Numu CC/ NC Separation in the ND & FD

N. Saoulidou, Fermilab, CC phone meeting 12-15-04

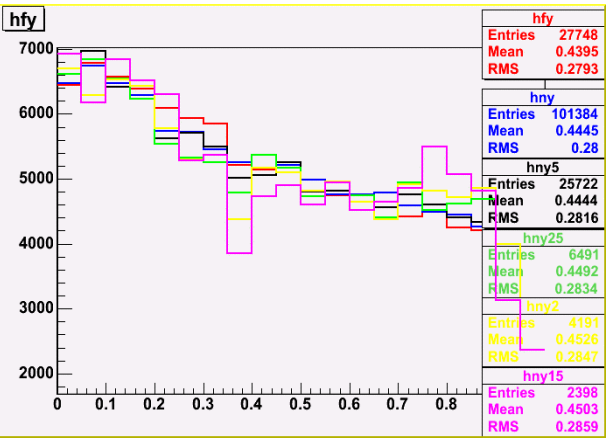
Outline

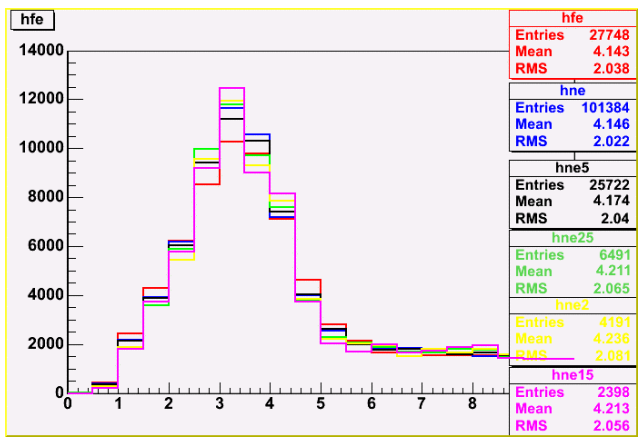
- Comparison between reco & truth quantities in ND & FD
- CC / NC Separation in ND & FD
  - Initial Results
  - Statistical & systematic errors (initial steps)
  - Attempt to obtain oscillation parameters (using just FAR "data")
- Summary and ongoing work

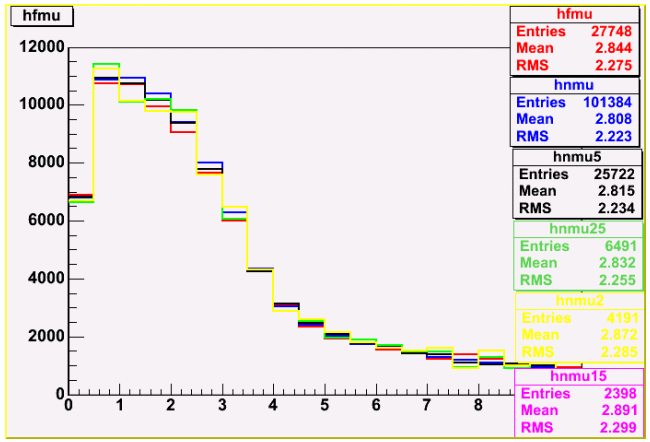
Events used and Fiducial Cuts

- I am using the MDC R1.12 files (all available for both Near and Far detector)
- Not (yet) used the "mock" Near of Far files.
- Fiducial cuts:
  - **ND :1m around the beam center and 0.4 < mcz < 6.5**
  - **FD :3m around the detector center and z > 1 && z < 14 OR z> 17 && z < 29**

Y True Muon & Neutrino energy for CC events



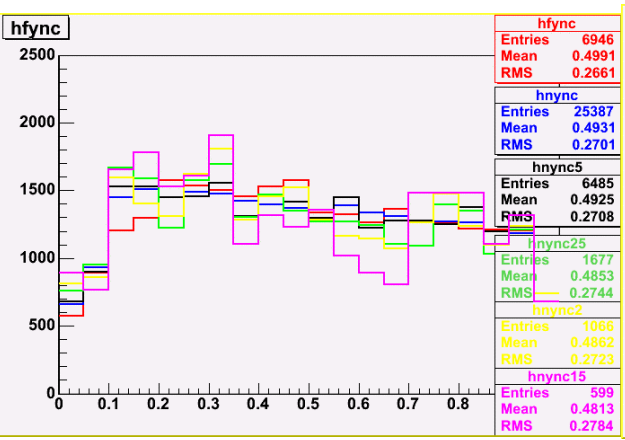


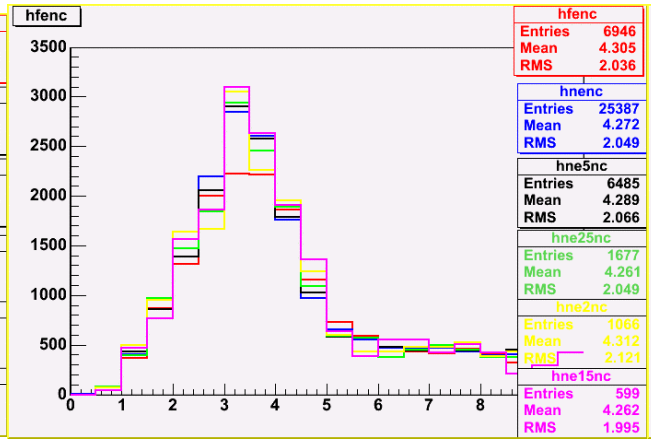


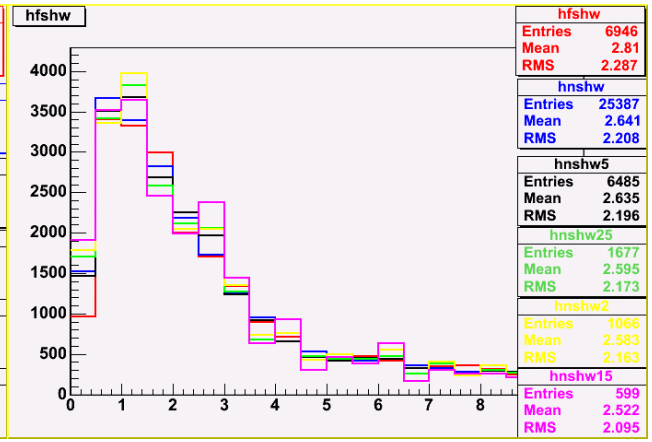
Y **Enu** **Pmu**

- Y true Enu & Pmu for the Far (**red histogram**) and Near Detector for different radii around the beam center : **1 m**, 0.5m, **0.25m**, 0.2m and **0.15m**. All distributions are normalized to have the same number of entries (for 0.25 0.2 and 0.15 m the statistics for the Near Detector are really poor).
- No significant differences between the Near and Far detector spectra.

