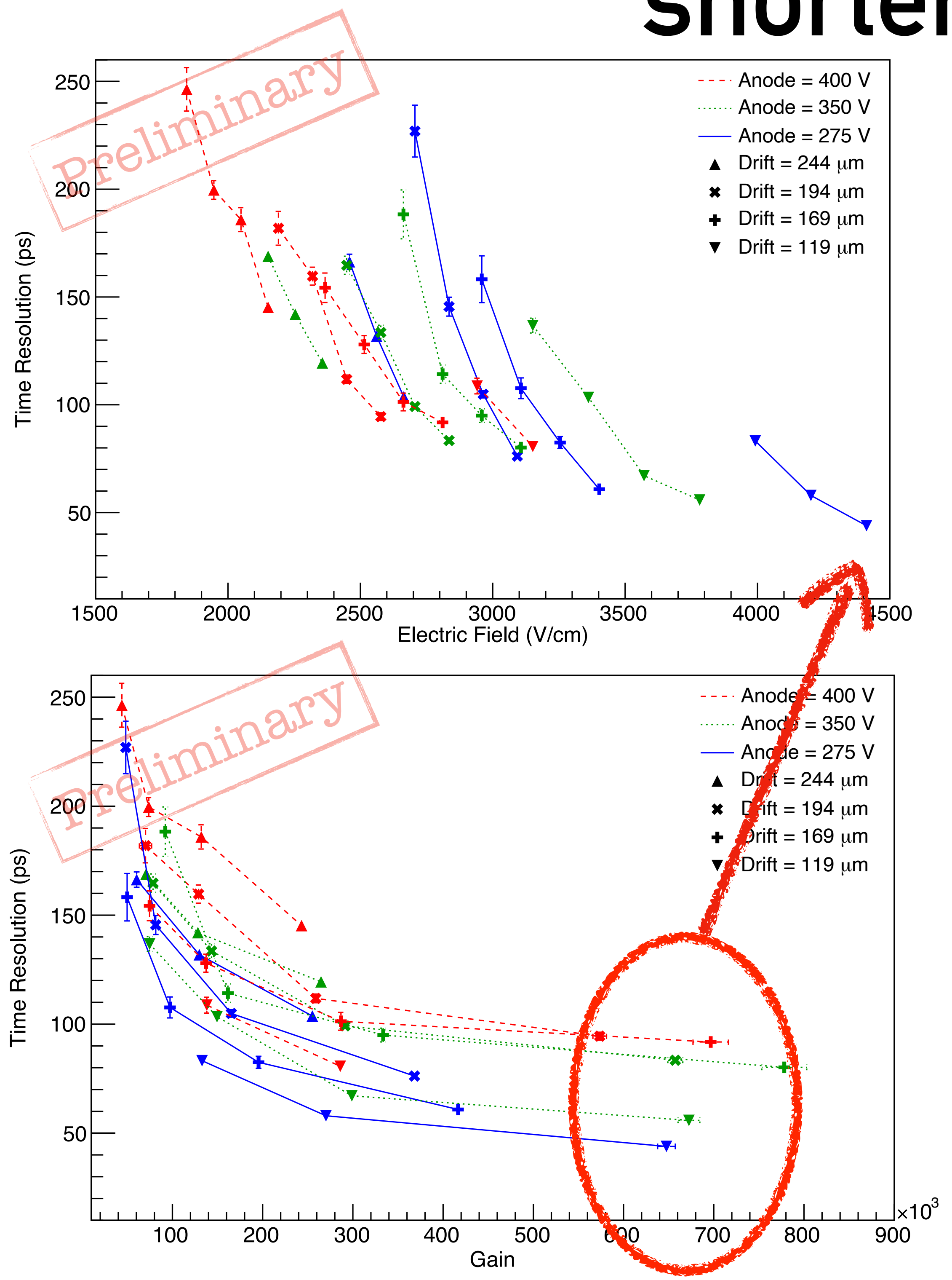

1 p.e.; Anode: 128 μm

- Time resolution improves with electric field
- Time resolution < 50 ps at 1 p.e. is possible with preamplification larger than amplification
- Smaller drift gap has better performance at same gain
  - Shorter drift time of the first electron before starting an avalanche gives a better time resolution

Gas mixture measurements in the Lab

- Up to now all measurements done with „COMPASS gas mixture“
  - 80 % Neon : 10 % Ethan : 10 % CF_4
- Understand impact of the gas mixture on PICOSEC-Micromegas

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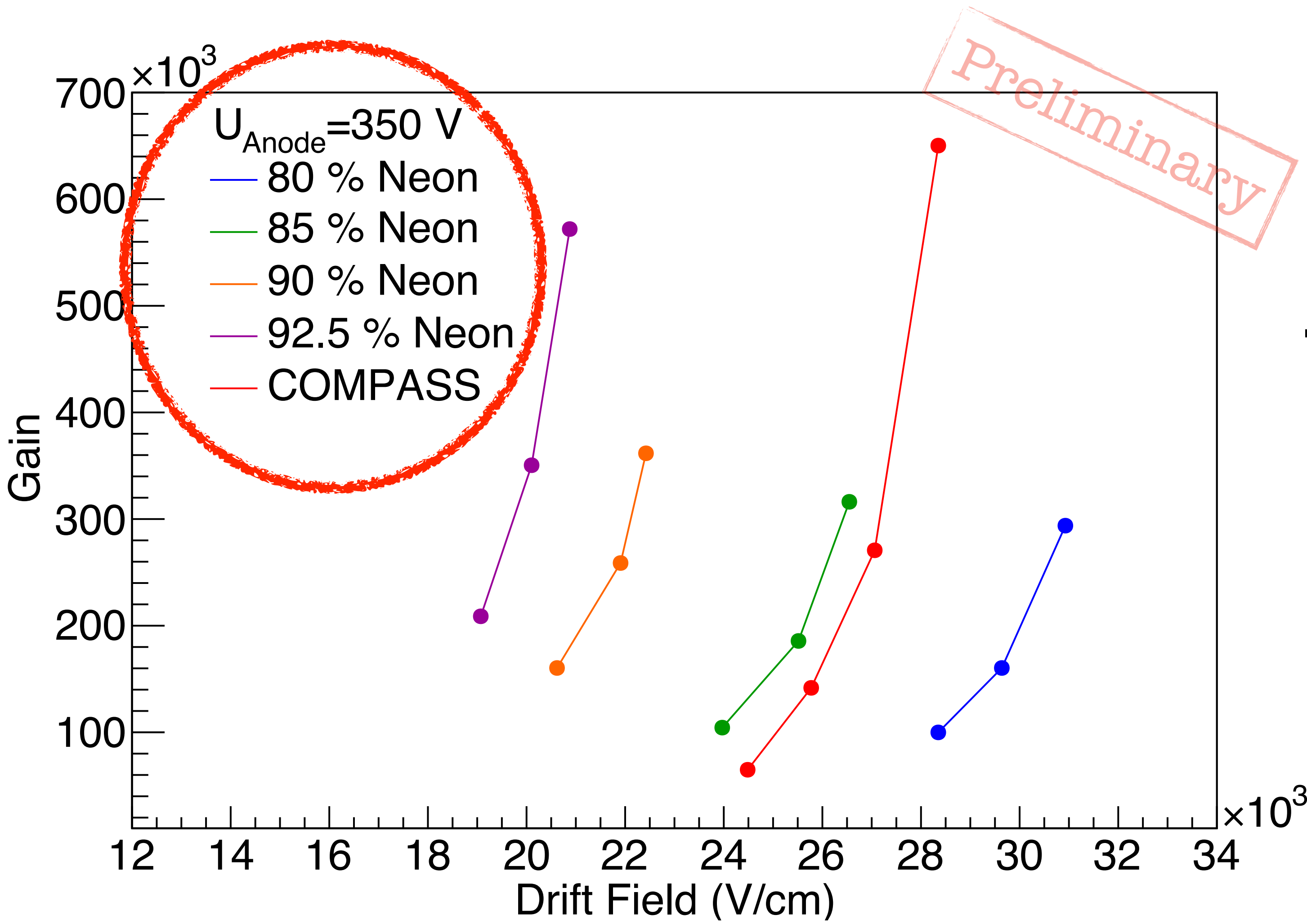
  - Longitudinal diffusion may not be limiting factor
  - Higher total gain may improve the resolution
  - Similar gain at lower field can give technical advantages
- Lab measurements of the gain under 1 p.e. conditions

Gain of different gas mixtures has been measured



- Neon - Ethan mixtures with different ratios are tested

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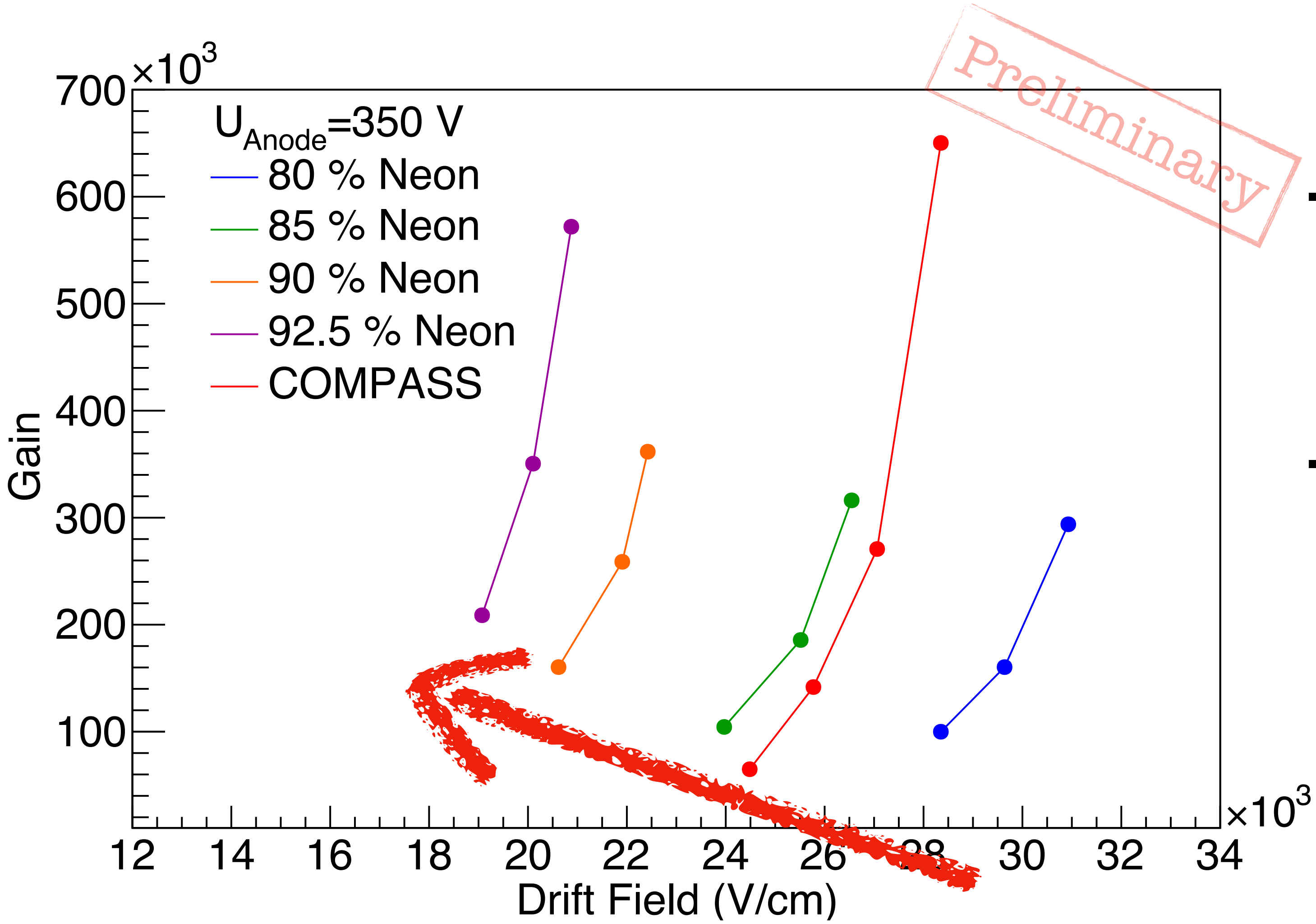

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- High Neon percentage gives higher gain at lower field

