INDIANA UNIVERSITY

Comp Graph Module for protoDUNE-VD PDS

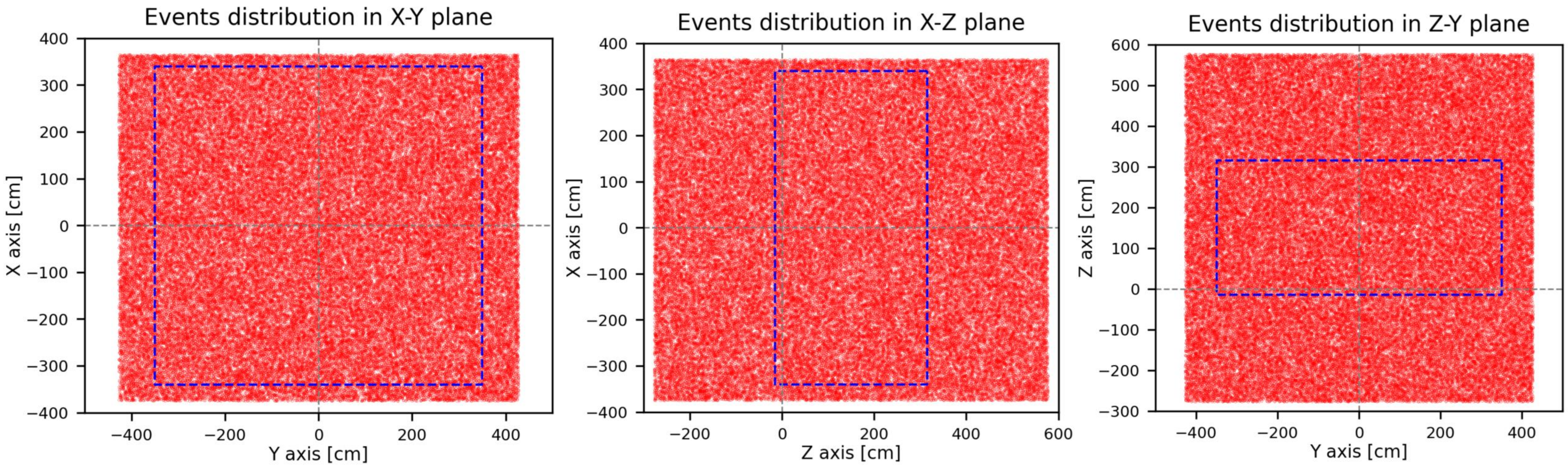
Shuaixiang (Shu) Zhang
Indiana University
ProtoDUNE PDS Sim/Reco meeting
Jan 8, 2023 (Mon)

Details of New Training

- ❖ Results of last training: https://indico.fnal.gov/event/62064/
- ❖ **Updates**:

  Training set: $100{,}000 \Rightarrow \mathbf{500,000}$

  Evaluation set: $10{,}000 \Rightarrow \mathbf{100,000}$
- ❖ Network & hyper-parameters are the same
- ❖ Evaluation events distribution:



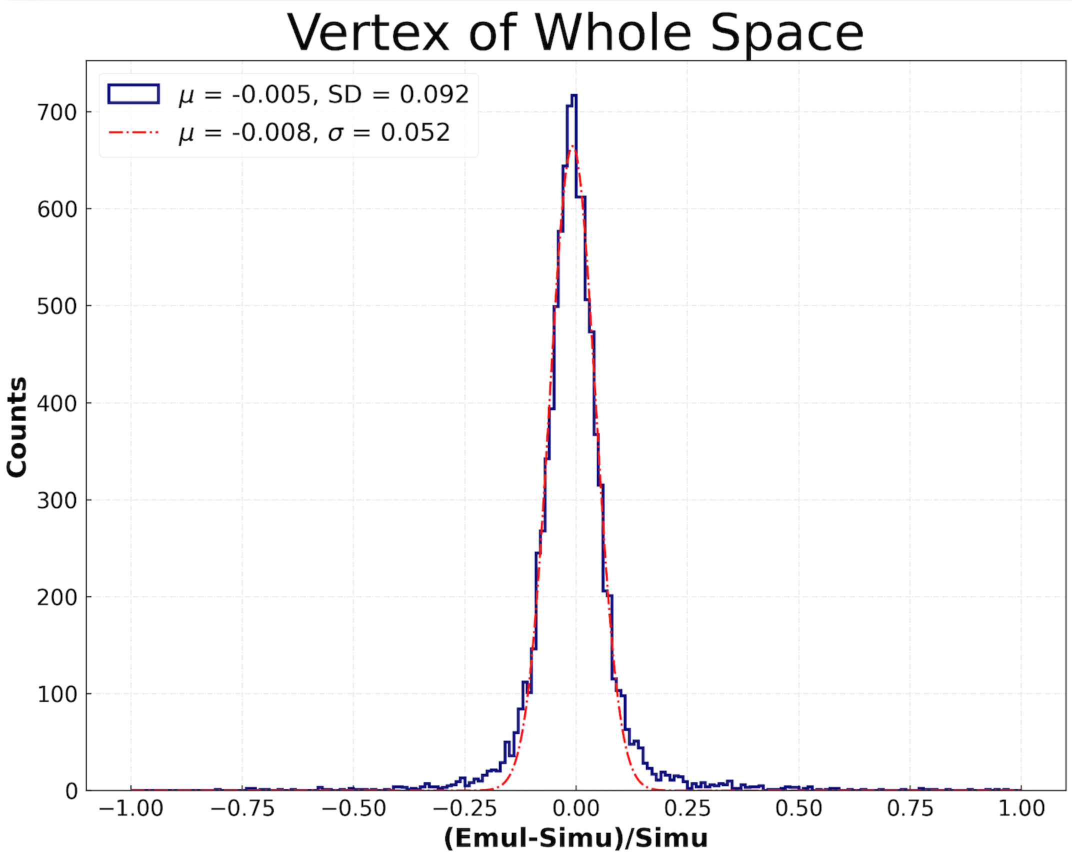
- ❖ Evaluation of collective performance
- ❖ Evaluation of Single optical channel

Bias Distribution

Previous training (last presentation)

$[-0.1, 0.1]$: **8,048 (86.2%)**, $[-0.2, 0.2]$: **8,745 (93.6%)**

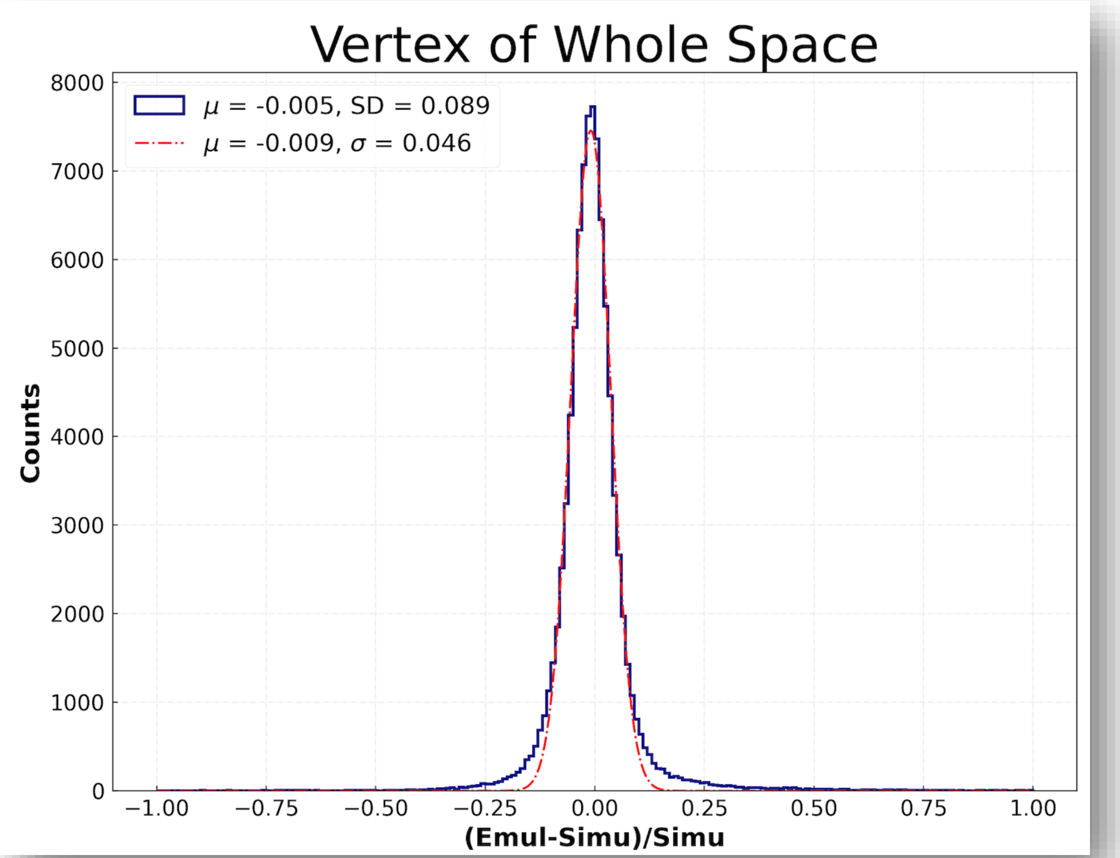
$[-1.0, 1.0]$: **9,319 (99.8%)**



New training (this presentation)

$[-0.1, 0.1]$: **82,293 (88.5%)**, $[-0.2, 0.2]$: **90,003 (96.8%)**

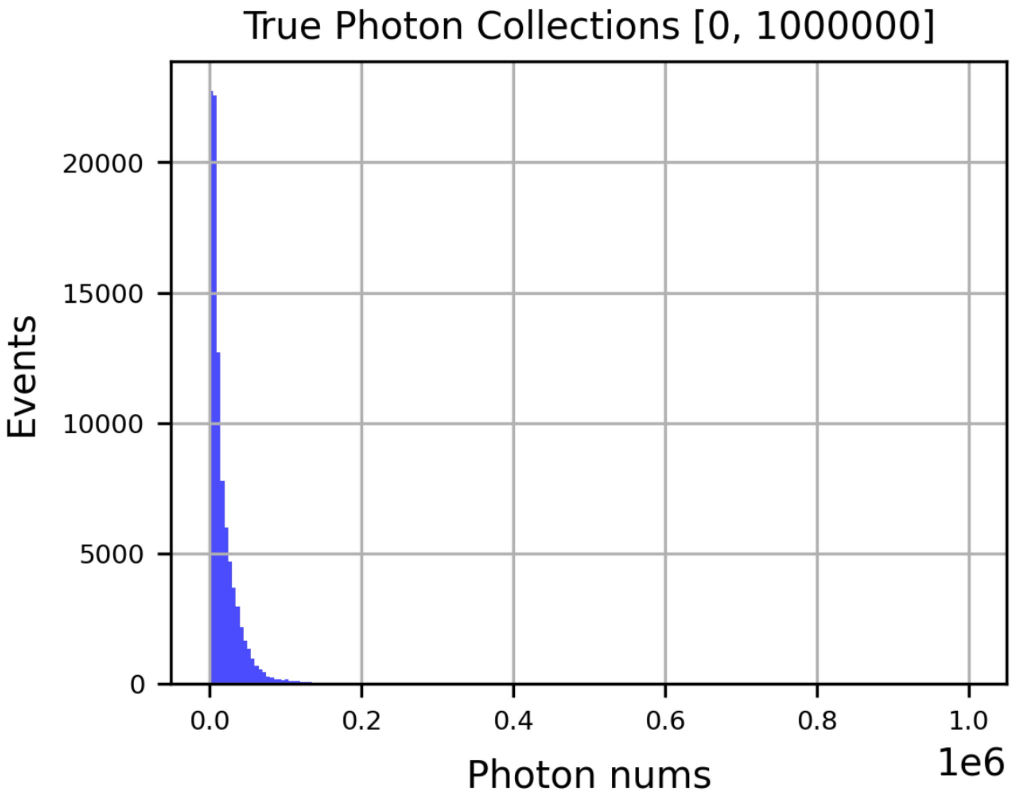
$[-1.0, 1.0]$: **92,850 (99.8%)**

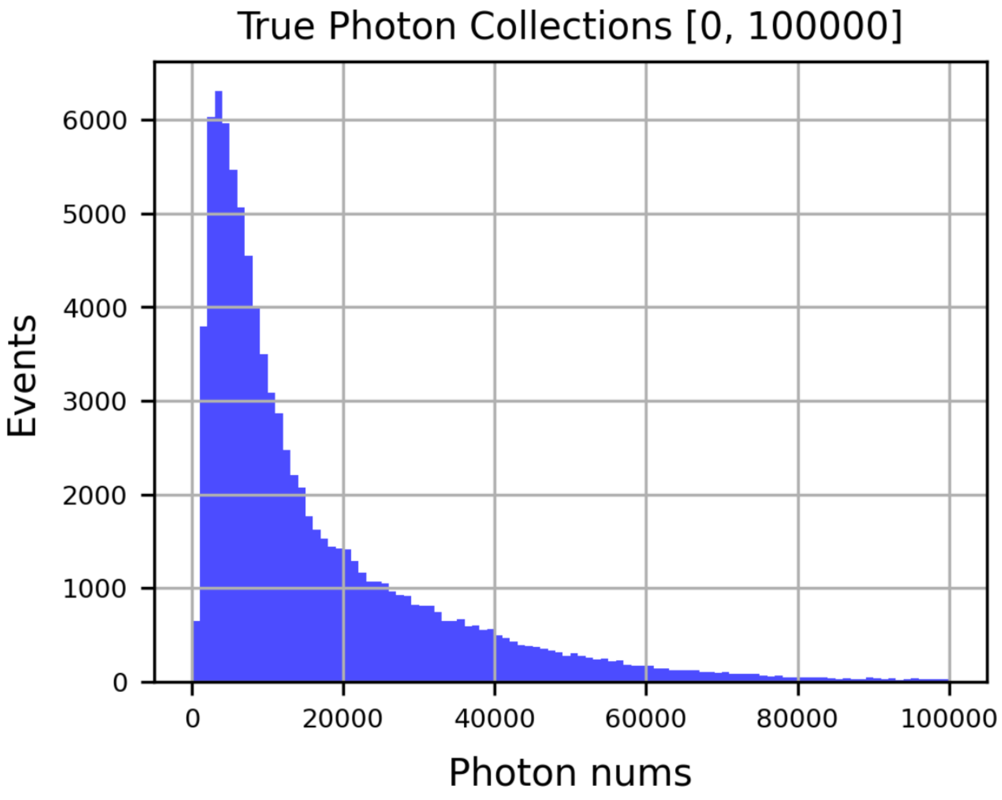


Photon Num distribution of Evaluation Set

- Since this page, the analyses are based on the **new** training
- Results here are based on GEANT4 simulation

