N2 ABSORPTION RESULT FROM BO

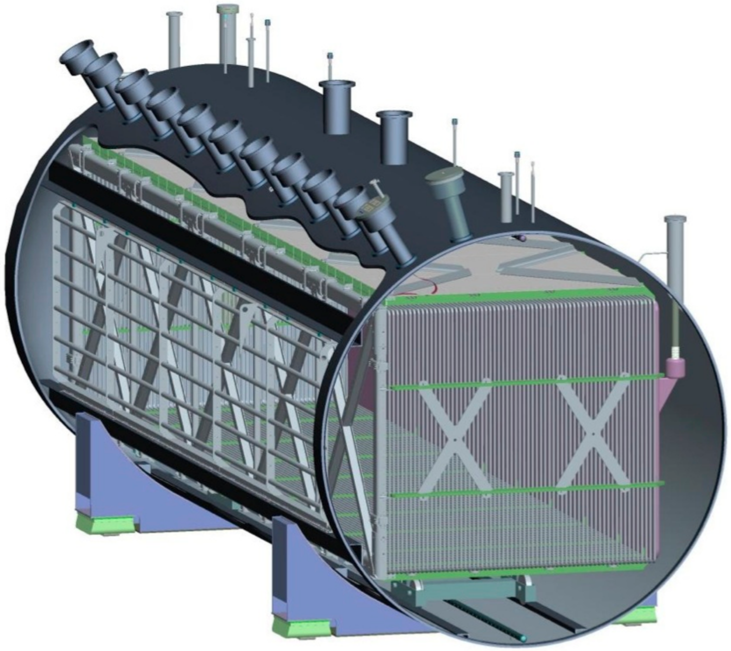
Ben Jones, MIT

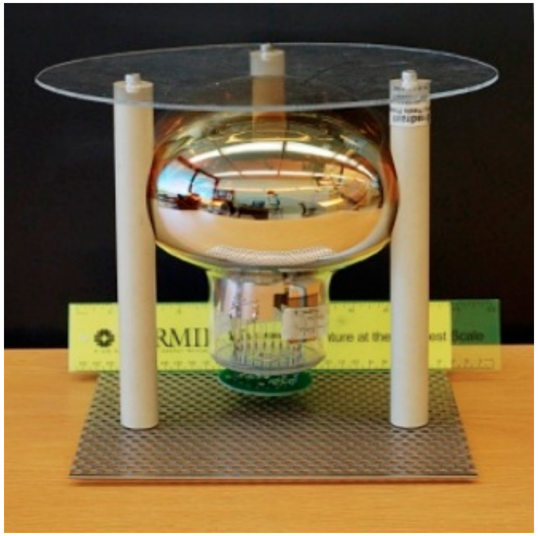
So Whats New?

- Many of you saw this measurement discussed at the LArTPC workshop at FNAL a couple of weeks ago
- At that point, data was hot off the press, and final analysis was still converging.
- Now we have completed the analysis and tied up all loose ends.
- What I am showing today may receive slight perturbations after feedback from other authors and some expert consultants.
- But apart from that, it is fairly final - so, “if you see something, say something!”

Motivation:

- O_2, N_2 and H20 all both quench and absorb UV light
- In LArTPCs, H20 and O_2 are both controlled a the 100ppt level to keep long charge drift
- However, N_2 is incredibly hard to remove, and does not damage charge drift
- Expect N_2 contamination at ppm levels
- Quenching effect has been measured by others (classic WArP R&D paper)
- But only ever studied in small test cells – the distance dependent attenuation has never been measured
- This could have a big effect on MicroBooNE and LBNE
- We measured it, and show that it does not (good!).





A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Parts Per Million Level

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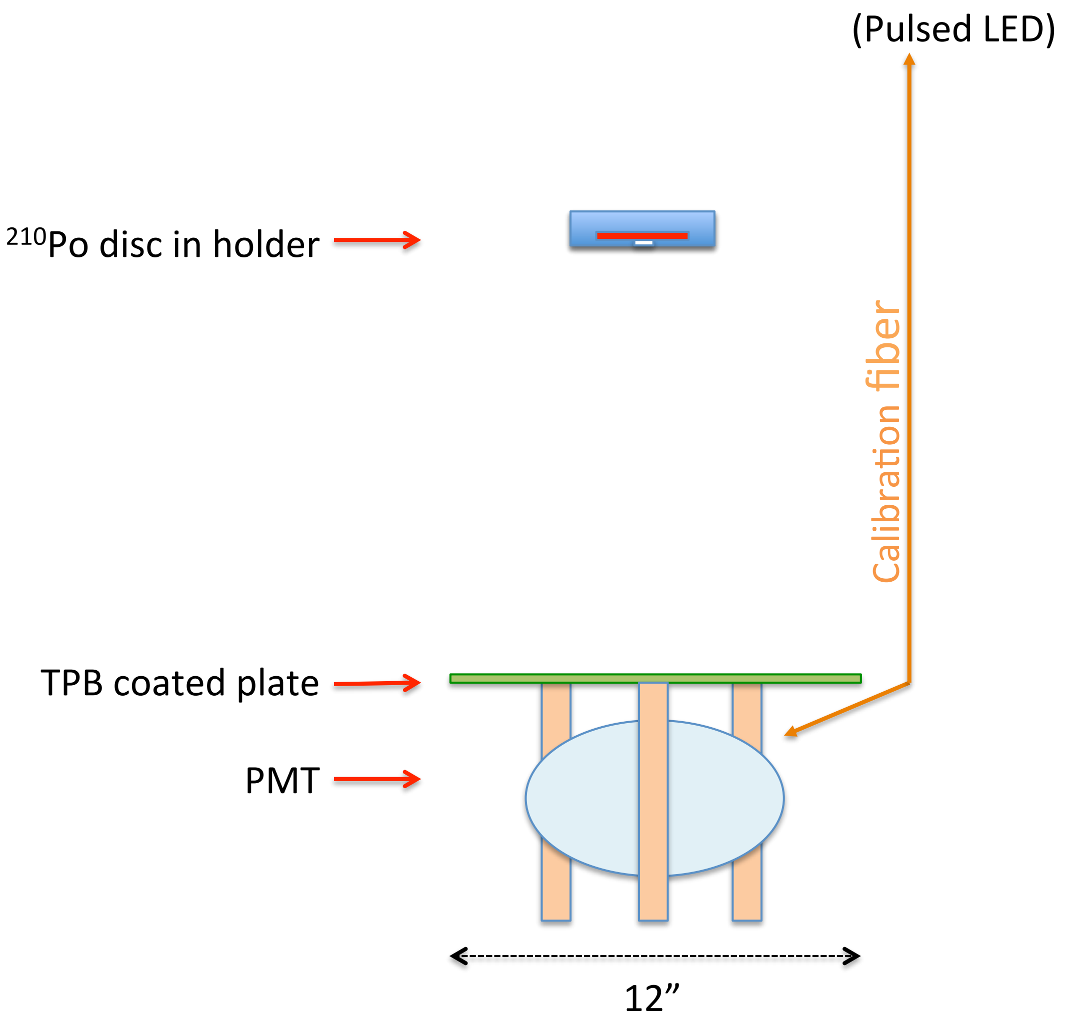
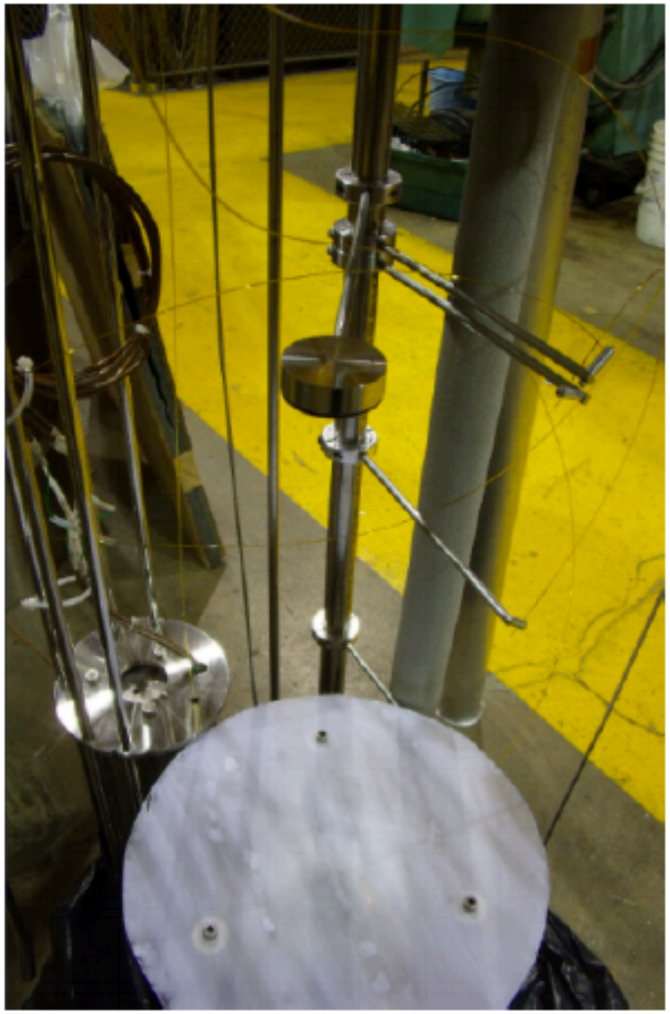
ABSTRACT: We report on a measurement of the absorption length of scintillation light in liquid argon due to dissolved nitrogen at the part per million level. We inject controlled quantities of nitrogen into a high purity volume of liquid argon and monitor the light yield from an alpha source. The source is a placed at different distances from a cryogenic photomultiplier tube assembly. By comparing the light yield from each position we extract the absorption cross section of nitrogen. We find that nitrogen absorbs argon scintillation light with strength $(1.46 \pm 0.16) \times 10^{-4}$ cm^{-1}ppm^{-1}, corresponding to an absorption cross section of $(4.85 \pm 0.52) \times 10^{-21}$ cm^{2}molecule^{-1}. We obtain the relationship between absorption length and nitrogen concentration over the 0 to 50 ppm range and discuss the implications for the design and data analysis of future large liquid argon TPC detectors.

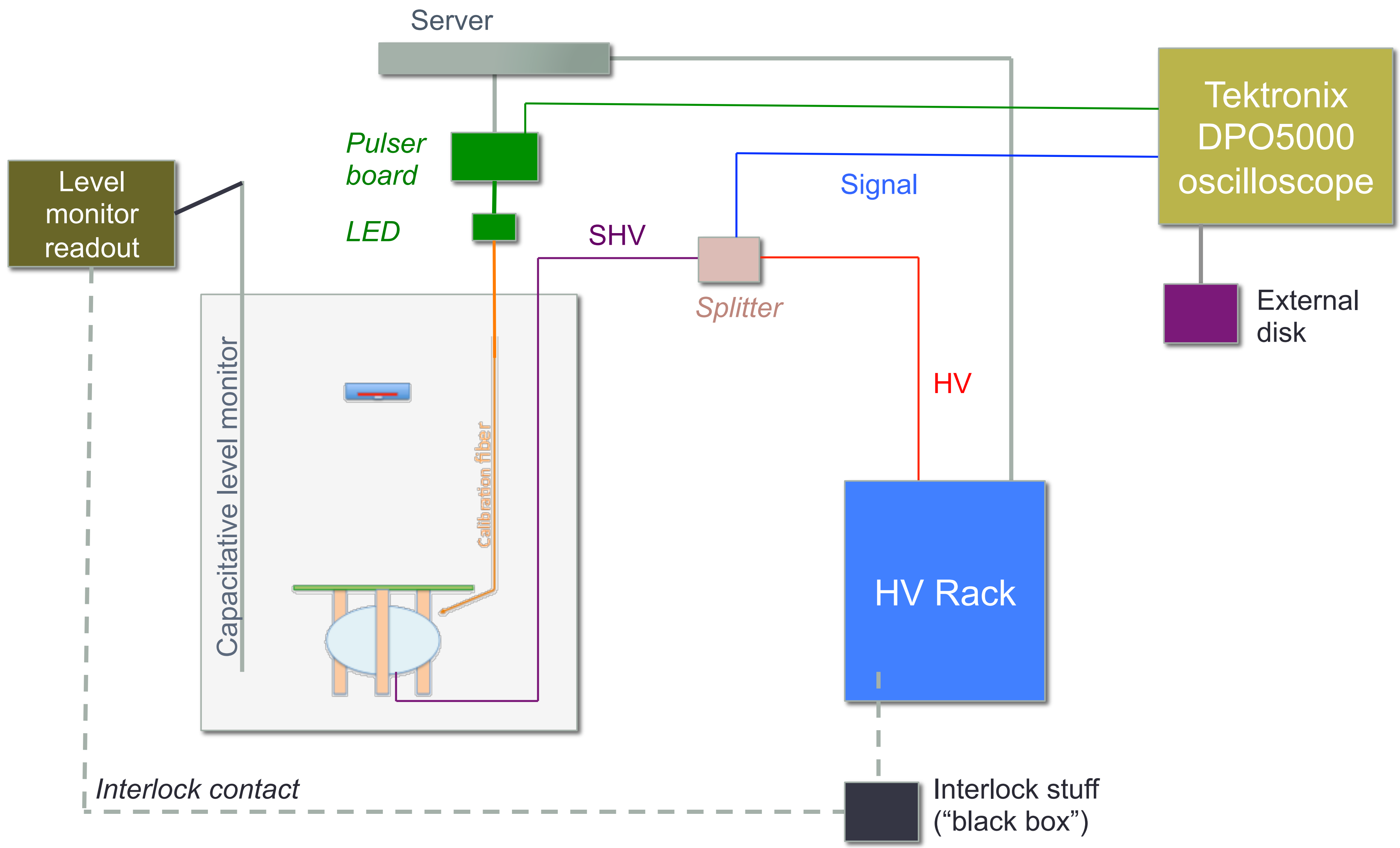
KEYWORDS: Noble-liquid detectors; Photon detectors for UV, visible and IR photons; Scintillators, scintillation and light emission processes.

Experimental Configuration for This Study

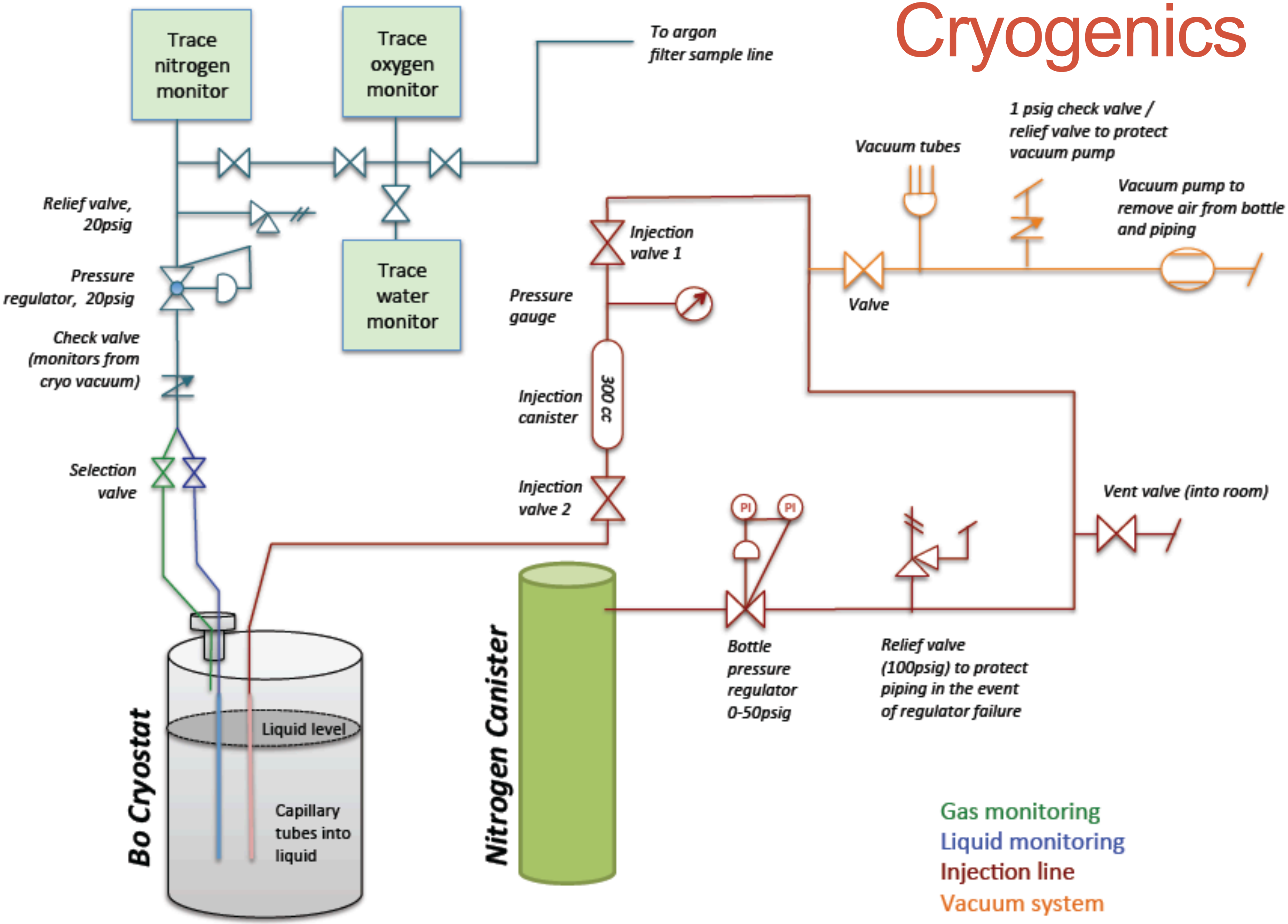




Readout and HV



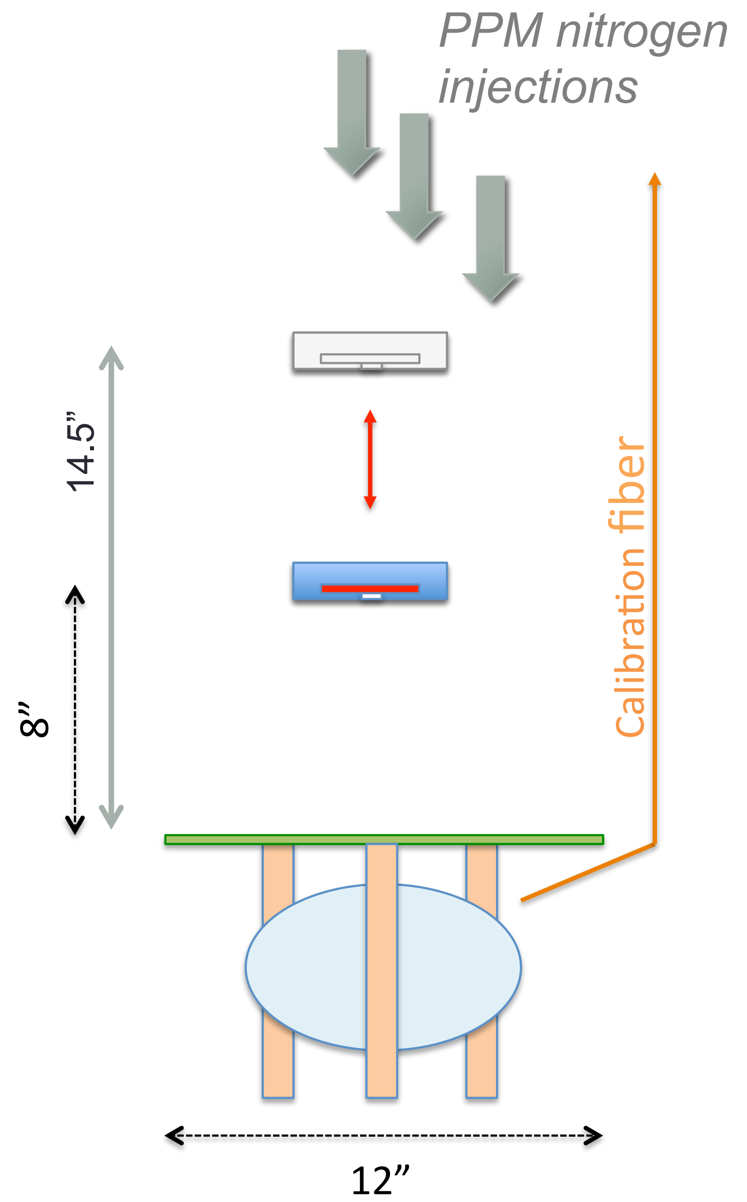
Cryogenics



Trace nitrogen monitor
Trace oxygen monitor
Trace water monitor
To argon filter sample line
Relief valve, 20psig
Pressure regulator, 20psig
Check valve (monitors from cryo vacuum)
Selection valve
Injection valve 1
Pressure gauge
Injection canister
300 cc
Injection valve 2
Vacuum tubes
1 psig check valve / relief valve to protect vacuum pump
Vacuum pump to remove air from bottle and piping
Valve
Vent valve (into room)
PI
PI
Bottle pressure regulator 0-50psig
Relief valve (100psig) to protect piping in the event of regulator failure
Bo Cryostat
Liquid level
Capillary tubes into liquid
Nitrogen Canister
Gas monitoring
Liquid monitoring
Injection line
Vacuum system

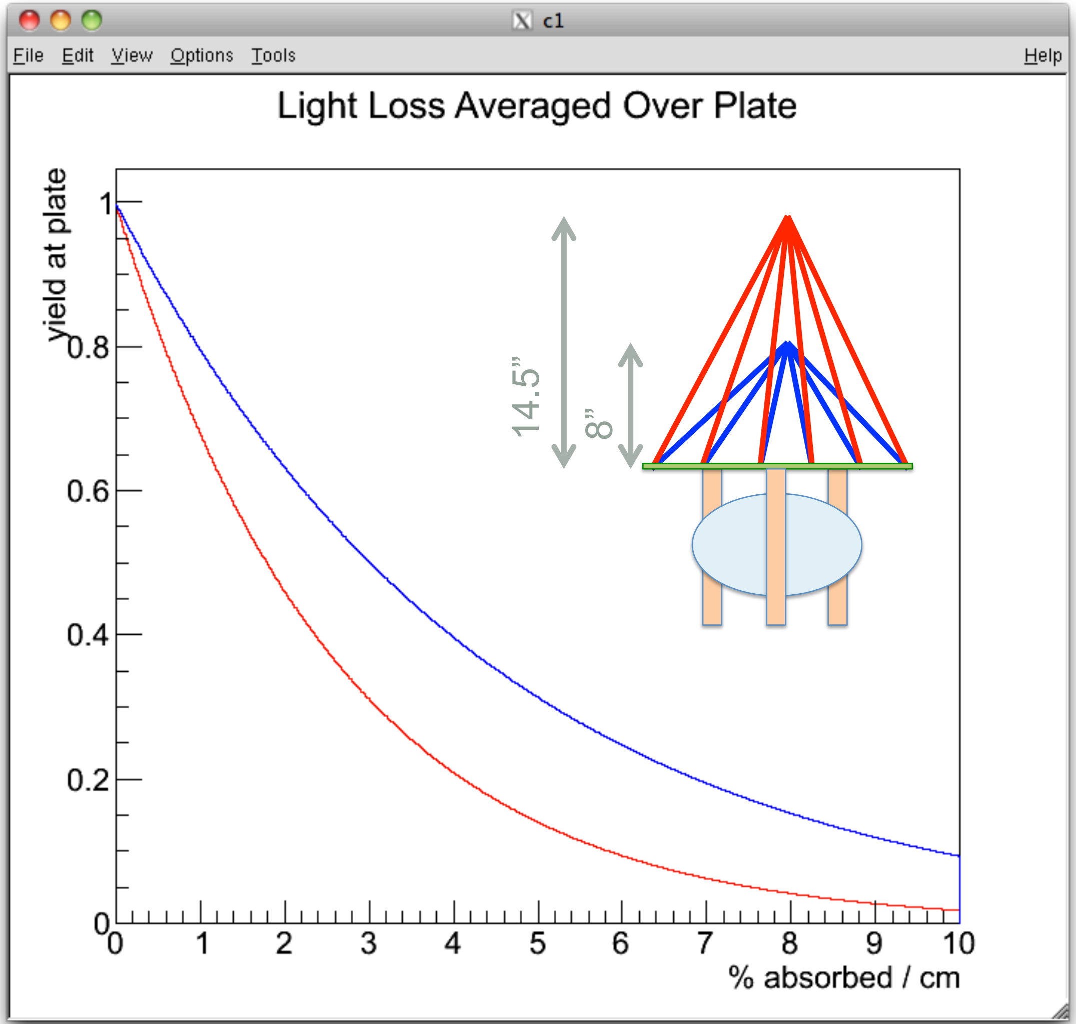
General Idea:

- Source set in one of two possible positions.
- Controlled amounts of N2 injected into the liquid, which will cause both quenching (drop in light production) and absorption (opacity of the liquid).
- We want to measure both effects.
- Quenching affects both positions equally, whereas absorption hinders the further more than the nearer one.
- Light yield of both sources as function of N2 content normalized to initial light yield, giving fractional loss.
- If fractional losses deviate from each other, we see an N2 absorption length effect.
- A future analysis will address the effects of quenching (more extensively studied by other groups) separately.

