

Physics in the LHC Era

*Precision control of the LHC partonic beams using
the combined LHC and Tevatron data.*

The role of future initiatives, ... or

What physics is complementary with LHC

Fred Olness

SMU

Conspirators:

T. Adams, P. Batra, L. Bugel, L. Camilleri, J.M. Conrad, A. de Gouvea, P.H. Fisher, J.A. Formaggio, J. Jenkins, G. Karagiorgi, T.R. Kobilarcik, S. Kopp, G. Kyle, W.A. Loinaz, D.A. Mason, R. Milner, R. Moore, J.G. Morfin, M. Nakamura, D. Naples, P. Nienaber, F.I. Olness, J.F. Owens, S.F. Pate, A. Pronin, W.G. Seligman, M.H. Shaevitz, H. Schellman, I. Schienbein, M.J. Syphers, T.M.P. Tait, T. Takeuchi, C.Y. Tan, R.G. Van de Water, R.K. Yamamoto, J.Y. Yu, P. Nadolsky, K. Park, M. Guzzi, K. Kovarik, C. Keppel, T. Stavreva

LPNHE - Paris
17 December 2010

LHC began collisions in 2010



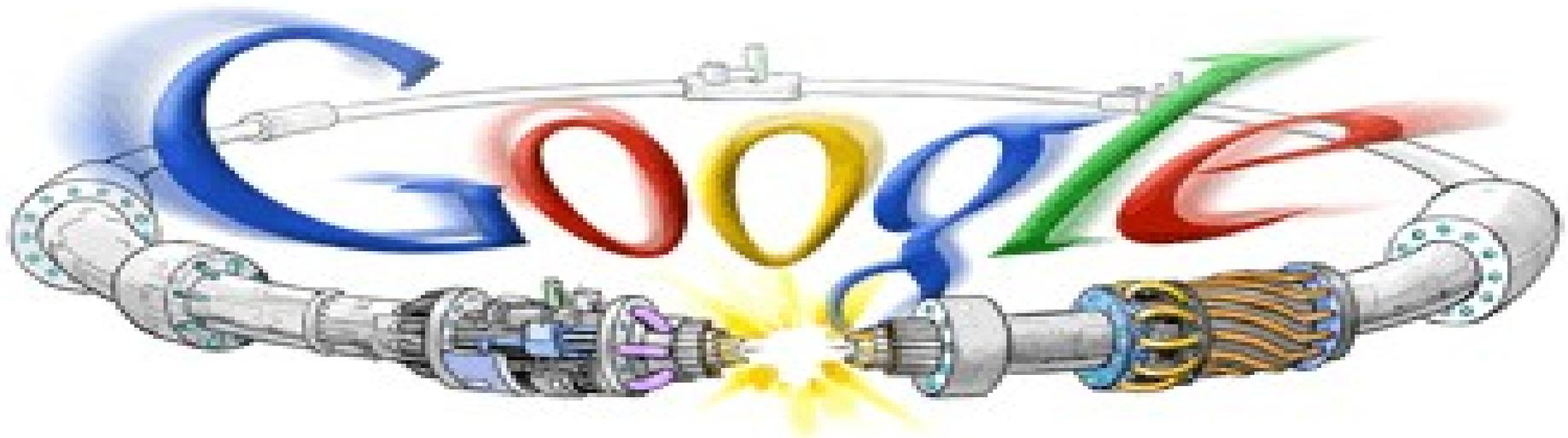
Will the world be absorbed by a black hole?

<http://www.HasTheLargeHadronColliderDestroyedTheWorldYet.com/>

<http://www.HasTheLargeHadronColliderDestroyedTheWorldYet.com/>

NOPE.

```
<script type="text/javascript">  
if (!(typeof worldHasEnded == "undefined")) {  
document.write("YUP.");  
} else {  
document.write("NOPE.");  
}  
</script>
```



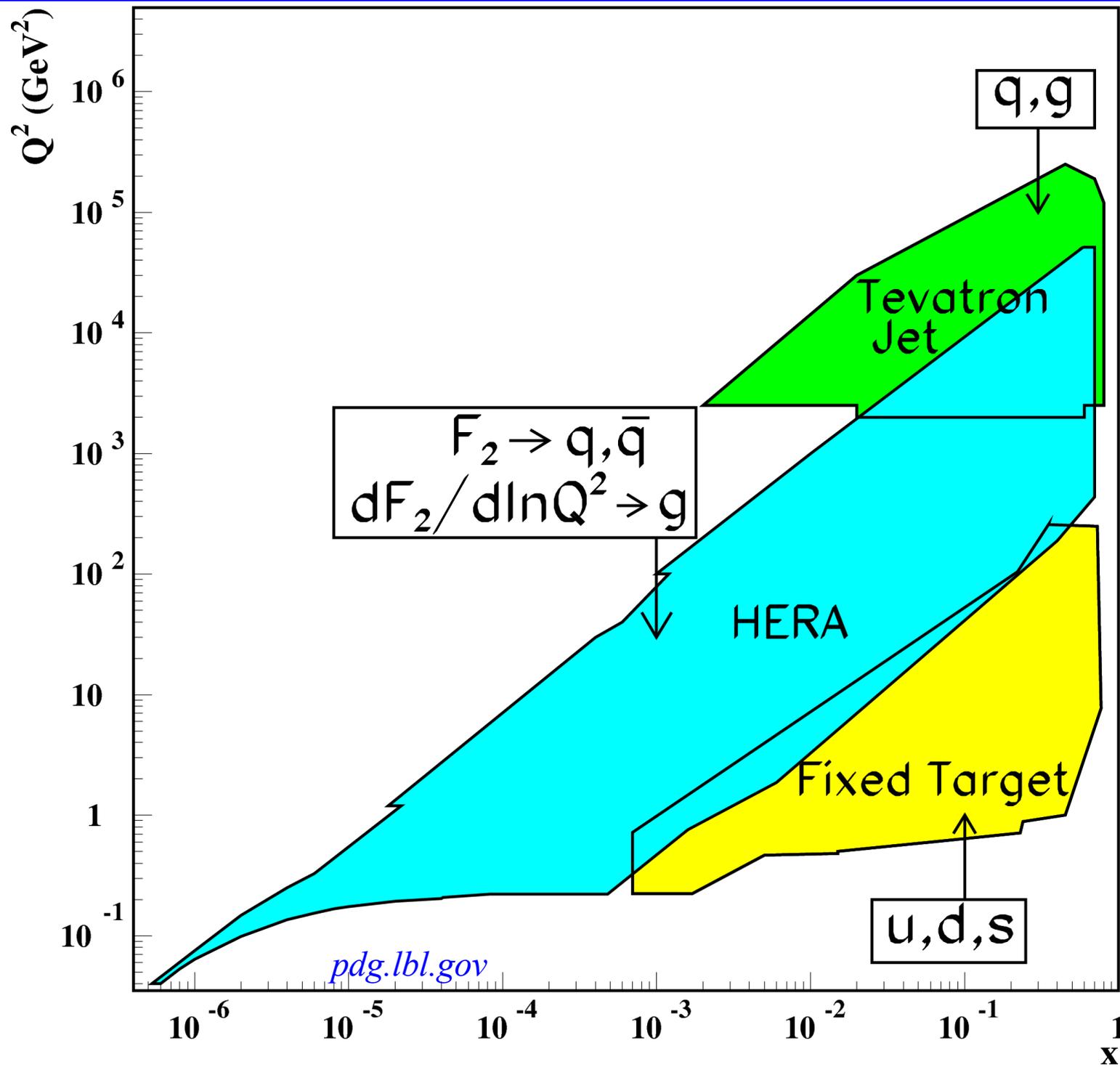
What Physics Programs will co-exist with the LHC???

The LHC is the ideal tool for a particular class of measurements
unprecedented energy allows us to explore new kinematic realm

a need

There is room for complementary experiments

Example: Tevatron & HERA & LEP -- vibrant complementary physics programs



Fixed Target:
 DIS charged lepton
 DIS neutrino
 DY
 Direct Photon

HERA (ep)

Tevatron:
 Jets
 W Asymmetry

LHC is ideal for certain measurements

For full picture, we need to combine with other measurements

**These measurements interdependent
and part of the foundation we use
to calibrate the search for “new physics”**

*I will look at some select examples
of where other measurements
might complement LHC measurements*

LHC is ideal for certain measurements

For some, other exp's are needed

PRECISION ELECTROWEAK

- **Extended W'/Z' and Higgs**
- **$\sin\theta_w$**
- **R-violating SUSY Models**
- **various lepto-quark models**

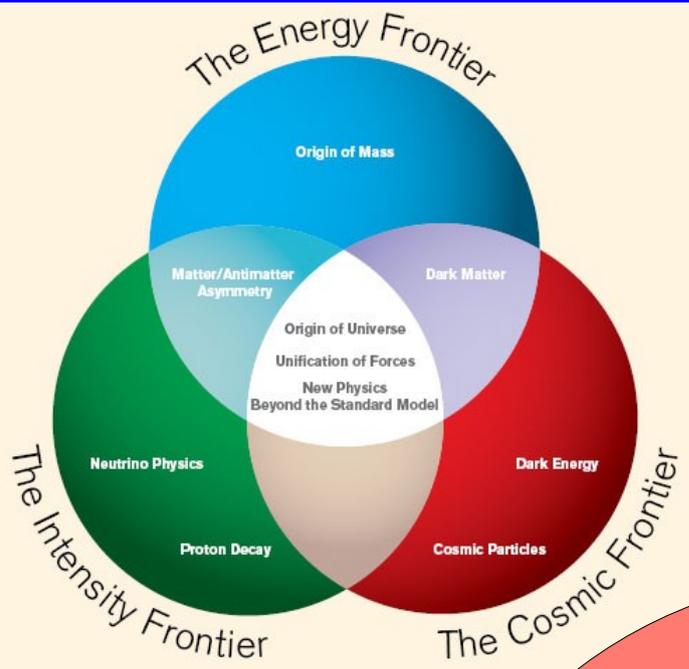
QCD STUDIES

- **PDFs Extraction**
- **Isospin Symmetry Violation**
- **s(x) & c(x) distributions**
- **W/Z Benchmarks @ LHC**

DIRECT SEARCHES

- **Higgs Boson**
- **SUSY and beyond**

**Tevatron
LHC**



Particle Physics Project
Prioritization Panel (P5)
A Strategic Plan for the
Next Ten Years
(June 2, 2008)

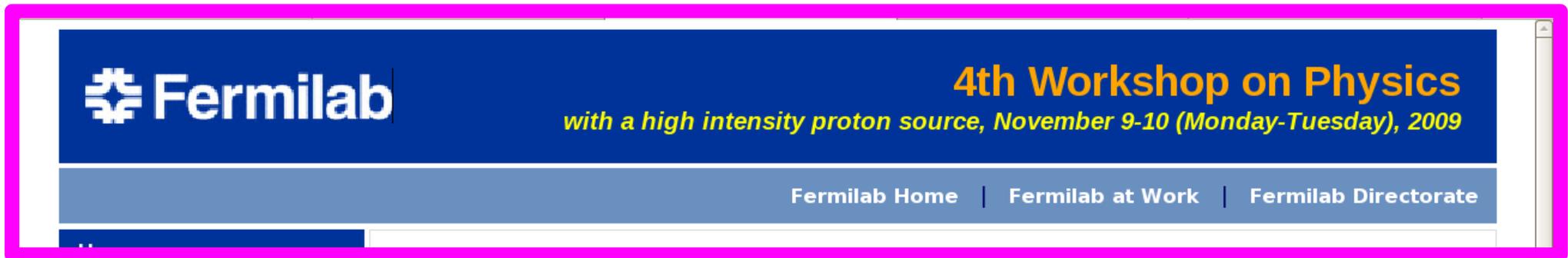
Lot's of activity on these fronts



HOME PAPERS TALKS SAC COMMITTEE STEERING C'TTEE LINKS CONTACT

CERN-ECFA-NuPECC Sponsored LHeC Workshop

The 3rd Plenary meeting of the LHeC workshop took place in Chavannes-de-Bogis, Switzerland, 12-13 November 2010.



 **Fermilab**

4th Workshop on Physics

with a high intensity proton source, November 9-10 (Monday-Tuesday), 2009

Fermilab Home | Fermilab at Work | Fermilab Directorate



EIC Detector Workshop

LINKS

- Announcement
- Registration
- Program
- Lodging
- Travel
- Visa
- Participants List

EIC Detector Workshop at JLab

EIC Workshop
June 4 & 5, 2010
Thomas Jefferson National Accelerator Facility
Newport News, VA

Announcement

Jefferson Lab is hosting the 5th JLab EIC the laboratory and the Jefferson Science



NuSONG

Neutrino Scattering On Glass

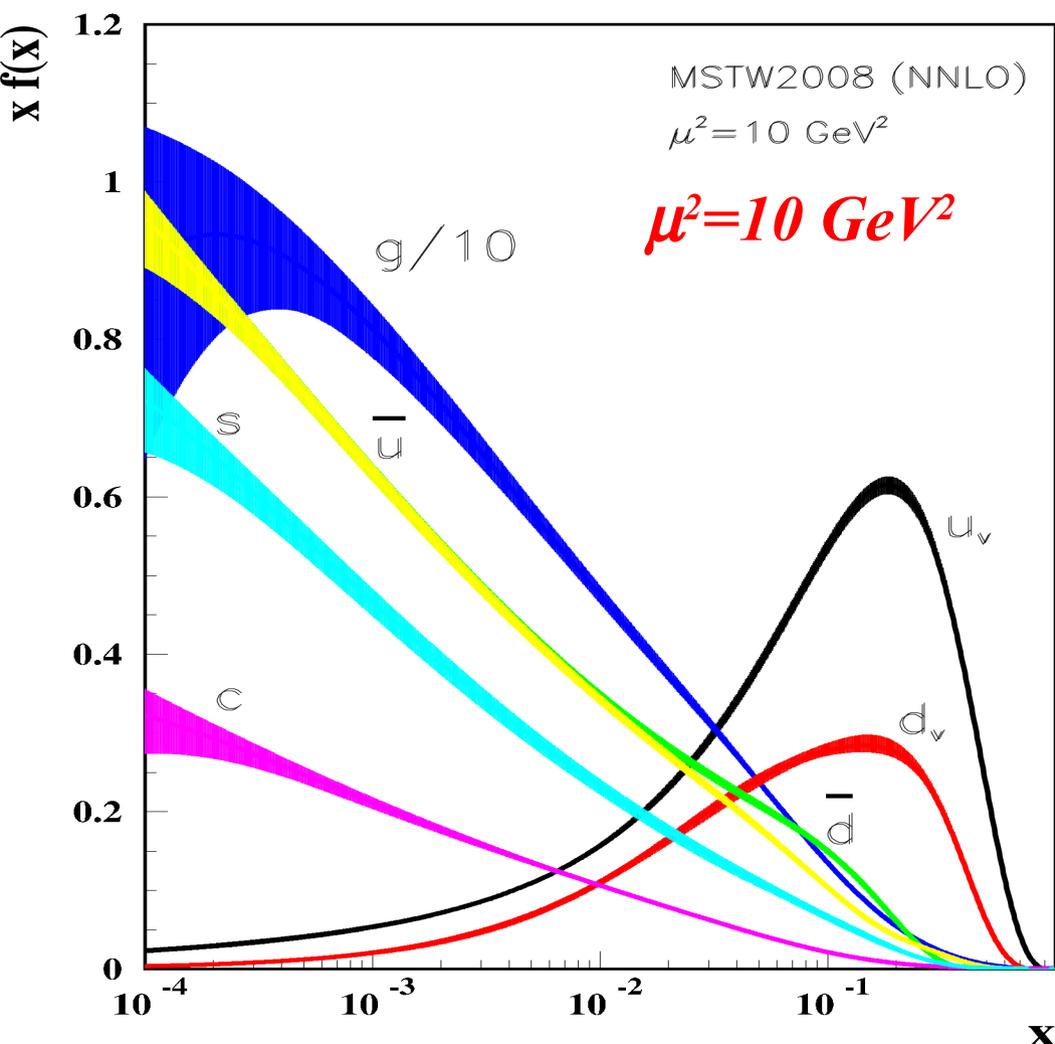
I'll look at select examples

To Start

an example
where one can
get caught

... or why we need to be more careful

PDFs are certainly one of the foundations
that our search for “new physics”
is built upon



Myth #1: I thought we did that already

We did, but with
assumptions

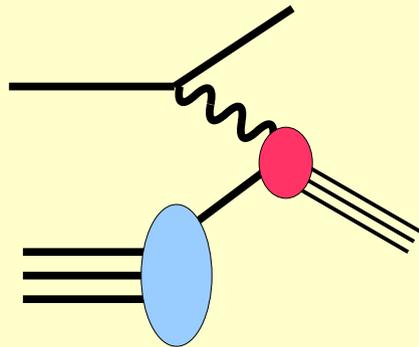
$$F_2^\nu = F_2^{\bar{\nu}}$$

$$F_2^{\ell^\pm Fe} \sim F_2^{\nu Fe}$$

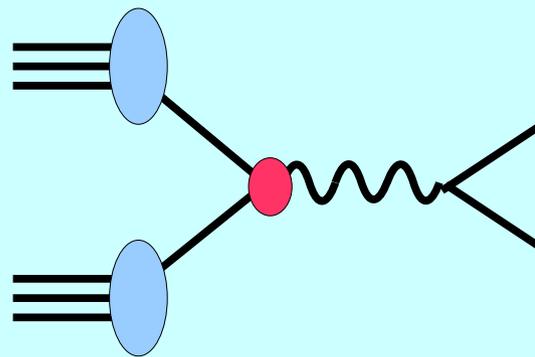
$$R_L^{\ell^\pm} = R_L^\nu = R_L^{\bar{\nu}}$$

$$u_{\text{proton}} = d_{\text{neutron}}$$

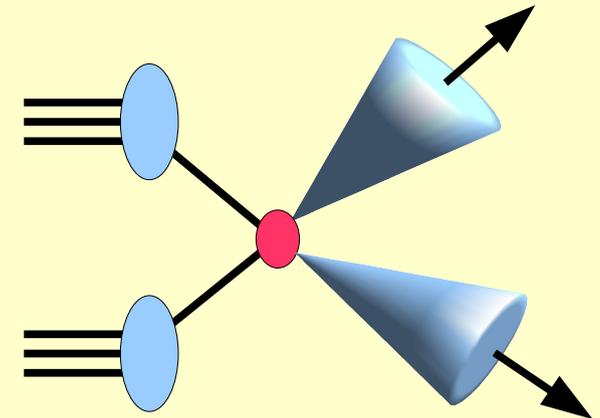
Myth #2: It doesn't matter



DIS Production



Drell-Yan



Jet Production

$$F_2^\nu \sim [d + s + \bar{u} + \bar{c}]$$

$$F_2^{\bar{\nu}} \sim [\bar{d} + \bar{s} + u + c]$$

$$F_3^\nu = 2 [d + s - \bar{u} - \bar{c}]$$

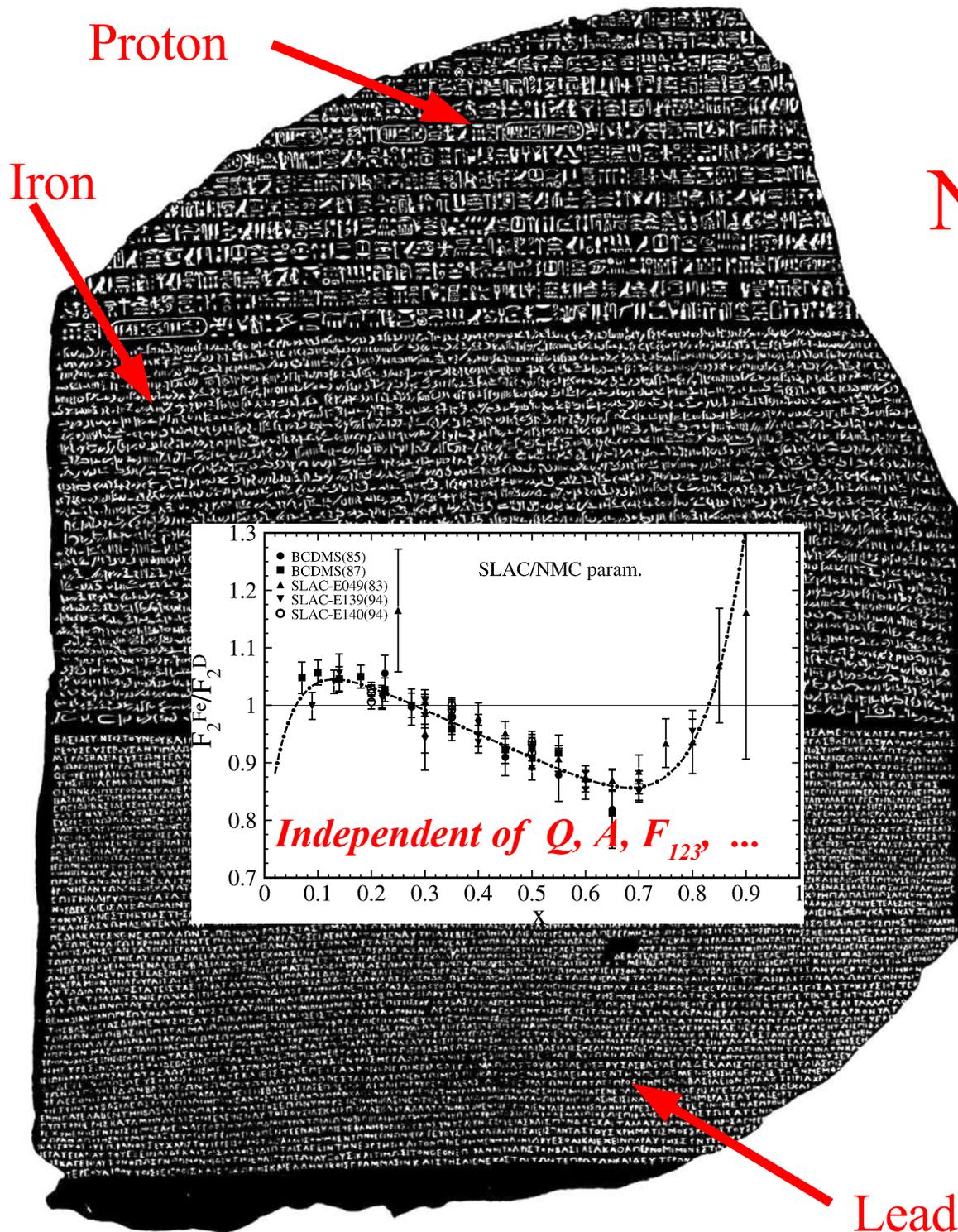
$$F_3^{\bar{\nu}} = 2 [u + c - \bar{d} - \bar{s}]$$

$$F_2^{\ell^\pm} \sim \left(\frac{1}{3}\right)^2 [d + s] + \left(\frac{2}{3}\right)^2 [u + c]$$

