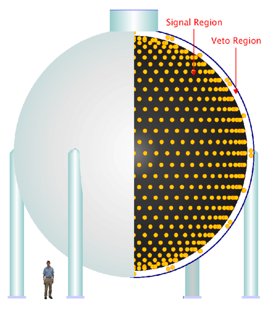

The combined ν_μ-ν_e oscillations fit for the BDT analysis in MiniBooNE

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Introduction:

The Boosted Decision Tree (BDT) oscillations analysis in MiniBooNE uses the observed ν_μ-CCQE events to normalize and constrain its Monte Carlo prediction and systematic errors for the ν_e events via the construction of an error matrix which contains the correlations between the bins of the energy distributions of the two samples. This matrix is then used in a χ^2 minimization procedure to fit for the oscillation parameters. A description of the method is given and a few examples of fits are described.

The ν_μ-CCQE event sample:

Require the occurrence of 2 sub-events, the second of which is consistent with an electron from μ^- decay at rest. The reconstructed vertex of this electron must be within 100 cm from the reconstructed endpoint of the track of its parent μ^-. The μ^- event (1st sub-event) is required to occur inside the beam window and to fire more than 200 tank PMT's and less than 6 veto PMT's, while the e^- is required to fire less than 200 tank PMT's. The reconstructed vertex of the μ^- event must be within 500 cm from the tank center.

The BDT ν_e event sample:

Pre-selection requirements include the occurrence of a single sub-event inside the beam window, firing more than 200 tank PMT's and less than 6 veto PMT's, and a fiducial radius cut of 500 cm. A number of input variables containing information about the light patterns produced by the events in the oil are fed to a Boosted Decision Tree algorithm to produce a powerful PID output variable. PID cut values are optimized in each energy bin to maximize sensitivity to oscillations.

The χ^2:

$$\chi^2=\sum_i (N_i^{Data}-N_i^{MC})M_{ij}^{-1}(N_j^{Data}-N_j^{MC})$$

$$N_i^{MC}=N_i^{MC}(\sin^2 2\theta,\Delta m^2),\quad i=E_\nu^{QE}\ bin$$

The index *i* runs across the ν_μ and ν_e bins. Only the number of Monte Carlo ν_e events depend on the oscillation parameters. The matrix *M* contains all possible sources of error, systematic and statistical. Fit for a signal described by 2 ν oscillations::

$$P(\nu_\mu\rightarrow\nu_e)=\sin^2 2\theta\ \sin^2(1.27\,\Delta m^2 L/E)$$

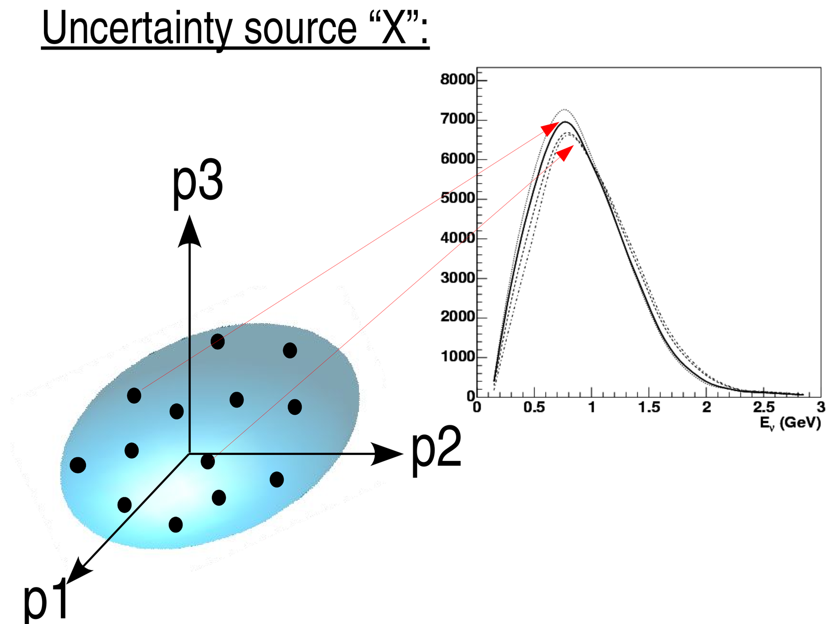
The error Matrix:

The total error matrix is formed by adding together the matrices from the various contributions to the experiment's uncertainty.

