Methods to improve $\overline{\nu}_\mu$ purity

David E. Jaffe
Brookhaven National Lab

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1 Event selection and scan results

Pre-selection criteria is cut5. Note cuts are cumulative (cutN includes cutN-1)

1. cut0 = well-defined charge and uncertainty on q/p
2. cut1 = + x,y,z fiducial cuts on vtx
3. cut2 = + |Uplane-Vplane| < 6 on vtx
4. cut3 = + fitpass && Prob(χ^2, ndf) > 0.1
5. cut4 = + Petyt PID > 0
6. cut5 = + q/p/sigma(q/p)>0 & rnear=(0.5,2.0) m

where rnear ≡ smallest radial position on the reconstructed track.

Thirty non $\overline{\nu}_\mu$ CC events in carrot LE-10 MC that passed the criteria above for a μ^+ candidate were visually scanned with NueDisplay. The results of the scan are given in Table 1. A significant fraction of the NC events actually had a positively charged track, frequently a proton. Protons were also reconstructed in a fraction of the CC ν_μ events. For such events one would expect that the measured dE/dx of the tarck would be a useful discriminant. A comparison of the momentum from curvature and range is roughly an equivalent test because the muon mass is assumed to convert the range to momentum. Such a comparison also appeared to be useful for a large fraction of CC events with a charge-sign error. Additional rejection may be possible by comparing the track vertex or end with the vertex or end of the shower. In a small fraction of the scanned events, the charged particle that was reconstructed actually went in the $-z$ direction, so that the shower appears to be at the end of the candidate track. In the following sections, both the comparison of P(range) and P(curvature), and the comparison of the track end and vertex with the shower end and vertex are studied.

Process	Events	Recon track was	Rejection method		
			$p_r \neq p_c$	$p_r \neq p_c$?	vertex/end
NC	9	$5p$, $3\pi^+$, $1\pi^-$	5	2	2
CC	19	$3p$, $14\mu^-$, $2X$	14		3
ν_e	1	$1p$			
Unknown	1	?	1		

Table 1: Results of scan.
Explanation of columns:
"Process" = NC, CC, ν_e CC or unknown. One event had incorrect MC truth/reconstruction matching.
"Events" = number of events with specified process.
"Recon track was" = the probable identify of the track that was reconstructed as the μ^+ candidate. X means either 2 tracks were stuck together or there was mass confusion due to many charged tracks.
"Rejection method" = possible rejection methods.
$p_r \neq p_c$ means disagreement between momentum from range and curvature.
A '?' indicates the rejection of that method is dubious.
"vertex/end" means that a comparison of the track and shower vertex and/or end may have some rejection.

$\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ cut	CC $\overline{\nu}_\mu$	CC ν_μ	NC
No cut	2592	1512	611
< 0.5	2259	539	300
< 0.4	2130	416	234
< 0.3	1956	366	208
< 0.2	1699	178	101
< 0.1	1151	82	48

Table 2: The number of CC $\overline{\nu}_\mu$, CC ν_μ and NC events with tracks that stop in the detector for various cuts on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ as derived from the plots in Figure 1.

2 Efficiency and purity of a cut on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$

Figure 1 shows plots of $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ *vs* 'signed' $P(\text{range})$ with the breakdown into CC ν_μ CC $\overline{\nu}_\mu$, NC and other. 'Signed' $P(\text{range})$ means that if the track did not stop in the detector, then $P(\text{range})$ is set negative for plotting purposes.

Figure 2 shows the same distributions as in Figure 1 for $-1 < P(\text{range}) < 10.5$ GeV$/c$ and $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})} > -0.5$

The general features confirm the scan results that $P(\text{curvature})$ is greater than $P(\text{range})$ for ν_μ CC events when charge sign is incorrectly assigned. Similarly NC events show a tail indicating $P(\text{curvature}) > P(\text{range})$ as observed from the scan. Table 2 shows the numbers of events (just raw MC counts, not normalized to protons on target) for the three main sources as a function of a cut on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ for tracks that stop in the detector. The efficiency and purity of the cut on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ is shown in Figure 3. It seems like we could get a $\sim$90% purity for a relative loss of efficiency for $\overline{\nu}_\mu$ of $\sim$50%.

