WCSim/SKDETSIM Model Comparison Study on Water Cherenkov Angle

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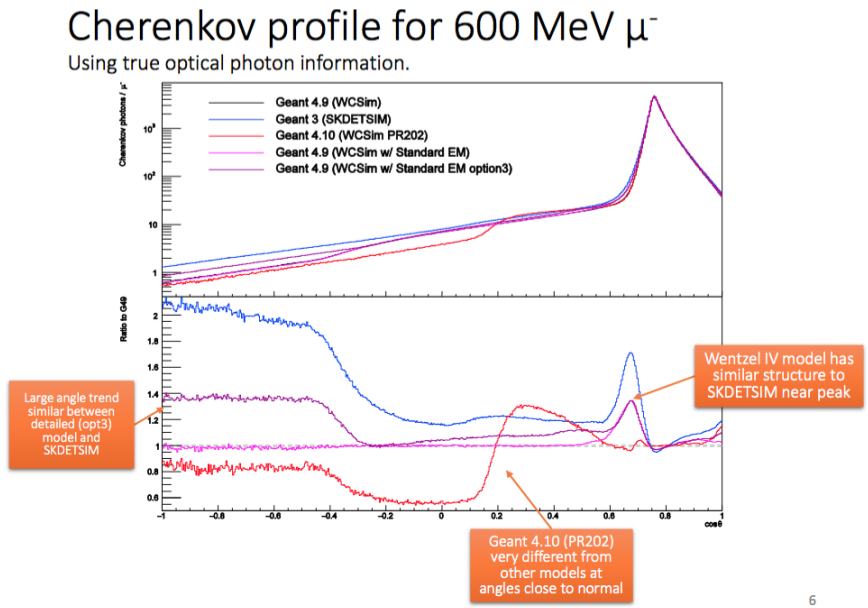
Outlines

Contents

Introduction

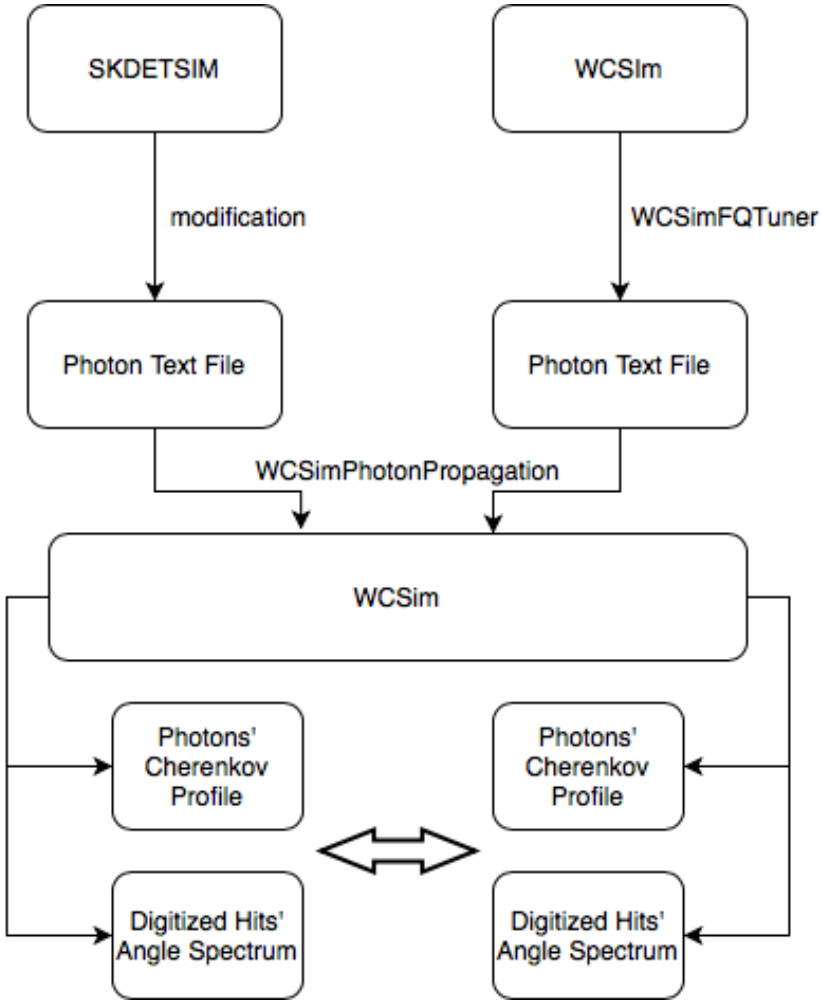
- WCSim/SKDETSIM: Geant4/Geant3 based water Cherenkov detector simulators supplying physics models for particle propagation in water.
- Previous studies show different models used in Geant have discrepancies in muon Cherenkov profile, indicating unknown model uncertainties which should be understood and reduced as much as possible.