Y True shower & Neutrino energy for NC events



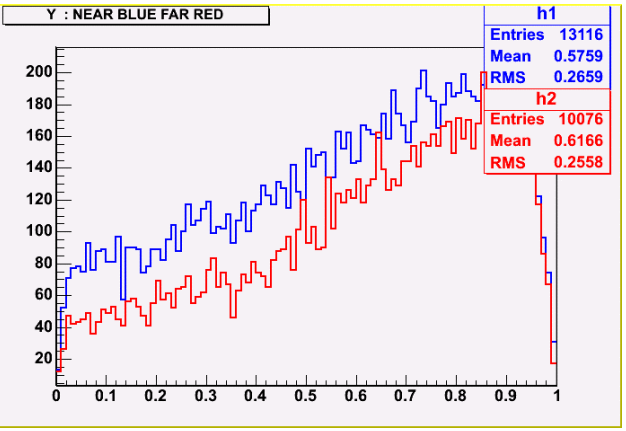


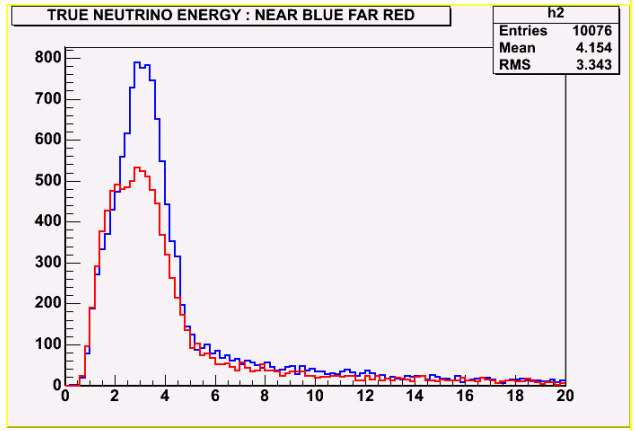


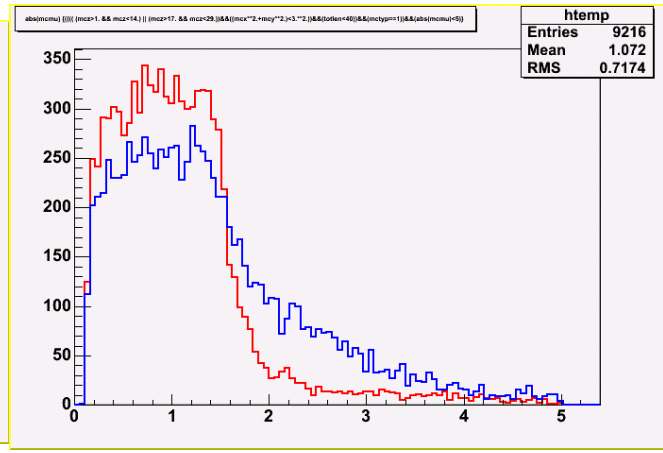
Y **Enu** **Eshw**

- Y true Enu & Pmu for the Far (**red histogram**) and Near Detector for different radii around the beam center : **1 m**, 0.5m, **0.25m**, 0.2m and **0.15m**. All distributions are normalized to have the same number of entries (for 0.25 0.2 and 0.15 m the statistics for the Near Detector are really poor).
- There are slight differences with the Far detector having a slightly higher Y, Enu and Eshw distribution that becomes more pronounce as we decrease the radius of the fiducial Near region.

Y True Muon & Neutrino energy for short (<40 planes) CC events



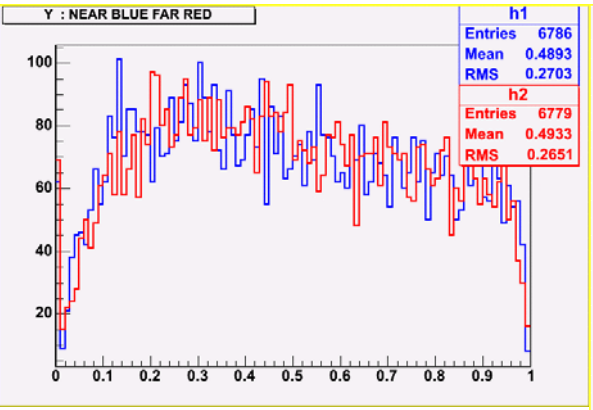


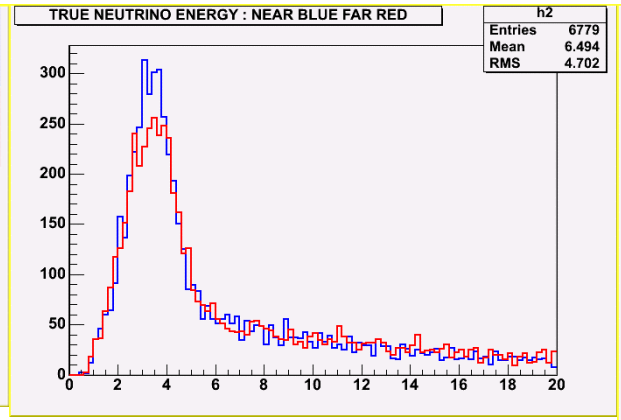


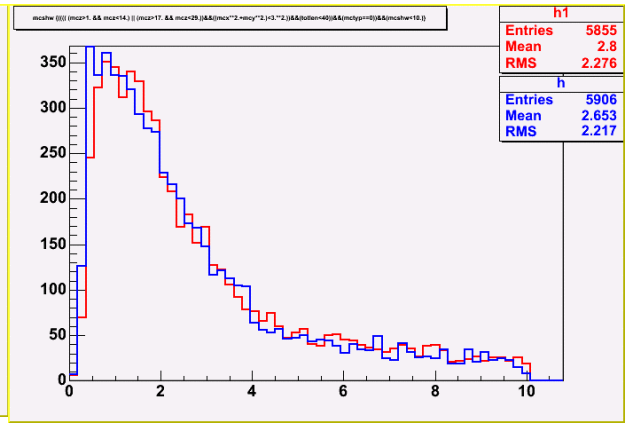
Y Enu Pmu

- Looking at short events since total CC events show no difference in these quantities and furthermore it is the sample I am using for the event classification.
- FAR (RED) CC short events appear to be higher Y and lower visible energy. This in general would mean shorter muons => less reconstructed tracks (TRUE MUON MOMENTUM is indeed lower for FAR events). This behavior is due to the smaller size of the Near Detector (more CC events with less than 40 planes that are actually higher momentum but exit the detector).