3 Correlation of $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ and $\text{Prob}(\chi^2, \text{ndf})$

Milind surmised that $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ and $\text{Prob}(\chi^2, \text{ndf})$ might be correlated since Pedro showed that a cut on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ after requiring

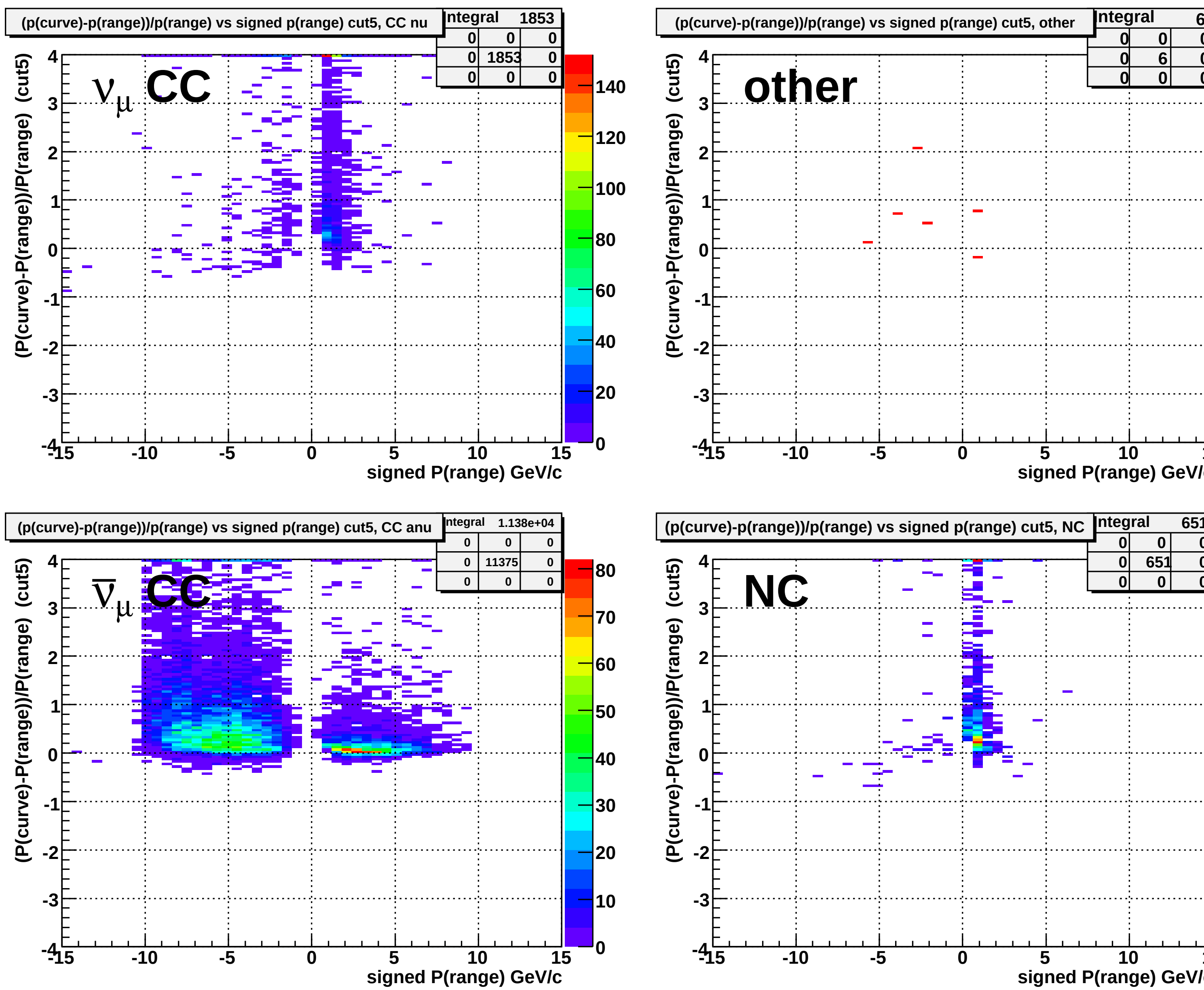

Figure 1: Plots of $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ vs 'signed' $P(\text{range})$ with the breakdown into CC ν_μ , CC $\overline{\nu}_\mu$, NC and other after cut5. Overflows are put into the extreme bins.

