Signal Processing and Alignment Techniques for the Analysis of PICOSEC Test Beam Data

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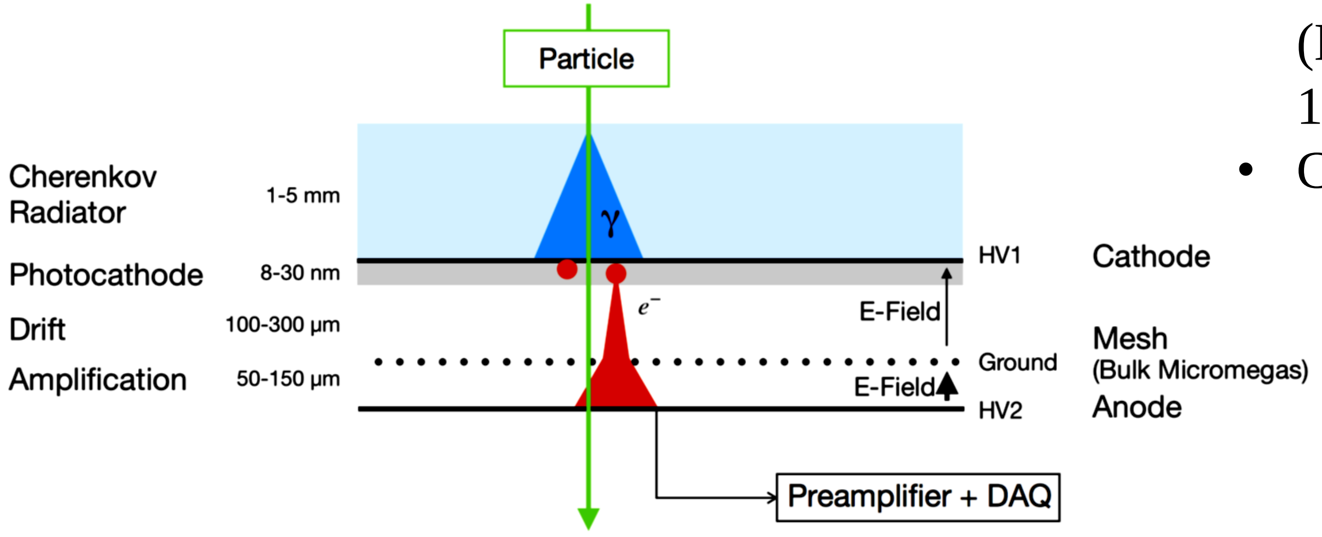
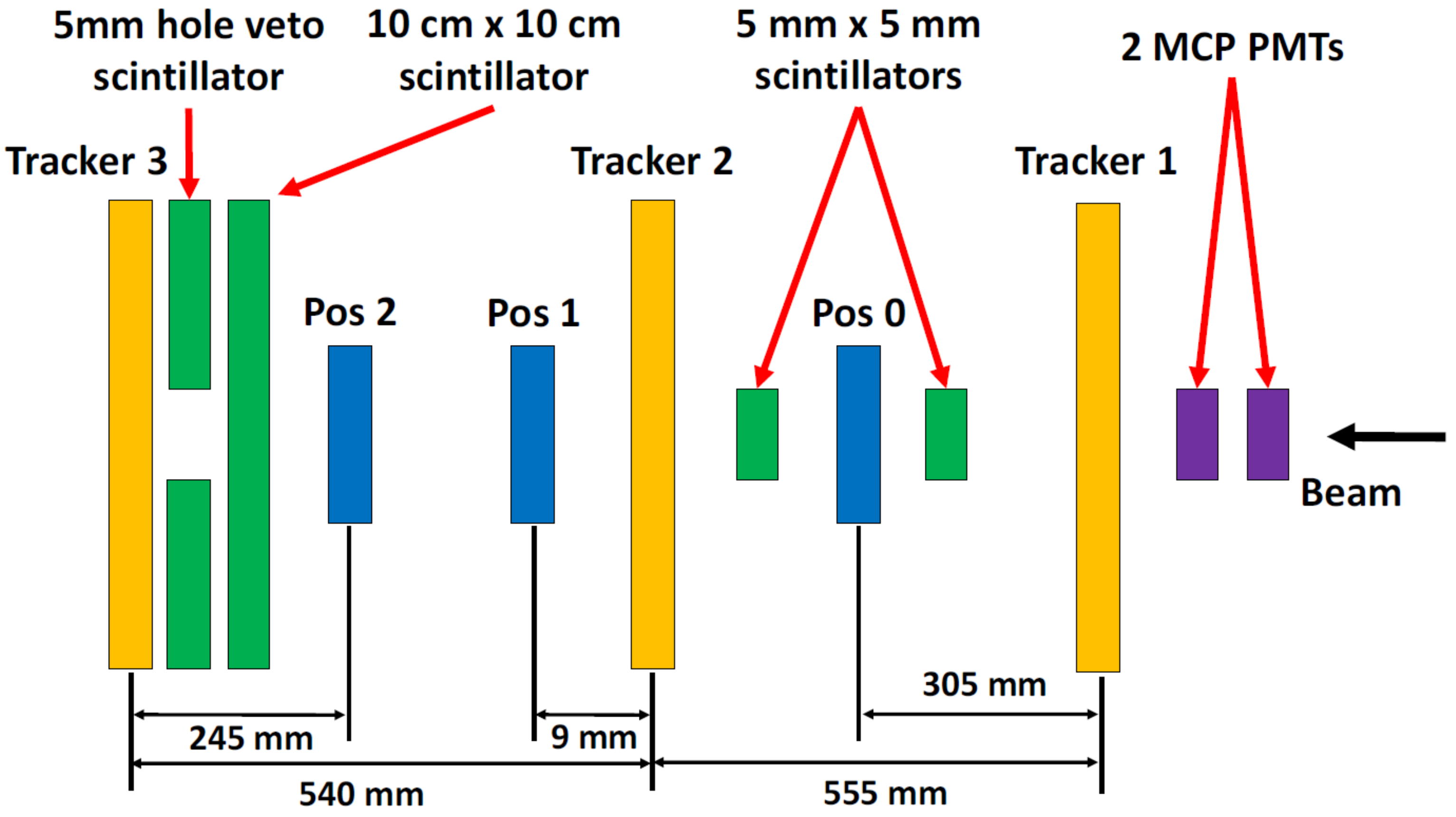
PICOSEC Micromegas



- "COMPASS gas" ($Ne+10\%C_2H_6+10\%CF_4$) at 1 bar
- $CF_4+20\%C_2H_6$ at 0.5 bar

The PICOSEC detection concept. The passage of a charged particle through the Cherenkov radiator produces UV photons, which are then absorbed at the photocathode and partially converted into electrons. These electrons are subsequently preamplified and then amplified in the two high-field drift stages, and induce a signal which is measured between the anode and the mesh.

