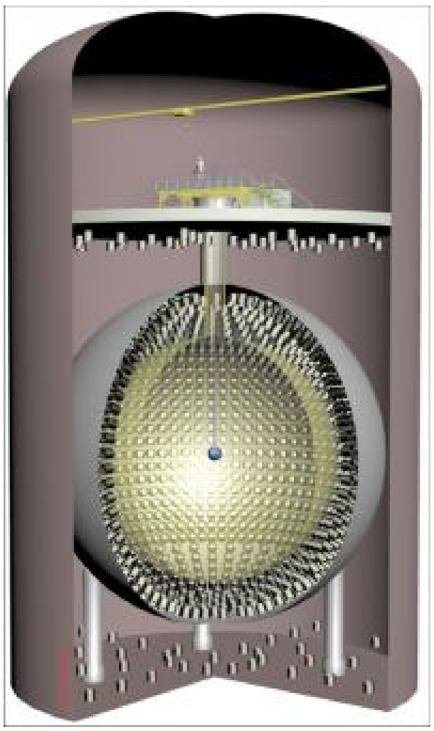
Physicists propose search for fourth neutrino

November 29 2011, by Lisa Zyga



In the proposed test for a fourth neutrino, a small electron antineutrino source (blue) located at the center of a large liquid scintillator detector would be used to bombard a target. The red curve represents the oscillation of the antineutrino rate as a function of the distance within the detector. If the bombardment involves sterile neutrinos, interactions of the electron antineutrinos would show a spatial modulation of a few percent over a few meters. Image credit: L. Scola (CEA)

(PhysOrg.com) -- Physicists know that neutrinos (and antineutrinos) come in three flavors: electron, muon, and tau. In several experiments, researchers have detected each of the neutrino flavors and even watched them “oscillate” back and forth between flavors. But starting in the early ‘90s, some experiments have also revealed a nagging anomaly: muon antineutrinos oscillate into electron antineutrinos at a 3% higher rate than predicted. Physicists can reconcile this discrepancy by adding a fourth neutrino with a specific mass, although such a move would require modifying the Standard Model, the theory of subatomic particles that has taken decades to build. In a new study, a team of physicists thinks it’s time to put the question of the fourth neutrino’s existence to the test.

In their study published in a recent issue of *Physical Review Letters*, Michel Cribier, et al., have proposed an experiment that would reveal whether a fourth flavor of neutrino really exists. If it does, then it would have huge implications not only for neutrino science, but also for understanding the building blocks of matter overall.

The first hints that something was amiss came in the early ‘90s from the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos National Laboratory. In the experiment, an antimuon beam bombarded a target, revealing a greater number of antielectron neutrino oscillations than predicted. Or in other words, antineutrino oscillations seemed to be occurring at a faster-than-expected rate.

But Cribier and his coauthors’ main motivation for carrying out a test of a fourth neutrino rests on the results of a more recent finding, which is now known as the Reactor Antineutrino Anomaly. In a recent study, physicists (including some from the recent paper) at the French Atomic Energy Commission (CEA) in Saclay recalculated the rate of antineutrino production in nuclear reactors that was first calculated in the 1980s. Using improved techniques, the scientists estimated that the rate of antineutrino production is about 3% more than previously predicted. Even after rechecking the new estimates, the 3% antineutrino surplus remains. As a consequence, the same physicists reanalyzed more than 20 previous reactor neutrino experiment results, finding more discrepancies.

The simplest physics explanation for this anomaly is the existence of a fourth neutrino. Physicists have estimated the mass of the fourth neutrino and also determined that it would be “sterile” because it doesn’t interact with matter through the weak nuclear force like the other neutrinos do. This property would make the fourth neutrino particularly difficult to detect; some physicists even suspect that it could be a dark matter candidate.

With so many implications riding on this hypothetical particle, Cribier and his coauthors have proposed a search that they say will unambiguously test for its existence. The experiment would involve firing a 1.85 PBq antielectron neutrino isotropic source (about 10 grams, or less than 4 cm) at a target in the center of a large liquid scintillator detector (LLSD). Possible detectors include Borexino, KamLAND, and SNO+, which contain about a thousand tons of ultrapure liquid scintillator inside a nylon or acrylic vessel. The antielectron neutrino generator would consist of a radioactive source such as cerium nuclei, a common fission product from nuclear reactors that can be extracted from spent fuel rods. In order to achieve a meaningful certainty level, the experiment would run for a full year.

If the bombardment of the target results in a sterile neutrino, the scientists could measure a unique oscillation signature to confirm the neutrino’s existence.

“A sterile neutrino, by definition, is not able to induce an interaction allowing its direct detection,” coauthor Thierry Lasserre from the CEA told *PhysOrg.com*. “Nevertheless, theory predicts oscillation between the three ordinary neutrinos and the sterile one. Thus the experimental signature of a sterile neutrino consists in the observation of interactions of the ordinary neutrinos with a modulation in energy and/or distance controlled by the mixing and masses of the fourth neutrino. The mass (eV scale) and coupling of the sterile neutrino able to explain the reactor antineutrino anomaly is such that interactions of neutrino/antineutrino of typical energy of 1-2 MeV would induce a spatial modulation of several percent over a few meters. Hence if an intense source of neutrino is placed at the center of a spherical liquid scintillator detector (see illustration), the radial distribution of the interaction vertex will deviate from a flat distribution with a sinusoidal modulation. The spatial period is inversely proportional to the mass of the sterile neutrino whereas the amplitude is a function of the coupling between the fourth and the usual electron neutrino."

Lasserre explained that this proposed experiment will provide greater certainty about the existence of a fourth neutrino compared to other experiments due to the neutrino source's smaller size.

"It is difficult to probe this oscillation using standard accelerator or reactor neutrino experiments because the oscillation length is quite small (a few meters with neutrinos of a few MeV)," he said. "A compact radioactive neutrino source provides a new window to look for such oscillations. Thanks to the small spatial dimensions of the source, our proposed experiment would have the potential to actually see the oscillatory behavior of the antineutrino interaction rate as a function of the detector radius (thus inside the detector!). No need to rely on the knowledge of the source activity to the sub-percent; we are looking for a relative oscillatory behavior inside the detector."

One of the biggest difficulties in any neutrino experiment is ruling out background noise, which could give false positives. Background noise can be induced by the environment, the detector, the antineutrino source, or the source's shielding. Due to type of decay event the scientists would analyze (inverse beta-decay), which involves a specific delay time, the scientists explain that this experiment should have the advantage of an almost background-free detection.

The greatest technical challenges of the proposed experiment would be producing the antineutrino source itself and fabricating a thick shielding material to surround the source. Due to these challenges and the kiloton-scale detectors needed, realizing the experiment would require a large collaborative effort. The researchers have begun to talk about carrying out such an experiment.

“I'm requesting some funding to realize the source and shielding to the European Commission for the period 2012-2018,” Lasserre said. “Furthermore, we are discussing with the host detectors, especially with Borexino and KamLAND that expressed an interest in this new source project. I will be in Japan in early December for four seminars and discussion.”

More information: Michel Cribier, et al. “Proposed Search for a Fourth Neutrino with a PBq Antineutrino Source.” Physical Review Letters 107, 201801 (2011). DOI: 10.1103/PhysRevLett.107201801