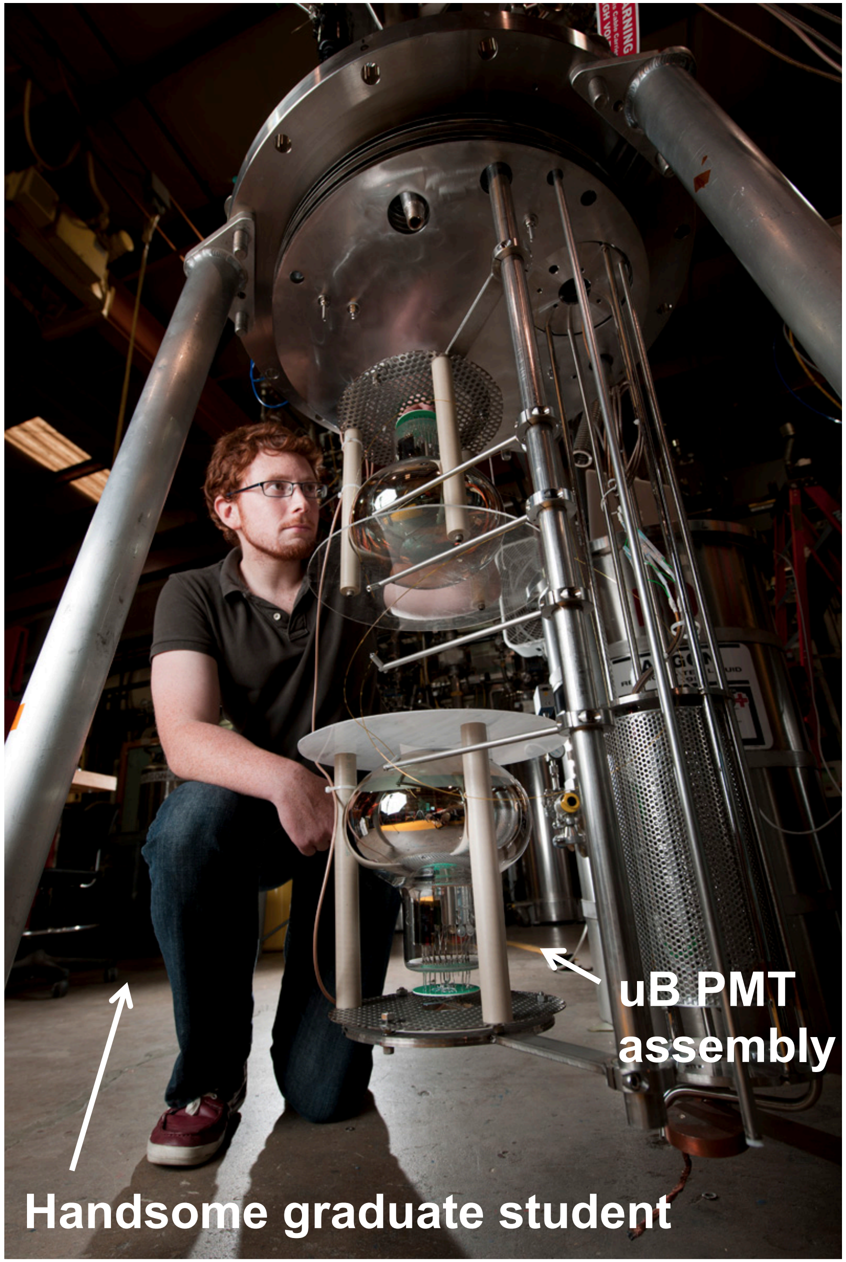
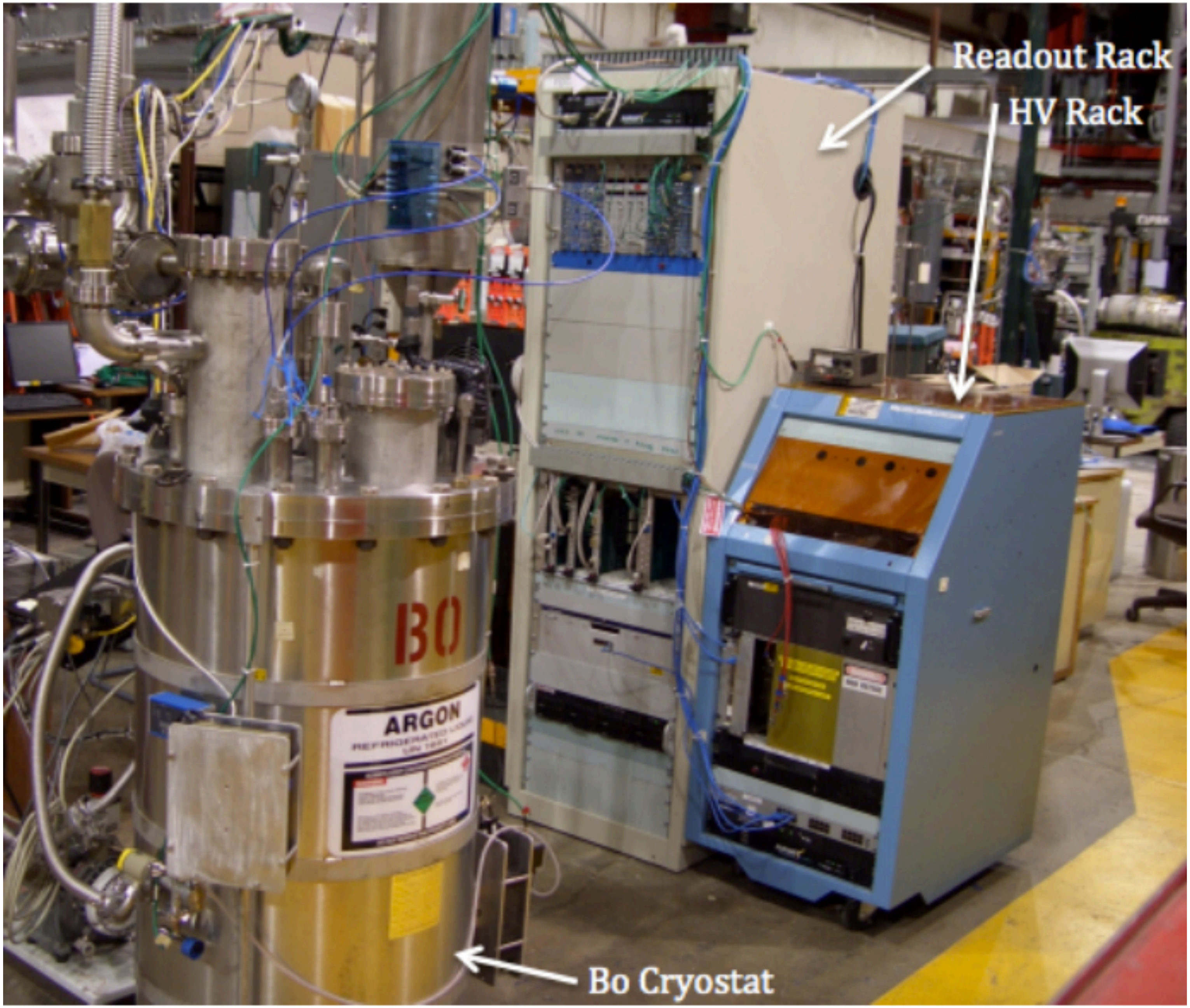
RESULTS FROM THE BO VERTICAL SLICE TEST FOR MICROBOONE

Ben Jones, MIT

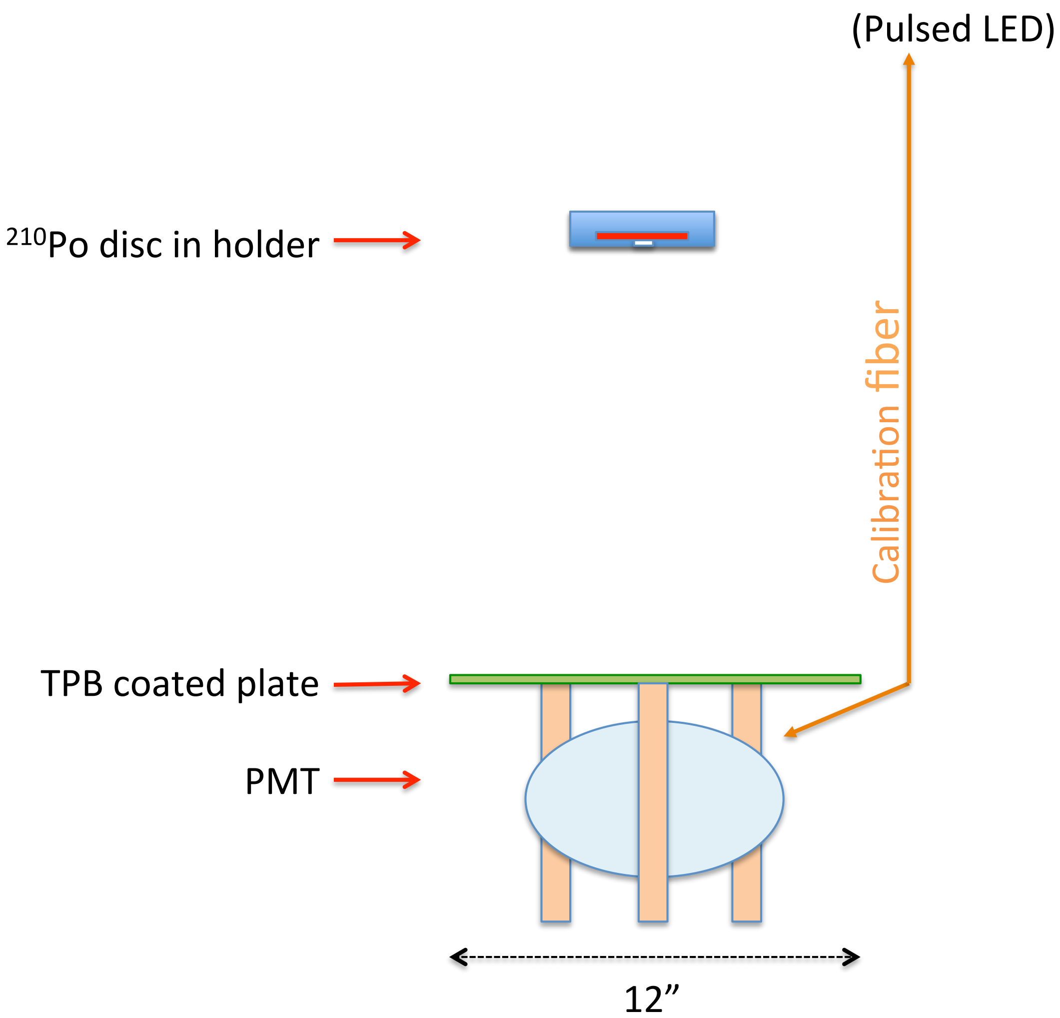
Bo VST Setup

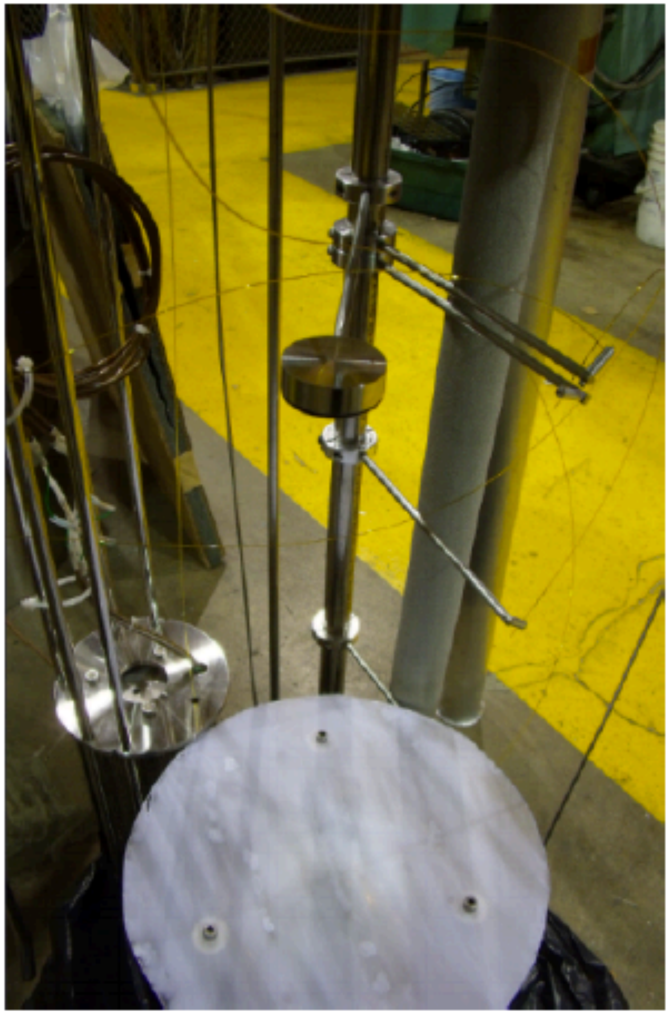
- Bo Vertical Slice Test is a training ground for one slice of the MicroBooNE optical system including:
  - *Cryogenic photomultiplier tubes*
  - *Base electronics*
  - *Wavelength shifting plate*
  - *High voltage system + interlocks*
  - *Cables and splitters*
  - *Readout electronics*
  - *Cryostat feedthrough*
  - *Trace impurity monitors*
  - *Etc…*




Readout Rack
HV Rack
Bo Cryostat
ARGON

Experimental Configuration for This Study





Assembly Characterizations for MicroBooNE

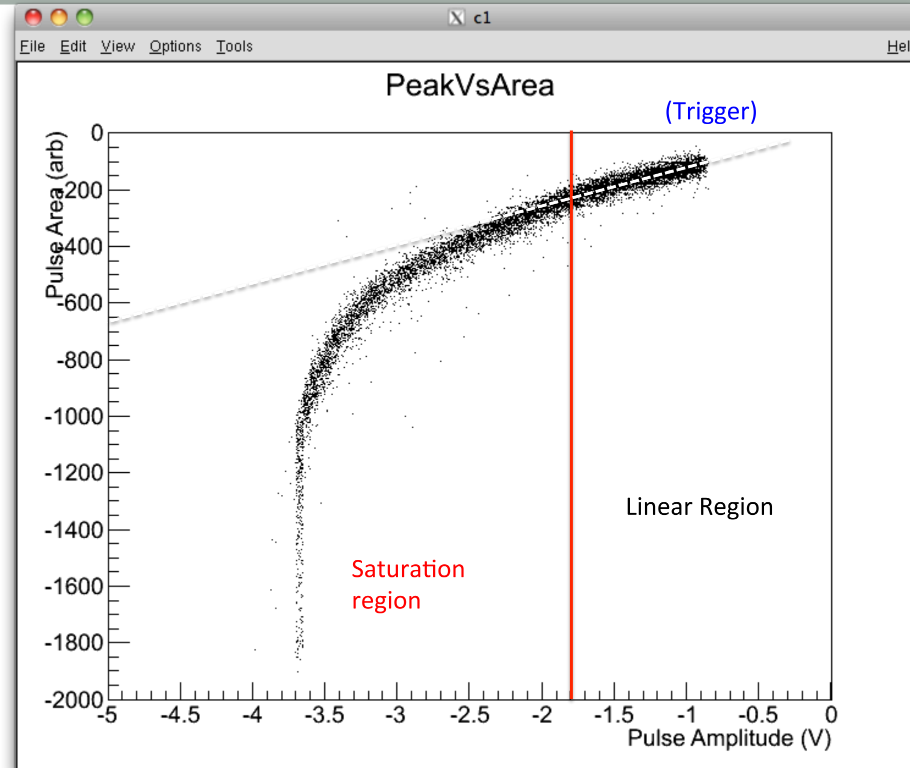
Vital inputs to uB detector simulation:

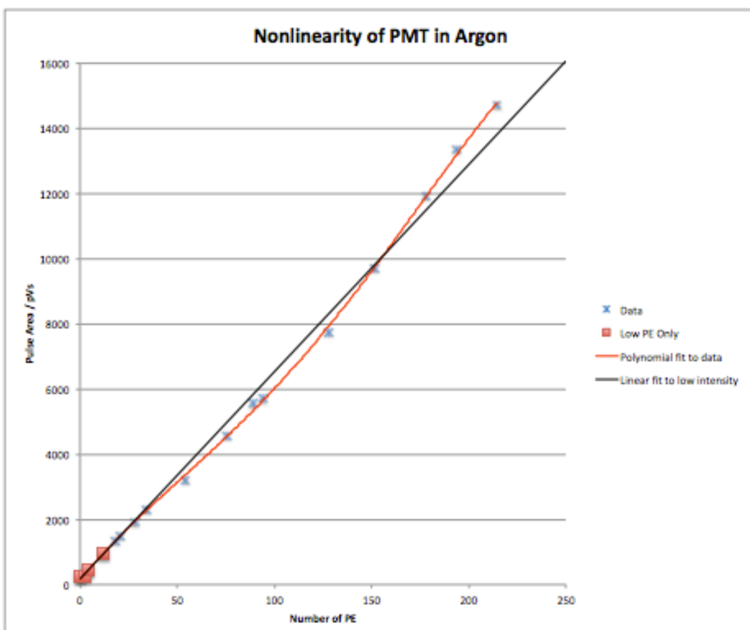
- SPE dark rates

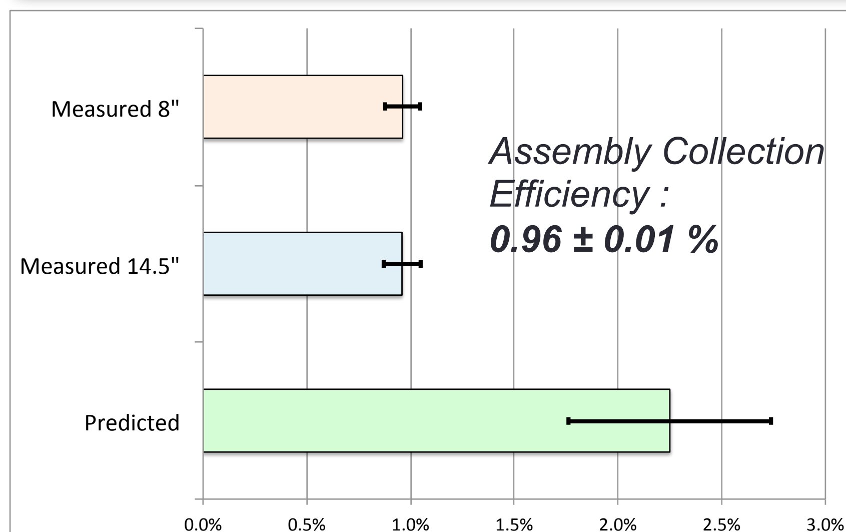
- Saturation point

- System global quantum efficiency

- PMT linearity measurement







Ongoing Physics Studies

- 1. Studies of Michel Electrons as Calibration Sources
- 2. Nitrogen Absorption Length
- 3. Nitrogen Quenching Effects

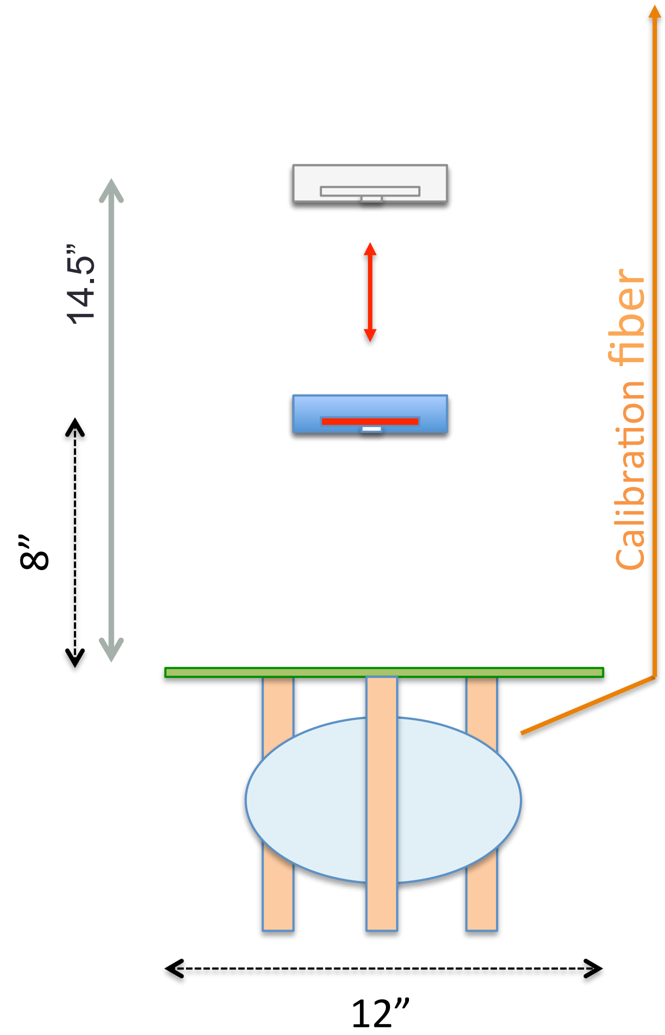
Ongoing Physics Studies

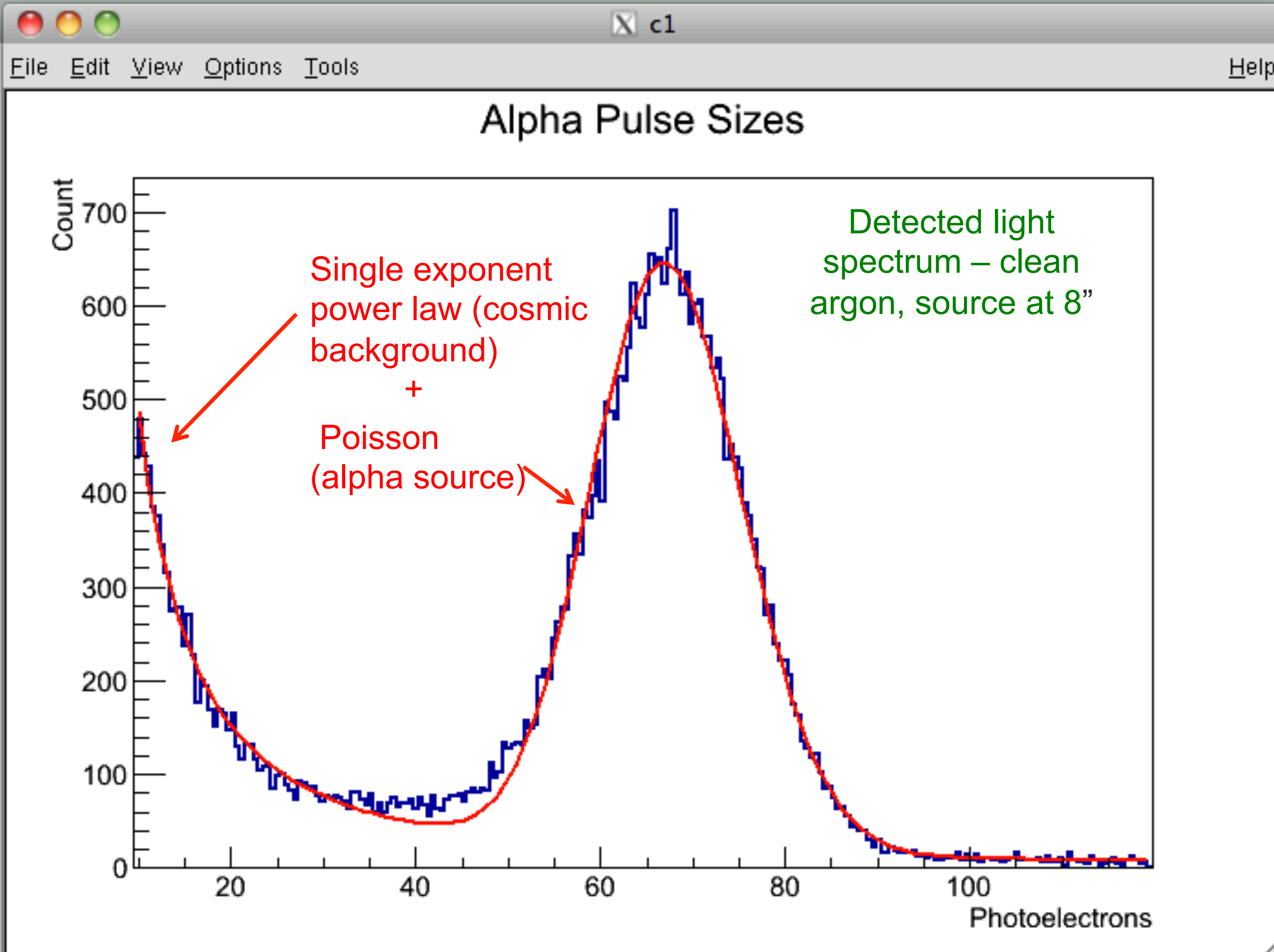
- 1. Studies of Michel Electrons as Calibration Sources
- **2. Nitrogen Absorption Length**
- 3. Nitrogen Quenching Effects