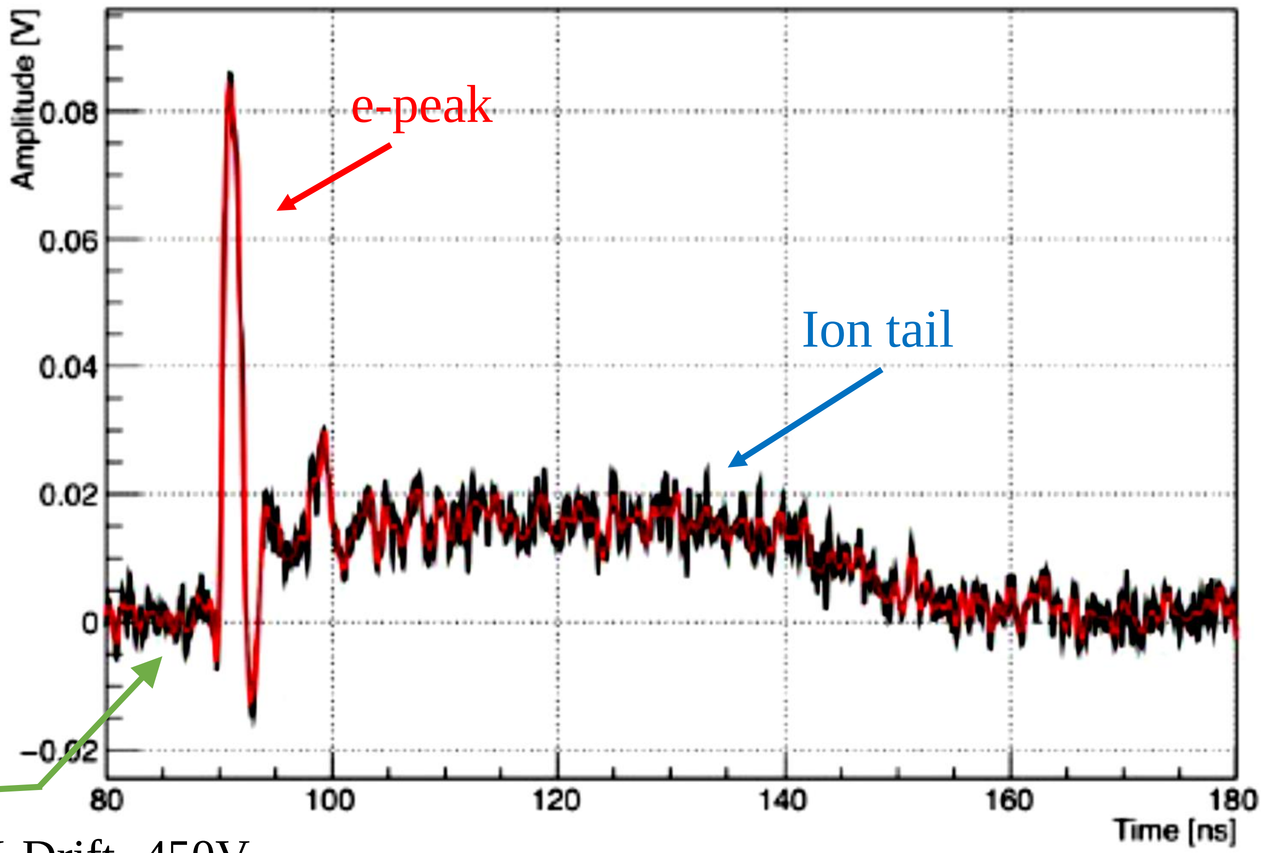
PICOSEC muon test beam calibration



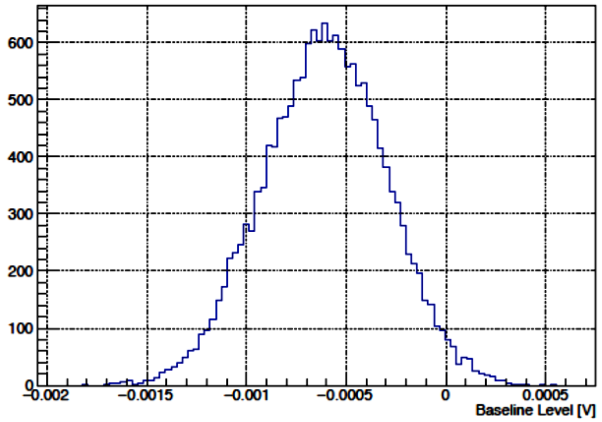
Layout of the experimental setup (not to scale) during the beam tests. The incoming beam (150GeV muon) enters from the right side of the figure; events are triggered by the coincidence of two 5x5mm^2 scintillators in anti-coincidence with a "veto" scintillator. Three GEM detectors provide tracking information of the incoming charged particles, and the timing information is measured in three PICOSEC detectors (Pos0, Pos1, Pos2).

PICOSEC Signal

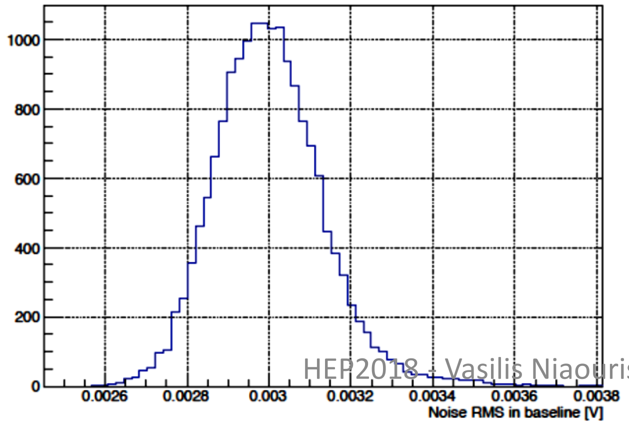
To calculate the baseline level and RMS, we chose the first part of the signal before the electron peak (e-peak) for every event. The distribution of mean baseline level and its RMS are shown below. RMS noise is approximately 3mV.



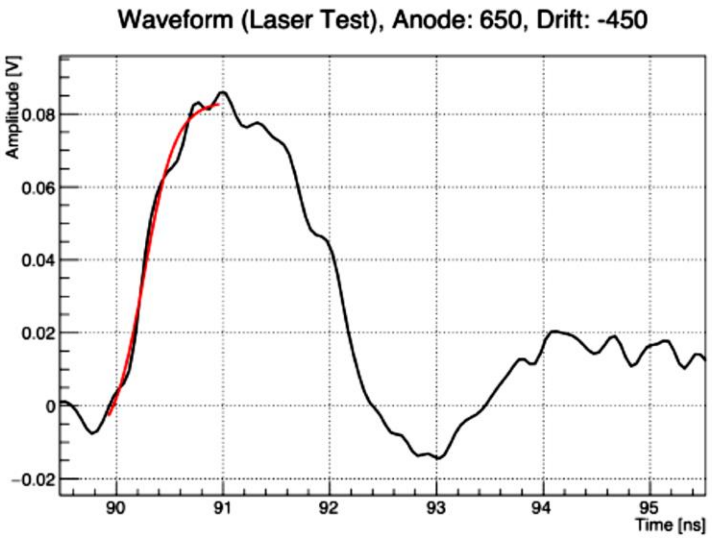
Baseline, Anode 650V, Drift -450V



Noise RMS, Anode 650V, Drift -450V



PICOSEC Signal: Fitting and Timing



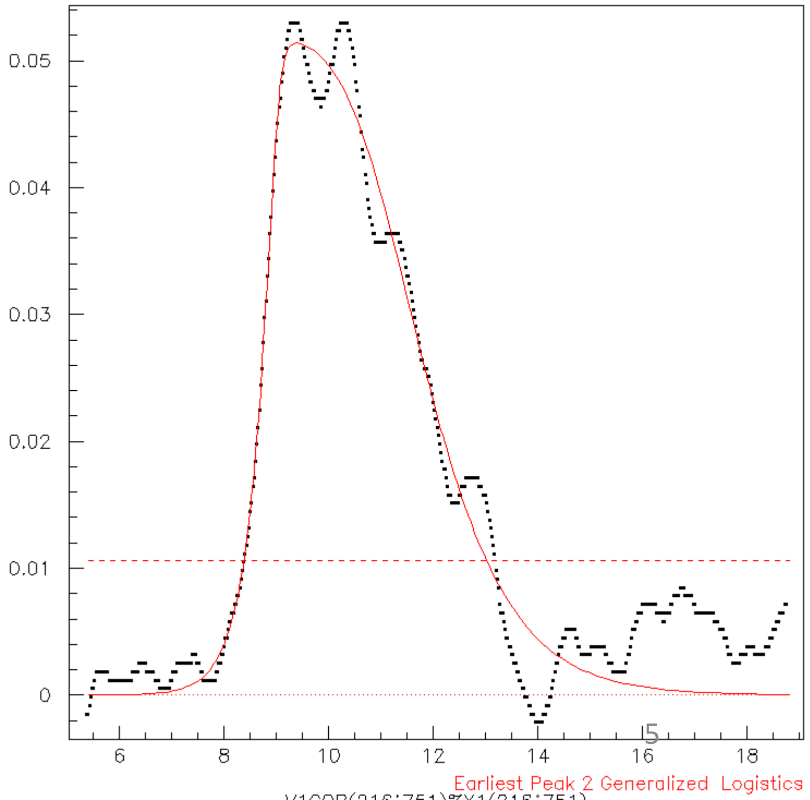
We tried different methods, including quadratic and cubic polynomial interpolation. We also tried to fit with the logistic and generalized logistic functions:

$$\frac{P_0}{1+\exp\left[-P_2\left(x-P_1\right)\right]}+P_3 \quad , \quad \frac{P_0}{\left(1+\exp\left[-P_2\left(x-P_1\right)\right]\right)^{P_3}}$$

