Nuclear Corrections and Parton Distribution Functions

Lessons Learned from Global Fitting

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Outline

- Introduction
- Global Fitting
  - Data sets using nuclear targets
  - Role of systematic errors
- Effects of NuTeV and E-866 data sets
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Global Fitting and Parton Distribution Functions - PDFs

PDFs are

- Key to perturbative QCD calculations in hadronic hard scattering processes
- Universal - independent of the hard scattering process
- The means for making the transition from hadronic to partonic beams and targets

In order to determine *nucleon* PDFs it would be best to have data on *nucleon* targets only

- For purely practical reasons - reduce the number of variables in the problem
- Sometimes have to deal with data taken on nuclear targets
- Necessitates the use of model dependent nuclear corrections

Global Fits

Traditional tool for determining PDFs is global fitting

- Use a variety of data types
  - DIS: $l^{\pm}p$, $l^{\pm}d$, $\nu/\overline{\nu}A$
  - lepton pair: pp, pd, pA
  - W, γ, jets: pp, $\overline{p}p$
- Primary goal of *most* global fits is determining *nucleon* PDFs
- Need to account for nuclear effects in order to use data taken with nuclear targets

But what if one wants to determine nuclear PDFs?

Two Approaches

- Use existing nucleon PDFs, parametrize the A dependence, then fit data
- Calculate process dependent nuclear corrections and apply to existing (or newly determined) PDFs in order to compare to data

But what if the PDF sets were fit to data sets which included some data taken on nuclear targets?

Precise treatment of nuclear effects has not been a significant issue in past global fits as the statistical and systematic errors were large enough to accommodate various treatments.

This is no longer true.

Examples from Recent Global Fits

- Start with a Reference Fit - CTEQ6.1M with heavy target data sets (CCFR $\nu/\overline{\nu}$) removed and (model dependent) deuteron corrections included where appropriate
- Compare to new Chorus and NuTeV cross section data for $\nu/\overline{\nu}$ on Fe and Pb, respectively.

But first a word or two about systematic errors.

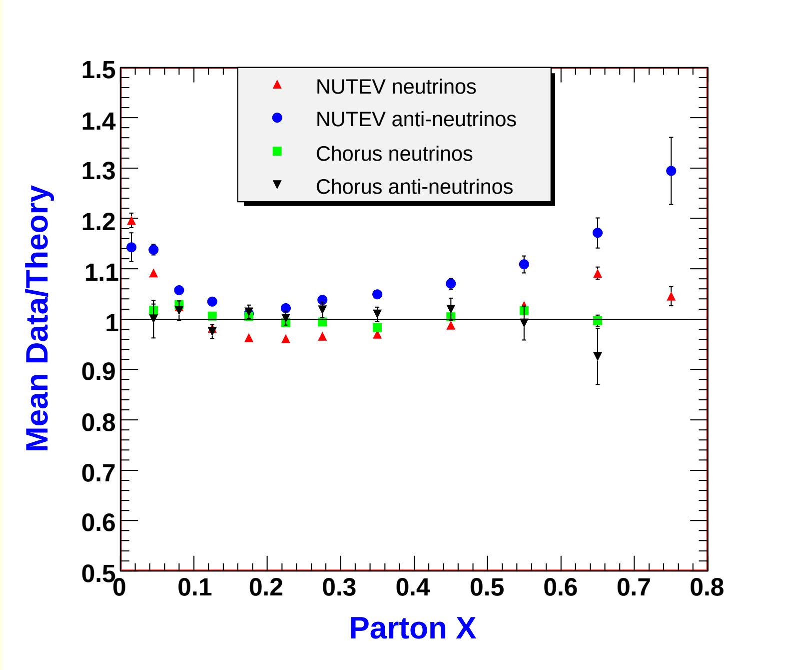
- Many experiments provide statistical, uncorrelated systematic, and correlated systematic errors on a point-by-point basis
- Old method of adding errors in quadrature leads to an overestimate of the errors and is no longer acceptable
- Correlated statistical errors can be treated by determining, as part of the fit, optimal shifts of each data point within the range allowed by the systematic errors

Systematic Errors (continued)

For each data point the experimental value is shifted according to

$$D_i \rightarrow D_i - \sum_{k=1}^{K} r_k \beta_{ki}$$

where the r_k are fitted parameters corresponding to the K different systematic errors β_{ki} on the i^{th} data point. This step is actually done analytically at the beginning of each fit.

