Study of Hyper-Kamiokande detector simulation

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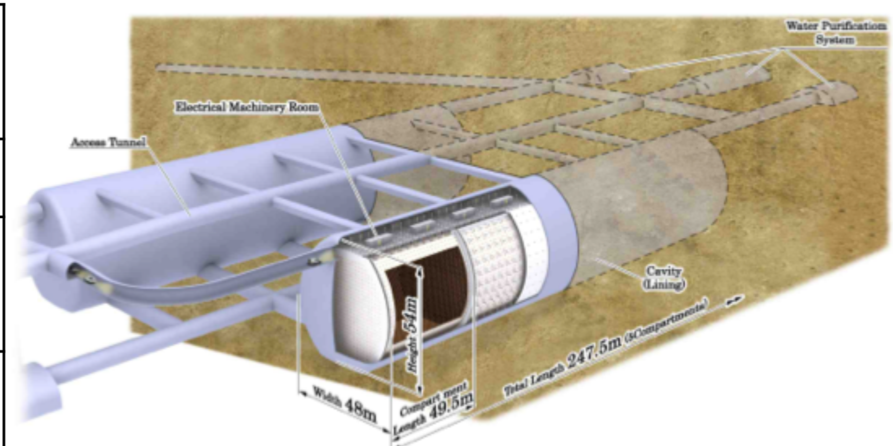
Outline

- About WCSim
- Progress until now
- HPD implementation work
- Comparison between Hyper-Kamiokande geometry with different length

Necessity of simulation

- The baseline design of Hyper-Kamiokande has already been decided
  - Optimize detailed design with respect to physics performance by using detector simulation

Volume	0.99 Mton (Super-K: 50 kton)
Number of compartment	10
Number of PD (Inner detector)	~99000 (Super-K: 11146)
Number of PD (Outer detector)	~25000 (Super-K: 1885)
Length per 1 compartment	49.5 [m]



Example of optimization target

- Photodetector
  - There are 3 candidates for photodetector in Hyper-Kamiokande
    (Super-K PMT, Box and Line PMT, HPD)
  - HPD and Box & Line PMT have better performance than SK PMT (Detail: Photodetectors session)
    - By using detector simulation, evaluate how the advantage will effect detector performance

Venetian blind type (Used in SK)

Box and Line type

Hybrid PhotoDetector (HPD)

Example of optimization target

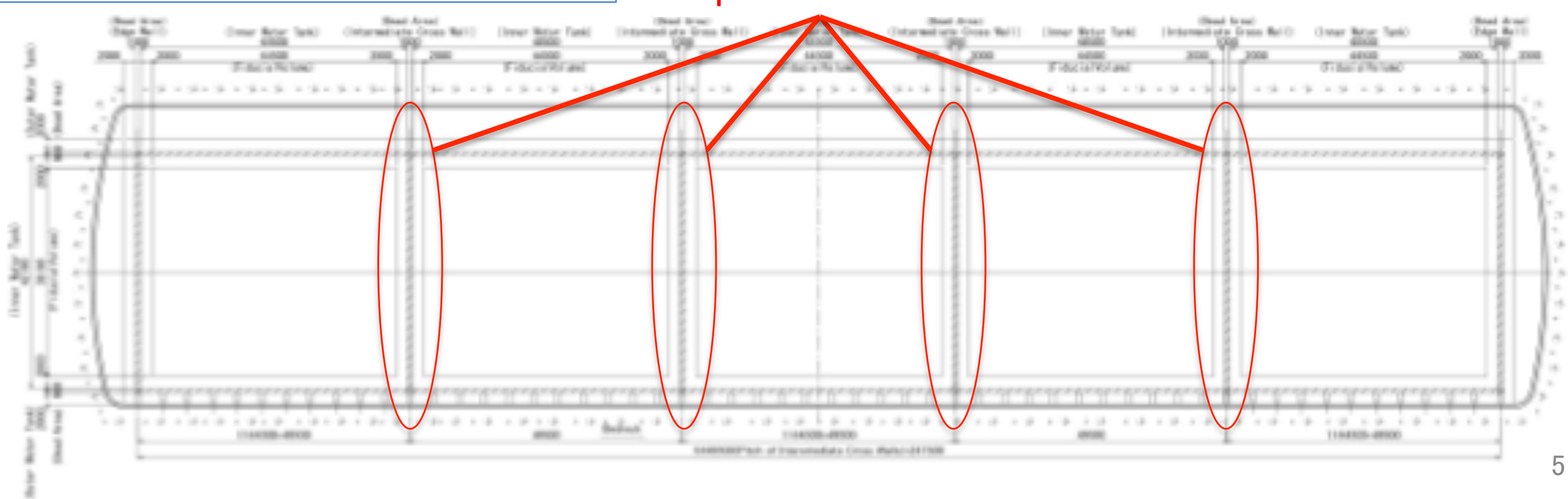
- The number of compartment in Hyper-K
  - The detector with more compartment has smaller effect of attenuation of light.
  - But need more photodetectors.

    (Number of photodetector on a separation wall: ～3000)

Number of PD in inner detector: ～99000

Profile of Hyper-K Baseline design

Separation walls



Detector Simulation

- SKDetSim
  - Geant3 based detector simulation which was developed for Super-Kamiokande.
  - Reproduce Super-Kamiokande data well and reliable
  - Fortran based, and it will be hard to maintain
- WCSim
  - Geant4 base water Cherenkov detector simulation
  - Originally developed for LBNE by Duke university
  - C++ based

Feature of WCSim

- Cylindrical detector can be made easily (Including Super-Kamiokande geometry)

- WCSim was developed based on SKDetSim.

