A detailed study of the PICOSEC response to MIPs: number of photoelectrons and timing resolution

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many thanks to F. J. Iguaz, Jona Bortfeldt, K. Paraschou and the AUTH team

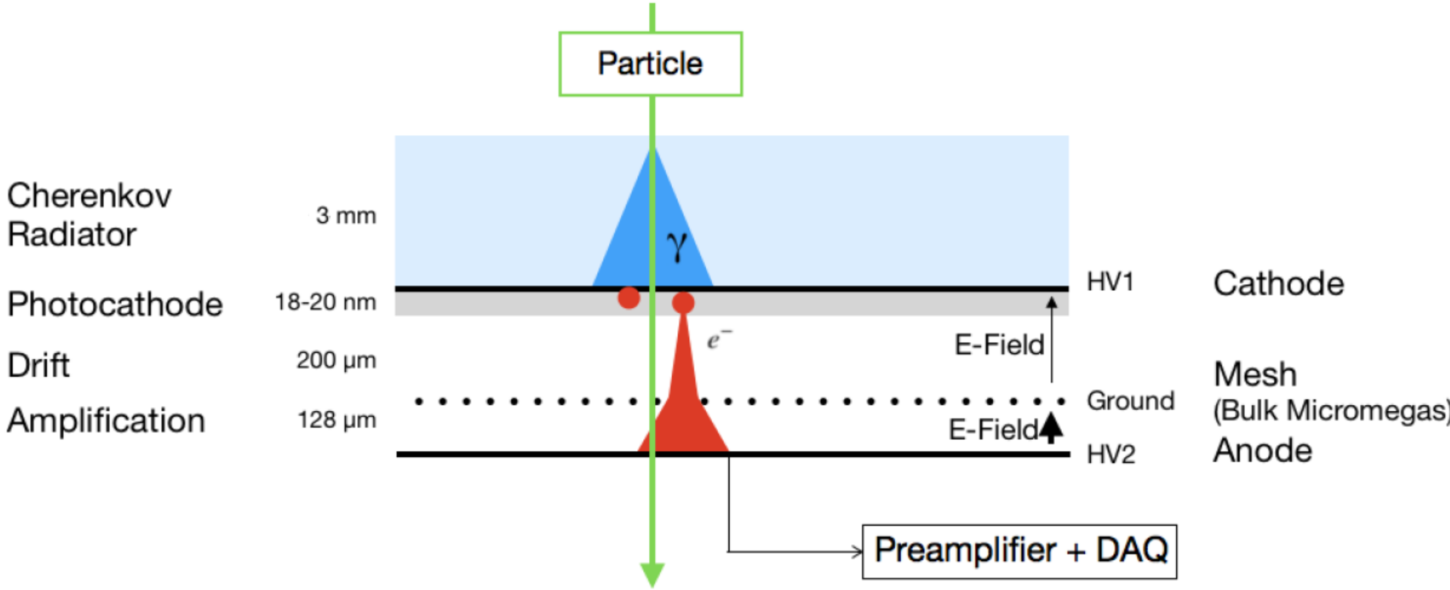
A sort review on the methods used to analyze muon beam data, in order to evaluate the number of photoelectrons produced per MIP, as well as timing performance of the PICOSEC-MicroMegas detector

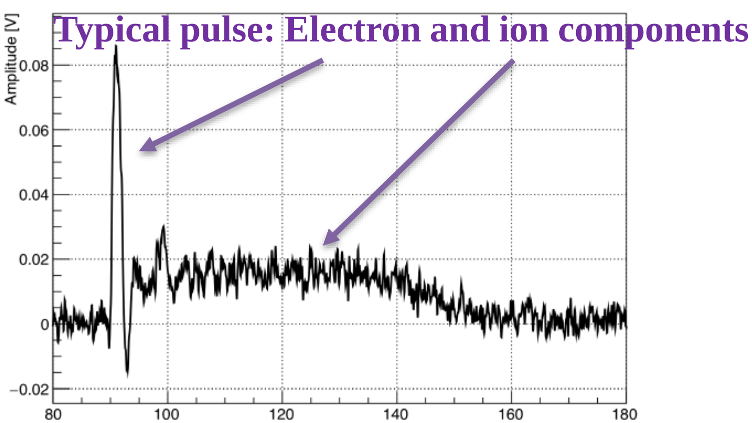
Study of the PICOSEC-MICROMEGAS Response to muon Beam Data

Response of the MicroMegas detector to the muon beam, as well as on single photoelectron from an LED source, in order to evaluate the number of photoelectrons extracted from the photocathode (per MIP) and the timing resolution of the detector.
In addition, findings on the geometrical acceptance of the Picosec detector are presented.

275V anode and 475V drift voltage settings

COMPASS (80% Ne + 10% CF_4 + 10% C_2H_6) gas filling





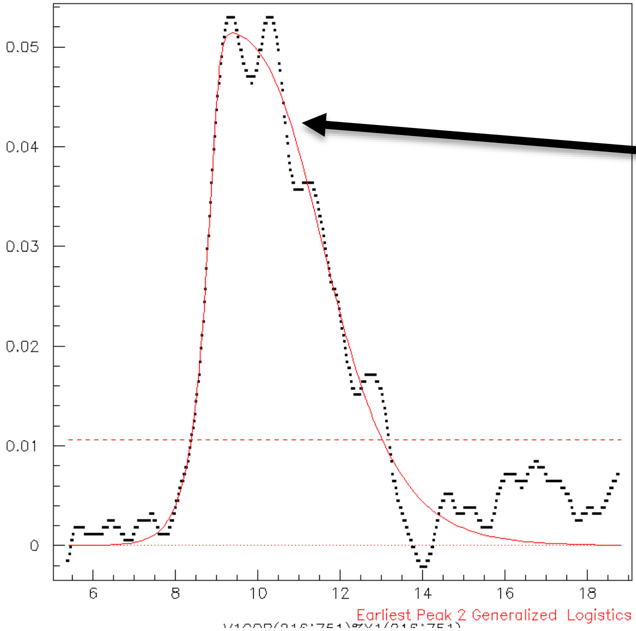
For calibration and timing purposes we used

- **Position tracker: GEMs**
- **Time reference: MCP**
- **Trigger: Scintillators (large or small area)**

