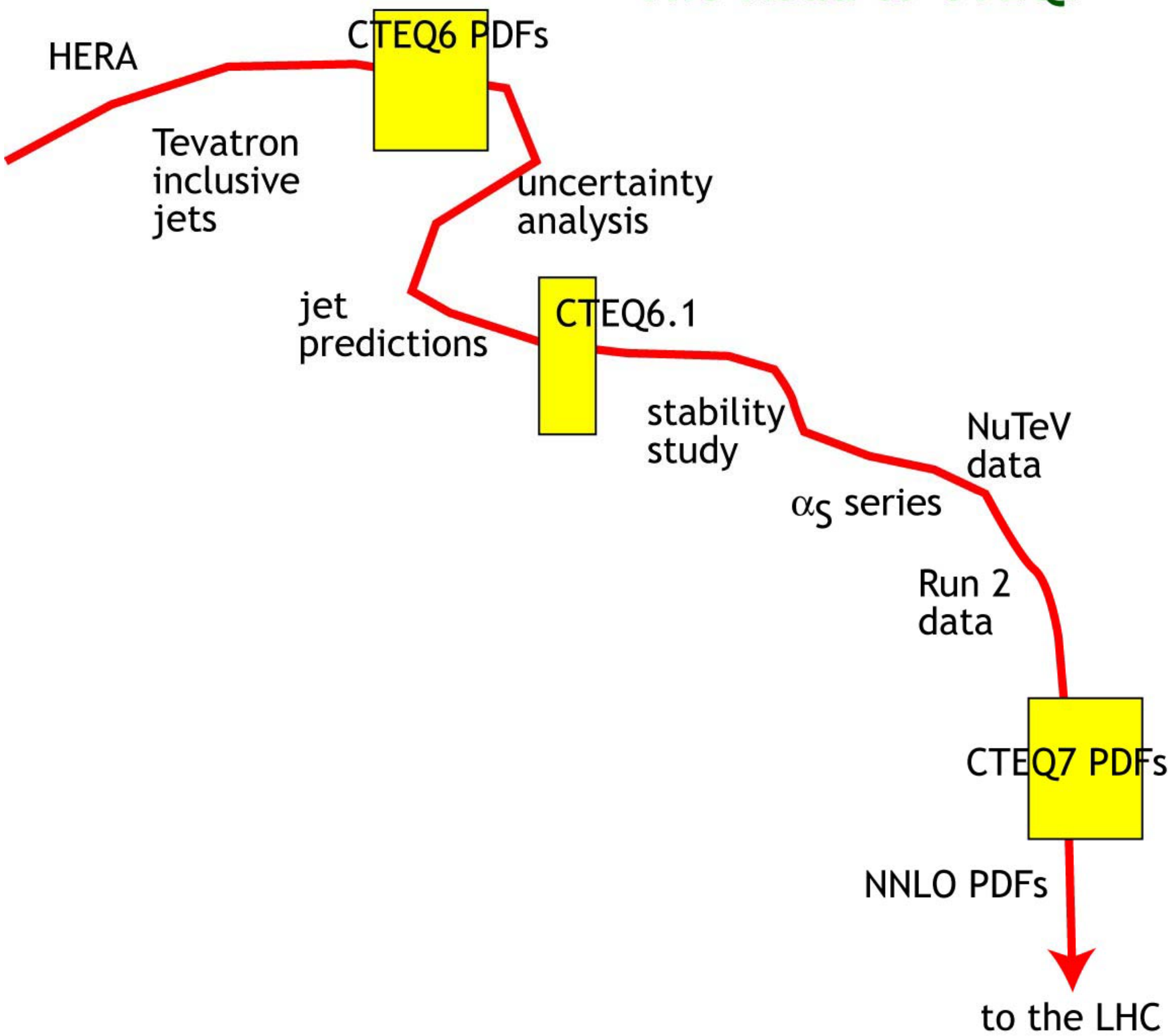
The Road to CTEQ7

Dan Stump
Michigan State University

The most recent set of CTEQ parton distribution functions – CTEQ6 – was published in 2002. The CTEQ global analysis group is currently working to construct the next generation of PDFs, which will be used in prediction and analysis of LHC cross sections.

The Road to CTEQ7



Parton distribution functions are important.

As long as experiments are taking place at hadron colliders (HERA, Tevatron in the past; LHC in the future) the PDFs are necessary to calculate cross sections.

Global Analysis is important.

We must use data from a variety of complementary short distances processes to construct the panoply of PDFs.

CTEQ6 provides a satisfactory fit to all these processes, in the next-leading order (NLO) approximation to QCD.

CTEQ6						
	process	data set	CorrMat	N	χ^2	χ^2/N
1	μ DIS	BCDMS F2p	Y	339	378	1.11
2	μ DIS	BCDMS F2d	Y	251	280	1.11
3	$\bar{e}$ DIS	H1 (a)	Y	104	98.6	0.95
4	e DIS	H1 (b)	Y	126	129	1.02
5	$\bar{e}$ DIS	ZEUS	Y	229	263	1.15
6	μ DIS	NMC F2p	Y	201	305	1.52
7	μ DIS	NMC d/p	Y	123	112	0.91
8	$p\bar{p} \to$ jet	D0	Y	90	69	0.77
9	$p\bar{p} \to$ jet	CDF	Y	33	49	1.47
10	$\nu(\bar{\nu})$ DIS	CCFR F2 + F3	Y/N	156	150	0.96
11	Drell-Yan	E605	N	119	95	0.80
12	Drell-Yan	E866 d/p	N	15	6	0.40
13	$p\bar{p} \to W$	CDF (Lasy)	N	11	10	0.91

H1 (a) 96/97 low-x e+p data

H1 (b) 98/99 high-Q e-p data

ZEUS 96/97 e+p data

D0 : $d^2\sigma/d\eta\, dpT$

The issue of compatibility

Systematic errors -- both experimental and theoretical -- lead to minor incompatibilities.

The best fit to one experiment is not the best fit to other experiments.

Or, there is a “tension”* between different data sets.

This issue contributes to the ***uncertainties*** of PDFs.

* MRST has used this word in referring to the the issue of compatibility.

The treatment of experimental systematic errors

CTEQ (and most other G.A. efforts) use a method of ***fitting of systematic errors***

$$\chi^2 = \sum_i \frac{\left(D_i - \sum_j \beta_{ji} s_j - T_i \right)^2}{\sigma_i^2}$$

… introducing systematic shifts $\{s_1 , s_2 , \ldots , s_n\}$ for the experimental systematic errors.

“Stability” of the NLO global analysis

A question raised by the MRST group:

Is the NLO fit to data ***stable*** with respect to reasonable cuts on x and Q?

CTEQ stability study

Is the NLO fit to data stable with respect to changes of kinematic cuts?

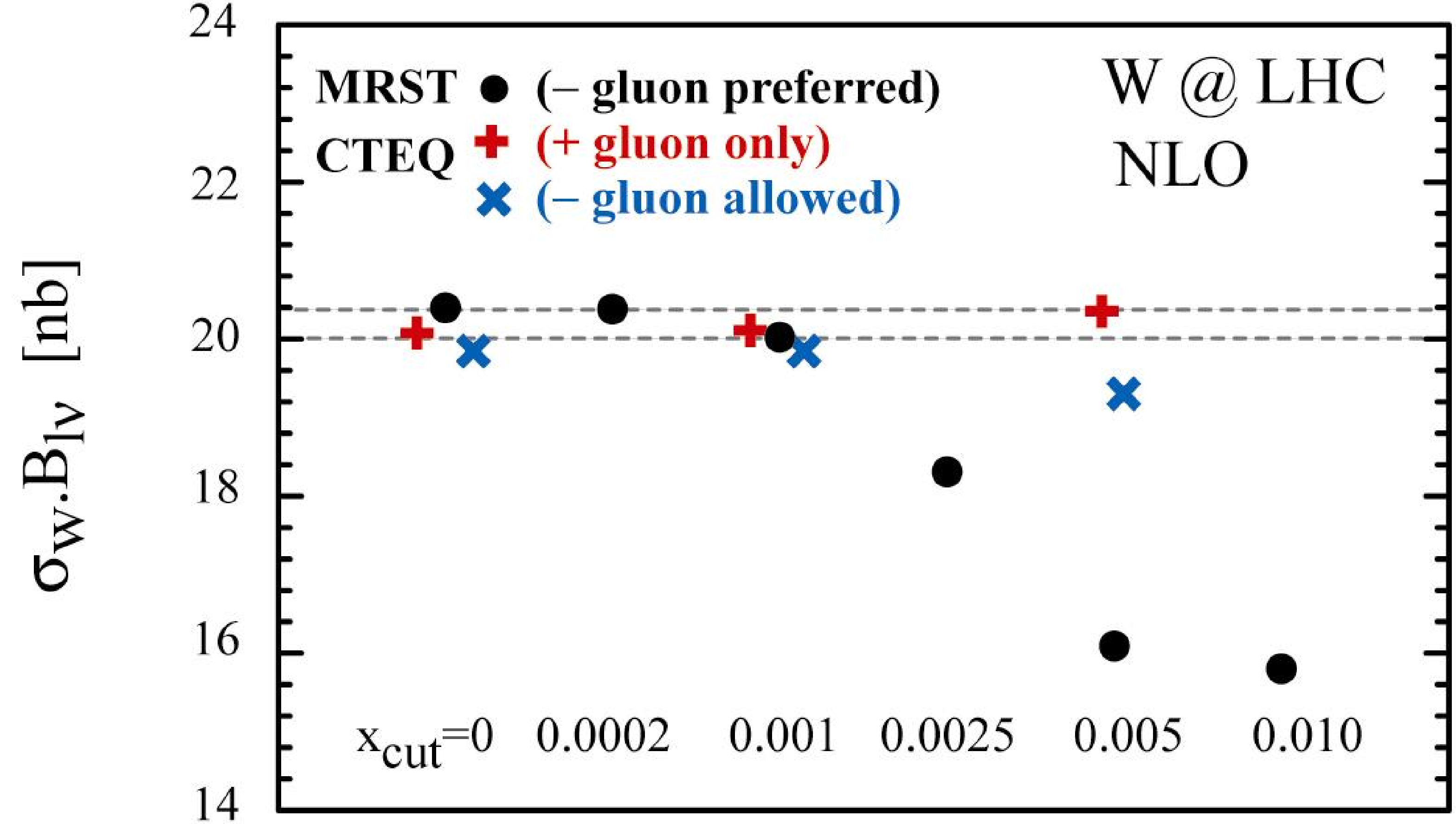
Cuts	Q_{min}	x_{min}	N_{pts}	χ^2_{1926}	χ^2_{1770}	χ^2_{1588}	$\sigma_W \cdot B$
standard	2 GeV	0	1926	2023	1850	1583	20.02
intermed	2.5 "	0.001	1770	--	1849	1579	20.10
strong	3.16 "	0.005	1588	--	--	1573	20.34