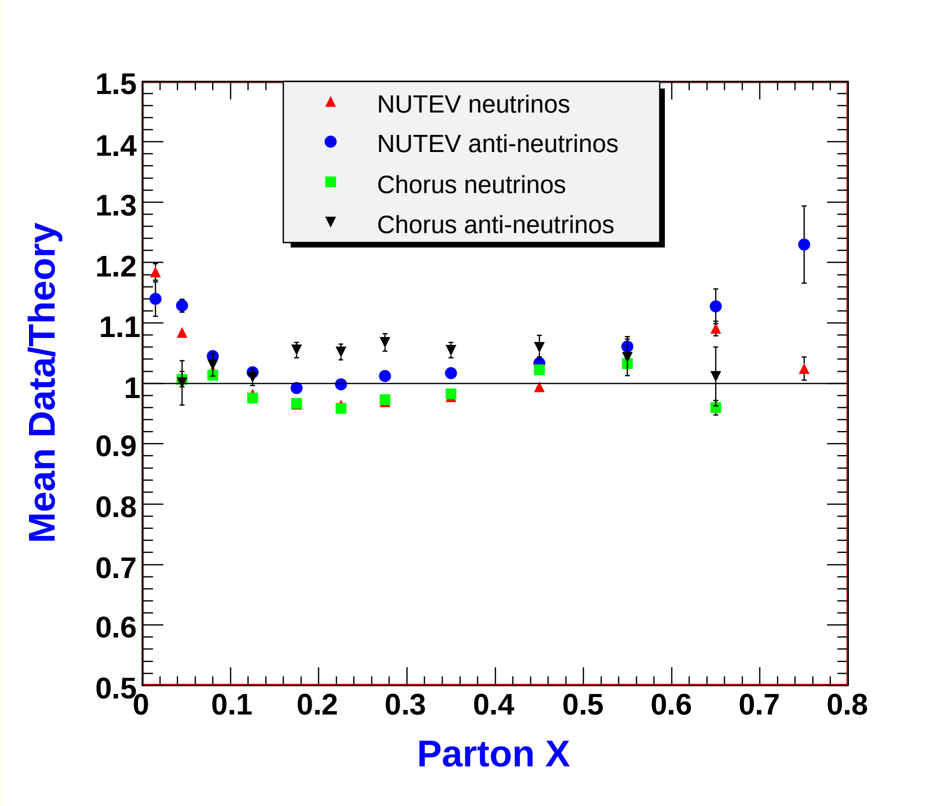


Comparison of Reference Fit (no heavy targets) to Chorus and NuTeV data

- Plot shows weighted average of data/theory integrated over Q^2 for each bin in x using *shifted* data
- Only normalizations have been fit - these data were not included in the fit
- Kulagin-Petti nuclear corrections included

Chorus data agree well with the Reference fit but the NuTeV data do not.

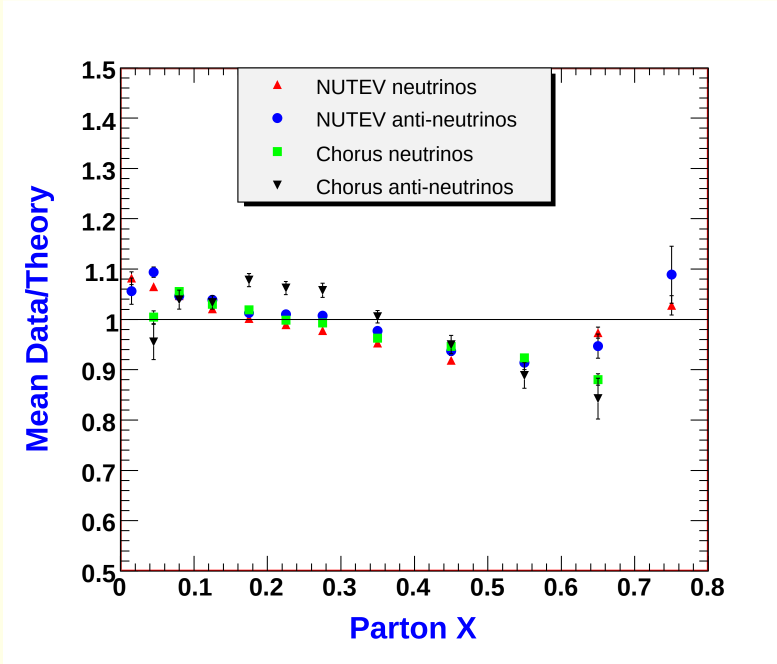
But, what if the plot is made using *unshifted* data?



