Nuclear corrections in νA DIS & Compatibility with global NPDF analyses

Ji-Young Yu
LPSC Grenoble

Collaborators: K.Kovarik, I.Schienbein, F.Olness, J.Owens, J.Morfin, C.Keppel, T.Stavreva

EPS-HEP2011
Grenoble, 20-27 July

I. Nuclear corrections in νA DIS

PRD77(2008)054013

Why neutrino DIS?

- **Data interesting for global analyses of proton PDF and nuclear PDF (nPDF)**
    - **Flavor separation:**
      Neutrino structure functions depend on different combinations of PDFs

- **Dimuon production:**
    - Main source of information on the strange sea
    - Large uncertainty on $s(x,Q^2)$ has significant influence on the W and Z benchmark processes at LHC

- **For proton PDF: need nuclear corrections!**

Why neutrino DIS?

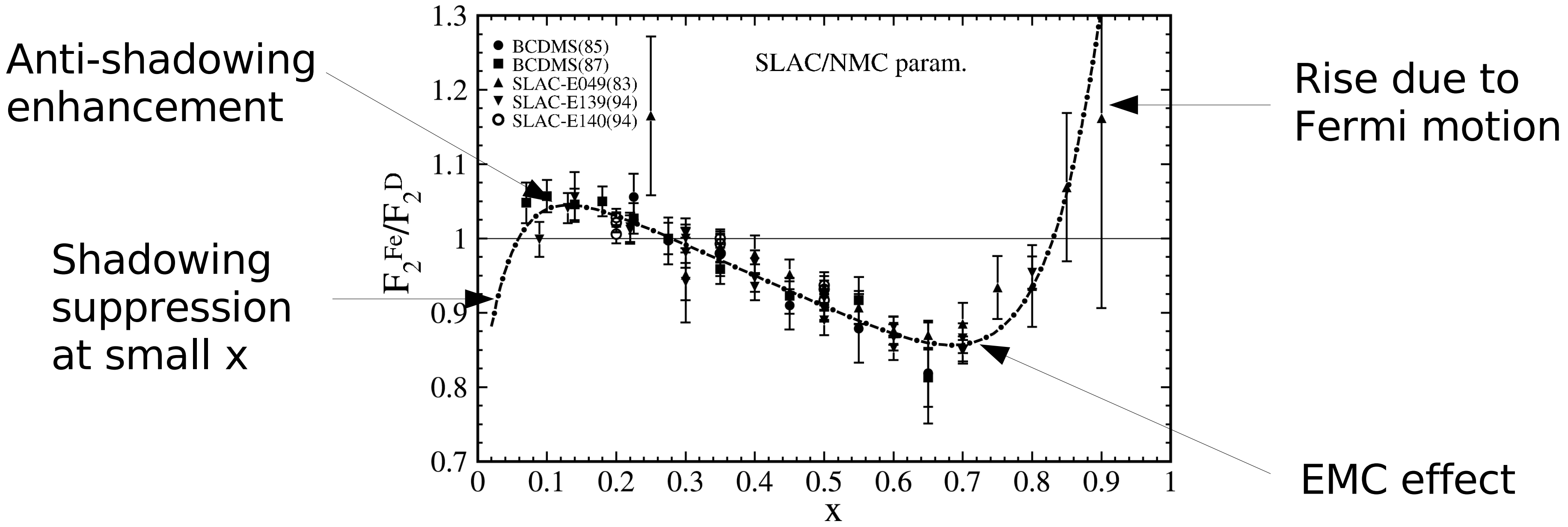
- **LBL precision neutrino experiments:**

  Need good understanding of ν-A cross sections (A=Oxygen, Carbon)

- **EW precision measurements:**

  Paschos-Wolfenstein analysis: extraction of $\sin^2\theta_W$

Nuclear corrections: Historically



- Historically, nuclear corrections from charged-lepton DIS data are applied to neutrino DIS data
- Same correction for all scales Q^2
- Same correction for all observables (F_2, F_3, cross section, dimuon production)
- **Idea:** study nuclear corrections in the parton model (PM) using nuclear PDF