[nb]

TABLE: The best fits for three choices of exclusionary cuts (standard, intermediate and strong). Note that χ^2 for the data that is retained changes very little ⇒ ***stability***.

Results, graphically:

CTEQ stability study



The predicted total cross section of $W^+ + W^-$ production at the LHC, for NLO calculations.

Lagrange Multiplier method

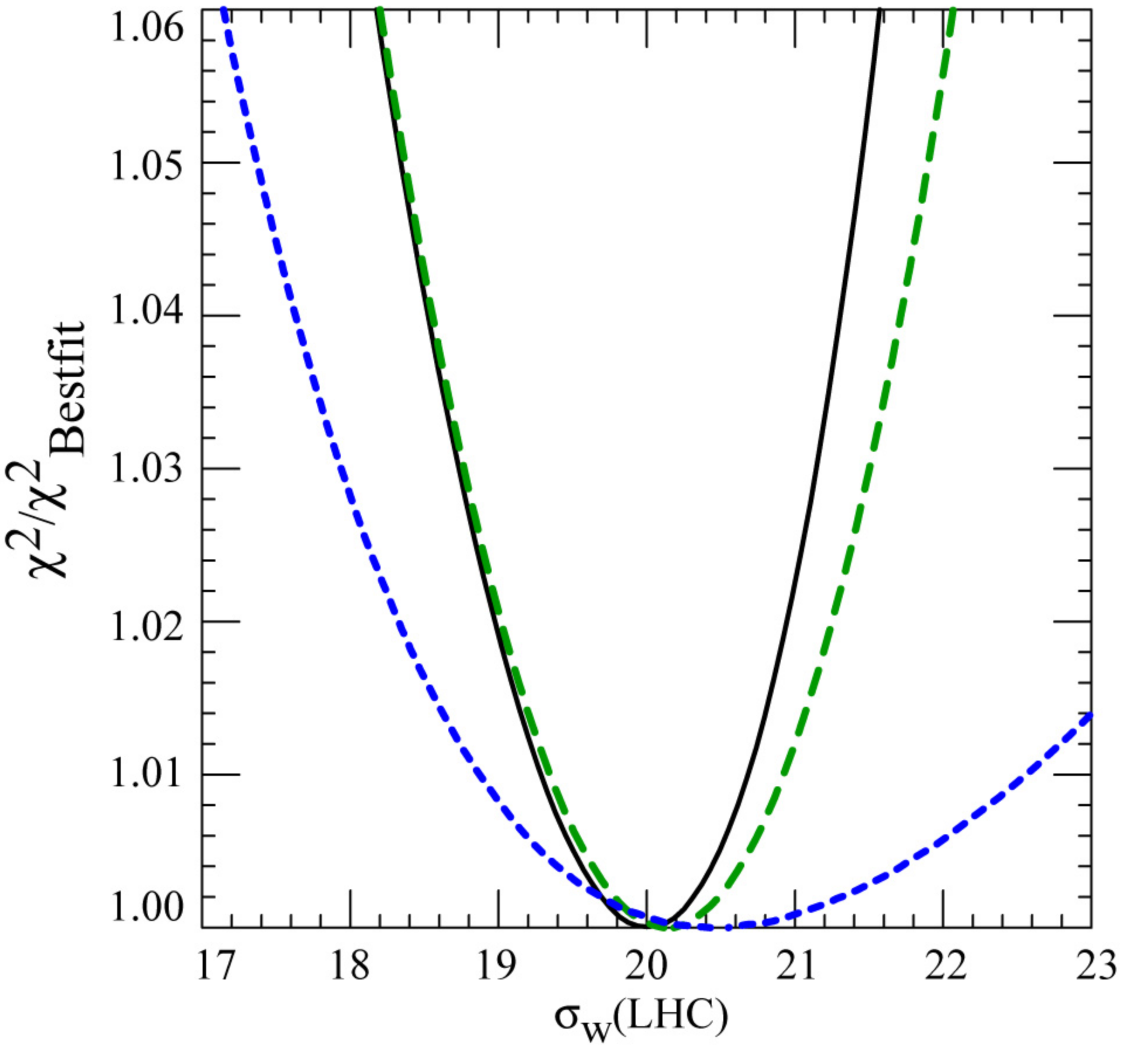
▶ **calculate χ^2 versus σ_W.**

Black curve:
standard cuts (x_{min}=0)
Blue curve:
strong cuts (x_{min}=0.005)

The effects of the strong cuts:

- ***the central prediction moves very slightly;***
- ***the uncertainty increases significantly.***

χ^2 versus σ_W



[positive gluon]

The success of CTEQ6.1

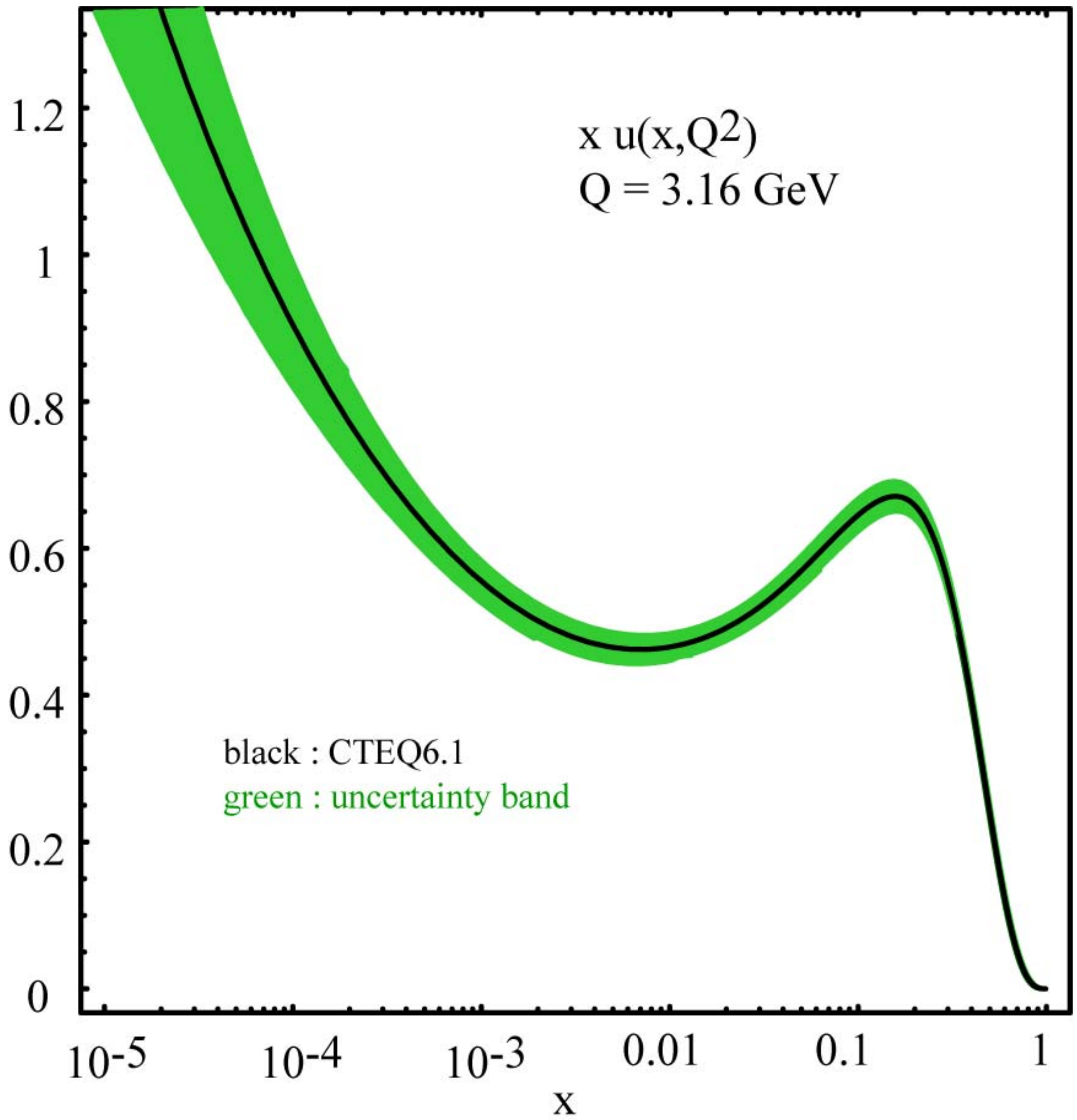
• a satisfactory central fit to all data sets