For a given contribution to the error we form N_{mult}=1000 (and 67 for the Optical Model) simulations of the neutrino energy distribution in which the relevant parameters have been varied within their estimated covariance. We call these simulations "*Multisims*".

The parameters associated with a given source of uncertainty are randomly thrown according to their covariance. Each throw produces an effect in the E^{QE}_ν distribution.

Uncertainty source "X":



$$M_{ij}^X=\frac{1}{N_{mult}-1}\sum_{k=1}^{N_{mult}}(N_i^k-N_i^{CV})(N_j^k-N_j^{CV})$$

The total error matrix is constructed by adding the matrices from all the different sources of uncertainty:

$$M_{ij}=\begin{matrix}M_{ij}^{\pi^+ flux}+M_{ij}^{\pi^- flux}+M_{ij}^{K^+ flux}+\\ M_{ij}^{K^0 flux}+M_{ij}^{Xsec}+M_{ij}^{\pi^0 rate}+\\ M_{ij}^{Dirt\,rate}+M_{ij}^{Optical\,Model}+M_{ij}^{Stat}\end{matrix}=\begin{pmatrix}\nu_e\,(s{+}b) & \nu_e/\nu_\mu\\ \nu_e/\nu_\mu & \nu_\mu\end{pmatrix}$$

The neutrino energy E^{QE}_ν is determined from the scattering angle and energy of the outgoing lepton in a QE interaction. Backgrounds will have mis-reconstructed value for this quantity.

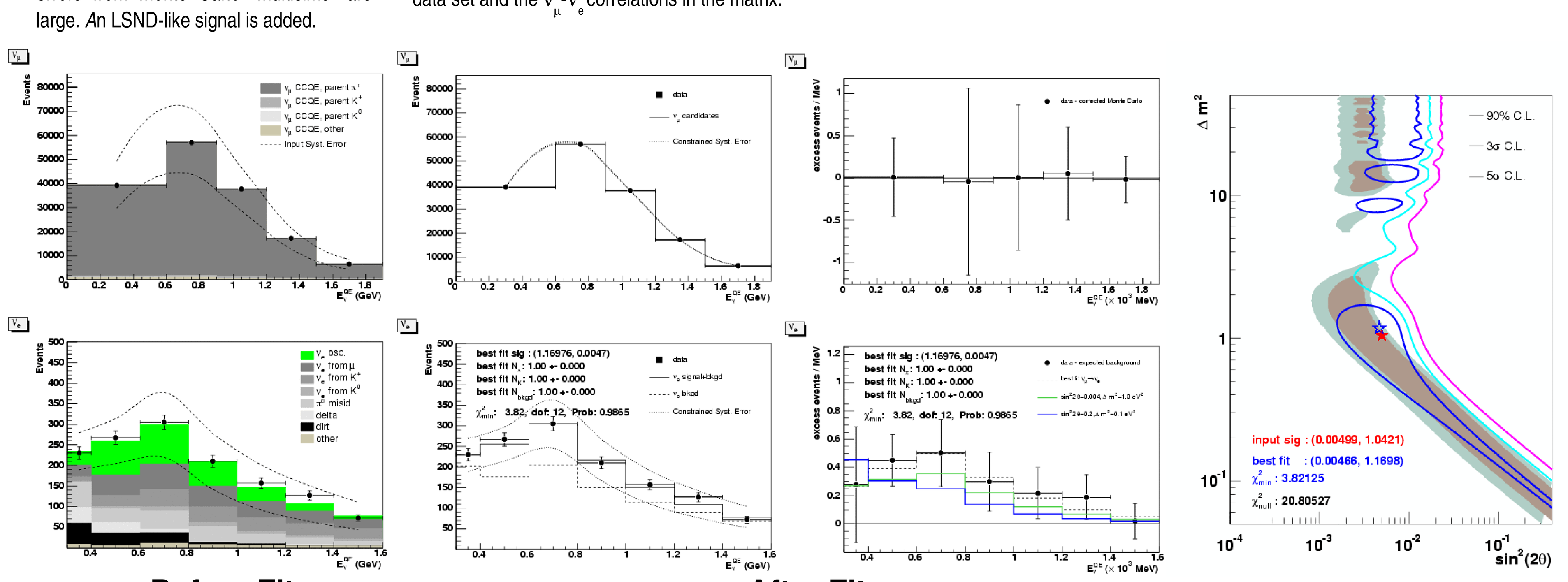
Fit to fake data with strong signal:

Fake data is a statistical fluctuation of the Monte Carlo prediction. The unconstrained errors from Monte Carlo "*multisims*" are large. *A*n LSND-like signal is added.

