THE CURRENT STATUS OF THE SUPER-KAMIOKANDE EXPERIMENT

K. Martens for the Super-Kamiokande Collaboration
ICRR, University of Tokyo, Kamioka Observatory,
Higashi-Mozumi, Kamioka-cho, Yoshiki-gun, 506-12 Gifu-ken, Japan

The Super-Kamiokande Experiment started taking data on April 1^{st} 1996. By November a first preliminary analysis of solar neutrino data from the first 100 days of data taking was completed. The flux measured above an energy threshold of 7 MeV is $(2.51^{+0.14}_{-0.13} \pm 0.18) \times 10^{6}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which agrees well with the old Kamiokande result. No conclusion can at this stage be drawn concerning a possible day/night effect. A calibration effort with a linear accelerator for electrons is currently under way. This is expected to greatly reduce the systematic errors.

1 The Experiment

1.1 Structure and Location

Super-Kamiokande is a large 50 kt water cherenkov detector for neutrino physics. Located 1000 m underground in a mine in Mt. Ikeno (Ikenoyama) in Kamioka-cho, Gifu-ken in Japan it is shielded from cosmic rays by an overburden equivalent to 2700 m of water. The cylindrical detector is divided into an inner detector (ID) and anticounter. The diameter of the inner detector is 33.8 m and its height is 36.2 m. The 32.5 kt of ultra-pure water it contains are read out by 11146 photomultiplier tubes (PMTs) of 20 inch diameter. The inner detector is completely surrounded by 2 m of water that is used as anticounter. The anticounter volume is seperated from the inner detector by a light barrier and instrumented with 1885 PMTs of 8 inch diameter.

1.2 Data Taking

Official data taking with the Super-Kamiokande detector started at 00:00 h on April 1^{st} 1996 - just as scheduled! The experiment currently runs at an efficiency for being alive of 93.5 %, the downtime being almost entirely attributable to ongoing calibration efforts. During the first weeks of Super-Kamiokande data taking calibration took a heavier toll on the livetime; the overall uptime of the experiment in the period from April through November of 1996 was 83.2 %.

1.3 Trigger

Inner detector and anticounter generate independent triggers that each lead to a full readout of the detector's > 13k electronic channels. The ID triggers are generated from logical signals of 200 ns duration that come for every hit on an ID tube. These logical signals are added into an analog sum which then is AC-coupled into a discriminator. This AC-coupling automatically subtracts the noise level generated by the dark rate of the 11146 PMTs. The average dark noise rate for a single PMT is 3.1 kHz. Two different thresholds in this discriminator currently generate two ID trigger levels. The lower threshold corresponds to 29 hit PMTs or, averaged over the whole fiducial volume, 5.5 MeV of energy released into cherenkov photons. The trigger rate at that threshold is 11 Hz. The higher threshold at 31 hits gives 5 Hz. The threshold for anticounter triggers is at 19 hits. With these settings the total data rate of formatted raw data is 12 Gbyte/d.

1.4 Calibration

For each hit on a PMT its time and charge are recorded. The arrival time of cherenkov light at the surface of an ID PMT will be used for vertex or track reconstruction while the charge accumulated in all PMTs struck in an event will measure energy. Thus both quantities have to be well calibrated to do the precision measurements Super-Kamiokande is designed for.

To guarantee uniformity of the detector's response throughout its vast volume the response of all ID PMTs to a standard light signal was balanced by adjusting the high voltage for each individual PMT. The standard light signal was generated by a Xe-lamp driving a scintillator ball. By moving the scintillator ball along the detector axis to minimize acceptance corrections the PMT responses were equalized to within 7 %.

The calibration of absolute timing for ID PMTs with respect to the trigger timing was done using short nitrogen laser pulses. The laser light was scattered uniformly from the center of the tank by a diffuser ball. Figures 1 and 2 show the pulse height dependence of the timing and the timing resolution. While in the time resolution plot the average over all ID PMTs is displayed, the so-called TQ map is a typical case for a single PMT.

The charge in the PMT signal is converted into photoelectron equivalents (PE). For higher energies the absolute energy scale is fixed by the energy spectrum of decay electrons from stopping muons, the correlation of track length and deposited energy for stopping muons, and the decays of neutral pions.