• full uncertainty analysis ⇒ the “eigenvector basis sets”, a complete set of alternative fits

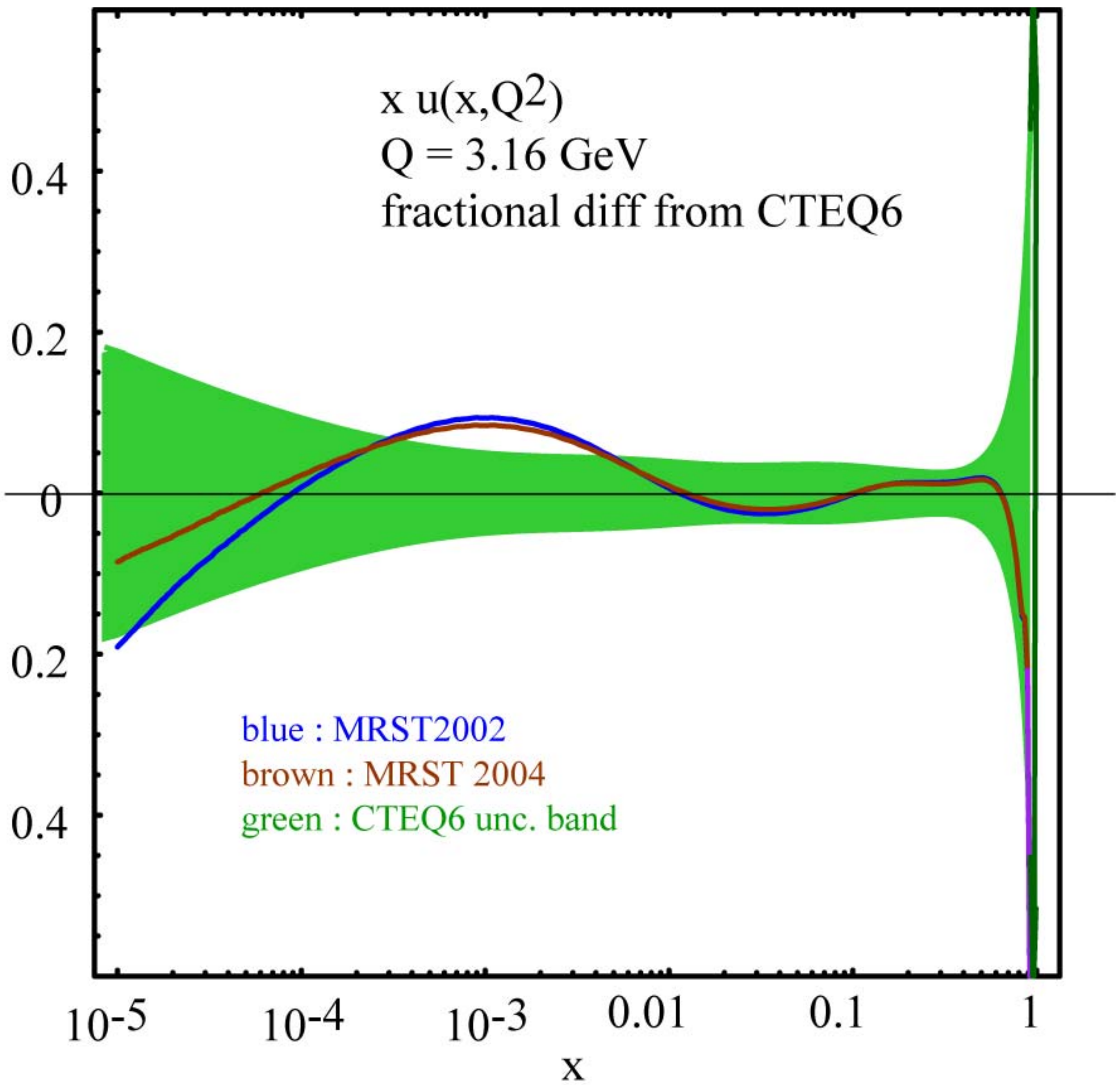
• the gluon distribution and inclusive jet production at the Tevatron. We obtain a good fit to jet production by having $g(x,Q)$ approach 0 slowly as $x \to 1$.

CTEQ6.1

The u-quark PDf and its full uncertainty band. (This representation is potentially misleading because low-x and high-x are correlated!)



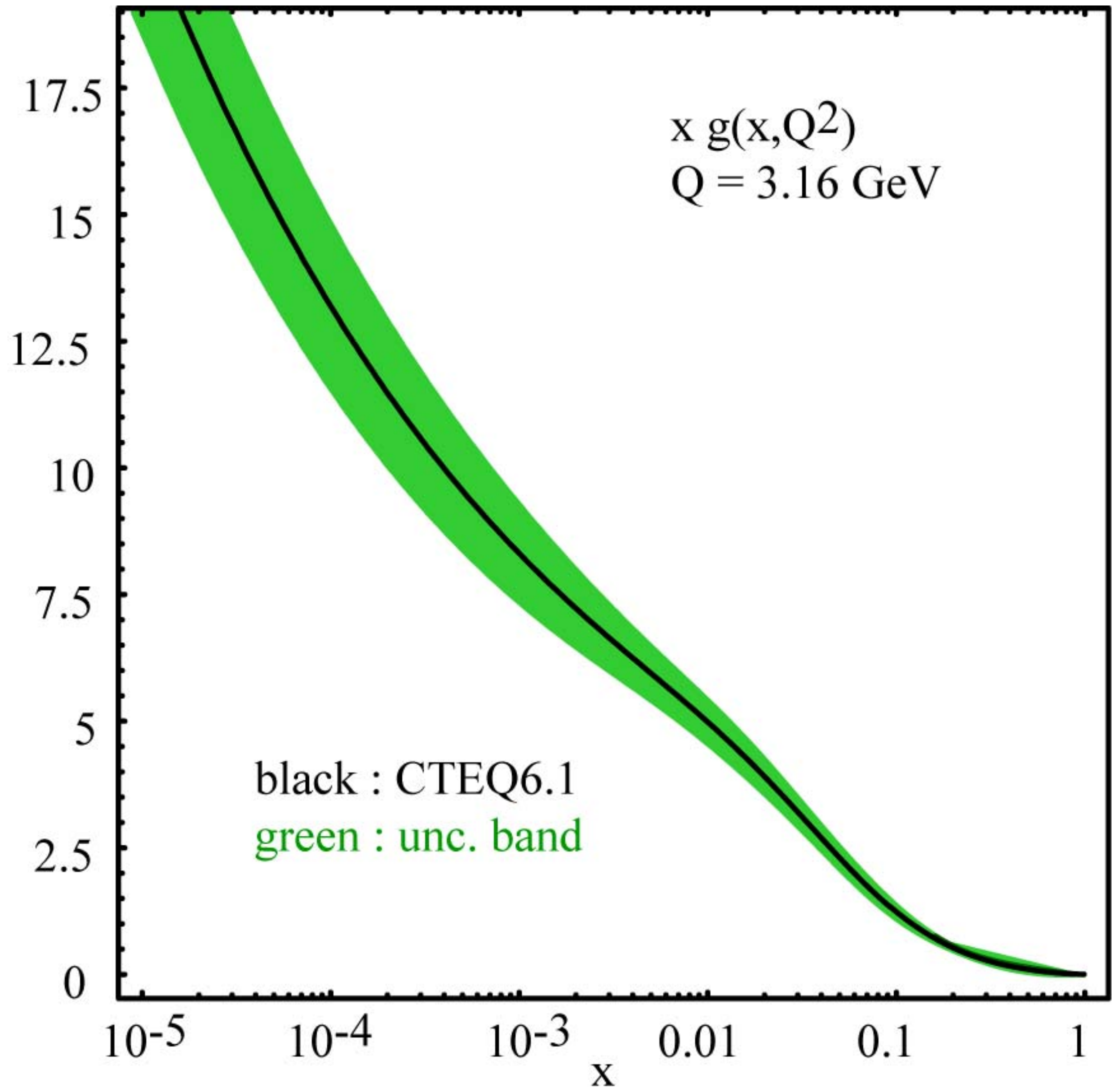
Comparison of MRST and CTEQ6.1
… u-quark