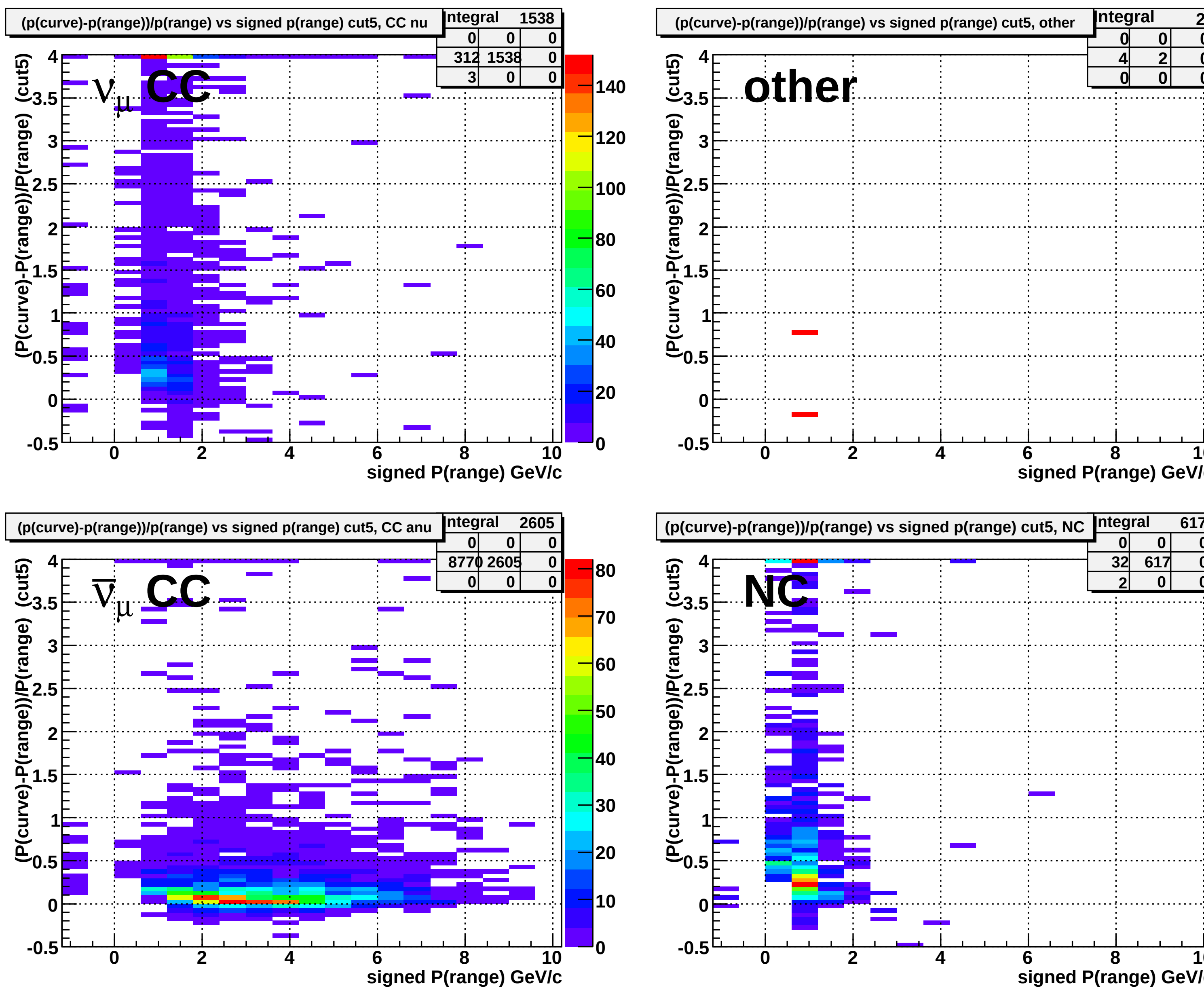

Figure 2: Same as plots in 1 for $P(\text{range}) > 0$ GeV/c and $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})} > -1.0$. Overflows are put into the extreme bins.

