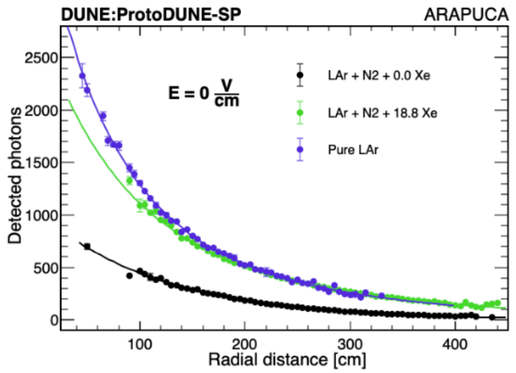
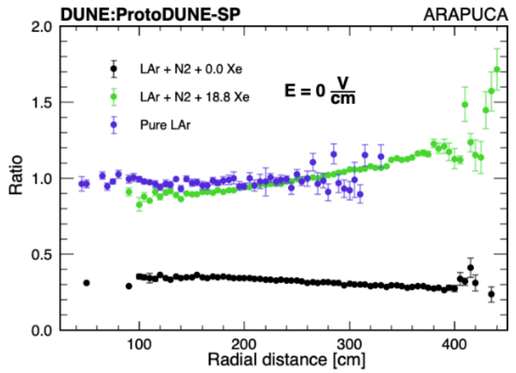
Comparing Field Off and Field On Light Yield Results from ProtoDUNE-SP

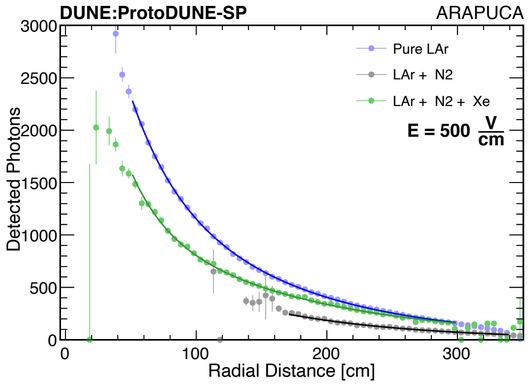
Intro

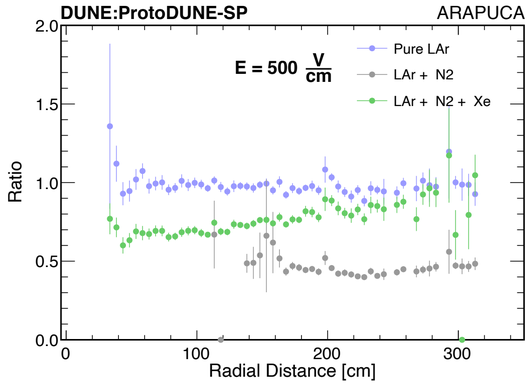
- Try to identify the cause of the discrepancy between field on and field off data seen in paper draft plots
- Note: Field on data had some contamination from cathode crossing tracks
  - These have been removed and all plots in this talk are updated
- Starting with Dante's 2D Plots, redo the field off analysis in the exact same method as the field on analysis and compare.
- Reference Jones et al. and Acciarri et al. to find expected absorption length for a total N2 contamination of 5.4ppm$_{mass}$

Paper plots



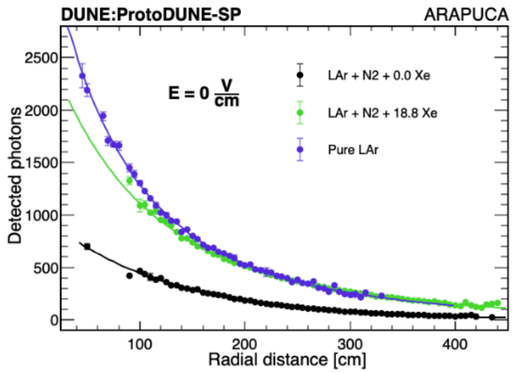


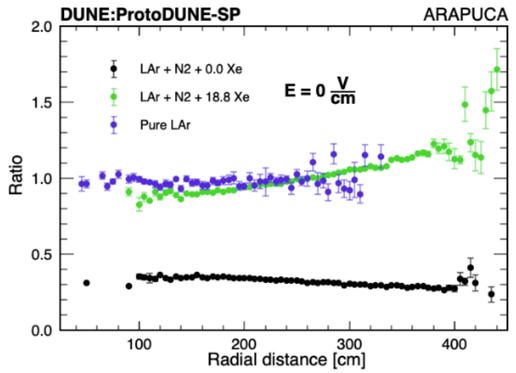


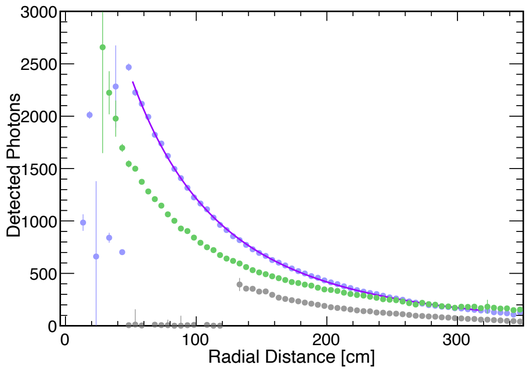


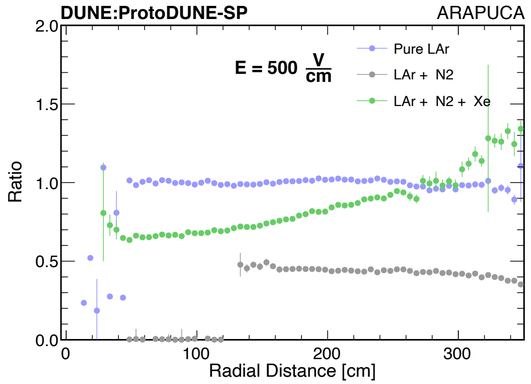
- Plots from paper shown
- Field off plots show some attenuation due to N2
- Field off shows greater gain from Xenon doping at long distances

Paper plots









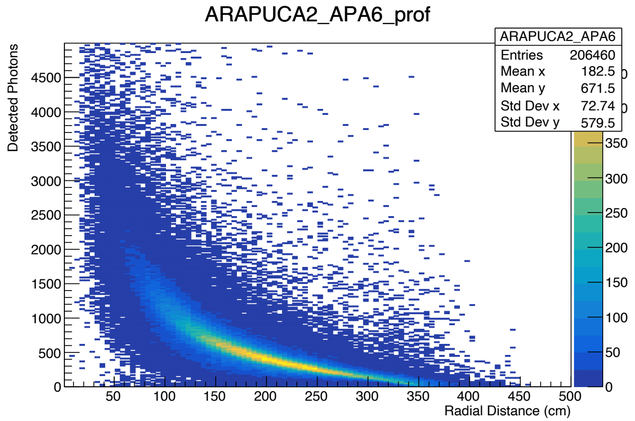
- Plots from paper shown
- Code error allowed cathode crossing tracks, resulted in lower light yield signals at long distances
  - Removed
- Switched to data/fit ratios to better match field off study
- Field off data still shows more N2 absorption.
- Differences in data selection, ratio method, and statistics

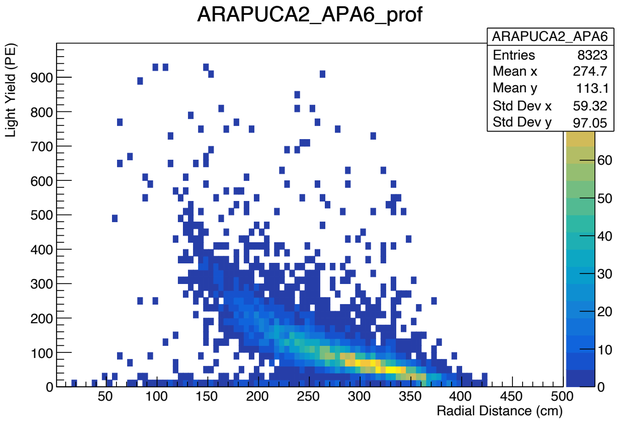
- Obtained 2D light yield vs distance plots from Dante
- Profile per the field-on analysis and compare results

