Results using MVA in an improved νSTORM reconstruction

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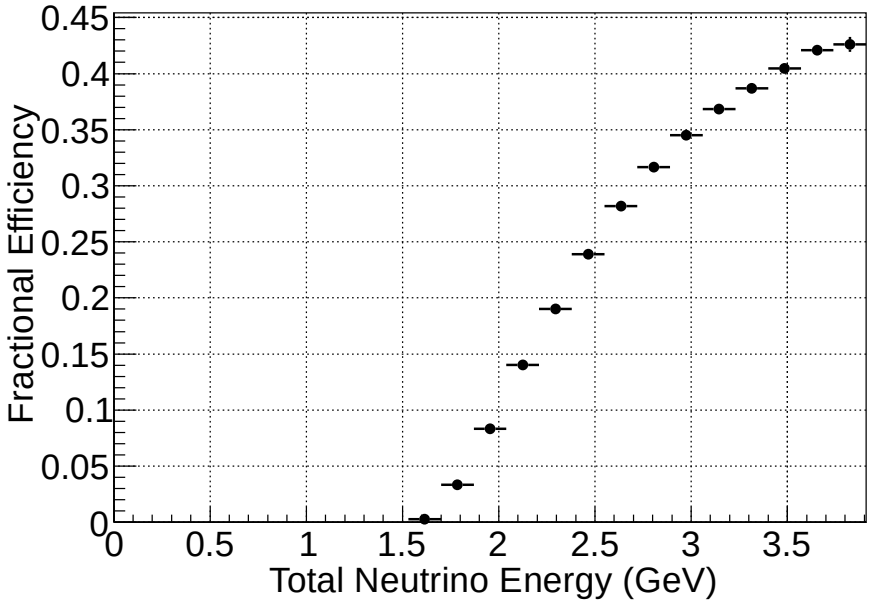
What's new?

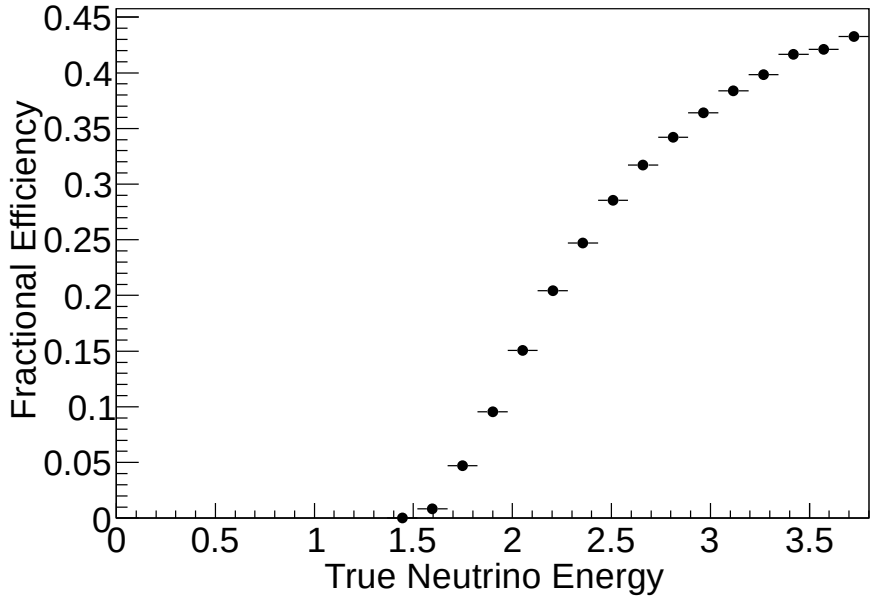
- Improvements have been made in MIND reconstruction.
  - Multiple track reconstruction.
  - Improved pattern recognition.
  - MVA analysis.
- Engaged a Master's student (Steve Bramsiepe) to investigate usage of MVA in νSTORM.
- Used the opportunity to check for improvements in SuperBIND appearance (and disappearance) analysis.
  - MVA analysis expected to lower energy threshold.
  - Multiple track expected to reduce charge mis-ID from low angle muon-like pions.
    - ★ Also allows selection based on the longest single track.
    - ★ Not the largest set of hits.
  - Improved pattern recognition includes radial and z-ordering of hits in event.

Comparing LOI to Current Results

LOI ν_μ CC



Current ν_μ CC



- Simulation assumes a 20 m long SuperBIND with 2 cm thick Fe plates.
- The efficiency is unchanged.
- Neutral current and charge current backgrounds are reduced.
- ν_e CC background is non-zero .
- Total background is greater for new analysis.

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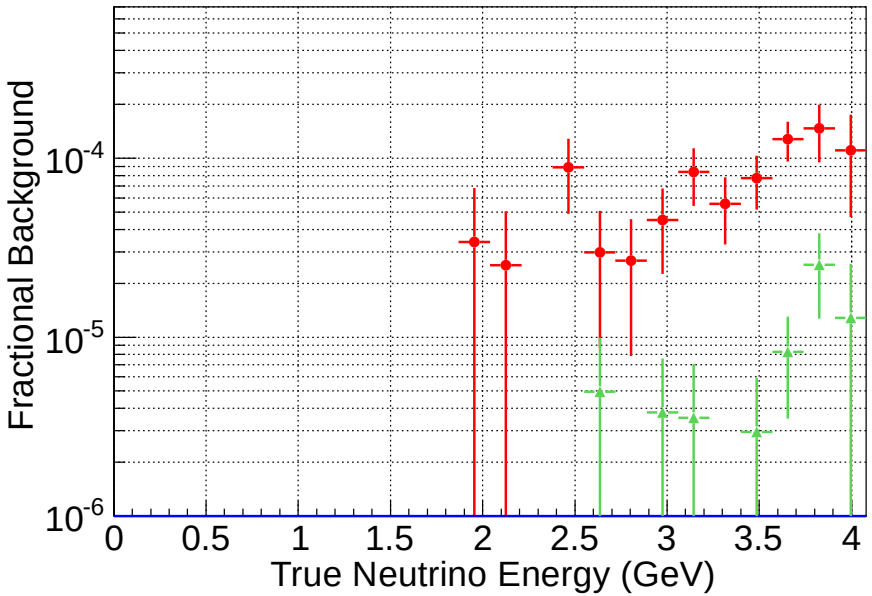

