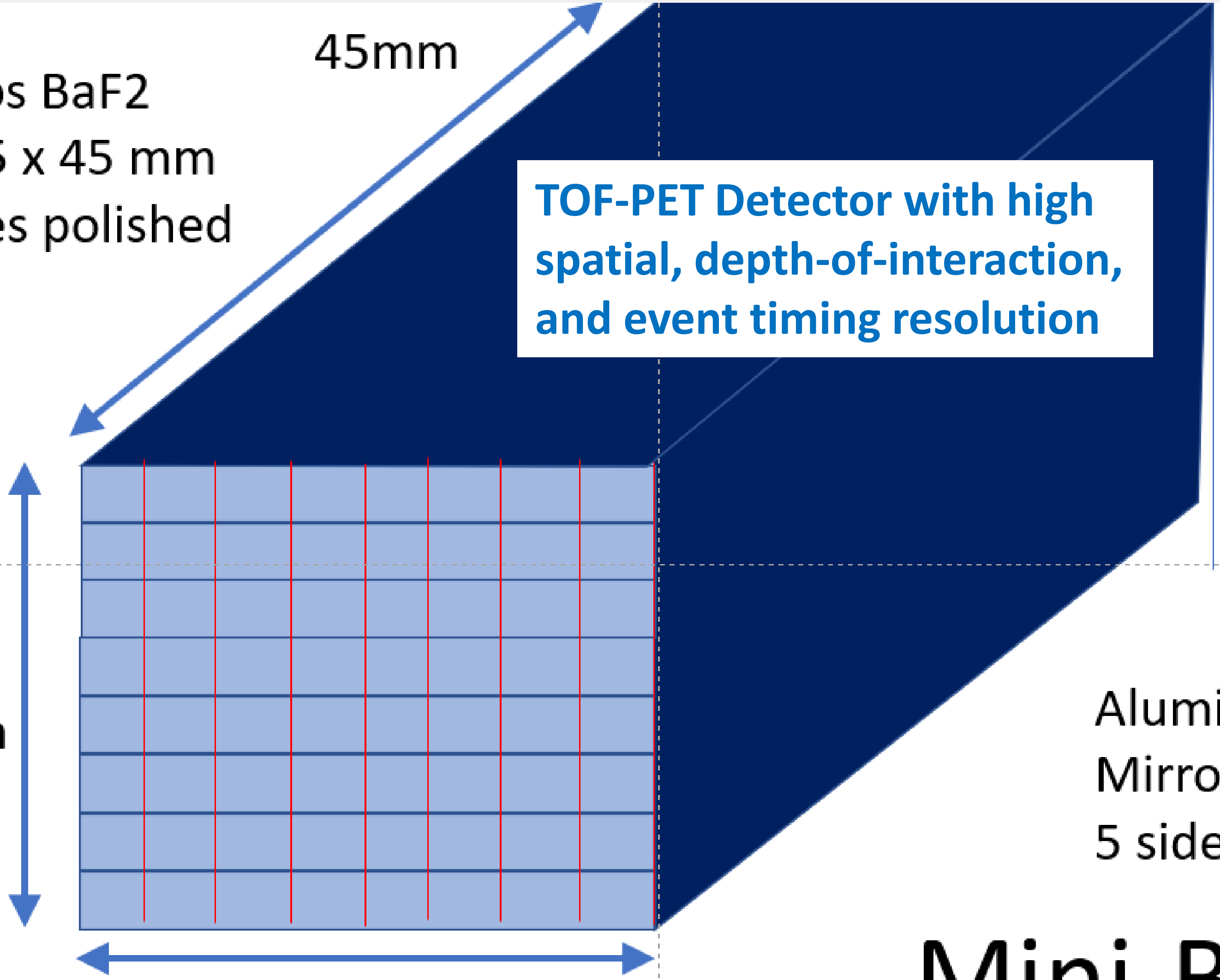
Specular Optics for TOFPET: Pytorch Model Validation

Bill Worstell

PicoRad Imaging

10/17/2023

8 slabs BaF2
3 x 25 x 45 mm
6 sides polished



Aluminum
Mirrored
5 sides

[x,y,z,t,Θ,Φ]|[dX,DX,dy,DY,dz,DZ,nx,ny,ηx,ηy]-> detected [X,Y, T] and multiple reflection survival probability

Isomorphism: There is a 1-to-1 map from a ray starting at a point within the Mini-Block then reflecting off mirrors (or by total internal reflection) -> a virtual ray traveling in a straight line through a double layer of 2D virtual lattices

X-reflection: [vx,vy,vz] -> [-vx, vy, vz]
Y-reflection: [vx,vy,vz] -> [vx,-vy, vz]
Z-reflection: [vx,vy,vz] -> [vx, vy,-vz]

5D imaging the 3D position, time, and energy of TOF-PET gamma ray interaction

Mini-Block

2-D Infinite Mirror at each pixel, and for Miniblock

Specular Optics preserve high spatial and temporal frequency signals

32 BaF2 Slabs (X)

t(X)=3mm

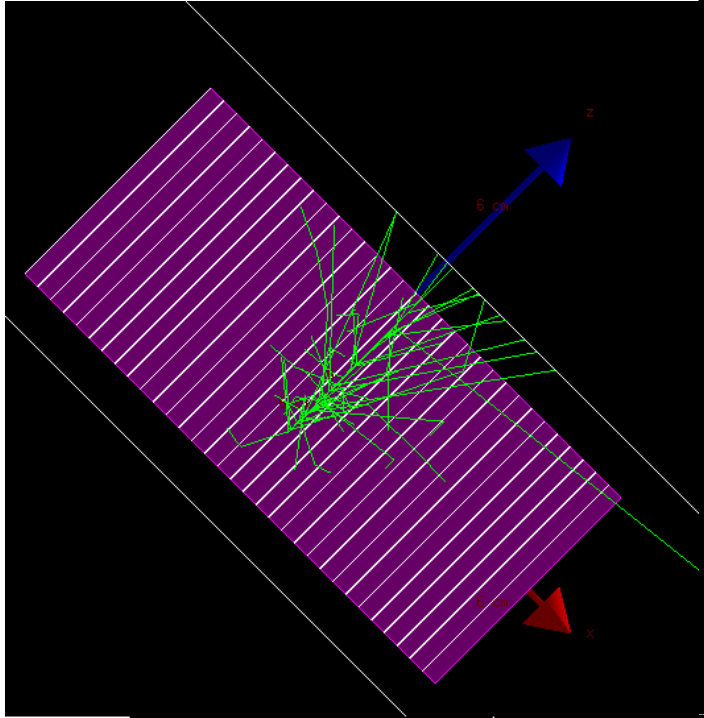
(pitch=3.1mm)

