ARISTOTLE UNIVERSITY OF THESSALONIKI

PICOSEC Micromegas

AUTH Contribution to the PICOSEC Micromegas Development

Evaluation of photoelectron yield

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On behalf of the AUTH team

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HEP 2019

Athens

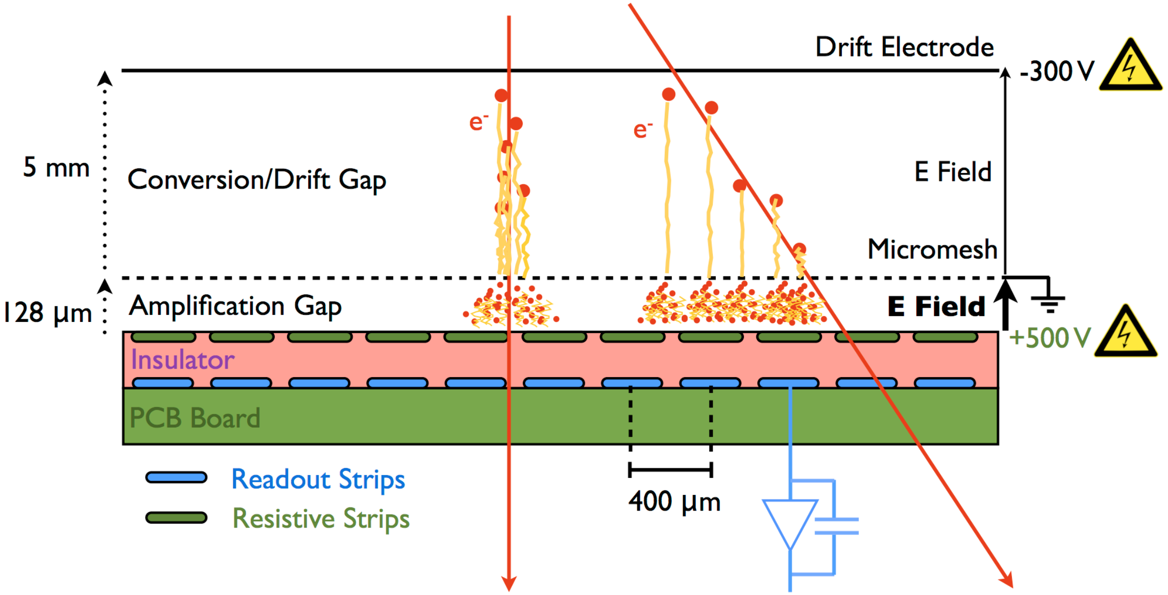
Outline

- PICOSEC Micromegas detector
  - Signal
  - Photocathodes
- A method to evaluate the photocathode yield
  - Alignment
  - Radial profile
  - Estimation of the PICOSEC response to a single photoelectron (pe)
  - Estimation of N_{pe} by fitting charge distribution
- Conclusion

PICOSEC Micromegas

Micormegas: Interaction of incoming particle with gas atoms → ion – *e*⁻ → Avalanche of interactions → detectable signal at the anode

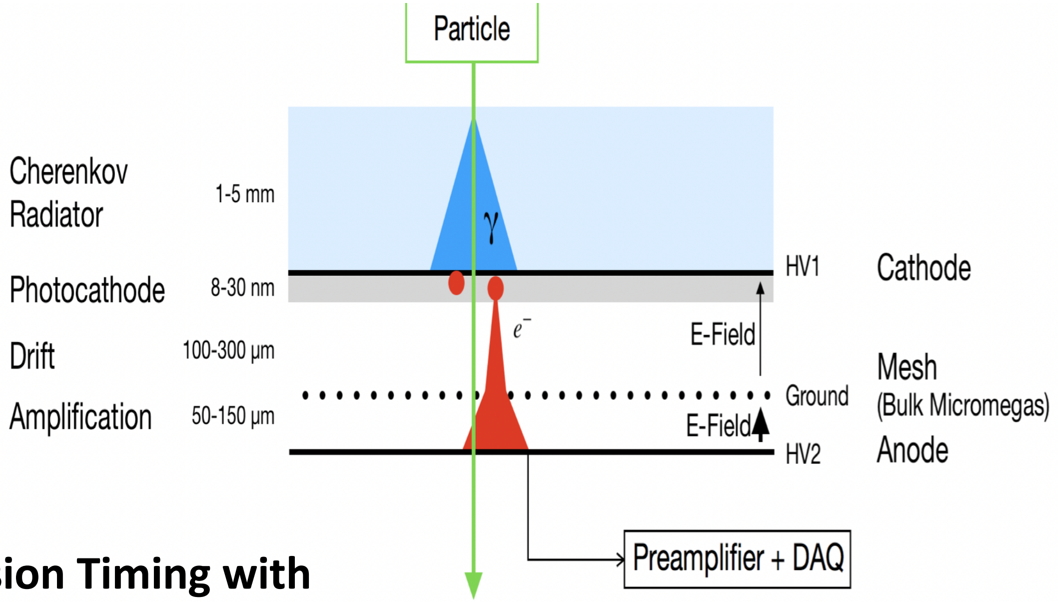
- Combines most of the qualities required for a high-rate position-sensitive particle detector (*Giomataris Y. et al., NIMA 376 (1996) 29)*
- Limit to the time resolution of the detector…There is no hope of improving this time resolution in a gas counter (*Principles of operation of multiwire proportional and drift chambers, Saouli, CERN, 1975*)



- Cherenkov Radiator above cathode
- Photons → e^- by using photocathode (CsI, DLC, etc)
- Photoelectrons traverse classic Micromegas

BUT

- Smaller Drift gap → intense electric field



Time Resolution

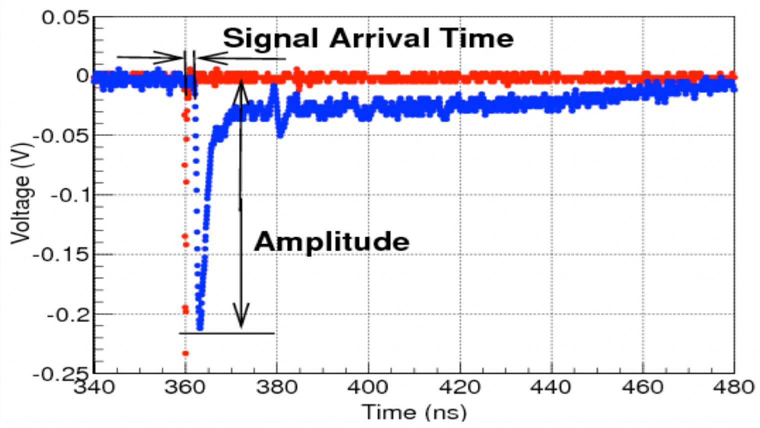
ns → ps

(micromegas) (PICOSEC Micromegas)

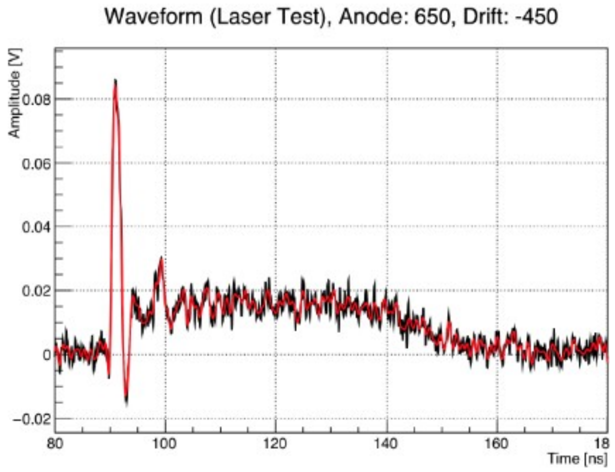
More: S. Tzamarias' talk 19/4 **"Recent Developments on Precision Timing with PICOSEC-Micromegas Detectors: Performance, Modeling and Applications "**

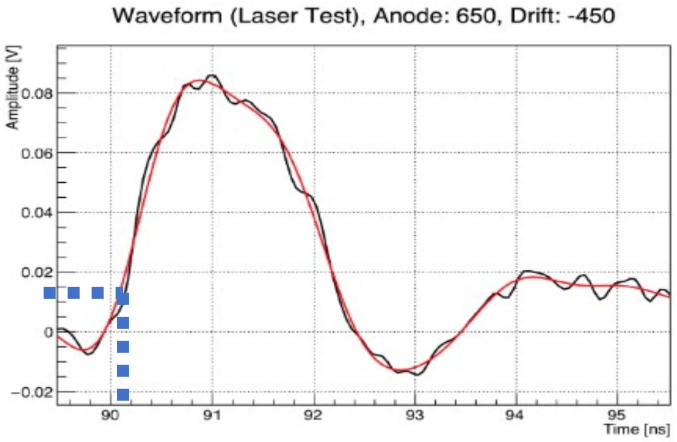
Signal

- e^- arrive faster than ions
  - Signal produced from both
- e^- : electron peak (0.5 ns) and ion tail(100 ns)



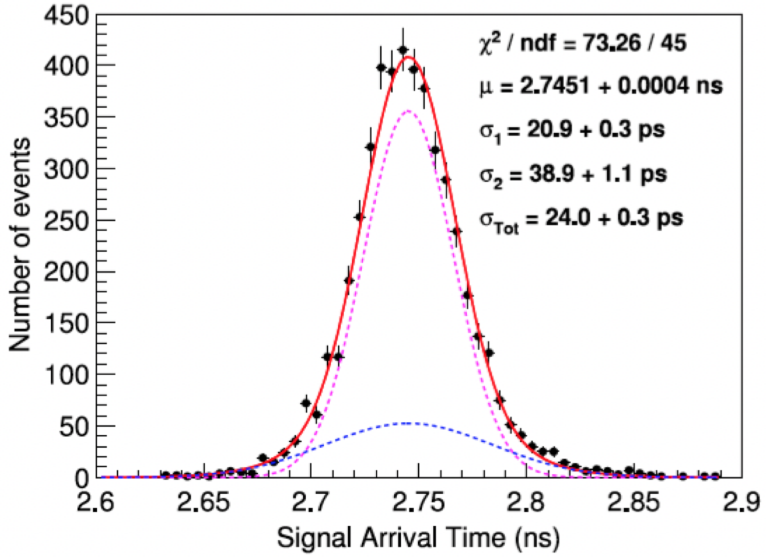
- After inversion of signal and fit processing
- Start point: point with amplitude > 3*RMS noise
- End point: local minimum between peak and ion tail
- Use of constant fraction discrimination (20 % of peak amplitude)

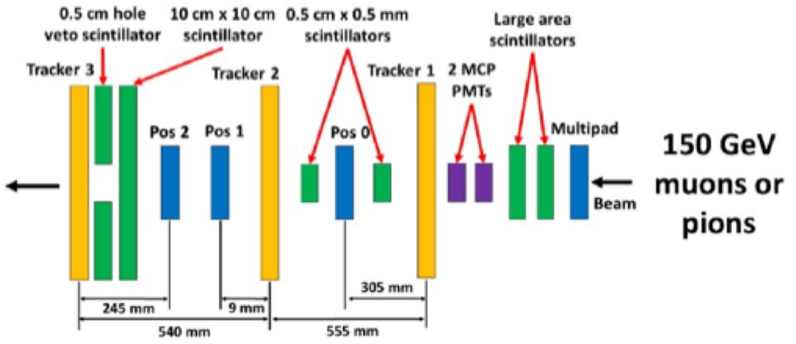




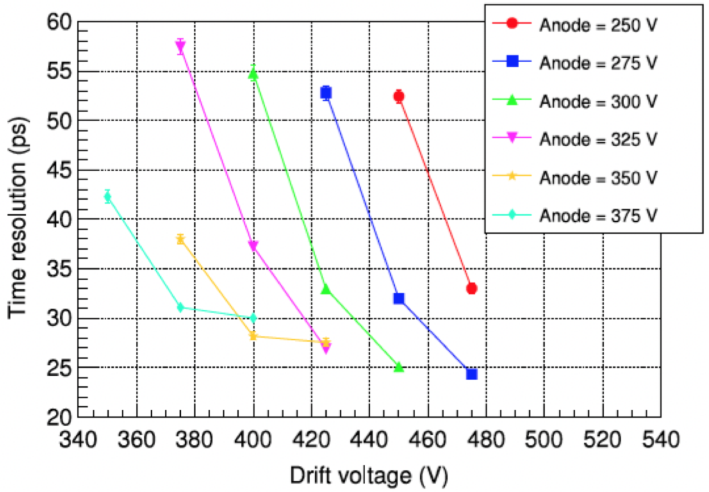
Reminder: The resolution determined in test beam data

- SAT: Timing of PICOSEC waveform - Reference time (photodiode)
  - Mean value → Mean SAT
  - RMS → time resolution
- Dependence of SAT on e-peak charge
  - Drift field (mostly)





- **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.



