Characterization of Photomultiplier Tubes for the Long-Baseline Neutrino Experiment

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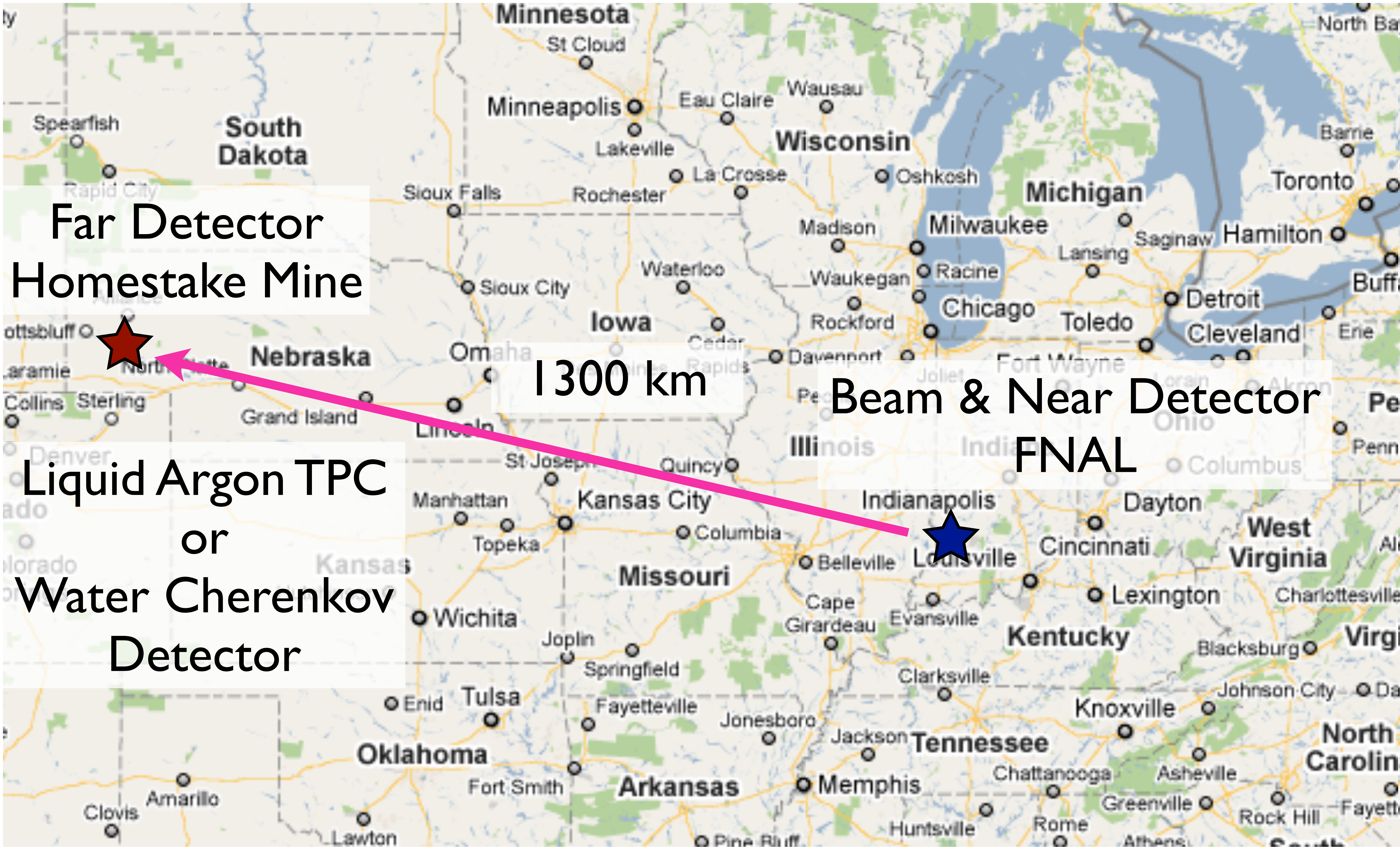
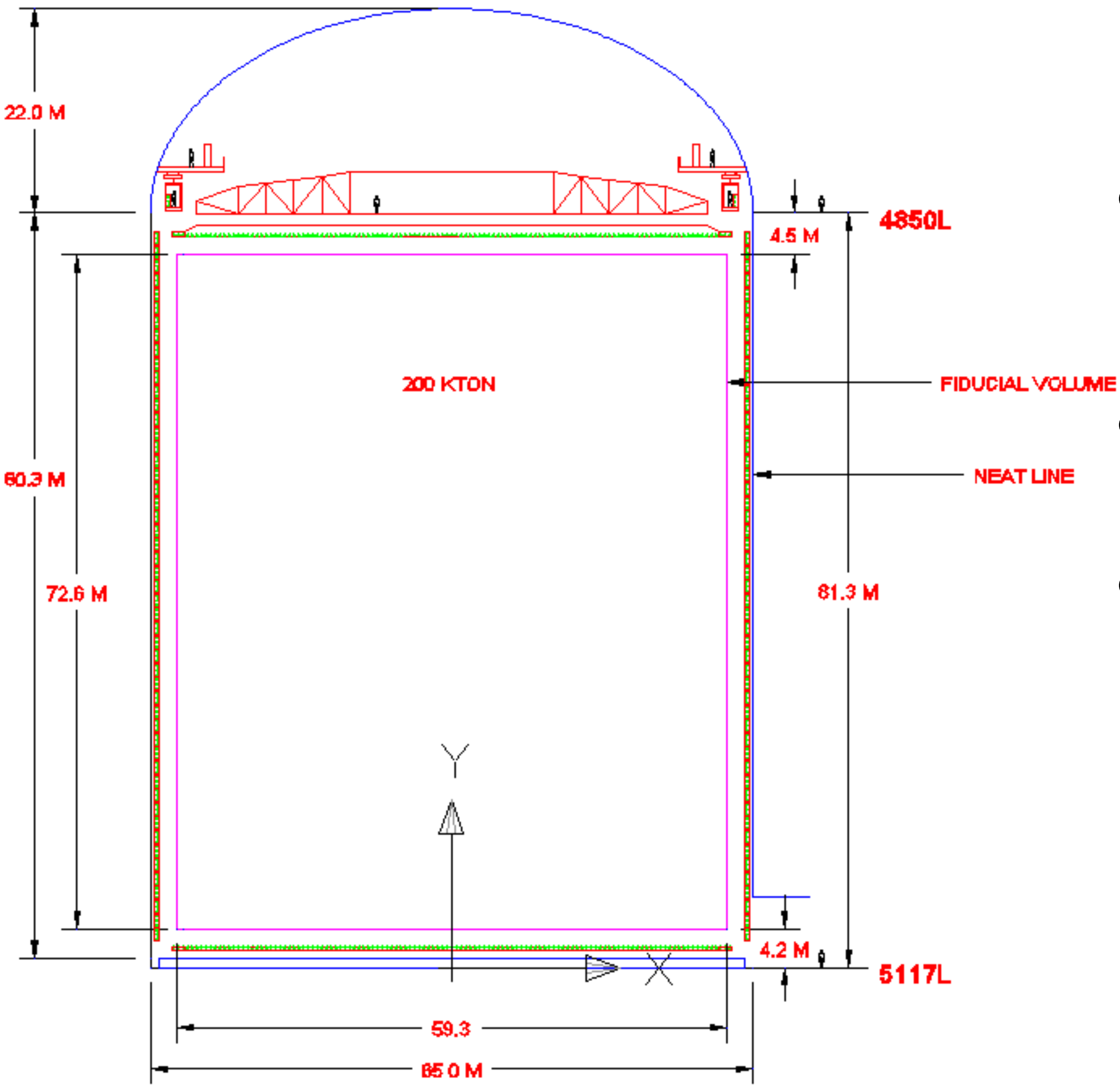
Advances in Neutrino Technology
October 10, 2011

Long-Baseline Neutrino Experiment



LBNE Water Cherenkov Detector



- Located underground at Homestake with 4300 m.w.e. overburden
- 200 kton fiducial volume
- Photocathode coverage equivalent to SuperK-II
  - ~29000 PMTs + some form of area-increasing light collectors

PMT Characteristics

- Detection Efficiency
  - Absolute efficiency as function of wavelength
  - Relative efficiency as a function of position
- Charge
  - Width of charge distribution
  - Peak to valley ratio
  - High charge tail
  - Saturation
- Time
  - Width of prompt transit time distribution
  - Late pulsing probability
  - Pre-pulsing probability
  - After-pulsing probability

PMT Characteristics

- Detection Efficiency
  - Abs
    fun
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    fun p
- Char
  - Wi n
    dist n
  - Pea e
  - Hig e
  - Sat
- Time
  - ransit
  - Late pulsing probability
  - lity
  - bility

Position Reconstruction

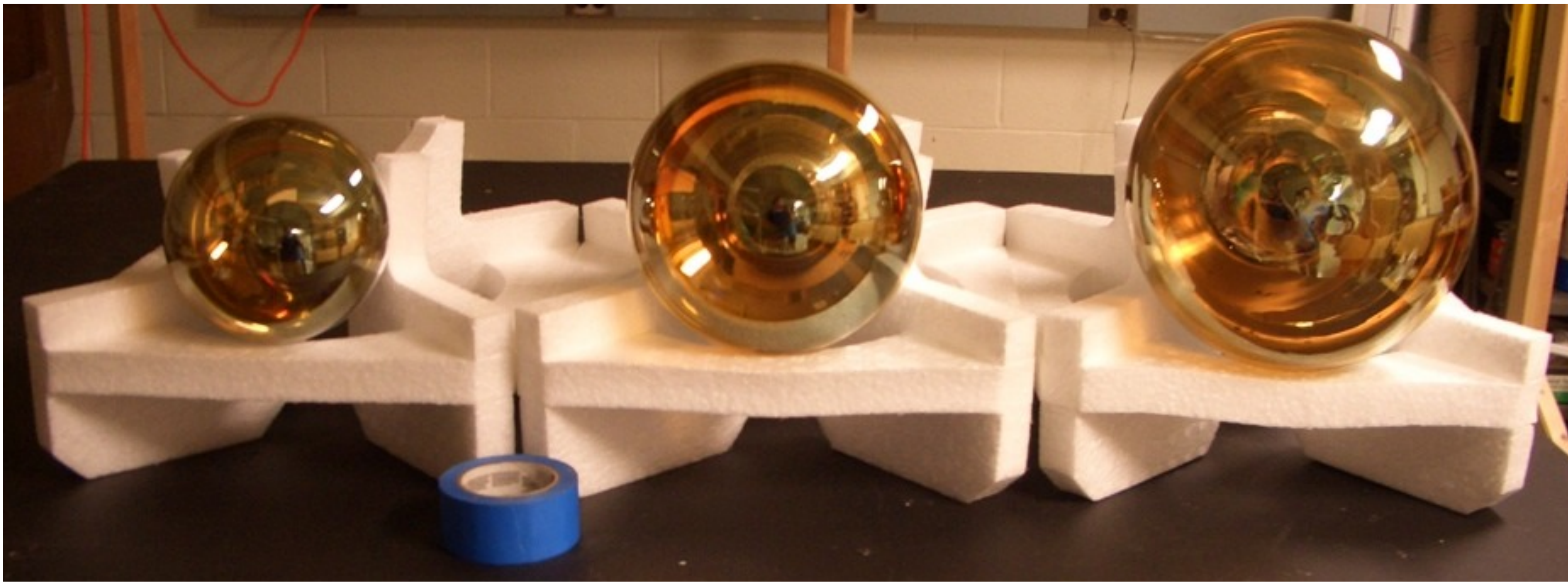
Energy Estimation

Particle ID

Some Candidate PMTs

Hamamatsu R7081 10”

Hamamatsu R11780 12”

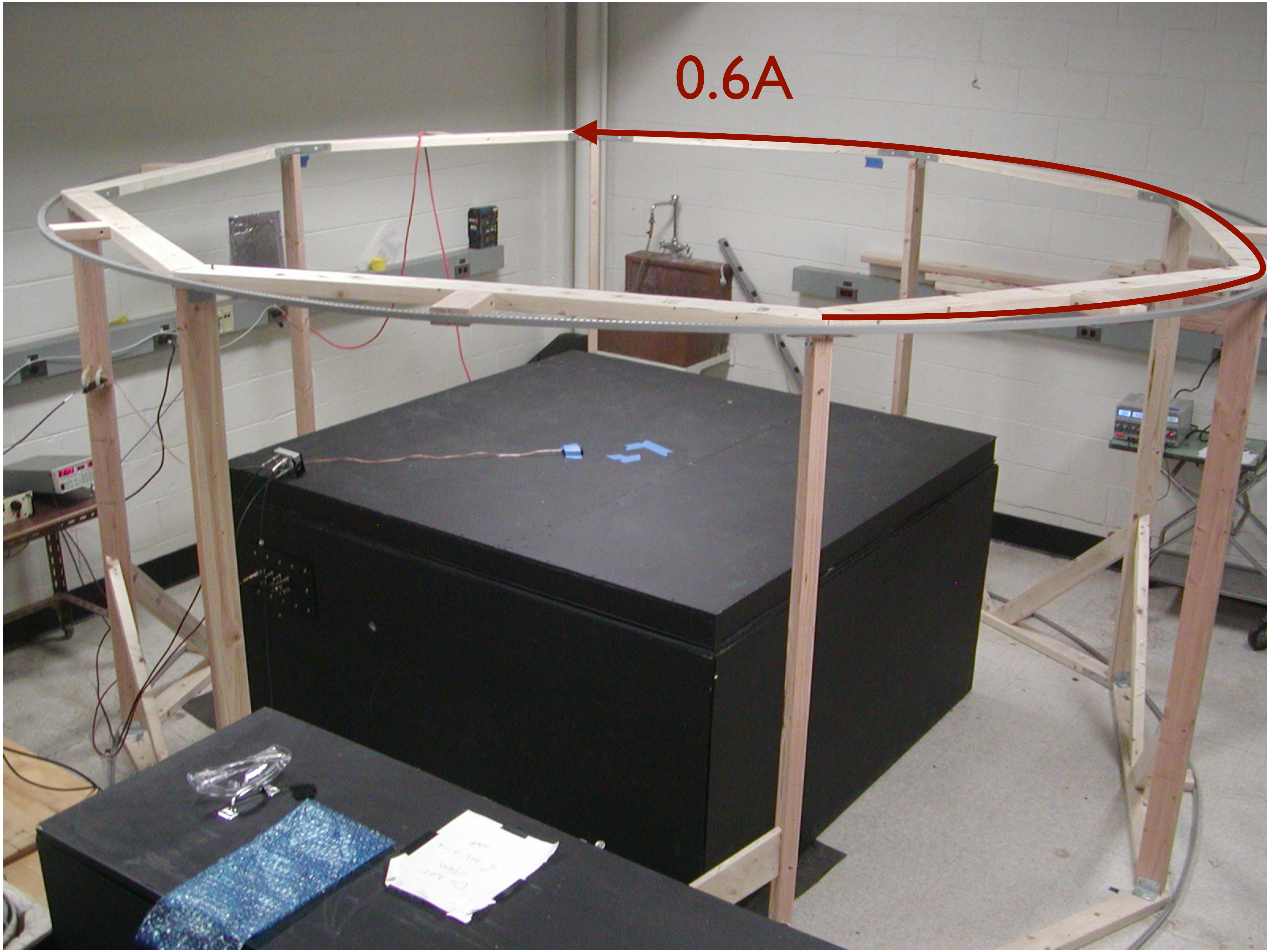


Hamamatsu R1408 8”
(“standard candle” comparison only)

