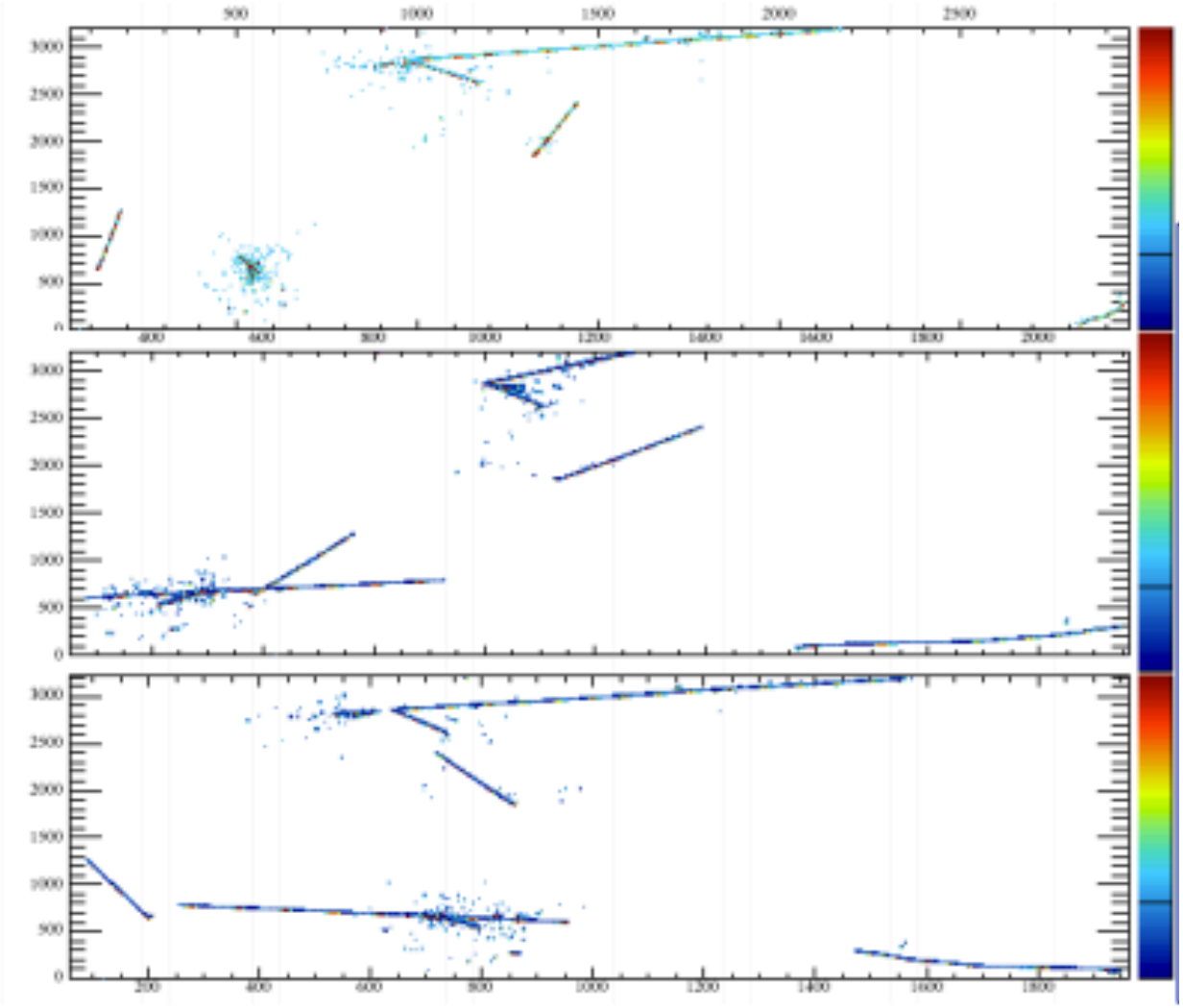
OPTICAL SIMULATION AND RECONSTRUCTION WITH LARSOFT

Ben Jones, MIT



Question 1 (20 points):

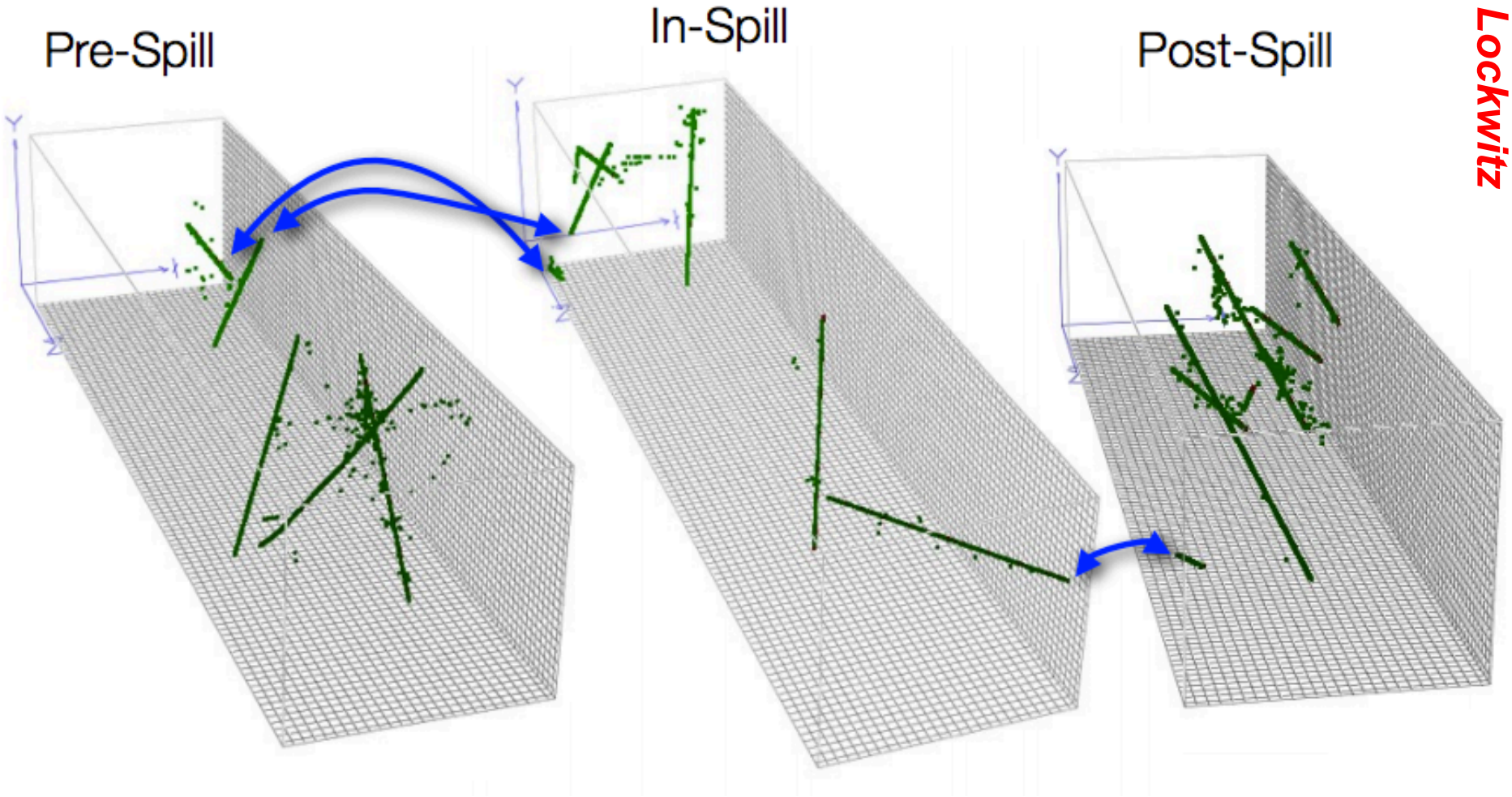
a) Do any of these tracks have something to do with a neutrino interaction?
(5 points)

b) If so, which ones?
(15 points)

c) Find some information about one or more of these tracks which is inaccessible to the TPC
(10 points extra credit)

Partial answer to Part (b) from the TPC

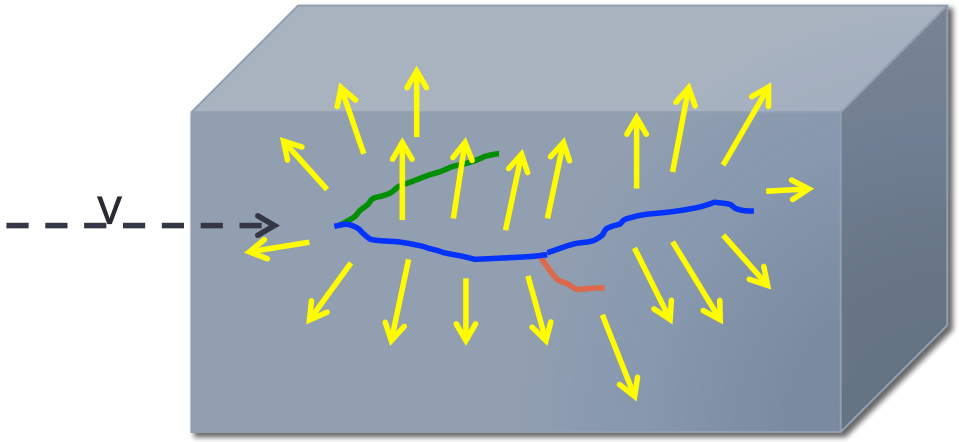
Sarah Lockwitz

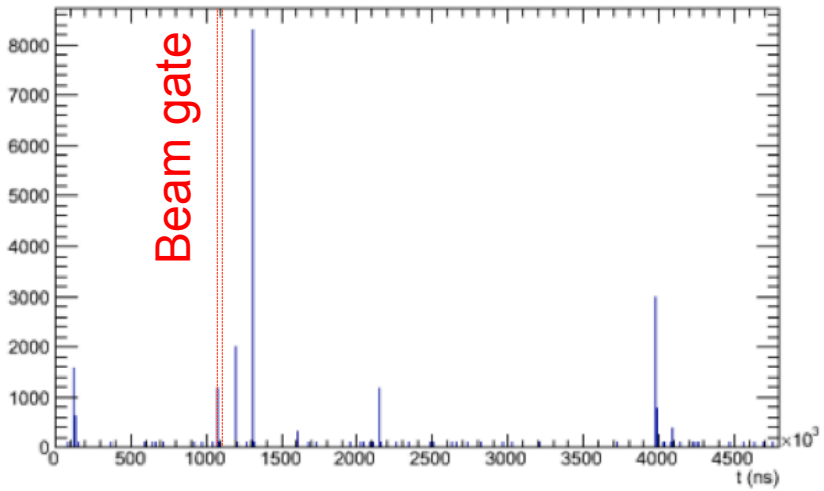


A large fraction (~70%) of cosmics are not contained within the readout window in MicroBooNE

Beyond that, you need light.

- Energy deposits in liquid argon produce copious scintillation light
- The photon yield is tens of thousands of γ / MeV at 128nm
- Argon is highly transparent to its own scintillation
- Light travels pretty fast
- Thus scintillation detection gives an excellent tool for obtaining timing information





Photon arrival times

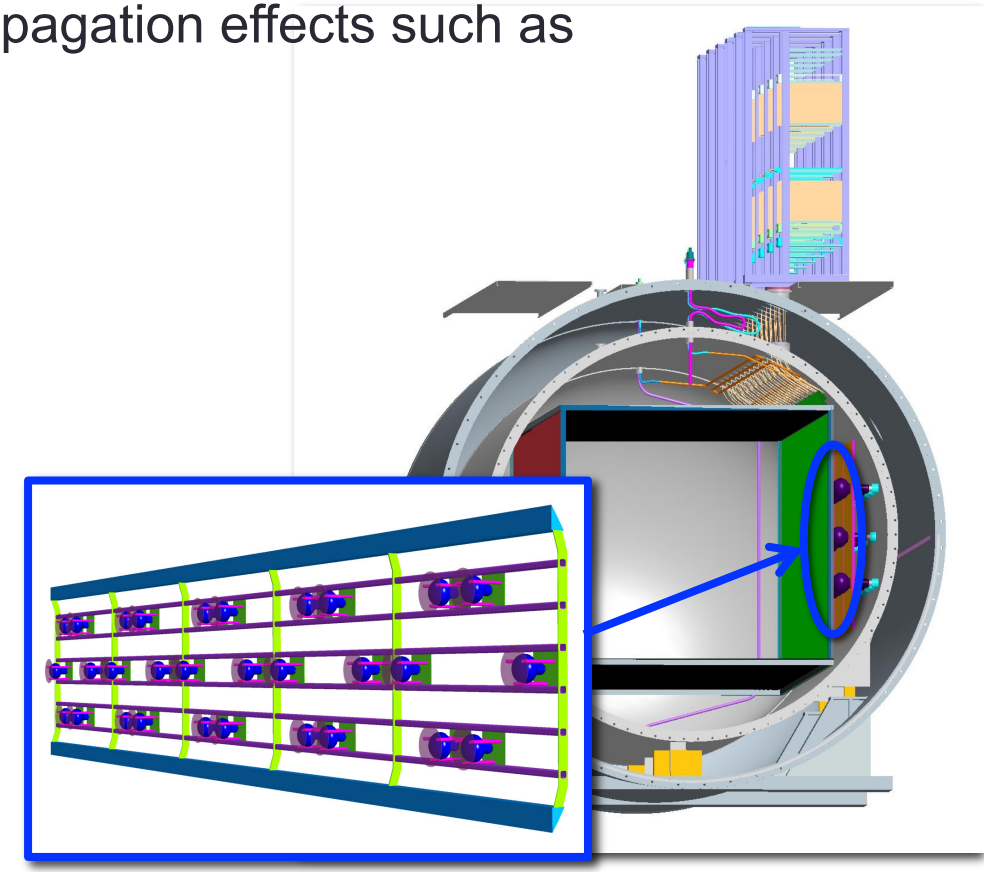
Collecting Light in LArTPCs

- Typically optical detectors arranged at the edge of the volume and have a low (~1%) collection efficiency

