INDIANA UNIVERSITY

RSL Studies in ProtoDUNE-VD

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ProtoDUNE PDS Sim/Reco meeting
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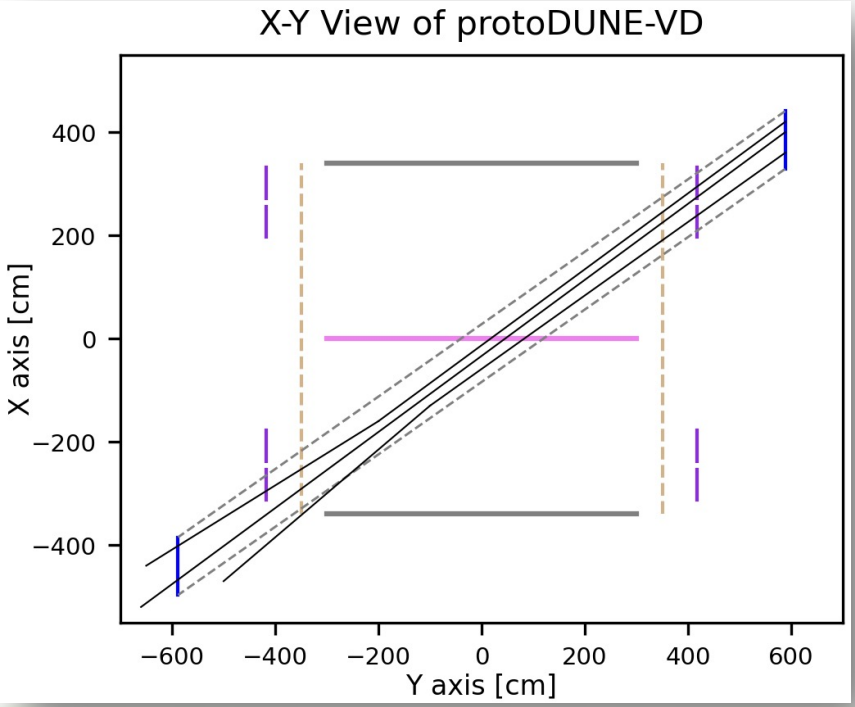
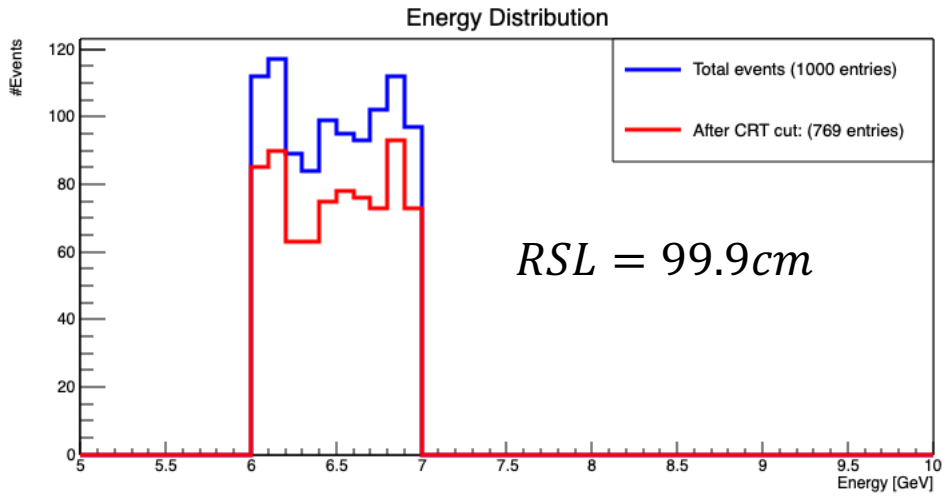
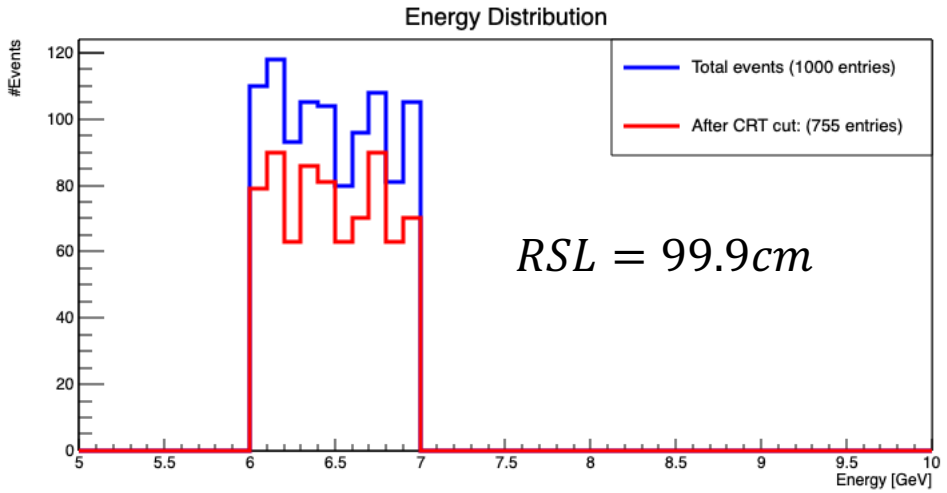
Simulation Details

- Previous presentation: DUNE Jan 2024 Collaboration Meeting
- Simulated particles: μ^-, # $= 2000$, $E \in [6,7] GeV$, uniformly distributed
- Starting from top CRT, toward bottom CRT
- Only events passing bottom CRT considered in following analysis
- Simulations based on $RSL = 50, 70, 99.9, 150 cm$ are separately made

