Director's Office

Building 510F
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-5414
Fax 631 344-5820
tkirk@bnl.gov

BROOKHAVEN NATIONAL LABORATORY

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Dr. Robin Staffin, Director
Office of High Energy Physics
U.S. Department of Energy, SC-20
19901 Germantown Road
Germantown MD 20874-1290

Dear Dr. Staffin:

This letter is submitted to the Office of High Energy Physics of the U.S. Department of Energy as a *preliminary proposal* from Brookhaven National Laboratory to construct a **Super Neutrino Beam** at BNL, using the substantially upgraded Alternating Gradient Synchrotron (AGS) accelerator as the 1 MW *proton driver source* for a newly constructed *wideband neutrino beam.* The resulting AGS-based Super Neutrino Beam will provide a megawatt-class neutrino beam for use in the planned future U.S. particle physics program in neutrino-oscillations. Technical details are provided in the attached Conceptual Design Report.

Our proposal provides a follow-up conceptual neutrino beam design for the **Very Long Baseline Neutrino Oscillations** (VLBNO) experiment[1], first presented to the HEPAP Future Facilities Workshop held on February 15-16, 2003 at Pittsburgh, PA. The BNL-AGS neutrino experiment seeks to explore and measure *all* the important parameters of neutrino oscillations and our VLBNO concept, was awarded the HEPAP classification of "absolutely central" to the field. The associated "Super Neutrino Beam" was later included as one of the future science facilities identified by DOE in *Facilities for the Future of Science – a Twenty-Year Outlook*[2], a planning document from the Office of Science in November 2003. The Super Neutrino Beam is part of Brookhaven National Laboratory's strategic plan as presented to the DOE Office of Science during our Institutional Plan Review held on April 26, 2004 at BNL.

We also note that our proposal is responsive to one of the top recommendations provided by the U.S. Office of Science and Technology Policy (OSTP) in their recent document titled, *Physics of the Universe – a Strategic Plan for Federal Research at the Intersection of Physics and Astronomy*[3], February 2004. In their Summary of Recommendations and denoted as, "Ready for Immediate Implementation and Direction Known", there are two bullets under the sub-heading, "Dark Matter, Neutrinos and Proton Decay", that describe a mechanism for road-mapping and identifying a core suite of experiments for an underground facility to be developed by the National Science Foundation acting as the lead federal agency. This activity is going forward at the present time as the "Deep Underground Science and Technology Laboratory"[4] (DUSEL) Initiative. BNL is fully involved in the NSF process, coordinating the AGS Super Neutrino Beam with the science goals in the very important neutrino physics element of the DUSEL program.

The conceptual technical design document for the AGS-based Super Neutrino Beam is attached to this letter. It is titled, *The AGS-Based Super Neutrino Beam Facility – Conceptual Design Report*, October 8, 2004, BNL Report 73210-2004-IR. It is available in PDF format from the BNL website, http://www.bnl.gov/henp along with other related documents. In the report, we provide a preliminary Total Estimated Cost (TEC) that

[1] "Super Neutrino Beam (Proton Driver)", M. Diwan, T. Kirk and W.T. Weng, February 15, 2003, http://www.bnl.gov/henp
[2] "Facilities for the Future of Science – a Twenty-Year Outlook", DOE Office of Science, November 2003, http://www.science.doe.gov (Revised December 2003)
[3] "Physics of the Universe – a Strategic Plan for Federal Research at the Intersection of Physics and Astronomy", February 2004, http://www.ostp.gov
[4] "Deep Underground Science and Technology Laboratory", http://www.nsf.gov/pubs/2004/nsf04595/nsf04595.htm .

adds to $407M in FY 2004 dollars. The TEC includes $273.4M of direct costs (see Table) plus indirect costs at the 14.5% BNL major construction project G&A rate for the complete AGS Upgrade and Super Neutrino Beam. The TEC also includes an average contingency of 30% applied to all project costs. A simple Table showing the high-level WBS elements of the Direct Project Cost is given here, with details in the conceptual design report. A near detector vault and generic detector is provided as a cost guideline but is not included in the cost estimate. A detailed detector design is not needed at this point for the VLBNO program.

Total Direct Cost for the BNL Super Neutrino Beam
(FY 2004 Dollar Millions)

Cost Item	EDIA	M&S	Labor	Total	%
Superconducting Linac Upgrade	6.9	98.5	16.8	122.2	44.7
AGS Upgrade to 2.5 Hz/1 MW	10.5	53.6	6.5	70.6	25.8
Neutrino Target and Horn System	0.7	3.4	1.2	5.3	2.0
Conventional Facilities	7.5	60.1	1.2	68.9	25.3
ES&H	0.1	0.3	0.4	0.8	0.3
Project Support	1.1	0.4	4.1	5.6	2.0
Total Direct Costs	**26.8**	**216.3**	**30.2**	**273.4**	**100.0**
Near Detector Facility	0.7	4.9	0.2	5.8	
Near Detector	0.9	4.4	1.8	7.1	

The schedule start is not known at this time, so escalation cannot be applied to this cost estimate. The attached conceptual design indicates a construction period of five fiscal years with three years of R&D initiated one year prior to the start of construction and overlapping the construction period by two years. BNL is prepared to begin the needed R&D as soon as funding can be secured. We imagine this to be not earlier than FY 2006. If such an early start is achieved, the beam will be ready to start the neutrino oscillations experiment in FY 2012. At that time, the VLBNO experiment will provide a world leading set of measurements in neutrino physics, not available or proposed by any other national group or country.

