WCSim Performance Study

Yuji Okajima
Tokyo Institute of Technology

3^{rd} Open Hyper-K Meeting, IPMU
June 22^{th}, 2013

Table of Contents

1) Comparison between SKDetSim and WCSim

2) Comparison between Super-K and Hyper-K

3) A preliminary performance study
   - Energy resolution
   - Particle Identification ability

WCSim used in this study is the version commited on Jun.13.
In this study, reconstruction tool (fiTQun) was not used.
(Comparison of MC output)

Please see Patrick's talk for fiTQun study.

And, dark noise was not switched on in this study.

1) Comparison between SKDetSim and WCSim

- I compared the output of WCSim and SKDetSim with the same Super-K geometry.

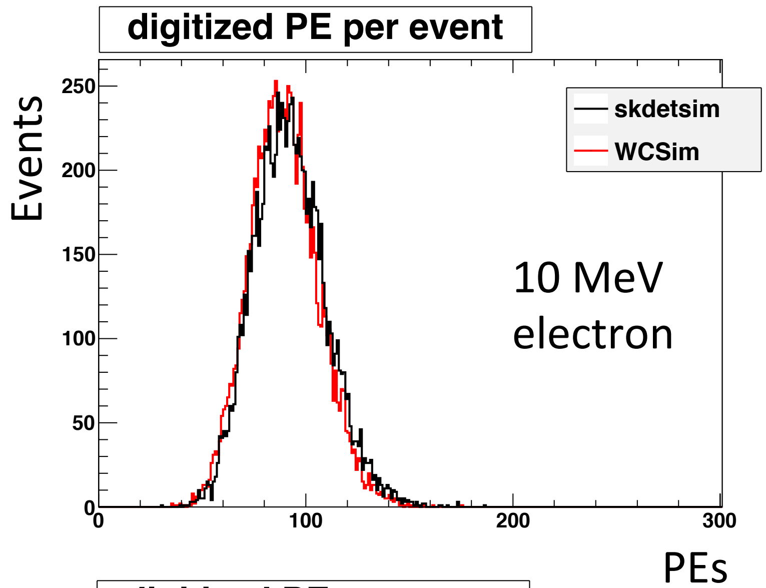
Software	WCSim and SKDetSim (SKDetSim was run by Koshio-san)
Detector	Super-K
Coverage	40%
Particle origin	Uniform in fiducial volume of the detector
Direction	Isotropic

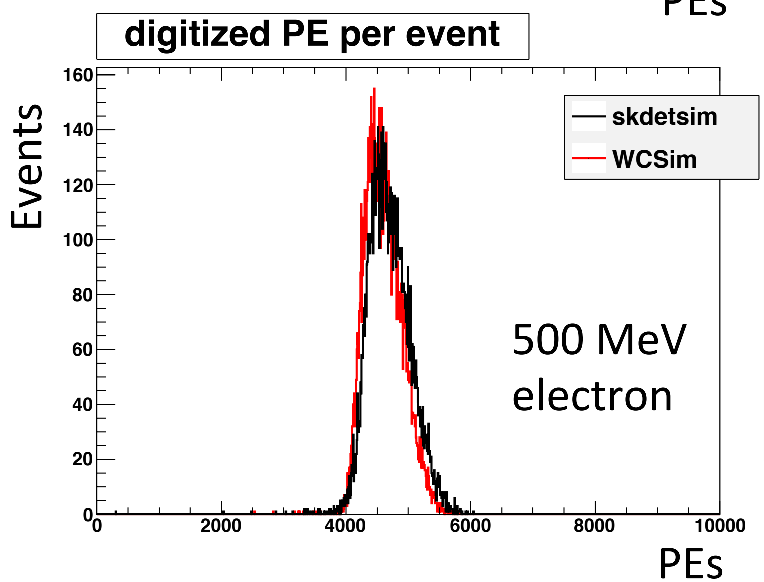
Fiducial Volume: The region at a distance of 2 [m] from the inner detector's wall