Nuclear correction factors in the PM

- Be O an **observable** calculable in the parton model

  Define **nuclear correction factor:**

$$R[\mathcal{O}] = \frac{O[\text{nuc.PDF}]}{O[\text{freePDF}]}$$

- Compare below: $\mathbf{R[F_2^{lA}]}$ (lA DIS) with $\mathbf{R[F_2^{\nu A}]}$ (υA DIS)

- Advantage:
  - very flexible (applicable to other observables: F_3, $d\sigma$, ...)
  - scale dependent

Iron PDFs from NuTeV data

- NuTeV cross section data
  - more than 1000 neutrino cross section data
  - more than 1000 anti-neutrino cross section data
  - correlated errors, radiative corrections,
    with and w/ o/ isoscalar corrections
- NuTeV/CCFR dimuon data (172 pts) to fix s(x) PDF
- Idea: Analyse iron data only (iron neutrino data)
  - Advantage: no A-dependence needs to be modeled
  - Only 2 Observables: not all PDFs constrained
    Need to be careful.

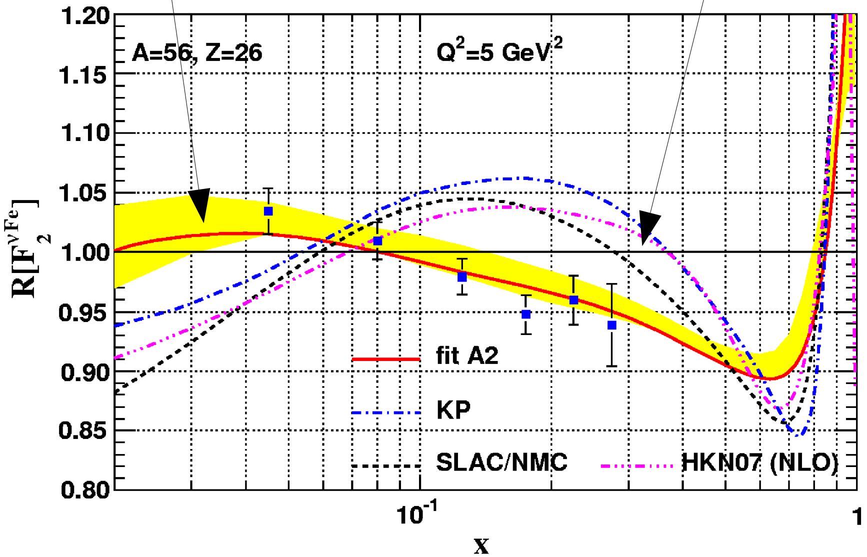
Iron PDFs from NuTeV data

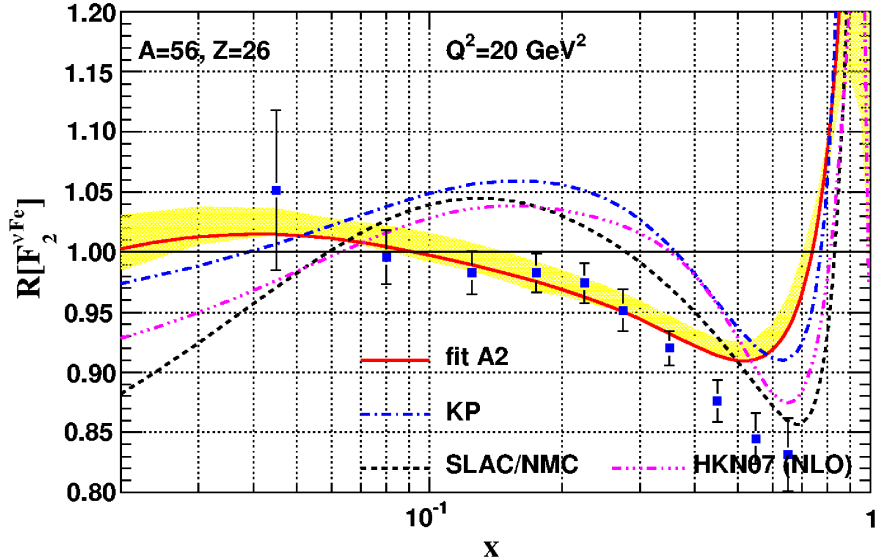
- Assumptions
  - Gluon PDF not constrained: Fix gluon to free proton gluon (supported by result of DS'04)
  - Assume corrections to dbar similar to corrections to ubar at moderate and small x
- 'Perform regression analysis' where only one parameter is left free at a time
- Band of fits with similar χ^2 / dof

