CTEQ-TEA update

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PDF4LHC meeting
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Recent history

- CTEQ6.6
  - published in 2008: in general use at LHC
    - Phys.Rev.D78:013004,2008.
      e-Print: arXiv:0802.0007 [hep-ph]
  - more recently: *Uncertainty induced by QCD coupling in the CTEQ-TEA global analysis of parton densities*
    - e-Print: arXiv:1004.462
    - α_s uncertainty should be added in quadrature with PDF uncertainty

$$\Delta X = \sqrt{\Delta X^2_{CTEQ6.6} + \Delta X^2_{CTEQ6.6AS}}$$

- CT09
  - *Collider Inclusive Jet Data and the Gluon Distribution*
    - mild tension between Run 1 and Run 2 jet data, but sets are compatible; decision to keep both Run 1 and Run 2 jets
  - published in 2009: not generally released
    - Phys.Rev.D80:014019,2009.
      e-Print: arXiv:0904.2424 [hep-ph]

Recent history

- CT09MC1,CT09MC2,CT09MCS
  - *Parton Distributions for Event Generators*
    - published in JHEP 1004:035,2010.
      e-Print: arXiv:0910.4183 [hep-ph]

CT10

- CT10/CT10W
  - new experimental data, statistical methods, parameterization forms
    - combined HERA data set, CDF/D0 Run 2 Z rapidity, inclusive jets
    - lepton asymmetry data from CDF/D0 Run 2
  - experimental normalizations N_i treated on same footing as other systematic errors
    - minimum of χ^2 with respect to N_i found algebraically
    - nominal shifts accounted for in producing eigenvector sets
    - all data weights set to 1 (except for some cases for CT10W)
  - more flexible parameterizations for $g(x,Q_o)$,$d(x,Q_o)$,$s(x,Q_o)$
    - 26 free parameters; 26 eigenvector directions
  - tolerance
    - look for 90% CL along each eigenvector direction
    - within the limits of the quadratic approximation, can scale between 68% and 90% CL with naïve scaling factor

CT10/CT10W

- Tension observed between D0 II electron asymmetry data and other data
  - W lepton asymmetry data constrains d(x)/u(x) at x->1; D0 Run 2 lepton asymmetry data apparently disagrees with existing constraints on d/u obtained from the NMC ratio data and the Run 1 W asymmetry data (with minor tension with BCDMS F2 data)
  - CDF electron data agrees with D0 electron data
- Tension between D0 II electron and muon asymmetry data
- Two series of PDF's are introduced
  - CT10: no Run 2 W asymmetry
    - χ^2/dof=3000/2750~1.1
  - CT10W: Run 2 W asymmetry with an extra weight

CT10

- Combined HERA data sets reduce low x uncertainties
- Somewhat higher χ^2 in CT10 fits

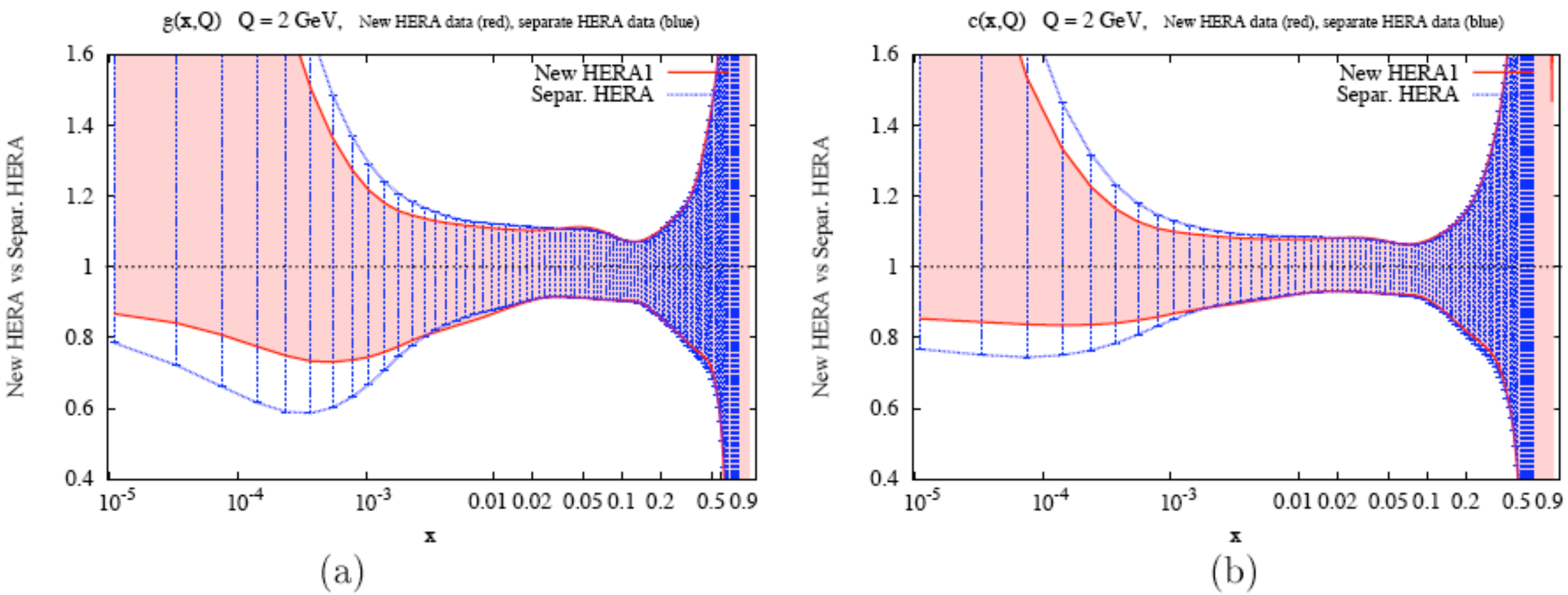
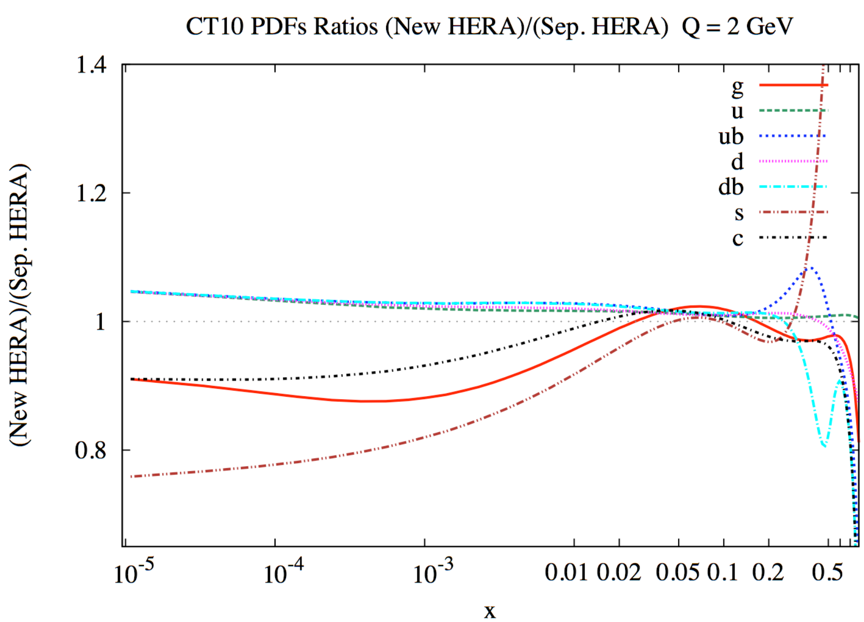
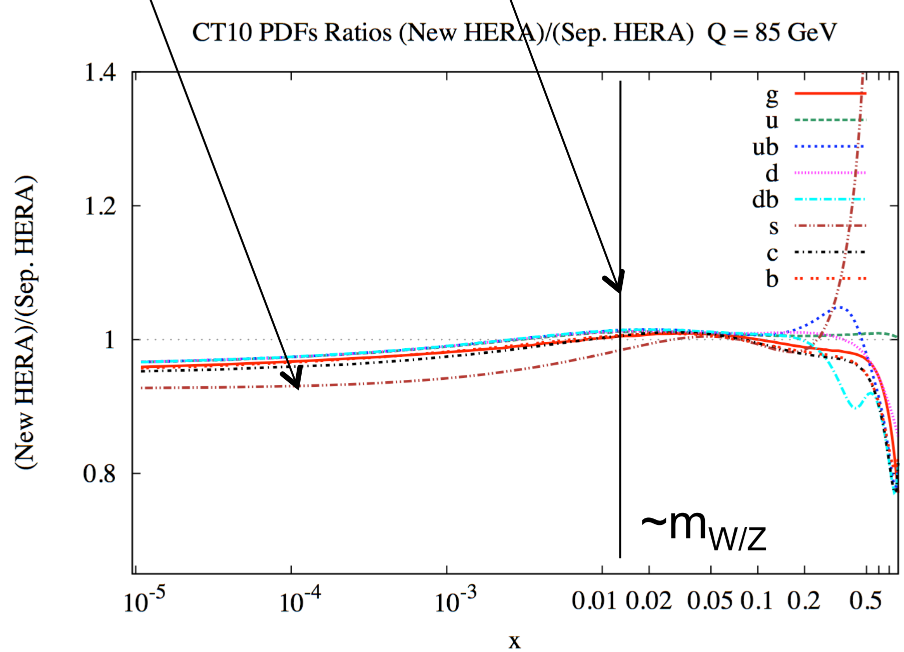


