Nuclear Parton Distribution Function (PDF)

Nuclear Corrections & Uncertainties
for LHC & Beyond

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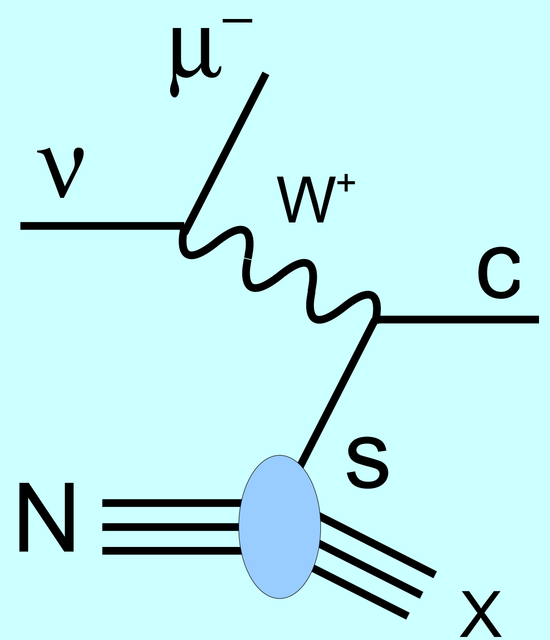
Conspirators:
I Schienbein, J.-Y. Yu,
J. Owens, J. Morfin, C. Keppel, ...

Ringberg
6 October 2008

Heavy Target Data Essential for Determining Separate Parton Flavors

- Charged Current Neutrino data complement Neutral Current to extract PDF flavors
- Neutrino data requires heavy targets (Fe, Pb)
- Nuclear Corrections must be applied to heavy target data.

Neutrino Charm Production: can determine s(x)



Tension between data sets

Charged Current (CC) & Neutral Current (NC) DIS

CC: Heavy Targets
NC: Light Targets

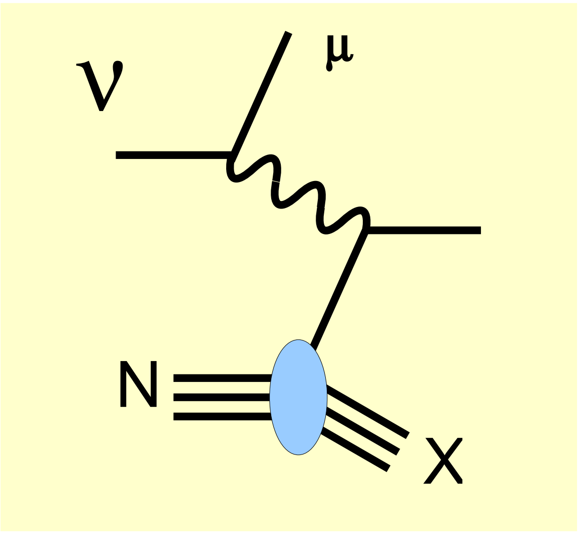
NuTeV Neutrino DIS & E866 Drell-Yan

affects d/u ratio

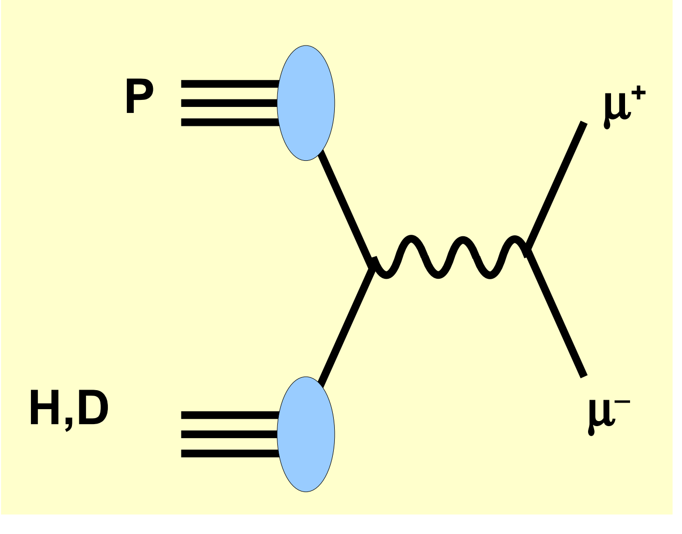
NEW DATA SETS

New & Updated Data Sets

Deeply Inelastic Scattering



Drell-Yan



NuTeV

Neutrinos on Iron
$\langle E_\nu \rangle = 120$ GeV
860K nu
230K nubar
1170+966 points

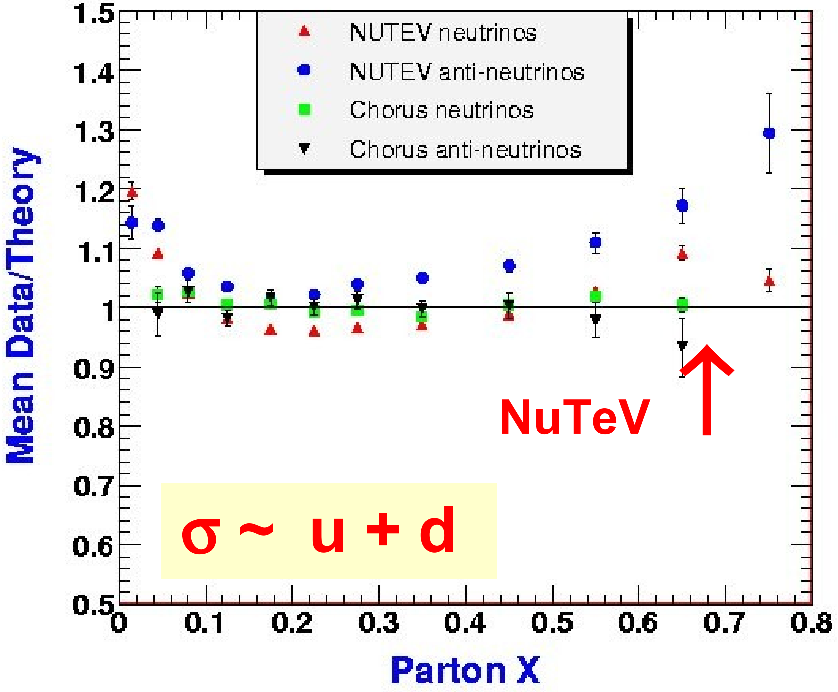
Chorus

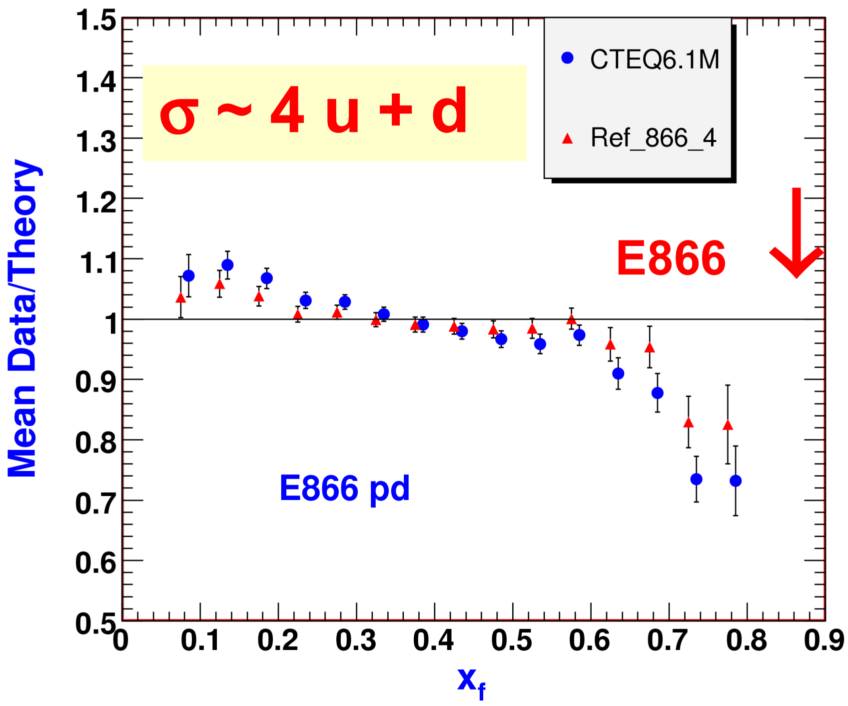
Neutrinos on lead
$0.01 < x < 0.7$
$10 < E_\nu < 200$ GeV
$p_\mu > 5$ GeV
412 points

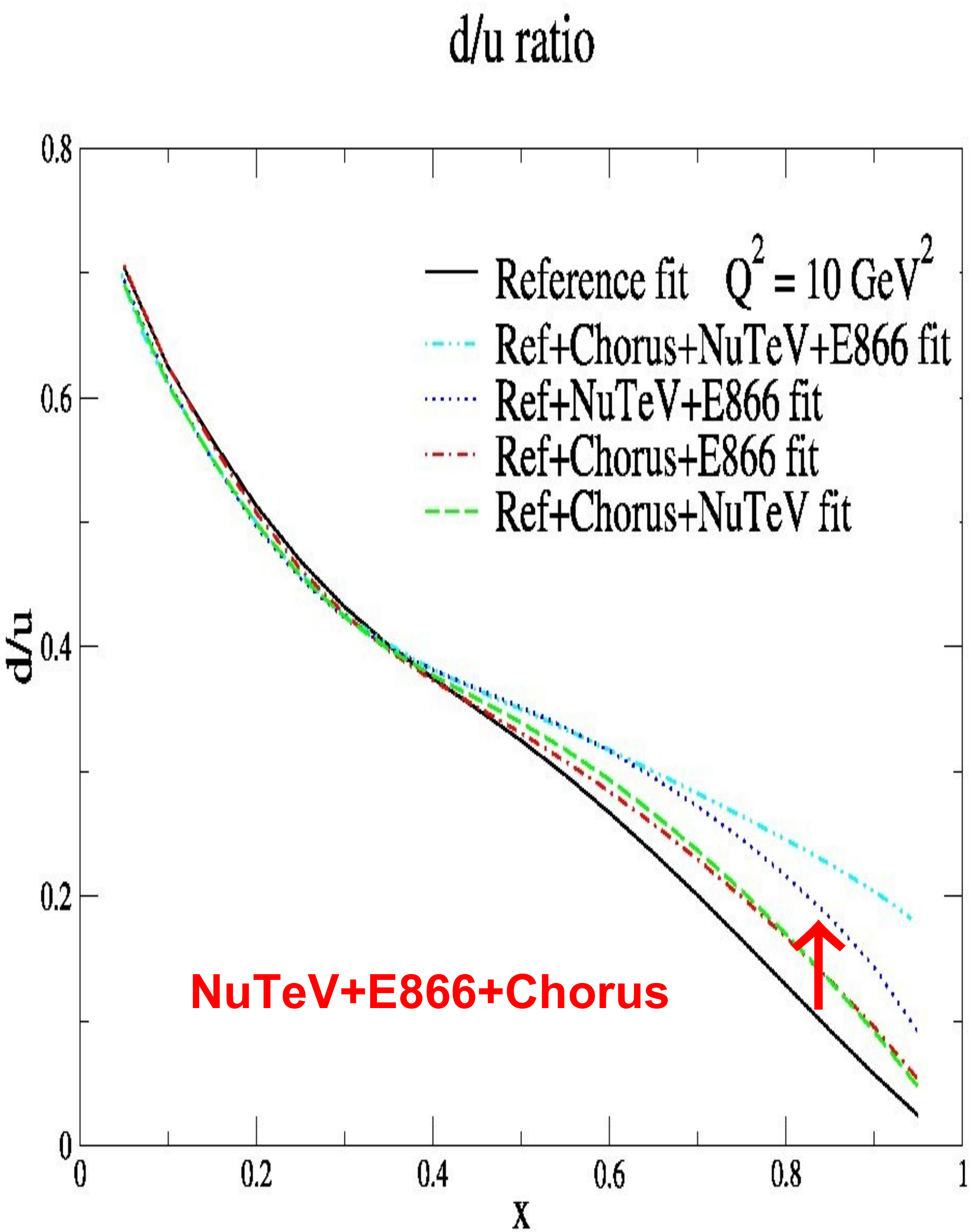
E866 NuSea:

800 GeV proton beam
on hydrogen & deuterium
140K DY muon pairs
$M_{\mu\mu} > 4.5$GeV *(Hi Mass)*
$0.020 < x < 0.345$
184+191 points

