CTEQ

Global Fitting Project

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Outline

- Global Fitting - procedures, software
- Recent Projects - new data sets
- Program Components
- Considerations for global analysis
- Conclusions

CTEQ Global Fitting Group

Group Members: J. Huston, J. Pumplin, D. Stump; J. Morfín (FNAL); S. Kuhlmann (ANL); F. Olness (SMU); J.F. Owens (FSU); W-K. Tung (U. Wash., ret)

Processes currently used in global fits

- DIS: (μp, μd, νFe, $\overline{\nu} Fe$, $e^{\pm} p$) – constrain $q, \overline{q},$ and, indirectly, g
- $\mu\mu$: (pN, pp, pd) – constrain $q, \overline{q}$
- $W^{\pm}$: $(\overline{p}p)$ – constrain d/u
- jets: $(\overline{p}p)$ – constrain g
- Approximately 2000 data points

Program Packages

- MSU Evolution and Fitting package
  - Developed by Wu-Ki Tung; extended/modified by others
  - Main package used for CTEQ pdfs
  - Now archived at SMU and maintained in CVS form by F. Olness
  - Wu-Ki Tung has his own extensively revised package
- Fitting and Evolution package originally developed by Duke and Roberts; extended and maintained by JFO.
  - Used for early LO fits and DIS analyses
  - Core for original MRS pdfs
  - Maintained to use as a cross check on the CTEQ fits
  - Also used for CCFR and NuTeV DIS analyses

CTEQ Project Procedures

- Each new project has a designated "leader"
  - Responsible for setting up phone conferences
  - Maintains web site for displaying notes, figures, etc during phone conferences
  - Coordinates tasks
- CVS Code Management
  - Fred maintains the current version
  - Others can contribute additions or changes needed for a particular project
- There have been several projects following the latest CTEQ6.1 PDFs
  - NuTeV/Chorus/E-866 data
  - More on $s - \overline{s}$
  - Nuclear PDFs
  - Topics involving heavy quarks
- Typically different author sets appear on the smaller analyses