The fit constrains the errors and re-shapes the distributions due to the high statistics of the ν_μ data set and the ν_μ-ν_e correlations in the matrix.

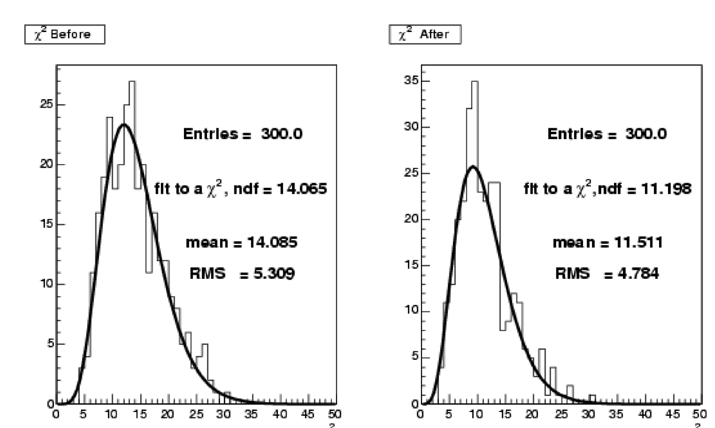
The excess of events can be compared for two possible LSND-like solutions. Here the points have the total errors.

The result of the fit is displayed in the oscillations parameter space.



Statistical robustness:

For fake data sets containing stat+syst. fluctuations, the χ^2 values before and after the fits are consistent with the number of *d.o.f.:* 14 before, 12 after.



Systematic uncertainties:

Source of uncertainty on ν_e background	TBA / BDT (*error* in %)	Checked or constrained by MiniBooNE data	Further reduced by tying ν_e to ν_μ
Flux from π^+/μ^+	6.2 / 4.3	✓	✓
Flux from K^+ decay	3.3 / 1.0	✓	✓
Flux from K^0 decay	1.5 / 0.4	✓	✓
Target and beam models	2.8 / 1.3	✓	
ν-cross section	12.3 / 10.5	✓	✓
NC π^0 yield	1.8 / 1.5	✓	
External Interactions ("Dirt")	0.8 / 3.4	✓	
Optical Model	6.1 / 10.5	✓	✓
DAQ electronics model	7.5 / 10.8	✓	

TBA: Track Based analysys (official published result) **arXiv:0704.1500 [hep-ex],2007**

BDT: Boosted Decision Tree analysis

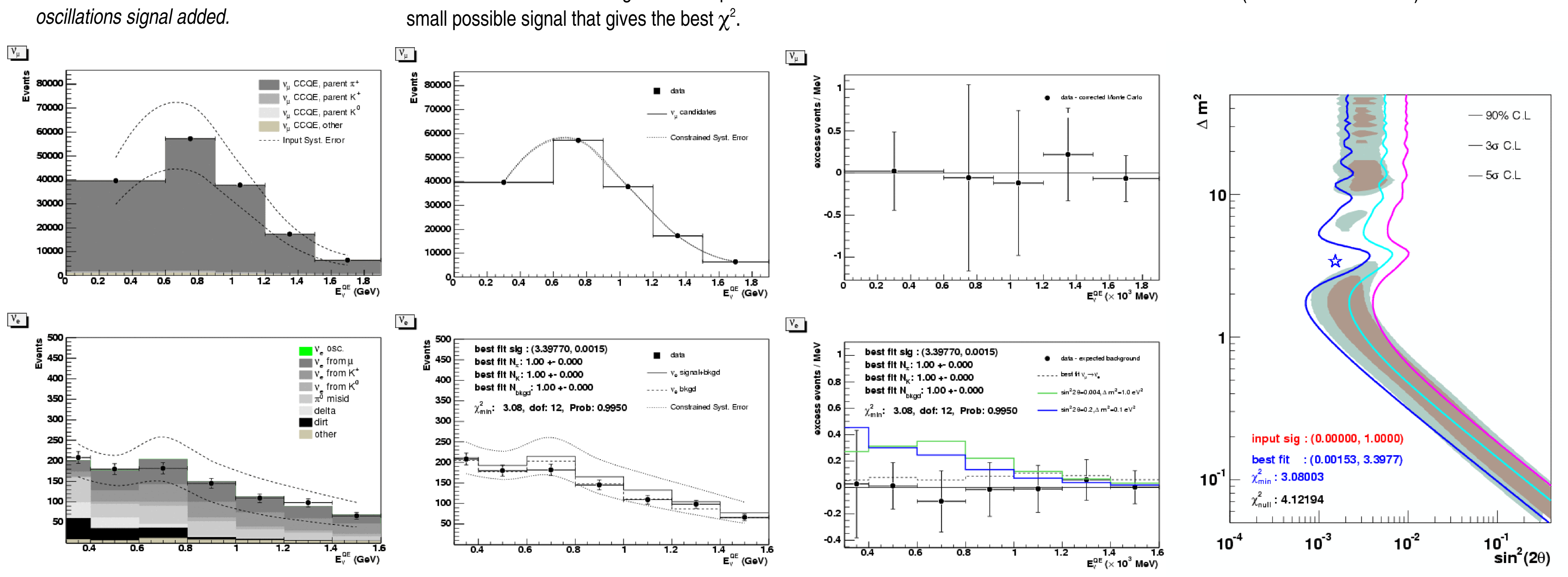
Fit to fake data with no signal (setting a limit):