- Have to account for nontrivial propagation effects such as
  - *Rayleigh scattering*
  - *Impurity absorption*
  - *Surface reflectivity*
  - *Shadowing from wireplanes*
  - *Etc*

- Real physics events have a nontrivial time structure

- Need an accurate monte carlo simulation



Optical Simulations in LArSoft

Optical Simulations in LArSoft - Technical Manual

Ben Jones, Massachusetts Institute of Technology

December 12, 2012

Abstract

This note describes the optical monte carlo simulation tools which have been developed within the LArSoft framework for MicroBooNE, LBNE and other detectors with optical systems. I try to give a full technical overview of the function of optical physics features in LArSoft and how they should be used. This note is intended to be used as a reference in conjunction with the LArSoft code repository, and of use to both users and developers of LArSoft optical simulations.

Long technote available on LArSoft wiki page

Please go to the LArSoft page rather than LBNE or MicroBooNE DocDB to find the up to date version!

- Steady development of optical tools in LArSoft over a period of ~3 years
- By the nature of LArSoft, can be translated “effortlessly” to any future LArTPC detector
- “Effortless” transition to LBNE is ongoing

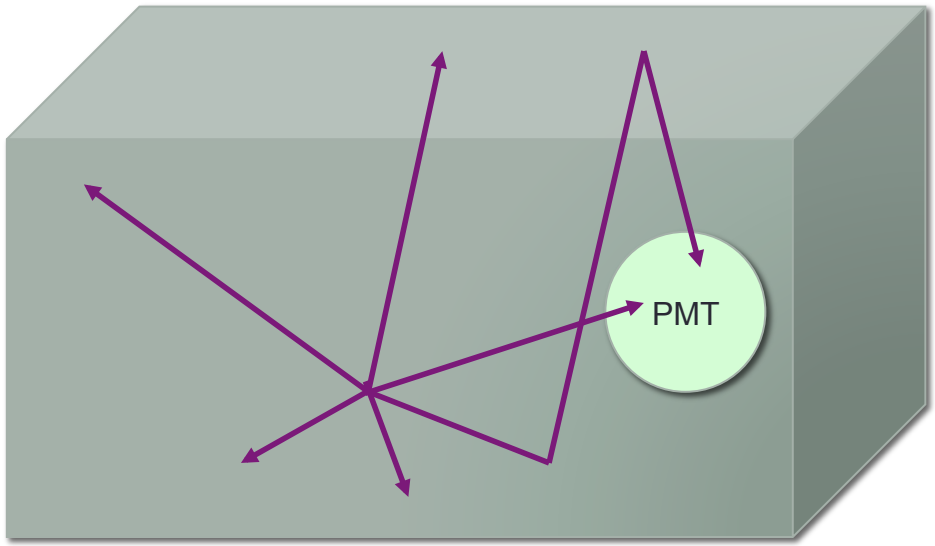
Two Modes of Simulation

- **Full Photon Stepping Simulation**

- Fast Photon Table Sampling Simulation

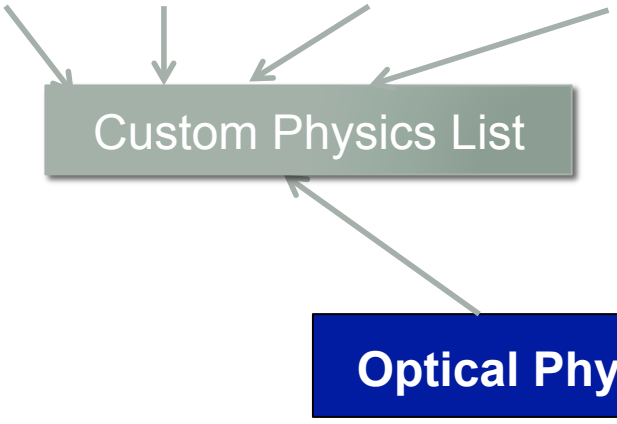
Full Simulation

- Step all tens of thousdands of photons around the detector for each event
- Very slow, and not practical for production jobs
- But a vital component for generating the fast time lookup table, and also an important and versatile tool for specific small scale studies.



Optical Processes in LArG4

- The physics list in LarSoft is configurable, with various physics constructors which can be switched on and off at job configuration time
- Optical physics processes are loaded via the ”OpticalPhysics” GEANT4 physics constructor, which was customized to fit our needs in LarSoft.



Scintillation production*
Cerenkov production
Rayleigh Scattering
Specular and Diffuse Reflections
Absorption at surfaces
Wavelength shifting
Absorption in argon bulk

* May soon be supplemented by NEST

Default G4 process
Custom written for LArSoft

Optical Properties of Materials

- Any simulation is only as good as its parameters!
- We parameterize all the items below – see technote for full details.

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

Refractive Index

Absorption

Absorption Length

Rayleigh Scattering

Scattering Length

WLS

Absorption spectrum
Emission spectrum
Time Constant
Yield out / in

Per Boundary Type

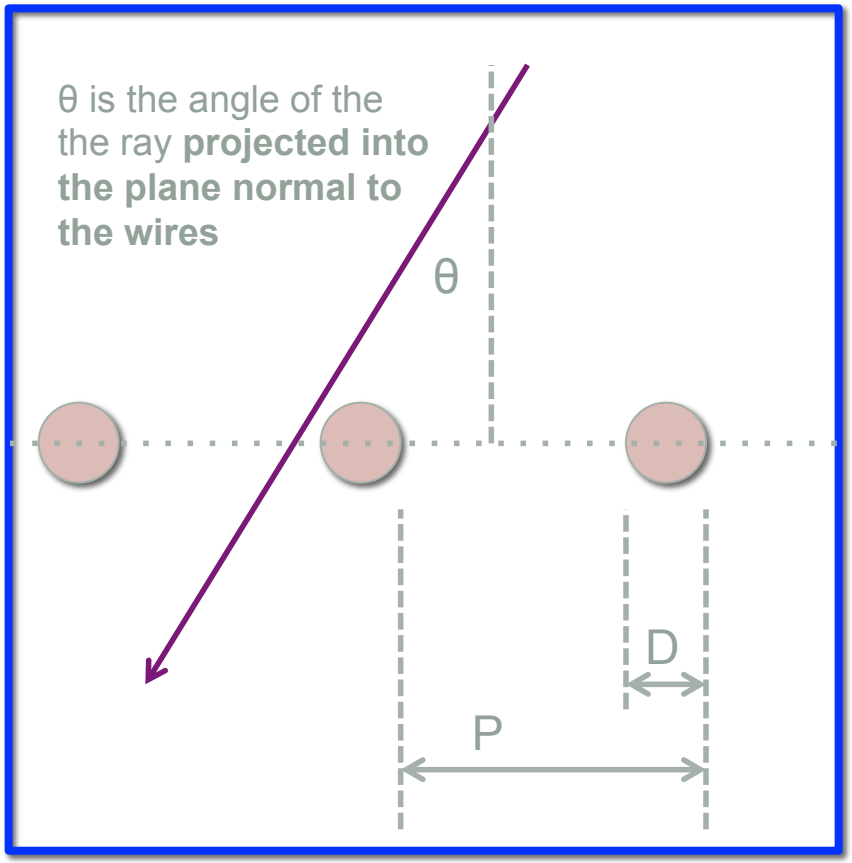
Reflections

Total Reflectivity
Fraction specular / diffuse

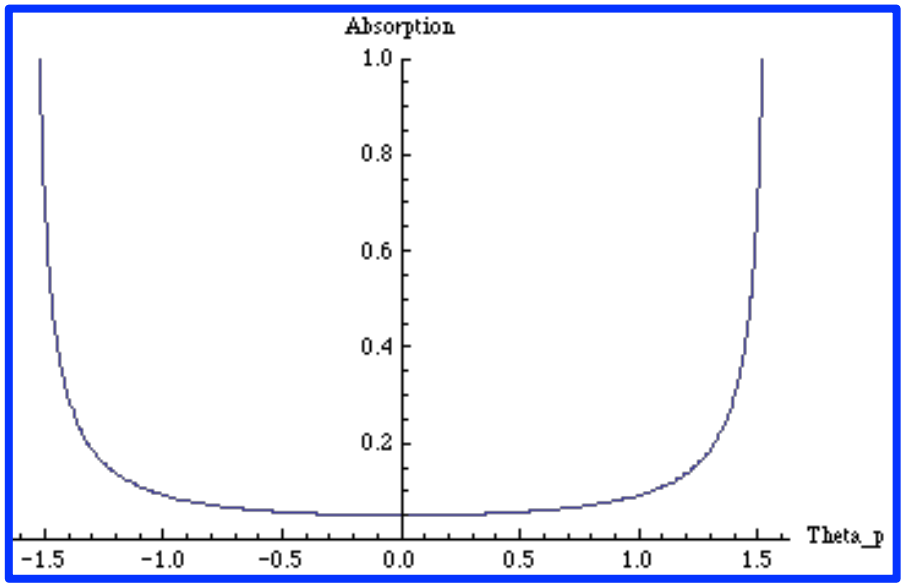
Wavelength dependent
Non wavelength dependent

Parameterized Wireplanes, etc

- Models transmittance as a function of incident light angle on a wireplane of pitch P and wire diameter D

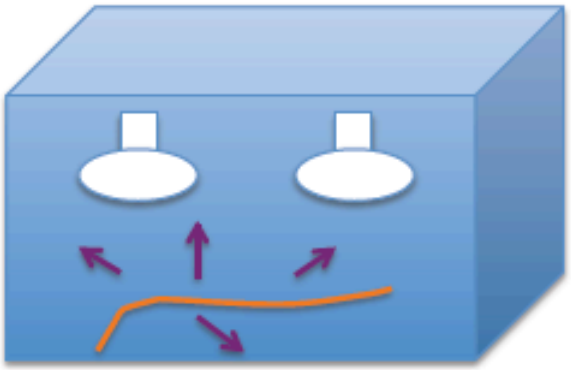


$$P_{trans} = \begin{cases} 1 - \frac{D}{P cos\theta} & cos\theta > \frac{D}{P} \\ 0 & cos\theta \leqslant \frac{D}{P} \end{cases}$$



"Real" world

No sensitive detectors

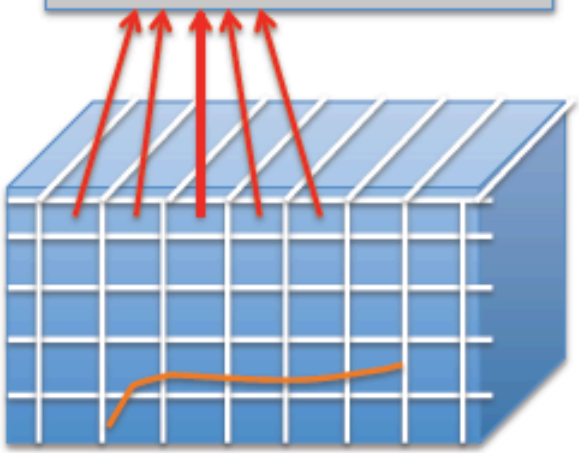


- Full physical geometry
- Both photons and particles stepping

LArVoxelReadoutGeometry
(TPC simulation)

Record energy losses

LArVoxelReadout

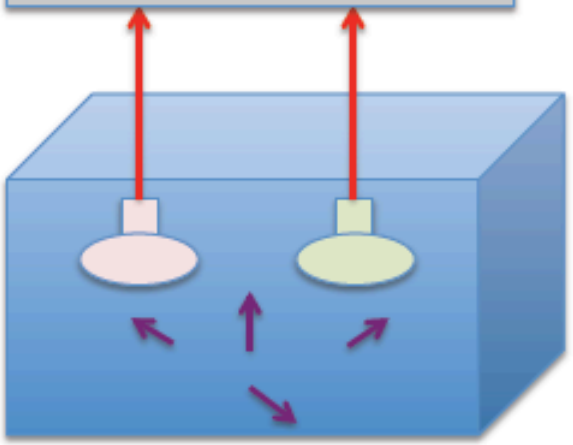


- Voxels for charge deposit measurement
- Photons do not exist

OpDetReadoutGeometry
(Optical simulation)

