Nuclear Parton distributions

... and beyond

*Outstanding issues and **uncertainties***

Fred Olness

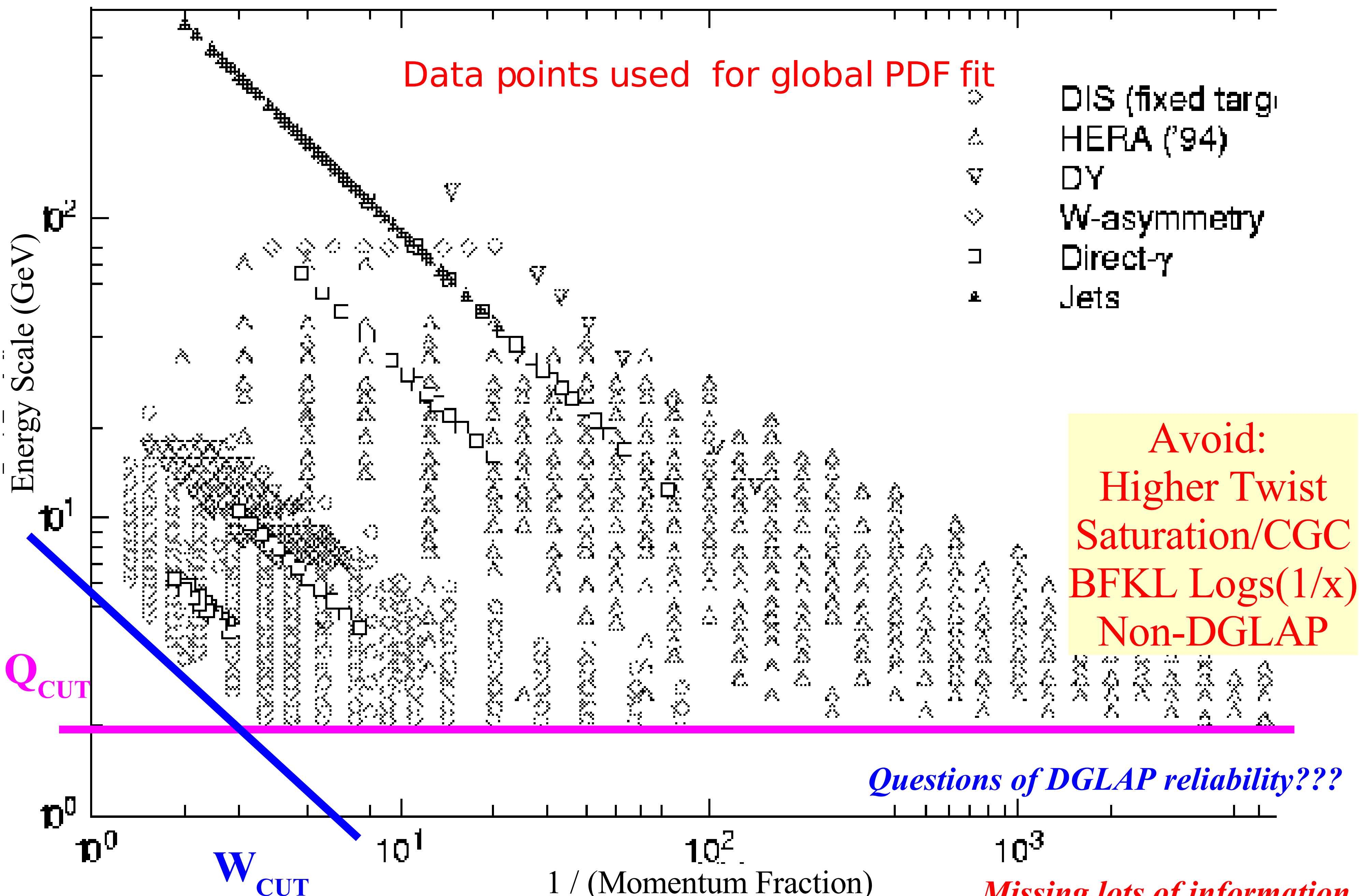
SMU

Conspirators:

P. Nadolsky, M.Guzzi, K. Park,
I Schienbein, J.-Y. Yu,
Karol Kovarik, T.P. Stavreva
J. Owens, J. Morfin, C. Keppel,

3rd International Workshop on
Nucleon Structure at Large Bjorken x
October 13-15, 2010
Jefferson Lab

Historically, {Q,W} Cuts have been Conservative

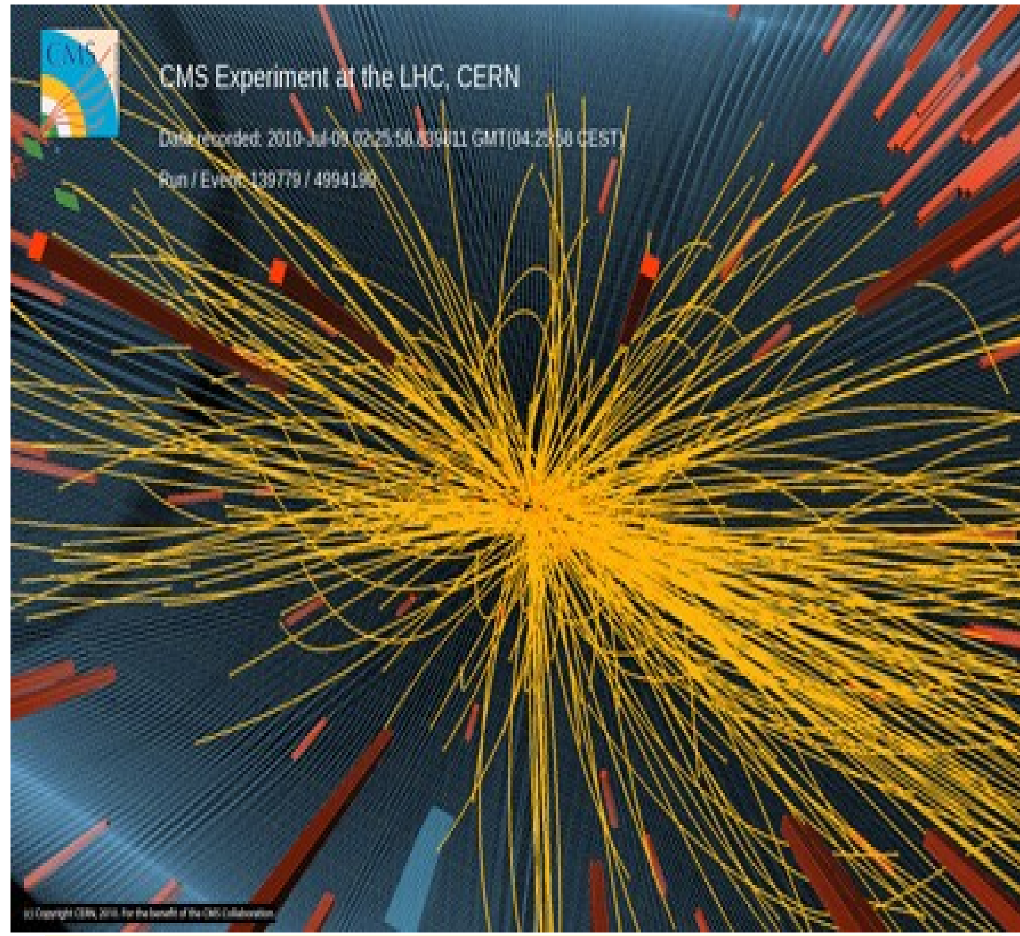


Questions of DGLAP reliability???

Missing lots of information

Search for "new physics" requires dependable foundation

Ability to discover
"New Physics"
is dependent on distinguishing
"Old Physics"

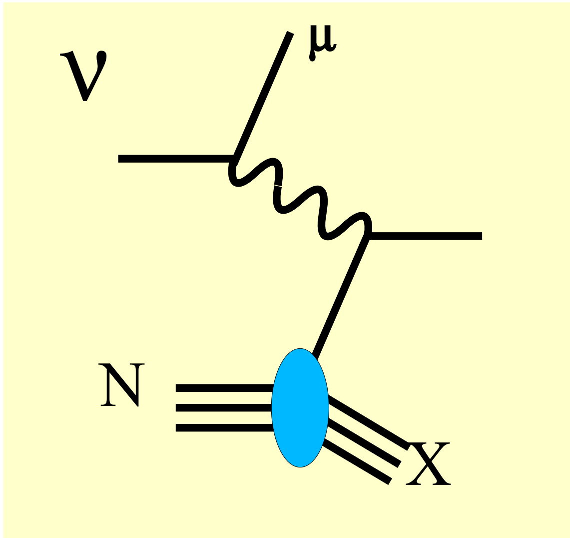


As experimental precision has increased, we need to be concerned about the details

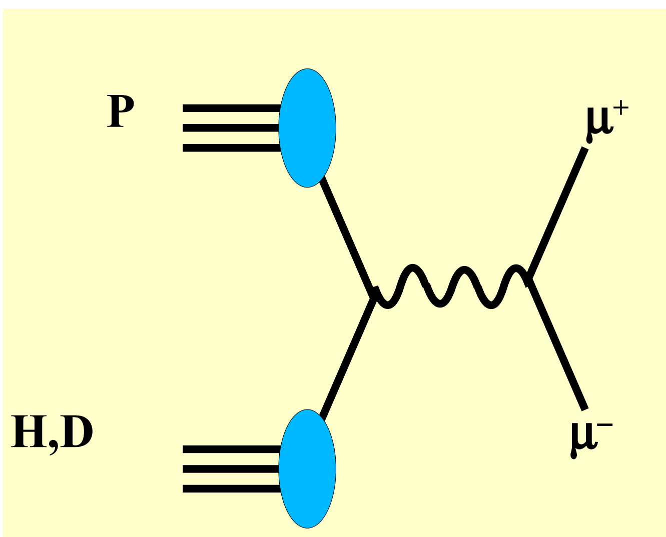
New Data Sets

Extend CTEQ6 PDFs with 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

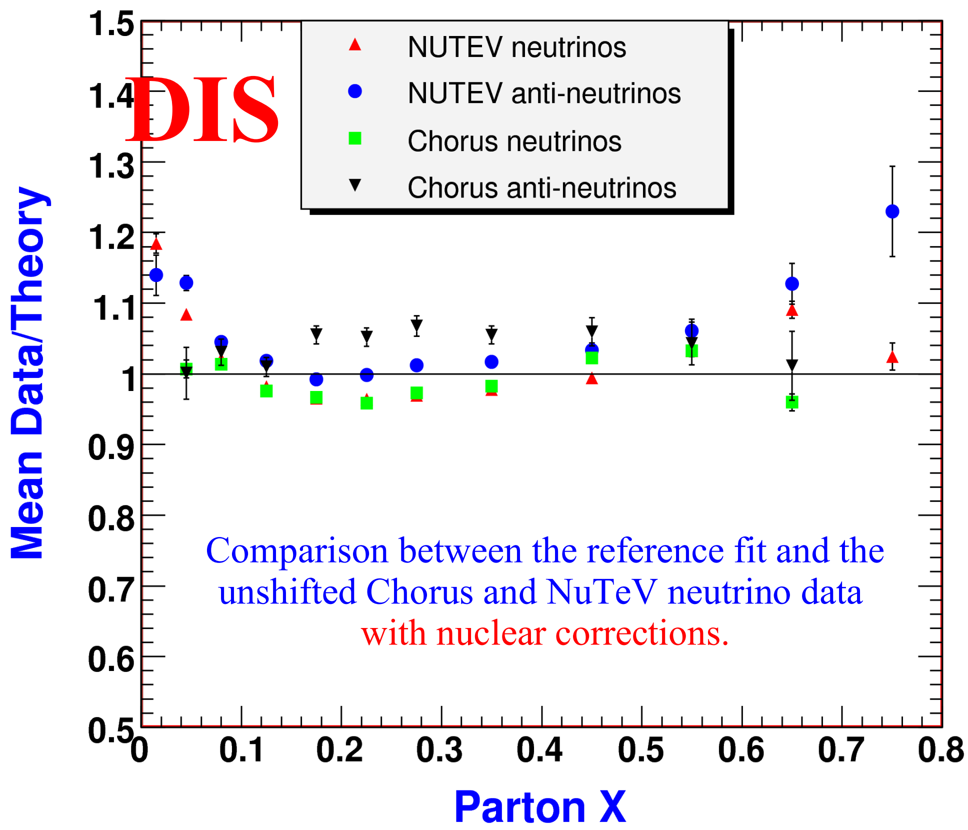
Neutrinos on lead
$0.01 < x < 0.7$
$10 < E_\nu < 200$ GeV
$p_\mu > 5$ GeV
412 points

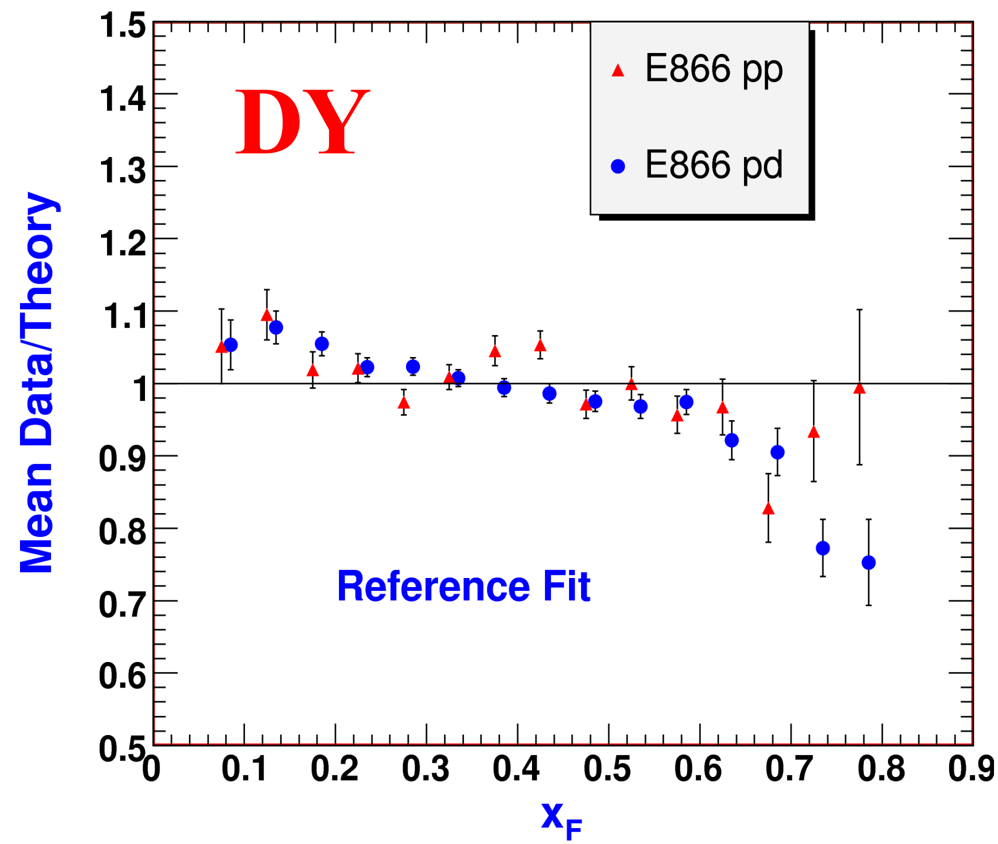
E866 NuSea:

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

Why are trends different for DIS vs. DY

See talk by Jorge Morfin





"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.