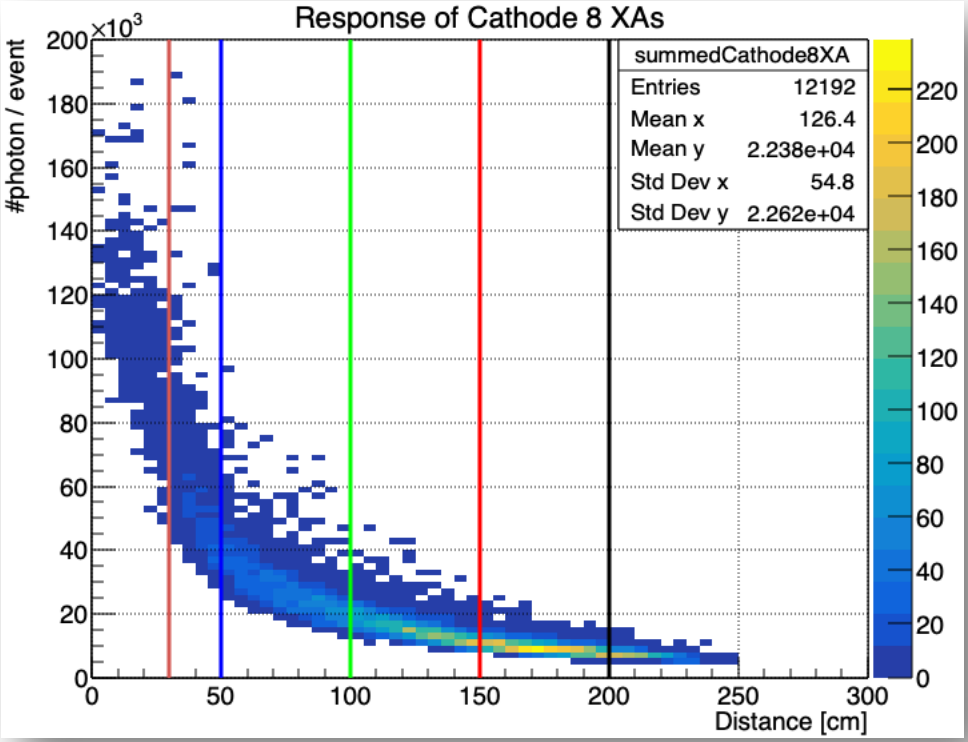


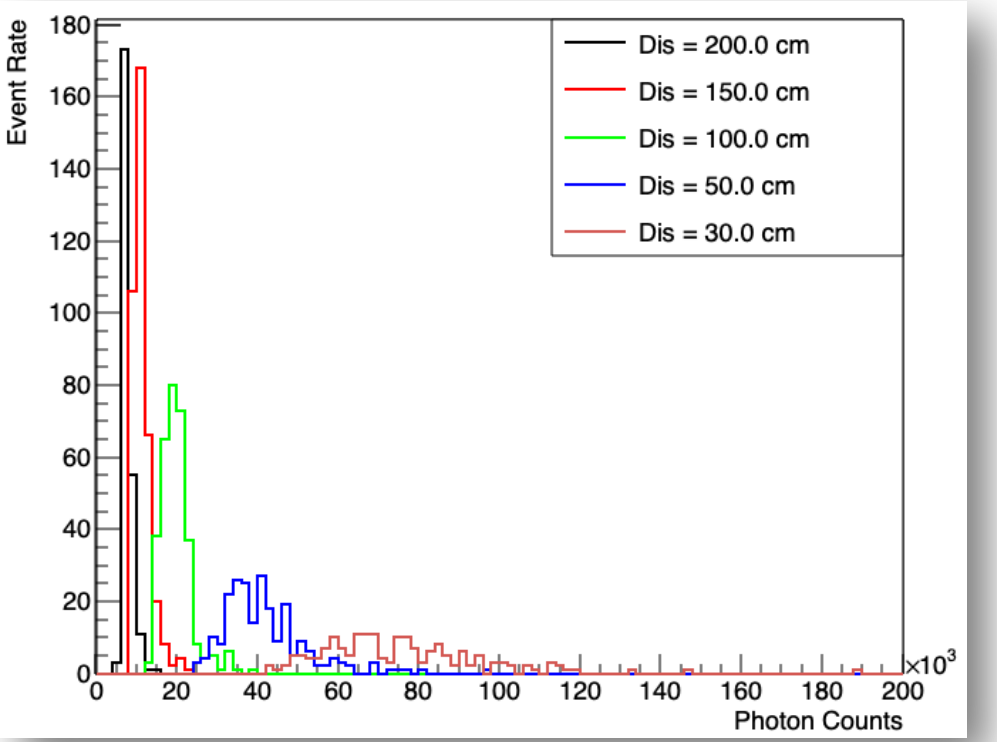




Performances of Cathode XA

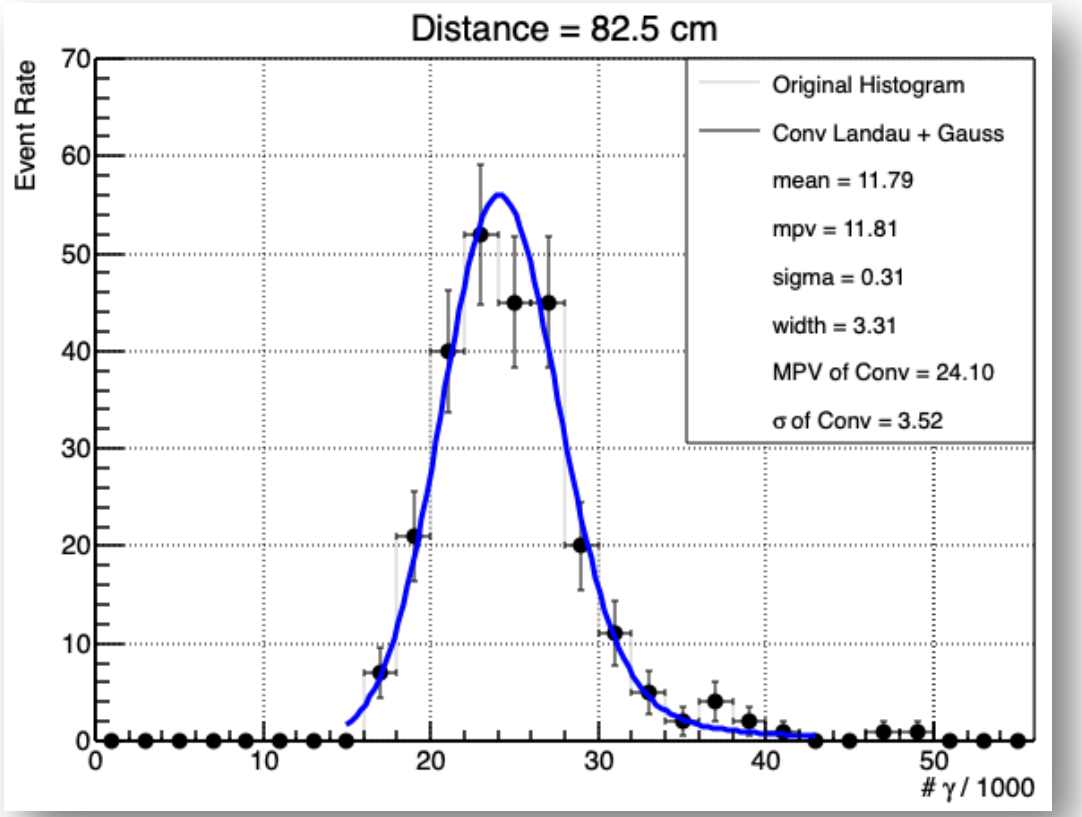
- $RSL = 99.9cm$; Photon detection efficiencies of all opCh are set as 3%
- Responses of 8 X-Arapuca on cathode are gathered
- $5cm/bin$ along x axis, 100 bins in total for y axis
- Landau-like distribution for slices at different distances

