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Establishing atmospheric neutrino oscillations with Super-Kamiokande

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Abstract

In this article we review the discovery of atmospheric neutrino oscillation by the Super-Kamiokande experiment. This review outlines the sequence of observations and their associated publications that solved the atmospheric neutrino anomaly and established the existence of neutrino oscillations with nearly maximal mixing of muon neutrinos and tau neutrinos. We also discuss subsequent and ongoing studies that use atmospheric neutrinos to continue to reveal the nature of the neutrino.

1. Introduction

The Super-Kamiokande experiment [1] commenced data taking on April 1, 1996, prepared for a broad range of inquiry in particle physics including the search for nucleon decay and the study of neutrinos from cosmic rays, nuclear reactions in the sun, and core collapse supernovae. Based

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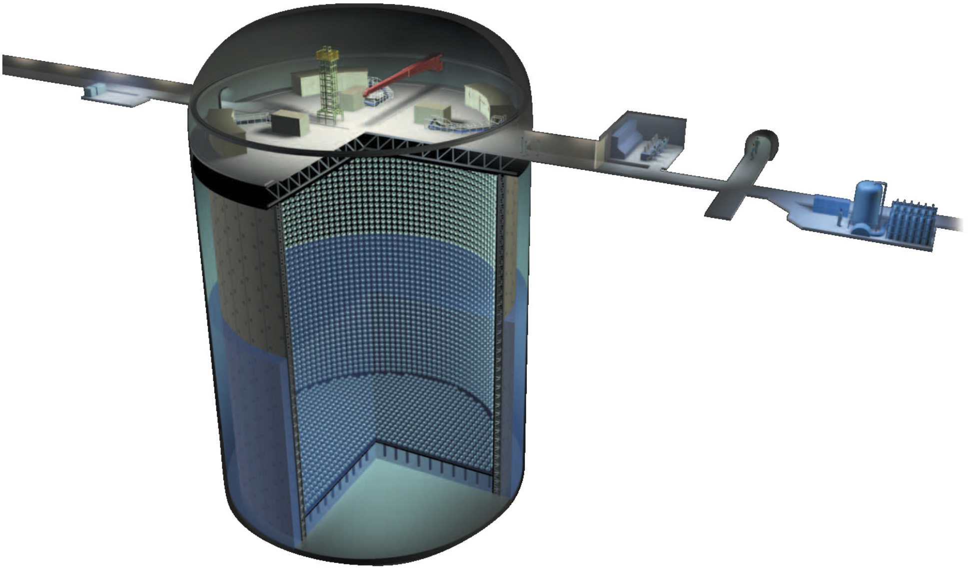

Fig. 1. The Super-Kamiokande detector, in cutaway, showing the inner and outer detector, partially filled with water. The detector dome contains front–end electronics and calibration devices such as the electron LINAC (tower is shown). Also shown are access drifts, the control room, and water purification system.

on unresolved indications in prior experiments, there were two immediate goals for neutrino studies: solving the "solar neutrino puzzle" [2] and resolving the "atmospheric neutrino anomaly" [3–6]. It was already anticipated that neutrino oscillations [7,8] could play a role in explaining the existing data. The Super-Kamiokande detector was designed to be large enough and have sufficient sensitivity to provide definitive results on these topics.

The Super-Kamiokande detector design [9] was influenced by the successes of the first generation experiment, Kamiokande [10], with which it shares its name. Super-Kamiokande (also referred to as Super-K or SK) was constructed in the same lead and zinc mine operated by the Kamioka Mining Company as its predecessor. In addition to increased fiducial mass, 22.5 kiloton versus 1 kiloton for Kamiokande, the photon collection coverage was increased from 20% to 40% with second-generation 50-cm PMTs [11] with improved time resolution of 2.2 ns and improved single photoelectron response. The outer detector veto region was increased to a thickness of 2 meters and highly instrumented by the U.S. group with PMTs recovered from the IMB experiment [12], a competing first generation water Cherenkov experiment that operated contemporaneously with Kamiokande. The high level of light collection and veto shielding, combined with an advanced water purification system that ensured good water clarity and low levels of radioactive background, allowed the experiment to lower the threshold for solar neutrino detection to 5 MeV (and lower, in later upgrades of the detector). Several advanced calibration systems [13] were implemented including an electron LINAC. For atmospheric neutrinos, the large detector mass resulted in roughly 3800 atmospheric neutrino events per year with excellent separation of muons from electrons, improved energy resolution, higher efficiency for counting decay electrons, and better performance for resolving multiple Cherenkov rings [14] compared to the first generation experiments Kamiokande and IMB. Fig. 1 shows an artist's rendering of the detector.

The Super-Kamiokande detector has gone through several operating stages in its twenty year history. Most of the work in establishing atmospheric neutrino oscillation used data from