INTERNATIONAL SCOPING STUDY OF A FUTURE ACCELERATOR NEUTRINO COMPLEX*

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Abstract

The International Scoping Study (ISS), launched at NuFact05 to evaluate the physics case for a future neutrino facility, along with options for the accelerator complex and detectors, is laying the foundations for a subsequent conceptual-design study. It is hosted by Rutherford Appleton Laboratory (RAL) and organized by the international community, with participants from Europe, Japan, and the U.S. Here we cover the work of the Accelerator Working Group. For the 4-MW proton driver, linacs, synchrotrons, and Fixed-Field Alternating Gradient (FFAG) rings are considered. For targets, issues of both liquid-metal and solid materials are examined. For beam conditioning, (phase rotation, bunching, and ionization cooling), we evaluate schemes both with and without cooling, the latter based on scaling-FFAG rings. For acceleration, we examine scaling FFAGs and hybrid systems comprising linacs, dogbone RLAs, and non-scaling FFAGs. For the decay ring, we consider racetrack and triangular shapes, the latter capable of simultaneously illuminating two different detectors at different long baselines. Comparisons are made between various technical approaches to identify optimum design choices.

INTRODUCTION

For some years now, regional studies have been undertaken to design an intense accelerator-based neutrino facility [1–7]. These studies considered many options for the accelerator complex and its various subsystems. In the past year, there has been growing recognition of the need to compare the alternative approaches on a common basis in order to begin building an international consensus on how to proceed to the next step. In addition, it is clear that there is a need to compare the physics potentials of several different approaches, including a high-intensity conventional neutrino beam ("Superbeam"), a muon-based Neutrino Factory, and a Beta Beam facility.

Just prior to NuFact05 (held in Frascati, Italy), CCLRC Chief Executive John Wood created a charge to carry out such a Study under RAL sponsorship. This was accepted by the relevant R&D organizations in Europe, Japan, and the U.S., namely the BENE network, the NuFact-J collaboration, and the Neutrino Factory and Muon Collider Collaboration (NFMCC). The structure for the ISS is indicated in Fig. 1. It consists of three working groups, along with an overall ISS leader. The working group leaders, together with the study leader, comprise the ISS Program Committee. The ISS formally commenced [8] at NuFact05 and will issue a report to the community at NuFact06 in August, 2006.

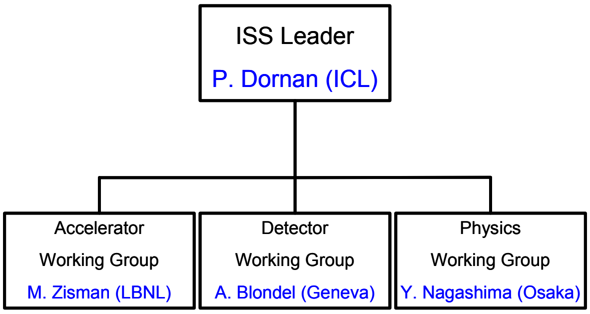

Figure 1: ISS organization chart.

There have thus far been three plenary ISS meetings, held at CERN, at KEK, and at RAL. A fourth meeting is scheduled at UC-Irvine on August 21–22, 2006, just prior to NuFact06. There have also been three workshops of the Accelerator Working Group, the first at BNL, the second at KEK, and the third at RAL; a fourth workshop is scheduled at Princeton University on July 26–28, 2006.

In this paper, the progress of the Accelerator Working group will be presented. Two scenarios have been investigated—a "linear" scheme with cooling, represented schematically in Fig. 2, and a "circular" scheme without cooling, shown schematically in Fig. 3. The discussion will be organized in terms of the main subsystems: proton driver; target; front end (comprising bunching, phase rotation, and cooling); acceleration; and decay ring.

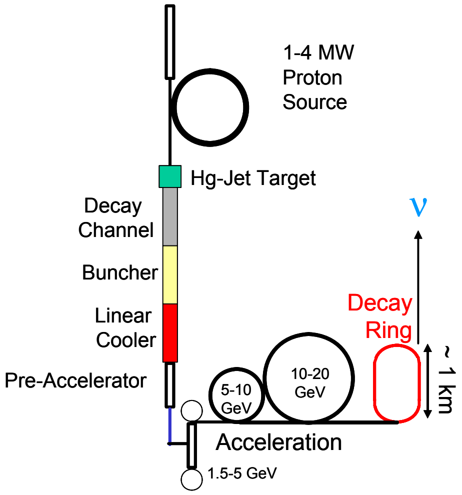

Figure 2: Schematic of linear-style Neutrino Factory.