Nuclear correction factors for $F_2^{\nu Fe}$

from our analysis of NuTeV
νFe cross section data

expectations from lA DIS





- Nuclear correction factor (yellow band) **surprisingly** different from expectations based on lA DIS
- Are nuclear corrections in lA DIS and νA DIS different?
- Need global analysis of **lA DIS + DY + νA DIS** data for definite conclusions!

II. CTEQ nuclear PDF

PRD80(2009)094004

nPDFs available at:

http://projects.hepforge.org/ncteq/

nCTEQ framework

Framework as CTEQ6.1 + A-dependent fit parameters:

x-dependence of our input distributions always the same:

$$\begin{aligned} x\, f_k(x, Q_0) &= c_0 x^{c_1} (1-x)^{c_2} e^{c_3 x} (1 + e^{c_4} x)^{c_5} \\ k &= u_v, d_v, g, \bar{u} + \bar{d}, s, \bar{s}\,, \\ \bar{d}(x, Q_0)/\bar{u}(x, Q_0) &= c_0 x^{c_1} (1-x)^{c_2} + (1 + c_3 x)(1-x)^{c_4} \end{aligned}$$

Introduce A-dependent fit parameters:

$$c_k \to c_k(A) \equiv c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right), \quad k = 1, \ldots, 5$$

- Note: In the limit $A \to 1$ we have $c_k(A) \to c_{k,0}$
- $c_{k,0}$ are the coefficients of the free proton PDF

nPDFs from lA DIS + DY data

- Global analyses of nPDF:
  - **HKN'07** [PRC76(2007)065207]
    LO,NLO,error PDFs, χ^2/dof = 1.2
  - **EPS'09** [JHEP0904(2009)065]
    LO,NLO,error PDFs, χ^2/dof = 0.8
  - **DS'04** [PRD69(2004)074028]
    first NLO analysis, 'semi-global', no error PDFs, χ^2/dof = 0.76
- Based on lA DIS+DY data

  (EPS'09 uses also inclusive π^0 data at midrap. from d+Au and p+p coll. at RHIC)
- **nCTEQ** use same data sets as HKN'07 (up to cuts)

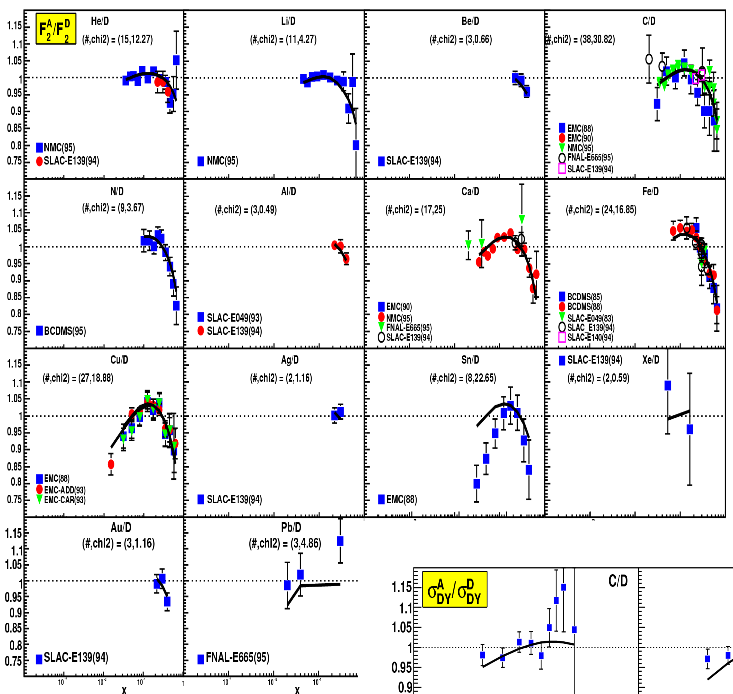
	R	Nucleus	Experiment	EPS09	HKN07	DS04
DIS		D/p	NMC		O	
	A/D	4He	SLAC E139	O	O	O
			NMC95	O (5)	O	O
		Li	NMC95	O	O	
		Be	SLAC E139	O	O	O
		C	EMC-88, 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		N	BCDMS 85		O	
			HERMES 03		O	
		Al	SLAC E49		O	
			SLAC E139	O	O	O
		Ca	EMC 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		Fe	SLAC E87		O	
			SLAC E139	O (15)	O	O
			SLAC E140		O	
			BCDMS 87		O	
		Cu	EMC 93	O	O	
		Kr	HERMES 03		O	
		Ag	SLAC E139	O	O	O
		Sn	EMC 88		O	
		Au	SLAC E139	O	O	O
			SLAC E140		O	
		Pb	FNAL-E665		O	
	A/C	Be	NMC 96	O	O	O
		Al	NMC 96	O	O	O
		Ca	NMC 95		O	
			NMC 96	O	O	O
		Fe	NMC 96	O	O	O
		Sn	NMC 96	O (10)	O	O
		Pb	NMC 96	O	O	O
	A/Li	C	NMC 95	O	O	
		Ca	NMC 95	O	O	
DY	A/D	C	FNAL-E772	O	O	O
		Ca		O (15)	O	O
		Fe		O (15)	O	O
		W		O (10)	O	O
	A/Be	Fe	FNAL E866	O	O	
		W		O	O	
π pro	dA/pp	Au	RHIC-PHENIX	O (20)		