How do new data affect the PDF's

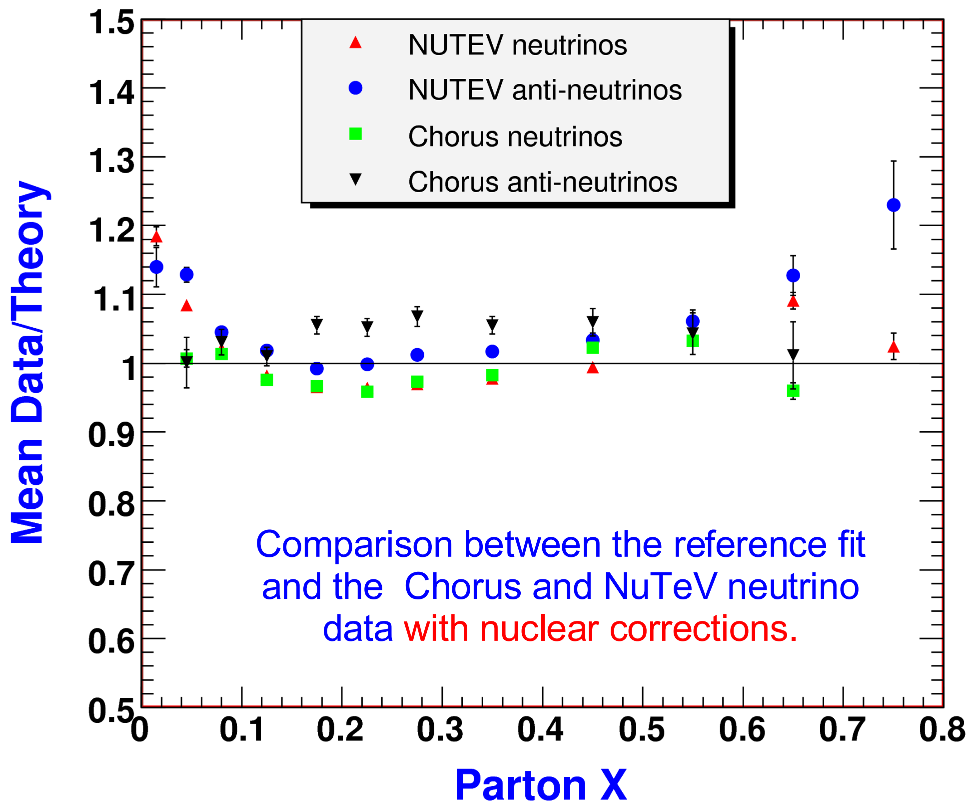


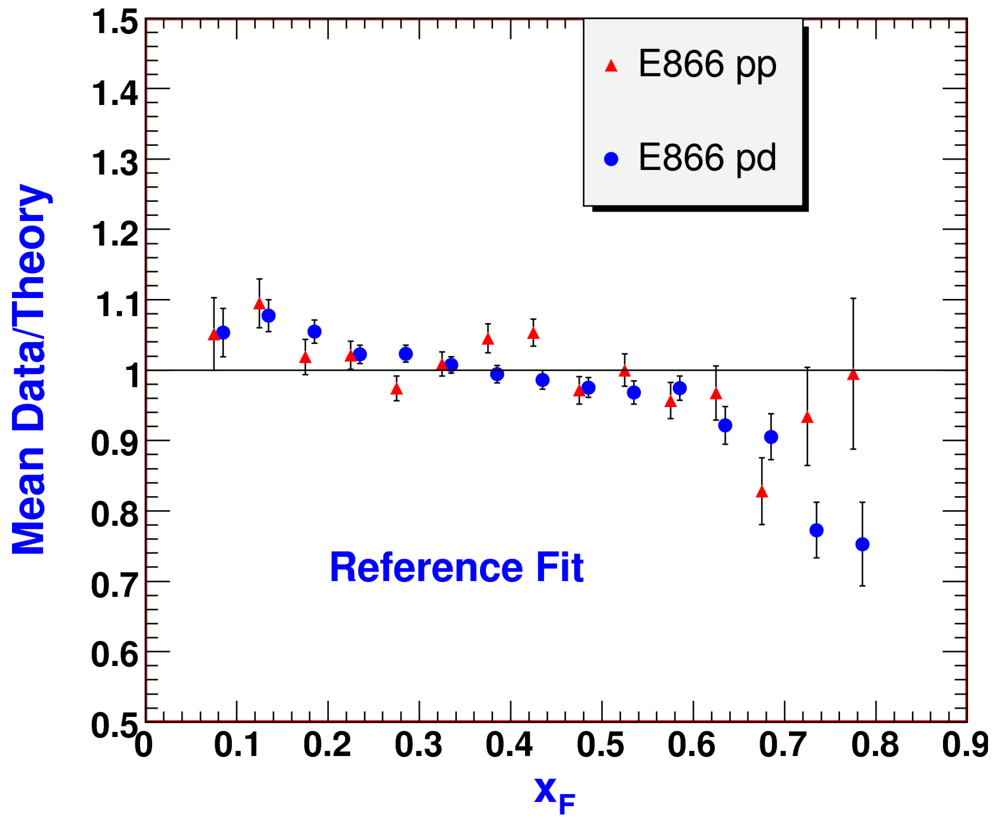




J.F. Owens, J. Huston, C.E. Keppel, S. Kuhlmann, J.G. Morfin, F. Olness, J. Pumplin, D. Stump, Phys.Rev.D75:054030,2007.

Could nuclear corrections be different for CC (W) or NC (γ,Z) processes???





"Thus, these results suggest on a purely phenomenological level that the nuclear corrections may well be very similar for the nu and nubar cross sections and that the overall magnitude of the corrections may well be smaller than in the model used in this analysis."

χ=7453/5062   Reference Fit
χ=6606/5062   Mod Nuclear Fit

Owens, Huston, Keppel, Kuhlmann, Morfin, Olness, Pumplin, Stump. Phys.Rev.D75:054030,2007.

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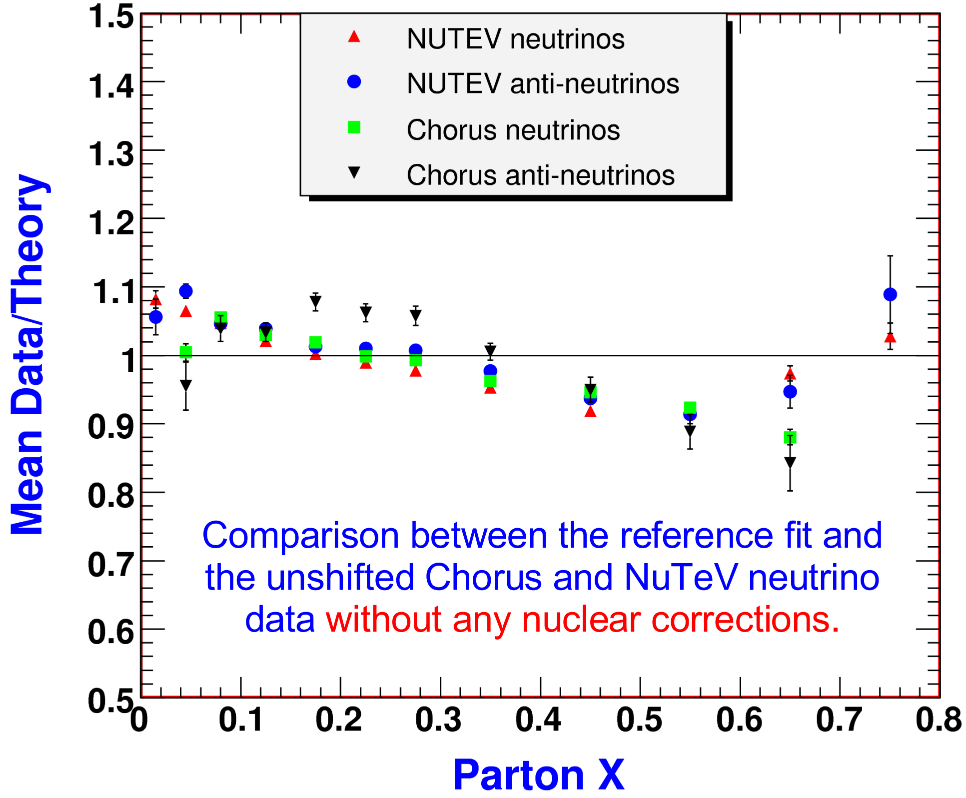

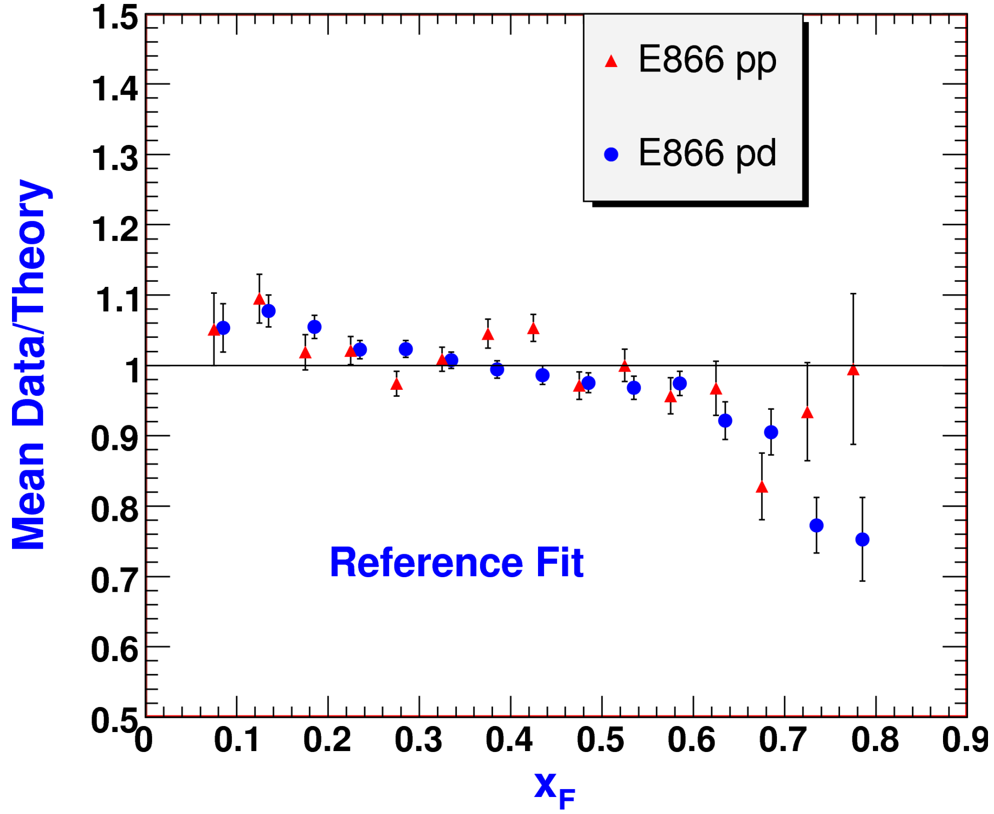

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TMC

Target Mass Corrections

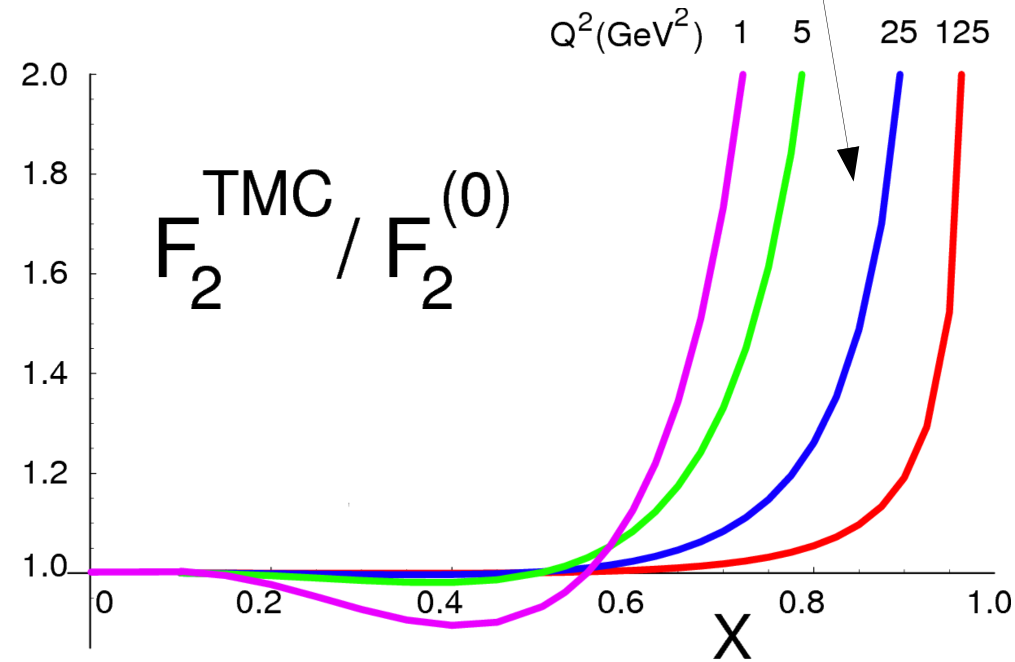
A Review of Target Mass Corrections:

$$F_j^{\mathrm{TMC}}(x,Q^2) = \sum_{i=1}^{5} A_j^i F_i^{(0)}(\eta,Q^2) + B_j^i h_i(\eta,Q^2) + C_j g_2(\eta,Q^2)$$

leading term; from Parton Model

- Obtain general structure:
- Valid at any order: LO, NLO,...
- Quark masses are included; both m_i and m_f
- Recover known results
  - Georgi, Politzer
  - Barbieri et al
  - Kretzer & Reno
- **The definitive reference for TMC**

