Reactor Neutrino Detector (RND)

Status: CD-0 Approved in November 2005

Mission Need

Neutrinos are elementary particles which were long thought to be massless, unlike other elementary particles such as quarks and electrons. However, one of the most significant developments in particle physics in the last several years has been the convincing evidence that neutrinos have mass. These masses are extremely small and have only been observed through a quantum mechanical phenomenon called neutrino oscillations. Oscillations can only occur if neutrinos have different masses and if the mass states of the neutrino are made up of a mixture of the various interaction states. The mixing of the neutrinos between mass and interaction states can be represented by 3 trigonometric angles called θ_{12}, θ_{23}, and θ_{13}. Two of these mixing angles, θ_{12} and θ_{23}, were measured with reasonable accuracy by various solar, atmospheric and accelerator based neutrinos experiments and are large. The third angle, θ_{13}, is known only to be relatively small but has not been measured and could be zero.

Charge-Parity (CP) symmetry relates the properties of particles to their antiparticles and is usually conserved. However, CP symmetry has been discovered to fail in some limited circumstances. These violations of CP symmetry are very important to us. CP violation is required to explain why matter vastly outnumbers antimatter in the universe. CP violation was first observed in 1964, in the decay of particles that contain one strange quark. Since the early 1990s, experiments at the Stanford Linear Accelerator Center (SLAC) and the Japanese High Energy Accelerator Research Organization (KEK) have also observed CP violations from the rare decays of particles containing bottom quarks. However, the level of CP violation observed in these two cases is too small to explain the matter-antimatter asymmetry of the universe.

CP violation can also occur in the neutrino sector and discovering it would be a major addition to our understanding. Measurement of neutrino CP violation will, however, only be possible if the presently unknown neutrino mixing angle, θ_{13}, is not zero. Therefore, the first step to determine the feasibility of measuring CP violation in the neutrino sector is to determine the magnitude of the neutrino mixing angle θ_{13}.

In response to the many exciting possibilities arising from the discovery of neutrino oscillations, four divisions of the American Physical Society recently completed a year long study of the opportunities available in neutrino physics. Among their recommendations is *"An expeditiously deployed multi-detector reactor experiment with sensitivity to* ν_e *disappearance down to* $\sin^2 2\theta_{13}=0.01$*…"*

The Reactor Neutrino Detector also supports the Department of Energy's Science Strategic Goal within the Department's Strategic Plan dated September 30, 2003: *To protect our National and economic security by providing world-class scientific research capacity and advancing scientific knowledge*. Specifically it supports the two Science strategies: *1. Advance the fields of high-energy and nuclear physics, including the understanding of dark energy and dark matter, the* *lack of symmetry in the universe, the basic constituents of matter…*and *7. Provide the Nation's science community access to world-class research facilities….*

Options

Reactors provide a high intensity, isotropic source of neutrinos with a well-known energy spectrum. Over the past few years, a number of experiments studied neutrino properties using reactors. They have observed evidence for neutrino oscillations confirming the results from solar, atmospheric and accelerator based neutrinos experiments. However, they were not sensitive enough to measure θ_{13}.

Compared to past experiments, the next generation reactor neutrino detector that HEP is proposing will make a more precise measurement of the disappearance of electron anti-neutrinos and, therefore, will be much more sensitive to θ_{13}. The improved sensitivity arises from having detectors at several distances from the reactor, reducing backgrounds, and using a higher intensity neutrino source (higher thermal power reactor).

Option 1: Participate in the Double Chooz experiment. Double Chooz is a proposed experiment in France that would measure the neutrino mixing angle θ_{13} with a modest sensitivity using identical small (approximately 12 ton) near and far detectors. The Chooz reactors provide a total of 8.5 GW of thermal power. Operation could start as early as 2008 if the experiment achieves quick approval and funding. Results from this experiment would be obtained several years earlier than for the other options, the cost to the U. S. would be low, and there is previous experience with a neutrino experiment at the site.

Option 2: Daya Bay. The Daya Bay experiment in China would measure the neutrino mixing angle θ_{13} with a high sensitivity, using multiple identical detectors, perhaps 10-30 tons each. There are two operating power plants in the area with reactors providing a total of 11.6 GW of thermal power. A third power plant is scheduled to come online in 2010 that will increase the thermal power to 17 GW. If approved, operation of the experiment would be expected to start in the 2010-2013 timeframe. The advantages of this experiment are that it has high thermal power, low U. S. cost, and strong support by China. The U. S. would need to reach a suitable agreement with China on the design, operation and funding of the experiment.

Option 3: Braidwood. The Braidwood experiment in Illinois would measure the neutrino mixing angle θ_{13} with high sensitivity, using four identical large (greater than 40 tons) movable detectors: two near and two far. The Braidwood reactors provide a total of 7.2 GW of thermal power. If the Braidwood experiment is approved operations would be expected to start in the 2010-2013 timeframe. This experiment has the advantage of being onshore, using multiple detectors, and measuring the mixing angle θ_{13} in two different ways, from the energy spectrum and from the rate. The cost to the U. S. would be higher than in the other options.

Option 4: Do nothing. The risks of doing nothing are varied. The U.S. will neither take scientific leadership nor be competitive and will lose the research capabilities to advance scientific knowledge in this area. Failure to pursue a complete understanding of CP violation leave the question of why the universe is dominated by matter unanswered.