- To directly compare the the models in SKDETSIM(Geant3) and WCSim(Geant4) in the same detector, a new method, WCSimPhotonPropagation, has been added to WCSim to read in photons from a text file and simulate their propagation.
  - Photon files are generated from SKDETSIM/WCSim output.
  - The model differences can be compared as digitized charge angular spectrum.



Introduction

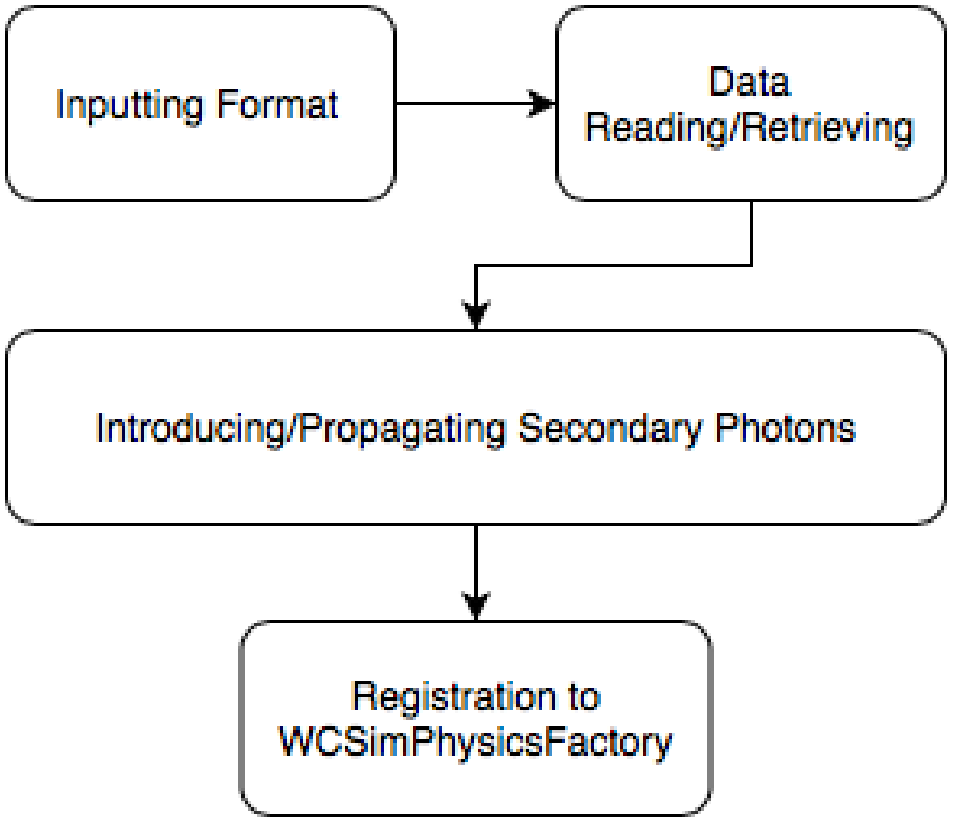
- Photons produced by SKDETSIM/WCSim can be put into text files.
- The text files are read in by WCSimPhotonPropagation
- The propagation of photons is simulated by WCSim, producing events
- In this way, detected photon distribution can be compared between SKDETSIM and WCSim models.



Contents

Overall Concepts of WCSimPhotonPropagation

- Design an inputting format
- Read in and store data for later usage
- Introduce secondary photons by a new process inherited from G4VProcess
- Register the process to the kernel of Geant4 via interface in WCSimPhysicsListFactory
- Build a messenger to enable users to turn on/off this mode manually in macros



