Appendix

A The Neutrino Factory and Beta Beam Experiments and Development Working Group

A.1 Introduction

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and

The Neutrino Factory and Muon Collider Collaboration

Two new types of facility have been proposed that could have a tremendous impact on future neutrino experiments—the Neutrino Factory and the Beta Beam facility. In contrast to conventional muon-neutrino beams, Neutrino Factory and Beta Beam facilities would provide a source of electron-neutrinos (ν_e) and -antineutrinos ($\bar{\nu}_e$), with very low systematic uncertainties on the associated beam fluxes and spectra. The experimental signature for $\nu_e \to \nu_\mu$ transitions is extremely clean, with very low background rates. Hence, Neutrino Factories and Beta Beams would enable very sensitive oscillation measurements to be made. This is particularly true at a Neutrino Factory which not only provides very intense beams at high energy, but also provides muon-neutrinos (ν_μ) and -antineutrinos ($\bar{\nu}_\mu$) in addition to electron-neutrinos (ν_e) and -antineutrinos ($\bar{\nu}_e$). This would facilitate a large variety of complementary oscillation measurements in a single detector, and dramatically improve our ability to test the three-flavor mixing framework, measure *CP* violation in the lepton sector (and perhaps determine the neutrino mass hierarchy), and, if necessary, probe extremely small values of the mixing angle θ_{13}.

At this time, we do not know the value of θ_{13}. If $\sin^2 2\theta_{13} < 0.01$, much of the basic neutrino oscillation physics program will be beyond the reach of conventional neutrino beams. In this case Neutrino Factories and Beta Beams offer the only known way to pursue the desired physics program.

The sensitivity that could be achieved at a Beta Beam facility presently looks very promising, but is still being explored. In particular, the optimum Beta Beam energy is under discussion. Low energy Beta Beam measurements would complement Superbeam measurements, but would achieve a θ_{13} sensitivity that does not appear to be competitive with that of a Neutrino Factory. Higher energy Beta Beams may approach the sensitivity possible with a Neutrino Factory, although systematics issues need further study. Thus, while a Beta Beam facility may have a significant role to play in the future global neutrino program, more work must be done on its design, development, cost estimate, and physics sensitivity to validate its potential. We note that, due to very limited

resources, there has been no significant activity in the U.S. on Beta Beams. Progress on Beta Beam development being made in Europe should be followed, especially if the higher energy solution continues to look favorable.

An impressive Neutrino Factory R&D effort has been ongoing in the U.S. and elsewhere over the last few years, and significant progress has been made towards optimizing the design, developing and testing the required accelerator components, and significantly reducing the cost, even during the current Study. (Although a full engineering study is required, we have preliminary indications that the unloaded cost of a Neutrino Factory facility based on an existing Superbeam proton driver and target station can be reduced substantially compared with previous estimates.) Neutrino Factory R&D has reached a critical stage in which support is required for two key international experiments (MICE and Targetry) and a third-generation international design study. If this support is forthcoming, a Neutrino Factory could be added to the Neutrino Physics roadmap in about a decade.

Given the present uncertainty about the size of θ_{13}, *it is critical to support an ongoing and increased U.S. investment in Neutrino Factory accelerator R&D to maintain this technical option.* A Neutrino Factory cannot be built without continued and increased support for its development. We note that the 2001 HEPAP Report advocated an annual U.S. investment of $8M on Neutrino Factory R&D. The present support is much less than this. Since R&D on the design of frontier accelerator facilities takes many years, support must be provided *now* to have an impact in about a decade.

A.2 Recommendations

Accelerator R&D is an essential part of the ongoing global neutrino program. Limited beam intensity is already constraining the neutrino physics program, and will continue to do so in the future. More intense and new types of neutrino beams would have a big impact on the future neutrino program. A Neutrino Factory would require a Superbeam-type MW-scale proton source. We thus encourage the rapid development of a Superbeam-type proton source.

The Neutrino Factory and Beta Beam Working Group's specific recommendations are:

- ***We recommend that the ongoing Neutrino Factory R&D in the U.S. be given continued encouragement and financial support.*** We note that the HEPAP Report of 2001 recommended an annual support level of $8M for Neutrino Factory R&D, and this level was considered minimal to keep the R&D effort viable.

  In addition, and consistent with the above recommendation,

  1. ***We recommend that the U.S. funding agencies find a way to support the international Muon Ionization Cooling Experiment (MICE), in collaboration with European and Japanese partners.*** We note that MICE now has scientific approval at the Rutherford Appleton Laboratory in the UK, and will require significant U.S. participation. This has been identified as an important experiment for the global Neutrino Factory R&D program. A timely indication of U.S. support for MICE is needed

to move the experiment forward.

2. ***We recommend that support be found to ensure that the international Targetry R&D experiment proceeds as planned.*** We note that this R&D activity is crucial for the short-, medium-, and long-term neutrino programs, and for other physics requiring high-intensity beams.
3. ***We recommend that a World Design Study, aimed at solidly establishing the cost of a cost-effective Neutrino Factory, be supported at the same level as Studies I and II.*** We note that the studies done here suggest that the cost of a Neutrino Factory would be significantly less than estimated for Studies I and II. This makes a Neutrino Factory a very attractive ingredient in the global neutrino roadmap.

- ***We recommend that progress on Beta Beam development be monitored, and that our U.S. colleagues cooperate fully with their EU counterparts in assessing how U.S. facilities might play a role in such a program.*** We note that there is no significant U.S. R&D effort on Beta Beams due to our limited R&D resources. Insofar as an intermediate energy solution is desirable, however, the Beta Beam idea is potentially of interest to the U.S. physics community.