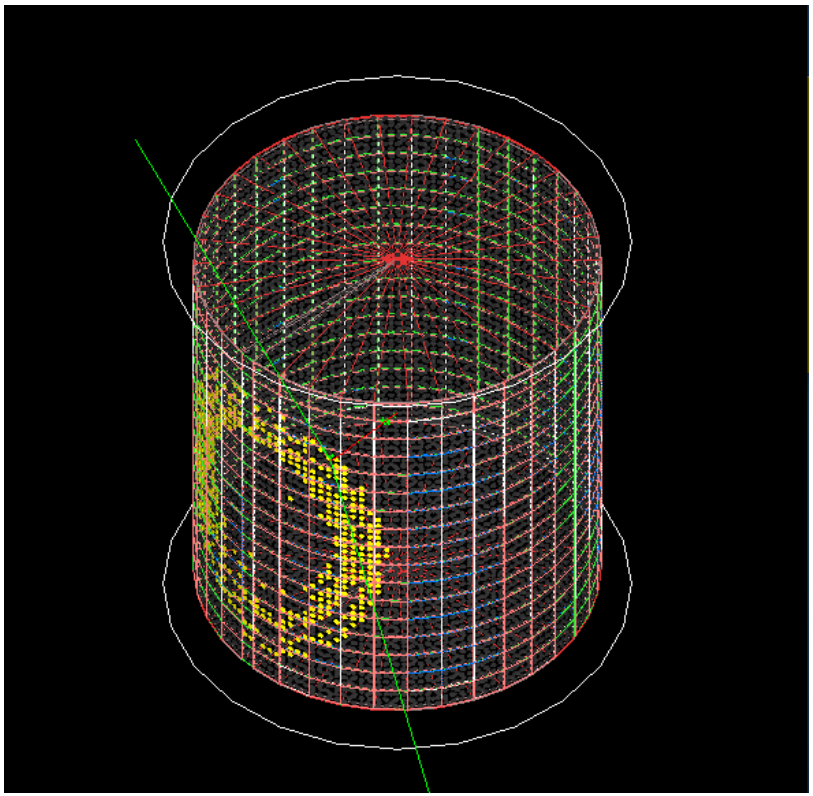
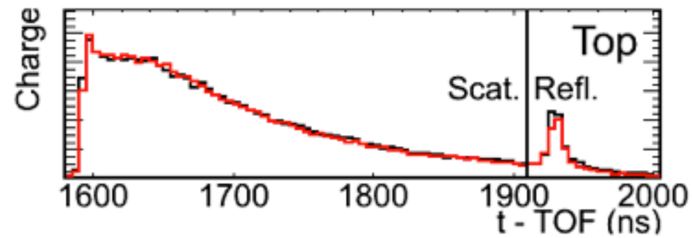
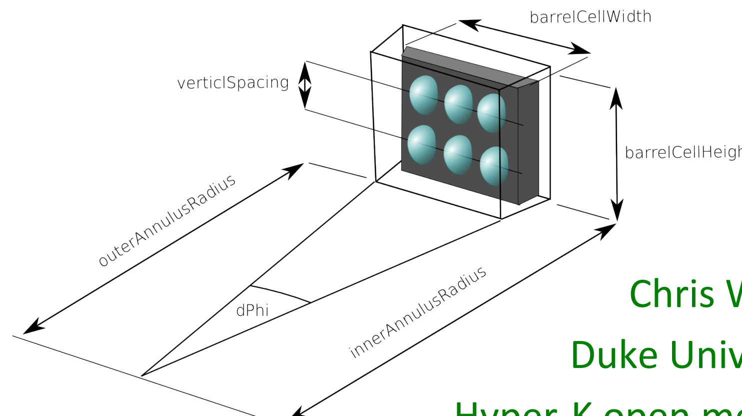
WCSim: a Geant4 based Water Cherenkov detector simulation

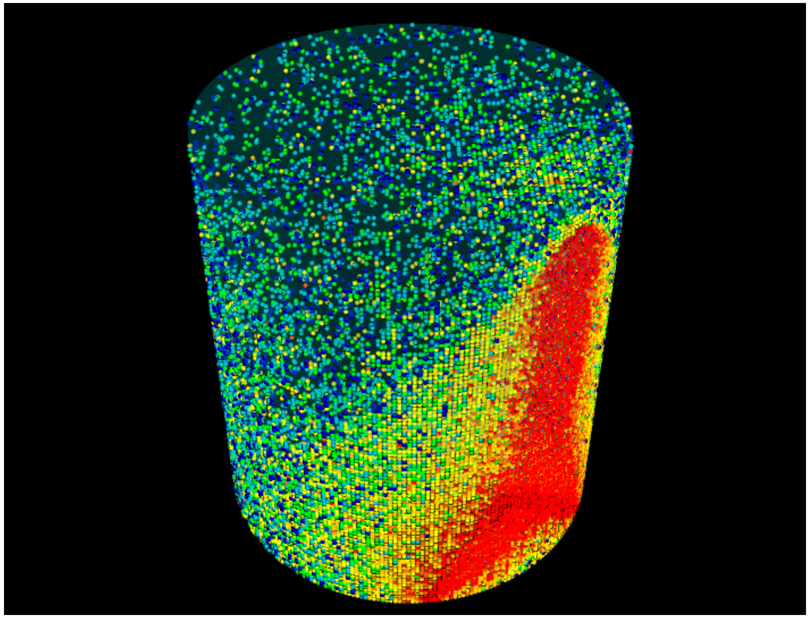






Chris Walter
Duke University
Hyper-K open meeting
Kashiwa Kavli IPMU
8/23/2012

The WCSim simulation package



For T2K we designed a complex 2KM away from the neutrino source which included a 1 kton WC detector optimized to have the same performance as SK.

We built a flexible system in Geant4 and used it to simulate several geometries including the K2K tank so we could tune the simulation with real data.

This code was used as base to build a new large WC simulation.

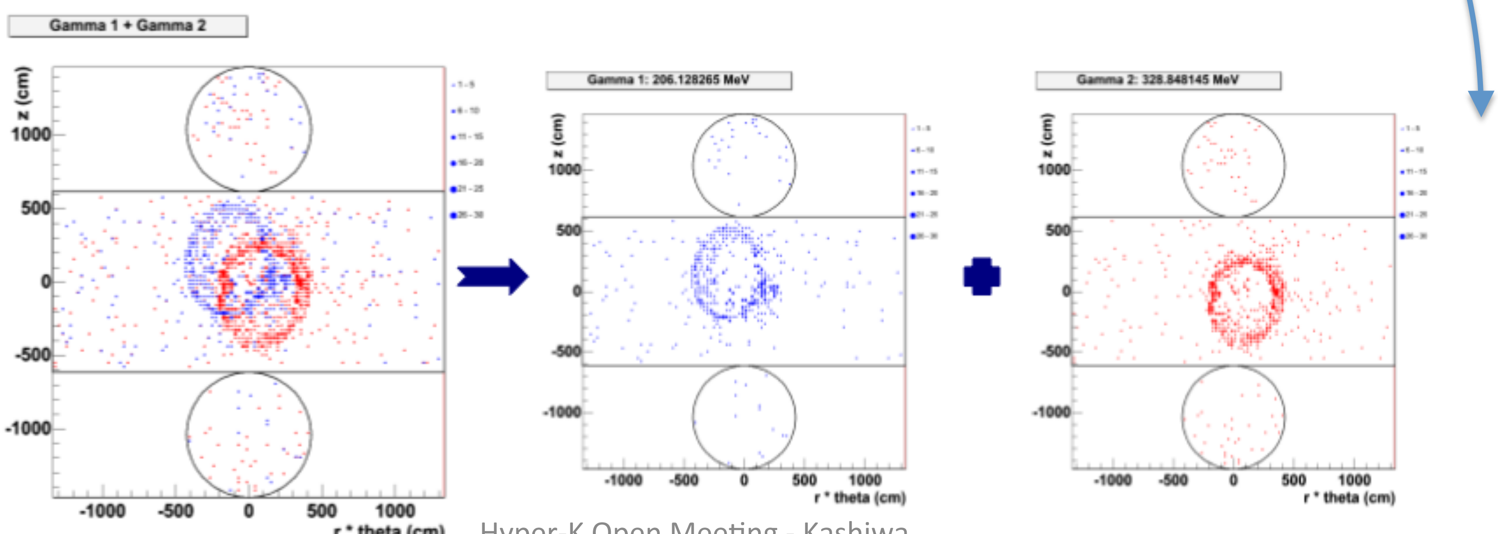
The code is validated against the SK MC which is tuned to the 1-3% level

➔Could be useful for Hyper-K

Use shared physics properties -> with many geometry configurations
(cavern size / shape / number or tubes / Tube characteristics/hadronic models all adjustable)

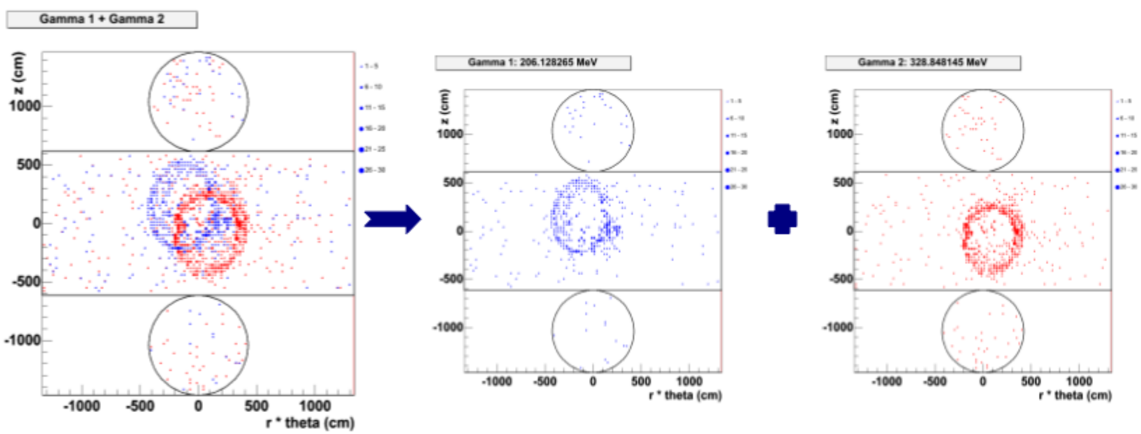
Some features of WCSim

- Configuration without compilation and Root output
- Full photon hit info + digitized output based on SKI-III electronics
- Can read NUANCE / Genie format vector files
  - (Also uses NEUT/Genie> NUANCE converter)
- Water and reflective material parameters tuned to SK MC.
- Specialized Geant4 extensions to attach information to each photon (NC studies)
- Outputs geometry information for use by downstream programs
- External root based event displays
- External conversions to SK format for reduction, display and and reconstruction
- Managed in SVN and updatable by collaborators and the larger WC community.



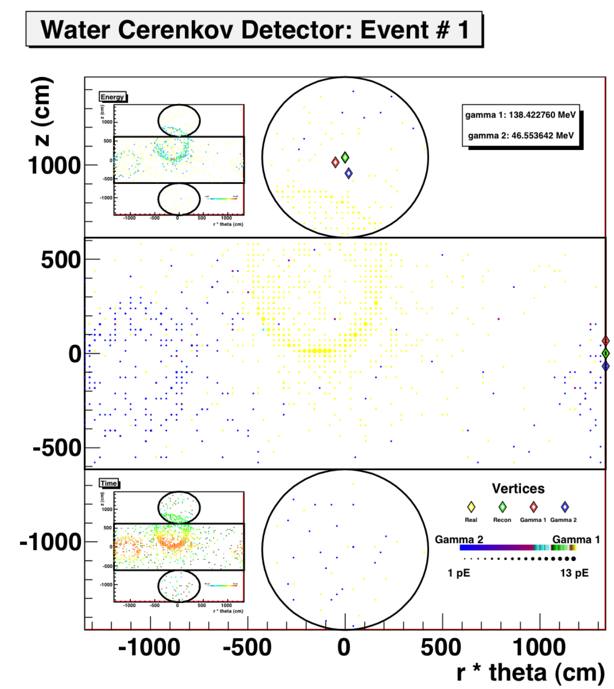
Same Pi0 event separated by parent γ in Root display (γ_1 = blue, γ_2 = red)

Raw ROOT based event display with specialized features for pizero studies.



