EXPRESSION OF INTEREST

Engineering and R & D for the Braidwood Neutrino Experiment

The Braidwood Collaboration

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1 Overview

This Expression of Interest requests funding to complete the design and engineering for a two-location neutrino oscillation experiment at the Braidwood Nuclear Power Station in Illinois.[2] The Braidwood experiment is designed to achieve 3σ discovery potential for $\sin^2 2\theta_{13} > 0.01$ and sensitivity at the 90% confidence level for $\sin^2 2\theta_{13} > 0.005$. This precision is necessary, as outlined in the APS Neutrino Study, both for furthering the knowledge of oscillation phenomena, and for making future plans to study the mass hierarchy and CP violation in the neutrino sector.

The Braidwood site, which has two 3.59 GW reactors, 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 available at Braidwood allows for a design with great flexibility, redundancy, and cross checks, making it possible to establish the validity of an oscillation signal and to verify quoted systematic errors.

The baseline design has four 65-ton fiducial-mass detectors, two at 200m and two at 1500m (horizontal distance) from the reactors; both near and far detectors are at the same depth of 183 m (464 mwe). Each 7 m diameter spherical detector includes two regions: an inner region ($r = 2.6$ m) filled with Gd-loaded (0.2% by weight) liquid scintillator in a spherical acrylic shell and an outer region ($r = 3.5$ m) filled with mineral oil. The inner surface of the 7m diameter vessel is covered with about 1000 8" photomultiplier tubes giving 25% photocathode coverage. Each spherical detector is surrounded by a tagging and shield system discussed below. Key design features include the following.

- The experiment has excellent sensitivity to the oscillation signal using either rate or energy spectrum measurements. Figure 1 shows the sensitivity as a function of time for rate and energy spectrum measurements separately, and also for the combined fit.
- Detectors can be moved between near and far locations to make a direct measurement of relative acceptances. For example, moving a far detector to the near site for 10% of the time can provide a check of the relative efficiency to the 0.3% level.
- The equal overburden at near and far sites will allow us to use spallation isotopes like ^{12}B to measure relative efficiency and energy calibration between near and far detectors.
- Multiple near and far detectors allow a direct cross check on detector systematics at 0.05% for the near detector pair and 0.3% for the far pair.

During the last year, while our 2004 Engineering and R&D proposal has been under review by the NSF and DOE (and by NuSAG), the Collaboration has continued to make rapid progress on several important issues using funds from the group's base grants. The highlights include:

- Detector Simulation. The group has completed a GEANT4 simulation of the detector, and implemented vertex and energy reconstruction algorithms. Initial studies with this GEANT4 simulation have confirmed results of earlier design studies based on our fast simulation program that relied on paramaterizations for many detector effects.

[2] The objective of this EOI is the same as that of the 2004 Engineering and R&D Proposal [1] submitted to the DOE and NSF by the Braidwood Collaboration (http://braidwood.uchicago.edu/doe_eoi/DOEprop2004.pdf).

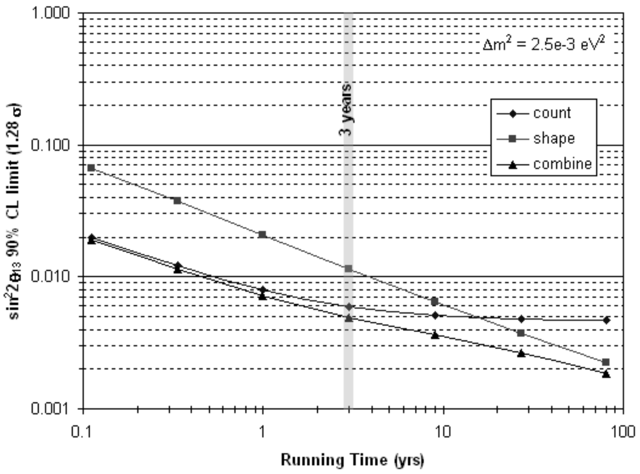

Figure 1: The 90% CL sensitivity of the Braidwood experiment versus running time for $\Delta m^2 = 2.5{\times}10^{-3}$ eV^2. The nominal data taking period is expected to be three years, which corresponds to a luminosity exposure of 2,800 GW-ton-years in the far detectors. The different types of fits are indicated by the markers on the line.

