Parton Uncertainties and the Stability of NLO Global Analysis

Daniel Stump
Department of Physics and Astronomy
Michigan State University

J. Huston, J. Pumplin, D. Stump and W.K. Tung,
Stability of NLO Global Analysis and Implications for Hadron Collider Physics,
hep-ph/0502080.

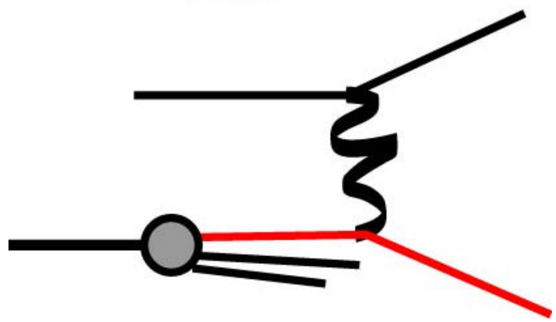
Outline:

1. Global Analysis and Uncertainties
2. The CTEQ stability study
3. The Lagrange Multiplier method and the gluon distribution function

1/ Global Analysis of QCD …

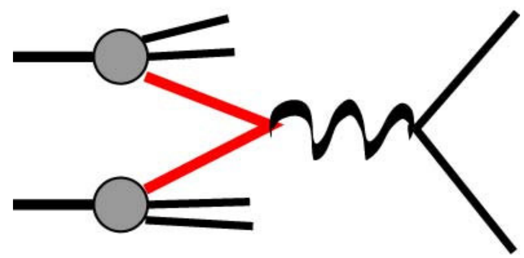
…uses data from many experiments to construct universal parton distribution functions (PDF's).

DIS



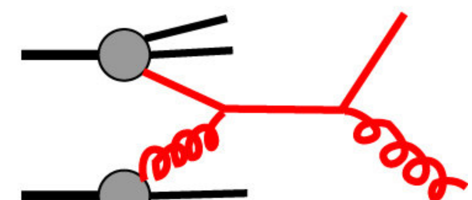
HERA ep, $\bar{e}p$
(H1 and ZEUS)
BCDMS μp, μd
CCFR ν Fe

Drell-Yan



E605 pp, pd
E866 pp, pd

Jet production



Tevatron $p\bar{p}$
(CDF and D0)

$$d\sigma\big|_{ep} = \sum_q f_q \otimes d\sigma\big|_{eq}$$

$$d\sigma\big|_{p\bar{p}} = \sum_{ij} f_i \otimes d\sigma\big|_{ij} \otimes f_j$$

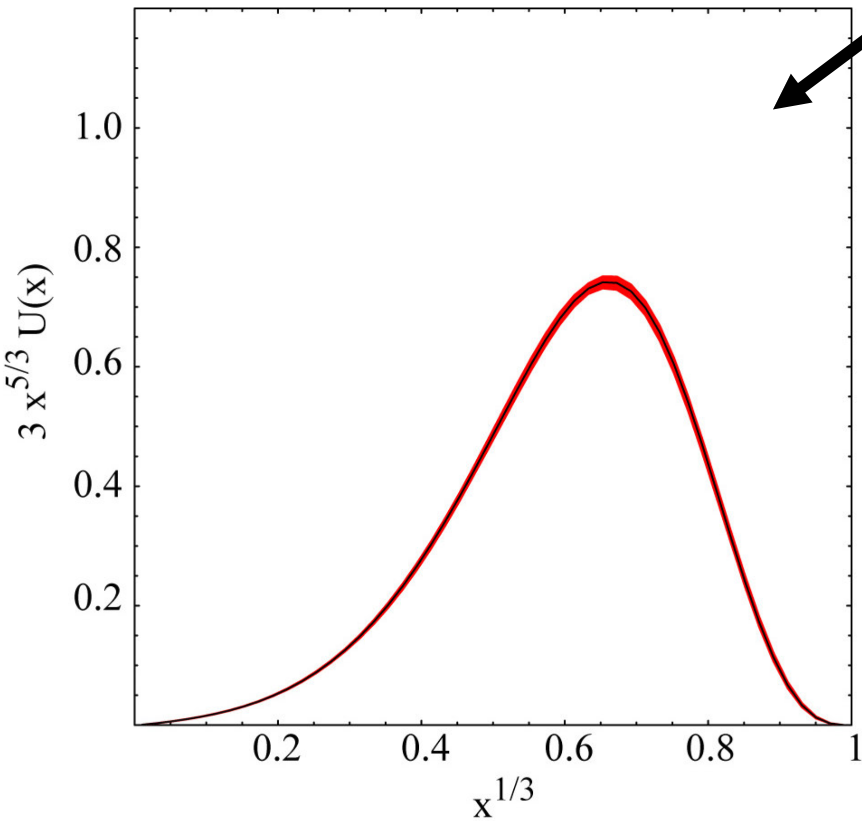
… based on features of QCD

- Factorization theorem
- Infrared safety of inclusive cross sections
- Asymptotic freedom (e.g., to justify the use of NLO perturbation theory)

