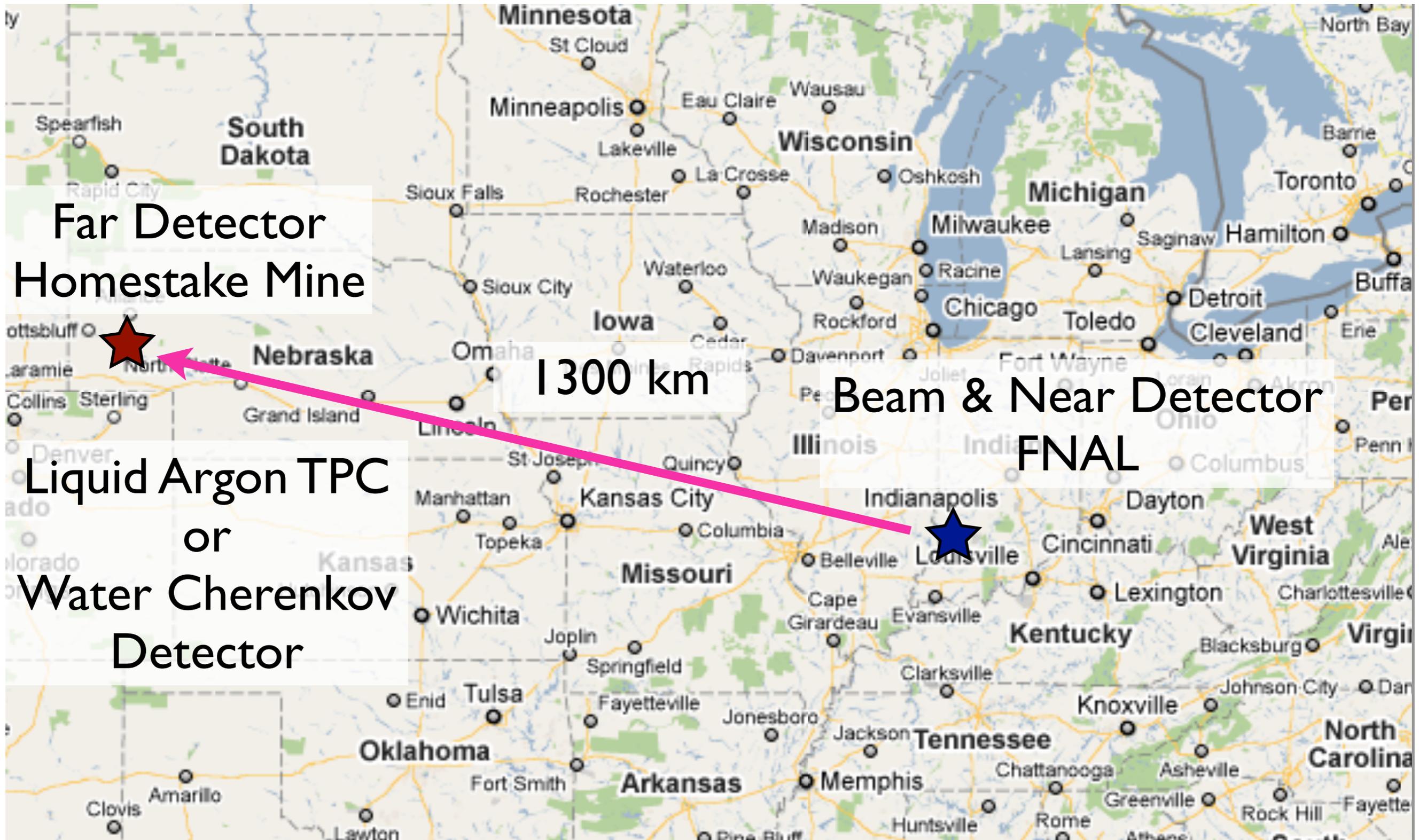


Characterization of Photomultiplier Tubes for the Long-Baseline Neutrino Experiment

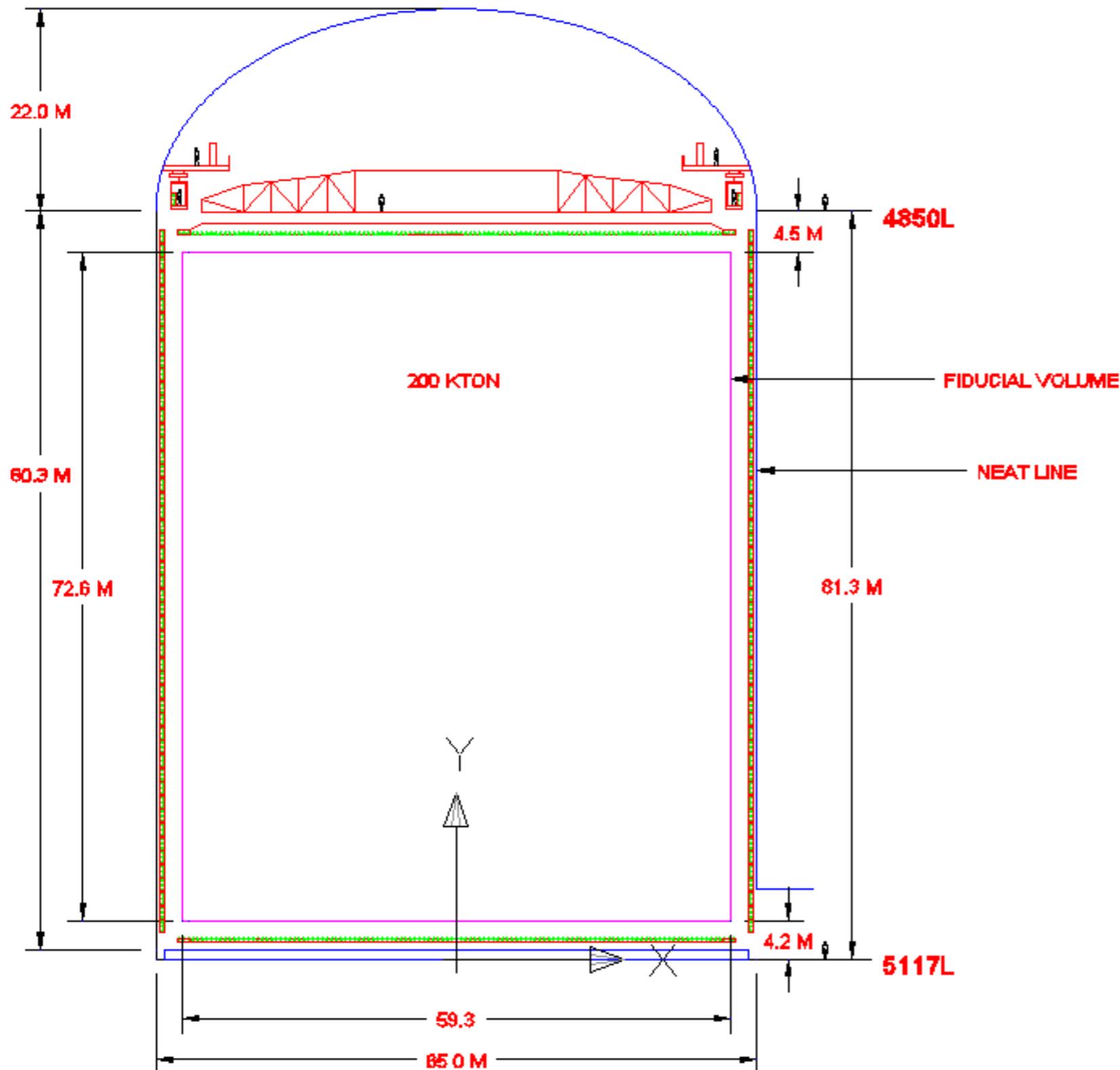
Robert Knapik, Anthony LaTorre, Kevin Shapiro,
Logan Ware, Brian Delgado, Josh Klein, Stanley Seibert
University of Pennsylvania

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**

- **Time**

- Absolute efficiency as a function of incident particle energy
- Relative efficiency as a function of particle energy
- Charge
- Width of the energy distribution
- Peak position
- High energy tail
- Saturation

- Transit time
- Late pulsing probability
- Position resolution
- Energy resolution
- Position stability

Energy Estimation

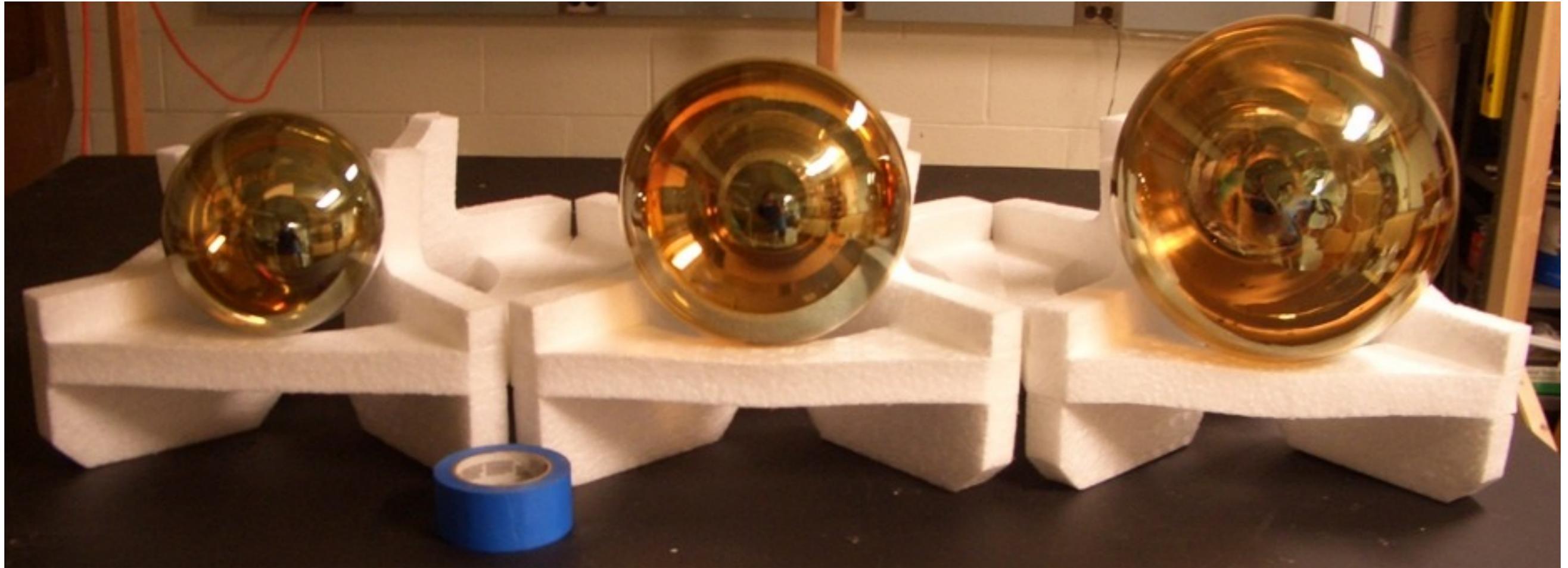
Position Reconstruction

Particle ID

Some Candidate PMTs

Hamamatsu
R7081 10"

Hamamatsu
R11780 12"

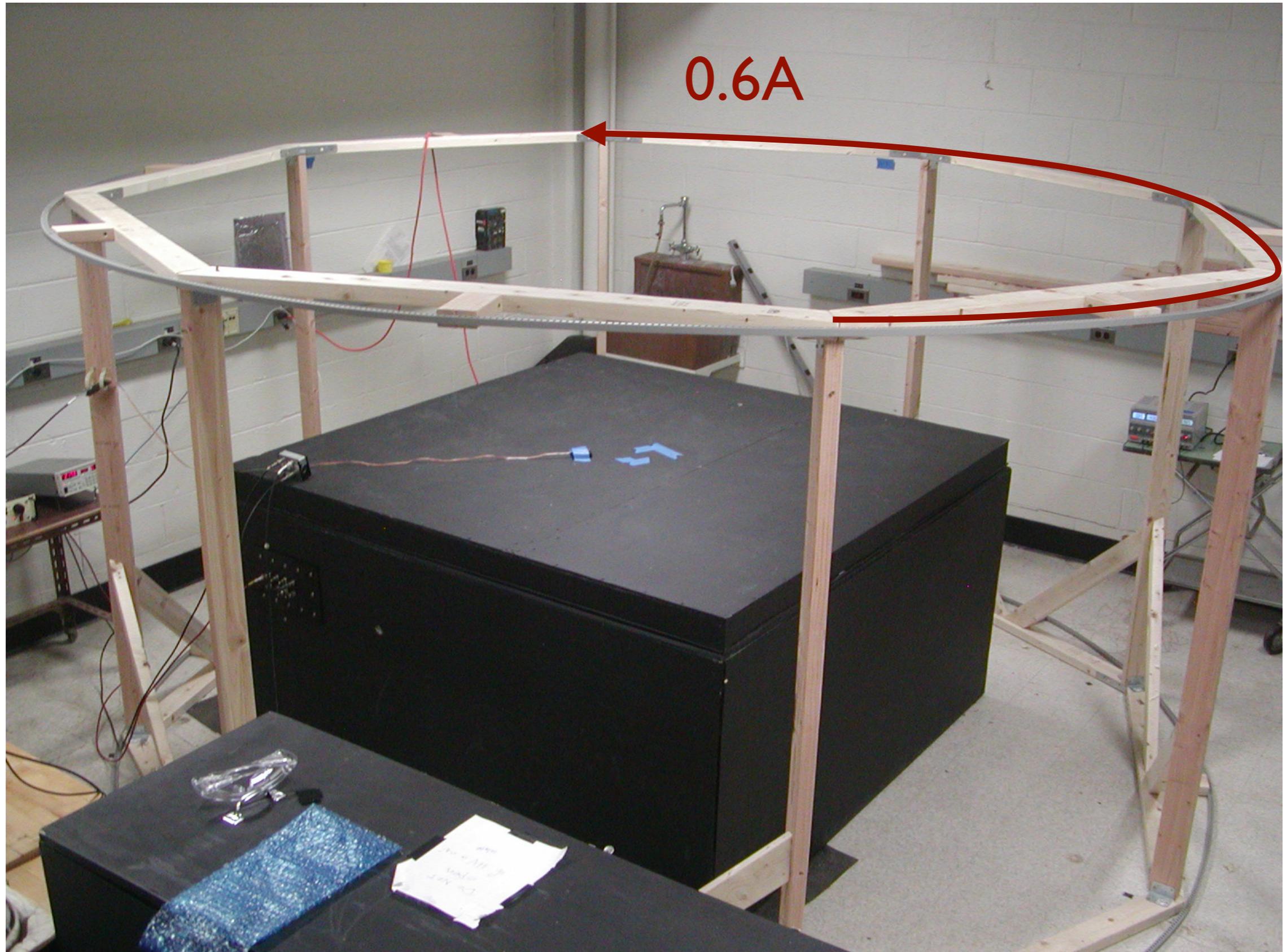


Hamamatsu R1408 8"
(*“standard candle”
comparison only*)