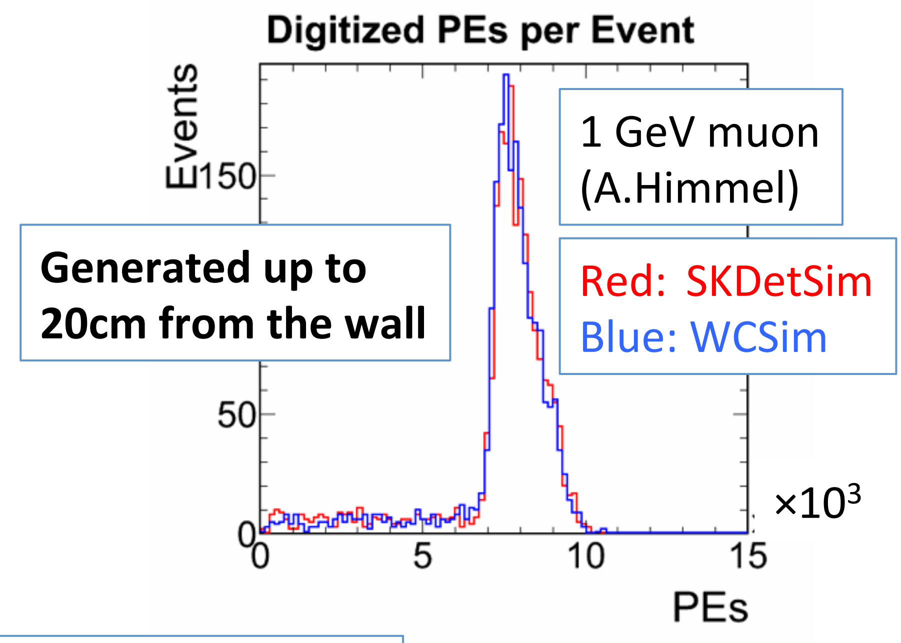
Output

- True photoelectron
- Digitized PE ←Total charge output of PMTs
- Number of PMT with true PE (Hit)
- Number of PMT with digitized PE (Digitized hit)

SKDetSim vs. WCSim







Mean±RMS of digitized PE

	SKDetSim	WCSim
10MeV e^-	92±18	90±17
500MeV e^-	$(4.7\pm0.3)\times10^3$	$(4.6\pm0.3)\times10^3$
1000MeV μ^-	$(7.4\pm1.8)\times10^3$	$(7.4\pm1.7)\times10^3$

Conclusion of SKDetSim vs. WCSim

The tuning of WCSim is validated with SKDetSim from 10 MeV to 1000 MeV and it seems good enough to set on to larger detector study.

Other variables (e.g. number of hits) do not show as good agreement as digitized PE (see backup) – maybe due to different distribution of single PE PMTs? (under investigation)

2) Super-K vs. Hyper-K

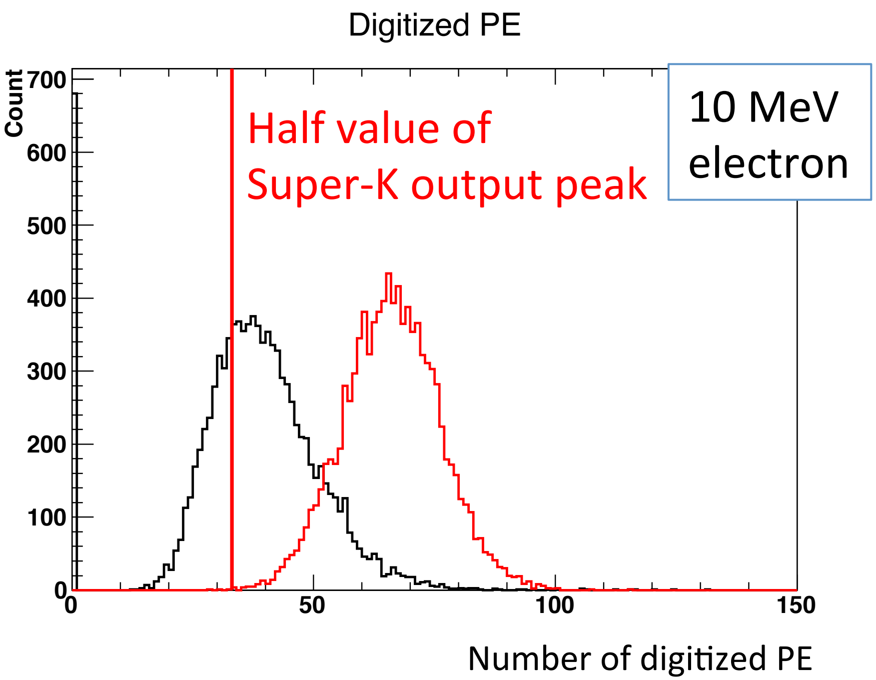
- Hyper-K geometry was introduced in WCSim.

