Excerpts from Mission Need Statement for an Electron Neutrino Appearance (EvA) Detector

Office of High Energy Physics
Office of Science

Recent developments are beginning to unravel the mystery of the neutrinos. Perhaps the most significant development in the last several years is the discovery that the three known types of neutrinos mix with one another. The results of a number of experiments together provide convincing evidence for neutrino oscillations, a quantum mechanical phenomenon in which neutrinos of one type turn into neutrinos of another type (oscillations). Neutrino oscillations can only occur if neutrinos have masses, since the rate of oscillation depends on the difference between the neutrino masses. This is indirect but compelling evidence that at least two of the neutrinos have masses. What makes this particularly striking is that the masses of the neutrinos appear to involve a different physical mechanism than the Higgs mechanism believed to be responsible for the masses of the other known particles, the quarks and charged leptons. The only way the Higgs mechanism can be responsible for neutrino mass is if there is a new fundamental symmetry of nature. In either case the fact that neutrinos have masses has revealed new facets of nature that we do not yet understand.

The experimental study of neutrino oscillations also can offer the possibility of observing a difference in the behavior of matter and antimatter, or CP violation. In the early universe equal quantities of matter and antimatter were created, but the present universe is filled with matter and not antimatter. A slight difference in the behavior of matter and antimatter has been observed in some decays of particles containing heavy quarks, but these effects are too small to explain the observed dominance of matter in the universe. There are interesting models for explaining the observed matter-antimatter asymmetry that involve new sources of CP violation in the neutrino interactions. Thus it is important to look for CP violation in the neutrinos as well as continuing studies of CP violation with quarks.

So far, three types of neutrinos have been observed; electron neutrino, ν_e, muon neutrino, ν_μ, and the tau neutrino, ν_τ; and different detection techniques are required to observe the different types of neutrinos. Therefore completely distinct experiments will be required to measure different types of neutrino oscillations.

For example, the disappearance of ν_μ has been observed by seeing fewer muon neutrinos at a distance hundreds of kilometers from the source than would be expected if neutrinos do not oscillate. It is assumed that most of muon neutrinos from the original neutrino source (neutrino beam) oscillated to $\nu_{\tau,}$ since the detectors were sensitive enough to detect ν_e for such a rate of oscillation but not ν_τ. The oscillation of ν_μ into ν_e over those distances may occur, but the rate of such oscillation is smaller than is detectable in current experiments.

Measurement of the oscillation rate from ν_μ to ν_e together with the current disappearance measurement of ν_μ to ν_τ can provide the first logical step towards answering two important questions stated above - the unknown physical source of the mass of the neutrino and the source of the matter-antimatter asymmetry (CP violation). Therefore, an experiment that is highly optimized to detect ν_e together with high intensity neutrino source will be needed. In addition, such an experiment with a neutrino beam that travels a long enough distance will provide necessary information to determine the neutrino mass spectrum by measuring the "mass hierarchy".

Although we now are confident that neutrinos have masses, we only know that there are differences in masses, of which two neutrinos are close in their masses and the other is either significantly heavier or lighter. However, we do not know which neutrino is heavier or lighter than the other two. Fully understanding neutrino masses will require that at least the mass of one neutrino be directly measured and that we determine whether the pair of similar mass neutrinos is heavier or lighter than the other neutrino (the "mass hierarchy"). It should be noted that the direct measurement of one of the masses will require a different technique such as using the neutrino-less double beta decay of certain nuclear isotopes.

A joint study on the future of neutrino physics was published in November 2004 by four divisions of the American Physical Society: Division of Nuclear Physics, Division of Particles and Fields, Division of Astrophysics, Division of Physics of Beams. They recommended *"a comprehensive U.S. program to complete our understanding of neutrino mixing, to determine the character of the neutrino mass spectrum and to search for CP violation among neutrinos."* The report describes one required component of the program as, *"A timely accelerator experiment with comparable* $\sin^2 2\theta_{13}$ *sensitivity and sensitivity to the mass hierarchy through matter effects."*

HEP is proposing an experiment based on a detector capable of addressing ν_μ to ν_e oscillations and the "mass hierarchy". This experiment and detector will support 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 will support the two Science strategies: *1. Advance the fields of high-energy and nuclear physics, including the understanding of … 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….*

Two of the questions discussed above: the observation of ν_μ to ν_e oscillations and the determination of the mass hierarchy can be answered by a single experiment. Such an experiment would use a beam of muon neutrinos produced at an accelerator and detected in two locations: one close to the accelerator to demonstrate that the beam at this point is nearly pure muon neutrinos and a second detector several hundred kilometers from the first detector. The observation of ν_μ to ν_e oscillations requires a large detector that is optimized to detect the interactions of electron neutrinos.

The Neutrinos at the Main Injector (NuMI) facility at Fermilab produces the world highest intensity neutrino beam and is being used for the MINOS experiment which has the far detector located in Soudan Mine in northern Minnesota. The MINOS experiment is measuring the neutrino oscillations by observing the disappearance of (lack of) ν_μ in the far detector. However, MINOS is not sensitive to detecting electron neutrinos. The intensity of the existing NuMI facility is sufficiently high enough that there will be no need for modification of the NuMI facility.

The DOE strategic goal to advance scientific understanding includes a strategy to study the lack of symmetry in the universe in order to reveal its key secrets. The study of CP violation falls under this strategy. Since the discovery of CP violation in 1964, it has been an important component of the DOE's high energy physics program. It was the main motivation for the construction of the B Factory, an electron-positron collider at Stanford Linear Accelerator Center (SLAC), where CP violation in the B meson sector was discovered in 1999 and will continue to be studied for several more years.

The successful measurements of CP violation at the B Factory have clearly shown that CP violation of B mesons alone is not sufficient to explain the matter-antimatter asymmetry of the universe. The neutrino sector is the most promising area for new discoveries in CP violation, and the Electron Neutrino Appearance Detector is the next logical step in that program.

Failure to approve this mission need statement will leave the United States without a world class facility in accelerator neutrino physics, which would be contrary to the DOE strategic goal, *providing world-class scientific research capacity and advancing scientific knowledge*. In addition, while the proposed Japanese experiment may yield some interesting results, the very long range neutrino beams needed to complete the program are only possible in the United States.

The selection of individual experiments that best fulfill the goals of the neutrino program will be done based on the recommendation of the Neutrino Scientific Assessment Group, a joint subpanel of the High Energy Physics Advisory Panel (HEPAP) and the Nuclear Science Advisory Committee (NSAC). This will be used as input to the CD-1, Approve Alternative Selection and Cost Range. The prioritization of neutrino experiments relative to other efforts in the HEP program will be done by Particle Physics Project Prioritization Panel (P5), a HEPAP subpanel. Since accurate cost information will needed by P5, a P5 recommendation will occur at or after CD-2, Approve Performance Baseline.

The technologies being considered are liquid scintillator, solid scintillator, liquid argon, water Cerenkov, and resistive plate chambers. All are well established in high energy physics. The goal of the research and development will be to determine how far the technologies can be successfully scaled up. Larger detector elements will require fewer channels of readout electronics for the same total volume of detector. The expense of readout electronics is proportional to channel count. Therefore the R&D will be aimed at determining how to minimize cost while achieving the physics goal of the experiment.