INDIANA UNIVERSITY

Comp Graph Module for protoDUNE-VD PDS

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ProtoDUNE PDS Sim/Reco meeting
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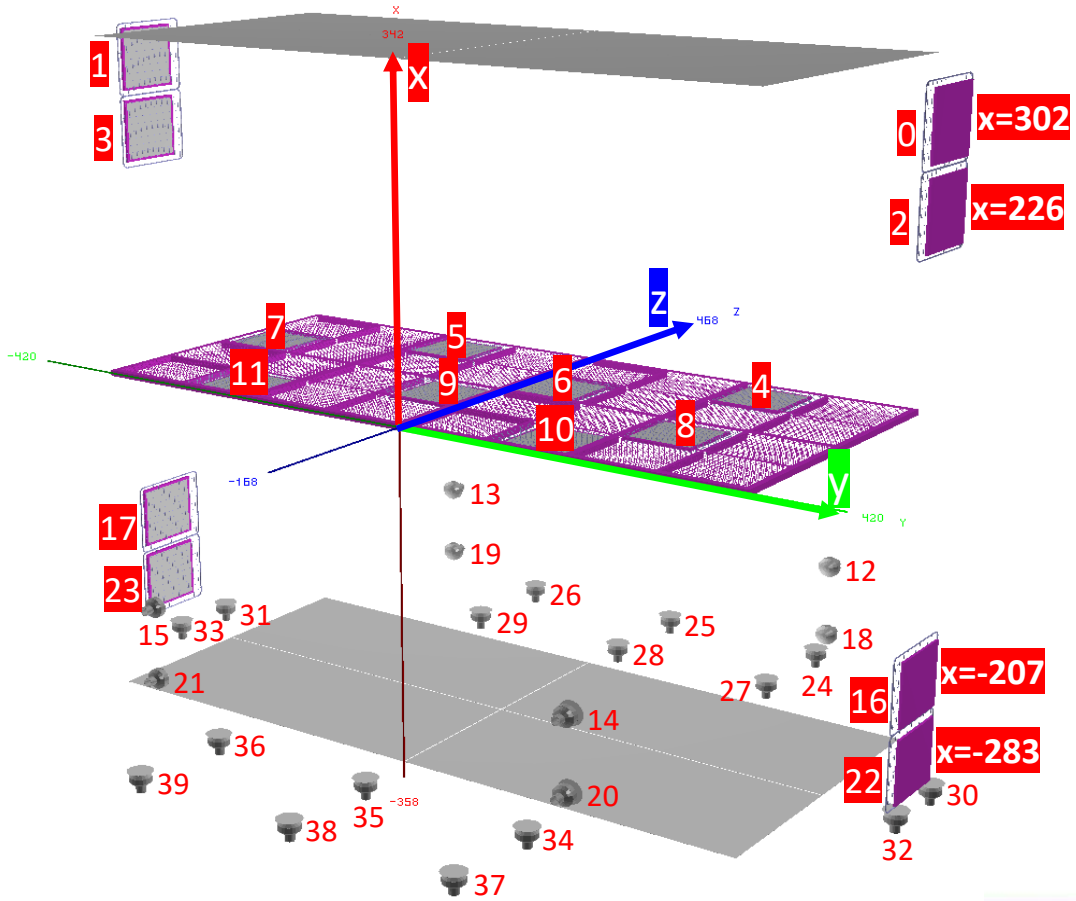
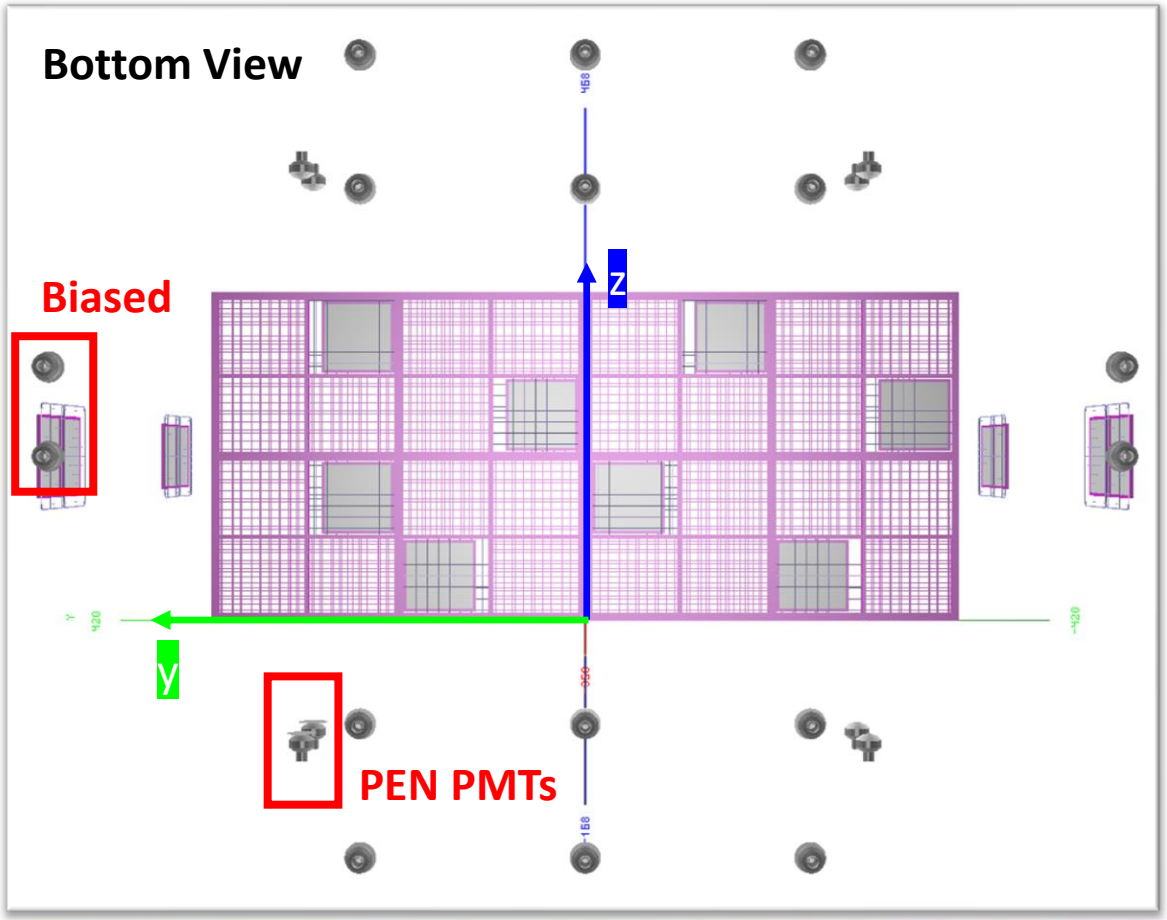
protoDUNE-VD Geometry Review