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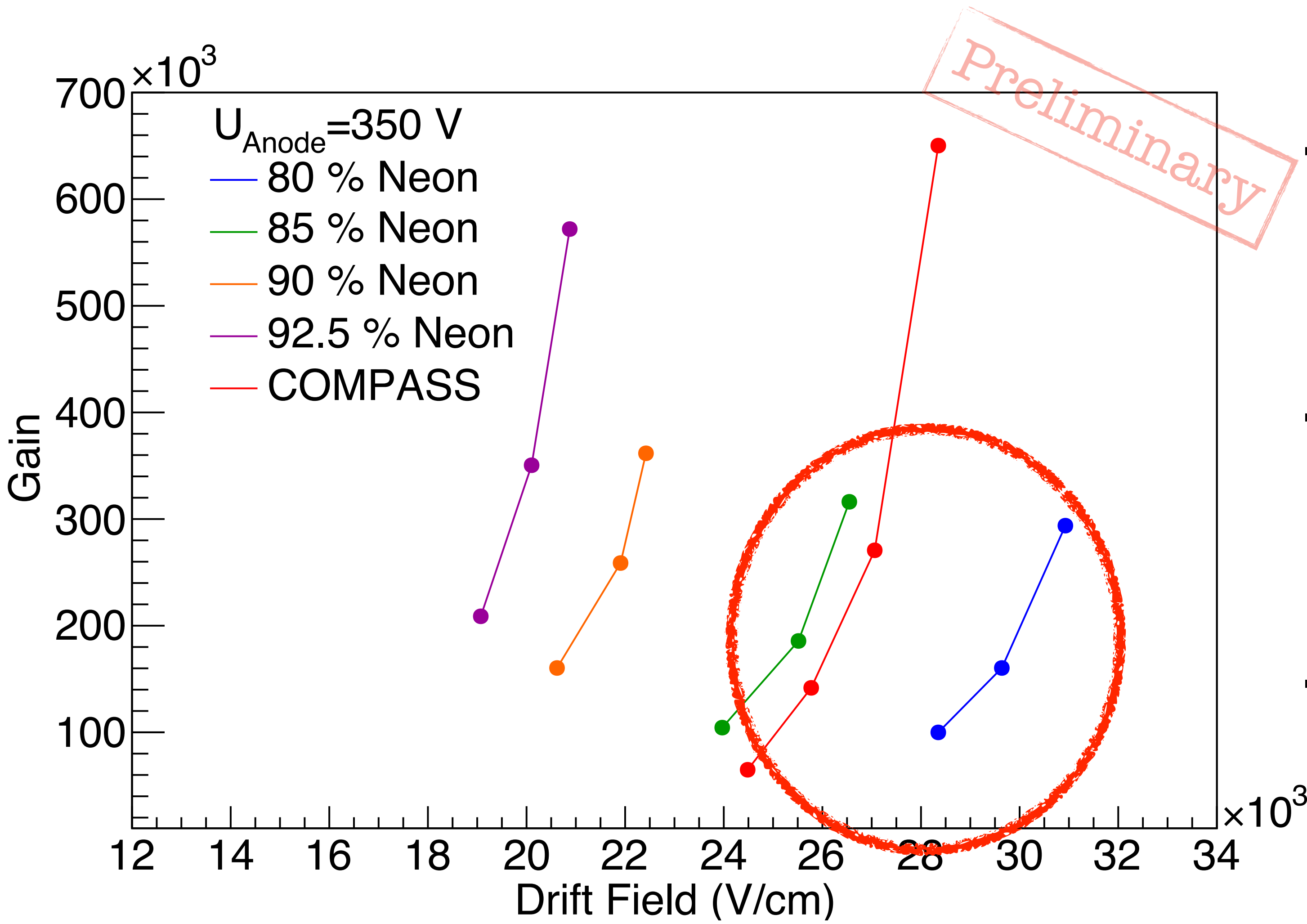
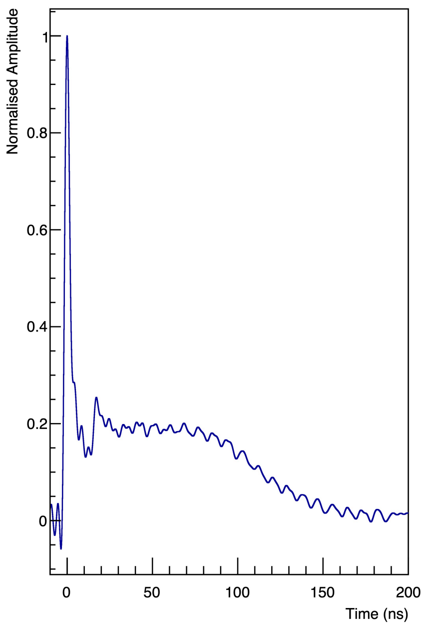
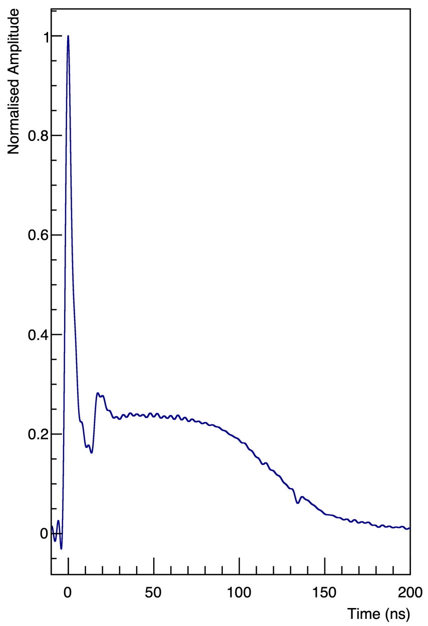


- Neon - Ethan mixtures with different ratios are tested
- High Neon percentage gives higher gain at lower field
- CF_4 improves the gain compared to pure Ethan

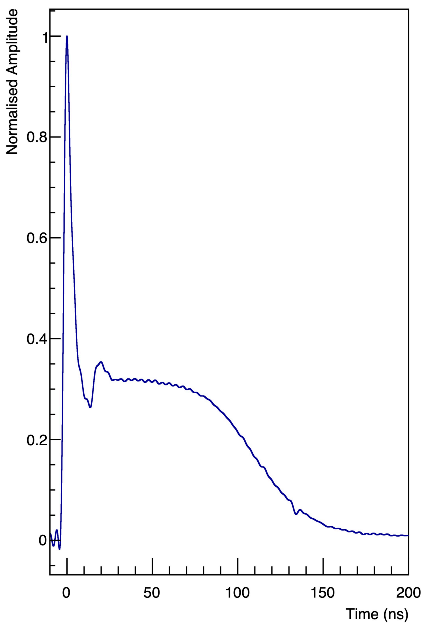
COMPASS GAS
A:350V D:500V



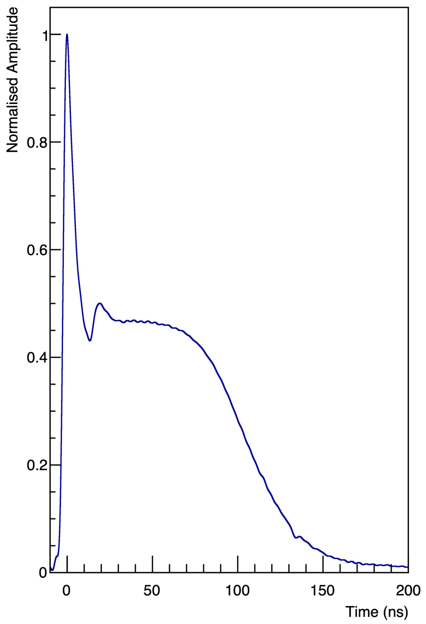
Ne 80%
A:350V D:575V



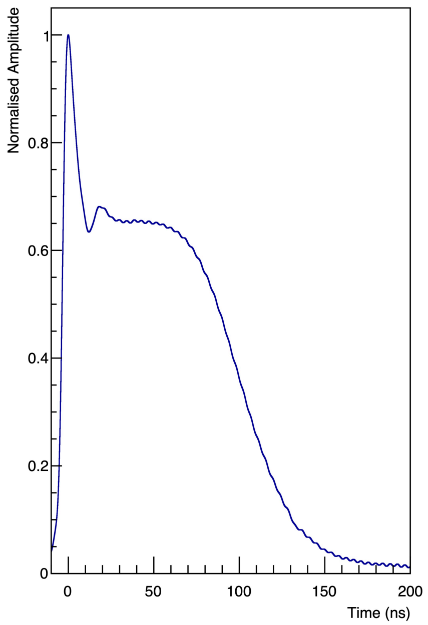
Ne 85%
A:350V D:495V



Ne 90%
A:350V D:425V

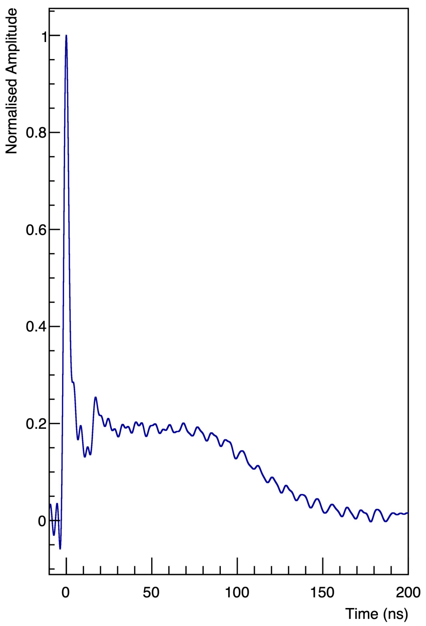


Ne 92.5%
A:350V D:390V



COMPASS GAS

A:350V D:500V



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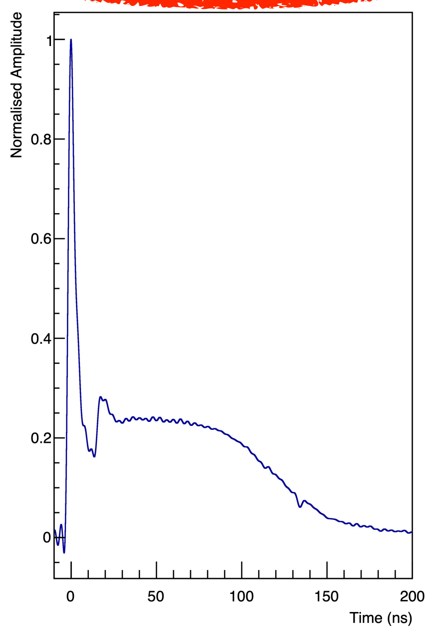
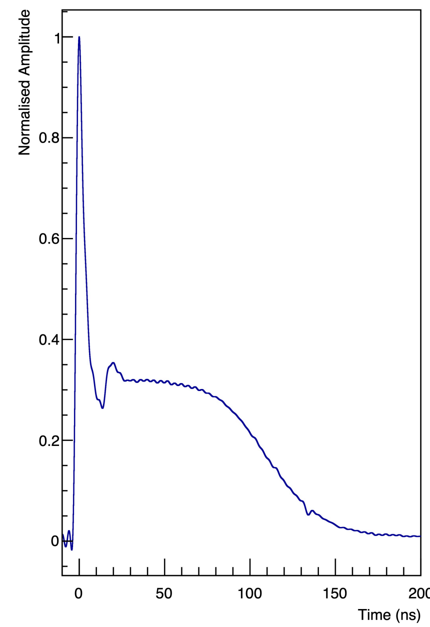
A:350V D:575V



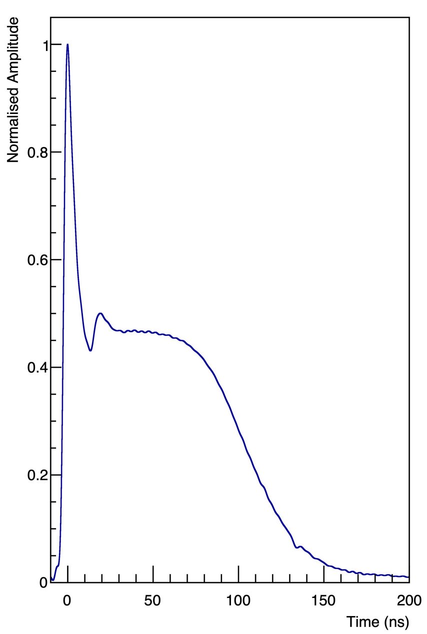
Ne 85%

A:350V D:495V



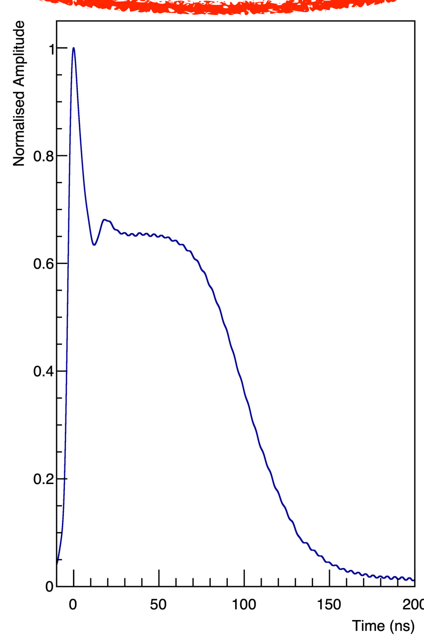
Ne 90%

A:350V D:425V



Ne 92.5%

A:350V D:390V



- Voltage settings are selected to provide the same mean amplitude at different gas mixtures
- Lower voltage are needed as more Neon provides a higher gain