W(Y)= 100mm

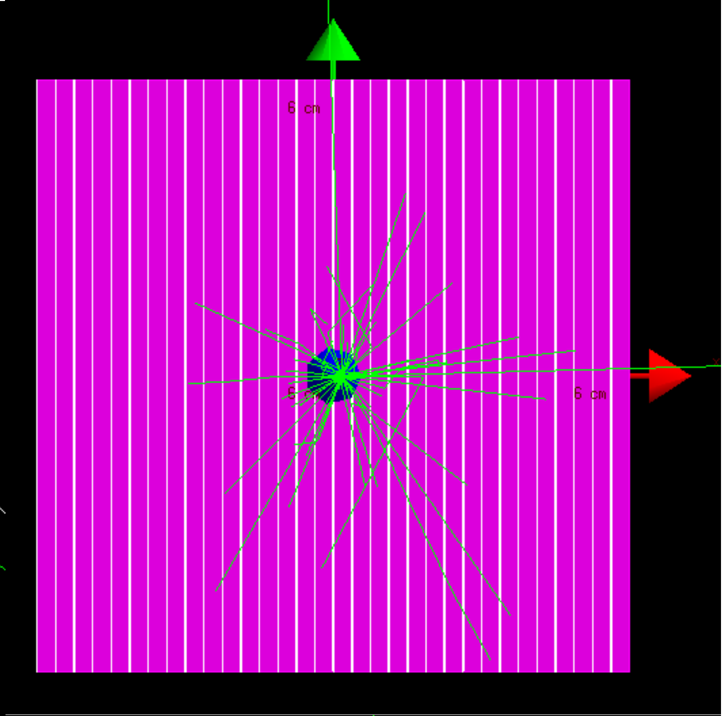
T(Z)=45mm

99.2mm x 100mm

x 45mm BaF2 blocks



Top View



End View

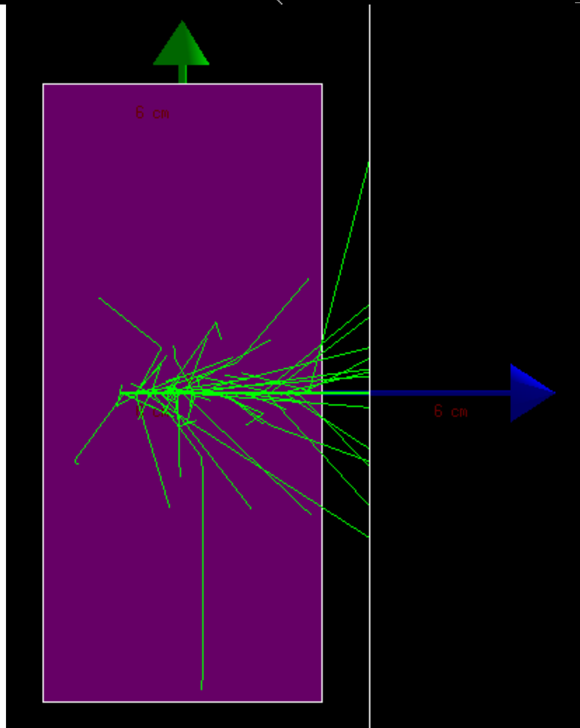
Assemble Block

with Air (Vacuum)

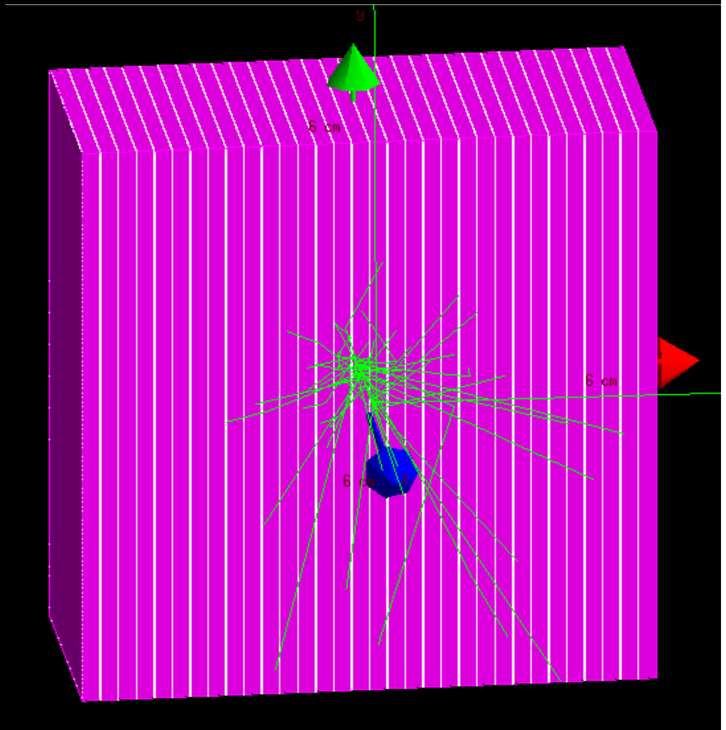
Gaps between Slabs

Photocathode

Deposited end-on



Side View



Oblique View

Parametrized Specular Detector Geometry

```
#Constant Geometry Parameters
DZ = 45. #mm
DetectNX = 8
dX = 3.0  #mm
DX = DetectNX * dX
XBins=torch.arange(-DX/2.,DX/2.,dX)+(dX/2.)
ic(XBins)
DetectNY = 12;
dY = 2.0; #mm
DY = DetectNY  * dY
YBins=torch.arange(-DY/2.,DY/2.,dY)+(dY/2.)
ic(YBins)
TMax=1000. #Maximum Time in ps
```

Parametrized Specular Detector Optics

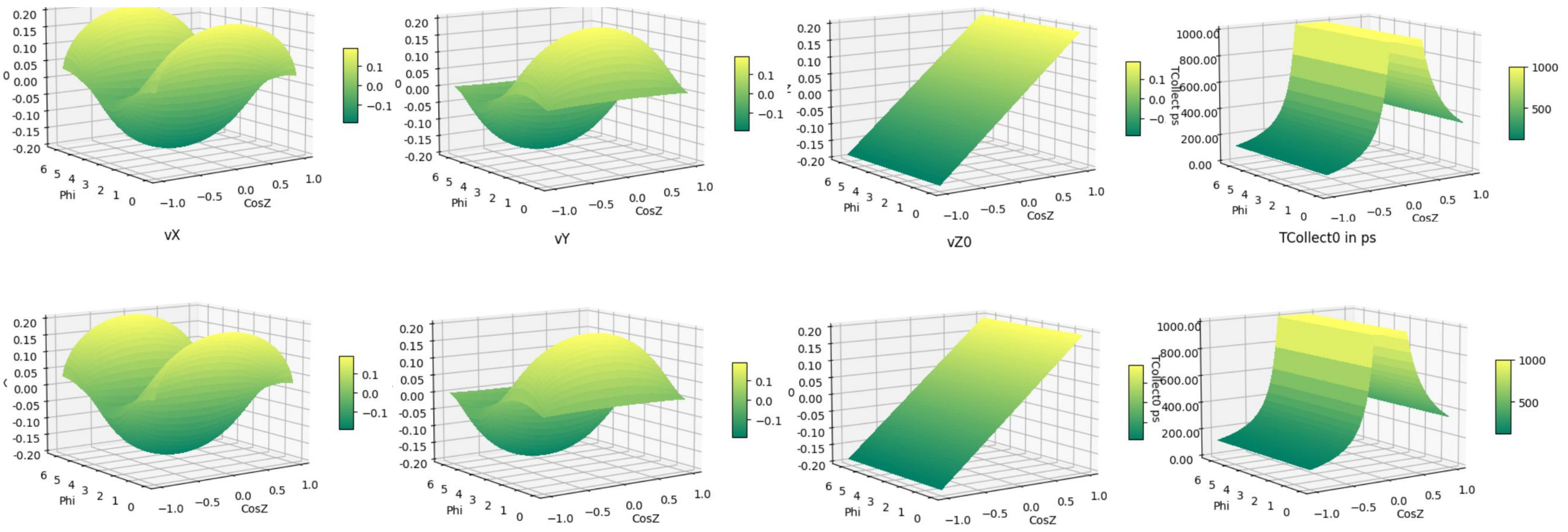
```
 Index of refraction for optical barriers
#  (Air and LIOB=Laser Induced Optical
Barrier)
IndexX=1.0
IndexY=1.40
#Number of photons to generate (511 keV x
ideal photosensor)
NFast=172.
NSlow=1059.
# Index of refraction for fast and slow
component
IndexFastBaF2=1.55
IndexSlowBaF2=1.50
# Reflectivity of mirrored surfaces
ReflectX=0.90
ReflectY=0.90
ReflectZ=0.90
```

https://colab.research.google.com/github/BillWorstell/BaF2_LAPPD/blob/main/SimpleOpticsPhotons.ipynb

Running in RandomAngles=false mode,
SimpleOpticsPytorch.ipynb first event of 1000 is identical to
SimpleOpticsPhotons.ipynb single event

Python->Pytorch translation validation

For Specular Optics, the emission spherical angle instance determines the photon CollectionTime