Y & Neutrino energy for short (all actually) NC events



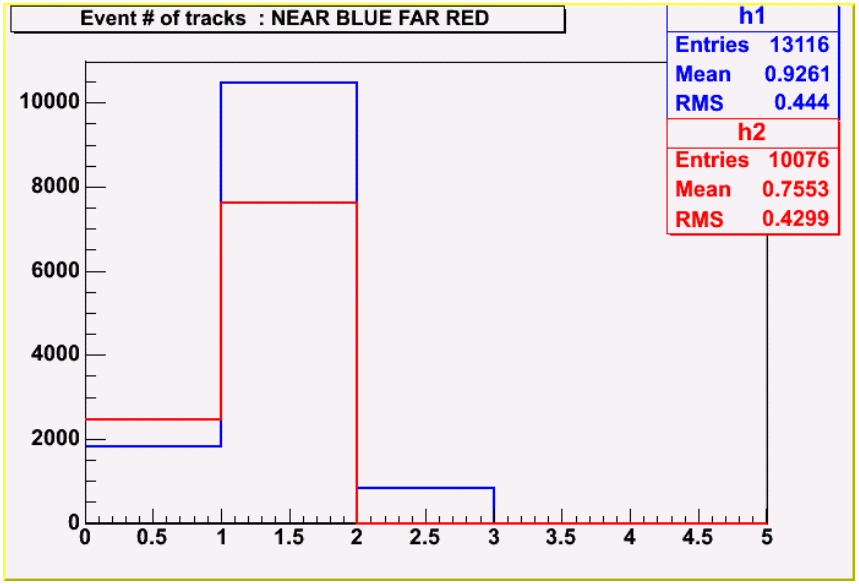


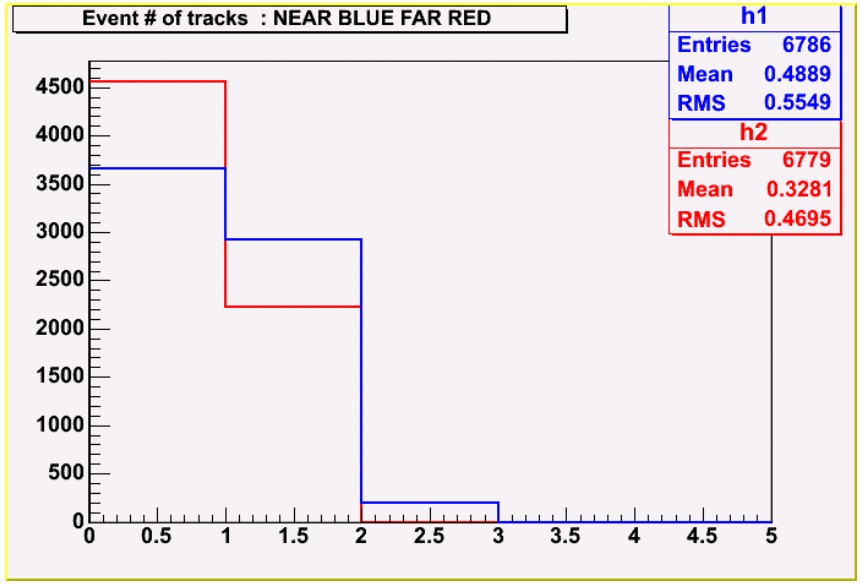


y Enu Eshw

- FAR (RED) NC events seem to have slightly higher Y and higher neutrino energy which means higher shower energies and in general fewer tracks. (Shower energy is higher).

Tracks for CC & NC short Events





- The higher percentage of CC events with tracks AND NC events with tracks in the NEAR detector seems like an "intrinsic" feature of the Far detector (less reconstructed tracks for short events in general). The true muon energy distributions for CC events for Near and Far did not show differences that would justify this result.

Tracks for CC & NC short Events con't

- Examined percentage of CC and NC short (< 40 planes) events with tracks in both Near and Far as a function of event length and for various fiducial cuts (radius around the beam center for ND):

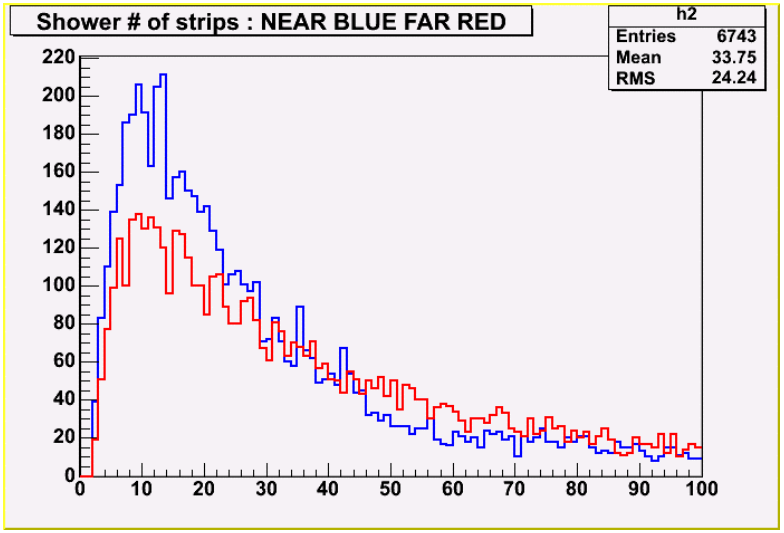
CC	ND 1m	0.25 m	FD
L<10	21	21	21
10<L<20	81	81	64
20<L<30	98	98	87
30<L<40	99	99	93

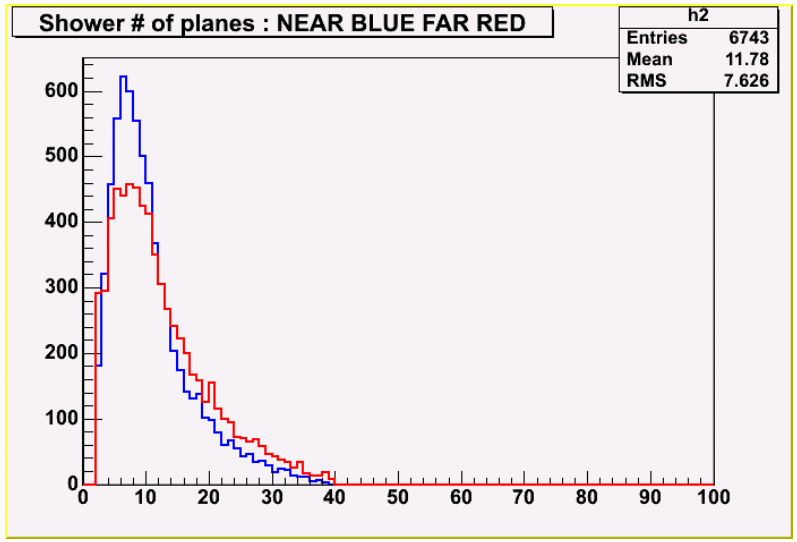
(above 40 planes tracking efficiency is the same)

NC	ND 1m	0.25 m	FD
L<10	13	13	13
10<L<20	65	65	44
20<L<30	90	90	50
30<L<40	94	94	50

- It seems like the track reconstruction in the Far detector is lower (reco pathology?, expected feature due to far multiplexing? Need to investigate….)