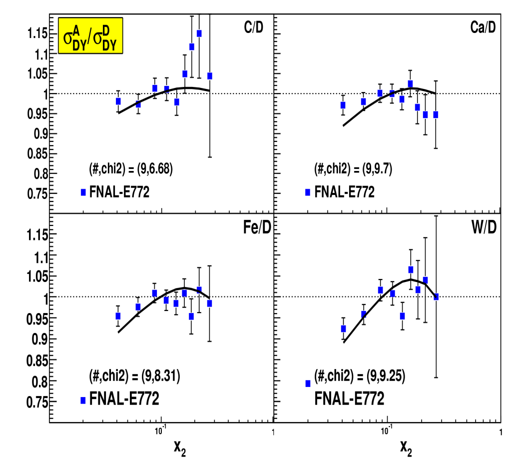
Table from Hirai et al, arXiv:0909.2329

Some results

PRD80(2009)

- 708 (1233) data points after (before) cuts
- 32 free paramters; 675 d.o.f.
- overall $\chi^2/dof = 0.95$
- individually:
  - for F_2^A/F_2^D: $\chi^2/pt = 0.92$
  - for $F_2^A/F_2^{A'}$: $\chi^2/pt = 0.69$
  - for DY: $\chi^2/pt = 1.08$





- **Our nCTEQ formalism works!**

III. Analysis of lA+DY + νA data

PRL106(2011)122301

Include neutrino data

Correlated errors!

Radiative correct.

with and w/o iso-scalar corrections

ID	$\mathbf{d\sigma^{\nu A}/dxdy}$: Observable	Experiment	# data
33	Pb	CHORUS ν	607 (412)
34	Pb	CHORUS $\bar{\nu}$	607 (412)
35	Fe	NuTeV ν	1423 (1170)
36	Fe	NuTeV $\bar{\nu}$	1195 (966)
37	Fe	CCFR ν di-muon	44 (44)
38	Fe	NuTeV ν di-muon	44 (44)
39	Fe	CCFR $\bar{\nu}$ di-muon	44 (44)
40	Fe	NuTeV $\bar{\nu}$ di-muon	42 (42)
	Total:		4006 (3134)