- Last talk: https://indico.fnal.gov/event/61866/
- Final protoDUNE-VD geometry (Hamza, Pablo & Jose): available on **dunecore**
- Optical channels: **40** (**16** X-Arapucas + **18** PEN pmts + **6** TPB pmts)



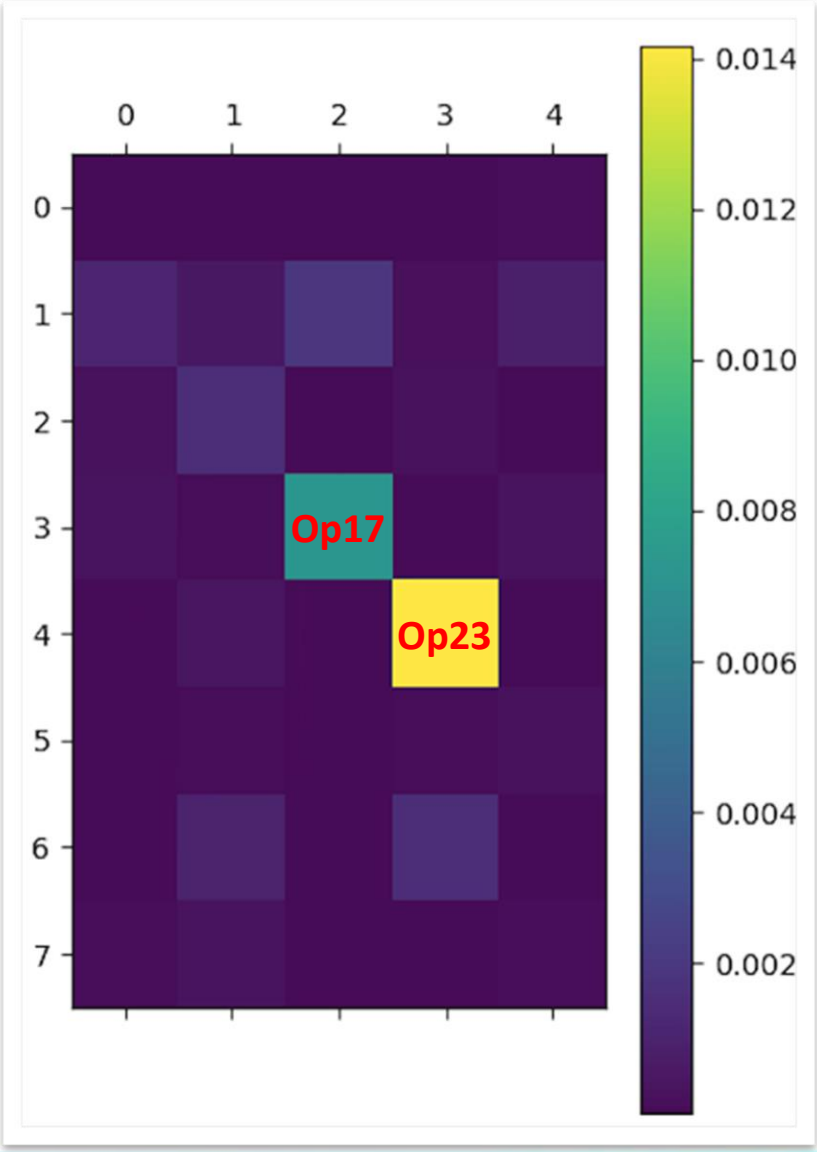


Production Details of Training Samples

Space distribution of events	Uniform
Boundaries	$x \in [-375,\ 415]cm, y \in [-427.4,\ 427.4]cm,$ $z \in [-277.75\ , 577.05]cm$
Events # (training set, validation set, test set)	$100{,}000;\ 10{,}000;\ 10{,}000$
Events Interval (training set)	$\sim \frac{800cm}{\sqrt[3]{100000}} = 17cm$
γ emission vertex (event)	# = 10^6 , isotropic
Energy distribution of γ	Gaussian with $(\mu, \sigma) = (9.69, 0.25)eV$
Rayleigh scattering length (RSL)	$99.9cm$ @ $9.69eV$
Absorption length (Abs)	$20m$ @ $9.69eV$
Reflectivity considered	[“STEEL_STAINLESS_Fe7Cr2Ni”, “Copper_Beryllium_alloy25", “G10”, “vm2000", “ALUMINUM_Al”]

Example of Training Set

- Each PNG corresponding to ONE event.
- Block color(detection rate): **(received photons)/1,000,000**
- Channel label: left to right, top to bottom $(0\sim39)$
- Photon emission vertex: : $(-311.966, -296.501, 133.542)cm$