The result is significantly different

- Chorus data are now further away from the fit than the NuTeV data
- Larger systematic errors on the Chorus data have allowed greater shifts than those for the NuTeV data which have smaller errors

Now, what if the nuclear corrections are removed?



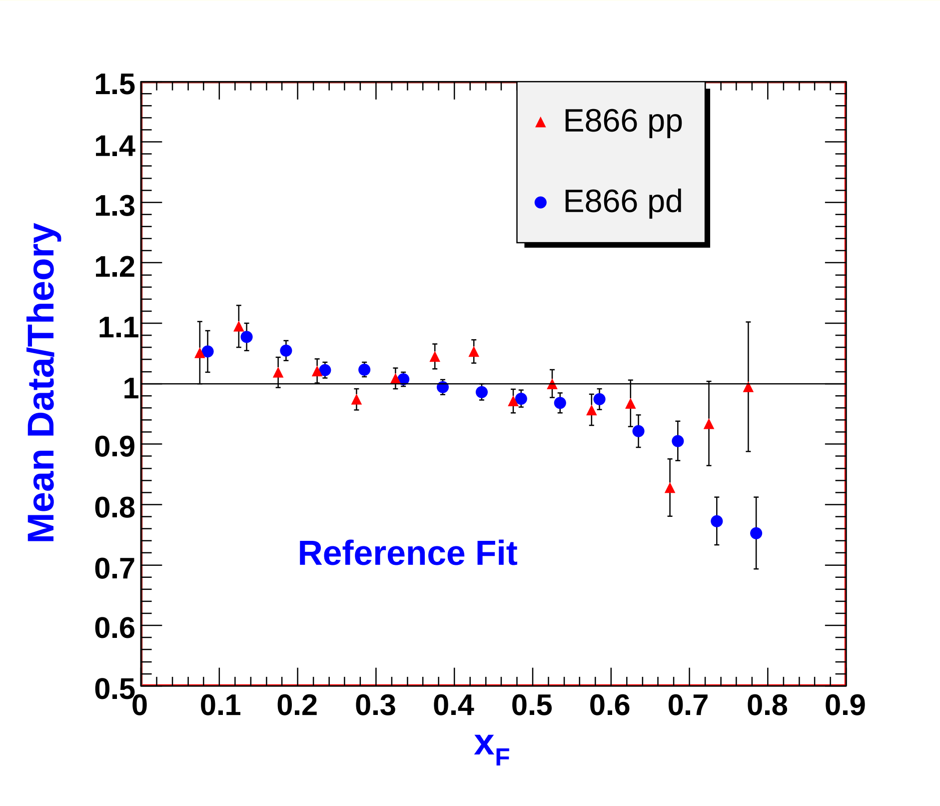
The results are strikingly different

- Different data sets are now more consistent, even if they do not agree totally with the Reference Fit
- Differences at large values of x look like the expected pattern of nuclear effects as seen in $l^{\pm}$ A DIS but reduced in magnitude
- Results suggest that the nuclear corrections for both ν and $\overline{\nu}$ cross sections may be rather similar