Same Pi0 event separated by parent γ in Root display (γ_1 = blue, γ_2 = red)

Feature: Tagging of parent particles



Feature:
Recording of gamma conversion points

Root Information

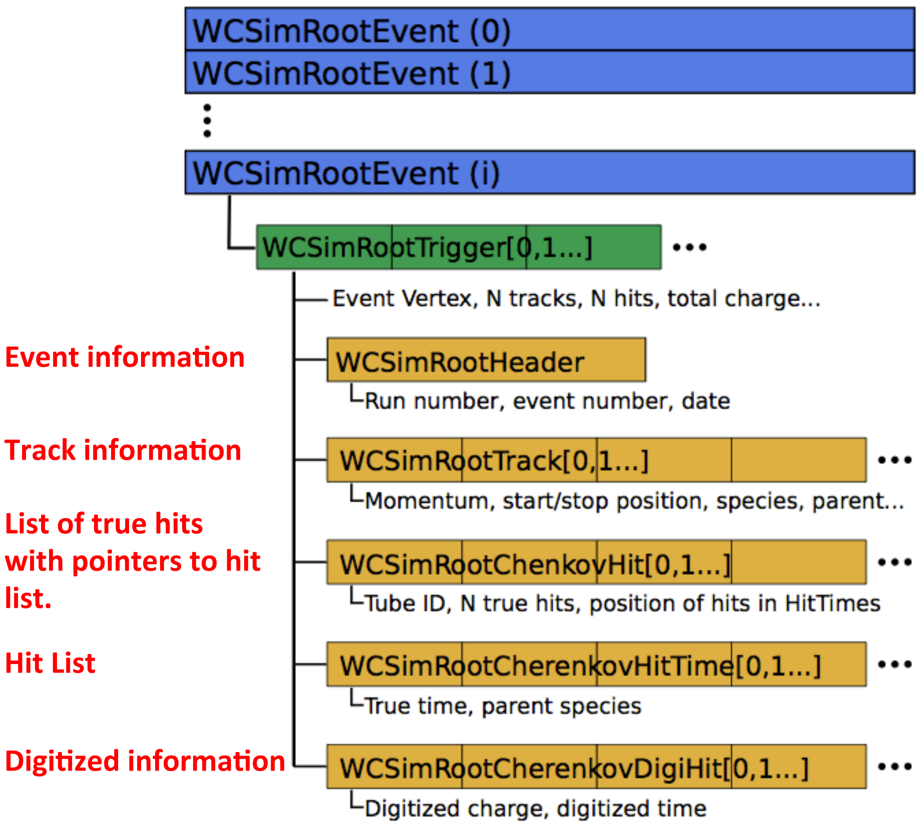
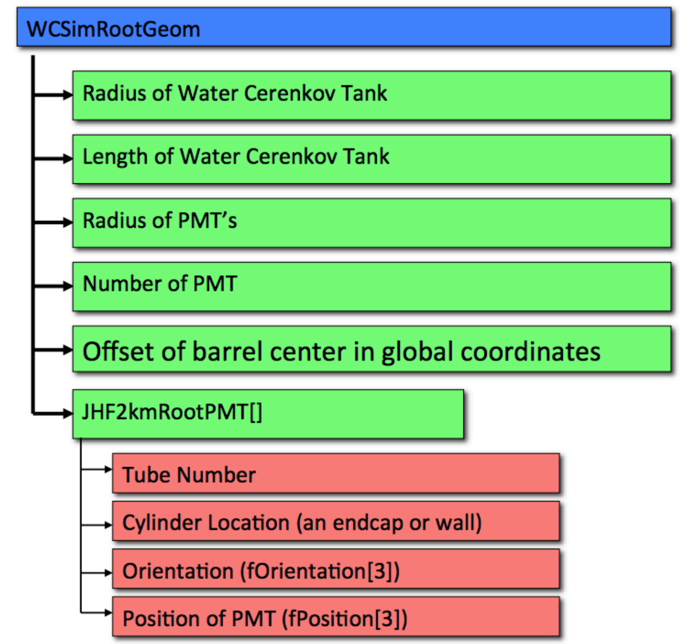


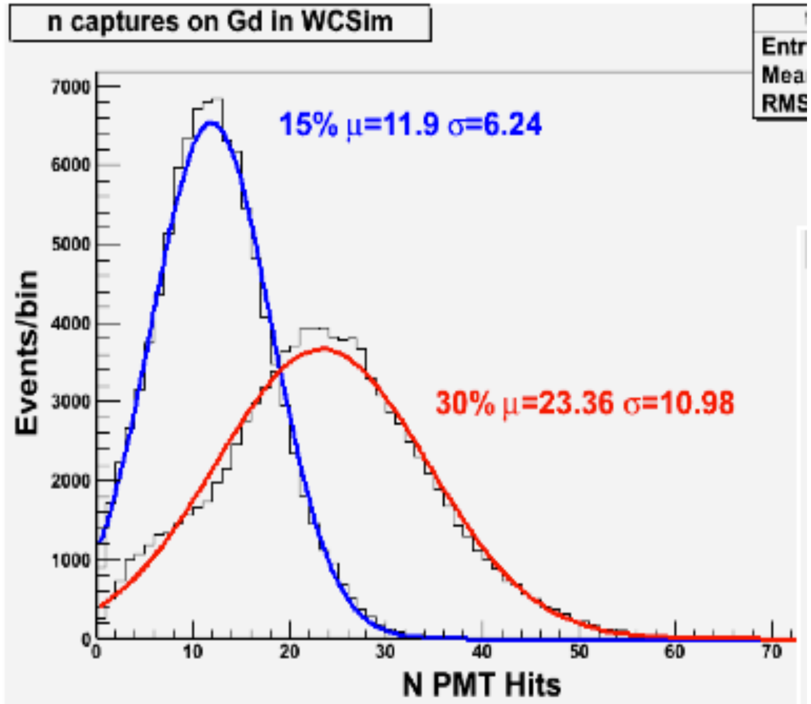
Figure 7: The class hierarchy of the WCSimRootEvent written to the output file.

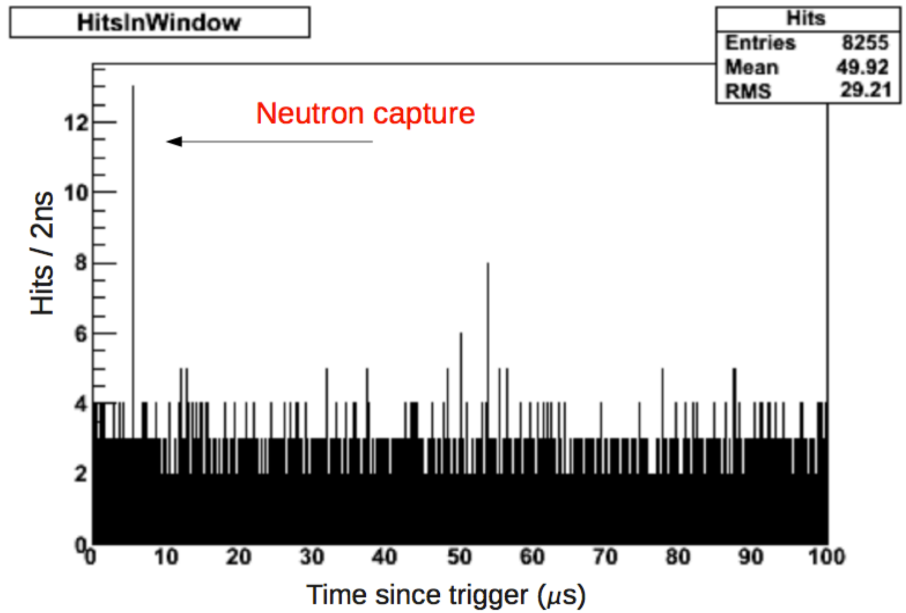


The geometry is stored in a separate ROOT tree. The structure specifies the size of the detector and the layout of the PMT's.

The data is written out in a root structure.

Both raw and digitized hits can be used to do studies.





Example: Gadolinium study for LBNE. In this study by John Felde true information is used to determine how many photons to expect in a Gd. loaded detector and the arrival time of each photon is checked to look for the neutron capture.

Looking for photons from the neutron capture.

Also, M. Smy has modified the C++ bonsai fitter to work with the root output.

The Simulation

Want this:

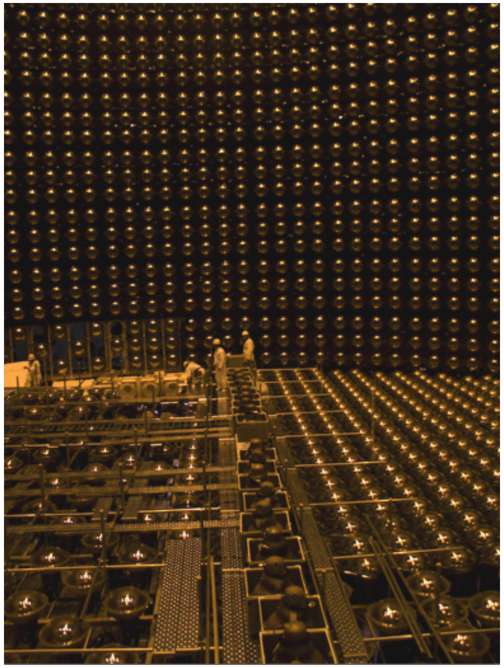
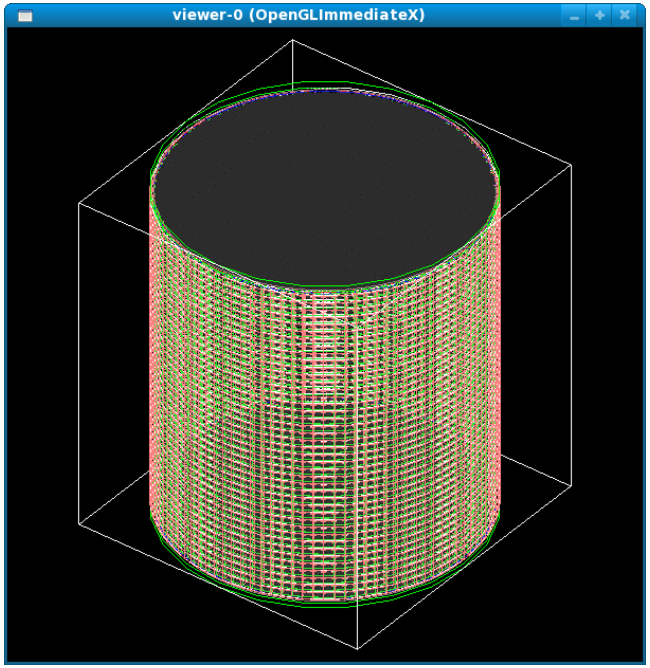


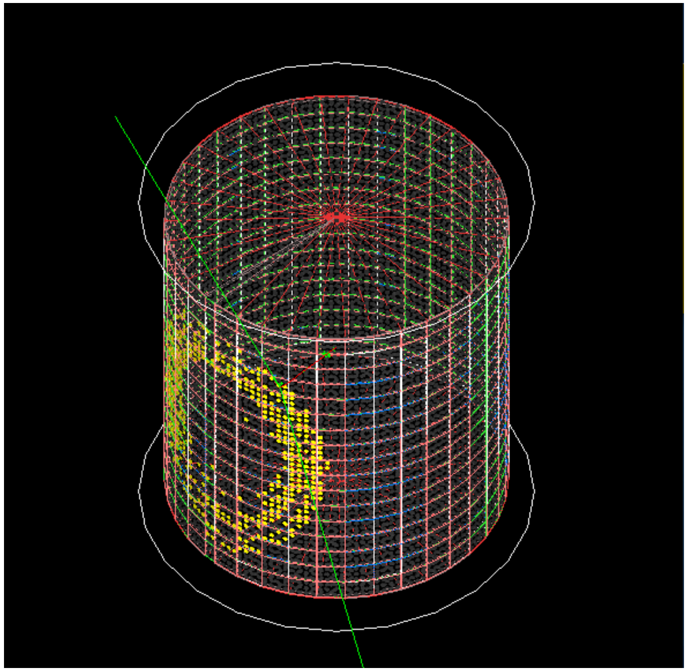
Photo of SK-III construction with both 40% and 20% coverage visible.

Start with this:



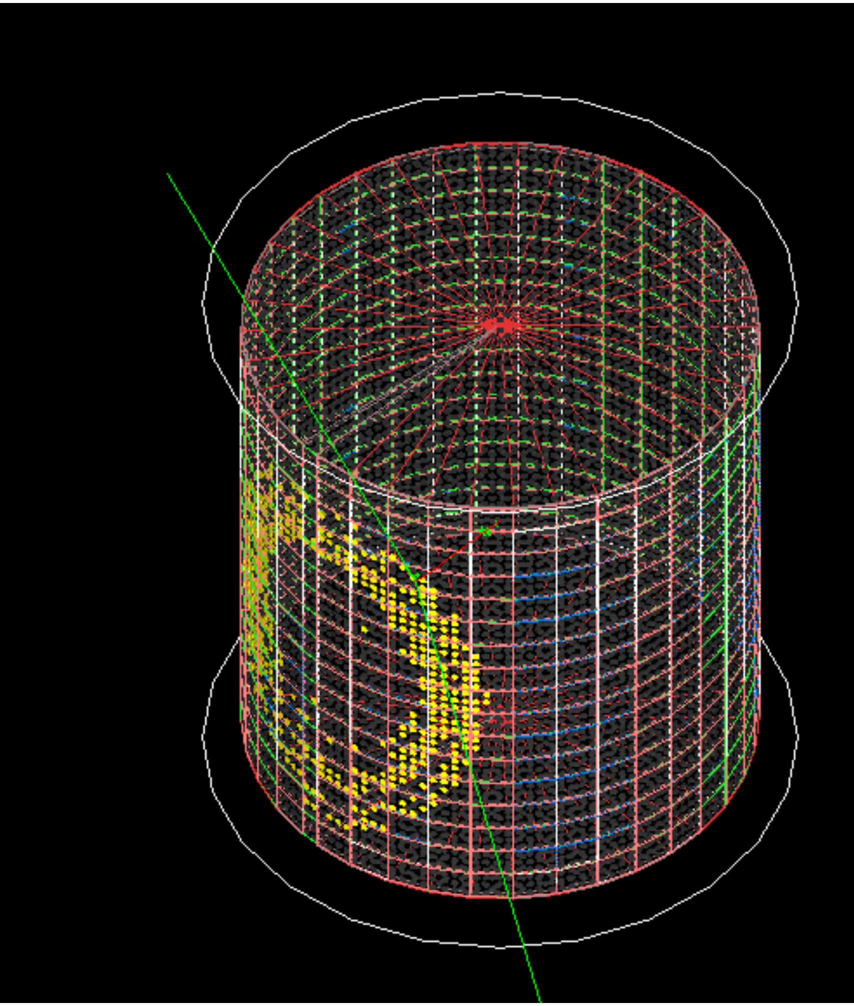
WC Detector in debug mode, showing all PMT cells and black sheet.