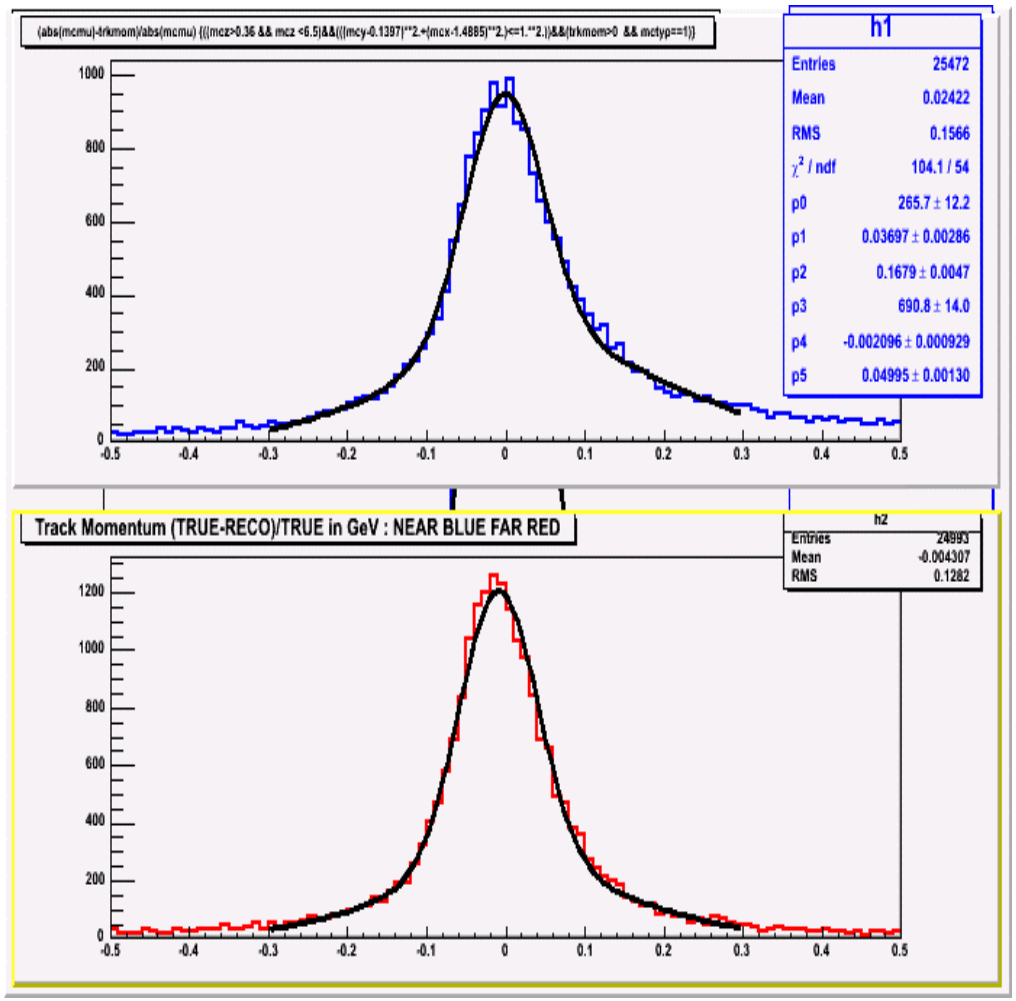
Shower # of strips & # of planes for NC short Events





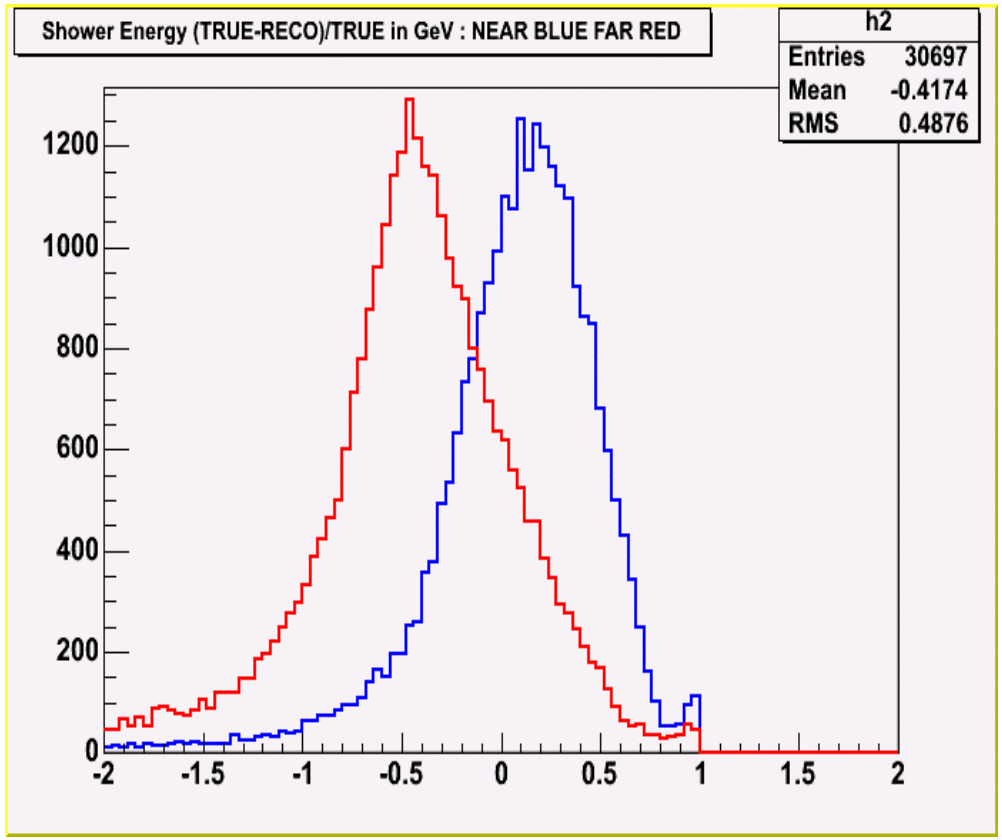
- Avoid (for the moment) to compare the total PH due to the fact that (as discussed in previous reco meetings) the NEAR detector PH might be lower/higher (?) by factors of 10-20%.
- However the total shower strips and planes are a more unbiased quantity to compare.
- The fact that the FAR detector has in general larger showers is in agreement with the Y Enu and Eshw FAR distributions (higher shower energies).