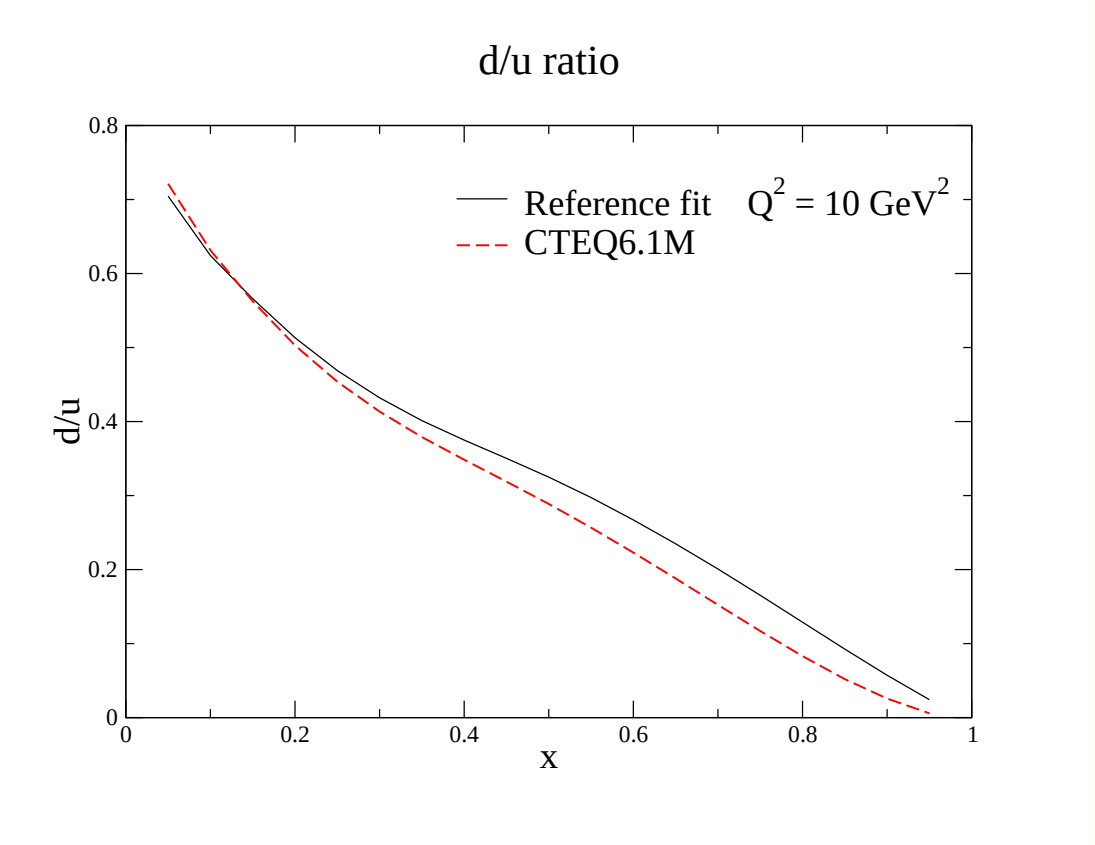
Organizational Considerations

- Project leader needed to keep each analysis moving
- All too easy to fall prey to other distractions
  - Group includes an Associate Dean, a Department Chair (now on sabbatical after completing his term), the spokesperson for MINOS, and several faculty members
  - Many other duties/distractions, so weekly meetings keep us on task
  - Sure would be nice to have a post-doc ...
- Language of choice is FORTRAN
  - Historical - the existing packages have all been developed over many years/decades
  - FORTRAN is what we all grew up with and understand (look again at the group composition)
  - It is a language which all new members of various projects understand, so the learning curve is not so steep

Recent Work - inclusion of NuTeV, CHORUS, and E-866 data in the Global Fits

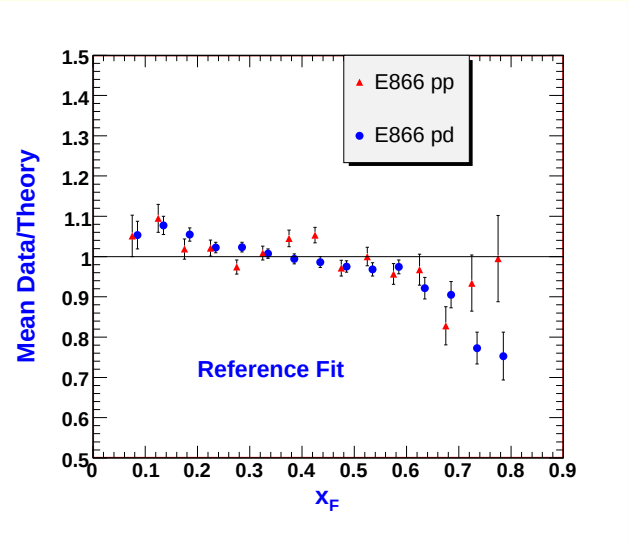
- New NuTeV and CHORUS neutrino and antineutrino cross section data on Fe and Pb, respectively
  - NuTeV data higher then the older CCFR data at high values of x
  - Need nuclear corrections for both data sets (used Kulagin-Petti model)
  - Expect the NuTeV data to pull the valence PDFs up at large x
- New E-866 pp and pd data for dimuon pair production
  - Data tend to pull the valence PDFs lower at high values of x

d/u ratio from the Reference Fit



- Define a Reference Fit as CTEQ6.1 but with CCFR data removed
- Also include deuterium corrections as appropriate