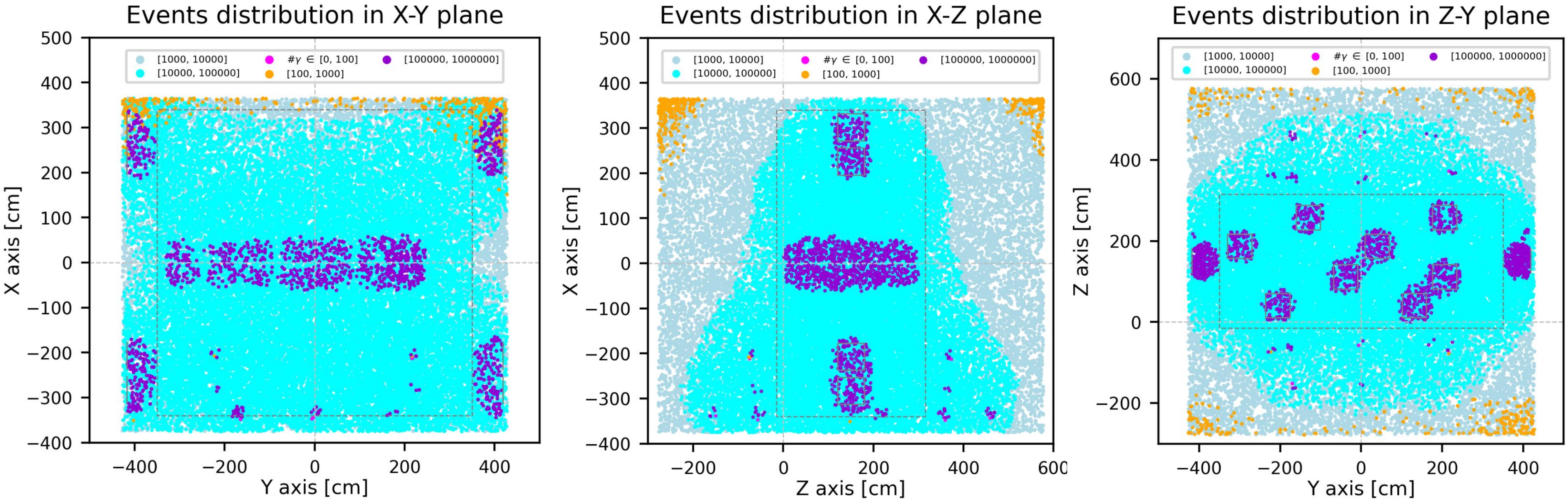
```
# event in [0, 100]          :  6
# event in (100, 1000]       :  644
# event in (1000, 10000]     :  44645
# event in (10000, 100000]   :  46498
# event in (100000, 1000000]:  1397
```





Events Distribution in the Space

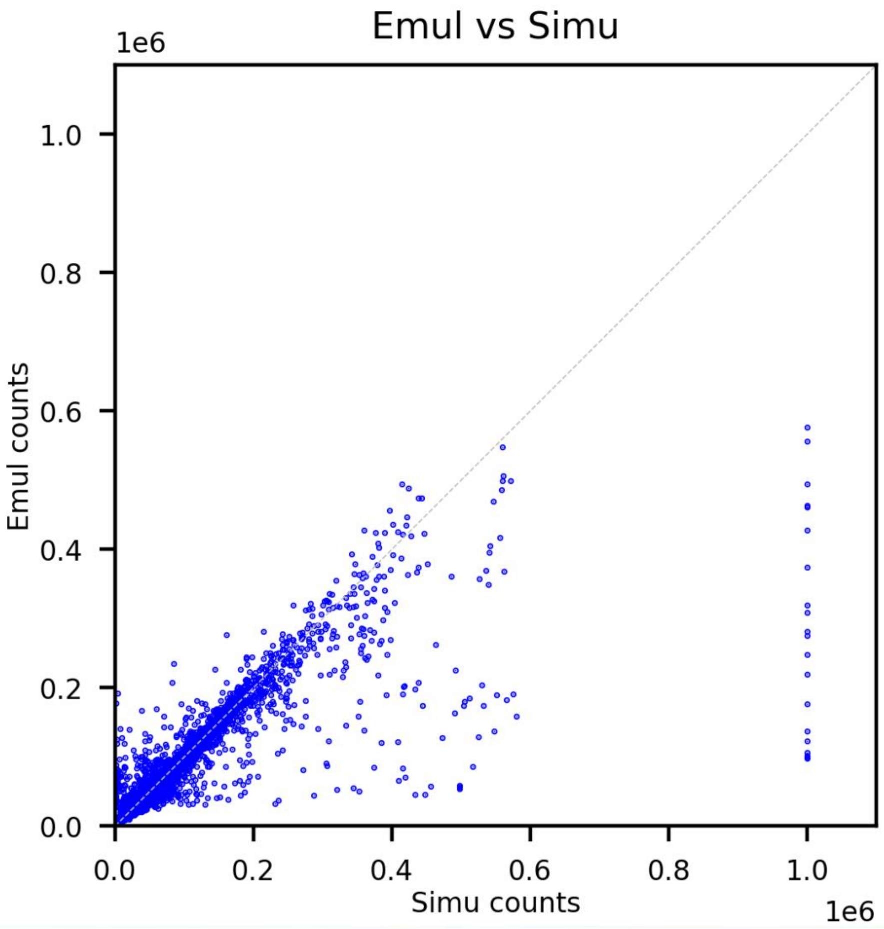
❖ For each event, the number of photons received by all optical channels is labeled

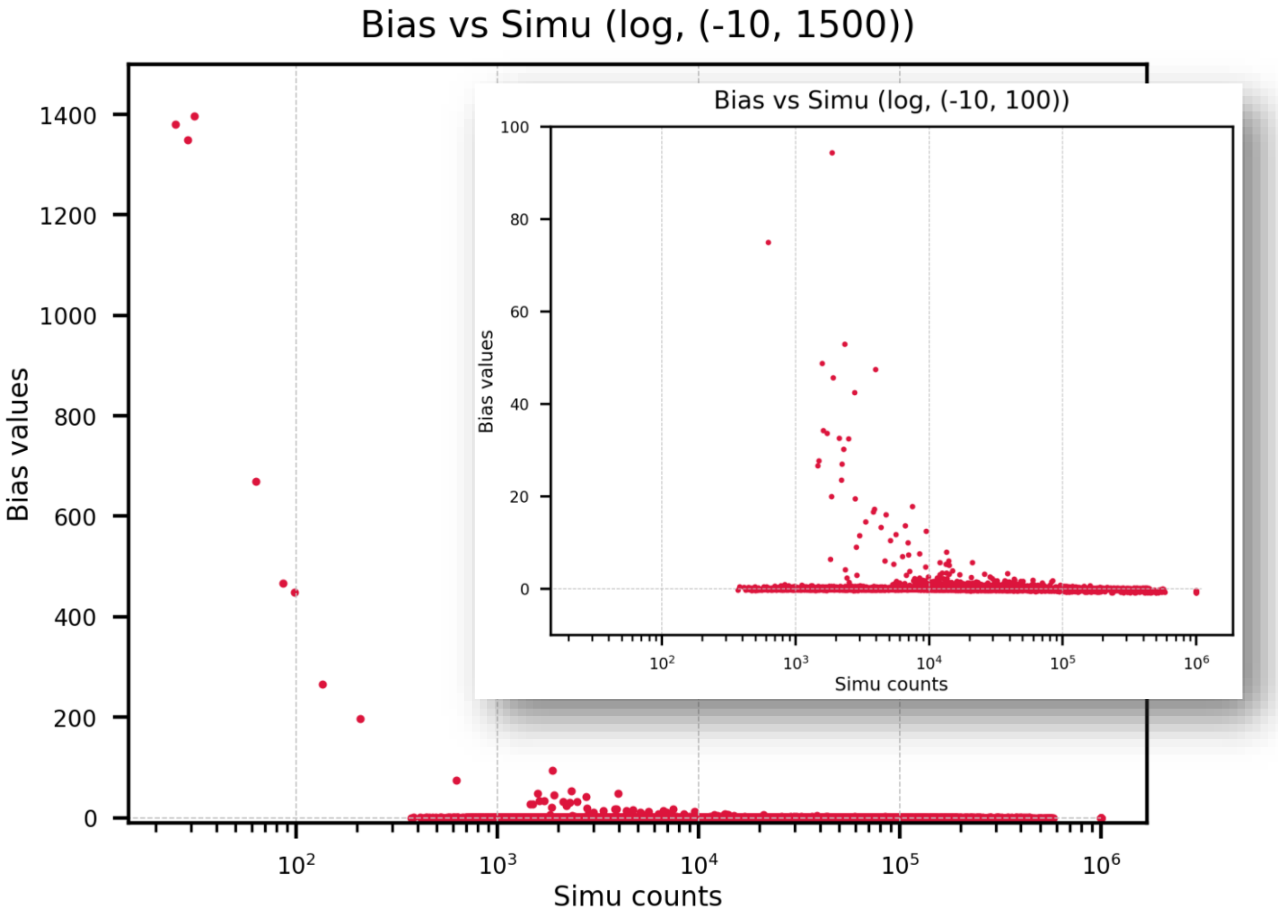


Comp Graph Module vs GEANT4 (I)

- Emul: Results from trained comp graph module
- Simu: Results from GEANT4, the "true" results

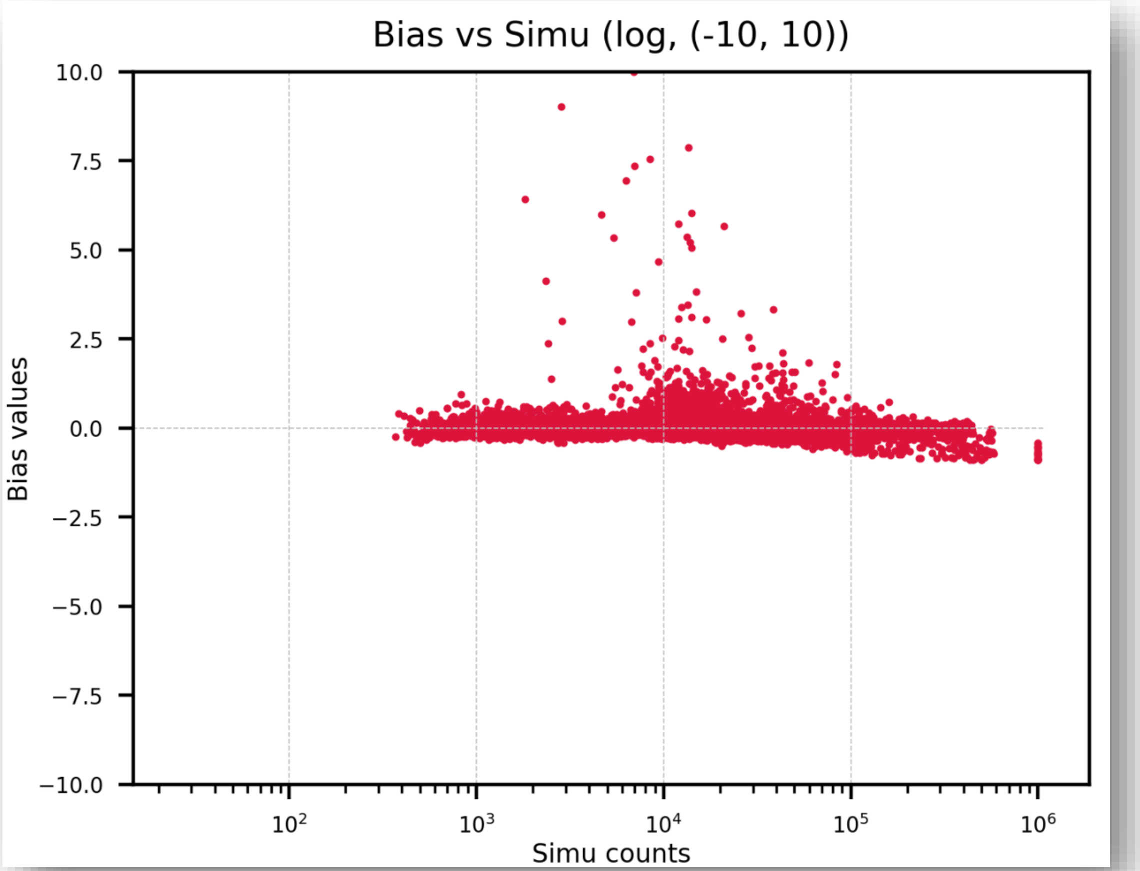
$$Bias = \frac{Emul - Simu}{Simu}$$

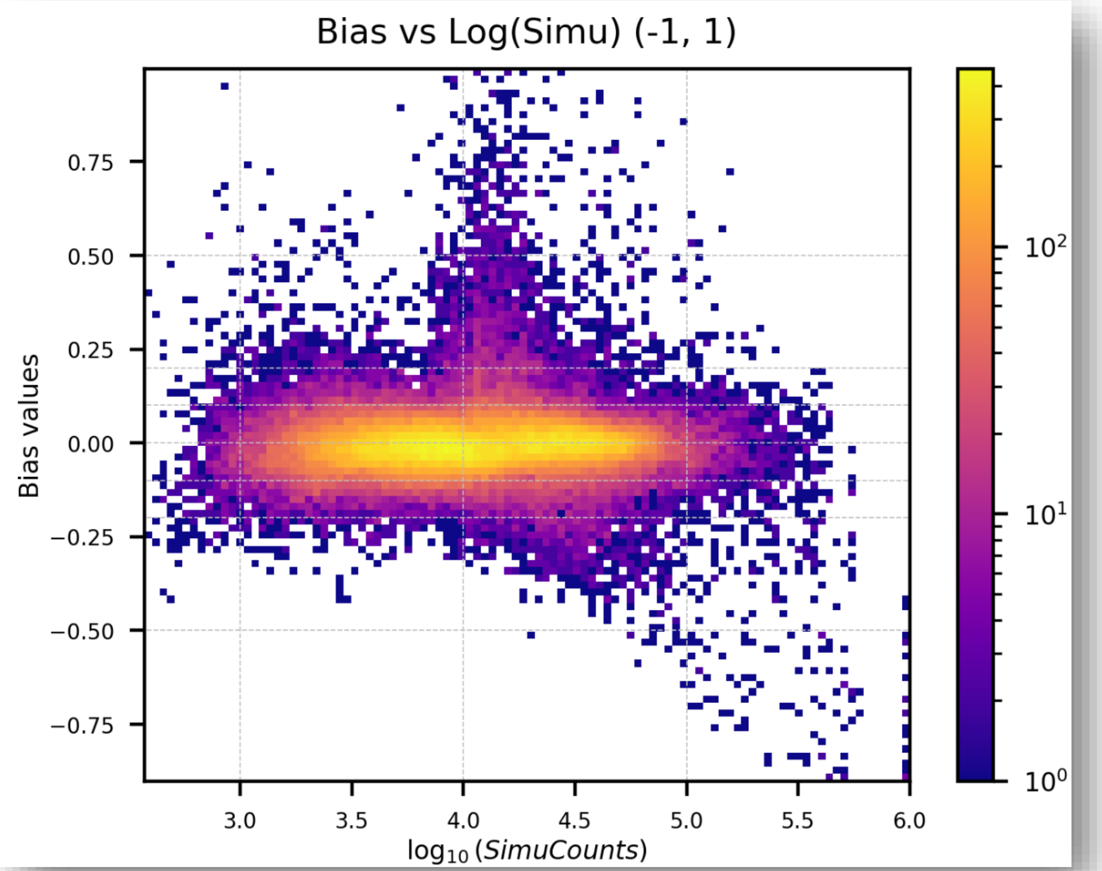




Comp Graph Module vs GEANT4 (II)