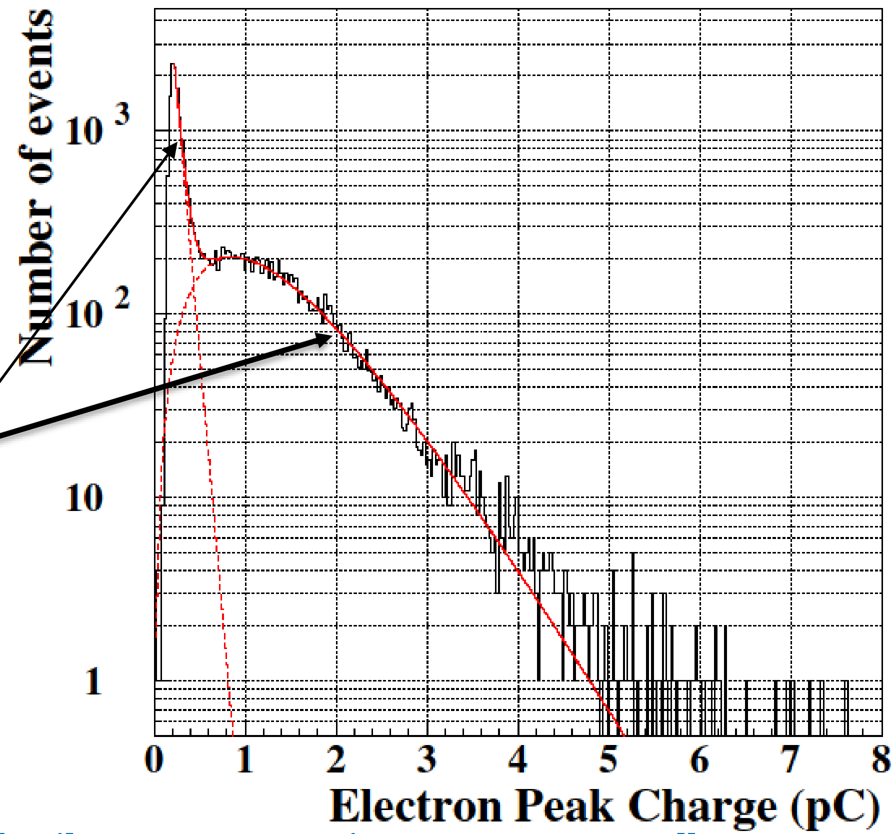
See also K. Paraschou and S.E. Tzamarias talks

Analyzing the LED data

One of signal worst cases



The charge of the electron peak is calculated by fitting the pulse with the sum of 2 Generalized logistics functions in order to reduce noise effects. Charge calculation was performed by several ways with similar results.

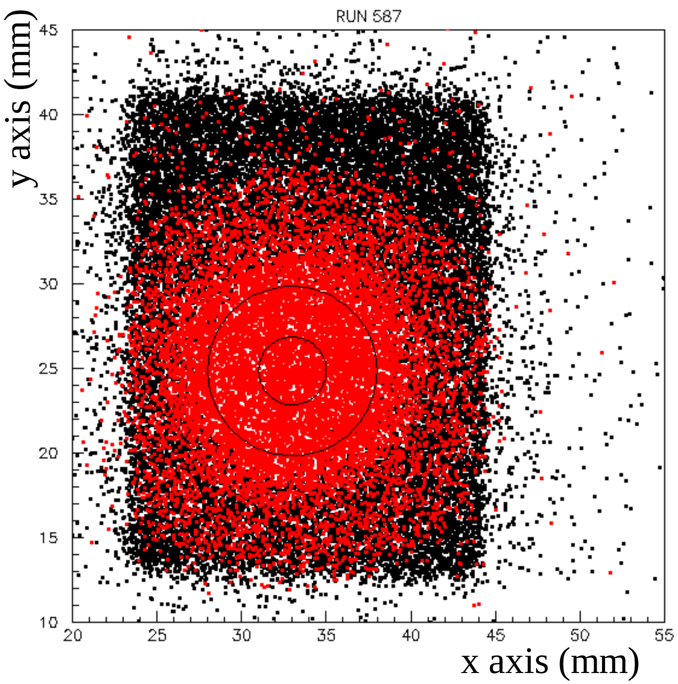


Charge distribution is parameterized by a Polya function.

Noise contribution is exponential.

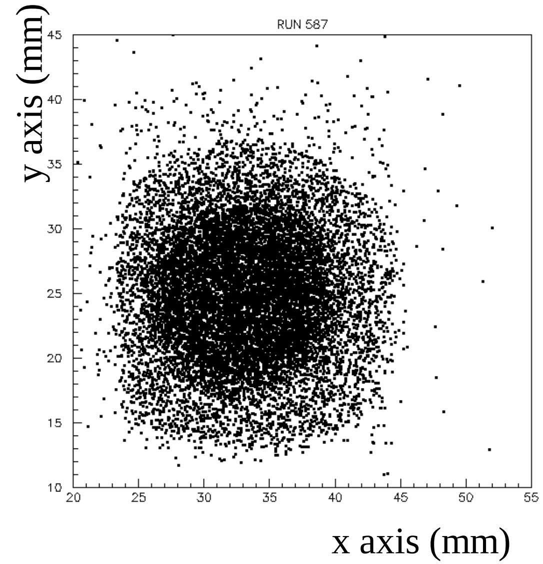
The reason we use these functions is explained in details on S.E. Tzamarias Open Lectures talk.

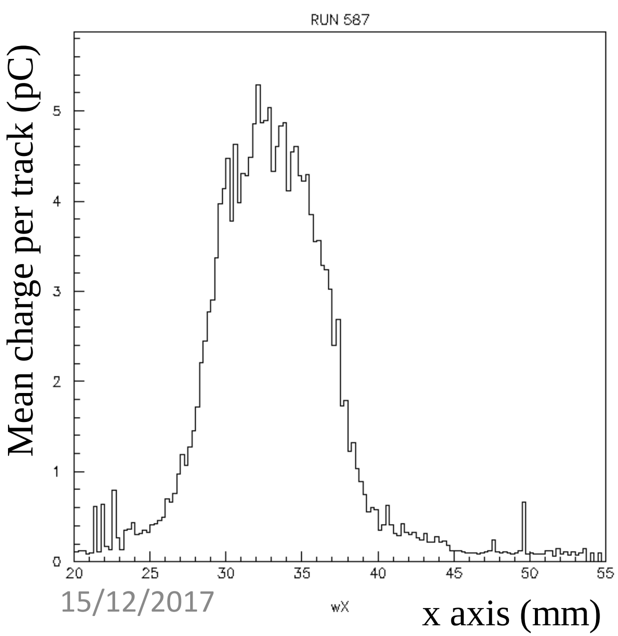
Data from muon beam



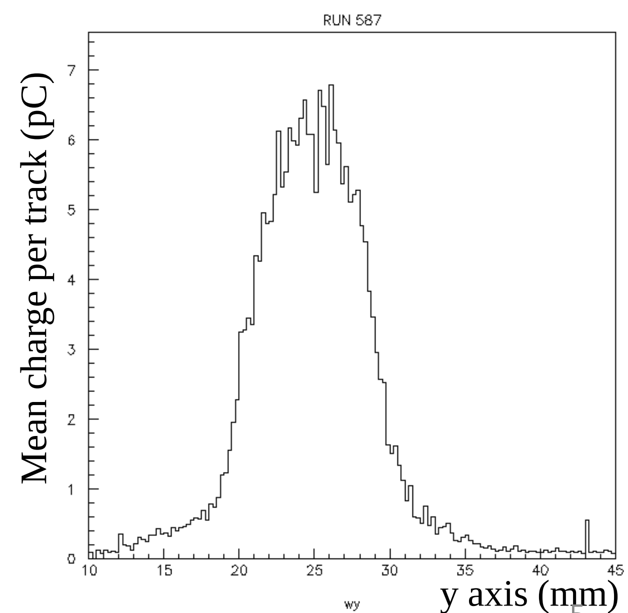
Black: tracks on the (large) scintillator