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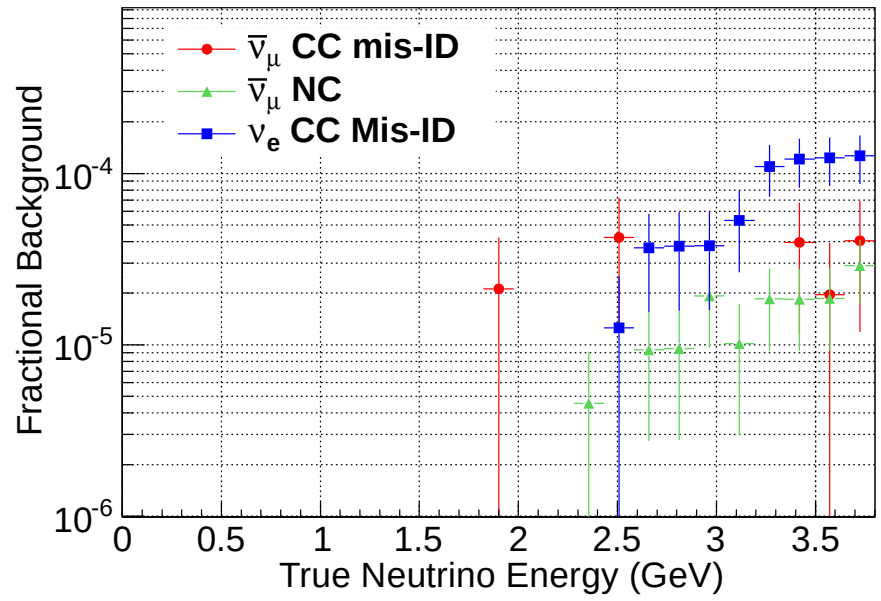

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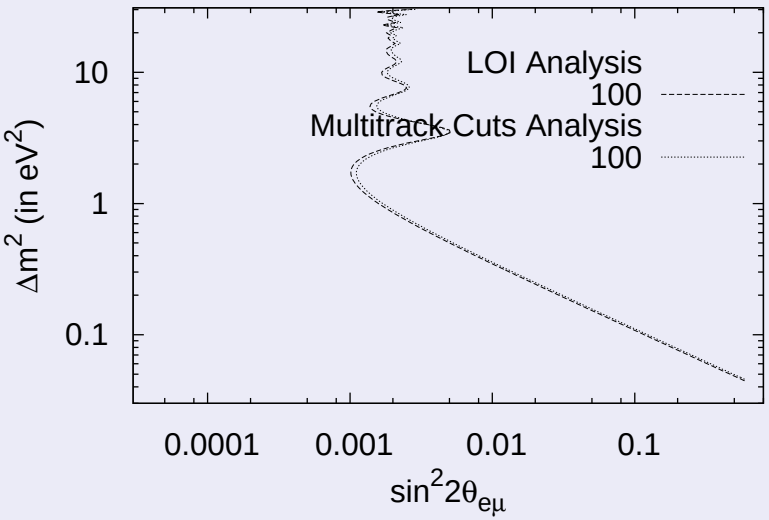
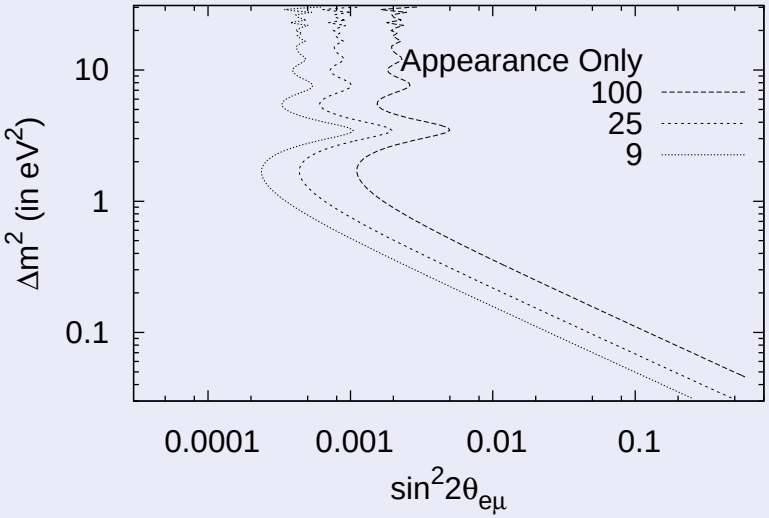
How Does This Affect the Sensitivity?

Comparison of 10 σ Contours



3 σ, 5 σ and 10σ Contours



- Matched multi-track reconstruction to LOI analysis as best as possible.
- Used response matrices developed for LOI as a basis of comparison.
- Difference likely due to increased ν_e CC background.
- Relaxing cut reduces sensitivity.

