Poster #22

Measurement of cosmogenic neutron in Super-Kamiokande

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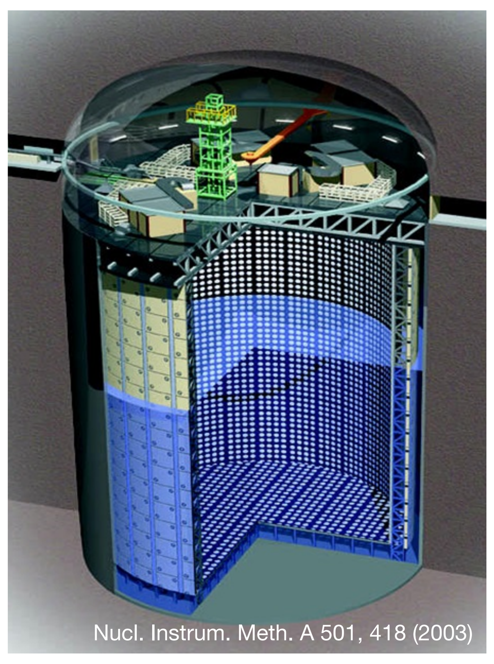
Unraveling the History of the Universe and Matter Evolution with Underground Physics 2022, Jun. 13-15, 2022, Tokyo University of Science

Cosmic-ray muons that enter the Super-Kamiokande detector cause hadronic showers, and the showers can produce radioactive isotopes out of ^{16}O via spallation. The produced neutrons and isotopes are major background sources for MeV-scale neutrino analysis and searches for rare events. Observations in Super-Kamiokande have been performed using ultra-pure water, and gadolinium was introduced into the water to improve the detection efficiency of neutrons and suppress the background due to radioactivities and PMT dark noises. In this study, we analyzed data for about one year after the gadolinium loading and measured the cosmogenic neutron production yield. The results will be presented in this poster.

1. Introduction

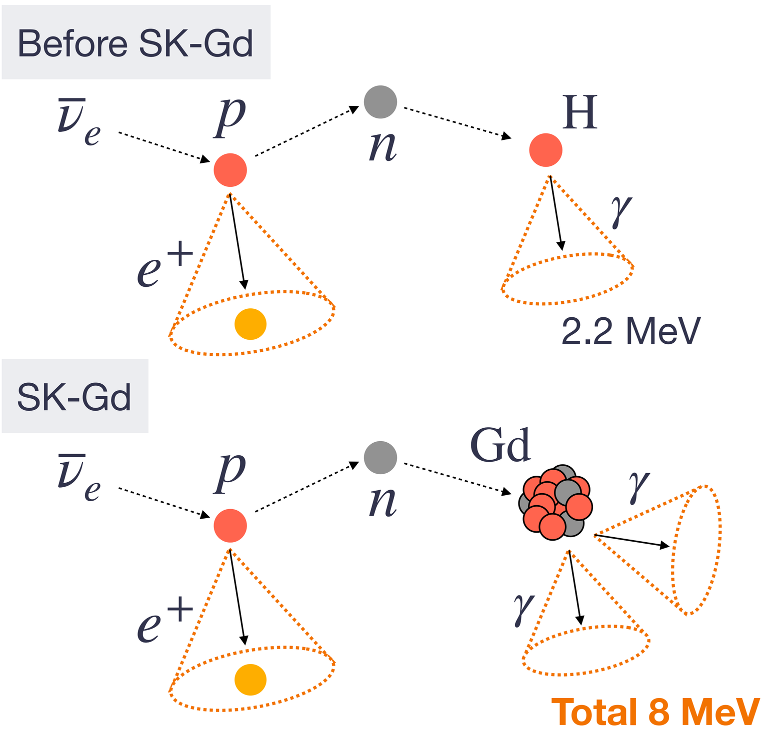
1.1. Super-Kamiokande (SK)

