FPRINT-98-18

Last updated on 9 May, 1997.

First Results From the Super-Kamiokande Experiment.

AUG 17 1998

Kenneth K. Young,

Department of Physics, University of Washington, Seattle WA

(for the Super-Kamiokande Collaboration.)

Abstract.

Neutrinos are elusive and still mysterious particles. They may have mass and may oscillate from one flavour to another. We have operated a very large 50 Kiloton water Cherenkov detector since April, 1996. The first 102 days of data have been analysed and the preliminary results on solar neutrinos were obtained. Based on the data with visible energies of >7MeV, the ^{8}B neutrino flux was 2.51 (+0.14/-0.13) +/- 0.18 x 10^6 /cm^2/sec. This is consistent with previous measurements which were interpreted to favour neutrino oscillations. The possible mass induced neutrino oscillation could be observed by observing the difference in flux between day and night. With the 102 days of data, the daytime and night time fluxes agree within statistical uncertainties. We are on track to be able to make a definitive determination with two more years of data.

Fermilab Library 0 1160 0064992 5

Introduction.

In 1987, we said GUTs has done some good. Thanks to GUTs, we had two real time proton decay experiments which then became neutrino observatories so that we could observe SN 1987A.

GUTs and proton decay are summarized here.

The unified theory of the electroweak force makes the assumption that neutrinos are masssless. The SM has well known shortcomings . It is one of the dominating themes of experimental particle physics to find experimental evidence for the need of extensions for the Standard Model theory by. Some GUT theories predict proton decay AS WELL as massive neutrinos.

No proton decay signals were observed by the last decade of experiments BUT hints of massive neutrinos were found

In 1996, we launched a purpose built real-time neutrino observatory designed to make definitive measurements on some of the extraordinary anomalies uncovered by the pioneer experiments [the real time experiments and the chemical analysis neutrino experiments]. To paraphrase Newton, we stand on the shoulders of Giants. Perhaps, we can pay back GUTS and also observe proton decay at even longer lifetimes than were predicted by GUTS originally.

The common wisdom is that the sun is powered by nuclear fusion. Since we know the surface energy flux, we can predict the flux of neutrinos that are produced. Every neutrino experiment found significantly lower neutrino fluxes than predicted by the SSM. This is the solar neutrino anomaly. However, we do have direct evidence that the sun does indeed produce ~MeV neutrinos. This is direct evidence that nuclear processes are involved. SuperK measurements are completely consistent with the old experiments.

In the original pioneer experiments, the atmospheric neutrinos [neutrinos produced in the cascades of hadronic interactions in the atmosphere initiated by cosmic protons] were a bothersome background to the proton decay experiments. Since the hadronic cascade and decay chain of pions and muons are well known, we have a nicely calibrated beam of electrons and muon neutrinos [calibrated to each other]. The observed flux of muon neutrinos to electron neutrinos should be the ratios of the produced neutrinos. They are not. This is the atmospheric neutrino anomaly.

Both of the observed anomalies are statistically significant but there have been many questions raised about the systematic uncertainties. These have been investigated thoroughly and the anomalies still stand.

Since one can invent theories faster than one can improve the measurements, we have many theoretical speculations to consider. For the solar neutrino anomaly, is it astrophysics problem? or are we seeing new unexpected behaviour of neutrinos. For the atmospheric neutrino anomaly, are we seeing misunderstood nuclear effects or are we seeing new and unexpected behaviour of neutrinos.

The common thread is the neutrino behaviour. The SM assumes that neutrinos are massless and stable. Direct measurements of neutrino mass have limits which give much latitude. A favoured interpretation that is consistent with all known experiments is that neutrinos are NOT stable. Recall, we have three flavours of neutrinos [electron, muon and tau] plus their anti particles. If the mass eigenstates of neutrinos are different from these flavours, then the neutrinos can oscillate between one flavour and another and back again. [We have seen this before with neutral K mesons.... a triumph of simple quantum mechanics.]

Vacuum Neutrino Oscillation.

To help yourselves think about this, think about three eigenstates of neutrinos propagating through a vacuum. If the masses are different, the three states have different wavelengths. This means that particular mix of the three states forming one flavour state [eg nu-e] would become a different mixture as a function of time and distance... as the three waves will have different phase. [Think of the beats of two acoustical tones which differ slightly in frequency.

The frequency of oscillation in proper time is proportional to the mass difference of the neutrino flavours. As expressed in the lab, the oscillation behaviour is manifested as:

$$P = \sin^2 (1.27\ \Delta m^2\ L/E)$$

where L is the distance that the neutrino has travelled and E is the neutrino energy. [L in meters and E in MeV andΔm^2 is in eV^2] In general there are three distinct mass differences.

Mass Induced Neutrino Oscillation.

The mass of the eigen states governing the propagation of neutrinos in matter depends on the density of electrons and on the neutrino flavour. Electron neutrinos interact six time more strongly through Z and W exchange with the electrons while muon and tau neutrinos interact only through Z exchanges. If there exists neutrino mixing it will be going through a resonance at a critical electron density which the neutrinos traverse on their way from the ore to the sun's surface. At resonance, there may then occur jumps between mass eigen states. This mechanism may explain the observed suppression ofν from

^{7}Be.

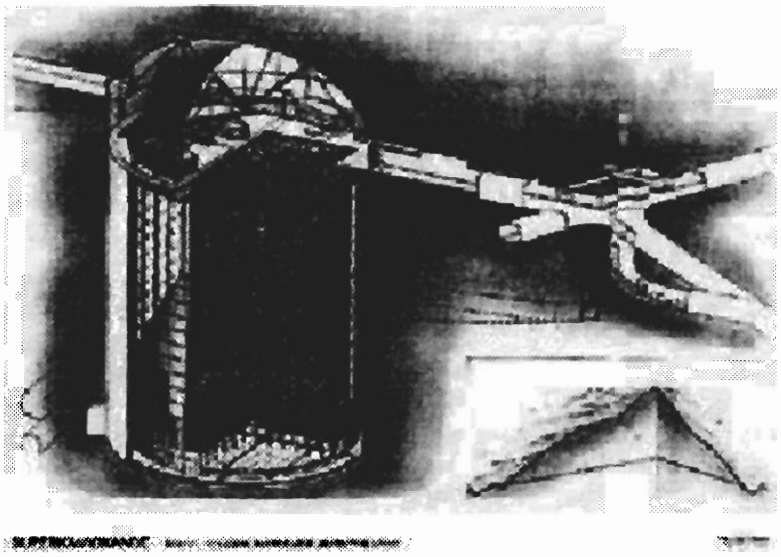
Implications of Neutrino Oscillation.

If we show a convincing mass difference, neutrinos have mass. The massive neutrinos could be part of the omnipresent DARK MATTER [which is another great discovery of the last decades] The composition of the DM is still unknown but the existence of massive neutrinos would help tighten the boundaries of the large numbers of theories of dark matter.

A CONVINCING measurement of neutrino oscillation might include the flavour change for at least one complete cycle with impeccable statistics as well as in systematic uncertainties. In S-K, the fiducial volume is 30X bigger than the fiducial volume in Kamiokande. We have a measured sample of 30 solar ν per day. We have L/E varying over 5orders of magnitude for the atmospheric neutrinos. It varies by 5% for the solar neutrino case. We will have extraordinary calibration to make the best of the situation as well as the possibility of mass induced neutrino oscillation when the sun sets below the horizon and especially below the earth's core. We expect that the measurements of 2 years duration will provide convincing evidence for or against neutrino oscillations for both the solar and atmospheric neutrino cases.

For the rest of this talk, I'll show you something of the observatory, the measurements so far and what we hope to achieve in

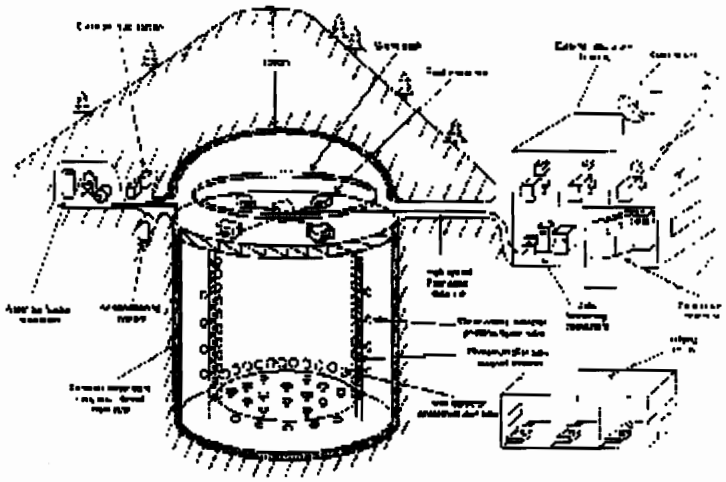
another year of running.



A cut-away view of the S-K detector.

The Super-Kamiokande Detector

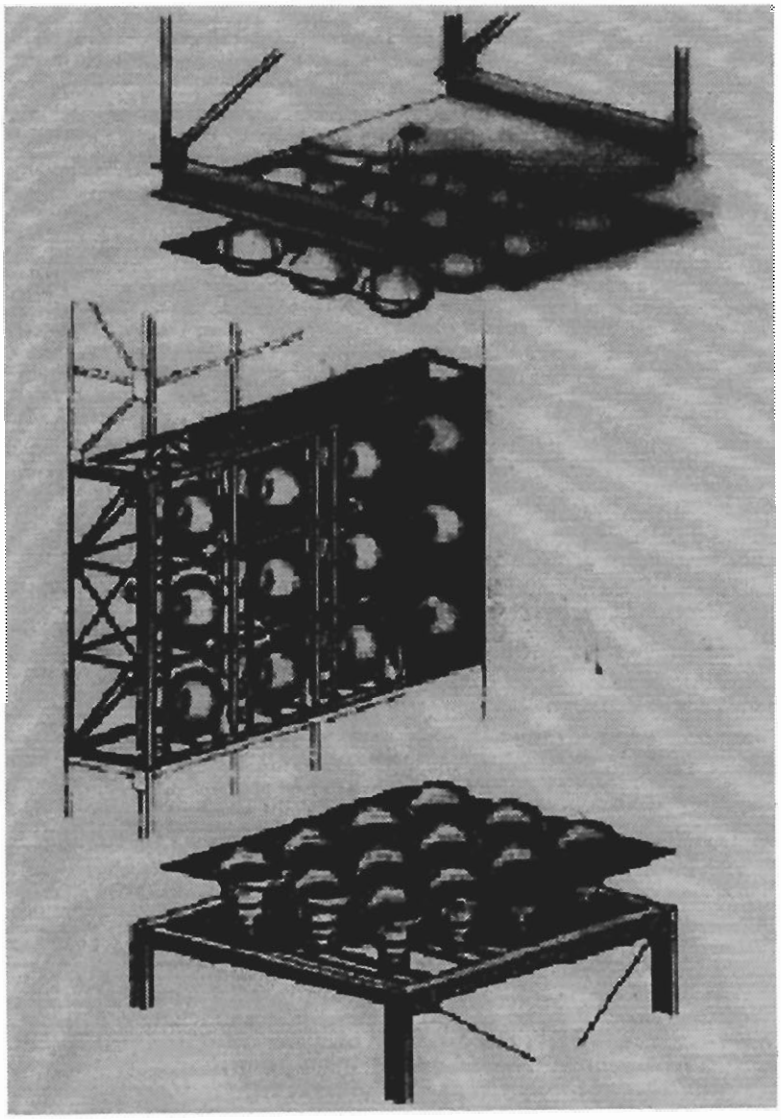
The SK observatory is a 50 KT water imaging cherenkov detector located at the Kamioka-Mozumi mine in Japan. The detector is a real-time detector with the ability to locate the direction of the source with a resolution of up to 1 degree for straight through muons and a resolution of 28 degrees for 10 MeV neutrinos. Thus, we will be able to measure the time-space-energy characteristics of neutrino sources to obtain the physics and astrophysics signatures of the sources.



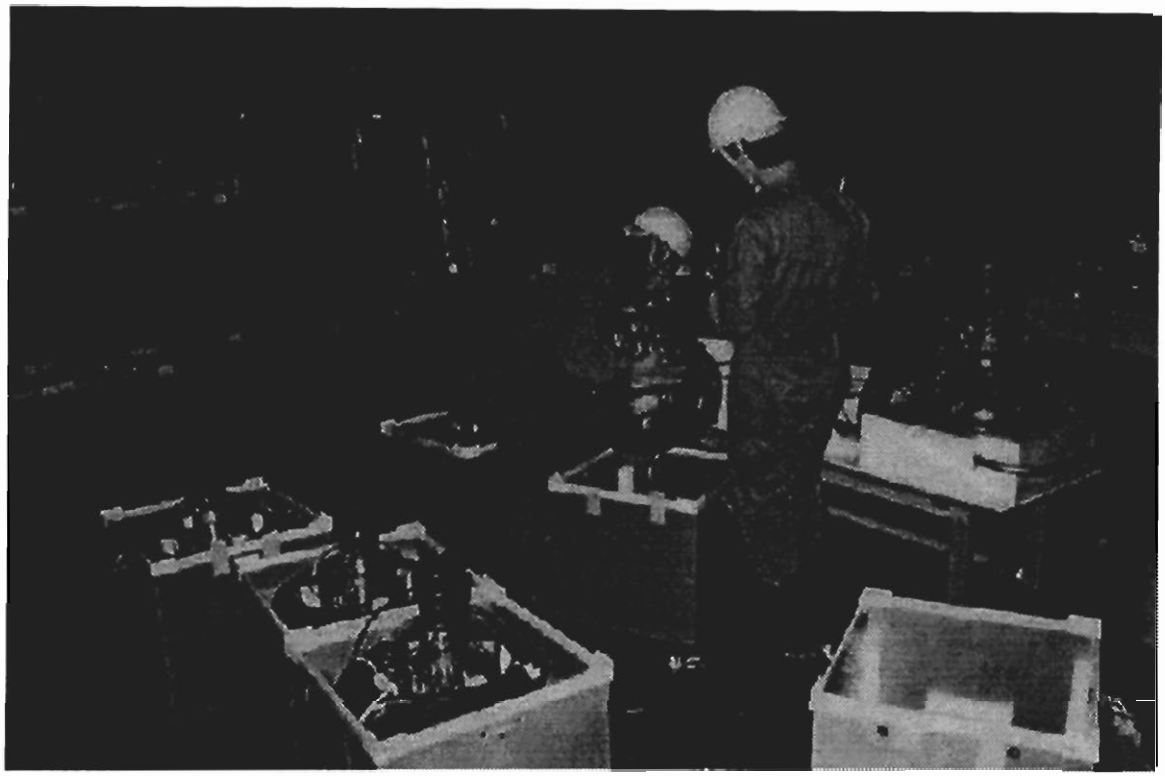
The inner detector (ID) is shielded underground by 2800 mwe and by a 4π instrumented, 2.5 m water shield, the outer detector (OD). The ID is viewed by 11,200 50 cm diameter PMTs which cover 40% of the wall area . The OD is viewed by 1890 20 cm diameter PMTs supplemented by wave length shifter plates and reflecting walls. Figure 6 shows the isometric view of the detector. The DAQ has been implemented with custom modules to have no deadtime in the ID. The OD has a DAQ system with commercial modules. The ID DAQ is capable of recording the charge of the PMT and the time of arrival to 1 nanosec and of recording double pulses separated by 1 microsec. The OD DAQ is capapable of recording the charge, the time of arrival to .5 nanosec and of multiple pulses separated by 20 nsec.