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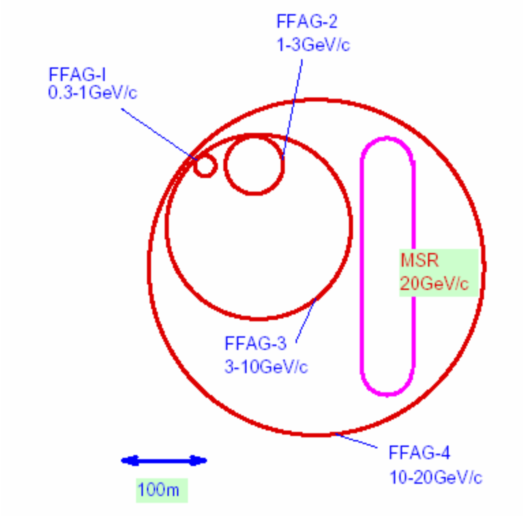

Figure 3: Schematic of circular-style Neutrino Factory.

PROTON DRIVER

Various options for a proton driver have been considered and compared [9], including linacs, synchrotrons, and FFAG rings. Issues examined include energy, intensity, bunch length, and repetition rate. Compared with the other systems, the proton driver is likely to be the most site-dependent. Different laboratories have local solutions that meet site constraints, and none of these is excluded *a priori* from consideration. Expressed differently, the proton driver is rather loosely coupled to the rest of the facility—any accelerator design that can provide the basic parameters should be suitable.

After discussion, it was decided not to choose a specific design but rather a range of parameters that was deemed acceptable based on their effect on downstream systems. These parameters are summarized in Table 1. Due to space-charge effects, achieving short bunches is easier for higher beam energies.

TARGET

Both solid and liquid-metal targets have been considered. Over the past year, a consensus has developed that the Hg-jet target is most suitable based on present knowledge. The MERIT experiment [10] should confirm this within the next year. The design of a suitable beam dump is also difficult, and using Hg for this purpose may be the only practical approach. Solid targets are not excluded, but are expected to be marginal at best with a 4 MW proton beam [11]. Carbon looks attractive at lower beam power and appears to provide high yield at lower proton energies.

Table 1: Proton driver parameters

Parameter	Value
Energy (GeV)	10 ± 5
Beam power (MW)	4
Repetition rate (Hz)	50
No. of bunch trains	4[a)]
Bunch length, rms (ns)	2 ± 1
Beam duration[b)] (μs)	≈40

[a)] Values ranging from 1–5 possibly acceptable.

[b)] Maximum spill duration for liquid-metal target.

FRONT END

Front-end systems developed in Refs. [3–5] were compared as part of the study. The designs in Refs. [4] (88 MHz) and [5] (201 MHz) both represent the linear style. Their performances were compared using identical input beams and the 201-MHz channel was shown to have a considerably larger acceptance. It is likely that the 88-MHz channel could be reoptimized to perform better but, in view of limited resources and limited time to do so, the 201-MHz cooling channel was preferred.

Comparisons between the circular and linear schemes are more difficult, as the approaches are quite different. Still, several disadvantages to the all-FFAG scheme were noted: it requires a very low RF frequency and hence gives a low real-estate gradient; it is expensive; and it is not easily compatible with simultaneous acceleration of muons of both signs. As the FFAG transverse acceptance is comparable to that of the front end in Ref. [5], the lack of cooling implies an overall performance reduction. For these reasons, the 201-MHz linear channel with cooling was taken as the baseline scenario.

ACCELERATION

The acceleration scheme described in Ref. [5] is a hybrid. It comprises a linac, a dogbone RLA, and two non-scaling FFAGs. The layout is shown in Fig. 4. It is anticipated to be much less expensive than the scheme illustrated in Fig. 3 and has been provisionally adopted as the baseline scenario. Tracking studies [12] have indicated some matching problems associated with using two (or more) cascaded FFAG rings, and it is not completely clear how practical it is to implement the scheme shown in Fig. 4. For this reason, a fallback option where the 5–10 GeV FFAG is replaced with an RLA is being examined. It is worth noting here that the ISS Physics Working Group has suggested that a higher energy of 40 GeV may be required. This will clearly favor replacement of the lower energy FFAG with an RLA to avoid the need to cascade three non-scaling FFAG rings.

It presently appears that the baseline scheme is compatible with the simultaneous acceleration of muons of both signs. We have now adopted this criterion as a requirement for the acceleration system, as it will save a substantial amount of running time and likely reduce the systematic errors in comparing the two beams.

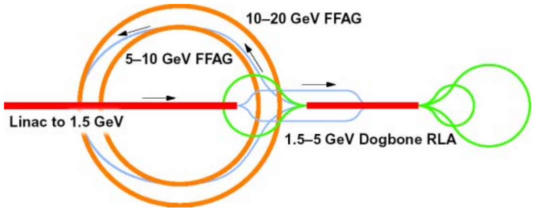

Figure 4: Layout of hybrid acceleration system [5].