Figure 2: Impact of the new HERA data on the PDFs uncertainties: $g(x), c(x)$, $Q = 2$ GeV.

CT10

- Some changes in quark and gluon distributions
- Small increases in some kinematic regions
- Decrease in low x strange quark

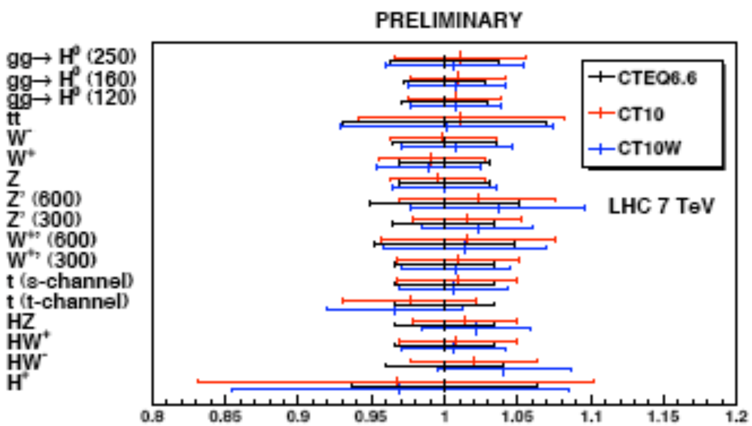


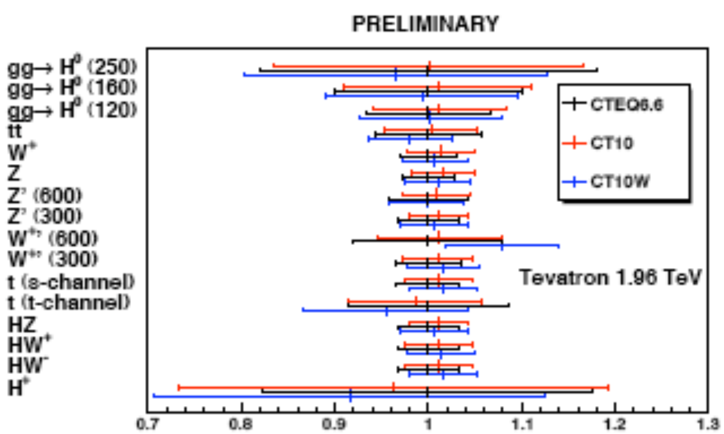


CT10/CT10W predictions

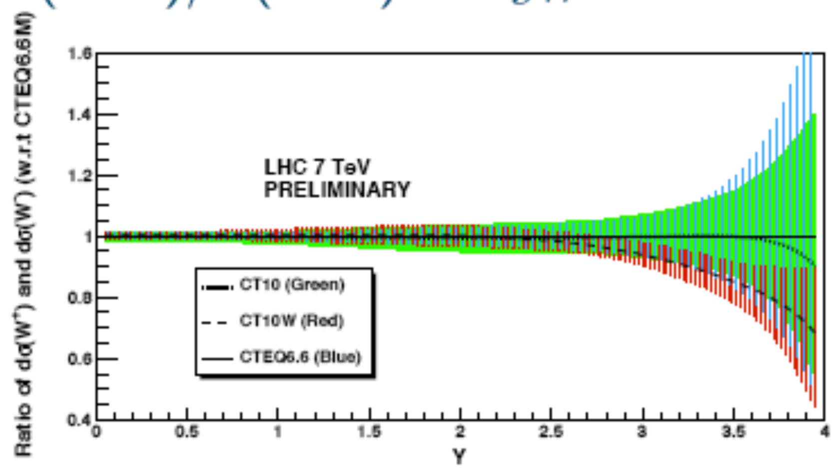
No big changes with respect to CTEQ6.6

Total cross sections

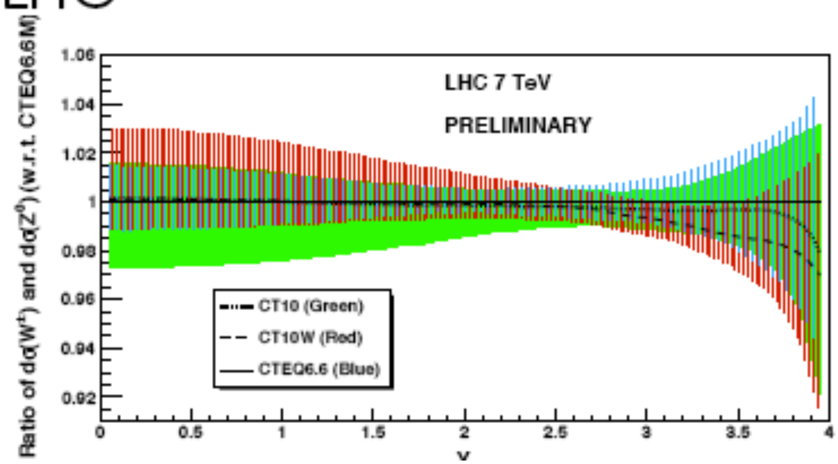