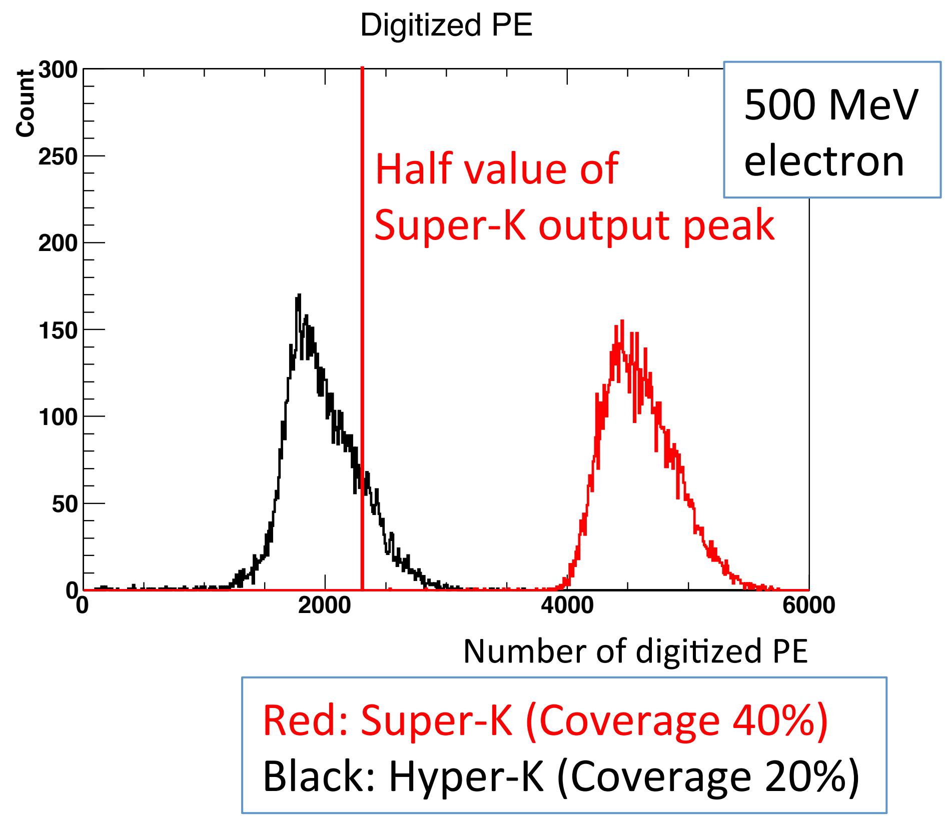
→I also compared the difference between Super-K and Hyper-K output with WCSim

Detector	Shape and inner size	Coverage
Super-K	Cylinder, ϕ 33.6 m × L 36.2 m	40%
Hyper-K	Egg-like, W 42 m × H 42 m ×L 48.5 m (A compartment of Hyper-K)	20%

Incident particle is electron, appearing uniformly in fiducial volume and pointing to isotropic directions

2) Super-K vs. Hyper-K





There is some difference between SK and HK detectors even after correction of photo-coverage.
(different detector structure)

3) Study of Compartment Length

Purpose: To evaluate the effect of configuration of detectors, I measured

1. Energy resolution
2. Particle identification

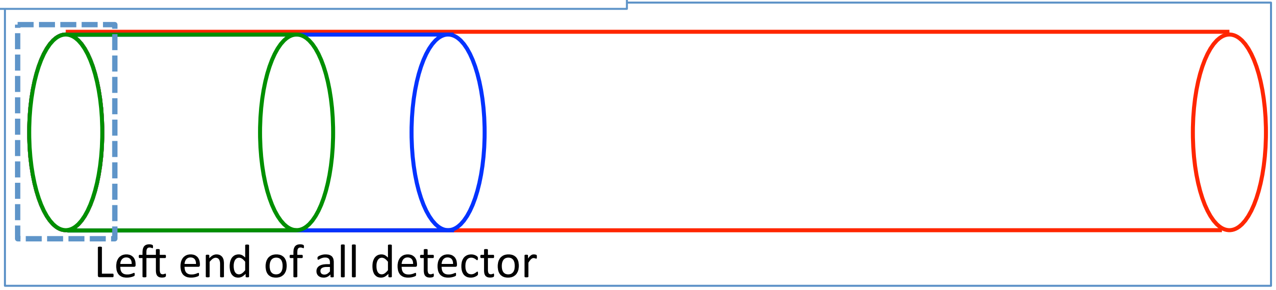
by using WCSim.