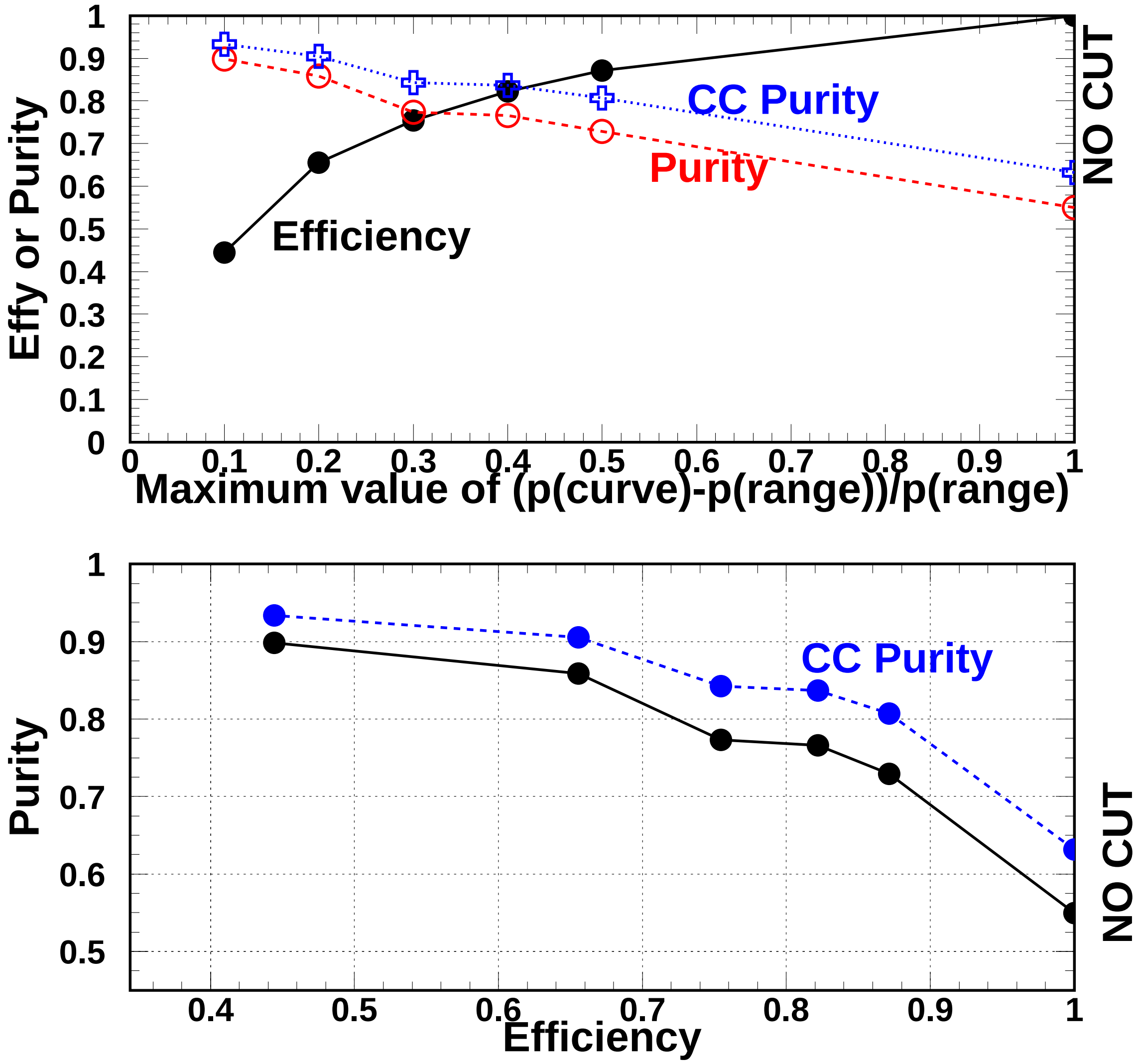

Figure 3: Efficiency and purity of a cut on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$. "Purity" is $\overline{\nu}_\mu$ rate divided by the sum of the $\overline{\nu}_\mu$, ν_μ and NC rates. "CC Purity" is the $\overline{\nu}_\mu$ rate divide by the total $\overline{\nu}_\mu$ and ν_μ rates.

Prob(χ^2, ndf) > 0.1 gave very little improvement in purity. Figure 4 shows that this is indeed true, although Prob(χ^2, ndf) may be a bit too brutal an instrument to suppress these events as it also removes a fair fraction of $\overline{\nu}_\mu$ events. In lieu of a replacement, Prob(χ^2, ndf) seems to be the best available tool.