Why are trends different for DIS vs. DY

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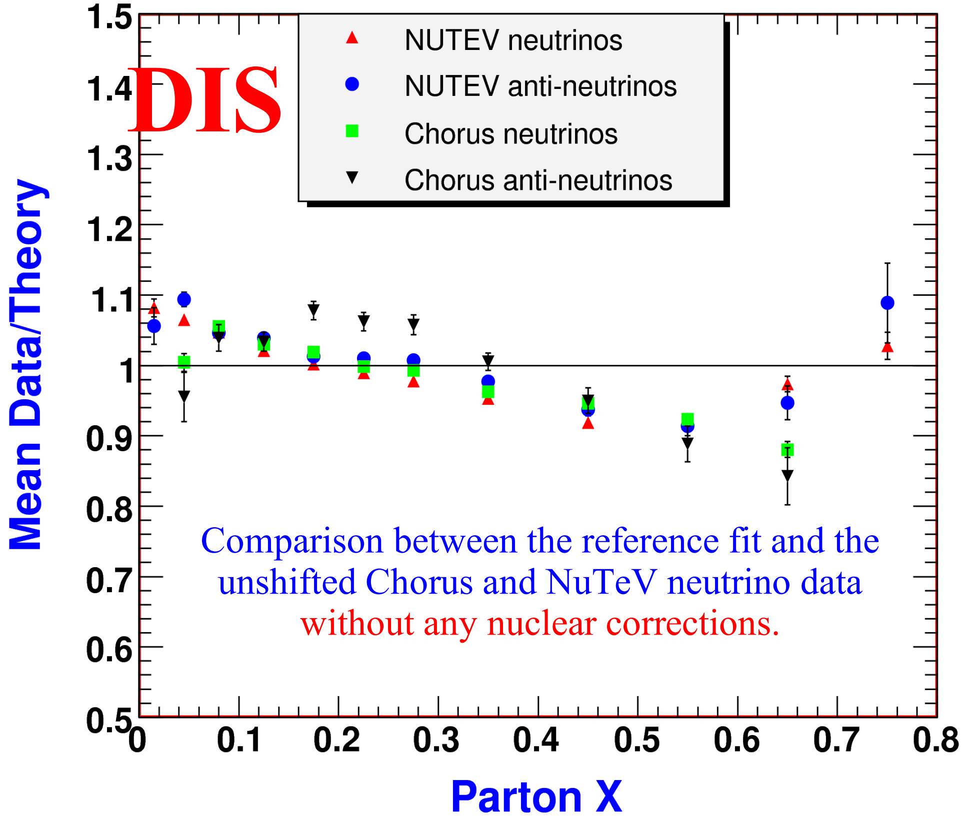

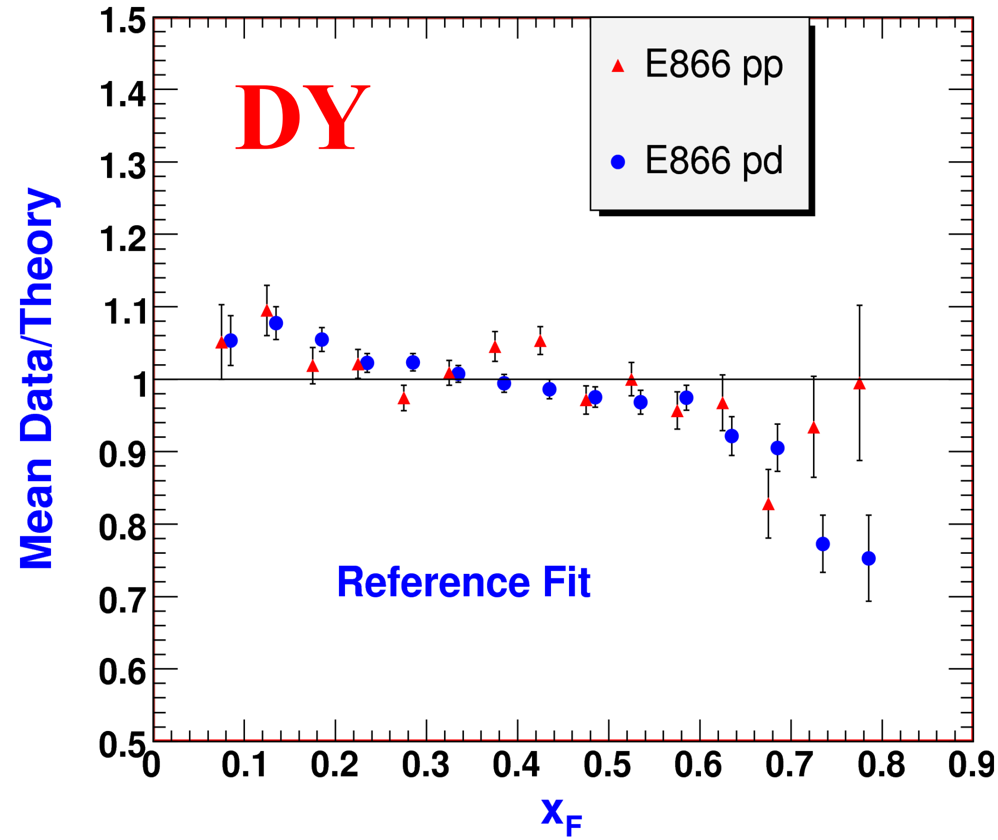

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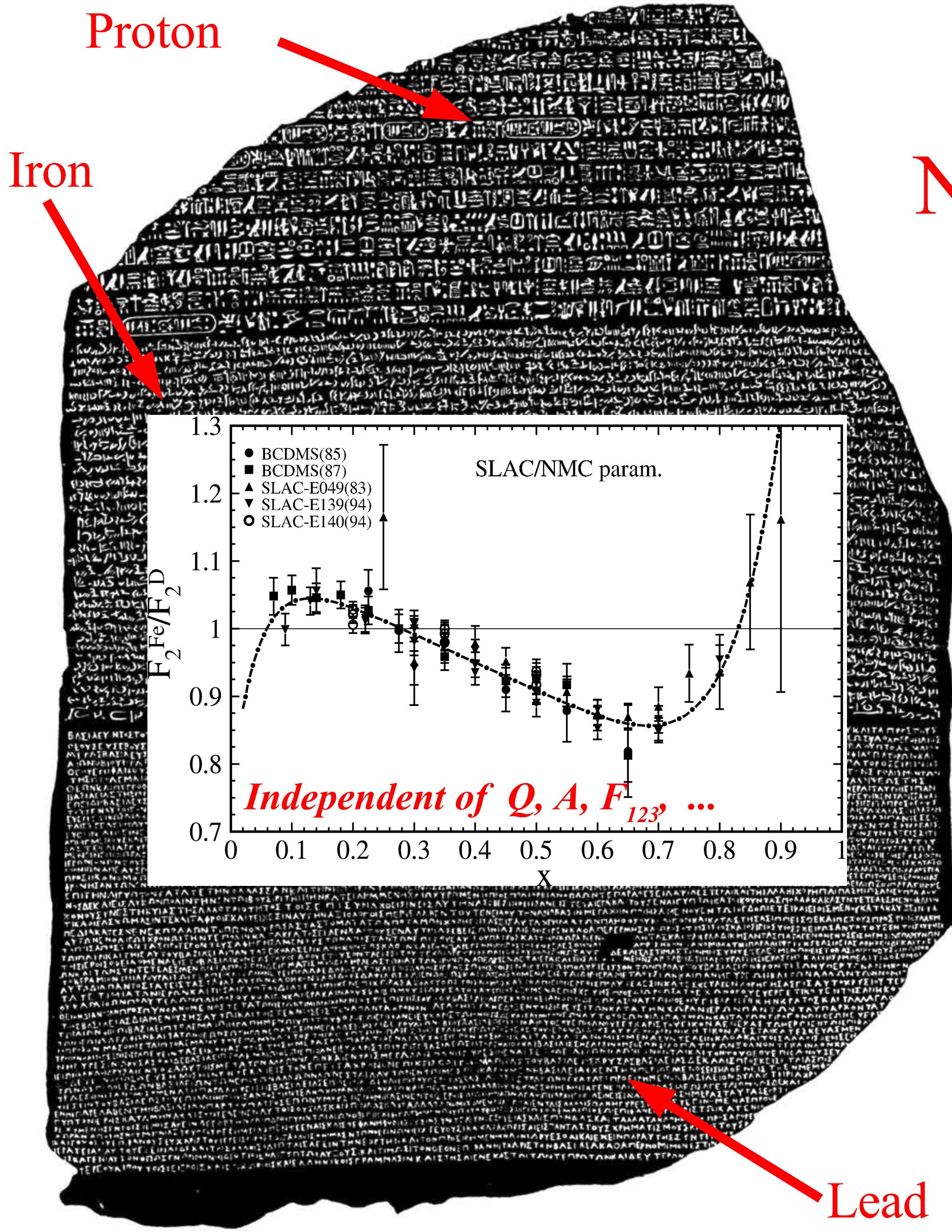
Where do nuclear corrections come from???

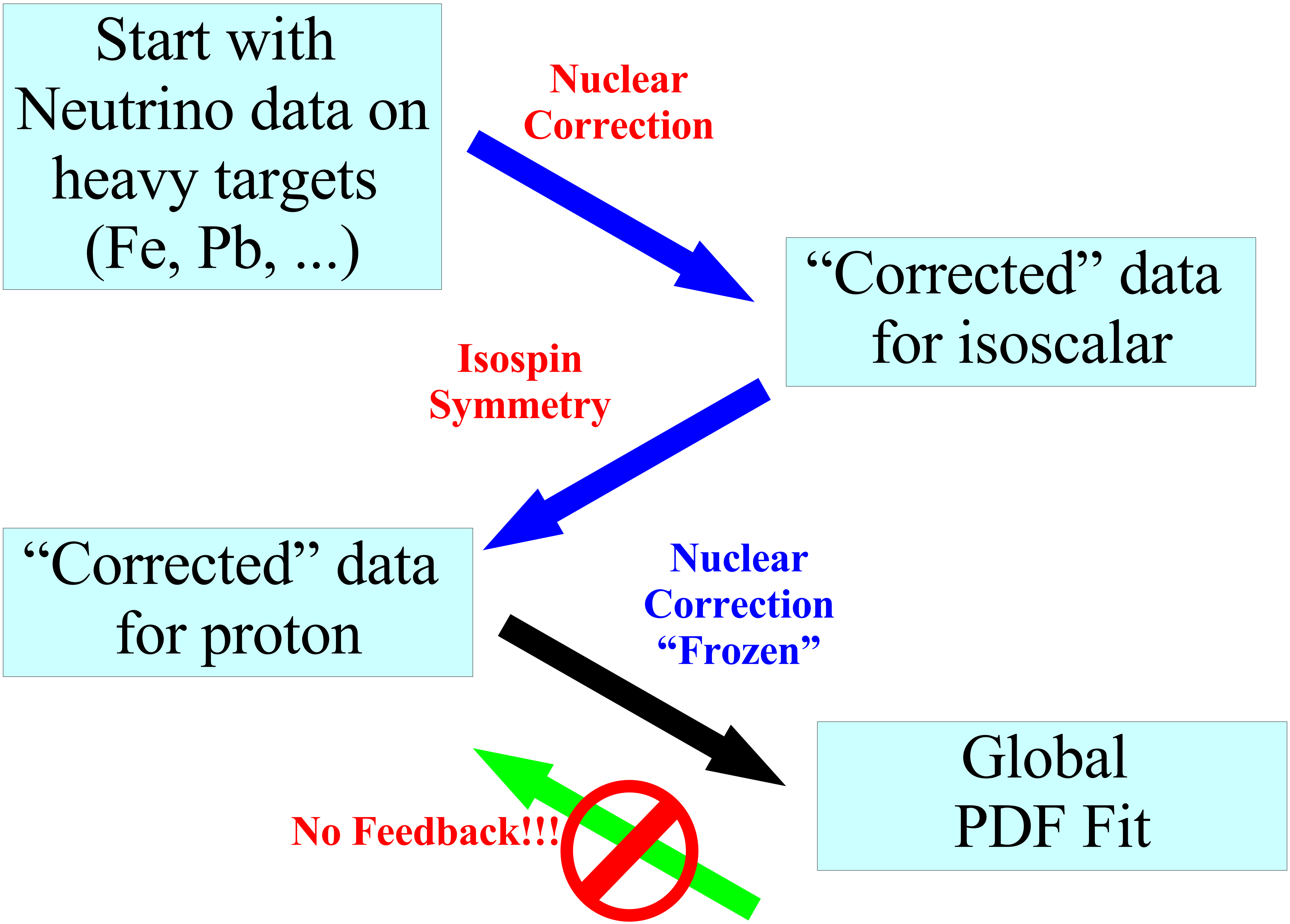
Where do Nuclear Corrections come from ???



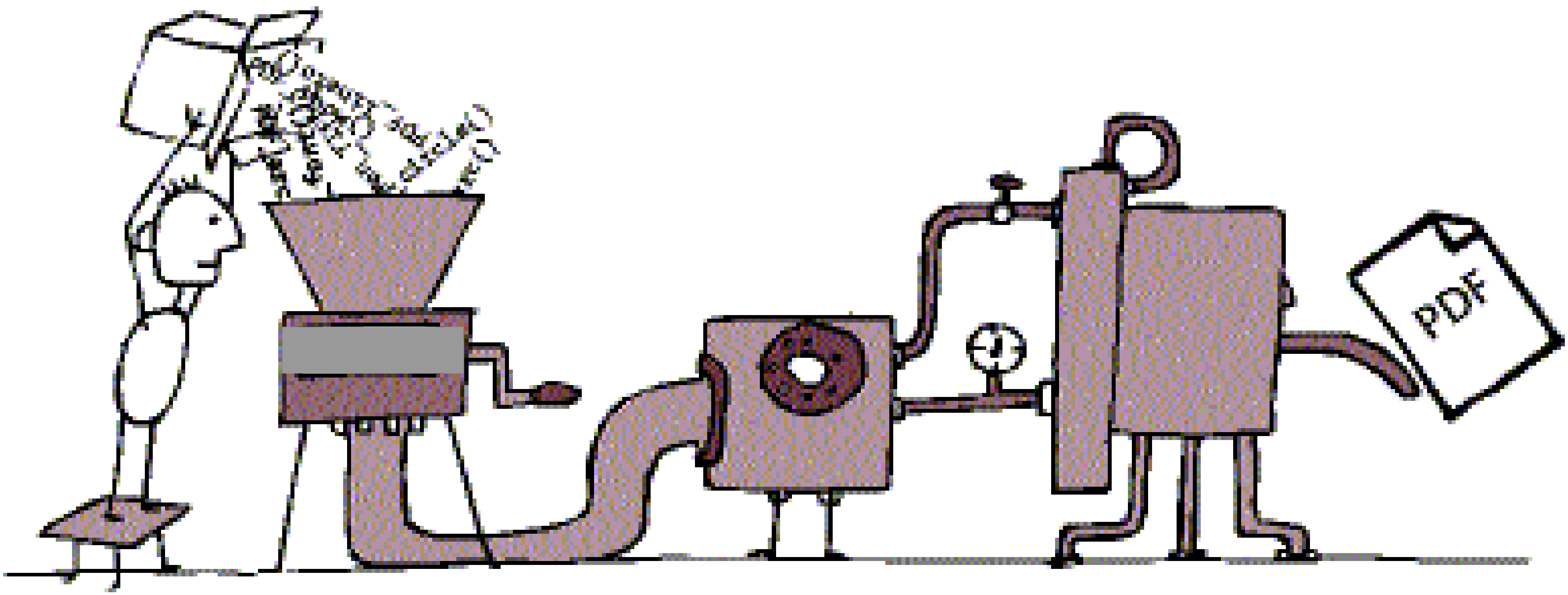
carved in stone

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.

Traditional Input to Global PDF Fit



Include Nuclear Dimension Dynamically



Extended CTEQ Framework

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

A-Dependent PDFs

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

$$a_i \longrightarrow a_i(A)$$

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

Nuclear PDFs from neutrino deep inelastic scattering.

