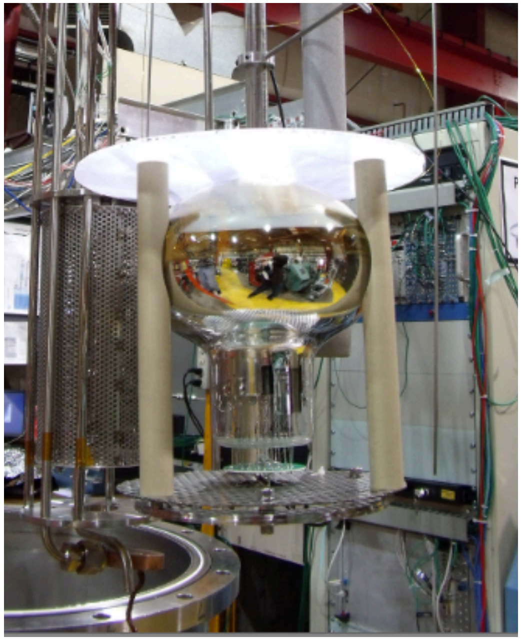
RESULTS FROM THE BO LIQUID ARGON SCINTILLATION TEST STAND AT FERMILAB

Ben Jones, MIT

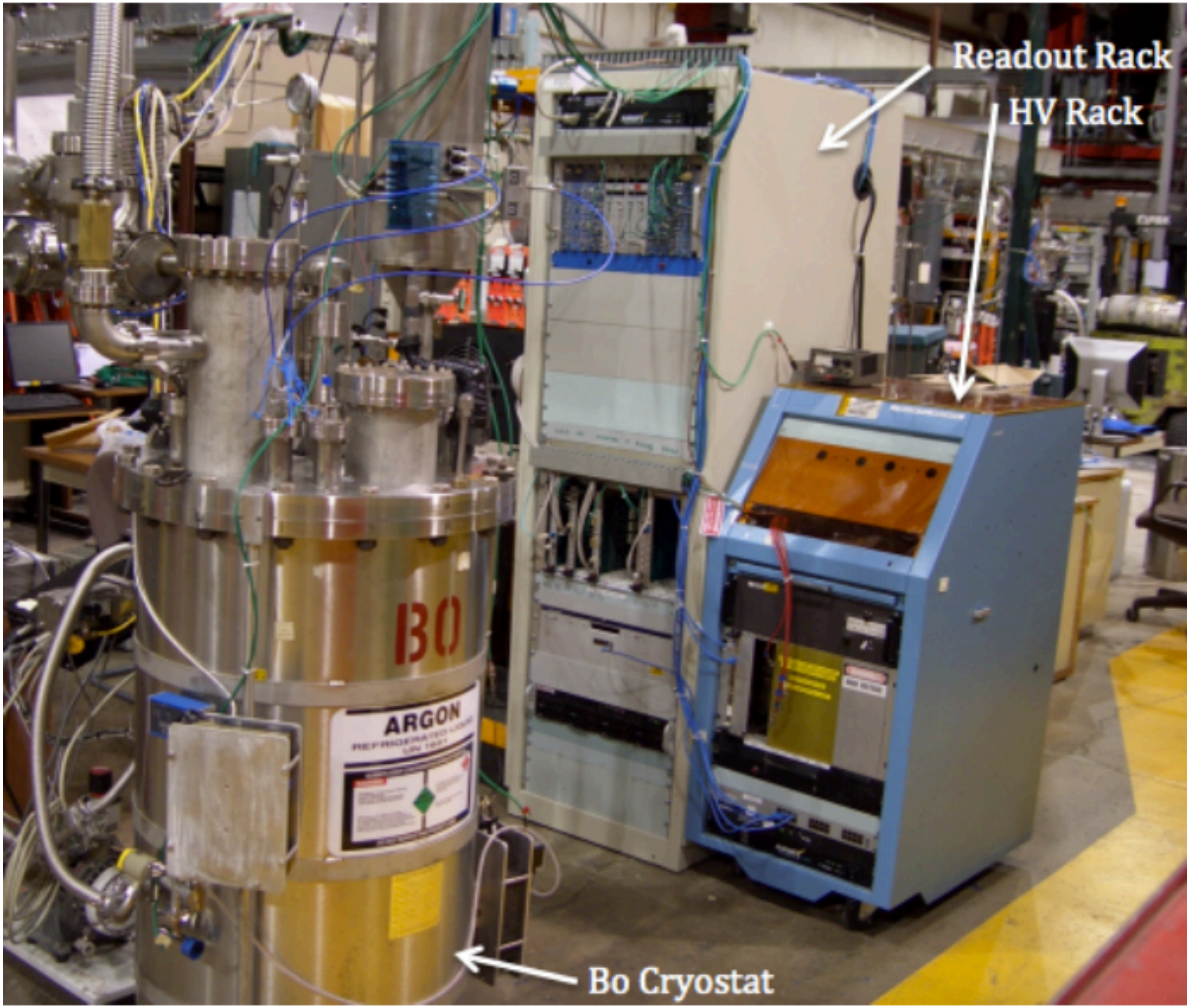
New Perspectives
Fermilab, June 11th 2013



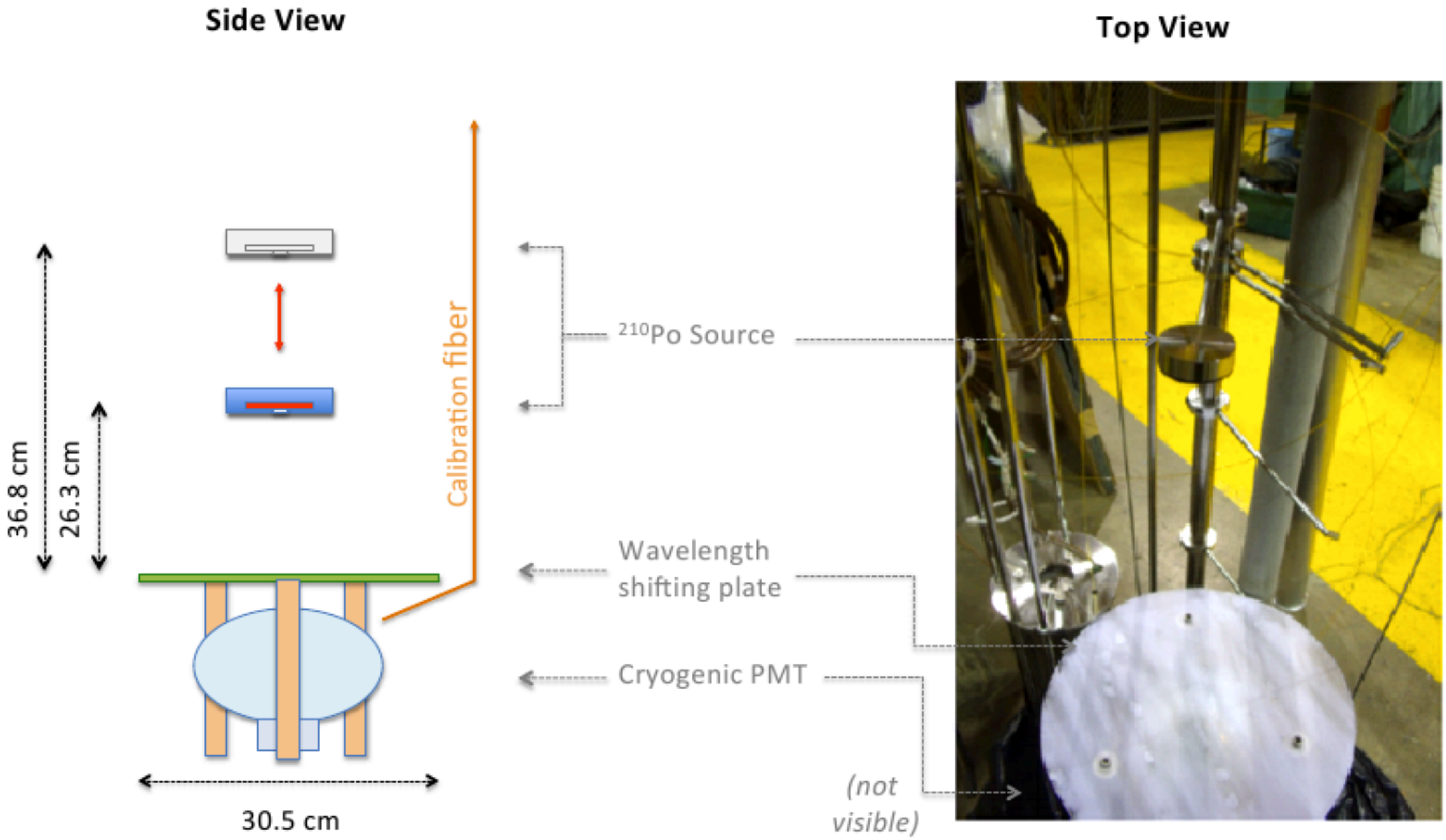
Bo VST Setup

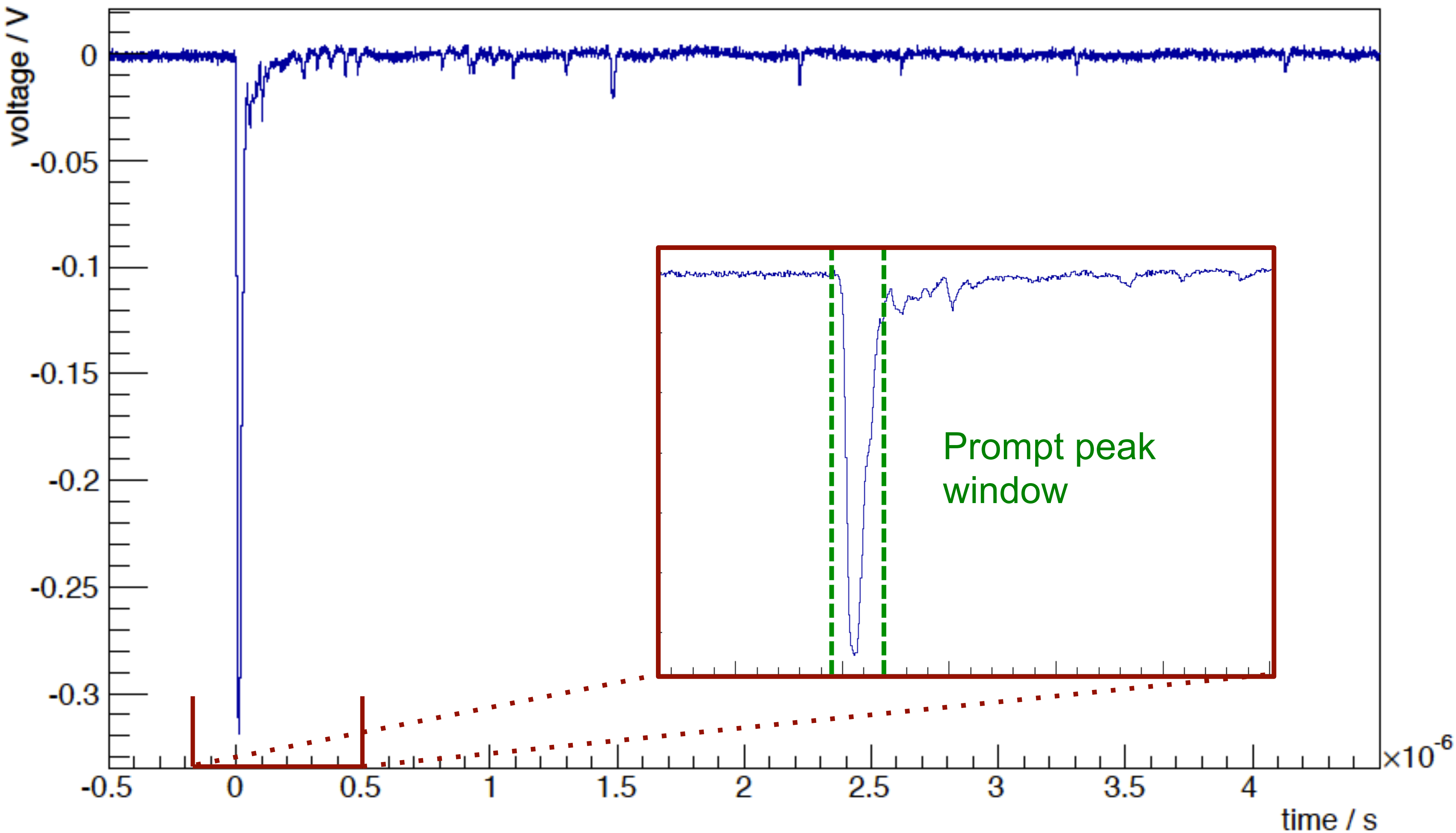
- Bo Vertical Slice Test is a training ground for one slice of the MicroBooNE optical system including:
  - *Cryogenic photomultiplier tubes*
  - *Base electronics*
  - *Wavelength shifting plate*
  - *High voltage system + interlocks*
  - *Cables and splitters*
  - *Readout electronics*
  - *Cryostat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

- **But also a fantastic R&D detector for studying liquid argon scintillation light**


Readout Rack
HV Rack
Bo Cryostat
ARGON
BO

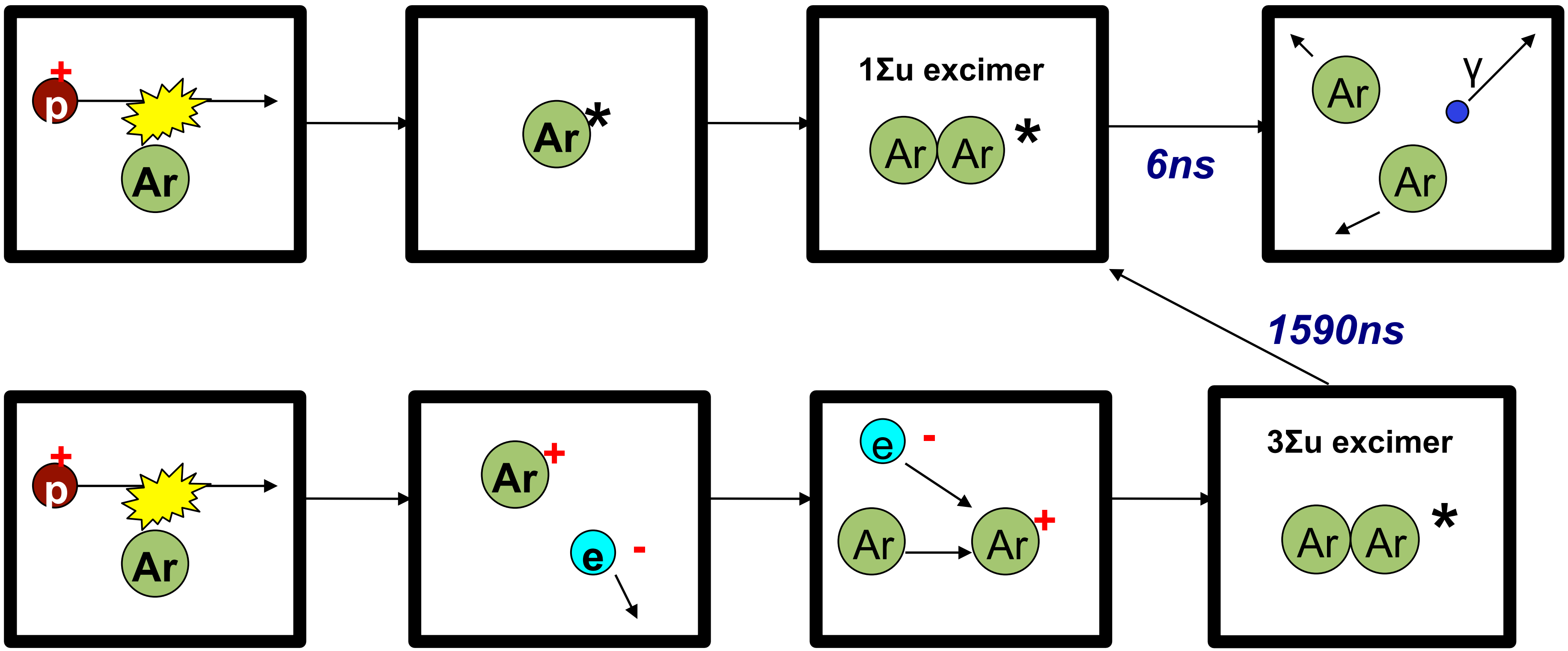
Experimental Configuration for This Study



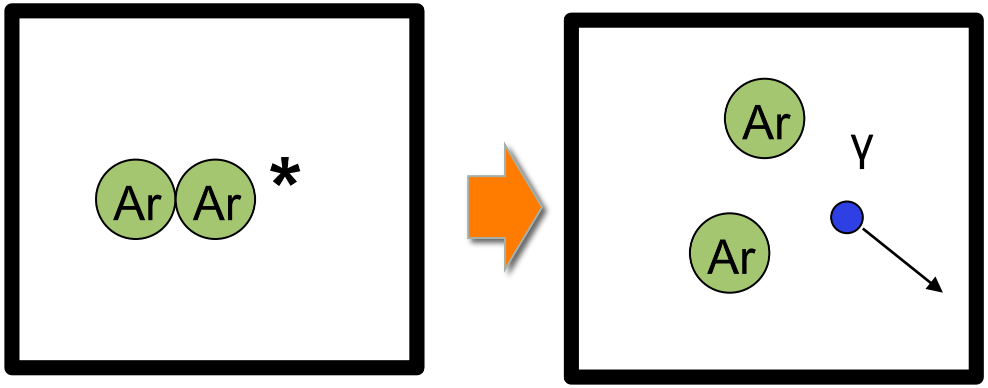

voltage / V
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
×10^-6
time / s
Prompt peak window

Light in Liquid Argon

- The scintillation light in liquid argon is produced copiously alongside all ionization charge deposits.
- There are two scintillation pathways, with different time constants – a fast component with t=6ns and a slow time constant with t=1500ns.

