# Nuclear and Deuteron Corrections

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The NNPDF fit includes data from

1. Neutrino DIS with Fe, Pb targets - (CHORUS, NUTEV)
2. DIS with deuteron targets - (NMC, SLAC, BCDMS)
3. DY with deuteron targets.

So far no corrections have been included for the different proton environments. To find these theoretical errors it is necessary to consider these three types of data separately.

There have been several attempts to account for nuclear corrections in PDFs, including

1. **CJ12 [arXiv:1212.1702] & CJ15 [arXiv:1602.03154]**. These apply a "nuclear smearing" method where deuteron effects are accounted for by convolving each bound nuclear structure function $F_2^N$ with a smearing function $f_{N/d}$ which accounts for the motion of the nucleon within the deuteron:

$$F^d(x,Q^2) = \sum_{N=p,n} \int dz f_{N/d}(z,\gamma) F_2^N(\frac{x}{z},Q^2) + \delta^{(off)} F_2^d(x,Q^2) \tag{0.1}$$

   where $z$ is the nucleon momentum fraction in the deuteron and $\gamma$ characterises the deviation from the Björken limit. The additive term includes relativistic and nucleon off-shell corrections.

   In this strategy the model dependency in the convoluted part comes from the form of the deuteron wavefunction. Models include AV18 [arXiv:nucl-th/9408016] and CD-Bonn [arXiv:nucl-th/0006014] (non relativistic) and WJC-1 [arXiv:1007.0778] and WJC-2 [arXiv:1404.1584] (relativistic).

Off-shell corrections have greater model dependency - some models include: [arXiv:hep-ph/0412425; 10.1103/PhysRevC.51.38; arXiv:nucl-th/9407007; arXiv:nucl-th/9609048]. Different PDFs (CJ12min, CJ12med and CJ12max) were produced by varying the wavefunction and degree of off-shell effects.

2. **MMHT14 [arXiv:1412.3989]**. They addressed both deuteron and heavy nuclear corrections. Deuterons were dealt with by averaging over proton and neutron structure functions with an overall correction factor $c(x)$ (parameterised and fitted to data):

$$F^d(x,Q^2) = c(x)\Big[\frac{F^p(x,Q^2)+F^n(x,Q^2)}{2}\Big]. \tag{0.2}$$

They used CJ12min, CJ12med and CJ12max to explore the range of $c(x)$.

For neutrino DIS (heavy nuclear) they used a comparison between partonic PDFs $f(x,Q^2)$ and nuclear PDFs $f^A(x,Q^2)$ from Florian & Sassot to find correction factors $R_f(x,Q^2,A)$:

$$f^A(x,Q^2) = R_f(x,Q^2,A)f(x,Q^2). \tag{0.3}$$

3. **NNPDF - Neutrino DIS: [arXiv:0906.1958], Deuterons: [arXiv:1303.1189]**. Used MMHT methodology to assess impact of deuteron corrections.

## 1 NEUTRINO DIS

One course of action would be to use the MMHT14 approach in [arXiv:1412.3989] but with several different nuclear PDF sets in order to find the distribution of $R_f$. As well as the one from Florian & Sassot there are two nuclear PDFs available in LHAPDF: nCTEQ and EPPS. The model variation would therefore be introduced via the different PDF sets.

## 2 DIS

The deuteron target DIS data in NNPDF are:

1. NMC $0.012 \le x \le 0.5$
2. SLAC $0.14 \le x \le 0.55$
3. BCDMS $0.07 \le x \le 0.75$.

The CJ15 fit also included HERMES ($0.006 \le x \le 0.9$).

Strategy would be to use the convolution approach in CJ12/CJ15 with as wide a range of deuteron wavefunction parameterisations and off-shell models as possible, in order to reduce the model dependency.

## 3 DY

DY is not addressed in these or related papers.