Simulation Setup

Num of compartment	1	3	5
Radius [m]	21.1 (Largest cylinder which can enter in Hyper-Kamiokande)		
Length of a compartment [m]	247	81.5	48.5
Coverage	40%, 20%, 10%		
Particle	electron		
Momentum	7 MeV～15 MeV (4 points) and 50 MeV～1000 MeV (5 points)		

In the simulation, particles appear from fiducial volume in these detectors randomly and pointing to isotropic direction.
This analysis includes all photoelectron (no spatial cut and no time cut)

Comparison of detector length



Red:1section
Blue:3section
Green:5section

3-1) Calculation of Energy Resolution

To evaluate energy of particles, I used

- number of PMT with digitized PE (7 MeV ～ 15 MeV)
- Digitized PE (corrected) (50 MeV ～ 1000MeV) (See below)

I measured energy resolution of low and high energy region in each detector.

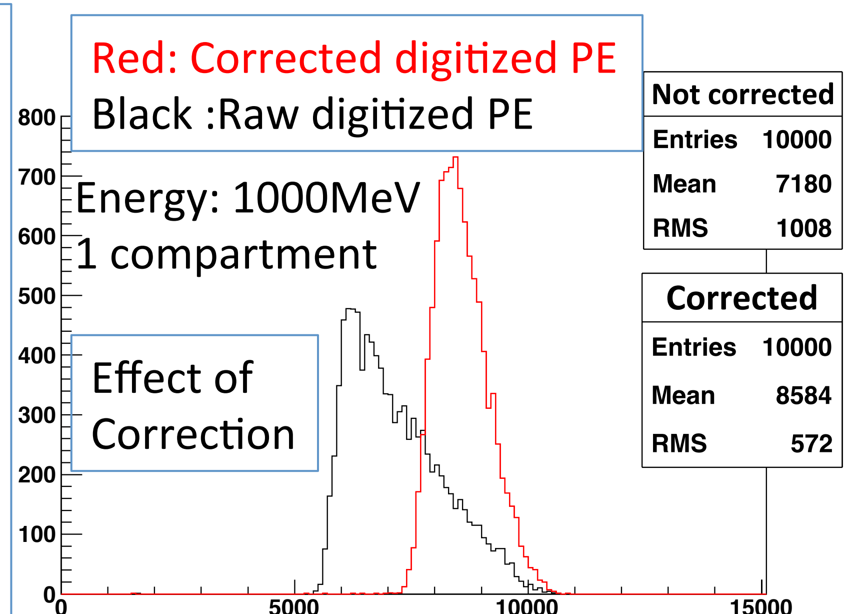
Taking light attenuation effect into account, I corrected digitized PE by light attenuation by using following equation

Correction of digitized PE

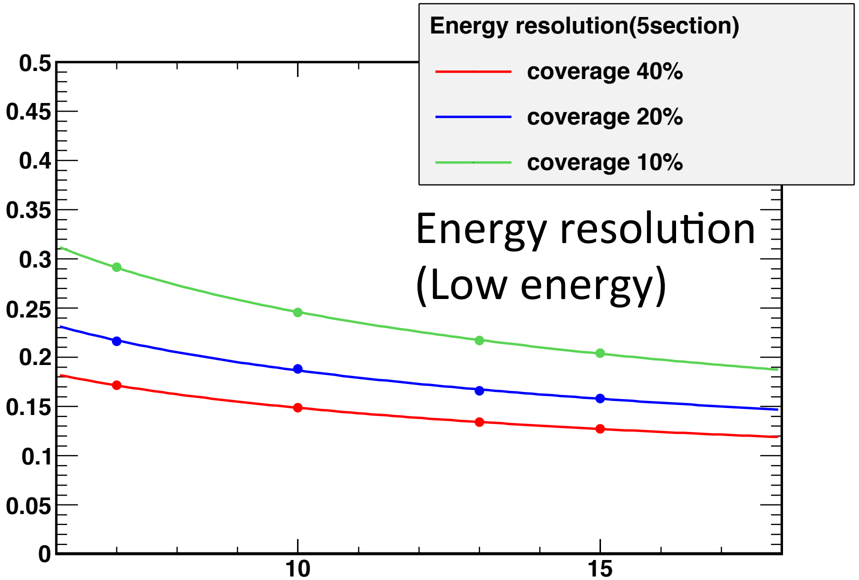
$$PE_{\mathrm{corr}} = PE_{\mathrm{obs}} \cdot e^{-10[m]/\lambda} / e^{-L/\lambda}$$

