Stability of NLO global pdf analyses

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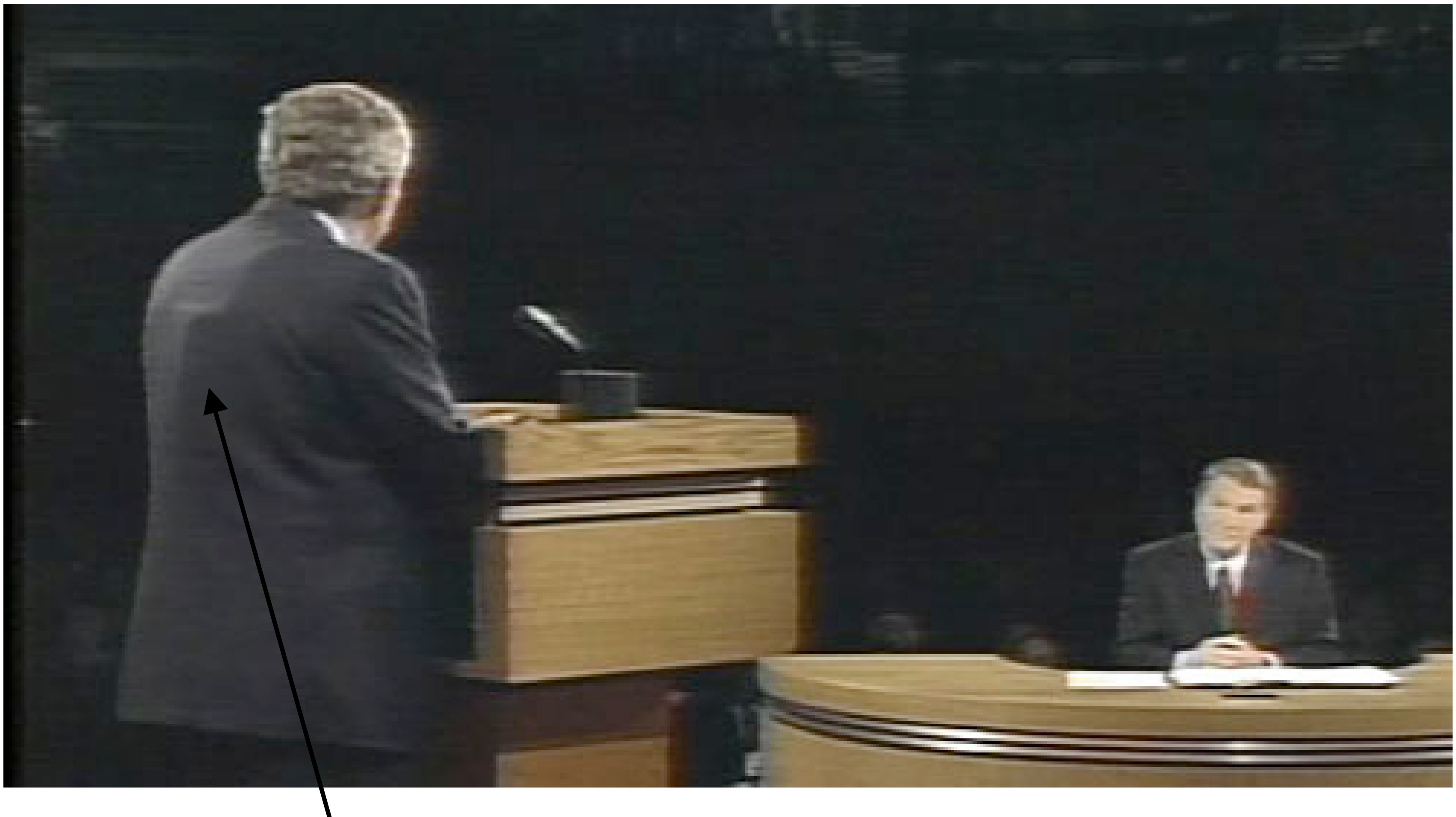
This is a spontaneous talk…I'm not wired



Bush's mystery bulge

The rumor is flying around the globe. Was the president wired during the first debate?

Global pdf fits

- Calculation of production cross sections at the Tevatron and LHC relies upon knowledge of pdfs in relevant kinematic range
- pdfs are determined by global analyses of data from DIS, DY and jet production
- Two major groups that provide semi-regular updates to parton distributions when new data/theory becomes available
  - MRS->MRST98->MRST99->MRST2001->MRST2002
  - CTEQ->CTEQ5->CTEQ5(1)->CTEQ6->CTEQ6.1
  - also GKK and Alekhin and experiment-derived fits
- All of the above groups provide a way to estimate the error on the central pdf
  - new methodology enables full characterization of parton parametrization space in neighborhood of global minimum
    - Hessian method
    - Largrange Multiplier
  - both of above techniques used by CTEQ and MRST as well as the other groups

Nuts/bolts of fits

- Functional form used in CTEQ fits is:
    - $xf(x,Q_o) = A_o\, x^{A1}\, (1-x)^{A2}\, e^{A3x}\, (1 + A_4 x)^{A5}$
        - Q_o = 1.3 GeV (below any data used in fit)
            - easier to do forward evolution than backward
            - MRST starts at 1 GeV (- gluon distribution)
        - functional form arrived at by adding a 1:1 Pade expansion to quantity d(log xf)/dx
        - more versatile than form used in CTEQ5 or MRST
        - there are 20 free parameters used in the global fit
            - MRST has 15 free parameters. somewhat less flexible functional form
        - MRST allows negative gluon; CTEQ normally not (except for some of results I will show here)
- Light quarks treated as massless; evolution kernels of PDFs are mass-independent
- Zero mass Wilson coefficients used in DIS structure functions
- NB: MRST pdf's use Roberts-Thorne treatment of heavy quarks at threshold
- CTEQ uses Q^2 cut of 4 GeV^2 on data; MRST uses Q^2=2 GeV^2

Uncertainties in pdf fits

- Two sources
  - Experimental errors
    - Hessian/Lagrange multiplier techniques designed to address estimate of these effects
      - question is what $\Delta\chi^2$ change best represents estimate of uncertainty (CTEQ uses $\Delta\chi^2$ of 100 (out of 2000) for 90% CL limit; MRST uses $\Delta\chi^2$ of 50); GKK/Alekhin uses 1 (for 1 sigma error)

that's not the subject of this talk →
so for the moment treat the choice of $\Delta\chi^2$ as

  - Theoretical
    - higher twist/non-perturbative effects
      - choose Q^2 and W cuts to try to avoid
    - higher order effects
      - is NNLO necessary yet?
    - edge of phase space effects
      - threshold resummation needed?
    - note that for the most part, CTEQ and MRST make the same cuts/assumptions so expect that theoretical *precision* should be better than theoretical *accuracy*

My MRST talk

- The MRST group has recently published an attempt to calculate the theoretical error associated with global pdf analyses
  - hep-ph/0308087
- This is an interesting and important exercise to try to quantify global uncertainties other than those from experimental errors, which previously has been the concentration for the global analysis groups
- They looked at the *tension* between low x and high x data by making cuts on the Q^2, W^2 and x values of the data included in the fit
- If all data were consistent/NLO DGLAP sufficient, then applying these cuts should not directly affect the fits to the remaining data, athough the uncertainty on these fits will increase
- The cuts do have an impact in the MRST exercise, leading them to believe that there is a tension that exists in the data and that a NNLO description of the data/global fit is called for
- The above point is a crucial one for the field and should be thoroughly tested
  - this will have an impact, for example, on the understanding of predictions for the W cross section at both the Tevatron and LHC

MRST study

- The x (Q) cut is successively increased and the impact on the remaining data in the fit sample is examined
- Improvement is obtained until at an x (Q) value of .005 (10 GeV^2), no further significant decrease of the χ^2 is observed
  - these determine the *conservative* pdf's
- This is interpreted as a conflict in the data between low x (HERA) and high x (Tevatron jet)

x_{cut} :	0	0.0002	0.001	0.0025	0.005	0.01
# data points	2097	2050	1961	1898	1826	1762
$\alpha_S(M_Z^2)$	0.1197	0.1200	0.1196	0.1185	0.1178	0.1180
$\chi^2(x > 0)$	2267					
$\chi^2(x > 0.0002)$	2212	2203				
$\chi^2(x > 0.001)$	2134	2128	2119			
$\chi^2(x > 0.0025)$	2069	2064	2055	2040		
$\chi^2(x > 0.005)$	2024	2019	2012	1993	1973	
$\chi^2(x > 0.01)$	1965	1961	1953	1934	1917	1916
Δ_i^{i+1}		0.19	0.10	0.24	0.28	0.02