Neural Network & Training Details

- Optical Channels are divided into different groups based on the layout:

0 ~ 3	4~ 11	12 ~ 15	16 ~ 17	18 ~ 21
22~ 23	24~ 29	30 ~ 33	34 ~ 39	

- Complete network: https://github.com/szhang17phys/compGraph_v4_git_20231125/blob/main/gnn_Muve/networks.py

- Training parameters of network:

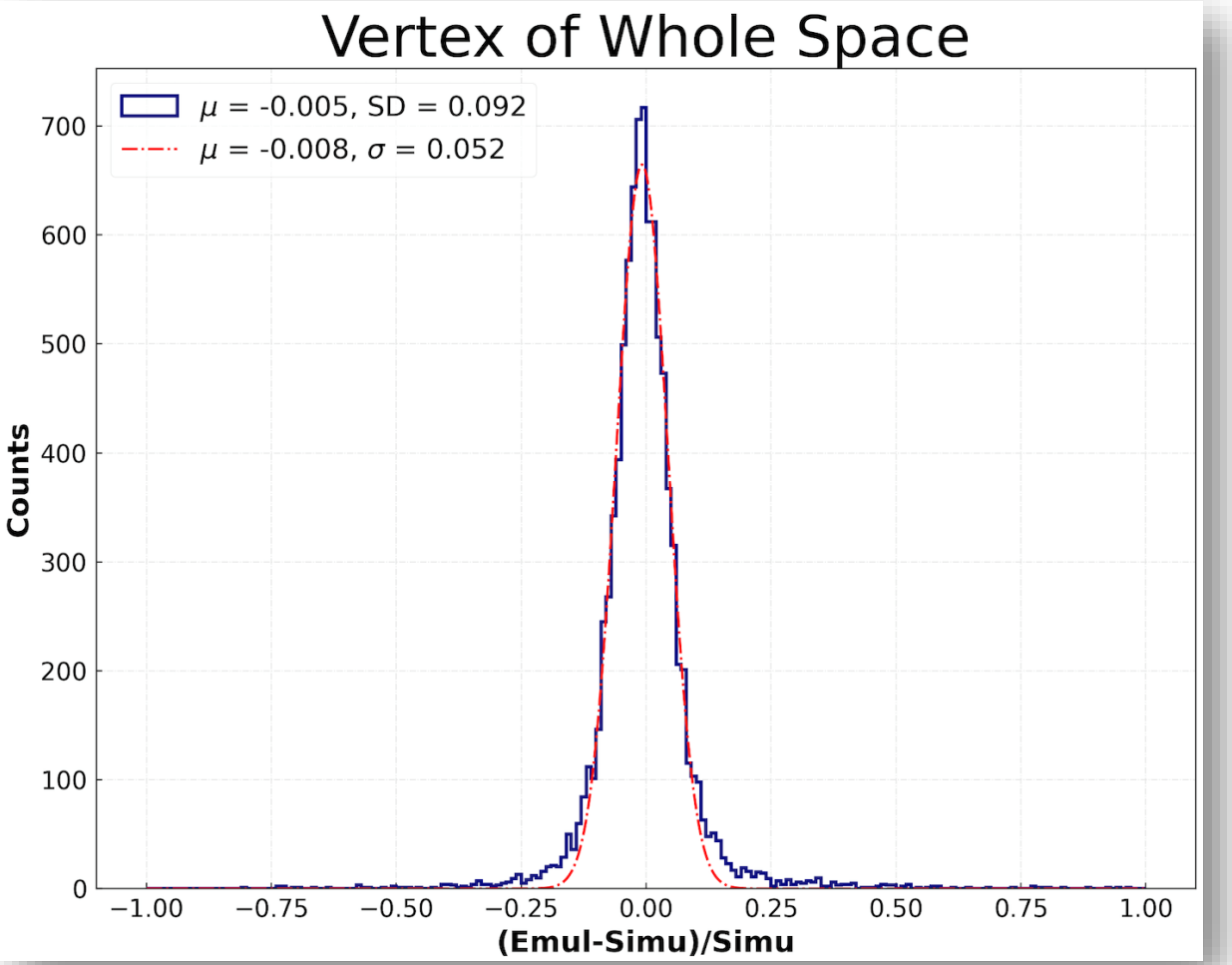
```
360 Total params: 162,922
361 Trainable params: 156,348
362 Non-trainable params: 6,574
```

- Training command & hyper-parameters:

```
$ python3 gnn_Muve/gnn.py -i ./dataset/train_93358 -o
output_2048b_10000e -t 0 -b 2048 -e 10000 -n 1000 -d 40 -
-train > train_2048b_10000e.log &
```

```
def model_protodunevd_v4(dim_pdr):#dim_pdr: num of opchannels
    pos_x       = Input(shape=(1,), name='pos_x')
    pos_y       = Input(shape=(1,), name='pos_y')
    pos_z       = Input(shape=(1,), name='pos_z')
    input_layer = [pos_x, pos_y, pos_z]

...
...

    #combine the nine blocks---
    feat_con = concatenate([feat_cov_1, feat_cov_2,
feat_cov_3, feat_cov_4, feat_cov_5, feat_cov_6, feat_cov_7,
feat_cov_8, feat_cov_9])
    feat_con = Dense(dim_pdr)(feat_con)
    feat_con = BatchNormalization(momentum=0.9)(feat_con)
    feat_con = ReLU()(feat_con)

    pdr      = Dense(dim_pdr, activation='sigmoid',
name='vis_full')(feat_con)
    model    = Model(inputs=input_layer, outputs=pdr,
name='protodunevd_v4_model')

    model.summary()
    return model
```

