Mission Need Statement for a Long Baseline Neutrino Experiment (LBNE)

Major System

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Office of High Energy Physics
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A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to support exploration of the physical universe through the discovery and study of the elementary constituents of matter and energy and the nature of space and time. These areas of research are an integral component for the advancement of all science and technology and an expression of society's timeless intellectual quest to understand the universe. The Standard Model of particle physics represents an unprecedentedly successful description of the elementary particles and their interactions; however, we know this model is incomplete and our present understanding indicates the existence of a more fundamental underlying theory. Elucidating this deeper theory requires a broad research program at the complementary and interrelated Energy, Intensity, and Cosmic Frontiers of particle physics.

At the Intensity Frontier, intense particle beams are utilized to investigate the properties of neutrinos and rare processes, both probes of new physics. Results from the last decade conclusively demonstrate that the three known neutrinos have nonzero mass, mix with one another, and oscillate between generations—properties which represent tantalizing hints of physics beyond the Standard Model. Cosmology indicates that the neutrino mass is less than one-millionth that of the electron, yet oscillation studies from experiments find tiny, but nonzero, mass differences between neutrino generations and large values for two of the three mixing angles. Currently, the individual masses are unknown and only an upper limit exists for the third angle.

The recent progress in neutrino physics has laid the basis for new discovery opportunities. As a fundamental physical constant, measurement of the unknown third mixing angle is of great interest and will influence the direction and evolution of an international neutrino program. Determining the relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model. The study and observation of the different behavior of neutrinos and antineutrinos traversing matter will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance. A popular hypothesis asserts that the asymmetry arises from neutrino interactions and is the subject of intense research.

The Office of High Energy Physics proposes construction of an experiment comprised of a large detector illuminated by a distant, intense neutrino source and a much smaller detector located close to the source. The far detector must be at a long distance from the neutrino source to increase sensitivity to neutrino oscillations and have sufficient sensitivity (through increased size and technological innovation or both) to improve neutrino detection. A new intense neutrino source, pointing towards the detector, is also needed along with a nearby detector to measure the initial composition of the neutrino beam. The increased research capabilities afforded by a long baseline (distance between the detector and the neutrino source) neutrino experiment will enable a world-class program in neutrino physics that can measure fundamental physical parameters, explore physics beyond the Standard Model, and better elucidate the nature of matter and antimatter.

B. Analysis in Support of Mission Need

The U.S. today enjoys a leadership role in exploration of the neutrino properties. The currently operating Main Injector Neutrino Oscillation Search (MINOS) experiment is designed to observe neutrino oscillations using two detectors, one located at Fermi National Accelerator Laboratory (Fermilab) and the other located 730 km away in northern Minnesota in the Soudan Mine. The neutrino source or beam, called Neutrinos at the Main Injector (NuMI), originates at Fermilab.

The neutrino beam is produced by directing a proton beam onto a target where it interacts and produces large numbers of pions. The pions are focused by a magnet into a decay pipe, wherein their decays produce neutrinos. There is a direct relationship between the power of the proton source and the intensity of the neutrino beam. The proton beam and decay pipe must point towards the neutrino detectors. For detectors that are hundreds of kilometers away, the decay pipe actually points down, at an angle, into the Earth.

The fourteen kiloton NuMI Off-axis Neutrino Appearance (NOνA) experiment, under construction approximately 800 km from Fermilab, will succeed MINOS and has been optimized to directly detect oscillations of the electron neutrinos in the NuMI beam. NOνA will provide initial information on the unknown mixing angle and matter-antimatter asymmetries.

Current results and the future promise of new knowledge and discovery indicate that a larger, longer baseline neutrino detector illuminated by a high intensity neutrino beam will be an important and unmatched facility for the US physics program. All three mixing angles could be measured to unprecedented precision and thus guide theorists with improved experimental results. Because the neutrino beam passes through the Earth, the long baseline would enhance matter effects, which, in turn, would improve sensitivity to both the mass ordering and origins of the matter-antimatter asymmetry. Such a facility would require a detector with sensitivity surpassing that of NOνA and be located 1000-1500 km from the neutrino beam source.