Robustness of photocathodes

- Precise timing capabilities (24 ps) → High electric field
- Ions backflow (IBF) as a result of high electric field
- Crashing on photocathode
  - Injuring CsI photocathode
- IBF > 60 % at high detector gain
- Robust photocathodes needed

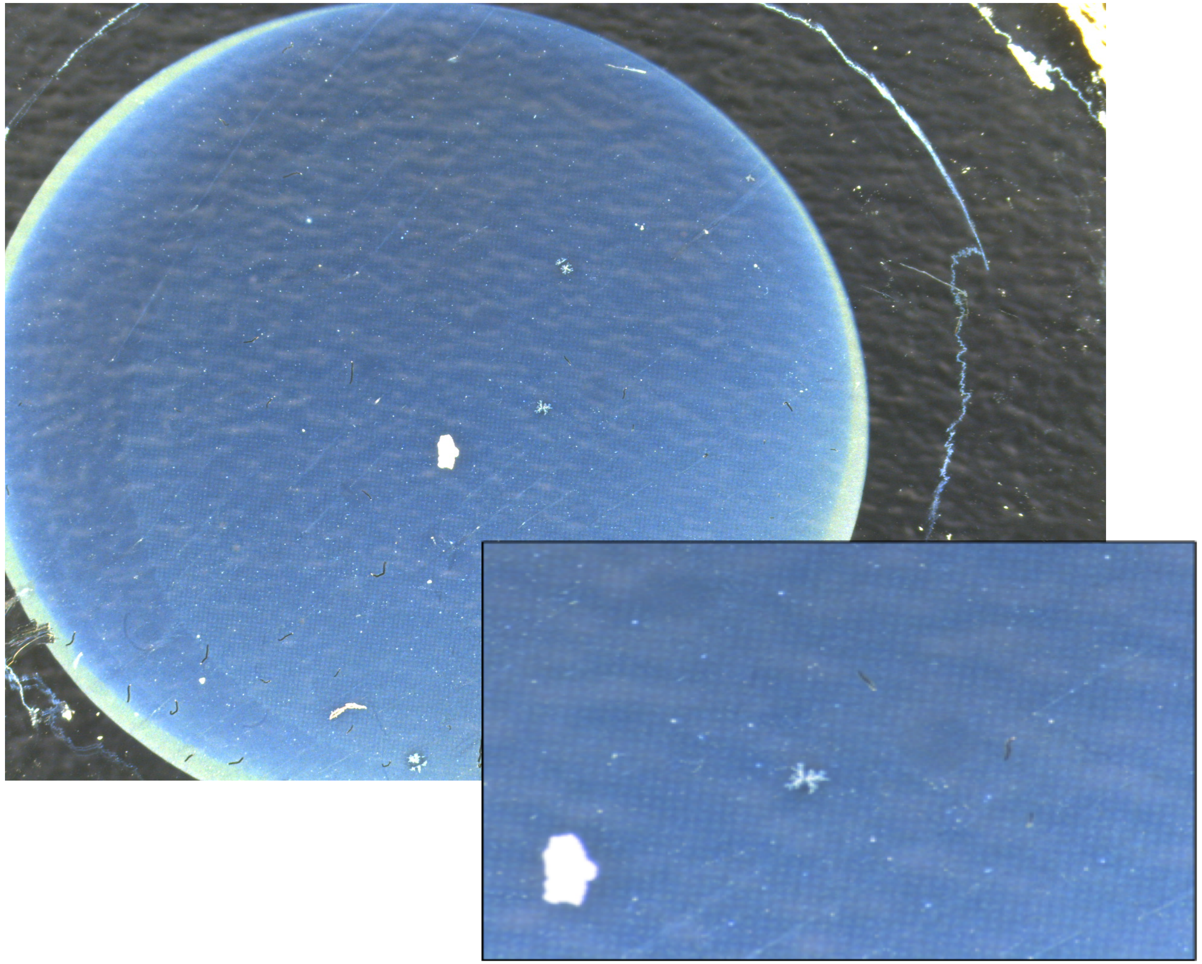


Table 4.2.: Measurement of the IBF in a pion beam at different field

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

L. Sohl, "Progress of the PICOSEC Micromegas concept towards a robust particle detector with segmented readout", 9th Symposium on large TPCs for low-energy rare event detection

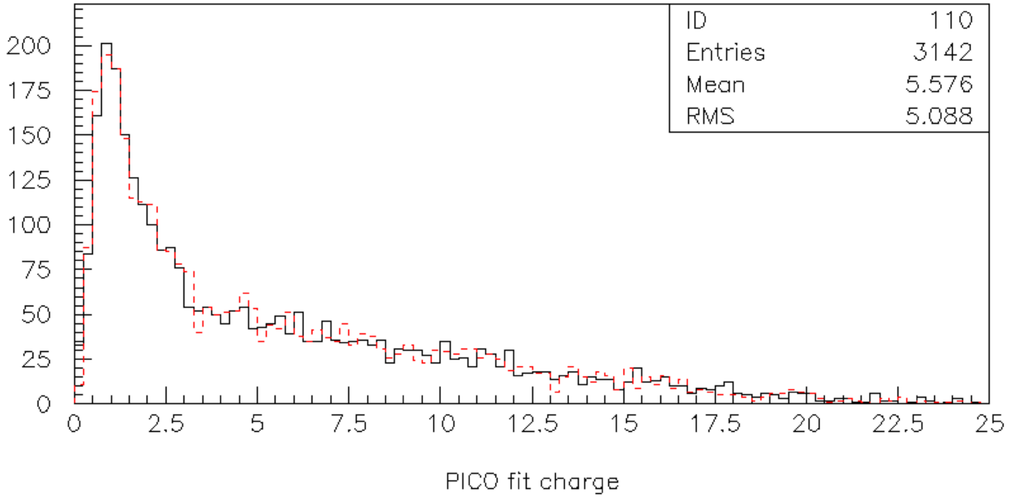
- The best timing resolution is achieved for certain combination of voltages. In principle high timing resolution is achieved at high fields.
- In such case though you risk high Ion Back-Flow which damages the photocathode
- On the other hand a sensitive photocathode provides many photoelectrons, which results in improving the time resolution (~$\sqrt{Npe}$))
- The perfect photocathode should be resistant to damage but it must be also able to provide high number of photoelectrons
- We have developed a technique to estimate consistently the photoelectron yield
- The rest of this talk describes the application of this method to data selected with CsI photocathode

e-peak charge and amplitude distribution

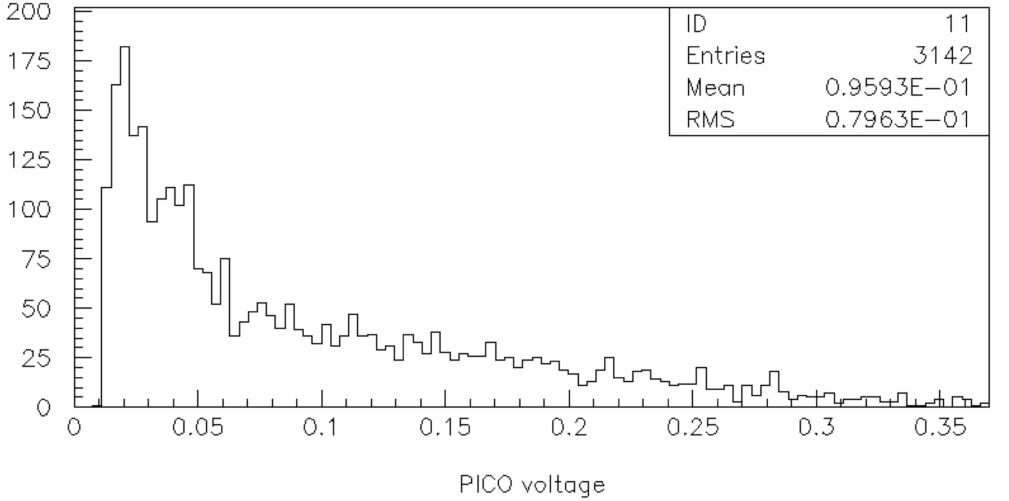
muon run with CsI (August 2018)

Selection criteria

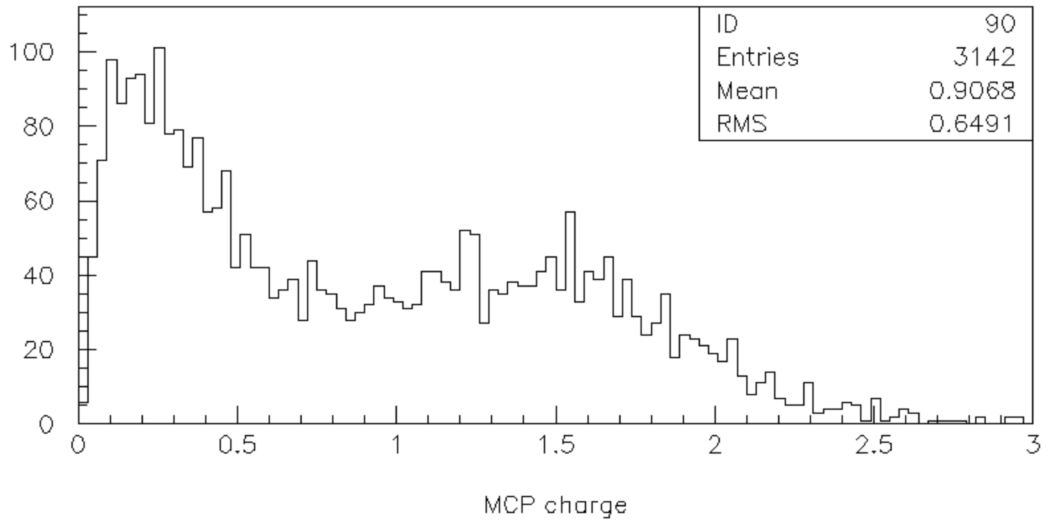
- track $\chi^2 < 0.1$
- 2 < Signal Arrival Time < 3.5 (ns)
- Also pulse amplitude cut < 0.35 V (overflow)