- Site investigation. The Exelon Corporation, which owns the Braidwood site, has been enthusiastic in their support of the project. In December 2004, we used a 3rd party contractor to drill bore holes to the full experimental depth at the near and far shaft locations, both on Exelon property, as a first step in finalizing the civil construction design. The bore hole analysis confirmed our assumptions concerning the shielding properties of the site's rock overburden making Braidwood an ideal site for the proposed experiment.

- Tagging and shield system design. The Collaboration has invested significant effort in refining our understanding of different sources of background, and in developing a conceptual design for a tagging and shield system to surround each spherical detector module. The tagging and shield system acts to reduce the background in the neutrino detector in two ways: the shield absorbs secondaries from cosmic ray interactions outside the shield and the tagger identifies charged particles at the surface of the shield. The system consists of 1 - 1.2 m of heavy concrete instrumented on the outer and inner surfaces with active detector elements having 99% coverage and efficiency, with $\sim$ 10 cm position resolution.

- Liquid scintillator (LS) development. Members of the Collaboration from the Brookhaven Nuclear Chemistry group have developed two Gd-loaded liquid scintillator options that have the properties required for our experiment (long-term chemical stability, high light output, and high optical transparency). One of these is based on pseudocumene (PC), a well-known LS, and the other uses Linear Alkyl Benzene (LAB), a new organic LS appears to have several advantages compared to PC. Figure 2 shows the stability of different formulations of Gd with PC. The 0.22% Gd in PC+dodecane, with a stable attenuation length of 22m, is a candidate scintillator for the experiment.

- Prototype detector. The group is currently fabricating a 1 ton prototype detector including six 8" PMTs. The prototype will allow us to validate several aspects of our simulation program, study performance of candidate readout electronics, and study samples of Gd-loaded LS.

The critical path item for the experiment is now the completion of the engineering design study (both civil and detector) needed to prepare a full, reviewable Braidwood proposal. Real progress toward an approved project will not happen if this step is delayed. The funding is crucial since

Table 1: Cost estimate for required civil engineering. This estimate is made in increments of $25K where one unit of $25K represents 1 senior engineer-month or 2 junior-engineer months.

Task	Cost (thousands of dollars)
Geology/Geo-technical	75
Civil/Structural	50
Electrical	25
Mechanical	25
Drafting	75
Cost & Schedule	25
Other Costs (e.g., Life Safety)	50
Management & Administration	75
Detector Moving Study	25
Contingency	100
Total	525

the Braidwood Collaboration does not have access to the usual National Laboratory funding that is typically used for these types of studies. The funding proposed in this EOI, which is essentially the same as the request in our 2004 proposal, addresses engineering and R&D work that is needed for this task, and which is beyond the scope of the collaboration's existing grants. The request includes: 1) funds to do a complete civil engineering design and cost estimate, 2) funds for detector engineering and R&D, and 3) funds to prepare larger samples of Gd-loaded scintillator for prototype studies, and to develop procedures for mass-production of Gd-LS. The following sections breifly summarize the proposed activities in these 3 areas. We are also requesting funds for undergraduates to participate in the outlined R&D studies. Section 5 gives the overall budget.

2 Civil Engineering

As described in [1], the civil construction for the Braidwood experiment will include excavation and outfitting of large vertical shafts and detector halls at the near and far sites. A surface building for detector assembly and infrastructure for transportation of detectors between the near and far sites also will be needed. The group plans to use a design and build contract for civil construction. This approach requires the collaboration to develop a detailed set of requirements for the project. Table 1, identical to that in [1], outlines the cost estimate for civil engineering required to establish these requrements, provide a reliable estimate of cost and schedule for the project, and to create a bid package suitable for completing a design and build contract. The specific elements of this study, and their approximate costs, are described in detail in [1].

3 Detector Engineering and R&D

Table 2, a slightly modified version of a table from [1], summarizes tasks/studies required to prepare a full engineering proposal for the Braidwood detector; the items are described in detail in [1]. While many of the tasks are mainly mechanical engineering, the group's work during the last year has identified some additional R&D tasks associated with the tagging and shield system. These involve making a final technology choice for the large area tracking detectors required for this system. Compared to [1], we have shifted \$32k from engineering to equipment to build a gas system and engineering prototype for a 4-gap RPC, and to construct a vessel for testing a scintillator-based tracking detector.

Table 2: Estimate of detector engineering and equipment costs (in thousands of dollars) for the Braidwood Experiment planned for coming year.