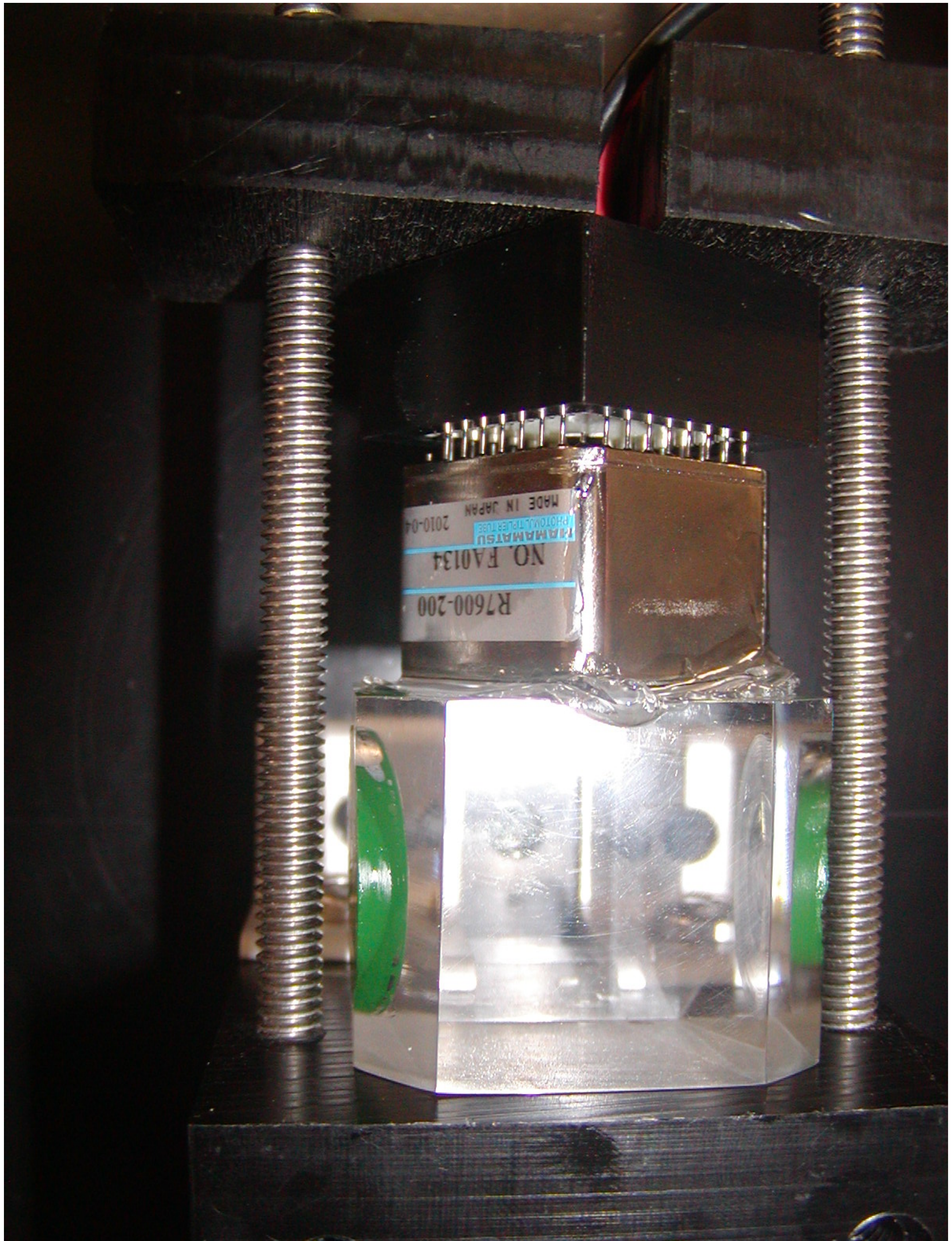
Now have 12” with standard, enhanced, and high quantum efficiency.

ETL PMTs to be tested later this year...

Dark Box



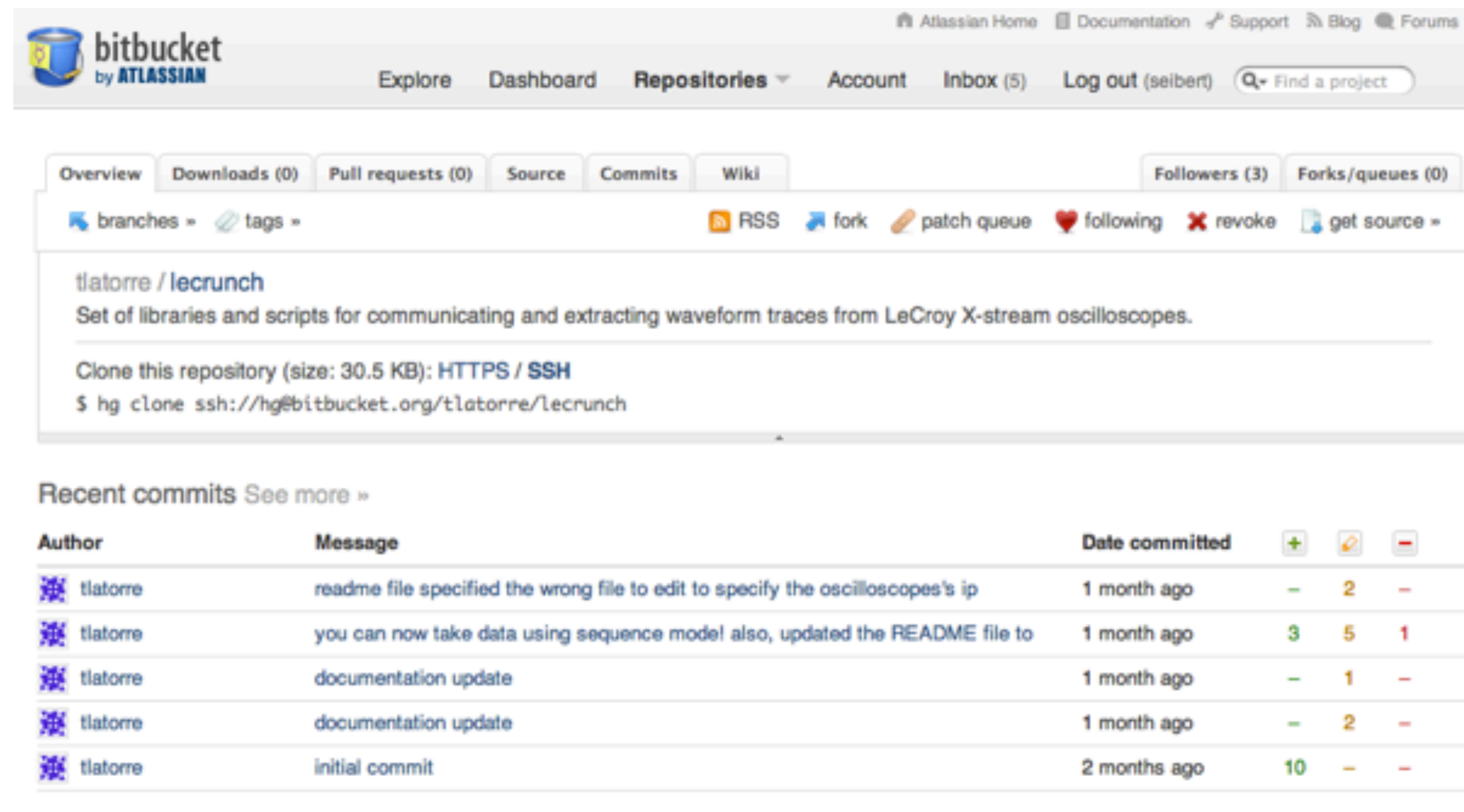
Cherenkov Source



- Two 0.1 µCi strontium-90 disks
- Cube of UV-transmitting acrylic (from SNO experiment)
- 2” high quantum efficiency trigger PMT with <100ps jitter

- Cherenkov events are very sharp in time
- Produces a wavelength spectrum very similar to the that observed in a water Cherenkov detector

LeCrunch

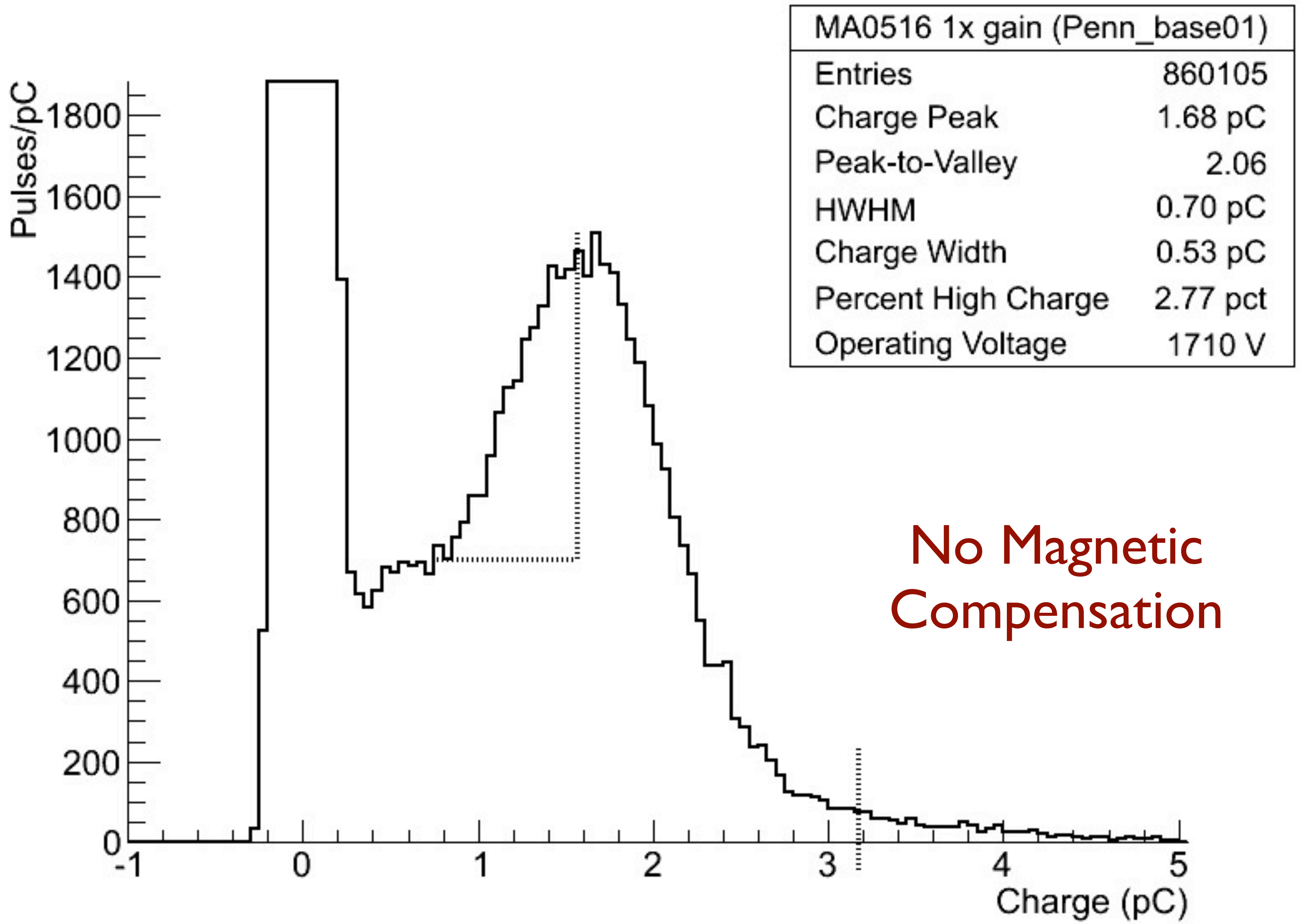


- Remotely acquire waveform data over Ethernet from any LeCroy oscilloscope running Windows.
- Save and restore oscilloscope configuration.
- Recording kHz trigger rates possible with proper oscilloscope config.
- Very space-efficient HDF5 file format.

