ORIGIN OF BACKGROUND EVENTS IN THE KAMIOKANDE MEASUREMENT

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Abstract

The observed number of background 5958±87 in 1036 days of the Kamiokande III measurement is not inconsistent with contribution of neutron flux generated in showers initiated by underground muons, whereas the contribution of atmospheric ν_e is less than 0.1 events.

1 Contribution of atmospheric electron-neutrinos

The number of total data sample in the fiducial volume of 680 ton with energies from 7 MeV or 7.5 MeV to less than 20 MeV is 6368 events for KM-III (1036 days), but not given the total number in KM-II + KM-III data for 2079 days (Fukuda et al. 1996). So we have to use the observed numbers in 1036 days of KM-III. Since the number of solar neutrino events is 390^{+35}_{-33}, the background number is 5958 ± 87 in which the error includes the statistical error of total number of 6368.

In general, the main background events seem to be caused with processis of scattering and nuclear capture by the low energy atmospheric neutrinos; $\nu_e + e^- \rightarrow \nu_e + e^-$ and $\overline{\nu}_e + p \rightarrow n + e^-$. The relevant cross sections are (Kolb, Stebbin and Turner, 1987)

$$\sigma(\nu_e\text{-}e^-) = 0.94 \times 10^{-43}\text{cm}^2(E_\nu/10MeV),$$
$$\sigma(\overline{\nu}_e\text{-}p) = 0.89 \times 10^{-41}\text{cm}^2(E_e/10MeV)^2.$$

The expected ratio of events, $R = \phi(\nu_e)n_e\sigma(\nu_e\text{-}e^-)/\phi(\overline{\nu}_e)n_p\sigma(\overline{\nu}_e\text{-}p)$, is in the range of $R \simeq 0.06 - 0.12(10MeV/E_\nu)$ where ϕ is the integrated flux of ν_e's (or $\overline{\nu}_e$'s), n_e is the number density of electrons, and n_p is the number density of free protons. Some calculations have recently estimated the atmospheric neutrino spectrum, although the intensities less than 1 Gev may be ambiguous. Flux intensities of the most recent calculation obtained by Honda et al. (1995) is middle between the intensity values of Gaisser et al. (1988) and of Bugaev et al. (1989). But the flux value of Gaisser et al. is almost consistent with Honda et al. in the present energy region. Using their predicted fluxes from 7 MeV to 20 MeV of ^{8}B neutrinos and the cross sections, we estimated the expected total number of less than 0.1 events from the scattering process and the capture process for KM-III observation. So we must emphasize there are no sources of neutrinos except the atmospheric neutrinos and the solar neutrinos. Accordingly the 4π solid angle anticounter surrounding the main detector and the rejection efficiency of the muon-induced background seem unable to completely protect the other events in triggering of the main detector.

2 Contribution of underground neutron flux

Ryazhskaya (1991a) has already discussed the contribution of neutrons, generated in nuclear cascade showers initiated by muons, produces strong background due to their interactions with the underground-detector nuclei. The measured flux values of neutrons in some energies at 2700 meter-water-equivalent (mwe) (Kamioka) and 3300 mwe (Gran Sasso) are given in Table 1. The values with kinetic energy of $20 \sim 90$ MeV are evaluated from their measurement at the depth of 570 mwe (Khalchukov et al., 1987) These values plotted in Fig. 1, obtained by different investigators for different energy region, do not seem to contradict among them in consideration of the contributions of real and virtual photons associated underground-muons. Hayakawa (1969) has obtained the expression for neutron flux produced by giant resonance and photopion proesses of high energy muons. The expression is

$$\begin{aligned} J_n(x) &= L\frac{N}{A}\int[q_n(q_\pi(\frac{x}{\cos\theta})+q_g(\frac{x}{\cos\theta}))]2\pi d\cos\theta. \\ &\simeq 1\times 10^{-3}\ln(8x)J_\mu(x). \end{aligned}$$

