SuperBIND:
A Detector For a Sterile Neutrino Search

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Experimental Particle Physics

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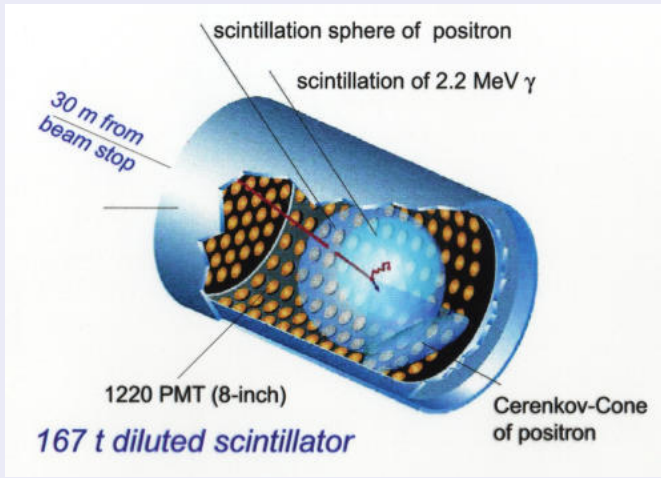
Sterile Neutrinos from Experiment

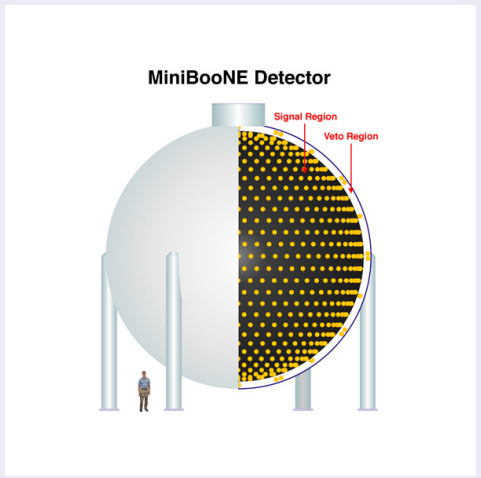
- LSND evidence from $\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$.
- MiniBooNE reports[a]:
  - 2.8σ $\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ excess.
  - 3.4σ $\nu_\mu \longrightarrow \nu_e$ excess.

[a] arxiv:1303.2588v2[hep-ph]

LSND



MiniBooNE

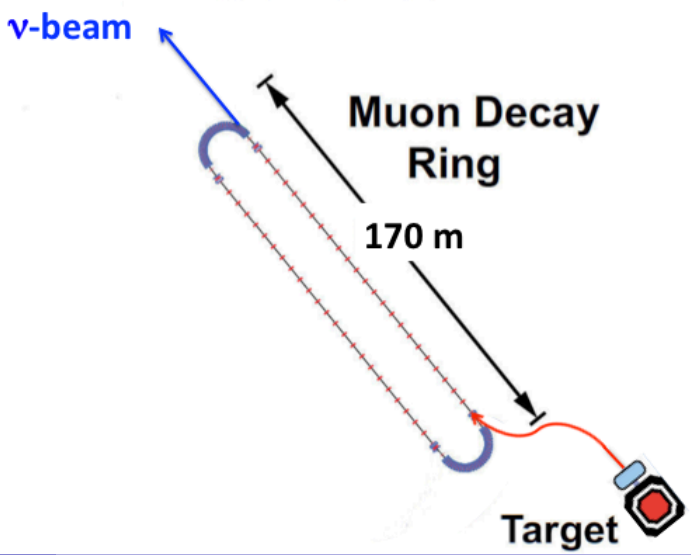


- Evidence in appearance but not disappearance data

3+1 observation probabilities

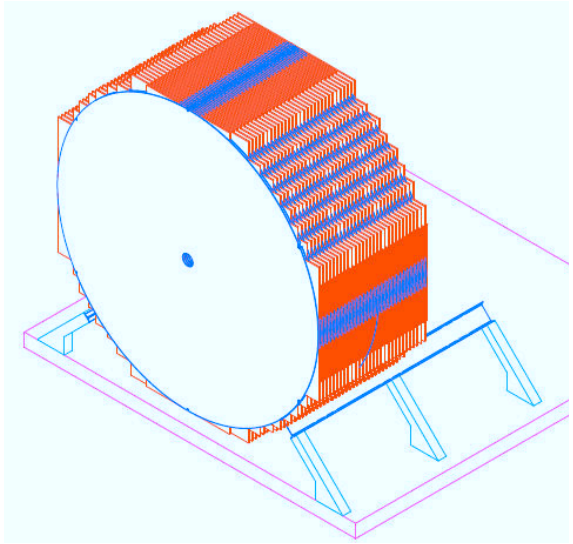
$$P_{\nu_e \to \nu_\mu} = 4|U_{e4}|^2|U_{\mu 4}|^2 \sin^2 \frac{\Delta m^2_{14} L}{2E}$$