In particular, the DIS combinations have historically been particularly useful

Different linear combinations – key for flavor differentiation

*The ν -DIS data typically use heavy targets, and this requires the application of **nuclear corrections***

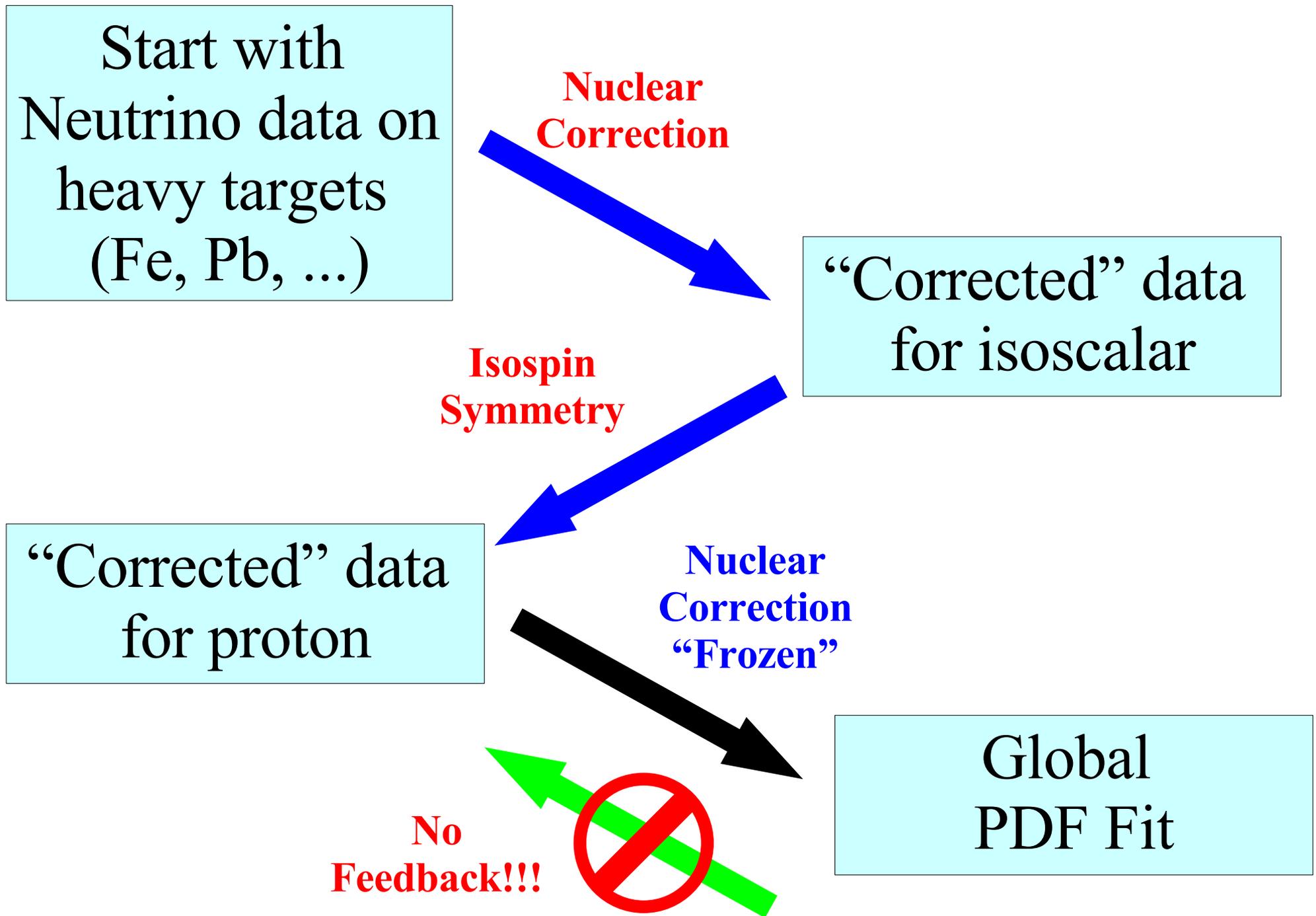


Where do
Nuclear Corrections
come from ???

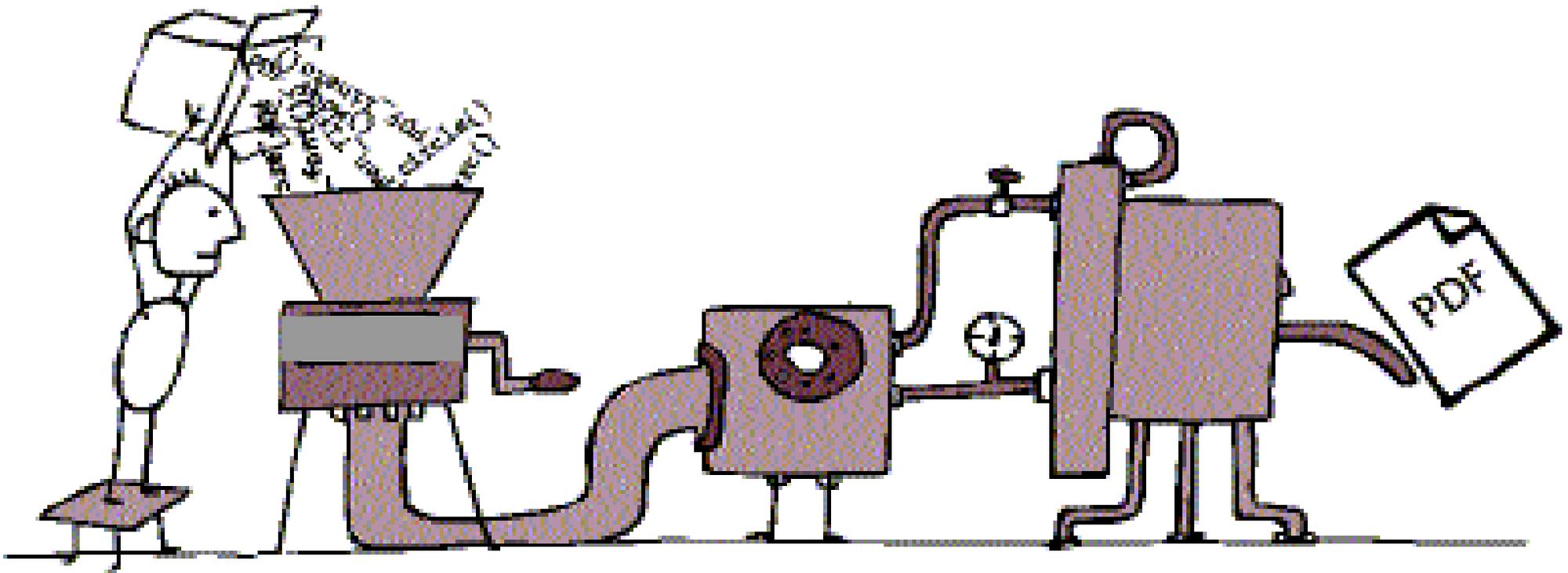
carved in stone

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.

*I don't care about nuclear PDFs,
I just want the proton!!!*



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

$$xf(x) = x^{a_1}(1-x)^{a_2}e^{a_3x}(1+e^{a_4x})^{a_5}$$

$$a_i \rightarrow a_i(A)$$

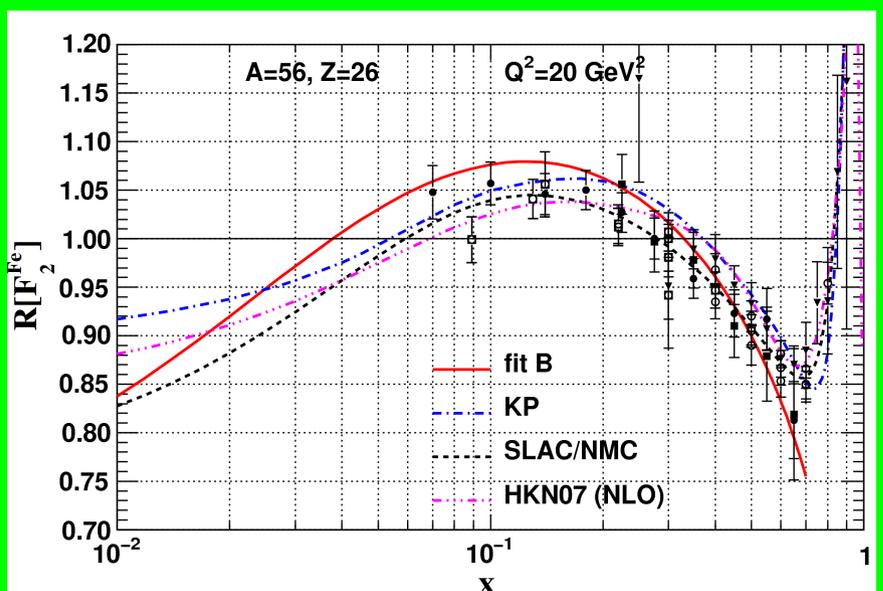
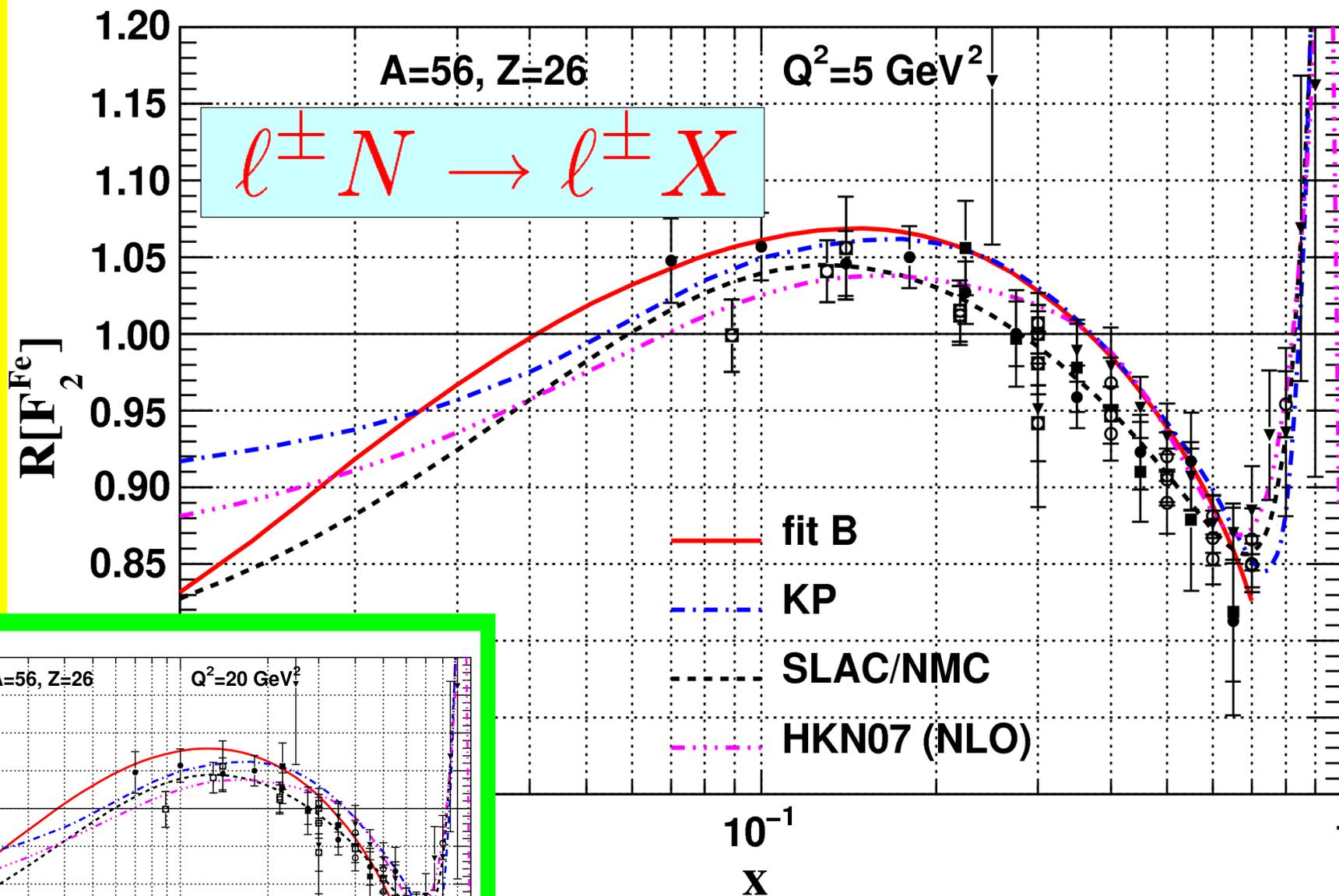
$$a_k = a_{k,0} + a_{k,1}(1 - A^{-a_{k,2}})$$

Observable	Experiment	Ref.	# data	x^1 A1L	x^1 A1M	x^1 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
Al/D	Hermes	[20]	92	94.5	62.42	58.94	5157
	SLAC-E049	[26]	18	32.2	20.42	20.38	5134
Ca/D	SLAC-E139	[18]	17	22.12	6.50	8.05	5136
	EMC-90	[23]	2	5.5	1.47	1.37	5109
	SLAC-E139	[18]	7	14.2	2.07	1.53	5140
Fe/D	NMC-95,re	[19]	15	48.6	12.75	13.74	5121
	FNAL-E665-95	[24]	4	16.2	7.88	7.67	5126
	BCDMS-85	[25]	6	5.3	3.91	4.39	5102
	BCDMS-87	[27]	10	35.0	8.58	9.81	5101
Cu/D	SLAC-E049	[26]	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
	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-95	[32]	15	14.3	5.87	5.82	5112
Al/C	NMC-95	[32]	15	14.1	5.17	5.19	5111
Ca/C	NMC-95	[19]	20	21.7	31.47	35.73	5120
	NMC-95	[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-95	[33]	144	312.5	102.82	96.29	5159
Pb/C	NMC-95	[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-E7						
Ca/D	FNAL-E7						
Fe/D	FNAL-E7						
W/D	FNAL-E7						
Fe/Be	FNAL-E8						
W/Be	FNAL-E8						
Total:							

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 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.