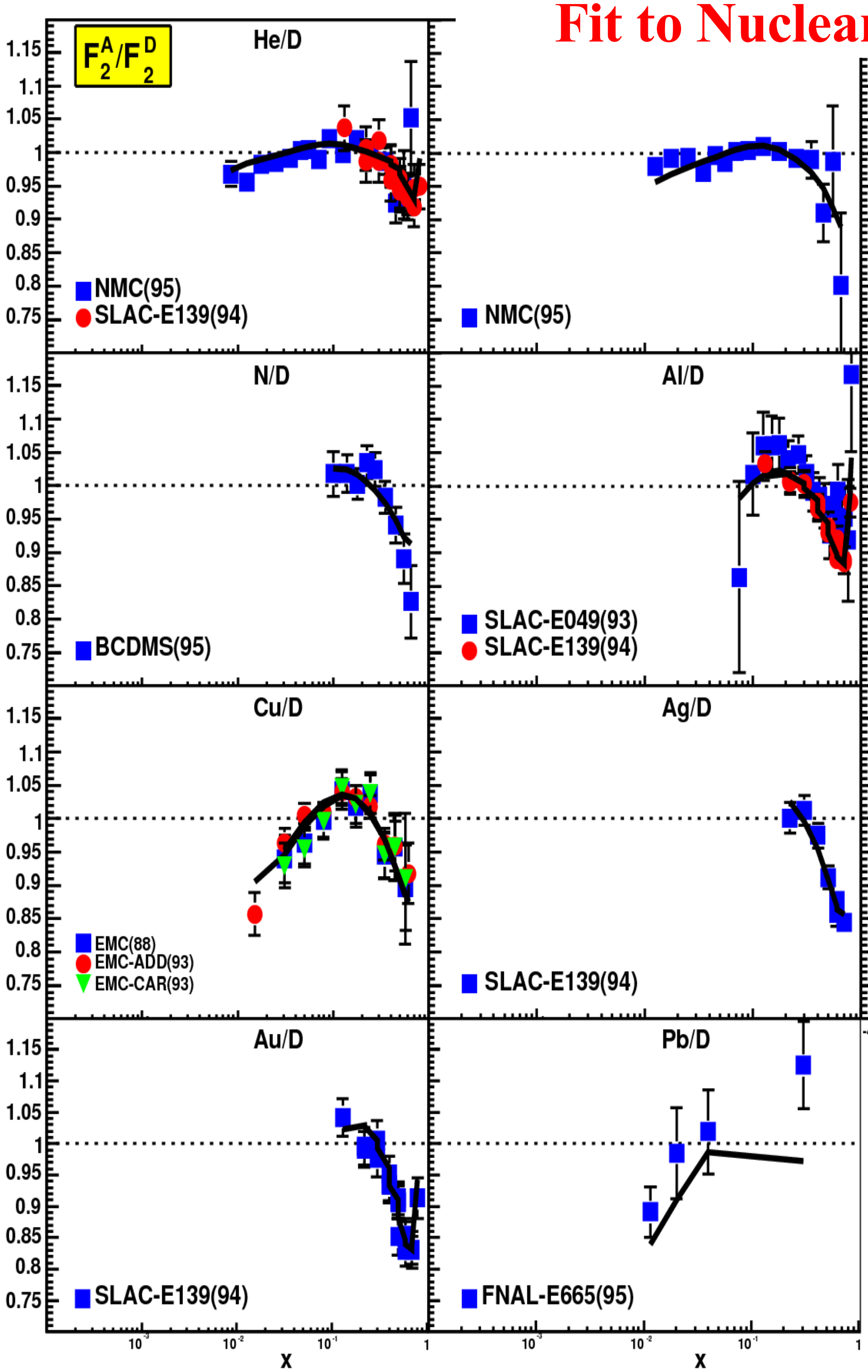
I. Schienbein, J.Y. Yu,

C. Keppel, J.G. Morfin, F. Olness, J.F. Owens.

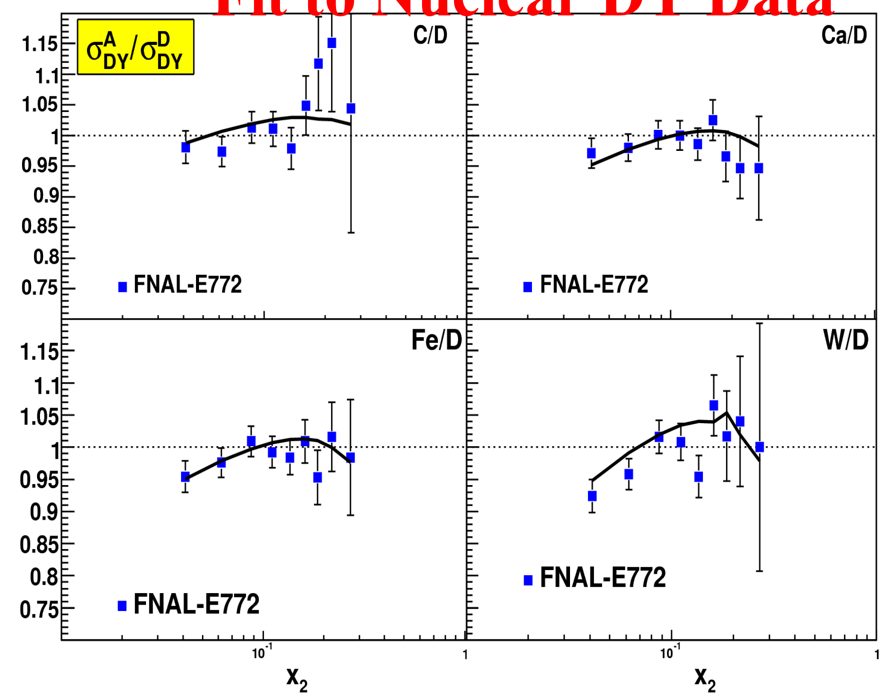
Phys.Rev.D77:054013,2008.

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	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	0.66	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

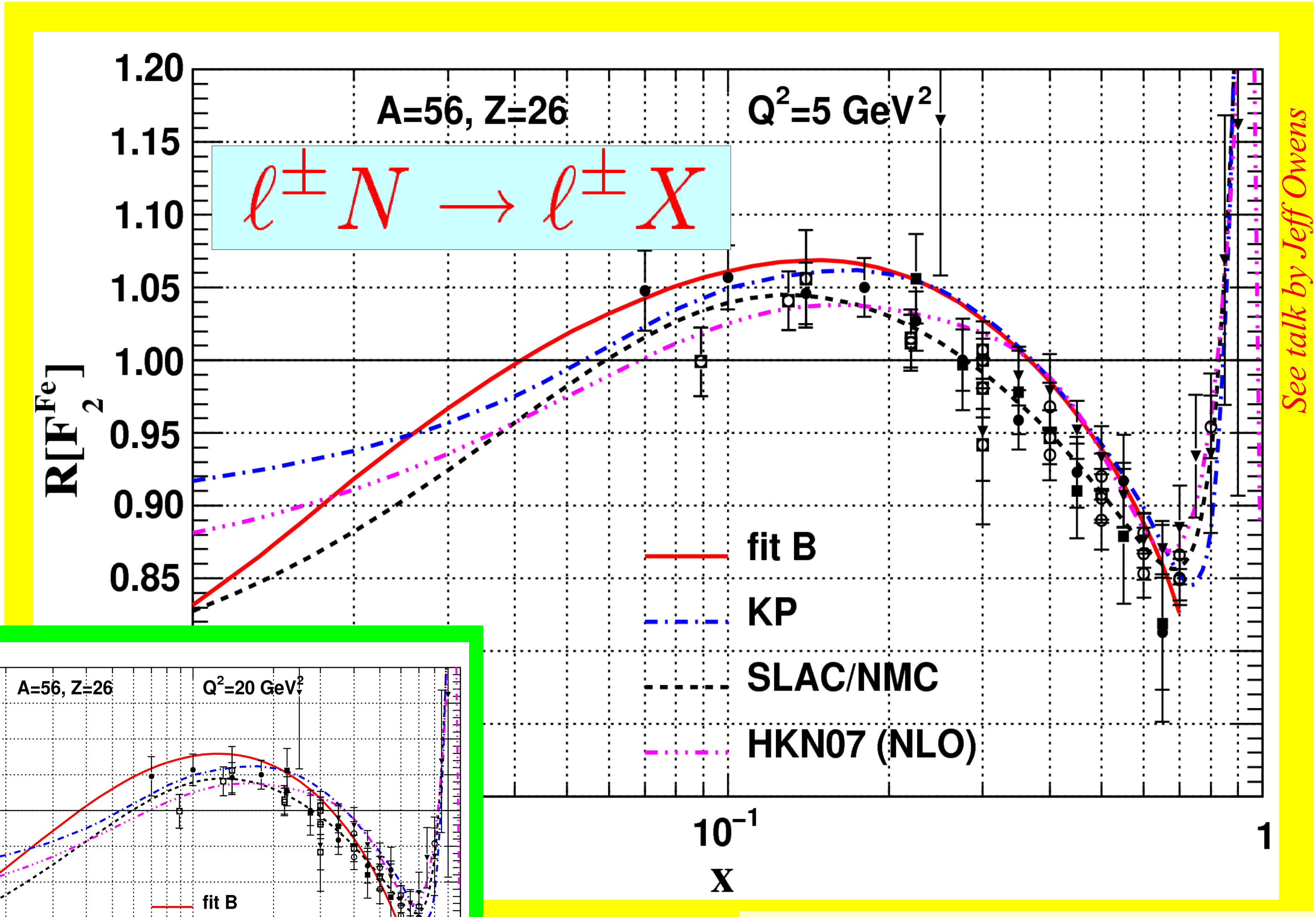


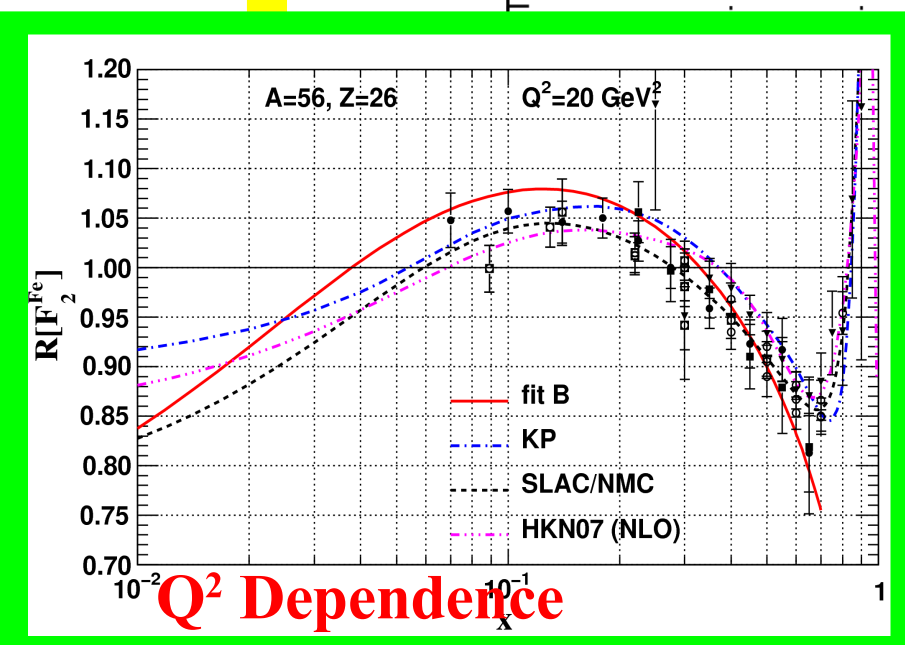
Fit to Nuclear DY Data



Nuclear Corrections: Charged Lepton (γ) Case

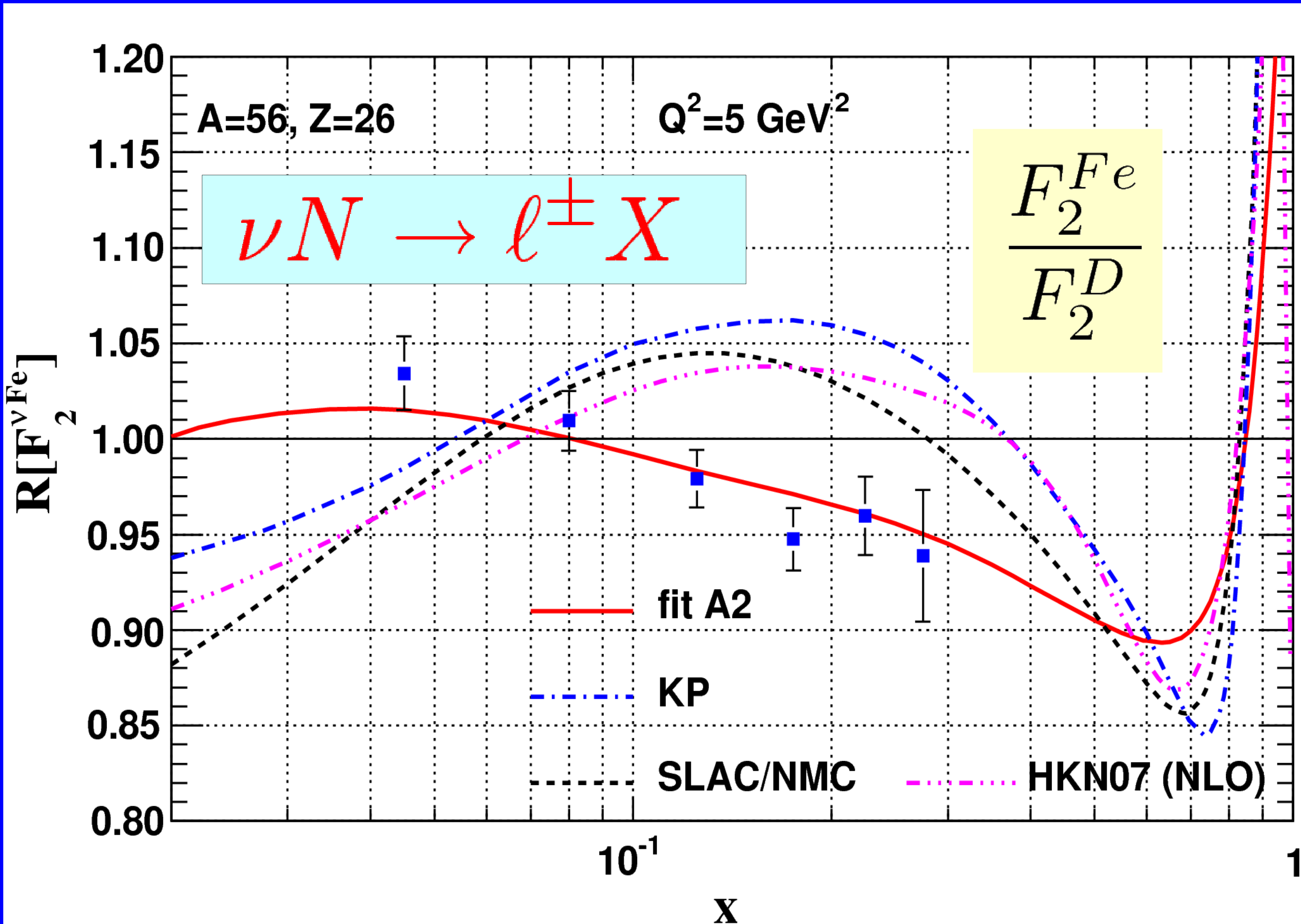
$$\frac{F_2^{Fe}}{F_2^D}$$





Also, other NPDF sets by:
M.Hirai, S.Kumano, T.-H.Nagai,
K.J.Eskola, H.Paukkune, C.A.Salgado,
S.Kulagin, R.Petti

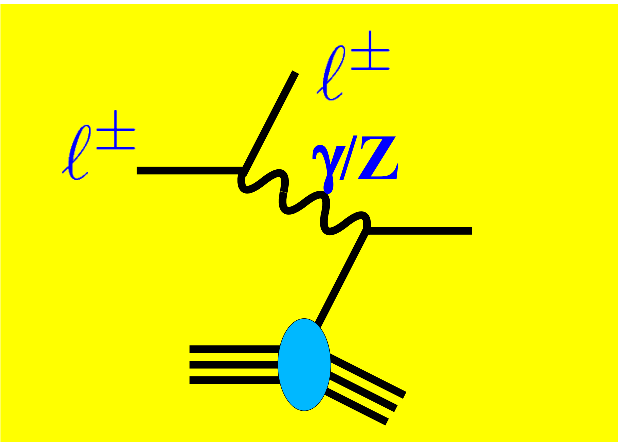
Nuclear Corrections: Neutrino ($W^{\pm}$) Case