- Many physical process already implemented in WCSim

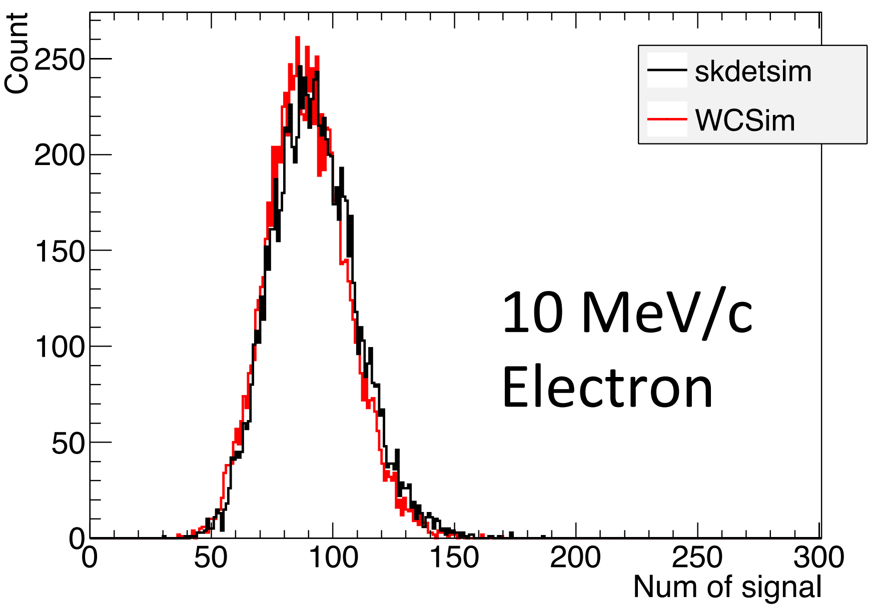
Physical processes in WCSim

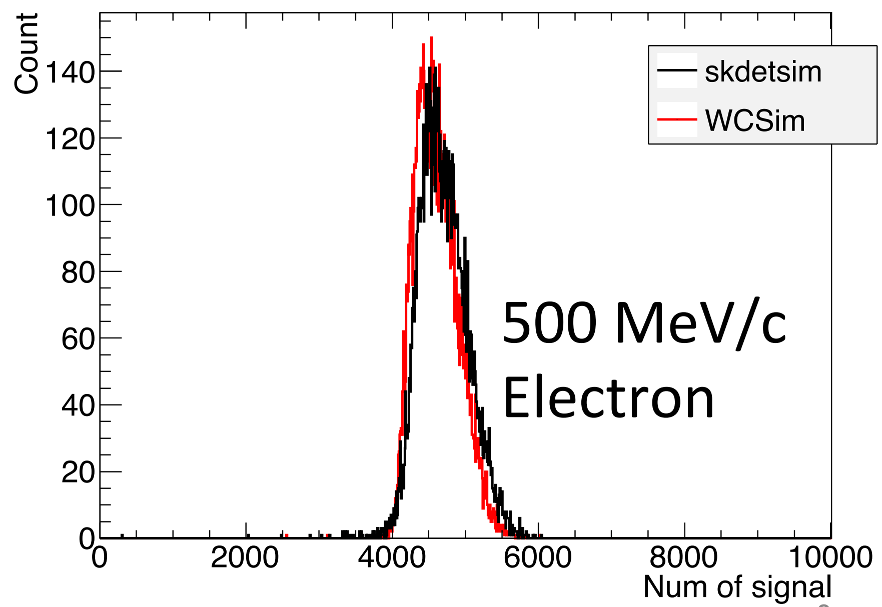
- Reflection on the surface of photodetectors and the detector wall
- Absorption of light in water, and Rayleigh scattering

Comparison between SKDetSim and WCSim

- We have compared these 2 detector simulations.

Detector	Super-Kamiokande
Vertex	Uniformly distributed in fiducial volume
Direction	Isotropic direction





The output of WCSim and SKDetSim agree well

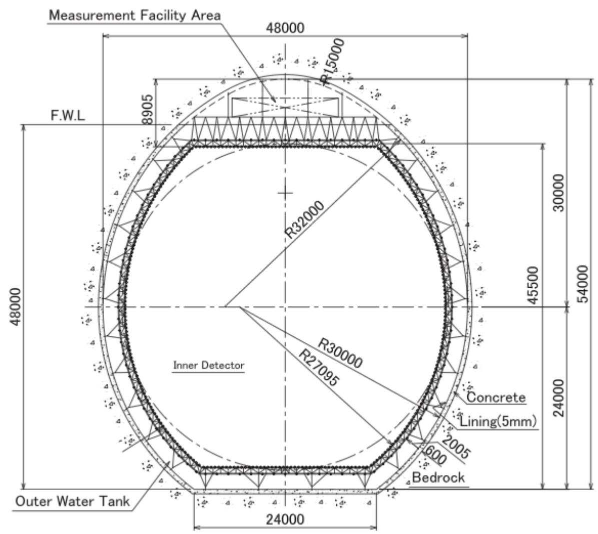
Progress until now

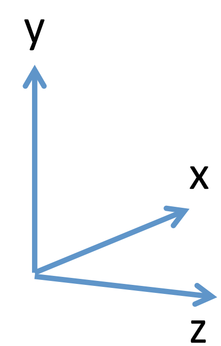
- The baseline geometry of Hyper-Kamiokande was implemented to WCSim (Peter Gumplinger's work)
- Dark noise was implemented in WCSim
- FitQun became able to reconstruct WCSim simulation output (FitQun group's work. The one after next talk)
  - FitQun: Event reconstruction tool for SK analysis
- Made option to change the Hyper-K geometry to the detector geometry with arbitrary compartment length.
- HPD characteristics except for timing resolution were implemented.