Multi-variate Analysis

- Allows the selection of signal given correlations between selection variables.
- Is a two pass analysis.
  - Train using signal (i.e. ν_μ CC) and background (i.e. $\bar{\nu}_\mu$ CC mis ID or $\bar{\nu}_\mu$ NC) samples.
  - Apply to arbitrary data sample.
- Reduces selection of event to a one variable cut.
- Includes a simple optimization algorithm based on significance.
- Further optimization based on physics output is possible.
- Consider three different methods
  - kNN — k Nearest Neighbour
  - BDT — Boosted Decision Tree
  - MLP — An artificial neural network

Cuts and Variable Definitions used in TMVA

Set of Fixed Cuts

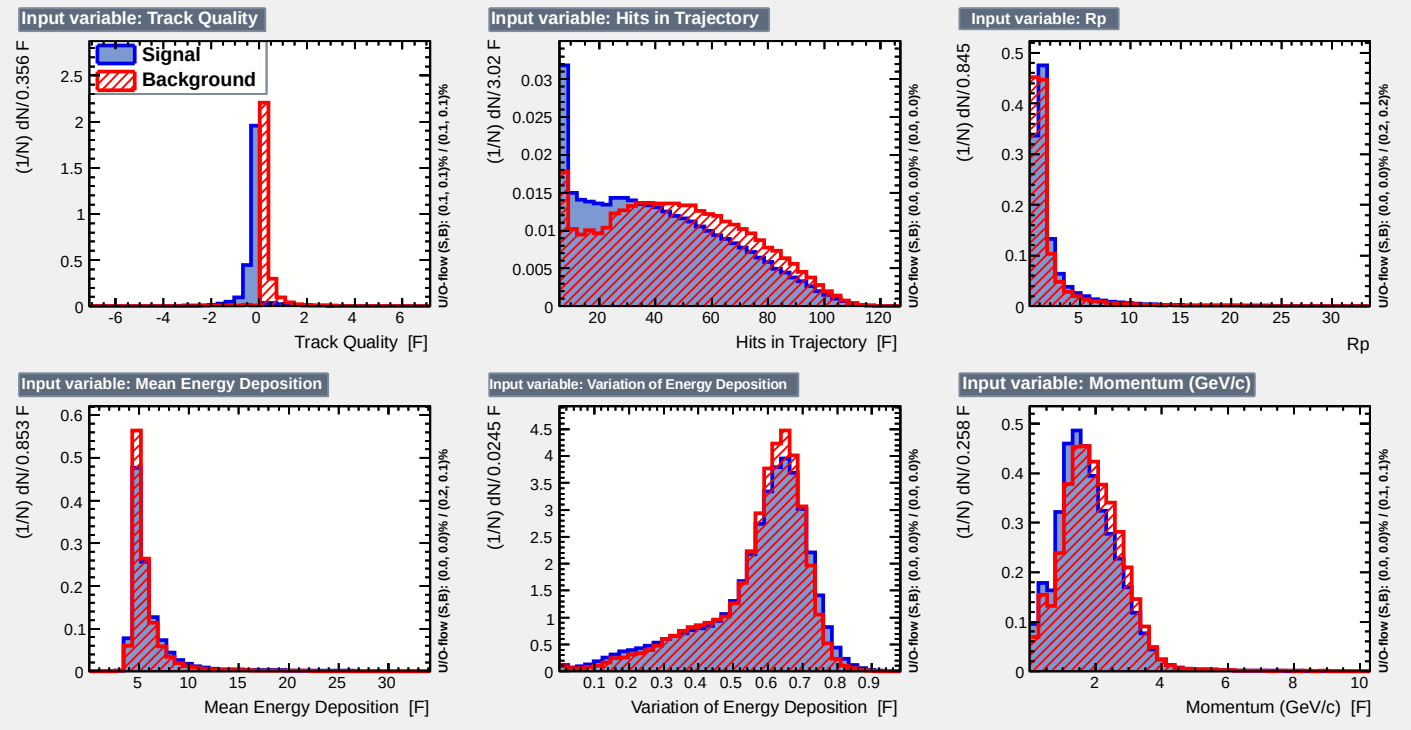
- At least one trajectory successfully fit.
- $p_\mu < 1.6 \times E_\mu$.
- Track vertex before last 1 m of detector volume
- Fitted track includes >60% of candidate hits

Variable Definitions

- $\sigma_{q/p}/(q/p)$: Require $|\sigma_{q/p}/(q/p)| < 20$
- N_{hits} used in fit for given trajectory.
- $R_p = (q_{init}/p_{init}) \times (p_{fit}/q_{fit})$: Require $R_p > 0$
- Mean energy loss over track $(\sum_{i=0}^{N_{hit}} \Delta E_i)/N_{hit}$
- Energy variation ratio $R_{var} = (\sum_{i=0}^{M} \Delta E_i)/(\sum_{j=M+1}^{N_{hit}} \Delta E_j)$ where $\Delta E_i < \Delta E_{i+1}$ and $2M \approx N$.
- Momentum: Require $p_\mu < 4 \times E_\nu^{max}$

Variables Used in Analysis

- CC Training
- NC Training
  - p_μ not helpful
- Correlations taken from CC training.
- Shows the significance of variables to analysis.