Inputting Format

Inspired by Nuance format

- begin: start of the event
- vertex: (x, y, z), time (muon vertex)
- track: PID, Kinetic energy, (DirX, DirY, DirZ)
- opticalphoton: (x,y,z), time, wave length, (DirX, DirY, DirZ), (PolX, PolY, PolZ), parentID
- end: the end of the event

```
18700 opticalphoton 742.448 -1.46181 -15.3996 2.83955 426.28 0.87832 -0.37060
      1 0.302009 0.122608 -0.435975 -0.891568 39232
18701 opticalphoton 743.005 -1.5476 -14.8538 2.8421 377.549 0.657447 0.405239
       0.635252 -0.10348 0.883637 -0.456594 39232
18702 end
18703 begin
18704 vertex 0 0 0 0
18705 track 13 212.5 1 0 0
18706 opticalphoton 0.441055 -0.000569191 -0.0012402 0.00155991 474.367 0.792
      749 -0.394308 0.464833 -0.609542 -0.509312 0.607503 1
18707 opticalphoton 1.43795 -0.0018557 -0.00404336 0.00508569 411.597 0.79130
      3 0.233931 0.564904 -0.611424 0.302927 0.731023 1
18708 opticalphoton 0.0174735 -2.255e-05 -4.91338e-05 6.17999e-05 338.221 0.7
      83869 -0.614938 0.0860271 -0.620919 -0.775639 0.113333 1
18709 opticalphoton 0.933061 -0.00120414 -0.00262367 0.00330003 609.574 0.793
      636 0.0678174 -0.604601 -0.60839 0.0910821 -0.788394 1
18710 opticalphoton 0.913779 -0.00117925 -0.00256945 0.00323183 383.262 0.789
      272 0.560956 0.249757 -0.614041 0.71968 0.32406 1
18711 opticalphoton 0.170529 -0.000220071 -0.000479509 0.000603121 430.986 0.
      790187 -0.572413 0.218971 -0.612859 -0.736219 0.287029 1
18712 opticalphoton 1.27595 -0.00164664 -0.00358783 0.00451273 332.694 0.7849
      27 0.613305 0.0880195 -0.619583 0.776364 0.115652 1
```

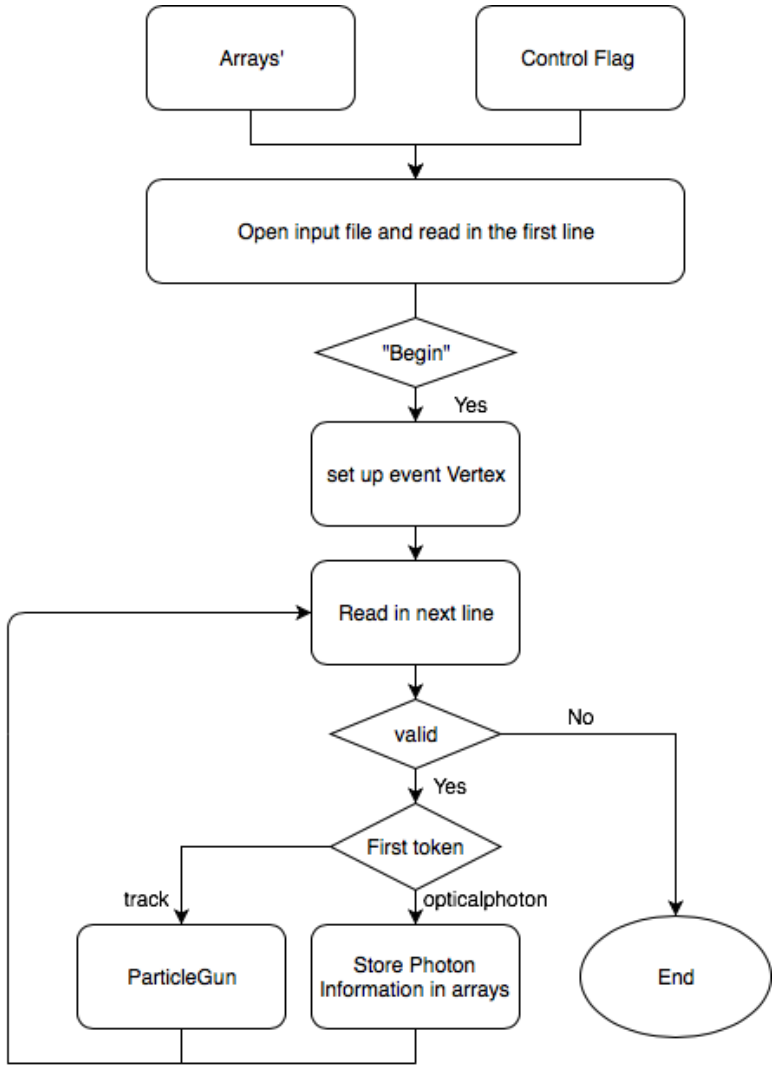
Data Reading/Retrieving

Modifications done in WCSimPrimaryGeneratorAction class

- Declarations of arrays to store data
- Declaration of Control flag: usePhoProEvt
- Reading in from input file, the photon information is stored in the arrays
- Definitions and declarations of member functions to return data and control flag.