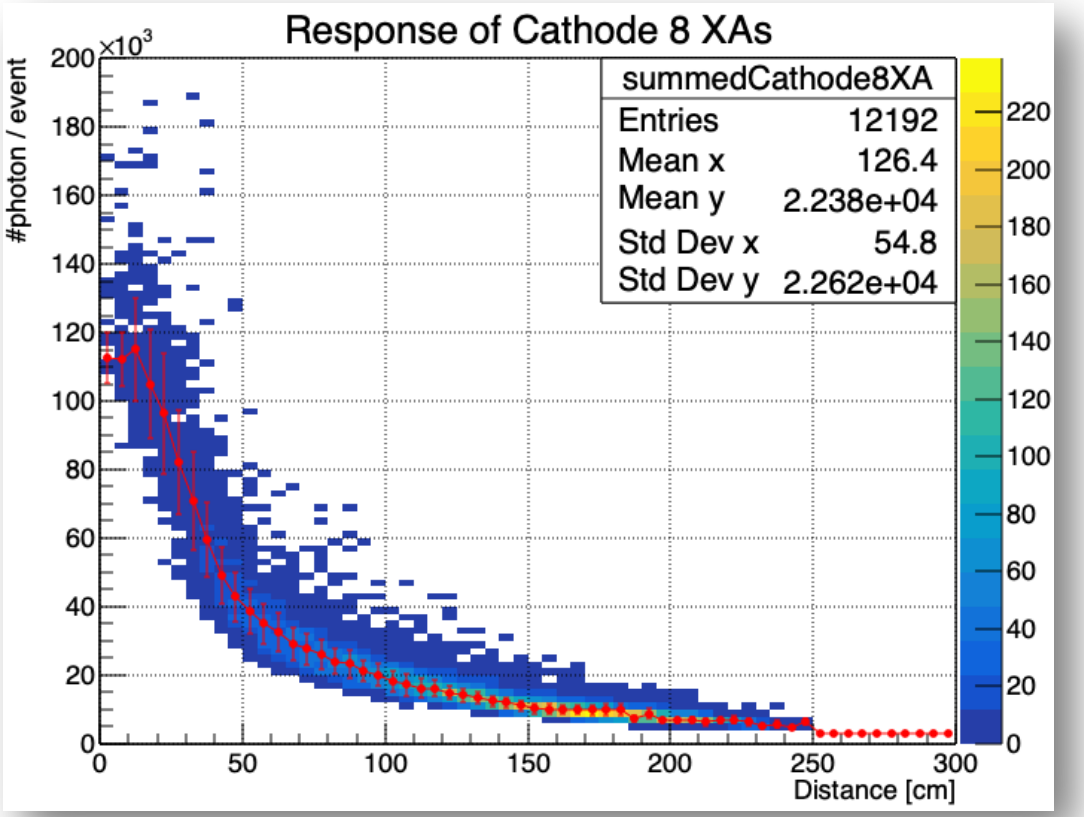




Fitting Method

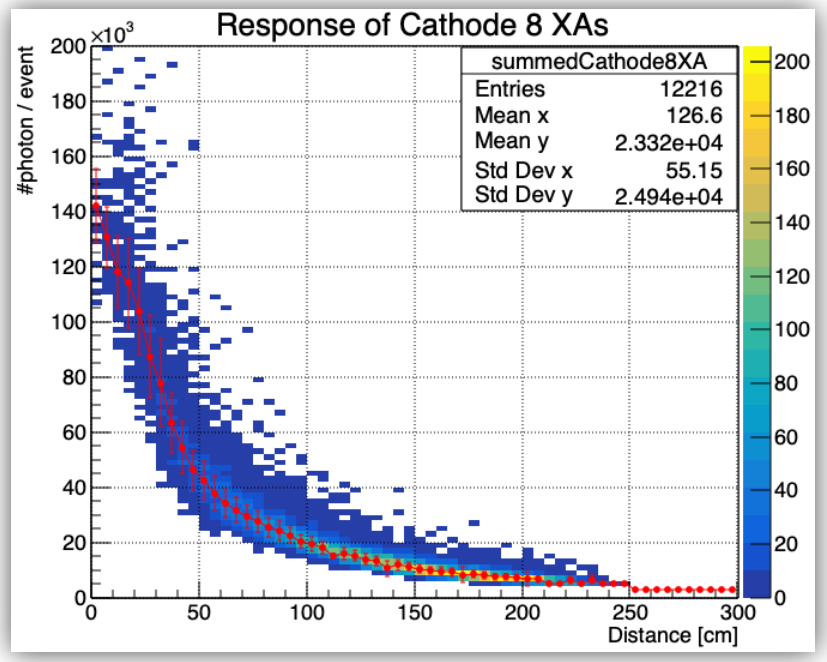
- Fitting function: Convolution of Landau and Gauss $\boldsymbol{L(mpv, sigma) \otimes G(mean, width)}$
- σ of fitting curve (Conv): $\boldsymbol{\sigma = \frac{FWHM}{2.355}}$



