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The 1000ton Liquid Scintillation Detector Project at Kamioka (Kam-Land)

F. Suekane

Tohoku University, Japan

AOBA SENDAI 980-77 JAPAN

The 1000ton Liquid Scintillation Detector Project at Kamioka [1] (Kam-LAND[2])

F.Suekane [3]

Faculty of Science
Tohoku University
Sendai, 980-77, JAPAN

Abstract. We are constructing 1,000ton liquid scintillation detector at the old Kamiokande cave in order to detect low energy (anti)neutrinos from various sources. The main physics target of this experiment is to measure the neutrino oscillation parameter; Δm^2 down to $10^{-5}eV^2$ by detecting reactor antineutrinos coming from 150 to 200 km away. An outline of this experiment is explained in this paper.

INTRODUCTION

Super Kamioka is the world's largest water Cherenkov detector and is presently observing various rare event phenomena with signals above 6MeV. After long deliberations of the future of the old Kamioka detector, it has been decided to convert it into a companion facility as the world's largest liquid scintillation detector specializing in rare events occurring at lower energies. Because liquid scintillator generally produces more photoelectrons than Cherenkov light per unit energy and has lower background in terms of radioactive contaminations, it is possible to detect low energy (anti)neutrino events down to few MeV level. Many interesting phenomena occur at these energies, such as antineutrinos from nuclear reactors, those from the Earth, ^7Be solar neutrinos, and so on. Delayed coincidence technique can be used

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[3] Email address: suekane@awa.tohoku.ac.jp

[2] The collaborators are; A.Suzuki, J.Shirai, F.Suekane, A.Hasegawa, T.Iwamoto, H.Ogawa, S.Enomoto, S.Kawakami, K.Mashiko, K.Oki, D.Takagi, T.Itoh, O.Tajima, T.Ujiie (Tohoku University), M.Higuchi(Tohoku Gakuin University), T.Chikamatsu(Miyagi Women's University.)

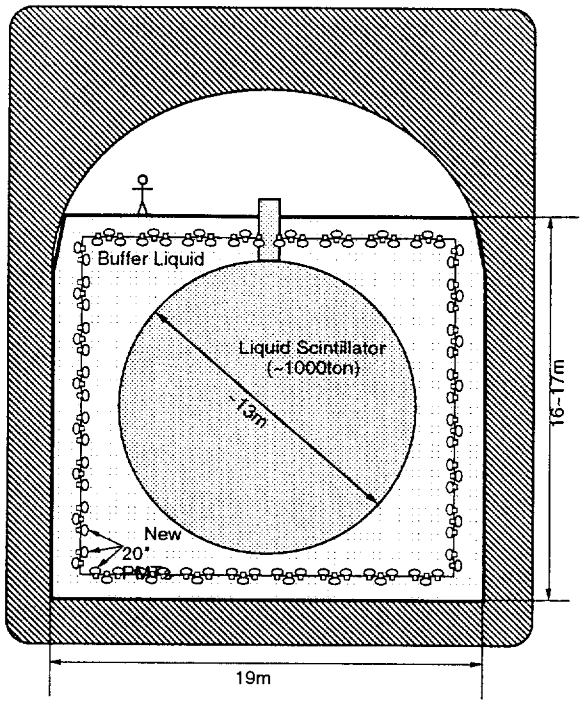

FIGURE 1. the Kam-LAND Detector

to identify electron-type antineutrinos, reducing background events significantly. As this is the world largest liquid scintillation detector located in a very low background environment, we will be able to perform several low energy (anti)neutrino physics with the best sensitivities.

