Status of the MIND Simulation

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NUFACT
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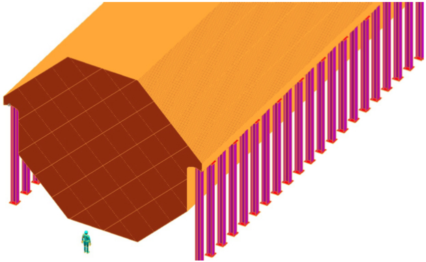
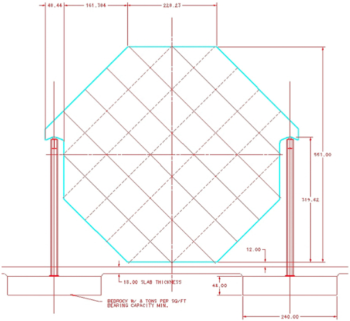
Introduction

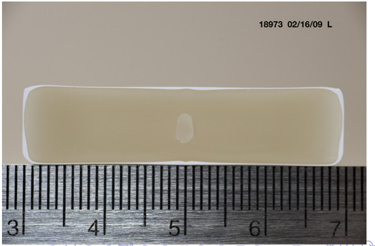
- Proposed far detector for Neutrino Factory.
- To be used with a near detector for measurement of θ_{13} and δ_{CP}.
- Optimized to carry out "Golden Channel" measurements.
    - Looking for $\nu_e \rightarrow \nu_\mu$ or $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ oscillations.
    - Detects muon of sign opposite to that generated by neutrino beam.
- Simulation of detector needed to characterize parameter sensitivity

Conceptual Design



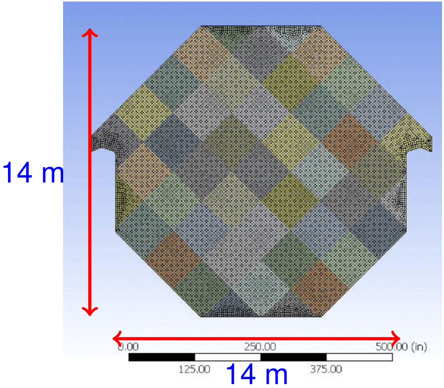
- Octagonal detector cross section.
- Alternating iron plates and scintillator planes.
- Scintillator planes to determine 2D hit position.
  - Composed of arrays of extruded scintillator bars ($\sigma_{pos} \sim 1$ cm).

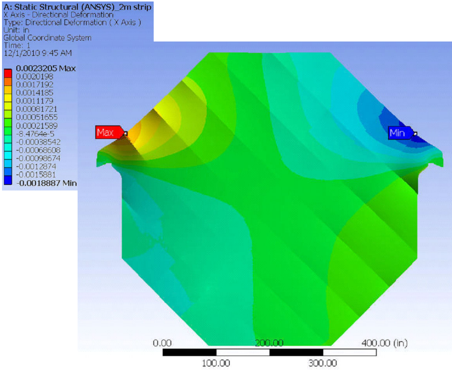




Engineering of Iron Plates

Iron plates to be constructed of overlapping 2 m strips.

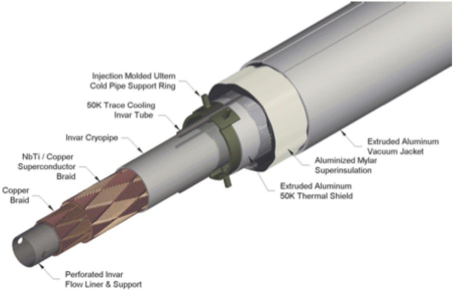




- Finite element model shown to be structurally sound

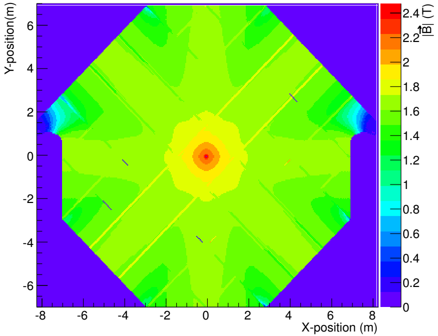
MIND Magnetic Field

- Required for identification of wrong sign muons.



