Refining VLENF SuperBIND (?) Cuts Analysis

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Outline

Cuts in VLENF Analysis

Fundamental Quality Cuts

- Fiducial: The event vertex occurs before last meter of detector.
- Max Momentum: P_μ should be less than the beam momentum, but should take resolution into account.
- Fitted Proportion: Number of hits fit must be greater than 60% of hits identified as part of the track.

Event Selection Cuts

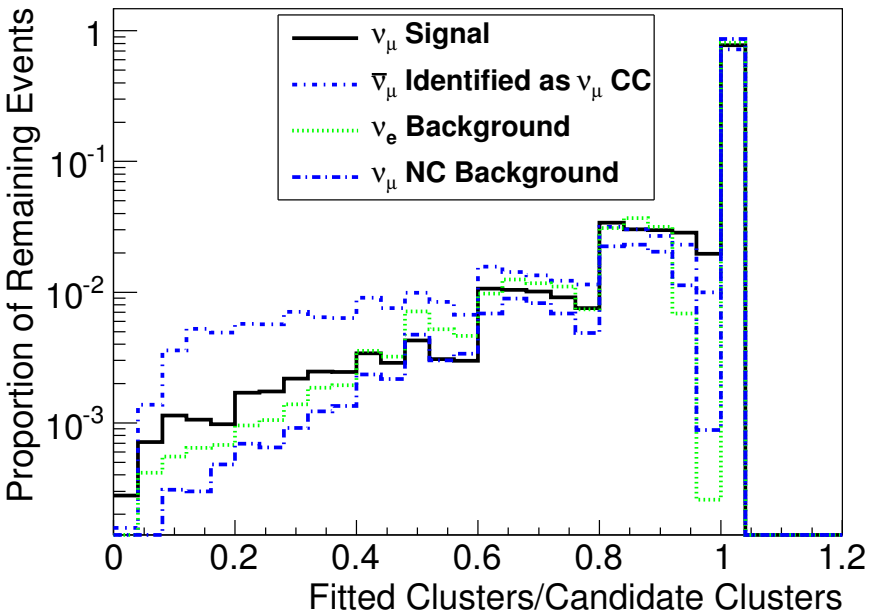
- Track Quality: Likelihood comparison between PDFs of statistical uncertainty of track.
- Displacement: backgrounds identified using event topology
- Quadratic Fit: Fit of track as function of radius to determine the charge.
- CC Selection: Likelihood comparison of PDFs of number of hits in track.
- Kinematic: isolates background based on $Q_t = P_\mu sin\theta_{\mu\nu}$, P_μ and E_{rec}.