Momentum resolution (ALL CC Events)



- Muon momentum in NEAR detector slightly more asymmetric (maybe not very efficient "stopping track definition given the difficult Near detector geometry).
- Distribution not gaussian (I fitted with two gaussians). False solutions?
- In general resolution of the order of 11%-12% for both detectors and Near - Far very similar.

Shower resolution (ALL Events)



- Shower energy resolution in GeV very different (at the moment) between Near and Far.

Nathaniel looked into this problem and found a "bug" in the way Near strip coordinates were used and made some fixes. When the MDC files will be reprocessed (changes are back-ported to R1.12) these distributions should look much more similar.

At the moment I am not using the estimated neutrino energy for anything…

Strategy for CC analysis

1. Event selection in NEAR and FAR

2. Corrections (and errors statistical & systematic) for
   - Reconstruction efficiency
   - Selection efficiency
   - Selection purity

3. Extrapolation (and systematic errors) from NEAR to FAR in order to get the reference (unoscillated numbers and spectra) in FAR to be able to compare.

4. True neutrino energy reconstruction (and systematic errors) for CC analysis.

Event Selection

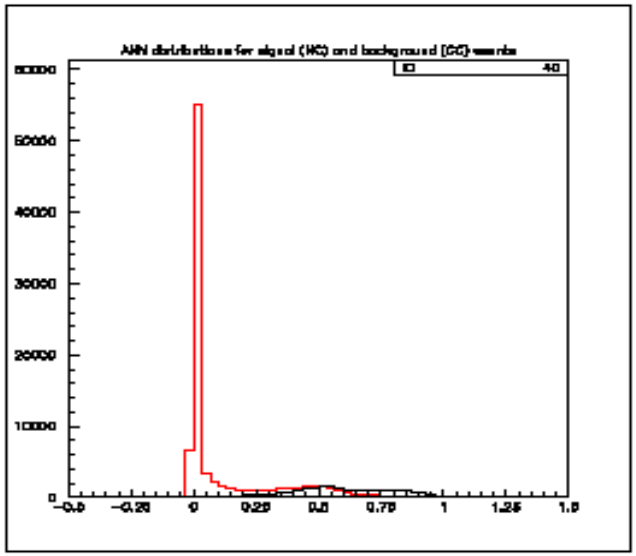
- Event selection method I am using : ANN

- Train ANNs in :

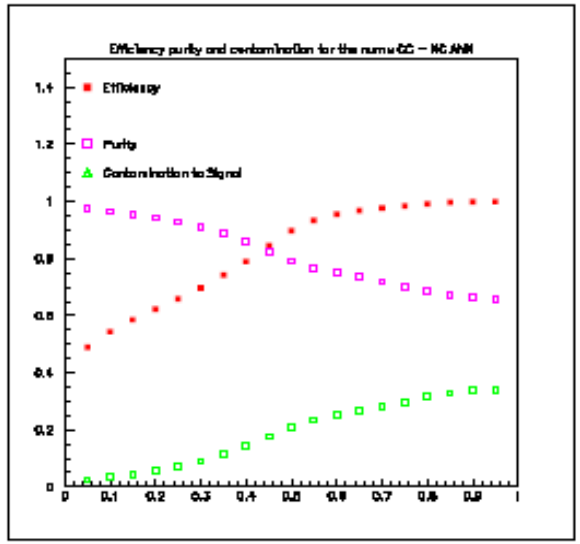
  - NEAR
  - FAR unoscillated
  - FAR oscillated with 2 different dm2 (0.002eV^2 and 0.0025 eV^2 with sin^2(2theta) = 0.95

  - Develop selection method (ANNs) for Far oscillated and unoscillated events in order to study how different the results are and determine how I should train/tune my selection procedure for the FAR detector and also estimate its systematic error.

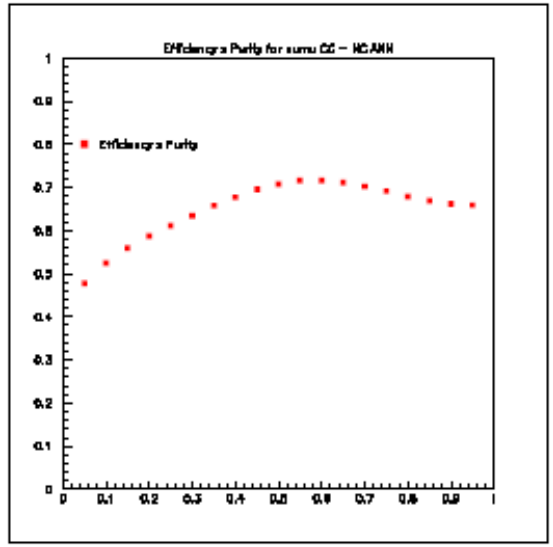
ANN Results NEAR



NN output function



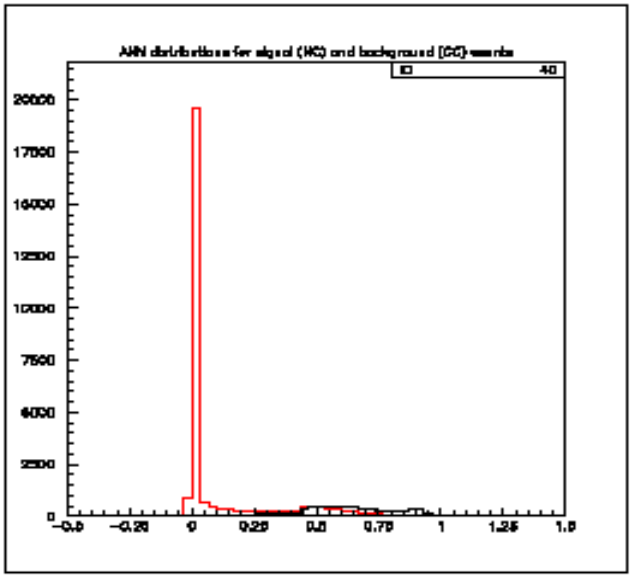
Efficiency (red) Purity (magenta)



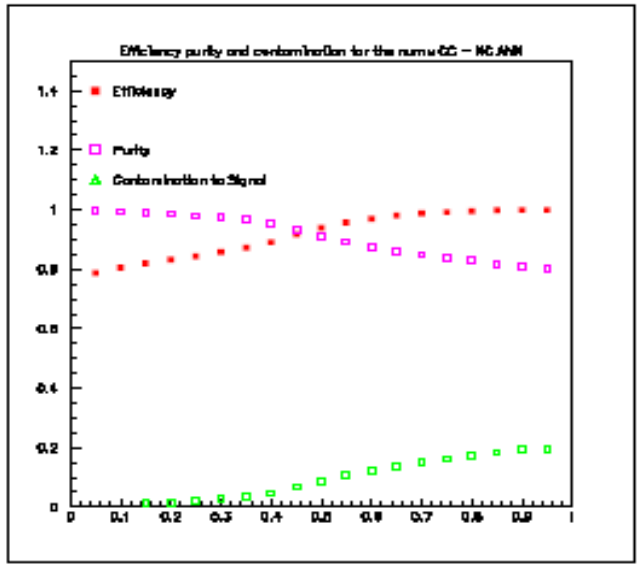
Efficiency x Purity

- The ANN performance is quite good. With a cut @ 0.45 the efficiency is 85 % and the purity 82%.

