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Neutrino Science at Berkeley Lab: Understanding Neutrino Oscillations

Model-Independent Evidence for the Flavor Change of Solar Neutrinos at SNO

The Sudbury Neutrino Observatory (SNO) is an imaging water Cherenkov detector located 2 km underground in the Creighton mine in Sudbury, Ontario, Canada. With 1000 tons of heavy water, SNO observes the interactions of solar 8B neutrinos through 3 different interaction channels. Neutrino interactions with deuterium give SNO unique sensitivity to all active neutrino flavors.

Evidence for Neutrino Oscillations

In 2002, SNO found that 2/3 of all solar electron neutrinos change their flavor on route to Earth and are detected as muon or tau neutrinos in the Sudbury Neutrino Observatory.

First Evidence for the Disappearance of Reactor Antineutrinos at KamLAND

KamLAND (Kamishima Liquid Scintillator Anti-Neutrino Detector) is a 1-kton liquid scintillator detector in the Kamioka mine in central Japan designed to measure the antineutrino flux from nearby nuclear power plants. KamLAND detects reactor electron antineutrinos through inverse β-decay of τ⁻ on protons.

Understanding the U_{MNS} Neutrino Mixing Matrix

Past, Present and Future Experiments

Results of the SNO solar neutrino experiment, the KamLAND reactor antineutrino experiment, and the evidence from the Super-Kamiokande atmospheric neutrino experiment have established the massive nature of neutrinos and point to a novel phenomenon called neutrino oscillations.

In the framework of neutrino oscillations the mass and flavor eigenstates of 3 active species are related through the $U_{MNS}$ matrix.

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix}$$

$$|\psi_E\rangle = U|\psi_M\rangle$$

Ratio of the measured $T_{\nu_e}$ flux to the expected reactor $T_{\nu_e}$ flux. The dashed line is the expectation for no neutrino oscillations. The dotted curve is representative of a best-fit "Large-Mixing-Angle" oscillation solution.

Determining the Last Undetermined Mixing Angle: A Reactor Neutrino Experiment to Measure $\theta_{13}$

With multiple detectors and a variable baseline a next-generation reactor neutrino experiment has the opportunity to discover sub-dominant neutrino oscillations and make a measurement of $\theta_{13}$.

$$P_{\nu_e} = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{31}^2 L}{4 E} - \cos^2 \theta_{13} \sin^2 2\theta_{23} \sin^2 \frac{\Delta m_{21}^2 L}{4 E}$$

The observed flavor change of solar electron neutrinos in SNO and the measurement of antineutrino disappearance at KamLAND provide evidence for the oscillation of neutrinos (under the assumption of CPT invariance). KamLAND's result narrows the allowed neutrino oscillation parameters to the 'Large-Mixing-Angle' solution and strongly disfavors other possible mechanisms of neutrino flavor change.