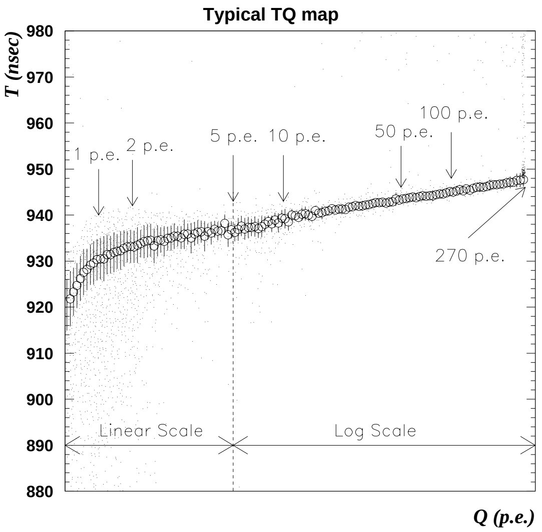

Figure 1: Absolute timings as a function of pulse height (single PMT)

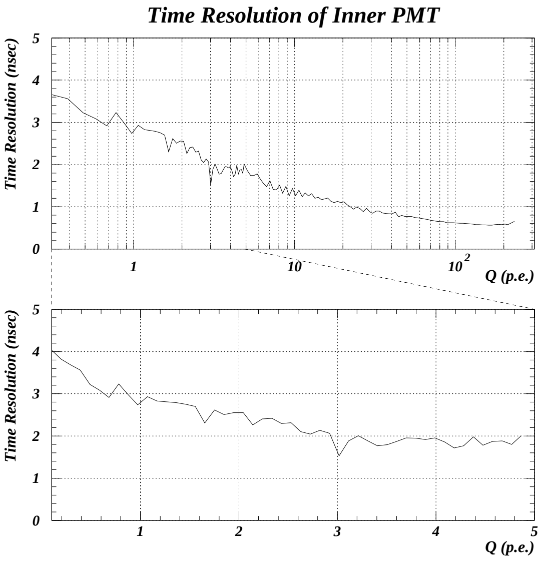

Figure 2: Timing resolution as a function of pulse height (average over all PMTs)

For low energy events fluctuations of the charge measured by the PMTs at the 1 PE level makes an energy calibration based on the total charge observed in the event rather imprecise. For these low occupancy events it is saver to count the number of hit PMTs under the assumption of 1 PE per tube. The absolute energy scale for these events is currently fixed by γ-rays emitted in a Ni (n,γ)Ni reaction. In our case the neutron needed to initiate this reaction is supplied by a ^{252}Cf fission source. A gas counter surrounding the ^{252}Cf source supplies a fission trigger signal at the time the neutrons are released. With a time constant of 85 μs subsequent γ-ray induced events are observed in the Super-Kamiokande detector. The average energy of the various γ lines emitted by Ni in this reaction is of order 9 MeV.

Besides being a calibration based on the detector response to γ-rays, the Ni calibration fixes the scale at one point only and is not accurate enough to yield the 1% precision needed for the important work on the solar neutrino spectrum. For a more precise energy calibration an electron LINAC is currently being prepared[a] in the mine right above the Super-Kamiokande detector. It will allow to inject electrons of varing energies into the inner detector volume at different positions.

1.5 *Detector stability*

A major concern in a water cherenkov detector the size of Super-Kamiokande is the attenuation length for cherenkov photons in water. Great care was invested into the construction of a water purification system that is designed to remove Radon - its radioactive isotops are a significant source of background at the low energy end of the solar neutino analysis - as well as impurities that could absorb or scatter cherenkov light in the tank.

Continuous monitoring of relative changes in the attenuation length can be provided by the detector response to through going muons - assuming a stable PMT response. Figure 3 indicates that through April and May the water transparency kept increasing significantly whereas by June it had reached equilibrium. $t = 0$ corresponds to April 1^{st} 1996.

Figure 4 shows the results of various Ni calibrations. The time scale on this figure is in parts of the calendar year 1996 and starts only shortly before the period of time relevant to our current data analysis. The number on its vertical axis, "n50", is a measure of ID hits associated with the event. Coming from a fit to high statistics n50 distributions, the error on the data points

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[a] First sets of data with electrons from the LINAC in the Super-Kamiokande detector were successfully taken shortly after the INS Symposium.

