Week 7
May 12, 2018

How Many Neutrinos?: Short-Baseline Oscillations

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Some experiments seem to be hinting at a new type of neutrino. An extra "sterile" neutrino could account for apparent flavor-changing oscillations over short distances, inexplicable in the standard three-neutrino picture. This fourth neutrino would affect oscillations but not otherwise interact with other matter. Experimental efforts are underway now to investigate this intriguing possibility.

This week, we will discuss short-baseline neutrino oscillations, including experimental hints for sterile neutrinos and a new program designed to definitively confirm or refute them.

I. The Anomalies

LSND: Starting in 1993, the Liquid Scintillator Neutrino Detector began studying muon antineutrinos produced by a particle accelerator. An excess of electron antineutrino events was seen and appeared consistent with neutrino flavor oscillations. However, we now know the distance over which the apparent oscillations occurred was much too short, indicating a much larger neutrino mass difference than solar or atmospheric neutrino experiments see. With now three distinct mass *differences* observed, one solution is that there is a fourth neutrino type.

Three Neutrinos at LEP: The Large Electron-Positron Collider was a particle accelerator at CERN in Switzerland. Using LEP data, physicists measured the number of neutrino types produced in Z boson decays to be exactly three. Therefore, we know that three neutrinos take part in weak interactions. This does not, however, rule out "sterile" neutrino types, which would not interact with matter but may still participate in neutrino oscillations.

The Gallium Anomaly: Solar neutrino experiments SAGE and GALLEX relied on (electron-type) solar neutrinos converting Gallium to Germanium inside the detector. To measure how efficient their detector was, they used highly radioactive Chromium-51 nearby as an artificial neutrino source. Both experiments saw a deficit in the number of ν_e observed, as if they had disappeared over a short distance; this observation was consistent with the effect seen in LSND.

The Reactor Anomaly: The Double Chooz experiment was a search for the disappearance of reactor antineutrinos in order to study neutrino oscillations. Initially lacking a detector near the reactor to measure to initial number of neutrinos, Double Chooz prompted a new, very detailed calculation of the flux. This disagreed with the old calculation, which had always matched experimental data. With the new model, all the existing data came in low, again as if neutrinos were disappearing in short distances before they even reached the near detectors.

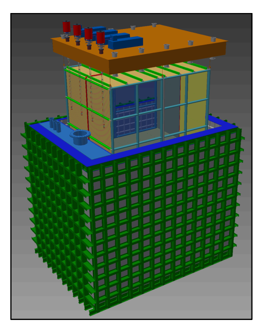
MiniBooNE: This experiment located at Fermilab used muon antineutrinos from a particle accelerator to follow up on the LSND result, but with a different neutrino energy, propagation distance, and detector technology. MiniBooNE saw an LSND-like appearance of electron antineutrinos in a muon antineutrino beam, and a prominent (but more difficult to explain) excess of electron neutrinos in a muon neutrino beam.

II. The Short-Baseline Neutrino Program

The Short-Baseline Neutrino (SBN) Program is a new experimental effort at Fermilab designed to definitively test the sterile neutrino hypothesis. It consists of three neutrino detectors situated along a high-intensity beam of muon neutrinos.

Three Detectors: The Short-Baseline Near Detector (**SBND**) is located immediately after where neutrinos are produced to measure the beam before any oscillations can occur. The **ICARUS** detector is the far detector, where an excess of electron-type neutrinos would appear in the case of sterile neutrinos. (ICARUS used to be located in Italy and was recently shipped to Fermilab.) The **MicroBooNE** experiment is a direct follow-up to address the MiniBooNE anomaly. It has been running since 2015, making it the first of the SBN detectors to come online.

LArTPCs: The SBN detectors are called Liquid Argon Time Projection Chambers and are essentially 3D cameras that capture neutrino interactions. Charged particles liberate electrons, and a very high electric field pushes the electrons to a waiting array of wires where they create tiny electrical pulses. Using these pulses, one can create a picture of the interaction and study in detail the particles that emerged.



Once all three detectors are running in 2019, the SBN program will be able to thoroughly test whether the anomalies are due to sterile neutrinos, ruling out this hypothesis or making a detailed study of sterile neutrino oscillations.