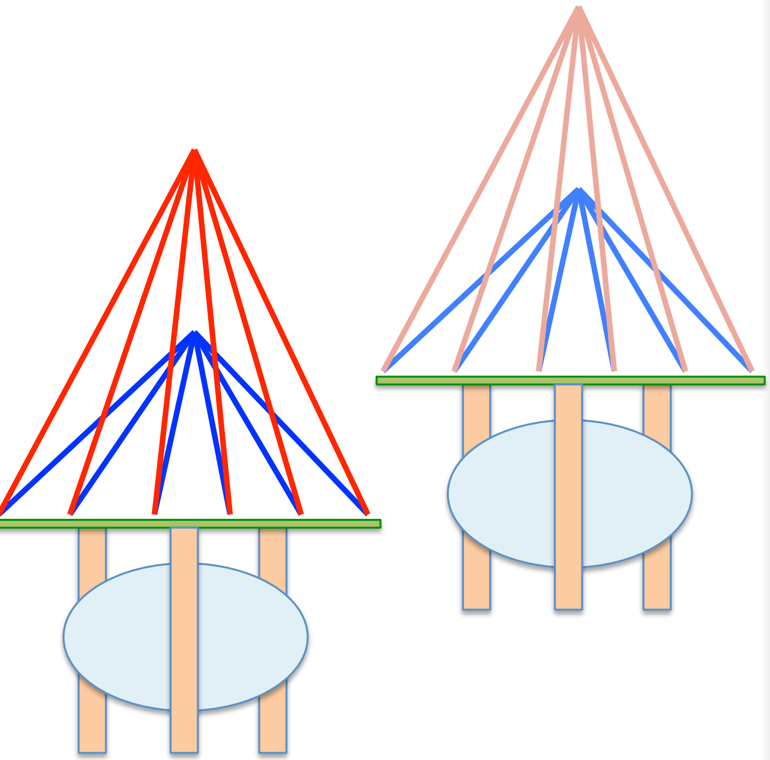


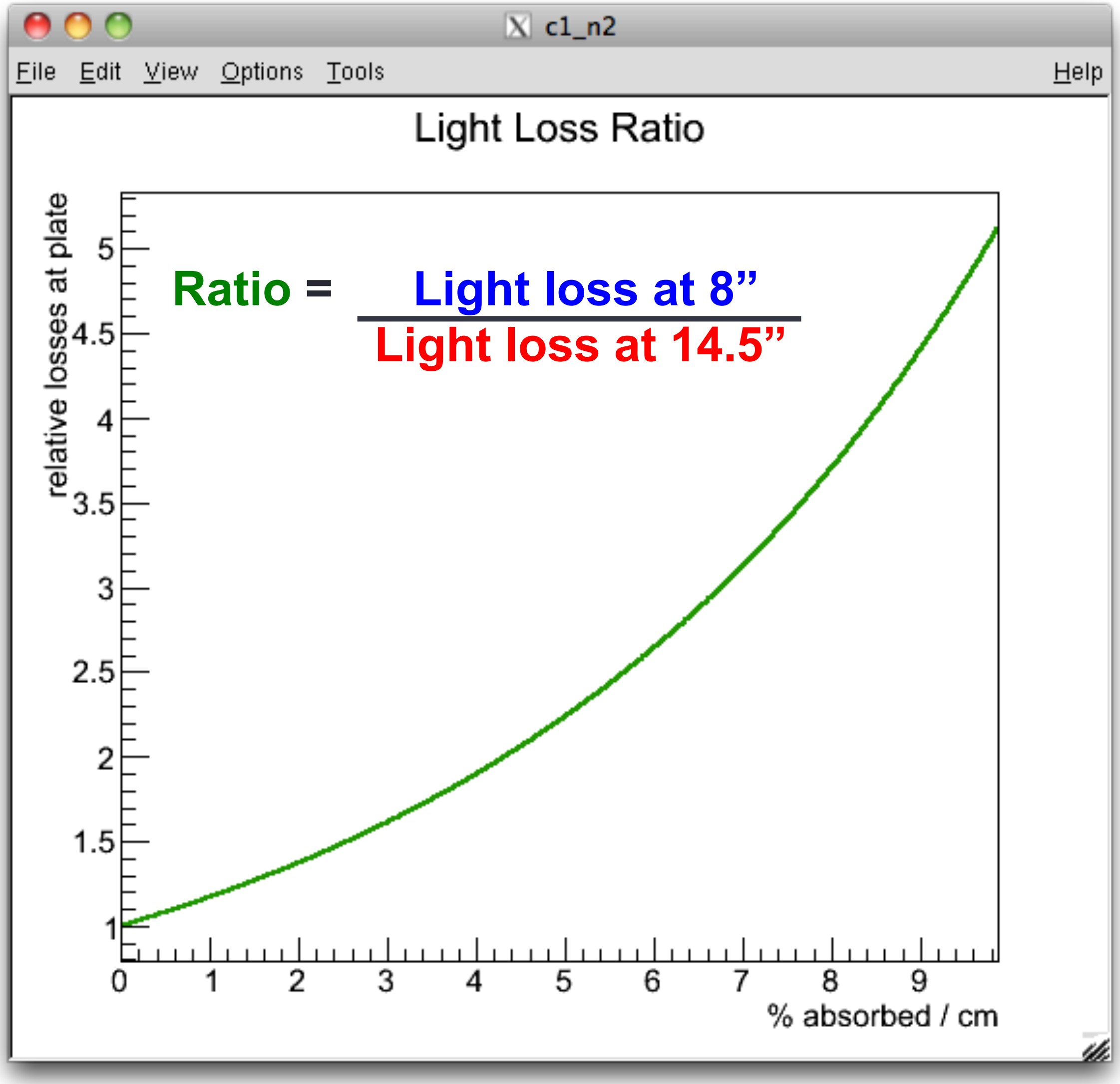
Understanding the Geometrical Effect

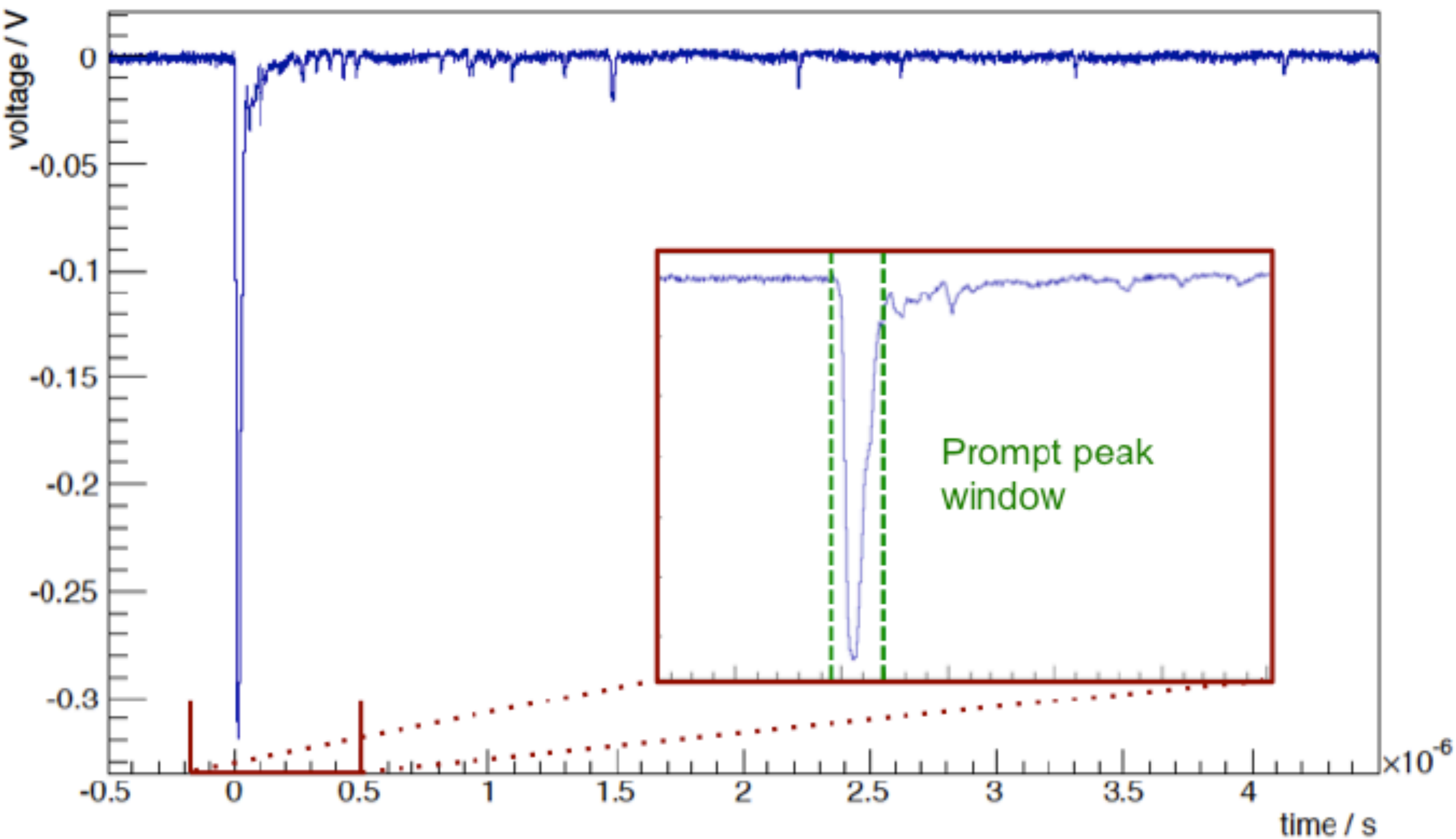
Ray trace to understand expected light yields per percent of absorption at each position



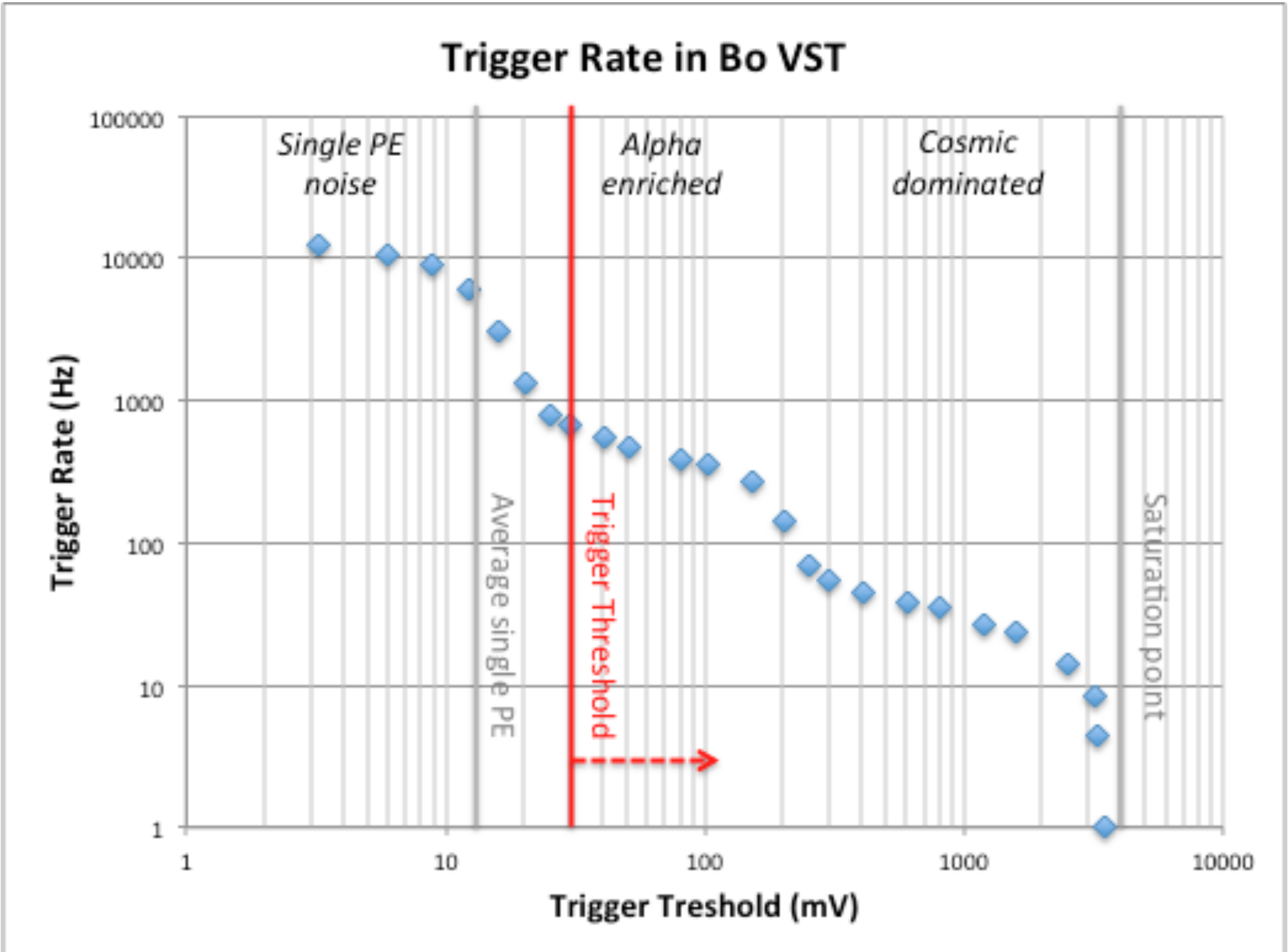
Taking ratio, any quenching effect cancels

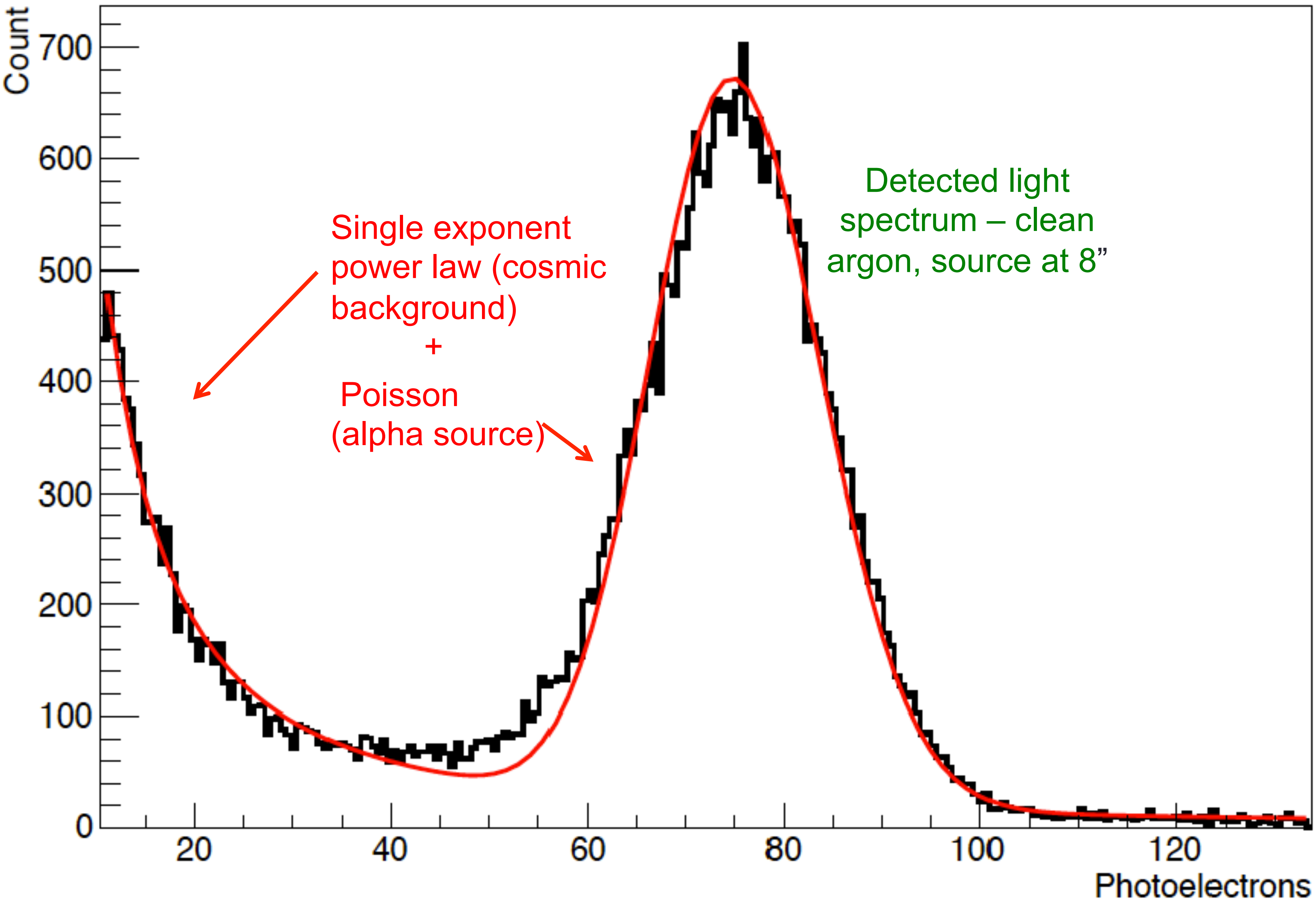




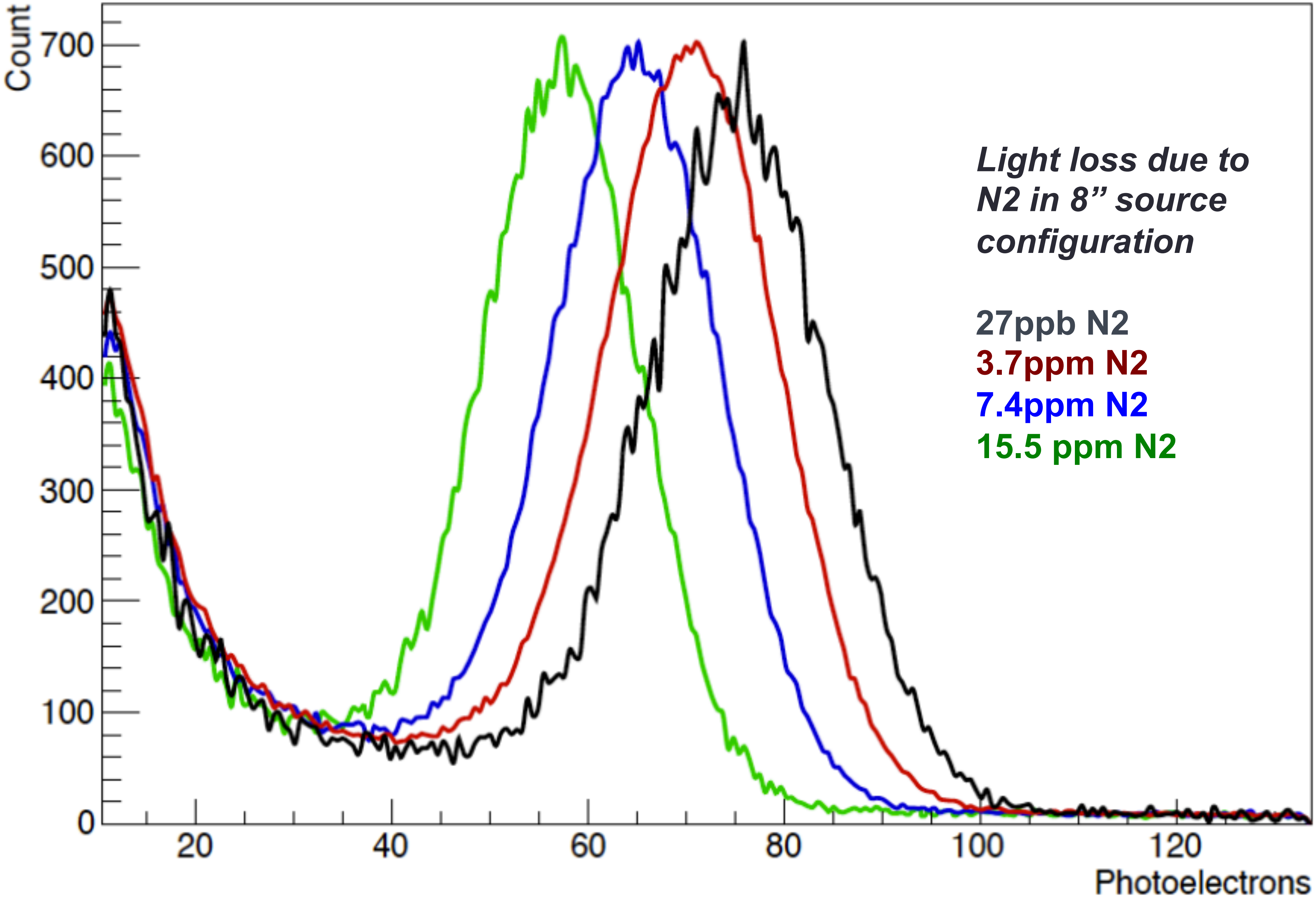


voltage / V
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
×10^-6
time / s
Prompt peak window


Trigger Rate in Bo VST
Single PE noise
Alpha enriched
Cosmic dominated
Average single PE
Trigger Threshold
Saturation point
Trigger Rate (Hz)
Trigger Treshold (mV)
100000
10000
1000
100
10
1
1
10
100
1000
10000



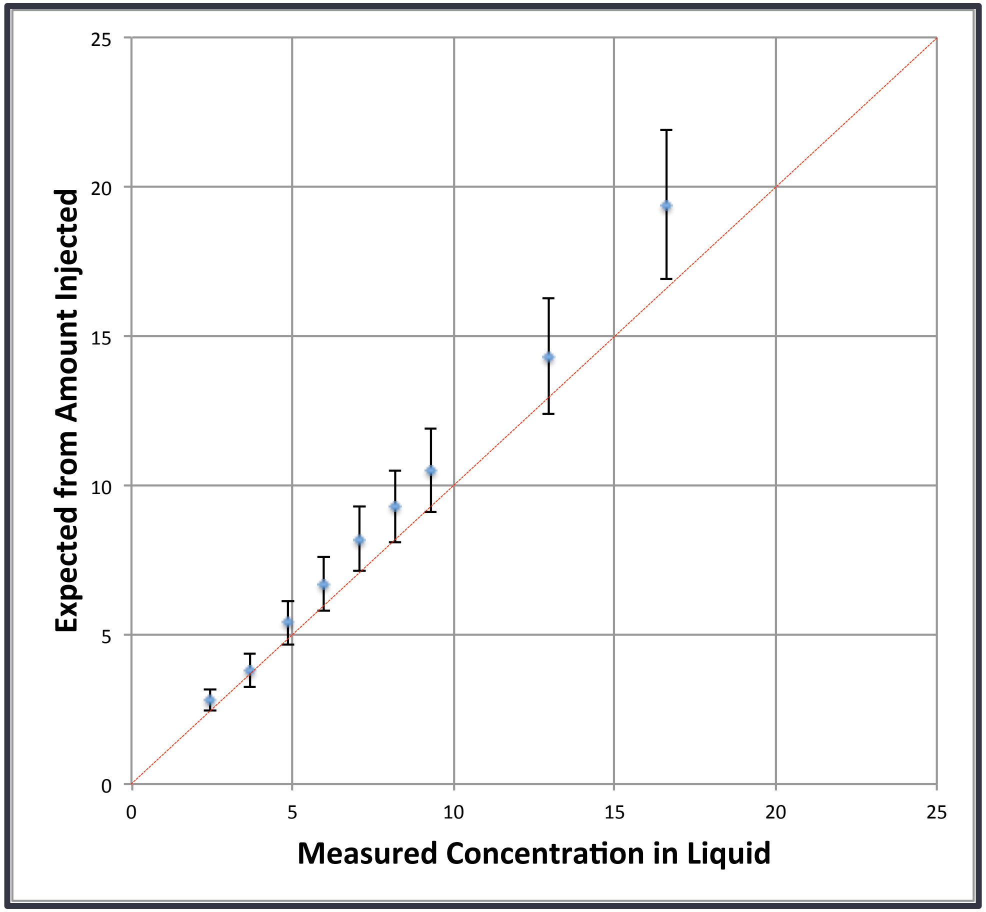
Count
700
600
500
400
300
200
100
0
20
40
60
80
100
120
Photoelectrons
Single exponent power law (cosmic background)
+
Poisson (alpha source)
Detected light spectrum – clean argon, source at 8”

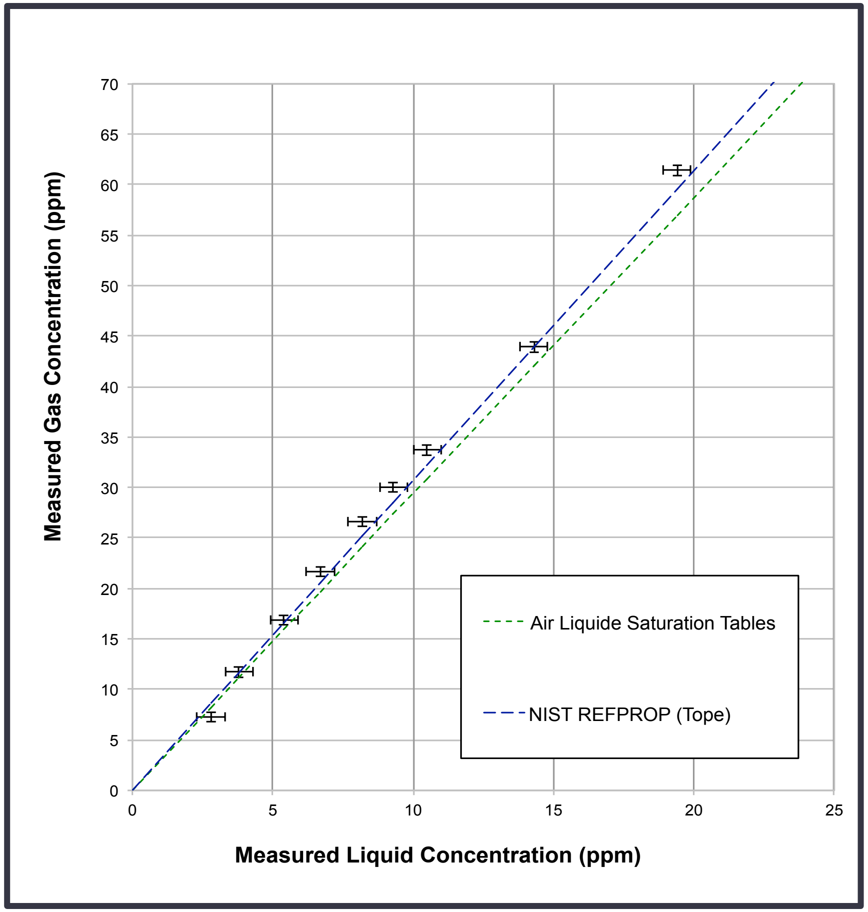


Count
700
600
500
400
300
200
100
0
20
40
60
80
100
120
Photoelectrons
Light loss due to N2 in 8" source configuration
27ppb N2
3.7ppm N2
7.4ppm N2
15.5 ppm N2

- PPM amounts of nitrogen are injected into the liquid from a gas canister, charged to a known pressure.
- From known volume of canister and known pressure we can calculate how many ppm we injected.
- Nitrogen concentration monitored in both liquid and gas phases using LDetek8000 N2 monitor
- We also monitor H20 and O2 to ~10ppb precision from the same sample lines.