$\sigma(W^+)/\sigma(W^-)$ vs. y_W at the LHC

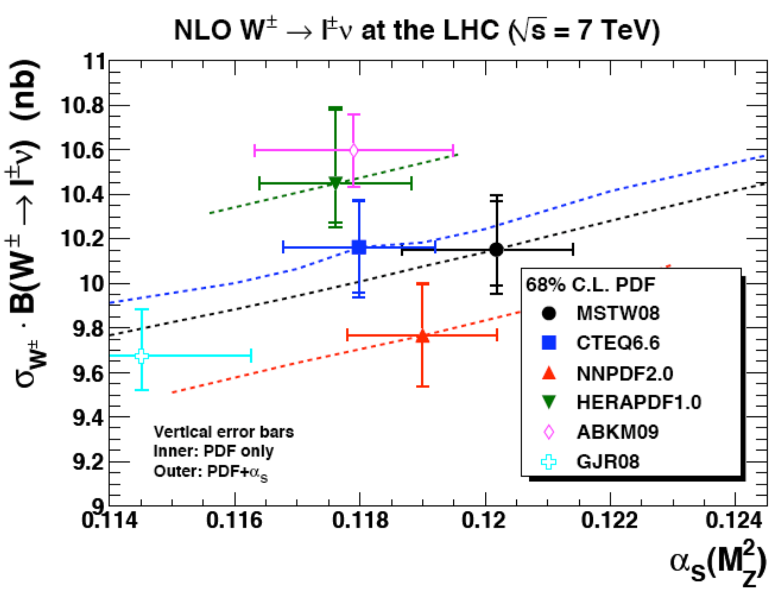


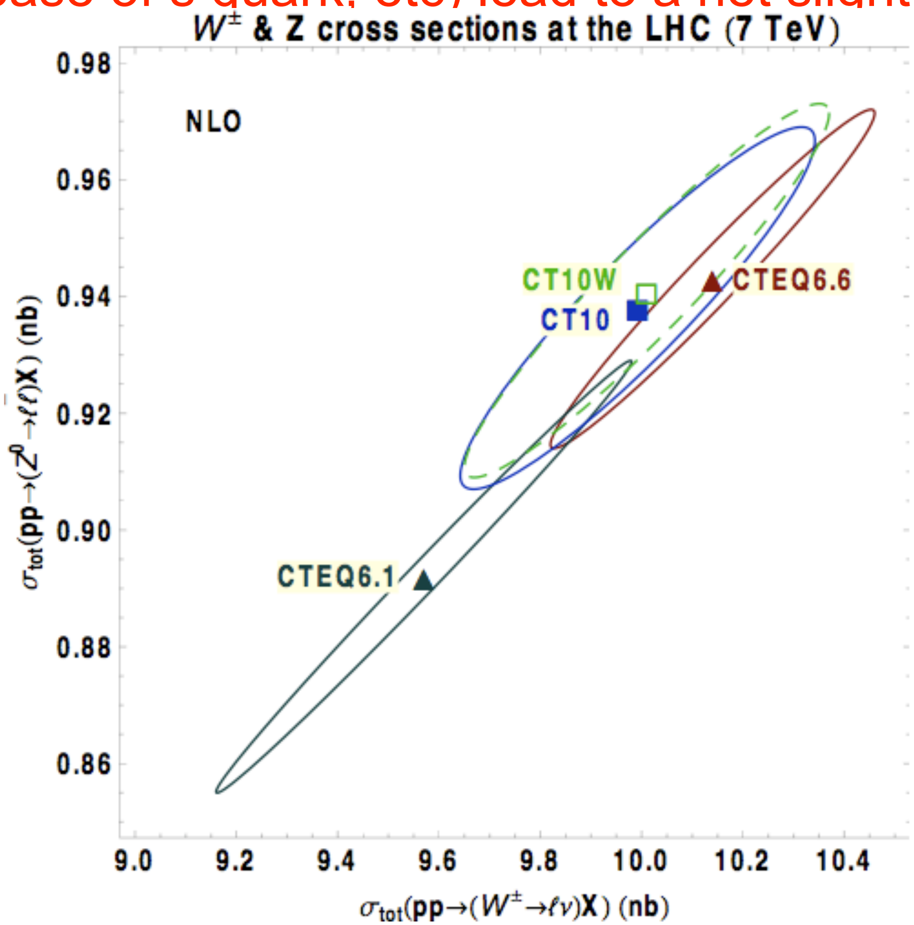
$\sigma(W^\pm)/\sigma(Z^0)$ vs. $y_{W/Z}$ at the LHC



Closeup of W/Z at 7 TeV

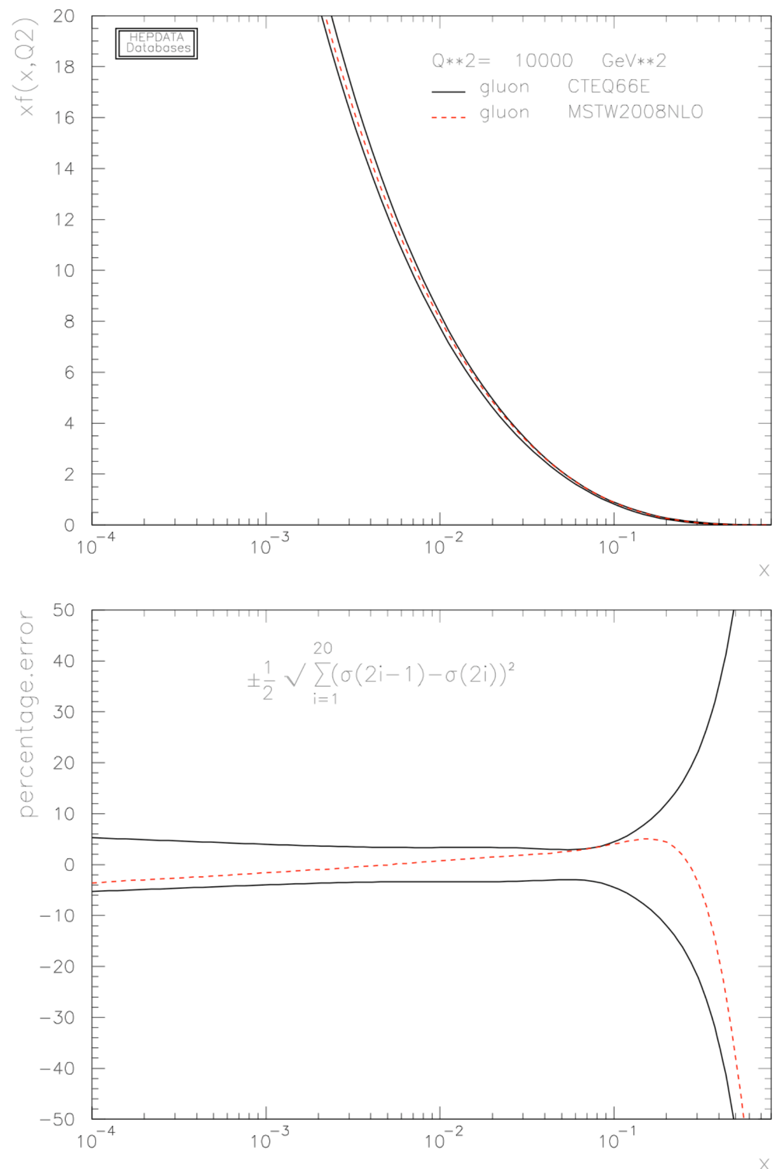
- W/Z cross sections at LHC (7 TeV) slightly decrease
  - impact of new combined HERA data alone lead to a small increase
  - other factors in fit (decrease of s quark, etc) lead to a net slight decrease