THE DETECTOR [1]

Fig.-1 shows a schematic view of the planned detector. The detector consists of $1,200m^3$ liquid scintillator surrounded by $3,300m^3$ buffer liquid. 1,500 new 20" photo multipliers look at the scintillator volume. The liquid scintillator will be a mineral oil base with the mineral oil concentration of 80% or more. Mineral oil has very good features such as, non-toxic, chemically stable, high flash point, transparent down to UV region, high H/C ratio, and very low radioactive contaminations. We are expecting to develop a scintillator with the light output of 30% Anthracene equivalent or more and light attenuation length of significantly longer than 7m. The liquid scintillator will be held in a large balloon with diameter of 13m. The buffer liquid is used as the shield for γ rays and neutrons come from detector walls and rocks, as well as cosmic ray veto counter. The material will be pure mineral oil to reduce the buoyant force of the scintillator balloon. A new 20" PMT is being developed to improve timing resolution to achieve a good position resolution. The PMTs will cover 25% of the effective area and 100 photoelectrons per 1MeV energy deposition in the scintillator are expected. Corresponding statistical energy resolution is 10% for 1MeV event. The tank will be made of stainless steel.

ANTINEUTRINO SIGNAL

Antineutrinos are detected using the delayed coincidence technique. That is, antineutrino produces a positron and a neutron through charged current interaction with a proton. The positron produces the prompt signal and the neutron produces the delayed signal when it is captured by a proton. The coincidence gate is a few hundred microsecond.

$$\bar{\nu}_e + p \rightarrow e^+ + n$$
$$\hookrightarrow n + p \rightarrow d + \gamma(2.2MeV)$$

As an option, Gadolinium may be loaded in the liquid scintillator if accidental background rate turns out to be too high. In this case the neutron capture signal is 7.9MeV gamma rays and the coincidence gate can be set much shorter. The threshold of the charged current reaction is 1.8MeV. As the energy of the reactor antineutrino is very small compared to the proton mass, the antineutrino energy is directly related to the event energy; $E_{\bar{\nu}} = E_{obs} + 0.8MeV$. This feature is very useful in studying deformation of the energy spectrum due to neutrino oscillation.

BACKGROUNDS

There expected to be several background sources which mimic the antineutrino signal. Uranium and Thorium contaminations in the liquid scintillator are expected to be less than 10^{-14} g/g and the potassium are expected to be less than 10^{-10} g/g. With this concentration, both the accidental and correlated background rate due to their decay chains and the fission are negligibly small. *Rn* has relatively short lifetime and its effect will become negligible a few months after the detector seal. The cosmic ray rate in the detector is roughly 0.3Hz and cosmic ray related backgrounds, such as prompt and delayed signal caused by spallations, will be reduced to a negligible level after 3s of dead time. The γ rays and neutrons from outside are shielded by 3m thick buffer liquid and outer scintillator shell region.

THE TEST BENCH

We are constructing an 1 ton scale liquid scintillator test bench detector. Basic studies of liquid scintillator properties, back ground properties, etc. are to be performed with it. After these studies, the detector will be brought

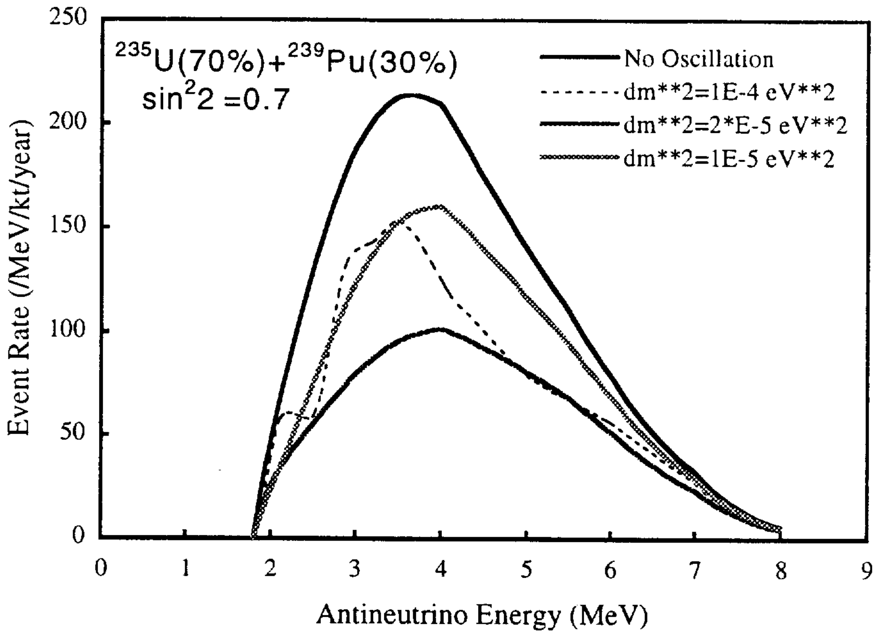

FIGURE 2. Event Energy Spectra with Oscillations

to a reactor site in order to calibrate reactor antineutrino flux, event energy spectrum and detection efficiency using the same liquid scintillator used in the main detector.