How do we know we get N2 concentration right?

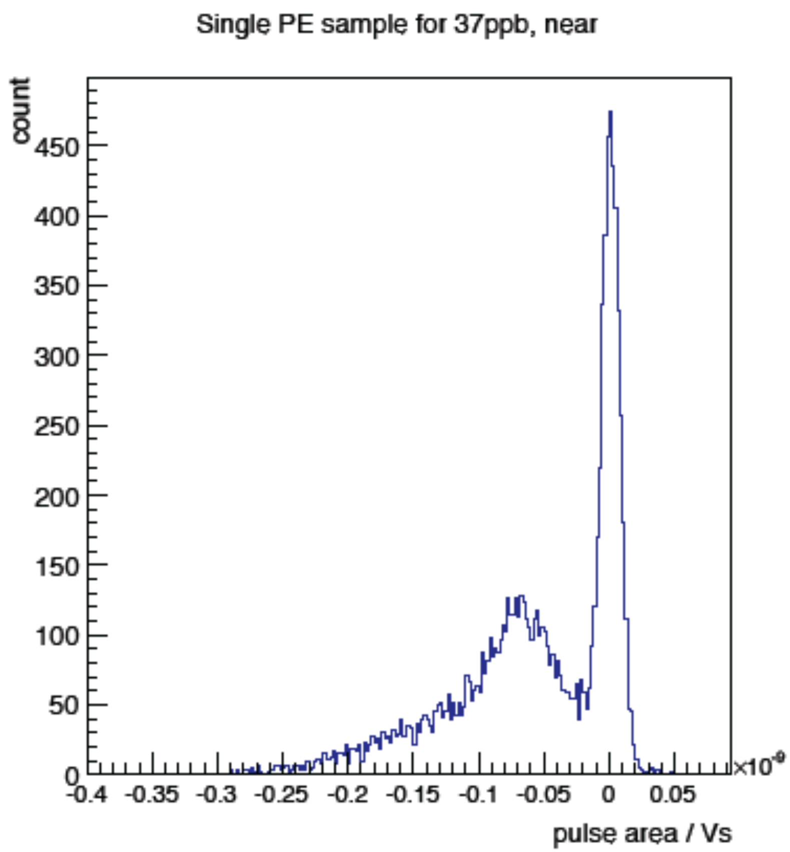


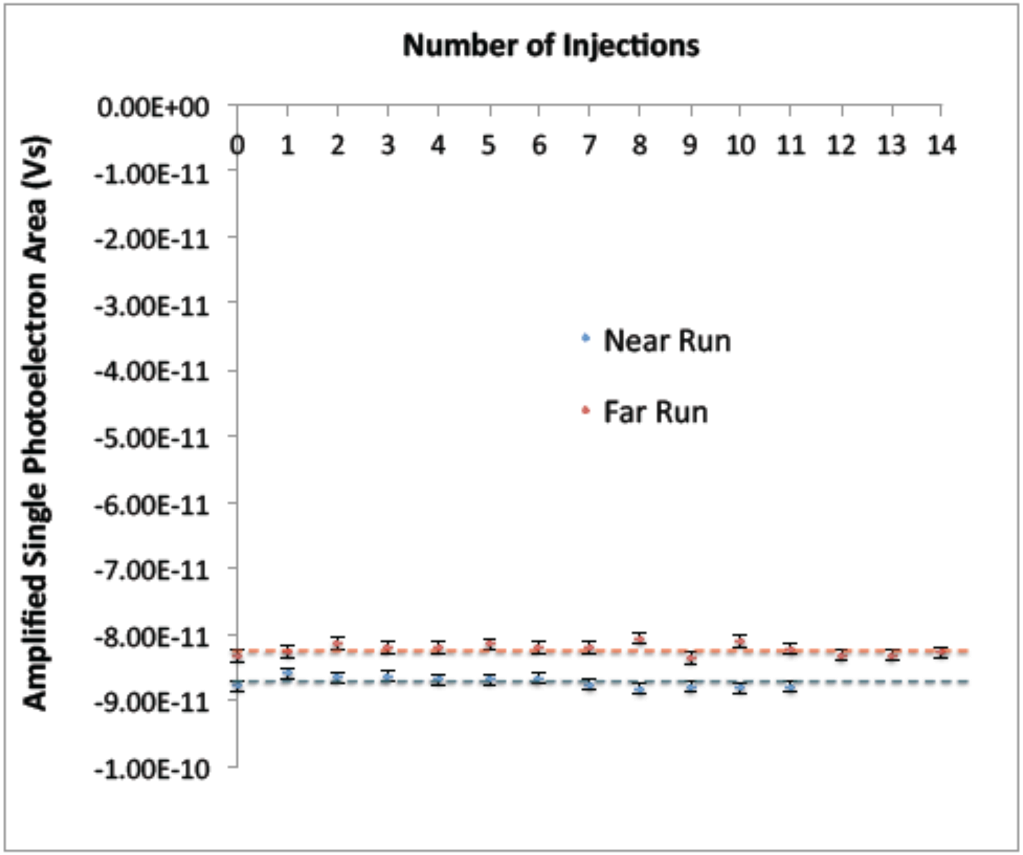


1) Amount of N2 in liquid agrees with amount injected to within our uncertainty of the injection volume.

2) Measurement from liquid and gas capillaries in agreement with saturation pressure based equilibrium calculation

Measurement of Single PE





Stability : 0.91% for Run 1
1.09% for Run 2

We say SPE is constant and fold in observed variation as a systematic error

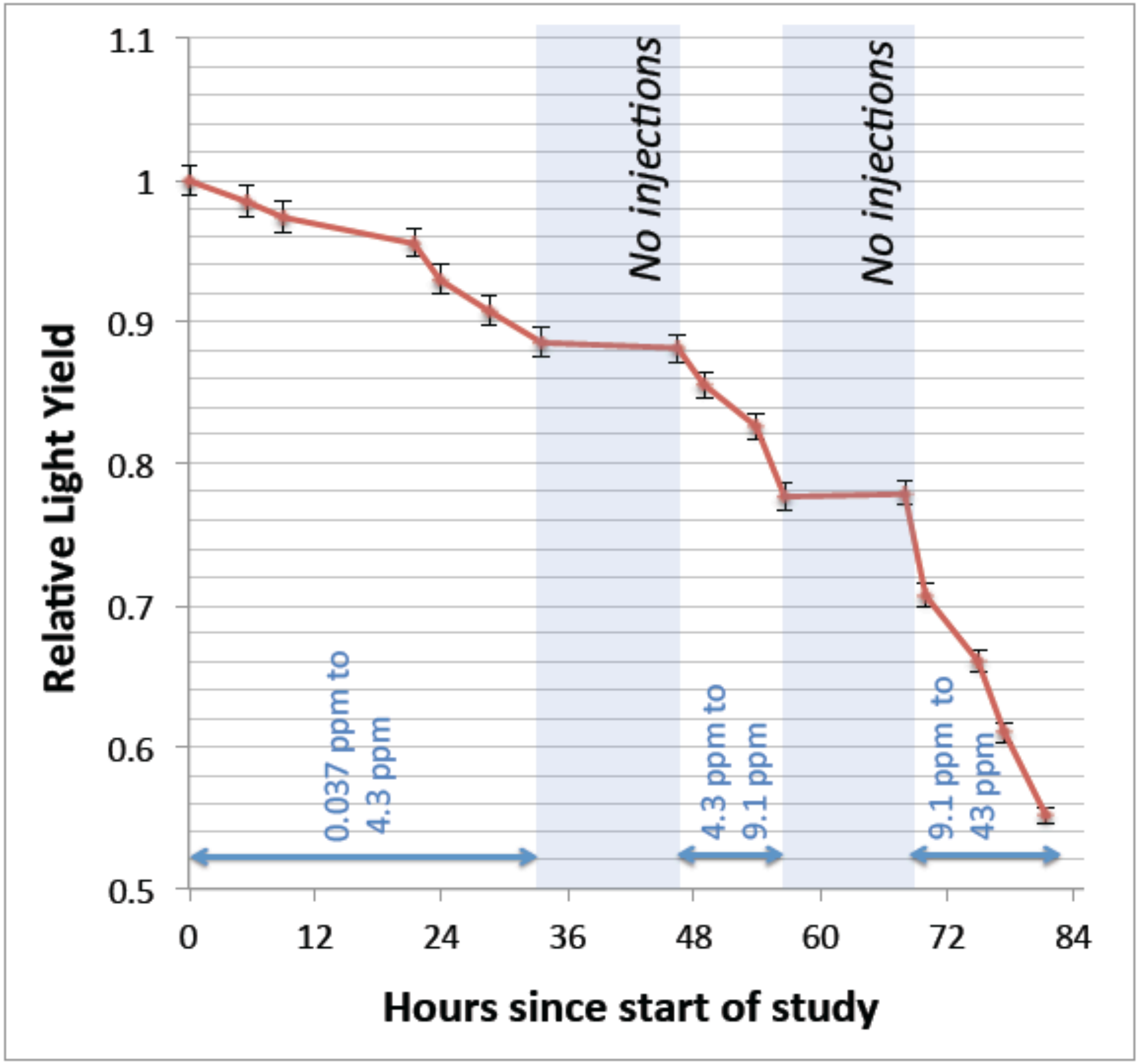
Light Yield Stability

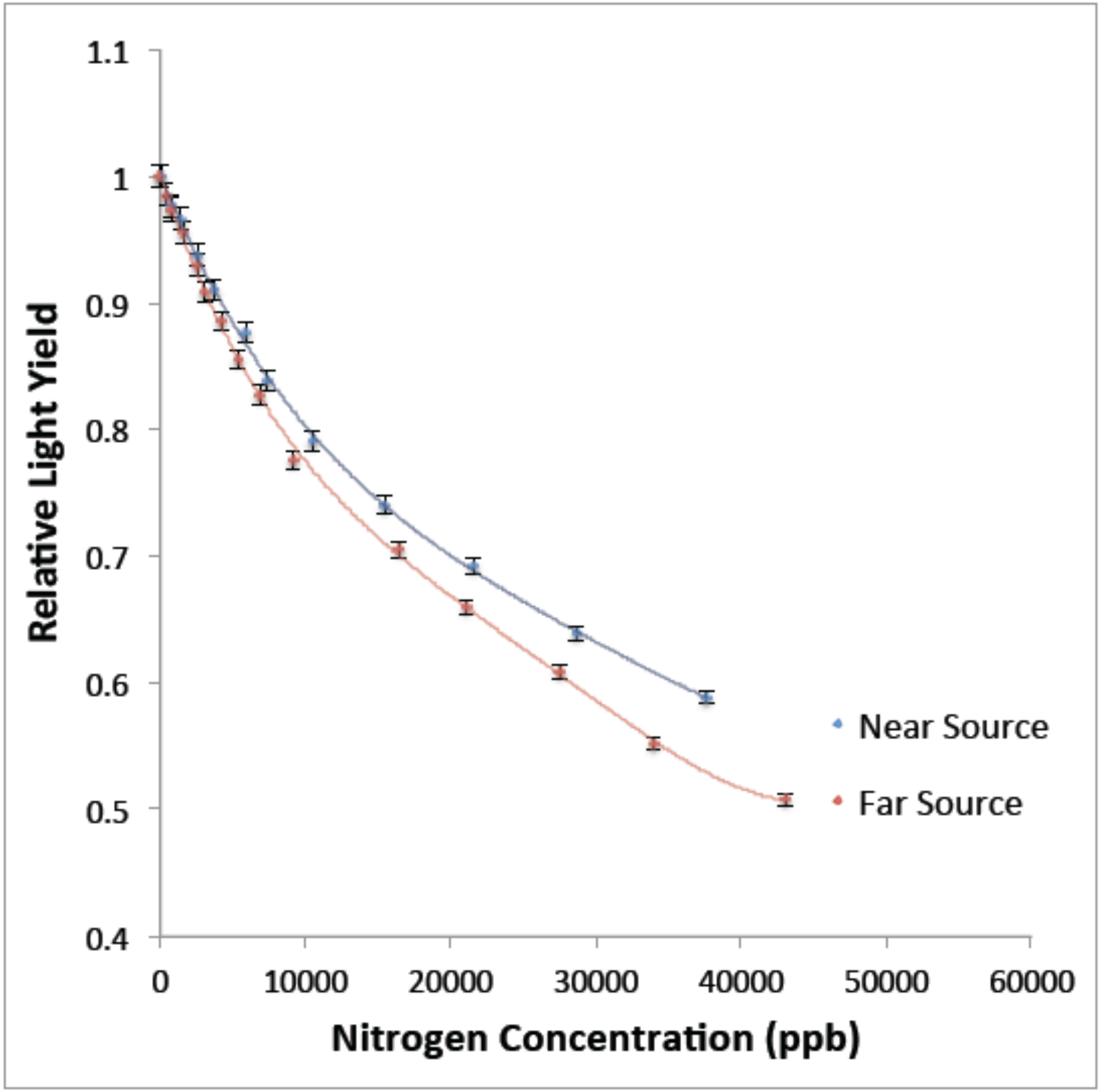
Are we sure it is the N2 causing the light loss?

Cross check : make sure no light losses if system is left for prolonged periods with no injections

Significant losses over 3 hour periods between measurements due to N2 injections

Stable over >8 hour injection-free periods to within 0.5%



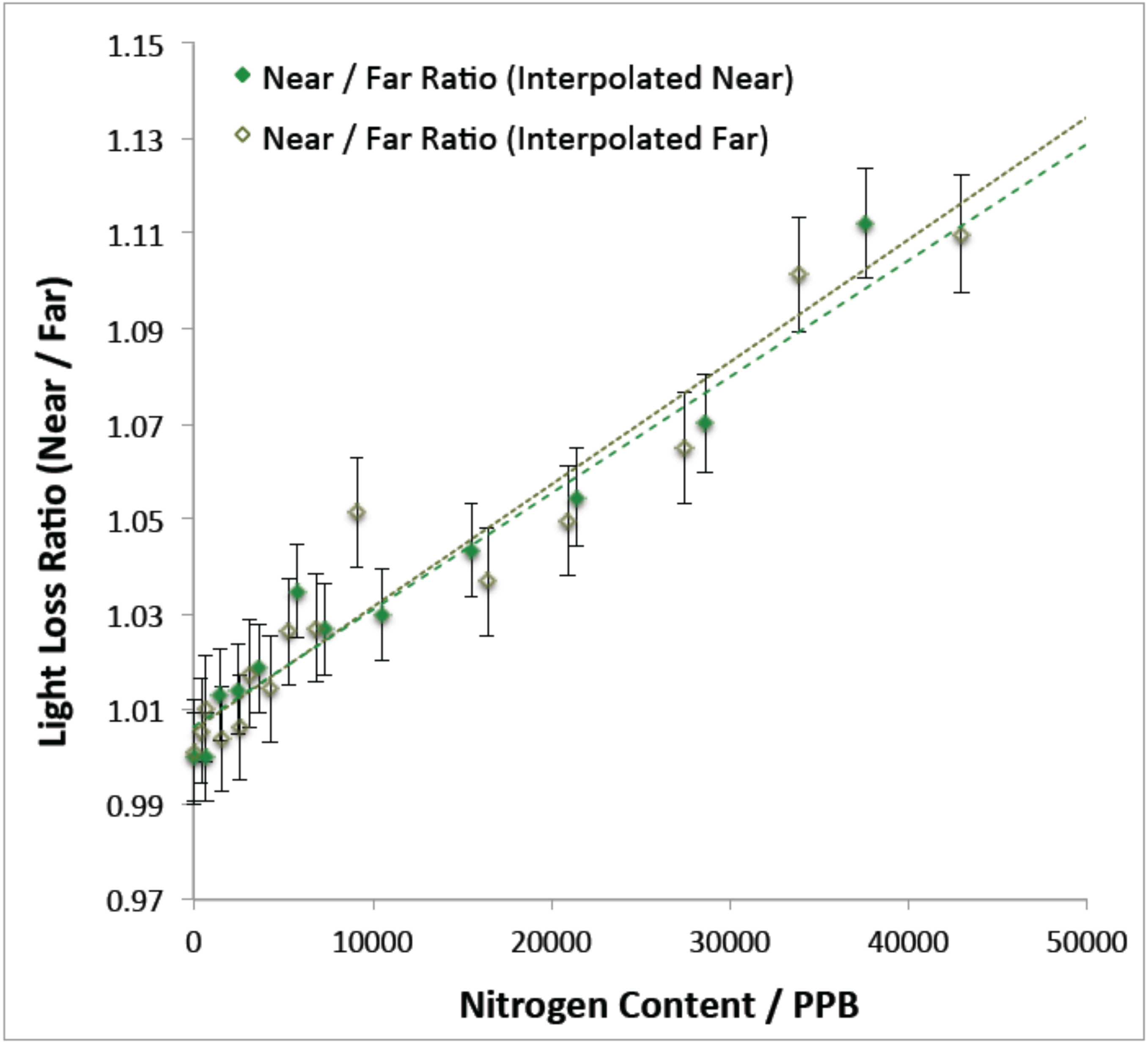


This plot shows all data points used in this measurement.

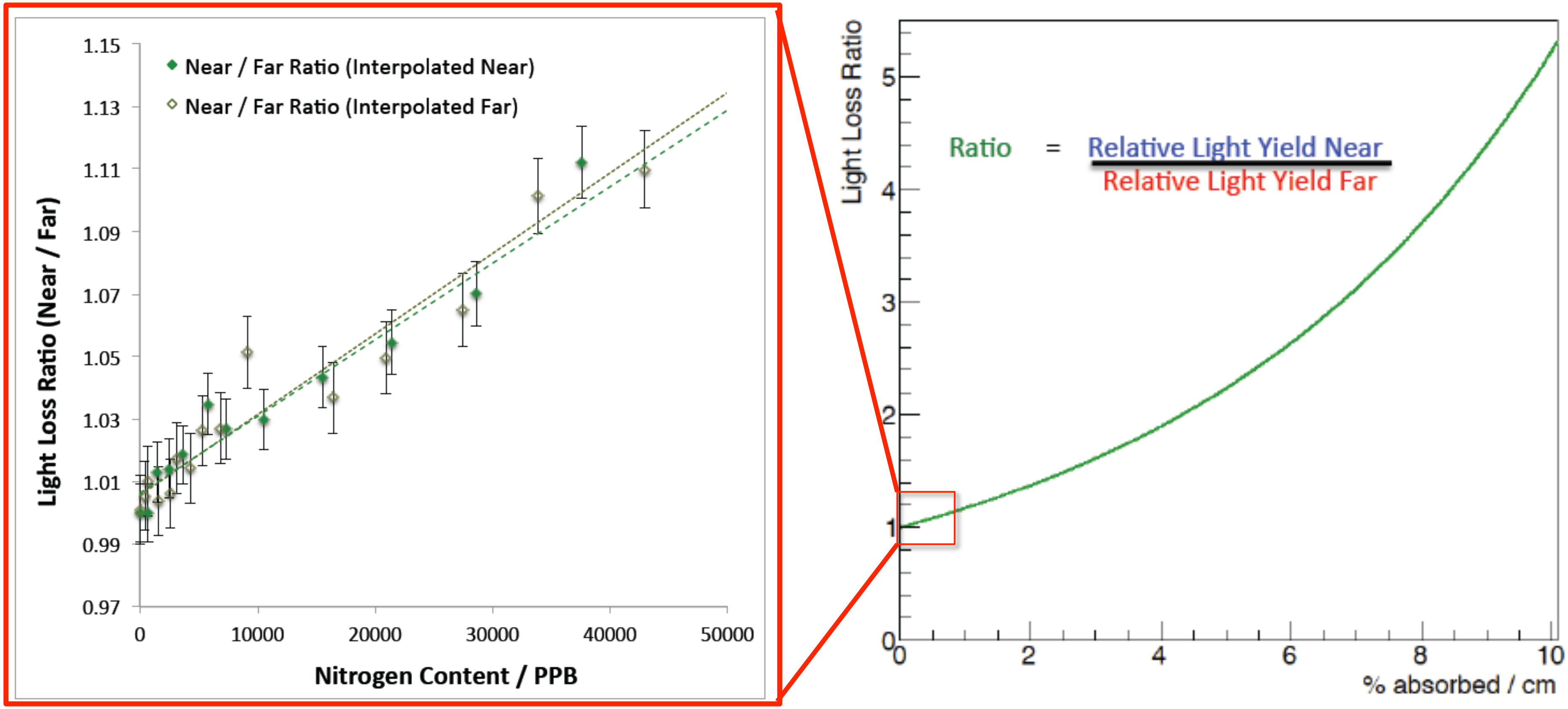
Clear divergence of near and far datasets – absorption effect is visible

Curves are quartic polynomial fit to data.

Interpolations allow us to take ratios at each concentration point.



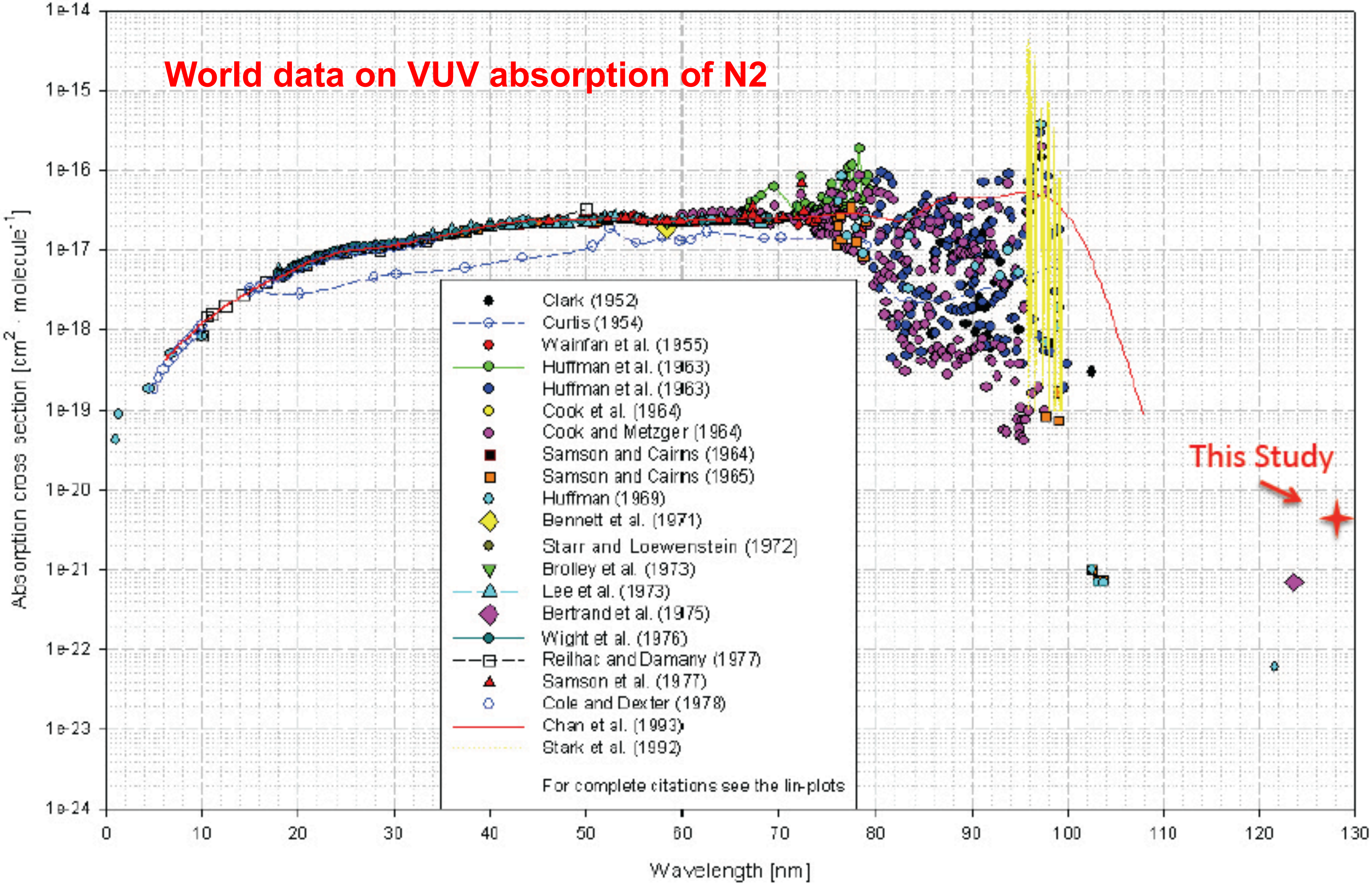
Near / Far Ratio (Interpolated Near)
Near / Far Ratio (Interpolated Far)
Light Loss Ratio (Near / Far)
Nitrogen Content / PPB
1.15
1.13
1.11
1.09
1.07
1.05
1.03
1.01
0.99
0.97
0
10000
20000
30000
40000
50000



Compare gradients to extract absorption strength of N2 per ppm

The Results

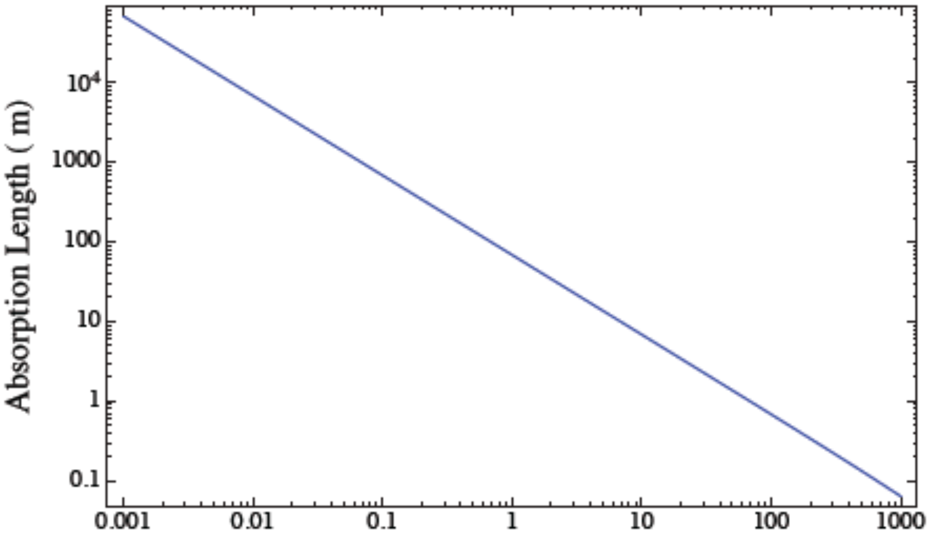
Interpolation Scheme	**Measured Absorption Strength** $cm^{-1}ppm^{-1}$	**Measured Cross Section** $cm^2 molecule^{-1}$
Interpolated Near	$(1.42 \pm 0.15) \times 10^{-4}$	$(5.00 \pm 0.51) \times 10^{-21}$
Interpolated Far	$(1.50 \pm 0.15) \times 10^{-4}$	$(4.71 \pm 0.50) \times 10^{-21}$
Average Value	$(\mathbf{1.46} \pm \mathbf{0.16}) \times \mathbf{10^{-4}}$	$(\mathbf{4.85} \pm \mathbf{0.52}) \times \mathbf{10^{-21}}$