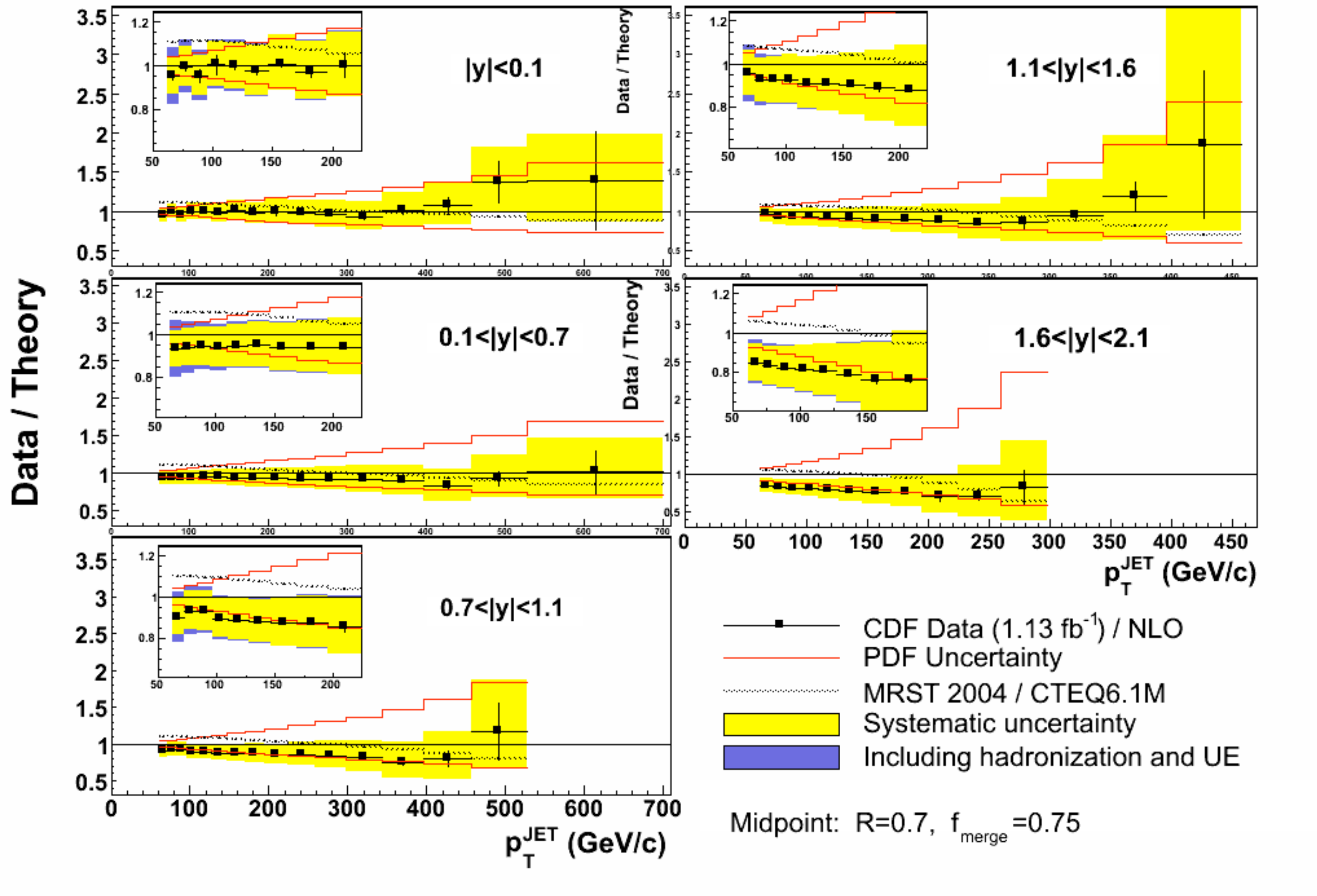
Jets: a tale of two runs

- There is a large uncertainty on the gluon distribution at high x; most of the existing constraints are from the Tevatron jet data
- Run 1 jet data (especially that from D0) prefer a larger gluon at high x->CTEQ6.6
- Run 2 jet data prefer a somewhat smaller gluon than CTEQ6.6 (more D0 than CDF), thus a mild tension
    - see *Collider Inclusive Jet Data and the Gluon Distribution*
- But datasets are compatible; Run1 data at a different energy; no reason to throw away Run 1 data