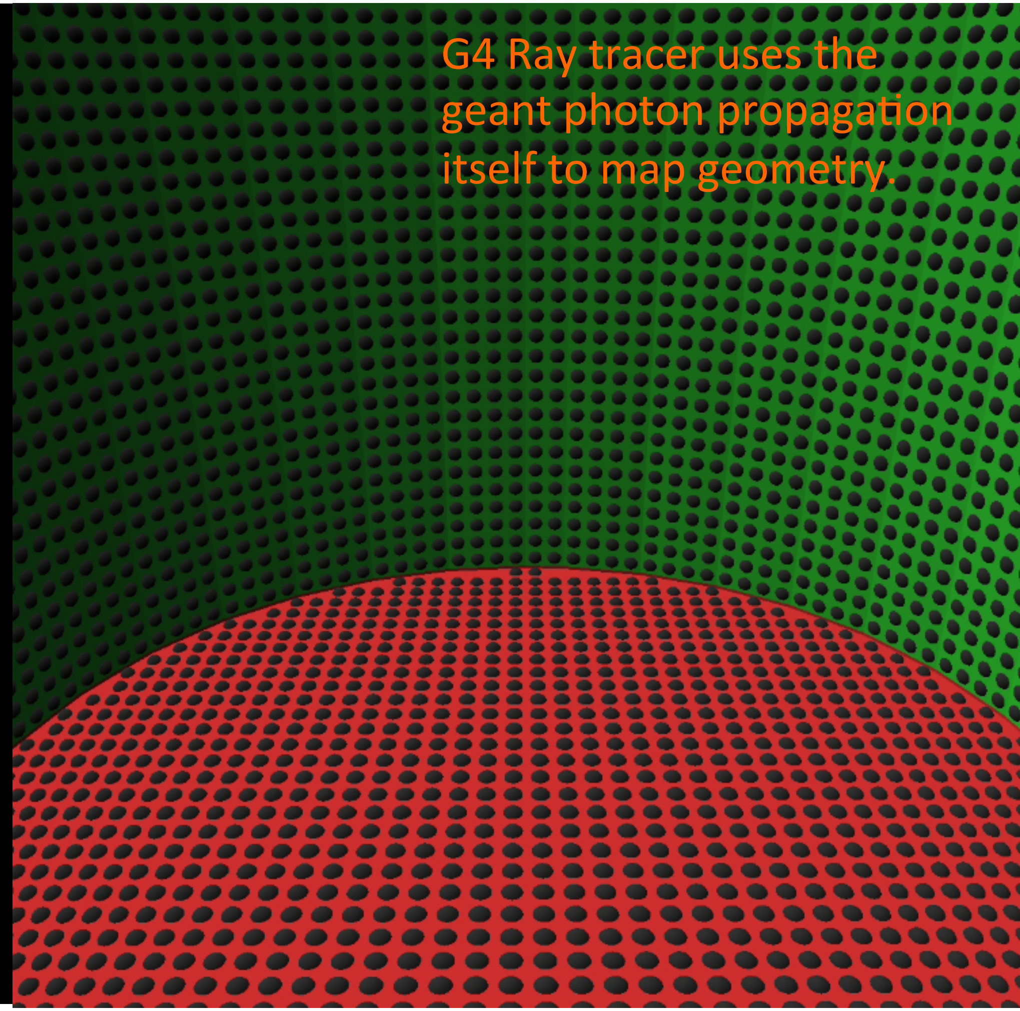
Get this:



WCSim display of digitized hits in an event.

There are automatic geometry overlap checks etc in in the program.

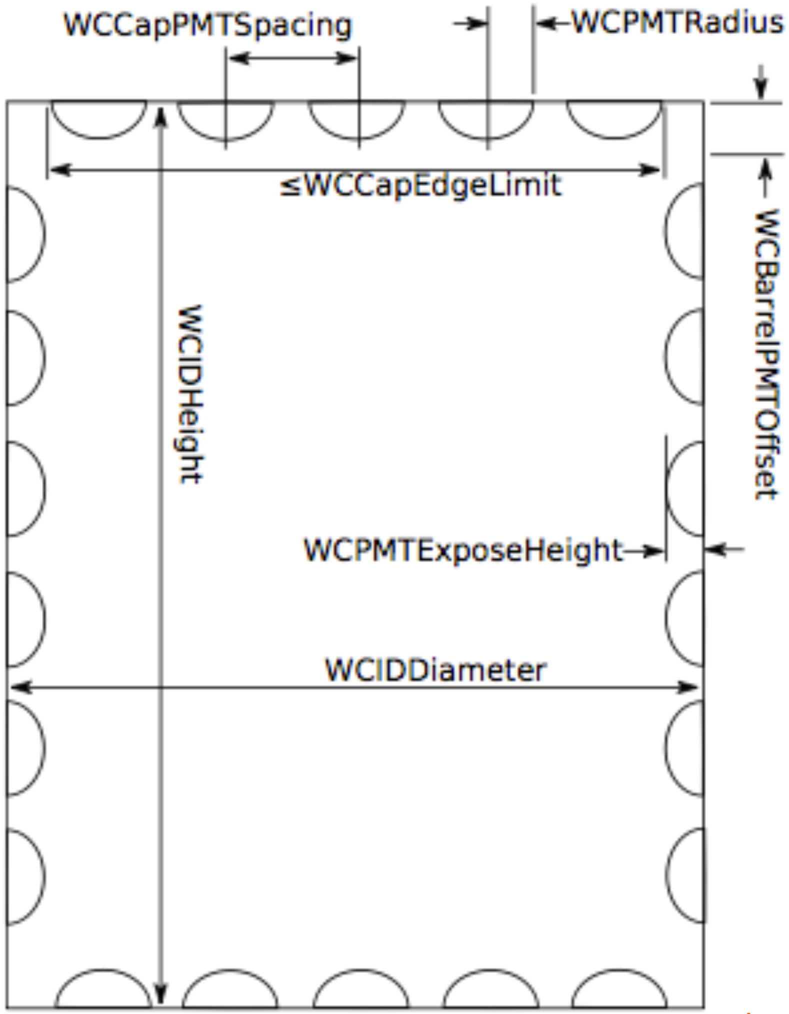




We want detector parameterization that describes realistic geometries

Note base 4X3 tube structure

The idea is to describe any detector parametrically.



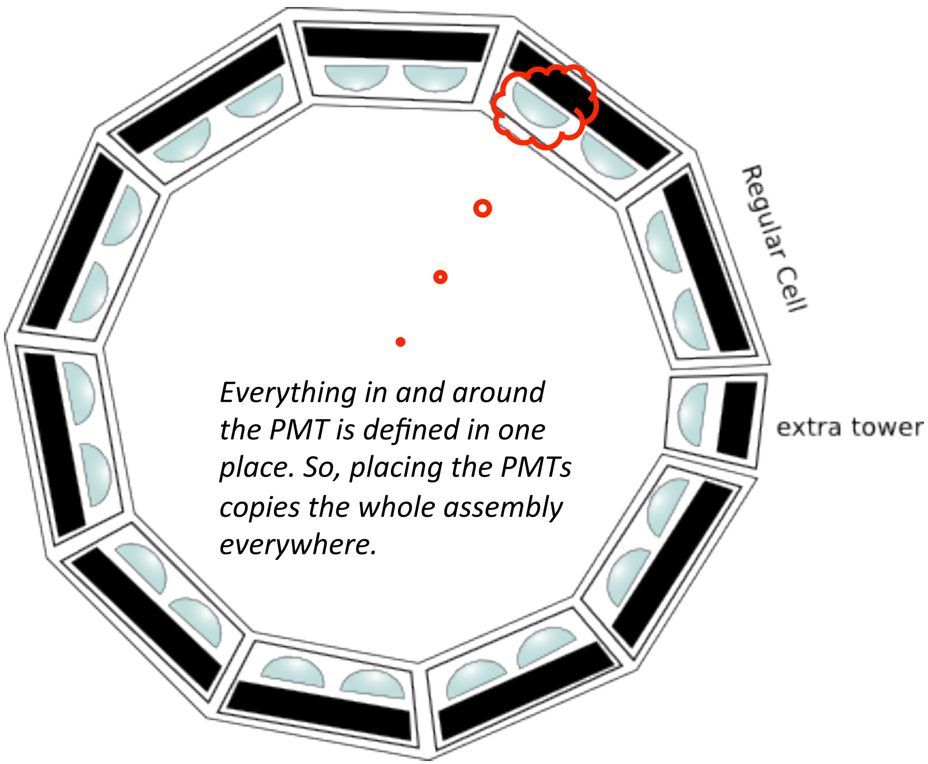
Write one function for each setup (Super-K, 100kton, etc)

```
void WCSimDetectorConstruction::SetSuperKGeometry()
{
  WCPMTName                 ="20inch";
  WCPMTRadius               =.254*m;
  WCPMTExposeHeight         =.18*m;
  WCIDDiameter              = 33.6815*m;//16.900*2*
                                        //cos(2*pi*rad/75)*m;
  WCIDHeight                = 36.200*m;
  WCBarrelPMTOffset         = 0.0715*m; //offset from vertical
  WCBarrelNumPMTHorizontal    = 150;
  WCBarrelNRings            = 17.;
  WCPMTperCellHorizontal= 4;
  WCPMTperCellVertical      = 3;
  WCCapPMTSpacing           = 0.707*m; // distance between centers
                                       // of top and bottom pmts
  WCCapEdgeLimit            = 16.9*m;
  WCPMTGlassThickness       = .4*cm;
  WCBlackSheetThickness = 2.0*cm;
  WCAddGd                   = false;
}
```

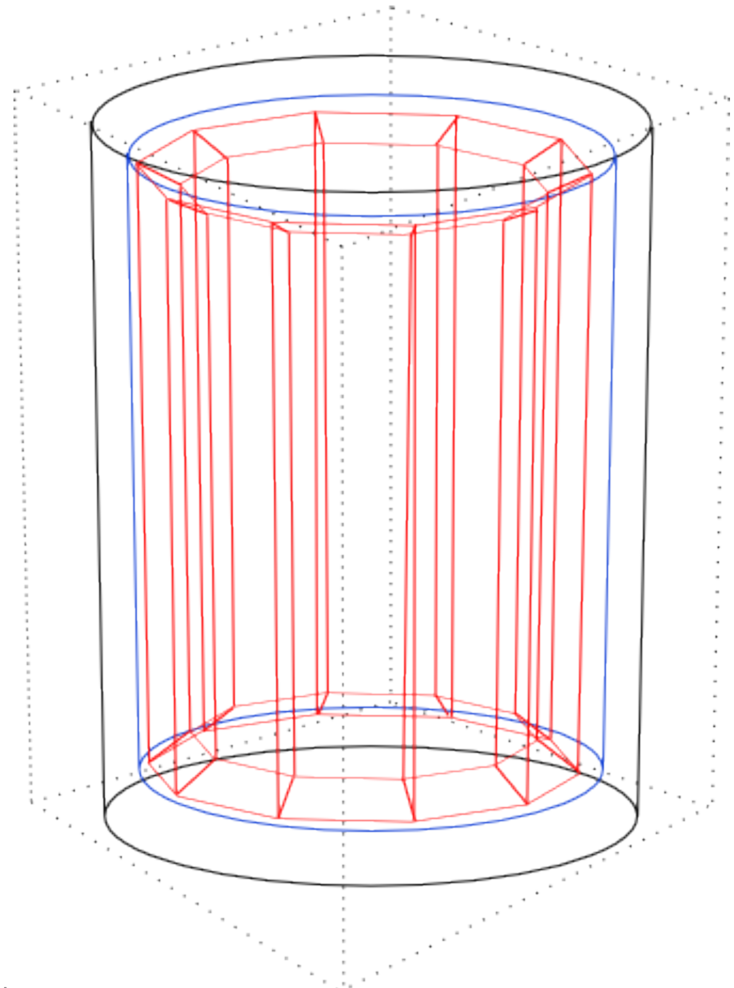
In principle the same thing can be done for other shapes

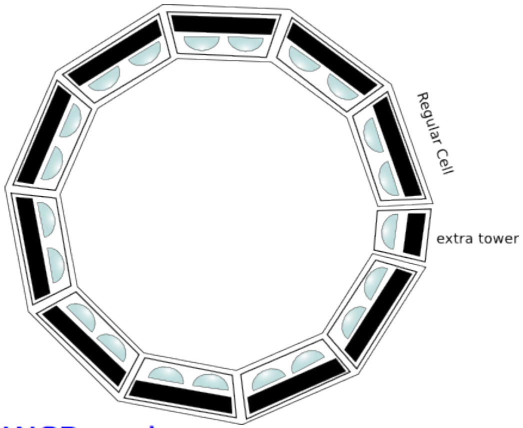
These parameters describe a cylindrical geometry