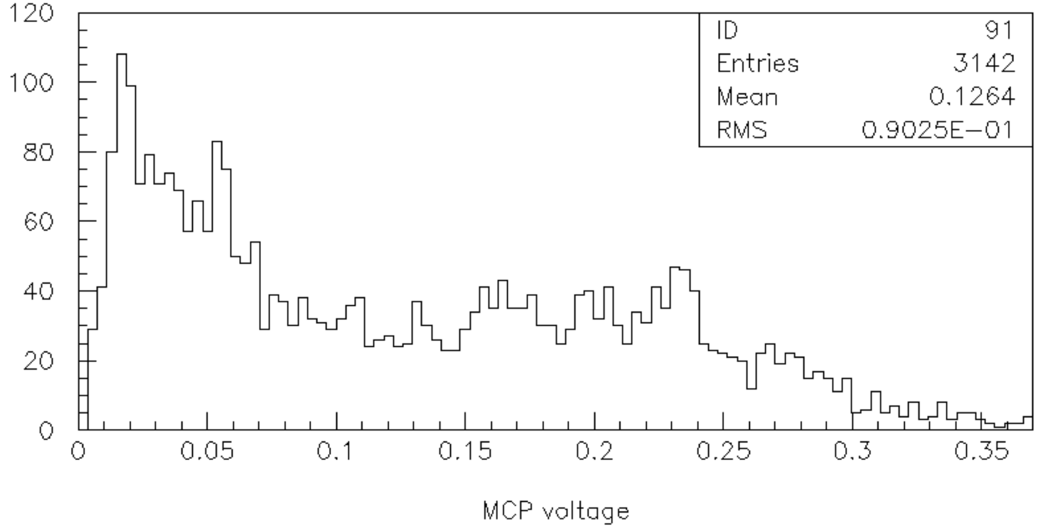


- Charge from fit : Black
- Charge from summing points :Red



The time-reference detector: MCP



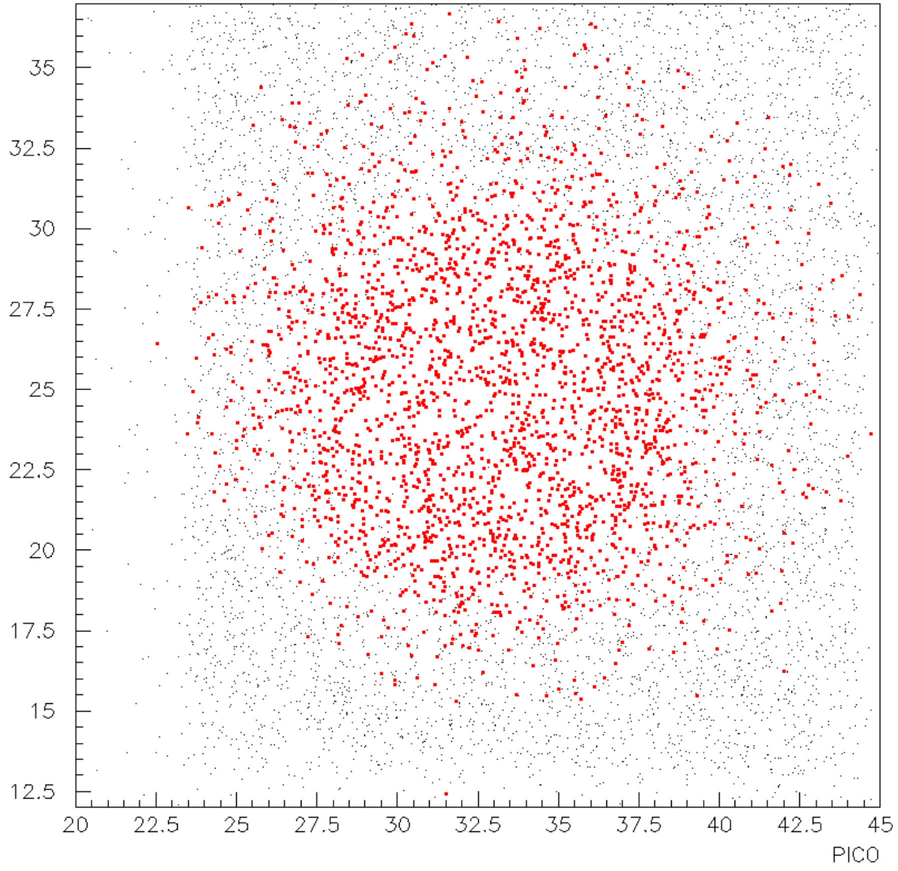


1) The first step: Align the detector

X vs Y tracks

Black points: All tracks
Red points: 2 < Signal Arrival Time < 3.5 (ns)

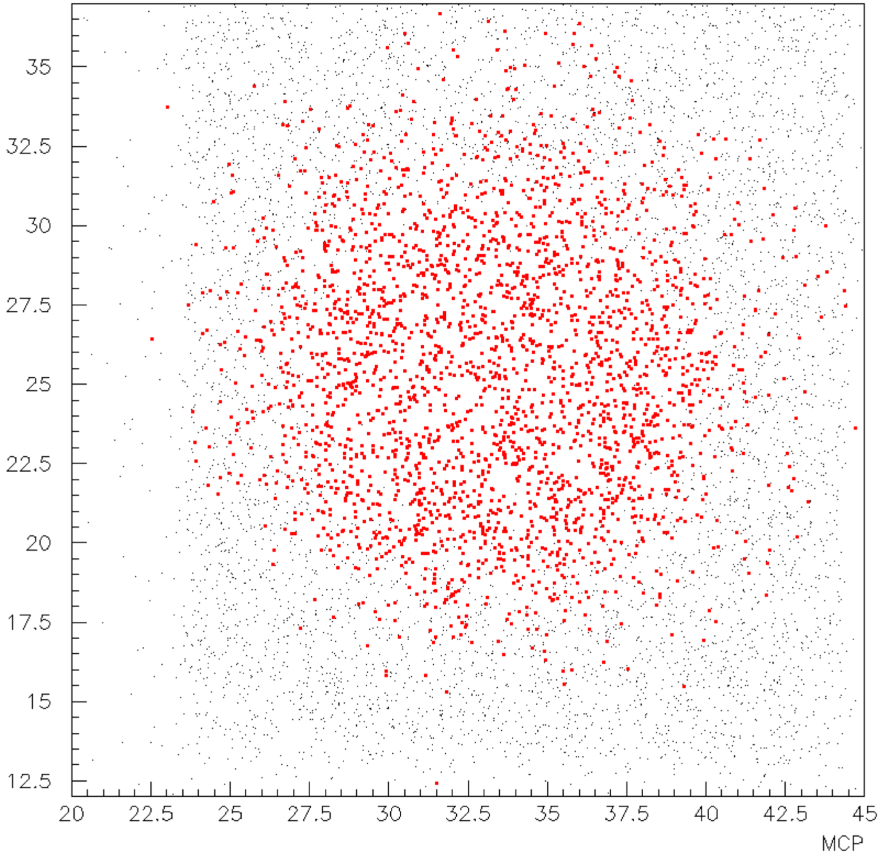
PICOSEC detector



q_e > 1 pC

q_e > 0.2 pC

MCP

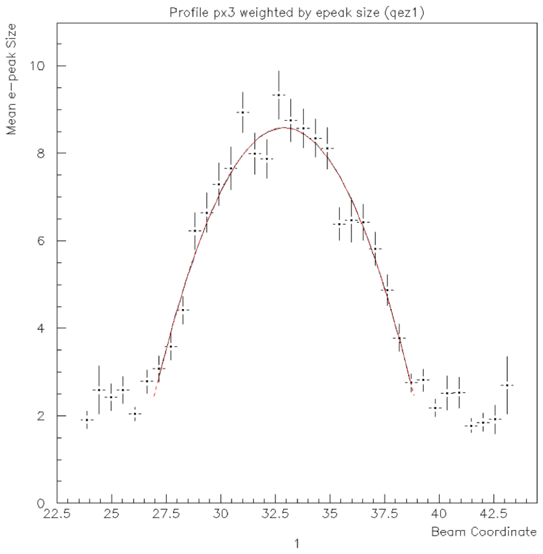


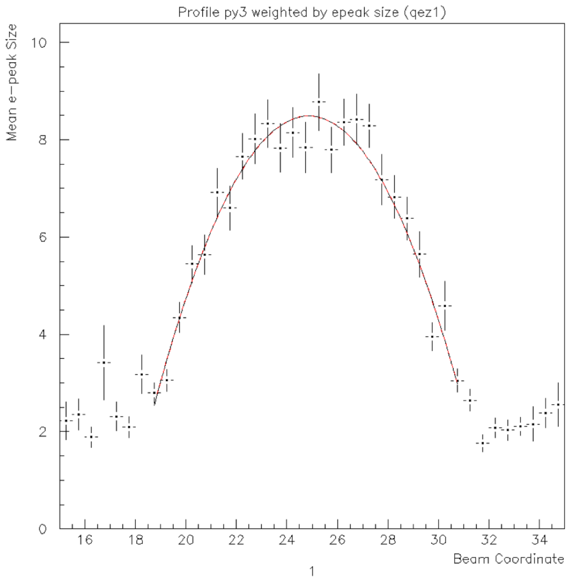
PICOSEC alignment

Symmetric shape → Parabolic fit

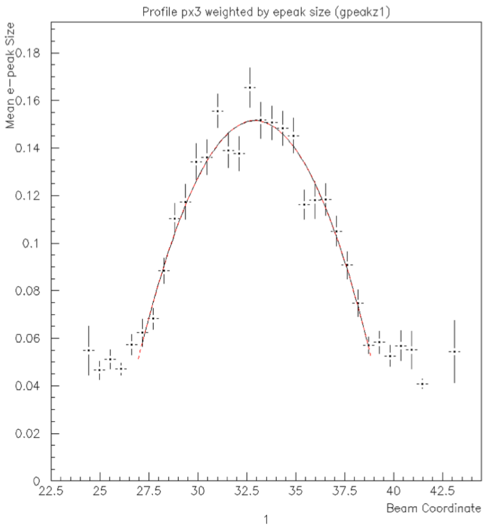
- x = 32.875 error = 0.05
- y = 24.869 error = 0.06

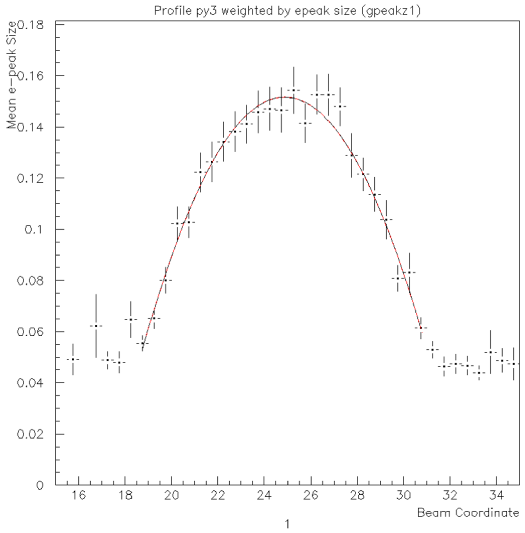
Weighted by e-peak charge





Weighted by e-peak amplitude

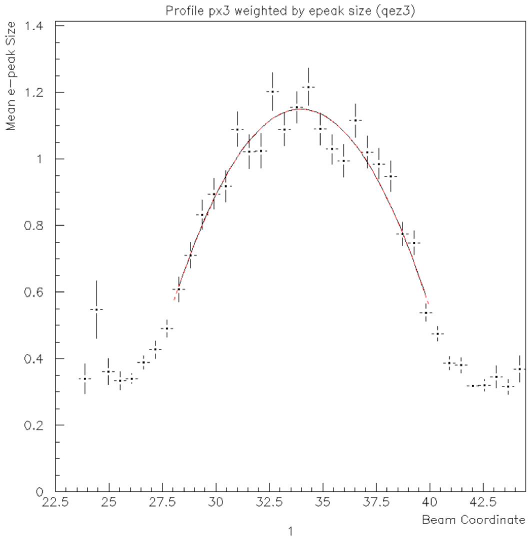


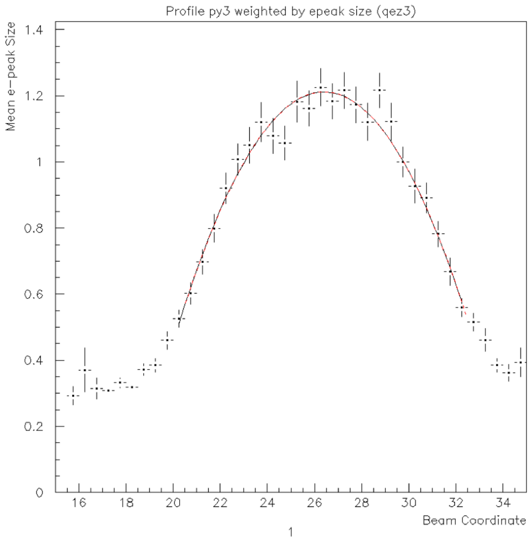


MCP alignment

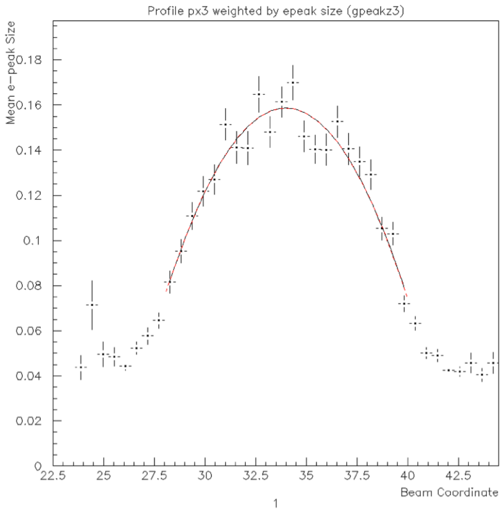
x = 34.096 error = 0.06
Y = 26.450 error = 0.06