strange PDF

Fits to lA + DY + νA data

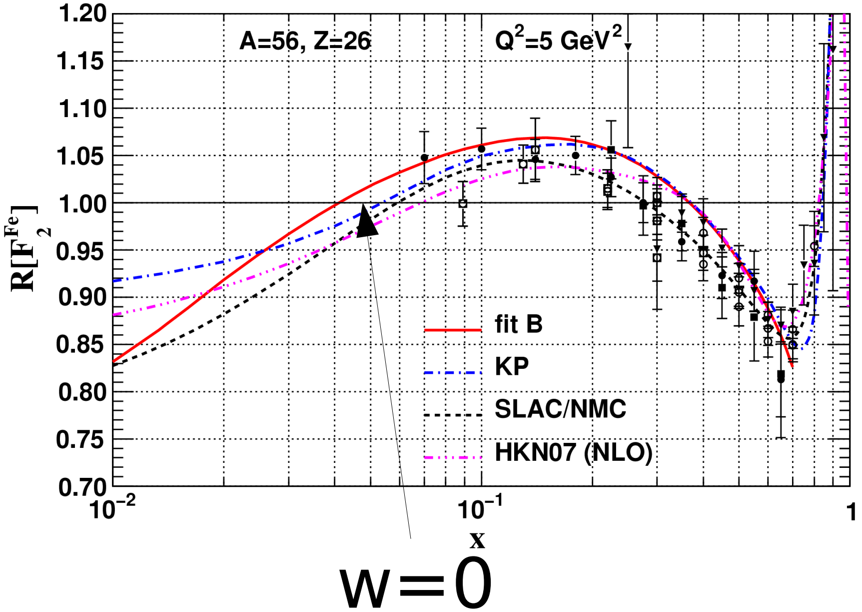
PRL106(2011)122301

- lA and DY data set as before
- Many neutrino data points
- Use a weight parameter w to combine data sets:

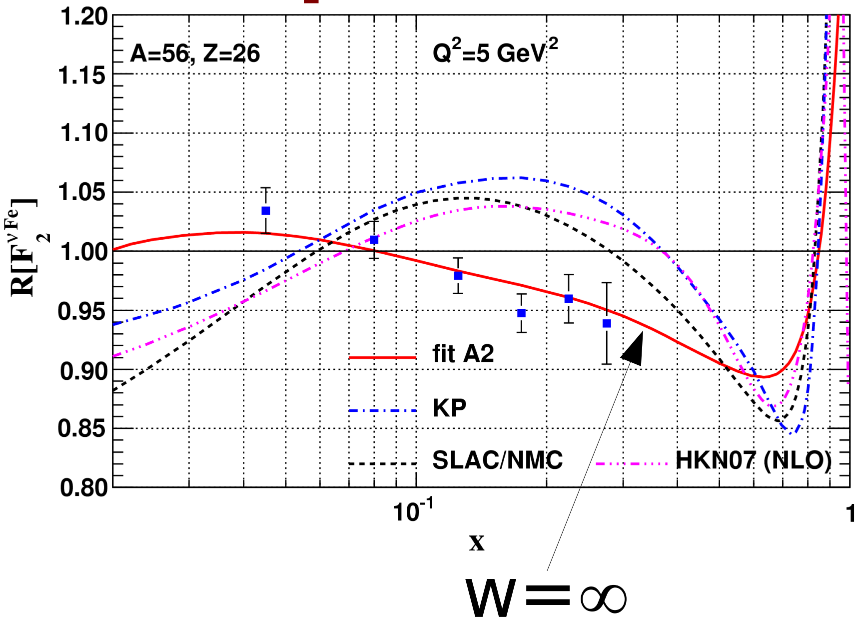
w=0: only lA+DY data $\rightarrow$ describes lA+DY data