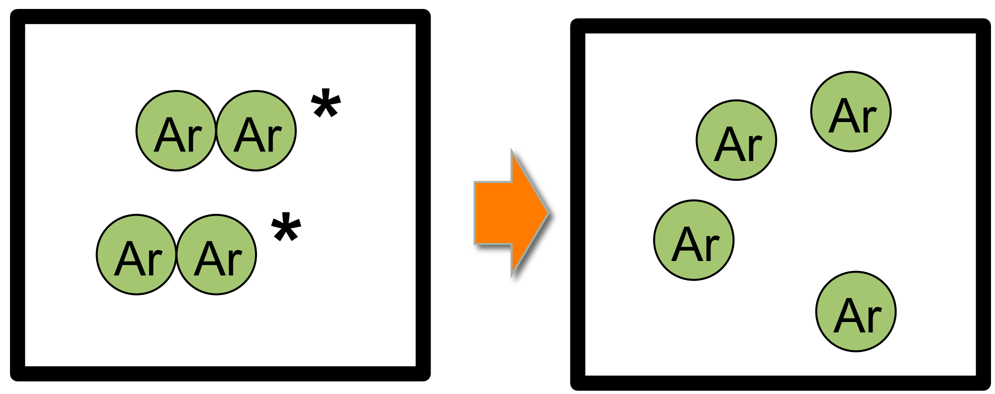


Special bonus – possible PID information



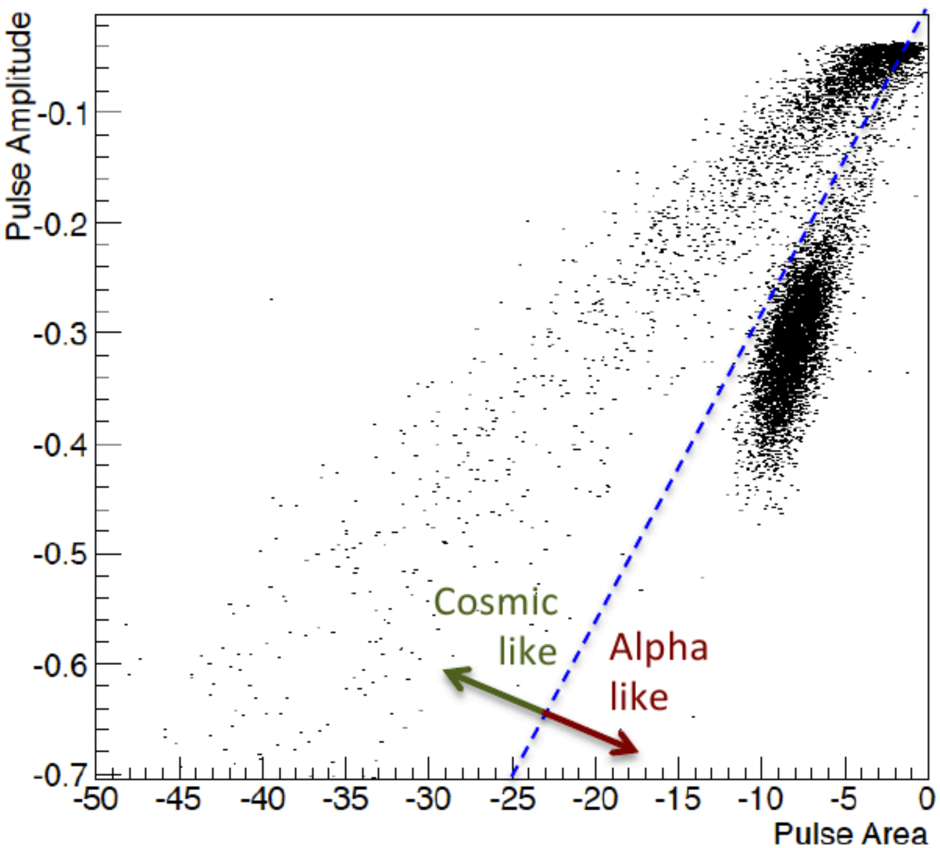
Scintillation process

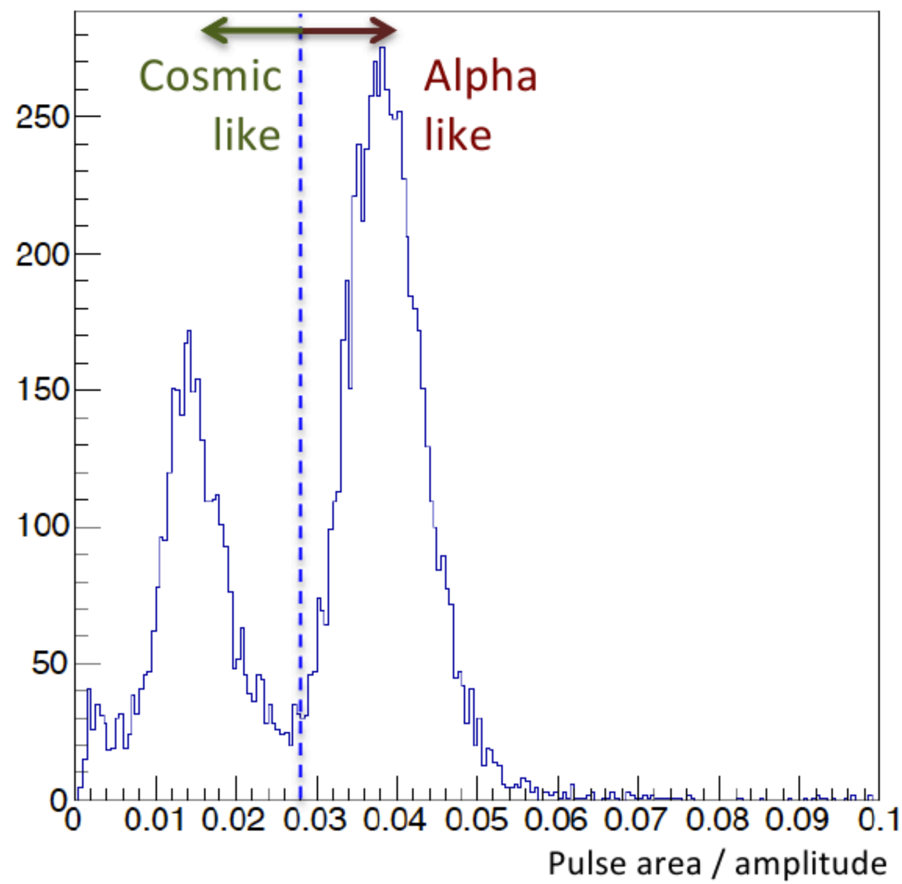
Competing Excimer Dissociation Process



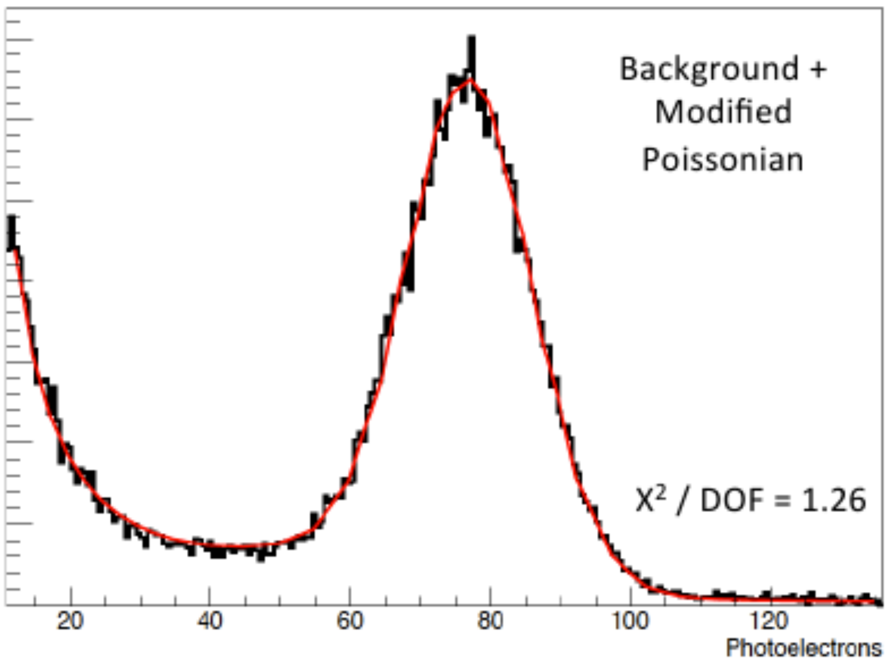
- Utlized in dark matter searches (MiniCLEAN, DEAP), and we are investigating the applications of this technique to augment TPC based particle ID in MicroBooNE.

Pulse shape discrimination – a vital tool in dark matter detection, also useful to us!

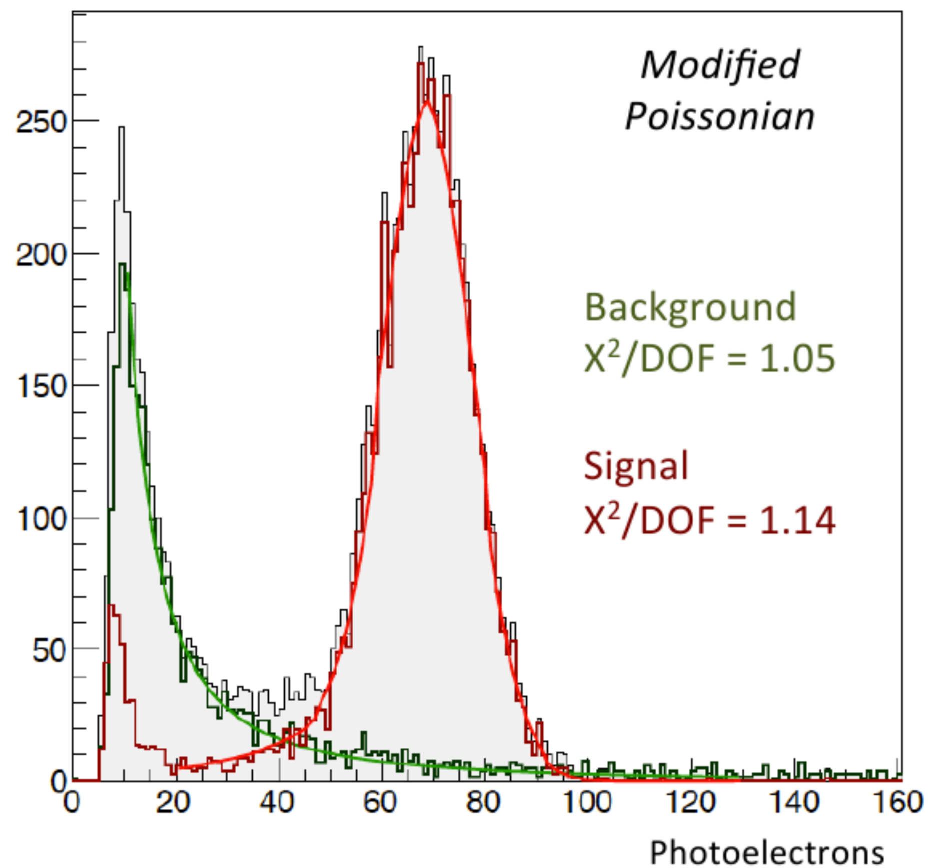




Fit function for alpha + background



Individual components (separated using PSD)



The Effects of Nitrogen in Argon

- Unlike oxygen and water, nitrogen does not disturb charge drift in LArTPCs, and is difficult to remove from argon.
- Part per million (ppm) levels of dissolved nitrogen are expected to be present in any large future LArTPC detector

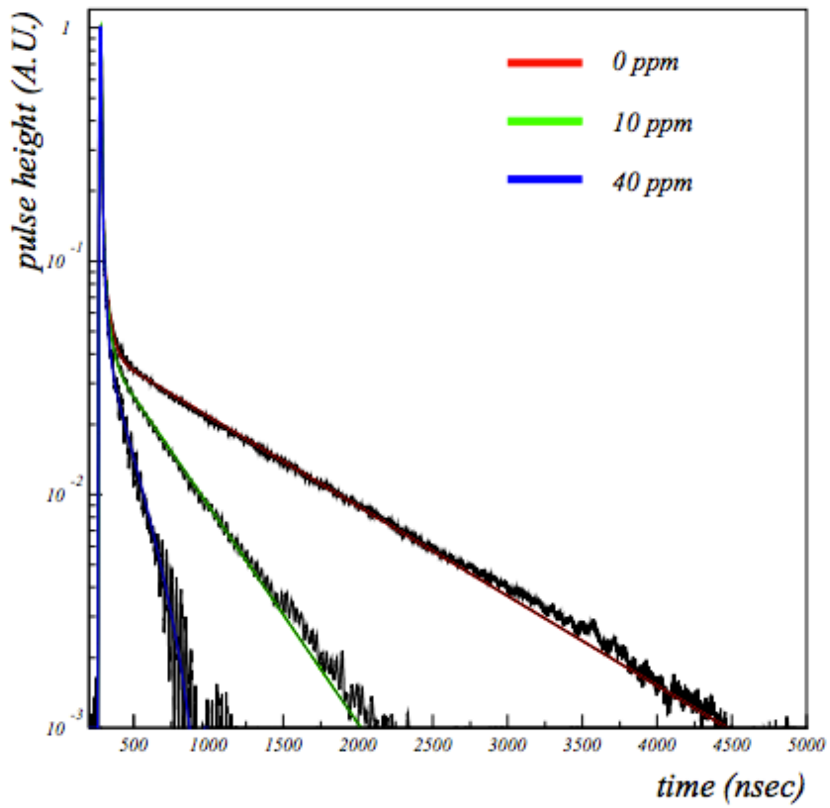
- Nitrogen at the ppm level leads to :

- **1) Scintillation Quenching**

  measured in a detailed study by the WArP collaboration in small test cells
  (R Acciarri et al 2010 JINST 5 P06003)

- **2) Absorption of Scintillation Light**

  Absorption effects of N2 in LAr have not previously been measured



(late light lifetime is affected by N2 – So can’t use PSD for this study)

Our Paper (coming soon…)