Magnetic field to be induced by superconducting transmission line

- Transmission line 7.8 cm in diameter.
- Contained in a 10 cm hole in the iron.



Small distortions caused by slots between strips

- Simulated using a 100 kA excitation current

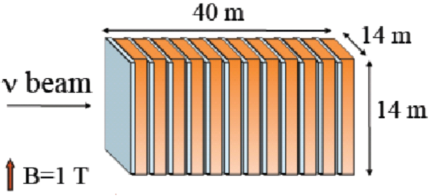
Baseline parameters for MIND

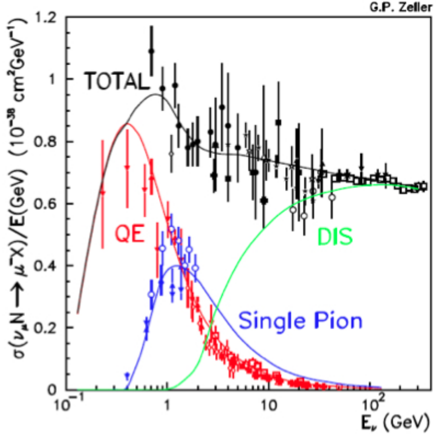
- Specifications of detector will depend on length of base-line.

Parameter	MIND 1	MIND 2
Distance (km)	3000-5000	7000-8000
Fiducial Mass (kTon)	100	50
Iron Plate Dimensions (cm)	$1500\times1500\times3$	$1500\times1500\times3$
Length of Detector (m)	125	62.5
Number of Iron Plates	2500	1250
Scintillator Bar Dimensions (cm)	$1500\times3.5\times1$	$1500\times3.5\times1$
Number scintillator bars per plane	429	429
Total number of scintillator bars	2.14×10^6	1.07×10^6
Total number of readout channels	4.28×10^6	2.14×10^6
Magnetic Field (T)	>1	>1

Simplified Detector Simulation

- Neutrino interaction events generated using NUANCE + LEPTO
- Detector simulated using GEANT 4

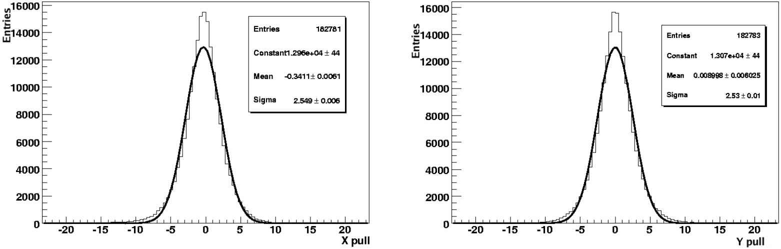




- Simulation includes:
  - Deep inelastic scattering
  - Quasi elastic scattering
  - Single pion production
  - Resonant pion production
  - Coherent pion production

Reconstruction

- Track fitting completed using Kalman fitting in Recpack [1] package.
    - Propagates an initial guess through hit clusters
    - Longest trajectory with smallest χ^2 is assumed to be candidate muon track.

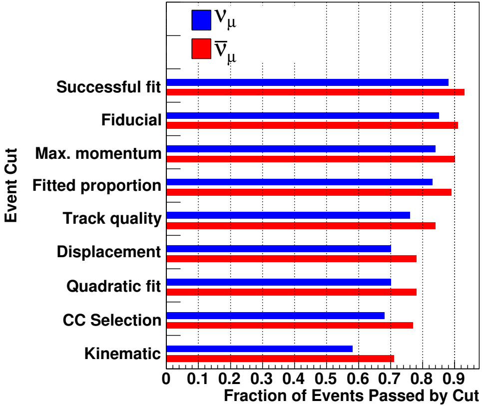


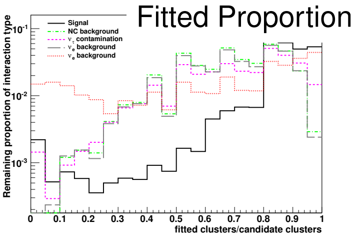
- Cellular automaton method used if Kalman fitting fails