Baseline design of Hyper-Kamiokande

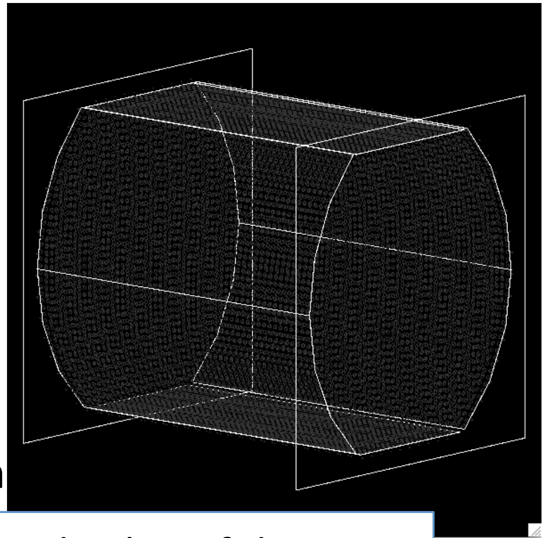
- The egg-shape geometry of Hyper-K has already been introduced.

Cross section of Hyper-Kamiokande





Define z-axis as the direction to longitudinal direction in WCSim

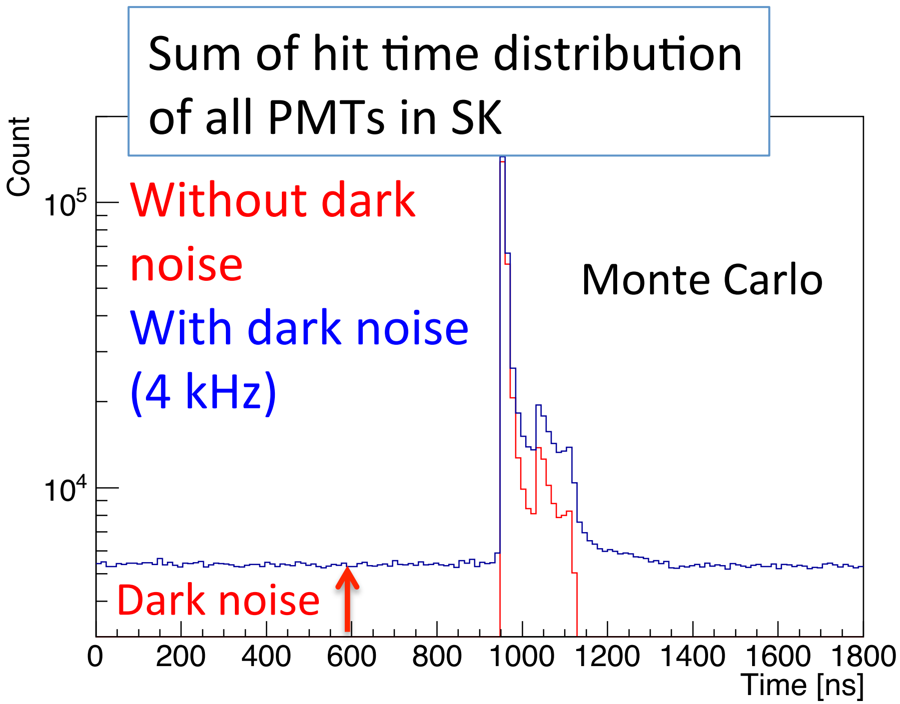


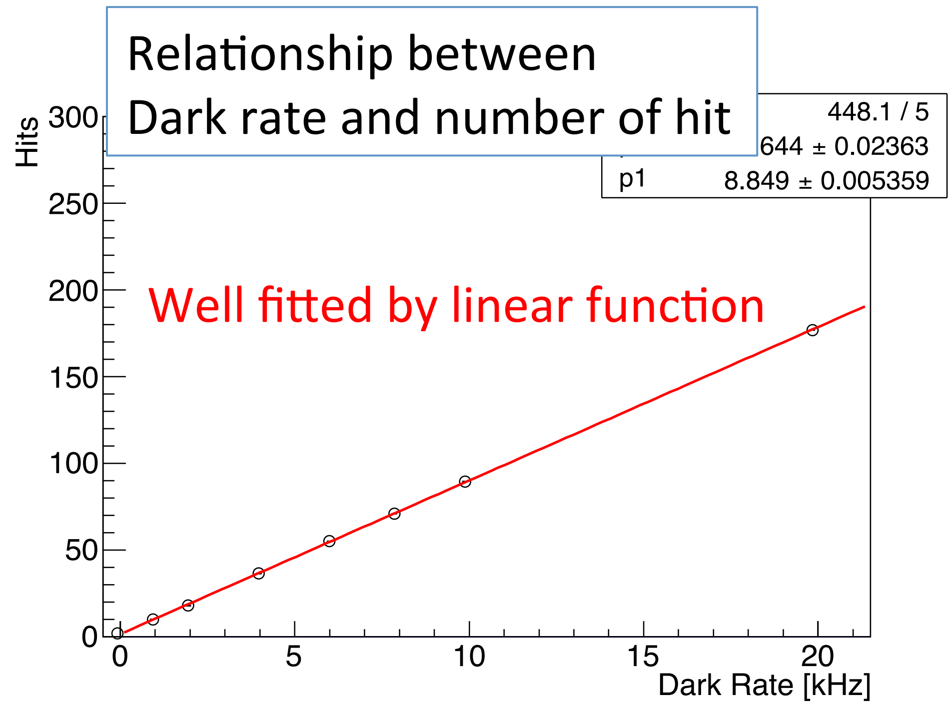
Event display of detector

Number of compartments	10
Length of a compartment	49.50 [m]