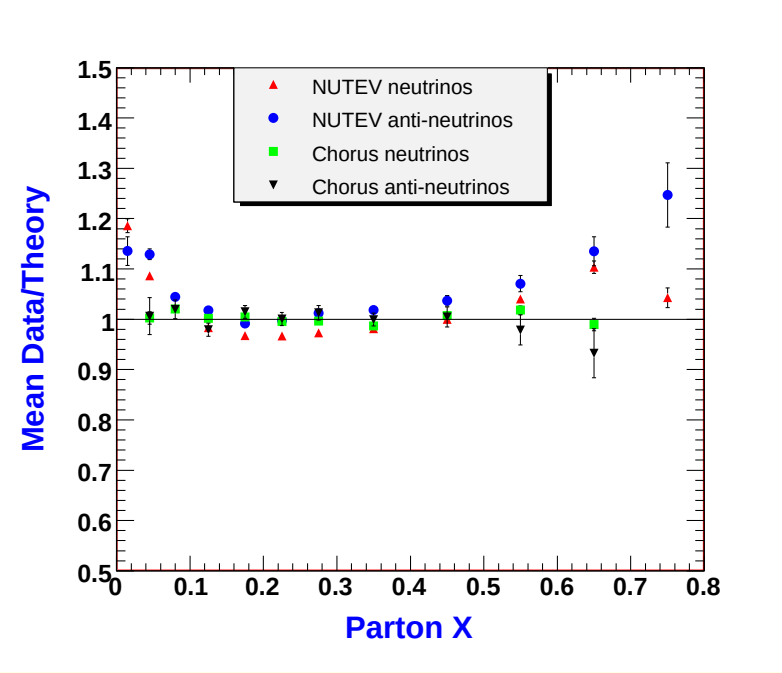
E-866 vs the Reference Fit



- Plot the mean value of data/theory in each x_F bin, integrated over M
- pp data are described reasonably well by the reference fit
- pd data suggest that the theory is somewhat high for large values of x_F.
- Note: Large x_F means large x for the *beam* and small x for the it target. The deuterium corrections in this region are measured to be small.

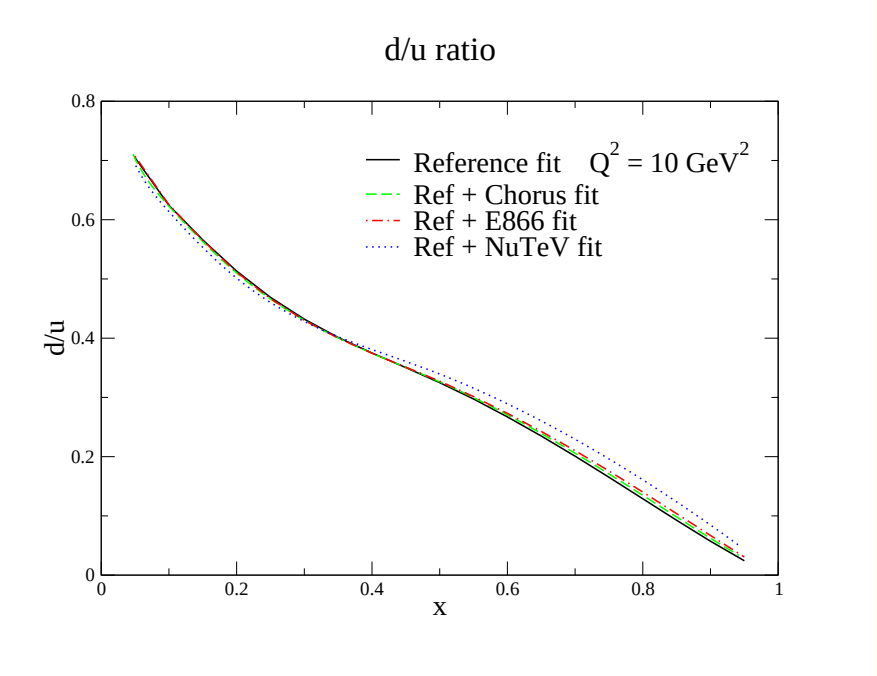
(Aside: one challenge is how to display the results of various fits in order to emphasize the underlying physics. Chi square tables summarizing thousands of data points are mind numbing and obscure what is going on.)

Chorus and NuTeV data



- Reference fit describes the Chorus data well
- NuTeV data lie above the Reference fit at high values of x
- Note: Kulagin-Petti nuclear corrections used for both experiments
- Only set of theoretical nuclear corrections designed for neutrinos
- Note: Data have been shifted by the optimal correlated errors. The larger errors for the Chorus data allow them to shift more than for the NuTeV data.