https://bitbucket.org/tlatorre/lecrunch

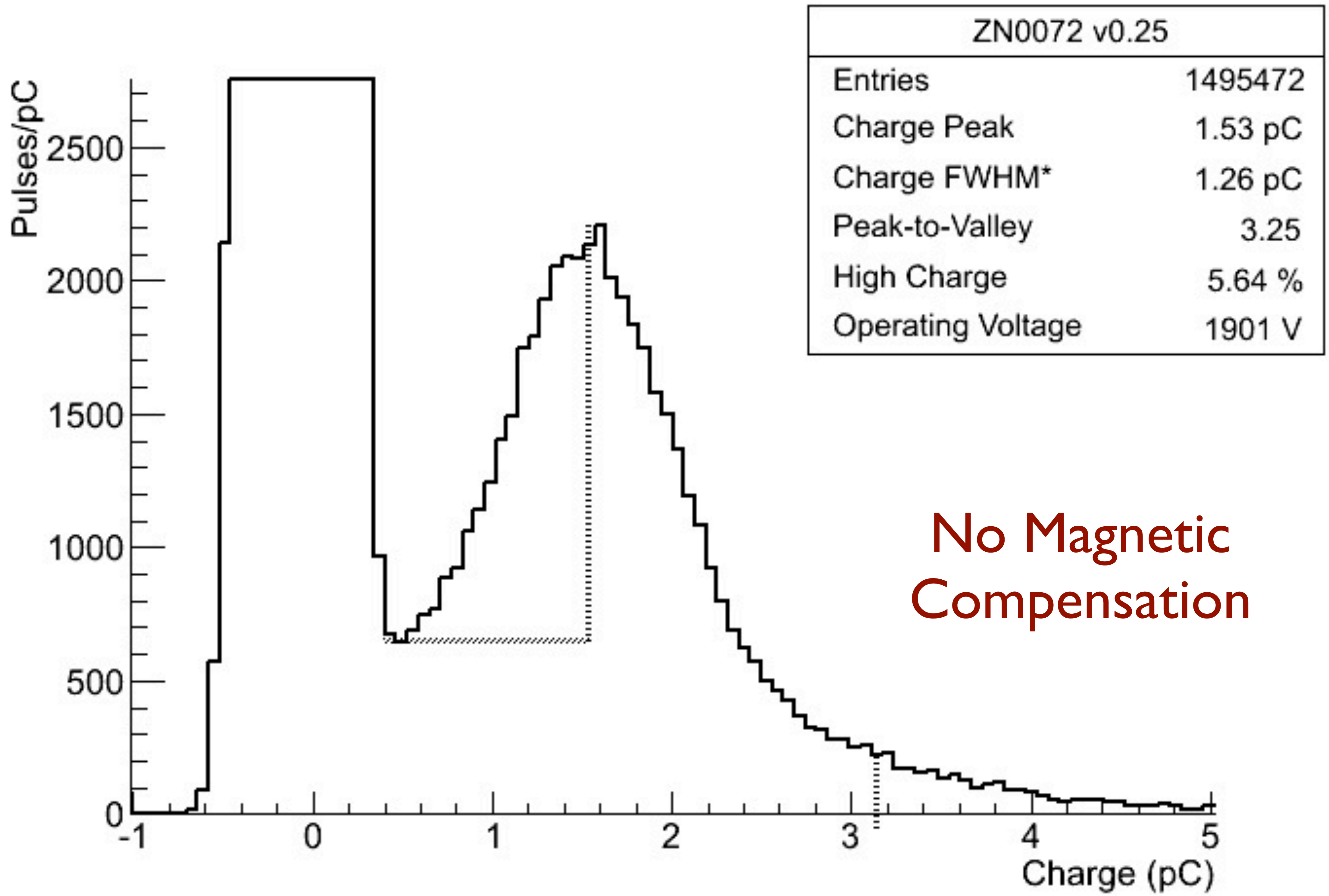
Results

Charge Distribution: 10” PMT



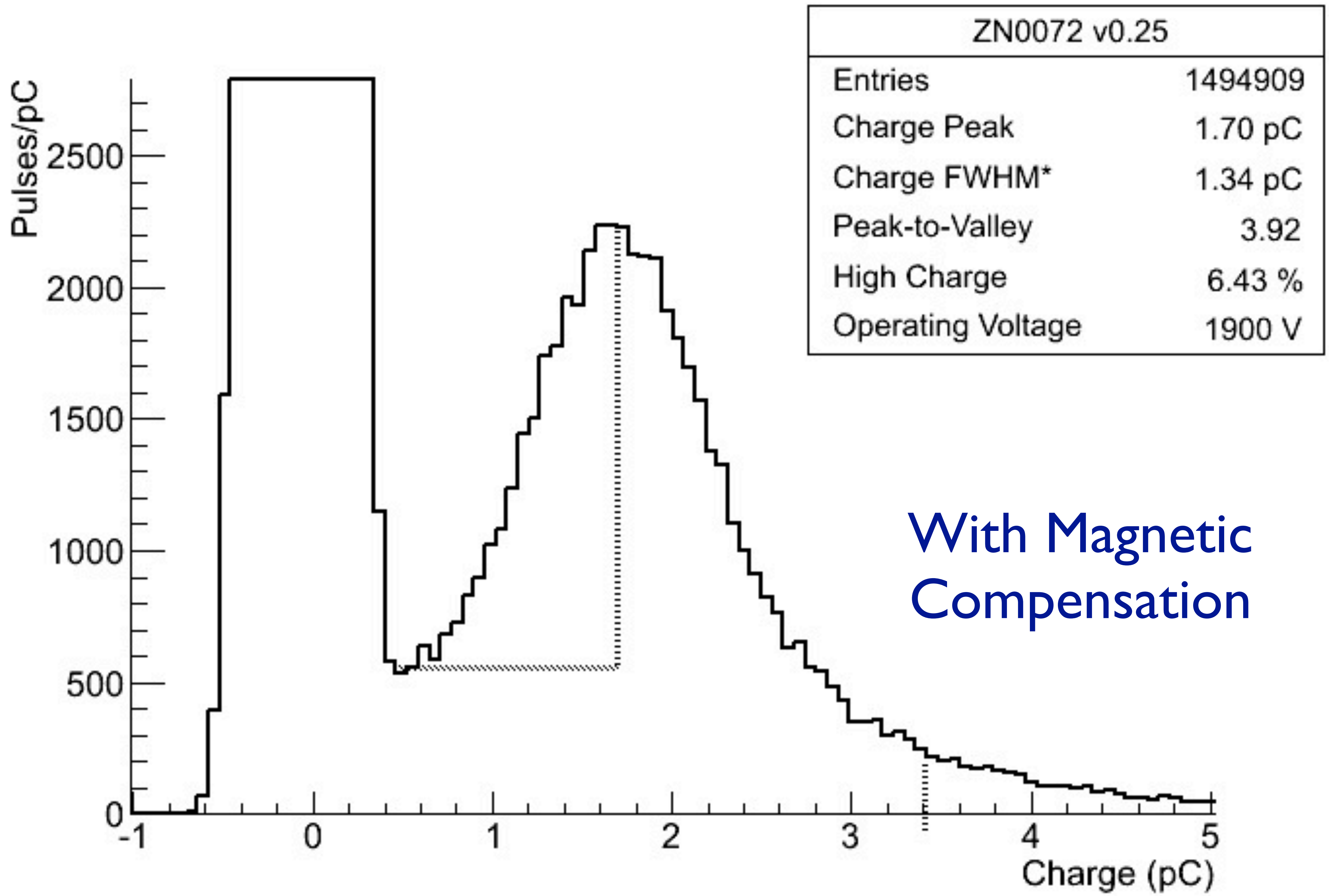
No Magnetic Compensation

Charge Distribution: 12” PMT



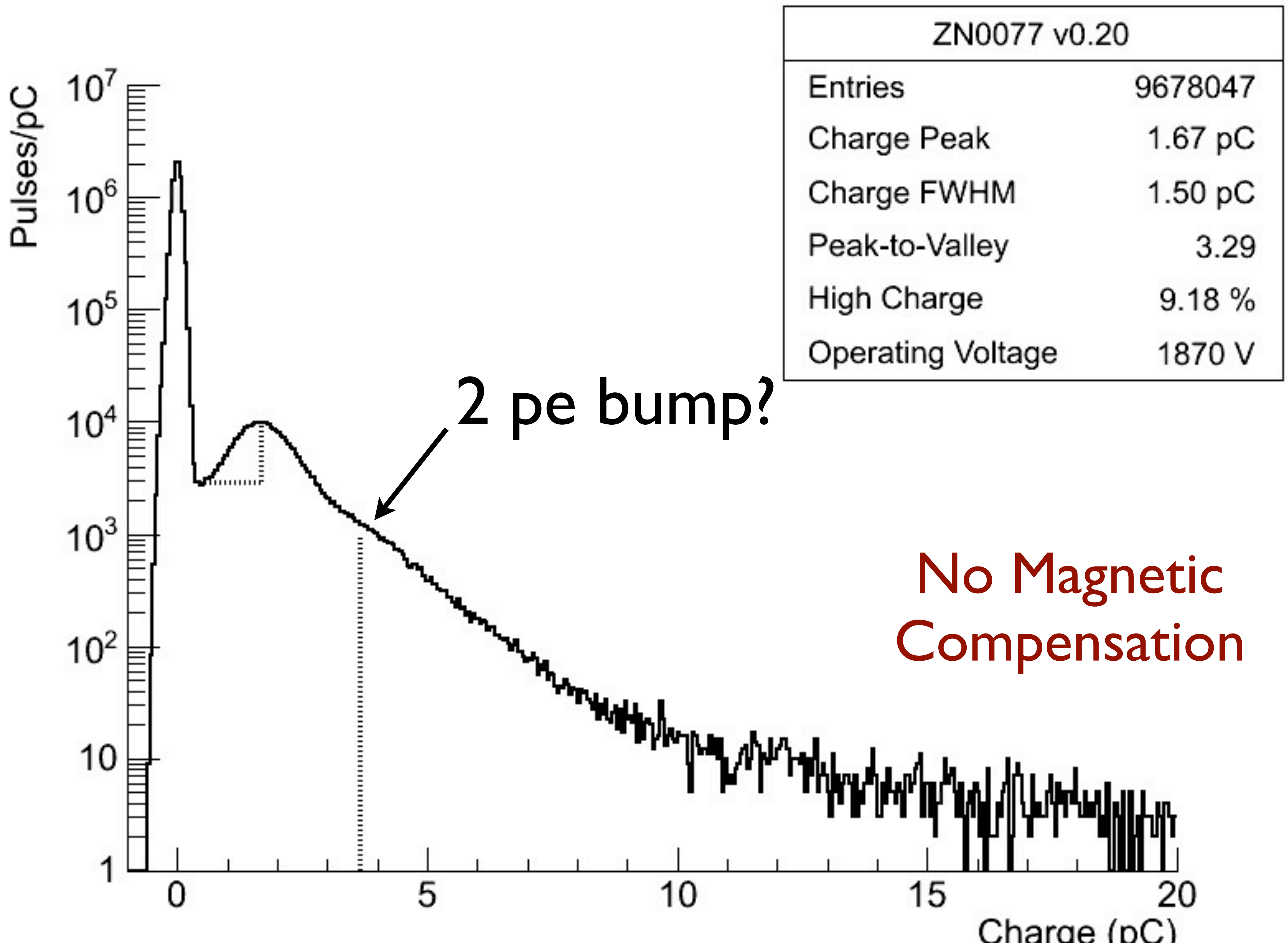
No Magnetic Compensation

Charge Distribution: 12” PMT

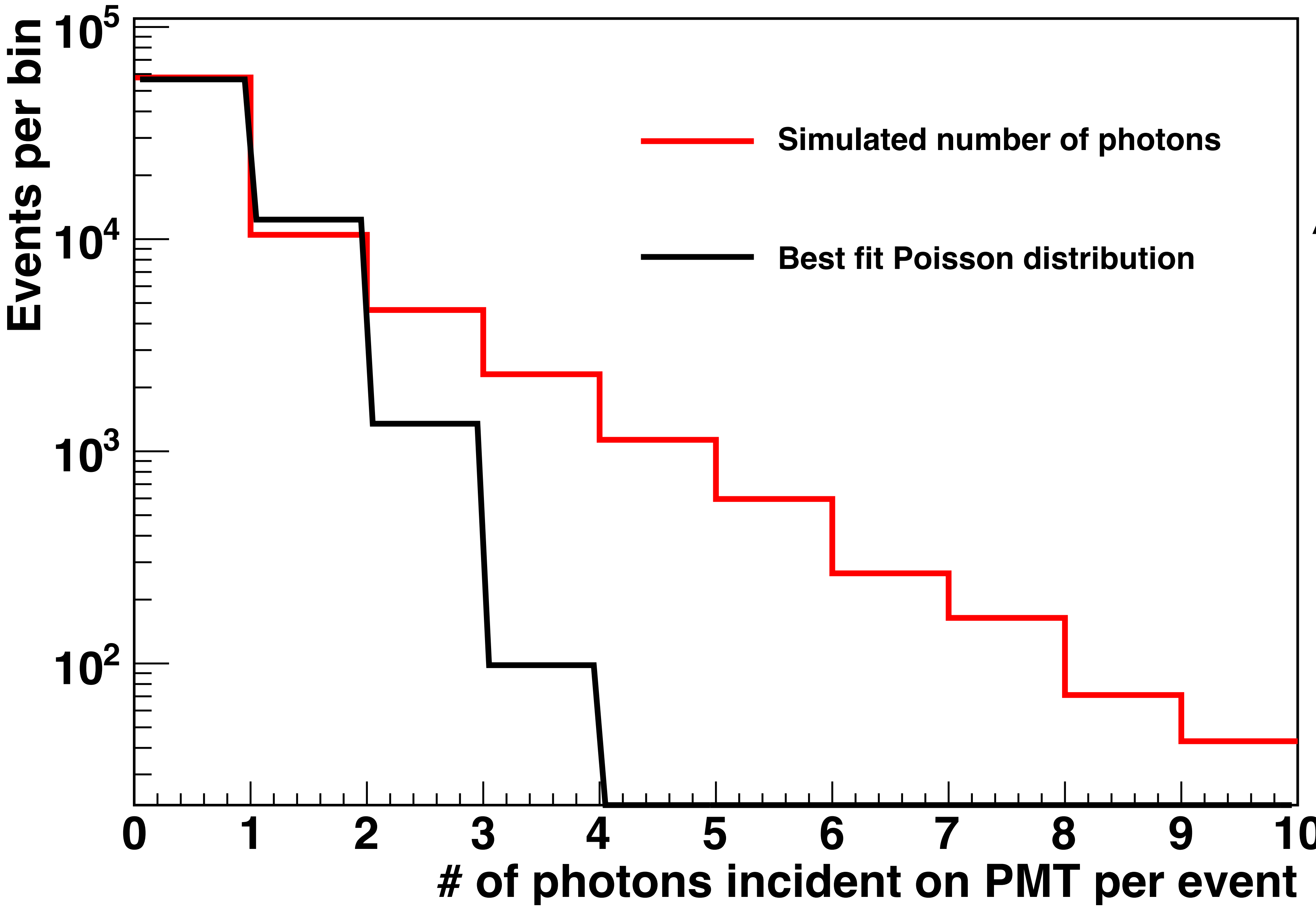


With Magnetic Compensation

High Charge Tail: 12" PMT

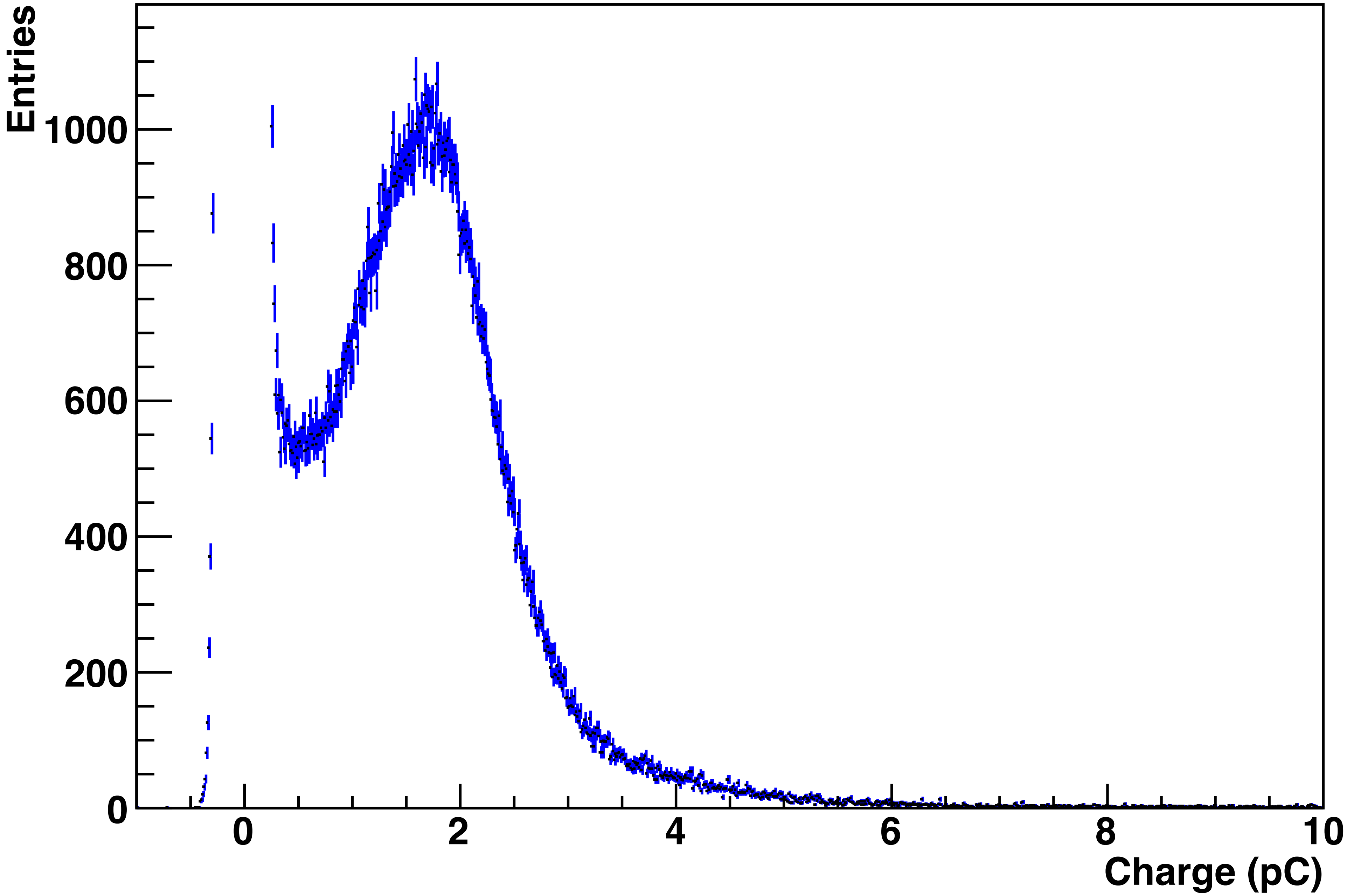


“High Charge Tail”: 12” PMT



A non-poisson tail produces more multi-PE events than one would predict from the coincidence rate.