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

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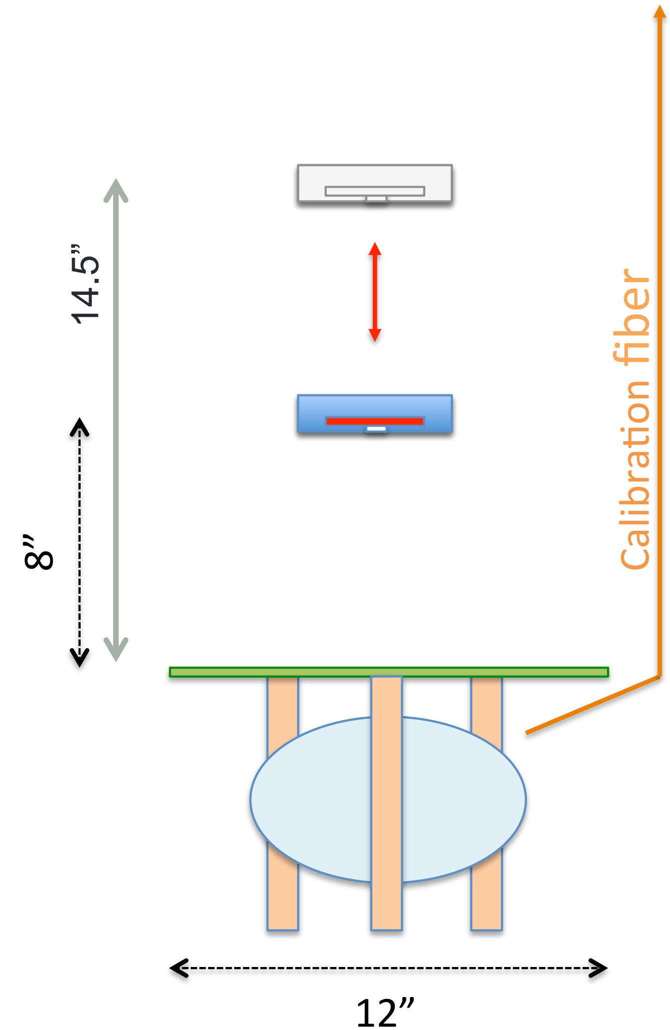
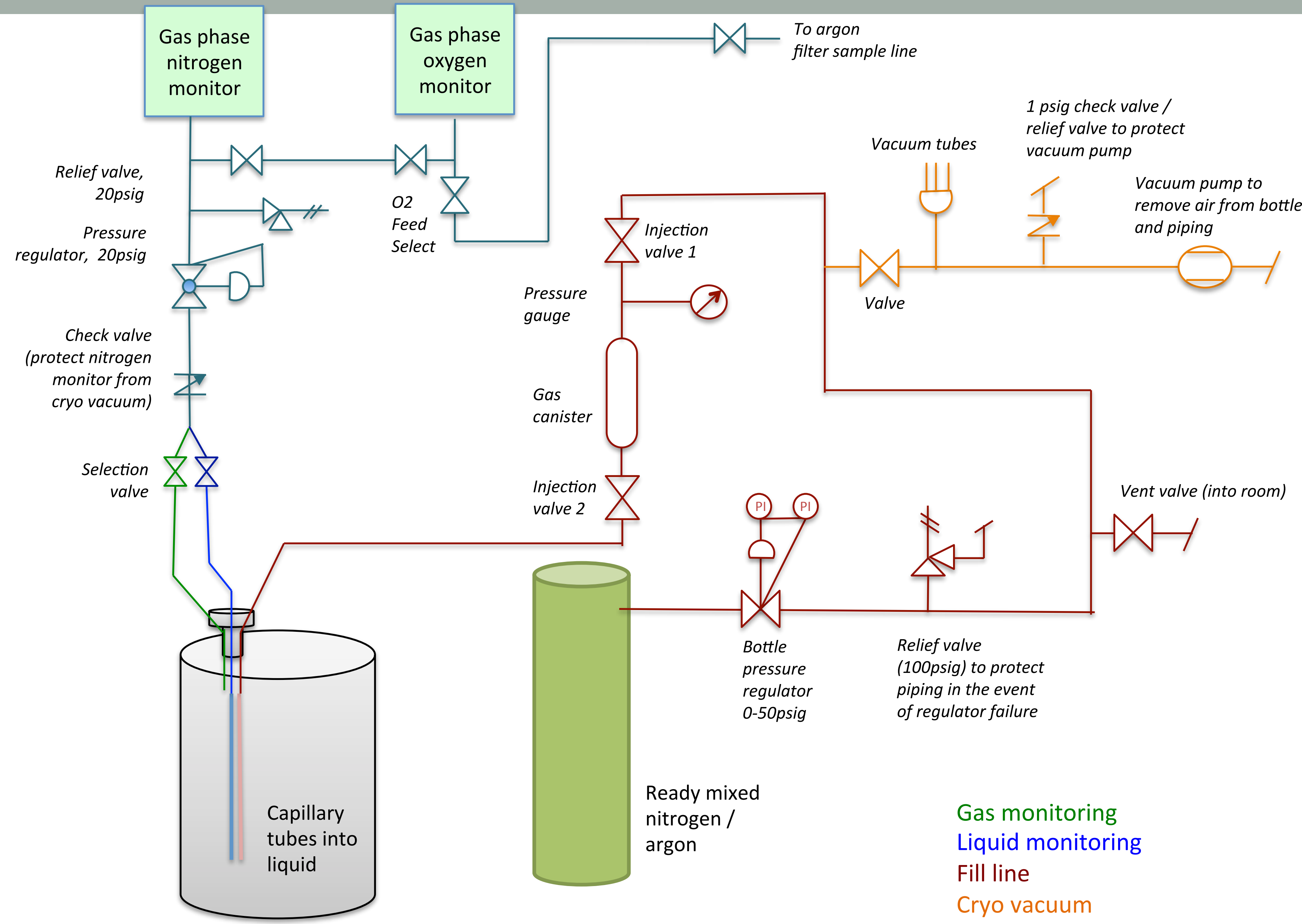
ABSTRACT: We report on a measurement of the absorption length of scintillation light in liquid argon due to dissolved nitrogen at the part per million level. We inject controlled quantities of nitrogen into a high purity volume of liquid argon and monitor the light yield from an alpha source. The source is 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 $(1.51 \pm 0.15) \times 10^{-4}$ cm^{-1}ppm^{-1}, corresponding to an absorption cross section of $(4.99 \pm 0.51) \times 10^{-21}$ 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 LArTPC detectors. Our results indicate that for a current generation LArTPC where a concentration of 2 parts per million of nitrogen is expected, the attenuation length due to nitrogen will be 30 ± 3 meters.

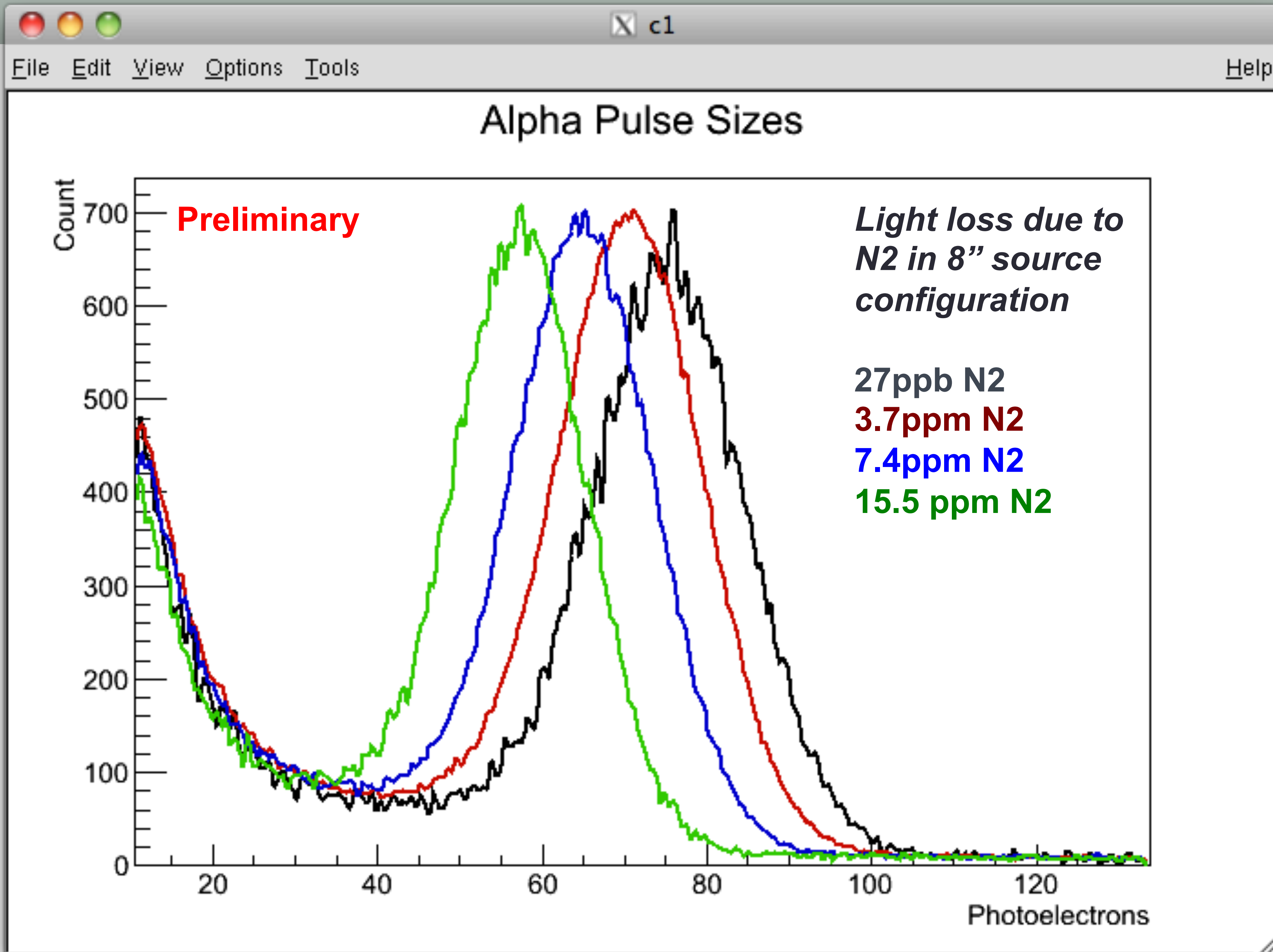
General Idea:

- Source set in one of two possible positions.
- Controlled amounts of N2 injected into the liquid
- Quenching affects both source positions equally
- Absorption hinders the further more than the nearer source.
- If fractional losses from each source deviate we see an N2 absorption length effect.
- A future analysis will address the effects of quenching (more extensively studied by other groups) separately.

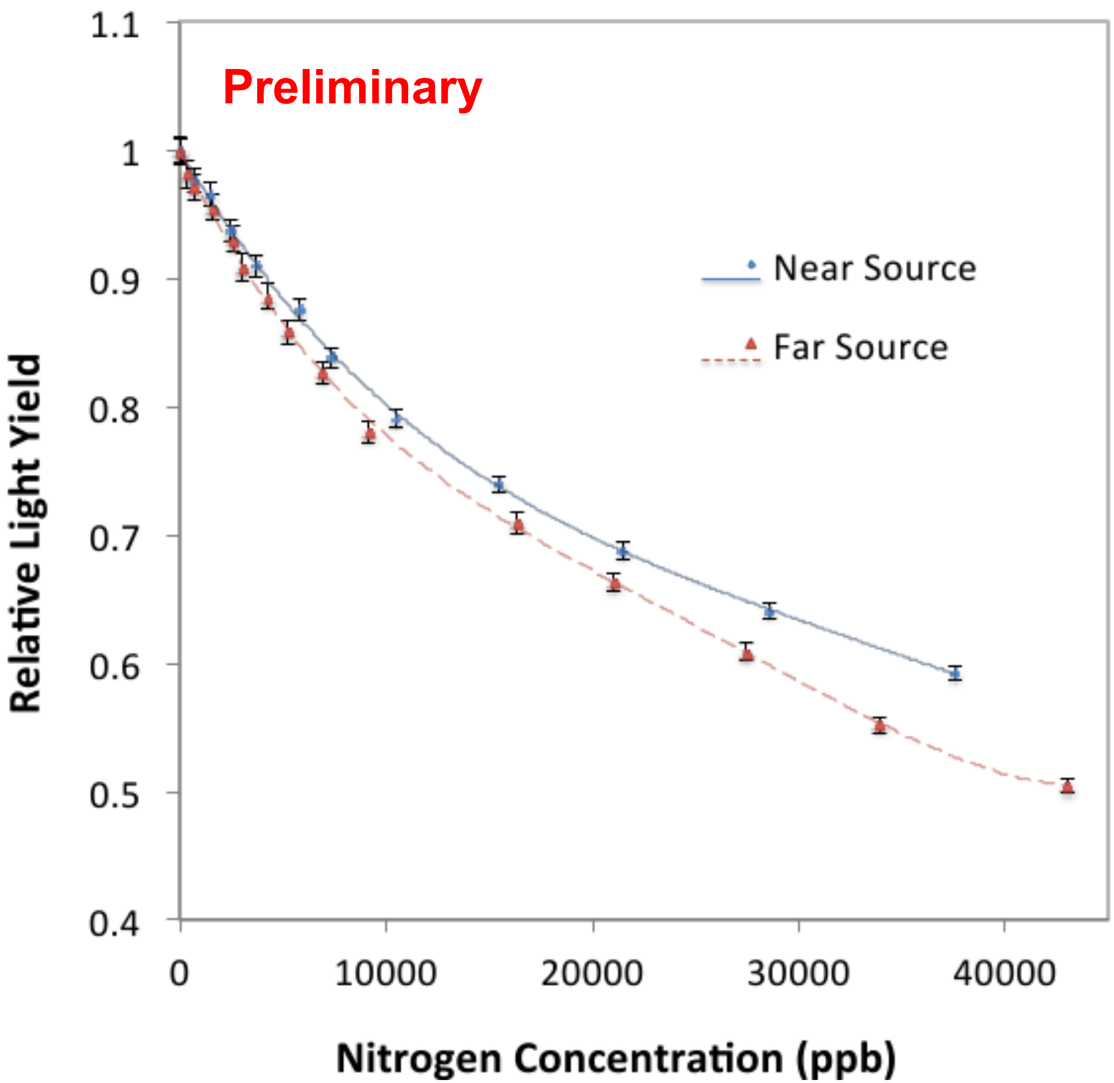


- PPM amounts of nitrogen are injected into the liquid from a gas canister, charged to a known pressure.
- From known volume of canister and known pressure we can calculate how many ppm we injected.
- Nitrogen concentration monitored in both liquid and gas phases using LDetek8000 N2 monitor
- We also 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
Check valve (protect nitrogen monitor from cryo vacuum)
Selection valve
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
Gas canister
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