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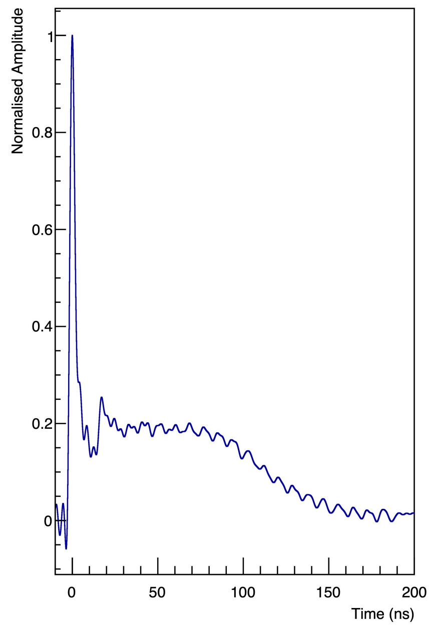

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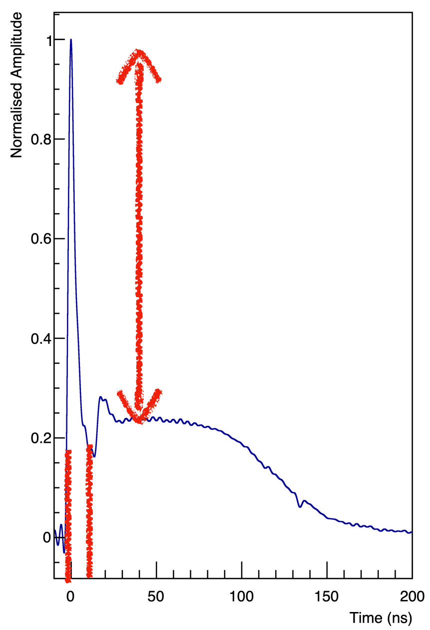
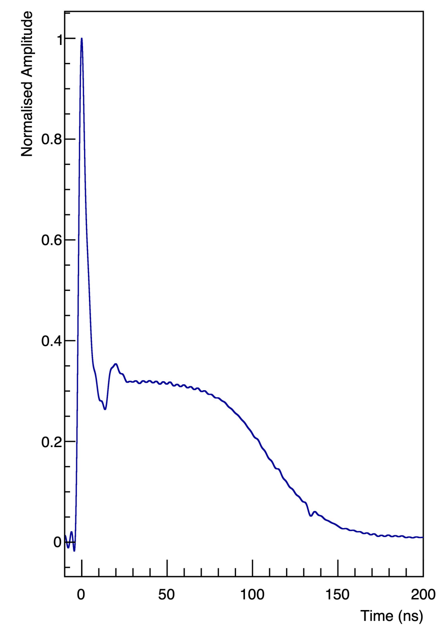
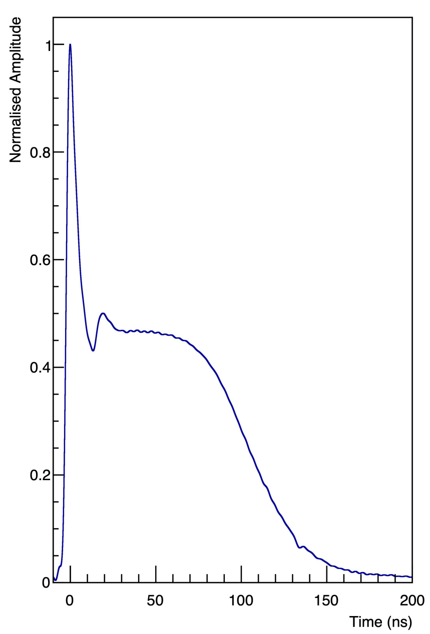


Ne 85%
A:350V D:495V



Ne 90%
A:350V D:425V



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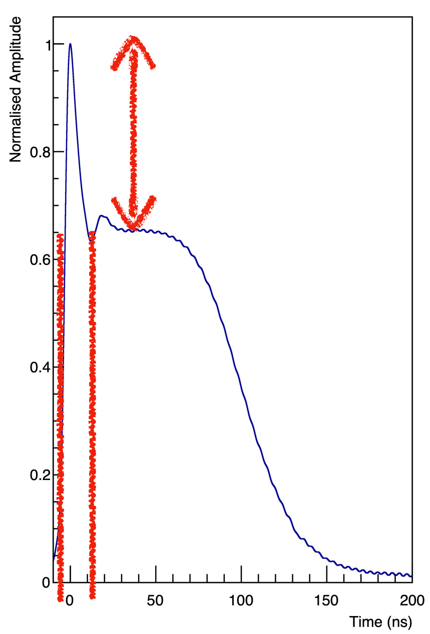
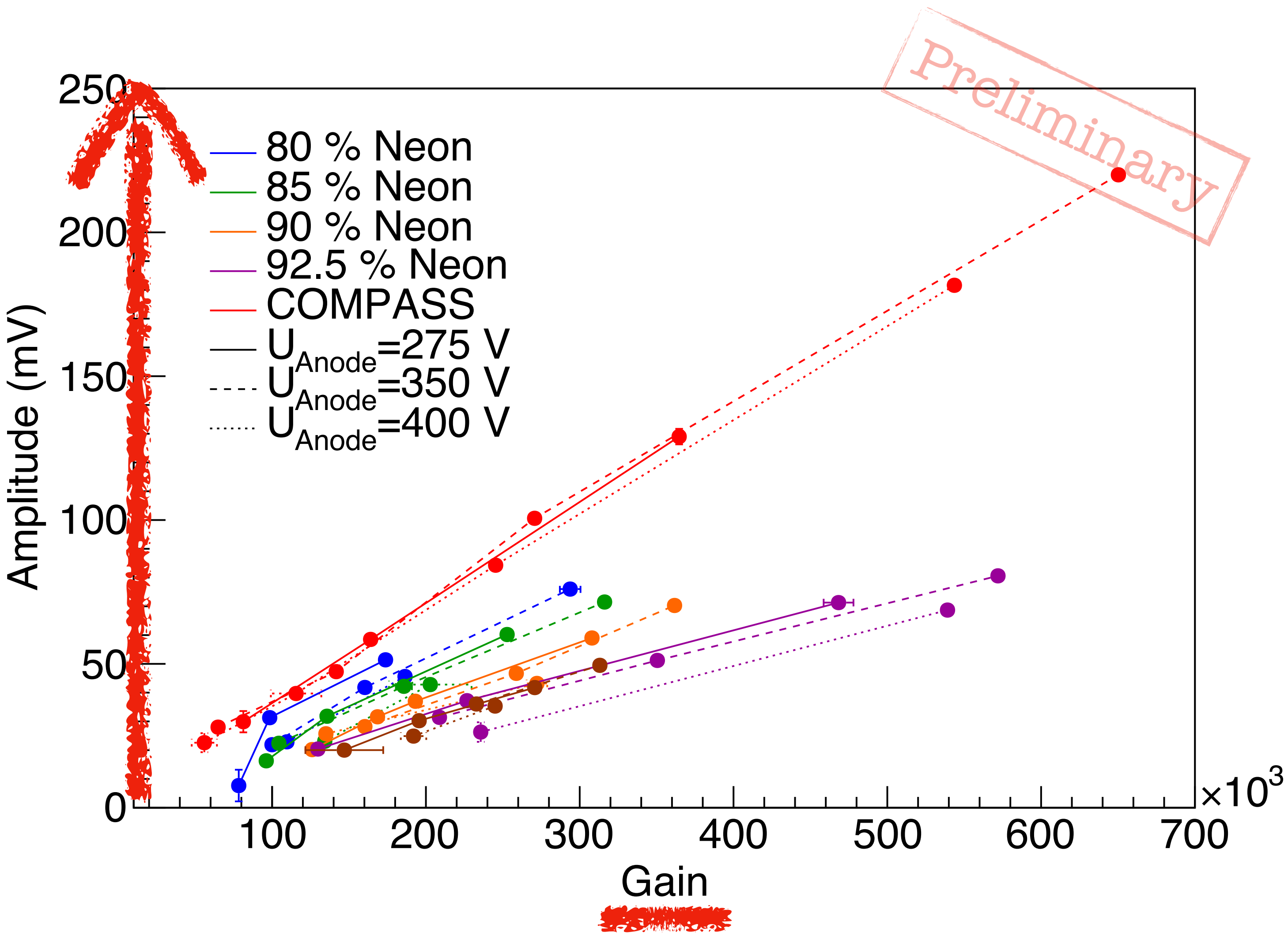
A:350V D:390V



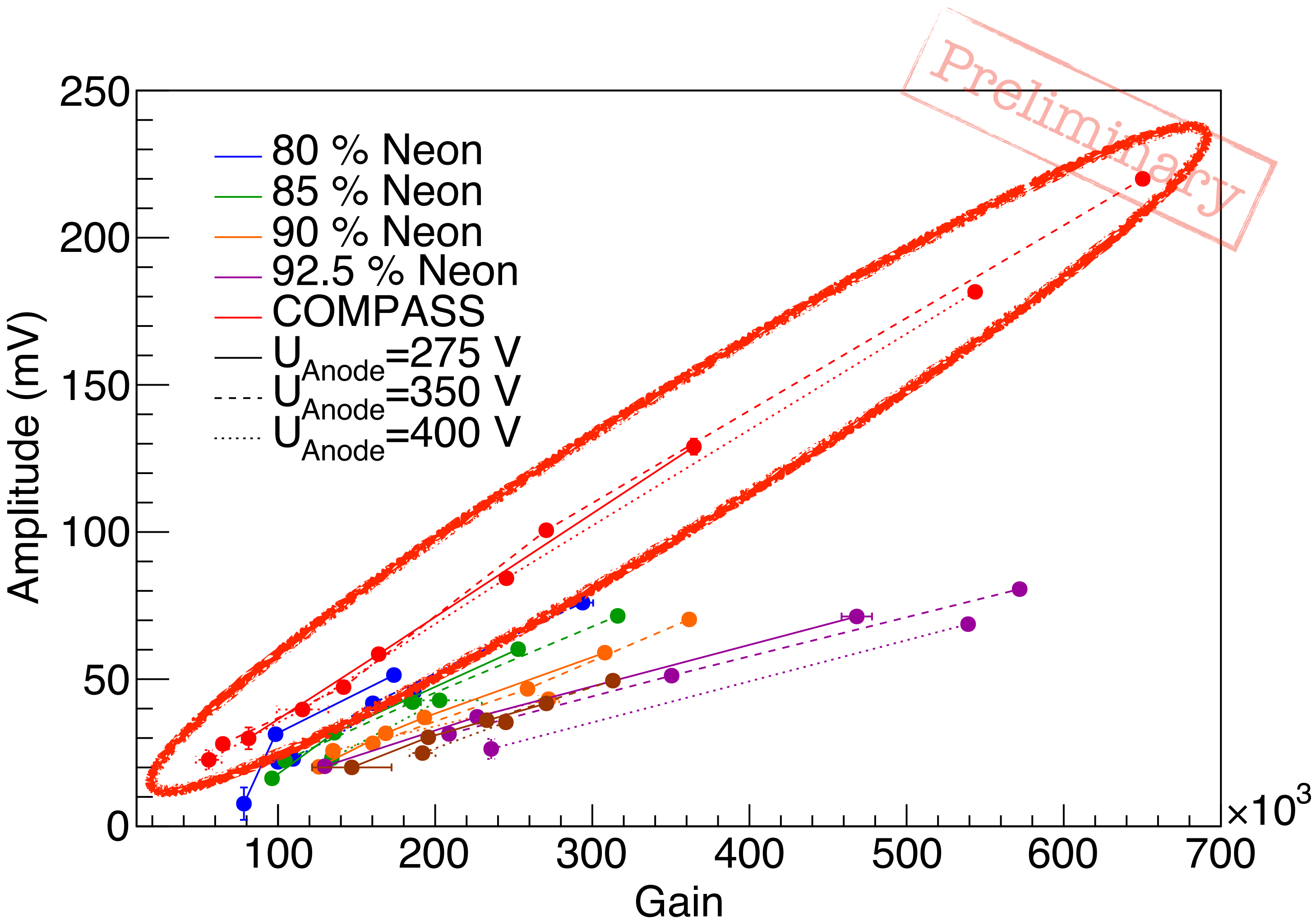
- Voltage settings are selected to provide the same mean amplitude at different gas mixtures
- Lower voltage are needed as more Neon provides a higher gain
- Ratio between electron peak amplitude and ion tail amplitude is rising at higher Neon mixture
  - Electron peak is widening

