Development of Geant4 based simulation for Super-Kamiokande

M.Harada (Okayama Univ.)
Y.Koshio, K.Hagiwara(Okayama Univ.), For Super-Kamiokande Collaborator

1. Introduction

Super-Kamiokande(SK)

- SK is the world largest Water-Cherenkov neutrino detector.
- SK will start new phase, that is "SK-Gd project", which dissolve Gadolinium in SK water for Supernova relic neutrino(SRN) and other neutrino search.
- Toward SK-Gd, SK tank refurbishment work has been conducted in 2018, and now restart pure water operation.
- In SK-Gd, γ-ray signal from neutron capture (n-capture) of Gd can be detected. **So, inverse beta decay signal will be enhanced. (Fig. 1)**

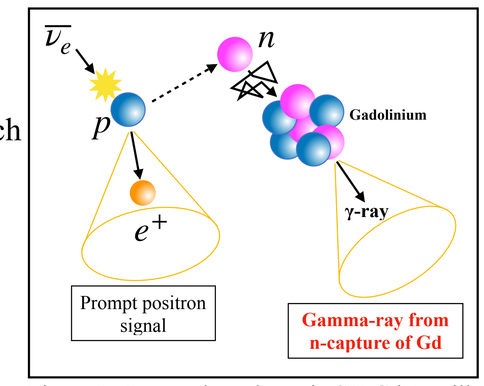


Figure 1 : Inverse beta decay in SK-Gd. It will become to be possible to "Delayed coincidence" measurement.

Simulation tool of SK

- Currently, SK simulation uses Geant3(SKDetSim), which is detector simulation written in FORTRAN. And the update of physics model is already stopped.
- For the next 10 years SK operation, up-to-date detector simulation is needed. Especially for SRN search in SK-Gd, precise neutron simulation is crucial.
- Therefore, **we try to develop Geant4 based SK simulation software, named "SKG4".**[1]
- **SKG4 will be the first overall simulation software of SK-Gd.**

What's new of SKG4

- The latest physics model suitable for SK can be used.
- The model of γ-ray emitted from Gd(n, γ) uses the world highest accuracy experiment results.[2]
- → **Precise simulation of neutrino and neutron will be possible.**

[1]S. Agostinelli et al. Nucl.Instrum.Meth. A506 (2003) 250-303

2. Geometry of SK

Geometry of SK tank

- Geometry of inner tank was already completed, it is based on the latest SKDetSim. (Fig. 2)
- SK has outer detector(OD) to separate the cosmic ray signal.→Remaining work

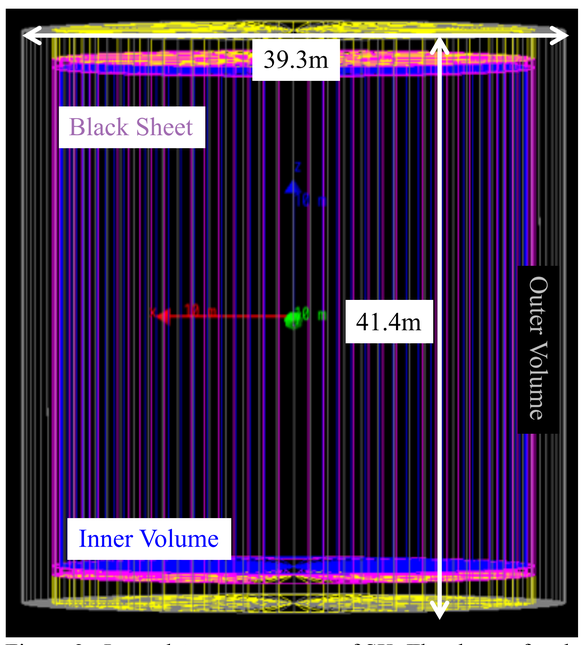


Figure 2 : Inner detector geometry of SK. The shape of tank is reproduced by the cylinder.

Light detector(PMT)

- All(11129) PMT in inner tank is already completed(Fig.3), and installed in the tank.
- There were no difference with SKDetSim in the structure.

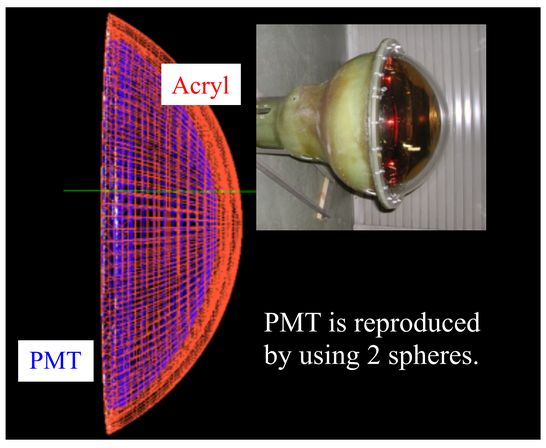


Figure 3: Inner tank PMT geometry of SK

✓SKG4 is now ready to compare with SKDetSim and real SK calibration data.

