Photon Library Investigations

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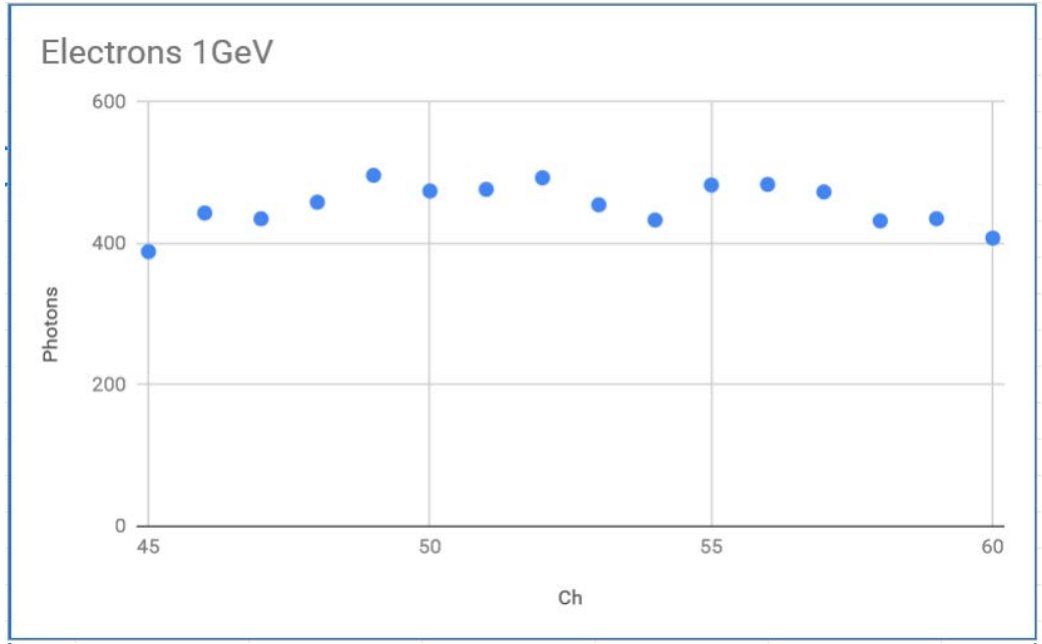
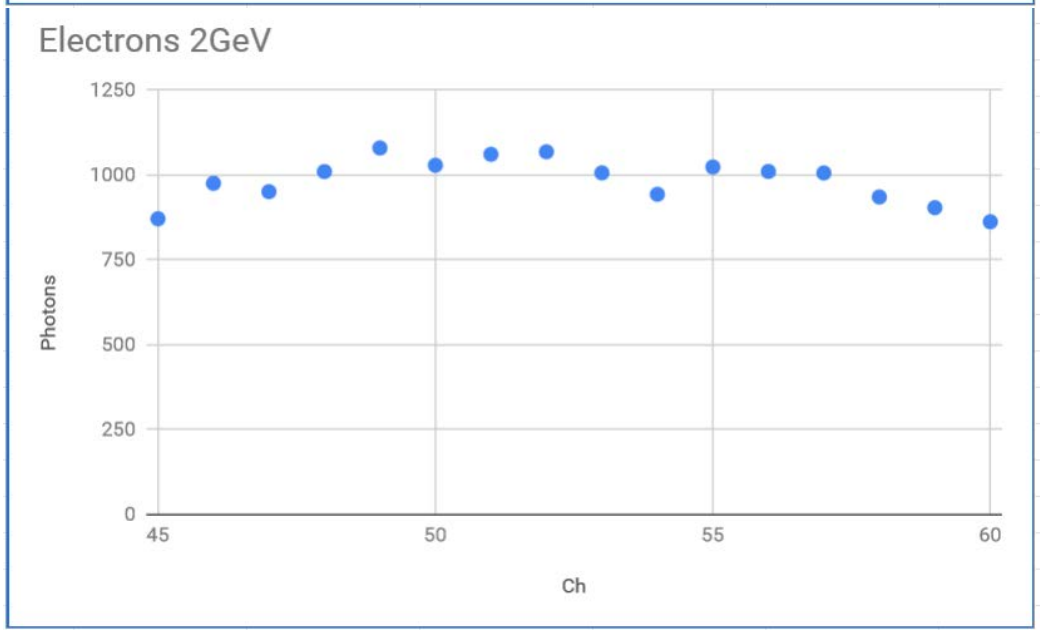
Motivation

- Curious about the large fluctuation of “landing photons” from the simulation
- Did not appear statistical (to me), should be smooth for distant shower at the cathode
- Persisted with “double” statistics, combining 250,000 and 200,000 photon/voxel library generation
- Persisted with tripling number of electron events, from about 1000 to 3000 (Laura)
- Fluctuations are the same in 1GeV and 2GeV electrons (plots at right)
  - Must come from the Photon Library