Record photon detection

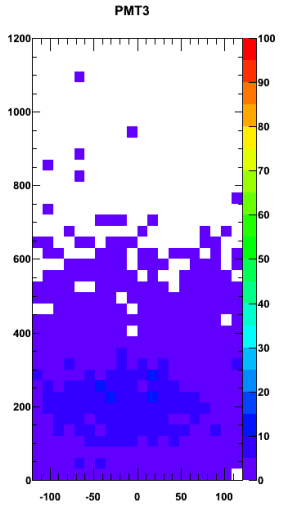
OpDetSensitiveDetector

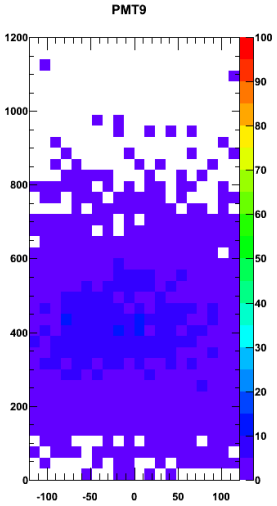


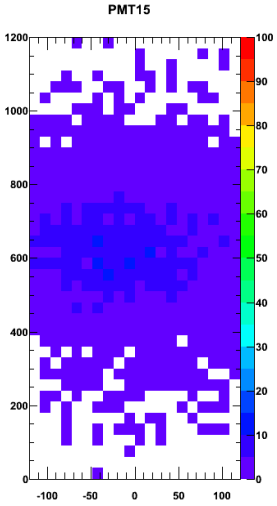
- Separate sensitive volumes per PMT
- Photons exist
- No other particles exist

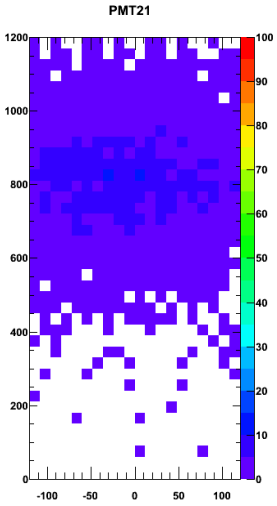
All carefully designed to allow any type of optical detector,
And be as efficient as possible for any TPC geometry.