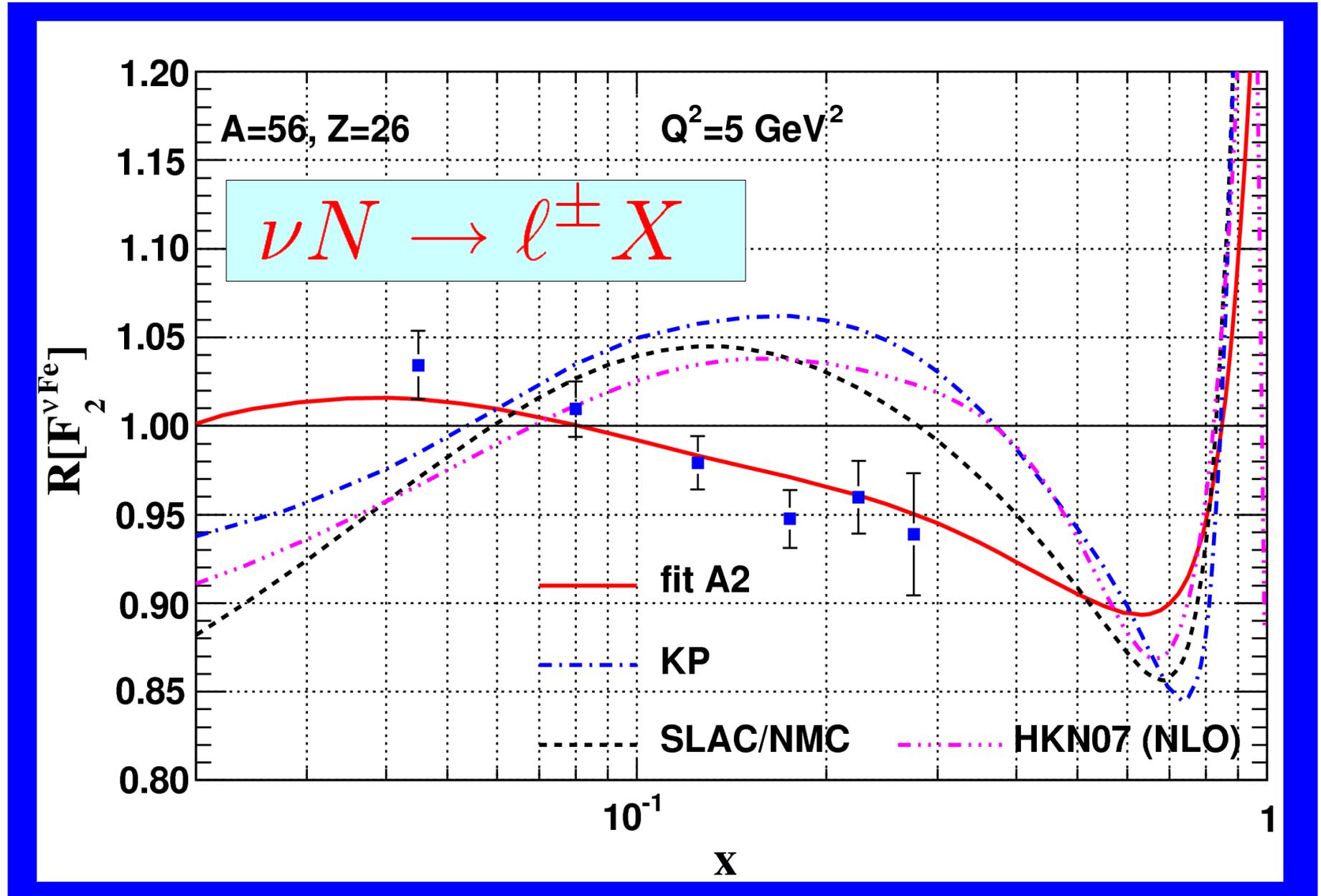
$$\frac{F_2^{Fe}}{F_2^D}$$



⇐ Q^2 Dependence

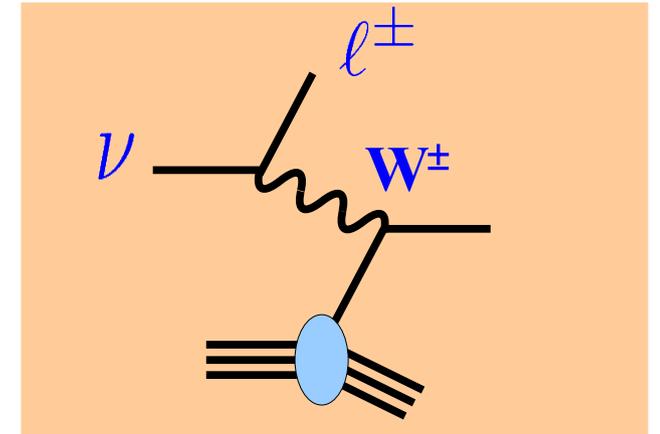
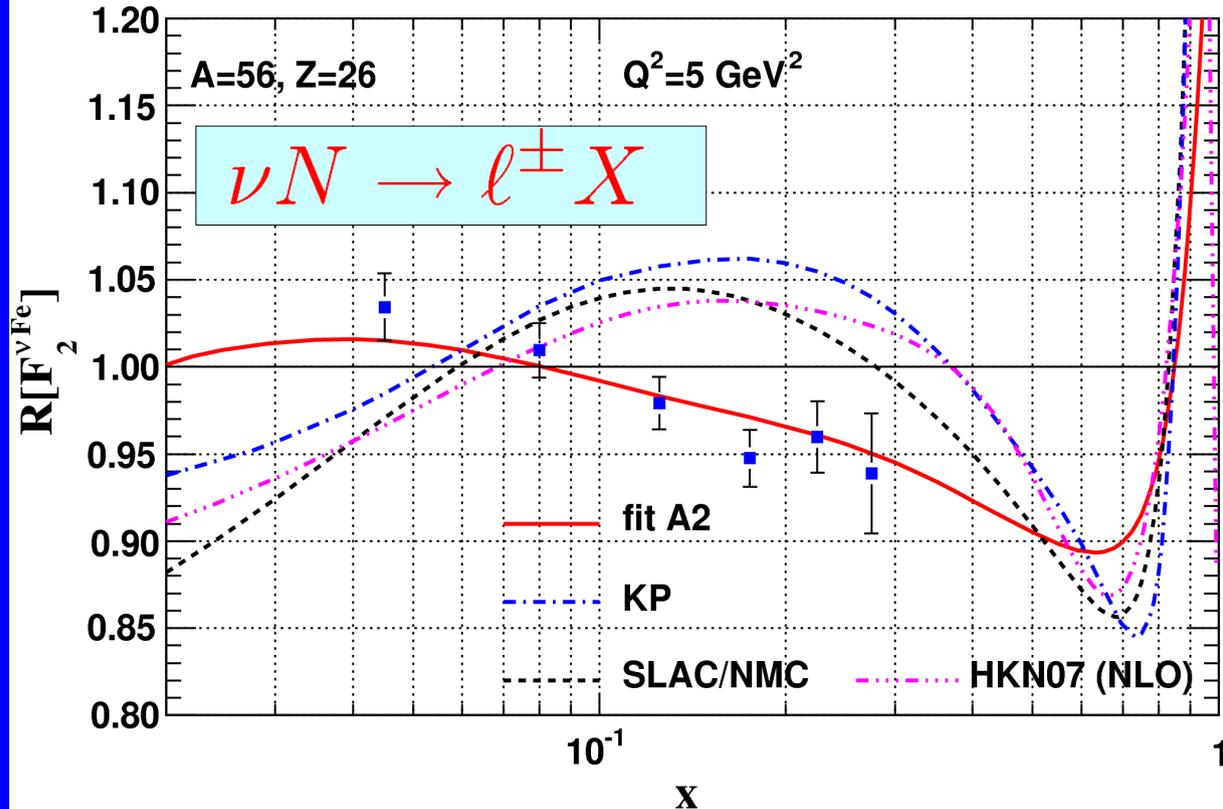
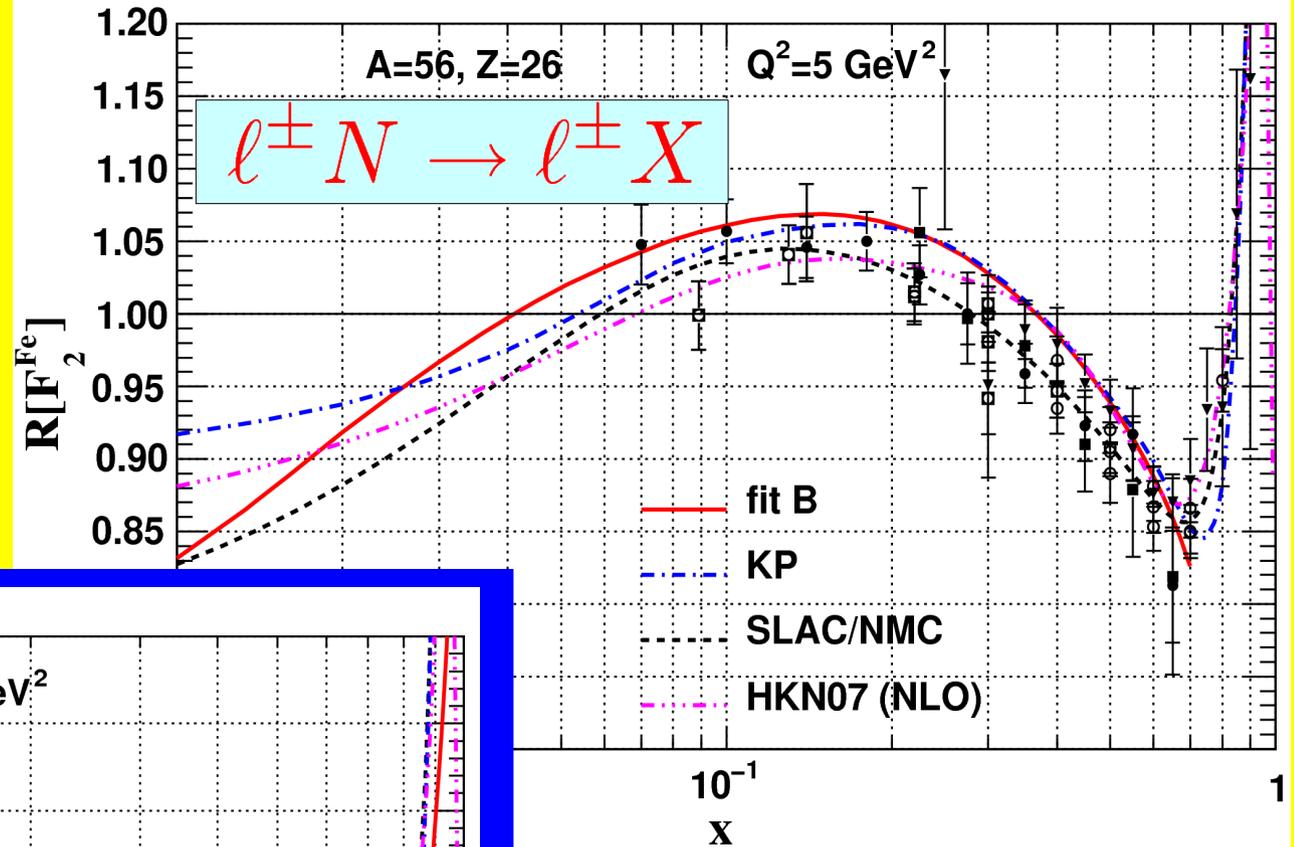
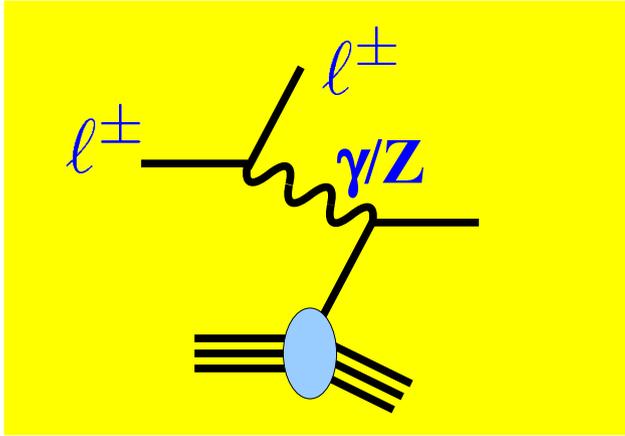
Also, other NPDF sets by:
 M.Hirai, S.Kumano, T.-H.Nagai,
 K.J.Eskola, H.Paukkune, C.A.Salgado,
 S.Kulagin, R.Petti

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



O o o o o p s !

Charged Lepton DIS ⇒



⇐ **Neutrino DIS**

~~Myth #1:~~ $\{\nu, \bar{\nu}, \ell^{\pm}\}$ can be different

Independent extraction

Determine Nuclear modifications separately

 $\{\nu, \bar{\nu}, \ell^{\pm}\}$

~~Myth #2:~~ It does matter

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

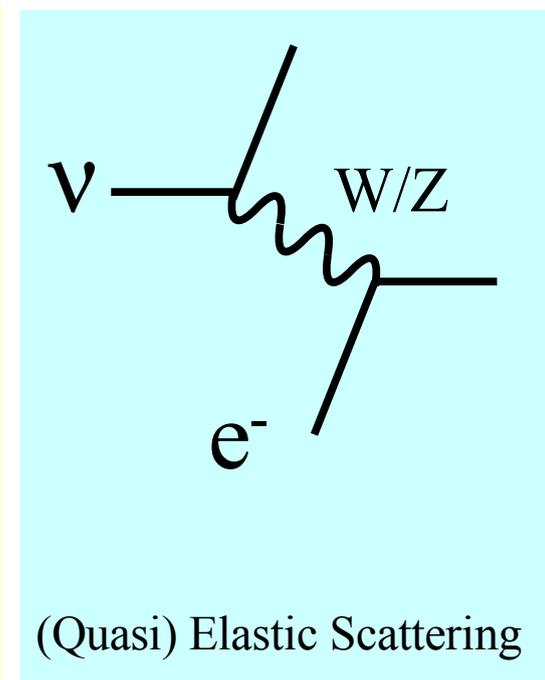
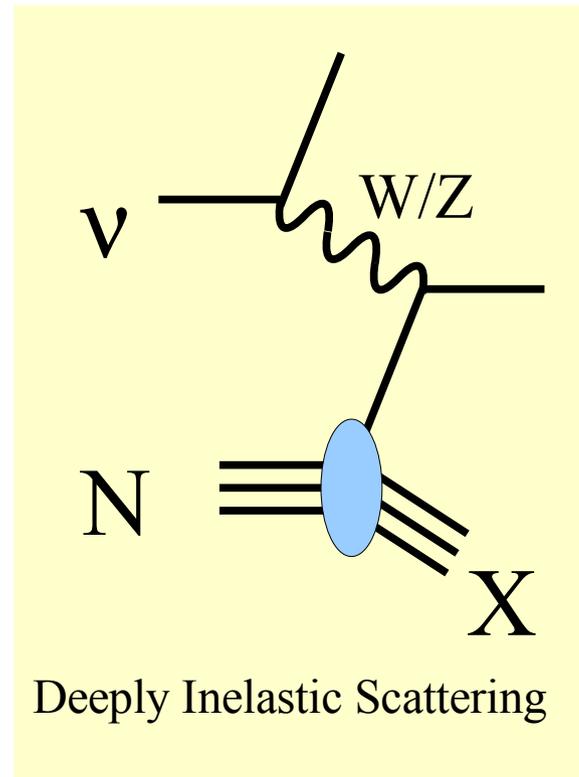
Future ν -DIS may have stats to resolve this:

Separate “A” and $\{\nu, \bar{\nu}, \ell^{\pm}\}$ Dependence

Use variety of target materials:

NuSOnG (~5 year run)

Events	Process
600 M	$\nu_\mu N \rightarrow \mu^- X$
190 M	$\nu_\mu N \rightarrow \nu_\mu X$
75 K	$\nu_\mu e^- \rightarrow \nu_\mu e^-$
700 K	$\nu_\mu e^- \rightarrow \mu^- \nu_e$
33 M	$\bar{\nu}_\mu N \rightarrow \mu^+ X$
12 M	$\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu X$



DIS Comparisons: Charged Current

Experiment	ν DIS events	anti- ν DIS events	Target	Isoscalar correction
CCFR	1.03 M	0.179 M	iron	5.67%
NuTeV	1.3 M	0.4 M	iron	5.74%
NuSOnG	600 M	33 M	glass	0%

<http://prola.aps.org/pdf/PRD/v64/i11/e112006>
<http://prola.aps.org/pdf/PRL/v87/i25/e251802>

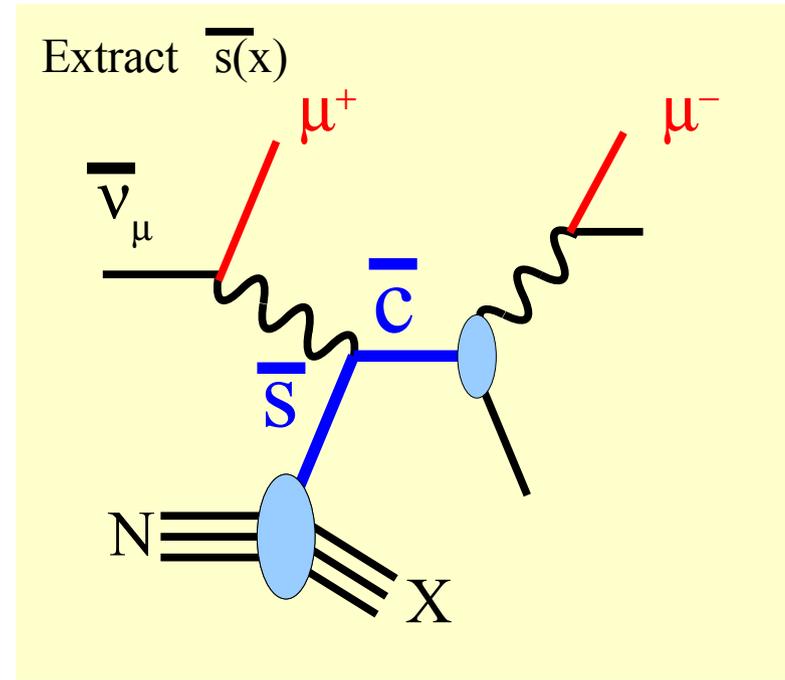
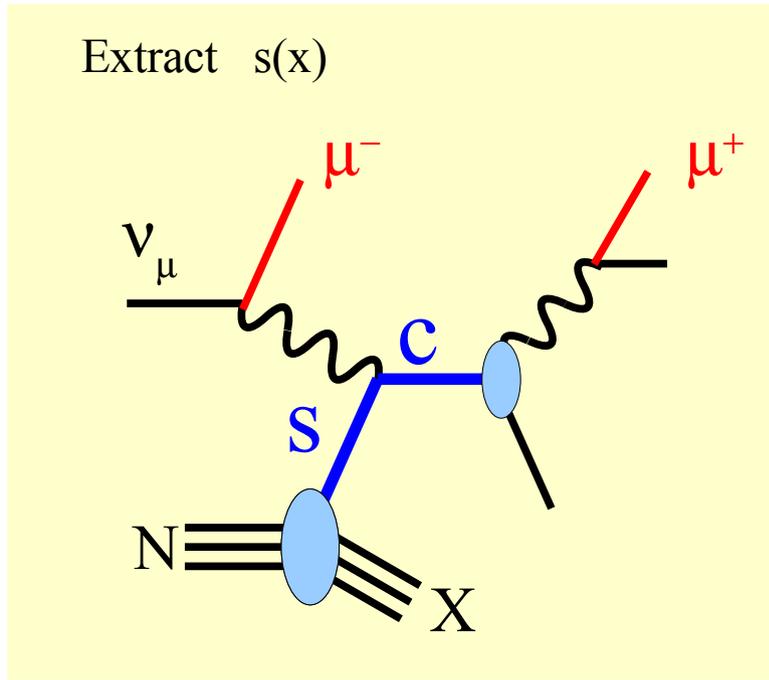
MINERvA Comparisons

Target	Mass (Tons)	Events
Fe	0.70	2 M
Pb	0.85	2.5 M
He	0.40	600 K
C	0.15	430 K
CH	3	9 M

<http://minerva.fnal.gov/>

Heavy Quarks

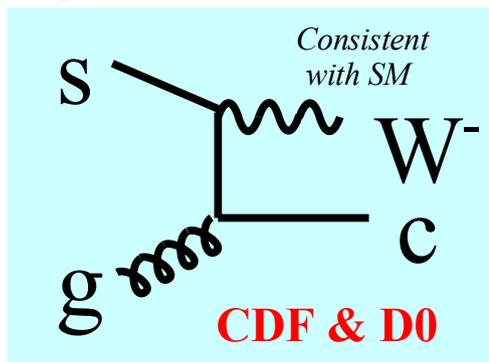
Strange



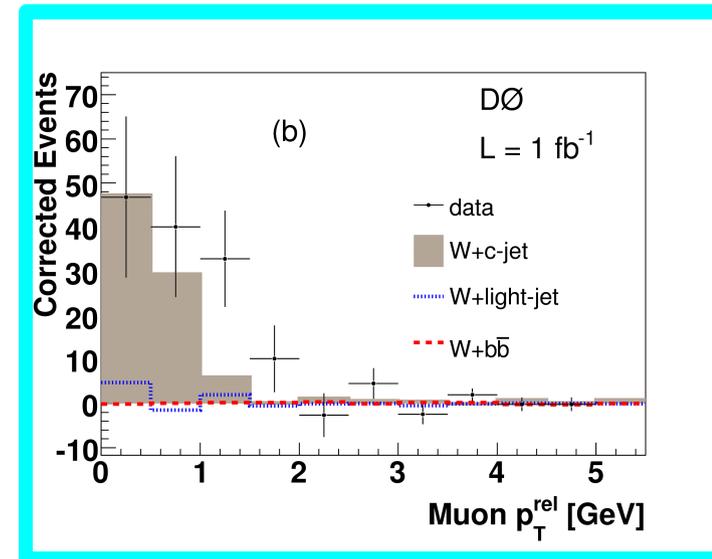
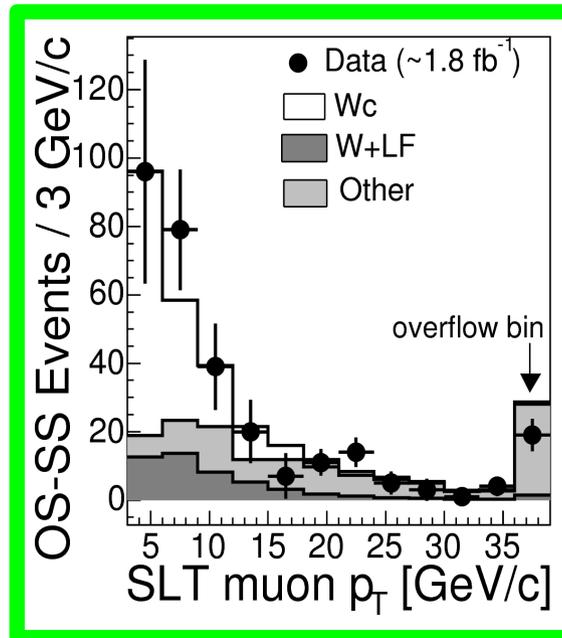
$s(x)$ and $\bar{s}(x)$ are essential in extraction of $\sin\theta_W$

Used in CTEQ6 Fits

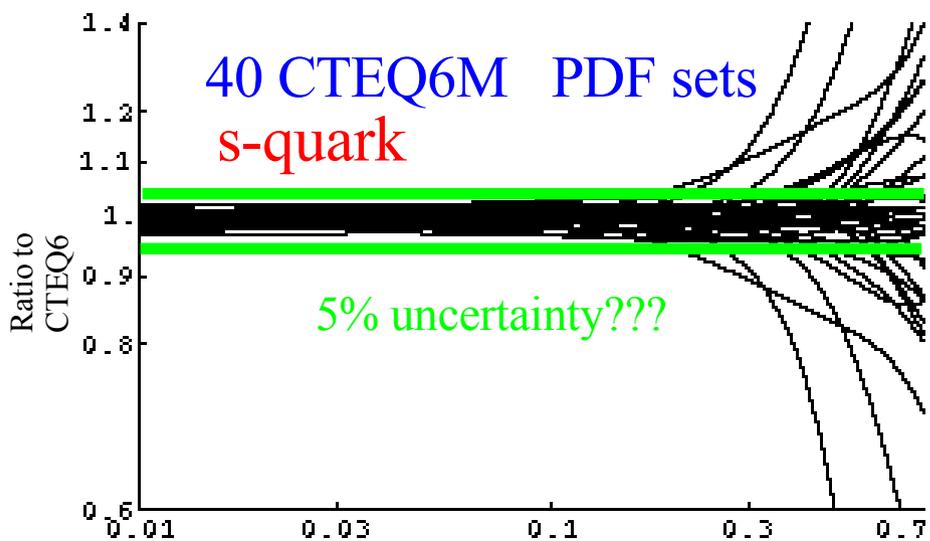
$s g \rightarrow Wc$ at the Tevatron



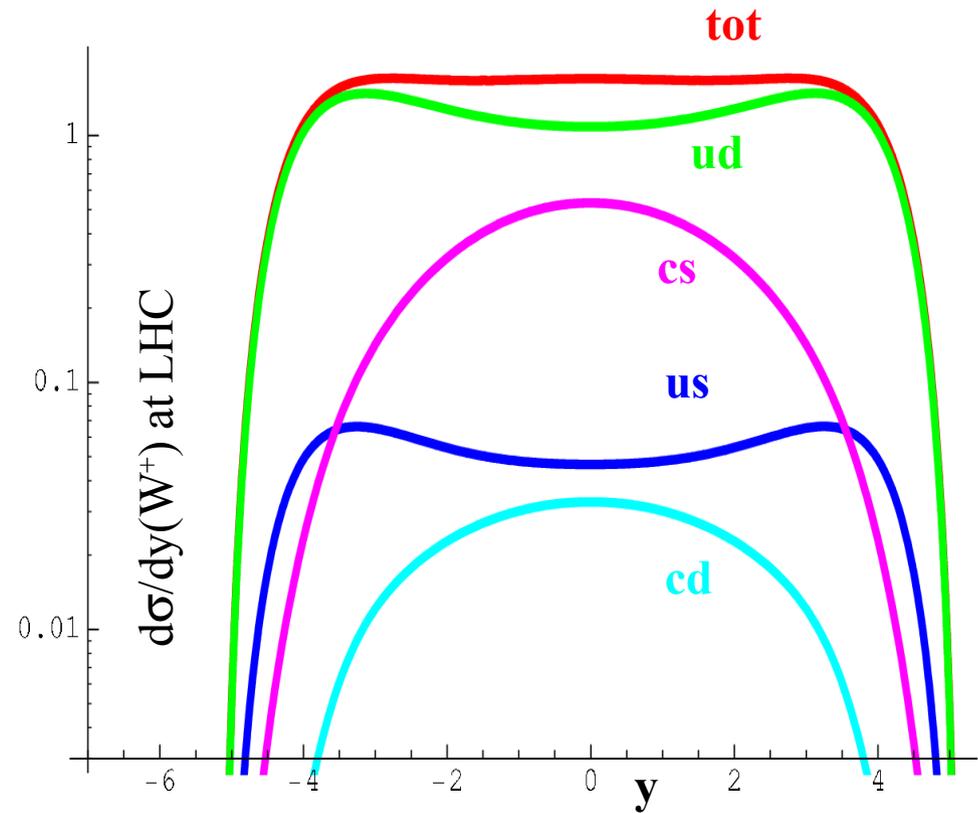
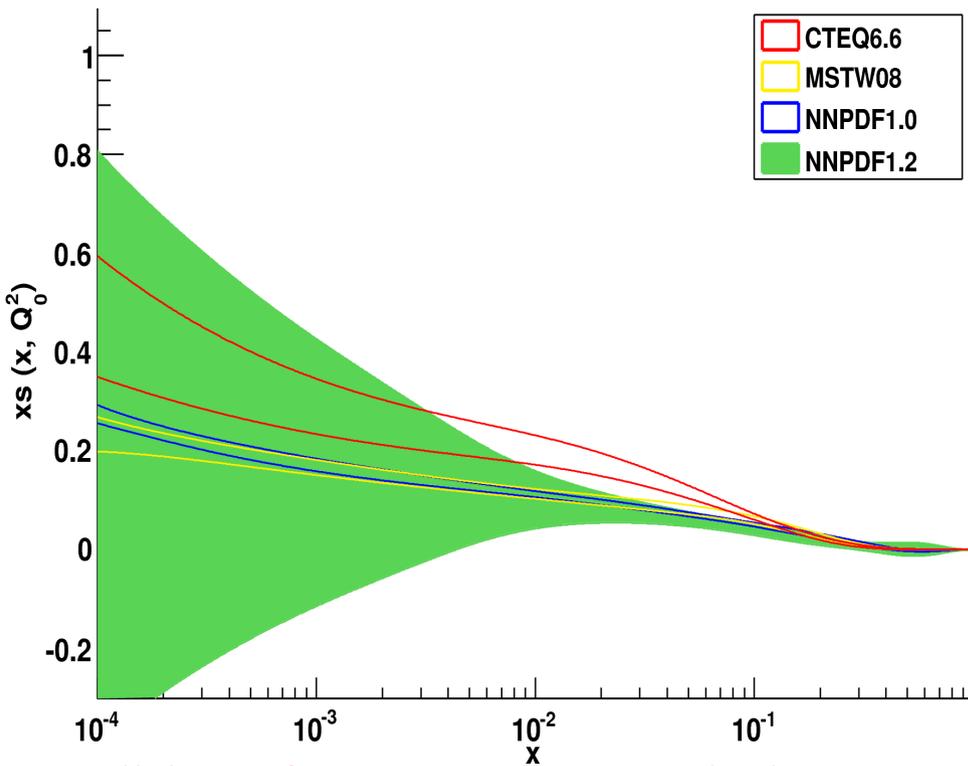
CDF: PRL 100:091803,2008.
D0: PLB666:23,2008.