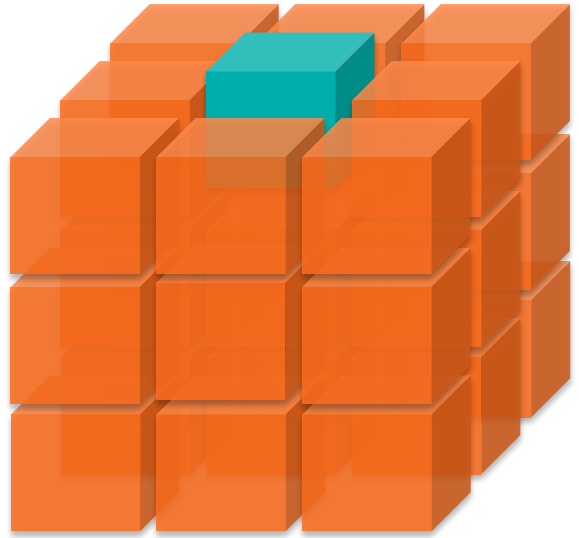




Photon Library

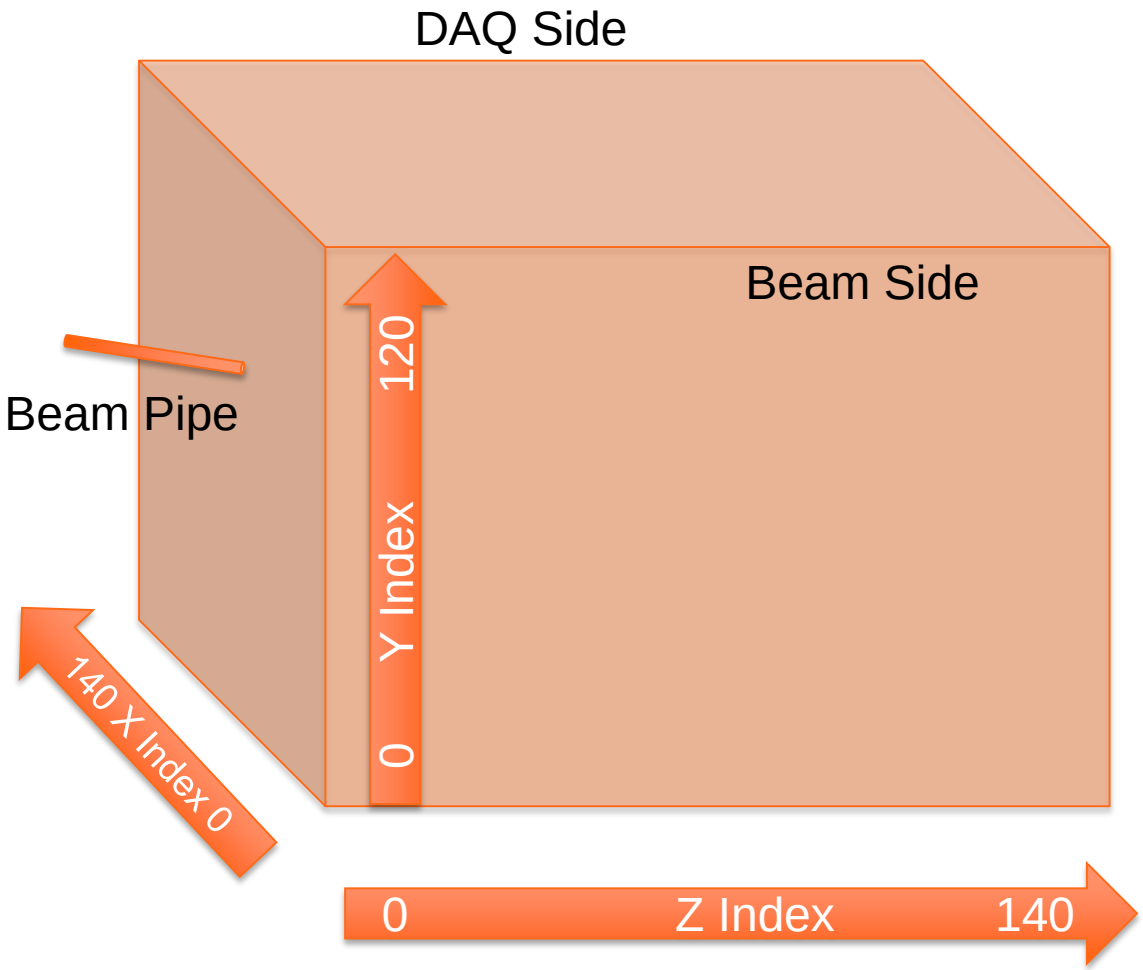
- Root Tree of “Visibilities” – Library used is Protodunev7_90cm_250000
- Each entry in the tree contains (VoxelID, OpChannel, Visibility)
- Visibility is fraction of simulated photons that would propagate to the sensitive area of an “OpChannel” for the simulated detector parameters (geometry, Rayleigh scattering length, attenuation length, ….)
- OpChannel is smallest distinct signal element (Bar, or Arapuca Cell)
- VoxelID is the encoded position: xIndex+(yVoxels*(yIndex+zVoxels*zIndex)
- Library parameters
  - # voxels: 2352000 (140 x 120 x 140) (X x Y x Z)
  - Voxel size: 5.55 cm x 6.25 cm x 6.13 cm

Each Voxel has up to 90 visibilities in the tree



Photon Library

- Coordinate system in voxel index is at upstream lower corner
- Some landmarks:
  - Beam-side APA at Xindex=4
  - Cathode plane at Xindex=63
  - DAQ-side APA at Xindex=123
  - APA 3 PDs run from about Z=15 to Z=43
- Library parameters
  - # voxels: 2352000 (140 x 120 x 140) (X x Y x Z)
  - Voxel size: 5.55 cm x 6.25 cm x 6.13 cm



Some numbers for the problem

- Moliere radius in LAr is 9cm (Wikipedia)
- Radiation Length - X_0 is 14cm in LAr
- 9 voxels along the shower should contain 90% of the shower energy
- 1GeV electron has average range $70 g/cm^2$ or about 50cm $\frac{70 g/cm^2}{1.4 g/cm^3}$
  - Restrict range to ~first APA or less for investigations
  - From NIST CSDA, so expect straggling in this range (https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions)
- Executive summary: Showers are small and narrow, hit about 100-200 voxels in ~3x3 core along z

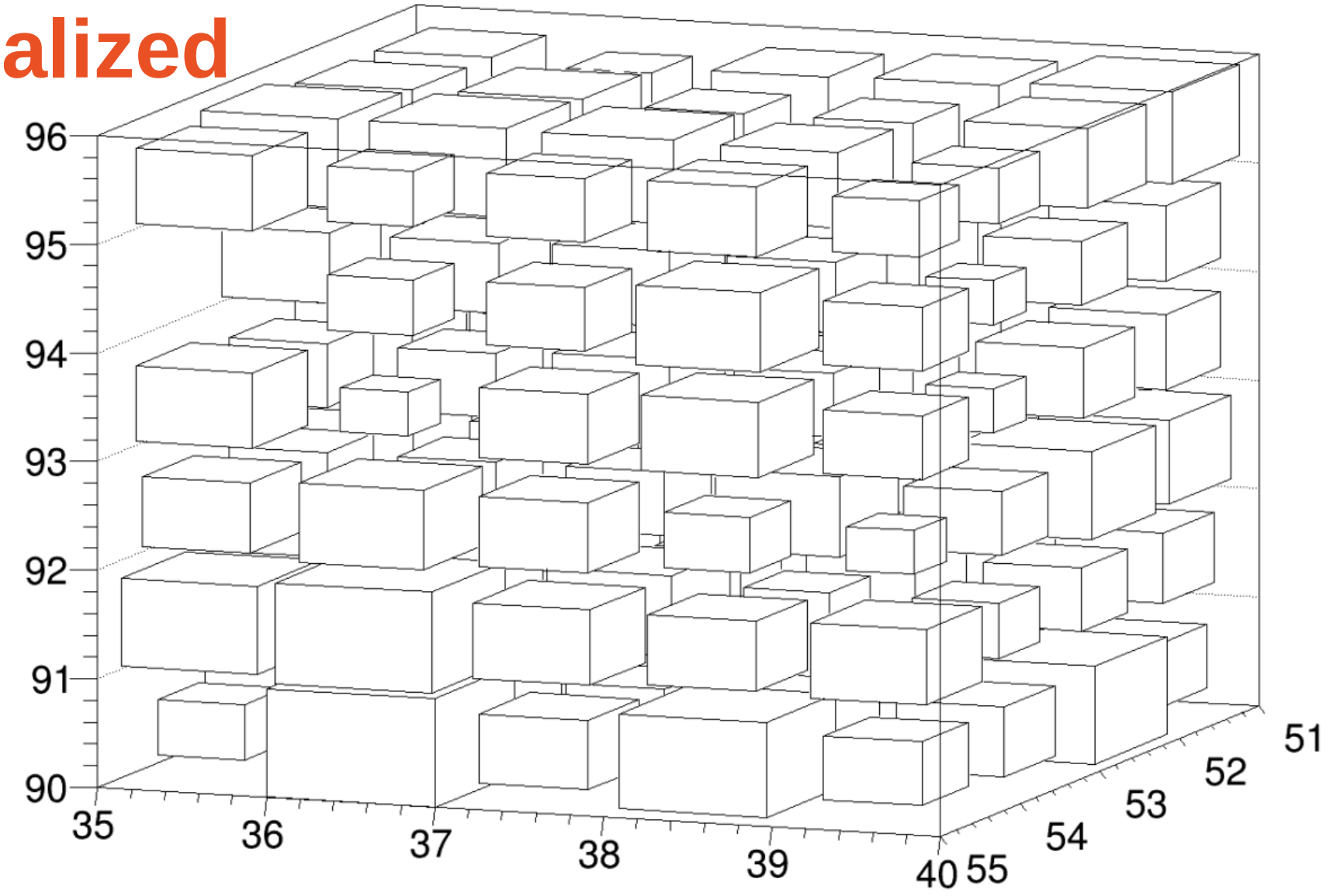
Visibility visualized

Visibility of 100 voxels for Channel 57

5 by 5 by 4 box near cathode approx. opposite detector

HUGE variation

Even a 0 at (35,94,54)