Correlations between variables and response

	Signal			Background		
	KNN	MLP	BDT	KNN	MLP	BDT
ErrqP	-0.187	-0.174	-0.010	-0.018	-0.046	+0.061
trHits	+0.300	+0.298	+0.942	-0.578	-0.630	-0.952
Rp	-0.096	-0.083	-0.332	+0.236	+0.210	+0.361
meanDep	-0.193	-0.187	-0.365	+0.475	+0.447	+0.333
EngVar	+0.129	+0.115	+0.198	-0.260	-0.230	-0.144
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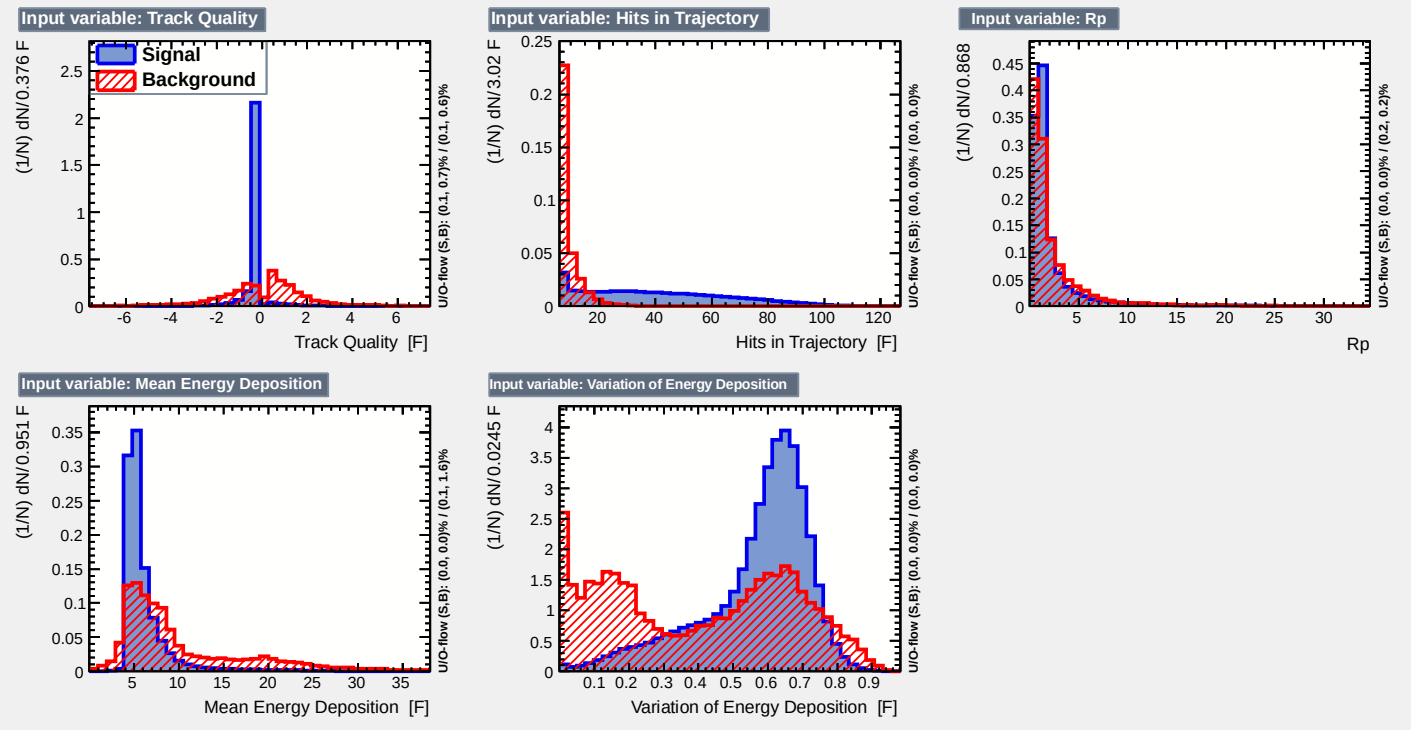