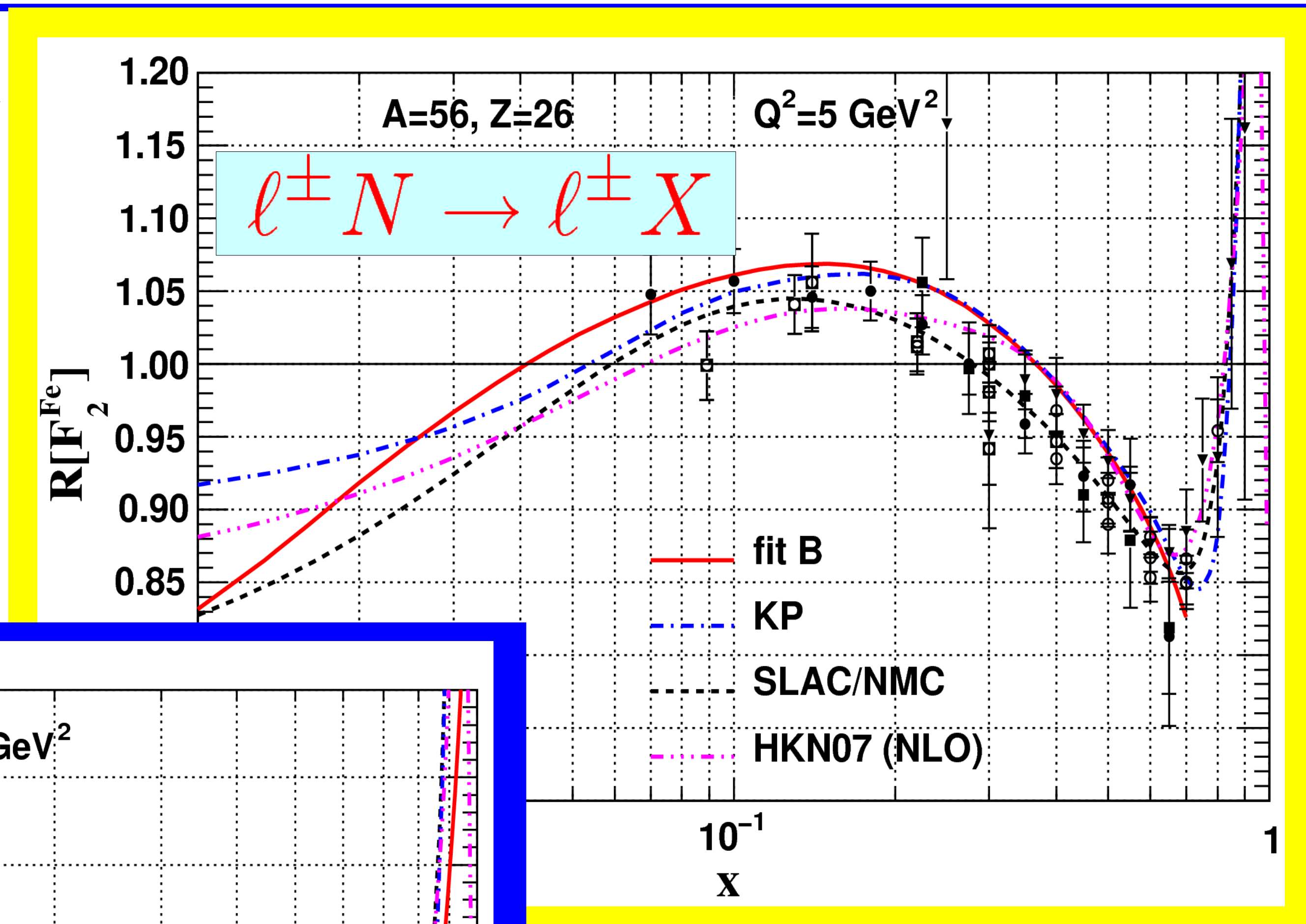


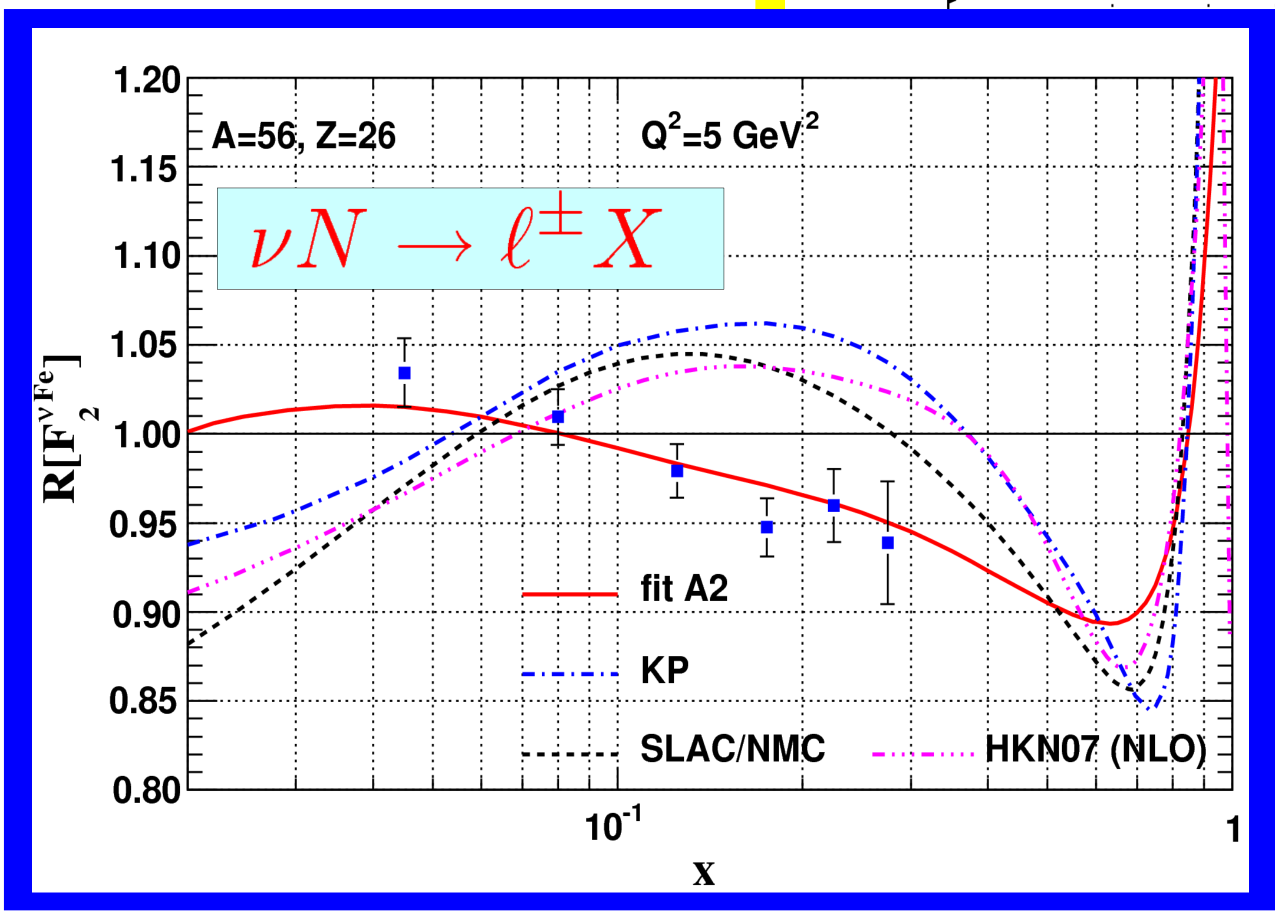
Oooooops!

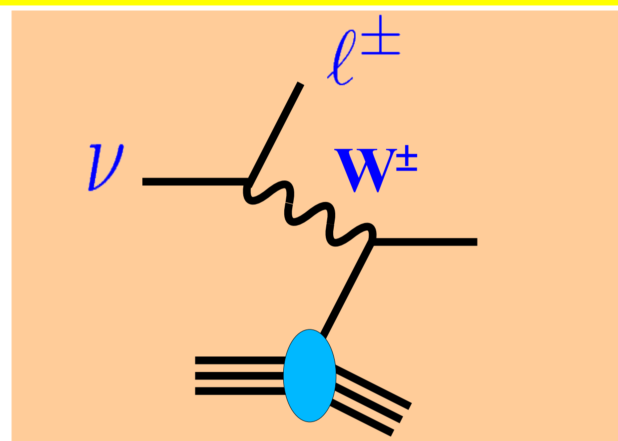
Nuclear Corrections: Compare Neutrino and Charged Lepton DIS

Charged Lepton DIS ⇒









⇐ Neutrino DIS

~~Myth~~ #1: Nuclear Corr's are all the same

Determine Nuclear modifications separately for Neutral and Charged Currents

~~Myth~~ #2: It doesn't matter

Can't we just drop the data set????

6 Structure Functions: {F2, F3, R} ⊗{nu, nubar}

... you're missing lots of information ...

E.g., CTEQ6.5 and beyond **do not** use heavy target ν-DIS data

PDF sets used for Tevatron & LHC are without this flavor differentiation

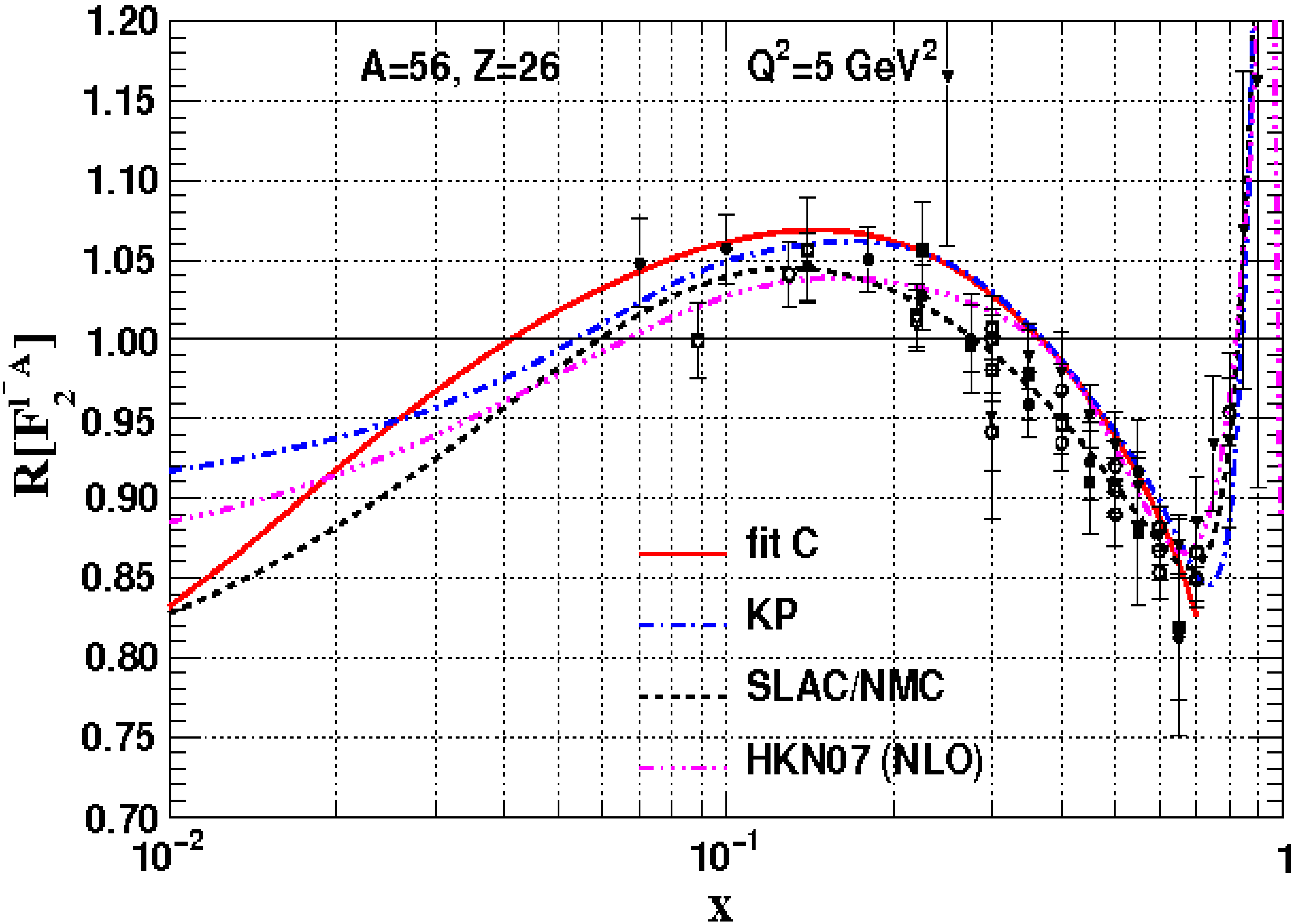
... ***except***, *for the dimuon data to resolve the strange PDF*

ν-DIS is key ingredient for PDF flavor differentiation!!!

Could there be a "compromise" fit

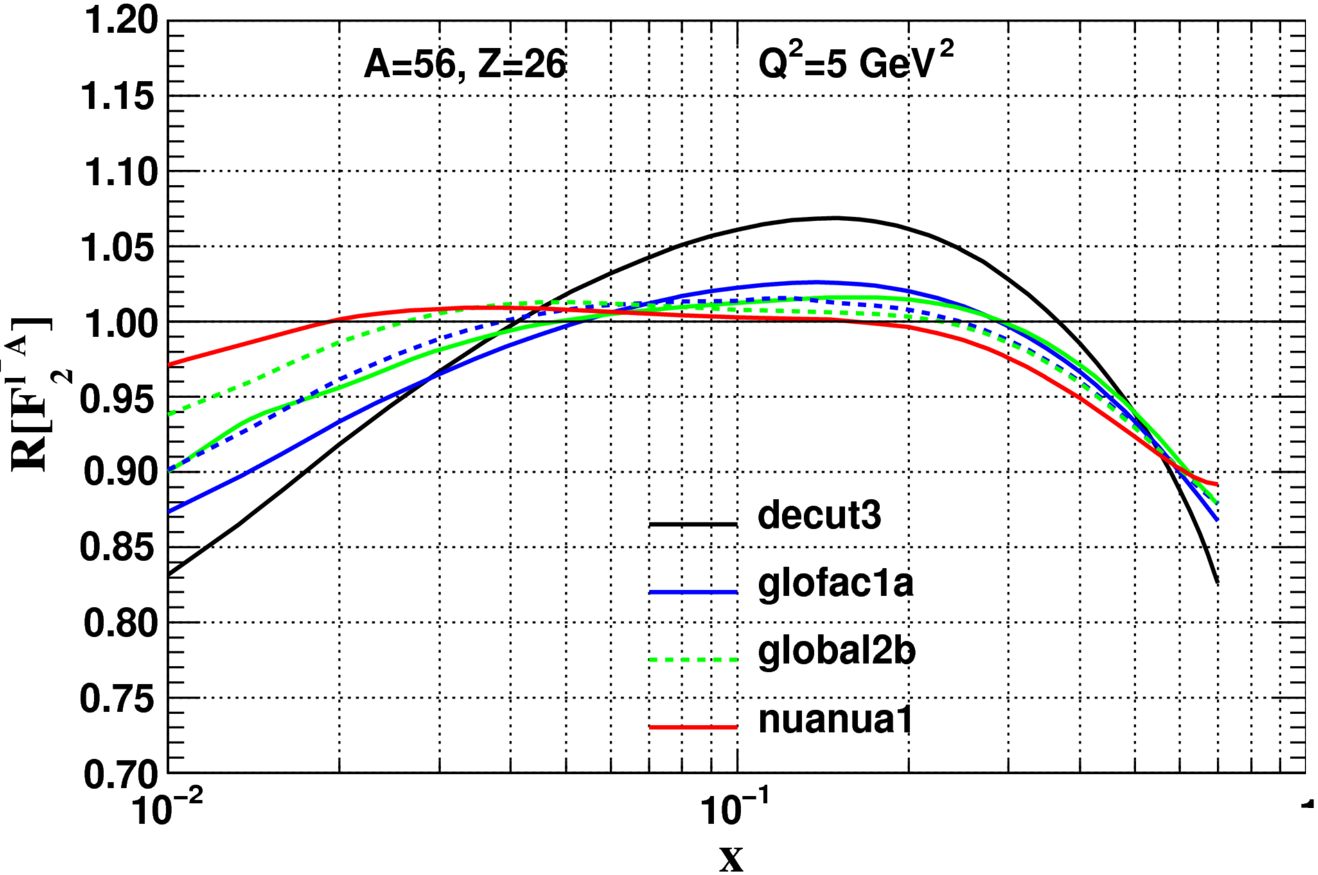
... some recent results by led by Karol Kovarik