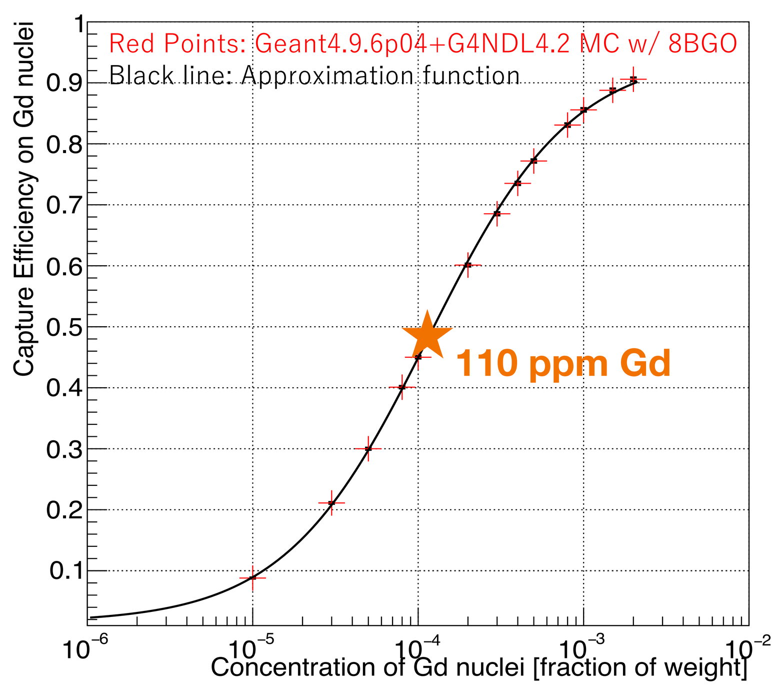


- 50-ktons water Cherenkov detector located at Kamioka, Japan
  - Overburden: 2,700 m.w.e.
- Diameter 39.3 m × Height 41.4 m
  - Fiducial volume: 22.5-ktons
- Detector wall is covered by PMTs.
  - Inner detector (ID): >11,000 20” PMTs
  - Outer detector (OD): >1,800 8” PMTs

1.2. SK-Gd experiment

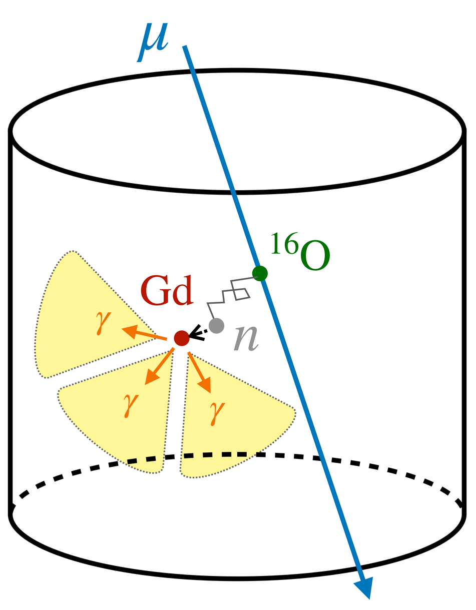
- SK-Gd experiment has been started.
  - To improve the neutron detection efficiency and suppress the background due to radioactivities and PMT dark noise.
- Gadolinium sulfate ($Gd_2(SO_4)_3{\cdot}8H_2O$) was dissolved in water.
  - Gd mass concentration: ~110 ppm
  - Neutron capture efficiency: ~50%
- Major physics motivation:
  The first observation of diffuse supernova neutrino background

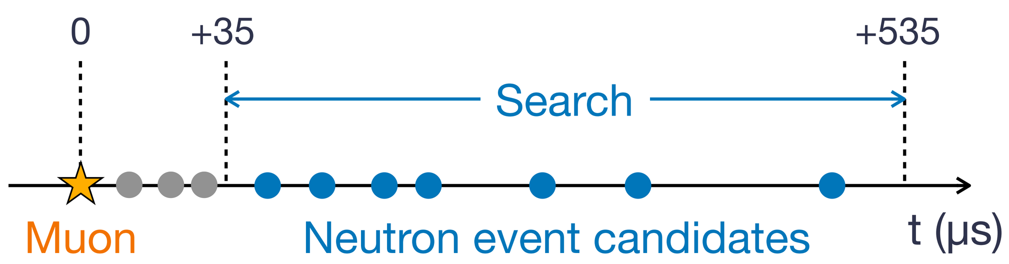




2. Cosmogenic neutron production

- Cosmic-ray muons flying into SK with a frequency of ~2 Hz.
  - The average energy is 258 GeV (calculated with MUSIC).
- Muons induce showers, which break ^{16}O and produce neutrons.
- Neutrons are thermalized and captured on Gd in ~116 μs.

