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Measurement of neutrino mixing angle θ_{13} and mass difference Δm^2_{ee} from reactor antineutrino disappearance in the RENO experiment

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Abstract

RENO (Reactor Experiment for Neutrino Oscillation) made a definitive measurement of the smallest neutrino mixing angle θ_{13} in 2012, based on the disappearance of reactor electron antineutrinos. The experiment has obtained a more precise value of the mixing angle and the first result on neutrino mass difference Δm^2_{ee} from an energy and baseline dependent reactor neutrino disappearance using ~500 days of data. Based on the ratio of inverse-beta-decay (IBD) prompt spectra measured in two identical far and near detectors, we obtain $\sin^2(2\theta_{13}) = 0.082 \pm 0.009(\text{stat.}) \pm 0.006(\text{syst.})$ and $|\Delta m^2_{ee}| = [2.62^{+0.21}_{-0.23}(\text{stat.})^{+0.12}_{-0.13}(\text{syst.})] \times 10^{-3}\ \text{eV}^2$. An excess of reactor antineutrinos near 5 MeV is observed in the measured prompt spectrum with respect to the most commonly used models. The excess is found to be consistent with coming from reactors. A successful measurement of θ_{13} is also made in an IBD event sample with a delayed signal of neutron capture on hydrogen. A precise value of θ_{13} would provide important information on determination of the leptonic CP phase if combined with a result of an accelerator neutrino beam experiment.

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1. Reactor antineutrino experiments

There have been great progresses in understanding the neutrino sector of elementary particle physics in the last two decades. The discovery of neutrino oscillation is a direct indication of physics beyond the Standard Model and it provides a unique, new window to explore at the Grand Unification energy scale. Nuclear reactors have played crucial roles in the development of neutrino physics. A fission reactor is a copious source of electron antineutrinos produced in the β-decays of neutron-rich nuclei. The discovery of the neutrinos was made at the Savannah River reactor in 1956 [1]. The KamLAND Collaboration observed disappearance of reactor neutrinos and distortion in the energy spectrum due to neutrino oscillations [2]. Daya Bay, Double-Chooz, and RENO Collaborations determined the smallest mixing angle θ_{13} based on the observed disappearance of reactor neutrinos [3–5].

In the present framework of three flavors, neutrino oscillation is described by a unitary Pontecorvo–Maki–Nakagawa–Sakata matrix with three mixing angles (θ_{12}, θ_{23} and θ_{13}) and one CP phase angle [6,7]. Neutrino oscillation was discovered in the atmospheric neutrinos by the Super-Kamiokande experiment in 1998, and the mixing angle θ_{23} was measured [8]. The solar neutrino oscillation was observed by the SNO Collaboration in 2001, and the mixing angle θ_{12} was determined [9]. All of the three neutrino mixing angles were measured to provide a comprehensive picture of neutrino transformation in 2012 when the reactor neutrino experiments determined the smallest mixing angle θ_{13} [3–5]. The next round of neutrino experiments are under consideration or preparation to determine the CP violation phase and the neutrino mass splitting type.

A few MeV, low-energy reactor neutrinos have relatively short oscillation lengths to compensate for rapid reduction of the neutrino flux at a distance. Reactor neutrino measurements can determine the mixing angle without the ambiguities associated with matter effects and CP phase. The reactor neutrino detector is not necessarily large, and construction of a neutrino beam is not needed. Past reactor experiments had a single detector located about 1 km or less from reactors. The new generation reactor experiments, Daya Bay and RENO, have significantly reduced uncertainties associated with the measurement of θ_{13} using two identically performing detectors at near and far locations from reactors. An accurate value of θ_{13} by the reactor experiment will be able to offer the first glimpse of the CP phase angle, if combined with a result from an accelerator neutrino beam experiment [10].

Previous attempts of measuring θ_{13} have obtained only upper limits from reactor neutrinos [11,12]. Indications of a nonzero θ_{13} value were reported by two accelerator appearance experiments, T2K [13] and MINOS [14], and by the Double Chooz reactor disappearance experiment in 2011 [15]. Global analyses of all available neutrino oscillation data have indicated central values of $\sin^2(2\theta_{13})$ that are between 0.05 and 0.1 (see e.g., [16,17]). In 2012, Daya Bay and RENO reported definitive measurements of the mixing angle θ_{13} based on the disappearance of reactor electron antineutrinos [4,5]. A combined result of the θ_{13} measurements was reported by the Particle Data Group as $\sin^2(2\theta_{13}) = 0.098 \pm 0.013$ in Ref. [18].

2. The RENO experiment

The experiment was proposed in 2005, and obtained a full construction fund of ∼10 M US dollars in 2006. Civil engineering began in 2007, and both near and far detectors were built in early 2011. Data-taking with both detectors began in August, 2011.