Also a challenge at LHC



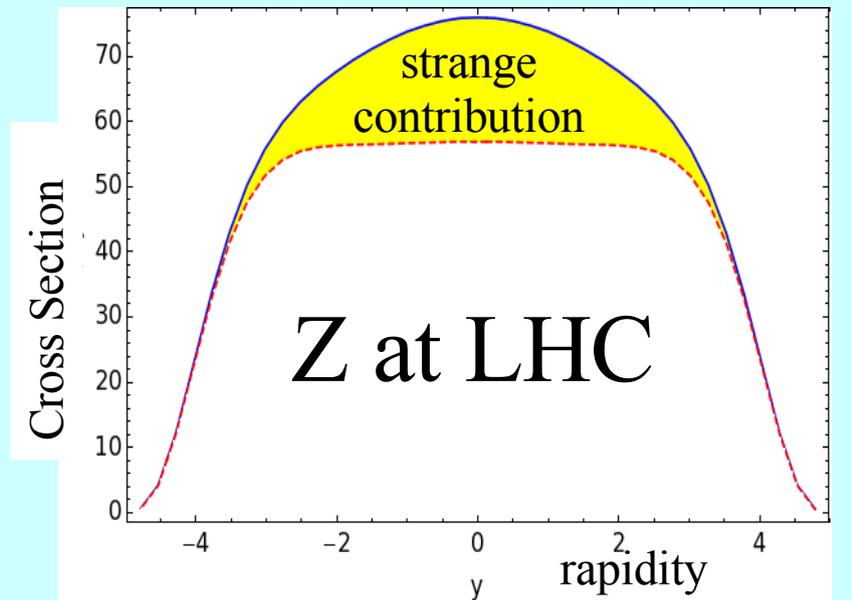
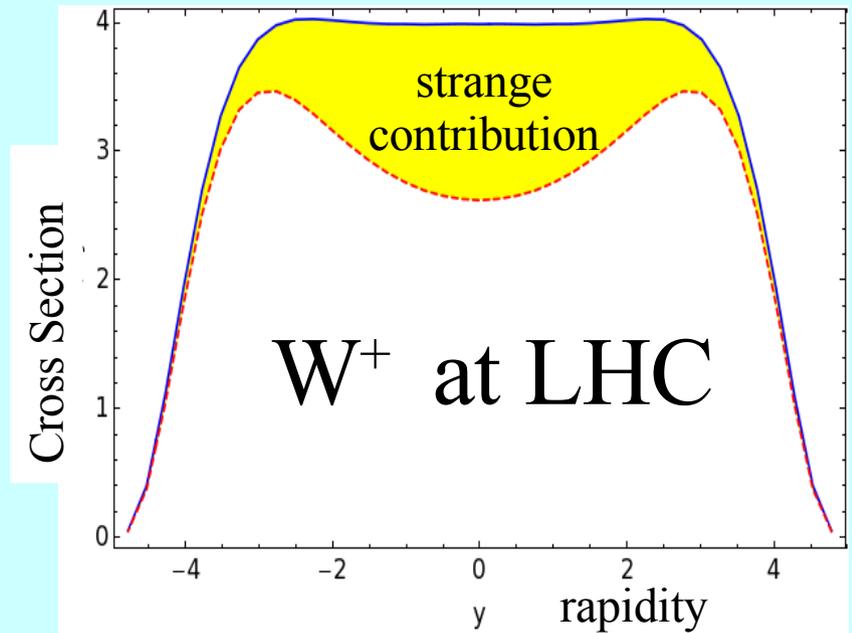
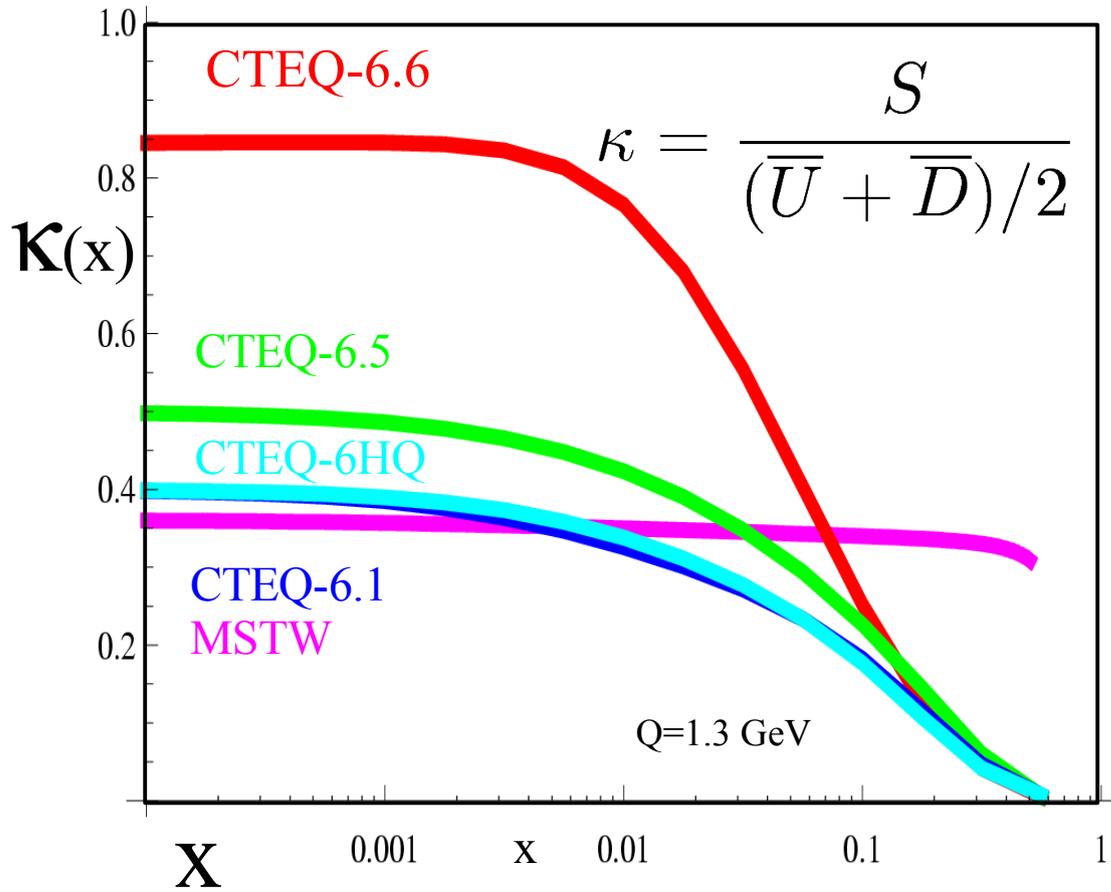
Heavy quark PDFs essential ingredient



Heavy Quark components play an increasingly important role at the LHC

See talk by Stefano Forte & Maria Ubiali

See talk by Friedrich Dydak & Sasha Glazov

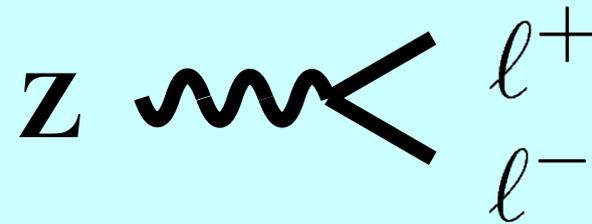
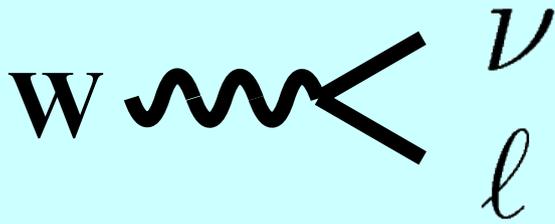


PDF Uncertainties will feed into LHC “Benchmark” processes

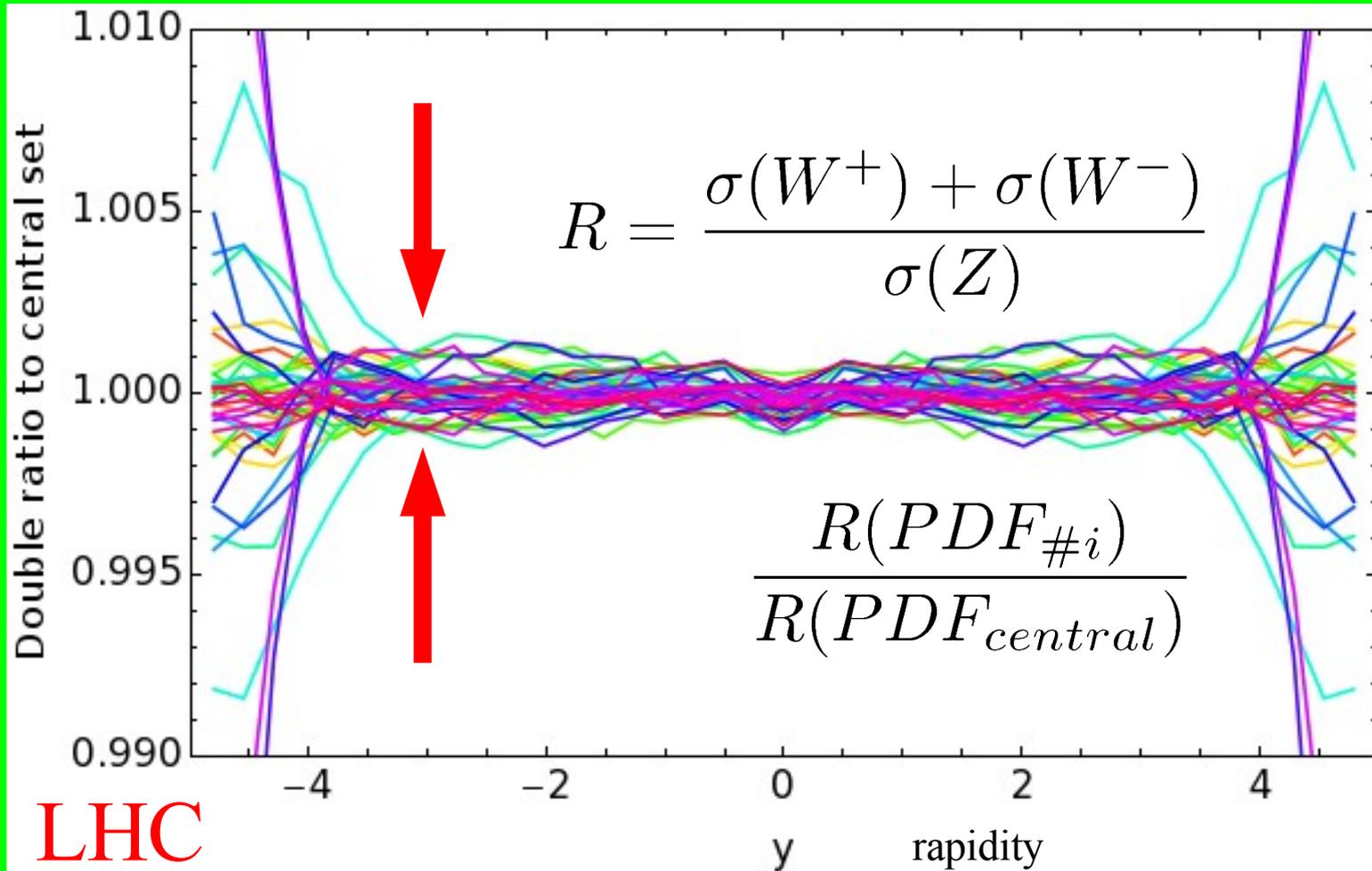
Comparison with new NNPDF sets: Les Houches 2009

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

Use Z to calibrate W



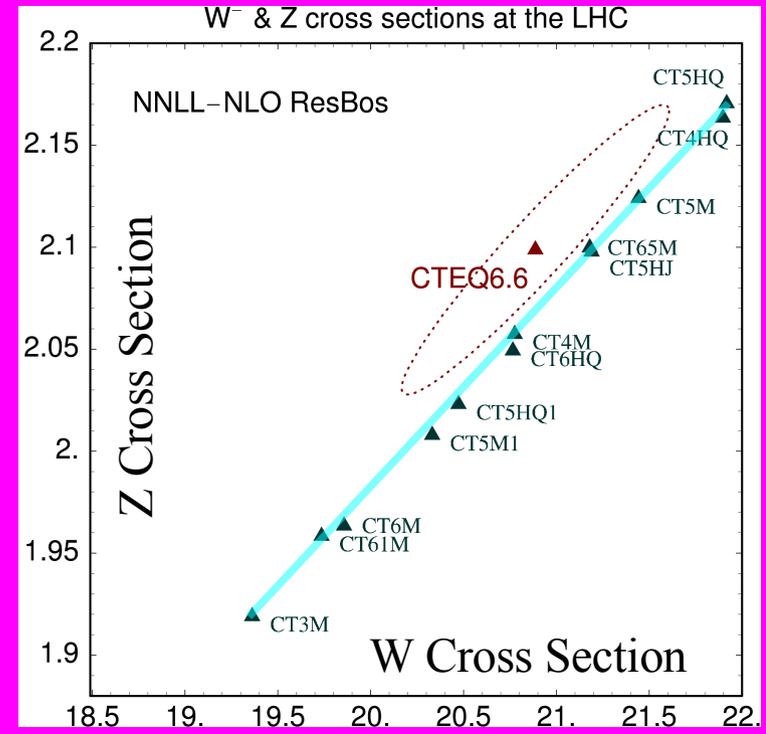
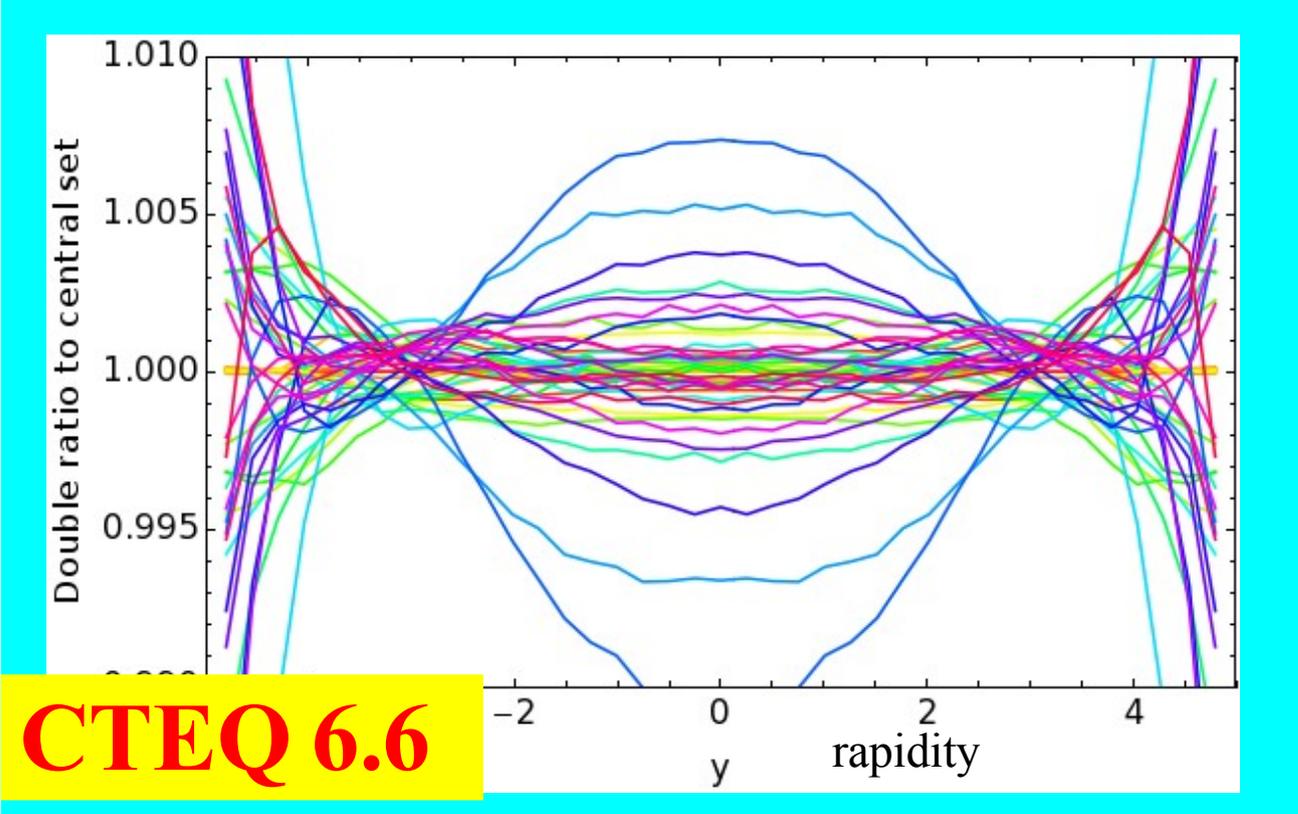
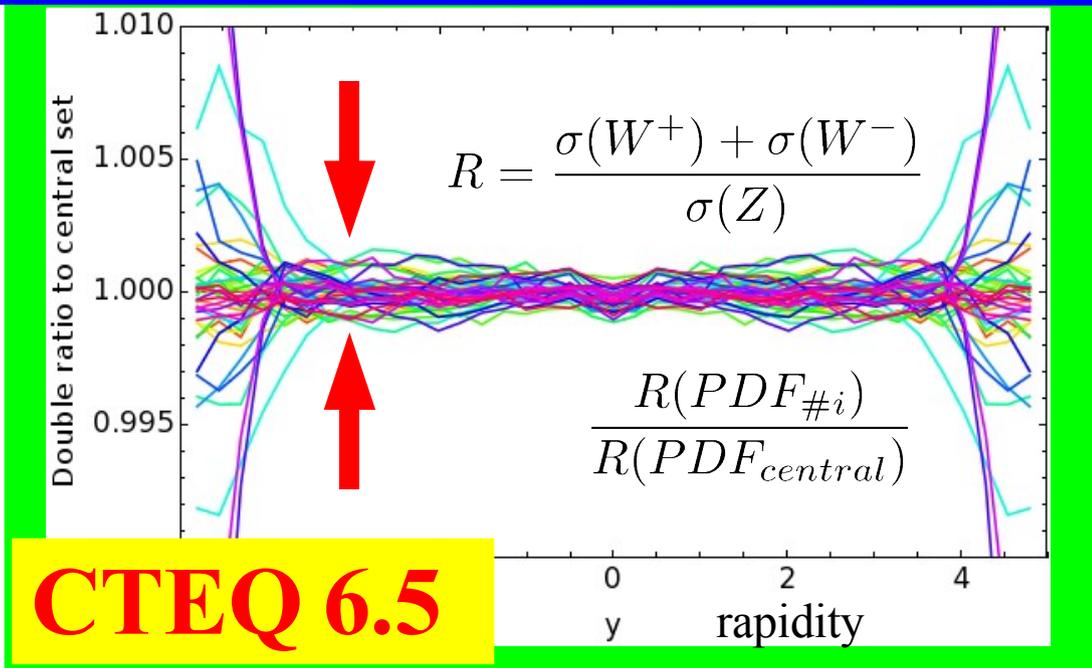
Useful for M_W
determination



Ooops!