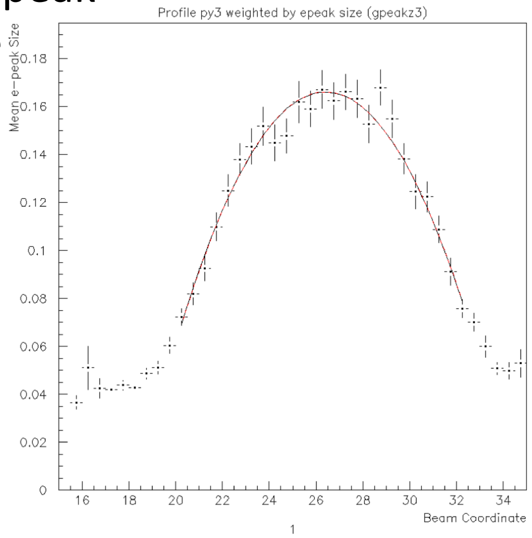
Weighted by e-Peak Charge





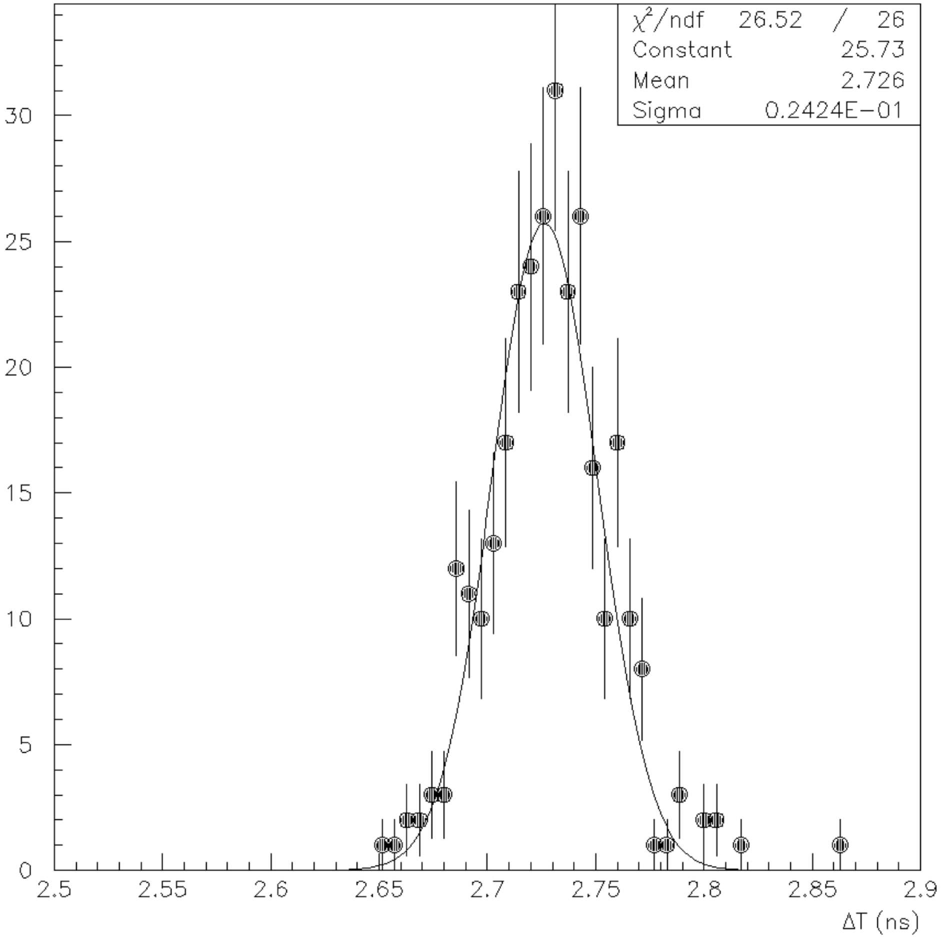
Weighted by e-peak Amplitude





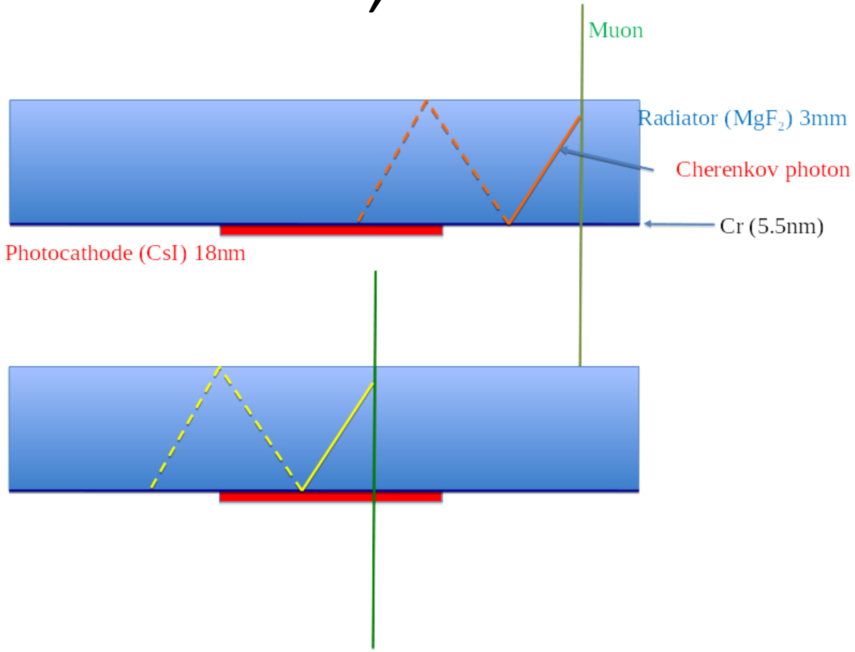
Having aligned the detector, we select tracks that are passing through the center of the PICOSEC (R< 3mm)

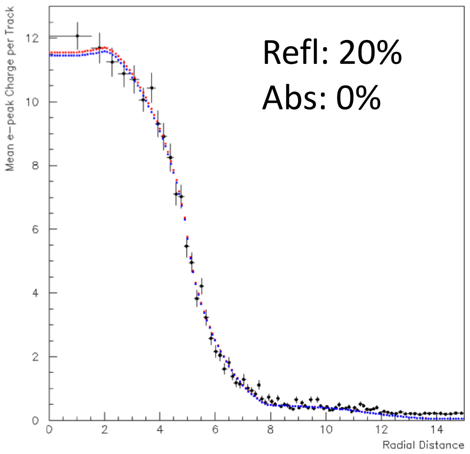
The Cherenkov ring of these tracks is fully contained in the effective area of the detector

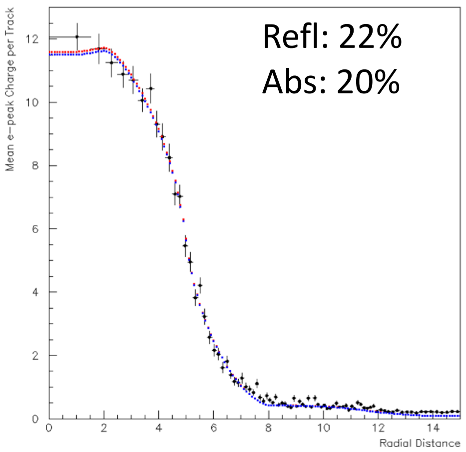


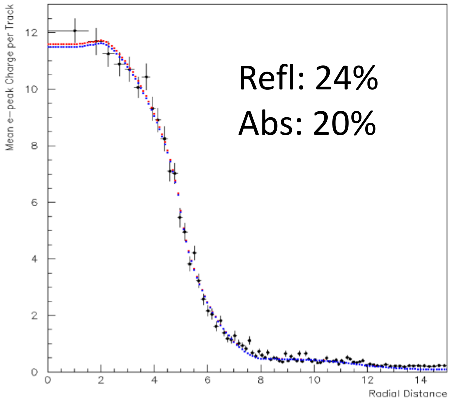
Time resolution of fully contained tracks (R<3mm)

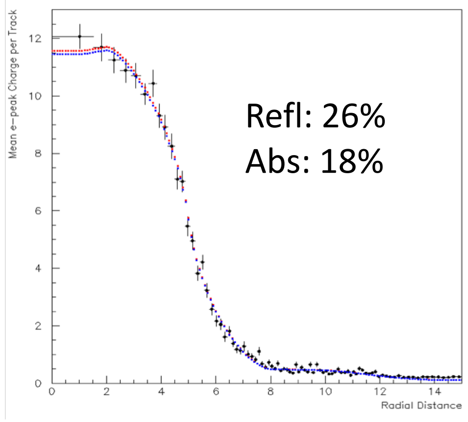
Radial Profile
However as the track passes further away from the center, the detector sees fewer photoelectrons











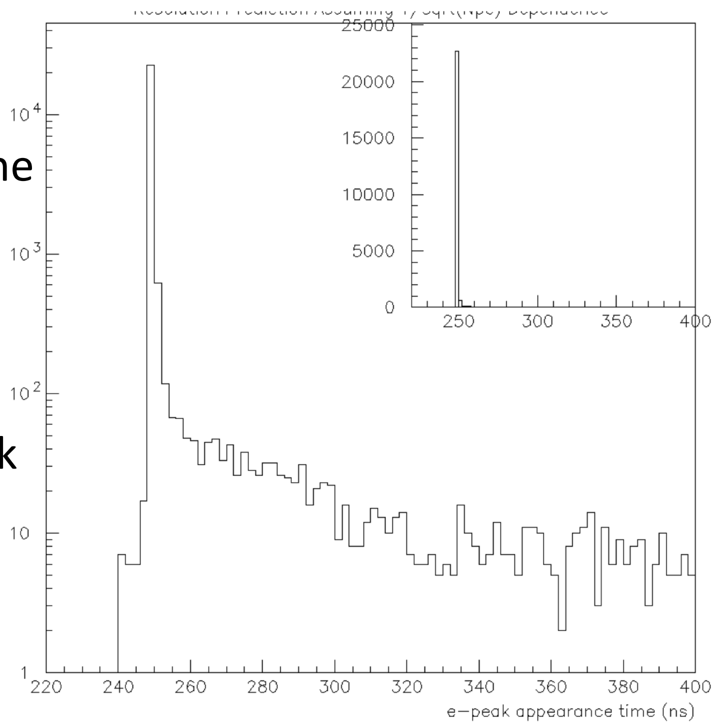
- Charge is estimated by fitting the e-peak waveform
- Red and blue: normalizing to number of events in deferent portions of the distribution

2) E-peak charge and amplitude distribution from single photoelectrons

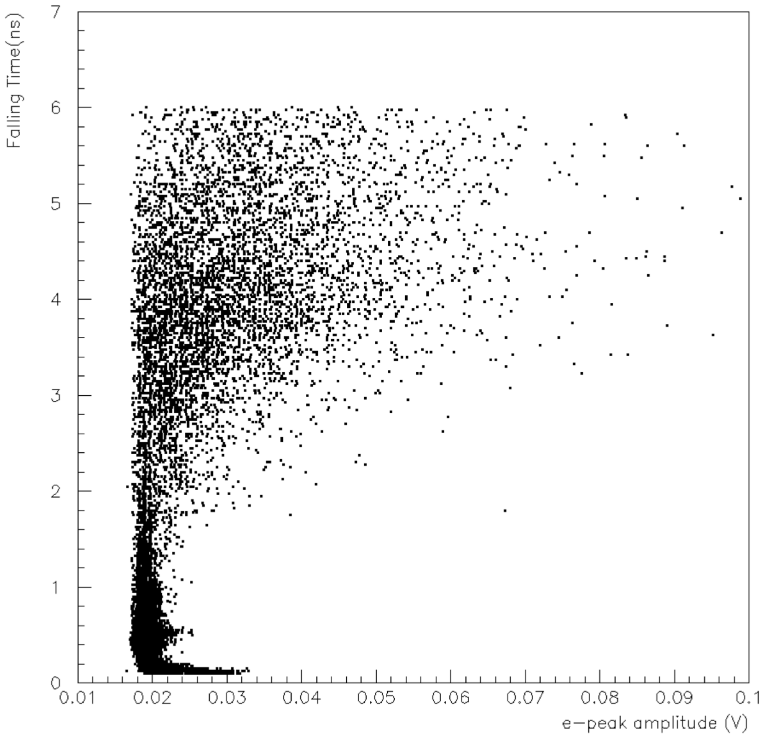
Single photoelectron and charge distribution

Selected pulses

- Falling time: Time at the end – time at the top of the e-peak
    - Falling time > 1.5 ns
        - Cut out very small pulses
- Appearance Time: time at the top e-peak
    - 245 < appearance time < 250 ns