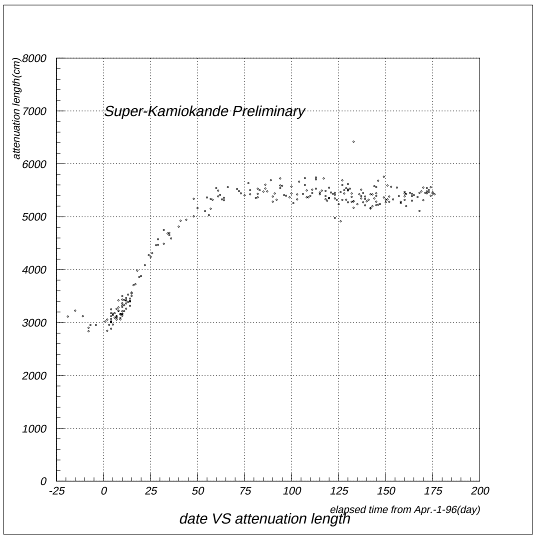

Figure 3: Attenuation length from horizontally through going muons

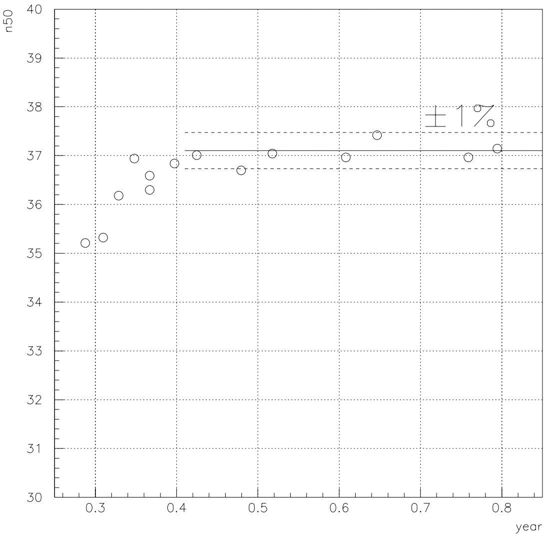

Figure 4: Ni calibration data as a function of time

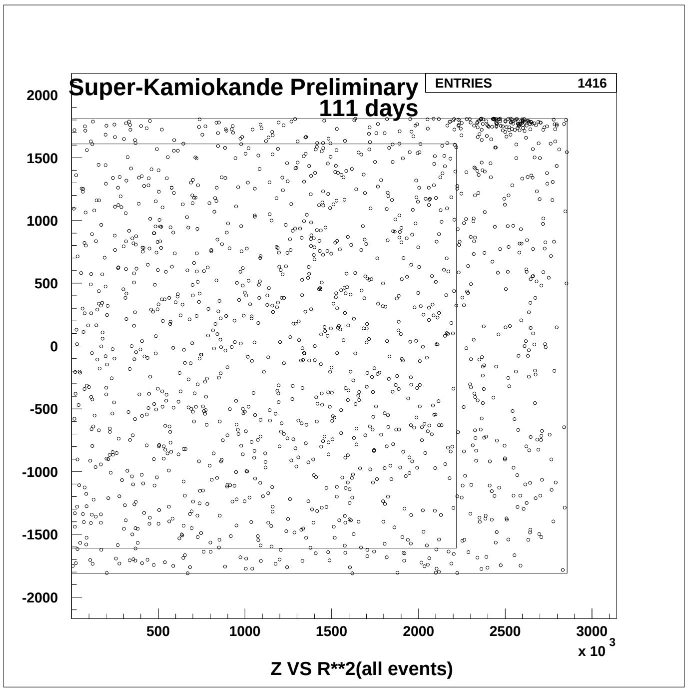

Figure 5: Vertex distribution for the contained event sample

is smaller than the circles used to display them. The initial rise seen in this quantity is expected from the improvements in water transparency. The figure demonstrates that during the time the data used in the analysis stem from the stability of the detector was stable within at least 1%.

2 First Preliminary Results

2.1 Contained Events

As discussed in the previous chapter the detector reached a regime of stable operation at the end of May 1996. Therefore data analysis at this stage is restricted to data taken after this date. 111 days [b] of livetime are currently

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[b] Since the symposium the data set for this analysis has been extended from 68 to 111 days.

being used in the analysis of fully contained events above an energy threshold of 30 MeV. A contained event is required to have no trigger signal from the anticounter attached to it or have < 25 hits in a 800 ns window from the anticounter. In the ID it has to have more than 200 PE in 300 ns. The resulting sample is then cleaned of through going or stopping muons, events caused by flashing phototubes, and events with too few hits in ID (low energy events).