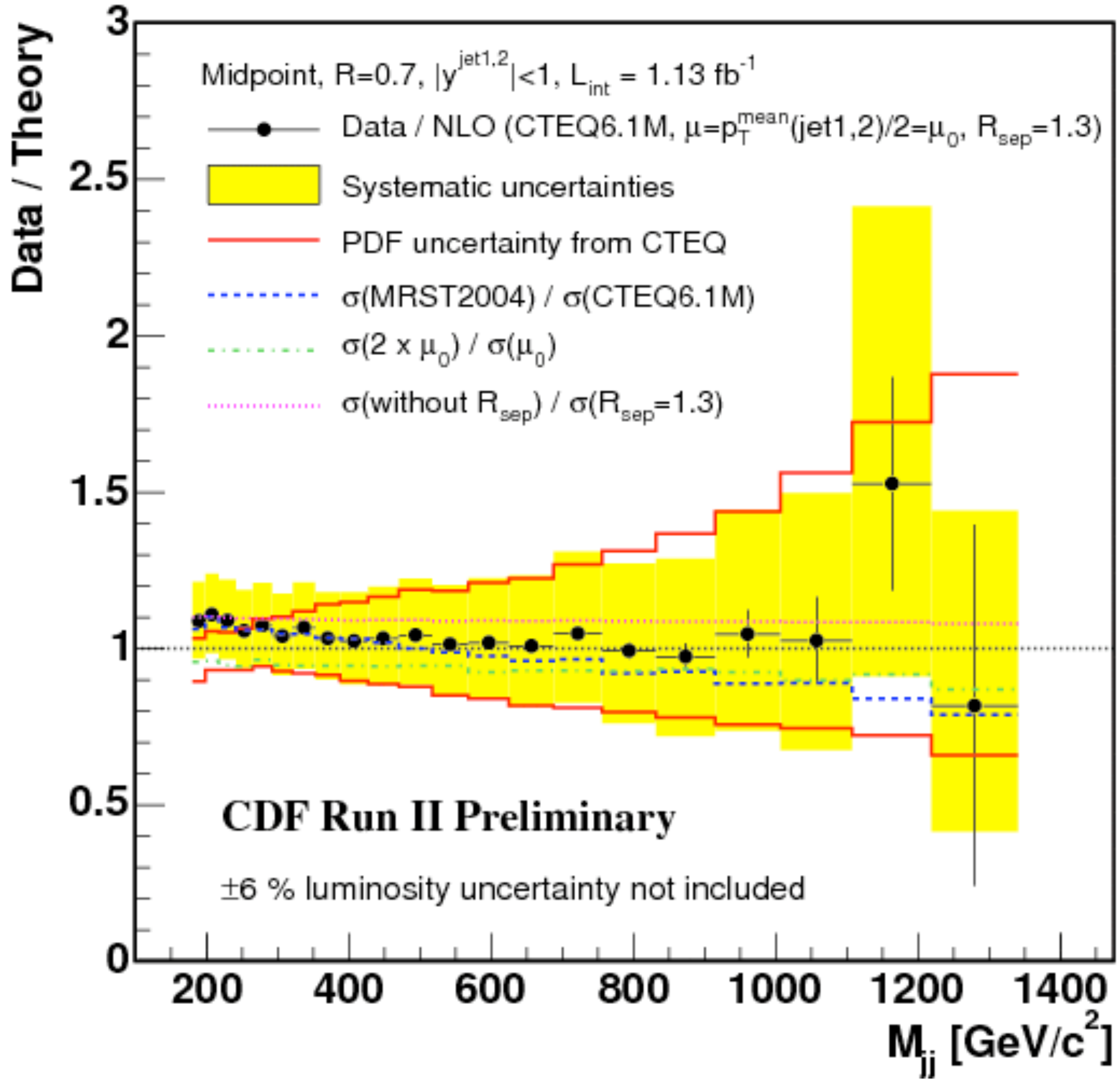
CDF Run 2 inclusive jet

…generally good agreement with CTEQ6.6 predictions even without any systemtic error shifts (note: $p_T^{jet}/2$ used by CDF)

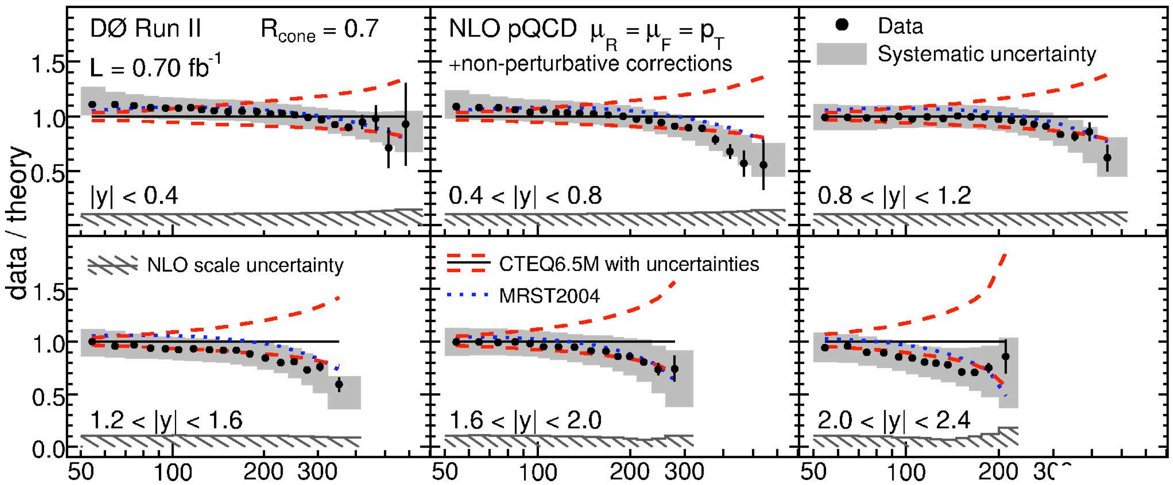


CDF Run 2 dijet

…again good agreement; average p_T^{jet} used by CDF



D0 Run 2 inclusive jet



…lower jet cross sections at high p_T; still good fit to CTEQ6.6 once correlated systematic errors taken into account; p_T^{jet} used by D0

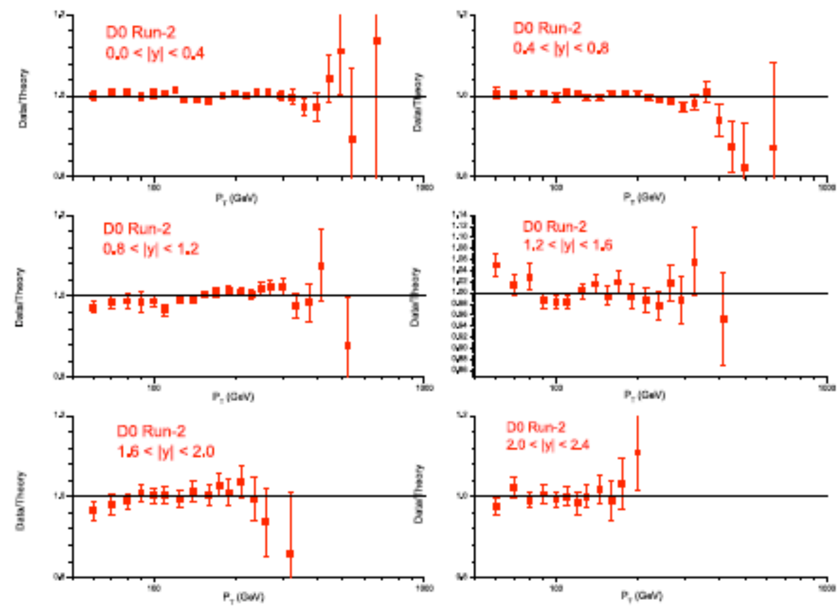


Figure 11: Central fit to D0 run II data.

