The International Scoping Study of a Neutrino Factory and Super-beam Facility

Neutrino physics is an expanding field of particle physics. Neutrinos are special among the elementary particles in that they do not carry charge or color and, until recently, it was believed that they carried no mass either. They are the most abundant constituent of the universe and have an important impact on astrophysical processes, from the first minutes after the Big Bang itself to supernovae explosions observed today. The demonstration, using natural sources, that neutrinos have mass and that the three generations mix has been the major event in particle physics in the last decade. This observation constitutes the first experimental evidence of new physics beyond the Standard Model. The processes leading to these unexpected masses and mixing parameters are thought to take place at energies never seen since the Big Bang, perhaps connected to the Unification of all forces. Precise determinations of the masses and mixing angles of the three families of neutrinos is a unique window of observation into these early times.

The recently discovered properties of neutrinos open the possibility of observing a difference in the oscillations of neutrinos and anti-neutrinos, so-called leptonic CP violation. This discovery would be extremely important and likely to give essential input to understand how the universe has evolved from the matter-antimatter equality at the time of the Big Bang to our present matter-dominated world.

These fascinating physics questions require an ambitious accelerator-based long baseline neutrino experimental program. Several neutrino sources have been envisaged to reach high sensitivity and redundancy well beyond the presently approved neutrino-oscillation programme. Studies so far have shown that the Neutrino Factory, an intense high-energy neutrino source based on a stored muon beam, gives the best performance over virtually all of the parameter space; its time scale and cost remain, however, important question marks. Second-generation superbeam experiments may be an attractive option in certain scenarios. Superbeams have many components in common with the Neutrino Factory. A beta-beam, in which electron neutrinos (or anti-neutrinos) are produced from the decay of stored radioactive ion beams, in combination with a second-generation superbeam, may be a competitive option.

The scoping study will therefore review the physics reach of the various proposed facilities and make quantitative performance comparisons. These comparisons will be used to define the programme needed to achieve international consensus on the facility or facilities required for an optimal programme of high-precision neutrino-oscillation measurements. This requires that the performance, cost and feasibility of the various proposed facilities, including the detector systems, be evaluated. The conceptual design of the beta-beam facility is being developed in the context of the EU Framework-Programme-6 funded EURISOL design study. Therefore, this scoping study will focus on evaluating the various options for the Neutrino Factory accelerator complex and neutrino super-beam.

In recent years, feasibility studies of possible configurations for a Neutrino Factory have been carried out in Europe, in Japan, and in the U.S. These studies have concluded that such a facility is feasible, although the performance specified for some components is unproven and the overall design remains to be optimized. The key R&D activities needed to demonstrate the required performance have been indicated. Many of these are already under way, most as international collaborations involving all three regions.

Experimental demonstration of muon ionization cooling is the aim of the international Muon Ionization Cooling Experiment (MICE), at Rutherford Appleton Laboratory's ISIS accelerator. It will test the operation and performance of an actual section of cooling channel under a variety of conditions, and will provide a solid indication of component fabrication costs. First beam is expected in Spring 2007. A second key area involves demonstrating a target technology capable of withstanding bombardment with a multi-MW proton beam while operating in a high solenoidal field. This experiment, nTOF11, also proposed by an international collaboration, is approved to run at CERN in 2007. Efforts to study the performance of fixed-field alternating gradient (FFAG) synchrotrons are also under way. Two examples of prototype "scaling" machines have already been built in Japan, and a proposal to build an electron model of a non-scaling ring has been submitted in Europe by an international team from all three regions.

What has not been done—and will be a focus of the International Scoping Study (ISS)—is to compare and contrast the differing approaches to a Neutrino Factory to identify the optimum and/or the most cost-effective ones. This will be accomplished by an international group comprising experts in all of the proposed technical approaches. Lastly the ISS will serve to review the R&D plan in support of a Neutrino Factory, modifying and augmenting it as necessary to make it consistent with the latest thinking on Neutrino Factory design.

In order to establish the cost and performance of the overall facility, the ISS will not consider the accelerator in isolation, but will examine it in conjunction with the cost and performance of the detector as well. Several technologies have been discussed to match the tremendous challenge of providing very large mass detector while preserving the ability to perform precision measurements.

Super-beam or beta-beam provide essentially one flavour of neutrinos and the emphasis is on large detector mass and muon and electron particle identification. These requirements are well matched by megaton-scale water Cherenkov detectors for low energy beams or perhaps as well by liquid argon or large volume scintillator detectors. The Neutrino Factory has the advantage of the golden channel – appearance of wrong sign muons – which requires a magnetic field. This leads most naturally to the magnetized iron calorimeter design. Another unique feature of the Neutrino Factory is the possibility to observe the silver channel, the ν_e à ν_τ transition, which could be observed with either emulsion based detectors, or a magnetized liquid argon TPC. In all detector concepts, there are important questions concerning cost, feasibility and time scales, as well as design optimizations to be made e.g. between energy/angle resolution, and mass. A realistic set of performance estimates is also important to serve as input to the physics comparisons between different options.

Finally, precise normalisation of flux and cross sections will be a fundamental requirement. The study of detector concepts for the near detector stations will be an important aspect of the international scoping study.

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ISS website http://hepunx.rl.ac.uk/uknf/wp4/scoping/.