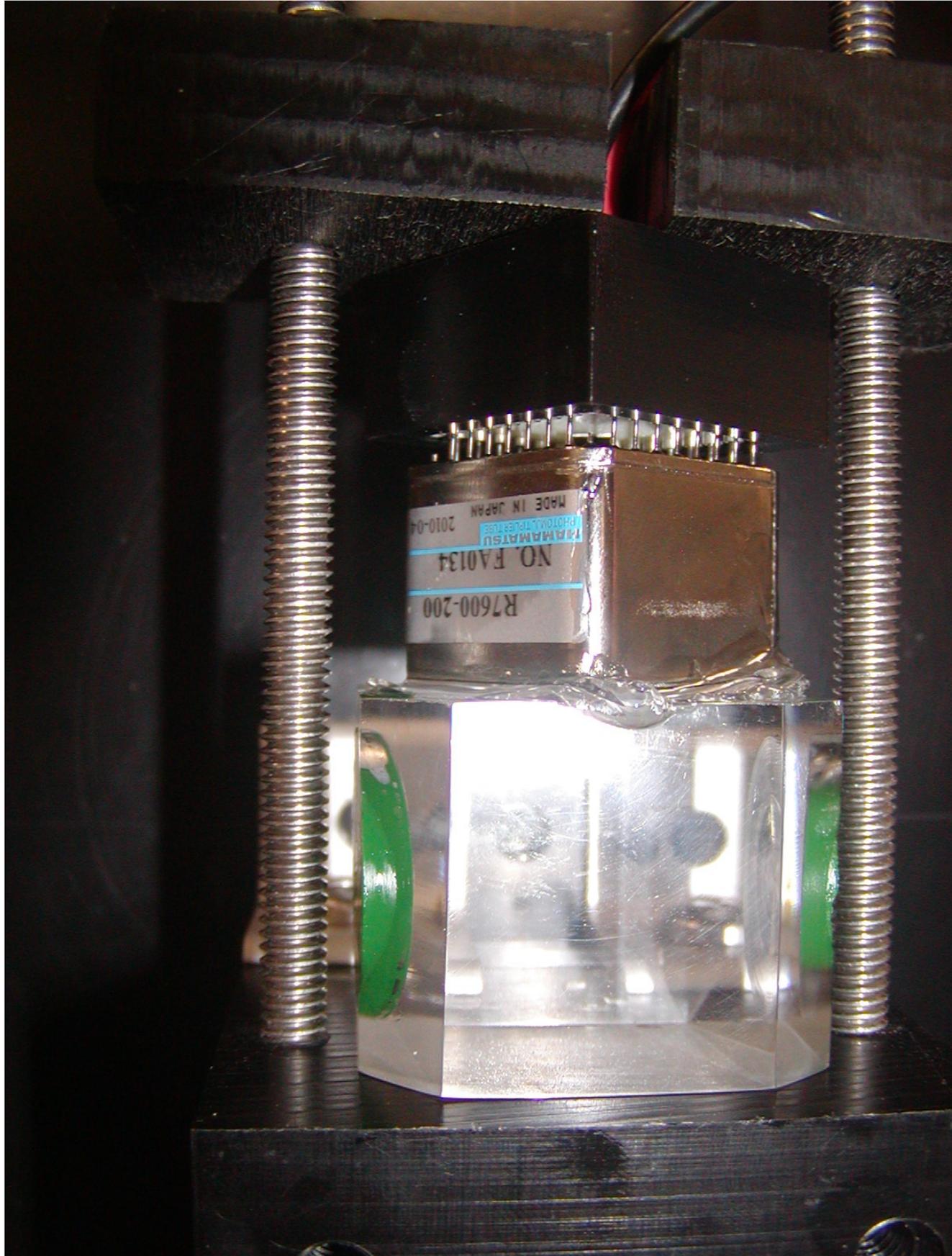
Now have 12" with standard,
enhanced, and high quantum efficiency.

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 $<100\text{ps}$ jitter
- Cherenkov events are very sharp in time
- Produces a wavelength spectrum very similar to the that observed in a water Cherenkov detector

LeCrunch



The screenshot shows a Bitbucket repository page for 'tlatorre / lecrunch'. The page includes a navigation bar with 'bitbucket by ATlassian' and links for 'Explore', 'Dashboard', 'Repositories', 'Account', 'Inbox (5)', and 'Log out (seibert)'. Below the navigation bar, there are tabs for 'Overview', 'Downloads (0)', 'Pull requests (0)', 'Source', 'Commits', and 'Wiki'. The repository description states: 'Set of libraries and scripts for communicating and extracting waveform traces from LeCroy X-stream oscilloscopes.' It also provides cloning instructions: 'Clone this repository (size: 30.5 KB): HTTPS / SSH' and '\$ hg clone ssh://hg@bitbucket.org/tlatorre/lecrunch'. A 'Recent commits' section follows, listing five commits by 'tlatorre' with their messages and dates.

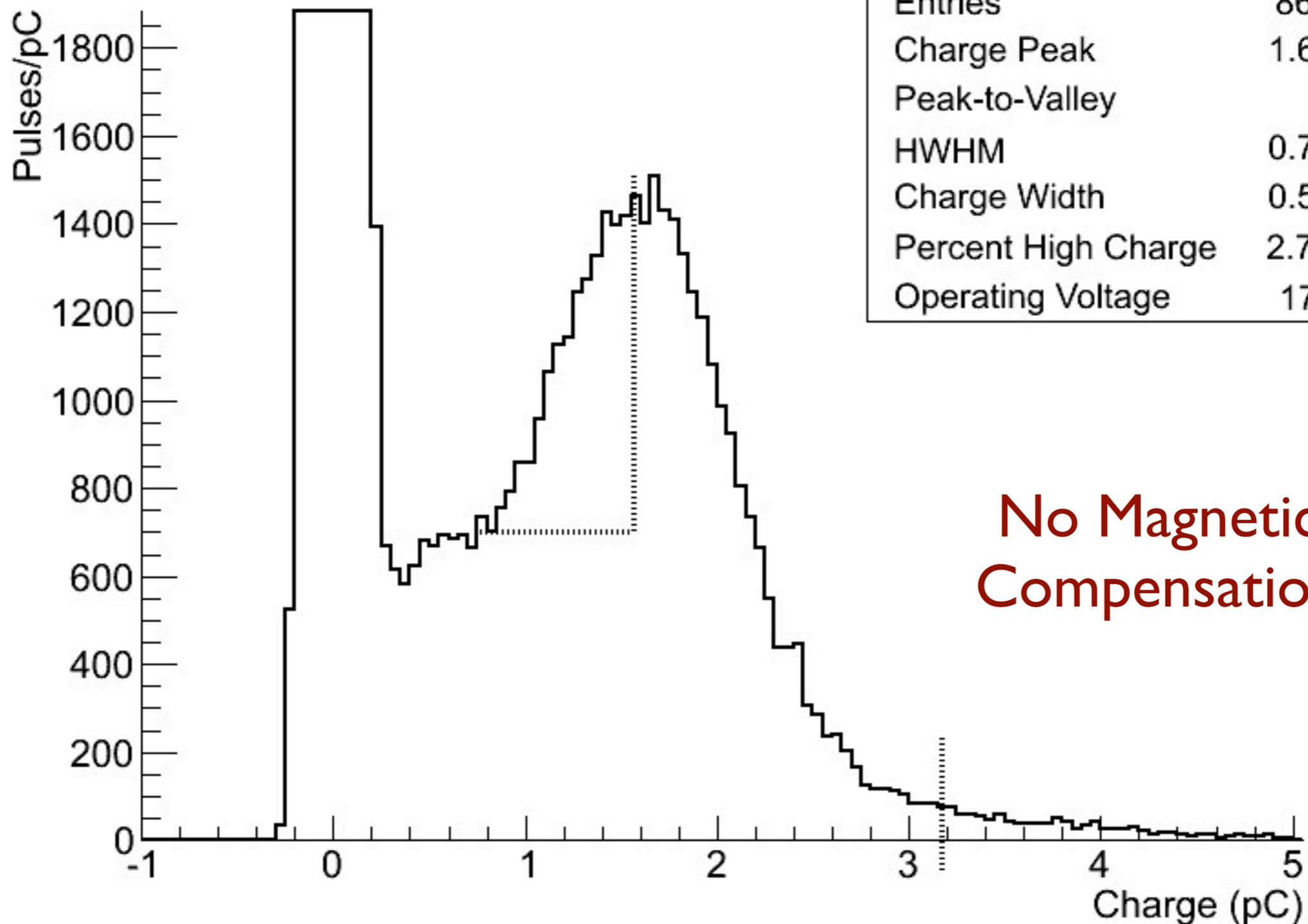
Author	Message	Date committed	+	🔄	-
tlatorre	readme file specified the wrong file to edit to specify the oscilloscopes's ip	1 month ago	-	2	-
tlatorre	you can now take data using sequence model! also, updated the README file to	1 month ago	3	5	1
tlatorre	documentation update	1 month ago	-	1	-
tlatorre	documentation update	1 month ago	-	2	-
tlatorre	initial commit	2 months ago	10	-	-

- 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

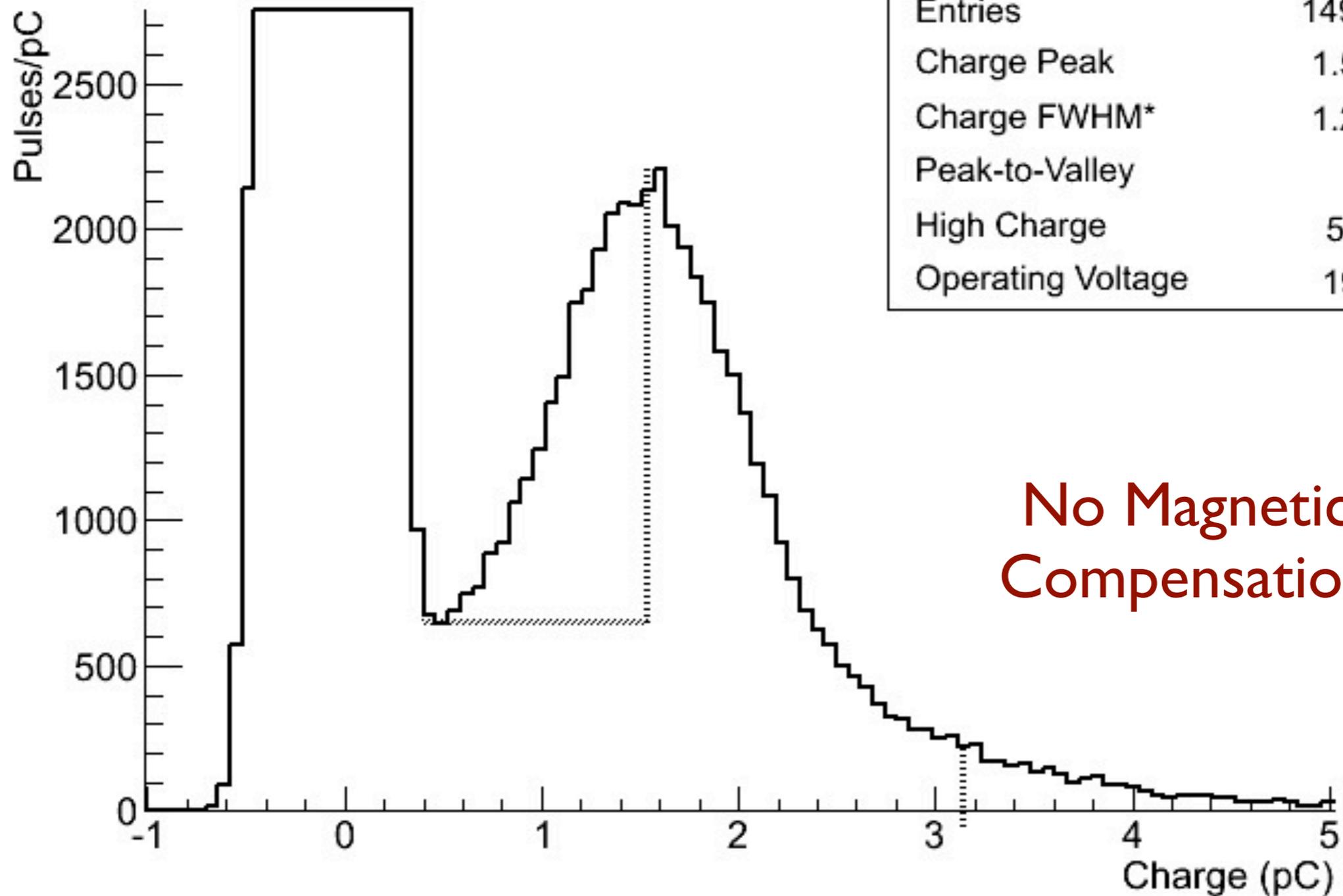
Charge Distribution: 10" PMT



MA0516 1x gain (Penn_base01)	
Entries	860105
Charge Peak	1.68 pC
Peak-to-Valley	2.06
HWHM	0.70 pC
Charge Width	0.53 pC
Percent High Charge	2.77 pct
Operating Voltage	1710 V