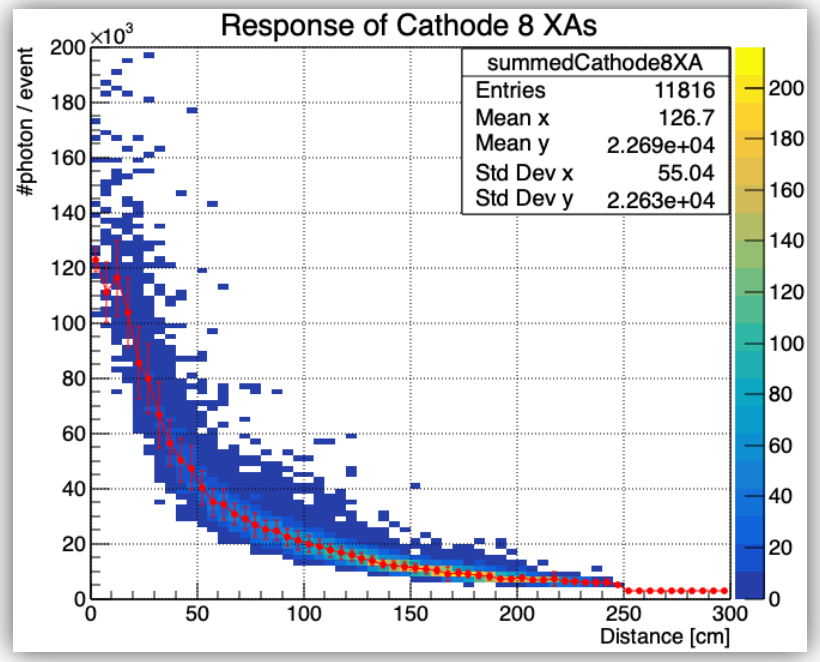


Apply Fitting to RSL50, 70 & 150

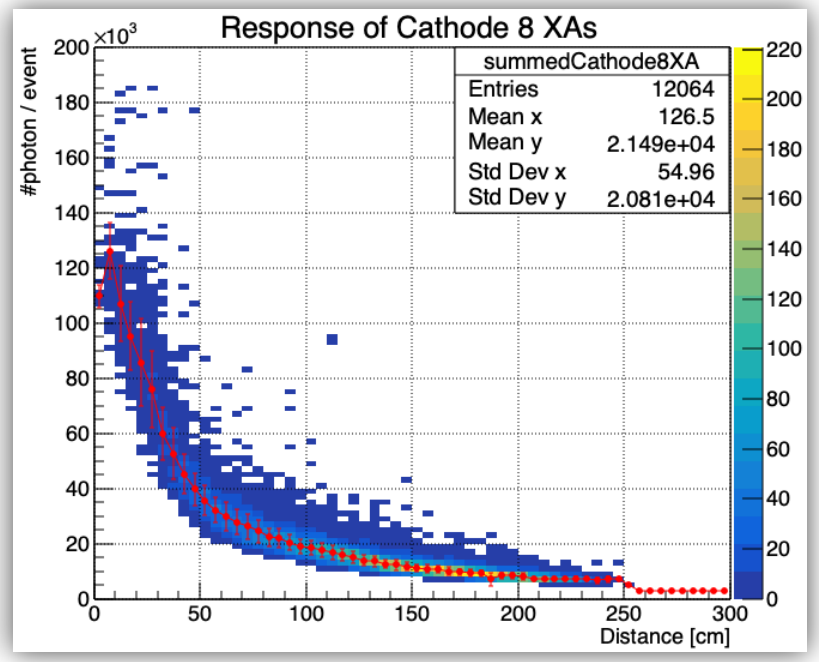
$RSL = 50cm$



$RSL = 70cm$

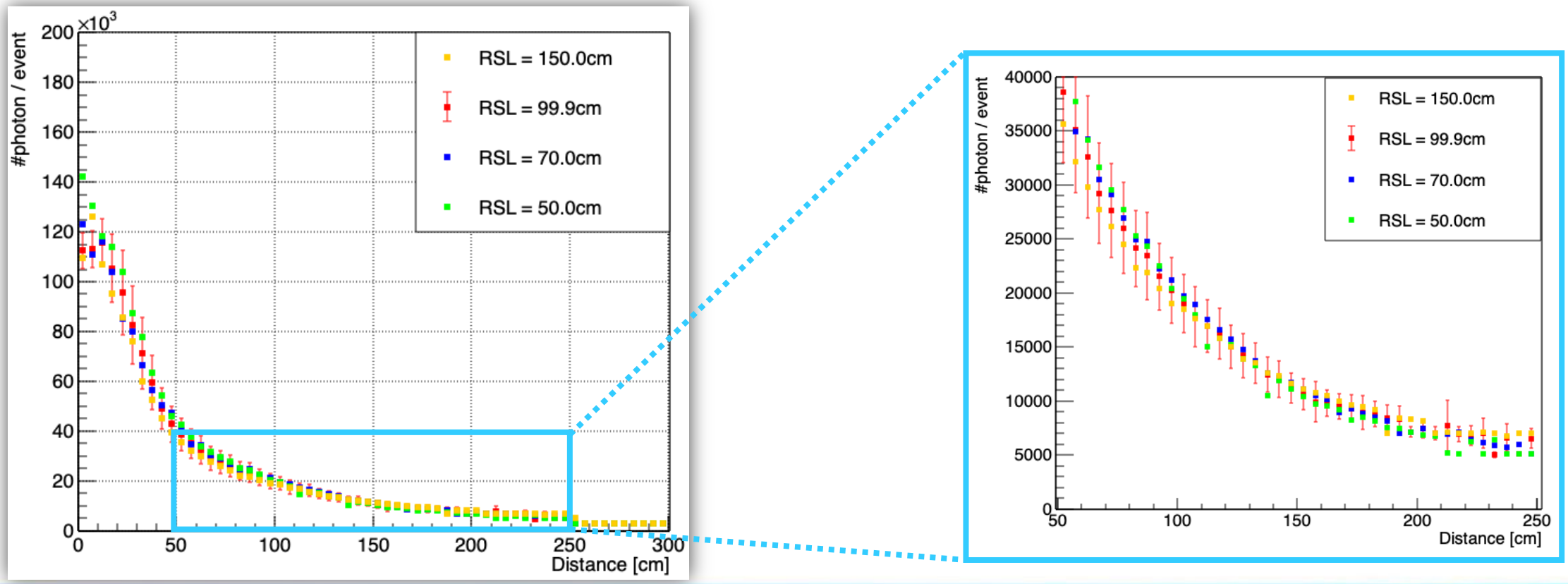


$RSL = 150cm$



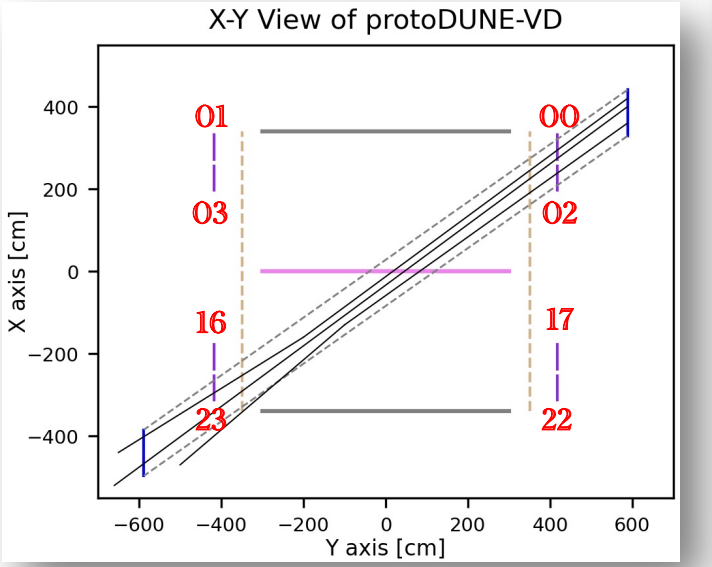
Comparison Among different RSLs

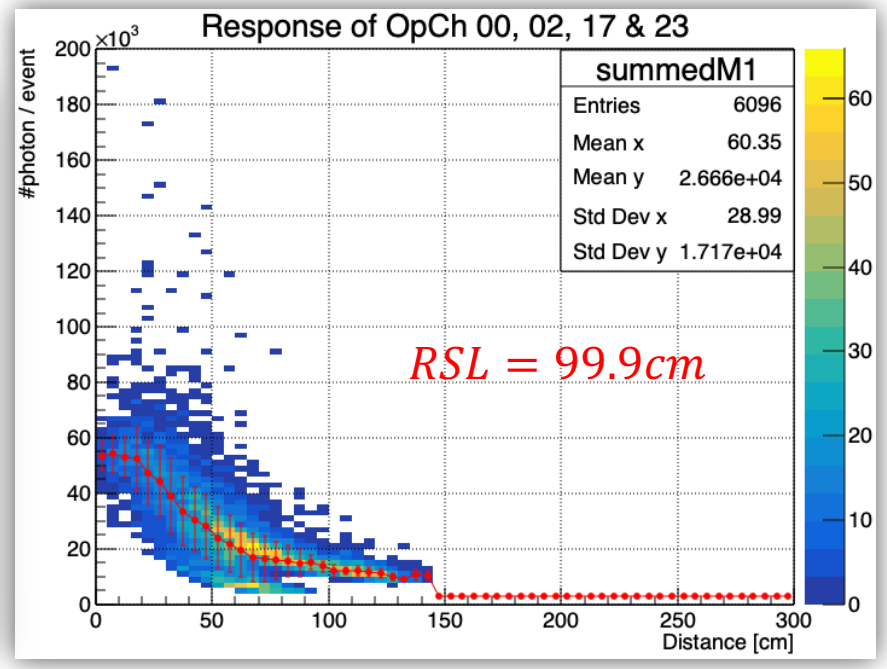
- [0, 50]cm: Differences among RSL=50, 99.9, 150cm are clear
- [0, 50]cm: Differences within std of RSL = 99.9cm, may be improved after increasing statistics
- [50, 250]cm: Not sensitive to different RSLs (within std of RSL = 99.9cm)
- [50, 250]cm: Interesting trends: As Distance ↑, $\frac{(RSL=150cm)}{(RSL=99.9cm)}$ ↑, $\frac{(RSL=50cm)}{(RSL=99.9cm)}$ ↓

