Nuclear Parton Distribution Function (PDF)

Nuclear Corrections & Uncertainties
for LHC & Beyond

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Conspirators:
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J. Owens, J. Morfin, C. Keppel, ...

Pheno 2009
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Heavy Target Data Essential for Determining Separate Parton Flavors

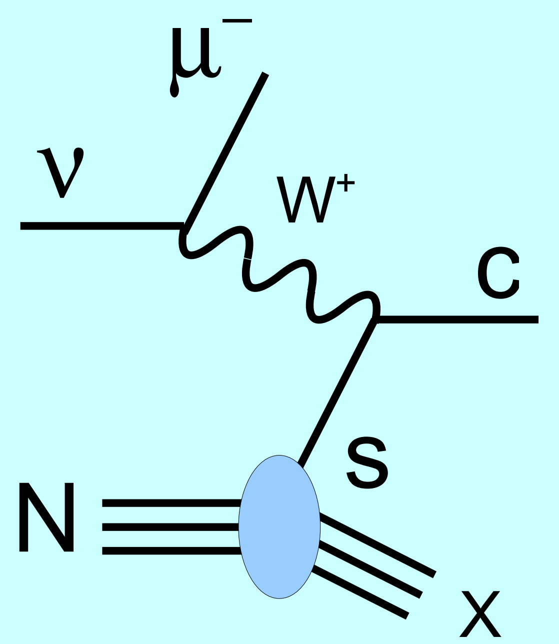
- Charged Current Neutrino data complement Neutral Current to extract PDF flavors
- Neutrino data requires heavy targets (Fe, Pb)
- Nuclear Corrections must be applied to heavy target data.

Tension between data sets

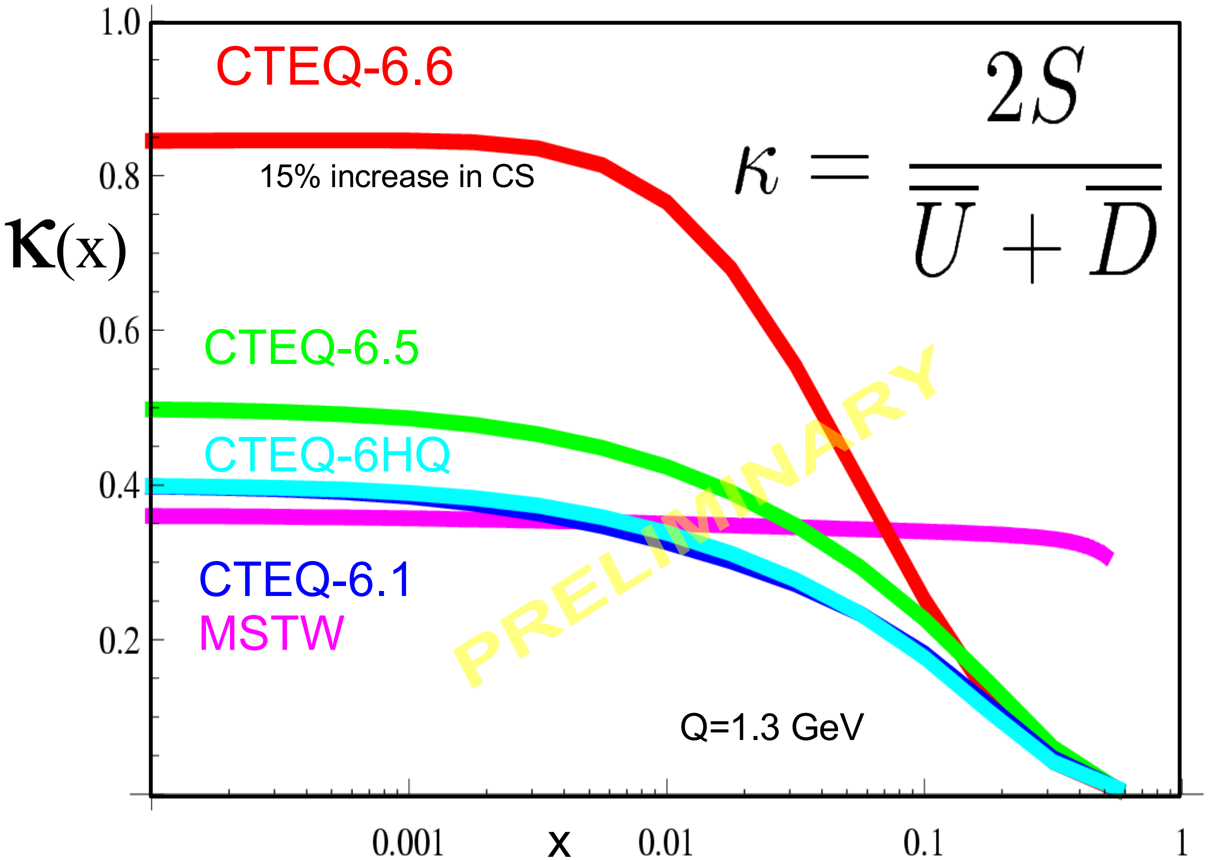
Charged Current (CC) &
Neutral Current (NC) DIS
CC: Heavy Targets
NC: Light Targets

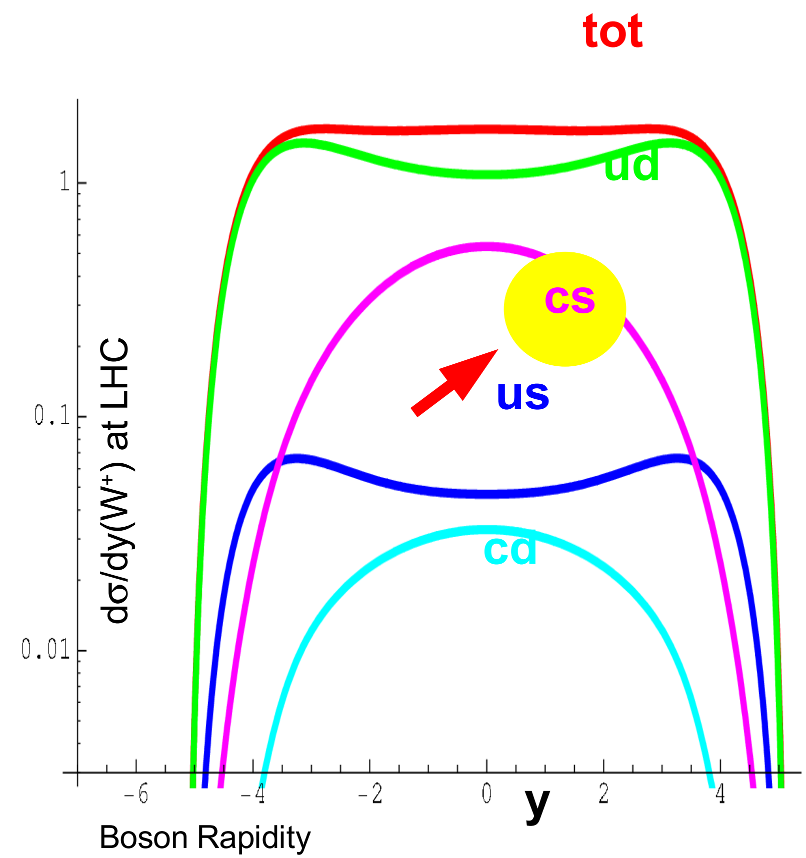
NuTeV Neutrino DIS
& E866 Drell-Yan
affects d/u ratio

Neutrino Charm Production:
can determine s(x)