**No Magnetic
Compensation**

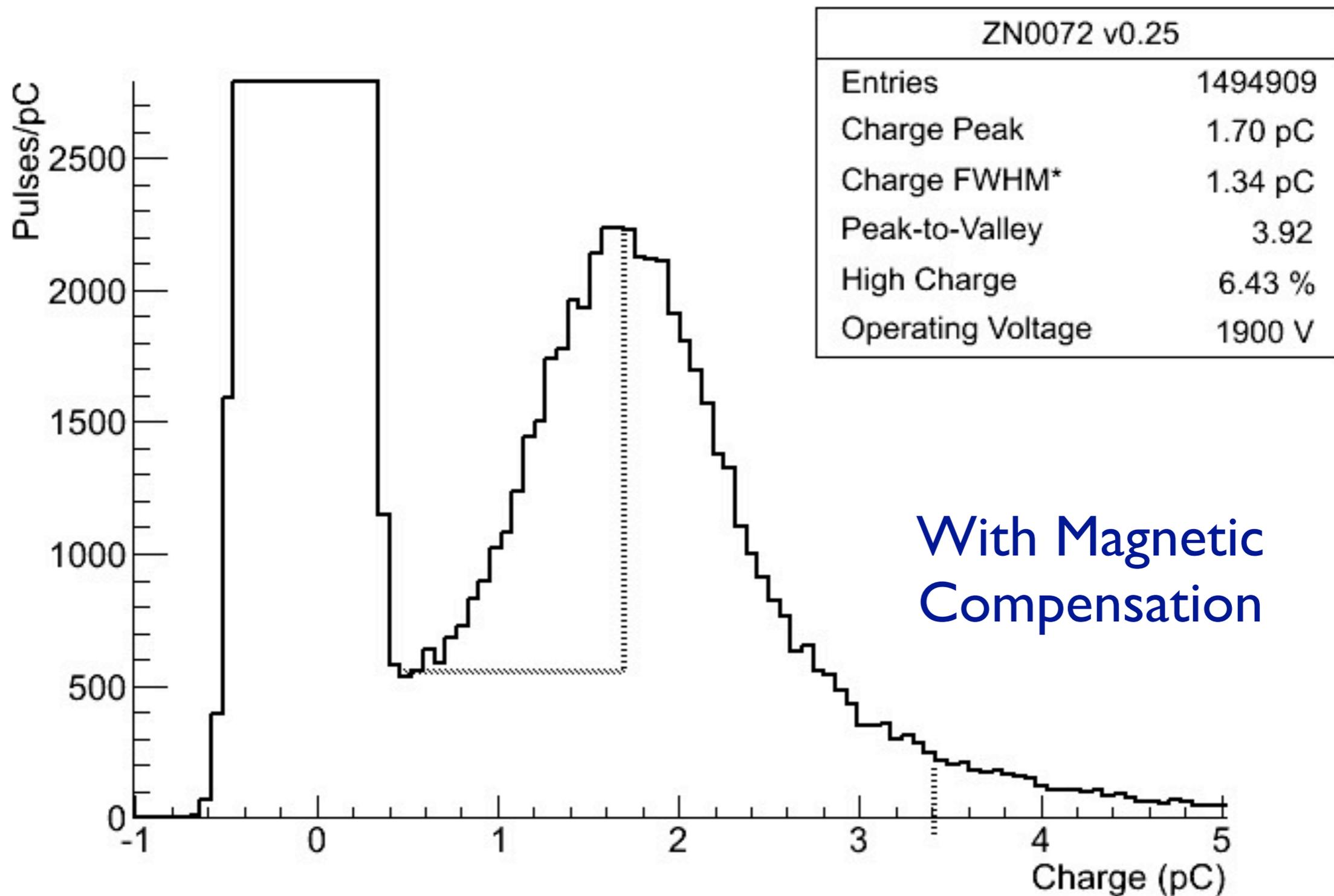
Charge Distribution: 12" PMT



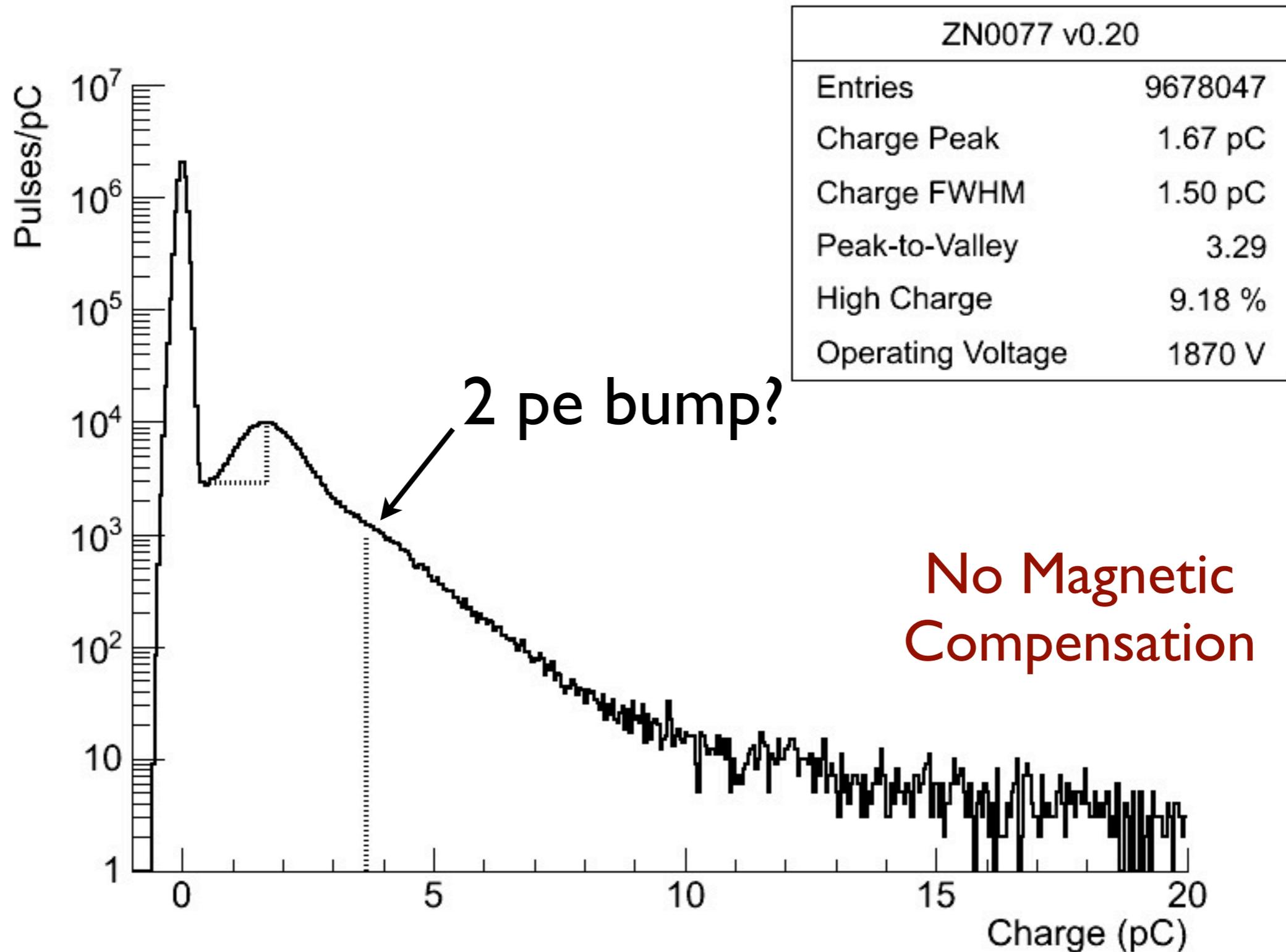
ZN0072 v0.25	
Entries	1495472
Charge Peak	1.53 pC
Charge FWHM*	1.26 pC
Peak-to-Valley	3.25
High Charge	5.64 %
Operating Voltage	1901 V