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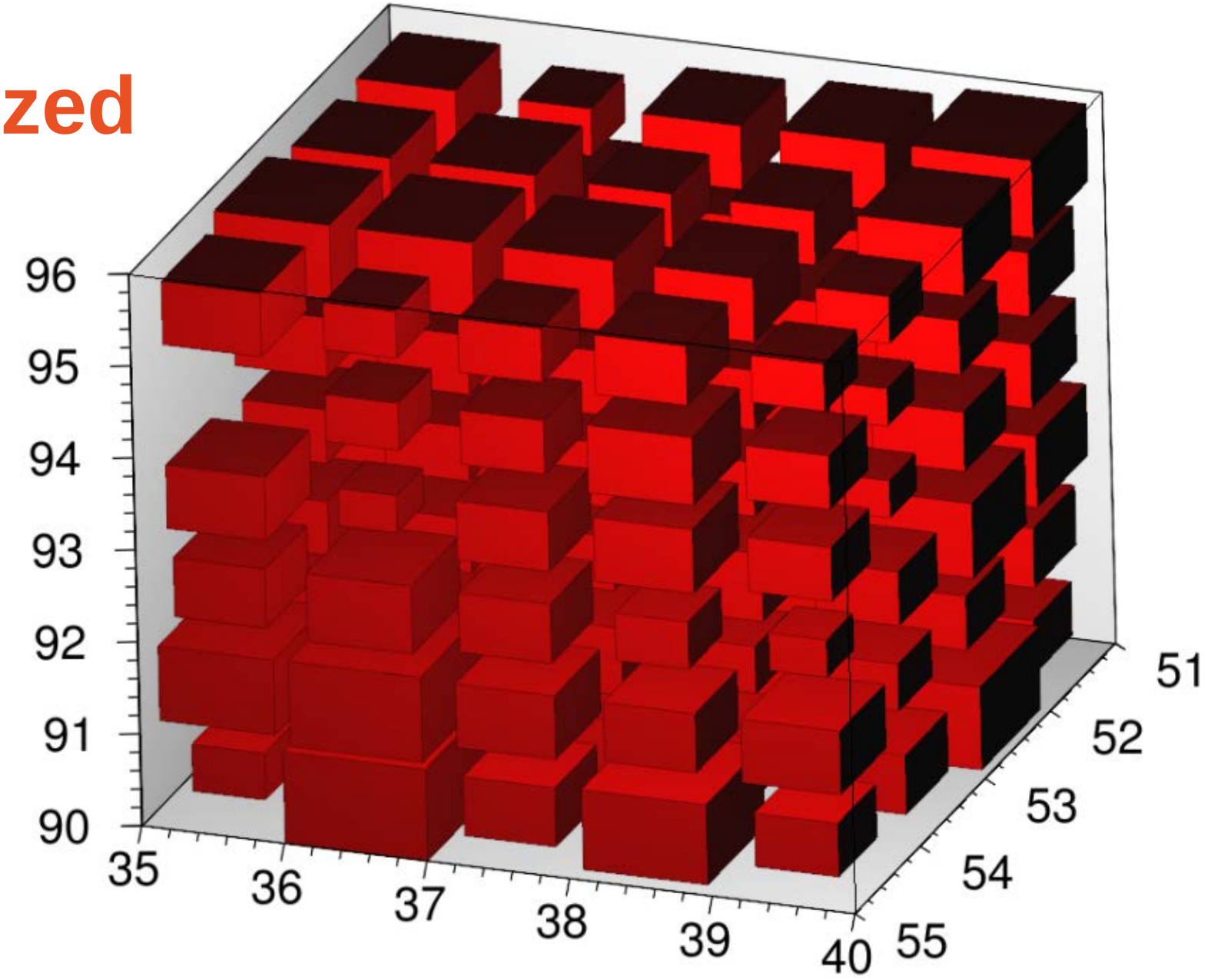
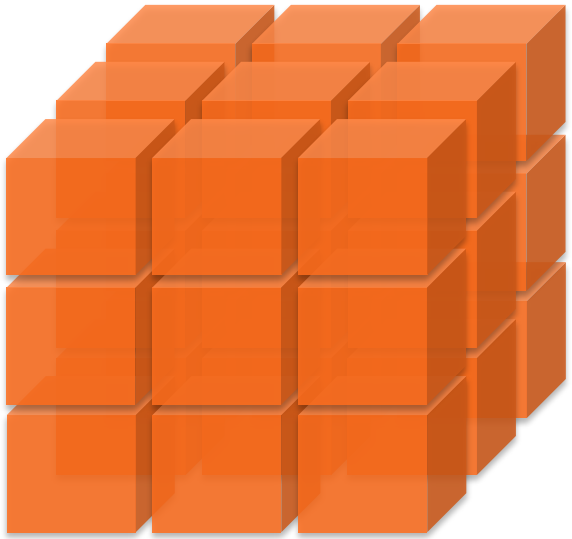


Calculate mean and RMS from a cube at each Z

- Step along Z and find mean and RMS OpChannel 57 for each 27 voxel box
- Table to the right shows for a particular set of z positions near the cathode, as seen in previous slides
- Shown is error in the mean, RMS/sqrt(27)

