

MIND Migration Matrices and Sensitivities

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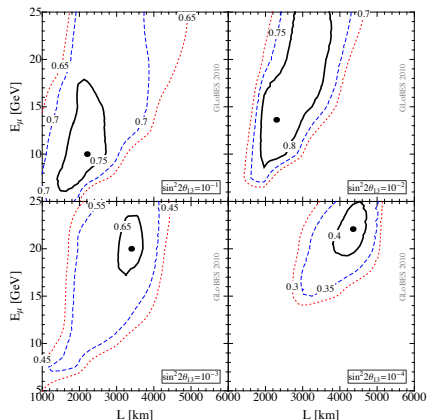
4th EUROnu Meeting
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- 1 Introduction
- 2 Simulation Overview
- 3 Analysis
- 4 Migration Matrices
- 5 Sensitivities
- 6 ν STORM
- 7 Conclusions

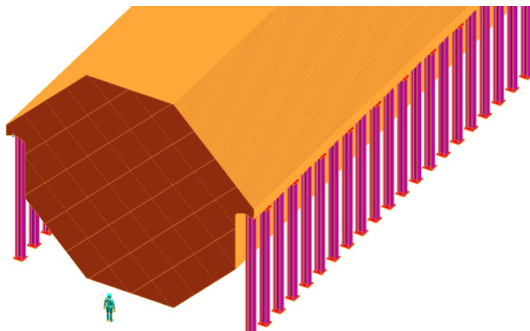
Consequences of Large θ_{13} on Neutrino Factory

- Physics priorities shift to measurement of CP violation.
- For measurement of θ_{13} used
 - ▶ Two baselines: 4000 km and 7000 km
 - ▶ 25 GeV stored μ energy.
- Re-optimization of baseline and beam energy required
- Best sensitivity to δ_{CP} achieved with
 - ▶ 2000 km baseline.
 - ▶ 10 GeV stored μ energy.
- MIND simulation used to examine sensitivities with these specifications.

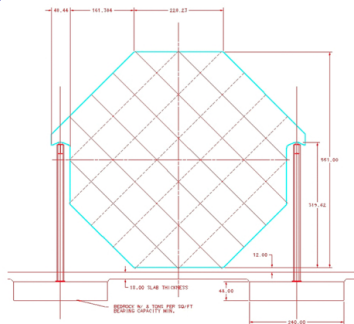


From IDS-NF-020, Interim Design Report

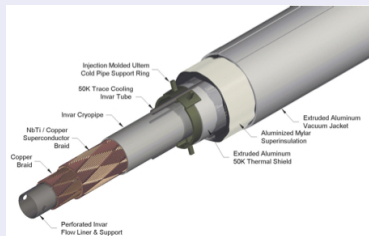
MIND Design for Neutrino Factory



- 100 kTon detector
- 14 m × 14 m × 140 m.
- X and Y views from 2 cm thick lattice of 1 cm × 3.5 cm scintillator bars.
- \vec{B} field from 3 cm Fe plates, induced by 120 kA current carried by 7 cm diameter SCTL

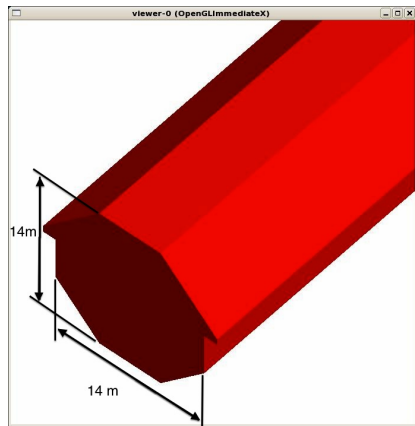
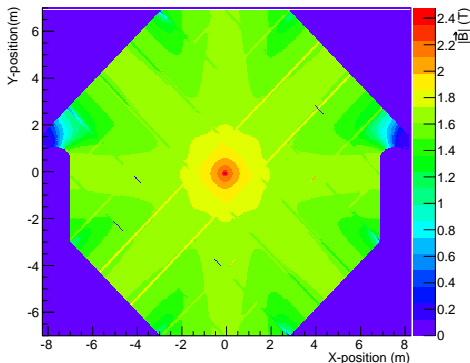


Superconducting Transmission Line



MIND Simulation

- Events simulated with GENIE.
- Full geometry & \vec{B} field in GEANT 4
- Realistic field map generated by Bob Wands at FNAL
 - ▶ default positive focussing.