Preliminary

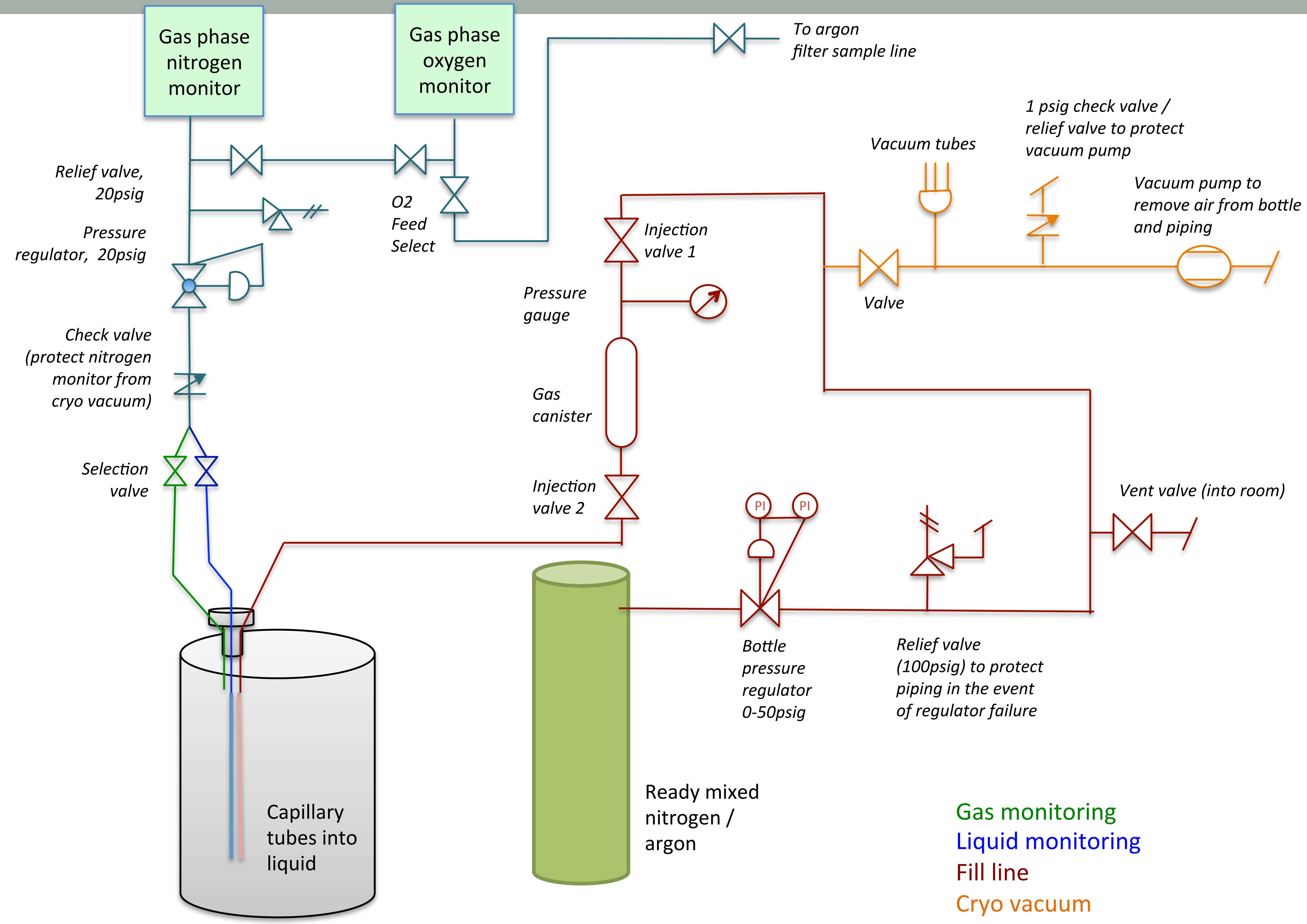
General Idea:

- 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.



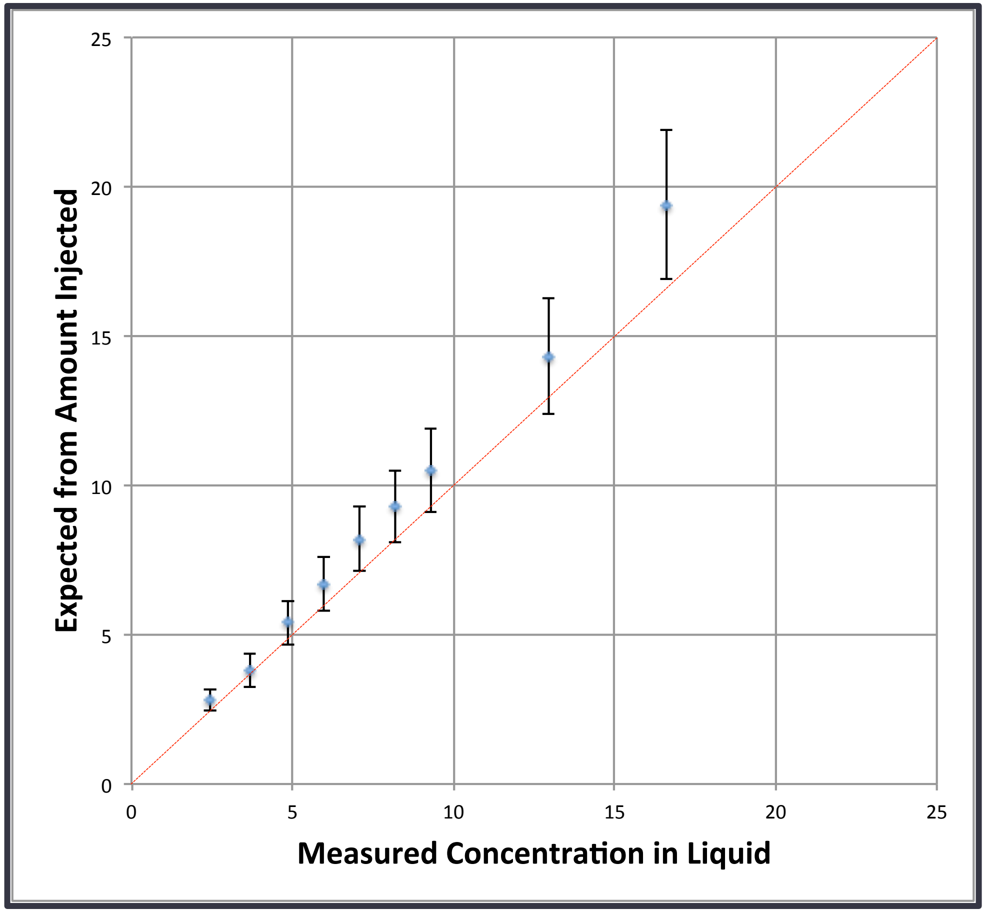

c1
File Edit View Options Tools Help
Alpha Pulse Sizes
Count
700
600
500
400
300
200
100
0
20
40
60
80
100
Photoelectrons
Single exponent power law (cosmic background)
+
Poisson (alpha source)
Detected light spectrum – clean argon, source at 8”

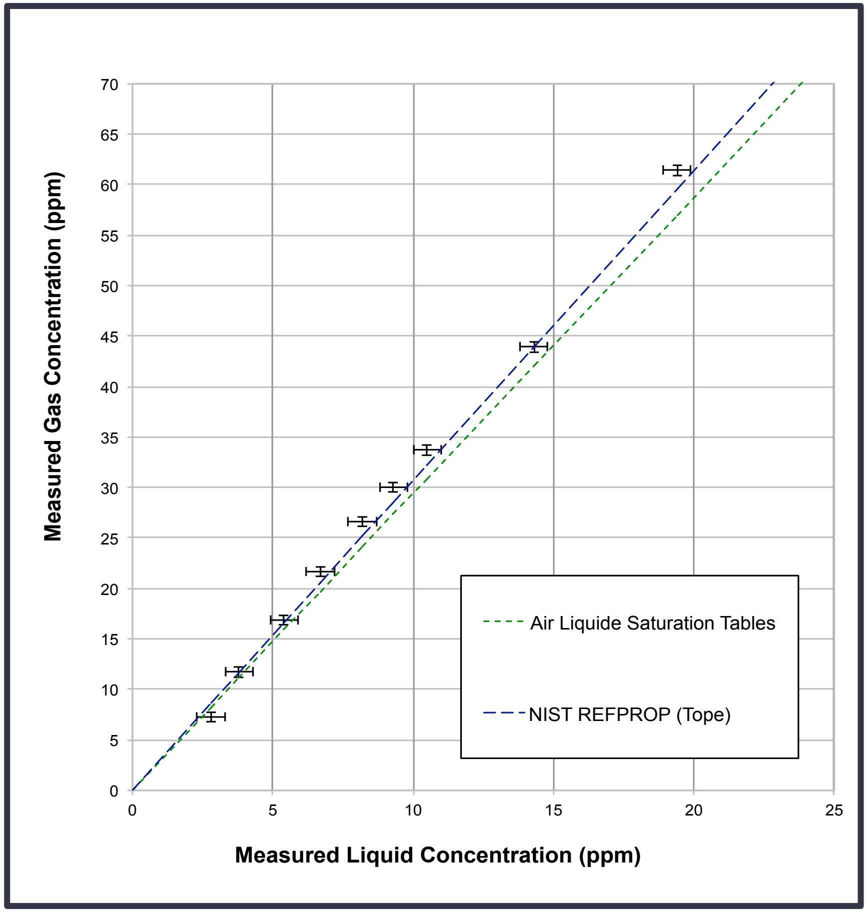
- PPM amounts of nitrogen are injected into the liquid from a gas canister, charged to a known pressure.
- From known volume of canister and known pressure we can calculate how many ppm we injected.
- Nitrogen concentration monitored in both liquid and gas phases using LDetek8000 N2 monitor
- We also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



Gas phase nitrogen monitor
Gas phase oxygen monitor
To argon filter sample line
Relief valve, 20psig
Pressure regulator, 20psig
O2 Feed Select
Vacuum tubes
1 psig check valve / relief valve to protect vacuum pump
Vacuum pump to remove air from bottle and piping
Injection valve 1
Pressure gauge
Valve
Check valve (protect nitrogen monitor from cryo vacuum)
Gas canister
Selection valve
Injection valve 2
Vent valve (into room)
PI
PI
Bottle pressure regulator 0-50psig
Relief valve (100psig) to protect piping in the event of regulator failure
Capillary tubes into liquid
Ready mixed nitrogen / argon
Gas monitoring
Liquid monitoring
Fill line
Cryo vacuum

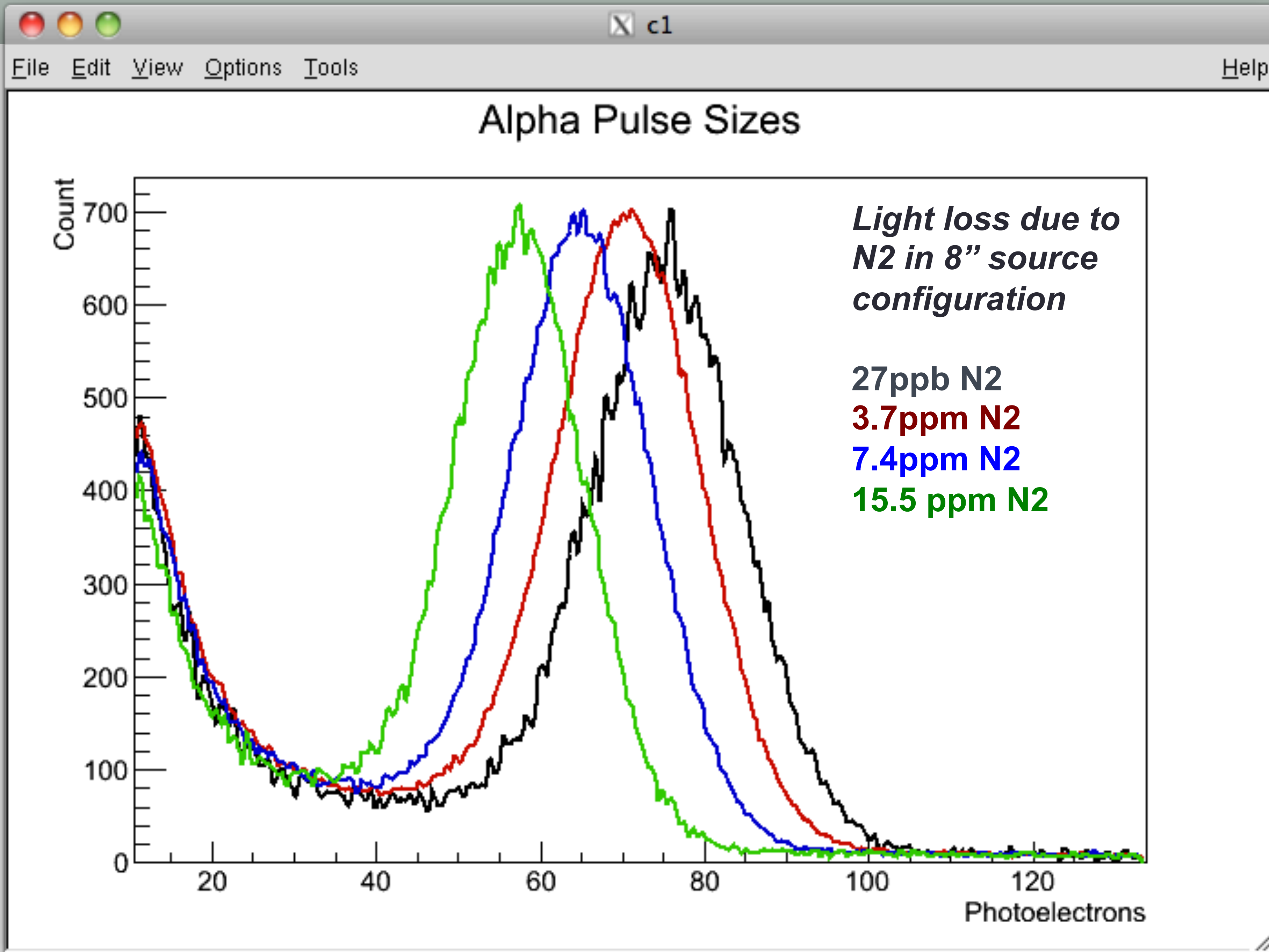
How do we know we get N2 concentration right?



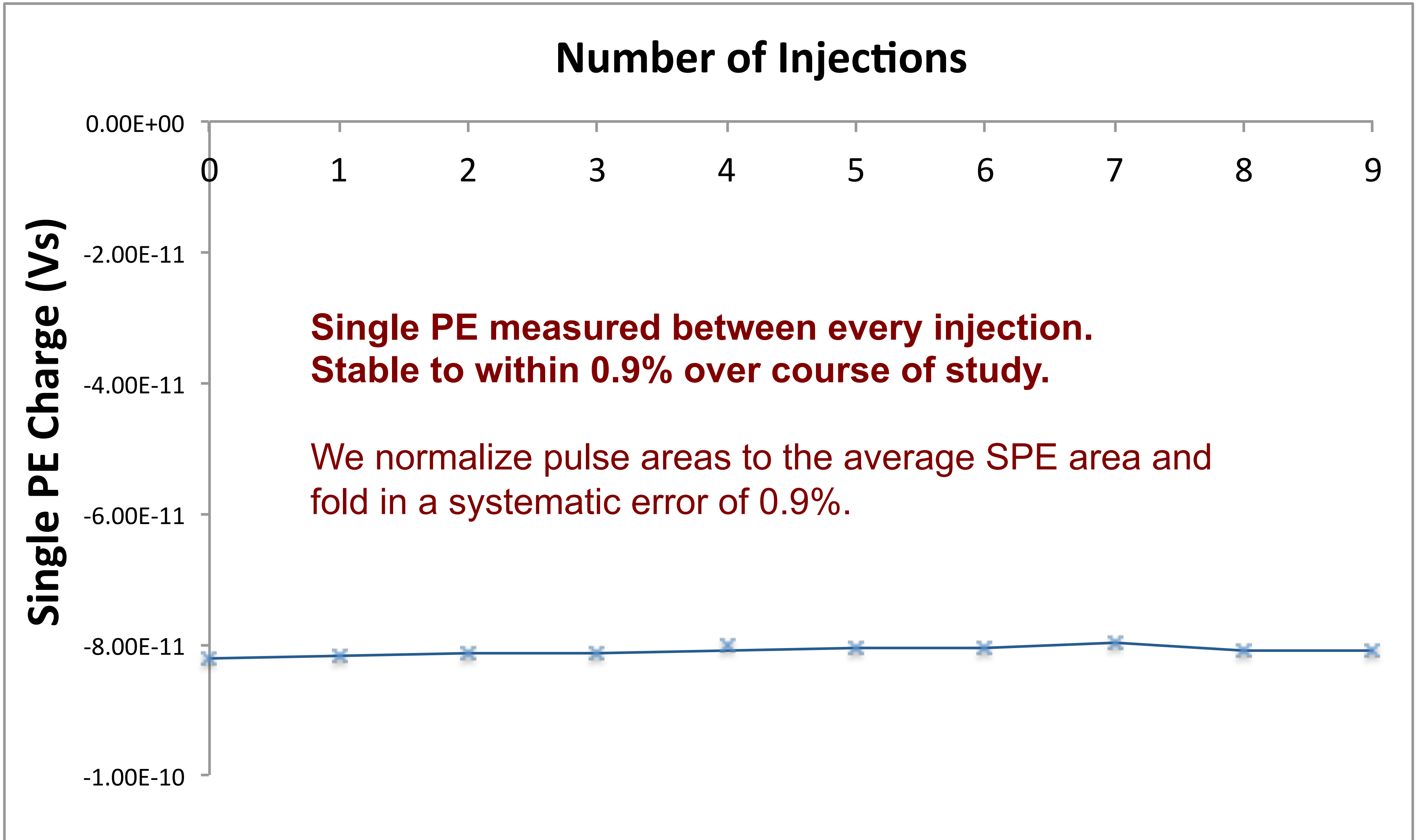


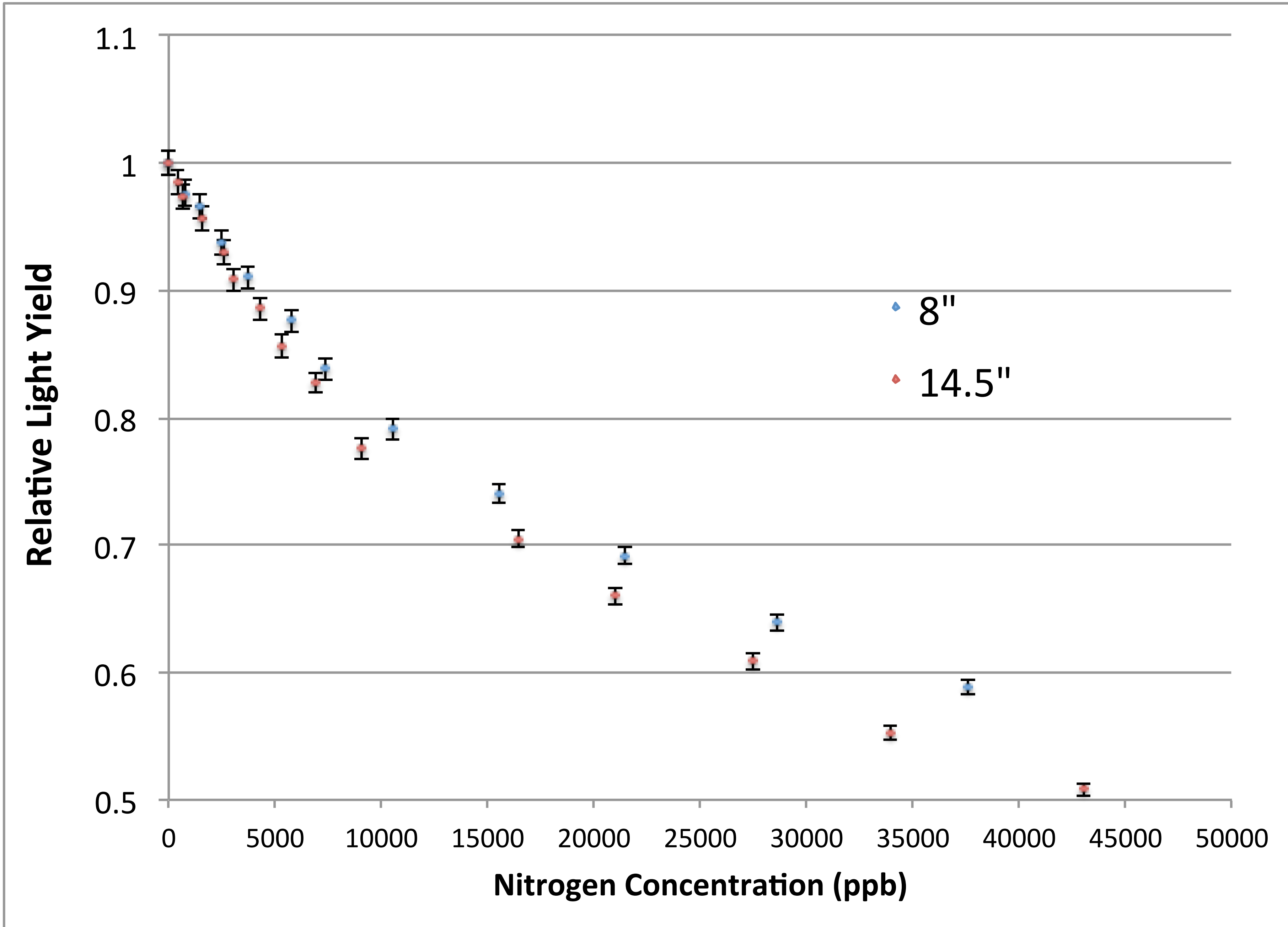
1) Amount of N2 in liquid agrees with amount injected to within our uncertainty of the injection volume.

