Status Report on Sensitivity Studies

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Background

- Outline of planned analysis presented at August NP04/T2K Collaboration meeting
  - See: http://jnusrv01.kek.jp/jhfnu/NP04nu/PresenFiles/nd2km/Casper2kmAug26.ppt
- Originally described in July 8, 2003 2km video meeting
  - See: http://neutrino.kek.jp/jhfnu/internal/2km/meeting/2003-JUL-08/casper-2kmJuly.ppt
- Current results are proof-of-concept only and should not be considered robust!

Goals

- Realistic sensitivity study, including:
  - Reconstructed observables
  - Far and near detectors
  - Statistical errors
  - Systematic errors:
    - Cross-section (correlated near/far)
    - Signal and background selection efficiencies
    - Energy scale
    - Fiducial volume
    - Flux (correlated near/far)

Technique

- We have started with the simpler ν_μ disappearance experiment, to set-up the machinery
  - Extension to appearance experiment should be straight-forward
- We use the SK/Fogli linearized "pull χ^2" technique for the systematic errors
  - G.L. Fogli *et al.*, Phys. Rev. **D 66**, 053010 (2002)
- Use the reconstructed E_ν spectrum for 1-ring, μ-like events in SK and 2km to fit ($\sin^2 2\theta_{23}$, Δm^2_{23})
- Use GCALOR fluxes (JNUBEAM 40 GeV, 5-years)

MC Samples

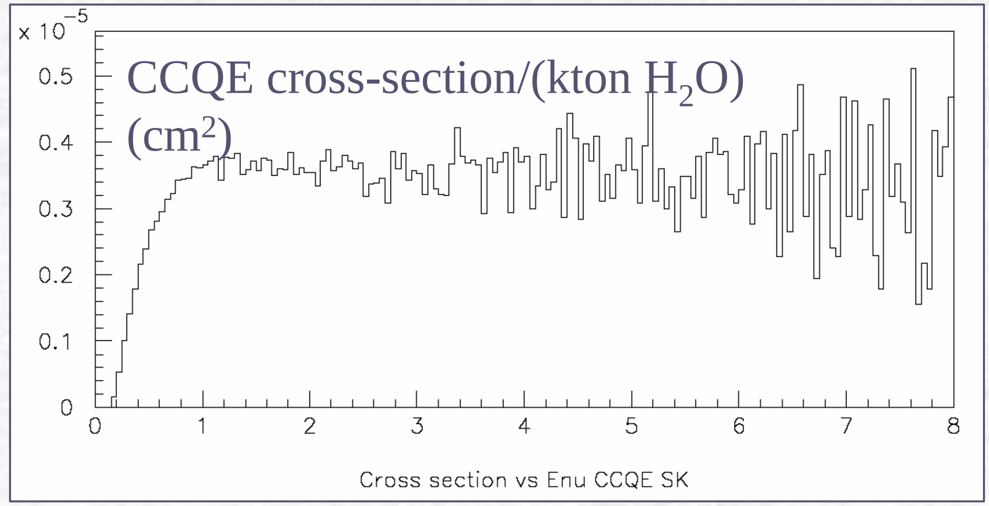
- Analysis requires predicting the reconstructed energy spectrum for:
  - All points in oscillation parameter space
  - All possible values of systematic parameters
- Use reconstructed 100-year SK atmospheric samples (from NUANCE) to extract:
  - E_{recon} vs. E_{ν} transfer matrices
  - Efficiencies for signal and background reactions
  - Signal and background cross-sections per kton H_2O