WCSimPrimaryGeneratorMessenger

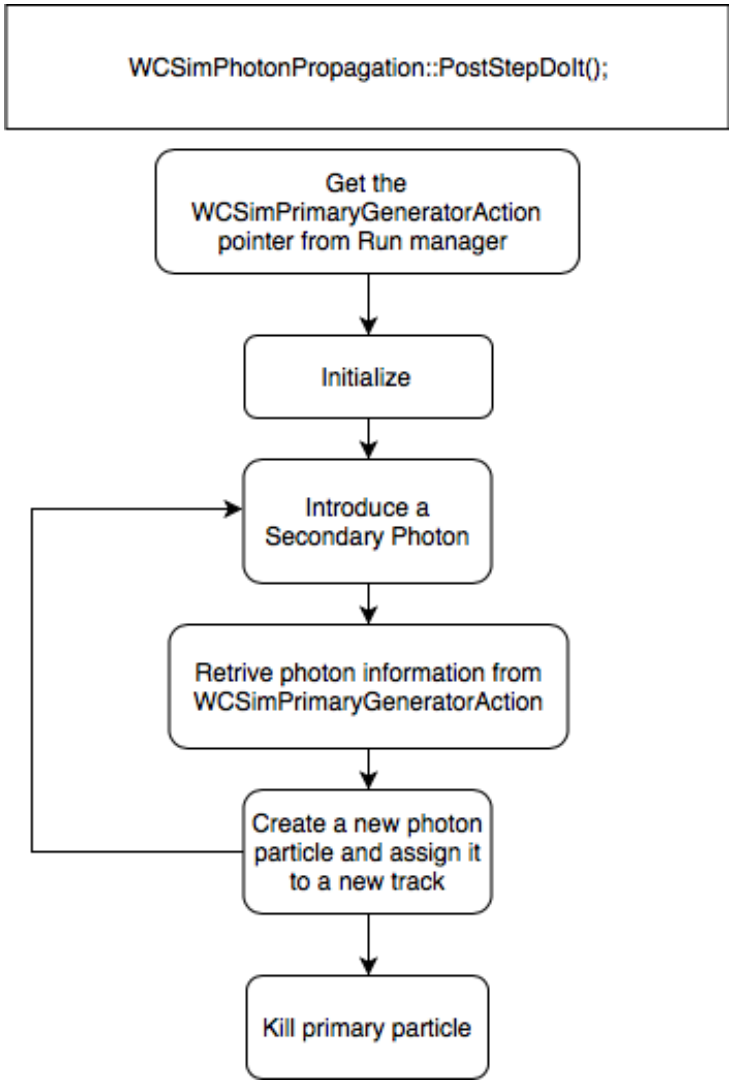
- /mygen/generator photonprop
  /mygen/phoprovecfile PATHtoFILE



Introducing/Propagating Secondary Photons

WCSimPhotonPropagation: a physics process inherited from G4VProcess

- Constructor, Destructor, Operator
- IsApplicable()
- BuildPhysicsTable()
- BuildThePhysicsTable()
- GetPhysicsTable()
- DumpPhysicsTable()
- SetTrackSecondairesFirst()
- GetTrackSecondariesFirst()
- GetMeanFreePath()
- PostStepDoIt()
- PostStepGetPhysicalInteractionLength()
- SetPhotonPropagation()
- IsUsingPhotonPropagation()



Registration and User Control

WCSimPhotonPropagationBuilder

- the corresponding concrete class inherited from G4VPhysicsConstructor for WCSimPhotonPropagation;
  the interface to Geant4 kernel
- is used to register the WCSimPhotonPropagation to certain candidate particles
- ConstructProcess()
  ConstructParticle()

WCSimPhysicsListFactory

- Register WCSimPhotonPropagationBuilder when initialized.

WCSimPhotonPropagationMessenger

- the concrete class inherited from G4UImessenger for WCSimPhotonPropagation;
  the interface to macro command
- is used to define user command in macro script to turn on/off photon propagation mode
- Constructor
  SetNewValue()

- /PhotonPropagation/mode on: set photon propagation mode,
  Interaction Length→DBL_MIN
- /PhotonPropagation/mode off: unset photon propagation mode,
  Interaction Length→DBL_MAX

Contents

WCSim/SKDETSIM Muon Angular Spectrum

Event Configuration

SKDETSIM

- 300MeV/c momentum μ^-
- generated at tank center shot to the wall
- all photons are tracked
- decay is turned off
- 50,000 events

WCSim

- SuperK geometry
- 212.403 MeV Kinetic μ^-
- generated at tank center shot to the wall
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay and capture is turned off
- 50,000 events

WCSimPhotonPropagation

- SuperK geometry
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay is turned off
- muon capture is turned off

Switching to Angle w.r.t Tank Center for Photons

To compare the true photon distribution with the digitized charge distribution, we redefine the angle of true photons to be w.r.t the tank center.