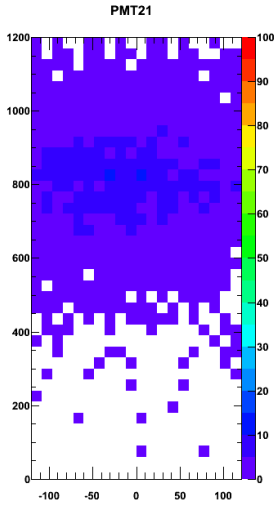
PMT Coverage Test

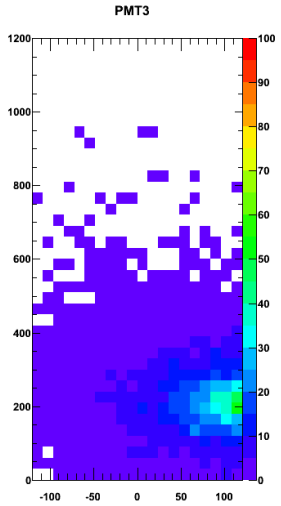


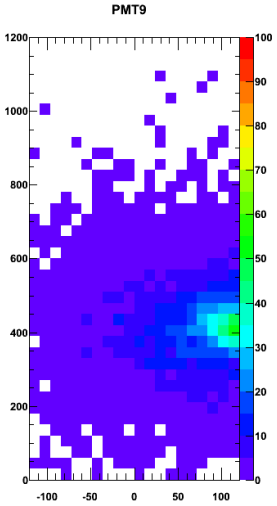


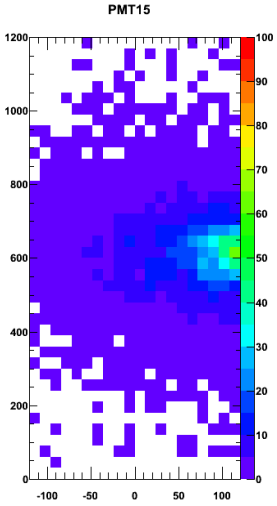


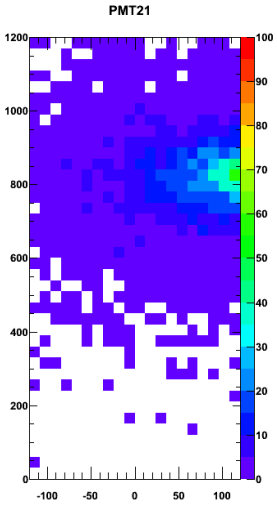


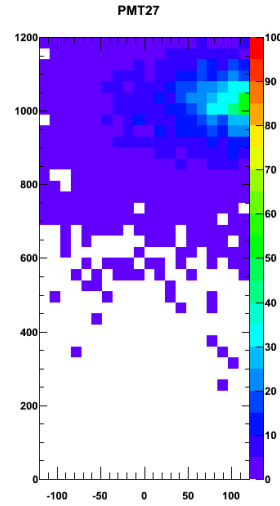




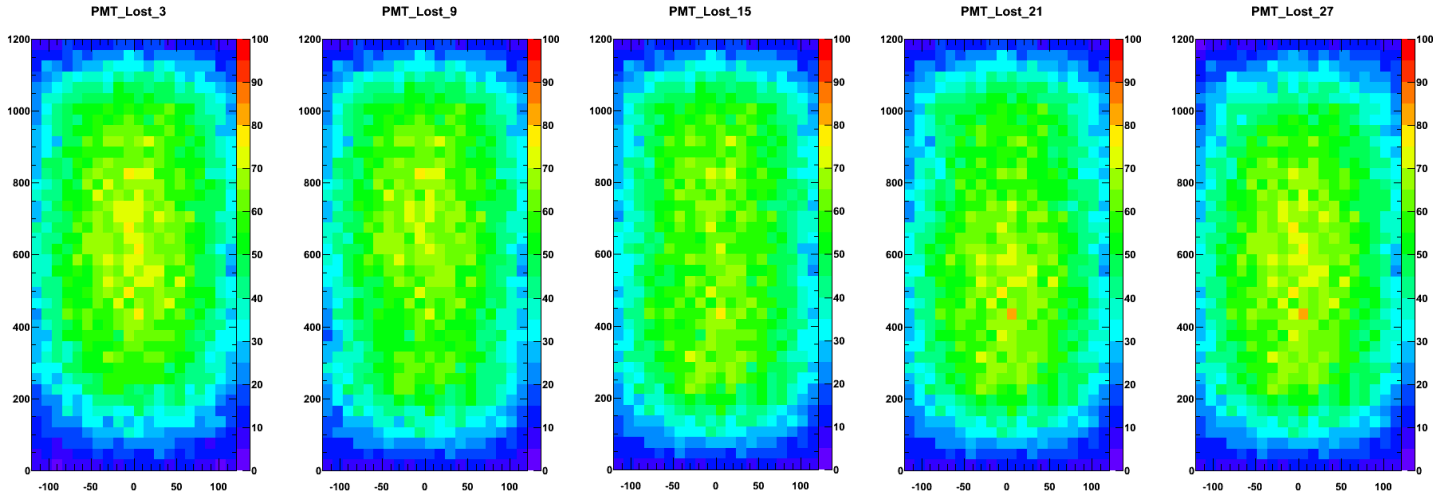


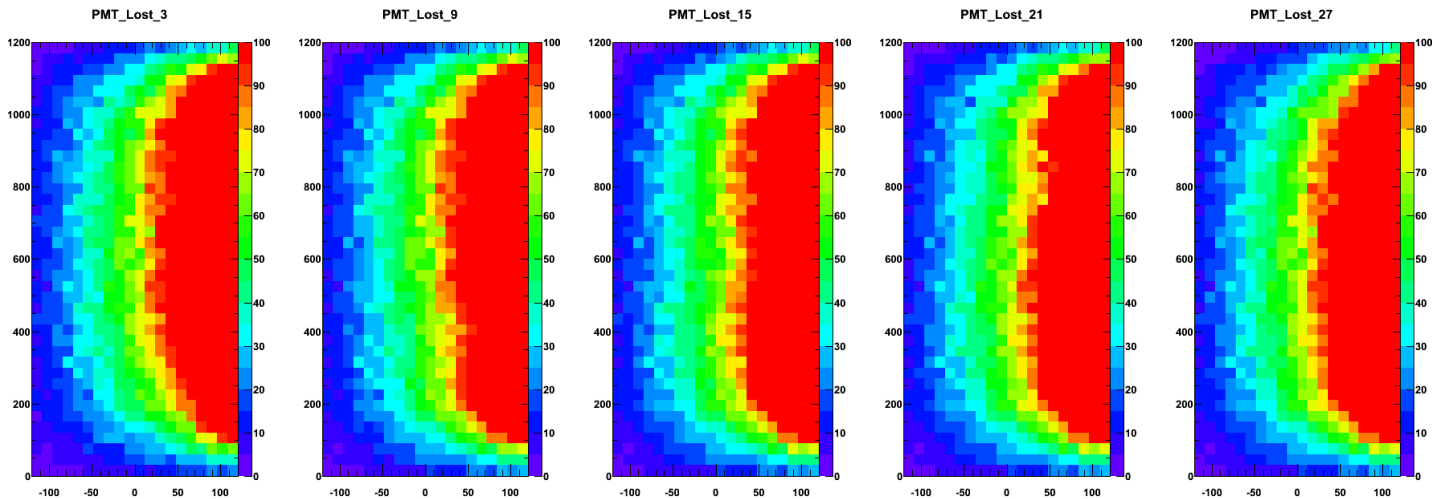




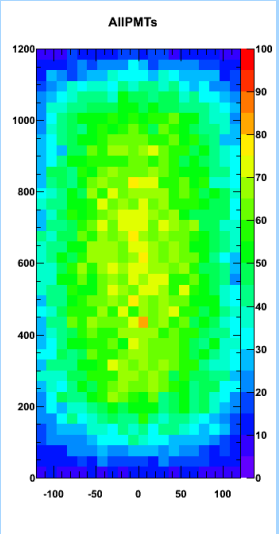


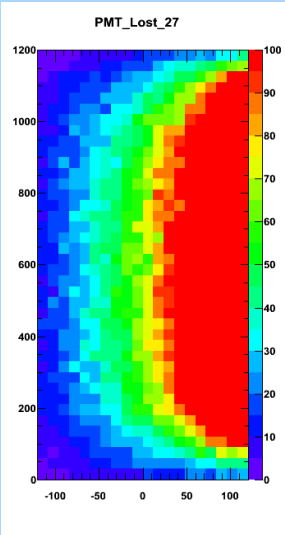
PMT Redundancy Test





ONE PMT MISSING





ALL PMTS

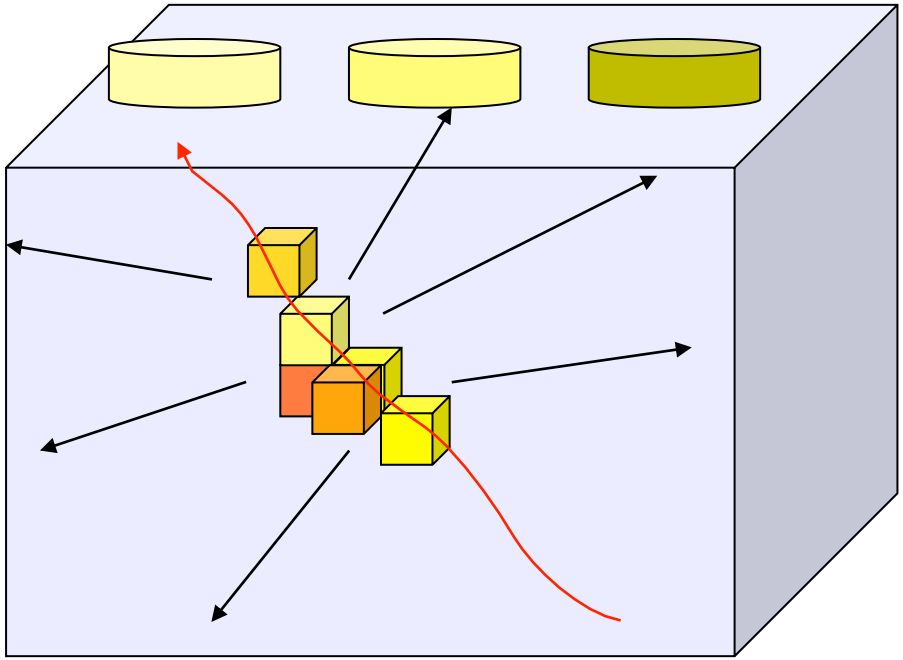
Two Modes of Simulation

- Full Photon Stepping Simulation
- *Whose only purpose is basically to enable…*

- **Fast Photon Table Sampling Simulation**

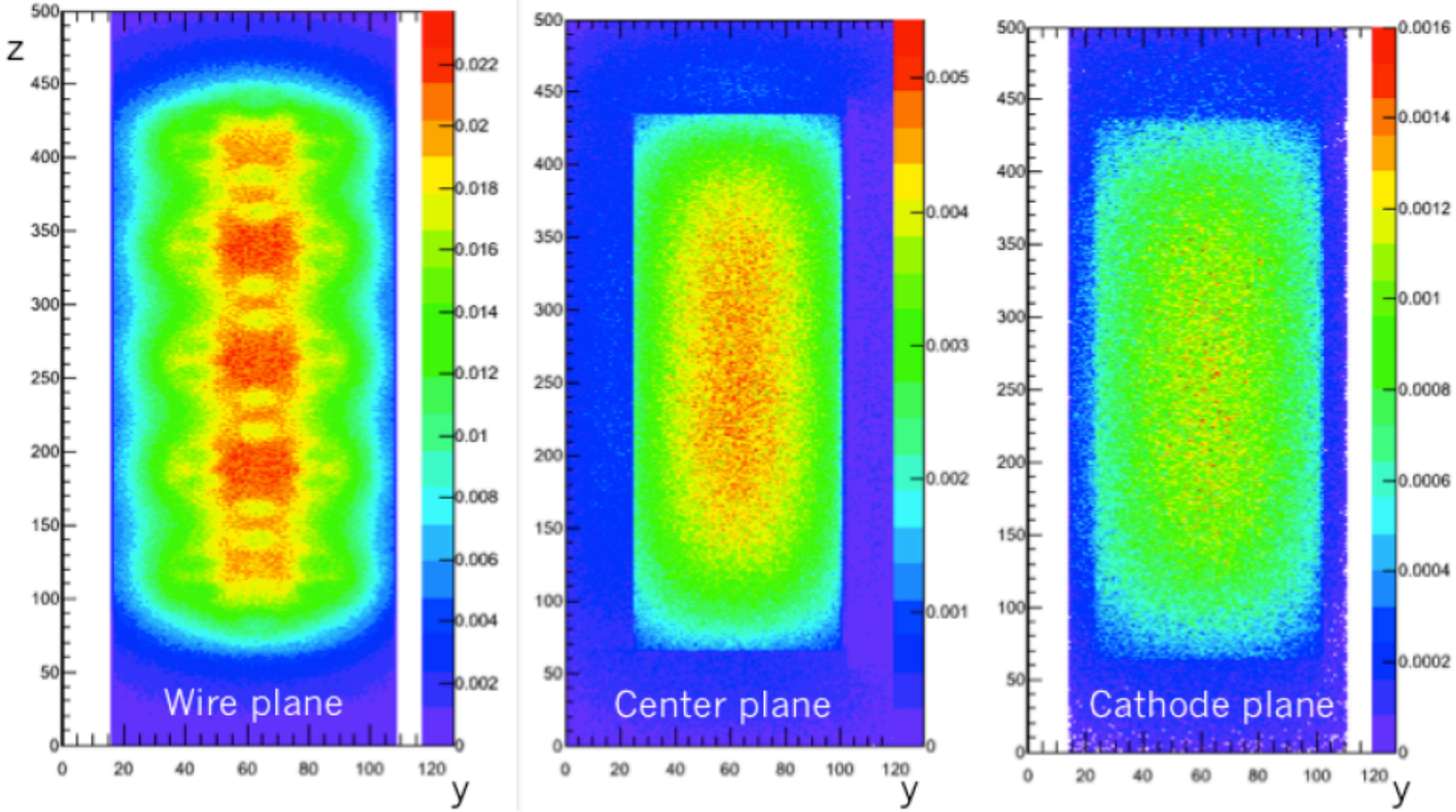
Fast Simulations and Photon Library Sampling

- 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 optical detector?

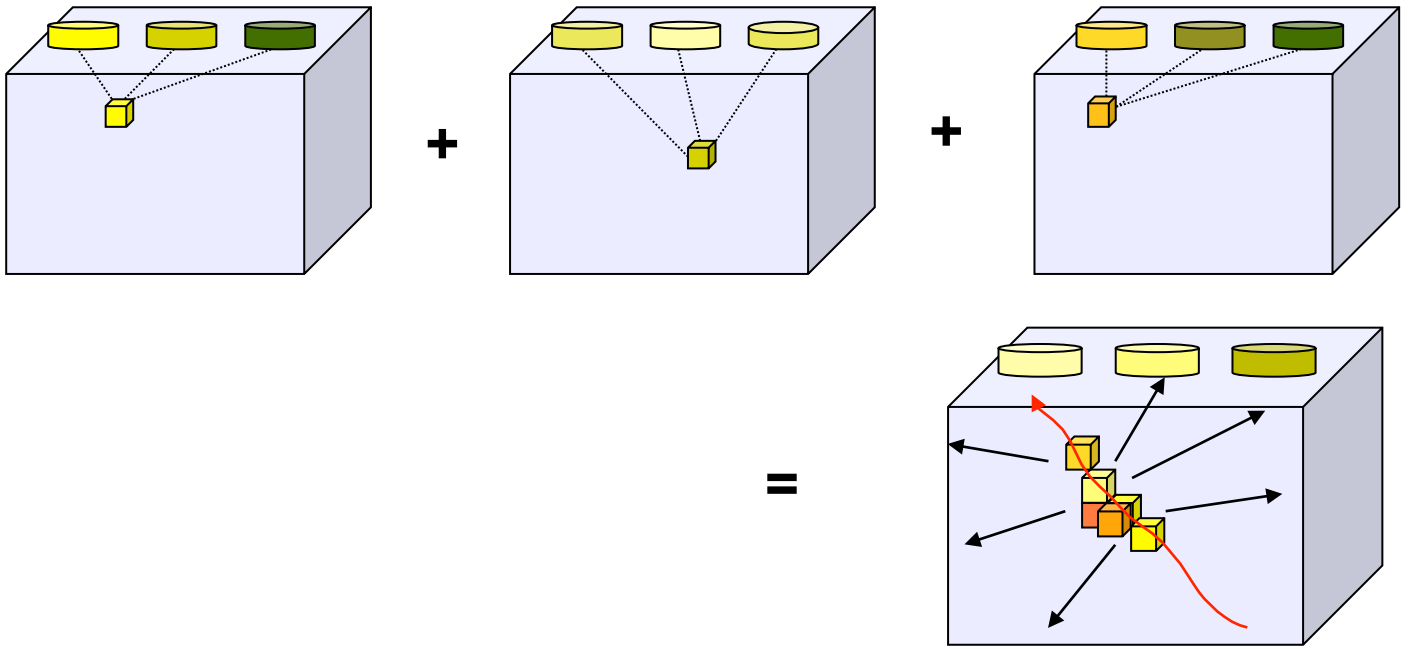
MicroBooNE Library Slices



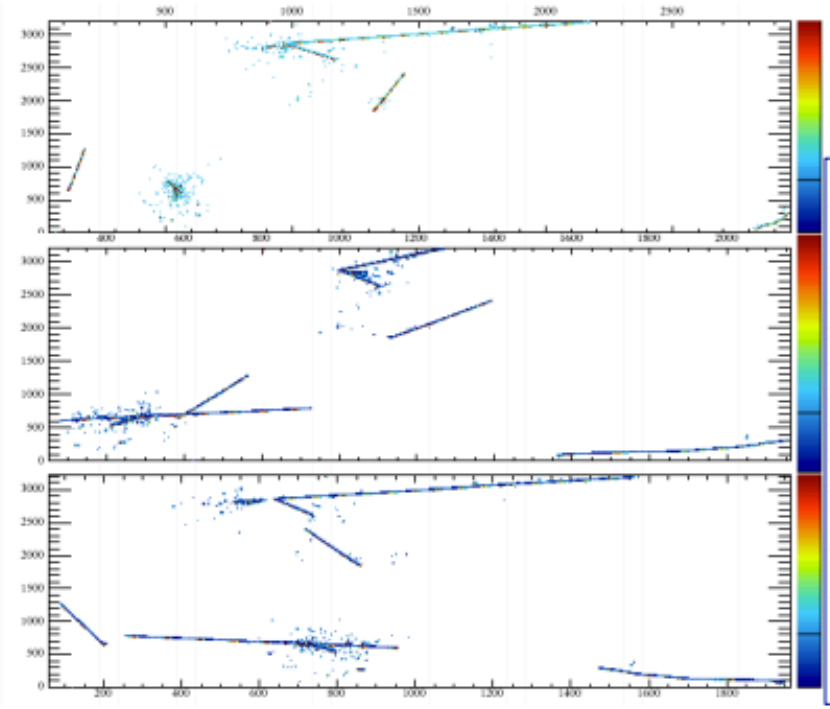
Photon library generated using point light sources across volume

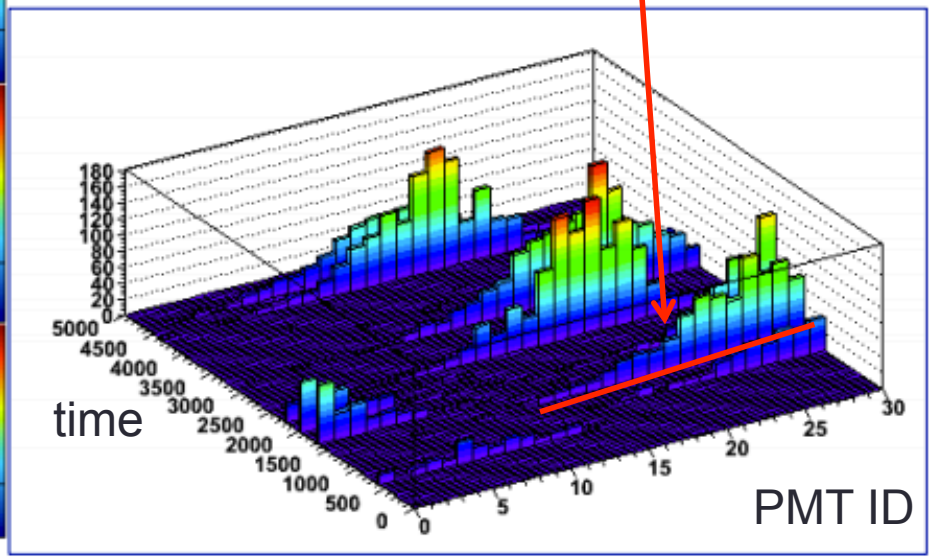
Library Sampling Scintillation Process

- Still treat all the microphysics of scintillation – timing, quenching, etc
- But instead of propagating any photon, look up response in pre-generated table



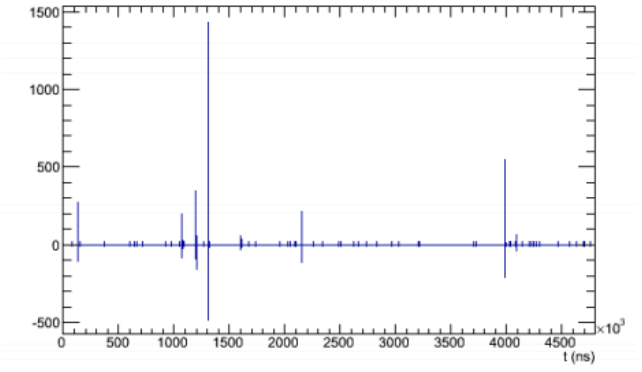
Light Detected from a Cosmic + Neutrino Event