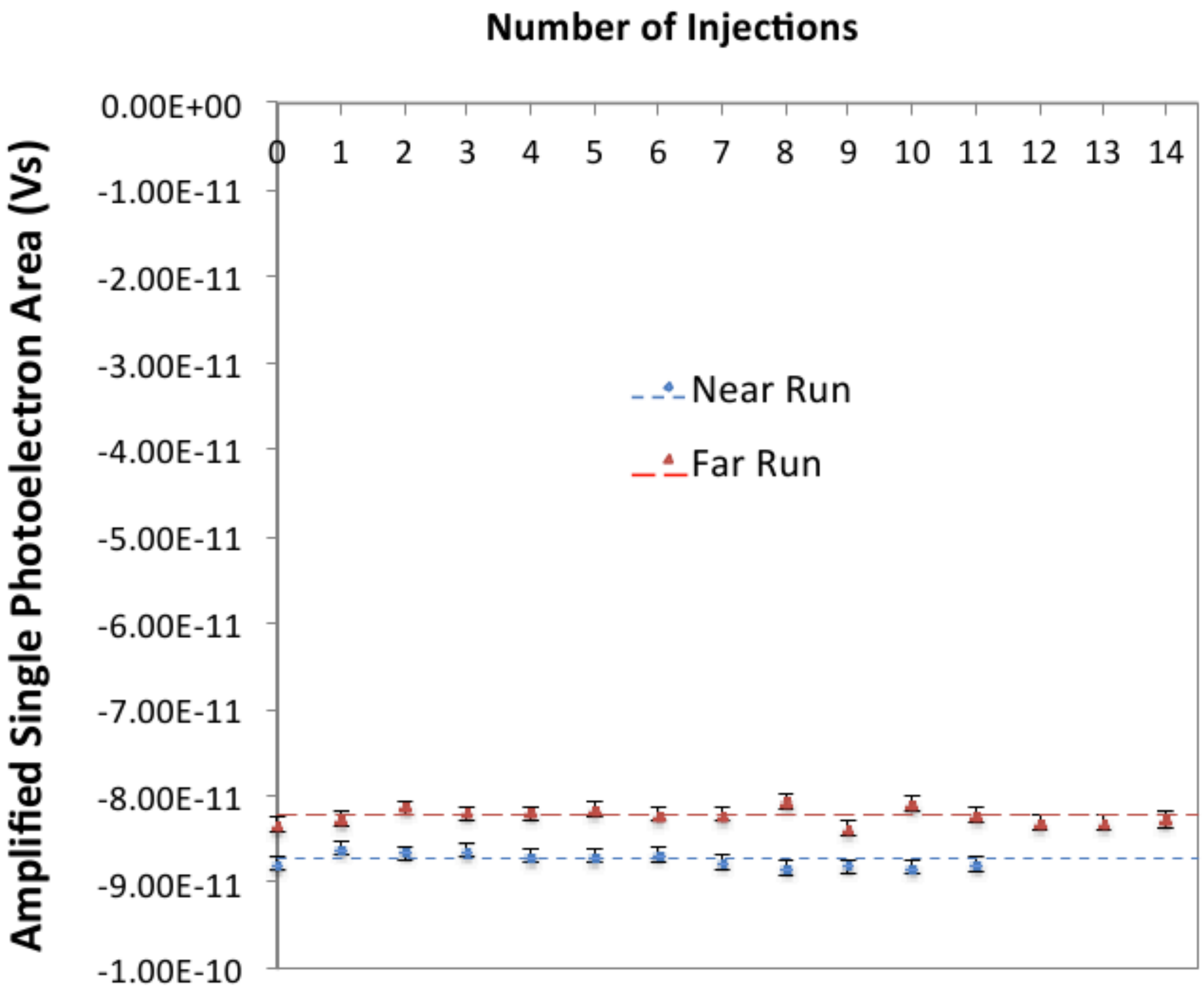

c1
File Edit View Options Tools Help
Alpha Pulse Sizes
Count
Preliminary
Light loss due to N2 in 8" source configuration
27ppb N2
3.7ppm N2
7.4ppm N2
15.5 ppm N2
0
100
200
300
400
500
600
700
20
40
60
80
100
120
Photoelectrons

Attenuation Data



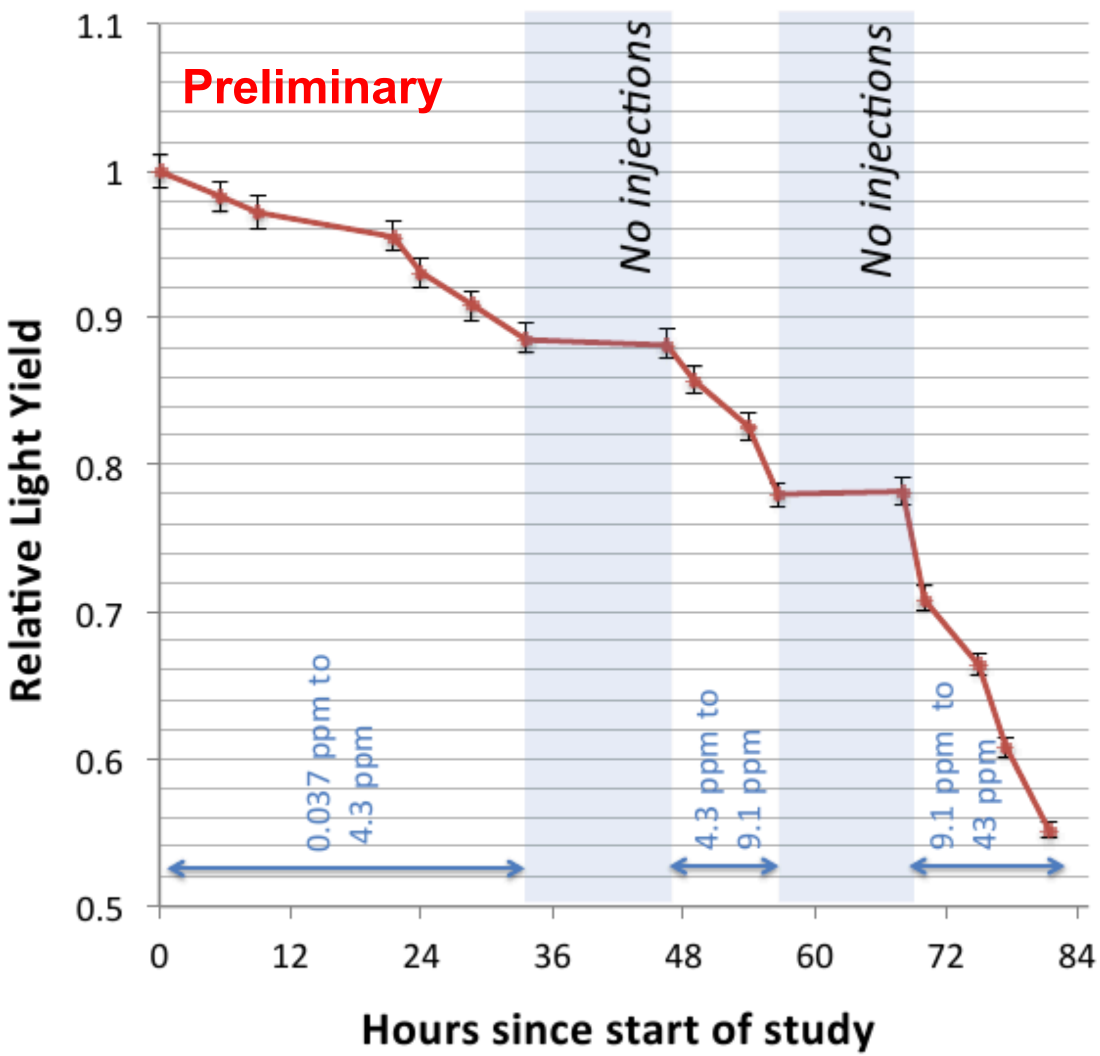
Divergence of these two lines is clear evidence for the nitrogen absorption effect!

Stability of 1PE



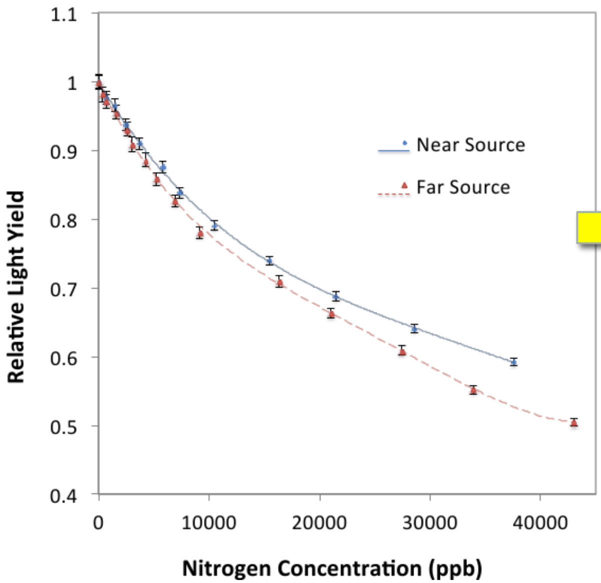
- SPE scale stable to within 1% for each run
- This is similar to the precision of our SPE measurements
- Therefore we assume constant and fold in variations as a systematic error on each point

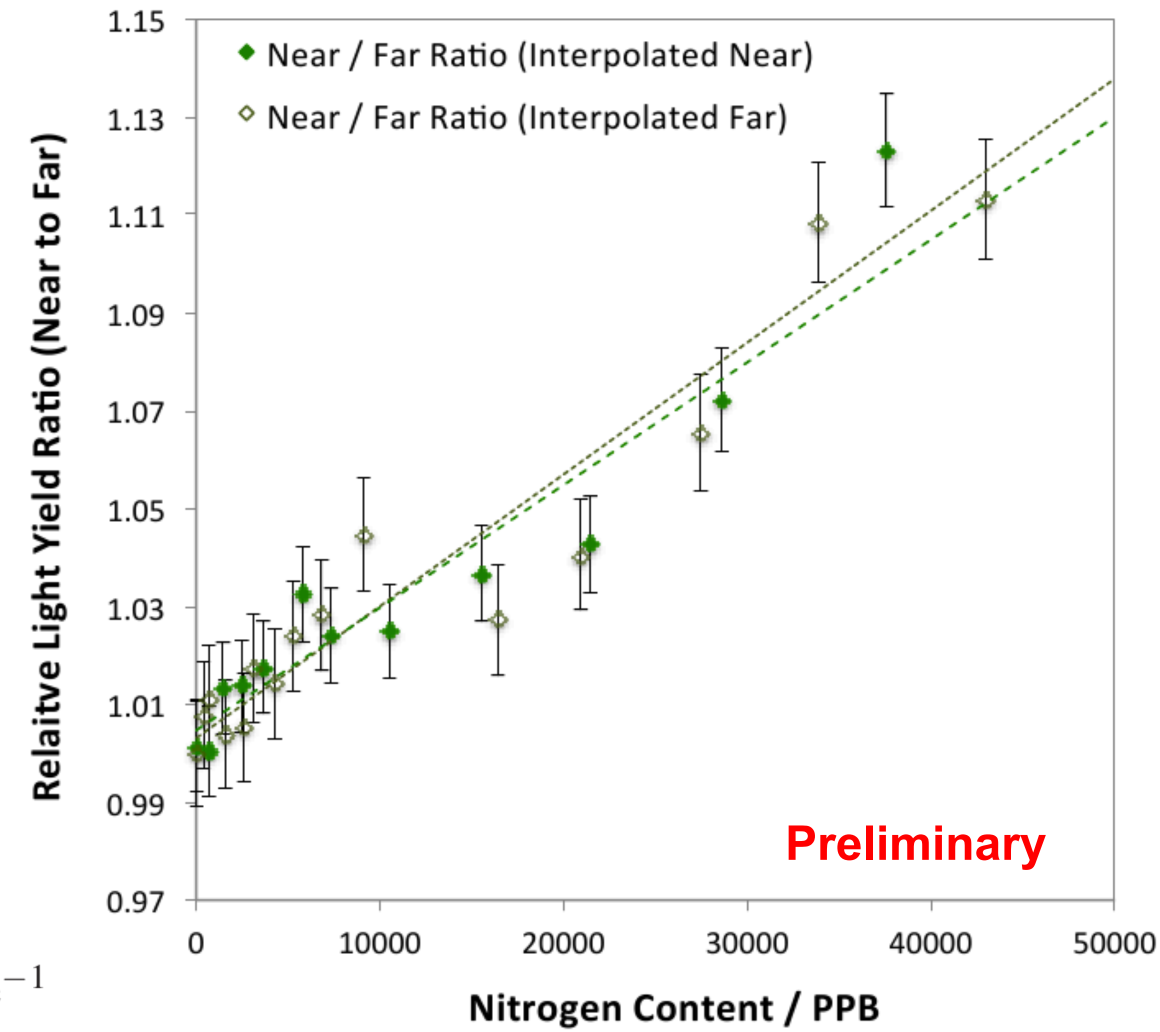
Just to be sure its really the nitrogen…



No light loss during periods with no nitrogen injection – gives confidence in system stability, constrains outgassing effects, etc.

Getting to the Attenuation Strength



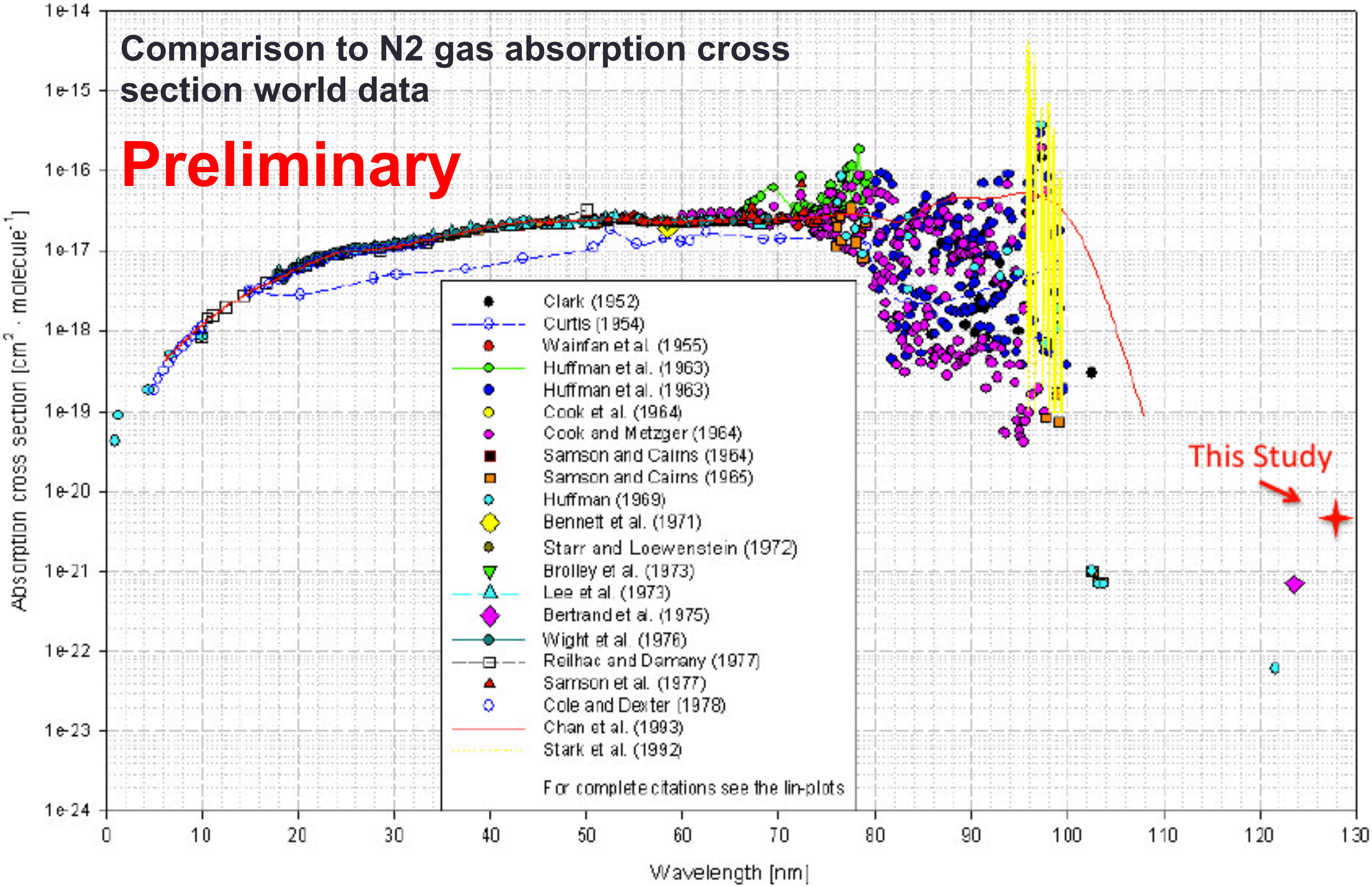


Measured Attenuation Strength:

$$(1.51 \pm 0.15) \times 10^{-4}\ \mathrm{cm}^{-1}\mathrm{ppm}^{-1}$$

Measured Absorption Cross Section:

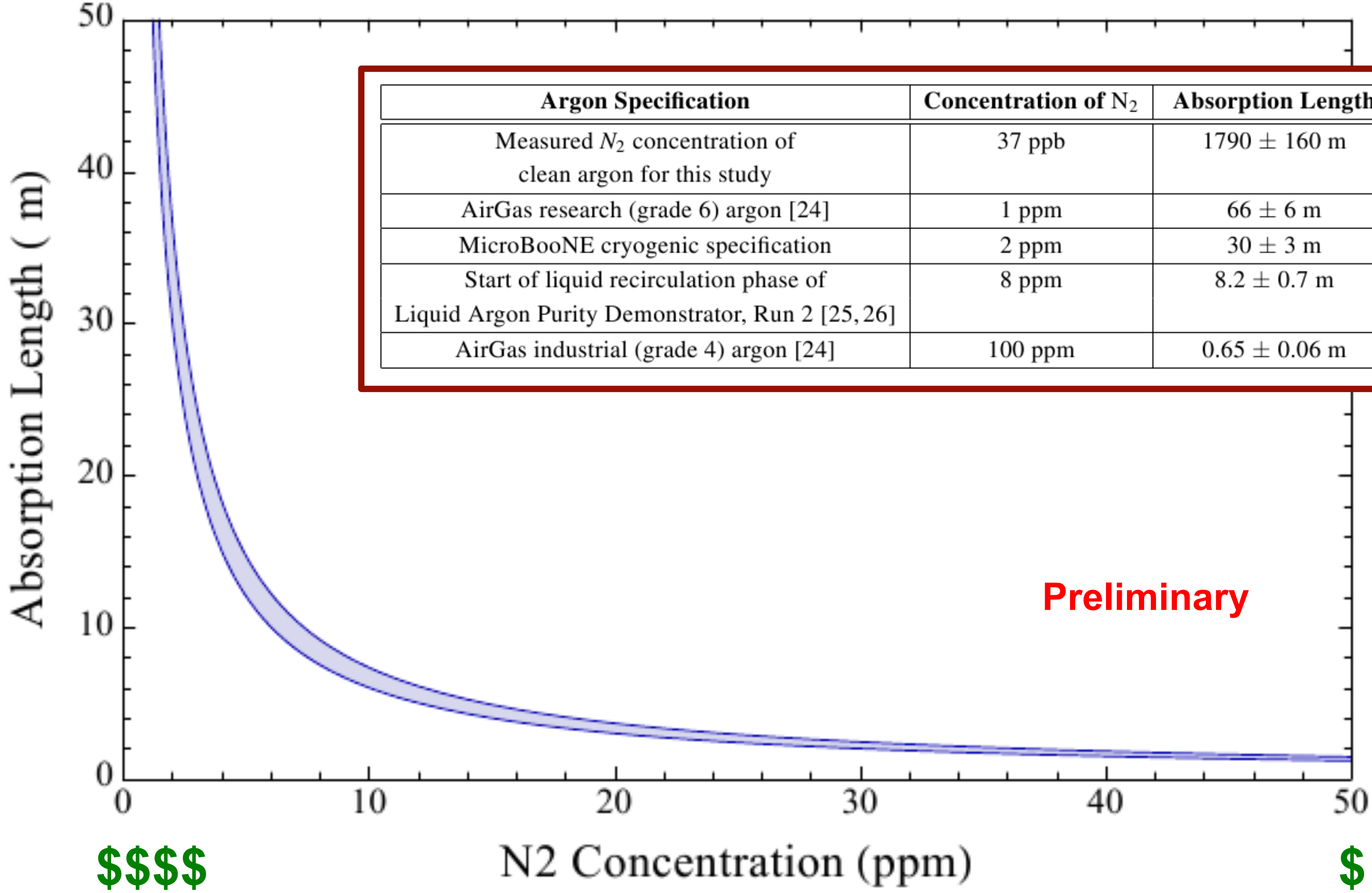
$$(4.99 \pm 0.51) \times 10^{-21}\ \mathrm{cm}^{2}\mathrm{molecule}^{-1}$$



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

Nice result, but whats it gonna do for *me*?

Argon Specification	Concentration of N_2	Absorption Length
Measured N_2 concentration of clean argon for this study	37 ppb	1790 ± 160 m
AirGas research (grade 6) argon [24]	1 ppm	66 ± 6 m
MicroBooNE cryogenic specification	2 ppm	30 ± 3 m
Start of liquid recirculation phase of Liquid Argon Purity Demonstrator, Run 2 [25, 26]	8 ppm	8.2 ± 0.7 m
AirGas industrial (grade 4) argon [24]	100 ppm	0.65 ± 0.06 m



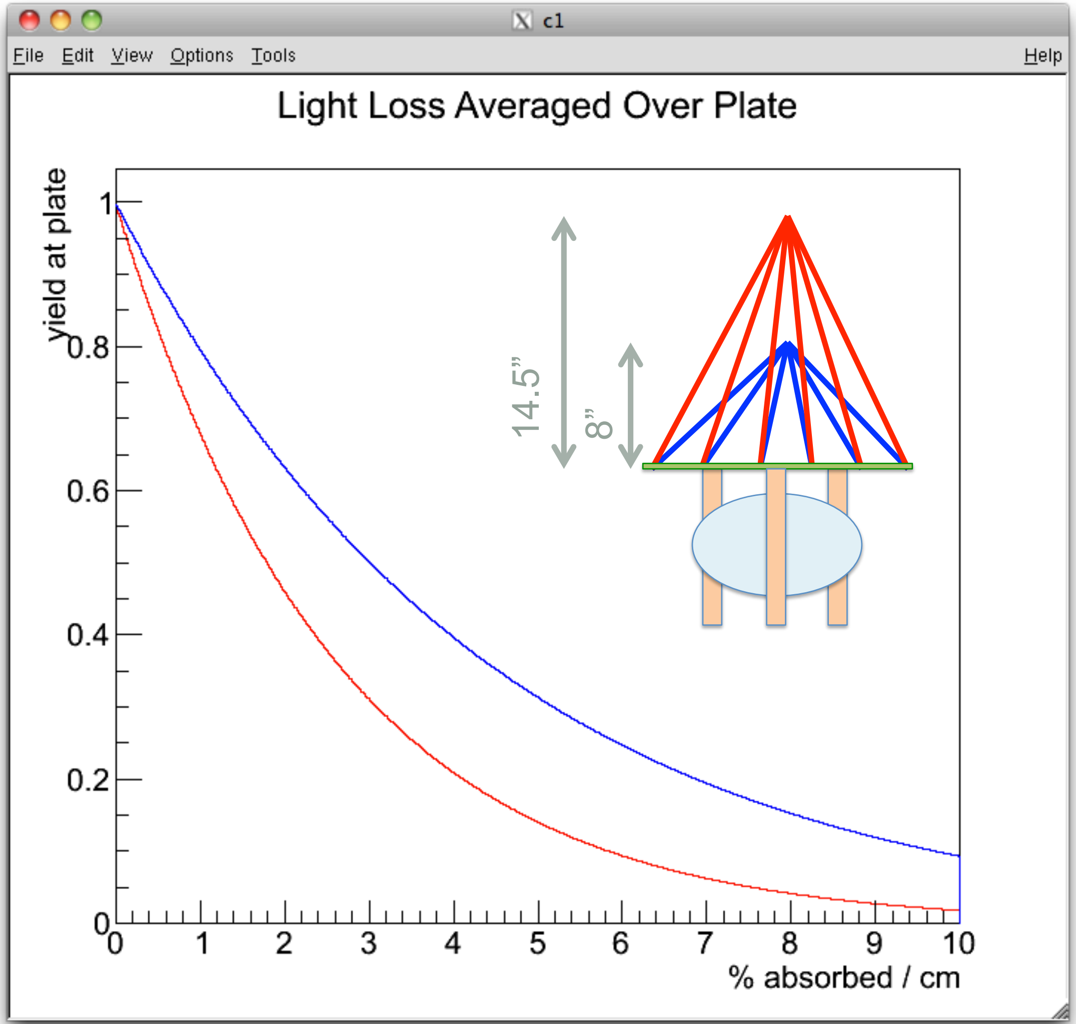
Summary + Prospects

- Bo VST has been constructed to test elements of MicroBooNE optical system – also an R&D detector for LAr scintillation light.
- Detailed studies of alpha source response have been made and area used in various Bo VST studies
- We have measured the effects of nitrogen absorption of 128nm argon scintillation light in liquid argon. We find that the effect is on the order 0.015% / (ppm cm)
- This means absorption is no problem for MicroBooNE, and could be useful information for the design of cryo systems for large LArTPCs

Backup Slides

Understanding the Geometrical Effect

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



Taking ratio, any quenching effect cancels

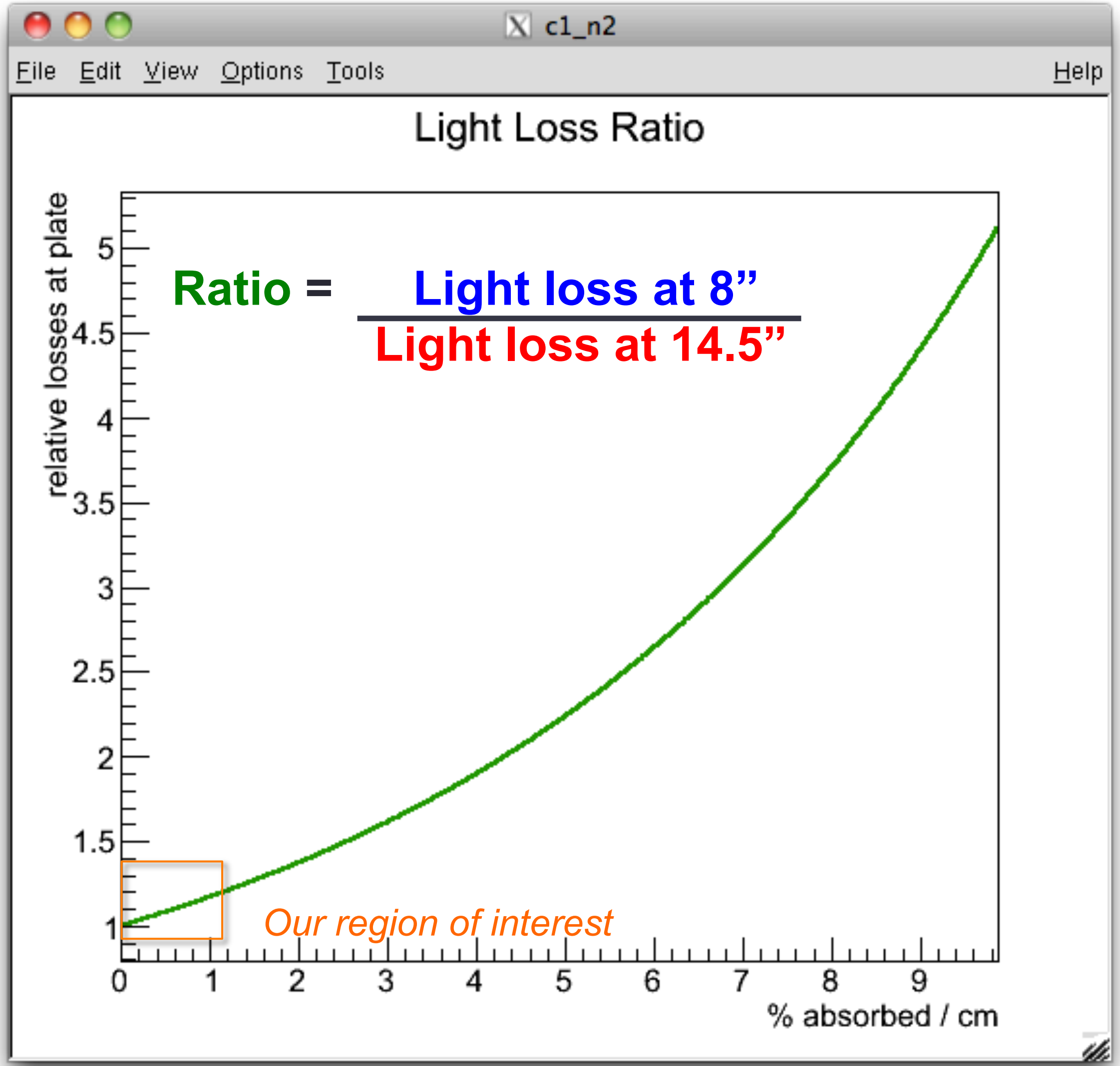
We will measure the nitrogen absorption effect as % light loss per ppm^-1 cm^-1.

First, measure the light loss ratio as a function of N2 concentration.

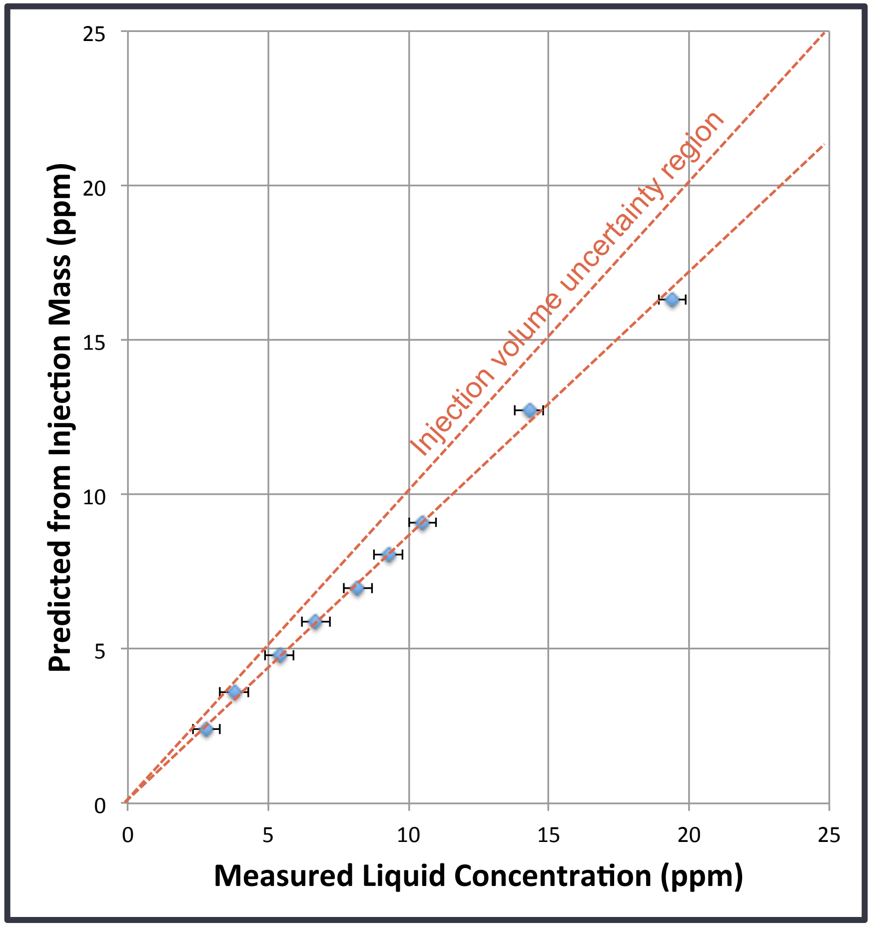
In our region of interest the relationship should be ~linear.