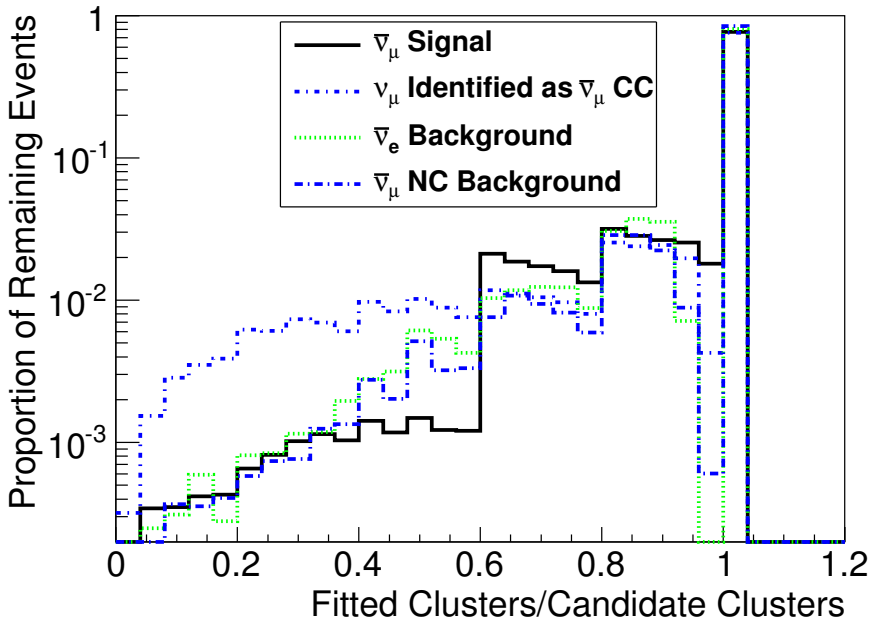
List of Cuts

Cut Name	25 GeV Cut	2 GeV Cut	Explanation
Fiducial	$z1 \leq 18000$ mm	$z1 \leq 9000$ m	20 m Detector
Max Momentum	$P_\mu < 40$ GeV	$P_\mu < 3.2$ GeV	ν momentum
Fitted Proportion	$N_{fit}/N_h \geq 0.6$	$N_{fit}/N_h \geq 0.6$	No Change
Track Quality	$\mathcal{L}_{q/p} < -0.5$	$\mathcal{L}_{q/p} < 0$	By Inspection
Displacement	$\frac{dispR}{dispZ} > 0.18 - 0.0026N_h$, $dispZ > 6000$ mm or $P_\mu \leq 3dispZ$	$\frac{dispR}{dispZ} > 0.75 - 0.026N_h$, $dispZ > 400$ mm	By Inspection By Inspection
Quadratic Fit	$qp_{par} < -1.0$ or $qp_{par} > 0.0$	$qp_{par} < -1.0$ or $qp_{par} > 0.0$	Radial Curve
CC Selection	$\mathcal{L}_1 > 1.0$	$\mathcal{L}_1 > 2.0$	By Inspection
Kinematic	$E_{rec} \leq 5$ GeV or $Q_t > 0.25$, $E_{rec} \leq 7$ GeV or $P_\mu > 0.3E_{rec}$	$E_{rec} \leq 1$ GeV or $Q_t > 0.025$, $E_{rec} \leq 0.1$ GeV or $P_\mu > 0.3E_{rec}$	By Inspection

Consideration of Fundamental Quality Cuts

- Fiducial and Max Momentum cuts are fixed.

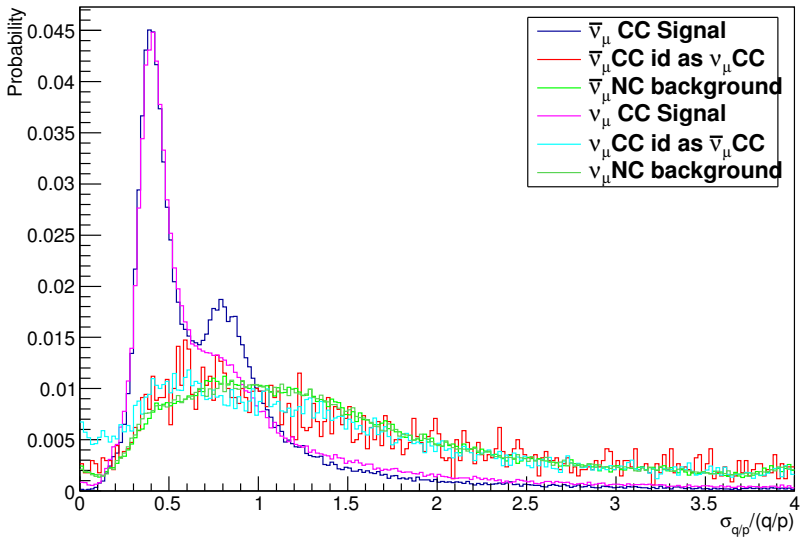




- Mean proportion of hits used in track fit decreases in charge mis-ID.
- Increase to 0.8 from 0.6 helps optimization of Signal to Background.

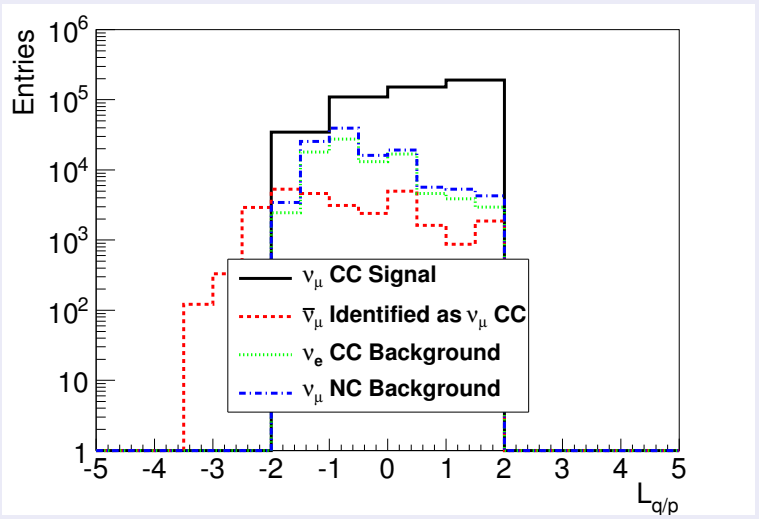
Track Quality

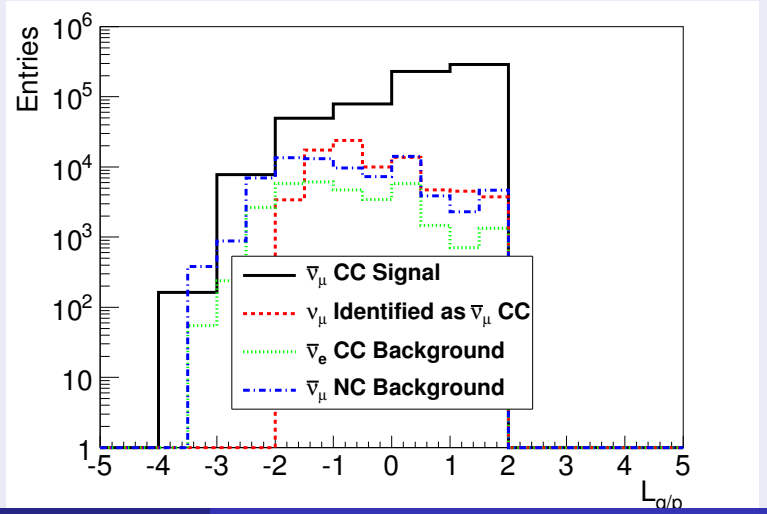
PDFs are a little strange



- Suggest two different classes of events contributing to signal distributions.
- Derived from event classification in