Nuclear Corrections ⇒ S(x) PDF ⇒ W/Z at LHC



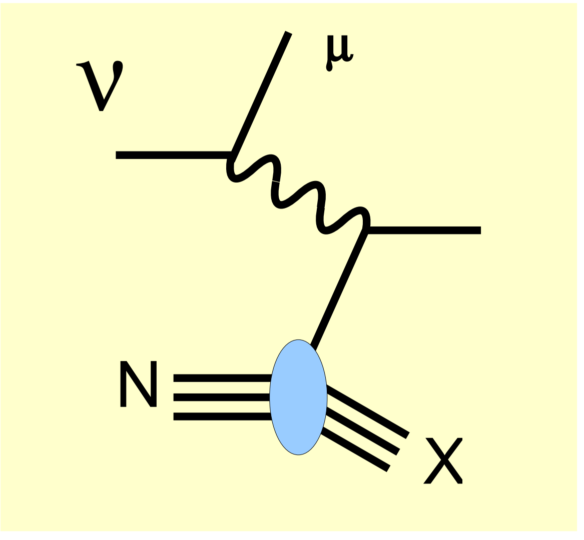


Nuclear PDF Uncertainties will feed into LHC "Benchmark" processes

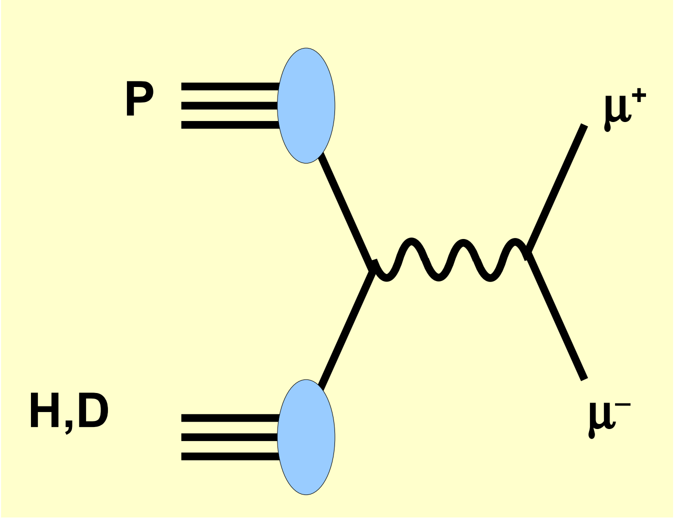
NEW DATA SETS

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

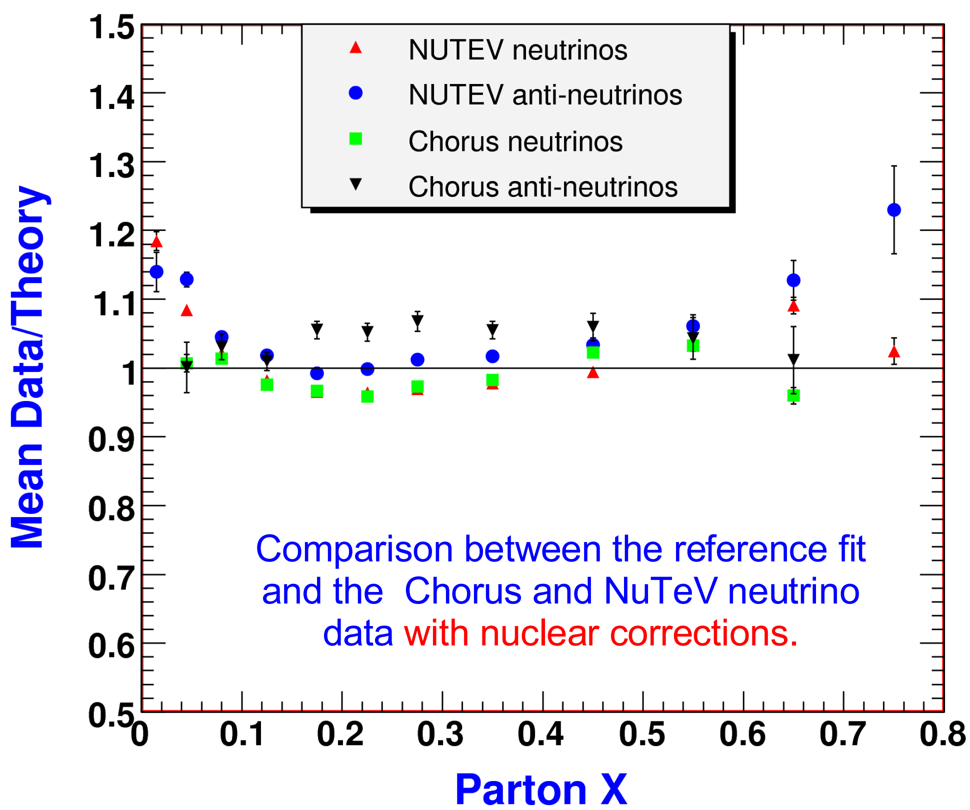
Chorus

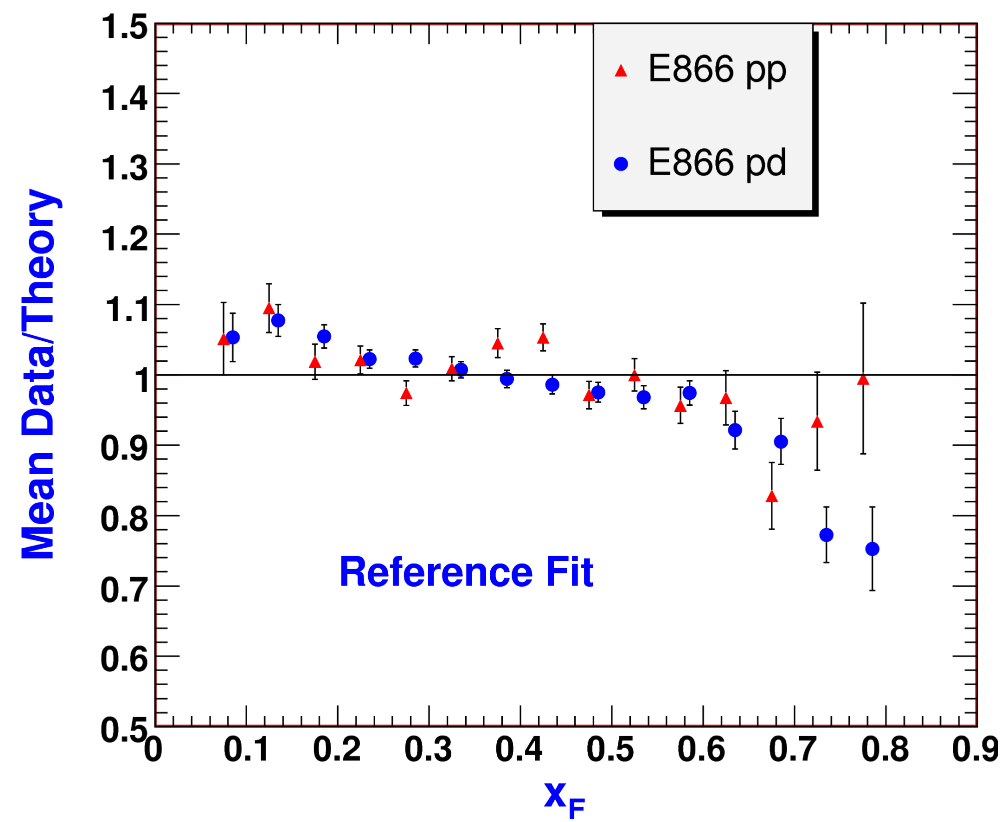
Neutrinos on lead
0.01< x <0.7
10< E_ν <200 GeV
p_μ >5 GeV
412 points

E866 NuSea:

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

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





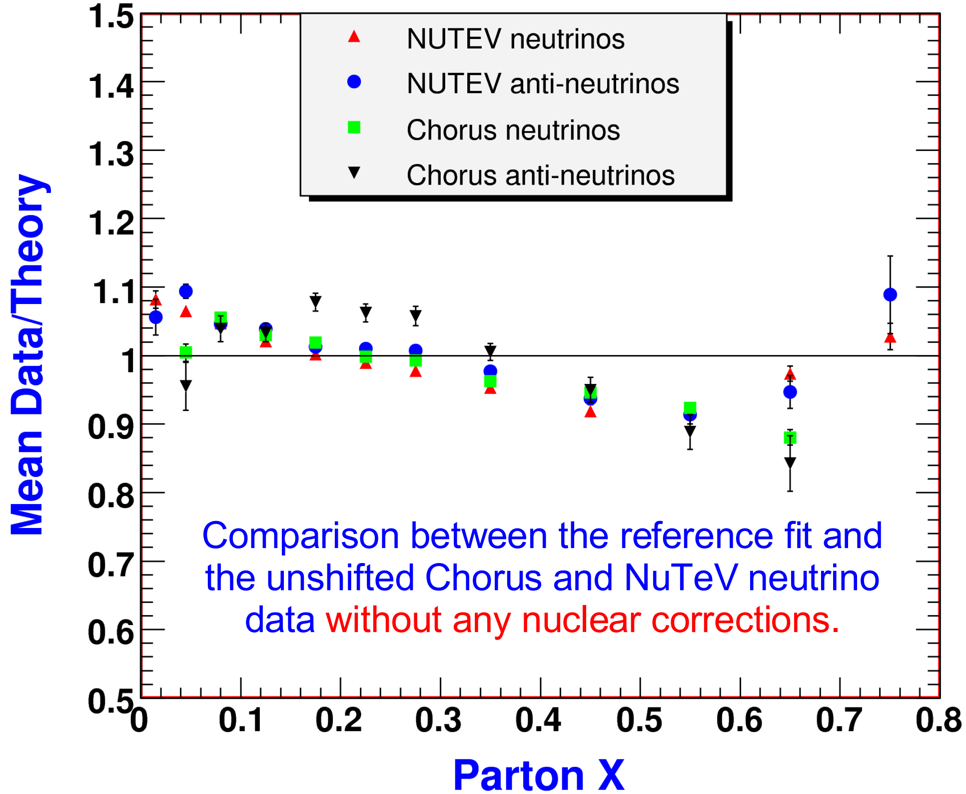
"Thus, these results suggest on a purely phenomenological level that the nuclear corrections may well be very similar for the nu and nubar cross sections and that the overall magnitude of the corrections may well be smaller than in the model used in this analysis."

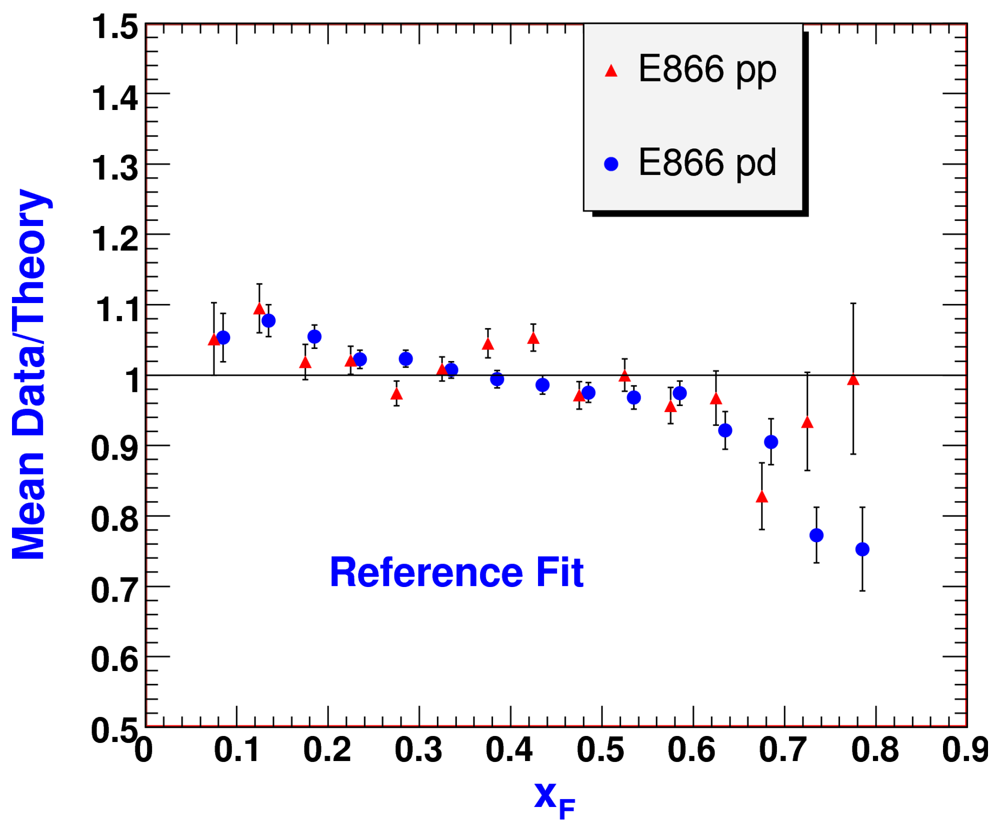
χ=7453/5062 Reference Fit

χ=6606/5062 Mod Nuclear Fit

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

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





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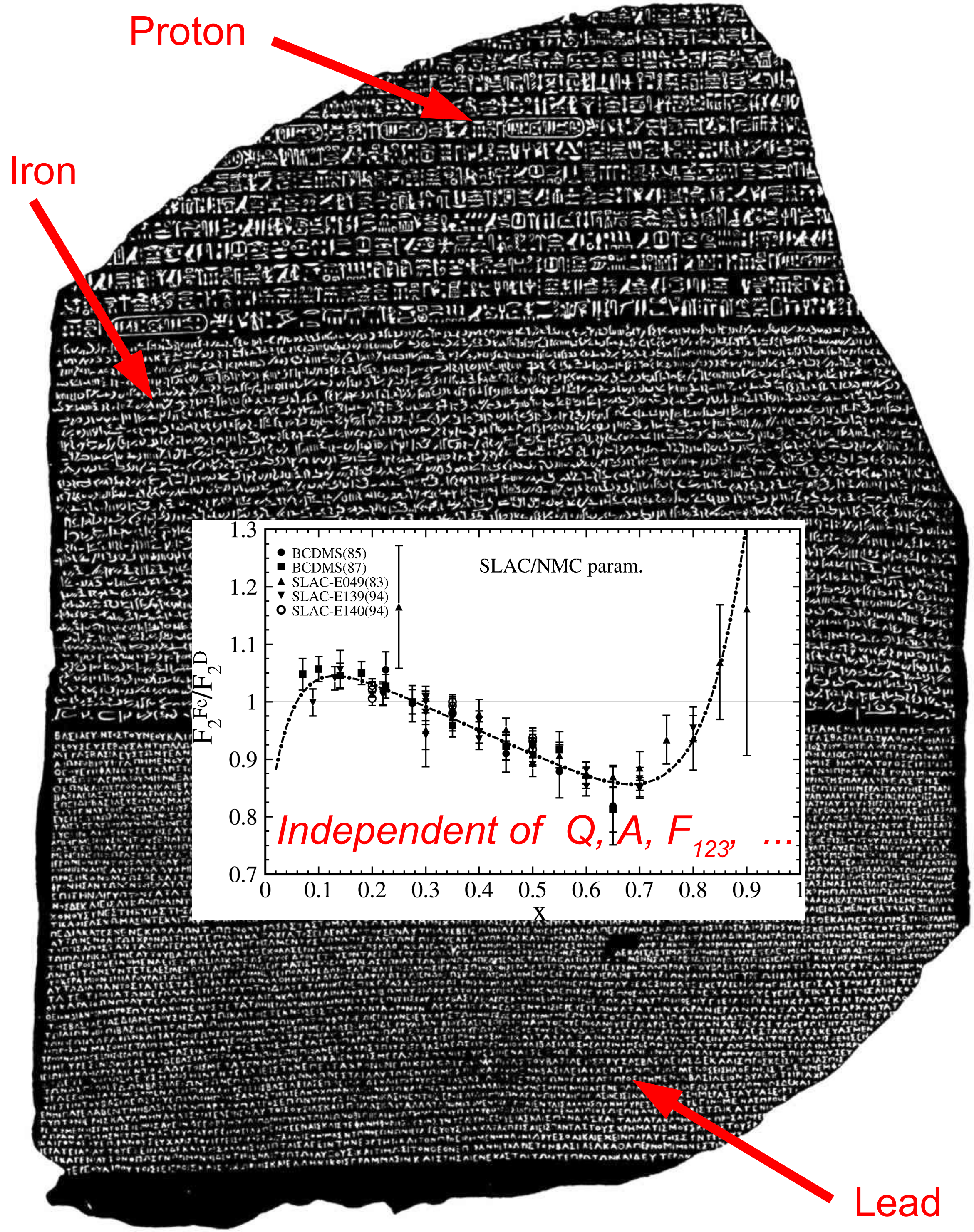
Where do nuclear corrections come from???