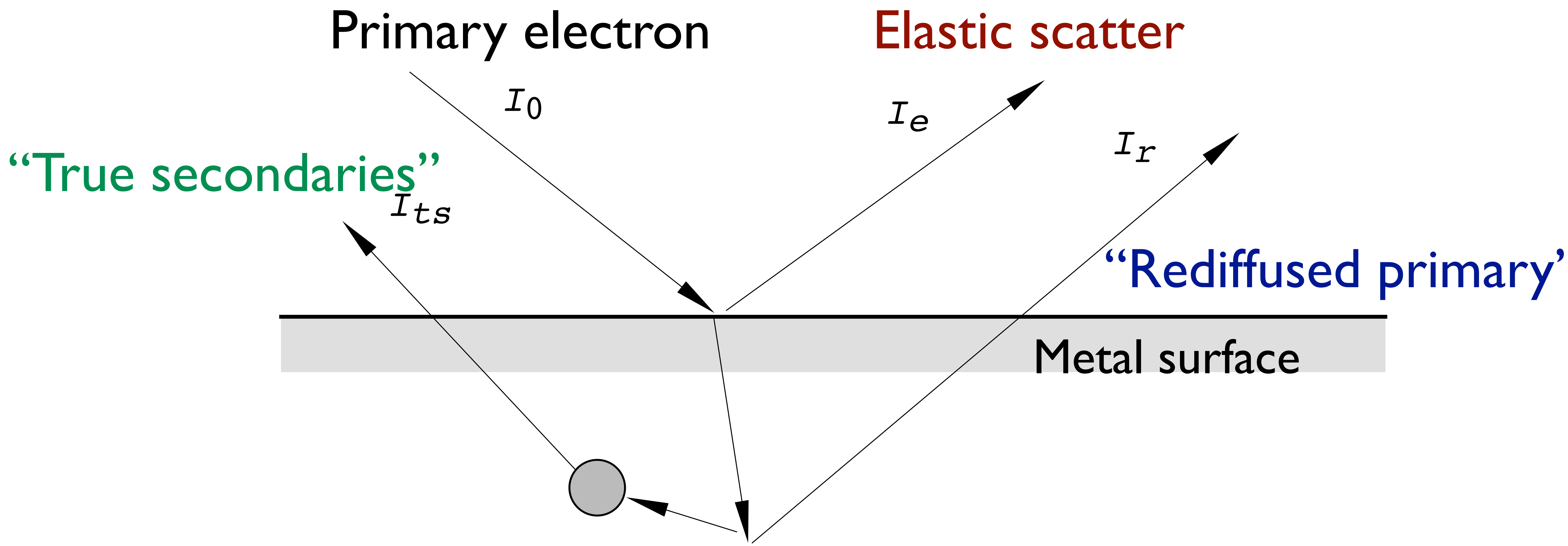
Digression: Modeling the PMT charge distribution



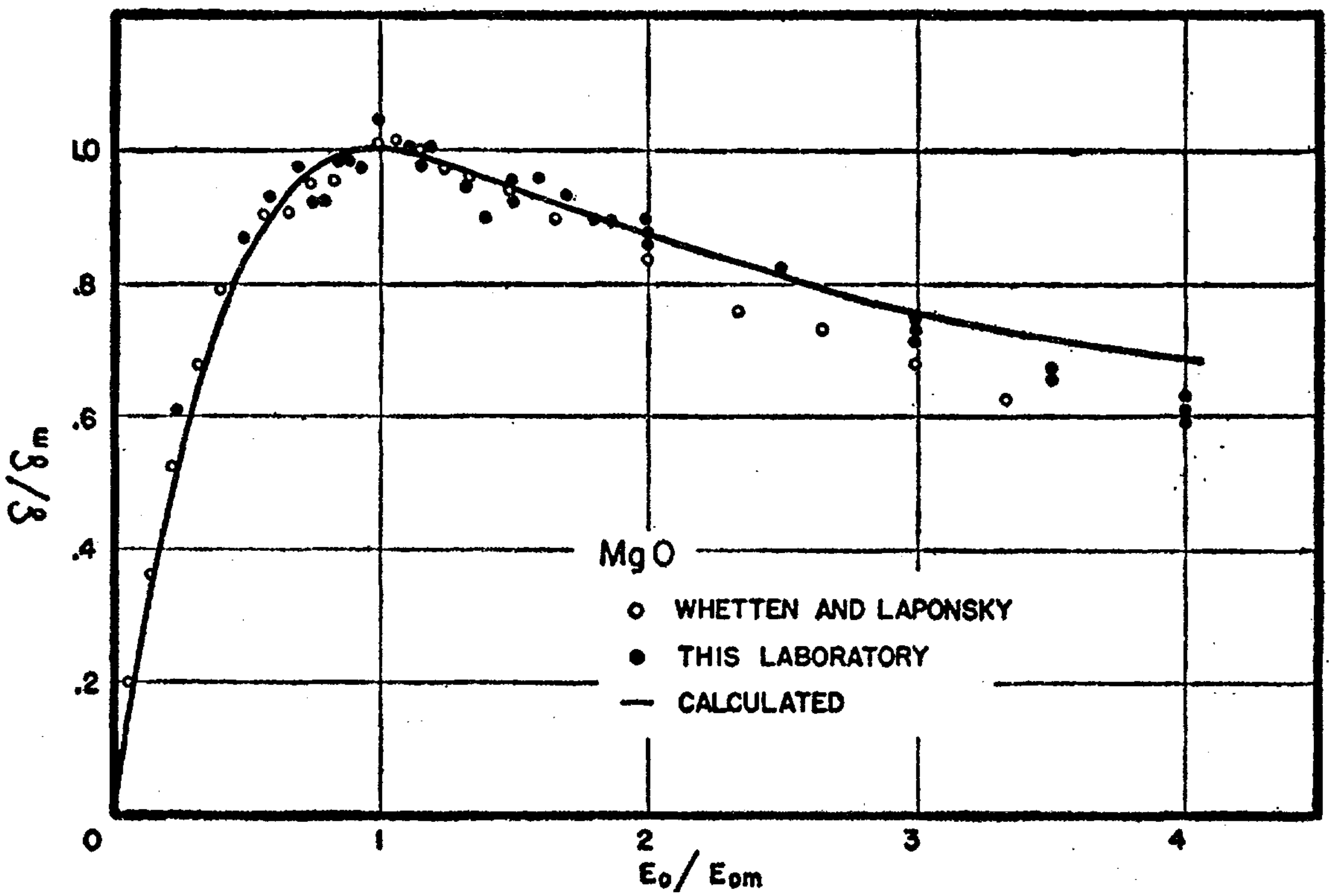
Can we implement a simple, but physical, model for PMT charge amplification?

Can we separate multi-PE effects from a charge tail?

Physics of secondary electron emission:



Universal yield curve:



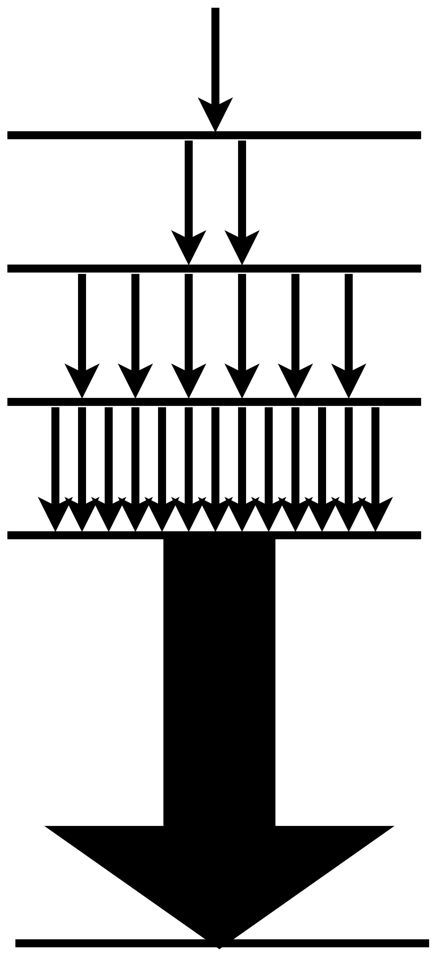
δ = mean of Poisson distribution of secondary electron production (dynode gain)

E = energy of primary electron (dynode potential difference)

$$\delta/\delta_m = \frac{1 - \exp\left(-(E/E_m)^{1.35}\right)}{(E/E_m)^{0.35}}$$

E_m is the energy at which the maximum gain, δ_m, is achieved.
It is a property of the dynode material.

A simple Monte Carlo model



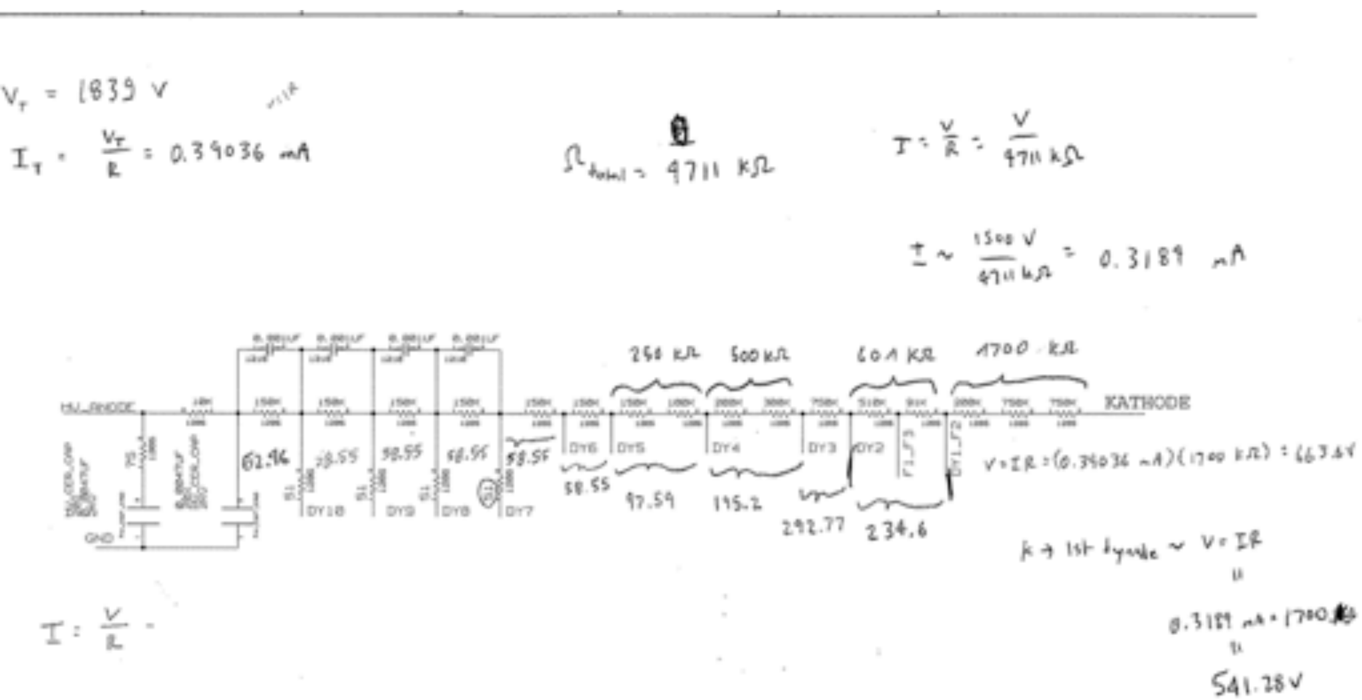
N stages of amplification

Each stage produces a random number of secondary electrons, drawn from a Poisson distribution, with a mean determined by the potential difference, the material properties (E_m, δ_m), and the universal yield curve.

The electrons produced by one stage are amplified by the next stage.

Adjustment: We find that the first stage appears to have two gain paths. More on that later...

It turns out you can simulate this fast!