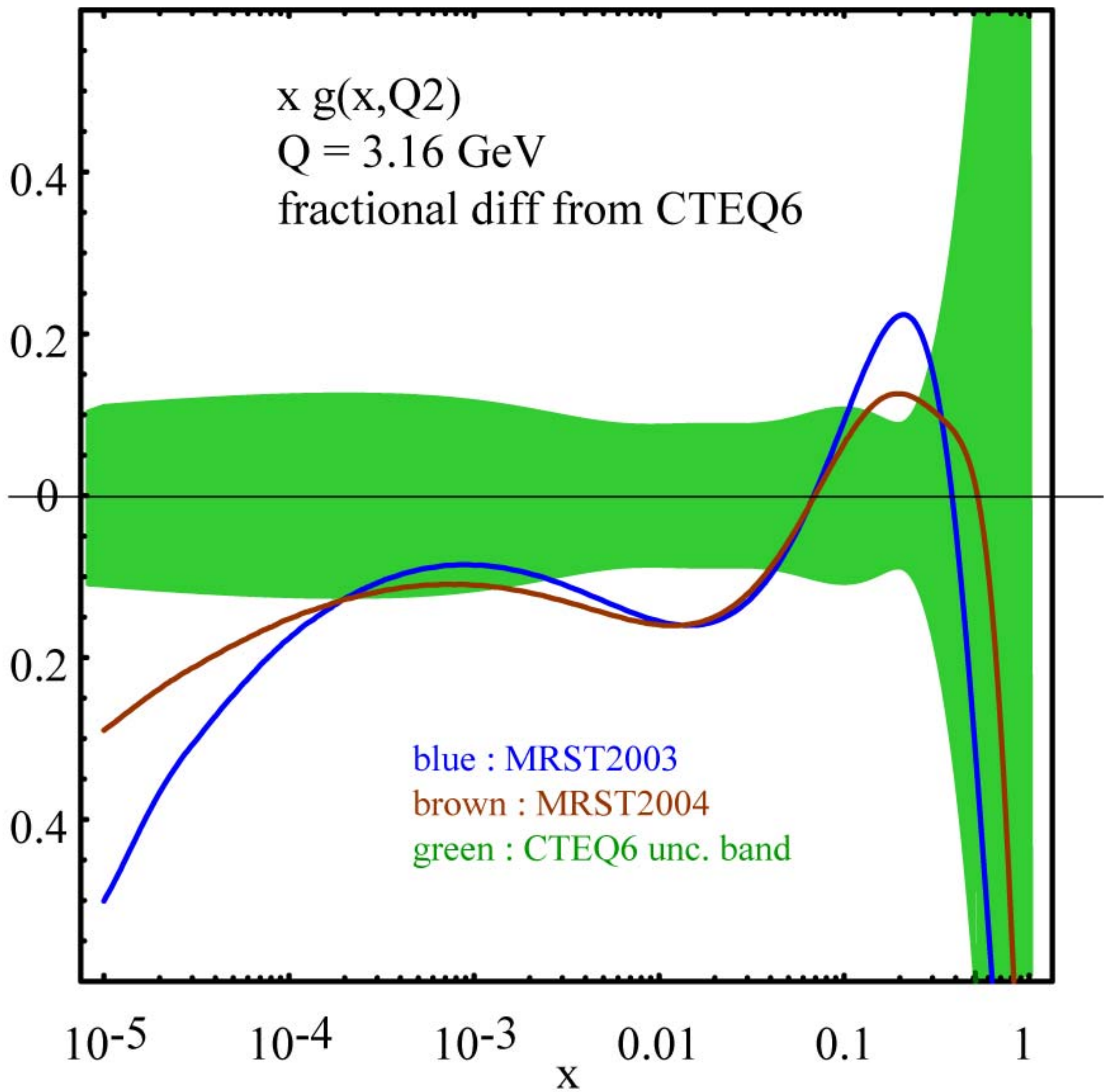
CTEQ6.1

The gluon PDf and its full uncertainty band.

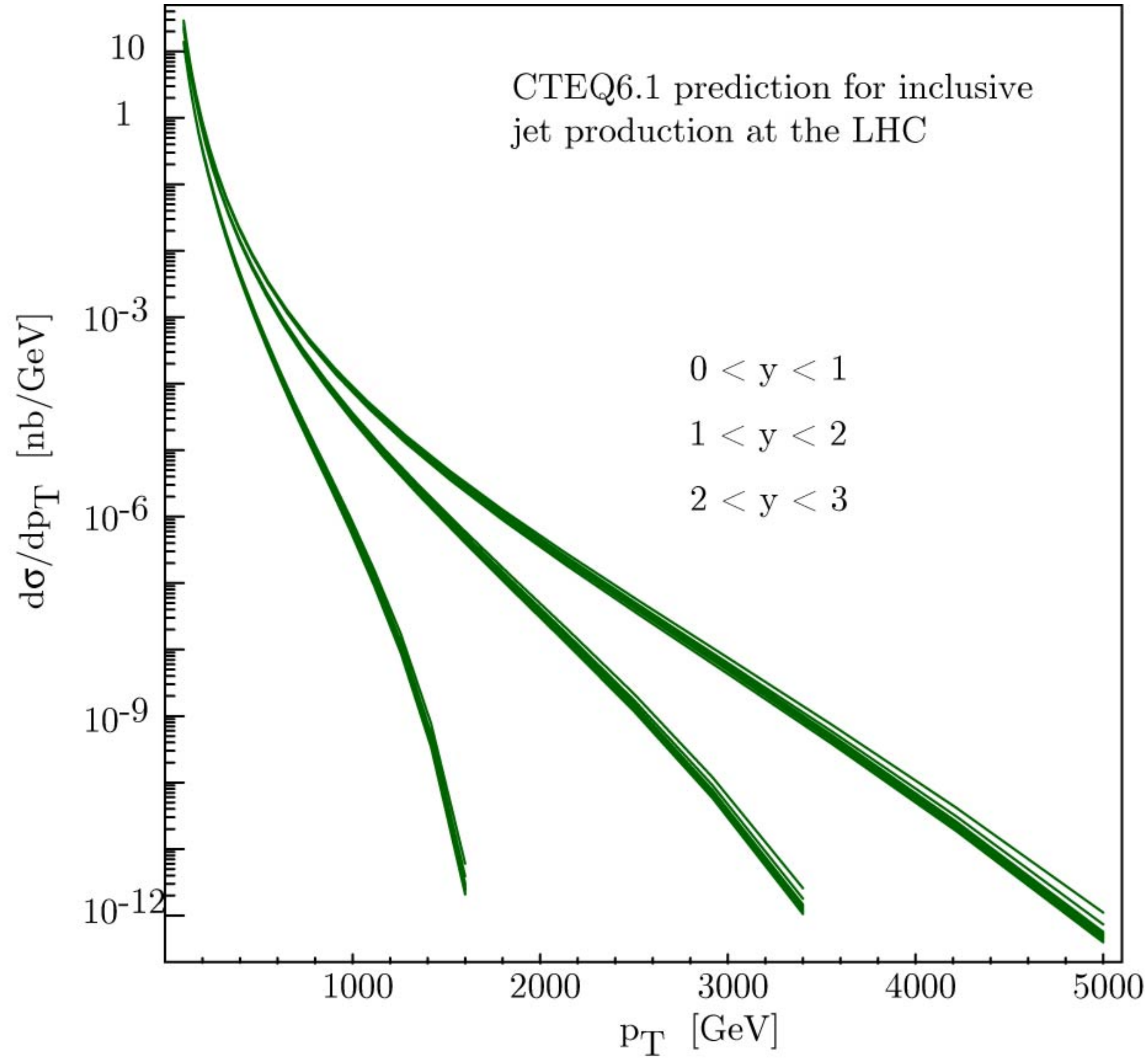
(This representation is potentially misleading because low-x and high-x are correlated!)