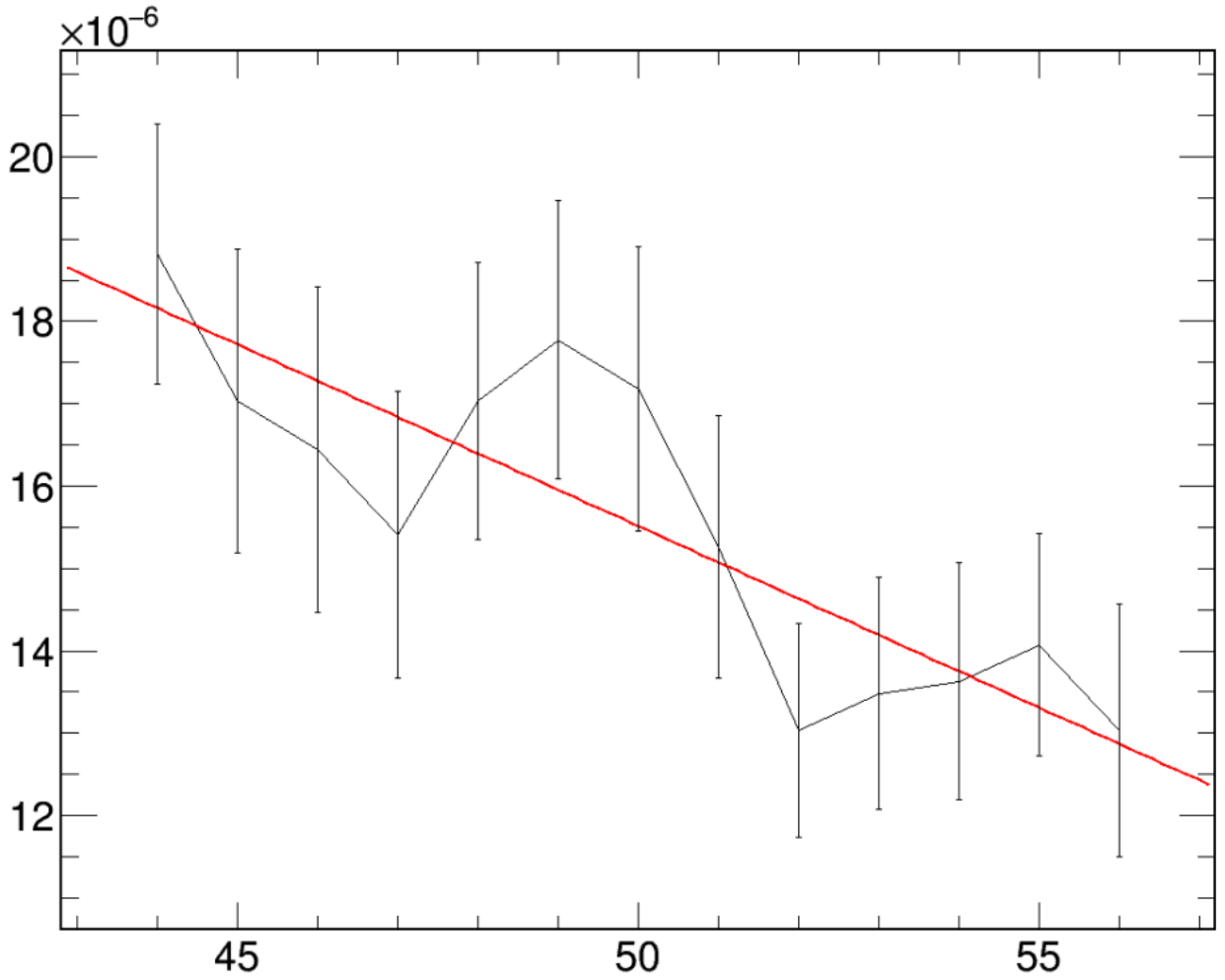


```
Avg at 44 = 1.88148e-05+-1.57922e-06
Avg at 45 = 1.7037e-05+-1.84553e-06
Avg at 46 = 1.64444e-05+-1.98024e-06
Avg at 47 = 1.54074e-05+-1.73661e-06
Avg at 48 = 1.7037e-05+-1.68385e-06
Avg at 49 = 1.77778e-05+-1.69347e-06
Avg at 50 = 1.71852e-05+-1.72534e-06
Avg at 51 = 1.52593e-05+-1.59611e-06
Avg at 52 = 1.3037e-05+-1.30156e-06
Avg at 53 = 1.34815e-05+-1.40777e-06
Avg at 54 = 1.36296e-05+-1.44031e-06
Avg at 55 = 1.40741e-05+-1.34758e-06
Avg at 56 = 1.3037e-05+-1.53378e-06
```

Plot Mean/RMS Visibility along z

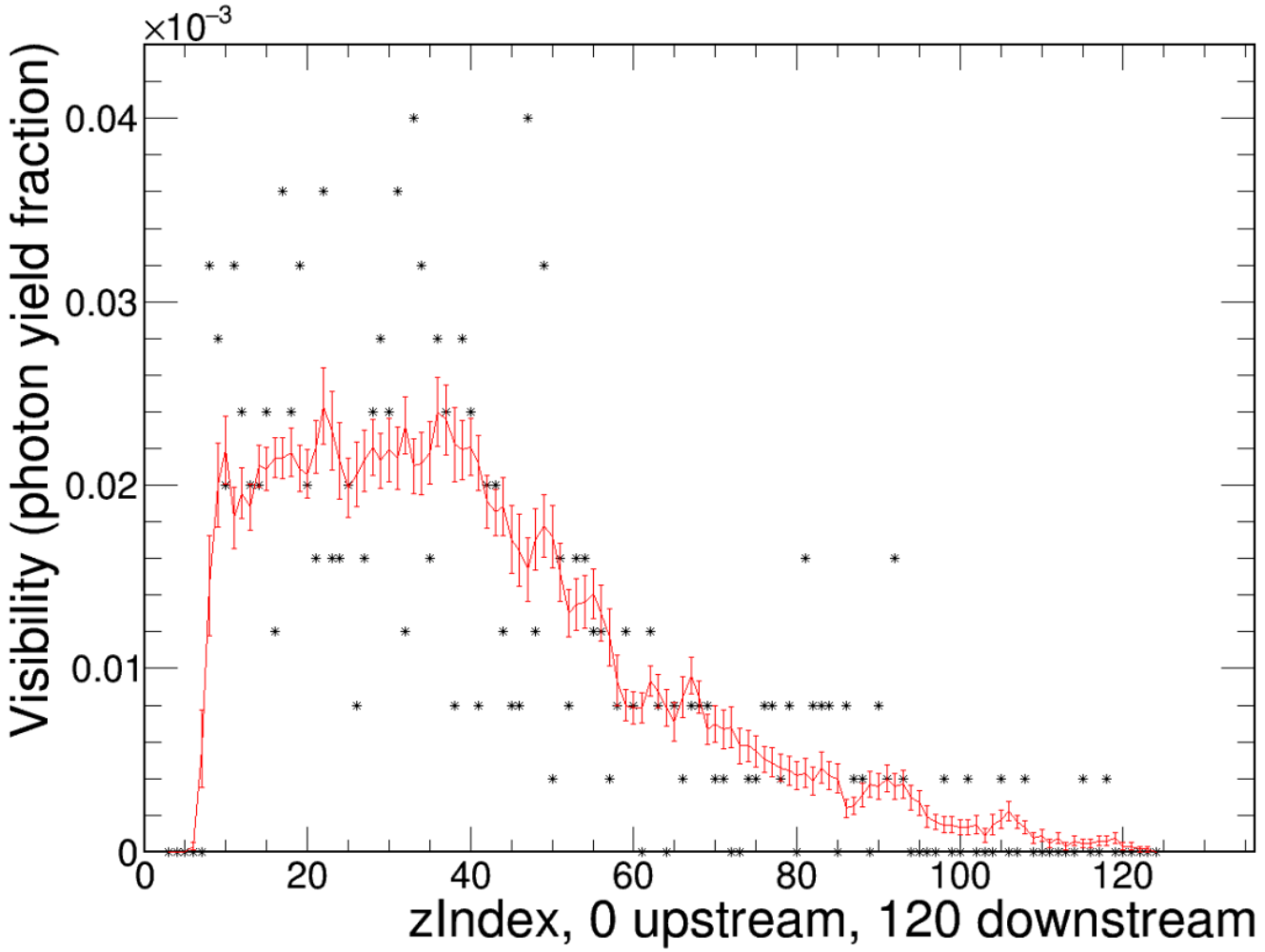
- Plot values from table on previous slide
- Fit a line to points
- About 25% error in slope still with 27 points averaged

```
TFitEditor::DoFit - using function PrevFitTMP  0x94fc610
 FCN=5.51577 FROM MIGRAD    STATUS=CONVERGED      42 CALLS          43 TOTAL
                     EDM=3.9797e-22    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  p0           3.75465e-05   5.96303e-06   5.16228e-08  -1.15605e-05
   2  p1          -4.40626e-07   1.17435e-07   5.16228e-08  -8.21818e-04
```



