PROCEEDINGS OF SCIENCE

Super-K: Neutrinos from MeV to TeV

Mark Vagins[*]
University of California, Irvine
4129 Reines Hall, Irvine, CA 92697, USA
E-mail: `mvagins@uci.edu`

The versatile Super-Kamiokande detector observes neutrino interactions which range in energy from a few MeV to many TeV. These neutrinos are produced by fusion processes within our Sun's core, cosmic ray interactions in the Earth's atmosphere, distant accelerator facilities, and someday, if we are lucky, by supernovas or other cataclysmic processes in deep space. In its nine years of existence Super-K has played a central role in the discovery of neutrino oscillations and the elucidation of these elusive particles' properties. Super-K's latest results are discussed.

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[*] Speaker

1. Introduction

Super-Kamiokande [Super-K, SK] is the product of the collaborative effort of approximately 140 astrophysicists primarily from Japan and the U.S., many of whom previously worked on either the Kamiokande or IMB water Cherenkov experiments. The Super-Kamiokande site is about 300 kilometers west-northwest of Tokyo near the small town of Mozumi in the Japanese Alps. Located under 1 kilometer of rock (2,700 meters water equivalent) in the same ancient zinc mine as the decommissioned Kamiokande, Super-K shares the same basic design as its former neighbor and namesake: a cylinder of ultra-pure water surrounded with inward-facing photomultiplier tubes [PMT's], a light barrier, a layer of outward-facing PMT's, and a veto region of water, all contained within a stainless steel tank.

Roughly an order of magnitude larger than its predecessors, Super-K has been designed to be a premier facility for studying solar neutrinos, atmospheric neutrinos, nucleon decay, and neutrinos from galactic supernovae. The neutrinos from these processes span many orders of magnitude in energy, with Super-K sensitive to neutrinos of about 5 MeV all the way up to 10’s of TeV. Weighing in at 50,000 tons of water, and holding over 11,000 fifty-centimeter diameter PMT's and 1,850 twenty-centimeter PMT's, Super-K is the world's largest underground water Cherenkov detector. The data-taking period as well as the detector’s configuration between its commissioning on April 1st, 1996, and its first major shutdown on July 15th, 2001, has been designated “Super-Kamiokande-I.” Following an accident in November 2001, the detector was rebuilt with about half of the original number of fifty-centimeter PMT’s. Data was taken in this configuration, known as “Super-Kamiokande-II,” between December 2002 and October 2005. As of this writing the detector is currently being restored to its full complement of PMT’s, and should resume operations as “Super-Kamionade-III” in June 2006.

Of course, three pages is a rather modest space in which to present the many results obtained by Super-K in its nine year history. Interested readers are directed to two of our recent publications [1,2] for considerably more details.

2. High-Energy (Atmospheric Neutrino) Results

When we talk about Super--Kamiokande's “high-energy” analysis, we mean events with greater than 100 MeV of visible energy deposited in the detector. Our primary source of these events (since proton decay has proven quite elusive!) are the result of interactions of cosmic ray particles with the upper atmosphere. Neutrinos of all energies are produced in the atmosphere by cosmic ray showers, arriving at the detector from all directions. Neutrinos arriving from above have traveled only about 15~km from their point of production in the atmosphere, while those arriving from below have traversed a distance comparable to the Earth's diameter (13,000 km). Thus the atmospheric neutrino flux, spanning many decades of both energy [E] and distance [L], provides an ideal beam for studying L/E-dependent oscillation effects.

Figure 1 shows the atmospheric neutrino signal in both SK-I and SK-II. Each small plot is one subset of the data, with upward going neutrinos on the left and downward going neutrinos on the right side of each plot. Note the deficit in upward going muons but not in electrons – this is evidence that the muon neutrinos are turning into something other than electron neutrinos. We find that the best fit to the data supports the oscillation of muon netrinos into tau neutrinos. Figure 2 shows the allowed regions of various data sets for SK-I in mass-squared vs. oscillation angle phase space. The best fits are given in Figure 1. While the statistics in SK-II are clearly worse than those of SK-I the neutrino oscillation results are in very good agreement.