Distribution of likelihood ratios

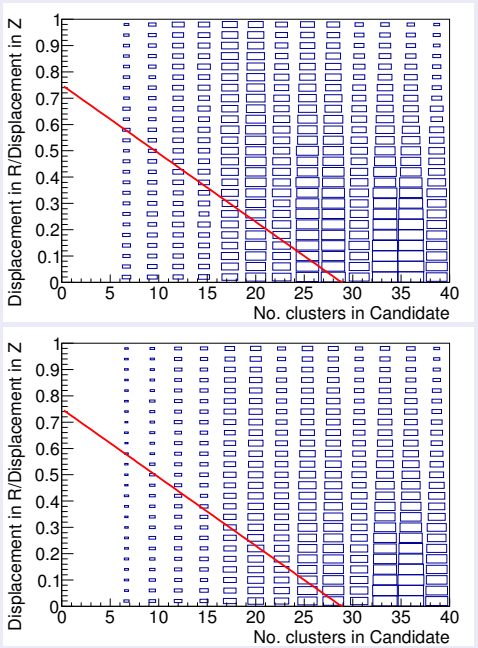




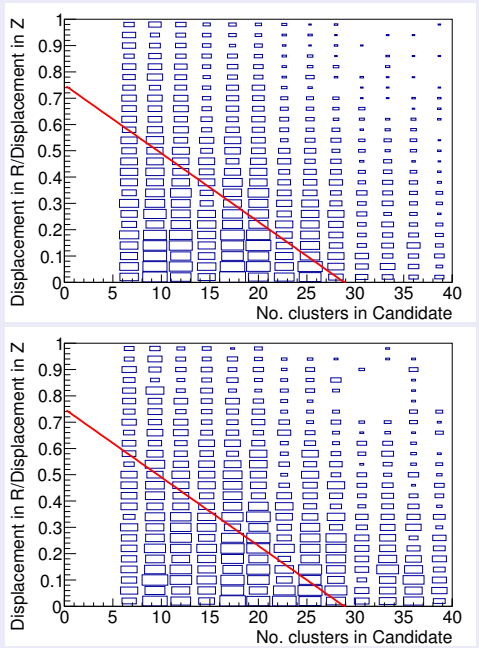
Transverse Displacement Verses Number of Hits

- ν_μ
- $\bar{\nu}_\mu$

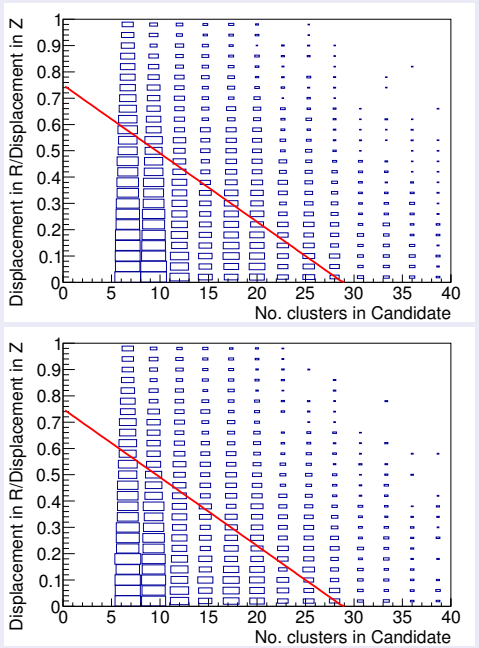
Signal



CC Background



NC Background

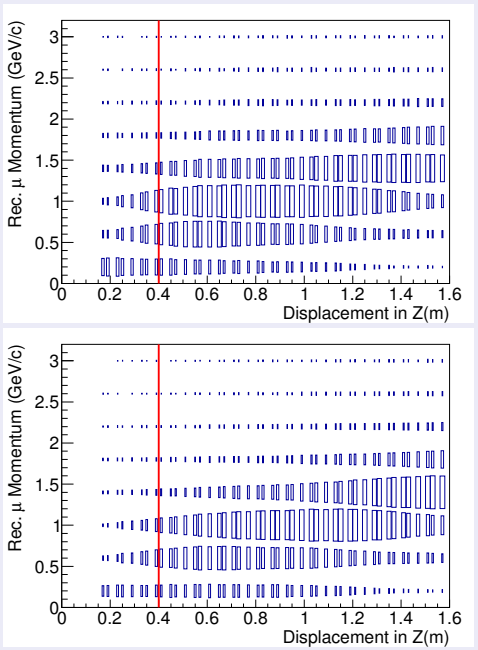


- Events below and left of line cut from analysis.