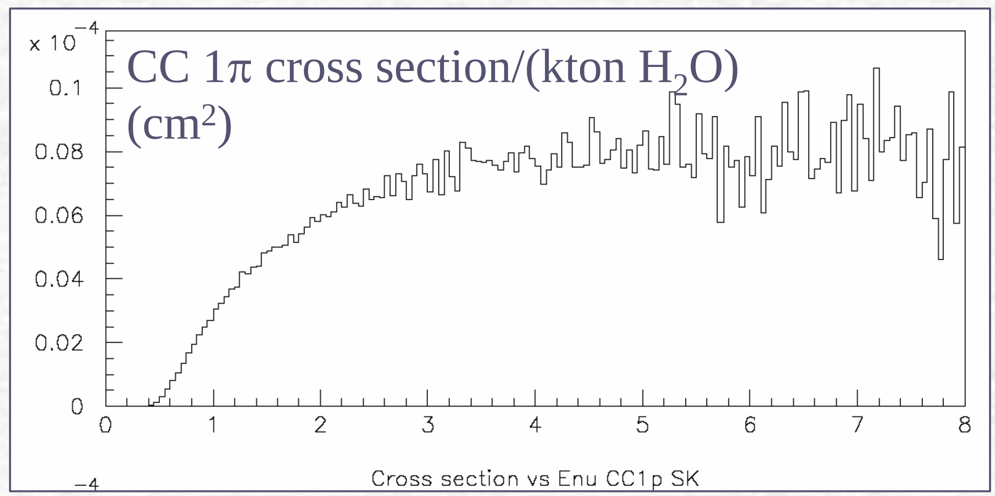
Reaction Channels

- To start, we divide interactions into four classes, based on the true MC reaction type:
  - Charged-current quasi-elastic (CCQE) = signal
  - Charged-current 1-pi (CC1P) = background
  - Charged-current other (CCother) = background
  - Neutral Current
- Each of the four reaction classes has:
  - An E_{recon} transfer matrix
  - An efficiency vs. E_{ν} function
  - An overall (energy-independent) uncertainty on the total cross-section
- This classification can be easily expanded to a more granular breakdown of reactions

Cross-sections

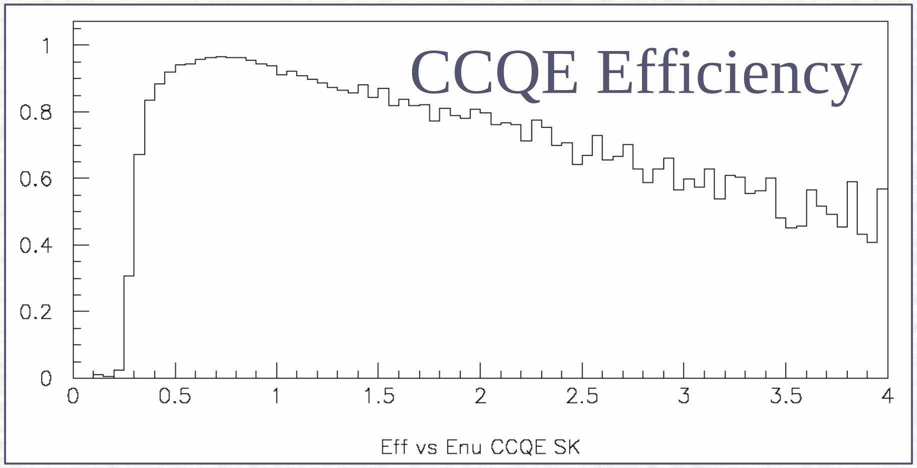
- Total cross-section (per kton H_2O), as a function of true E_ν, is extracted from the generated SK atmospheric Ntuples for each of the four reaction classes