- Appearance analysis provides clear signal despite suppression
- νSTORM provides ν_e for ν_μ appearance



The SuperBIND Detector

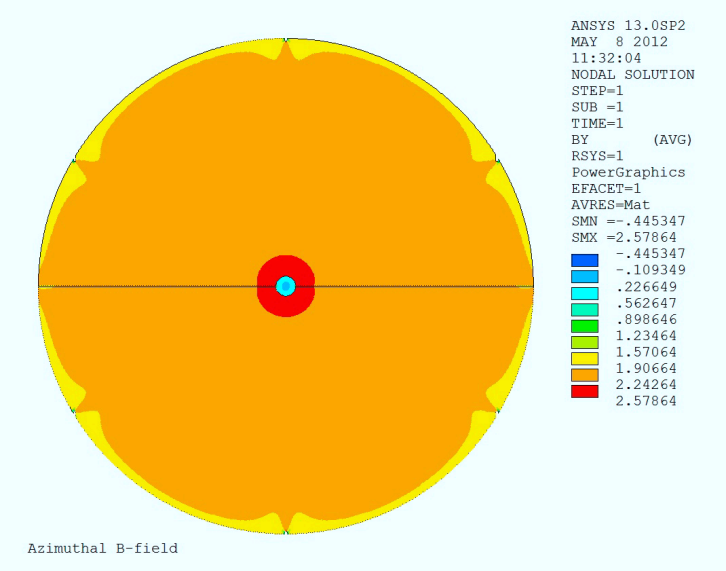
- Detector optimized for charge selection of muons.
- Allowances made for detection of ν_e and NC events.

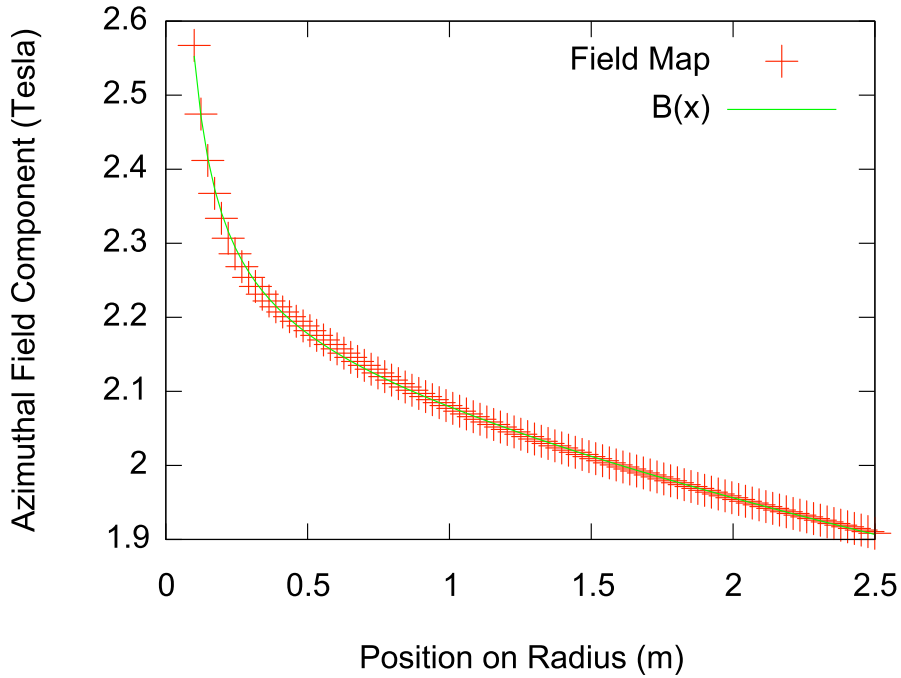


Detector Description

- 1.5 cm thick Steel Plates, 6 m in diameter.
- Scintillating planes yield space points with 1×1 cm^2 Sci. bars.
- 0.5 cm Air gap for each module.
- 16 m total detector length; 1.4 kTons in mass.
- Readout with SiPM coupled to WS fibres at both ends.
- Magnetic field induced by 270 kA carried by SCTL

The Definition of the Magnetic Field





- Finite element simulation of magnetic field in 5 m diameter steel plane simulated.
- Fit to azimuthal component with radius used in simulation and reconstruction.
- Assume the the radial behaviour is consistent for 6 m diameter plate.