Implementation of Dark noise

- Dark noise is implemented in WCSim





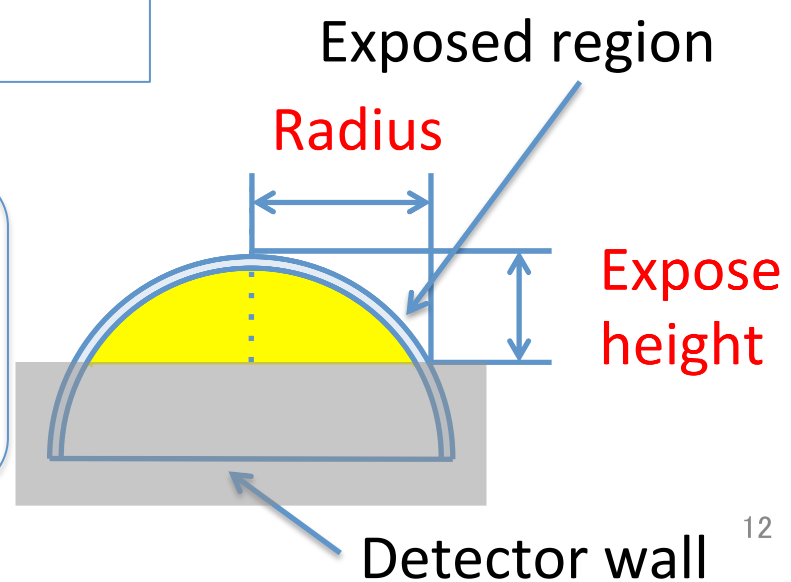
HPD implementation

- Implementation and validation of HPD parameters

HPD characteristics value

- Shape of photo sensor
- Single photoelectron distribution
- Quantum efficiency
- Timing resolution

The photodetector shape in WCSim is a part of sphere.
We can make detector shapes by changing the radius and expose height



Status of HPD

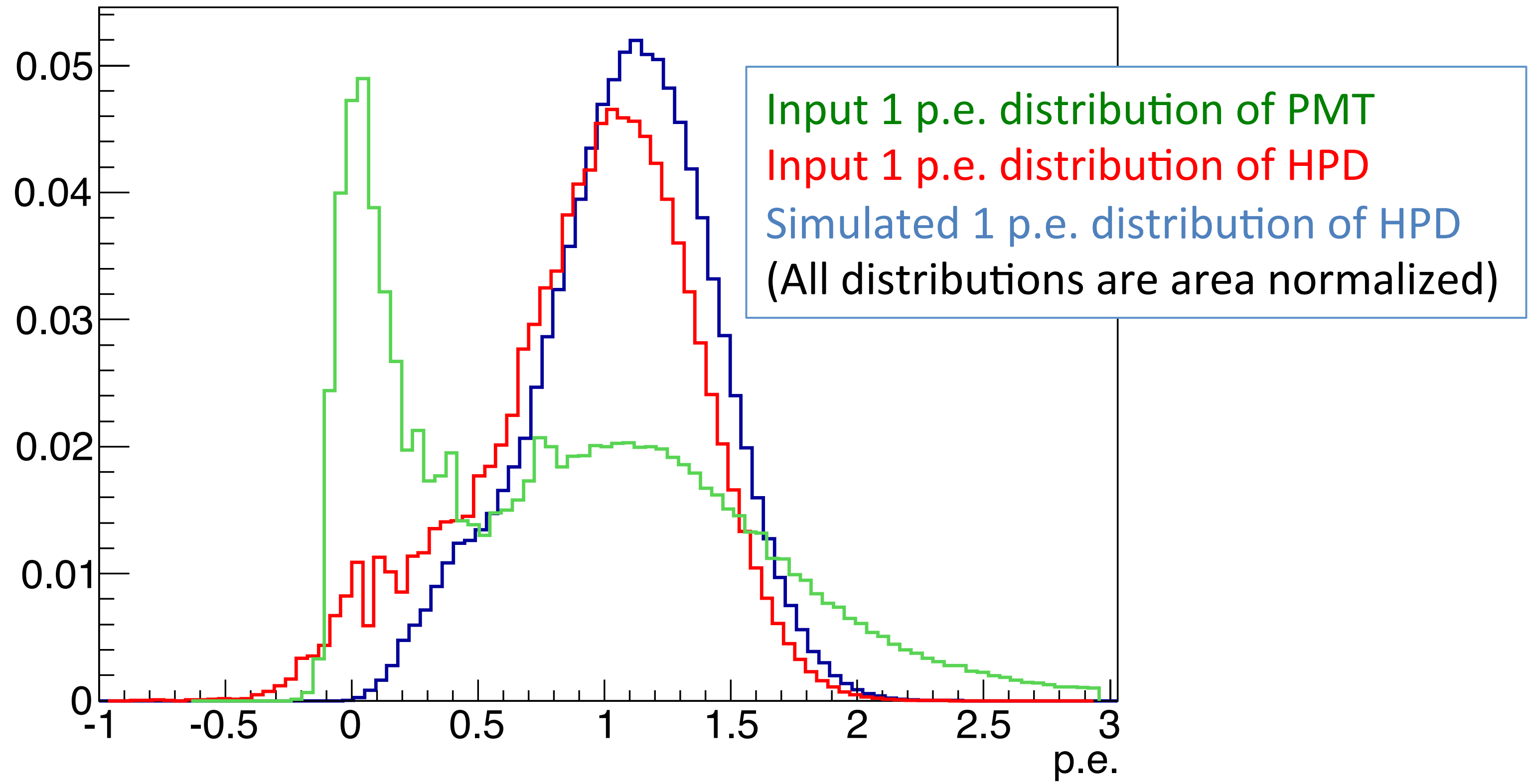
- Parameter of HPDs
  - ✓Shape of photo sensor
  - ✓Single photoelectron distribution
  - ✓Quantum efficiency
  - – Timing resolution
    (The evaluation will complete soon!)