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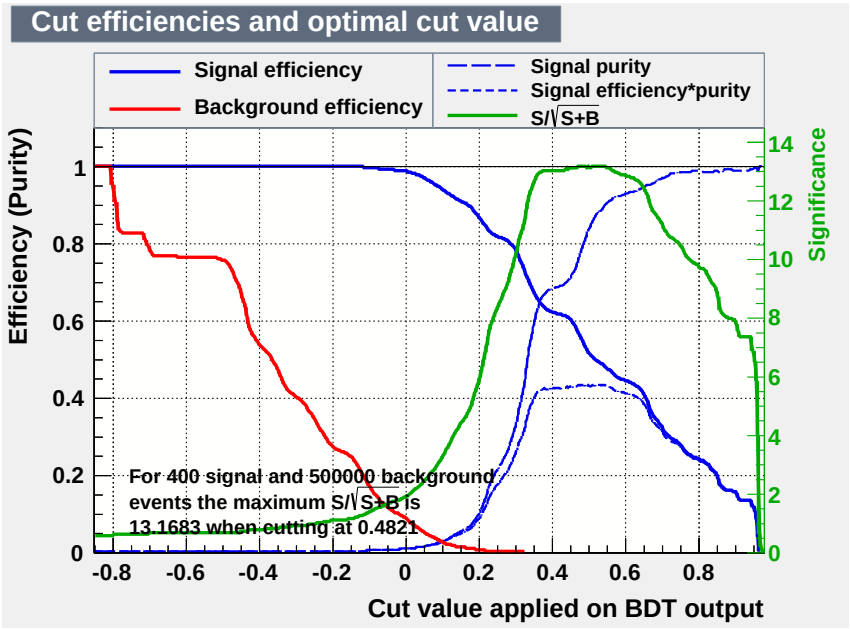
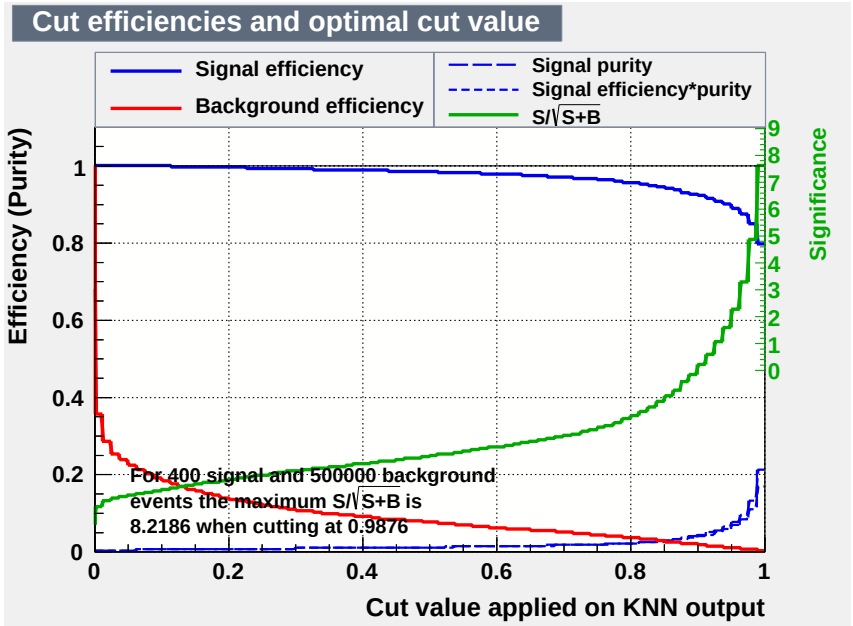
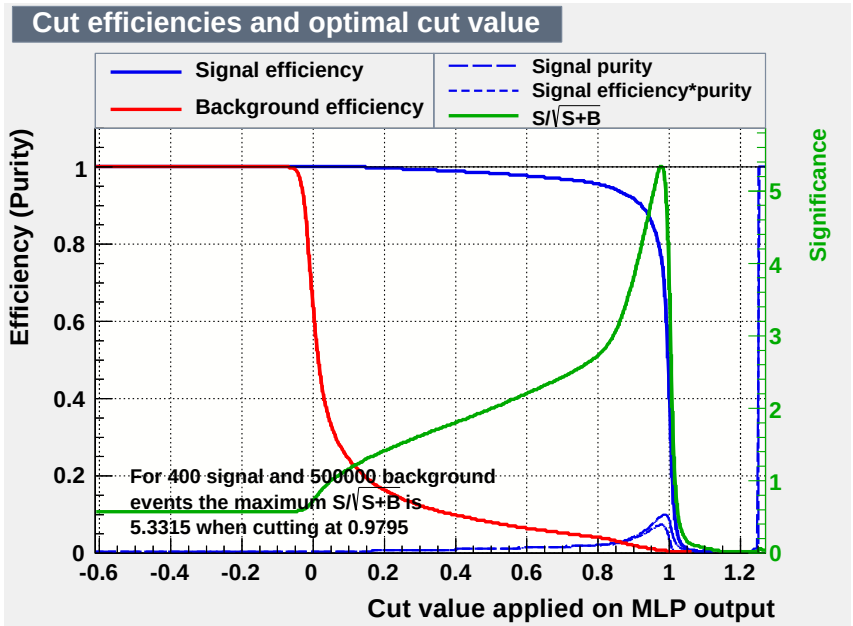
Efficiencies for Variable Optimization