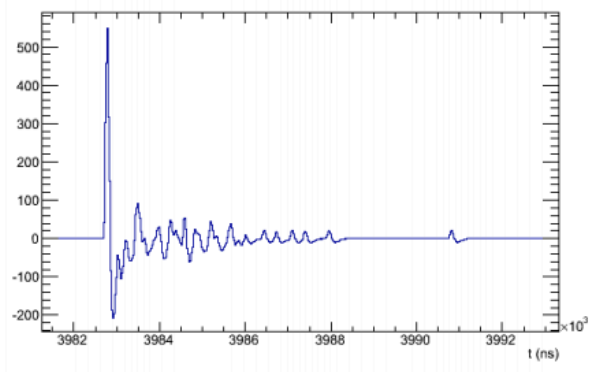




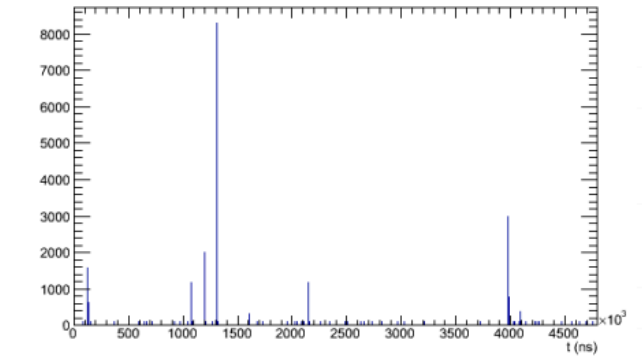
Modeling Electronics Response

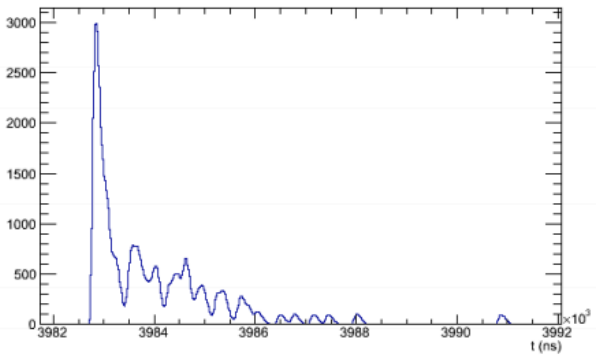
- After optical simulation, we produce realistic digitized signals by convolving with a real single PE function from uB electronics *
- We also add single PE dark noise at real measured dark rate *





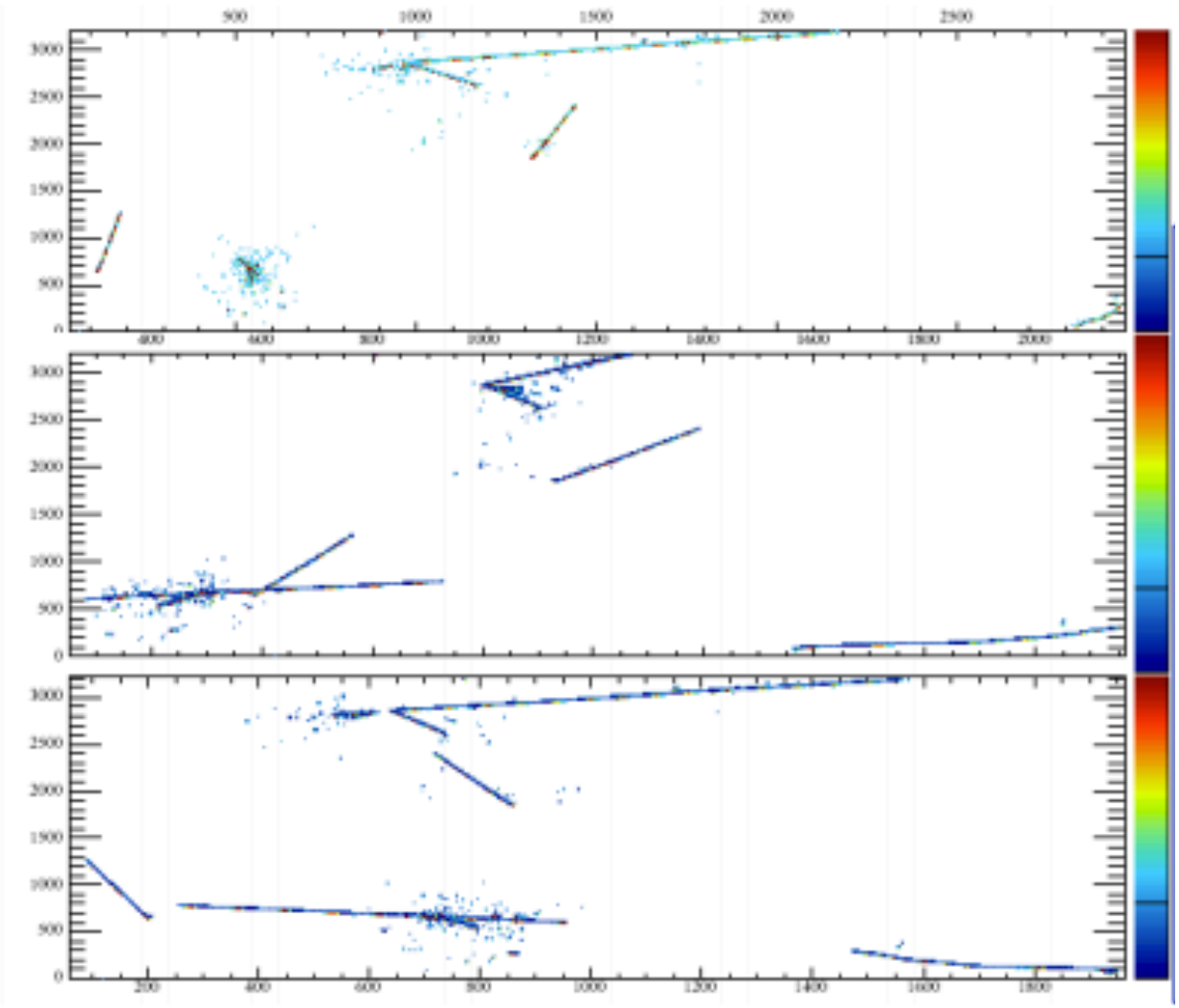
Simulated with bipolar shaper





Simulated with unipolar shaper

* Both measured in Bo test stand – come to my talk tomorrow morning!



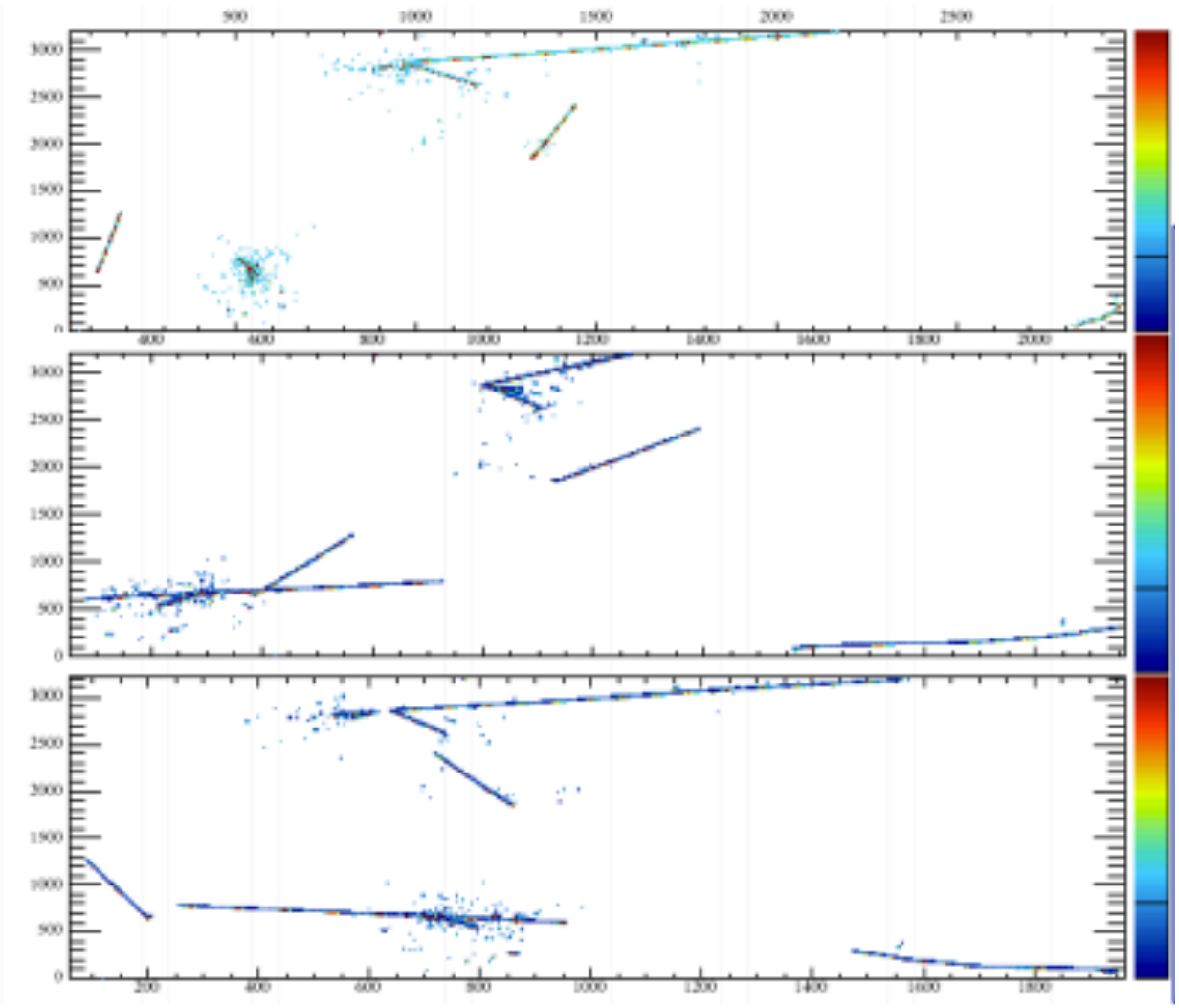
Question 1 (20 points):

a) Do any of these tracks have something to do with a neutrino interaction?
(5 points)

b) If so, which ones?
(15 points)

c) Find some information about one or more of these tracks which is inaccessible to the TPC
(10 points extra credit)

We can now check if there a flash in time with the beam. 5 points!



