The performance evaluation of Geant4-based simulation in SK-Gd experiment

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1. Introduction

Supernova Relic Neutrinos (SRNs)

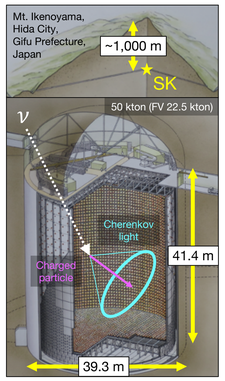
- Neutrinos from all past core-collapse supernovae are accumulated to form an integrated flux → SRNs
- Detecting SRNs would provide valuable information about the supernova mechanism and the star formation history [1]

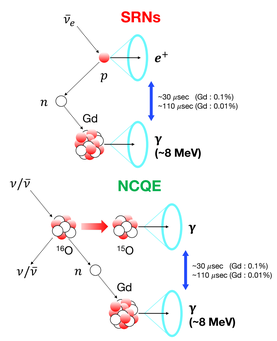
SK-Gd (2020 -)

- Loads 0.1% (currently 0.011%) of gadolinium (Gd) to enhance the neutron tagging efficiency to ~80% (currently ~50%)
  → Can reduce the background of SRNs search [2]

Atmospheric neutrino background of SRNs search

- Neutral-current quasielastic (NCQE) interactions
  → Cannot be removed even in SK-Gd → Need to estimate precisely by MC





2. Performance evaluation of Geant4-based simulation

- So far GEANT3-based detector simulation program (**SKDETSIM**) has been used
  → An accurate neutron transport model and a model of γ-rays from neutron capture are not implemented in GEANT3
  → Geant4-based detector simulation program (**SKG4**) was developed
- Need to evaluate its performance at all energy region to use it for physics analyses
  → Evaluated its performance using e and μ with 1 GeV kinetic energy

SKG4 Super-Kamiokande Geant4 based Simulation

Evaluation method

- Generate 100,000 e or μ from center of SK tank isotropically both in SKDETSIM and SKG4
  → Compare basic distributions between SKDETSIM and SKG4 (Show the distributions in **bold**)
  - **Total charge** (energy)
  - **Angle distribution of Cherenkov light**
  - **PID** (particle identification)
  - # of Cherenkov rings
  - Momentum

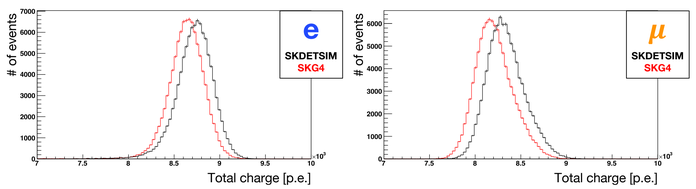
3. Results

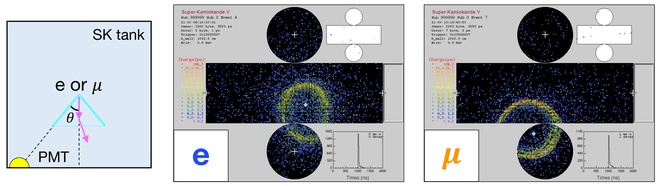
Total charge

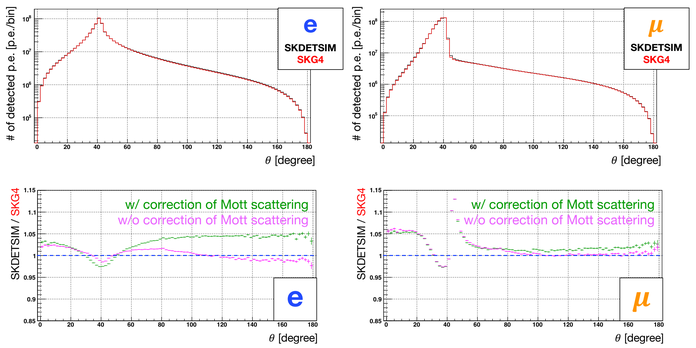
- Total charge at peak is different by ~1.5% between two simulations
  → Comes from **ionization model (dE/dx)**
  SKDETSIM : $(dE/dx)_{H_2O}$ (Based on [3], [4])
  SKG4 : $(16/18)(dE/dx)_O + (2/18)(dE/dx)_H$
  → Should change dE/dx of SKG4

Angle distribution of Cherenkov light

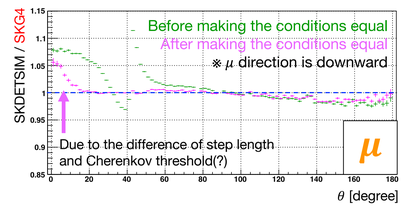
- Cherenkov angle difference between e and μ is important for PID
- The difference is large at high angle
  → There is a **correction of Mott scattering** in multiple scattering model of Geant4 (SKG4) while there is not in that of GEANT3 (SKDETSIM)
- Remove the correction as a check
  → The difference becomes small
- Decide if we apply correction of Mott scattering in SKG4 by looking at data





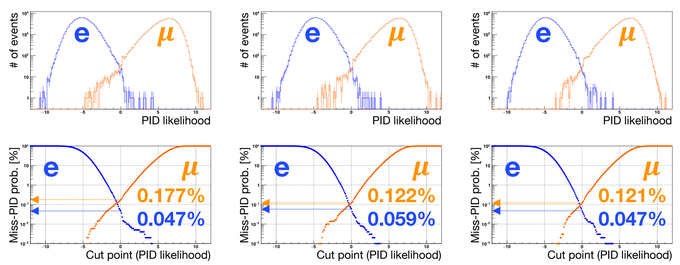


- In μ, the difference is large at low angle
  → Mainly comes from **multiple scattering model** and **ionization model (dE/dx)**
- Make the conditions equal between two simulations
  (e.g.) No scattering, No δ-rays, Use dE/dx of SKDETSIM, etc.
  → The difference becomes small



PID

- Miss-PID
  e : PID likelihood > 0
  μ : PID likelihood < 0
- Currently using PID likelihood function produced by SKDETSIM
  → Miss-PID probability is very small in any case (< 0.2%)
  → PID is robust from the difference of physics model



4. Summary and Plan

Summary

- Want to use SKG4 for physics analyses in future
  → Confirmed the physics models in SKDETSIM and SKG4
  → Mainly multiple scattering and ionization models are different between two simulations

Plan

- Study neutron multiplicity in atmospheric neutrino MC
- Compare basic distributions of event reconstruction both for NCQE and SRNs events in MC
- Estimate atmospheric neutrino background of SRNs search in SKG4

[1] K. Abe *et al.*, Phys. Rev. D **104**, 122002 (2021) [2] J. F. Beacom and M. R.Vagins, Phys. Rev. Lett. **93**, 171101 (2004) [3] R. M. Sternheimer *et al.*, Phys. Rev. B **26**, 6067 (1982) [4] R. M. Sternheimer *et al.*, BNL-33571 (1983)

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