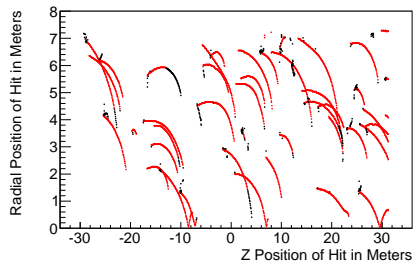


- Dimensions of detector easily altered for
 - ▶ optimization.
 - ▶ testing variations.

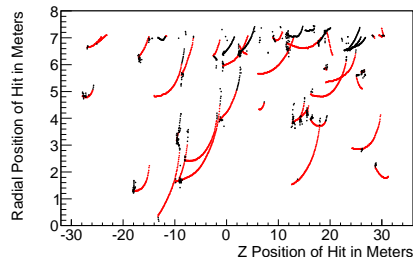
MIND Event Reconstruction

- Simulated events digitized.
 - ▶ Hits positions smeared and energy deposition attenuated.
 - ▶ Edep clustered into 3.5 cm×3.5 cm units.
- Tracks identified by Kalman Filter or Cellular automata.
- Kalman fitting used to determine momentum and charge.
- Algorithms from RecPack.
 - ▶ supported by Cervera-Villanueva *et al.*
 - ▶ Details in talk by Tapasi Ghosh

- 50 $\bar{\nu}_\mu$ CC events.



- 50 ν_μ CC events.



- Fitted hits in red others in black.

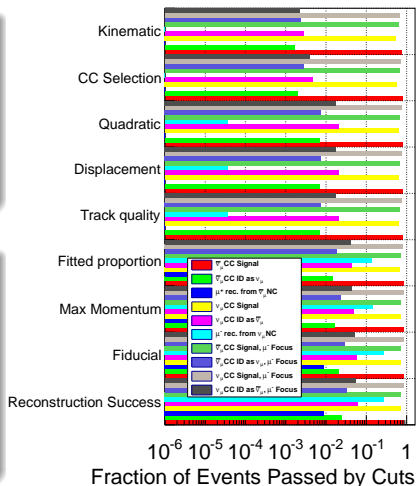
Cuts Based Golden Analysis

Described in detail in IDR.

- Separates NC like from CC like events.
- CC backgrounds are reduced as they are partially NC like.

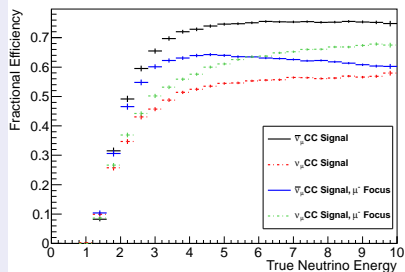
Departures from IDR Analysis

- Quadratic and displacement cuts removed.
- Kinematic cuts replaced by a uniform requirement $Q_t > 0.15$ GeV

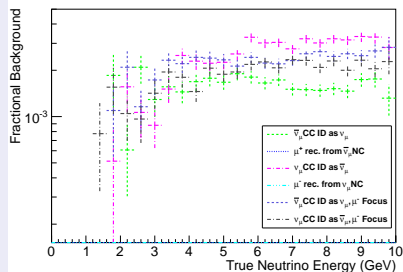


Charge Current Selection Efficiencies

Signal Efficiencies



Background

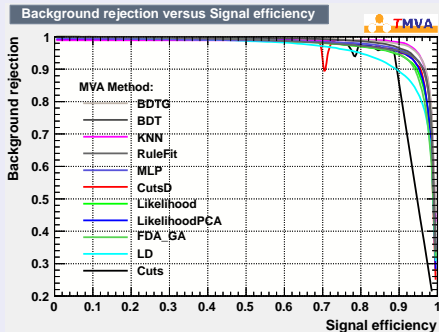


- All reconstruction efficiencies at or above 50%.
- Background suppressed by parts in 10^3 .
- NC backgrounds completely suppressed.