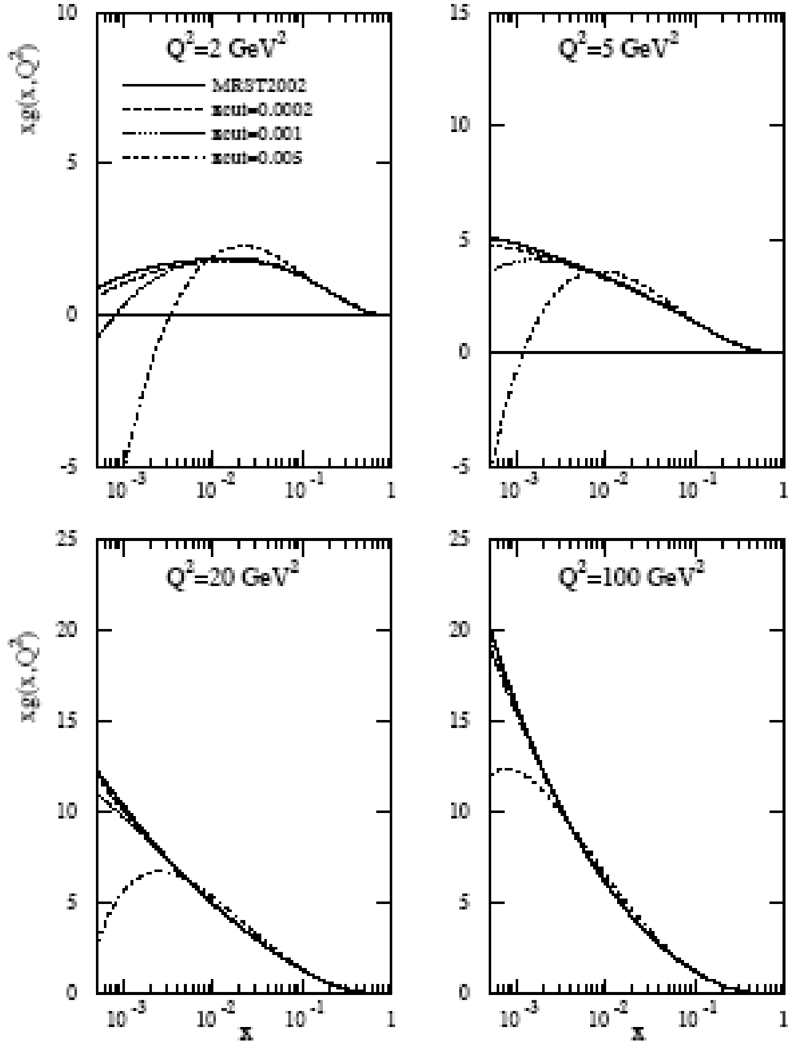
Table 1: Each column shows the χ^2 values obtained from a NLO global analysis with a different choice of x_{cut}, together with the number of data points fitted and the value of $\alpha_S(M_Z^2)$ obtained. The first χ^2 entry in a given column is the total χ^2, and the subsequent entries show the contributions to χ^2 from subsets of the data that are fitted. The quantity Δ_i^{i+1}, shown in the final row, is a measure of stability to changing the choice of x_{cut}, as explained in the text. In these analyses we take the default cut in Q^2, that is $Q^2_{cut} = 2$ GeV^2.

Q^2_{cut} (GeV^2) :	2	4	7	10	14	20
# data points	2097	1868	1681	1537	1398	1244
$\alpha_S(M_Z^2)$	0.1197	0.1194	0.1185	0.1180	0.1169	0.1174
$\chi^2(Q^2 > 2)$	2267					
$\chi^2(Q^2 > 4)$	2046	2022				
$\chi^2(Q^2 > 7)$	1844	1824	1806			
$\chi^2(Q^2 > 10)$	1716	1694	1670	1656		
$\chi^2(Q^2 > 14)$	1594	1573	1553	1536	1533	
$\chi^2(Q^2 > 20)$	1406	1388	1370	1354	1351	1348
Δ_i^{i+1}		0.11	0.10	0.10	0.02	0.02

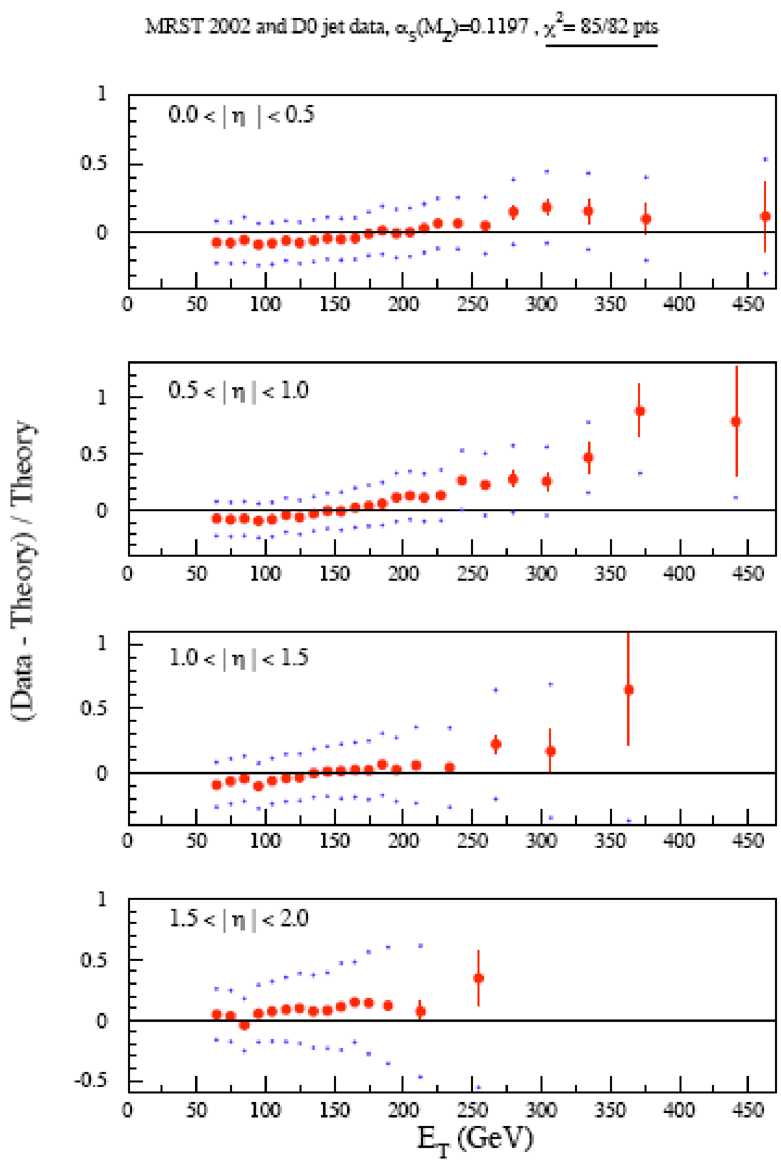
Table 2: Each column shows the χ^2 values obtained from a NLO global analysis with a different choice of the cut in Q^2, together with the number of data points fitted and the value of $\alpha_S(M_Z^2)$ obtained. The first χ^2 entry in a given column is the total χ^2, and the subsequent entries show the contributions to χ^2 from subsets of the data that are fitted. Δ_i^{i+1}, shown in the final row, is a measure of stability to changing the choice of Q^2_{cut}, as explained in the text.