**No Magnetic
Compensation**

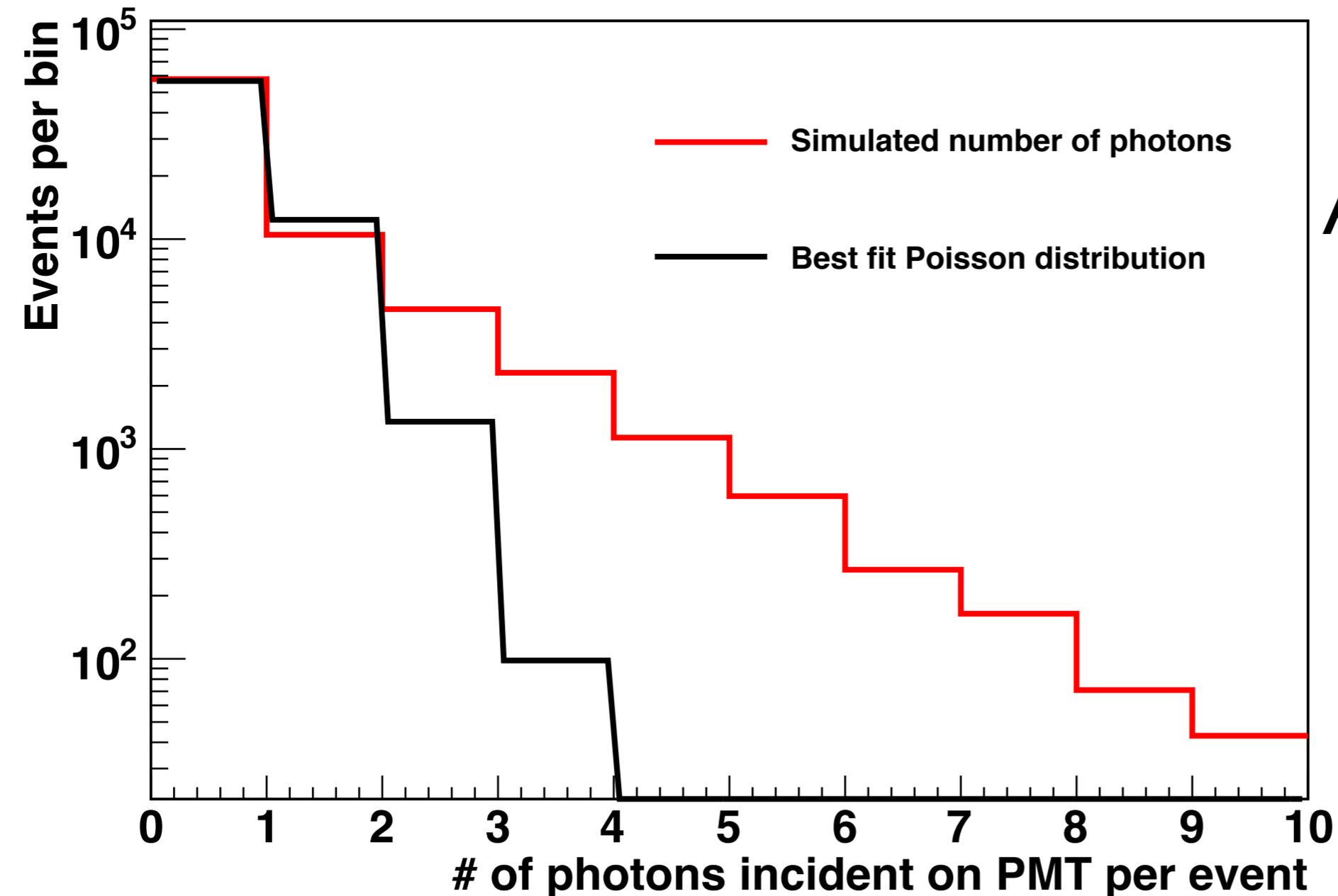
Charge Distribution: 12" PMT



High Charge Tail: 12" PMT

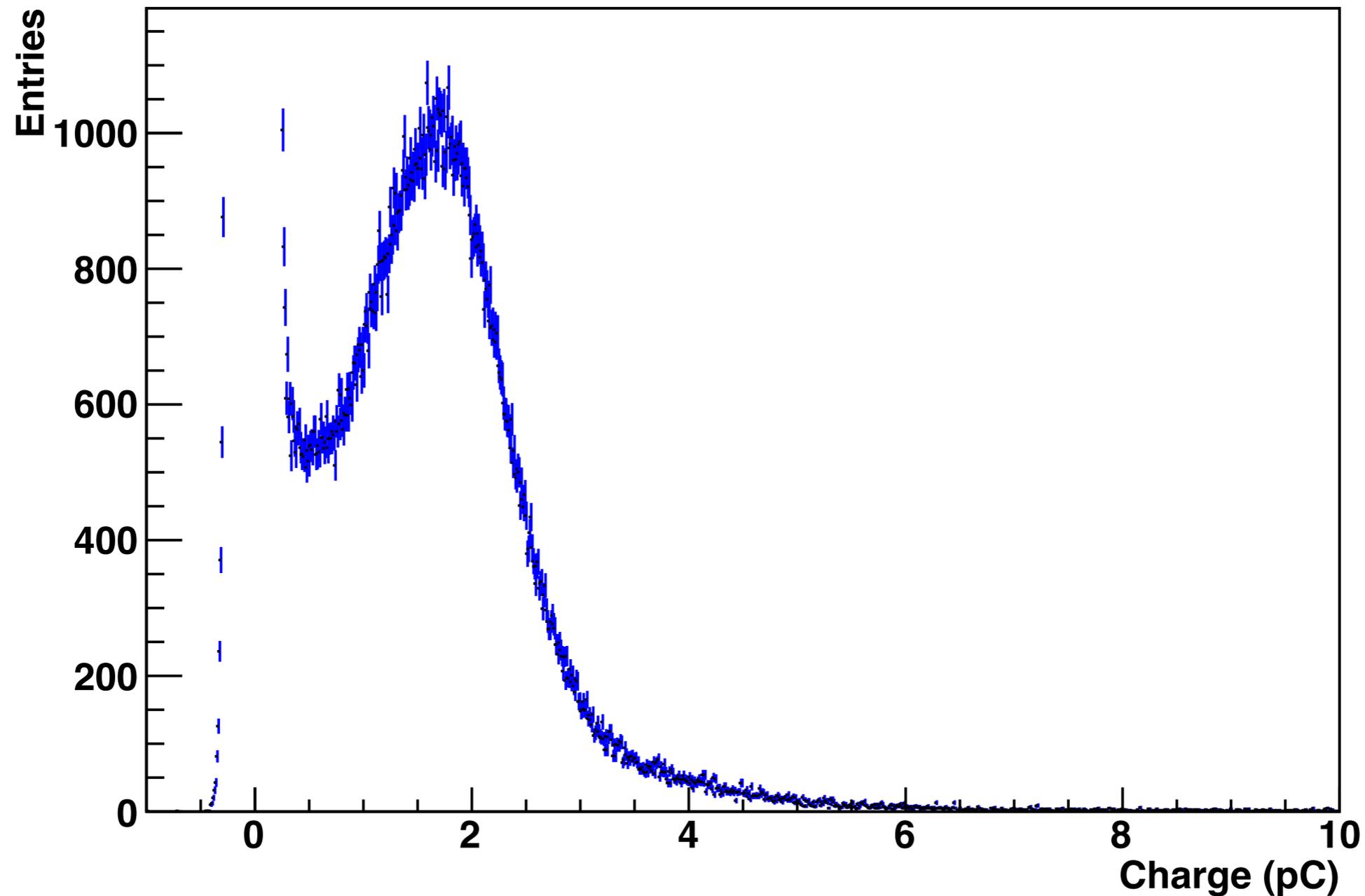


“High Charge Tail”: 12” PMT



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

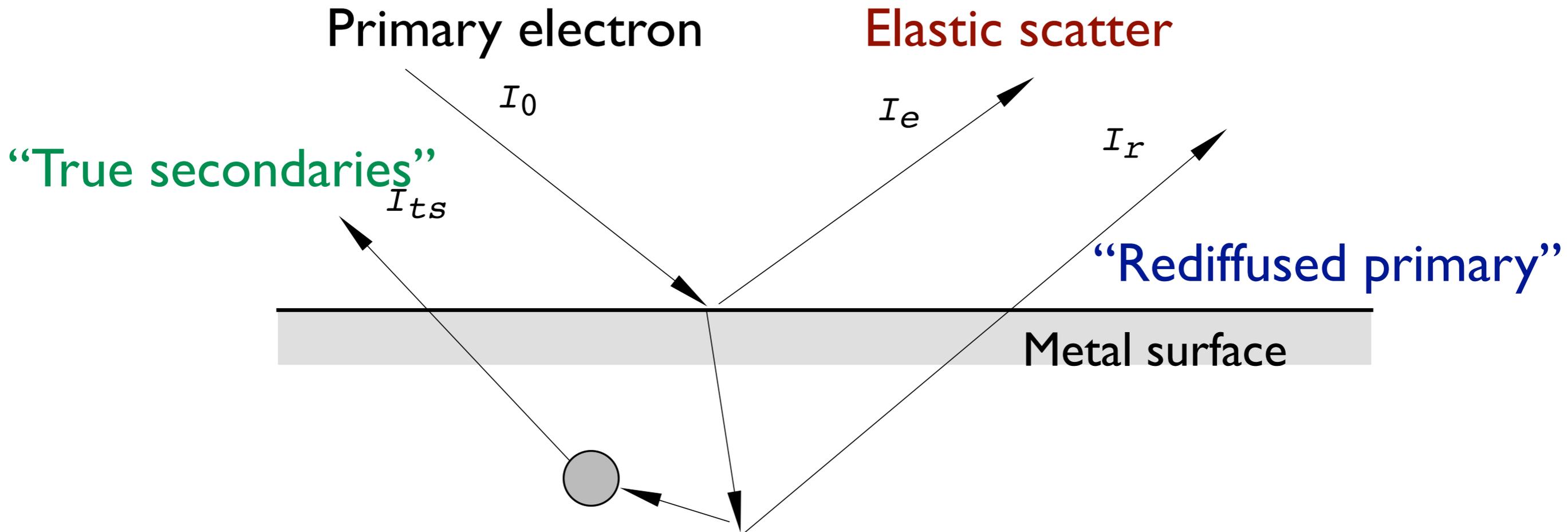
Digression: Modeling the PMT charge distribution



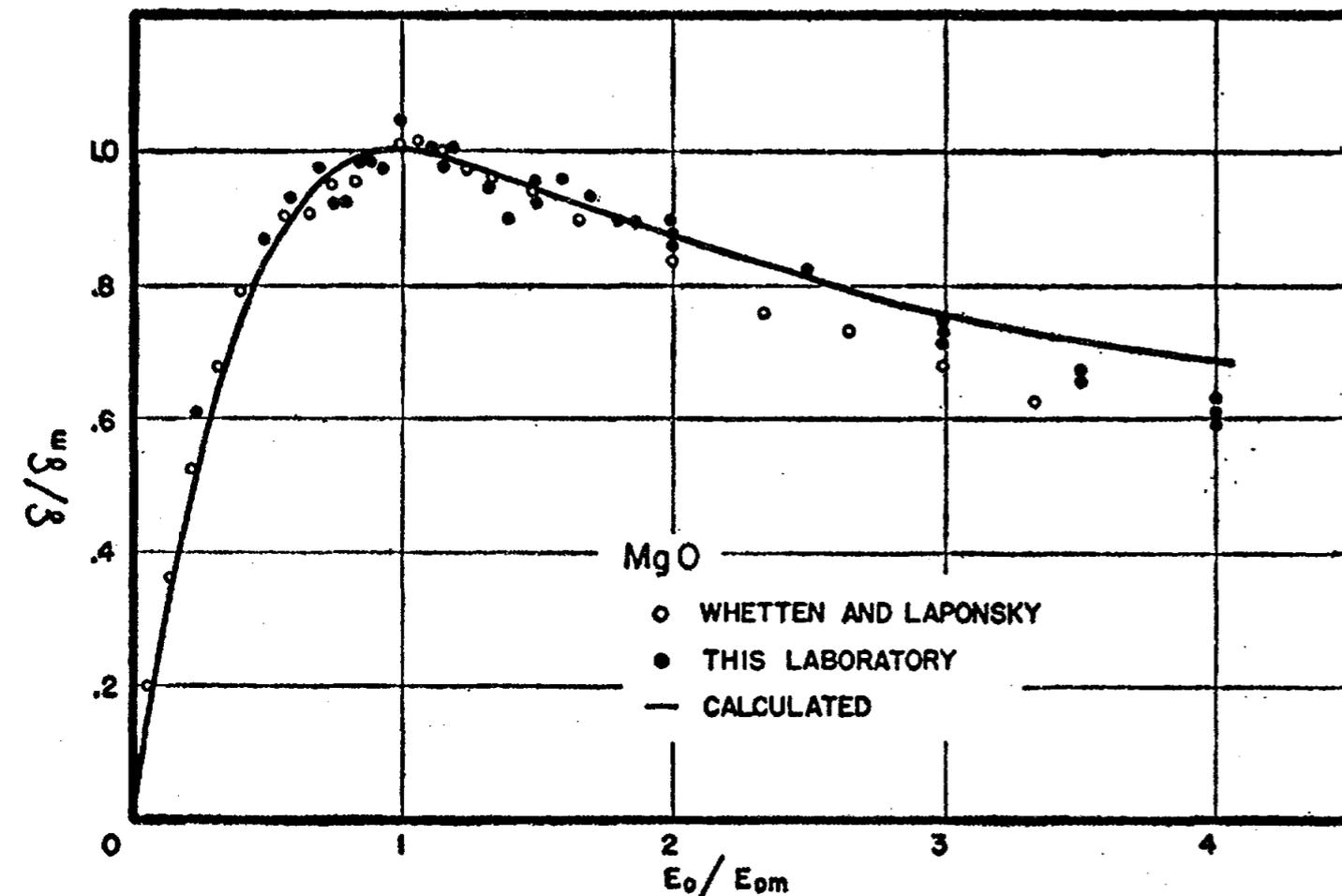
Can we implement a simple, but physical, model for PMT charge amplification?

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**)

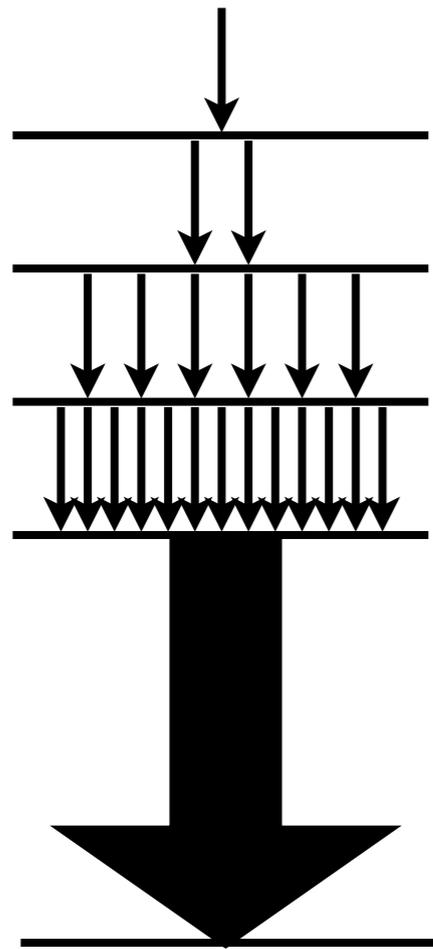
E = energy of primary electron
(**dynode potential difference**)

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

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

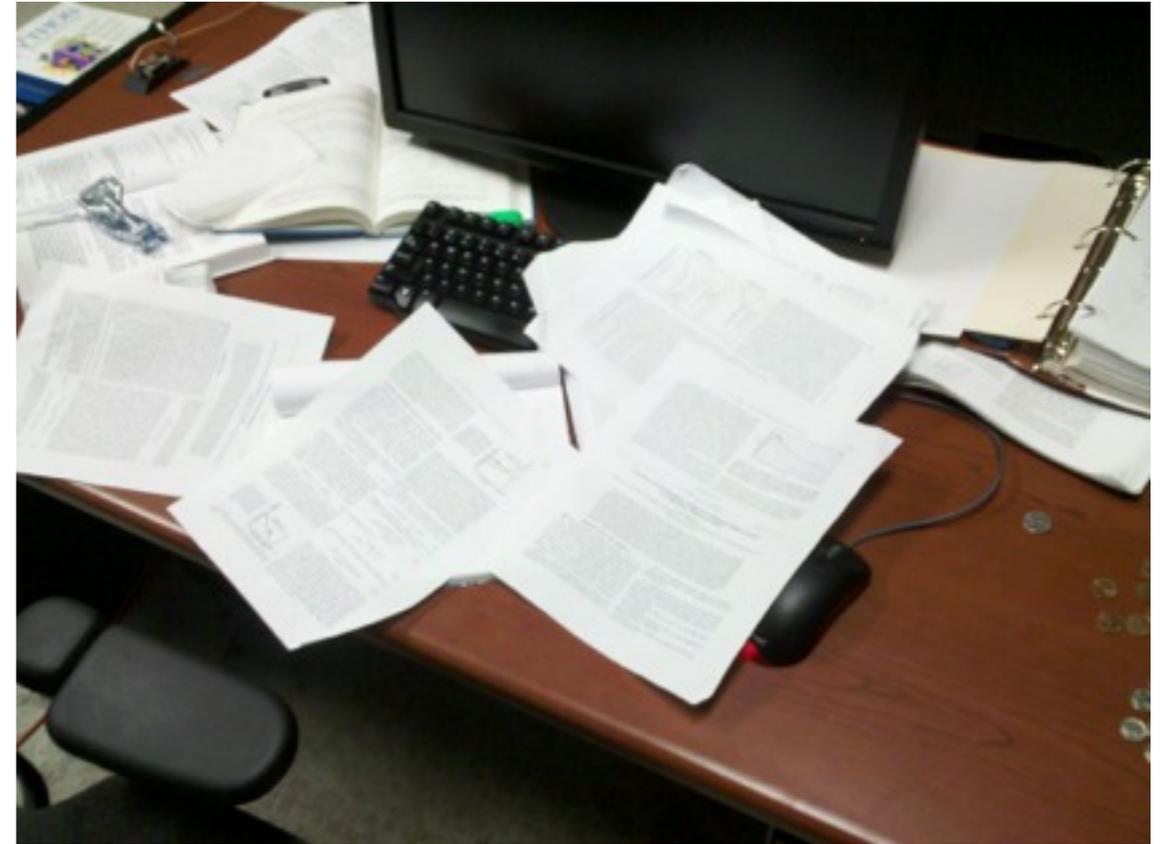
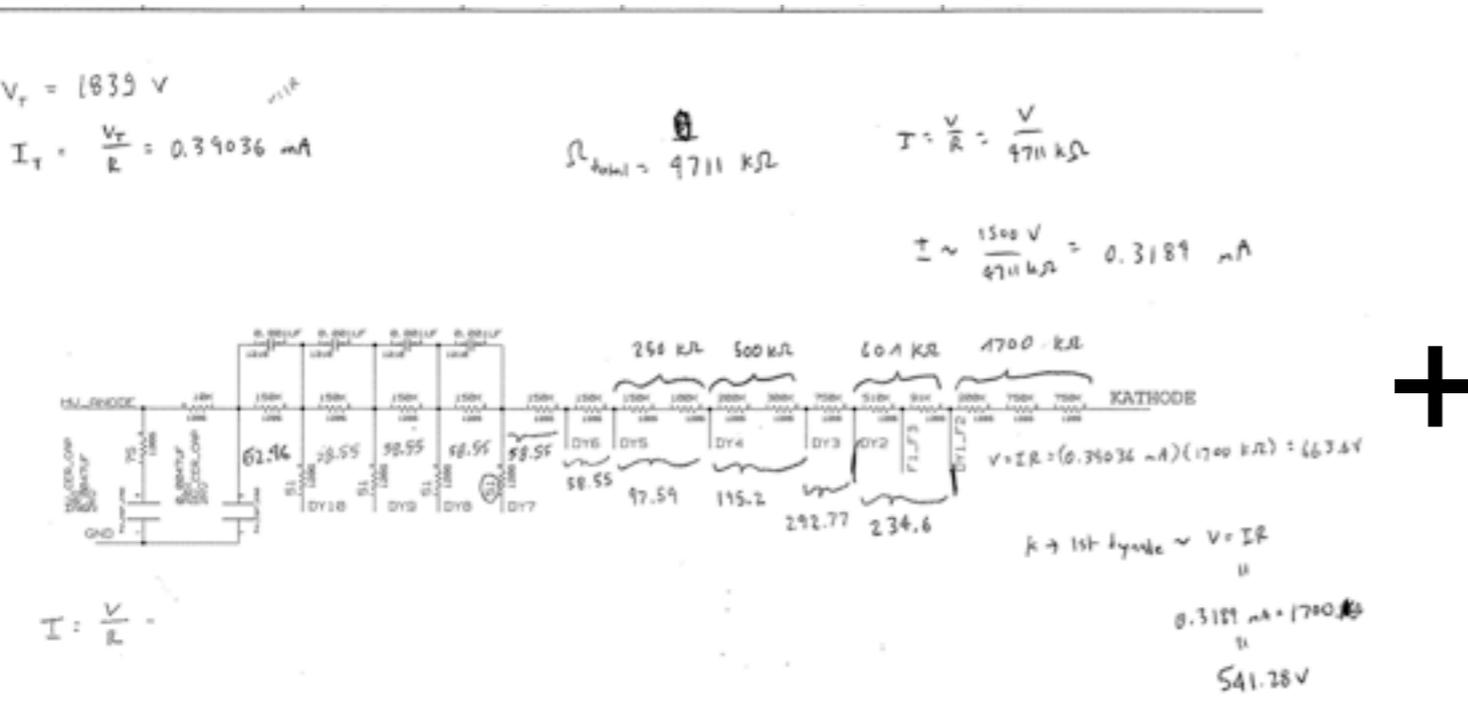


Each stage produces a random number of secondary electrons, drawn from a Poisson distribution, with a mean determined by the **potential difference**, the **material properties** (E_m, δ_m), and the **universal yield curve**.