Preliminary Training Results (I)



- Collective performance of all optical channels
- **Emul**: Computational graph approach
- **Simu**: Geant4 approach
- Data point: sum up photon counts received by each opCh based on two different approaches, then evaluate their difference
- Total Events/Vertex: 9,339

$[-0.1, 0.1]$: 8,048 (86.2%)

$[-0.2, 0.2]$: 8,745 (93.6%)

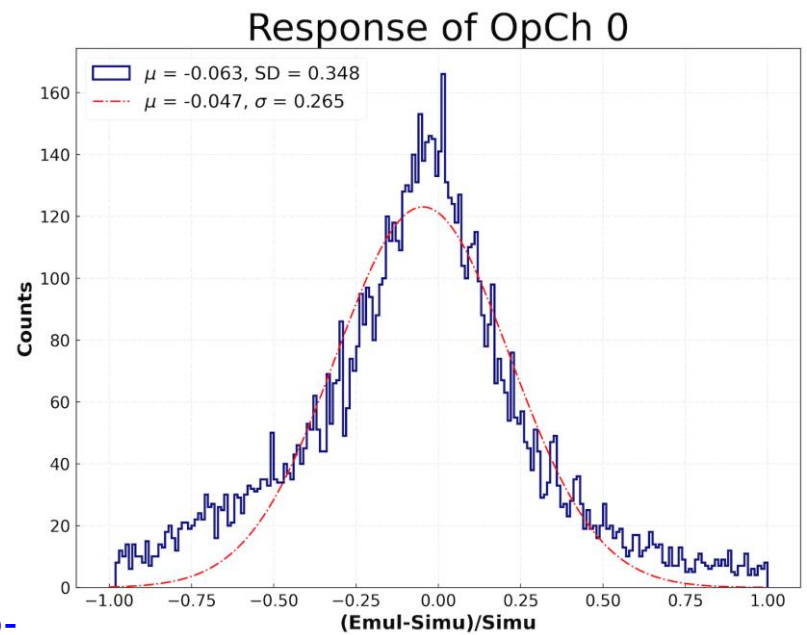
$[-1.0, 1.0]$: 9,319 (99.8%)

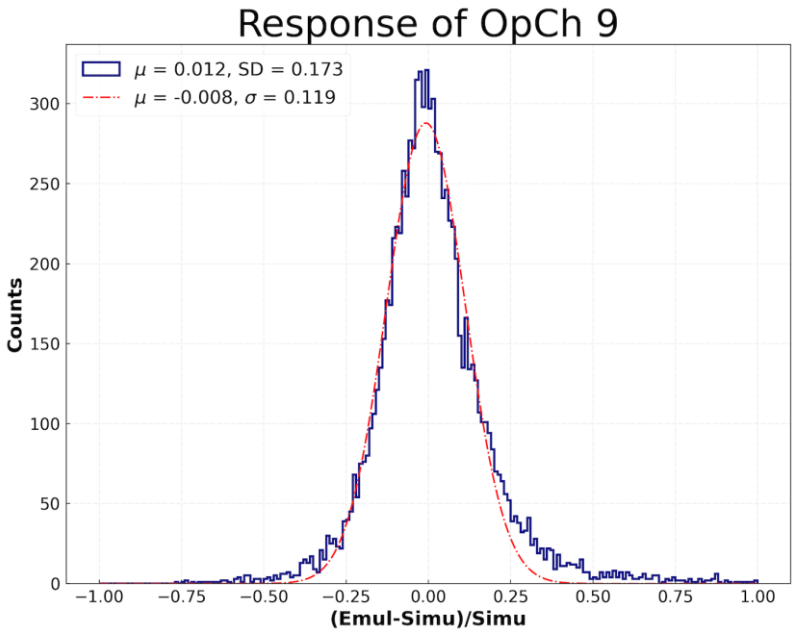
Preliminary Training Results (II)

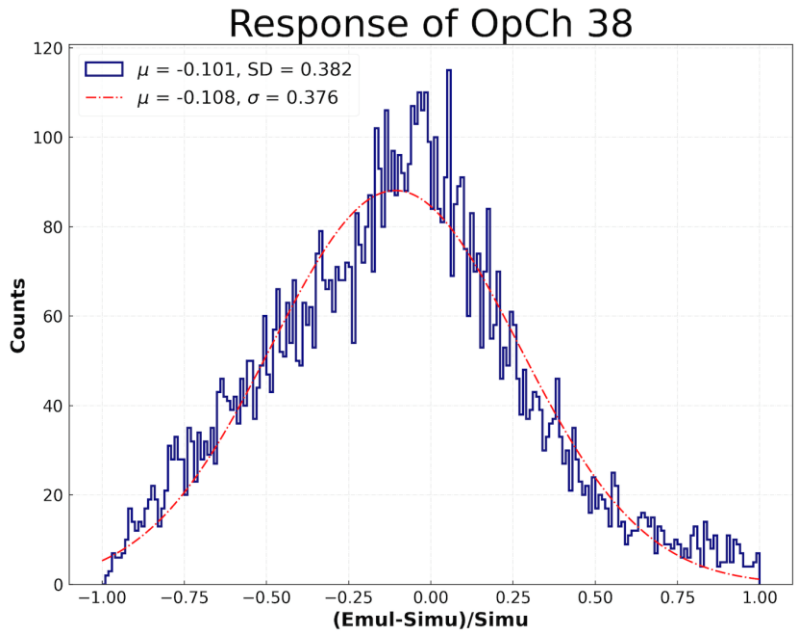
❖ Performance of single optical channel:

OpCh:	0	9	38
Within $[-1.0, 1.0]$	8,975	9,311	8,364
Out of $[-1.0, 1.0]$	364 (3.9%)	28 (0.3%)	975 (10.4%)

