ν_e Appearance in the MINOS Experiment

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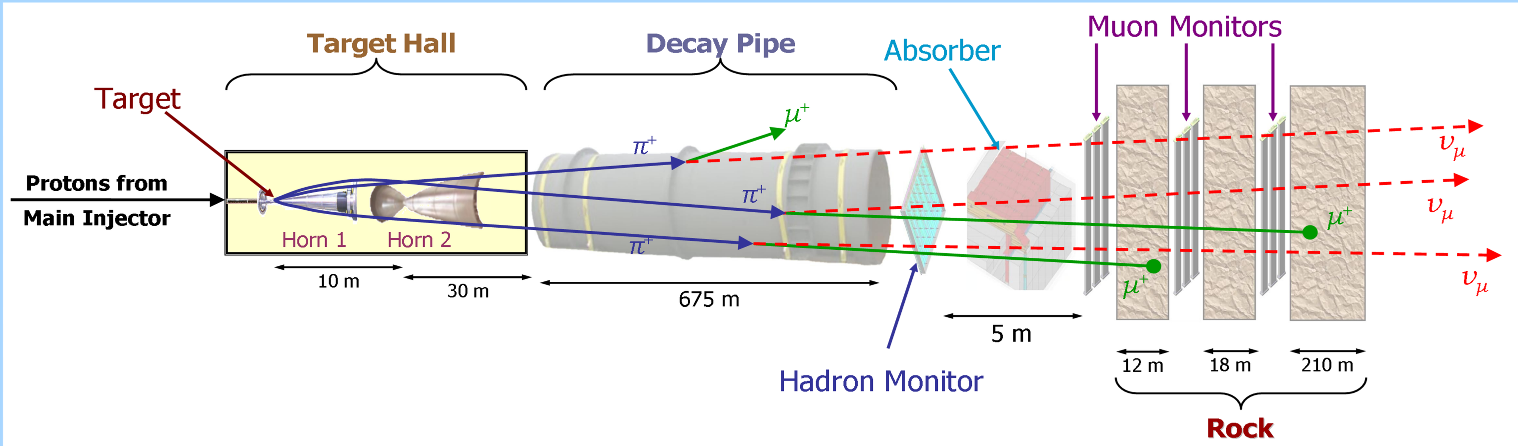
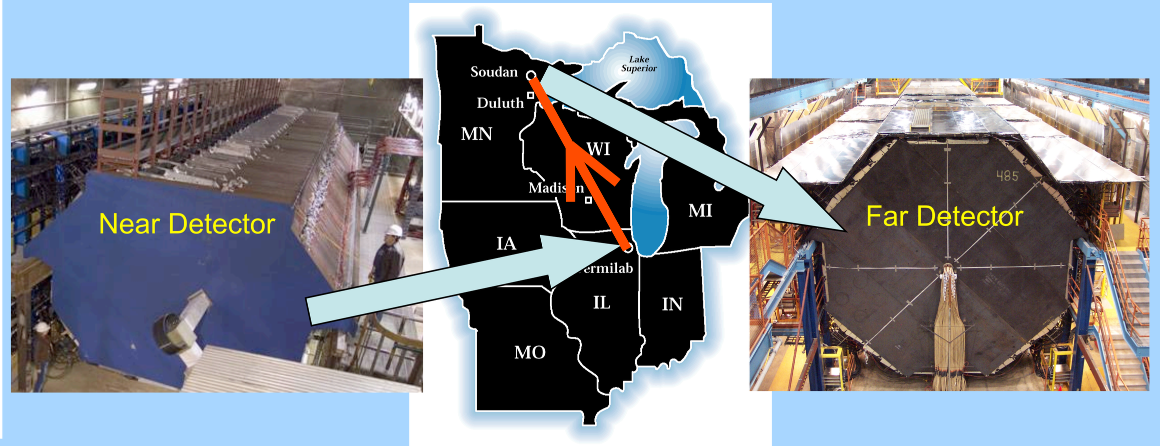
Generating a Neutrino Beam