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!

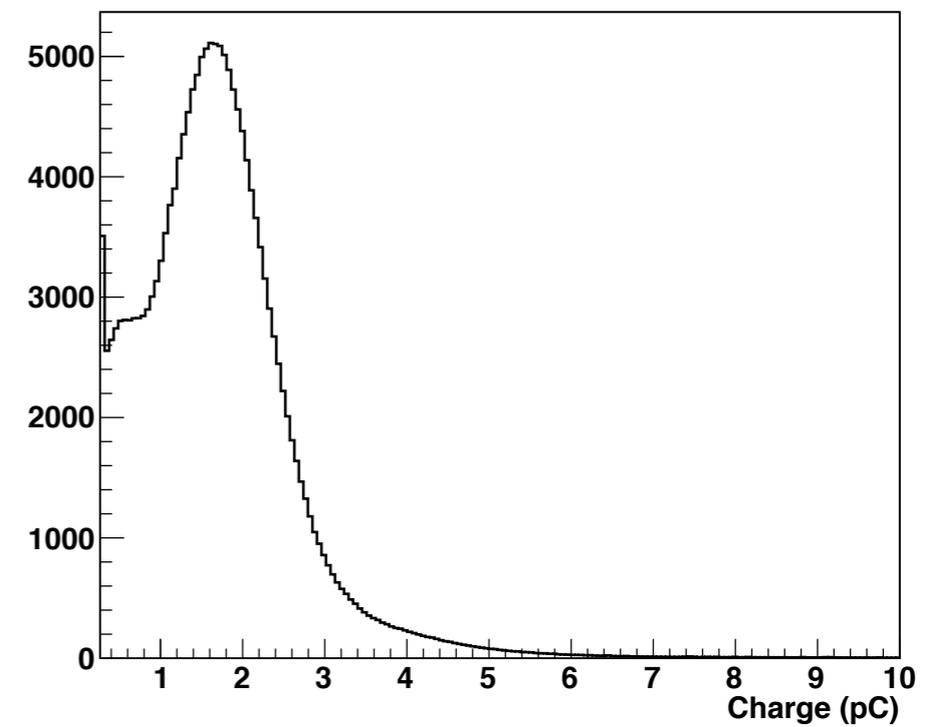


+



+

=



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

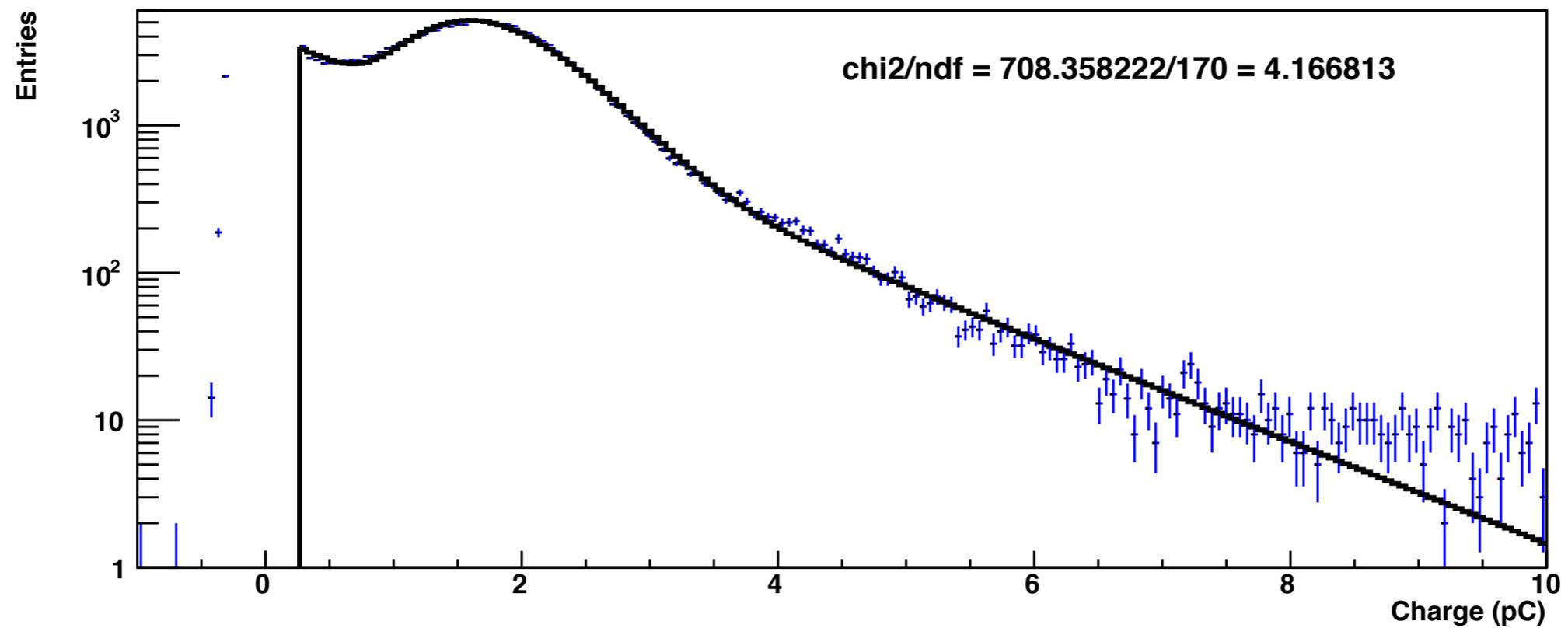
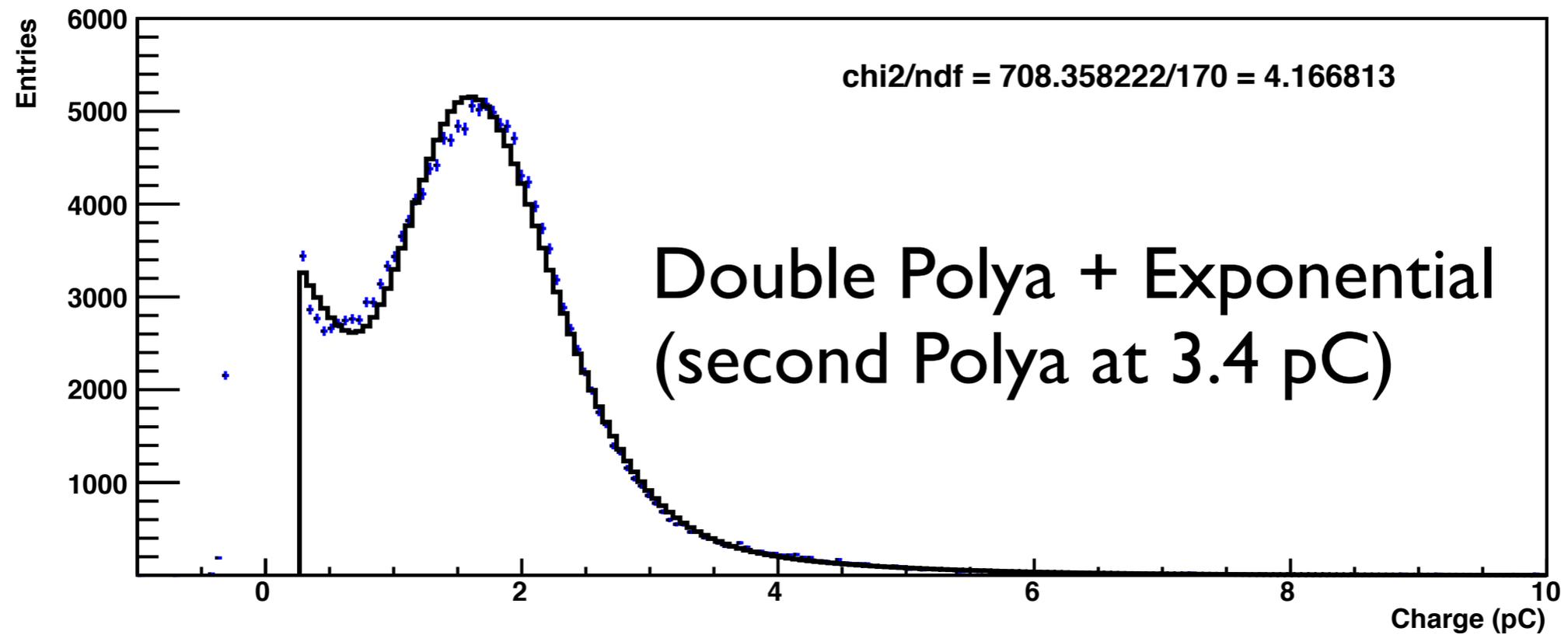
δ_{alt} : alternate gain at first
dynode

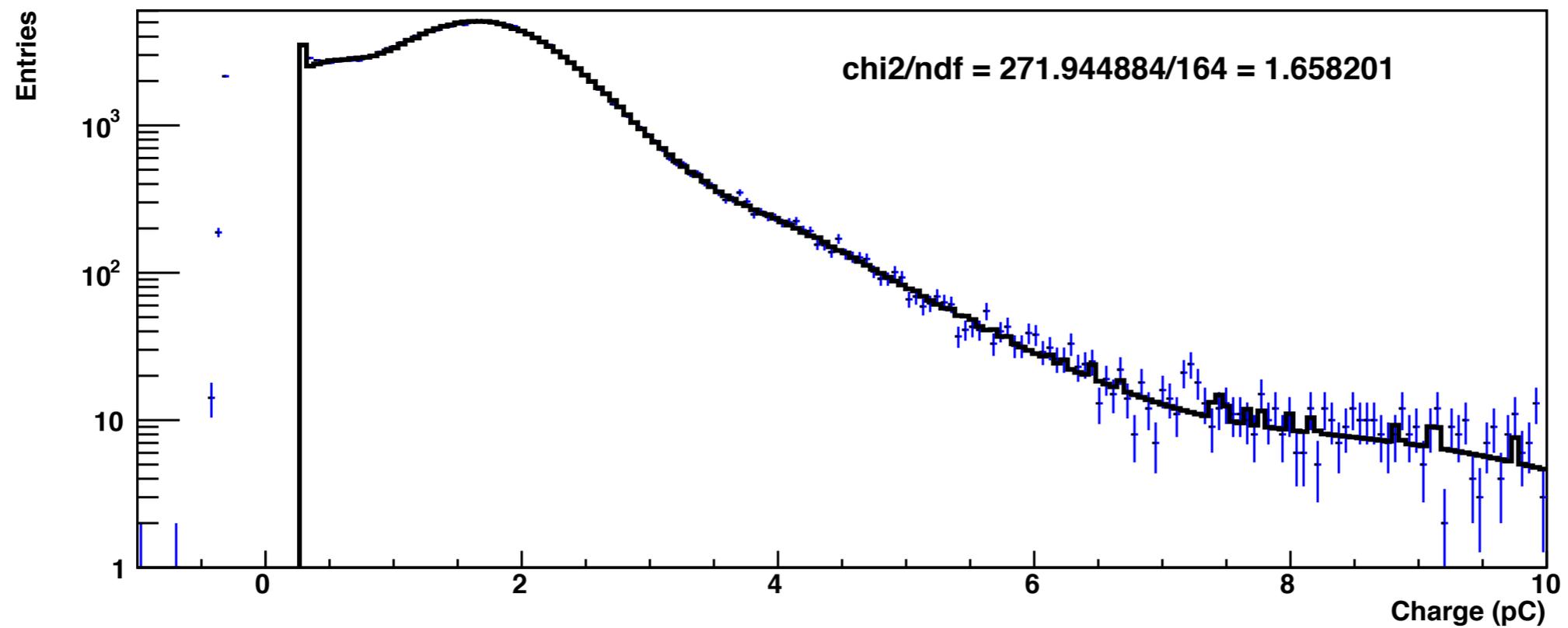
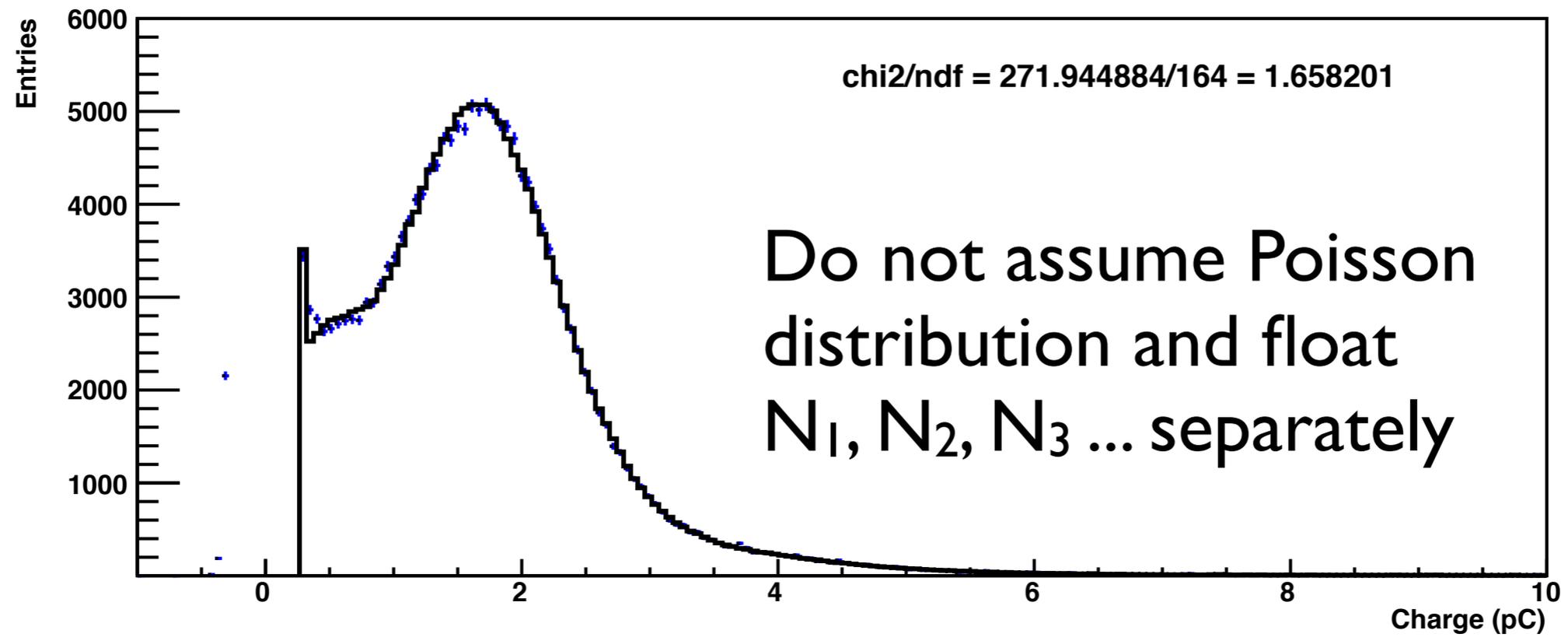
N_{noise} : # of “noise” events