The characteristics of SK are compared with KIII and IMB in table 1.

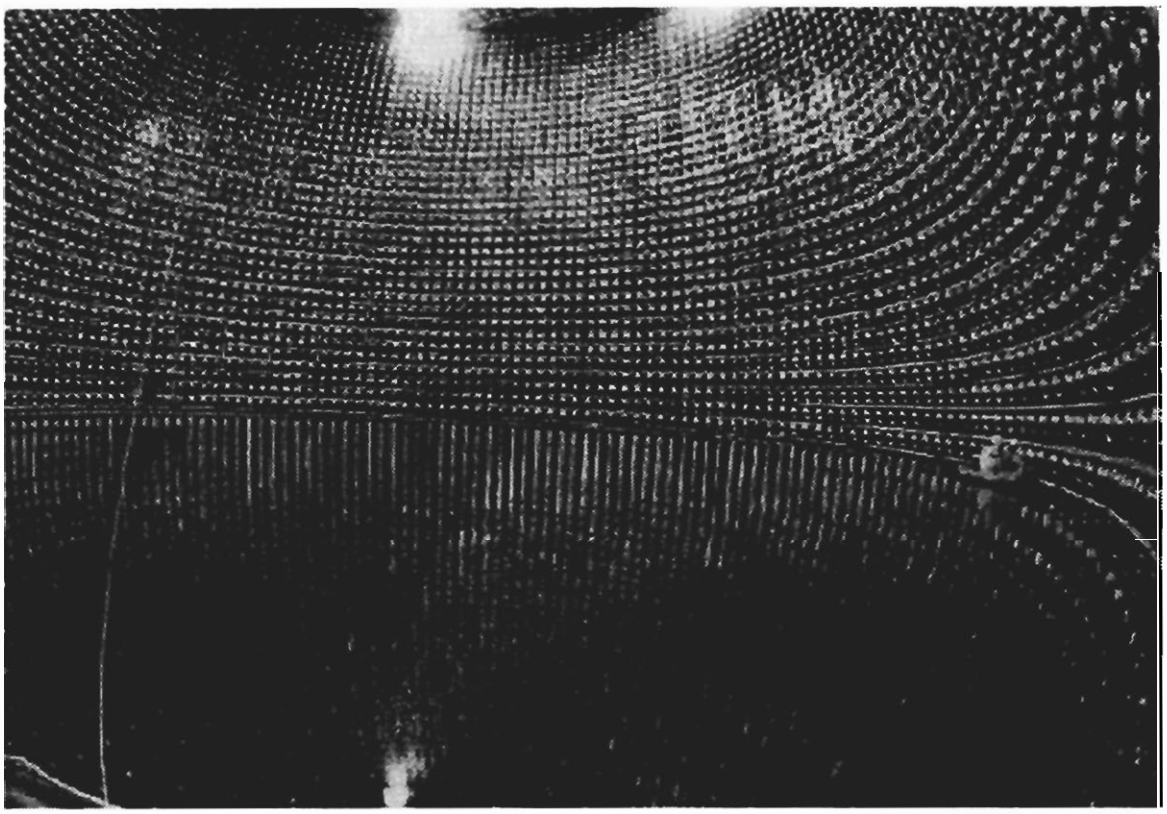
Especially notable are: a) the fiducial volume for solar neutrinos is increased by a factor of 32 over Kamiokande III , b) the energy threshold for analysis will be decreased to 5 MeV from 7.5 MeV and c) the spatial reconstruction resolution will be enhanced by factors of 1.5 to 2. The latter enhancement results from the upgraded PMT technology and PMT coverage. The OD



The method of making the walls between the Inner and Outer Detectors; and the method of mounting the PMTs.



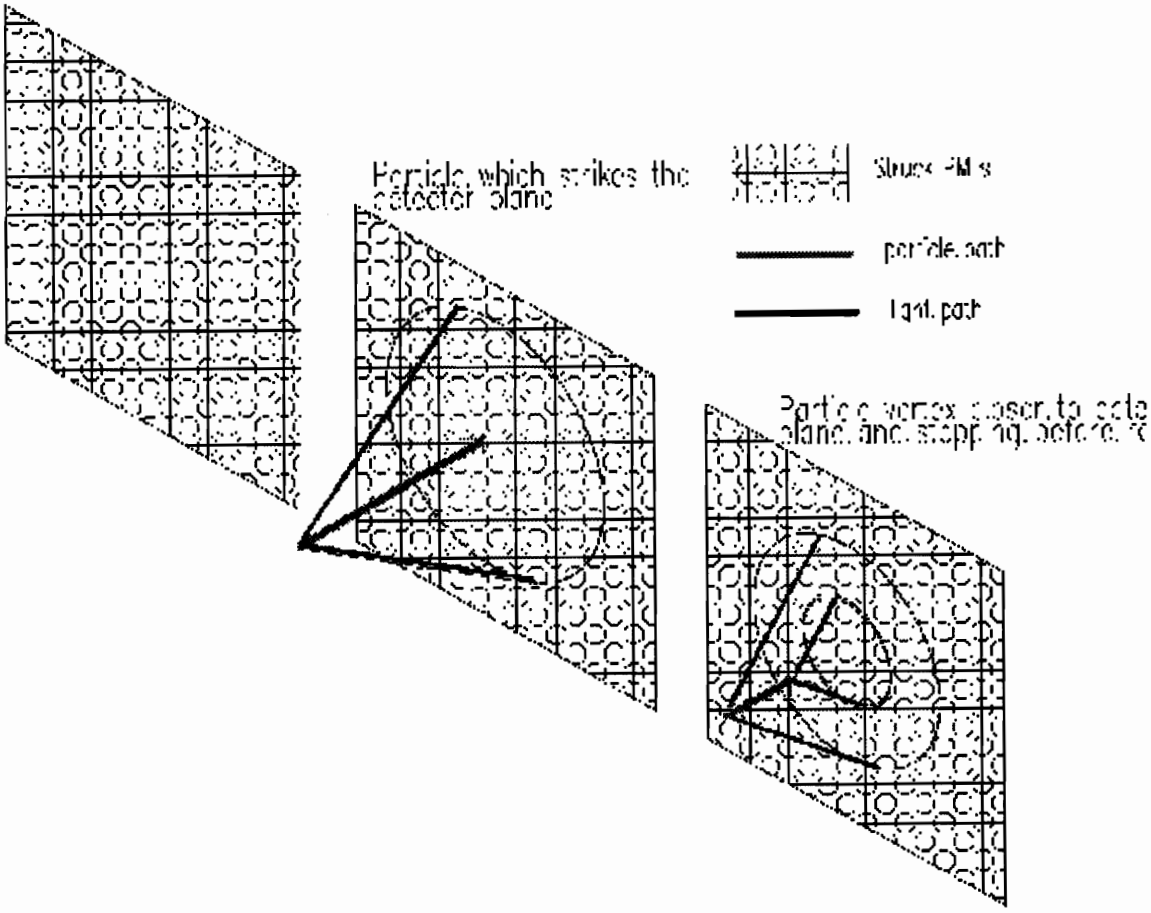
The cathedral-like view of Super-Kamiokande while under construction. This is a view from the floor of the tank with one segment of the wall already constructed. The prepared PMTs are laid out on the floor for construction into modules.



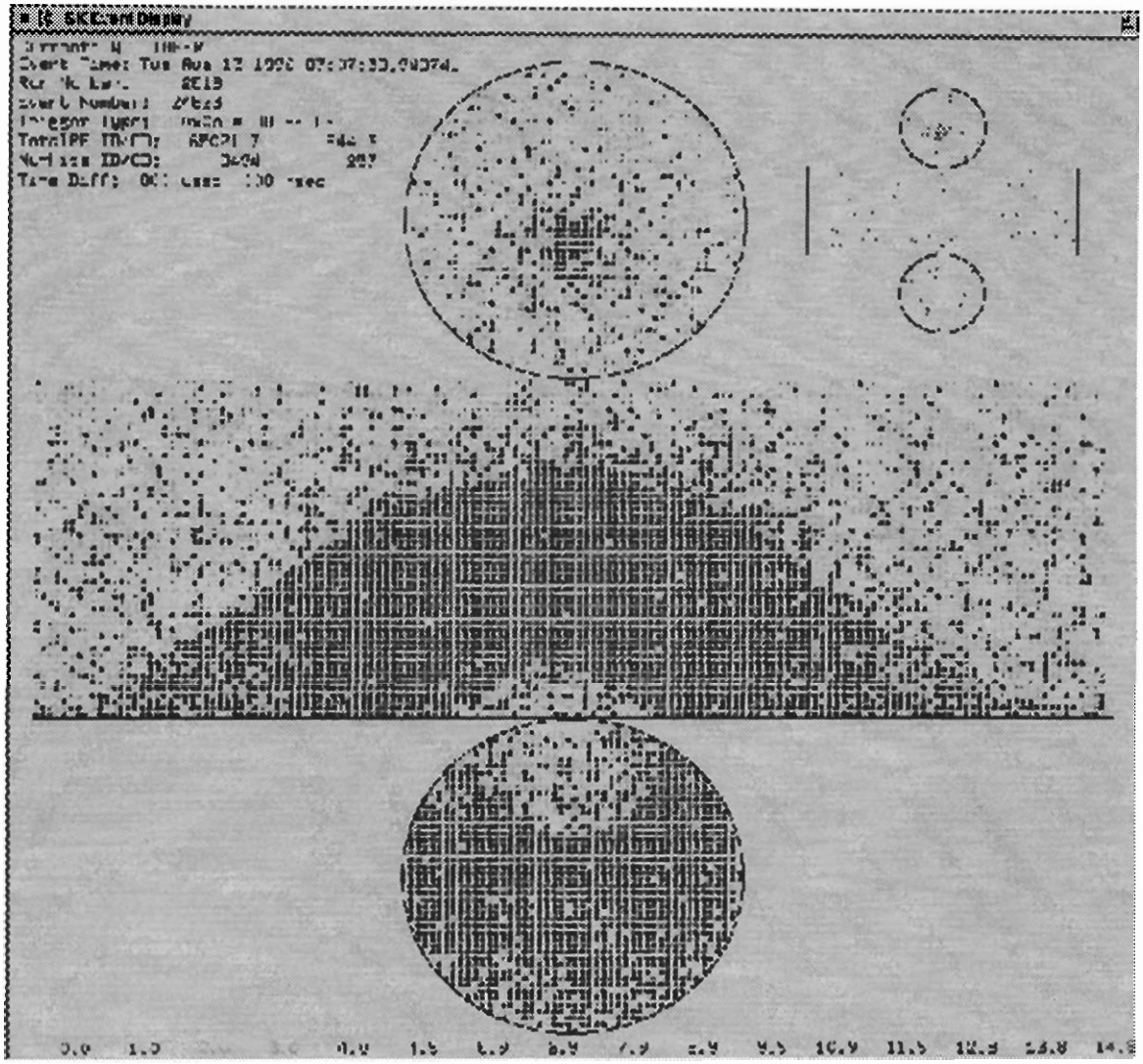
The Super-Kamiokande inner detector with the super clean water partially filling the tank. A boat crew is making some last

minute adjustments to the PMTs.