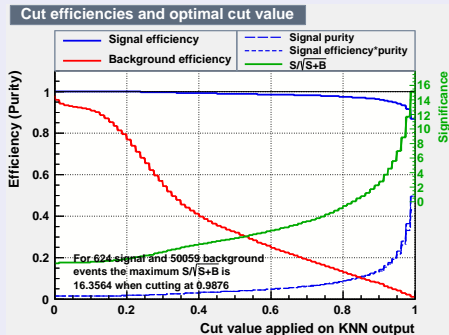
Multi-Variate Analysis

- A full multivariate analysis is under development.
 - ▶ Use a set of correlated variables to select signal from background.
- Should be able to achieve higher efficiency than existing analysis.
- Still a work in progress.

Variety of Methods Tested



Example KNN Method



Extracting Sensitivities from Simulation

- Use the simulation to produce "migration matrices"
 - ▶ Relates true neutrino energy to reconstructed energy.
 - ▶ Contains efficiency, energy resolution, and response information.
- Run pseudo-experiments with simulation package (ie. NuTS).
- Data is sum of signal and background multiplied by MMs

Required Simulations

● ν_μ Appearance

- ▶ ν_μ CC (μ^- signal)
- ▶ $\bar{\nu}_\mu$ CC (μ^- background)
- ▶ ν_e CC
- ▶ ν_τ CC
- ▶ $\bar{\nu}_\tau$ CC
- ▶ Neutral Current channels

● $\bar{\nu}_\mu$ Appearance

- ▶ $\bar{\nu}_\mu$ CC (μ^+ signal)
- ▶ ν_μ CC (μ^+ background)
- ▶ $\bar{\nu}_e$ CC
- ▶ ν_τ CC
- ▶ $\bar{\nu}_\tau$ CC
- ▶ Neutral Current channels

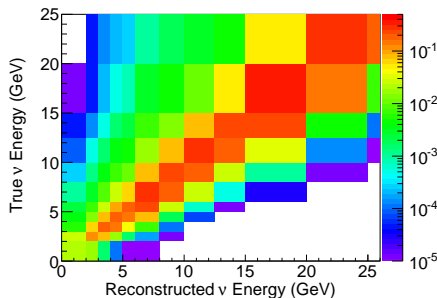
● Systematic uncertainties —

Number of Interactions & Known $\nu/\bar{\nu}$ difference.

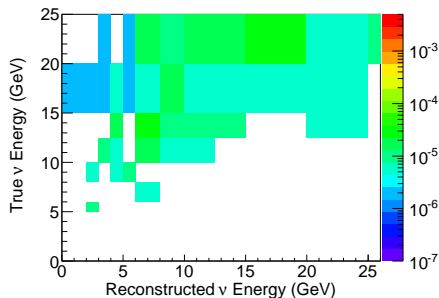
Existing Neutrino Factory Migration Matrices

- Literature uses response from cuboid geometry with a dipole field
- Detector model not physically realistic.
- Existing MMs use GENIE for ν_τ events and NUANCE otherwise.
- Have updated MMs using GENIE throughout

ν_μ Appearance Signal



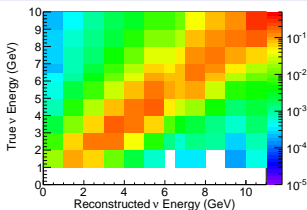
ν_μ App. $\bar{\nu}_\mu$ CC Background



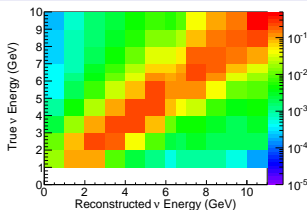
Preliminary Migration Matrices for Octagonal MIND