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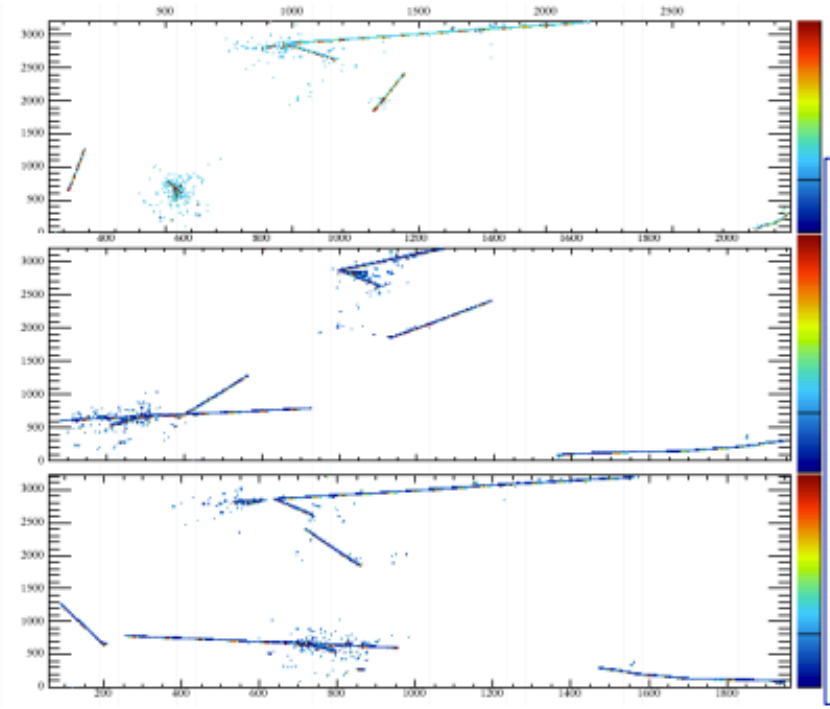
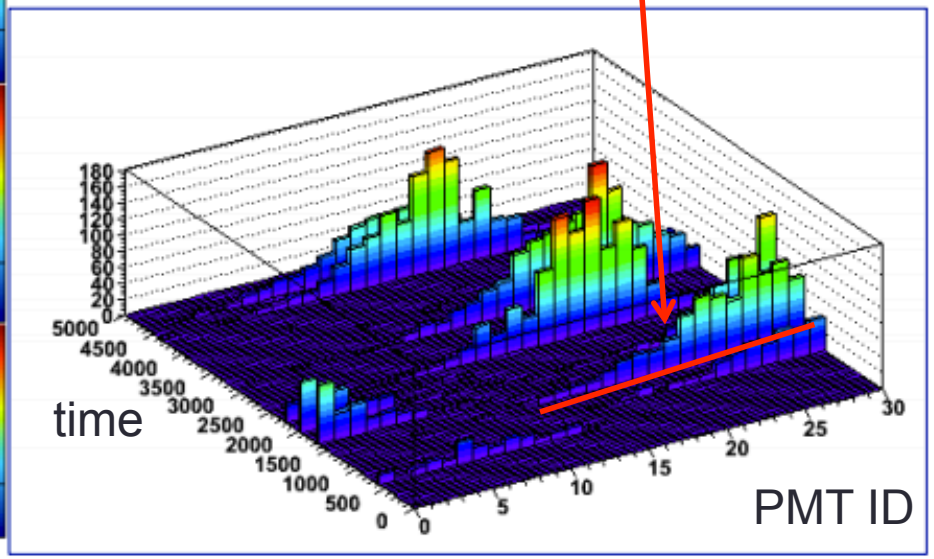
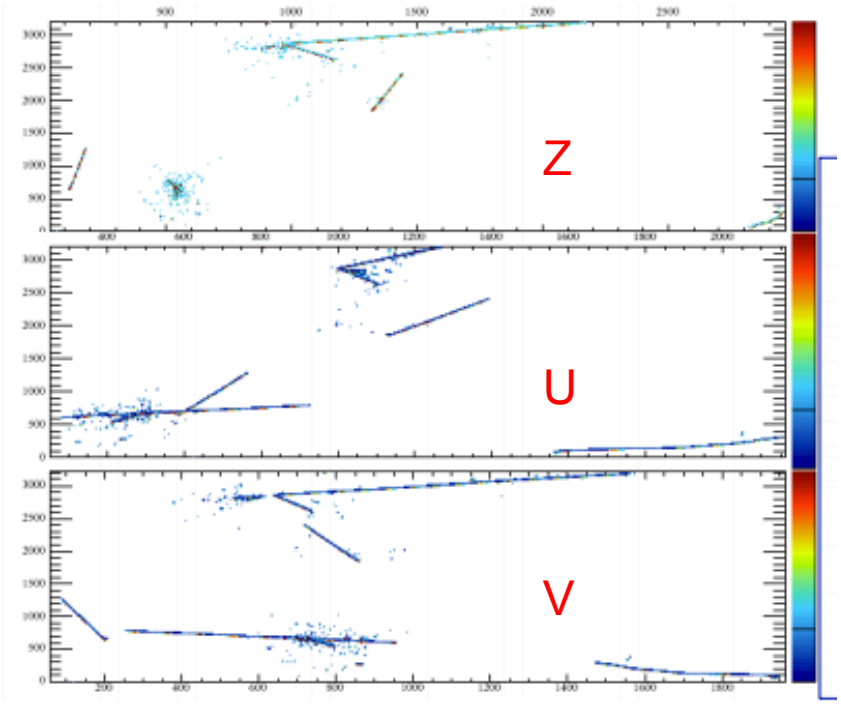
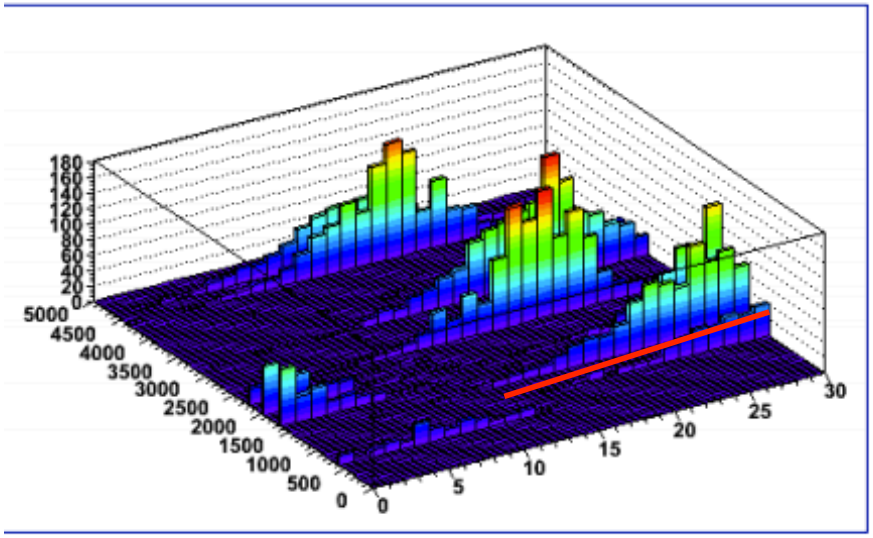




How do we match flashes to tracks?


Z
U
V


180
160
140
120
100
80
60
40
20
0
5000
4500
4000
3500
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2500
2000
1500
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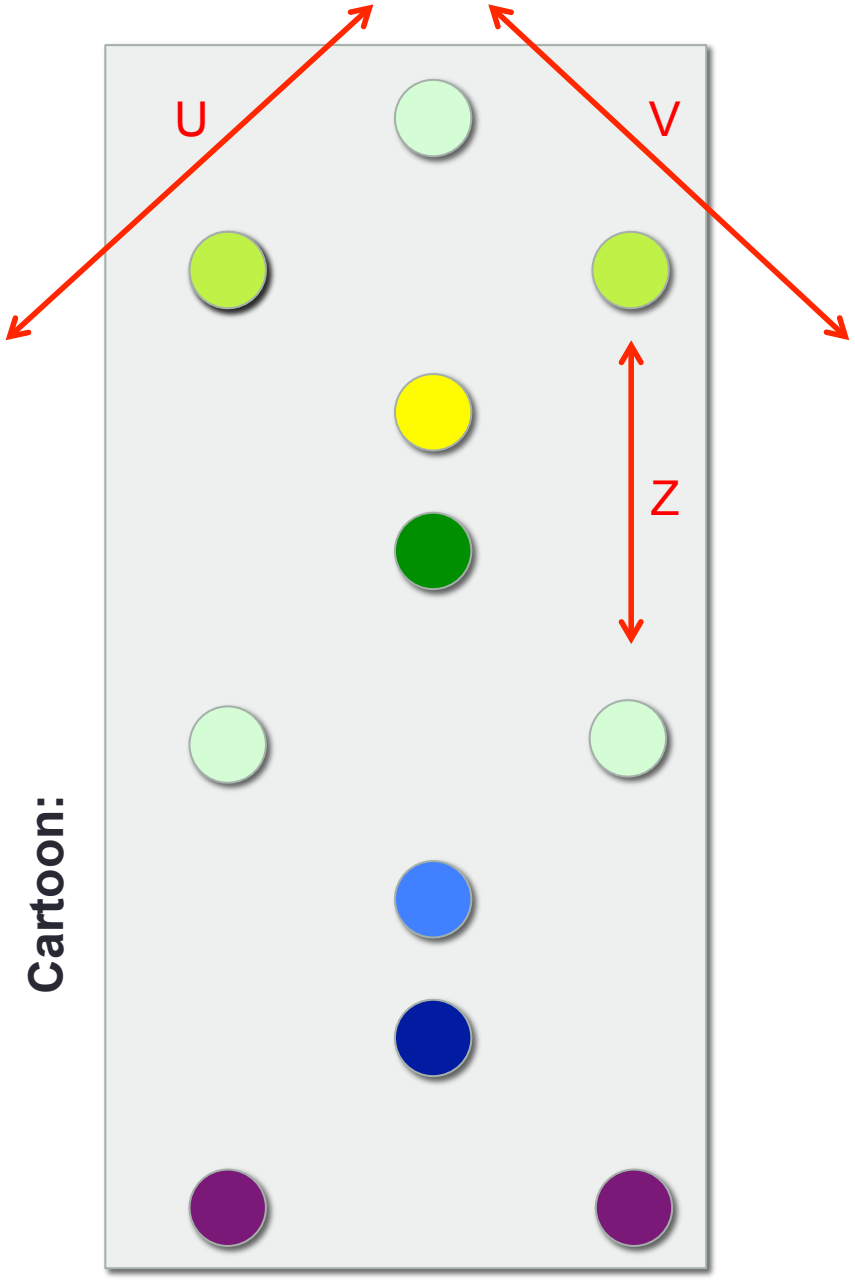
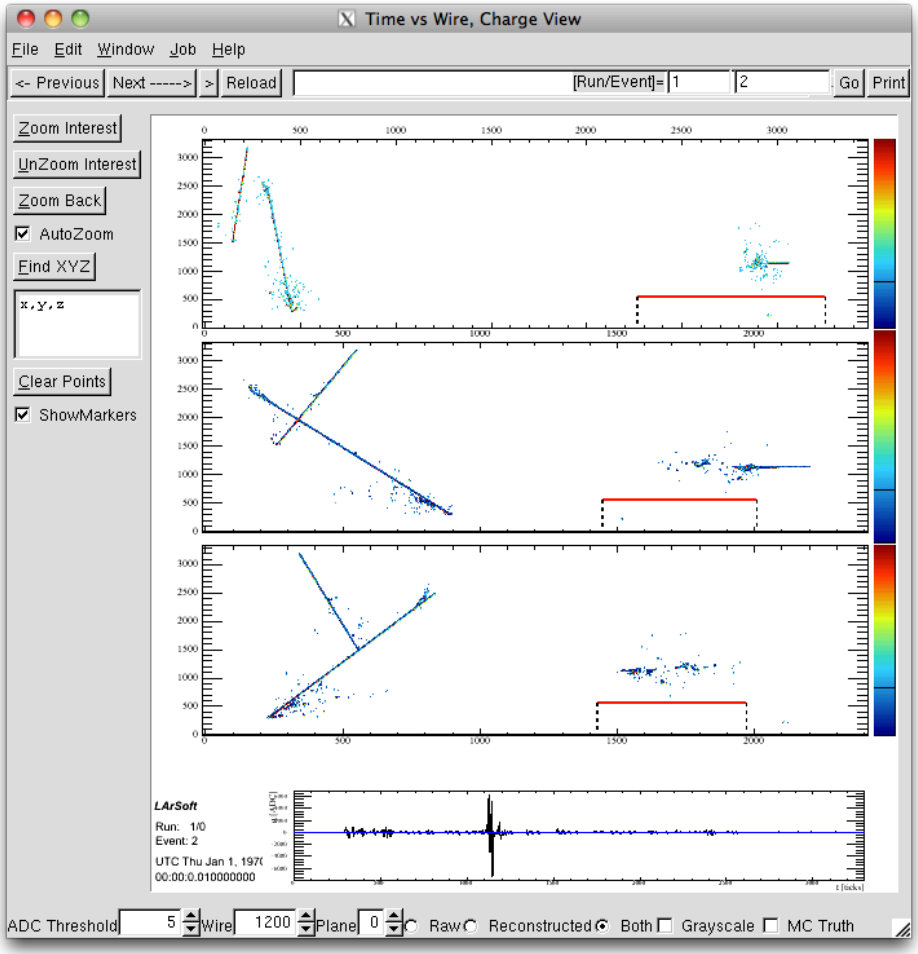
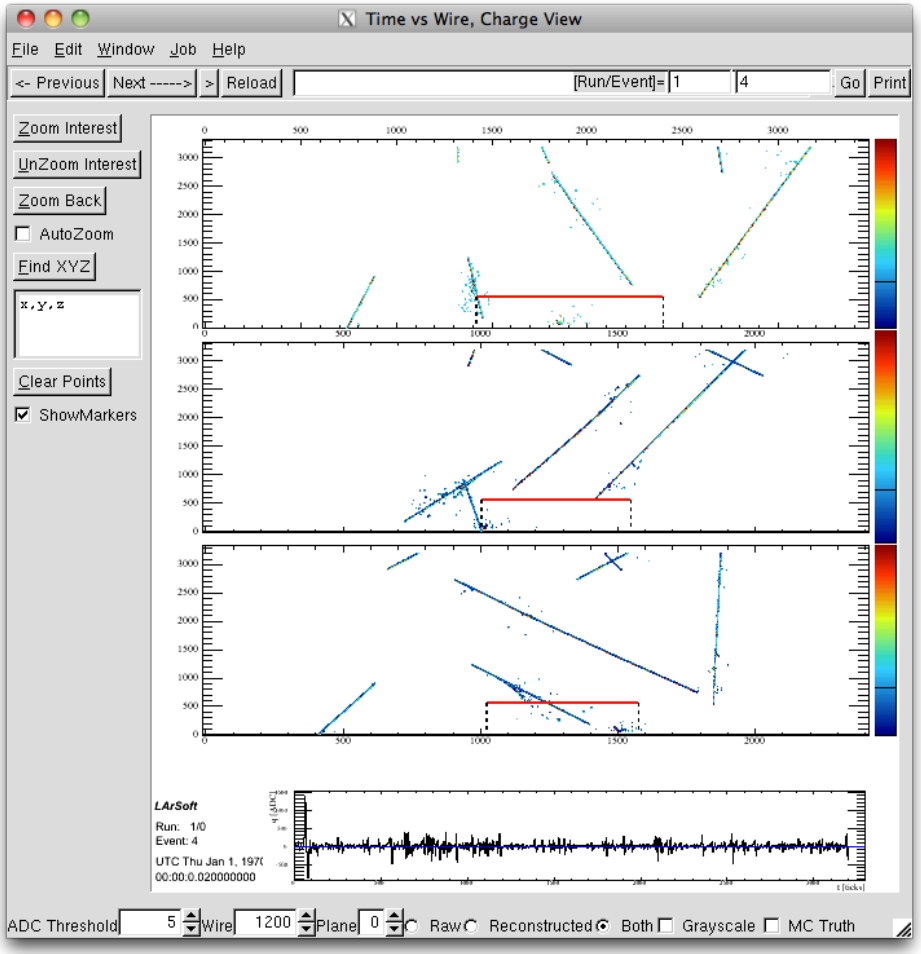
500
0
0
5
10
15
20
25
30