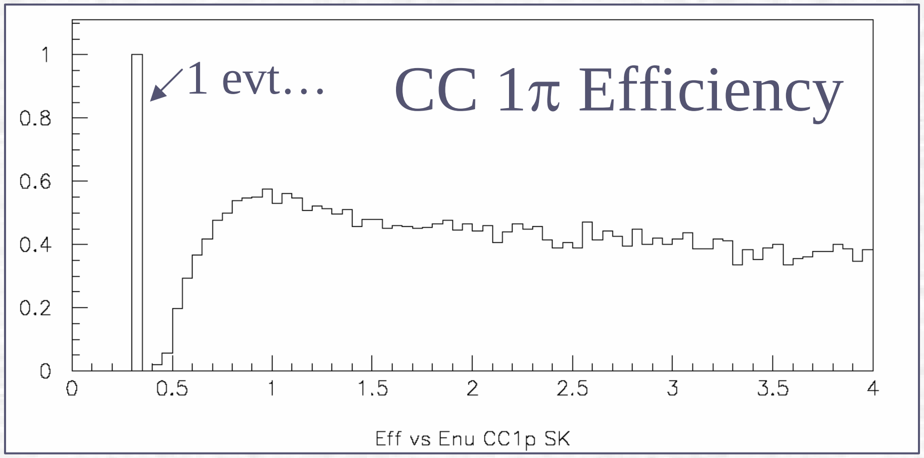




Efficiencies

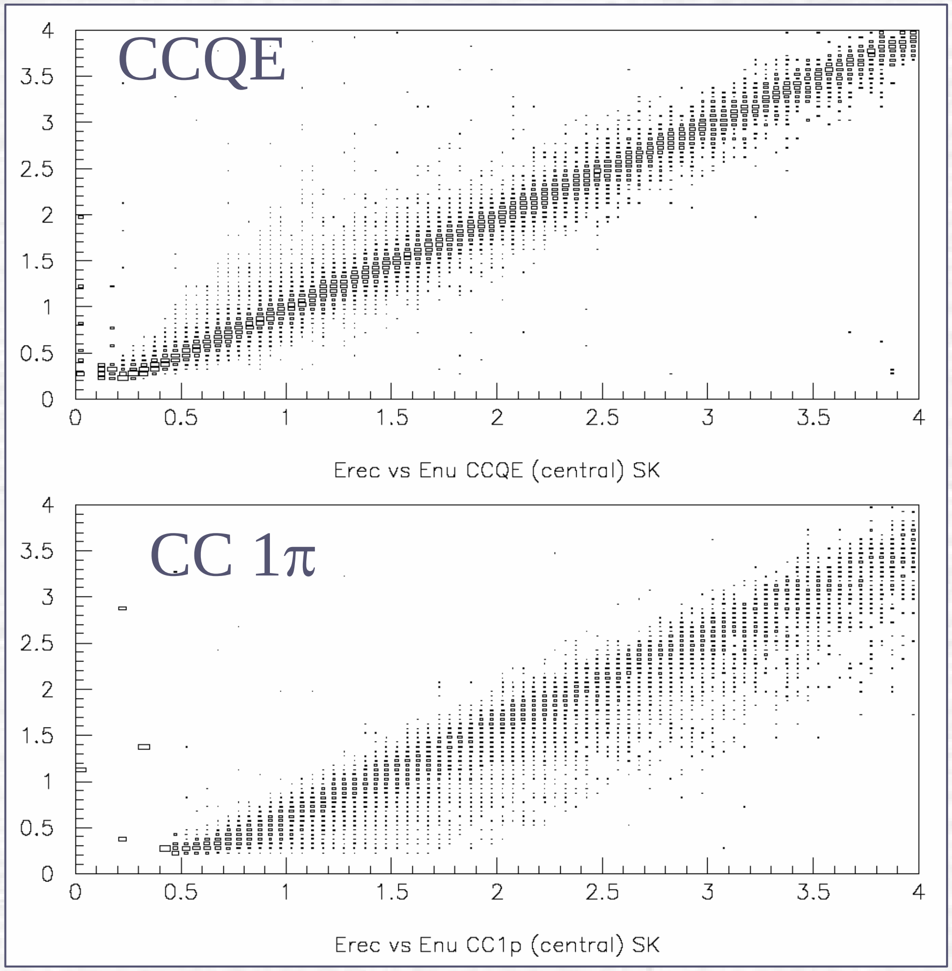
- "Efficiency" means the fraction of events of a certain class which pass the selection criteria, as a function of true E_ν
- For disappearance, selection criteria are quite simple: FC 1-ring, μ-like events
- Ideally, the efficiency should be high for the signal channel (CCQE) and small for the three background channels





Reconstructed Energy

- Using the reconstructed ntuples, and assuming the neutrino direction is known, we construct a matrix for each reaction type which converts E_ν to E_{recon} for events of that class which pass the cuts
  - ~Diagonal for signal
  - Non-diagonal for background