Red: tracks on the Picosec



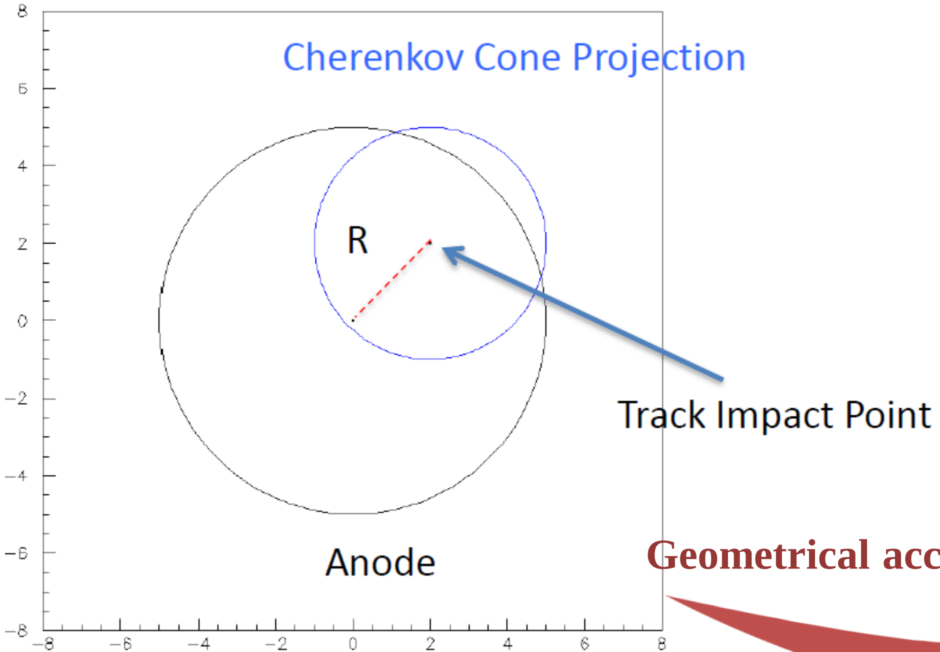


Evaluation of the Picosec position center from the mean values



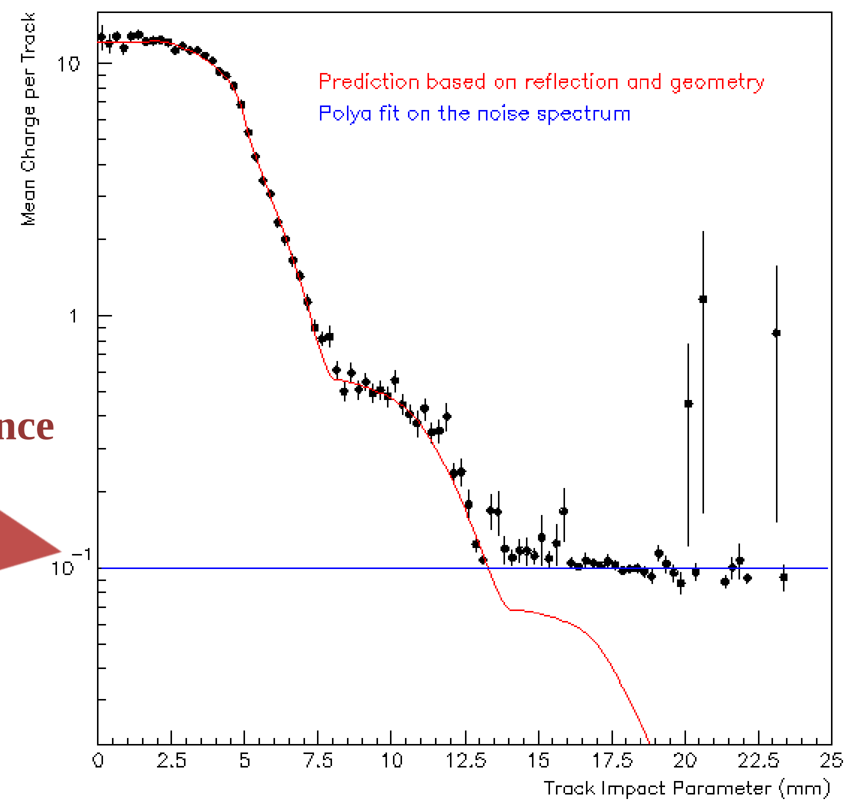
Picosec radius: 5 mm