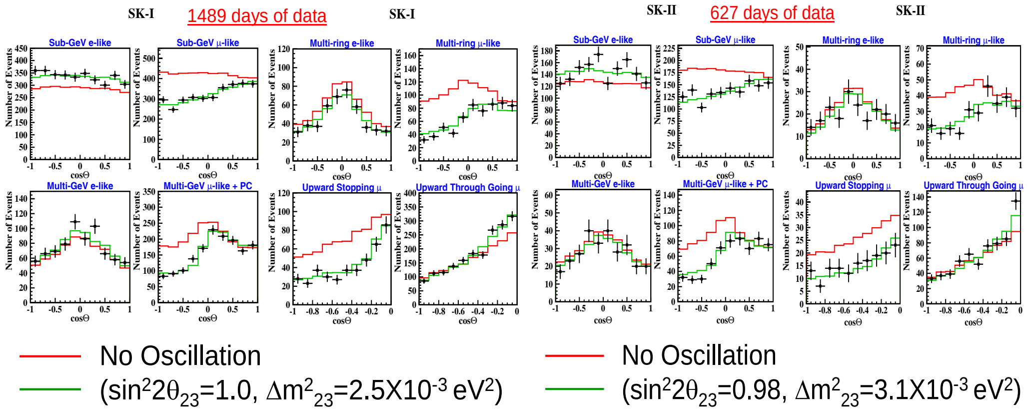

Figure 1: Atmospheric neutrino results from Super-K-I (left) and SK-II (right).

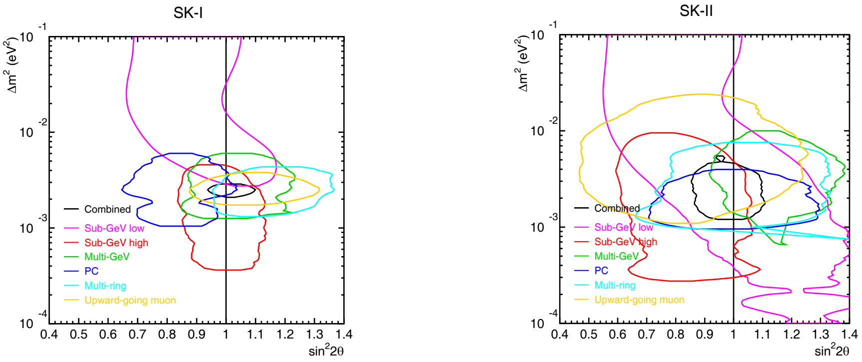

Figure 2: Allowed regions from the best fits in Figure 1.

3. Low-Energy (Solar Neutrino) Results

When we talk about Super-Kamiokande's “low-energy” analysis, we generally mean events with less than 100 MeV of visible energy deposited in the detector. With an endpoint energy of about 15.0 MeV, Super-Kamiokande's primary source of solar neutrinos are those produced by ^{8}B reactions in the Sun’s core. These ^{8}B neutrinos are seen in Super-K via neutrino-electron elastic scattering. We have obtained what is by far the largest sample of solar neutrino events in the world.

Figure 3 shows our solar neutrino samples. The area under the peak in the solar direction are our solar neutrinos. Note that, unlike atmospheric neutrinos, one can only identify solar neutrinos in a statistical fashion. For this reason, reducing the sea of background events under the solar peak is of central importance in all low-energy investigations. From these plots we can determine the flux of these ^{8}B solar neutrinos. In both SK-I and SK-II we find the flux of these electron neutrinos is just 41% of that expected without oscillations. However, if we assume that electron neutrinos are completely mixing into muon and tau neutrinos (which scatter off electrons with about 1/6th the cross section of electron netrinos due to the lack of charged current processes for the heavier flavors) then this is almost exactly the total flux which one would expect to see. Again, SK-I and SK-II agree very well. Figure 4 (left) shows the very flat energy spectrum of our solar neutrinos, while the right side shows the very small allowed area (in the so-called “Large Mixing Angle” region) for neutrino oscillations obtained by combining Super-K-I’s solar results with those of all other solar neutrino and reactor experiments.