The physics case for the VLBNO experiment, including the role of the Super Neutrino Beam and DUSEL, will not be described in this proposal. The case has been made in several neutrino forums already, including the 2003 National Research Council Study (NRC), *Neutrinos and Beyond*[5] and the 2004 *APS Neutrino Study*[6]; the main scientific elements are available in published scientific papers[7]. Here, we simply observe that this experiment is able to measure *all* the important neutrino oscillation parameters with the possible exception of the CP-violation parameter δ_{CP}. The CP-violation measurement will not be possible if the mixing parameter $\sin^2 2\theta_{13}$ (magnitude presently unknown) is numerically below 0.01. The VLBNO will provide the following measurements:

- *precise determination of the oscillation parameters Δm_{32}^2 and $\sin^2 2\theta_{23}$;*
- *detection of the oscillation of $\nu_\mu \rightarrow \nu_e$ and measurement of $\sin^2 2\theta_{13}$ (if the value is > 0.01);*
- *measurement of $\Delta m_{21}^2 \sin^2 2\theta_{12}$ in a $\nu_\mu \rightarrow \nu_e$ appearance mode, independent of the value of θ_{13};*
- *verification of matter enhancement and the sign of Δm_{32}^2 (determine the neutrino mass hierarchy);*
- *determination of the CP-violation parameter δ_{CP} in the neutrino sector (if $\sin^2 2\theta_{13} > 0.01$).*

To clarify some of the physics points made above, it is useful to make comparisons to other neutrino oscillations experiments now contemplated or under construction around the world. Most of the near-term future experiments are aimed at the observation of a finite value for the neutrino oscillation parameter $\sin^2 2\theta_{13}$. The leading candidates for this important measurement are reactor-based experiments. These

[5] "Neutrinos and Beyond" , National Research Council , 2003, http://www.nap.edu , search on 'Neutrinos and Beyond'.
[6] "APS Multi-Divisional Neutrino Study ", http://www.interactions.org/cms/?pid=1009695 .
[7] "Very Long Baseline Neutrino Oscillations Experiment for Precise Measurements of Mixing Parameters and CP Violating Effects", M. Diwan, *et al.*, **PRD 68** (2003) 012002.

experiments offer the ability to measure the numerical value for this parameter (or set a more restrictive upper bound) within the next five years. The upper bound inferred from the CHOOZ[8] experiment is now approximately 0.2 at the 90% confidence level. BNL's VLBNO experiment is capable of measuring the CP-violation phase-angle parameter δ_{CP} to about ±20° out of 360°, assuming $\sin^2 2\theta_{13} > 0.01$. If the value of $\sin^2 2\theta_{13}$ is less than this limit, no super beam based experiment will be able to measure CP-violation. The VLBNO experiment, however, will still be able to reach all the remaining physics goals in the bullets above and is not otherwise compromised by this physics outcome.

There are also several long baseline experiments planned or proposed in Japan, Europe and the U.S. that rely on the use of, so-called, 'off-axis' neutrino beams to investigate the magnitude of $\sin^2 2\theta_{13}$ and purport, in some cases, to resolve the mass hierarchy issue for neutrino mass ordering. In most cases, the location of neutrino beam sources relative to the intended detectors is limited to baselines of less than 1000 km. In the case of the J-PARC (Tokai, Japan) to Super Kamiokande (Western Honshu, Japan) experiment (295 km), the locations of both source and detector are already fixed. This is also true for the NOνA proposal from Fermilab to an off-axis detector site near Soudan, MN (735 km). In this case, the neutrino beamline tunnel already exists and the curvature of the Earth limits the distance from the beam source to the NOνA detector. In Europe, the distance from CERN to Gran Sasso is 730 km and no plan has emerged for a satisfactory alternative with a longer baseline. Why is this important? The 2003 NRC study, *Neutrinos and Beyond* [5] stated that, "To optimize long-baseline studies of neutrino oscillations, a new underground facility should be located farther than 1,000 km from existing, high-intensity proton accelerators." Only the United States has the continental distances sufficient to meet or exceed this criterion and so far, only BNL's VLBNO proposal seeks to exploit this U.S. national geographical advantage.

