Detector Simulation and Performance

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1. Simulation Overview
2. Analysis
3. Outlook and Future Development

Introduction

- Both ν_e and $\bar{\nu}_\mu$ are present in the νSTORM beam
- Four oscillation detection modes are possible
  1. ν_μ appearance: $\nu_e \rightarrow \nu_\mu$, μ^- signal
  2. $\bar{\nu}_\mu$ disappearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, μ^+ signal
  3. ν_e disappearance: $\nu_e \rightarrow \nu_\mu$, e^- signal
  4. $\bar{\nu}_e$ appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, e^+ signal
- Central requirement is charge discrimination
- Requires a magnetic field and good detector efficiency
- A magnetized iron neutrino detector fulfills these requirements for a $\mu^\pm$ signal.

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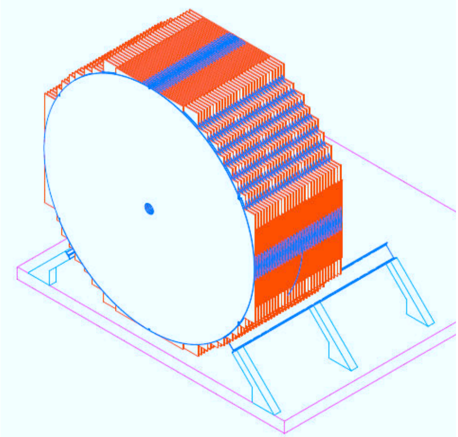
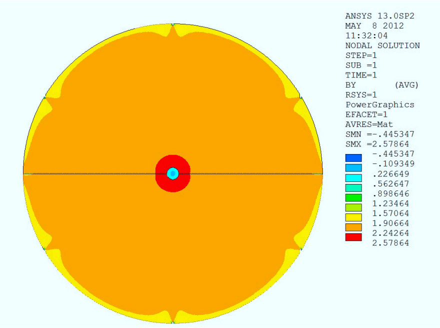
Detector Design

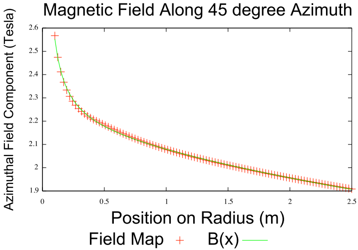
- Detector consists of layered iron and scintillator planes
- Iron plates 1 cm(2 cm) thick.
- Scintillator planes 2 cm thick.
    - Composed of scintillator bars 1 cm thick and 1 cm width.
    - Measure x and y position at each plane.
- Circular cross-section, 5 m diameter.
- 20 m long for 1 kton mass.
- Magnetization achieved with SCTL



SuperBIND Simulation

- Based on MIND simulation for the Neutrino Factory
- Neutrino events simulated in GENIE.
- Detector geometry and materials simulated with GEANT4.
- Scintillator plane simulated as a polystyrene slab.
  - hits grouped into discrete bars and attenuate in digitization.
- Use toroidal field: model from fit to simulation of field.

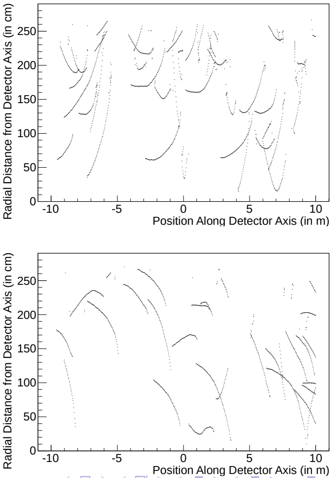




Reconstruction

- Uses a Kalman filter for pattern recognition and track fitting.

- Longest set of single hits identified as muon.
- Further hits filtered into track.
- Fits assume
  - range of track as estimate of momentum .
  - sum of deviation of track from straight-line in magnetic field estimates the charge.
- Only the muon track is fit.
- No hadron reconstruction from digitized events.