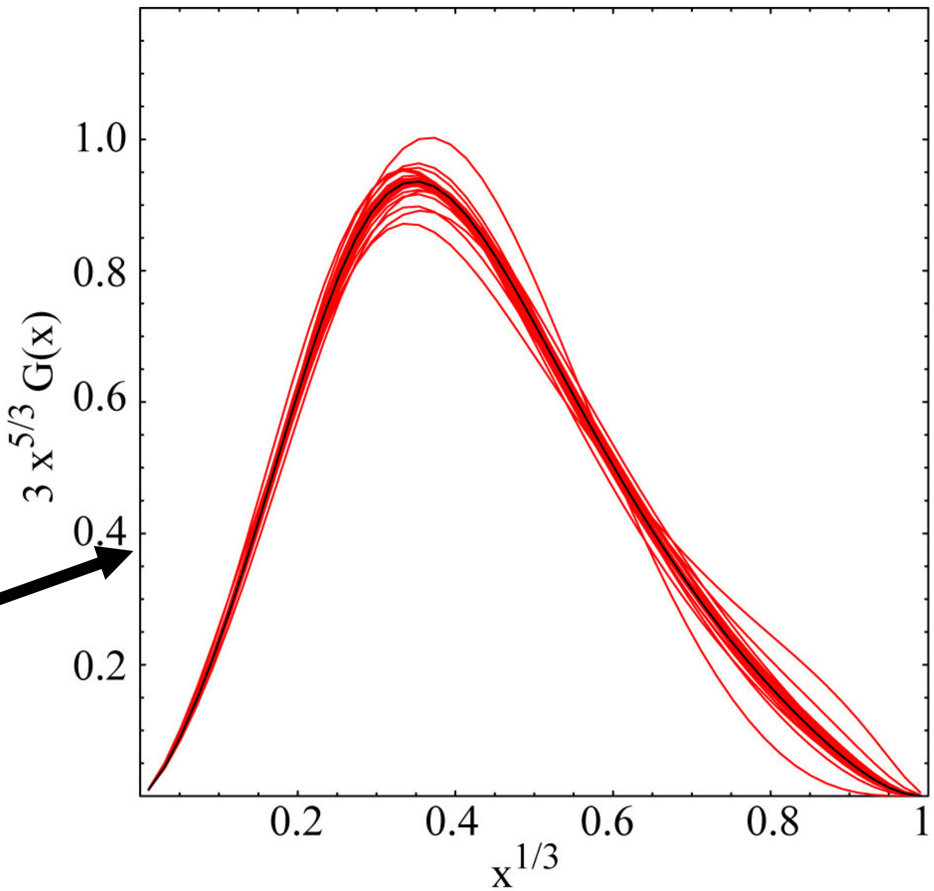
Uncertainties

of Parton Distribution Functions

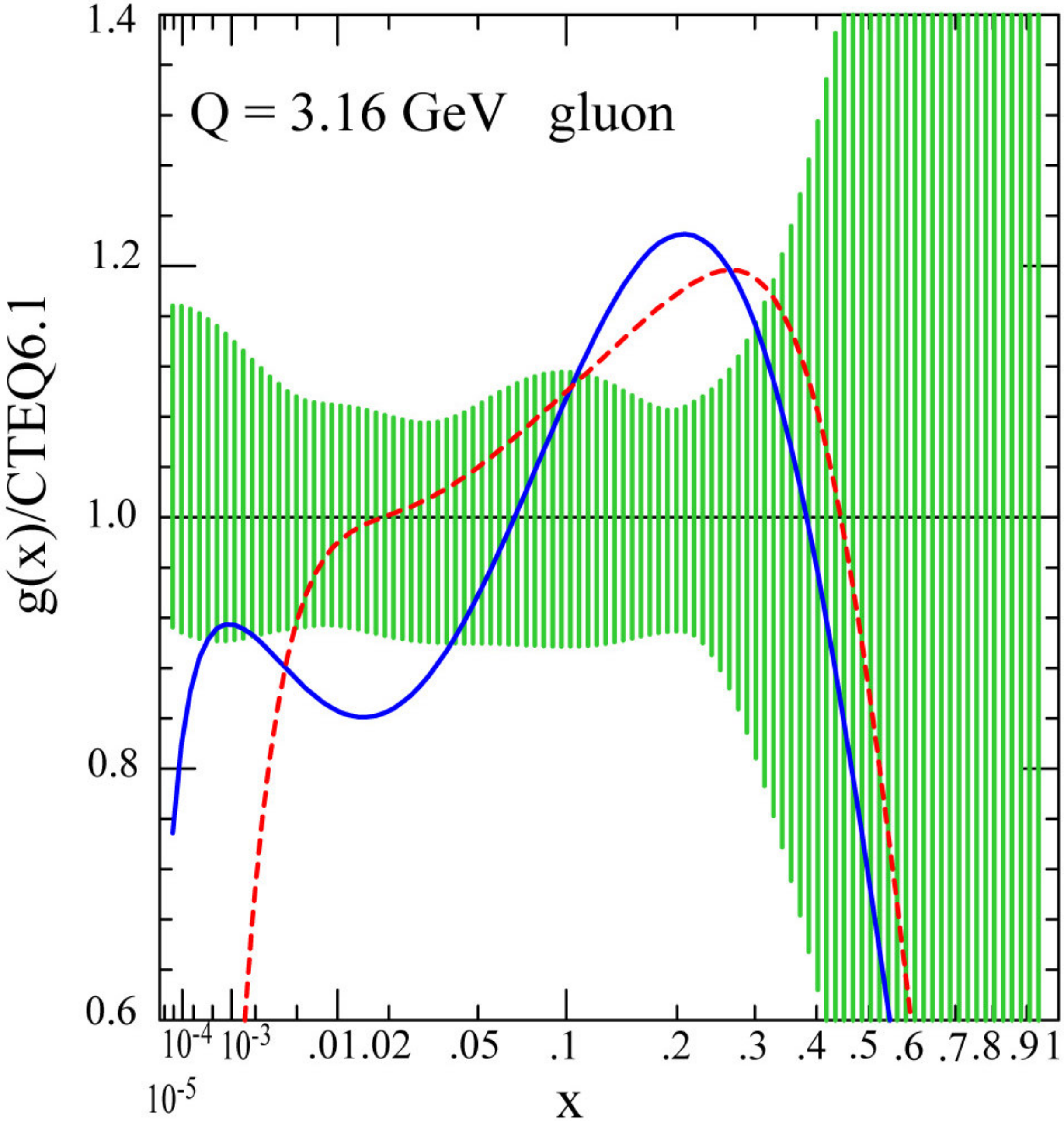
U-quark



$Q^2 = 10\ GeV^2$



Gluon



Blue: MRST2002

Red: MRST2003c

- The question of compatibility

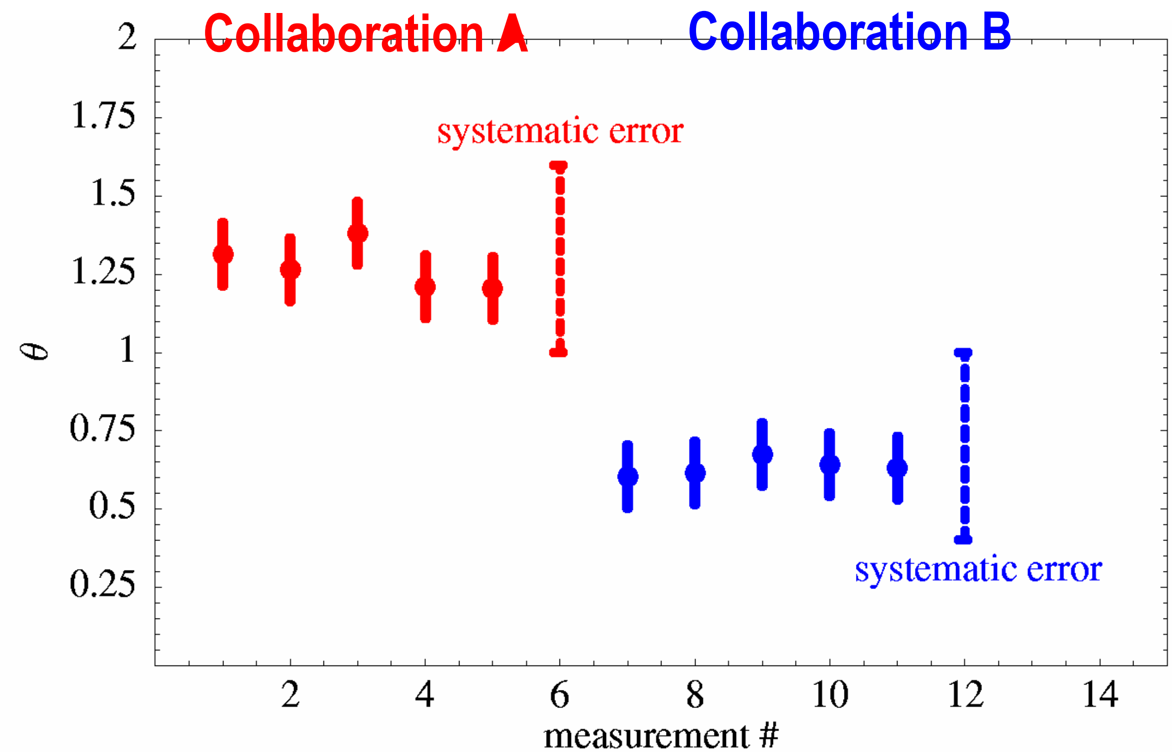
  Are data sets from different experiments compatible?