Simulation of Far Detector Experiment

GENIE Simulation

- Provides neutrino events.
- Run in "geometry blind" mode.

GEANT4 Simulation

- Customizable geometry implemented
- Simulates material interactions of neutrino interaction products with detector.
- QGSP_BERT library used to specify hadron interactions.

Digitization of Simulation

- Simple digitization implemented.
- Clusters ionization positions into 1×1 cm^2 voxels.
- Attenuates energy deposition over WS Fibre length.

Reconstruction of Simulation

- Relied on RecPack for Kalman implementation.

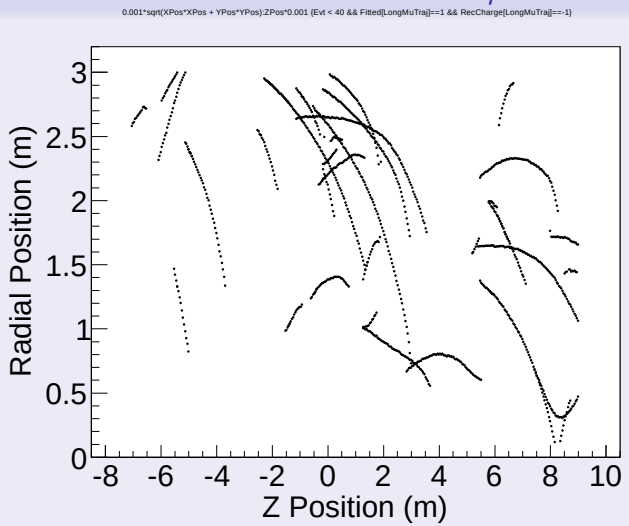
Pattern Recognition

- Longest set of single hits assigned to track
- Kalman filter applied track (number of hits used to seed momentum).
- Process is repeated on remaining hits until less than 5 hits left.

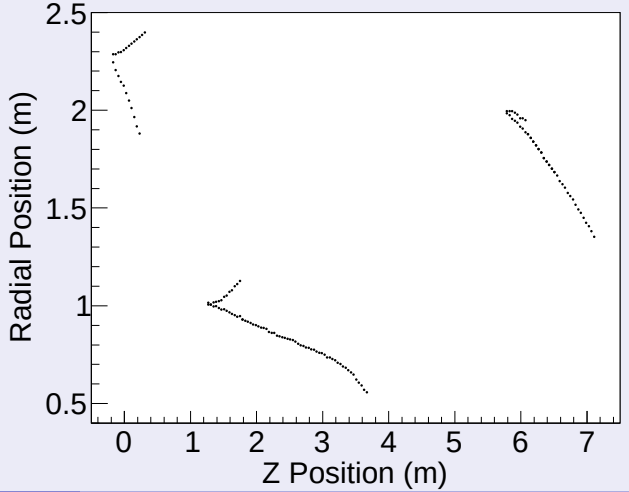
Track Fitting

- Tracks fit using Kalman Fitter
- Fitter seeded using the momentum from the track range.
- All tracks are fit (with varying degrees of success).