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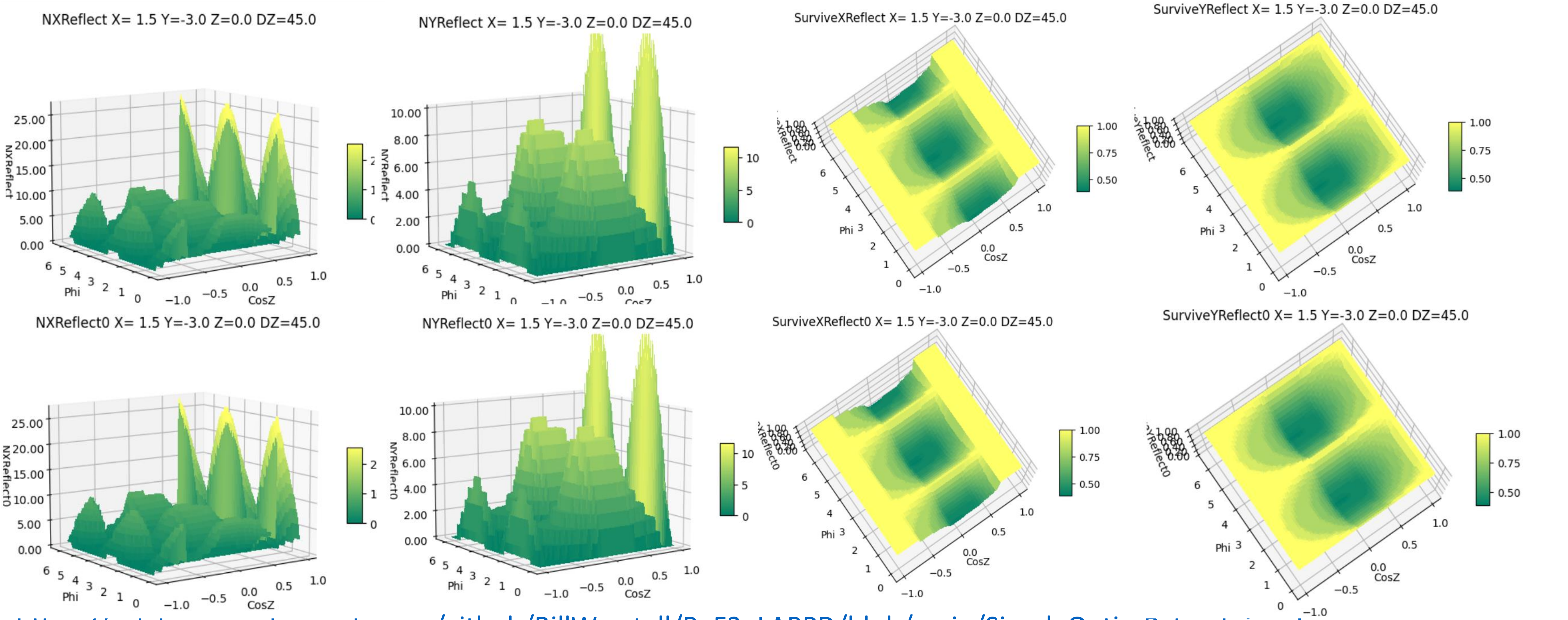
For Specular Optics, the emission spherical angle instance determines the (specular) photon SurvivalLikelihood



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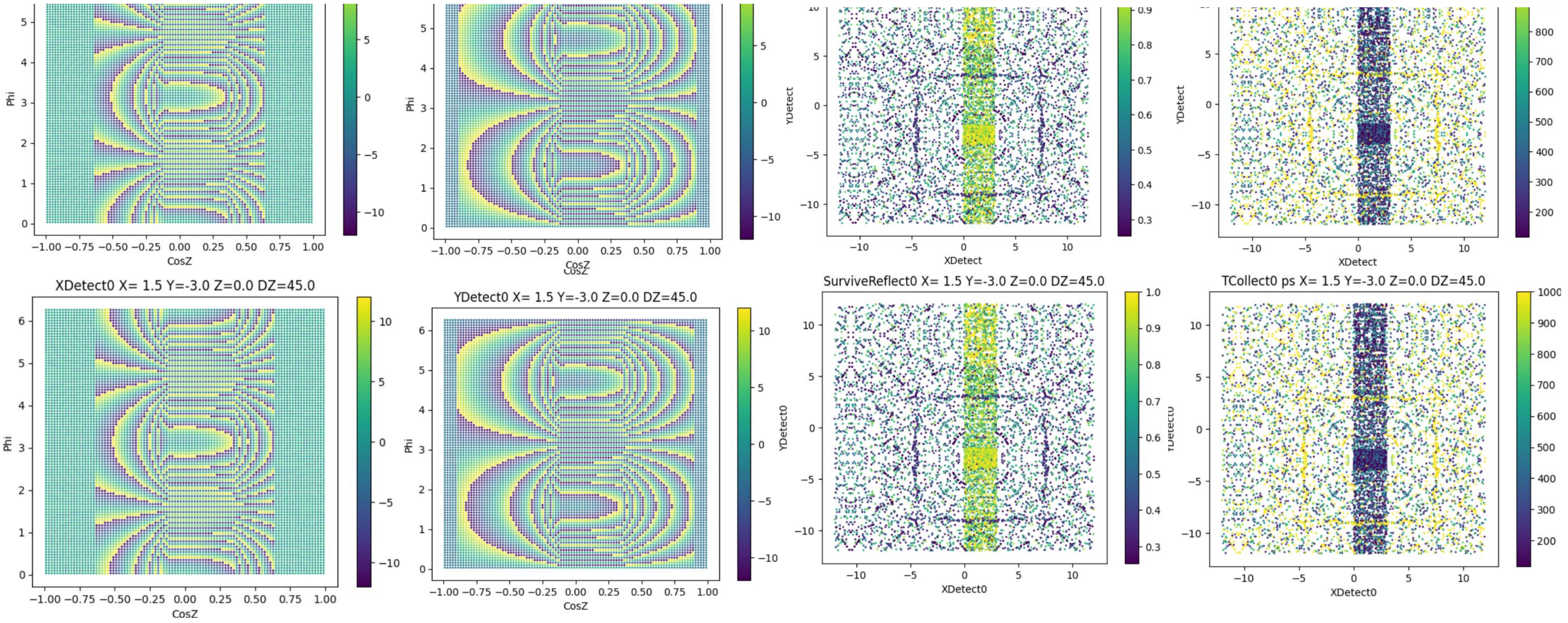
For Specular Optics, the emission spherical angle instance determines the (specular) photon DetectionCoordinate