Tentative conclusions masked by the large Chorus systematic errors

Effects of new data sets on PDF fitting

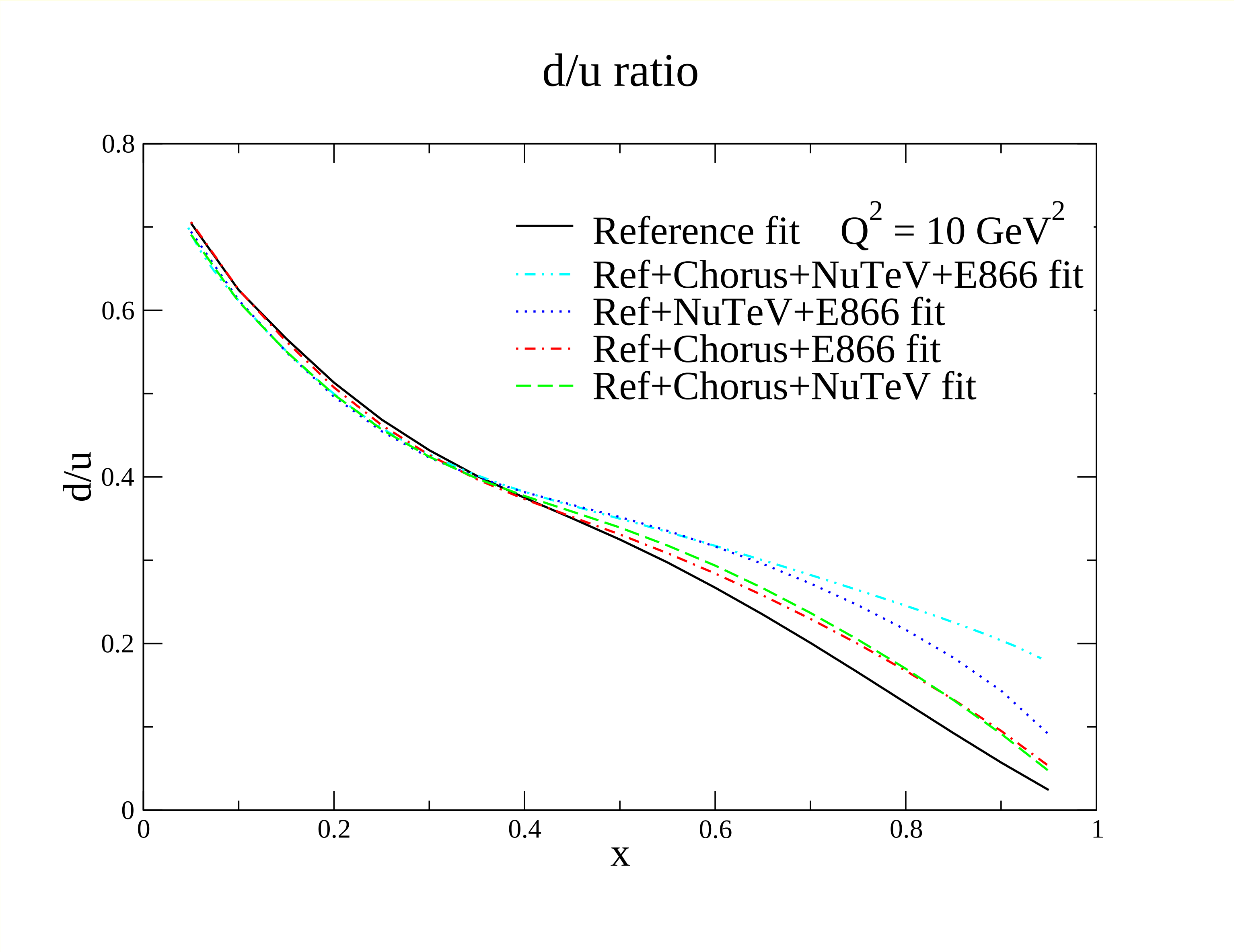
- Add to the Reference Fit data from
  - E-866 pp and pd dimuon production
  - NuTeV
  - Chorus
- Add data sets singly, in pairs, and all at once
- Goal is to see how the various data sets pull the PDFs
- Kulagin-Petti nuclear corrections are used for both the NuTeV and Chorus data sets
- Use the fitted d/u ratio as in indicator of what is going on
- Easier to understand than lengthy chi square tables



- Comparison to the Reference Fit suggests that the E866 data will pull the high-x valence distributions downward
- Previous plots suggest that the NuTeV data will pull the high-x valence distributions upward
- Expect tension between the two

Basic results

- Can get reasonable fits when any single data set is added, although adding NuTeV does cause the chi squares to increase for other DIS experiments
- Adding NuTeV and Chorus or E-866 and Chorus in pairs results in acceptable fits
- Adding E-866 and NuTeV results in a poorer fit and a d/u ratio which differs from the usual results



- See significant increase in d/u when NuTeV and E-866 are both included in the fit
- Results from the tension between the conflicting demands of the NuTeV and E-866 data sets