4 Comparison of track and shower vertices and endpoints

Figure 5 shows the difference in plane number between the end of the track and the shower *vs* the reconstructed neutrino energy. A cut at 15 to 20 planes would be very effective at removing a substantial fraction of both the NC and ν_μ CC background. The price to pay would be the near complete loss of acceptance for $\overline{\nu}_\mu$ CC below $\sim$1 GeV. Figure 6 shows the difference in plane number between the end of the track and the shower vertex *vs* the reconstructed neutrino energy. An energy-dependent cut might retain some very low energy $\overline{\nu}_\mu$ with sufficient suppression of the NC and $\overline{\nu}_\mu$ CC backgrounds. Note that no cuts have been made on $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ to make these distributions.

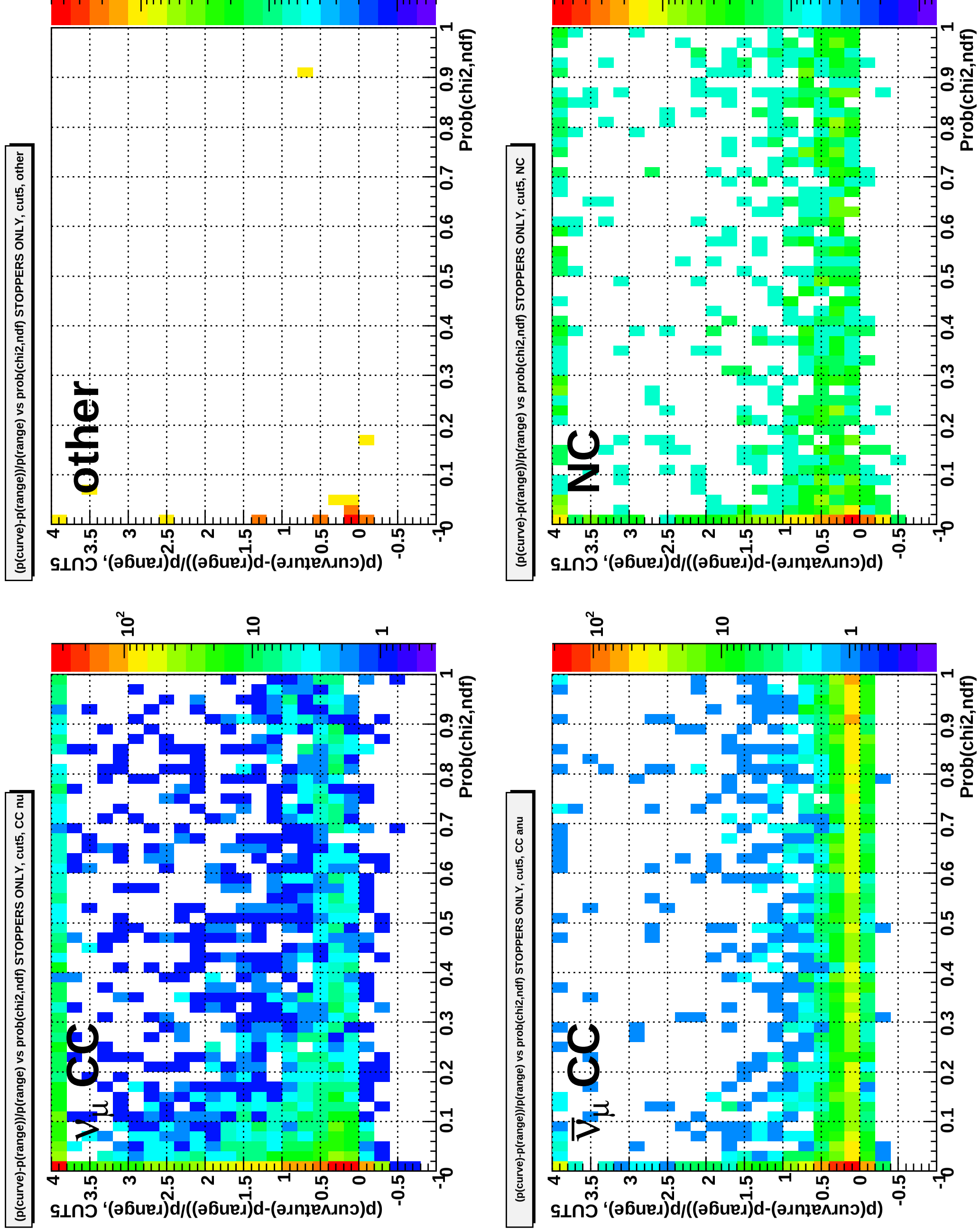

Figure 4: $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ *vs* Prob(χ^2, ndf) after applying cut5 (Section 1). To make this figure, the requirement of Prob$(\chi^2, \text{ndf}) > 0.1$ in cut3 was (obviously) removed. Overflows in $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ are put in the uppermost bin. Note the logarithmic scale. One sees a clear correlation between large values of $\frac{P(\text{curvature})-P(\text{range})}{P(\text{range})}$ and small values of Prob(χ^2, ndf) for ν_μ CC and NC.