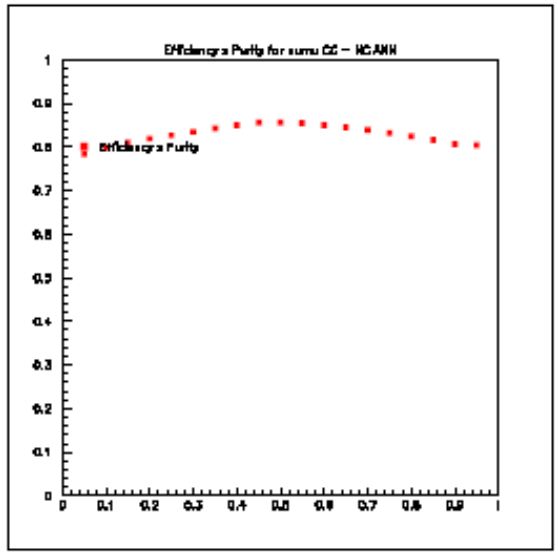
ANN Results FAR no oscillations



NN output function



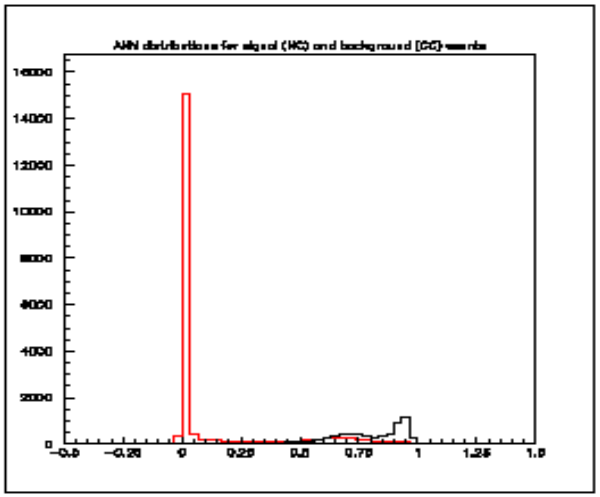
Efficiency (red) Purity (magenta)

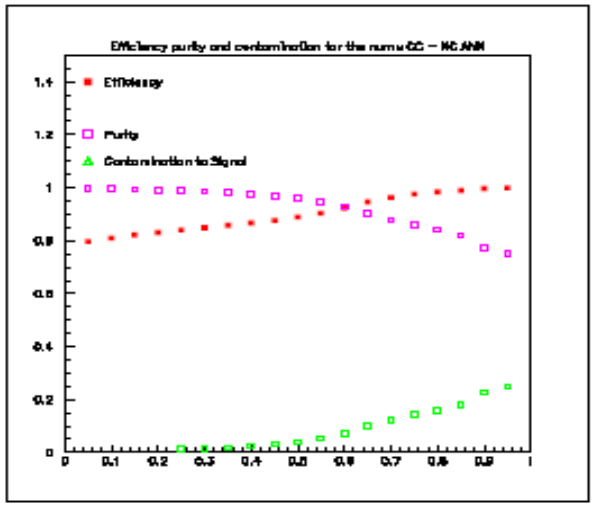


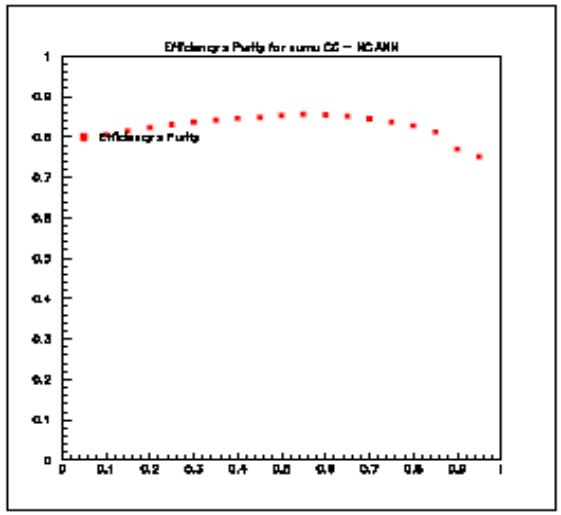
Efficiency x Purity

- The results are better than in the Near detector probably due to the higher fraction of CC long events in the Far detector which is an artifact of the z fiducial cuts I have used in the Near that are quite loose.Also that difference in the number of reconstructed tracks between Near and Far can also play a role.(I will correct the z cut in the Near detector and compare again the results).
- If we set the cut @ 0.45 we have an efficiency of 92% and a purity of 93%.

ANN Results FAR oscillated with $\sin^2(2\cdot\theta)=0.95\,\&\,\Delta m^2=0.0025$





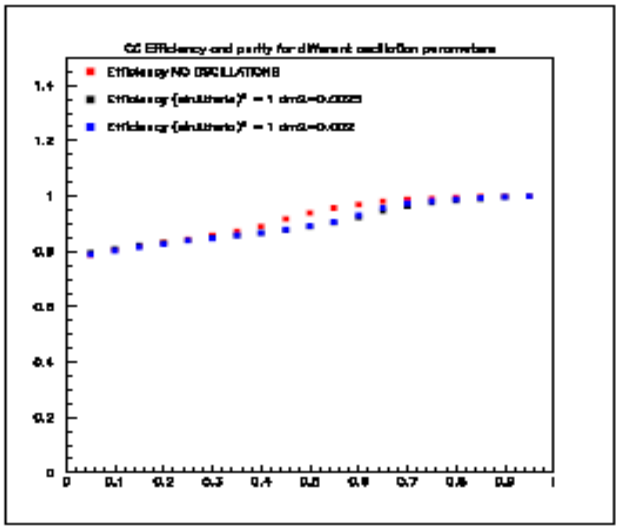


A priori probabilities 1:1.4 Efficiency (red) Purity (magenta) Efficiency x Purity