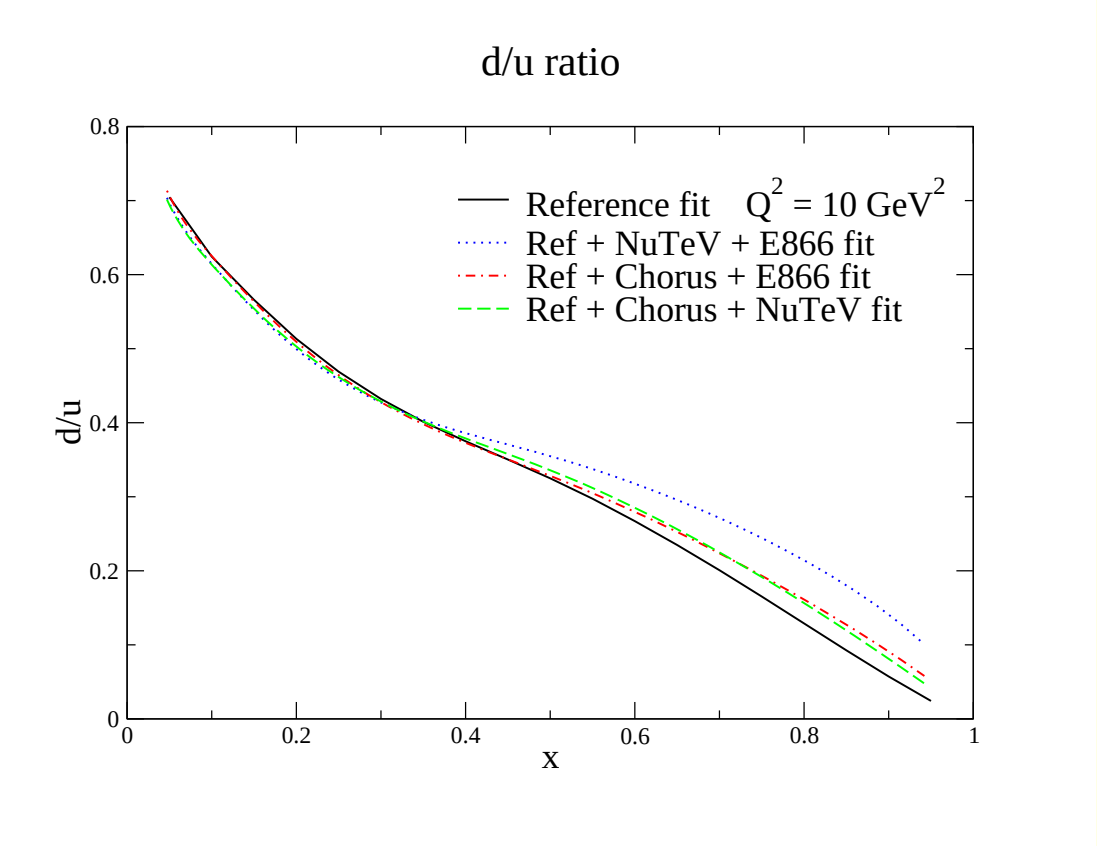
Now add each of the data sets one at a time and refit



The results cluster around the Reference fit result. No significant changes are noted in any of the pdfs