Comparison of MRST and CTEQ6.1
… gluon



Predictions with uncertainties



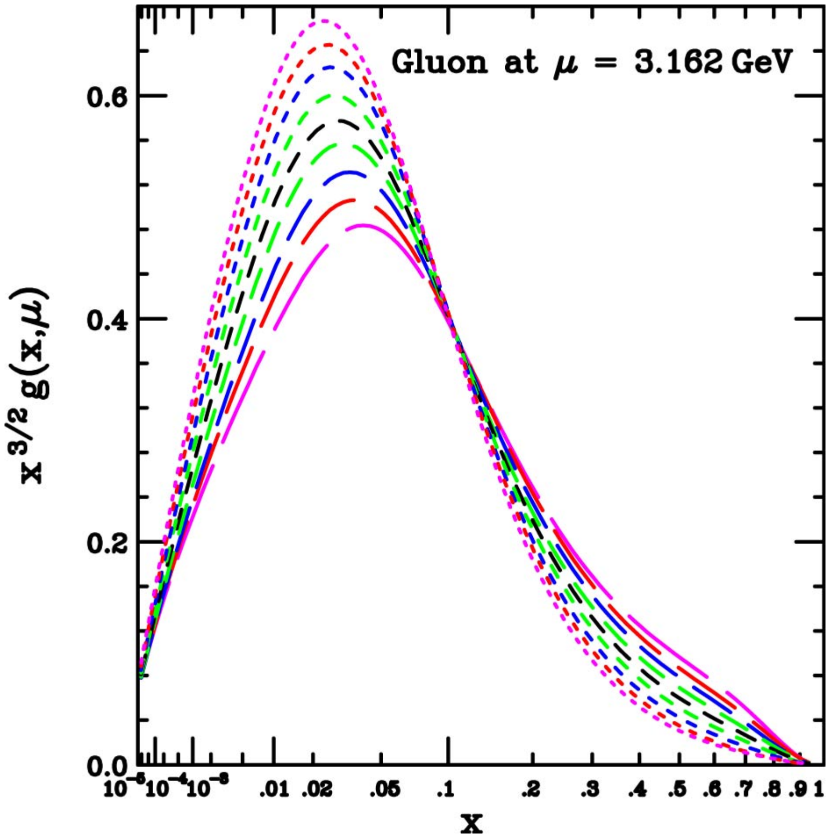
The α_S series (based on CTEQ6.1)

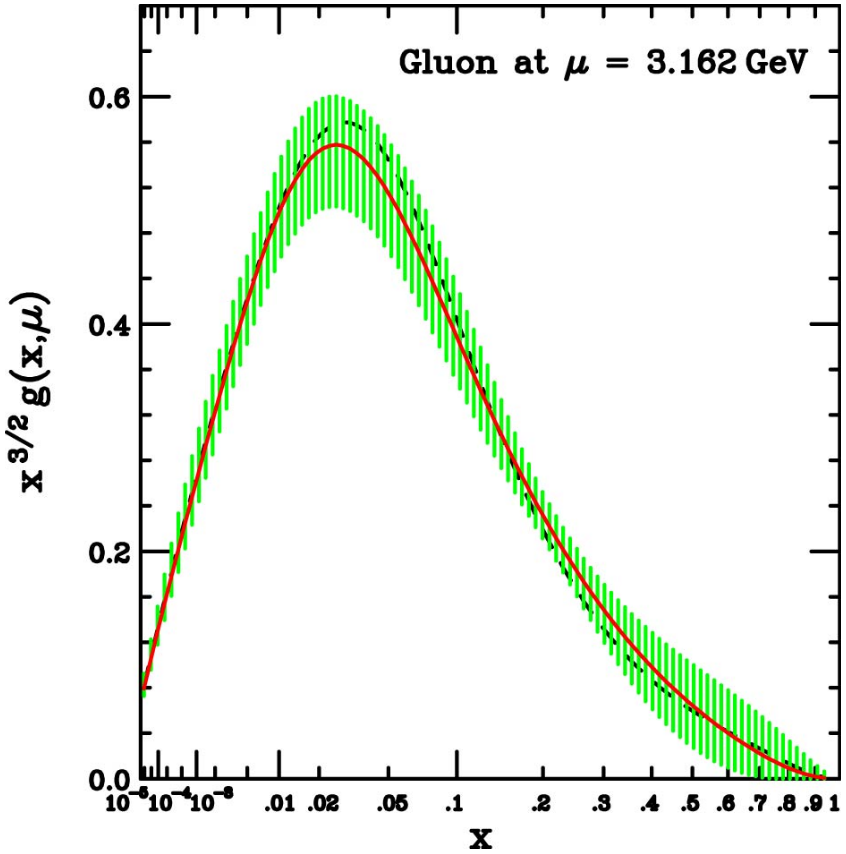
To construct CTEQ6, we specified $\alpha_S(M_Z) = 0.118$.

But what if we take $\alpha_S(M_Z)$ to be a fitting parameter?

Following requests from some experimental groups, we have generated a series of PDFs with $\alpha_S(M_Z)$ from 0.110 to 0.128.