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


c1
File
Edit
View
Options
Tools
Help
Alpha Pulse Sizes
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

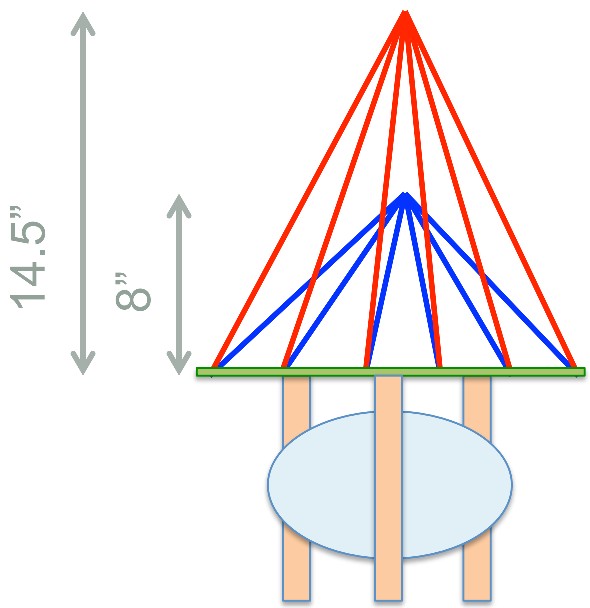
Stability of 1PE

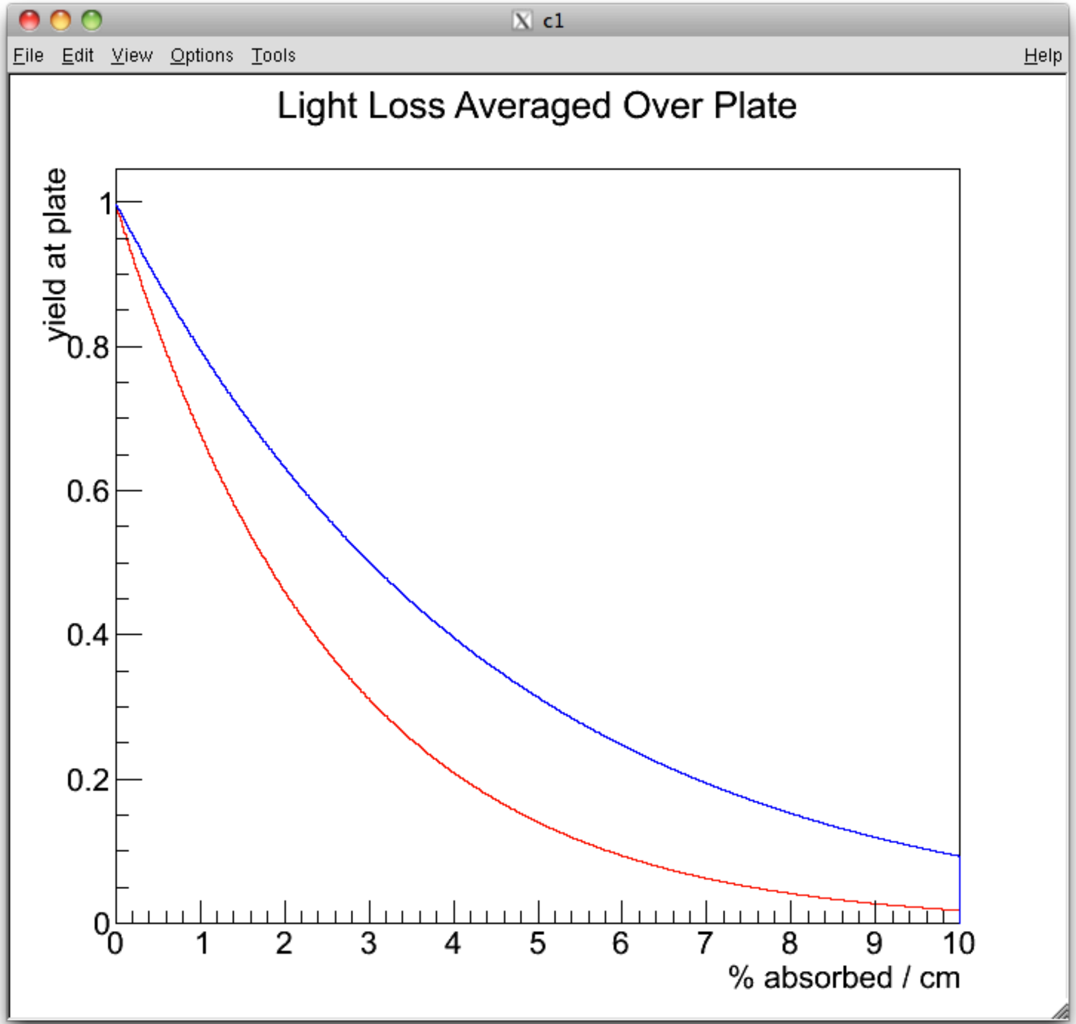



1.1
1
0.9
0.8
0.7
0.6
0.5
Relative Light Yield
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Nitrogen Concentration (ppb)
8"
14.5"

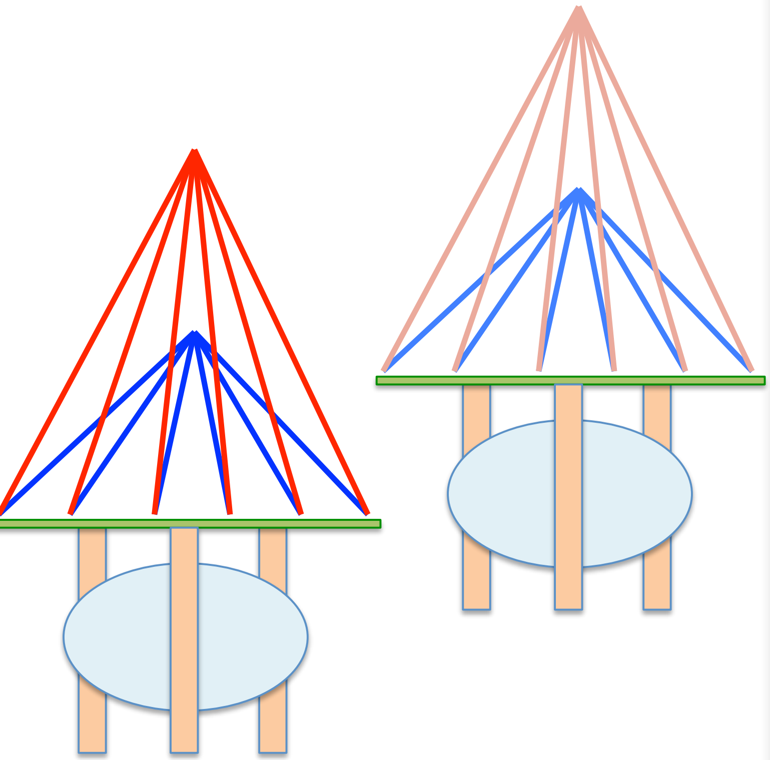
Understanding the Geometrical Effect

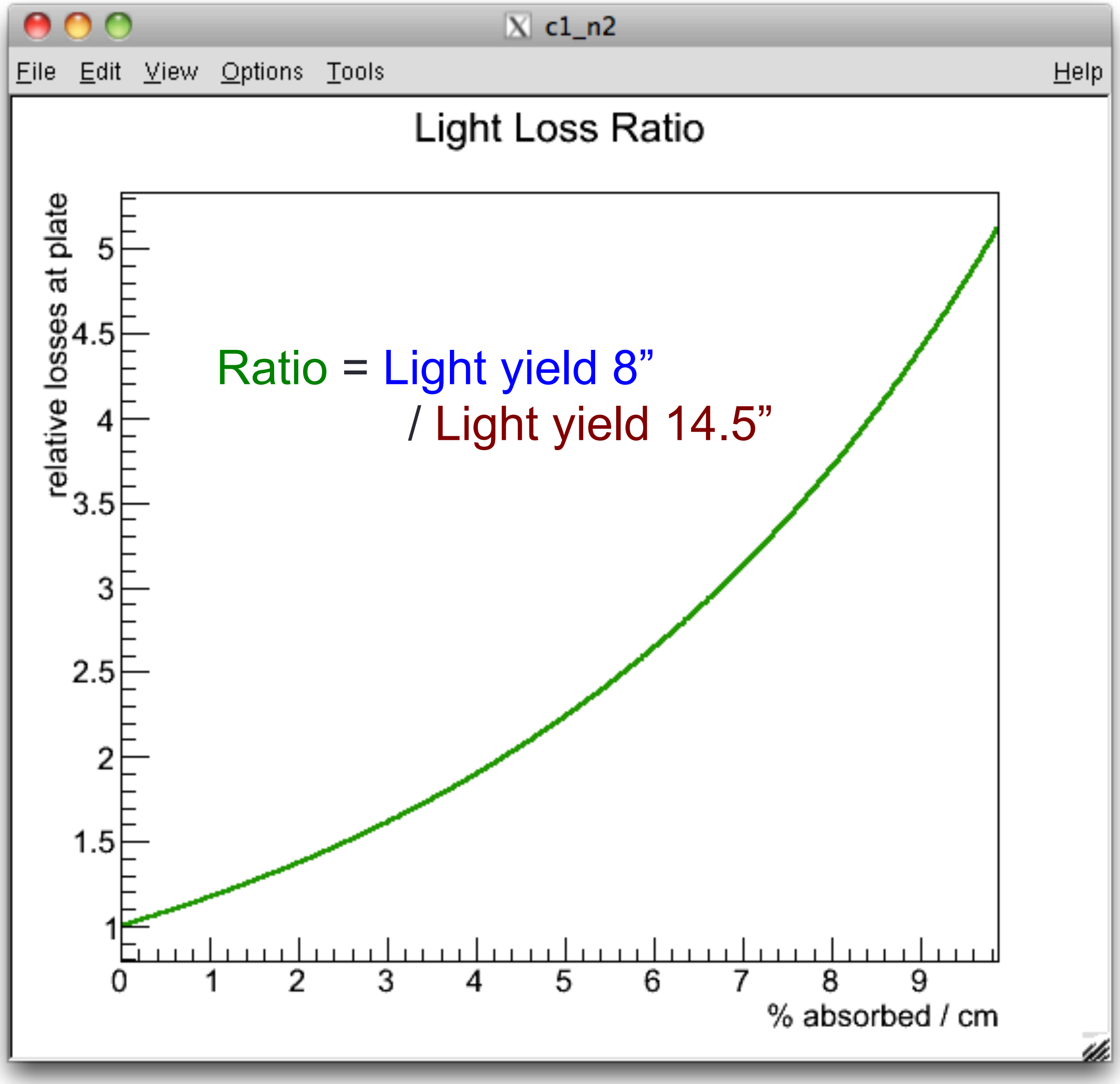
Ray trace to understand expected light yields per percent of absorption at each position

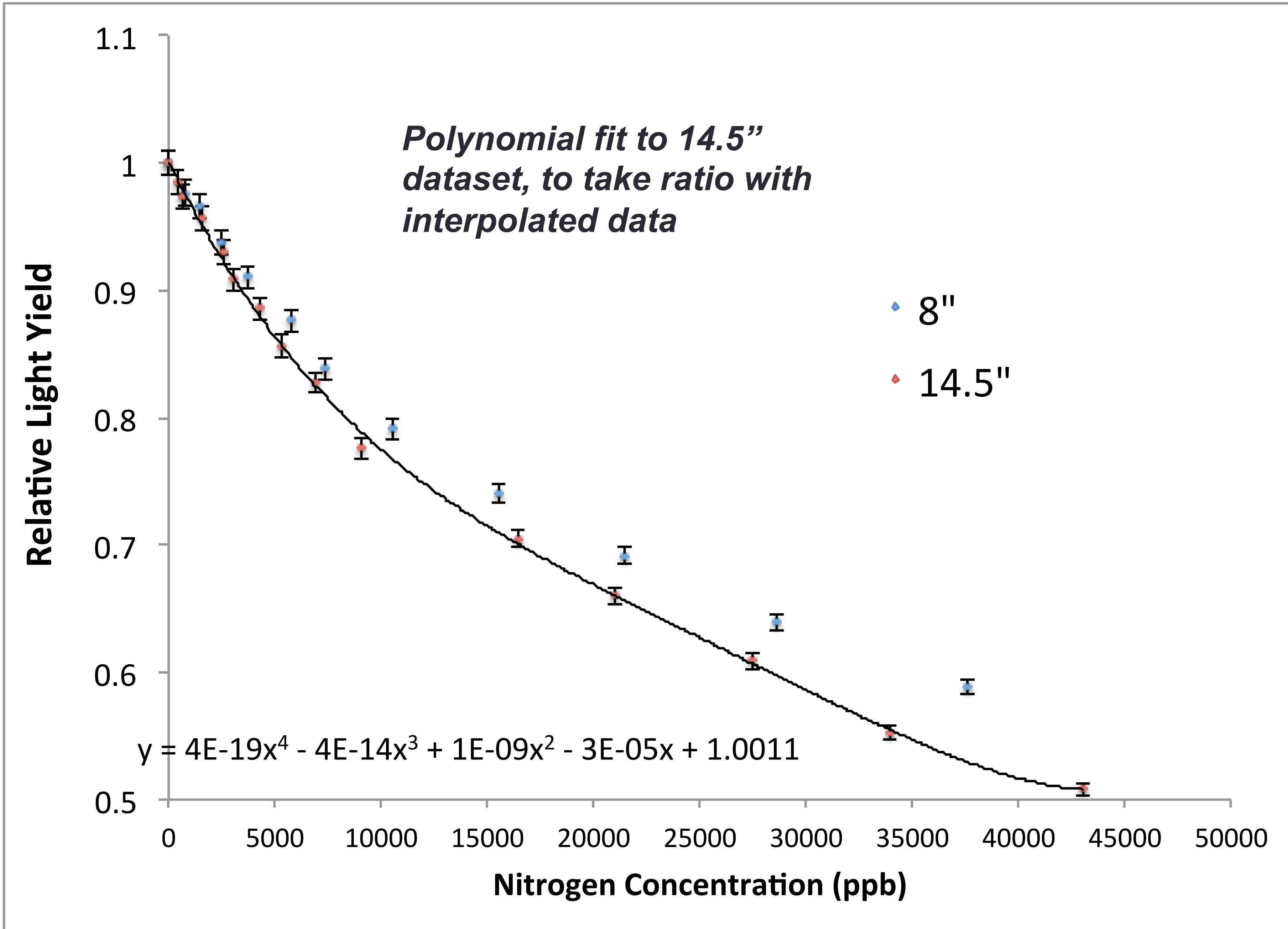


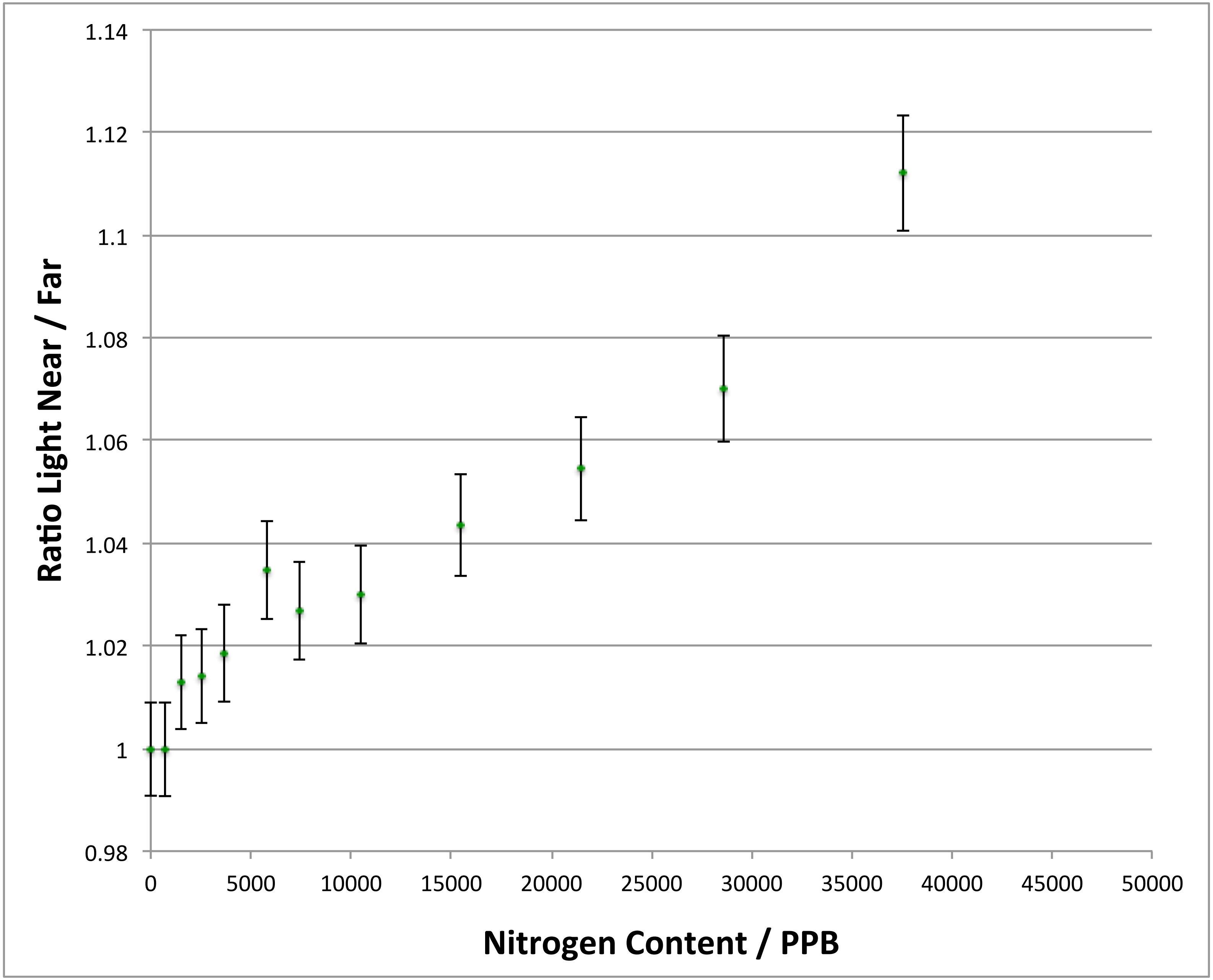


Taking ratio, any quenching effect cancels



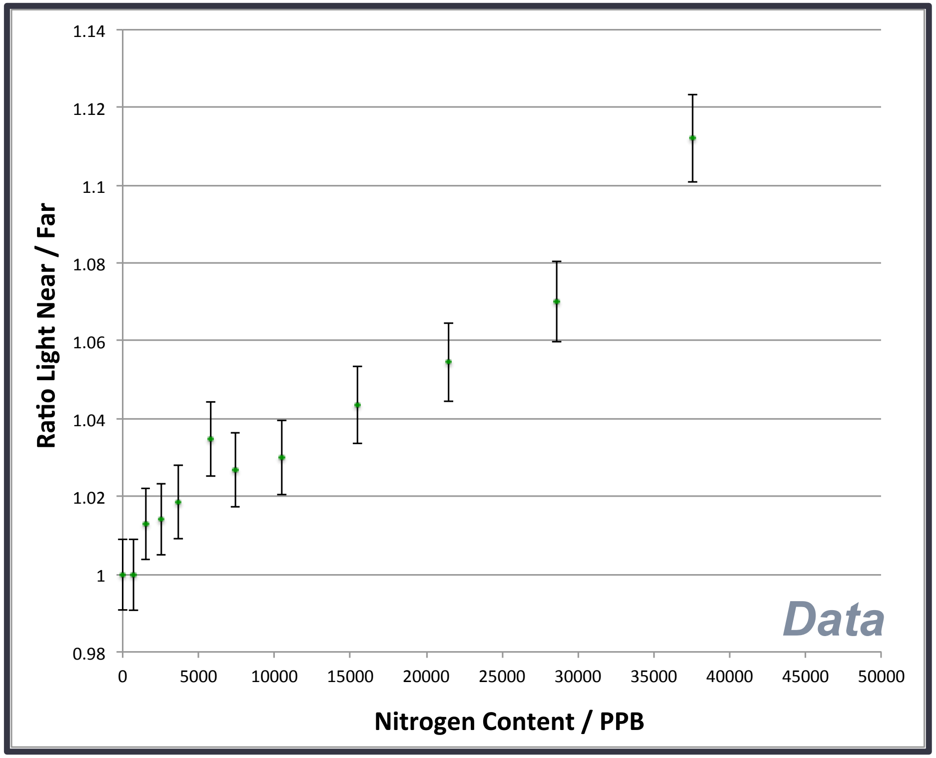


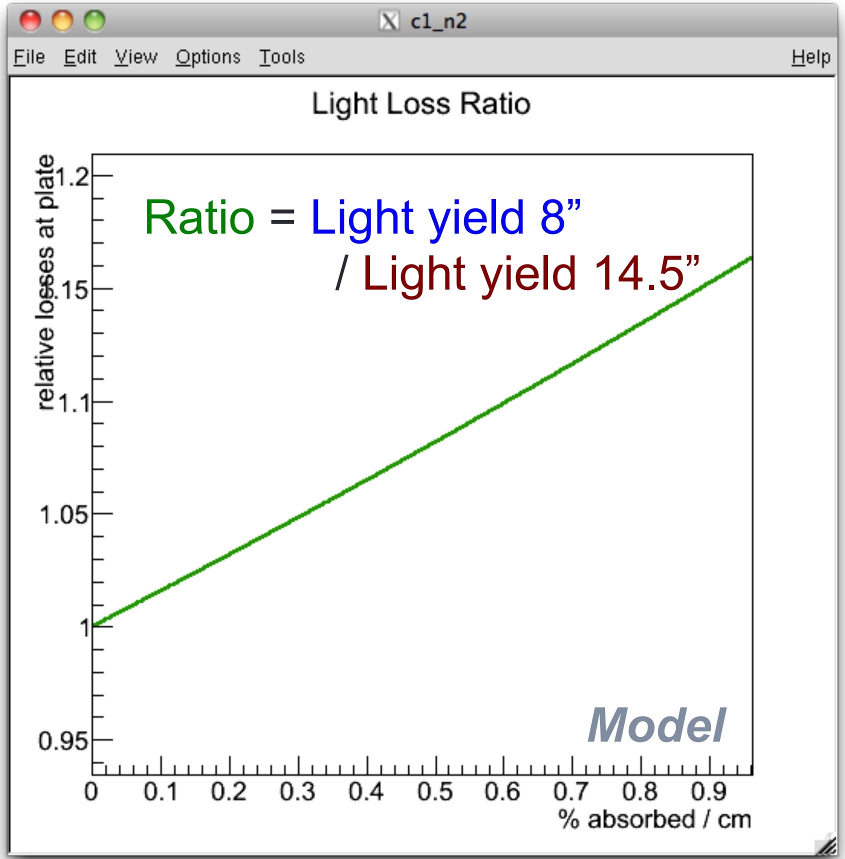

Polynomial fit to 14.5" dataset, to take ratio with interpolated data
Relative Light Yield
Nitrogen Concentration (ppb)
8"
14.5"
y = 4E-19x4 - 4E-14x3 + 1E-09x2 - 3E-05x + 1.0011
1.1
1
0.9
0.8
0.7
0.6
0.5
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000



Ratio Light Near / Far
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Nitrogen Content / PPB