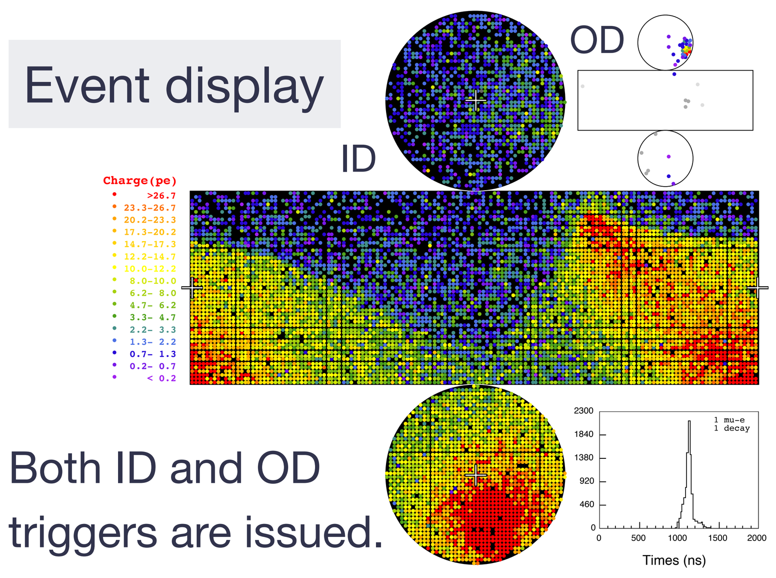


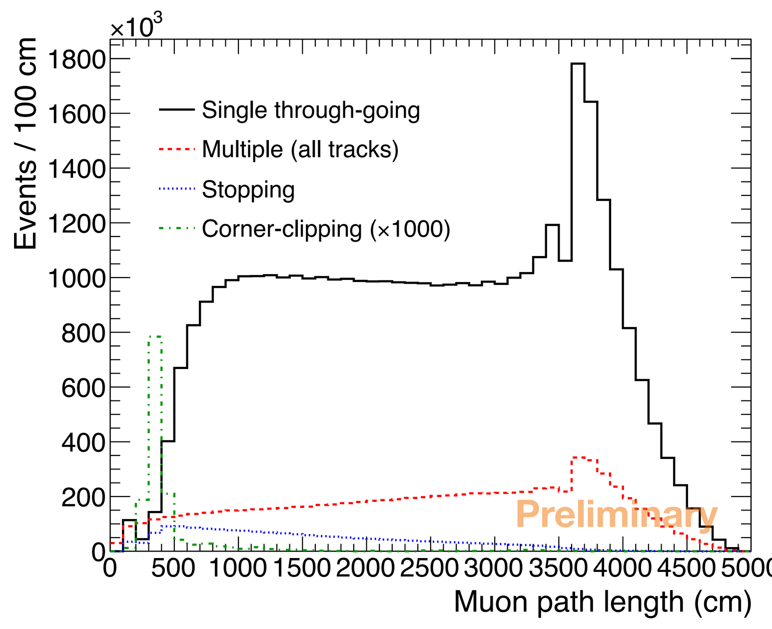


- Neutrons are searched within 35-535 μs.
- Events in 0-35 μs are not used to remove signals from decay-e and PMT after pulse.

