Optical Simulations for MicroBooNE

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Ben Jones, MIT

PAWGFEST EDITION

This Talk:

1) Introduction to MicroBooNE optical systems

2) Rapid review of general properties of the optical simulation

3) Results from preliminary sensitivity studies

4) Status of fast simulation for standard MicroBooNE simulation chain

For more details, see: http://microboone-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1000

Optical Components for MicroBooNE

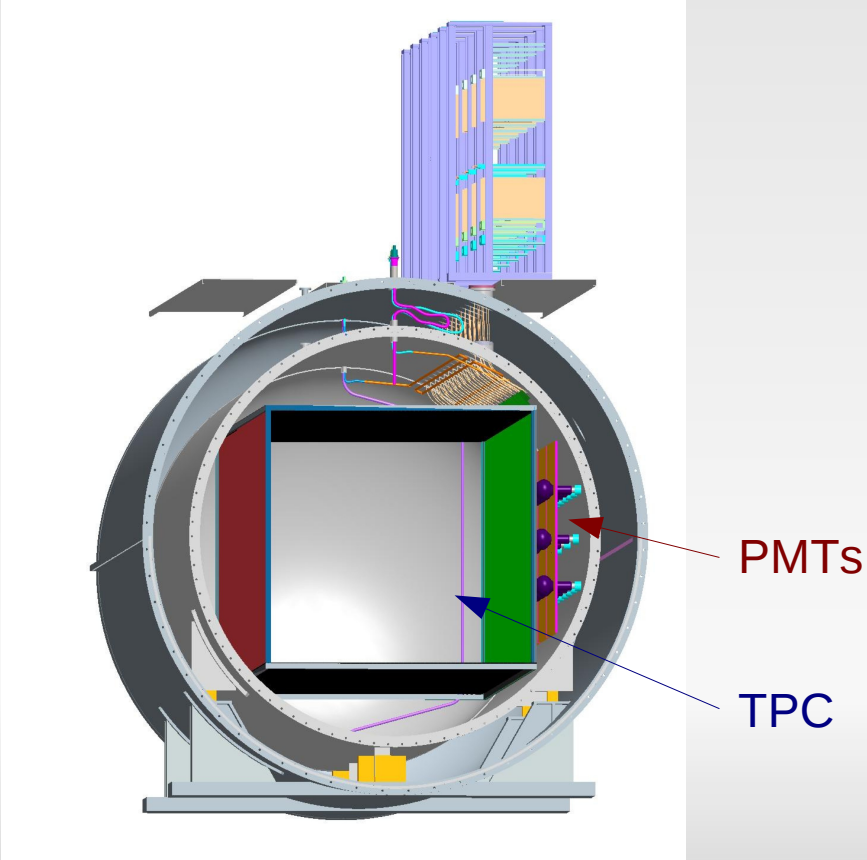
- As well as a TPC system to measure charge deposit, MicroBooNE also contains PMTs to aid in triggering and reconstruction.
- The PMT system produces much less data than the TPC so it can be read out quickly – useful for triggering
- PMT system also gives access to information which the TPC cannot provide, including:

  - A measurement of T=0 of the event (compare this to beam window for triggering only on beam)

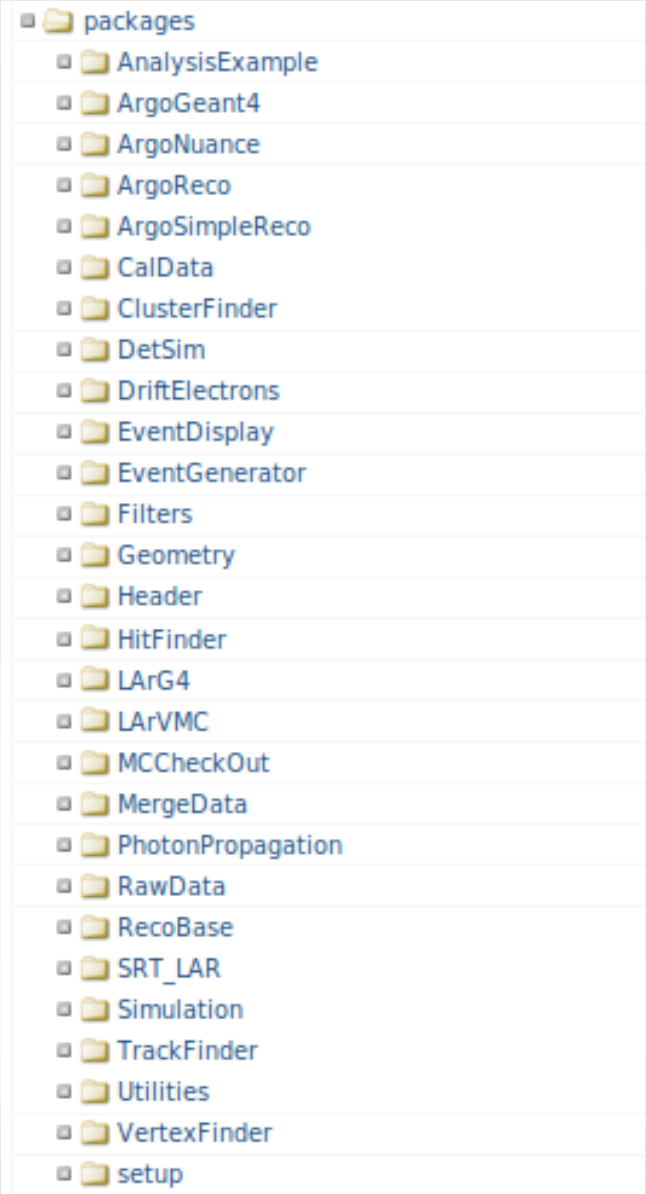
  - Few nanosecond precision timing information (TPC ~ microsecond)

  - Ability to rapidly locate an event in the Z direction

  - Comparison of scintillation light to TPC information, which may eventually be useful for particle ID



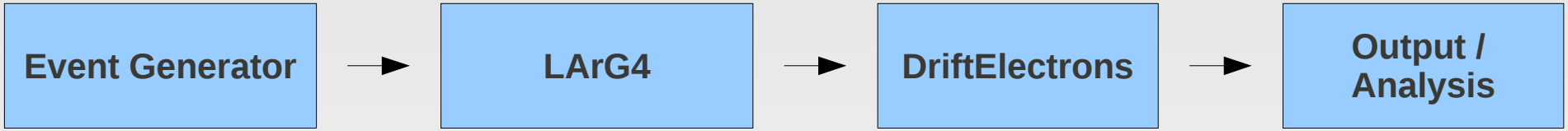
Optical Monte Carlo Simulations



- The standard simulation package for MicroBooNE is **LArSoft** (also the standard package for ***Argoneut***, ***LBNE***, etc).
- MicroBooNE is the first LArSoft experiment to incorporate **optical systems** and attempt **optical simulations**
- We have been developping code for optical simulations since Summer 2010, and we are now beginning to reap results.
- Still some problems which need to be addressed, so these results are still preliminary
- I will present our preliminary findings and give a hint of what we expect to be capable of in a few months

LArSoft Simulation Chain

- Simulation jobs in LArSoft are broken down into discrete steps.
- A typical simulation chain is shown below



Code Development

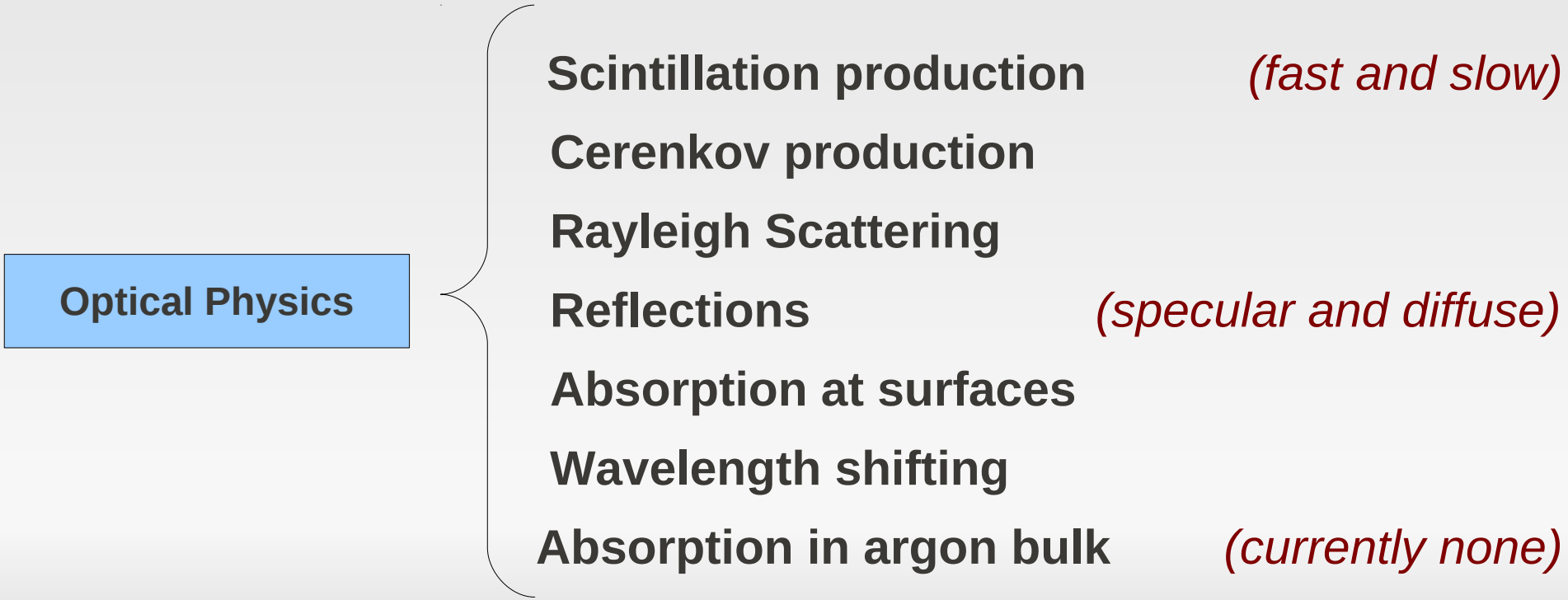
July 2009

- New physics list handling system added to LArSoft
- Optical physics GEANT4 constructor defined, to enable optical processes
- Material property loading built into LarG4 with appropriate material properties supplied for LAr and some reflective interfaces
- Monitoring tools for LarG4 added
- PMT data formats defined and built into LArSoft
- PMT sensitive regions and hit generation implemented
- Optical components defined and added to microboone geometry
- Parallelization of optical and LArVoxel geometries to improve performance
- Light source event generator written for optical studies
- Fast sim voxelized library data format and relevant tools written
- Library sampling for fast sim implemented to form part of the standard simulation chain