Use Z to calibrate W

The W-Z correlation is limited by the uncertainty coming from the strange quark distribution



New kinematic realm
 New precision
 New problems

Thanks to Maarten & friends

Strange PDF: Recap

Nuclear Corrections limit our ability to use ν -DIS for strange PDF extraction

Strange PDF plays an increasingly important role at LHC

- affects W/Z cross sections
- affects W-Z correlations

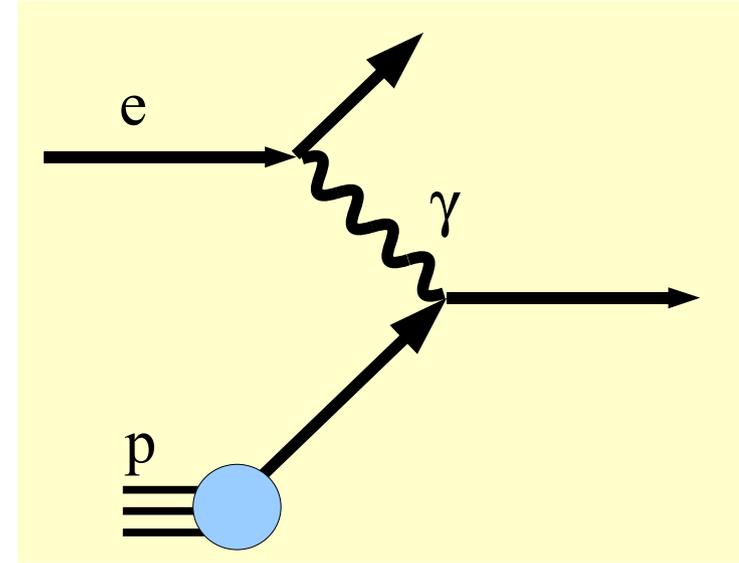
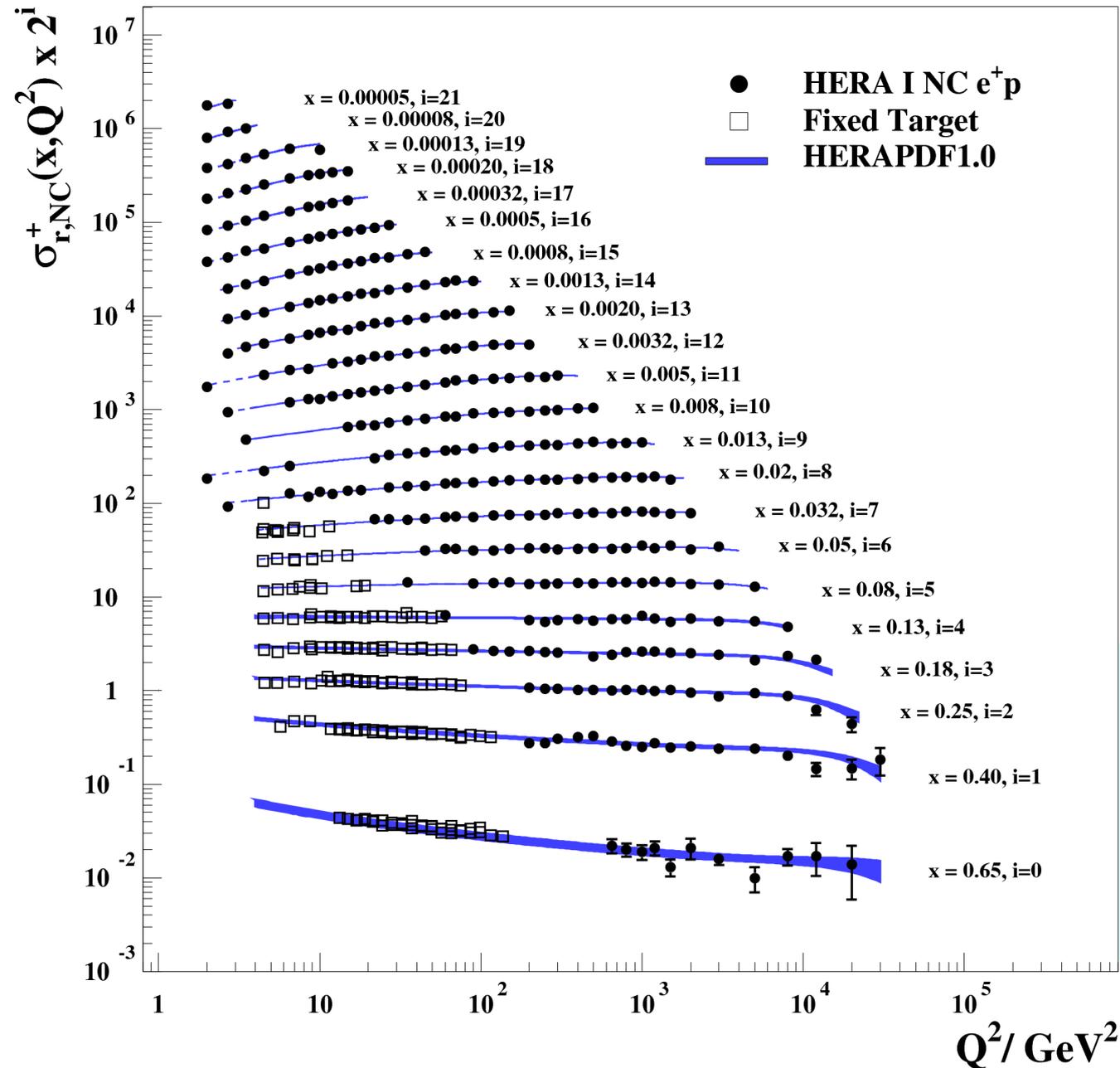
These are LHC Benchmark processes!!!

Heavy Quarks

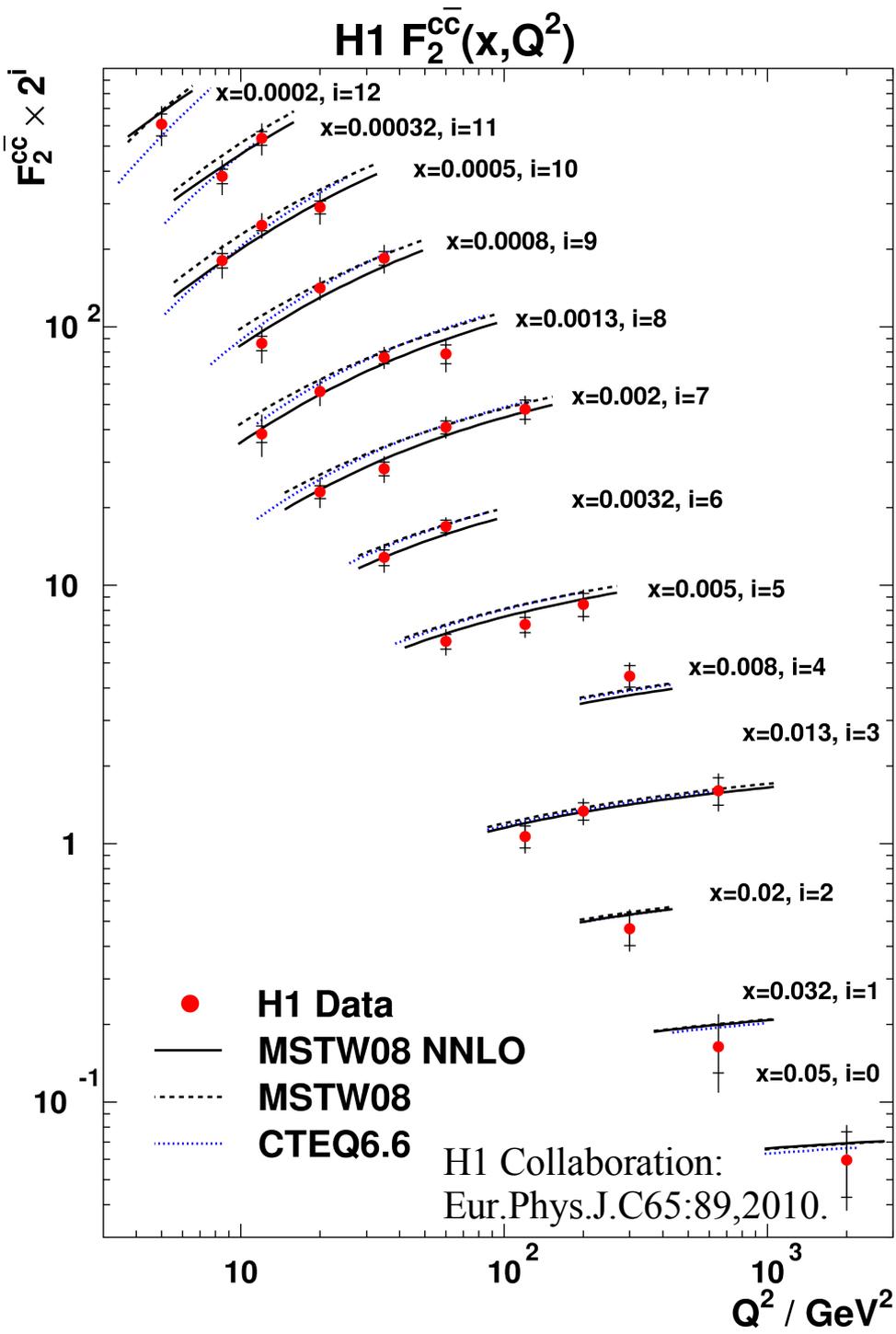
c & b

Extrinsic & Intrinsic

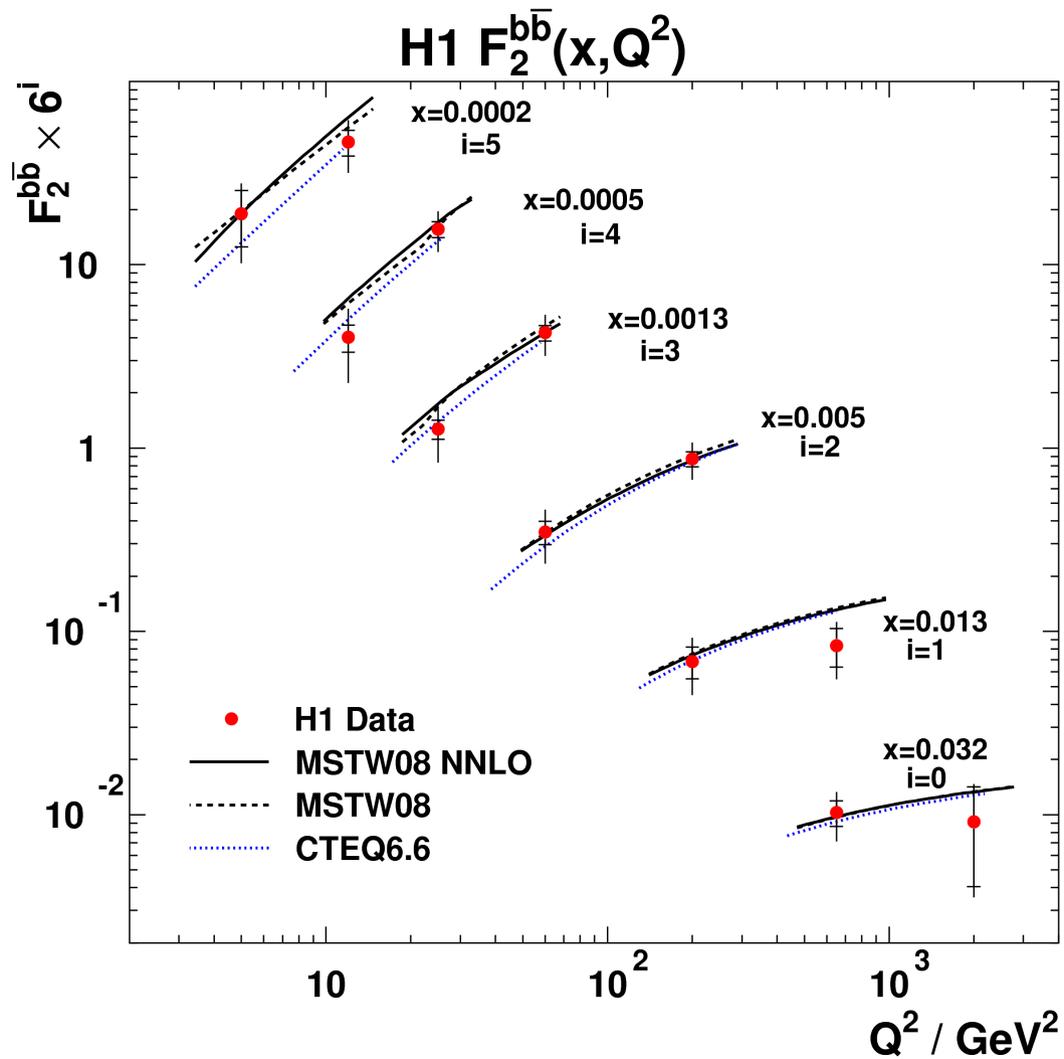
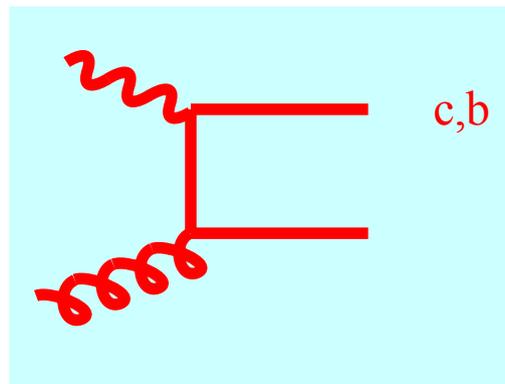
H1 and ZEUS

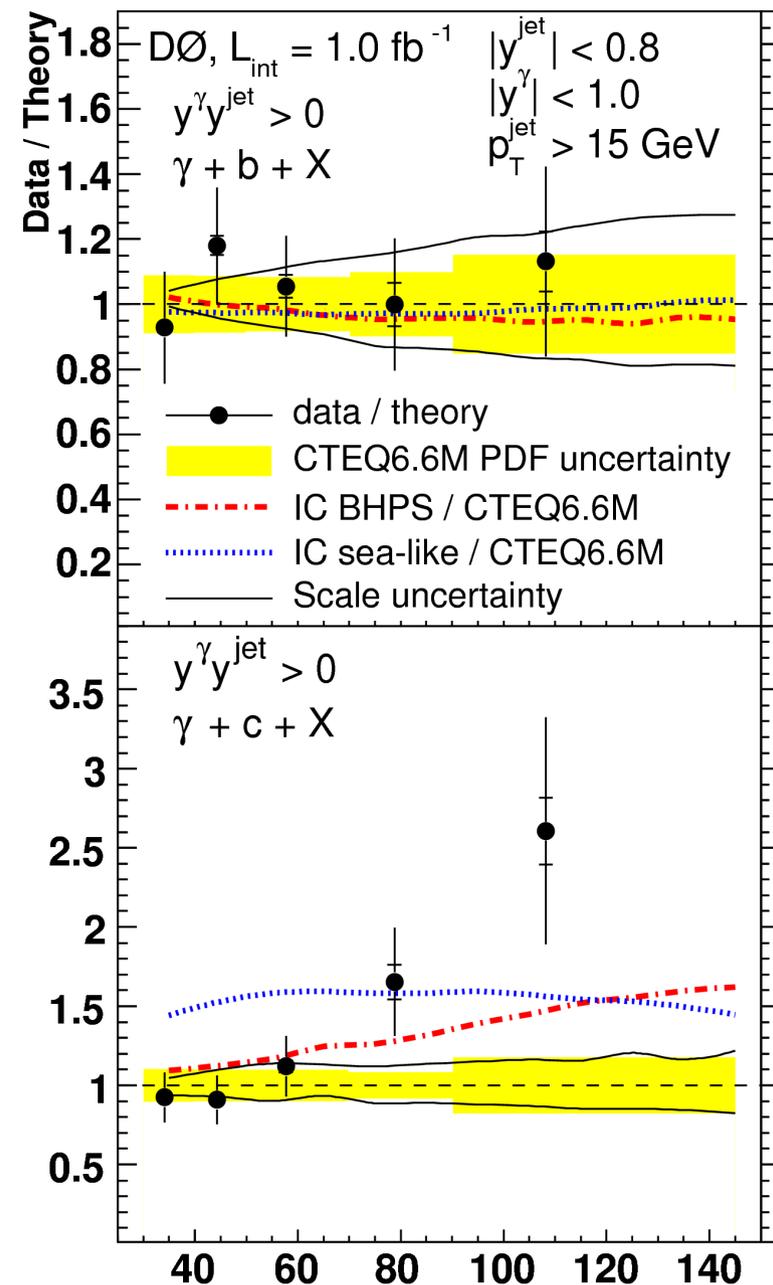
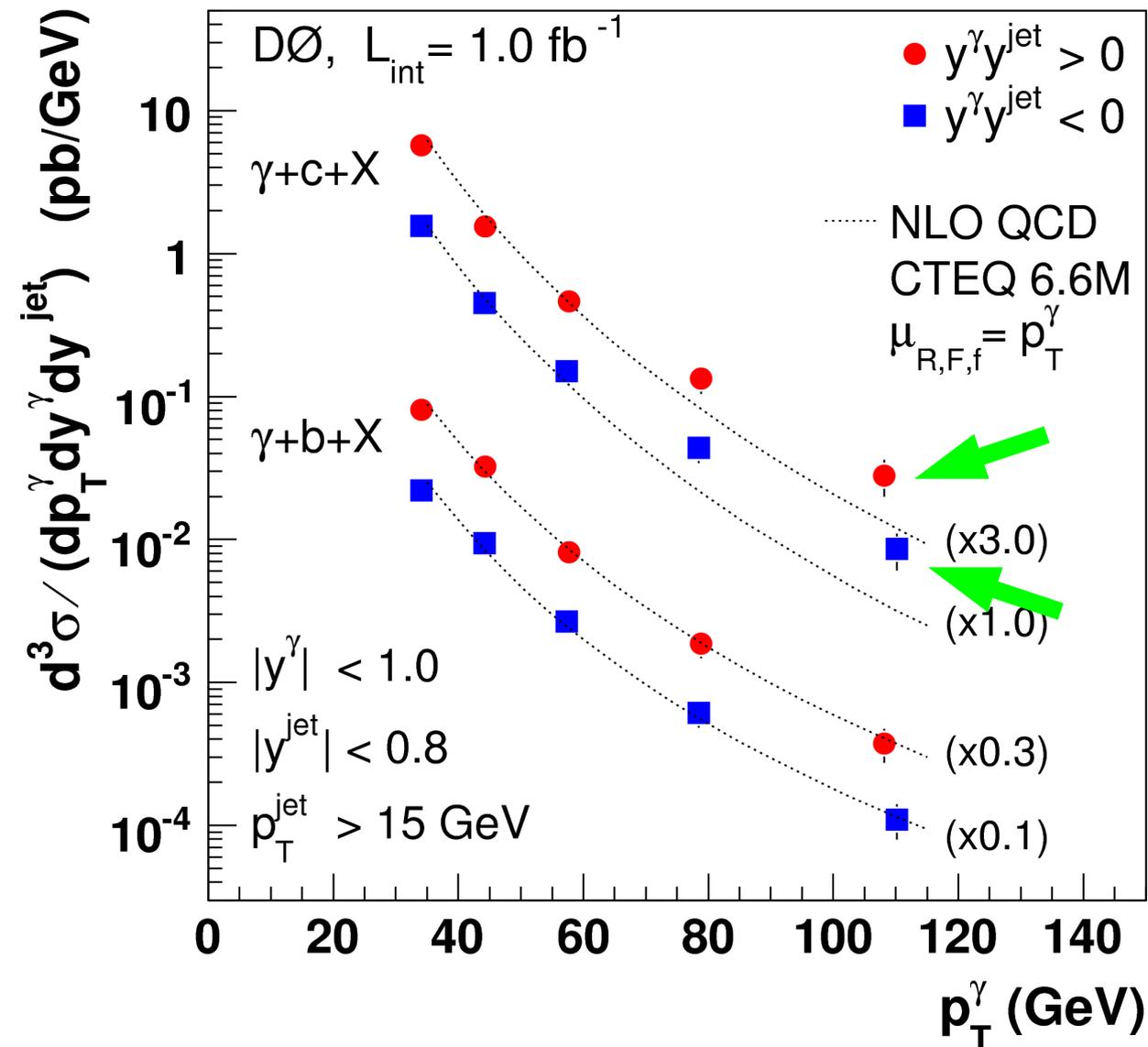


$$F_2^{ep} \sim \frac{4}{9} (u + \bar{u} + c + \bar{c}) + \frac{1}{9} (d + \bar{d} + s + \bar{s})$$



