Uncertainties in determining the d quark PDF at large values of x

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Outline

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Introduction

Cast of characters in the CTEQ-JLAB Collaboration - Alberto Accardi, Eric Christy, Cynthia Keppel, Simona Malace, Wally Melnitchouk, Peter Monaghan, Jorge Morfín, JFO, and Lingyan Zhu

Goals:

- Overall goal - Improve the precision of the d PDF
- Extend PDF fits to larger values of x and lower values of Q
- Wealth of data from older SLAC experiments and newer JLAB experiments
- Study effects of different target mass correction methods
- Explore role of higher twist contributions
- Quantify the uncertainty due to nuclear corrections for deuteron targets
- Study the parametrization dependence of the results

Motivation

- Traditional global fits focus on leading twist PDFs convoluted with hard scattering partonic cross sections
- Typically use DIS cuts similar to $Q > 2$ GeV and $W > 3.5$ GeV
- Limits x coverage to $x \lesssim 0.7$
- Goal is to relax the cuts in order to access higher values of x
- Current results obtained with $Q^2 > 1.69$ GeV^2, $W^2 > 3$ GeV^2
- Current project results in arXiv:1102.3686

Previous analysis (Phys. Rev. **D81**:034016, 2010) showed the following

- Good fits could be obtained using the lower Q and W cuts on the DIS data
- Different target mass correction prescriptions gave equivalent fits as long as a simple parametrization of higher twist contributions was added
- Leading twist PDF was stable as the TMC prescription was varied

Residual questions:

- How do the results depend on the models used for the nuclear corrections for DIS data from deuterium targets (deuteron wavefunction, offshell corrections)?
- How do the results depend on the parametrization used for the d PDF?

Information on the d PDF

DIS

- $F_2^P(x, Q^2) \sim 4u + d$
- $F_2^d(x, Q^2) \sim 5(u + d)$, but requires nuclear corrections

Lepton Pair Production

- $x_1 x_2 = \frac{M^2}{s}$ and $x_F = x_1 - x_2$
- Can get to large x_1 if high-x_F data are available
- E-866 reaches to $x \approx .8$
- $\sigma_{pp} \sim \overline{u}(x_2)[4u(x_1) + d(x_1)\overline{d}(x_2)/\overline{u}(x_2)]$
- $\sigma_{pn} \sim \overline{d}(x_2)[4u(x_1) + d(x_1)\overline{u}(x_2)/\overline{d}(x_2)]$
- At large $x_F, x_1 \gg x_2$
- To the extent that $\overline{u}(x_2) \simeq \overline{d}(x_2)$, which is roughly satisfied for small x_2, one is still sensitive to $4u + d$

W asymmetry

- $x_{1,2} = \frac{M_W}{\sqrt{s}} e^{\pm y}$
- W asymmetry directly sensitive to large x d/u at large y
- Effect is reduced if decay lepton asymmetry is used
- Newer data reach to $x \approx .8$, but the last bin is wide and the central value corresponds to $x \approx .57$

Vector boson production

- W and Z production are sensitive to different linear combinations of PDFs than for Drell-Yan pairs
- Potential constraints from data at high values of rapidity