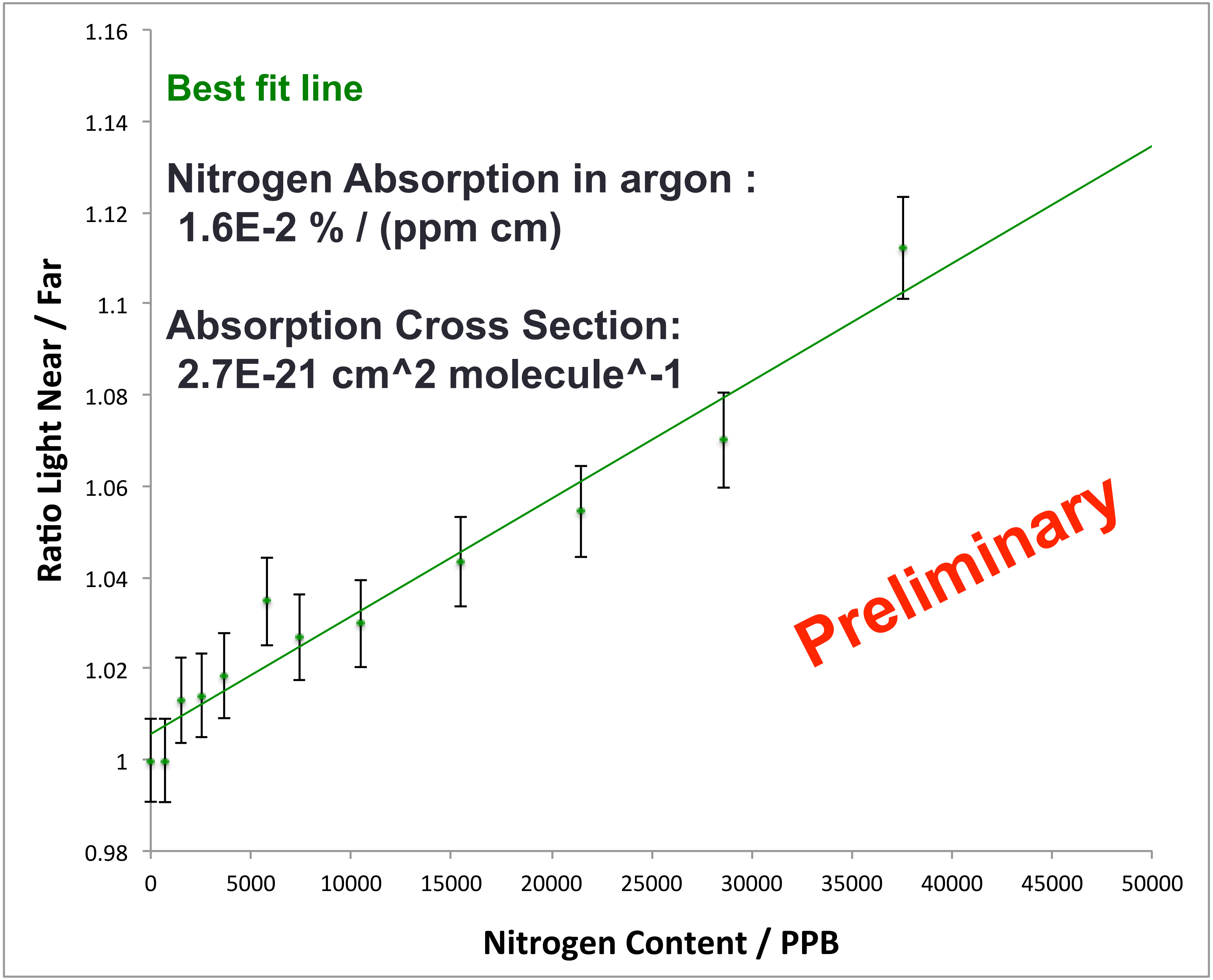
Getting a number out…



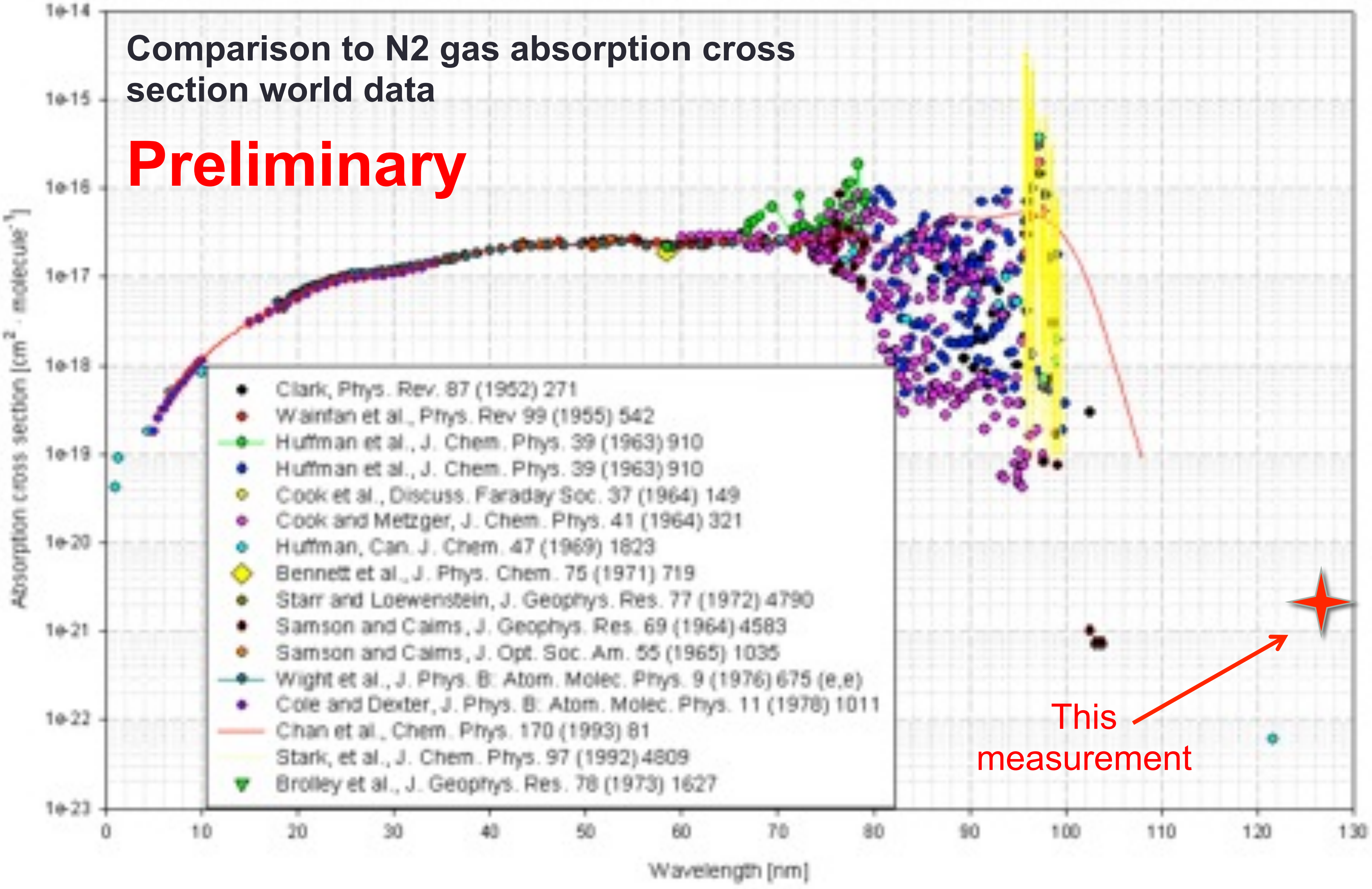


Now to find how much absorption we get per ppb N2…

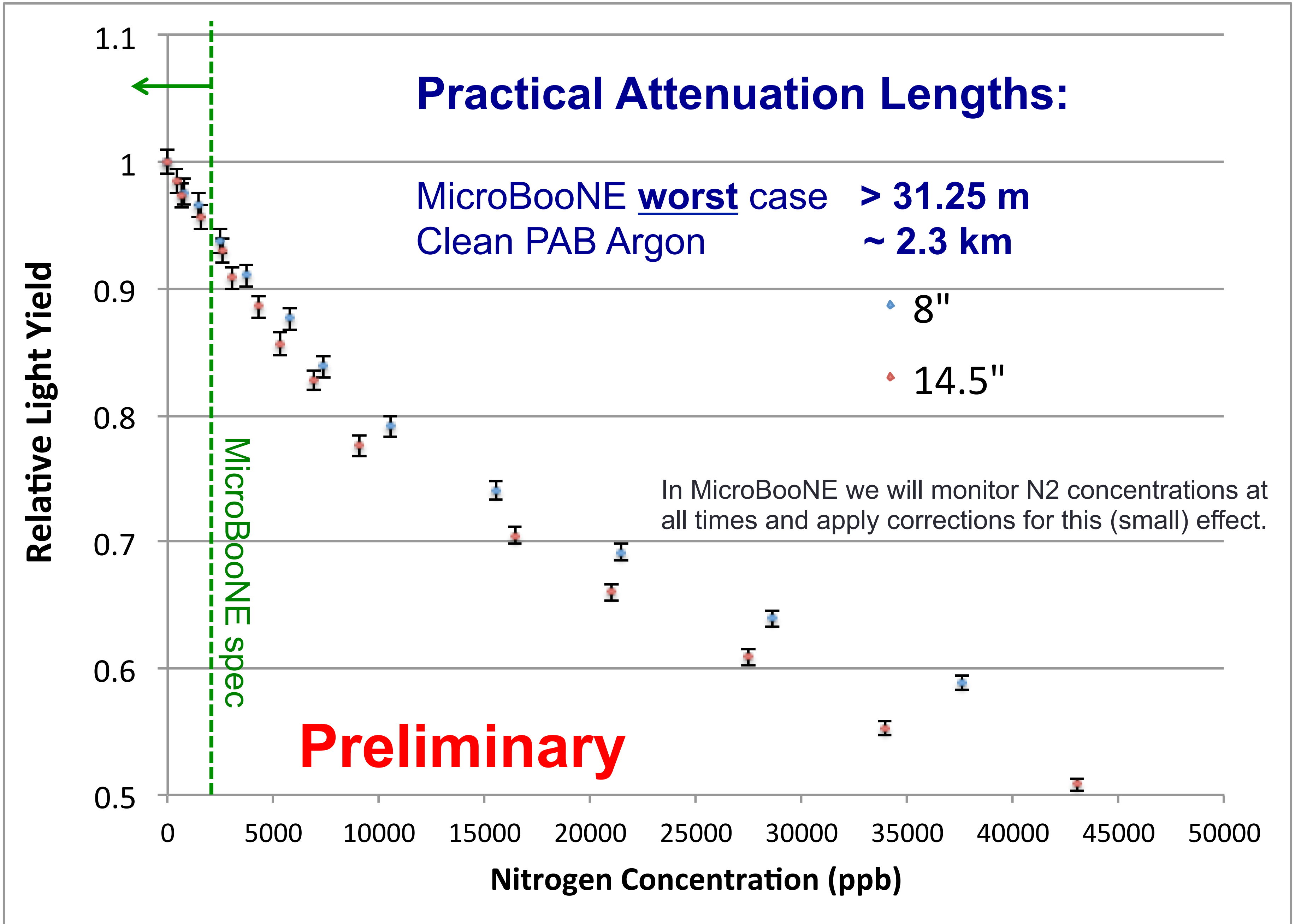
Green curve is very linear at these small concentrations, gradient = 0.16


Best fit line
Nitrogen Absorption in argon :
1.6E-2 % / (ppm cm)
Absorption Cross Section:
2.7E-21 cm^2 molecule^-1
Preliminary
Ratio Light Near / Far
Nitrogen Content / PPB
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

Comparison to N2 gas absorption cross section world data



VUV absorption cross sections of nitrogen N_2 at room temperature

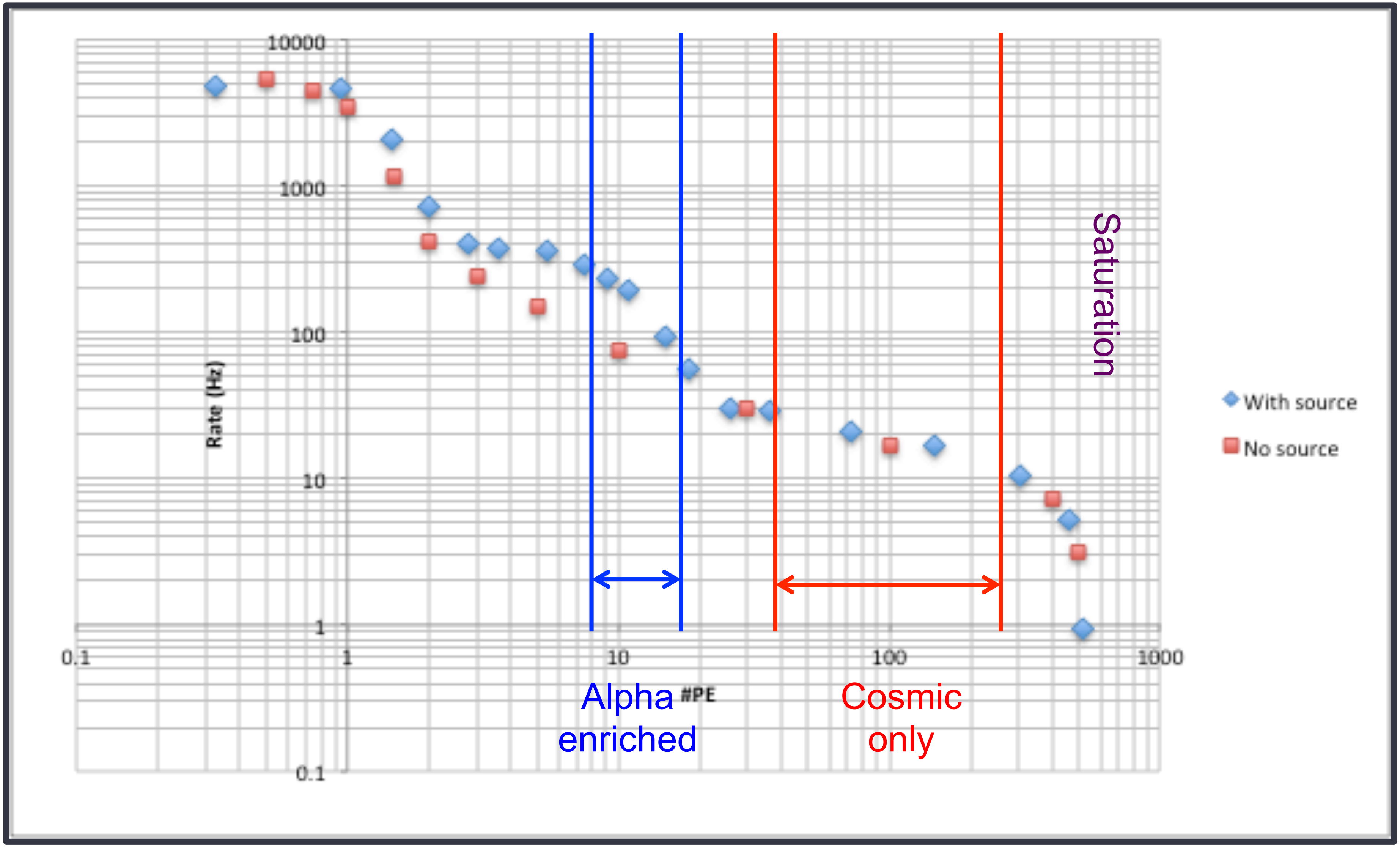

Practical Attenuation Lengths:
MicroBooNE worst case > 31.25 m
Clean PAB Argon ~ 2.3 km
8"
14.5"
In MicroBooNE we will monitor N2 concentrations at all times and apply corrections for this (small) effect.
MicroBooNE spec
Preliminary
Relative Light Yield
Nitrogen Concentration (ppb)
1.1
1
0.9
0.8
0.7
0.6
0.5
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

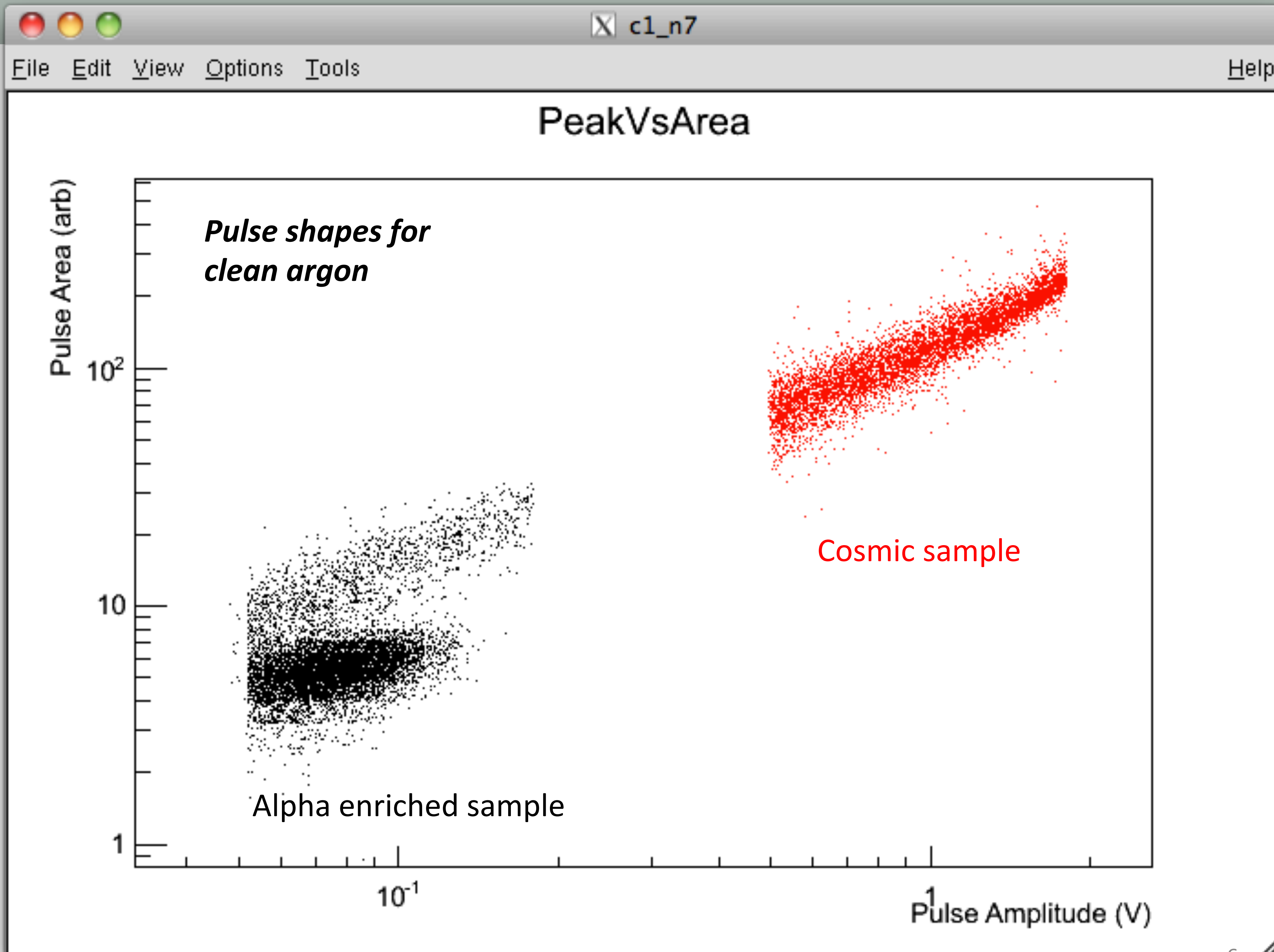
Summary + Prospects

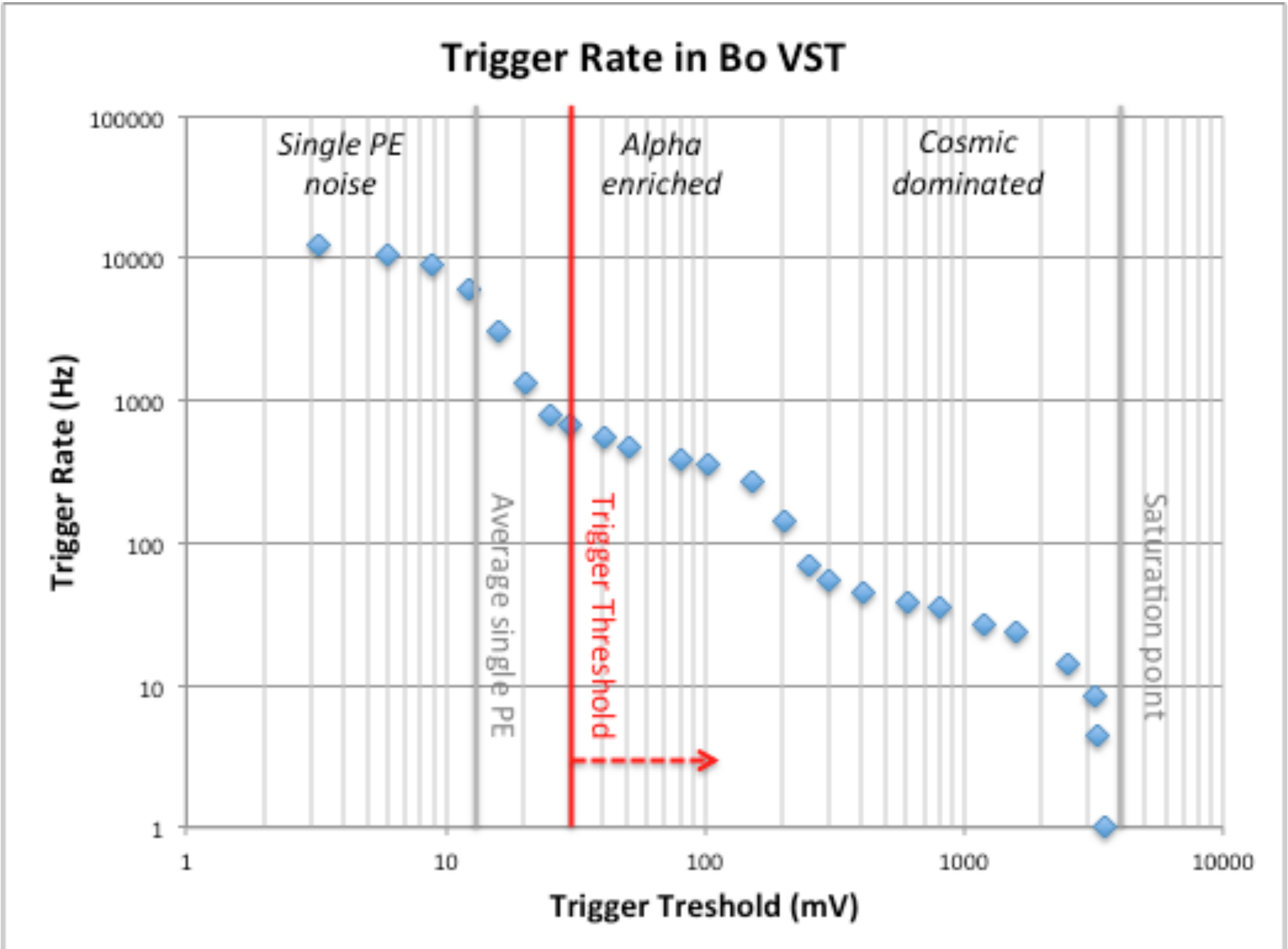
- We have measured the effects of nitrogen absorption of 128nm argon scintillation light
- We find that the effect is on the order 0.016% / (ppm cm)
- As well as absorption, we see clear evidence of quenching. We are also actively investigating these effects.
- This is only one of many physics studies we are working on with Bo, for the benefit of MicroBooNE, LBNE and other optical systems.
- We have a lot of great physics to investigate, but we are always happy to hear new ideas!