Pure LAr

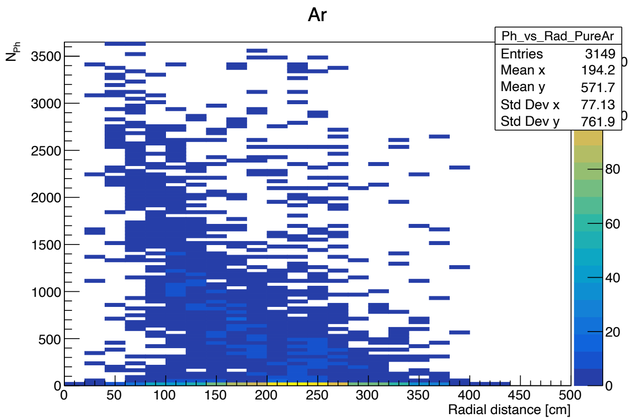
LAr + N2

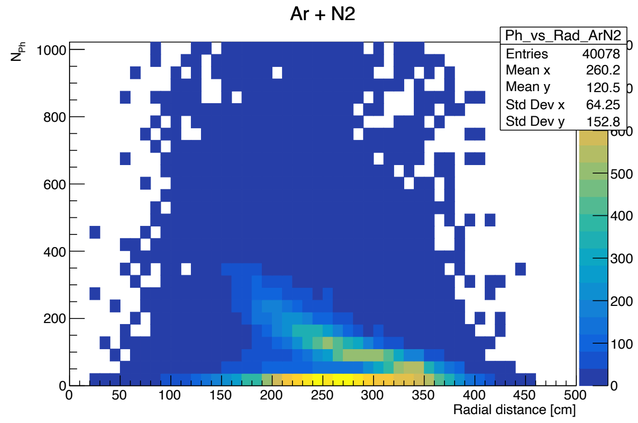
Field On



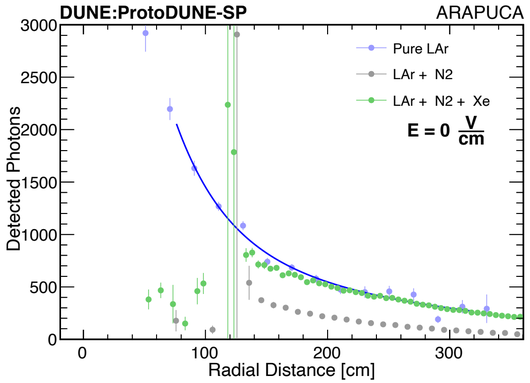


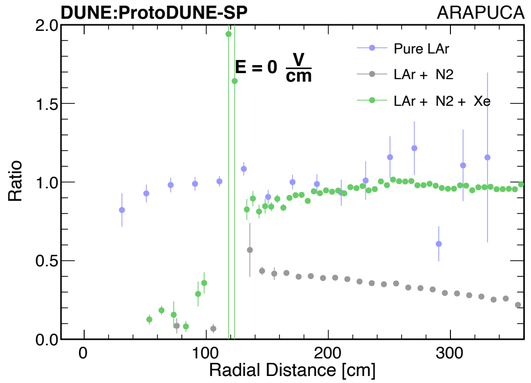
Field Off

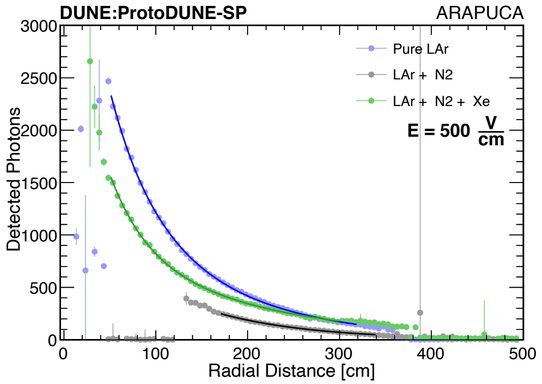


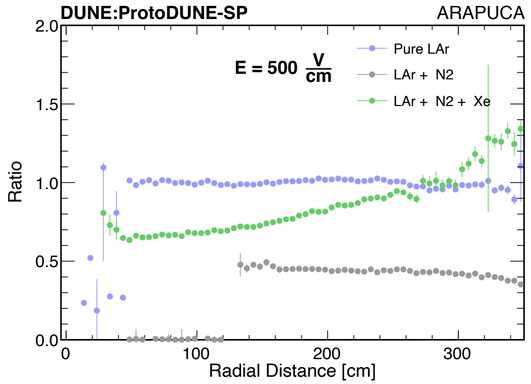


Paper plots









- Different statistics (different selection?) compared to field off paper plot
- Similar qualitative behavior to field off paper plot
- Follow Dante's procedure to identify N2 quenching and absorption coefficients

Dante's fit results

We repeated this with both field off and field on data.

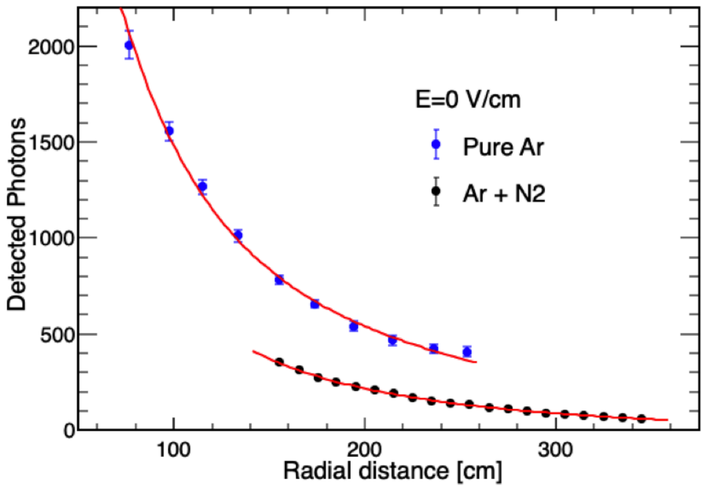
Photons vs radial distance

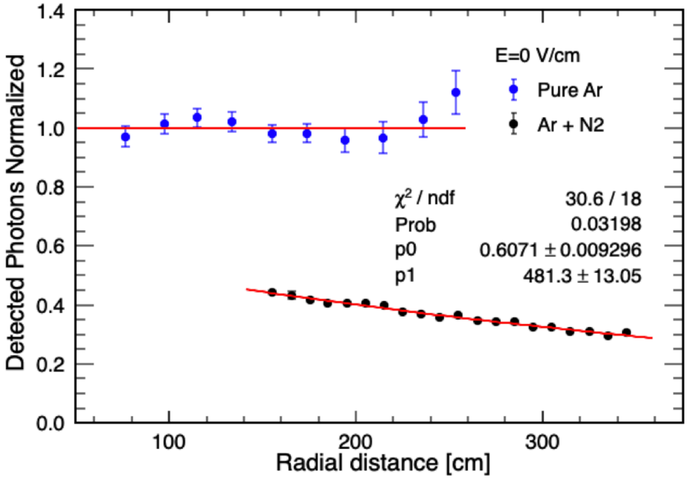
$$f_1(r) = A \cdot exp(-r/B) + C \cdot exp(-r/D)$$

$$f_2(r) = f_1(r) \cdot Q \cdot exp(-r/\Lambda)$$

Simultaneous fit:
"Pure Ar" in [40, 260] cm range, using f_1
"Ar+N2" in [140, 360] cm range, using f_2

Minimizer is Minuit2 / Migrad			
Chi2 = 37.7869		NDf	= 24
Edm = 4.24885e-06		NCalls	= 1313
A	= 1780.52	+/-	213.239
B	= 156.872	+/-	14.1282
C	= 6846.19	+/-	1601.89
D	= 39.3462	+/-	3.9354
Q	= 0.607084	+/-	0.0609271
Λ	= 481.331	+/-	125.075





The main parameters we are interested are:

Q = 0.61 +/- 0.06 (N2 quenching)
Λ = 4.8 +/- 1.2 m (N2 absorption)

They refer only to the N2 amount entered during the contamination accident.