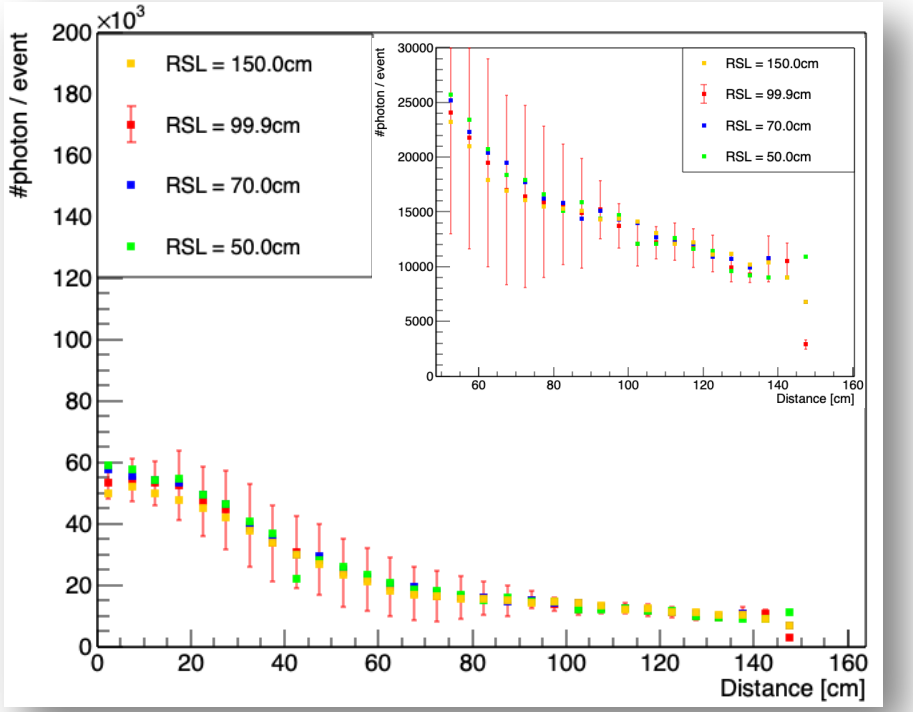


Performances of OpCh 00, 02, 17 & 23

- Membrane X-Arapucas close to muon track
- Not sensitive to Different RSLs

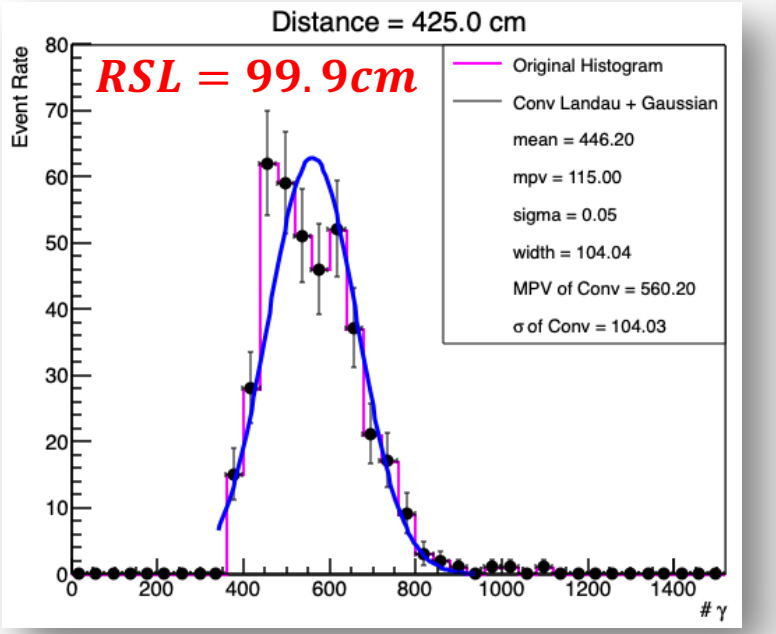


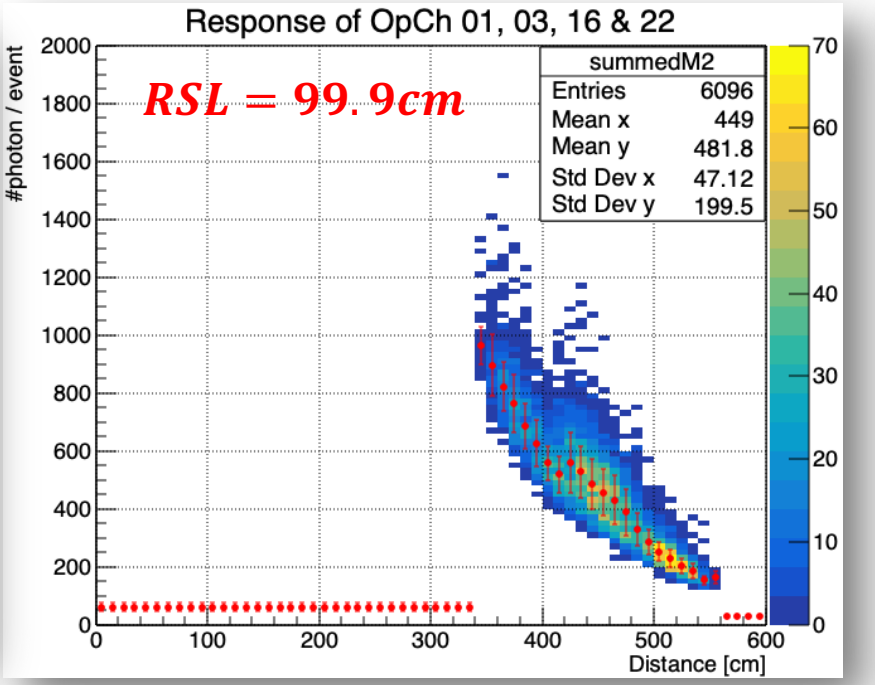


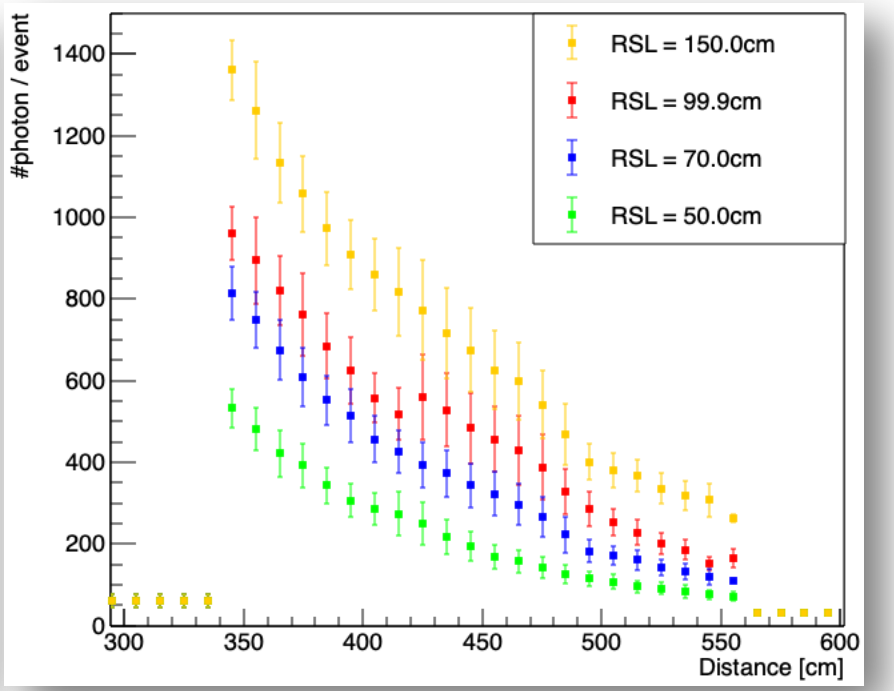


Performances of OpCh 01, 03, 16 & 22

- Membrane X-Arapucas far away from muon track
- MPV of fitting different from MPV of histogram when Distance $\in [400, 500] cm$, Especially at $425, 445, 465, 475 cm$
- Very sensitive to different RSLs