3. Event selection

3.1. Cosmic-ray muon

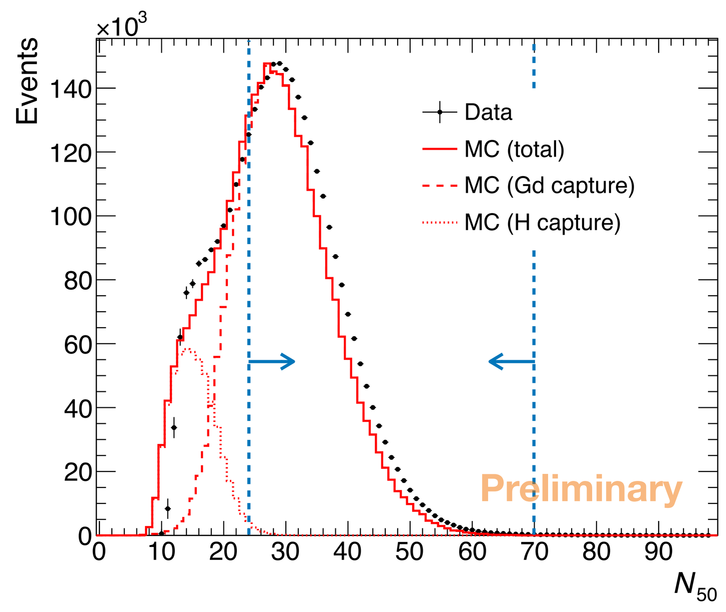


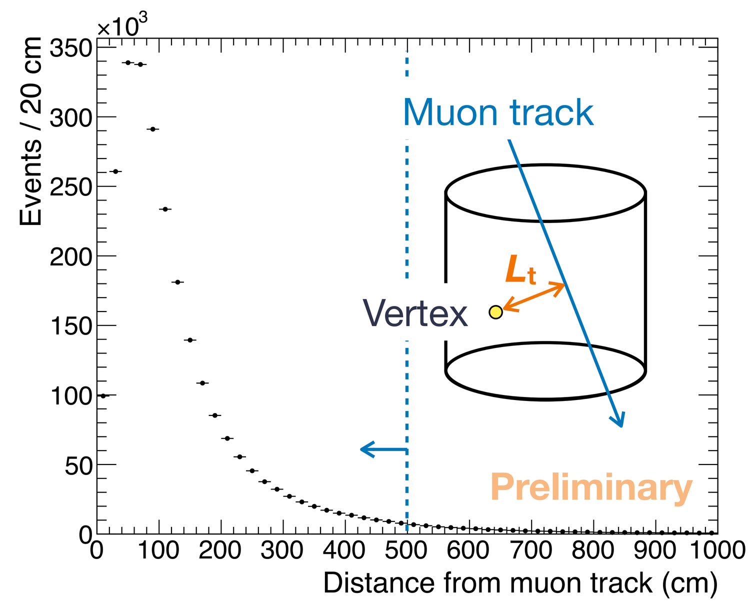


3.2. Neutron capture event

Neutron capture events are selected with two variables: N_{50} and L_t.

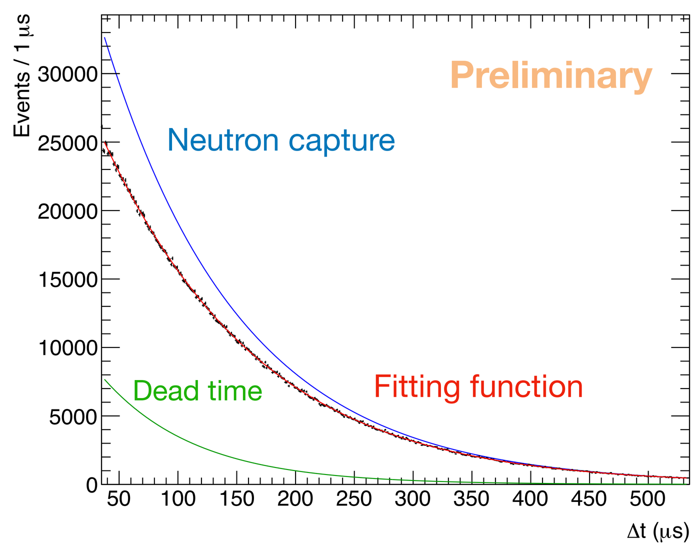
- N_{50}: Number of coincidence PMT hits within 50 ns time window
- L_t: Transverse distance between muon track and neutron events





4. Number of cosmogenic neutrons

- Neutron capture time follows exponential function.
- Capture time constant is measured to be 116.4 ± 0.3 μs by Am/Be.