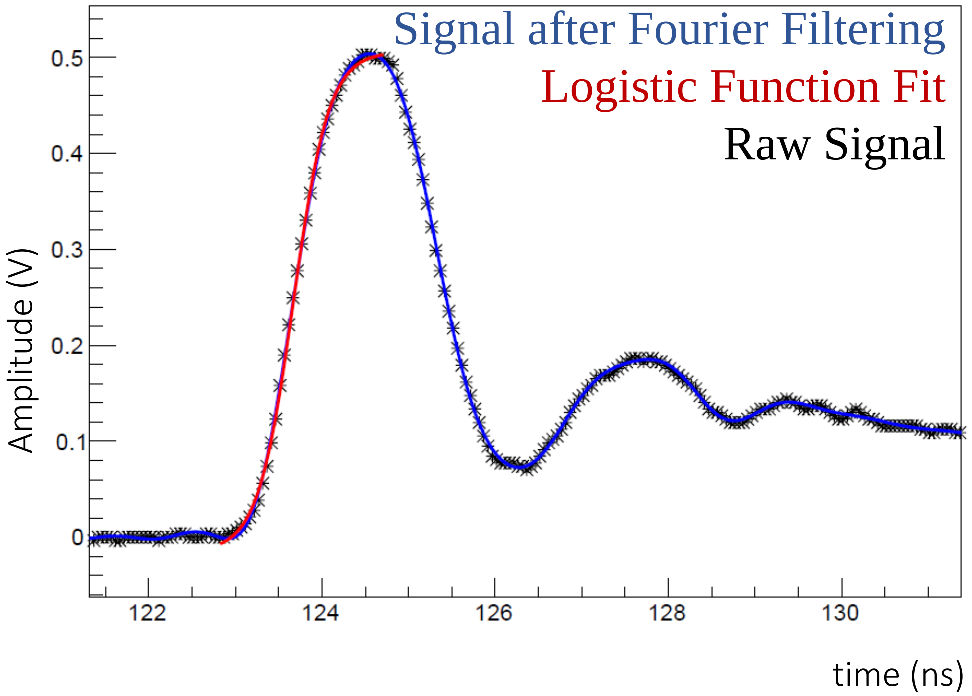
In order to extract information from the nosiest signals, we modeled the e-peak with the difference of two generalized logistic functions:

$$f(t;p_0,p_1,p_2,p_3,p_4,p_5,p_6)=\frac{p_0}{\left(1+e^{-(t-p_1)p_2}\right)^{p_3}}-\frac{p_0}{\left(1+e^{-(t-p_4)p_5}\right)^{p_6}}$$

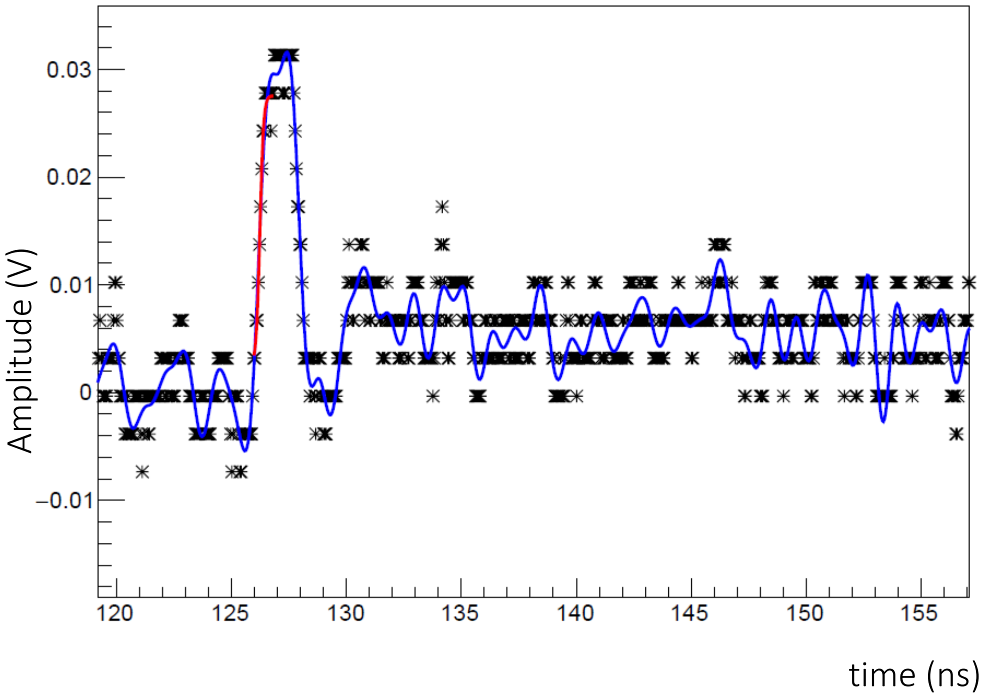
To time the signal, we use software 20% constant fraction discrimination



An attempt for PICOSEC Signal Processing



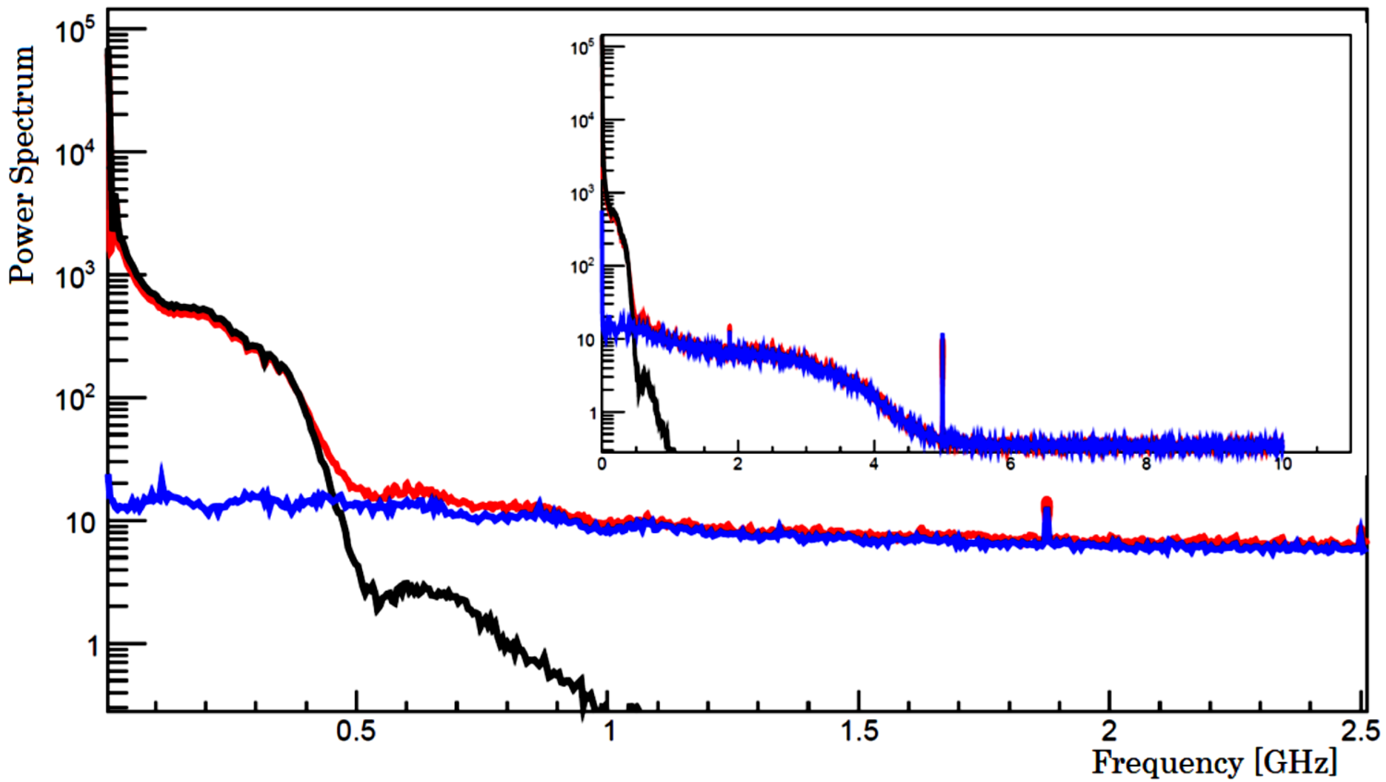
(a) High peak - voltage pulse



(b) Low peak - voltage pulse

The black dots represent the signal initially acquired form the experiment, whilst the blue line represents the waveform of the Fourier filtered signal. The red line is the logistic fit which was eventually used for the timing of the detector.

PICOSEC Signal Spectral Density



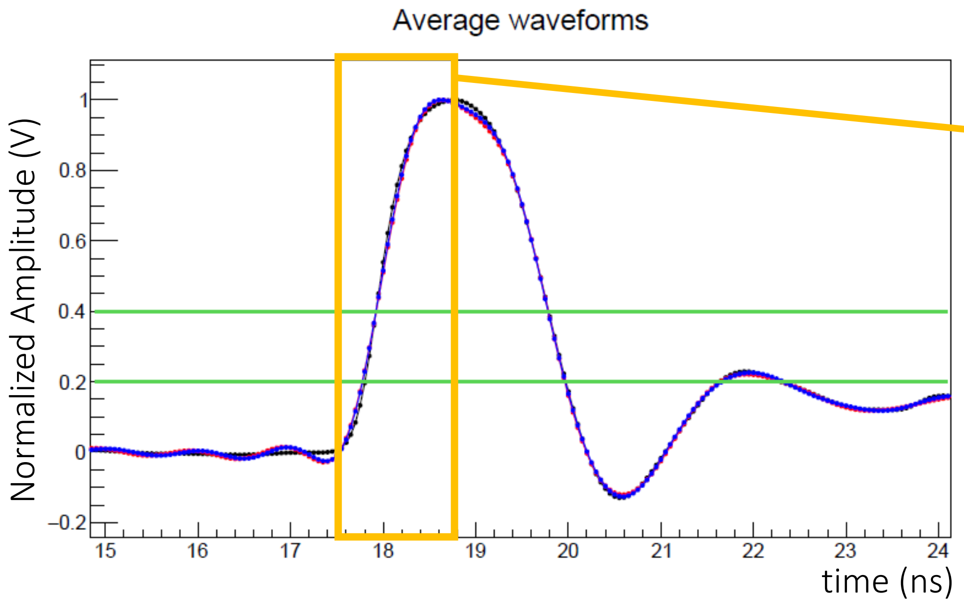
Spectral Density of the average normalized pulse: Normalize the waveform of every pulse. After averaging the normalized pulses, we take the spectral density by applying FT (**noise is averaged out**).

