Neutrino Factory Working Group Plans : Neutrino Physics Part

INTRODUCTION

Neutrino Oscillation physics provides the main motivation for a Neutrino Factory.

There have been studies almost every year addressing the physics potential at a Neutrino Factory … so much is known. I think the working group should briefly revisit what is already known to see if there are any new developments. However …

The main physics focus of the working group should (I believe) be on extending our understanding of what can be done with Neutrino Factories & NEUTRINO FACTORY TECHNOLOGY.

We should not forget the non-oscillation physics program, which can broaden and enrich the science pursued at a Neutrino Factory.

What is Known from Previous Studies

1. Beam properties.

2. Signal and Background rates for $\nu_e \rightarrow \nu_\mu$ oscillations.

3. Flexibility: events tagged by wrong-sign muons, right-sign muons, tau-leptons, electrons/positrons, no leptons.

4. Sensitivity for small θ_{13}. Neutrino Factories are sensitive to θ_{13}, the sign of $\Delta m_{32}{}^2$, and CP violation for $\sin^2 2\theta_{13}$ down to $O(10^{-4})$.

5. Long list of non-oscillation physics topics.

Beam Properties at a Neutrino Factory

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \rightarrow 50\%\ \nu_e\ ,\ 50\%\ \bar{\nu}_\mu$$

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu \rightarrow 50\%\ \bar{\nu}_e\ ,\ 50\%\ \nu_\mu$$

Decay kinematics well known → minimal systematic uncertainties in:

1. Spectrum
2. Flux
3. Comparison of neutrino with antineutrino results

… but, most important, there are ν_e as well as ν_μ in the initial beam.

Electron Neutrinos & Wrong-Sign Muons

The primary motivation for interest in neutrino factories is that they provide electron neutrinos (antineutrinos) in addition to muon anti-neutrinos (neutrinos). This enables a sensitive search for $\nu_e \rightarrow \nu_\mu$ oscillations.

$$\mu^+ \rightarrow e^+ \, \nu_e \, \bar{\nu}_\mu \quad \bar{\nu}_\mu \overset{CC}{\Rightarrow} \mu^+$$

$$\nu_e \downarrow \nu_\mu \underset{CC}{\Rightarrow} \mu^-$$

$\nu_e \rightarrow \nu_\mu$ oscillations at a neutrino factory result in the appearance of a "wrong-sign" muon … one with opposite charge to those stored in the ring:

Backgrounds to the detection of a wrong-sign muon are expected to be at the 10^{-4} level $\Rightarrow$ background-free $\nu_e \rightarrow \nu_\mu$ oscillations with amplitudes as small as $O(10^{-4})$ can be measured !

Signal Rates & Signal/Background

Note: backgrounds for $\nu_e \rightarrow \nu_\mu$ measurements (wrong-sign muon appearance) are much easier to suppress than backgrounds to $\nu_\mu \rightarrow \nu_e$ measurements (electron appearance).

Many groups have calculated signal & background rates. Recent example
Hubner, Lindner & Winter; hep-ph/0204352

JPARC-SK:	Beam = 0.75 MW, M_{fid} = 22.5 kt, T = 5 yrs
JPARC-HK:	Beam = 4 MW, M_{fid} = 1000 kt, T = 8 yrs
NUFACT:	Beam = 2.6×10^{20} decays/yr, M_{fid} = 100 kt, T = 8 yrs

$\Delta m_{32}^2 = 0.003$ eV^2 , $\Delta m_{21}^2 = 3.7\times10^{-5}$ eV^2 , $\sin^2 2\theta_{23} = 1$, $\sin^2 2\theta_{13} = 0.1$, $\sin^2 2\theta_{12} = 0.8$, $\delta = 0$

	Superbeams		Neutrino Factory
	JPARC-SK	JPARC-HK	
Signal	140	13000	65000
Background	23	2200	180
S/B	6		360

$\sin^2 2\theta_{13}$, sign Δm^2_{32} & CPV Sensitivity

Huber & Winter, hep-ph/0301257
(50 GeV Neutrino Factory)