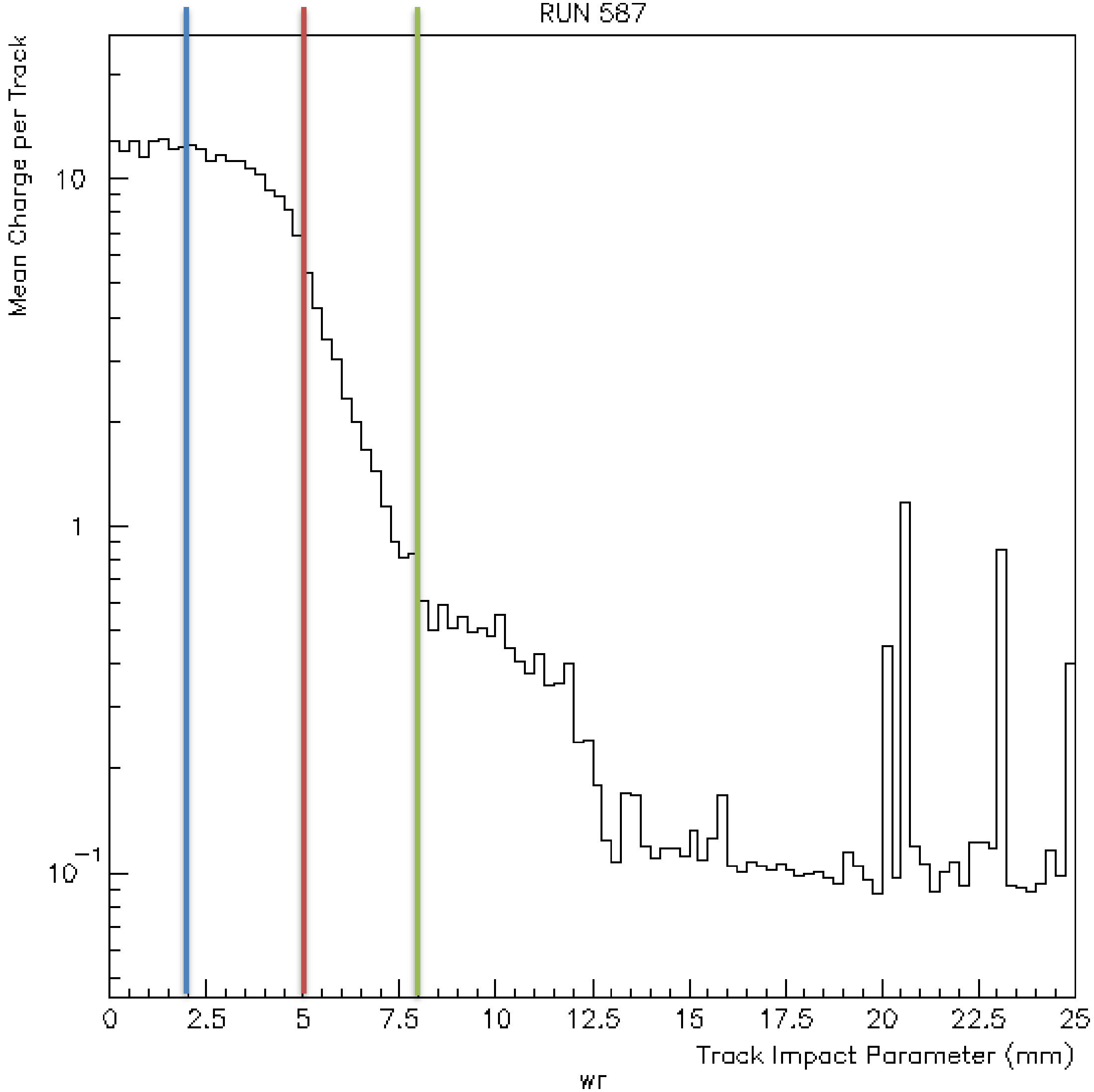
Cherenkov cone radius: 3 mm

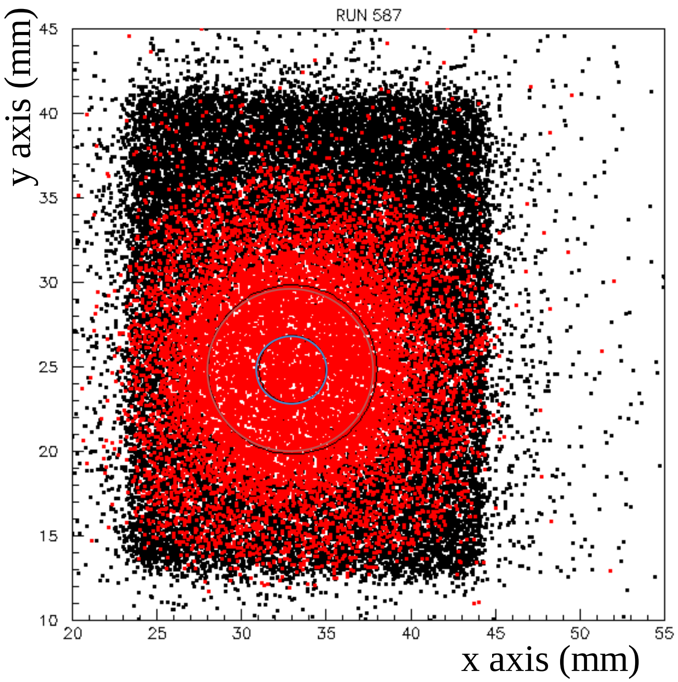


Geometrical acceptance

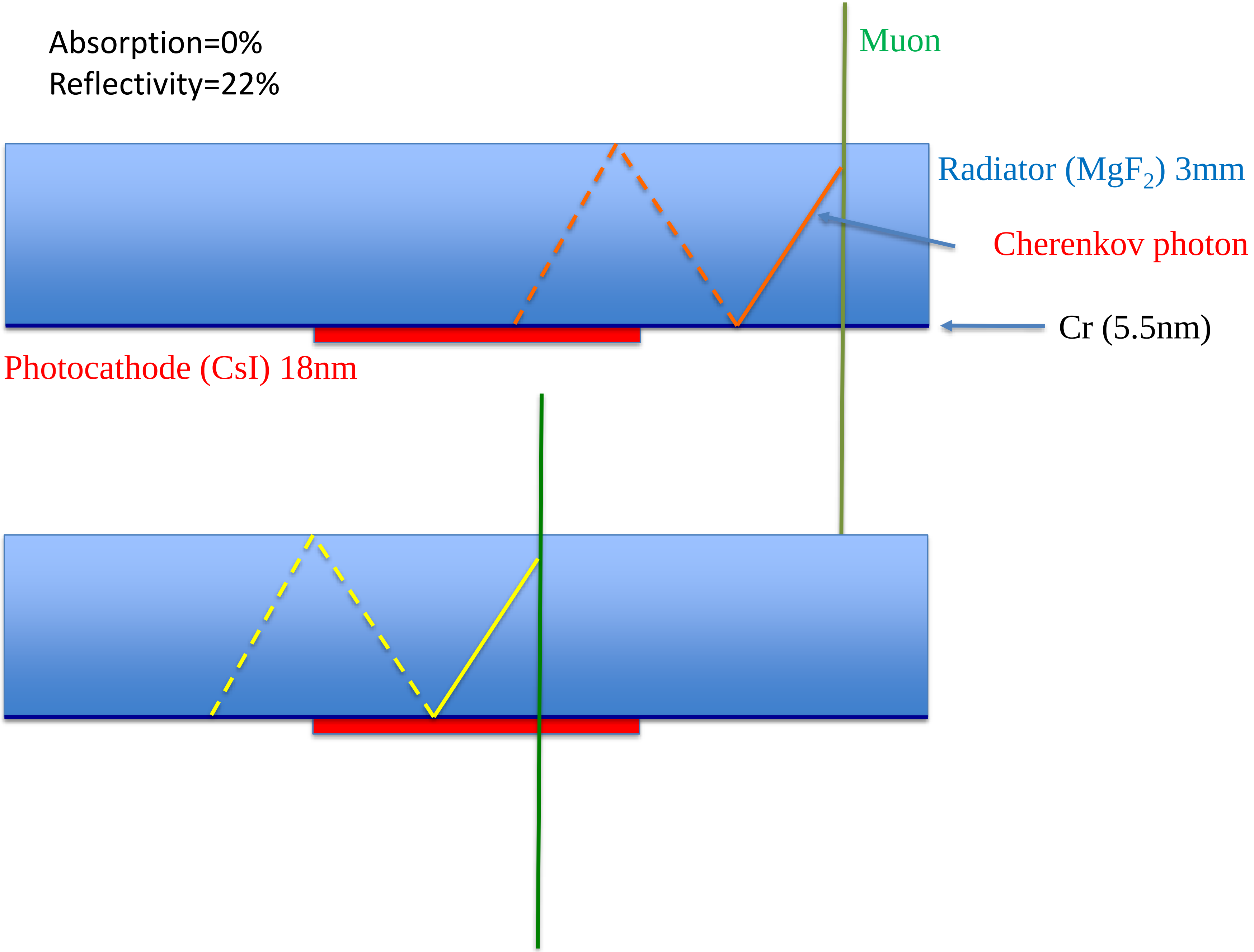
Toy MC