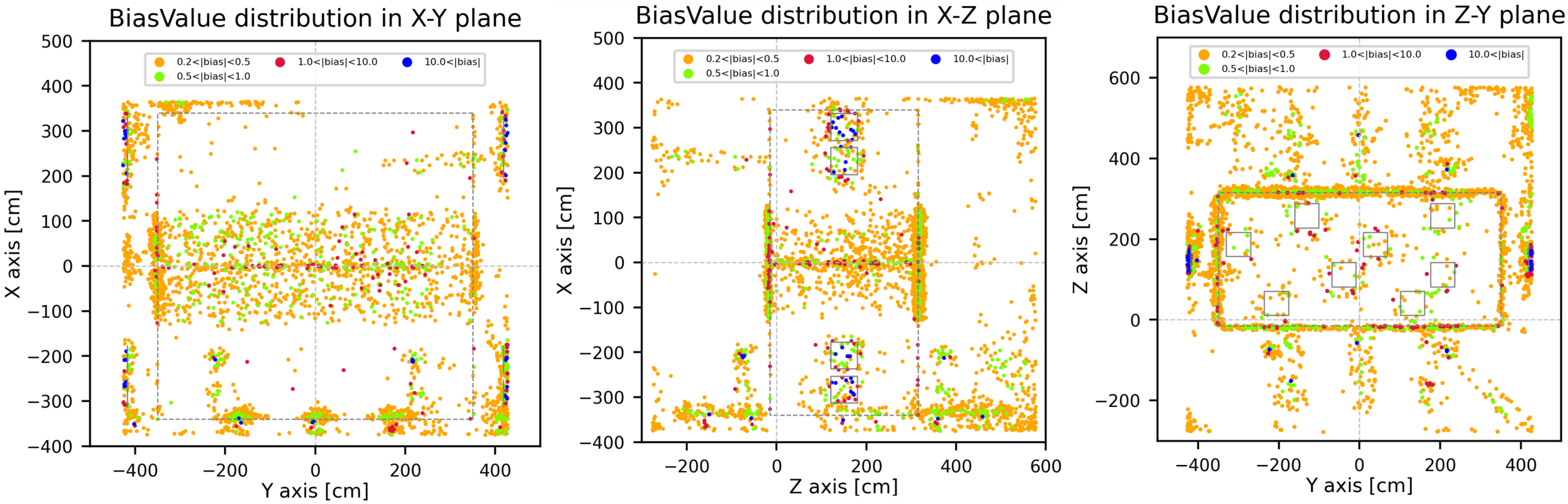
- Big bias events come from $\#\gamma \in [10^3, 10^4]$ and $\#\gamma \in [10^4, 10^5]$
- Small peak in Bias $\in [-1, +1]$ can be explained by events close to field cage and other special regions





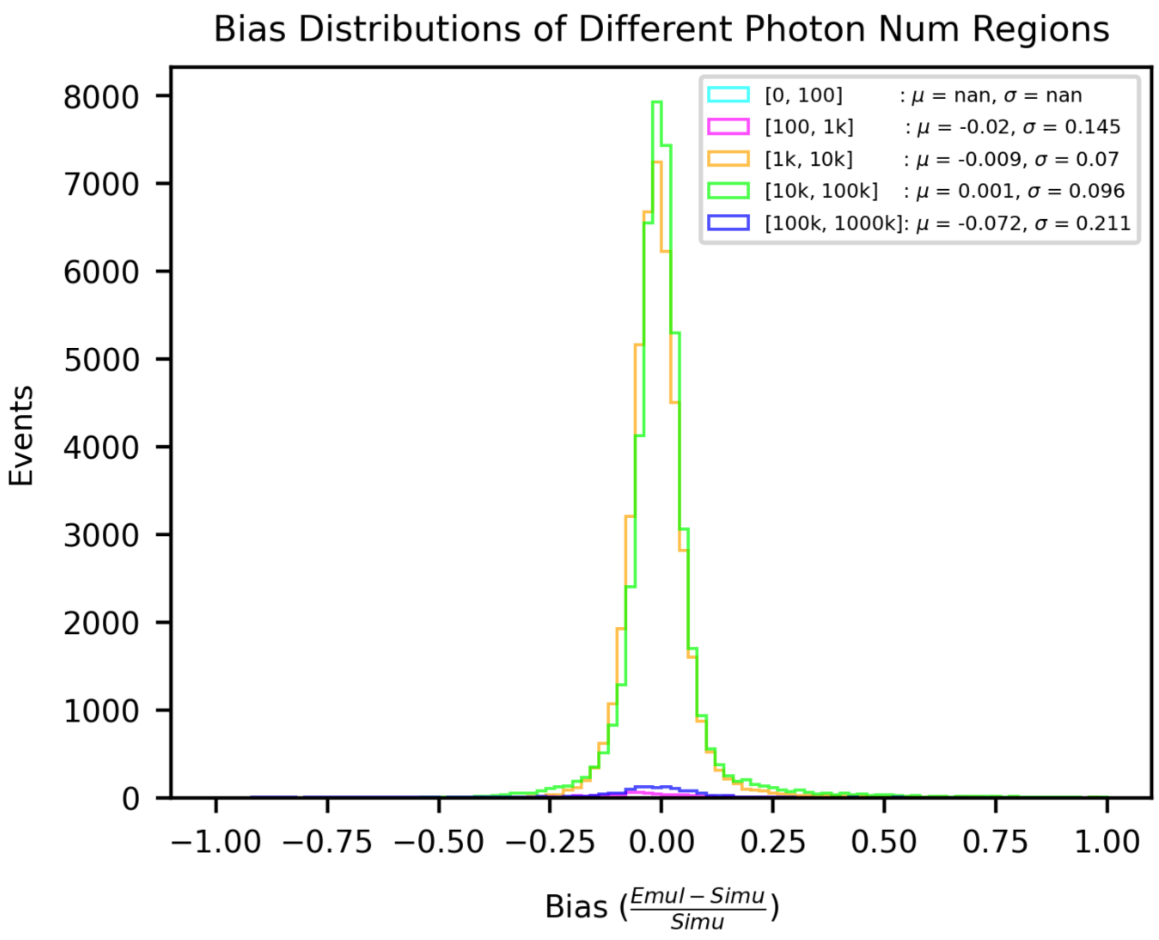
Big-biased Events Distribution

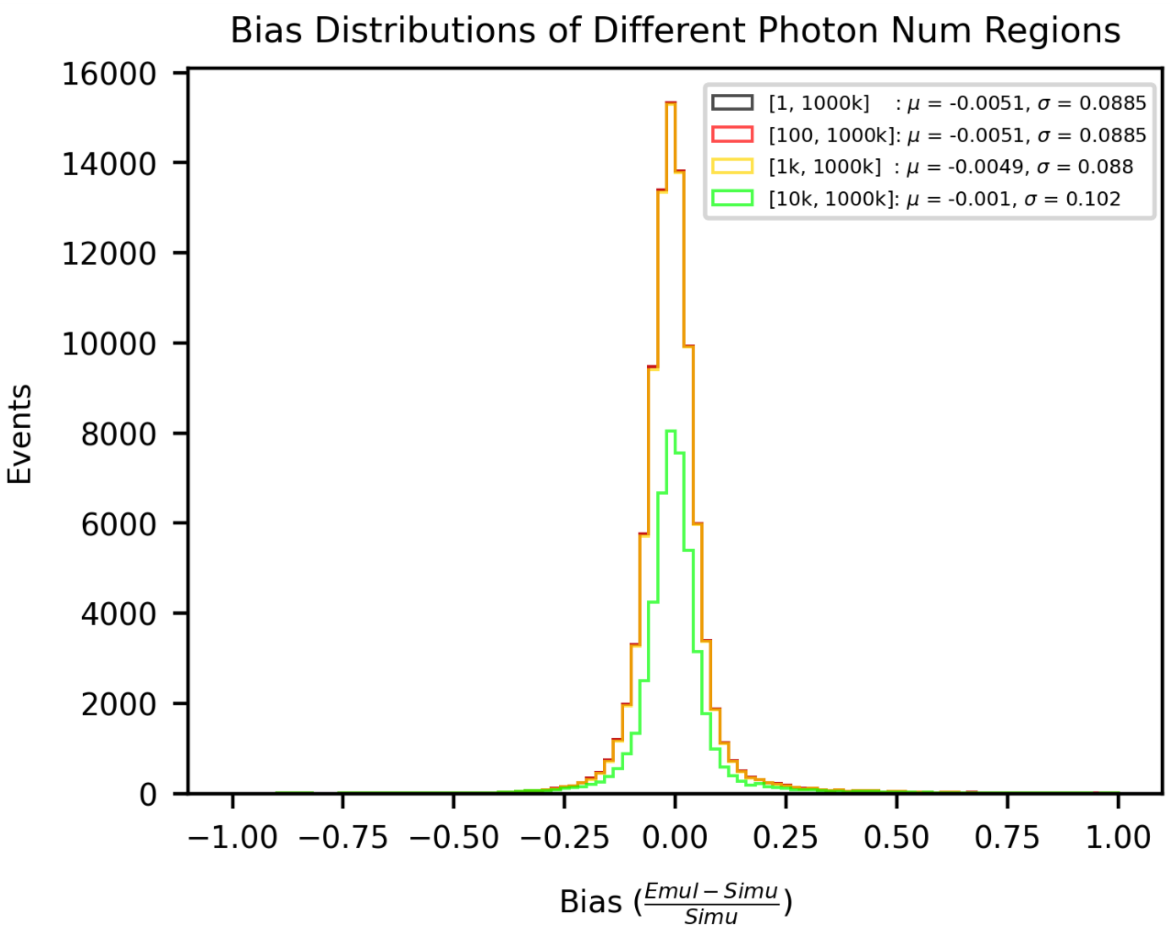
❖ Near field cage, back of optical channels, corners & beam pipe



