Nuclear 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
- Lessons learned
- Outlook
- Conclusions

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

Given a set of nucleon PDFs one would like to understand how they are altered in a nuclear environment

- For purely practical reasons - in order to utilize more types of targets
- In order to learn more about the nuclei involved

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.

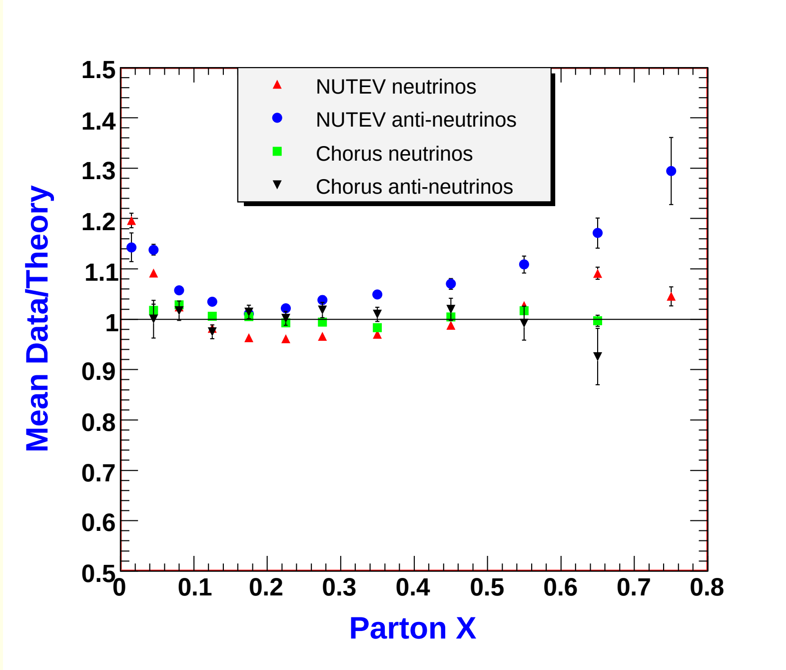
- Many experiments provide statistical, uncorrelated systematic, and correlated systematic errors on a point-by-point basis
- Old method of adding errors in quadrature leads to an overestimate of the errors and is no longer acceptable
- Correlated statistical errors can be treated by determining, as 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.

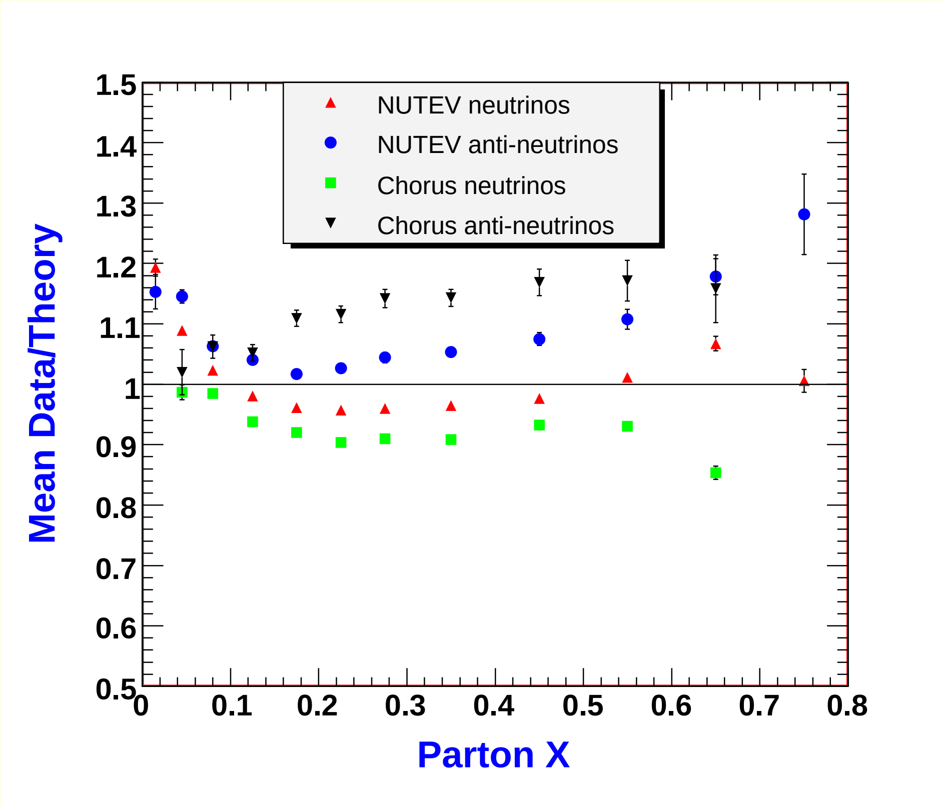


Comparison of Reference Fit (no heavy targets) to Chorus and NuTeV data

- 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.