Cartoon:


U
V
Z

Getting Coordinate Information from Flashes



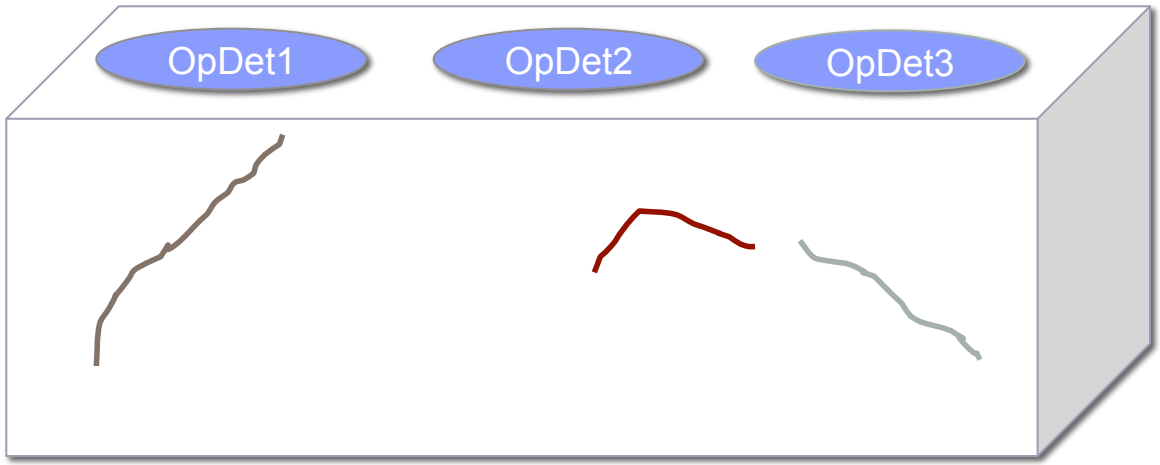


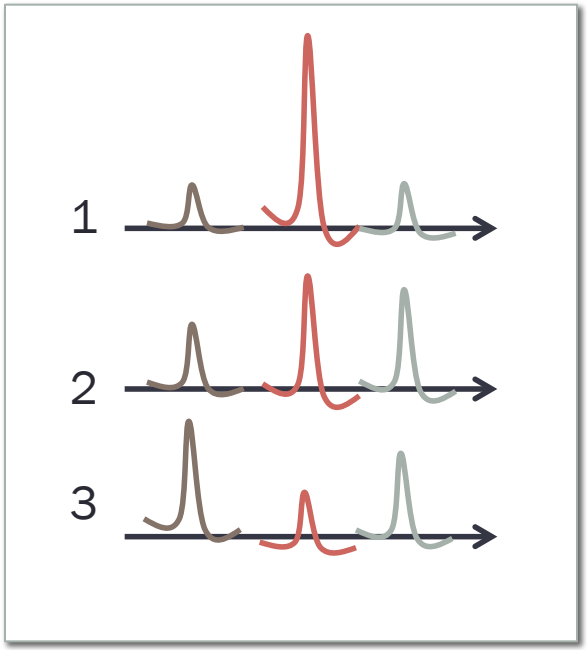
The Critical Next Step

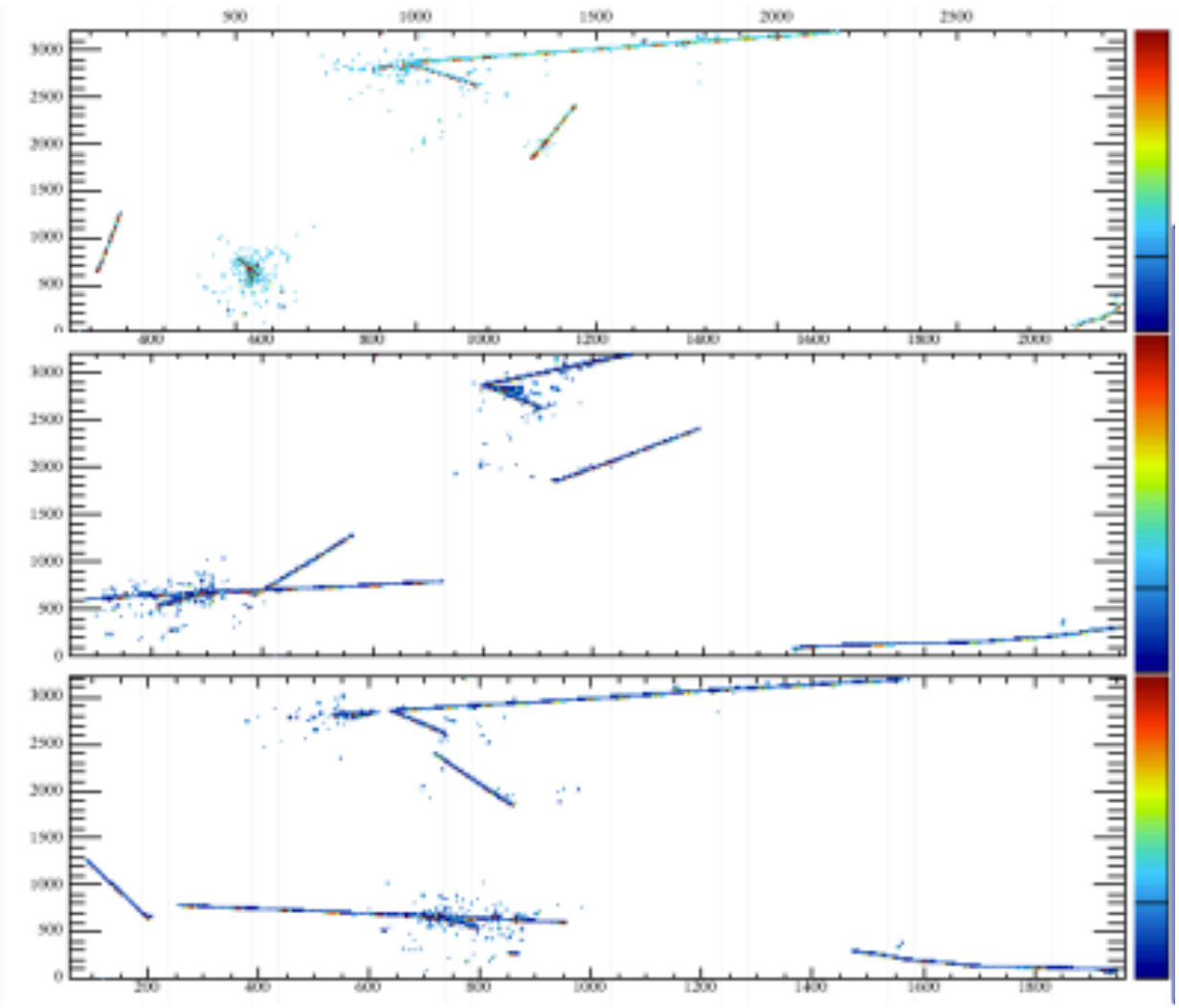
1: Find subevents by matching large PMT signals in time

2: Make hypotheses of relative amount of light per PMT for each track (may need to allow track to float in drift direction)

3: Likelihood fit to match track to light hypothesis, and find T0.







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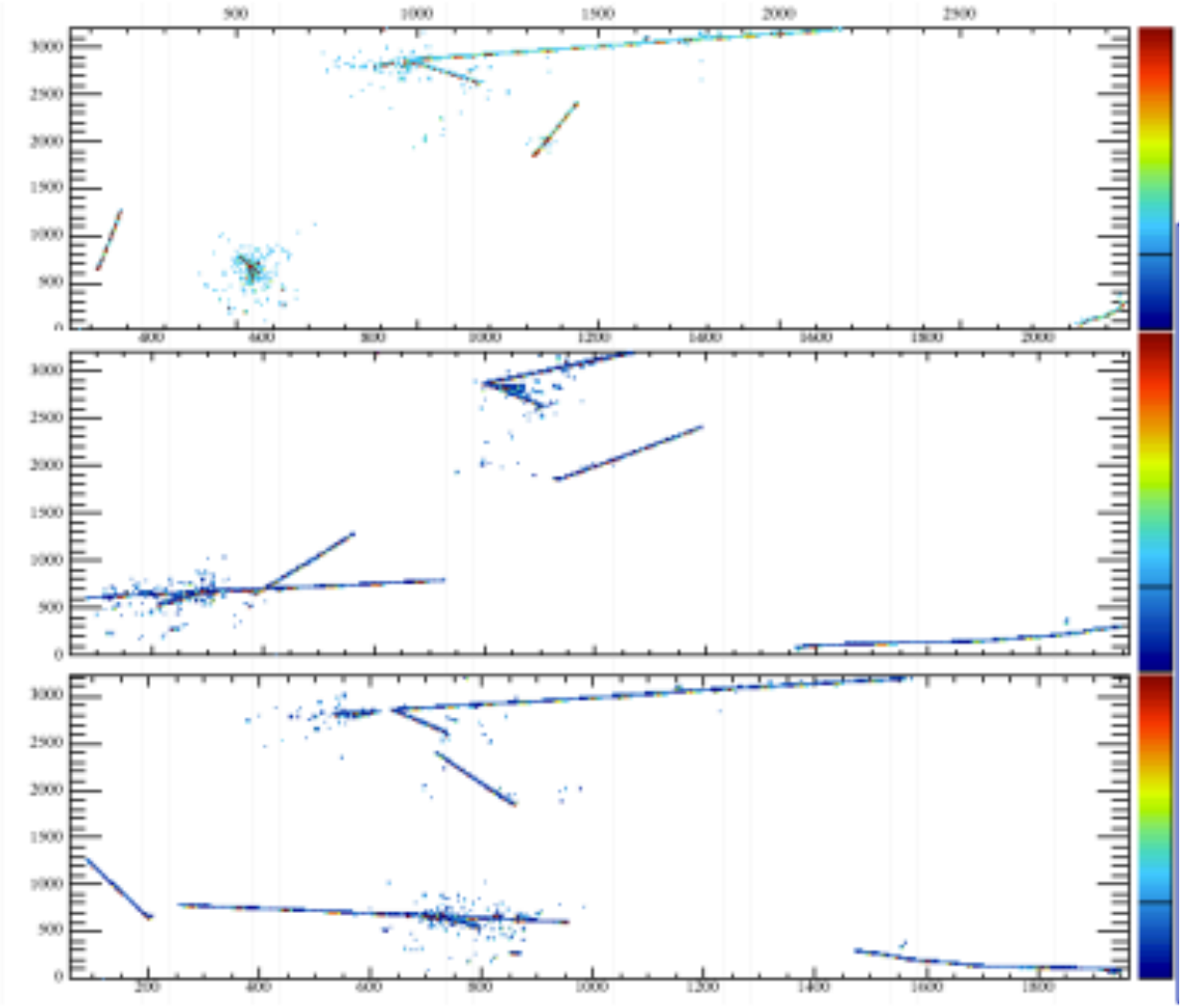
(10 points extra credit)

We are well on our way…



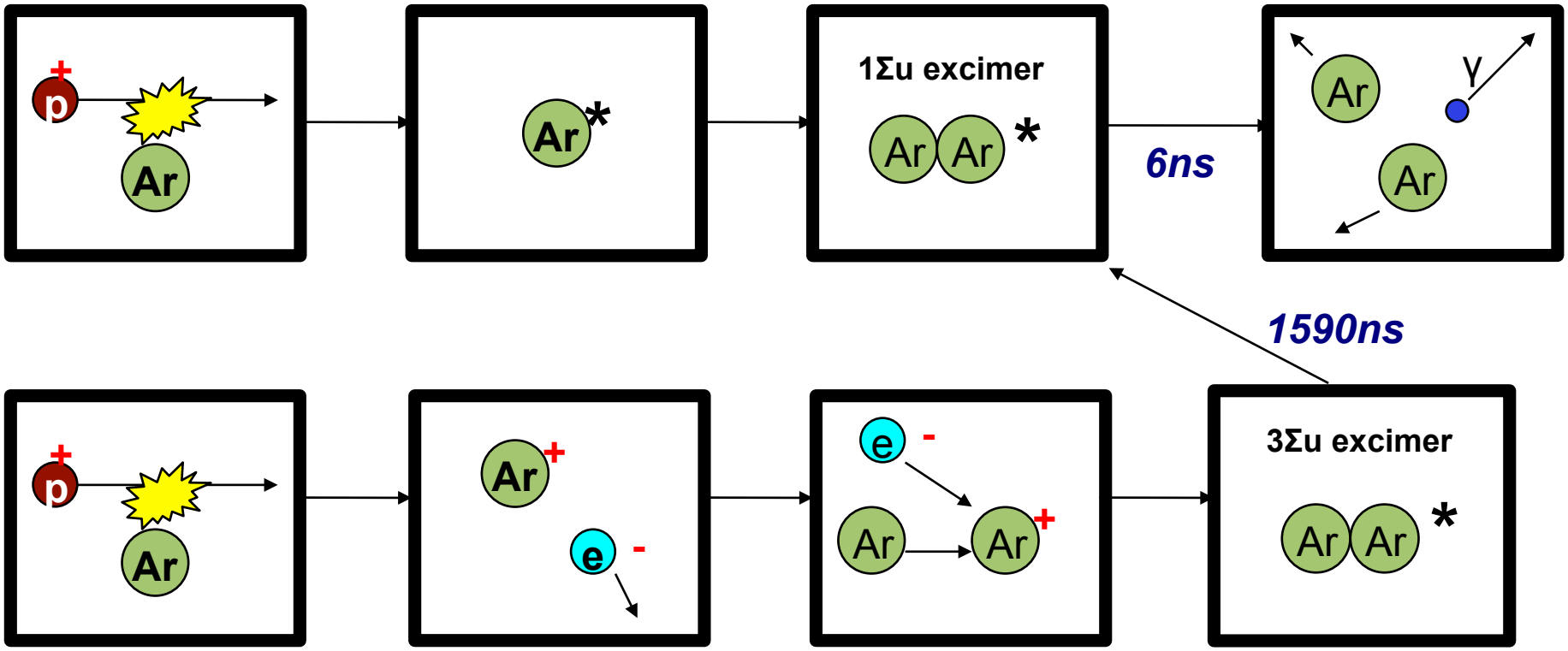
Question 1 (20 points):