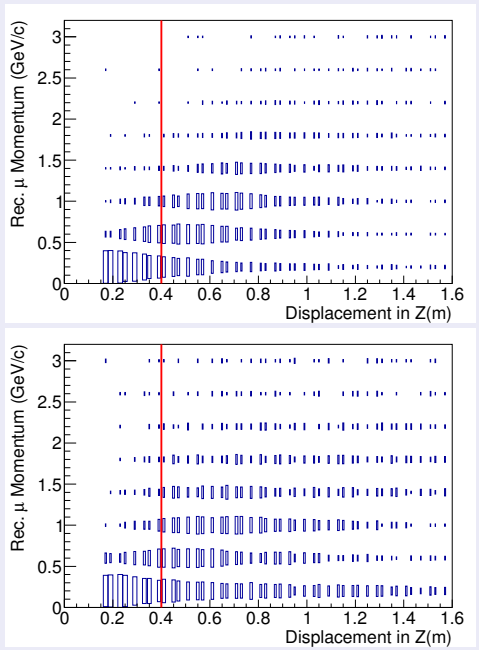
Reconstructed Momentum versus Longitudinal Displacement

- ν_μ
- $\bar{\nu}_\mu$

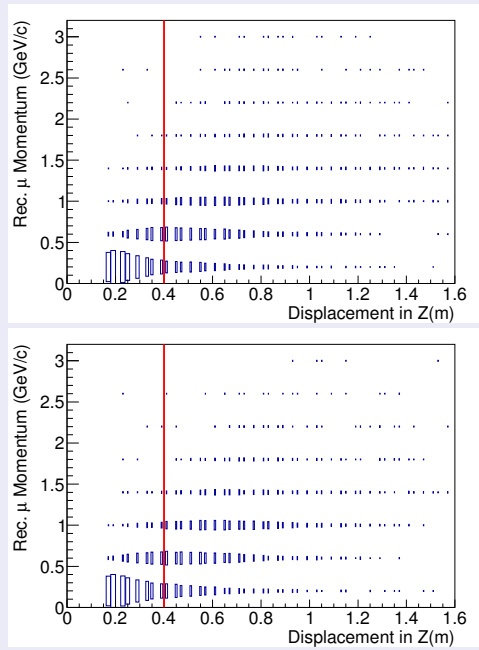
Signal



CC Background



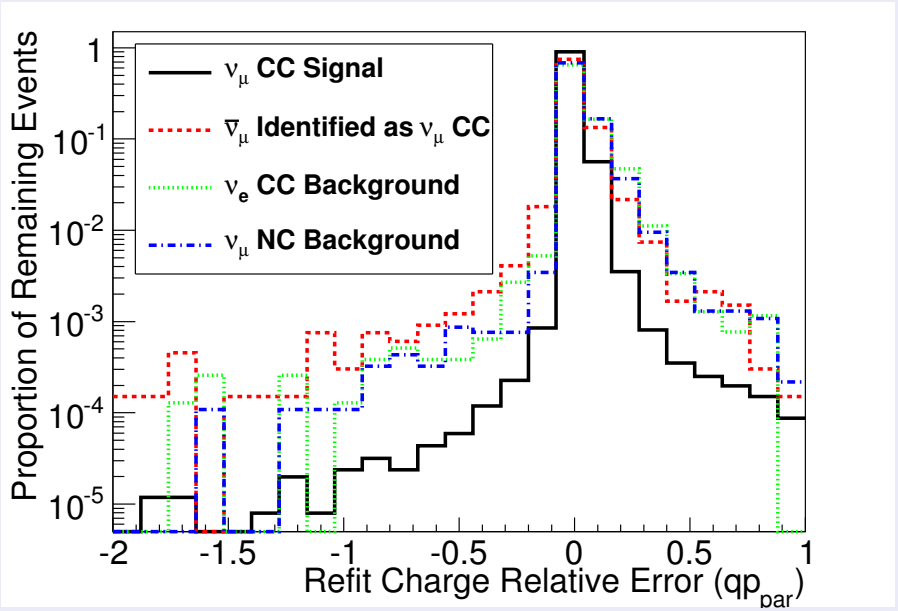
NC Background



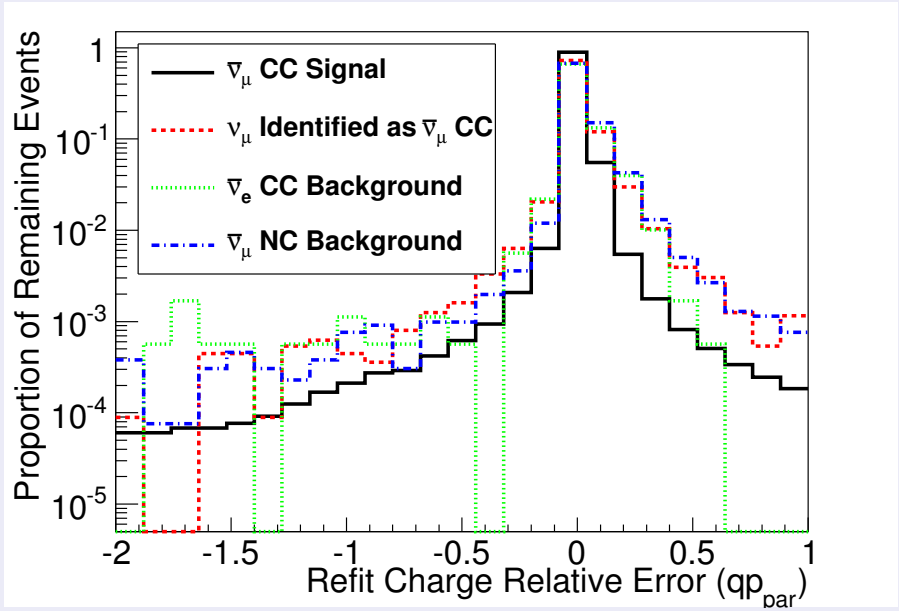
- Events to left of line removed

Quadratic Cut

Fits from ν_μ Tracks



Fits from $\bar{\nu}_\mu$ Tracks

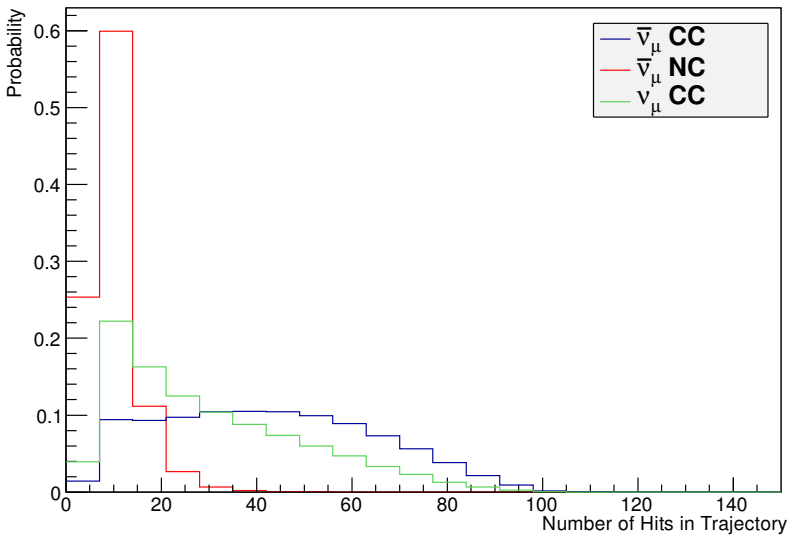