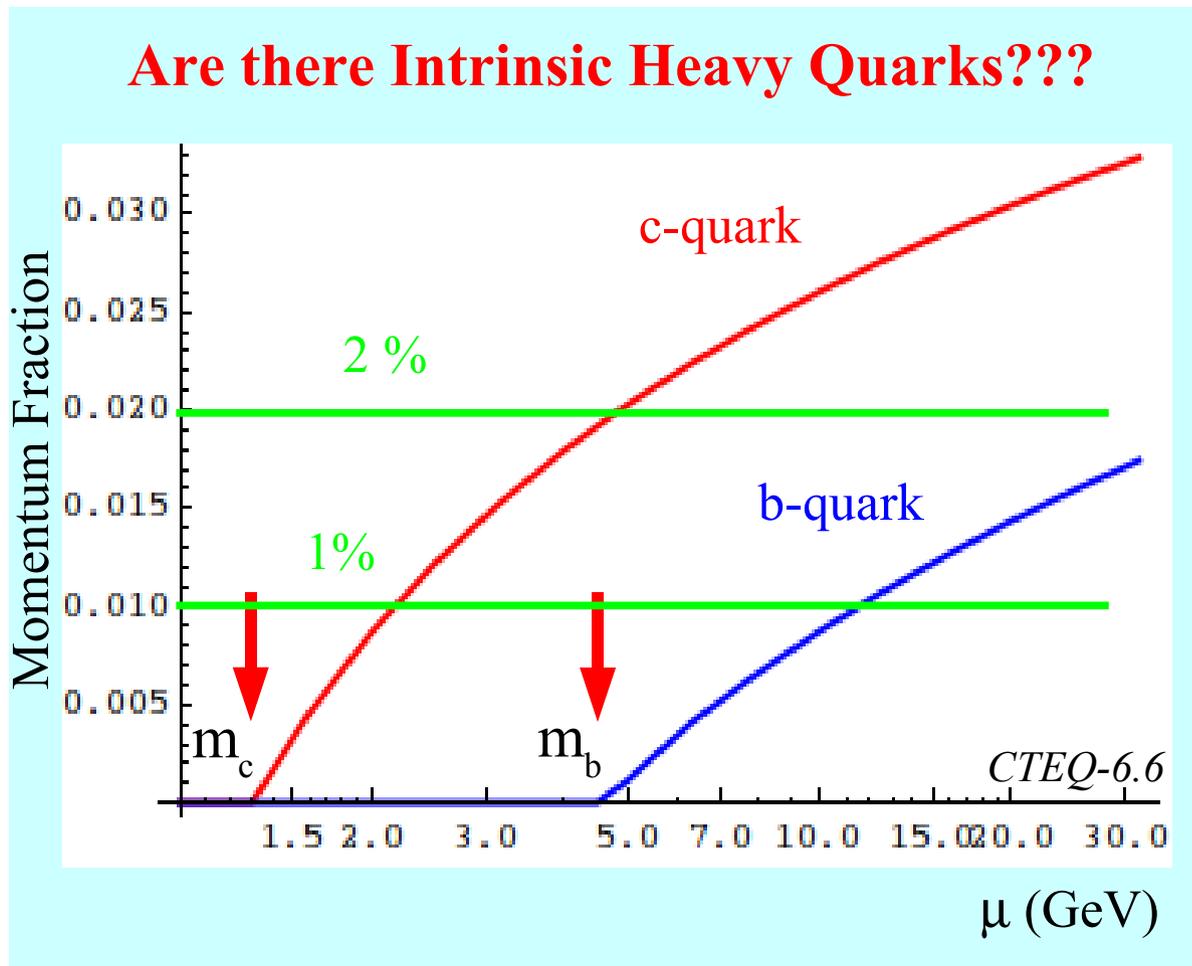
**c & b
tied to
gluon PDFs**





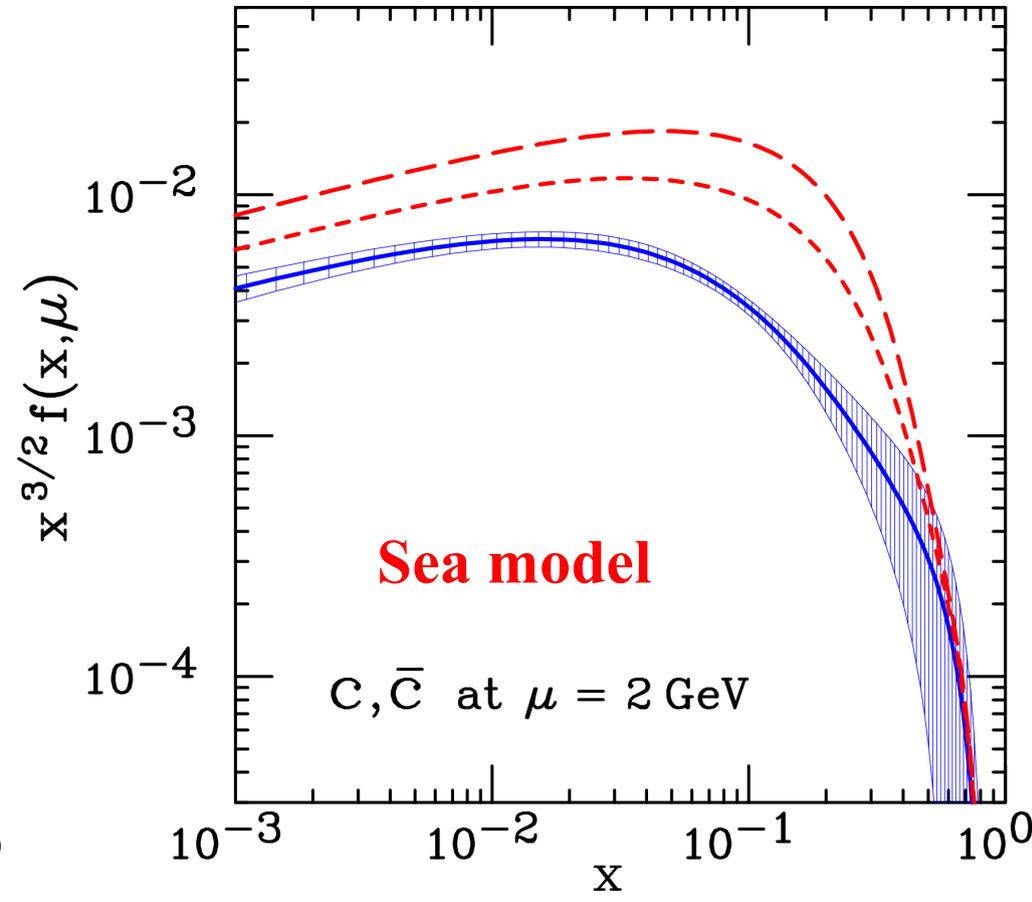
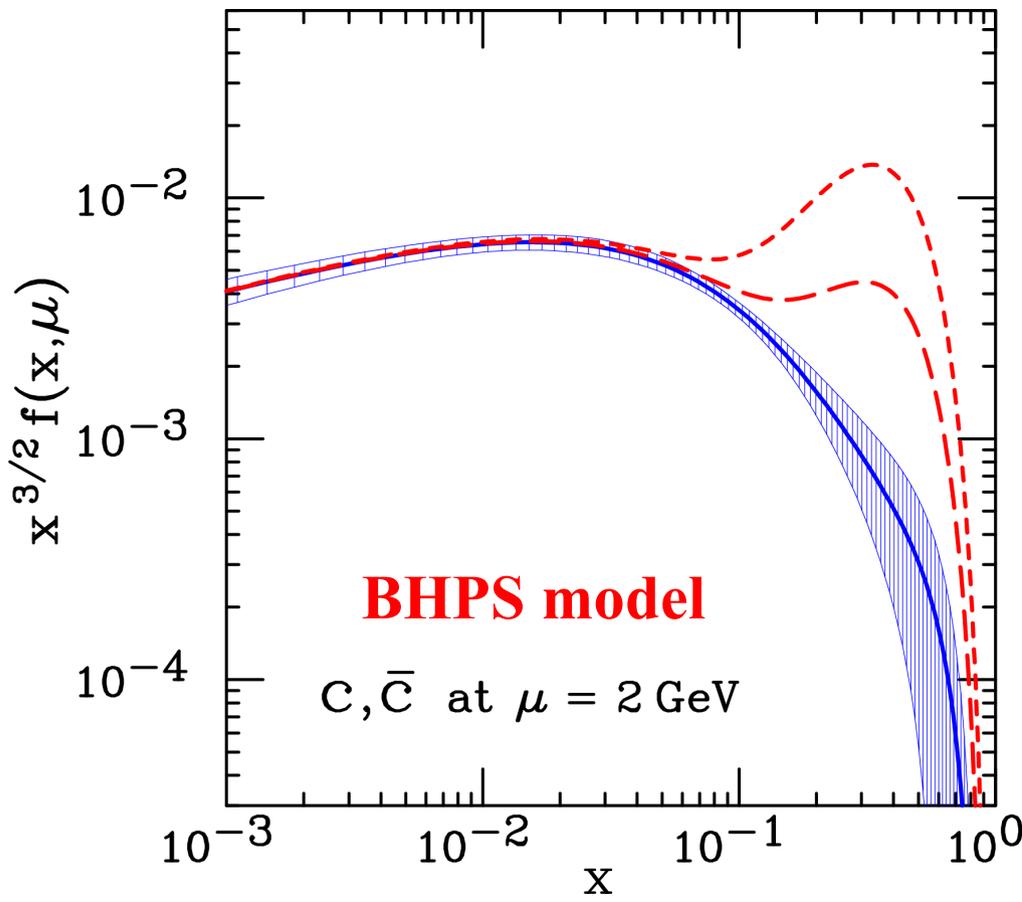
Intrinsic C & B

Are there Intrinsic Heavy Quarks??? Do they matter???



- * Most sensitive near threshold
- * What happens if we allow the evolution to determine charm?

Zero: No intrinsic charm
 Positive: Intrinsic charm
 Negative: Inconsistent

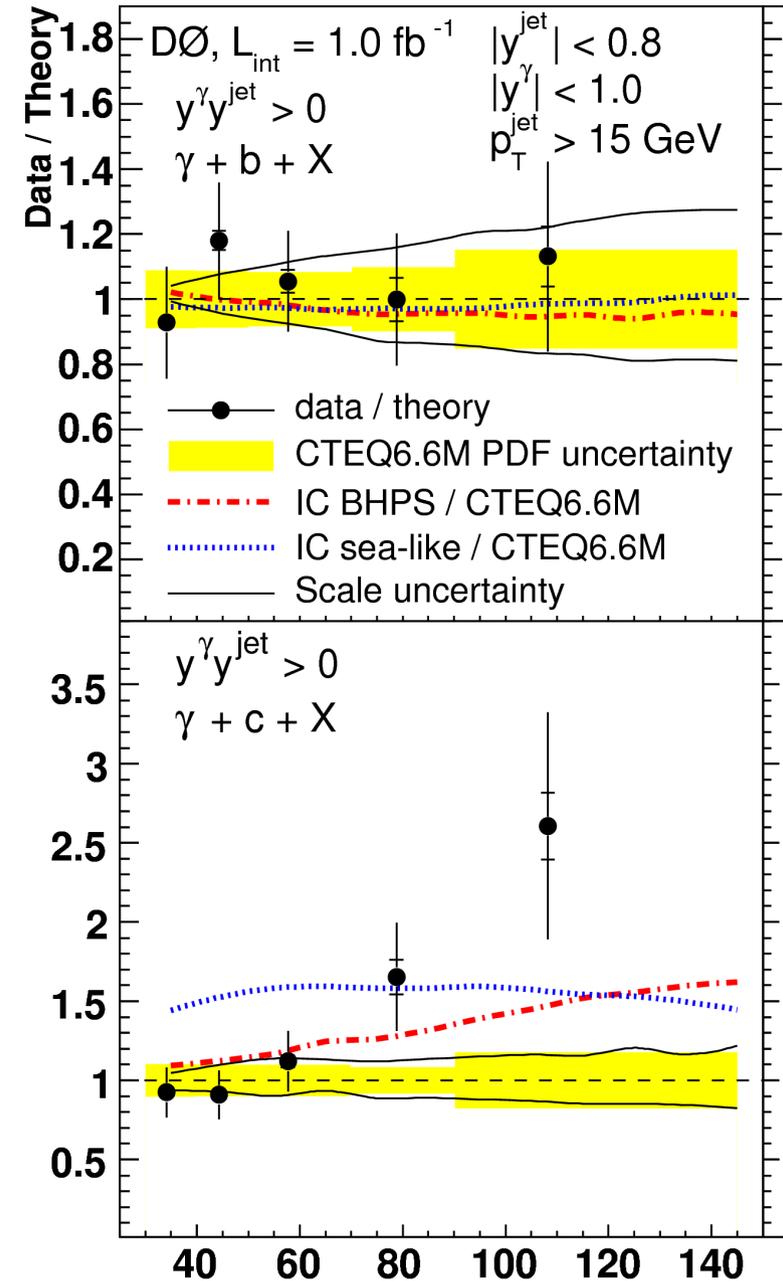
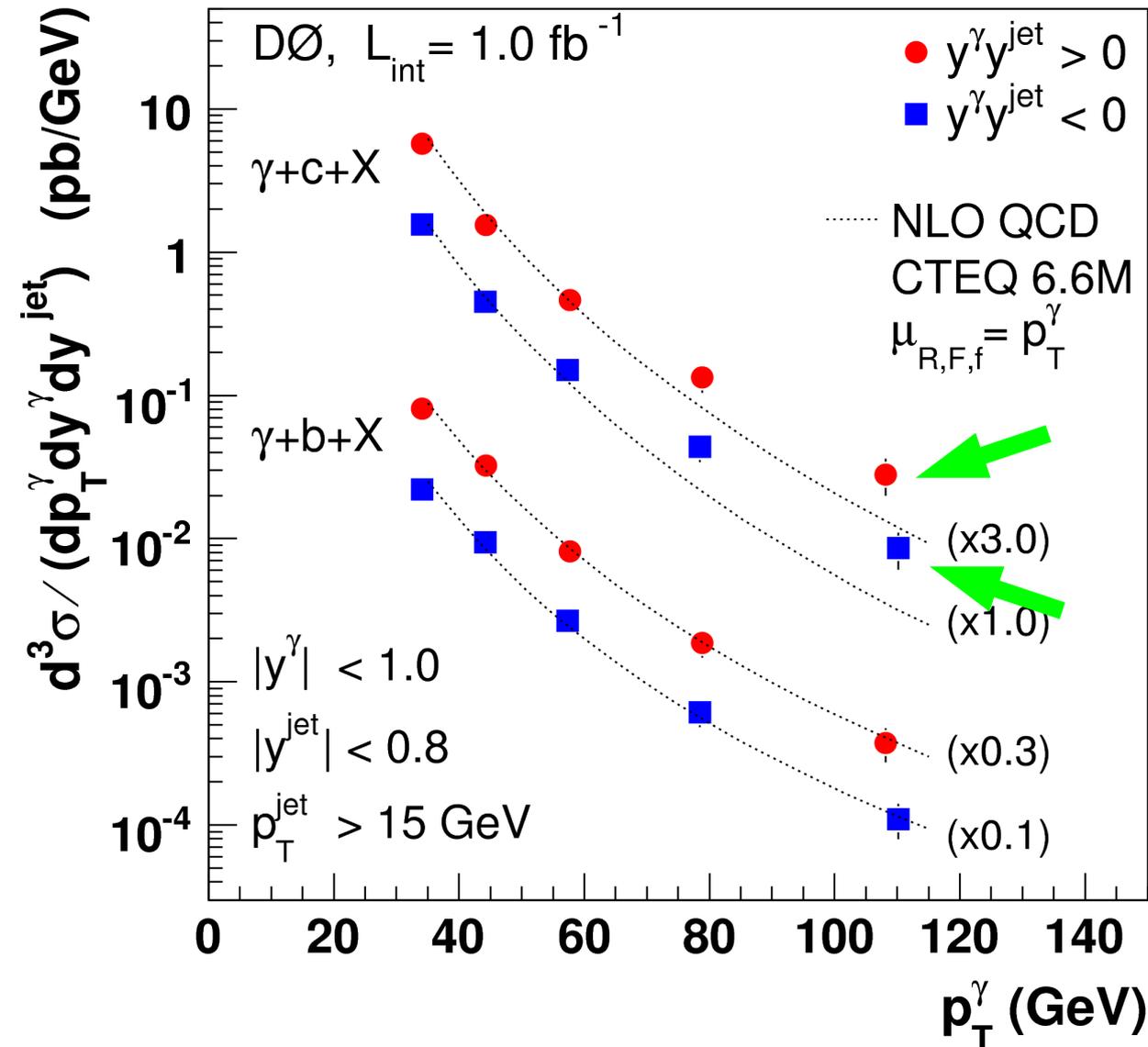


Add 1% or 2% momentum fraction
in intrinsic component

Note, structure persists to higher (e.g.,
 $Q \sim 100 \text{ GeV}$) scales

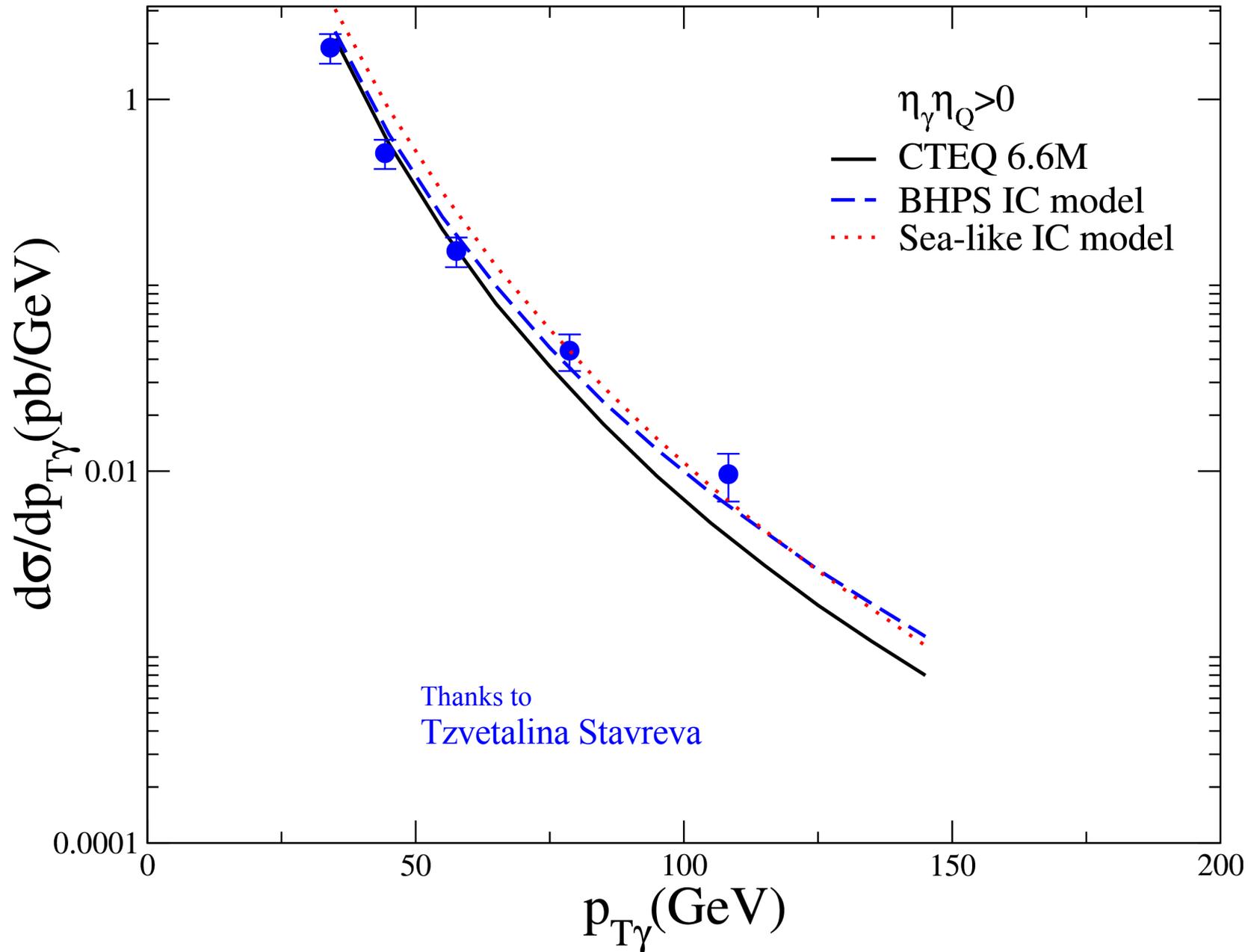
BHPS MODEL:
The Intrinsic Charm of the Proton.
Brodsky, Hoyer, Peterson, Sakai,
Phys.Lett.B93:451-455,1980.

The Charm Parton Content of the Nucleon.
J. Pumplin, et al., Phys.Rev.D75:054029,2007.