Amplitude vs. gain ratio gives hint about signal shape



- Sharper electron peaks have higher amplitude at the same signal charge

Amplitude vs. gain ratio gives hint about signal shape



- Sharper electron peaks have higher amplitude at the same signal charge
- COMPASS gas mixture signals are given steeper rising edges than the other mixtures
- Probably better time resolution
- To be verified in the Laser

What is next …

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- Further Laser measurements
  - Time performance test of different gas mixtures and pressures

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  - ASSET chamber at CERN
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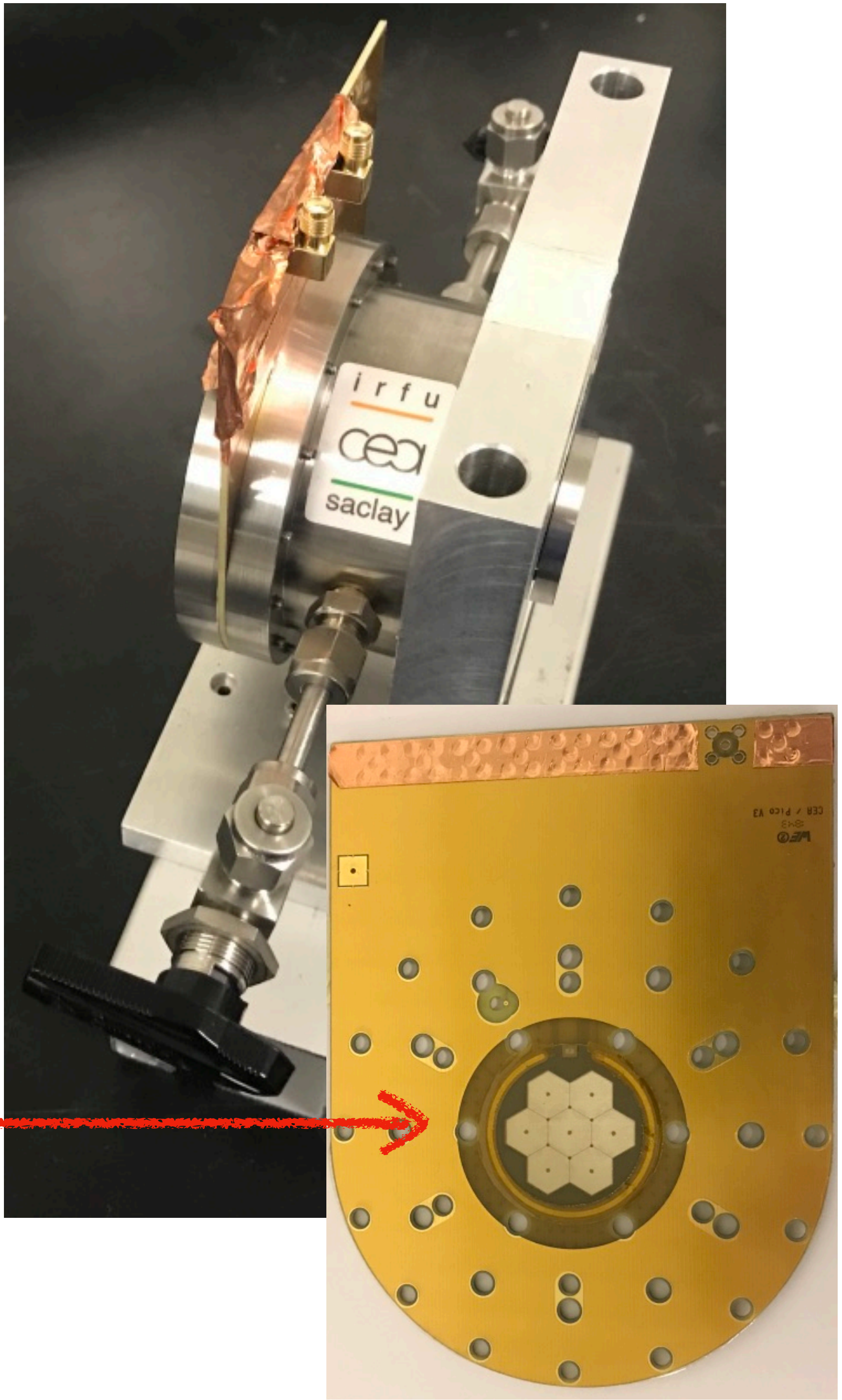

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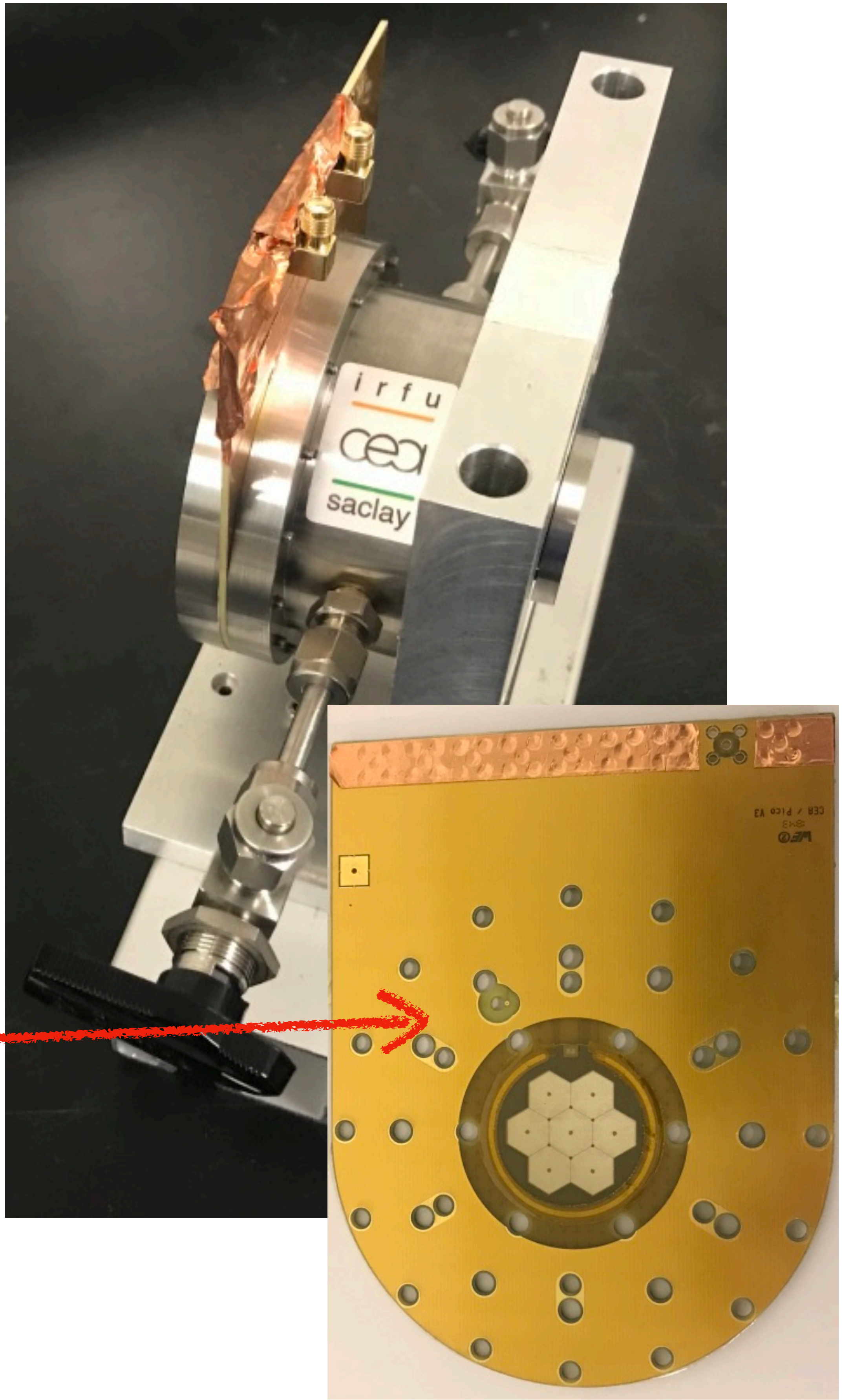
    - Irradiation and Q.E. measurements at USTC
    - ASSET chamber at CERN
    - Cosmic bench at CEA
- Development of a resistive multipad Picosec chamber
- Detailed simulation and modelling at AUTH
- (Embedded) electronics for segmented readout