Task Name	Equipment (k\$)	Work (hours)	Total Cost (k\$)
Spherical Detectors			
Steel tanks	0	160	14
Acrylic vessels	0	378	35
Oil	10	168	27
Oil plumbing system	0	364	35
PMT system	0	200	19
Cable system	0	160	9
Tank support system	0	320	29
Detector electronics	0	104	10
Radioactive source scanning system	0	616	56
Tagger and Shield System			
Passive shielding	0	498	44
Muon tracking system	32	180	48
Subtotal	42	3,320	326
Contingency (25%)	11	830	82
Total	53	4150	408

4 R & D for Gd-loaded Liquid Scintillator

During the next year, the BNL Nuclear-Chemistry Group will prepare multi-liter sized samples of Gd-LS for evaluation by the Braidwood collaboration in prototype detector modules. The BNL group will also perform the R&D for the scale-up in size required for planned industrial-scale production of $\sim$ 260 tons of Gd-LS. If this production can be done in cooperation with the chemical industry, the BNL Group will develop the detailed acceptance specifications and do the Quality Control of the product Gd-LS. If industry cannot produce a high-quality product, it is likely that new chemical synthesis facilities will have to be built at BNL. As part of this proposal, BNL will begin to acquire larger-scale chemical equipment than it has been using so far in its lab-bench scale procedures, such as separation and mixer-dilution systems, distillation rigs and ion-exchange columns for purification procedures, and centrifuges for liquid separations.

To perform the chemical and radiochemical R&D tasks that remain to be done for this proposal, the BNL group will have to increase in size. To help this process, BNL recently awarded LDRD funding to support $\sim$ 1/2 postdoc. This R&D request contains a funding request for another $\sim$ 1/2 postdoc (\$50 k). An additional \$28 k, as noted in [1], is for (a) the chemicals and equipment needed to continue and finalize R&D on the synthesis of high-quality Gd-LS, and for other issues that the Group has recently begun to study, such as (b) the chemical compatibility of the Gd-LS

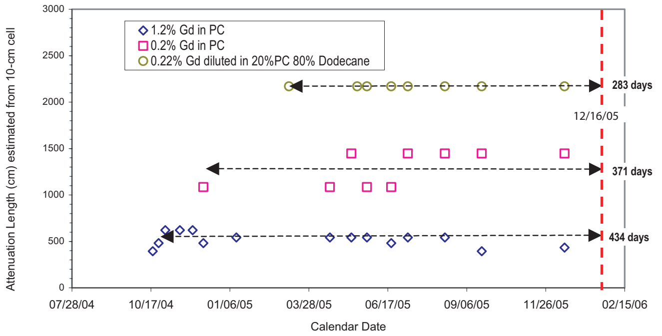

Figure 2: Measured attenuation length versus number of days for different liquid scintillators. The 0.22% Gd diluted in PC and dodecane is a candidate scintillator for Braidwood.

with the detector vessel (which will likely be made of acrylic), and (c) the assay, removal and control of chemical impurities and radioactive impurities in the Gd-LS.

5 Summary

In this EOI, we have described R&D and engineering required to prepare a full proposal with well-supported cost and schedule for the Braidwood Neutrino Experiment. Much of the technical R&D required to refine the detector design will be carried out by collaborating physicists using support of their base grants. The funding requests in this EOI, summarized in Table 3, are for engineering/R&D tasks that are beyond the existing resources of the groups.

Table 3: Proposed budget. (Compared to the budget in [1], the liquid scintillator entry includes an additional $50k for 1/2 postdoc as described in Section 4.)

Category	Request in thousands of dollars
Civil engineering	525
Detector engineering	408
Liquid scintillator	78
Undergraduates	78
Total	1089

Institutional responsibilities for the proposed activities,[3] as well as our plan for management of the grant, are described in [1]. (Additional information provided to the NuSAG review is available in [2].)

References

[1] The Braidwood Collaboration, Engineering and R&D for the Braidwood Neutrino Experiment, submitted to the DOE and NSF, 2004, http://braidwood.uchicago.edu/doe_eoi/DOEprop2004.pdf.

[2] The Braidwood Collaboration, Materials submitted to the 2005 NuSAG Review, http://braidwood.uchicago.edu/nusag/nusag.html.

[3] It is worth noting that our British collaborators have taken responsibility for design of the PMT support structure, reflective concentrators, and an embedded optical calibration system. They have already received financial support for this work from their funding body, PPARC.