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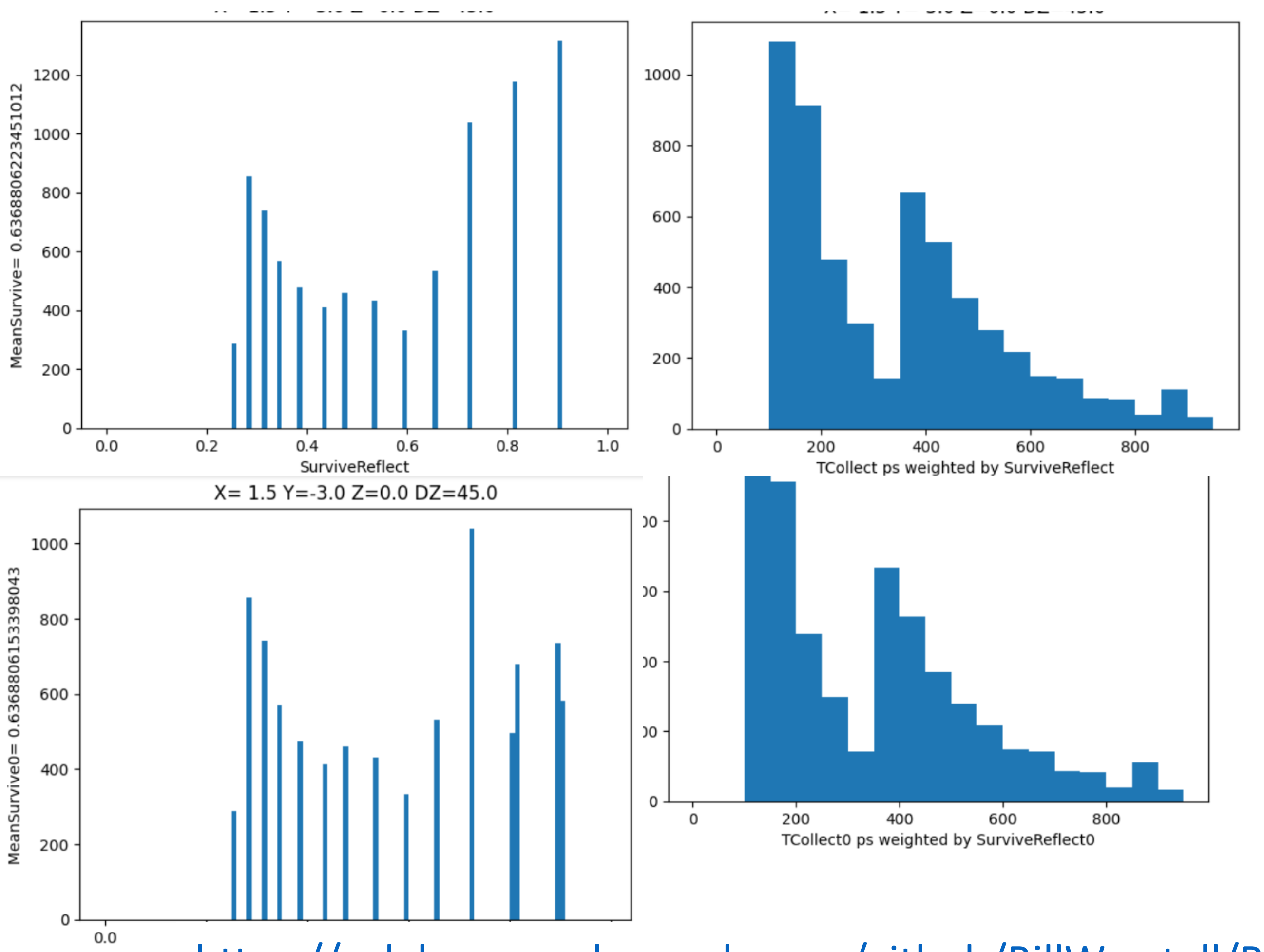
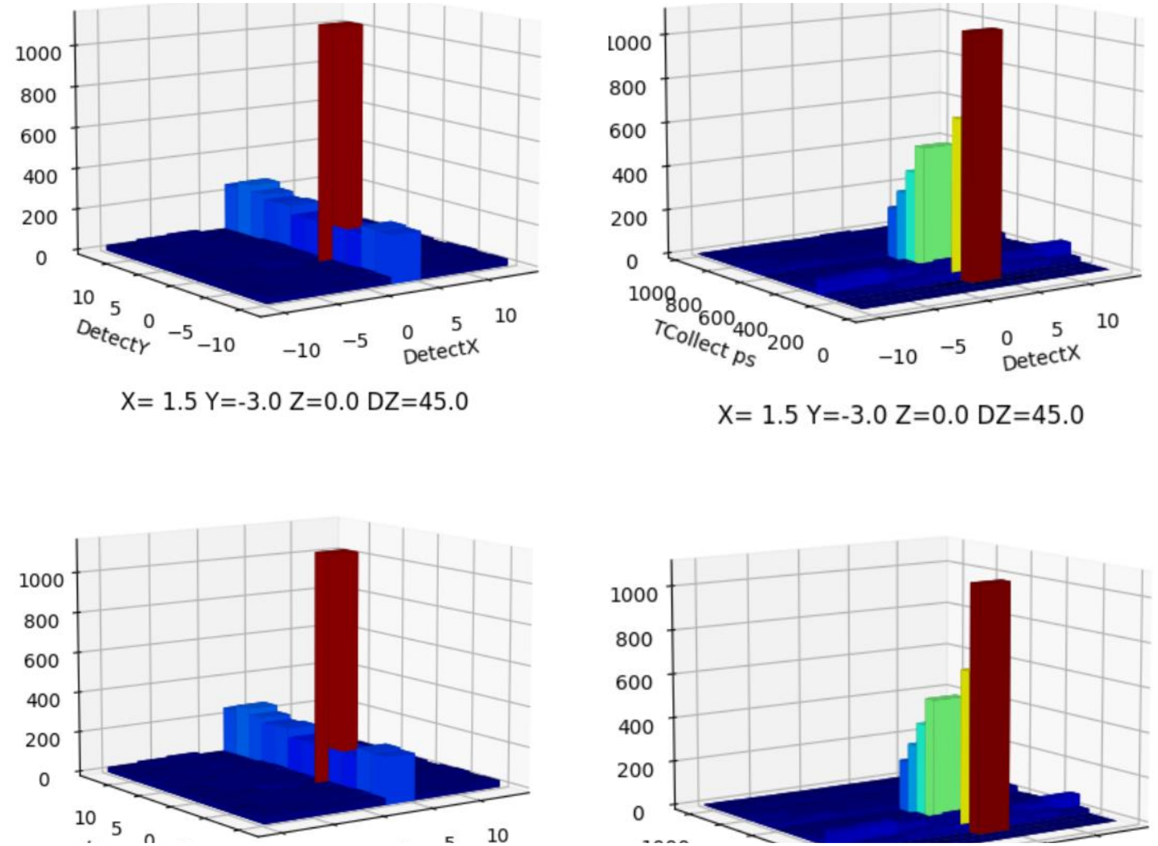


For Specular Optics, the 3D emission instance determines the (specular) likelilhood-weighted photon XYT Coordinate parent distribution



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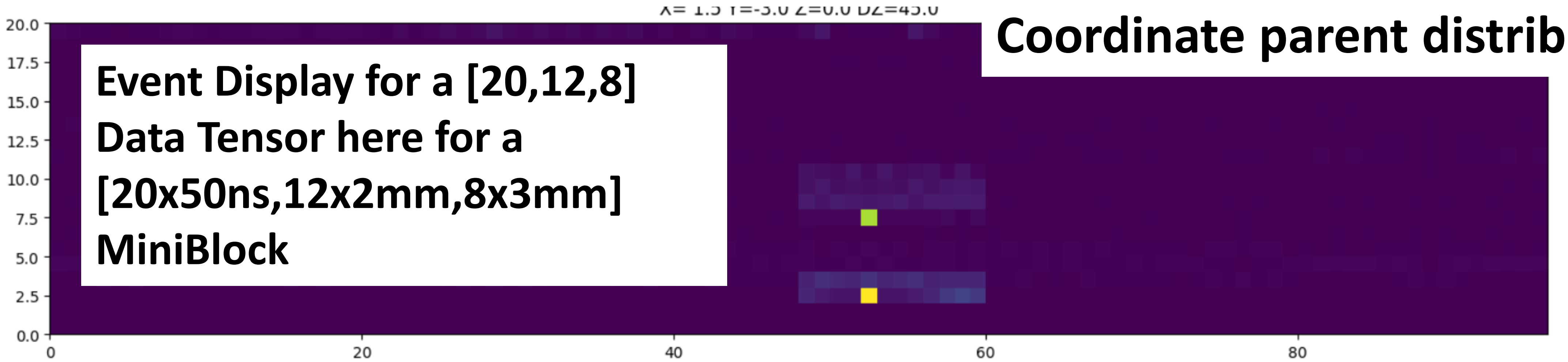
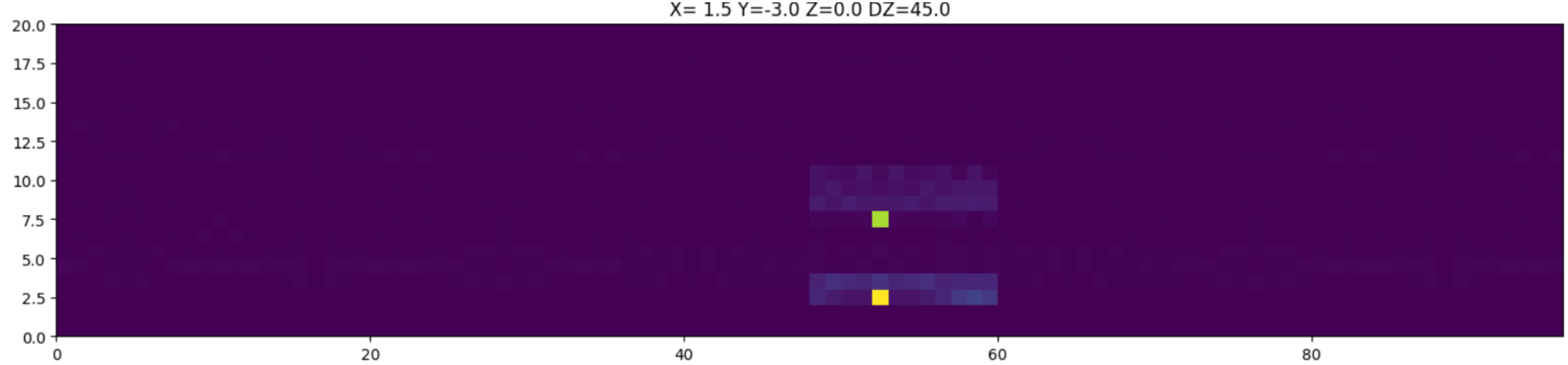
Event Display for a [20,12,8] Data Tensor here for a [20x50ns,12x2mm,8x3mm] MiniBlock





