PROCEEDINGS OF SCIENCE

Detectors for leptonic CP violation at the Neutrino Factory

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The Neutrino Factory is the most powerful of the proposed facilities to search for CP violation in the lepton sector via neutrino oscillations. It delivers a well known beam of electron neutrinos and muon-antineutrinos from positive muon decay (electron-antineutrinos and muon neutrinos from negative muon decay) produced in the straight sections of the storage rings in which the muons are confined at an energy of 25 GeV. 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 (at 4000 km and 7500 km) optimised 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 – as a compromise between feasibility, cost, and performance – consists of two, 100 Kton magnetised iron sampling calorimeters, similar to the existing MINOS detector, but with 20 times more mass and improved performance. The other far-detector options, which have better granularity, offer an improved energy threshold and energy resolution, 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. A near detector of much smaller mass for precise measurement of neutrino flux and neutrino cross-sections will be situated close to the end of the muon storage ring straight section. The various detector options will be discussed, covering the most important aspects: performance; technological challenges; as well as the R&D program and cost drivers.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

[*] Speaker.

[†] Many thanks to Anselmo Cervera, Paul Soler, Ken Long and the wider IDS collaboration for there help in preparing this document

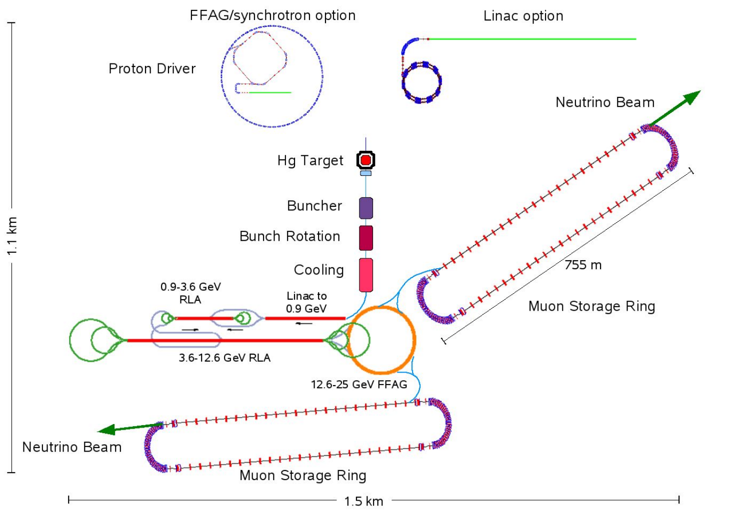

Figure 1: *Current design for the neutrino factory facility.*

1. The Neutrino Factory and motivation for the measurement of leptonic CP violation

The Neutrino Factory (NF) is an accelerator facility creating an intense multi-flavour beam of neutrinos from the decay of muons currently being designed under the auspices of the IDS-NF [1] and Euro-ν [2] collaborations. The primary physics goal of such a facility will be to measure the CP-violating phase δ_{CP} through the observation of subdominant appearance channels. A non zero value for this quantity could have ramifications in the understanding of the matter antimatter asymmetry observed in the universe.

In order to achieve this goal, it is invisioned that the facility (current design illustrated in Fig. 1) would have two muon storage rings, one with a straight section pointing towards a detector placed at $\sim$3000-4000 km and another pointing at a detector placed at $\sim$7500 km. The combination of neutrino and antineutrino appearance signals taken at both of these detectors and cross-section and flux spectrum measurements taken at one or more detectors within 1 km of the facility was shown in [3] to be the experiment with the greatest coverage of the parameter space. The design of the detectors and analyses must include sufficient magnetic field to separate the signal interactions from those of the beam inherent neutrinos as well as suppressing any background from the misidentification of non-oscillation neutrinos to at least the 10^{-3} level.

2. Near detector

The near detector design is still in its infancy but it is clear that any detector should be a high granularity tracking calorimeter with the ability to measure neutrino cross-sections for both neutrinos and anti-neutrinos of both beam species as well as measure key backgrounds which will not be easily identifiable at the far detectors. Some combination of a silicon vertex detector, to measure the production of charmed mesons whose leptonic and semi-leptonic decays can mimic primary oscillation muons, with a scintillating fibre or bar tracker should be sufficient to carry out the primary tasks. This basic design could also be augmented in order to exploit possible new physics channels.

3. Far detectors

A number of possible designs are being considered in the design studies. All will be required to have high mass and be able to suppress backgrounds efficiently while maintaining signal efficiencies allowing measurement of the signal down to at least 3 GeV, this level was shown in [3] to be the threshold at which sensitivity to δ_{CP} saturates.

3.1 Liquid Argon TPC

One possible technology for the far detector would be a large liquid argon TPC (LAr TPC). The detection power of this technology for neutrinos has been shown recently by the ArgoNeuT [4] experiment, where the high position and energy resolution showed theat this technology has great potential for neutrino detection. However, a great deal of R&D work will be required to prove that high mass can be achieved and that magnetisation is possible. The LAGUNA project [5] studied large LAr TPCs with other studies ongoing. A clear advantage of this technology would be access to ν_e $(\overline{\nu}_e)$ and perhaps even ν_τ $(\overline{\nu}_\tau)$ appearance channels.