- The question of stability

  Are the final results of the global analysis stable and robust?

Compatibility

Two experimental collaborations measure the same quantity θ :



The two data sets are consistent within the systematic errors, but there is a systematic difference.

The combined value is a *compromise*, with uncertainty from the systematic errors.

- PDF’s from global analysis are a ***compromise***, with uncertainties from systematic errors.

- ***Are data sets compatible?***

  The only way to compare different processes, e.g., DIS and $p\bar{p}$ jet production, is through the global analysis.

- Because of systematic errors, we do find minor incompatibilities: The best fit to one data set is not the best fit to another data set. Nevertheless, all data sets can be fit simultaneously *within the systematic errors*.

2/ The question of stability

Minor changes of inputs (data and theory choices) should not produce large changes of the PDF’s.

But the stability of NLO global analysis has been challenged by an interesting result of the MRST group.

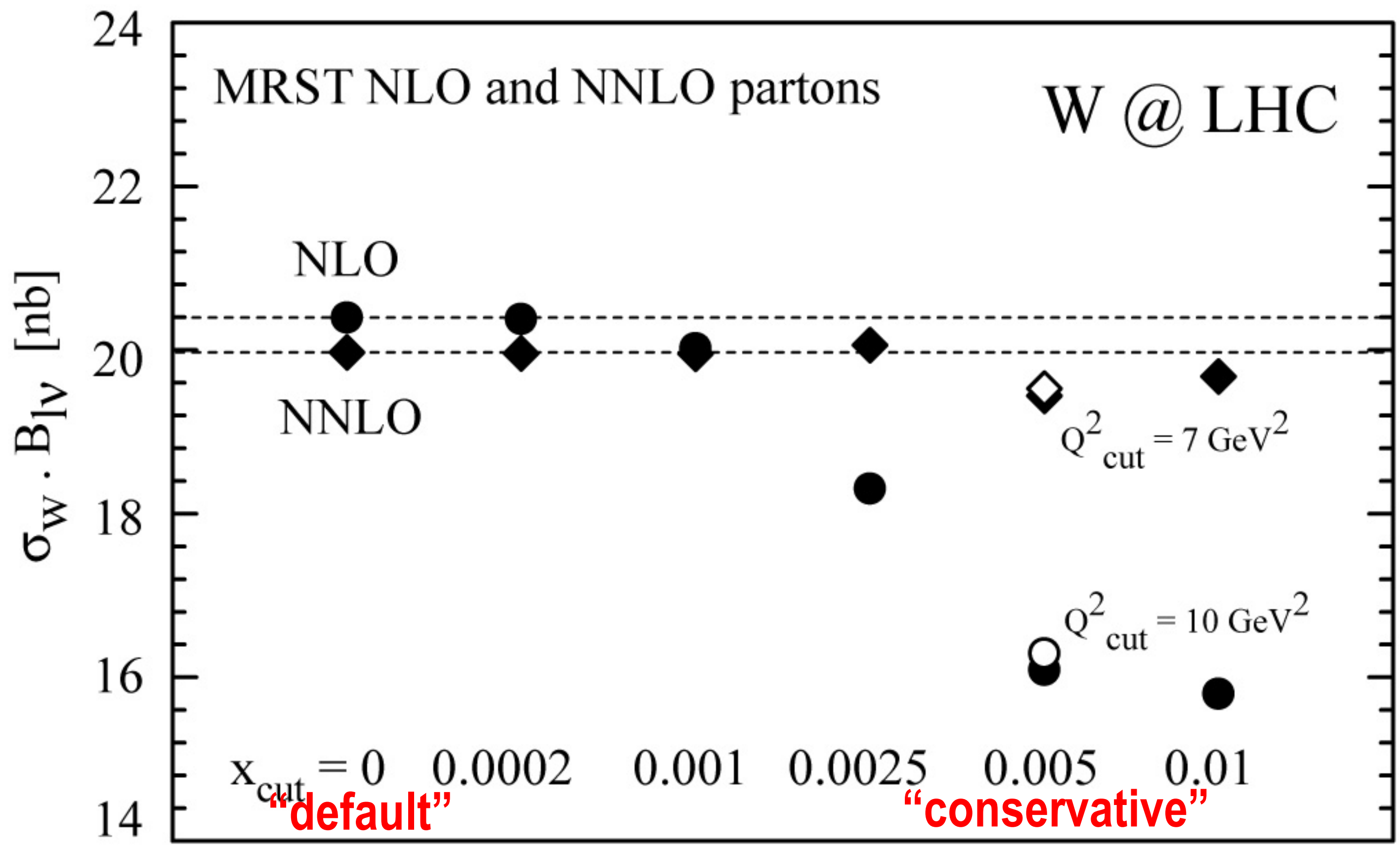
Reference:
Martin, Roberts, Stirling and Thorne, Eur Phys J C35, 325 (2004).

Remove low-Q and low-x data; i.e., require

$$Q > Q_{cut} \text{ and } x > x_{cut}.$$

Are the resulting PDF’s stable with respect to changes of Q_{cut} and x_{cut}?

A surprising "instability" of σ_W*(LHC)* in the NLO approx'n.