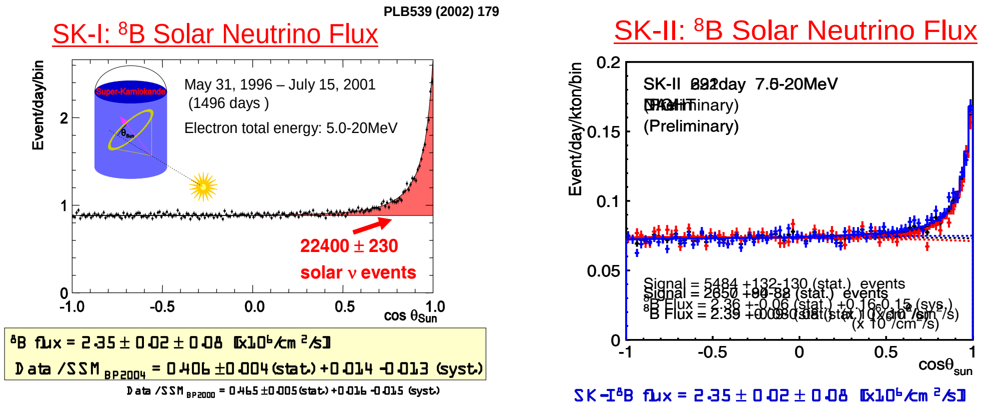

Figure 3: Solar neutrino events in SK-I (left) and SK-II (right).

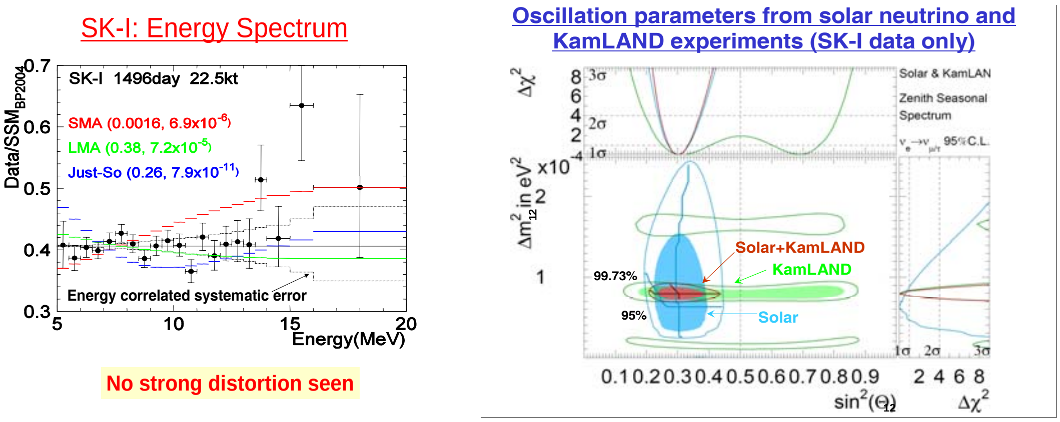

Figure 4: Solar neutrino energy spectrum in SK-I (left) and allowed region for solar neutrino oscillations (right).

References

[1] Y. Ashie *et al.*, *A Measurement of Atmospheric Neutrino Oscillation Parameters by Super-Kamiokande I*, *Phys.Rev* **D72:** 052007, 2005 [`hep-ex/0502026`]

[2] J. Hosaka *et al.*, *Solar Neutrino Measurements in Super-Kamiokande-I*, Submitted to Phys.Rev.**D** [`hep-ex/0508053`]