Effect on gluon

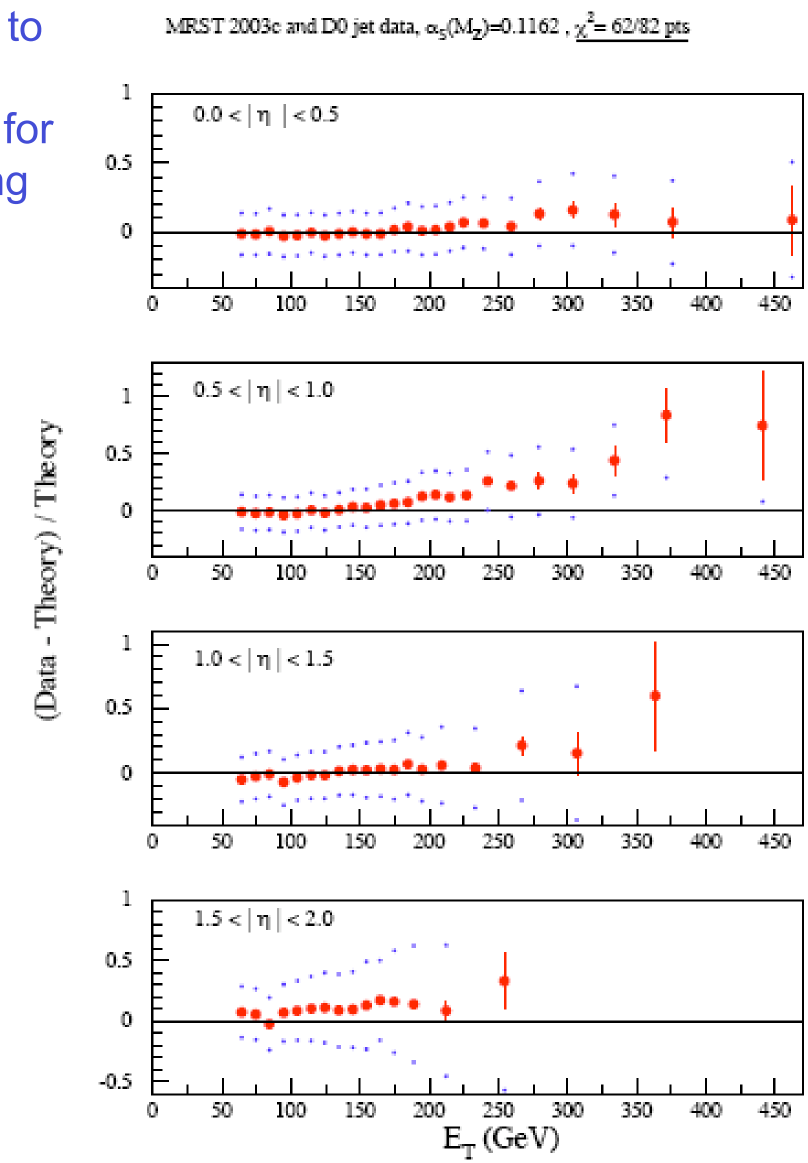
- Without the constraint of the low x data, the gluon becomes increasingly negative at low x and Q^2



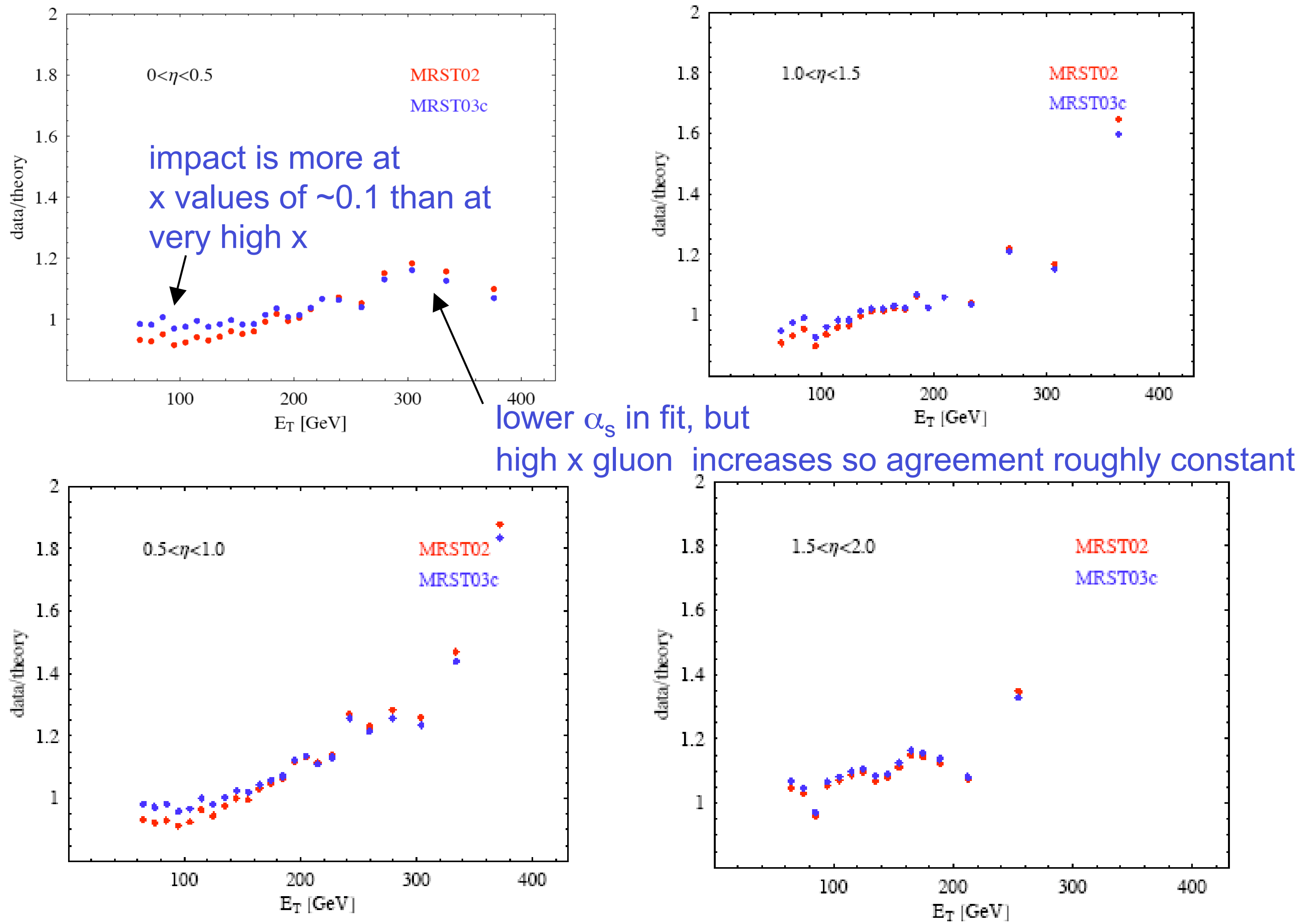
MRST comparison to Run I D0 jet cross sections



Thanks to Robert Thorne for providing plots



Impact of conservative cuts



W cross section as standard candle

Standard Candle:
σ(W) and σ(Z) : precision predictions and measurements at Tevatron Run 2 and the LHC.

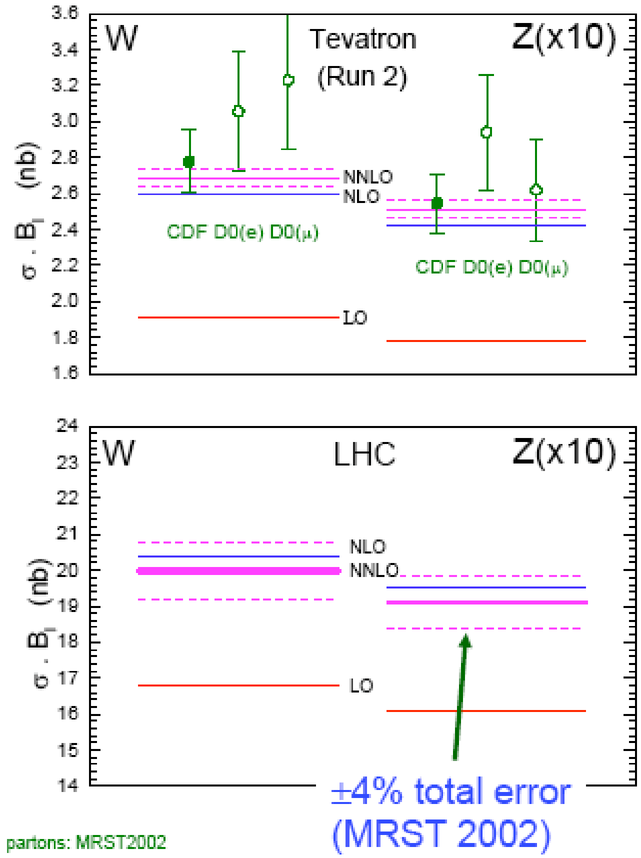
Exptl uncertainties:

LHC	**σ_{NLO}(W) (nb)**
MRST2002	204 ± 4 (expt)
CTEQ6	205 ± 8 (expt)
Alekhin02	215 ± 6 (tot)

similar partons — different Δχ²

different partons

(Stirling, HeraLhc Workshop 2004)



partons: MRST2002
NNLO evolution: van Neerven, Vogt approximation to Vermaseren et al. moments
NNLO W,Z corrections: van Neerven et al. with Harlander, Kilgore corrections

W cross section at the Tevatron: MRST study

- The NLO prediction for the W cross section at the Tevatron rises as the x cut increases due to the increased evolution of the quarks driven by the increase of the gluon in the relevant range
- At NNLO the changes are small
  - NNLO DGLAP more stable than NLO DGLAP?
- Cutting on Q^2 reduces the W cross section due to the loss of the NMC data and a subsequent reduction in the gluon

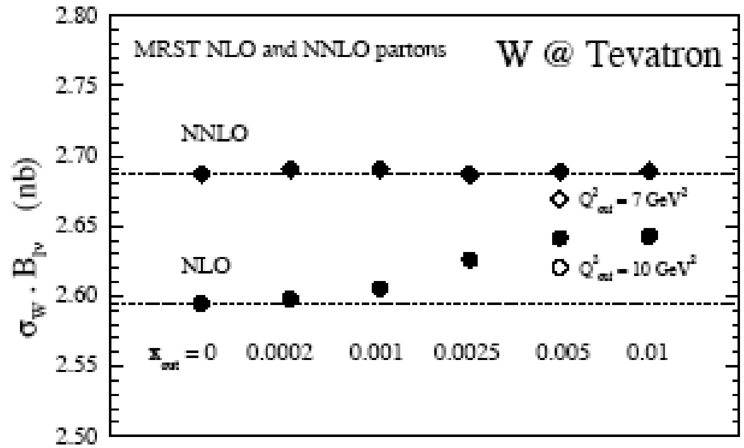


Figure 16: Predictions for the W cross section (times the leptonic branching ratio $B_{l\nu} = 0.1068$) at the Tevatron ($\sqrt{s} = 1.96$ TeV) at NLO and NNLO for various values of x_{cut}, and for the 'conservative' partons with a cut on both x and Q^2 (shown as open symbols).

W cross section at the LHC: MRST study

- At the LHC, there is a very dramatic decrease in the W cross section as the x cut is increased
- Both the low x quark and gluon (at low Q^2) distributions are significantly decreased
  - see next slide

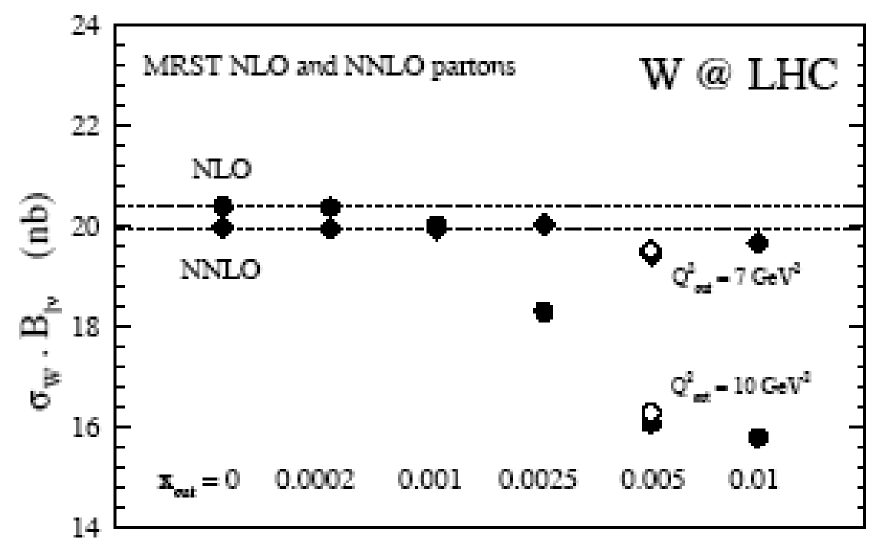


Figure 18: The same as Fig. 16, but for the LHC energy of $\sqrt{s} = 14$ TeV.

Effect on W rapidity distribution

- The conservative W rapidity distribution at the LHC becomes fairly extreme

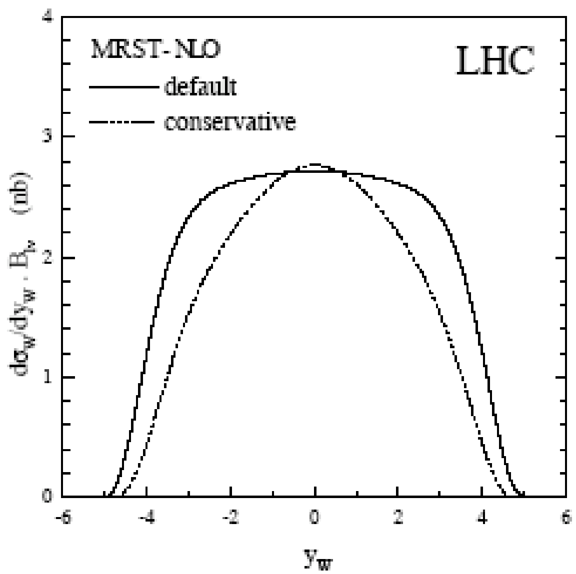
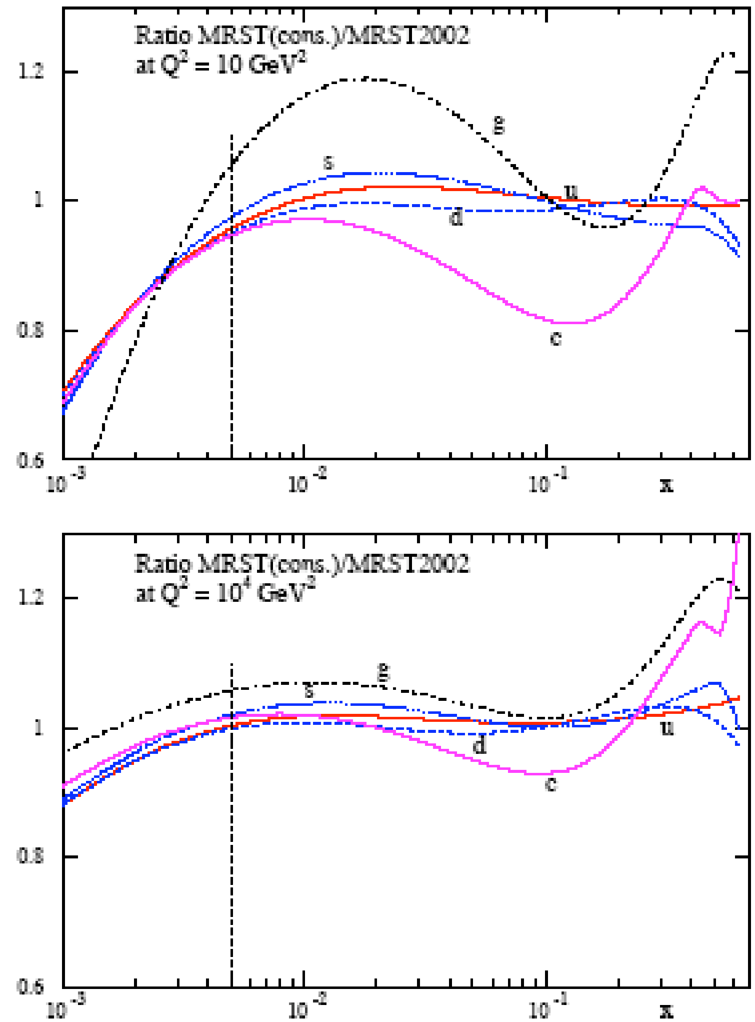
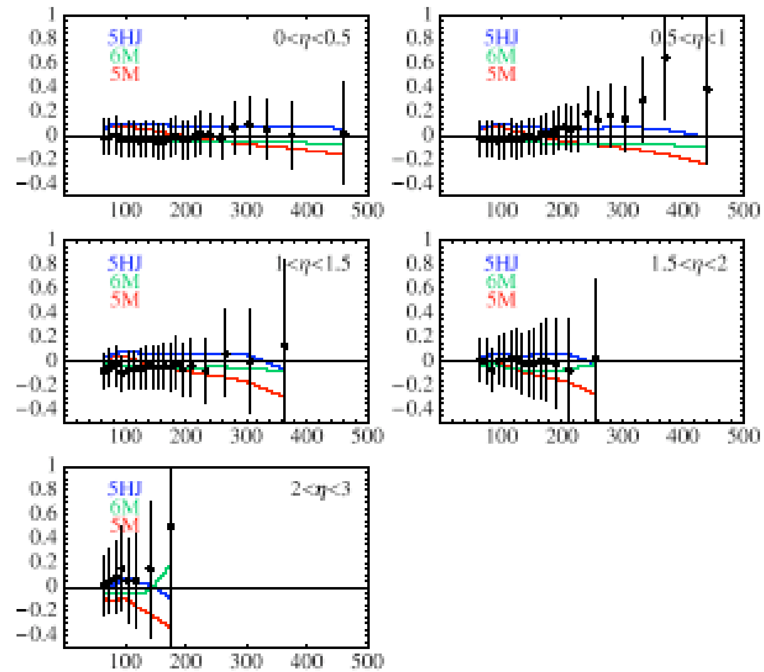