Expected Nitrogen Quenching

Nitrogen quenching

Three exponentials fit results:

Comp.	Sing. [ns]	Int. [ns]	Trip. [ns]
Pure Ar	12.72 ± 0.01	62.0 ± 0.5	1257 ± 1
Ar + N2	13.24 ± 0.05	77 ± 2	621 ± 1

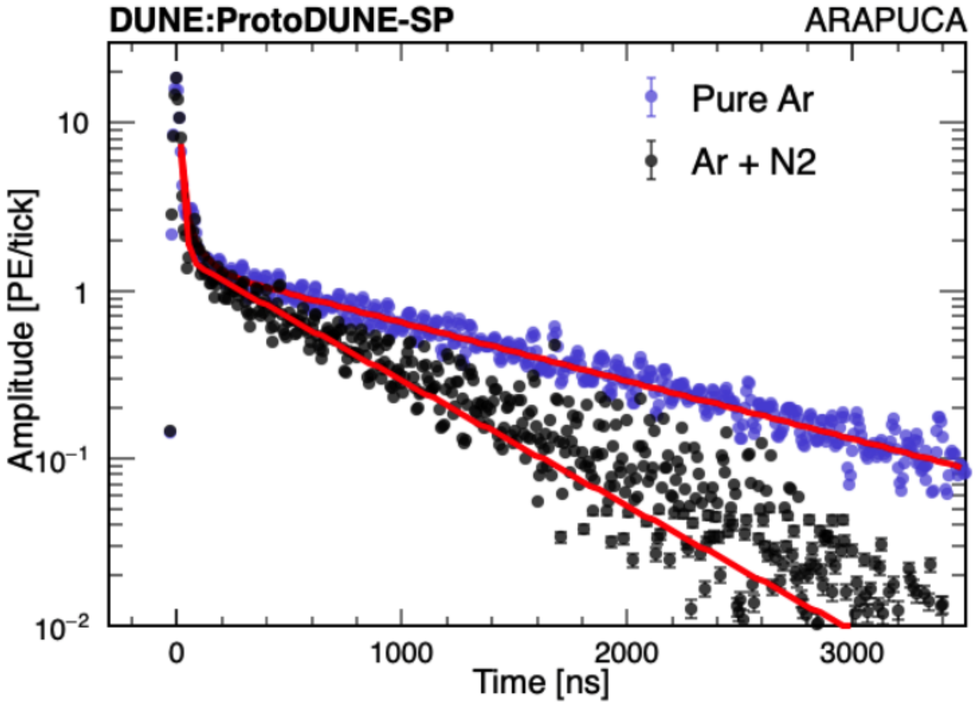
Two comp (*):
Singlet = 23% Triplet = 77%

Three comp (*):
Sing. = 18.8% Int = 7.4% Trip. = 73.8%

(*)Effects of Nitrogen contamination in liquid Argon
R Acciarri *et al* 2010 *JINST* **5** P06003

Both compatibles with the parameter from the simultaneous fit:

(N2 quenching) Q = 0.61 +/- 0.06



Assuming N2 quenching acts only on the Triplet, the expected reduction is:

$$R_{2c} = 0.23 + 0.77 \cdot \frac{621}{1257} \simeq 0.61$$

$$R_{3c} = 0.26 + 0.74 \cdot \frac{621}{1257} \simeq 0.62$$

From Dante

Expected Absorption Length

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

B.J.P. Jones, C.S. Chiu, J.M. Conrad, C. M. Ignarra[a], T. Katori, M. Toups

$$A = \frac{-1m}{100\ln(1 - p\chi 1cm)}$$

$$p = (1.51 \pm .15) \times 10^{-4} cm^{-1} ppm^{-1}$$

From Dante's triplet analysis

$$\chi = 7.7 \pm .15 ppm_{atomic} = 5.4 \pm .1 ppm_{mass}$$

$$A = \frac{-1m}{100\ln(1 - 1.51 \times 10^{-4} cm^{-1} ppm^{-1} \times 7.7 ppm \times 1cm)} = 8.6 \pm .9m$$

Moving from the absorption strength coefficient found in the paper and calculating the expected absorption length for the *total* N2 amount in ProtoDUNE-SP, we find an expected value of
A = 8.6 ± .9m

From Dante's triplet lifetime analysis and Acciarri et al we expect
Q=.6 ± .06

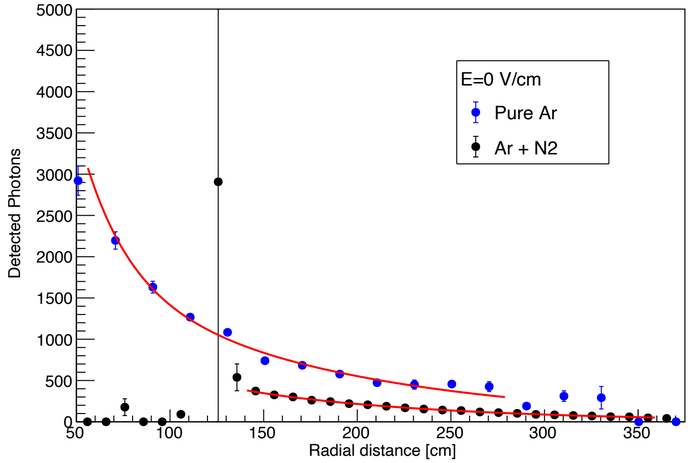
Initial Fits

- Using Dante's simultaneous fit method for similar ranges.
  - Full scan of fit ranges in backups
- From these fits we get neither the Q or Λ we expect.
  - Large correlation between the two
  - Cannot simultaneously measure Q and Λ?

Field on correlations*

	0	1	2	3	4	5
0	1	-0.9931	0.707	-0.9037	-0.518	0.5976
1	-0.9931	1	-0.6535	0.8627	0.5252	-0.6137
2	0.707	-0.6535	1	-0.9314	-0.2915	0.3242
3	-0.9037	0.8627	-0.9314	1	0.4178	-0.4719
4	-0.518	0.5252	-0.2915	0.4178	1	-0.977
5	0.5976	-0.6137	0.3242	-0.4719	-0.977	1

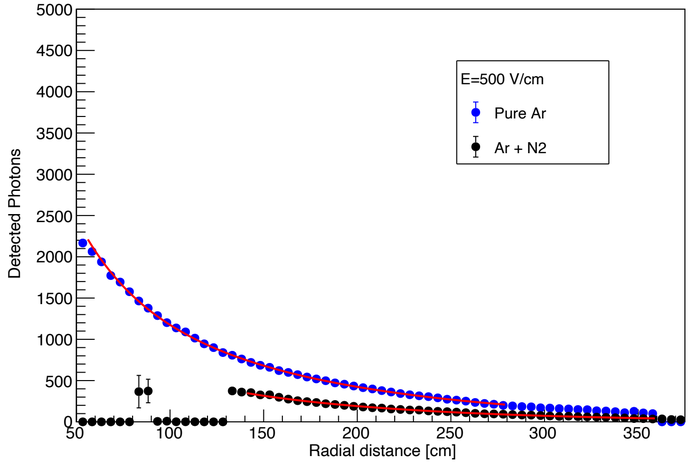
Field off



Minimizer is Minuit2 / Migrad

Chi2	=	77.9443		
NDf	=	27		
Edm	=	8.08478e-06		
NCalls	=	725		
A	=	2575.64	+/-	347.35
B	=	129.472	+/-	12.2979
C	=	14666.3	+/-	6816.38
D	=	23.9356	+/-	3.87534
Q	=	0.497173	+/-	0.0623917
#Lambda	=	822.264	+/-	477.787