Reference: Martin, Roberts, Stirling, Thorne, Eur. Phys. J. C35, 325 (2004)

Is the instability a breakdown of NLO QCD, or a consequence of PDF uncertainties, or an artifact of the parameterization?

CTEQ stability study

First step – apply the MRST procedure to the CTEQ parameterization of PDF's

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

TABLE 1: The best fits for three choices of exclusionary cuts (standard, intermediate and strong) with a **positive-definite parameterization** of the gluon PDF.

CTEQ stability study

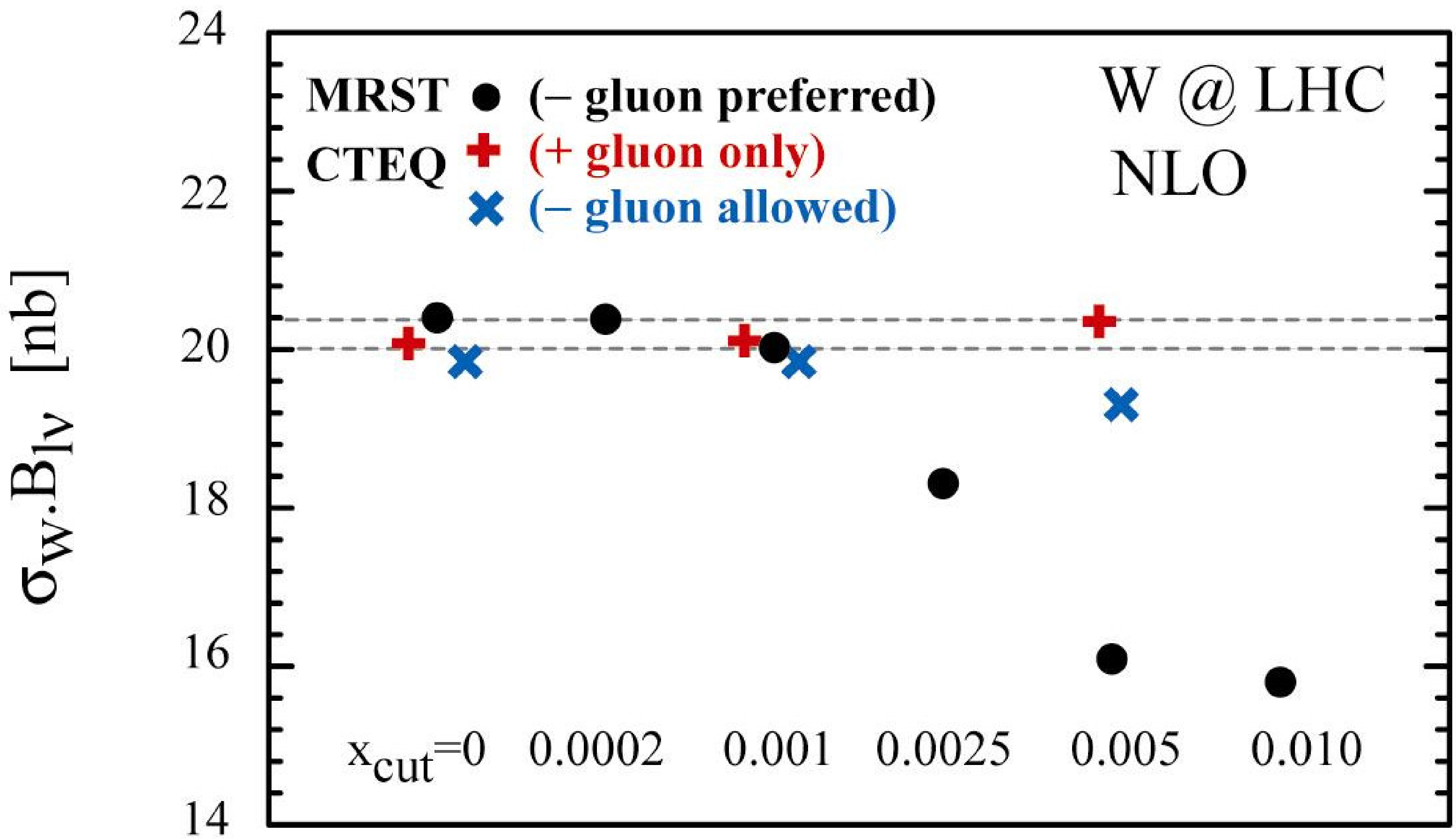
allowing g(x) < 0 (for small x and Q) …

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	2011	1845	1579	19.94
intermed	2.5 "	0.001	1770	--	1838	1574	19.80
strong	3.16 "	0.005	1588	--	--	1570	19.15

[illegible]

TABLE 2: The best fits for three choices of exclusionary cuts (standard, intermediate and strong) with an extended parameterization *that allows g(x) < 0.*

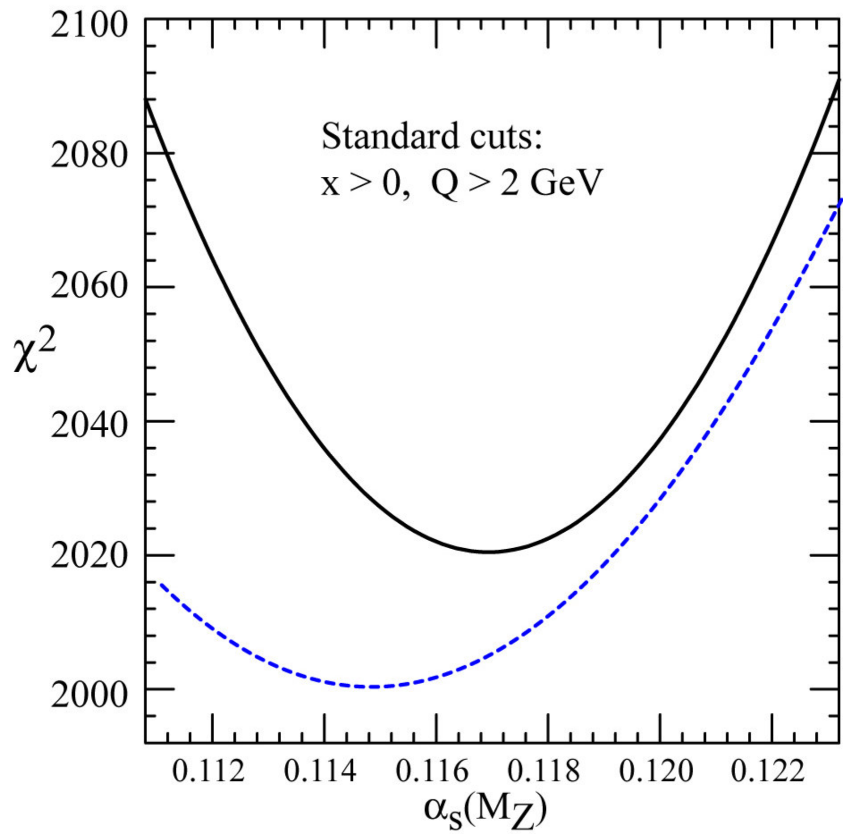
Results, graphically:

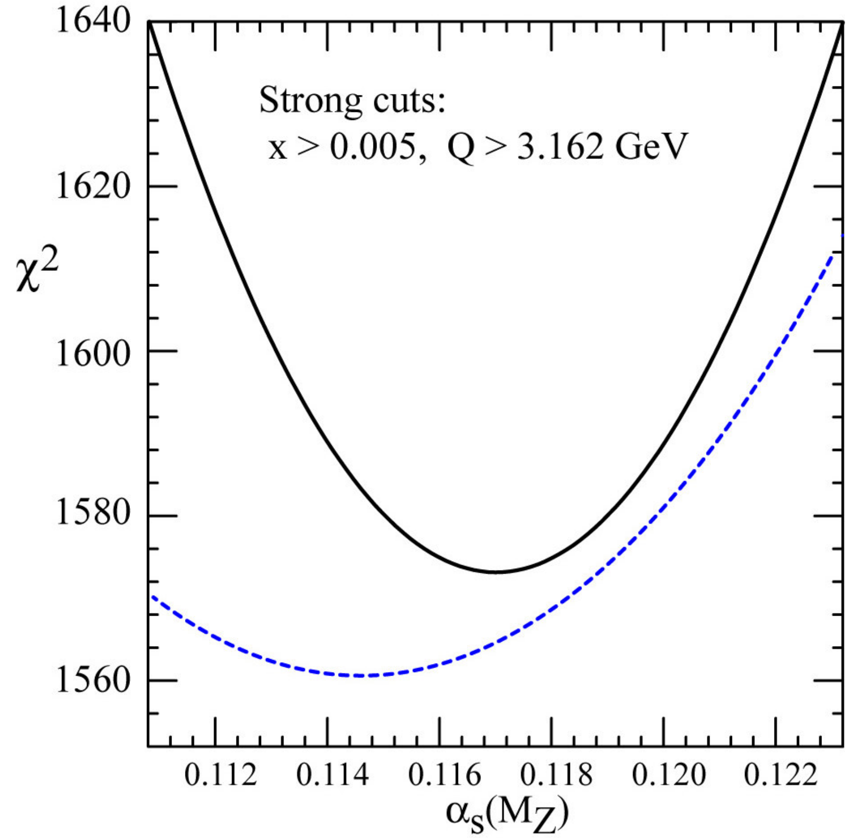


The predicted total cross section of $W^{+}+W^{-}$ production at the LHC, for NLO calculations.

Stability of the extracted value of α_S

The global fit χ^2 as a function of $\alpha_S(M_Z)$





Black: positive-definite ***g(x)***;
Blue: negative gluon is allowed.

Extracted values of $\alpha_S(M_Z)$

Cuts	positive gluon	g(x) < 0 allowed
Standard	0.1169 ± 0.0045	0.1148 ± 0.0050
Strong	0.1168 ± 0.0044	0.1159 ± 0.0051

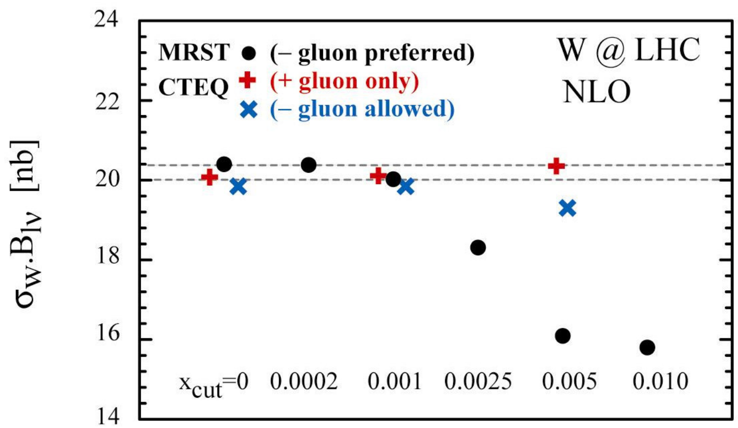
i.e., the extracted value of α_S is clearly stable with respect to x- and Q- cuts on data.

3/ The Lagrange Multiplier method

To gain more insight into the results…

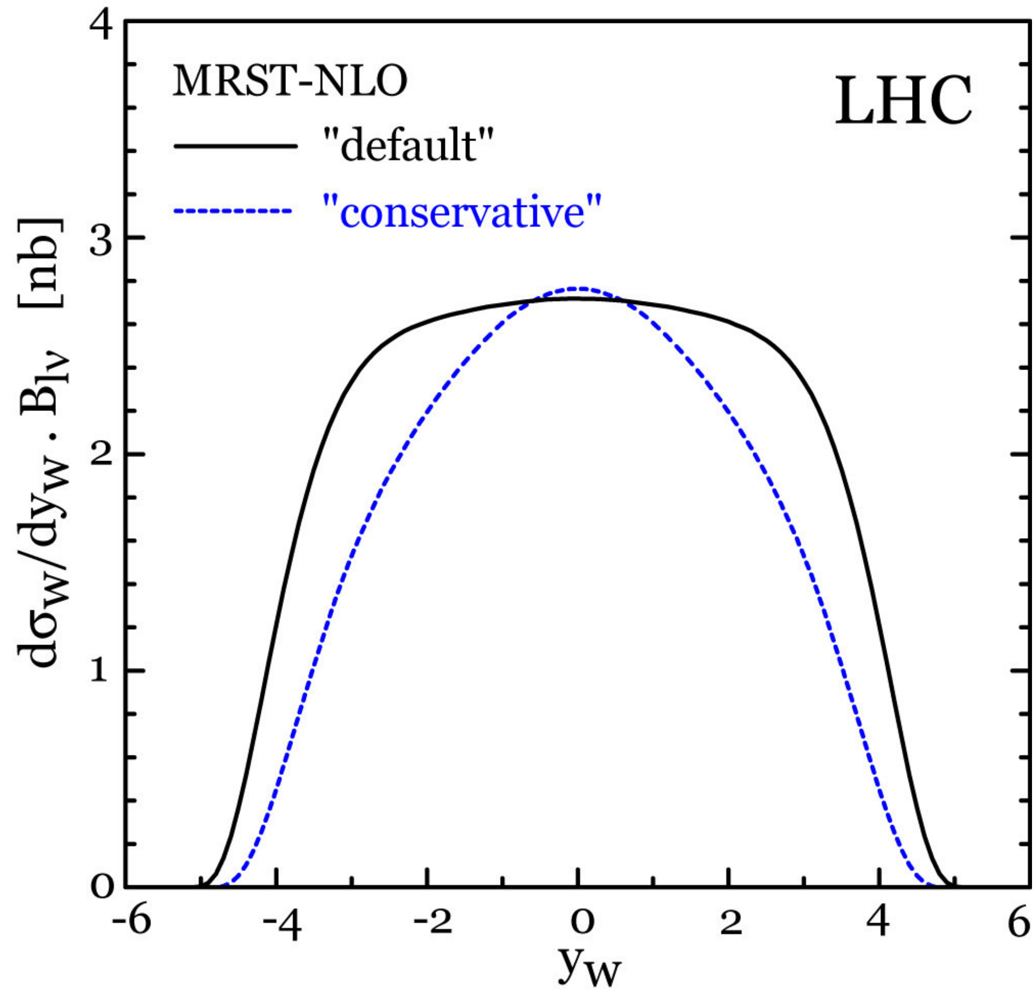
… probe the *uncertainty* of a prediction from the global analysis