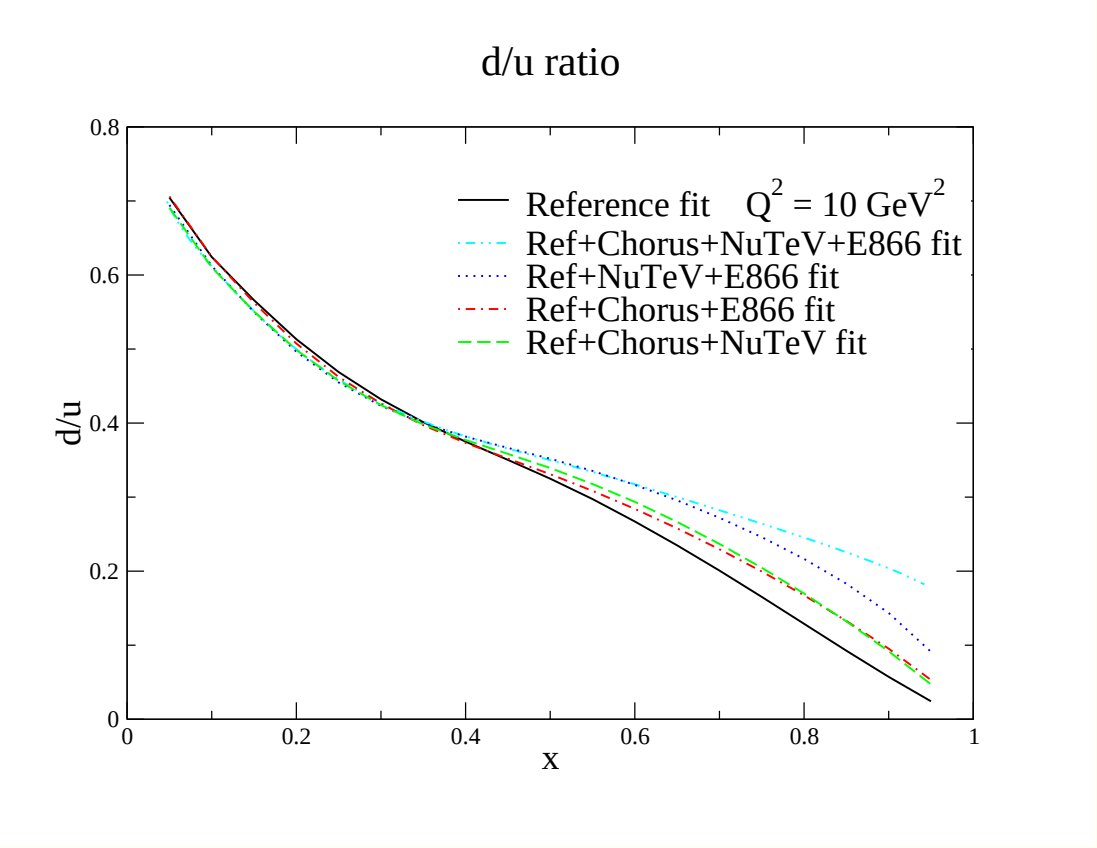
(Aside - we chose to use the d/u ratio to illustrate the effects of adding different data sets. The variations are NOT meant to imply error bands. The interplay between the neutrino and Drell-Yan data affects most directly the d/u ratio because of the electromagnetic vs weak couplings of the quarks.)

Now add the data sets two at a time



- Begin to see more of a spread between the various fits.
- Largest increase in the d/u ratio occurs for the E866+NuTeV combination