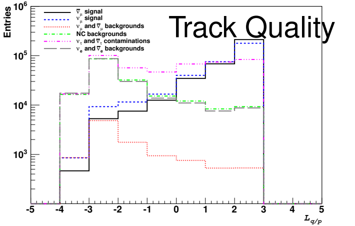
[1] NIM, A534:180-183, 2004

Analysis and Event Selection

- Track quality and charge current selection done by cutting on selected likelihood distributions

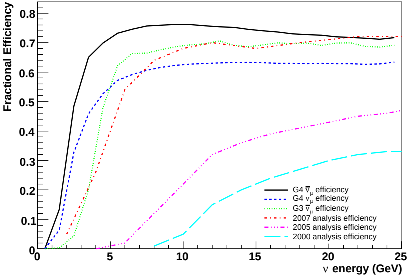




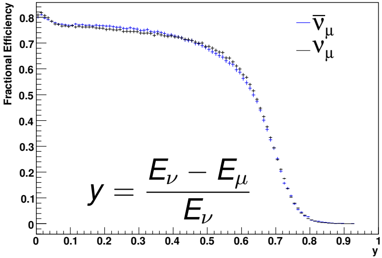


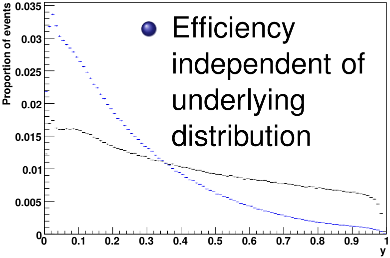
Efficiency of Reconstruction

Results presented at NUFACT10



- Optimal CC efficiency at $E_\nu = 10$ GeV
- $\bar{\nu}_\mu$ event detection more efficient than ν_μ event detection

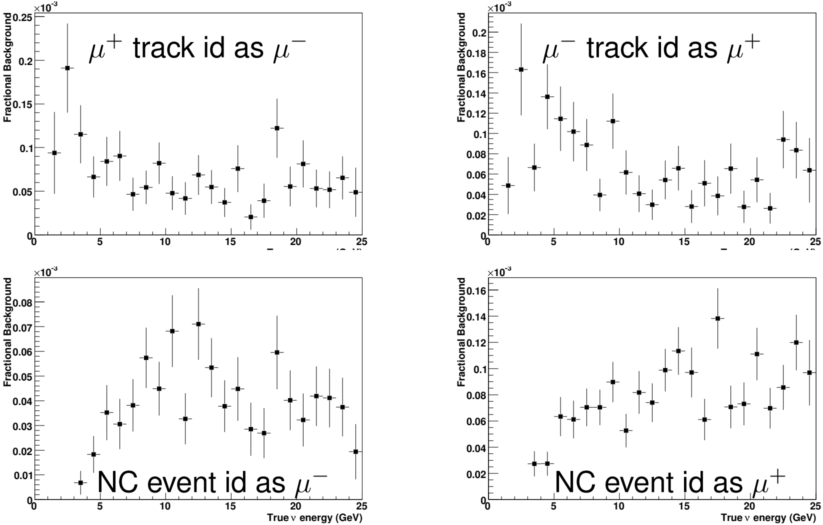




- Efficiency independent of underlying distribution

Reconstruction Background

Need suppression of background at $< 10^{-3}$ level



Fitting δ_{CP} and θ_{13}

Simulated response used to predict experiment potential

- Fluxes and oscillation probabilities calculated using the Neutrino Tool Suite (NuTS)[2]
- Assume 25 GeV muon Storage ring 2.5×10^{20} μ^+ and μ^- decays/y
- Use a function to simultaneously fit for δ_{CP} and θ_{13}