$N_1, N_2, N_3 \dots$: Number of 1, 2,
3, ... photon events

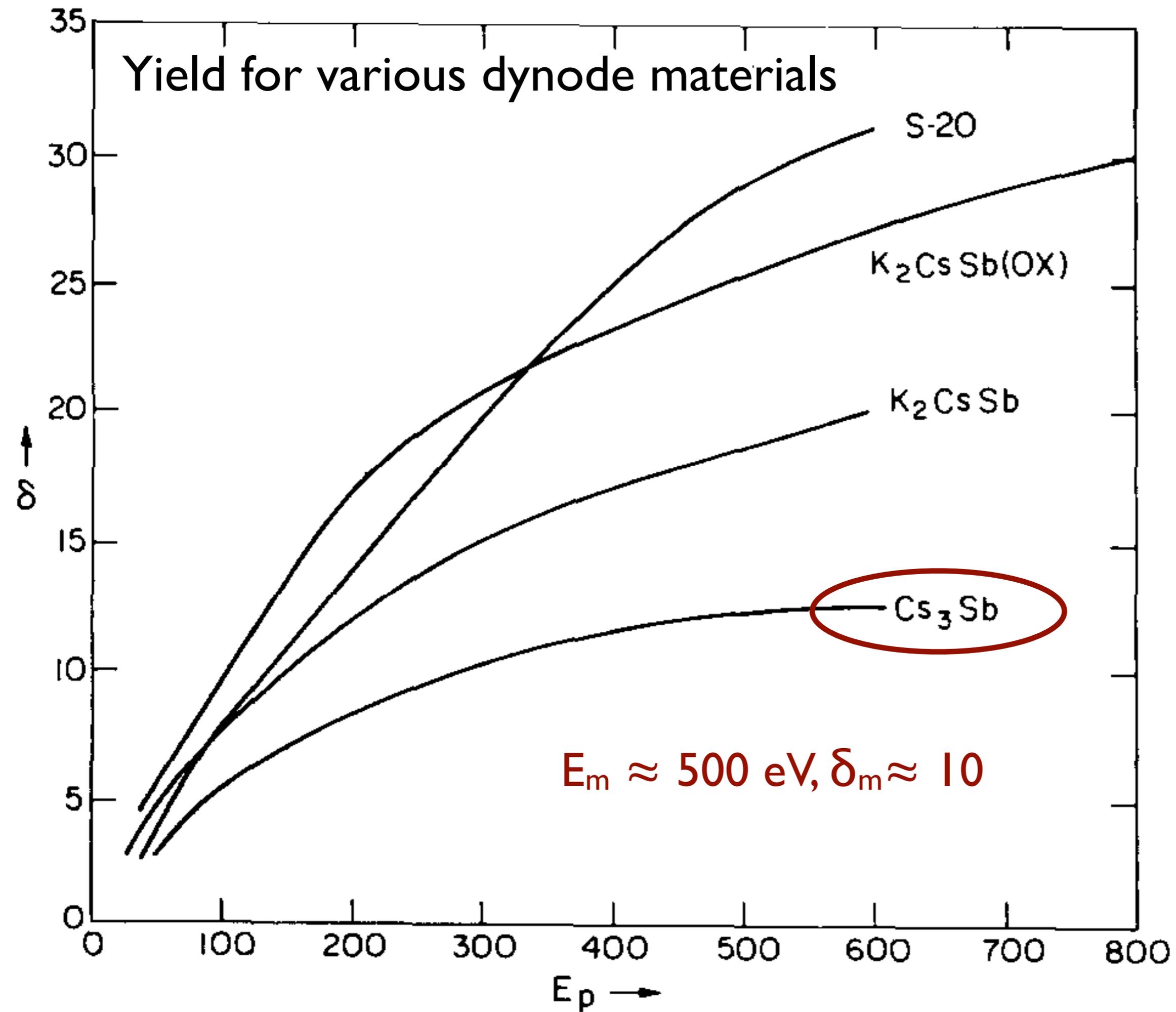
$\sigma_{baseline}$: pedestal width

$\mu_{baseline}$: pedestal offset





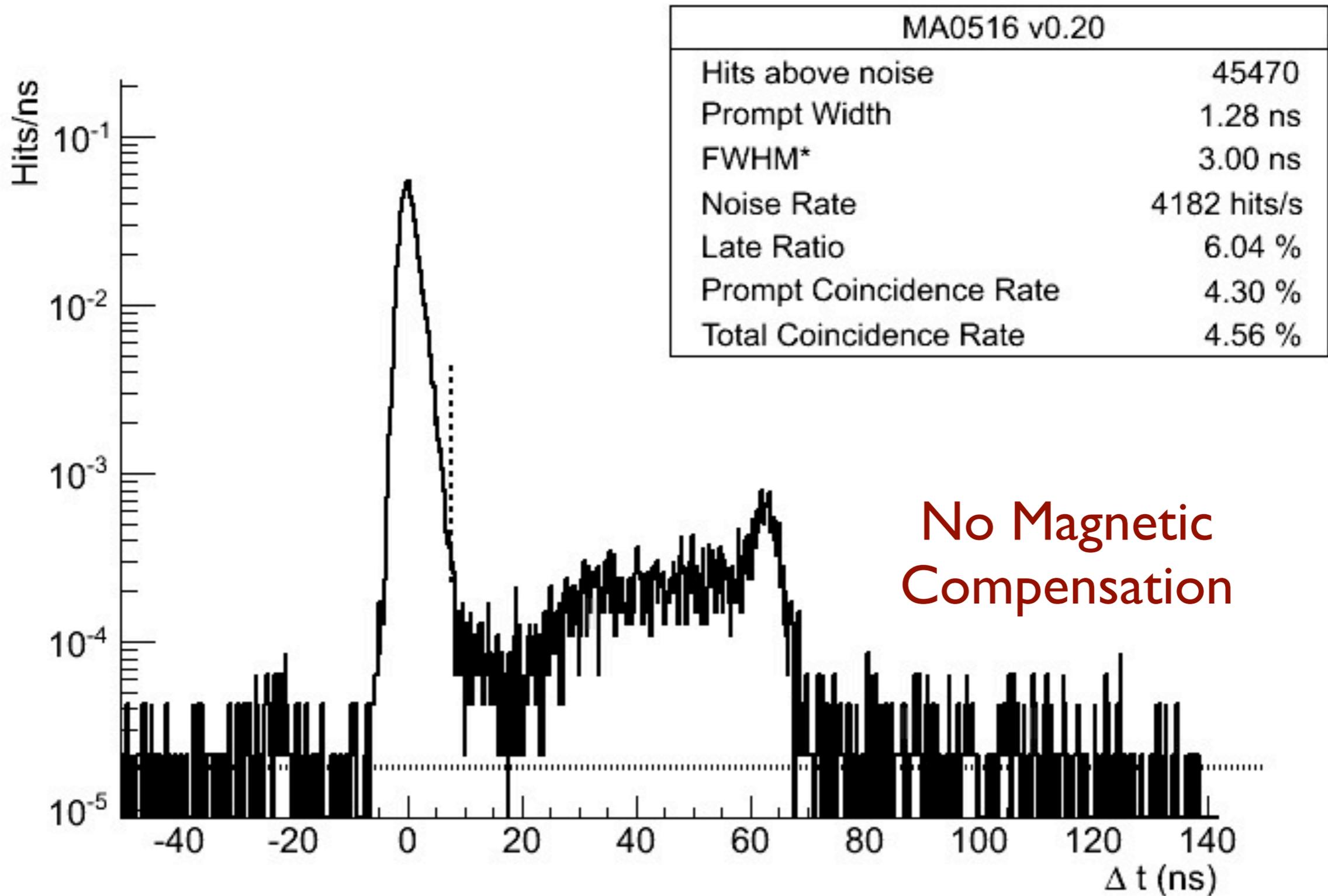
Yield for various dynode materials



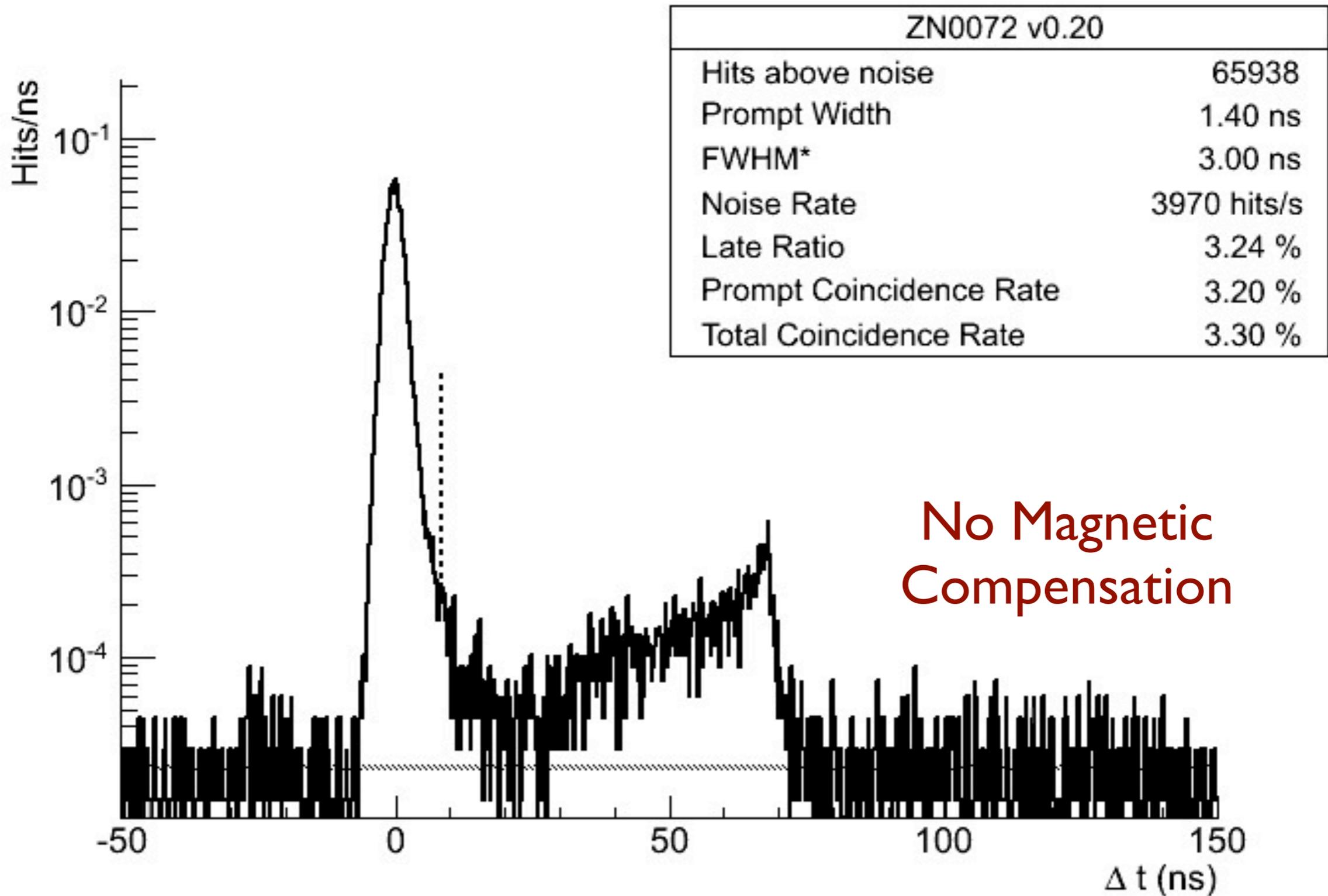
Back to Timing...

And that low gain path....