Apply Cut to Bias distribution

- Preliminary Cut: $\#\gamma \geq 1{,}000 \mapsto$ **negligible** improvement



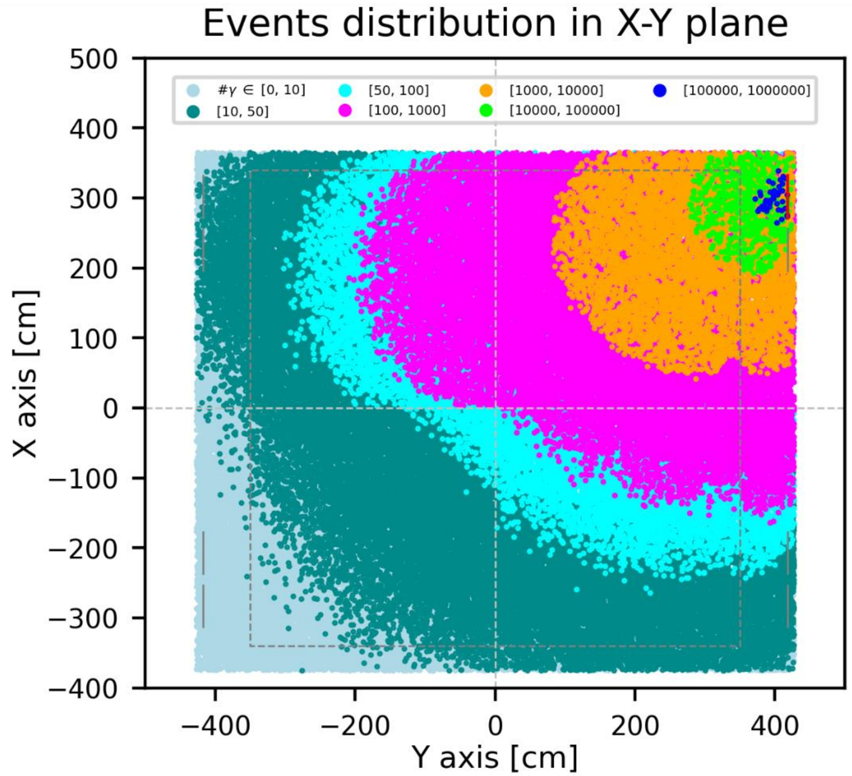


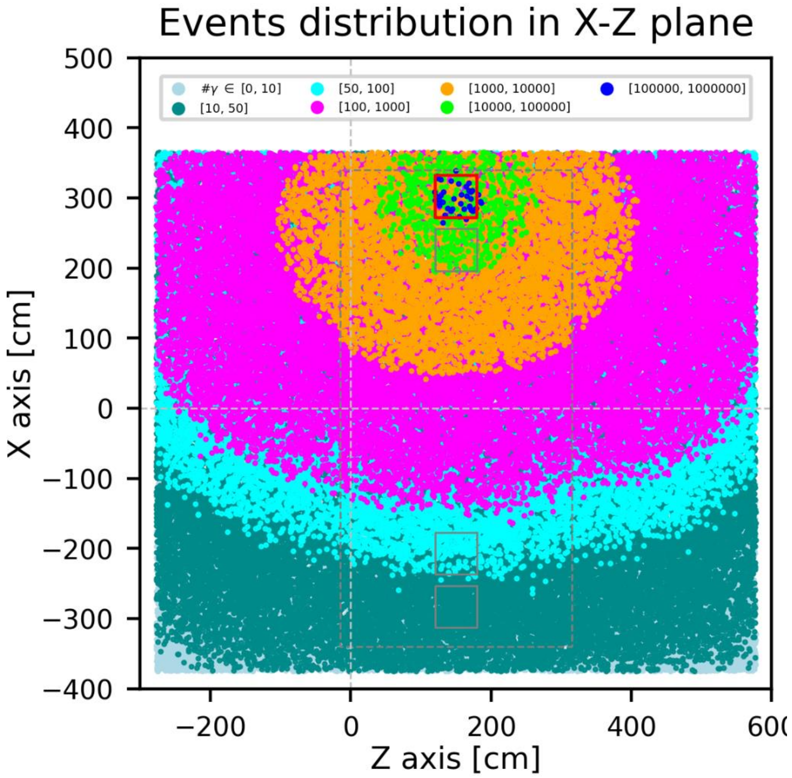
❖ Evaluation of collective performance

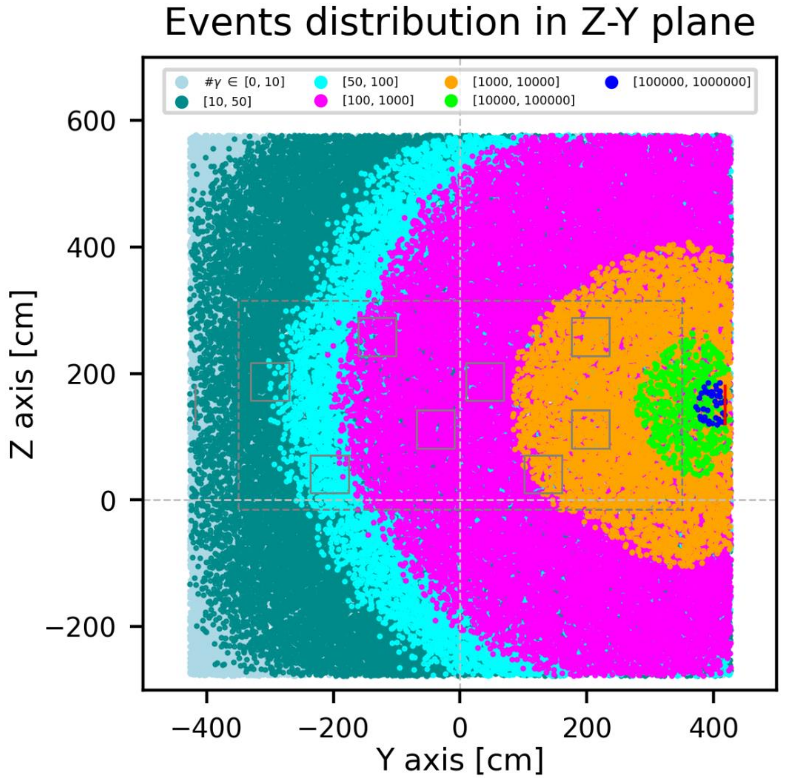
❖ Evaluation of Single optical channel

OpCh00: Events Distribution

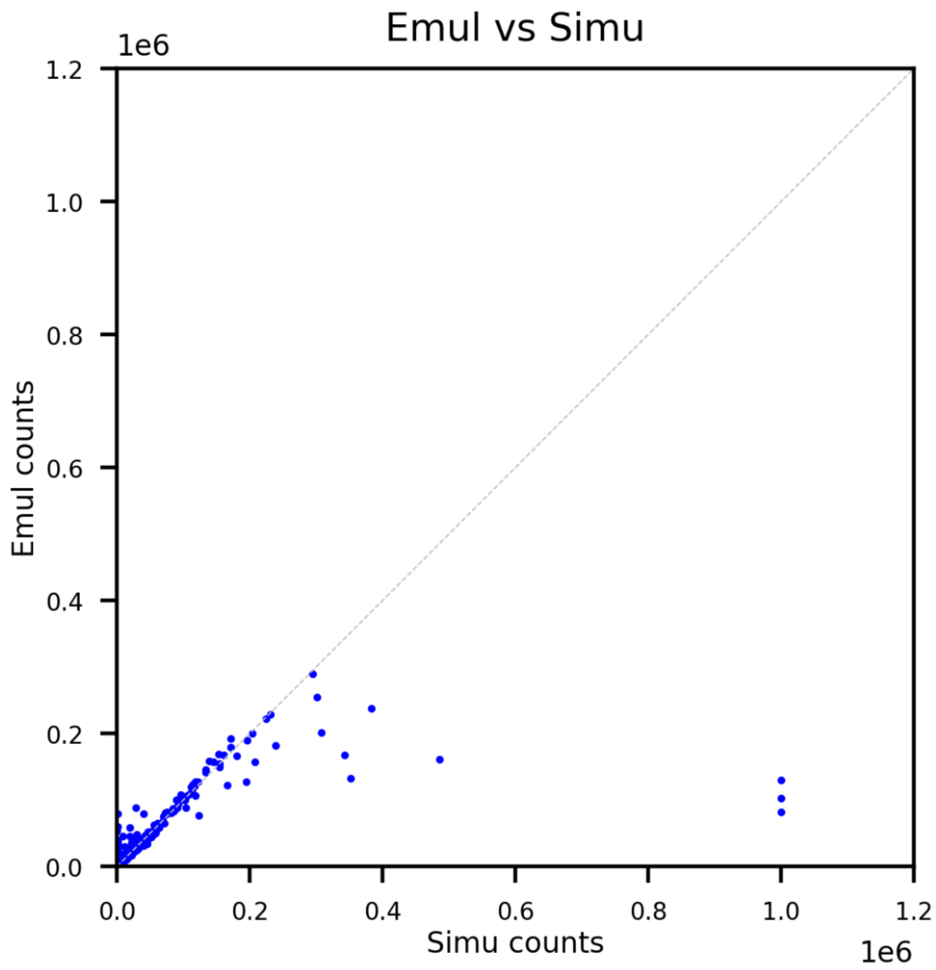
❖ This is still the events of evaluation set

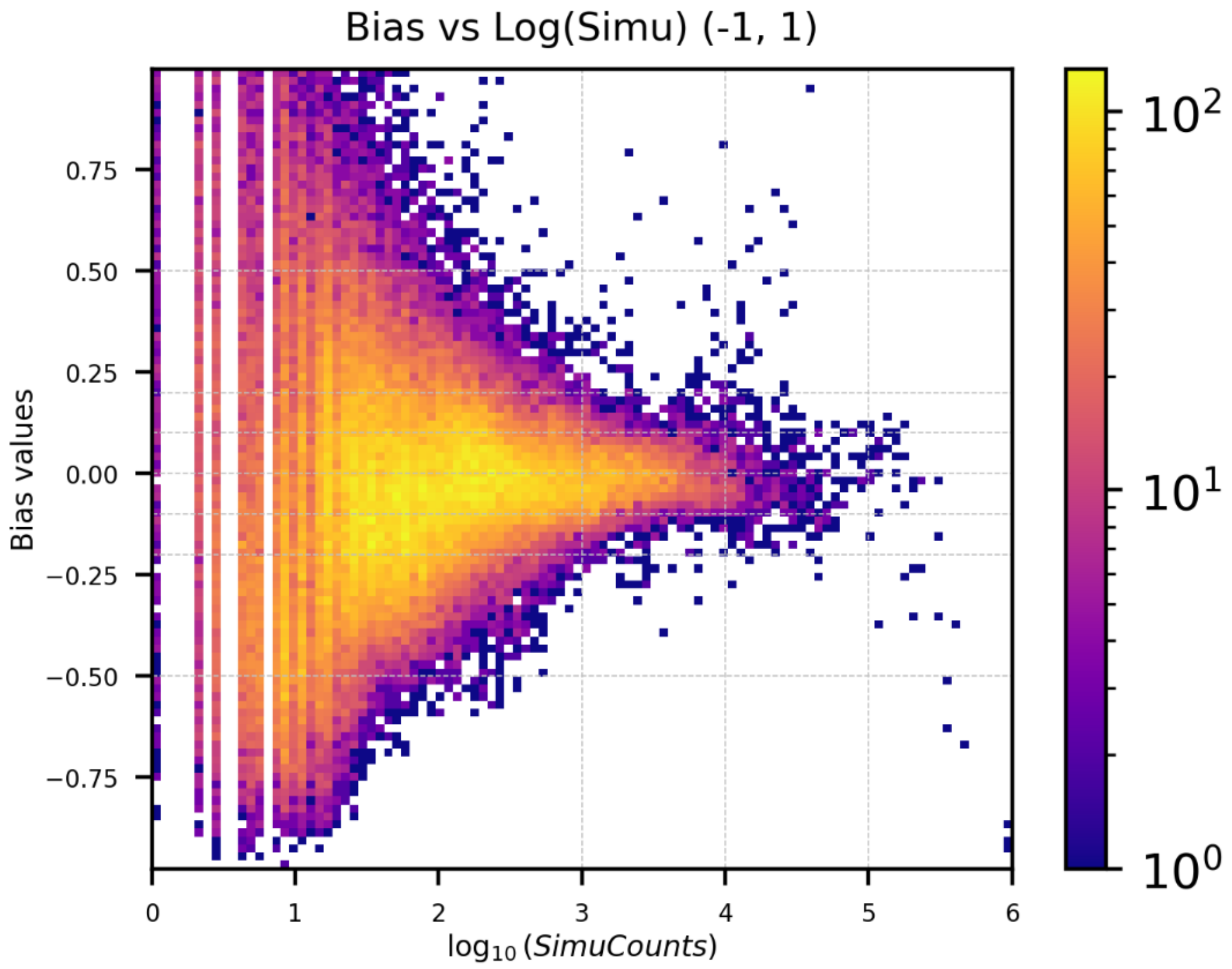






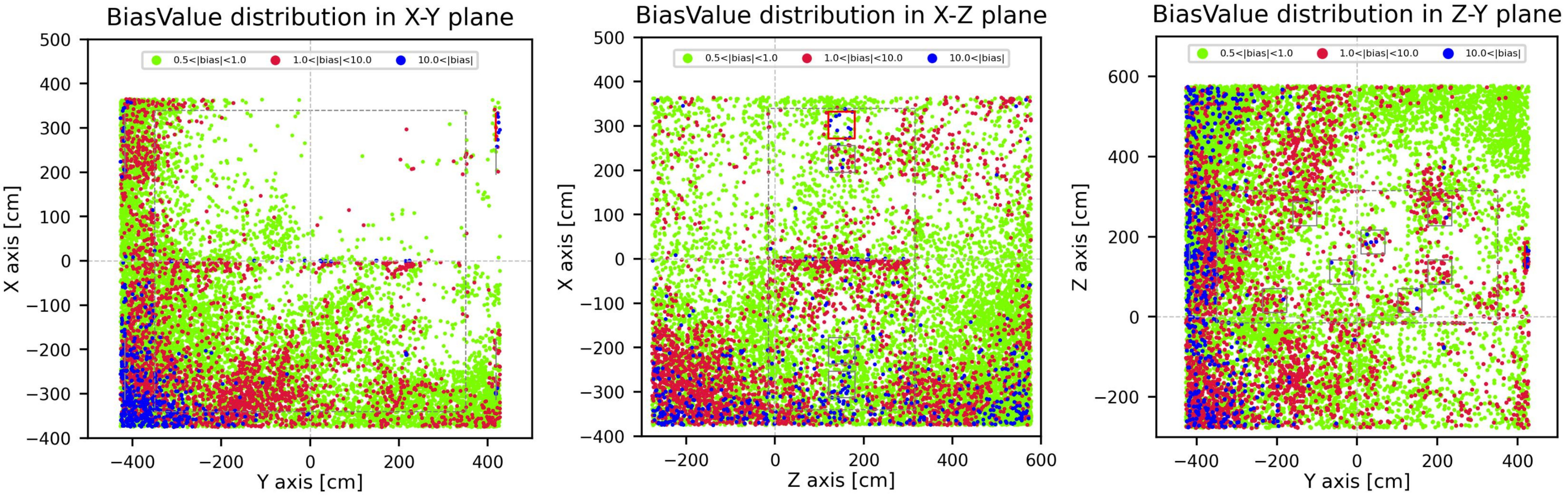
OpCh00: Emul Counts & Bias





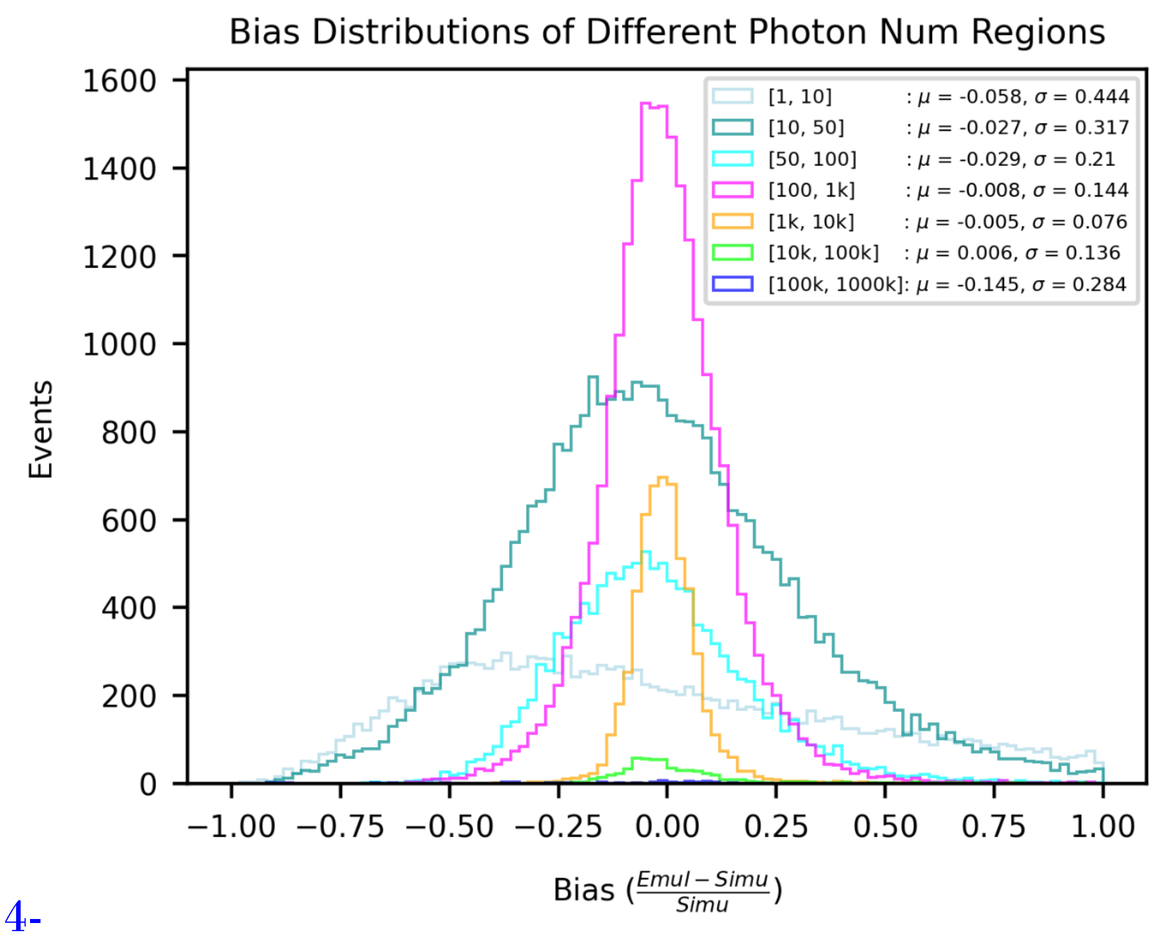
OpCh00: Big Bias Events in Space

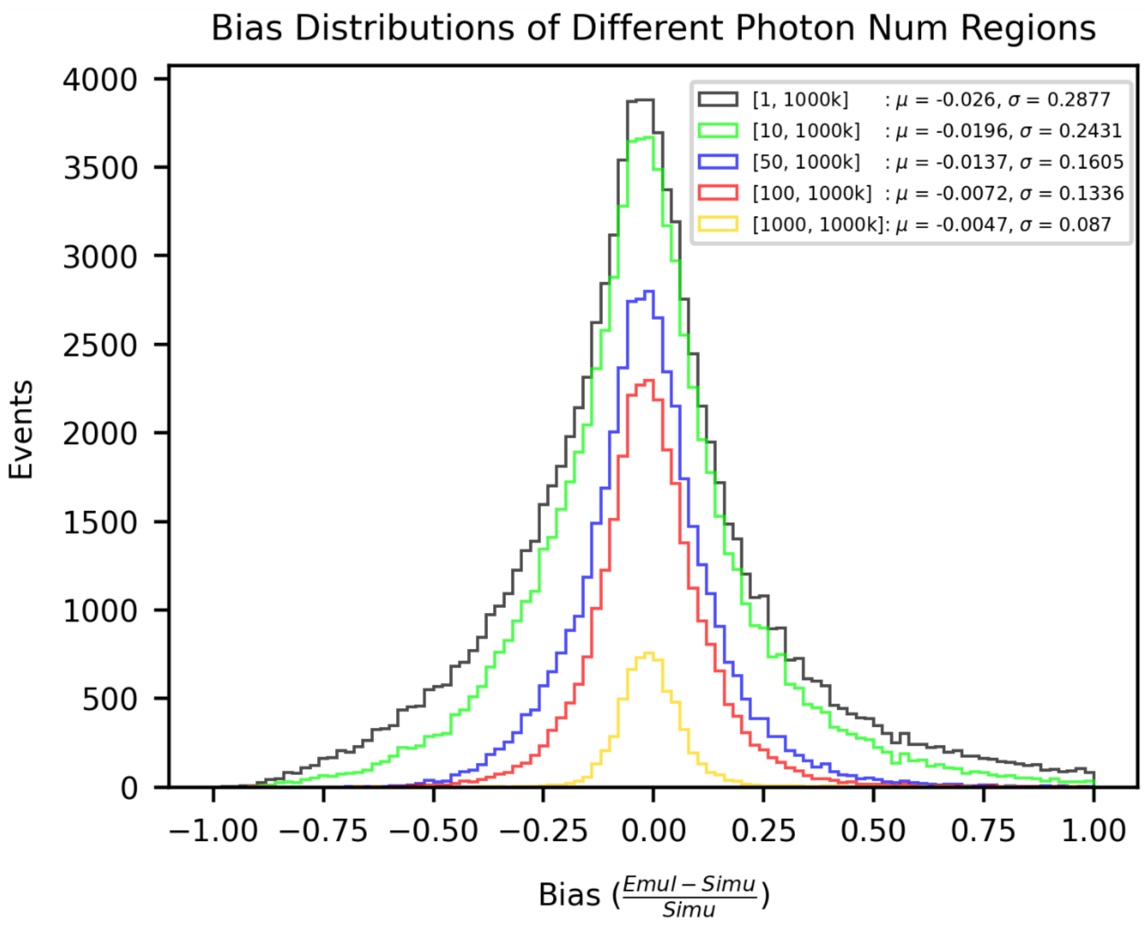
❖ Region away from OpCh00: Across field cage, bottom left, bottom right & top left