Alpha series for the gluon PDF; $0.110 < \alpha_S < 0.126$

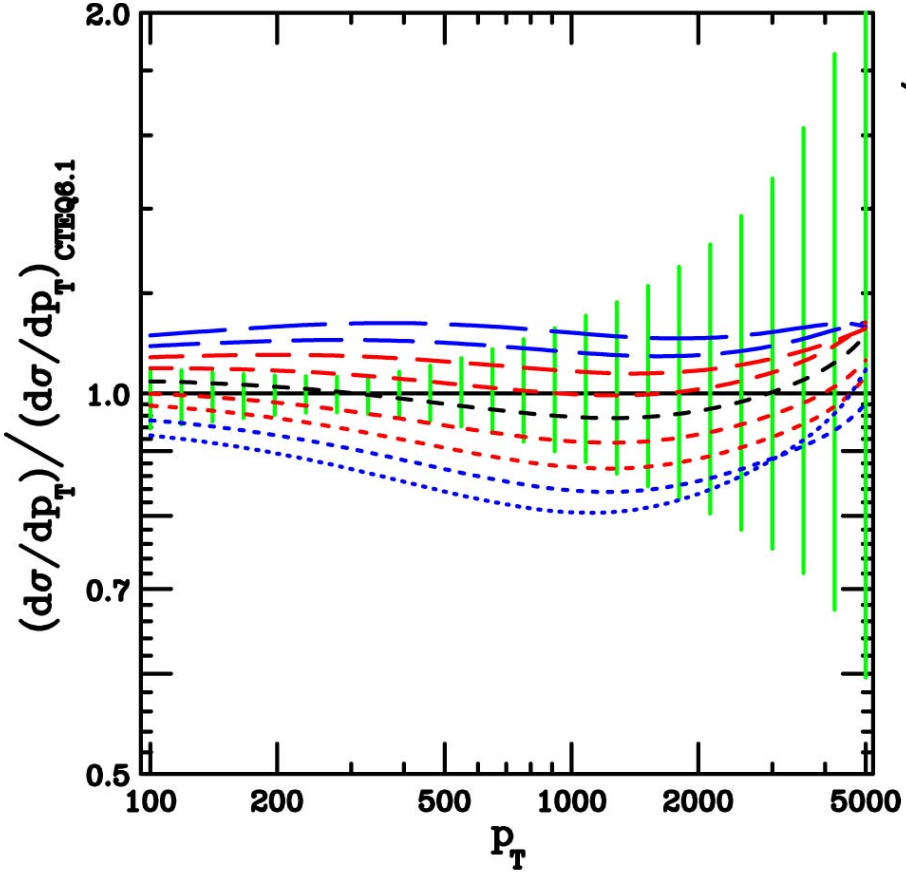


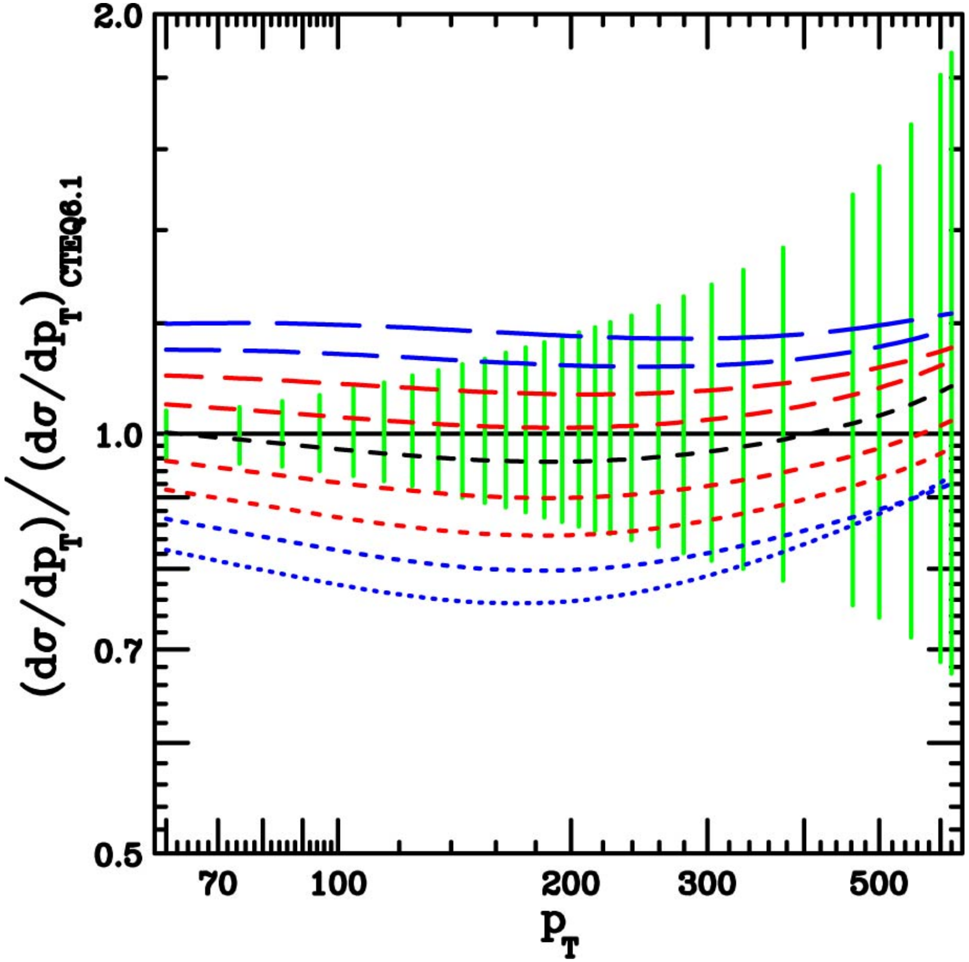


Uncertainty band for the gluon PDF in CTEQ6.1

Inclusive jet production

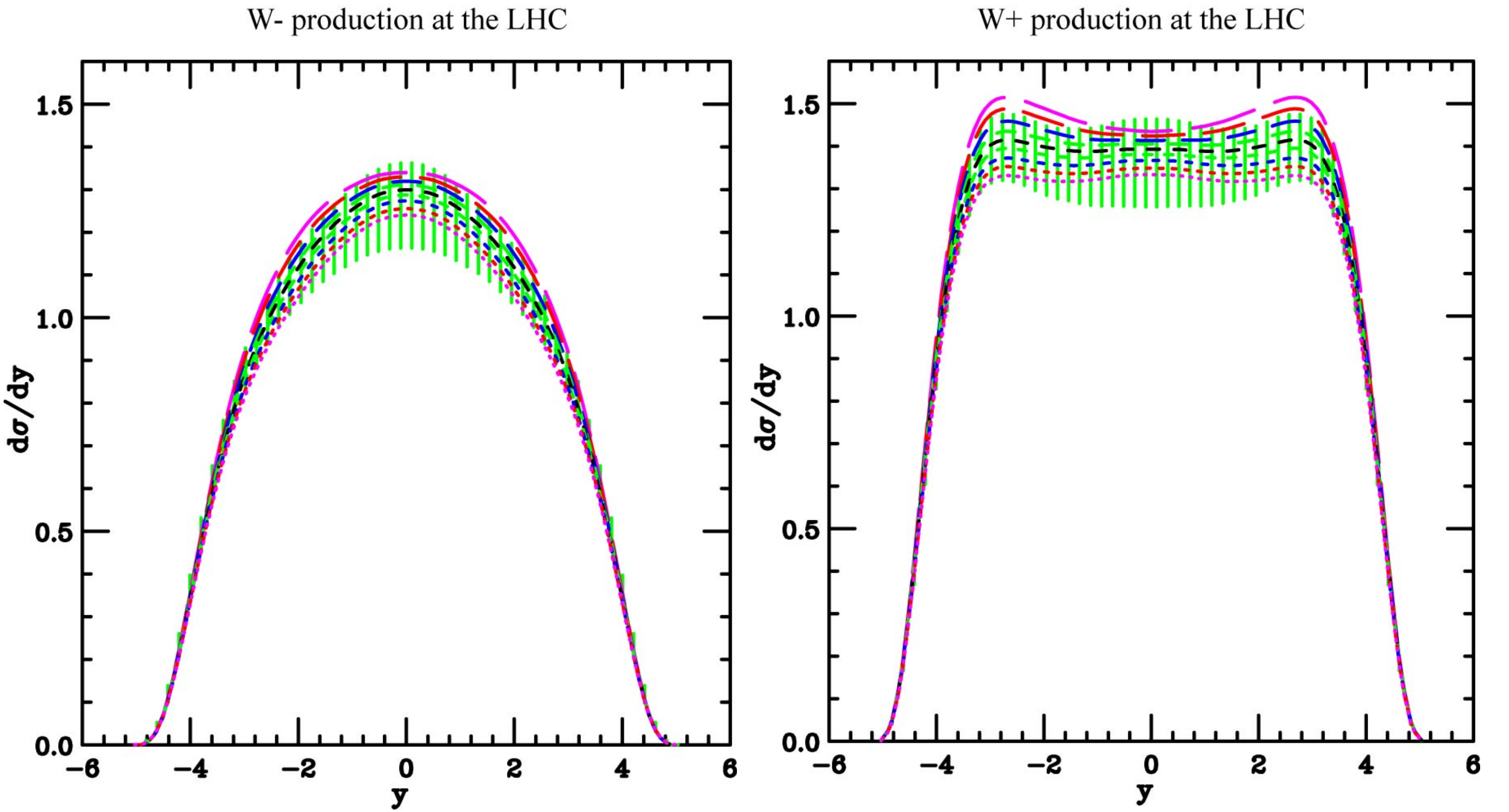
LHC





Tevatron Run 2

Example. $W^{\pm}$ production at the LHC

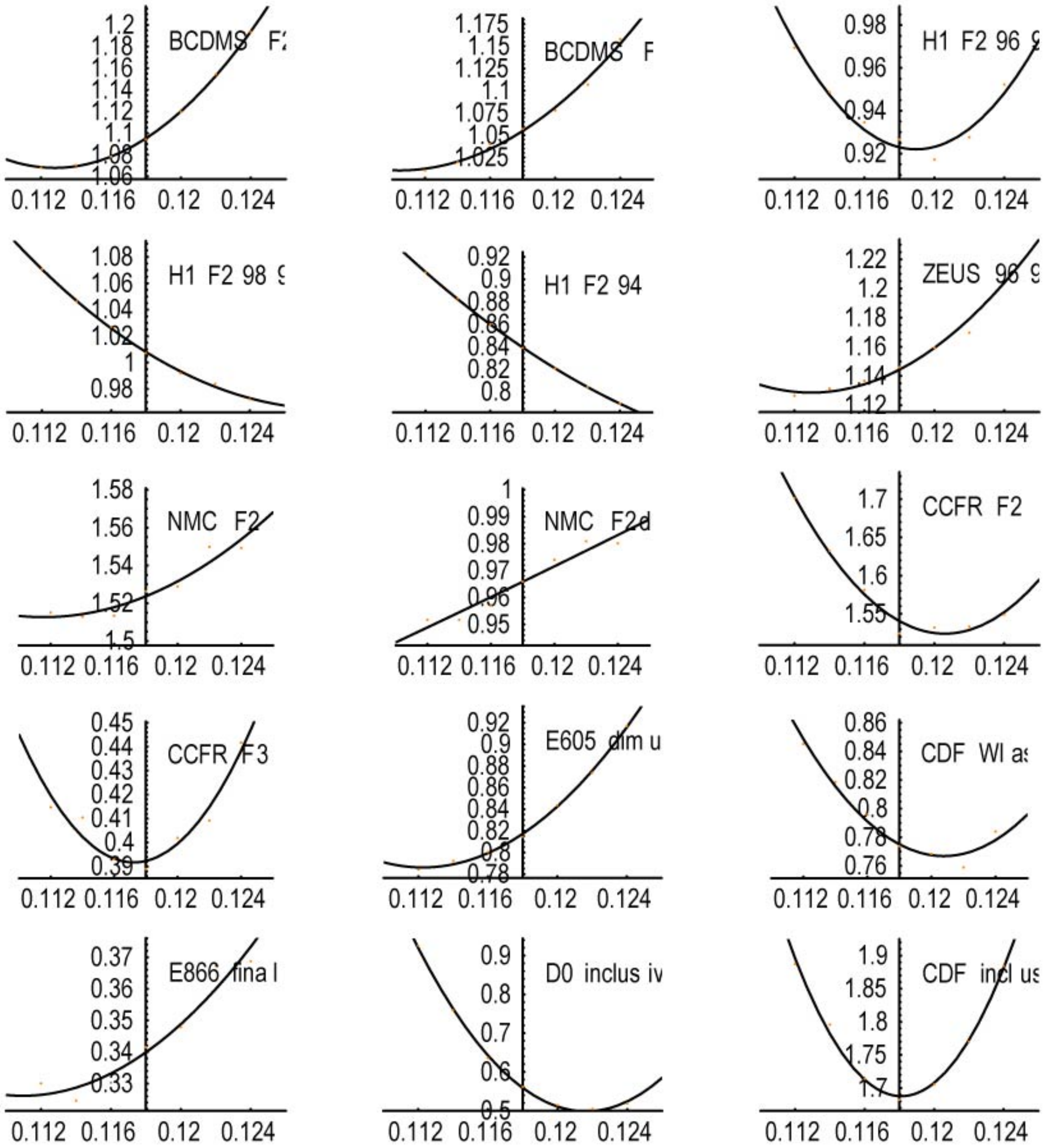


Green shaded area = PDF uncertainty; Curves = α_S series from 0.110 to 0.128

χ^2 parabolas –

χ^2 versus $\alpha_S(m_Z)$

… illustrates the "tension" between experiments:
 the best value for one experiment is not the best value for another.