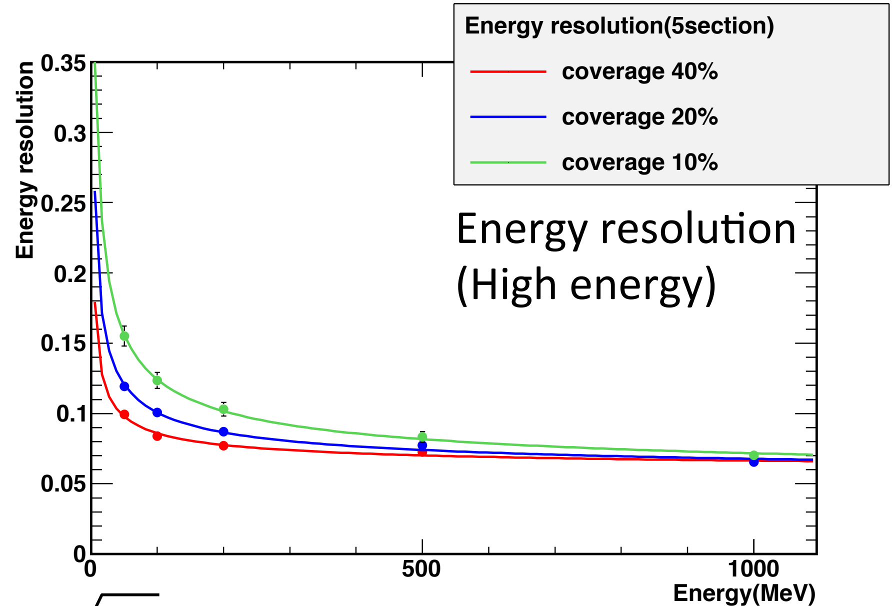
λ : attenuation length

L : Length between particle origin and each PMT



Dependence on Coverage





The fitted curve follows $\sigma/E = a/\sqrt{E} + b$

The energy resolution depends on coverage.

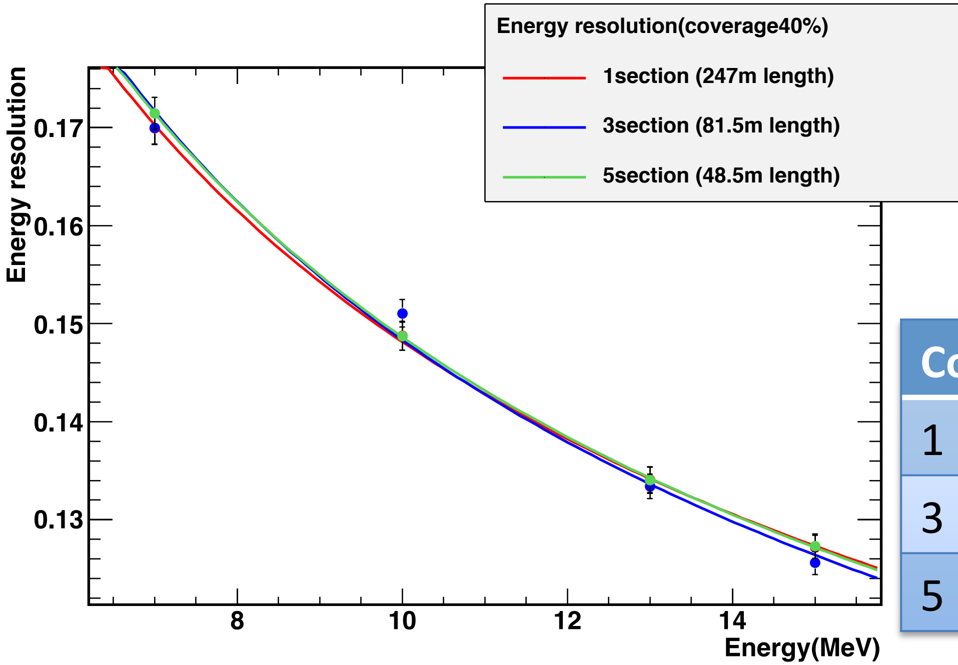
Fitted curve of low energy

	a [MeV$^{1/2}$]	b
40%	(3.7±0.2)×10^{-1}	(3.2±0.5)×10^{-2}
20%	(5.0±0.2)×10^{-1}	(3.0±0.7)×10^{-2}
10%	(7.3±0.3)×10^{-1}	(1.5±0.9)×10^{-2}