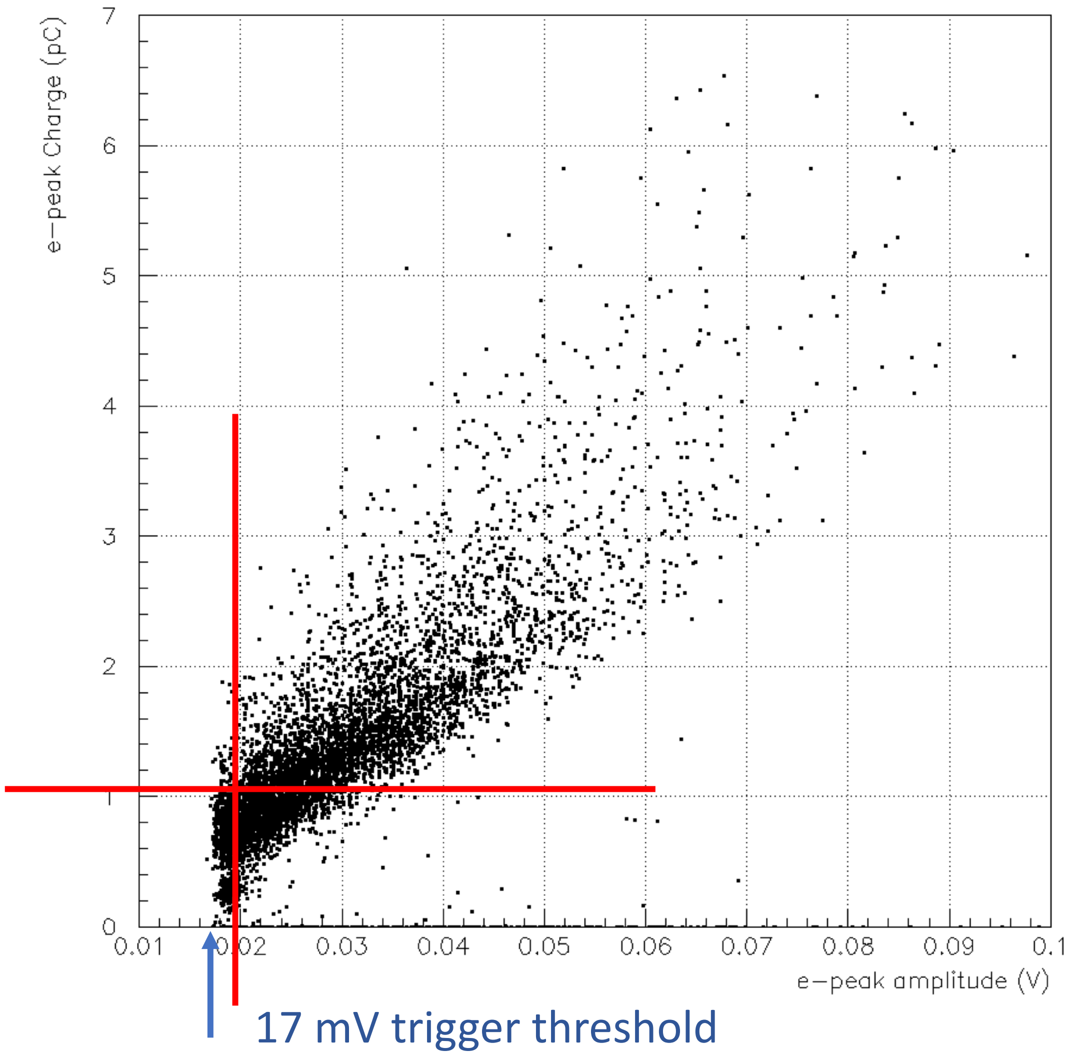
Special run with UV lamp: no lower threshold on e-peak amplitude



E-peak charge vs Amplitude for the selected pulses

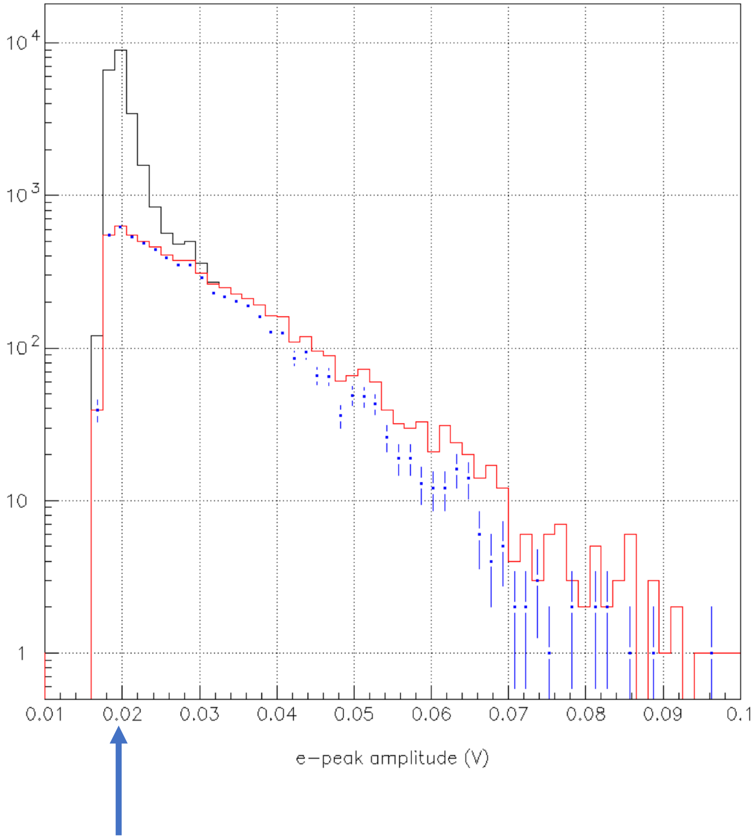
Signal pulses should have correlation between e-peak charge and amplitude

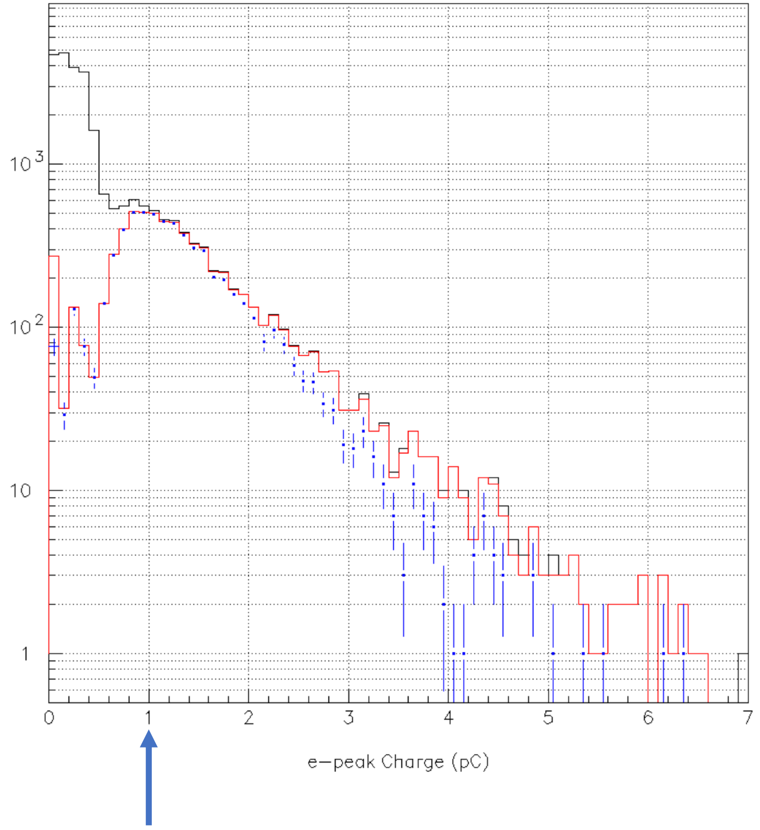
Trigger selects pulses with amplitude > 17 mV



E-peak charge and amplitude distribution

Black: All
Red: Falling time > 1.5 ns
Blue: falling time >1.5 ns and 245 < appearance time < 255 ns



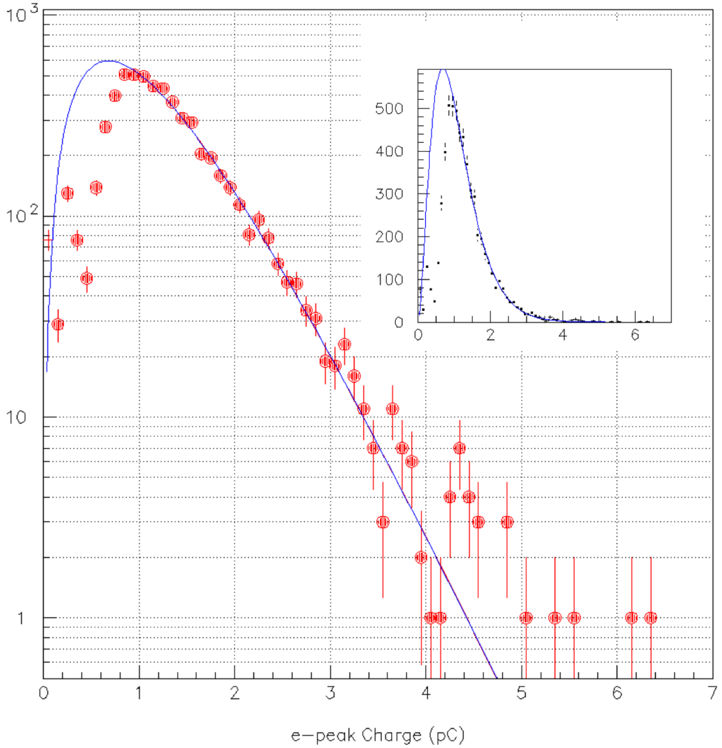


Avoid trigger turn on: e-peak amplitude > 20 mV

e-peak charge > 1 pC

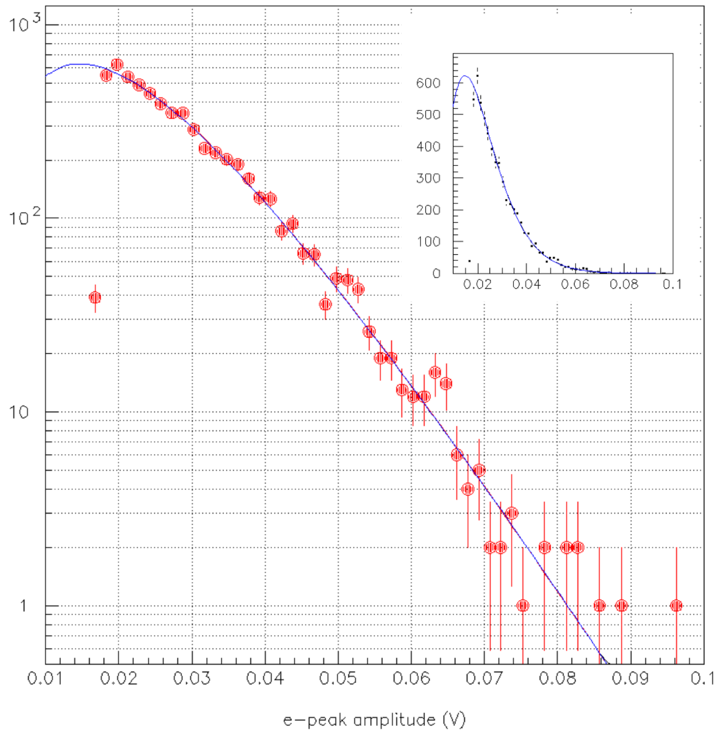
Fitting the e-peak charge and amplitude distributions

Polya fit on both histograms



Charge

Amplitude



The Polya distribution is defined by the following (normalized to unity) function:

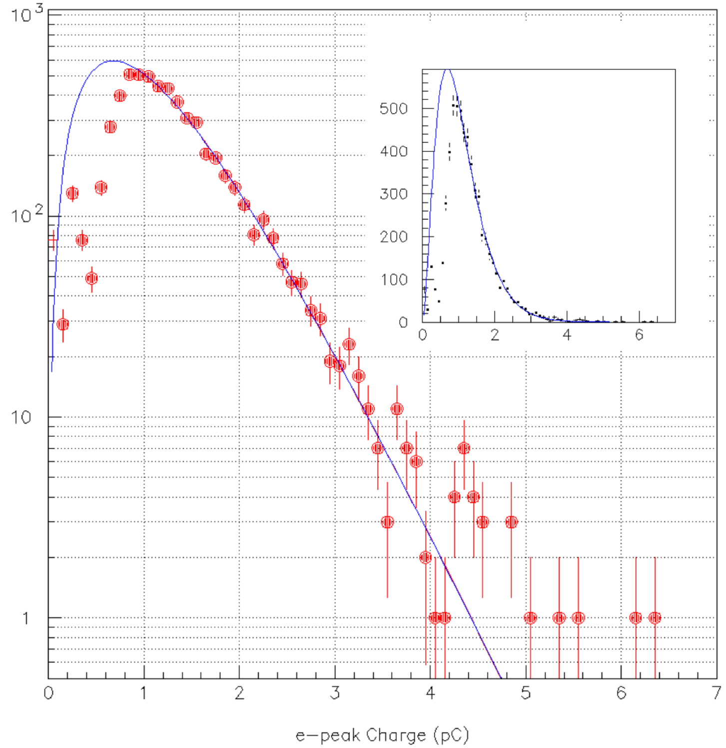
$$P_{spe}\left(Q; a=b=\theta+1, \bar{Q}_e\right)dQ = \frac{1}{Q_e}\frac{(\theta+1)^{(\theta+1)}\left(Q/\bar{Q}_e\right)^{\theta}}{\Gamma(\theta+1)} e^{-(\theta+1)Q/\bar{Q}_e}dQ$$

$$E\left[Q_{spe}\right] = \bar{Q}_e = \langle Q_e \rangle$$

$$V\left[Q_{spe}\right] = \frac{1}{\theta+1}\langle Q_e \rangle^2 = RMS^2$$

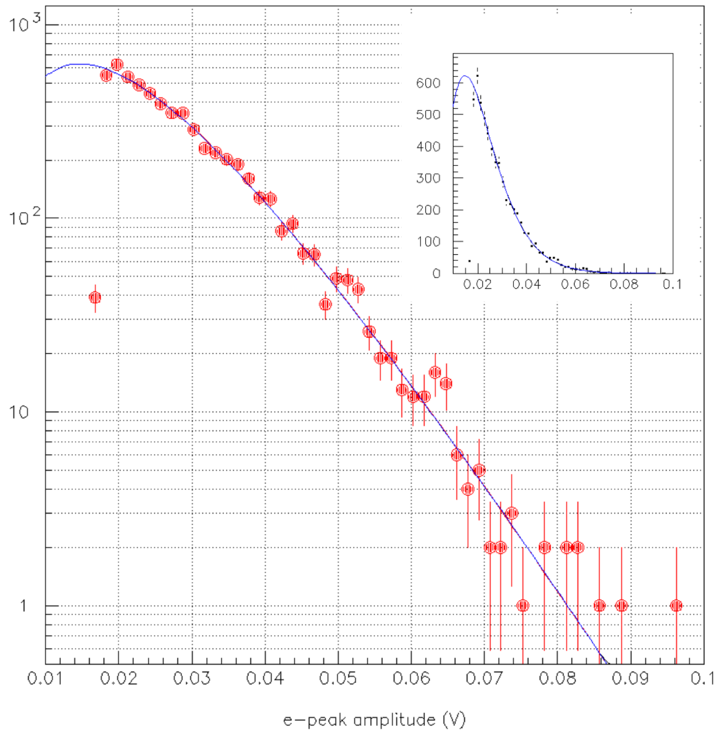
Fitting the e-peak charge and amplitude distributions

Polya fit on both histograms



Charge

Amplitude



	RMS	Mean
Fit for e-peak charge > 1 pC	0.6433	1.0668
Try other fit regions as well e.g > 1.1 pC	0.6498	1.1102
	0.6452	1.117
	0.6388	1.0786
	0.6398	1.028
	0.64305	1.0118

	RMS	Mean
Fit for e-peak amplitude > 0.02 V	0.01166	0.02023
Try other fit regions as well e.g > 0.021 V	0.011734	0.019967
	0.01169	0.020111
	0.011671	0.021089
	0.0117	0.020998
	0.011643	0.021195

3) E-peak charge and amplitude distribution from muons

E-peak Charge distribution for muons

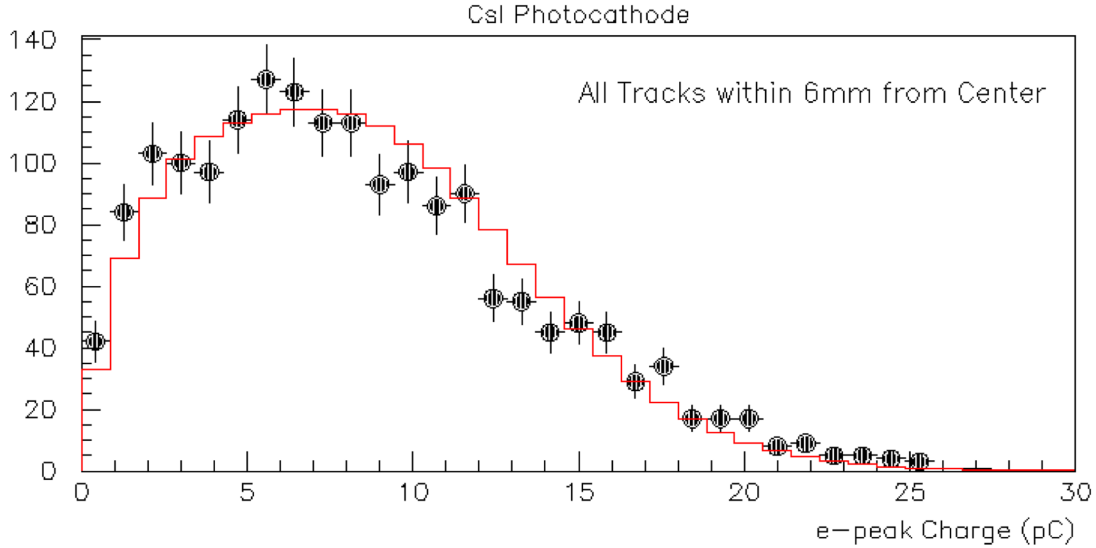
Analysis for CsI photocathode

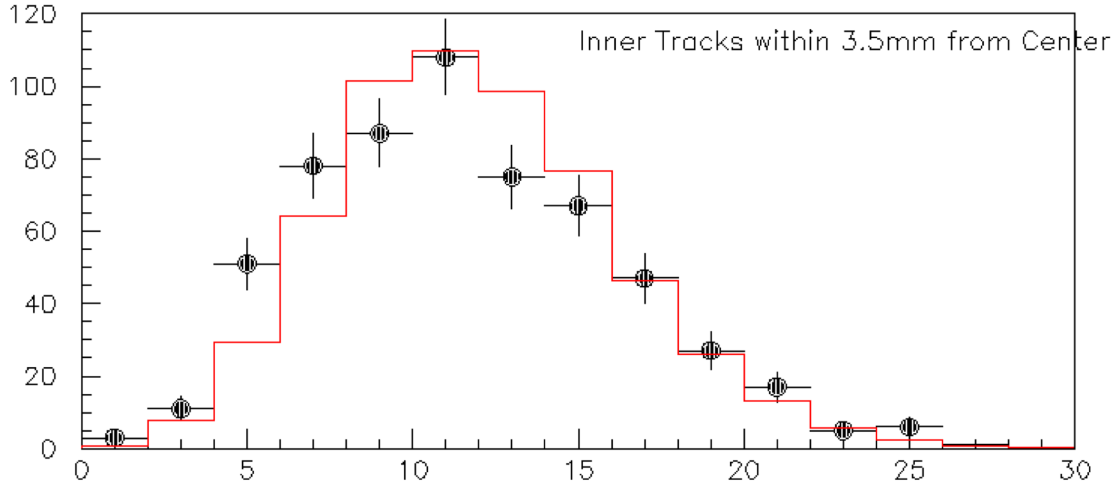
Photocathode properties for radial profile:
Reflection = 22%
Absorption = 20%

Polya parameters for single photoelectrons:
Mean = 1.0668
Error = 0.6433

A muon produces many of photoelectrons with a mean value N_{pe}
E-peak charge distribution is the sum of many single p.e Polya.
Convolution of single p.e Polya and Poison :
* Poison for the number of actual number of p.e's when the mean is N_{pe}
*the single p.e Polya to be used depends on the track impact point which changes the average charge as seen at the radial charge profile

Fit result: Npe=11.65 photoelectrons produced on average from each muon



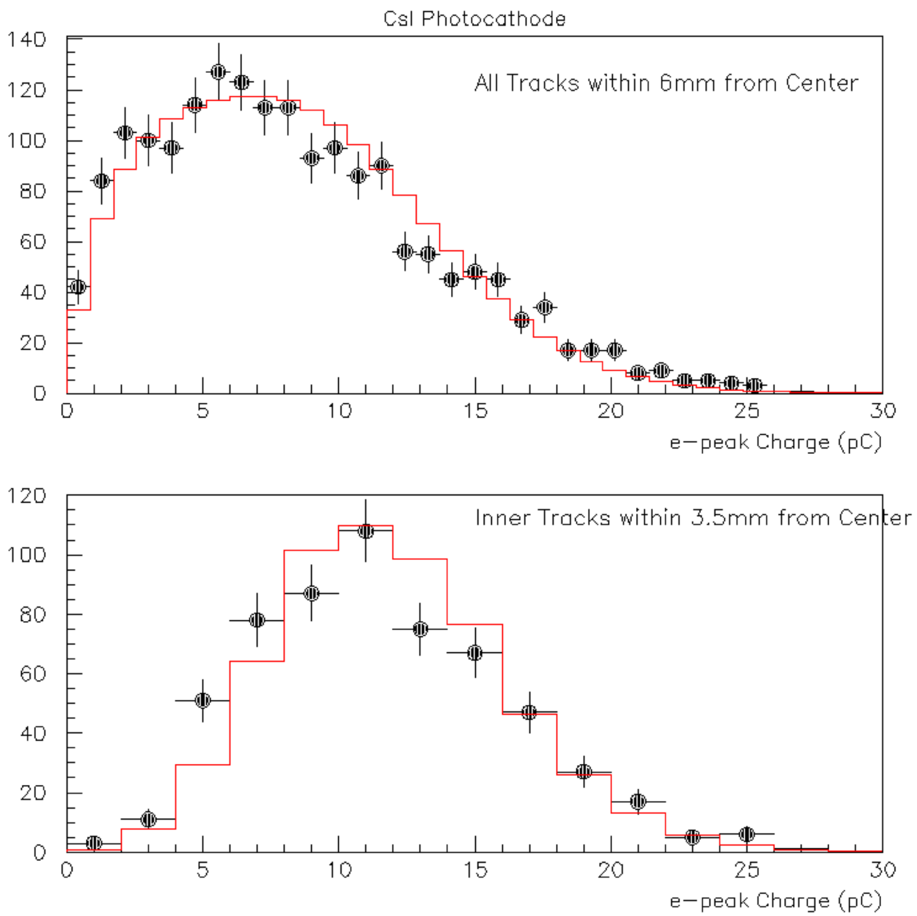


For more details see S.E Tzamarias in Dec 2017 RD51 Open Lectures (https://indico.cern.ch/event/676702/contributions/2769936/attachments/1574514/2485821/RD51-Paradigms-I.pdf)

Systematic uncertainties on Npe: change radial profile and background rejection cuts