Figure 19: The predictions for the rapidity distribution of the W cross section at the LHC for both the default MRST2002 set and for the 'conservative' set.



CTEQ global fits

- The Tevatron jet data from Run 1 has had increasingly greater importance in the global fits
- D0 jet data over full rapidity range in particular has lead to an a larger gluon at high x
  - but the integrated gluon momentum at very high x is still fairly small



1: The DØ inclusive jet cross section versus E_T for five rapidity bins compared to NLO :tions using the CTEQ6.1M PDF's. The abscissa is E_T in GeV. The ordinate is (data − y)/theory. The curves show the CTEQ5M, CTEQ5HJ, and CTEQ6M predictions, as frac- differences compared to CTEQ6.1M. The error bars are the statistical and systematic errors ned in quadrature.

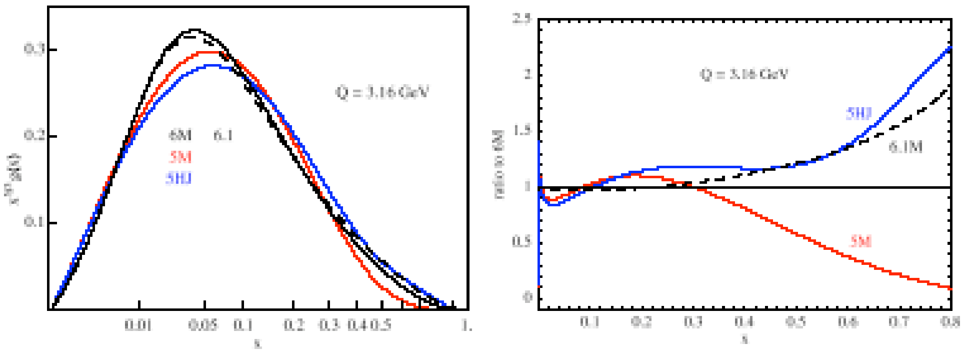


FIG. 2: Left: The CTEQ5M, CTEQ5HJ, and CTEQ6M gluon distributions at $Q^2 = 10\ \mathrm{GeV}^2$. Right: The ratios of CTEQ5M and CTEQ5HJ gluon distribution to that of CTEQ6M. The dashed curves show the CTEQ6.1M gluon distribution.

Uncertainty on jet cross sections

- Great deal of remaining uncertainty on the Tevatron jet cross sections, primarily from uncertainty on high x gluon distribution

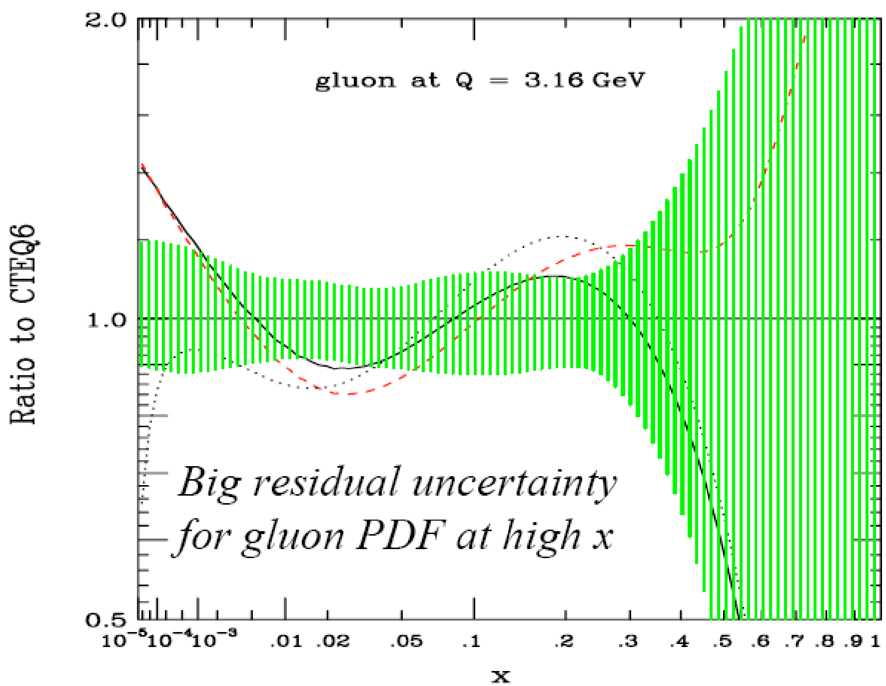
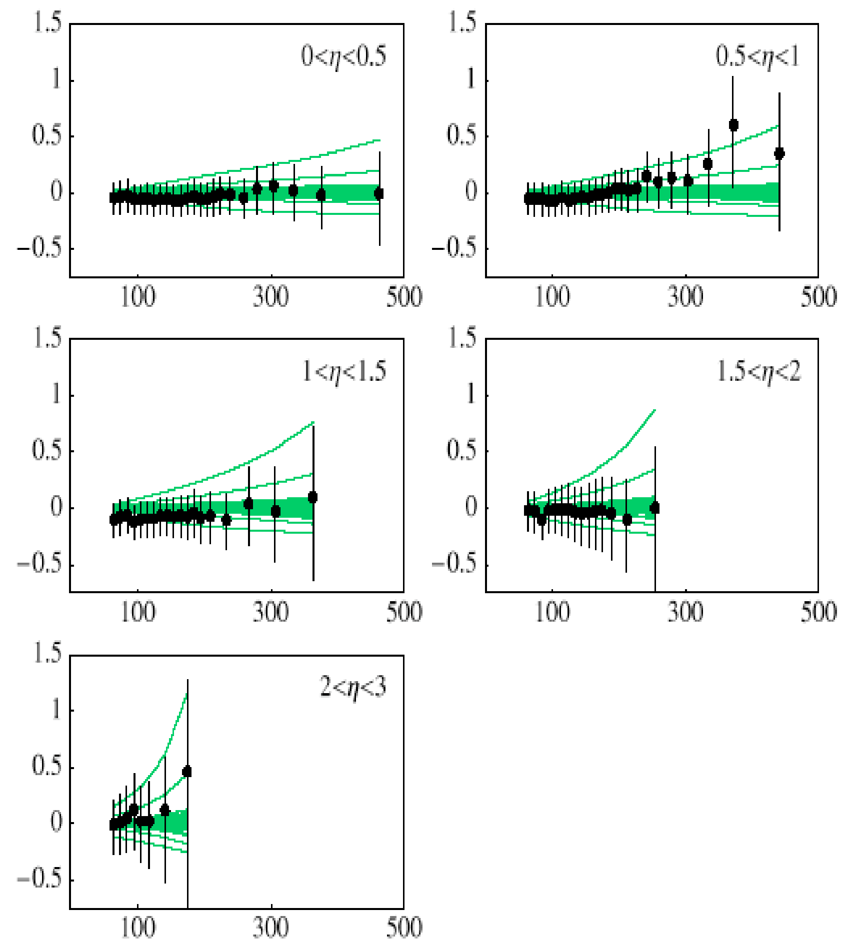


FIG. 14: The inclusive jet cross section as a function of E_T for the five rapidity bins of the Run 1b DØ measurements. Predictions of all 40 eigenvector basis sets are superimposed. The points are the DØ data, and the error bars are the statistical and systematic errors combined in quadrature.