Assuming 10 GeV factory

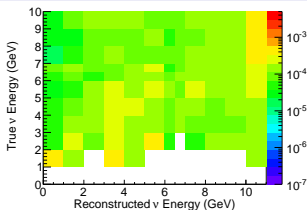
ν_μ Appearance Signal



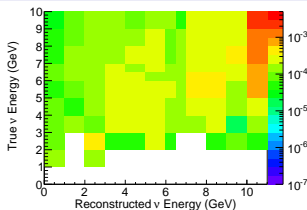
$\bar{\nu}_\mu$ Appearance Signal



ν_μ App. $\bar{\nu}_\mu$ CC Background



$\bar{\nu}_\mu$ App. ν_μ CC Background

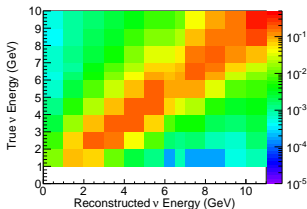


- Generated from cuts-based analysis.
- Two \vec{B} settings.
- μ^+ Focussing.
- μ^- Focussing.
- Field settings run separately.
- Optimization still required

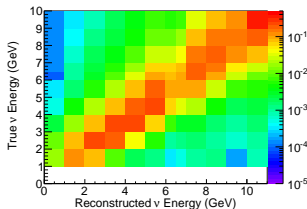
Preliminary Migration Matrices for Octagonal MIND

Assuming 10 GeV factory

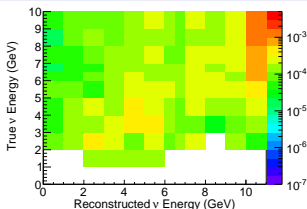
ν_μ Appearance Signal



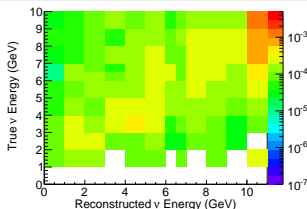
$\bar{\nu}_\mu$ Appearance Signal



ν_μ App. $\bar{\nu}_\mu$ CC Background



$\bar{\nu}_\mu$ App. ν_μ CC Background



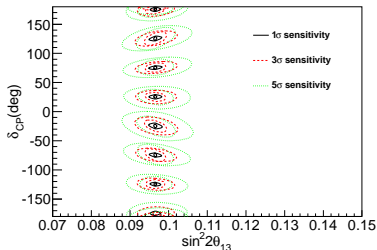
- Generated from cuts-based analysis.
- Two \vec{B} settings.
- μ^+ Focussing.
- μ^- Focussing.
- Field settings run separately.
- Optimization still required

CP Violation Precision for Cuboid MIND

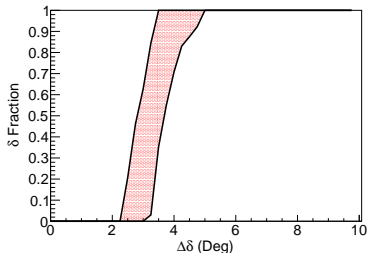
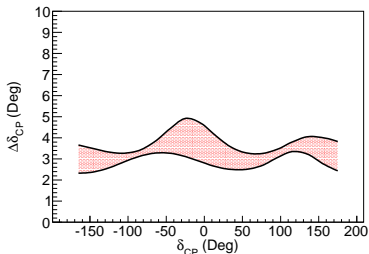
Assuming 25 GeV Factory, 10 years Running, $0.5 \times 10^{21} \mu^+ + 0.5 \times 10^{21} \mu^-$ per year

- Analysis is mature.
- An optimistic estimate of the Neutrino Factory precision.
- Systematic variations shown (1%,1%) \rightarrow (2.5%, 3%).

χ^2 Contours from fits to Arbitrary δ_{CP} ,
 $\theta_{13} = 9^\circ$



Error in δ_{CP} from 1 σ curves

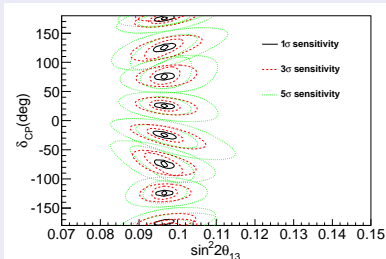


Preliminary Precision in δ_{CP} For Octagonal MIND

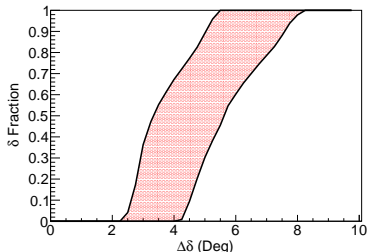
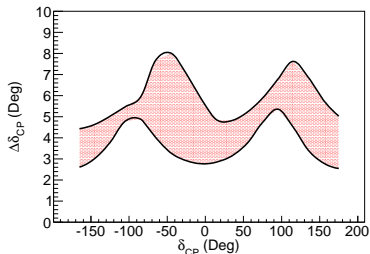
Assuming 10 GeV Factory, 10 years Running, $0.5 \times 10^{21} \mu^+ + 0.5 \times 10^{21} \mu^-$ per year