using the Lagrange Multiplier method.



MRST paper:
Removing the constraints of data with x < 0.005 radically changes the NLO PDF's and hence the cross section for W production.

The differential cross section, $d\sigma/dy$. [MRST, Eur Phys J C35, 325 (2004)]



Lagrange Multiplier method

▶ calculate χ^2 versus σ_W.

Black curve:

standard cuts (x_{min}=0)

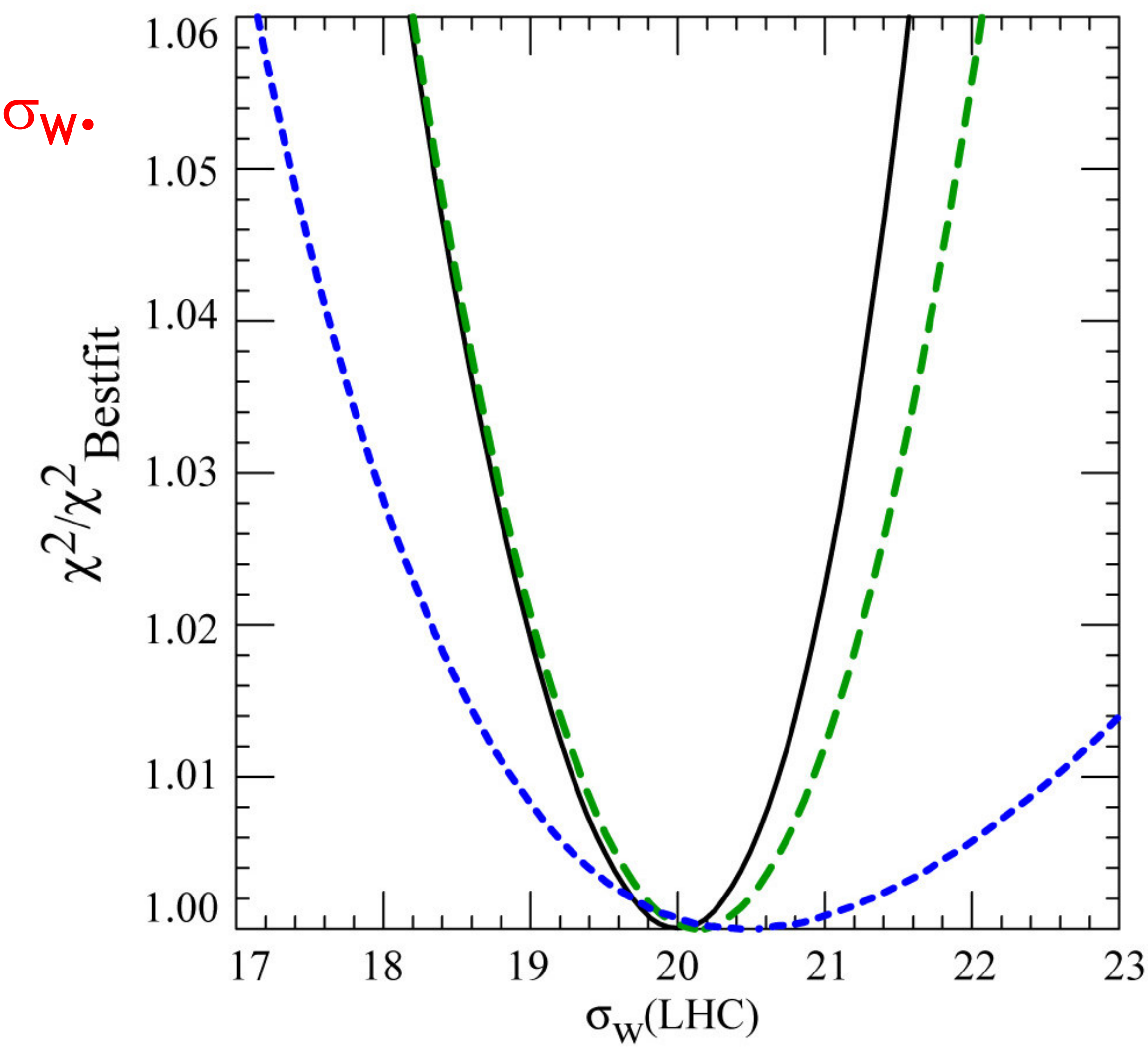
Blue curve:

strong cuts (x_{min}=0.005)

The effects of the strong cuts:

- ***the central prediction barely moves;***
- ***the uncertainty increases significantly.***

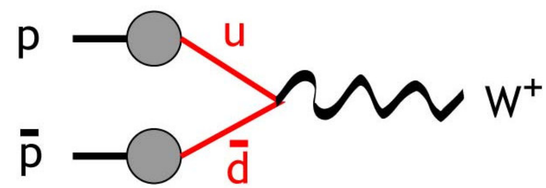
χ^2 versus σ_W



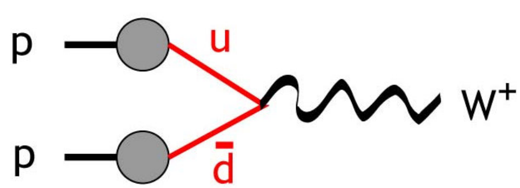
[positive gluon]

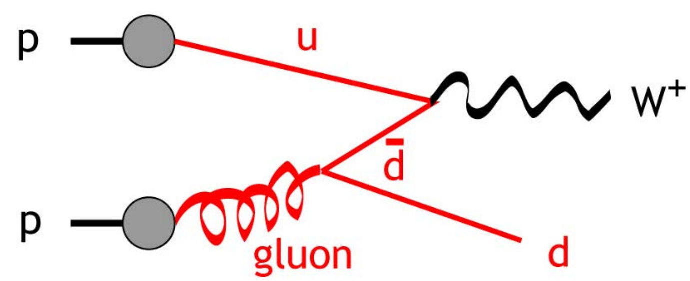
W production at the LHC is sensitive to the gluon distribution function.