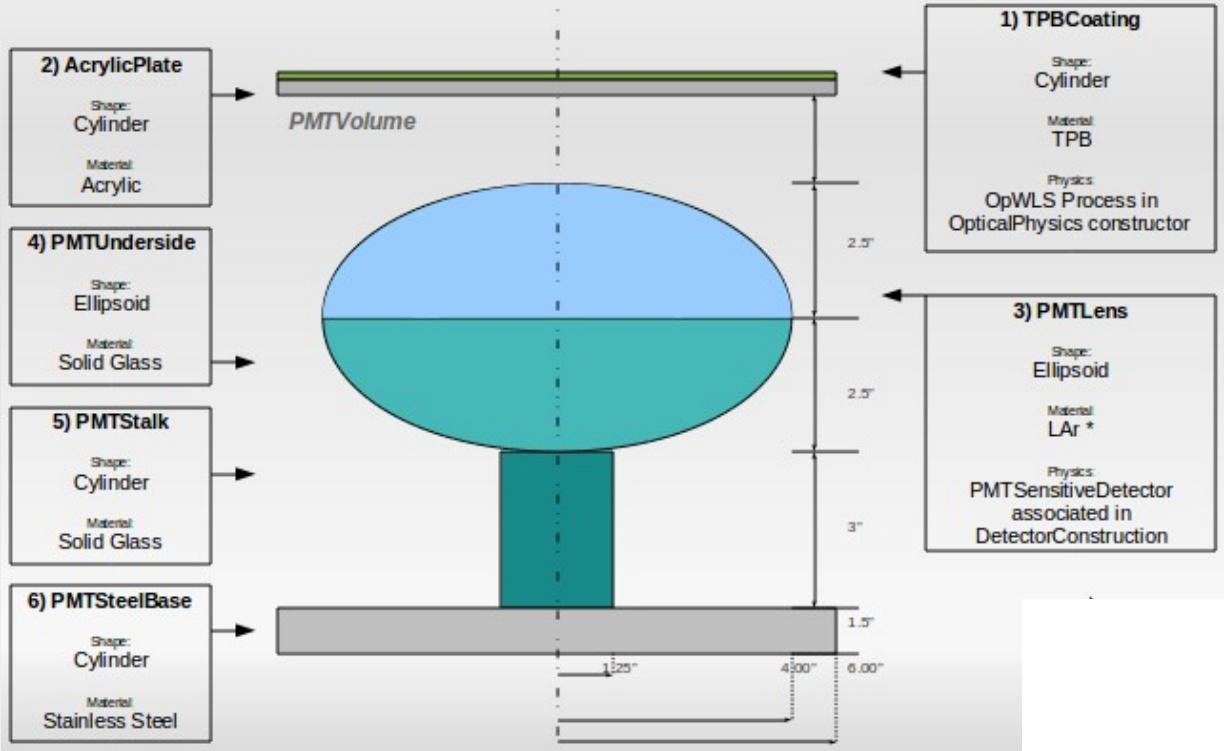
Today

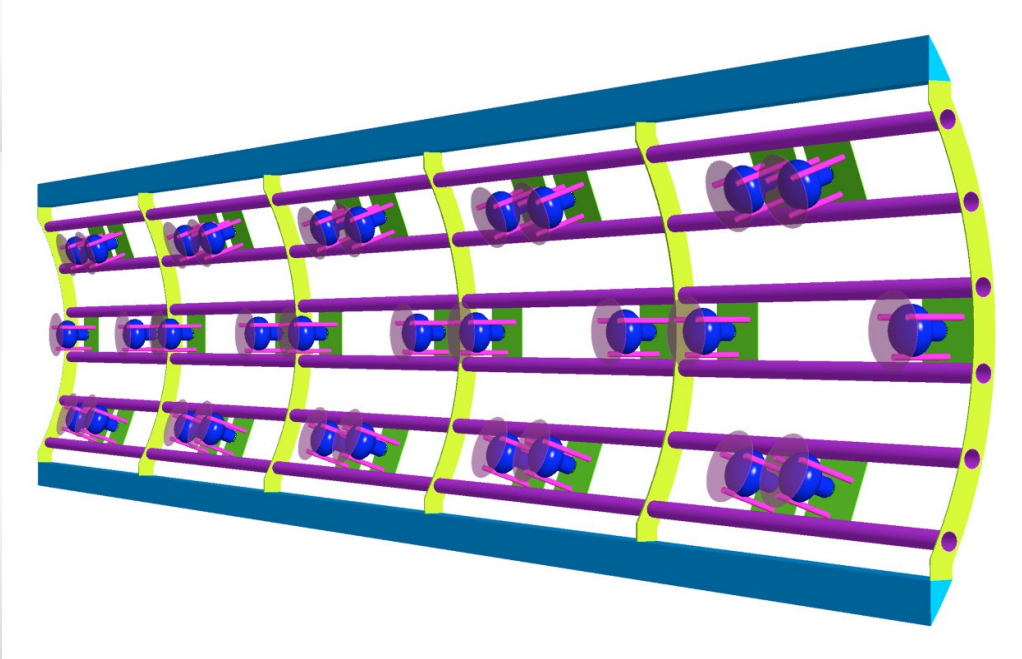
Optical Processes in LArG4

Optical physics processes are loaded via the ”OpticalPhysics” GEANT4 physics constructor, which was customized to fit our needs in LArSoft.



Geometry and Sensitivity





The Light Source Event Generator

- Event generator which simulates an extended, isotropic light source at some position in the detector
- Two modes of operation:

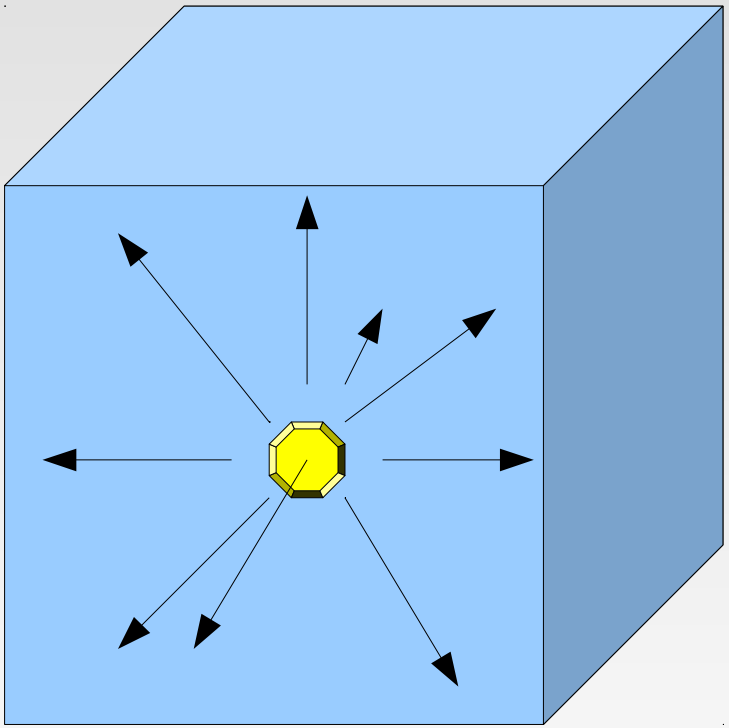
  - Scan Mode

  Voxelize the detector into cuboidal regions, and step through the volume depositting N photons uniformly across one voxel per event.

  - File Mode

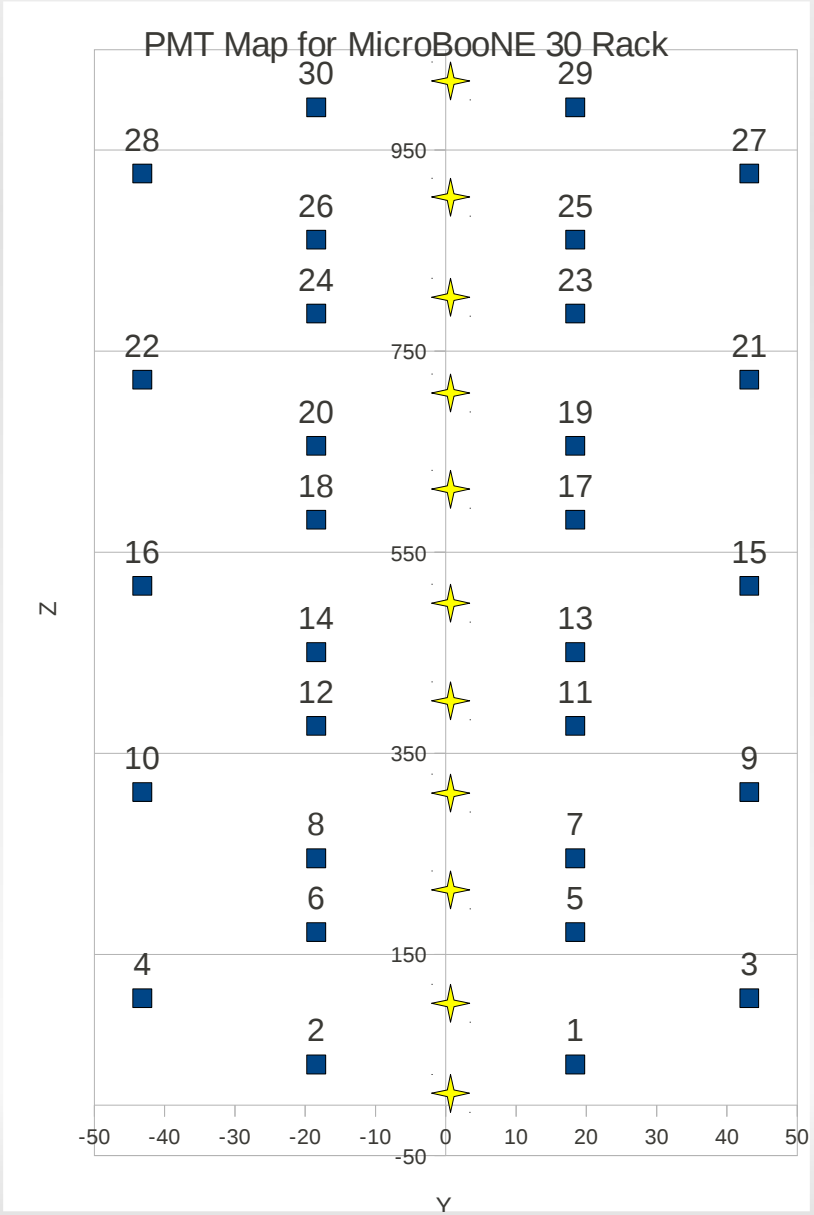
  Specify the size, intensity, shape and position of one light source for each event in a text file which is specified in the config file for the module.

- Optionally, a data structure can be stored in the event with details of the light source configuration

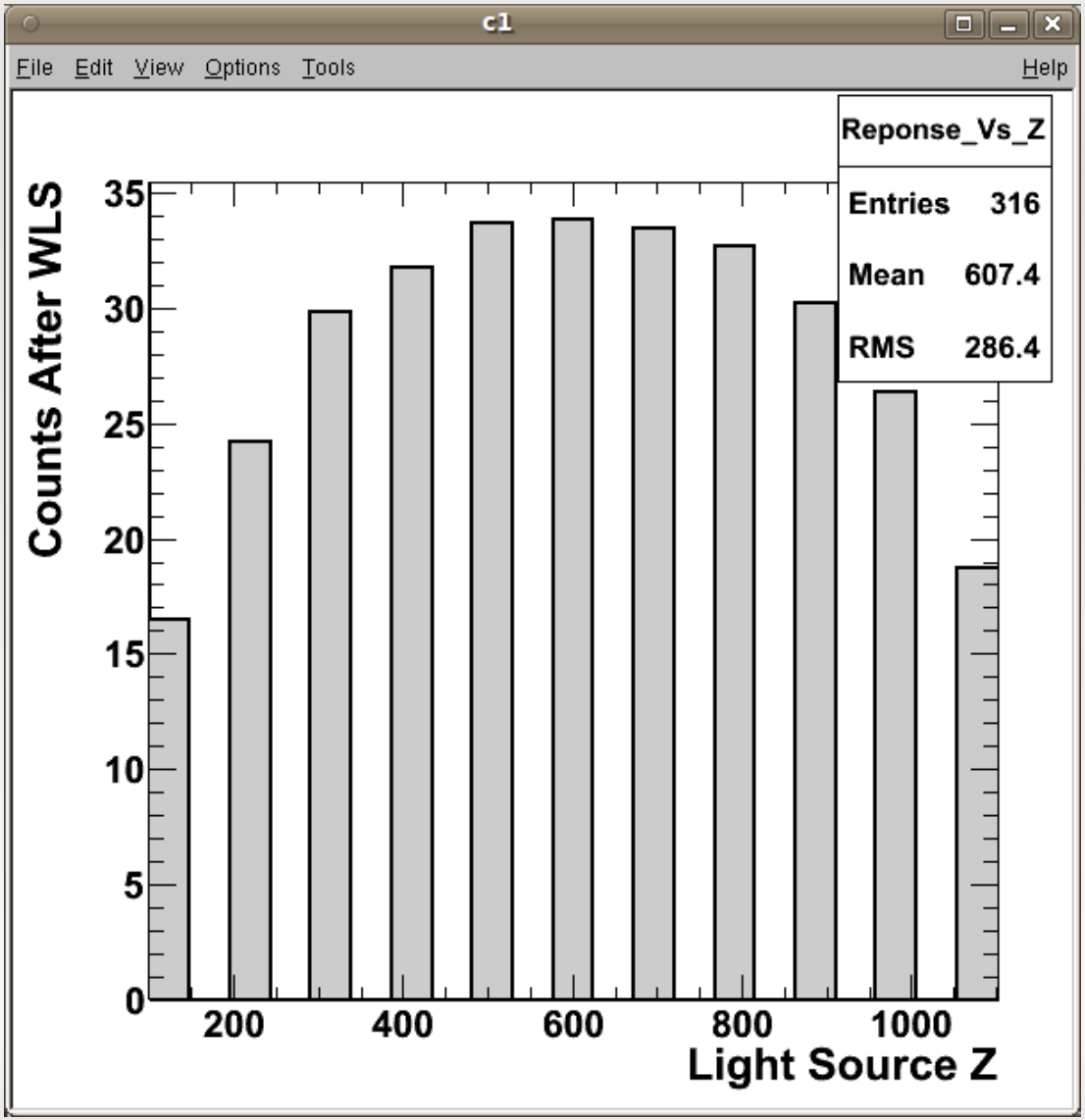


On Axis Point Source Test

- Place point light sources at various points in the detector using light source in file mode
- Run full simulation with photons corresponding to **5MeV scintillation** (120,000 photons)
- Count photons reaching PMT lens
- Note – PMTs here are naked with no wavelength cut, need to include WLS efficiency. In our TDR, we estimate this to be 0.03.
- Until we have computing power to do more, we only consider on-axis points