Field on



Minimizer is Minuit2 / Migrad

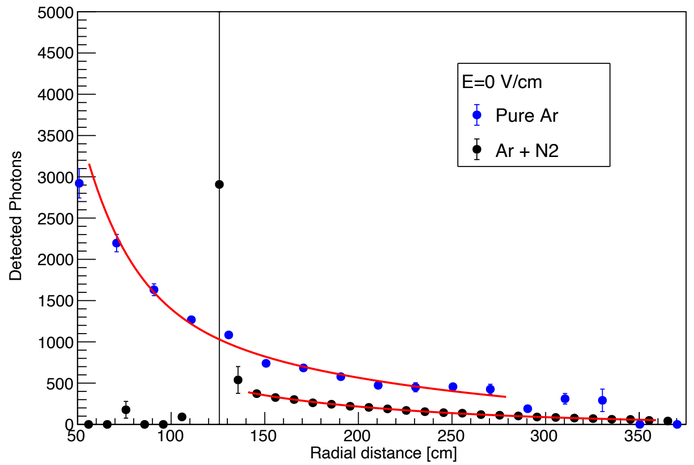
Chi2	=	352.801		
NDf	=	83		
Edm	=	2.52477e-06		
NCalls	=	420		
A	=	2449.49	+/-	34.5892
B	=	113.215	+/-	0.759245
C	=	4813.66	+/-	281.576
D	=	29.503	+/-	0.944231
Q	=	0.511005	+/-	0.00806932
#Lambda	=	1562.61	+/-	162.791

*Field off correlations in backup

Fits with Q Fixed

- From previous slide we can see that Q and Λ are highly correlated.
- If we fix Q= .6 from Effects of Nitrogen contamination in liquid Argon R Acciarri *et al* 2010 *JINST* **5** P06003
- Field off Λ matches Dante's previous result
- Field on Λ closer to expected

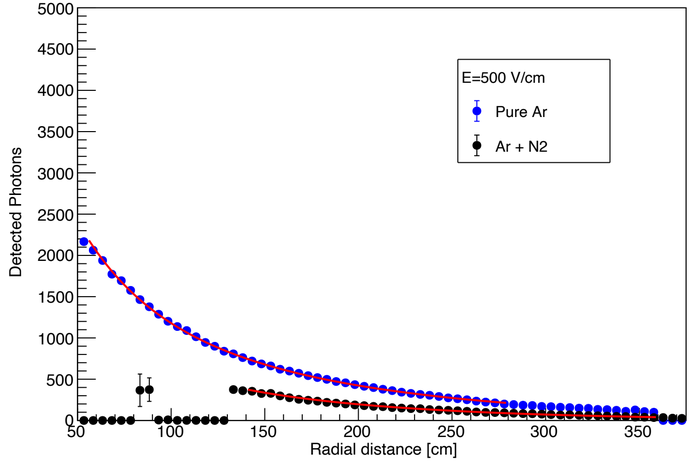
Field off



Minimizer is Minuit2 / Migrad

Chi2	=	80.1642		
NDf	=	28		
Edm	=	1.97504e-06		
NCalls	=	467		
A	=	2071.66	+/-	47.1024
B	=	152.606	+/-	3.616
C	=	14716.6	+/-	4557.58
D	=	26.1761	+/-	2.63412
Q (fixed)	=	0.61		
#Lambda	=	426.364	+/-	25.6029

Field on



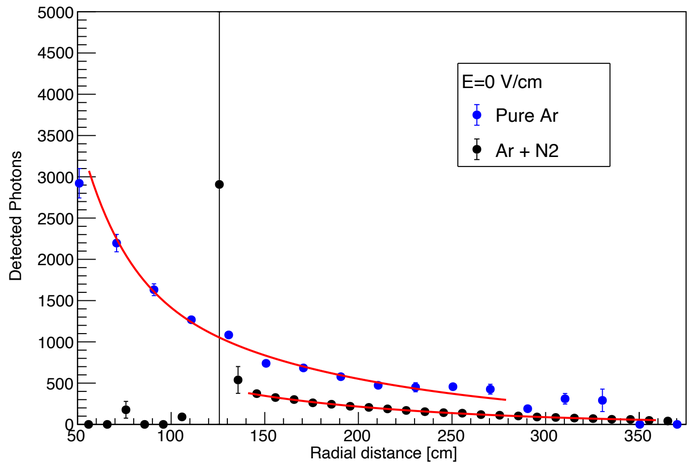
Minimizer is Minuit2 / Migrad

Chi2	=	475.297		
NDf	=	84		
Edm	=	1.41397e-05		
NCalls	=	277		
A	=	2198.75	+/-	41.7183
B	=	119.15	+/-	1.01997
C	=	4063.46	+/-	171.474
D	=	34.7802	+/-	1.06712
Q (fixed)	=	0.61		
#Lambda	=	724.577	+/-	7.56921

Fits with Λ fixed

- If we fix Λ = 8.6m
- Field off Q a little low
- Field on Q agrees with expectation

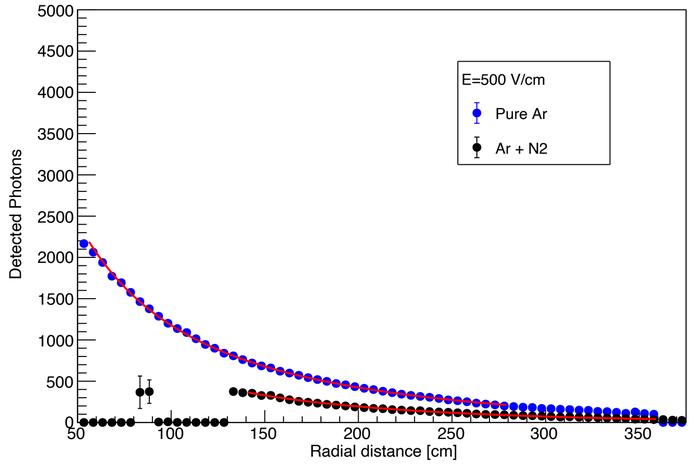
Field off



Minimizer is Minuit2 / Migrad

Chi2	=	77.9493	
NDf	=	28	
Edm	=	5.45087e-07	
NCalls	=	293	
A	=	2600.9	+/- 90.1208
B	=	128.557	+/- 1.18122
C	=	14676.3	+/- 6959.7
D	=	23.8208	+/- 3.57186
Q	=	0.492599	+/- 0.0125021
#Lambda (fixed)	=	860	