Figure 5 shows a two dimensional projection of the vertex distribution for the contained event sample. Although the vertices are evenly distributed throughout the fiducial volume there is a clearly visible cluster of excess vertices near the edge at the top of the inner detector volume. Above these are the feedthroughs for the massive bundles of cables from the 13 k PMTs in the detector. These cable bundles provide blind spots in the anticounter. The affected areas will soon be covered with scintillators.

The inner box drawn in this figure delimits the fiducial volume. It is chosen to be 2 m from the physical boundaries of the inner detector and contains 22.5 kt of water.

Of the 934 contained events found inside the fiducial volume 606 are found to have a single cherenkov ring associated with them, 162 events have two rings and 166 events have three or more cherenkov rings.

2.2 Solar Neutrino Flux

This preliminary analysis is based on 101.9 live days of low energy data taken between May 31^{st} and October 7^{th} 1996. Event selection criteria for the low energy data stream require the event to be complete [c] and have a time difference to the previous event $\geq .20\,\mu$s, a total charge $\leq$ 1000 photo electron equivalent (PE) and $\leq$ 20 hits over 600 ns in the anticounter. 48 M events enter this preliminary analysis. In the next step event characteristics are checked to eliminate events generated by flashing PMTs or electronic noise. The remaining events undergo vertex fitting. Two reasons exist that this might fail: Too few (< 10) suitable hits are found in the event or the fit does not converge reasonably. A total of 47 M events survive these two steps.

The bulk of these events come from locations very near the walls of the inner detector and/or have very low energies. The same fiducial volume cut as in the analysis of contained events - 2 m from the ID physical boundaries, corresponding to 22.5 kt of water - plus an energy threshold imposed at 7 MeV

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[c] Incomplete events occur when automatic pedestal data taking blocks one eighth of the inner detector electronics channels.

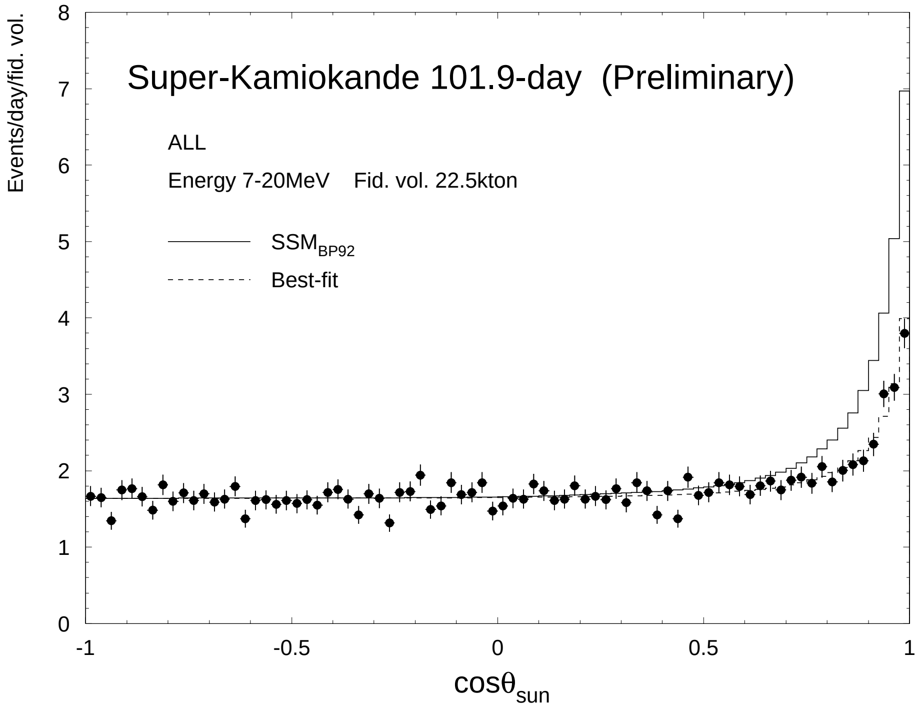

Figure 6: Forward scattering peak from solar neutrino interactions in the Super-Kamiokande detector

reduces this number to the 106124 events that this preliminary solar neutrino analysis is based on.