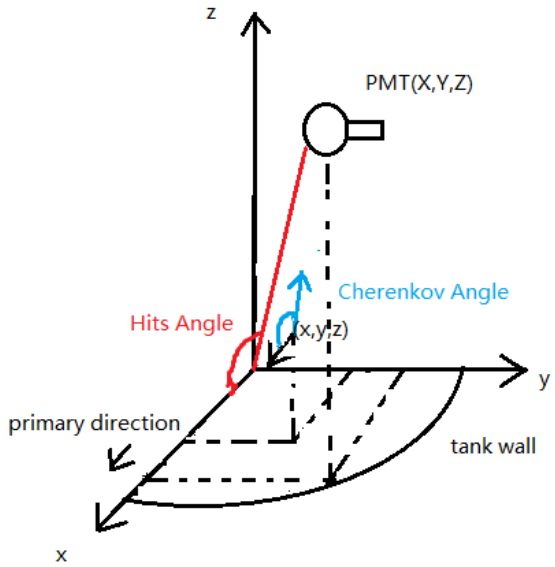
Cherenkov Angle of Photon:

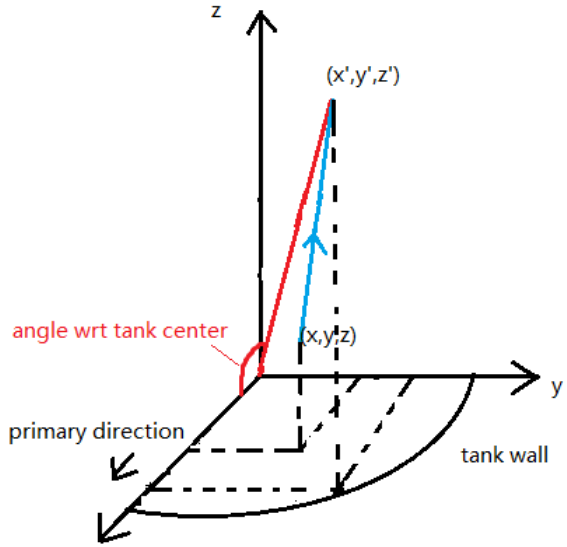
$$\cos(\theta) = \frac{\vec{p_\mu} \cdot \vec{p_\gamma}}{|p_\mu||p_\gamma|}$$

$\downarrow$

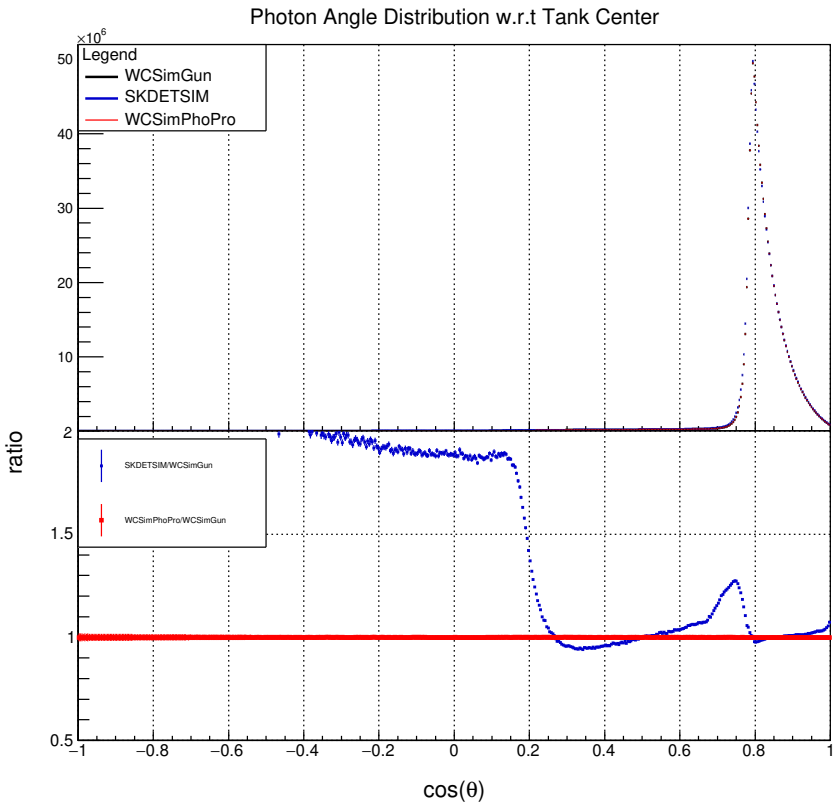
Angle of Photon w.r.t Tank Center:

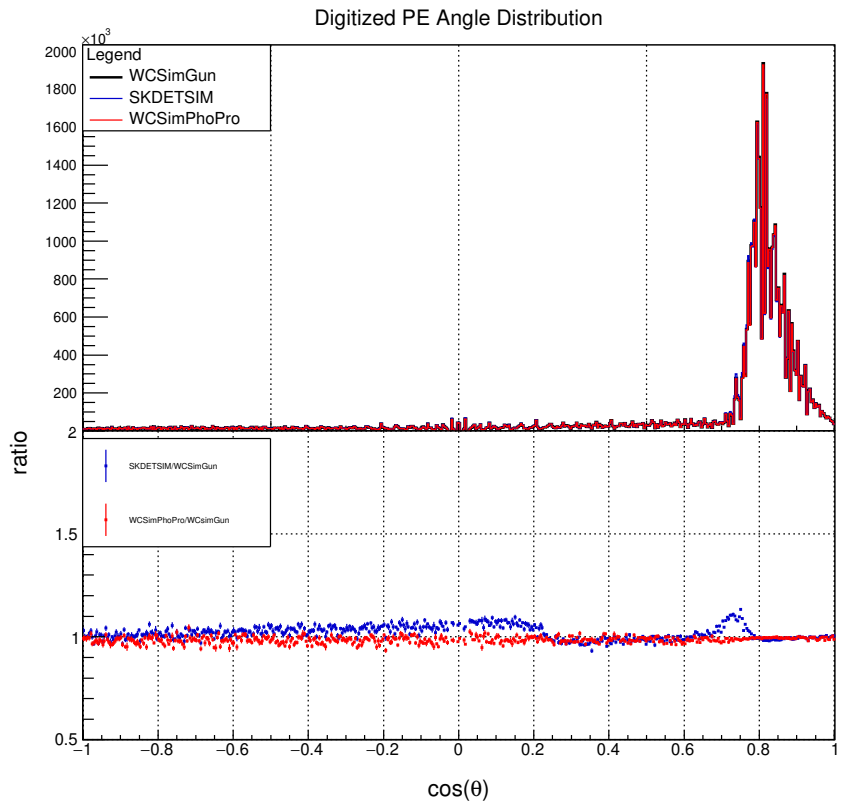
$$\cos(\theta') = \frac{\vec{p_\mu} \cdot \overrightarrow{(x',y',z')}}{|p_\mu||(x',y',z')|}$$





WCSim/SKDETSIM Muon Angular Spectrum Comparison





Range	SKDETSIM	WCSimPhoPro	Ratio	Range	SKDETSIM	WCSimPhoPro	Ratio
0.7-0.8	3.33667e+08	3.22468e+08	1.035	0.7-0.8	1.16048e+07	1.12978e+07	1.027
-1.0 - 0.2	1.41762e+07	7.42062e+06	1.910	-1.0 - 0.2	4.85718e+06	4.61103e+06	1.053

- The features in the true angular distribution can be seen in the digitized charge distribution, but the magnitudes are somewhat reduced due to scattering/reflections.

Contents

WCSim/SKDETSIM Muon Angular Spectrum

Event Configuration

SKDETSIM

- 300MeV/c momentum μ^-
- generated at (-180cm,0,0)
- all photons are tracked
- decay is turned off
- 50,000 events