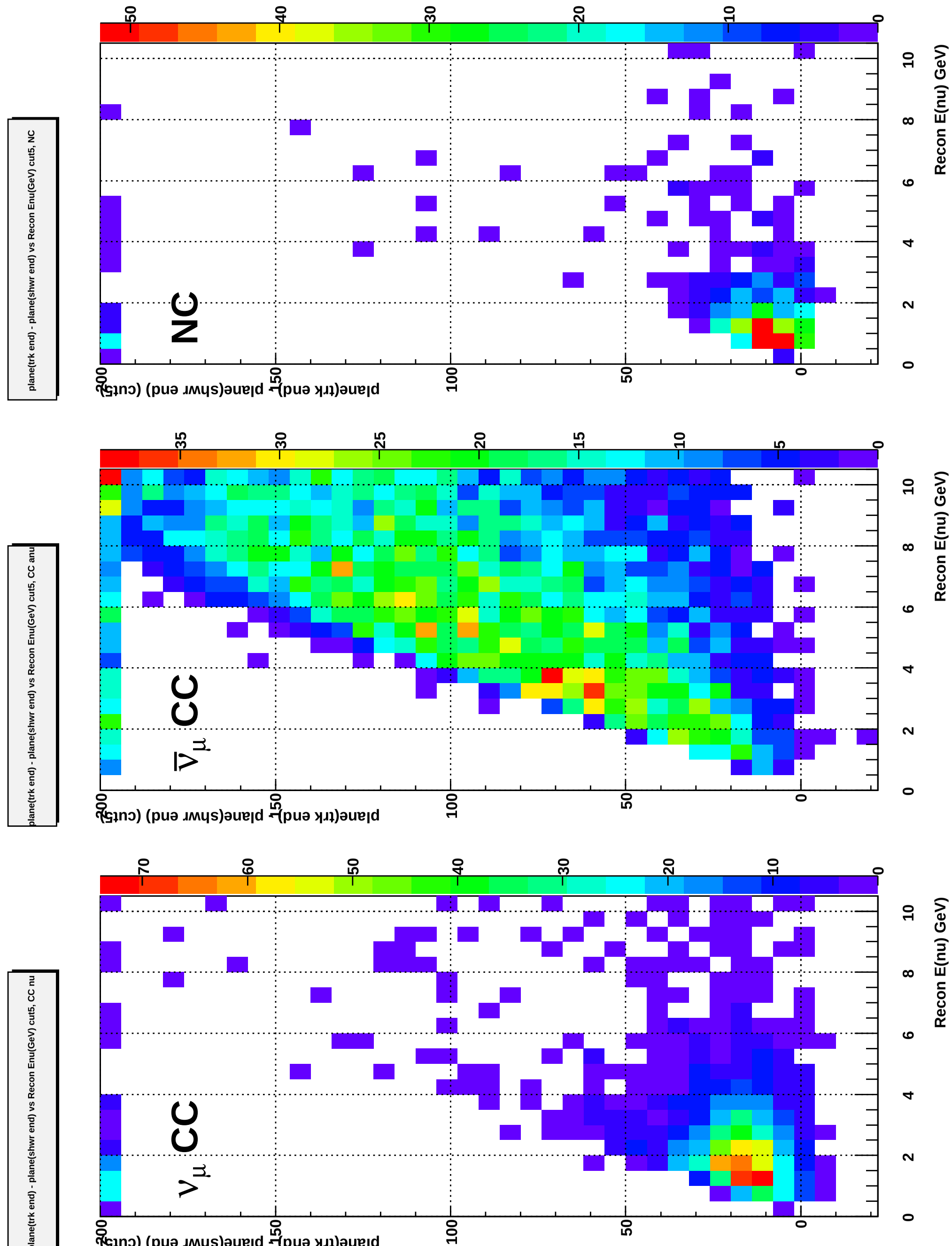

Figure 5: plane(track end) − plane(shower end) *vs* the reconstructed neutrino energy for CC ν_μ, CC $\overline{\nu}_\mu$ and NC events after application of cut5. Candidates without a shower are entered in the uppper most bin in the distributions.