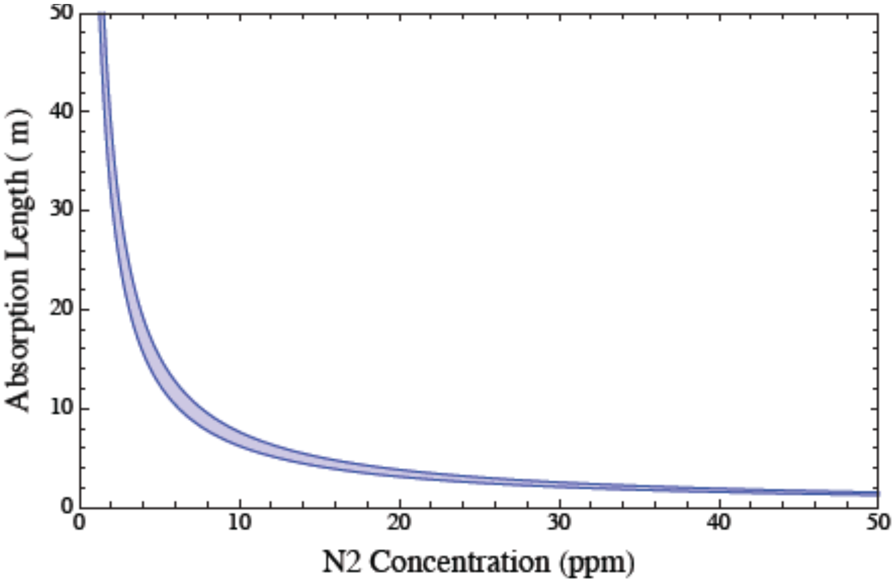


VUV absorption cross sections of nitrogen N_2 at room temperature (1-123 nm)

Implications for LArTPCs

Argon Specification	Concentration of N_2	Absorption Length
Measured N_2 concentration of clean argon for this study	37 ppb	1850 ± 170 m
AirGas research (grade 6) argon [15]	1 ppm	68 ± 6 m
MicroBooNE cryogenic specification [ref]	2 ppm	34 ± 3 m
Start of liquid recirculation phase of Liquid Argon Purity Demonstrator [16]	8 ppm	8.6 ± 0.8 m
AirGas industrial (grade 4) argon [15]	100 ppm	0.67 ± 0.06 m

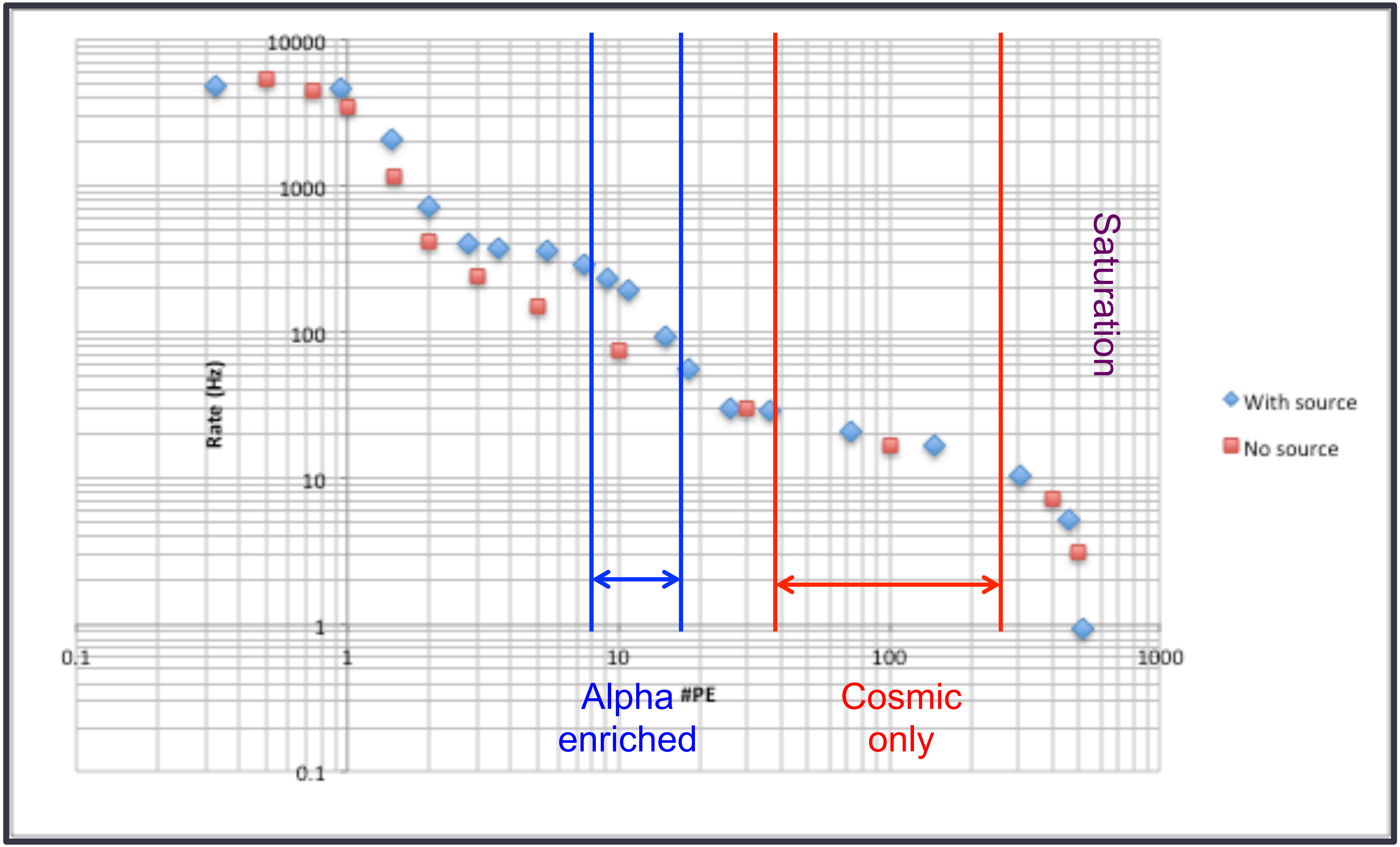


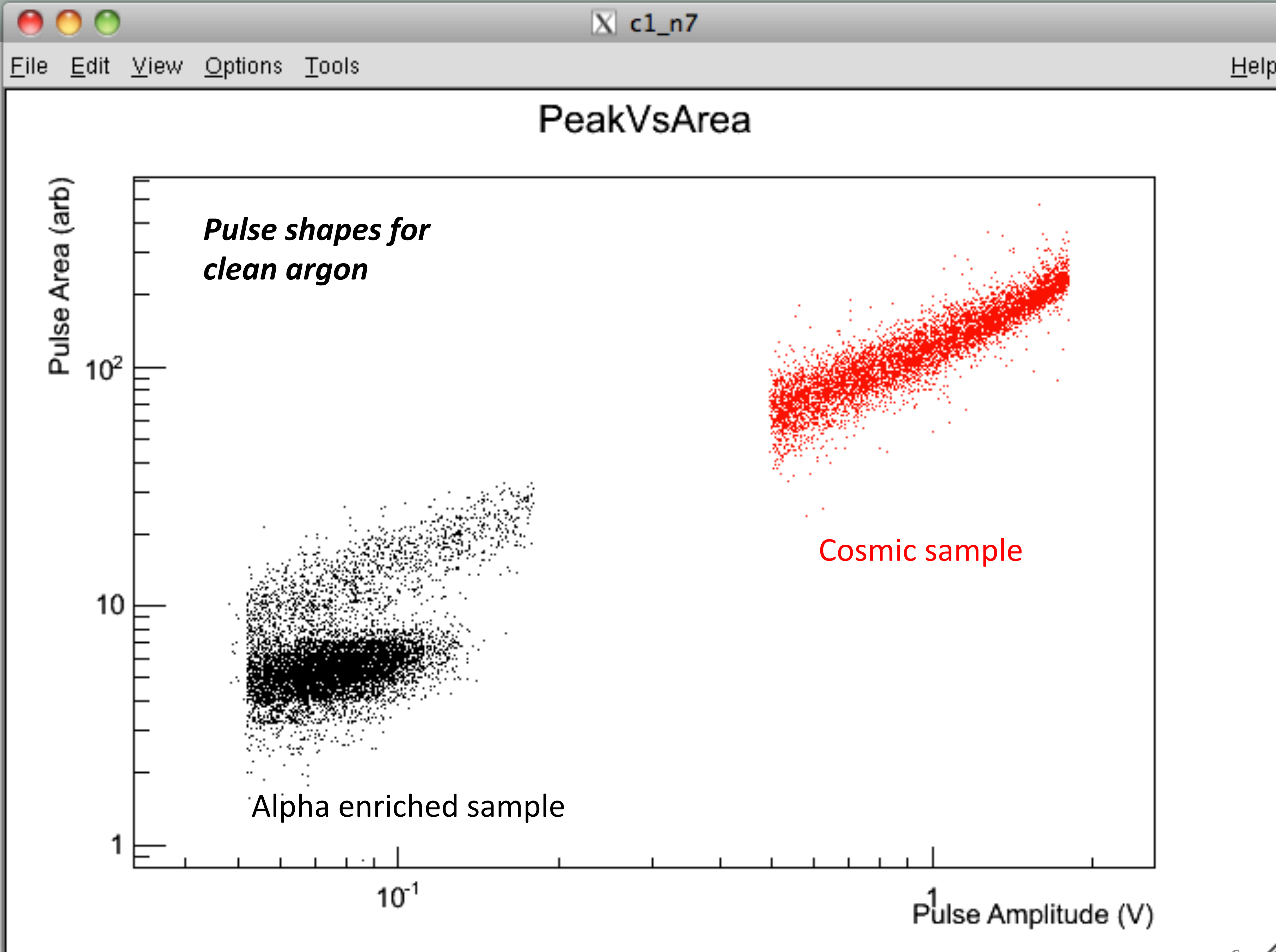


Thank you for your Attention.

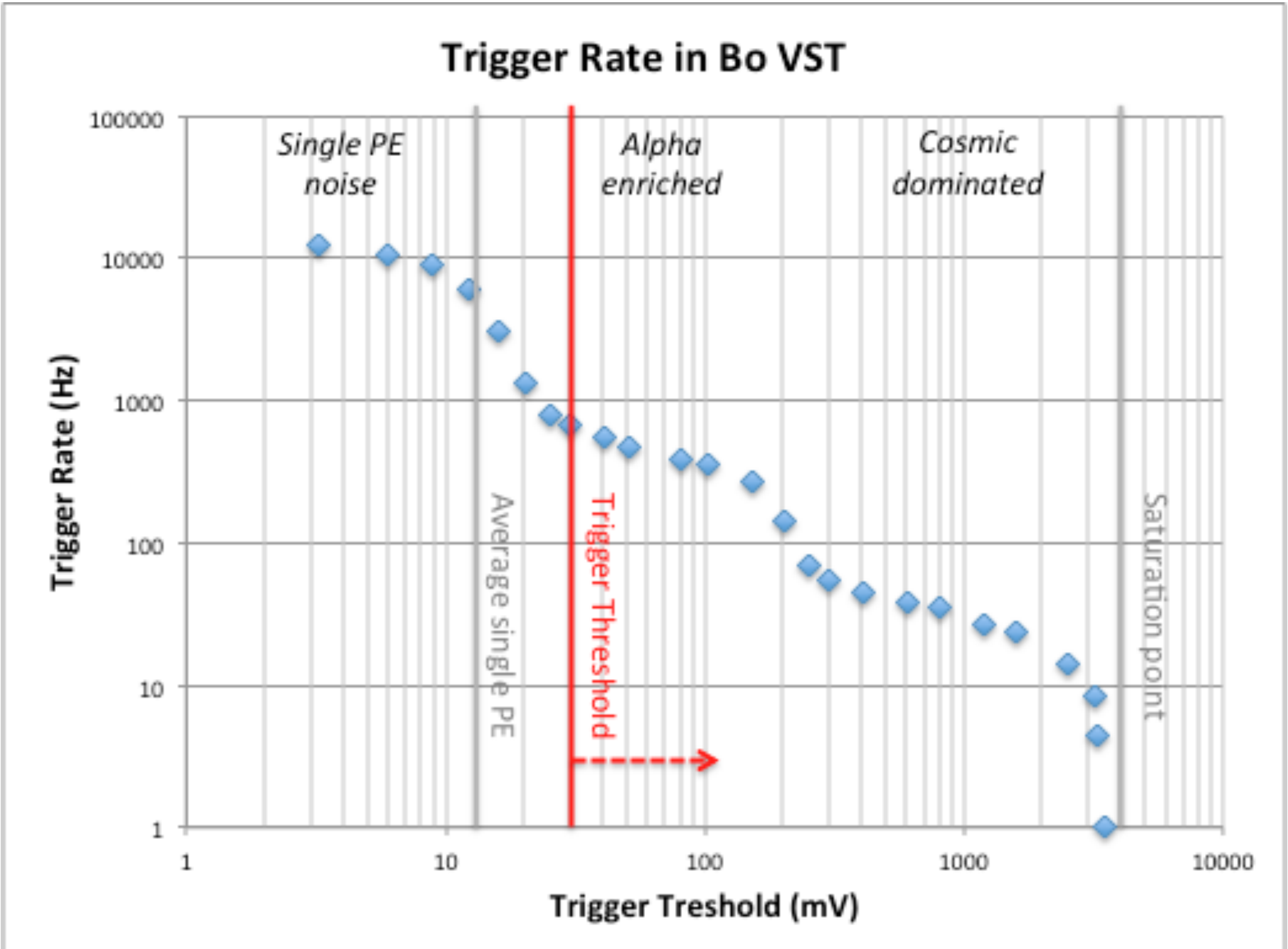
Backup Slides

Aside: Pulse Shape Discrimination in Action





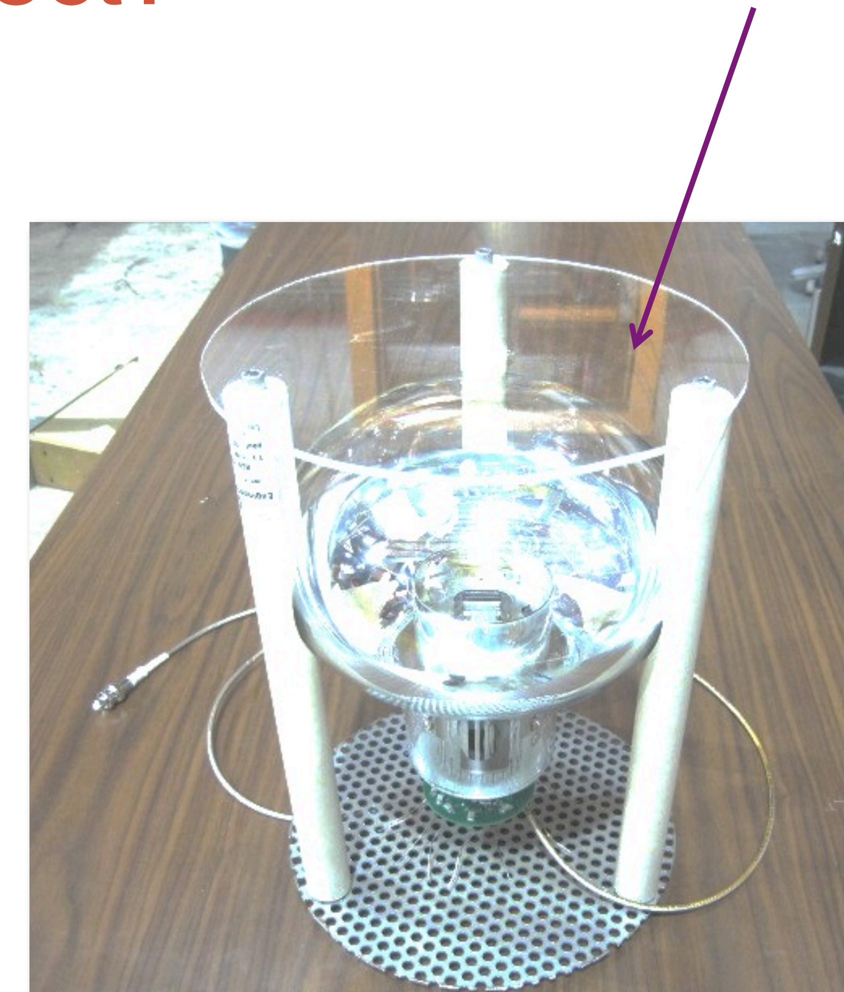
c1_n7
File Edit View Options Tools Help
PeakVsArea
Pulse shapes for
clean argon
Pulse Area (arb)
10²
10
1
Cosmic sample
Alpha enriched sample
10⁻¹
1
Pulse Amplitude (V)


Trigger Rate in Bo VST
Trigger Rate (Hz)
Trigger Treshold (mV)
100000
10000
1000
100
10
1
1
10
100
1000
10000
Single PE noise
Alpha enriched
Cosmic dominated
Average single PE
Trigger Threshold
Saturation point

Contents

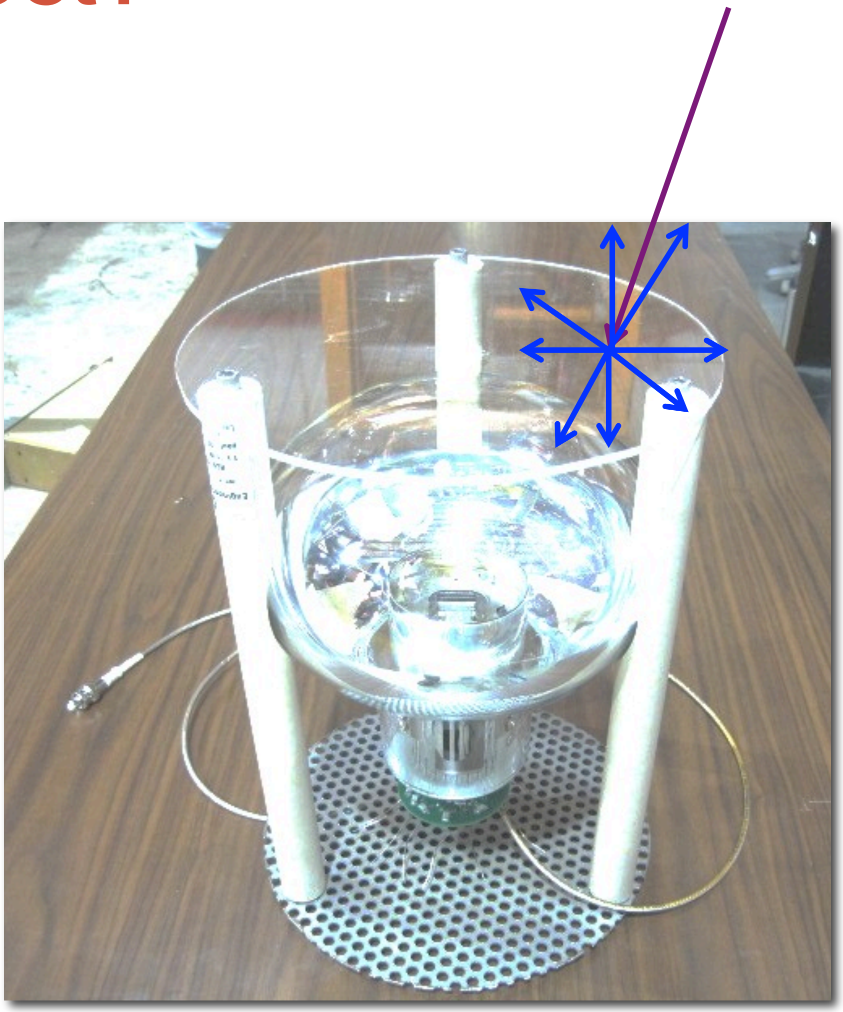
What Do We Expect?

- A photon arrives at the TPB plate



What Do We Expect?

- A photon arrives at the TPB plate
- It may be shifted to a visible photon by TPB coating.



Predicting WLS Efficiency

- Is very hard, because to deal with 128nm light you have to use either a vacuum or liquid argon
- And it is ALWAYS very hard to know how many photons you started with.
- Thankfully, some people have fancy equipment to overcome both these problems:

arXiv.org > astro-ph > arXiv:1104.3259

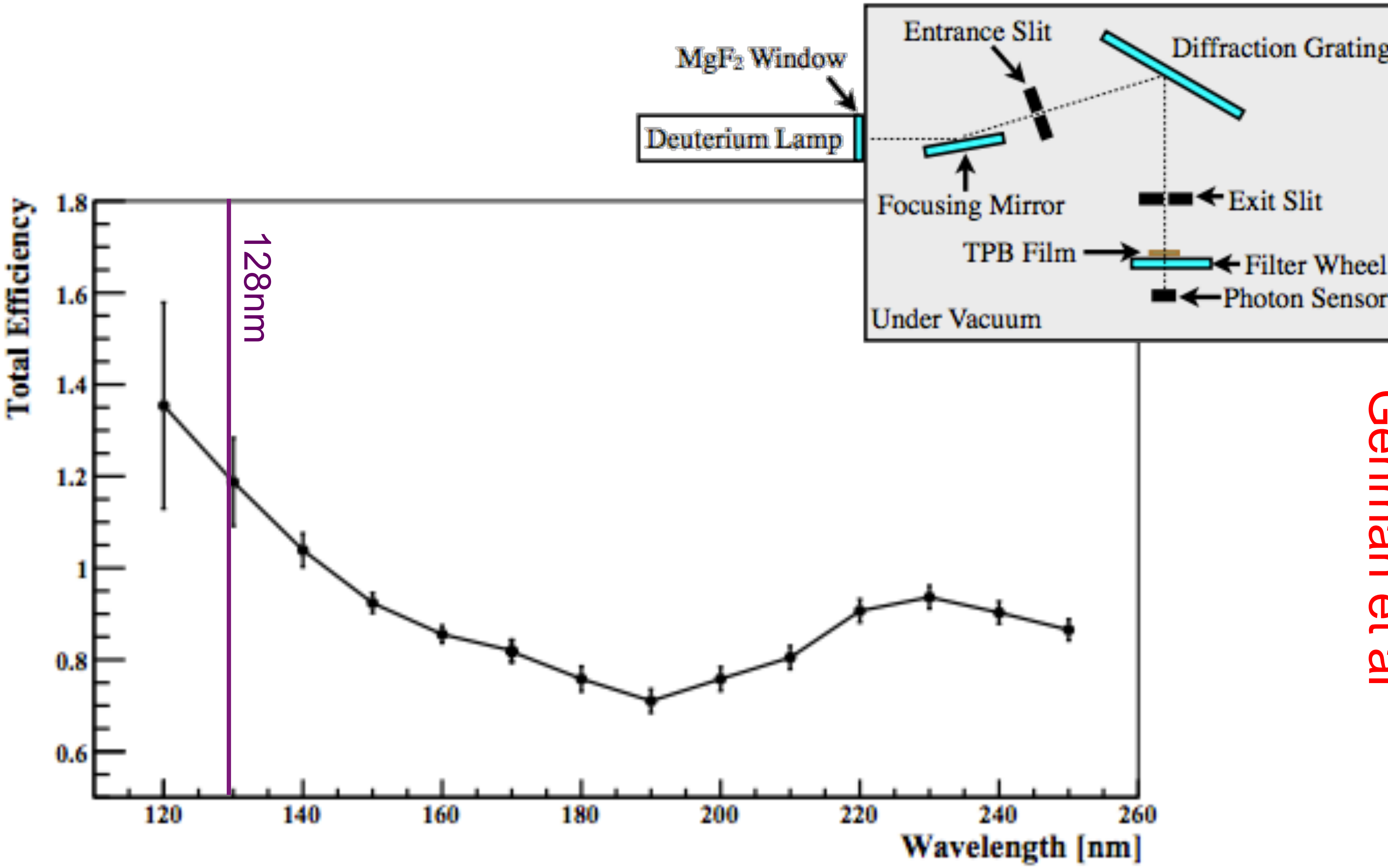
Search

Astrophysics > Instrumentation and Methods for Astrophysics

Fluorescence Efficiency and Visible Re-emission Spectrum of Tetraphenyl Butadiene Films at Extreme Ultraviolet Wavelengths

V. M. Gehman, S. R. Seibert, K. Rielage, A. Hime, Y. Sun, D.-M. Mei, J. Maassen, D. Moore

(Submitted on 16 Apr 2011 (v1), last revised 22 Sep 2011 (this version, v2))