On Axis Point Source Test

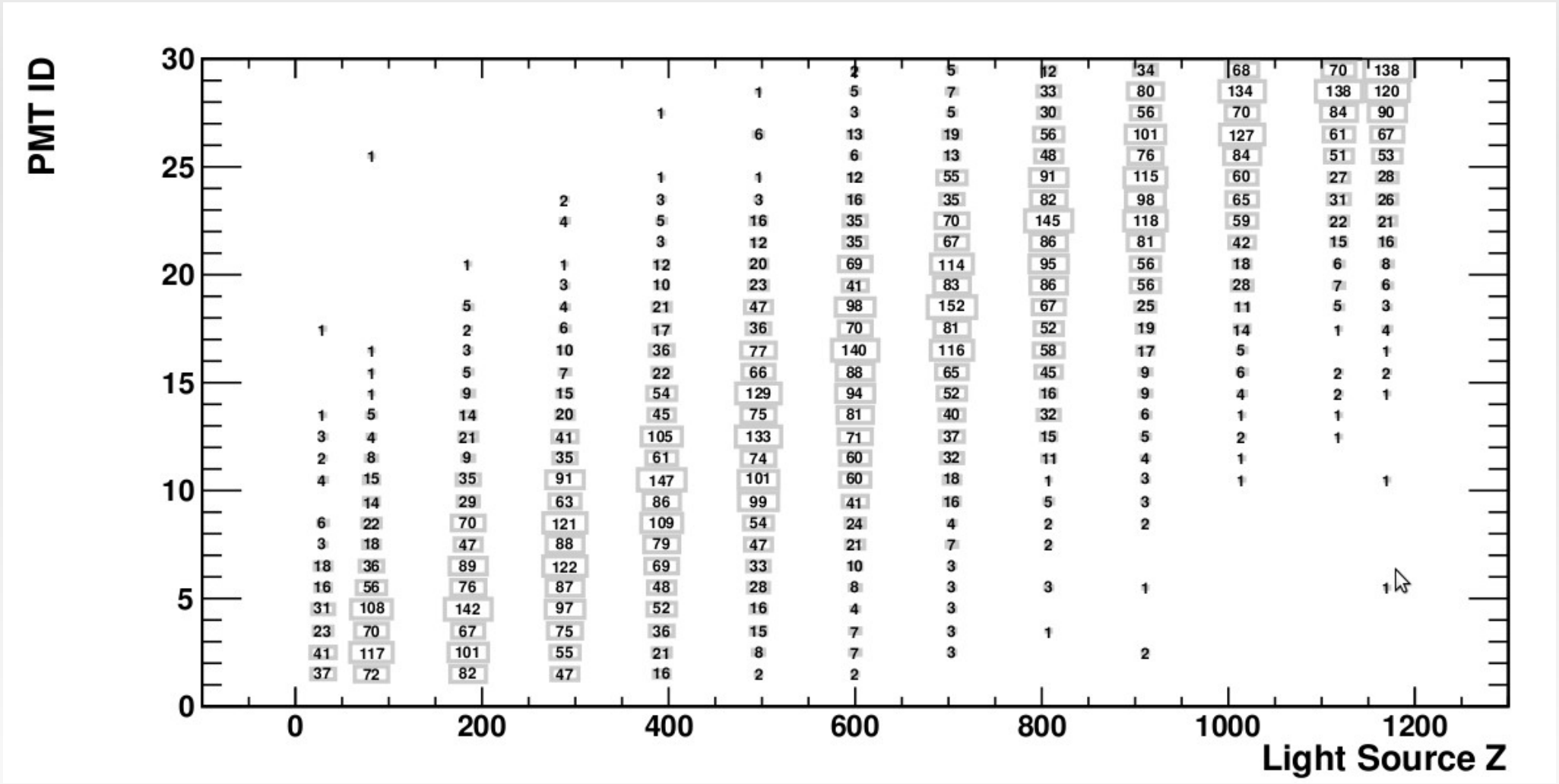


> 15 photoelectrons for each on-axis point in the fiducial volume!

Suggests we have good efficiency for even 5MeV of scintillation

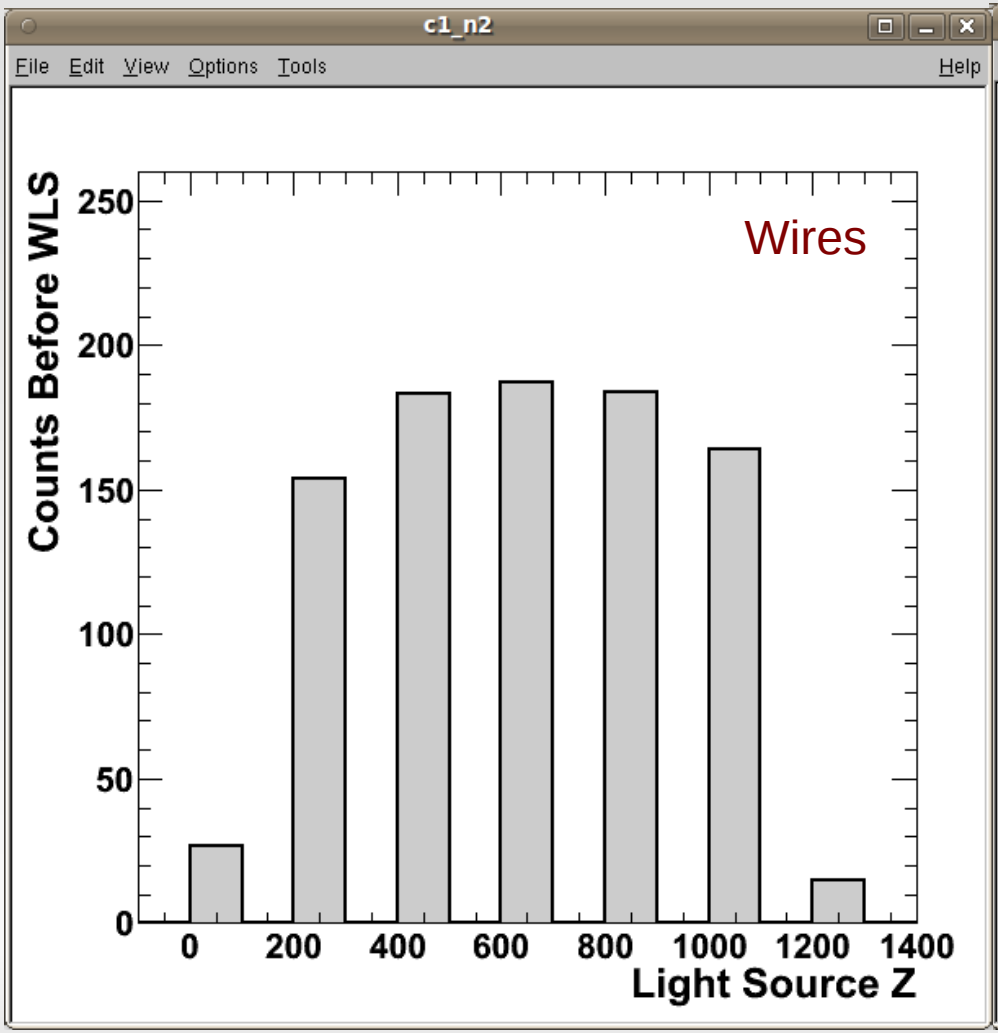
(Subject to geometry modifications)

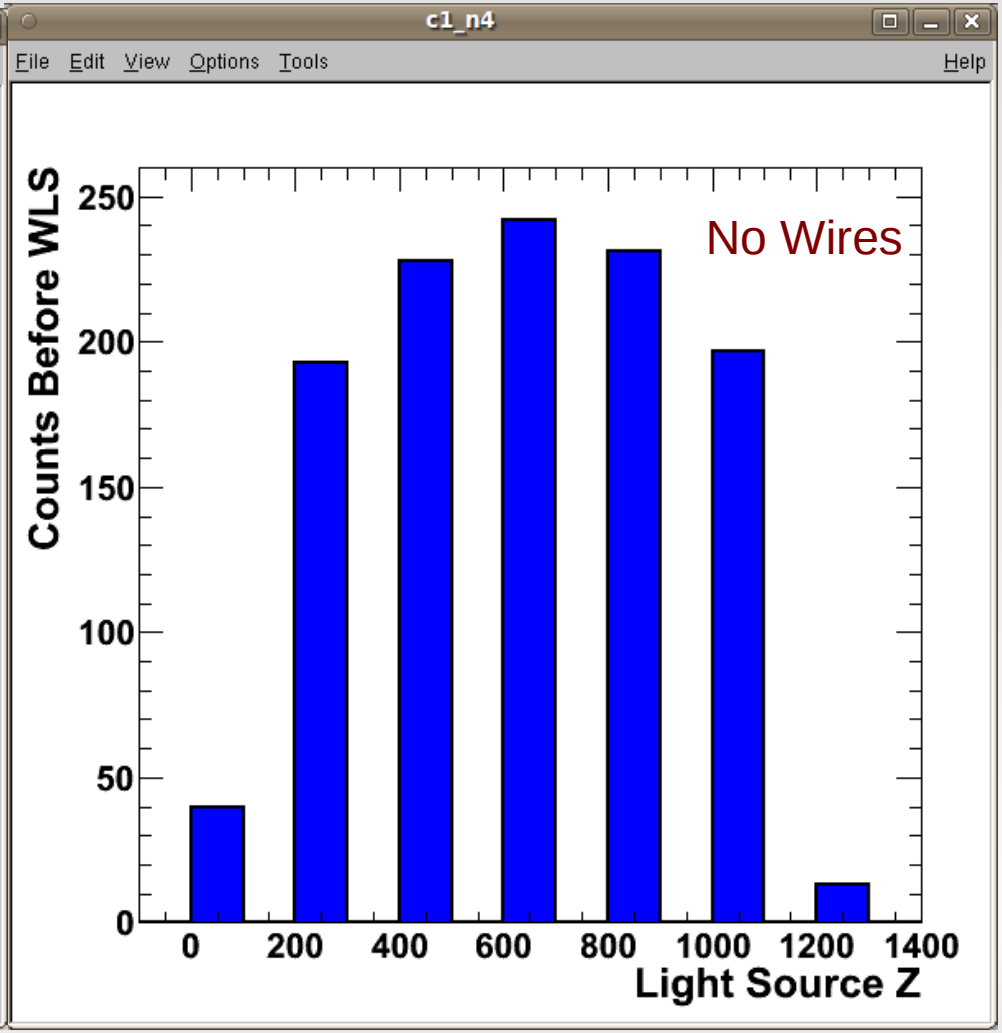
On Axis Point Source Test



Effect of Wires

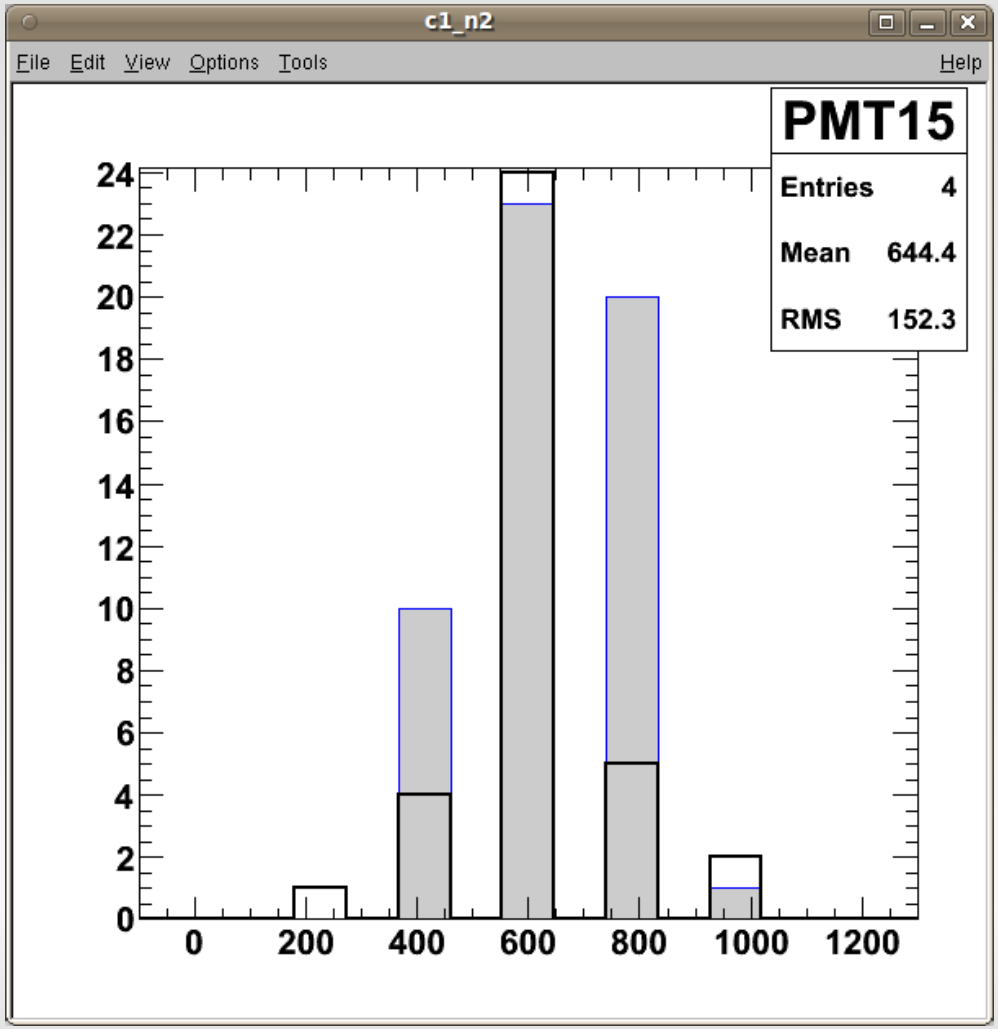
- Wires block ~20% of the light. Note the flattening...