Where do Nuclear Corrections come from ???

carved in stone

Discovered by the French in 1799 at Rosetta, a harbor on the Mediterranean coast in Egypt. Comparative translation of the stone assisted in understanding many previously undecipherable examples of hieroglyphics.

Fred Olness: Pheno 2009

Nuclear PDFs

Generalize PDF

for Nuclear A

Allows CTEQ PDFs as a simple limit

Nuclear PDFs

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

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

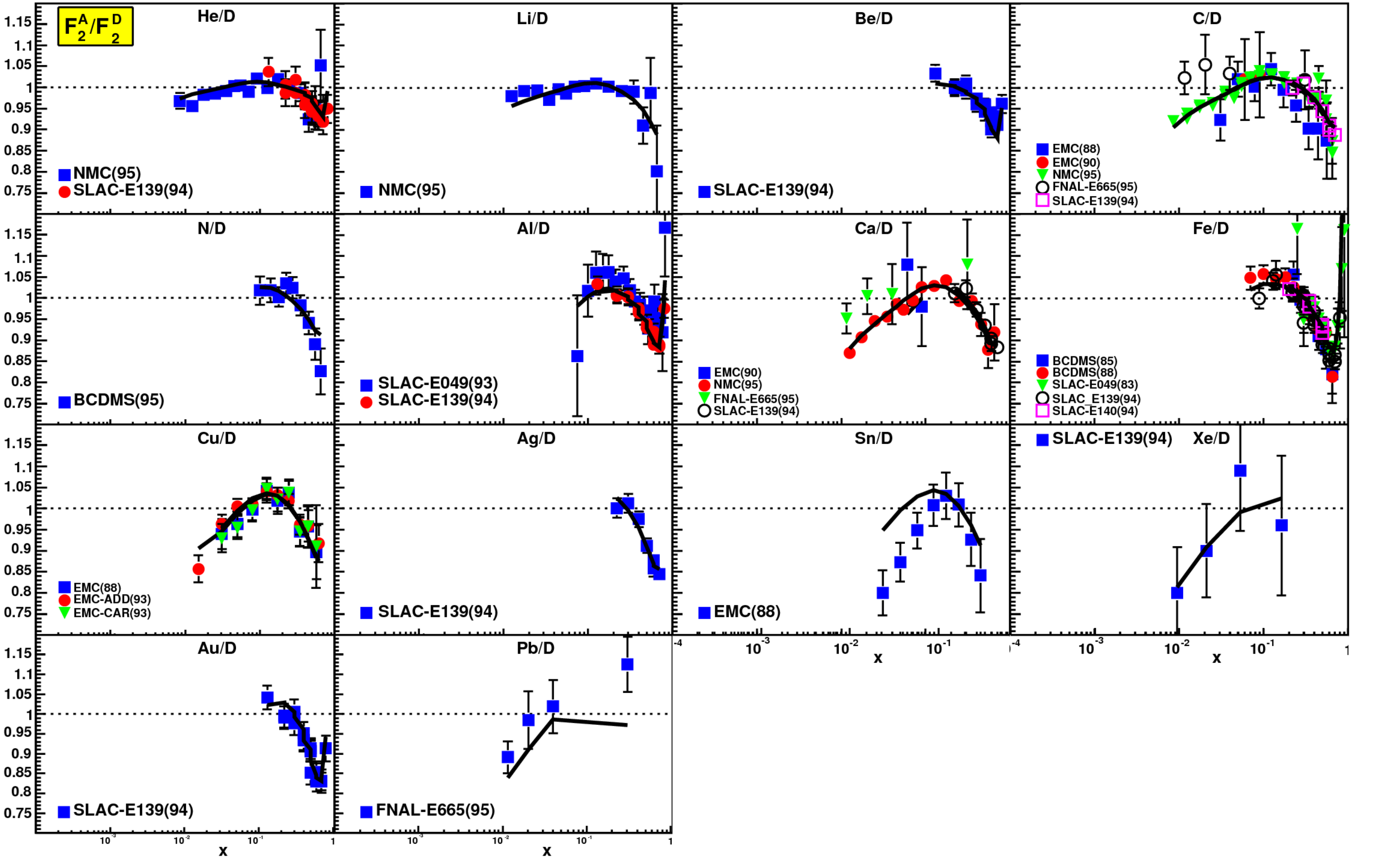
$$a_i \rightarrow a_i(A)$$

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

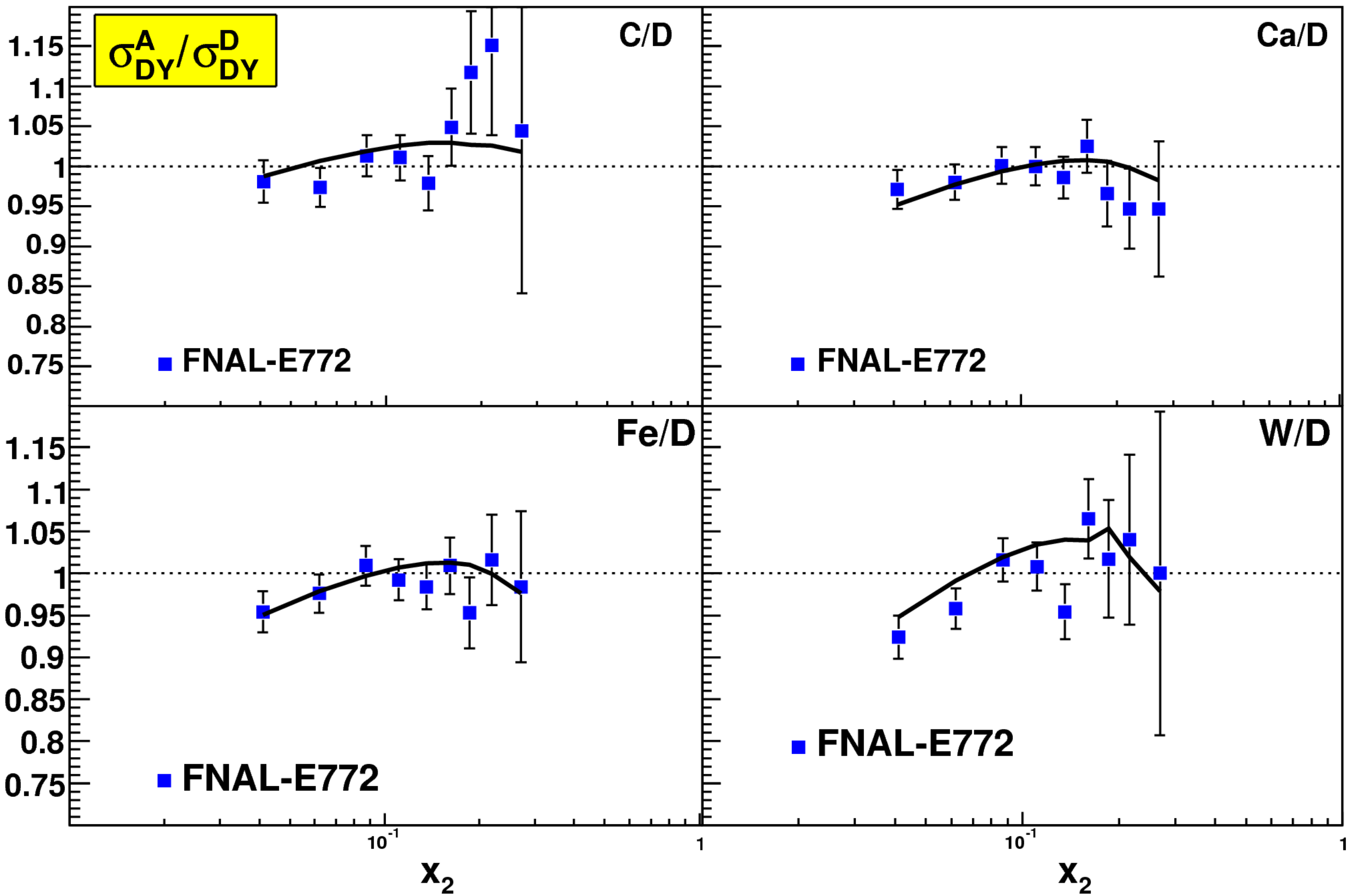
Nuclear PDFs from neutrino deep inelastic scattering.
I. Schienbein, J.Y. Yu, C. Keppel, J.G. Morfin, F. Olness, J.F. Owens.
Phys.Rev.D77:054013,2008.

