Detectors for leptonic CP violation at the Neutrino Factory

A. Laing, 24 July 2010
on behalf of the IDS-NF collaboration
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Contents

- The neutrino factory and motivations for CP violation measurement.
- Near detector at a neutrino factory.
- Possible technologies for far detectors.
- The baseline and its simulation status.
- R&D
The Neutrino Factory and leptonic CP violation

Measurement requires the study of appearance channels. Spectral information greatly improves resolution. Multiple detector baselines and/or channels advantageous.

The measurement of CP violation in neutrino oscillations opens a potential window on leptogenesis.

\[ P_{\nu_e \rightarrow \nu_\mu} = s_{23}^2 \sin^2(2\theta_{13}) \frac{\Delta_{13}^2}{B} \sin^2\left(\frac{B L}{2}\right) + c_{23}^2 \sin^2(2\theta_{12}) \sin^2\left(\frac{A L}{2}\right) + J \left(\frac{\Delta_{12}}{A} \frac{\Delta_{13}}{B}\right) \sin\left(\frac{A L}{2}\right) \sin\left(\frac{B L}{2}\right) \cos(\pm \delta - \frac{\Delta_{13}}{2}) \]

Related presentations at ICHEP 2010

M. Bonesini, “MICE PID System”, Poster 803.
N. Mondal, “India Neutrino observatory”, Poster 394.
The Neutrino Factory as a neutrino source

Subdominant oscillations contain most information.
Golden channel identified as most important signal due to relative ease of detection.
Requirements for the detection of subdominant oscillations

- Magnetic field to separate the charge of the primary lepton.
  - High interaction rate of surviving beam neutrinos.

- High suppression of hadronic particles.
  - Pions, Kaons and decay leptons can act as background.

- Measure flux and cross-sections to a high degree of accuracy.
Near Detector

- A near detector facility placed within 1 km of the source would have a number of functions:

  - **Absolute flux measurement:**
    - Inverse muon decay for purity.
    - Full spectral reconstruction with multiple channels.
  
  - **Multiple subdetectors or small scale FD?**
  
  - **Cross-section measurement:**
    - High granularity possible.
    - Massive flux means unprecedented interaction rate.
    - All channels measured to 1% level?
    - Unprecedented understanding of suppressed processes.

Karadzhov, Matev, Tsenov, Uni. Sofia.
Possible Far detector technologies

Magnetised Iron Neutrino Detector

Pros:
- Large mass
- High hadronic suppression
- Easily magnetised

Cons:
- Only for golden channel
- High energy threshold

Totally active scintillator

Pros:
- Low energy threshold
- High resolution
- Possible silver channel

Cons:
- Lower mass
- Difficult to magnetise

Liquid Argon TPC

Pros:
- V. high resolution
- V. low energy threshold
- Multi-channel

Cons:
- New technology
- Difficult to magnetise
- Large mass difficult

MIND has been chosen as the baseline detector technology for IDS-NF.
Large scale liquid argon

A number of R&D programs exist to realise a high mass LAr TPC.

- The Laguna project is studying sites and engineering in Europe.
- LBNE in USA are looking into designs for a 20kT detector.
- Other efforts in Japan etc. looking at technology.

Challenges include:
- Engineering of the vessel.
- Cooling and maintaining purity.
- Drift distances.
- Magnetisation.
LAr TPC (cont.)

- The spacial resolution of a LAr TPC is similar to that of a bubble chamber.
- Proof of the feasibility of the technology and of magnetisation required.
- Has the potential to study other neutrino sources and perform other physics studies.

ArgoNeuT collaboration

Totally Active Scintillator Detector

- Like Nova but made from extruded plastic scintillator decreasing dead area.
- Triangular cross-section bars similar to Minerva for increased spacial resolution.

- R&D required to achieve magnetic field.
- Possibility of Magnetised cavern using superconducting transmission lines.
Initial studies simulating free muons indicate a low energy threshold for golden channel signal identification.

400 MeV/c e$^-$$^{}$ 3 GeV/c e$^+$

Indication also of potential platinum channel sensitivity through electron identification.

Magnetised Iron Neutrino Detector

- High suppression of hadronic backgrounds.
- Easily magnetised.
- High mass.
- Technology well understood

Chosen as the baseline detector for IDS-NF for these reasons.

Need to prove that an energy threshold of 3 GeV or lower can be maintained without high backgrounds.
Are the electronics to overcome cross-talk affordable?
Is only the Golden Channel enough?
Simulation status

Geant4 simulation of MIND:
Cuboidal structure
1T uniform dipole field*

Staged development to include toroidal field, optimise cross-sectional shape and scintillator segmentation. Can ultimately be used for studies of TASD using the same framework.

*Studies underway into a realistic toroidal fieldmap and octagonal cross section.
Field strength likely to be achieved using a Superconducting Transmission Line (SCTL) developed originally for the VLHC.
Analysis

- All detectors require dedicated studies of reconstruction and analysis to suppress beam inherent backgrounds.
  - Kalman filter/Cellular automaton to reconstruct candidate muons from events.
  - Helix fit of candidates using Kalman filter to reconstruct Charge and momentum.

Separation of signal and background using fit quality, event topology and kinematics.

-- NC
-- Signal
Current status of MIND

- Signal efficiency and background for the appearance of $\nu_\mu$ and $\bar{\nu}_\mu$ have been studied under current assumptions.
Required R&D

Testing of SCTL technology in the context of the magnetic cavern.

Optimisation of cable geometry for toroidal field for MIND.

Testing of very long scintillator bars for mechanical strength and attenuation.
Double or single sided read-out, electronics technologies.

MIND has large amount of synergy with the Indian Neutrino Observatory detector.
Work with INO colleagues on prototyping using RPC and scintillator read-out.

Mondal et al, TIFR.
Summary

- Measurement of leptonic CP violation at the neutrino factory requires optimisation of detectors.
- A number of technologies are under study.
- Simulations indicate required efficiency and background suppression is possible.
- Interim design report within the year. Reference design report to be published by 2013.
Backup
Efficiency and inelasticity