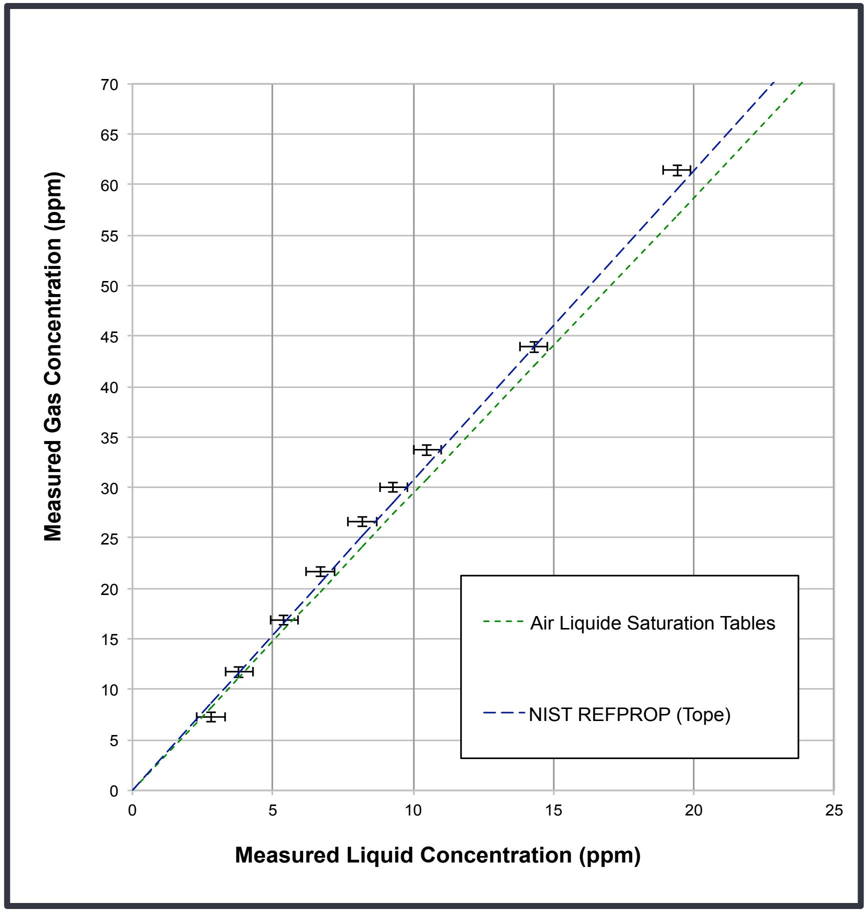
Absorption strength extracted by comparing the gradient of the measured line to the gradient of the line right, which gives proportionality factor for X axis scales.

This factor tells us the % light loss per ppm cm of nitrogen.



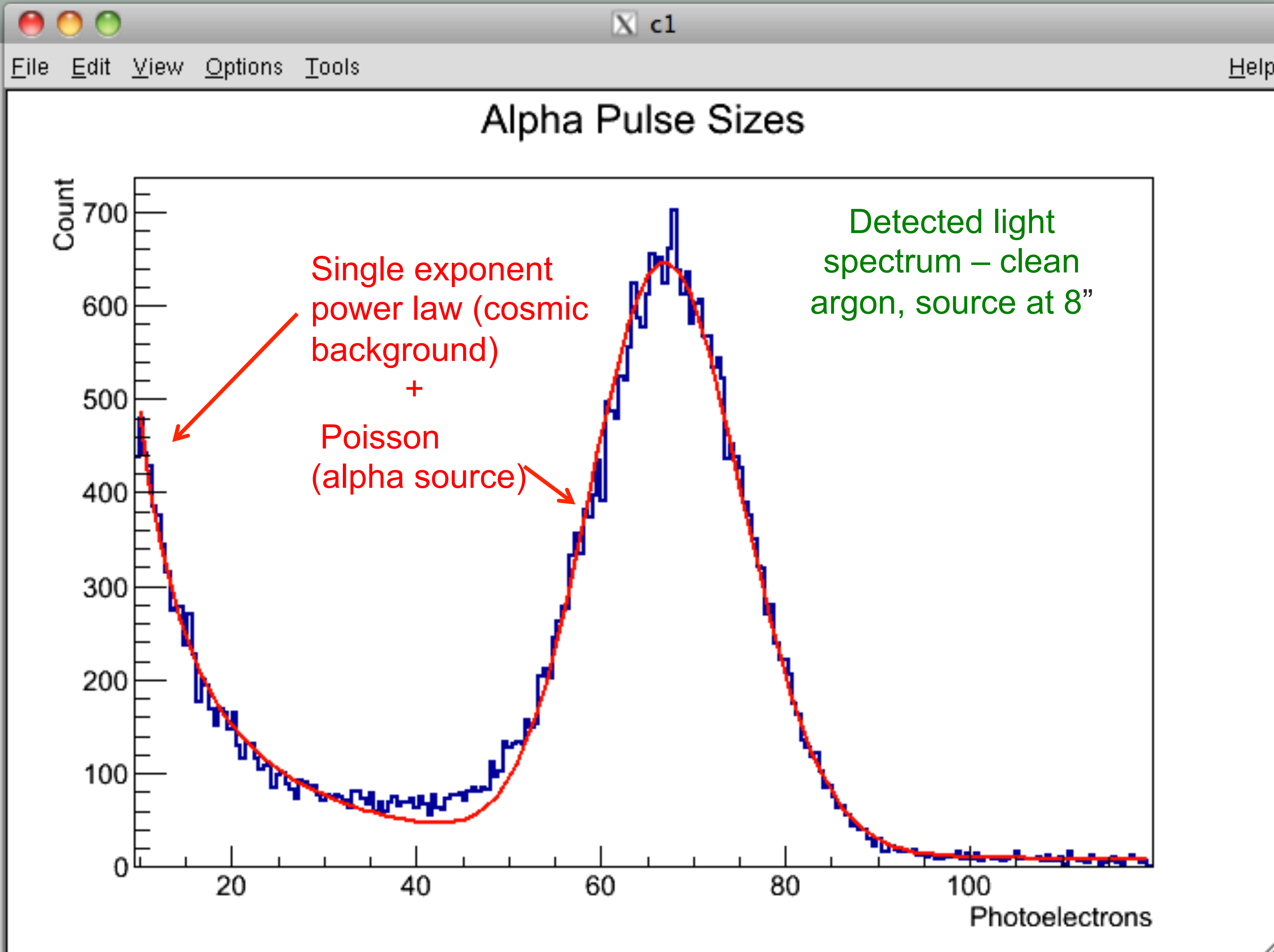
How do we know we get N2 concentration right?

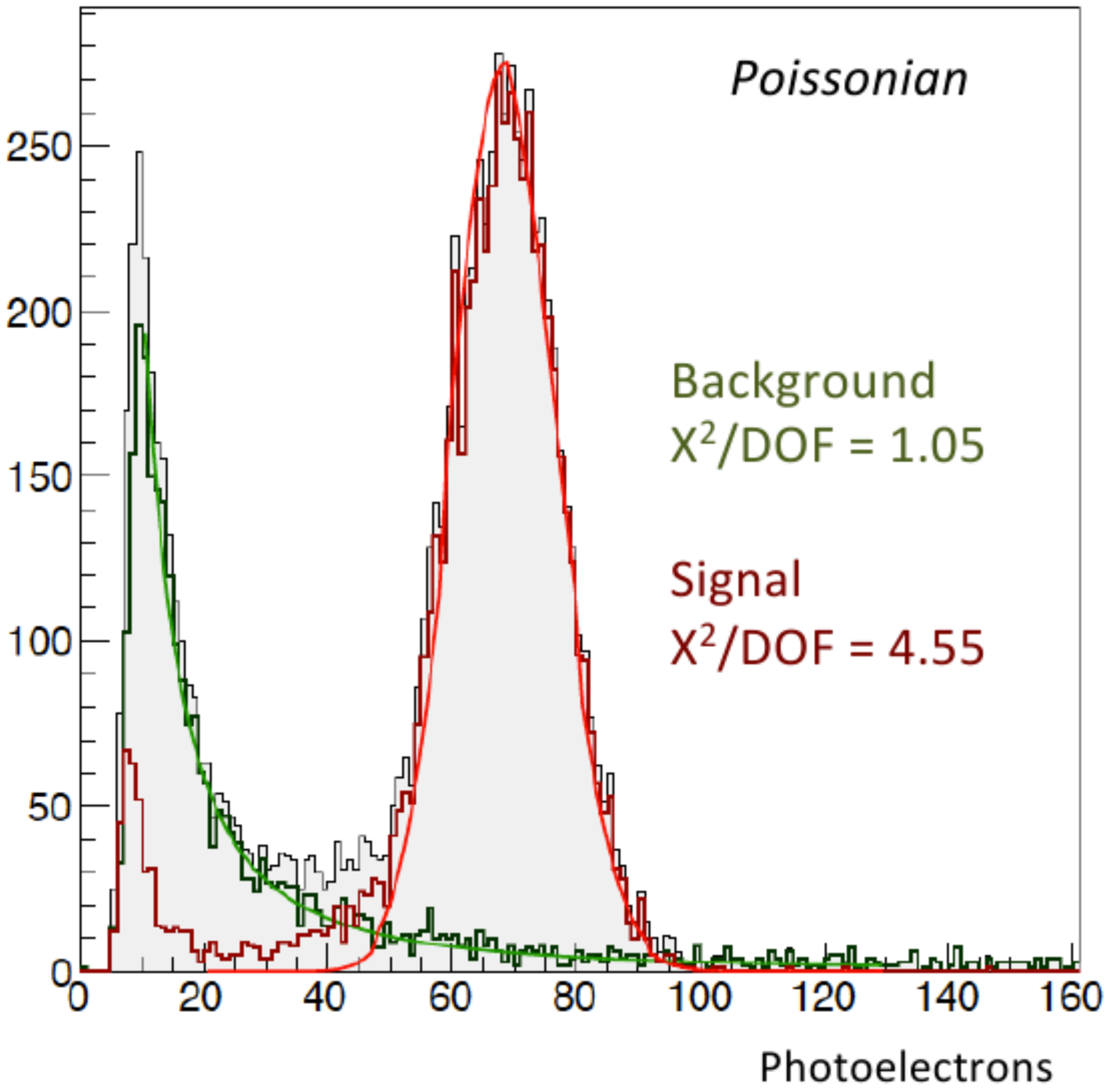




1) Amount of N2 in liquid agrees with amount injected to within our uncertainty of the injection volume.

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



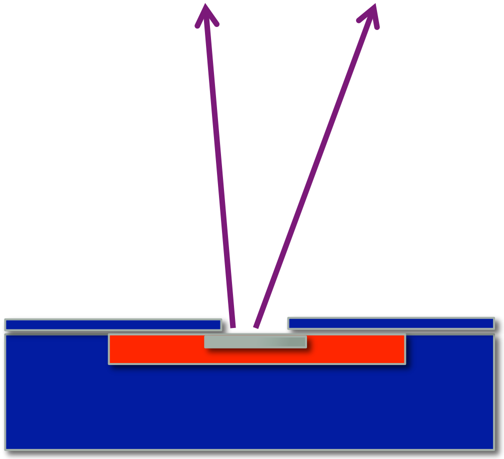
Check on functional form of fits:

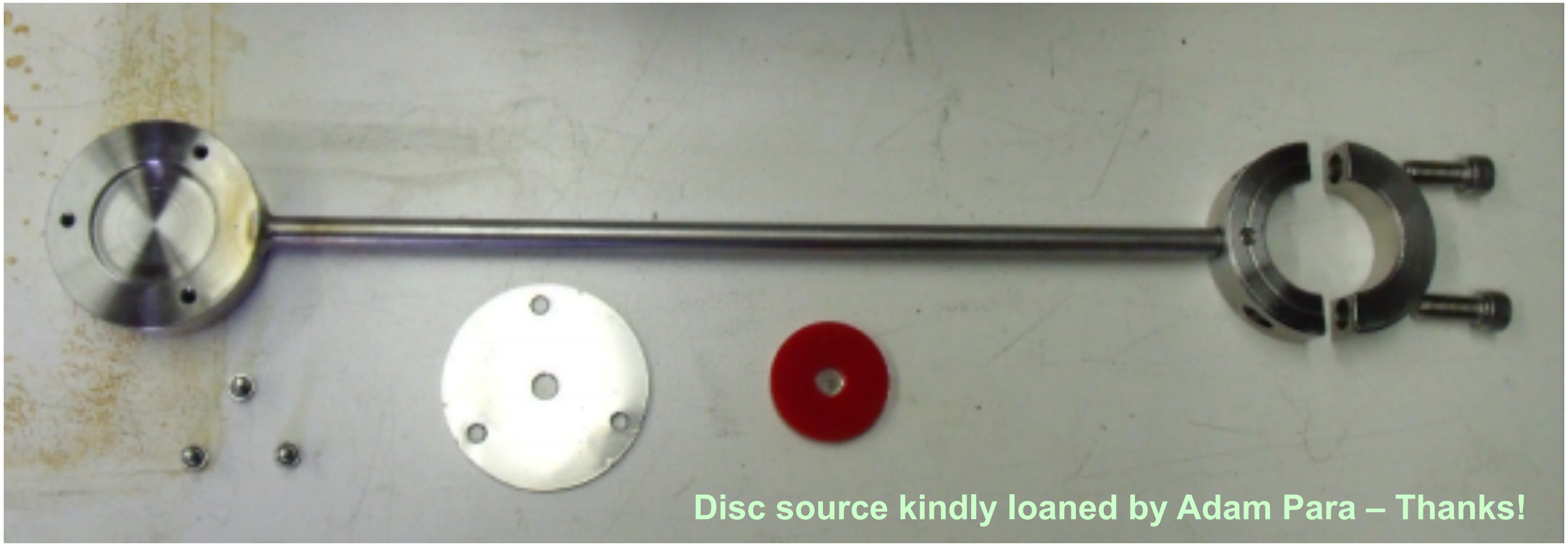
Power law background is great.
Alpha fit needs improvement (not exactly poissonian).

Why?

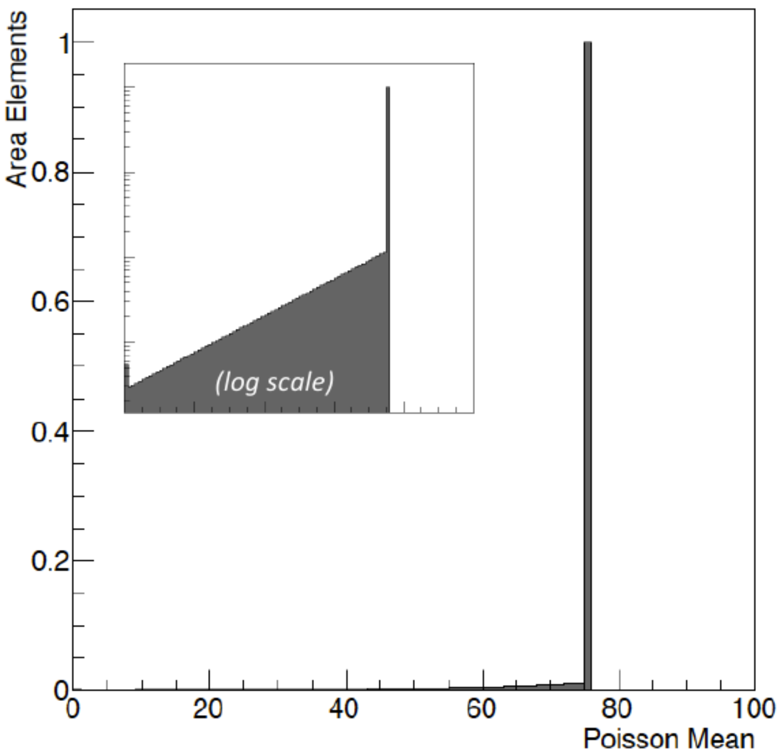
“Shadowing” of outer source edges leads to reduced poisson mean light yield from edge area elements