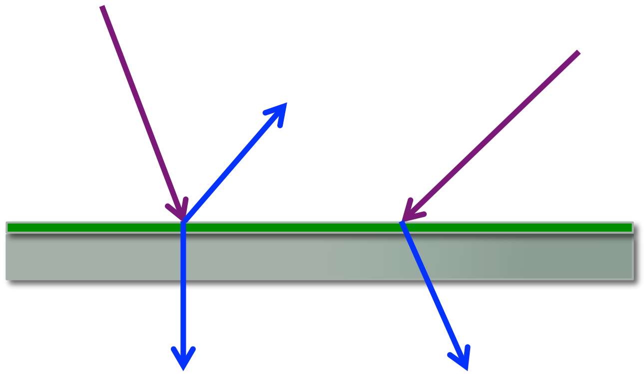
Gehman et al

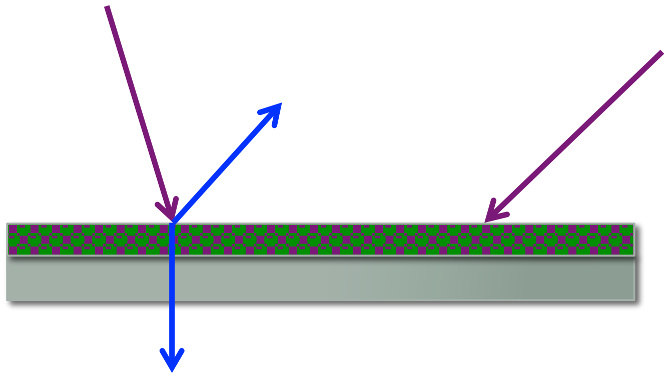
1.18 ± 0.1

Visible photons out / UV photon in for evaporative TPB

But not all coatings are the same

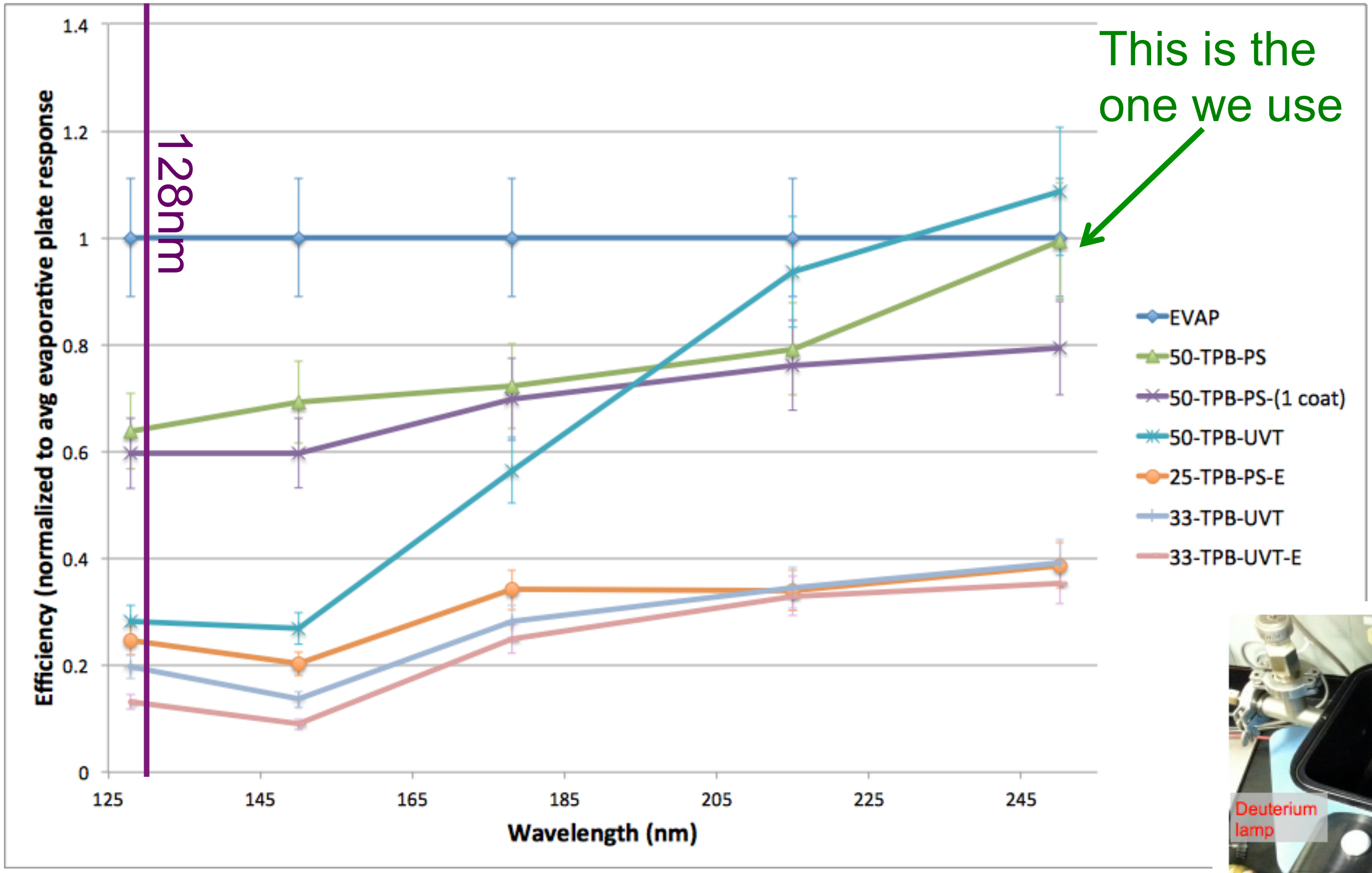
- Gehman et al use an evaporative coated, pure TPB layer
- When developing the optical system, we found this coating to be very delicate.
- We use a more robust but less efficient coating of TPB in a polystyrene matrix.
- The PS substrate is not transparent to 128nm light, so some light is lost before being shifted to the visible.

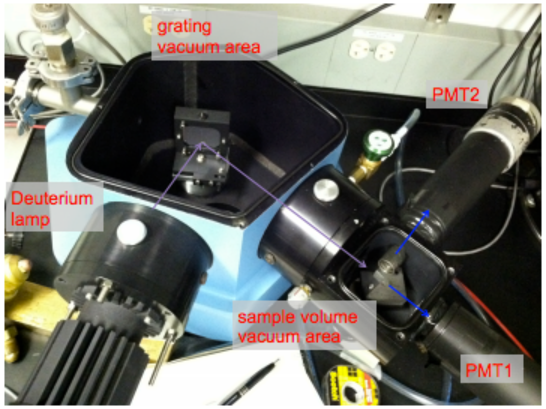




Comparison of uB plates to evaporative plates in vacuum

Ignarra (MIT)



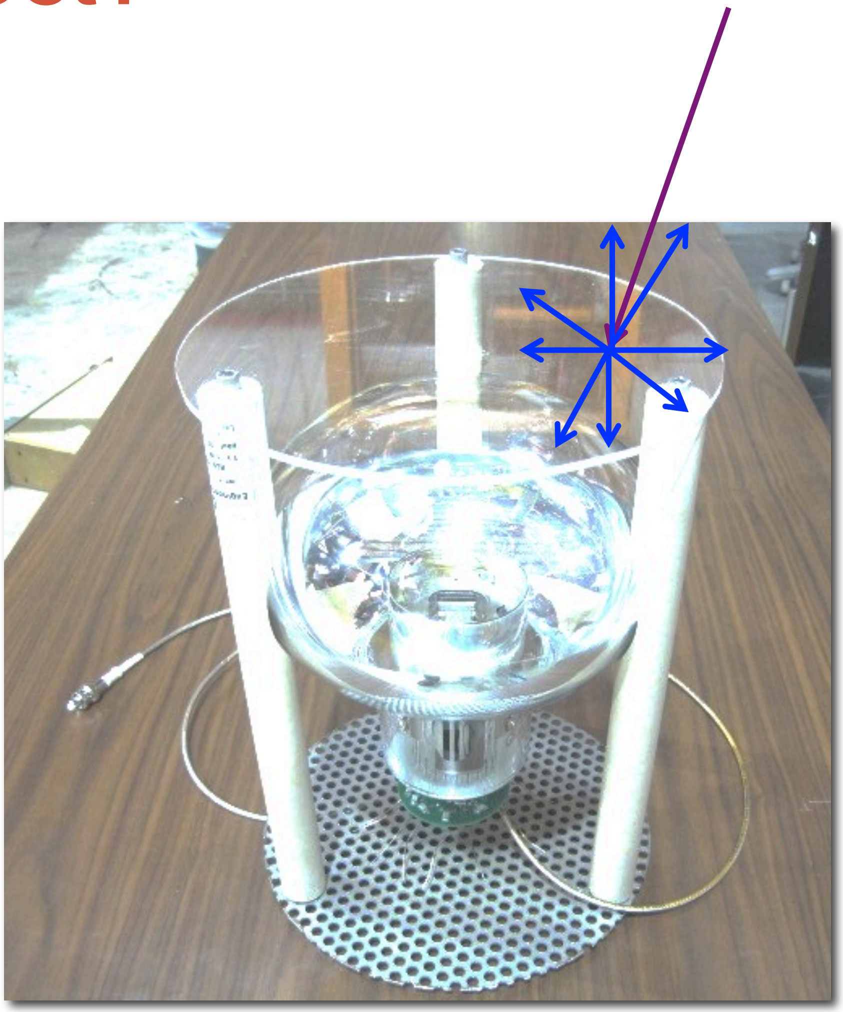


0.64 ± 0.11

Performance of uB plate compared to evaporative

What Do We Expect?

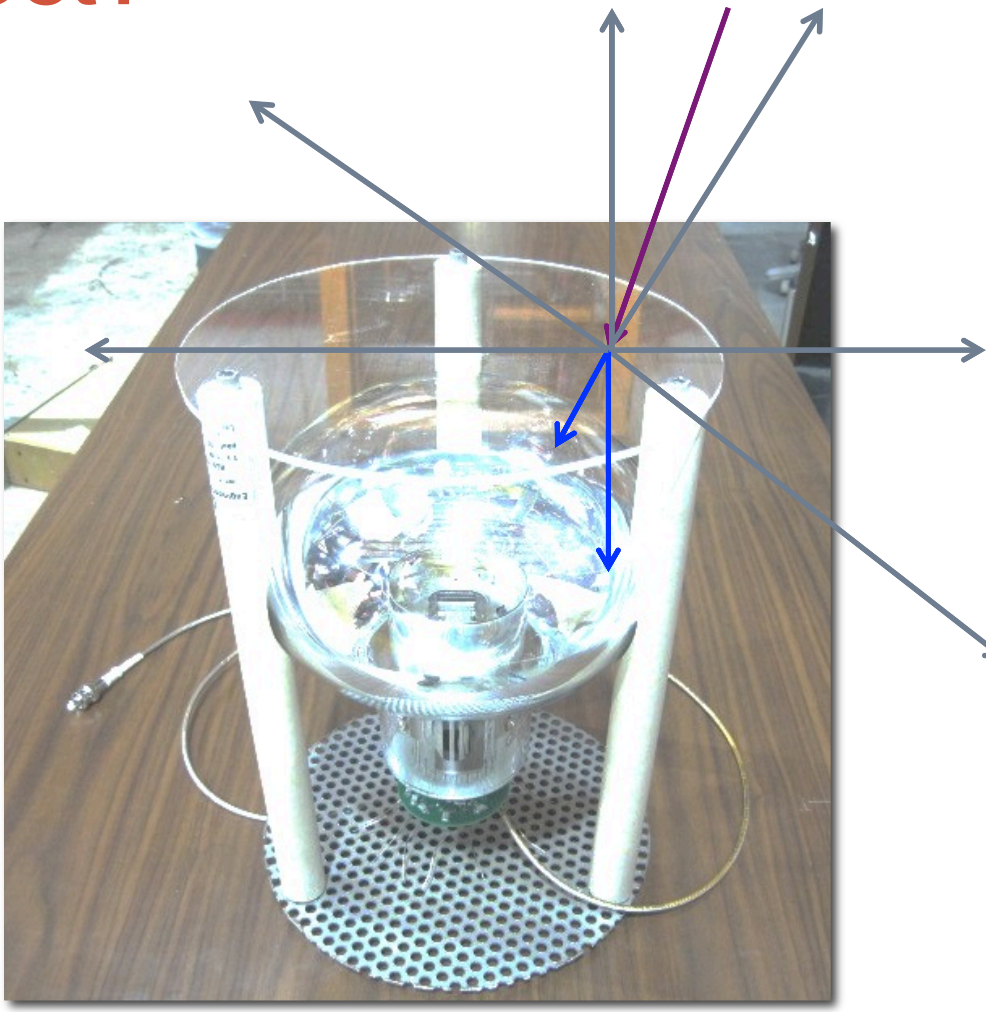
- A photon arrives at the TPB plate
- It may be shifted to a visible photon by TPB coating.



What Do We Expect?

- A photon arrives at the TPB plate
- It may be shifted to a visible photon by TPB coating.
- Only some of the emitted rays get to the PMT

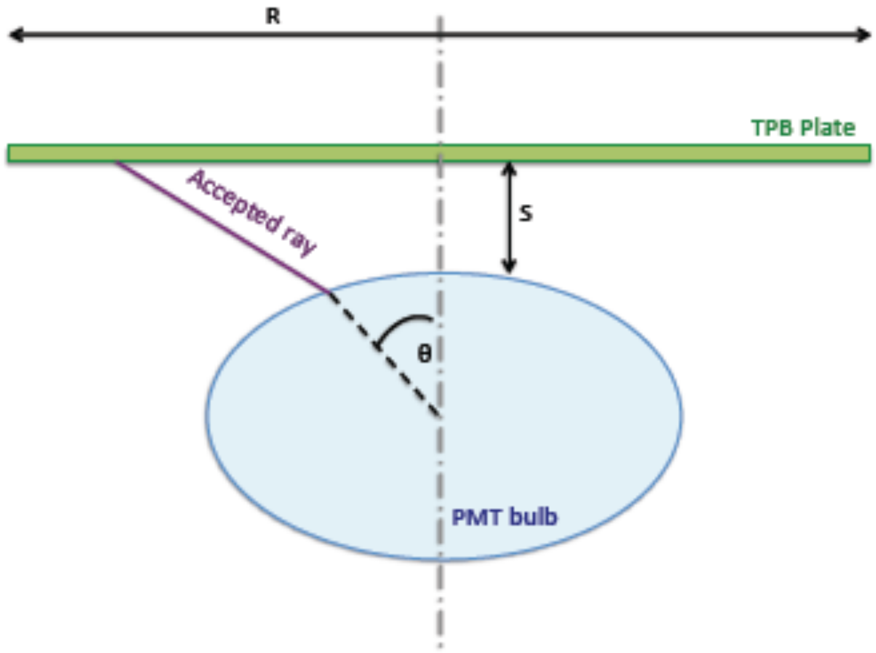
(lose 50% straight away – backwards going)



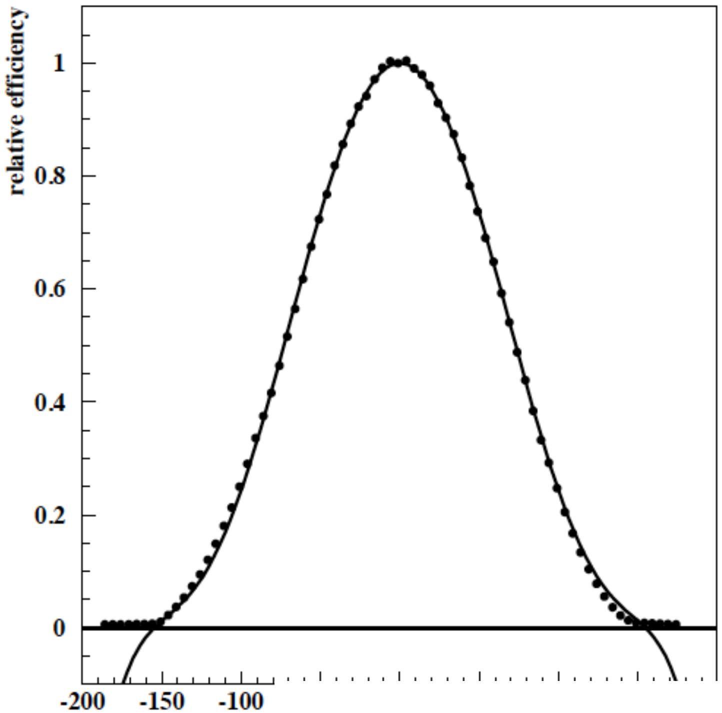
Acceptance of Light

Jones and Toups (MIT)

- This is more complicated than it seems.
- Different points on the TPB plate will illuminate different parts of the PMT face, and different parts of the PMT face have different acceptances.
- Not only this, but there is also a dependence on incident ray angle
- We don't know any of these dependencies.

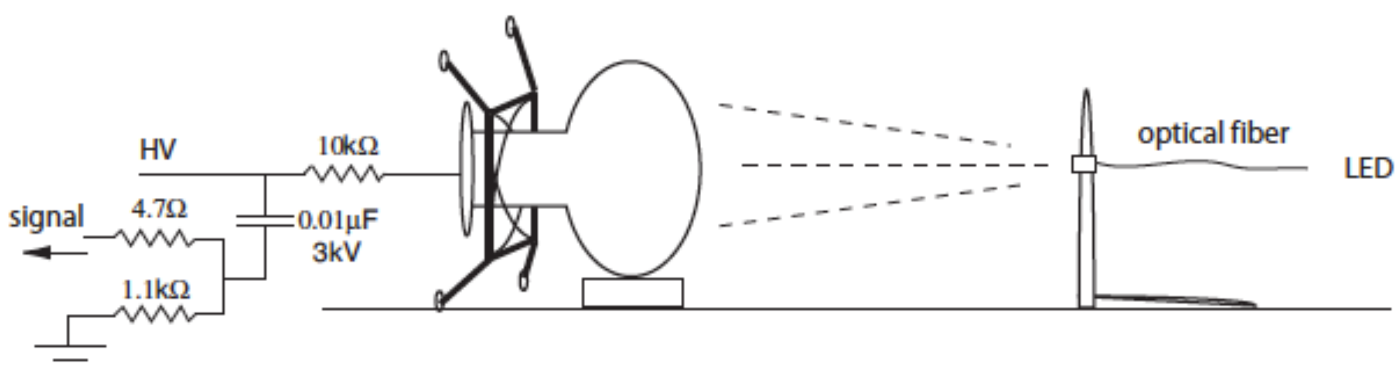


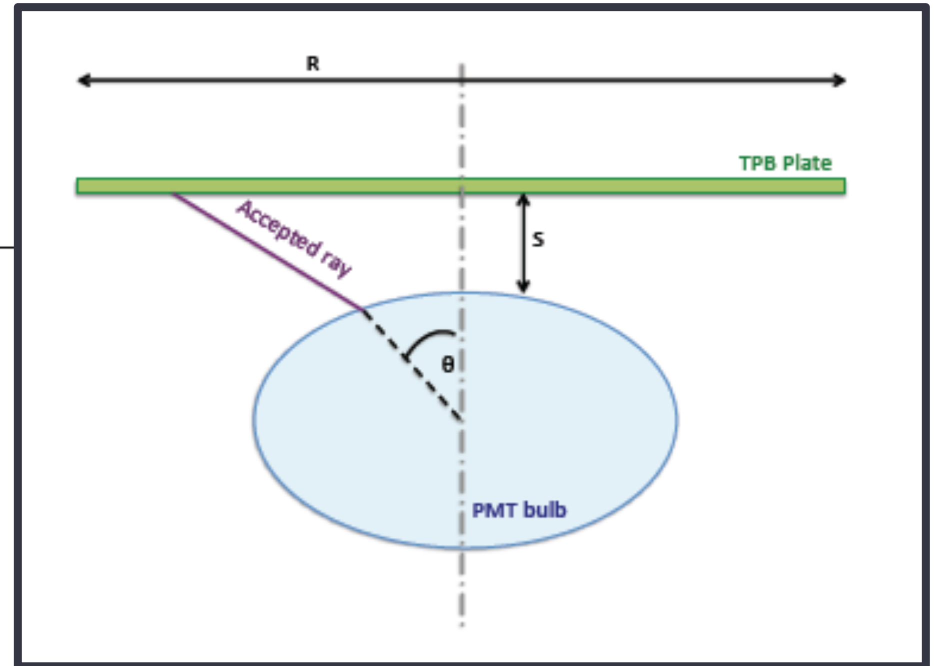
Angular Acceptance

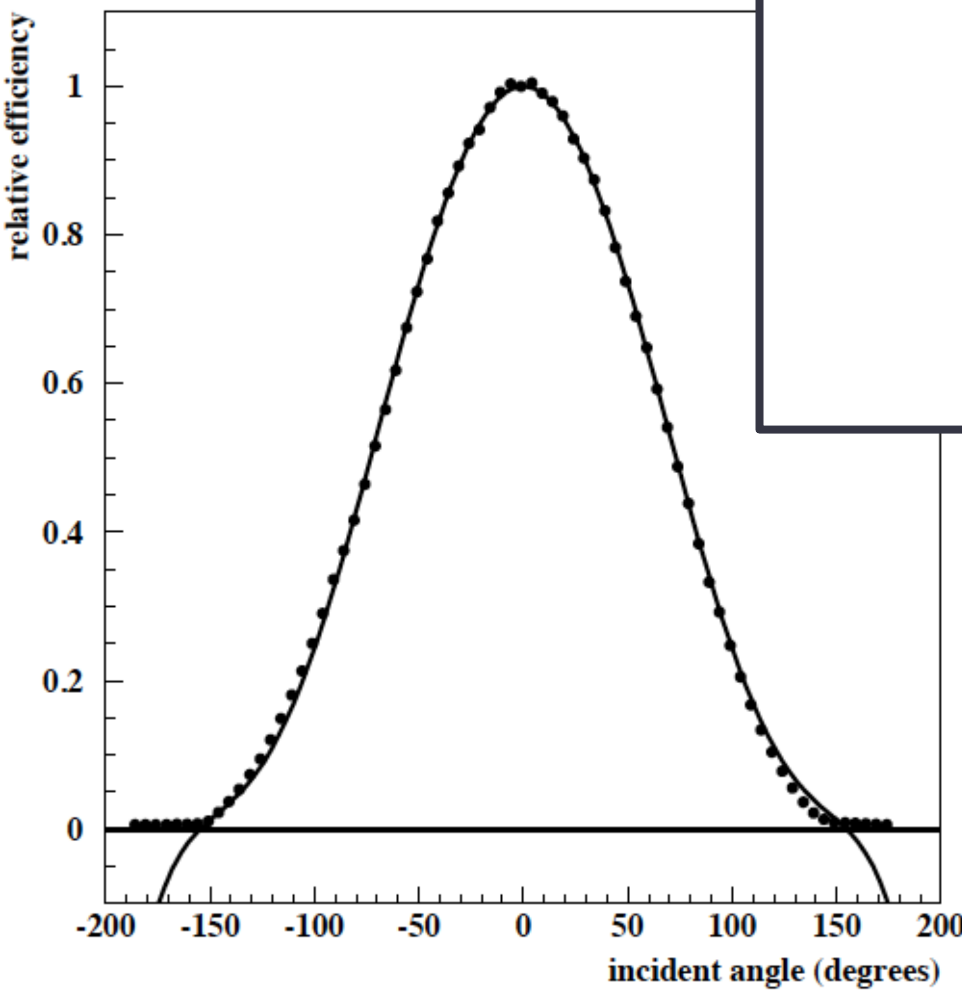


- MiniBooNE measured response of tube at different angles to "distant" light source
- Resulting data points were fit to a polynomial in theta
- Each point corresponds to tube illuminated all over front face, but at different angle
- Can we use this? Sort of…

SJ Brice et al (MiniBooNE)





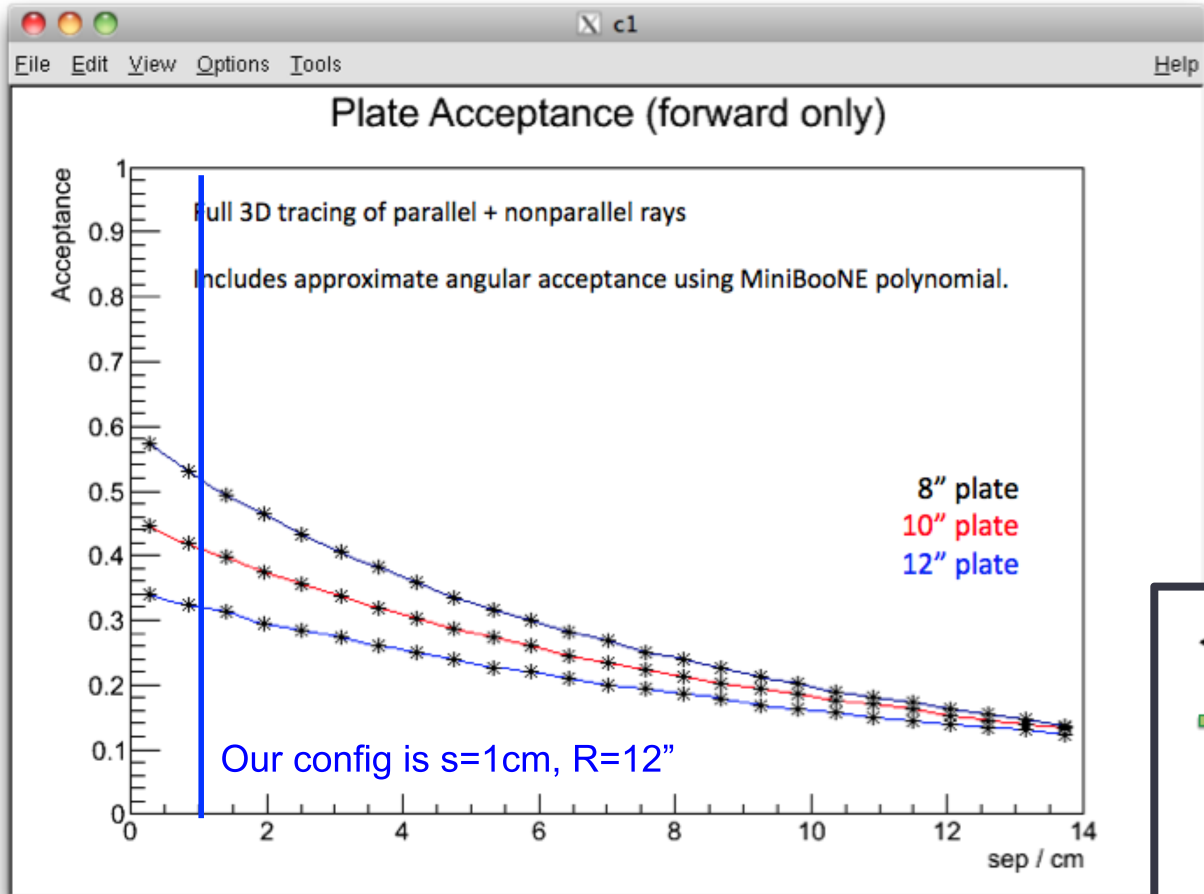


Jones and Toups (MIT)

- We assume that theta in this diagram can be equated to MiniBooNE theta
- We guess that effects of other coordinates average out
- This assumption is shaky. All the more reason to measure GQE.

