THE STATUS OF THE SEARCH FOR SOLAR NEUTRINOS AT KAMIOKANDE II*

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SUMMARY

The upgraded Kamioka Nucleon Decay detector, known as KAMIOKANDE II, is being used to search for neutrinos emitted by the sun. The status of this search is discussed.

Introduction

KAMIOKANDE II, the upgraded Kamioka Nucleon Decay Experiment, has the capability to observe single isolated electrons with energies down to approximately seven MeV. This capability may lead to the observation of electrons produced by elastic scattering of neutrinos which are emitted by the sun. The rate at which these electrons are produced is 0.5 per day using the neutrino flux predicted by the standard solar model.[1] This note summarizes the status of the search for solar neutrinos in the KAMIOKANDE II detector as of July 1986.

For many years the interest in experiments which study solar neutrinos has been motivated by the discrepancy between the single experiment of R. Davis, Jr.,[2] and collaborators, and the prediction of the so-called standard solar model. This discrepancy is discussed in detail elsewhere in these proceedings.[3] For the purpose at hand it is sufficient to note that the discrepancy is statistically significant, and that many checks have been performed which confirm that the experimental result is sound. The interpretation of the discrepancy, presuming it is confirmed to exist, is that the standard solar model needs revision, or that the propagation of neutrinos from the sun to the earth is not understood. The KAMIOKANDE II experiment is the first experiment since that of Davis to attempt to bring new data to bear on this problem.

The study of solar neutrinos is made possible by the recent upgrade of the KAMIOKANDE detector.[4] Briefly, the detector consists of 3000 tons of water contained in a cylindrical steel tank located at a depth of 2700 mwe in a mine in western Japan. Twenty inch diameter photomultiplier tubes are mounted on a one meter grid on the inner walls of the tank. Cerenkov radiation emitted when charged particles traverse the water produces signals in the photomultipliers. The time and amplitude (energy) of these signals are recorded on magnetic tape. These data are processed off line to reconstruct the event which triggered the detector.

The upgraded detector has two new features. The active volume of the detector is surrounded by an active 4π, hermetic anticounter consisting of 1.5 meters of water optically separated from the central detector and viewed by twenty inch diameter photomultipliers. The second feature is the implementation of multi-hit time and charge digitizing electronics, rather than the single charge measurement which was implemented on the original detector. These features permit the study of low energy electrons produced by solar neutrinos by *1)* attenuating radiation from the rock walls of the cavity, *2)* assuring through use of the anticounter that the candidate events are isolated in time and space, *3)* allowing the reconstruction of low energy events by use of timing and topology, and *4)* making possible a simple majority logic low energy trigger which is insensitive to radioactive decays of trace elements in individual photomultipliers.

Signal

The spectrum of electron kinectic energy for electrons produced by solar neutrinos interacting through the reaction $\nu_e + e^- \rightarrow \nu_e + e^-$ is illustrated in Figure 1. The ordinate is the number of electrons of kinectic energy T_e per MeV–second–target electron, assuming the standard solar model flux of neutrinos. The seven MeV threshold makes this experiment sensitive to the high energy part of the ^8B neutrino spectrum. The kinematics of neutrino electron scattering require that the electron direction be within about 140 milliradians of the neutrino direction for electron energies above a seven MeV threshold.

Multiple scattering of the electrons in the water of the detector causes the directional information to be diluted. Figure 2 is a representation of the trajectories of twenty Monte Carlo generated 10 MeV/c electrons in water, all with the same initial momentum direction. The multiple scattering is seen to be large, but the information about the initial direction of the electron, and hence that of the neutrino, is not lost. The di-