- Fitting function

$$A\exp\left(-\frac{\Delta t}{116.4\,\mu s}\right) - B\exp\left(-\frac{\Delta t}{\tau_d}\right) + C$$

Neutron capture | Dead time | BG

- Number of neutrons

$$N_n = \epsilon^{-1} \times \int_{35\,\mu s}^{535\,\mu s} A\exp\left(-\frac{\Delta t}{116.4\,\mu s}\right) d(\Delta t)$$

5. Neutron production yield

5.1. Definition

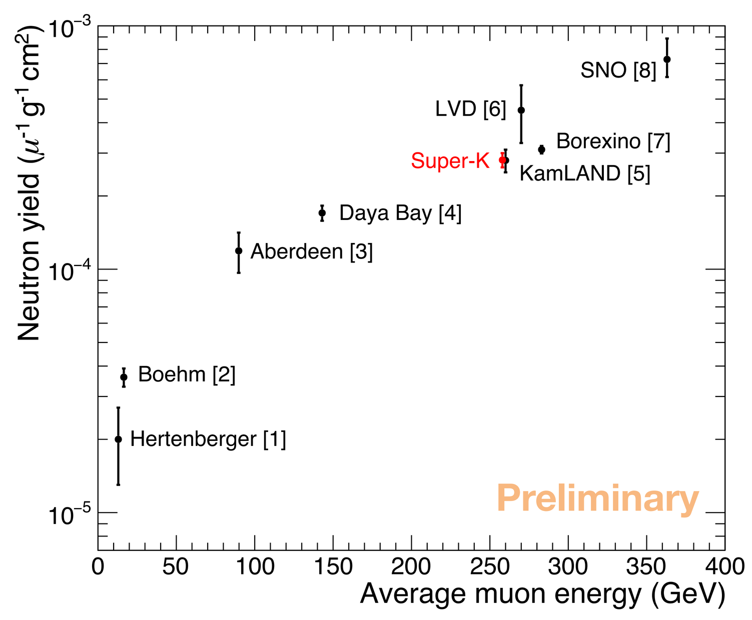
$$Y_n = \frac{N_n}{N_\mu L_\mu \rho}$$

- Y_n : Neutron yield
- N_n : Number of neutrons
- N_μ : Number of muons using for analysis
- L_μ : Muon path length
- ρ : Gd water density

5.2. Result

2.81 ± 0.06 (stat.) ± 0.18 (syst.)

(The unit is 10^{-4} $\mu^{-1}g^{-1}cm^{-2}$.)



Summary

- Super-Kamiokande gadolinium (SK-Gd) experiment had been started with Gd dissolved to SK since Aug. 2020.
- The cosmogenic neutron production yield was measured with SK-Gd data from Sep. 2020 to Sep. 2021.

2.81 ± 0.06 (stat.) ± 0.18 (syst.) × 10^{-4} $\mu^{-1}g^{-1}cm^{-2}$

Reference [1] R. Hertenberger, M. Chen, and B. L. Dougherty, Phys. Rev. C 52, 3449 (1995). [2] F. Boehm et al., Phys. Rev. D 62, 092005 (2000). [3] S. C. Blyth et al. (Aberdeen Tunnel Experiment Collab- oration), Phys. Rev. D 93, 072005 (2016). [4] F. P. An et al. (Daya Bay Collaboration), Phys. Rev. D 97, 052009 (2018). [5] S. Abe et al. (KamLAND Collaboration), Phys. Rev. C 81, 025807 (2010). [6] M. Aglietta et al., 26th International Cosmic Ray Conference (AIP Conference Proceedings, 1999). [7] G. Bellini et al. (Borexino Collaboration), J. Cosmol. Astropart. Phys. 08 , 049 (2013). [8] B. Aharmim et al. (SNO Collaboration), Phys. Rev. D 100, 112005 (2019).