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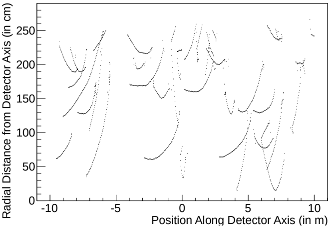
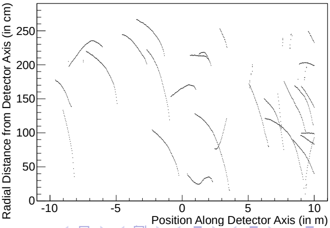
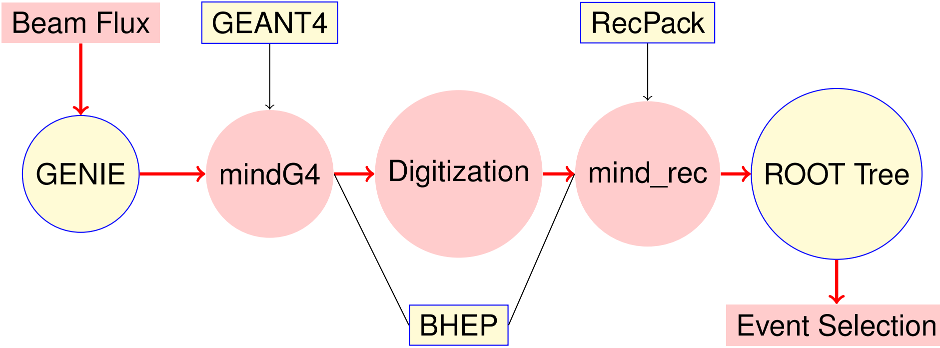




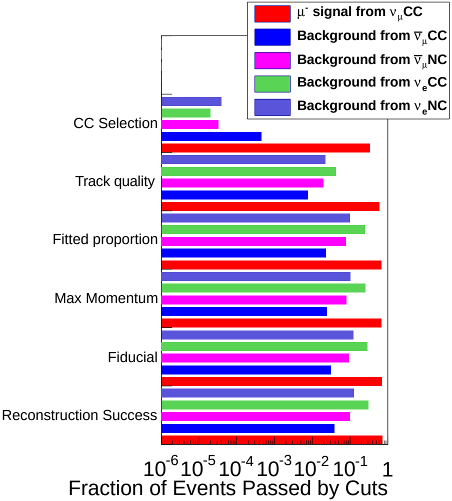
Software Summary

- Software is modular.
- Parts are interchangeable.
- Information between simulation and reconstruction uses a "bhep" format.

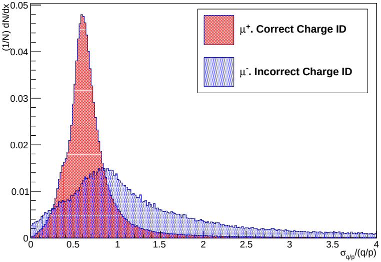


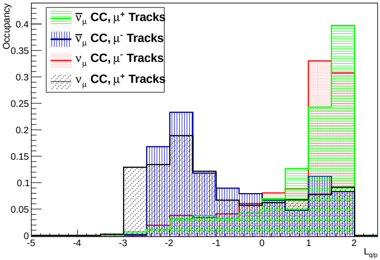
Charge Current Selection

- Identify muon signals.
- Reject tracks from NC events and shower processes.
- Analysis simplified to six cuts.
    - Successful reconstruction
    - $p_\mu < 1.6 \times E_\mu$.
    - Track vertex before last 1 m of detector volume
    - Fitted track includes >60% of candidate hits.
    - Scaled curvature uncertainty is CC event like.
    - Number of candidate hits is CC event like.
- Greatest analytic power in likelihood cuts.