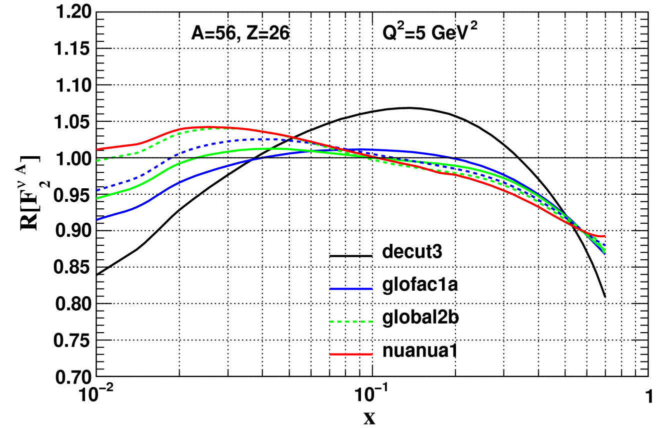
Comparison: Charged Lepton and Neutrino DIS

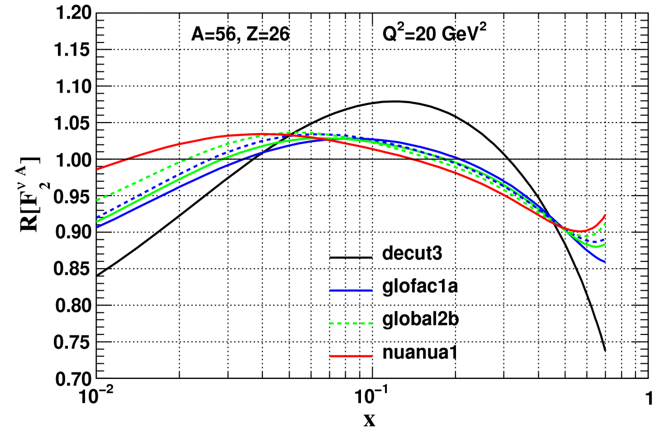


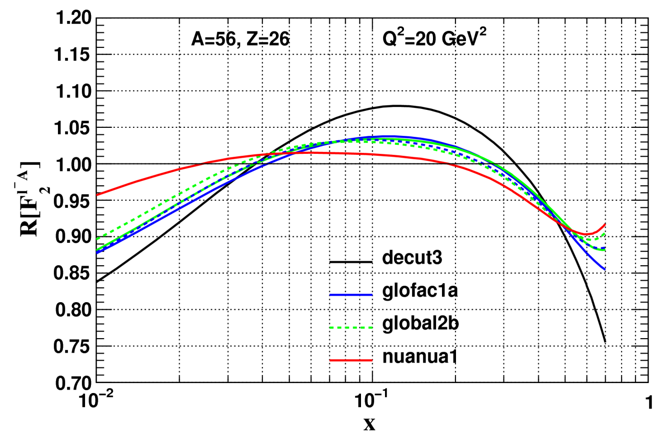
http://www.physics.smu.edu/olness/ftp/misc/npdf/fred_v2.gif

Comparison: Charged Lepton and Neutrino DIS





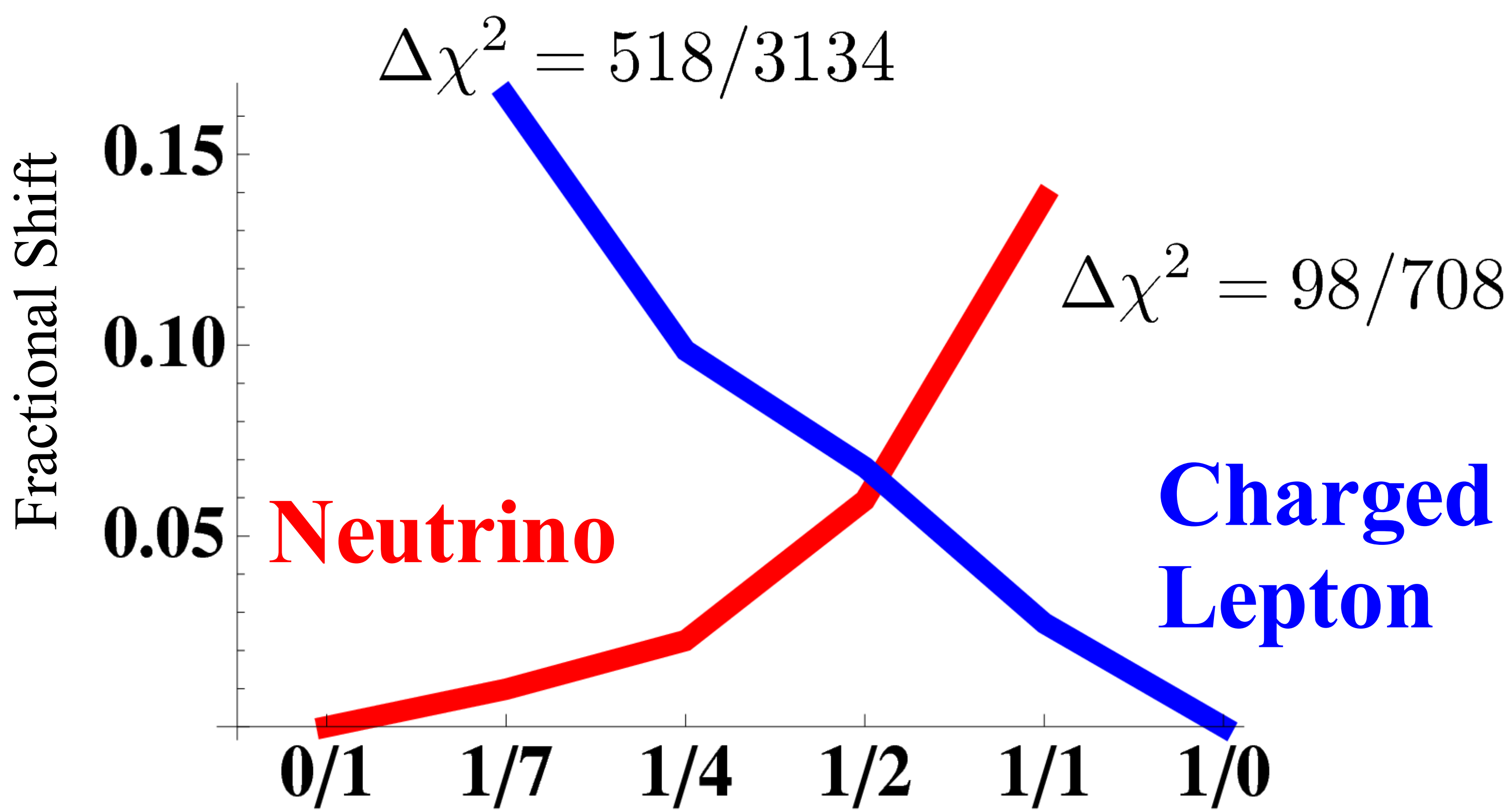




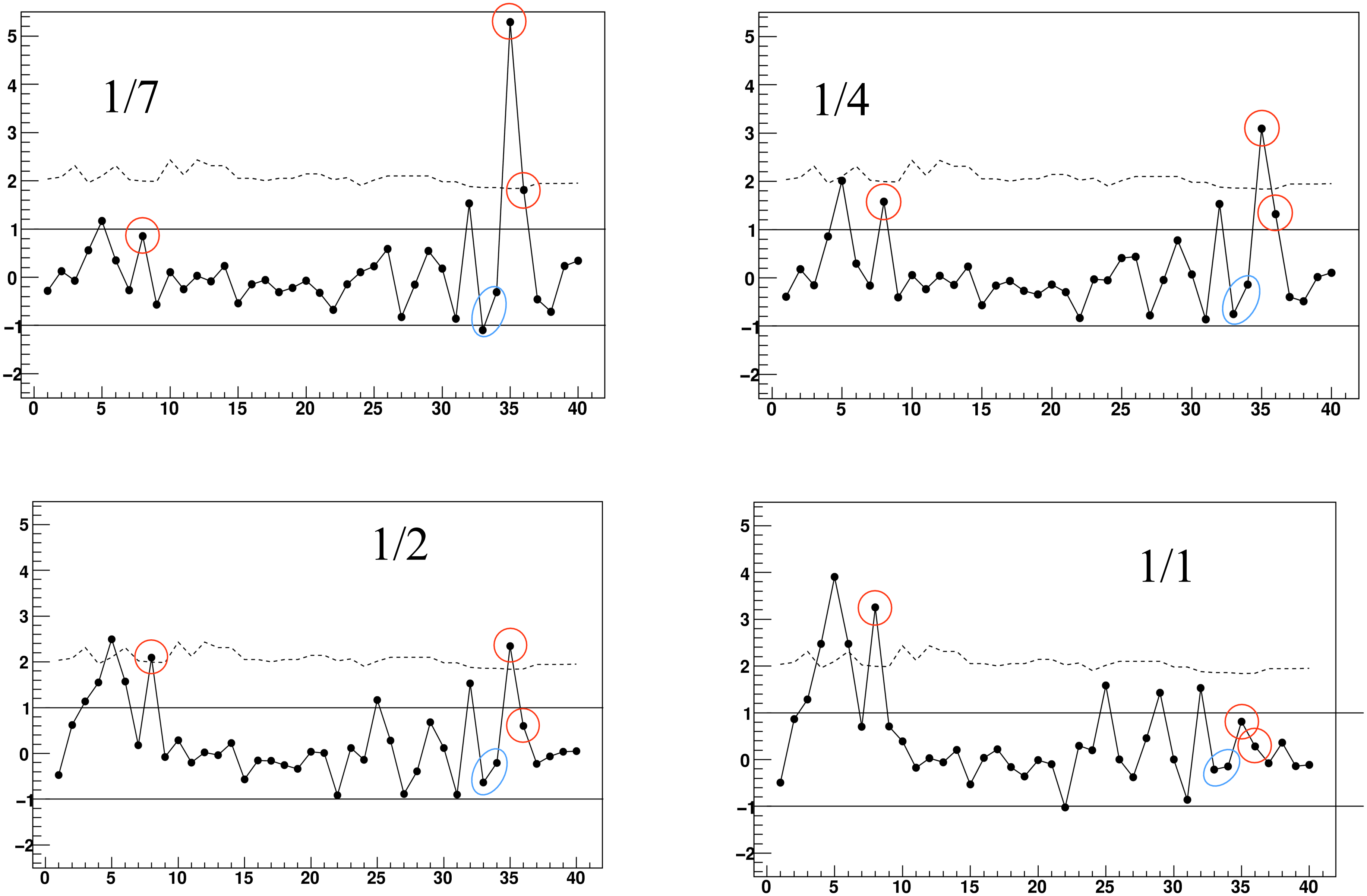
We can "pull" fit by weighting
Charged Lepton and Neutrino
data sets differently

Comparison: Charged Lepton and Neutrino DIS

Weight	Name of fit	$l^{\pm}A$ data	χ^2 (/pt)	νA data	χ^2 (/pt)	total χ^2 (/pt)
$w = 0$	decut3	708	638 (0.90)	-	-	638 (0.90)
$w = 1/7$	glofac1a	708	645 (0.91)	3134	4710 (1.50)	5355 (1.39)
$w = 1/4$	glofac1c	708	654 (0.92)	3134	4501 (1.43)	5155 (1.34)
$w = 1/2$	glofac1b	708	680 (0.96)	3134	4405 (1.40)	5085 (1.32)
$w = 1$	global2b	708	736 (1.04)	3134	4277 (1.36)	5014 (1.30)
$w = \infty$	nuanua1	-	-	3134	4192 (1.33)	4192 (1.33)



χ^2/DOF Per Experiment



1-He/D	2-Li/D	3-Be/D	4-C/D	5-N/D	6-Al/D	7-Ca/D
8-Fe/D	9-Cu/D	10-Ag/D	11-Sn/D	12-Xe/D	13-Au/D	14-Pb/D
15-Be/C	16-Al/C	17-Ca/C	18-Fe/C	19-Pb/C	20-C/Li	21-Ca/Li
22-He/D - Q^2	23-Kr/D - Q^2	24-Sn/C - Q^2	25-N/D - Q^2	26-C/D - DY	27-Ca/D - DY	28-Fe/D - DY
29-W/D - DY	30-Fe/Be - DY	31-W/Be - DY	32-F_2^D	33-νPb	34-$\bar{\nu}$Pb	35-νFe
36-$\bar{\nu}$Fe	37-CCFR ν	38-NuTeV ν	39-CCFR $\bar{\nu}$	40-NuTeV $\bar{\nu}$		

Comparison: Charged Lepton and Neutrino DIS

Weight	Name of fit	$l^{\pm}A$ data	χ^2 (/pt)	νA data	χ^2 (/pt)	total χ^2 (/pt)
$w = 0$	decut3	708 √	638 (0.90)	- X	-	638 (0.90)
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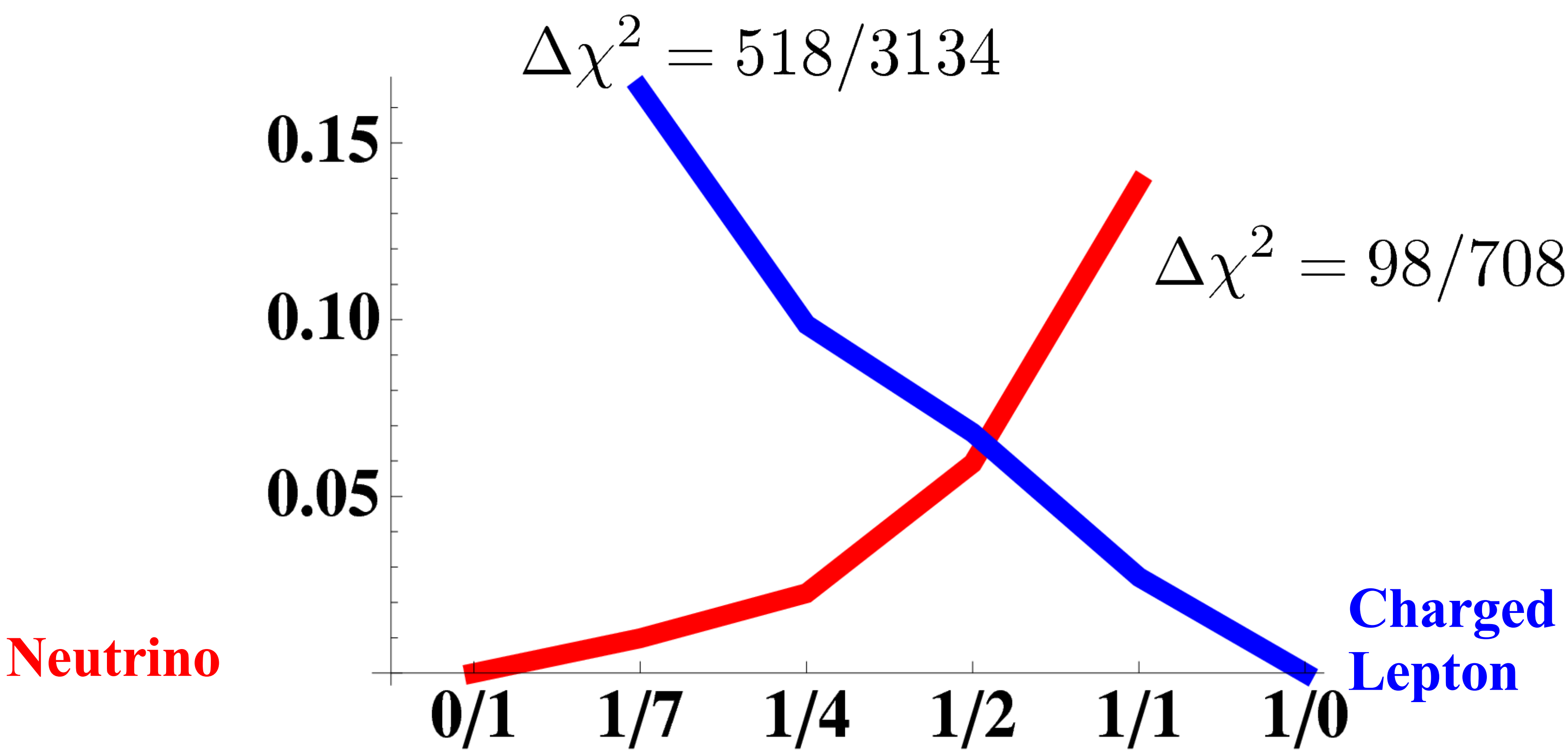
$w = \infty$	nuanua1	- X	-	3134 √	4192 (1.33)	4192 (1.33)



Could charged lepton and neutrino results be compatible?