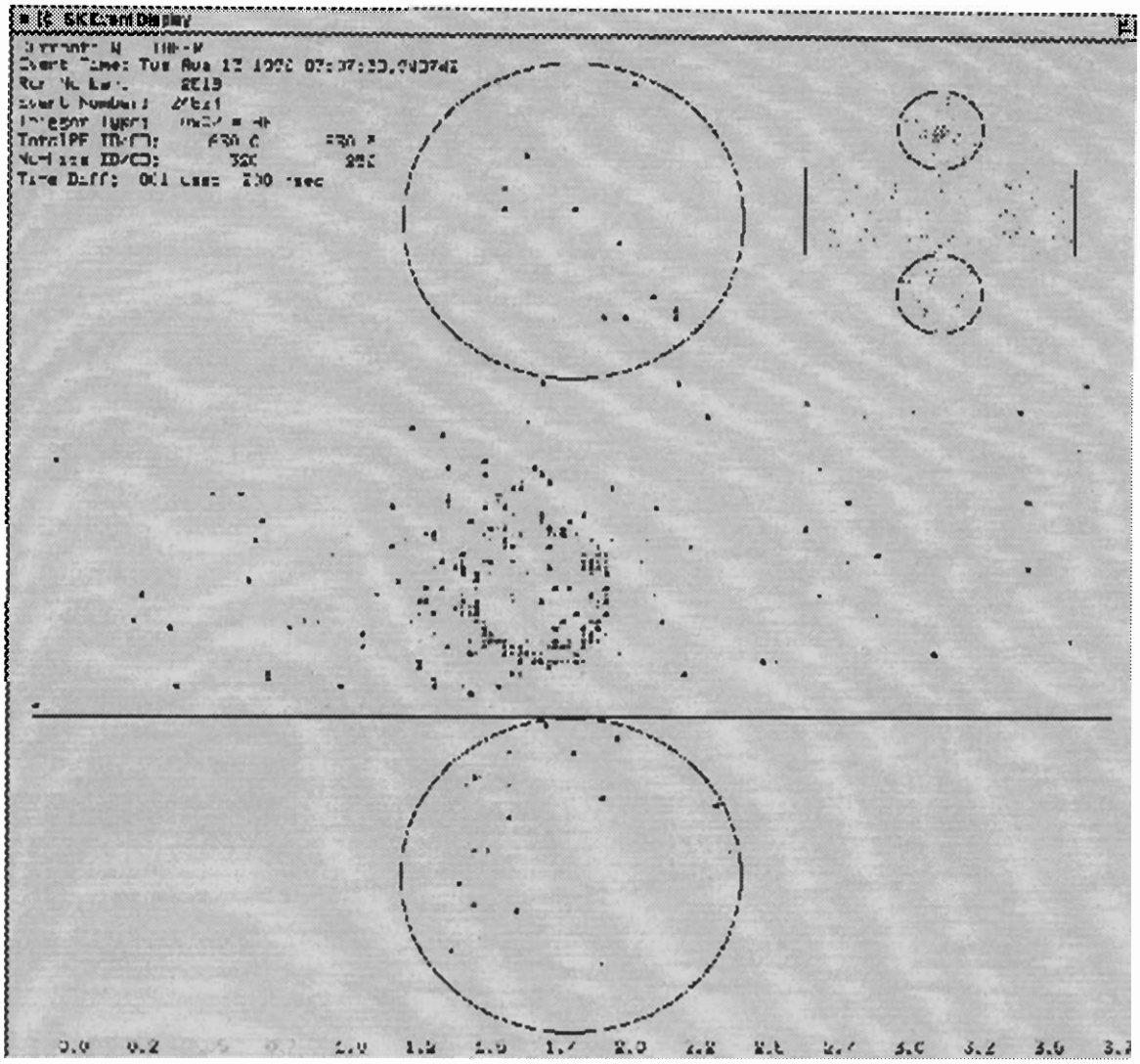
The signal.



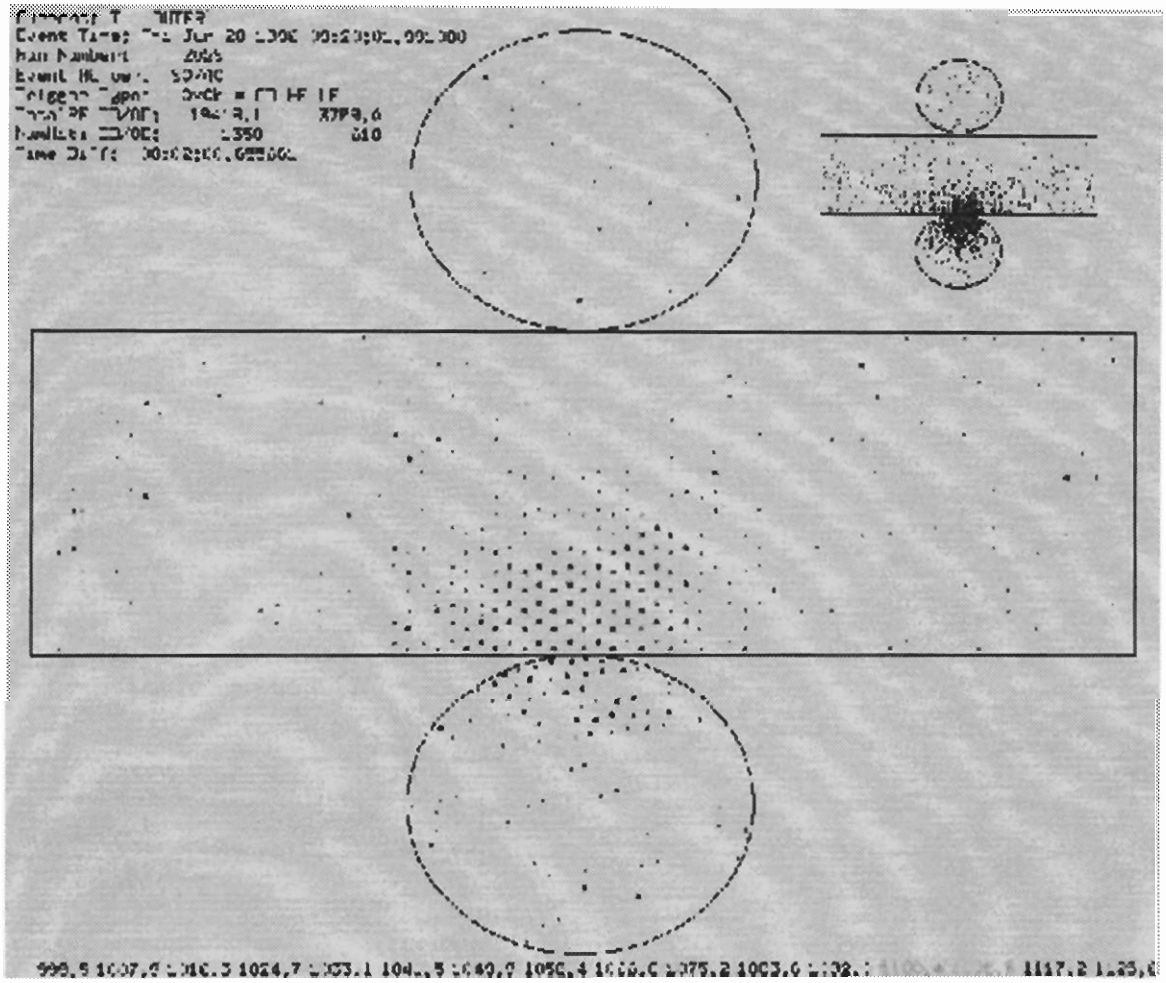
The pictures of events.



This us an even display of a downward going muon which penetrates the top of the detector and then stops about ¾ way down. The image on the cylinder has been unfolded so that the cylinder walls are unrolled and the top and bottom are opened up and down. The outer detector display is on the upper right showing the penetrating muon's entrance signal but no exit signal.



This is an event display of the decay electron from the muon in the previous picture. Notice that the image edges are blurred because the electron scatters and showers thereby producing light from many off-axial cherenkov cones. This is a fully contained electron event with no signals in the outer detector which are in-time with the electron signal.

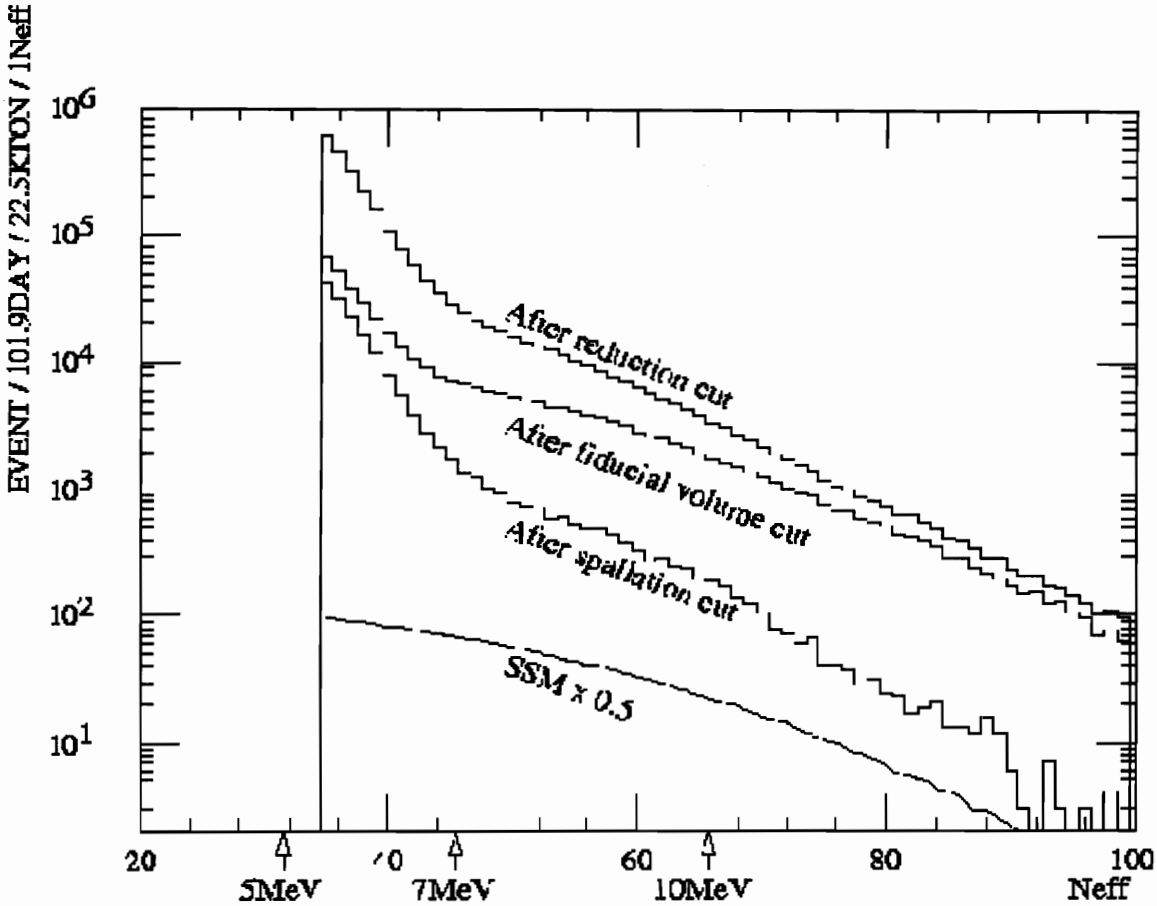


An event display of a neutrino scattering in the detector with the charged secondary escaping from the tank and penetrating the outer detector. The outer detector is displayed with the large image. The upper right hand corner displays the image of the inner detector.

Obstacles to Getting a Good Clear signal and What We've done about it.

The Major backgrounds

The chief low energy backgrounds in the Kamiokande III[6] experiment are from radioactivity of isotopes resulting from the decay of radon and the β decays of isotopes produced in spallation events caused by through-going μ's. In SK, we are improving the technology of the present KIII to exclude radon from entering the detector volume by airborne and waterborne radon. This is done by introducing low radon air to the volume above the detector tank, better sealing of the tank and by improved processing of the water entering and circulating in the tank. The γ from radioactivity in the rocks surrounding the detector will be shielded by a thicker anti-shield OD and will have a decreased surface/volume by virtue of the larger volume. We are achieveing a decrease in radon induced background by a factor of 20 compared to the circa 1992 Kamiokande III backgrounds. The background from spallating muons will be removed using the event by event process of vetoing on the cylindrical volume [several meters in diameter] encompassing the passage of a spallating muon for an appropriate time [seconds] after the passage of the muon.



The calibration.

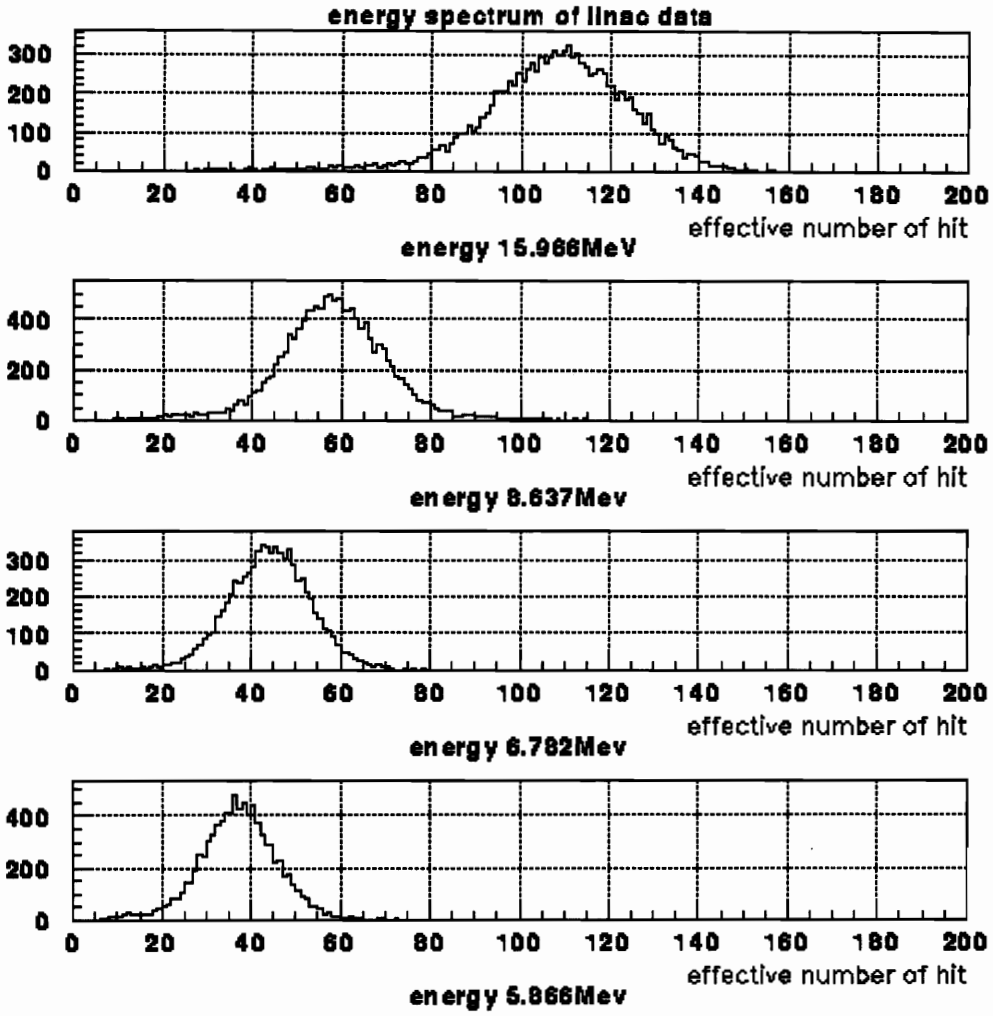
We have installed a wide range of calibration instruments to assure that we will can reconstruct the energy and direction of the particles over the entire volume of the detector. We also use penetrating muons [whose fluxes and properties are well-known] to determine the calibration. The array of calibration instruments include an electron accelerator, radioactive sources, UV-laser light pulses . These all deliver signals to a matrix of positions within the detector.