❖ 1. Cathode X-Arapuca performs better than membrane XA & PMTs; 2. Whole space is the excessive requirement

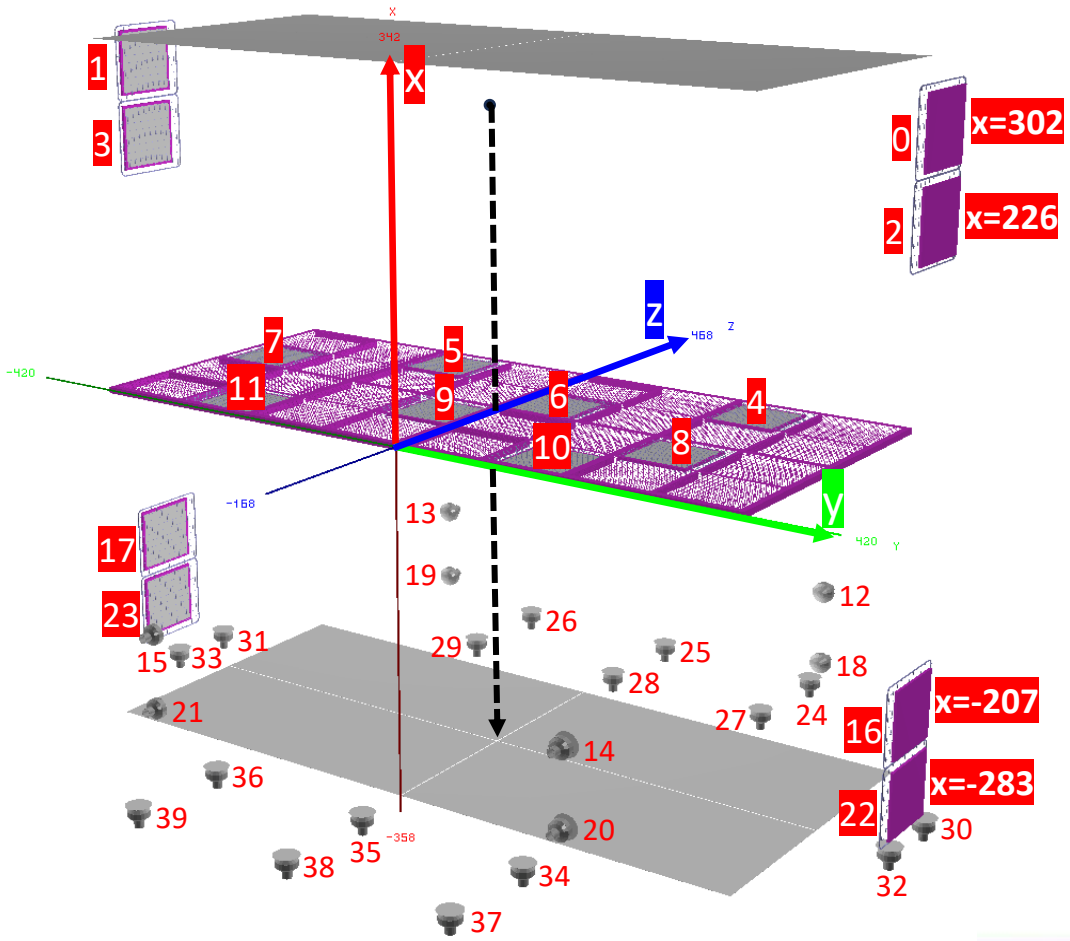


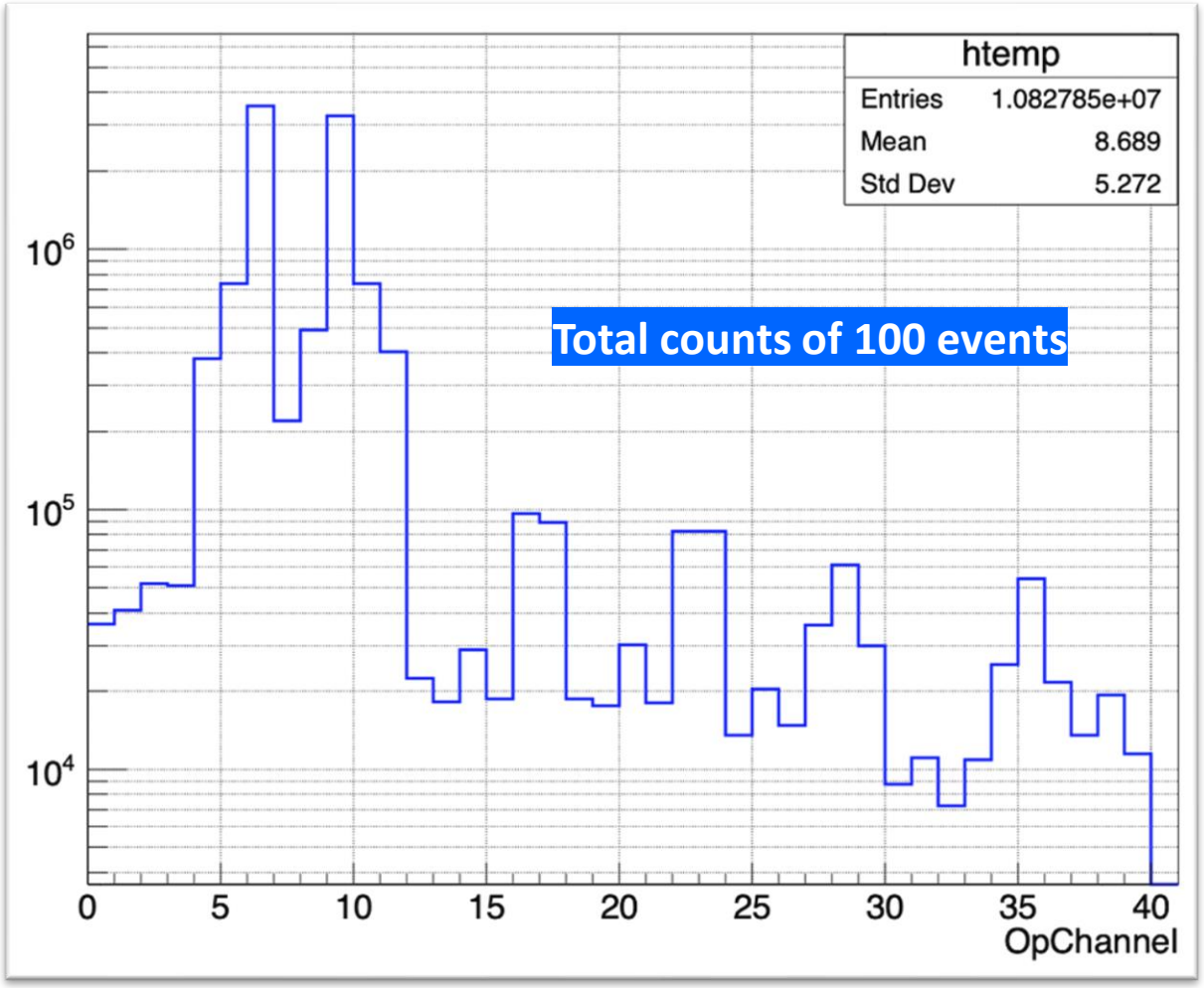




Performance of Comp Graph Module

- 7GeV μ^-, $\# = 100$; starting at $(300, 0, 150)cm$, downward.





Summaries & Further Steps

Summaries:

- Training samples considering RSL, Abs & Reflectivity produced.