Explanation

- For large values of x $\sigma^{\nu N} \propto u + d$
- $\sigma(pp \rightarrow \mu\mu + X) \propto 4u(x_1)\overline{u}(x_2) + d(x_1)\overline{d}(x_2)$
- $\sigma(pd \rightarrow \mu\mu + X) \propto [4u(x_1) + d(x_1)](\overline{u}(x_2) + \overline{d}(x_2))$
- NuTeV wants an increase in the high-x valence distributions while E-866 wants a decrease
- Can achieve both by increasing d and decreasing u (decrease of u is weighted by 4 in the dimuon process)
- Explains the increase in the d/u ratio

Note: Variations of the d/u ratio for large values of x are likely well within the range allowed by the PDF errors. These are not meant to represent error bands. It is simply an easy way to see how the PDFs respond to the conflicting demands of the data sets.

Conclusions

- Larger systematic errors on the Chorus data allow it to shift and agree with theory whereas the NuTeV data can't
- Unshifted data suggest that the nuclear corrections may be similar in ν and $\overline{\nu}$ A DIS
- Nuclear corrections in $\nu/\overline{\nu}$ A DIS may be similar to or less than the corrections in $l^{\pm}$ A DIS
- Including NuTeV (with Kulagin-Petti nuclear corrections) and E-866 results in relatively poor chi squares overall
- Shift in d/u results are indicative of the tension between the two data sets
- Can't use high statistics nuclear DIS data to constrain *nucleon* PDFs without a better understanding of the nuclear corrections
- For additional details see J.F. Owens *et al.*, hep-ph/0702159, Phys. Rev. D75:054030,2007.

Data set	Ref	Ch	Nu	E866	Ch+866	Nu+866	Ch+Nu	All	mod nuc
BCDMS F_2^p	1.10	1.11	1.29	1.13	1.13	1.23	1.26	1.20	1.23
BCDMS F_2^d	1.10	1.11	1.36	1.15	1.17	1.36	1.32	1.30	1.31
H1 $F_2^p(1)$	0.93	0.94	1.20	0.94	0.93	1.11	1.22	1.12	1.03
H1 $F_2^p(2)$	0.99	1.00	0.95	1.00	0.98	0.93	0.93	0.93	0.94
H1 $F_2^p(3)$	0.77	0.78	0.76	0.76	0.76	0.74	0.75	0.73	0.73
Zeus F_2^p	1.22	1.21	1.17	1.22	1.21	1.18	1.21	1.15	1.14
NMC $\frac{F_2^d}{F_2^p(x)}$	1.05	1.01	1.20	1.11	1.02	1.60	1.06	1.35	1.20
NMC F_2^p	1.46	1.47	1.79	1.47	1.47	1.78	1.81	1.77	1.64
NMC $\frac{F_2^d}{F_2^p(x,Q^2)}$	0.96	0.96	0.99	0.97	0.97	1.11	1.03	1.09	0.97
E-605	0.79	0.82	0.89	0.70	0.80	0.91	0.92	0.93	0.85
CDF Wasy	1.15	1.08	1.08	1.26	1.15	1.23	1.14	1.25	1.02
E866 $pd/2pp$	0.43	0.45	0.44	0.50	0.47	0.52	0.43	0.46	0.41
DØ jets	0.94	0.84	0.66	0.98	0.97	0.65	0.69	0.74	0.93
CDF jets	1.62	1.65	1.63	1.63	1.65	1.64	1.61	1.63	1.63
Total chi square	1947								
# points	1727								
E-866 pp	*1.23*	-	-	1.16	1.15	1.22	-	1.21	1.15
E-866 pd	*1.85*	-	-	1.49	1.49	1.84	-	1.80	1.59
NuTeV ν	*2.19*	-	1.65	-	-	1.68	1.67	1.71	1.64
NuTeV $\overline{\nu}$	*1.51*	-	1.27	-	-	1.29	1.27	1.28	1.21
Chorus ν	*1.30*	1.27	-	-	1.27	-	1.29	1.27	1.28
Chorus $\overline{\nu}$	*1.08*	1.09	-	-	1.08	-	1.16	1.15	1.18
Total chi square	7453	2838	5218	2393	3357	5836	6247	6827	6606
# points	5062	2551	3863	2102	2926	4238	4687	5062	5062