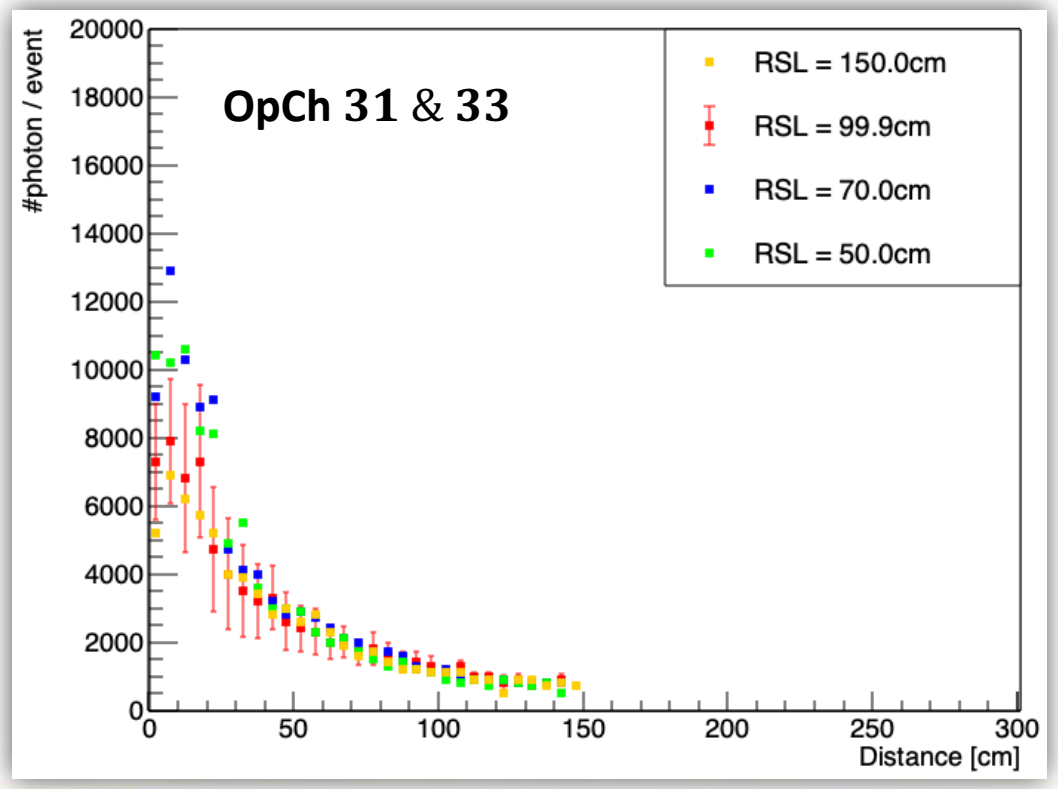


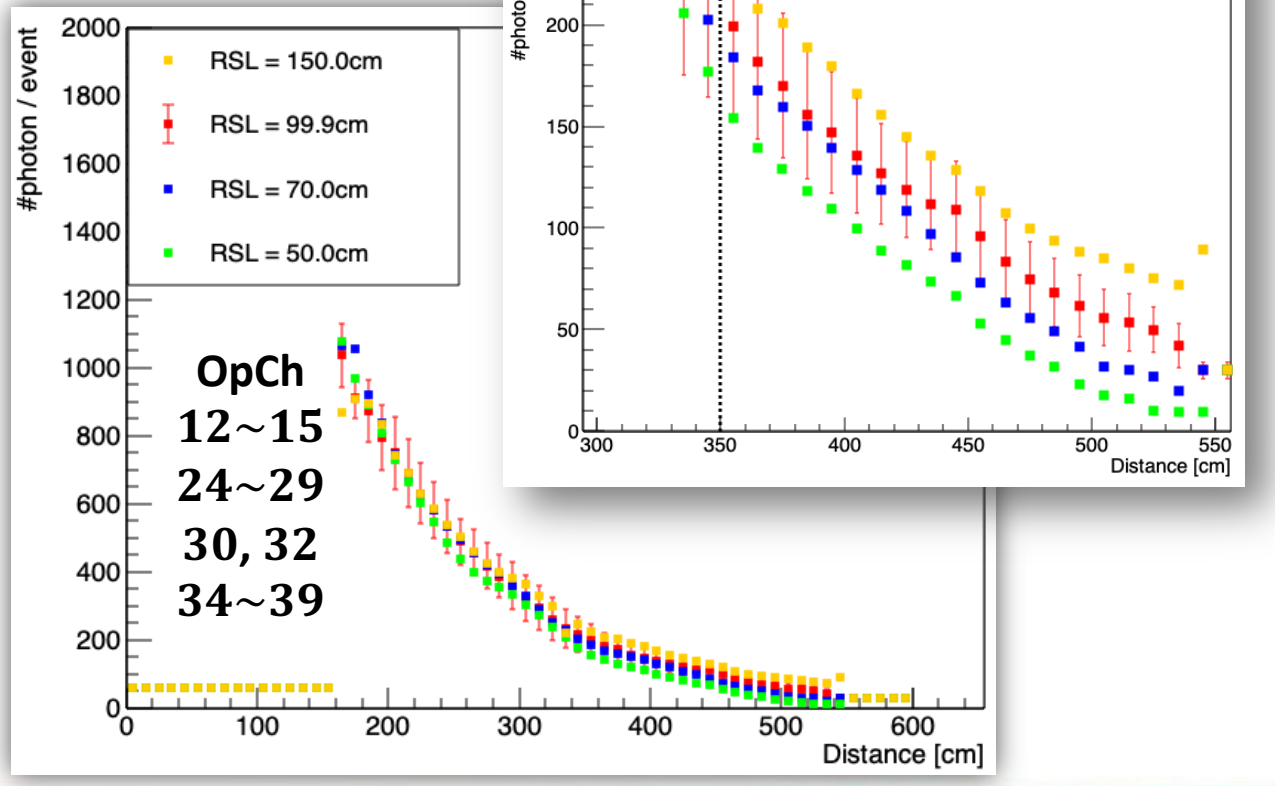




Performances of PMTs

- OpCh 31 & 33 (PMT group 1): along the track of muon
- OpCh 12~15, 24~29, 30, 32, 34~39 (PMT group 2): away from muon tracks
- PMT group 1: NOT sensitive to different RSLs
- PMT group 2: apparent distinctions when $Distance > 350cm$





Summaries

- Fitting to slices of different distances were made; Most look fine
- Comparisons based on different Rayleigh scattering lengths were made
- Cathode X-Arapucas not very sensitive to RSLs, higher statistics may improve the performance
- Membrane X-Arapucas close to muon track NOT sensitive to RSLs
- Membrane X-Arapucas away from muon track sensitive to RSLs
- PMTs far away from muon track sensitive to RSLs