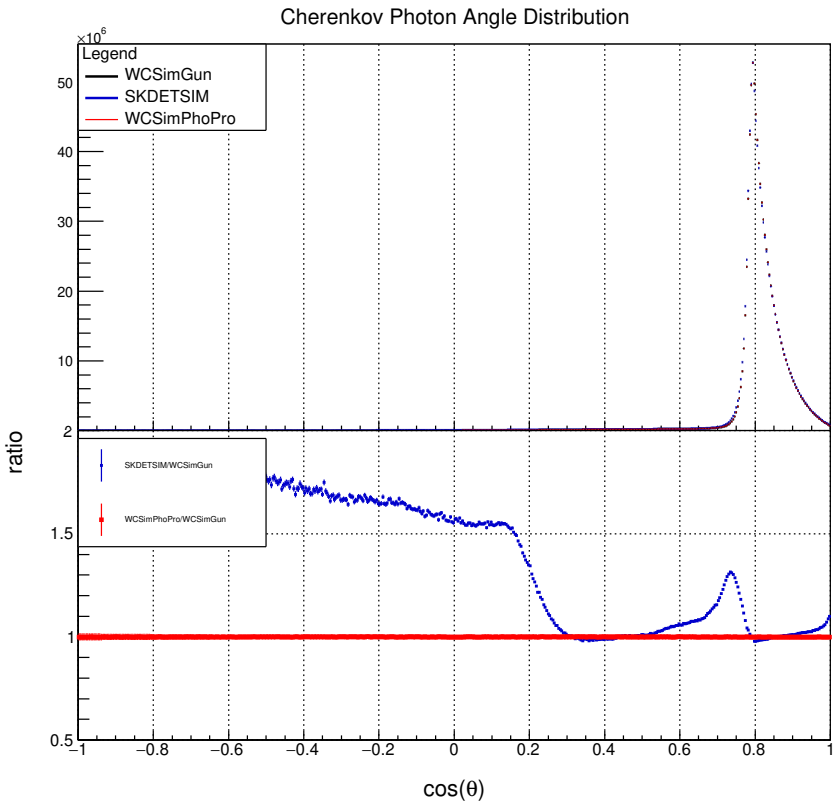
WCSim

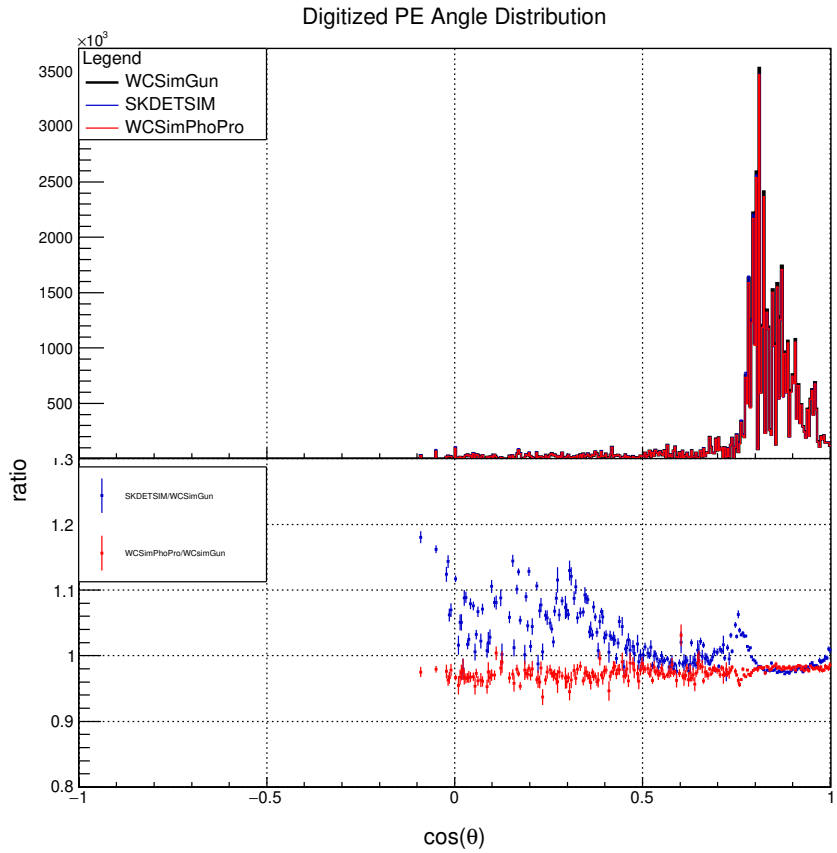
- nuPRISMBeamTest_mPMT geometry
- 212.403 MeV Kinetic μ^-
- generated at tank wall,(-180cm,0,0)
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay and capture is turned off
- 50,000 events

WCSimPhotonPropagation

- nuPRISMBeamTest_mPMT geometry
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay is turned off
- muon capture is turned off

WCSim/SKDETSIM Muon Angular Spectrum: True Photon / Digitized Charge





- The photon's angle is w.r.t primary track direction, while the charge's angle is w.r.t the vertex of the primary muon
- The differences between WCSim and SKDETSIM models are still detectable in the digitized charge distribution.

WCSim/SKDETSIM Muon Angular Spectrum

Event Configuration

SKDETSIM

- 500MeV/c momentum μ^-
- generated at (-180cm,0,0)
- all photons are tracked
- decay is turned off
- 50,000 events