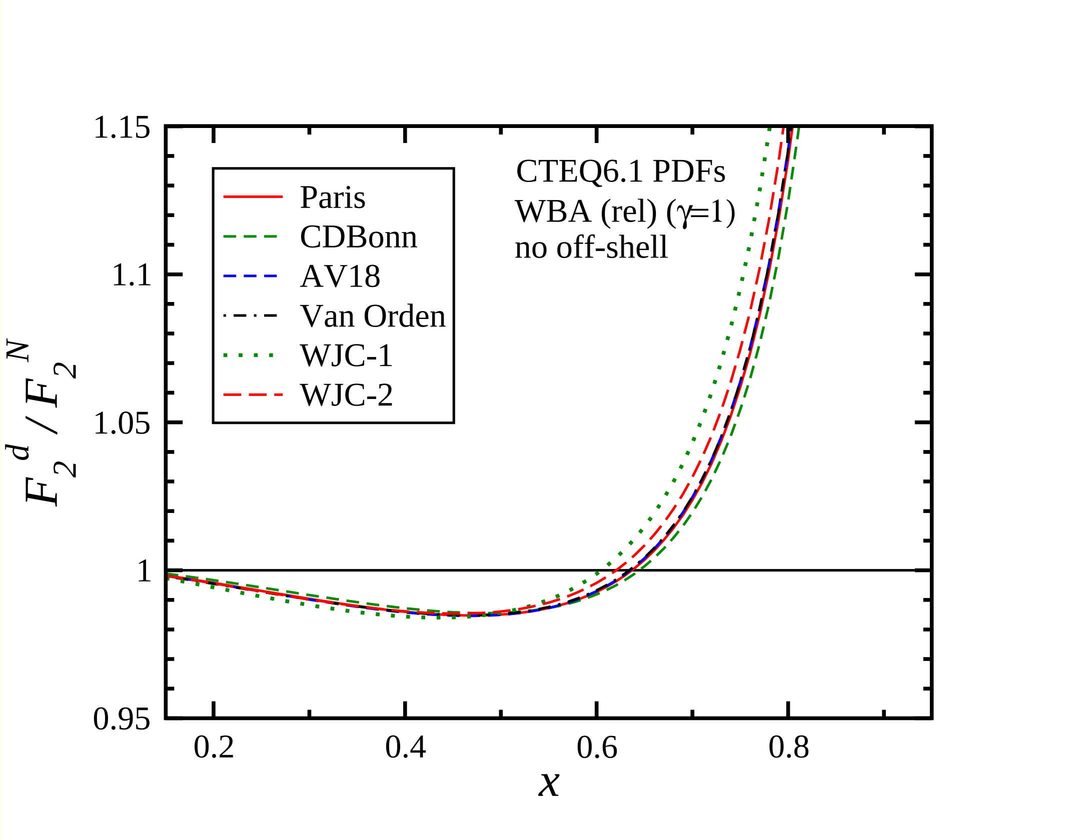
Jet Data

- All parton pairs contribute, weighted by their respective subprocess cross sections
- Leads to an anticorrelation between the d PDF and the u and g PDFs

General idea is to study the effects of nuclear corrections and d PDF parametrization choices while watching the effects on various data sets

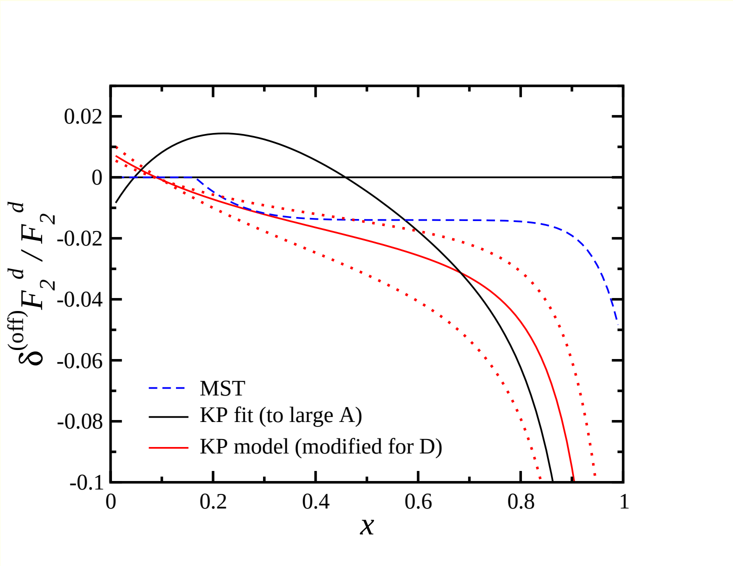
Nuclear Corrections

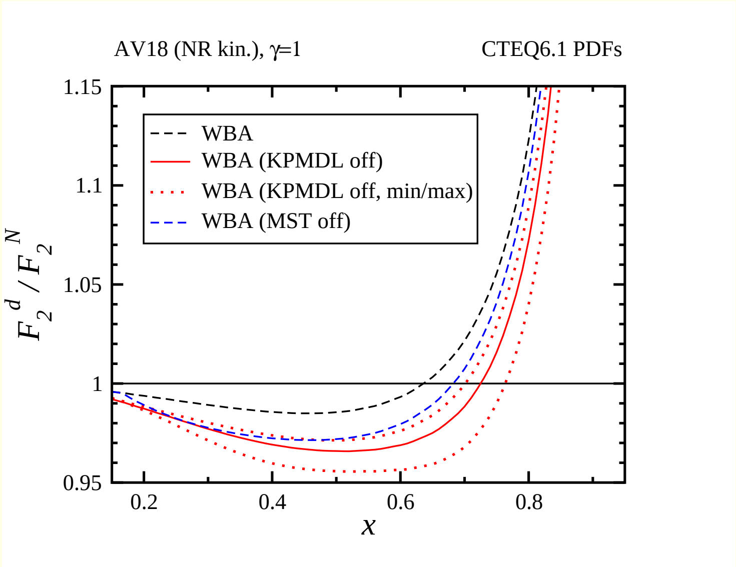
- Fermi motion smearing done using the Weak Binding Approximation (WBA) - see Sec. 2 of the current analysis for details
- Various choices of wavefunctions explored