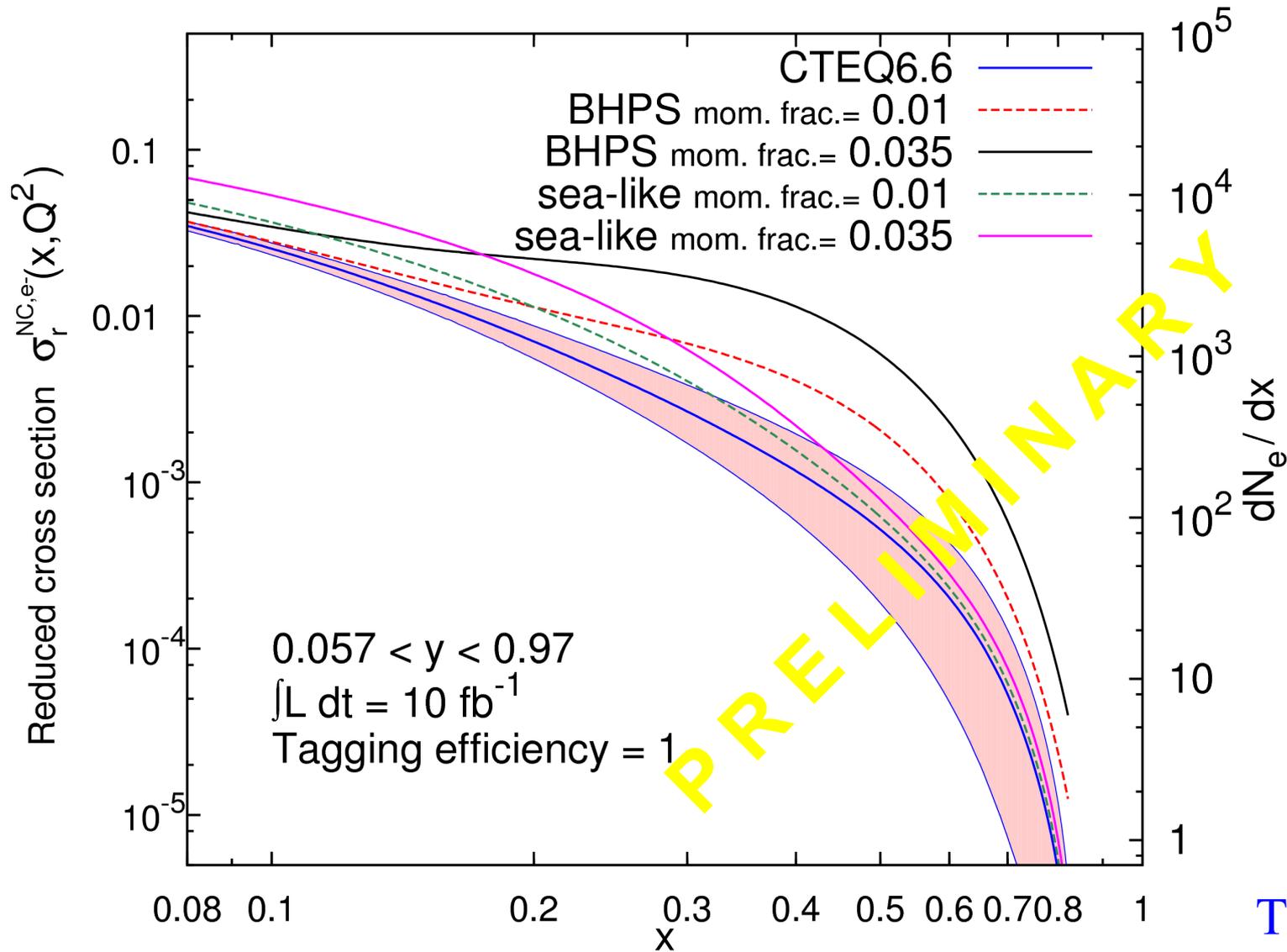
$$p+p \rightarrow \gamma+c+X$$

$$\sqrt{S} = 1.96 \text{ TeV}$$



Sample Cross Section for an Electron Ion Collider

$e^- p$ DIS, $\sqrt{s} = 105 \text{ GeV}$, $Q^2 = 625 \text{ GeV}^2$



Thanks to
Marco Guzzi
for this
calculation

F_L

Why is F_L so special ???

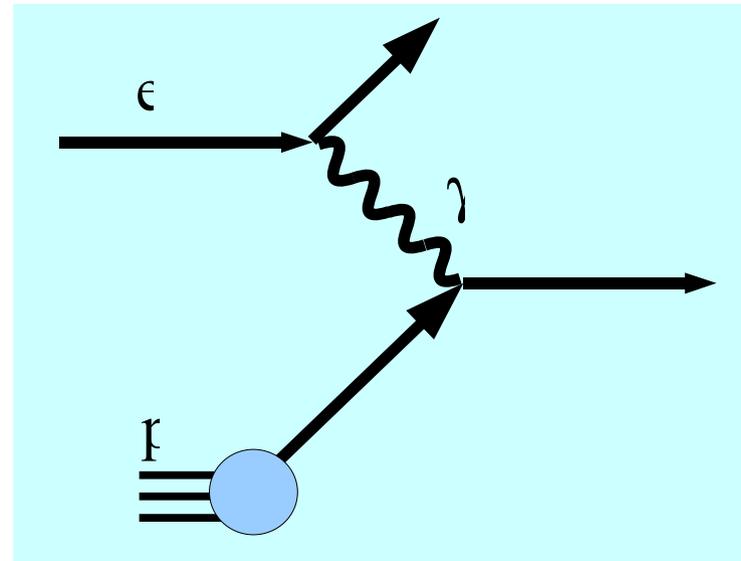
$$\frac{d\sigma^{\nu DIS}}{dx dy} = (1-y)^2 \bar{q}(x) + (1-y) \phi(x) + q(x)$$

$$\frac{d\sigma^{\nu DIS}}{dx dy} = (1-y)^2 F_+(x) + (1-y) F_0(x) + F_-(x)$$

$$F_0 = \frac{F_2}{2x} - F_1$$

$$F_0 = 0 \implies F_2 = 2x F_1$$

Callan-
Gross



$$F_L \sim \frac{m^2}{Q^2} q(x) + \alpha_S \{c_g \otimes g(x) + c_q \otimes q(x)\}$$

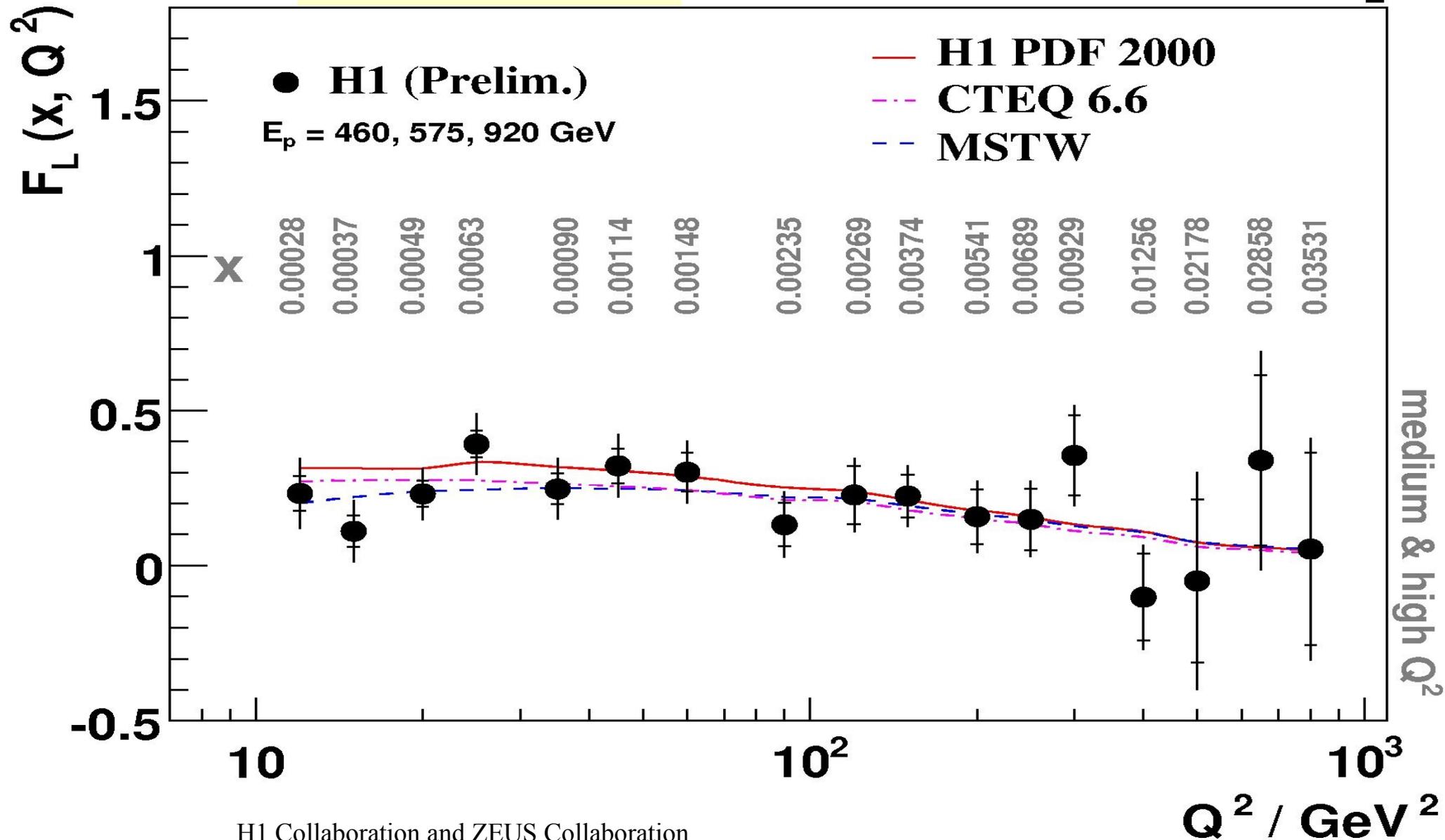
Masses
are
important

Higher Orders
are important

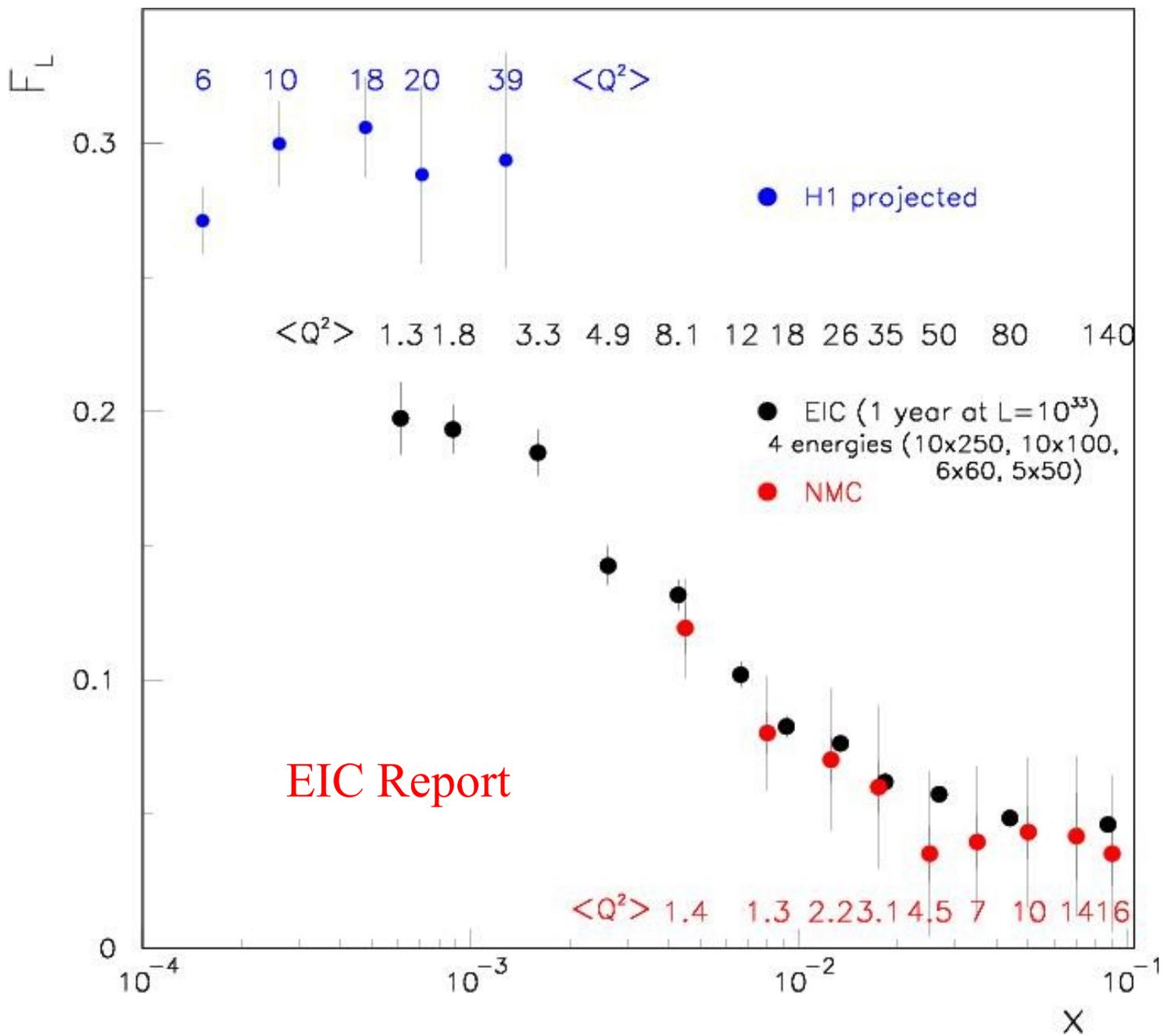
New F_L Measurements: New Perspective

Updated results soon ...

H1 Preliminary F_L



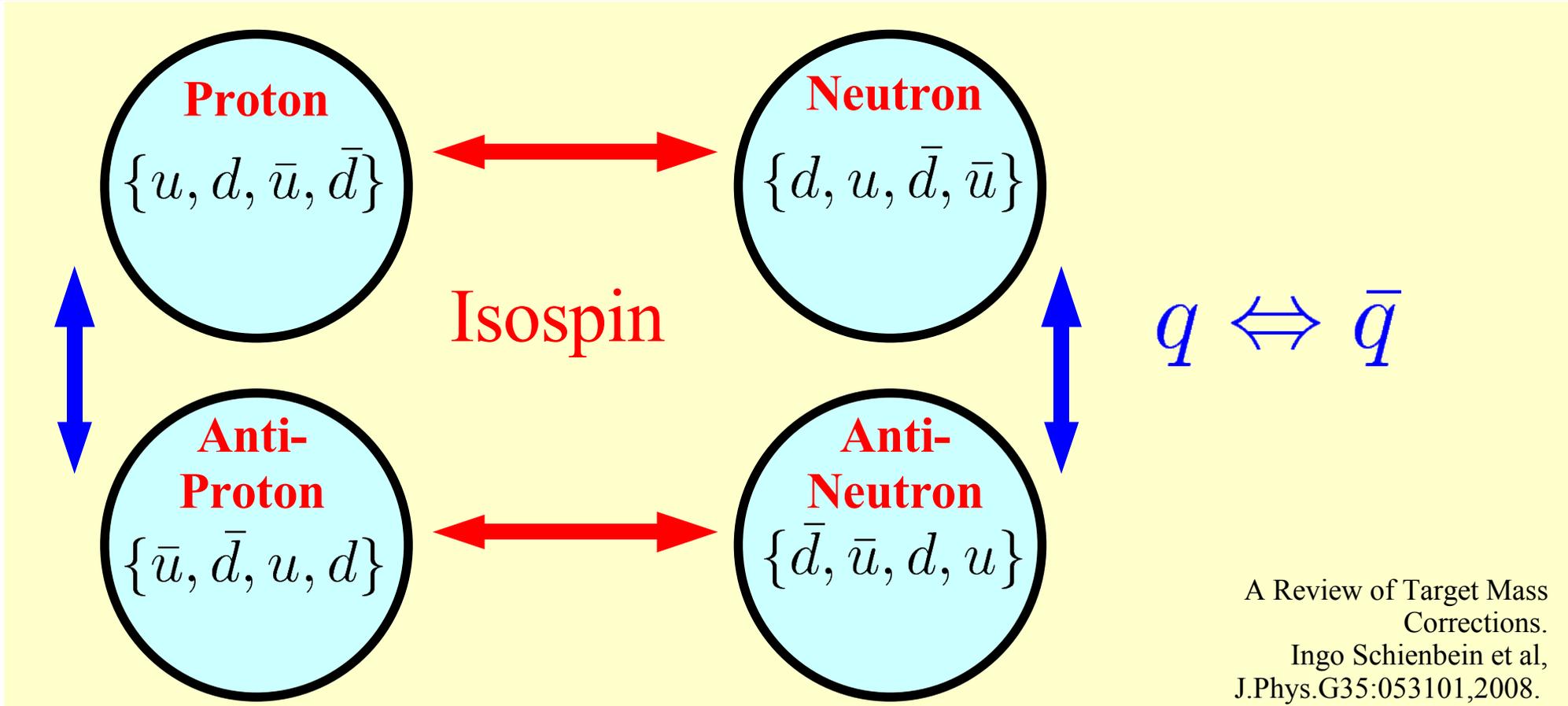
H1 Collaboration and ZEUS Collaboration
 (S. Glazov for the collaboration).
 Nucl.Phys.Proc.Suppl.191:16-24, 2009.



Transition from HERA to Fixed-Target w/ improved stats

Isospin Symmetry

... taken for granted



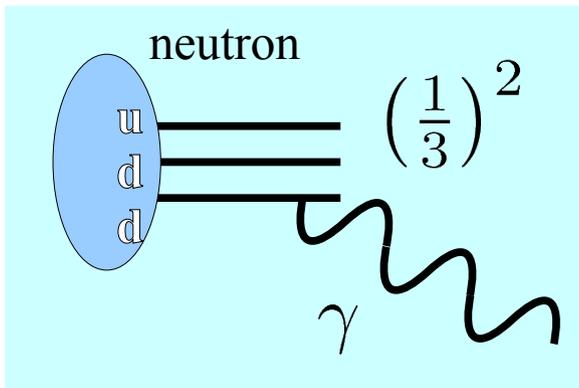
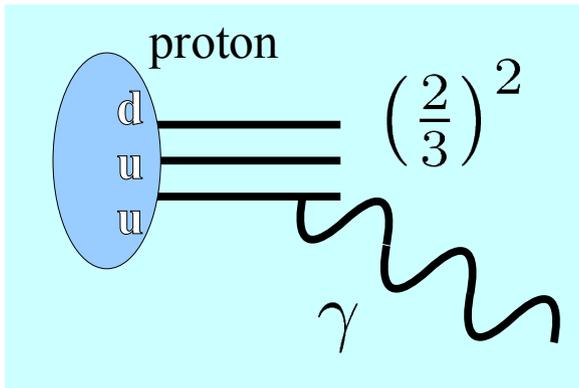
$$\Delta x F_3^A = x F_3^{\nu A} - x F_3^{\bar{\nu} A} = +2x s_A^+ - 2x c_A^+ + x \delta I_A$$

$$\Delta F_2^A = \frac{5}{18} F_2^{CC} - F_2^{NC} = +\frac{1}{6} x s_A^+(x) - \frac{1}{6} x c_A^+(x) + \frac{1}{6} x \frac{N}{A} \delta I_A$$

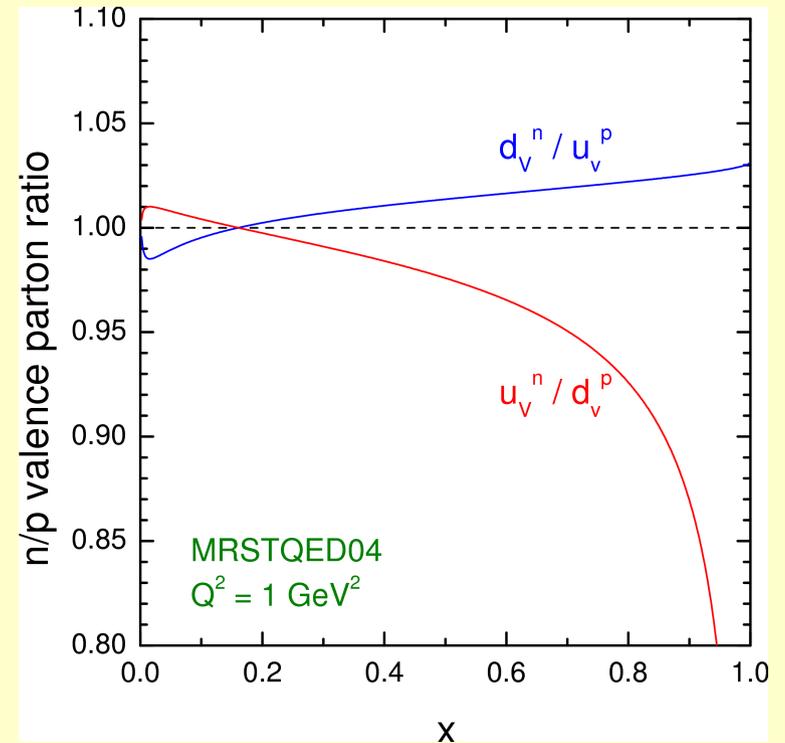
$$\delta I_A = (\delta d + \delta \bar{d}) - (\delta u + \delta \bar{u})$$

$$\delta u = \delta u_p - \delta d_n$$

Photon is not flavor blind!!!