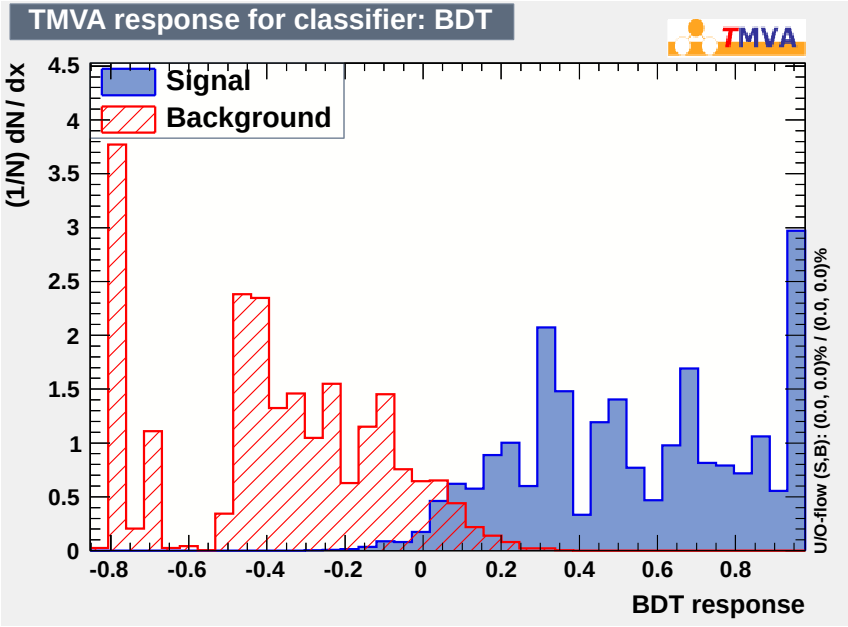


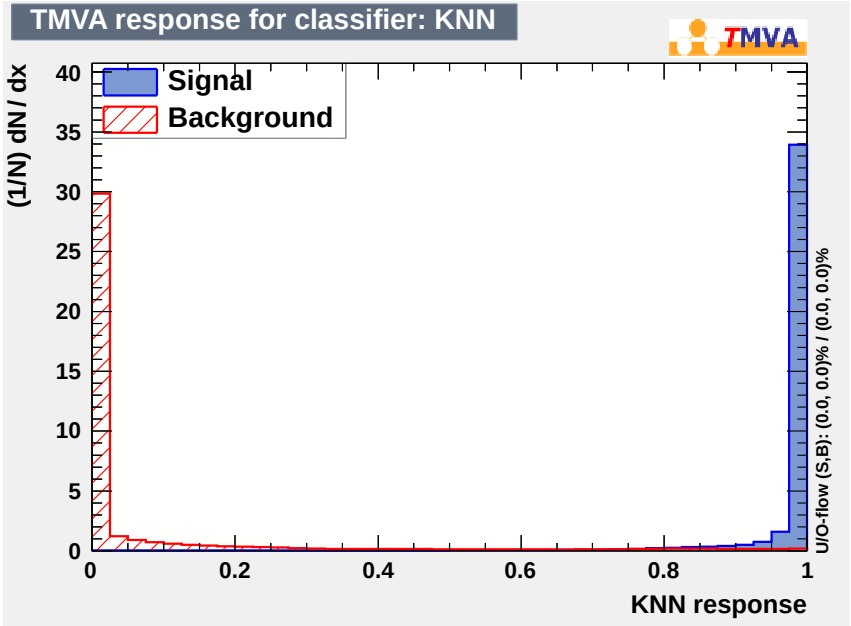




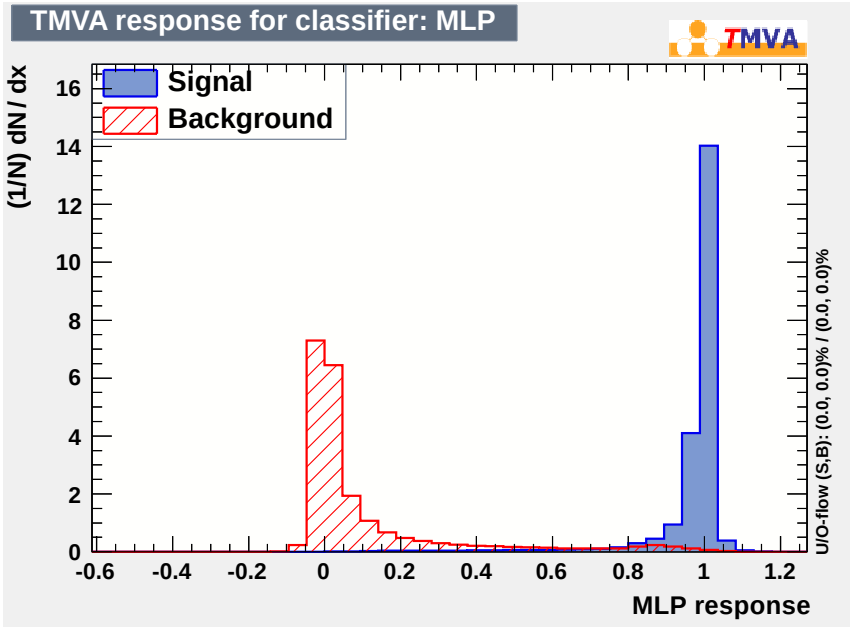
- Trained with "Physical" $\bar{\nu}_\mu$ background sample
- BDT yields the largest significance.
- Also trained with NC background...

MVA Response for Future Optimization



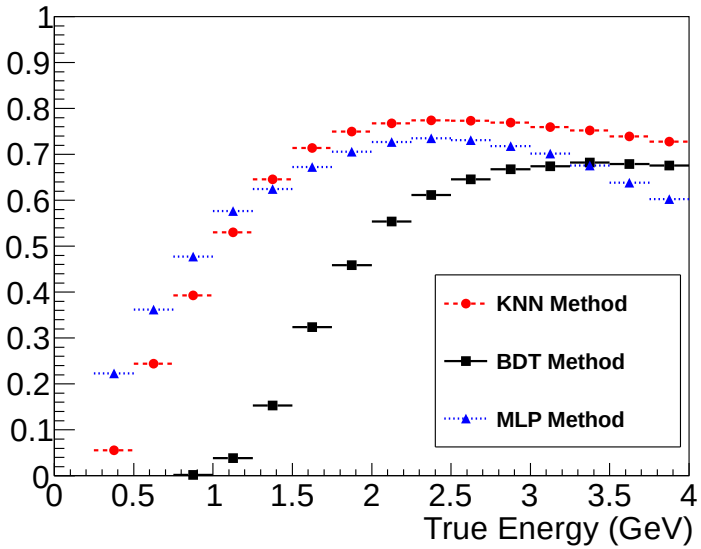


- Evaluation of MVA for a trajectory produces a single number.
- Can select different values for the selection of signal.
- Will likely do some small tuning exercises to check optimal values.