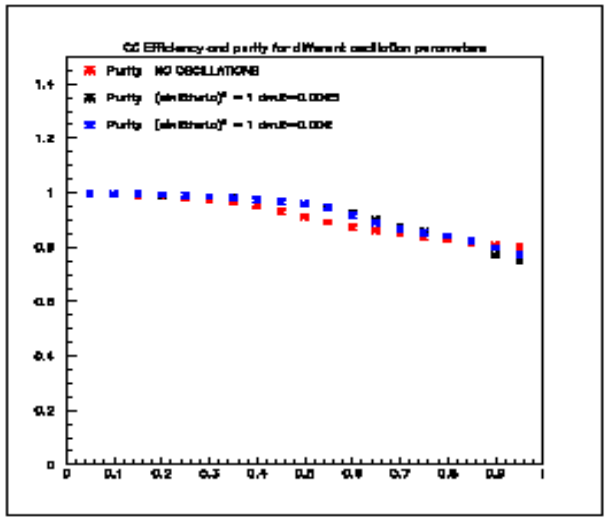
- The results are slightly different than the unoscillated mostly due to the lower S/B ratio.
- If we set the cut @ 0.45 (i.e) we have an efficiency of 87% and a purity of 97%.
- As numus "oscillate" the efficiency of selecting them decreases (the oscillation does not reduce the CC population uniformly) and the purity increases because the NC /CC separation becomes better (higher NC/CC ratio).

ANN Results FAR :

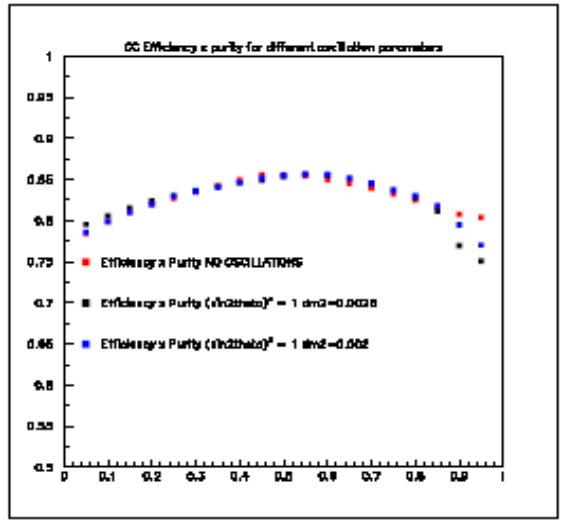
No oscillations - $\sin^2(2\cdot\theta)=0.95\,\&\,\Delta m^2=0.0025$ $\sin^2(2\cdot\theta)=0.95\,\&\,\Delta m^2=0.0025$



Efficiency



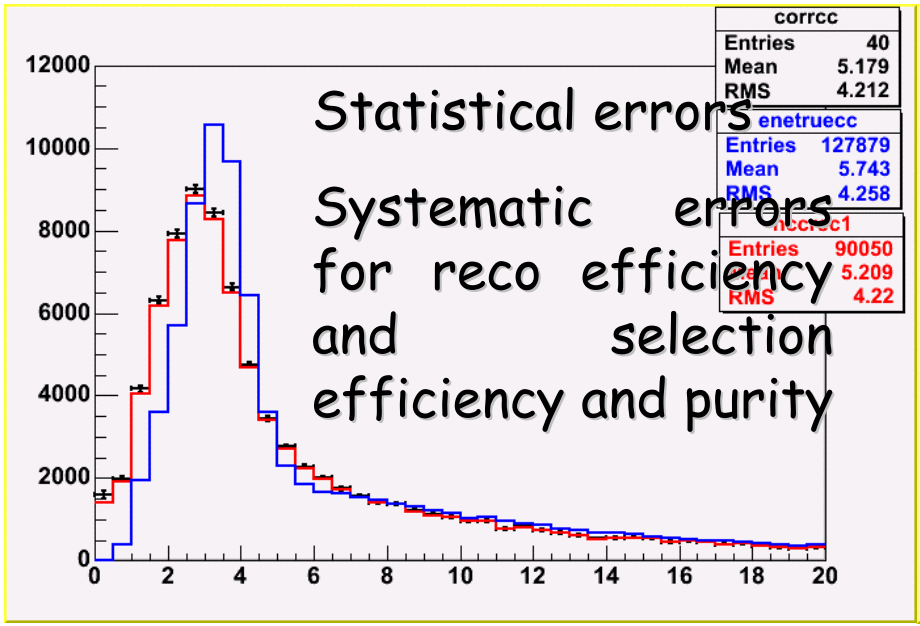
Purity

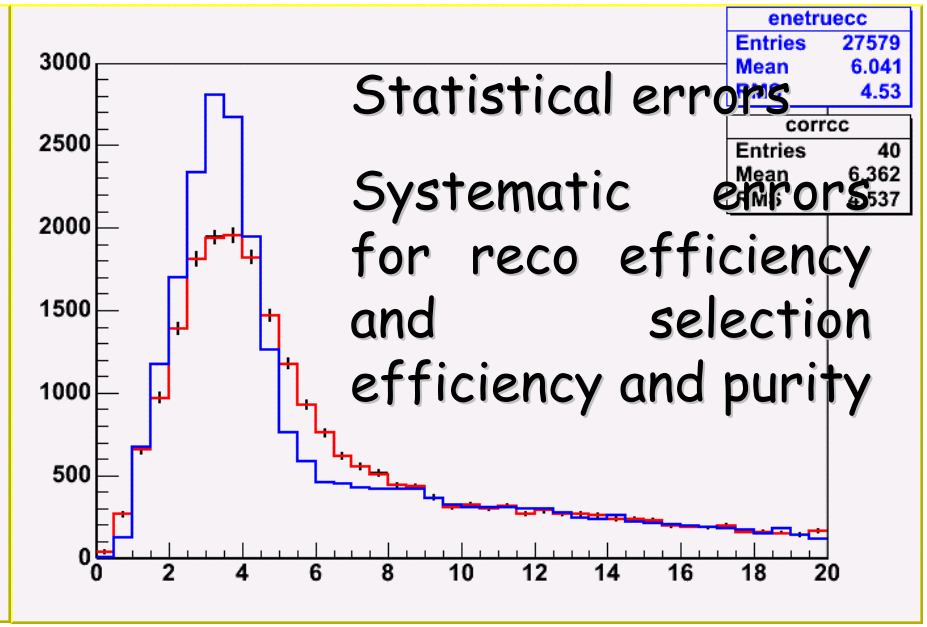


Efficiency x Purity

- For the CC population the ANN results are slightly different when we train with the unoscillated events or with the oscillated ones but the differences are small and they can be used to estimate the systematic uncertainties of this classification method.