- Network for 40 optical channels written
- Performance of network looks good.

Further steps:

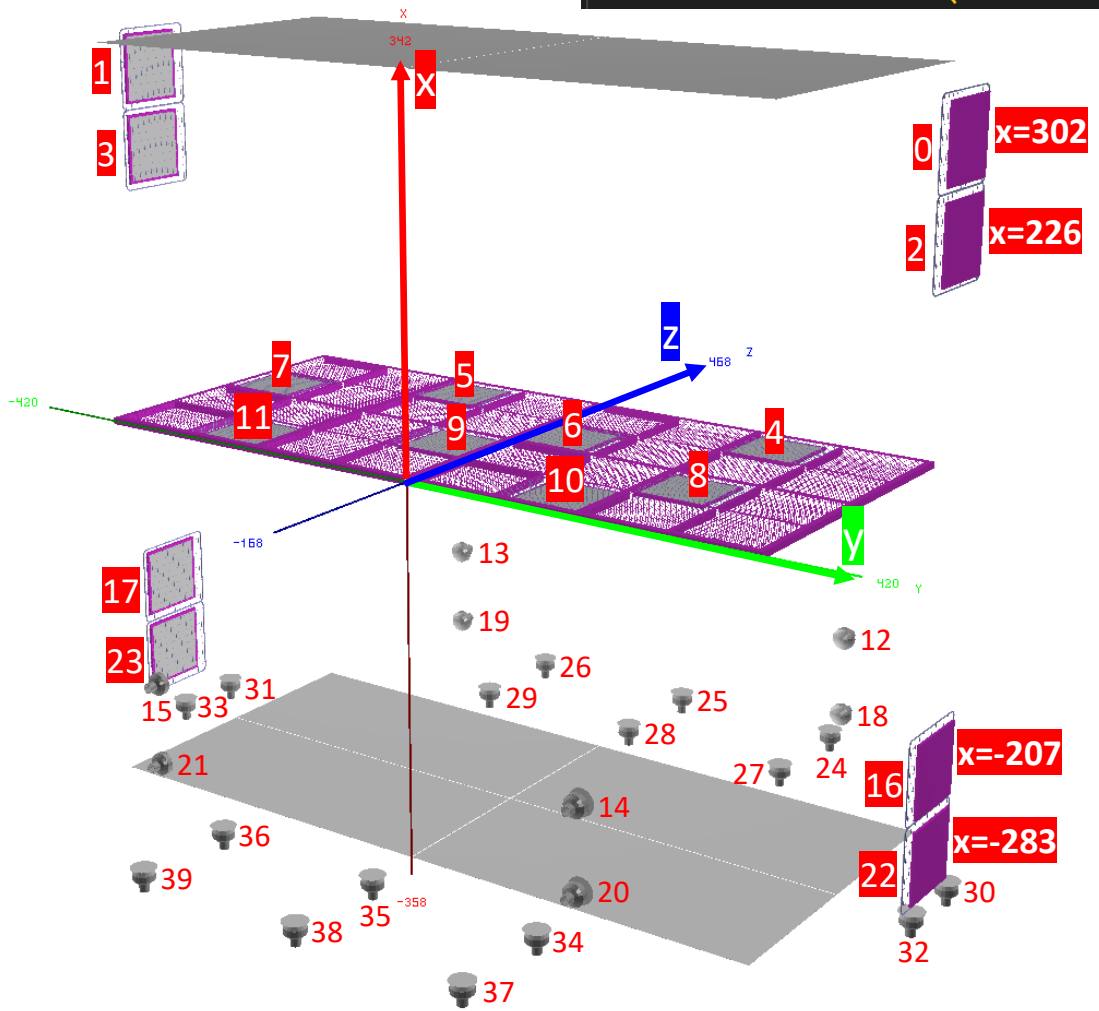
- Increase training samples moderately
- Optimize current network (Any advice is appreciated!)
- Do necessary tests to adjust hyper-parameters
- Develop more detailed codes to evaluate training results
- Train similar comp graph module for Xenon-doped protoDUNE-VD