D0 Run 2 dijets

…apparently even larger disagreements, but…

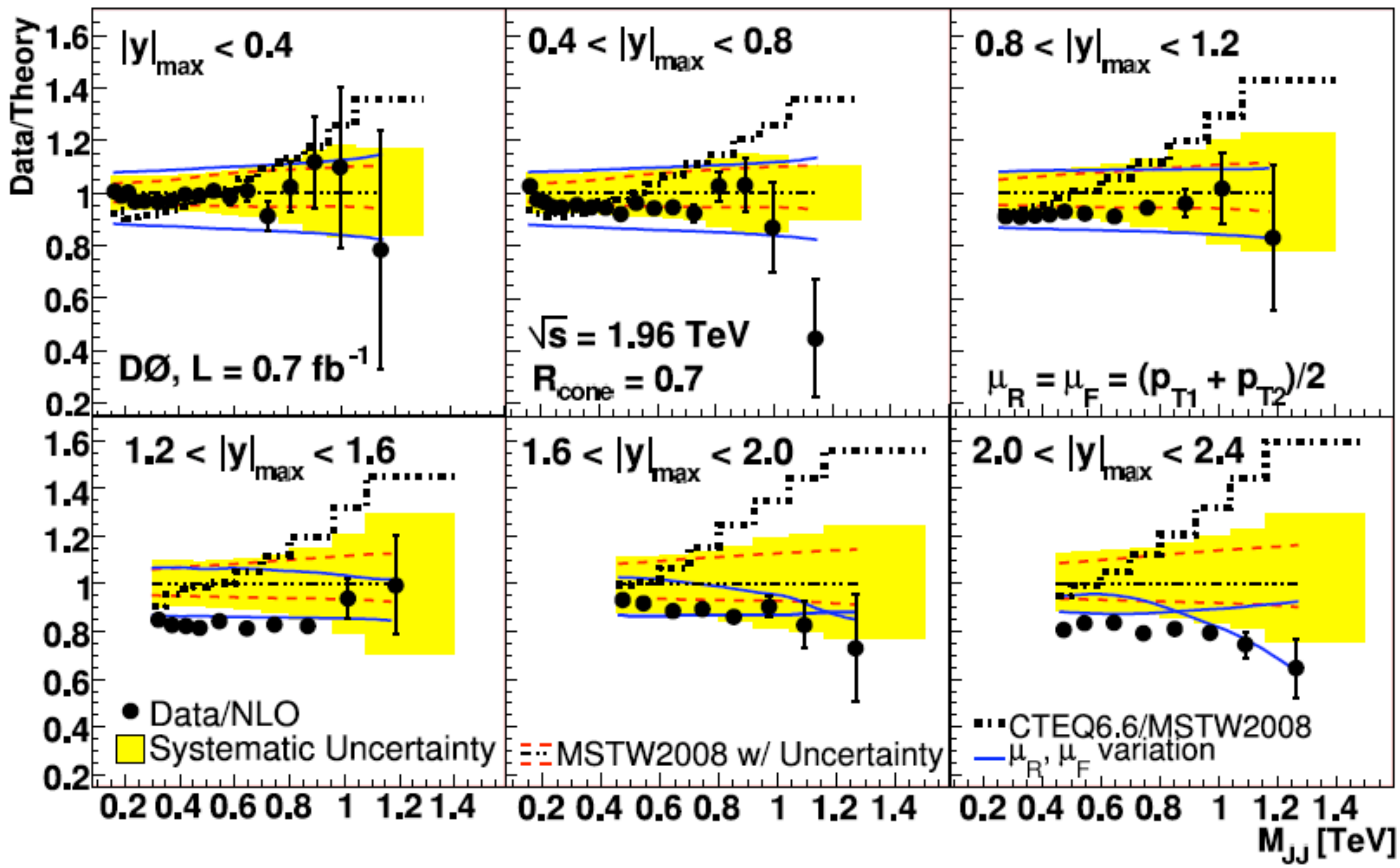


FIG. 2: (color online) Ratio of data over theoretical expectation using MSTW2008NLO PDFs in all six $|y|_{max}$ bins. The measurement systematic uncertainty is shown as a shaded band. There is an additional fully correlated uncertainty of 6.1% due to the integrated luminosity determination which is not shown in the plots. The legend for all six plots shown is spread out over the three bottom plots with other relevant information in the top three plots.

LO/NLO/scales

- Typically a scale of $p_T^{jet}/2$ has been used in inclusive jet cross sections, both in fits and in comparisons to data
- For much of the kinematic range, this scale is near the point where LO and NLO cross, i.e. K-factor~1
- For CTEQ6.1,we also found that this scale results in the best fit (χ^2) to the jet cross section (varying the scale from $p_T^{jet}/2$ to $2*p_T^{jet}$)

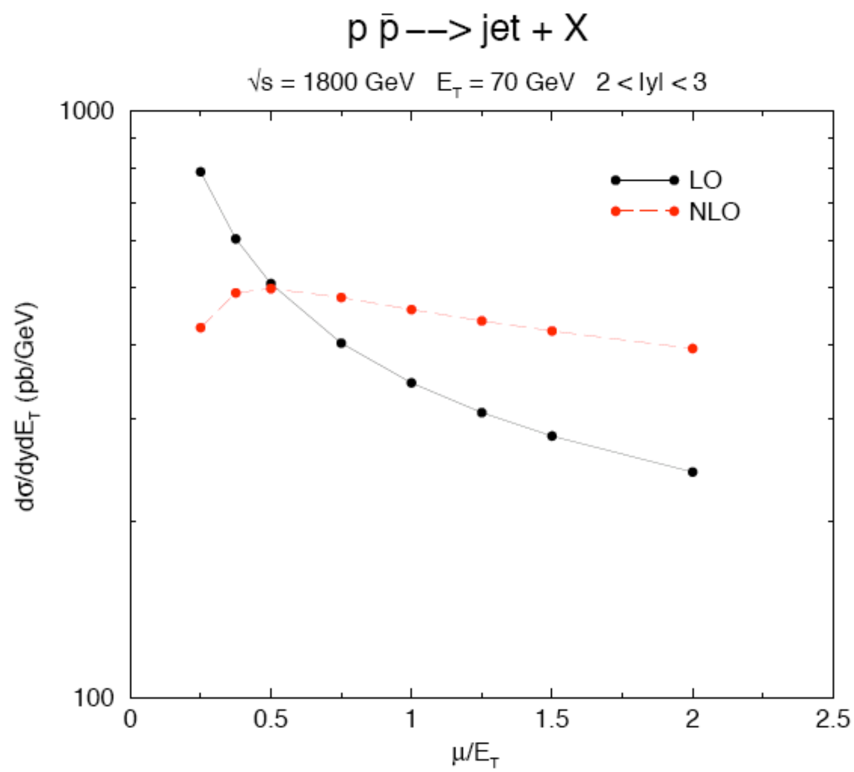


FIG. 16: Comparison of the scale dependence of the jet cross section at E_T=70 GeV/c for the leading- and next-to-leading-logarithm calculations

LO/NLO/scales

- The kinematics are different in the forward rapidity region, high p_T region; the K-factor at a scale of $p_T^{jet}/2$ is now < 1, and the NLO prediction is now no longer at the maximum
- CTEQ6.6 fit the gluon distribution for the Run 1 cross sections using this scale
- If we used a scale of p_T^{jet}, then the gluon distribution would have been somewhat lower
- The cross section predictions that D0 ran were with a scale of p_T^{jet}, resulting in a larger cross section prediction in the forward/high p_T region

- Nothing wrong with any of these choices, but just a lesson for situations where the data have a significant impact on the PDFs