Fitted curve of high energy

	a [MeV$^{1/2}$]	b
40%	(2.8±0.2)×10^{-1}	(5.7±0.1)×10^{-2}
20%	(4.8±0.3)×10^{-1}	(5.3±0.2)×10^{-2}
10%	(7.7±0.6)×10^{-1}	(4.7±0.4)×10^{-2}

Dependence on Compartment Length (low energy)



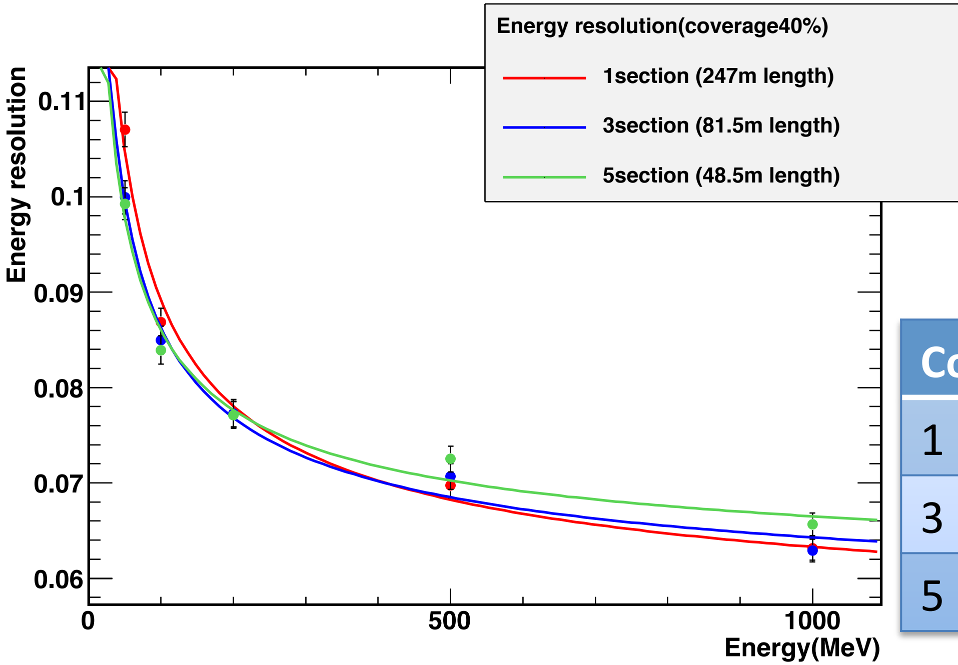
The fitted curve follows

$$\sigma/E = a/\sqrt{E} + b$$

Compartment	a [MeV$^{1/2}$]	b
1 (247 m)	$(3.6\pm0.2)\times10^{-1}$	$(3.5\pm0.5)\times10^{-2}$
3 (81.5 m)	$(3.8\pm0.2)\times10^{-1}$	$(2.9\pm0.5)\times10^{-2}$
5 (48.5 m)	$(3.7\pm0.2)\times10^{-1}$	$(3.2\pm0.5)\times10^{-2}$

In low energy, the effect of compartment length is less significant than that of coverage.

Dependence on Compartment Length (high energy)



The fitted curve follows

$$\sigma/E = a/\sqrt{E} + b$$

Compartment	a [MeV$^{1/2}$]	b
1 (247 m)	$(3.8\pm0.2)\times10^{-1}$	$(5.1\pm0.1)\times10^{-2}$
3 (81.5 m)	$(3.2\pm0.2)\times10^{-1}$	$(5.4\pm0.1)\times10^{-2}$
5 (48.5 m)	$(2.8\pm0.2)\times10^{-1}$	$(5.7\pm0.1)\times10^{-2}$

As the energy becomes higher, the energy resolution of larger detector is better than that of smaller one.