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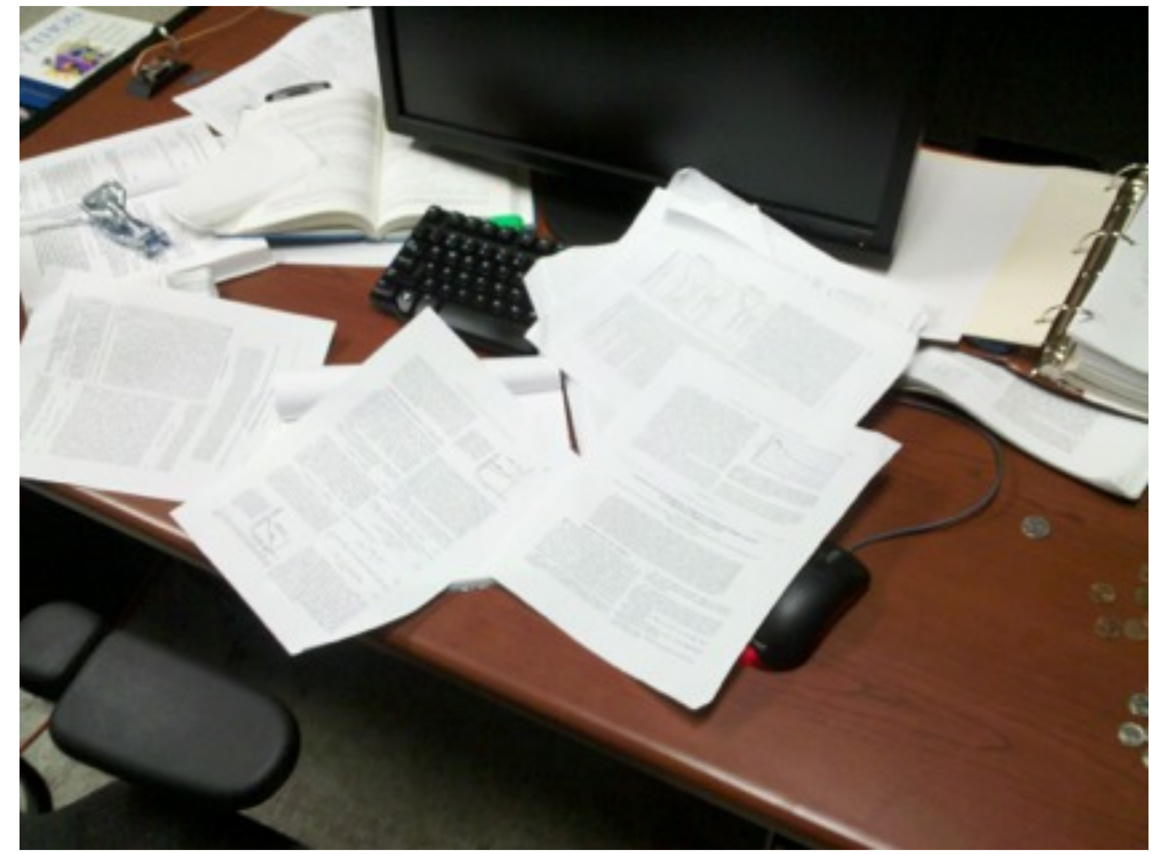

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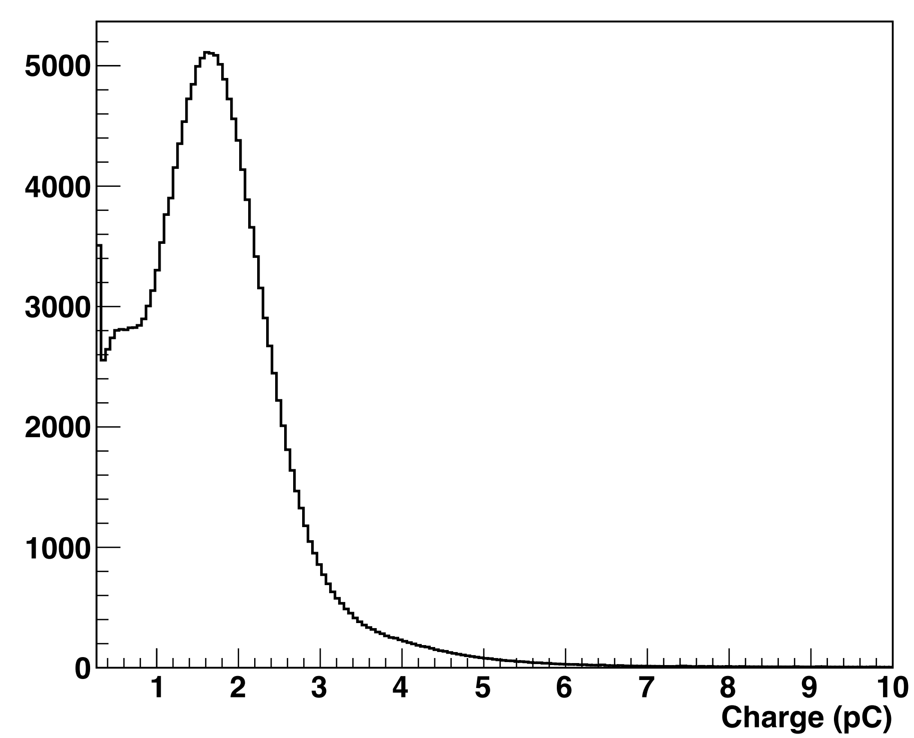
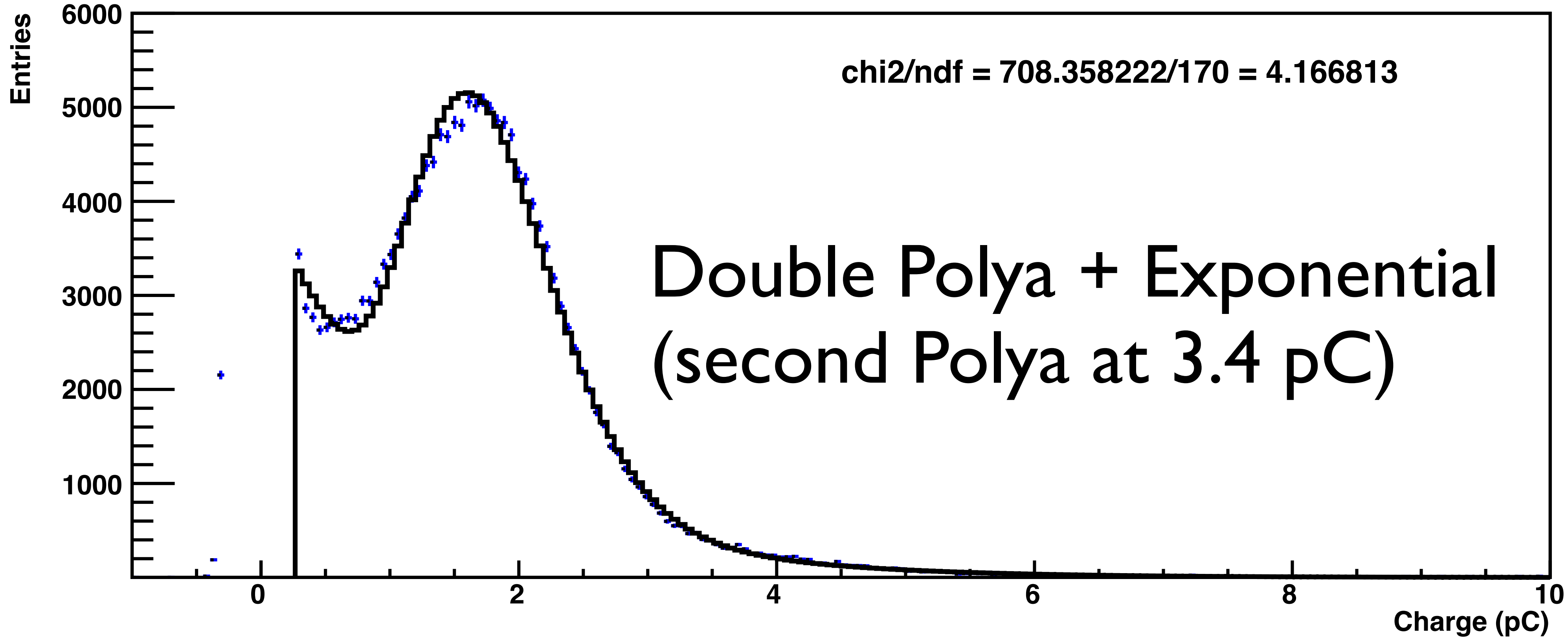
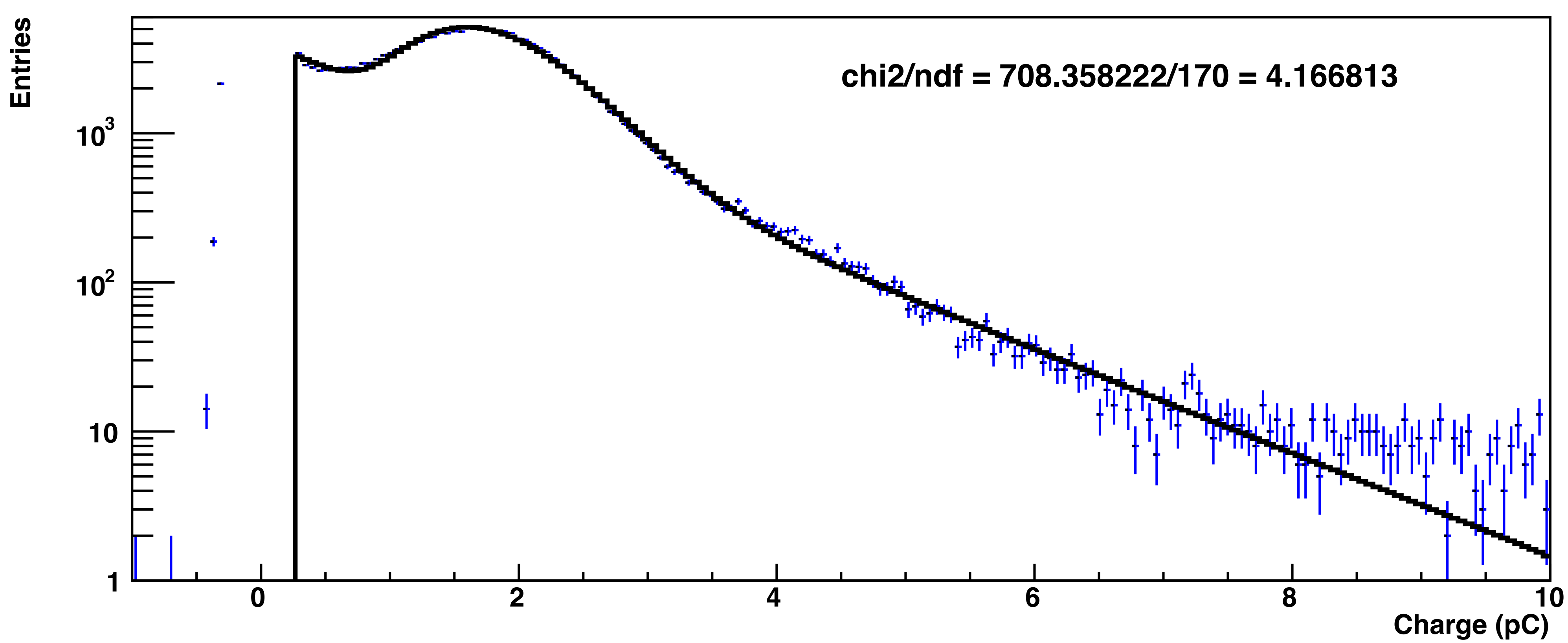
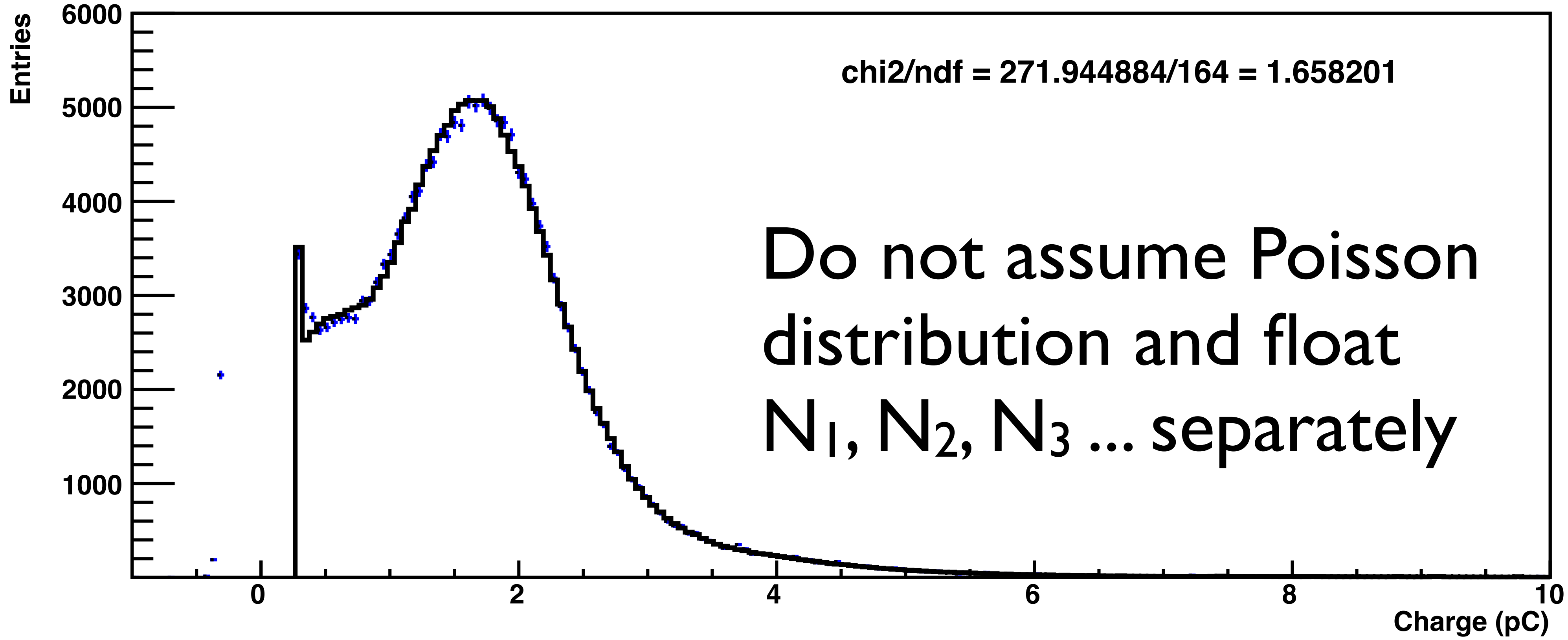


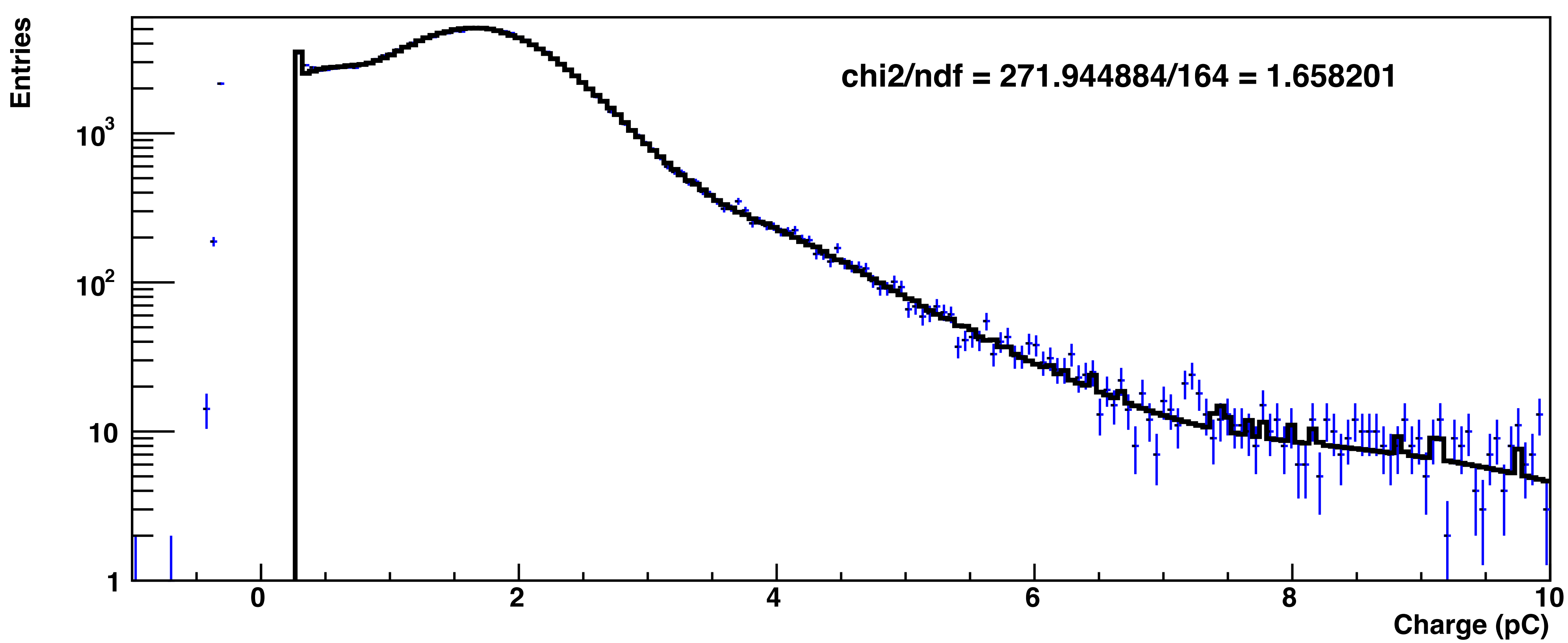
	PMT Model	Measurement Process
Fixed Inputs	V_i : dynode voltages	$N(q)$: charge distribution of no-signal window
Free Parameters	E_m : Energy for max gain δ_m : Max gain P_{alt} : probability of "alternate production" at 1st dynode δ_{alt} : alternate gain at first dynode	N_{noise} : # of "noise" events N_1, N_2, N_3 ... : Number of 1, 2, 3, ... photon events $\sigma_{baseline}$: pedestal width $\mu_{baseline}$: pedestal offset

