Measurement of cosmogenic ^{9}Li isotope production in SK-Gd

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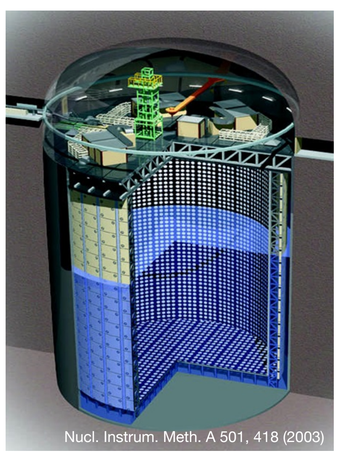
Cosmic-ray muons that penetrate Super-Kamiokande (SK) generate hadron showers in water, producing unstable radioactive isotopes through spallation. These isotopes are major background sources for neutrino analysis at the MeV scale and for the search for rare events. In this study, we measured muon-induced ^{9}Li isotope. It is difficult to distinguish the decay event from the inverse β decay reaction caused by an $\bar{\nu}_e$. Before the gadolinium loading, the SK experiment had an energy threshold of ~8 MeV for searching for the decay electrons from ^{9}Li isotope. In this study, the threshold was lowered to 4.5 MeV for the measurement. In this presentation, we will report on the measurement method and analysis status.

1. Introduction

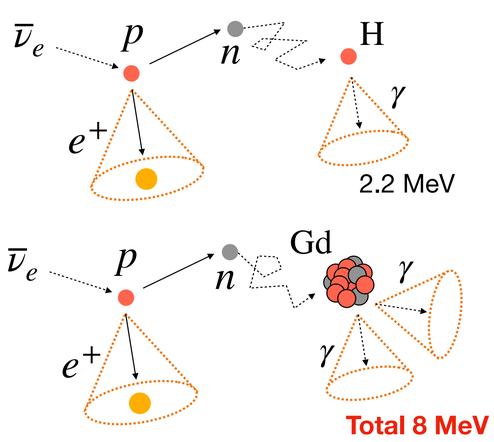
1.1. Super-Kamiokande (SK)

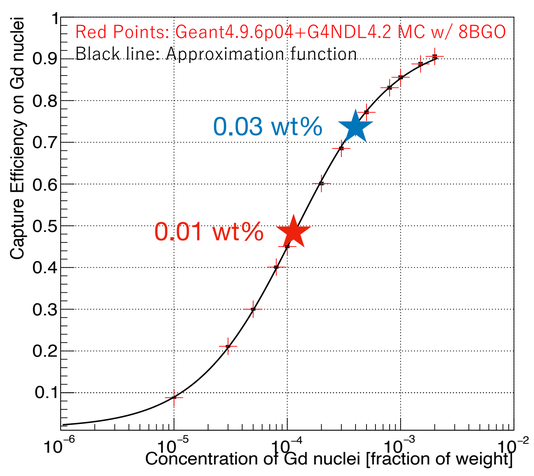


- 50-ktons water Cherenkov detector located at Kamioka, Japan
  - Overburden: 2,700 m.w.e.
- Diameter 39.3 m × Height 41.4 m
  - Fiducial volume: 22.5 kton
- Detector wall is covered by PMTs.
  - Inner detector: ~11,000 20” PMTs
  - Outer detector: ~1,800 8” PMTs