PICOSEC

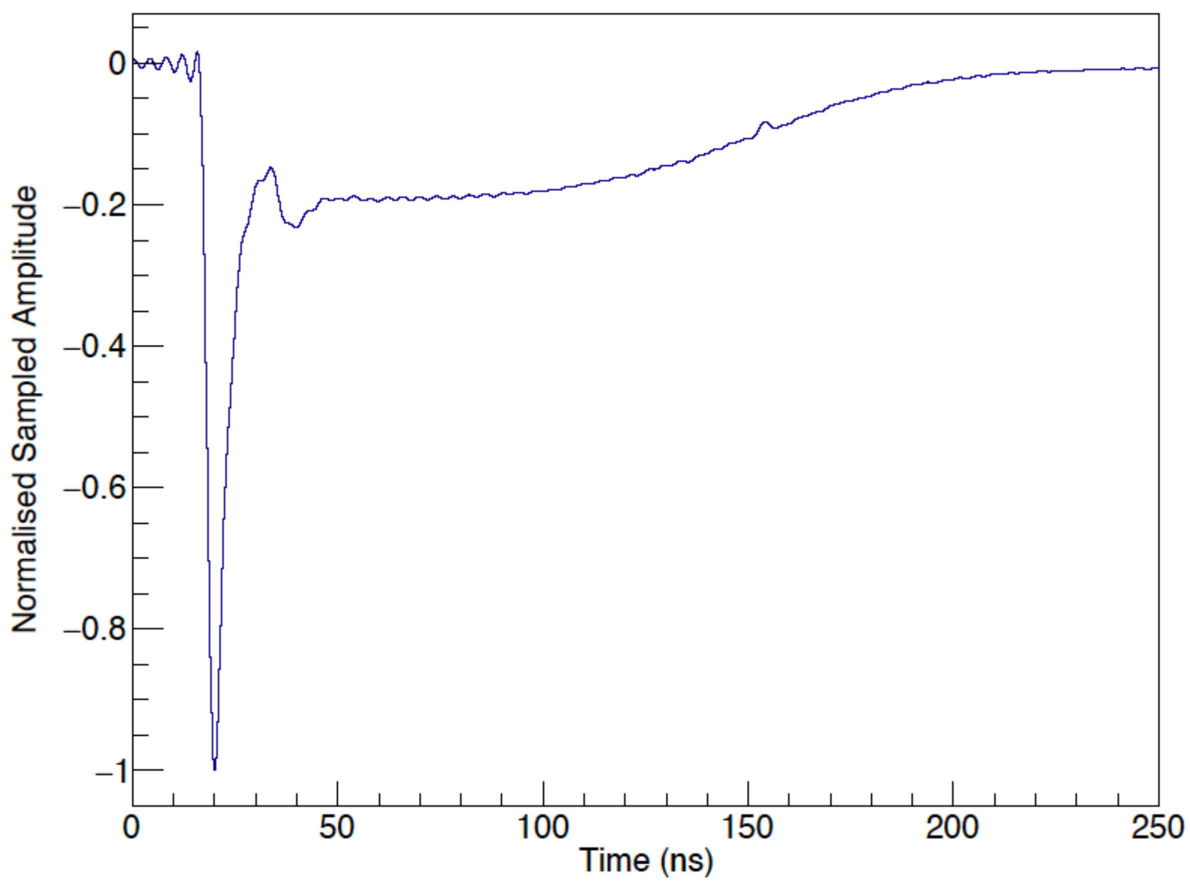
Micromegas

Backup

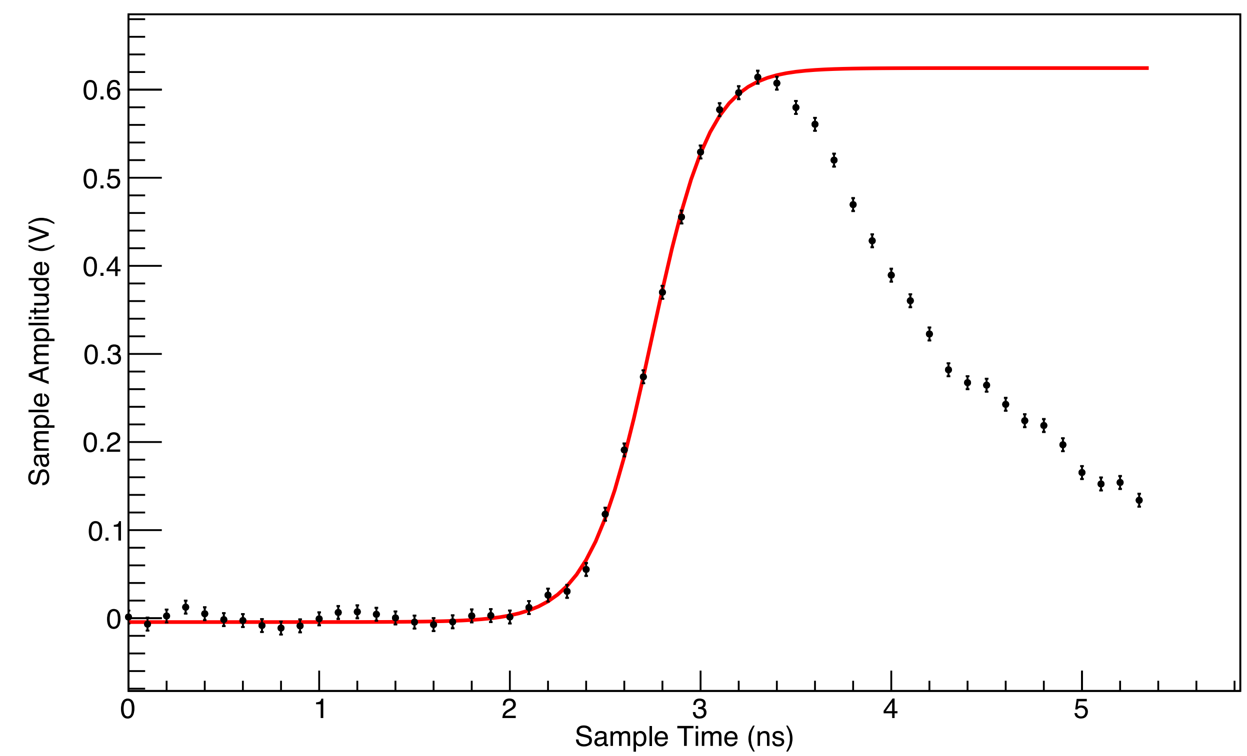
Calculating the Time Resolution

1. Sigmoid fit of the rising edge

Digitised PICOSEC-Micromegas signal



Generalised sigmoid fit of the rising edge



The SAT calculation of a continues function is more accurate than from discrete values

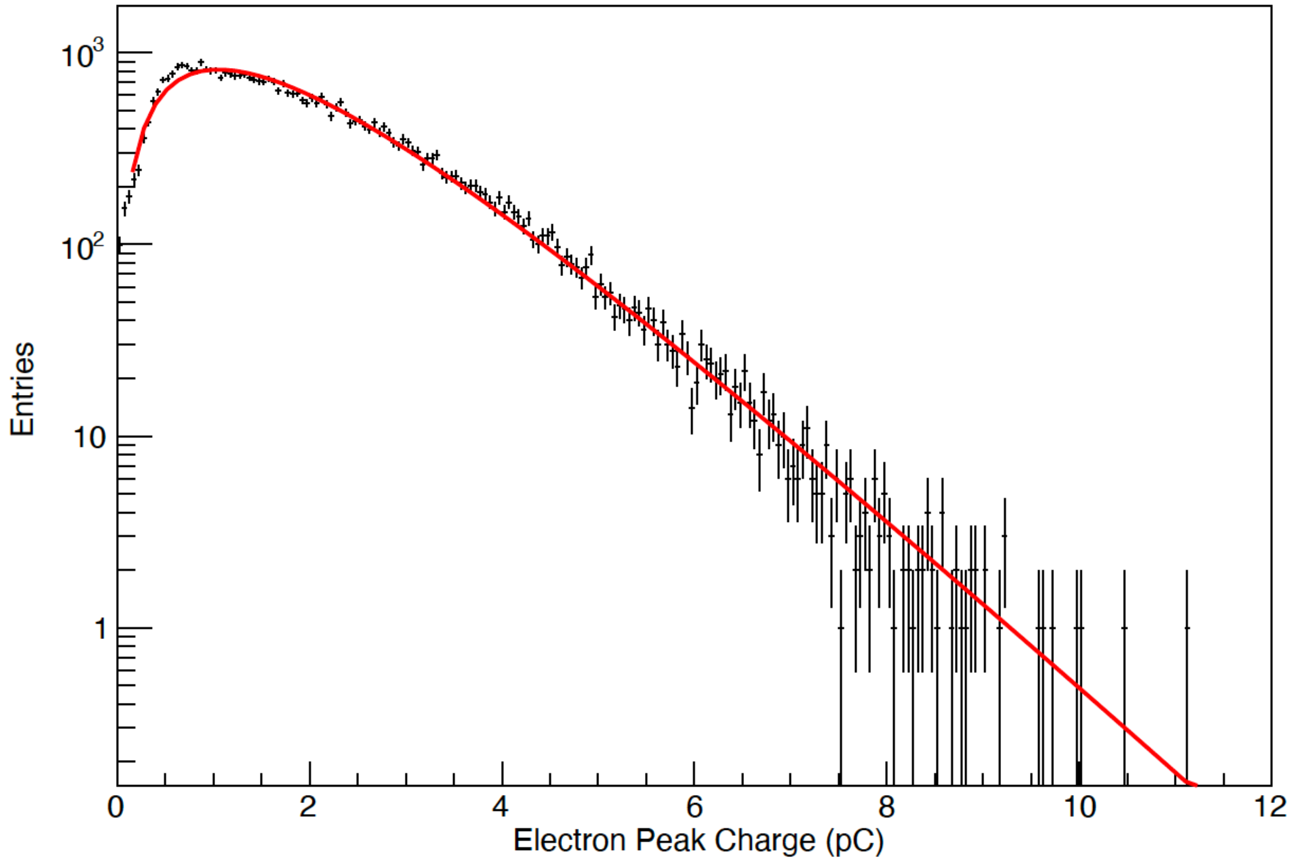
➡The rising edge of the electron peak is fitted by a generalised sigmoid function

$$S_{(t)} = \frac{P_0}{\left(1 + P_1 e^{-P_2(t-P_3)}\right)^{P_4}}$$

Calculating the Time Resolution

2. Polya fit of the Charge Distribution

E-peak distribution and Polya fit



- The integral of the electron peak is giving the charge
- Charge distribution is fitted by Polya function

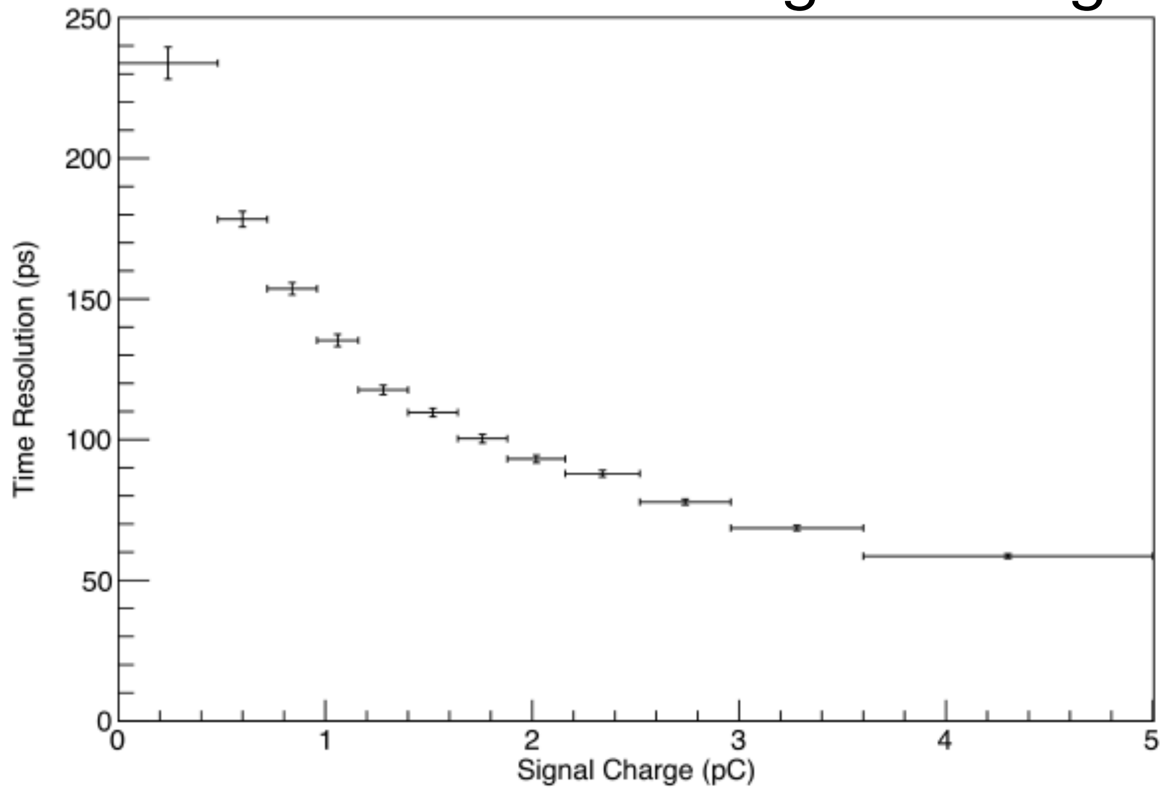
$$P(Q;c;\Theta;\bar{Q}) = \frac{c}{Q}\frac{(\Theta+1)^{\Theta+1}(Q/\bar{Q})^{\Theta}}{\Gamma(\Theta+1)}e^{-(\Theta+1)Q/\bar{Q}}$$

- Fit is giving information of mean signal charge
- Needed for calculating p.c. light yield