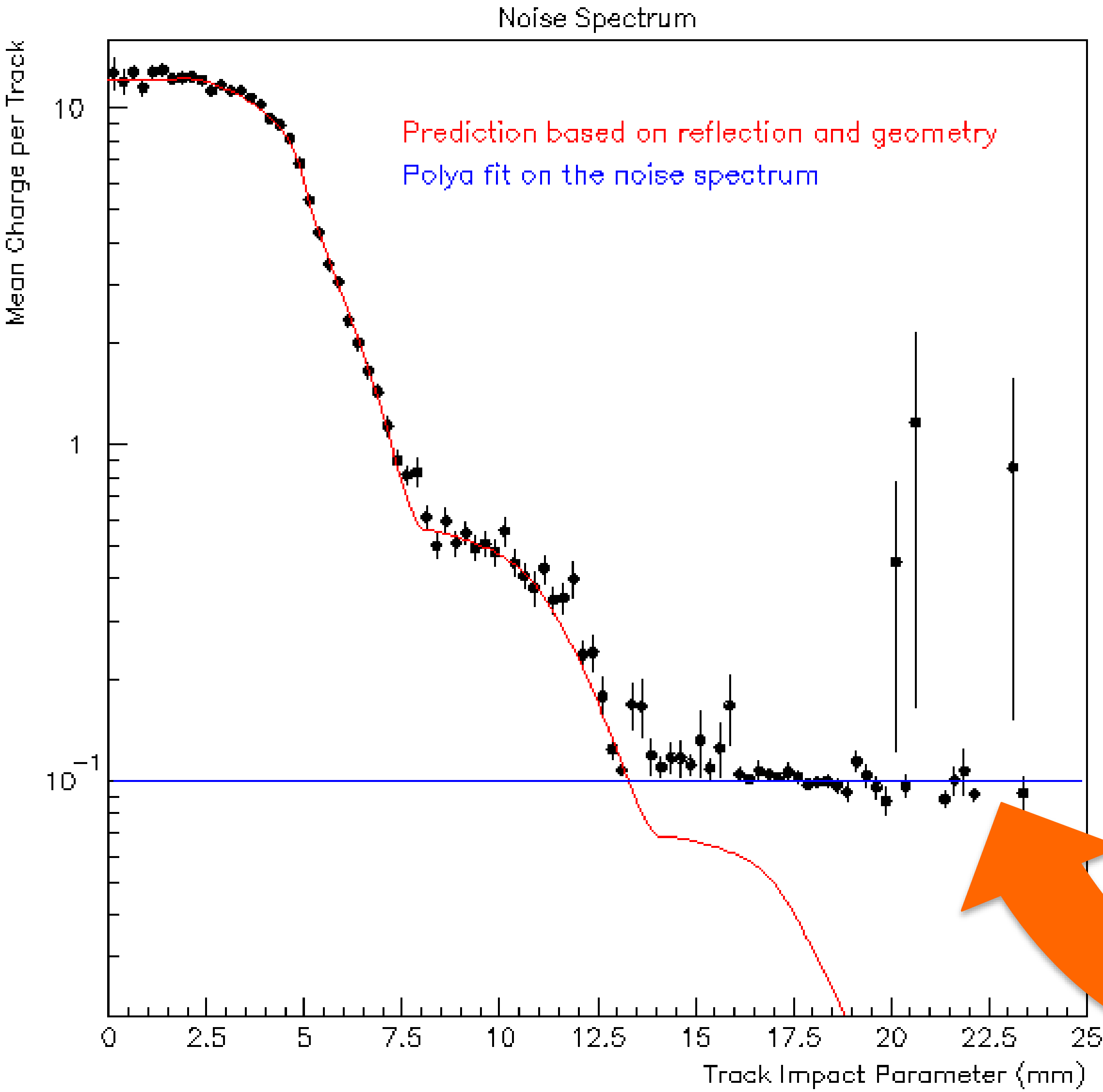


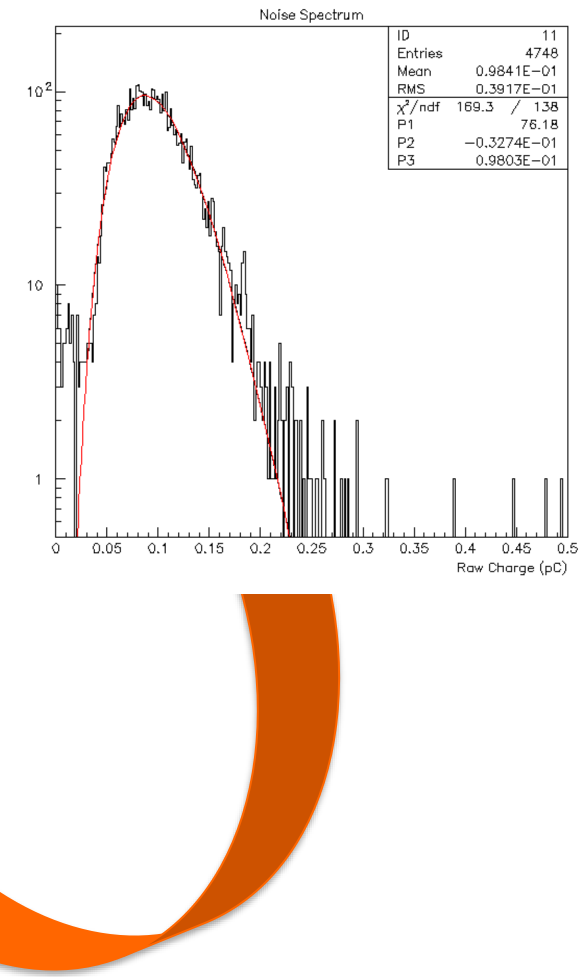

RUN 587
Mean Charge per Track
10
1
10^{-1}
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
Track Impact Parameter (mm)
wr