Backup Slides

Aside: Pulse Shape Discrimination in Action




c1_n7
File Edit View Options Tools Help
PeakVsArea
Pulse Area (arb)
Pulse Amplitude (V)
Pulse shapes for
clean argon
Cosmic sample
Alpha enriched sample
10^2
10
1
10^{-1}
1

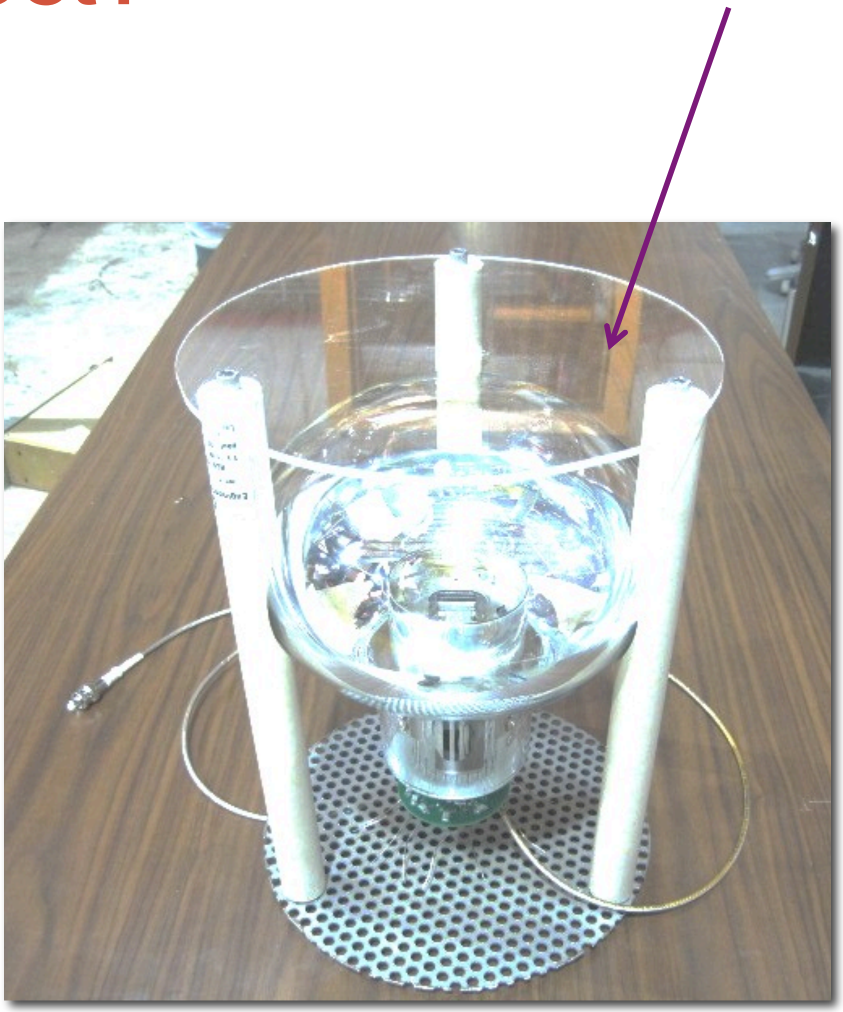

Trigger Rate in Bo VST
Single PE noise
Alpha enriched
Cosmic dominated
Average single PE
Trigger Threshold
Saturation point
100000
10000
1000
100
10
1
1
10
100
1000
10000
Trigger Rate (Hz)
Trigger Treshold (mV)

Contents

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

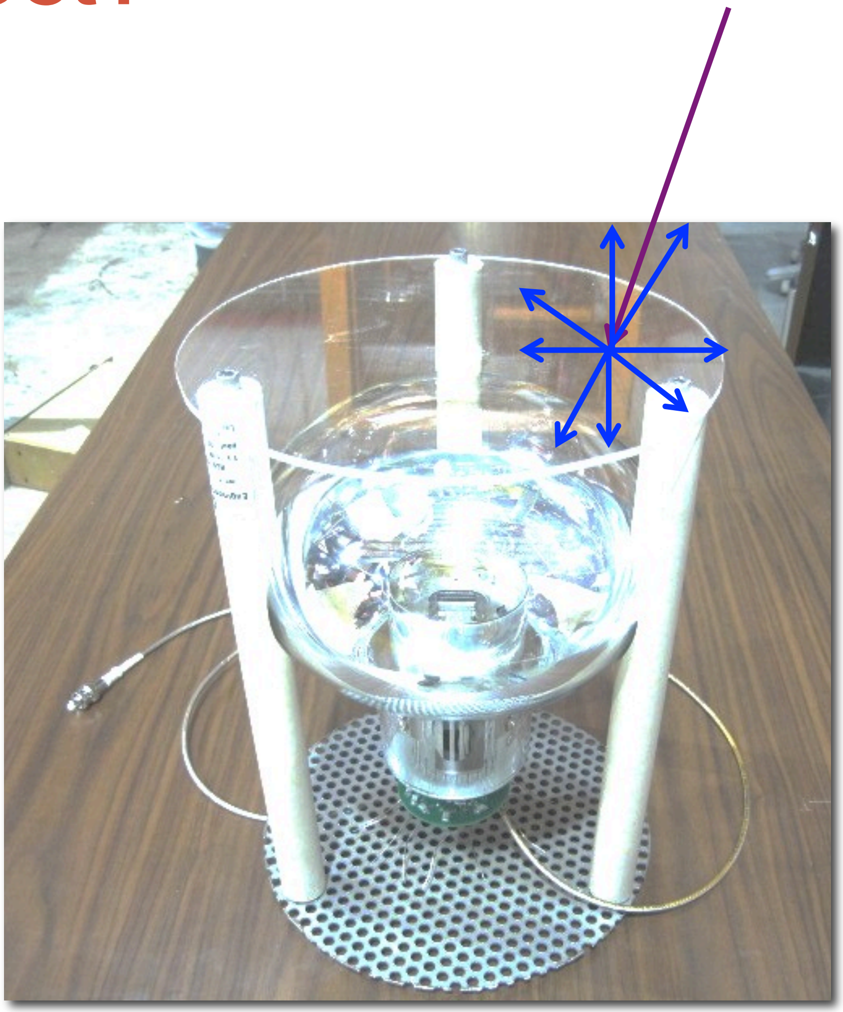
What Do We Expect?

- 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

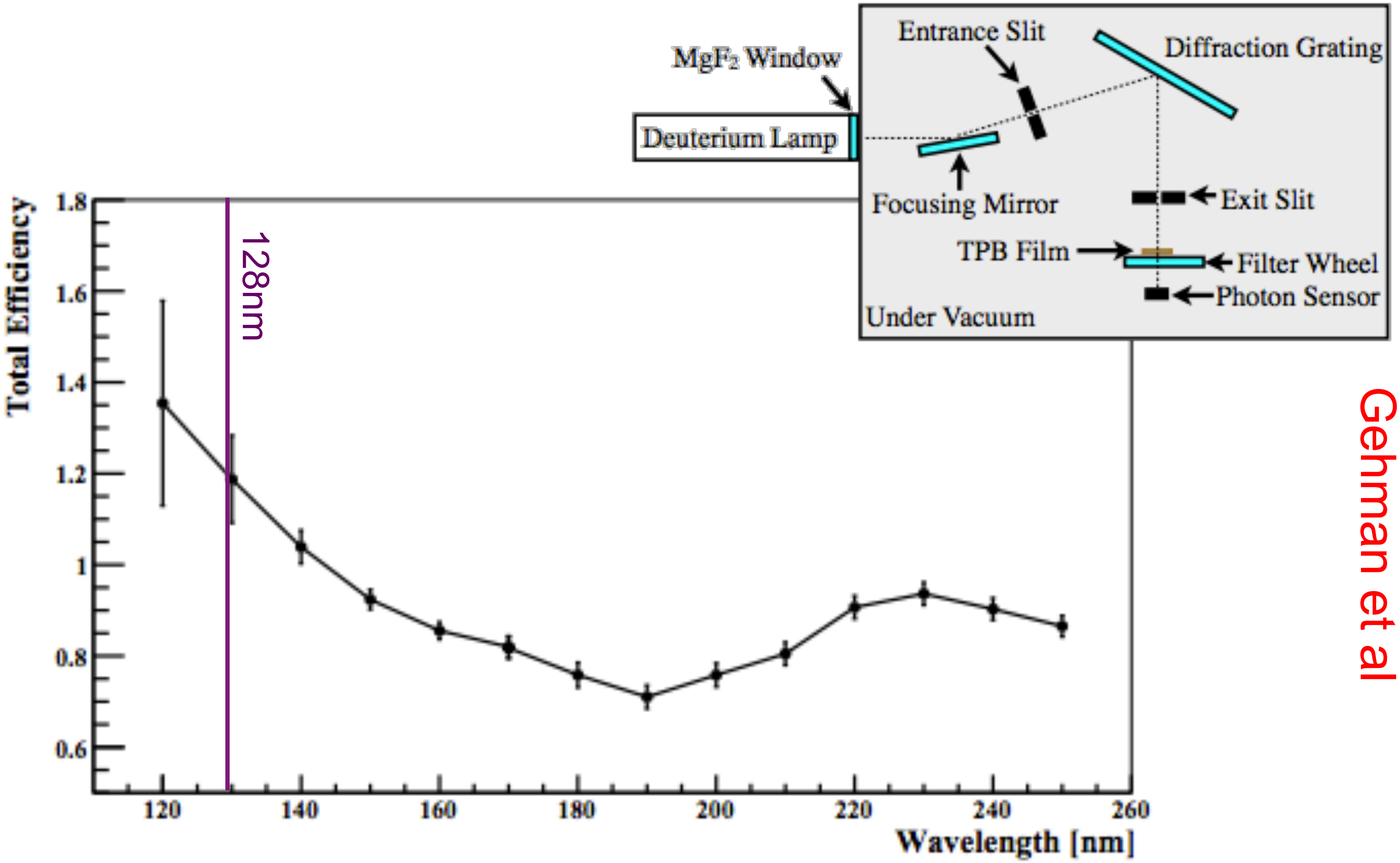
Search

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))



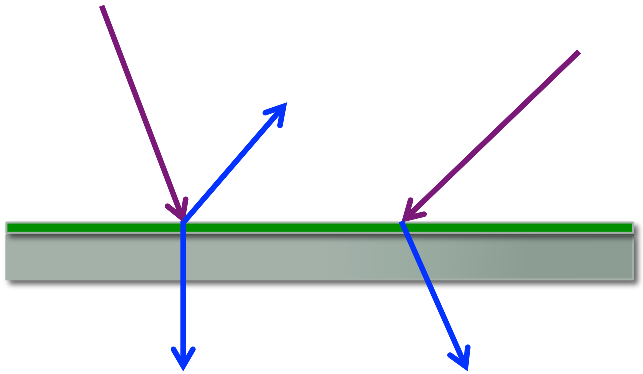
Gehman et al

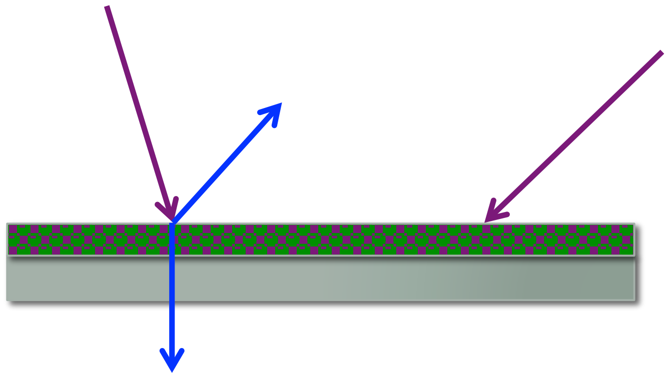
1.18 ± 0.1

Visible photons out / UV photon in for evaporative TPB

But not all coatings are the same

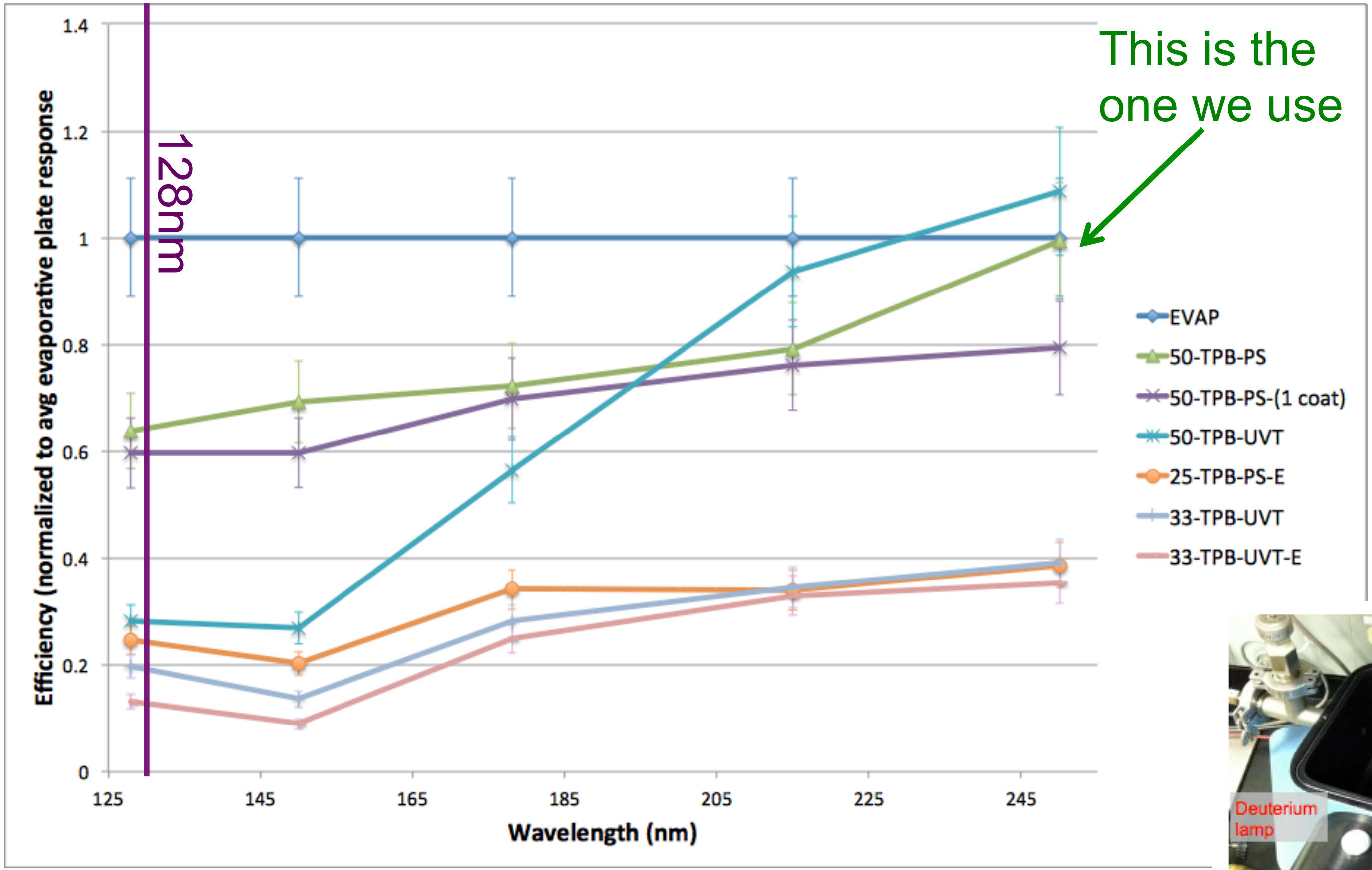
- Gehman et al use an evaporative coated, pure TPB layer
- When developing the optical system, we found this coating to be very delicate.
- We use a more robust but less efficient coating of TPB in a polystyrene matrix.
- The PS substrate is not transparent to 128nm light, so some light is lost before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

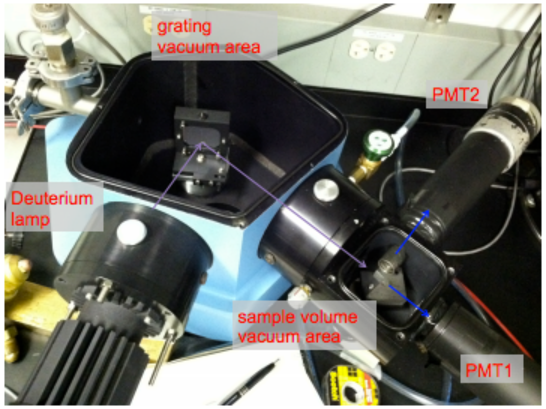




Comparison of uB plates to evaporative plates in vacuum

Ignarra (MIT)



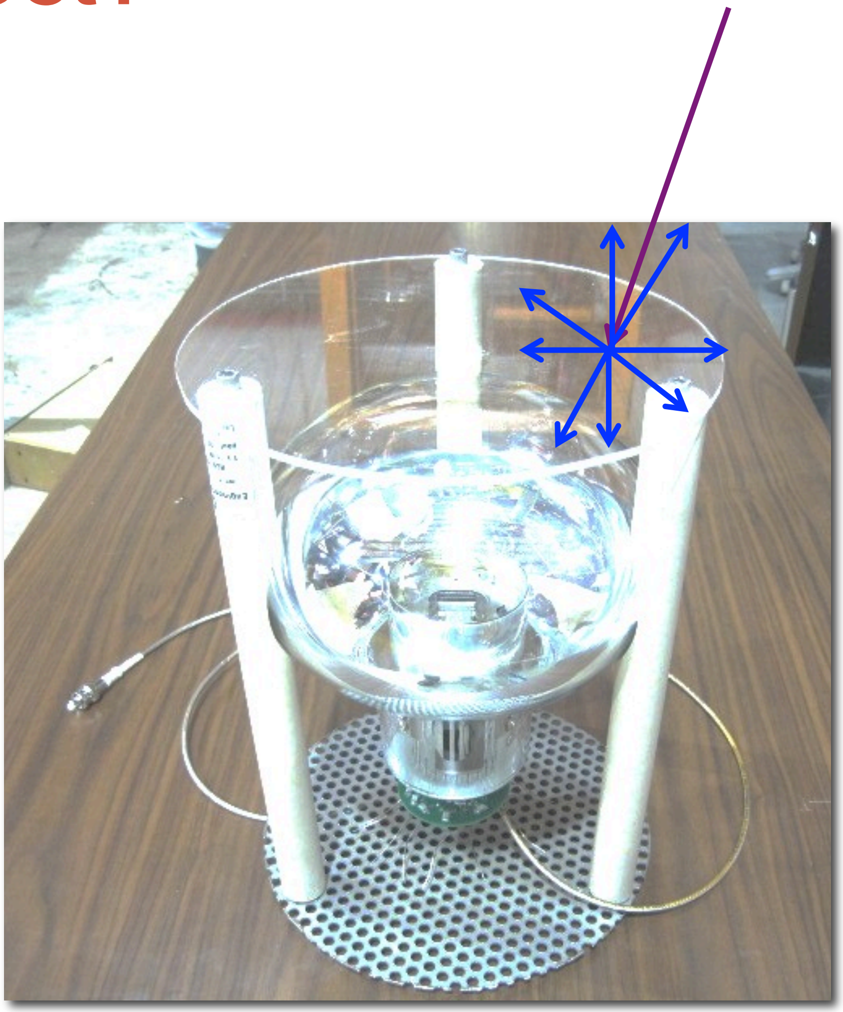


0.64 ± 0.11

Performance of uB plate compared to evaporative

What Do We Expect?

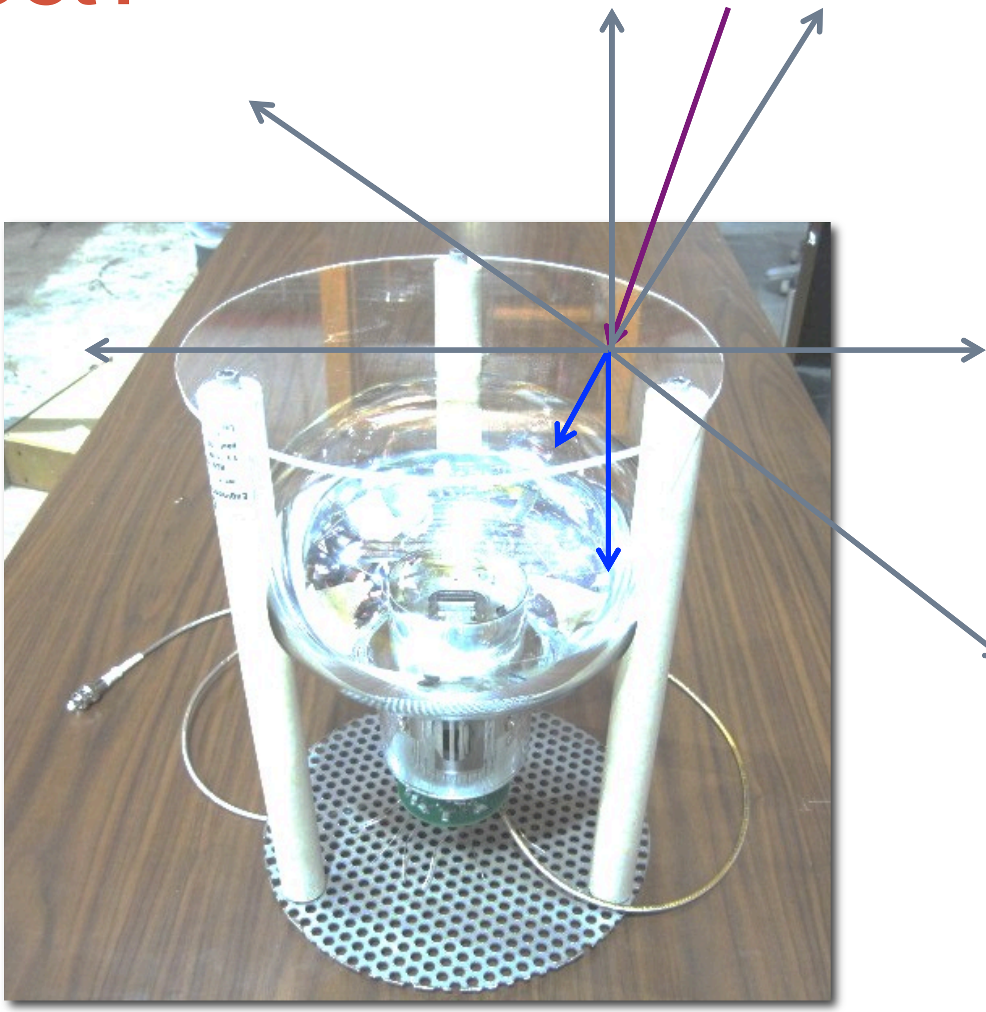
- A photon arrives at the TPB plate
- It may be shifted to a visible photon by TPB coating.



What Do We Expect?

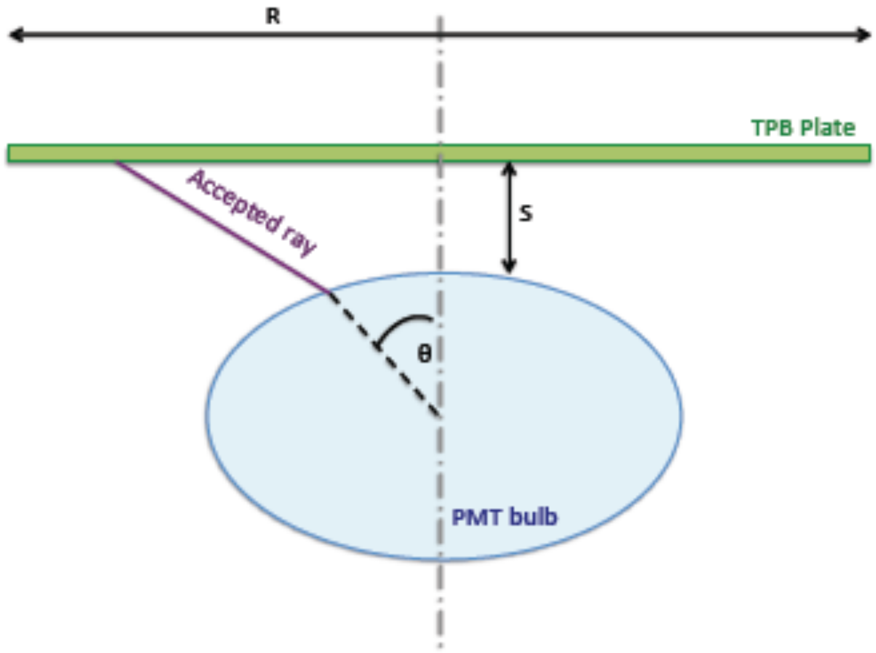
(lose 50% straight away – backwards going)

- 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



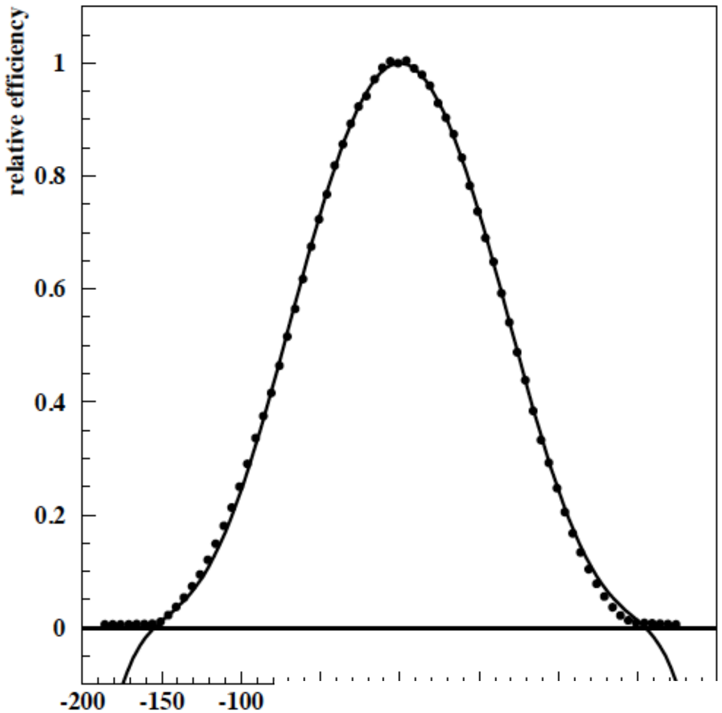
Acceptance of Light

- 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.