TMC important at large x, small Q^2



A Review of Target Mass Corrections. Ingo Schienbein, Voica A. Radescu, G.P. Zeller, M. Eric Christy, C.E. Keppel, Kevin S. McFarland, W. Melnitchouk, Fredrick I. Olness, Mary Hall Reno, Fernando Steffens, Ji-Young Yu. **J.Phys.G35:053101,2008.**

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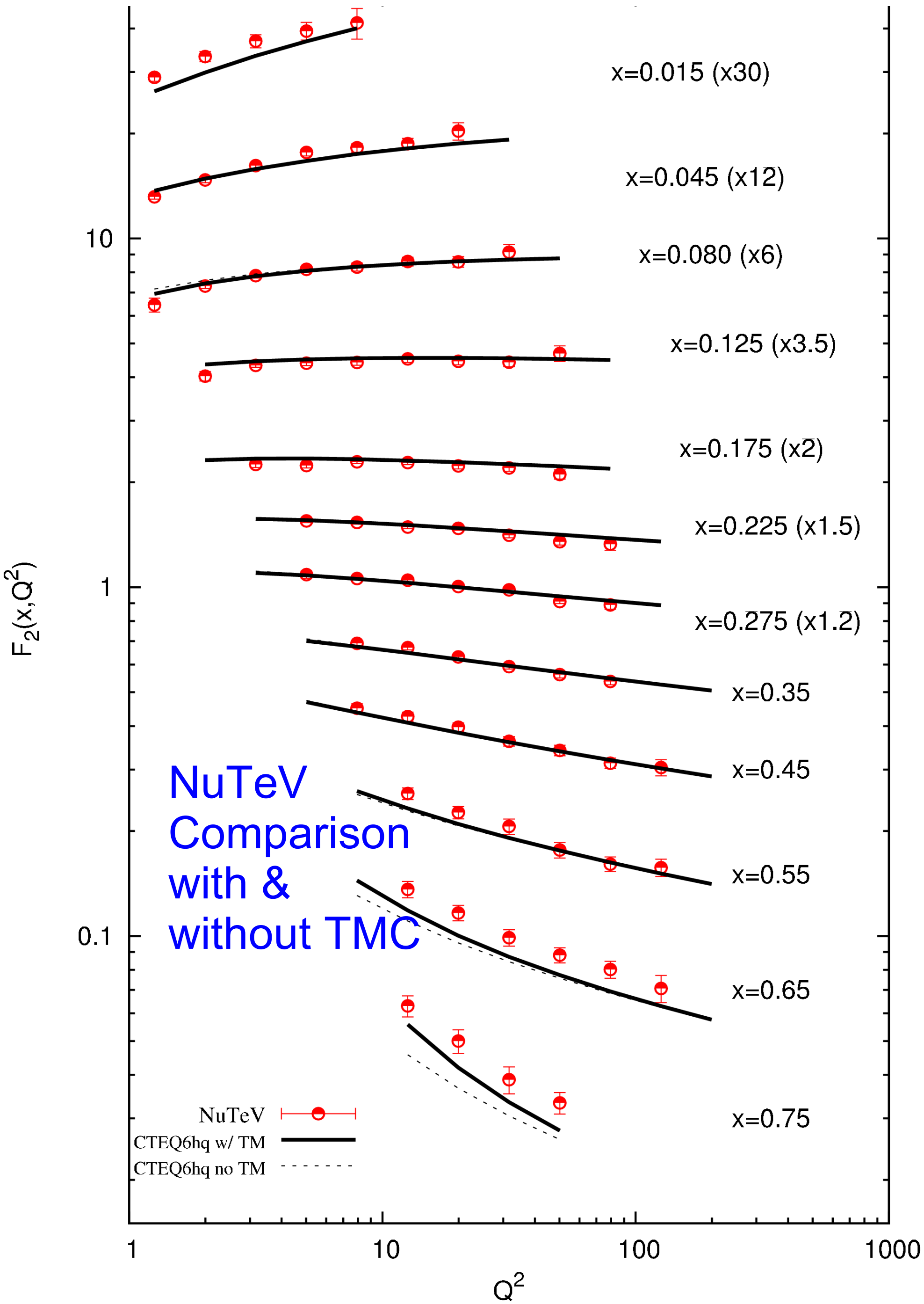
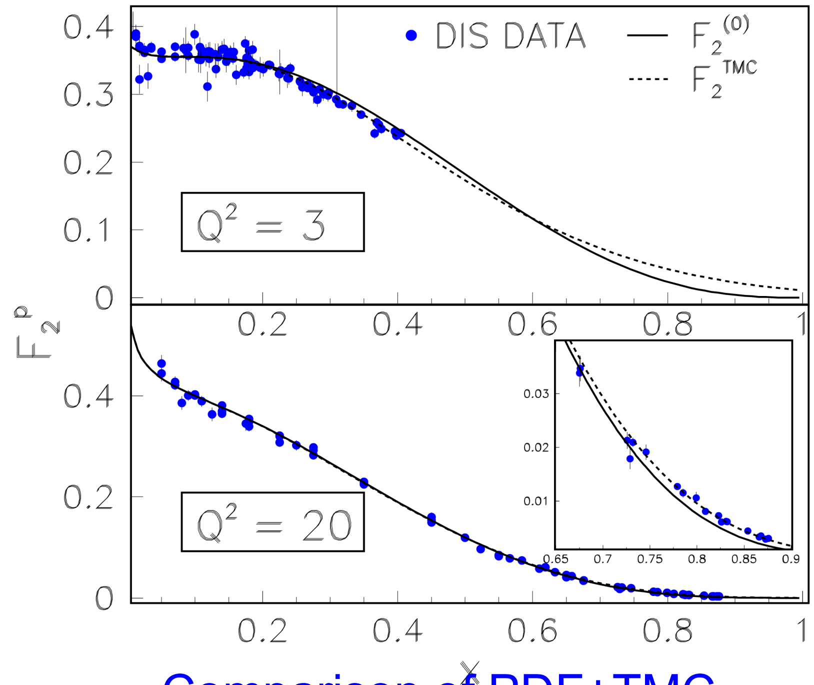
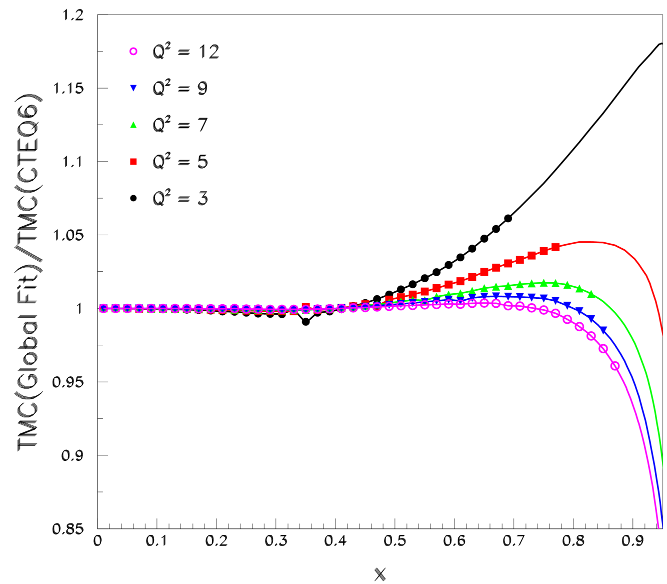