RUN 587
y axis (mm)
45
40
35
30
25
20
15
10
20
25
30
35
40
45
50
55
x axis (mm)

Absorption=0%
Reflectivity=22%




Noise Spectrum
Mean Charge per Track
Prediction based on reflection and geometry
Polya fit on the noise spectrum
Track Impact Parameter (mm)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
10
1
10^{-1}


Noise Spectrum
ID 11
Entries 4748
Mean 0.9841E−01
RMS 0.3917E−01
χ^2/ndf 169.3 / 138
P1 76.18
P2 −0.3274E−01
P3 0.9803E−01
Raw Charge (pC)

How to estimate the number of photoelectrons per MIP

Polya for multiple photoelectrons charge distribution $P(Q; n, Q_e, rms_e)$

Poisson for the mean number of pes in the Cherenkov cone $f(n;\mu) = \frac{e^{-\mu}\mu^n}{n!}$

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

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

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

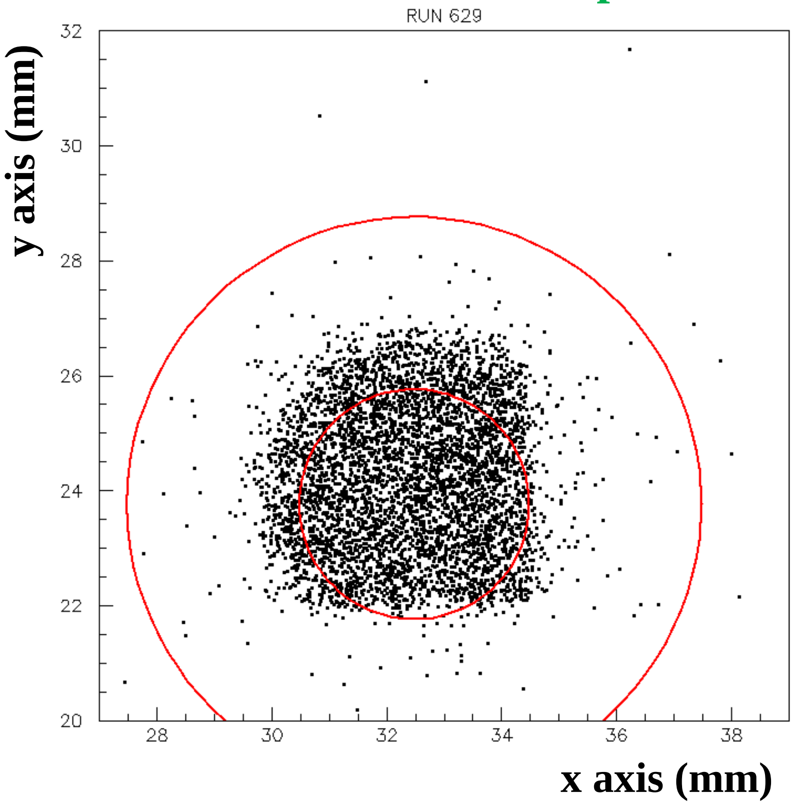
Track displacement $r_i = [(x_i - \delta x)^2 + (y_i - \delta y)^2]$

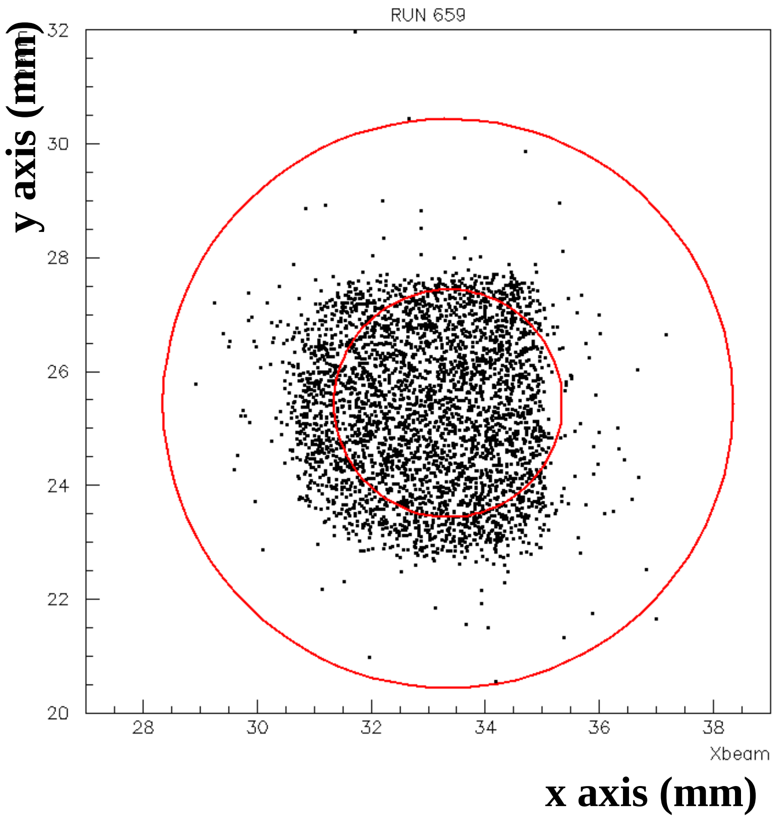
Likelihood minimization to estimate mean number of pes (μ) and true impact parameters (x,y)

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

For detailed explanation see at the AUTH note part A and S.E.Tzamarias talk in Open Lectures.

