The measurement of gamma rays from neutron-oxygen interactions

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Abstract. Neutrino neutral-current elastic interaction by atmospheric neutrinos is one of the main background in Supernova relic neutrino (SRN) search at Super-Kamiokande with Gadolinium. Understanding of gamma-ray production via neutron interaction on oxygen is important for the study of neutrino neutral-current elastic interactions. A measurement of gamma-rays production from such reactions was performed by using a 30 MeV quasi-mono energetic neutron beam in the Research Center for Nuclear Physics, Osaka University. In this proceedings the current status and future prospects of this measurement are presented.

1. Introduction

The atmospheric neutrino neutral-current quasi elastic (NCQE) scattering is one of the main background in supernova relic neutrino (SRN) search. This background cannot be distinguished from SRN in Super-Kamiokande (SK), therefore it should be estimated by a simulation. NCQE interaction cross section is measured by the T2K long baseline neutrino experiment [1,2]. In this experiment, the neutrino peak energy (~600 MeV) is near the peak of the atmospheric neutrino flux. However, the result suffers from large systematic errors that is caused by nucleons emitted by neutrino-oxygen interaction. Especially, neutrons interact with other oxygen inside SK leading to additional gamma-rays (secondary gamma-rays : Figure 1). Secondary gamma-rays are difficult to distinguish from primary neutrino-oxygen gamma-rays because they have similar energies and are emitted within O(10) ns. Neutron beam experiment (E487) was carried out in Research Center for Nuclear Physics (RCNP) in Osaka University [4-6] for the understanding of secondary gamma-rays from neutron-oxygen interactions [3] to provide data that can help understanding of secondary gamma-rays. Similar experiment, E525, is conducted with different neutron energy. Neutron flux, emitted by the T2K experiment neutrino-oxygen NCQE reactions, is estimated and 30 MeV is the peak energy and falls gradually to 300 MeV. E487 experiment used 80 MeV and E525 used 30 and 250 MeV for further verification. This proceedings reports current status from the E525 experiment.

2. E525 Experiment

E525 experiment was carried out at the RCNP in October and December, 2018. A proton beam is accelerated by two cyclotrons and interact with lithium target to produce an almost mono energetic neutron beam via the $^7\text{Li}(p,n)^7\text{Be}$ reaction. Mono energetic neutron can decrease contamination from neutron of other energy. The energies of proton are 30 MeV and 250 MeV.

A cylindrical acrylic container was placed on the beam axis, and container was filled with water.
or air. A high-purity germanium (HPGe) detector was placed upstream of the water target to measure gamma-rays. The HPGe was read out by a USB-MCA APG7300L and a 14-bit CAEN DT5725 Flash-ADC. Neutron beam flux and the backgrounds from neutrons scattered in the water-filled target were also measured. For the neutron beam flux measurement, the water target was replaced with an organic liquid scintillator (BC-501A, Saint-Gobain 20LA32). The BC-501A coupled to Hamamatsu H6527 PMT was read out by the Flash-ADC. A CsI(Tl) crystal coupled to the H6410 PMT was also placed upstream of the water target and measured scattered neutrons. For the normalization, the proton beam current was monitored by the Faraday cup during the experiment.

3. Analysis of the gamma-ray Spectrum

Figure 3 shows energy spectrum of the HPGe in 30 MeV experiment. Several peaks were observed as in the 80 MeV experiment, and the physics processes that produce these gamma-rays are summarized in Table 1.
The 5.27 MeV gamma-ray was produced from nucleon knock-out, or nuclear decay after elastic scattering. This experiment does not have the ability to distinguish between these production mechanisms. The 4.44 MeV gamma-ray was produced from alpha knock-out or the decay of $^{16}$O with an alpha emission. As in the 5.27 MeV case, these processes cannot be separated.

Since the 6.32 MeV peak is not seen clearly in this process, the gamma-ray is considered to be emitted from $^{15}$N created by knock-out process but inelastic process. Therefore, we conclude that the 5.27 MeV and 4.44 MeV gamma-rays are also emitted by the inelastic process. However, knock-out process is dominated in the current simulation model. This is considered to be cause of discrepancy between data and simulation.

| Energy [MeV] | Physics process |  
|------------|----------------|  
| 6.13       | $^{16}$O(n,n')$^{16}$O* inelastic               |  
| 5.27       | $^{16}$O(n,n')$^{16}$O* then $^{16}$O* → $^{15}$N* +p inelastic knock out |  
|            | $^{16}$O(n,p)$^{15}$N* knock out                |  
| 4.44       | $^{16}$O(n,n')$^{16}$O* then $^{16}$O* → $^{12}$C* +α inelastic knock out |  
| 3.84       | neutron capture by $^{16}$O inelastic           |  
| 6.32       | $^{16}$O(n,np)$^{15}$N* knock out               |  

Table 1. Observed gamma-rays from neutron-$^{16}$O interaction with their parent processes.

4. Status and Conclusion

We measured the gamma-ray from 30, 80 and 250 MeV neutron beam-oxygen interaction to improve the simulation model. It is considered that inelastic process is dominant to produce the secondary gamma-ray. But knock out process is dominant in the current simulation model. The simulation model should be improved using this data. At present, the E525 experimental analysis is in progress. After that, a new table of the neutron oxygen interaction should be installed in the simulation model.

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[1] K. Abe et al. (T2K Collaboration), Nucl. Instr. and Meth. Phys. Res. A, 659 (2011).
[2] K. Abe et al. (T2K Collaboration), Phys. Rev. D 90, 072012 (2014).
[3] Y. Ashida et al., arXiv:1902.08964 [nucl-ex] (2019).
[4] T. Miura et al., Proceedings of 13th International Conference on Cyclotrons and their Applications, Vancouver, Canada (1992).
[5] T. Saito et al., Proceedings of 14th International Conference on Cyclotrons and their Applications, Cape Town, South Africa (1995).
[6] S. Ninomiya et al., Proceedings of 17th International Conference on Cyclotrons and their Applications, Tokyo, Japan (2004).
[7] D. Satoh et al., JAEA-DATA/ CODE 2006-023 (2006).
[8] T. Kajimoto et al., Nucl. Instr. and Meth. Phys. Res. A 665 (2011).