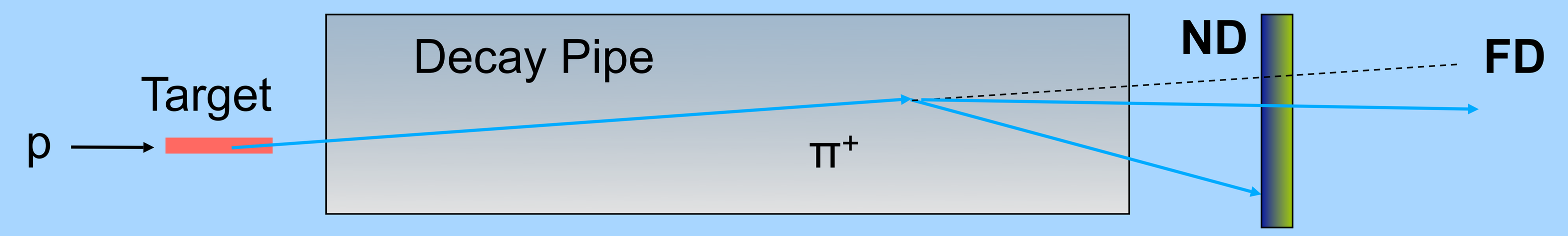


Protons from the main injector interact with a carbon target and produce a shower of charged pions and kaons. Two magnetic horns focus and select a charge and energy range of these pions and kaons. These particles decay in a evacuated pipe, producing primarily muon type neutrinos with a small fraction of electron type neutrinos. Hadrons which failed to decay in the decay pipe are absorbed, and muons which are associated with neutrino production are measured in a set of three muon monitors which provide information on accelerator and beam conditions. The neutrinos pass through rock, interact in the near detector, and then travel 734 km through the earth before having an opportunity to interact with the far detector.

Predicting the Far Detector Spectrum

Even before oscillations the neutrino energy spectra differs between the two detectors because of the beamline geometry and detector acceptance. Located 735 km from the target, the far detector sees the beam as a point source. The near detector is close enough to the decay pipe that to first order the emitted neutrinos appear instead as a line source.

$$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2}$$



$$\text{Flux} \propto \frac{1}{L^2}\left(\frac{\gamma}{1+\gamma^2\theta^2}\right)^2$$

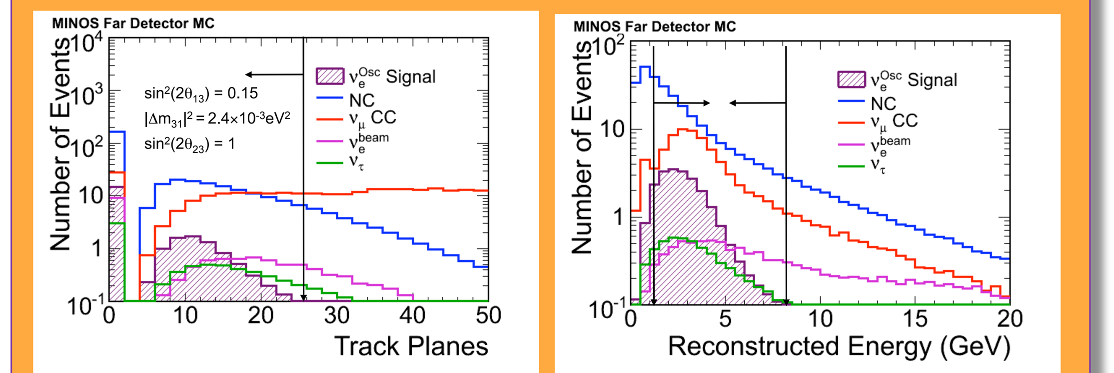
Differences from geometry and detector specific effects can be taken into account by using the ratio of Far Monte Carlo to Near Monte Carlo multiplied by the measured Near Detector Data to produce a robust Far Detector prediction that has reduced dependence on specific models of hadronization, flux, or cross section.

