Project Summary

This proposal requests funding to complete the design and engineering for a two-location neutrino oscillation experiment at the Braidwood Nuclear Power Station in Illinois. The goal of the experiment is to measure θ_{13}, the last unmeasured angle of the neutrino mixing matrix, with a sensitivity of $\sin^2 2\theta_{13} \sim 0.01$.

Intellectual Merit Recent years have seen enormous progress in the physics of neutrino mixing, but several critical questions remain: What is the value of θ_{13}, the last unmeasured mixing angle in the neutrino mixing matrix? What is the mass hierarchy? (i.e., what is the sign of $m_1^2 - m_3^2$). Do neutrino oscillations violate CP symmetry? Why are the quark and neutrino mixing matrices so different? The value of θ_{13} is central to each of these questions. Its value sets the scale for experiments needed to resolve the mass hierarchy and to search for CP violation. In addition, the size of θ_{13} with respect to the other mixing angles may give insights into the orgin of these angles and source of neutrino mass. Reactor experiments hold the promise of unambiguously determining the θ_{13} mixing angle.

The Braidwood Experiment will be sensitive to $\sin^2 2\theta_{13}$ at the level of 0.01. The APS Multidisciplinary Study on the Future of Neutrino Physics identified a reactor experiment with this precision as one of the highest priorities in the field. The Braidwood site is ideal for the θ_{13} measurement, and also has the unique potential to make a precise measurement of the weak mixing angle, $\sin^2 \theta_W$. The flat overburden at Braidwood allows for a design with great flexibility, redundancy, and cross checks. The baseline design has four 65 fiducial tonne detectors, two at 200m and two at 1500m (horizontal distance) from the reactor. The detectors can be moved between locations to provide cross calibration and to respond to physics results.

The Exelon Corporation, which owns the Braidwood site, has encouraged us to move toward submission of a full proposal as soon as possible. With this cooperation, a reactor experiment is a timely and cost-effective way to perform this measurement: the neutrino source exists and the required detectors are of modest size and complexity.

The plan described here will take our design from the pre-proposal stage to the level needed for submission of a full proposal. Our request addresses three key issues: 1) civil engineering, 2) detector engineering, and 3) R&D related to the Gd-loaded liquid scintillator.

Broader Impact As outlined in the APS Multidisciplinary Study on the Future of Neutrino Physics, the future program in neutrino oscillation physics depends on a question that the Braidwood Experiment will answer: is θ_{13} large or small? Currently planned long baseline experiments using MegaWatt proton sources will have the possibility to measure the mass hierarchy and observe CP violation only if $\sin^2 2\theta_{13}$ is greater than 0.01. Otherwise, techniques such as super-long-baseline beams, beta-beams, or neutrino factories will be required. Since the investment for these programs is very large, it is important to choose the most effective approach. The Braidwood Experiment will provide the needed information.

Should the Braidwood experiment demonstrate that θ_{13} is large, searches for CP violation will be particularly compelling. CP violation in the neutrino sector may ultimately help explain the baryon-antibaryon asymmetry in the universe through leptogenesis. In this process, a small lepton asymmetry develops from CP violation effects in the neutrino sector and is then transferred to the baryons. Although most models of leptogenesis rely on direct CP violation in decays of heavy Majorana neutrinos, observation of any CP violation in the neutrino sector would be an important clue to one of the most fundamental questions in particle physics.

As alluded to above, the parameter θ_{13} also provides a window into the regime of Grand Unified Theories (GUTs). In most GUTs, θ_{13} is expected to be large since the other angles, θ_{12} and θ_{23}, are nearly maximal. On the other hand, if θ_{13} is shown to be small, it might indicate some new symmetry in the neutrino sector, giving a hint about how the neutrino masses and mixings come about.

Since the R&D in this proposal is ideal for involving and training students, we have developed a program to include undergraduates in this exciting phase of the experiment. The program will support undergraduate research during the summer, and will include an intensive three-day summer school on neutrino physics and the Braidwood experiment.