3. Physics Comparison

Neutron capture(n-capture) process from Gd

- Gd(n,γ) process is crucial for SK-Gd project. When Gd capture a neutron, Gd emit γ-rays with total ~8 MeV.
- In SKG4, high accuracy model based on the experiment was adopted for γ-rays from Gd n-capture.

Optical Process

- Optical photon behavior is one of the most important in SK physics.
- In Geant4, Scattering and, Absorption, Material Boundary physics (Refraction, Reflection) are defined as Optical process.

Situation of Comparison

- n-capture Physics : 200 keV neutron was emitted from center of tank, some behaviors of n-capture process were compared.(Fig. 4)
- Optical Physics : Photons were emitted from top of tank. PMT hit position and hit timing were compared.(fig. 5)

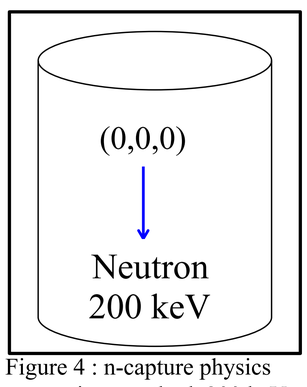


Figure 4 : n-capture physics comparison method. 200 keV neutron emit from center of tank.

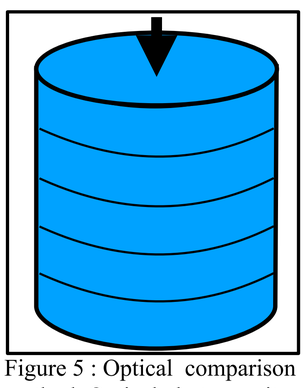


Figure 5 : Optical comparison method. Optical photon emit from (0,0,1800), to downward.

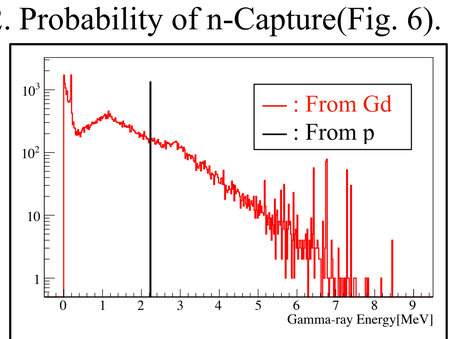
4. Results

n-capture Physics

- These behaviors were compared between Gd-water and pure water.
  1. Neutron capture time and distance (Table 1).
  2. Probability of n-Capture(Fig. 6).

	Time	Distance
Capture by p (Pure water)	196±3 μs	107±60 mm
Capture by p (Gd-water)	18±1 μs	68±31 mm
Capture by Gd (Gd-water)	27±1 μs	70±33 mm

Table 1 : Neutron capture time and distance. Capture time of Gd is ~27 μsec, distance is <50 cm for 200 keV neutron.



Capture by Gd	86.7±0.93%
Capture by p	13.27±0.36%
Capture by O	0.01±0.01%

Figure 6 : Emitted γ-rays from n-capture(Figure). Probability of n-Capture(Table). ~90% neutron is captured by Gd.[3]

- The model of γ-ray emission was compared.

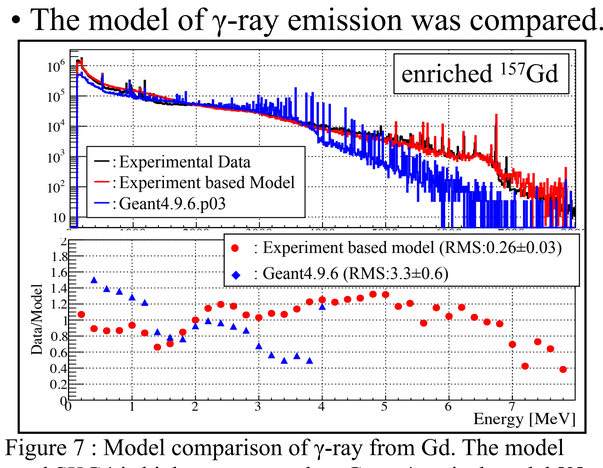


Figure 7 : Model comparison of γ-ray from Gd. The model used SKG4 is higher accuracy than Geant4 typical model.[2]

✓n-Capture of Gd for SK-Gd was estimated using experimental data.

Optical Physics

- Absorption was compared by the reduction of PMT hit. (Fig. 8)
- Scattering was compared by the timing distribution in each Z-axis region.
  -Wave length : 350(Fig. 9), 450, 550, 650 (nm).
- Each distributions were consistent with SKDetSim.