Comparison of PDF+TMC vs “Unfolding” Method

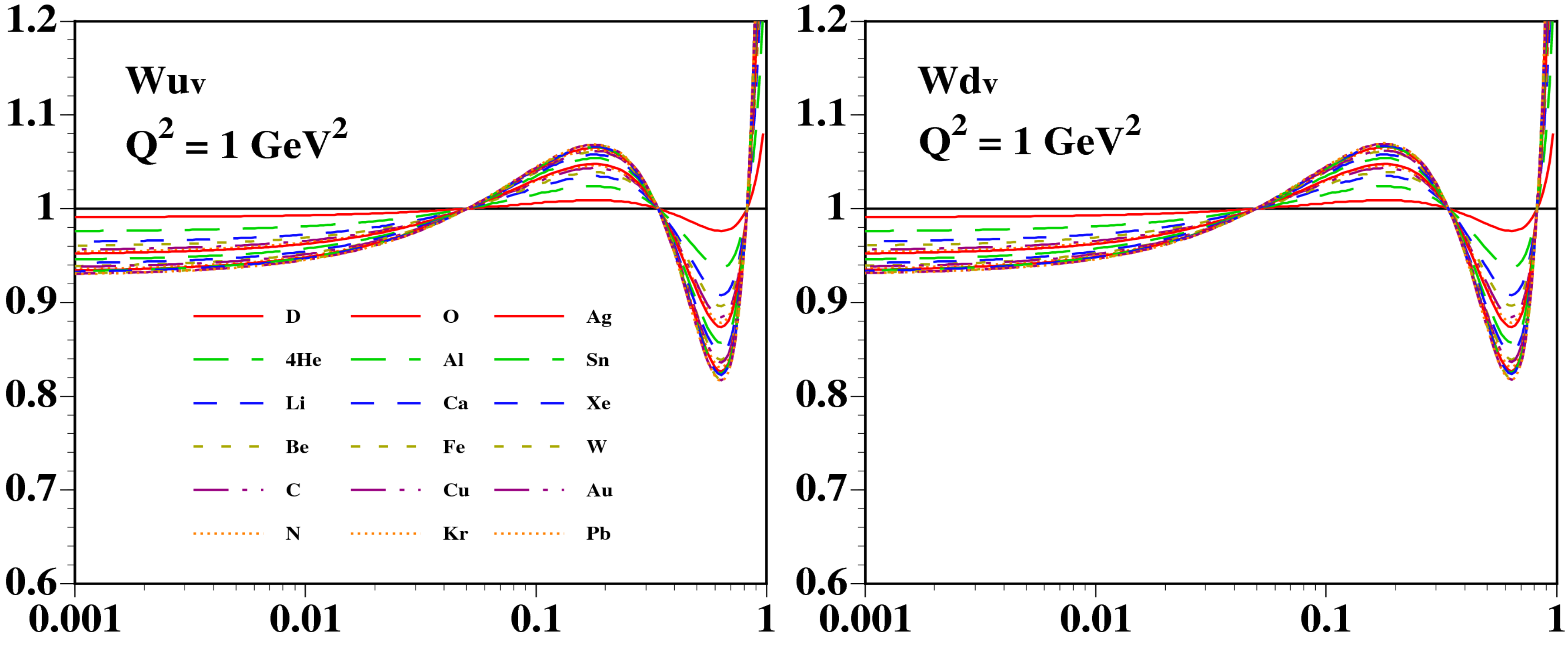


Nuclear PDFs

Recent work in Nuclear PDFs: *Hirai, Kumano, Nagai*

$$f_i^A(x,Q_0^2) = w_i(x,A,Z)\ \ f_i(x,Q_0^2)$$

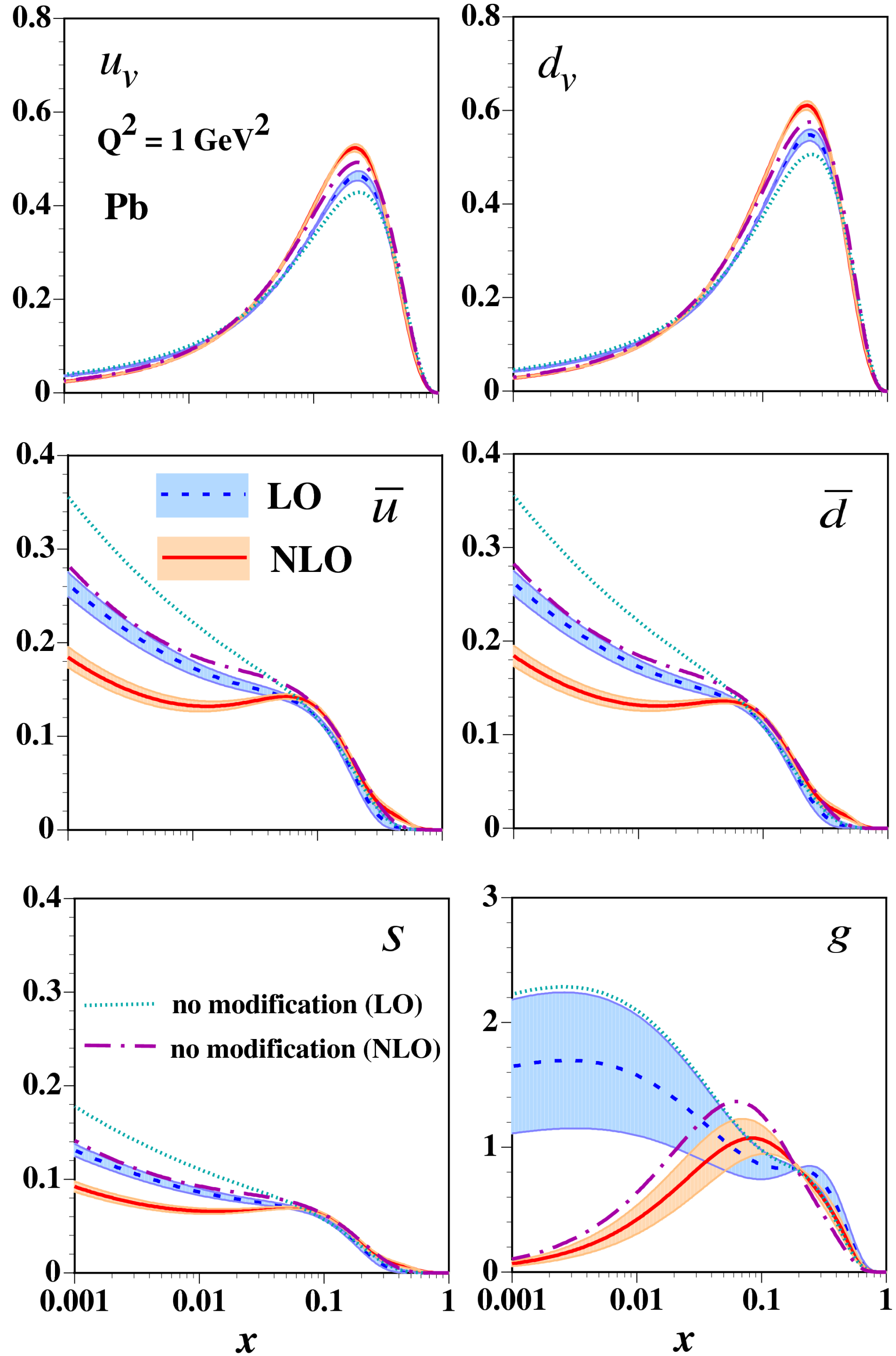
$$w_i(x,A,Z) = 1 + \left(1 - \frac{1}{A^\alpha}\right)\frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}$$



Hirai, Kumano, Nagai, Phys.Rev.C76:065207,2007.

Recent work in Nuclear PDFs: *Hirai, Kumano, Nagai*

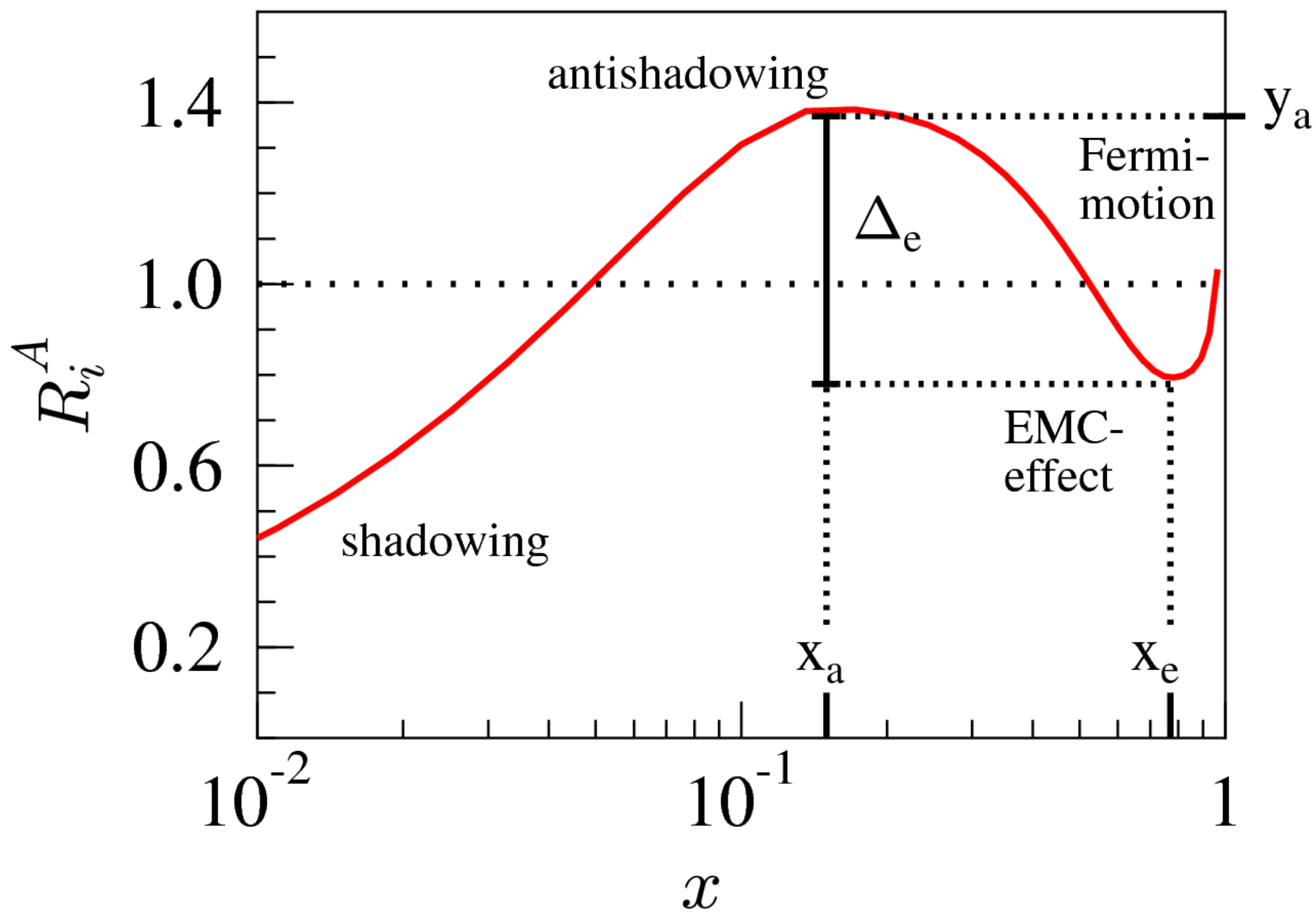
Lead nPDFs



Hirai, Kumano, Nagai,
Phys.Rev.C76:065207,2007.

Recent work in Nuclear PDFs: *Eskola, Paukkunen, Salgado*

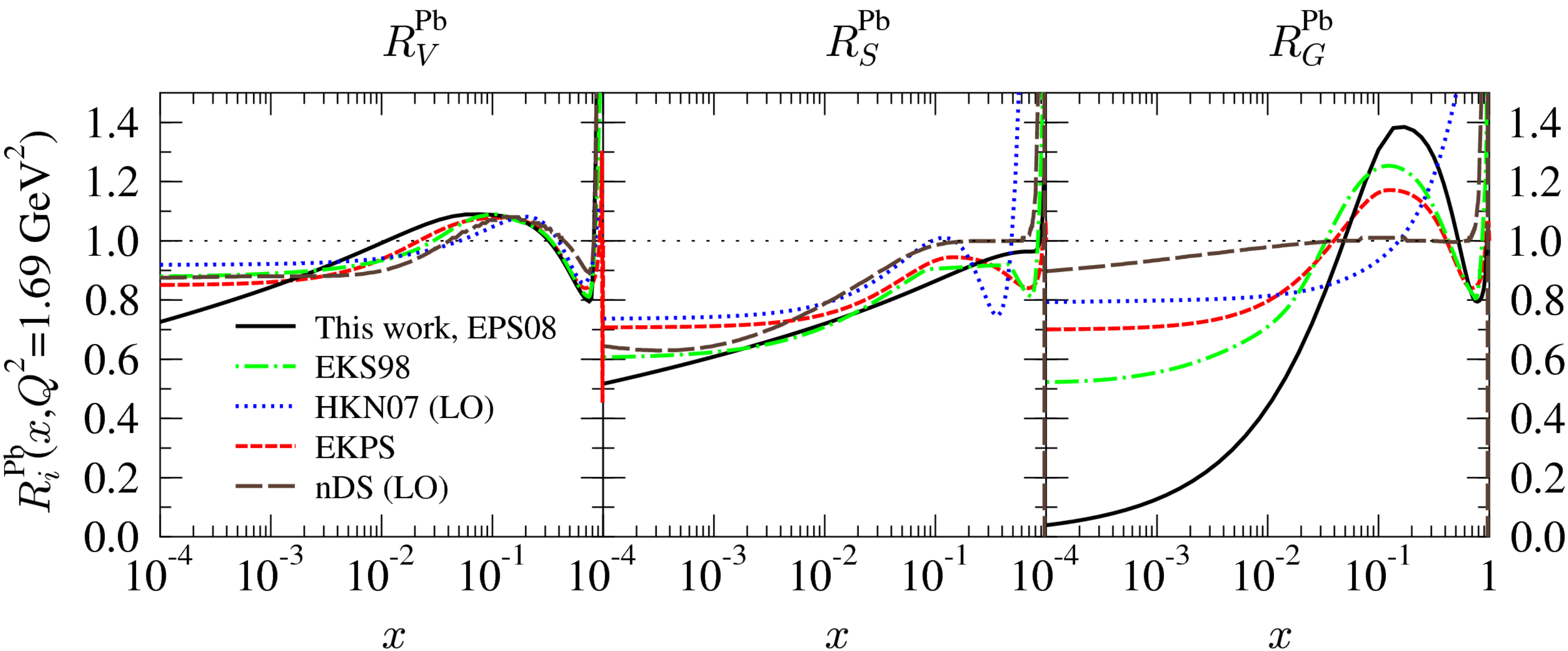
$$f_i^A(x,Q^2) = R_i^A(x,Q^2)\ f_i(x,Q^2)$$



$$
\begin{aligned}
R_1^A(x) &= c_0^A + (c_1^A + c_2^A x^{\alpha^A})[\exp(-x/x_s^A) - \exp(-x_a^A/x_s^A)], && x \le x_a^A \\
R_2^A(x) &= a_0^A + a_1^A x + a_2^A x^2 + a_3^A x^3, && x_a^A \le x \le x_e^A \\
R_3^A(x) &= \frac{b_0^A - b_1^A x}{(1-x)^{\beta^A}} + b_2^A (x - x_e)^2, && x_e^A \le x \le 1.
\end{aligned}
$$

Eskola, Paukkunen, Salgado, JHEP 0807:102,2008.

Recent work in Nuclear PDFs: *Eskola, Paukkunen, Salgado*



Eskola, Paukkunen, Salgado, JHEP 0807:102,2008.