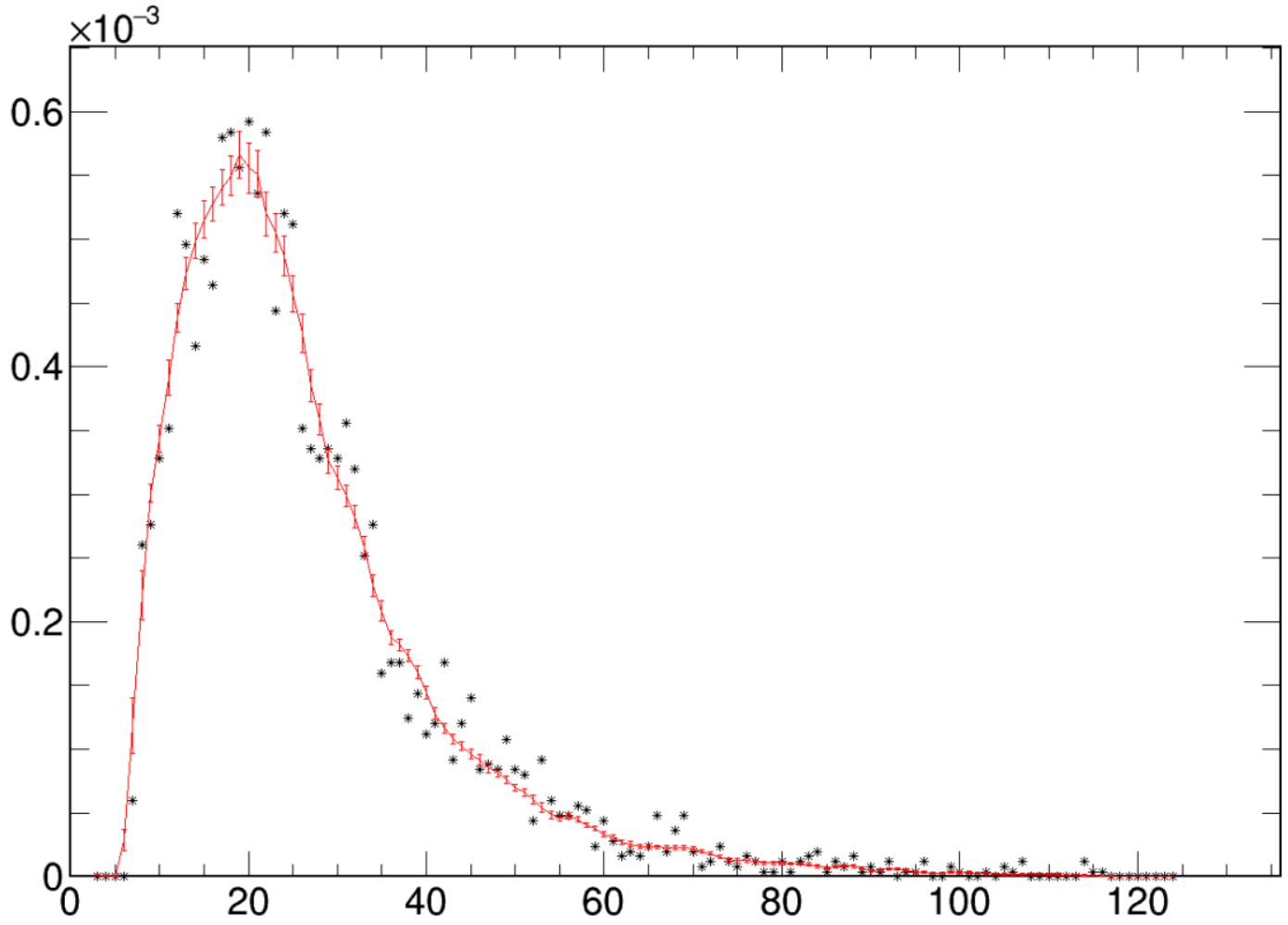
Plot Mean/RMS Visibility along z at x=59,y=60

- Red points/line show visibility averaged over 27 neighbors in a cube
- Black points show actual Visibility values in Photon Library that would be used for calculating photon landing
- Channel 57, near upstream end of Arapuca module



Plot Mean/RMS Visibility along z at x=16,y=60

- Red points/line show visibility averaged over 27 neighbors in a cube
- Black points show actual Visibility values in Photon Library that would be used for calculating photon landing
- Channel 57, near upstream end of Arapuca module



Conclusions

- Photon library shows far too much variation
- It will introduce mismeasurements of efficiency of modules, and possibly simulations of events.
- Near the cathode, fluctuations can be factor of 20 or more (some voxels with vis==0!)
- Need to smooth the library
- More statistics can help, but even with averaging 27 voxels, the error in the mean is still at 10%
- Bars will have smaller fluctuations, since they have larger area, but still likely require averaging or other smoothing techniques
- Can use current library, but need to average it (and smooth it?)
  - Could be tricky at boundaries (cathode)
- May be an even bigger effect for events that hit very few voxels, like SN neutrinos

Backup – other checks of visibility

Visibility for one channel

Visibility for one Arapuca channel

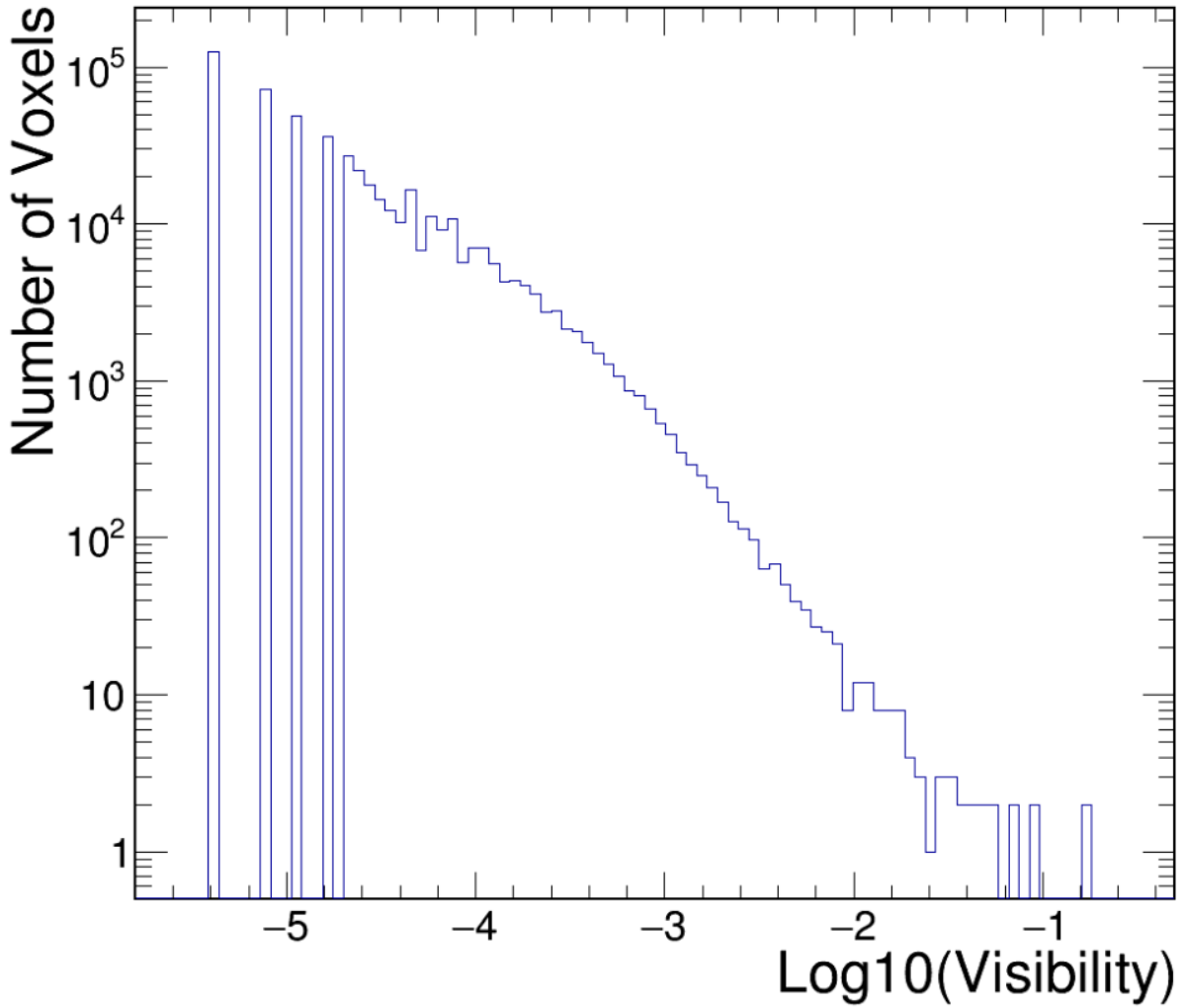
(Log10(Vis) so you can see it all)

Lower right corner from the few voxels that are right in front of the window

Upper left, very frequent, but very low visibility voxels.