Fitted Tracks of first 40 Events; $\bar{\nu}_\mu$ CC sample

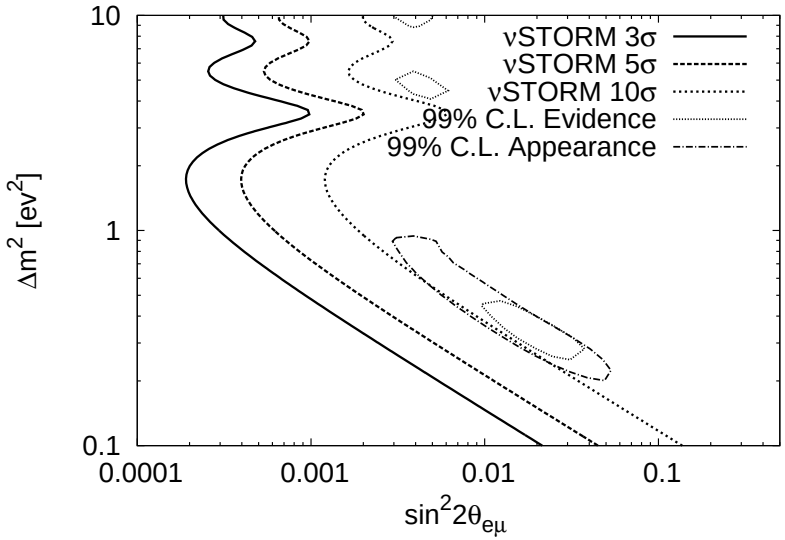


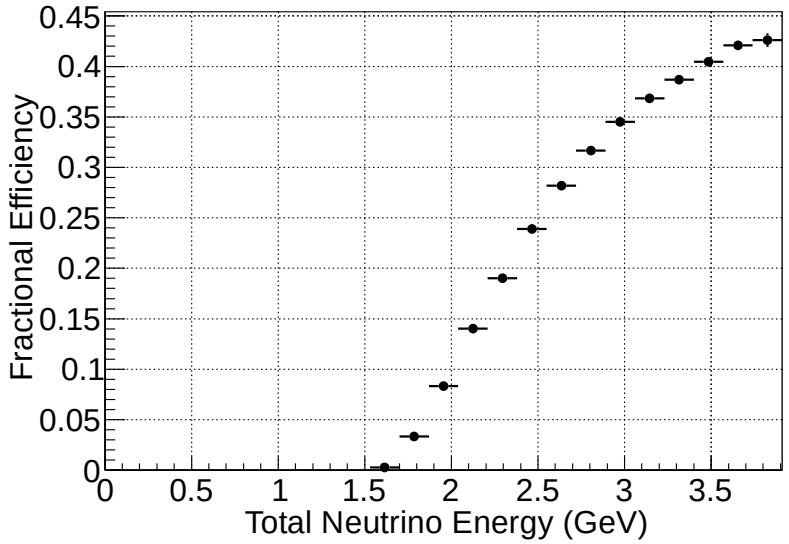
Subset with two tracks

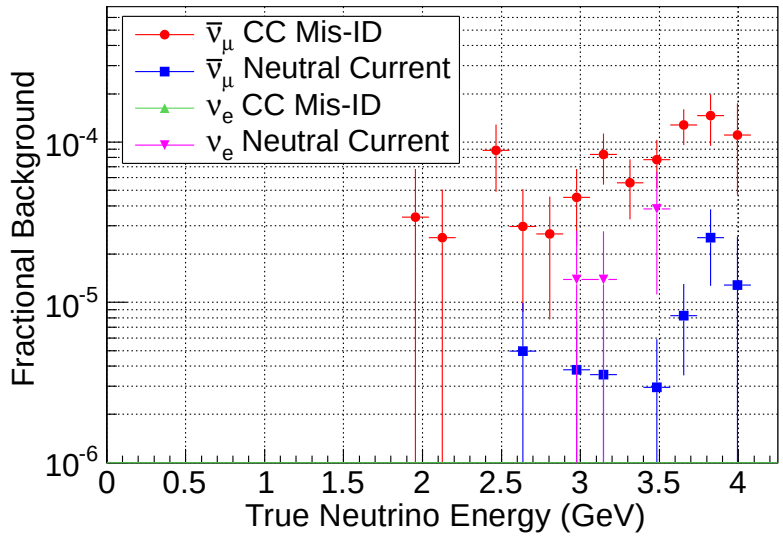


Cuts based implementation

- Used a cuts based analysis for LOI[a]
- Isolated signal from background based on
  - number of hits in track.
  - error in track curvature.
- Energy threshold a function of p_z.