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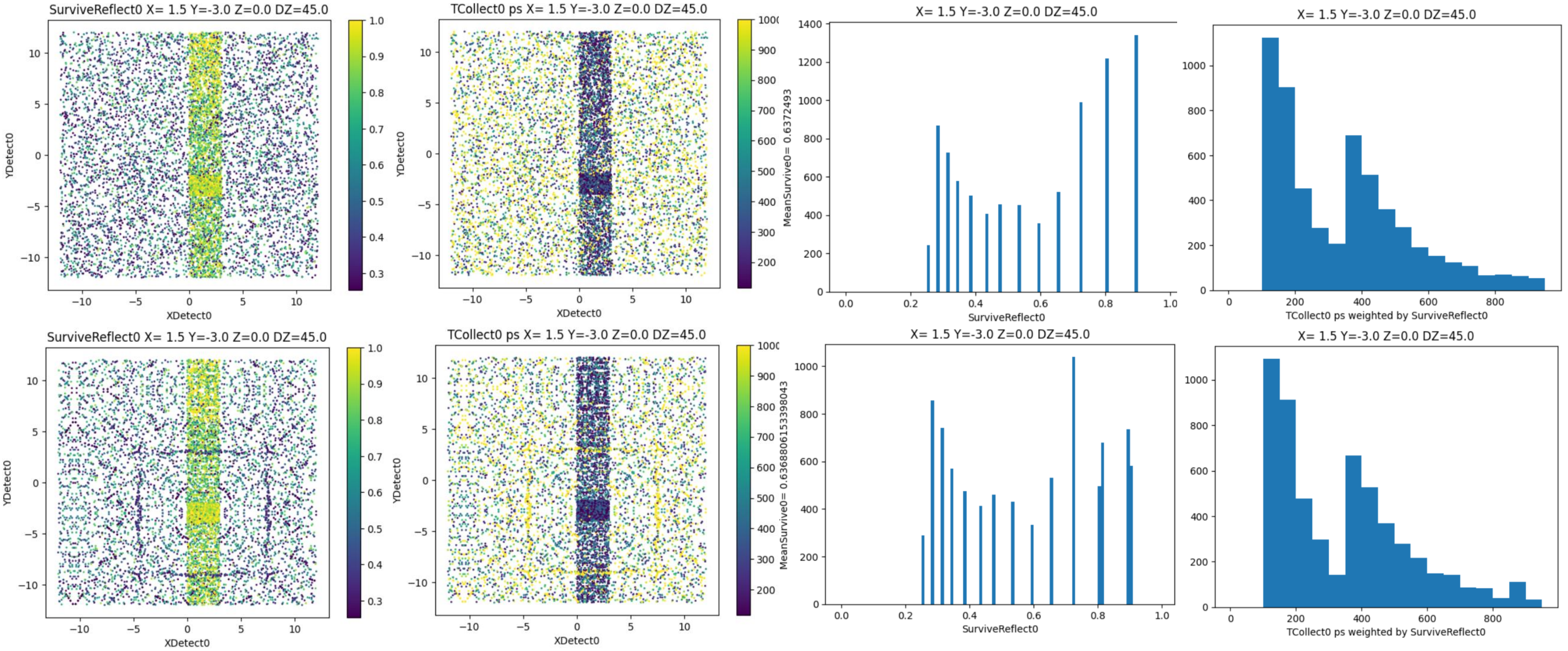
Random sampling shows similar distributions as with regular sampling

Random Isotropic Emission Angles – 10000 photon event



Fixed Equi-distributed Isotropic Emission Angles – 10000 photon event

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X= 1.5 Y=-3.0 Z=0.0 DZ=45.0

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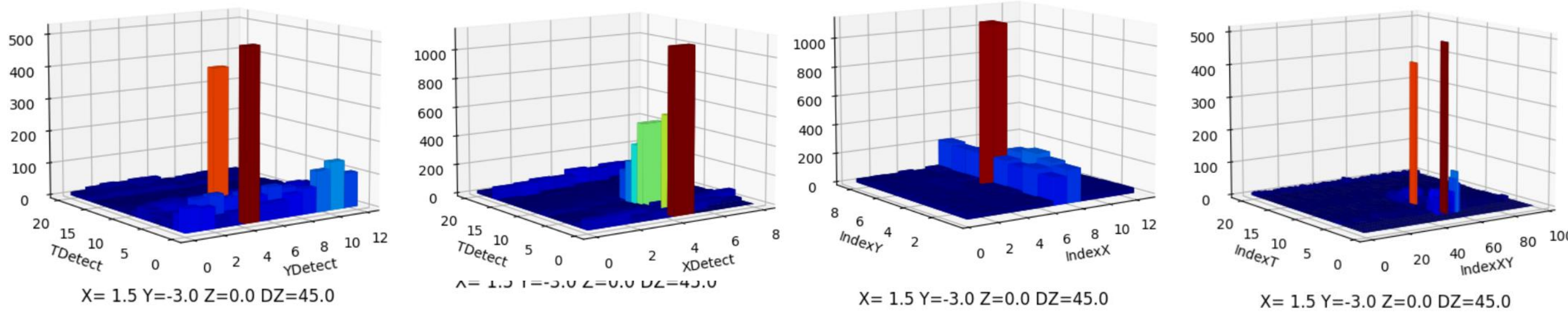

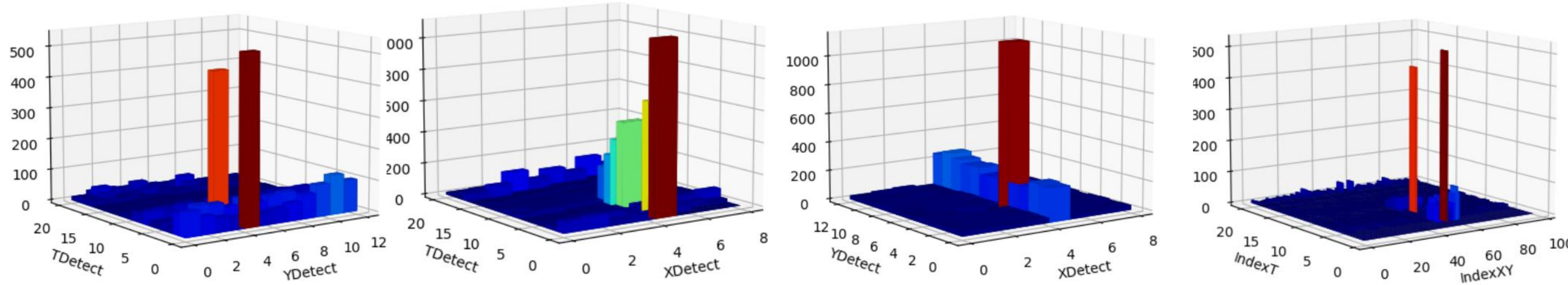

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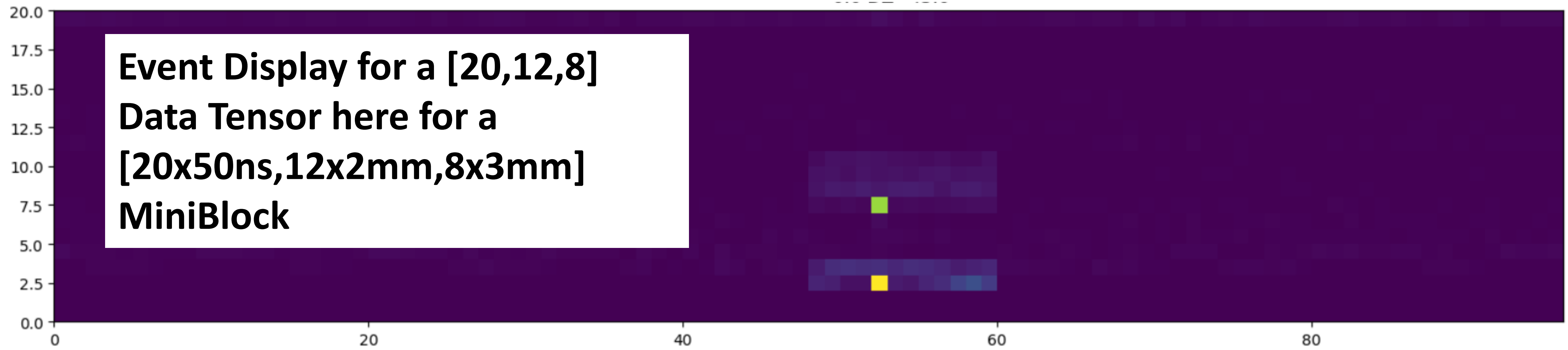


Event Display for a [20,12,8] Data Tensor here for a [20x50ns,12x2mm,8x3mm] MiniBlock