Single photoelectron distribution

- The charge of 1 p.e. is determined using the distribution and a threshold cut on pulse height amplitude is applied to produce a hit. (Discriminator was set to ～1/6 p.e.)
  - This distribution was implemented to WCSim as 1 p.e. distribution before pulse amplitude threshold cut.

- The response for p.e. is evaluated based on this distribution, and a threshold cut on pulse height amplitude is applied to produce a hit.

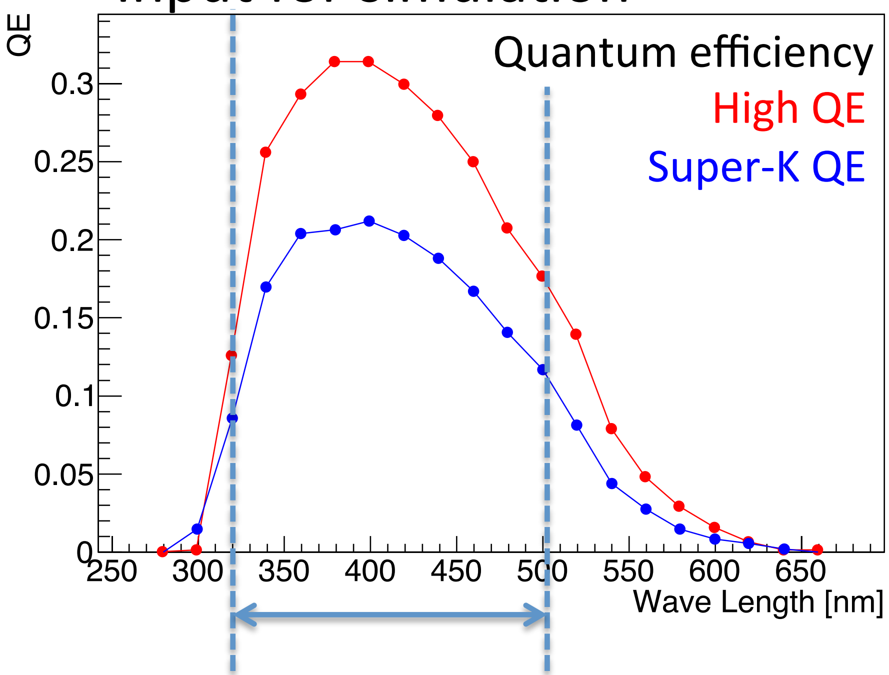
Charge distribution of 1 p.e. signal



Amplitute threshold is applied to each pulse and it affects the output p.e. distribution.
Need to disable the amplitude threshold for more precise evaluation.

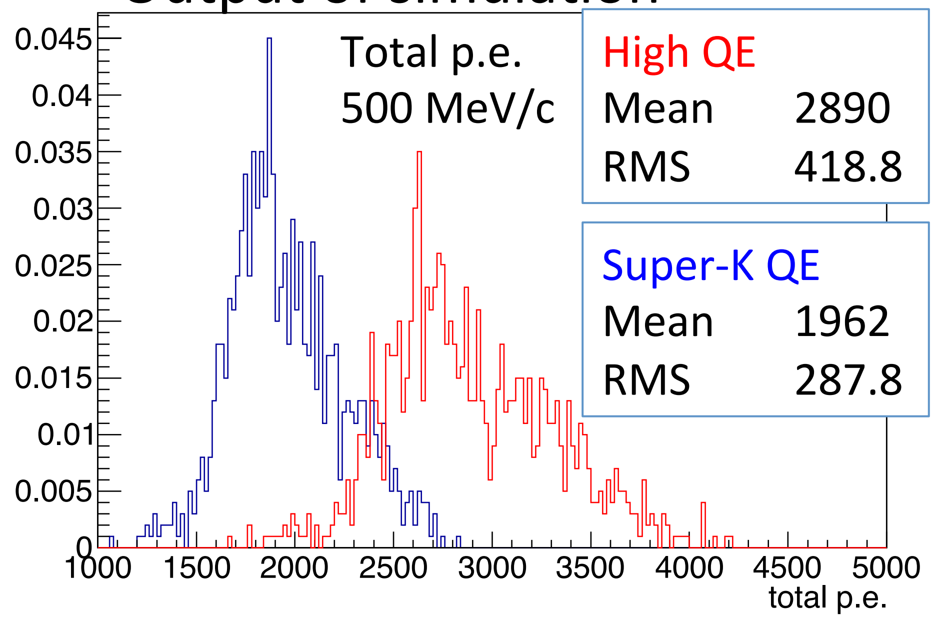
Quantum efficiency

Input for simulation



High QE / SK PMT QE ～1.5

Output of simulation



Total p.e. comparison: 2890/1962～1.5

QE comparison (High QE/SK PMT QE): ～1.5 (350-500 nm)