$$Far_\alpha^{Predicted}(E_i) = Near_\alpha^{Data}(E_i)\frac{Far_\alpha^{MC}(E_i)}{Near_\alpha^{MC}(E_i)}$$

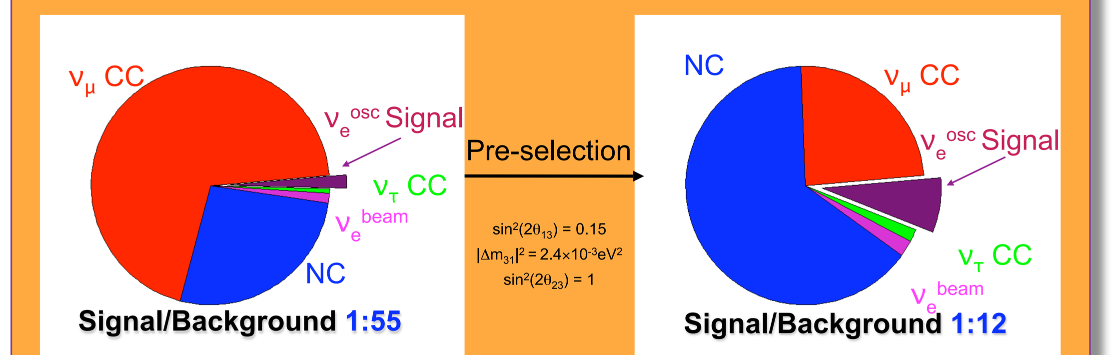
As each background type oscillates differently the extrapolation is done separately for each type of neutrino α.