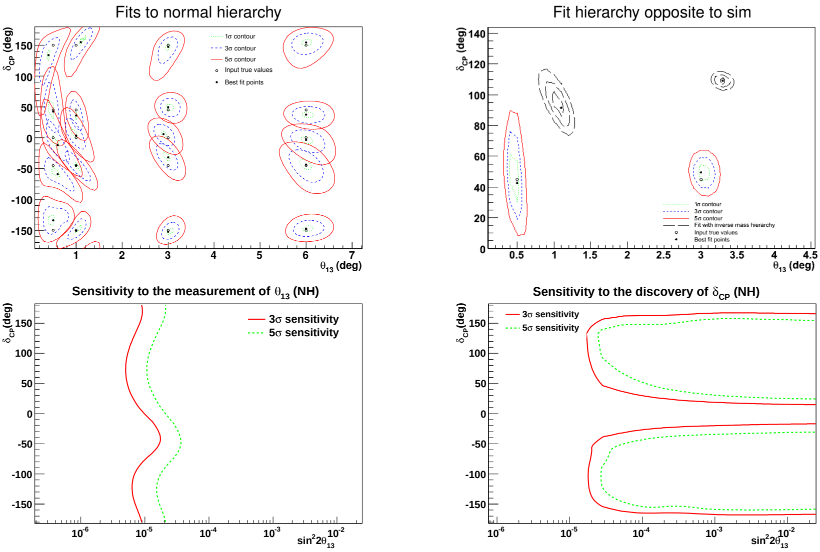
$$\chi^2 = \sum_j \left\{ 2 \times \sum_e^{E_\mu} \left(A_j x_j N^e_{+,j}(\theta_{13}, \delta_{CP}) - n^e_{+,j} + n^e_{+,j} \log\left(\frac{n^e_{+,j}}{A_j x_j N^e_{+,j}(\theta_{13},\delta_{CP})}\right) + A_j N^e_{-,j}(\theta_{13}, \delta_{CP}) - n^e_{-,j} + n^e_{-,j} \log\left(\frac{n^e_{-,j}}{A_j N^e_{-,j}(\theta_{13},\delta_{CP})}\right)\right) + \frac{(A_j-1)^2}{\sigma_A} + \frac{(x_j-1)^2}{\sigma_x} \right\}$$

- $n^e_{i,j}$ is “data” for energy bin e
- $N_{i,j}$ is prediction for bin e

- A_j and x_j are free parameters
- σ_A and σ_x are associated errors.

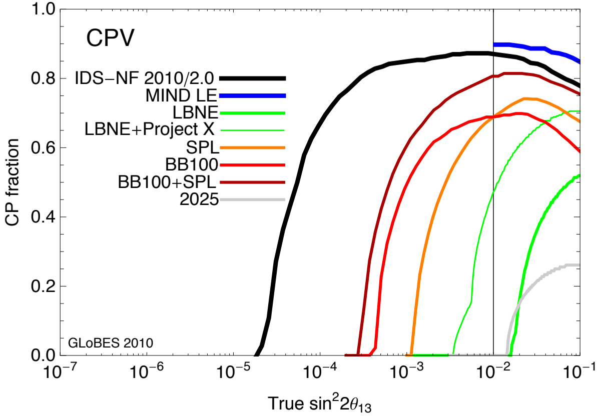
[2] J. Burguet-Castell, *et. al.*, Nucl. Phys., B608, 301 (2001).

Sensitivity to δ_{CP} and θ_{13}



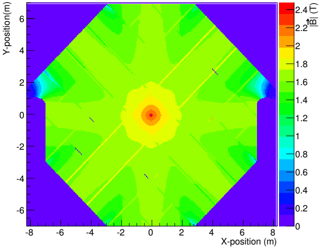
Summary of Sensitivities

- Expect a 3σ sensitivity for $\sin^2 2\theta_{13} > 7.6 \times 10^{-5}$ or $\theta_{13} > 0.25^\circ$.
- Sensitive to large fraction of CP values for $\sin^2 \theta_{13} > 7.6 \times 10^{-5}$.



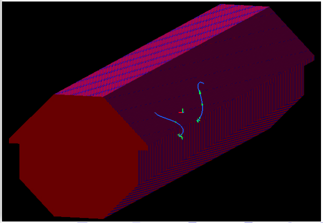
Toward a Realistic Simulation

- Replaced NUANCE neutrino generator with GENIE.
- Adopted octagonal geometry in simulation.
- Introduced a realistic, toroidal field map.