CTEQ study of effect of x and Q^2 cuts

- As x cut is increased, there does not seem to be any improvement in the fit to the remaining data, especially the jet data which should benefit from having more gluon momentum at their disposal
- So tension not evident

x cut	χ^2/points	χ^2_{CDF}	χ^2_{D0}
0 (cteq6)	1954/1811 (1.107)	1.47	0.718
.001	1900/1754 (1.107)	1.48	0.715
.0025	1850/1709 (1.107)	1.47	0.723
.005	1824/1681 (1.11)	1.47	0.726
.01	1758/1625 (1.11)	1.48	0.697

CDF χ^2 will always be large due to statistical fluctuation of 2 data points

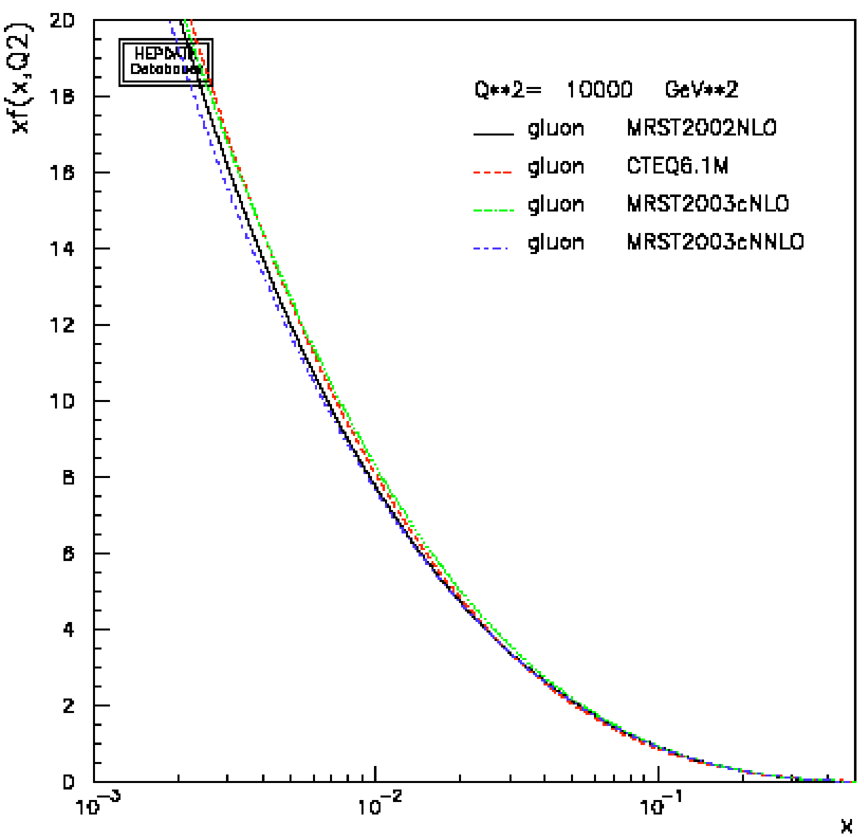
CDF jet data

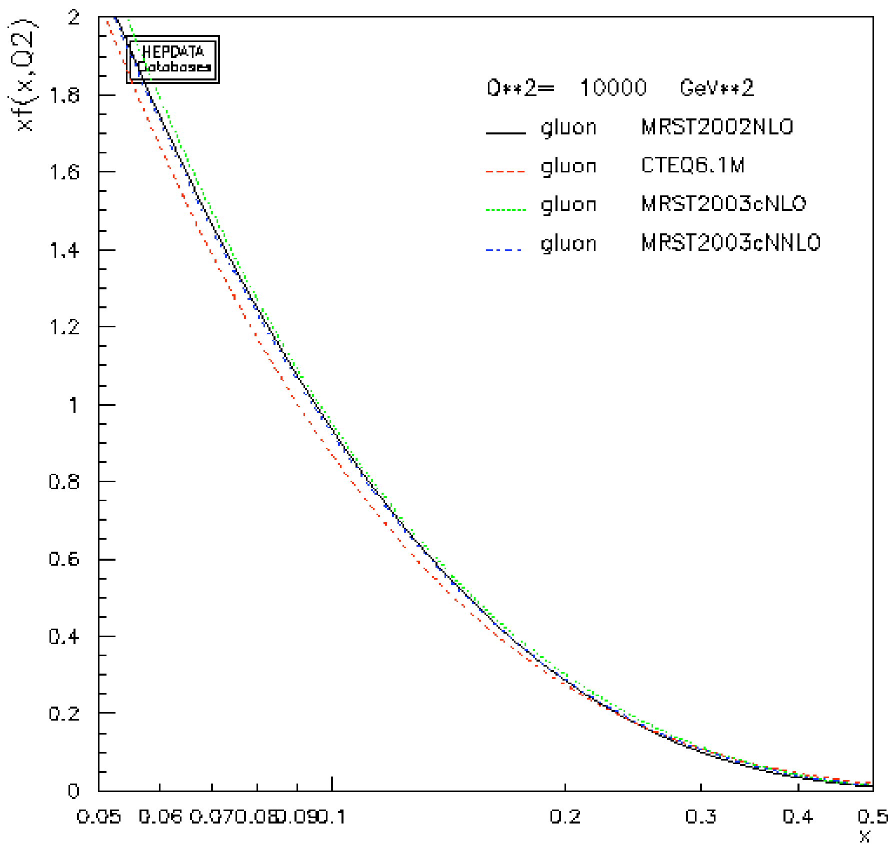
- Use the values of data/theory for the last 5 bins of the CDF Run 1 jet cross section to look for changes in the high x gluon distribution as the x cut is increased
- Expect more momentum to flow to high x if low x competition is removed
- There is movement in this direction but no significant changes observed

p_T(GeV/c)	cteq6	.001	.0025	.005	.01
291	1.085	1.083	1.086	1.112	1.094
312	1.06	1.058	1.061	1.087	1.068
334	1.207	1.205	1.208	1.237	1.215
362	1.367	1.364	1.368	1.399	1.373
412	1.283	1.279	1.284	1.312	1.284

Comparing gluons

CTEQ6.1 gluon is actually smaller than MRST2002 at x=0.1, but larger at lower and higher x



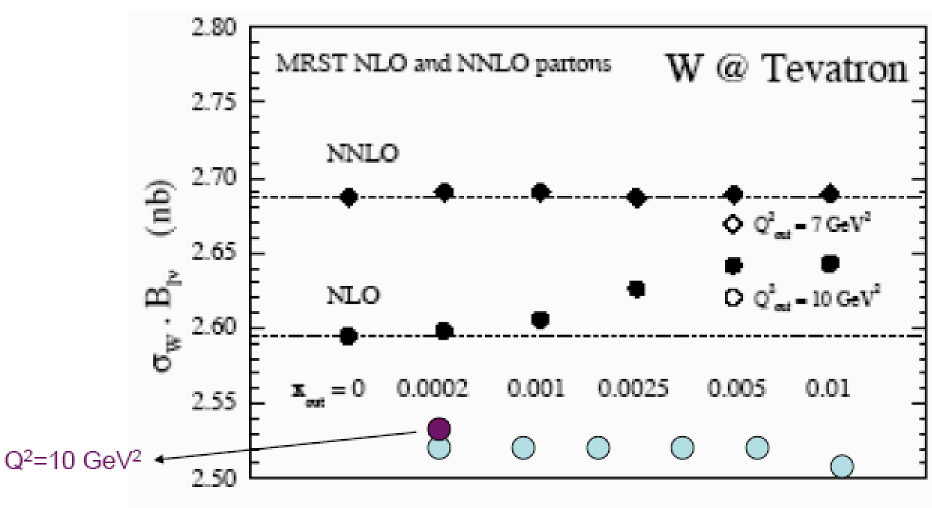


W cross section predictions: CTEQ and MRST studies

CTEQ conclusion is that the W cross section seems to be stable with respect to cuts in x and Q^2. Aside from an overall K-factor, NNLO not needed to lend stability to the calculations.

