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Background Study for KamLAND Reactor Neutrino Experiment

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Abstract. One of the goals of the KamLAND experiment is a search for anti-neutrino oscillation via inverse β decay with the characteristic delayed-coincidence method in the liquid scintillator. For a more precise measurement than previous KamLAND result [1], we have improved the background estimations of (α, n) and fast neutrons. We present the estimated number of backgrounds in our data set from Mar. 2002 to May 2007.

In KamLAND, the dominant background is ^{13}C(α, n)^{16}O reaction. This reaction makes prompt signal by proton scattering, 6.05MeV e^+e^- pair creation or 6.13MeV γ-ray from excited states and delayed signal by neutron capture. Therefore, this reaction can make fake signal of anti-neutrino inverse β decay. The primary α source is the decay of ^{210}Po, a daughter of the ^{222}Rn decay chain introduced during the liquid scintillator filling. In Ref.[1], 32% error for the reaction to ^{16}O grand state was assigned from ambiguities of ^{210}Po rate, the cross section to ^{16}O grand state, neutron angular distribution and proton quenching. 100% error was assigned to that of the excited states conservatively since the cross section uses the model calculations[3]. To reduce these large uncertainties, we have done several work. First, the proton quenching factor was measured by n beam at OKTAVIAN, Osaka Univ. Proton quenching affects the prompt energy spectrum of the background. After the measurement, the uncertainty of the quenching factor was reduced from 10% to 2%. Secondly, to know the precise ^{210}Po decay rate in our fiducial volume, we improved a vertex fitter. The visible energy of 5.304 MeV ^{210}Po α energy is $\sim$ 0.21MeV in KamLAND. In this energy region, the past vertex fitter has about 15cm bias. Now it is improved to within 3cm. Thus, the uncertainty of ^{210}Po decay rate is reduced from 10% to 4%. Lastly, to measure the (α,n) prompt spectrum, detector calibration with identical ^{210}Po^{13}C reaction was performed. The expected spectrum was also simulated by the ^{13}C(α, n)^{16}O cross sections from Ref.[2][3] and compared with the data. The newly measurement cross section[2] has 4% accuracy in the total cross section, but it doesn't specify the final state separately. Thus the subtraction of the reaction rate of the excited states estimated from the cross section in Ref.[3] is needed for this new measurement. The first ^{16}O excited state emits e^+e^- , but they can't escape from the source capsule . In KamLAND, these events are observed at $\sim$ 1.02MeV due to annihilation gammas. Therefore, the reaction rate of each state can be measured separately by ^{210}Po^{13}C calibration source. The rate of the second excited state was consistent with the calculation[3] without scaling. For the first excited state, the expected spectrum agreed with the calibration data if scaled by 0.6. After the subtraction of the cross sections to excited states, then that to the grand state had been obtained. If the reaction rate of the grand state is scaled by 1.05, the expected spectrum was in good agreement with the data. With these improvement, we assign an uncertainty of 11% for the grand-state and 20% for the excited states. Since the expected spectrum is in good agreement with the ^{210}Po^{13}C data, we don't assign the uncertainty of quenching factor in the analysis. Finally, the number of background event of ^{210}Po^{13}C in our data set from Mar. 2002 to May 2007 is estimated to be 182 $\pm$ 21.7 events.

Cosmogenic neutrons, which are produced by muons going through outer-detector(OD) insensitive regions, sometimes enter the fiducial volume without making OD signals. These neutrons are called "fast neutron backgrounds". They can recoil protons and then make delayed capture signal, just like anti-neutrino's signal. We consider two possibilities of OD inefficiency and rock through muons. In Ref.[1], we estimated the OD inefficiency from muons passing through the detector. However, it is not a definite value for fast neutrons since muons which make fast neutrons may have different topology. To do more precise estimation, we calculated OD inefficiency for fast neutrons by MC including photon information using MUSIC and GEANT4 [4]. As a result, the fast neutron's OD inefficiencies are 0.8 % for muons passing through OD and 37 % for rock through muons. This simulation indicates that the neutron prompt energy spectrum is approximately flat in our energy window from 0.9MeV to 8.5MeV. We also estimate the other backgrounds from atmospheric neutrinos. They are estimated with NUANCE simulation . These simulations indicates that both the neutron prompt energy spectrum and prompt spectrum of the atmospheric neutrinos are approximately flat in our energy window from 0.9MeV to 8.5MeV. Finally, the number of fast neutrons and atmospheric neutrinos are estimated to be less than 9 events in our data set.

Cosmogenic ^{8}He/^{9}Li events emit beta-ray and neutron, and mimic anti-neutrino. To minimize this background, we apply 2 sec within 3 m cylindrical volume veto along muon tracks for well reconstructed muons and 2 sec whole volume veto for high charge muons. There remains 13.6 $\pm$ 1.0 ^{8}He/^{9}Li after these veto.

The accidental coincidence background is estimated using off-time window from 10 msec to 20 sec. The expected background is 80.5 $\pm$ 0.1 events above 0.9 MeV prompt energy threshold. The contribution of other backgrounds such as (γ,n) and spontaneous fission are negligible. Finally, the total background in our data set is 276.1 $\pm$ 23.5 events. All backgrounds are summarized in Table 1.

Table 1. Summary of backgrounds in our data-set taking into account of the detection efficiency

Background	contribution
Accidentals	80.5 $\pm$ 0.1
^{8}He/^{9}Li	13.6 $\pm$ 1.0
Fast neutrons and Atmospheric ν	$<$ 9.0
^{13}C(α, n)^{16}O G.S.	157.2 $\pm$ 17.3
^{13}C(α, n)^{16}O ^{12}C(n, $n\gamma$)^{12}C (4.4 MeV γ)	6.1 $\pm$ 0.7
^{13}C(α, n)^{16}O 1st excited state (6.05 MeV e^+e^-)	15.2 $\pm$ 3.5
^{13}C(α, n)^{16}O 2nd excited state (6.13 MeV γ)	3.5 $\pm$ 0.2
Total	276.1 $\pm$ 23.5

References

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