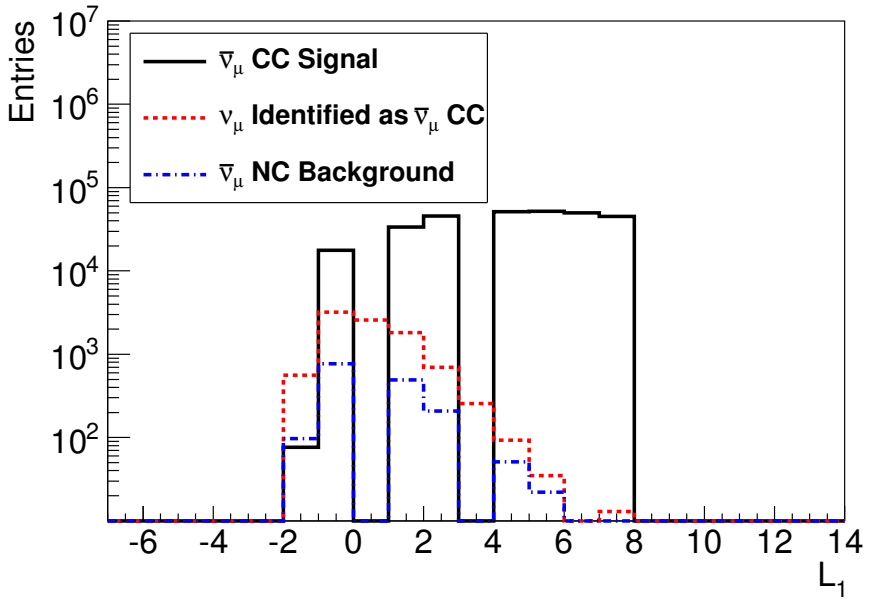
- Very little variation between sources.
- Purpose is to identify charge mis-ID
- Changing limits does not add anything to analysis.

CC Selection

Charge current selection uses the distribution of hits in trajectory in a log likelihood selection algorithm i.e. $L_1 = \log(I_{hit}^{CC} / I_{hit}^{NC})$.

- Strongly momentum dependent. Dictated by muon range.
- Mean and Variation in Energy Deposition also available.