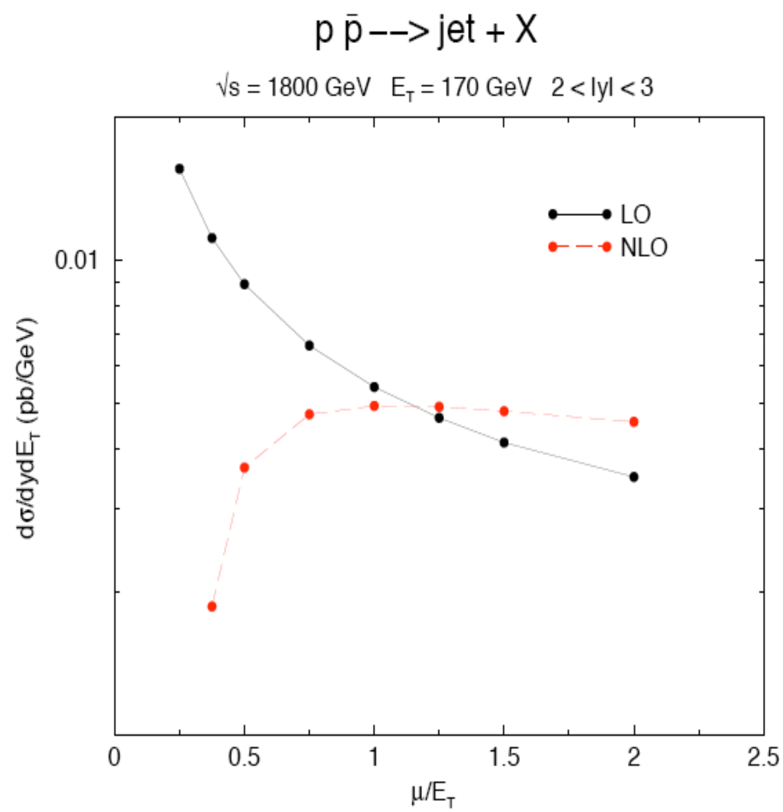
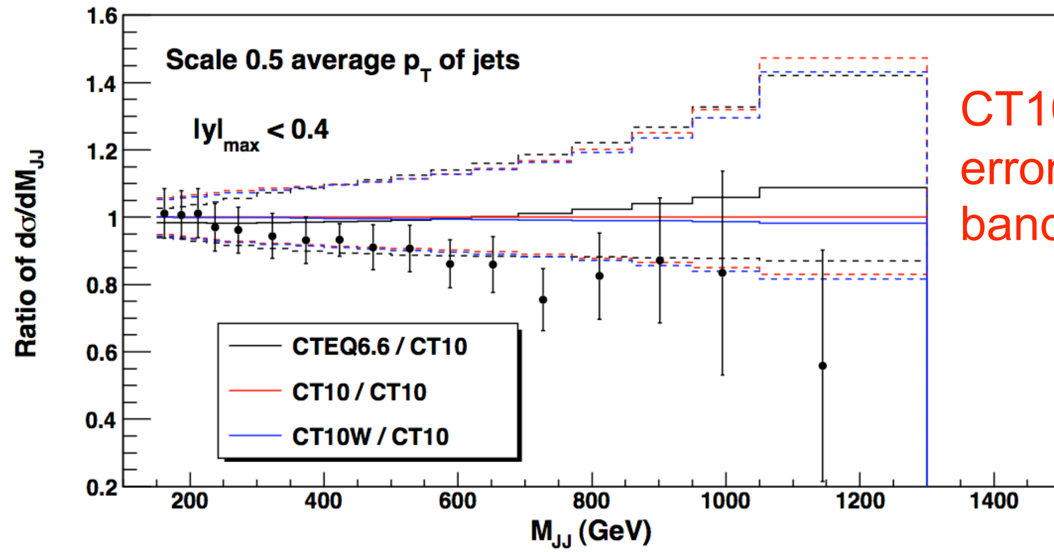


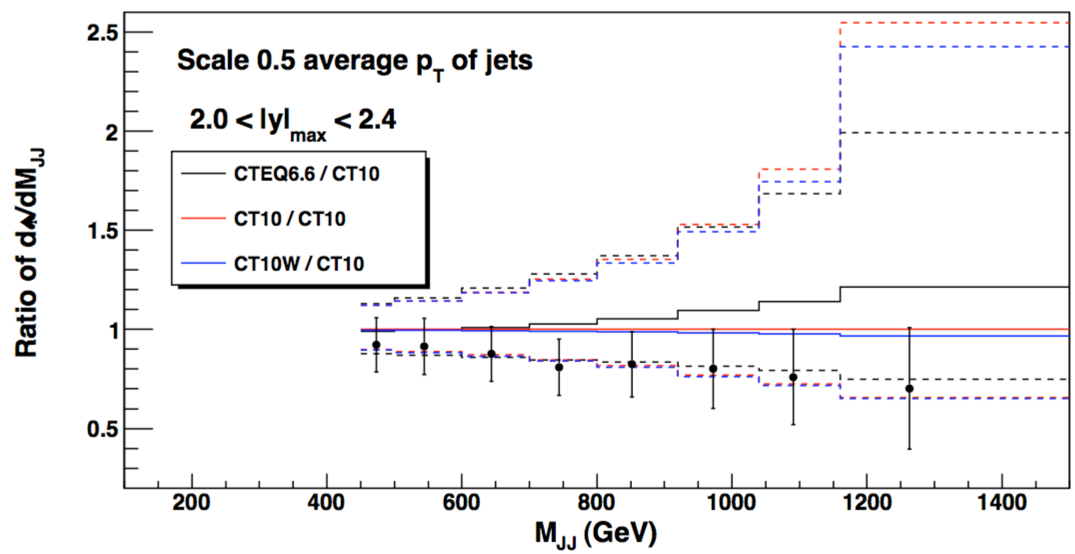
FIG. 17: Comparison of the scale dependence of the jet cross section at E_T=170 GeV/c for the leading- and next-to-leading-logarithm calculations

$p_T^{jet}/2$

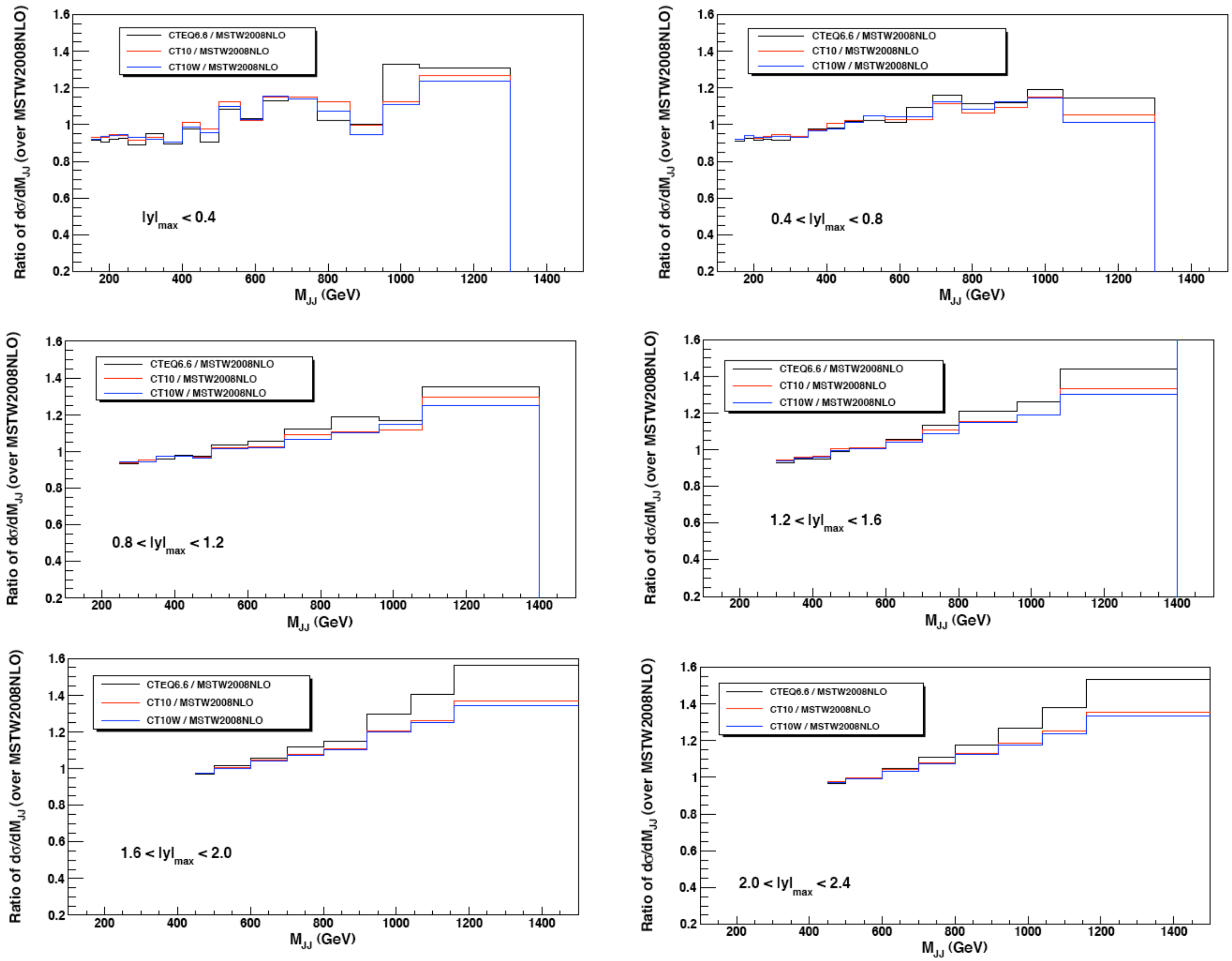
- Evaluating the D0 cross sections with a scale of $p_T^{jet}/2$ leads to somewhat smaller predictions in some regions, though still above the data; no Run 2 data in CTEQ6.6
  - but note that D0 data largely within the CTEQ6.6 PDF error bands
  - MSTW2008prediction also within CTEQ6.6 PDF error bands
  - as we've seen in the benchmarks, the CTEQ and MSTW errors are similar in most kinematic regions, but not for the high x gluon
- CT10 prediction has Run 2 jet data (while retaining Run 1 data), resulting in somewhat lower predictions
- This is all before any systematic error shifts, which lead to even better agreement between data and theory



