NUFACT00: Interface between machine and physics working group summary

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Abstract

The main conclusions from the working group 3 presentations and deliberations at NUFACT00 are summarized.

I. INTRODUCTION

The goal of Working Group 3 at NUFACT00 was to arrive at a set of neutrino factory parameters, taking into account physics needs and accelerator limitations. Fortunately there has been much work on both the machine design [1,2] and the physics phenomenology [3] since the first neutrino factory proposal [4] based on a very intense muon source [5,6] was made in November 1997. In addition the discussions and consensus at NUFACT99 formed a solid foundation for the phenomenological work done between NUFACT99 and NUFACT00. In particular, the agreement between various calculations [7–9] of the neutrino oscillation physics possibilities at a neutrino factory gives us some confidence that the physics needs for oscillation physics are well understood if three–flavor oscillation provides the right theoretical framework to describe the atmospheric and solar neutrino deficits. If it turns out that there is a surprise in store for us (for example, the LSND $\nu_\mu \to \nu_e$ results are confirmed) then there may be a strong case for lower intensity and/or lower energy and shorter baseline experiments than described in the following. We can hope for a surprise, but since we cant count on one our considerations are based on more conventional three–flavor oscillation scenarios.

II. BASIC PARAMETERS: INTENSITY, ENERGY, AND BASELINE

There is general consensus on the following set of basic neutrino factory parameters:

(i) Storage ring energy $E_\mu = 50$ GeV.

(ii) Number of muon decays per year within the beam–forming straight section times the fiducial mass of the detector $= O(10^{22})$ kt–decays. For example, a 50 kt detector with 10^{21} muons injected into the storage ring each year, yielding $\sim 2-3\times 10^{20}$ useful decays per year in the straight section, and after 5 years of running a data sample $\sim 5\times 10^{22}$ kt–decays.

(iii) Baseline greater than or of order 3000 km.

These parameters are based on the very strong desire to search for CP–violation in the lepton sector [10]. This will be possible if the large mixing angle MSW solution correctly describes the solar neutrino deficit and the leading oscillation amplitude parameter $\sin^2 2\theta_{13}$ is not too small. In general, after choosing the optimal baseline, the oscillation physics reach at a neutrino factory increases slowly with energy. The highest energy considered so far by the machine designers is $E_\mu = 50$ GeV [1]. Since acceleration is one of the cost–drivers for a neutrino factory higher energies are probably not (initially) affordable. The baseline choice $L \sim 3000$ km seems to give the optimal CP–sensitivity, whilst also facilitating the observation of matter effects in $\nu_e \to \nu_\mu$ oscillations, and hence the determination of the hierarchy of neutrino mass eigenstates.

III. DETECTOR MASS

Eventually, to understand the best way of achieving $O(10^{22})$ kt–decays per year there will need to be some optimization between the machine intensity and detector mass. We are not in a position to embark on this optimization yet, and it will take some time to understand how to correctly optimize. In particular we need a better understanding of the cost effectiveness of various detector technology choices. Apart from cost, there does not appear to be any other limitation on the total detector mass that could be installed within a very large cavern, with the possible exception of safety issues associated with storing extreme volumes of cryogenic liquids (liquid Argon) underground (Campanelli). At the workshop a first attempt was made (Harris) to compare liquid argon, iron/scintillator, hybrid emulsion, and water cherenkov detector costs per unit mass. The real value of this exercise was to begin to understand how to make this comparison, which is not straight forward since existing detectors have been built at different times using different accounting systems, and different currencies. As might be expected, water cherenkov detectors are the cheapest per kt, and hybrid emulsion detectors the most expensive. However, different detector technologies can have very different efficiencies once a reasonable set of signal selection cuts have been imposed. Hence there is more to do before we can understand detector cost versus effective mass, and whether a vigorous detector R&D program is needed. It is the recommendation of the WG3 conveners that the group of people that have been interacting trans-Atlantic on these issues continue to hold regular meetings to make progress for NUFACT01.

IV. FAR DETECTOR SITE

There is now a tool (Gruber) which provides a catalogue of potential accelerator sites and far detector sites, and calculates baseline etc. The question arises, are "deep" sites around the world so limited that only a discrete set of baselines are possible, or are there so many potential sites that the baseline can be chosen to be anything we want? There are clearly a limited number of deep underground sites, one of which is at Carlsbad and was discussed in detail (Cline) at the workshop. Our personal view is that a Gran Sasso like solution (horizontal access through the side of a mountain) is much preferable for the extremely large neutrino factory detectors under discussion. Hence, it is desirable to catalogue suitable mountain sites around the world.