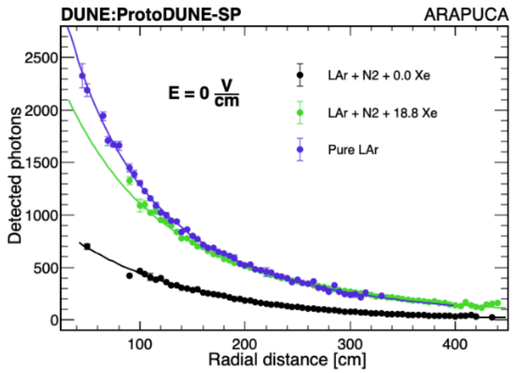
Field on

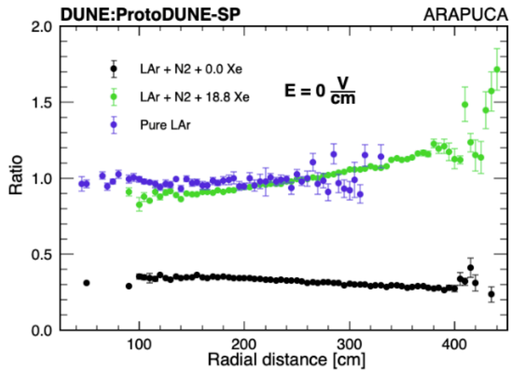


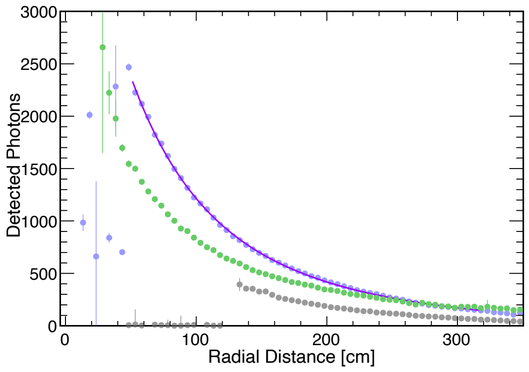
Minimizer is Minuit2 / Migrad

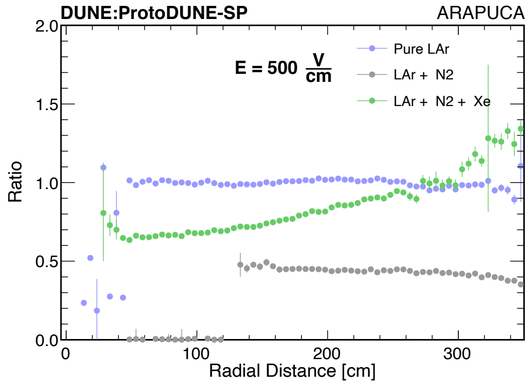
Chi2	=	412.273	
NDf	=	84	
Edm	=	3.90111e-06	
NCalls	=	259	
A	=	2263.93	+/- 35.6651
B	=	117.587	+/- 0.836654
C	=	4217.15	+/- 190.115
D	=	33.38	+/- 0.972512
Q	=	0.576226	+/- 0.00193402
#Lambda (fixed)	=	860	

Paper plots







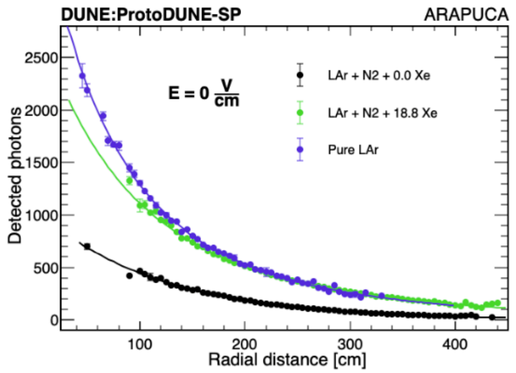


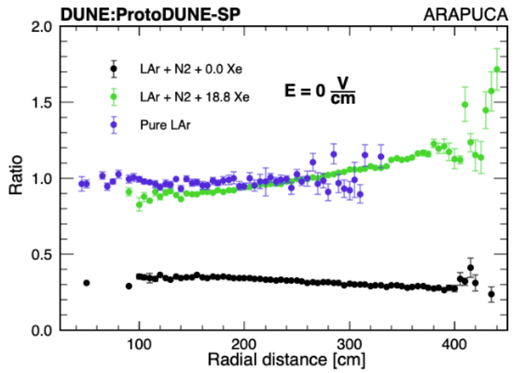
From previous few slides, we conclude:

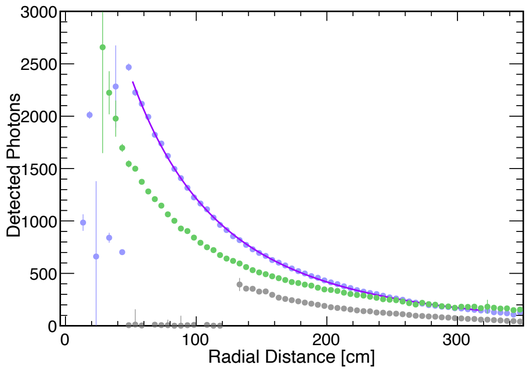
- The shape of attenuation curve for the field of data agrees more with field off data after removal of cathode crossing tracks
- The field on data agrees well with expectations of N2 quenching and absorption from literature
- The overall N2 quenching seems to be less severe in the presence of the field
  - Possibly due to singlet/triplet behavior in field?
- The gain in light yield due to Xenon is also somewhat muted due to the field

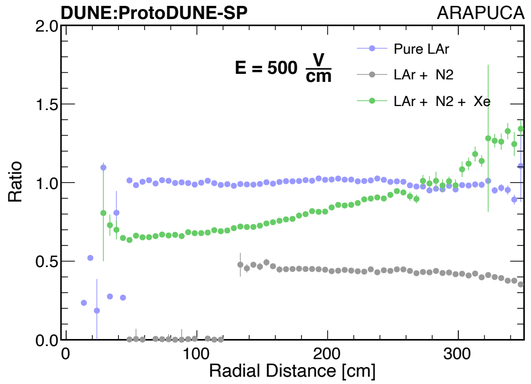
Paper plots

Our recommendation









- Go with these plots
- Field off plots are Dante's current versions in the paper draft
  - data to field off fit ratio
- Field on plots are updated to data to field-on fit ratios
  - Selections may be slightly different but seem compatible

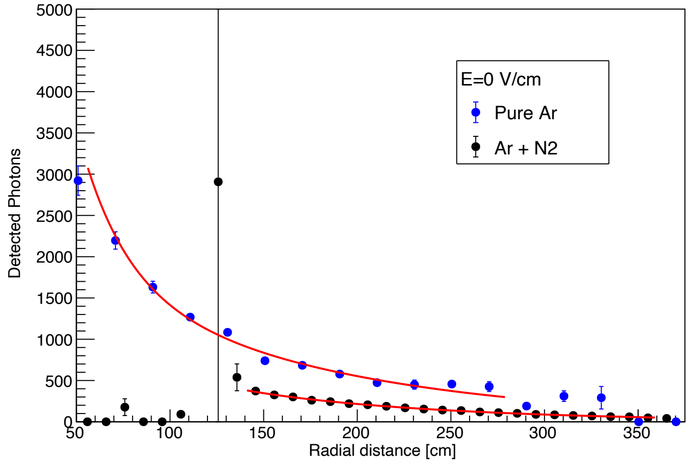
Initial Fits

- Using Dante's simultaneous fit method for similar ranges.
  - Full scan of fit ranges in backups
- From these fits we get neither the Q or Λ we expect.
  - Large correlation between the two
  - Cannot measure Q and Λ together

Field off correlations

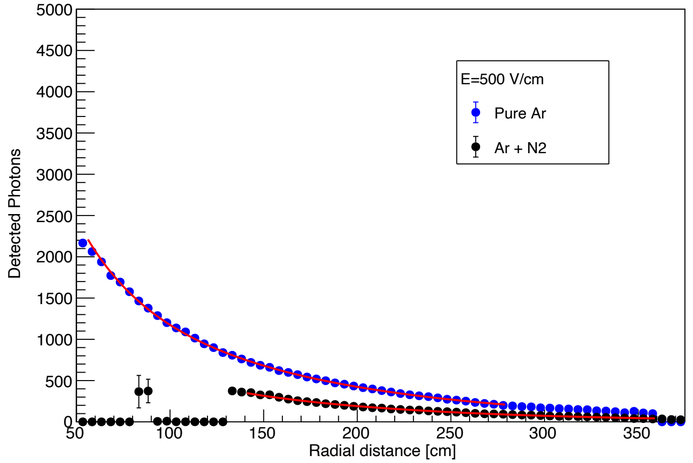
	0	1	2	3	4	5
0	1	-0.9785	0.1697	-0.5577	-0.9883	0.9662
1	-0.9785	1	-0.09107	0.4638	0.9768	-0.9952
2	0.1697	-0.09107	1	-0.8854	-0.09277	0.04367
3	-0.5577	0.4638	-0.8854	1	0.4822	-0.4147
4	-0.9883	0.9768	-0.09277	0.4822	1	-0.9794
5	0.9662	-0.9952	0.04367	-0.4147	-0.9794	1

Field off



Minimizer is Minuit2 / Migrad
Chi2 = 77.9443
NDf = 27
Edm = 8.08478e-06
NCalls = 725
A = 2575.64 +/- 347.35
B = 129.472 +/- 12.2979
C = 14666.3 +/- 6816.38
D = 23.9356 +/- 3.87534
Q = 0.497173 +/- 0.0623917
#Lambda = 822.264 +/- 477.787