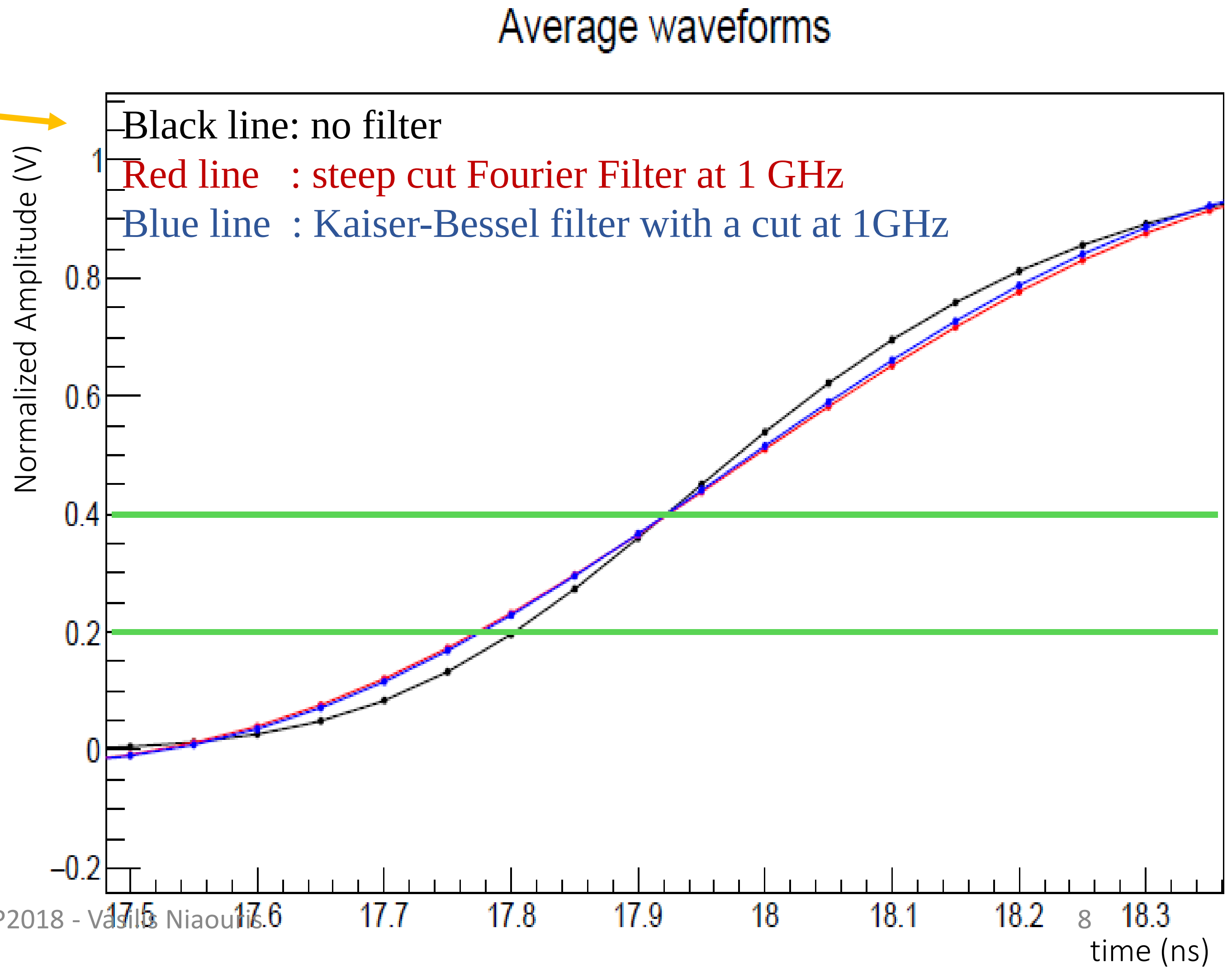
Average Spectral Density of the pulses: Apply FT on each pulse and the take the average spectral density. This is the average spectral density of the pulses. **The average noise spectrum is included in this plot**.

Average Spectral Density of the noise: Take the region before the e-peak which is only noise. Apply FT on each one of them and then take the average. **This is the spectral density of the noise.**

As the signal does not seem to have any dominant frequencies after 1GHz, the Fourier Filter can be applied as a lowpass filter with a cut in the region of 1-2GHz.

PICOSEC Pulse distortion of lowpass FF



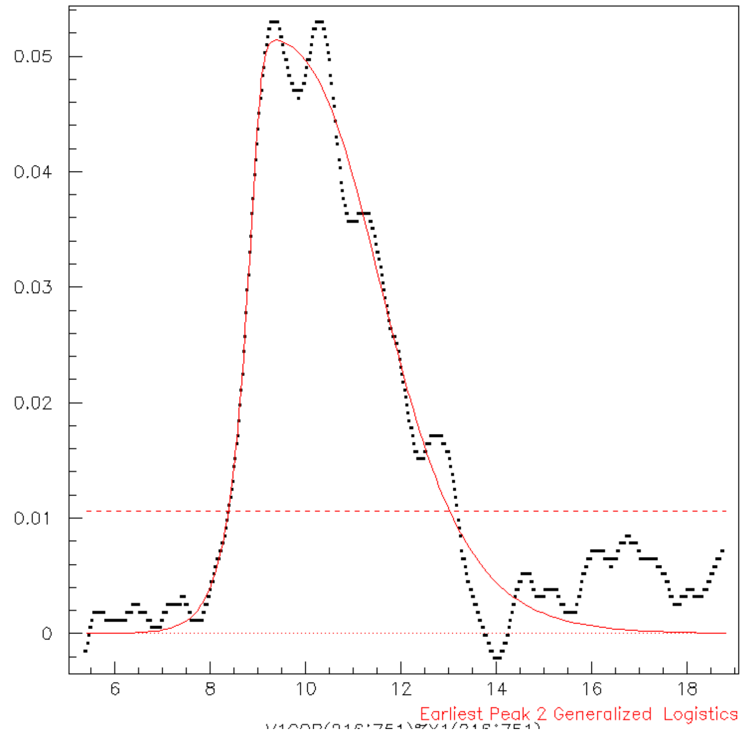


The leading edge of the waveform has large frequencies and the aforementioned cuts distort it and make less sharp. This results to a worse time resolution.

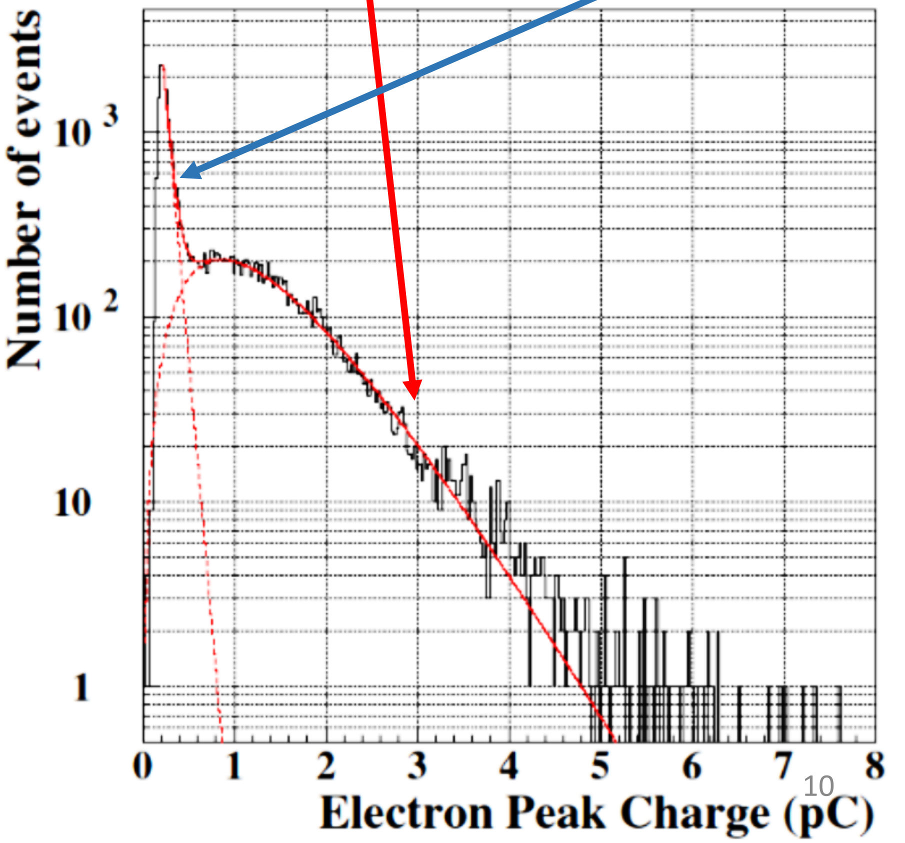
Calibration using muon test beam data and evaluation of the mean number of photoelectrons per muon