The energy calibration of SK, so important in measuring the distortions in the spectrum of the solar neutrinos, will be accomplished to the necessary 1% level by the use of two methods. One is monenergeticγ and e sources. The γ sources will be neutron activated isotopes which range from 6.7 to 11.5 MeV.

The second, new method is the use of a calibrated electron beam. We have installed an electron linear accelerator [LINAC] system that can deliver monoenergetic e's into the detector volume at a matrix of positions.. Thus, we will produce a map for position and energy to produce a calibration suitable for measuring the energy spectrum of solar neutrinos. The use of this instrument obviates the uncertainties of the electron vertex and finite width energy spectrum coming from using theγ sources The LINAC delivers a 1 Hz beam of electrons through a vacuum transport system into the tank. We use a trigger scintillator at the exit window of the beam pipe to signal the arrival of an electron.

The PMT gains were set to 10^7 and their variations measured to 7% by means of a Xe lamp system. The timing resolution is typically 2.9ns r.m.s at the one photoelectron level.

The efficacy of our efforts to calibrate and to model the energy behaviour of the detector are shown below. These are the measured energy spectrum of the linac beam at various energies.

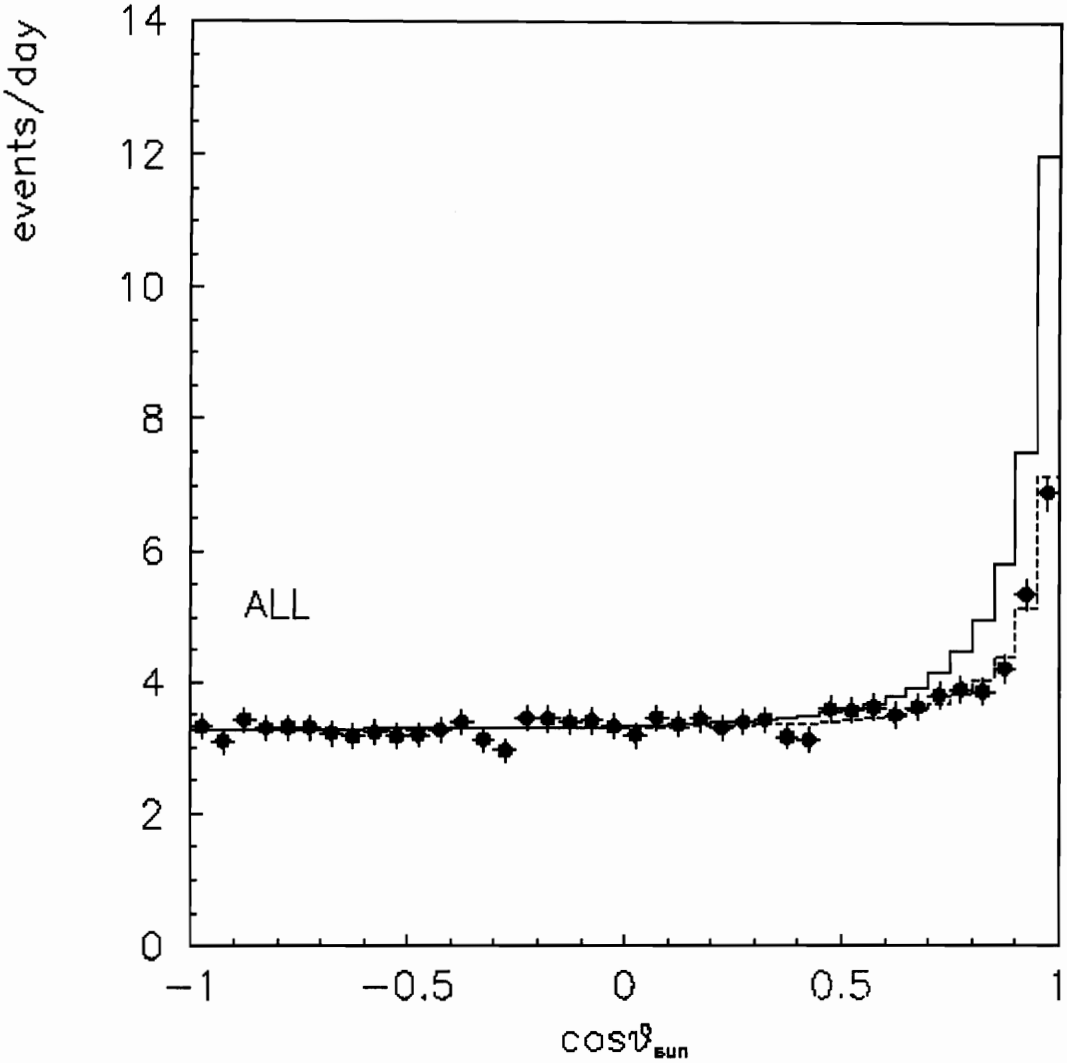


The test results were found to agree with the Monte Carlo simulations within an accuracy of 1% in energy and the beam position and direction were in accord with our MC expectations. The trigger system for the experiment was confirmed to have a sharp threshold.

Measured fluxes.

Solar Neutrino fluxes.

The solar neutrino signal is best displayed in the figure showing the neutrino flux as a function of the angle of the detected electron relative to the sun's direction [ν's from the sun have cosθ=1.] The background should be approximately random so would be flat in this figure while the solar neutrinos will be peaked in the sun's direction. The width of the peak is determined by the variation of the electron's direction relative to the neutrino direction and partly by the instrumental resolution. Our fits of the data agree with the expected shape but has a significantly lower flux than the flux predicted in the SSM.



Cosθ sun distribution for Evis > 7 MeV after fiducial-volume and spallation cuts. Excess events near the forward direction are signals produced by solar neutrinos. Data correspond to 101.9 days of live-time.

The solar neutrino flux has been measured for the day and night [when the neutrinos must pass through , at least, part of the earth. If the neutrinos have their flavour changed by passing through matter, the effects could be seen here. For the large neutrino coupling hypothesis, it is expected that the nigh time flux would be enhanced. The flux enhancement would be especially pronounced as the sun set below the earth's core. At this time, the data is consistent with no day-night effect.

Based on the data with Evis > 7 MeV, the ^{8}B neutrino flux is 2.51 +0.14/-0.13 +/- 0.18 x 10^6 /cm^2/sec. The systematic error will soon be reduced significantly thanks to the precise LINAC calibration. This result is quite consistent with what Kamiokande obtained in over 2,000 days of live-time.

These results can be compared with the 1992 version of the Standard Solar Model of Bahcall and Pinsonneault.

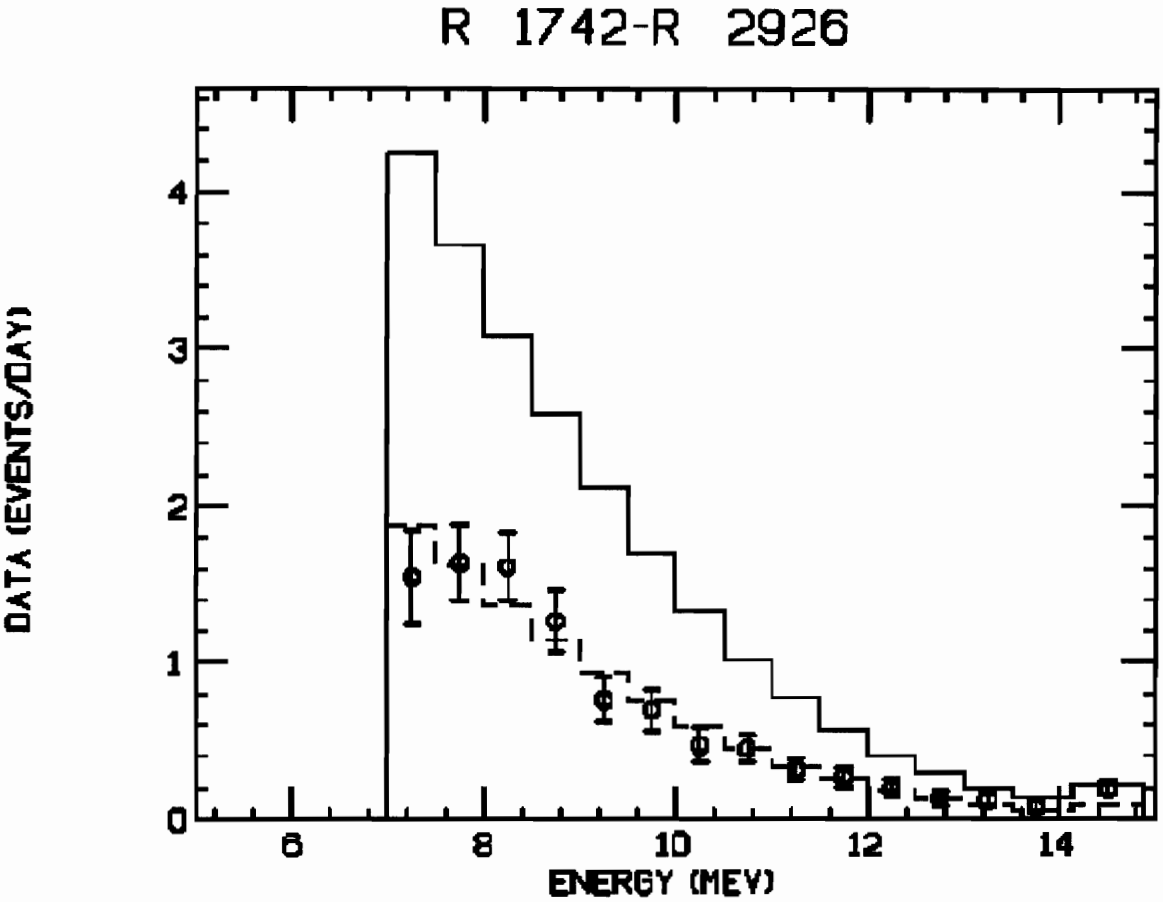
Data/SSM = 0.441 +0.024/-0.023 +/- 0.032

This is consistent with the Kamiokande II result :

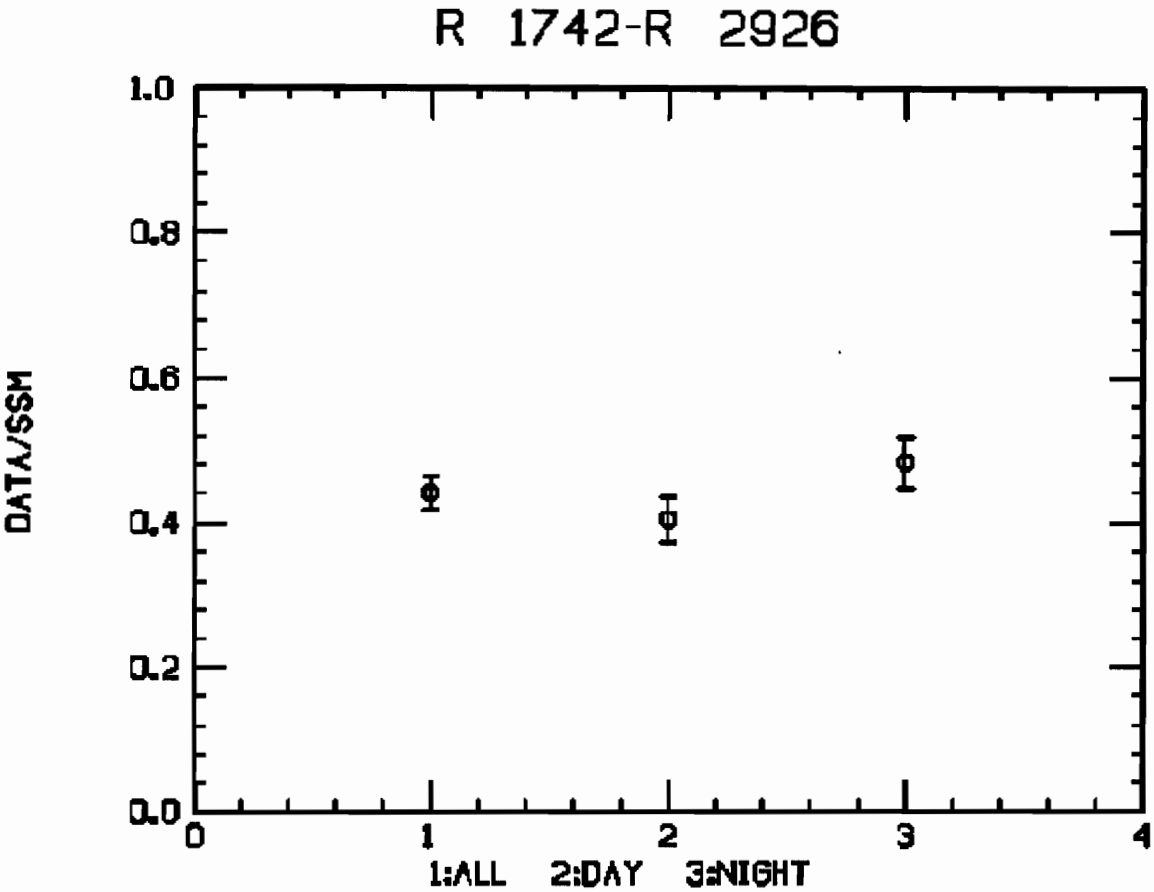
Data/SSM = 0.496 +0.044/-0.042 +/- 0.048