[a] arxiv:1206.0294v1[hep-ph]

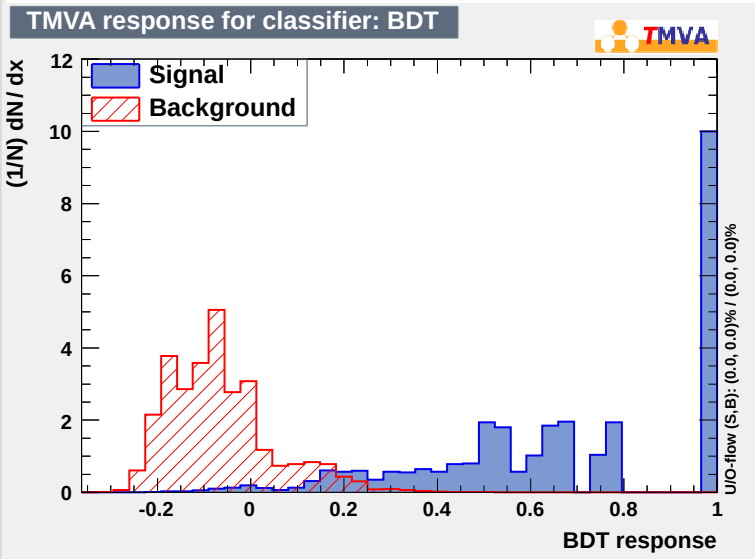
[b] Appearance and Evidence contours from Kopp et. al., arxiv:1303.3011[hep-ph]

Adoption of TMVA

- Use multiple variables for signal discrimination.
- Properly accounts for correlations.
- Reduces multiple variables into one classifier variable.