DECAY RING

Two geometries have been considered [13] for the decay ring—a racetrack design and a triangular design (see Fig. 5). There are several potential advantages of the latter design. It can service two detectors at two different long baselines simultaneously and it typically has a larger efficiency (measured as the ratio of production straight section length to total circumference) than the racetrack design. An issue for both designs is the depth of the ring [14]. Especially for the racetrack design, a long straight section length and a long baseline mean that the ring is inclined at a steep angle, as much as 35° for the longest baseline considered (7500 km). This puts the lower end of the ring quite deep, which could be a site constraint for a location where the depth of the local water table is an administrative limit.

We have concluded that either ring geometry requires a *pair* of rings to illuminate two different baselines with two different signs of muon beam. In the case of the racetrack, this is rather obvious. The two rings must be independently oriented to aim at two different baselines, though the two signs of muon can be aimed at the same detector in a given ring. In the triangle case, a single ring can aim at two different baselines, but a second ring is needed to orient the opposite sign muons toward the same pair of detectors. In practice, it is not so easy to find suitable pairs of sites that can be illuminated by a triangular geometry. Indeed, in most of the examples looked at to date, the return straight section in the triangle ring is nearly vertical, which is viewed as a disadvantage in terms of installation, though unlikely to be a fatal flaw.

We have provisionally chosen the racetrack design as our baseline configuration, as it offers the possibility of staging the scientific program. However, this will be revisited in view of specific baselines and specific possible sites as we proceed.

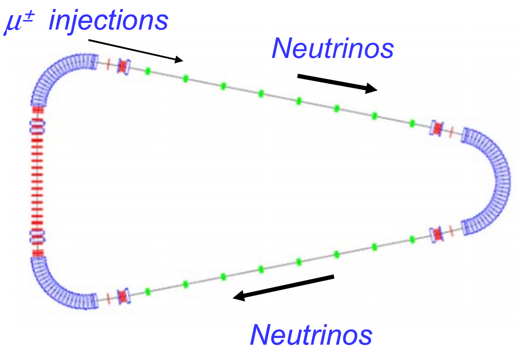

Figure 5: Schematic diagram of triangular decay ring.

CONCLUSIONS

In the past year, considerable progress has been made in developing a common understanding and performance metric for a Neutrino Factory. Participants from Europe, Japan, and the U.S. have worked together well to accomplish this task. A particularly beneficial aspect of the ISS has been the opportunity to bring the physics, detector, and accelerator communities together to understand the issues and constraints that each must deal with.

REFERENCES

[1] N. Holtkamp, D. Finley (eds.), "A Feasibility Study of a Neutrino Factory Based on a Muon Storage Ring," August 2000; http://www.fnal.gov/projects /muon_collider/nu/study/report/machine_report/.

[2] S. Ozaki, R. Palmer, M. S. Zisman, J. Gallardo (eds.), "Feasibility Study II of a Muon-Based Neutrino Source," BNL-52623, June 2001; http:// www.cap.bnl.gov/mumu/studyii/final_draft/The-Report.pdf.

[3] Y. Kuno and Y. Mori (eds.), "A Feasibility Study of a Neutrino Factory in Japan," http://www-prism.kek.jp/nufactj/nufactj.pdf.

[4] P. Gruber (ed.), "The Study of a European Neutrino Factory Complex," see http://slap.web.cern.ch/slap /NuFact/NuFact/nf122.pdf.

[5] C. Albright *et al.*, "Neutrino Factory and Beta Beam Experiments and Development, http://www.aps.org/ neutrino/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=58766.

[6] P. Zucchelli, Phys. Lett. B 532, 166 (2002).

[7] D. A. Harris, "Superbeam Experiments," Nucl. Phys. B (Proc. Suppl.) 149, 34 (2005).

[8] http://www.hep.ph.ic.ac.uk/iss/

[9] W.-T. Weng *et al.*, "Considerations on Proton Driver Parameters for a Neutrino Factory," paper MOPCH138, these proceedings.

[10] H. G. Kirk *et al.*, "A High-Power Target Experiment," Proc. 2005 Particle Accelerator Conf., Knoxville, TN, p. 3745.

[11] J.R.J. Bennett, "UK Studies of Solid Targets for Neutrino Factories," Nucl. Phys. B (Proc. Suppl.) 149, 262 (2005).

[12] S. Machida, "FFAG as a Muon Accelerator for Neutrino Factory," paper TUPLS024, these proceedings.

[13] G. Rees and C. Johnstone, "20 and 50 GeV Muon Storage Rings for a Neutrino Factory," paper WEPLS010, these proceedings.

[14] C. Johnstone and G. Rees, "General Design Considerations for a High-Intensity Muon Storage Ring," paper WEPLS011, these proceedings.