Here all the definitions follow to Hayakawa's book. L is the attenuation length of neutrons and uses as $\simeq$150 g$\cdot cm^{-2}$ and $J_\mu(x)$ is the omnidirectional muon intensity at x mwe. The q_π and q_g are the neutron-production rate per nucleus by the photopion process of virtual photons and the giant resonance process by real photons. Most of the produced neutrons are isotropic. Applying the expression at 2700 mwe undeground and using the Kamiokande observed muon flux of 0.37 s^{-1}, we can estimate the number of neutrons of 2.3×10^5 in taking the attenuation length of neutrons of 150 $g\cdot$ cm^{-2} for the fiducial mass of 680 ton in the 1036 days. The days include the deficits of 16.3% in the data taking and of 14.6% in the analysis. Most of the background events at the threshold energy 7 (7.5) MeV are caused by electrons with E_m of 10.44 MeV (intensity: 26%) due to β decay of the nuclide $^{16}N_7$ with decay time of 7.13 sec appearing in reaction $^{16}O(n,p)^{16}N$ (ed. Lider et al.). Since the rejection efficiency of the muon-induced background is estimated to be 95% by the Kamiokande group (Hirata et al., 1991a) under the selection condition of $\Delta R \geq 3$m and $\Delta T \leq 20$ sec, then the background number in account of the residual 5% value becomes 3,000 events. Furthermore neutrons by produced incident muons within the dead time of 20 sec must be taken in considerations. In the similar way, but only $\Delta R \geq 3$m, the background number is 1.5×10^3 events, the addition of which to 3.0×10^3 events is 4.5×10^3 events which is little smaller than the observed number $5,958\pm87$ of background events. The estimated value might be lower than the actual one because the above-used cross section expression may not contain sufficiently the interactions proceed via conpound-nuclues at TeV muons. In actually, the comparison of the expression value with the experimental data even in muon energy 100 GeV is shown lower (Hayakawa, 1969). Also the effect of nuclear cascades by pions may be effective according to Dedenko et al. (1995). The other hand, Ryazhskaya's estimation may include neutron productions in the hadronic cascades. The estimated neutron number using the Kamiokande muon flux of 0.37s^{-1} is 13.6×10^5. The estimated way uses an average path length of muons with $600g/cm^2$ and a production fraction of 3% producing $^{16}N_7$ that may correspond to the selection condition of $\Delta R\geq 3$m and $\Delta T\leq 20$ sec. The number of neutron flux and the background numbers folowing to the Ryazhskaya's estimation are tabulated together with our estimated values in Table 2. Ryazhskaya's estimation is about 3 times higher than the observed number $5,958\pm87$ of background events. But if taking the production fraction of 1.1% producing $^{16}N_7$ owing to Dedenko et al. (1995), the value is consistent with the observed number. Our estimation may be the lower limit and the number of neutrons estimated with $5.78\times10^{-7}s^{-1}m^{-3}$ at 2700 mwe of Dedenko et al. (1995) seems fewer because of the flat surface approximation. Otherwise any other origins than neutrinos must exist to explain the observed background.

From the above discussion, also, the individual ^{8}B neutrino event and background event of neutrons within the direction of the sun are impossible to distinguish each other. This shows that the Kamiokande experiment is not a real time experiment in the exact sense. Accordingly searching for short time variation of ^{8}B neutrinos may be difficult for finding it. Namely, the difference disappears in the Kamiokande latest report (Fukuda et al., 1996) although the previous Kamiokande report (Hirata et al., 1991b) had indicated an existence of variation between the day-time and night-time fluxes of the solar neutrinos.

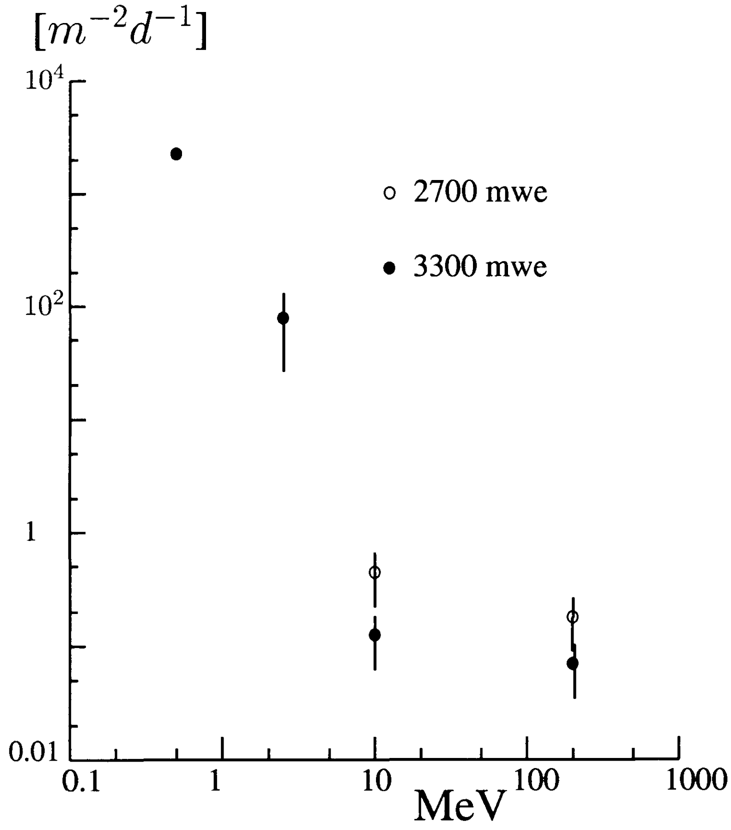

Figure 1: Neutron flux at underground depths of 2700 mwe and 3300 mwe.

Table 1: Fast neutron flux in various energy region of underground measurements and estimations.

Enegy region (MeV)	*Neutron flux* 3300 mwe	2700 mwe	Reference
$0.5 < E < 10$	$2212 \pm 233\ (m^{-2}d^{-1})$		Rindi et al. (1989)
> 2.5	$78 \pm 52\ (m^{-2}d^{-1})$		Criber et al. (1995)
> 10	$45 \pm (50\%)\ (m^{-2}y^{-1})$	$160 \pm (50\%)\ (m^{-2}y^{-1})$	Khalchukov et al., (1989)
> 200	$25 \pm (50\%)\ (m^{-2}y^{-1})$	$65 \pm (50\%)\ (m^{-2}y^{-1})$	Ryazhskaya, (1991a), (1994b).

Table 2: Estimations of the background number caused by Fast neutron flux generated from underground muons.

Estimation	*Neutron flux*	*$^{16}N_7$ flux* under the selection condition ($\geq$ 3m and $\leq$ 20 sec)	escaped from the selection condition	*Total background* number
Ours	2.3×10^5	3,000	1,500	4,500
Ryazhskaya	13.6×10^5	10,600	6,600	17,200

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