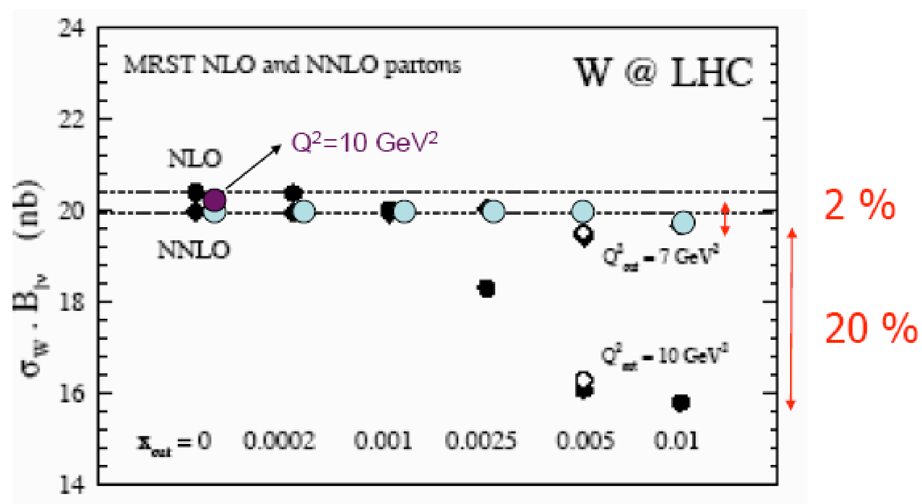
with positive-definite gluon

σ_W at the Tevatron



○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit

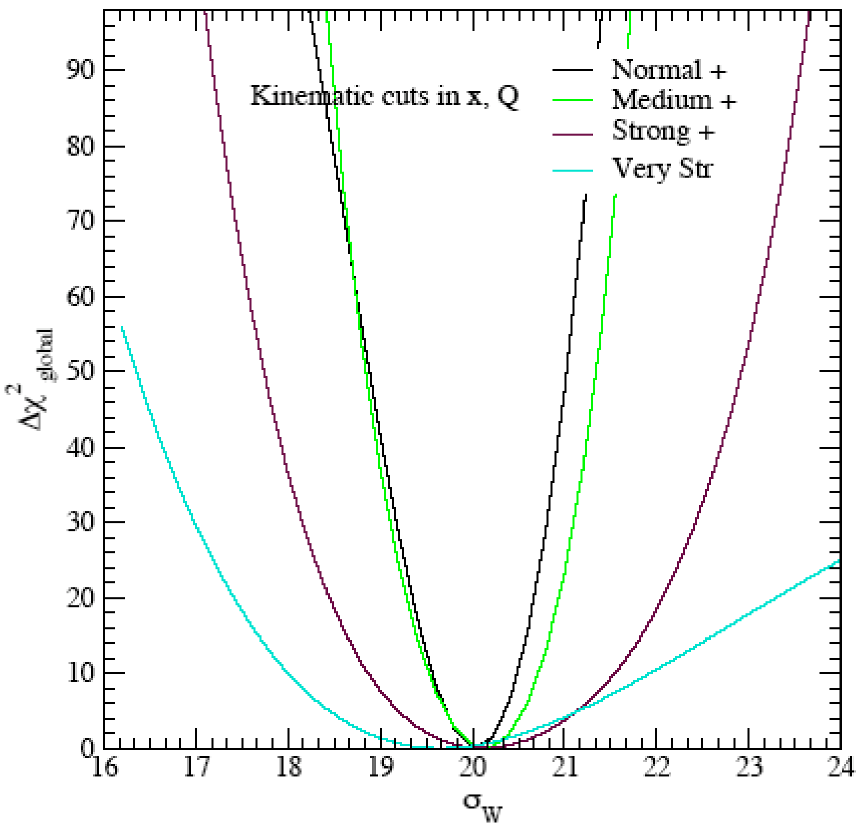
W total cross section at the LHC

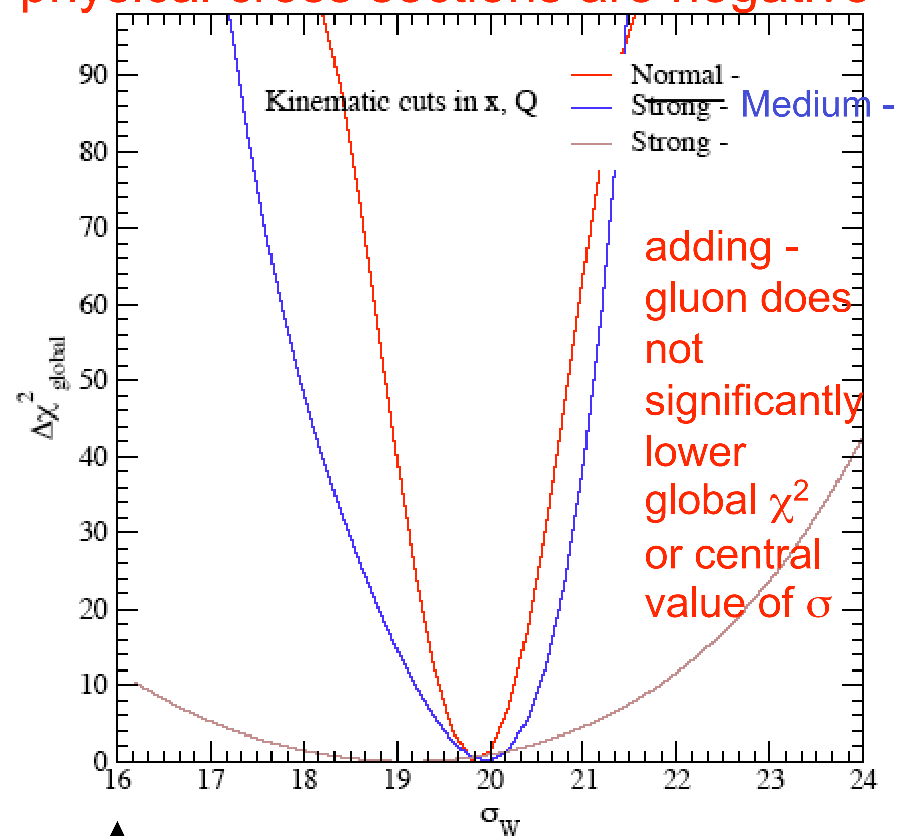


○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit.

CTEQ LM multiplier study of W σ at LHC

As cuts in x and Q^2 are increased, W cross section at the LHC becomes less constrained, but central value remains relatively constant. The uncertainty increases if a negative gluon is allowed, especially if a signficant amount of low x/Q^2 data is removed from the fit. NB: with negative gluon and large x,Q^2 cuts can easily get into regime where physical cross sections are negative