The Road to CTEQ7

- New data
- New theoretical results
- Continuing importance of the uncertainty analysis

New data for CTEQ7

- "Routine" updates; e.g., ZEUS data that has been published since CTEQ6.

- The NuTeV data on ν and $\bar{\nu}$ deep inelastic scattering.

- Inclusive jet production from Run 2 at the Tevatron.

- Inclusive jet production at HERA. *{cf. the ZEUS-JETS fit*}*

- Other data; e.g., the p_T-dependent cross section for W and Z production at the Tevatron ***(?)***

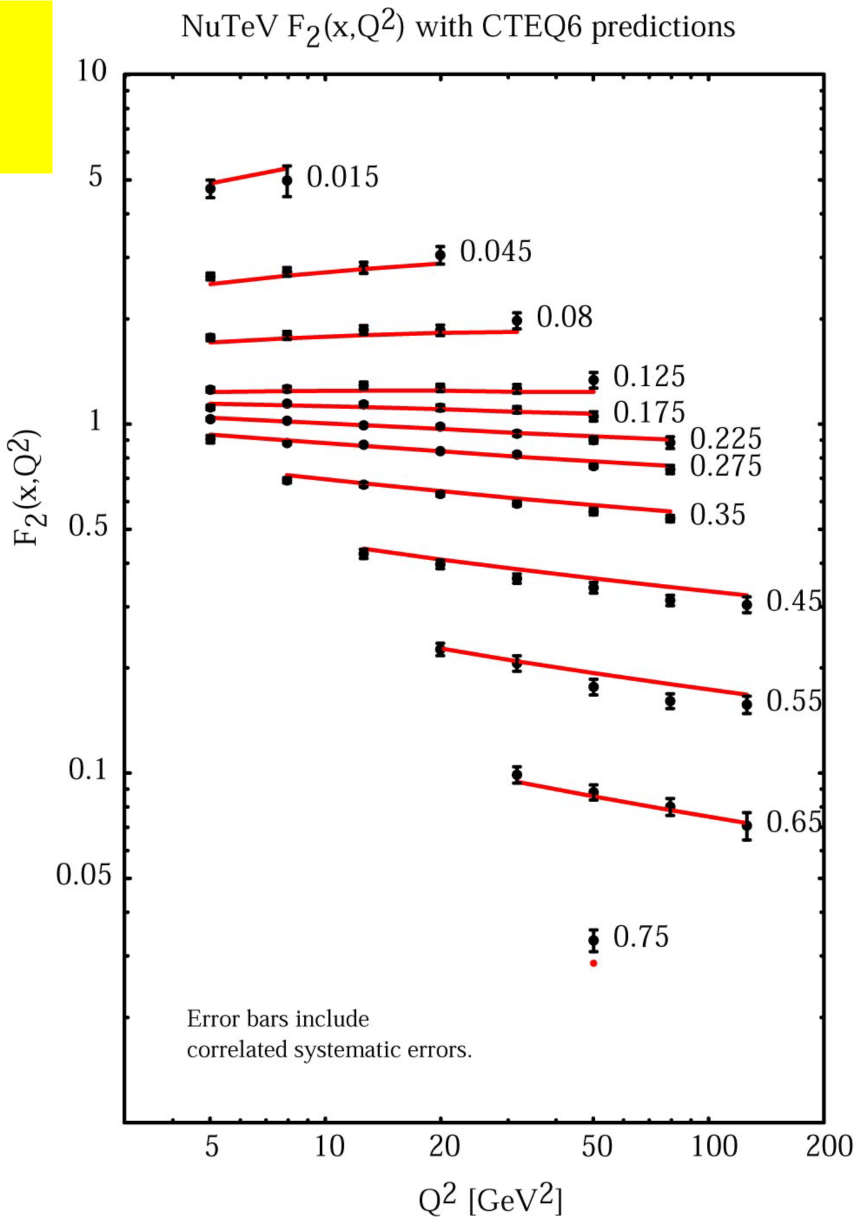
*Gwenlan, Cooper-Sarkar, Targett-Adams, hep-ph/0509220

NuTeV measurement of ν and $\bar{\nu}$ deep inelastic scattering.

In the figure, the error bars include 6 highly correlated systematic errors. On this log scale, the agreement looks deceptively good.

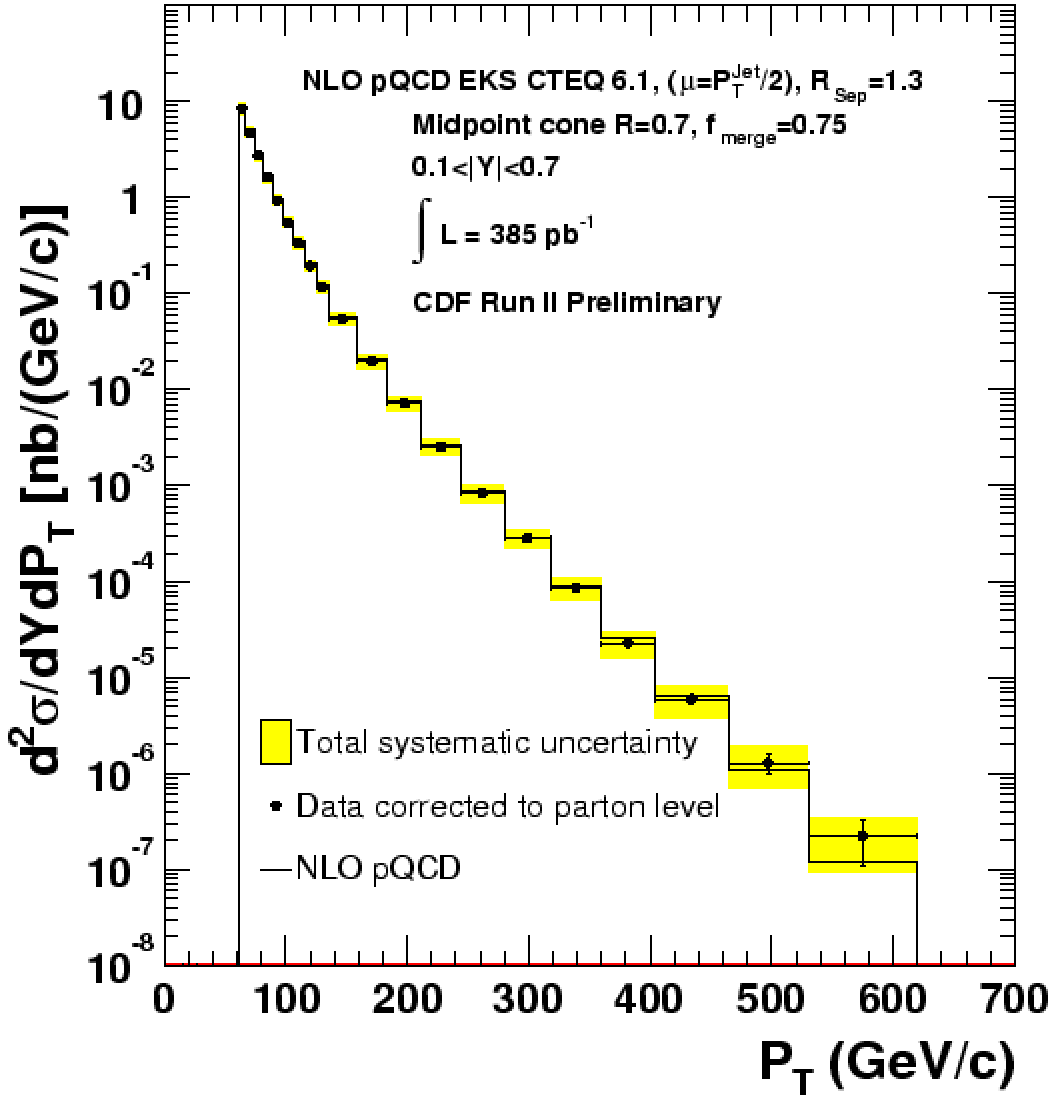
Open questions:

- ***Nuclear corrections (EMC effect)***
- ***Fitting the systematic errors***
- ***Refitting the PDFs (⇒ CTEQ7)***



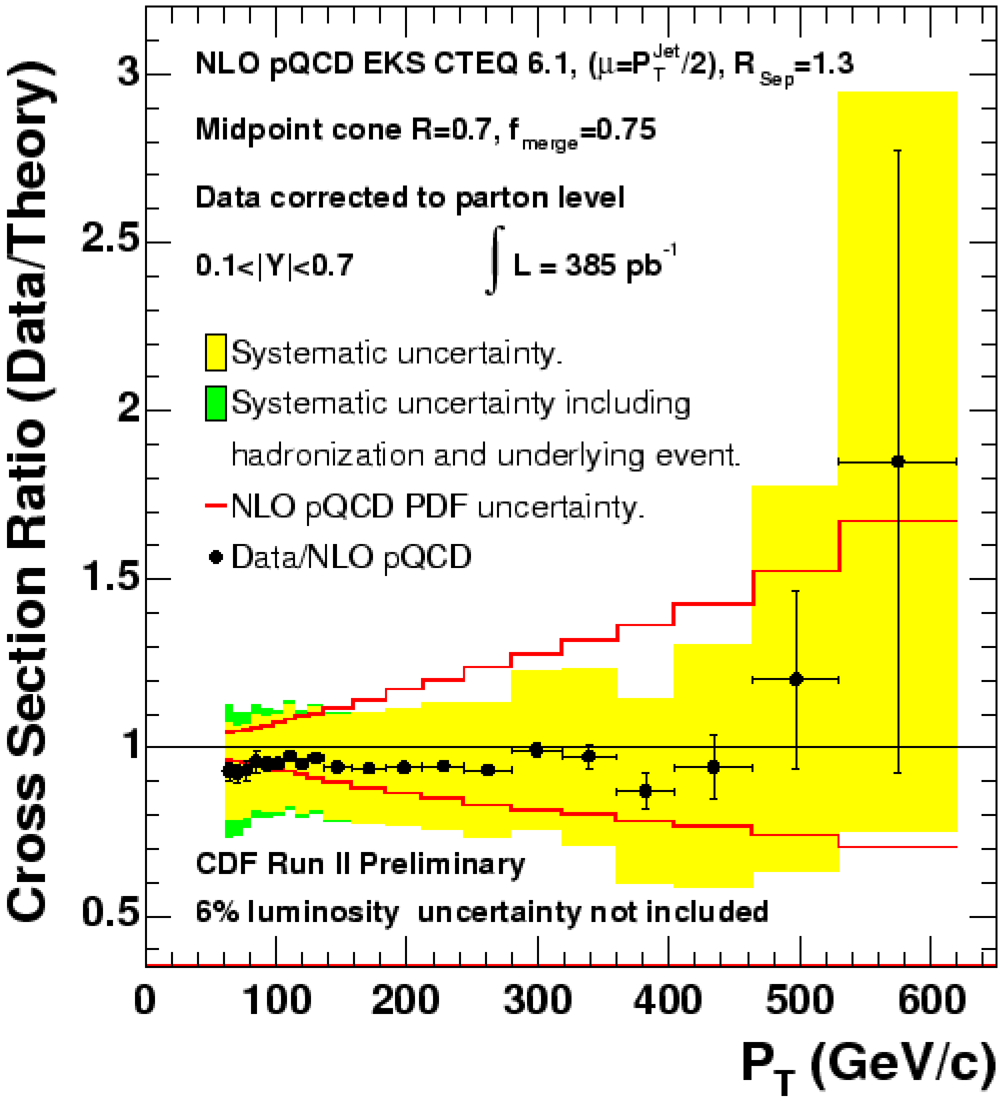
Inclusive jet production from Run II

CDF Run II Preliminary



Inclusive jet production from Run II

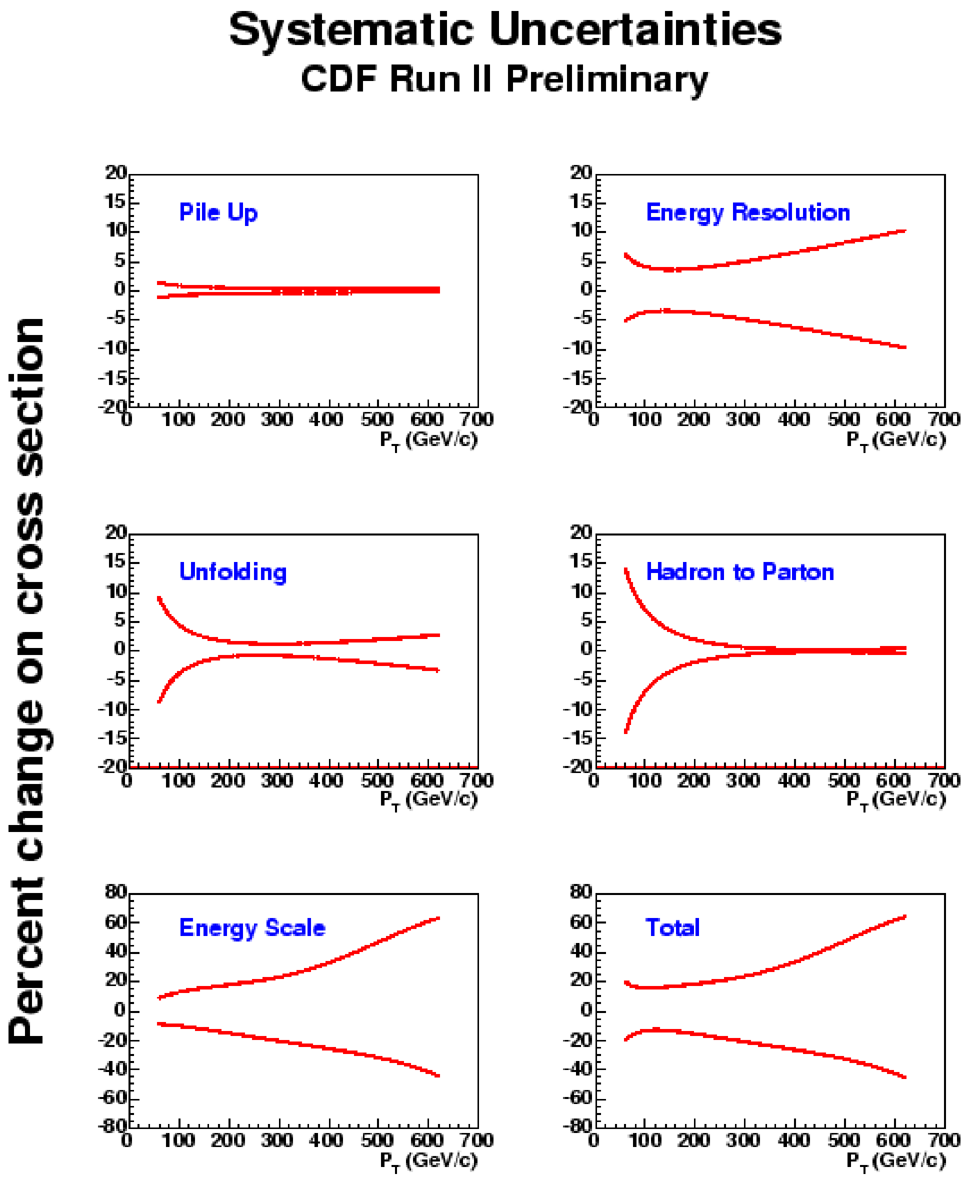
Comparison with PDF uncertainty



Inclusive jet production from Run II

As the statistical error gets smaller, the systematic errors become even more important.

The Run 2 data will be used in CTEQ7, but the gluon uncertainty may still be large.



New theoretical results for CTEQ7

Heavy quark mass effects

… already developed for CTEQ6, although not used in the standard fits; S. Kretzer et al, Phys.Rev. D69 (2004) 114005.

NNLO evolution of PDF's

… already implemented in MRST studies; under development for CTEQ.

We expect the differences between NLO and NNLO evolution to be small. How will the difference compare to PDF uncertainties from experimental errors?

(Conversely – no LO fit will be supplied!)

Conclusions

CTEQ7 may be quite similar to CTEQ6 – the new data is already fairly consistent with CTEQ6. I.e., the new data may verify what was learned in CTEQ6.

For the LHC, the uncertainty analysis is crucial. Is an observed disagreement between data and theory within the uncertainties, or a sign of new physics?