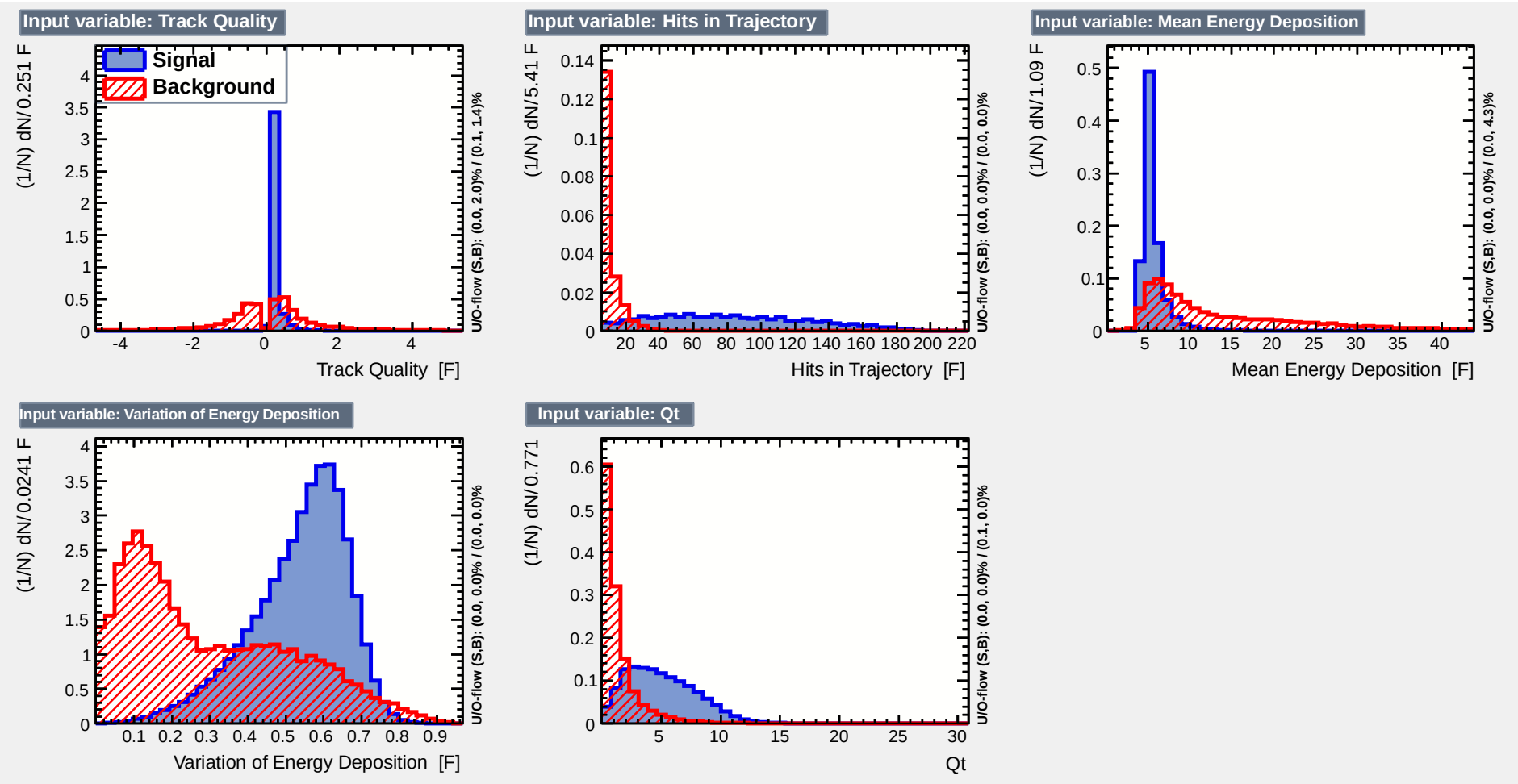
Variables for MVA

Variable	Description
Track Quality	$\sigma_{q/p}/(q/p)$, the error in the trajectory curvature scaled by the curvature
Hits in Trajectory	The number of hits in the trajectory
Mean Energy Deposition	Mean of energy deposition of hits in fit of the trajectory
Variation in Energy	$\sum_{i=0}^{N/2} \Delta E_i / \sum_{j=N/2}^{N} \Delta E_j$ where the energy deposited per hit $\Delta E_i < \Delta E_{i+1}$.
Q_t	Muon isolation $Q_t = p_\mu \sin^2 \theta_\mu$



- Focussed on Boosted Decision Tree (and related) method.

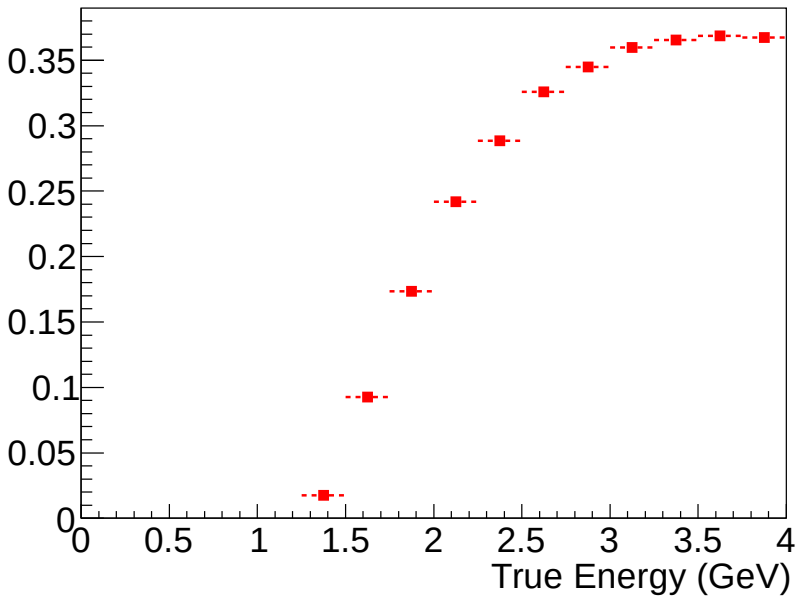
Event Variables used in Analysis



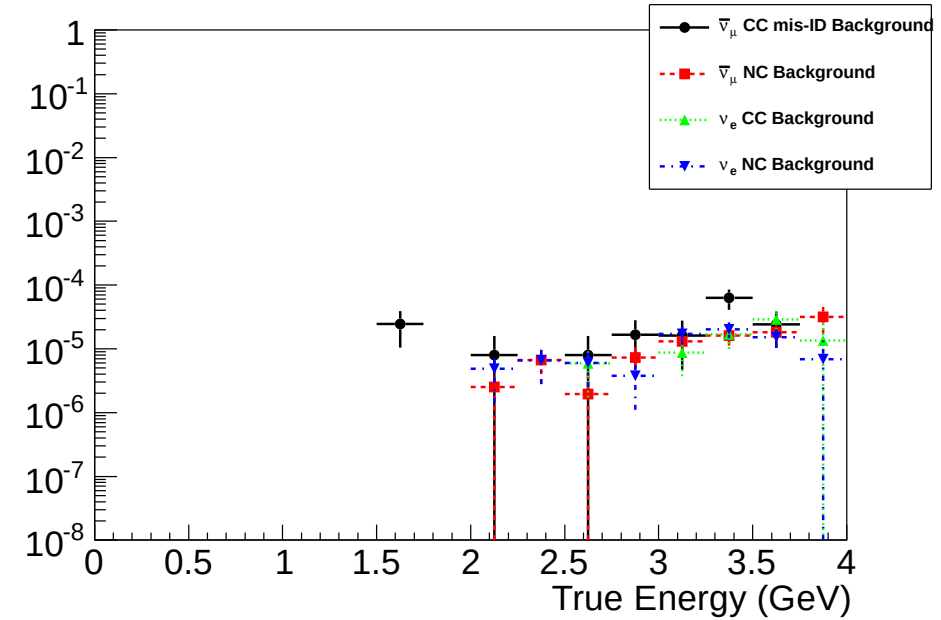
- Five variables selected show limited correlations
- Variables chosen which provide separation between ν_μ CC and $\bar{\nu}_\mu$ NC events