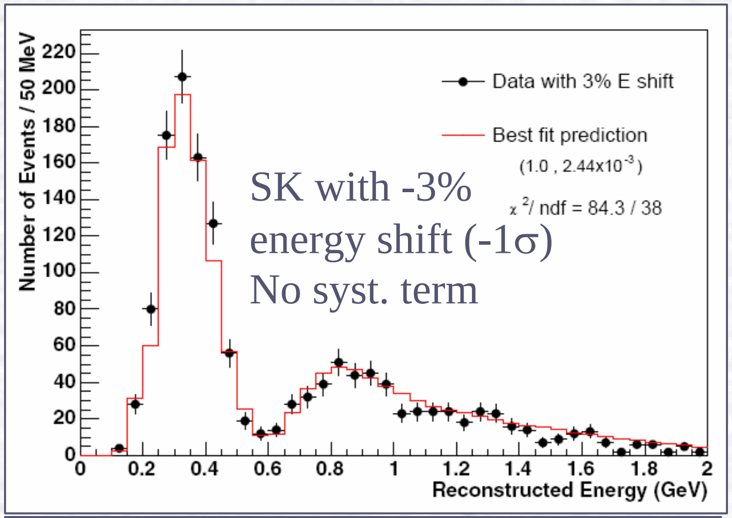


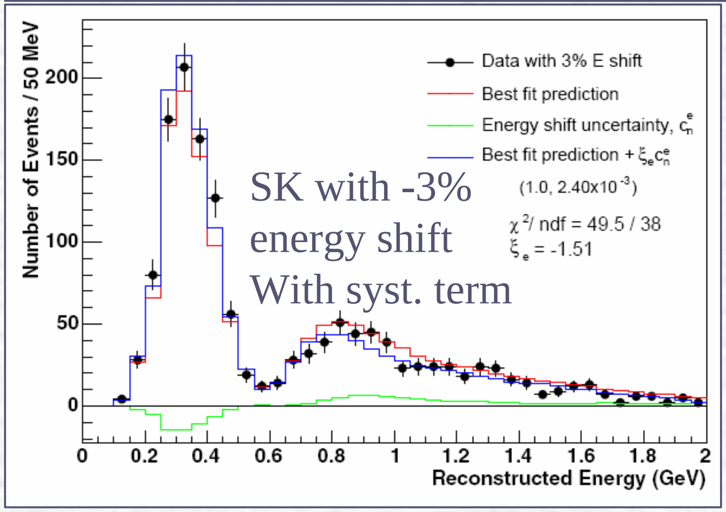
E_{recon} Spectra

- Using the tabulated fluxes, cross-sections, efficiencies and transfer matrices we can now predict the observed E_{recon} spectrum in both SK and 2km, for any oscillation hypothesis
- With the linearized treatment of Fogli, we can include systematic errors as well

