# CTEQ-TEA update
# +some discussion topics

J. Huston

for the CTEQ-TEA group

Michigan State University

QCD@LHC St. Andrews

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…borrowing transparencies from my DPF QCD plenary talk and from Pavel's DESY SM talk

# Recent history

- CTEQ6.6
  - published in 2008: in general use at LHC; one of the PDFs used for the PDF4LHC interim recommendations
    - Phys.Rev.D78:013004,2008.
      e-Print: arXiv:0802.0007 [hep-ph]
  - *Uncertainty induced by QCD coupling in the CTEQ-TEA global analysis of parton densities*
    - e-Print: arXiv:1004.462
    - $\alpha_s$ 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]
    - BTW: since Powheg/MC@NLO now being used for many cross sections at the LHC with NLO PDFs for matrix element evaluation,and UE tunes exist for most NLO PDFs can also use NLO PDFs for UE/parton showering
- CT10/CT10W
  - *New Parton Distributions for Collider Pysics*
    - published in PRD82:074024,2010
    - most up-to-date, includes Tevatron jet data from both Run 1 and Run 2, HERA1 combined data, as well as D0 Run 2 W lepton asymmetry data (for CT10W)

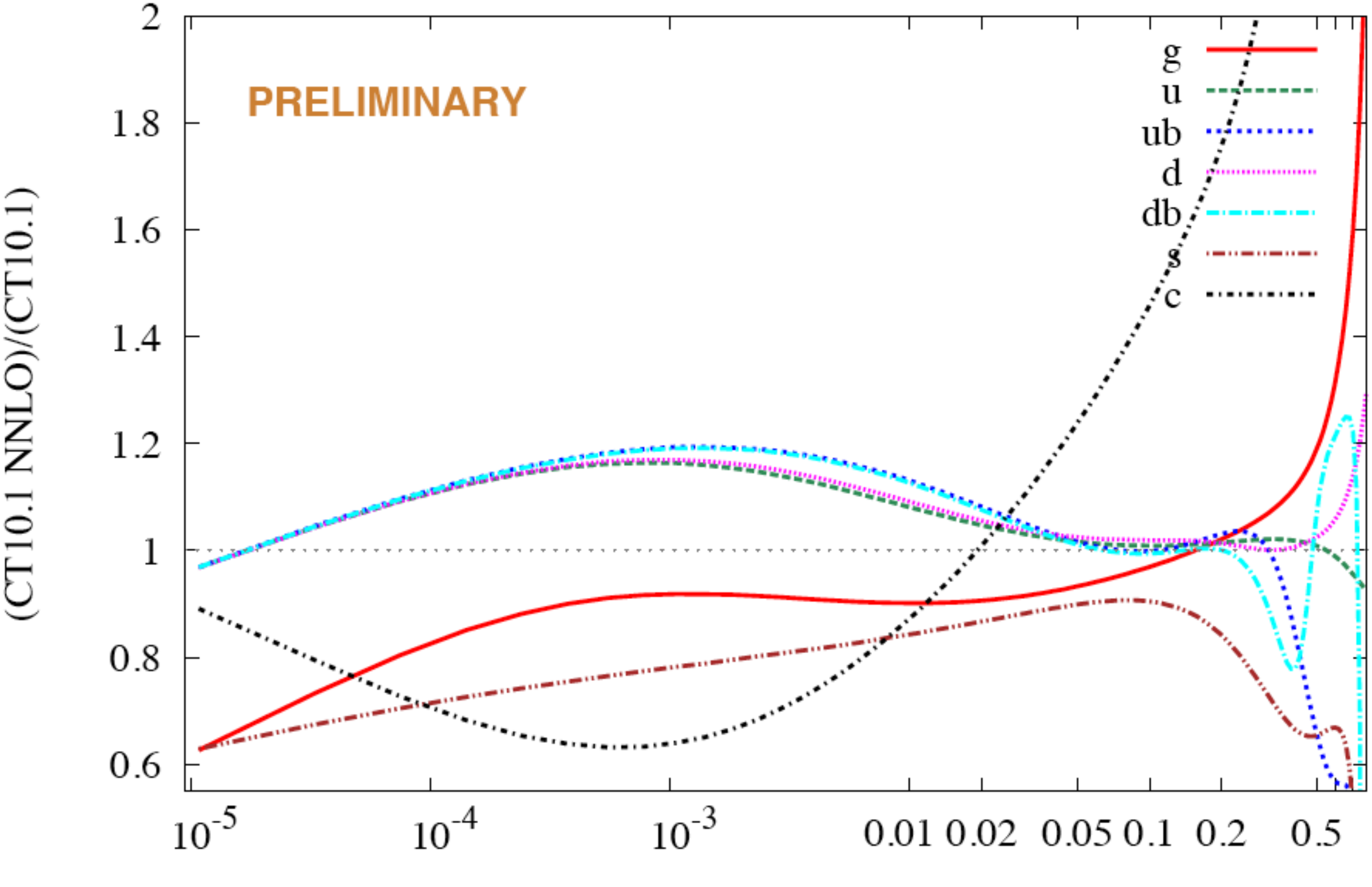
# CT10

- 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 $\chi^2$ 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