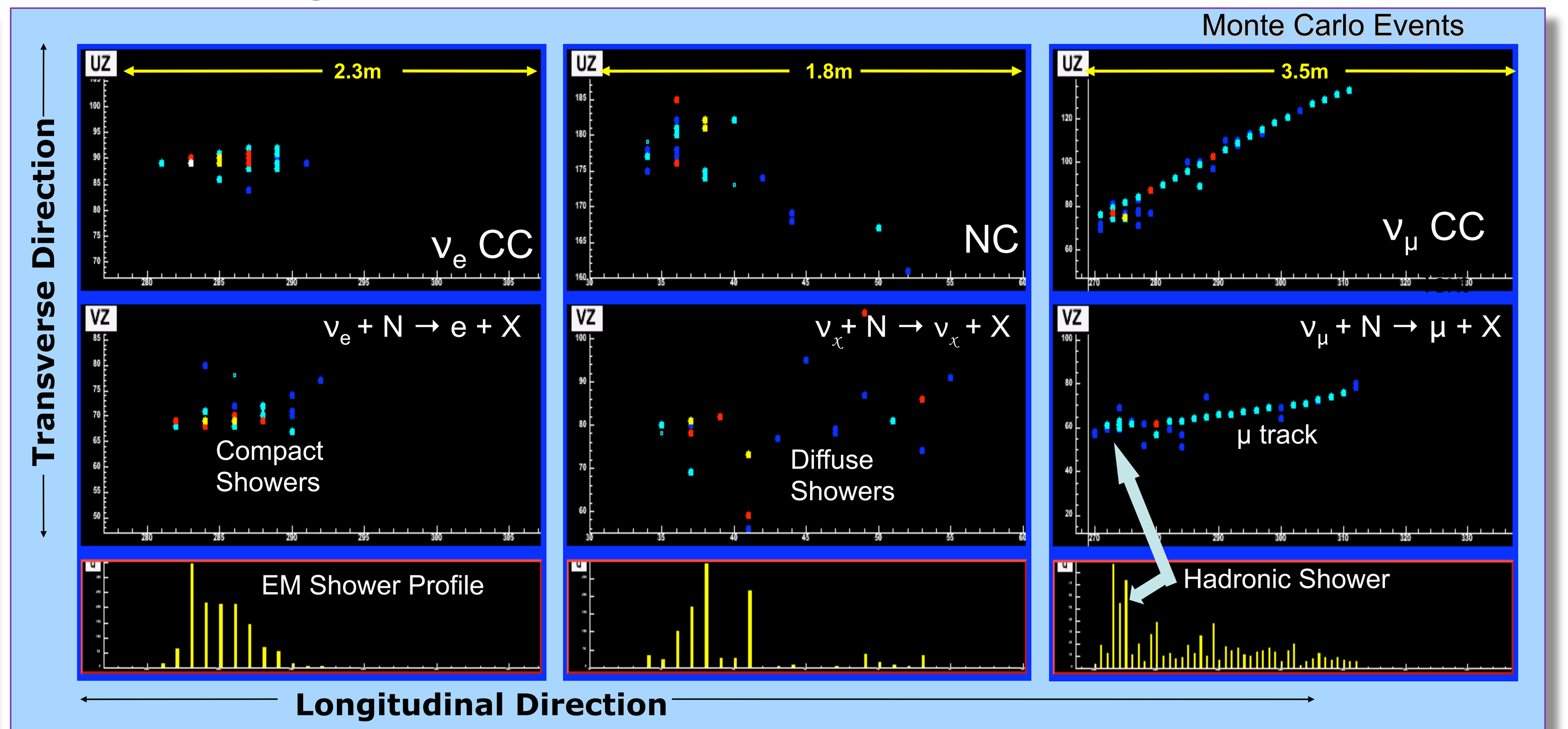
Selecting ν_e Events

Step One: Remove Obvious Backgrounds



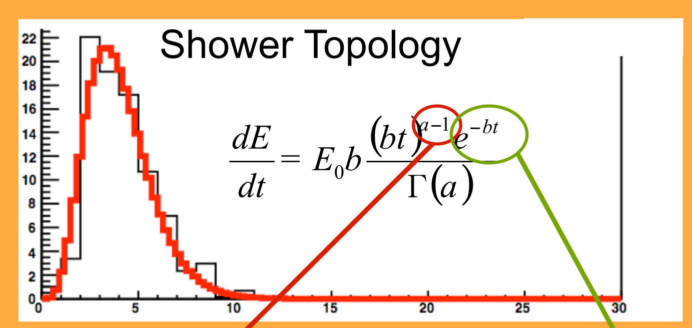
Pre-selection Cuts: Track Length < 25 planes 1GeV<E<8GeV