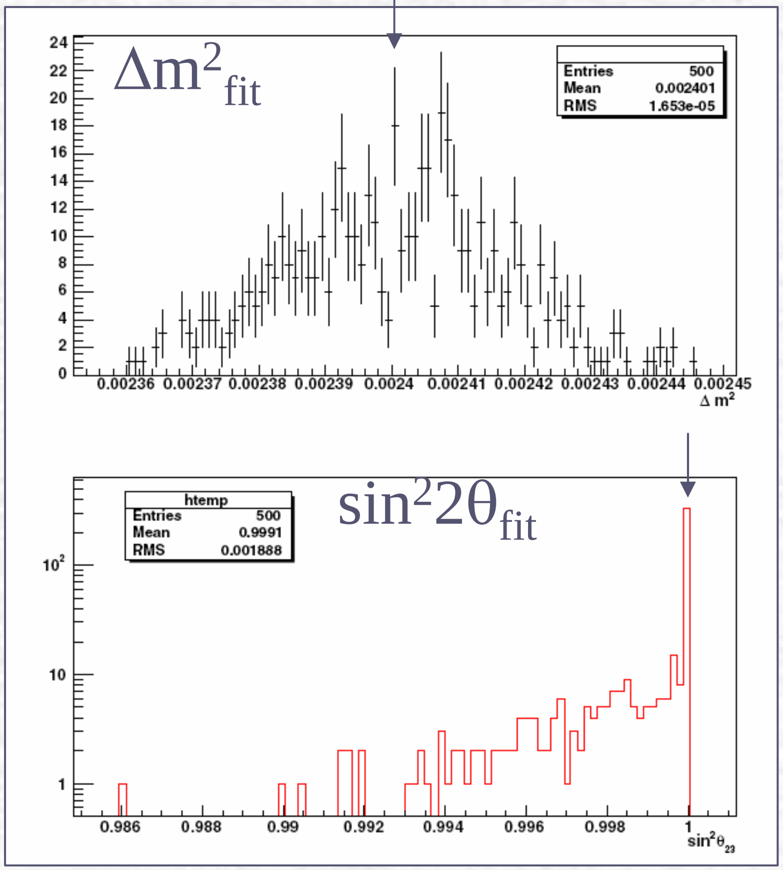
Oscillation Fit

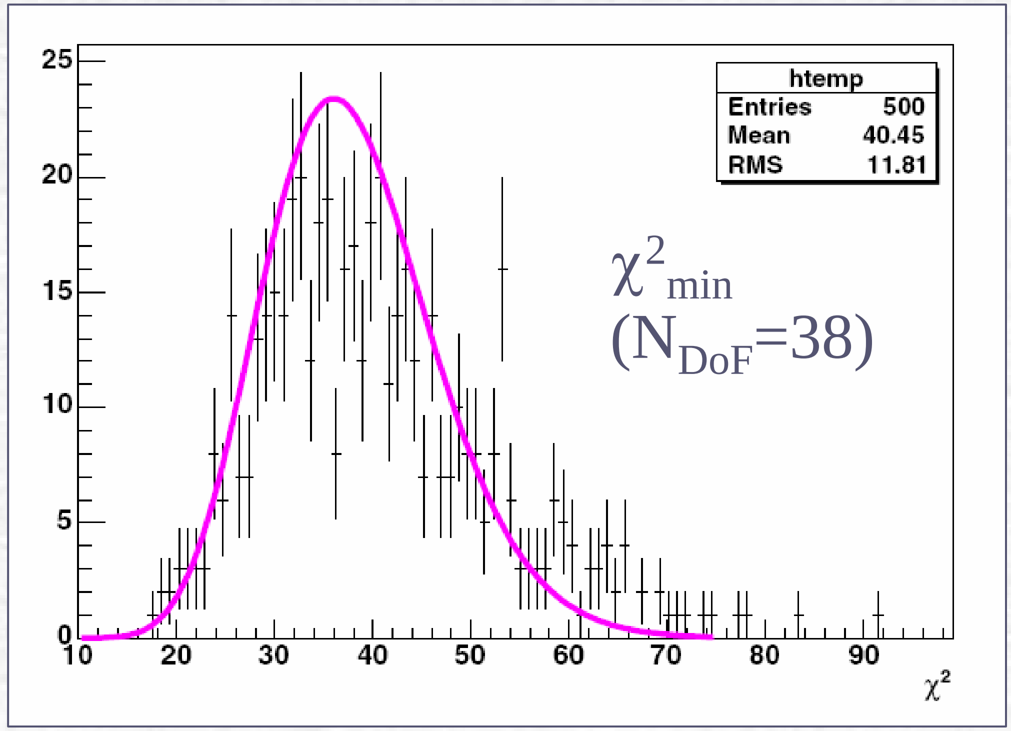
- Oscillation fit is similar to SK atmospheric:
  - Choose “true” oscillation parameters
  - Choose “true” systematic parameters
  - Generate a fake “data” sample
  - Fit the fake “data” spectra in SK and 2km (if present) simultaneously to extract oscillation and systematic parameters