However the absolute flux value is not a main issue any more. What is important is to find the true mechanism that causes the solar-neutrino anomaly. Super-Kamiokande intends to measure the precise shape of the^{8}B neutrino spectrum independent of the absolute flux value. The following figure shows the energy spectrum of the solar neutrinos along with the expected SSM spectrum. The shape itself agrees with the expected spectrum within statistical uncertainties. Unfortunately the current statistics is not large enough to find a faint spectral distortion

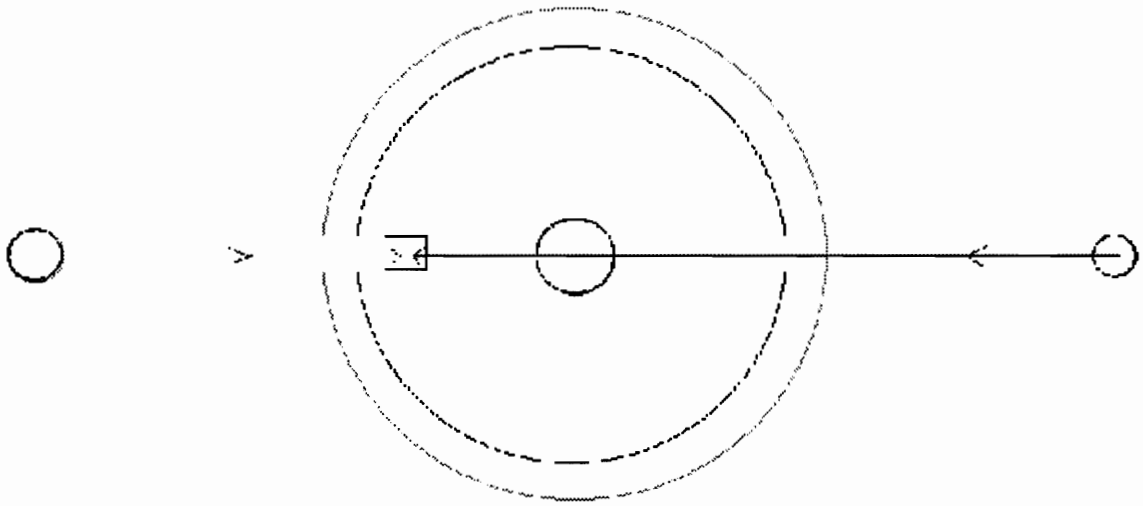
predicted by the small-angle solution of the MSW mechanism, which is thought to be one of the best candidate solutions to the solar-neutrino anomaly.



Evis distribution of solar-neutrino events. The solid histogram is the prediction from the Bahcall-Pinsonneault's theory, while the dashed one is the best fit with a scale factor of 0.441 to the theoretical prediction.

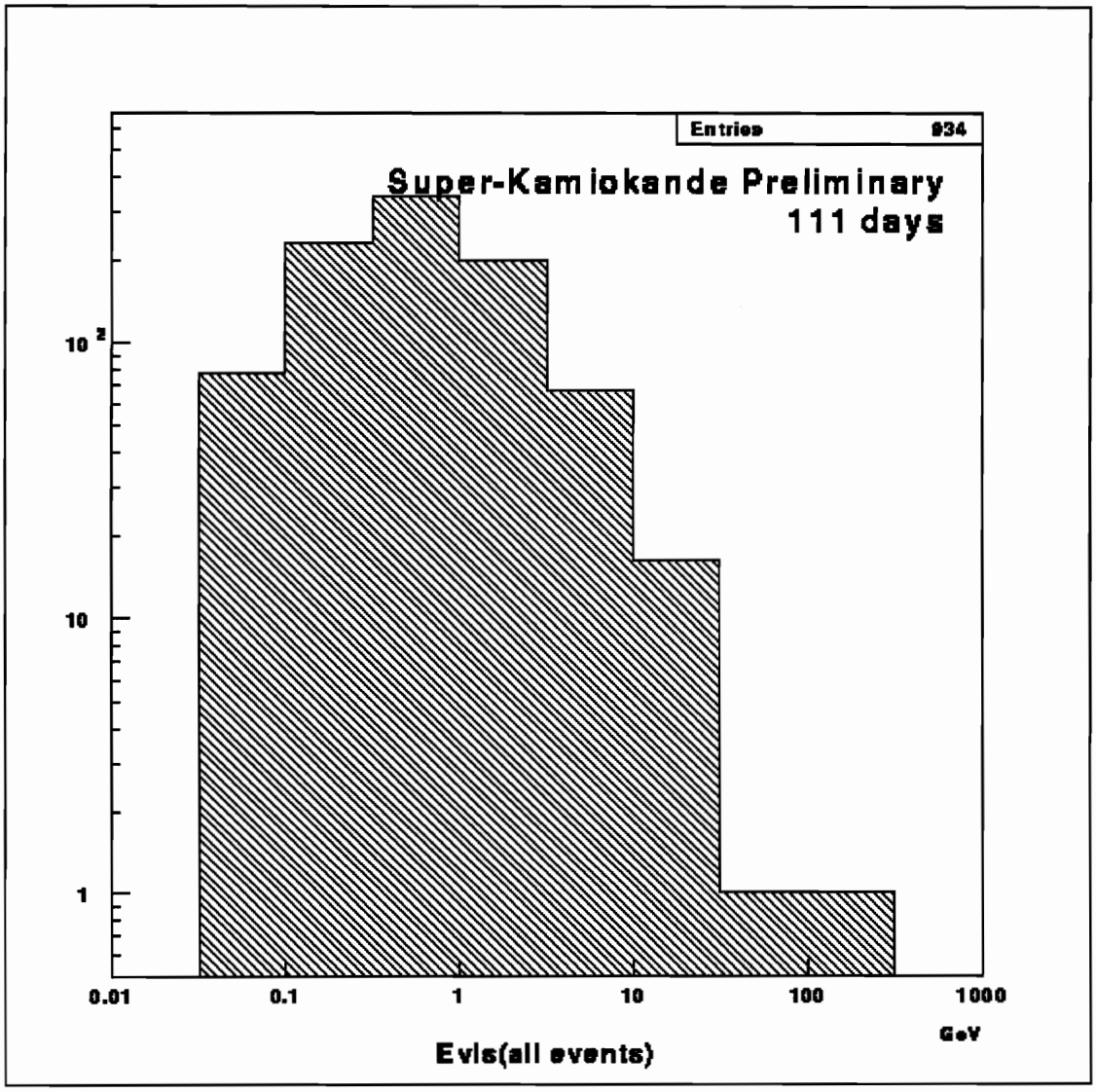


The large angle solution of the MSW mechanism predicts a small effect of raising the nightime flux due to the regeneration of the ν as they pass the earth's core. The measured fluxes for day and night are 2.30 +0.18/-0.17 +/-0.17 x 10^6 and 2.76+0.21/-0.20 +/-0.20 x 10^6 /cm^2/s respectively. There is no difference between these fluxes within the statistical uncertainties.

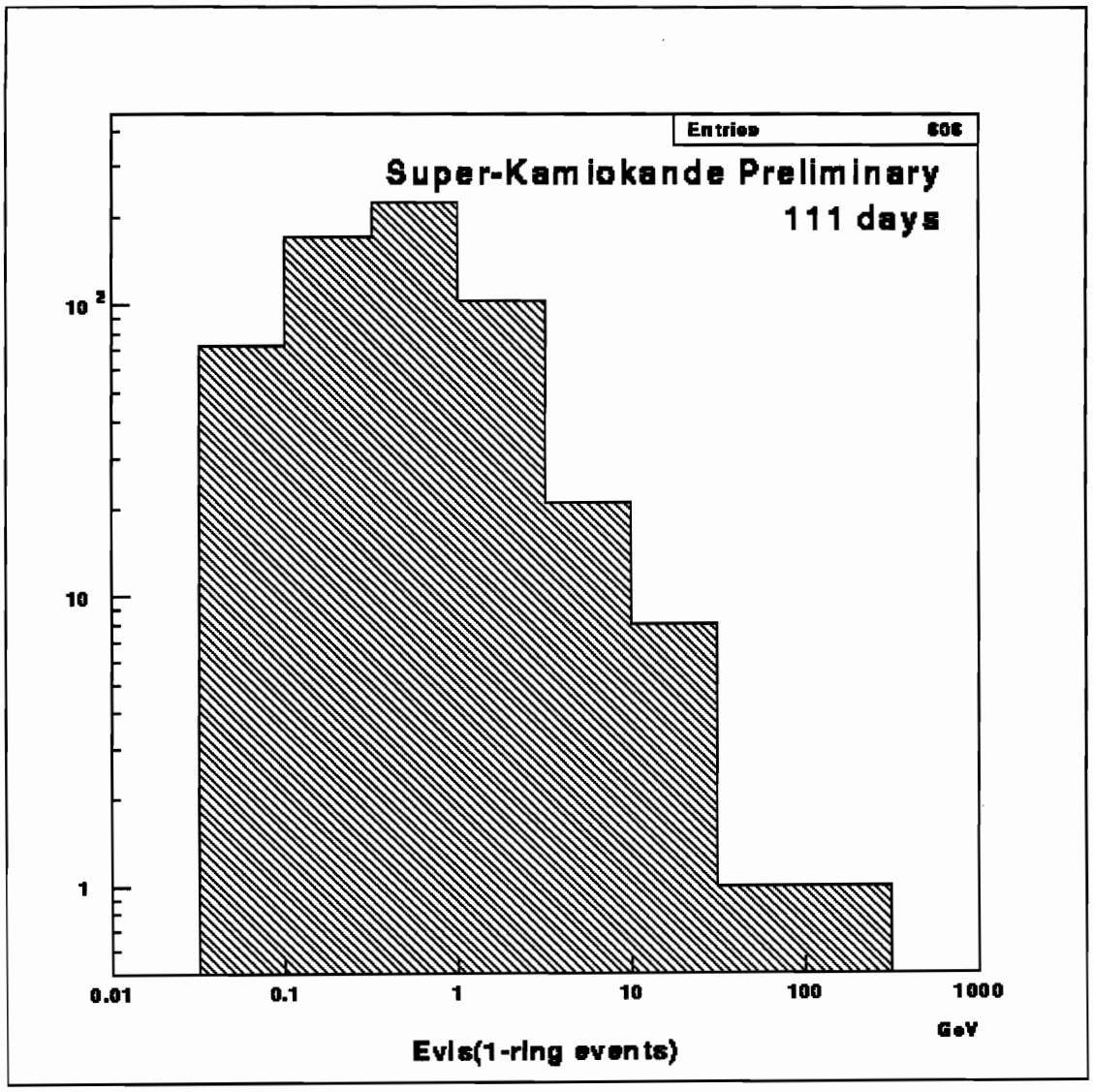


Atmospheric Neutrinos

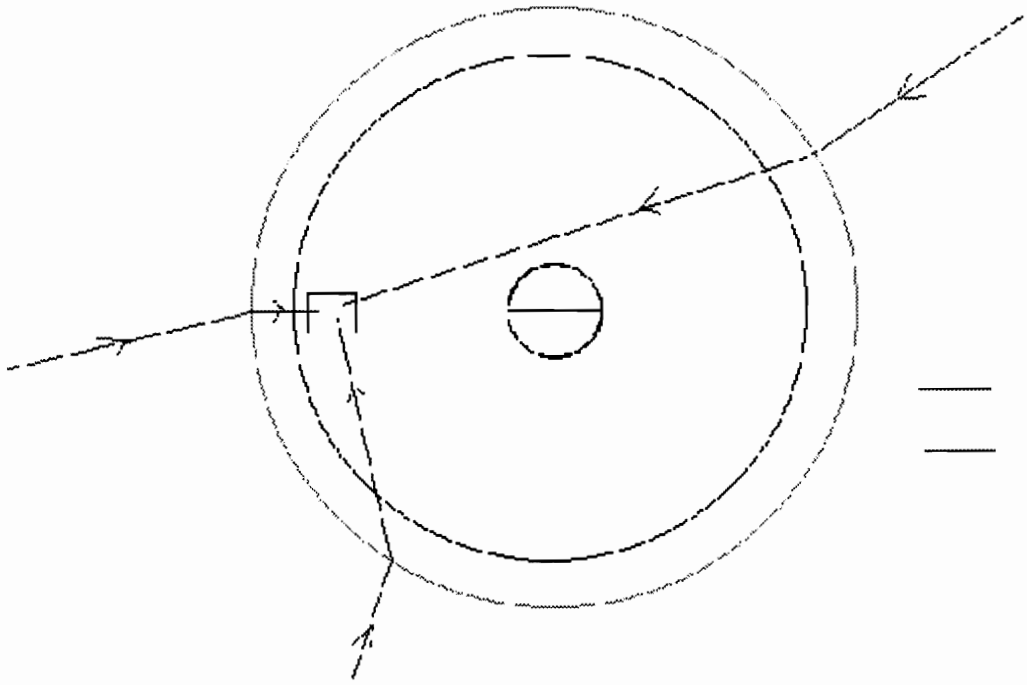
For Fully Contained events., E < 1.33 GeV and for 2.24 K-Ton-year of data, we obtained 257 events. This gives us a raw rate of 0.31 +/- .02 event/Kton/year. This raw rate is consistent with the Kamiokande III raw rate within the estimated uncertainties. We now have much more data analyzed and are using the greater statistics to evaluate the systematic uncertainties in our measurement.



Distribution in visible energy of all higher energy events.



Energy distribution of events with a single charged particle in the final state.