w=∞: only νA data $\rightarrow$ describes neutrino data

$R[F_2^{lFe}]$, lA DIS data



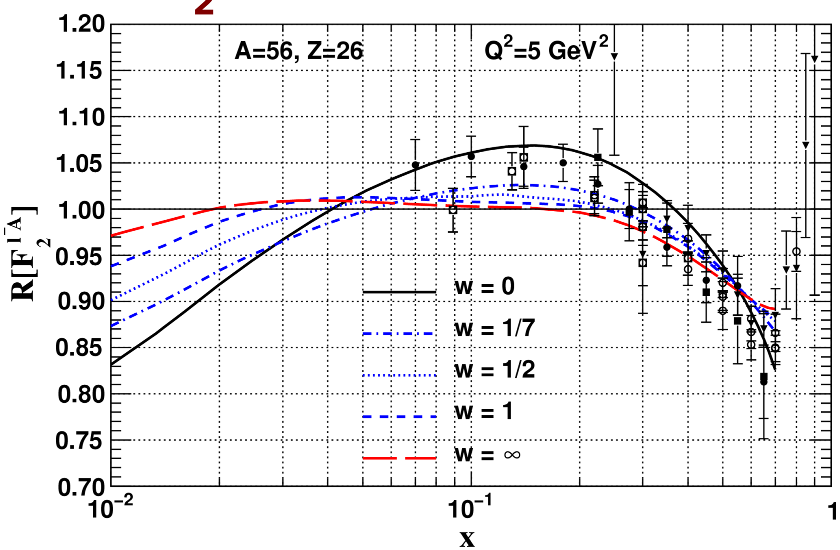
$R[F_2^{\nu Fe}]$, νA DIS data



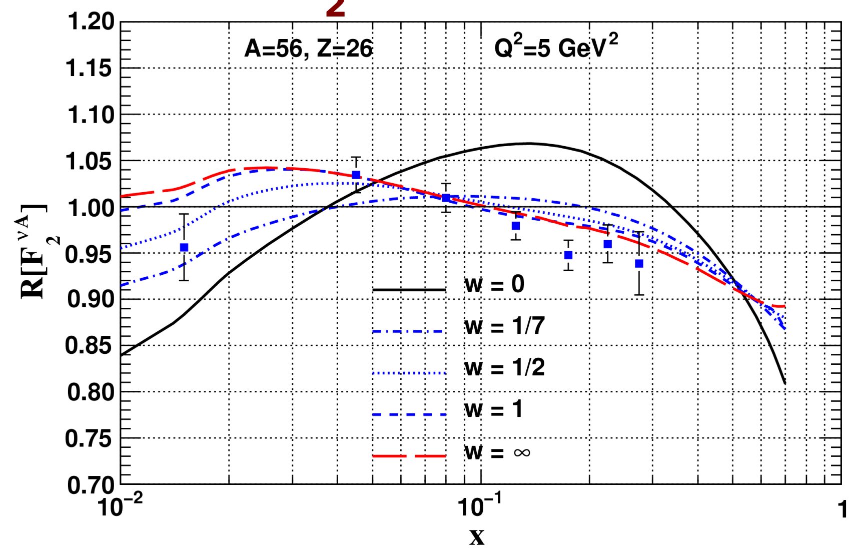
Nuclear correction factors

Weight	ℓ data	χ^2 (/pt)	ν data	χ^2 (/pt)	total χ^2 (/pt)
$w = 0$	708	639 (0.90)	-	-	639 (0.90)
$w = 1/7$	708	645 (0.91)	3134	4710 (1.50)	5355 (1.39)
$w = 1/4$	708	654 (0.92)	3134	4501 (1.43)	5155 (1.34)
$w = 1/2$	708	680 (0.96)	3134	4405 (1.40)	5085 (1.32)
$w = 1$	708	736 (1.04)	3134	4277 (1.36)	5014 (1.30)
$w = \infty$	-	-	3134	4192 (1.33)	4192 (1.33)

$R[F_2^{lFe}]$: w=0,1/7,1/4 ok



$R[F_2^{\nu Fe}]$: w=1,∞ ok



No good compromise fit describing lA+DY **and** νA data!

Discussion

- **Nuclear correction factors**: there is no good compromise fit to the combined lA+DY+νA data

- Same conclusion based on a **tolerance criterion**. See PRL106(2011)122301 for details

- Incompability is a "precision effect": the result changes when using uncorrelated errors

- The incompability could be due to:
  - factorization breaking (at twist-2 level)
  - nuclear enhanced higher twist terms

Conclusions

- Nuclear correction factors in νA and lA DIS different

- Global nCTEQ fits able to describe lA+DY data well:
  - see **http://projects.hepforge.org/ncteq/**

- There is **no** good compromise fit to the combined lA+DY+νA data

- Important consequences for
  - global analyses of proton and nuclear PDF
  - models explaining the nuclear effects
  - precision observables in the neutrino sector