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Status of the KamLAND neutrino detector

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Abstract. The new KamLAND detector of the Kamioka Observatory in Japan is nearing completion. The 1-kiloton liquid scintillator-based detector will measure the spectrum and flux of anti-neutrinos from distant Japanese nuclear reactors in hopes of detecting neutrino oscillations in a mass and mixing angle region relevant to the Solar Neutrino Problem within three years.

1 Introduction

The deficit of neutrinos coming from the sun, known as the solar neutrino problem, has long been established by past experiments (Cleveland , 1964; Fukuda , 1996; Abdurashitov , 1999; Anselmann , 1994; Fukuda , 2001). Taken together, these experiments imply an energy-dependent suppression of the neutrino flux as compared to calculations (Bahcall , 2000). It is generally thought that this suppression might be due to neutrino flavor oscillations (Wolfenstein , 1978; Mikheyev and Smirnov , 1985). Global analyses comparing the rate predictions with experiments under the assumption of two-component oscillations typically give four allowed regions: (1) a "small mixing angle solution" (SMA, $\Delta m^2 \approx 10^{-5}$ eV^2, $\sin^2 2\theta \approx 10^{-2} \ldots 10^{-3}$), (2) a "large mixing angle solution" (LMA, $\Delta m^2 \approx 10^{-4} \ldots 10^{-5}$ eV^2, $\sin^2 2\theta > 0.5$), (3) a "low solution" (LOW, $\Delta m^2 \approx 10^{-7}$ eV^2, $\sin^2 2\theta \approx 0.9$),[1], and (4) a "vacuum oscillation solution" (VAC, $\Delta m^2 < 10^{-9}$ eV^2). Recent solar-model independent measurements of the time variation and energy spectrum of ^8B at Super-Kamiokande strongly disfavor the SMA and VAC solutions, since no significant deviation for the no-oscilaltion hypothesis is seen. Thus, there is great interest in investigating the LOW and LMA regions. While investigation of the LOW region would require measurement of the sub-MeV flux of pp or ^7Be neutrinos from the sun, the LMA solution can be tested using power reactors as a source of $\overline{\nu}_e$.

This technique has the advantage that the neutrino source is better understood than the solar neutrinos (with the exception of the pp flux). In addition, unlike the sun, nuclear reactors have significant time variation of the flux due to reactor down time and/or long-term power excursions to match seasonally-dependent electrical loads (typically as much as 30% in Japan). This allows the absolute flux to be well-determined even in the presence of background.

The goal of the Kamioka Large Anti-Neutrino Detector (KamLAND) is to look for neutrino disappearance from several nuclear power reactors which are on the order of 100 km distant. To do this, the classic Reines-Cowan reaction will be used: $\overline{\nu}_e + p \rightarrow n + e^+$. The threshold for this reaction is 1.8 MeV, with the positron carrying off most of the kinetic energy. After creation, the neutron slows down and is absorbed on a proton, giving a characteristic 2.2 gamma-ray roughly 200 μsec after the positron. This reaction has the dual advantage of allowing the neutrino spectrum to be measured indirectly through the ionization energy deposited by the positron, while at the same time suppressing background using the double-coincidence tag.

2 Detector Description

KamLAND is a roughly 1-kton scintillator detector being built at the same Kamioka Observatory in Gifu, Japan, that houses Super-Kamiokande (see figure 1). The detector consists of a large water tank in which a 9-m radius SS sphere is supported on concrete pylons. On the inner surface of the sphere are mounted 1922 17-inch and 20-inch [2] PMT's.

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[1] This solution only appears at 99% C.L., however it is usually discussed as a possible solution.