Offshell corrections

- Start with a parametrization due to Kulagin and Petti which is fitted to data for a range of heavy nuclei
- Parameters were adjusted (Wally Melnitchouk) to provide a range of corrections representative of the average offshellness of nucleons in a deuteron





- Easy way to think about the effects of the nuclear corrections on the PDFs
- The deuterium data are divided by this ratio, yielding effectively the sum of neutron and proton data
- When the ratio is less than one the data are enhanced and the d PDF will increase
- Conversely, the d PDF will be reduced when the ratio is greater than one

Fitting Package

We are using my NLO DGLAP fitting package which I have continued to update and extend

- Can fit DIS, Drell-Yan, W lepton asymmetry, jets, and γ + jet
- W lepton asymmetry routine allows for a single p_T cut, but a generalization to allow for multiple p_T cuts has been developed
- Added PDF errors (Hessian method)
- Multiple TMC and HT terms added (Alberto Accardi)
- Some correlated errors added
- Options for nuclear corrections added (Wally Melnitchouk, Alberto Accardi)

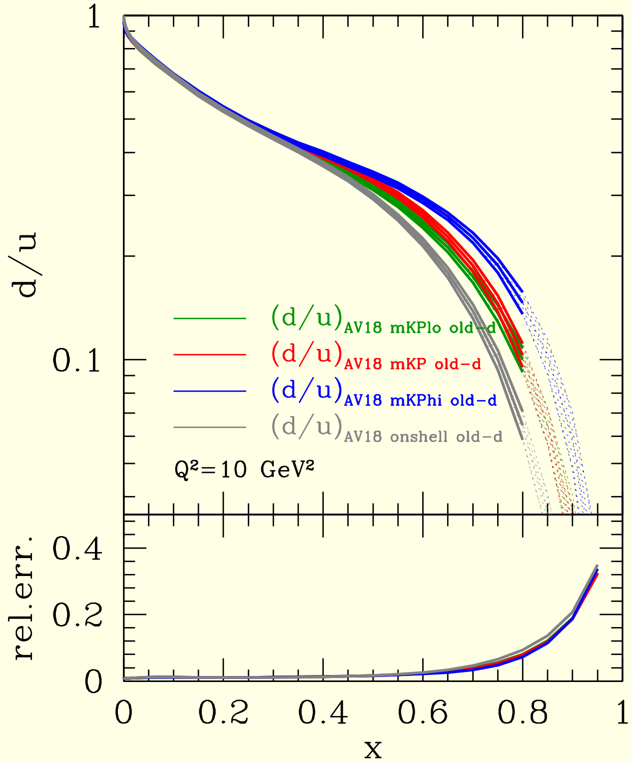
Data Sets

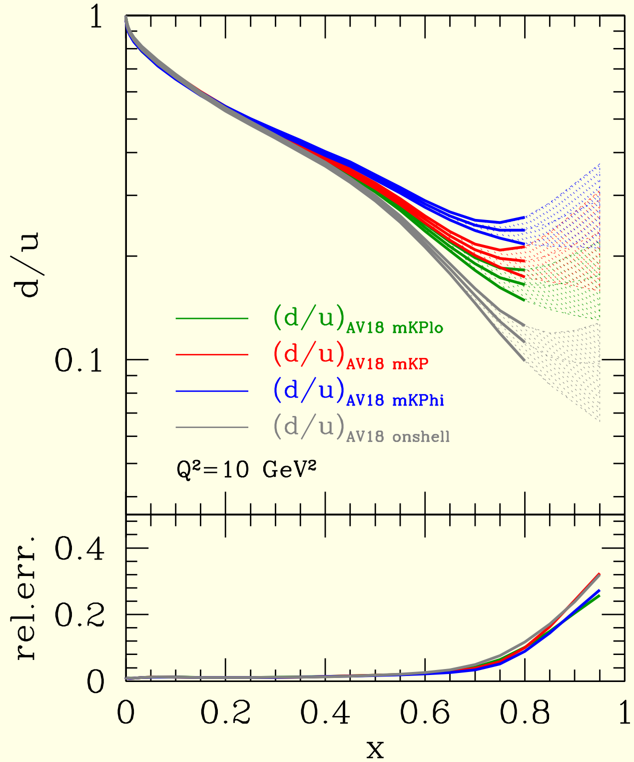
- BCDMS, SLAC, NMC, H1, Zeus, and JLAB DIS data
- E-605 and E-866 lepton pair data
- CDF and D0 jet data
- W asymmetry and W-lepton asymmetry data
- DØ γ + jet data
- Data sets similar to those used in CTEQ6.1 except CCFR removed, E-866 added, DØ γ + jet added, and some new W asymmetry data added