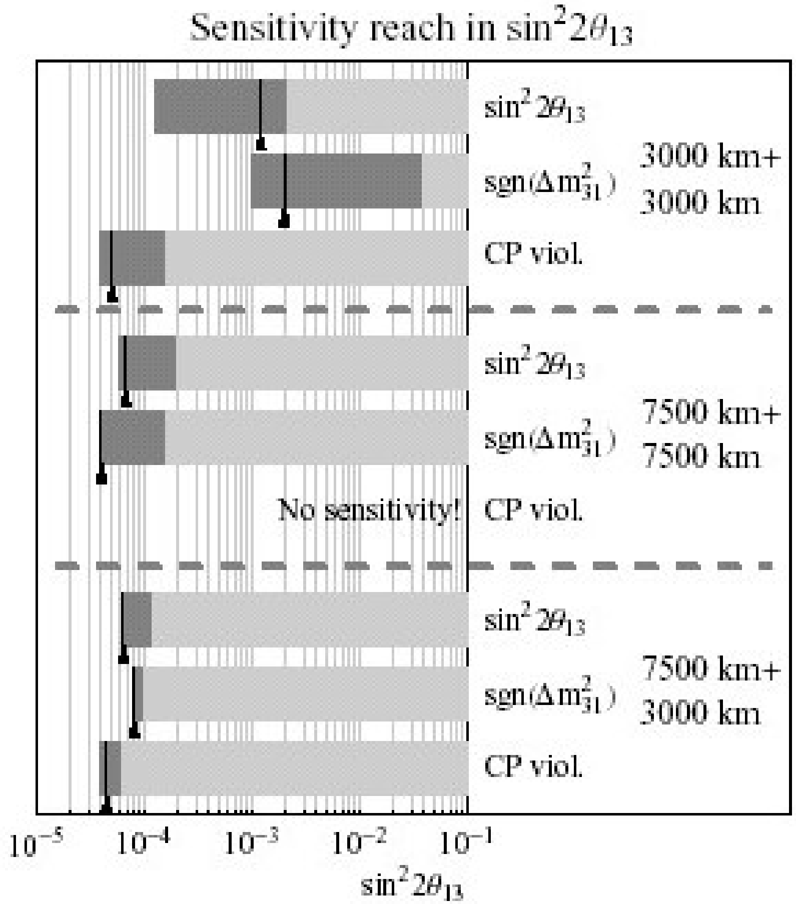

FIG. 3: The sensitivity reaches as functions of $\sin^2 2\theta_{13}$ for $\sin^2 2\theta_{13}$ itself, the sign of $\Delta m^2_{31} > 0$, and (maximal) CP violation $\delta_{CP} = \pi/2$ for each of the indicated baseline-combinations. The bars show the ranges in $\sin^2 2\theta_{13}$ where sensitivity to the corresponding quantity can be achieved at the 3σ confidence level. The dark bars mark the variations in the sensitivity limits by allowing the true value of Δm^2_{21} vary in the 3σ LMA-allowed range given in Ref. [19] and others ($\Delta m^2_{21} \sim 4 \cdot 10^{-5}\,\mathrm{eV}^2 - 3 \cdot 10^{-4}\,\mathrm{eV}^2$). The arrows/lines correspond to the LMA best-fit value.

With 2 carefully chosen baselines, the correlations & ambiguities can be overcome at a Neutrino Factory.

The calculated $\sin^2 2\theta_{13}$ reach (3σ) is below 10^{-4} for all three physics goals (measuring $\sin^2 2\theta_{13}$, determining the mass hierarchy, & observing maximal CPV) !!

Room for New Work - 1

1. For $\sin^2 2\theta_{13} = 0.1$ (0.01) preliminary work suggests that Neutrino Factories can improve the sensitivity to small δ_{CP} by a factor of 2 (3). This needs confirming. What are the limitations ? Can we do better ?

2. Oscillation physics at Neutrino Factories beyond measuring parameters – testing the framework.

3. Neutrino beam properties using Neutrino Factory Targetry, Pion Collection, and Decay Channel technologies, and the associated:

   i) Neutrino oscillation physics reach.
   ii) Neutrino interaction physics capabilities.

Room for New Work - 2

4. Detectors for lower energy neutrino factories and/or downstream of a low energy muon decay channel.

5. Other Neutrino interaction physics topics ?

6. Sensitivity of beta-beams including all systematics, correlations and ambiguities ?