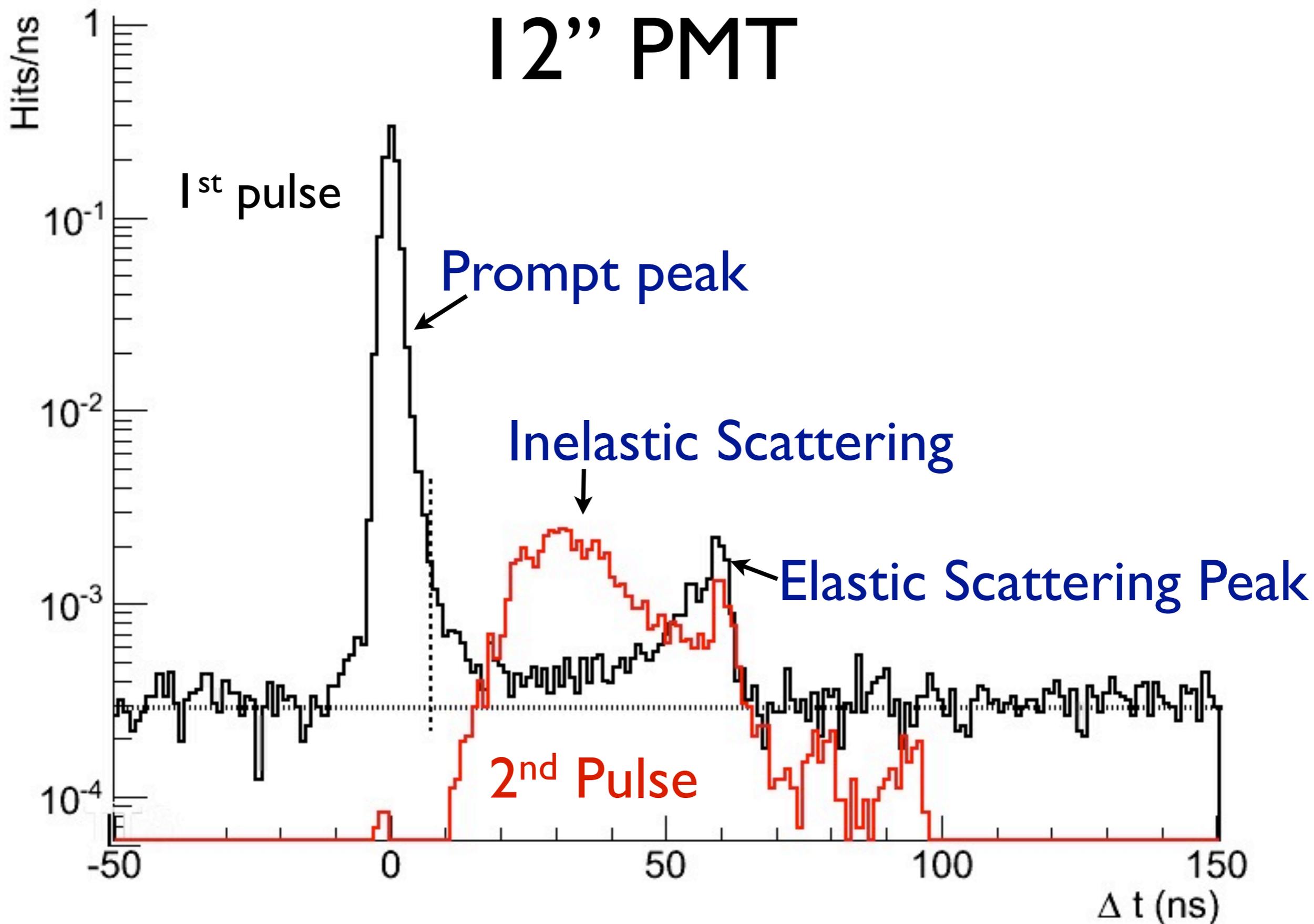
Transit Time Distribution: 10" PMT



Transit Time Distribution: 12" PMT



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

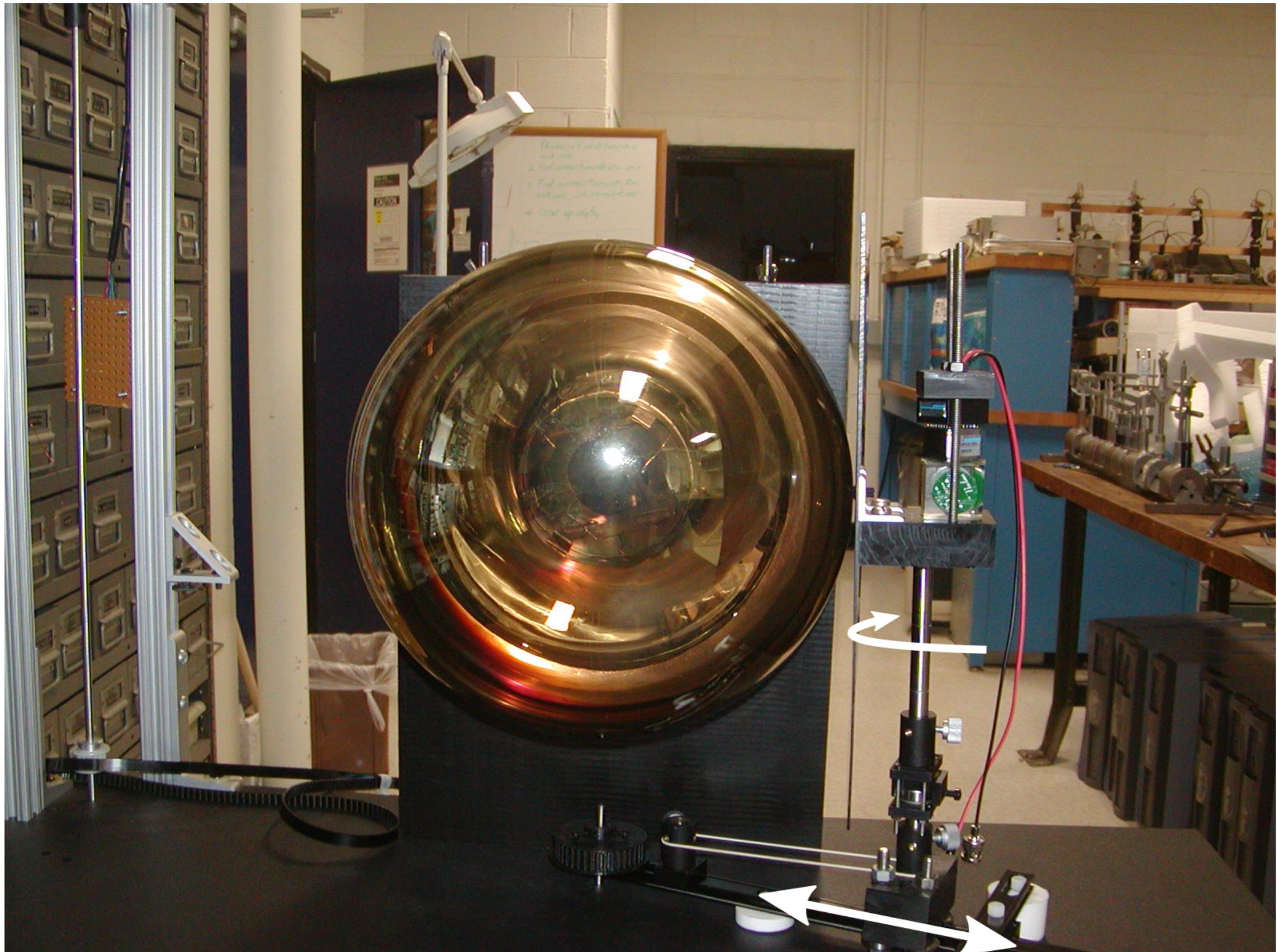
10 PMTs

5 PMTs

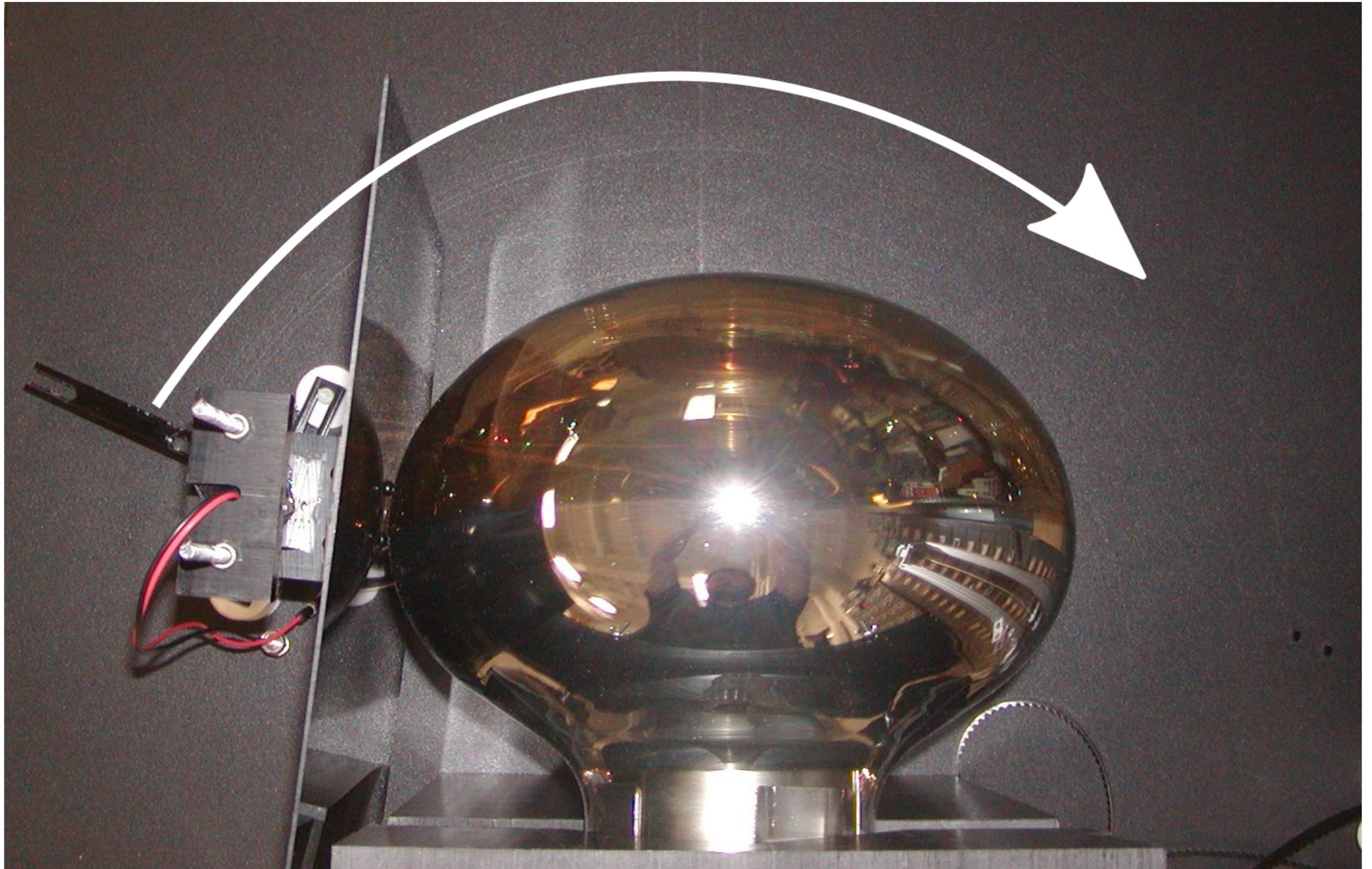
1 PMT

**No Magnetic
Compensation**

Scanning Arm

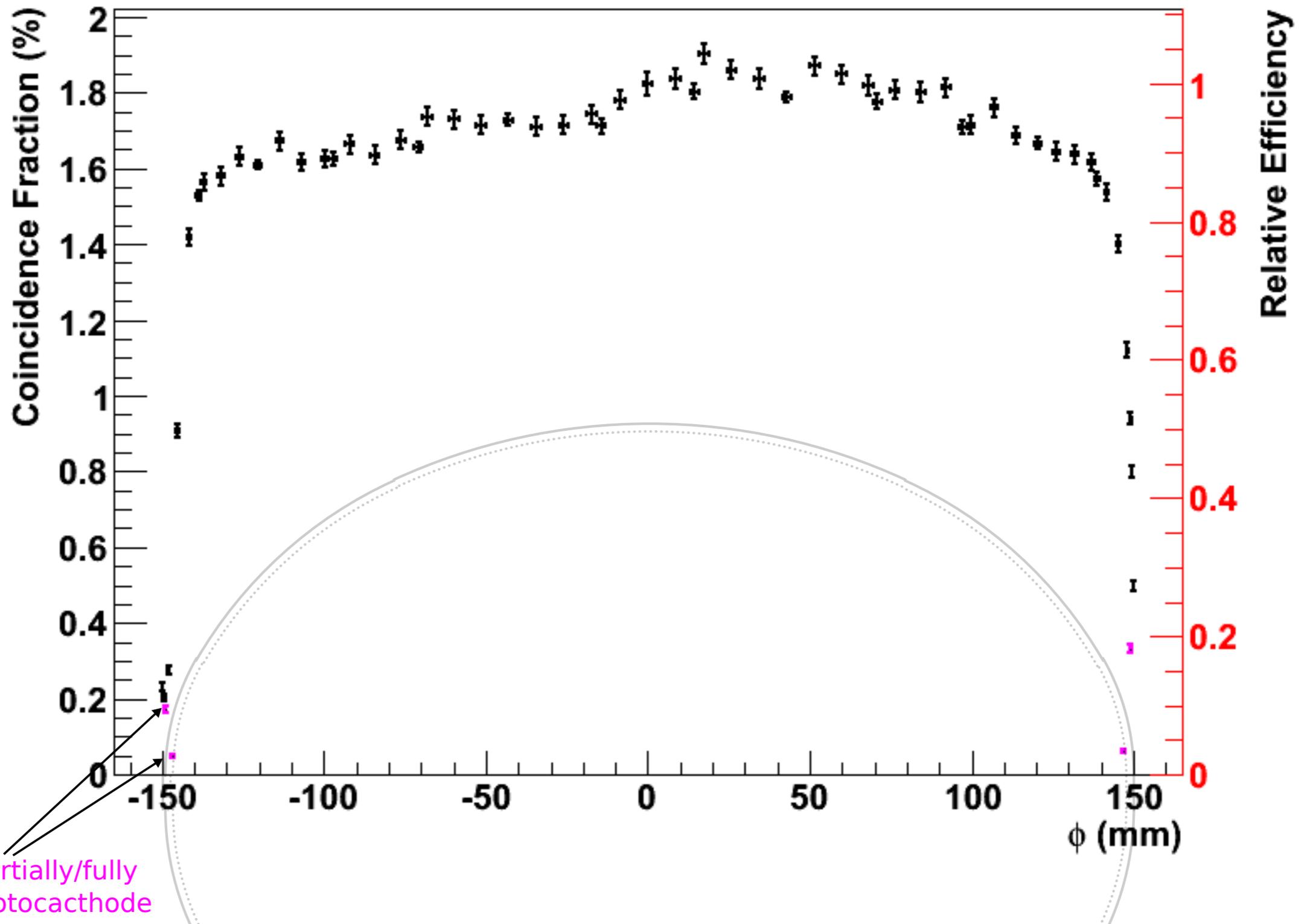


Scanning Arm



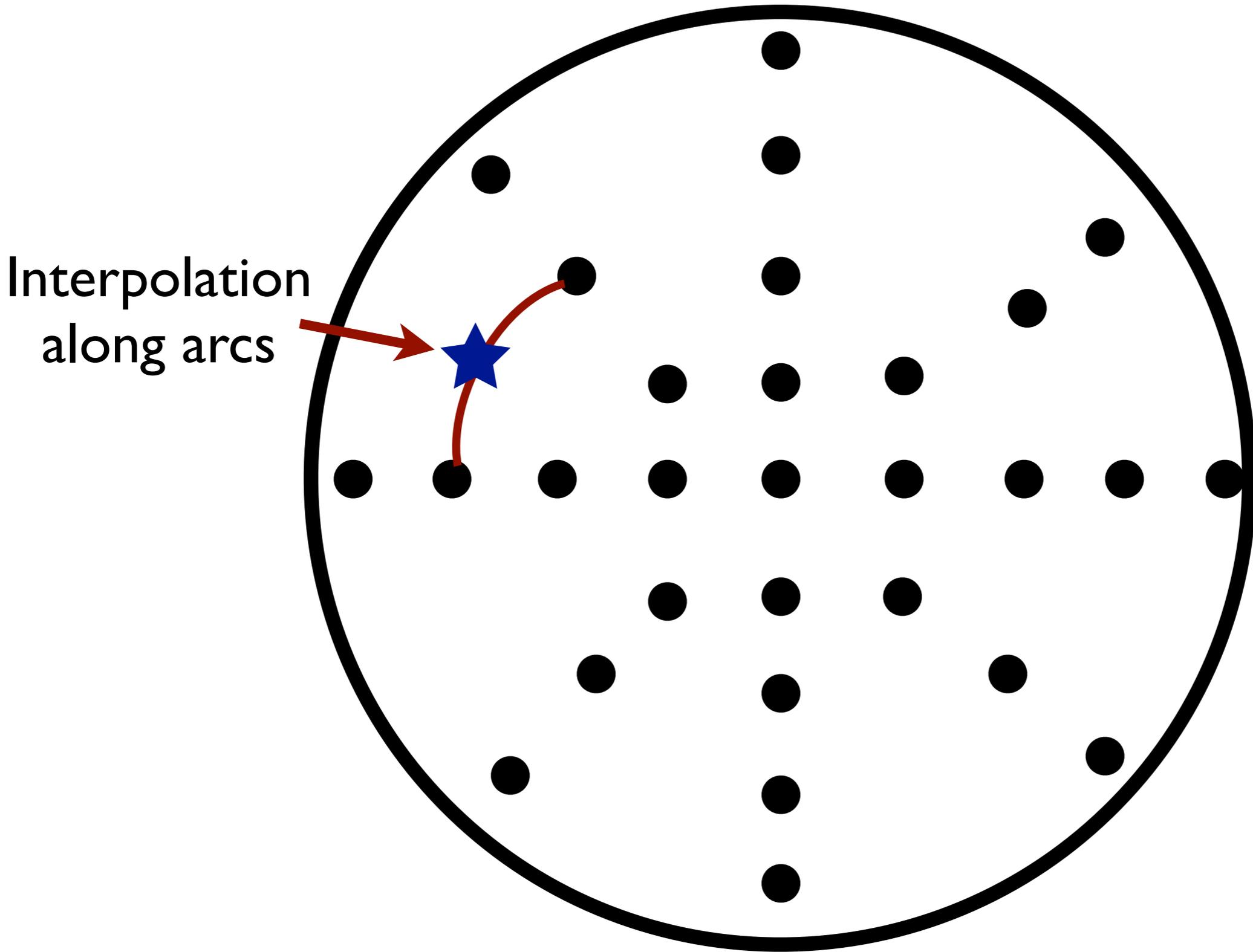