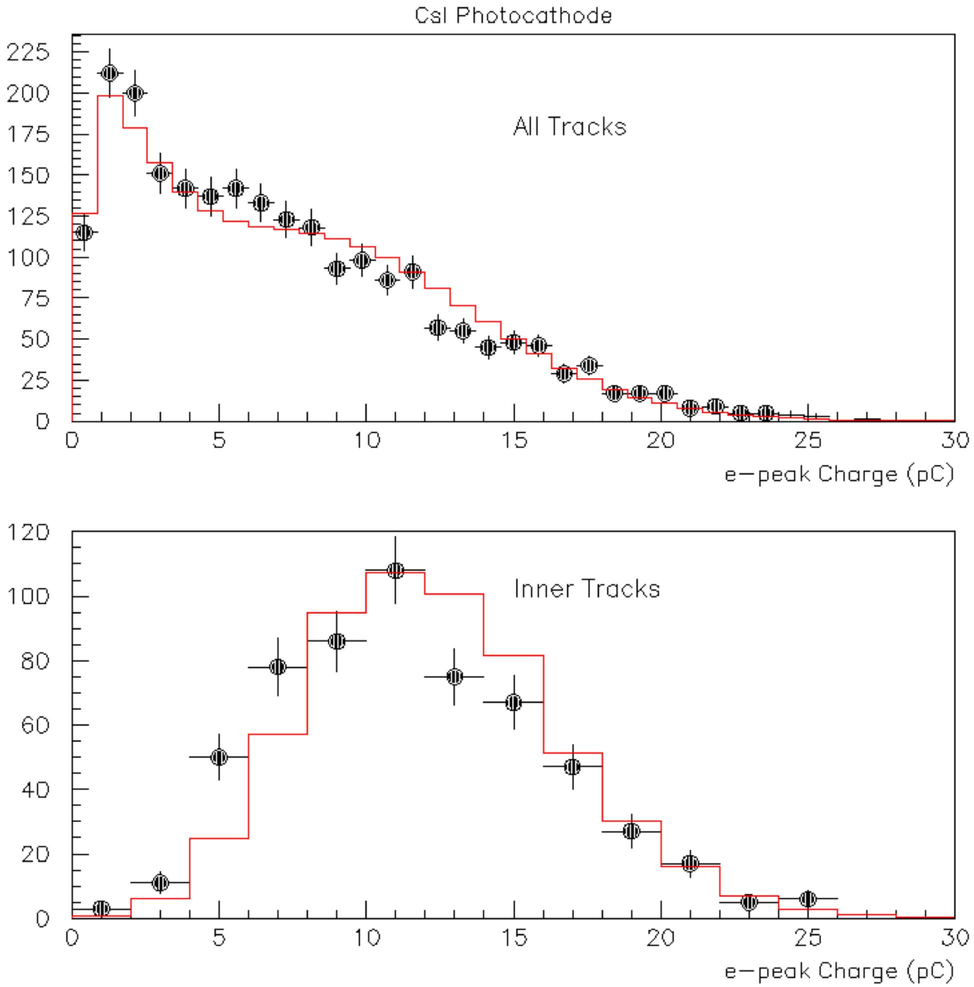
Polya parameters:

Mean = 1.0668
Error = 0.6433



Reflection = 22% Absorption = 20%

11.65 photoelectrons produced



Reflection = 10% Absorption = 40%

12.05 photoelectrons produced

Position moved by 0.2 mm in x and 0.1 mm in y

Systematic uncertainties on Npe: change the single pe Polya parameters

RMS	Mean	Npe
0.6433	1.0668	11.7 ± 0.3
0.6498	1.1102	
0.6452	1.117	11.5 ± 0.3
0.6388	1.0786	11.9 ± 0.3
0.6398	1.028	
0.64305	1.0118	12.6 ± 0.4

Npe estimate from e-peak amplitudes

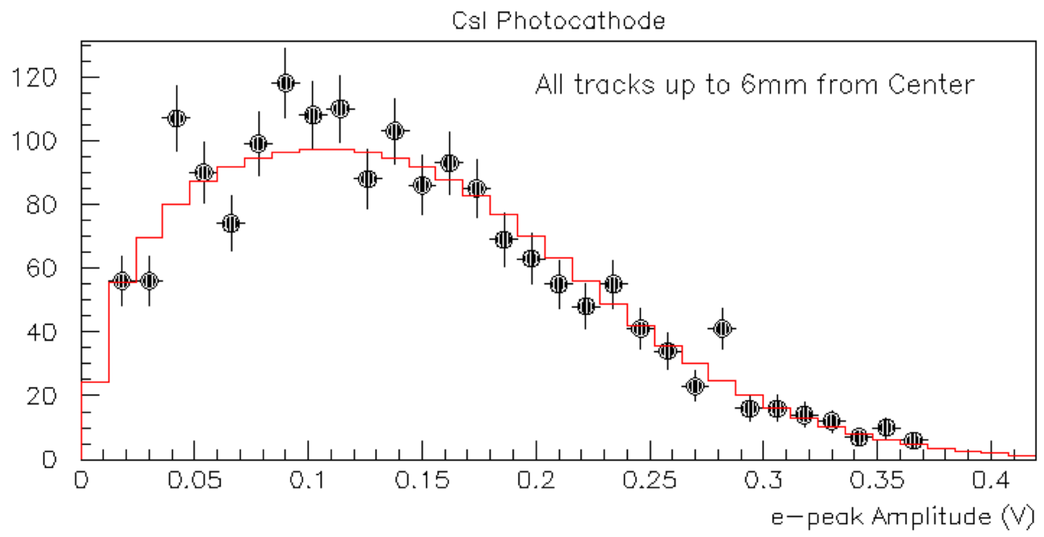
(this is a biased estimation!)

Polya parameters:

Mean = 0.019967
Error = 0.011734

Reflection: 22%
Absorption: 20%

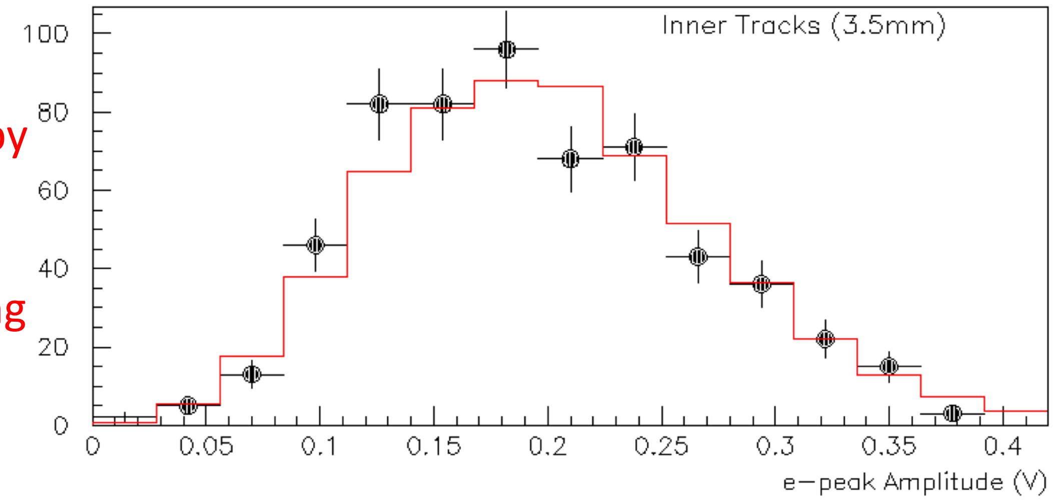
10.5 photoelectrons produced



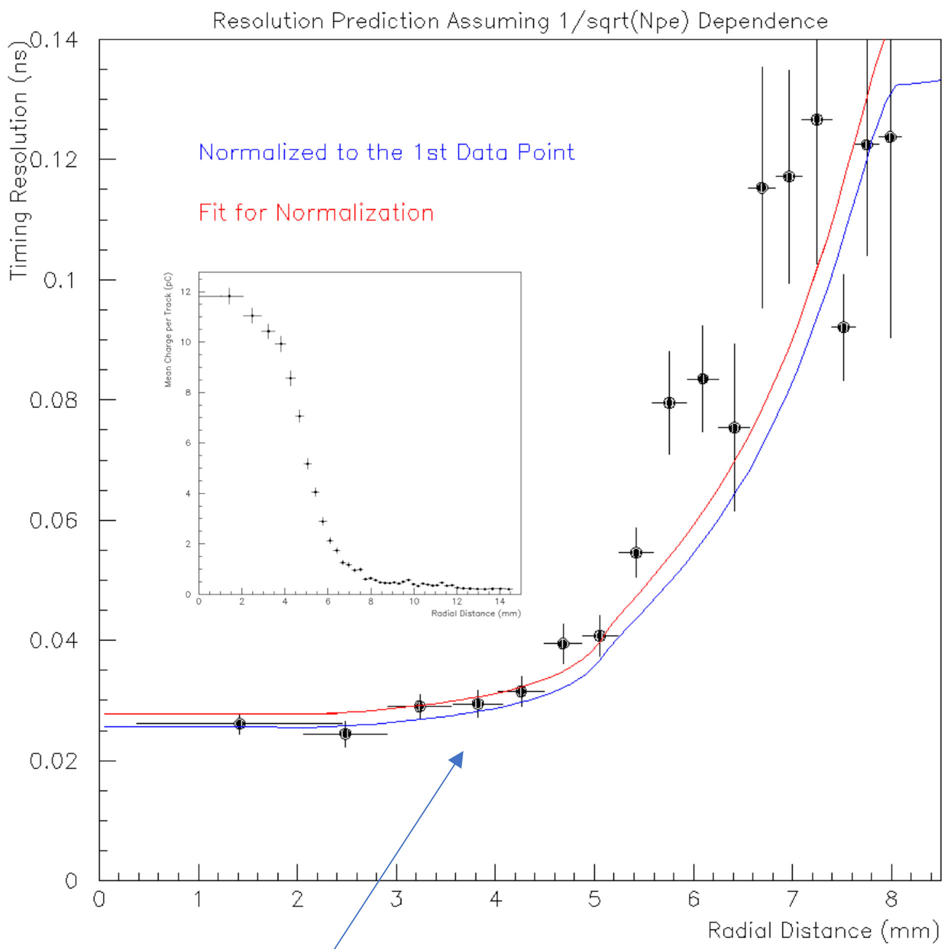
Estimations by fitting the e-peak amplitude distribution

RMS	Mean	Npe
0.01166	0.02023	same
0.011734	0.019967	10.5± 0.4
0.01169	0.020111	10.4± 0.4
0.011671	0.021089	same
0.0117	0.020998	same
0.011643	0.021195	same

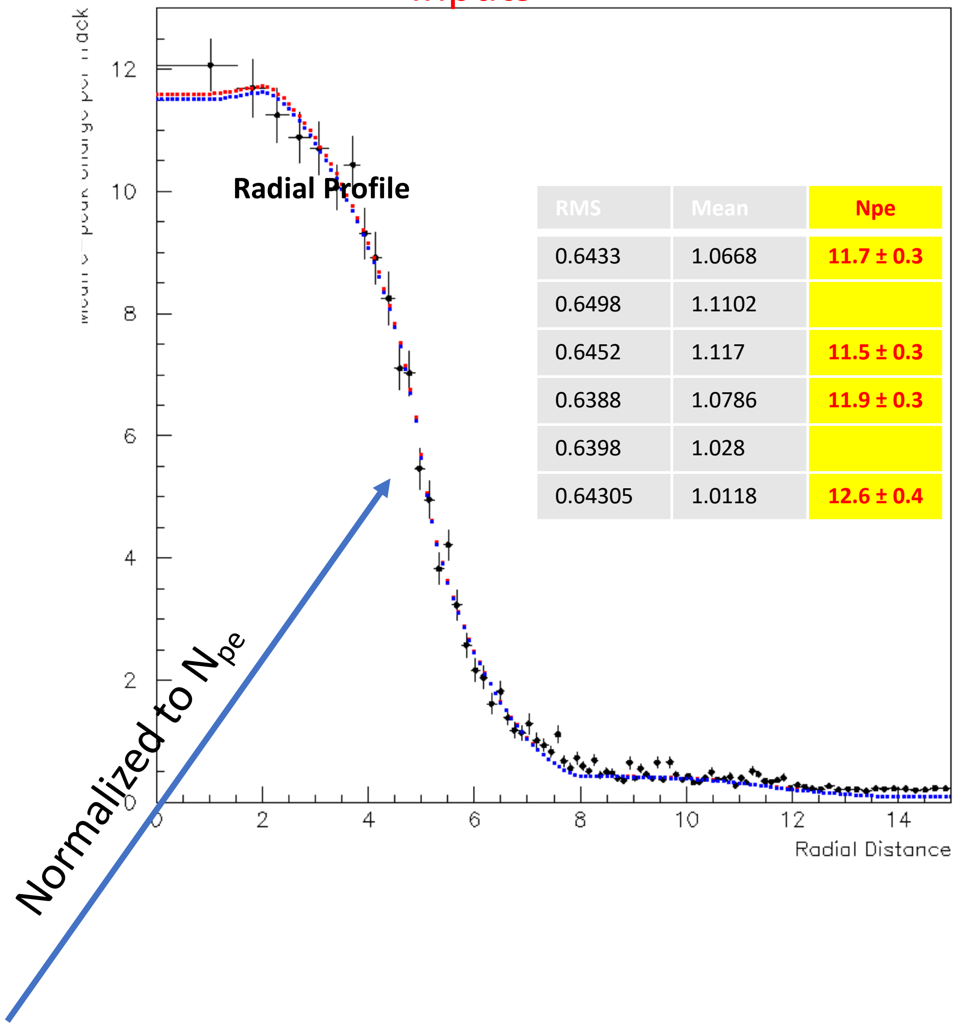
The estimated Npe by fitting the amplitude distributions are less (by ~1 pe) than the corresponding estimations when fitting charge distributions.
It is expected !!!