"Thus, nuclear effects in νA DIS are in line with those extracted from charged lepton DIS and Drell-Yan dilepton production."

Hannu Paukkunen, DIS10

corrubtible measure: The χ^2-values

χ^2-values without radiative or target mass corrections:

No RAD + No TM	CTEQ6.6	CTEQ6.6 + EPS09
NuTeV	1.35	1.05
CHORUS	1.23	1.06
CDHSW	0.96	0.85

χ^2-values with radiative and target mass corrections:

RAD + TM	CTEQ6.6	CTEQ6.6 + EPS09
NuTeV	1.51	1.05
CHORUS	1.15	0.78
CDHSW	1.10	0.69

Extremely good χ^2-values!

Something strange going on with the NuTeV data?

Uncorrelated Errors

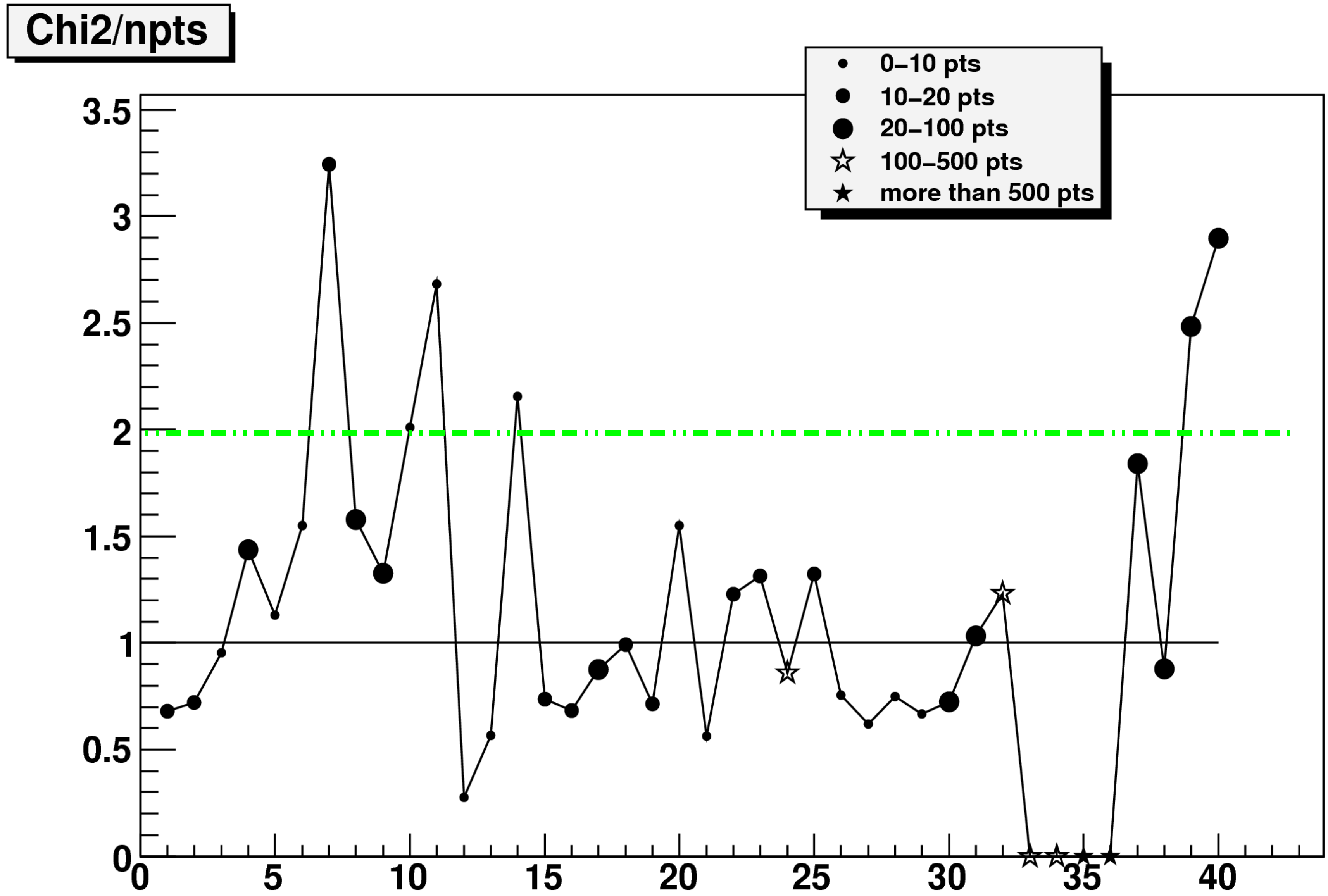
Paukkunen & Salgado, arXiv:1009.3143

χ^2/DOF	CTEQ6.6	CTEQ6.6×EPS09
NuTeV	1.51	1.05
CHORUS	1.15	0.79
CDHSW	1.10	0.71

nCTEQ with Uncorrelated Errors

χ^2/DOF	$Q^2 > 4$	$Q^2 > 5$	$Q^2 > 5$ + gluon
charged lepton	1.16	1.13	1.06
neutrino	1.00	0.95	0.98
Total	1.02	0.99	1.00

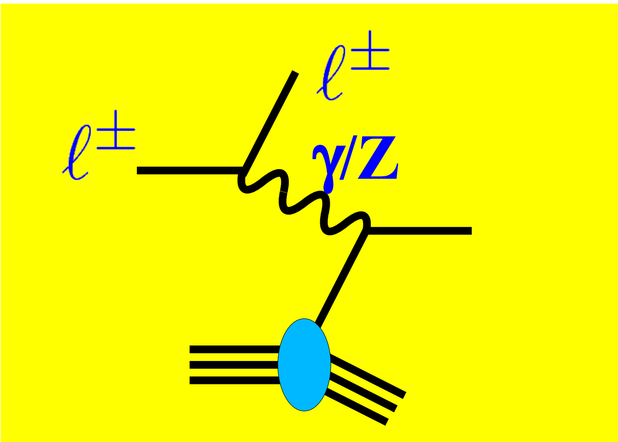
Uncorrelated Errors: χ^2/DOF ~ 1

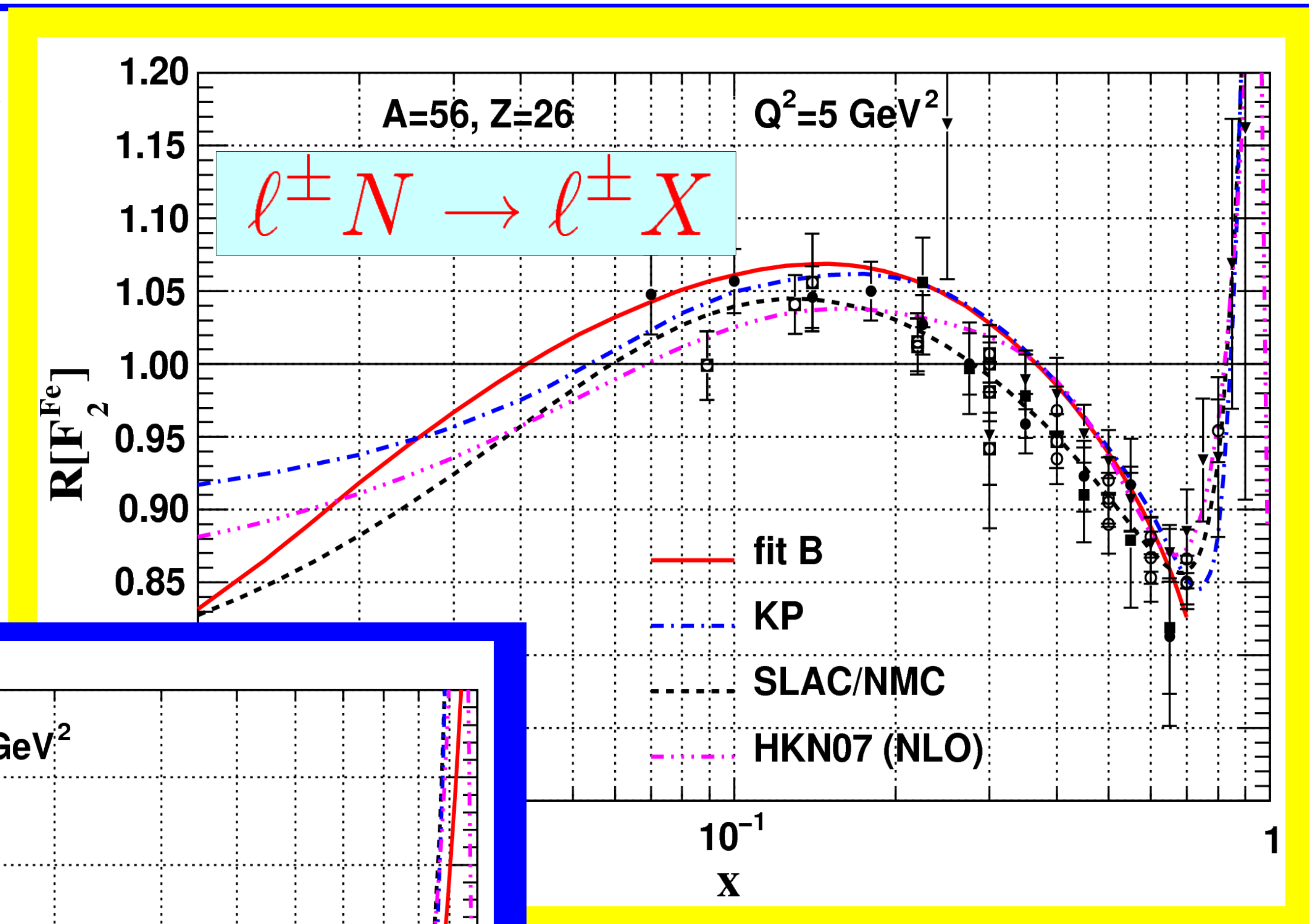


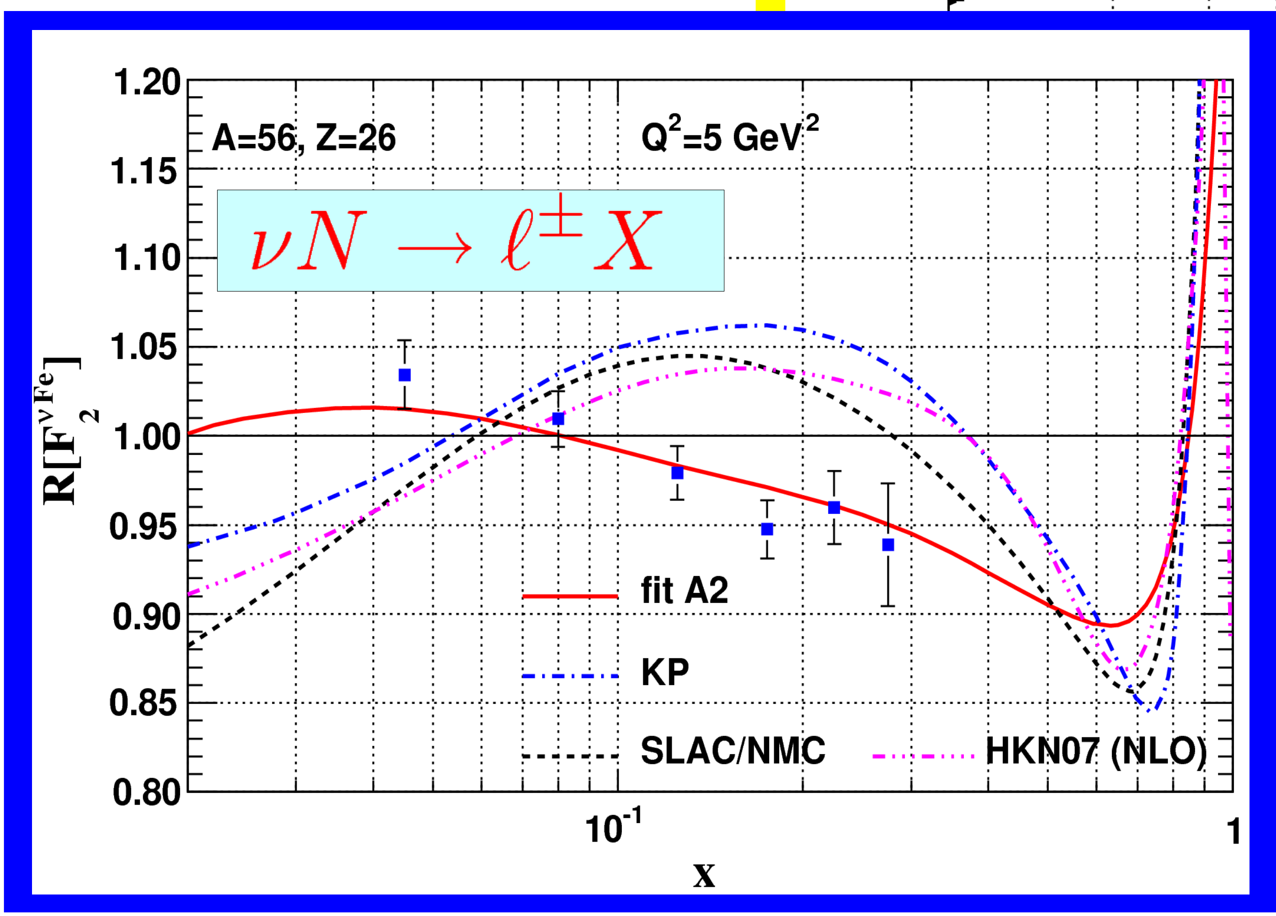
1-He/D	2-Li/D	3-Be/D	4-C/D	5-N/D	6-Al/D	7-Ca/D
8-Fe/D	9-Cu/D	10-Ag/D	11-Sn/D	12-Xe/D	13-Au/D	14-Pb/D
15-Be/C	16-Al/C	17-Ca/C	18-Fe/C	19-Pb/C	20-C/Li	21-Ca/Li
22-He/D - Q^2	23-Kr/D - Q^2	24-Sn/C - Q^2	25-N/D - Q^2	26-C/D - DY	27-Ca/D - DY	28-Fe/D - DY
29-W/D - DY	30-Fe/Be - DY	31-W/Be - DY	32-F_2^D	33-νPb	34-$\bar{\nu}$Pb	35-νFe
36-$\bar{\nu}$Fe	37-CCFR ν	38-NuTeV ν	39-CCFR $\bar{\nu}$	40-NuTeV $\bar{\nu}$		

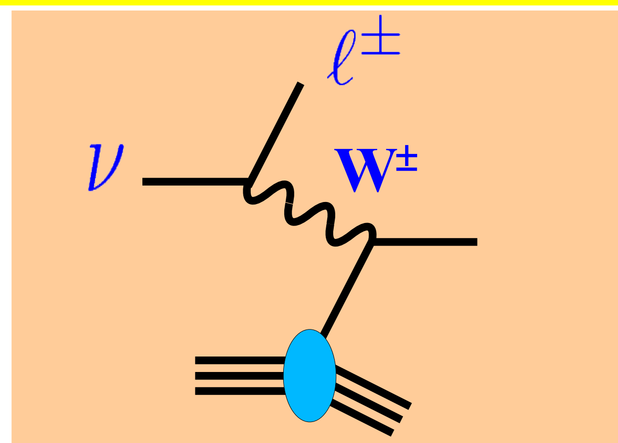
What is the interpretation????????????????????