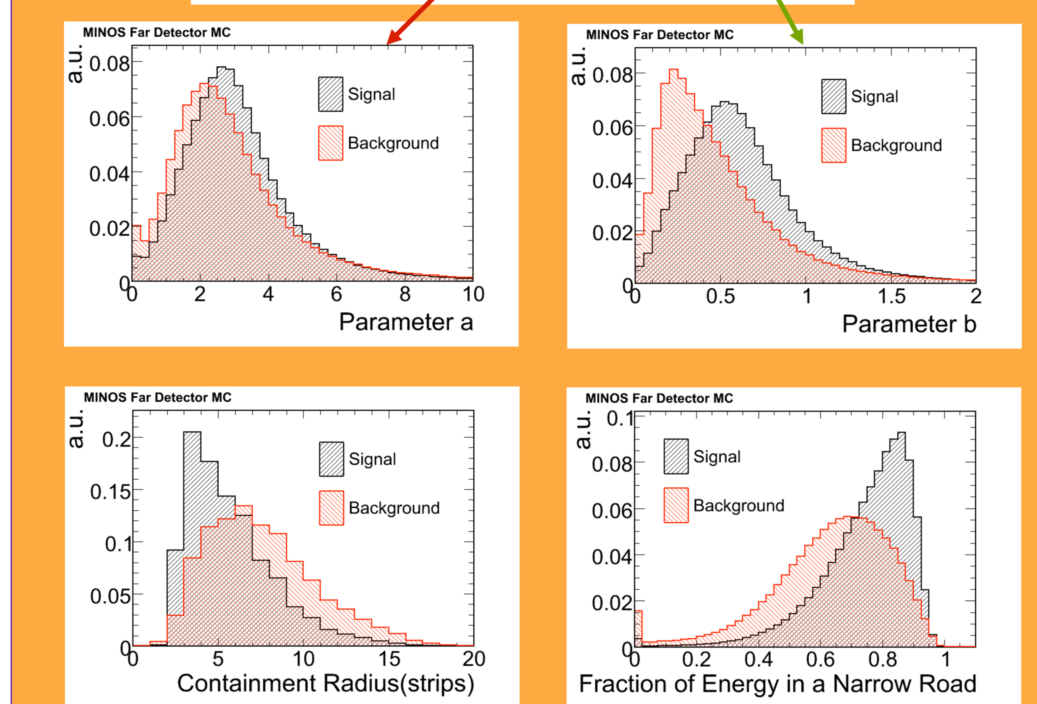




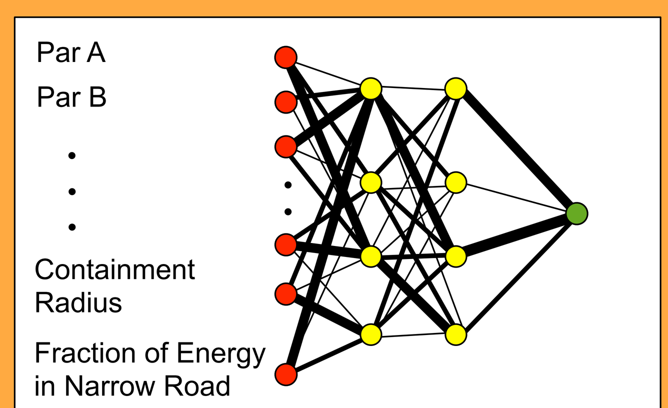
MINOS distinguishes neutrino and interaction types by event topology. Electron neutrino events are characterized by a dense deposition of energy near to the event vertex that is consistent with an electromagnetic shower. Neutral current interactions tend to produce more diffuse showers without a muon track. Muon neutrino charged current interactions are characterized by the presence of a muon.

Step Two: Build Topological Variables





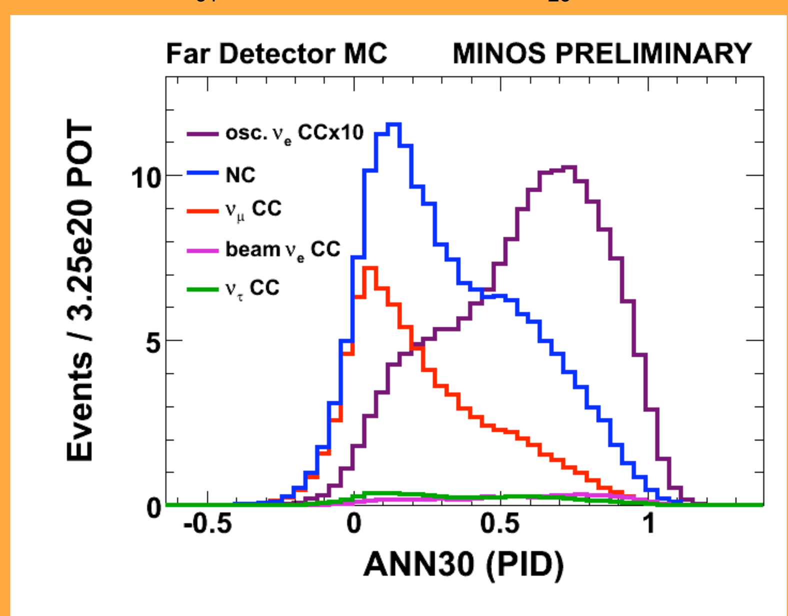
Step 3: Build a Neural Network



Several machine learning algorithms have been developed to combine the separation variables into a single PID. Shown here is a neural network that uses 30 input variables and one hidden layer to discriminate between different types of events. A figurative illustration of the relative weights and corresponding mapping of variables as determined by PID training on Monte Carlo data in the ANN30 PID is presented above. The separation capability of the ANN30 PID is presented to the right.