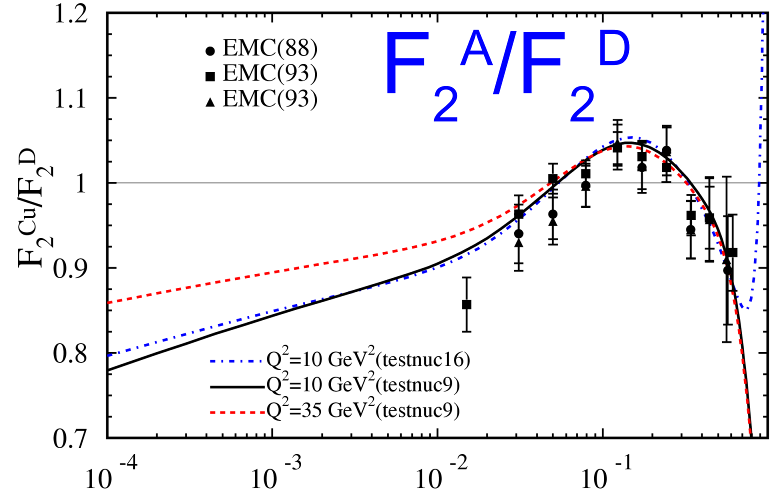
Relate general Nuclear A to A=1 (proton)

Allows CTEQ PDFs as a simple limit

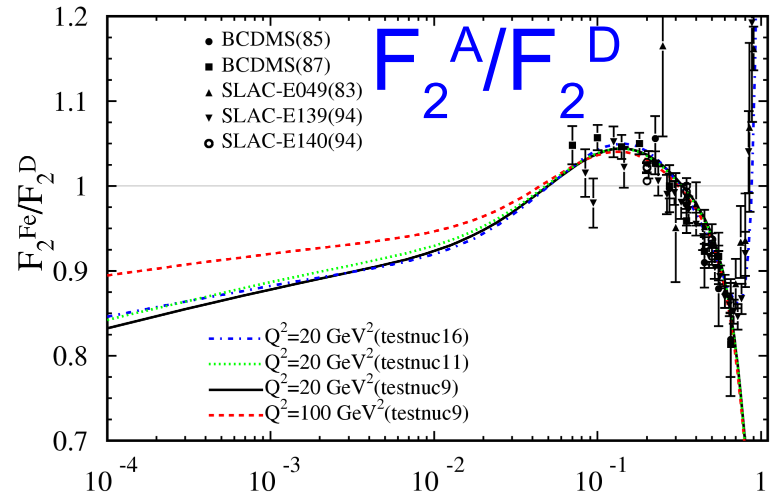
Nuclear PDF and Correction Factors

- ✔ CTEQ global fit extended
  can handle various nuclear targets
- ✔ CTEQ Data + nuclear DIS & DY
  [~15 targets; ~2000+ data]
- ✔ A-dependence modeled;
  NLO fits work well

Nuclear Corrections affect proton PDFs



Copper/Deuterium



Iron/Deuterium

x

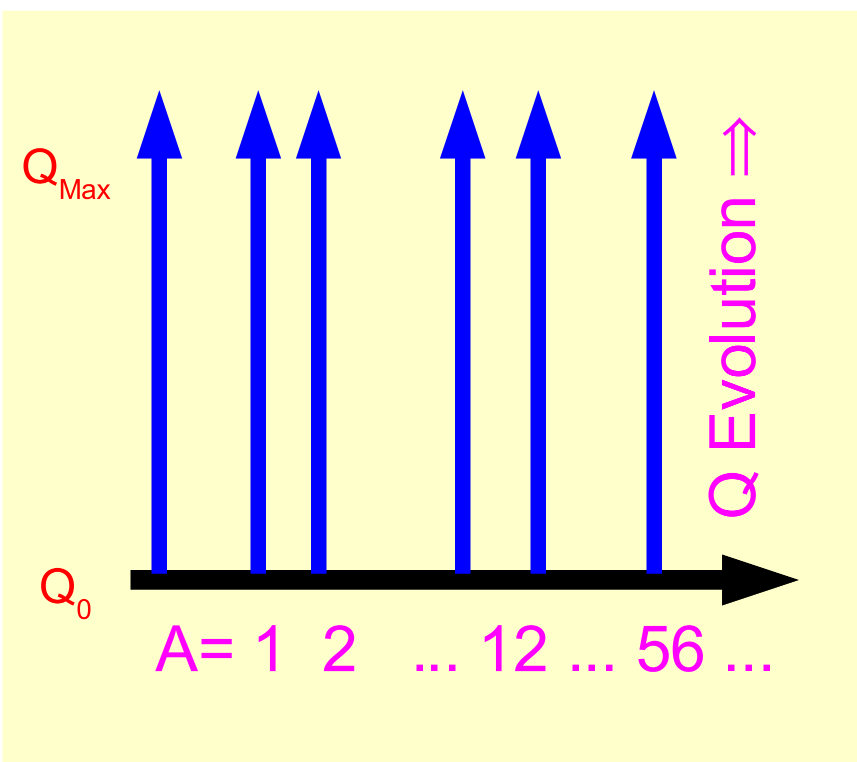
Nuclear PDFs from neutrino deep inelastic scattering.
I. Schienbein, J.Y. Yu, C. Keppel, J.G. Morfin, F. Olness, J.F. Owens.
Phys.Rev.D77:054013,2008.