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	36.0	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	26.9	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

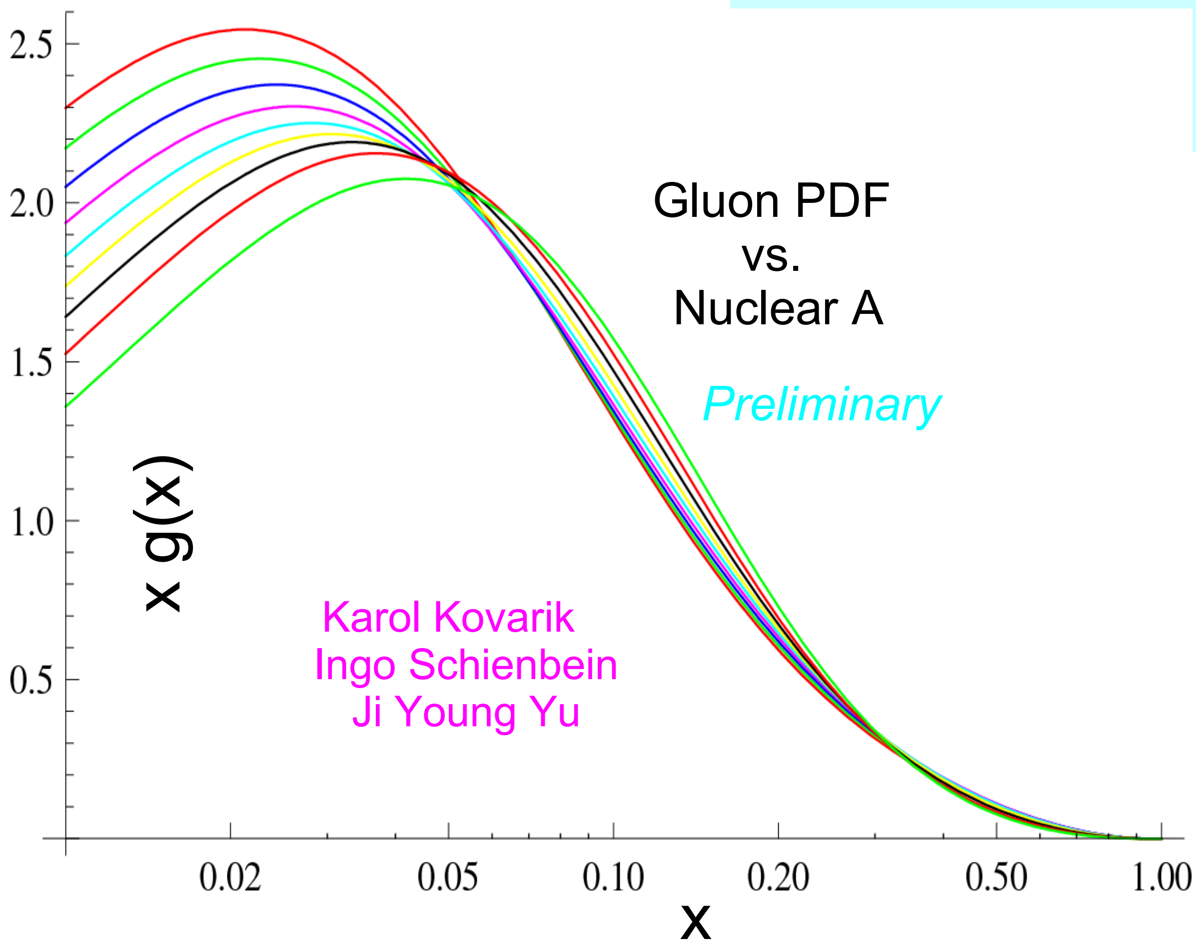
Yields full NLO nuclear PDFs: $f_i(x,Q,A)$

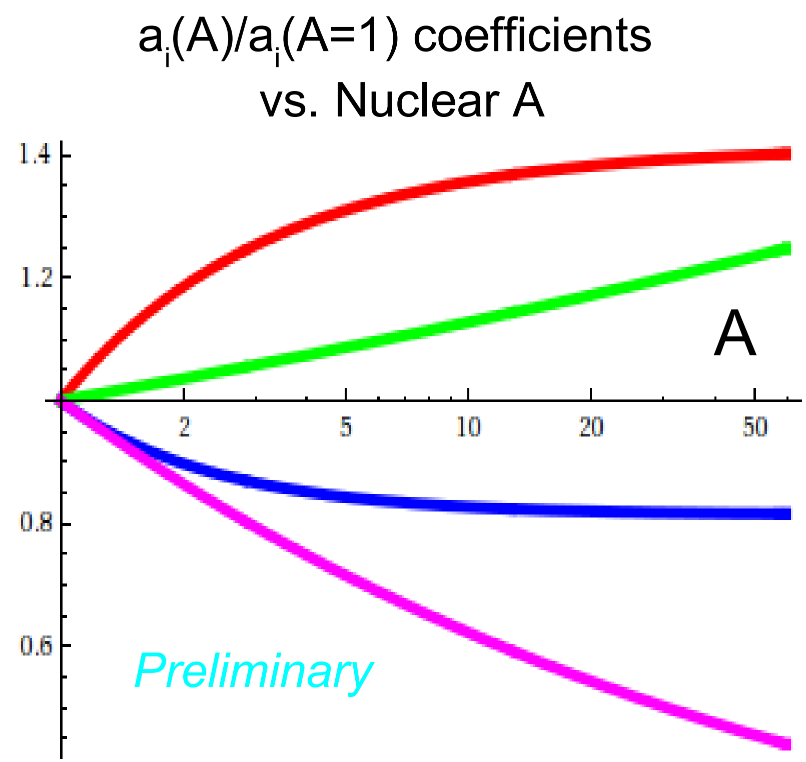
Designed to reduce to proton PDF in limit $A \rightarrow 1$

Nuclear corrections not written in stone!