Muon Selection from Uncertainty in Curvature



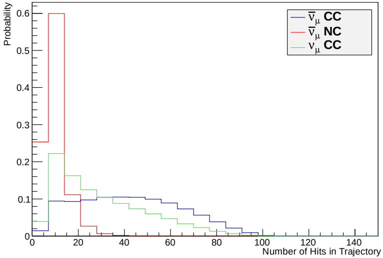


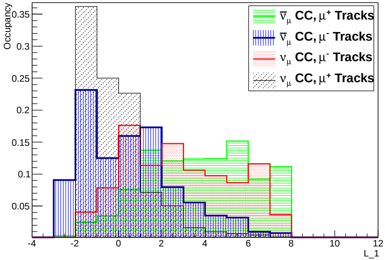
- Distributions of $|\frac{\sigma_{q/p}}{q/p}|$ compiled for
  - CC events with correct charge
  - CC events with incorrect charge
  - NC events
- Distributions used to define a quantity

$$\mathcal{L}_{q/p} = \log \frac{P(\sigma_{q/p}/(q/p)|CC))}{P(\sigma_{q/p}/(q/p)|NC))}$$

- Allow events with $\mathcal{L}_{q/p} > 0.5$.
- A "weak" cut to remove signal from background.

Muon Selection from Number of Hits





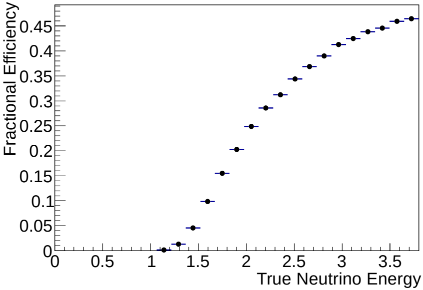
- Number of candidate hits in muon trajectory compiled for
  - CC events
  - NC events
- Distributions used to define a quantity

$$\mathcal{L}_{CC} = \log \frac{P(N_{cand}|CC))}{P(N_{cand}|NC))}$$

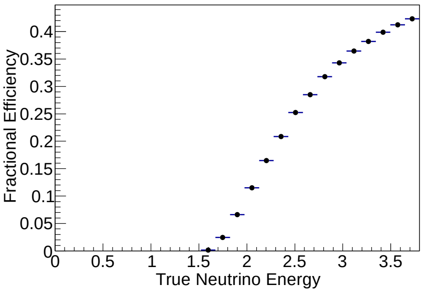
- Allow events with $\mathcal{L}_{CC} > 6.5$
- A very strong cut to remove background.
- Also good at eliminating low energy signal.

Efficiency and Background Rejection

1 cm Plate



2 cm Plate



- 1 cm Fe plates and 2 cm Fe plates considered.
- 1 cm plate initially favoured to improve energy threshold.
- Rejection of charge mis-ID events better in 2 cm plate.
- Improvement due to the larger magnetic field.

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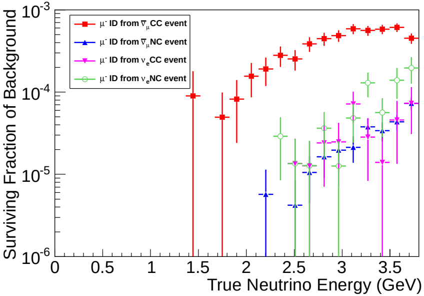
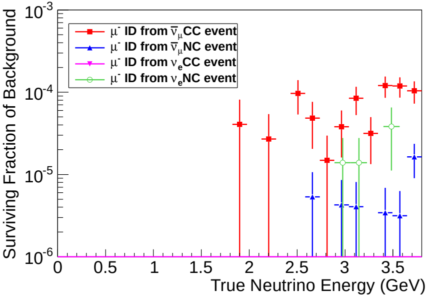