Quantized steps are from voxels that had 1,2,3,4,… photons that hit the window

One MIP would deposit about 20MeV in a voxel. That should yield about 500,000 photons.
(50,000 photons at -1 and 1 photon at -4.7)



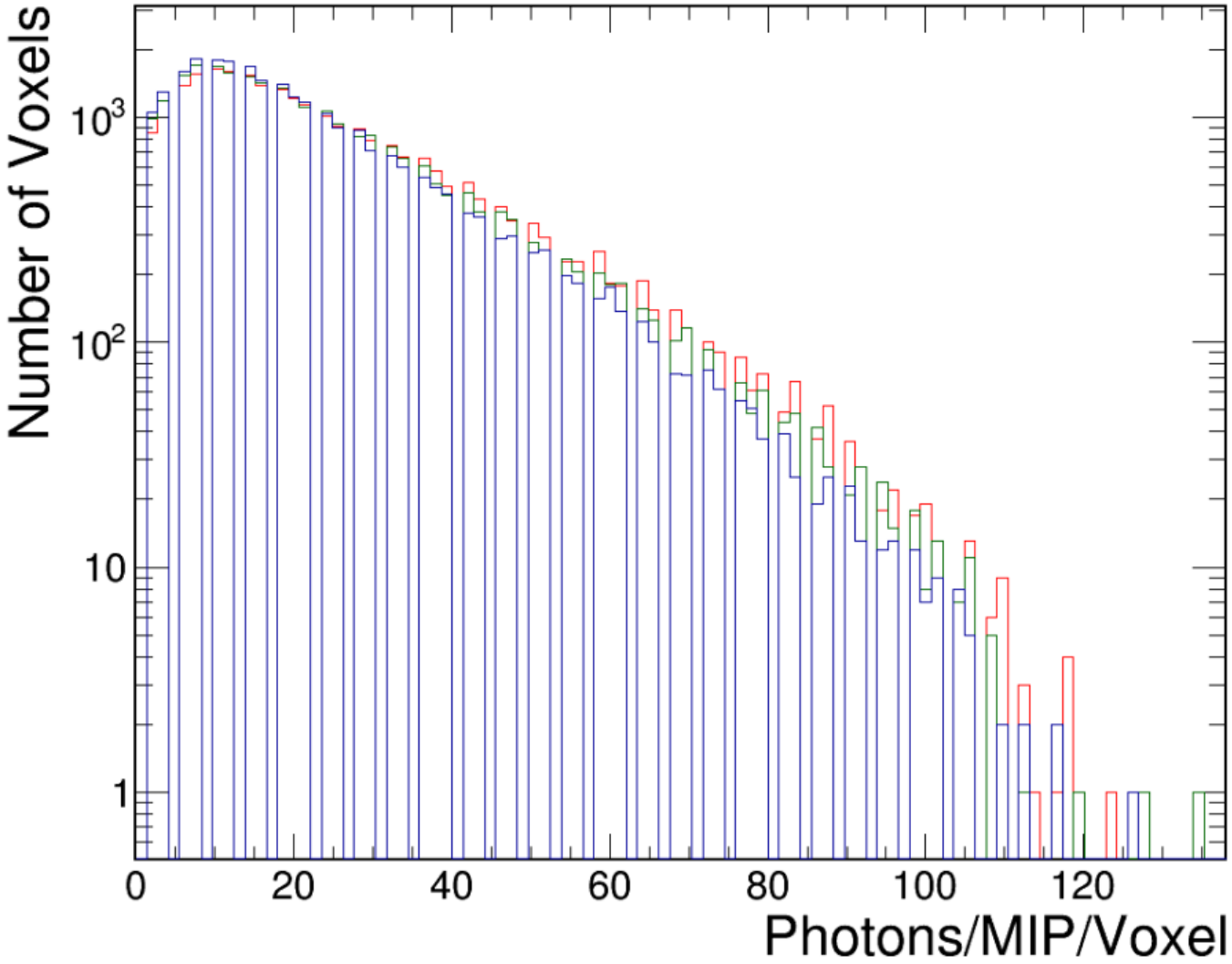
Photons/voxel/mip for voxels near the beam

Box is within 32 (of 59) voxels to the cathode, 20 voxels wide, (60-80) out of 108 in height and in the first 50 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

32000 Voxels in the box

For 3 channels, 57,58,59 (R,G,B)