- Required for optimization.
- Uses cuts-based analysis.
- Still under development.
- Systematic variations shown (1%, 1%) \rightarrow (2.5%, 3%).

χ^2 Contours from fits to Arbitrary δ_{CP} ,
 $\theta_{13} = 9^\circ$

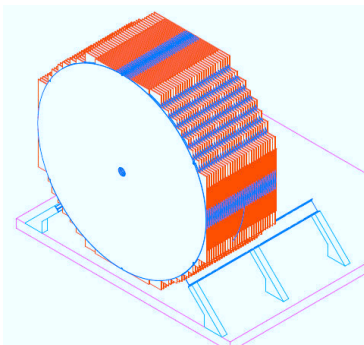
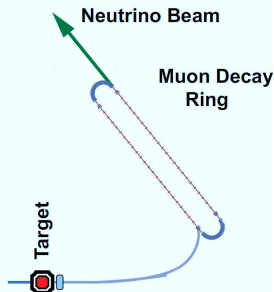


Error in δ_{CP} from 1 σ curves



ν STORM: A Beginner's Neutrino Factory

- Muon storage ring: no muon cooling, little acceleration.
- 3.8 GeV stored μ Energy
- 2×10^{18} useful μ per year.
- Measure:
 - ▶ Short baseline sterile neutrino oscillations.
 - ▶ **electron ν cross-sections**
- Use an altered MIND detector for ν_{μ} App.
 - ▶ Thinner (1-2 cm) plates, 2 cm thick Scint. lattice
 - ▶ 5 m diameter circular cross-section
 - ▶ 1 kTon mass, 20 m length
- Baseline of 2 km(1.5 km)

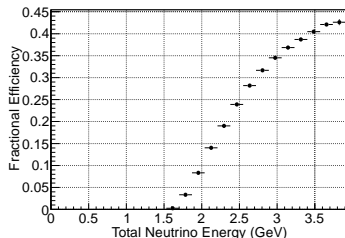


ν_μ Appearance Sensitivity

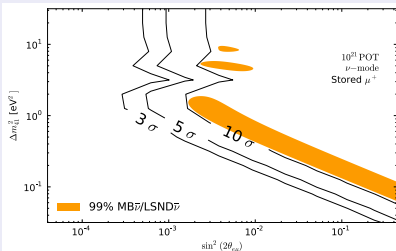
For Sterile ν Discovery

- Analysis is similar to ν_μ App. in neutrino factory
- Used migration matrix method with GLoBES (Chris Tunnel)
- Analysis still evolving.
- For more information see: [arXiv:1206.0294v1](https://arxiv.org/abs/1206.0294v1)

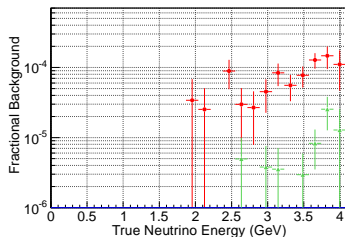
Signal Efficiency (2 cm Fe plate)



Sterile Neutrino Sensitivity



Background (2 cm Fe plate)



Outlook

There has been great progress in the past year.

- Complete change to GENIE event generator.
- Introduction of realistic octagonal geometry
- Improvement of reconstruction to allow toroidal field.

Still work in progress

- Reconstruction of secondary, hadron tracks.
- Update to use multi-variate analysis.
- Optimize analysis for physics outcomes.

Early conclusions

- δ_{CP} precision is between 2° and 5° with dipole magnetic field.
- Preliminary precision of δ_{CP} between 2° and 8° with toroidal magnetic field.