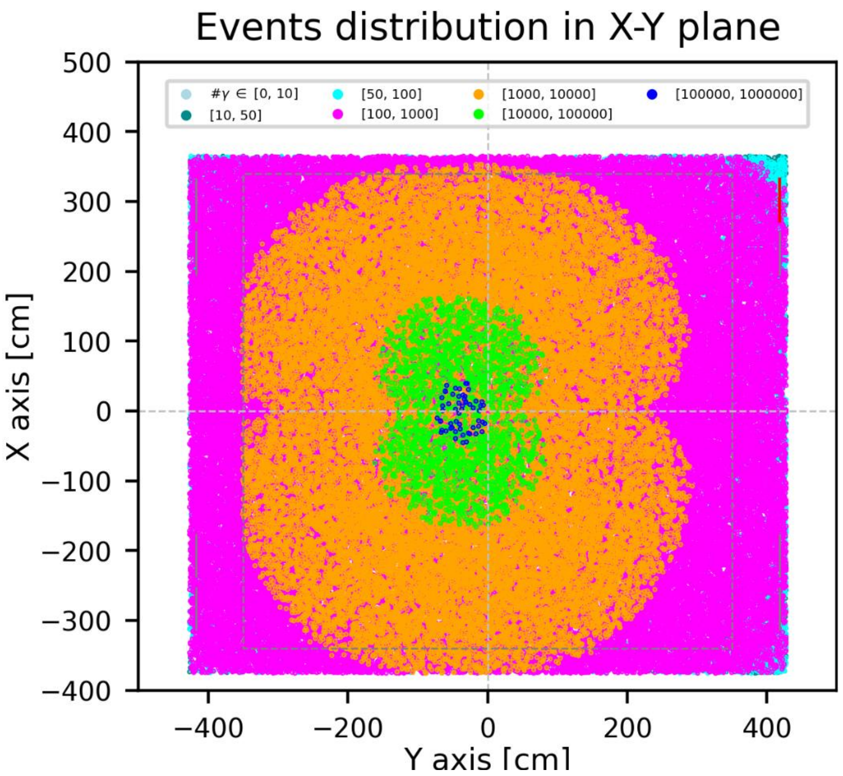
OpCh00: Apply Cut

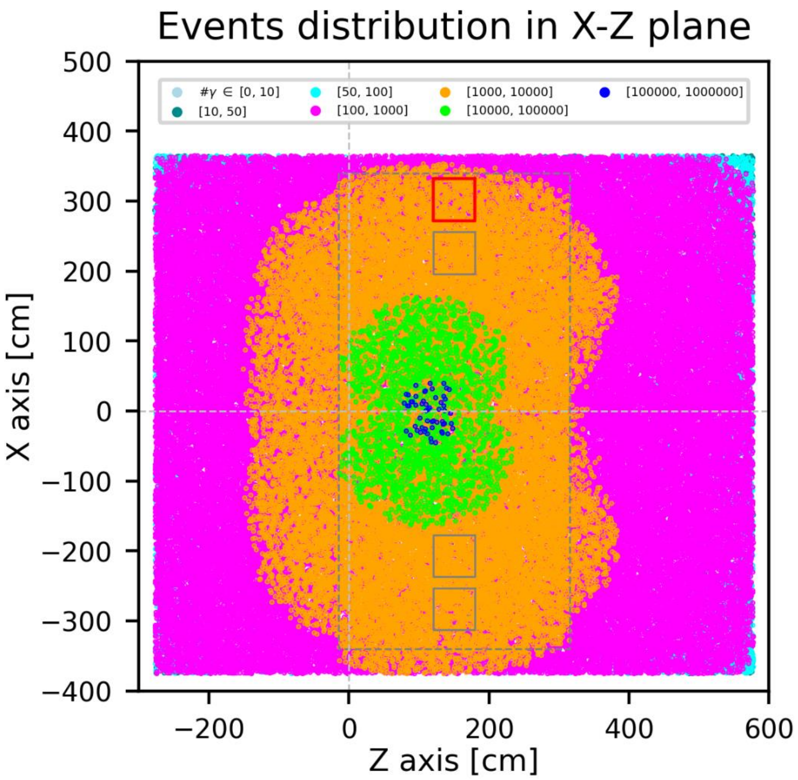
- Results comparison (without cut): $\mu = -0.063, \sigma = 0.348$(previous) $\Longrightarrow \mu = -0.026, \sigma = 0.287$(**current**)
- Cut: Throw events with photon counts $< 100 \Longrightarrow \mu = -0.007, \sigma = 0.134$