1.2. SK-Gd experiment

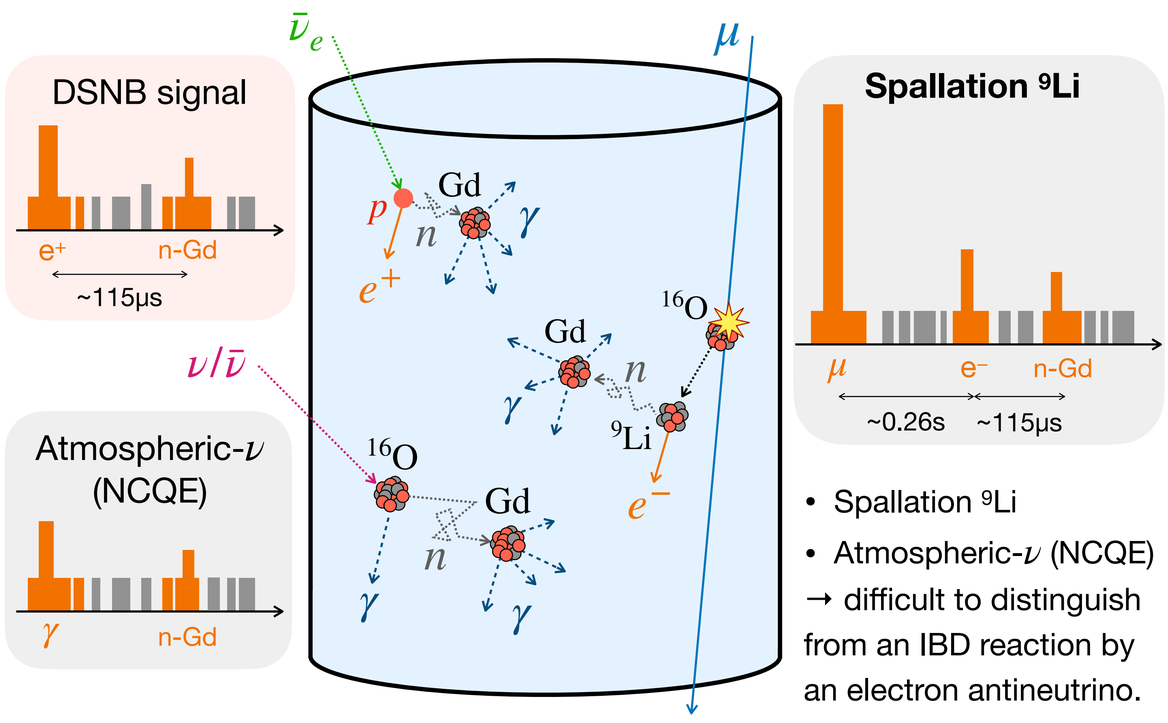
- SK-Gd has been started since Aug. 2020 [1].
  - To improve the neutron detection efficiency and suppress the background due to radioactivities and PMT dark noise.
- Gadolinium sulfate ($Gd_2(SO_4)_3 \cdot 8H_2O$) was dissolved in water.
  - Gd mass concentration: ~0.01 wt% (Aug. 2020-Jun. 2022)
  - After Jun. 2022, Gd concentration is increased to ~0.03 wt%.
- Major goal of SK-Gd:
  First observation of diffuse supernova neutrino background (DSNB)





[1] K. Abe et al. (Super-Kamiokande Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A 1027, 166248 (2022).

2. Signal & Background for DSNB search

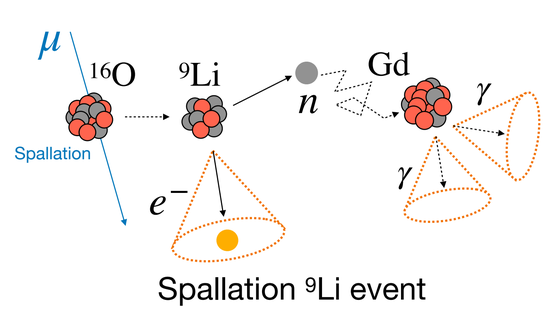


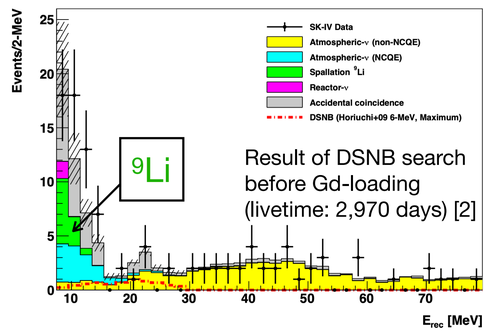
- Spallation ^{9}Li
- Atmospheric-ν (NCQE)

→ difficult to distinguish from an IBD reaction by an electron antineutrino.

3. Cosmogenic ^{9}Li production

- Cosmic-ray muons flying into SK with a frequency of ~2 Hz.
- Muons induce showers, which break ^{16}O and produce unstable nuclei.
- ^{9}Li is a major background source for DSNB search below ~14 MeV.
  - It is a long-lived radioactive isotope with the lifetime of ~0.26 sec.
  - It emits an electron and a neutron at the branching ratio of 50.8%.



