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KamLAND's precision neutrino oscillation measurements

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Abstract

The KamLAND experiment started operation in the Spring of 2002 and is operational to this day. The experiment observes signals from electron antineutrinos from distant nuclear reactors. The program, spanning more than a decade, allowed the determination of LMA-MSW as the solution to the solar neutrino transformation results (under the assumption of *CPT* invariance) and the measurement of various neutrino oscillation parameters. In particular, the solar mass-splitting Δm^2_{21} was determined to high precision. Besides the study of neutrino oscillation, KamLAND started the investigation of geologically produced antineutrinos (geo-$\bar{\nu}_e$). The collaboration also reported on a variety of other topics related to particle and astroparticle physics.

1. Introduction

Japan began operation of its first commercial nuclear power plant in the mid-1960s. The country invested heavily in nuclear reactors to generate electricity in the subsequent decades and by the year 2000 about 50 nuclear reactors provided 30% of the country's electricity. Besides producing electricity, nuclear reactors also emit electron antineutrinos ($\bar{\nu}_e$) isotropically in the decay of neutron-rich radioactive products of the fission process. These well-defined sources of $\bar{\nu}_e$'s give the opportunity to study neutrino properties.

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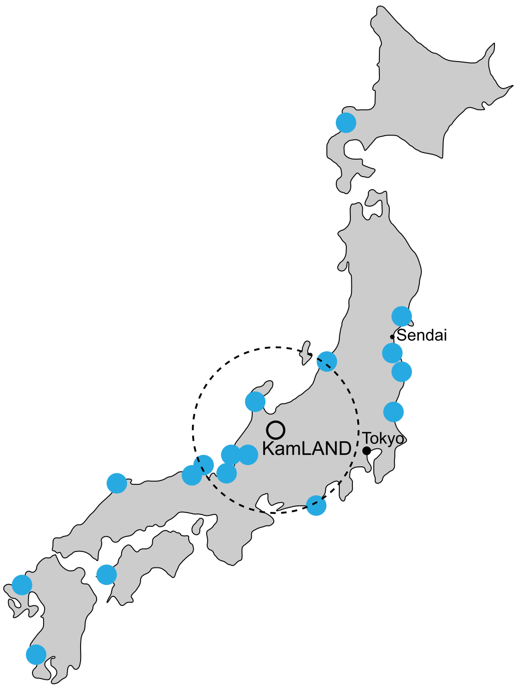

Fig. 1. The KamLAND experiment is located in the Kamioka Mine. The experiment is surrounded by more than 50 nuclear reactors at various commercial Nuclear Power Plants (blue dots). Most Nuclear Power Plants operate multiple reactors. The flux-weighted average distance of the reactors to KamLAND is ∼180 km (dashed circle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The Kamioka Liquid Scintillator Anti-Neutrino Detector (KamLAND) experiment was proposed in 1994 [1,2] and was approved by the Japanese government in 1997. In the following years, groups from Japan and the U.S. built the experiment in the old Kamiokande [3] cavity in the Kamioka Mine (Gifu Prefecture, Japan). The initial goals of KamLAND were the search for neutrino oscillation, the first observation of neutrinos originating from radioactive decays in the Earth's mantle (so-called geo-neutrinos) and the possible detection of galactic Supernovae. The KamLAND experiment was completed in early 2002. After a brief detector commissioning phase, regular scientific data recording started on March 9, 2002.

The location of the Kamioka Mine in relation to the Japanese nuclear power reactors provided a flux-weighted average distance of ∼180 km. About 80% of the neutrino flux in 2002 came from 26 reactors within a distance range of 138–214 km, see Fig. 1. The 180 km baseline, together with the emitted $\bar{\nu}_e$ spectrum peaking at ∼4 MeV, made KamLAND primarily sensitive to the neutrino oscillation solutions of the 'solar neutrino problem' for solar mass-splitting values of $\Delta m^2_{21} > 10^{-5}$ eV^2.

This review summarizes the KamLAND results obtained in five neutrino-oscillation-related data-releases between 2002 and 2013 [4–8].

2. The KamLAND detector

The KamLAND detector is located in the Kamioka Mine under Mount Ikenoyama at a depth of ∼2700 m water-equivalent. The primary volume consists of 1 kton of ultra-pure liquid scin-