REACTOR ANTINEUTRINO OSCILLATION

In a nuclear reactor, antineutrinos are generated in beta decays of the fission products. A ^{235}U fission produces 6 antineutrinos accompanied by 200MeV of energy release in average. The energy spectra of reactor antineutrinos are shown in the references [2]. The typical energy of the antineutrino is a few MeV.

There are 17 commercial nuclear power plants in Japan, supplying one third (=120GW(thermal)) of the total electric power in the country [3]. At Kamioka, $3 \times 10^6/cm^2/s$ ($1 \times 10^6/cm^2/s$ for $E_{\bar{\nu}} \geq 1.8MeV$) of antineutrinos are coming from the reactors. Of them, 80% comes from the reactors located between 150 to 200km from Kamioka, that is, the flight distances are rather unique. The expected $\bar{\nu}p \rightarrow e^+n$ event rate is 700/kt/year for C_nH_{2n} target. The energy spectrum of the antineutrino event has the maximum at $E_{\bar{\nu}} = 4MeV$ as shown in the Fig.-2.

From these numbers, this experiment is sensitive at $\Delta m^2 > 10^{-5}eV^2$ and $\sin^2 2\theta > 0.2$ as shown in the Fig.-3. This covers both large angle MSW solution for the problem of solar neutrino deficit and $\nu_e - \nu_\mu$ mixing solution for atmospheric neutrino problem.

If neutrino oscillation exists, the event energy spectrum will be deformed as

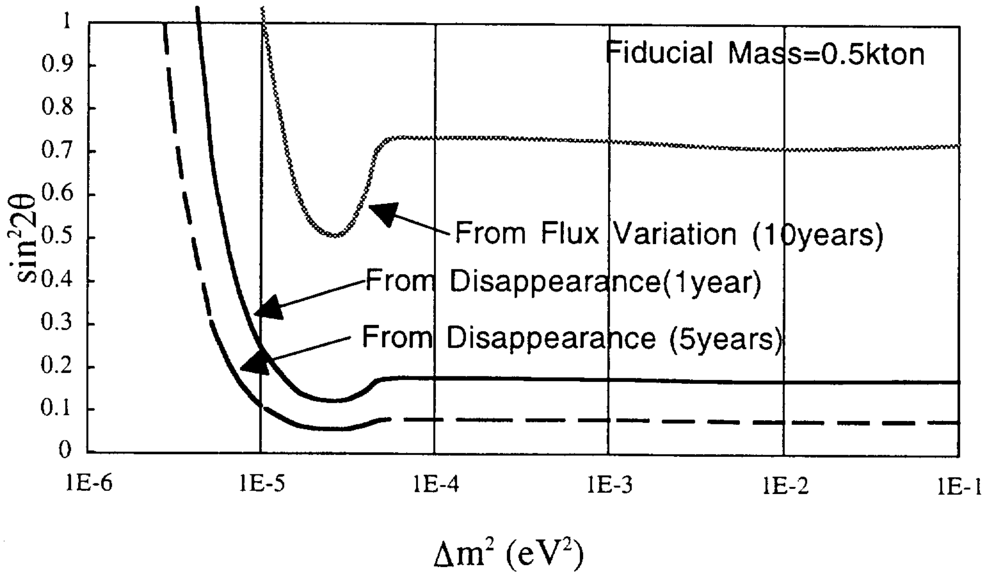

FIGURE 3. Sensitivity for the Neutrino Oscillation Parameters

shown in the Fig.-2. As antineutrino energy can be measured, it is possible to measure this deformation to search for neutrino oscillation.
The reactor generating power has seasonal variation because energy demand is high in summers. There is at most 30% difference of antineutrino flux between high flux month and low flux month. Making use of this difference, it is possible to perform background less-dependent search. The Fig.-3 also shows the sensitivities of this method.