Single Photoelectron e-peak charge distribution

Data collected with LED UV-lamp

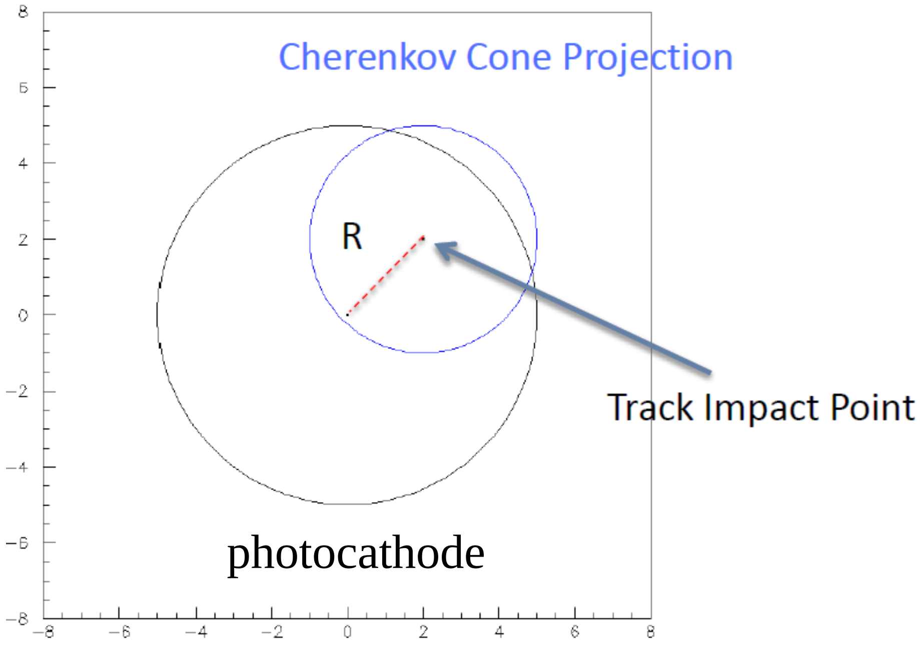


Distribution of electron peak charge is shown with black, while red lines correspond to a global fit of an exponential (noise contribution) and a Polya distribution (charge distribution).

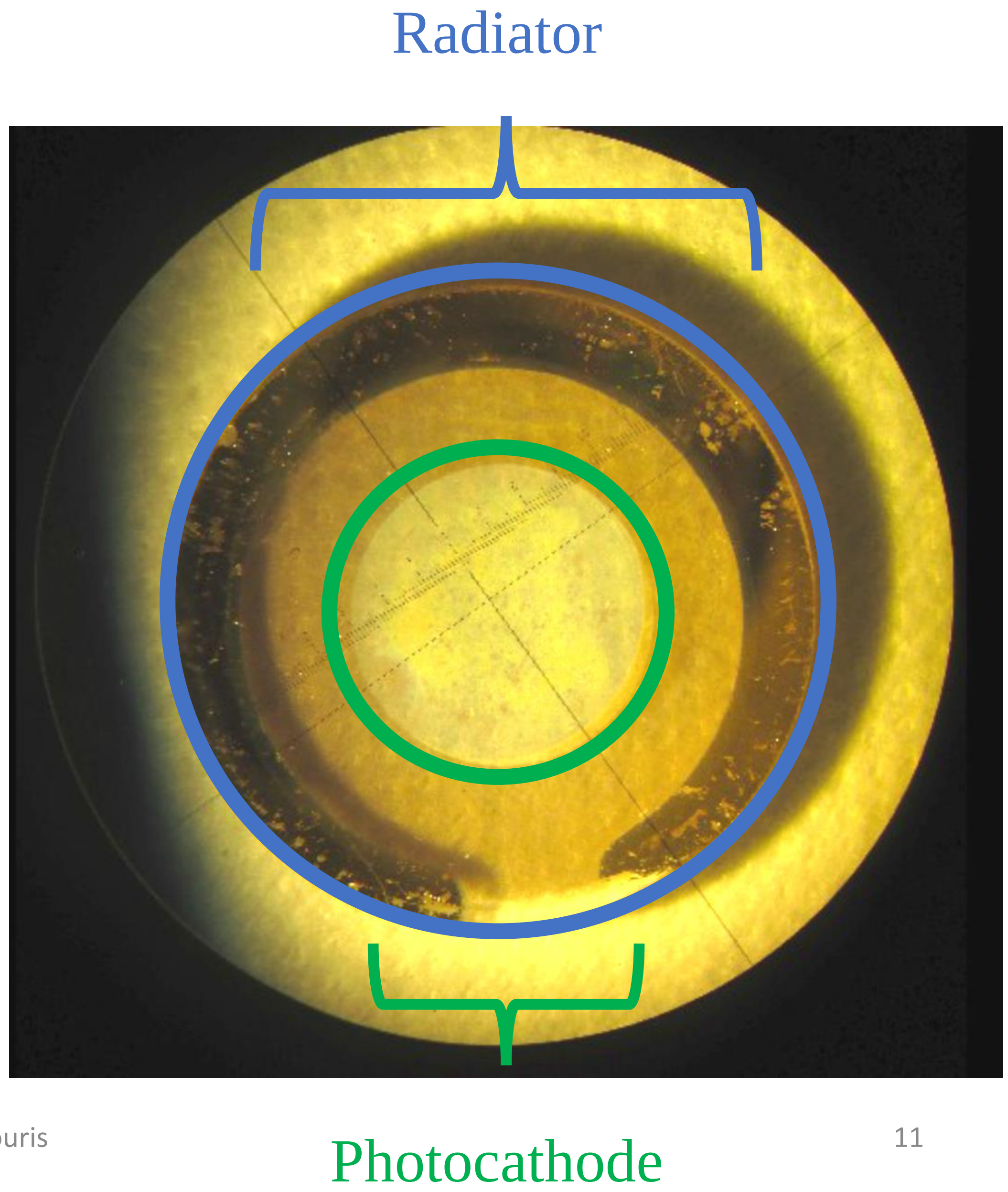


The e-peak charge was calculated by integrating the fit.