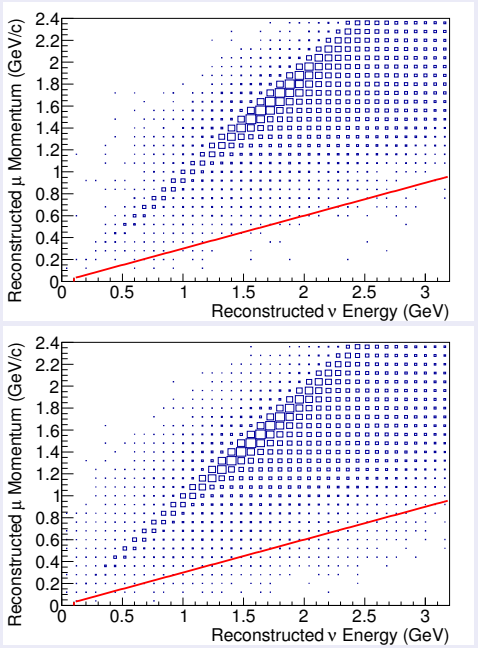




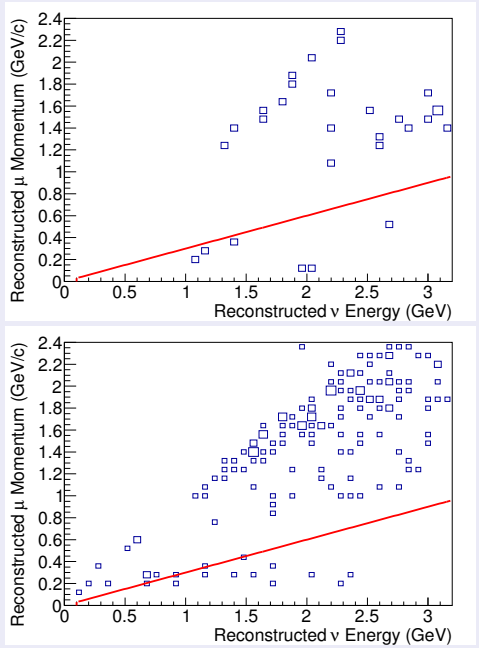
Kinematic Cuts: Reconstructed Momentum and Energy

- ν_μ
- $\bar{\nu}_\mu$

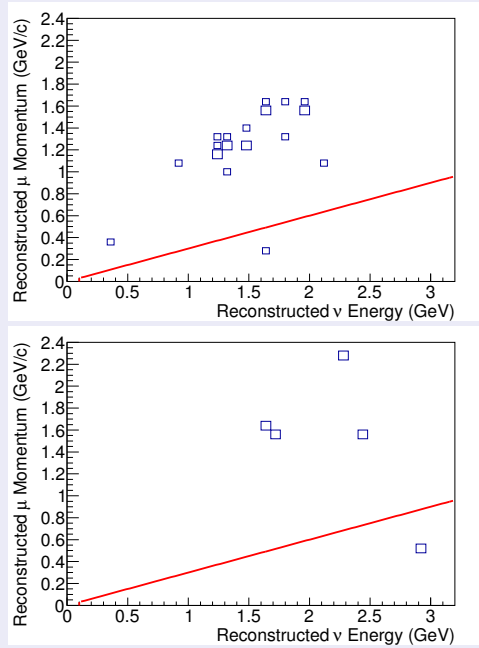
Signal



CC Background



NC Background

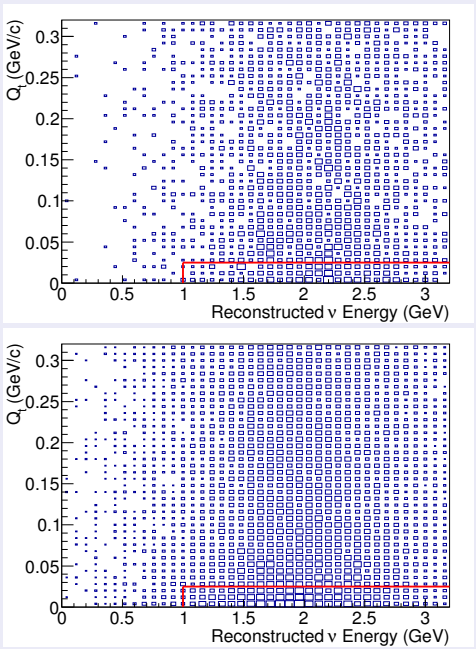


- Events below line removed
- Does nothing to improve purity.

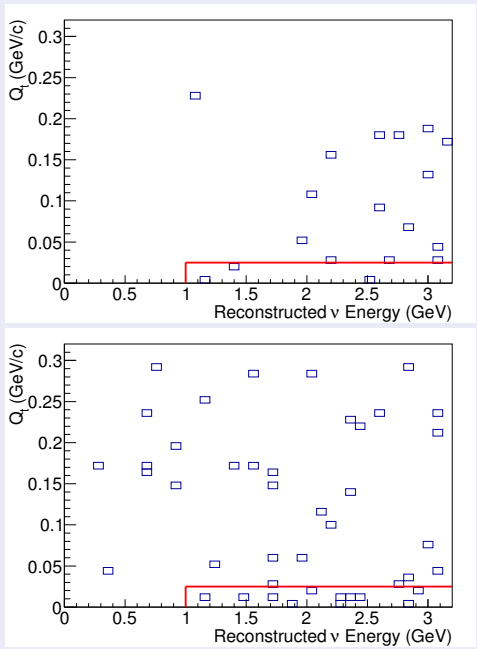
Kinematic Cuts: Reconstructed Energy and Q_t