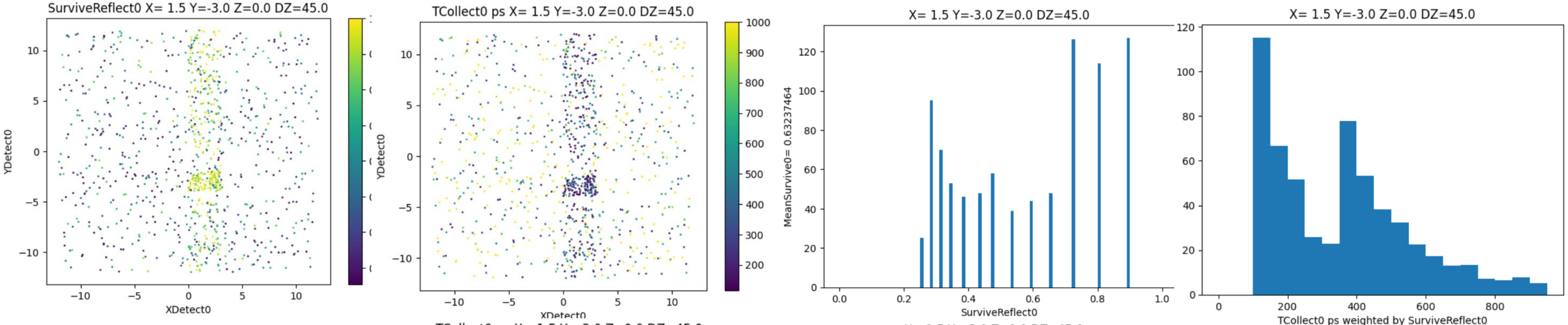
Fixed Equi-distributed Isotropic Emission Angles – 10000 photon event

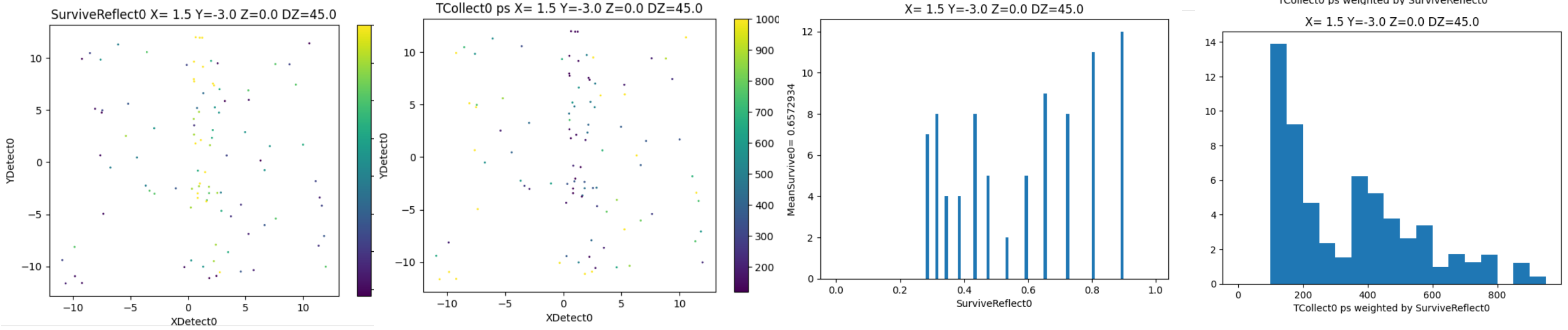
Running with Nphotons=1024 and 100 show similarity for, SimpleOpticsPytorch.ipynb first event of 1000 relative to sampling with Nphotons=1000,

Python->Pytorch translation validation

Random sampling shows reasonable similarity to sampling with high-statistics and fixed angles for debugging

Random Isotropic Emission Angles – 1024 photon event





Random Isotropic Emission Angles – 100 photon event

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Python->Pytorch translation validation

Event X,Y, and T signals are robust at reduced photon statistics, with the t gap between two peaks coding for z

X= 1.5 Y=-3.0 Z=0.0 DZ=45.0 X= 1.5 Y=-3.0 Z=0.0 DZ=45.0 X= 1.5 Y=-3.0 Z=0.0 DZ=45.0

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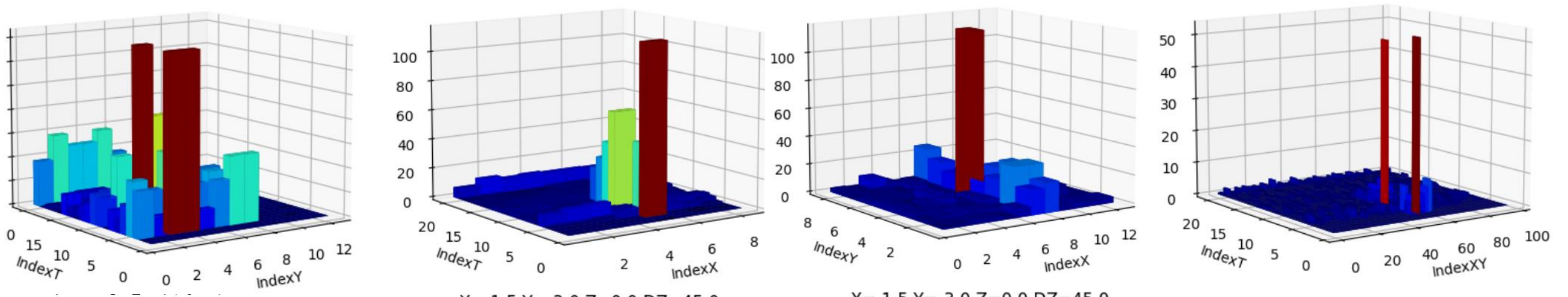

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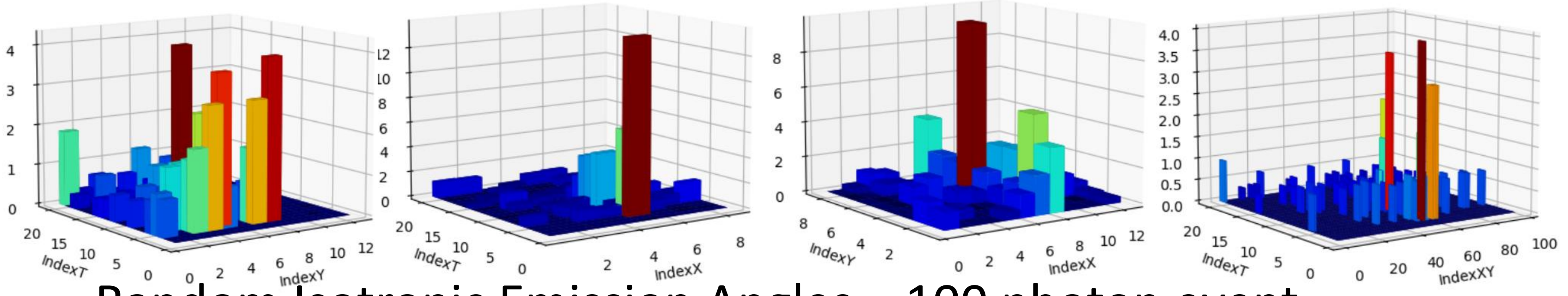

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The 20x12s8=1920 element tensor may be summed and sliced directly in Pytorch, as for XY vs XYT readout