Application of the Analysis to Simulation

Signal Efficiency



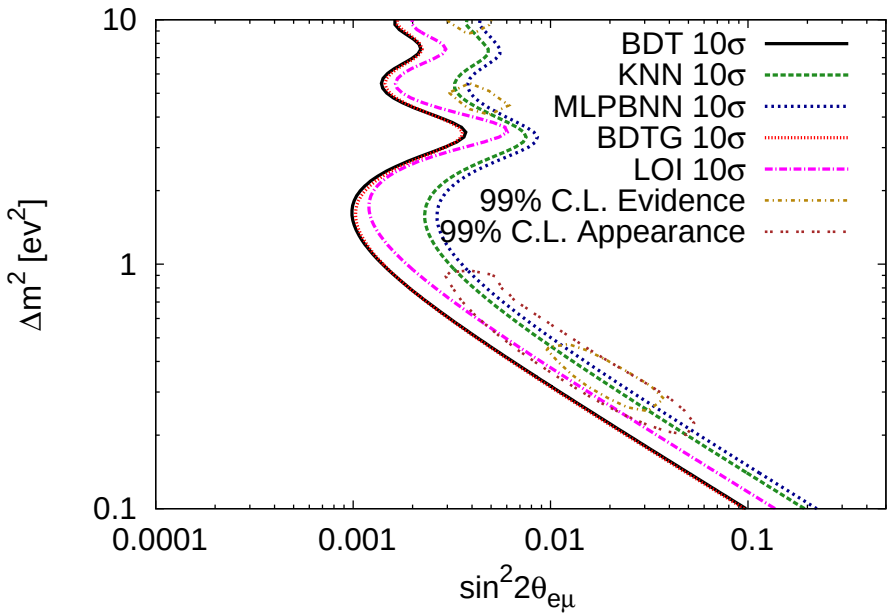
Background Efficiency



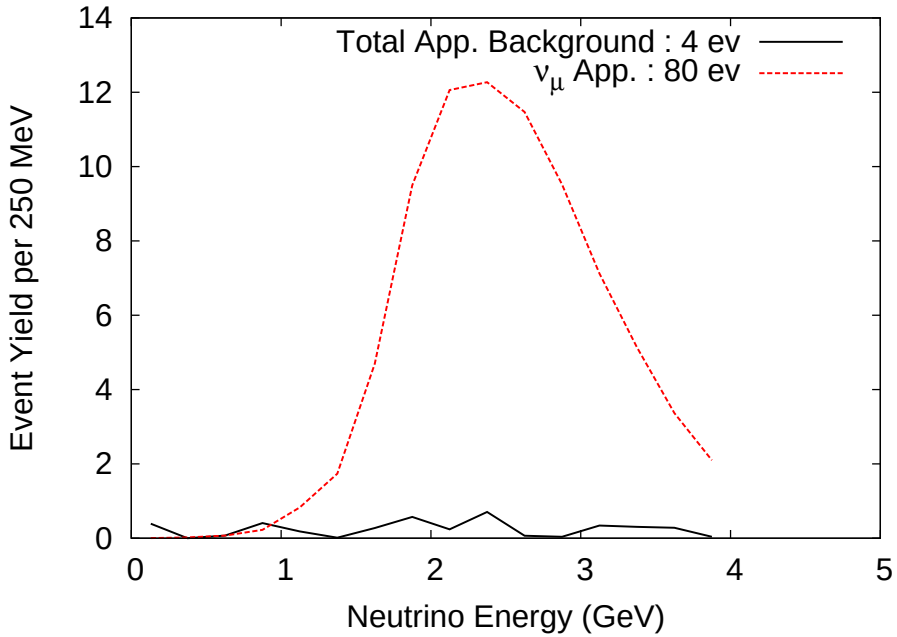
- Integrated efficiency better
- Better detection threshold
- Lower maximum efficiency

- Efficiency for all backgrounds order 10^{-5}
- Exceeds experimental requirements.