- Further steps:
    1. Apply χ^2/ndf to characterize fitting goodness
    2. Improve statistics to check if cathode X-Arapucas better performance
    3. Train more comp graph modules with different RSLs, i.e. $60, 80, 90, 110, 120, 130, 140cm$
    4. Consider effects of radiological background, ex: Ar39, Kr85
    5. …

Thank you!

Backups

X-Arapuca Labels in v4 geometry

Beam enter point: $\sim(210, 150, 0)$
CRP height: $\pm 342cm$
Thickness of XA: $\sim 2.5cm$

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Cryo Boundaries
Xmin: -375 Xmax: 415 Ymin: -427.4 Ymax: 427.4 Zmin: -277.75 Zmax: 577.05
 drift coordinate: 1 (X direction)
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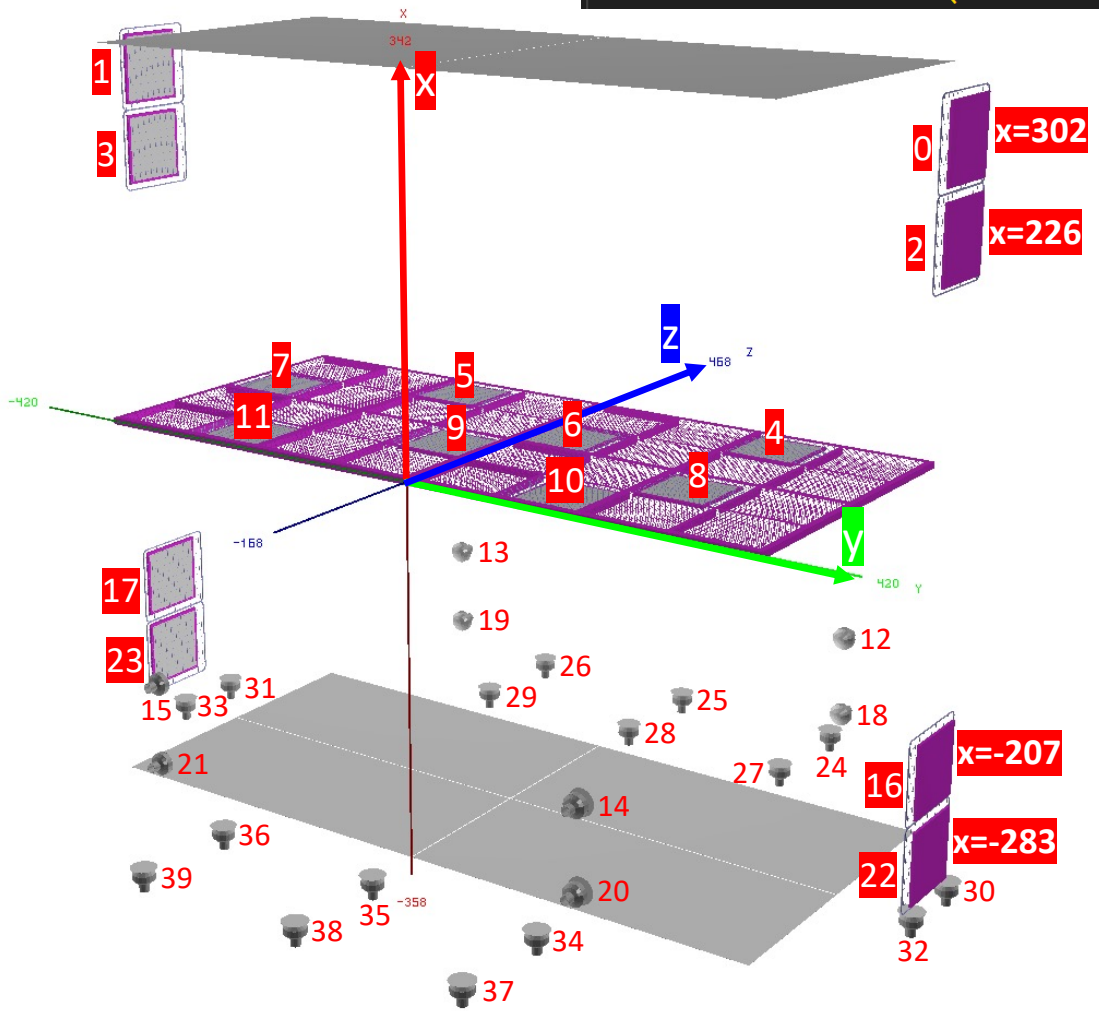