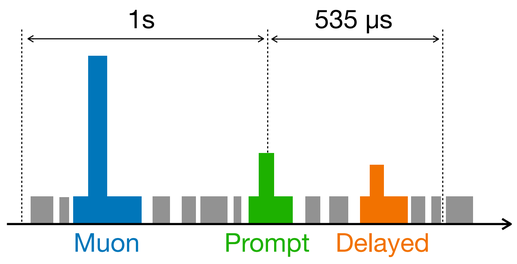


[2] K. Abe et al. (Super-Kamiokande Collaboration), Physical Review D 104, 122002 (2021).

4. Search for ^{9}Li candidates

4.1. Search method

^{9}Li event candidates are obtained by triple coincidence of muon-prompt-delayed events.

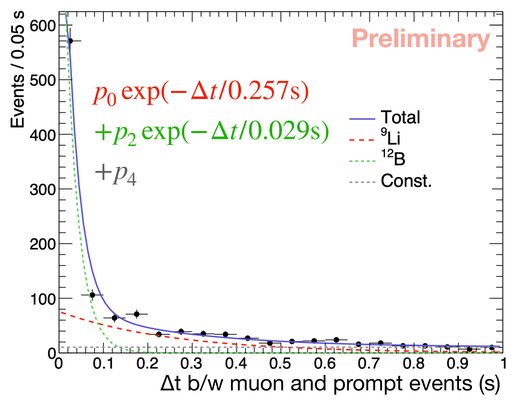


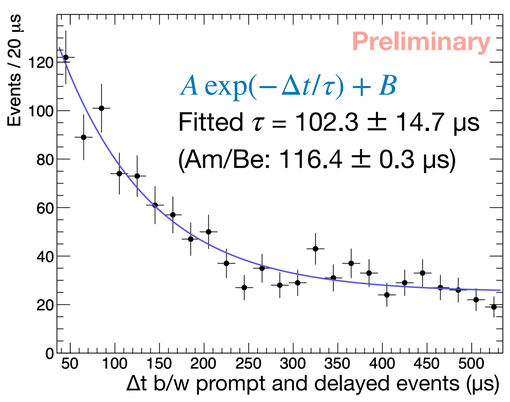
4.2. Selection criteria

1. Prompt-delayed pair
   - Prompt (electron):
     - 4.5 MeV $\leq E_{rec} <$ 14.5 MeV
   - Delayed (neutron capture):
     - 3.5 MeV $\leq E_{rec} <$ 10 MeV
     - Δr from prompt $<$ 350 cm
2. Parent muon
   - Select the largest likelihood which are defined using spallation variables.
   - ΔL b/w μ track and prompt $<$ 500 cm

5. Result

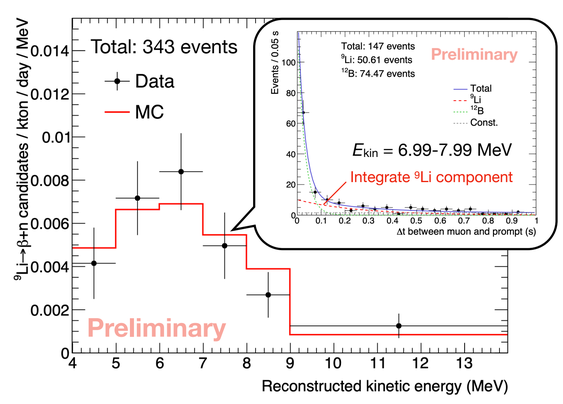
5.1. Δt distributions





5.2. β energy spectrum

- Δt distribution between muon and prompt events was fitted for each reconstructed energy.
  - The β energy spectrum was measured while lowering the energy threshold to 4.5 MeV.
- Production rate will be evaluated including the syst. uncertainties.



Summary

- SK-Gd experiment had been started with Gd dissolved in water since Aug. 2020.
- The cosmogenic ^{9}Li production was measured with SK-Gd data from Sep. 2020 to Apr. 2022.
  - The β energy spectrum was measured while lowering the energy threshold to 4.5 MeV.
  - Future prospect: ^{9}Li production rate will be evaluated including the systematic uncertainties.