- ν_μ
- $\bar{\nu}_\mu$

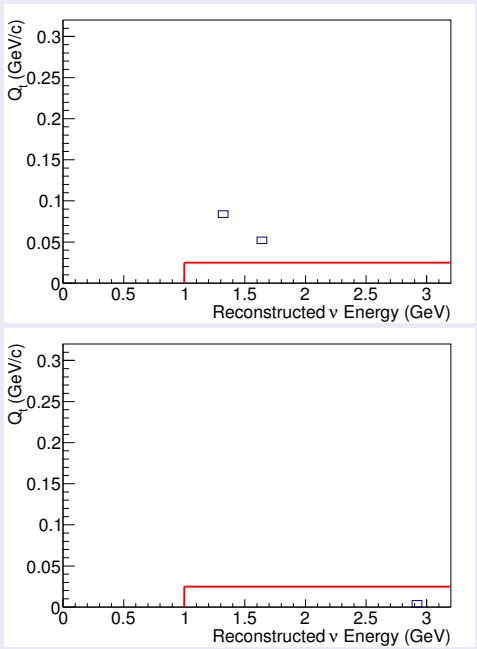
Signal



CC Background



NC Background



- Events below line removed
- Only removes signal events.

Changing Cuts

Optimizing the Signal/Background

- Use the likelihood cuts on track quality and CC Selection
- All other cuts fixed to values shown in above table.

Cut Quantities		Target Species			
		$\bar{\nu}_\mu$		ν_μ	
L_1	$L_{q/p}$	Eff	S/B	Eff	S/B
2.0	-0.5	0.44	280	0.26	180
4.0	-0.5	0.40	1286	—	—
5.0	0.0	0.31	2680	0.11	269
5.0	0.5	0.20	3331	0.068	267

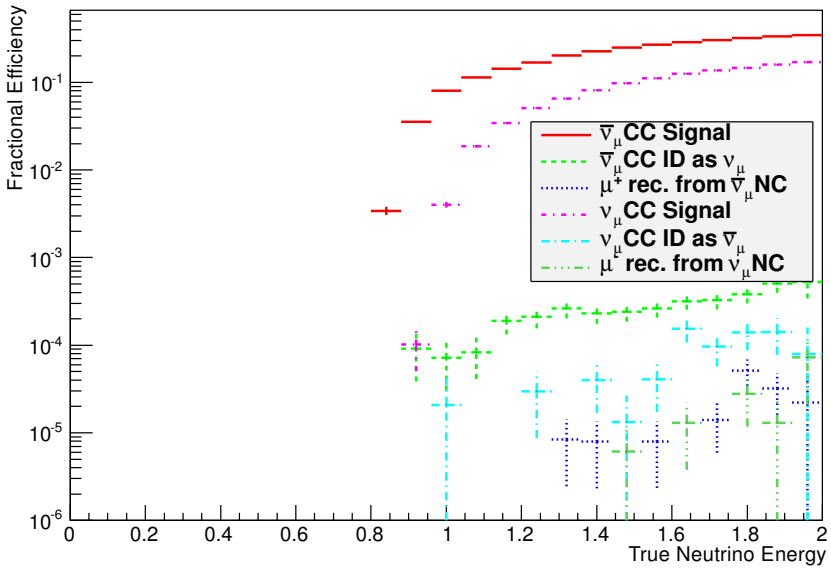
Conclusion

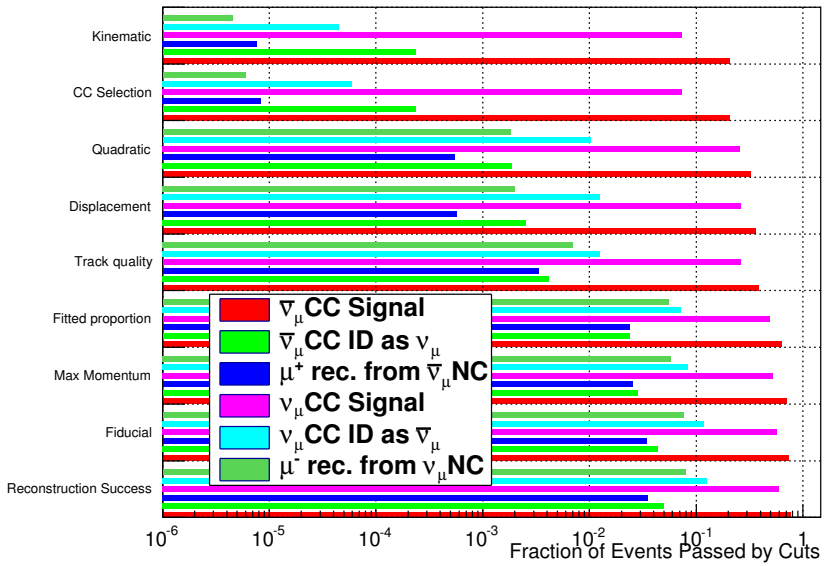
It is possible to maximize the signal to background ratio, at the expense of signal rate, for particles focused by the magnetic field.