WCSim geometry details

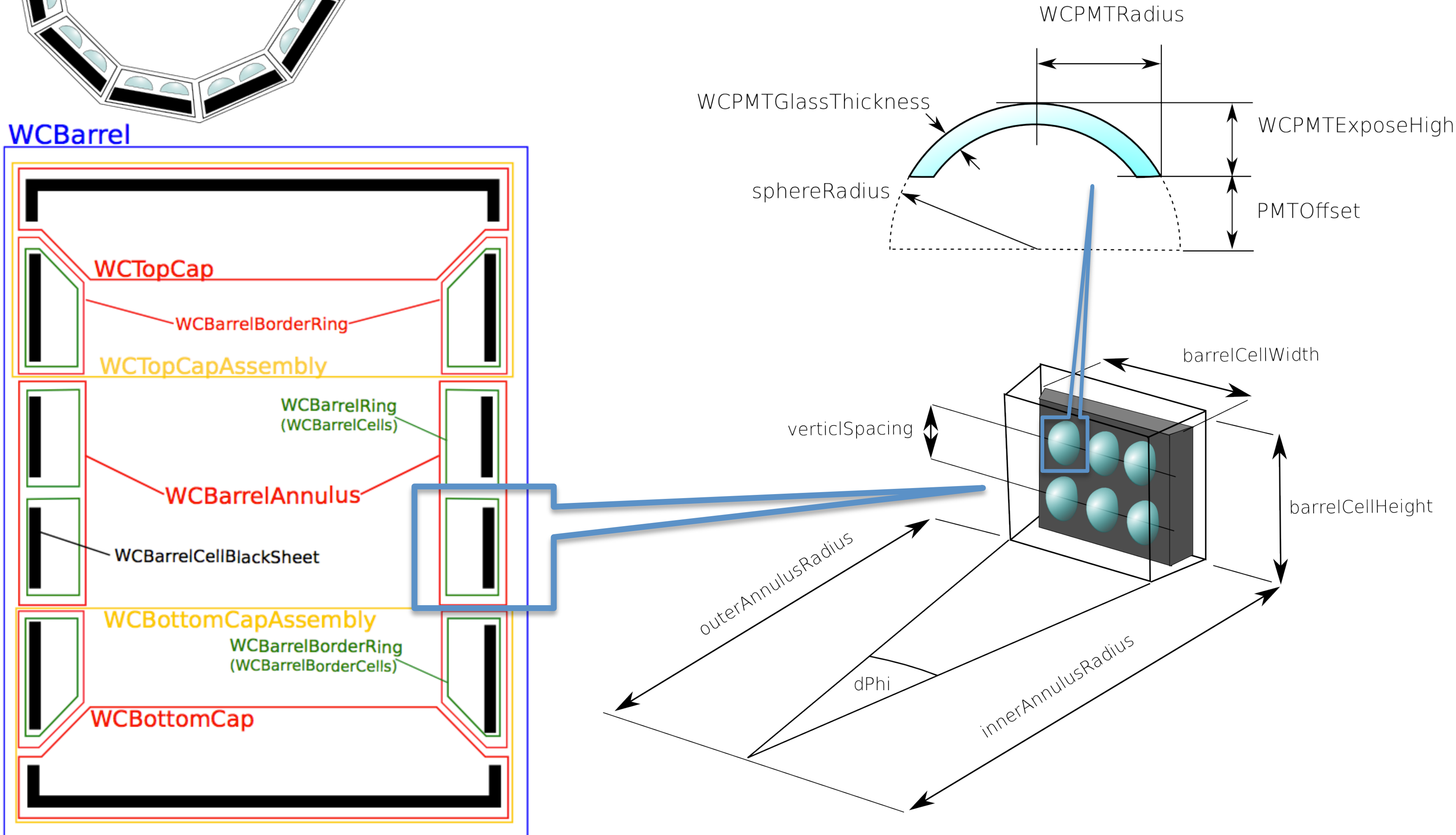


Everything in and around the PMT is defined in one place. So, placing the PMTs copies the whole assembly everywhere.





The program is extremely flexible. By specifying a set of parameters we can define and simulate any cylindrical geometry and tube combination.



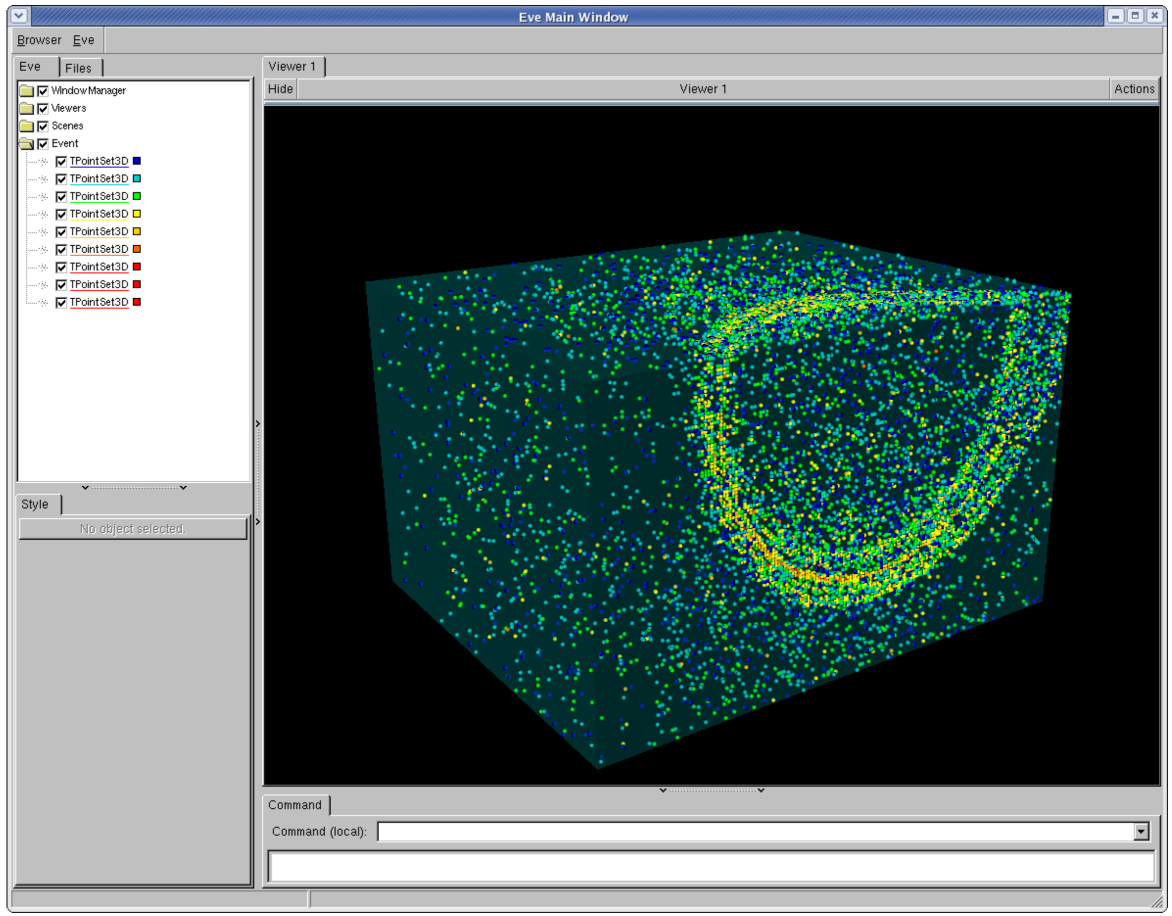
Geometry and physics configurations can be chosen without compilation through macro files.

We can simulate any cylindrical geometry to optimize our reference design and can even simulate alternative shapes for cavity studies.

The program produces self descriptive geometry and output files.

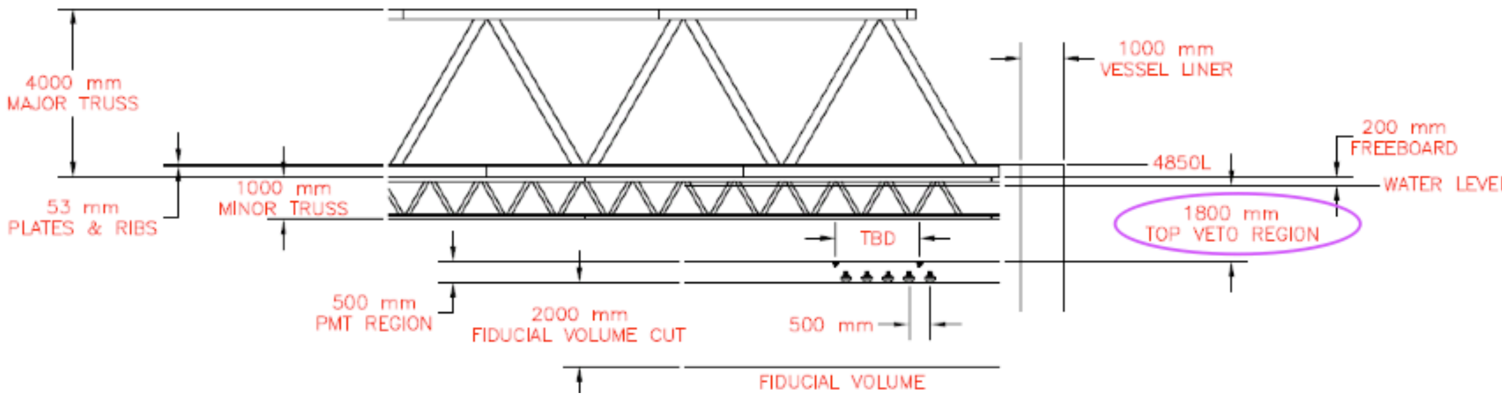
You describe the geometry you want and the program generates it and simulates the events. It then writes out all of the tube information and other self descriptive information needed for reconstruction and display by external programs further down the analysis chain.

Programs can read this information and properly display the output without recompilation.

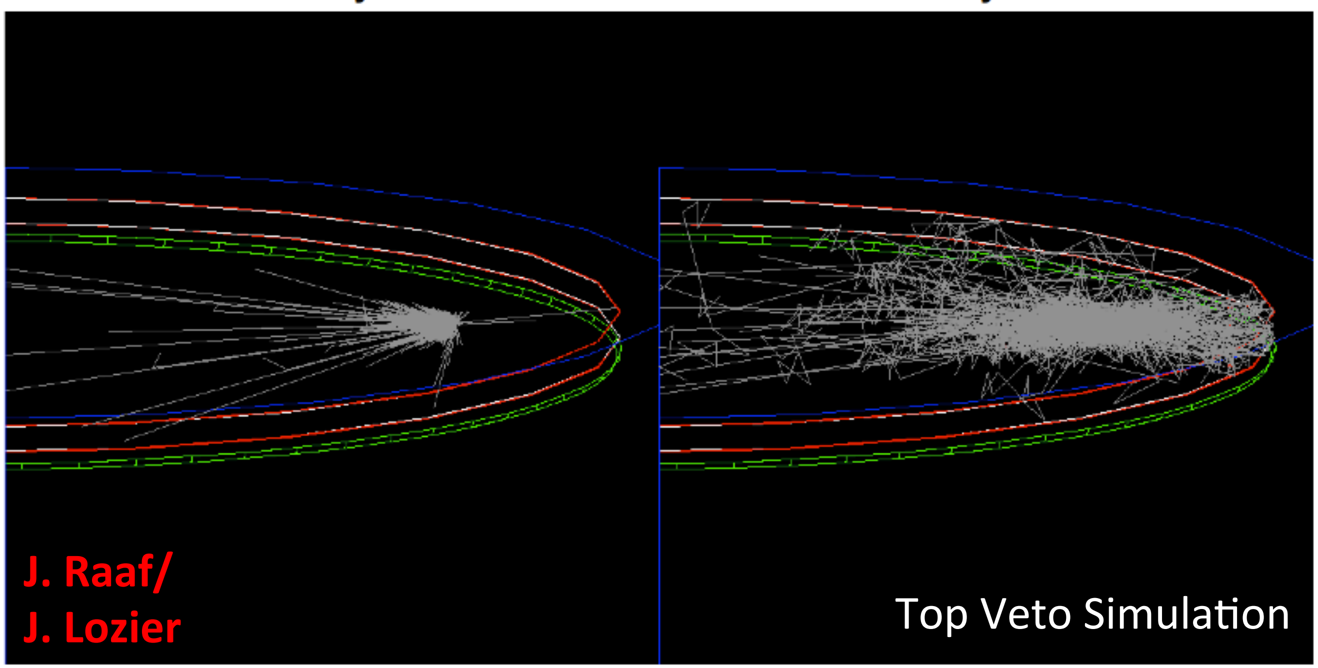


Example: 150 kton Mailbox design with 30% PMT coverage displayed in root based display.