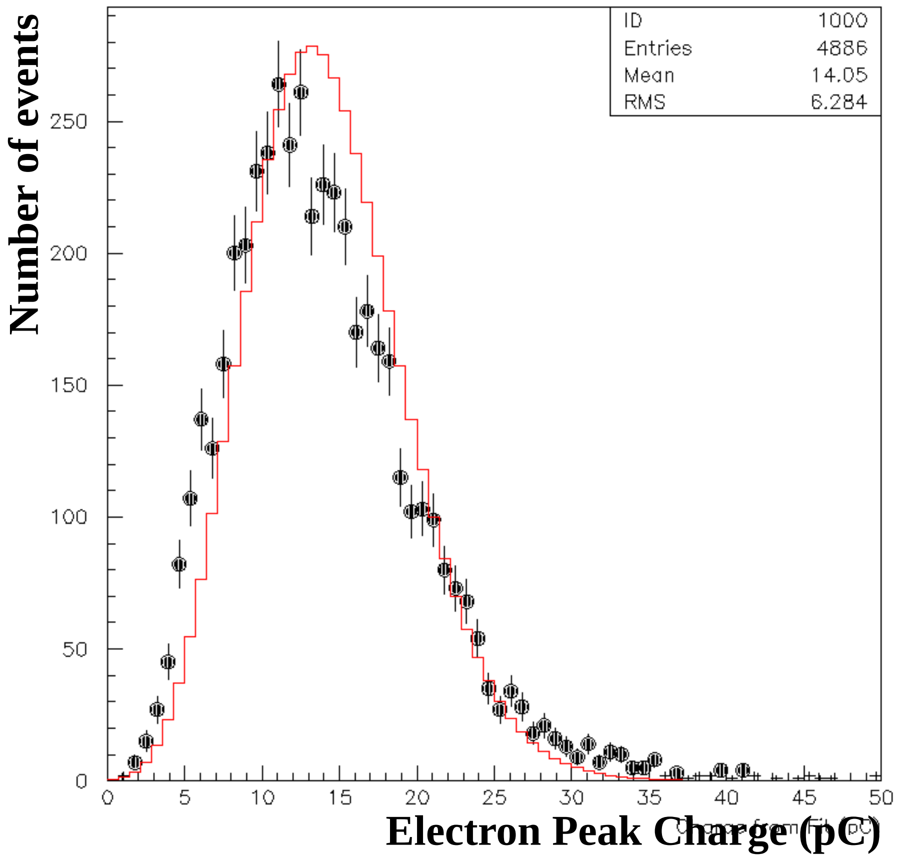
Muon data with small area scintillator trigger
Scatter plot of tracks impact parameter



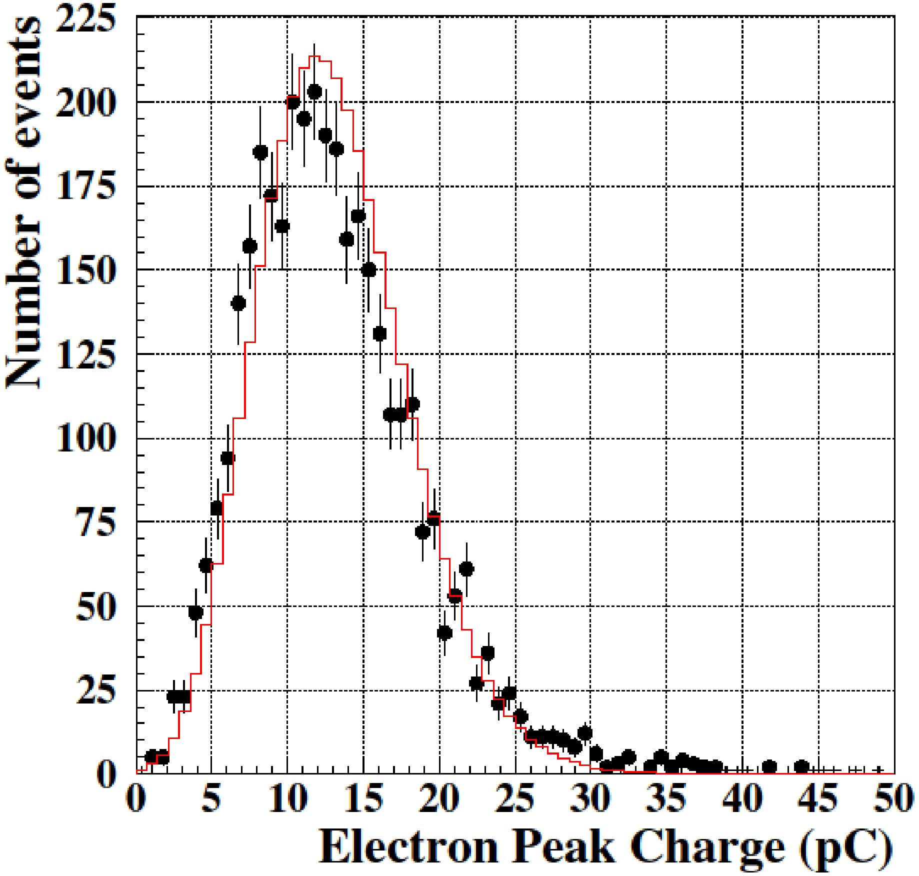


Inner circle - 2mm radius (all photons deposited in photocathode)
Outer circle - 5mm radius (Picosec detector limits)