Atmospheric Neutrinos

$p(He) + Air \rightarrow \pi^{\pm}, K^{\pm} + X$

$\hookrightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu})$

$\hookrightarrow e^{\pm} + \nu_e(\nu_e) + \bar{\nu}_{\mu}(\nu_{\mu})$

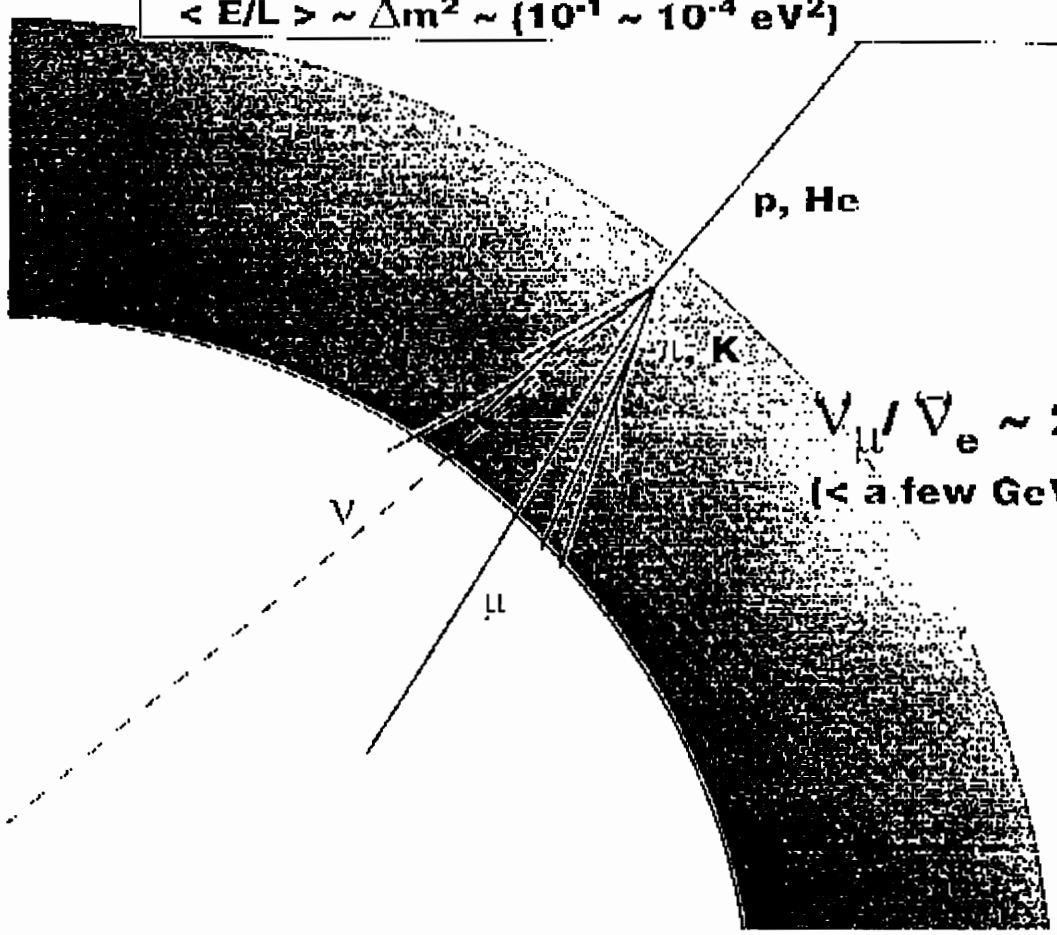
$< E_{\nu} > \sim$ 1 GeV (fully contained : sub-GeV)

$\sim$ 10 GeV (mult-GeV)

$\sim$ 100 GeV (upward going muons)

$< L > \sim$ 10km $\sim$ 13,000 km

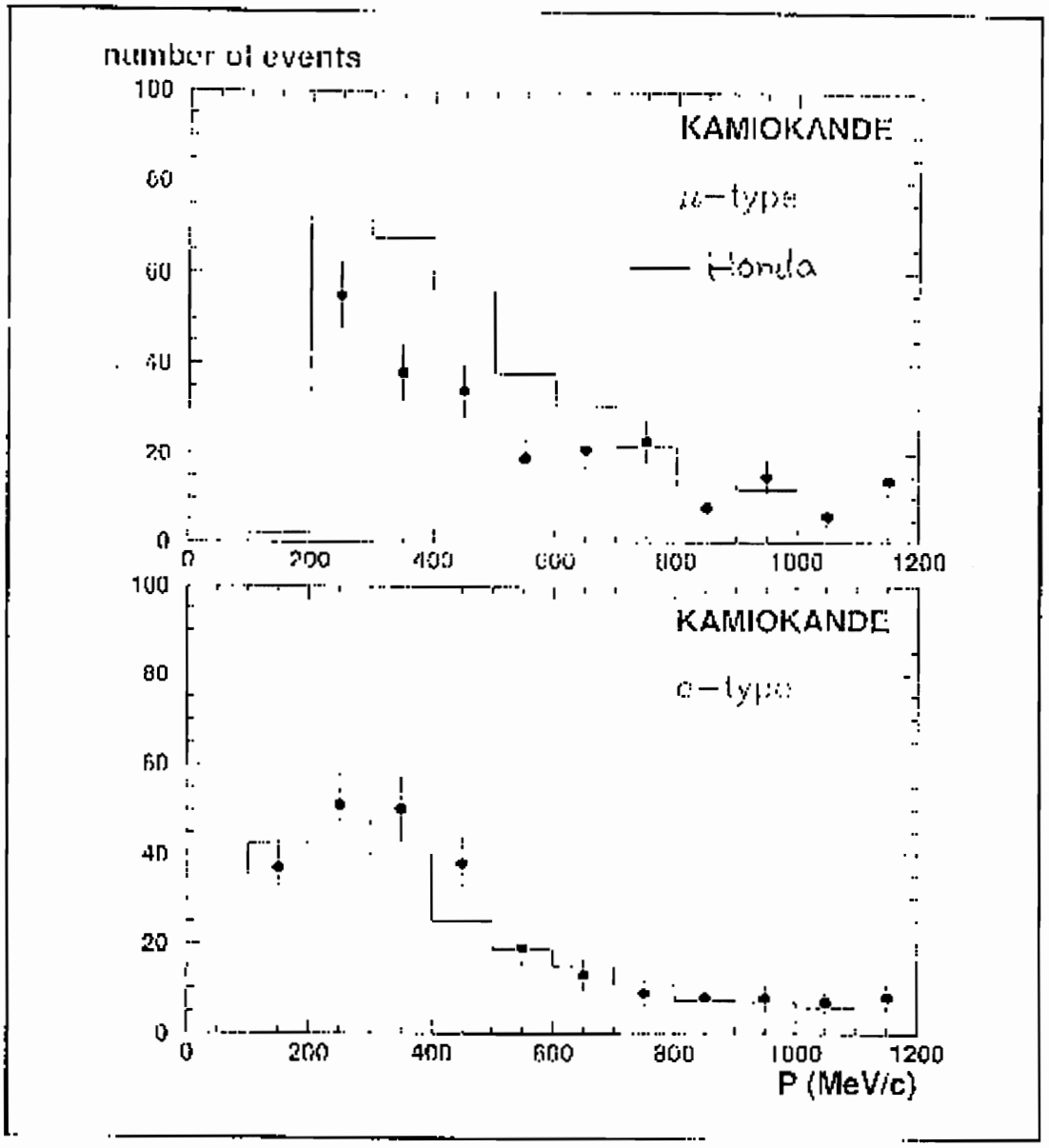
$< E/L > \sim \Delta m^2 \sim (10^{-1} \sim 10^{-4}\ eV^2)$



$\nu_{\mu} / \nu_e \sim 2$

(< a few GeV)

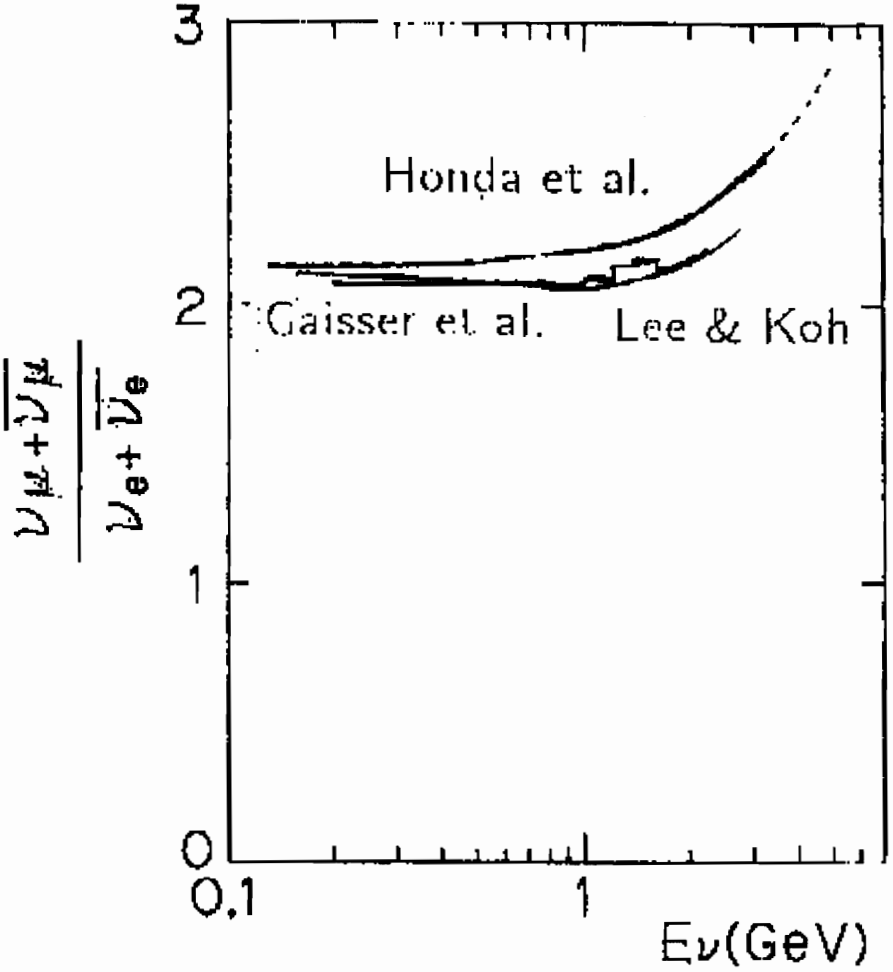
Atmospheric neutrino problem



--- looks like "μ-deficits"

--- but "μ-dificits" or "e-excess"

--- flux uncertainty (~20~30%)


3
2
1
0
0.1
1
Honda et al.
Gaisser et al.
Lee & Koh
$\frac{\nu_\mu+\bar{\nu}_\mu}{\nu_e+\bar{\nu}_e}$
Eν(GeV)

Summary of the Atmospheric Neutrino Data

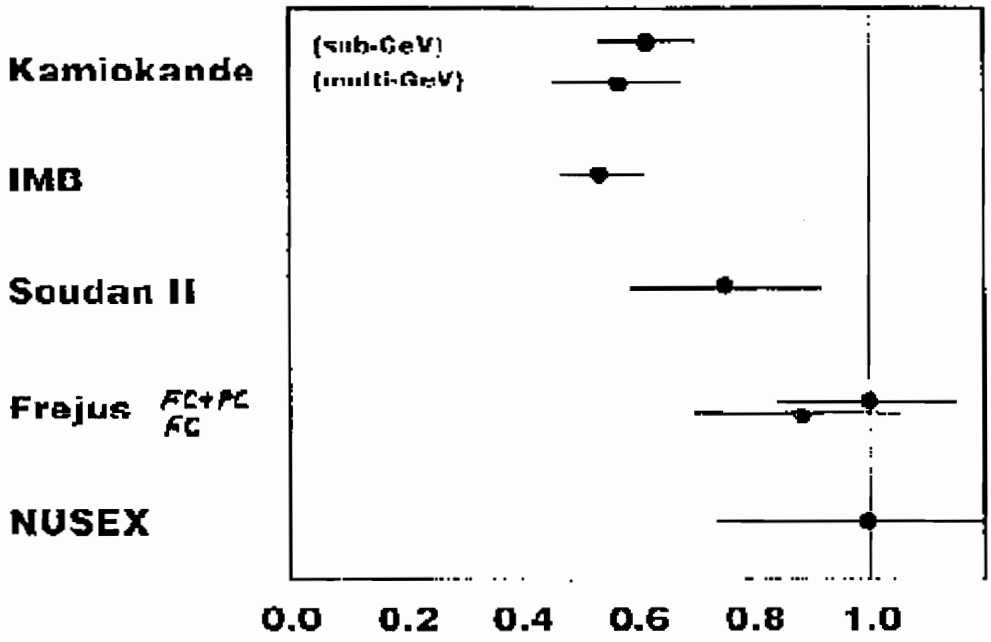
In order to reduce errors (Contained events)

take double ratios: $R((\mu/e)_{data}/(\mu/e)_{MC})$

~~750 events (~10yrs)~~

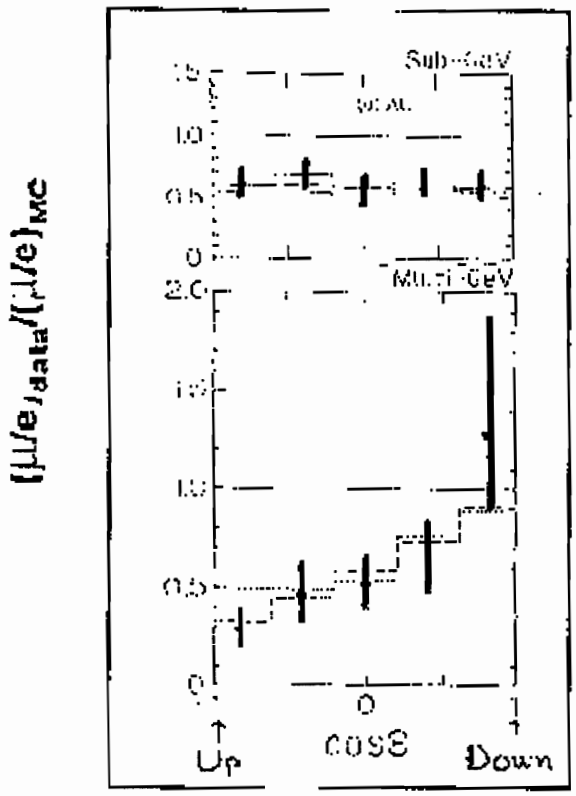
Kamiokande(sub-GeV)	0.62±0.06±0.06	8.3 ktyr
Kamiokande(multi-GeV)	$0.57+^{0.08}_{0.07}+0.07$	8.2, 6.0 ktyr
IMB	0.54±0.02±0.07	7.7 ktyr
Frejus (FC+PC)	1.00±0.15±0.08	1.56 ktyr
FC	0.97±0.16	
NUSEX	$0.99\pm^{0.35}_{0.25}$	0.4 ktyr
*Soudan II	0.75±0.16±0.10	1.5 ktyr
pa-09-022	(169 events) @ν-96	
*Super-Kamiokande (36.68days)	257 events (sub-GeV)	2.24ktyr
pa-09-***	355 events (fully contained)	

* on going experiments



Multi-GeV data (Kamiokande)

→ non-monotonous suppression in Zenith Angle Dis.