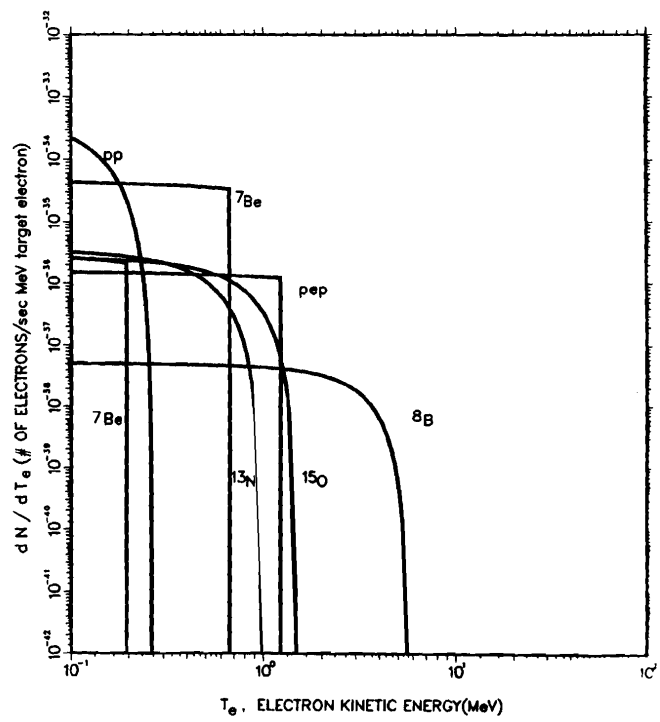

Figure 1. The spectrum of recoil electron kinetic energies for solar neutrinos scattering elastically from electrons. The solar neutrino flux is taken from the standard solar model. The KAMIOKANDE II threshold energy of 7 MeV makes the experiment sensitive to the upper end of the spectrum of neutrinos emitted in the decay of ^8B.

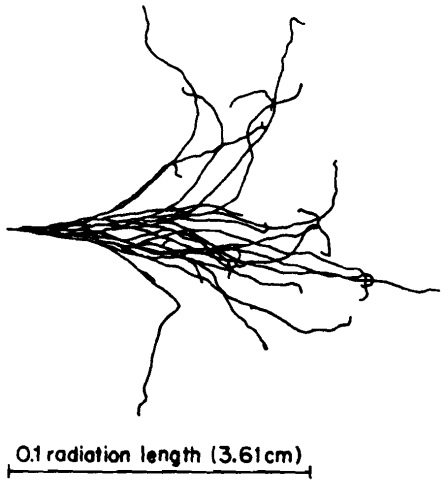

Figure 2. Representation of the trajectories of twenty Monte Carlo generated 10 MeV/c electrons in water. The initial direction of all electrons is the same.

rectionality of the Cerenkov radiation produced by the electron preserves the angular information such that the reconstructed electron direction points to the solar source of neutrinos within an r.m.s. angular uncertainty of approximately thirty degrees.

The measurement of recoil electrons from solar neutrino interactions in the KAMIOKANDE II detector is in real time, unlike the thirty day time resolution of the existing radiochemical measurement. The reconstructed electron momentum points to the sun as the source of the neutrinos, and through the electron detection threshold, there is information about the energy spectrum of the neutrinos. Assuming a neutrino flux three times lower than the standard solar model calculation,[1] the flux sensitivity of the measurement, as observed in the angular distribution of the electron direction relative to the direction to the sun, is a five standard deviation signal in one year if the isotropic background is ten times the signal.

The Experiment

Selection of a data sample to search for solar neutrino induced electron events is quite simple. The two principal selection criteria limit the total energy in the inner detector (to select low energy events) and limit the signal in the anticounter (to assure that the event is isolated and contained in the inner detector). Two additional cuts are made to reject electrons from muon decay (time since preceding event must be greater than 100 microsec), and to reject large noise pulses (from radioactivity) in individual photomultipliers. The corresponding distribution of events with respect to NHIT, the number of photomultipliers which are over threshold, is shown as data points (a) in Figure 3 for 48 days of live time. Also shown in the same figure is a Monte Carlo calculation of the distribution expected from the standard solar model[1]. The background to events produced by solar neutrinos is large, but not intractable.

The distributions of these events in the cylinder height coordinate, z, is shown in Figure 4. The distribution in r^2 where r is the radial coordinate is similar. From these distributions, it is clear that there are substantial backgrounds near the edge of the detector, but they are attenuated toward the center of the detector. A fiducial volume is defined inside of which the distribution of events is uniform in volume. The NHIT distribution for events in the fiducial volume is shown in Figure 3 as data points (b).