Run 629
Number of pes: 10.7±0.5

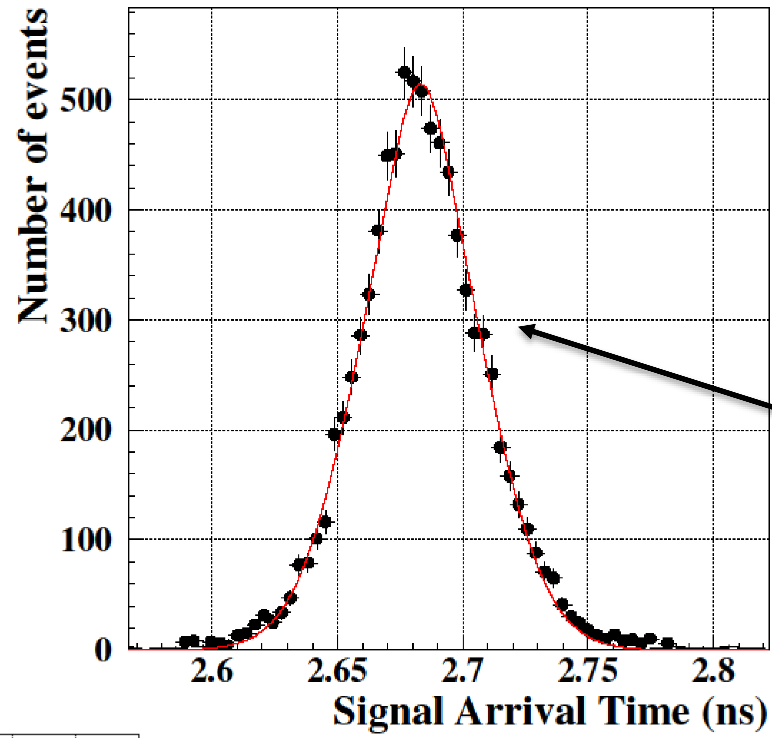


Run 659
Number of pes: 10.0±0.5

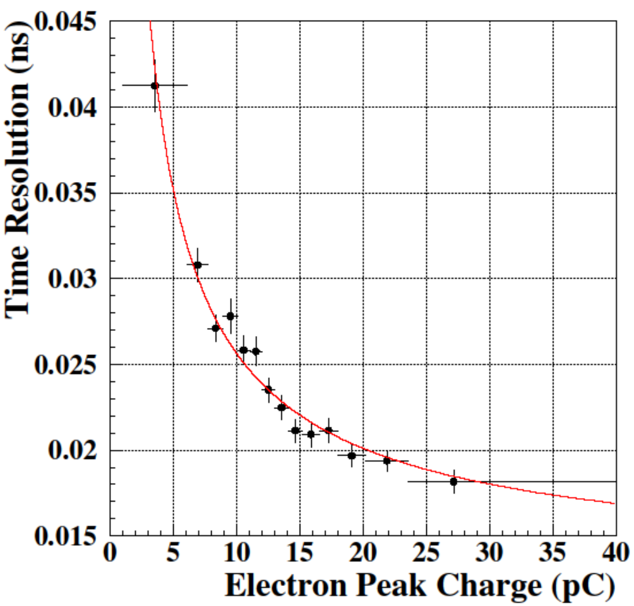


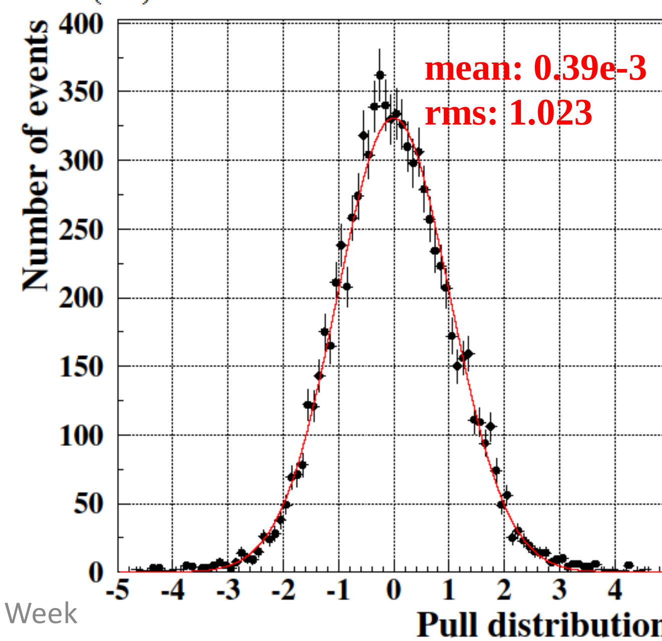
Black: data

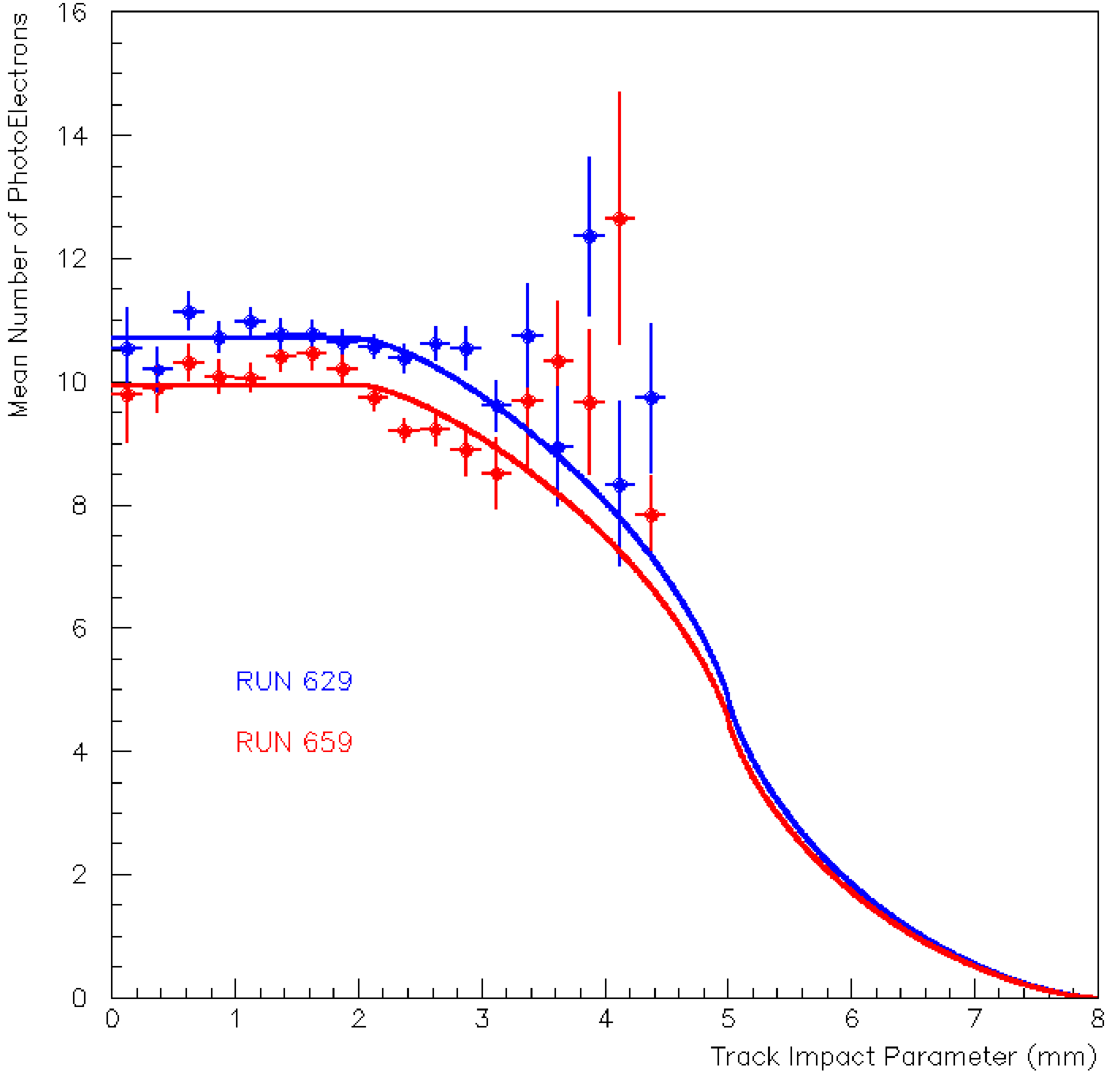
Red: Prediction



24ps resolution!!!!
(rms=24.0±0.3ps)







Muon beam data, trigger from small area scintillator

Mean number of pes distribution w.r.t the track impact parameter for both data sets.

Conclusions

- 24ps timing resolution achieved!
- Better understanding of the detector geometry effects and accurate estimation of the mean number of photoelectrons per MIP.
- Now, we are analyzing the August and October 2017 data from test beam, in different voltage settings and photocathodes
- Resistive PICOSEC MicroMegas included in these tests, with slightly worse resolution, but results are very preliminary.

Thank you for your attention!