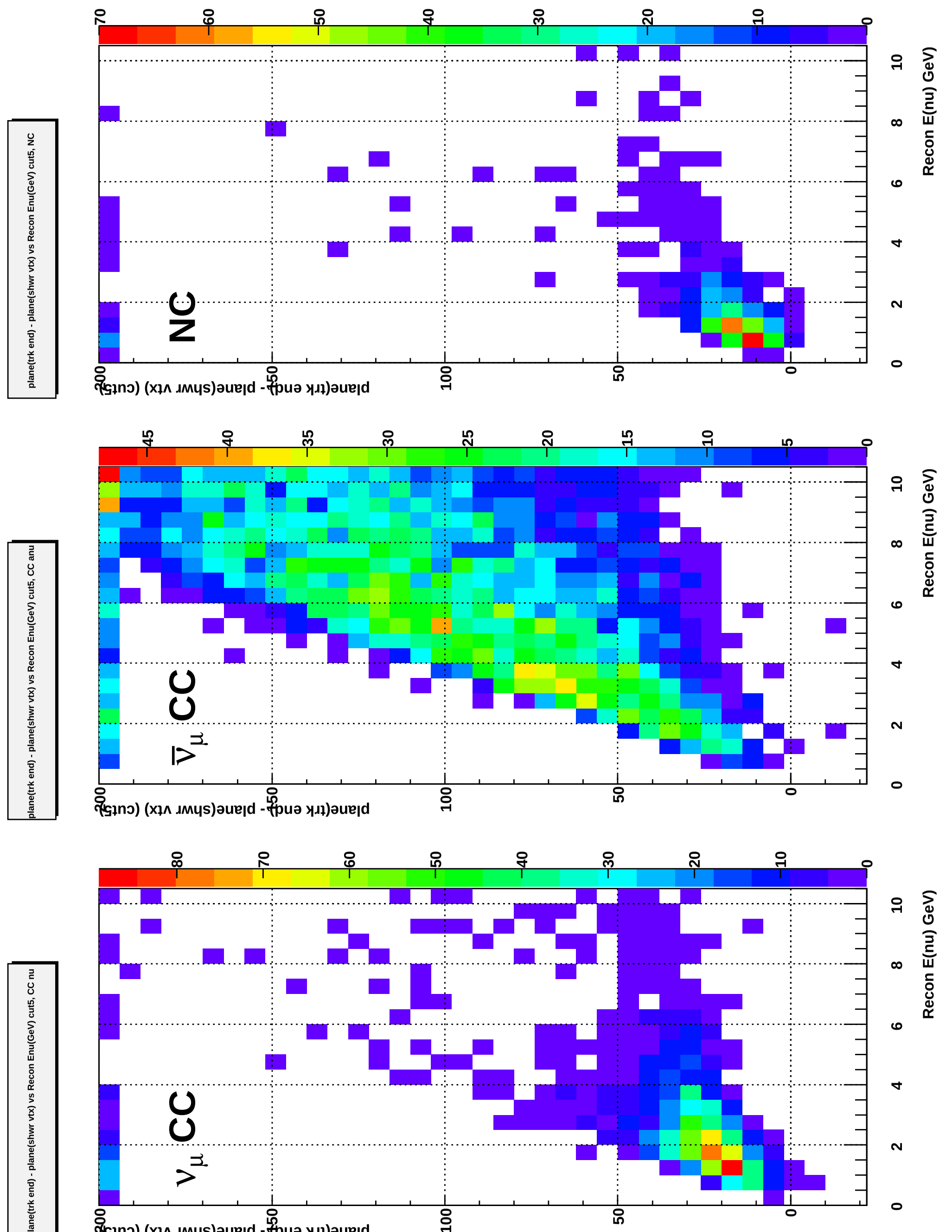

Figure 6: plane(track end) − plane(shower vertex) *vs* the reconstructed neutrino energy for CC ν_μ, CC $\overline{\nu}_\mu$ and NC events after application of cut5. Candidates without a shower are entered in the uppper most bin in the distributions.