Reconstructed CC spectrum in Near-Far (unoscillated)

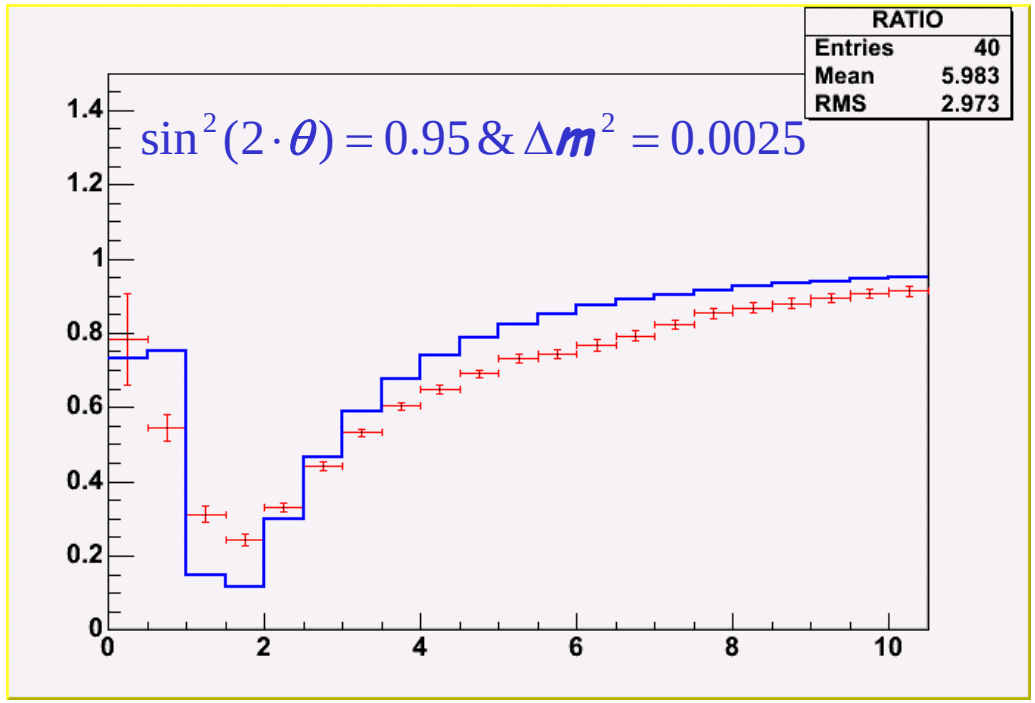




- Blue is the true CC energy spectrum, red is the true CC spectrum using reco (measured) energy (instead of true) and the black points is the CC reconstructed spectrum after correcting for reconstruction and selection efficiency and purity.
- Black and red are very similar (expected since we applied all possible corrections) but the blue histograms are quite different (more pronounce shift in the Near Detector) due the difference between true and reconstructed neutrino energy.

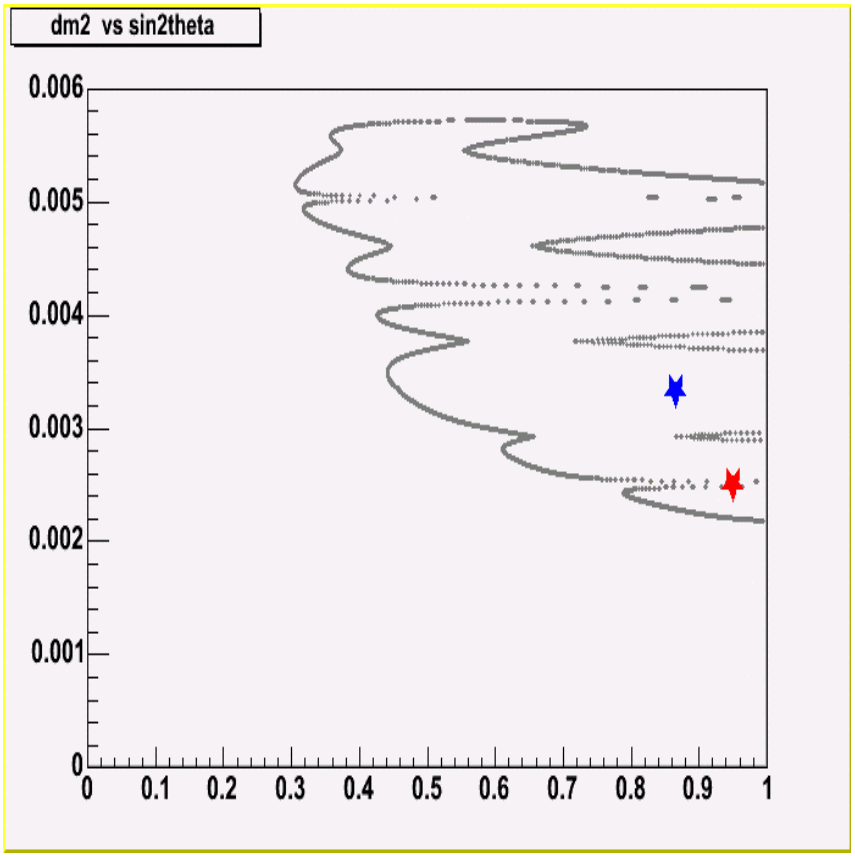
(The ANN selection efficiency and purity does not include systematic uncertainties due to oscillations)

Ratio of oscillated to unoscillated sepctrum (FAR)



- In the actual analysis the reference unoscillated *CC* spectrum will come from the Near detector spectrum extrapolated to the Far.
- As a starting point I have assumed "perfect" extrapolation (using the Far unoscillated *CC* spectrum) and attempted a very simple estimation of the oscillations parameters using the reconstructed neutrino energy.
- Blue is the true oscillated/unoscillated ratio and red is the reconstructed. The events correspond to 45×10^{20} POT(!).

Estimation of oscillation parameters using a simple global scan.



- I preformed a simple x^2 fit using errors on both the ratio and the input reconstructed energy (30%*E) and the results of course are not very good.
- I plan to use the Feldman –Cousins method (Kendal Stuart ordering principle using likelihood ratios) since it is known to give better results as far as proper coverage is concerned.
- However the best point (blue star) using a simplified global scan method is far from the input point (red start). It is shifted in higher Dm^2 and lower sin^(2theta). The higher Dm^2 probably reflects the higher reconstructed neutrino energy compared to the true one and the lower mixing angle reflects the reconstructed neutrino energy smearing the reduces the distance between lower-higher ratio points.

Summary / On going work

- Performed CC/NC separation in Near and Far using NNs with quite satisfactory results. Need to redo analysis for a better Near z fiducial cuts.
- Started going through the analysis steps in order to estimate statistical and systematic uncertainties (just started, work in progress).

- To Do:
  - Use Near "mock" challenge set to estimate beam systematic uncertainties.
  - Perform the Near Far extrapolation and estimate uncertainties from that source.
  - Use Feldman- Cousins method to obtain the oscillation parameters and confidence intervals.