Add all three data sets together

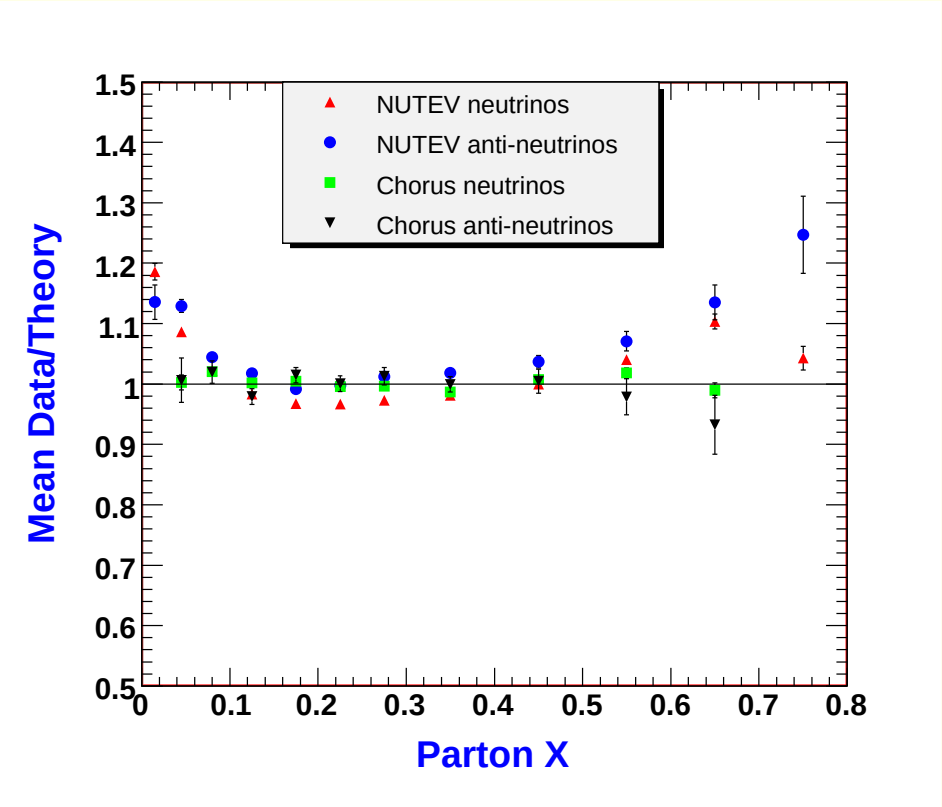


- Trend continues - highest d/u ratio occurs when all three data sets are added together
- It is clear that there is an interaction, especially between the E-866 and NuTeV data sets - What is it?

- NuTeV data are corrected to correspond to an isoscalar target so the cross sections at large values of x are sensitive to the combination $u + d$
- E-866 pd data are sensitive to

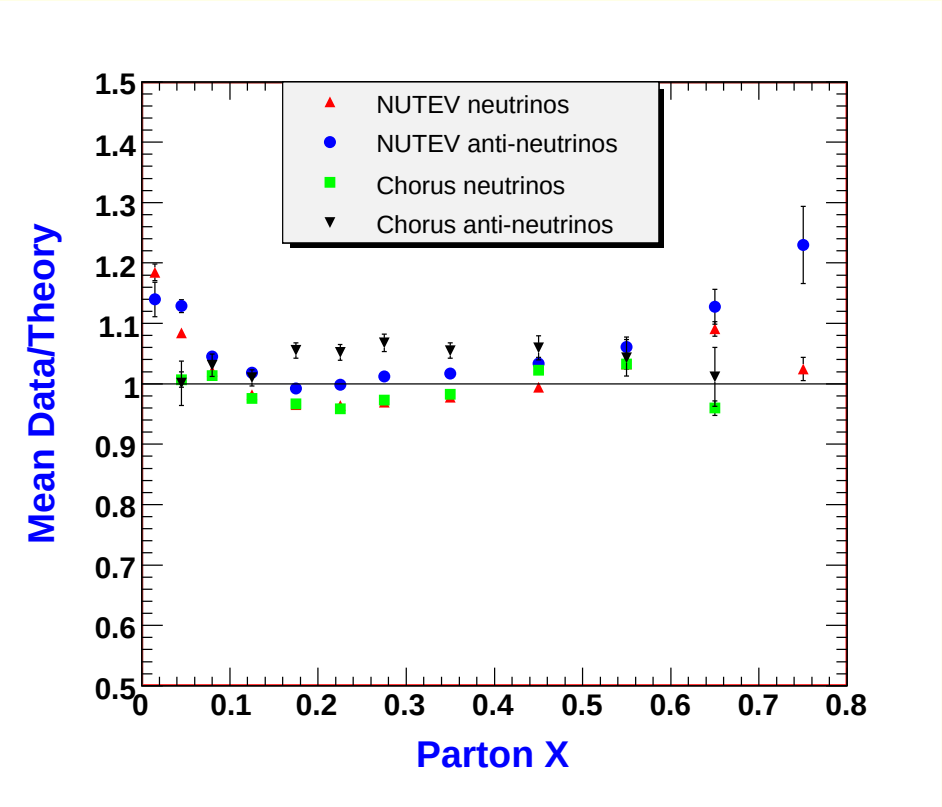
$$[4u(x_1) + d(x_1)][\overline{u}(x_2) + d(x_2)]$$

- Can increase the NuTeV theory by increasing either d or u or both
- Can both increase NuTeV and decrease E-866 theory if d is increased and u is decreased since there is an extra factor of 4 multiplying u for the E-866 pd theory
- Fitting program finds a new solution, but one which causes d/u to increase significantly
- Chi square for other DIS data sets also increases as the pdfs are pulled away from the Reference Fit