Assuming that the resolution is proportional to $1/\sqrt{N}$ and using the radial profile and the estimated number of photoelectrons we can predict the dependence of the timing resolution on the radial distance of the track



Inputs



RMS	Mean	Npe
0.6433	1.0668	11.7 ± 0.3
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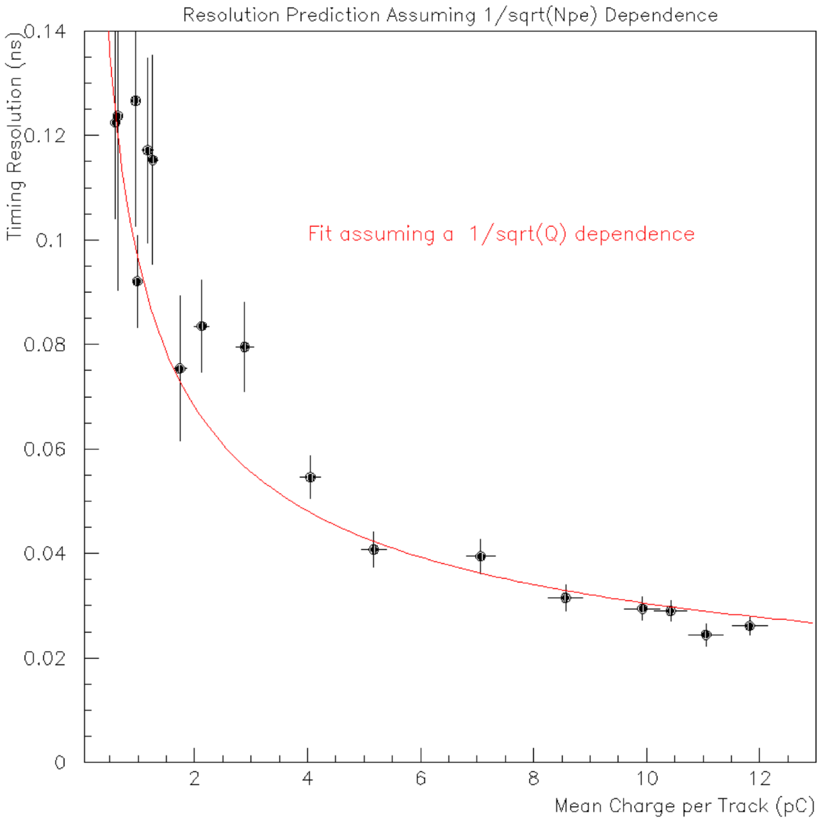
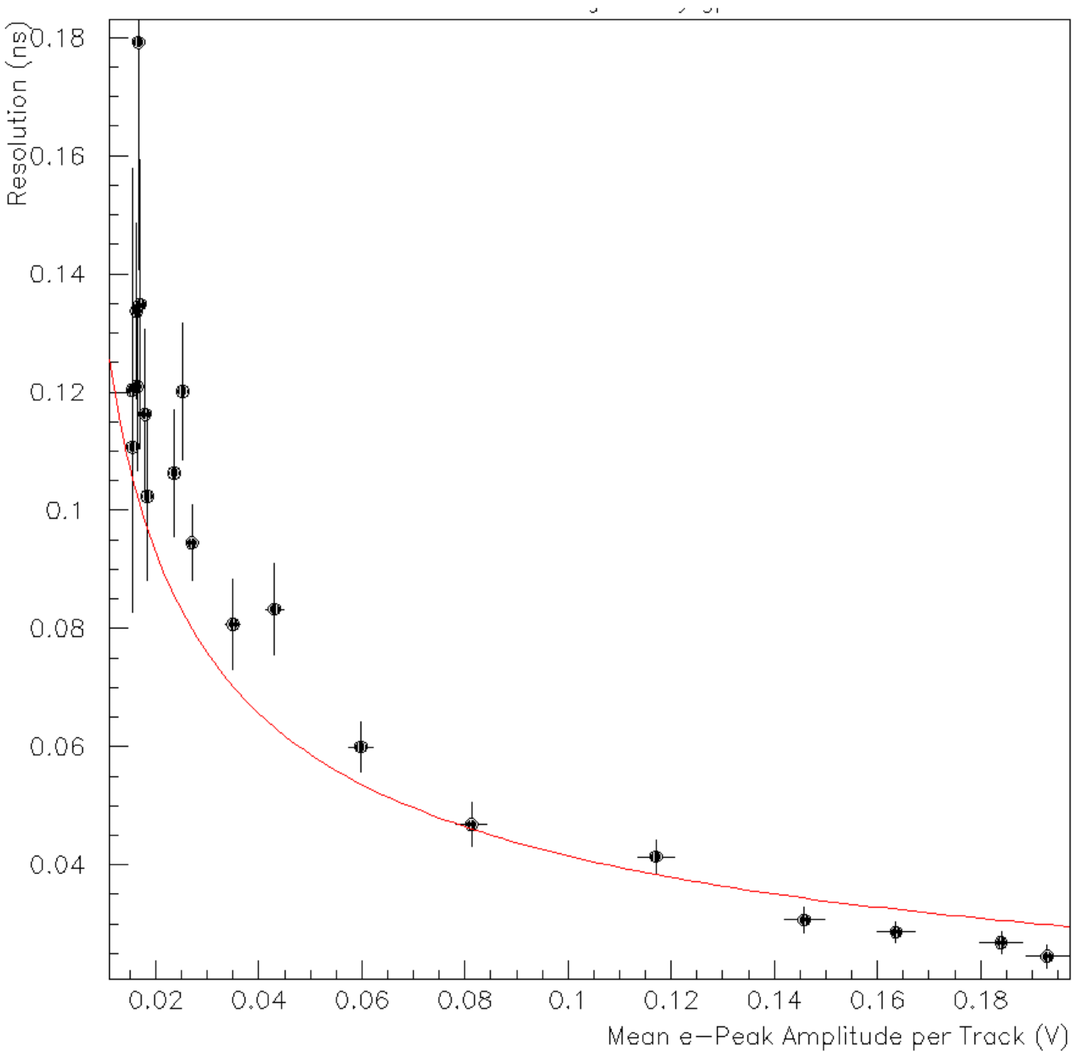
0.6452	1.117	11.5 ± 0.3
0.6388	1.0786	11.9 ± 0.3
0.6398	1.028	
0.64305	1.0118	12.6 ± 0.4

$$Resolution(R) = \frac{const}{\sqrt{N}} = \frac{const}{\sqrt{\mathrm{P(R)}}}$$

The prediction of the resolution vs radial distances agrees very well with the data because the timing resolution depends on the e-peak charge as $1/\sqrt{Q}$



In conclusion, the timing resolution varies (almost) as $1/\sqrt{Q}$ which can be expressed as a $1/\sqrt{N_{pe}}$dependence. Consequently, the timing resolution as a function of the track radial distance can be expressed in terms of the above $1/\sqrt{\ }$ dependence and the Cherenkov ring geometrical acceptance.



The variation of the timing resolution as a function of the e-peak amplitude is also consistent with a $1/\sqrt{V_{e-Peak}}$ dependence

Conclusions

- We have developed a statistical method to estimate the number of photoelectrons produced by a track passing through the MgF_2 radiator using:
  - The radial profile (mean e-peak charge/track vs radial distance),
  - The Polya parameters for single photoelectron determined by special UV runs
  - The charge (or amplitude) distribution of the PICOSEC response to muon tracks

- We estimated the photoelectron yield of CsI photocathode per track as 11.5 ± 0.4 (stat) ±0.5 (syst)

- Using the e-peak amplitude, the number of photoelectrons per track estimated was found to be less but, this is a biased estimation due to the fact that the e-peaks related to different photoelectrons are not synchronous.

- The resolution vs the track radial distance found to be consistent with the assumption that the resolution varies as $1/\sqrt{Npe}$

- We are applying this technique to test beam data in order to evaluate the photoelectron yield of different photocathodes and our results will soon be published

The PICOSEC collaboration

Thank you

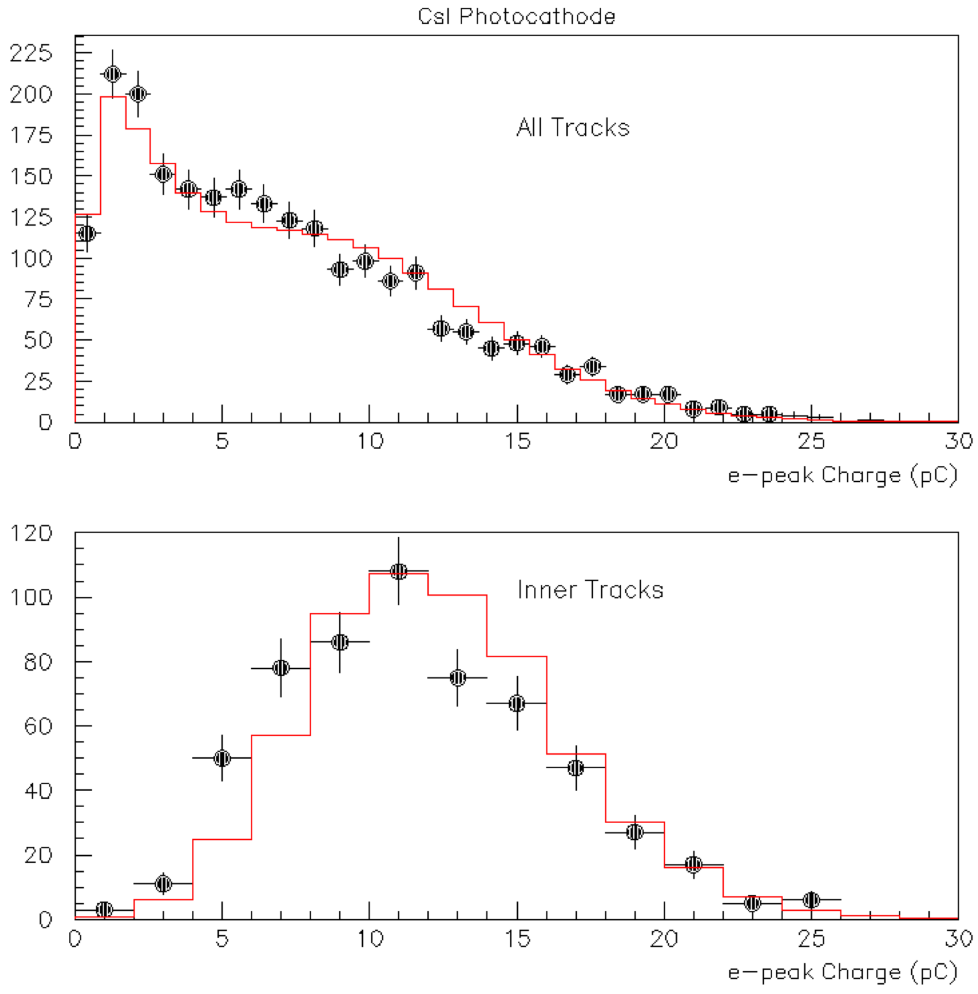
Systematic uncertainties on Npe: change radial profile and sing

Diffenet Photocathode properties:

Reflection = 10%
Absorption = 40%

Position moved by 0.2 mm in x and 0.1 mm in y

12.05 photoelectrons produced



Number of photoelectrons

$$A(Q|N,Q_e,\theta) = \frac{(\theta+1)^{N(\theta+1)}}{\Gamma(N(\theta+1))}\left(\frac{Q}{Q_e}\right)^{N(\theta+1)-1} \exp\left[-(\theta+1)\frac{Q}{Q_e}\right]$$

$$\mathscr{L}(N|(Q_i)_{i=1}^{n}) = \prod_{i=1}^{n}\left(\sum_{j=0}^{\infty}\frac{N^j e^{-N}}{j!} \times A(Q_i|j,Q_e,\theta)\right)$$

- Data from UV lamp test → signal from single photoelectrons
- Polya distribution

- Minimize likelihood

Convolution Poisson with Polya

- N → mean number of photoelectrons / muon

N_{pe} = 10.4 ± 0.4