2 cm Plate



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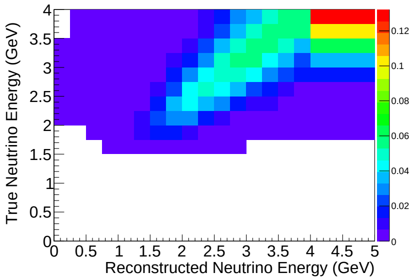
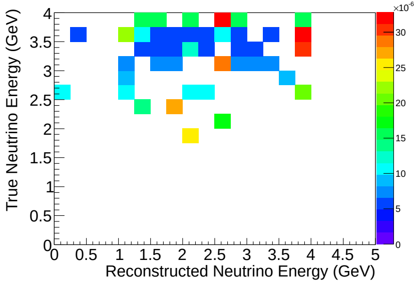
Detector Response

Signal Response, 2 cm Plate



Background Response

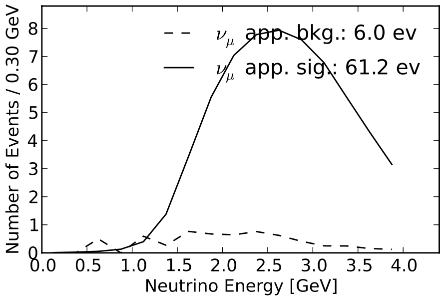


- Full energy reconstruction still lacking.

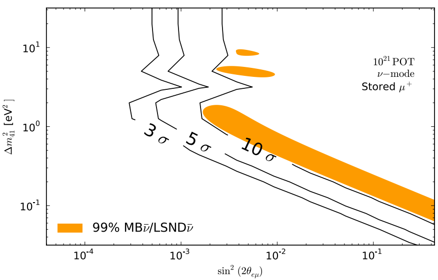
$$E_\nu = \frac{m_N E_\mu + \frac{1}{2}(m_{N'}^2 - m_N^2 - m_\mu^2)}{m_N - E_\mu + p_\mu \cos\theta} \text{ for QES events, or}$$

$$E_\nu = E_\mu + E_{had}, E_{had} \text{ is smeared by } \frac{\delta E_{had}}{E_{had}} = \frac{0.55}{\sqrt{E_{had}}} + 0.03$$

Sensitivity to Sterile Neutrinos



- Only statistical uncertainties included.
- Consideration of systematic errors required.

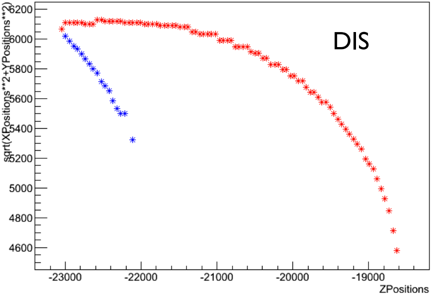


- Above results synthesized by Chris Tunnel into sensitivities
- 10σ goal is reasonable achieved.

Short Term Progress

- Improvements made parasitically to NuFact MIND development
- Fit multiple trajectories.
  - Allow for muon reconstruction at lower momenta.
  - Identify set of hadron hits.
- Introduce multi variate analysis for CC selection
  - Use more variables than N_{hits}
  - Possible variables include mean energy deposition and variation in energy deposition.
- Quantify systematic uncertainties
  - Background due to cosmic rays.
  - Cross-section uncertainties.
  - Fiducial uncertainty.

Multiple Trajectory Fits



- Figures from Tapasi Ghosh, 4th Annual EUROnu Meeting.

- Secondary tracks observed in DIS and QES events.
- Reduces event into series of trajectories
  - Longest set of hits identified.
  - Hits filtered into trajectory.
  - Repeat with remaining hits.
  - Stop when less than 5 hits are left.
- Working on the best way to use this information.