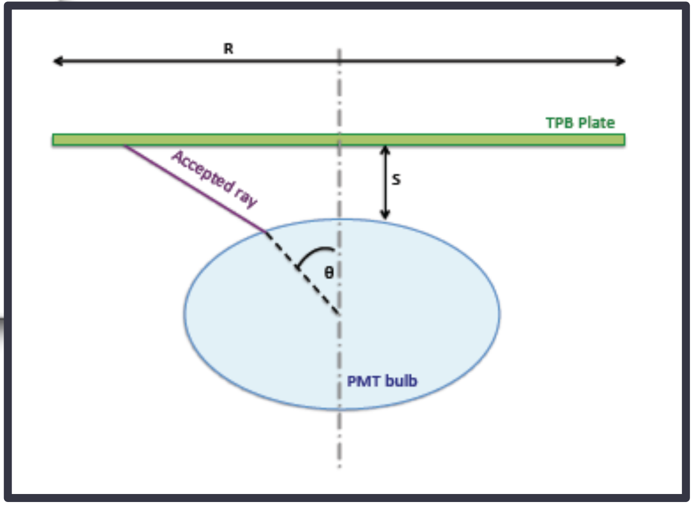
Then its just a question of raytracing

Jones and Toups (MIT)



Two independent simulations agree to within ~10%

Likely discrepancy due to slightly different assumed geometry

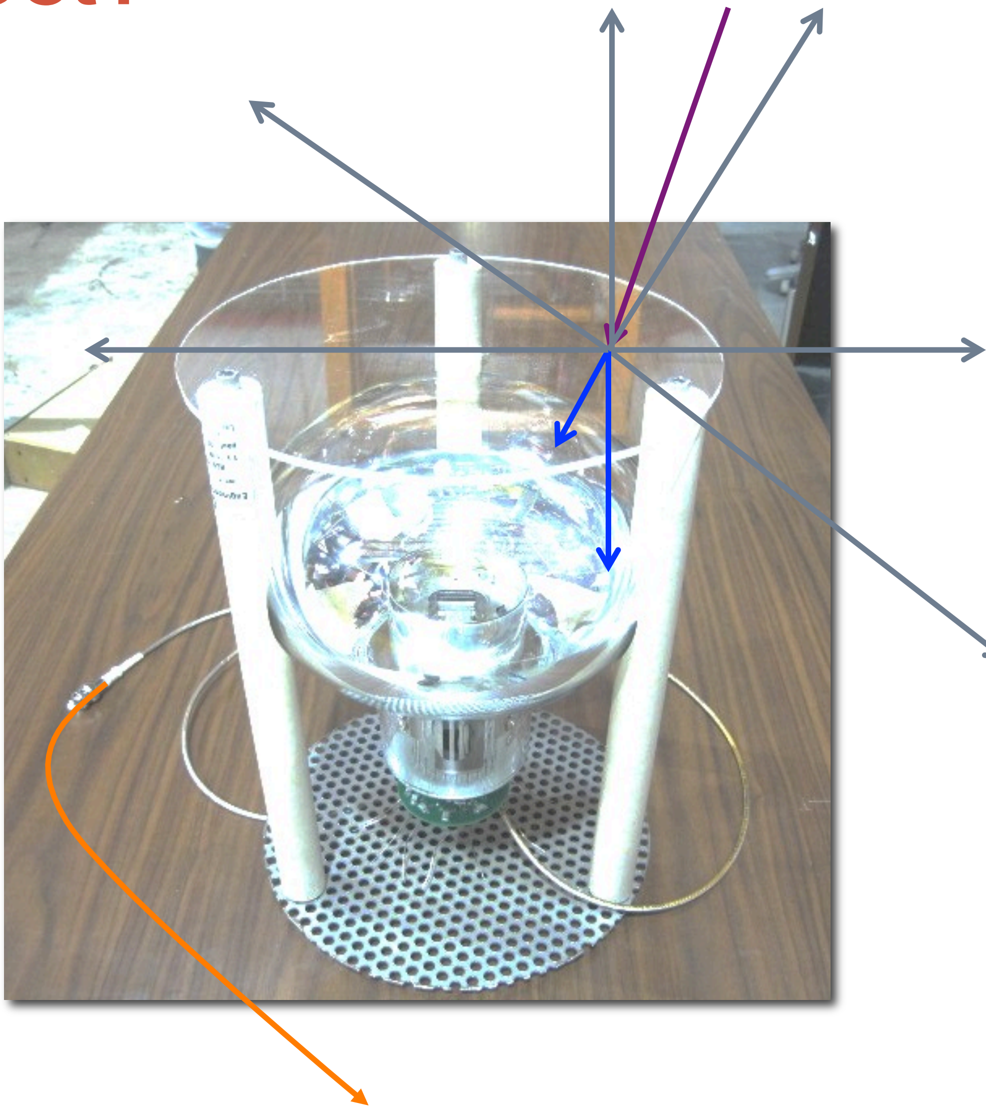


0.3 ± 0.03

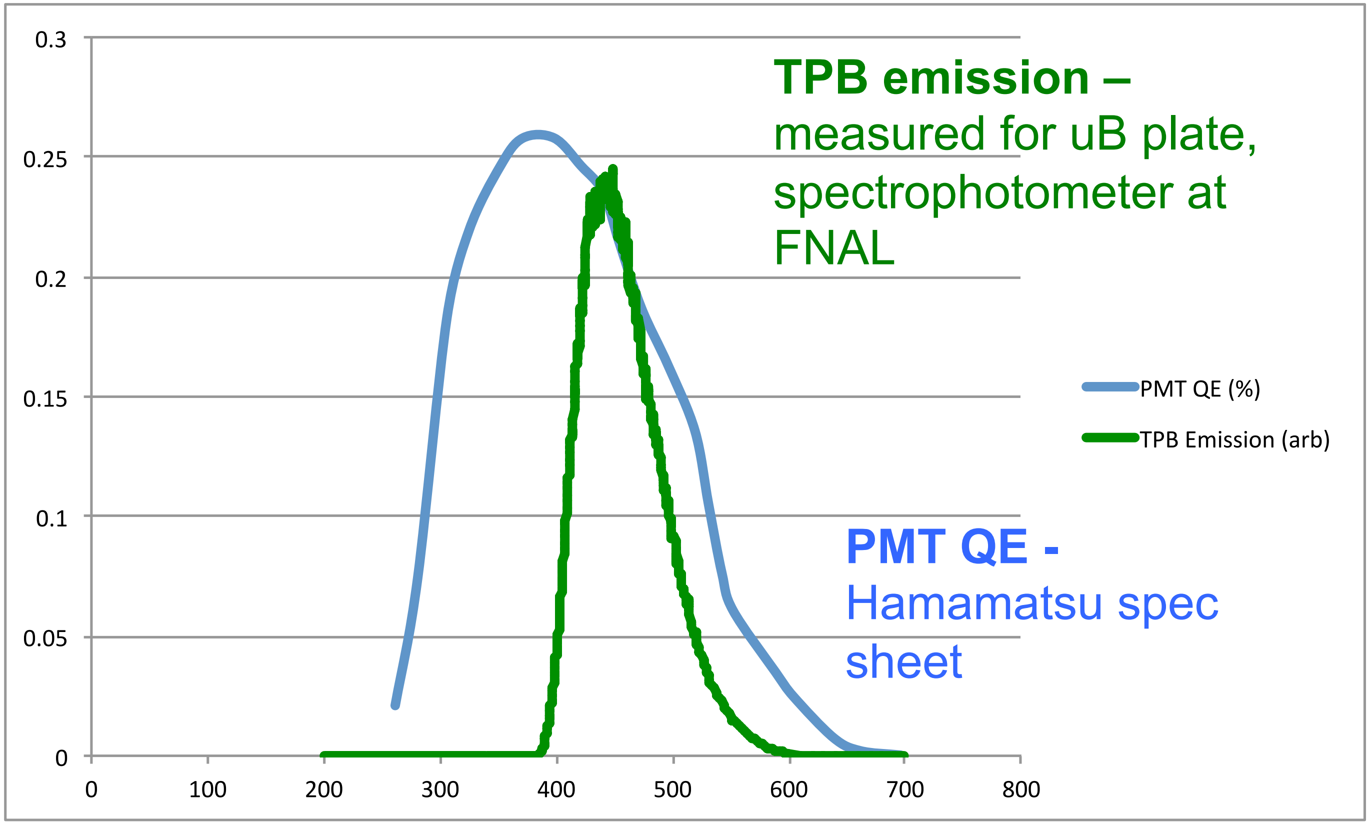
PMT angular + geometrical acceptance

What Do We Expect?

- A photon arrives at the TPB plate
- It may be shifted to a visible photon by TPB coating.
- Only some of the emitted rays get to the PMT
- Of these, only some generate photoelectrons



- MiniBooNE polynomial is normalized to 1 at normal incidence.
- This is the Hamamatsu quoted PMT quantum efficiency.
- QE can be found on spec sheet, wavelength dependent



0.199 ± 0.002
PMT angular + geometrical acceptance

Predicted GQE

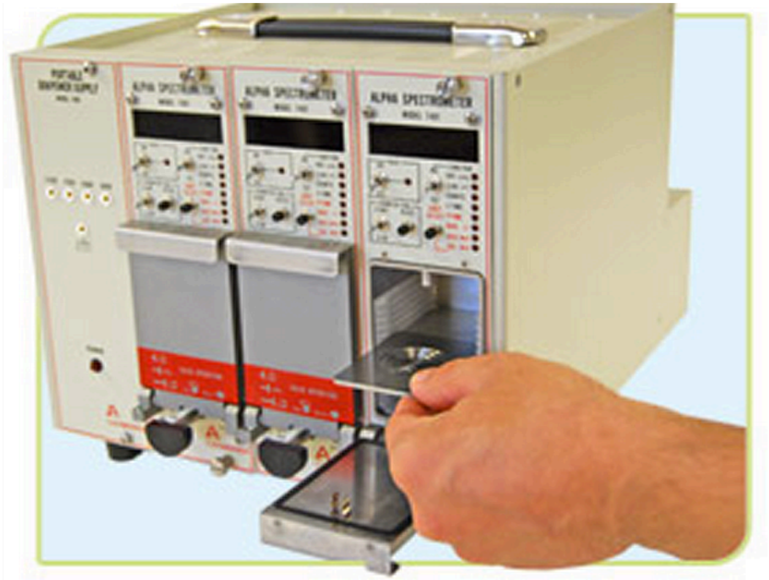
	Our Estimate	*Uncertainty*	*Source*	*Note on Uncertainty*
Absolute WLS efficiency of evaporative plates	1.18	0.1	Gehman et al, arXiv:1104.3259	Error bar from paper
Performance of MicroBooNE plates relative to evaporative plates	0.64	0.11	Our vacuum spec measurements	Error bar from observed fluctuations
Forward vs backward emission	0.5	0	Fixed at 50%	No uncertainty
Photomultiplier tube quantum efficiency	0.199	0.002	Averaged Hamamatsu QE over TPB emission spectrum	Plot digitization error (no error bar given)
Acceptance of light from plate	0.3	0.03	Ray tracing MC simulations	Discrepancy between MC outputs
Predicted GQE:	***2.25%***	**0.49%**		

Contents

- 1. Prediction of expected GQE
- **2. Expected Light Yield in Bo**
- 3. Extraction of GQE from Bo Data
- 4. Implications for MicroBooNE

Polonium Disc Source Energy

- Polonium 210 is a pure alpha emitter which produces alphas of 5.3MeV.
- United Nuclear disk sources are produced with a thin plastic coating over chemically plated polonium onto metalDoes this plastic absorb any of the alpha energy?
- Disk source emission spectrum was checked using alpha spectrometer at MIT.



Feb 2013 source: 5313 keV

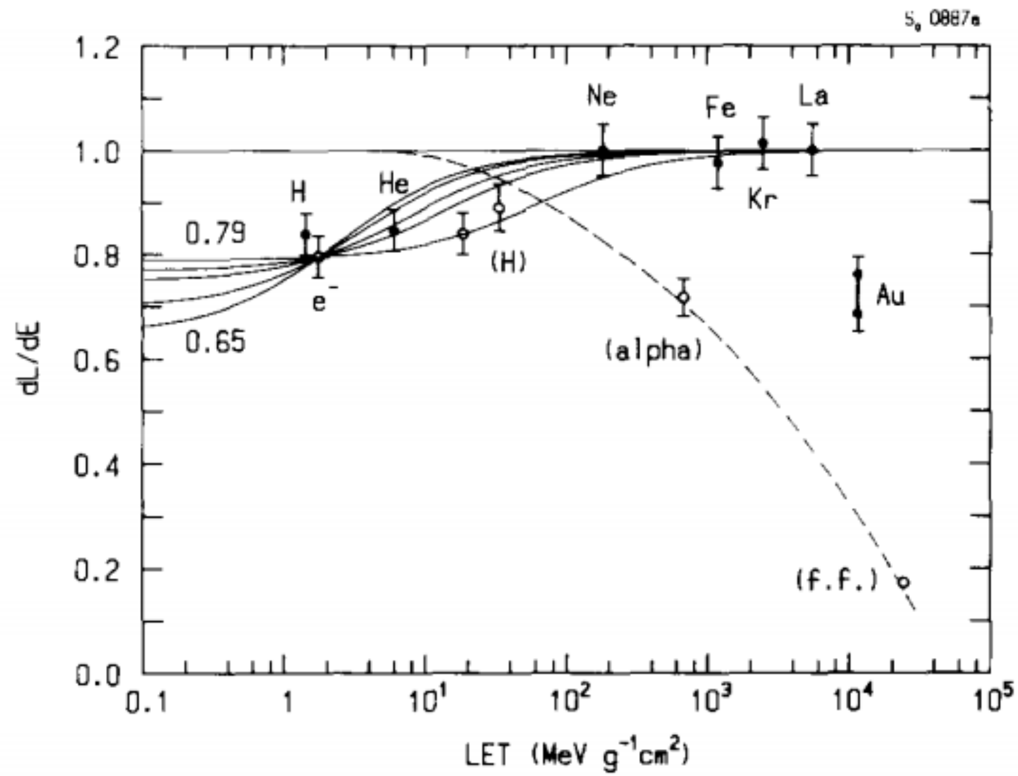
Jan 2013 source: 5309 keV

Feb 2012 source: 5309 keV

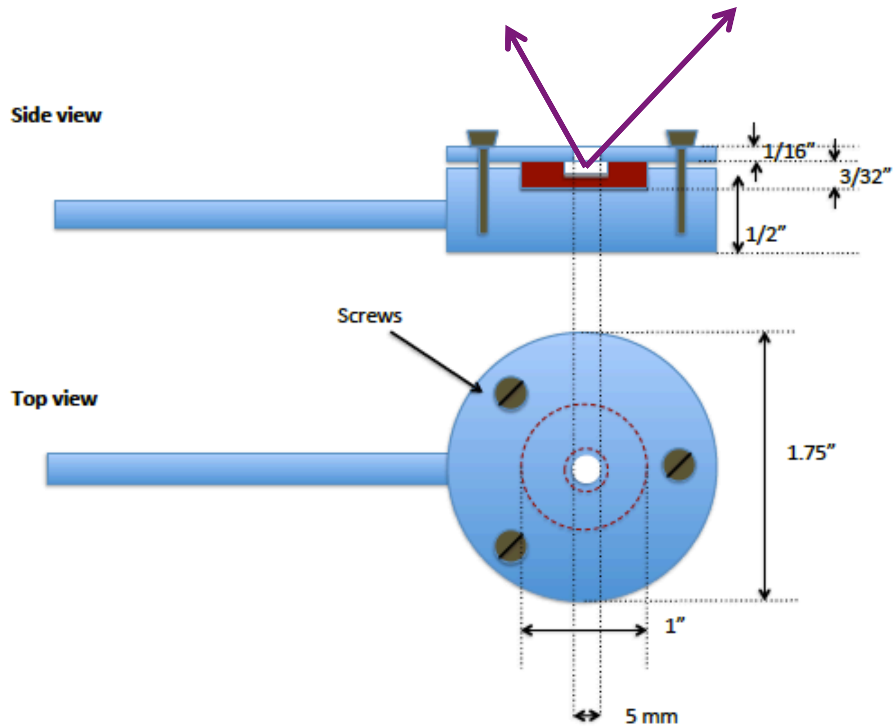
Ignarra + Toups (MIT)

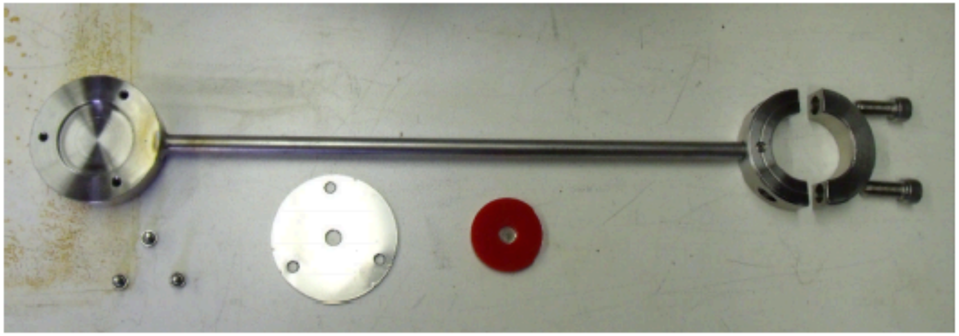
Scintillation Yield Per Alpha

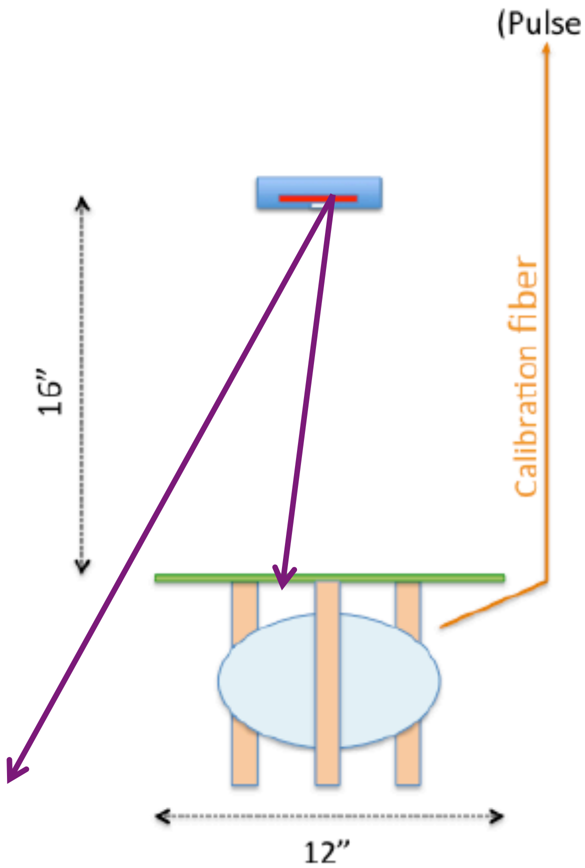
- Ideal scintillation yield with no E field is
  51,000 γ / MeV
- Alpha is nonrelativistic and highly ionizing – quenched by
  Q = 0.71
- We only collect light in first 50ns. This is 99.99% prompt light and 3% late light. Therefore
  f_fast = 0.565



Expected Light Yield at Plate

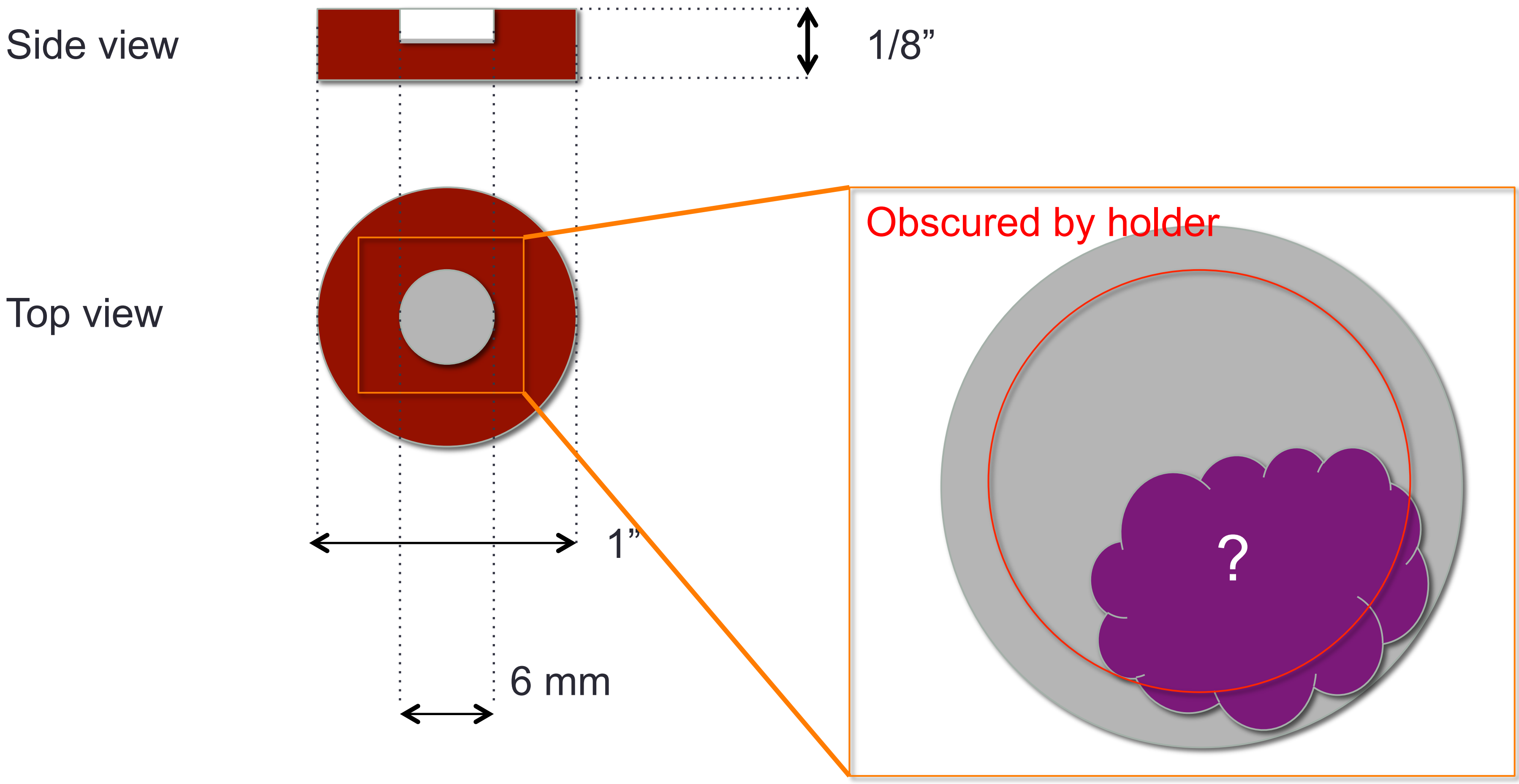






More ray tracing, should be straightforward enough…

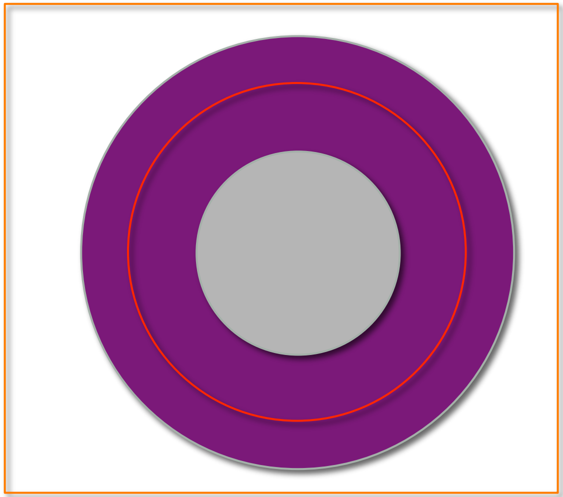
- Nope



Try a few options;

System has cylindrical symmetry, so distribution in phi does not matter.