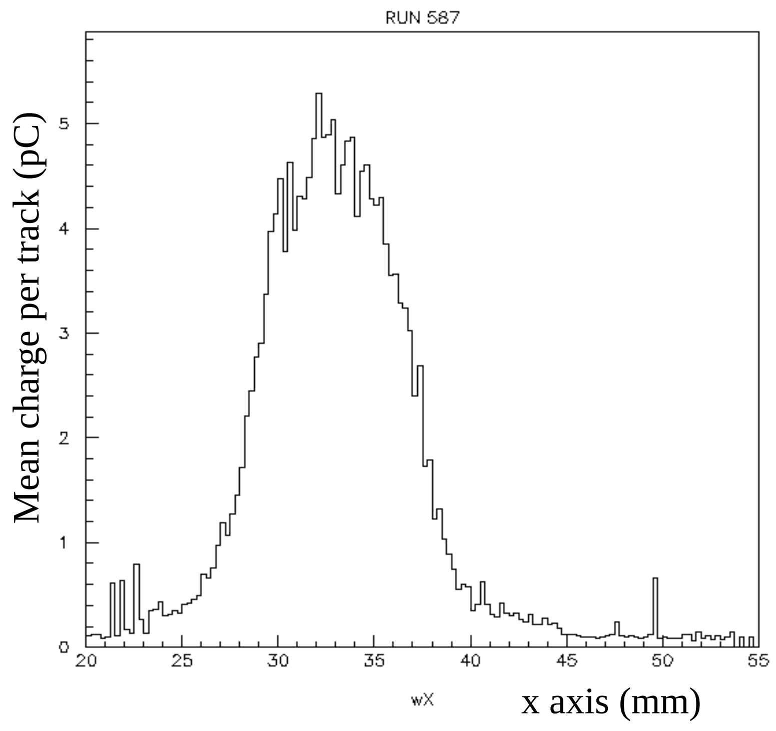
Geometrical Acceptance

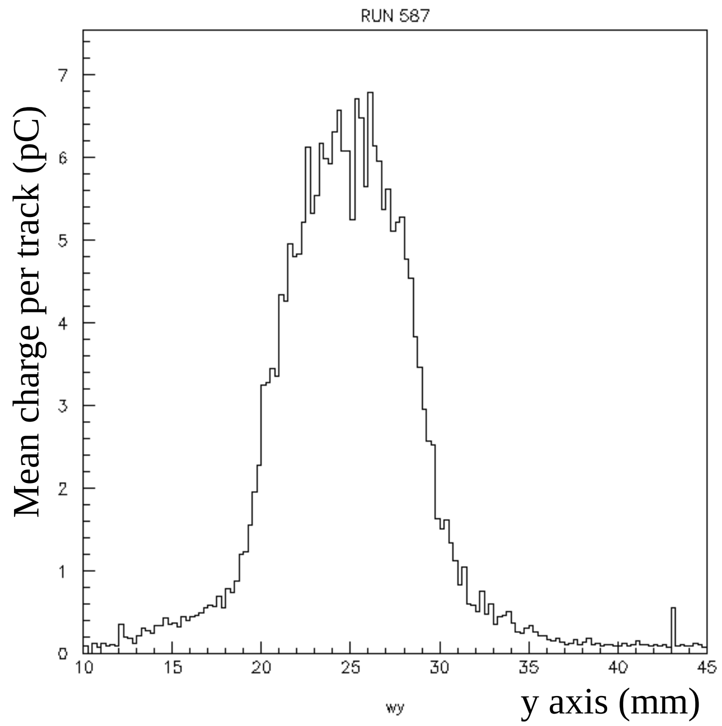


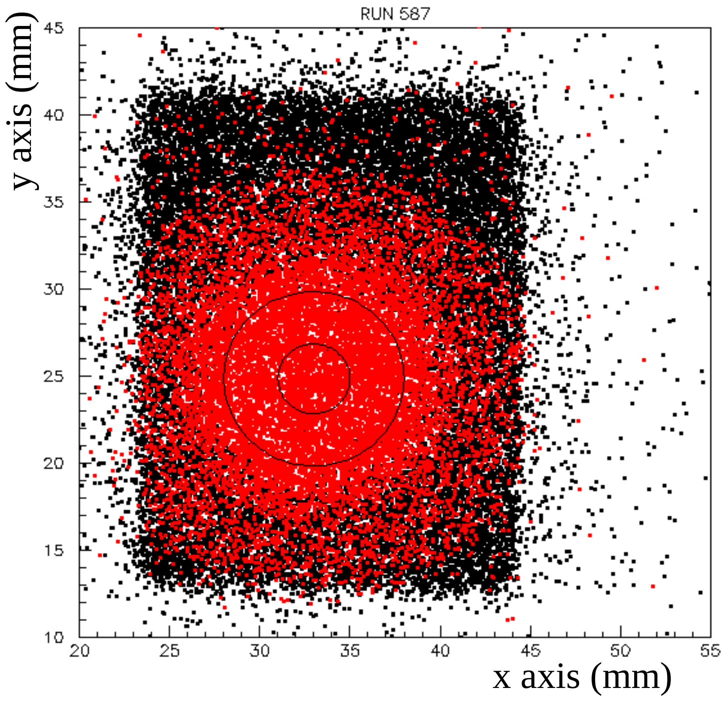
Every muon produces Cherenkov Photons whose population follows a Poisson distribution. However, not all the photons are deposited in the active area (photocathode). There exists a geometrical acceptance which describes the fraction of the accepted photons. Because it is a smooth function decreasing with the impact parameter, the center of the detector can be estimated.



First estimate of the PICOSEC center







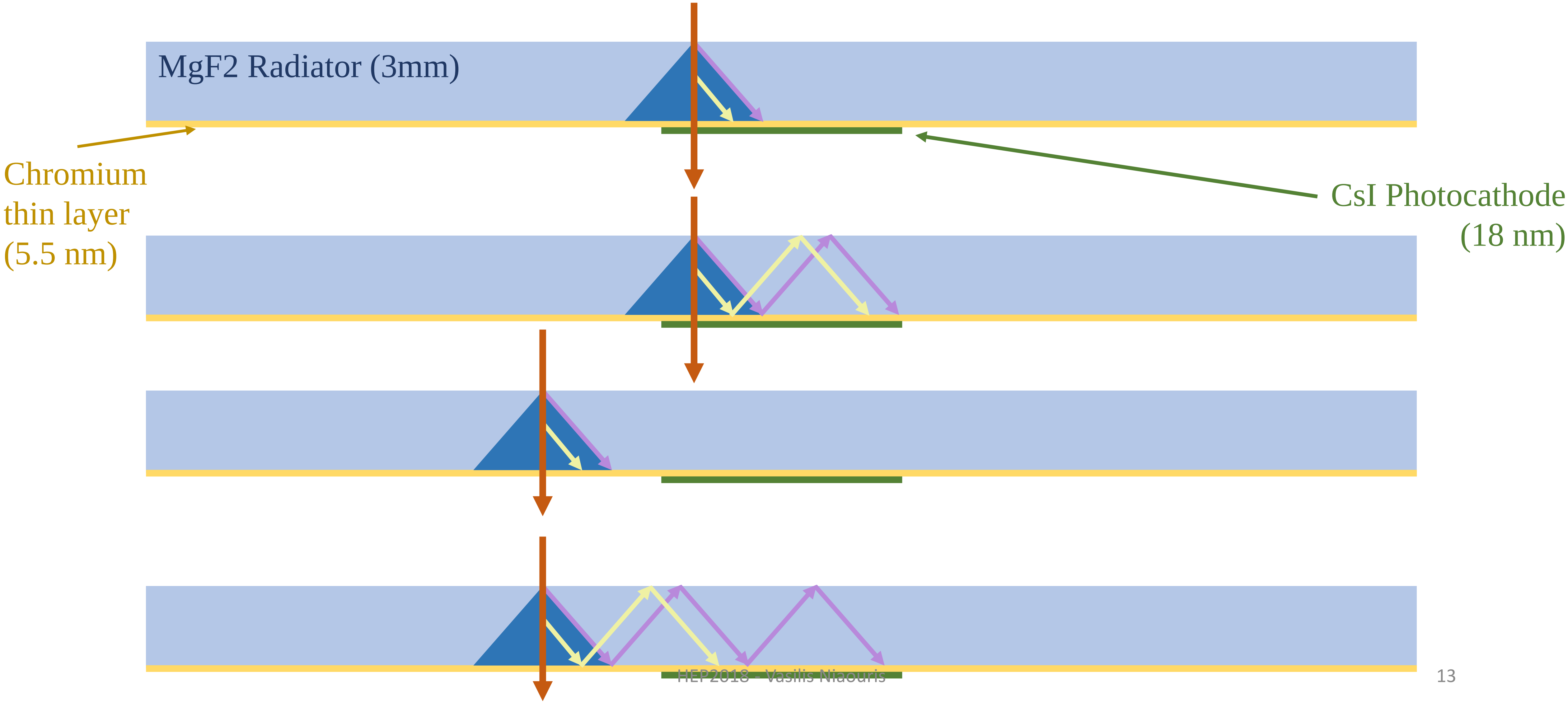
The mean of these distributions corresponds to the PICOSEC's center.

Scatter plot of x-y components of the beam impact parameter.

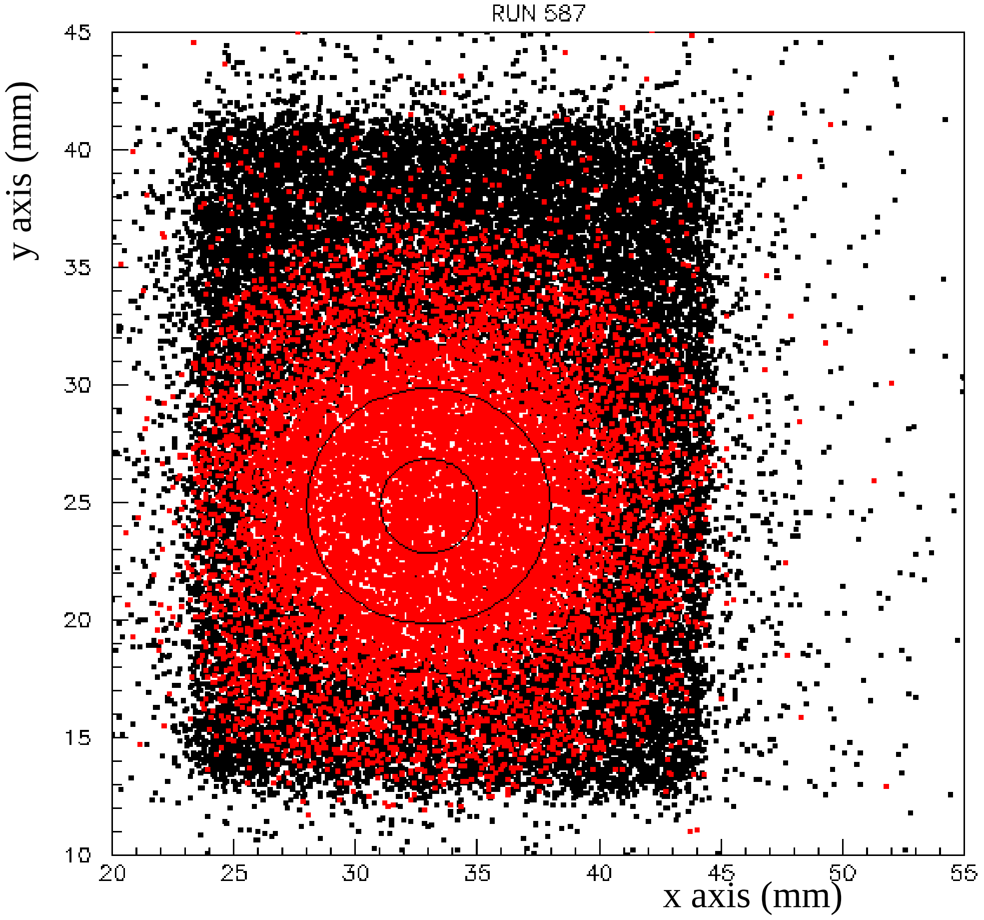
Black: Tracks on large scintillator.