V. NEAR DETECTOR ISSUES

A neutrino factory would provide the opportunity to pursue a variety of interesting non–oscillation physics using detectors just downstream of the source. Since the beam–spot would be contained within the fiducial area of a moderately compact near detector, event rates would be proportional to the beam energy E_μ. Much of the non–oscillation physics program benefits from having the highest possible energy, and an energy of at least 40–50 GeV is desirable (McFarland). A fairly short straight–section for near detector physics is acceptable. To illustrate this, consider a 50 GeV storage ring with a 1900 m circumference, and let the near detector be compact ($r < 10$ cm), and be located at a reasonable distance from the end of the storage ring straight section to permit shielding ($L = 30$ m). In this case a 50 m straight section will yield about 5000 CC events/kg/10^{20} injected muons (McFarland). Increasing the straight section length to 800 m increases the event rate by less than a factor of two since most of the neutrino flux passing through the detector comes from decays not too far away.

Finally, there must be adequate shielding between the storage ring and near detector to reduce background rates to an acceptable level. MARS calculations (Mokhov) have been performed for a 1 m long liquid hydrogen target with $r = 50$ cm positioned 50 m downstream of a straight section producing 10^{20} decays of 50 GeV muons per year. Various shielding geometries were studied. For example, with 40 m dirt, 15 cm tungsten, and 10 m of vacuum with $B = 2$ T, the resulting background rates correspond to a few tens of charged particles per spill. This seems to be acceptable.

VI. BEAM SYSTEMATICS

To ensure a very well understood neutrino flux at the far detector downstream of a 50 GeV ring we require the following:

(i) A beam divergence of at most $0.1/\gamma$ seems practical and desirable (Johnstone, Kuno, Mori).

(ii) For a flux uncertainty less than 1%, the muon polarization must be known to 2% (Papadopoulos) , and

(iii) assuming a muon beam divergence of $0.1/\gamma$, the divergence needs to be known to 15% (Papadopoulos), which is considered practical (Keil, Finley).

(iv) A very good pointing accuracy of 10μm seems desirable and practical provided there are shafts for surveying (Keil).

A corresponding wish list for a 30 GeV storage ring is discussed in Ref. [11].

VII. POLARIZATION ?

Manipulating the polarization in a muon storage ring will effectively manipulate the flavor content of the neutrino beam [4], switching the ν_e component on or off. Muon polarization studies are not yet complete, so neither the amount of polarization likely to be achieved in a neutrino factory, nor its importance for the physics program, have been comprehensively established. The good news is that polarization tracking is now in ICOOL (Fernow), so a simulation tool is in place. The preservation of the muon polarization within the ring is probably OK (Blondel, Raja). In addition we now have one interesting quantitative example of how polarization helps. The example is that of T-Violation ($\nu_e \rightarrow \nu_\mu$ cf $\nu_\mu \rightarrow \nu_e$) for which a $\pm 40\%$ effective polarization is equivalent to an increase in statistics by a factor of 1.8 (Blondel & Campanelli). Given that producing $\pm 40\%$ polarization might be expensive, requiring rf cavities within the pion decay channel that might otherwise be absent, the case for polarization does not seem to be compelling. This might change with further study, but at present polarization is viewed as desirable, but not mandatory.

VIII. STAGING

If you don't have to stage, don't do it. Unfortunately we may be obliged to stage, either due to the cost of a high performance neutrino factory, or because of the need to climb a learning curve via a more modest facility. If we do have to stage there are several possibilities. We could start with proton driver upgrades used to produce high intensity conventional neutrino beams. An optional extra might be a very intense low energy muon source, e.g. PRISM at the JHF (Kuno). To understand the viability of this sort of staging scenario we need more work on the potential of upgraded conventional neutrino beams (lets call them "superbeams"). Can a few–hundred–MeV ν_μ beam with $L = 300$ km really probe CP violation? Some think it might (Sato, Nanokawa, Kuno). Finally, a lower intensity lower energy "entry–level" neutrino factory [7] might provide a convenient step, both in cost and technical development. For example, an initial neutrino factory at the JHF might use a 1 MW proton driver to produce muons for a 20 GeV ring. Later the proton driver might be upgraded to 4.4 MW, and the muon energy to 50 GeV (Kuno).

IX. WISH LIST FOR NUFACT01

A good place to end is with a wish–list for NUFACT01, by which time it would be good to have accomplished:

(i) Completed a first serious attempt to compile the cost and performance information needed to understand optimization of the detector technology choice, and the associated fiducial mass.

(ii) Settled how deep the far detector has to go underground.

(iii) Made a more complete and systematic catalogue of candidate detector sites, paying special attention to mountain sites with horizontal access.

(iv) Obtained one or two detailed examples of non–oscillation physics capabilities, including realistic calculations of rates after cuts, backgrounds, and systematics.

(v) Made a more comprehensive study of the physics motivation for polarization.

(vi) Made a comprehensive study of the physics capabilities of superbeams.

In addition, of course, we will no doubt be further along with neutrino factory design studies. Perhaps NUFACT01 will offer a good opportunity to quantitatively compare the various designs.

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