Each cell gets ~400 photons/GeV from the simulation



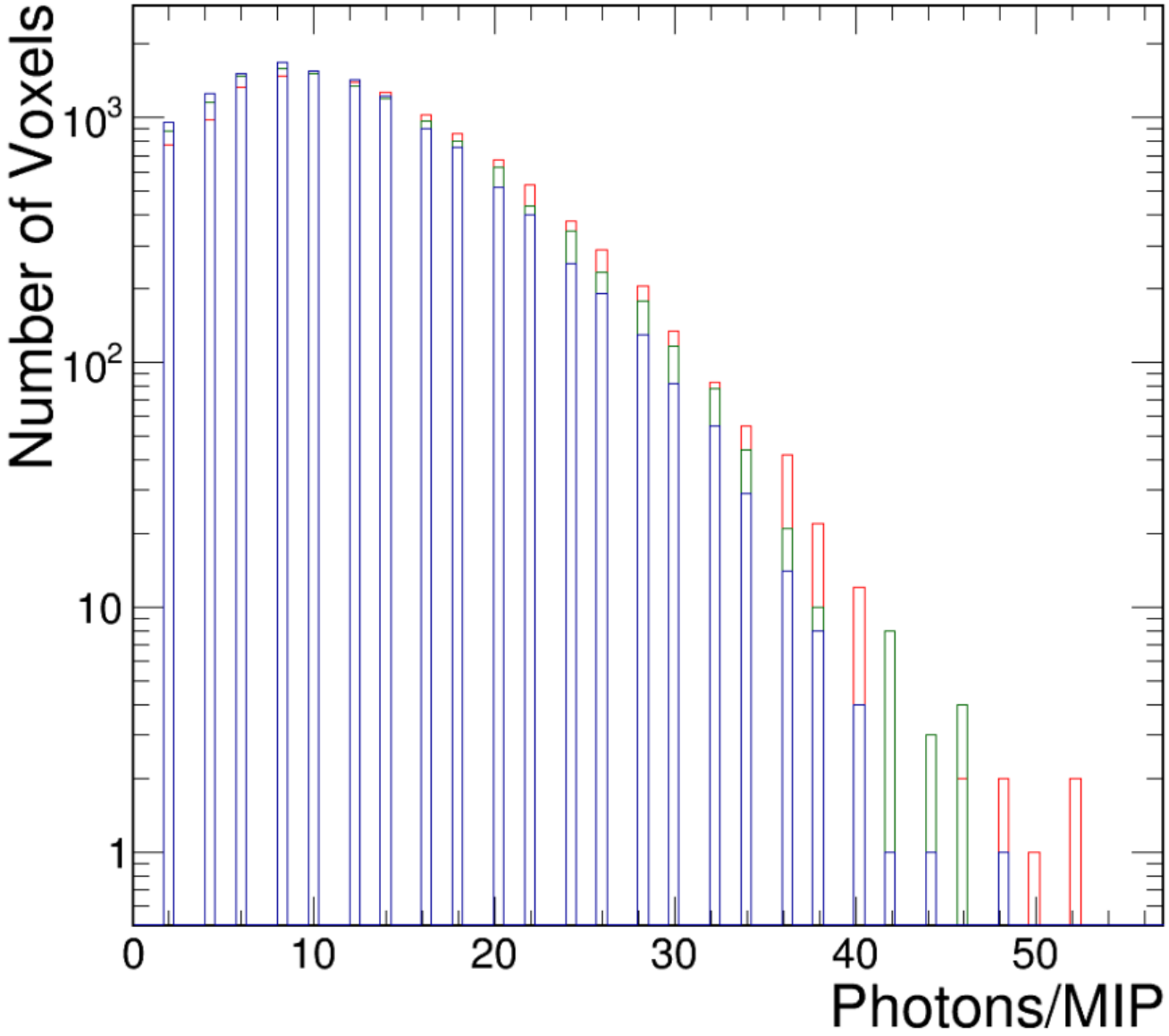
Photons/voxel/mip even closer to beam

Box is within 16 (of 59) voxels to the cathode, 20 voxels wide, (60-80) out of 108 in height and in the first 50 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

16000 voxels in the box

For 3 channels, 57,58,59 (R,G,B)

Each cell gets ~400 photons/GeV from the simulation



Photons/voxel/mip in a line parallel to cathode

Box is 5 away, +-1 (of 59) voxels to the cathode, 3 voxels tall, (59-61) out of 108 in height and in the first 50 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

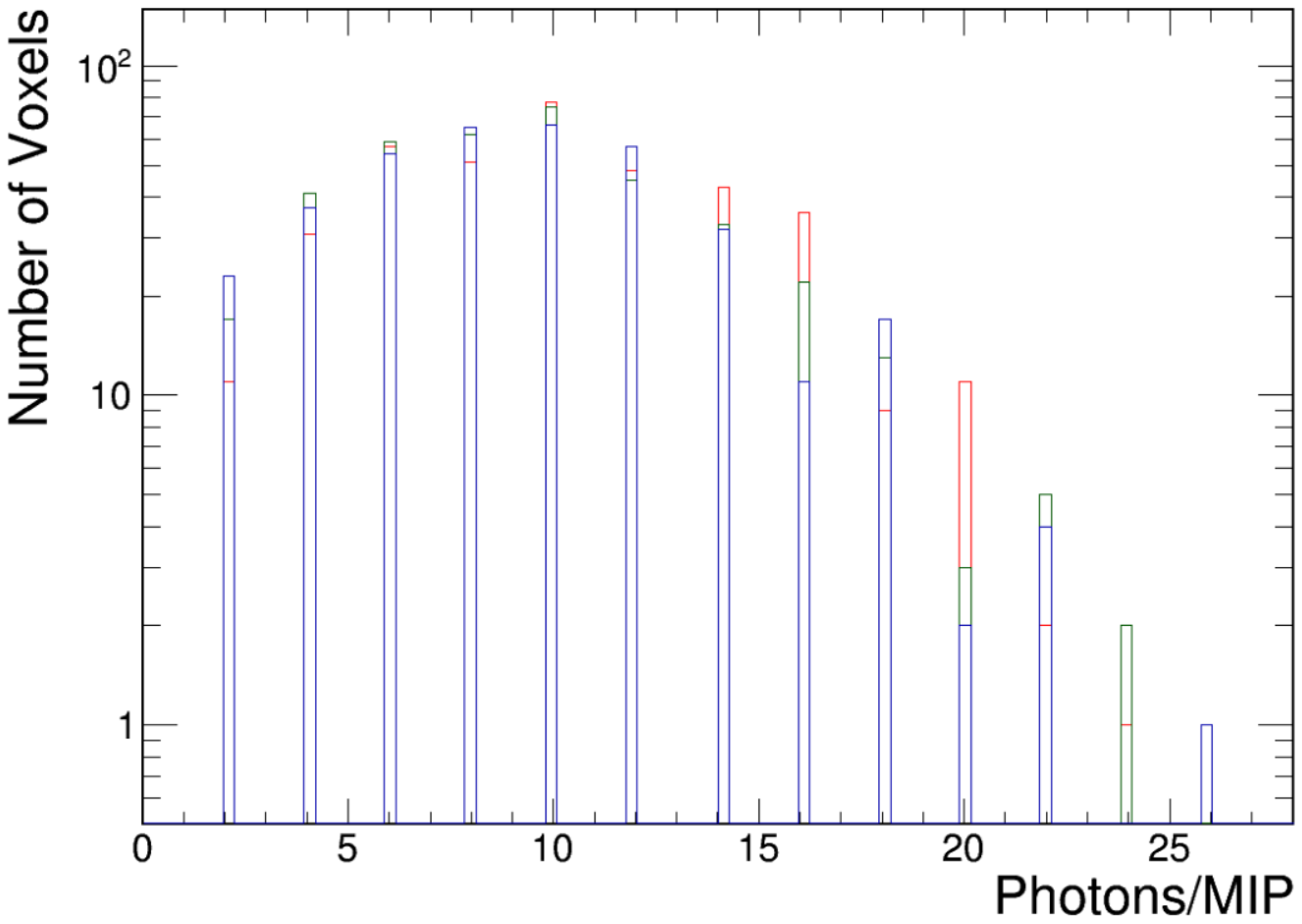
450 voxels in the box

~80 Voxels/channel that are 0,

not shown (most probably outside)

For 3 channels, 57,58,59 (R,G,B)

Each cell gets ~400 photons/GeV from the simulation



Photons/voxel/mip in a very small box

Box is 5 away, +-1 (of 59) voxels to the cathode, 3 voxels tall, (59-61) out of 108 in height and in the first 25+-6 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