Sources of background which can mimic the solar neutrino signal in the detector arise from radioactivity in the environment and in the detector materials, and backgrounds which are induced by cosmic rays. The first of these backgrounds consists of photons and neutrons from the rock walls, radioactivity from the components on the surface of the detector such as the photomultiplier tubes, and radioactivity in the water of the detector. The surface associated backgrounds are excluded by the fiducial volume definition, while radioactivity in

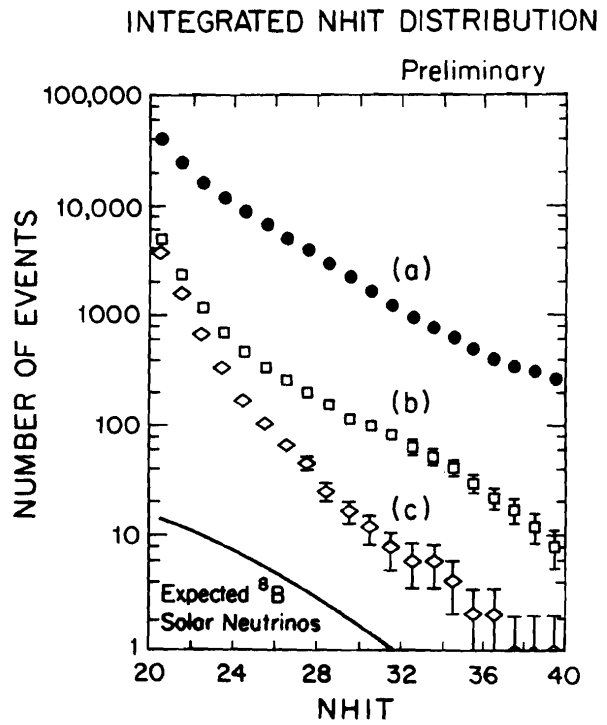

Figure 3. The integral electron event rate vs. the number of photomultipliers (NHIT) in an event: a) includes all event candidates, b) includes events passing the fiducial volume cut, and c) includes events which survive cuts which eliminate candidates for beta decay electrons from cosmic ray induced spallation of oxygen nuclei. The solid curve is the Monte Carlo expectation for the signal from solar neutrinos scattering elastically from electrons. The exposure is 48 days.

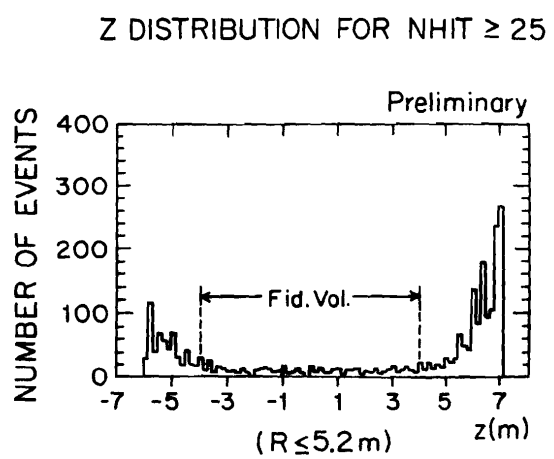

Figure 4. The z distribution of event candidates. Event candidates are uniformly distributed inside the fiducial volume.

the water contributes to the volume distributed background. Studies have shown that events arising from the radioactivity in the water can be reduced by removing uranium, thorium, and radium from the water using ion exchange purifiers. Installation of such purifiers is scheduled for late summer of 1986. Small scale laboratory studies have shown that a factor of one hundred reduction in the water radioactivity can be expected.

Cosmic ray induced backgrounds are due to the beta decay of light nuclei produced by the spallation of ^{16}O nuclei interacting with stopped or penetrating muons. These nuclei have beta decay endpoint energies up to 17 MeV and lifetimes ranging from 10 milliseconds to seven seconds.

The capture of a μ^- on ^{16}O can lead to the formation of ^{16}N which has a seven second half life and a 10 MeV endpoint beta decay. The calculated rate for this process produces a background of less than one event per day, but the background can also be eliminated in the analysis by vetoing for fifty seconds all events which follow a stopping mu without a decay electron. The associated dead time for this procedure is negligible.