Sanity Checks on Fit





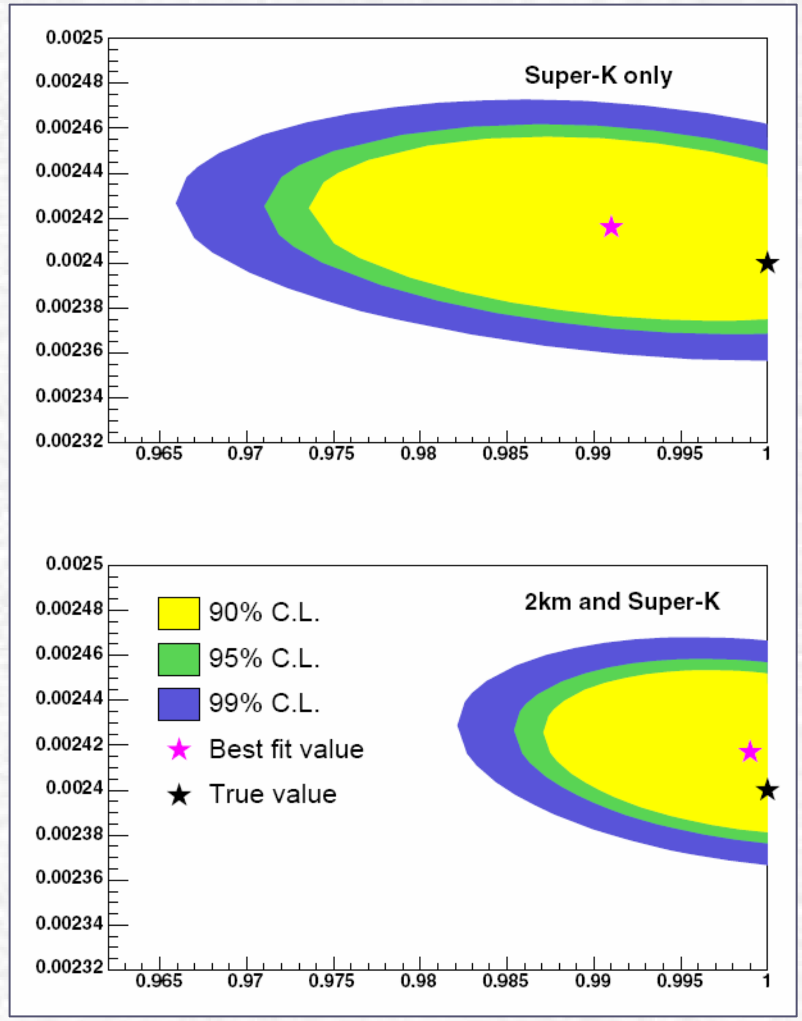
500 experiments, no near detector

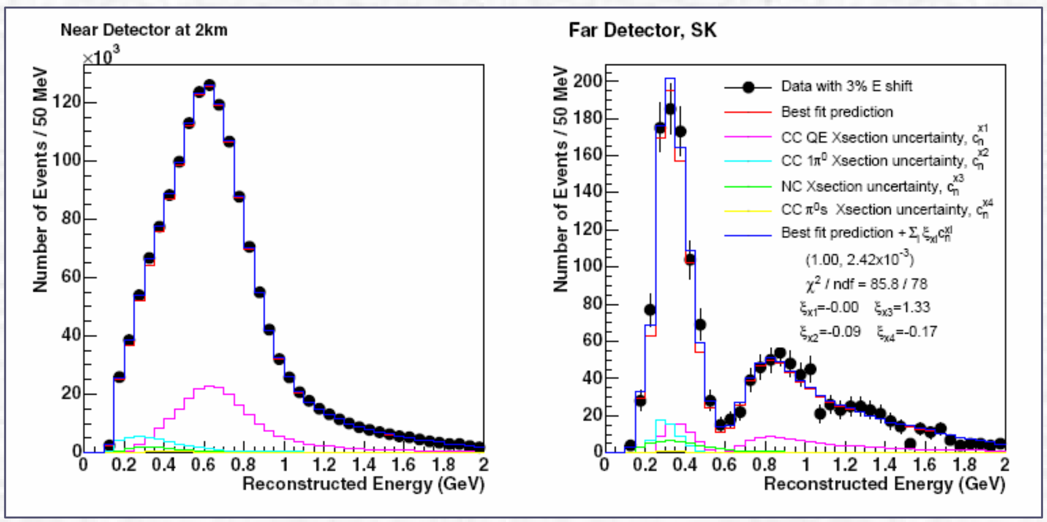
Energy scale uncertainty only

Unphysical region not yet included

Test Fit with Near Detector

- Asssume +20% (=1σ) systematic error in NC cross-section
- Include 20% cross-section uncertainty on all four channels in fit
- Fit one experiment, with and without 2km detector