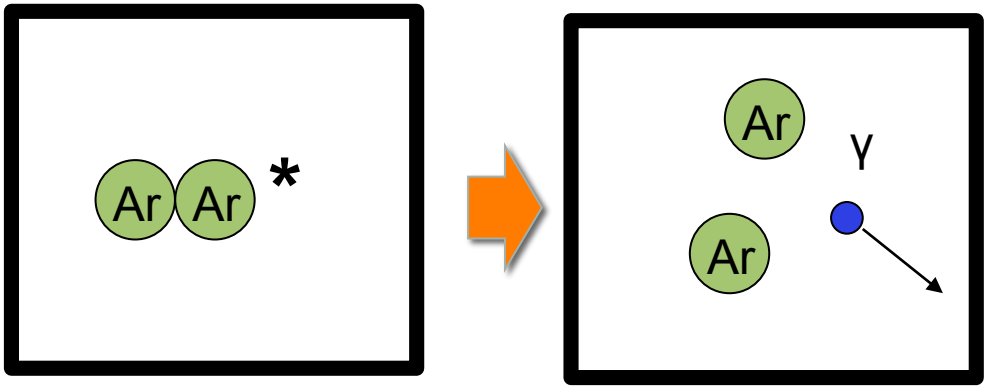
a) Do any of these tracks have something to do with a neutrino interaction?
(5 points)

b) If so, which ones?
(15 points)

c) Find some information about one or more of these tracks which is inaccessible to the TPC
(10 points extra credit)

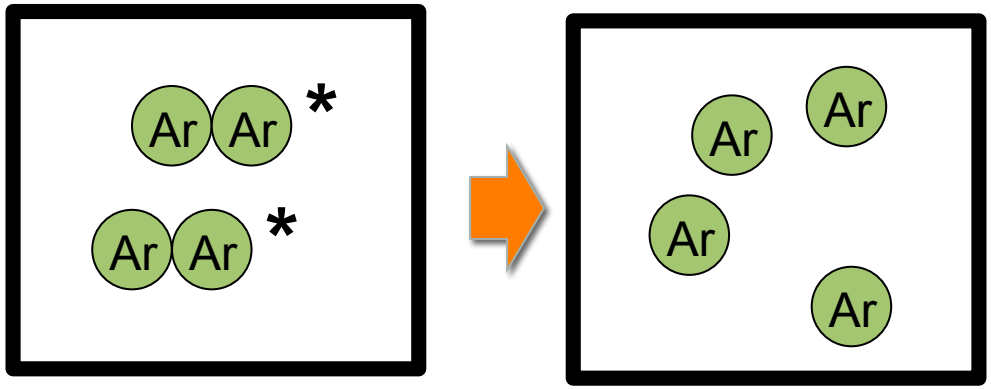
Argon Time Constants

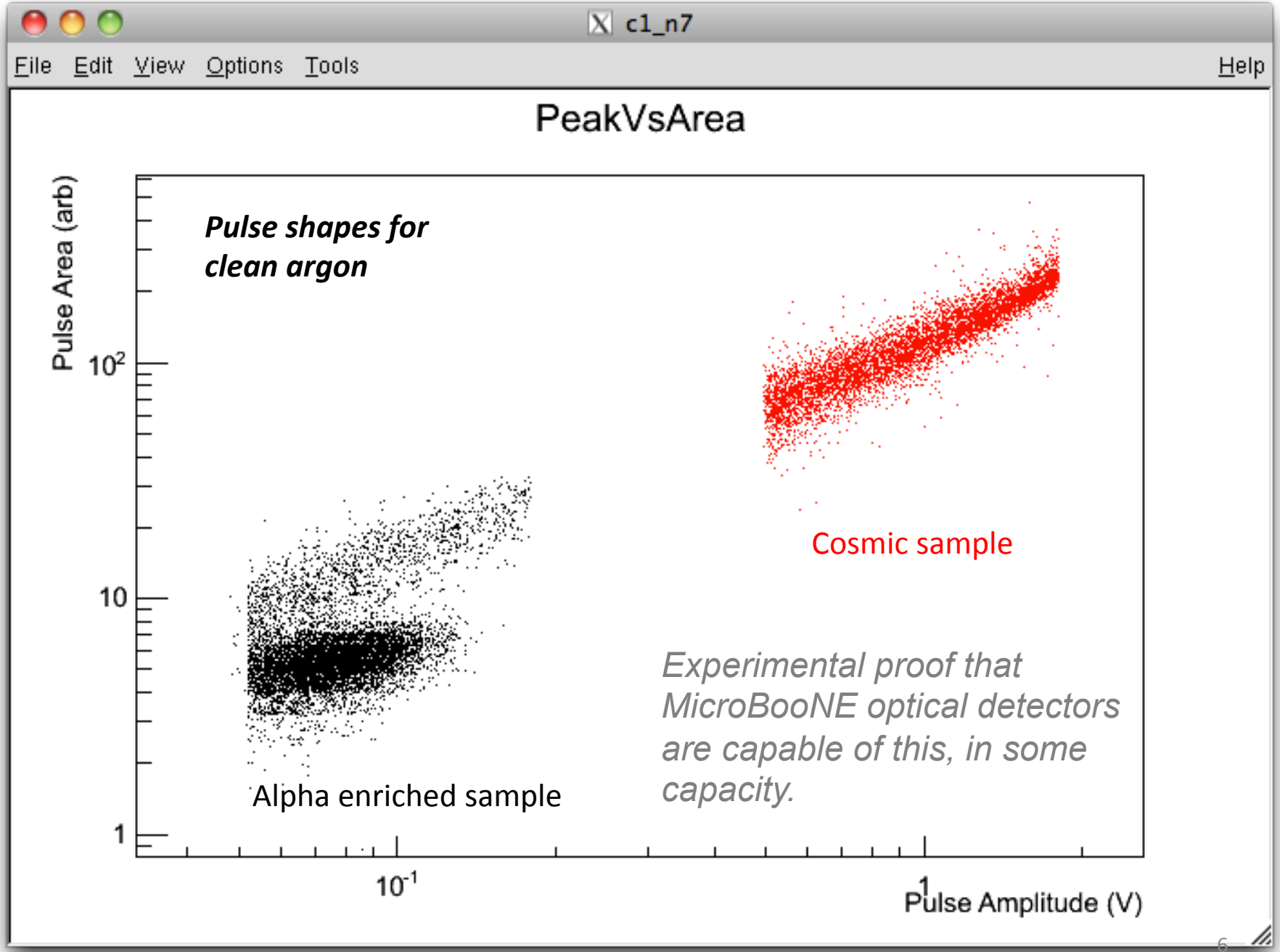




Scintillation process

Competing Excimer Dissociation Process



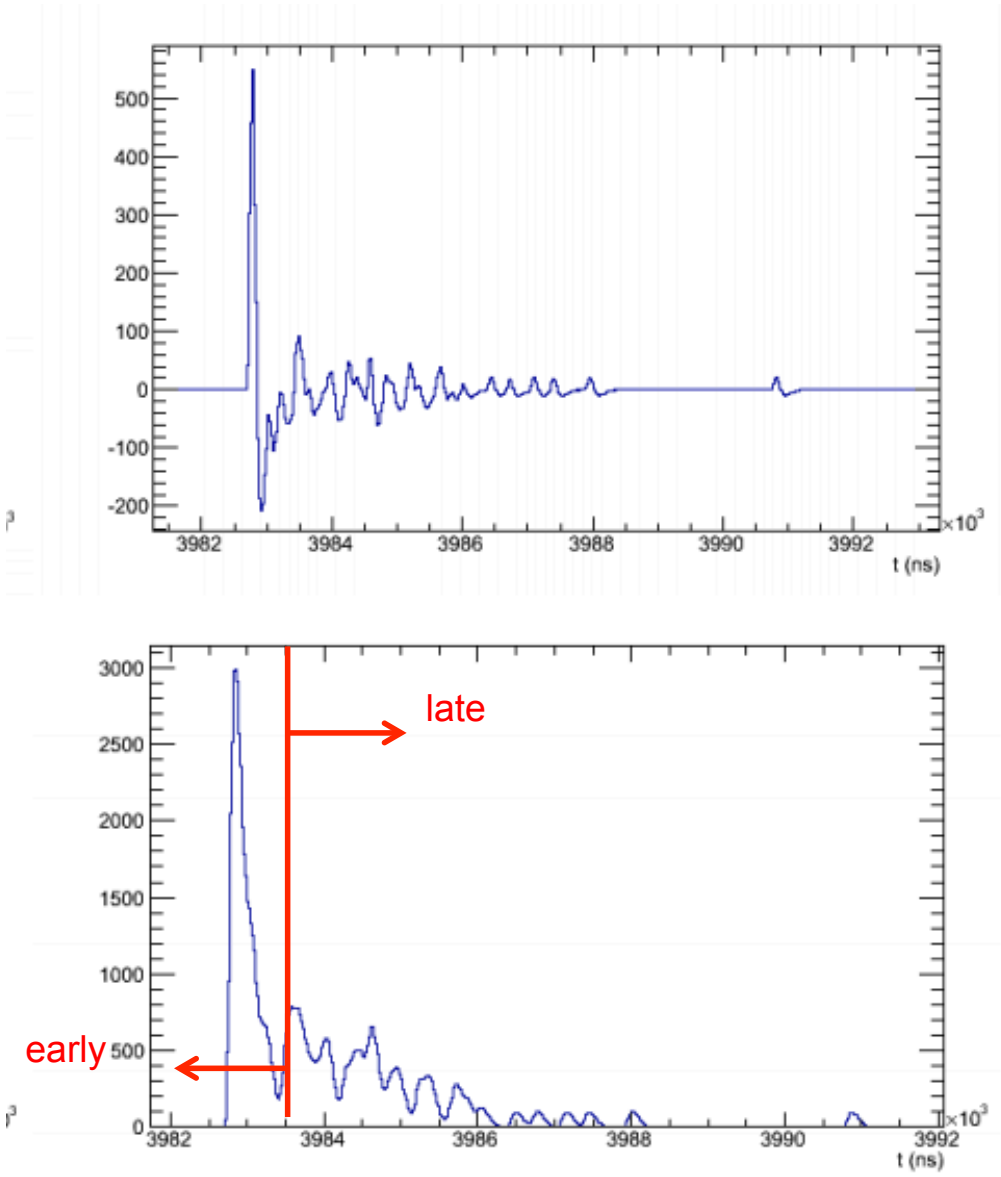

c1_n7
File Edit View Options Tools Help
PeakVsArea
Pulse Area (arb)
10^2
10
1
10^{-1}
1
Pulse Amplitude (V)
Pulse shapes for clean argon
Cosmic sample
Alpha enriched sample
Experimental proof that MicroBooNE optical detectors are capable of this, in some capacity.

Early / late ratio is already extracted by optical reco algorithms in LArSoft.

Studies are underway to investigate capability for using this information as a PID tool.

Expect that it is unlikely to be very powerful on its own, but definitely a possible variable for multivariate PID algorithms

Also other applications : tagging michel electrons, neutron captures, etc…



Summary

- LArSoft contains working full and fast optical simulations for LArTPCs
- They have been exercised on MicroBooNE MC and are evolving all the time
- MC output can be used to produce realistic digitized pulses including noise and accounting for proper signal shape
- We have the first layers of optical reconstruction implemented, which can be extended for any LArTPC
- By the end of summer we should have track-by-track t0 determination which can be used right away for MicroBooNE
- Everything we have done can be used for any other LArTPC with a LArSoft geometry.