→ Necessity of further correction.
(e.g. acceptance of PMT)

3-2) Particle Identification

Simulation Setup

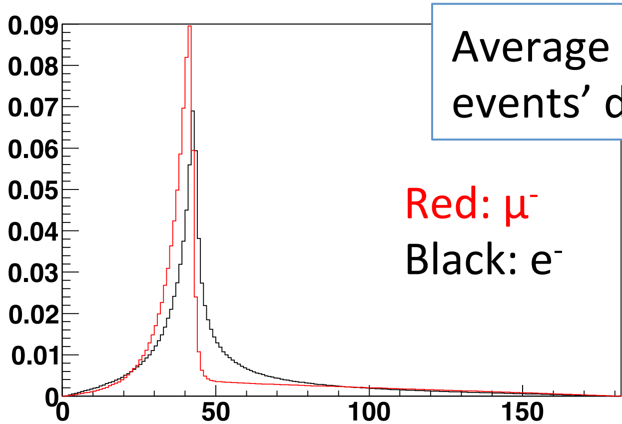
Num of partition	1 (247 m length)	3 (81.5 m length)	5 (48.5 m length)
Coverage	40%, 20%, 10%		
Particle	electron, muon		
Energy	500 MeV		
Particle origin	Uniform in fiducial volume of the detector		
Direction	Isotropic		

Each detector's structure is the same as those used on energy resolution measurement

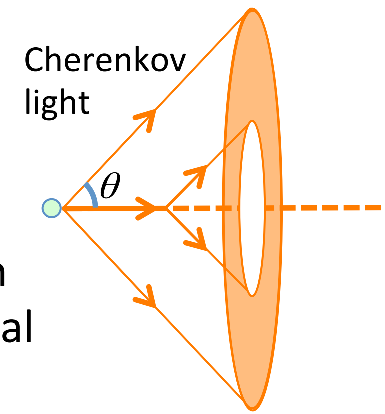
As a method of PID, I used the angular distribution of corrected digitized PEs.

Particle ID by Likelihood Test

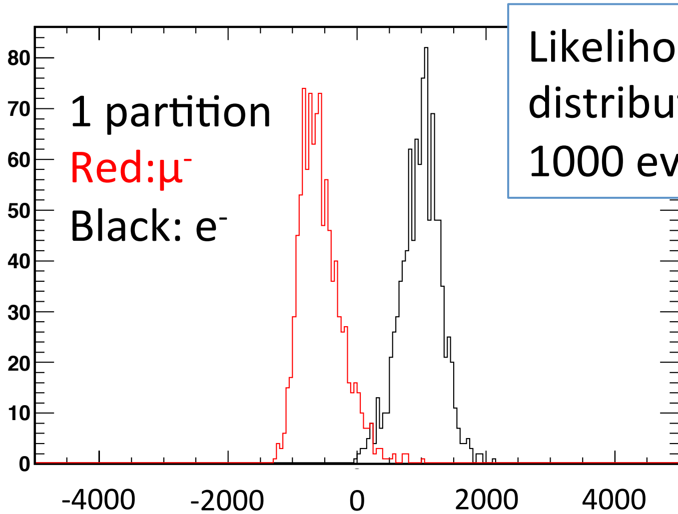
First of all, normalize electron's and muon's angle distribution of digitized PE (corrected) and define them as probability density function (PDF) template.



θ :Angle formed by particle direction and the direction of PMT with signal



Then, angular distribution of digitized PE in each event is tested against electron and muon PDF, and log-likelihood is calculated.



Likelihood distribution of electron and muon.
If electron (black line) has negative likelihood, then it is misidentified to muon.
If muon (red line) has positive likelihood, then it is misidentified to electron.

Result of Simulation

Misidentification rate [%]

Num of Compartment	1section (247 m)		3section (81.5 m)		5section (48.5 m)	
Particle	e^-	μ^-	e^-	μ^-	e^-	μ^-
Coverage 10%	0.9	7.8	0.4	9.4	1.1	11.3
Coverage 20%	0.5	6.5	0	7.9	0.2	10.5
Coverage 40%	0.1	6.4	0	8.4	0.3	9.7

As coverage becomes higher, the misidentification rate seems to become smaller.
Misidentification rate of μ in larger volume detector is smaller than that in smaller volume detector.
The reason is under investigation.