Fake data is a statistical fluctuation of the Monte Carlo prediction. Unconstrained errors from Monte Carlo "*multisims*". *No oscillations signal added.*

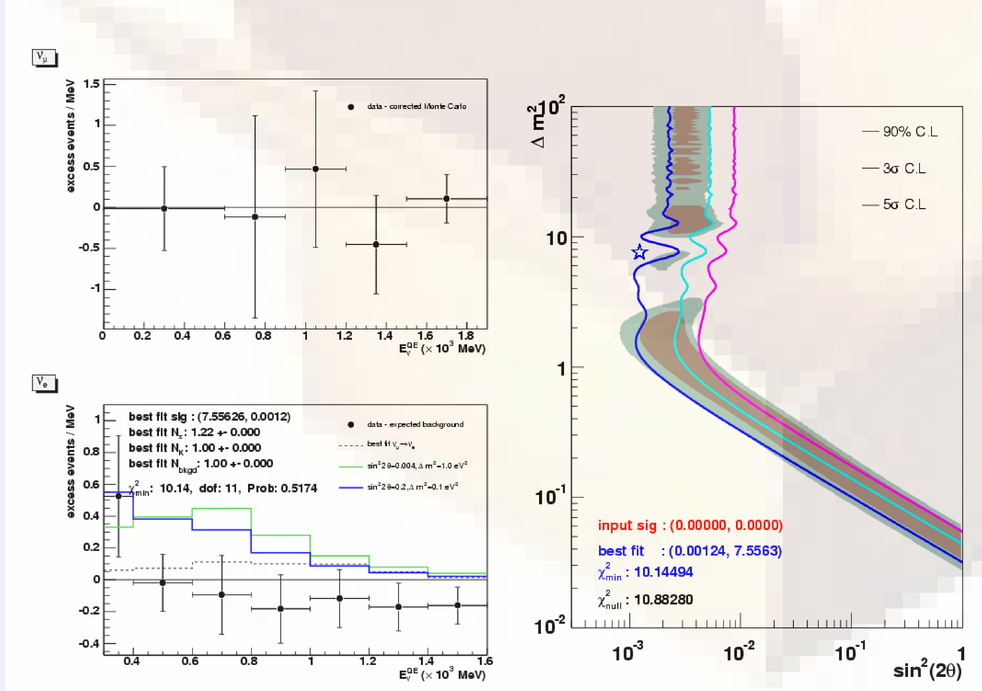
After the fit, the errors have been constrained by the high statistics of the ν_μ data set. Fake data is consistent with no signal. The fit picks a small possible signal that gives the best χ^2.

The excess plot shows the result in a similar way. The points have total errors.

This allows us to set a limit by making a 1-dimensional fit to $\sin^2 2\theta$ for every Δm^2 (*raster scan* method).



Fit to the MiniBooNE data:



In the fit to the data the ν_μ Monte Carlo is scaled by 1.22 to match the data normalization. This scaling factor is allowed by the unconstrained ν_μ uncertainties.

The MiniBooNE result is a limit to 2-neutrino oscillations.

The authors acknowledge the support of Fermilab and the NSF.