Some veto design/simulation exists



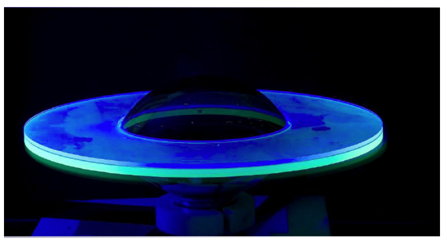
Without Tyvek With Tyvek



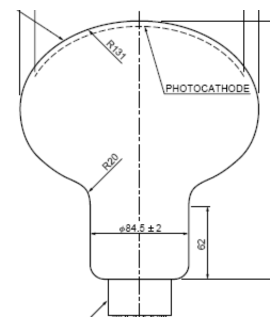
Options for photon production

There was R&D for LBNE on wavelength shifting devices. For this reason we expanded the light generation options. This is also useful for low energy physics

To save CPU by default we apply the QE at photon



*production (SK ATMPD model). However, for low energy or with devices that shift wave-lengths this is not appropriate. (***Xin Quan***)*



Options

- Apply QE at production (default)
- Propagate every photon, Apply QE at tube
- Apply overall factor + apply at tube

Code is available to community at experiment non-specific SVN

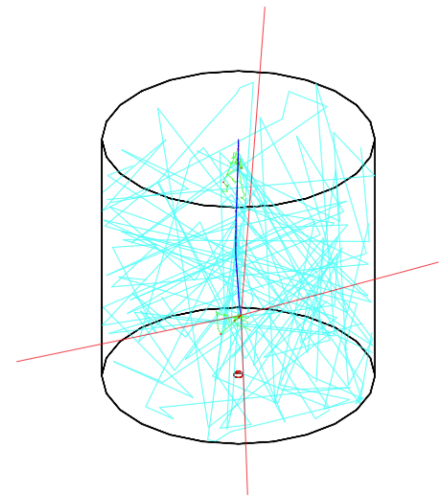
Anyone can access (guest/guest or account including hosting of *dev* branches)

http://svn.phy.duke.edu/repos/neutrino/dusel/WCSim/

neutrino - Revision 1501: /dusel/WCSim/trunk

- ..
- GNUmakefile
- README
- README.ROOT
- WCSim.cc
- doc/
- include/
- jobOptions.mac
- jobOptions2.mac
- novis.mac
- sample-root-scripts/
- src/
- tuning_parameters.mac
- vis.mac

Powered by Subversion version 1.6.11 (r934486).

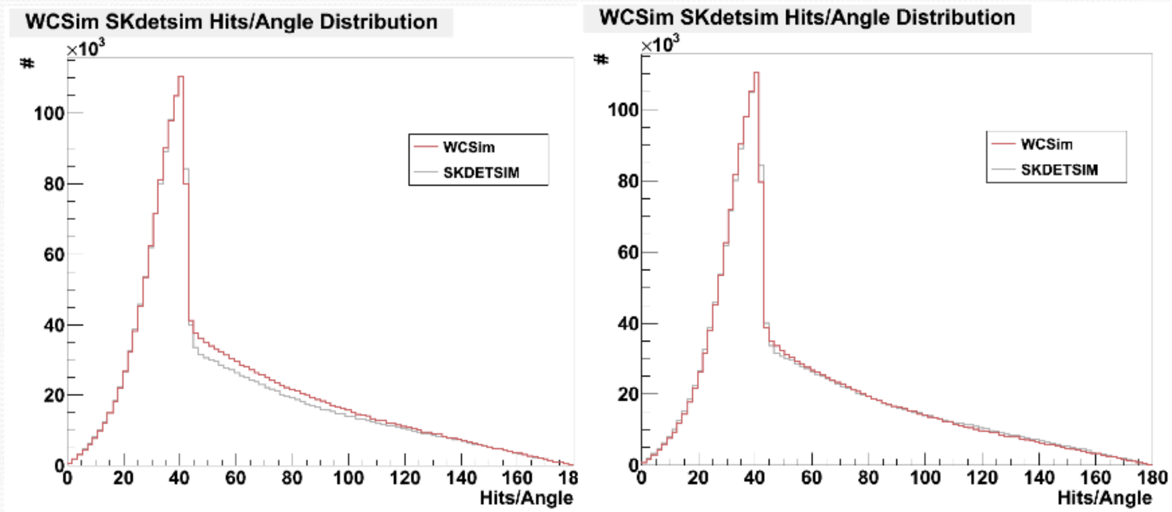


Simulated tank from LHASSO high energy Air-shower array.

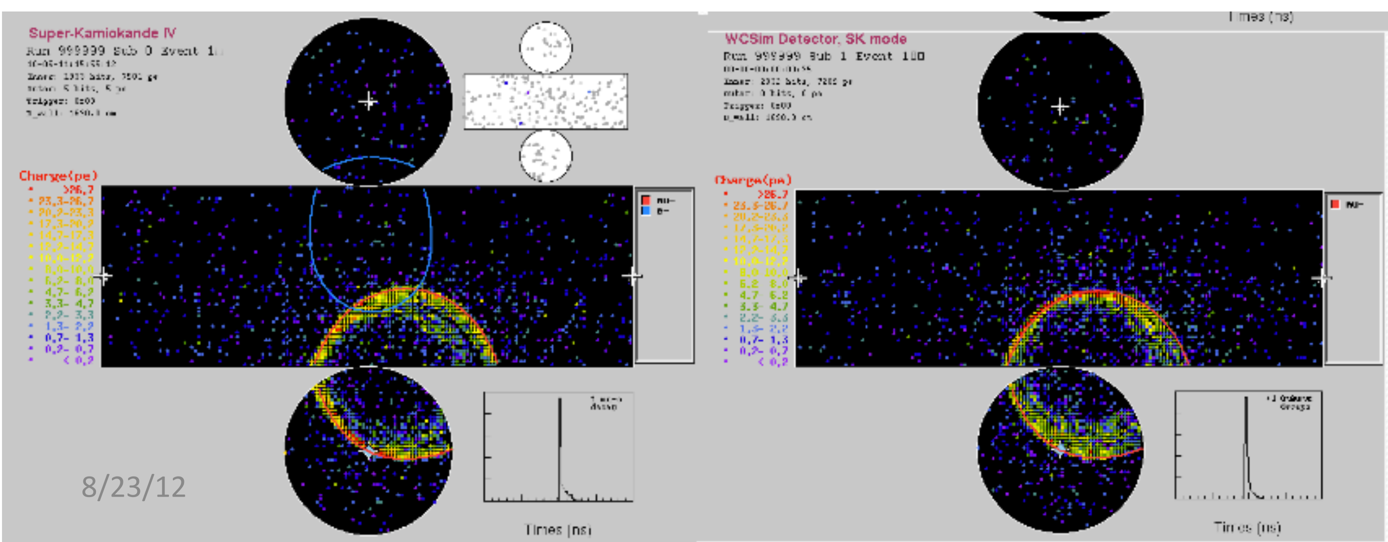
Other R&D programs:
- Picosecond timing project
- Neutron production beam test

SK validation/reconstruction work

Our most powerful handle: Tuning and validation against the SK MC.

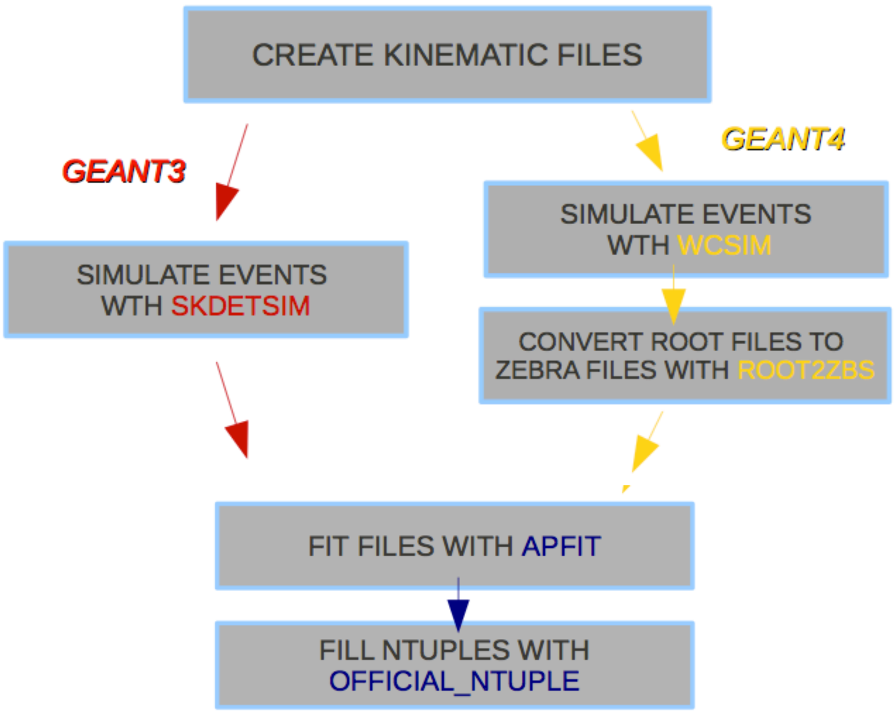


The SK MC is tuned to the 1% level. WCSim includes a SK Mode We can use to tune the MC to the validated SK MC. After tuning only geometry and tube configuration is changed.



This work allowed us both to tune the Monte Carlo and improve the underlying Geanr4 optical model.

Technique for validation



Note: Physics models are sometimes different between Geant3 and Geant4 so that parameters we are tuning don't always mean the same thing.

Tools Developed:

*"**geomod**"* version of SK library

- Replaces hardcoded tube positions with values read from geofile.txt

- Also, has larger size arrays for flexibility.

- Exists as a branch in SK repository.

WCSim version of ***root2zbs***

Superscan: compile flags exist in the standard code for use with the "geomod" version of libraries.

WCSim Tuning

SK Monte Carlo (Geant3)

- **Goal:** Tune WCSim's optical properties to skdetsim
  - SKDETSIM has been well-tuned to a running water Cherenkov detector

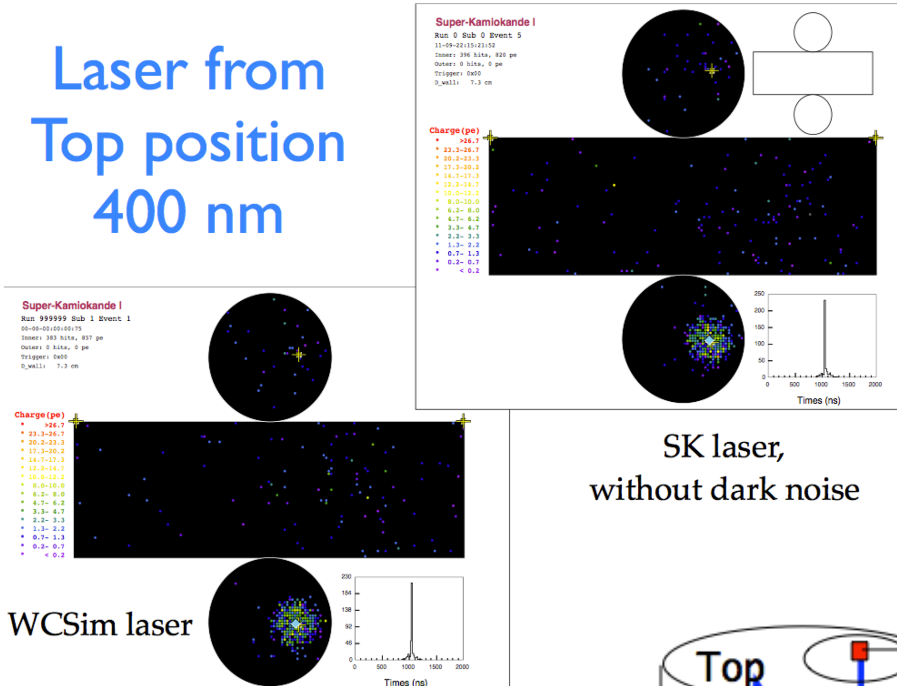
- Parameters being tuned:
  - Black Sheet Reflectivity (higher = more reflection)
  - Glass/Cathode Reflectivity (higher = more reflection)
  - Absorption Length (higher = less absorption)
  - Rayleigh Scattering (higher = less scattering)

- Tuning against three samples:

– 1 GeV μ- – 1 GeV e-	Particles (produce photons) [Uniform / Isotropic]
– 337 nm calibration laser	Photons (SK laser system)

