Neutrino Oscilation at the Super Kamiokande

Rosi Reed

UC Davis

Abstract. Oscillation between muon neutrinos and tau neutrinos was detected by the Super-Kamiokande in 1998.[1] Neutrino oscillation is observed when a neutrino of a specific flavor is later measured to have a different flavor. This occurs because the mass eigenstates of neutrinos are not the same as their flavor eigenstates. Since Standard Model neutrinos are massless, neutrino oscillation is an indication of physics beyond the standard model.

Keywords: neutrinos,oscillations,Kamiokande

INTRODUCTION

In the late 1960s the Homestake experiment led by Dr. Raymond Davis counted solar neutrinos, which come from the fusion reaction $H^1 + H^1$ -> $H^2 + \nu_e + e+$. The measured result was 1/3 of the theory prediction. This anomaly between experimental and theoretical results was known as the solar neutrino problem. Initially it was not known whether the problem was with the model of the sun or with the experimental data. Bruno Pontecorvo was the first person to develop a theory of neutrino oscillation, which was similar to the oscillation between neutral Kaons.

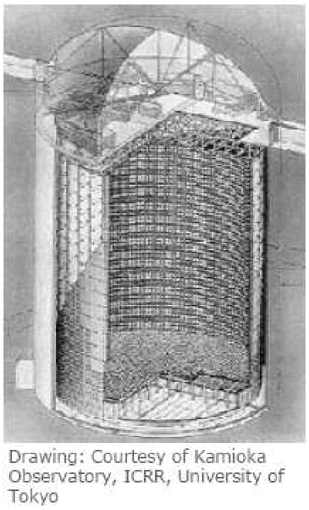

FIGURE 1. Super Kamiokande Detector [2]

In 1989 the Kamiokande detector, a precursor to the Super Kamiokande, confirmed the missing solar electron neutrino measurement.[1] Unlike the Homestake experiment, the Kamiokande could determine the direction of the neutrinos. This allowed the Kamiokande experiment to directly differententiate between solar neutrinos and cosmic ray neutrinos. In conjunction with GALLAS and SAGE it was determined that the number of missing electron neutrinos varied with the energy of the neutrino.

NEUTRINO OSCILLATION THEORY

This paper will consider a three flavor neutrino model only. The neutrino flavor eigenstates are labeled as ν_e, ν_μ, ν_τ while the neutrino mass eigenstates are labeled as ν_1, ν_2, ν_3. The mass eigenstates are the eigenstates of the Hamiltonian, which is what determines the propagation of the neutrinos. The relationship between the mass eigenstates and

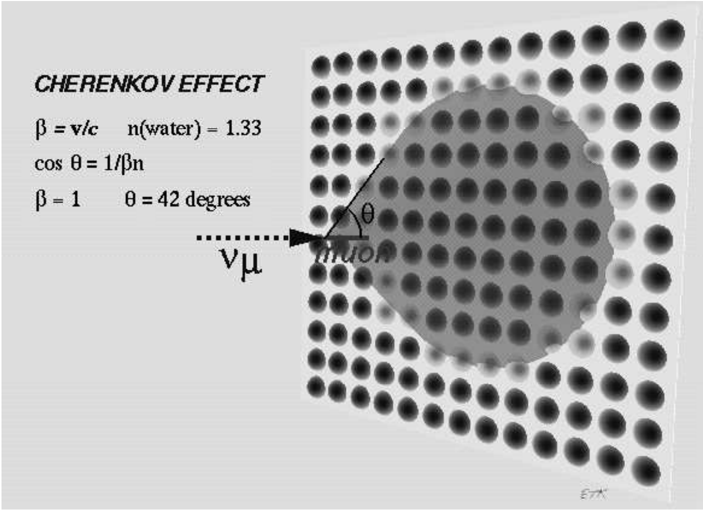

FIGURE 2. Cherenkov light being detected by PMTs[3]

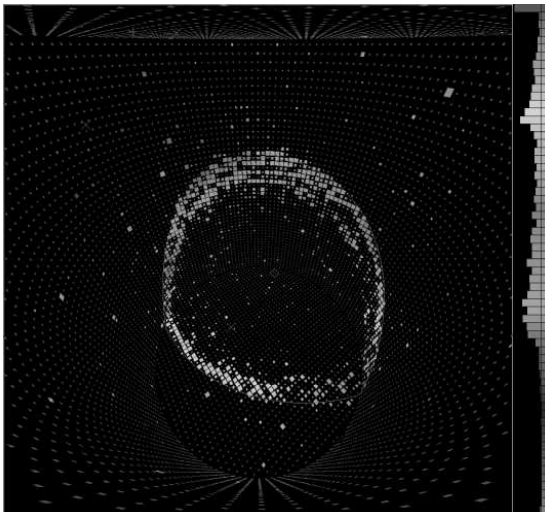

FIGURE 3. Graphical display of an event in the Super Kamiokande[4]

the flavor eigenstates can be written as:

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = U \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

If the mass eigenstates were the same as the flavor eigenstates, the matrix U would be the identity matrix. The form of U has been determined to be[1]:

$$\begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

where $c_{ij} = cos\theta_{ij}, s_{ij} = sin\theta_{ij}$ andδ is non-zero only if neutrino oscilation violates CP symmetry, which is unknown at this time.

The time evolution of the mass eigenstates in the Heisenburg picture is($\hbar$ = c = 1)

$$|\nu_i(t)\rangle = e^{-iE_it}|\nu_i(0)\rangle$$

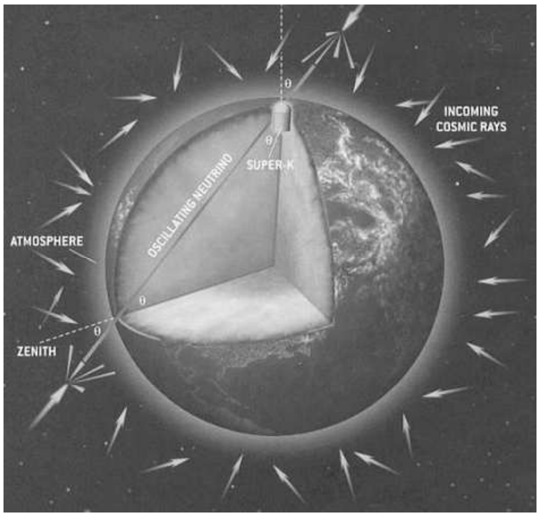

FIGURE 4. Picture of the Super Kamiokande measuring cosmic ray neutrios

When a neutrino of a definite flavor state is created, it can be expressed as $|\nu_\alpha\rangle = \sum U^*{}_{\alpha i}|\nu_i\rangle$. At any time it is possible to calculate the probability of measuring a particular flavor in the following manner:

$$P(\nu_\beta) = |\langle\nu_\beta|\sum U^*{}_{\alpha i} e^{-iE_i t}|\nu_i\rangle|^2$$

For highly relativistic neutrinos, the probability of flavor conversion has been calculated to be:

$$P_{\alpha->\beta} = sin^2 2\theta sin(1.27\delta m^2(eV)_2 L(km)/E_\nu(GeV))$$

[1]

SUPER KAMIOKANDE

The Kamiokande detector was upgraded in 1996 to study solar neutrinos and look for proton decay. It is located 1 km underground in the Mozumi mine in Hida City, Japan. The underground location is necessary in order to shield the detector from cosmic ray muons. The detector is filled with 50,000 tons of ultra-pure H_2O. It is made up of two concentric cylinders with the outer cylinder being 40 meters tall, 40 meters in diameter and lined with 3000 20 cm photomultiplier tubes (PMTs). The inner cylinder is 36 meters tall,36 meters in diameter and lined with 11,000 50 cm PMTs.[5]

In 1998 neutrino oscillation between muon neutrinos and undetectable taon neutrinos was confirmed.[1] The 2002 Nobel Prize was given to Raymond Davis and Masatoshi Koshiba from the Homestake and the Kamiokande experiments respectively, for their "pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos". The investigation of neutrino oscillation has now turned to measuring the values of the mixing angles shown in the matrix U. The mass eigenstates also need to be measured and a determination of whether neutrino oscillation violates CP symmetry must be made.

The Super Kamiokande has been repaired and will be measuring a beam of $\neq_e$ neutrinos produced at the J-PARC facility 295 km away. The oscillation between ν_μ and ν_e will allow a measurement of θ_{13}. Super Kamiokande will also make precision measurements of $\delta m^2{}_{23}$ and θ_{23}.

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REFERENCES

1. K. Scholberg for the Super-Kamiokande collaboration. hep-ex/9905016v1.
2. http://ale.physics.sunysb.edu/superk/detector/.
3. http://hep.bu.edu/ superk/cherenkov.html.
4. http://www.ps.uci.edu/ tomba/sk/tscan/pictures.html.
5. Y.Fukuda et al., *Phys. Lett.* **B433** (1998) 9. hep-ex/9803006.