Nuclear PDF evolution

$$xf(x) = x^{a_1}(1-x)^{a_2}e^{a_3 x}(1+e^{a_4}x)^{a_5}$$

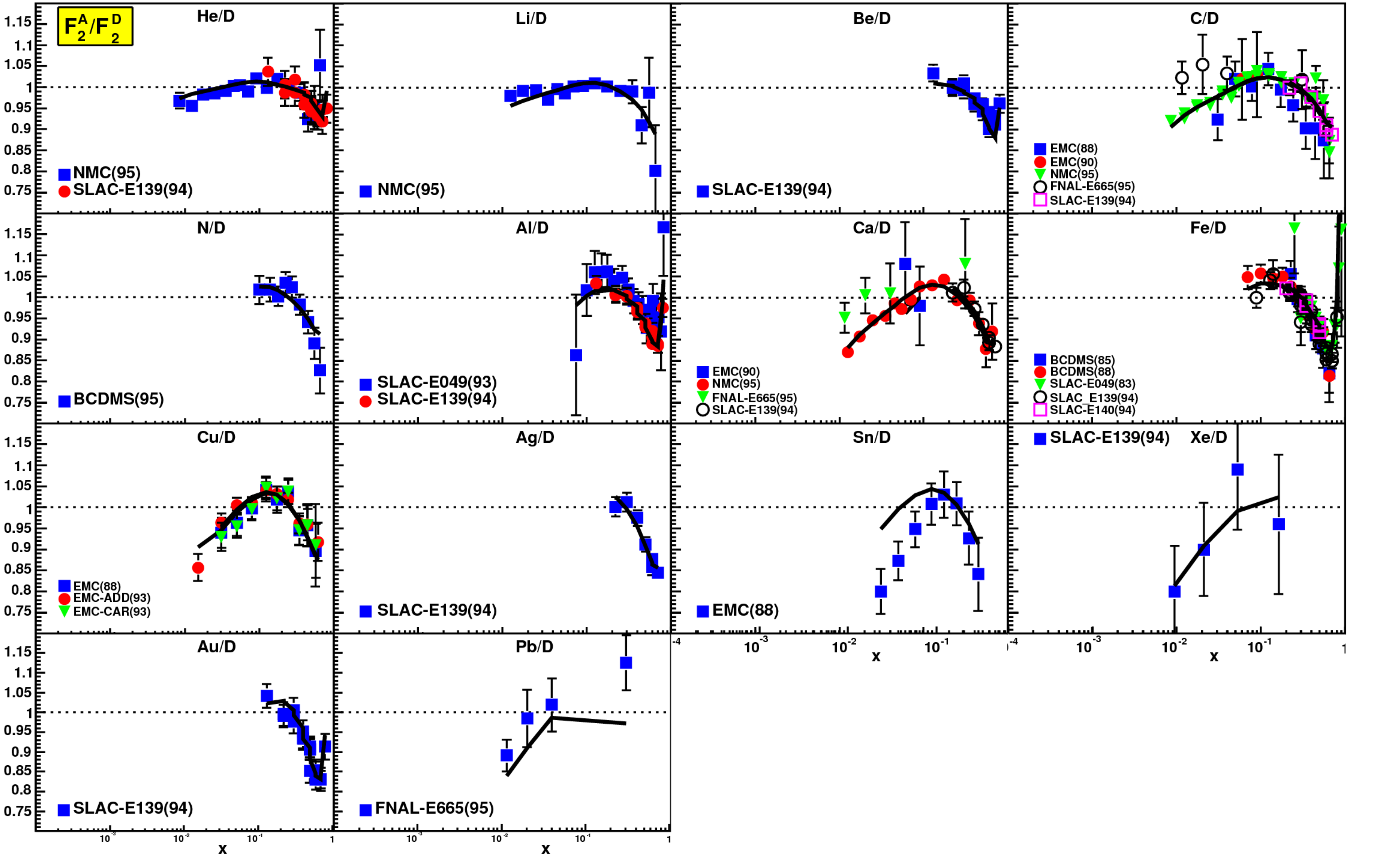
$$a_i \rightarrow a_i(A)$$

$$a_k = a_{k,0} + a_{k,1}(1 - A^{-a_{k,2}})$$

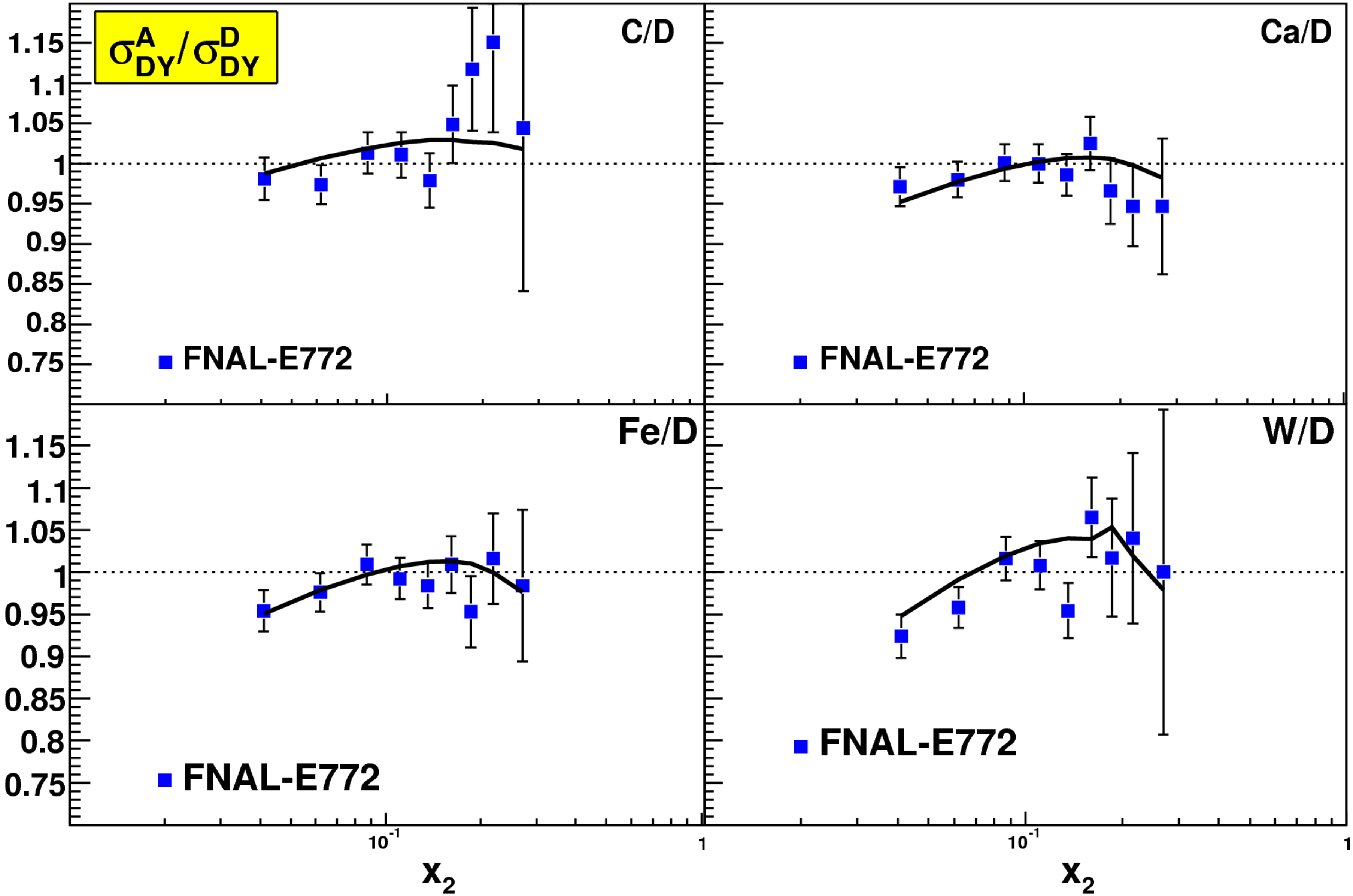


Observable	Experiment	Ref.	# data	χ^2 A1L	χ^2 A1M	χ^2 A1A	ID
F_2^A/F_2^D :							
He/D	SLAC-E139	[18]	18	9.8	6.82	6.28	5141
	NMC-95,re	[19]	16	35.6	16.91	18.31	5124
	Hermes	[20]	92	134.0	72.14	71.05	5156
Li/D	NMC-95	[21]	15	45.0	18.80	19.68	5115
Be/D	SLAC-E139	[18]	17	52.7	21.48	20.75	5138
C/D	EMC-88	[22]	9	10.3	7.29	7.11	5107
	EMC-90	[23]	2	0.2	0.14	0.11	5110
	SLAC-E139	[18]	7	31.3	4.06	4.51	5139
	NMC-95,re	[19]	16	13.9	16.12	16.62	5114
	NMC-95	[21]	15	13.9	7.13	7.26	5113
	FNAL-E665-95	[24]	4	23.4	8.81	8.29	5125
N/D	BCDMS-85	[25]	9	12.1	6.94	7.26	5103
	Hermes	[20]	92	94.5	62.42	58.94	5157
Al/D	SLAC-E049	[26]	18	32.2	20.42	20.38	5134
	SLAC-E139	[18]	17	22.12	6.50	8.05	5136
Ca/D	EMC-90	[23]	2	5.5	1.47	1.37	5109
	SLAC-E139	[18]	7	14.2	2.07	1.53	5140
	NMC-95,re	[19]	15	48.6	12.75	13.74	5121
	FNAL-E665-95	[24]	4	16.2	7.88	7.67	5126
Fe/D	BCDMS-85	[25]	6	5.3	3.91	4.39	5102
	BCDMS-87	[27]	10	35.0	8.58	9.81	5101
	SLAC-E049	[28]	14	8.8	10.39	6.24	5131
	SLAC-E139	[18]	23	43.4	35.14	35.31	5132
	SLAC-E140	[29]	6	16.8	2.93	4.87	5133
Cu/D	EMC-88	[22]	9	7.1	4.24	4.47	5106
	EMC-93(addendum)	[30]	10	14.4	6.13	6.89	5104
	EMC-93(chariot)	[30]	9	9.8	6.18	6.53	5105
Kr/D	Hermes	[20]	84	120.7	64.53	62.98	5158
Ag/D	SLAC-E139	[18]	7	22.5	4.04	2.88	5135
Sn/D	EMC-88	[22]	8	28.3	19.82	20.09	5108
Xe/D	FNAL-E665-92(em cut)	[31]	4	4.0	0.65	0.61	5127
Au/D	SLAC-E139	[18]	18	48.6	8.22	7.89	5137
Pb/D	FNAL-E665-95	[24]	4	20.3	7.77	7.45	5129
$F_2^A/F_2^{A'}$:							
Be/C	NMC-96	[32]	15	14.3	5.87	5.82	5112
Al/C	NMC-96	[32]	15	14.1	5.17	5.19	5111
Ca/C	NMC-95	[19]	20	21.7	31.47	35.73	5120
	NMC-96	[32]	15	19.8	5.39	5.31	5119
Fe/C	NMC-95	[32]	15	25.9	9.54	9.35	5143
Sn/C	NMC-96	[33]	144	312.5	102.82	96.29	5159
Pb/C	NMC-96	[32]	15	13.4	7.31	8.09	5116
C/Li	NMC-95	[19]	20	49.7	21.82	20.37	5123
Ca/Li	NMC-95	[19]	20	38.3	24.62	23.53	5122
$\sigma_{DY}^{pA}/\sigma_{DY}^{pA'}$:							
C/D	FNAL-E772-90	[34]	9	14.3	7.26	6.88	5203
Ca/D	FNAL-E772-90	[34]	9	14.1	3.81	3.33	5204
Fe/D	FNAL-E772-90	[34]	9	21.7	3.71	3.15	5205
W/D	FNAL-E772-90	[34]	9	49.7	11.07	11.27	5206
Fe/Be	FNAL-E866-99	[35]	28	38.3	29.95	29.33	5201
W/Be	FNAL-E866-99	[35]	28	38.3	25.54	25.30	5202
Total:			958	1514.4	777.0	768.3	

Fit to Nuclear DIS Data



Fit to Nuclear DY Data



Make Nuclear "A" Dependence an ***Dynamic*** Component of Fit

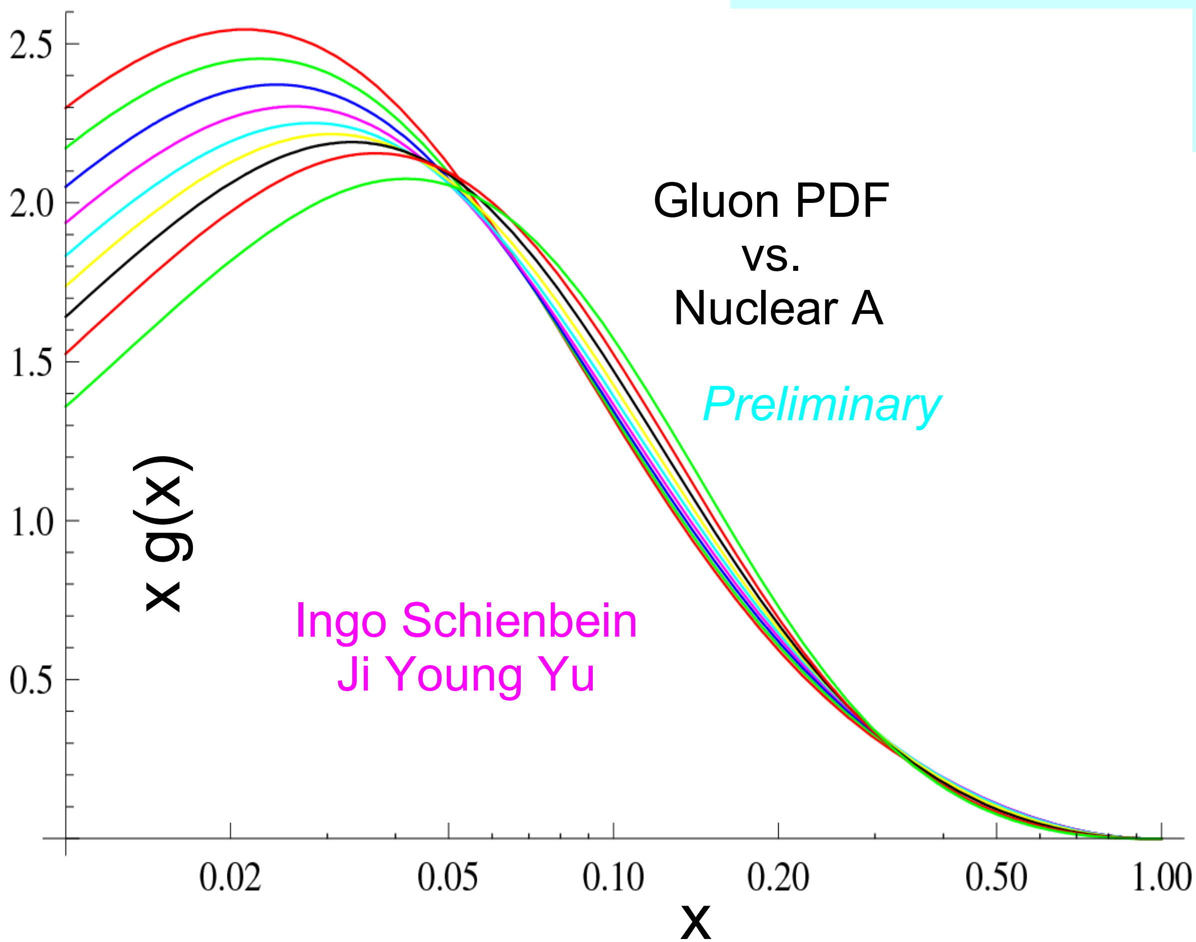
Yields full NLO nuclear PDFs: $f_i(x,Q,A)$

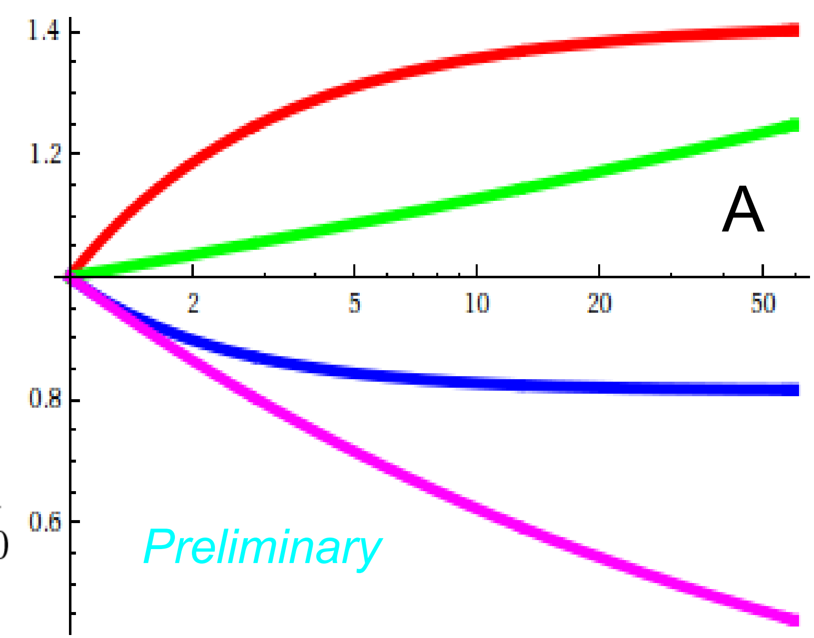
Designed to reduce to proton PDF in limit A→ 1

Nuclear corrections not written in stone!

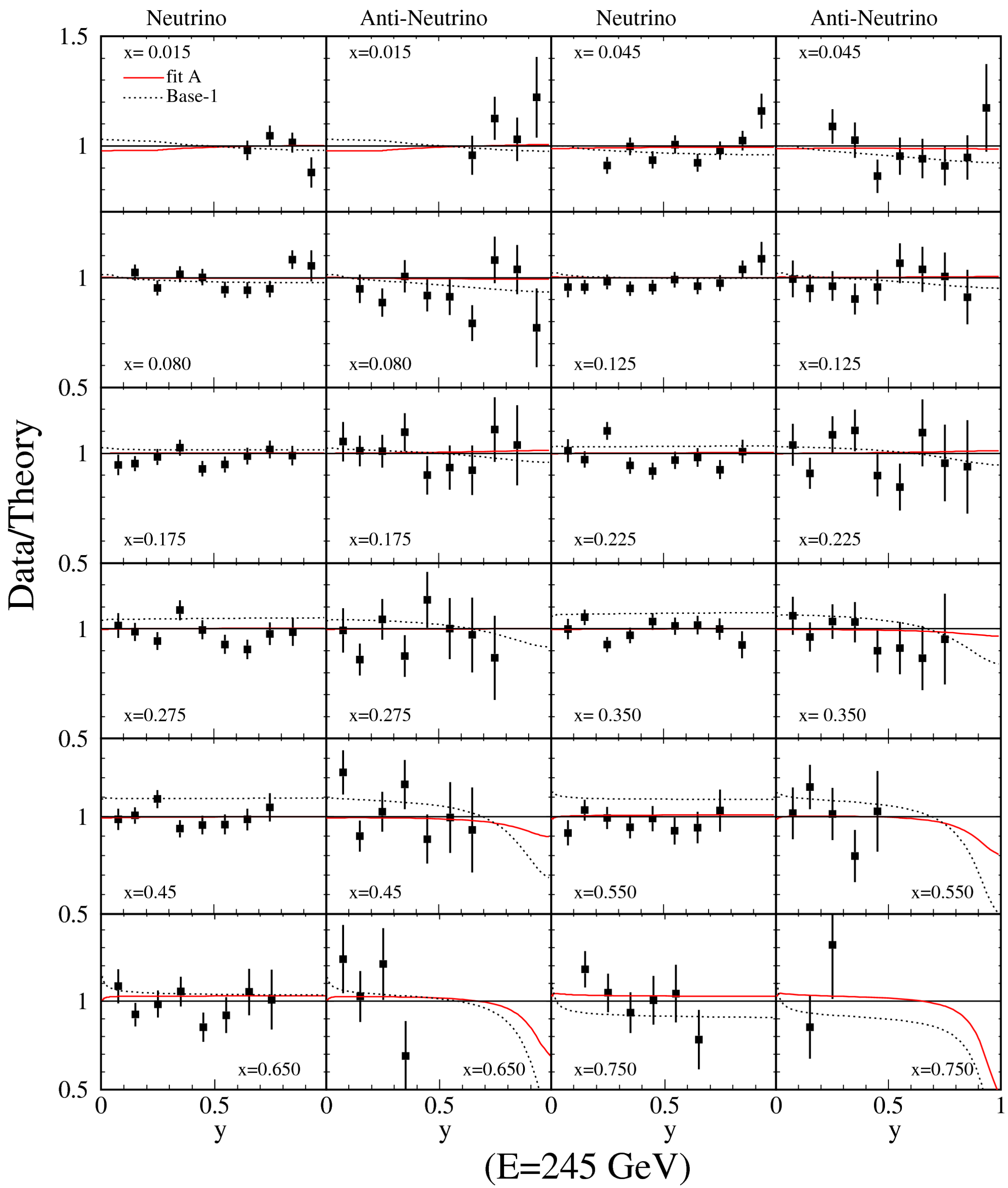
$$xf(x) = x^{a_1}(1-x)^{a_2}e^{a_3 x}(1+e^{a_4}x)^{a_5}$$