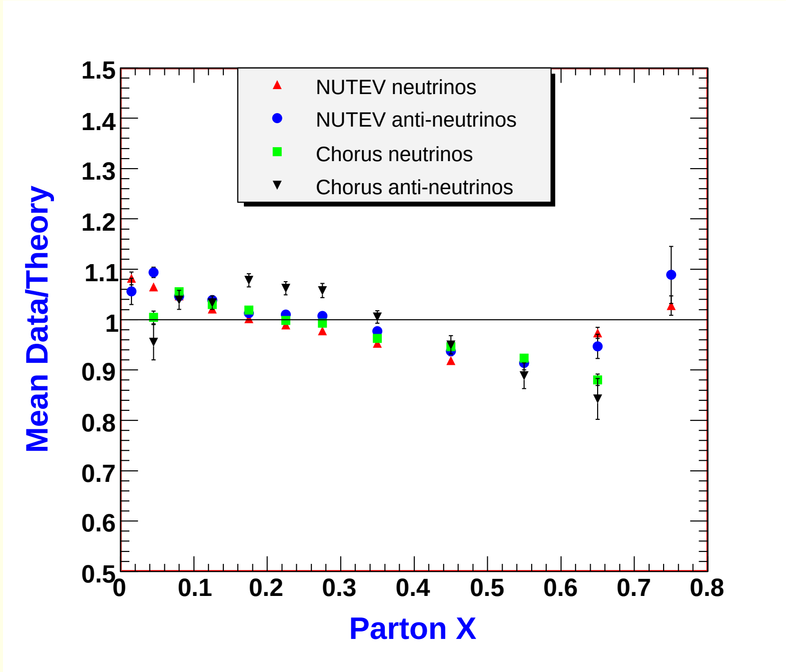
But, what if the plot is made using *unshifted* data?



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

Lessons Learned

- Larger systematic errors on the Chorus data allow it to shift and agree with theory whereas the NuTeV data can't
- Pattern remained the same when the NuTeV and Chorus data were included in the fits
- Unshifted data suggest that the nuclear corrections may be similar in $l^{\pm}A$ and $\nu/\overline{\nu}$ A DIS
- Can't use high statistics nuclear DIS data to constrain *nucleon* PDFs without a better understanding of the nuclear corrections

General Comments

- PDFs should be a property of the parent nucleon or nucleus, *i.e.*, they should be universal
- If the nuclear corrections are different for different types of probes, then this has to be incorporated into the hard scattering cross sections
- Need more study of how the probes determine what the PDFs appear to be

Antiquarks in the nucleus

Information on antiquarks traditionally comes from

1. DIS at small values of x
2. Lepton pair production (Drell-Yan)

Comments

- Use F_2 and xF_3 in neutrino scattering to disentangle valence quarks and antiquarks
- lepton pair production at large x_F directly probes the small-x antiquark distribution

Lepton pair production kinematics

Using lowest order kinematics the beam (x_1) and target (x_2) momentum fractions for producing a lepton pair of mass M and longitudinal momentum fraction x_F at an energy $\sqrt{s}$ are given by

$$x_{1,2} = \frac{\pm x_F + \sqrt{x_F^2 + 4M^2/s}}{2}$$

- Large x_F yields large x_1 and small x_2
- x_1 will then preferentially correspond to a valence quark
- This leaves an antiquark at small values of x_2

Comparing lepton pair production from nuclear and nucleon targets yields information on the modification of the antiquark distributions in nuclei,*e.g.*, Fermilab experiment E-906

Comment: the same problem noted earlier is present here - one must have a thorough understanding of the *nucleon* PDFs before one can disentangle the nuclear effects.

Summary

If one wants to study partons in the nucleus then one needs

- Improved understanding of nuclear effects for various hard scattering processes (at least $l^{\pm}$, ν, $\overline{\nu}$ DIS, lepton pair production)
- Good knowledge of nucleon PDFs obtained without the use of heavy targets
- High statistics data (with small systematic errors) for a range of DIS processes and lepton pair production.