Optical Channels positions:	40	
0	302.18	417.61	149.65
1	302.18	-417.61	149.65
2	226.38	417.61	149.65
3	226.38	-417.61	149.65
4	0	205.65	258.525
5	0	-131.35	258.525
6	0	39.15	187.275
7	0	-297.85	187.275
8	0	205.65	112.025
9	0	-39.15	112.025
10	0	131.35	40.775
11	0	-205.65	40.775
12	-205.9	221	380.988
13	-205.9	-221	380.988
14	-205.9	221	-68.1242
15	-205.9	-221	-81.6884
16	-207.23	417.61	149.65
17	-207.23	-417.61	149.65
18	-281.7	221	380.988
19	-281.7	-221	380.988
20	-281.7	221	-68.1242
21	-281.7	-221	-81.6884
22	-283.03	417.61	149.65
23	-283.03	-417.61	149.65
24	-336.474	170	455.65
25	-336.474	1.13687e-13	455.65
26	-336.474	-170	455.65
27	-336.474	170	353.65
28	-336.474	1.13687e-13	353.65
29	-336.474	-170	353.65
30	-336.474	405.3	217.75
31	-336.474	-405.3	217.75
32	-336.474	405.3	149.65
33	-336.474	-405.3	149.65
34	-336.474	170	-54.35
35	-336.474	1.13687e-13	-54.35
36	-336.474	-170	-54.35
37	-336.474	170	-156.35
38	-336.474	1.13687e-13	-156.35
39	-336.474	-170	-156.35

RSL, Abs & Reflectivity

Rayleigh scattering length:

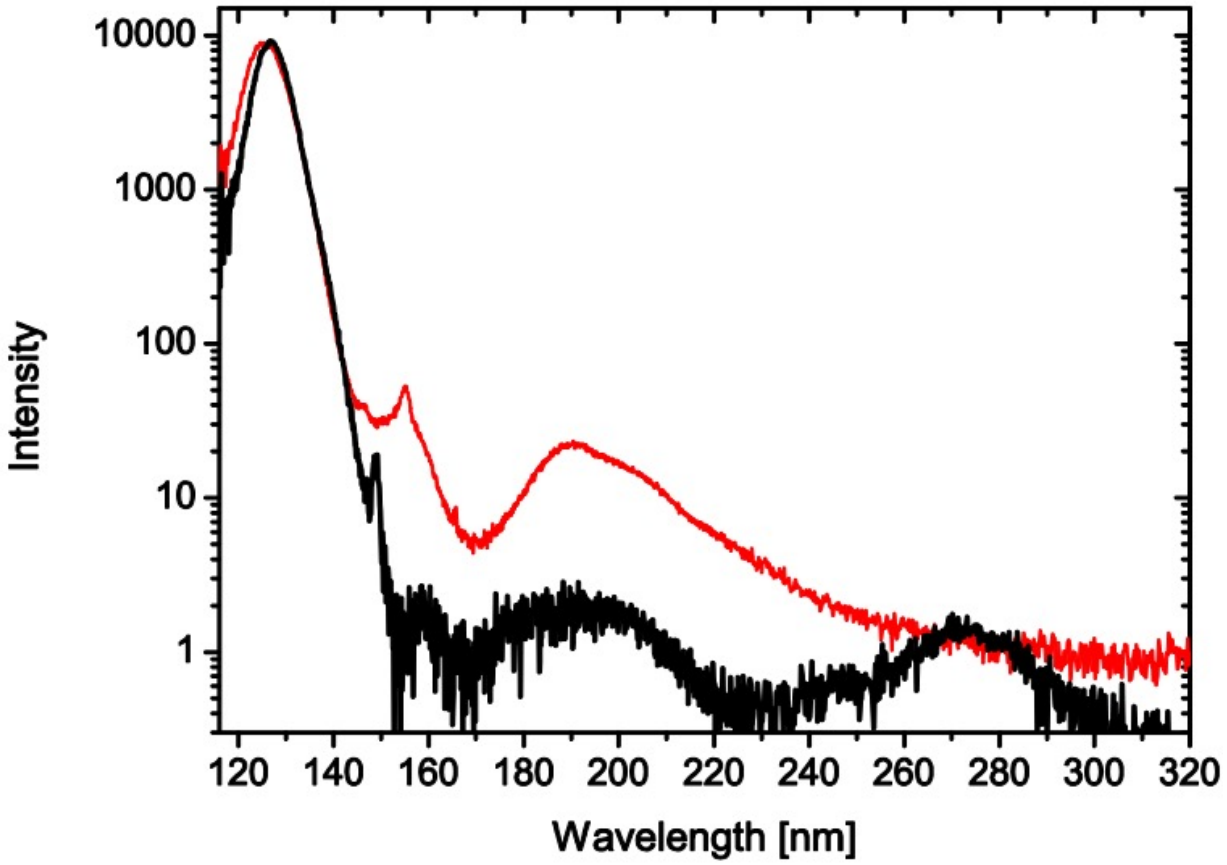
```
118   services.LArPropertiesService.RayleighEnergies: [1.18626, 1.68626, 2.18626, 2.68626, 3.18626, 3.
      68626, 4.18626, 4.68626, 5.18626, 5.68626, 6.18626, 6.68626, 7.18626, 7.68626, 8.18626, 8.68626,
      9.18626, 9.68626, 10.1863, 10.6863, 11.1863]
119   services.LArPropertiesService.RayleighSpectrum: [1200800, 390747,  128633,  54969.1, 27191.8,
      14853.7, 8716.9,  5397.42, 3481.37, 2316.51, 1577.63, 1092.02, 763.045, 534.232, 371.335, 252.
      942, 165.38,  99.9003, 51.2653, 17.495,  0.964341]
```

Absorption length:

```
127   services.LArPropertiesService.AbsLengthEnergies: [4,5,6,6.5,7,7.5,8,9,10,11]
128   services.LArPropertiesService.AbsLengthSpectrum: [2000,2000,2000,8000,8000,8000,2000,2000,2000,2000]
```

For more details, refer to (dunegpvm) /dune/data/users/szh2/rsl_Nov2023/work/photonFull_module0_sim.fcl

Photon Spectrum of LAr



- Black: LAr, Red: GAr
- LAr: Peak @ **126.8**nm, FWHM: 7.8nm [122.9, 130.7]nm
  Energy: Peak @ 9.78eV, FWHM: 0.602eV

- Assuming Gaussian distribution:
  $(\mu, \sigma) = (9.78, 0.256)eV$

Normal distribution [edit]

See also: Gaussian beam § Beam waist

If the considered function is the density of a normal distribution of the form

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x - x_0)^2}{2\sigma^2}\right]$$

where σ is the standard deviation and x_0 is the expected value, then the relationship between FWHM and the standard deviation is[1]

$$\text{FWHM} = 2\sqrt{2\ln 2}\,\sigma \approx 2.355\,\sigma.$$

https://arxiv.org/ftp/arxiv/papers/1511/1511.07718.pdf
https://iopscience.iop.org/article/10.1088/1748-0221/15/09/P09009/pdf

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