PROCEEDINGS OF SCIENCE

Detectors for leptonic CP violation at the Neutrino Factory

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Studies carried out in the framework of the International Design Study for the Neutrino Factory (the IDS-NF) show that the sensitivity to the CP violating phase and the last unknown mixing angle θ_{13} is maximised when two far detectors optimized to detect the sub-leading ν_e to ν_μ oscillation are combined. Several technologies are being discussed for these detectors: magnetised iron calorimeters; giant liquid argon TPCs; and totally active scintillating detectors. The IDS-NF baseline option, a compromise between feasibility, cost, and performance, is documented in the Interim Design Report (IDR) that has recently been completed. It consists of two magnetised iron sampling calorimeters, similar to the existing MINOS detector, but with 10-20 times more mass and improved performance. A detector of mass 100 kton is assumed at the intermediate baseline (between 2500 km and 5000 km) and a 50 kton detector at the long baseline (between 7000 km and 8000 km). The other far-detector options, which have better granularity, may be able to detect additional oscillation channels, thus improving the overall performance of the facility. However, these options are likely to be more expensive and require significant R&D.

The 2011 Europhysics Conference on High Energy Physics, EPS-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes, France

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PoS(EPS-HEP2011)394

1. Introduction

The Neutrino Factory has the best overall performance for the discovery of CP violation in the neutrino sector out of all possible future facilities [1, 2]. The proposed far detector at a Neutrino Factory is a Magnetised Iron neutrino Detector (MIND). This is to be used with a near detector for measurement of θ_{13} and δ_{CP}. The detector is optimised to carry out the "Golden Channel" measurements [3] (a search for $\nu_e \to \nu_\mu$ or $\overline{\nu}_e \to \overline{\nu}_\mu$ oscillations), by detecting the muon of sign opposite to that generated by the neutrino beam.

2. MIND Conceptual Design

There are two Magnetised Iron Neutrino Detectors (MIND). One detector of 100 kton is at a distance between 2500 and 5000 km, and the other of 50 kton is between 7000 and 8000 km [2]. MIND consists of large octagonal iron plates of dimensions 14 m $\times$ 14 m $\times$ 3 cm, followed by two planes of scintillator bars, one with x orientation and one with y orientation, with each bar 1 cm thick and 3.5 cm wide (see Figure 1). A toroidal magnetic field between 1.0 and 2.2 T is created in the iron, by a Superconducting Transmission Line (STL) of diameter 7.8 cm, within a 10 cm bore, carying 100 kA of excitation current (Figure 2). The modules repeat themselves for a length of 140 m for the 100 kton MIND (70 m for the 50 kton MIND).

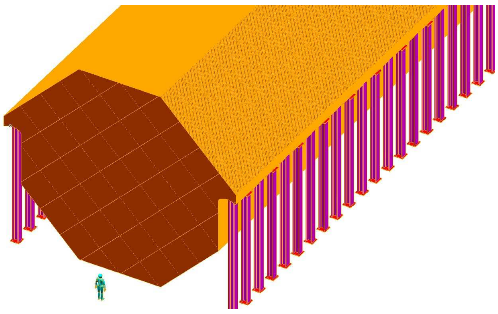

Figure 1: Schematic drawing of MIND.

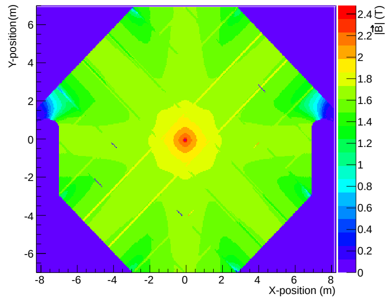

Figure 2: Magnetic field map simulated in the realistic geometry of the iron plate.

3. MIND Simulation, Reconstruction and Analysis

A simplified detector was used for the simulation and analysis. This detector used a square cross section and was immersed in a uniform dipole magnetic field of 1 T oriented in the positive y direction. GEANT4 [4] was used to provide the material interactions of charged species, while a combination of NUANCE [5] and LEPTO [6] were used to generate the neutrino interactions in the detector. The simulation included a wide range of neutrino interaction, including deep inelastic scattering, quasi-elastic scattering, and pion production channels.

Muon tracks resulting from the neutrino interaction events were identified and fit using a Kalman filter supplied using the RecPack software package [7]. A selection process is applied to the output of the Kalman fit using a number of criteria, such as the length of the track, the number of hits used in the analysis, the quality of the reconstructed track, the amount and direction of bending of the track, and the likelihood that the track is the result of a charged current event. The effect of these cuts on sets of μ flavoured neutrino charge current events is shown in Figure

3. The first step towards a realistic simulation has been to use GENIE [8] as the event generator. The efficiency of the muon reconstruction improves as a result of this change due to differences in the parton distribution functions used in GENIE compared to LEPTO (see Figure 4). We have now also adopted the full octagonal geometry in the simulation, introduced a realistic, toroidal field map and a re-optimisation of the reconstruction for this environment is in progress.

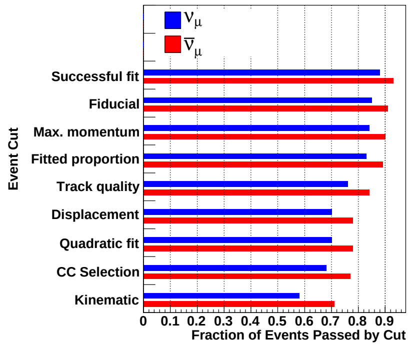

Figure 3: Fraction of events left after the application of the listed cuts applied to isolate charge current events.

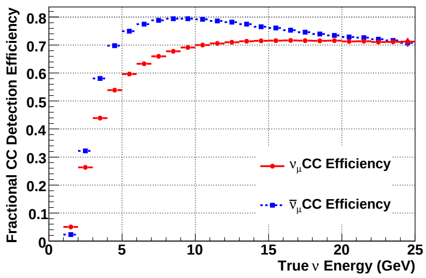

Figure 4: Charge current detection efficiency as a function of neutrino energy using the GENIE neutrino generator.

A Totally Active Scintillating Detector (TASD) or a Liquid Argon TPC have also been proposed as far detectors for a Neutrino Factory. The benefit of using these detectors are their sensitivity to lower energies compared to MIND, and that they can also measure $\nu_\mu(\overline{\nu}_\mu) \to \nu_e(\overline{\nu}_e)$, platinum channel oscillations, in addition to the golden channel. The challenge of these detectors is that the magnetic field for charge identification must be generated outside of the detector.

The International Design Study for a Neutrino Factory published the Interim Design Report in March 2011 [2]. The IDS-NF is on target to produce a Reference Design Report, including performance and costs of accelerator and detector systems, by 2013.

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