CT10 error band



Some comparisons



CT10 prediction still larger than that from MSTW2008 (perhaps due to Run 1 jet data), but is lower than that of CTEQ6.6 (as a result of the Run 2 D0 jet data)

Figure 25: The ratios of LO di-jet invariant mass distribution at Tevatron Run II, using CTEQ6.6 (black), CT10 (red) and CT10W (blue) PDFs over MSTW2008NLO PDFs.

Summary

- CT10/CT10W PDFs include combined HERA data set, Tevatron Run 2 jet data, Tevatron Run 2 asymmetry data
- The latter in particular results in tension with existing data sets present in CTEQ6.6; thus 2 new PDFs
- Draft nearly complete
- Work continuing on NNLO PDFs

Interim note discussion

Can we provide all predictions in this (or similar) common format?

$\alpha_s(m_Z)$	$\sigma_{W^+} * BR(W^+ \to l^+\nu)$[nb]	$\sigma_{W^-} * BR(W^- \to l^-\nu)[nb]$	$\sigma_{Z^o} * BR(Z^o \to l^+l^-)[nb]$	$\sigma_{t\bar{t}}[pb]$
0.116	5.957	4.044	0.9331	149.2
0.117	5.993	4.068	0.9384	156.2
0.118	**6.057**	**4.106**	**0.9469**	**156.2**
0.119	6.064	4.114	0.9485	160.5
0.120	6.105	4.139	0.9539	164.3

Table 1: Benchmark cross section predictions for CTEQ6.6 for $W^{\pm}, Z, t\bar{t}$ production at 7 TeV, as a function of $\alpha_s(m_Z)$. The results for the central value of $\alpha_s(m_Z)$ for CTEQ6.6 (0.118) are shown in bold.

$\alpha_s(m_Z)$	$\sigma_{gg\to Higgs}(120GeV)[pb]$	$\sigma_{gg\to Higgs}(180GeV)[pb]$	$\sigma_{gg\to Higgs}(240GeV)[pb]$
0.116	11.25	4.69	2.52
0.117	11.42	4.76	2.57
0.118	**11.59**	**4.84**	**2.61**
0.119	11.75	4.91	2.66
0.120	11.92	4.99	2.70

Table 2: Benchmark cross section predictions for CTEQ6.6 for $gg \to Higgs$ production (masses of 120, 180 and 240 GeV) at 7 TeV, as a function of $\alpha_s(m_Z)$. The results for the central value of $\alpha_s(m_Z)$ for CTEQ6.6 (0.118) are shown in bold. Cross sections have been corrected for the finite top mass effect (a factor of 1.06 for 120 GeV, 1.15 for 180 GeV and 1.31 for 240 GeV).

Interim note discussion

Process	Cross section	PDF errors (asym)	PDF errors (sym)	$\alpha_s(m_Z)$ error	combined
$\sigma_{W^+} * BR(W^+ \to l^+\nu)[nb]$	6.057	+0.123/-0.119	0.116	0.045	0.132
$\sigma_{W^-} * BR(W^- \to l^-\nu)[nb]$	4.106	+0.088/-0.091	0.088	0.029	0.092
$\sigma_{Z^o} * BR(Z^o \to l^+l^-)[nb]$	0.9469	+0.018/-0.018	0.018	0.006	0.0187
$\sigma_{t\bar{t}}[pb]$	156.2	+7.0/-6.7	6.63	4.59	8.06
$\sigma_{gg \to Higgs}(120GeV)[pb]$	11.59	+0.19/-0.23	0.21	0.20	0.29
$\sigma_{gg \to Higgs}(180GeV)[pb]$	4.840	+0.077/-0.091	0.084	0.091	0.124
$\sigma_{gg \to Higgs}(240GeV)[pb]$	2.610	+0.054/-0.058	0.056	0.055	0.078

Table 3: Benchmark cross section predictions and uncertainties for CTEQ6.6 for $W^{\pm}, Z, t\bar{t}$ and Higgs production (120, 180, 240 GeV) at 7 TeV. The central prediction is given in column 2. Errors are quoted at the 68% CL. (For CTEQ6.6, this involves dividing the normal 90%CL errors by a factor of 1.645. Both the symmetric and asymmetric forms for the PDF errors are given. In the last column, the (symmetric) form of the PDF and $\alpha_s(m_Z)$ errors are added in quadrature.

Interim note discussion

y_W	$\frac{d\sigma_{W+}}{dy} * BR(W^+ \to l^+\nu)[nb]$	$\frac{d\sigma_{W-}}{dy} * BR(W^- \to l^-\nu)[nb]$	$\frac{d\sigma_{Z^o}}{dy} * BR(Z^o \to l^+l^-)[nb]$
-4.4	0.002	0.000	0.000
-4.0	0.094	0.019	0.005
-3.6	0.367	0.122	0.031
-3.2	0.634	0.274	0.071
-2.8	0.806	0.414	0.106
-2.4	0.878	0.517	0.127
-2.0	0.886	0.597	0.141
-1.6	0.883	0.653	0.148
-1.2	0.867	0.697	0.155
-0.8	0.862	0.723	0.166
-0.4	0.855	0.739	0.161
0.0	0.864	0.750	0.162
0.4	0.854	0.740	0.161
0.8	0.865	0.728	0.158
1.2	0.870	0.690	0.155
1.6	0.882	0.654	0.148
2.0	0.890	0.606	0.141
2.4	0.872	0.508	0.114
2.8	0.806	0.416	0.106
3.2	0.640	0.274	0.071
3.6	0.364	0.120	0.031
4.0	0.095	0.023	0.005
4.4	0.003	0.000	0.000

add PDF errors per y bin?

Table 4: Benchmark cross section predictions ($d\sigma/dy$ in nb) for CTEQ6.6 for $W^\pm$, Z^o production at 7 TeV, as a function of boson rapidity.

What other conventions can we work on?

- Heavy quark masses?
  - I'll trade Robert the charm mass for $\alpha_s(m_Z)$?
- Scale uncertainties?