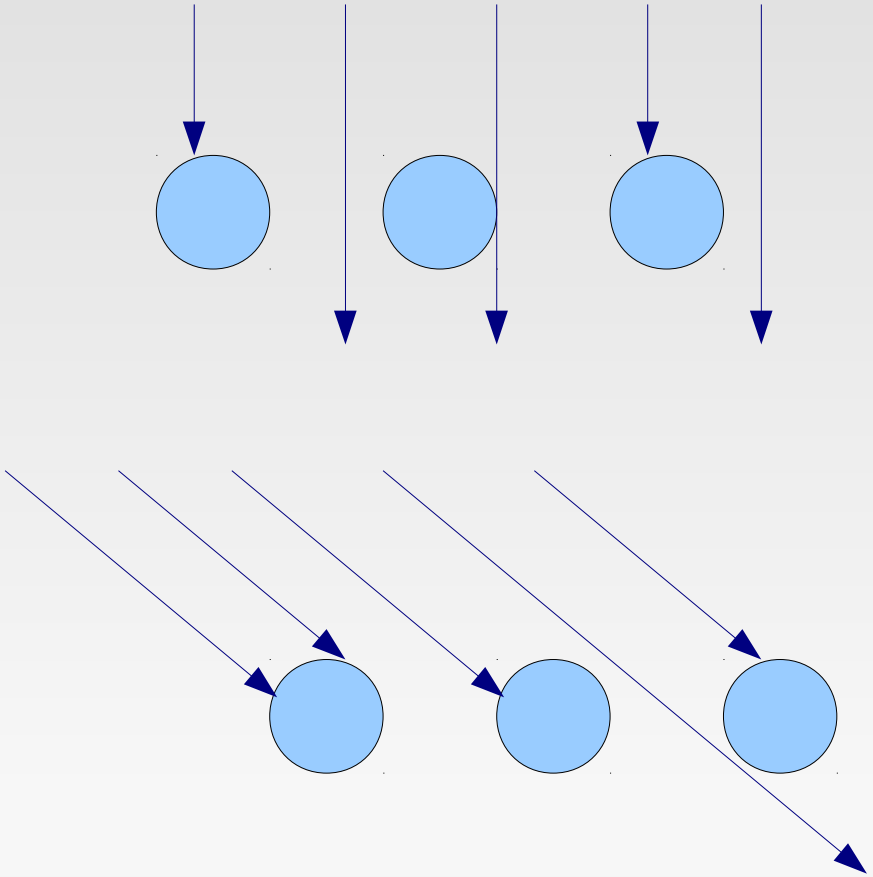




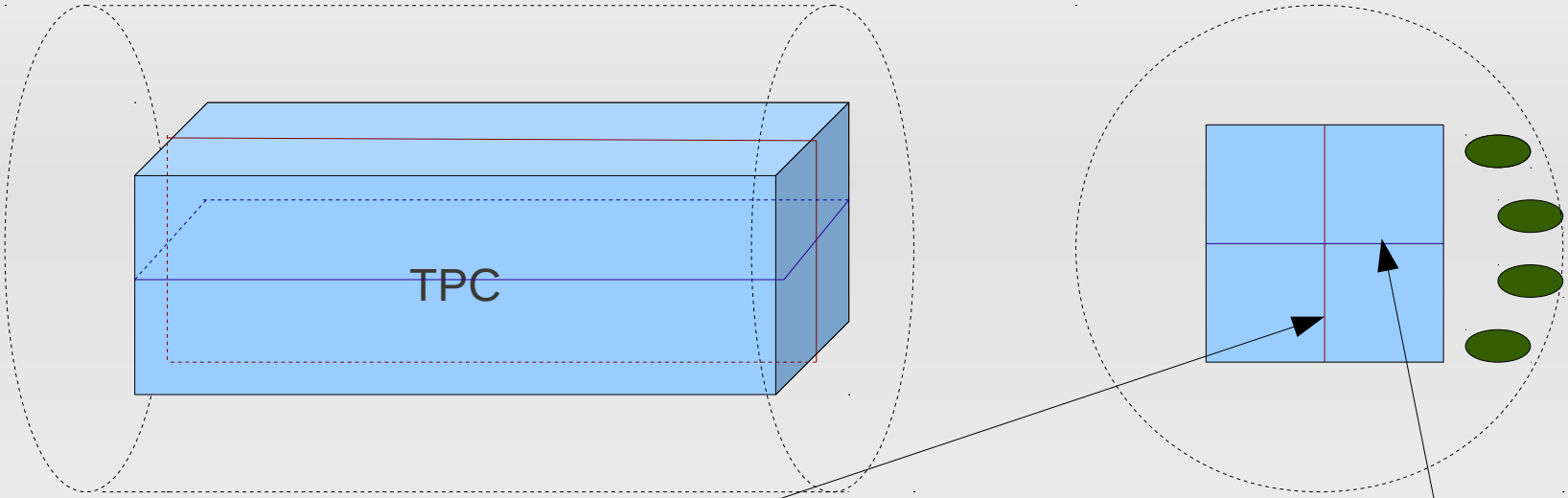
Effect of Wires

- Considering only one central PMT – note that the large angle light is more strongly blocked. Explains the flattening on the previous slide.

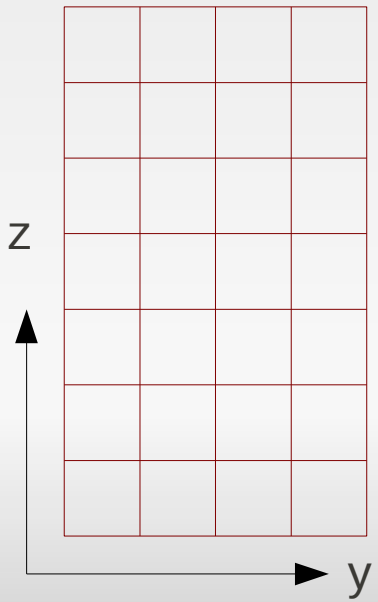




Off Axis Voxelized Test



x=0 plane,
segmented in y,z



y=0 plane,
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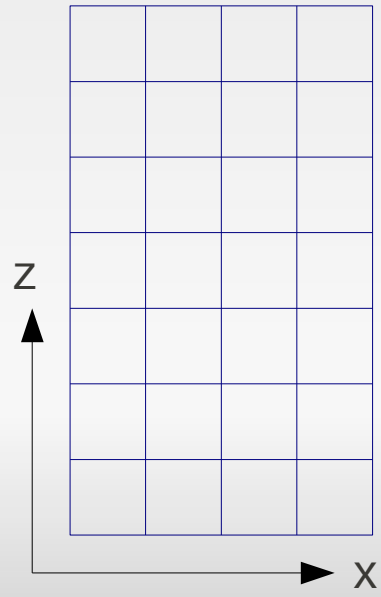

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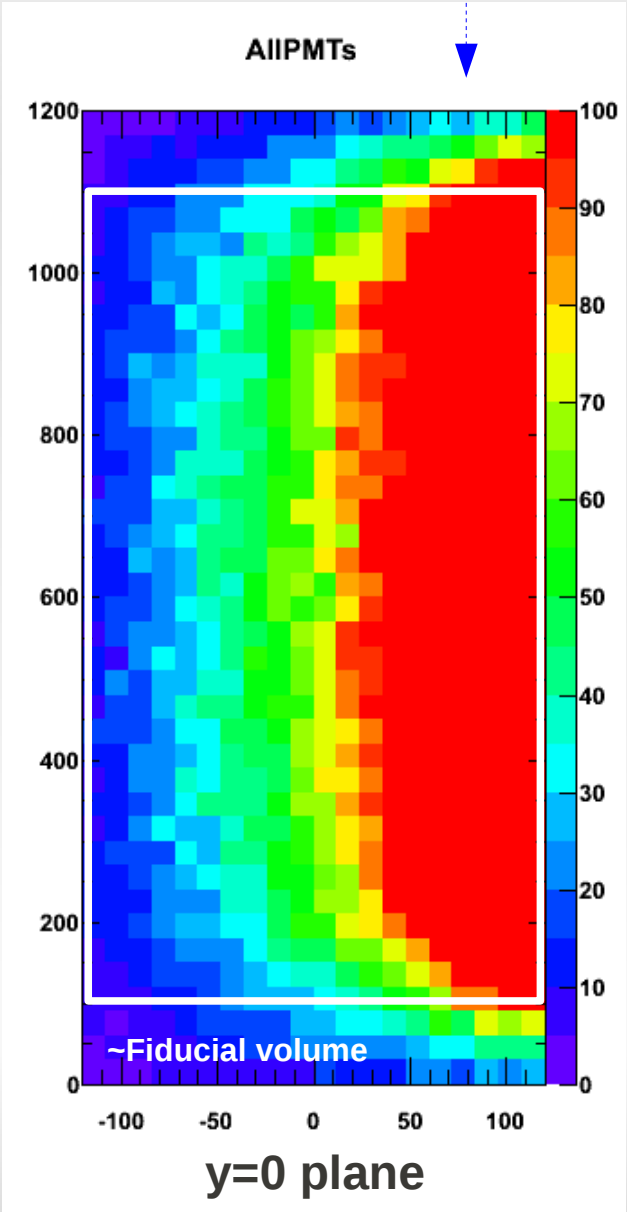
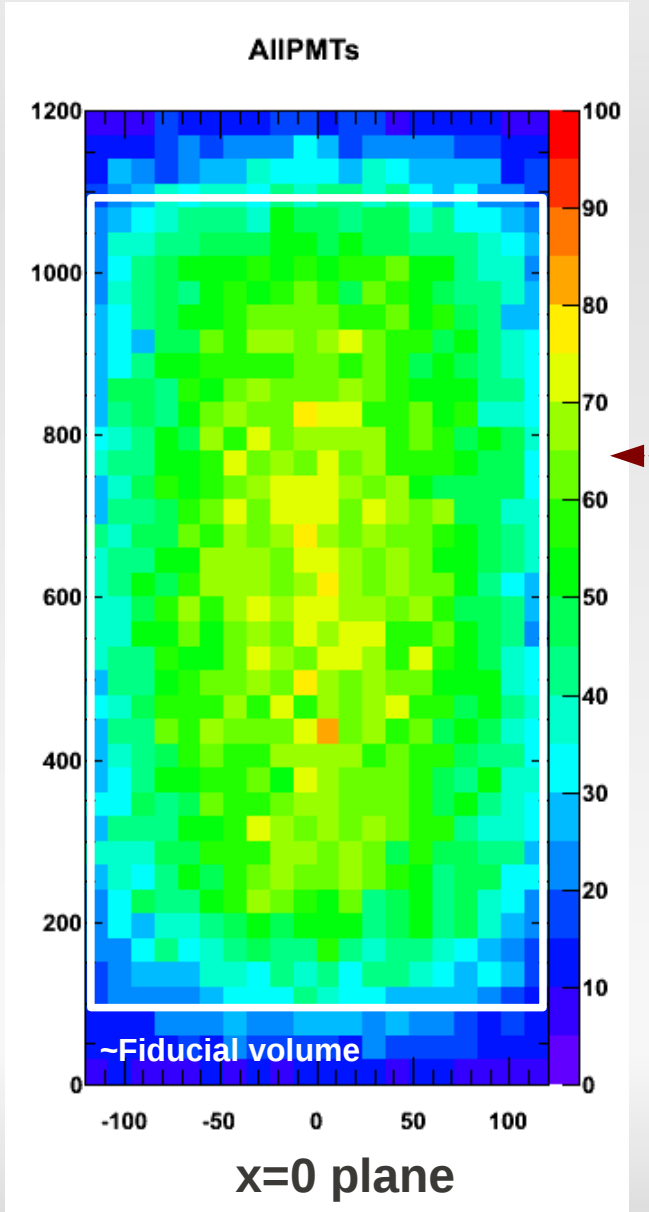
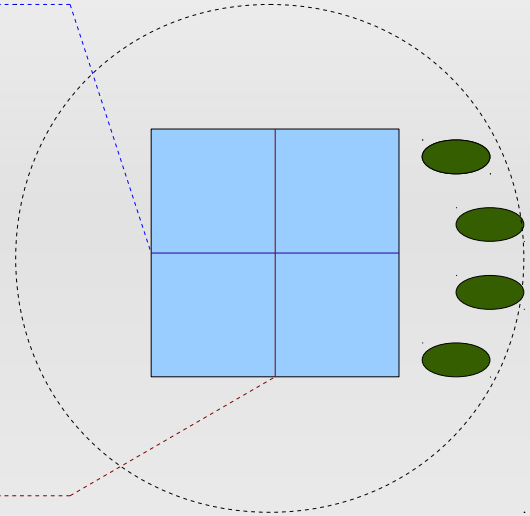