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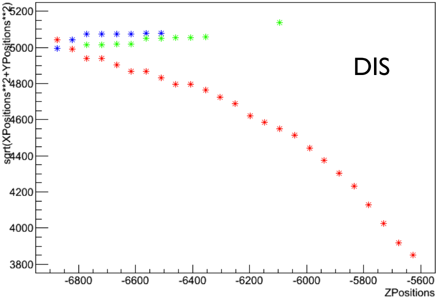

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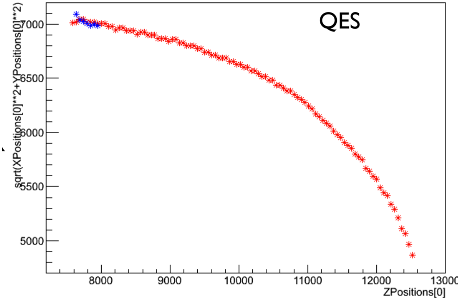

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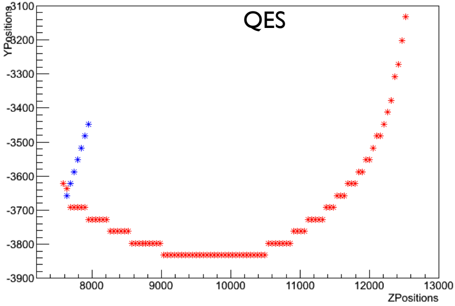

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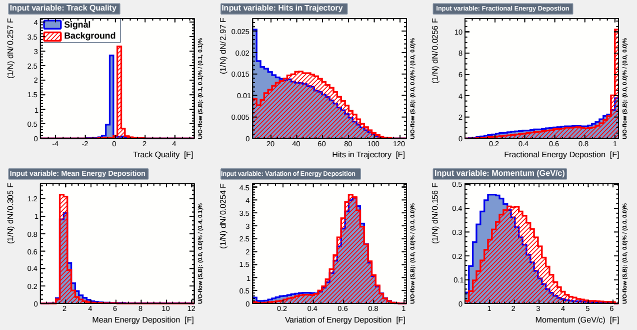
Multi-variate Analysis



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- Trained for CC and NC bkgnd rejection
- Still needs work
  - better understanding of variable distributions

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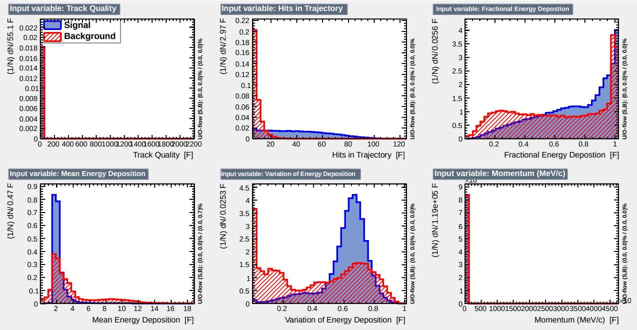

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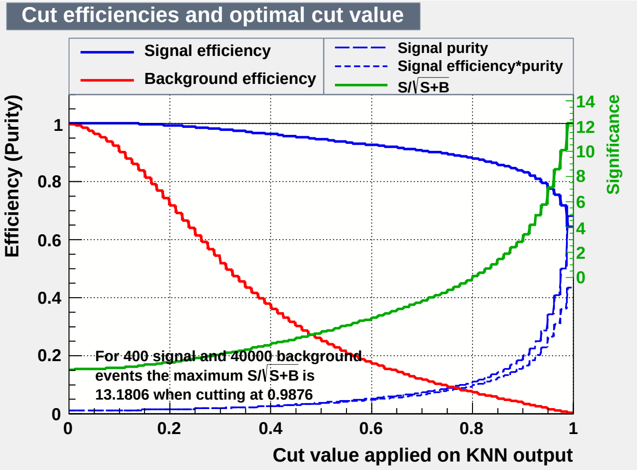

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- Approximate NC background analysis
- Variables in CC background analysis are not suitable.

Summary

- We have a simulation of a MIND developed for the neutrino factory
- MIND simulation has been used to develop SuperBIND.
- Detector can achieve sterile neutrino physics goals.
  - In absence of knowledge of systematics 10σ.
- Next steps:
  - Develop hadron reconstruction.
  - Develop multi-variate analysis.
  - Quantify systematics.
  - Make improved user interface.