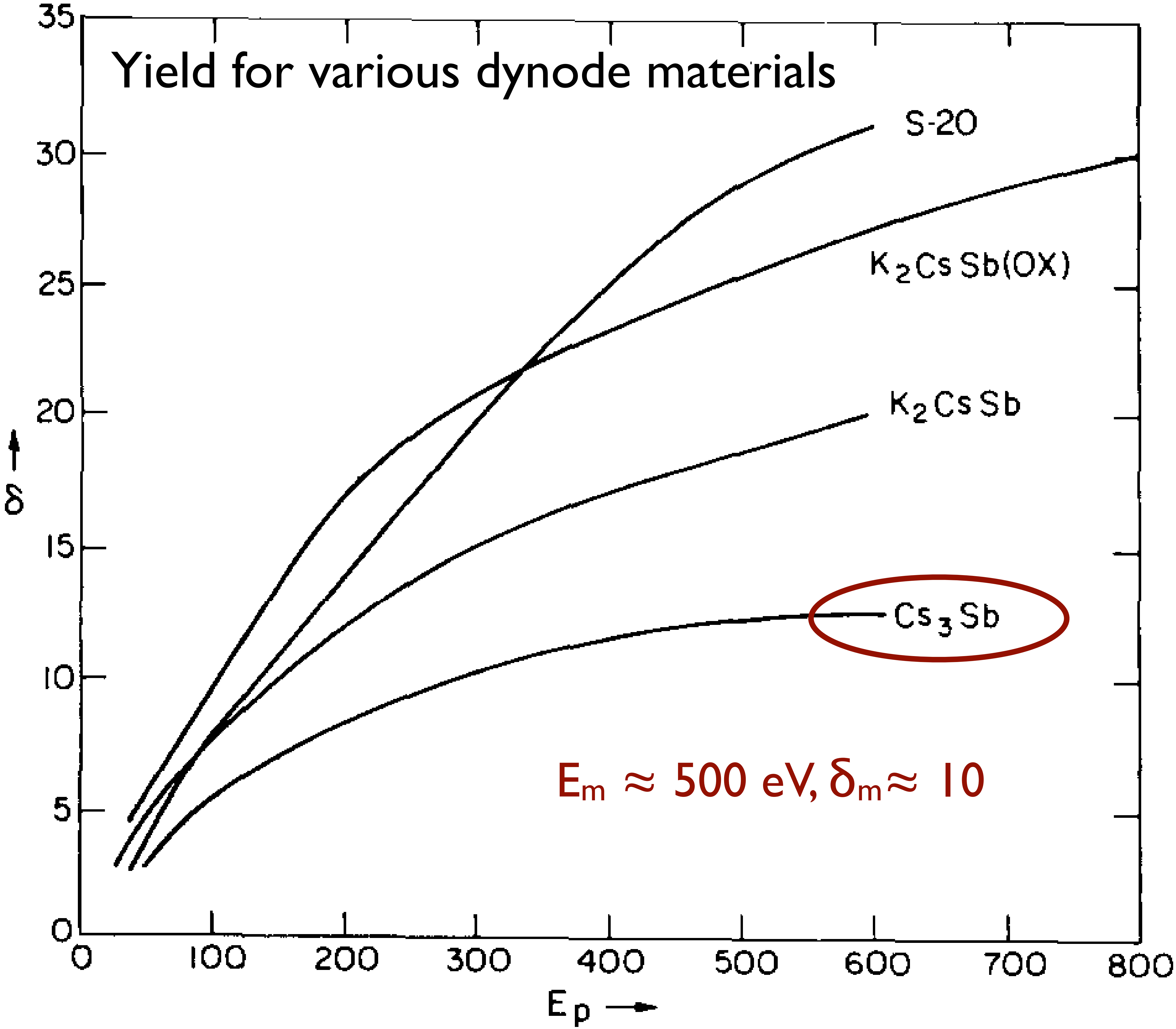

Entries
6000
5000
4000
3000
2000
1000
chi2/ndf = 708.358222/170 = 4.166813
Double Polya + Exponential
(second Polya at 3.4 pC)
0
2
4
6
8
10
Charge (pC)


Entries
10^3
10^2
10
1
chi2/ndf = 708.358222/170 = 4.166813
0
2
4
6
8
10
Charge (pC)

Do not assume Poisson distribution and float N_1, N_2, N_3 ... separately



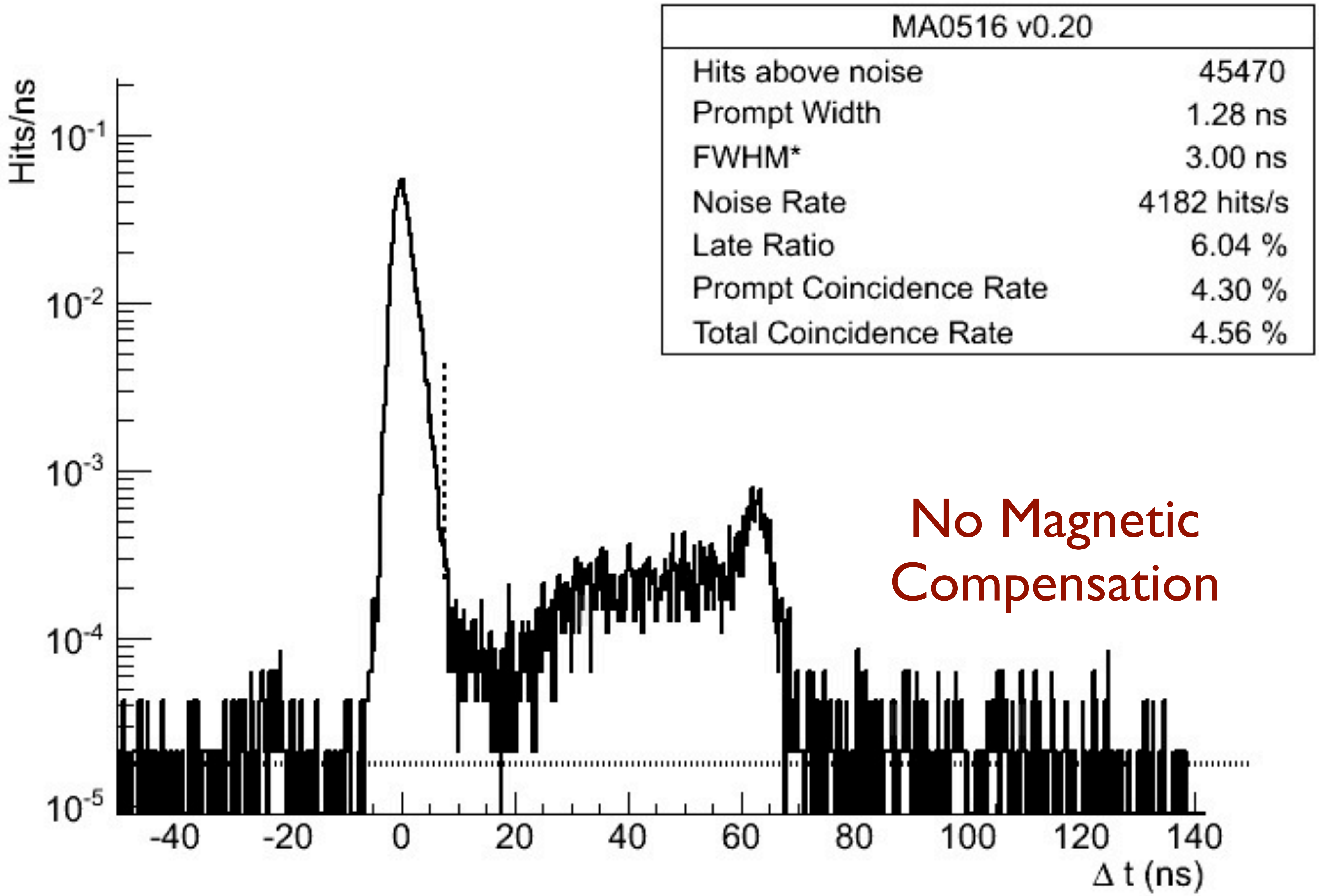



Yield for various dynode materials
S-20
K2CsSb(OX)
K2CsSb
Cs3Sb
Em ≈ 500 eV, δm ≈ 10
δ
Ep
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800

Back to Timing...

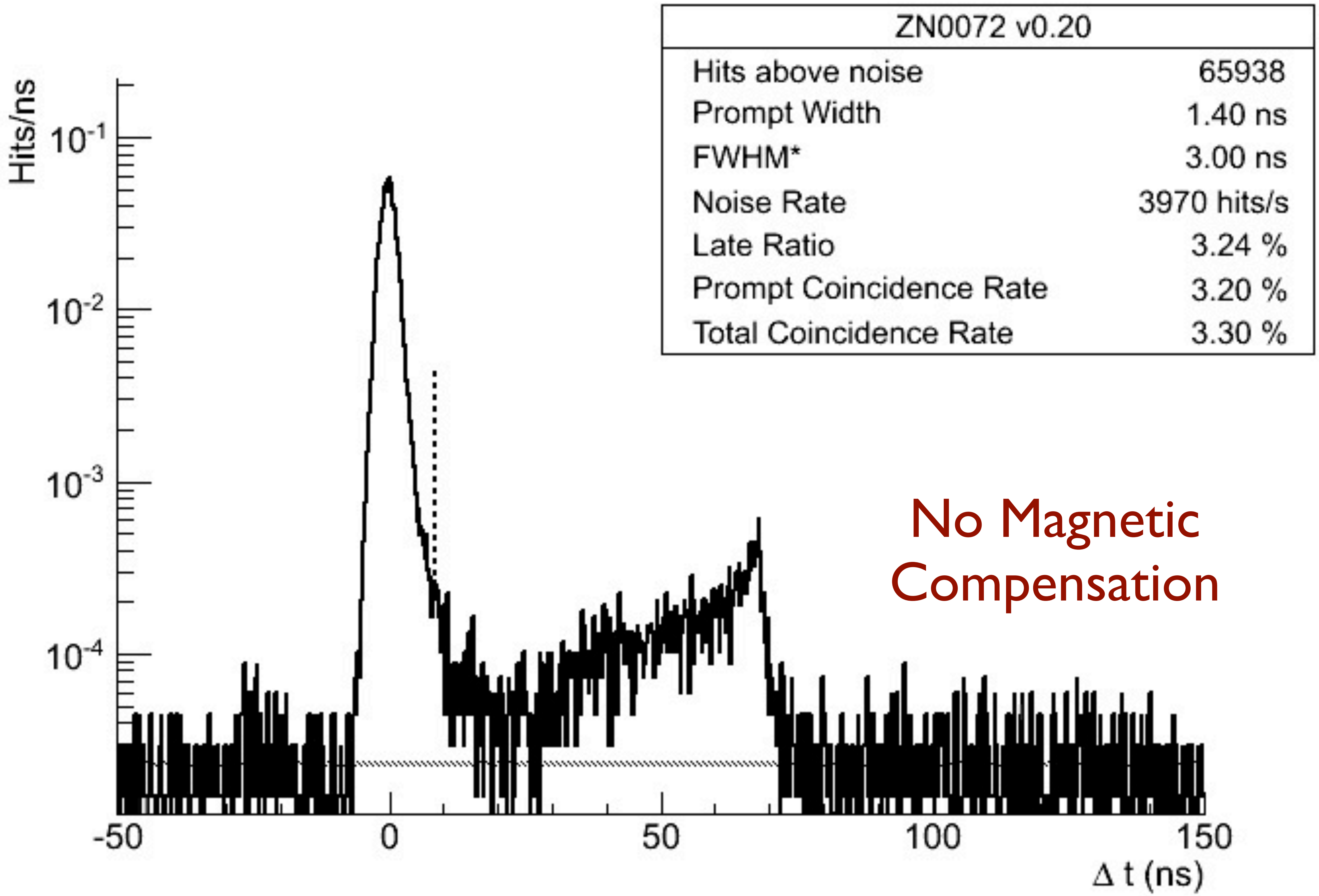
And that low gain path....