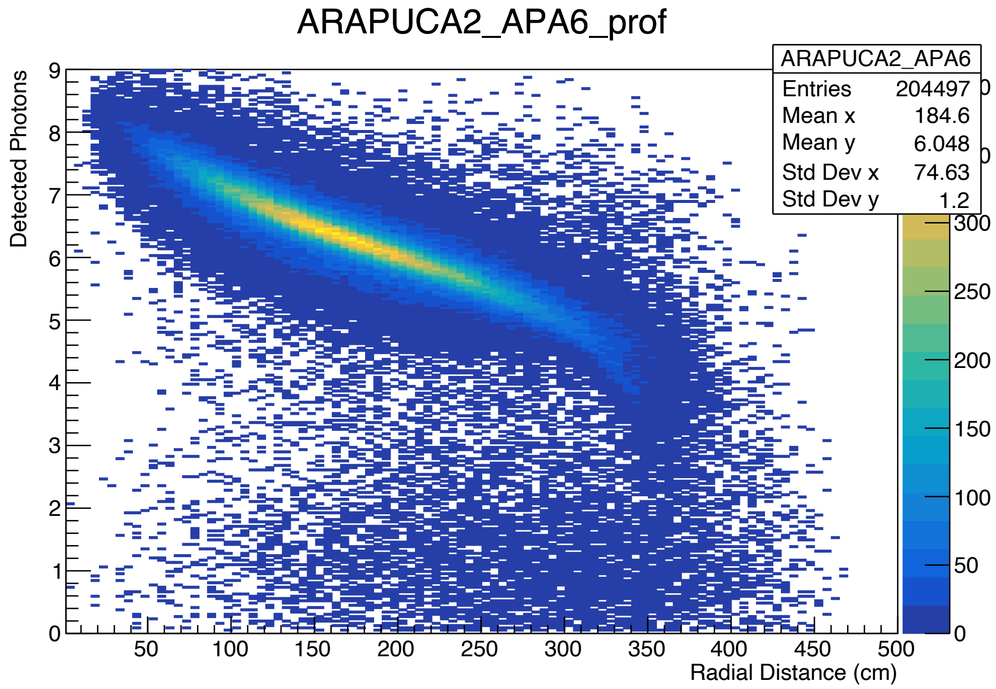
Field on



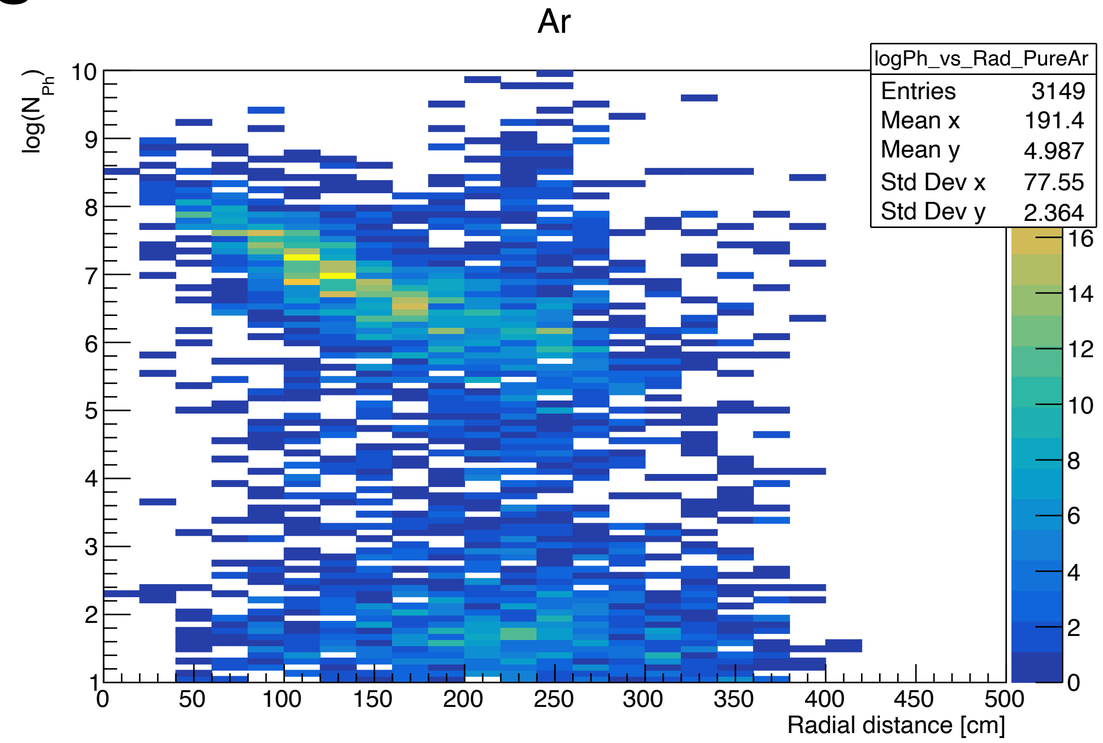
Minimizer is Minuit2 / Migrad
Chi2 = 352.801
NDf = 83
Edm = 2.52477e-06
NCalls = 420
A = 2449.49 +/- 34.5892
B = 113.215 +/- 0.759245
C = 4813.66 +/- 281.576
D = 29.503 +/- 0.944231
Q = 0.511005 +/- 0.00806932
#Lambda = 1562.61 +/- 162.791