3.2 Totally Active Scintillator Detector

The totally active scintillator detector (TASD) would be comprised entirely of extruded plastic scintillator. Initial studies of this technology in a neutrino factory context [6] assumed a magnetic field of 0.5 T generated using a magnetic cavern constructed using superconducting transmission lines (STL) and showed a low energy threshold for ν_μ detection should be achievable. Some efficiency for ν_e detection could also be achieved. However, significant R&D is required to realise the magnetic cavern concept and hadronic background suppression could be challenging.

3.3 Magnetised Iron Neutrino Detector

The Magnetised iron neutrino detector (MIND) was chosen as the baseline detector for the neutrino factory by the ISS study [7] due to the large achievable mass and relative ease with which such a detector can be magnetised. While this technology could not be used to detect channels other than those involving ν_μ $(\overline{\nu}_\mu)$ the statistical power of this channel means that δ_{CP} can be accurately measured with this channel alone [3].

Development of simulation and analysis tools to optimise this technology is underway with the first application of pattern recognition and analysis presented in [8]. It is envisioned that the same framework will be used to compare and contrast the different technologies, particularly to compare MIND to TASD which can be considered as the limit of the MIND technology as the iron content tends to zero.

The most recent analysis of MIND using a geant4 [9] simulation and neutrino events generated using Nuance [10] results in the efficiencies shown in Fig 2 and suppresses all expected backgrounds to at or below the 10^{-4} level [11]. This level of suppression should allow measurement of CP violation over most of the currently allowed parameter space.

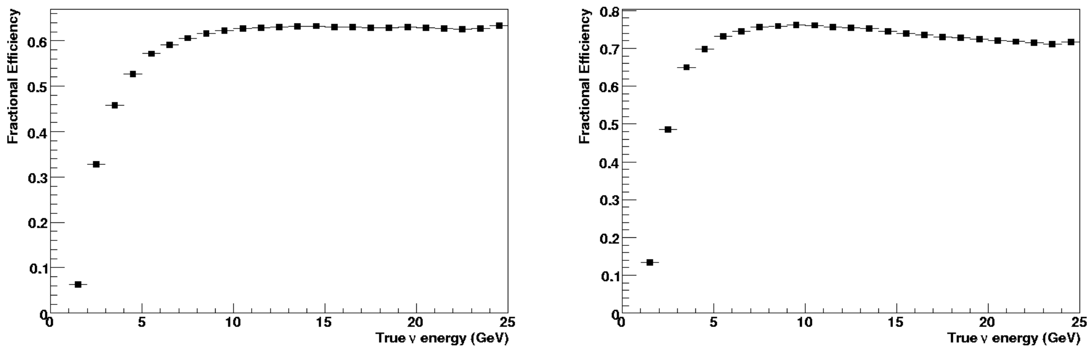

Figure 2: *Signal efficiencies for the appearance of ν_μ (left) and $\overline{\nu}_\mu$ (right).*

4. Conclusions

The design and optimisation of neutrino factory detectors for the measurement of leptonic CP vioilation is underway. The latest results of simulation of the baseline detector design indicate that leptonic CP violation could be measured over most of the allowed parameter space.

References

[1] The International Design Study for the Neutrino Factory. URL: https://www.ids-nf.org/wiki/FrontPage.

[2] EUROnu: A High Intensity Neutrino Oscillation Facility in Europe. URL: http://www.euronu.org/.

[3] A. Bandyopadhyay et al. Physics at a future Neutrino Factory and super-beam facility. *Rept. Prog. Phys.*, 72, 2009.

[4] Maddalena Antonello. ArgoNeuT and MicroBooNE: LAr-TPC's at Fermilab. *AIP Conf. Proc.*, 1222:257–261, 2010.

[5] L. Oberauer. LAGUNA. *Nucl. Phys. Proc. Suppl.*, 188:321–322, 2009.

[6] Alan Bross, Malcolm Ellis, Steve Geer, Olga Mena, and Silvia Pascoli. The low-energy neutrino factory. *AIP Conf. Proc.*, 981:187–189, 2008.

[7] T. Abe et al. Detectors and flux instrumentation for future neutrino facilities. *JINST*, 4:T05001, 2009.

[8] A. Cervera, A. Laing, J. Martıń-Albo, and F.J.P. Soler. Performance of the mind detector at a neutrino factory using realistic muon reconstruction. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, In Press, Corrected Proof:–, 2010.

[9] Geant4 Physics Reference Manual. http://cern.ch/geant4/UserDocumentation/UsersGuides/PhysicsReferenceManual/html/.

[10] D. Casper. The nuance neutrino physics simulation, and the future. *Nucl. Phys. Proc. Suppl.*, 112:161–170, 2002.

[11] A Laing. *Optimisation of detectors for the golden channel at a neutrino factory*. PhD thesis, School of Physics & Astronomy, University of Glasgow, 2010.