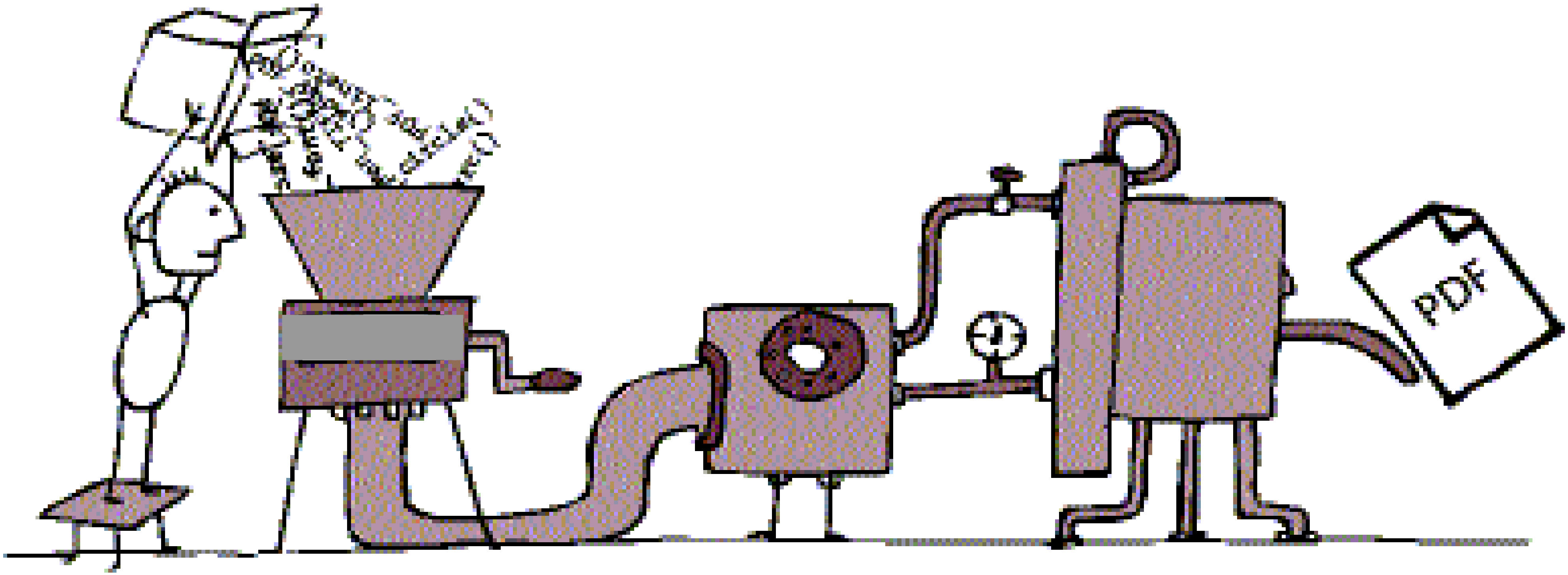
$$xf(x) = x^{a_1}(1-x)^{a_2}e^{a_3 x}(1+e^{a_4}x)^{a_5}$$

$$a_i \longrightarrow a_i(A)$$





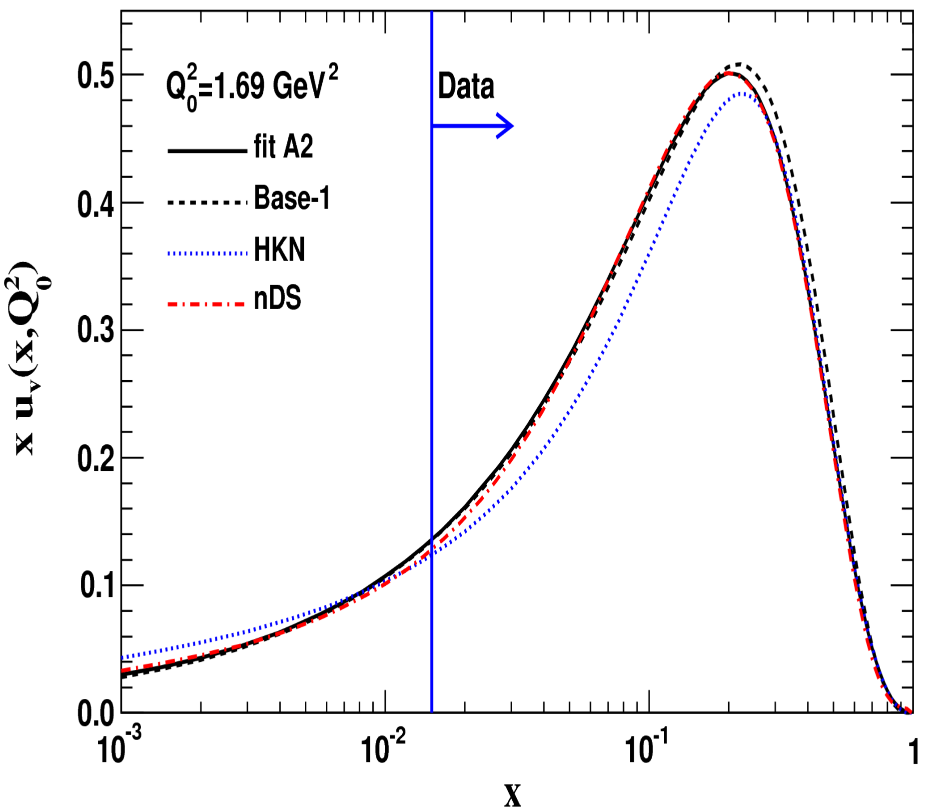
Use νN CC Data



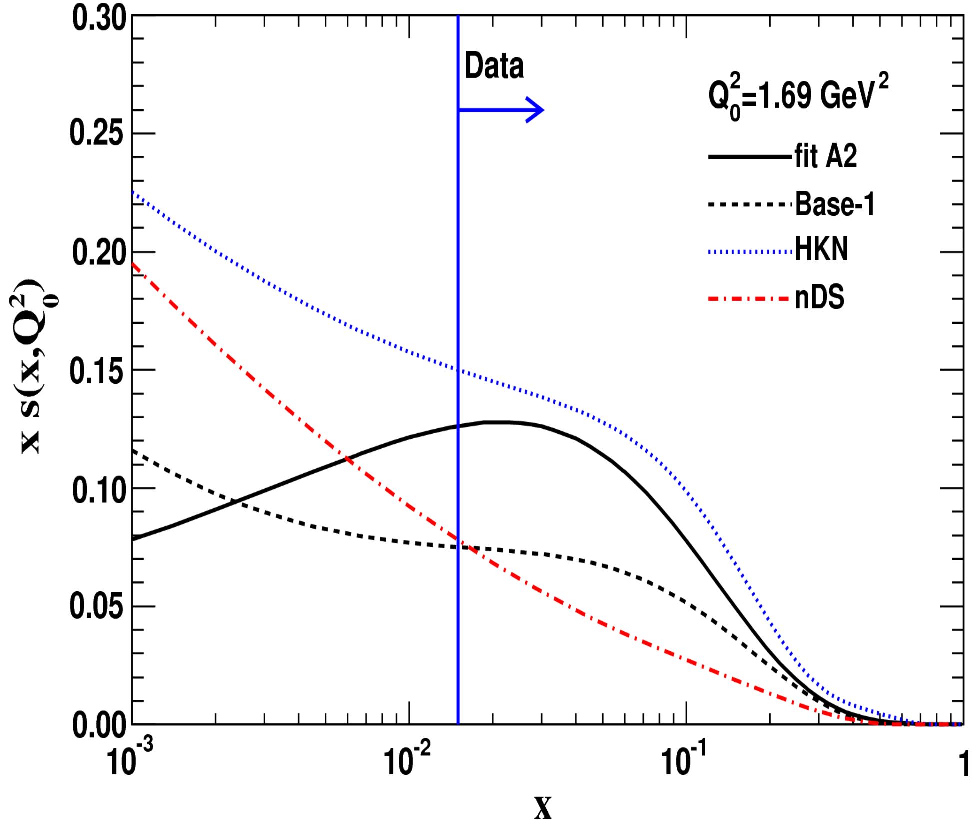
Extract **Fe** nPDFs

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

u(x,Q)