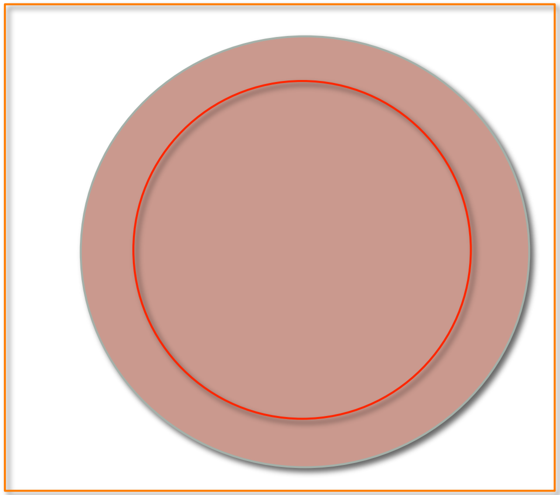
More Obscured



0 < r < 1.5mm : Empty
1.5 < r < 3mm : Uniform source

¾ of plate area covered

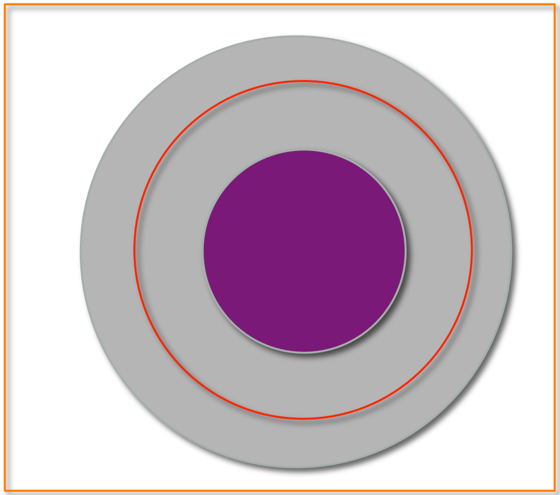
Baseline



0 < r < 3mm : Uniform Source

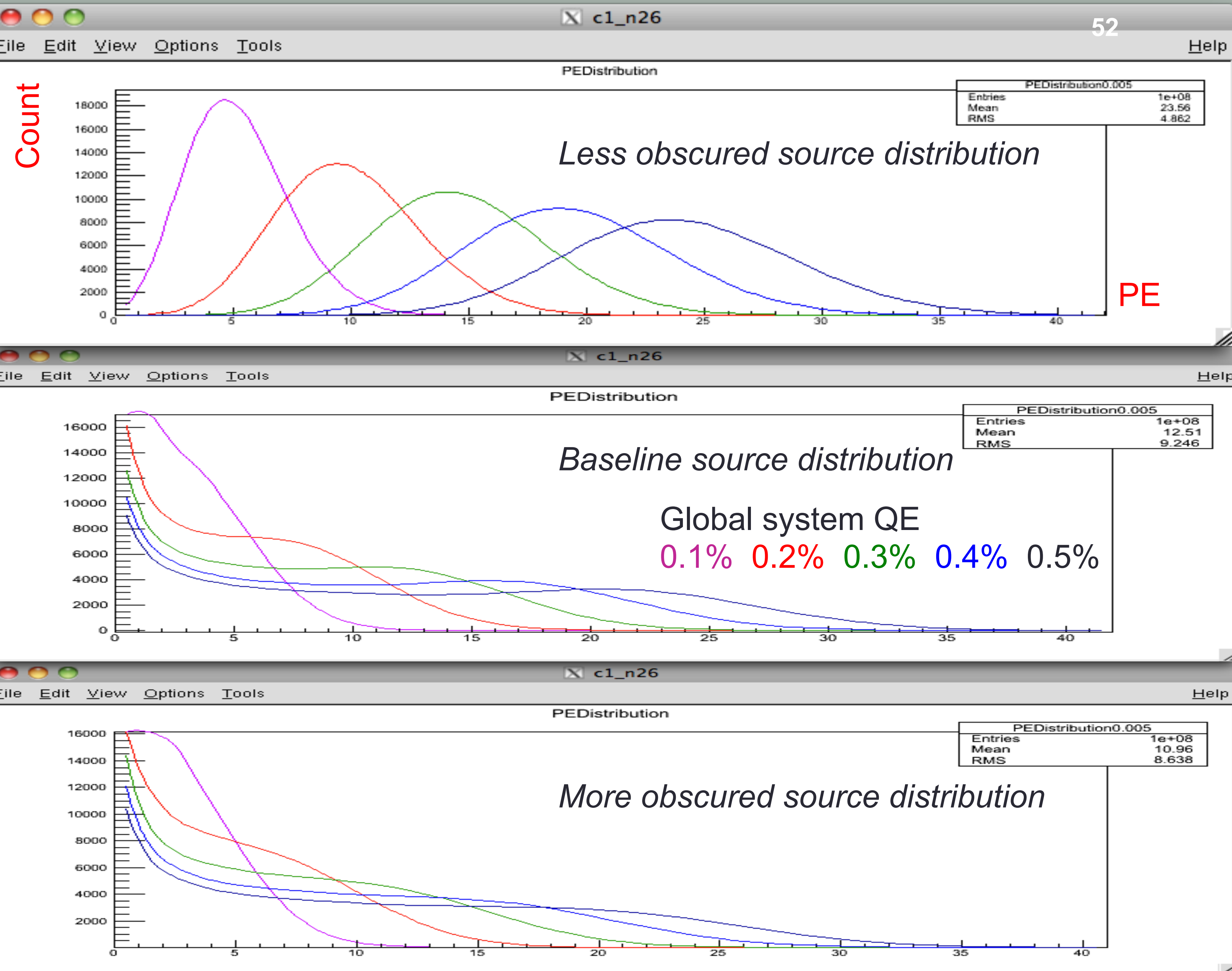
Full plate area covered

Less Obscured



0 < r < 1.5mm : Uniform source
1.5 < r < 3mm : Empty

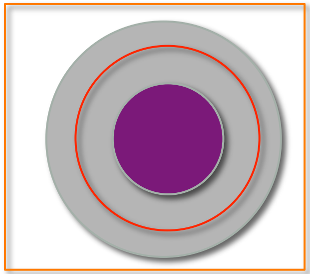
¼ of plate area covered

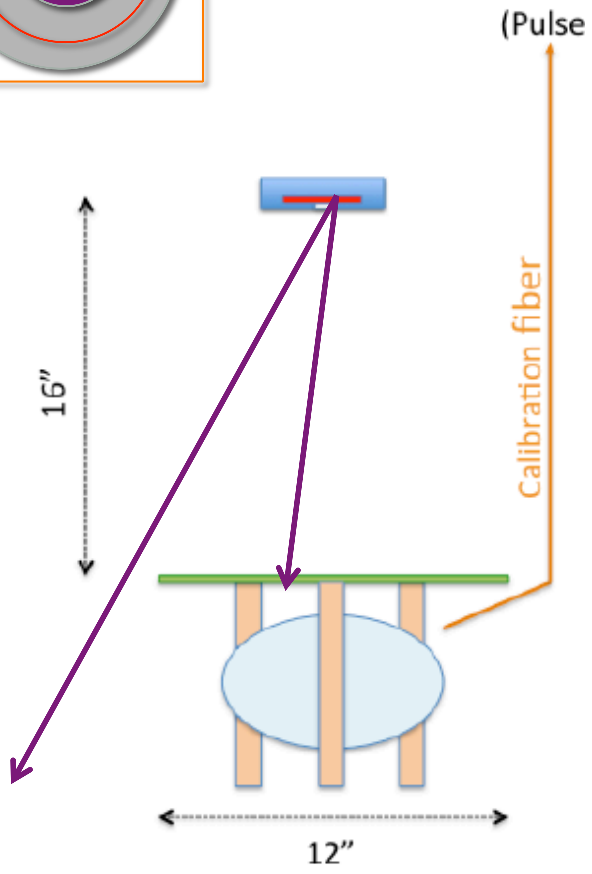


c1_n26
File Edit View Options Tools Help
PEDistribution
PEDistribution0.005
Entries 1e+08
Mean 23.56
RMS 4.862
Count
Less obscured source distribution
PE
c1_n26
File Edit View Options Tools Help
PEDistribution
PEDistribution0.005
Entries 1e+08
Mean 12.51
RMS 9.246
Baseline source distribution
Global system QE
0.1% 0.2% 0.3% 0.4% 0.5%
c1_n26
File Edit View Options Tools Help
PEDistribution
PEDistribution0.005
Entries 1e+08
Mean 10.96
RMS 8.638
More obscured source distribution

Do we need to marginalize over this?

- Thankfully, in this case we are lucky.
- You will see later that we find a very poisson-shaped distribution, suggesting source is mostly deposited in un-obscured region
- This makes extraction of mean number of PE insensitive to the precise deposition shape
- We can safely assume the “less obscured configuration” and perform the “simple” raytracing only





3.75 ± 0.1 %
Solid angle acceptance from source to plate

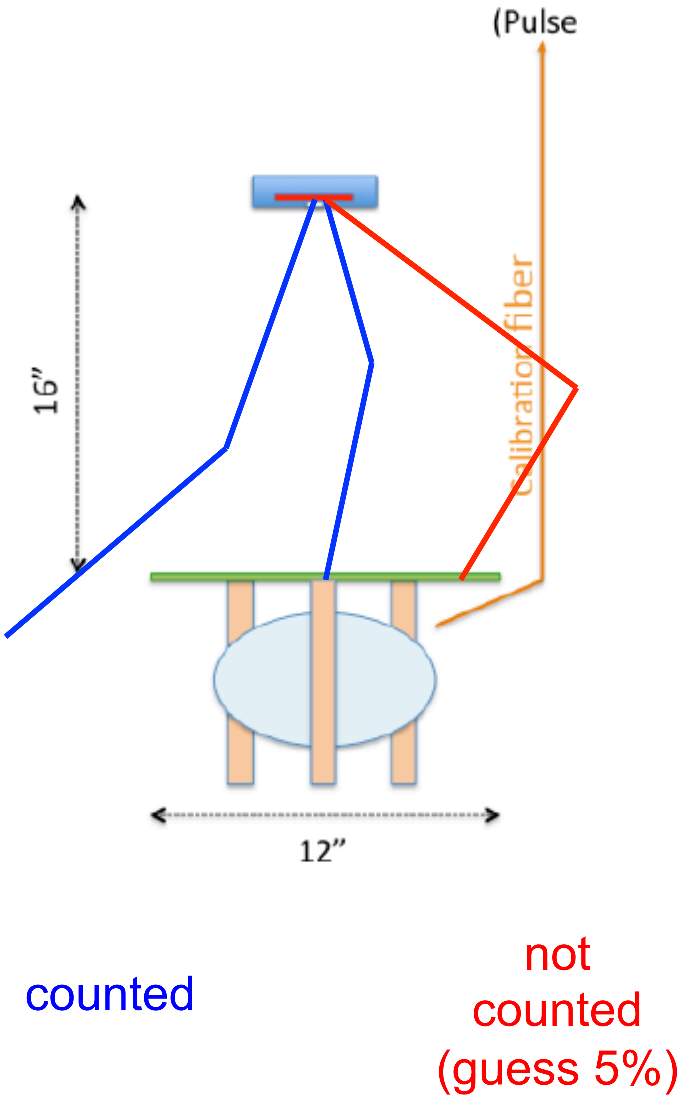
Propagation Effects – Rayleigh Scatters

- Rayleigh scattering has an effective length of 90cm.
- Our source-plate distance is ~40cm
- We analytically calculate the fraction of rays expected to scatter off course in this length to be 36.4%.
- Of these, ~6.1% still reach the plate.
- Our first order guess is therefore

  f_rayleigh = 0.703

- We add a further 5% to this to account for "helpful scatters" back into the volume, and give big systematics so

  f_rayleigh = 0.75 ± 0.05



Propagation Effects – Impurity Absorption

- No theoretically known absorption mechanism at 128nm in pure argon
- But ~ppm impurities can lead to finite absorption lengths.
- For this test we monitored O2, N2 and H20 at <10ppb precision

Impurity	Monitor	Level
N_2 *	LDetek LD8000	$20 \pm 10ppb$
O_2	Servomex DF-310E	$39 \pm 2ppb$
H_2O *	TigerOptics Halo+	$< 70ppb$

* = First installation and test of actual MicroBooNE cryo analytics!

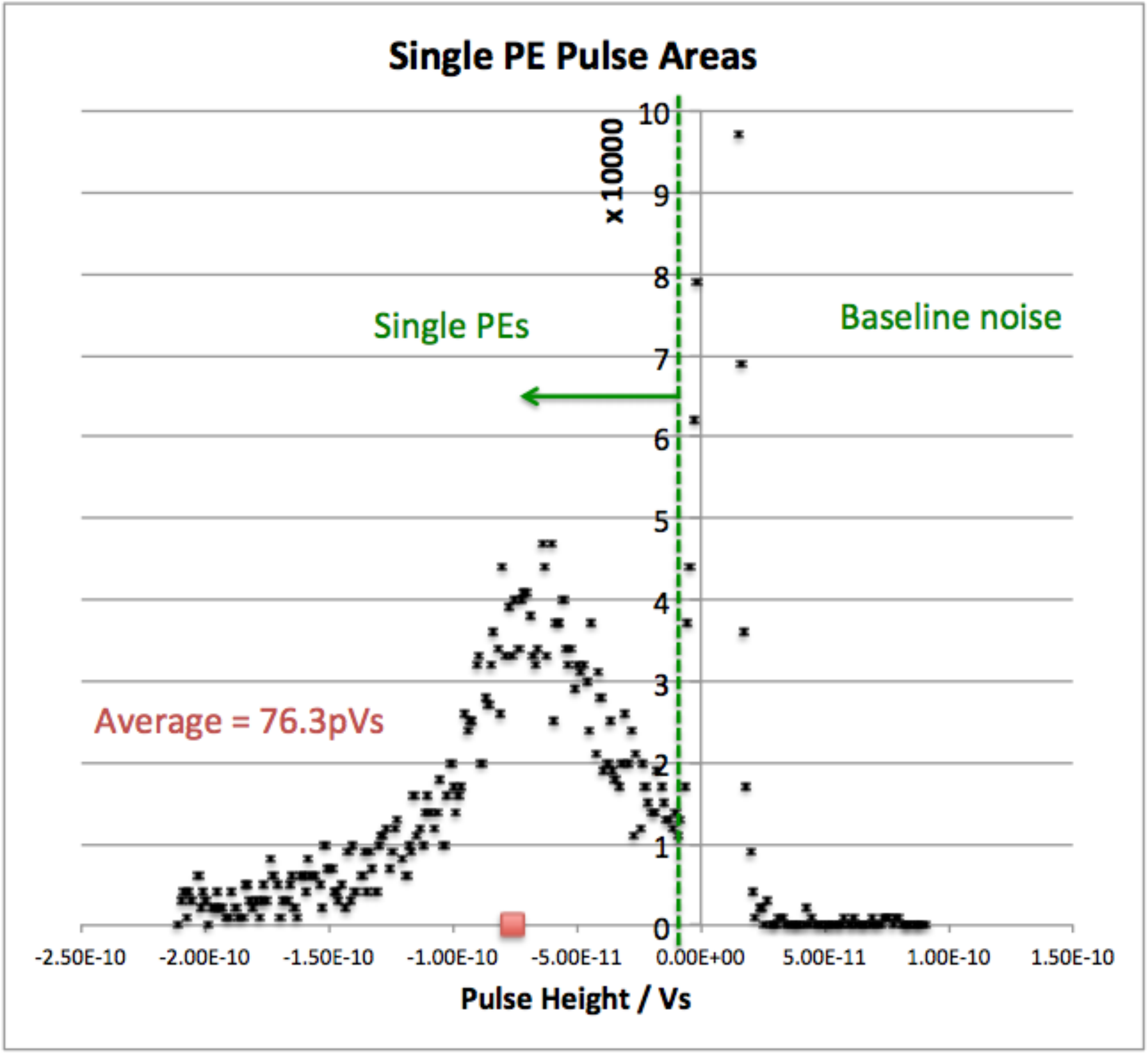
Light yield prediction for Bo

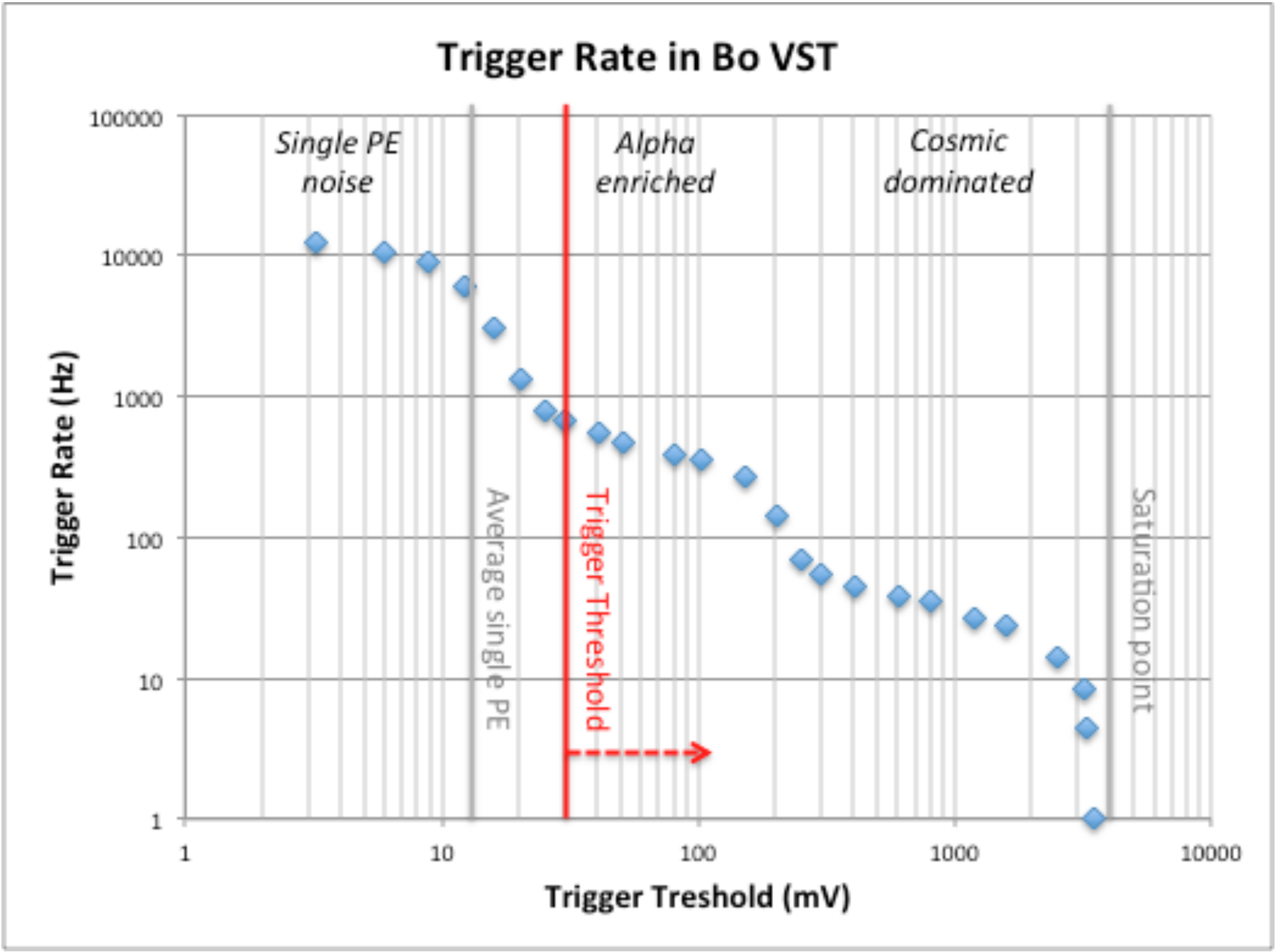
	Value	Uncertainty	*Source*	Uncertainty Comment
210Po Alpha Energy (MeV)	5.3	0.1	From MIT range straggling studies	
Ideal Scint Yield (photons / MeV)	51000	1000	Doke et al, NIM A Volume 269, Issue 1, 291–296	Spread of values given in paper
dEdx Quenching for alpha	0.71	0.04	Doke et al, NIM A Volume 269, Issue 1, 291–296	Error bar from yield vs LET plot
Prompt light for alpha	0.565	0.005	ICARUS Light Collection (unpublished)	Number of significant figures given
Fractional Solid Angle	0.0375	0.001	Calculated accounting for well geometry and source distribution	Variation between extreme source deposition distributions
Rayleigh Scattering losses	0.75	0.05	Calculated 0.71 in worse case, and assume some "helpful scattering"	71% is worst case, add on 5% for helpful scatters
Average γ / α	*3050*	292		

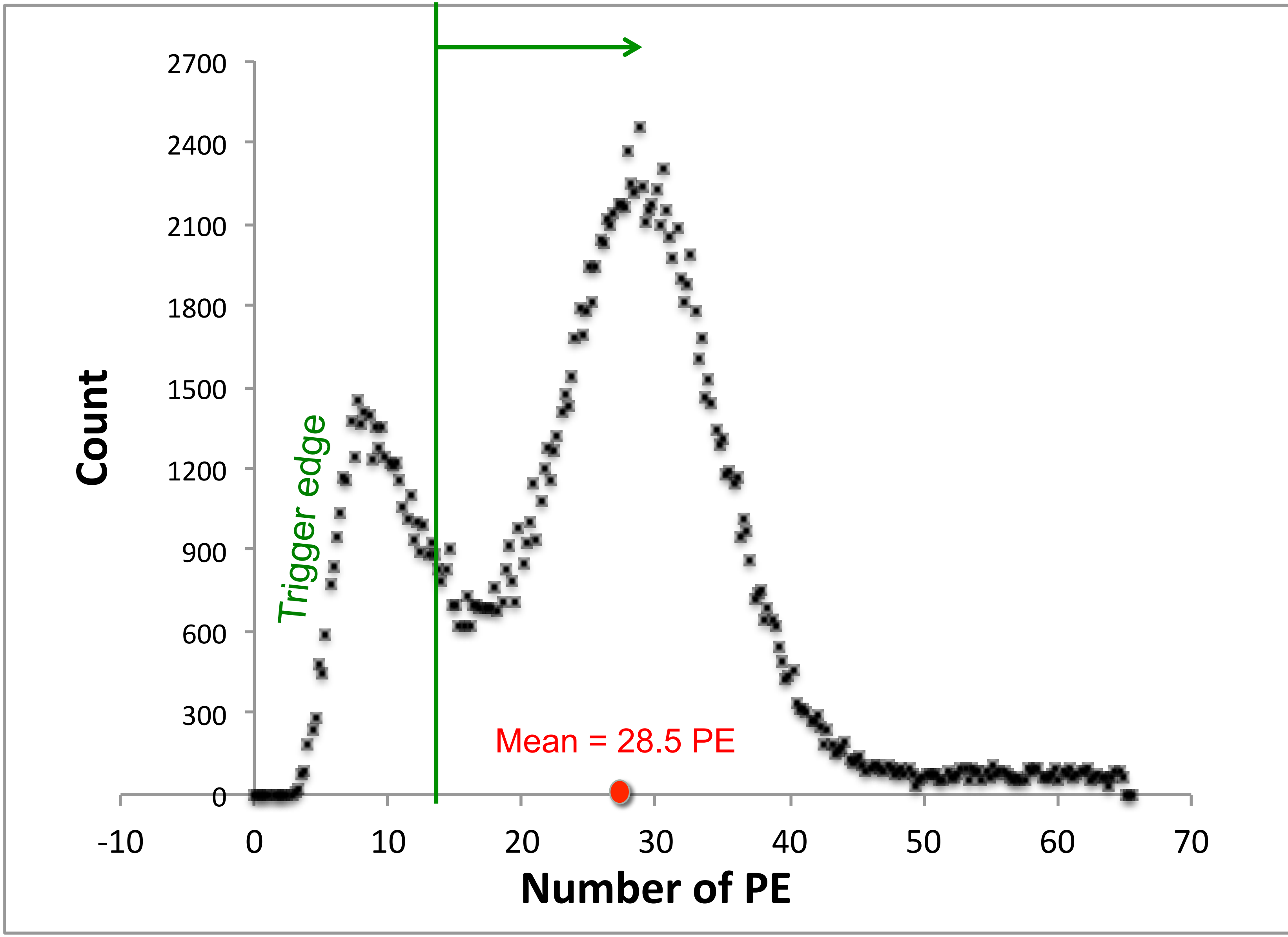
Contents

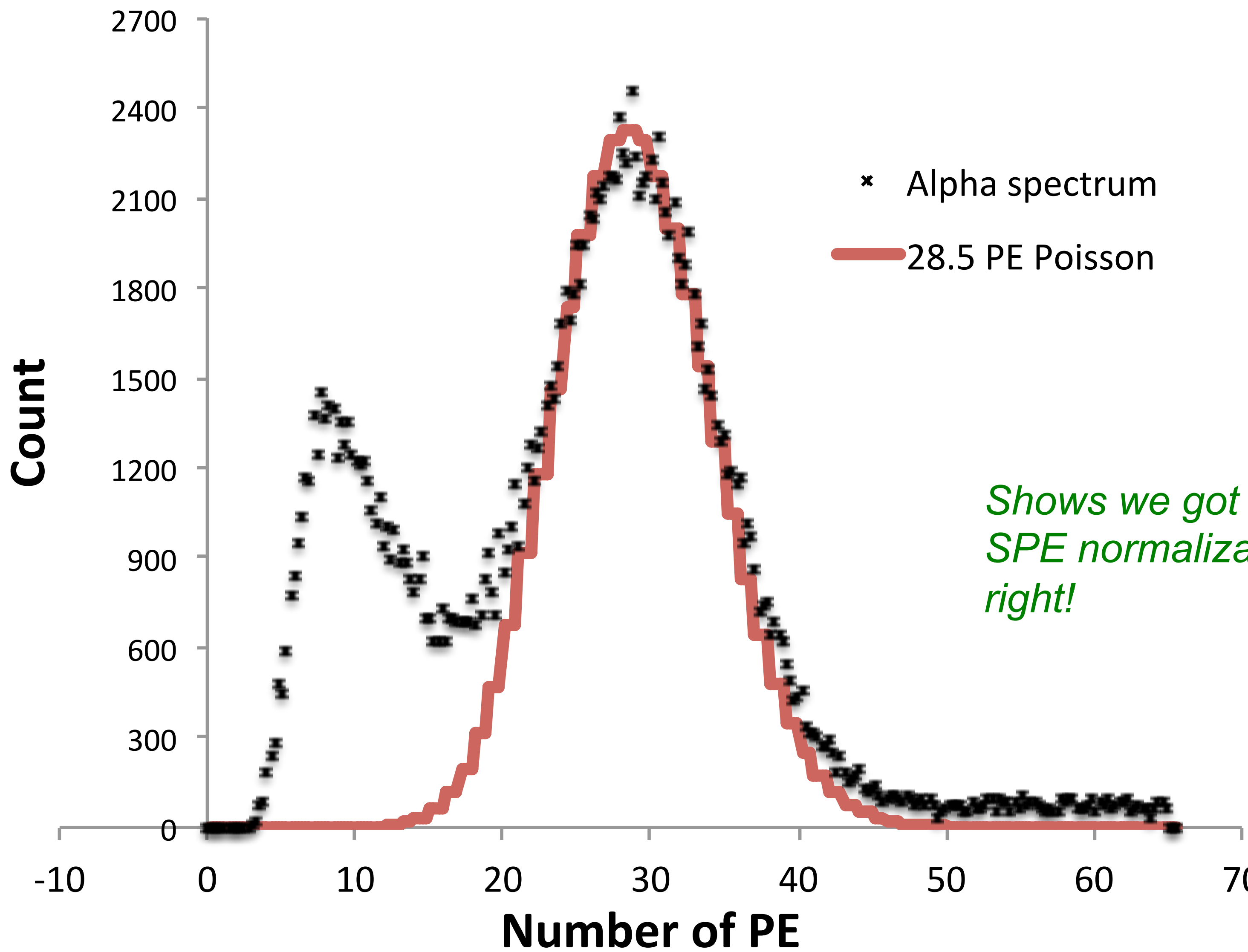
How to Extract GQE

- Measure single PE pulse area spectrum using low intensity pulsed LED
- Measure distribution of areas in a sample of PMT pulses from alpha scintillation light
- Normalize to average single PE area and read off mean # of PE.
- Divide by light prediction to find GQE