$\sin^2(2\theta_{13}) = 0.15$ (at CHOOZ)

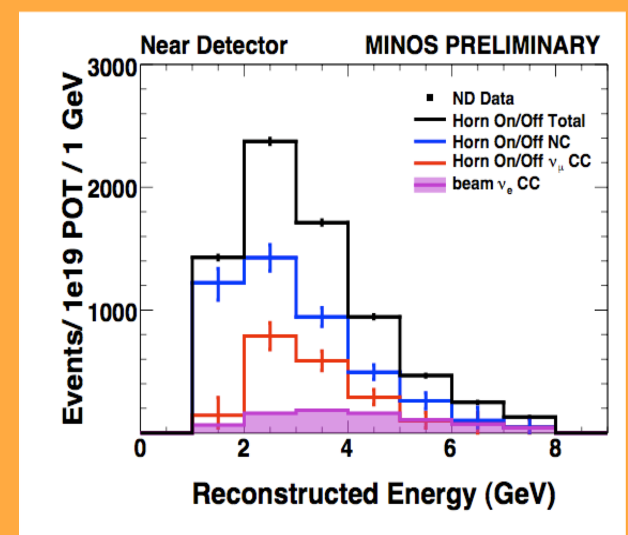
$|\Delta m_{31}|^2 = 2.4\times10^{-3}\text{eV}^2$, $\sin^2(2\theta_{23}) = 1$



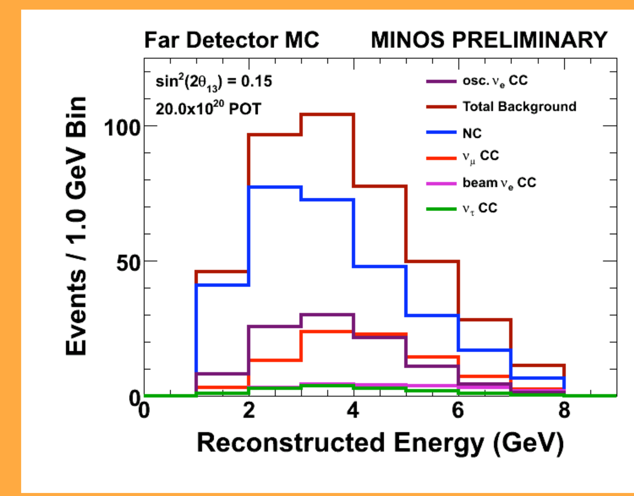
ν_e efficiency ~ 50%
NC rejection ~ 90%
ν_μ CC rejection ~ 99%

Making a Data Driven Sensitivity

Robust data separation methods have been developed to take the Near Detector Data and determine the NC, ν_μ CC and beam ν_e CC components. These measurements are then used with the Far/Near ratio extrapolation method to predict the number of background events in the MINOS Far Detector.