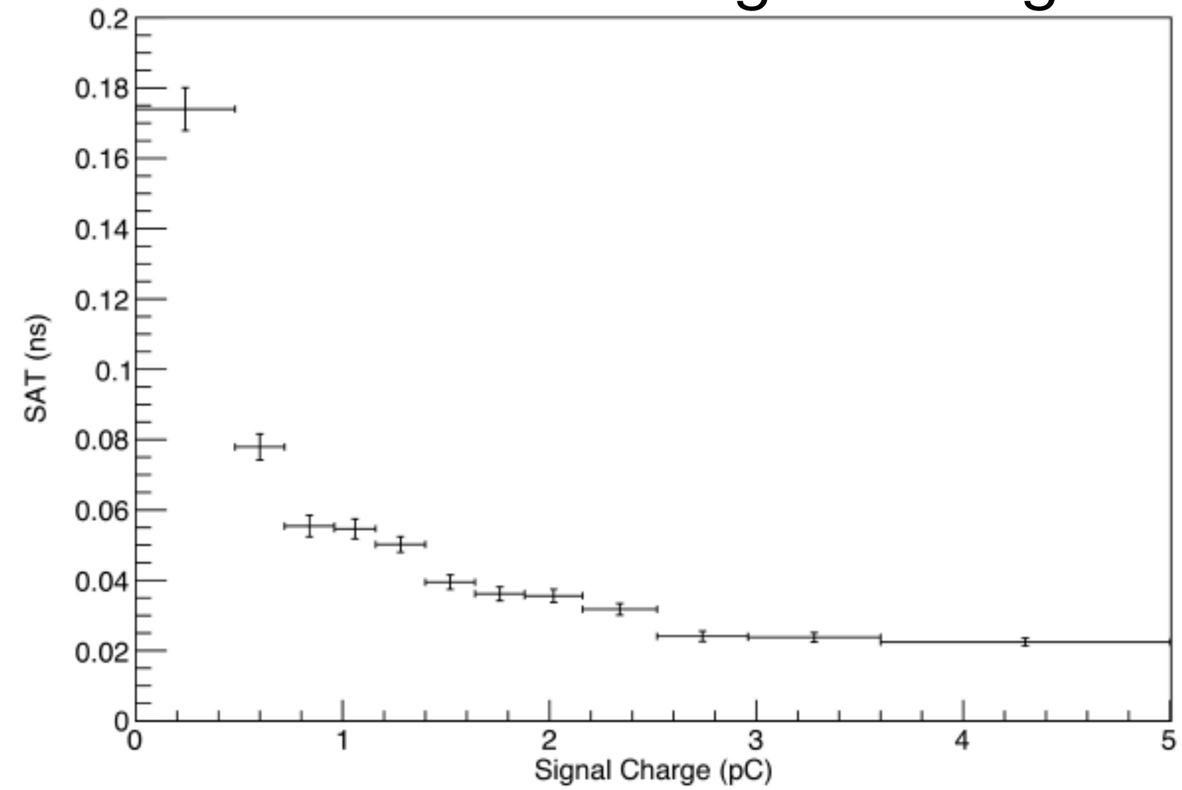
Calculating the Time Resolution

3. Slewing Correction

Time resolution vs. Signal Charge



Mean SAT vs. Signal Charge



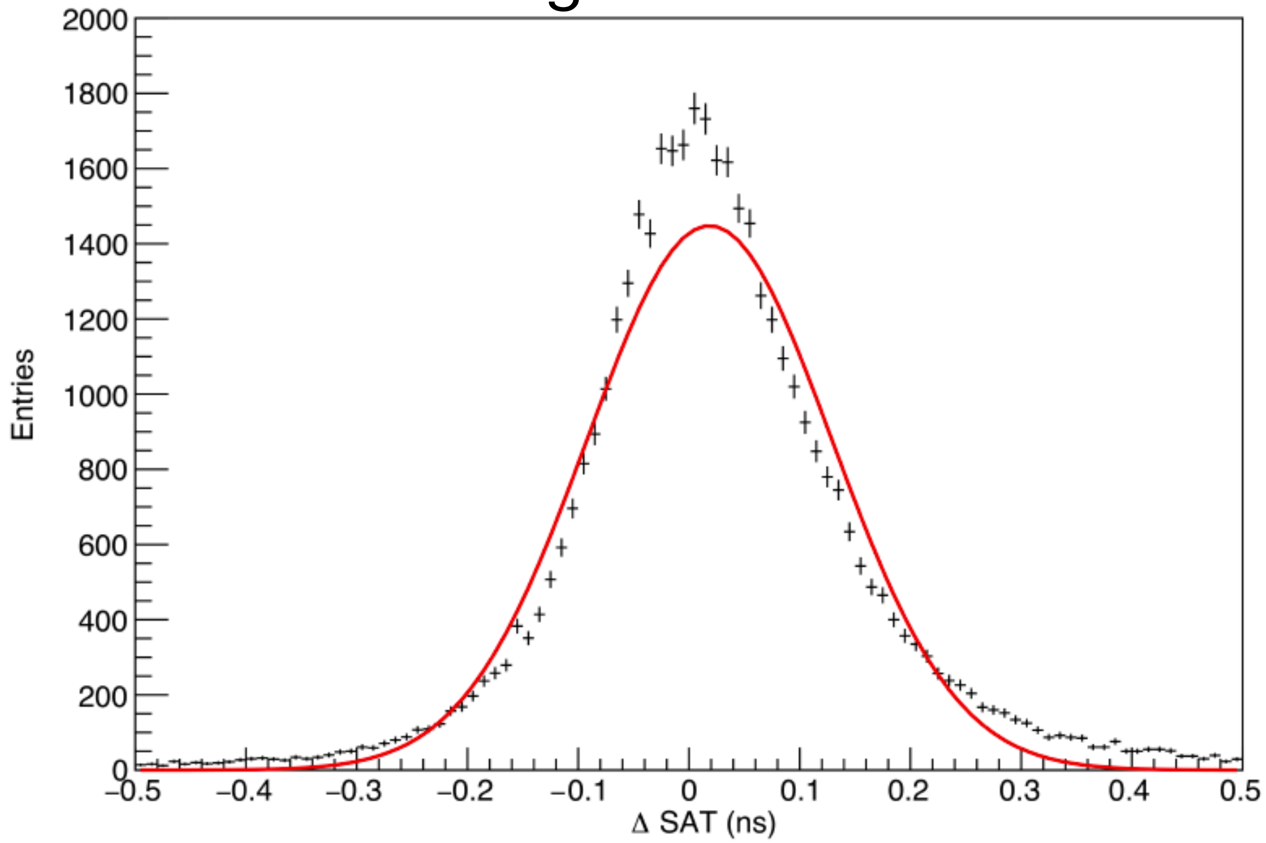
- Time resolution improves and mean SAT moves at higher signal charge
- Binning is selected according to the Polya fit
- Total time resolution is calculated by the convolution of the individual time resolutions

$$\sigma^2 = \sum_{i=1}^{n} a_i \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} a_i \times a_j \times \left(\sigma_i^2 + \sigma_j^2 + (\mu_i - \mu_j)^2\right)$$

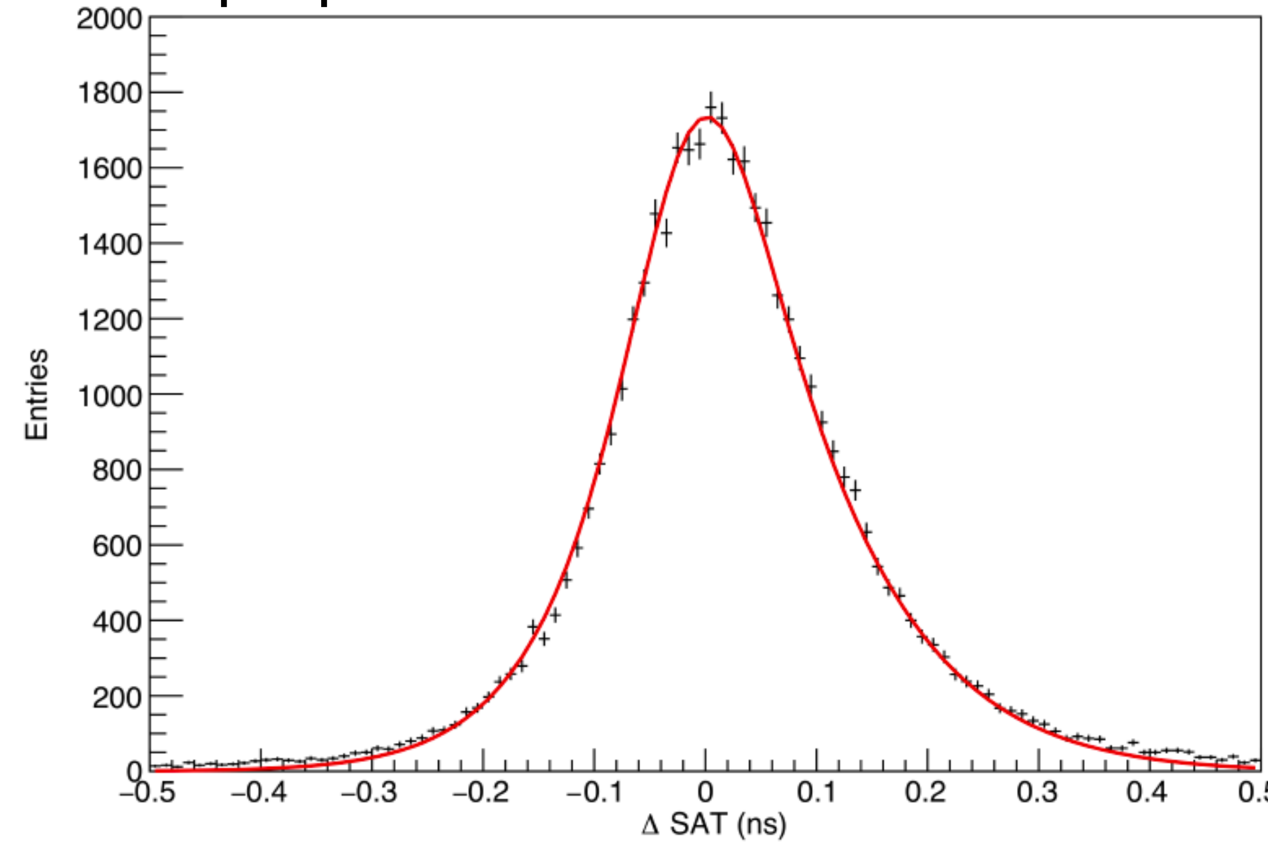
Calculating the Time Resolution

4. Multi Gaus fit

Single Gaus fit



Superposition of several Gaus curves

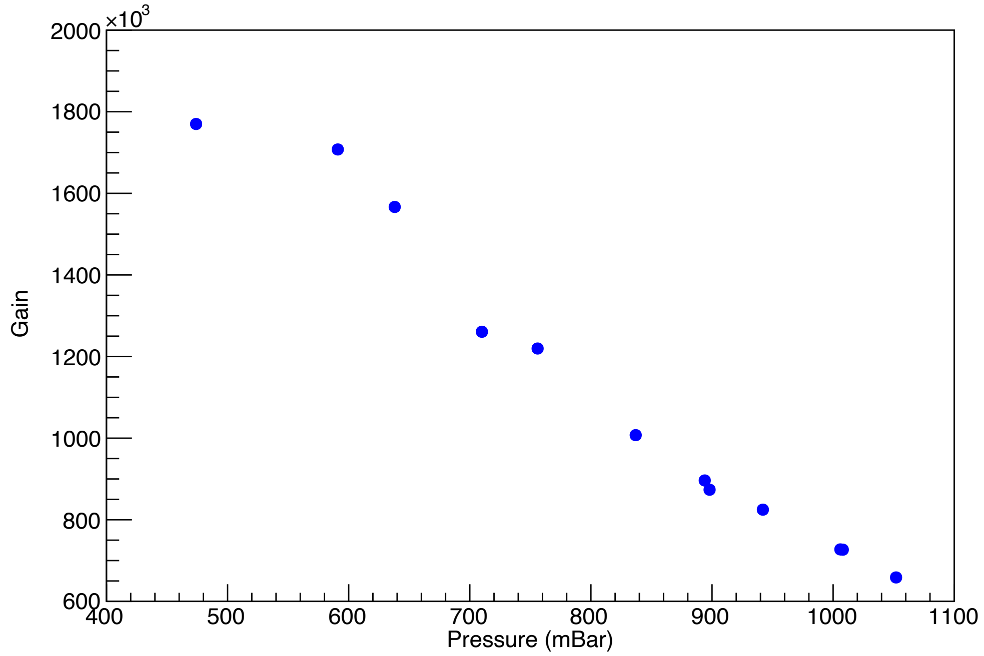


- Time resolution is determined by the sigma of the SAT difference between the DUT and a t0 reference
- Correction of the slewing effect improves the fit of the distribution

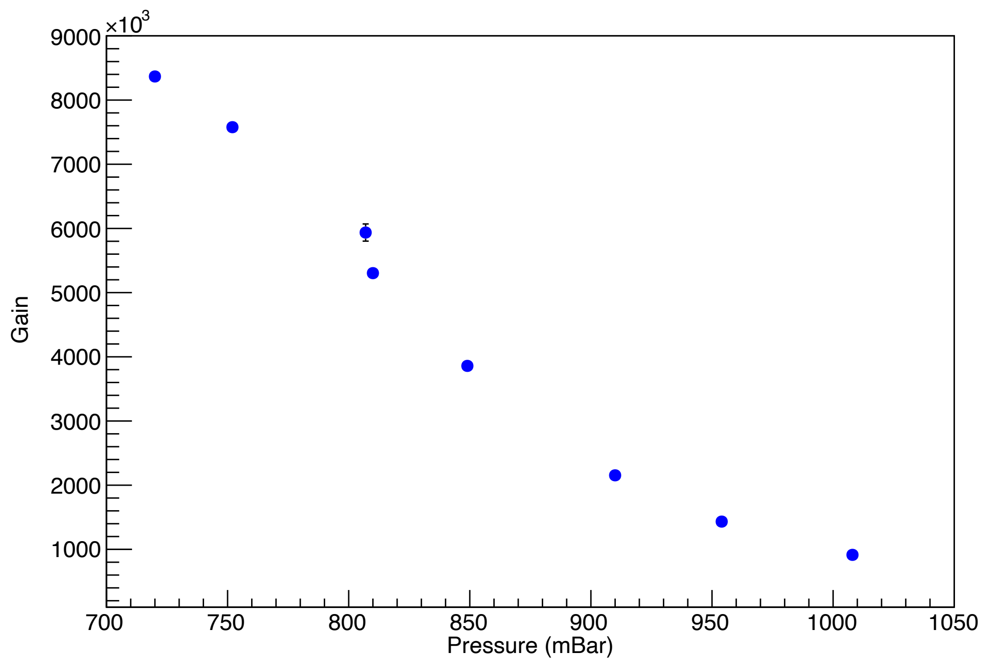
$$\sigma^2 = \sum_{i=1}^{n} a_i \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} a_i \times a_j \times \left(\sigma_i^2 + \sigma_j^2 + (\mu_i - \mu_j)^2\right)$$