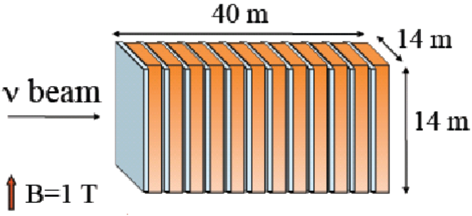


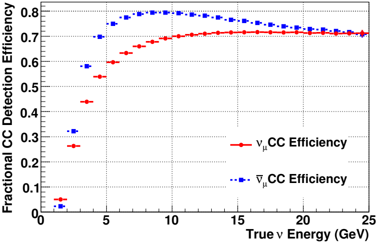
In Progress

- Reconstruction and Analysis need to be re-optimized for new geometry.
- Hadronic reconstruction.
- Complementary muon momentum measurements from range.
- Investigation of cosmic and tau backgrounds.

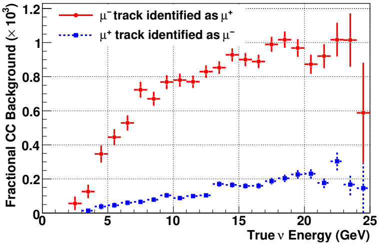


Adoption of GENIE ν Event Generator

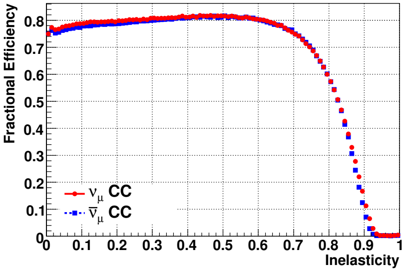


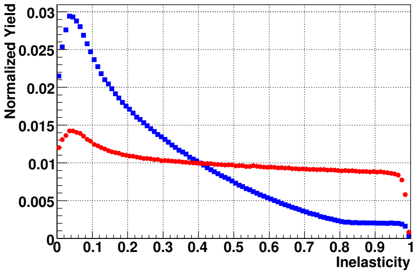


- Used the simplified detector geometry.
- Overall increase in efficiency.
- μ^- background is larger.
- Source of increases is still unknown.



Change in Inelasticity spectra using GENIE





- Rise in efficiency for $y < 0.5$;
- Efficiency in ν_μ and $\bar{\nu}_\mu$ events almost identical.
- Source of qualitative difference with NUANCE/LEPTO unknown.

- Qualitative difference in ν_μ event Inelasticity between GENIE and NUANCE.
- Probably due to differences in PDFs used.

Alternate Far Detector: Totally Active Scintillating Detector

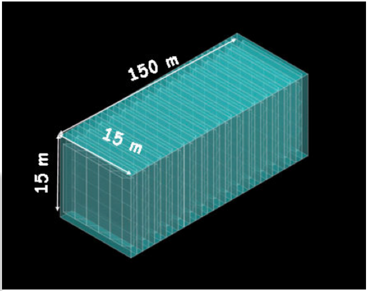
- Sim developed by Malcolm Ellis.
- Composed entirely of scintillator bars.
- Dimensions similar to MIND.

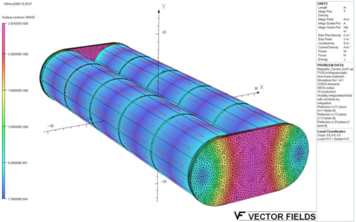
Pros:

- Lower energy threshold.
- Can measure $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations.

Cons:

- Magnetic field must be generated external to the detector.
- Further R&D required.





Conclusion

- A good simulation is vital both for prototyping a ν-factory far detector and understanding its output.
- An intermediate MIND simulation has been produced.
  - Uses a simplified detector and magnetic field geometry
  - Shows high efficiencies and very good background suppression.
- A new MIND simulation is in progress with more realistic geometry.
  - Analysis and reconstruction is being re-optimized in new geometry
- Complete simulation will be done within a year.