Charged Lepton DIS ⇒





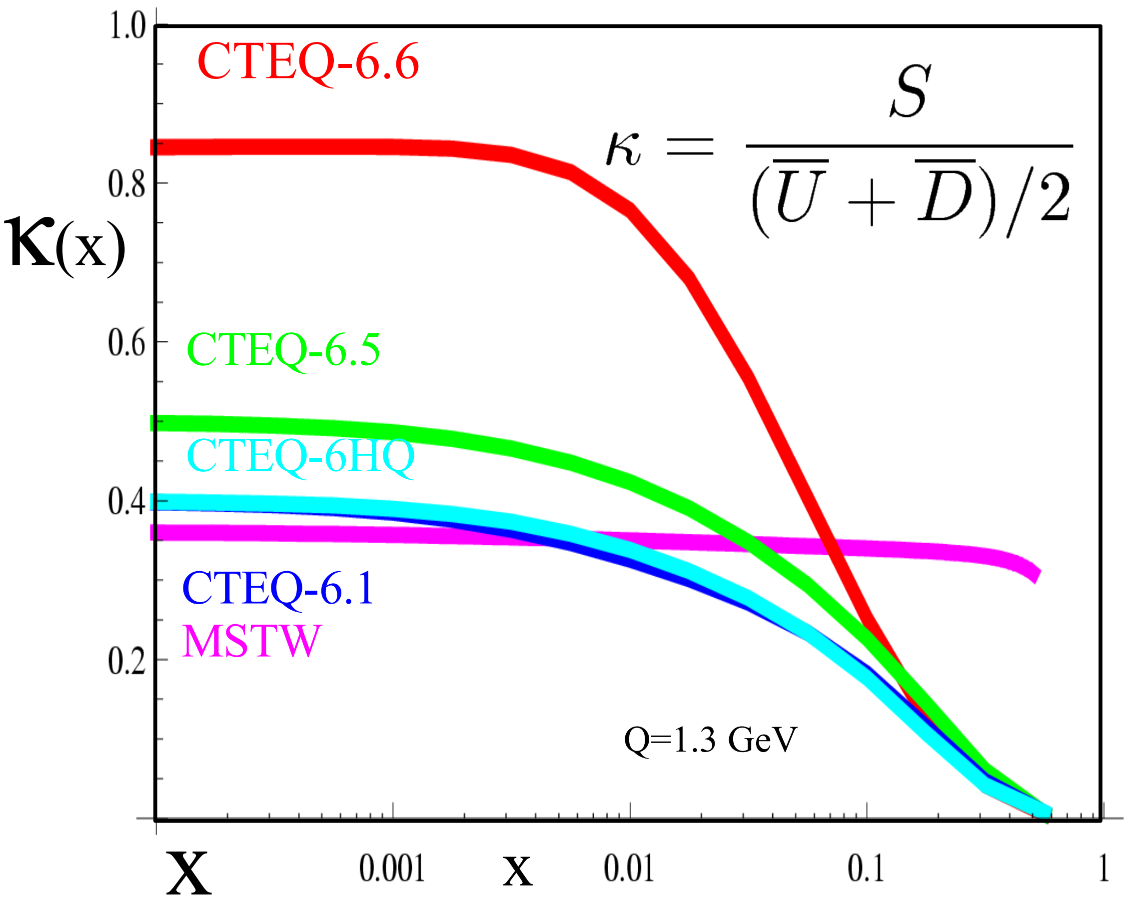




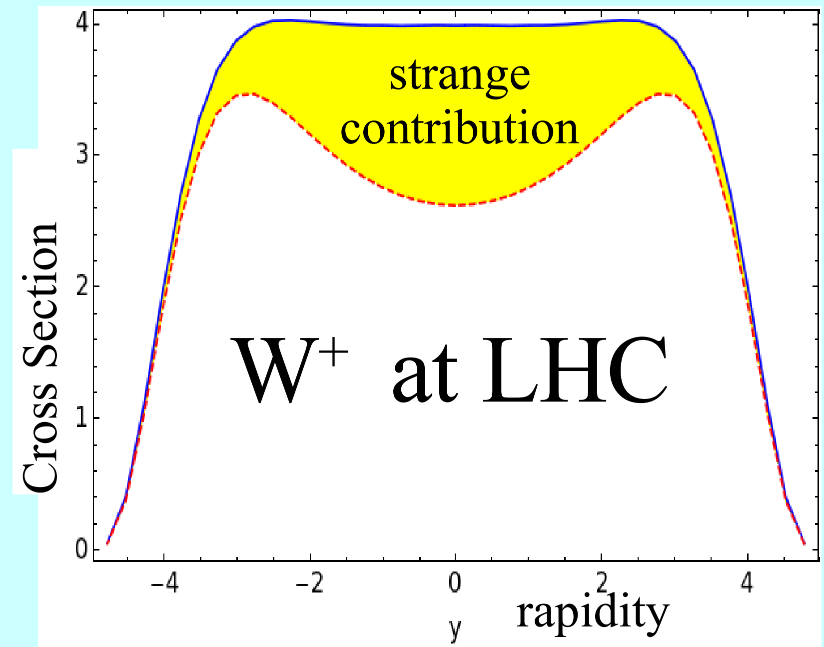
⇐ Neutrino DIS

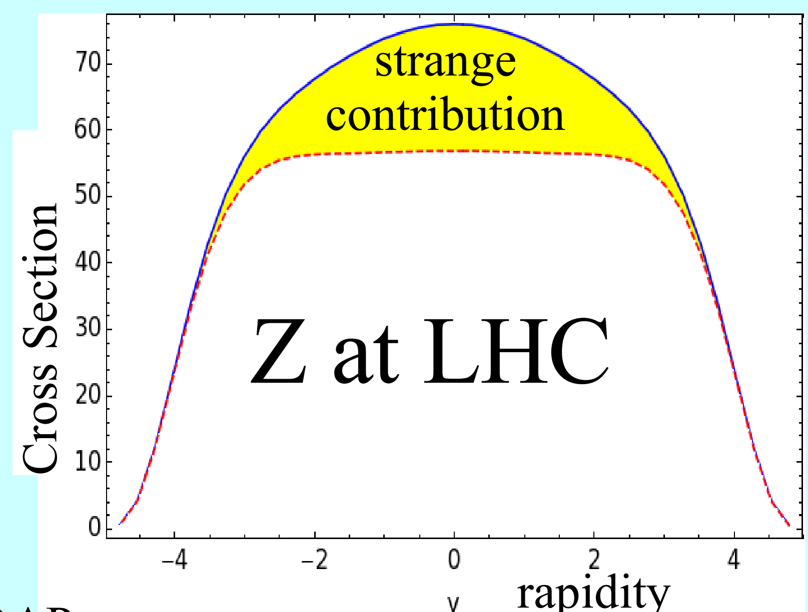
Why should the LHC or Tevatron care???

PDF Uncertainties ⇒ S(x) PDF ⇒ W/Z at LHC



PDF Uncertainties will feed into LHC "Benchmark" processes





VRAP Code

Anastasiou, Dixon, Melnikov, Petriello, Phys.Rev.D69:094008,2004.

Conclusions

Nuclear Corrections for PDFs

- Many open questions;
- Key for flavor differentiation
- Need input, both experimental and theoretical

Improvements possible/needed in many areas

- Increased attention in recent years
- ... see talks by **Kumano, Petti**, ...

These measurements are foundation for PDFs

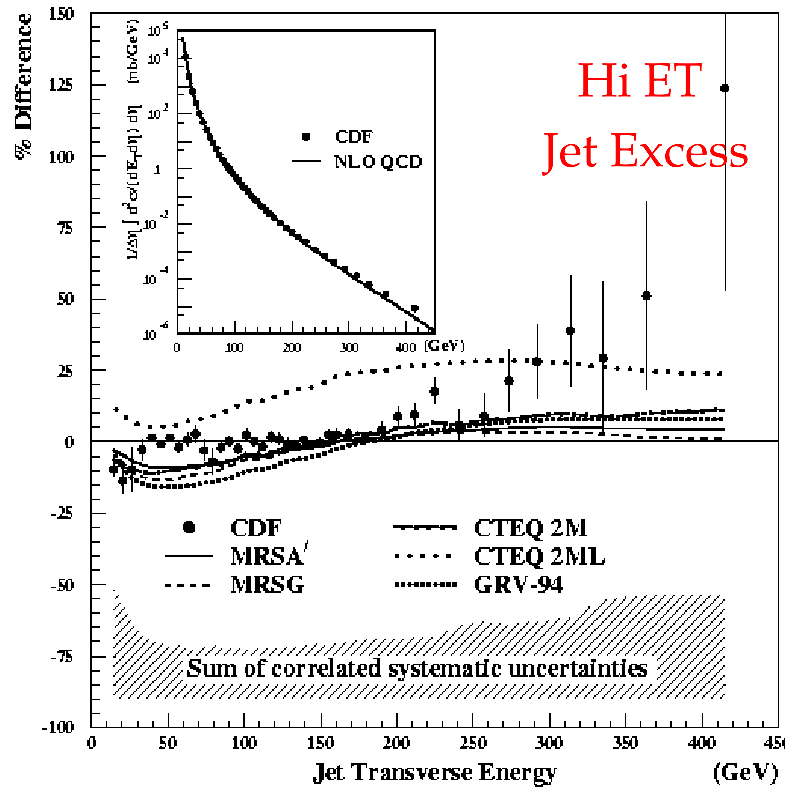
- Any "new physics" must be calibrated against "old physics"
- Low Q^2 measurements set Boundary Conditions for Hi Q^2

Forms the foundation for Tevatron & LHC Physics

LEFT OVER

Search for "new physics" requires dependable foundation

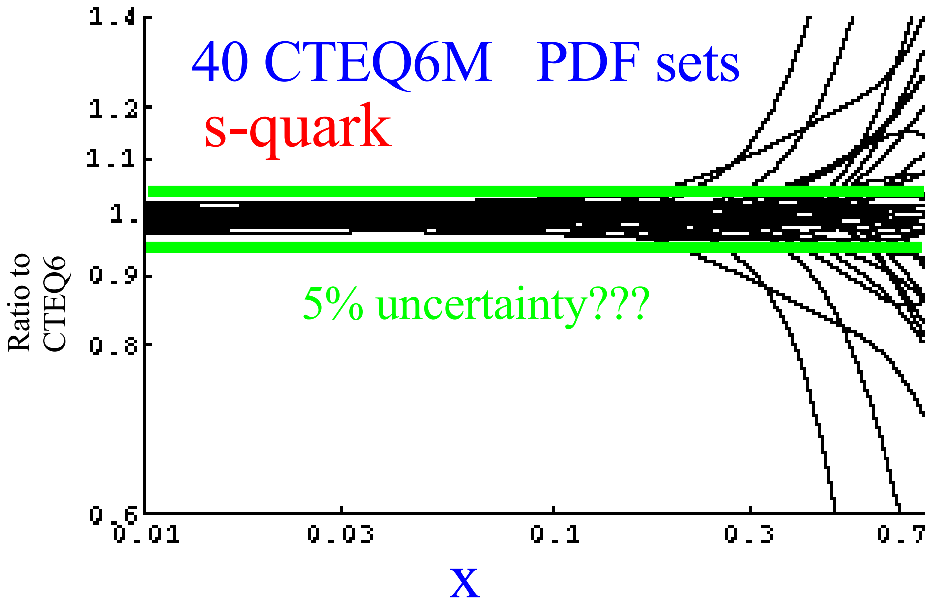
Measurements depend on this foundation—that is what we use to calibrate the search for "new physics"

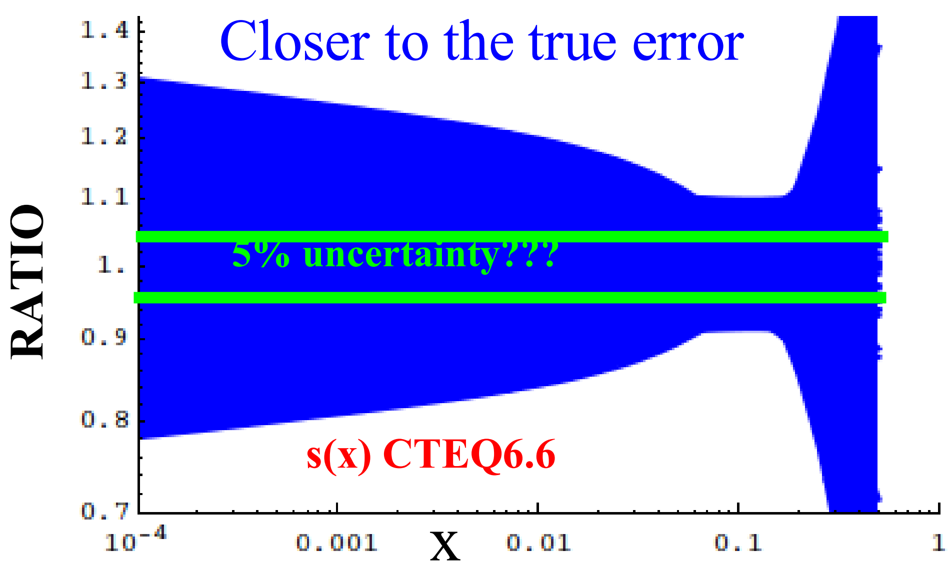


PRL 77, 438 (1996)