Penetrating muons can cause spallation of oxygen nuclei by electro- magnetic process, or by interaction with the products (pions) of high energy inelastic interactions of muons. Figure 5 shows the time of events which satisfy the selection criteria relative to the time of passage of a preceeding muon which deposits a large amount of energy in the detector. There is a clear exponential decay time associated with these events. Candidates for the parent nucleus include ^{12}N, ^{12}B, ^{13}B, and ^{14}B, with ^{12}N and ^{12}B most probable. The event time distribution indicates contributions from both isotopes. The associated NHIT distribution for these events is shown in Figure 6. The superimposed histogram is a Monte Carlo calculation of the NHIT distribution expected for the beta decay of ^{12}N. From these two figures there is a hint that the clean identification of a subset of the spallation background may be able to provide an energy calibration of the detector at low energies. A simple cut is constructed to remove the spallation background associated with large energy deposits in the detector. The effect of this cut is shown as the data points (c) in Figure 3. It is expected that further study will produce techniques which remove even more of this spallation background.

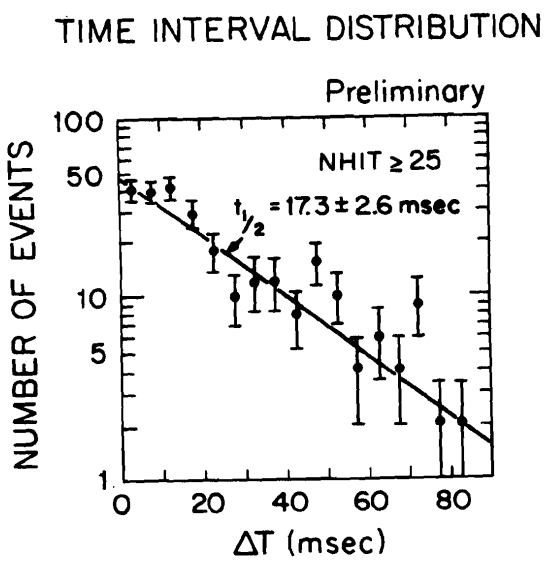

Figure 5. The distribution of time interval since the preceeding cosmic ray muon for event candidates following muons with large energy deposition.

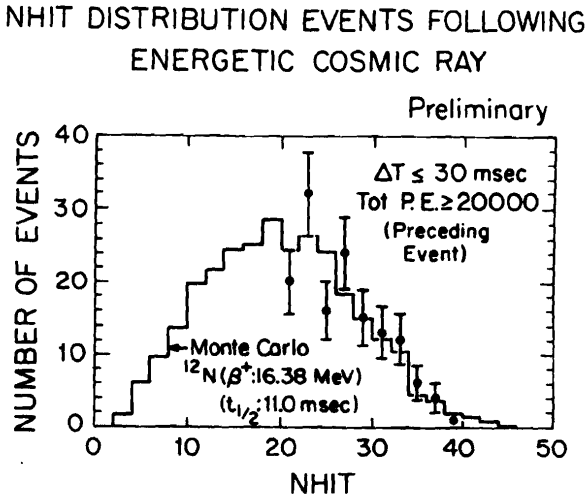

Figure 6. Number of photomultipliers hit for event candidates following within 30 millisec of the passage of an energetic muon. The histogram is a Monte Carlo estimate of the distribution expected from the beta decay of ^{12}N. The requirement that the total P.E. (photo electrons) of the preceeding event be greater than 20,000 selects cosmic ray events with visible energy greater than twice that of a single vertical penetrating muon.

Conclusion

The study of backgrounds to the signal of electrons produced by the interaction of solar neutrinos in the KAMIOKANDE II detector is, to date, very encouraging. Removal of radioactive contamination of the detector water and further study of cosmic ray induced backgrounds are expected to reduce the backgrounds to the point where the interactions of solar neutrinos can be detected. It appears that the decay of cosmic ray induced spallation products will provide an internal energy calibration of the detector.

The present discussion is based on results presented to the 12th International Conference on Neutrino Physics and Astrophysics.[5] This work is supported by the United States Department of Energy and the Japanese Ministry of Education, Culture and Science.

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