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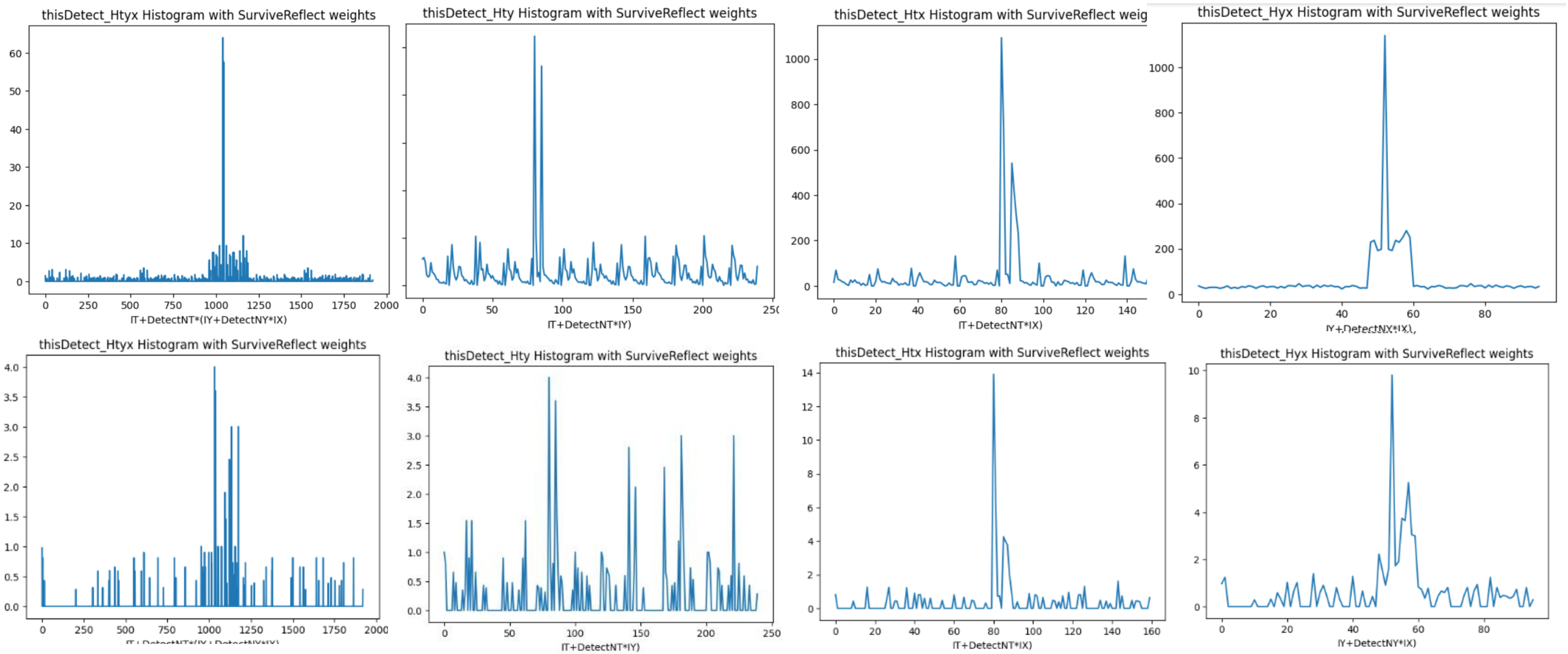

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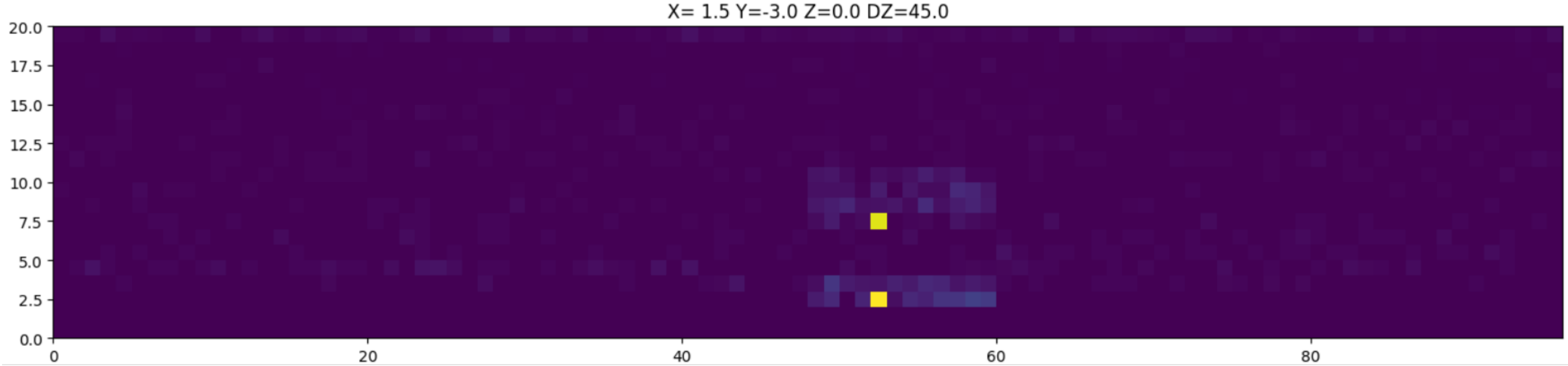
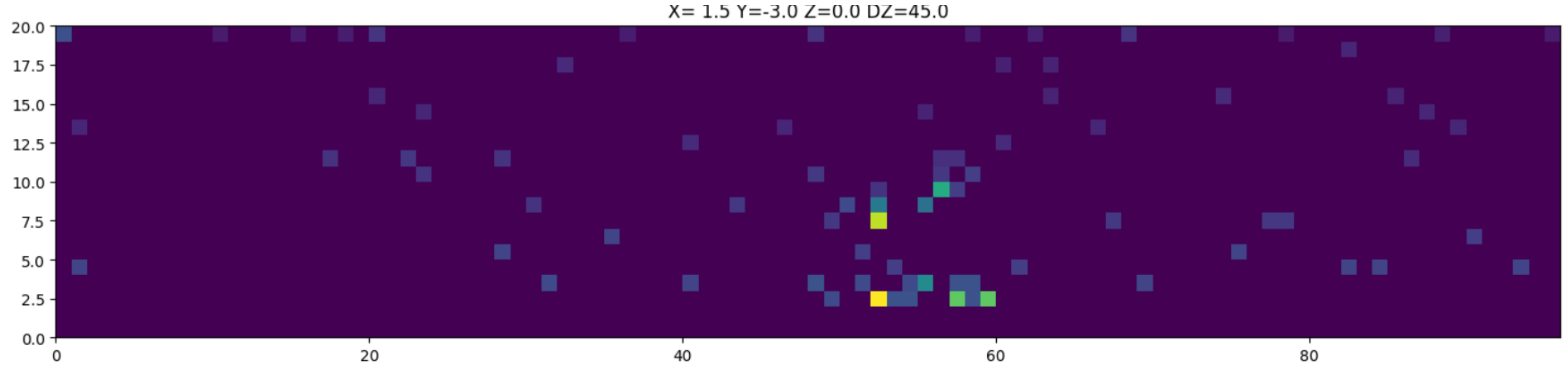
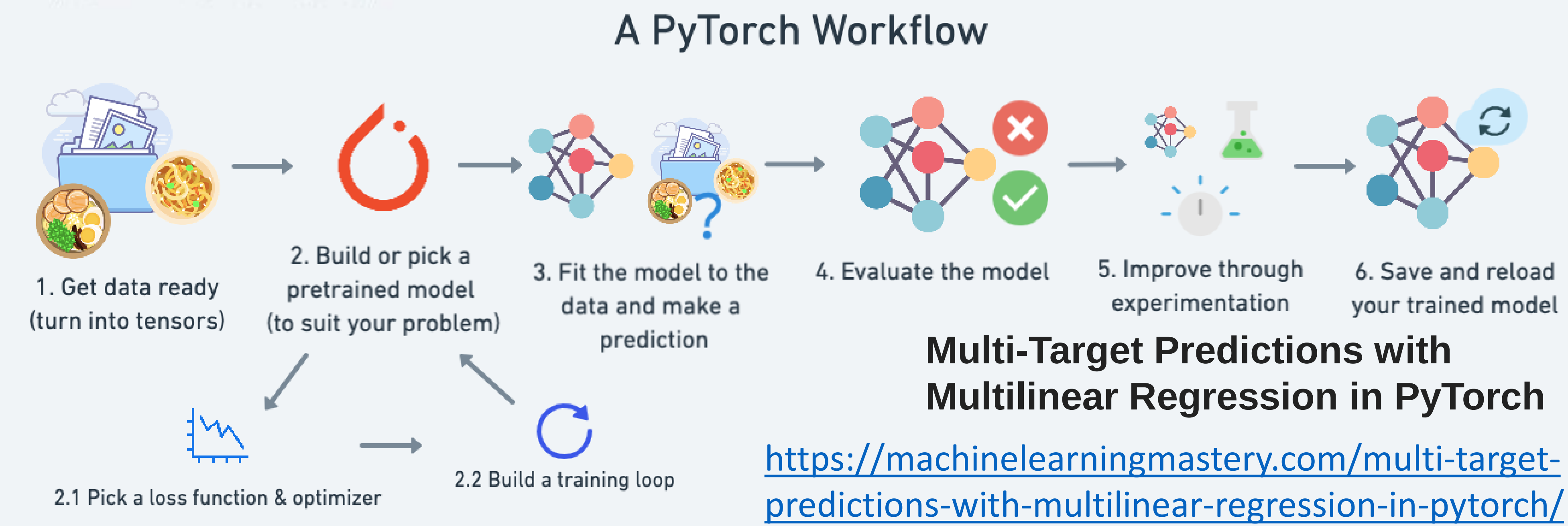