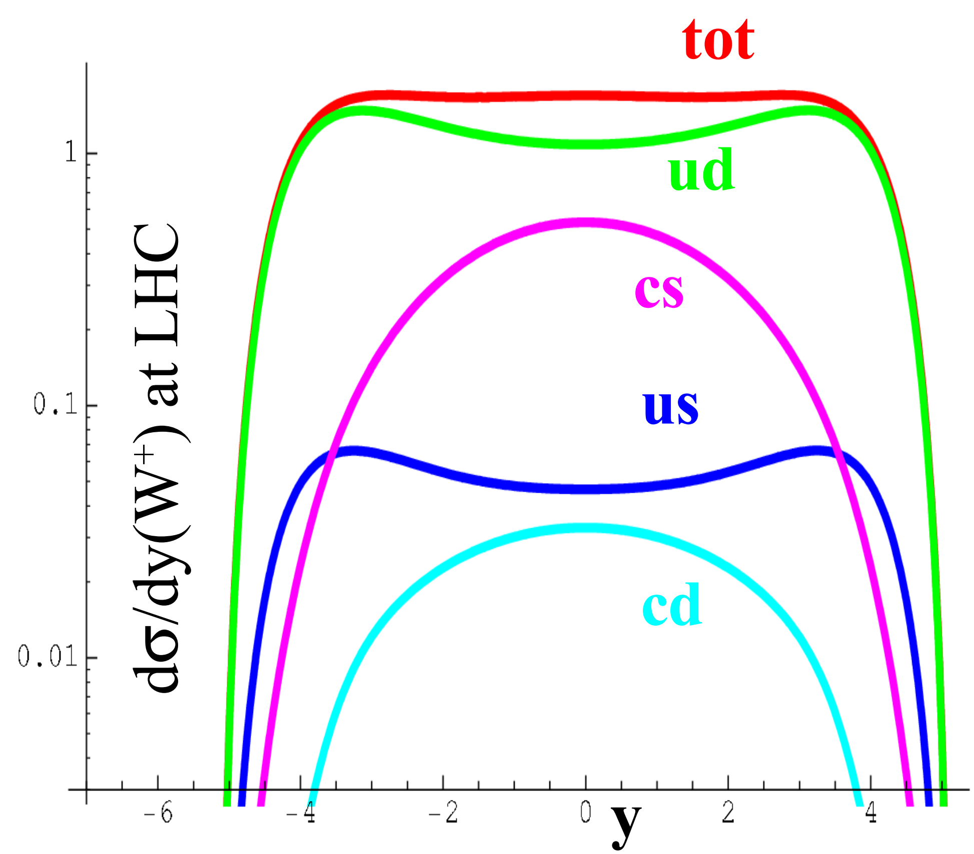
Will present some examples where the foundations might be improved

W Production at LHC: A Benchmark Cross Section



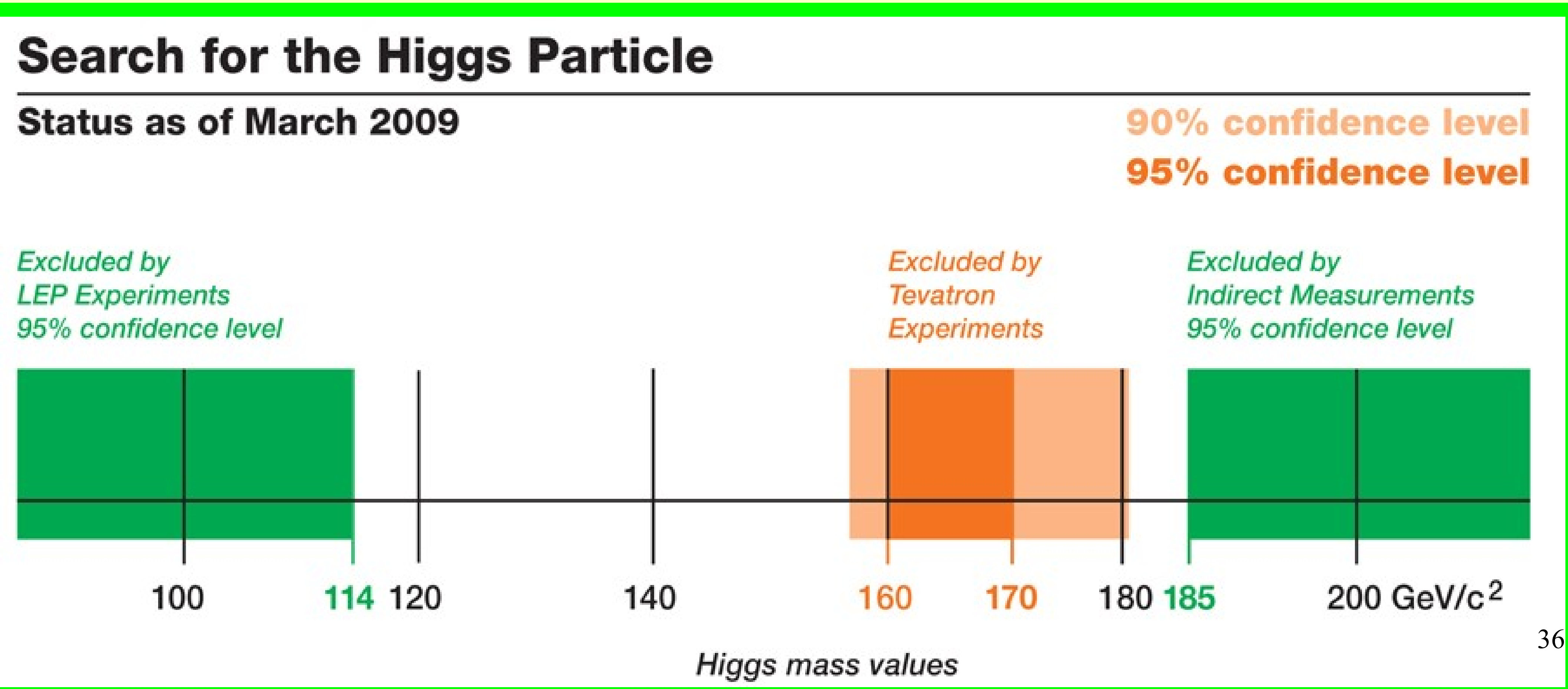


Heavy quark PDFs essential ingredient

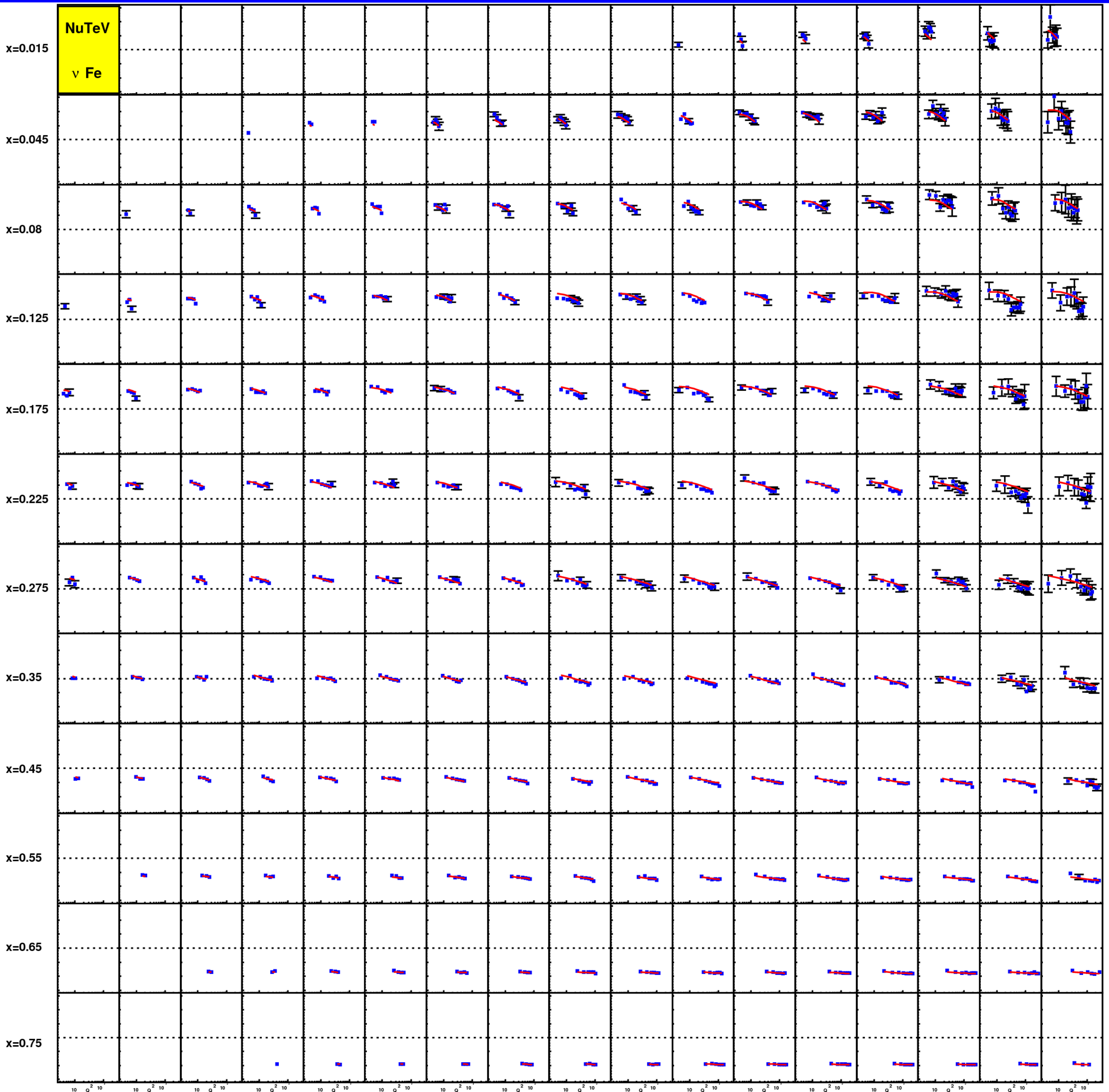


Heavy Quark components play an increasingly important role at the LHC

W/Z at LHC
& the race for the Higgs



NuTeV Comparison with Theory

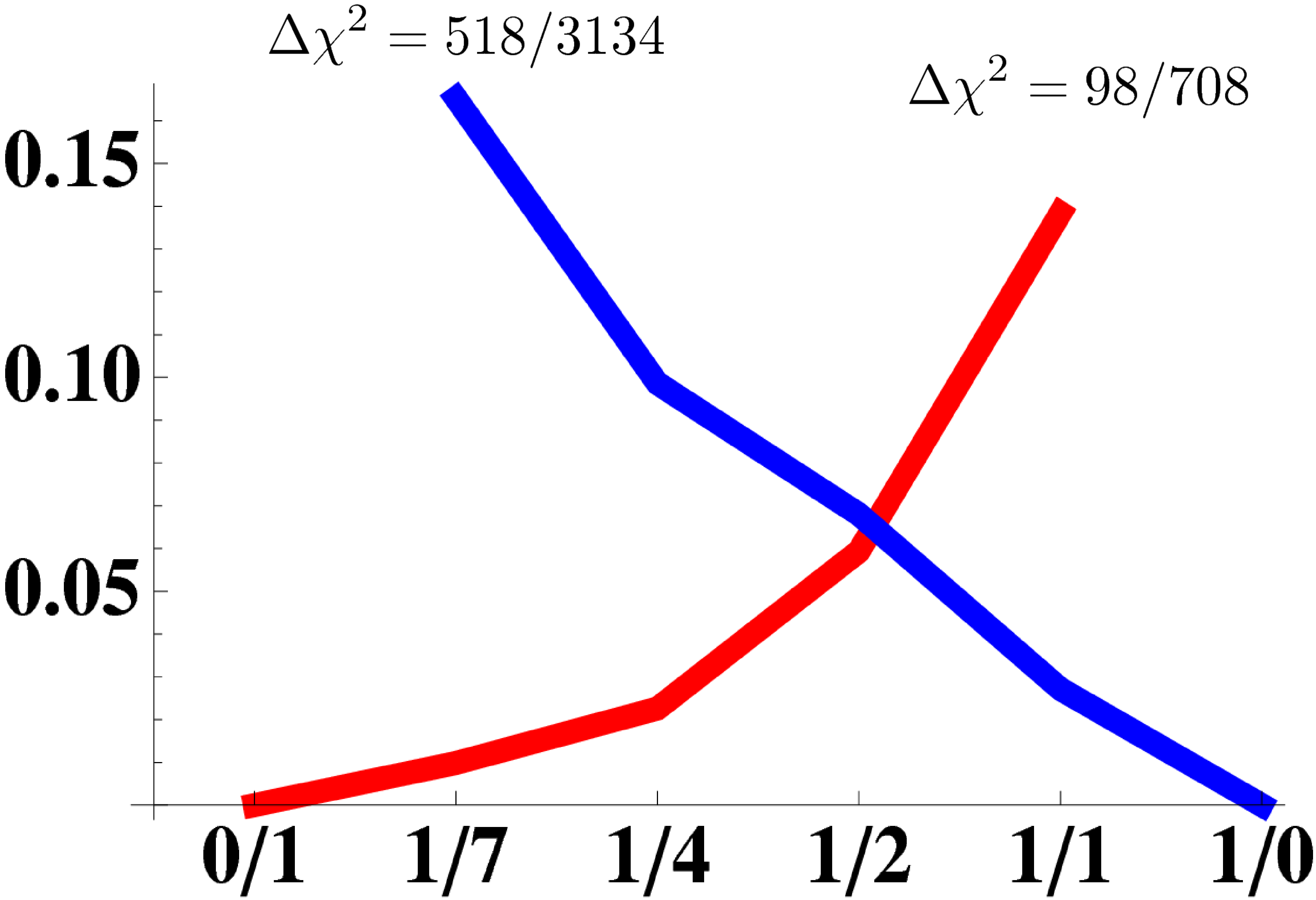


Conclusions

ID	$F_2^A/F_2^{A'}$: Observable	Experiment	Ref.	# data
1	He/D	SLAC-E139	[9]	18
		NMC-95,re	[23]	16
2	Li/D	NMC-95	[24]	15
3	Be/D	SLAC-E139	[9]	17
4	C/D	EMC-88	[25]	9
		EMC-90	[26]	2
		SLAC-E139	[9]	7
		NMC-95,re	[23]	16
		NMC-95	[24]	15
		FNAL-E665-95	[27]	4
5	N/D	BCDMS-85	[6]	9
6	Al/D	SLAC-E049	[28]	18
		SLAC-E139	[9]	17
7	Ca/D	EMC-90	[26]	2
		SLAC-E139	[9]	7
		NMC-95,re	[23]	15
		FNAL-E665-95	[27]	4
8	Fe/D	BCDMS-85	[6]	6
		BCDMS-87	[7]	10
		SLAC-E049	[5]	14
		SLAC-E139	[9]	23
		SLAC-E140	[10]	6
9	Cu/D	EMC-88	[25]	9
		EMC-93(addendum)	[29]	10
		EMC-93(chariot)	[29]	9
10	Ag/D	SLAC-E139	[9]	7
11	Sn/D	EMC-88	[25]	8
12	Xe/D	FNAL-E665-92(em cut)	[30]	4
13	Au/D	SLAC-E139	[9]	18
14	Pb/D	FNAL-E665-95	[27]	4
15	Be/C	NMC-96	[31]	15
16	Al/C	NMC-96	[31]	15
17	Ca/C	NMC-95	[23]	20
		NMC-96	[31]	15
18	Fe/C	NMC-95	[31]	15
19	Pb/C	NMC-96	[31]	15
20	C/Li	NMC-95	[23]	20
21	Ca/Li	NMC-95	[23]	20
22	He/D	Hermes	[32]	92
23	Kr/D	Hermes	[32]	84
24	Sn/C	NMC-96	[33]	144
25	N/D	Hermes	[32]	92
32	D	NMC-97	[34]	275
	Total:			862

ID	$\sigma_{DY}^{pA}/\sigma_{DY}^{pA'}$: Observable	Experiment	Ref.	# data
26	C/D	FNAL-E772-90	[35]	9
27	Ca/D	FNAL-E772-90	[35]	9
28	Fe/D	FNAL-E772-90	[35]	9
29	W/D	FNAL-E772-90	[35]	9
30	Fe/Be	FNAL-E866-99	[36]	28
31	W/Be	FNAL-E866-99	[36]	28
	Total:			92

ID	$d\sigma^{\nu A}/dxdy$: Observable	Experiment	Ref.	# data
33	Pb	CHORUS ν	[37]	412
34	Pb	CHORUS $\bar{\nu}$	[37]	412
35	Fe	NuTeV ν	[16]	1170
36	Fe	NuTeV $\bar{\nu}$	[16]	966
37	Fe	CCFR ν di-muon	[38]	44
38	Fe	NuTeV ν di-muon	[38]	44
39	Fe	CCFR $\bar{\nu}$ di-muon	[38]	44
40	Fe	NuTeV $\bar{\nu}$ di-muon	[38]	42
	Total:			3134



$\Delta\chi^2 = 518/3134$
$\Delta\chi^2 = 98/708$
0.15
0.10
0.05
0/1
1/7
1/4
1/2
1/1
1/0