Tevatron: W production can occur by a LO process with valence quarks.

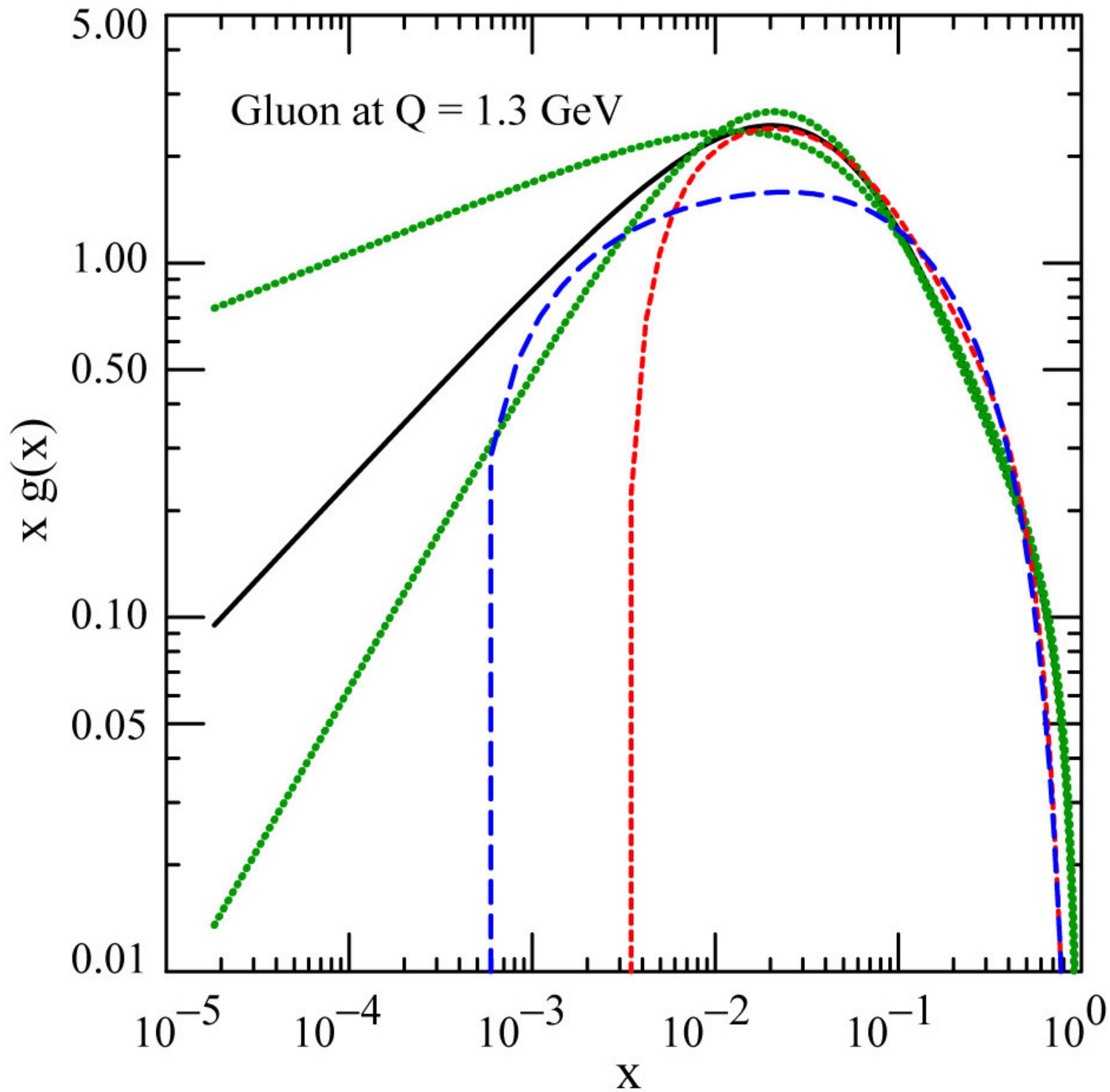


LHC: The LO contribution must involve a sea quark; and there is an NLO contribution from a gluon.