Backups

X-Arapuca Labels in v4 geometry

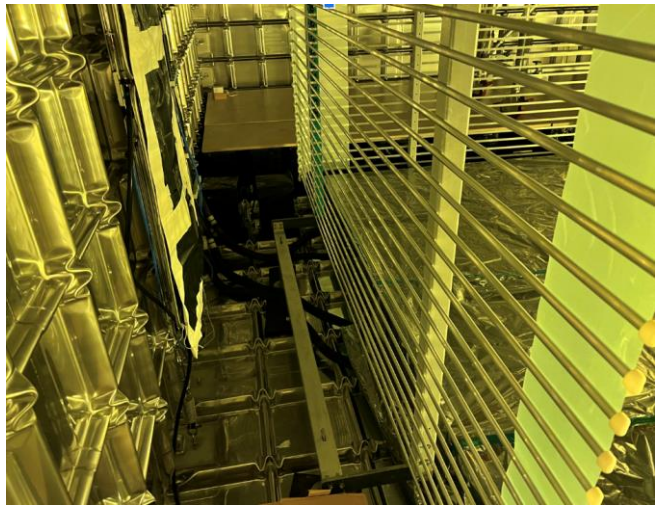
```
Optical Channels positions:  40
0  302.18  417.61  149.65
1  302.18  -417.61  149.65
2  226.38  417.61  149.65
3  226.38  -417.61  149.65
4  0  205.65  258.525
5  0  -131.35  258.525
6  0  39.15  187.275
7  0  -297.85  187.275
8  0  205.65  112.025
9  0  -39.15  112.025
10  0  131.35  40.775
11  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
```

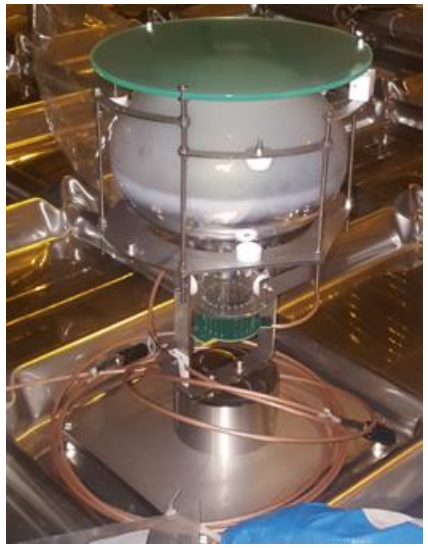
```
Cryo Boundaries
Xmin: -375 Xmax: 415 Ymin: -427.4 Ymax: 427.4 Zmin: -277.75 Zmax: 577.05
 drift coordinate: 1 (X direction)
```



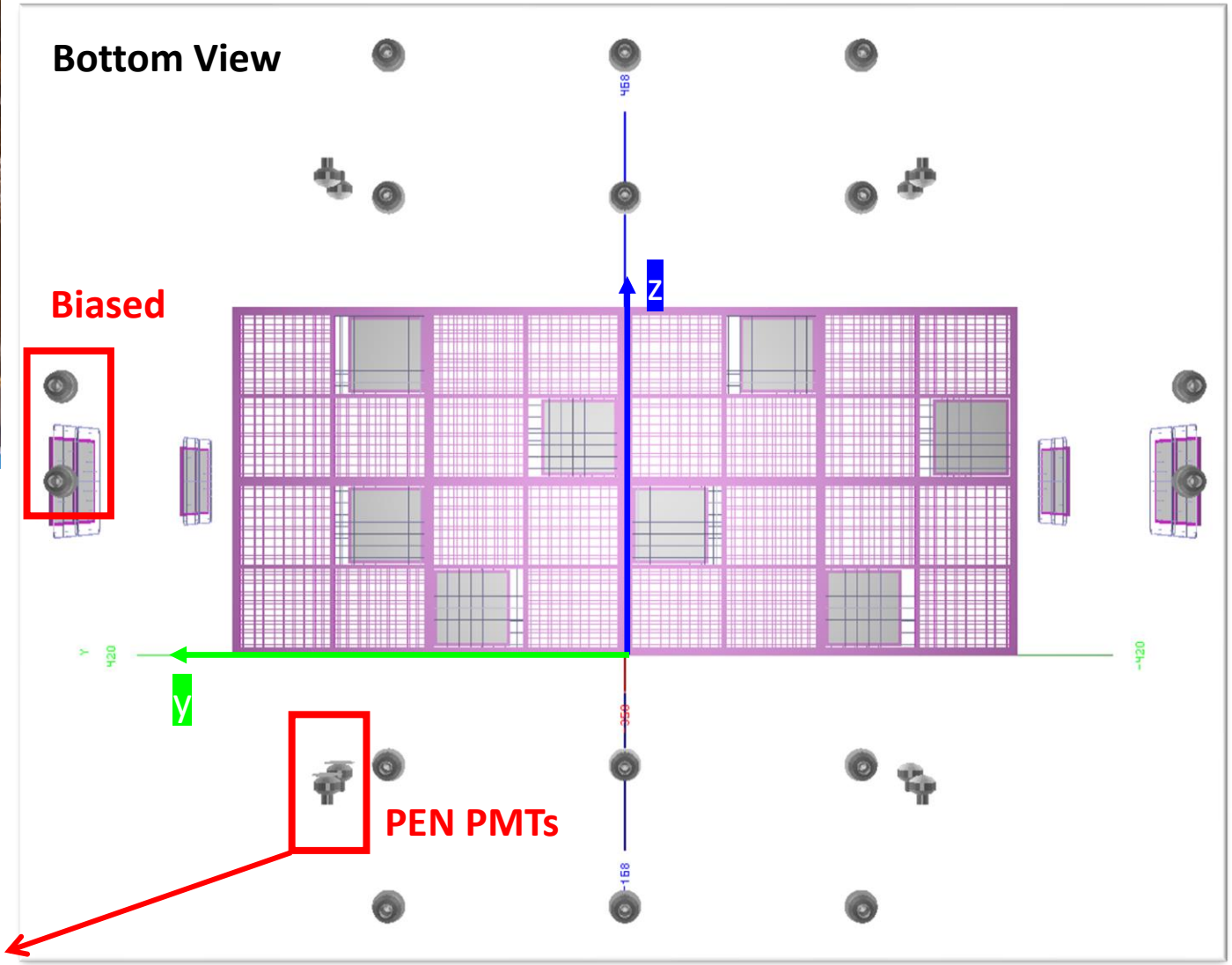

```
21  -281.7  -221  -81.6884
22  -283.03  417.61  149.65
23  -283.03  -417.61  149.65
24  -336.474  170  455.65
25  -336.474  1.13687e-13  455.65
26  -336.474  -170  455.65
27  -336.474  170  353.65
28  -336.474  1.13687e-13  353.65
29  -336.474  -170  353.65
30  -336.474  405.3  217.75
31  -336.474  -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
```