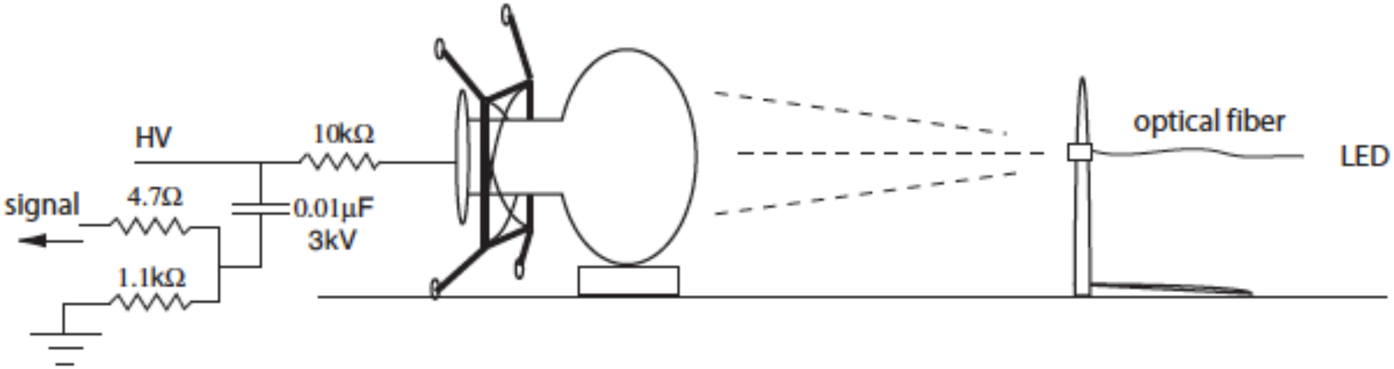
Jones and Toups (MIT)

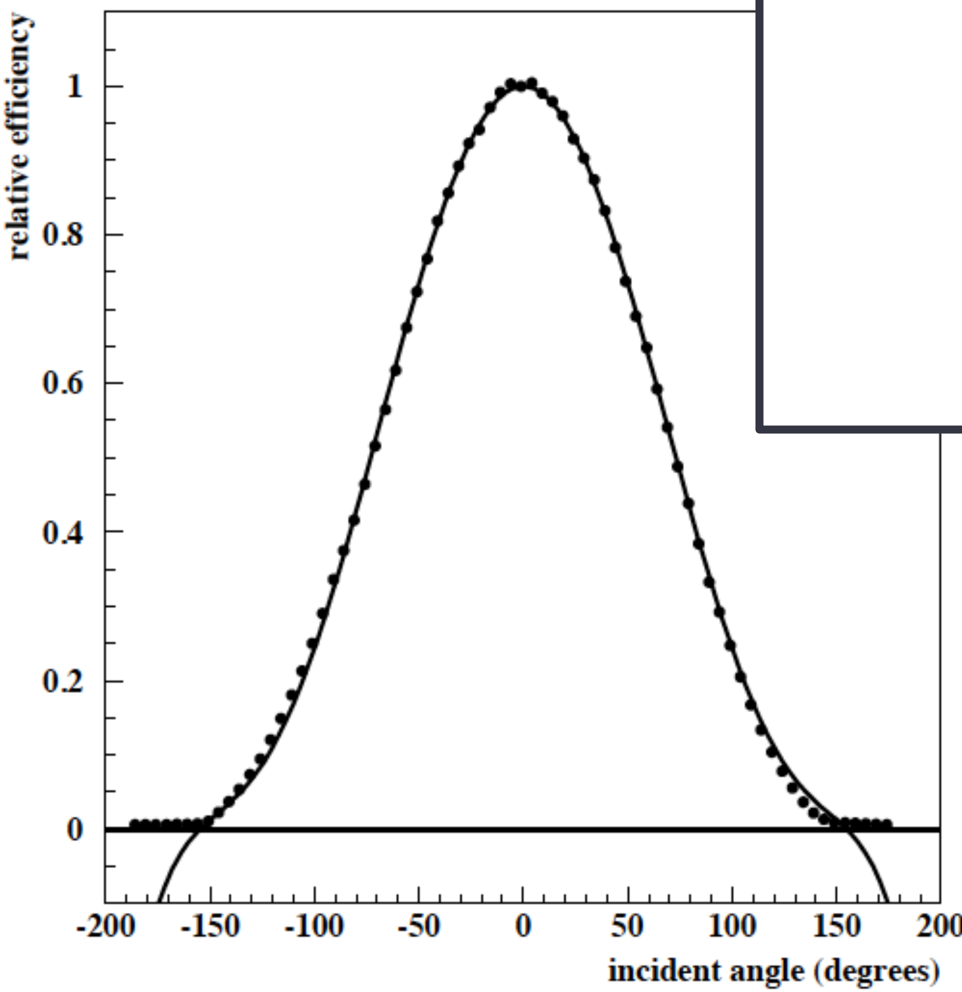
Angular Acceptance

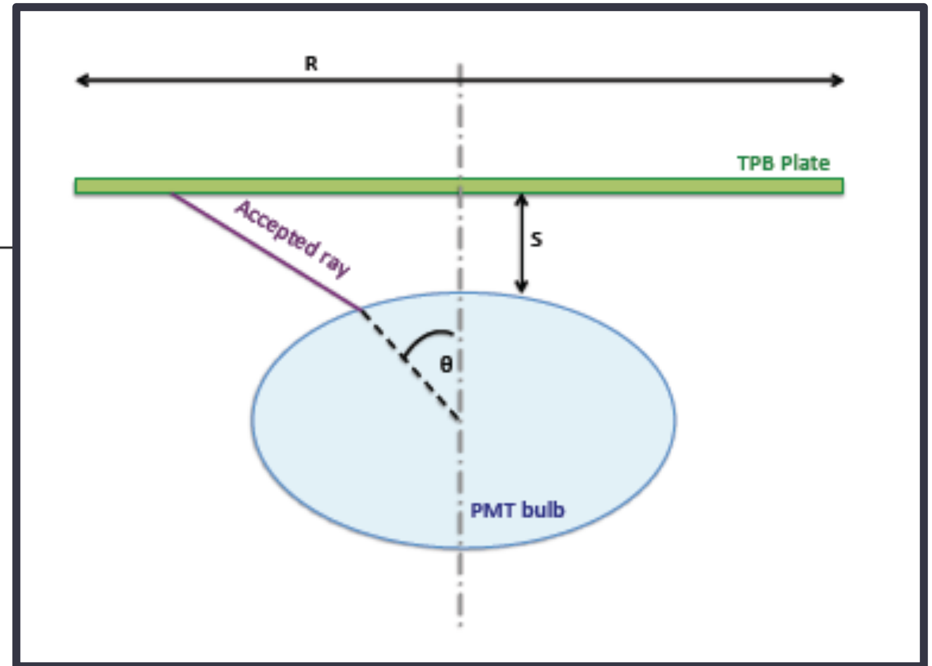


- MiniBooNE measured response of tube at different angles to “distant” light source
- Resulting data points were fit to a polynomial in theta
- Each point corresponds to tube illuminated all over front face, but at different angle
- Can we use this? Sort of…

SJ Brice et al (MiniBooNE)





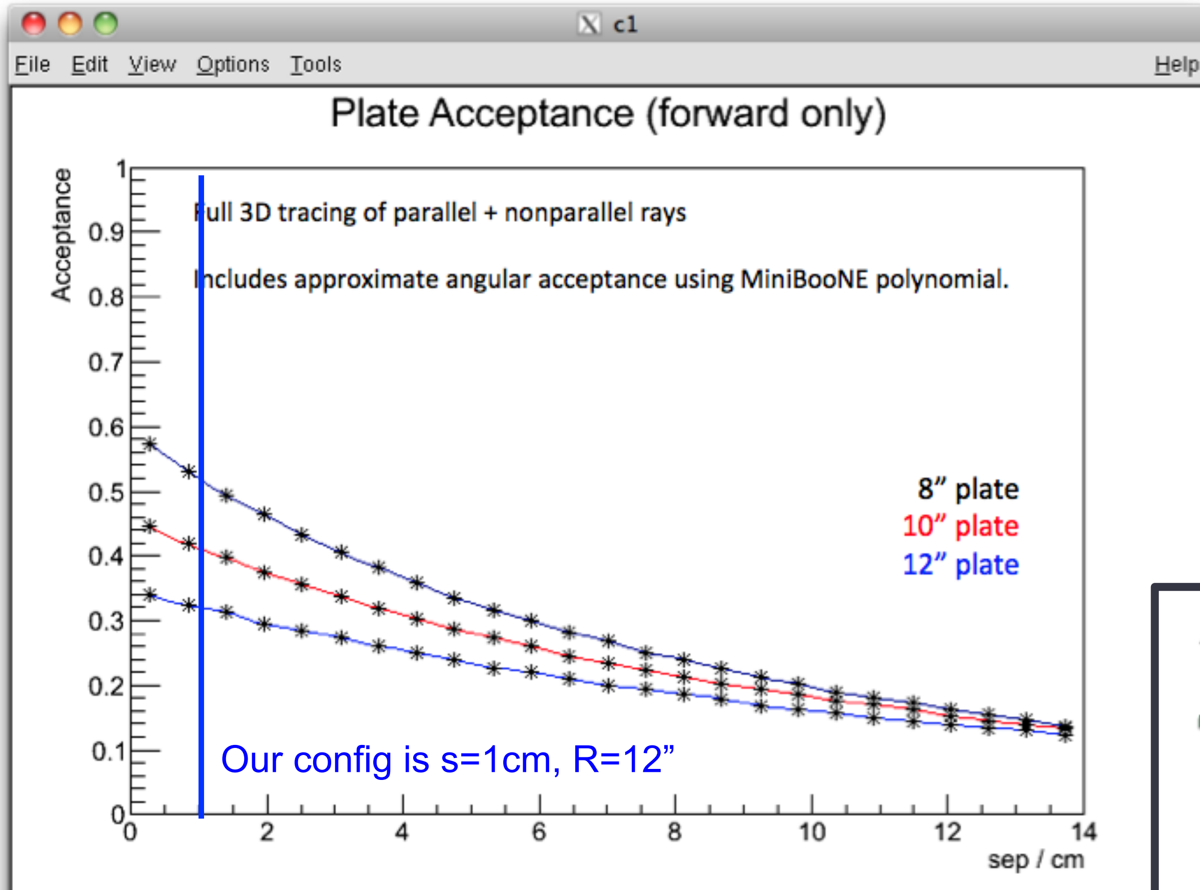


Jones and Toups (MIT)

- 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.

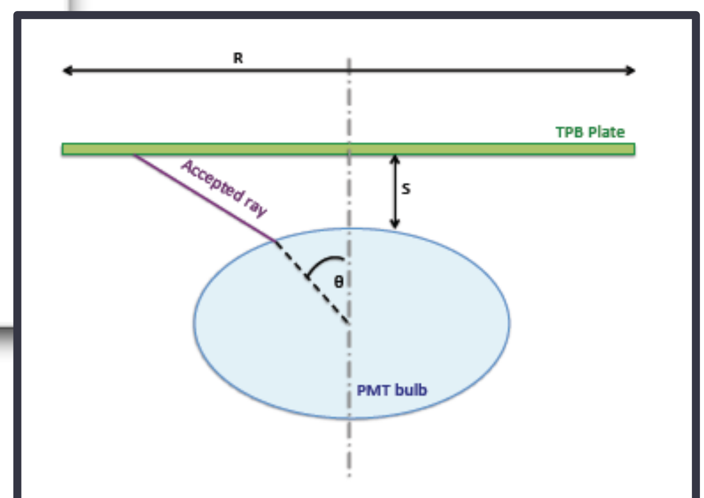
Then its just a question of raytracing

Jones and Toups (MIT)



Two independent simulations agree to within ~10%

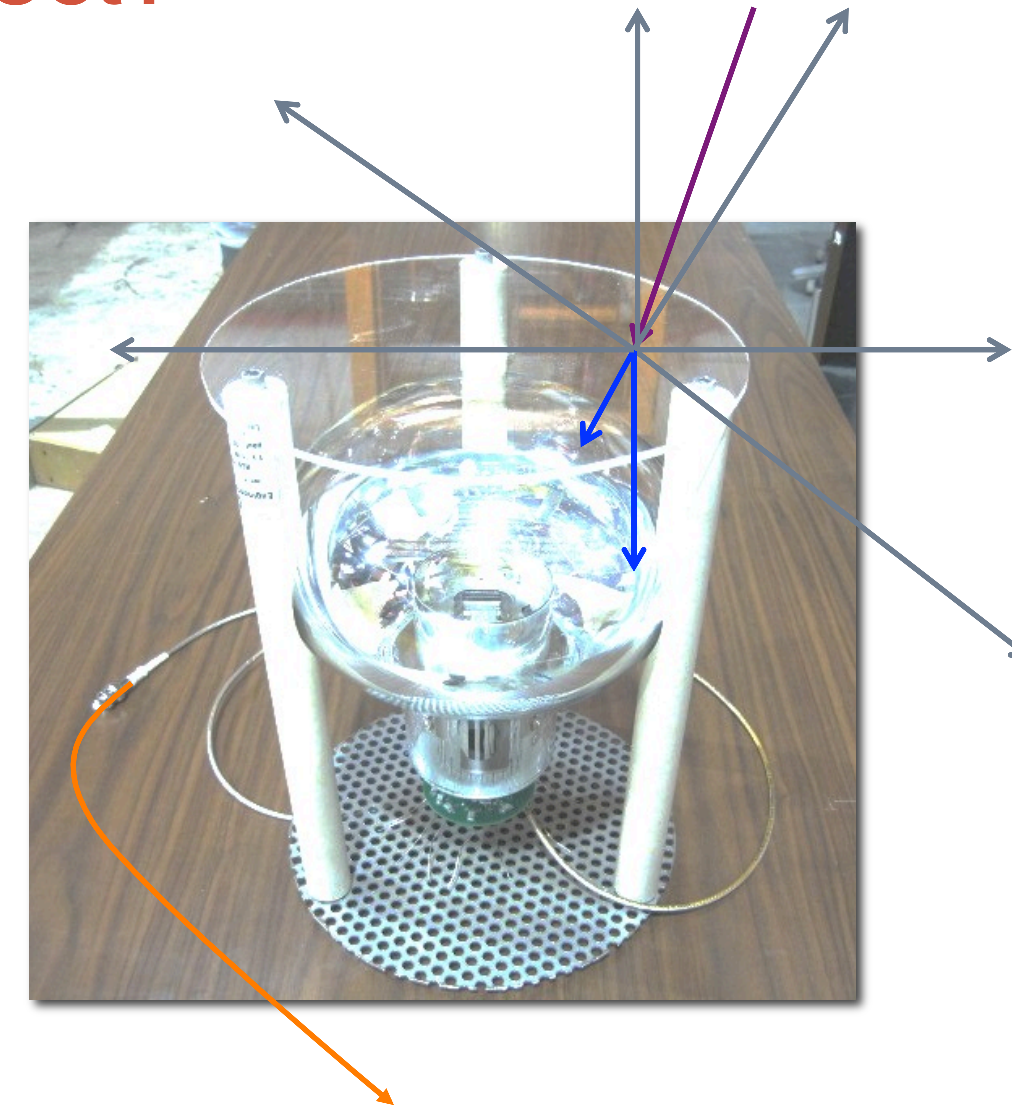
Likely discrepancy due to slightly different assumed geometry



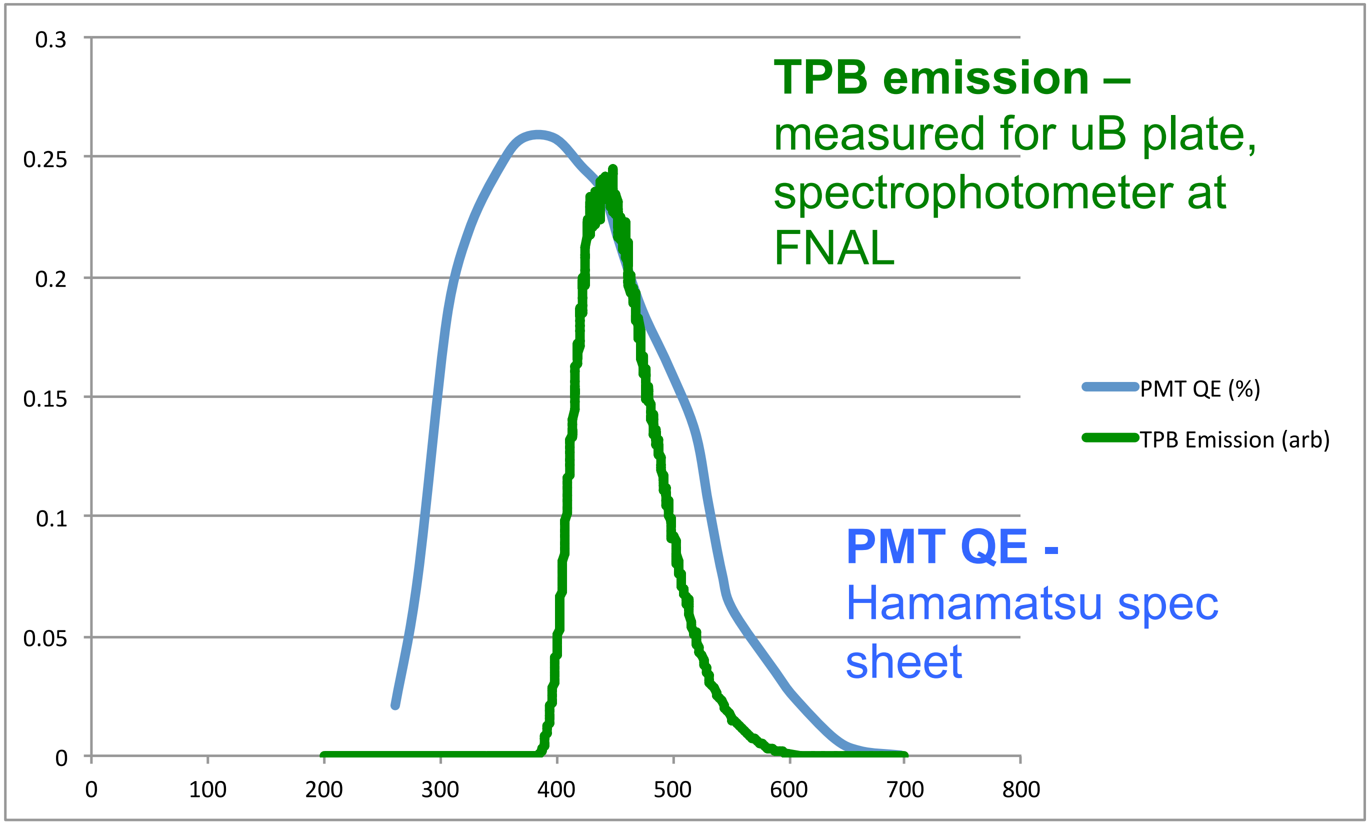
0.3 ± 0.03
PMT angular + geometrical acceptance

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

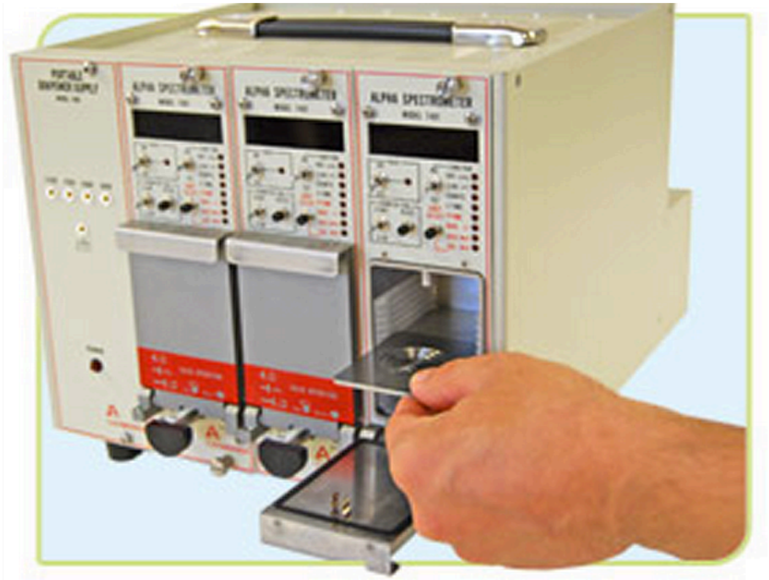
	Our Estimate	*Uncertainty*	*Source*	*Note on Uncertainty*
Absolute WLS efficiency of evaporative plates	1.18	0.1	Gehman et al, arXiv:1104.3259	Error bar from paper
Performance of MicroBooNE plates relative to evaporative plates	0.64	0.11	Our vacuum spec measurements	Error bar from observed fluctuations
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

Polonium Disc Source Energy

Ignarra + Toups (MIT)

- 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.