Summary

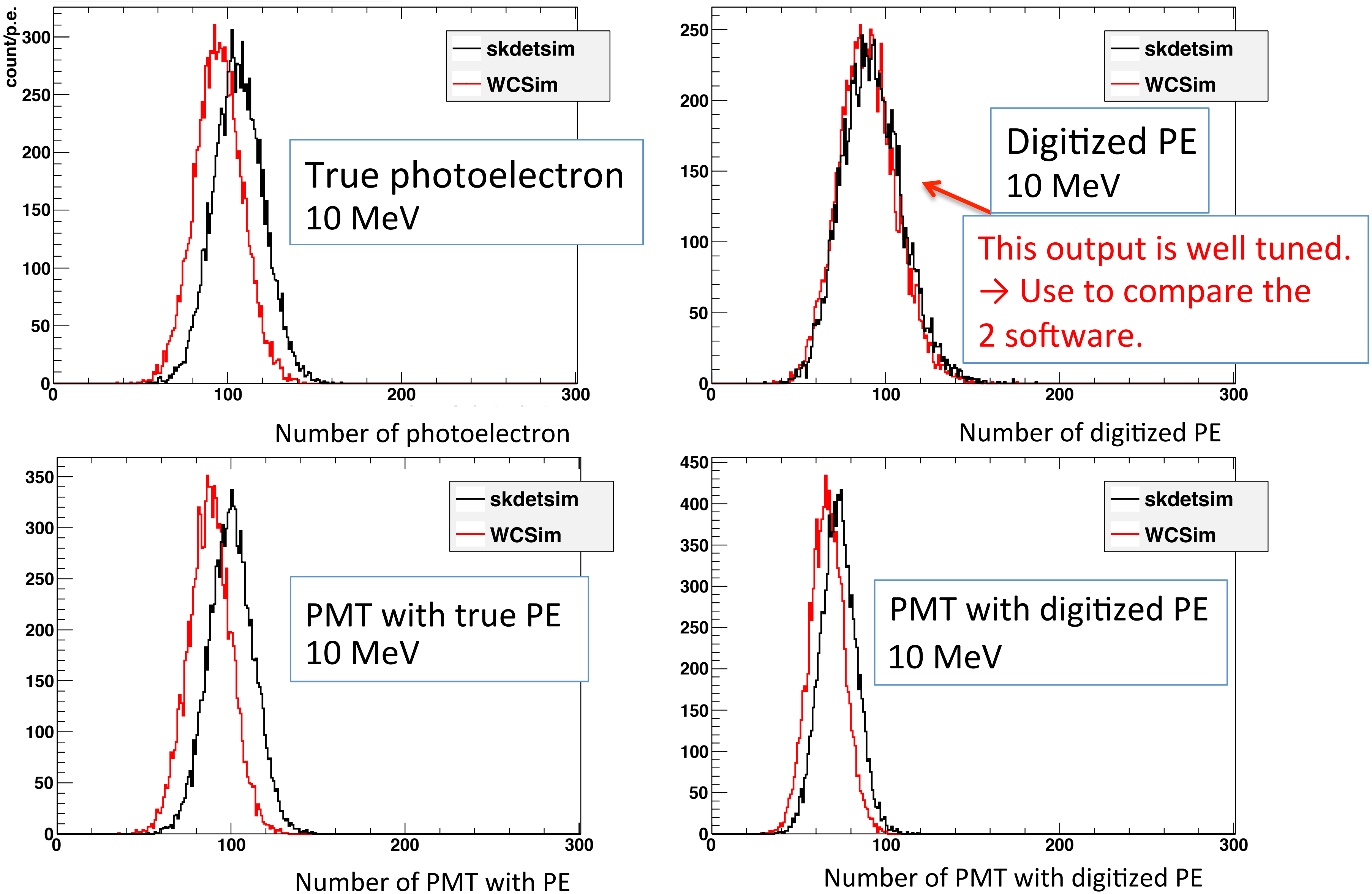
- I compared SKDetSim output with that of WCSim on Super-K geometry.
  - Both programs agree well.
- I compared Super-K and Hyper-K output with WCSim
  - There is some difference due to different detector structure.
- I made preliminary performance study
  - Energy resolution
  - Particle Identification
  - I just started the study and it is first status report.
    I will need to check and understand the results.

Future Plan

- Continue Validation of Hyper-K geometry in WCSim.
- Use real Hyper-K geometry in performance study.
- Analyze energy resolution and particle identification ability more precisely by using FiTQun and further corrections.

Back up

SKDetSim vs. WCSim



SKDetSim vs. WCSim