Oscillation → non-oscillation transition may be seen

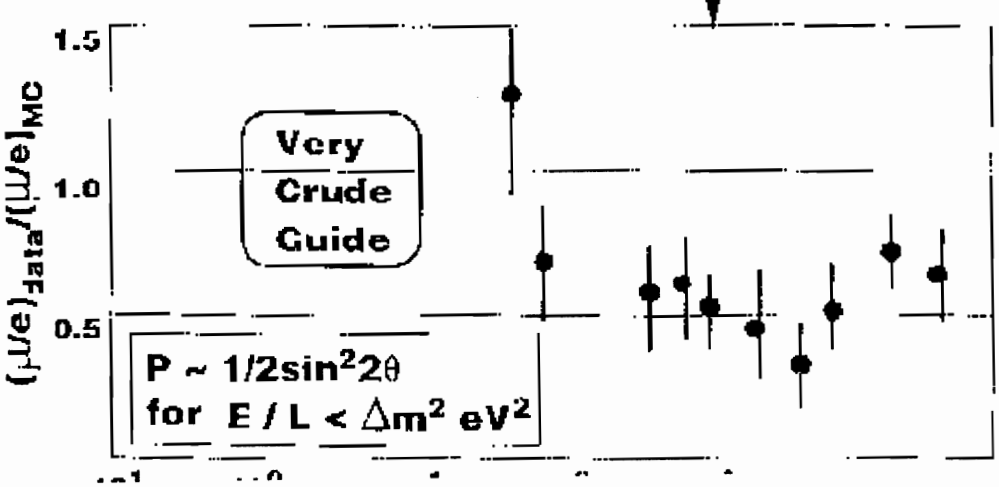
Simple minded Interpretation

$\langle E \rangle / 1.27 \langle L \rangle \rightarrow \Delta m^2$ eV^2

$\langle L \rangle$: cos θ

$\langle E \rangle$: ~0.7 GeV for sub-GeV

: ~6.0 GeV for multi-GeV



Questions to the Data

(Kamiokande & IMB)

(1) Water Cherenkov vs Calorimeter

→ Soudan II ?
pa-09-022

(2) Particle Identification : $\mu \leftrightarrow e$

→ Beam Test @ KEK
(Kamiokande & IMB)

OK.

(3) Neutron Induced π^0 Backgrounds in "e-like" events ?

NO !

→ π^0 identification
(Kamiokande)

To be appeared in PL.

How can we settle the Atm-ν problems

(1) Super-Kamiokande

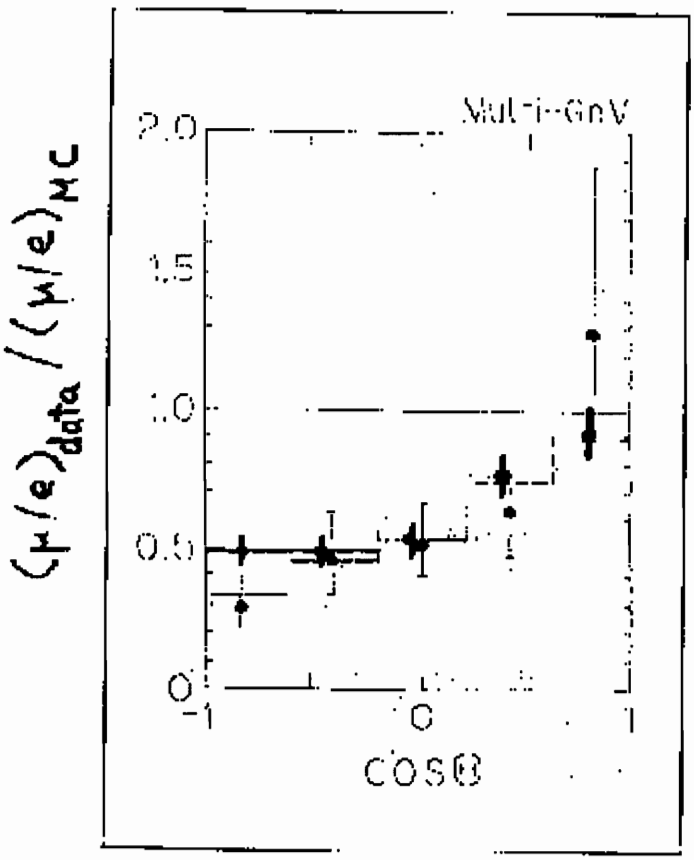
Started already

Very high statistics (2.24ktons in 37days)

① Detailed study on zenith angle dependence

② $\nu_\mu \rightarrow \nu_e \leftrightarrow \nu_\mu \rightarrow \nu_\tau, \nu_s$

discrimination



SK: 3yrs

$\nu_\mu \rightarrow \nu_e$

$(1.8\times10^{-2}, 1.0)$

$(1.6\times10^{-3}, 1.0)$

$\nu_\mu \rightarrow \nu_\tau, \nu_s$

Particle identification.

Data were obtained at a KEK test beam with identified electrons and muons which were injected into a test cherenkov counter of 1 Kton size, the Baby Kamiokande. Baby-Kamiokande was instrumented to resemble Kamiokande III. The beam was varied in energy and the direction as well as the position of injection was varied. The algorithm for electron-muon separation was tested and found to have a very high efficiency, especially for the higher energies. The MC to simulate the particles and the application of the algorithm verified the efficacy of the simulations to apply to untested conditions.

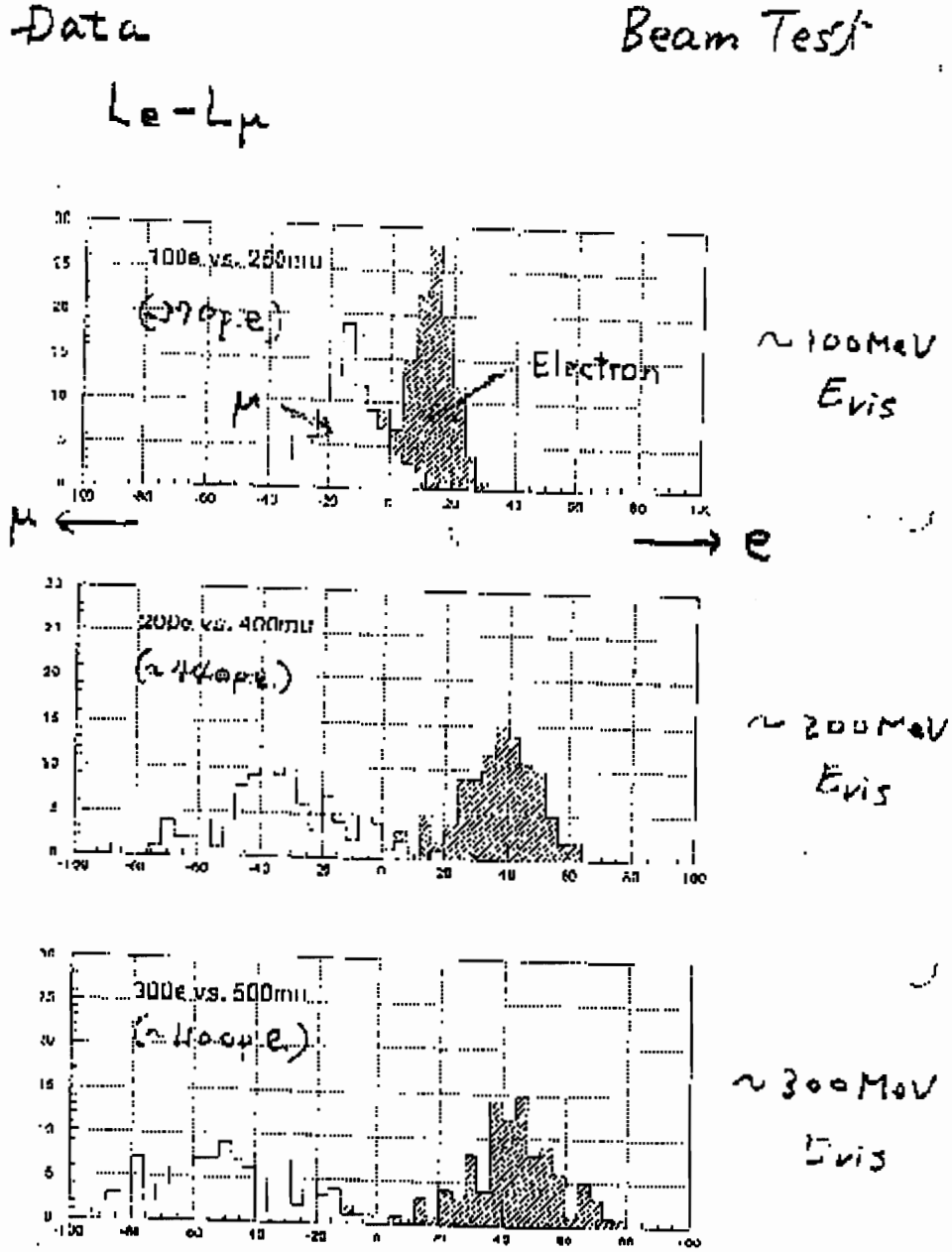


Figure 4.27: The [ ] distribution for the real data at the C-position.

MC

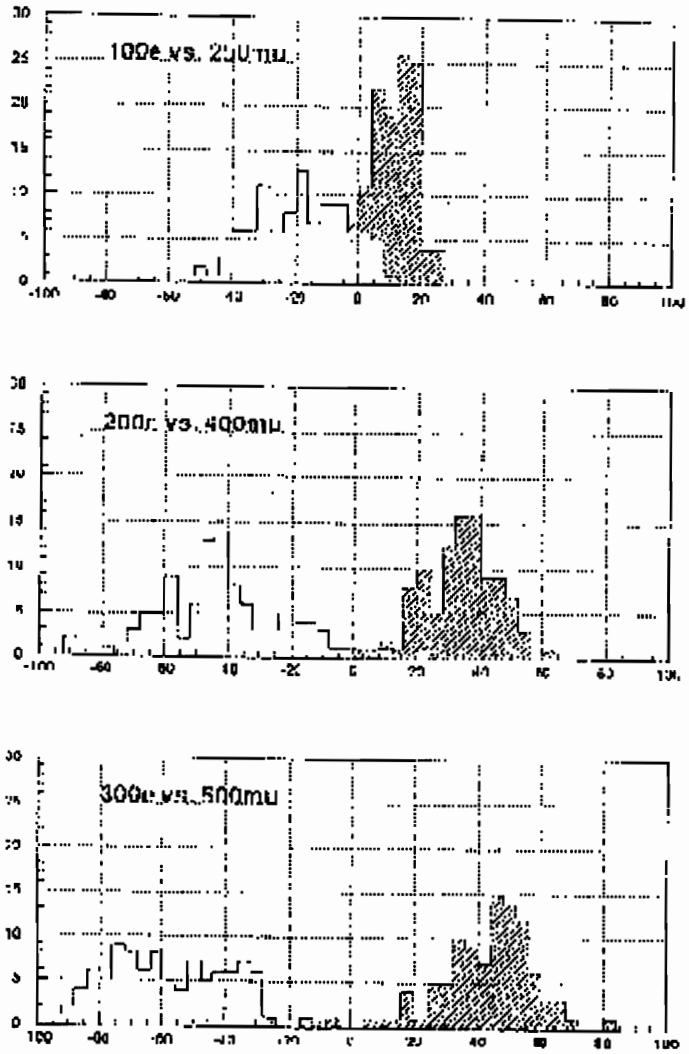
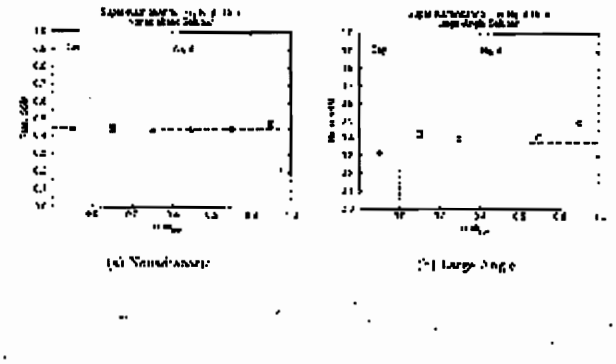


Figure 4.28: The [redacted] distribution for the Monte Carlo annihilation at the C position.