A large, long baseline detector and neutrino beam facility can serve a broad, multipurpose program and probe the universe on both the microscopic and astronomical scales. The large detector, if located underground, and thus shielded from cosmic backgrounds, could also be sensitive to proton decay, predicted by grand unified theories which are natural extensions of the Standard Model. As a probe of grand unified theories, proton decay offers access to the highest energy scales in particle physics. Furthermore, an underground detector could serve as an observatory for neutrinos generated by supernovae since the beginning of time and for neutrinos generated more recently by supernovae in our galactic neighborhood, yielding new information on the collapse mechanisms of stars.

The physics program enabled by a large, long baseline, detector and neutrino beam facility is fully consistent with the Secretarial Strategic Priority of Science, Discovery, and Innovation. The program would demonstrably "Advance fundamental knowledge in high energy physics and nuclear physics that will result in a deeper understanding of matter, energy, space and time." A diverse program in neutrino physics would also help ensure that the U.S. maintains leadership at a scientific forefront of particle physics.

The May 2008 report of the Particle Physics Project Prioritization Panel (P5, a subpanel of the High Energy Physics Advisory Panel or HEPAP) strongly recommended continued exploration of the Intensity Frontier and, particularly, of neutrino properties. To quote, "The panel recommends a world-class neutrino program as a core component of the US program, with a long-term vision of a large detector in the proposed DUSEL and a high-intensity neutrino source at Fermilab." The proposed Deep Underground Science and Engineering Laboratory (DUSEL) is under development by the National Science Foundation (NSF).

The large, long baseline detector and neutrino beam project and program are well coordinated with the current and planned activities of the U.S. particle physics program. The NSF proposed DUSEL site at Homestake Mine in Lead, South Dakota, represents a good possible location of the detector since it offers depth for shielding and distance for neutrino oscillations. As part of the NuMI/MINOS project, Fermilab has already developed the expertise for construction of neutrino beams. The 700 kW upgrade of the Fermilab proton source, a component of the current NOνA project, offers a platform from which to launch a new neutrino beam for a long baseline detector.

Capability Gap

There is a capability gap in the U.S. High Energy Physics program and world-wide particle physics program for neutrino physics. Further progress in the investigation of neutrino mass ordering and matter-antimatter asymmetry requires a combination of larger detectors and more powerful beams capable of observing an order of magnitude more neutrino interactions where the beam and detector(s) must be separated by 1000-1500 km. No existing or planned facility in the U.S. or internationally fills this capability gap.

C. Importance of Mission Need and Impact If Not Approved

The members of the P5 HEPAP subcommittee examined the scientific opportunities and options for mounting a world-class program over the next decade and identified a US program at the Intensity Frontier as a unique, compelling scientific opportunity that would deliver outstanding discoveries and advancements while also providing the foundations for a potential return of the Energy Frontier to a US facility. These new capabilities could be realized in a cost-effective manner by building on existing infrastructure at Fermilab and US expertise in detector technology and through a partnership between DOE and NSF. This long baseline neutrino experiment project is the first and a critical step towards realizing this long term strategic plan for the US HEP program.

Neutrino oscillations experiments with baselines less than 1000 kilometers are running or being developed in the United States, Japan, and Europe. However, only the United States has the ability to extend the baseline to greater than 1000 kilometers. Neither, the Japanese or the Europeans have been able to identify a suitable site with a long baseline due to the fact that they would need to extend into other countries and therefore would need to find partners in those countries willing to host the detector. Despite discussions at the level of the interested scientists, no international partnerships have developed. For example, a long baseline experiment utilizing the neutrino beam in Japan would need to have a detector in China or Korea. Neither country has expressed interest in such a program

Lack of approval would deny US researchers the opportunity to maintain and enhance a world-leading program in neutrino physics. Lack of approval would undermine DOE HEP's strategic plan to mount a balanced and vital US program in particle physics in the next decade. Without the research capabilities implemented in this project, crucial information fully characterizing the neutrino sector, such as the value of the third mixing angle and the degree of CP violation, would not be obtained; our ability to understand the matter-antimatter asymmetry in the universe would be compromised.