117 voxels in the box

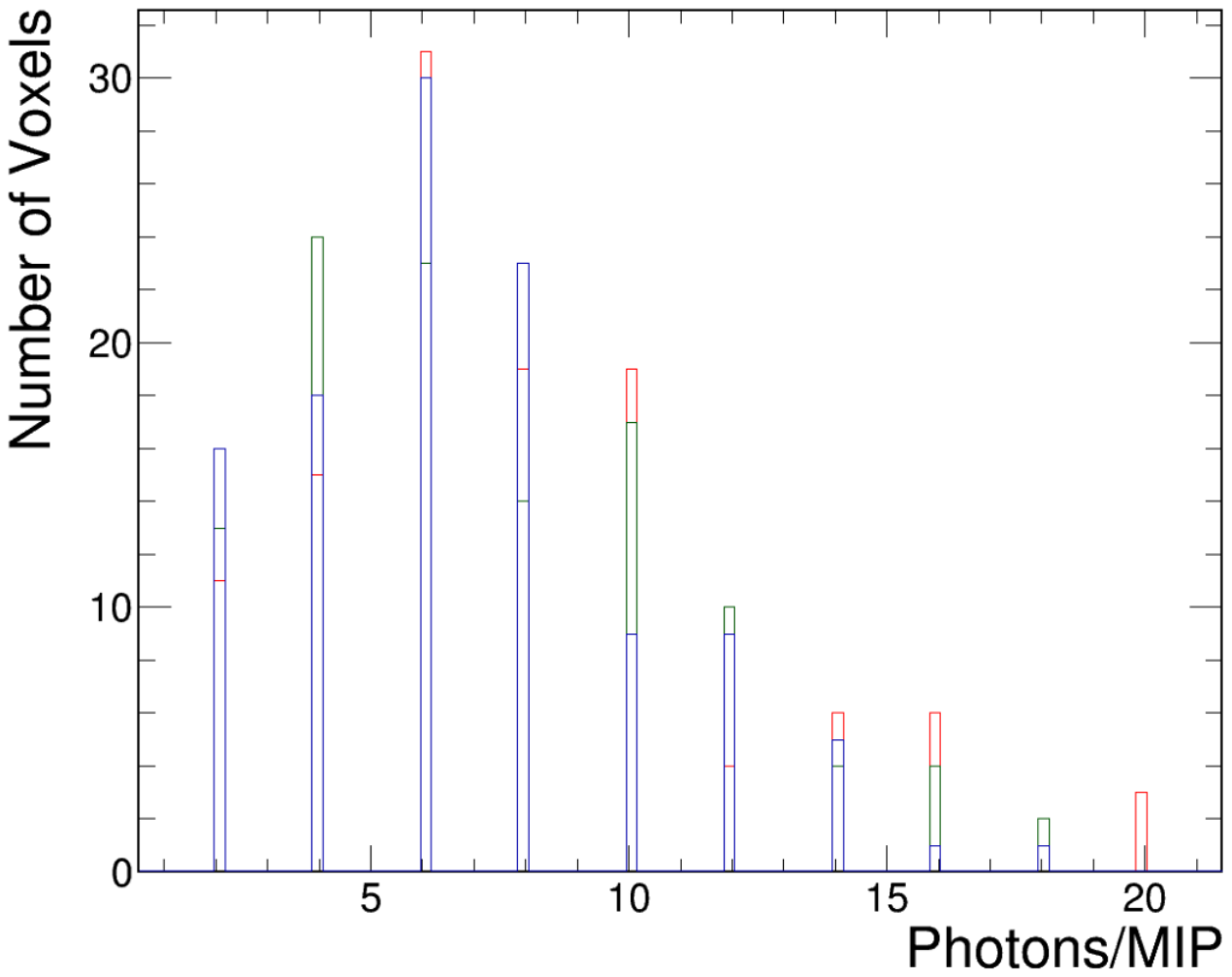
~5 Voxels/channel that are 0,

not shown

For 3 channels, 57,58,59 (R,G,B)

Each cell gets ~400 photons/GeV from the simulation

Spread about factor of 3?



Photons/voxel/mip for a few bar channels

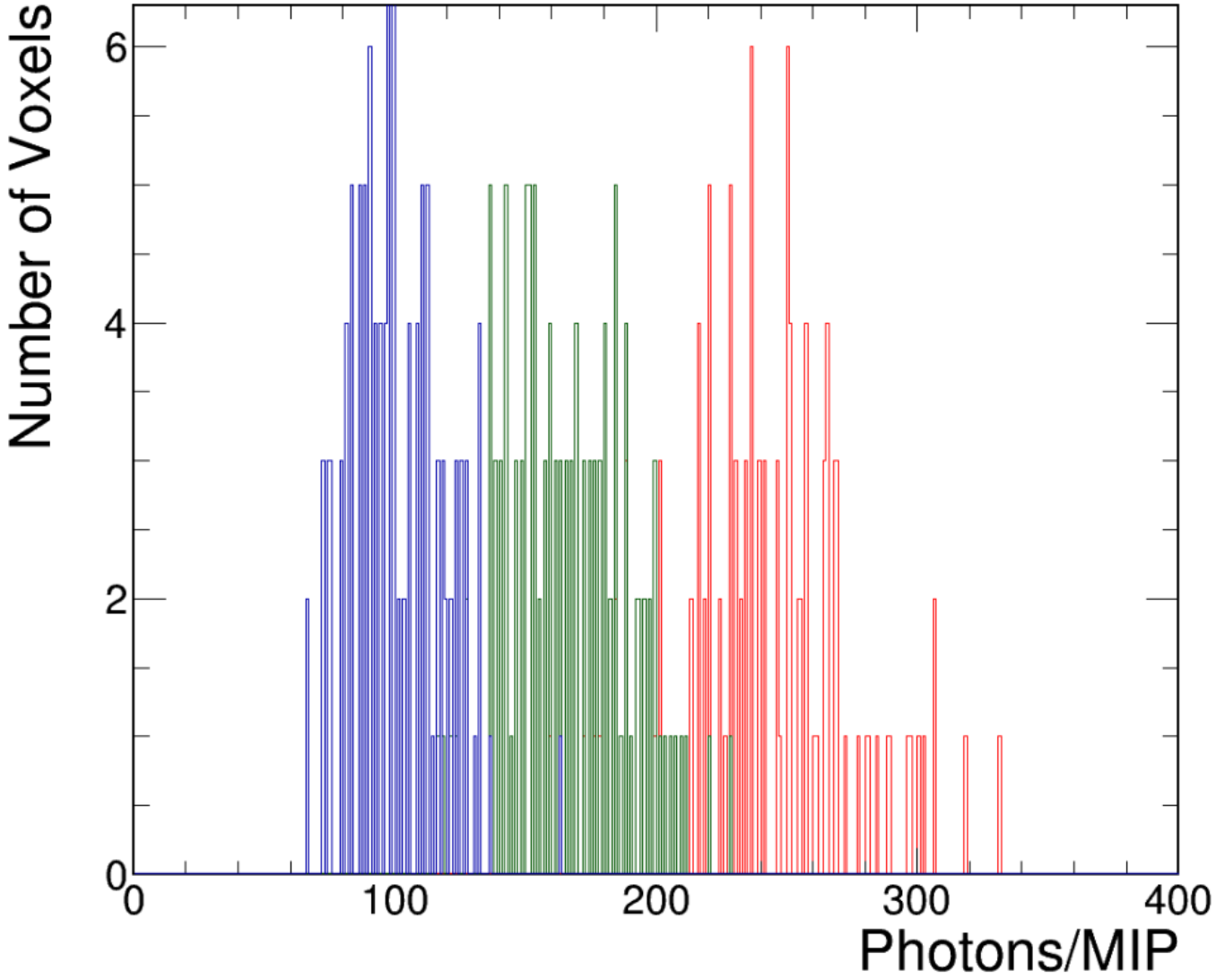
Box is 5 away, +-1 (of 59) voxels to the cathode, 3 voxels tall, (59-61) out of 108 in height and in the first 25+-6 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

117 voxels in the box

For 3 bars channels, 87,88,89 (R,G,B)

Each cell gets ~??? photons/GeV from the simulation

Spread ~30%



Photons/voxel/mip

Number of voxels in a box

Box is 5 away, +-1 (of 59) voxels to the cathode, 3 voxels tall, (59-61) out of 108 in height and in the first 25+-6 of 140 voxels in Z. This is meant to be neighborhood of electron beam events.

117 voxels in the box

For 3 bars channels, 81,82,83 (R,G,B)

Each cell gets ~??? photons/GeV from the simulation

Spread ~30%