Results

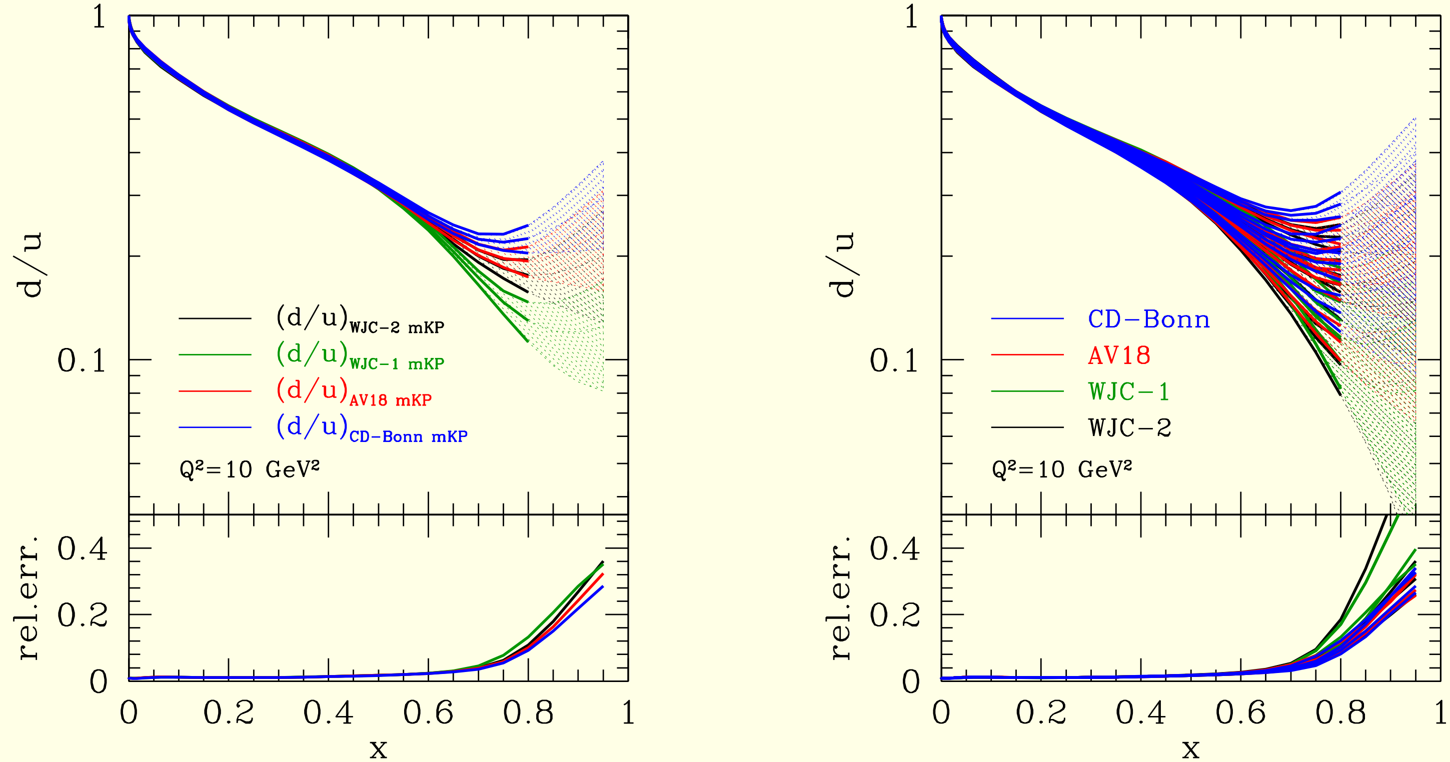
- Summarize results by showing d/u ratios
  - The u PDF is already well constrained
  - The different nuclear corrections have the largest effect on the d PDF
  - Basically, the d PDF shifts to accommodate whatever nuclear model is used and the other PDFs adjust to compensate for the shift
- Consider first a traditional parametrization where the d PDF vanishes as $x \rightarrow 1$
- Then, compare to a parametrization where $d \rightarrow d + c * u * x^b$ so that $d/u \rightarrow c$ in the limit that $x = 1$
- For clarity, the bands denote the PDF uncertainty resulting from the experimental errors with $\Delta\chi = 1$