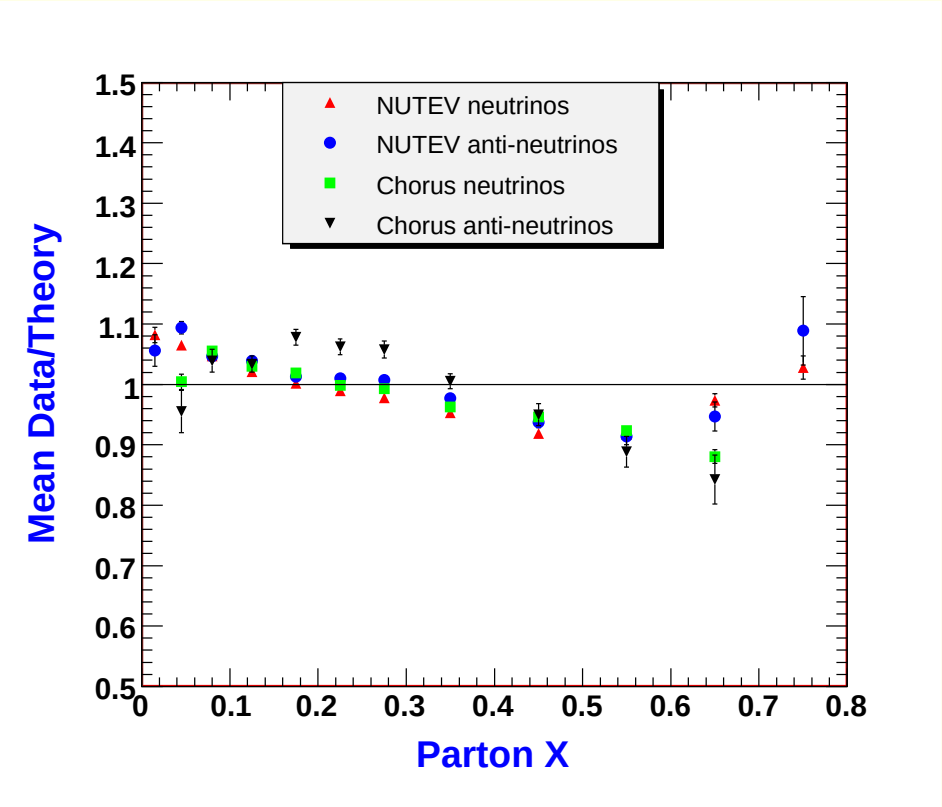
- Reference fit versus the Chorus and NuTeV shifted data. Kulagin-Petti nuclear corrections have been used
- This is one of the plots shown earlier

Make the same plot, but use *unshifted* data



- Note the large spread, especially for the antineutrino data/theory
- Chorus data have been shifted significantly in the earlier plots
- Large spread is due to the application of the nuclear corrections used here

Now, repeat the same plot but without the nuclear corrections



- Neutrino and antineutrino data/theory points at large x follow a classic nuclear correction shape
- Suggests the corrections should be the same for ν and $\overline{\nu}$ - not the case for the Kulagin-Petti corrections
- The overall magnitude of the required corrections appears smaller than those from the Kulagin-Petti set

Conclusions

- Have tested a reference fit against three new data sets
- Have examined how each data set pulls the reference fit and how the data sets pull against each other
- If state of the art nuclear corrections are used it appears that the NuTeV and E-866 data sets pull against each other and the fitting program finds a solution with a significantly enhanced d/u ratio in the large-x region
- This conclusion can be altered by varying the weight given to each experiment in the fit
- The conclusion also depends on the precise nuclear correction model used
- There is some suggestion that the nuclear corrections used may be too large and that the corrections should be similar for both ν and $\overline{\nu}$ processes

Other Projects

- Nuclear PDFs - goal is to determine a self-consistent set of iron PDFs using the NuTeV data and calculate nuclear correction factors for various observables by comparing to the free nucleon values - this is essentially complete (Schienbein/Olness)
- NLO $s - \overline{s}$ analysis - in progress (Olness)
- Large-x PDFs using new W-lepton asymmetry data and new BONUS d/u data when it becomes available (Owens)

Comments

- Preceding examples show how we have organized various projects within the global fitting group
- Individuals contribute to those projects they are interested in
- Major projects such as new PDF versions have more inclusive author lists
- Past experience shows that without a designated "lead" person little progress will be made
- It helps to have a single person dedicated to the project (postdoc) - we have not had that in CTEQ since the mid 1990's