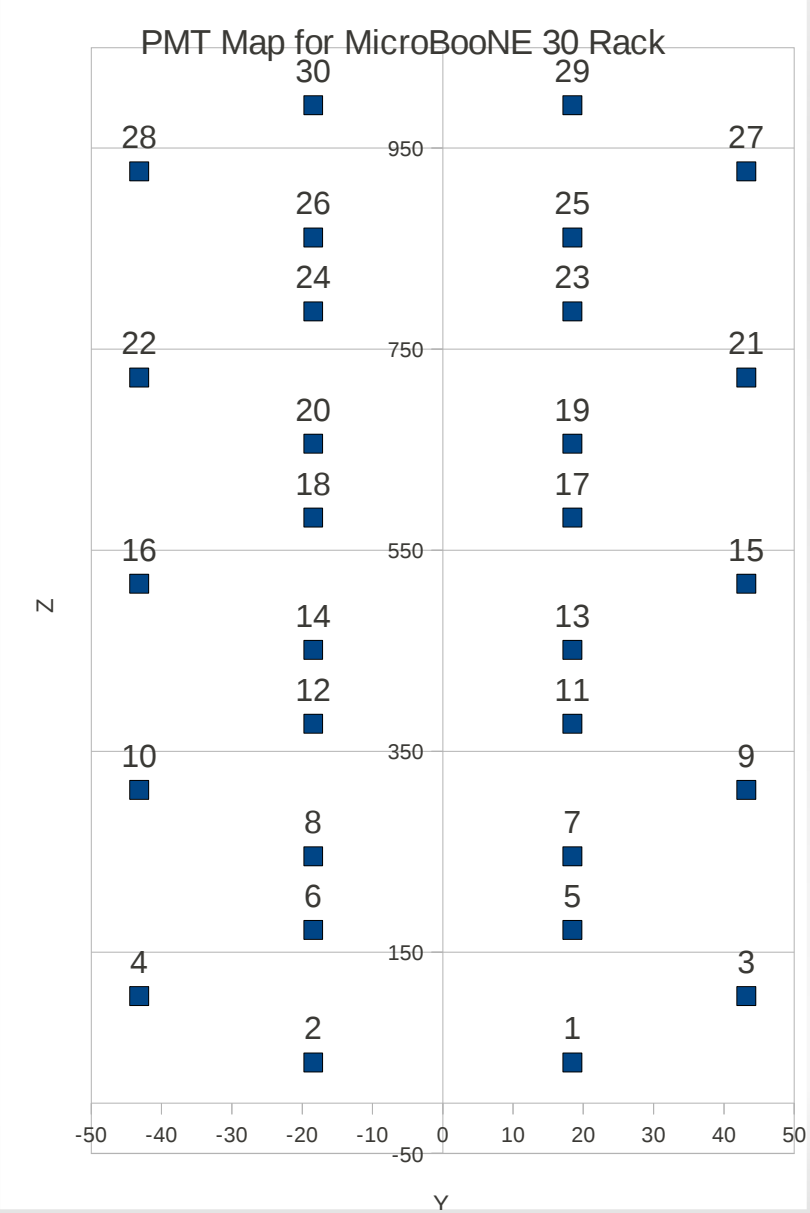




Number of photoelectrons summed over all PMTs for point source of **5MeV** equivalent at different detector points

Trigger should be possible on 1 p.e. We are sensitive at all points on these plains within fiducial volume.

Off Axis Voxelized Test – Individual PMTs

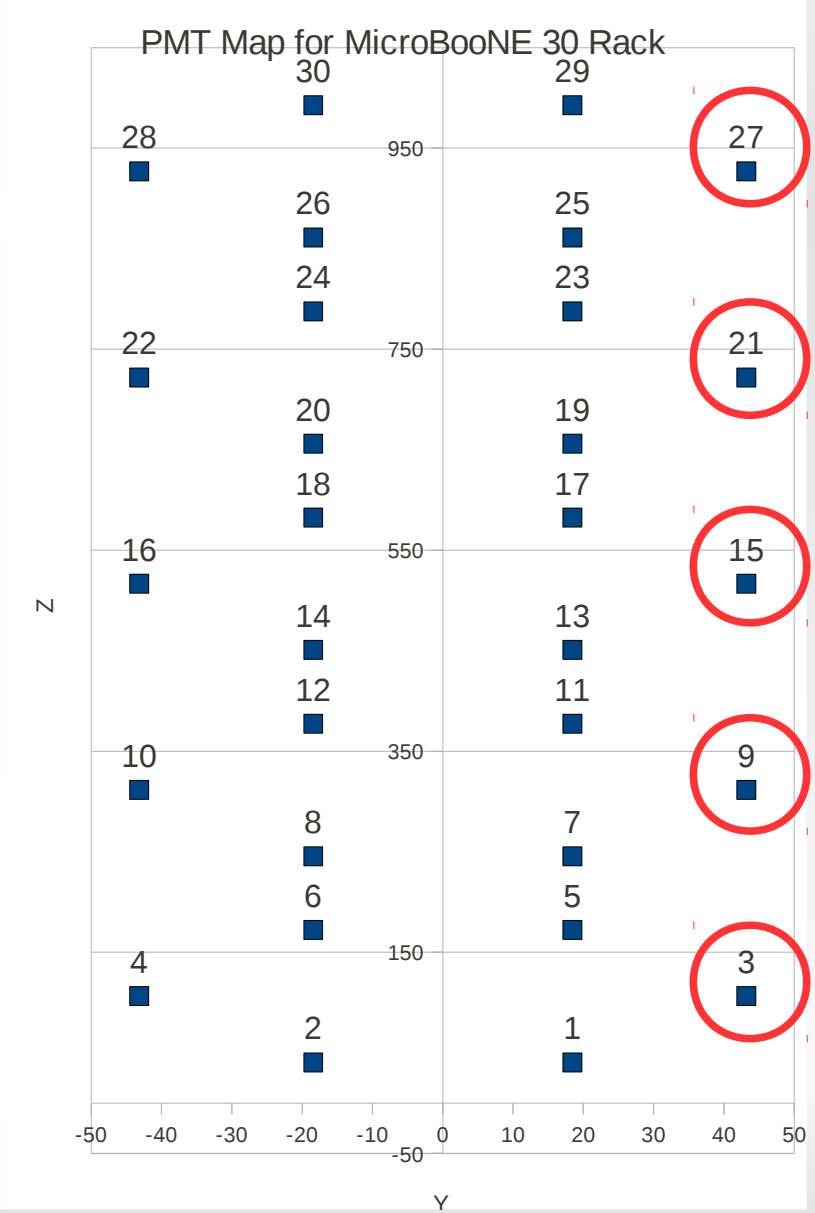


Ask two questions:

1) How is the coverage of each PMT in isolation?

2) How well can we do with one PMT signal missing?

Off Axis Voxelized Test – Individual PMTs



Ask two questions:

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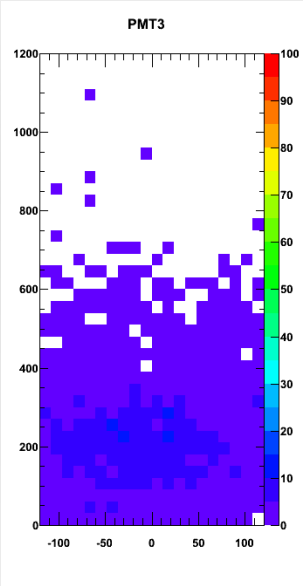
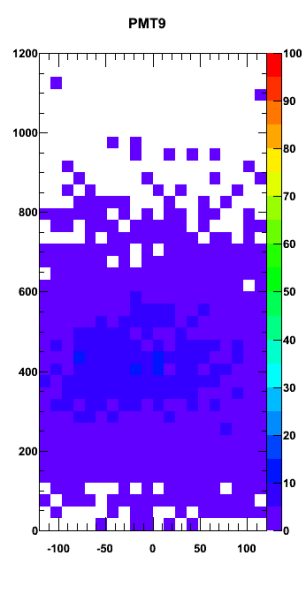
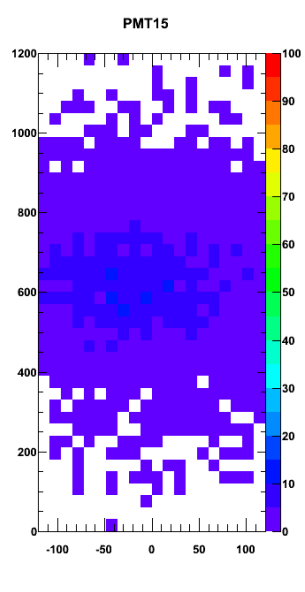
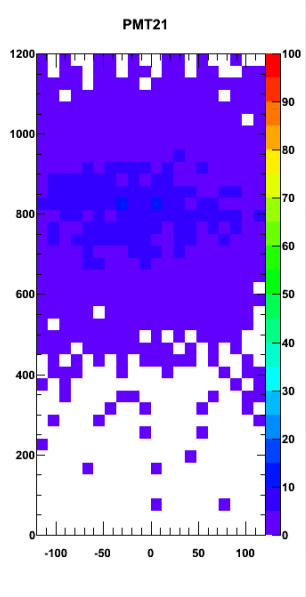
First consider a line of PMT's in Z.

