Excerpts from Mission Need Statement for the Reactor Neutrino Detector

Office of High Energy Physics
Office of Science

Neutrinos are elementary particles which were long thought to be massless, unlike other elementary particles such as quarks and electrons. Thus, in the highly successful Standard Model of particle physics, neutrinos are assumed to be massless. However, one of the most significant developments in particle physics in the last several years is that convincing evidence has been obtained that neutrinos have masses and that the three known types of neutrinos mix with one another. A number of experiments taken together provide convincing evidence for neutrino oscillations, quantum mechanical phenomena in which neutrinos of one type turn into neutrinos of another type. Neutrino oscillations only occur if neutrinos have masses and a difference in the masses of two neutrinos allows different types of neutrinos to mix with each other. This discovery of neutrino mass and mixing provides a first indication of physics beyond the Standard Model. Neutrino masses, which are more than a million times smaller than quark masses, are thought not to derive from the same mechanism as for other particles but instead to arise from physics at very high energies such as those present in the big bang. Thus there is great interest in precisely determining the masses and mixing parameters to gain insight into the new physics.

The mixing of the neutrinos 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 long-baseline neutrino 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. However, unlike a perfectly conserved symmetry, such as conservation of energy or electric charge, CP symmetry has been discovered to fail in some limited circumstances. These small failures, or violations, of CP symmetry are very important to our understanding of the universe. CP violation is required to explain the fact that matter vastly outnumbers antimatter in the universe. CP violation was first observed in 1964, in the decay of particles called K mesons 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 studied CP violations from the rare decays of particles containing bottom quarks. However, the level of CP violation observed has been too small to explain the matter-antimatter asymmetry of the universe.

There could be other sources of CP violation, such as in the neutrino sector, and discovering these sources would be a major addition to our understanding of the universe. There is no fundamental reason to believe that the mechanism for neutrino CP violation is the same as the one observed in the quark sector. Only experimental measurements can determine the size of CP violation among neutrinos. Neutrino mixing offers the possibility of observing CP violation in the neutrino sector. Measurement of this 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 various possible approaches to measuring CP violation in the neutrino sector is to determine the magnitude of the neutrino mixing angle θ_{13}. Knowing the value of θ_{13} will be important in developing cost effective plans for precisely measuring CP violation in the neutrino sector.

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….*

The reactor provides 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 as the neutrino sources. They have observed evidence for neutrino oscillations and confirmed other results from solar, atmospheric and accelerator based long-baseline neutrinos experiments. These experiments were designed to detect signals due to large mixing which are easier to measure with a limited sensitivity. However, they were not able to make measurements of neutrino mixing parameters such as θ_{13} which require high precision.

Based on the knowledge gained from these past experiments, a next generation reactor neutrino experiment is proposed that will make a precision measurement of the disappearance of electron anti-neutrinos due to neutrino oscillations and will be much more sensitive to θ_{13} then previous experiments. The improved sensitivity arises from having detectors at several distances from the reactor, reduced backgrounds and the use of a higher intensity neutrino source (higher reactor thermal power). A precise determination of θ_{13} is important in order to clarify the difficulty of measuring CP violation in the neutrino sector and to improve our understanding of the physics of neutrinos. Therefore, HEP is proposing the Reactor Neutrino Detector.

There are no existing reactor-based neutrino detector facilities in the U. S. or overseas that are capable of measuring $\theta_{13.}$

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 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. This area of research would be new for Chinese scientists and thus it would be crucial to have a strong U. S. science team guiding the project.

The discovery of neutrino mass and mixing provides evidence for exciting new physics beyond the standard model of particle physics and also offers possibilities for measuring CP violation in the neutrino sector. If the U. S. does not participate in a reactor-based measurement of a crucial mixing angle that is needed to pursue the new physics then other countries will take scientific leadership in this area. The U. S. will not be competitive because it will lack the research capabilities to advance scientific knowledge in this area. Thus it would not support the Department of Energy Science strategic goal, described in the last paragraph of section A, of "… providing world-class scientific research capacity and advancing scientific knowledge" and the two science strategies of 1. advancing the understanding of "... the lack of symmetry in the universe.." and "… the basic constituents of matter.." and 7. providing "… access to world-class research facilities."