Other Improvements

- “Removal” of Kinematic cuts will improve signal strength
  - All limits are set to zero.
- Raising limit on “Fit proportion” will help ratio of Signal over background
  - Charge mis-ID background is relatively constant up to 0.8

Performance After Changed Cuts

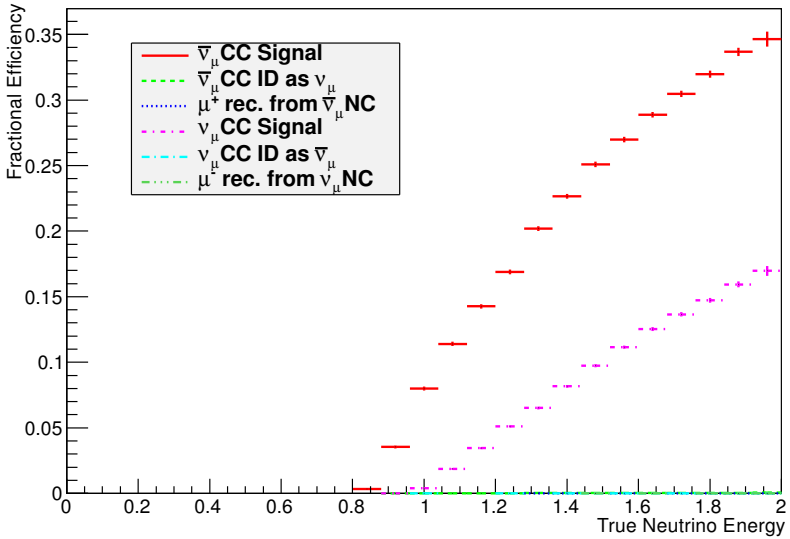




- Includes adjustments to Fitprop and Kinematic Cuts.
- Factor of $\sim$4630 background suppression for $\bar{\nu}_\mu$.
- Factor of $\sim$311 background suppression for ν_μ.

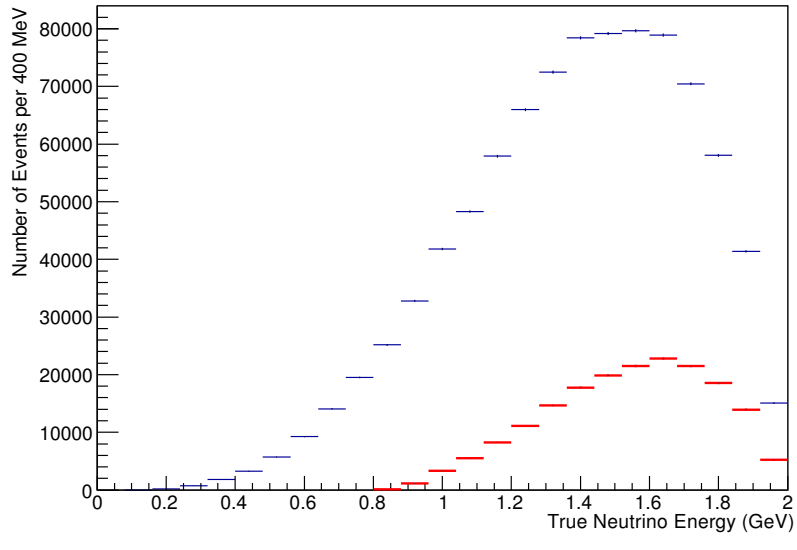
Spectra After Reconstruction

Linear Efficiencies



- Reconstruction and CC selection favours large energies.

Source and Selected Spectra



- Generated $\bar{\nu}_\mu$ CC spectrum in black
- Selected $\bar{\nu}_\mu$ CC spectrum in red

Are We There Yet?

Event Survival Fractions

Species	Event Fraction
$\bar{\nu}_\mu$ CC	0.2058
ν_μ CC ID as $\bar{\nu}_\mu$	4.44×10^{-5}
$\bar{\nu}_\mu$ NC	7.66×10^{-6}
ν_μ CC	0.07289
$\bar{\nu}_\mu$ CC Id as ν_μ	2.34×10^{-4}
ν_μ NC	4.5×10^{-6}

- Focused backgrounds at is part in 10^5.

Targets (copied from Paul)

- Want 20 $\bar{\nu}_\mu$ events with $\sim$ 0.5 background events
- Assume
  - $\sim 20000\nu_\mu$
  - $\sim 20000\bar{\nu}_e$
  - Oscillation Probability $P \sim 10^{-3} \rightarrow 20\bar{\nu}_\mu$
- mis-id rate $= \frac{0.5}{20000} = 0.25 \times 10^{-4}$.
- This is half the current background rate

- If this is as good as we can do then longer run times will be required.

Conclusions

- Three of seven cuts have the influence to produce required charge selection
  - Fit Proportion
  - Track Quality Likelihood Selection
  - Charge Current likelihood Selection
- Kinematic cuts are redundant in VLENF analysis.
- If we are stuck with current analysis then need longer running time.
- Analysis is not complete.
  - There must be some unexplored reconstruction improvements.
  - Have not used all available information in analysis.