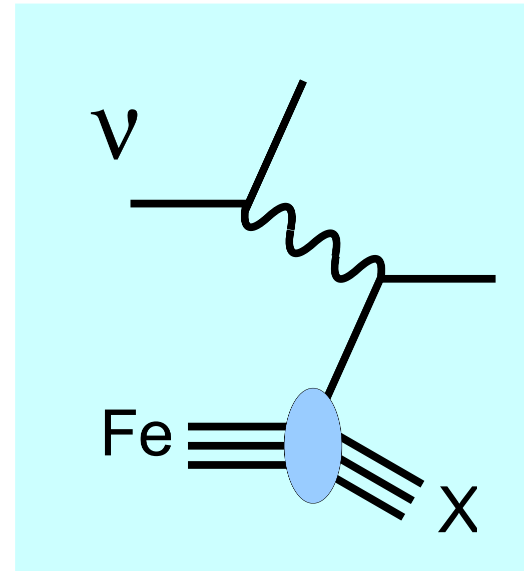
$$a_i \to a_i(A)$$





Use Nuclear Data to Extract Nuclear PDFs Directly: *(Model Independent)*





Comparison of
NuTeV Iron data
with
Nuclear PDF Fit

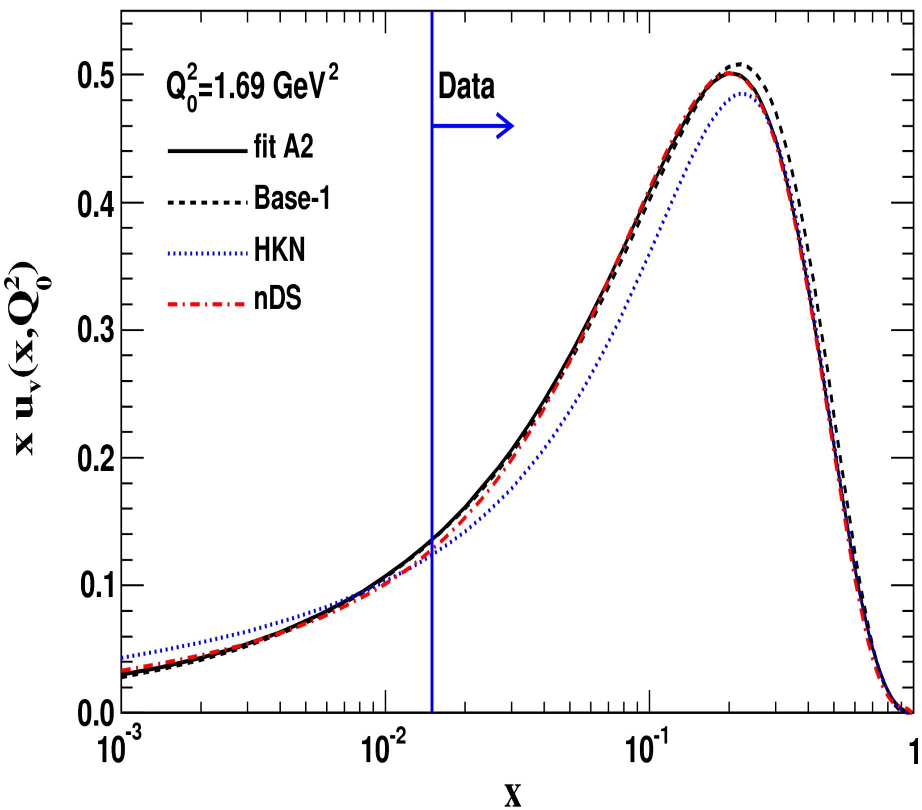
using CTEQ values

fix $g(x)$ & $\bar{d}/\bar{u}$

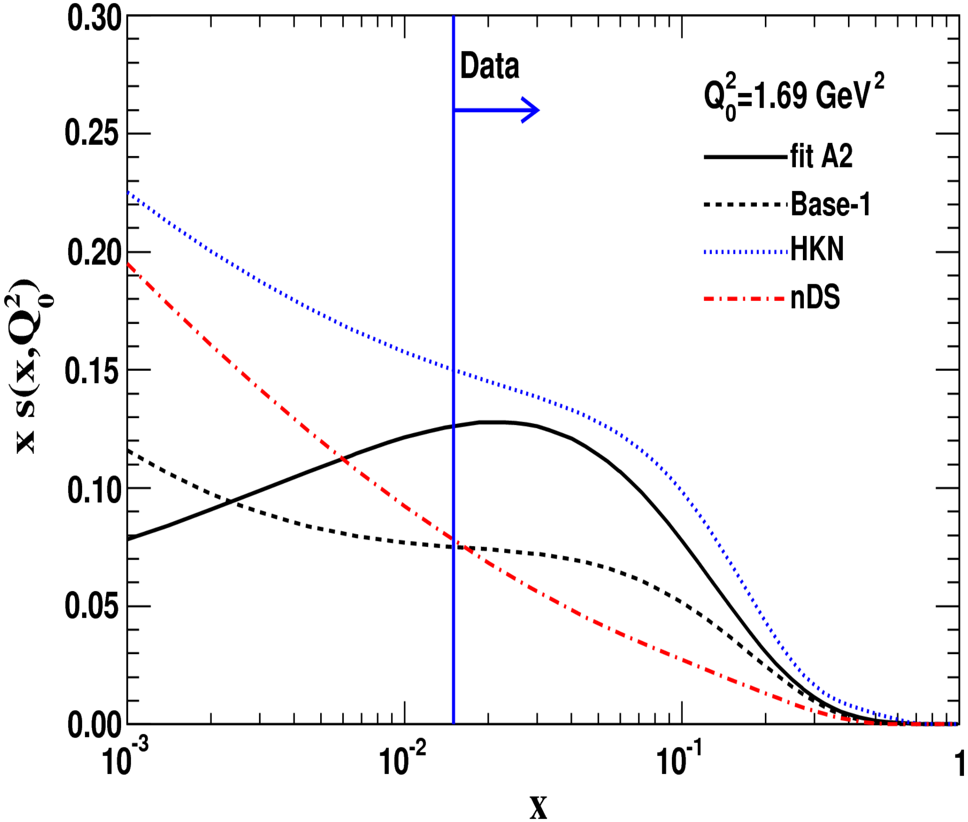
Schienbein, Yu, Keppel, Morfin, Olness, Owens, Phys.Rev.D77:054013,2008.

Use Nuclear Data to Extract Nuclear PDFs Directly: *(Model Independent)*

u(x,Q)

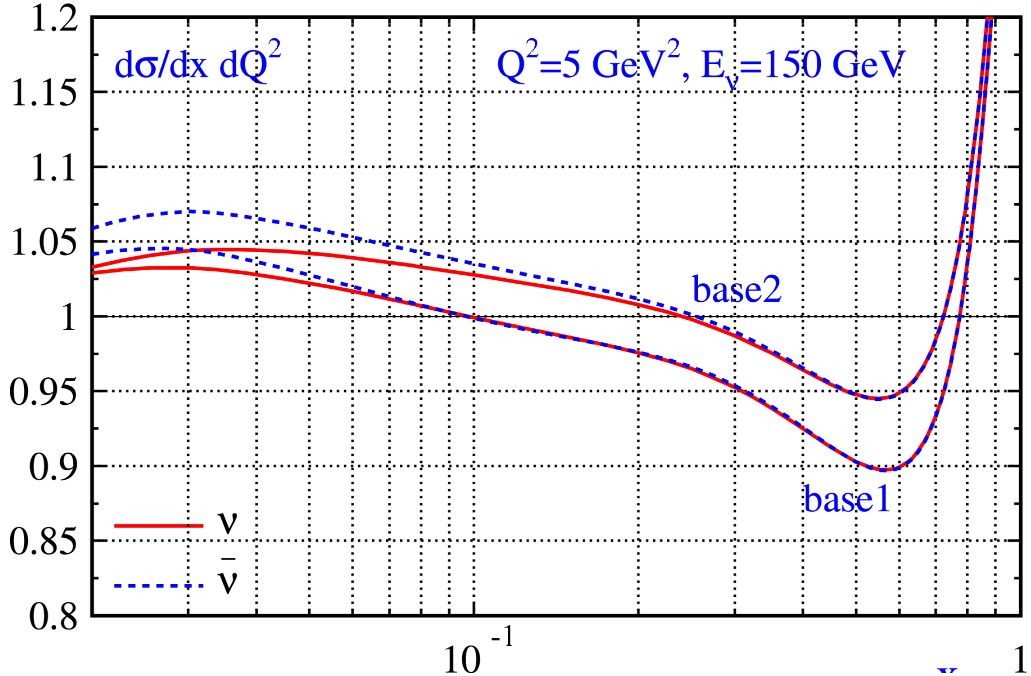


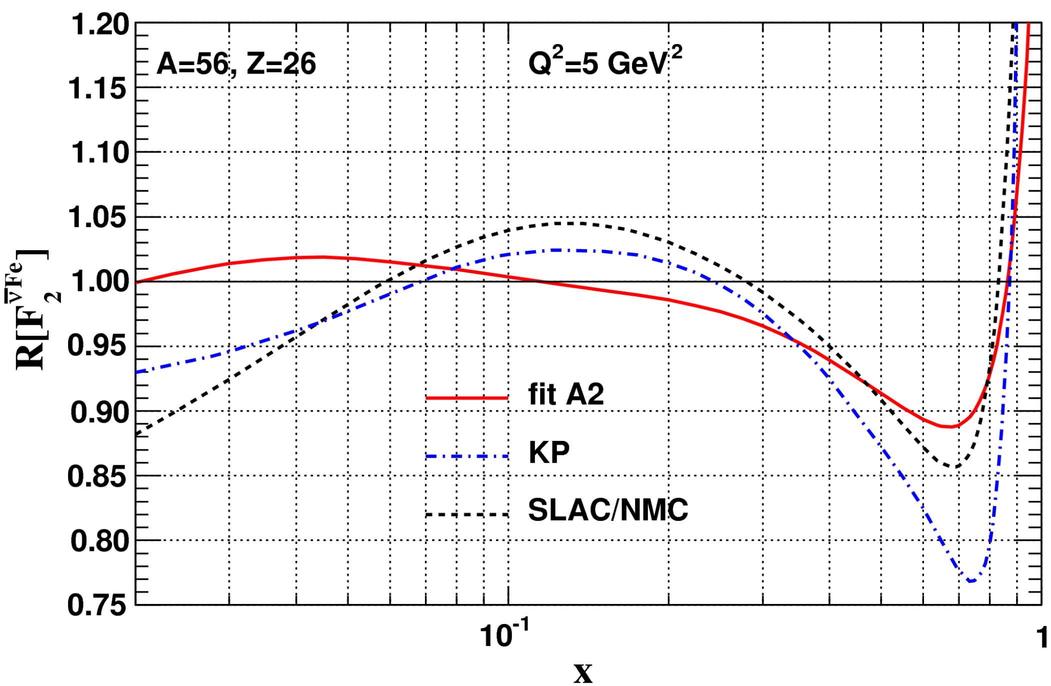
s(x,Q)



Schienbein, Yu, Keppel, Morfin, Olness, Owens, Phys.Rev.D77:054013,2008.