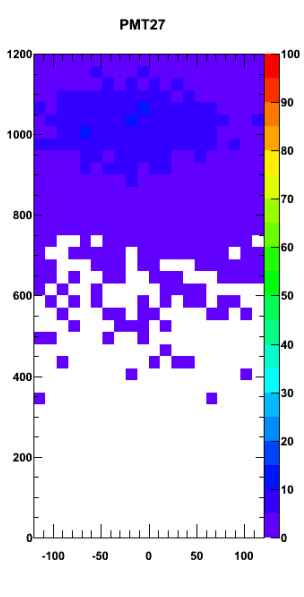
Individual PMT Coverage

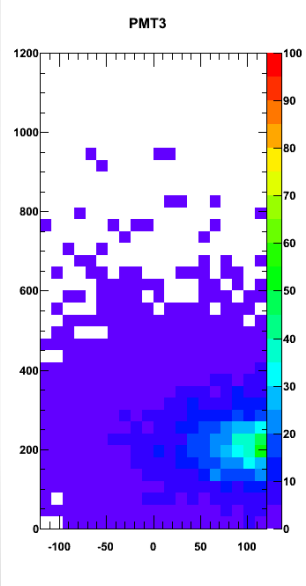


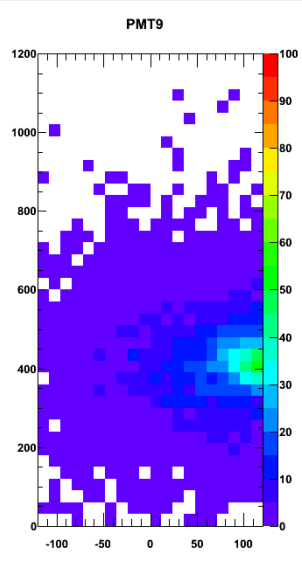


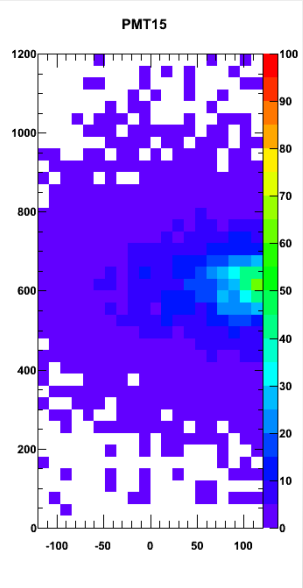


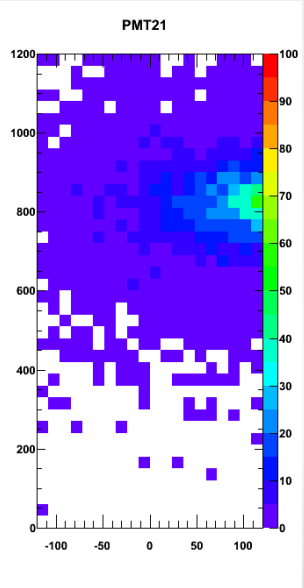


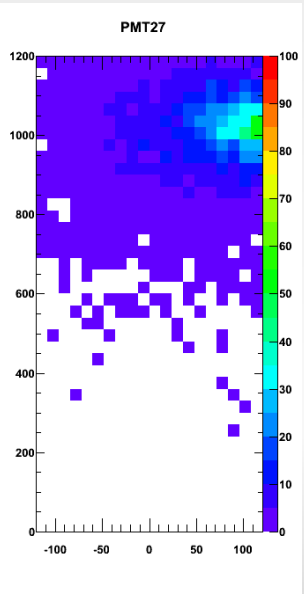




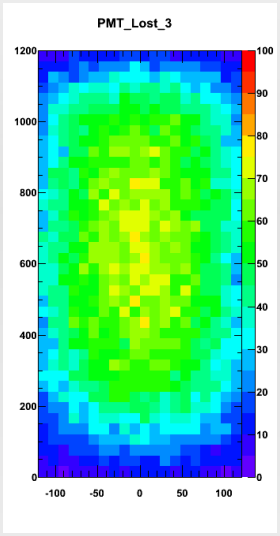


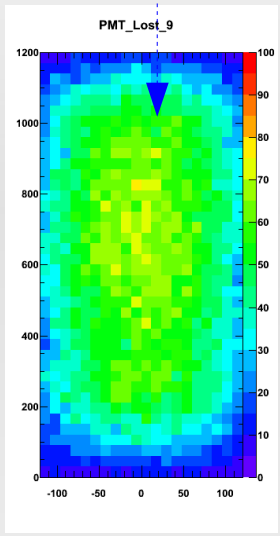


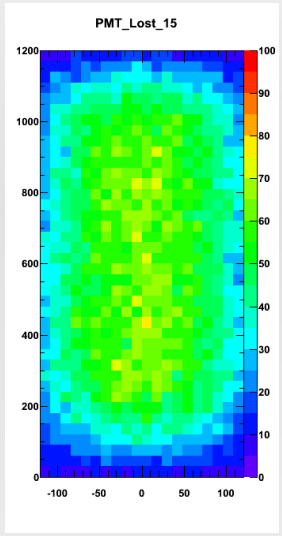


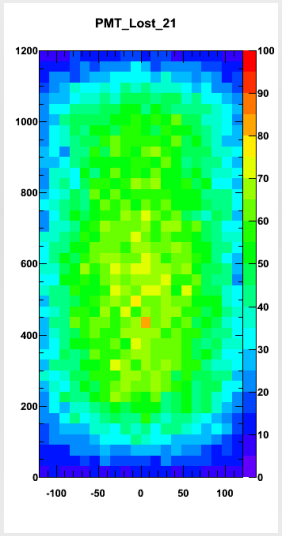


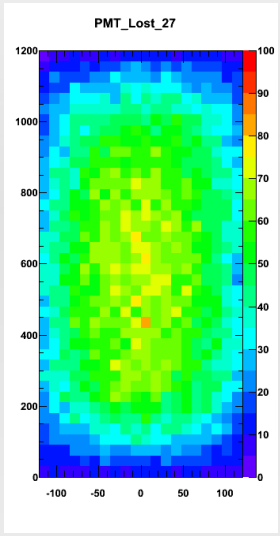
Individual PMT's missing

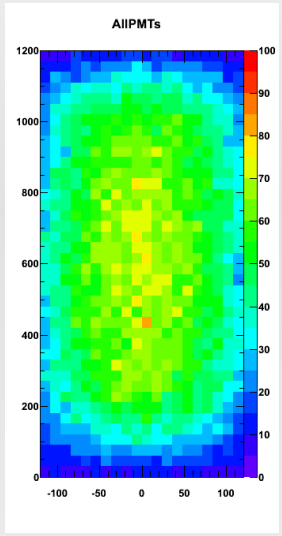


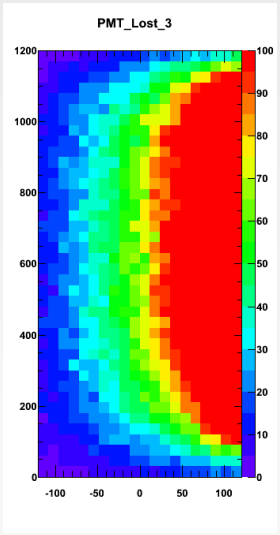


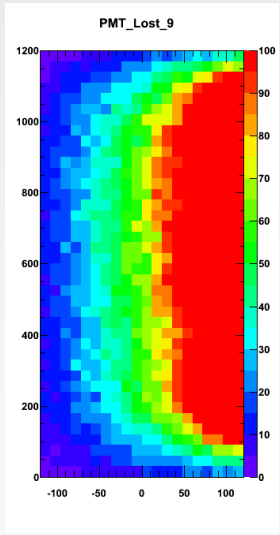


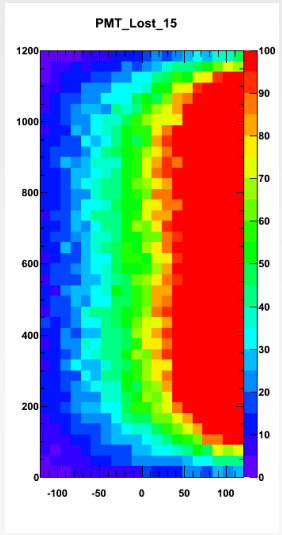


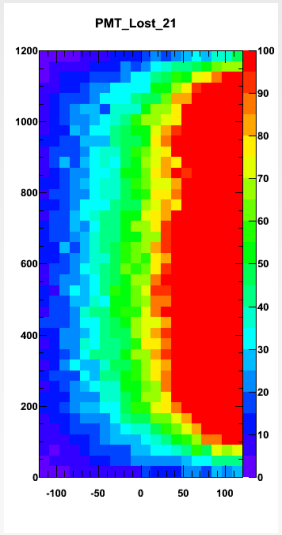


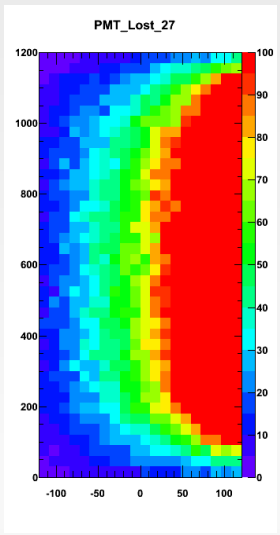


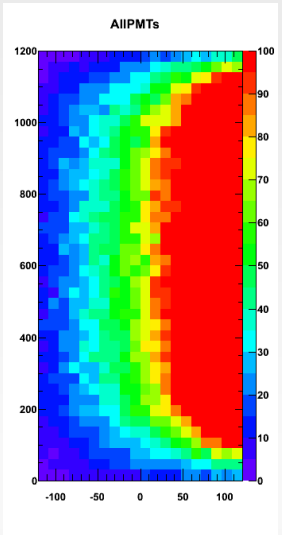








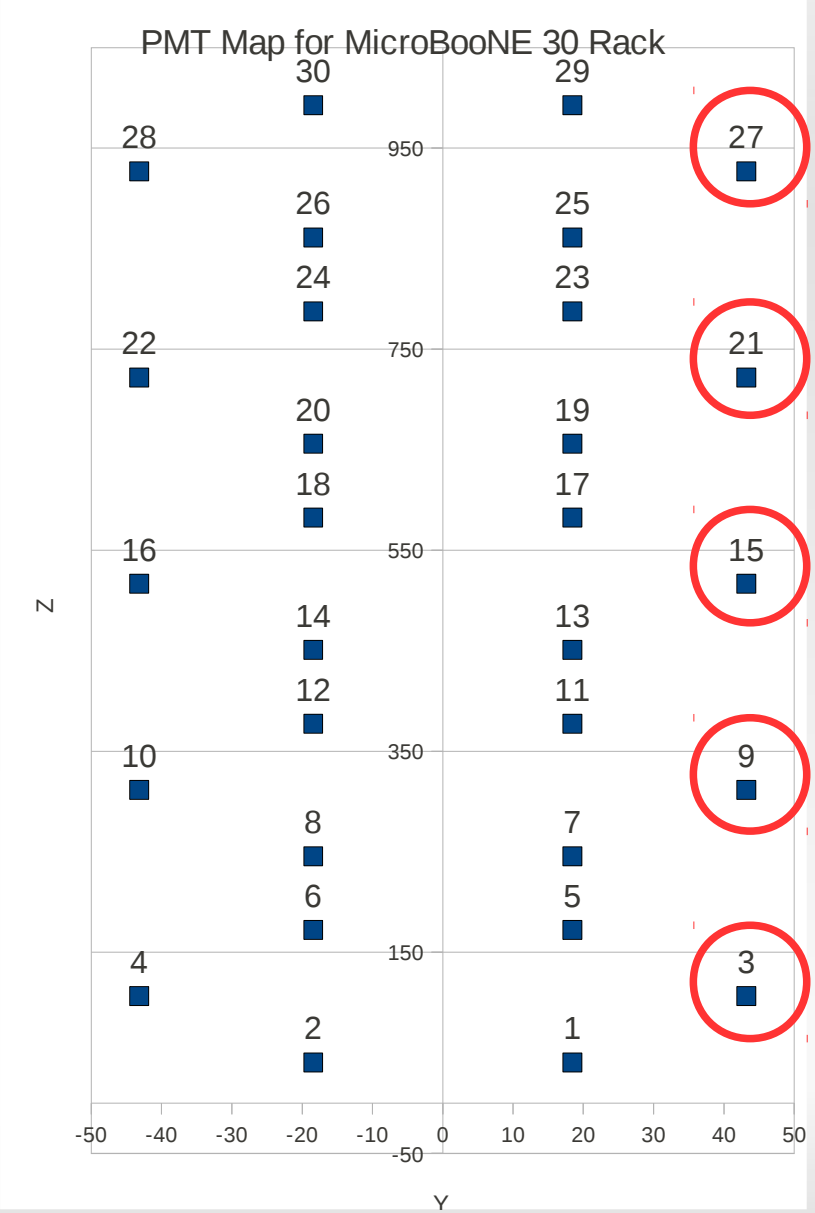




The Bottom Line : Losing 1 PMT is no problem for trigger sensitivity.

For comparison: No PMTs missing

Off Axis Voxelized Test



Ask two questions:

1) How is the coverage of each PMT in isolation?

2) How well can we do with one PMT signal missing?

First consider a line of PMT's in Z.

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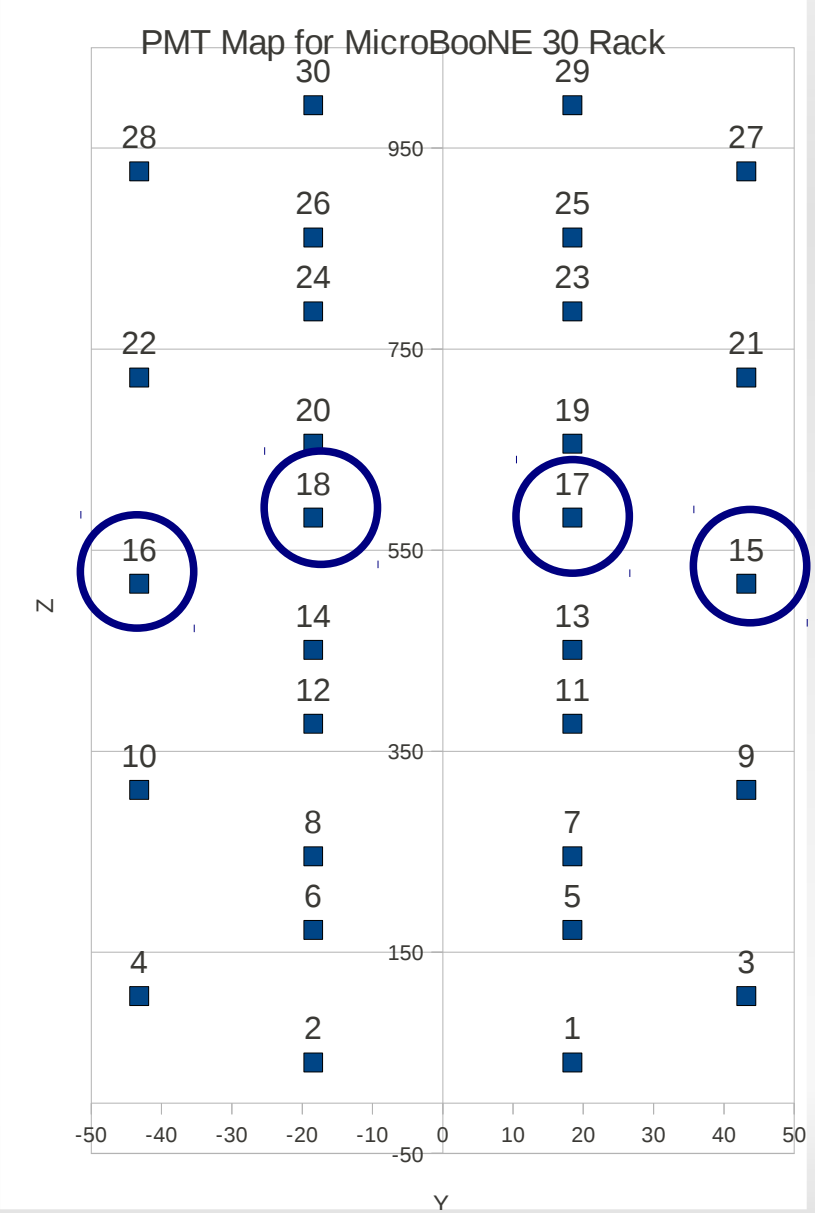


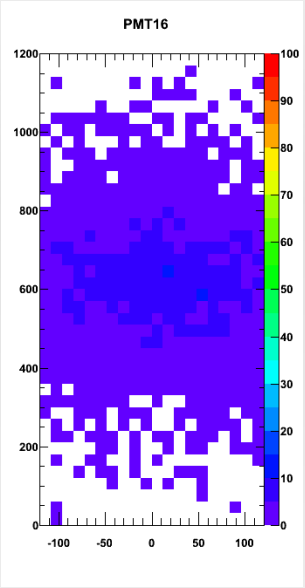
Ask two questions:

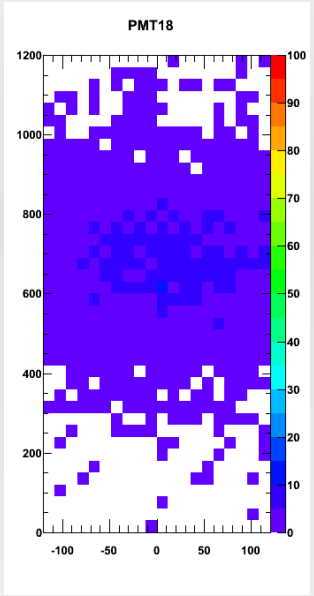
1) How is the coverage of each PMT in isolation?

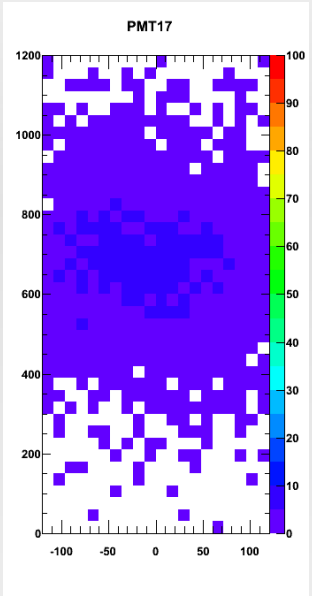
2) How well can we do with one PMT signal missing?