Transit Time Distribution: 10" PMT



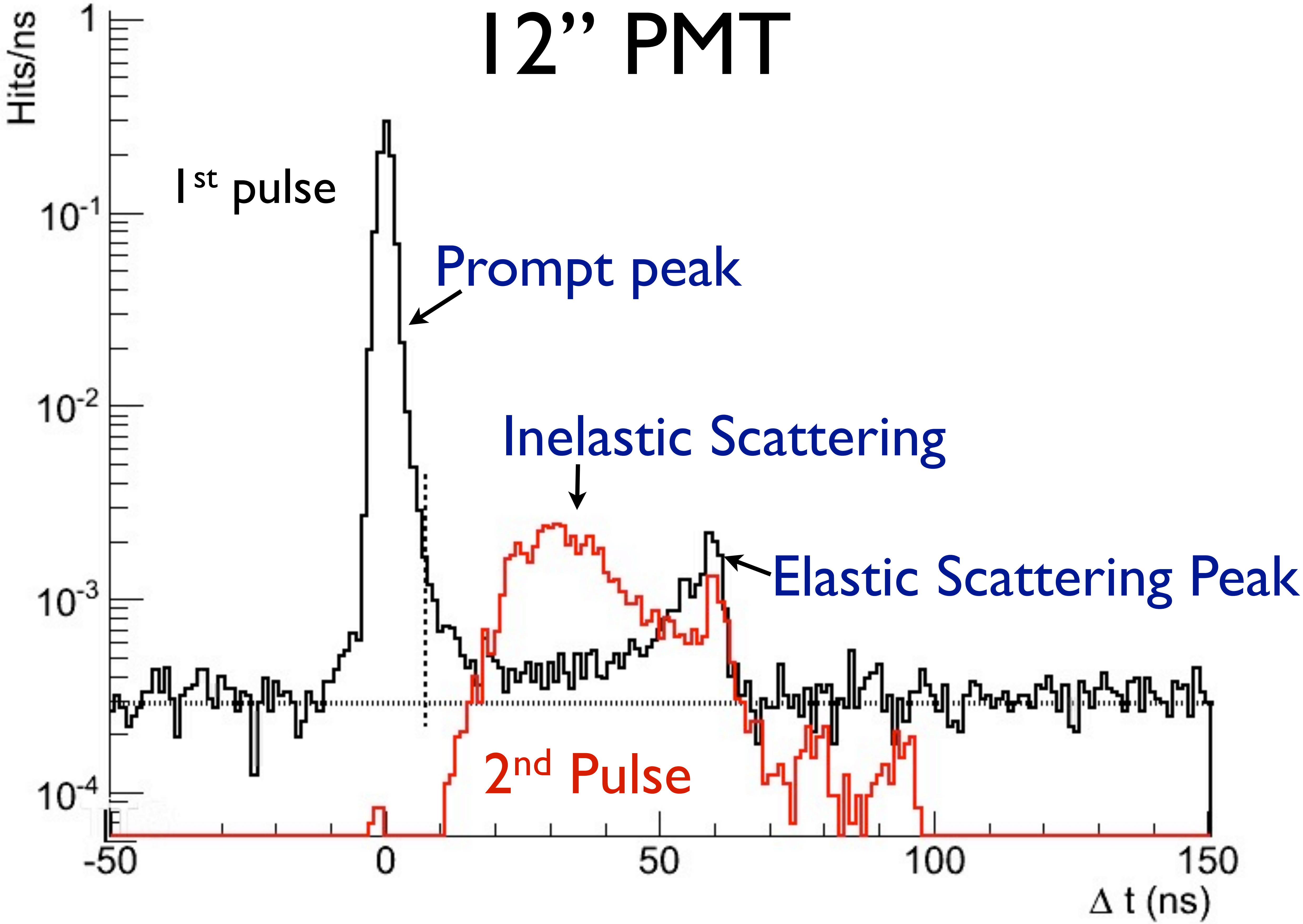
No Magnetic Compensation

Transit Time Distribution: 12” PMT



No Magnetic Compensation

Double Pulsing: 12" PMT

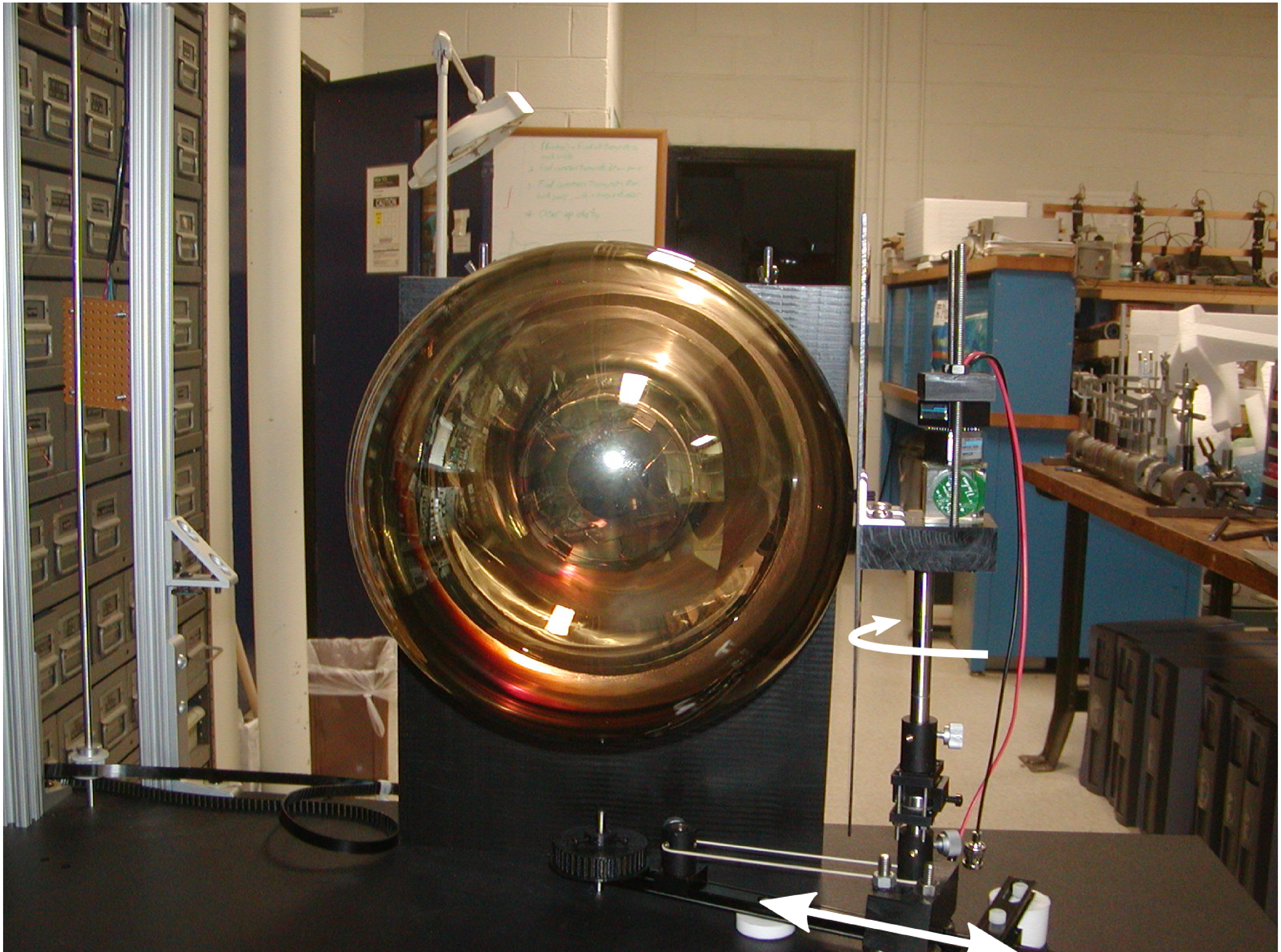


Summary Table

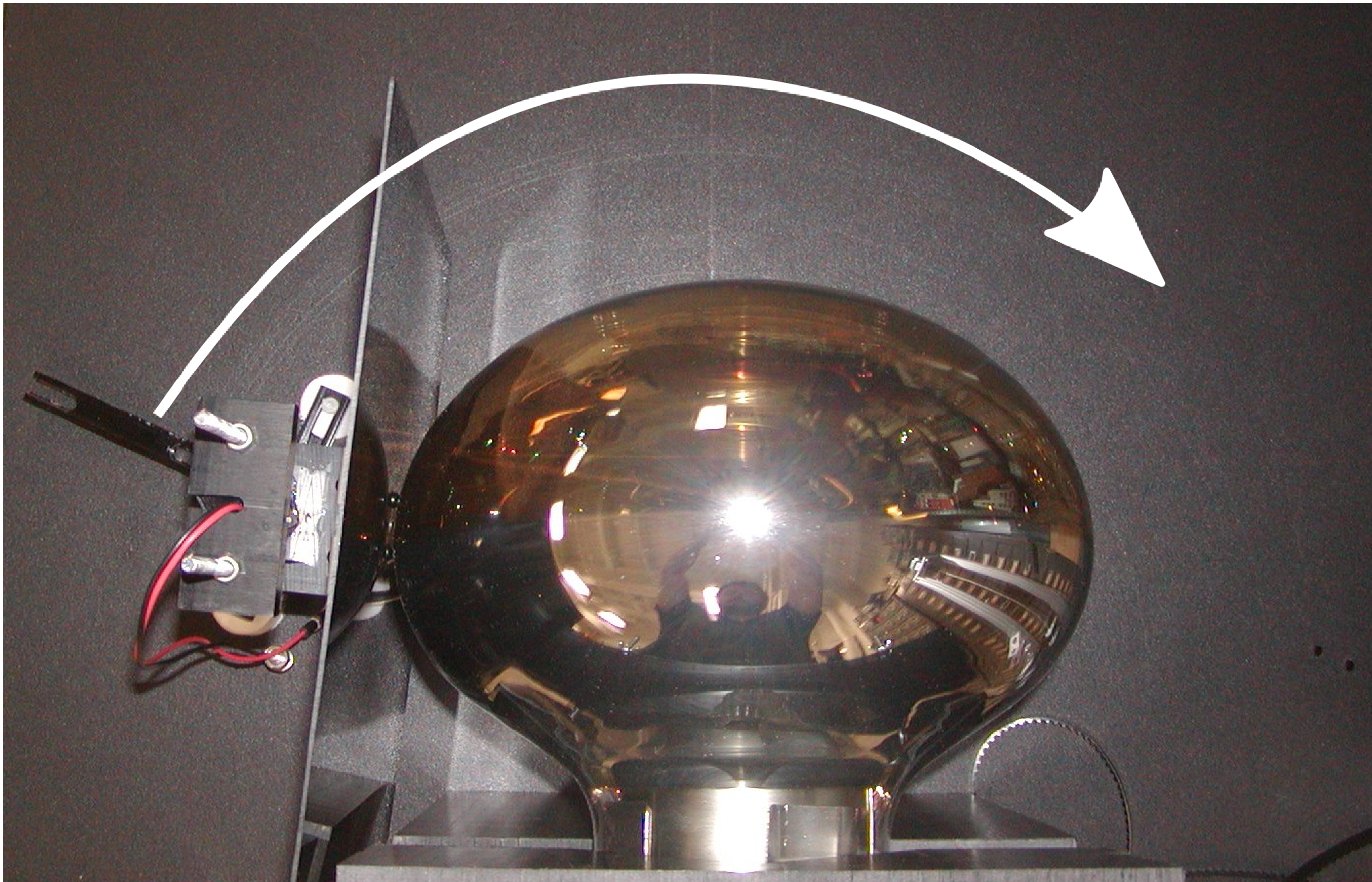
	R11780-SQE 12 inch*	R7081-HQE 10 inch**	ETL 8 inch***
Voltage (V)	1921	1550	1650
Dark Hits (Hz)	4530	5360	2400
Peak/Valley	3.17	2.12	2.25
TTS width (ns)	1.33	1.54	1.30
Late Pulsing (%)	3.63	5.89	6.27
High Charge (%)	7.97	4.40	9.30
	10 PMTs	5 PMTs	1 PMT