[2] these were originally used in the Kamiokande experiment at the same site

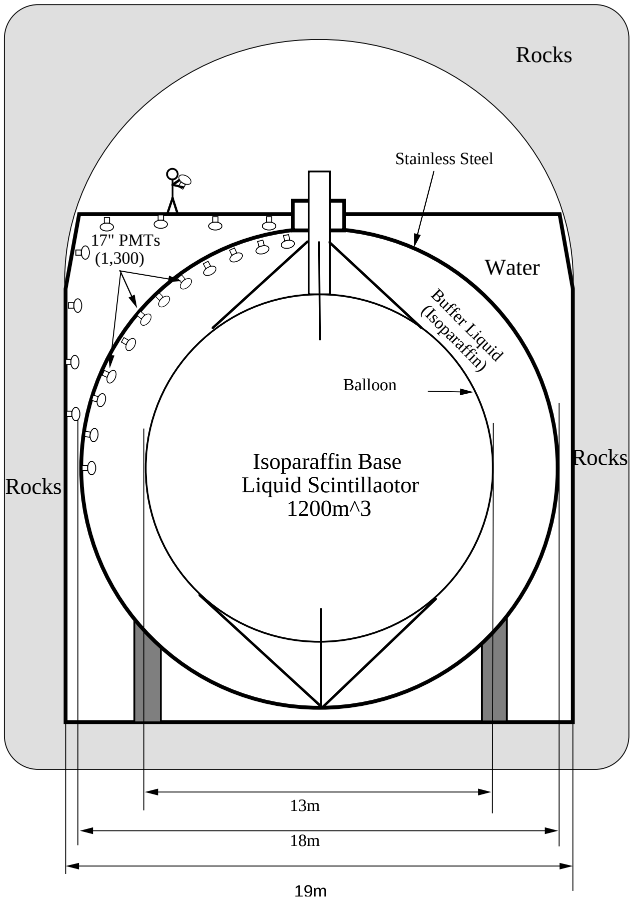

Fig. 1. The KamLAND detector. Not shown is the acrylic barrier between the balloon and PMT's.

3mm-thick acrylic plates are bolted on steel frames covering the PMT's in order to stop radon from U-Th contamination in the PMT glass from reaching the inner detector. Suspended by kevlar ropes from a "chimney" at the top is a 100 micron-thick balloon EVOH-nylon-EVOH sandwich material. This balloon will hold the kiloton of scintillator suspended in paraffin oil on the outside. The scintillator is composed of 80% paraffin oil, 20% psuedocumine, and 1.5 g/g of PPO.

The scintillator and buffer oil are purified using independent systems of filters, water extraction towers, and drying towers. For the reactor experiment, it is necessary to reach a U/Th level of $< 10^{-14}$ g/g, which is obtainable with the current system. Future considerations (such as the possibility of lowering the threshold to less than 500 KeV to look for ^7Be solar neutrino reactions) would require $< 10^{-16}$ g/g and thus an improved system would likely have to be devised.

Outside the steel PMT sphere there is a cylindrical volume filled with pure water instrumented with 20 inch PMT's. This volume (the outer detector) serves as both an active veto for cosmic ray muons (expected rate of 3 per second) and a passive shield for gamma rays and neutrons from the rock.

Reactor Site	Thermal Power (GW)	Distance (km)	Rate (events/year)
Kashiwazaki	24.6	160	360
Ohi	13.7	180	159
Takahama	10.2	191	105
Hamaoka	10.6	214	87
Tsuruga	4.5	139	87
Mihama	4.9	145	87
Shika	1.6	81	92
Fukushima	28.4	344	90

Table 1. Major contributors to the KamLAND neutrino event rate.

KamLAND is instrumented with custom waveform digitizers on every PMT channel. These self-launching digitizers are trigger by external FPGA-programmed trigger electronics and can take 128 2-ns samples of the PMT waveform. Each PMT pulse is sampled at three different gains to give a large dynamic range of roughly 1 to 100 photoelectrons (programmable and selectable). Each "A" bank of 3 digitizers is duplicated in a "B" bank to allow ping-ponging, making the system close to deadtime-less.

3 KamLAND Event Rate

Table 1 shows the contribution to the event rate from the closest of these reactors. Above 2 MeV 629 events/kton/year are expected with no oscillations and 100% power and efficiency. Since the reactor spectrum peaks around 4 MeV and we have a typical distance of 200 km, then the δm^2 for a single oscillation is about 3×10^{-5} ev^2 for maximal mixing. This is near the center of the Large Mixing Angle (LMA) solar neutrino solution.

4 Sensitivity

Based on the above event rates and assuming a 78% average reactor factor the figure 2 shows the oscillation parameter sensitivity expected after 3 years of operation. This assumes a 3% uncertainty in the expected non-oscillation neutrino flux and a signal:noise background ration of 10:1, which can be expected from reasonable background assumptions about fast neutron production from muons, random coincidences from backgound events caused by scintillator impurities, and gammas from the steel, rock, and PMT glass.