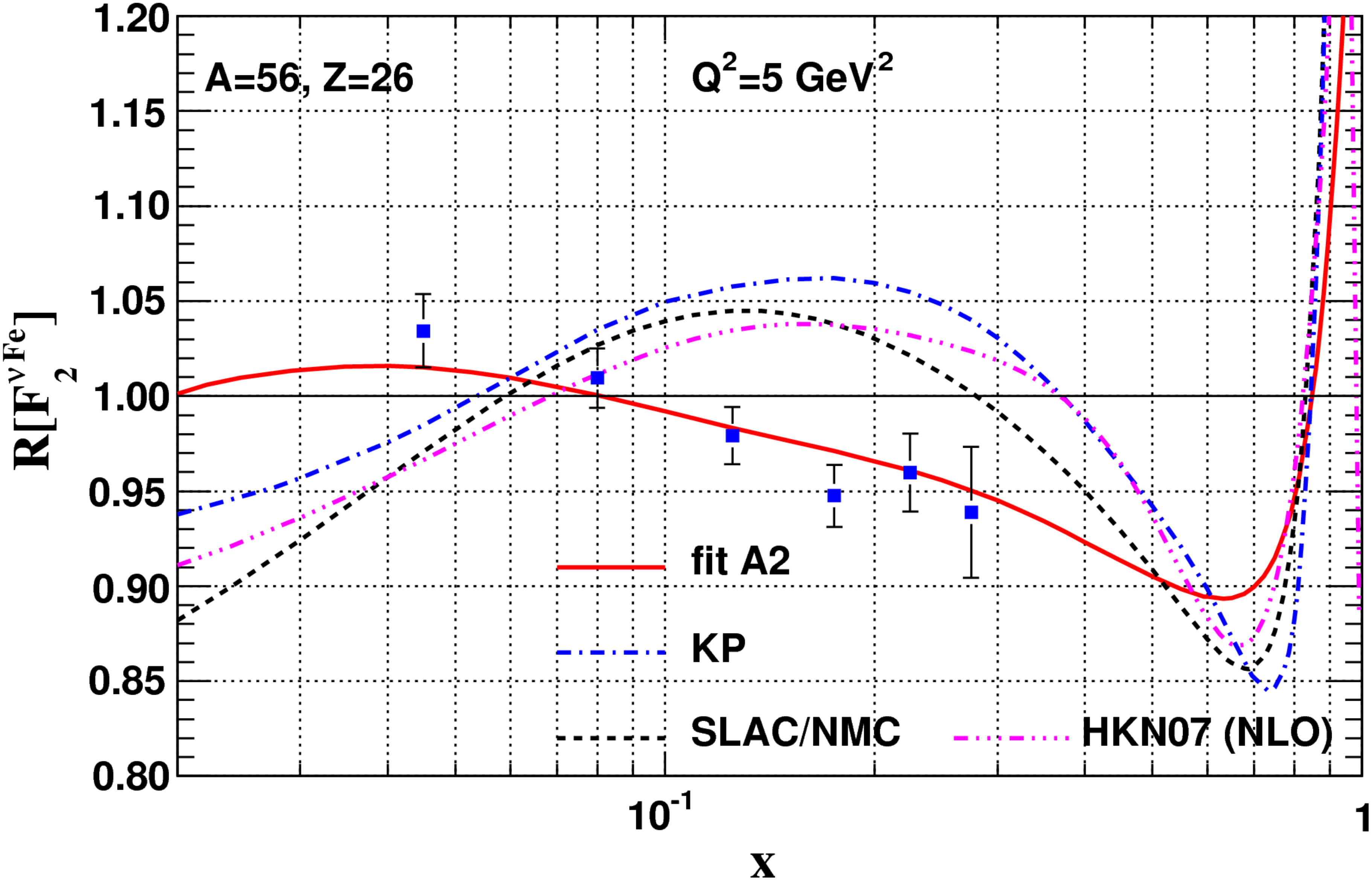


s(x,Q)



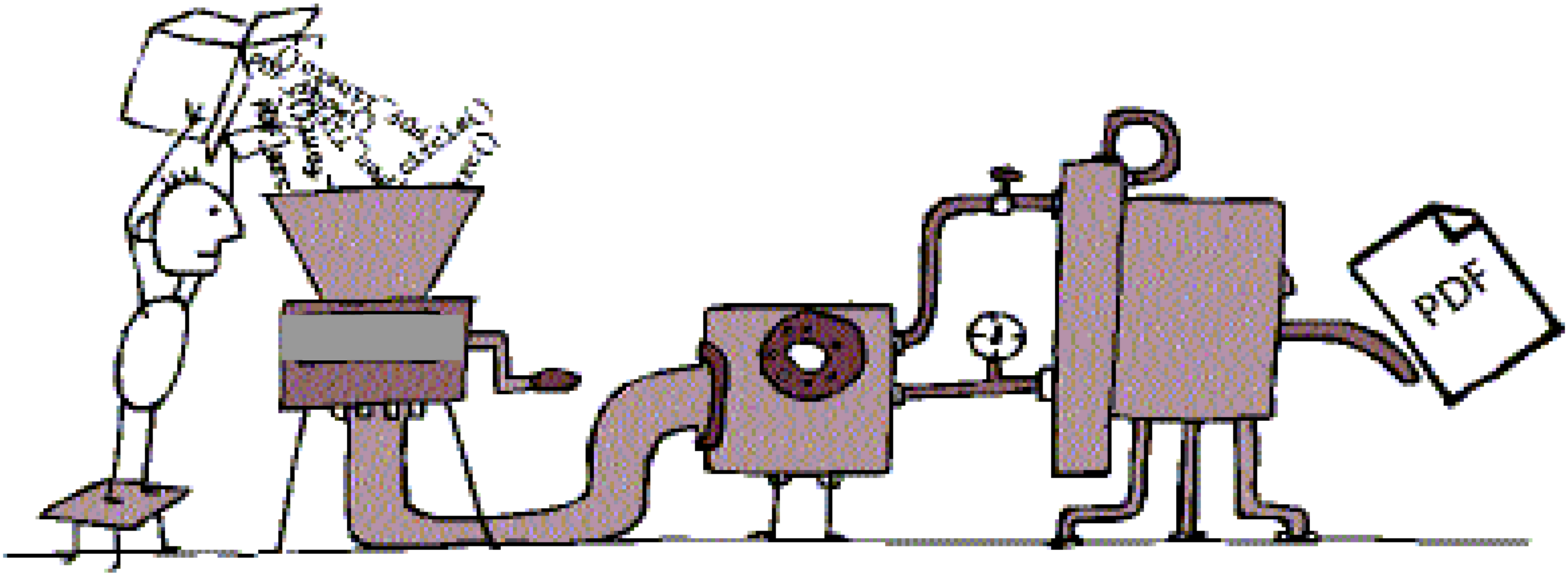
Schienbein, Yu, Keppel, Morfin, Olness, Owens, Phys.Rev.D77:054013,2008.