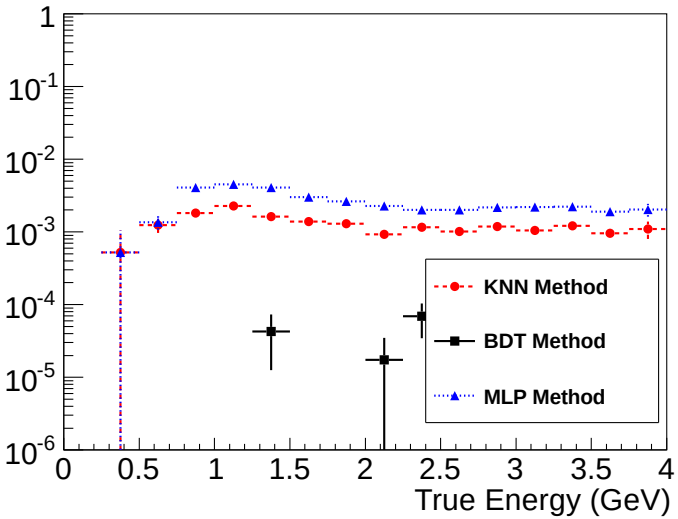


Efficiency for Optimized Methods

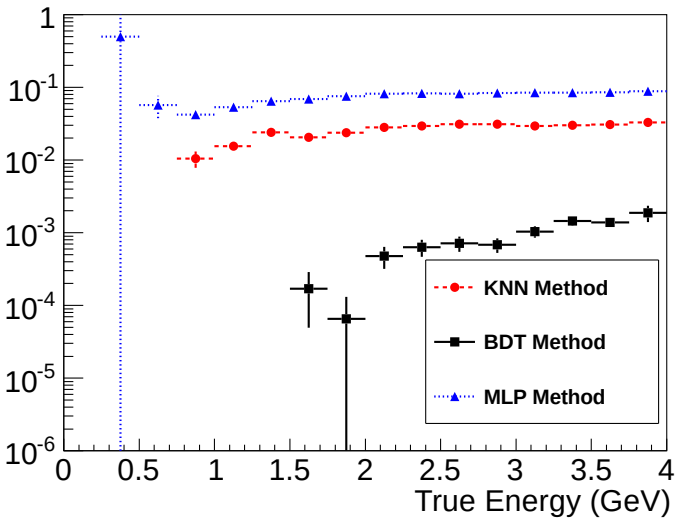
ν_μ Signal Efficiency



$\bar{\nu}_\mu$ CC Charge Mis-ID



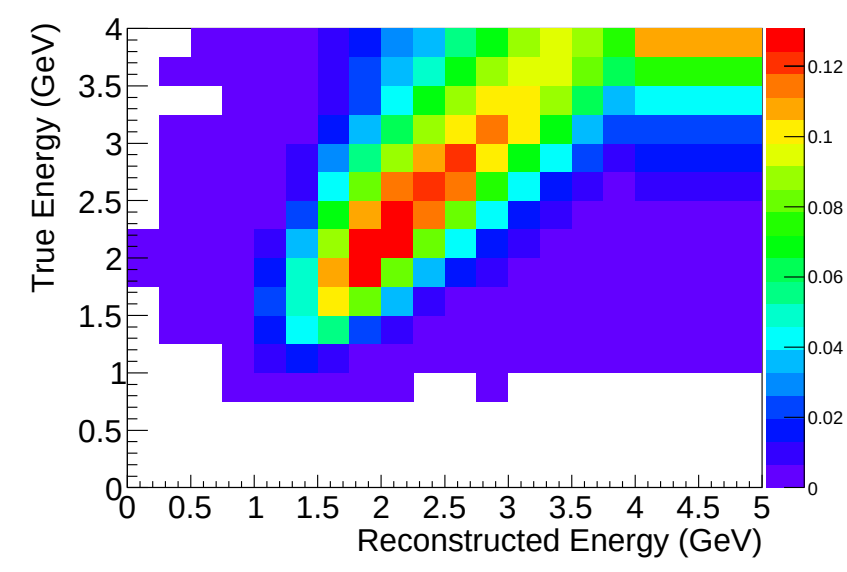
$\bar{\nu}_\mu$ NC Mis-ID



- Used default optimal values
  - assumed $\approx$ 400 signal events and 500000 background.
- Efficiency best for KNN method.
- Background rejection best for BDT method.

Detector Response to BDT Method

ν_μ Signal Efficiency



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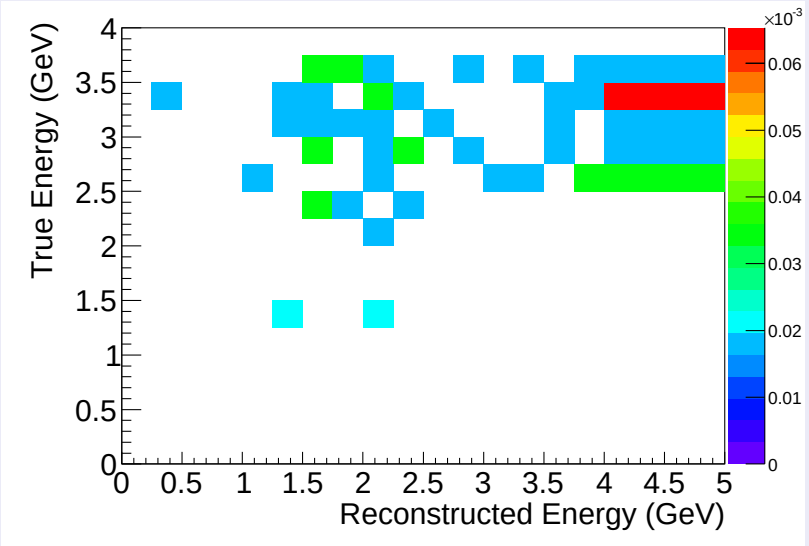