OTHER PHYSICS POTENTIALS

Terrestrial Antineutrinos [4]

The earth is radiating 40TW of heat from the surface. Significant part of the energy is considered to come from decay energy of radioactive nuclei in the earth and there has been several discussions on possibilities of terrestrial neutrino detection [5]. According to some model, $2 \times 10^7/cm^2/s$ ($5 \times 10^5/cm^2/s$ for $E_{\bar{\nu}} \geq 1.8MeV$) of effective antineutrinos flux come from the earth and we will see 60/kt/year of the terrestrial antineutrino events. Fig.-4 shows the terrestrial and reactor antineutrino event spectra at Kamioka. The observation of the terrestrial antineutrinos is important because they carry direct information of inner structure of the earth.

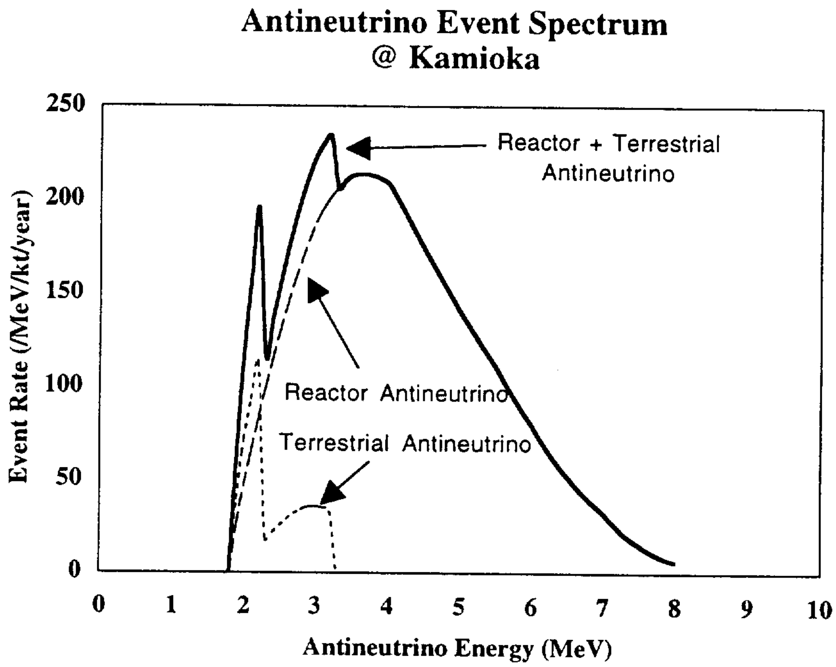

FIGURE 4. Antineutrino spectra

The Solar Neutrinos

There coming larger number of neutrinos from the sun than that of reactor antineutrinos. If the background is small enough to set the threshold energy at 0.25MeV, we will see 500/day/kt of ^7Be, pep, ^{13}N , ^{15}O neutrino events [6].

(Anti)Neutrinos from Supernova Burst

If there is a supernova burst at the distance of 10kpc, we will see 300 $\bar{\nu}_e p$ events within a few seconds [7].

The Double Beta Decays [8]

Liquid scintillators can dissolve Xe with relatively high concentration. By making use of the low background environment, it is possible to measure Majorana neutrino mass of $0.2 \sim 0.3eV$ by loading hundred kilograms of ^{136}Xe in the liquid scintillator.

SCHEDULE

This project was approved in April, 1997. We will finish the construction by the year 2000 and will produce the first physics output from the year 2001.

SUMMARY

We are constructing 1000ton liquid scintillator detector at the old Kamiokande cave. The main physics target is to measure neutrino oscillation parameter down to $\Delta m^2 \sim 10^{-5} eV^2$ using reactor antineutrinos. There are several other physics topics. The construction will be finished by the year 2000 and we expect to produce the first physics output from the year 2001.

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