Simulation of Laser System

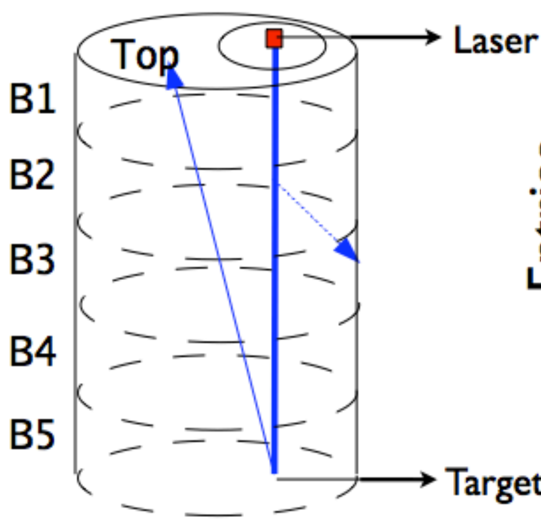
Laser from
Top position
400 nm

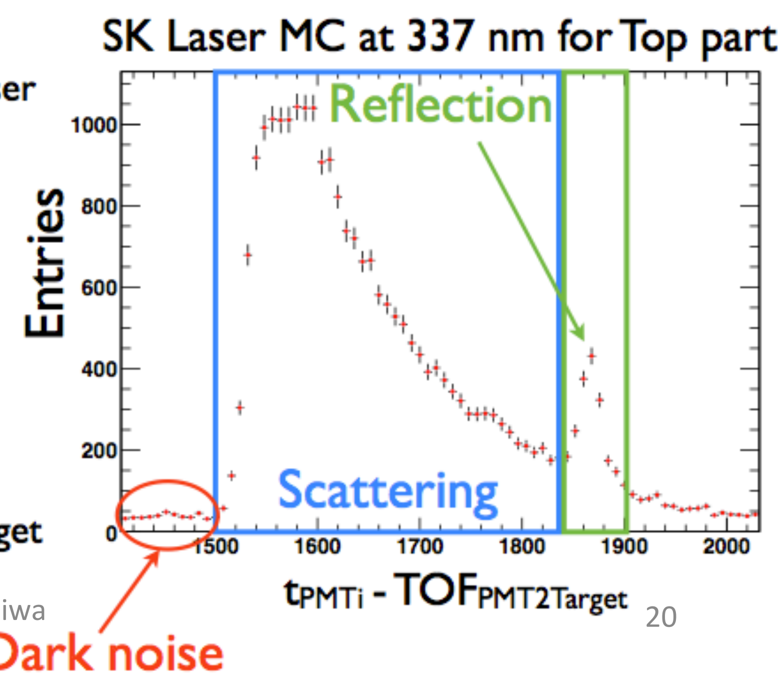


SK laser,
without dark noise

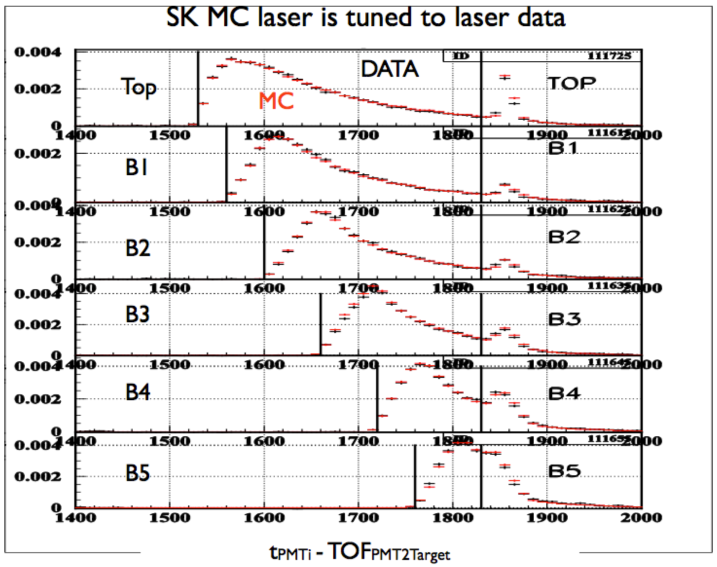
WCSim laser

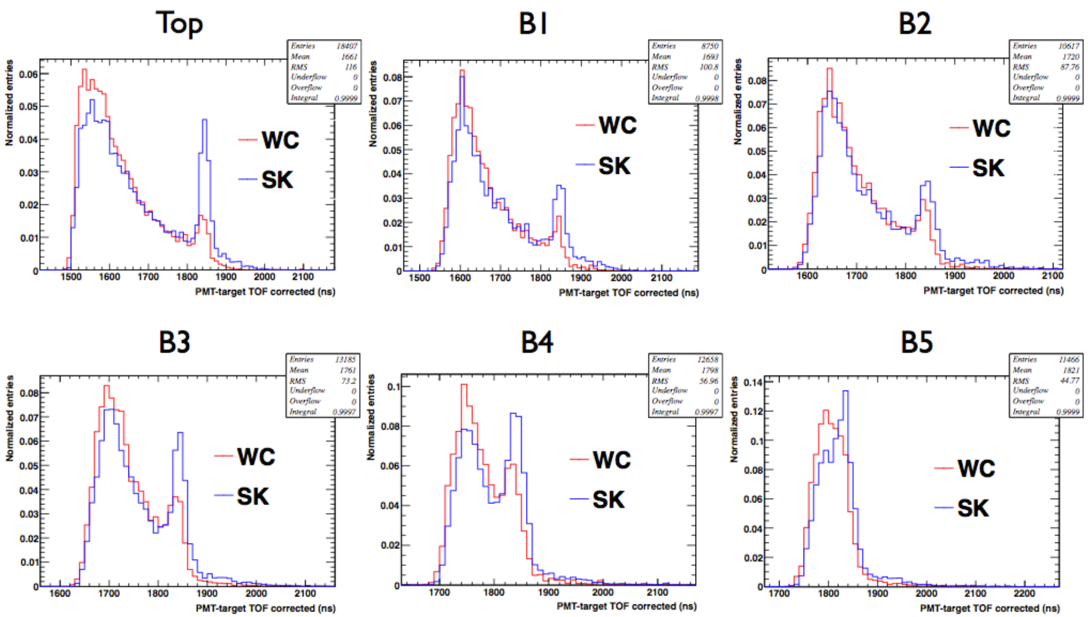
The SK laser calibration allows us to measure the optical scattering and reflection parameters seperately at the same time. We also **implemented the laser system in WCSim**.





Data and MC





Super-K **Data** vs **MC**.

(tuned)

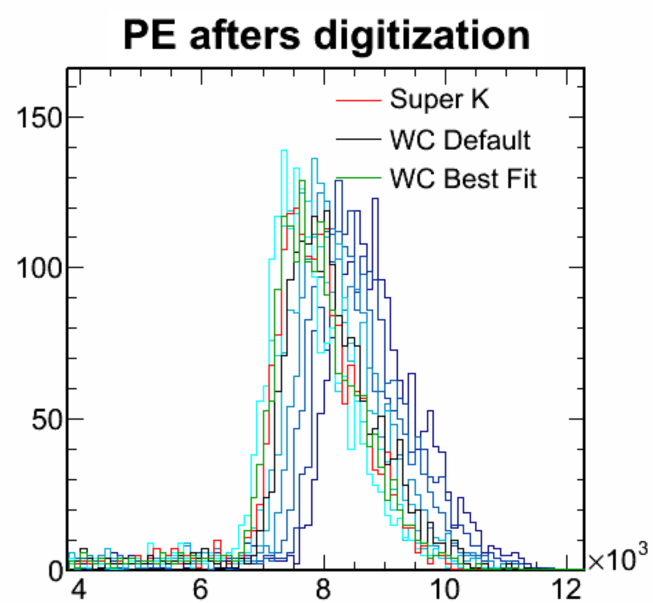
WCSim **MC** vs Super-K **MC**.

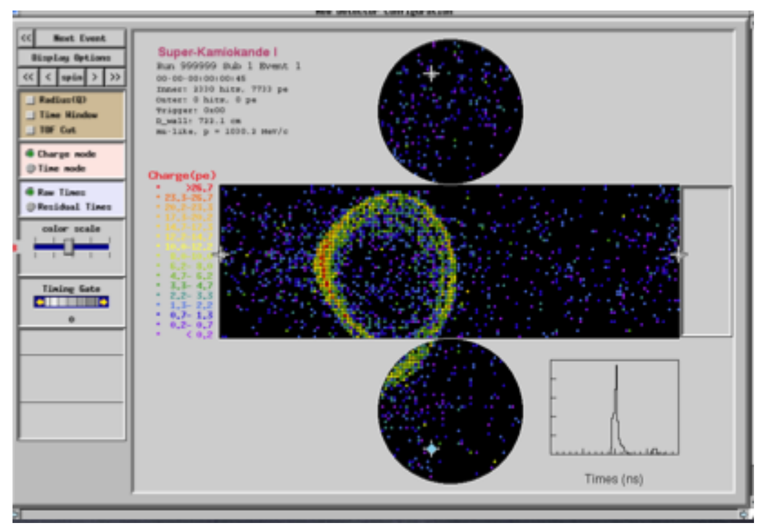
(not-tuned)

Electron and Muon Samples

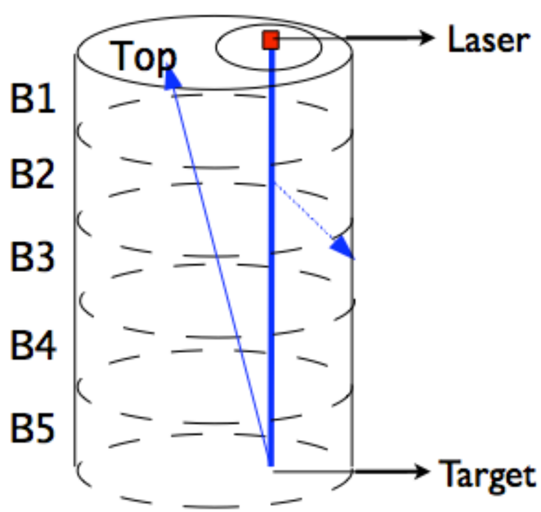
- Electrons and muons give the proper production of Cherenkov photons (amount, polarization etc) but also includes physics effects.

- **MC-MC** Histograms compared:
  - Total Digitized PEs
  - N hits (q > 2.5)
  - Q vs. θ (q > 2.5)
  - Total Backside PEs
  - Total Backside Hits
  - Q vs. distance (direct)

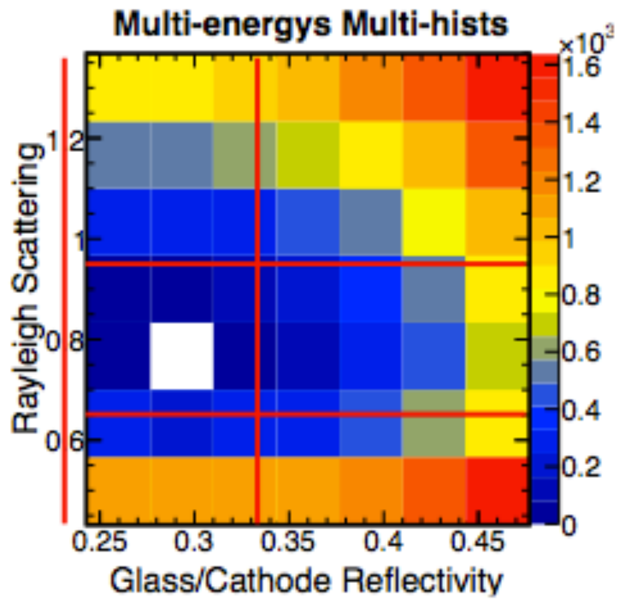




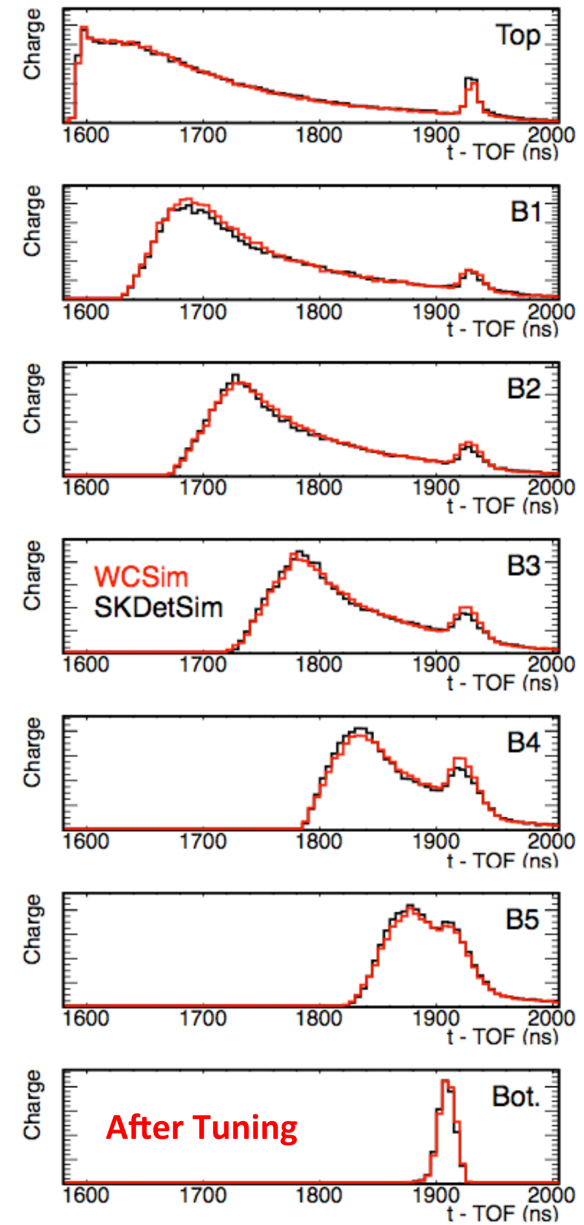
We expanded on how this calibration is done in SK.