On top of these basic geographical circumstances, we believe that the wideband neutrino beam method of VLBNO enjoys a fundamental advantage over any of the off-axis concepts. This is related to the issue of ambiguities in determination of the CP-violating phase δ_{CP}, ambiguities that are intrinsic to any shorter baseline, narrow-band beam method. These ambiguities arise because several parameters in a complicated formula affect the appearance of electron neutrinos. The advocates for the off-axis, narrow-band beam method argue that a multiplicity of detector sites and measurements could resolve the ambiguities. We point out that the time frame to get to this state of knowledge is comparable with our more comprehensive measurements plan, a method that minimizes systematic errors and avoids constructing expensive, limited-purpose experiments. It has also been pointed out many times, in a variety of physics forums, that combining the neutrino oscillation experiment with the next-generation nucleon decay experiment, including its sensitivity to supernova neutrino bursts and to cosmic relic neutrinos, will maximize the benefits to science of the required megaton-scale detector that is common to all these experiments. This philosophy is part of the DUSEL development effort and was noted in *Physics of the Universe*.

Returning to the proposal at hand, construction of the Super Neutrino Beam at BNL, we note that the conceptual design submitted here presents a complete and build-able plan for a 1 MW wideband super neutrino beam, together with a well-developed cost estimate. It is submitted by a group of experienced and accomplished accelerator physicists and engineers who have recently completed BNL accelerator projects of comparable sophistication and complexity (RHIC, SNS Ring, LHC Superconducting Magnets, Optically Polarized Proton Ion Source and Booster Applications Facility for NASA). We submit our preliminary proposal to the DOE OHEP at this time in order to have a complete and responsive beam design on record in the fall of 2004 as the national neutrino oscillations future-directions discussions begin in earnest.

Of course, as time goes by, we will continue to develop new ideas for further improvement of the BNL upgrade and neutrino beam design. Because the conceptual design document is modular, we anticipate substituting improved technical sections into the design report as these concepts mature and provide improvements to our baseline design. A principal focus of the improvements is to raise the energy of

[8] "Global Analysis of Neutrino Oscillation", S. Goswami, A. Bandyopadhyay, S. Choubey, Talk given by S. Goswami at 21st International Conference on Neutrino Physics and Astrophysics (Neutrino 04), Paris, France, 14-19 June, 2004.

the proton beam on the neutrino target. With the improvements foreseen so far, we can see our way to a 2 MW target capability. When this increase in target power is combined with a more aggressive running schedule (currently, we assume only 10^7 operating seconds per year), we anticipate that an overall factor of 4 can be achieved in the per-year event rate relative to our current, conservative assumptions. All the improvements being discussed so far are capable of being substituted into the design without compromising any overall technical considerations. To make our ongoing development plan more specific, we next comment briefly on the design evolutions presently under discussion.

The proposed superconducting linac upgrade raises the currently available linac beam energy from 200 MeV to 1.2 GeV. It makes use of the existing AGS Linac and adds three superconducting rf sections, the first at 805 MHz and the next two at 1650 MHz. This change of frequency is necessary to get the full 1.2 GeV out of the new linac in the space available. In Appendix B of this report, we provide a next conceptual design step, in which we extend the existing 200 MeV linac to 400 MeV using proven warm technology and follow this with a uniform 805 MHz superconducting section, taken directly from the SNS design, to reach a final proton beam energy of 1.4 to 1.5 GeV. Although this improved design was not complete and ready to be cost-estimated in time for this report, we can already foresee that it will enable us to extend the neutrino beam source power from 1.0 MW to 1.5-2.0 MW, providing design margin in case the final VLBNO experiment requires a higher-power neutrino beam source.

We are also studying how to incorporate the capability of producing an auxiliary off-axis neutrino beam in the same decay pipe, using a second proton target and focusing system to achieve this. We will only develop this capability if the ongoing detector studies indicate that supplementary running in a narrow-band neutrino beam is needed to resolve certain physics background problems that could occur in the wideband beam. These studies are ongoing.

Finally, we realize that the DOE Office of Nuclear Physics must also agree to this upgrade and use of the AGS and the neutrino program must not conflict with the NSF's RSVP program at BNL. We foresee no significant issues here and are ready to discuss these topics, including our plans for the operations phase of the VLBNO experiment.

Sincerely,

(Original signed by T. Kirk)

Thomas B.W. Kirk
Associate Laboratory Director
High Energy and Nuclear Physics

Attachment (1)

Cc: P. Chaudhari, BNL Director
P. Bond, BNL Deputy Director
A. Byon-Wagner, DOE OHEP Program Officer
M. Holland, DOE Site Manager
N. Narain, DOE Site S&T Officer
D. Kovar, DOE ONP Director
G. Rai, DOE ONP RHIC Program Officer
J. Simon-Gillo, DOE ONP Program Officer
J. Dehmer, NSF Physics Division Head
M. Goldberg, NSF RSVP Program Manager