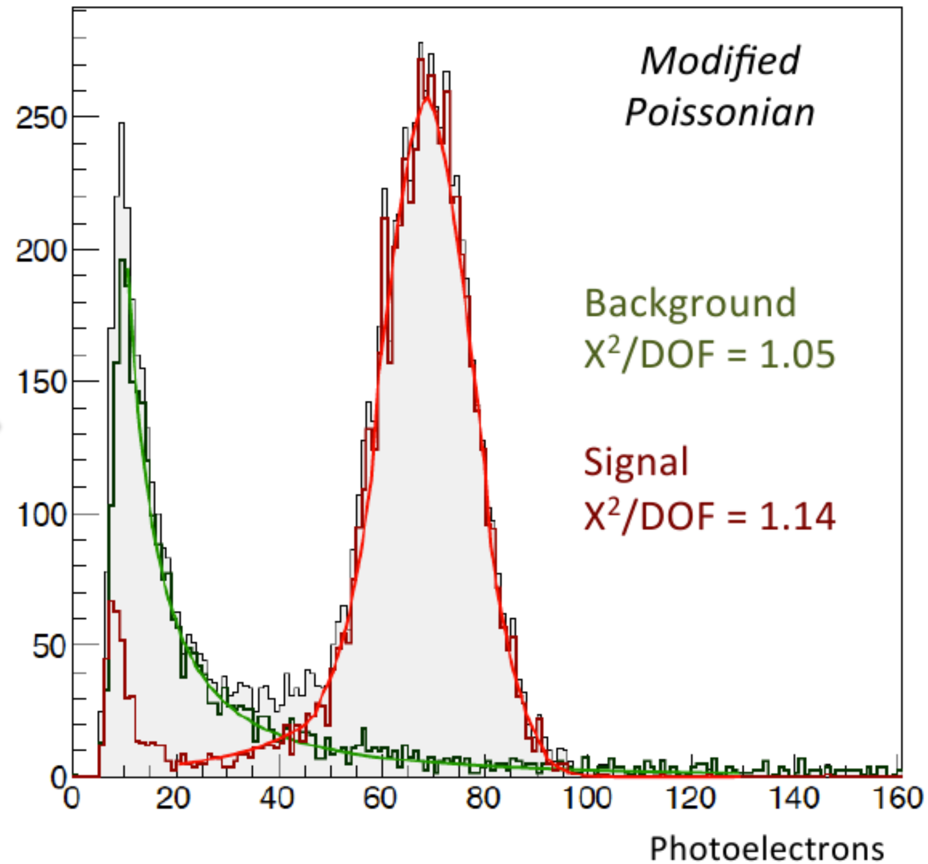
This leads to an enhanced low tail of the source spectrum





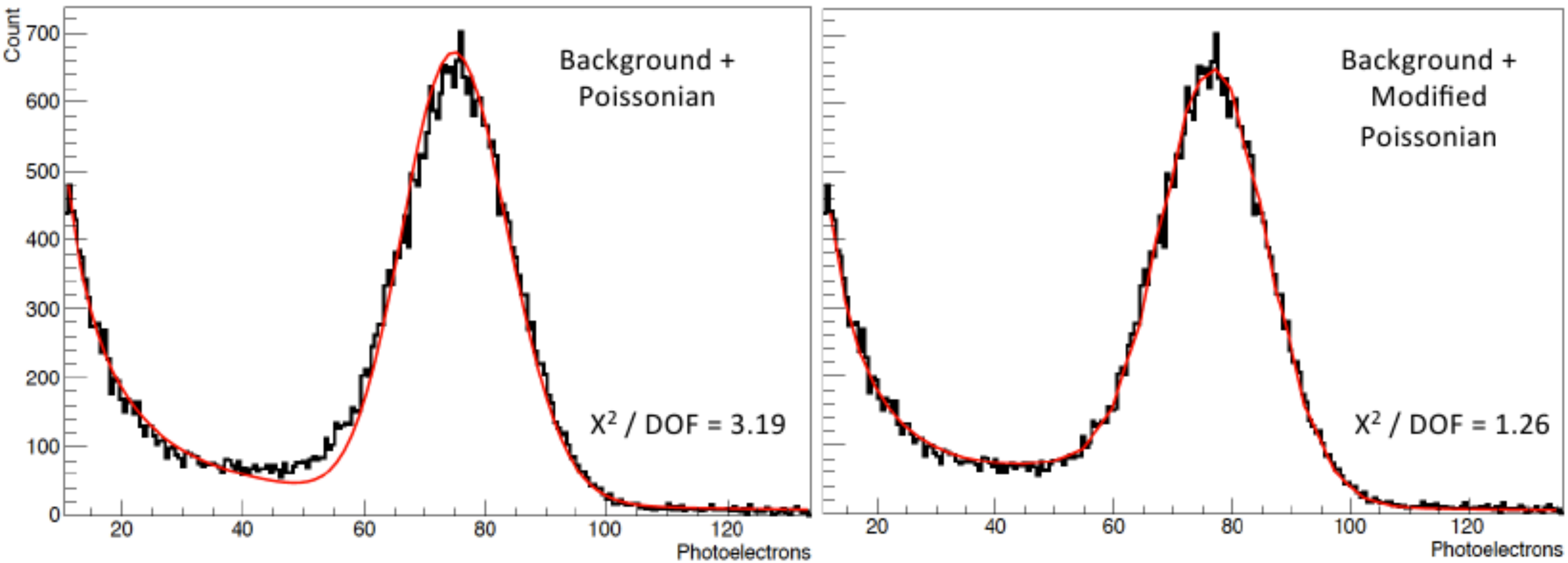
So we Measure the Shadowing Function…





Now we know how the source is shadowed, we know how to fit all points.

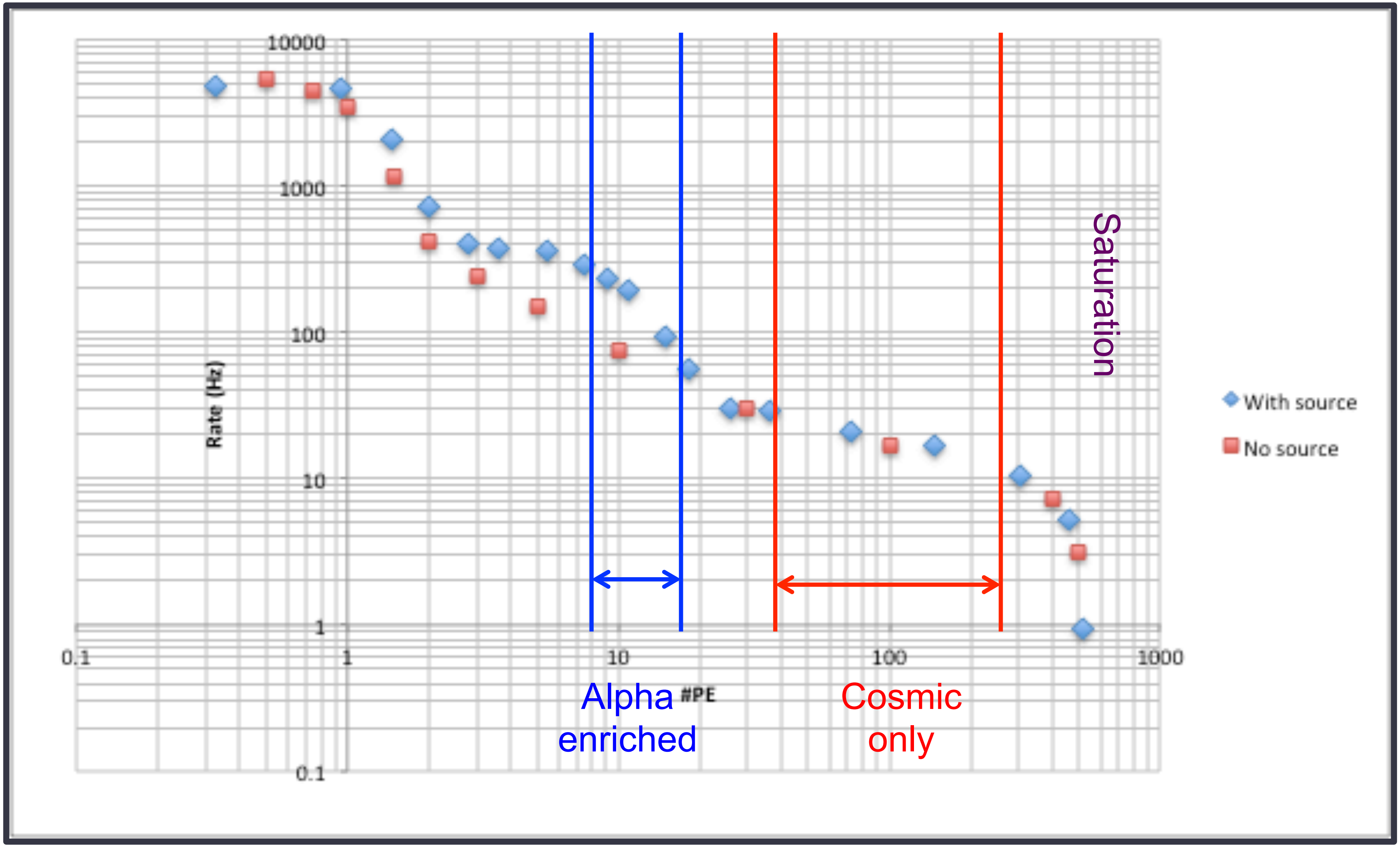
Improved fit from shadowing function

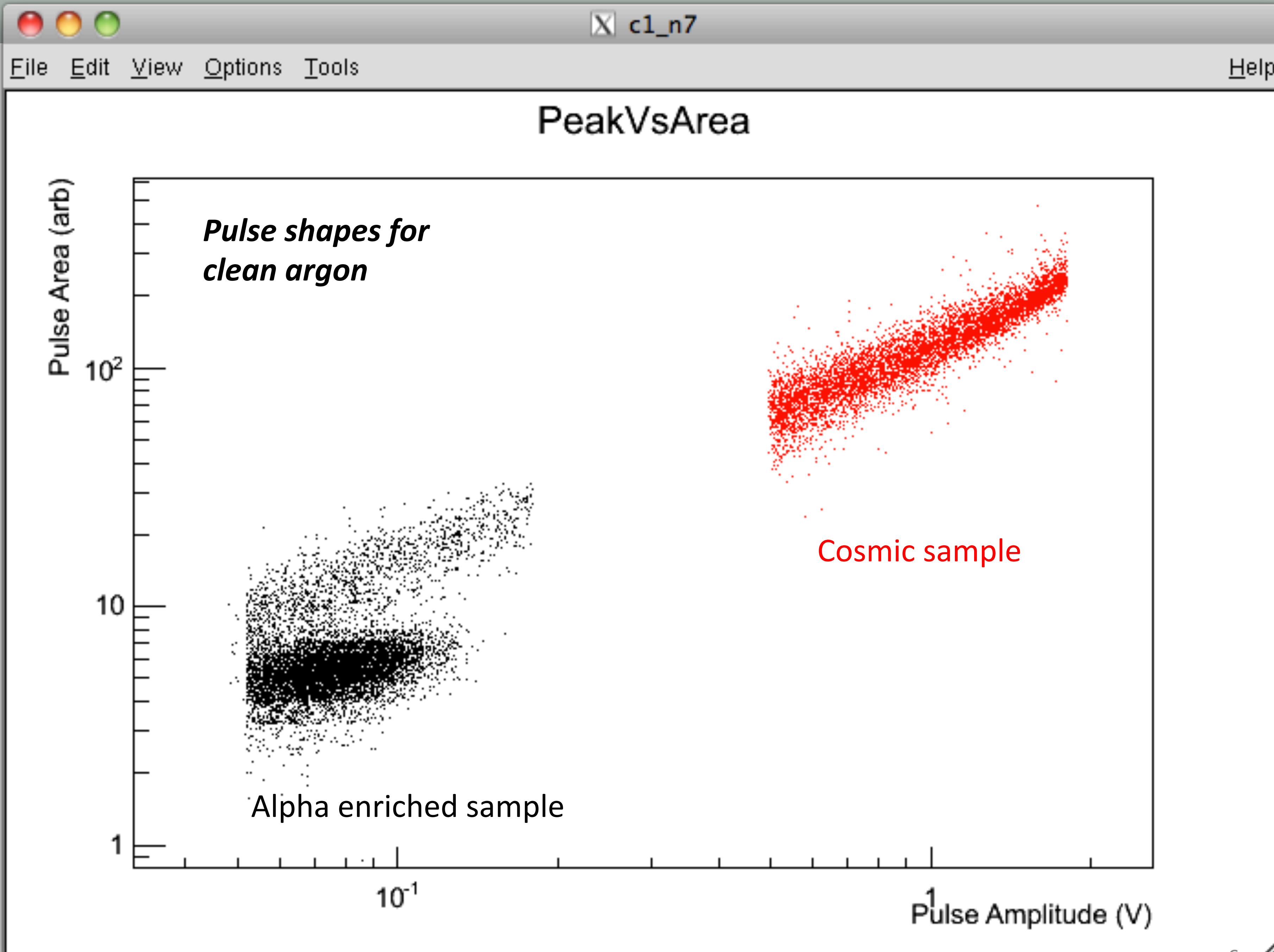


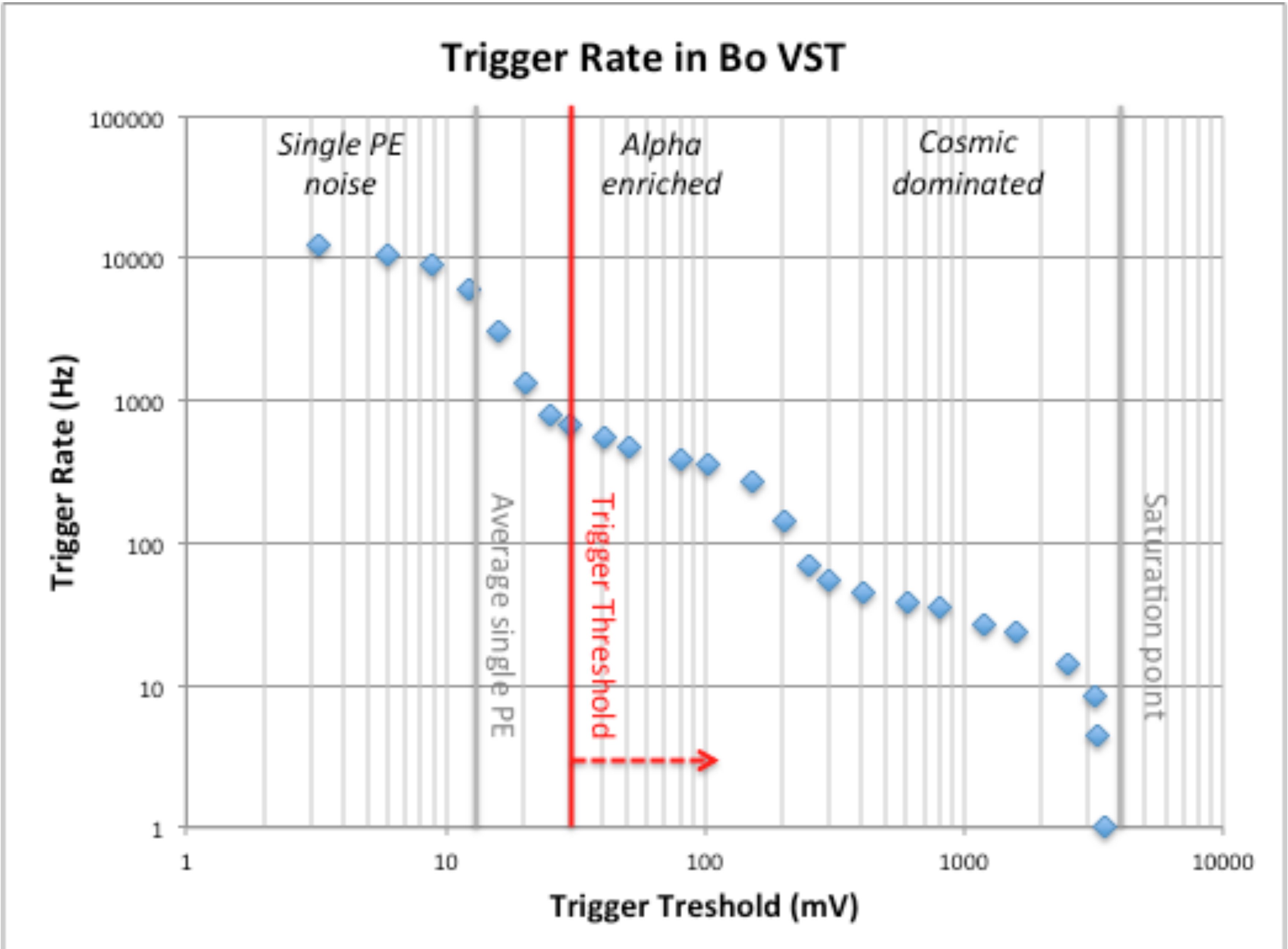
Major improvement with new fit function.