Sensitivity of Experiment to Sterile Neutrinos



- Decision trees outperform LOI analysis.
- Other analysis methods (i.e. KNN and neural nets) still make strong statements about existing evidence (not at 10σ).

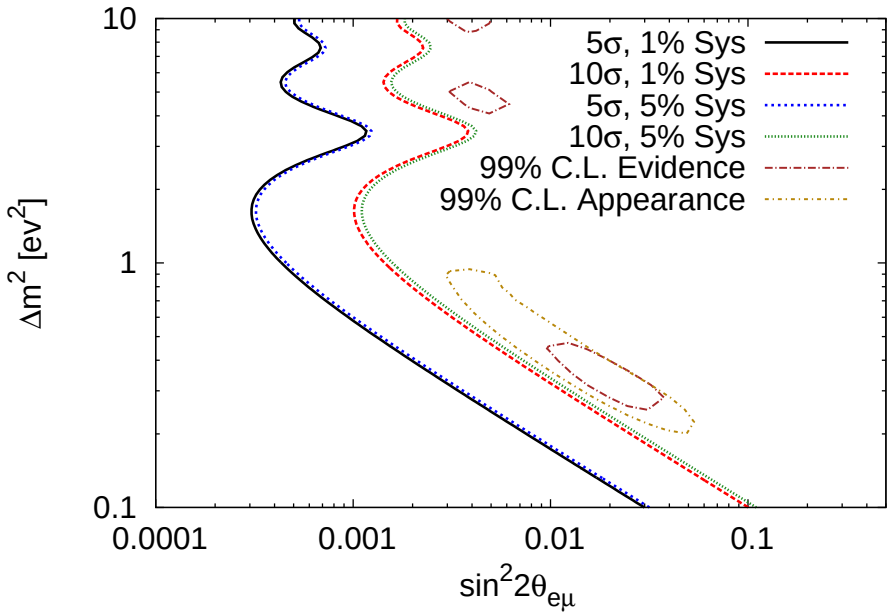


- Sample of spectrum after BDT analysis.
- Extremely high purity.

Signal vs Background

	MVA	Cuts
1.5 cm	80:4	NA
2 cm	113:10	61:6

Response to Systematics



- Systematics expected to include:
  - Number of neutrinos at detector (i.e. flux)
  - $\nu_\mu/\bar{\nu}_\mu$ X-sec ratio (background only).
  - Relative magnitude of QES cross sections

- All affect the number of neutrinos detected
- Total systematic is expected $\approx$ 1%(signal) and $\approx$ 10% (background)
- Increasing both systematics by factor of 5 does not change the conclusion.

Cosmic Ray Simulation in SuperBIND

- Used the CRY generator in the mindG4 simulation.
- Applied fiducial cuts
  - 30 cm radial skin depth veto.
  - 50 cm endcap veto.
- upstream end cap shows that external event self veto is feasible.
  - Majority of cosmic rays that pass cuts are travelling backwards.
  - Timing information is needed.

- Cosmic rays generated on five surfaces containing 6 m long SuperBIND.
- Each simulation subjected to BDT analysis to extract efficiency per event.
- Assume
  - Horizontal surface flux: $2.7\mu/\mathrm{s}/\mathrm{m}^2$
  - Vertical surface flux: $0.7\mu/\mathrm{s}/\mathrm{m}^2$
  - Machine duty factor: 10^{-4}

Expected rates of cosmic rays

Surface	W/O Fid. Cut	W. Fid. Cut
top	166	35
right	9	3
left	9	3
upstream	34	0
downstream	40	35
Total	260	76

Conclusions

- SuperBIND has received a small update
  - Change to geometry baseline (plate radius, Fe thickness, length)
  - Changed analysis to a multivariate analysis.
- Sensitivity to sterile neutrinos is still greater than 10σ in region allowed by LSND et al.
  - Boosted decision tree analysis improves on LOI result.
  - Results are robust to systematic uncertainties.
- An estimate of effects of cosmic rays have been investigated.
  - Contamination of the same order as the signal size.
  - Indications are that a time based veto will remove remaining contamination.
- There are things yet to be done:
  - Proper consideration of disappearance analysis: i.e. Near-Far extrapolation.
  - Is ν_e reconstruction viable in SuperBIND?