Near Detector Data



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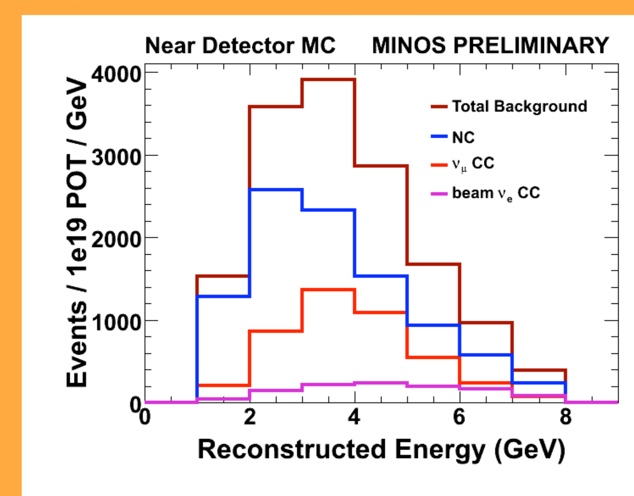
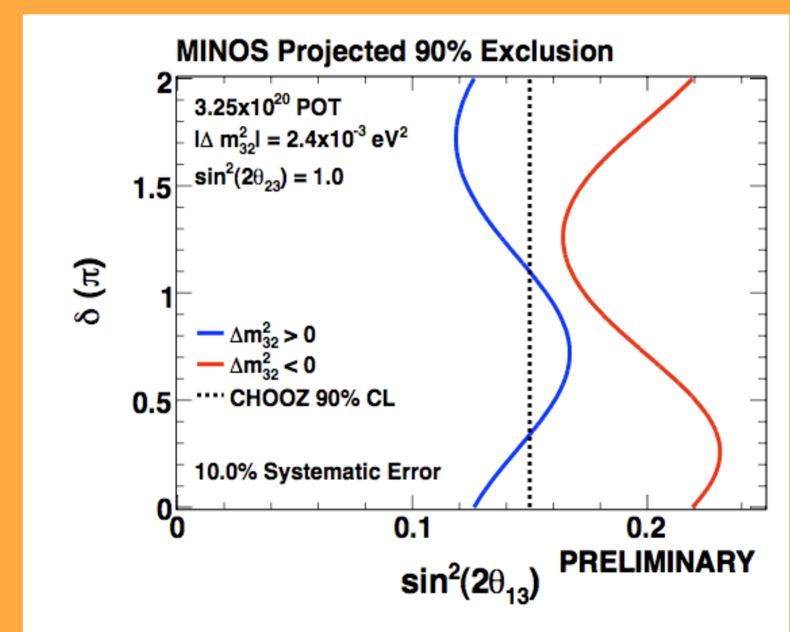


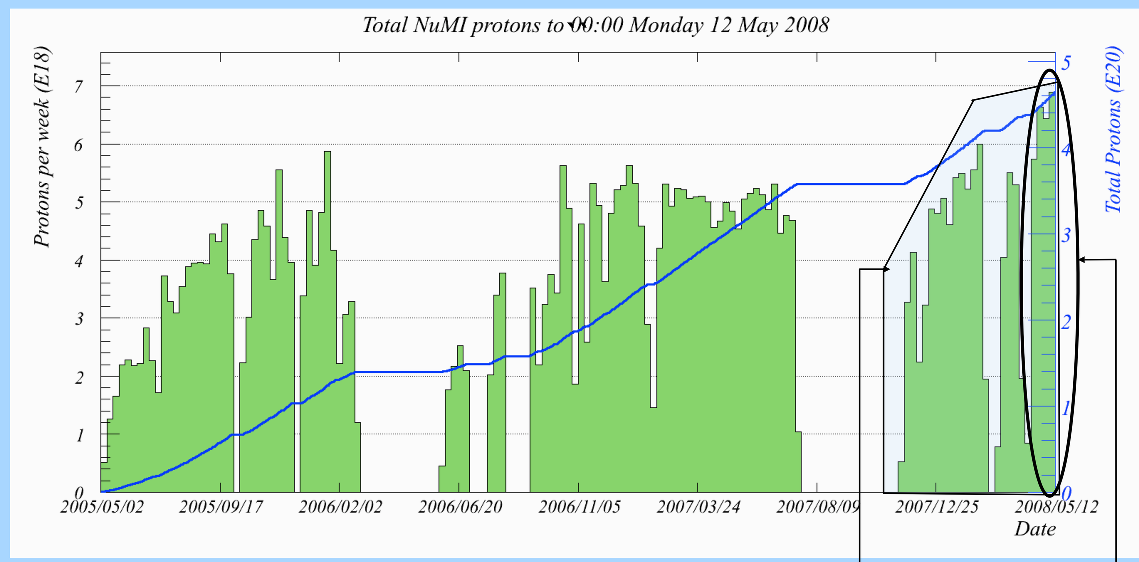
Generating the prediction for different values of the oscillation parameters allows a sensitivity contour to be generated



With current data set we can go beyond the CHOOZ limit!

Future Prospects

We expect to double our data within the next year. Our final anticipated exposure will allow us to halve the CHOOZ limit or potentially measure an appearance signal.



New Data

Record levels of intensity!