Pure LAr

ln(Detected Photons) on vertical axis



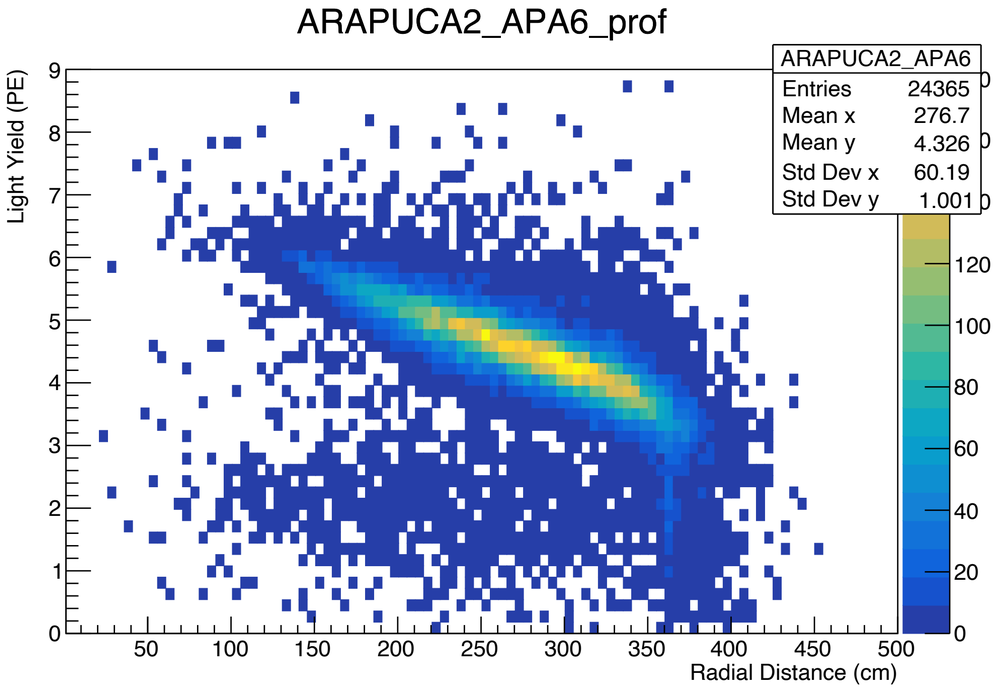
Field On



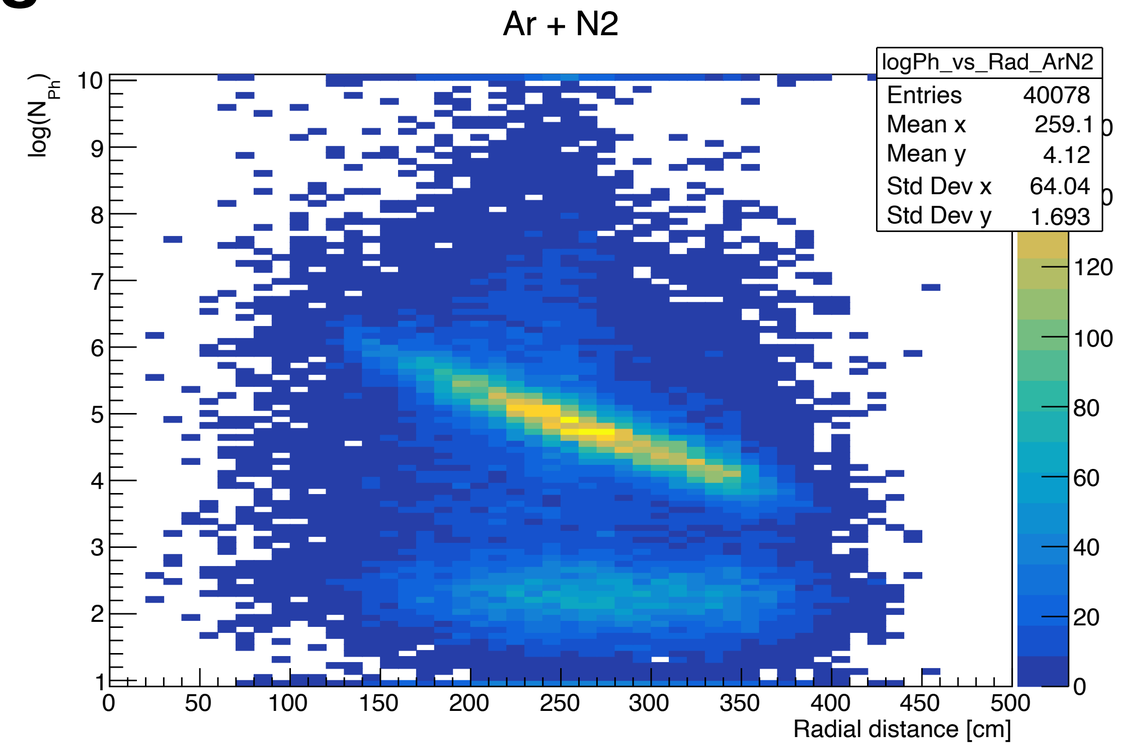
Field Off

LAr + N2

ln(Detected Photons) on vertical axis



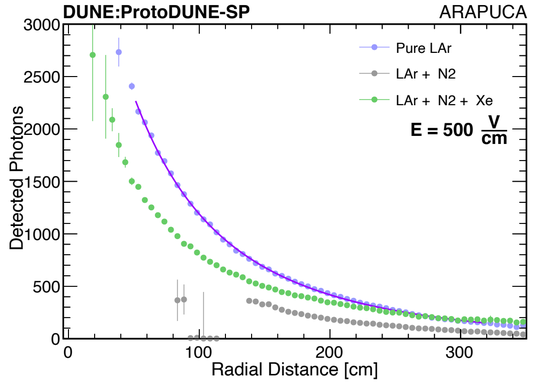
Field On

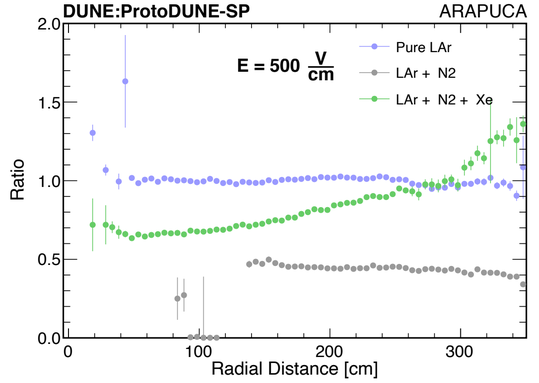


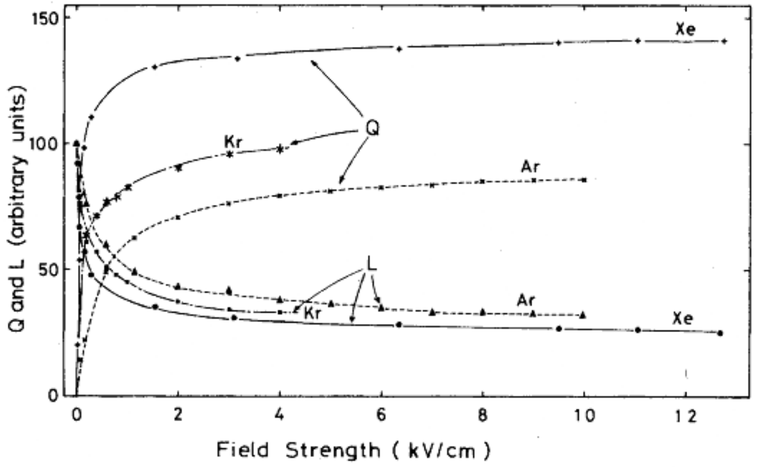
Field Off

SCE correction

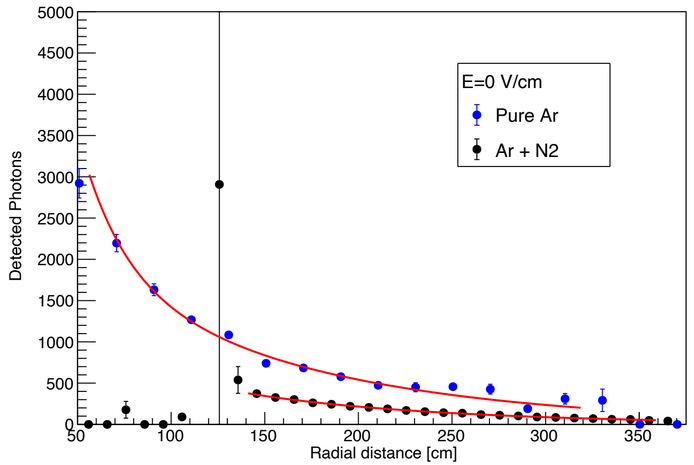
- ProtoDUNE has well done space charge maps readily available
- Locate the position of closest approach of the track and find the electric field value at this point
- Use plot on the right (digitized) to find light yield multiplier
- Correct measured PE by this value.
- Overall negligible effect





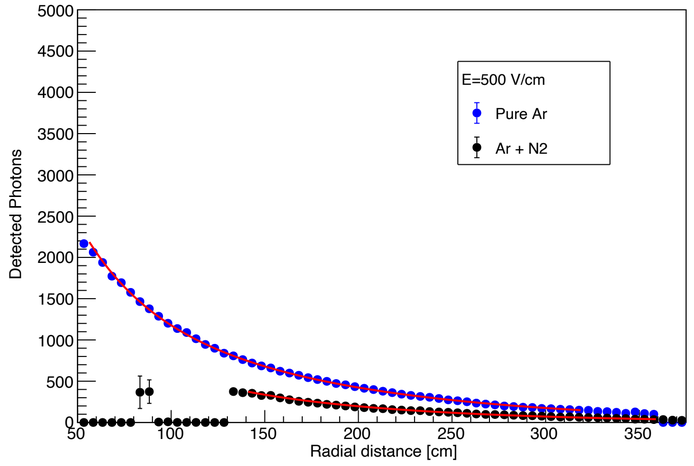


Field off



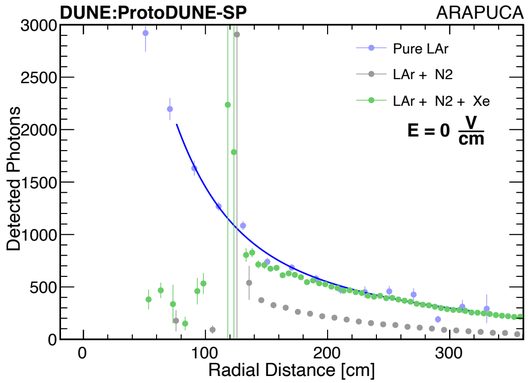
Chi2	=	84.0662	
NDf	=	29	
Edm	=	2.15216e-06	
NCalls	=	846	
A	=	2824.2	+/- 292.856
B	=	120.794	+/- 7.86993
C	=	14457.5	+/- 6476.61
D	=	23.0268	+/- 3.73321
Q	=	0.455427	+/- 0.0450237
#Lambda	=	1480.18	+/- 1148.22