Figure 3 shows the background-free expected positron spectrum for three kt-years of operation. The solid crosses show the no-oscillation spectrum and the dashed crosses show the measured spectrum for the current Super-Kamiokande best-fit point in the LMA region ($\delta m^2 = 7 \times 10^{-5}$ ev^2 and $sin^2 2\theta = 0.87$). Detector resolution is taken into account

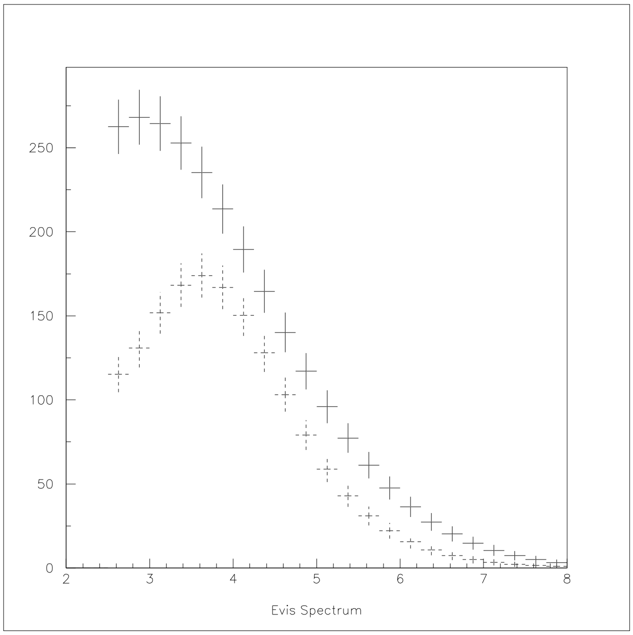

Fig. 3. Measured positron spectrum (including expected detector resolution) for 3 kt-years of operation with no oscillations (solid crosses) and oscillations at the Super-Kamiokande best-fit point in the LMA region ($\delta m^2 = 7 \times 10^{-5}\ ev^2$ and $sin^2 2\theta = 0.87$).

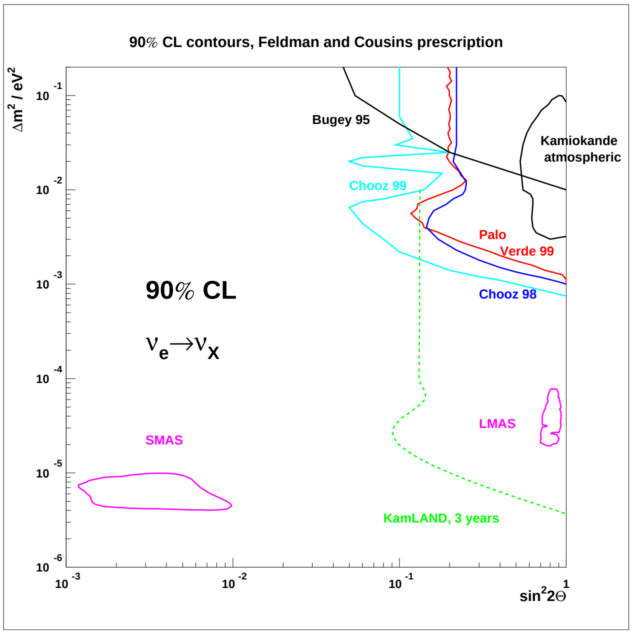

Fig. 2. The sensitivity of KamLAND after three years of operation.

and errors are statistical only. It is obvious that this solution would be easily detecable with KamLAND.

5 Construction Status

Currently (June 2001) the central balloon is in place and all PMT's are installed in the inner and outer detector. The balloon is inflated with radon-free dry nitrogen and the detector is being filled slowly with purified mineral oil and scintillator. It is expected that filling will be completed in October, 2001 and normal operations should start in early 2002.

6 Conclusions

The KamLAND detector will be operational by late 2001. It has excellent sensitivity to oscillation solutions of the Solar Neutrino Problem in the LMA region and will be able to positively ascertain if the LMA parameters are correct within three years of operations.

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