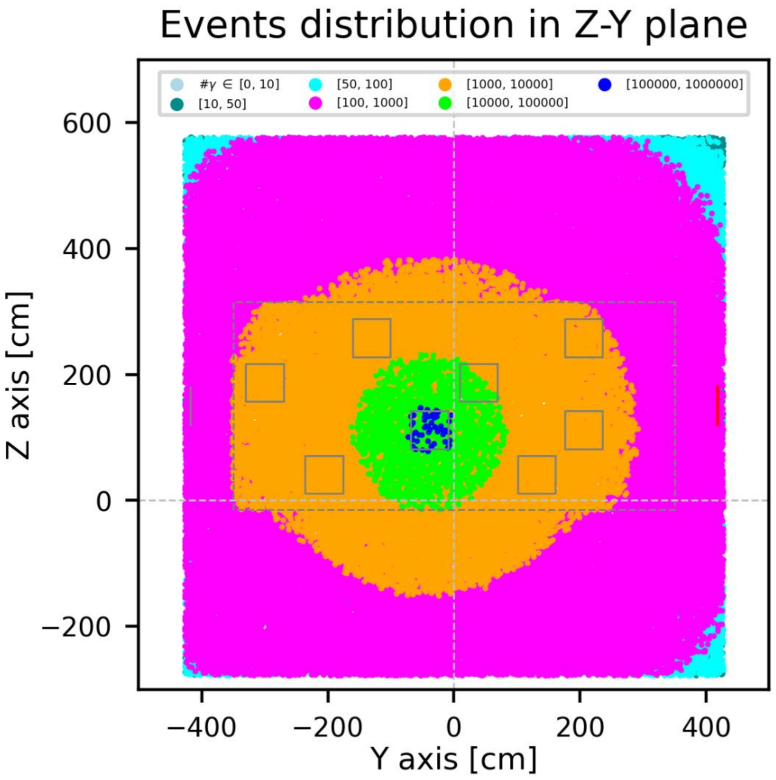




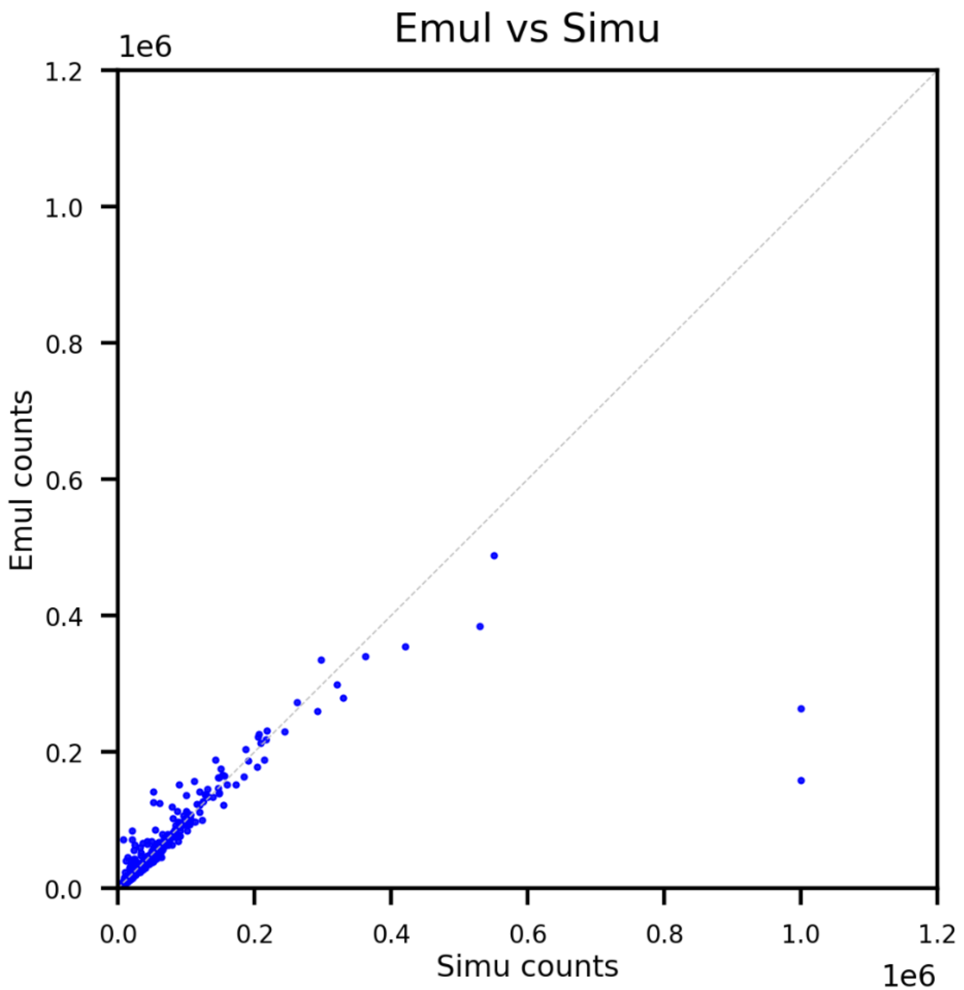
OpCh09: Events Distribution

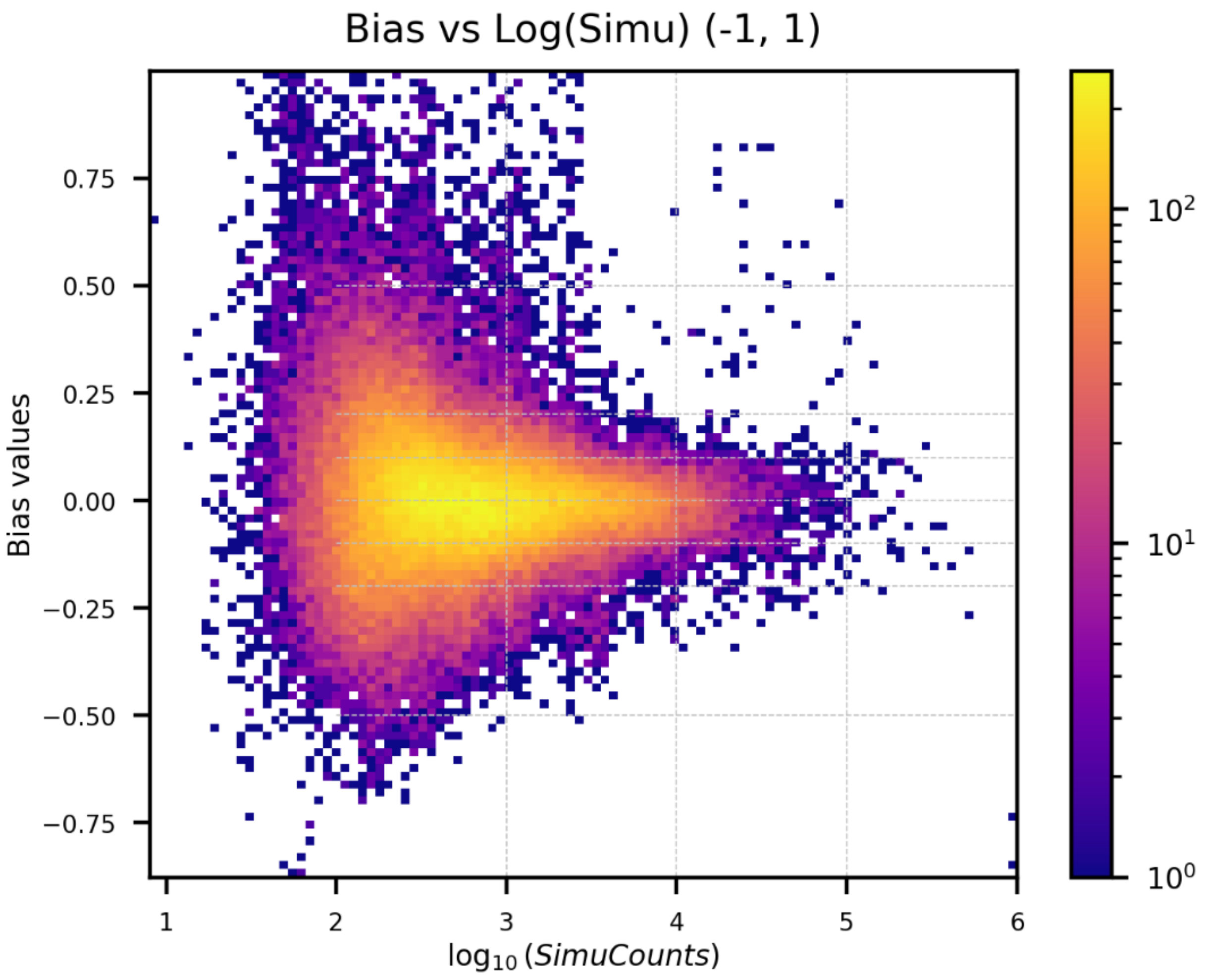






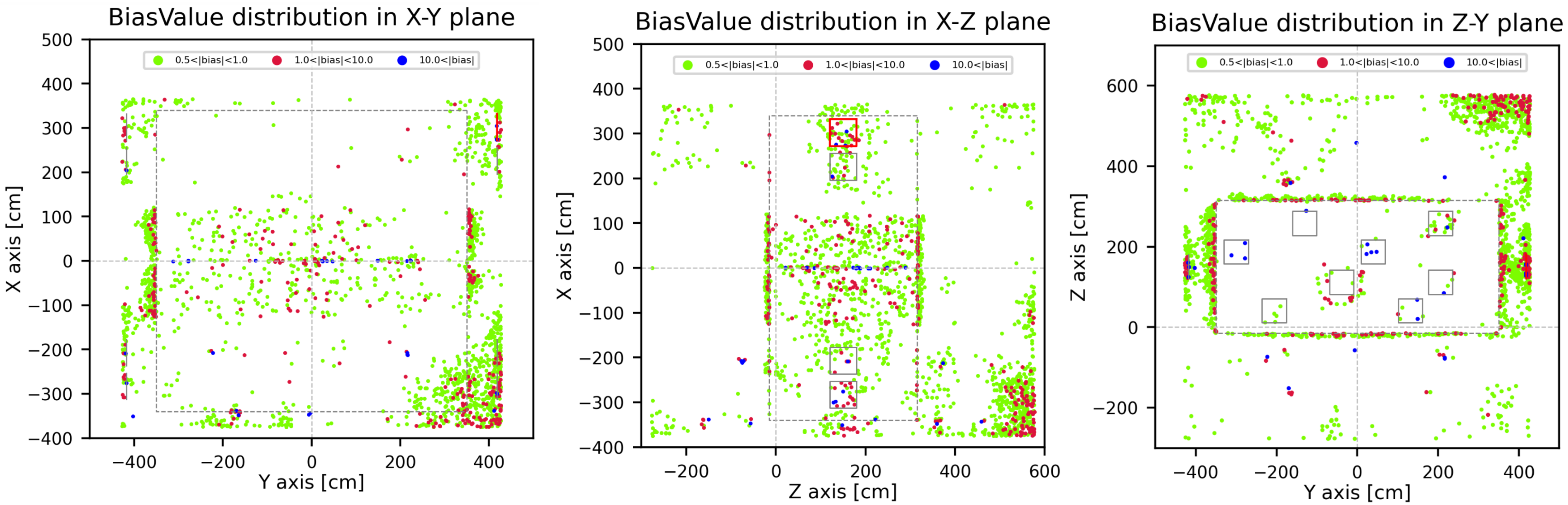
OpCh09: Emul Counts & Bias





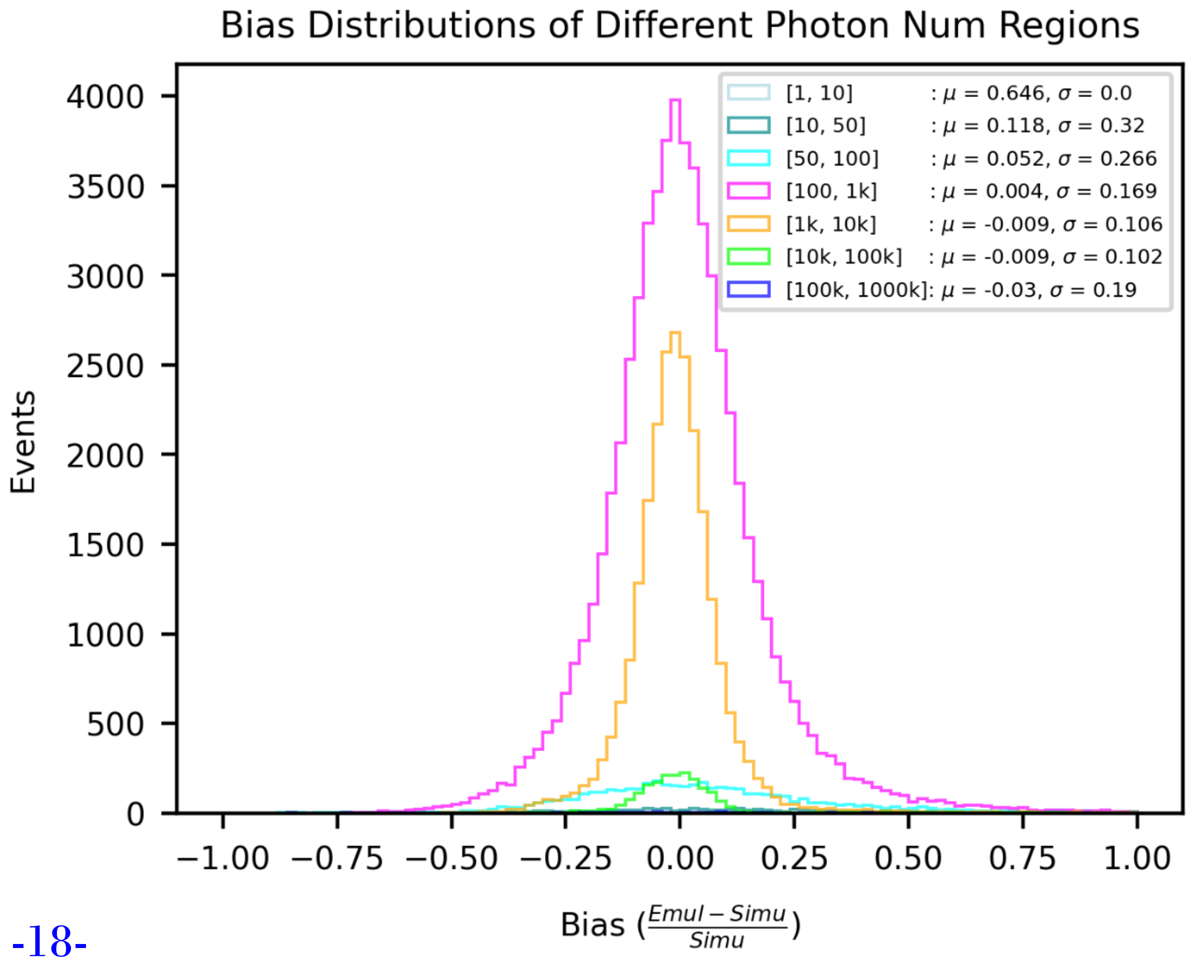
OpCh09: Big Bias Events in Space

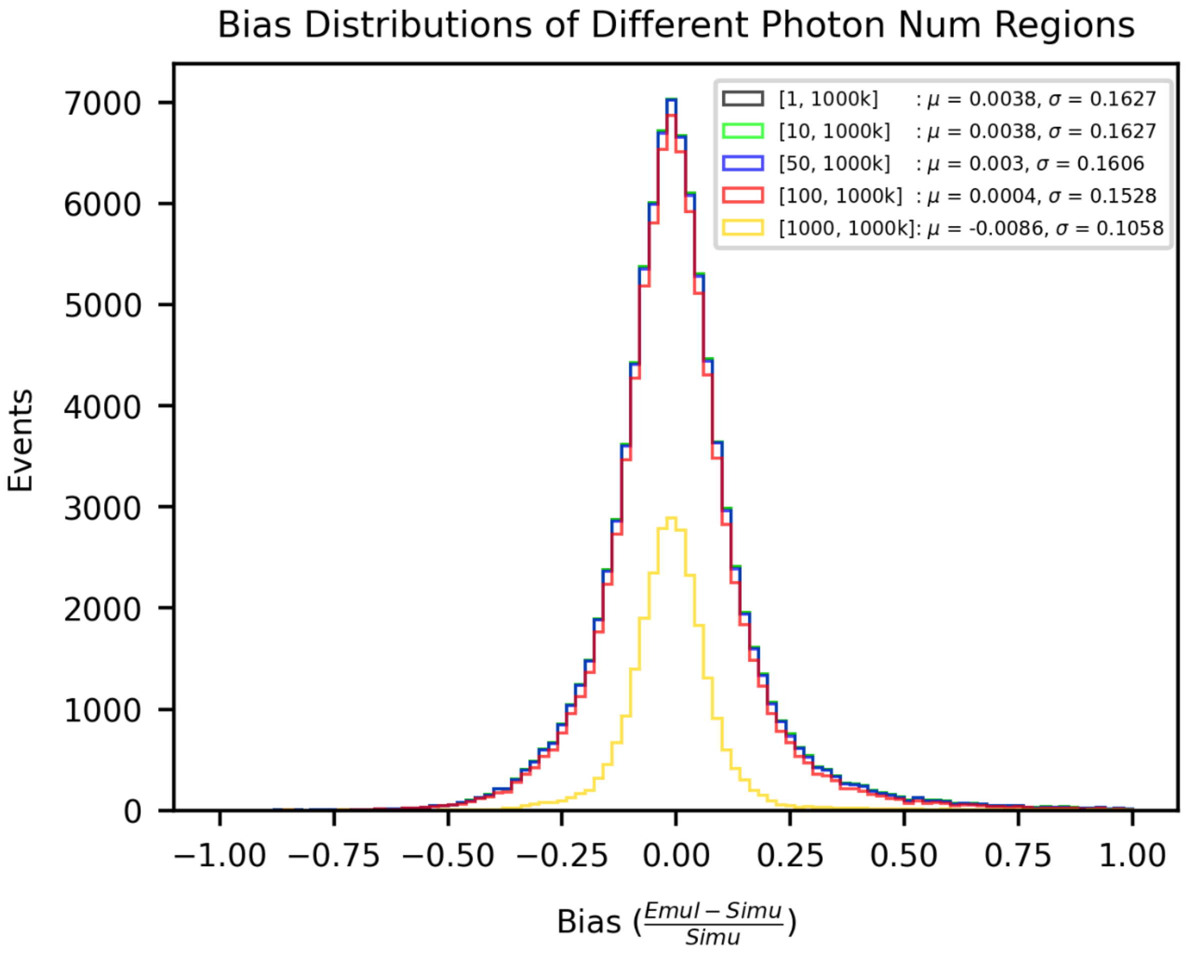
❖ Highly affected by field cage



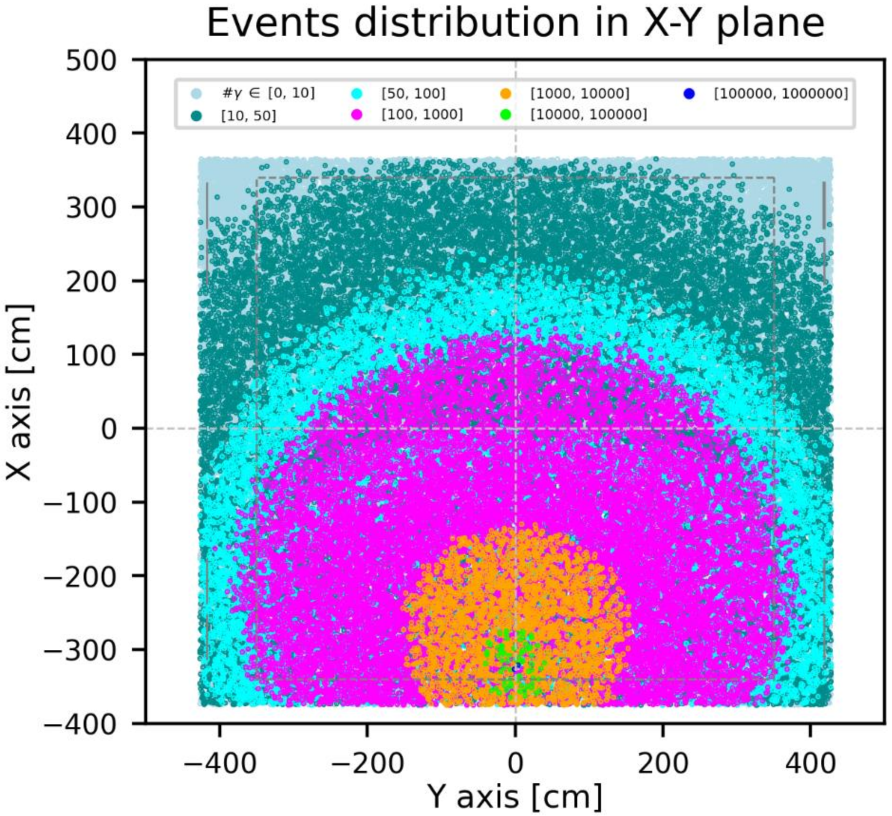
OpCh09: Apply Cut

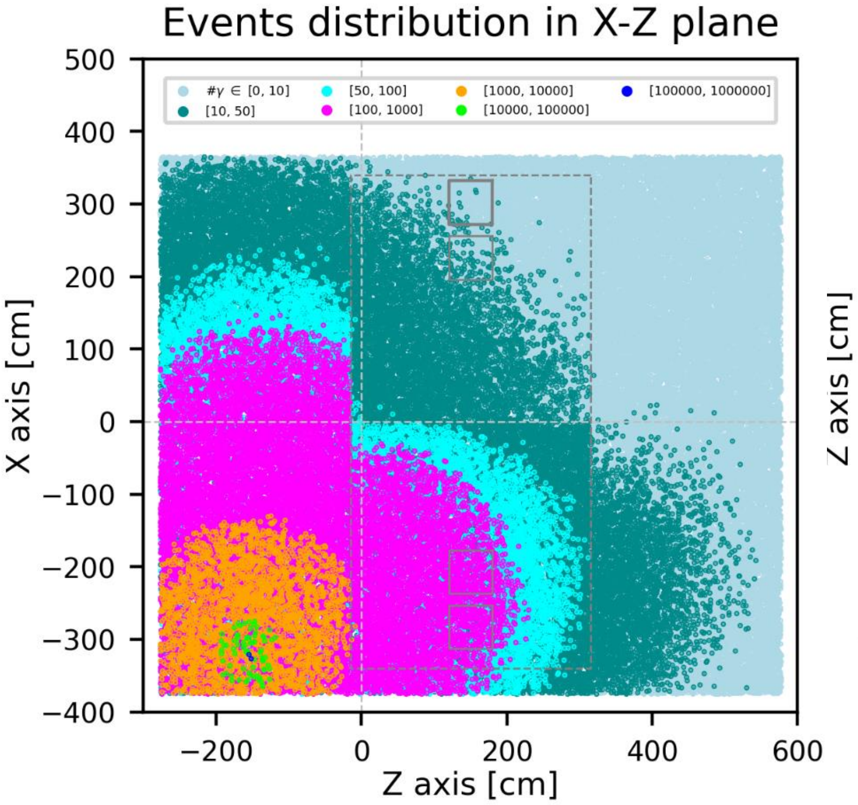
- Results comparison (without cut): $\mu = 0.012, \sigma = 0.173$(previous) $\Longrightarrow \mu = 0.004, \sigma = 0.163$(**current**)
- Cut: Throw events with photon counts $< 100 \Longrightarrow \mu = 0.0004, \sigma = 0.153$