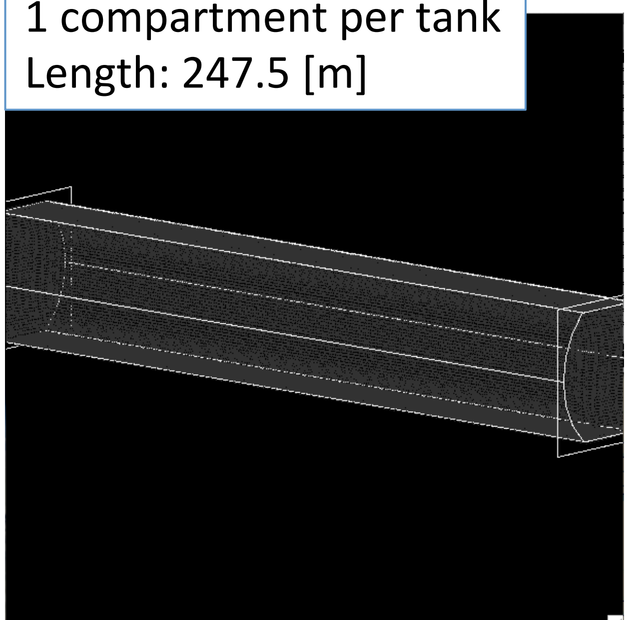
The ratio of total p.e. of High QE PMT to that of Super-K QE PMT is consistent with their QE implemented in WCSim.

More precise measurement is required to validate.

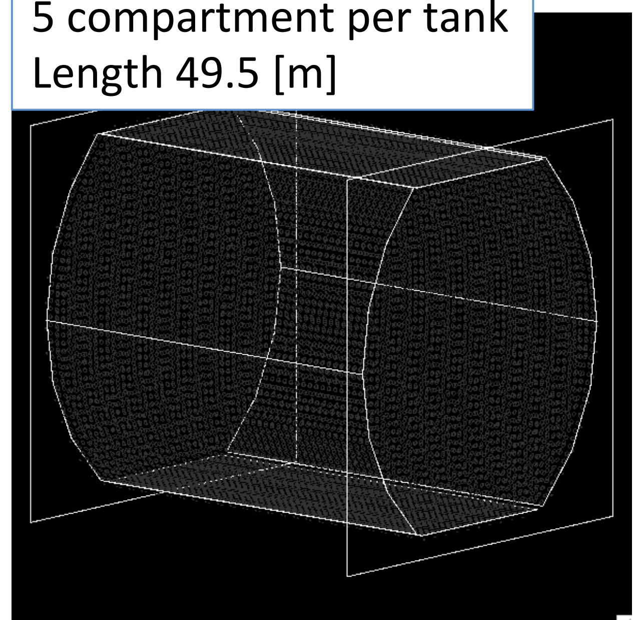
Changing compartment length

- In baseline geometry, the compartment length is 49.5 [m].
  - Need to evaluate the performance of detectors with different detector length.

1 compartment per tank
Length: 247.5 [m]



5 compartment per tank
Length 49.5 [m]