Single PE Pulse Areas
x 10000
10
9
8
7
6
5
4
3
2
1
0
Single PEs
Baseline noise
Average = 76.3pVs
-2.50E-10
-2.00E-10
-1.50E-10
-1.00E-10
-5.00E-11
0.00E+00
5.00E-11
1.00E-10
1.50E-10
Pulse Height / Vs


Trigger Rate in Bo VST
Trigger Rate (Hz)
100000
10000
1000
100
10
1
Single PE noise
Alpha enriched
Cosmic dominated
Average single PE
Trigger Threshold
Saturation point
1
10
100
1000
10000
Trigger Treshold (mV)

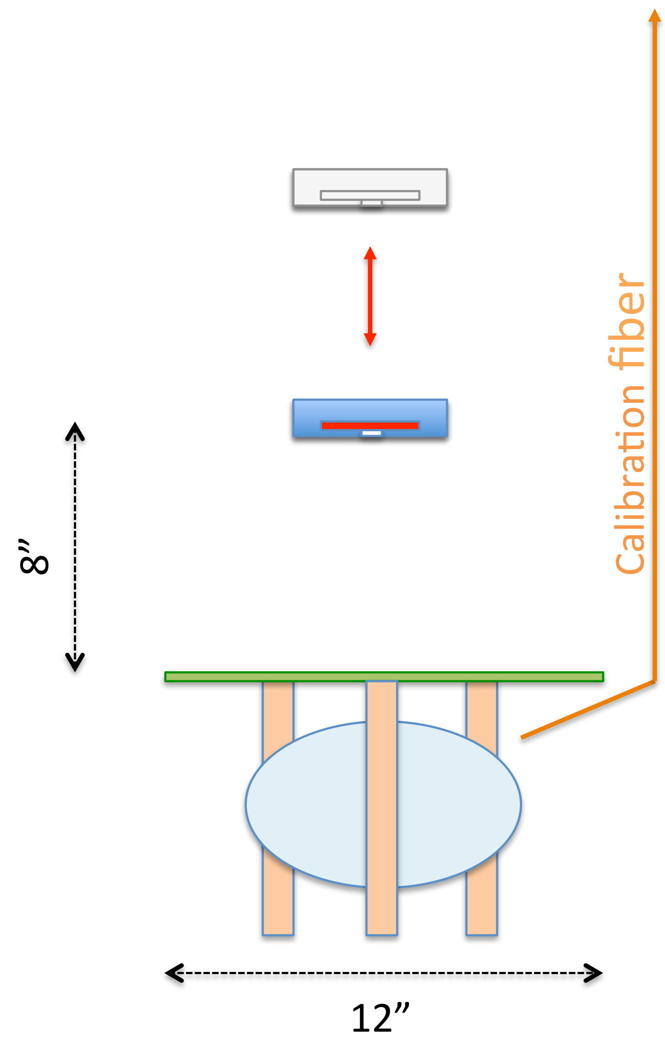

2700
2400
2100
1800
1500
1200
900
600
300
0
Count
Trigger edge
Mean = 28.5 PE
-10
0
10
20
30
40
50
60
70
Number of PE



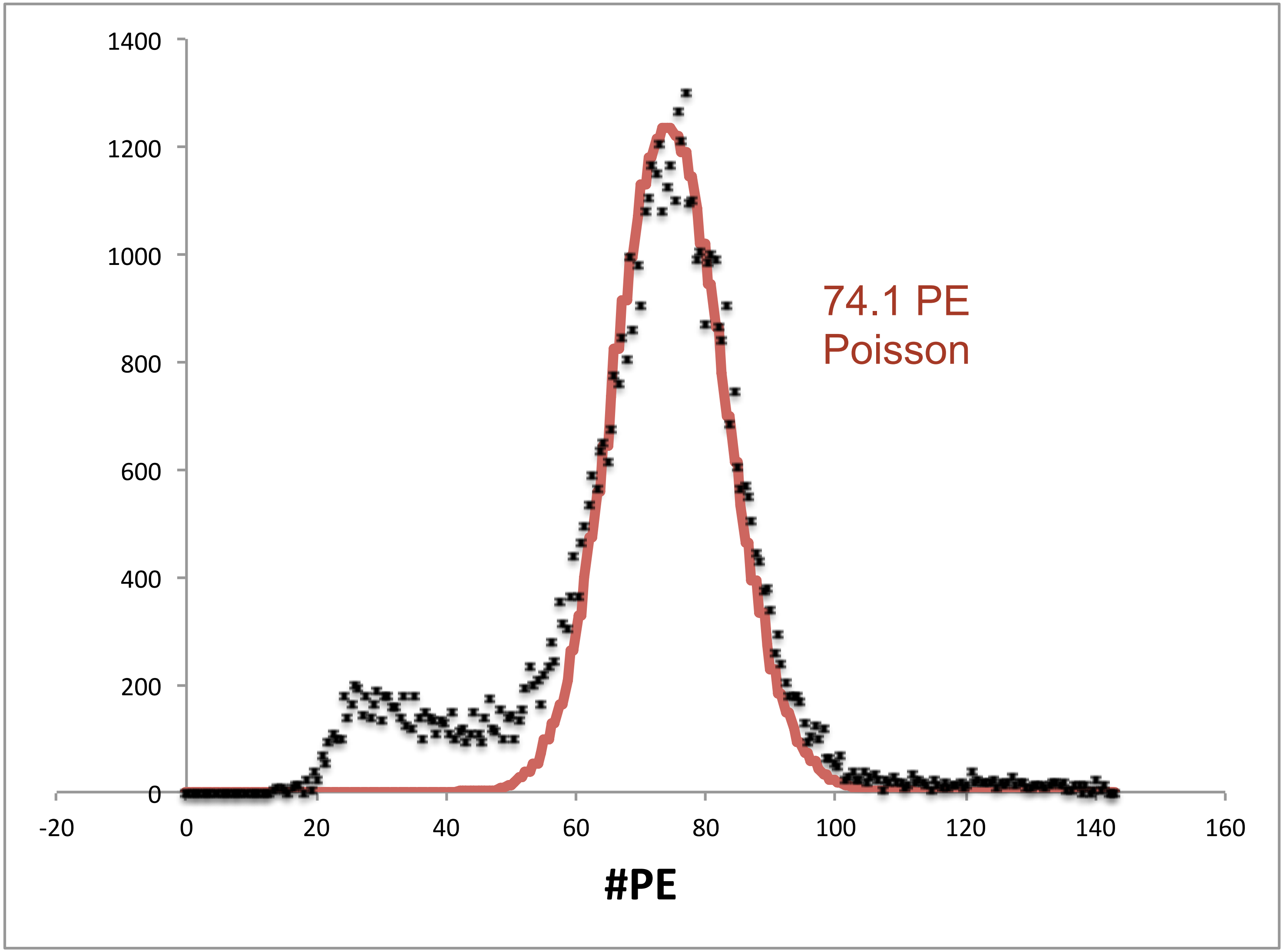
Shows we got the SPE normalization right!

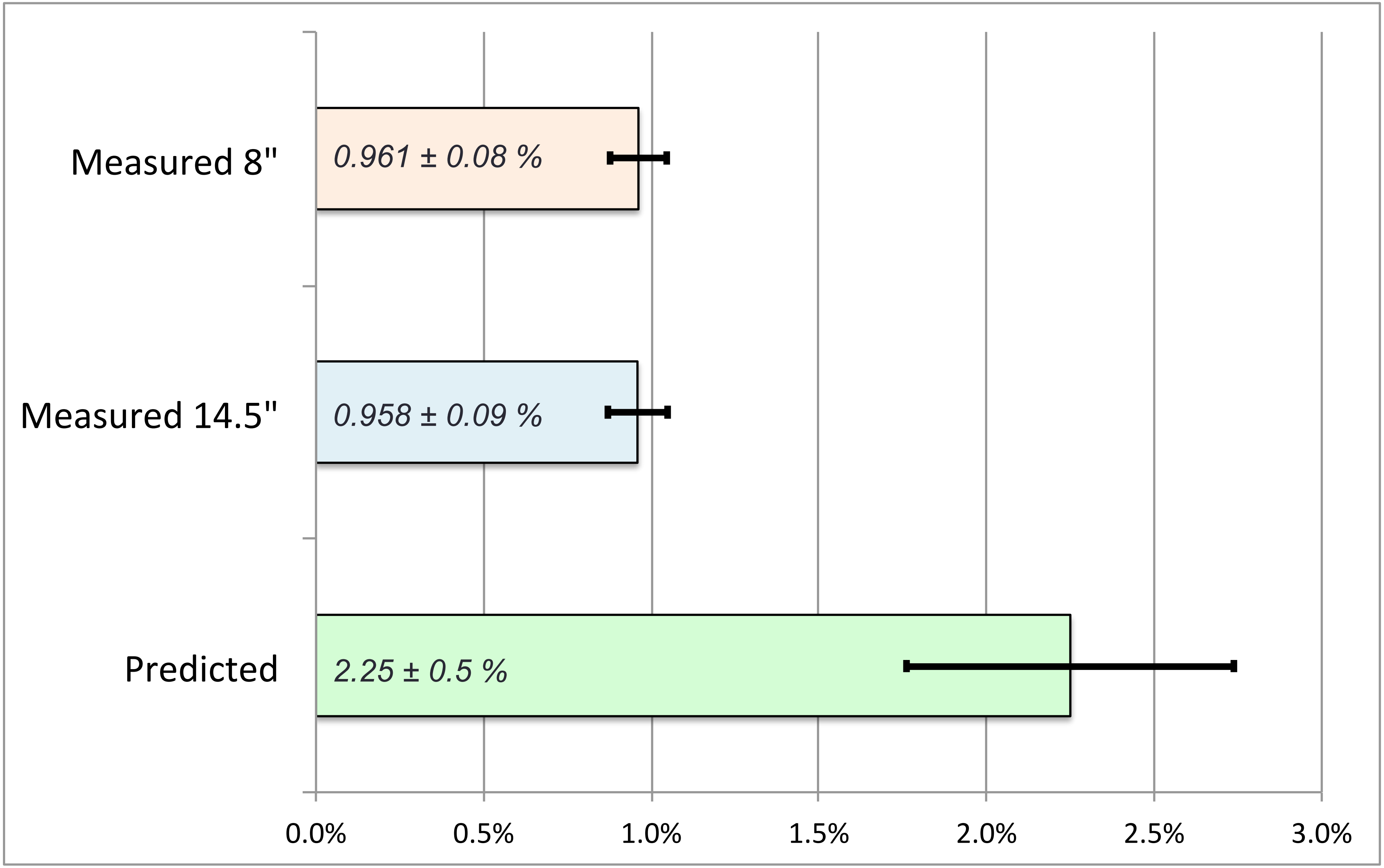
A crosscheck

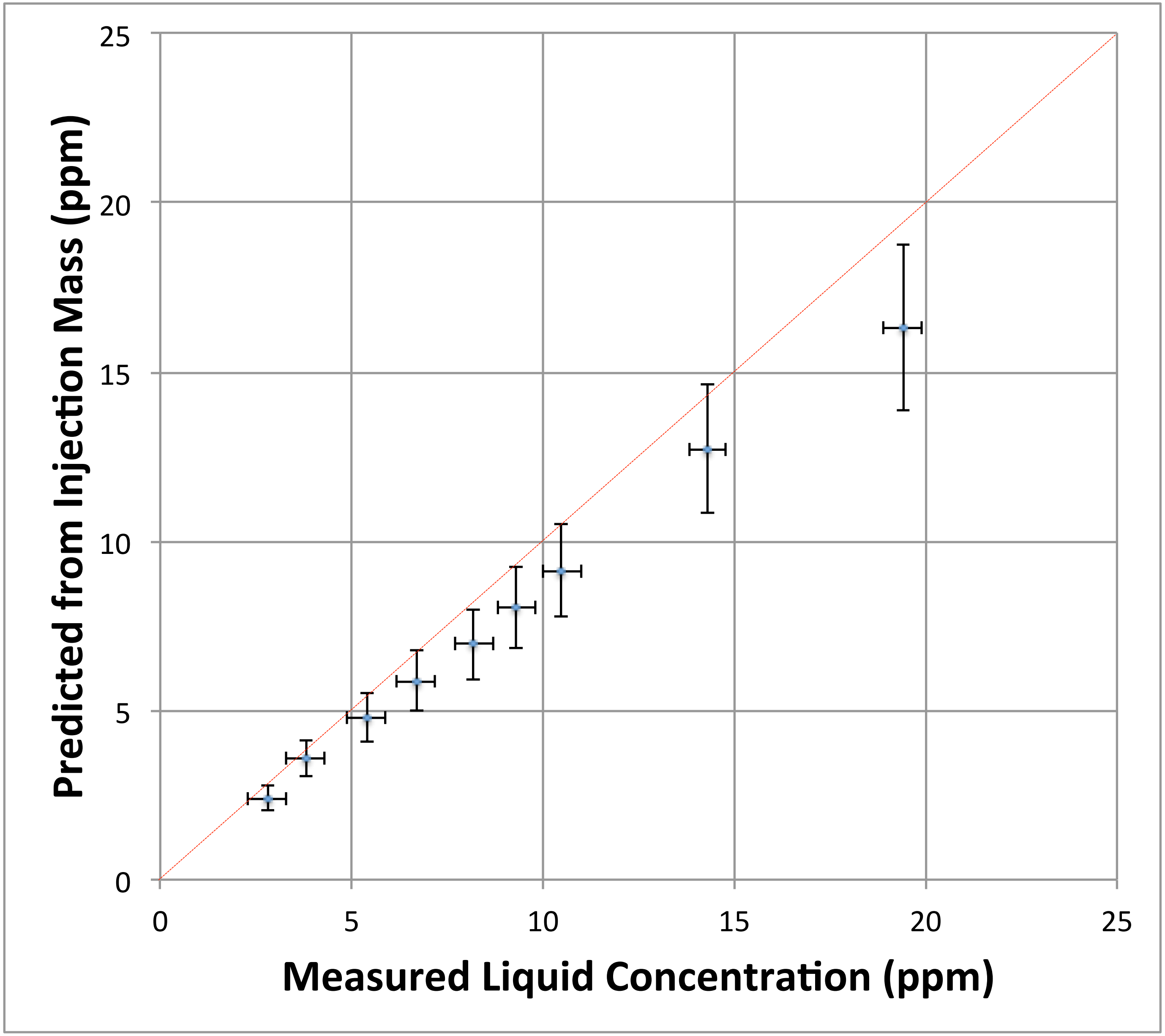
- We repeated all the above analysis with the source moved down to 8” from the plate.
- The following change:
  - Solid angle subtended (we calculate)
  - Rayleigh scattering effect (we calculate)
  - Impurity absorption, if any (we neglect)
  - Non-uniform plate illumination effect (we neglect)



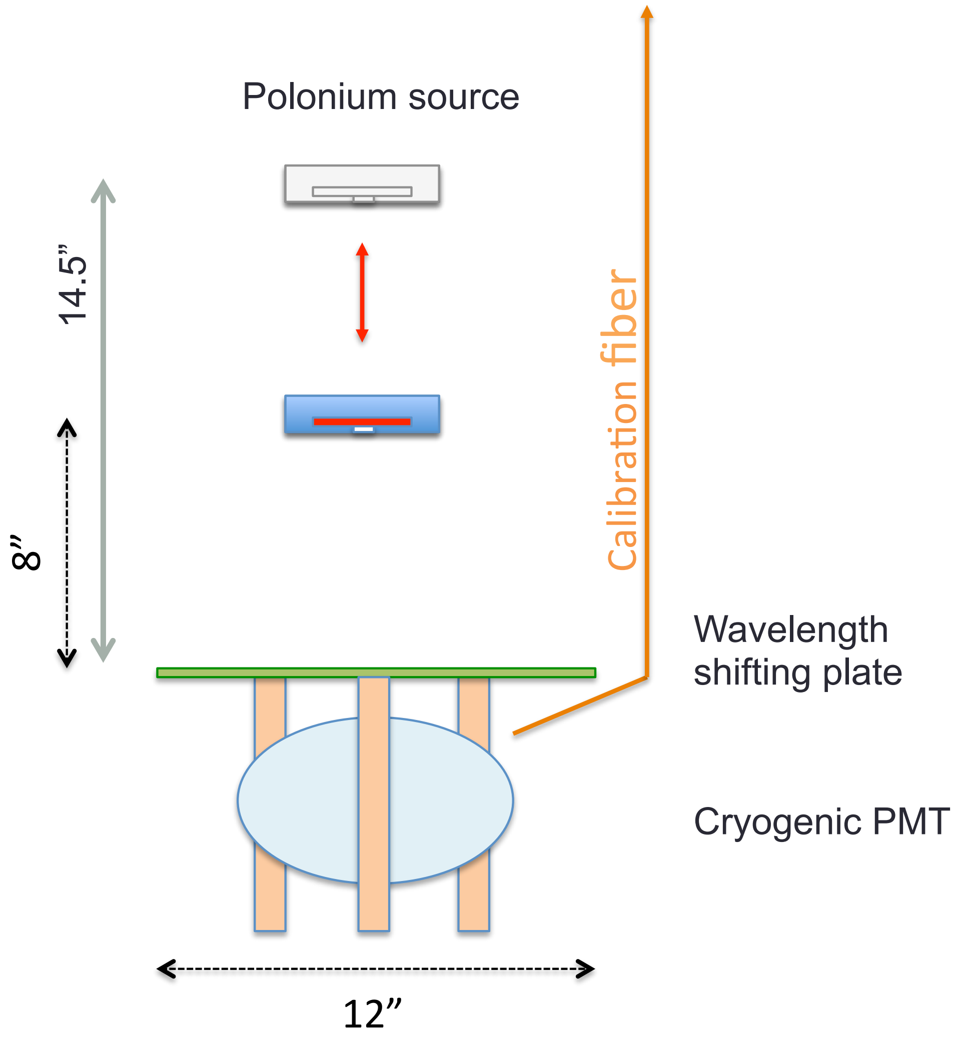
Distribution with 8” Separation



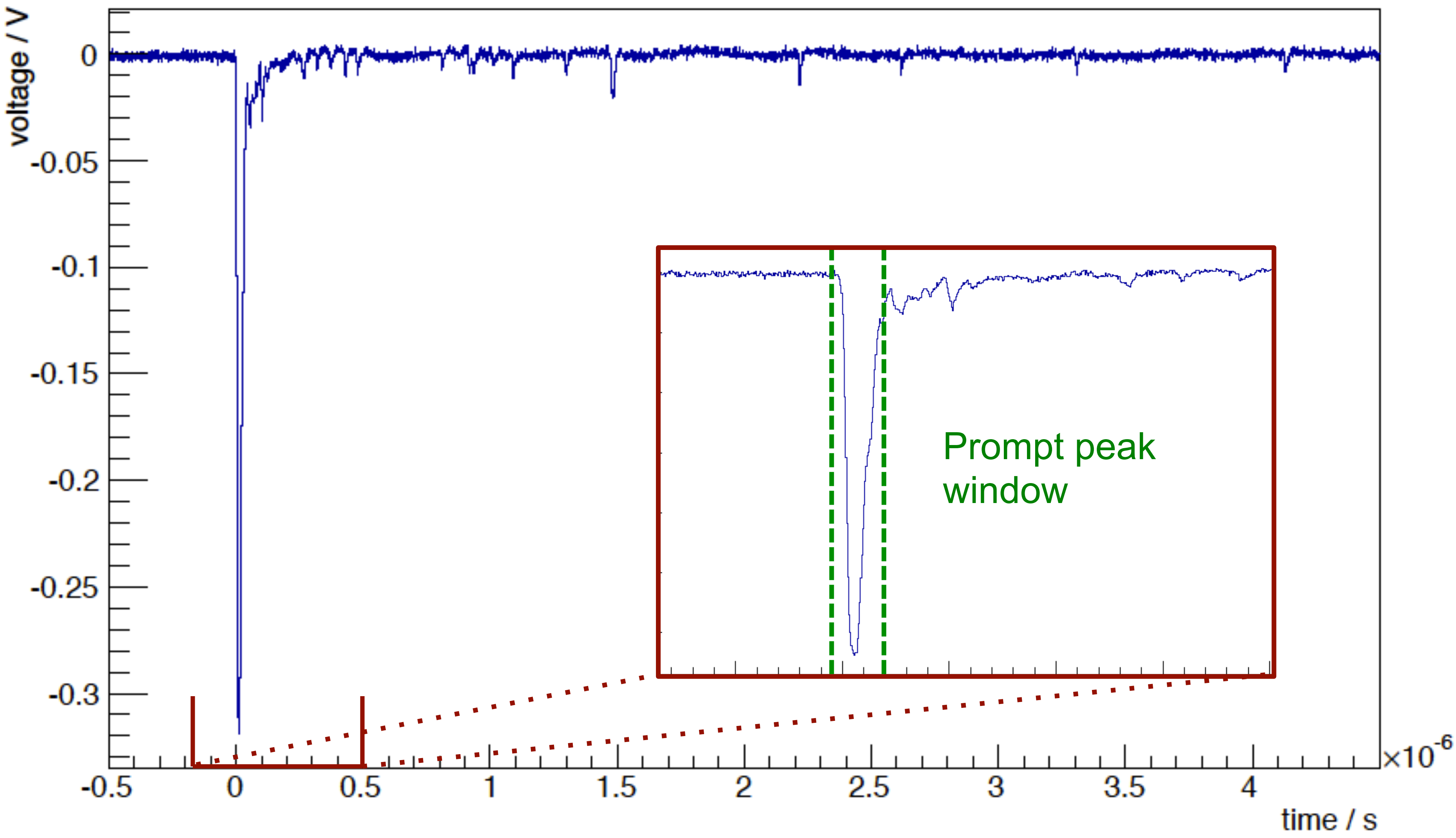

Measured 8"
0.961 ± 0.08 %
Measured 14.5"
0.958 ± 0.09 %
Predicted
2.25 ± 0.5 %
0.0%
0.5%
1.0%
1.5%
2.0%
2.5%
3.0%



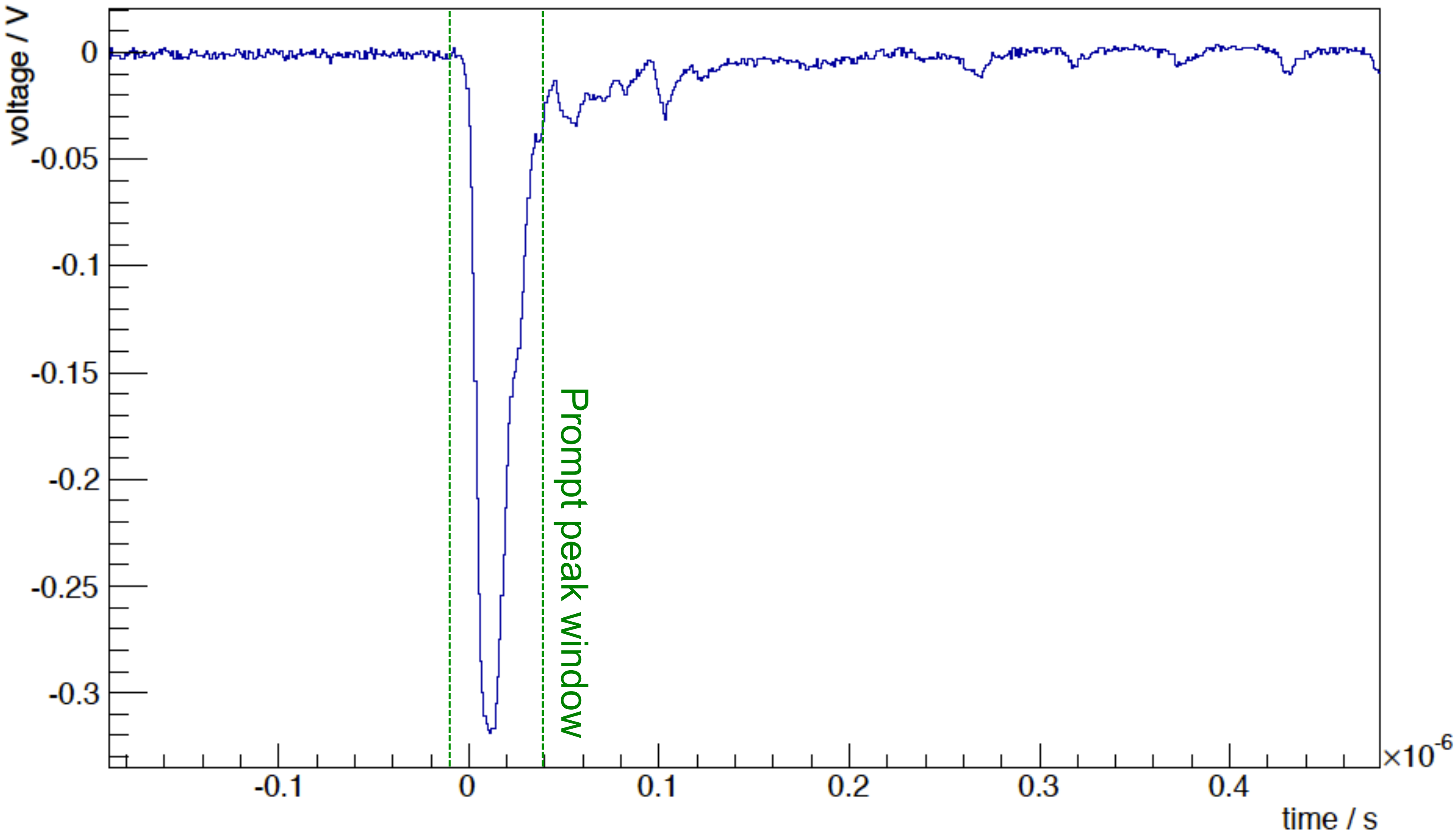
Predicted from Injection Mass (ppm)
Measured Liquid Concentration (ppm)
0
5
10
15
20
25



Polonium source
14.5"
8"
Calibration fiber
Wavelength
shifting plate
Cryogenic PMT
12"



voltage / V
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
$\times 10^{-6}$
time / s
Prompt peak window



voltage / V
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.1
0
0.1
0.2
0.3
0.4
×10^-6
time / s
Prompt peak window