Nuclear Correction Factors from neutrino-Nucleon CC Data



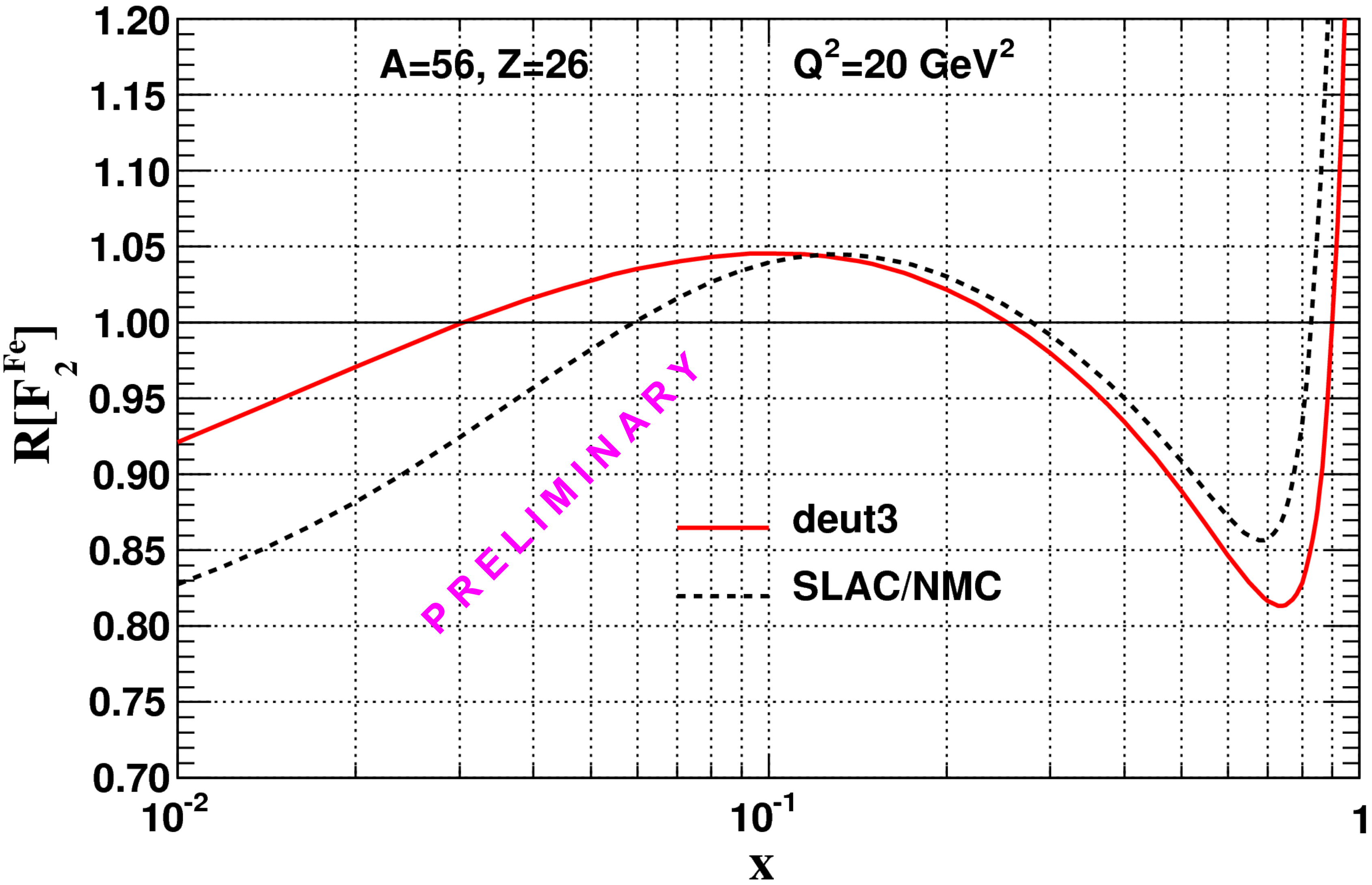
Schienbein, Yu, Keppel, Morfin, Olness, Owens, Phys.Rev.D77:054013,2008.

Use ℓN NC Data



Extract $f(x,\mu,A)$

Nuclear Correction Factors from ℓ-Nucleon NC Data



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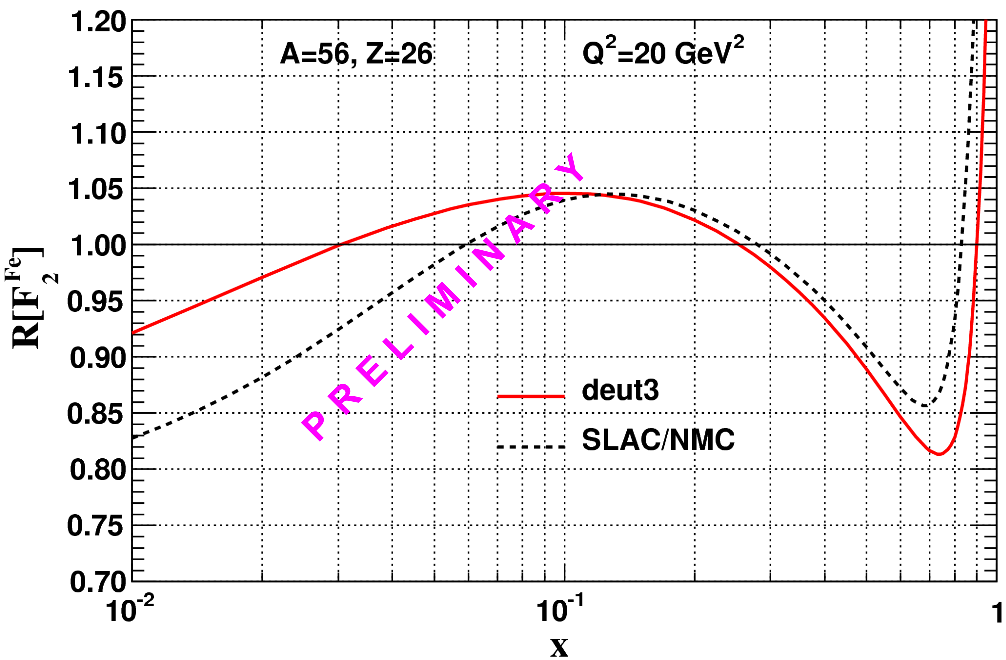

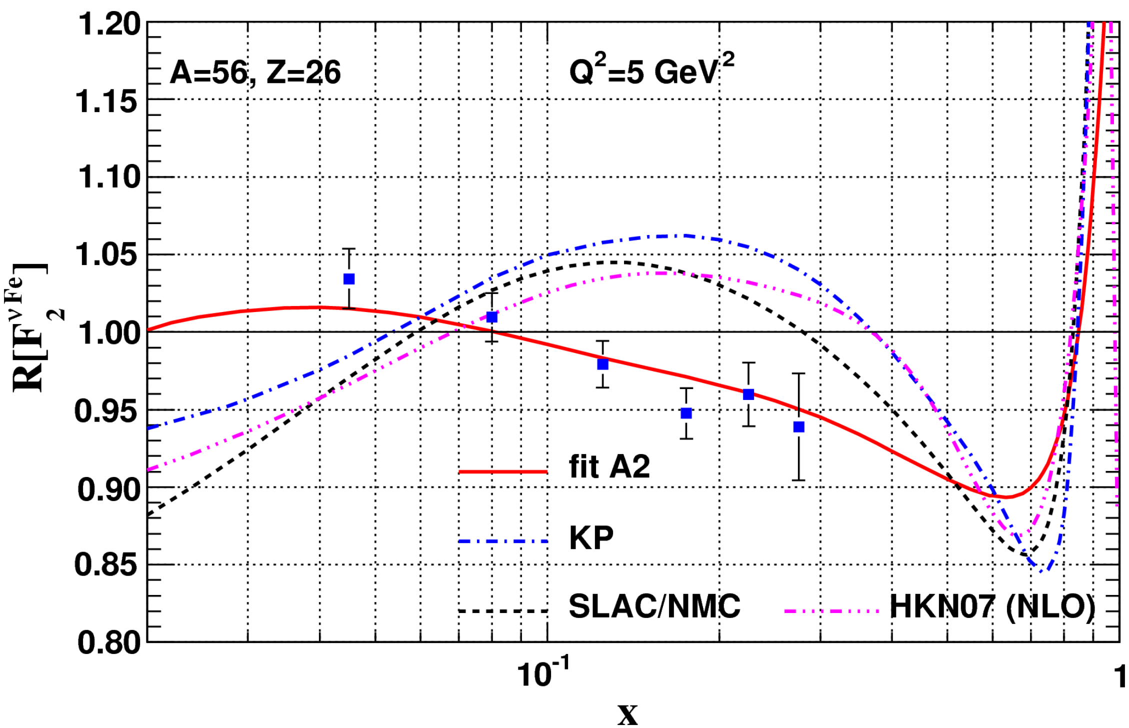

Question:
How to resolve differences???

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

Nuclear Corrections: Important uncertainty of PDFs

At LHC, nuclear corrections play a prominent role: $\Rightarrow$ *{s,c,b…},*

… key in W/Z production

Tensions between various data sets:

Historically, neutrino CC and charged-lepton NC

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