No Magnetic Compensation

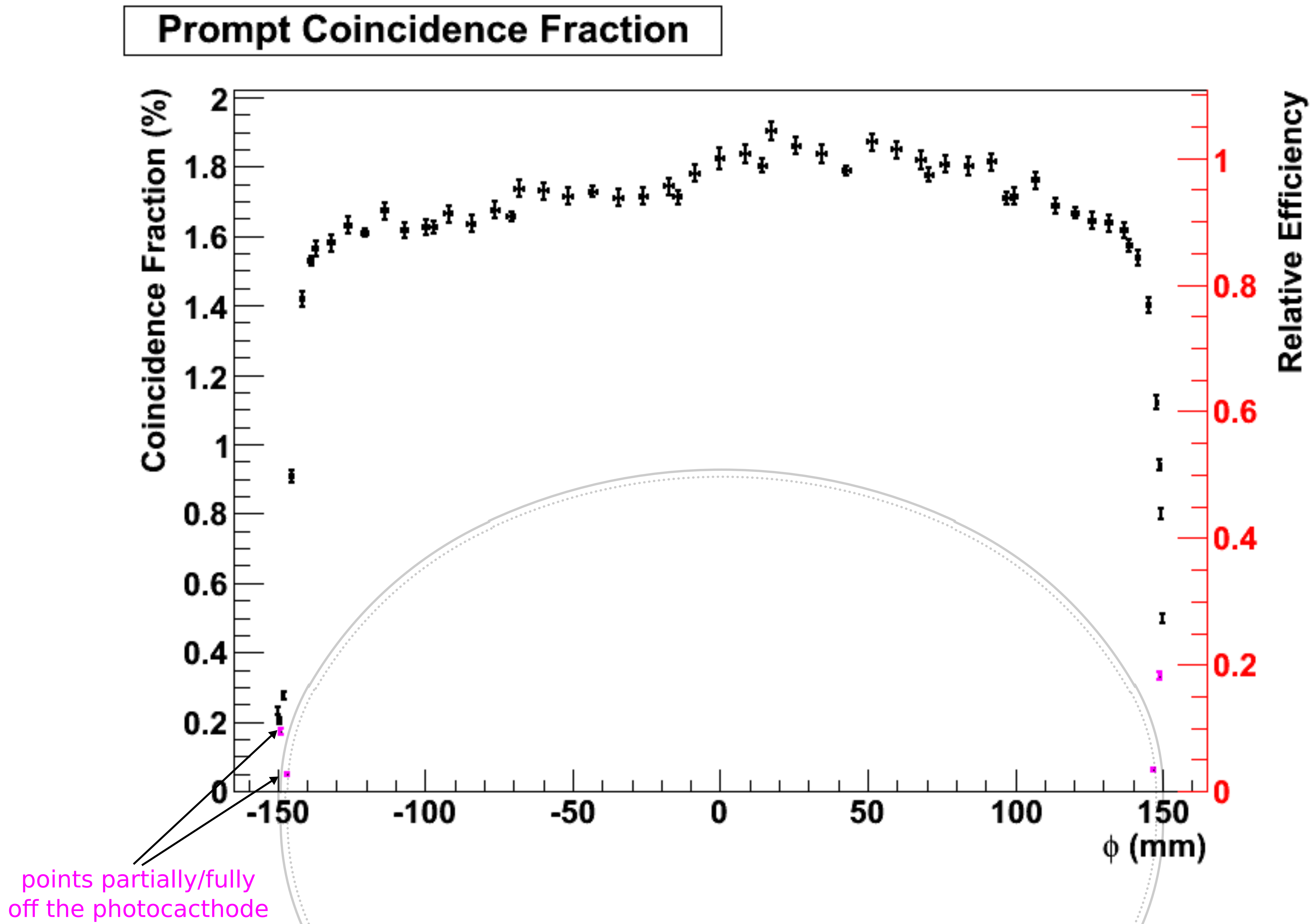
Scanning Arm



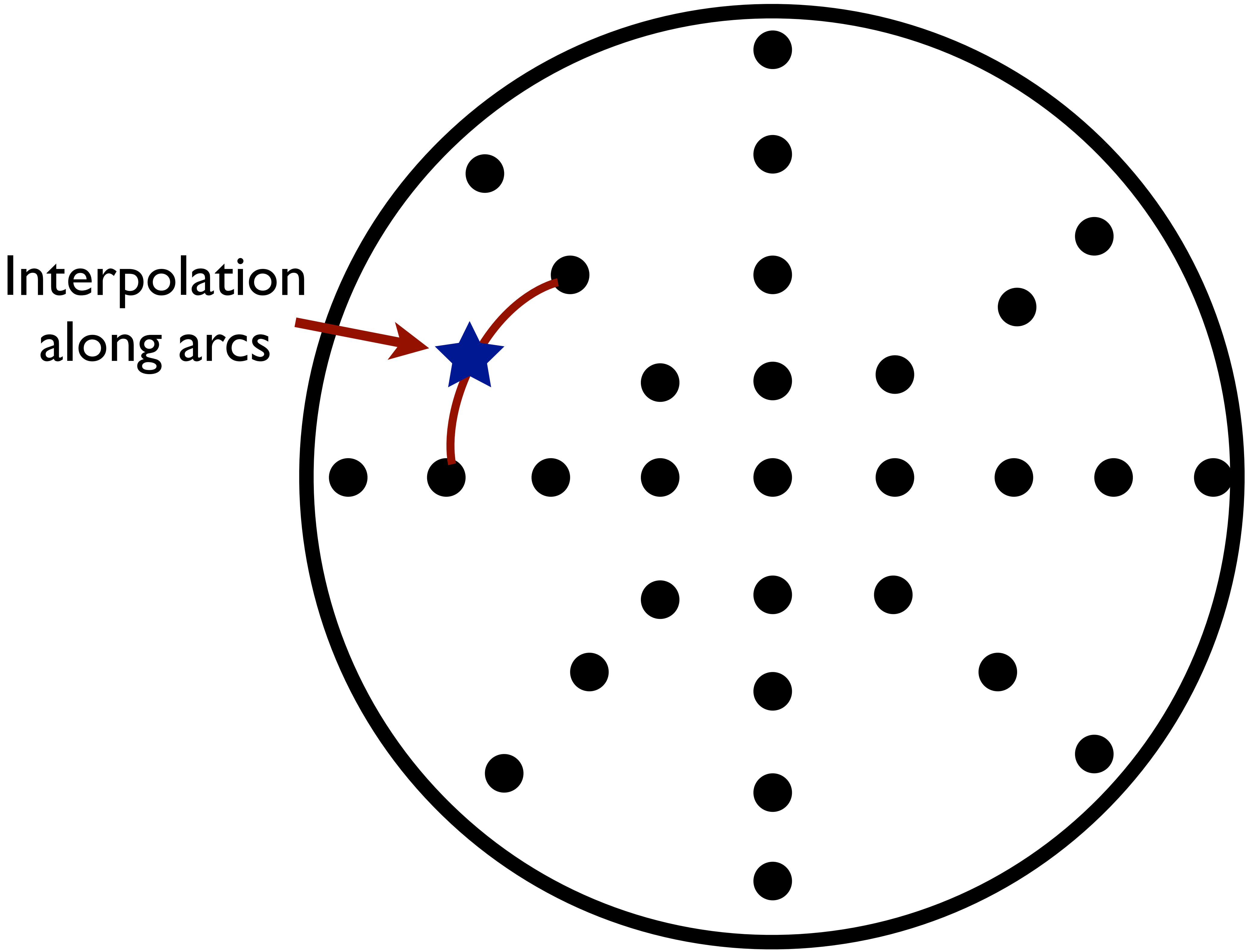
Scanning Arm



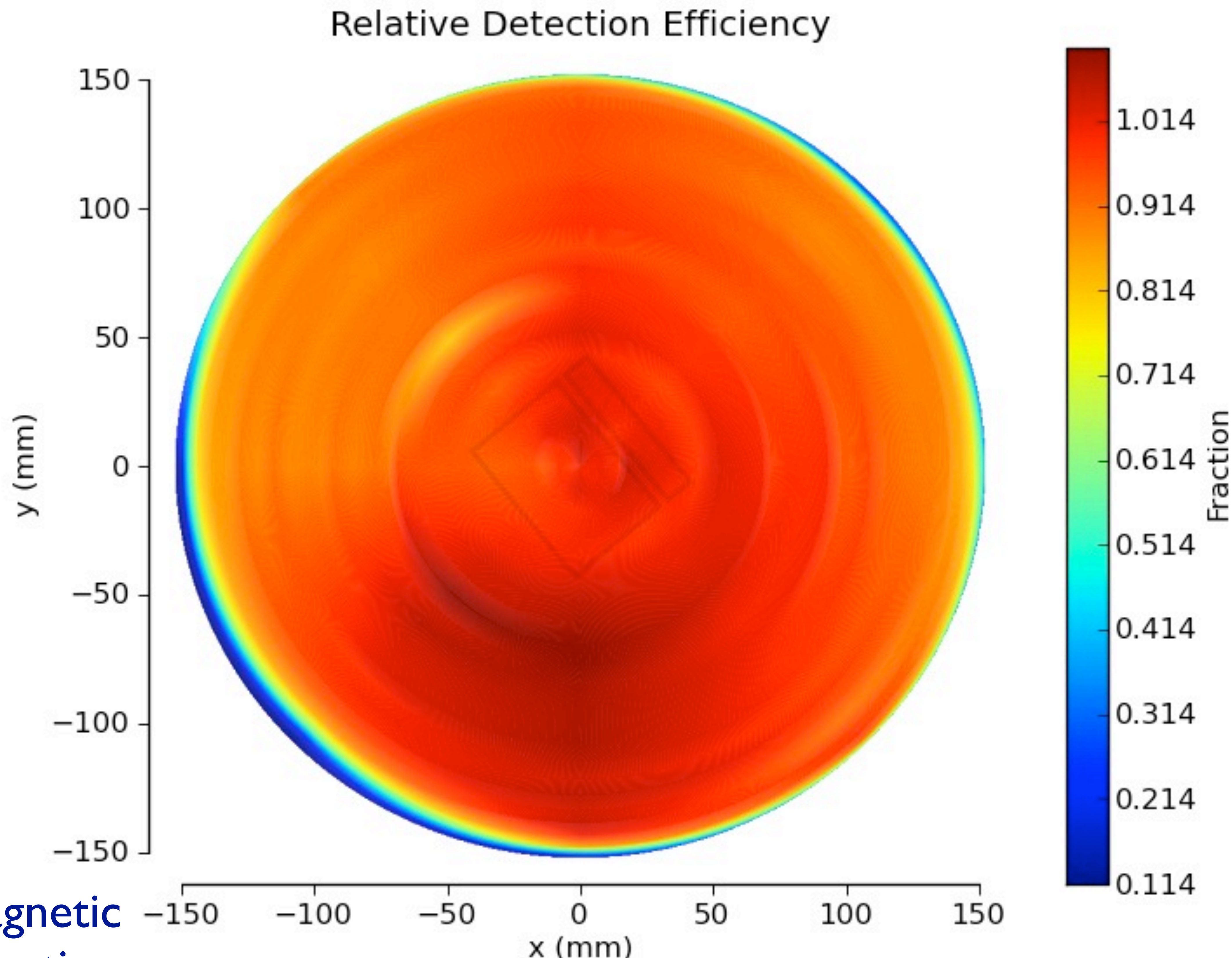
Relative Efficiency: 12” PMT



2D scan

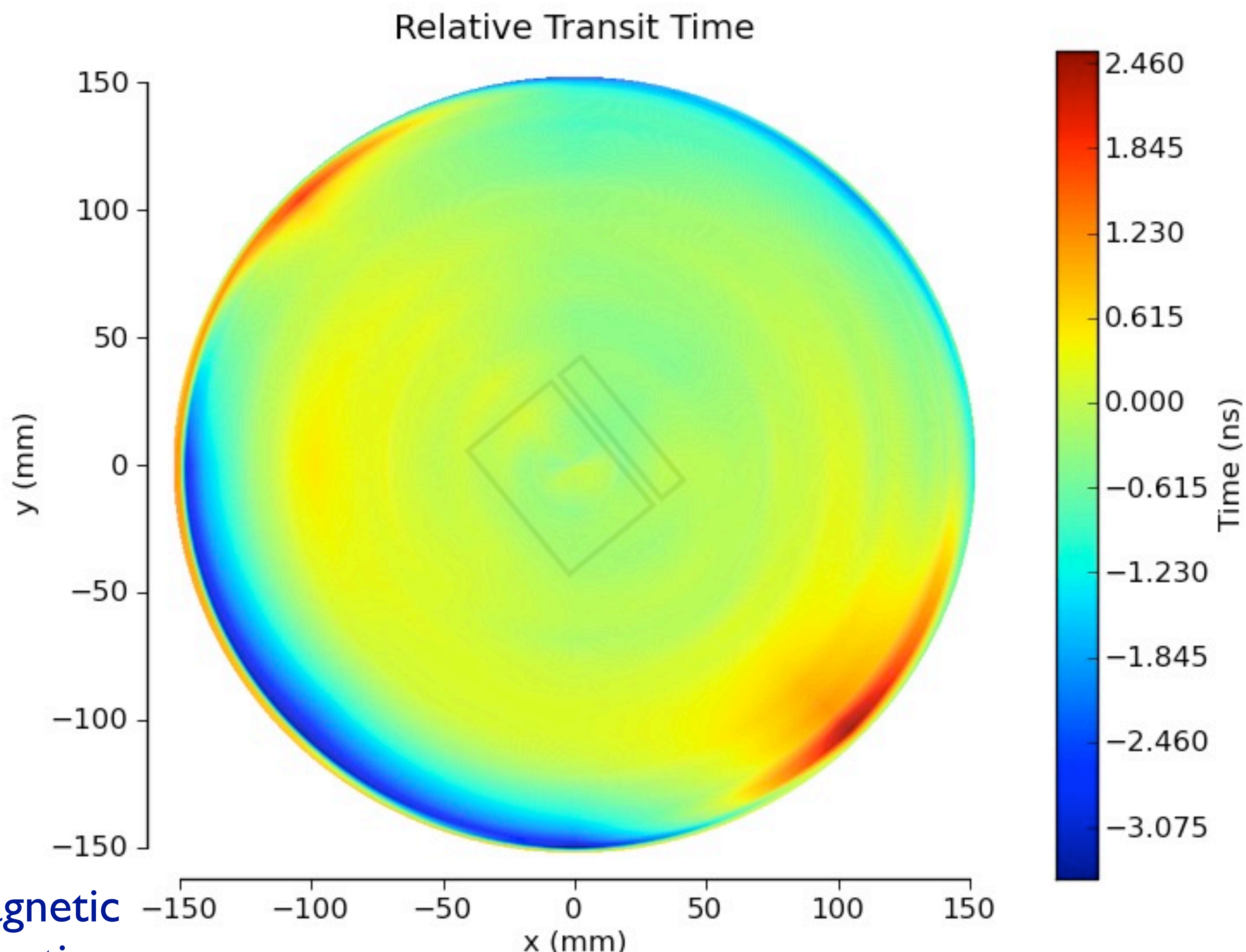


Position Dependence: 12” PMT



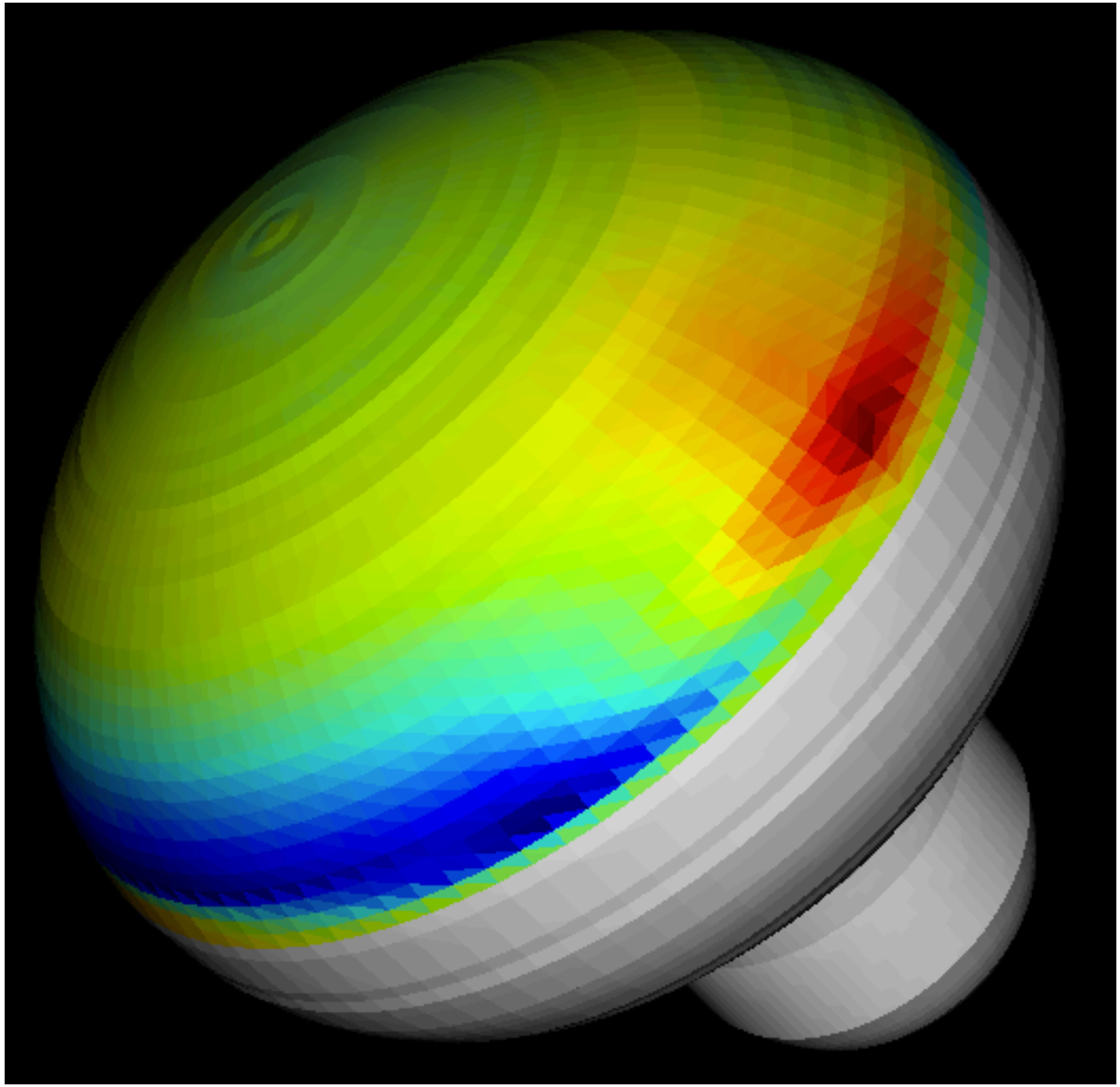
With Magnetic Compensation

Position Dependence: 12” PMT



With Magnetic Compensation

Position Dependence: 12” PMT



With Magnetic Compensation

Conclusions

- An acrylic Cherenkov source can be used to test PMTs with light very similar to that seen in a Water Cherenkov detector.
- Both the 10” and 12” PMTs have excellent charge and timing performance.
- The 12” PMTs have fairly uniform detection efficiency when viewed from the front.
- The relative transit time can vary by +/- 3ns for photons hitting the edge.
- The non-Poisson nature of the light source may lead to an overestimate of the number of high-charge events, but we are looking at physical models to understand this contribution.