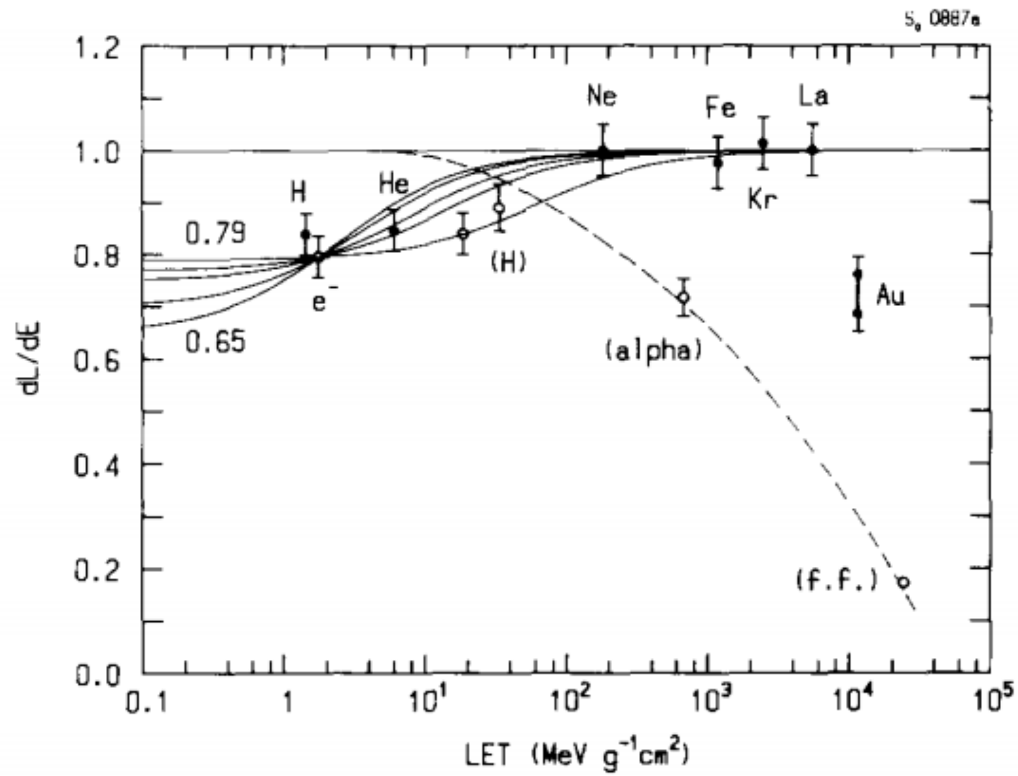
Feb 2013 source: 5313 keV

Jan 2013 source: 5309 keV

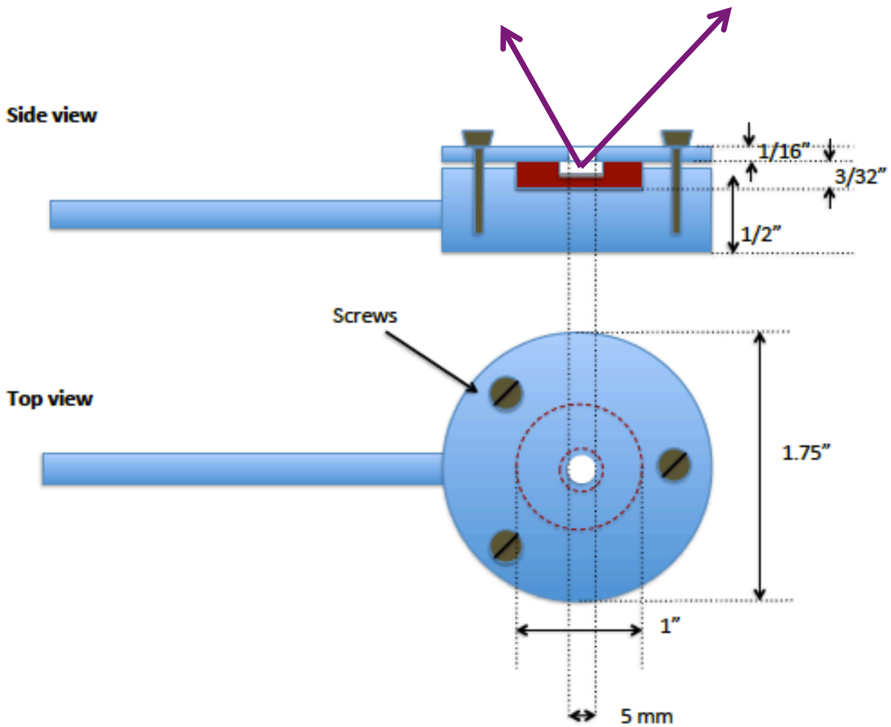
Feb 2012 source: 5309 keV

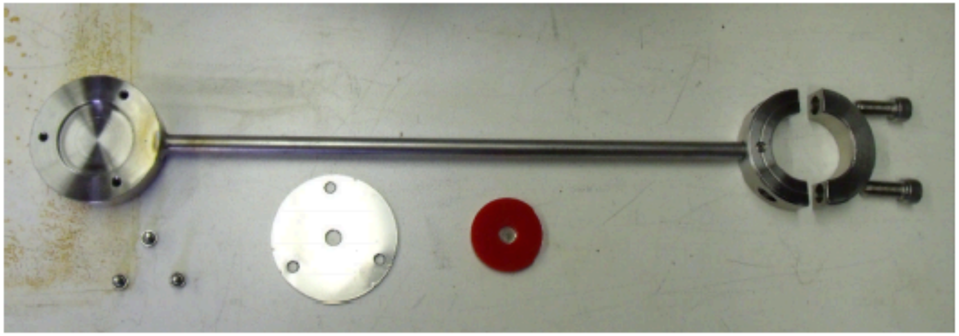
Scintillation Yield Per Alpha

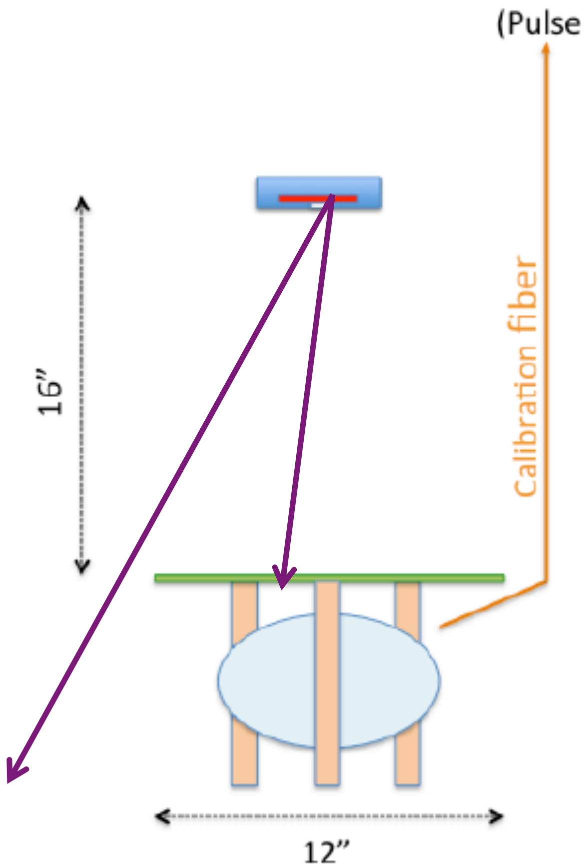
- Ideal scintillation yield with no E field is
  51,000 γ / MeV
- Alpha is nonrelativistic and highly ionizing – quenched by
  Q = 0.71
- We only collect light in first 50ns. This is 99.99% prompt light and 3% late light. Therefore
  f_fast = 0.565



Expected Light Yield at Plate

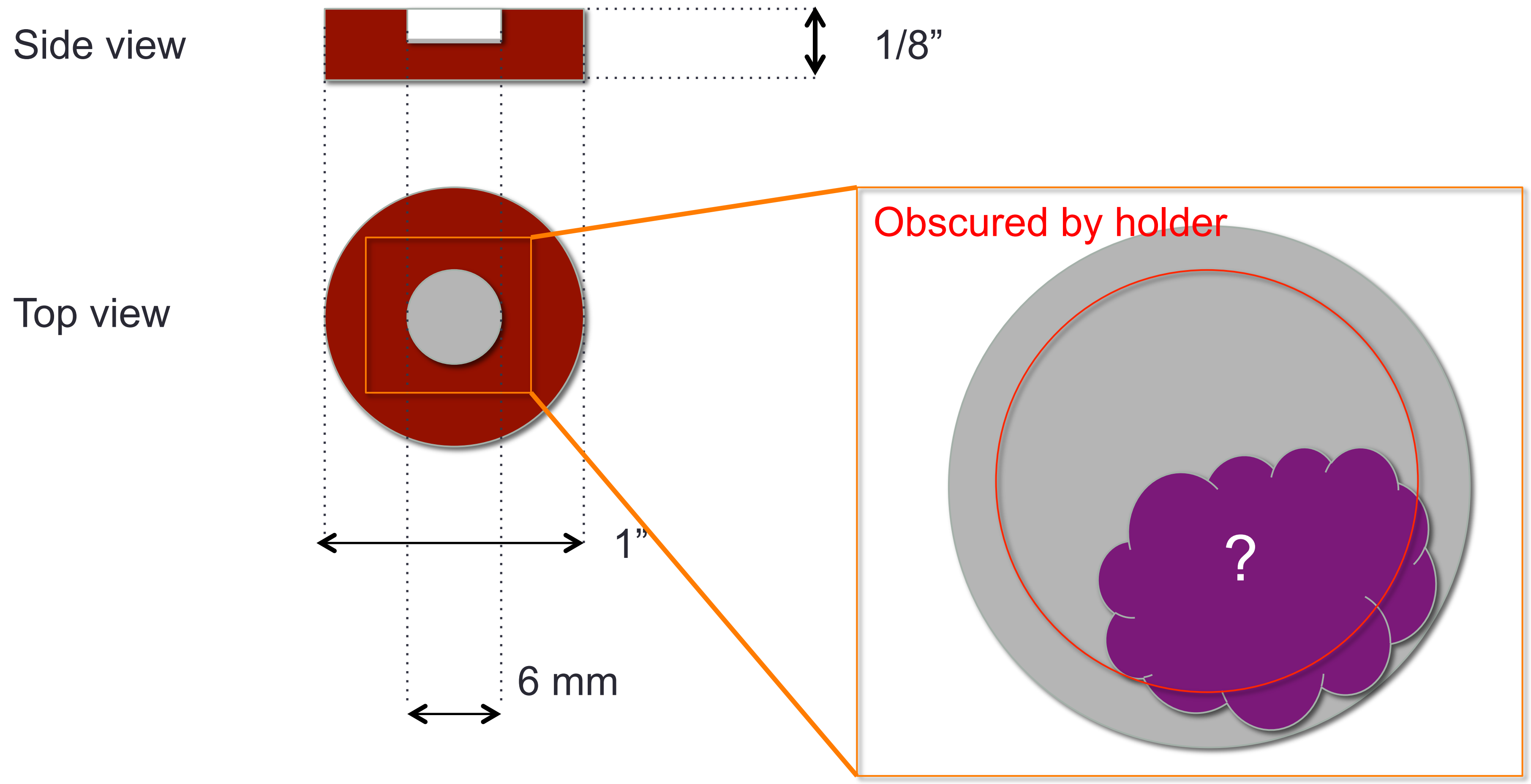






More ray tracing, should be straightforward enough…

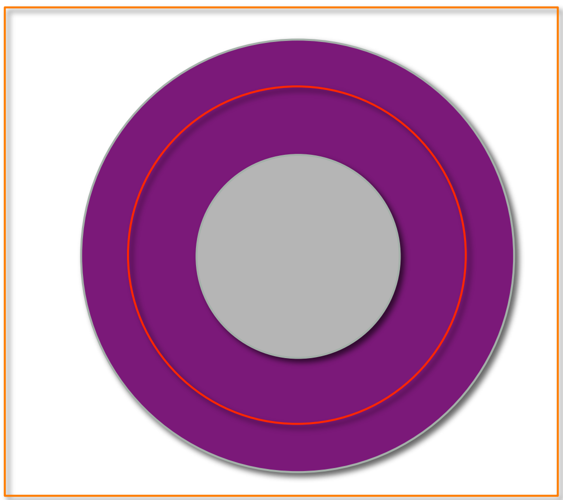
- Nope



Try a few options;

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

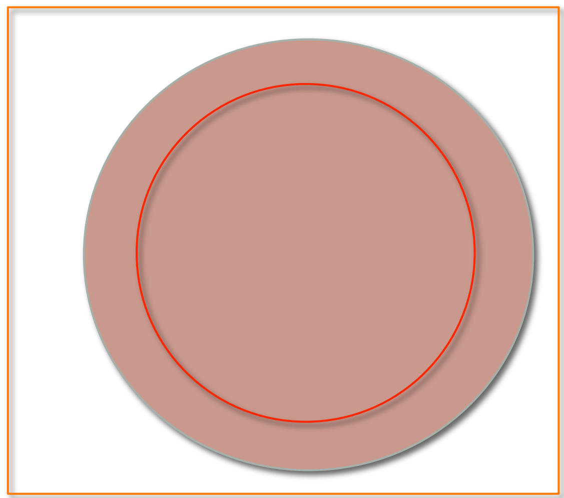
More Obscured



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

¾ of plate area covered

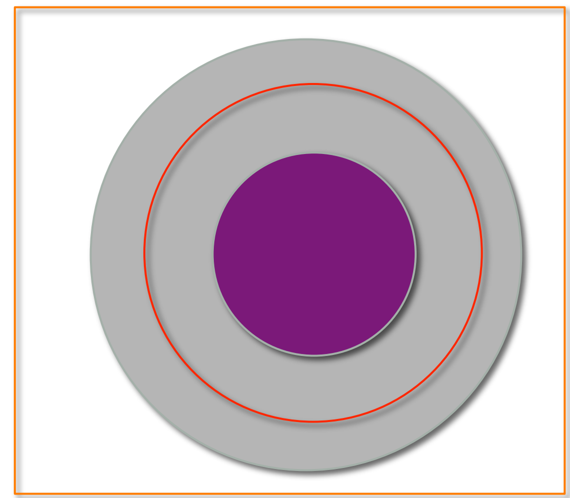
Baseline



0 < r < 3mm : Uniform Source

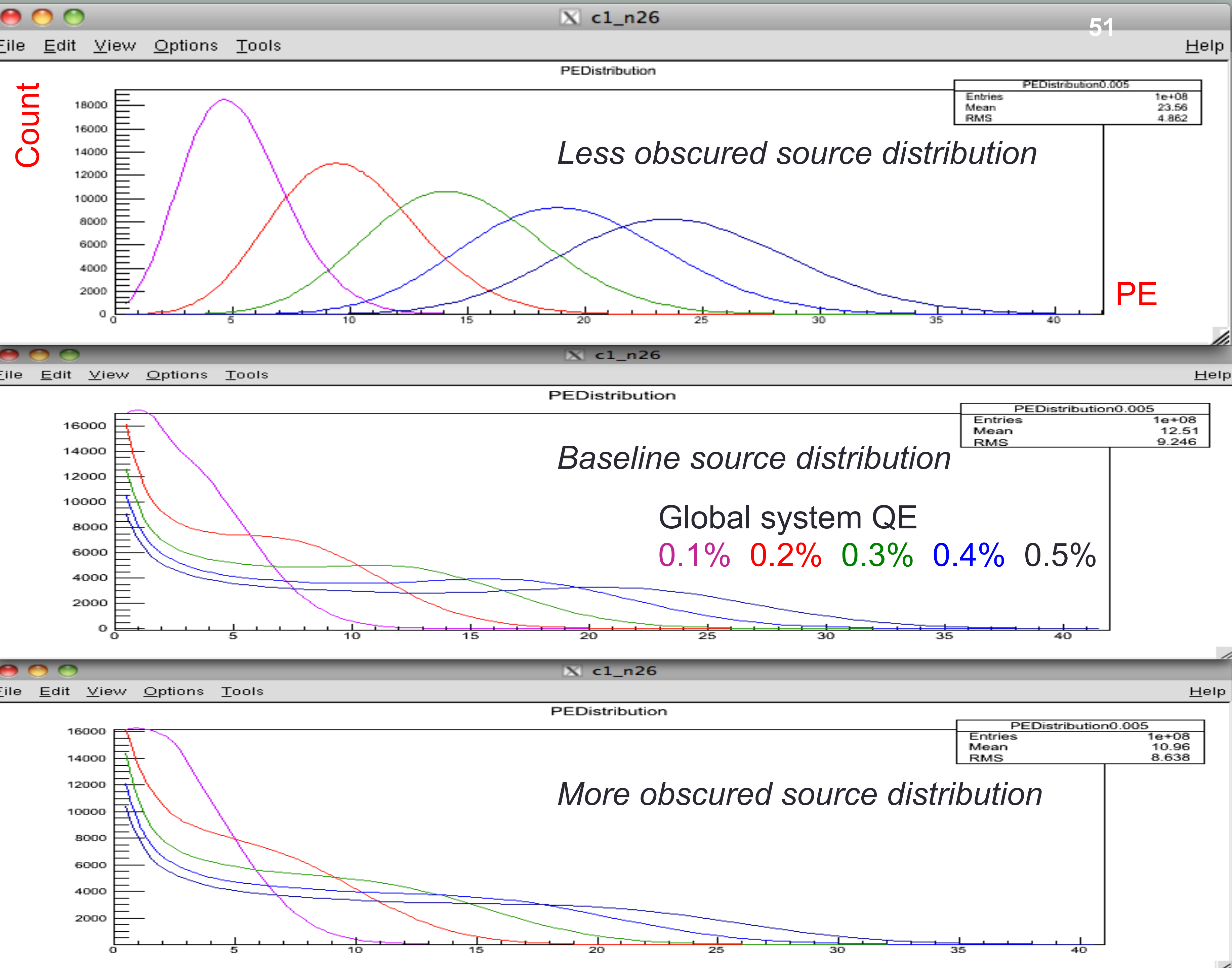
Full plate area covered

Less Obscured



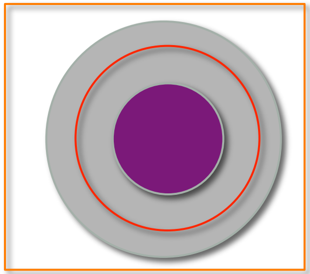
0 < r < 1.5mm : Uniform source
1.5 < r < 3mm : Empty

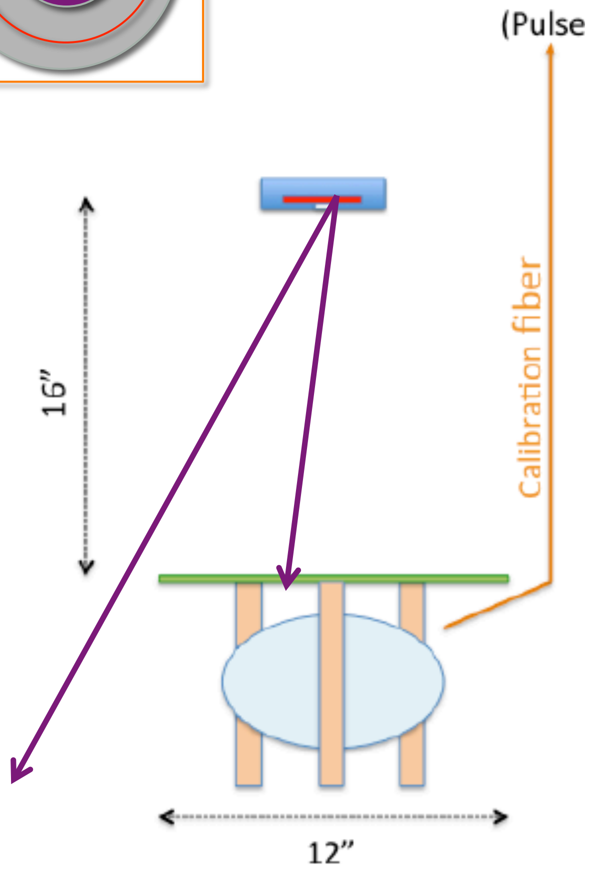
¼ of plate area covered


c1_n26
File Edit View Options Tools Help
PEDistribution
PEDistribution0.005
Entries 1e+08
Mean 23.56
RMS 4.862
Count
PE
Less obscured source distribution
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



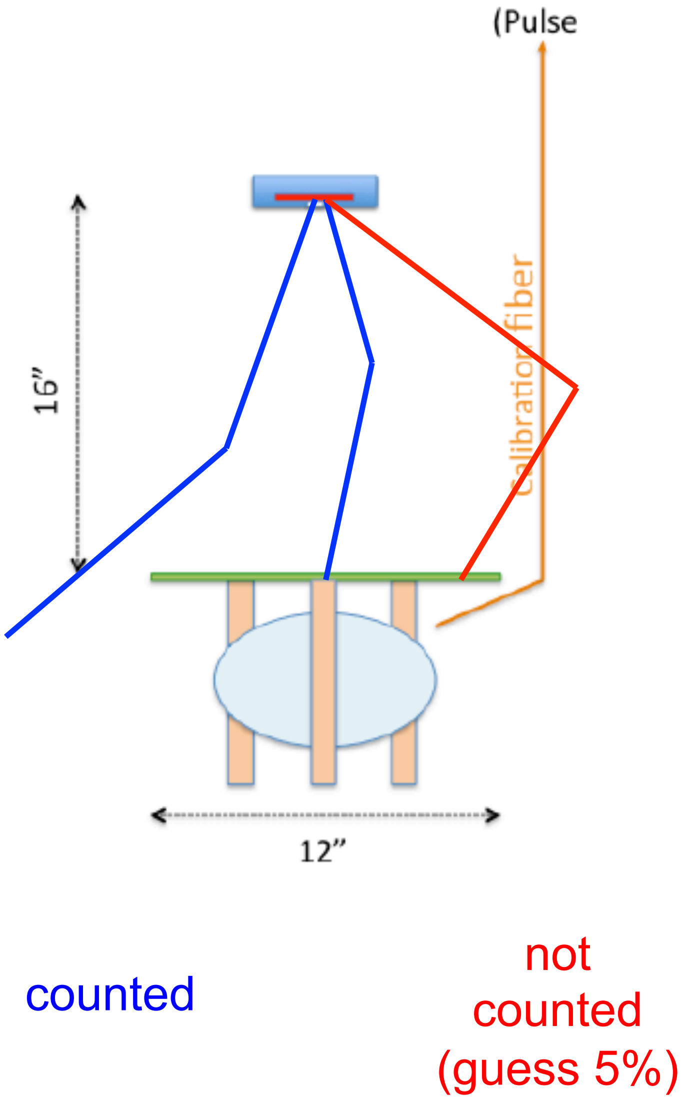


3.75 ± 0.1 %
Solid angle acceptance from source to plate

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

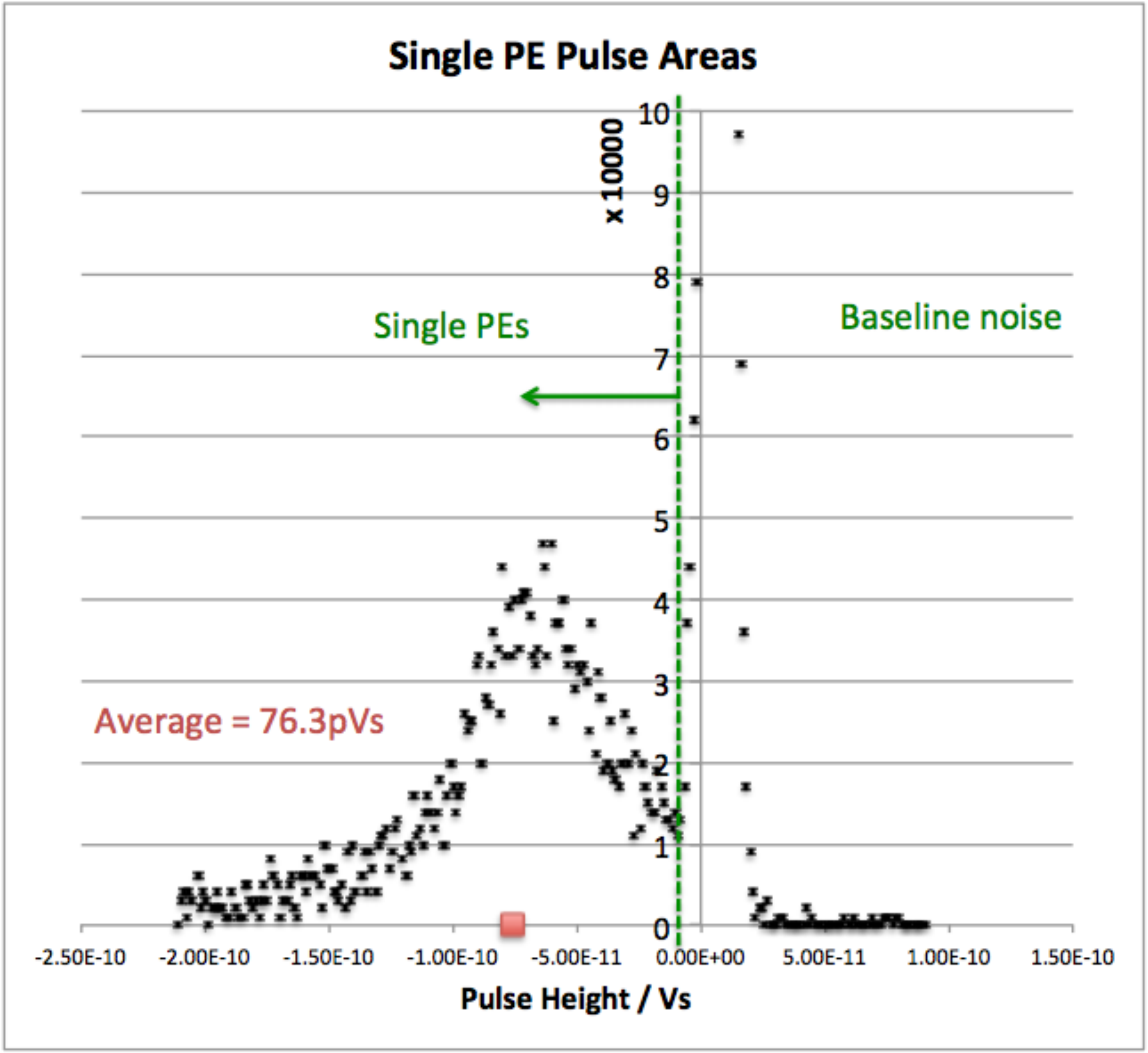
	Value	Uncertainty	*Source*	Uncertainty Comment
210Po Alpha Energy (MeV)	5.3	0.1	From MIT range straggling studies	
Ideal Scint Yield (photons / MeV)	51000	1000	Doke et al, NIM A Volume 269, Issue 1, 291–296	Spread of values given in paper
dEdx Quenching for alpha	0.71	0.04	Doke et al, NIM A Volume 269, 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		