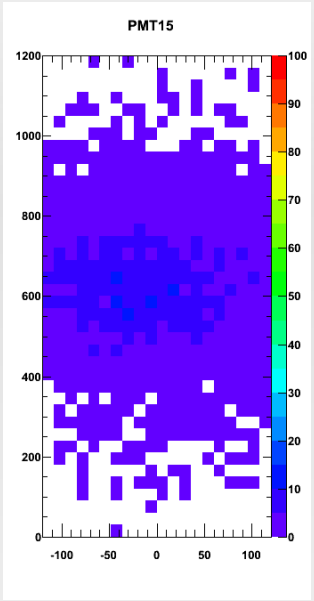
Also look at the line of PMTs in y

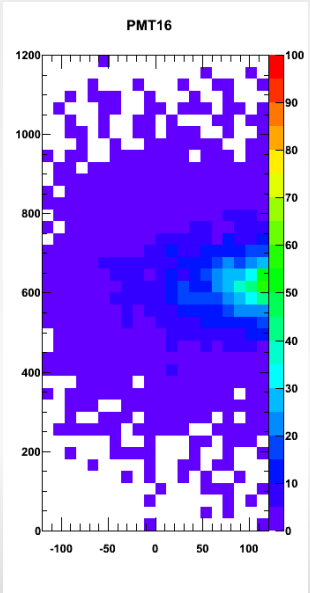
Individual PMT Coverage

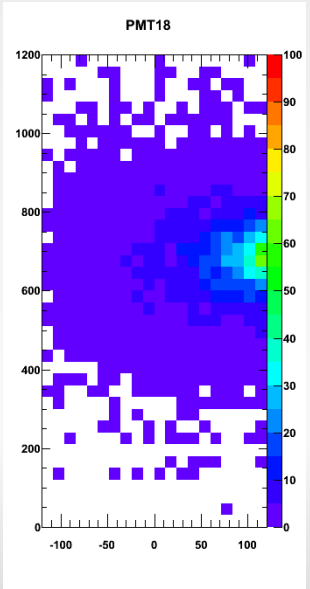


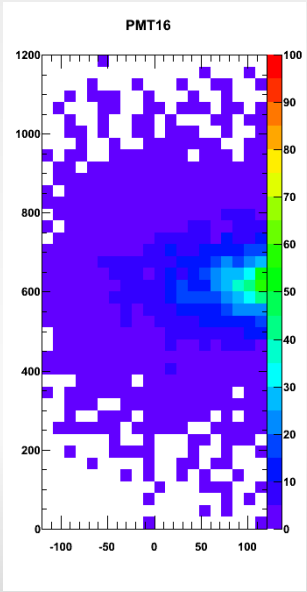


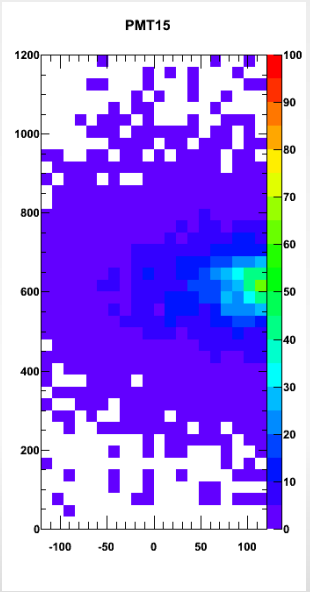








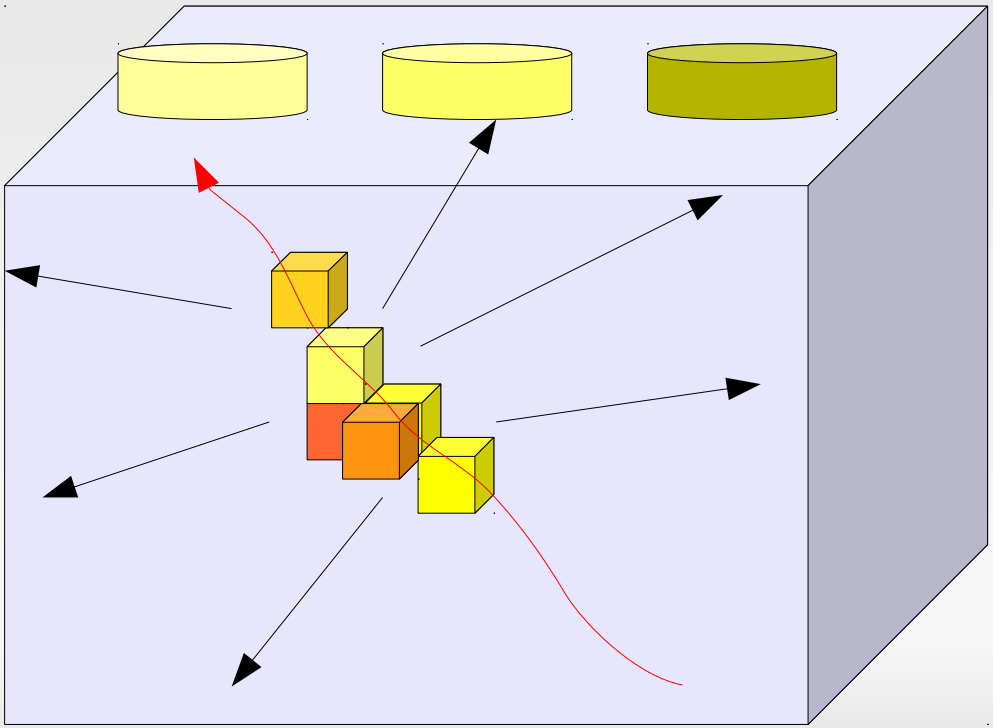




Also, still no significant drop in sensitivity due to missing PMTs

Fast Simulations and Photon Library Sampling

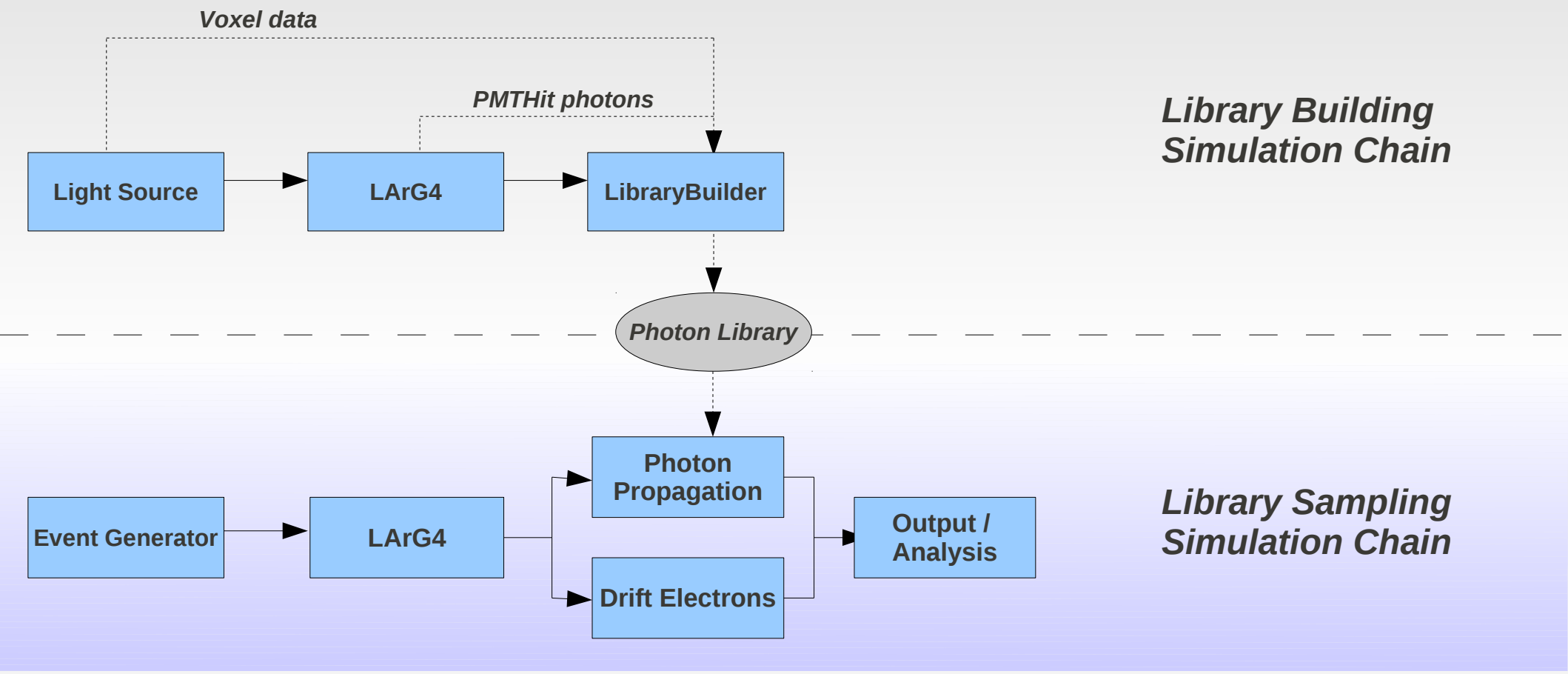
- GEANT4 simulation of 100,000s of photons per event takes a very long time – not a feasible approach for long monte carlo runs
- Scintillation photons are produced isotropically and in large numbers so we can take a different approach and sample from a library of typical responses



How many photons from each ”voxel” will reach each PMT?

How will their angles of incidence and positions on the PMT face be distributed?

Voxelized PhotonLibrary Building And Sampling Chains



- Library is built using a light source with gaussian spectrum of **9.7 +/- 1 eV** in each voxel
- Later sampled by new module **PhotonPropagation**, which runs in parallel with DriftElectrons
- During the LarG4 step of the sampling chain, we do not step any photons, simply provide the **number produced in each voxel**

Voxelized Library Sampling

Get number ***N*** of photons deposited in voxel ***VoxID***

If ***N*** > cutoff, lookup entry for this voxel in library

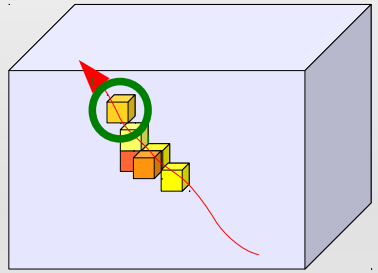
*Get number **LibNum** of photons used to build this library entry*

*Decide how many photons to take from the library using a poisson fluctuated fraction **f = LibNum / N***

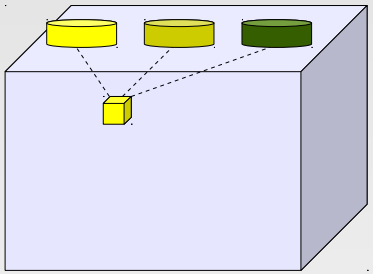
*Randomly select fraction **f** of the photons from each PMTHit in this library entry*

*Add this **PMTHitCollection** to the overall collection for the event*

*Next **VoxID***

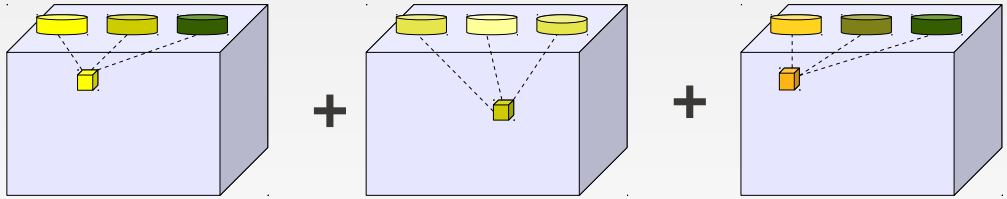


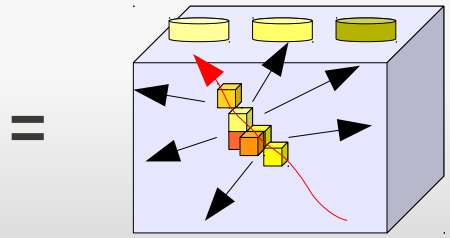
LArG4



PhotonLibrary

Photon Propagation Module





Conclusions / On The Horizon

Once we have computing power and an accurate geometrical description of the detector, we will:

- Build a sampling library for the fast simulation
- Run full scans over the entire detector volume to determine scintillation thresholds for triggering
- Simulate full events at energies above 5MeV minimum and investigate reconstruction application

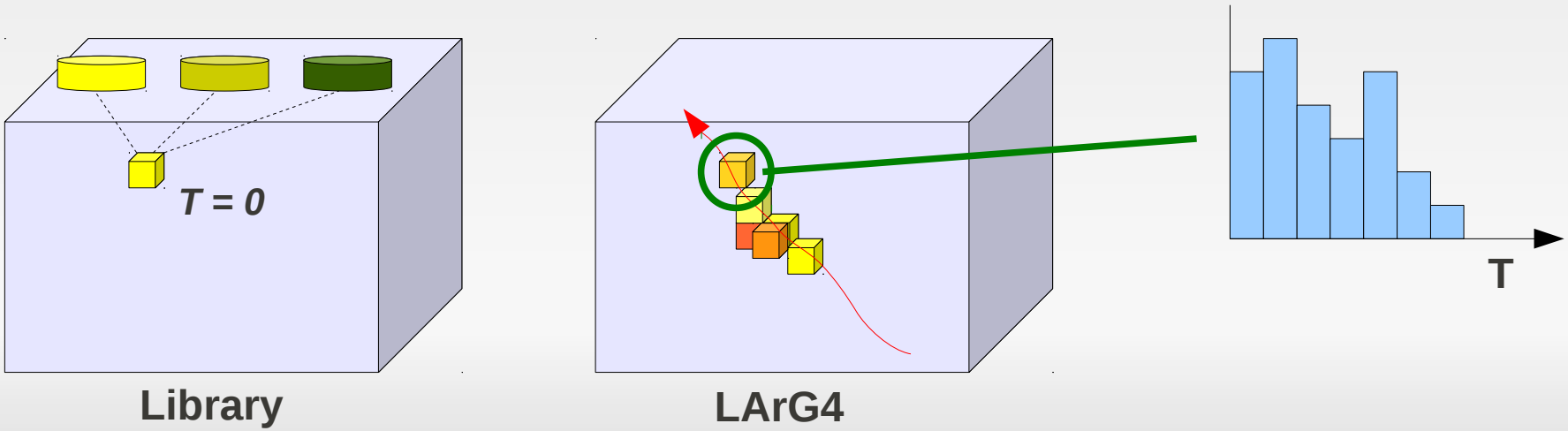
Preliminary investigations:

- Show that we have workable MC to use for generating real results in the near future
- Lend support to other calculations suggesting that the design choices made for the optical systmes were appropriate

BACKUP SLIDES

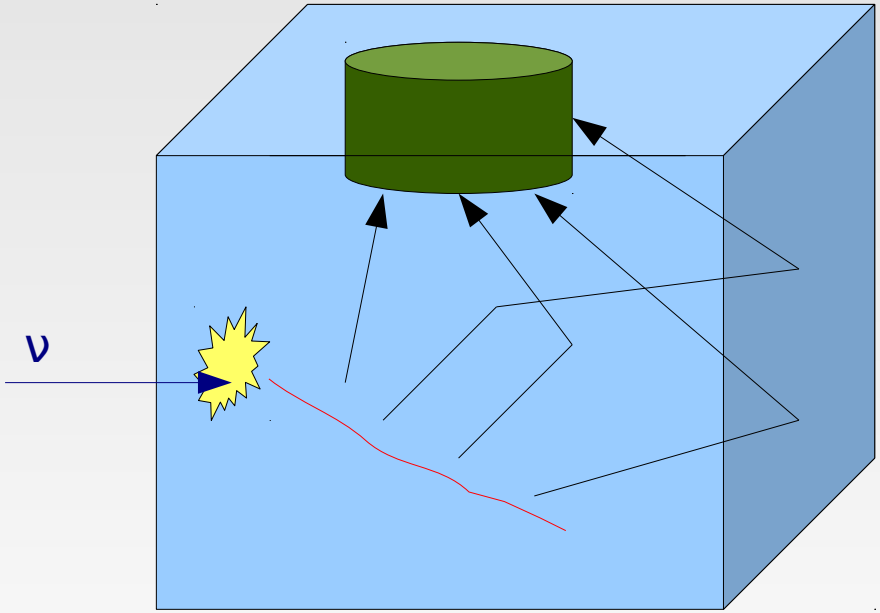
TBI - Timing

- One of the main tasks of the PMT's is triggering – here we require a coincidence with the beam window. Hence timing is important for trigger studies.
- Library entries are generated by photons at time **t = 0.**
- Accompanying **PMTHits store a time value** for each photon which reached the PMT
- But in the current voxelization scheme we lose the timing information for photons depositted.
- ***To be implemented*** : as well as reading # of photons per voxel, store a time profile for that voxel. Then time smear PMT hits sampled from library using this profile.



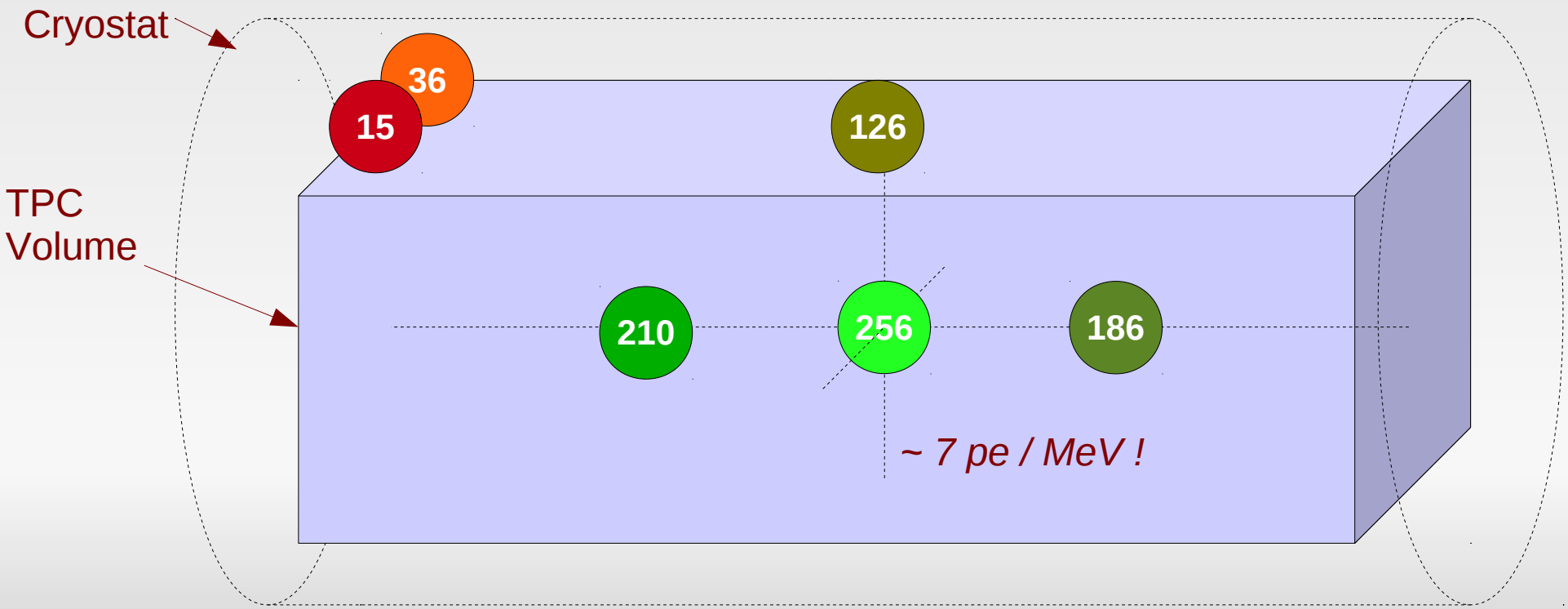
Photon Stepping

- Photons are produced via either scintillation or cerenkov production along the track of a charged particle in GEANT4.
- They are then stepped geometrically through the detector.
- Bulk absorptions and rayleigh scatters occur at random at the end of each step
- At an interface, a random specular or diffuse reflection, or absorption is applied according to the supplied reflectivity properties
- If a photon is incident upon a wavelength shifting volume, it is randomly absorbed according to a supplied absorption spectrum, and one or more photons are randomly emitted according to a supplied emission spectrum
- If a photon steps into a ”sensitive” volume, it is stopped and killed and a PMT hit is generated



Preliminary Sensitivity Studies

- Place light sources which produce 10,000 photons per event at different points in the detector geometry. This is over a factor of 10 smaller than a scintillating 5MeV proton.
- Ask how many photons make it to a PMT lens – all reflections and scatters enabled
- Note that in this preliminary study, PMT lenses are naked - no wavelength shifting plates. Hence we still need to factor in WLS related efficiencies. We estimate a factor of 0.03 (see TDR)



Optical Properties of Materials

- Optical properties of materials are loaded during the detector construction step using the MaterialPropertyLoader class.
- The requirement of loading wavelength dependent parameters required us to step outside the default gdml parser and implement this new class.
- Several implementations are possible (xml reading, hard coded, etc)

Per Material Type

Scintillation

Fast component spectrum
Slow component spectrum
Scintillation yield
Fast time const
Slow time const
Proportion fast / slow
Quenching per particle

Cerenkov

- none -

Absorption

Absorption Length

Rayleigh Scattering

Scattering Length

WLS

Absorption spectrum
Emission spectrum
Time Constant
Yield out / in

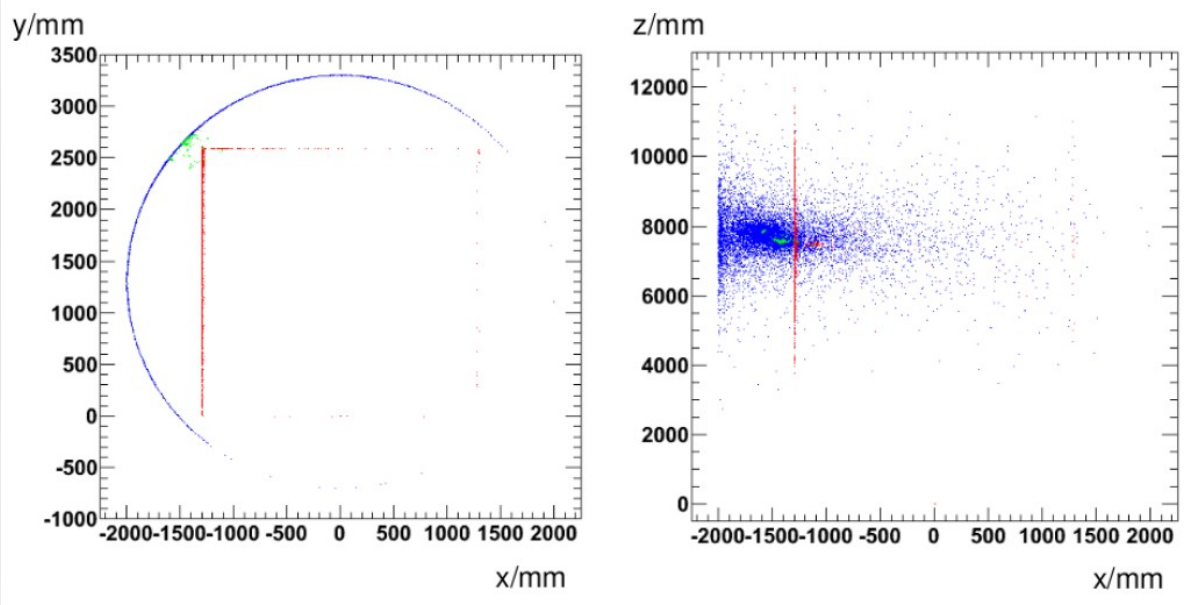
Per Boundary Type

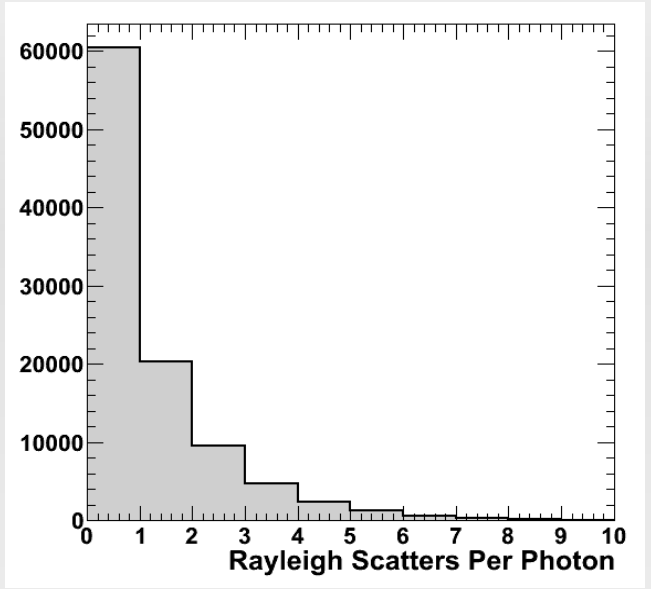
Reflections

Total Reflectivity
Fraction specular / diffuse

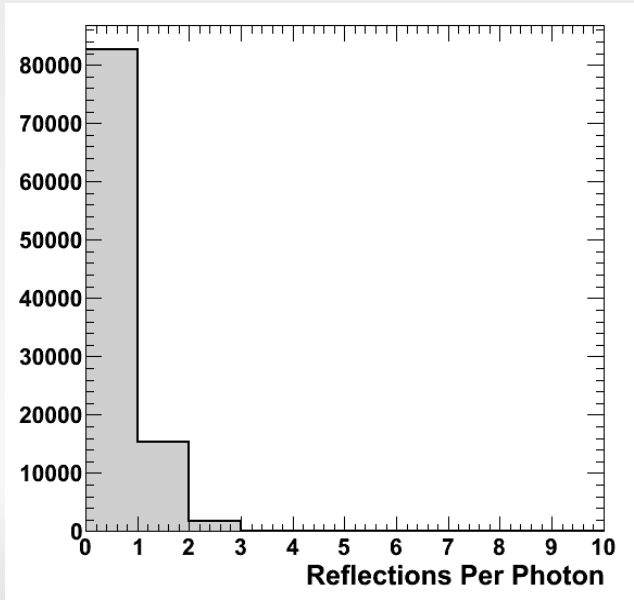
Wavelength dependent
Non wavelength dependent

A Sample Neutrino Event in LArG4





Green - Photon production
Blue - Photon absorption at surface of known reflectivity
Red - Photon absorption at surface with no reflectivity data



- 95161 photons were generated of which 58996 were eventually absorbed at a steel surface and 20932 were absorbed into a ”black area”
- Each photon underwent a mean of 0.76 Rayleigh scatters and 0.19 reflections