Sample results obtained using the AV18 wavefunction

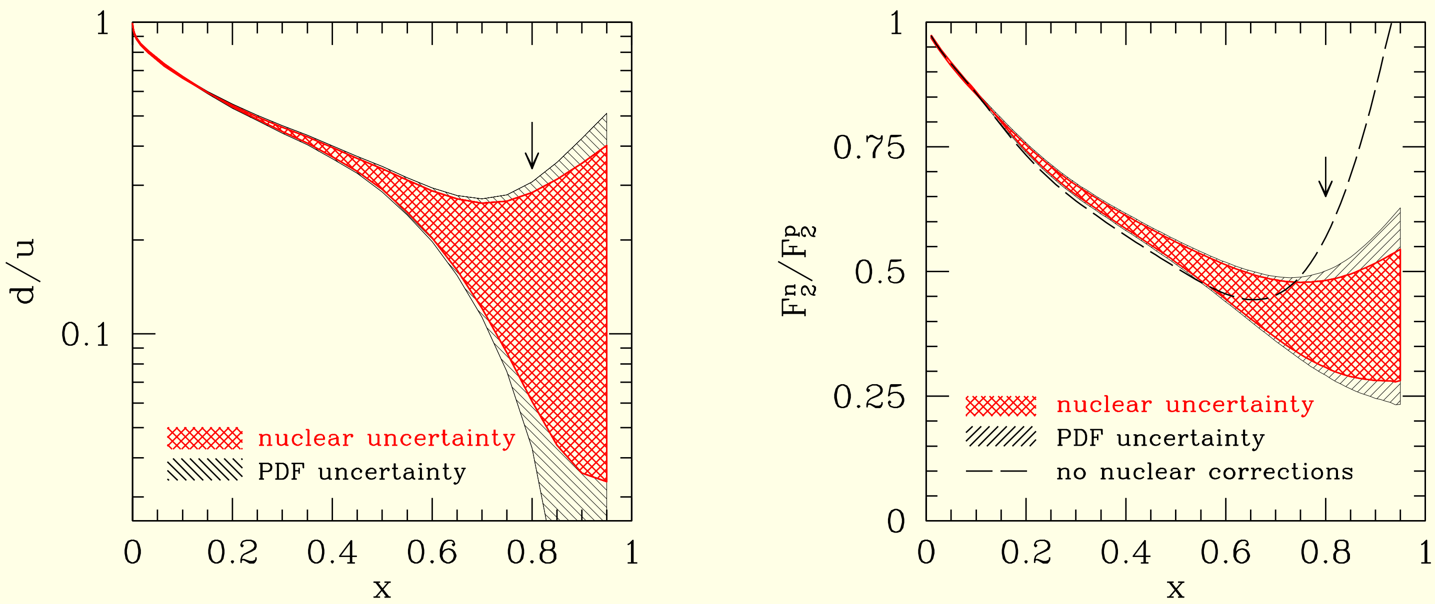




Either parametrization gives good fits, with a very slight chi square preference existing for the right-hand plots ($d/u \to c$ at $x = 1$)