Note : no extra free parameters, since shadowing function was tuned on an independent dataset.

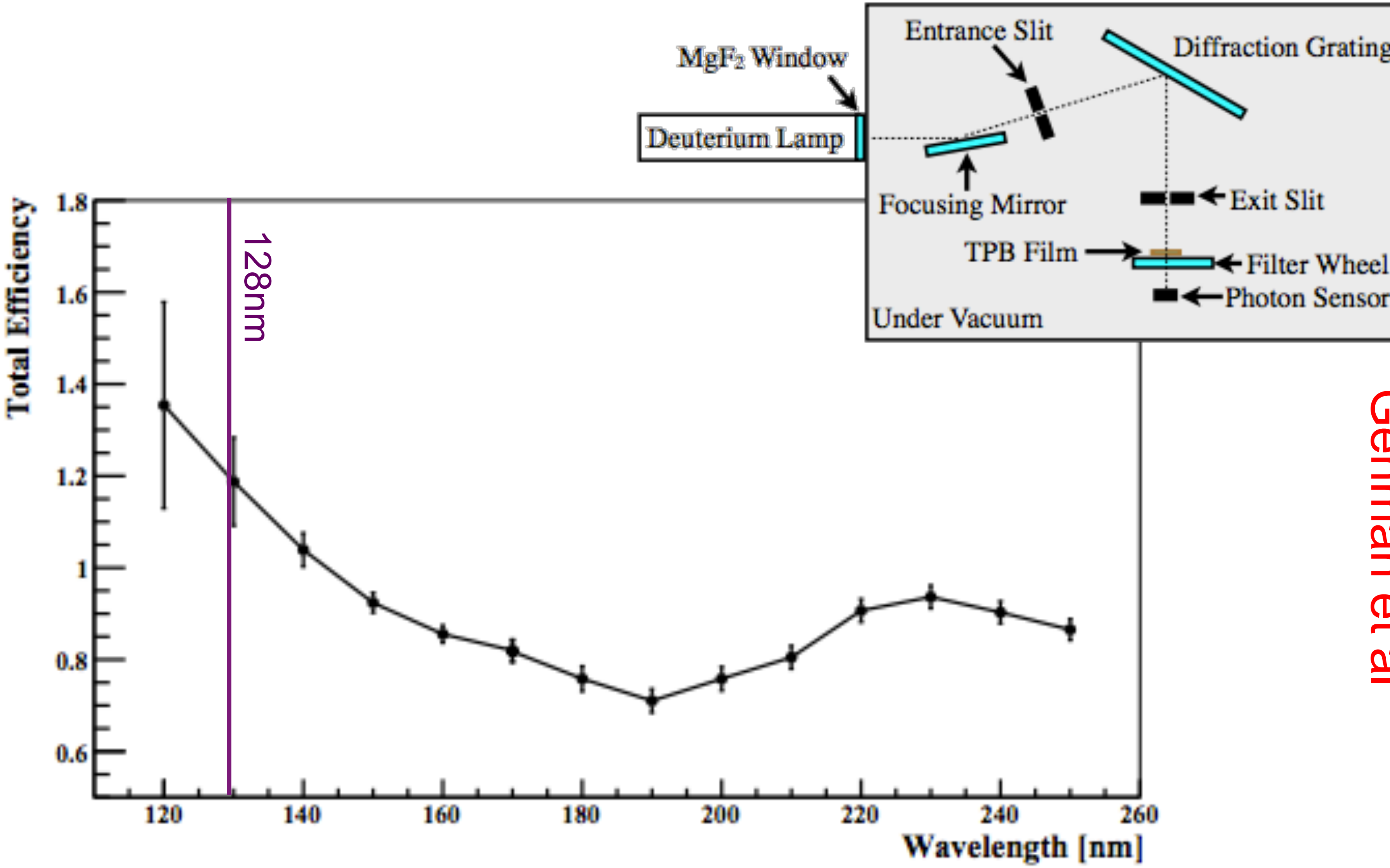
Aside: Pulse Shape Discrimination in Action




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



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

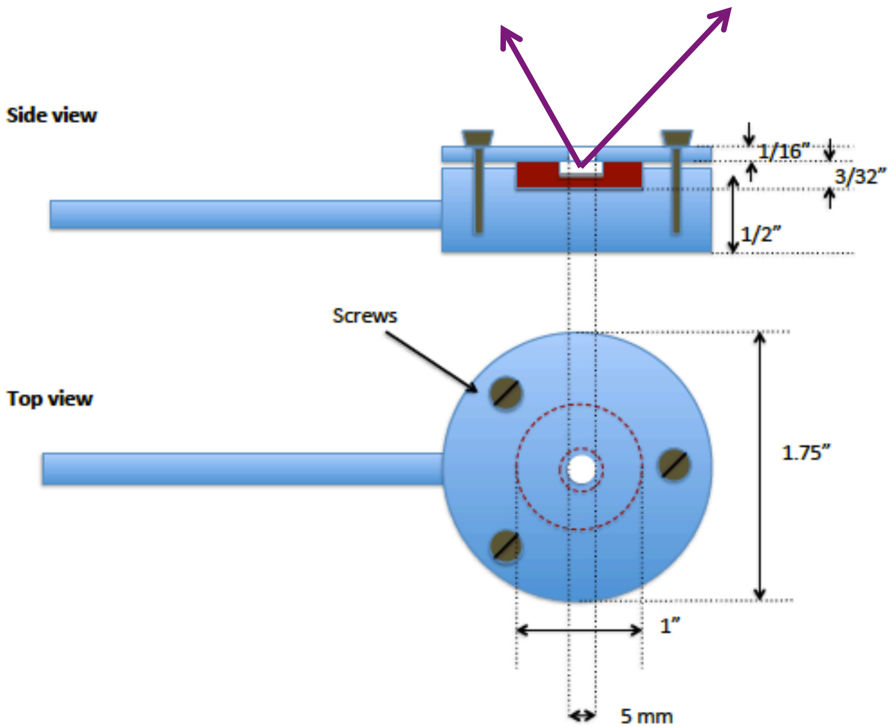


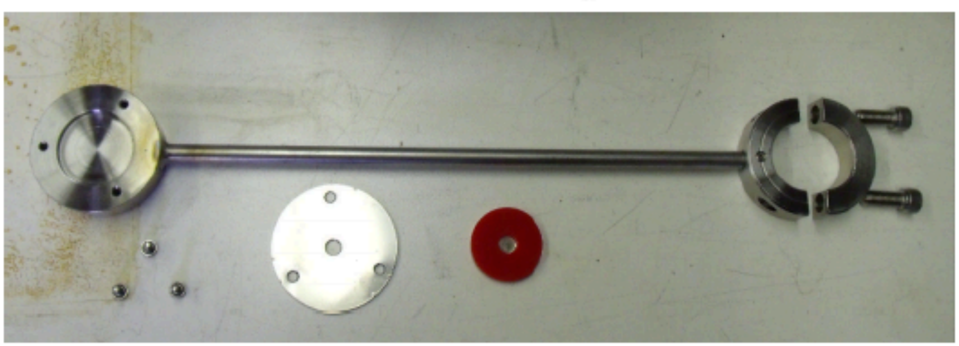
Gehman et al

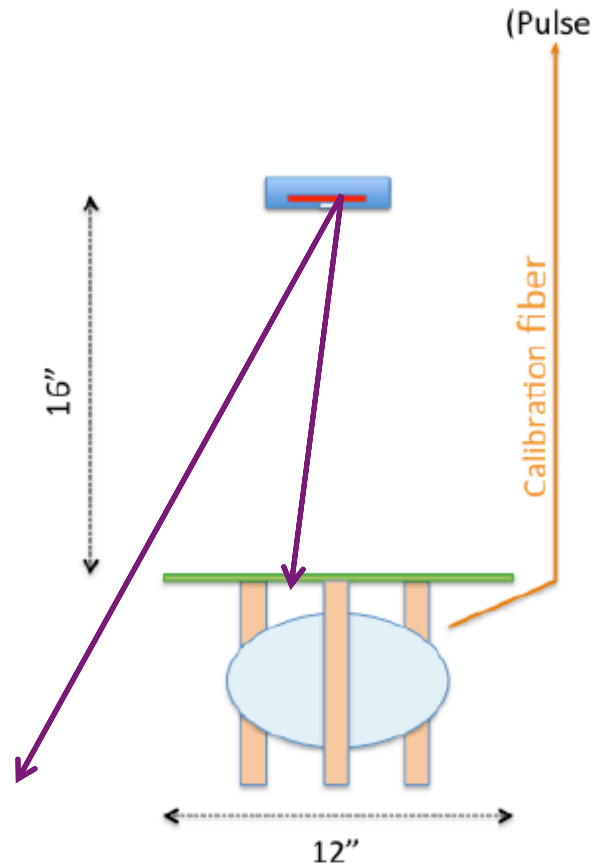
1.18 ± 0.1

Visible photons out / UV photon in for evaporative TPB

Expected Light Yield at Plate

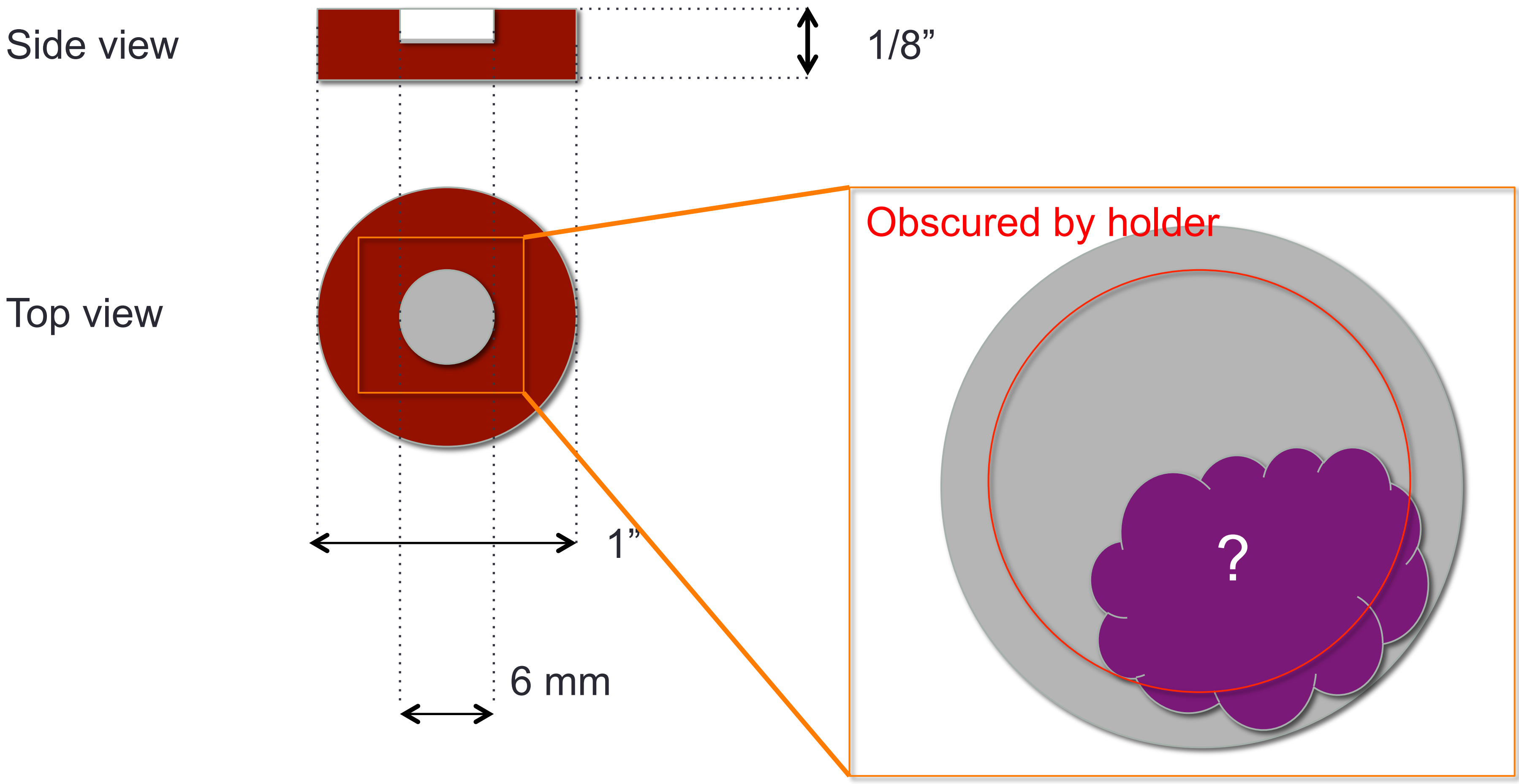






More ray tracing, should be straightforward enough…

- Nope



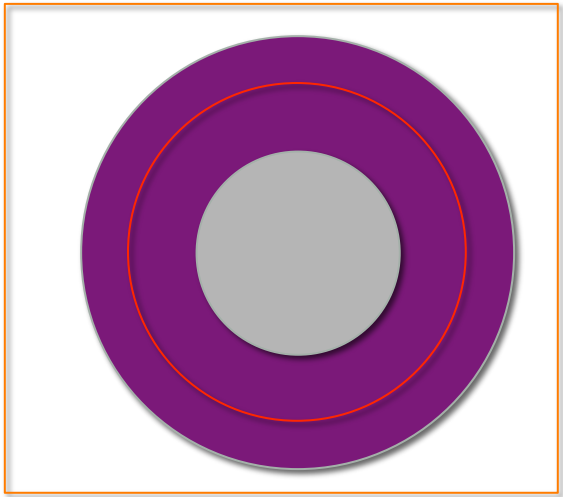
Try a few options;

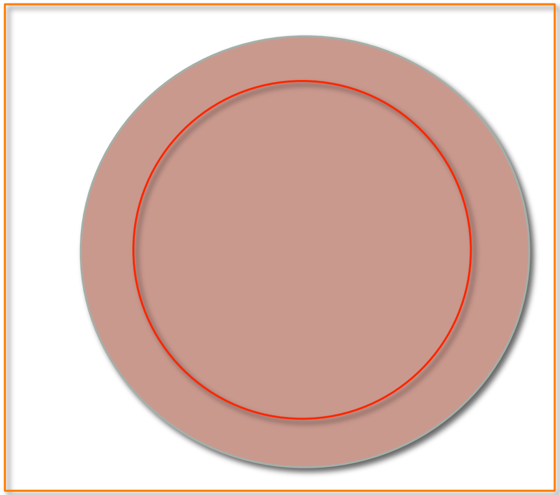
System has cylindrical symmetry, so distribution in phi does not matter.

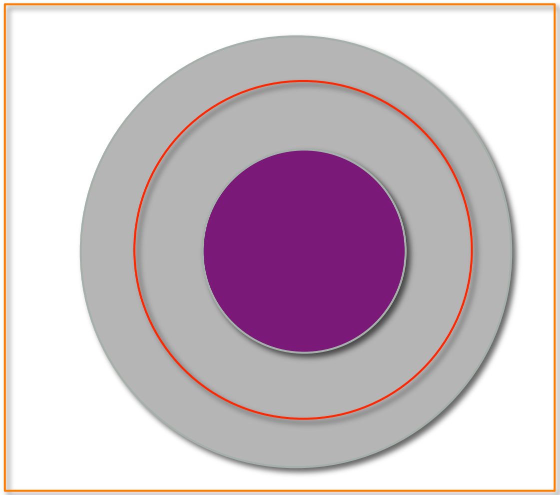
More Obscured

Baseline

Less Obscured







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

¾ of plate area covered

0 < r < 3mm : Uniform Source

Full plate area covered

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

¼ of plate area covered

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!

SPE Insensitivity