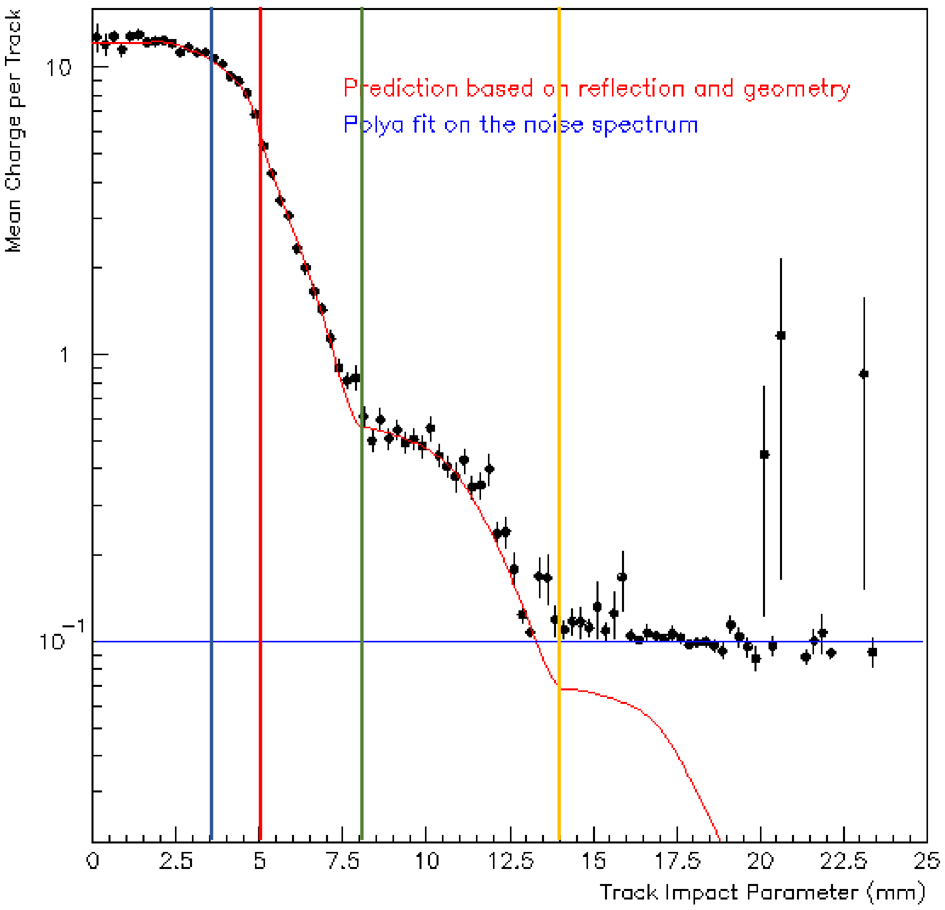
Red: Tracks on the PICOSEC.

Why we detect signal that far away?
Answer: Reflections!



Geometrical Acceptance: A toy Monte Carlo





We used a toy Monte Carlo to find the geometrical acceptance using the geometry of the detector and a free parameter for the probability of reflection. By adjusting the probability of reflection we can describe the mean charge per track versus the impact parameter very nicely. The red line corresponds to the toy model, whilst the blue line to the background noise.

How to estimate the number of photoelectrons per MIP

Number of PEs in the Cherenkov cone: Poisson

$$f(N;\mu) = \frac{e^{-\mu}\mu^N}{N!}$$

Geometrical acceptance

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

Alignment Parameters

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

Multiple photoelectrons charge distribution: Polya

$$P(Q; N, Q_e, \theta) = \frac{1}{Q_e}\frac{(\theta+1)^{N(\theta+1)}(Q/Q_e)^{N(\theta+1)-1}}{\Gamma(N(\theta+1))}e^{-(\theta+1)Q/Q_e}$$

No photoelectrons

$$g(Q) \equiv noise, if\ n = 0$$

Charge distribution for zero and non-zero photoelectrons

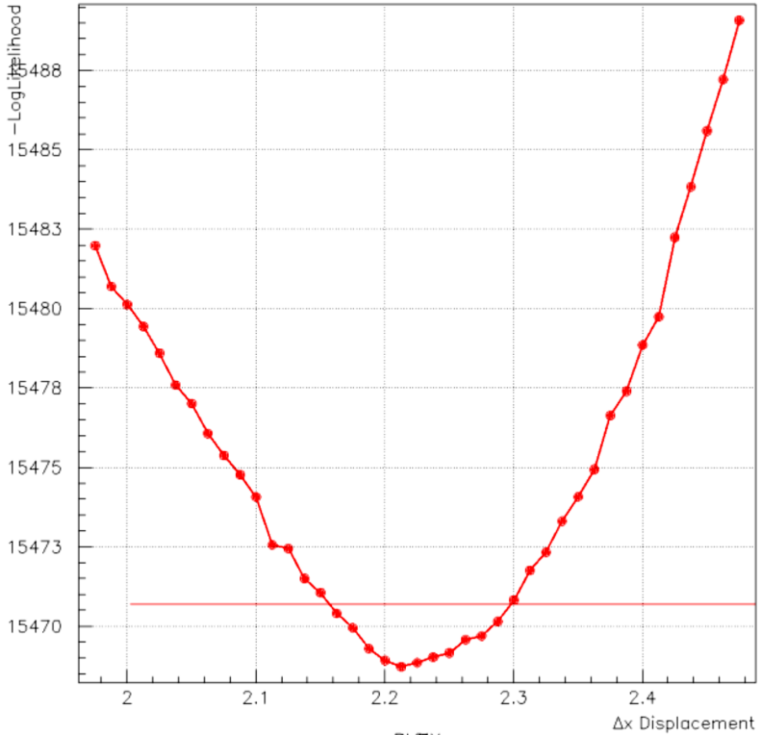
$$G(Q;N) = \begin{cases} P, if\ N > 0 \\ g, if\ N = 0 \end{cases}$$

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

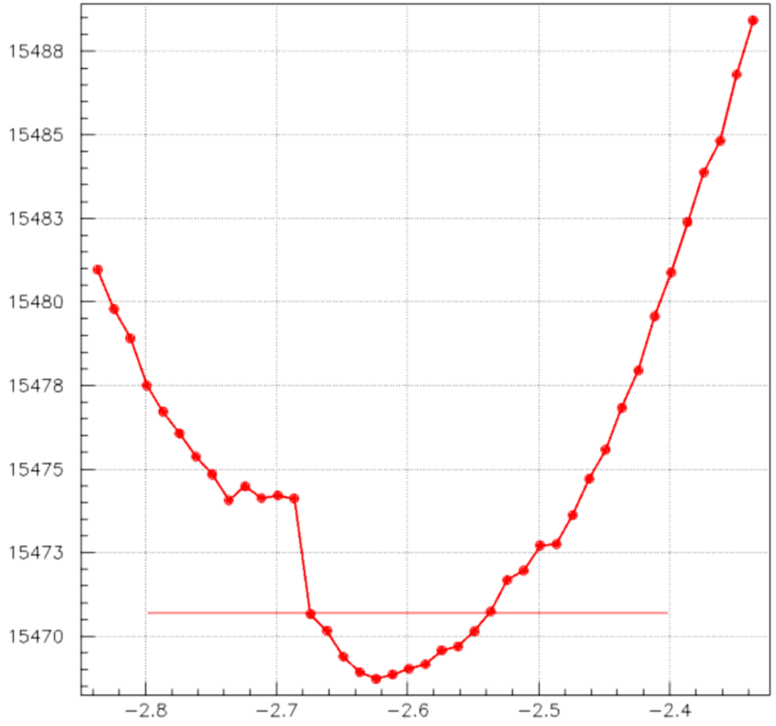
$$L(Q_1, Q_2 \dots Q_M, x_1, x_2 \dots x_M, y_1, y_2 \dots y_M; \mu, \delta x, \delta y) = \prod_{i=1}^{M}\sum_{N=0}^{\infty}\frac{e^{-\mu\cdot\epsilon(r_i)}\cdot(\mu\cdot\varepsilon(r_i))^N}{N!}\cdot G(Q_i; N, Q_e, rms_e)$$