Gain rises and saturates at lower pressure

Anode 500 V; Drift 100 V

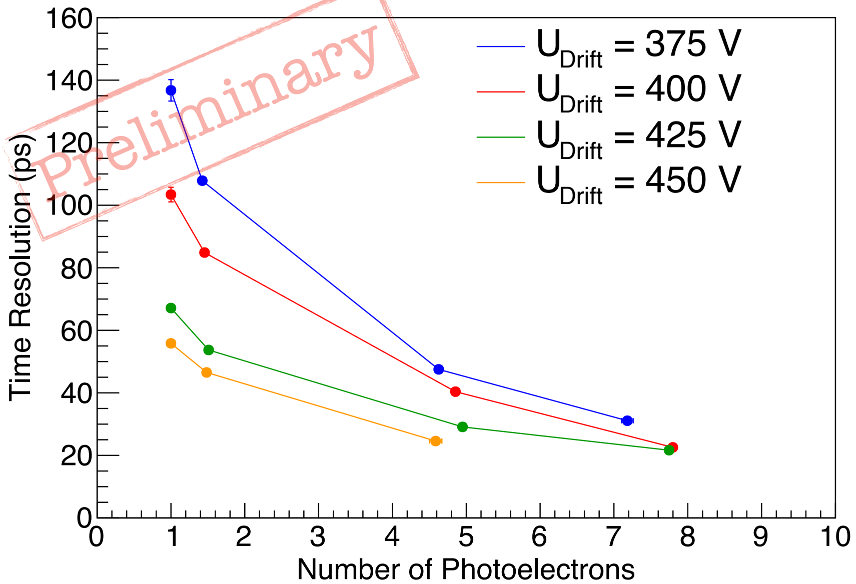


Anode 275 V; Drift 450 V

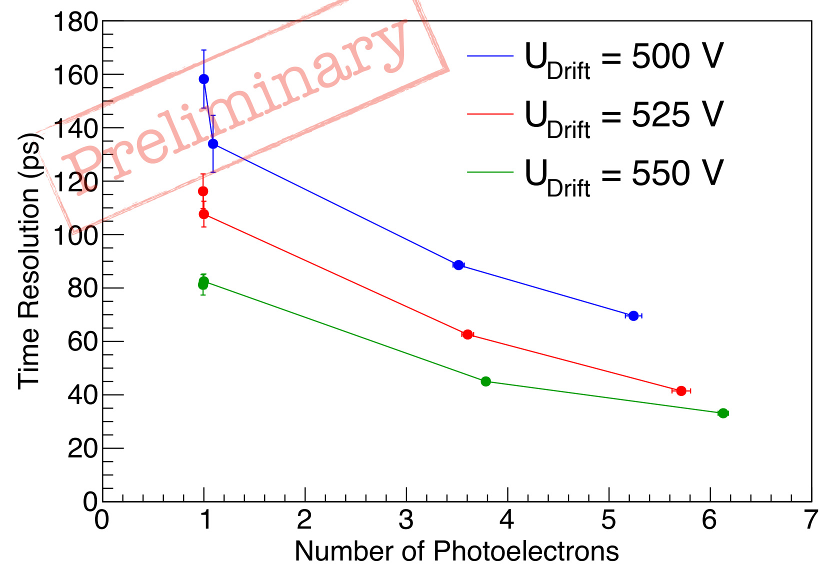


- Measurement done for COMPASS gas only
- Gain saturates at lower pressure
- Natural atmospheric pressure fluctuation can affect gain and thus time resolution
- Time resolution measurements at different gas pressures are planned