Nuclear Correction Factors depend on A, Q, and Observable





Nuclear Correction Factors:

1) Extract Iron PDFs

2) Use Iron PDFs to compute Iron
$\Rightarrow$ Proton correction factors

No "model" input

3) Nuclear correction depends on Q, A, & observable

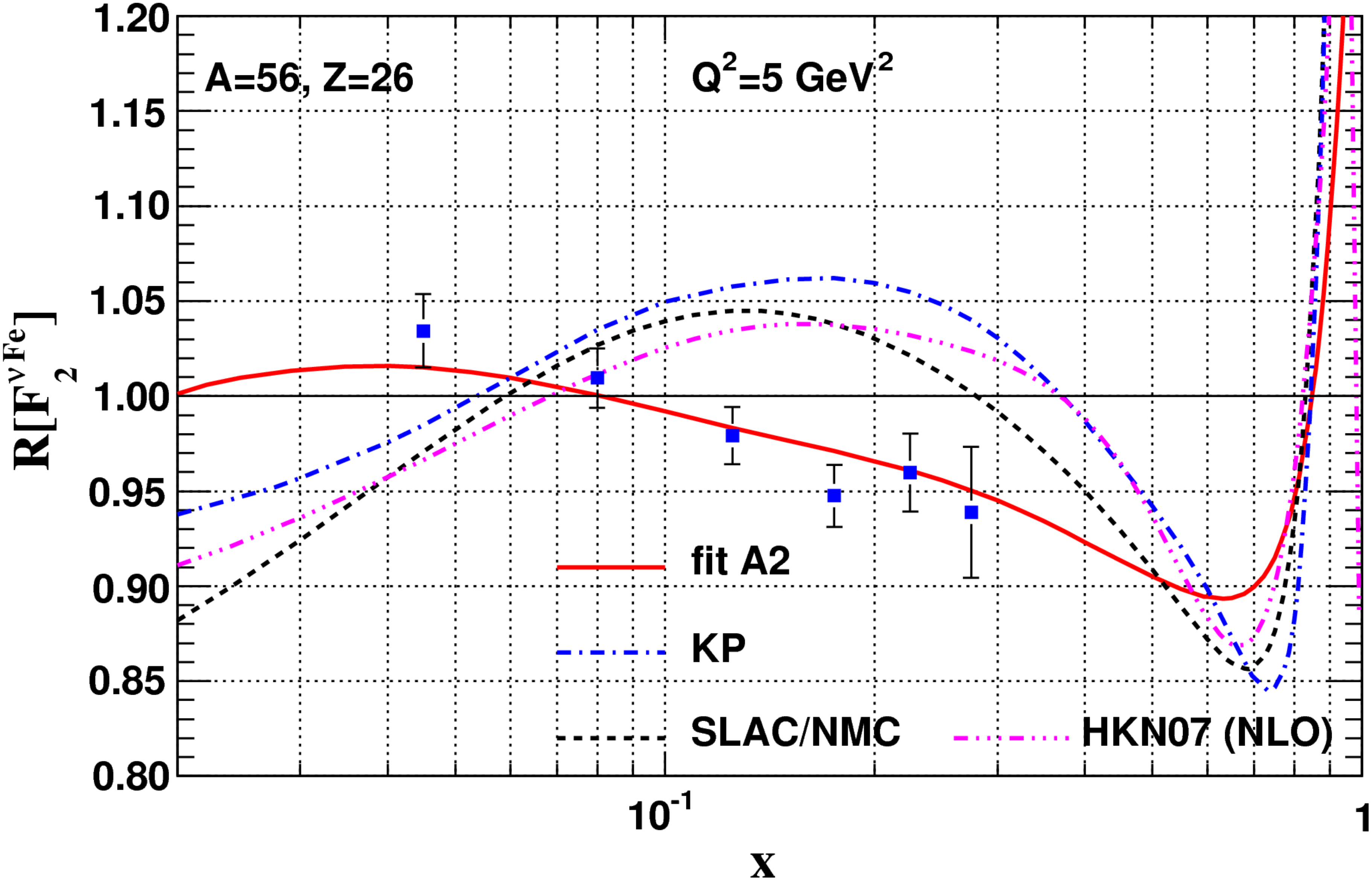
4) Compare with SLAC/NMC & KP

$$R[\mathcal{O}] = \frac{\mathcal{O}[Nucleon]}{\mathcal{O}[proton]}$$

S.A. Kulagin, R. Petti
Phys.Rev.D76:094023,2007.
Nucl.Phys.A765:126-187,2006.

Schienbein, Yu, Keppel, Morfin, Olness, Owens, arXiv:0710.4897 [hep-ph]

Nuclear Correction Factors depend on A, Q, and Observable



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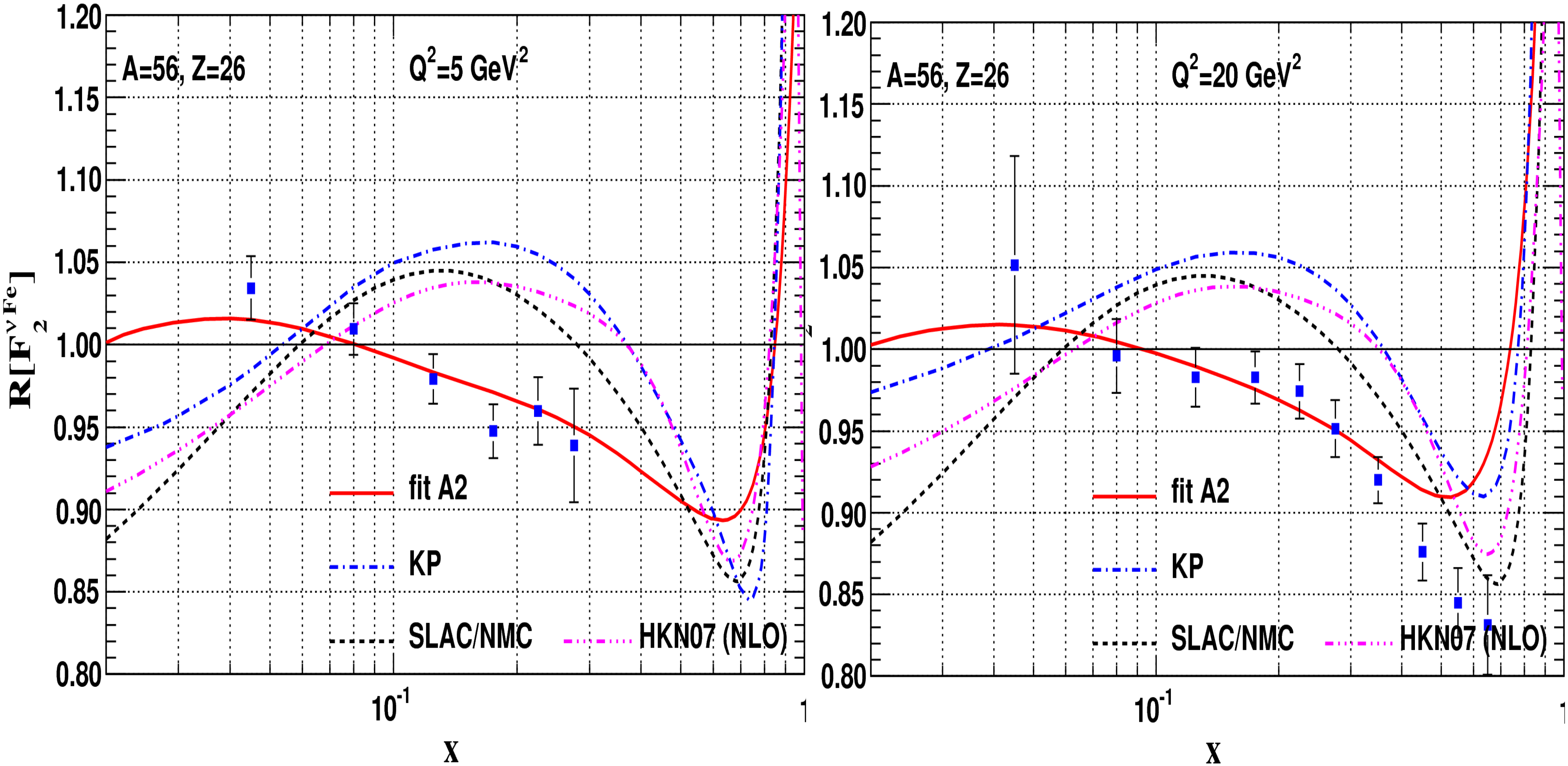

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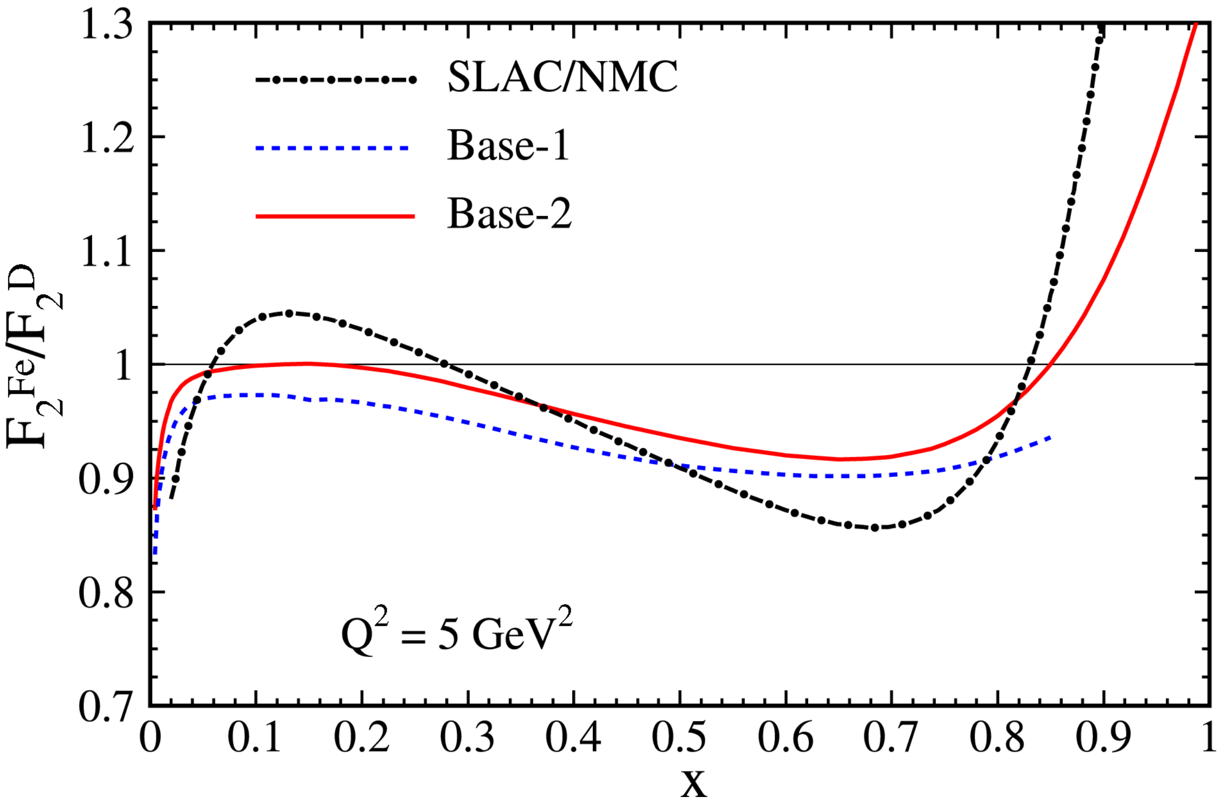
Could nuclear corrections be different for CC (W) or NC (γ,Z) processes???

$$R[\mathcal{O}] = \frac{\mathcal{O}[Nucleon]}{\mathcal{O}[proton]}$$

Use CC Iron PDFs to compute NC DIS Nuclear Corrections



Question:
How to resolve differences???

1) There might be a compromise set of nuclear corrections that adequately satisfies both NC and CC data

2) It may be necessary to apply separate CC and NC corrections

Conclusions

Conclusions

Important to quantify PDF Uncertainties

- ... both "known" and "unknown"
- At LHC, heavy quarks play a prominent role *{s,c,b...}*,
  - *... even in W/Z production*

Tensions between various data sets:

- Historically, CC and NC
- NuTeV & E866 impact on d/u ratio

New global fitting program includes heavy target effects **DYNAMICALLY**

- Nuclear corrections are not "carved in stone"
- Incorporates proper errors and systematics
- May allow for a "compromise" fit

Extensible to all nuclear A values

- Yields NLO nuclear PDFs: $f_i(x,Q,A)$

Important ingredient for standard CTEQ fits