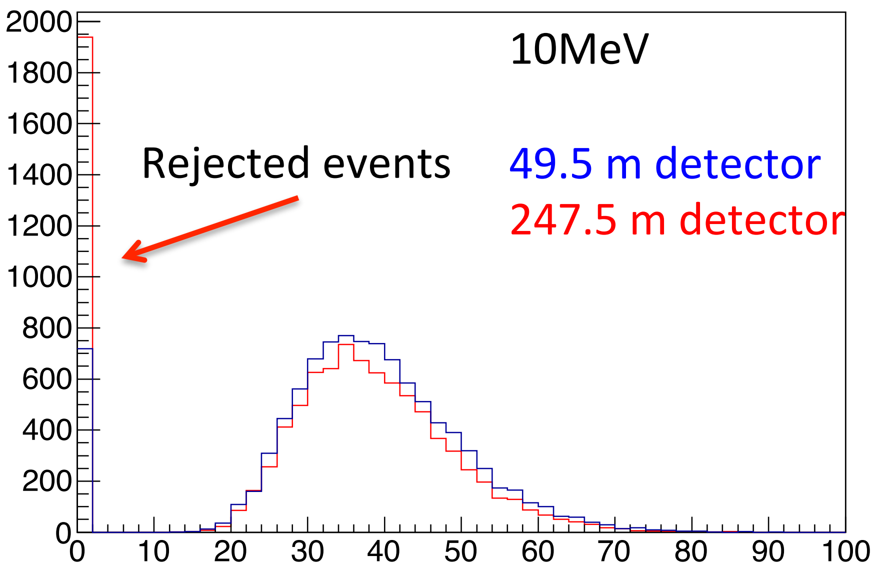


Condition of simulation

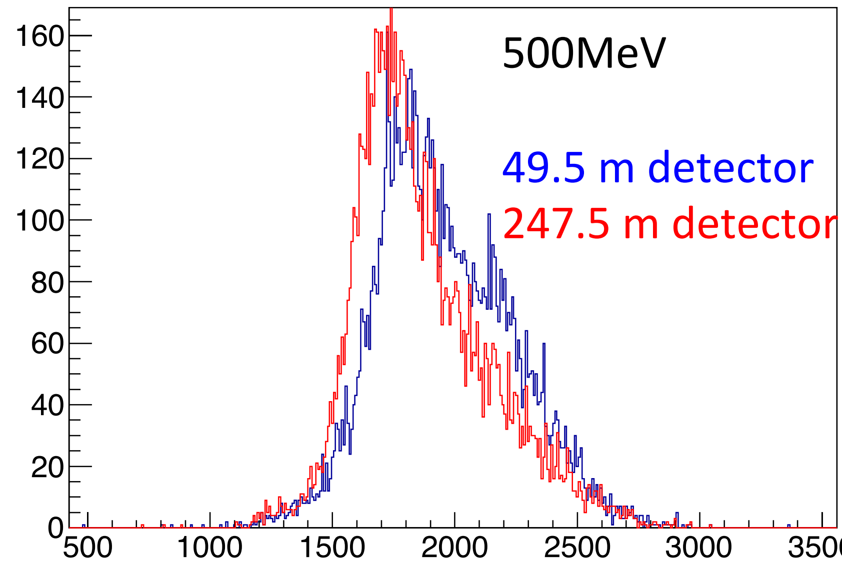
- In order to check some factors, Events in detectors with 247.5 m and 49.5 m length were simulated.

Length	247.5 [m]	49.5 [m]
Interval between photodetectors	0.990 [m]	
Dark noise	4 kHz	
Incident particle	Electron	
Incident energy [MeV]	50, 500	
Vertex	Uniformly distributed in the fiducial volume	
Direction	Isotropic direction	

Total Number of p.e.



Total p.e.



Total p.e.

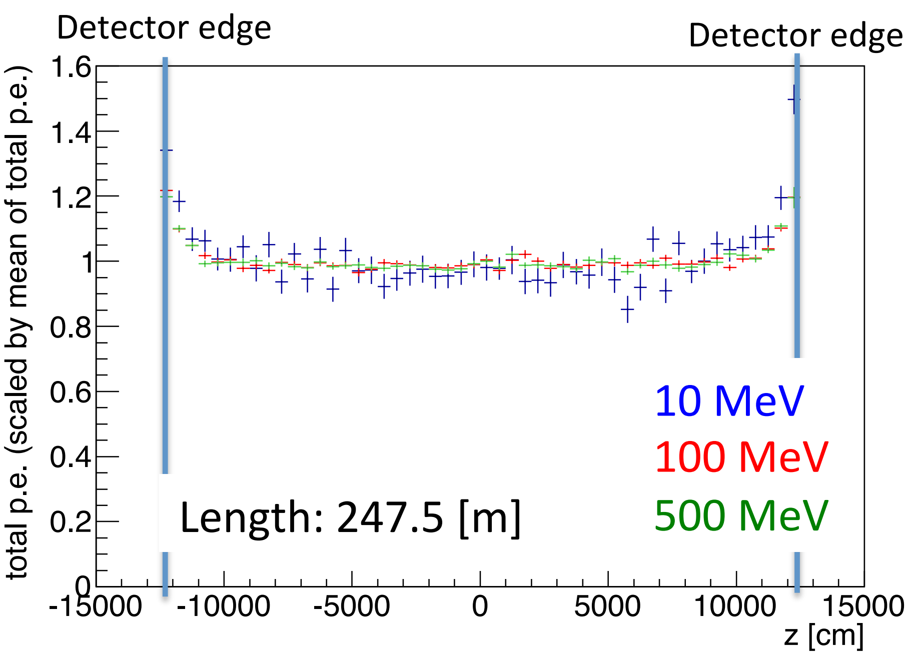
Rate of events cut by threshold (Number of PMT with hit < 25)	
49.5 m detector:	7.18 %
247.5 m detector:	19.39 %

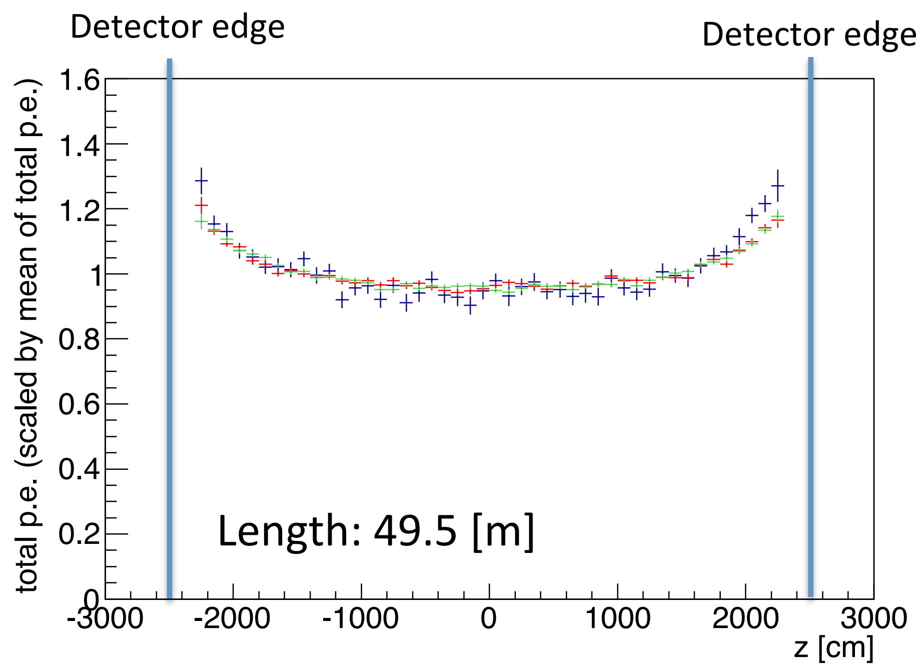
In low energy range, much more events are rejected by number of PMT threshold in the detector with 247.5 m length than 49.5 m length

Mean of the number of PE	
49.5 m detector:	1954
247.5 m detector:	1864

Charge distribution in the detector with 247.5 m length is about 5 % lower than that with 49.5 m

Position dependence of total number of photoelectron





In the detector with 247.5 [m] length, the number of PE seems to be stable in the range of -100 [m] < z < 100 [m], more than 20 [m] from the separation wall.