Laser setup

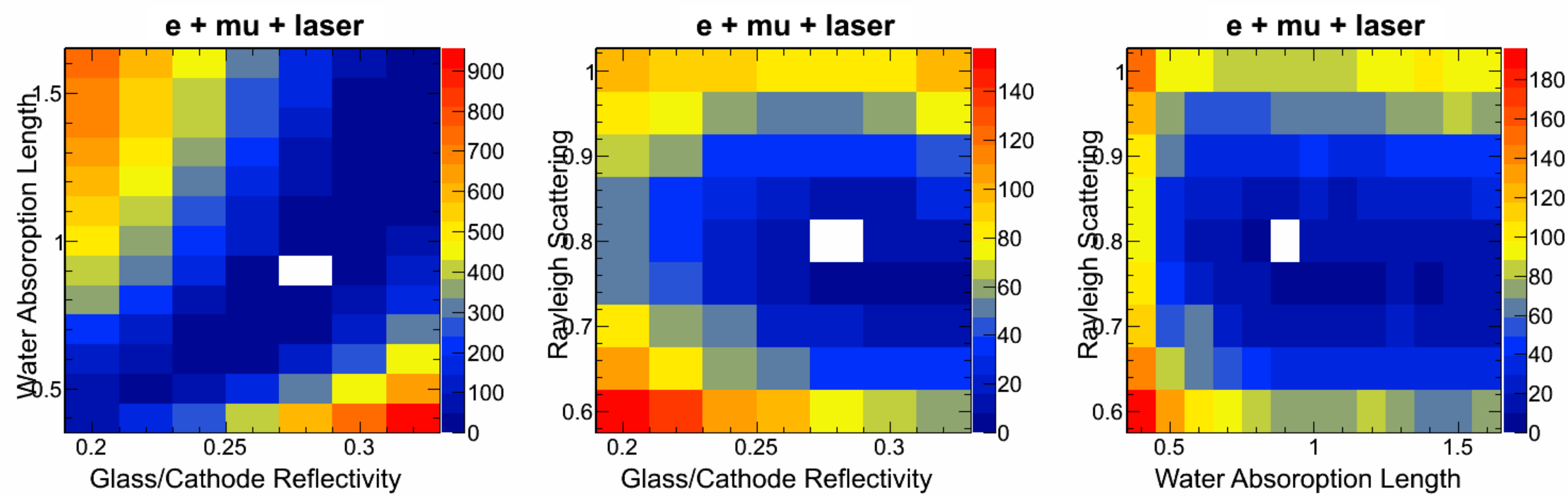


Parameter minimization



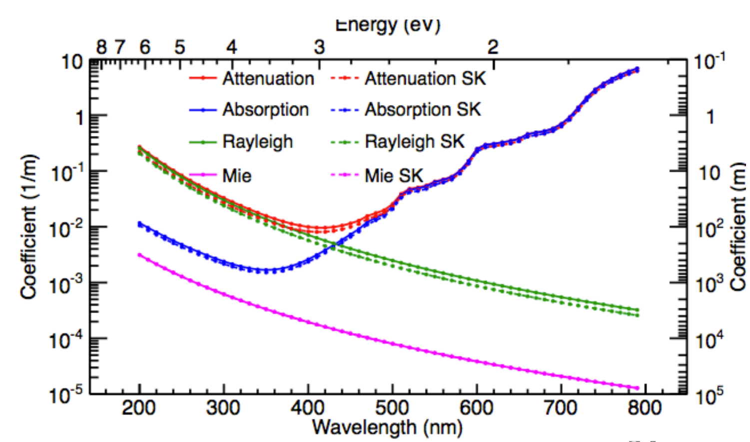
Simultaneous tuning of four or five optical parameters
With laser and particle simulations.

Fit Laser + Particles together



- This is a further extension of how we do things in SK.

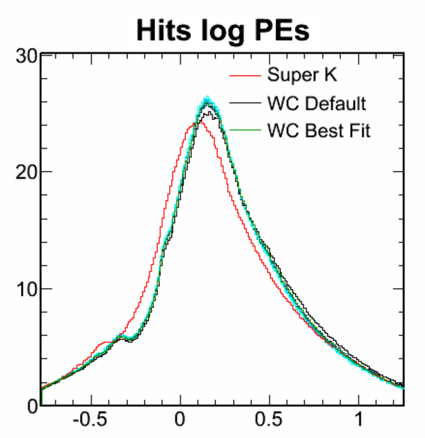
- Tunings are consistent and complimentary:
  - RAY = 0.800 (63.3 m @ λ=340 nm)
  - ABW = 0.900 (583 m @ λ=340 nm)
  - RGC = 0.280 (28% for all λ)
  - BSR = 2.100 (9.45% @ λ=340 nm)

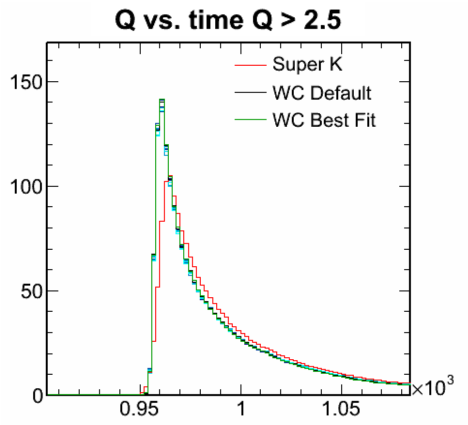


Current Limitations

- The tuning of the optical parameters was sufficient to get reasonable agreement with the SK Reconstruction.
- However, there are some detailed disagreements between the simulations that cannot be fixed by tuning
  - Has limited the distributions that can be used to tune
- These differences are likely do to underlying model differences (needs study)

Example: Digitizer Differences?



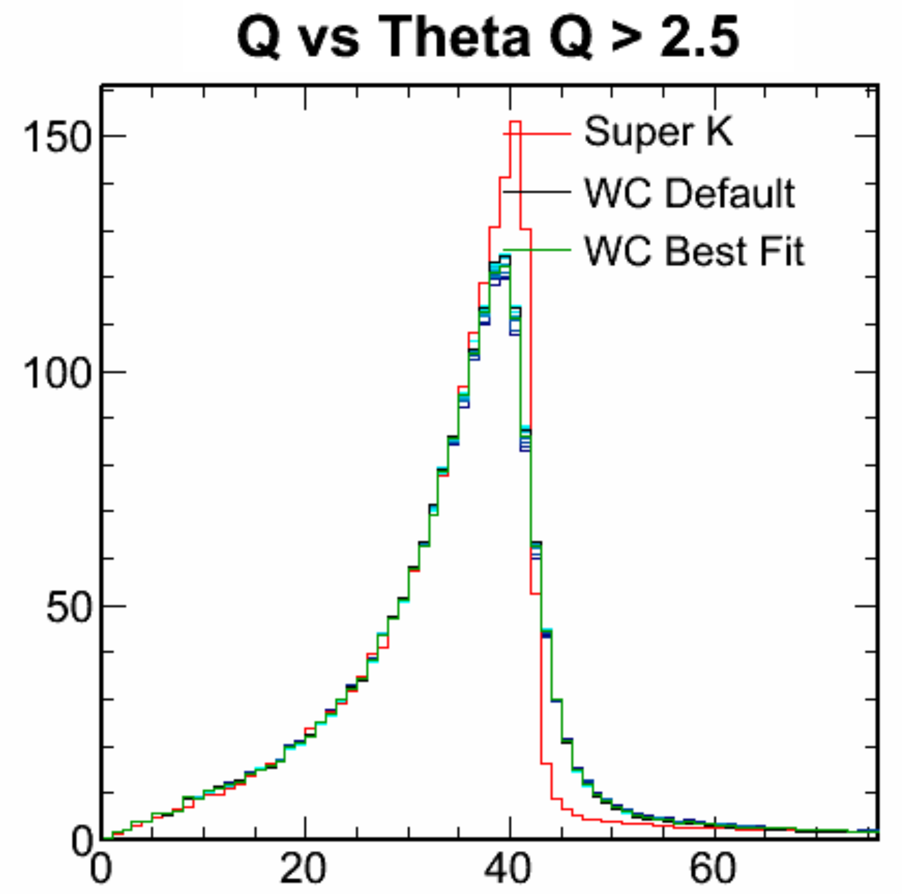


Disagreements in the individual PMT distributions:
- Digitized charge, particularly at low charge
- Charge vs. time

Cannot be removed by tuning
- Probably requires playing with the digitizer

Another example: Q vs. Angle

- WCSim rings appear not to cut off as sharply at 42°
  - μ^- shown at right
- Again, this difference is insensitive to the tuning parameters



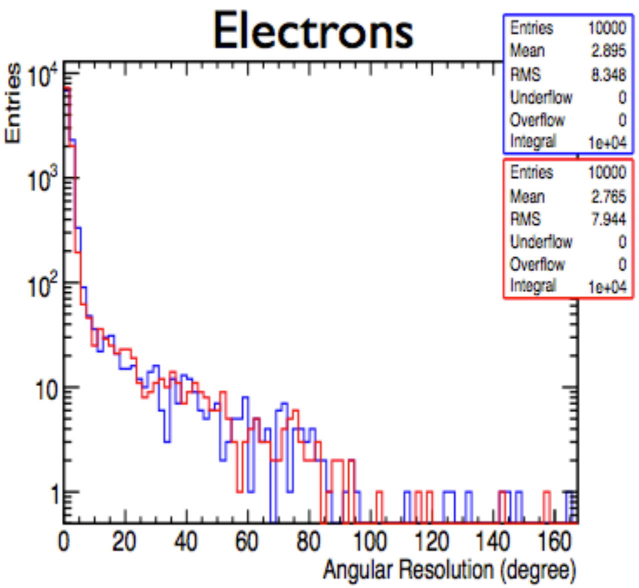
Results from SK Reconstruction

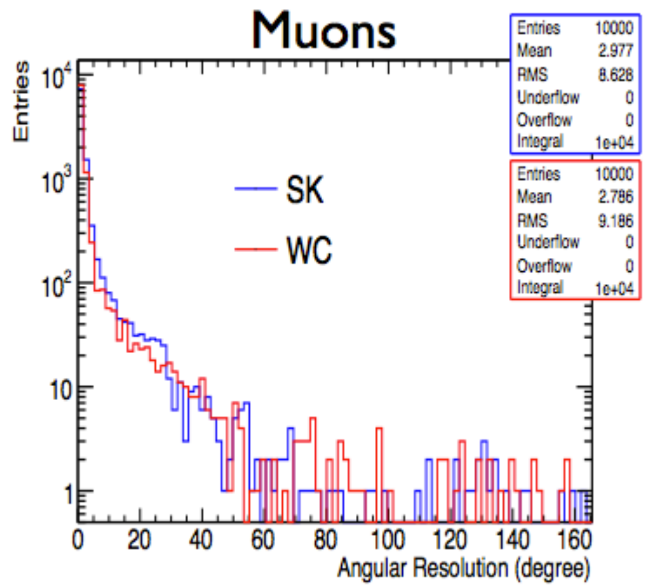
- 1 GeV electrons
- 1 GeV muons
- 1 GeV pions
- 250 MeV pions

Results after optical tuning.

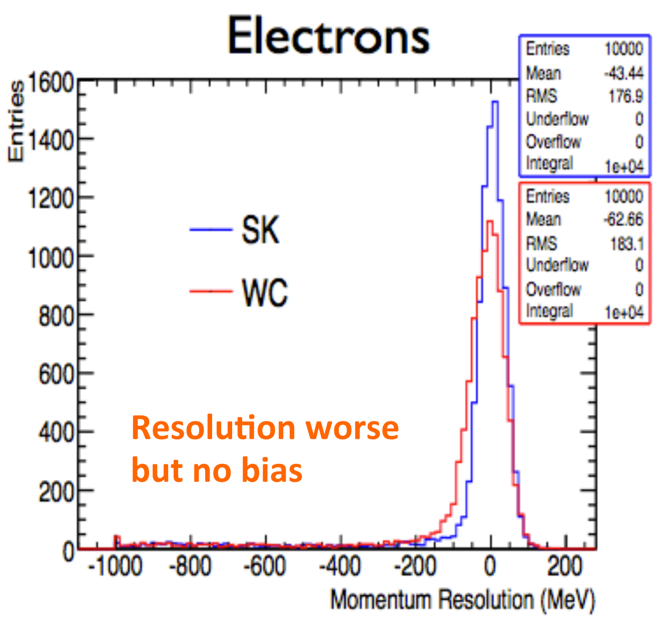
SK / WCSim	Muons	Electrons
Vertex resolution in cm (68%)	17.4 / 17.6	24.4 / 25
Momentum resolution (%)	2.4 / 3.1 ± 0.1	3.4 / 4.5 ± 0.2
Direction resolution (degree)	1.14 / 1.08 ± 0.57	0.85 / 0.82 ± 0.45
Particle MisID (%)	4 / 3.2 ± 0.2	2 / 2.7 ± 0.2
#Rings≠1 (%)	4.7 / 4.3 ± 0.2	4.6 / 4.2 ± 0.2