The Gluon distribution

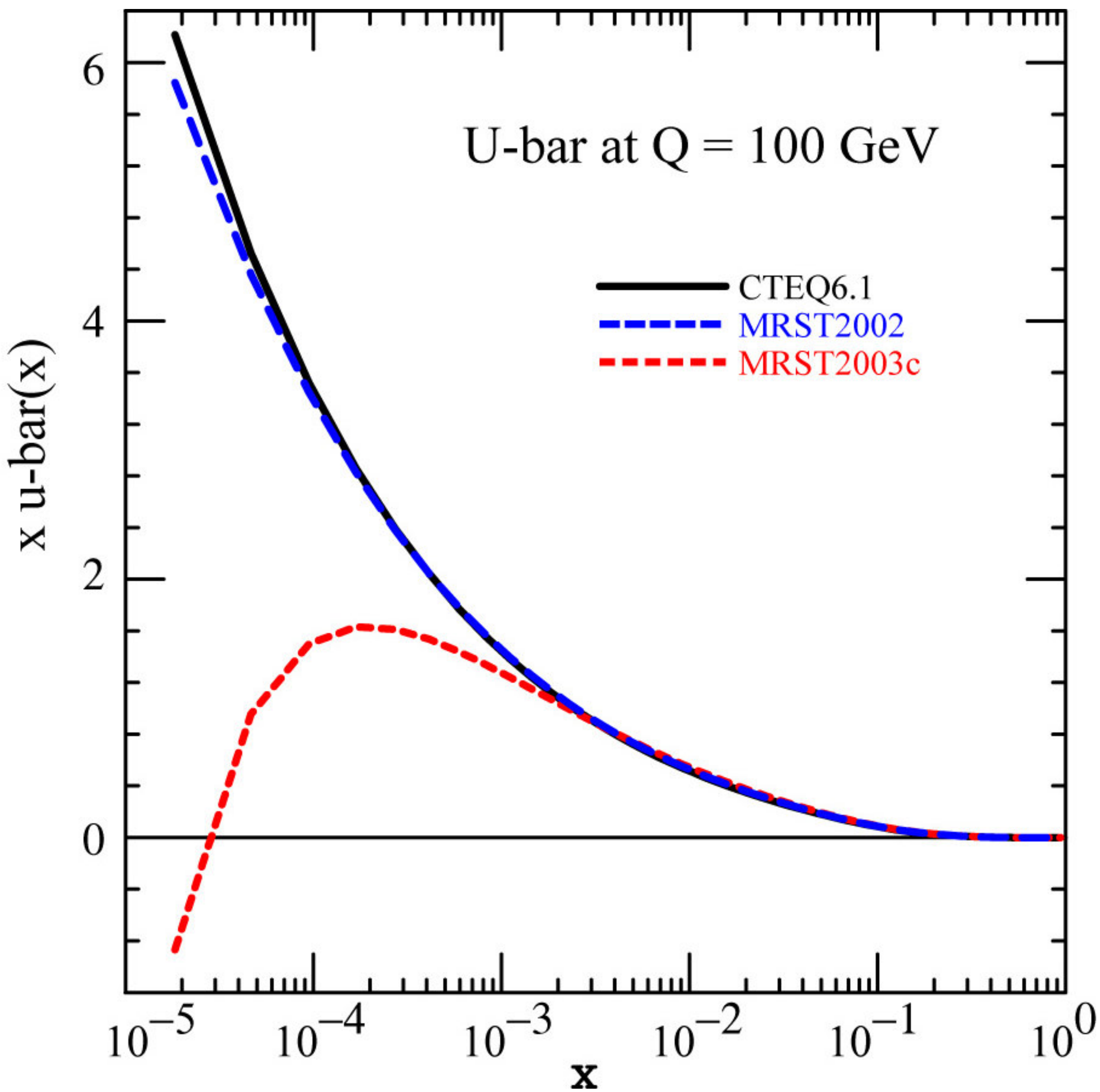


Black: CTEQ6.1

Green: Extremes of 40 EV sets

Blue: MRST2002 (default)

Red: MRST2003c (conservative)



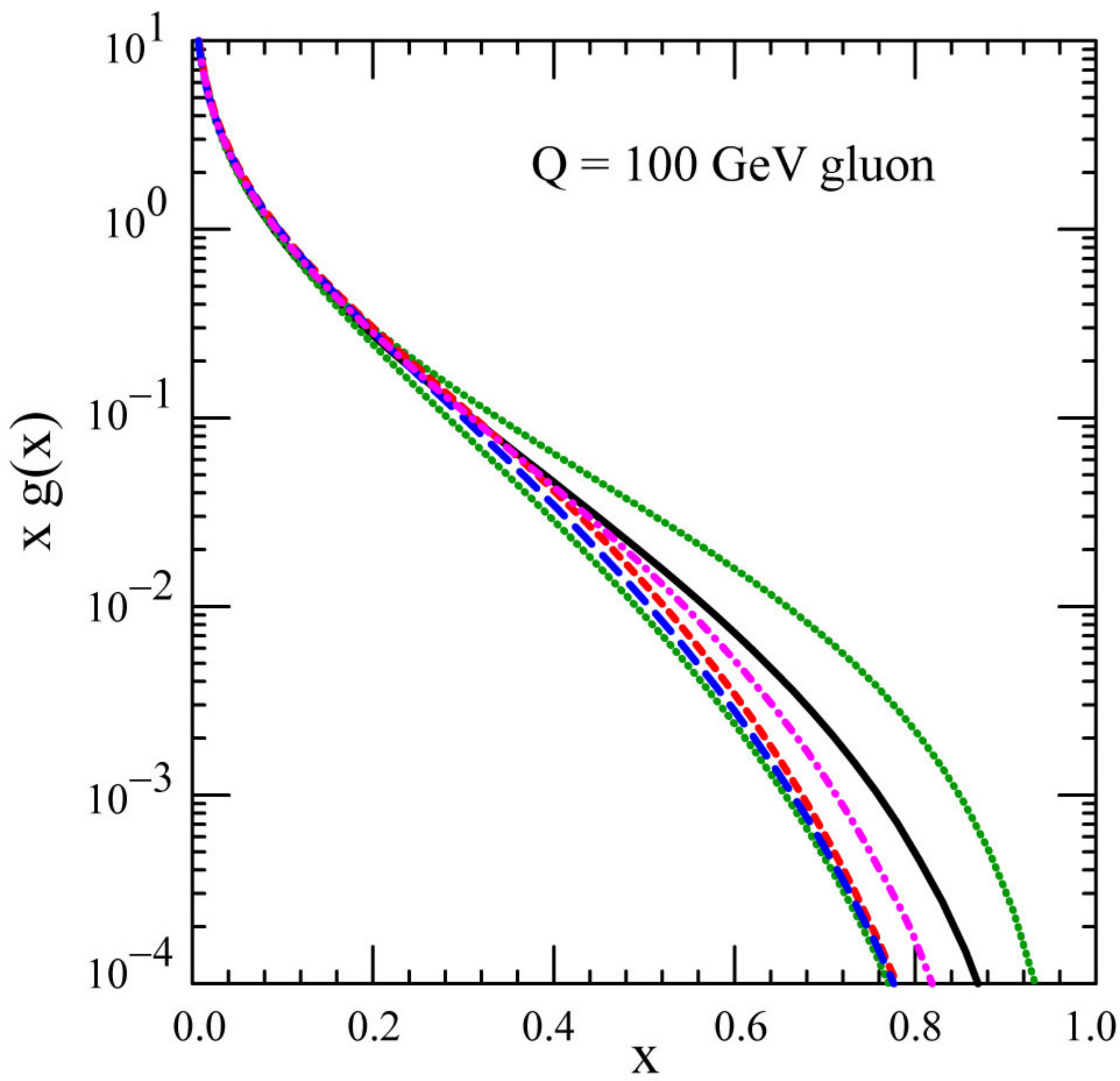
Sea quarks:
u-bar distribution

Black: CTEQ6.1

Blue: MRST2002 (default)

Red: MRST2003c (conservative)

The Gluon PDF at large x



Black: CTEQ6.1

Green: extremes of the 40 eigenvector basis sets

Blue: MRST2002

Red: MRST2003c (conservative)

Violet: MRST2004 (physical)

Conclusions

For the CTEQ parameterization …

- The NLO global analysis is stable with respect to cuts on x and Q. (A strong cut on x is not needed to fit DIS and Tevatron data simultaneously; and it would increase the uncertainty.)

- A positive-definite gluon parameterization is satisfactory.

- Additional data will be needed to constrain the gluon PDF for accurate LHC predictions.