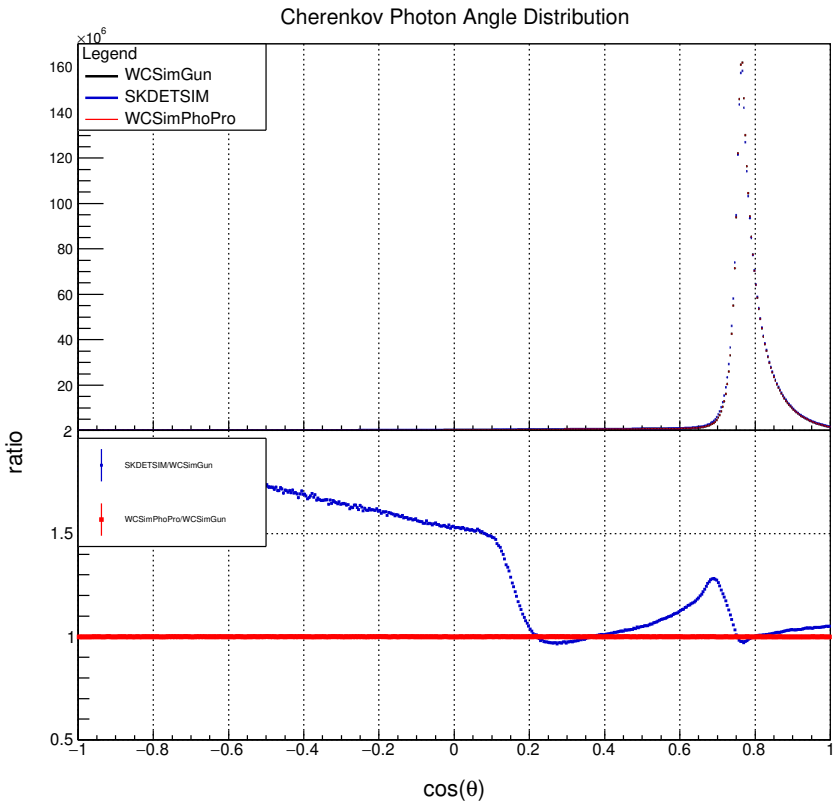
WCSim

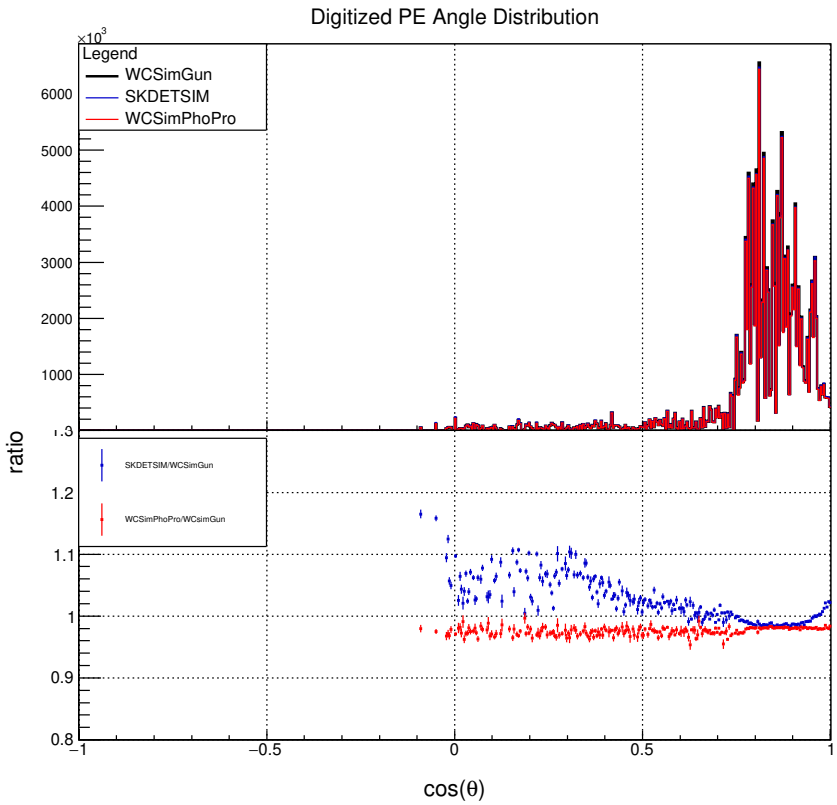
- nuPRISMBeamTest_mPMT geometry
- 405.384 MeV Kinetic μ^-
- generated at tank wall,(-180cm,0,0)
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay and capture is turned off
- 50,000 events

WCSimPhotonPropagation

- nuPRISMBeamTest_mPMT geometry
- QE mode: sensitive detector only
- dark rate set to 0
- muon decay is turned off
- muon capture is turned off

WCSim/SKDETSIM Muon Angular Spectrum: True Photon/Digitized Charge





- As the momentum of primary muon is raised, there are much more photons generated; due to the small tank volume, reflection and scattering show obvious impact on reducing the model differences in digitized charge distribution.

Contents

Summary

- WCSimPhotonPropagation is a mode in WCSim designed to read in Cherenkov photons' information and then simulate their propagation under WCSim computing environment. After validation, this mode is used to compare WCSim/SKDETSIM model difference in muon's Cherenkov Angular spectrum in WCTE geometry.
  - The validation is made in SuperK geometry with the photon angular distribution with respect to tank center as the metric to make a more similar comparison with charges' angular spectrum.
  - The features shown in true photons' angular spectrum can be preserved by WCSimPhotonPropagation and be seen at digitized charge level.
- The discrepancy between SKDETSIM and WCSim in photons' angular spectrum can be detectable in the WCTE experiment at digitized charge level.
  - The difference between SKDETSIM and WCSim is clearer at charge level when the primary muon's momentum is lower.
  - When the momentum of muon is higher, the reflection and scattering of cherenkov photons washes out some of the differences shown at charge level because of the limited tank volume.

Summary

- Further studies:
  - improving the simulation details, including varying the primary particle's momentum and direction to take into account the expected resolution of the test beam instruments.
  - improving the mode's performance, like the compatibility to cope with different primary particles of various momentum, the parallel computing robustness