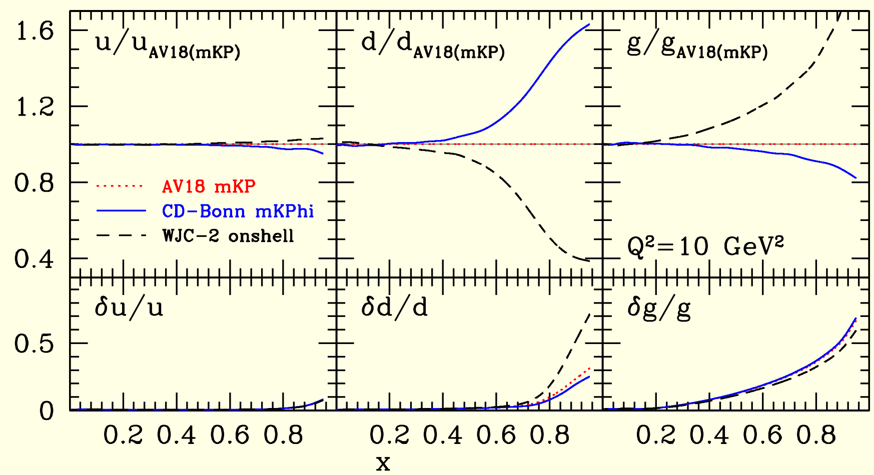


Left-hand plot shows the wavefunction dependence with a fixed offshell model while the right-hand plot shows the full effect of varying both the wavefunction and the offshell model



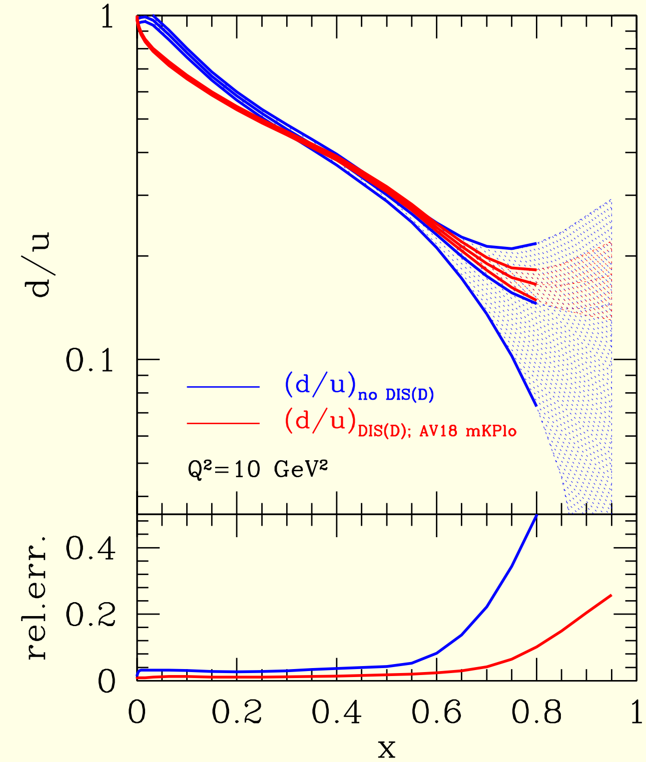
- These figures shows the resulting uncertainty bands for d/u and F_2^n/F_2^p
- Neutron/proton F_2 ratio is bounded below at $1/4$
- Resulting uncertainty in the structure function ratio is reduced relative to that for the d/u ratio

Compare the PDFs resulting from the upper and lower extremes of the d/u ratios



- Center panels show the d PDFs for the upper and lower extremes
- A very small shift (few percent) in the u PDF compensates
- Primarily because the DIS and Drell Yan data are sensitive to $4u + d = u(4 + d/u)$ in a region where d/u is already small
- Gluon PDF compensates the change in the d PDF for the jet data
- Uncertainty in the d PDF due to the variation of the nuclear corrections feeds into increased uncertainty in the large-x gluon PDF

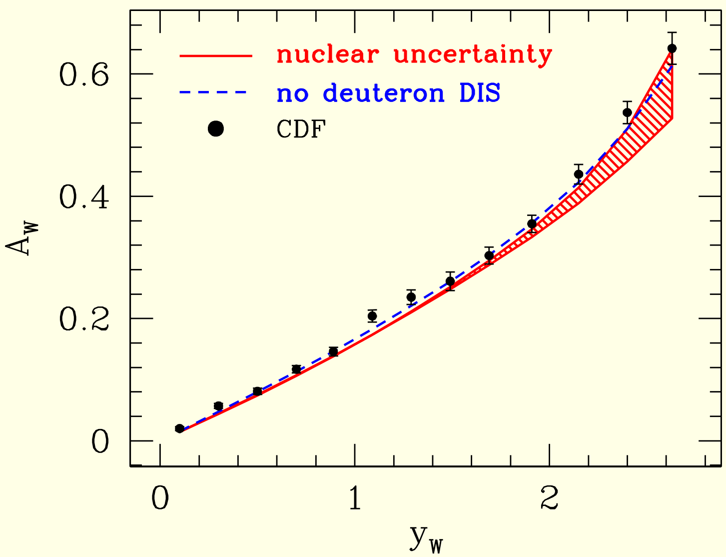
The figure below shows the result of removing the deuterium DIS data from the fit.