Relative Efficiency: 12" PMT

Prompt Coincidence Fraction

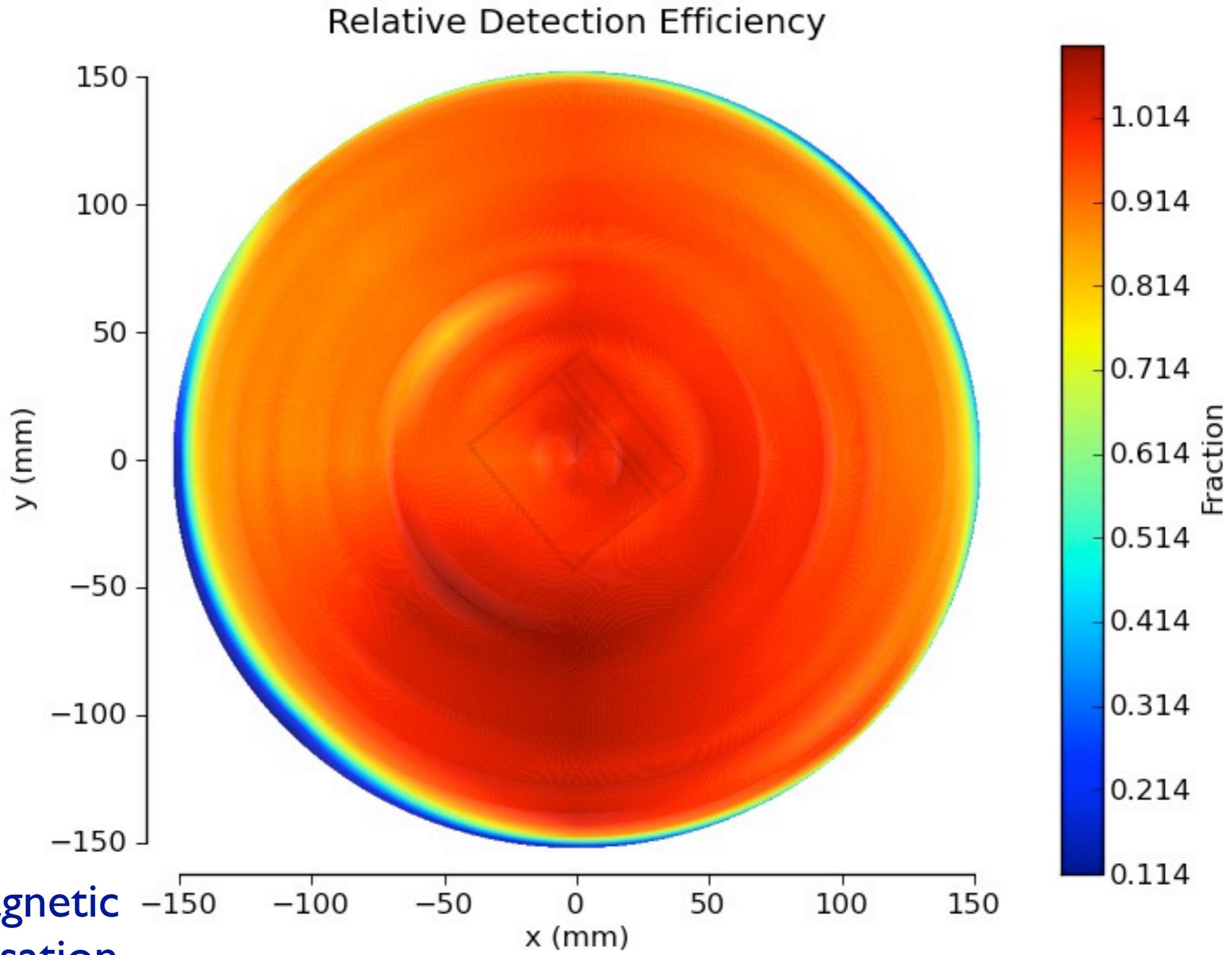


points partially/fully off the photocathode

2D scan

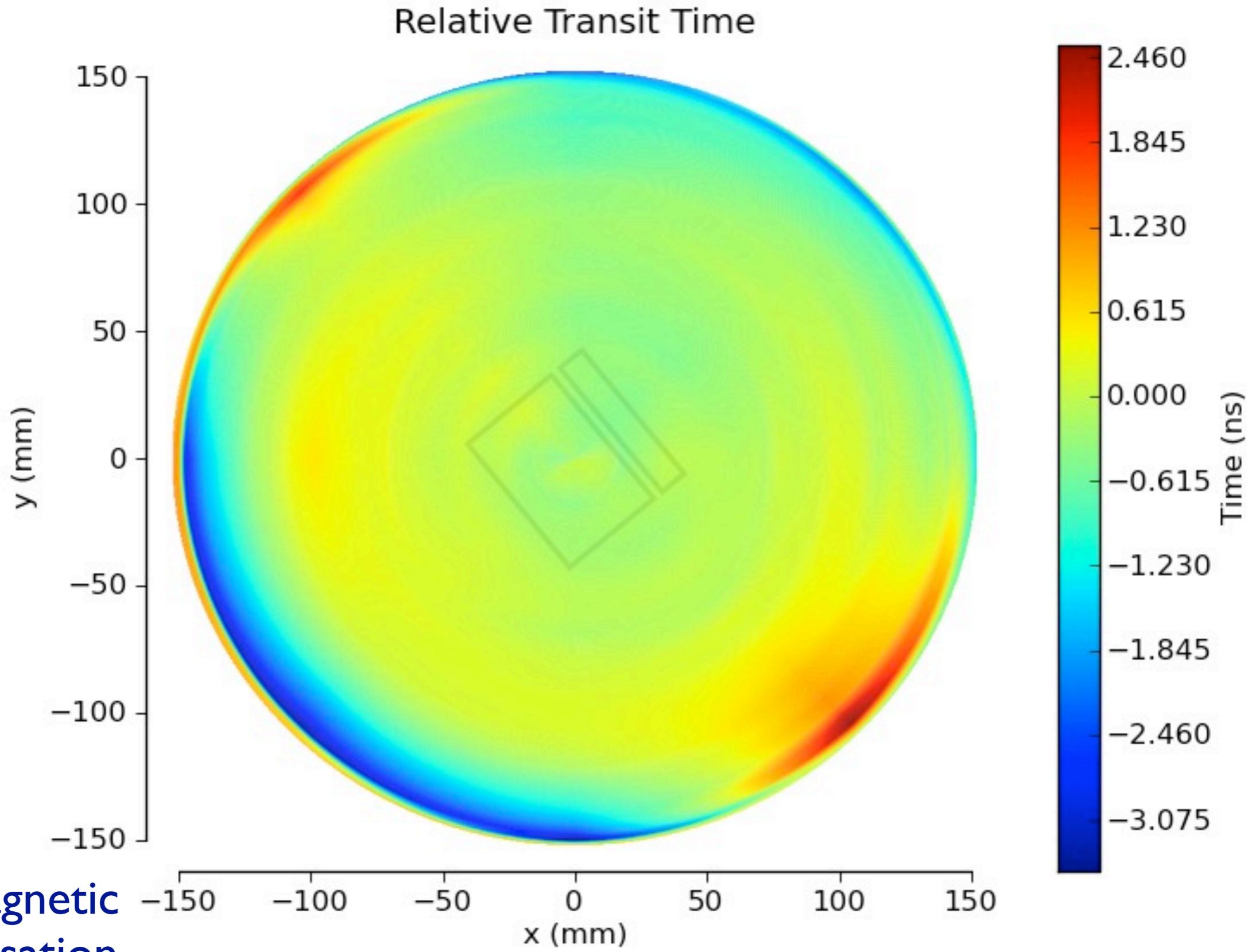


Position Dependence: 12" PMT



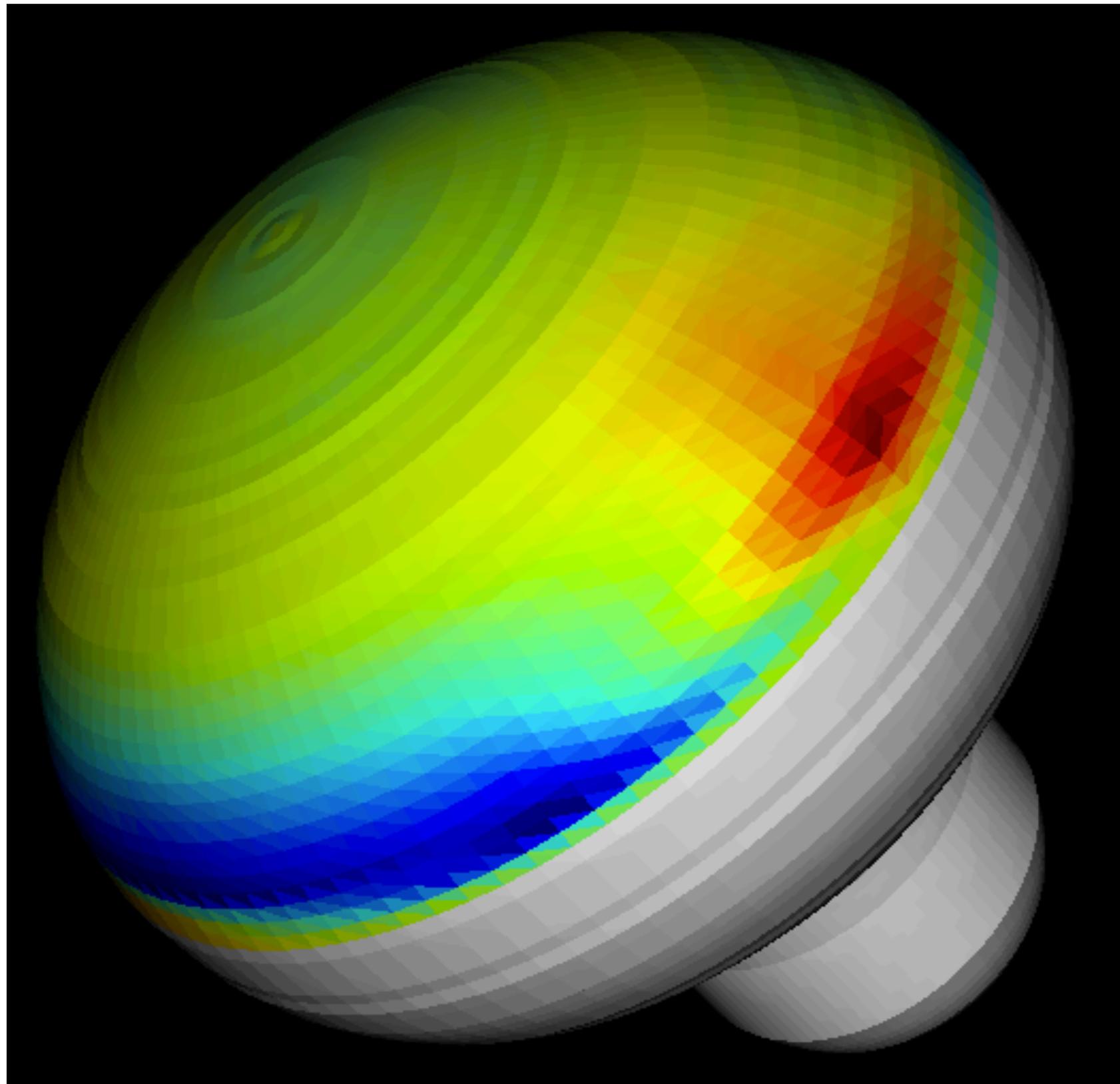
With Magnetic Compensation

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 ± 3 ns 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.