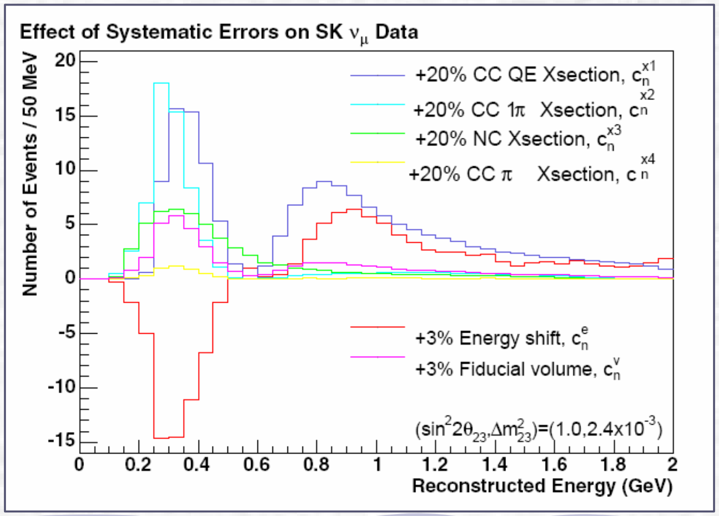


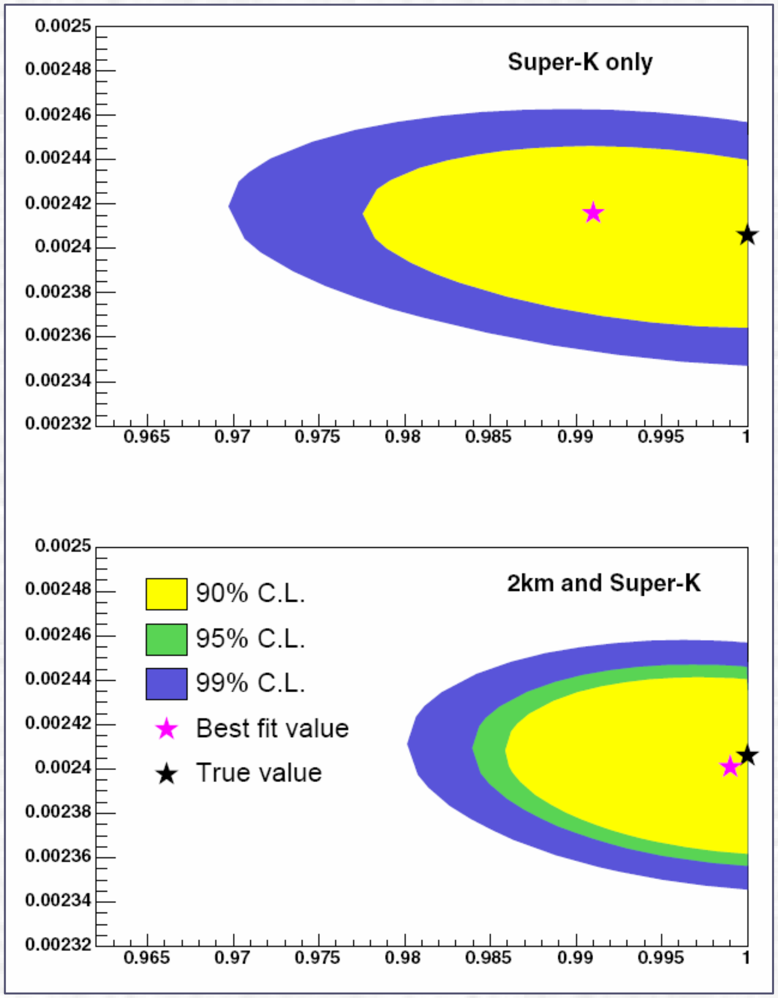


$\xi_{NC} = 1.33$

A More Complicated Test Fit

- Include multiple systematic errors
  - +3% SK fiducial volume (1σ)
  - +3% SK energy shift
  - -10% CCQE cross section
  - +30% NC cross section
  - 8 systematic terms in fit





Flux Uncertainties

- Flux errors are essential to include, because they greatly complicate the job of a single near detector
  - Also complicate the spectrum prediction in the fit
- Plan:
  - Add systematic terms to unoscillated expected flux at Super-K
  - Propagate to near detector(s) using far/near correlation matrix
- Unresolved question:
  - What is the best way to model flux uncertainties?
    - Brute force: assign a systematic parameter to each SK energy bin?
    - Can we use an auto-correlation (far/far) matrix?
    - Parameterize or interpolate difference between different models?
    - Best would be to relate flux uncertainties to a smaller number of physical uncertainties in the beam model

ND280

- It will be impossible to make a convincing case for 2km without including ND280 in the analysis
- In the last week, we have started exchanging mails/code with Steve Boyd, who is working on the ND280 design/simulation
- For the short-term, we probably have to use crude guesses about ND280 performance

Appearance Study

- Appearance experiment is a bit more complicated
  - Requires modeling both ν_e and ν_μ response
  - Requires more oscillation parameters
  - Requires modeling non-signal channels like 2-ring π^0 production
  - Requires more complicated cuts (Polfit)
    - Would like to get latest Polfit run on atmospheric MC samples

Next Steps

- Include unphysical region properly in fit
- Finish sanity checks on disappearance fit, using many simulated experiments
  - Compare with earlier studies
- Check response inputs using SK Neut MC sample
  - Don't expect significant differences, good to make sure
- Incorporate flux uncertainties
- Tabulate response inputs for appearance experiment
- Cook-up some model of ND280 response as a placeholder