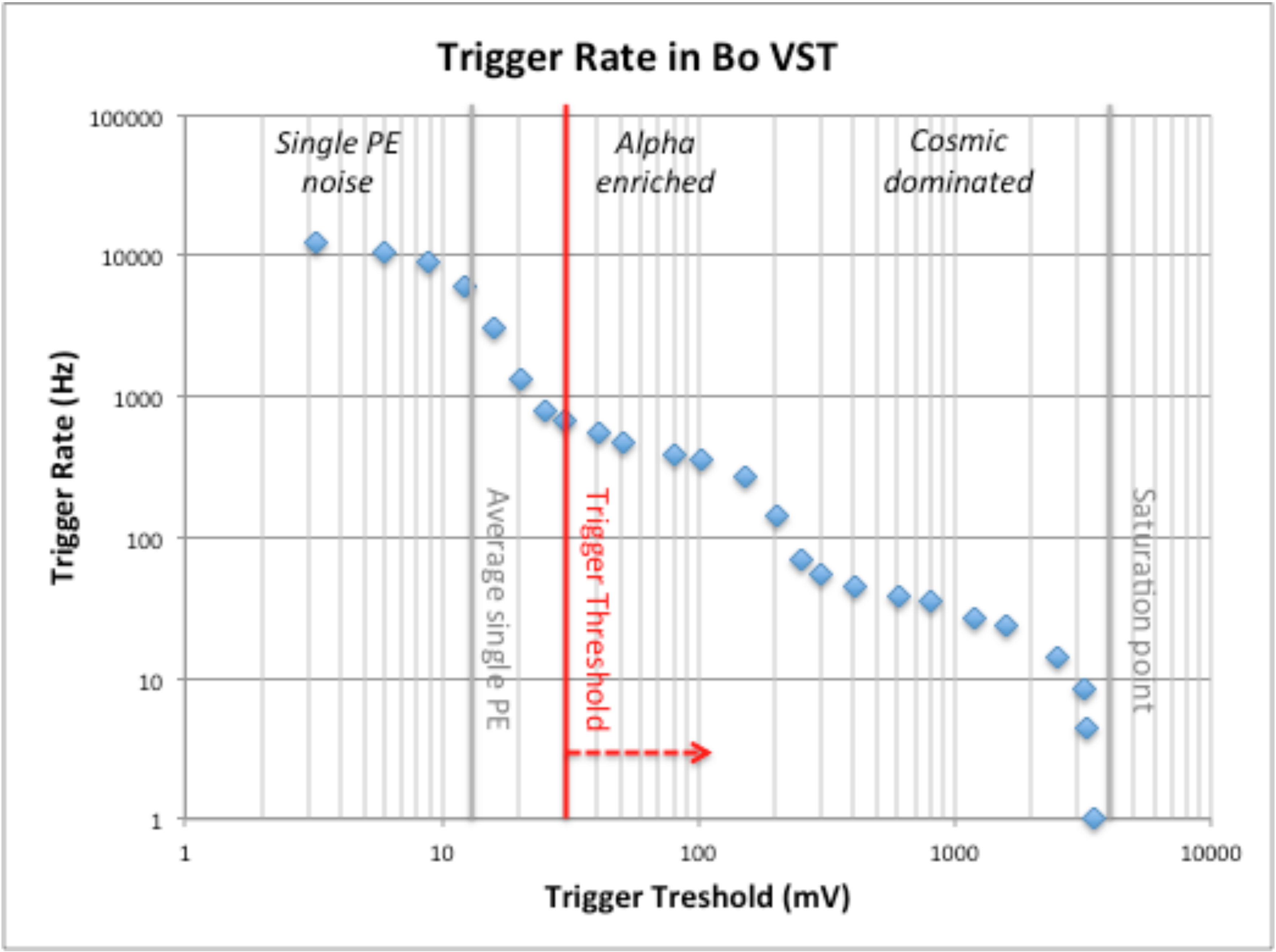
Contents

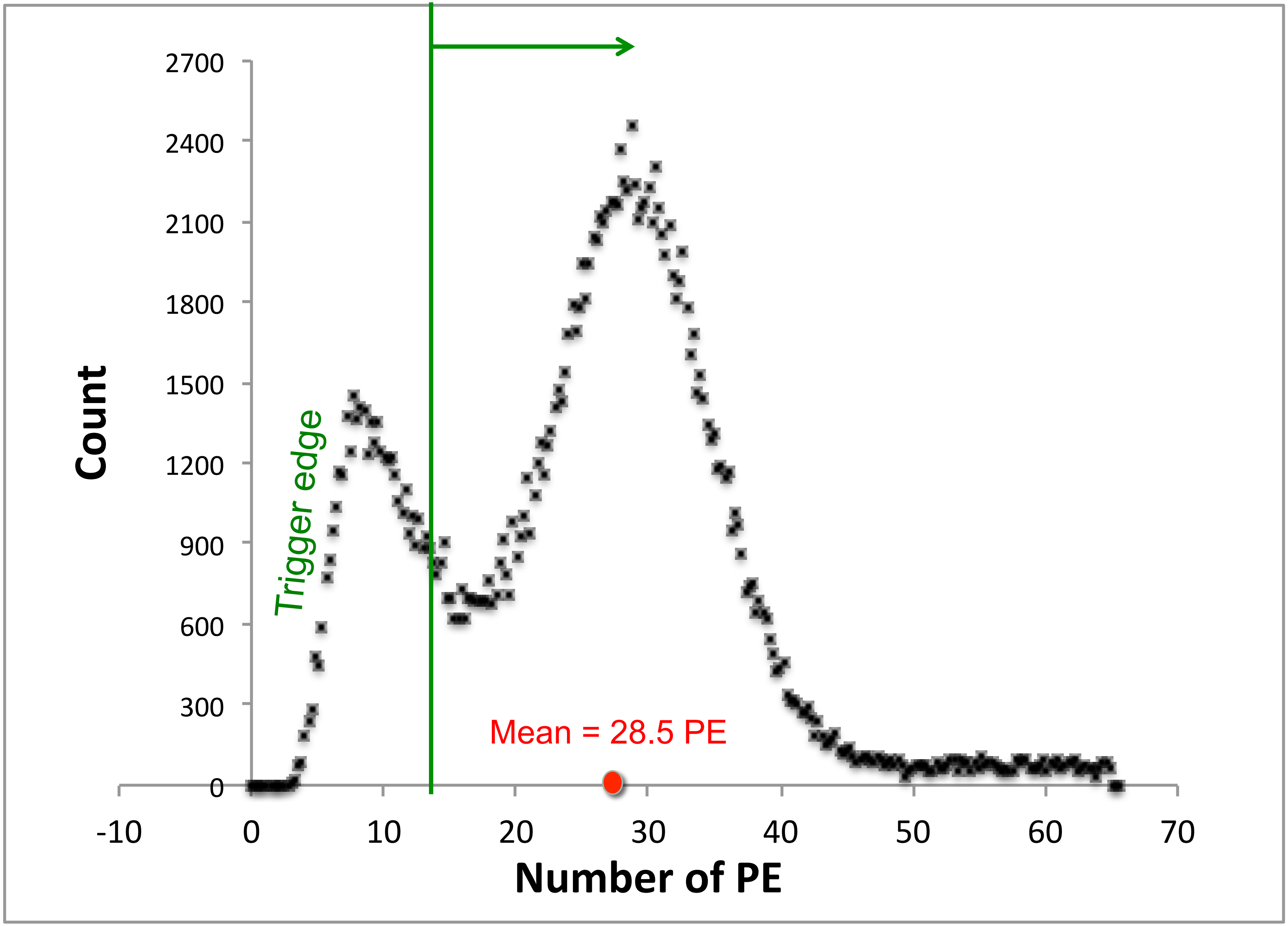
- 1. Prediction of expected GQE
- 2. Expected Light Yield in Bo
- **3. Extraction of GQE from Bo Data**
- 4. Implications for MicroBooNE

How to Extract GQE

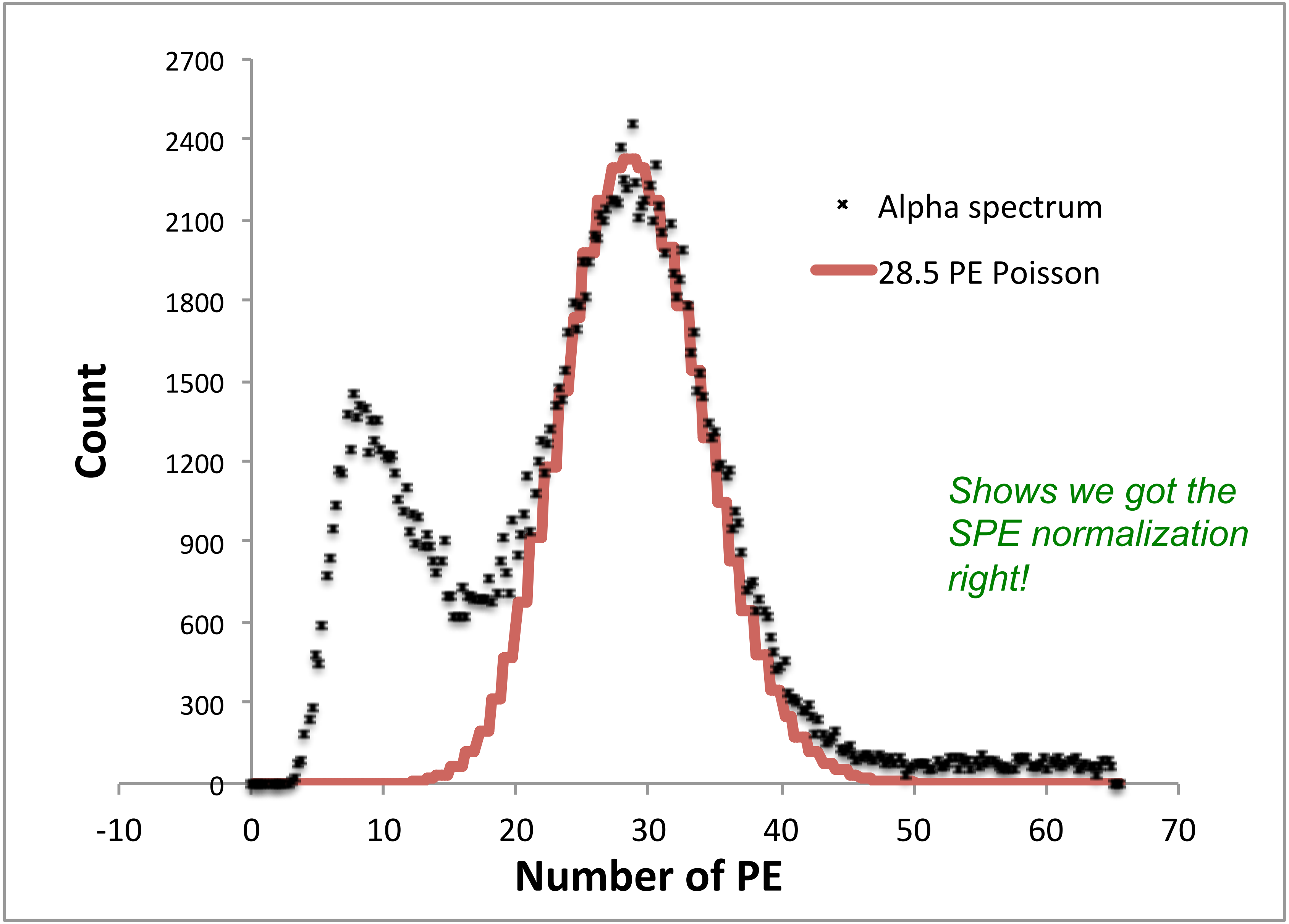
- Measure single PE pulse area spectrum using low intensity pulsed LED
- Measure distribution of areas in a sample of PMT pulses from alpha scintillation light
- Normalize to average single PE area and read off mean # of PE.
- Divide by light prediction to find GQE


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
1
10
100
1000
10000
Trigger Treshold (mV)
Single PE noise
Alpha enriched
Cosmic dominated
Average single PE
Trigger Threshold
Saturation point



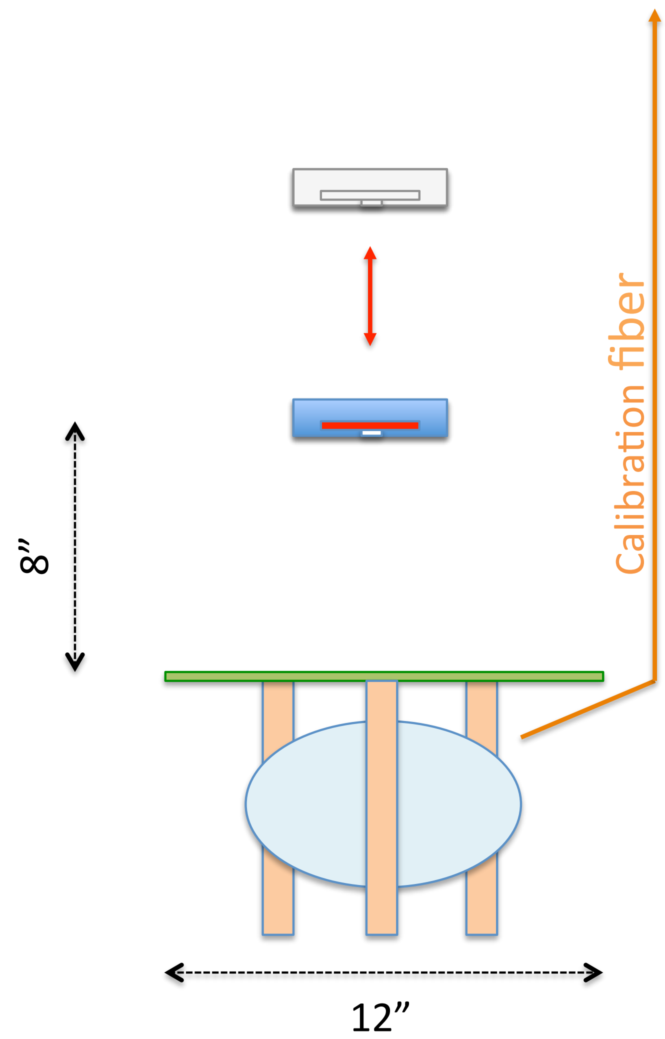
Count
2700
2400
2100
1800
1500
1200
900
600
300
0
-10
0
10
20
30
40
50
60
70
Number of PE
Trigger edge
Mean = 28.5 PE



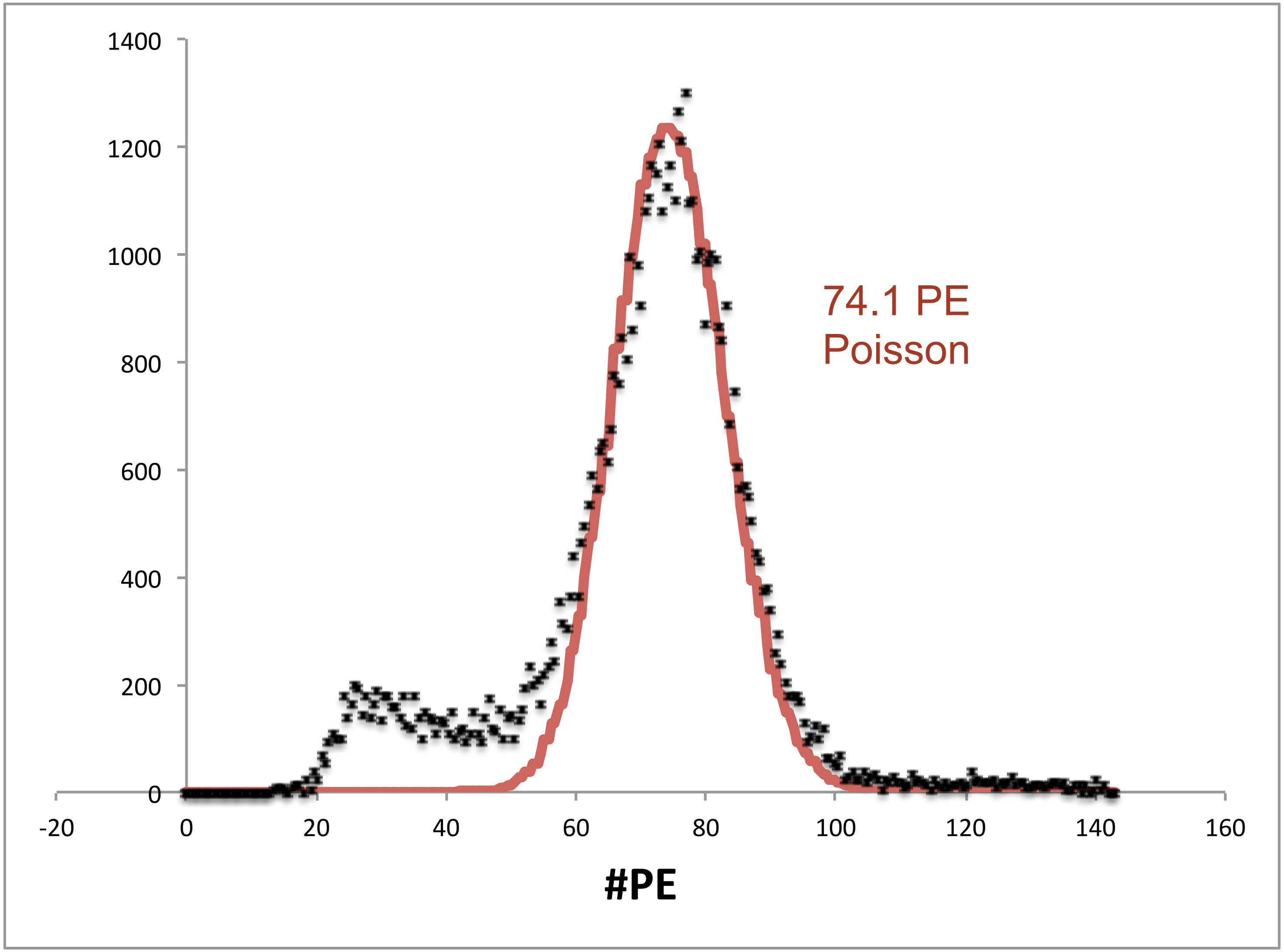
Count
2700
2400
2100
1800
1500
1200
900
600
300
0
-10
0
10
20
30
40
50
60
70
Number of PE
Alpha spectrum
28.5 PE Poisson
Shows we got the SPE normalization right!

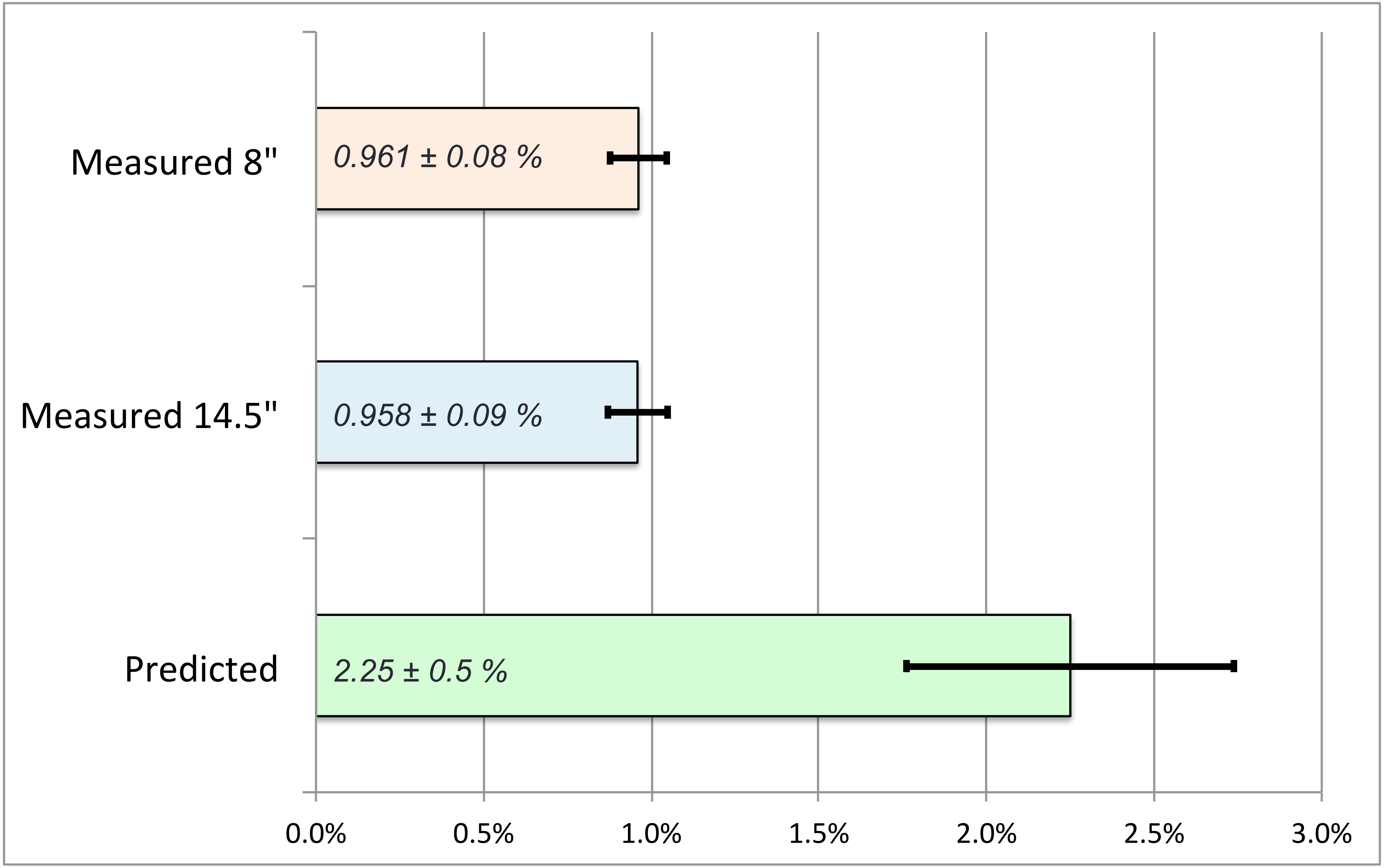
A crosscheck

- 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%