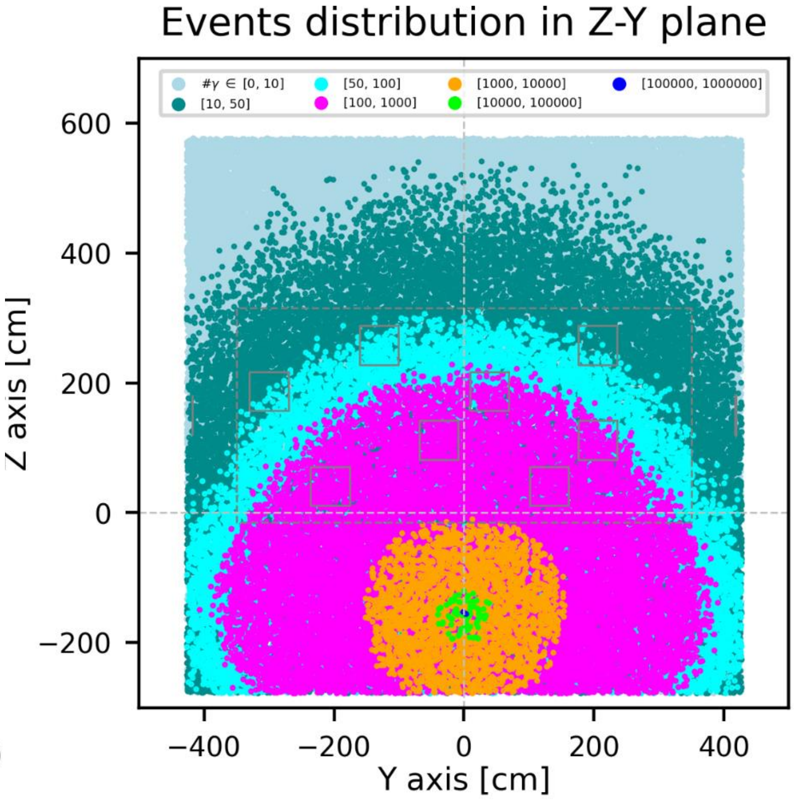




OpCh38: Events Distribution

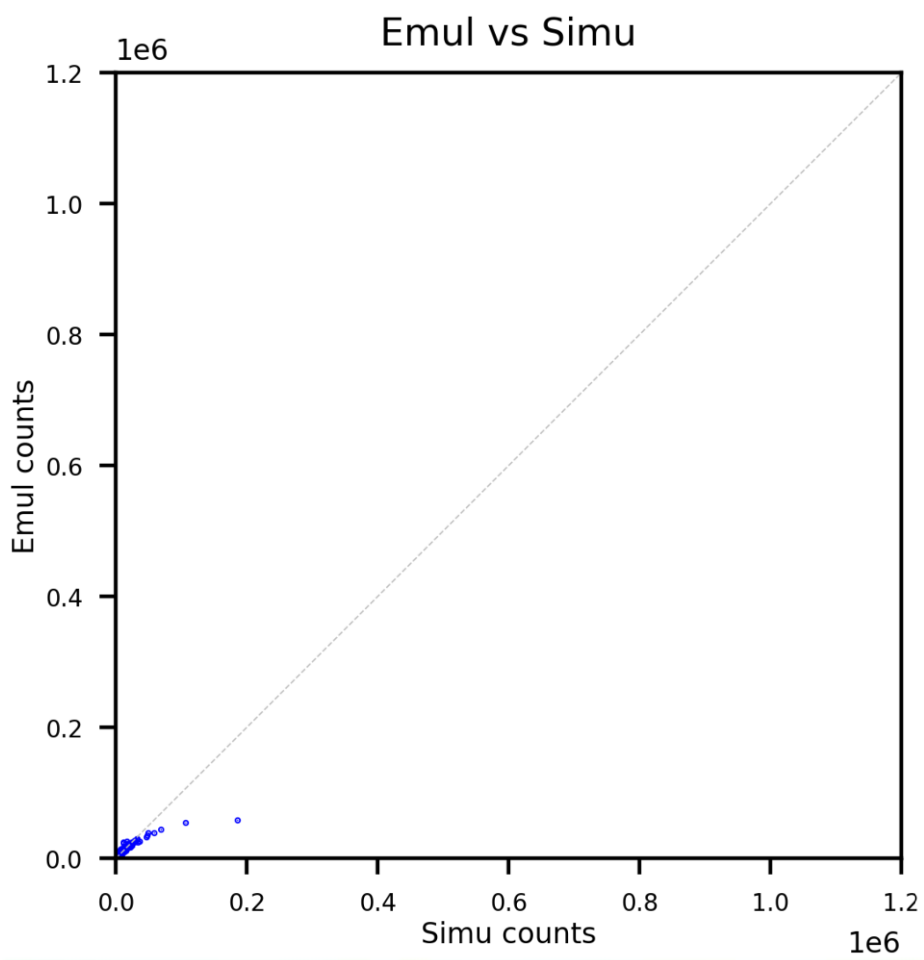


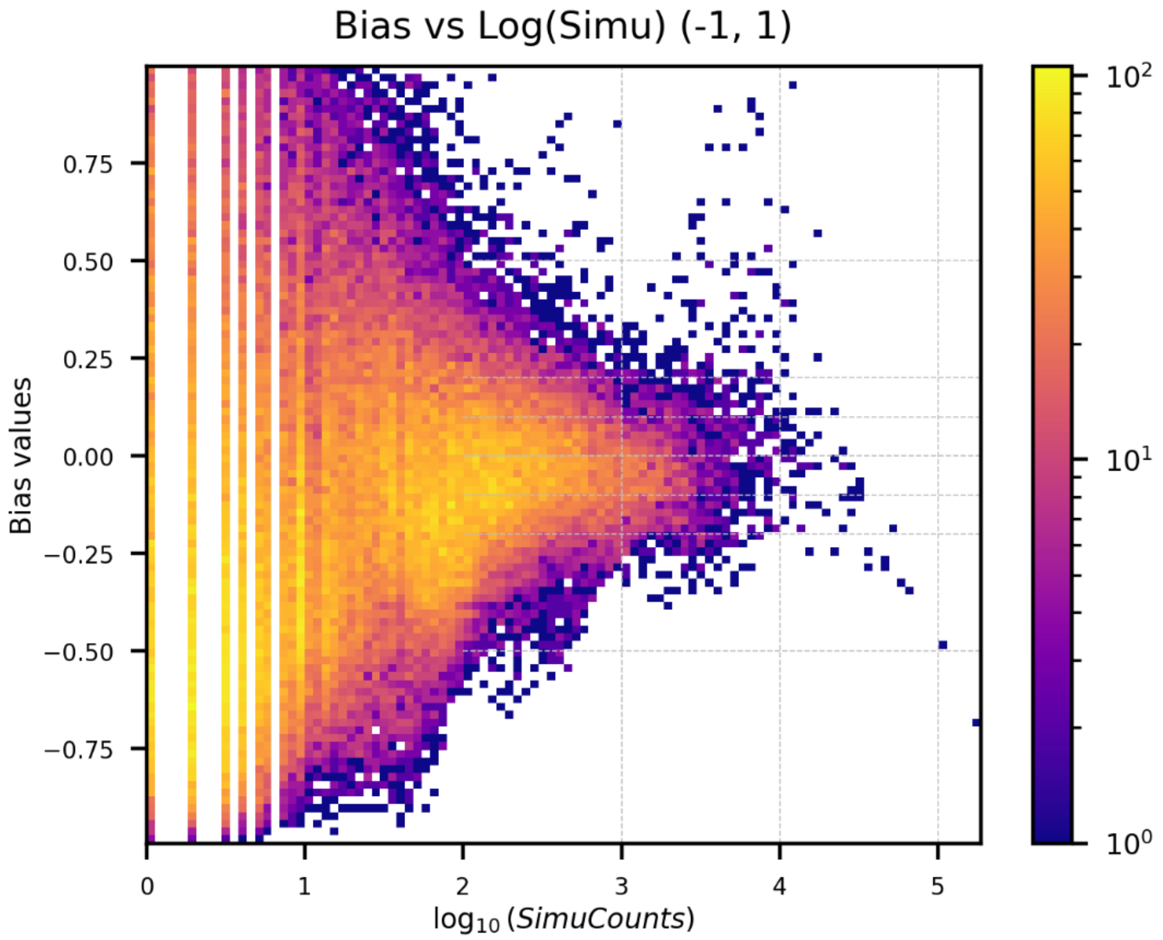




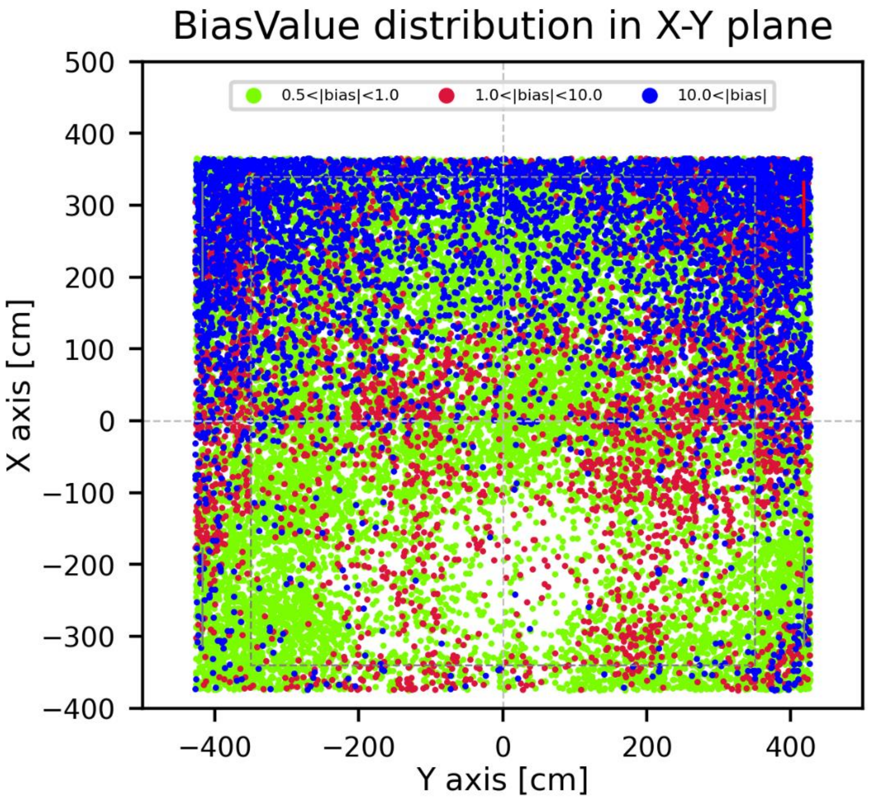
OpCh38: Emul Counts & Bias

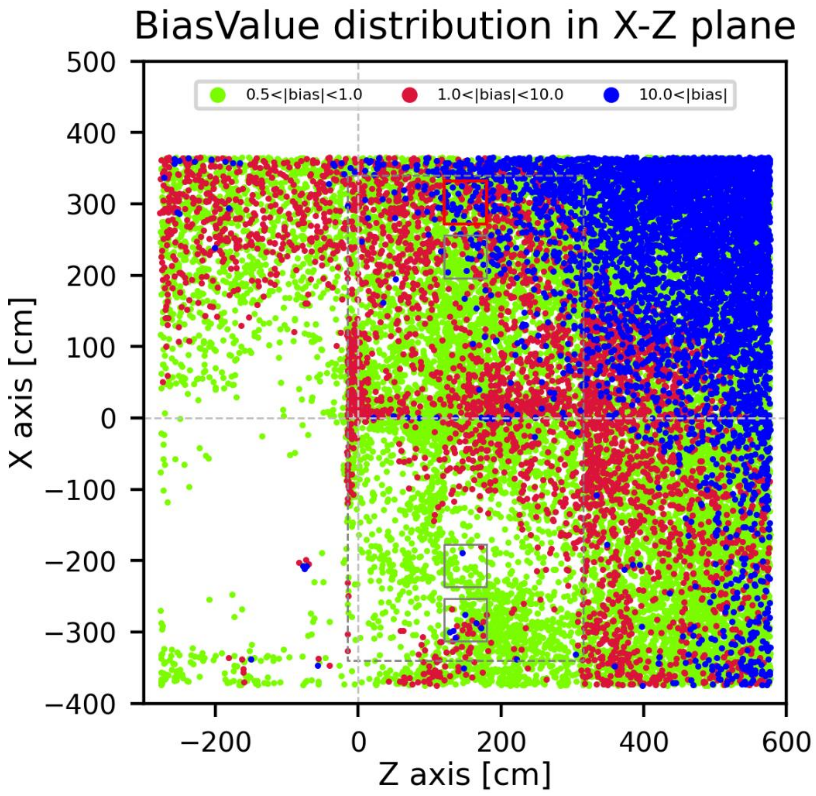
❖ Events with $\#\gamma < 10$ contributes a lot to big-biased events