Random Isotropic Emission Angles – 100 photon event

Next Steps:

- Implement simple neural net and train with high signal-to-noise tensors
- Make the model progressively more realistic by including in sequence:
  - Sampling with BaF2 fast signal Photostatics and emission decay time distribution
  - Sampling with Photodetector quantum efficiency and convolving with Photodetector pulse shape and detector timing jitter
  - Sampling including detector readout baseline noise and realistic Photodetector pulse amplitude distributions



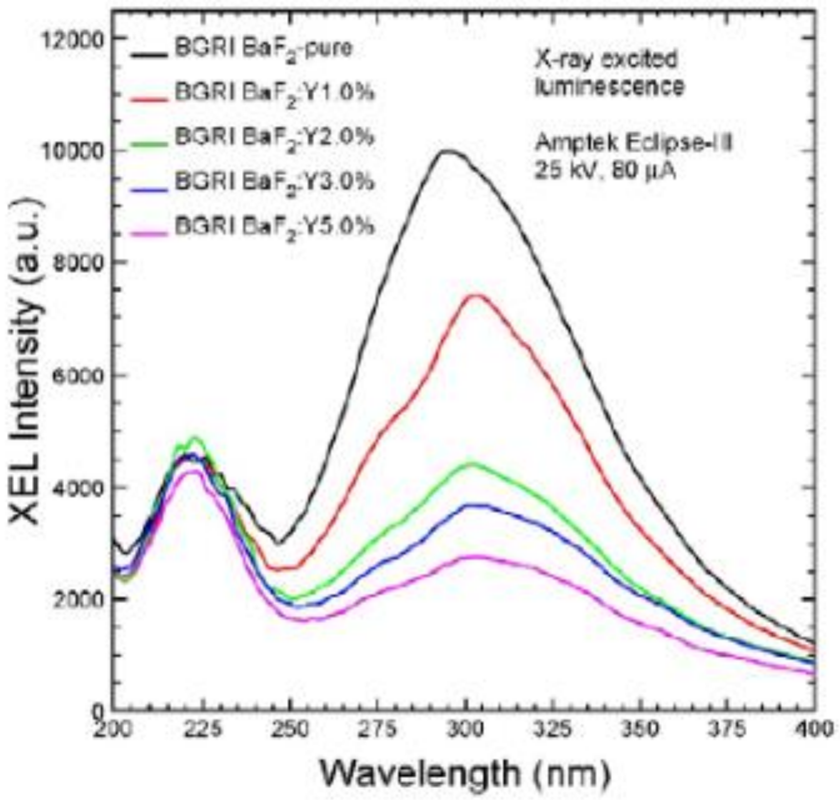
Multi-Target Predictions with Multilinear Regression in PyTorch

https://machinelearningmastery.com/multi-target-predictions-with-multilinear-regression-in-pytorch/

Future Goals:

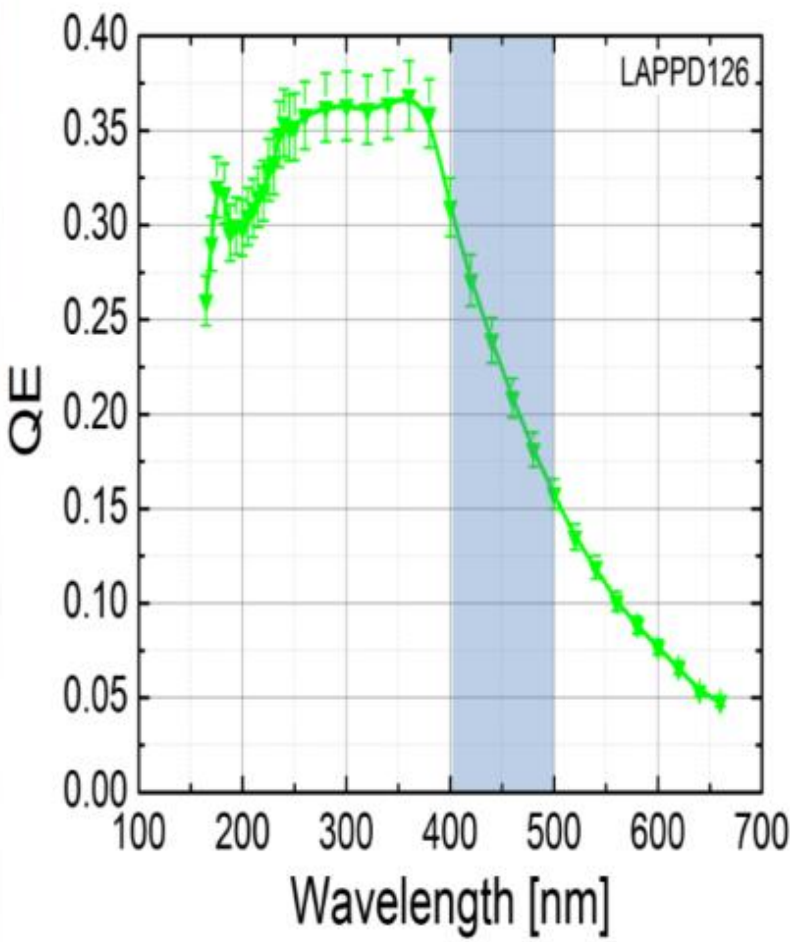
- Estimation of DOI Depth-of-Interaction resolution expected with NN
- Estimation of Timing Resolution expected with NN showing robustness against DOI with long Xtals

Intrinsic light yield, LY_{intr} (ph/MeV) $1400^{a\,b\,h}$–$7000^{b\,i}$



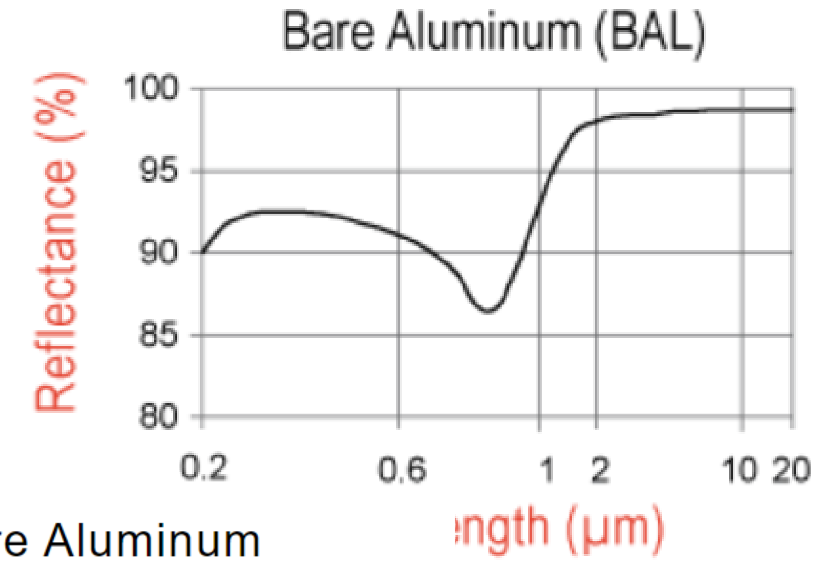
BaF2	Fast	Slow
Decay Time	700ps	600ns
Wavelength	220nm	310 nm
Photons /511keV	715	3577
Collection Fraction	0.8	0.8
Photons Collected	572	2862
QE	0.30	0.37
N = PEs/511keV	172	1059
1/sqrt(N)	8%	3%

LAPPD QE



Photoelectron Statistics

http://rmico.com/bare-aluminum



Metal Mirror » Bare Aluminum

Bare Aluminum offers greater than 86% reflectance from near UV to mid IR.

Aluminum will slowly oxidize, resulting in a significant loss of reflectance in the UV, and slight scattering throughout the spectrum. Therefore, it is best if aluminum has a protective dielectric overcoat.

A protective overcoat will also substantially improve abrasion resistance, so that the coating is less susceptible to damage during cleaning and handling.

https://www.esourceoptics.com/vuvmirrorcurves.html

***ES # 200*: >= 88% - 90% Reflectance @ 200nm**

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VUV-UV Optical Filters & Mirrors/Windows/Lenses/Prisms