When we have two years of data.



a) Solar Neutrinos[1,2]

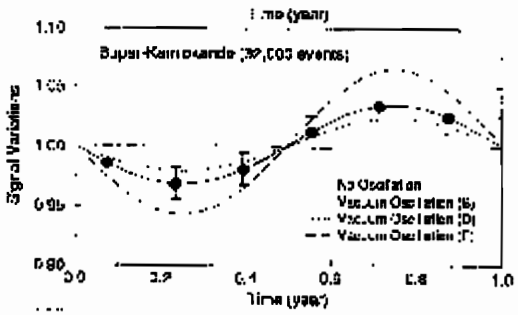
The solar neutrino measurements are especially compelling. Reliable data from the current four operating experiments suggest physics interpretation beyond the Standard Model. Not only are the rates considerably lower than the expectations of the standard solar model, but also comparison of the results for the four experiments suggests that the largest suppression is in the middle of the spectrum. This is hard to accommodate by any astrophysical or nuclear physics mechanisms, suggesting that even highly nonstandard solar models cannot by themselves explain the data.

Neutrino oscillations, particularly of the MSW sort, provide an attractive solution that fits all the data. Truly conclusive proof will require a physics signature that is independent of astrophysical arguments, and there are 3 such signatures.

A total solar neutrino flux that is larger than the solar neutrino flux of electron flavoured neutrinos. This is measured by the ratio of flux in neutral current interaction to charged current interactions greater than unity.

distortions of the shape of the ^{8}B electron-neutrino spectrum measured by charge current interactions.

dependence in the charged-current neutrino rate on the sun-earth distance and the mass between the detector and the sun.



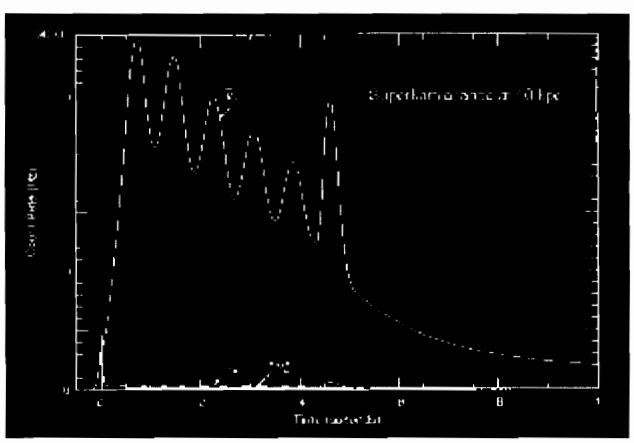
Superkamiokande will be able to measure the latter two of these signatures. Super Kamiokande will detect the ^{8}B solar neutrinos through the neutrino electron scattering,

$\nu e^- \rightarrow \nu e^-$, and measures the neutrino arrival time, the direction and the energy. The neutral /charge current ratio will be measured by comparing the CC fluxes from SK with the NC fluxes from SNO.

The following figures show the expected accuracy of the measurements for: 1) Distortion to the solar neutrino spectrum. (In figure 1, The MSW non-adiabatic solution corresponds to parameters $\sin^2 2\theta = 6.5 \times 10^{-3}$ and $\Delta m^2 = 6.1 \times 10^{-6}$. The MSW large angle solution corresponds to $\sin^2 2\theta = .62$ and $\Delta m^2 = 9.4 \times 10^{-6}$. The vacuum oscillation solutions correspond to $\Delta m^2 \sim 10^{-10}$ eV^2 and $\sin^2 2\theta > 0.7$.)

2) day-night effect for the solar neutrinos due to the MSW effect for the allowed solutions.

3) seasonal variation of the solar neutrinos. due to the orbit eccentricity and due to vacuum oscillations.



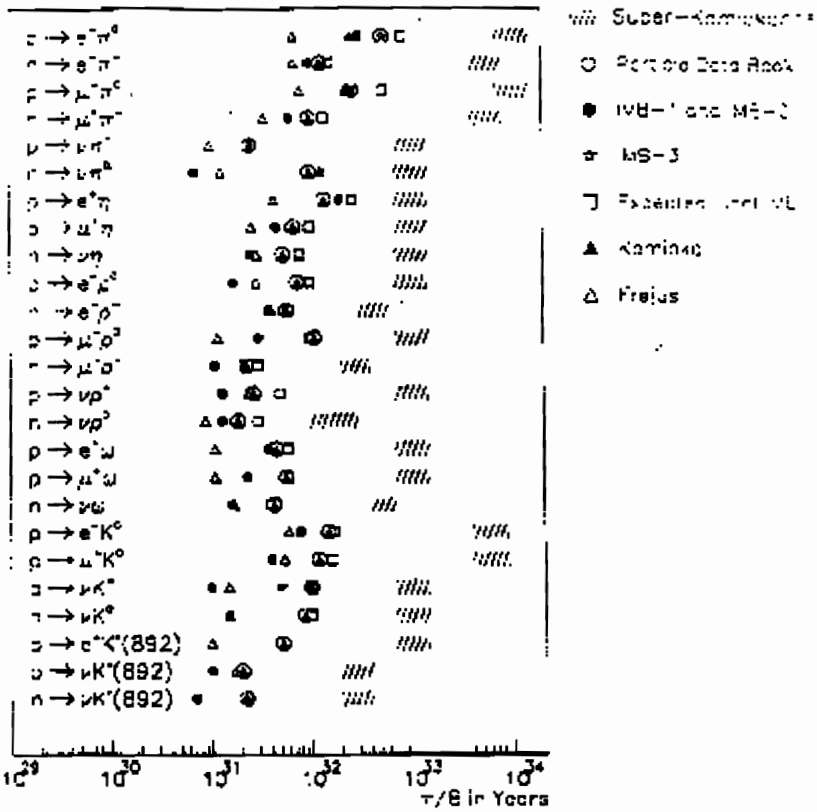
b) Real-time Supernova Neutrinos[1].

There are many models of supernova mechanisms. The expected response of SK to a supernova occurring at a distance of 10 kpc shows a pulse of neutrinos with oscillations. We expect to detect about 4000 neutrino events during the first 10 seconds. Figure 4 shows a calculated neutrino event rate for SK for a supernova at the galactic center. The sensitivity of Superkamiokande will allow us to detect the occurrence of supernovae at a distance of 100 kpc and to look through the haze of stars in the Milky Way center to enhance the possibility of detecting a relatively close by SN. There are estimates that SN will occur once every ten years in the Milky Way.

c) Atmospheric Neutrinos[1,3]

The ratio of the fluxes of muon and electron neutrinos created in the atmosphere, has been measured with good statistical accuracy to be significantly different from expectations based on the standard particle model. This measurement and interpretation has been augmented by measuring and interpreting the energy and zenith angle variation. These data suggest neutrino oscillations but with parameters that differ from the ones suggested by the solar neutrino experiments. Superkamiokande is expected to have better sensitivity as well as improved energy and angular resolution compared to the present Kamiokande experiment. This will allow us to have an improved grasp of the systematic uncertainties in the interpretation of the result as well as a much higher statistical accuracy.

d) Nucleon Decays[4]



The much larger sample of nucleons and the improved measurement in SK will allow us to extend the limits of the nucleon decay measurements to another order of magnitude for many nucleon decay possibilities. There have been suggestions that this realm of proton lifetime will offer good possibility of finally seeing proton decay. Figure 5 shows the present limits and the expected limits that will be set by Super-K.

Conclusions.

.Super-Kamiokande is working almost as well as we had planned . We have already collected more events than the previous experiments during their entire life of running. The measured fluxes of solar neutrinos and atmospheric neutrinos are consistent with the results from the previous experiments.

We have achieved most of our benchmarks. Only one of our goals has not achieved, namely to lower the threshold energy to 5 MeV. The water purity has reached a low enough level but there are still enough background events below 7 MeV which prohibit further study of solar neutrinos down to 5 MeV. We are still working hard on these events and hope to resolve the problem in the near future.

We probably need two more years of observations to definitely see if the ^{8}B neutrino spectrum is really distorted or if the flux in the nightime is indeed larger than the daytime.

The on-line supernova (SN) watch has been installed and SN alarms are issued on an average once every month, the rate of which is adjustable depending on the detection efficiency. No events remained until now after inspecting the spatial uniformity o the alrarm events: They were clusters of spallation productions by hard interactions of muons. Currently, Super-Kamiokande is 100% efficient to find SNs at a distance as far as 100 Kpc. Obviously the detector must be running all the time as the SN bursts lasts for only 10s of seconds. The current data taking efficiency is about 95%. The loss is due to the frequent calibration work. It may eventually reach 97-98% very soon.

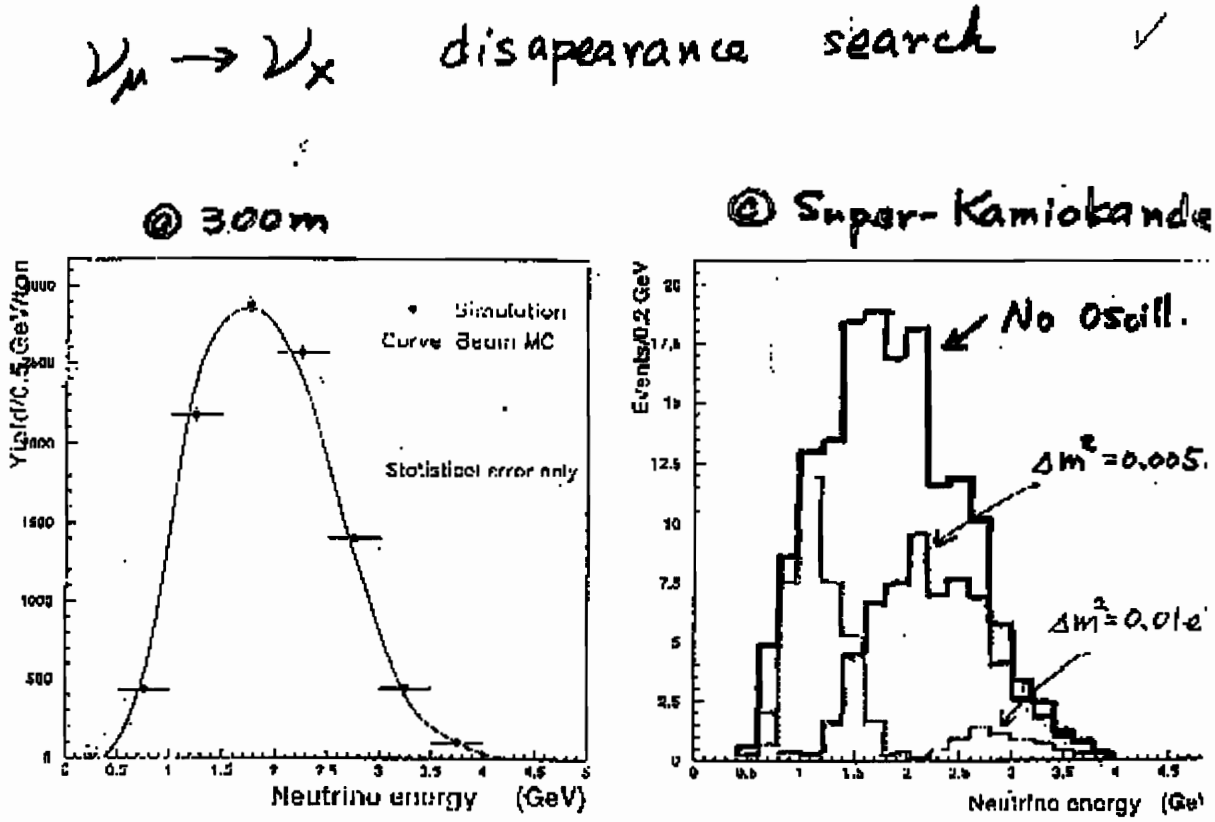
The atmospheric neutrino measurement is on track to produce the planned data. We have statistics which are already larger than the total data obtained in Kamiokande. The raw measured fluxes are consistent with those measured in Kamiokande III which were consistent with the presence of neutrino oscillations. The first results of the atmospheric neutrinos will be presented in the summer this year with statistics several times larger than the total data obtained in Kamiokande. Two more years of data will produce data of a quantity to observe a possible oscillation cycle in L/E space. In order to confirm the atmospheric-neutrino anomaly in a convincing way, we will carry out the long-baseline neutrino-oscillation experiment, K2K, between Super-Kamiokande and KEK from the beginning of 1999.

Proton decay is being and will be search for as long as the Super-Kamiokande experiment continues, hopefully for more than 50 years. Our effort is especially focused on the decay mode $p \rightarrow \nu K^+$

which is predicted by the SUSY GUTs. In five years we will reach the sensity of 3×10^{33} years for this decay mode.

If the atmospheric neutrino anomaly is a result of neutrino oscillation, the K2K experiment which will begin operations in 1999 will be able to detect a rather large neutrino oscillation effect. The neutrino beam produced at KEK will be aimed at Super-Kamiokande 250 Km away.

Cartoon of the KEK produced neutrino beam aimed at Super-Kamiokande which is 250 Km away. The neutrinos will have an average energy of 1.5 GeV.



The flux at the near detector and at Super-Kamiokande with and without oscillation for various parameters

---

References

J.N. Bahcall and M. Pinsonneault, Rev. of Mod. Phys. 64, 885 (1992) and 67, 781 (1995).

K. Hirata et al, Phys. Rev. Lett. 58, 1490 (1987), and Phys. Rev. D 38, 448(1988);

R.M. Bionta et al, Phys. Rev. Lett. 58, 1494 (1987);

Fukuda et al, Phys. Lett. B 335, 237 (1994);

S.P. Mikheyev and A.Y. Smirnov, Sov. Jour. Nucl Phys. 42, 913 (1985);

Wolfenstein, Phys. Rev. D17, 2369 (1978);

For Background Information, please see:

Boris Kayser. The Physics of Massive Neutrinos;

Survey of Neutrino physics. K Winter, CERN http://preprints.cern.ch/cern/hypertext/ppe165/node5.html;

Essay on Dark matter, J. Silk, UCB. http://physics7.berkeley.edu/darkmat/essay.html.