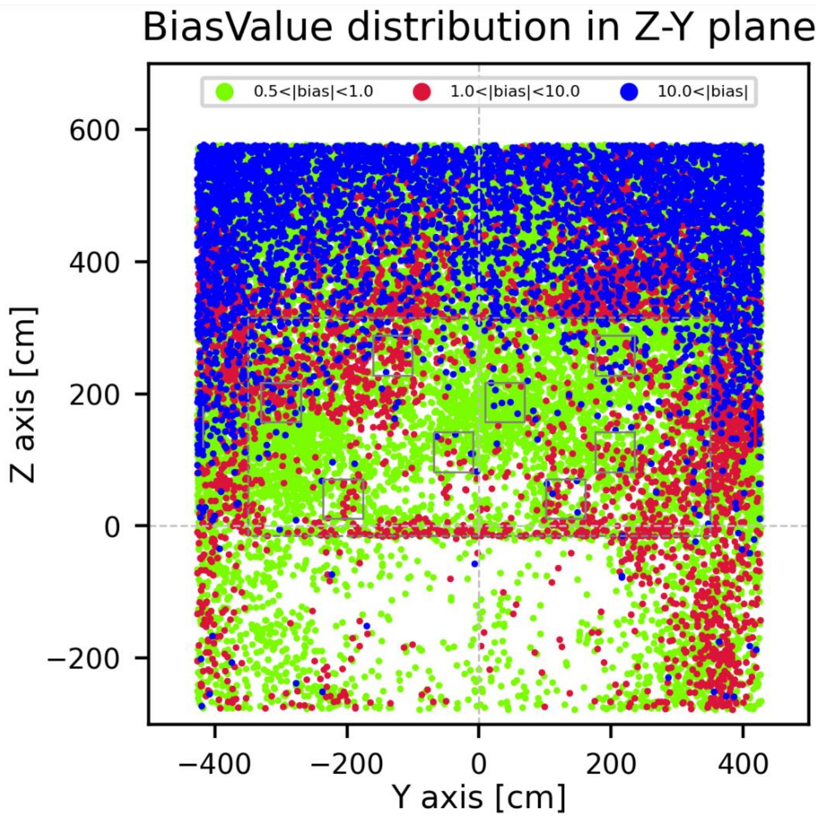




OpCh38: Big Bias Events in Space

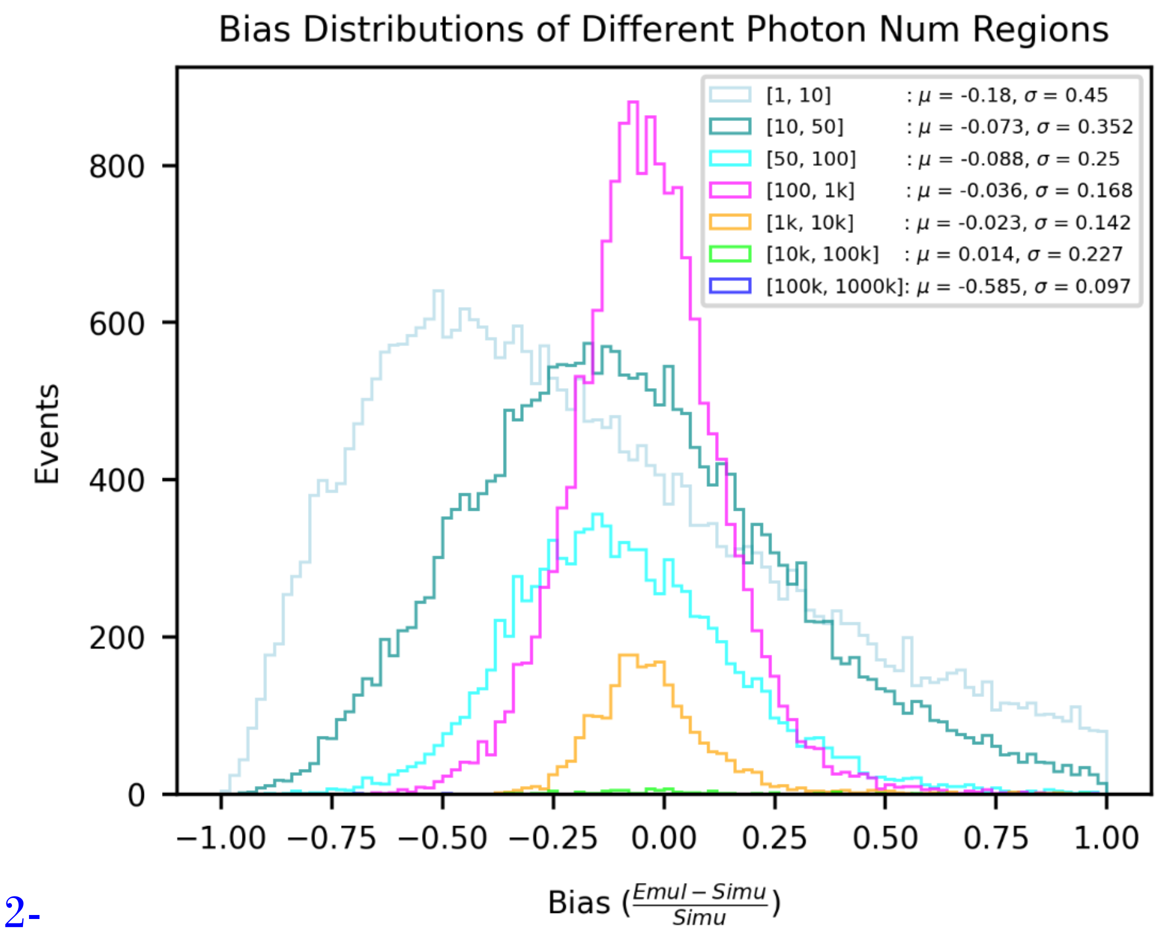


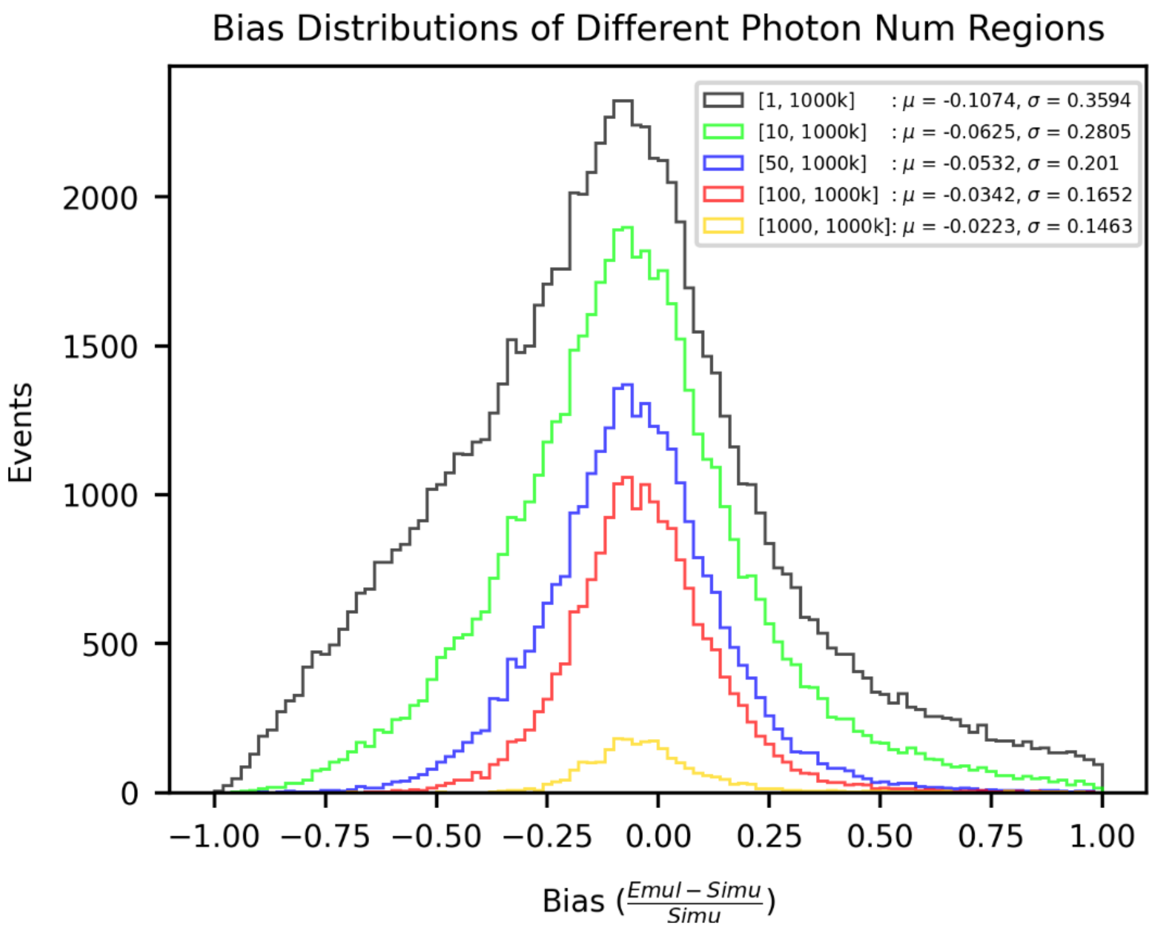




OpCh38: Apply Cut

- Results comparison (without cut): $\mu = -0.101, \sigma = 0.382$(previous) $\Longrightarrow \mu = -0.107, \sigma = 0.359$(**current**)
- Cut: Throw events with photon counts $< 100 \Longrightarrow \mu = -0.0342, \sigma = 0.165$





Summaries

- Detailed evaluation methods developed
- New training has better performance over old training
- Applying proper cuts improves performance apparently
- Further steps:
    1. Determine the criteria of performance: How good is good?
    2. Further improve evaluation methods (Any suggestions is appreciated!)
    3. Expand evaluations to the left 37 optical channels
    4. Optimize current network (e.g change learning rate, hyper-parameters)
    5. Increase training samples: Current $\mathbf{500,000} \Longrightarrow \sim\mathbf{2,000,000}$

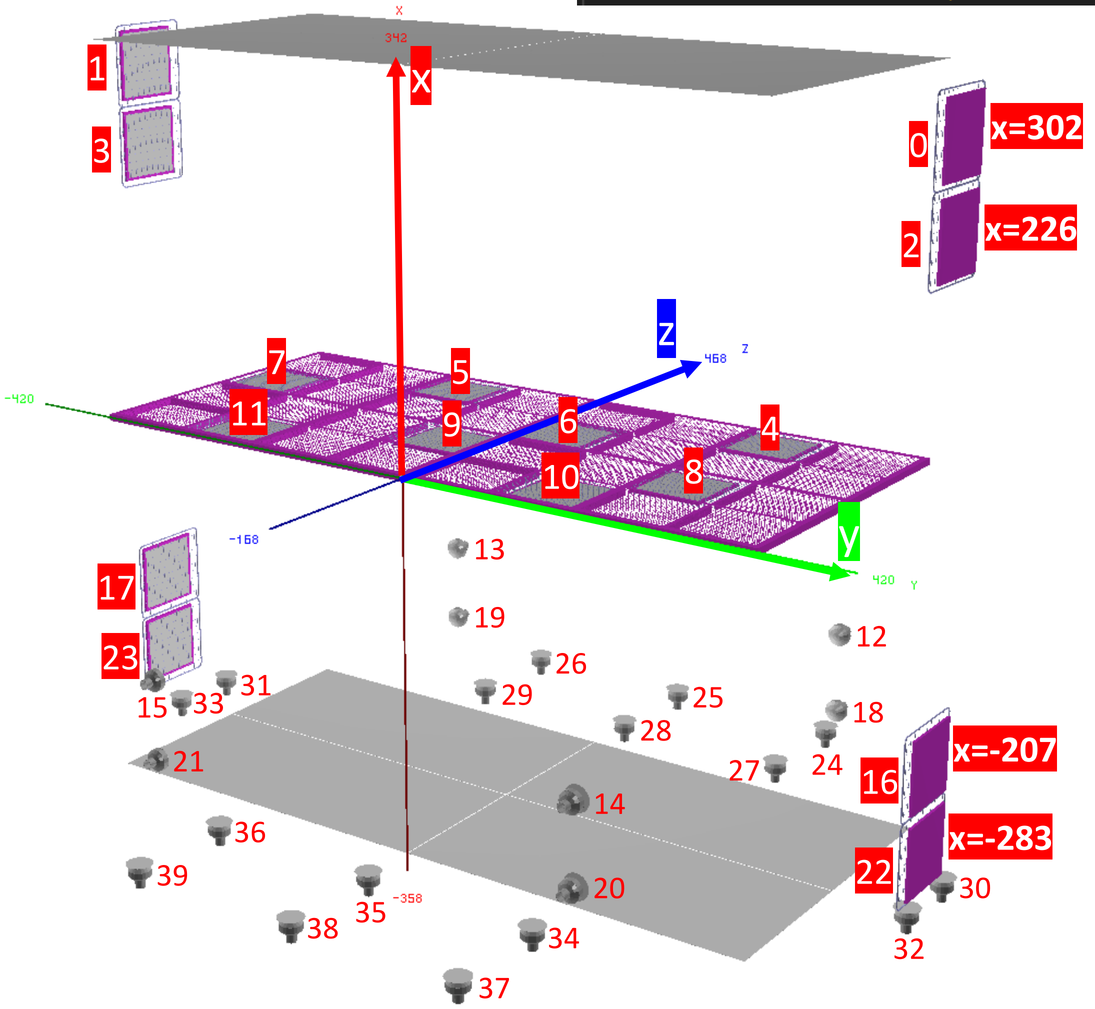
Backups

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

RSL, Abs & Reflectivity

Rayleigh scattering length:

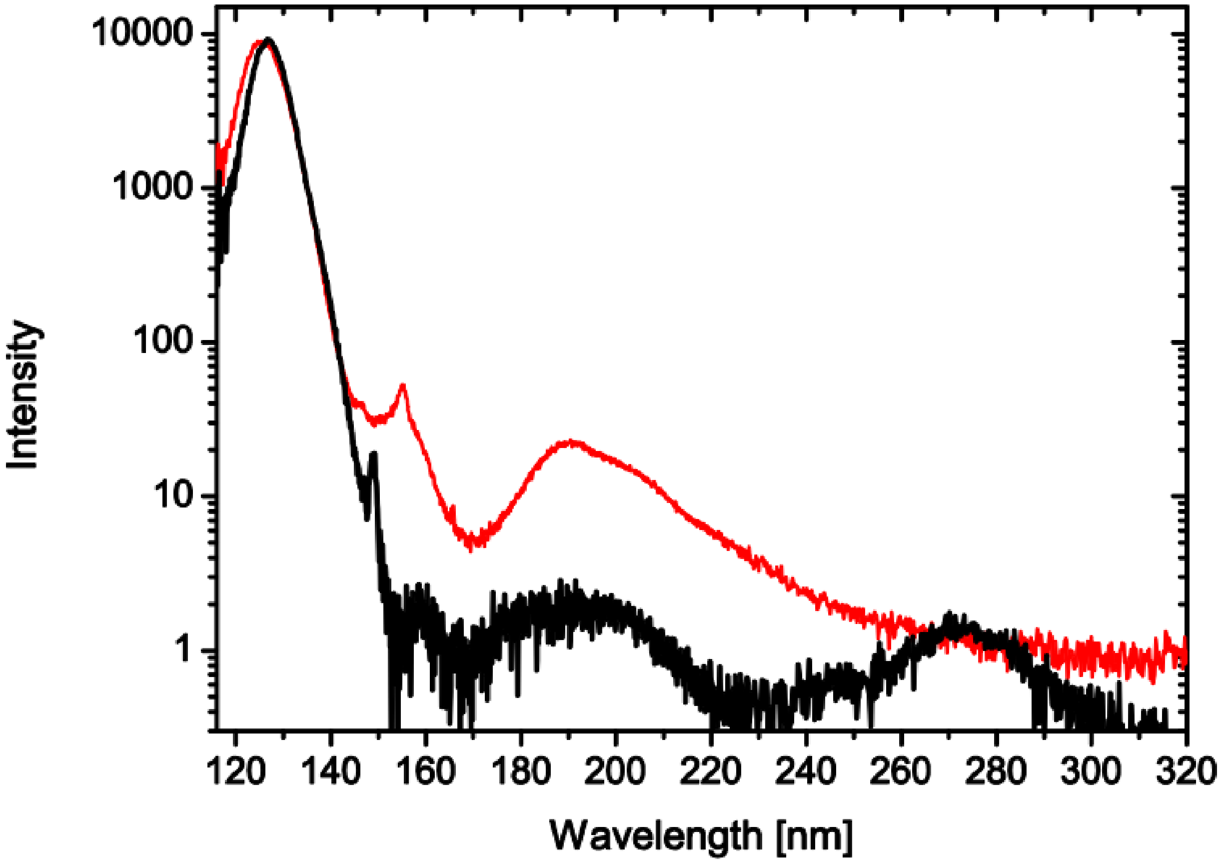
```
services.LArPropertiesService.RayleighEnergies: [1.18626, 1.68626, 2.18626, 2.68626, 3.18626, 3.68626, 4.18626, 4.68626, 5.18626, 5.68626, 6.18626, 6.68626, 7.18626, 7.68626, 8.18626, 8.68626, 9.18626, 9.68626, 10.1863, 10.6863, 11.1863]
services.LArPropertiesService.RayleighSpectrum: [1200800, 390747,  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:

```
services.LArPropertiesService.AbsLengthEnergies: [4,5,6,6.5,7,7.5,8,9,10,11]
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]

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

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

X