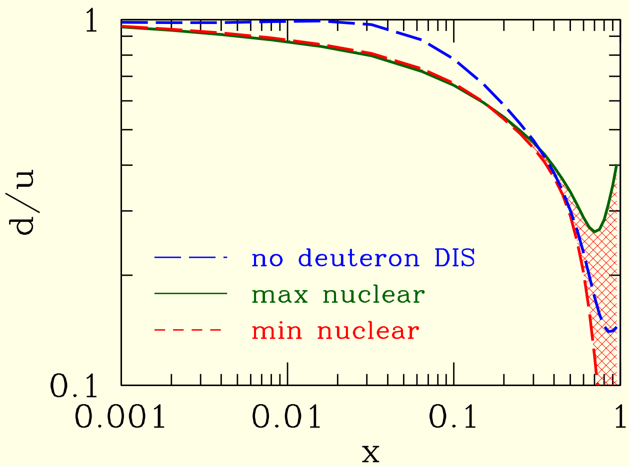


- For a fixed choice of the nuclear models the uncertainty on the d PDF is decreased when the deuterium data are included.
- Notice the relatively large shift in the d/u ratio at low values of x
- Shift is unexpected based on standard error propagation

- Suggests that at least some of the deuterium DIS data (BCDMS, NMC, SLAC, and JLAB) is pulling against the other non-deuterium data sets
- Shadowing corrections are expected to be at the 1% level and can't account for the difference
- Suggests that the d PDFs may be underestimated at low values of x
- Where else might this effect show up?

- CDF W asymmetry is not particularly sensitive to the nuclear corrections we have been studying - The weighted bin center for the highest rapidity bin corresponds to $x = 0.57$
- On the other hand, the description of the data is improved significantly in the "No deuterium" fit.
- The W asymmetry data are providing about half of the chi square improvement and seem to be responsible for much of the shift shown previously when the deuterium DIS data are removed





What can be done?

- How can one resolve the dilemma posed by the fact that the d PDF simply adjusts to whatever nuclear model is used while the other PDFs are anticorrelated and vary in order to maintain good fits to the non-deuterium data?
- Need new data which constrain the d PDF but which are not sensitive to nuclear corrections
- Examples include the BONUS, MARATHON, and PVDIS experiments at Jefferson Lab
- Could also consider experiments done with proton targets such as ν and $\overline{\nu}$ p DIS data, perhaps from the Minerνa experiment. These will directly constrain the d/u ratio
- Another example - finer binning on W asymmetry data at high values of rapidity in order to get to large x values

Current and Planned Developments

- Have extended the fitting package
  - Interfaced with FastNLO in order to handle NLO jet calculations for Tevatron Run I and Run II data sets
  - Added capability to fit HERA combined cross section data
  - Added NLO treatments of CDF and DØ Z rapidity distributions
- Currently updating the previous results
- Studying parametrization choices
- Plan to produce PDF sets using several representative sets of nuclear corrections

Summary and Conclusions

- Nuclear corrections - Fermi smearing and offshell corrections - have significant effects on the behavior of d PDF when it is constrained by deuterium DIS data
- Good descriptions of the data are easily obtained and the d PDF varies significantly, depending on the nuclear model choice
- Other PDFs are anticorrelated with the d PDF (mostly the u and gluon PDFs) so that the fits to all other data sets are essentially independent of the nuclear corrections
- When the deuterium DIS data are removed from the fits there is a significant shift of the d/u ratio, especially at low values of x, suggesting that one or more of the remaining data sets is pulling against the deuterium DIS data
- One strong source of such a pull is the W asymmetry data from CDF - its description is much improved without the deuterium data in the fit
- To further constrain the d PDF we need data which are sensitive to the d PDF while not being sensitive to nuclear corrections. This includes experiments such as MARATHON, BONUS, and PVDIS. It also includes additional observables taken on proton targets.