MRST-QED 04

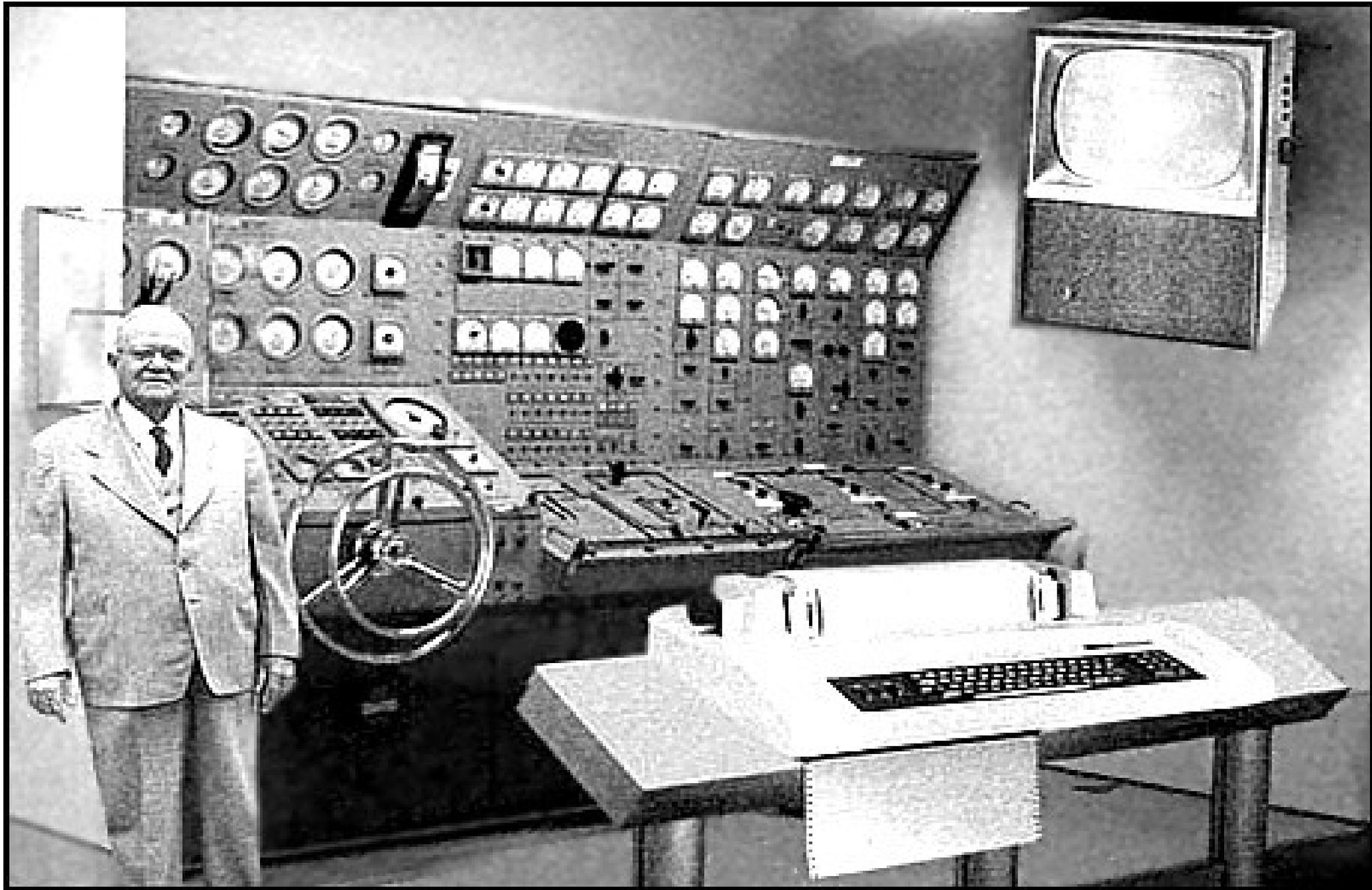


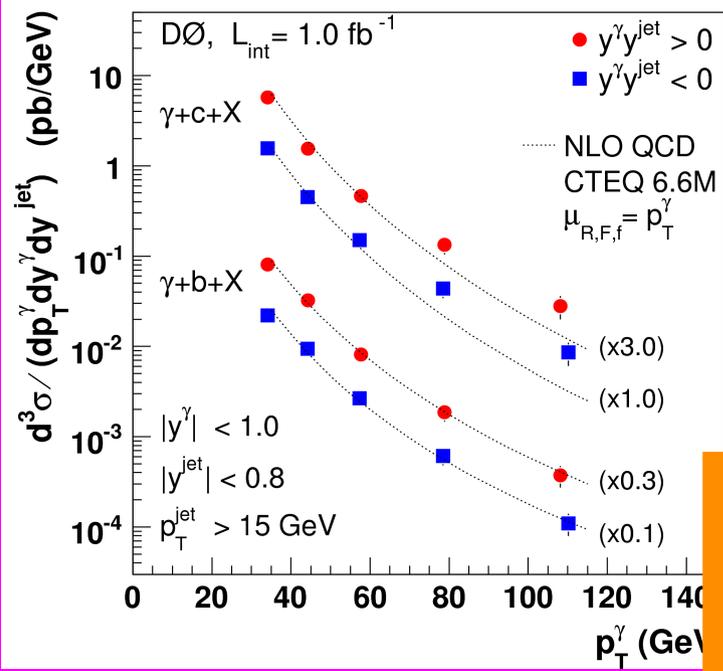
MRST, Eur.Phys.J.C39:155-161,2005.

Isospin terms are comparable to NNLO QCD

Could Isospin terms affect Tevatron W-Asymmetry???

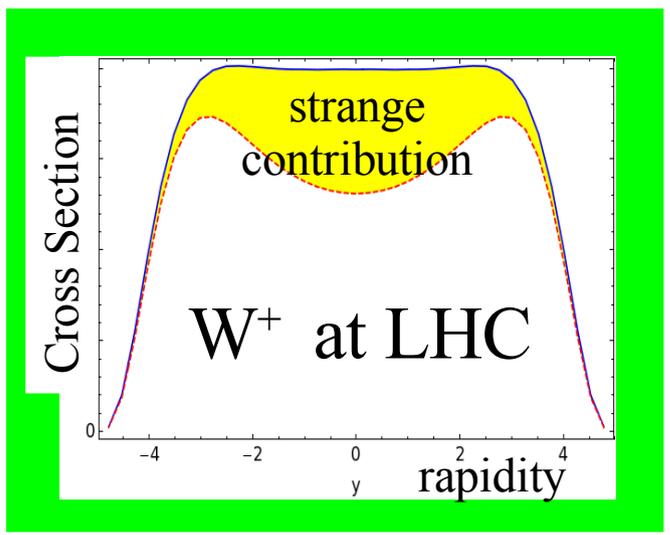
HISTORY





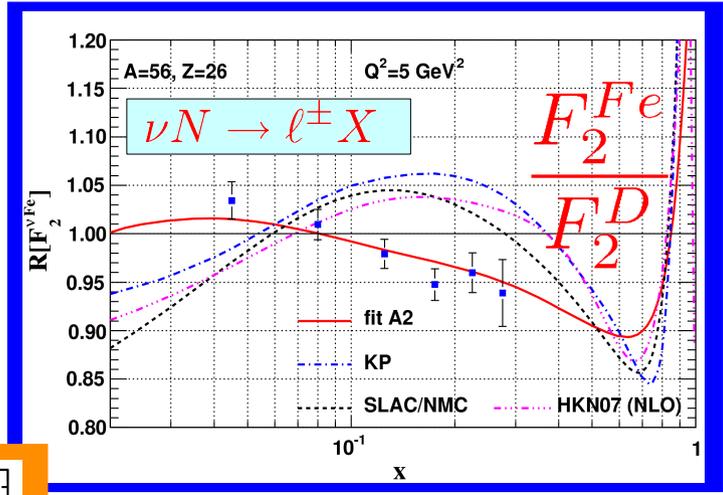
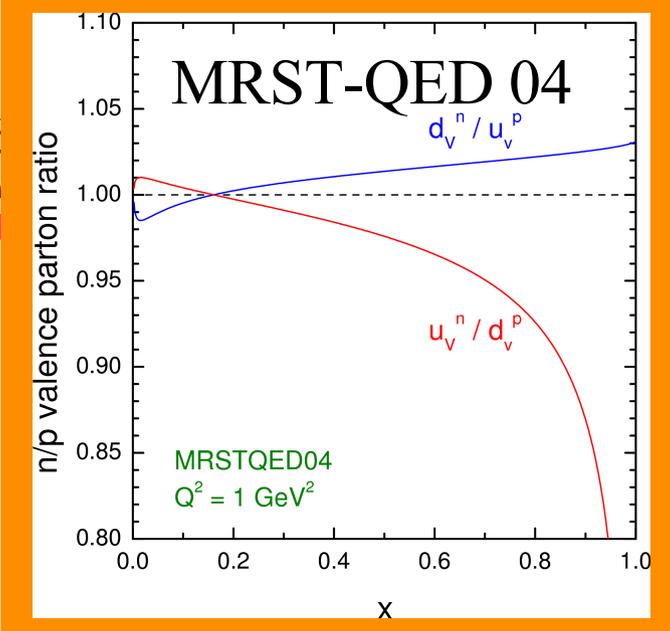
Charm+ γ at Tevatron

$s(x)$ uncertainty: implications for LHC



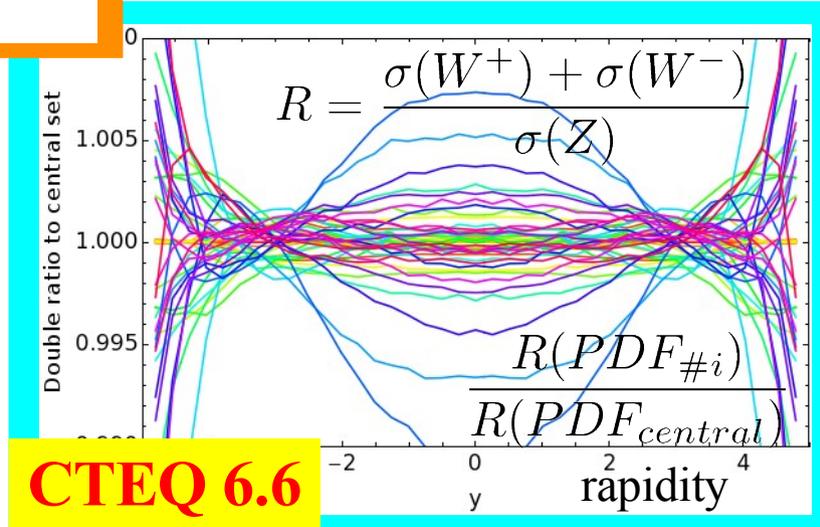
The Puzzles

Isospin Violation: cannot ignore



Nuclear Modifications limit PDFs

$s(x)$ uncertainty: Challenge for W/Z



CTEQ 6.6

FUTURE



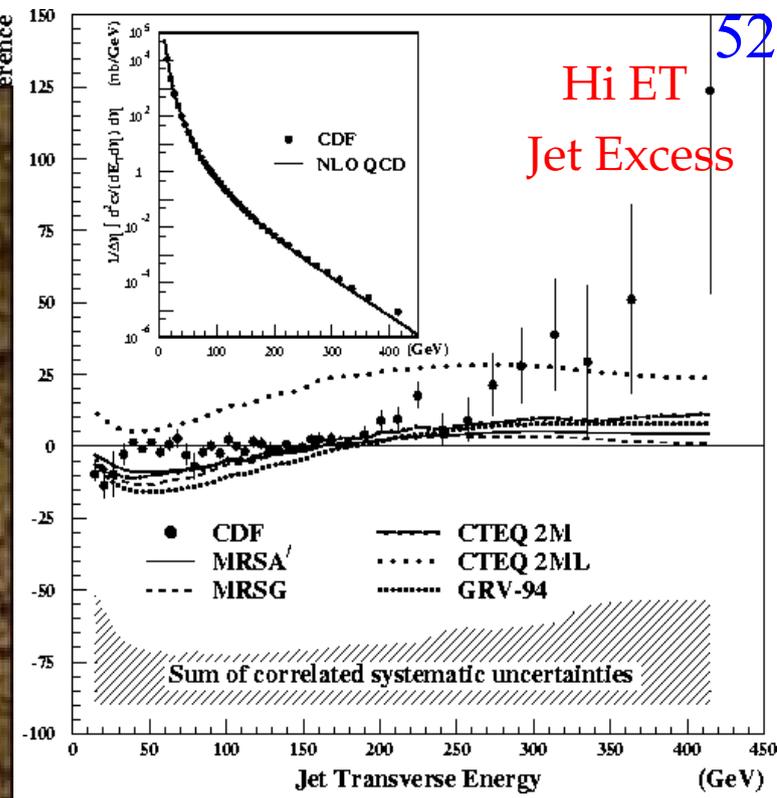
The race is not always to the swift, nor the battle to the strong -
but that's the way to bet.

Runyon's Law

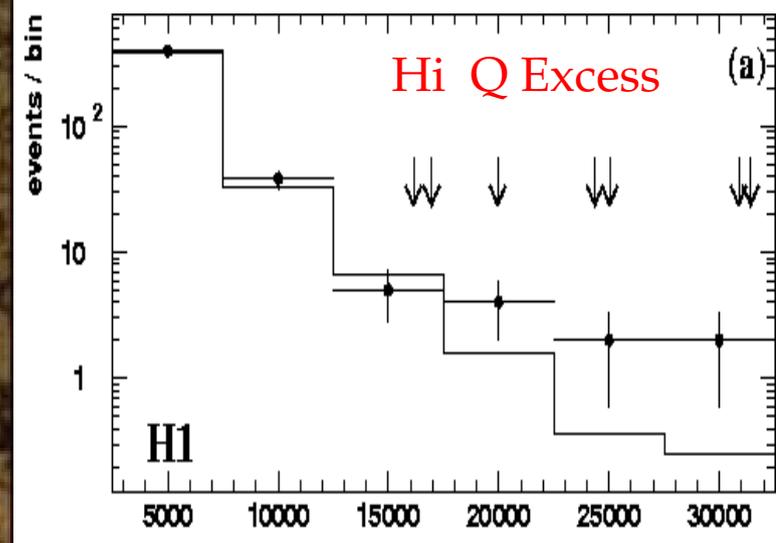
We're sure to see some interesting things at the LHC



confusions.com



CDF Collaboration, PRL 77, 438 (1996)



H1 Collaboration, ZPC74, 191 (1997)
ZEUS Collaboration, ZPC74, 207 (1997)



PRECISION ELECTROWEAK

- Extended W'/Z' and Higgs
- $\text{Sin}\theta_w$
- R-violating SUSY Models
- various lepto-quark models

QCD STUDIES

- PDFs Extraction
- Intrinsic PDFs
- Isospin Symmetry Violation
- $s(x)$ & $c(x)$ distributions
- W/Z Benchmarks @ LHC

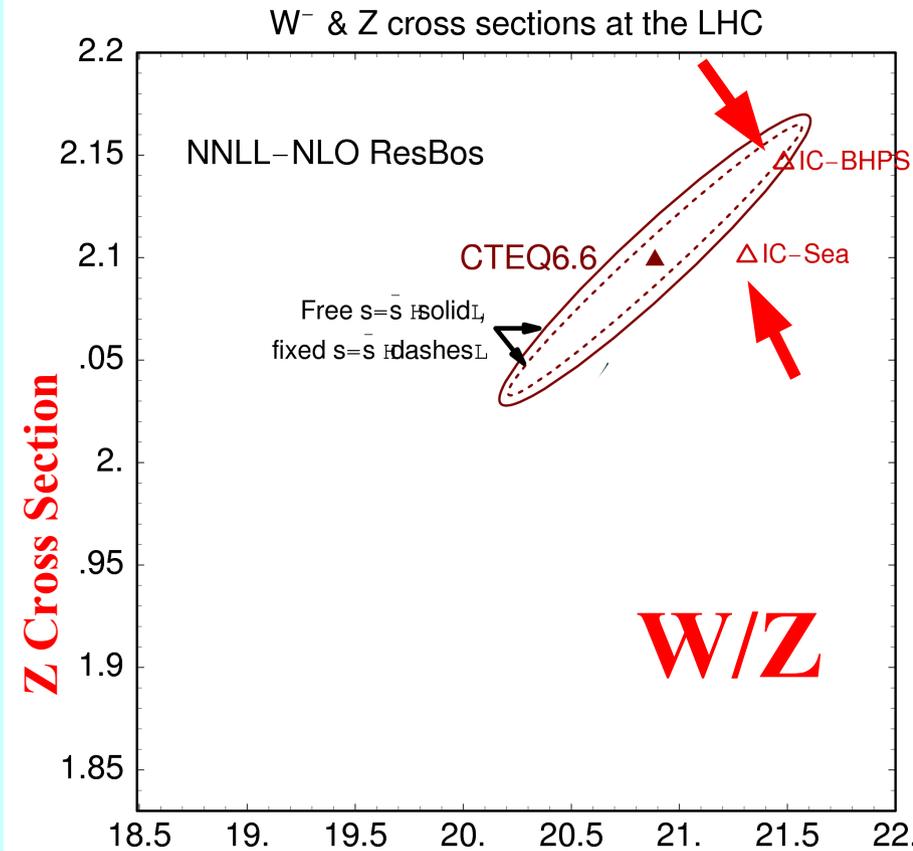
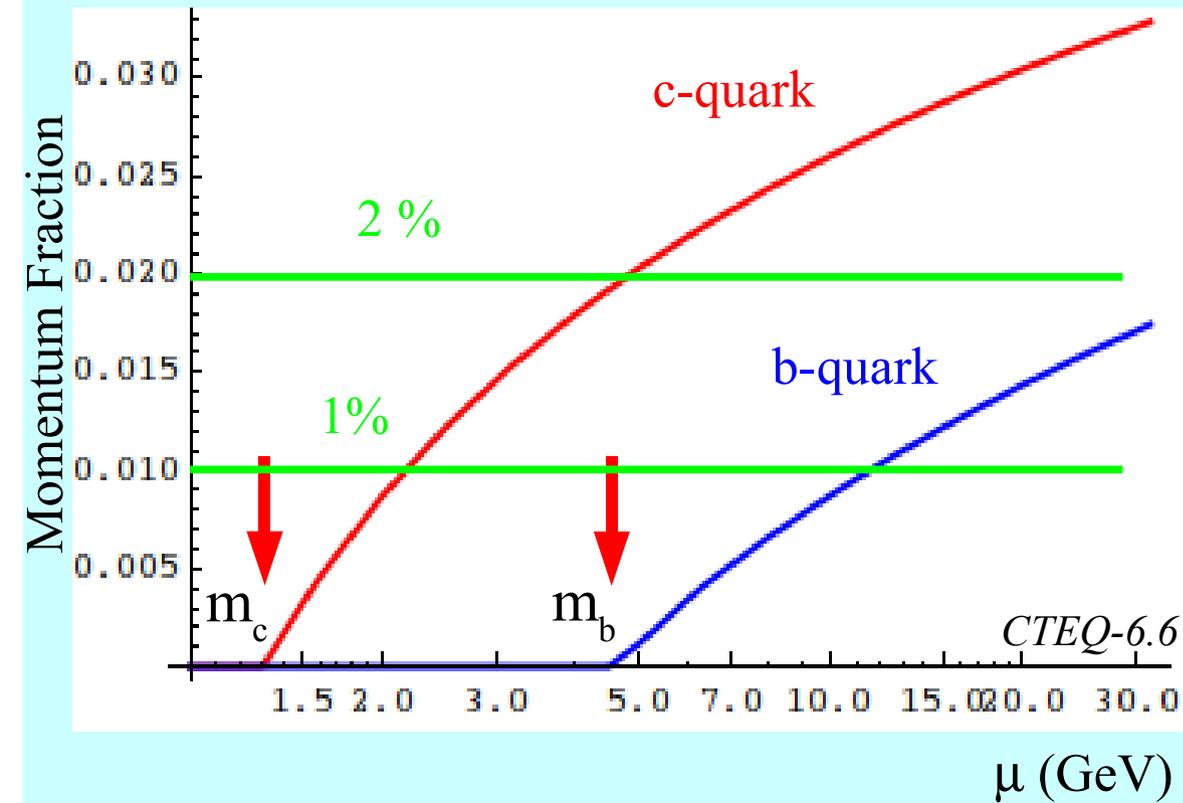
DIRECT SEARCHES

- Higgs Boson
- SUSY *and beyond*

Tevatron
LHC

Are there Intrinsic Heavy Quarks??? Do they matter???

Are there Intrinsic Heavy Quarks???



W Cross Section

Nadolsky, et al., Phys.Rev.D78:013004,2008.

J. Pumplin, Phys.Rev.D75:054029,2007.

- * Most sensitive near threshold
- * What happens if we allow the evolution to determine charm?

Zero: No intrinsic charm
 Positive: Intrinsic charm
 Negative: Inconsistent

Also, the 2-scale problem: $\{m, Q\}$