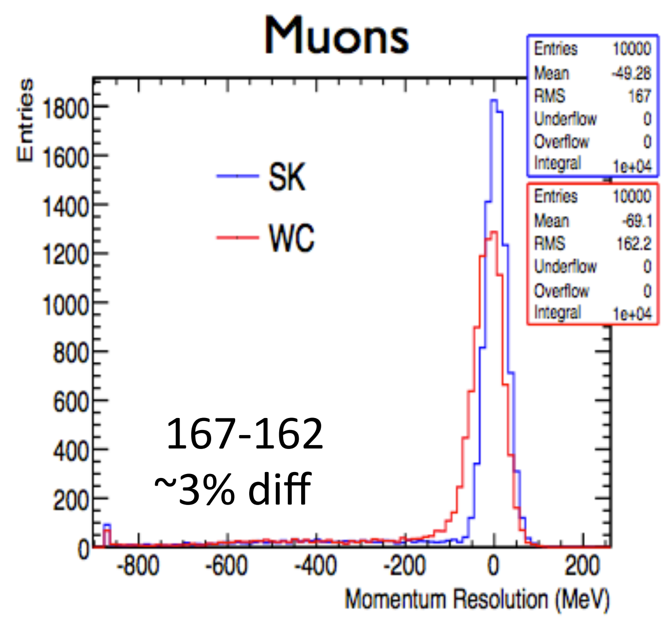
Direction



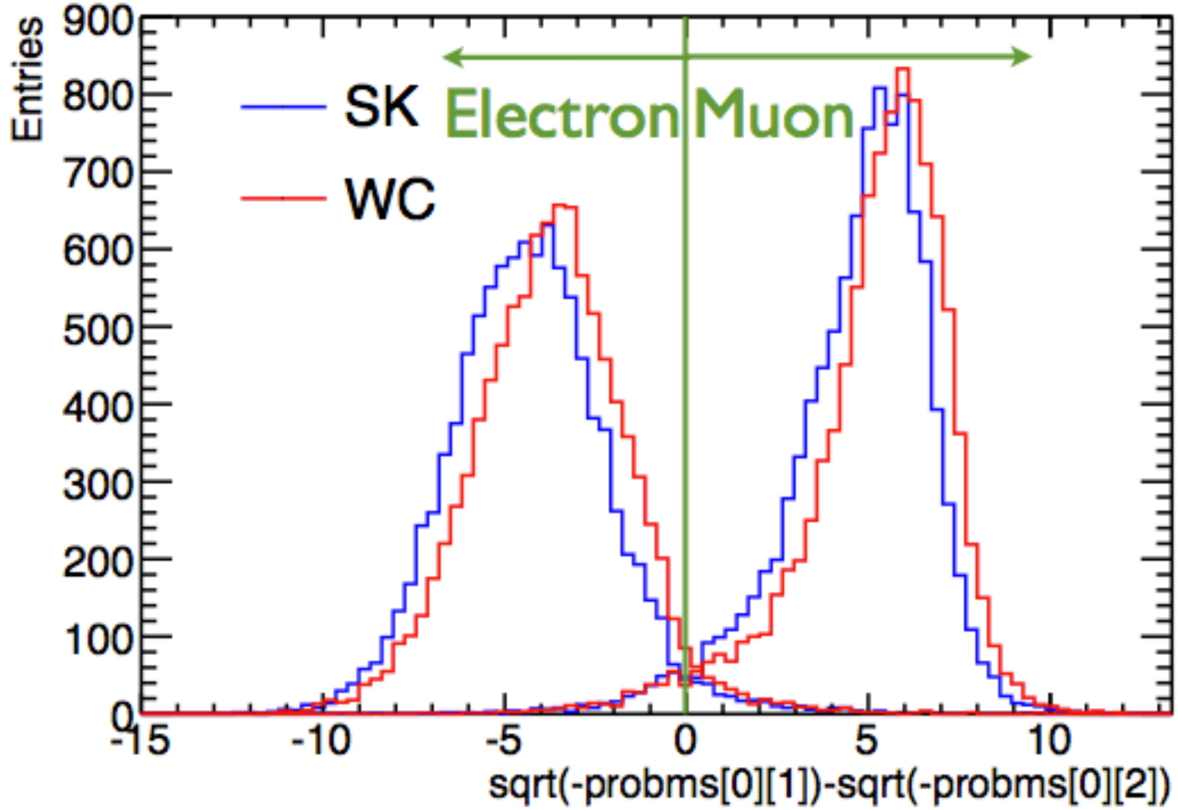


Momentum





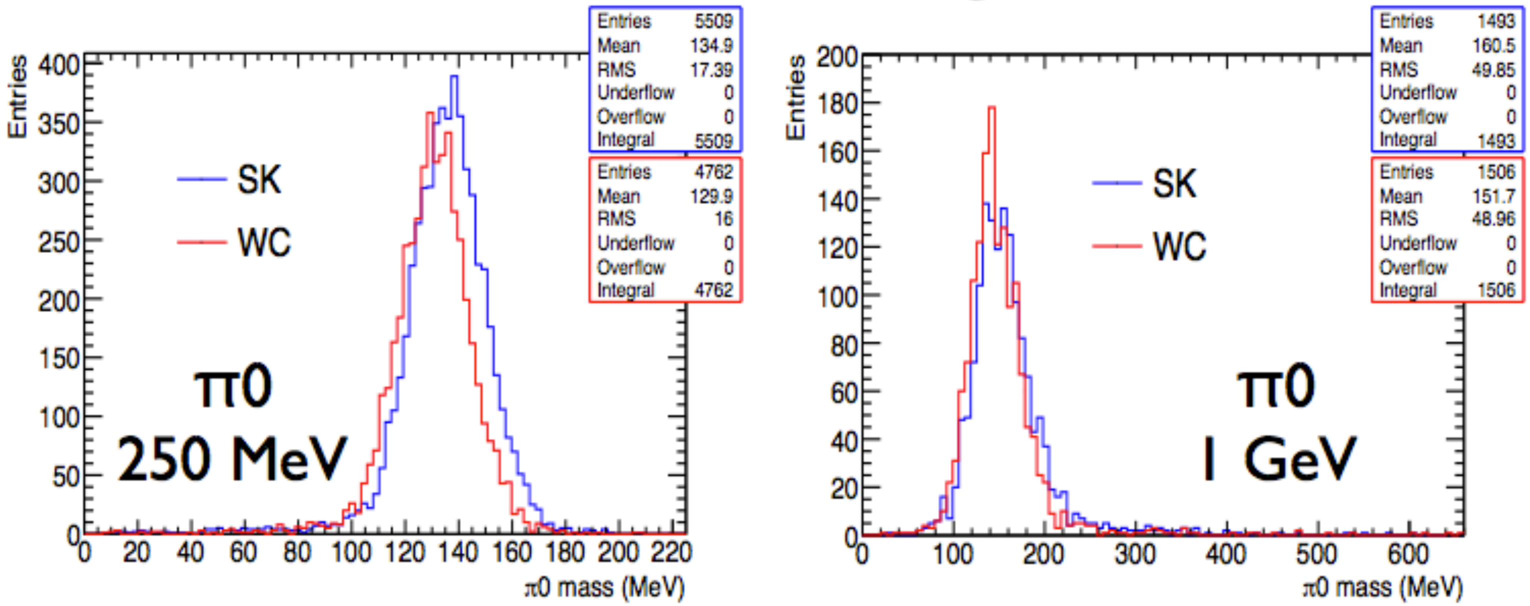
PID performance?



WCSim a little less “fuzzy”. Could be difference in patterns or scattering. Could be reconstruction problem… Need study.

Pizero mass

FCFV, 2 e-like rings



$\mu = (136.4 \pm 13.3)$ MeV

$\mu = (130.9 \pm 12.7)$ MeV

$\mu = (148.3 \pm 23.6)$ MeV

$\mu = (139.1 \pm 19.8)$ MeV

Better resolution for WCsim, but mass shifted a bit (~5%) lower in mass.

Try a "real" analysis: electron appearance selection

Don't try any extra tuning of algorithms etc.

T2K loose CCQE νe cuts

There is 6 cuts (no neutrino reconstructed energy cut here):

- **FCFV**: No activity in the outer detector, reconstructed vertex at least 2m away from the wall
- **evis>100 MeV**: the visible energy should be above 100 MeV to reject obvious background events
- **1 ring**: in CCQE there should be only one electron, get rid of pi0 with two clear rings
- **e-like**: get rid of identified muons CCQE interactions
- **no decay e-**: get rid of most of the remaining muons CCQE interactions misidentified
- **mπ0<105 MeV**: get rid of Pi0 using POLfit

1: FCFV

2: evis

3: 1 ring

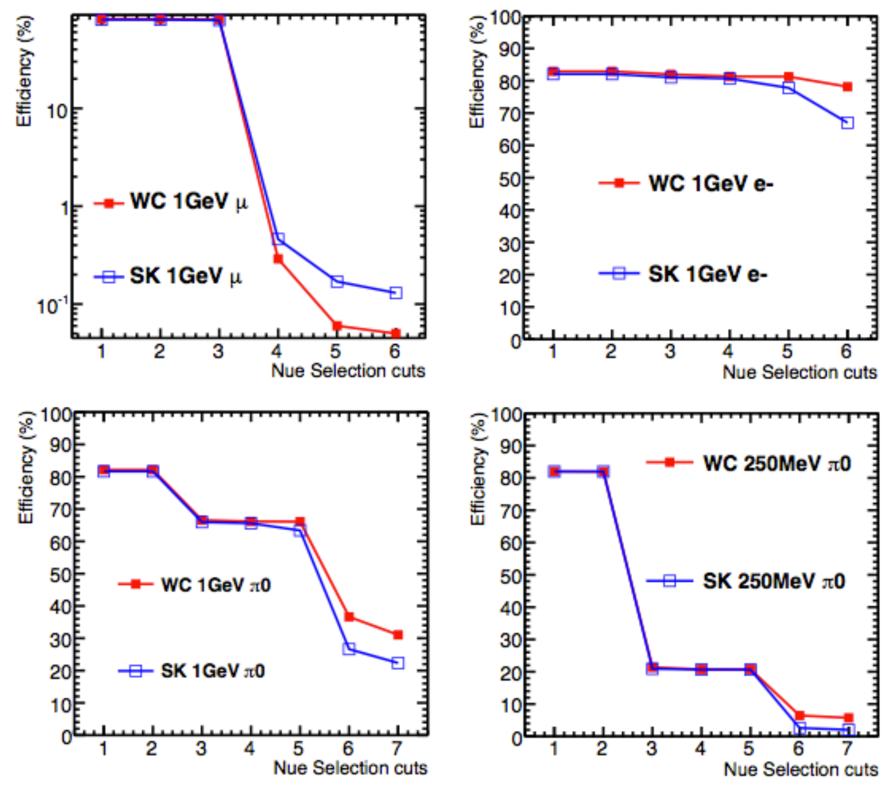
4: e-like

5: no decay e-

6: mπ0

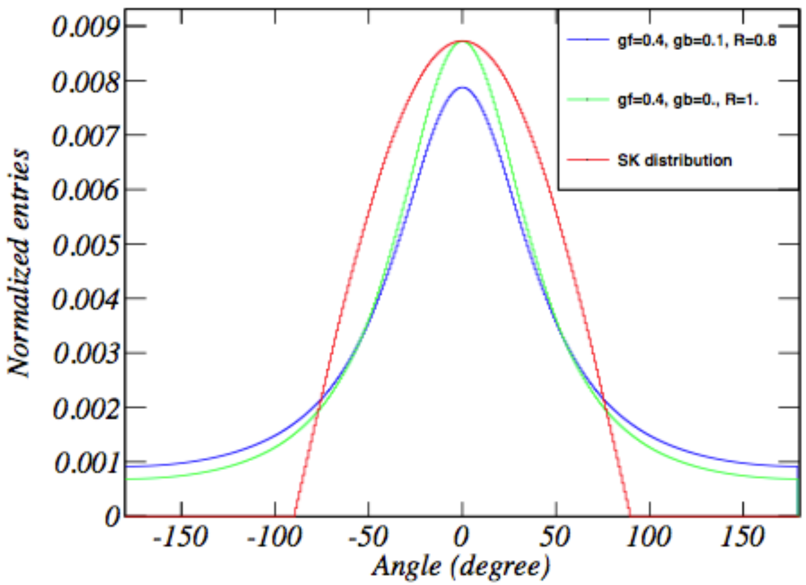
(7: π0 likelihood)

Specialized algorithm to reduce pizero background (didn't tune with new light patterns)



Works! (~10% level)

“Philosophy” Point



Parameterized Mie scattering implemented first in WCSim and then sent to Geant4 team. Now included by default.

Xin Quan (Caltech) + Drexel undergraduate.

Any changes or mistakes we find in the basic Geant4 distribution we send back the Geant4 team.

We don’t just put custom code into WCSim. Examples:

➔ Mistake found in Raleigh scattering angular distribution -> **Fix!**

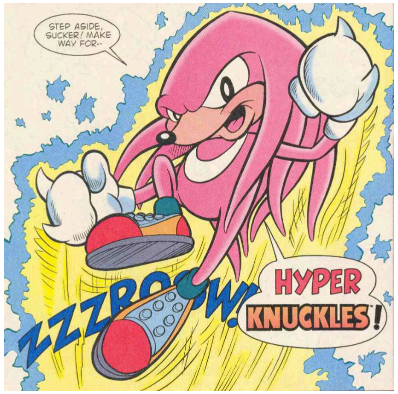
➔ Mie scattering not included -> **Add!**

We could add other models (e.g. hadronic interaction models).

Untested/Uncompleted items

- The "standard" physics lists are now available.
- We merged in some outstanding work into trunk.
- However, other code exists in development branches that could be useful from various LBNE collaborators (but require work to use)
  - Validation/testing code
  - Rough ideas for holding PMT info in text files
  - Rough ideas for swappable digitizers
  - More complicated PMT efficiency functions
  - Light collector and WLS plate work

Lessons / Conclusions



Lessons

- It is more important to study and make the basic things that we know work first before trying to find new alternatives.
- It's hard to make older reconstruction software work with new detectors.

Conclusions

- WCSim is a Geant4 based water Cherenkov detector designed to be very flexible and open.
- Tuning with SK MC and reconstruction software has validated the MC and made it into a possible tool useful for Hyper-K.