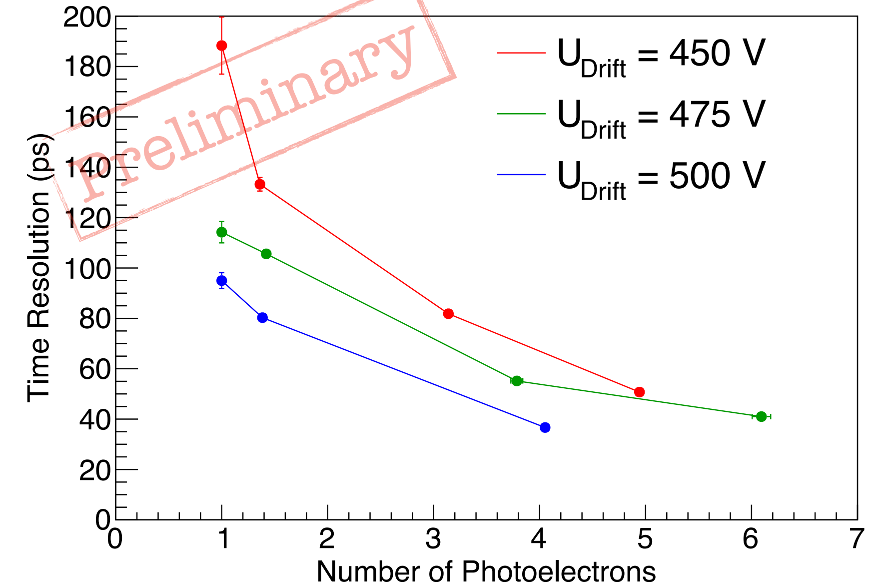
119 μm; Anode 350 V



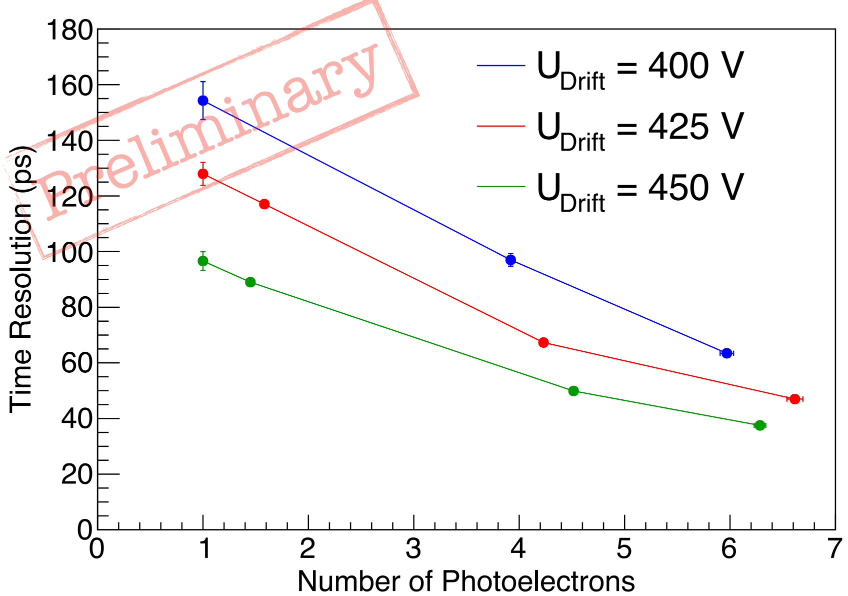
169 μm; Anode 275 V



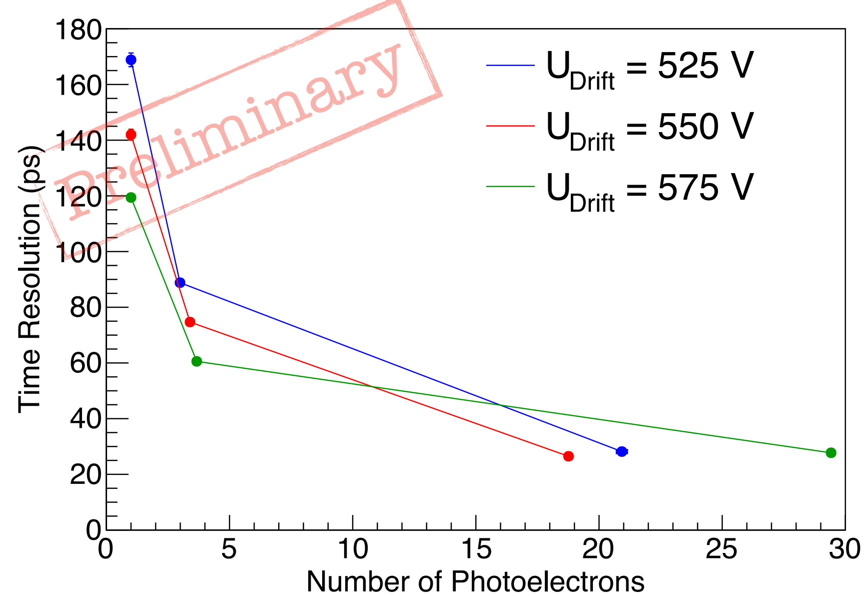
169 μm; Anode 350 V



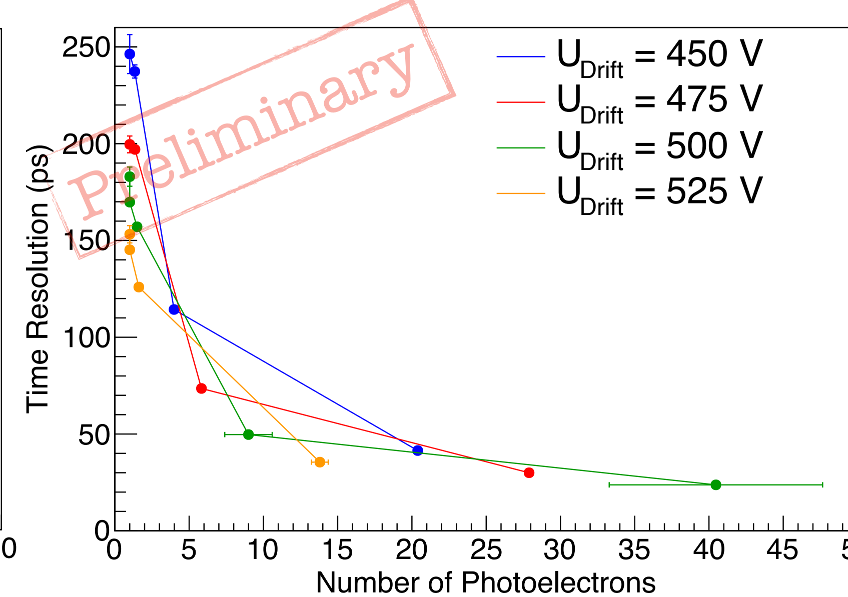
169 μm; Anode 400 V



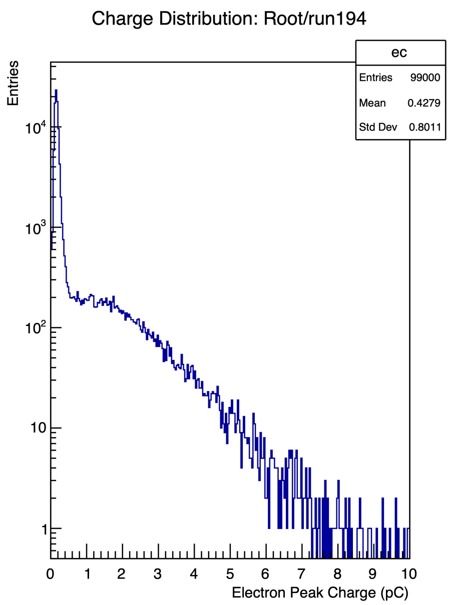
244 μm; Anode 350 V

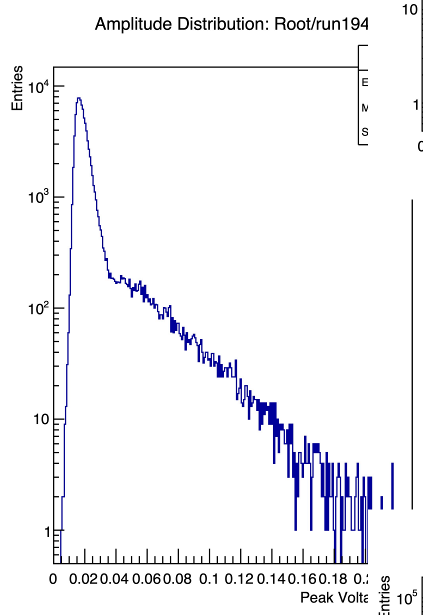


244 μm; Anode 400V

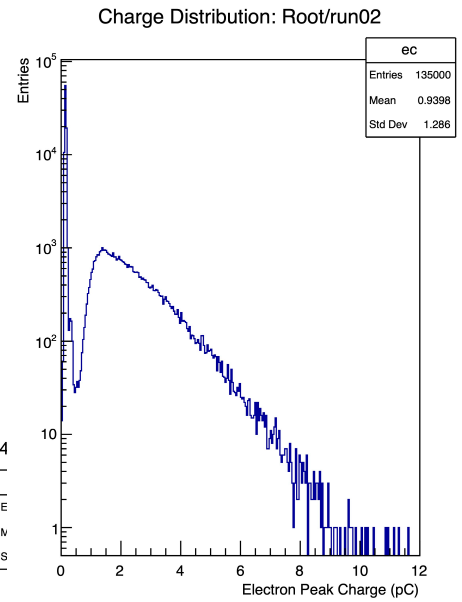


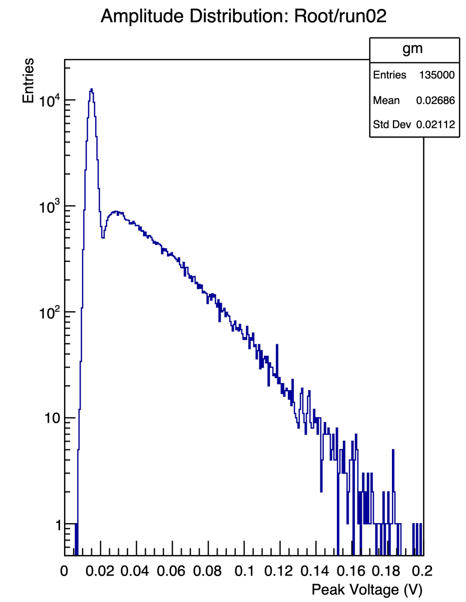
COMPASS GAS
A:350V D:500V



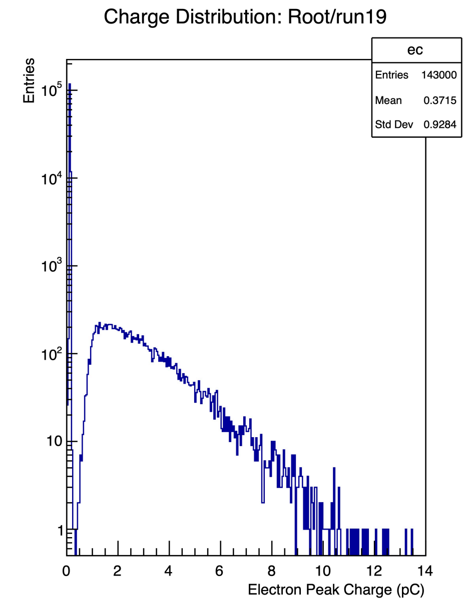


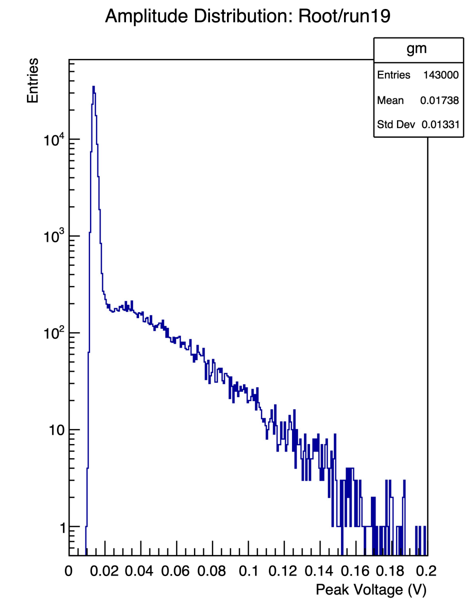
Ne 80%
A:350V D:575V



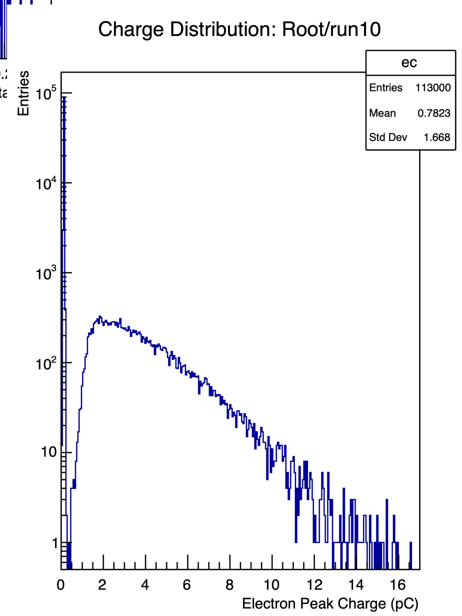


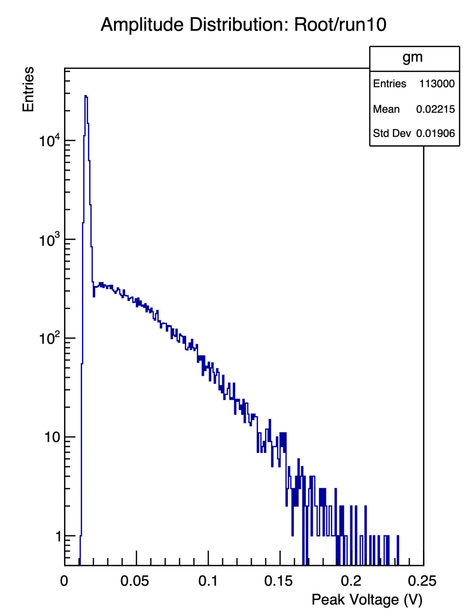
Ne 85%
A:350V D:495V



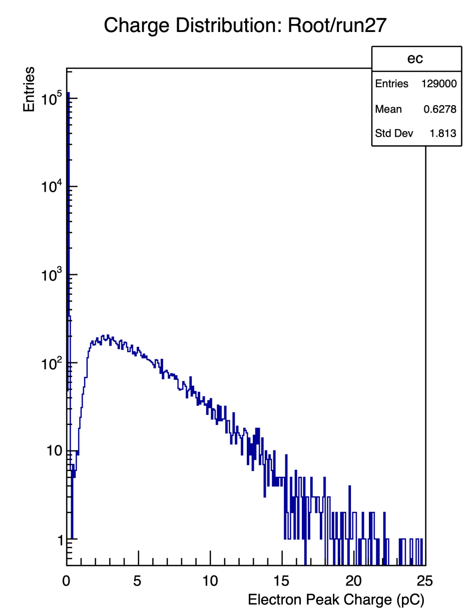


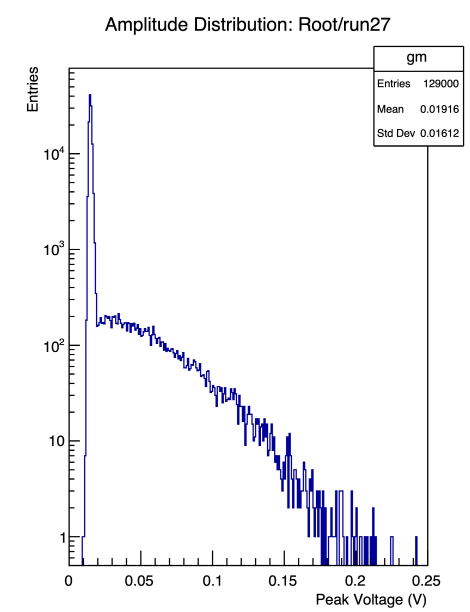
Ne 90%
A:350V D:425V





Ne 92.5%
A:350V D:390V





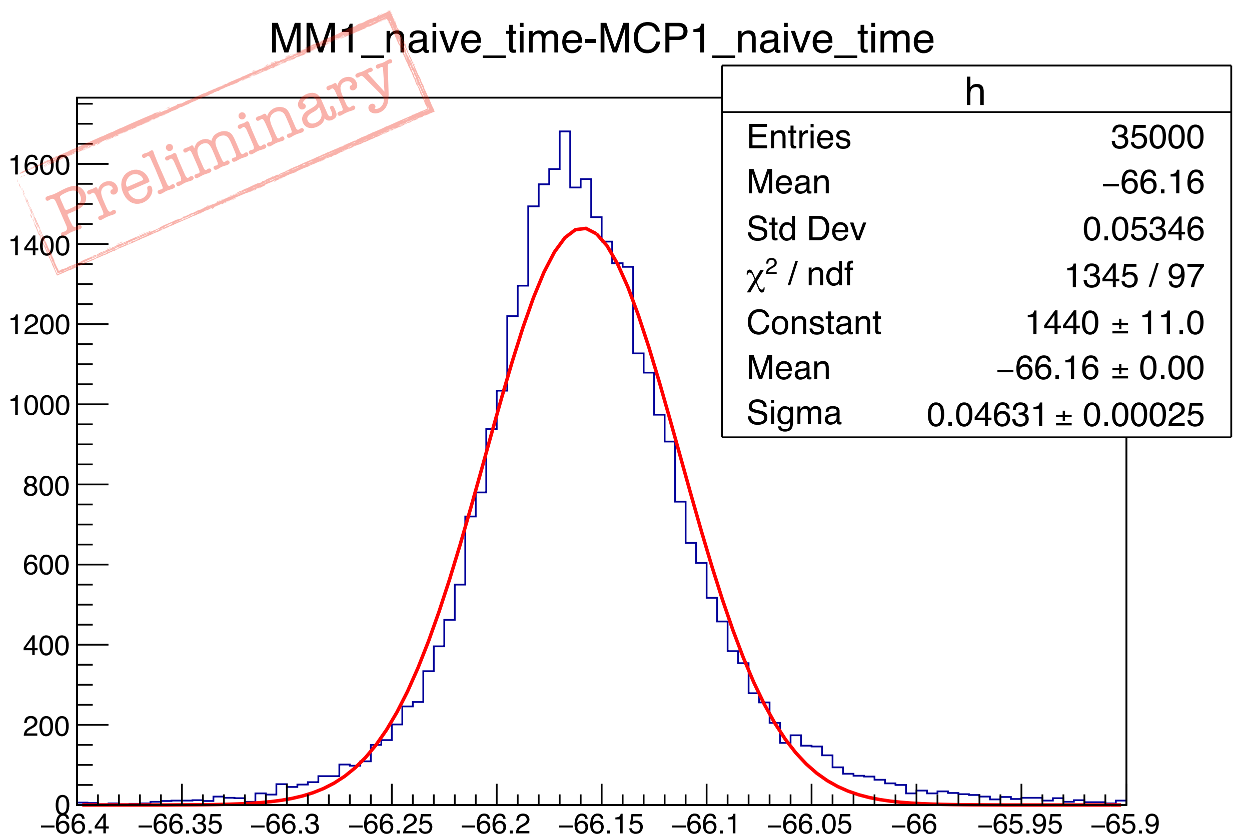
New Amplifier Tested

PICOSEC Amplifier „ATHR N3“

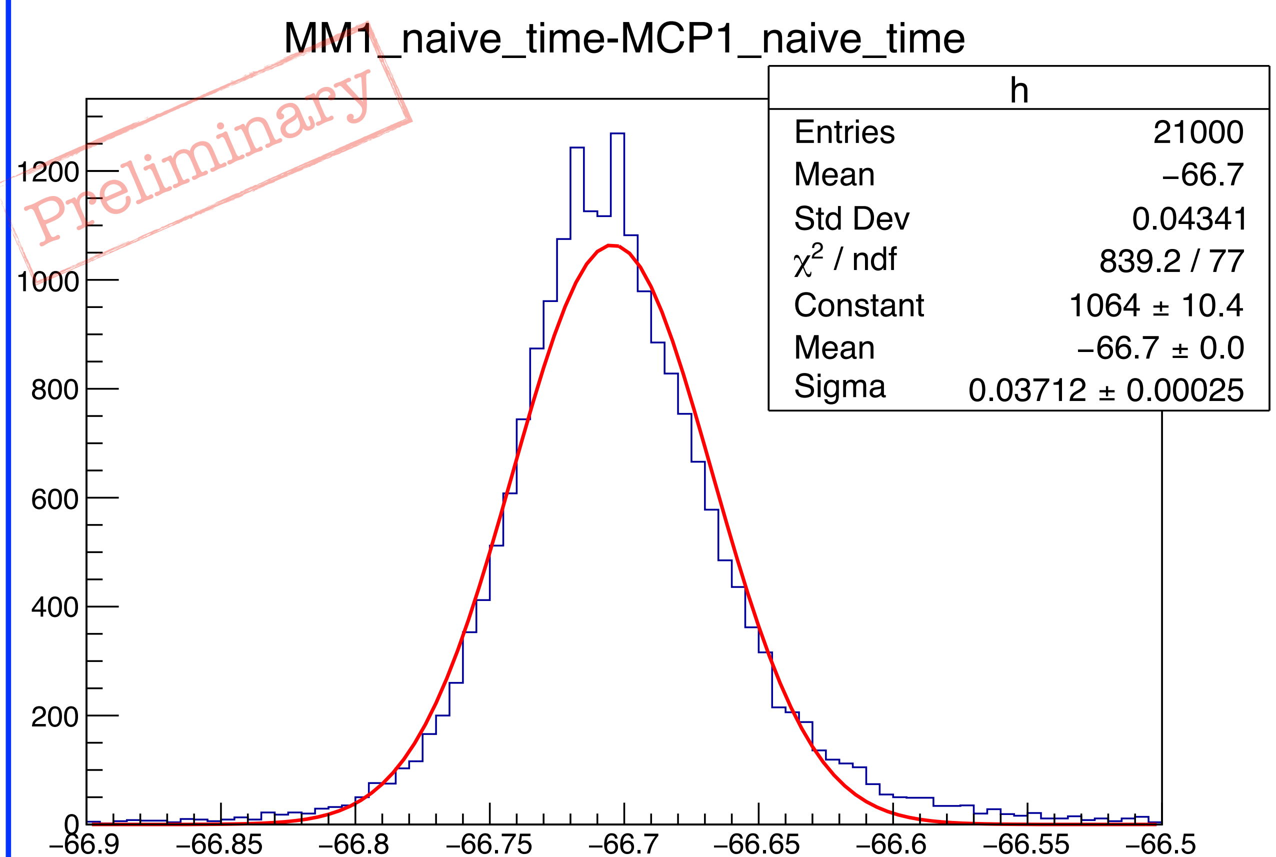
CIVIDEC „C2HV0177“

Anode: 275 V
Drift: 600 V
Drift gap: 194 µm
4 photoelectrons

ATHR N3



Cividec



Comparison of selected waveforms