↑ Because the width and height of 247.5 m detector is much shorter than the length, the detector can assume infinity length cylinder when the vertex is far from the separation wall

Still to be studied

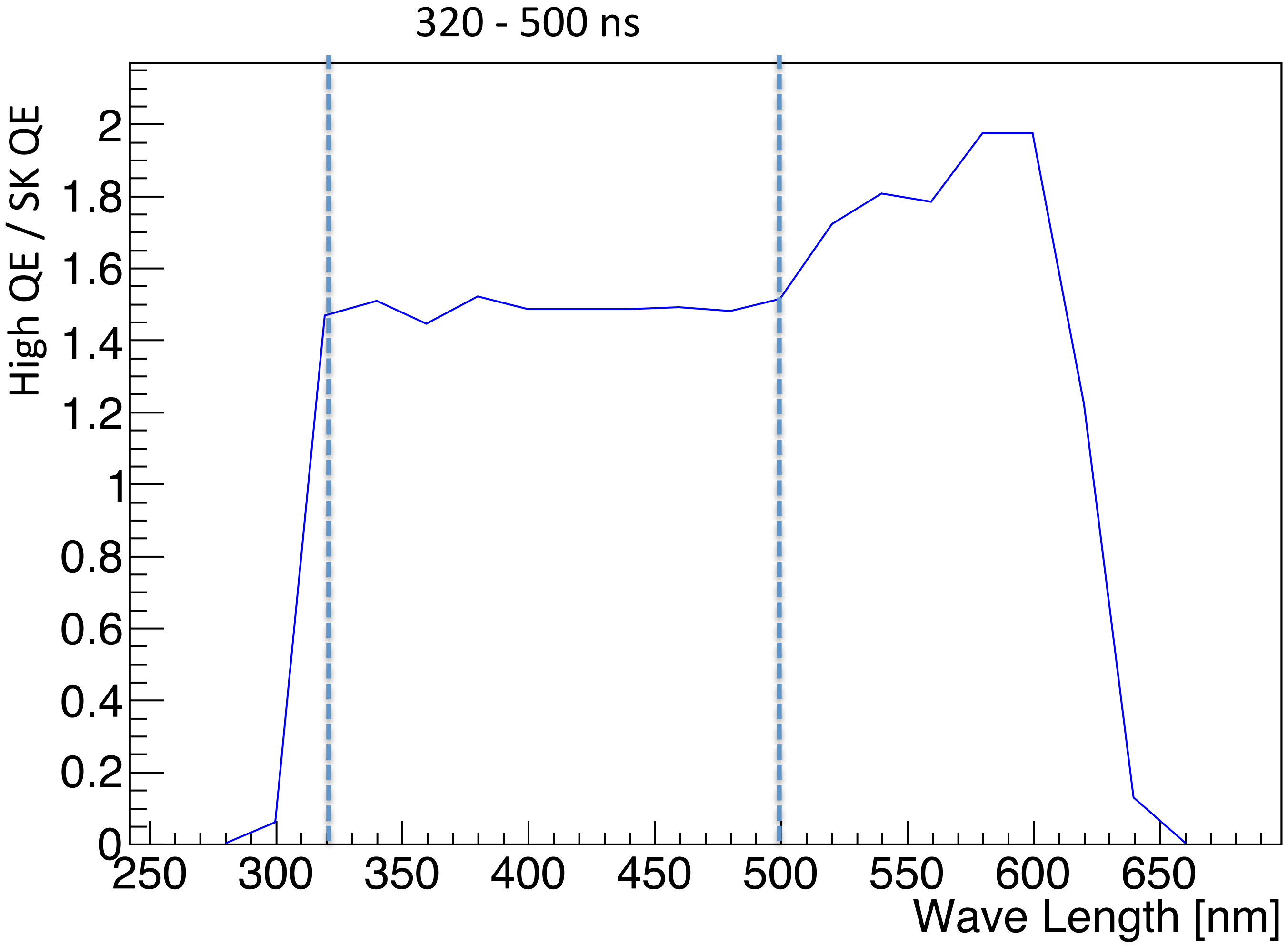
- Threshold for HPD
  - Current amplitude threshold of HPD is set to that with 0.5 p.e. charge
- More precise validation of HPD's characteristic value
- Implementation of HPD timing resolution
  - The relationship between charge and hit time already measured
- Evaluate position dependence by using reconstruction tool

Summary

- WCSim has been developed for detailed evaluation of Hyper-Kamiokande detector design
- HPD characteristic value is under implementation in WCSim and validation
- The function for compartment length modification is implemented in Hyper-K simulation
  - Study and optimization of compartment length will be done with WCSim

Appendix

QE comparison



Threshold for HPD

- The PMT threshold voltage is set to 0.25 p.e. level
- Current HPD threshold of pulse height is set to that of 0.5 p.e. , and the relationship between pulse height and charge distribution is not measured