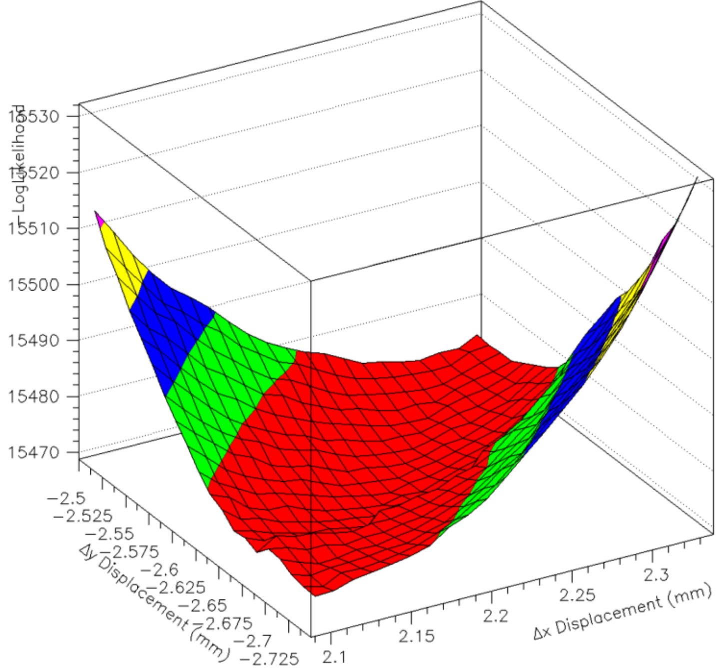
How to estimate the number of photoelectrons per MIP

Xprofile Likelihood

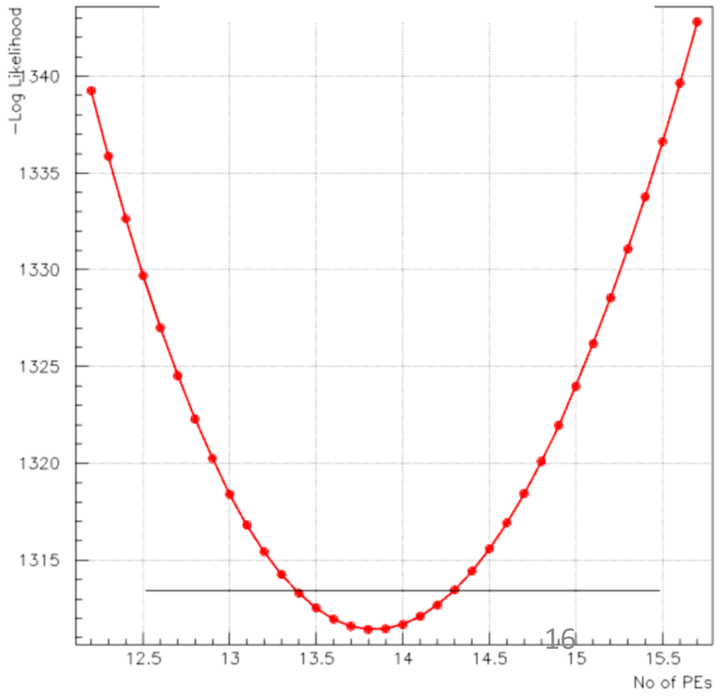


Yprofile Likelihood



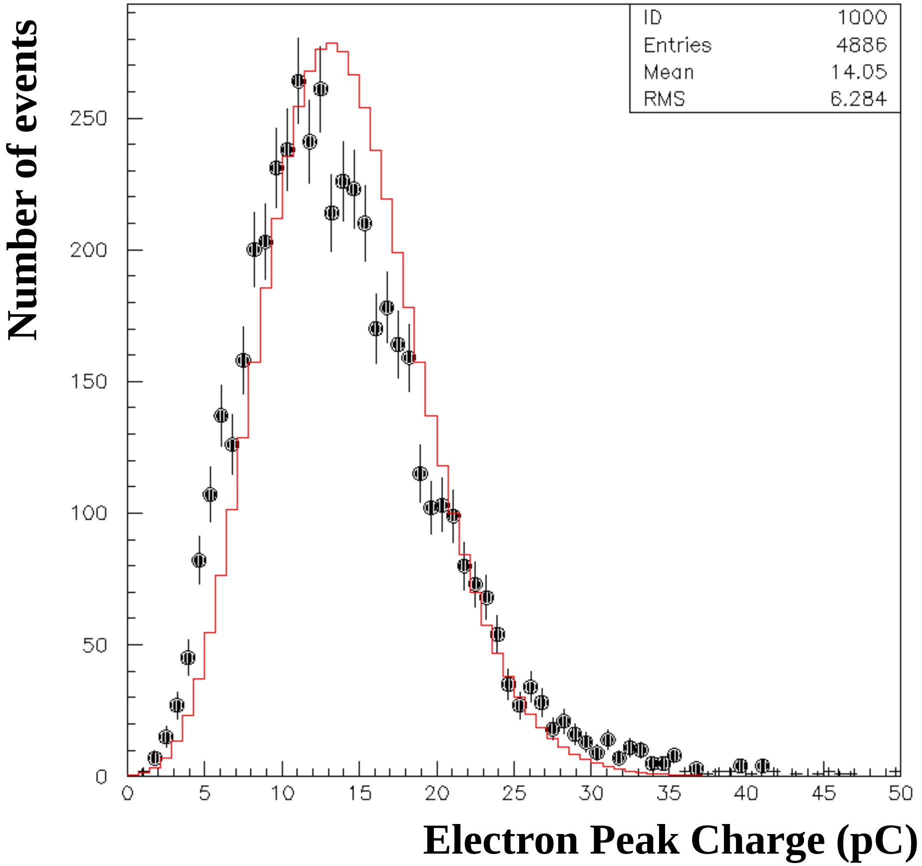


N of PEs Likelihood

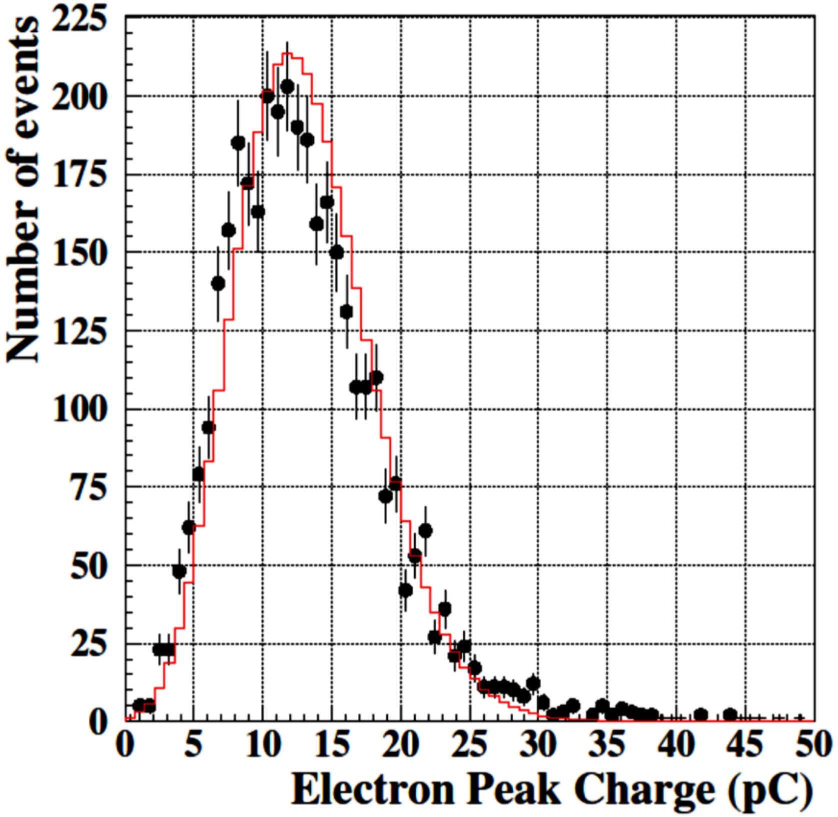


Comparison of experimental results with prediction based on the fit

Run 629
Number of pes: 10.7±0.5



Run 659
Number of pes: 10.0±0.5



Black: data
Red: Prediction

Conclusions

- Fourier Filters do not seem to be able to improve the timing resolution of the PICOSEC signal.
- The timing of the pulse, along with other properties of the e-peak, is extracted from the signal by fitting the e-peak with the difference of two generalized logistic functions.
- The current configuration of the PICOSEC allows the detection of particles that do not pass through the active area via reflected Cherenkov photons.
- The used model for the charge distribution of multiple photons describes the muon test beam data.

Thank you for your Attention!

Back-up Slides

Back-up: Scatter plots for Runs 629&659

Anode: 275 V
Cathode: 475 V
COMPASS Gas