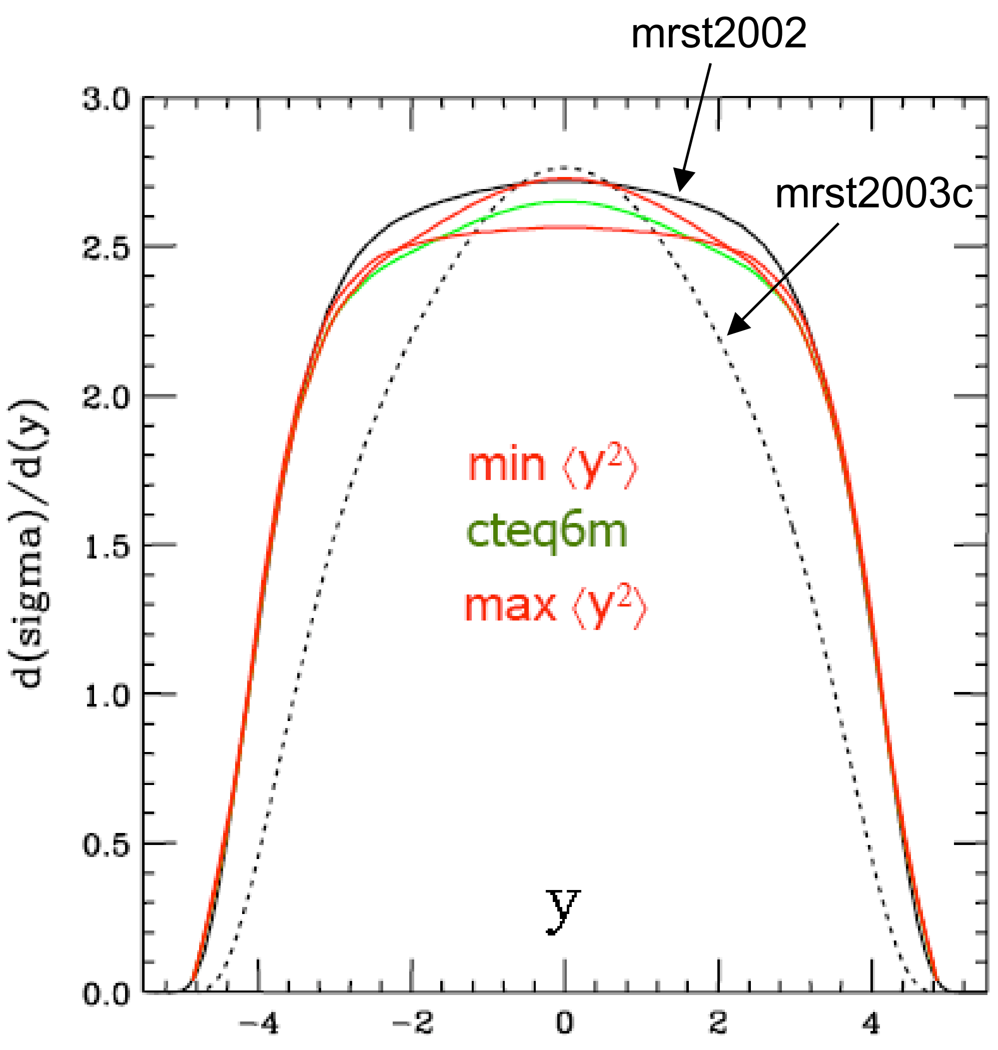


MRST2002c prediction

W rapidity at the LHC

CTEQ study of the W rapidity distribution at LHC (Pumplin)

- Search in the parton parameter space, using eigenvector solutions in the improved Hessian approach, to probe the extremes in predicted shape–max/min $\langle y^2 \rangle$.



Jets in Run 2

Data should pin down the gluon distribution more precisely

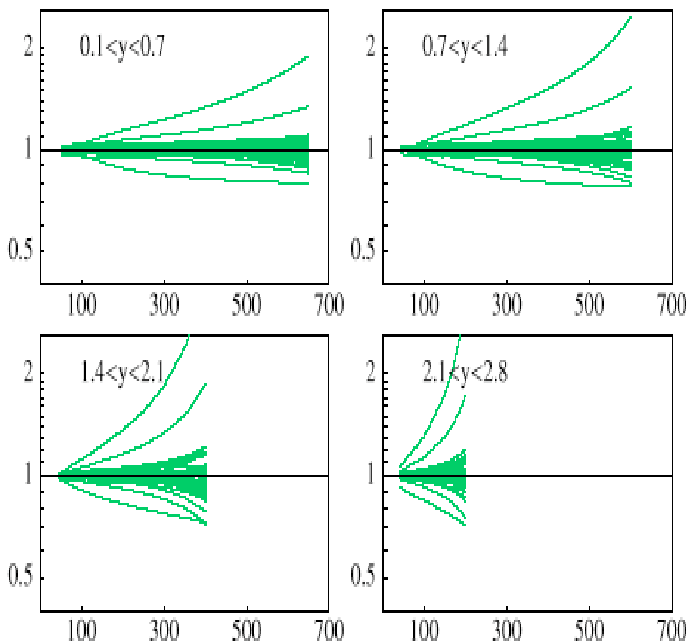
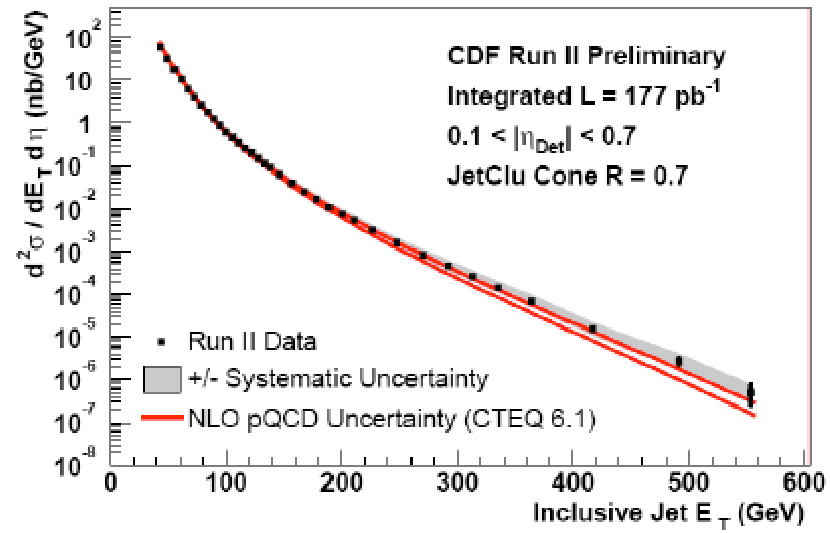
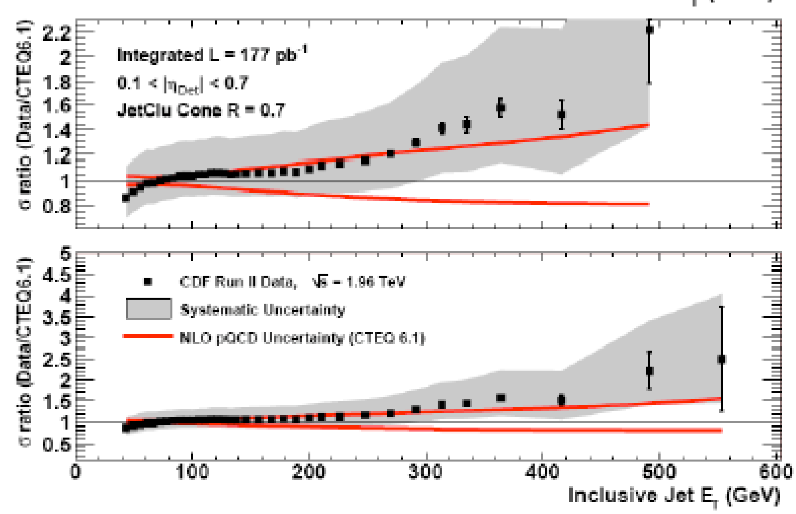


FIG. 28: Uncertainty range of the Run 2 cross section for the CDF rapidity bins. The curves show the ratios of the 40 eigenvector basis sets compared to the central (CTEQ6.1M) prediction (ordinate) versus p_T in GeV (abscissa).





Summary

- CTEQ6 global fits seem fairly robust to cuts on x and Q^2
  - NLO DGLAP seems to provide stable predictions at both Tevatron and LHC
    - tension not observed by CTEQ
  - in particular, W cross section changes little at both the Tevatron and LHC when kinematic cuts are applied to input data
  - gluon does not really want to go negative
  - other cross checks:
    - if I change Q^2 cut on data to 2 GeV^2 rather than 4 GeV^2, additional data is poorly described by fit but predictions for jet/W cross sections remain similar
    - if I fit with a simpler functional form, predictions for jet/W cross sections remain similar
    - if I place a lower weight on the jet data, the description of the jet data worsens but the W cross section predictions do not appreciably change

Summary

- Differences with MRST analysis under study by both groups
- CTEQ working on NNLO analyses, approximate until Nigel finishes his 5 year mission (*a la Star Trek*) of NNLO jet cross sections