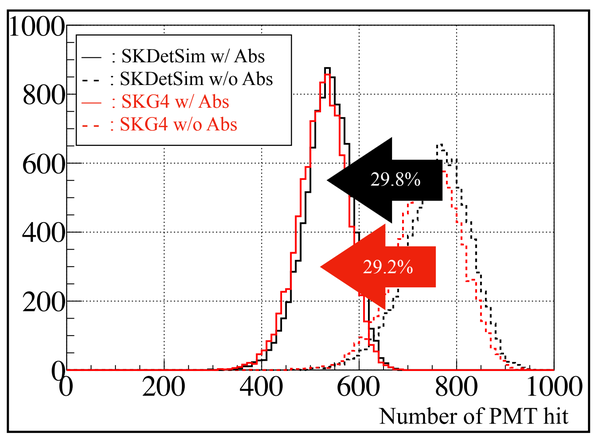


Figure 8 : Influence of reduction of PMT hit by absorption

✓Optical physics of SKG4 is consistent with SKDetSim

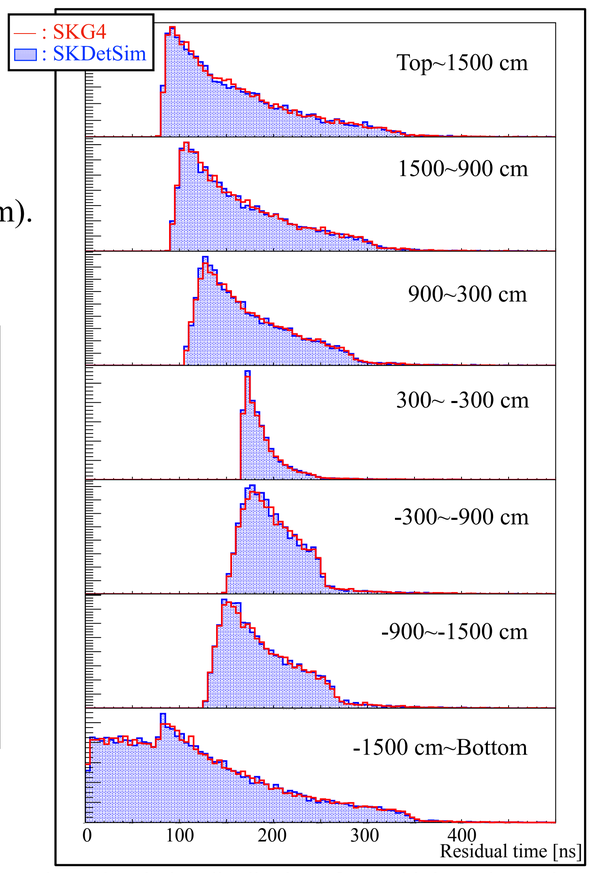


Figure 9 : Timing distribution of PMT hit in each Z-axis region. This is the example of wave length 350 nm.

[2] K.Hagiwara et al. Prog. Theor. Exp. Phys. (2018), arXiv:1809.02664v1
[3] Beacom and Vagins. Phys. Rev. Lett. 93,171101 (2004)

5. Conclusion & Future work

Conclusion

✻SK-Gd project will start soon, so we try to construct new Simulation for SK-Gd, named "SKG4".

✻Geometry of SK tank and PMT were reproduced in Geant4, except for the outer detector.

✻Some physics models were installed and compared with SKDetSim.
→Optical process was correctly installed and Gd(n,γ) process was evaluated.

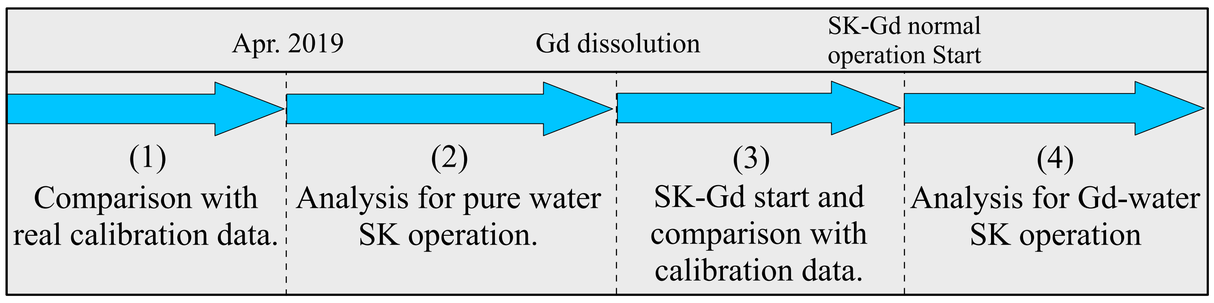
Remaining work

✻Outer detector PMT, which shape is different from inner PMT construction.

✻Comparison of 1 GeV muon, and electron with higher energy than 10MeV.

✻Comparison with SK calibration data and tuning SKG4.

Future work



✻During pure-water operation, SKG4 will be tuned and used for the pure water SK analysis.

✻After dissolving Gd in SK water, SKG4 will be used for various analyzes in SK-Gd.