Given the measures implemented to control the radon concentration in the detector, the major background to the solar neutrino analysis above 7 MeV is radioactive spallation products from through going muons interacting with oxigene nuclei in the detector. Livetimes of these spallation products range from tens of seconds down to milliseconds. Individual events become suspected of being radioactive decays of spallation products by being correlated in time and space with muons passing through the detector. Muons themselves become suspected of creating spallation products by depositing excessive amounts of energy in the detector. Exploiting these correlations a set of cuts is employed to eliminate spallation products from this final event sample. The spallation cut in this preliminary analysis reduces the sample size to 14376 events at the expense of 37.8 % additional deadtime.

The resulting forward scattering peak with respect to the sun is shown in figure 6. The energy range used for this plot extends from 7 to 20 MeV. The fiducial volume contains 22.5 kt of water and the detector livetime is 101.9 days. The measured solar neutrino flux is $(2.51^{+0.14}_{-0.13} \pm 0.18) \times 10^6\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. As usual the errors are given in the order statistical first and systematic second. The systematic error is highly preliminary.

The forward scattering peak from these first 102 days contains a total of 1005 neutrino interactions. Kamiokande III[1] in its sample of 836 days of data in the same energy range plus its 200 days of data in the energy range from 7.5 to 20 MeV observed a total of 390 solar neutrino interactions. The fiducial volume of Kamiokande was 0.68 kt. In its 2079 days of livetime available to the measurement of solar neutrinos Kamiokande II+III observed a total of 597 events in the forward scattering peak. Compared to the 1992 version of the Standard Solar Model of Bahcall and Pinsonneault the Kamiokande III data yielded:

$$\frac{\mathrm{DATA}_{\mathrm{KamIII}}}{\mathrm{SSM}_{\mathrm{BP92}}} = 0.496^{+0.044}_{-0.042} \pm 0.048$$

The preliminary result from Super-Kamiokande translates to:

$$\frac{\mathrm{DATA}_{\mathrm{SK}}}{\mathrm{SSM}_{\mathrm{BP92}}} = 0.441^{+0.024}_{-0.023} \pm 0.032$$

and thus is a confirmation of the old Kamiokande results.

No decisive answer can yet be obtained from the data to the important question of whether or not there is a day/night effect. The data can be divided in 56.3 days of daytime data (sun above the horizon) and 45.6 days of nighttime data (sun below the horizon). The fluxes measured for these subsamples are:

$$\begin{array}{lll} & (2.30^{+0.18}_{-0.17} \pm 0.17) \times 10^6\,\mathrm{cm}^{-2}\mathrm{s}^{-1} & \text{for daytime} \\ \text{and} & (2.75^{+0.21}_{-0.20} \pm 0.20) \times 10^6\,\mathrm{cm}^{-2}\mathrm{s}^{-1} & \text{for nighttime.} \end{array}$$

3 Conclusions

The Super-Kamiokande experiment has started successfully. A first preliminary analysis of 100 days of solar neutrino data reproduces the results of the Kamiokande experiment. We expect to consolidate this current analysis for a formal publication before summer 1997.

The important next step for the Super-Kamiokande solar neutrino analysis will be the lowering of the trigger threshold of the detector. Measures are currently being devised to cope with the trigger rate we will incur by moving towards the envisaged 5 MeV analysis threshold. The pending calibration with electrons from the LINAC will greatly reduce our systematic errors.

The first 8 month of running the Super-Kamiokande experiment have proven that we indeed built a very fine detector. What are the physics issues we want to address with it? In the near future we should see a decisive result on a possible day/night effect in the solar neutrino data from matter enhanced neutrino oscillations in the earth. Within 2 y from lowering the trigger threshold we shall be able pinpoint possible distortions in the low energy end of the ^{8}B solar neutrino spectrum. At about the same time we shall receive the first neutrinos from the KEK neutrino beam for the long baseline experiment. After 3 years of data taking the zenith angle distribution of the μ/e-ratio in atmospheric neutrinos should give us another handle on oscillation parameters. And in 5 years Super-Kamiokande will test SUSY predictions for proton decay.

And all the while we are on the watch for supernova explosions...

Acknowledgments

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References

1. Y. Fukuda et al., *Phys. Rev. Lett.* **77**, 1683 (1996)