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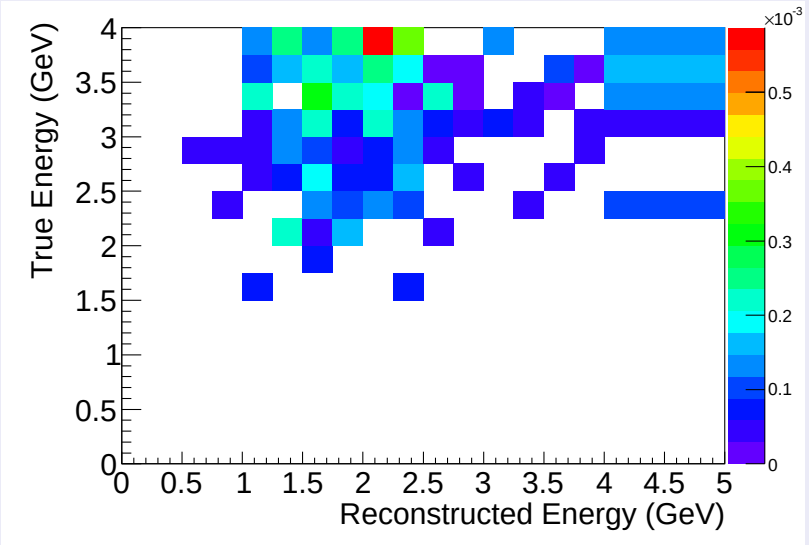
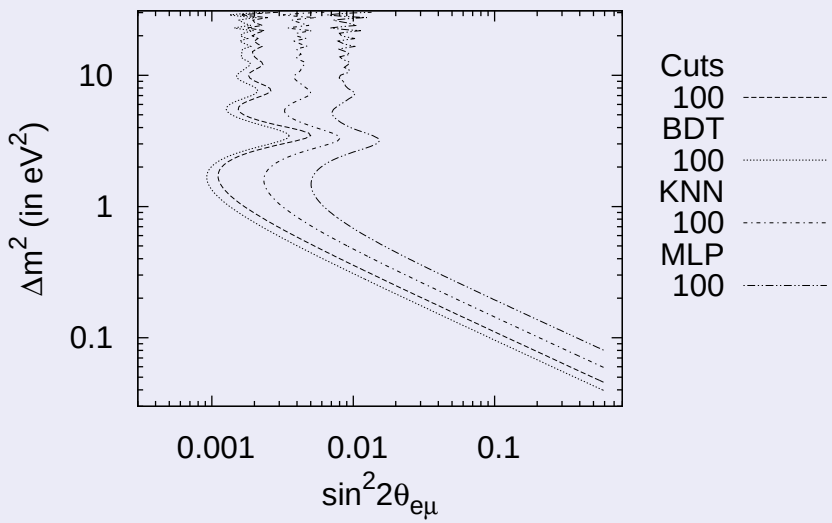


- Reminder: detector responses is goal — not efficiency.
- Response is nearly diagonal.
- Background response has weak correlation to signal.

Sensitivity to Sterile Oscillations in an Appearance Analysis

Method comparison: CC trained



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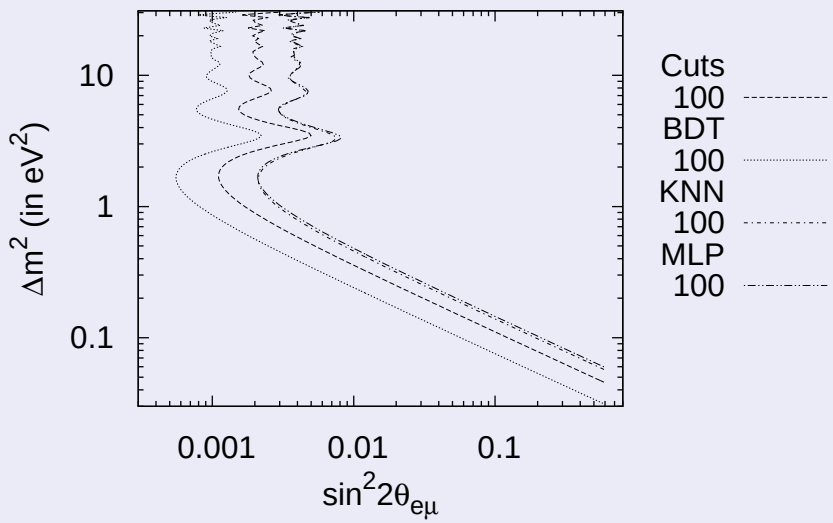

- BDT method shows a clear improvement over all other methods, including LOI analysis.
- KNN and MLP methods do not improve on LOI results.
- Includes 1% signal and 10% background "normalization" errors.
- Training with NC background samples performs better than with "Physical" (primarily CC) samples.

Conclusions

- Introduced changes into the reconstruction
  - Allows for the reconstruction of multiple tracks
  - Better selection of muon track.
  - Potentially better energy reconstruction.
  - Makes no change for νSTORM
- Tested three different multi variate analysis methods.
  - k-Nearest Neighbour method provides
    - ★ the best efficiency
    - ★ but poor background rejection.
    - ★ works better for a Neutrino Factory
  - Boosted decision trees provide
    - ★ better efficiency than cuts based analysis
    - ★ and comparable background rejection
- BDT provides clear improvement in sensitivity to sterile oscillations.
- Can add disappearance analysis if systematics are "known".

One Final Thought