Layout of X-Arapucas & PMTs





From Clara Cuesta:
The PMTs are placed in the squares of the corrugated membrane, then they can only be placed at a certain places. In this region there are only three squares and one has a cable tray, hence there are only two PMTs placed in the other squares



From Hamza: There are no spare TPB-coated PMTs

RSL, Abs & Reflectivity

Rayleigh scattering length:

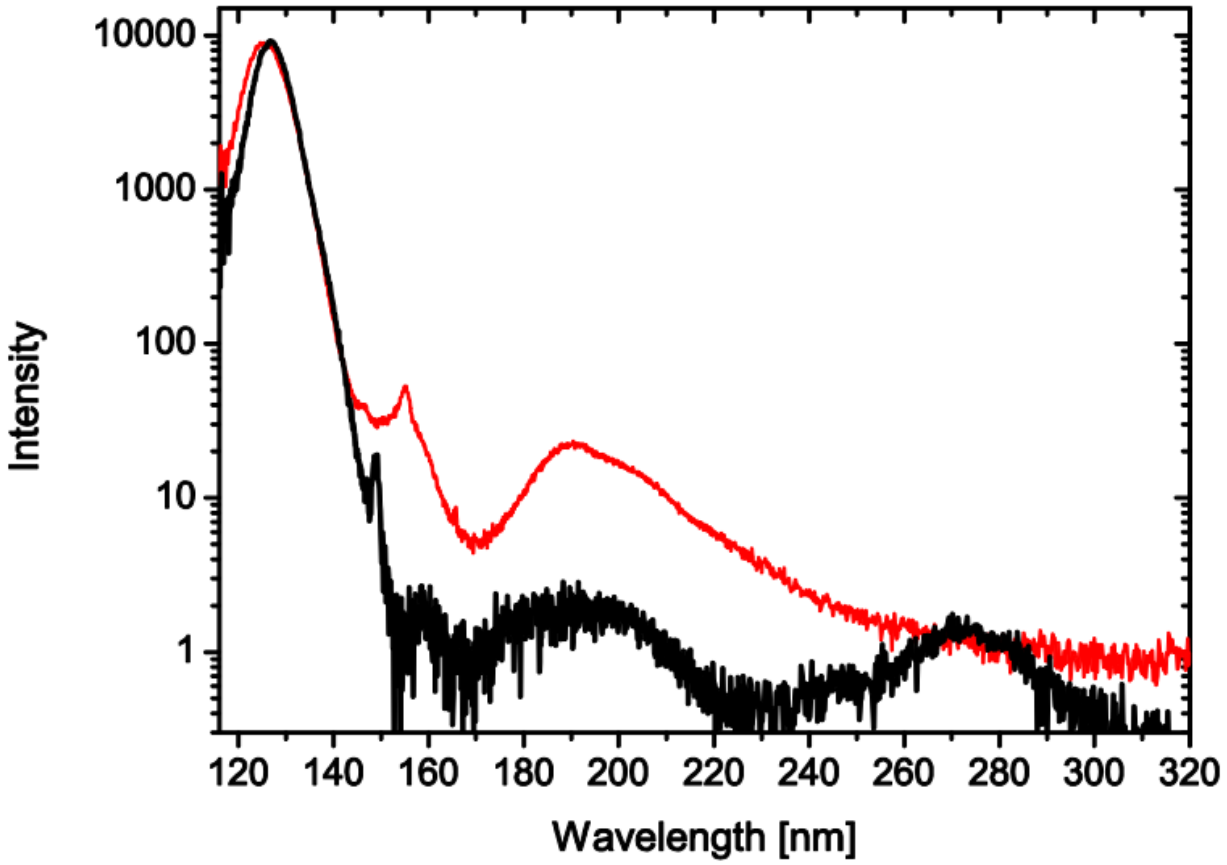
```
118   services.LArPropertiesService.RayleighEnergies: [1.18626, 1.68626, 2.18626, 2.68626, 3.18626, 3.
      68626, 4.18626, 4.68626, 5.18626, 5.68626, 6.18626, 6.68626, 7.18626, 7.68626, 8.18626, 8.68626,
      9.18626, 9.68626, 10.1863, 10.6863, 11.1863]
119   services.LArPropertiesService.RayleighSpectrum: [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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