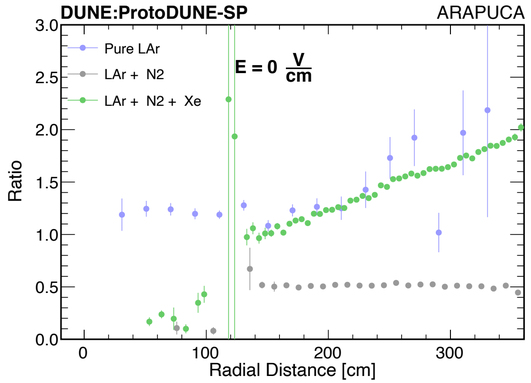
Field on

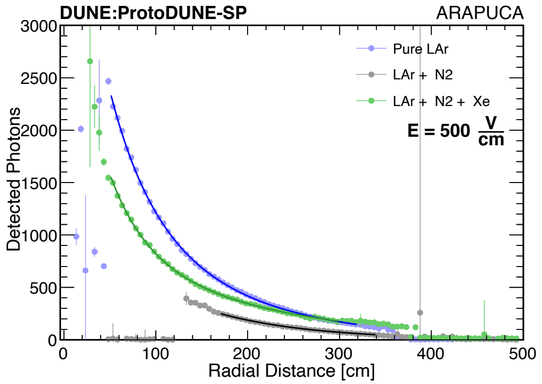


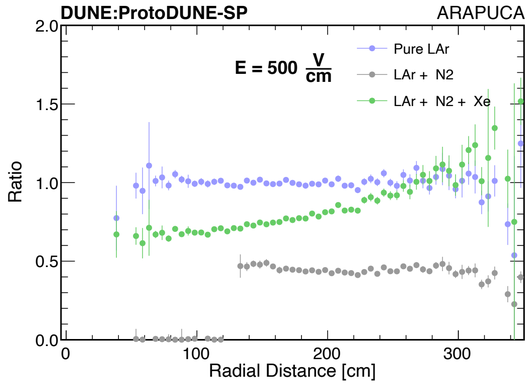
Minimizer is Minuit2 / Migrad

Chi2	=	500.686	
NDf	=	96	
Edm	=	8.93223e-06	
NCalls	=	267	
A	=	2324.79	+/- 30.9705
B	=	115.957	+/- 0.689063
C	=	4312.77	+/- 205.29
D	=	32.3521	+/- 0.90871
Q	=	0.6	
(fixed)			
#Lambda	=	780.912	+/- 8.01276

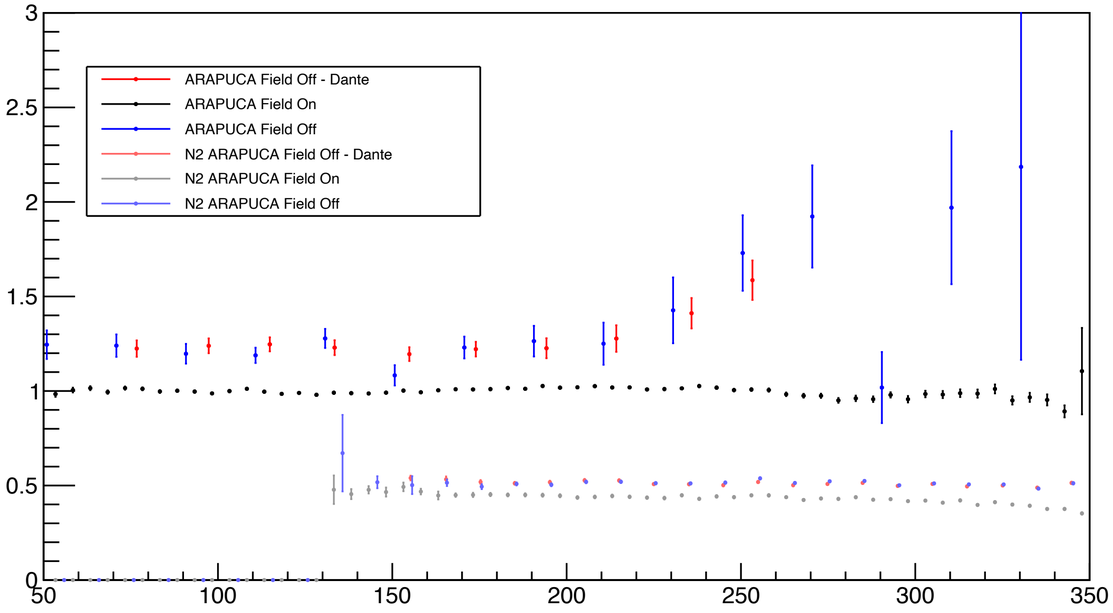






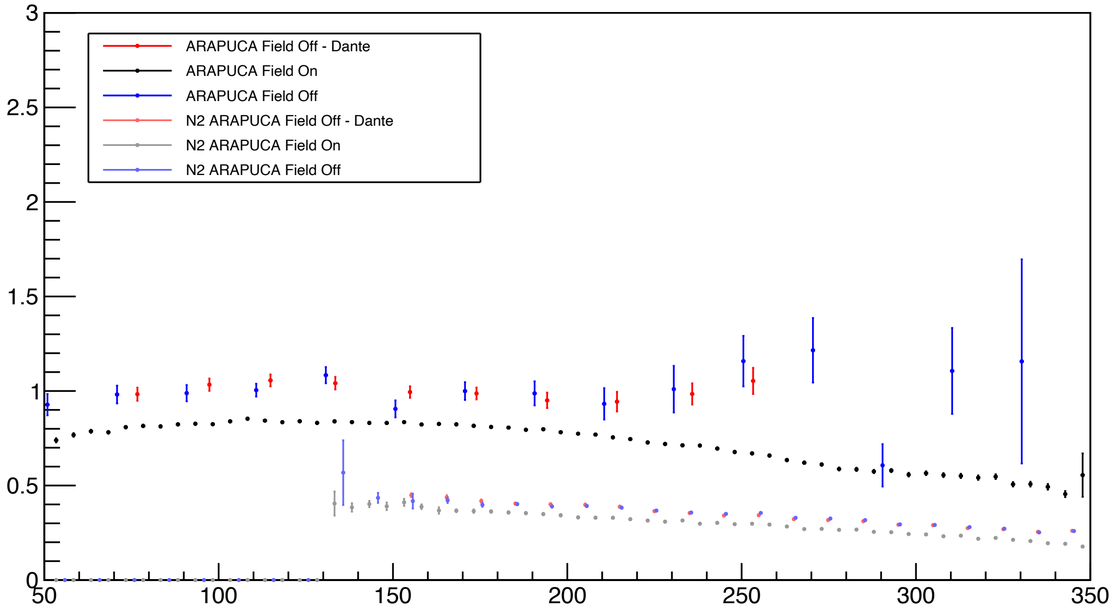


- All data compared to field on pure LAr fit



Field on data, field off data (both methods)

Field on Pure LAr fit



Field on data, field off data (both methods)

Field off Pure LAr fit

Both analyses use the data/fit method. Using the fit to the field on data make use of long distance(>250cm) track data.
Field on LAr data/ Field on LAr fit is consistent with 1 for entire range.
Field off LAr data/ Field off LAr fit starts to deviate around 250cm.

If we then switch to using data/field off fit - we see a N2 dependent absorption slope, but still see a large disagreement in the field off pure LAr data at >250cm. And overall poor modeling of the field on pure LAr data.

This shows a clear dependence of the fit on the long range (>250cm) data, and since the field off data has low statistics in this region, it returns a less robust result.

- Using technique from Jones et al we have found an expected absorption in ProtoDUNE-SP to be **8.6 ± .9m**
- Since Q and Λ are so highly correlated, we fixed Q = .6 from Acciarri et al
- Fits to field on data using this procedure produce Λ = 7.25 ±.075m