# CT10.1/CT10.2

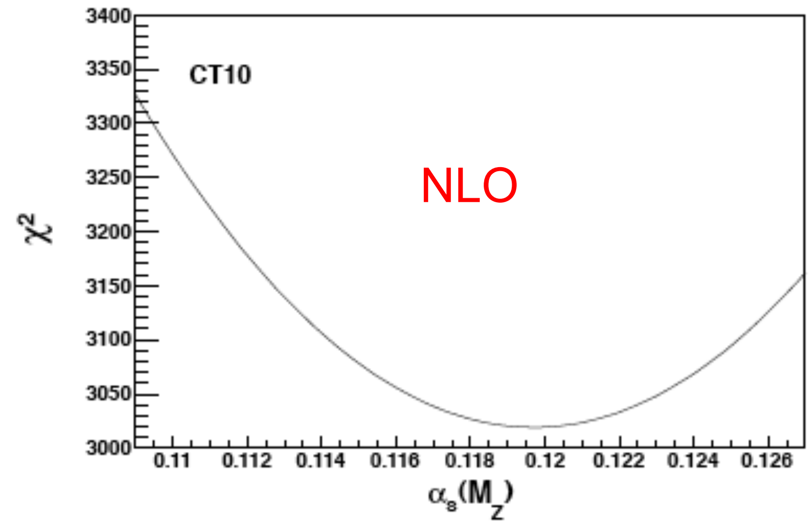
- CT10.1 NLO: extension of CT10(W) analysis, with alternative treatment of some data sets
  - Tevatron Run 2 electron charge asymmetry
  - inclusive jet production
- CT10.2 NNLO: first NNLO PDF from CTEQ
  - S-ACOT heavy quark scheme used (see Pavel's talk)
  - $\alpha_s(m_Z)=0.118$, $m_c^{pole}=1.3$ GeV, $m_b^{pole}=4.75$ GeV
  - slightly worse $\chi^2$ (3154/2765 for NNLO compared to 3090 for NLO)
  - differences between NLO and NNLO sets are comparable to similar differences observed by other groups
    - reduced gluon at x->0; increased light quarks at $x \sim 10^{-3}$; lower strangeness
  - finishing up work on some issues related to gluon distribution before releasing PDFs

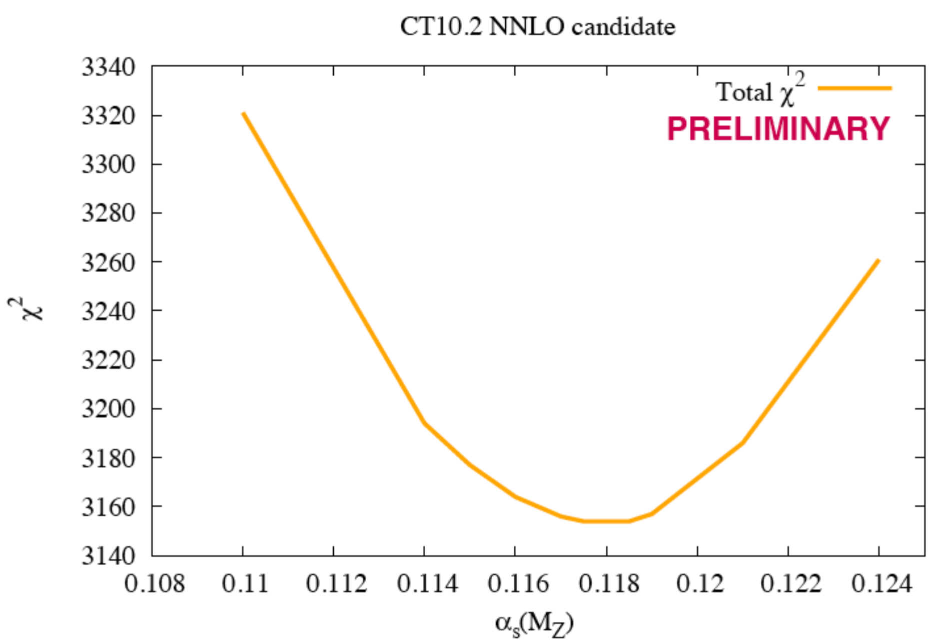
# NNLO to NLO comparison



# $\alpha_s$ at NNLO

NB: small changes in $\alpha_s$ have little impact on global PDF fits, but major impacts on LHC cross sections



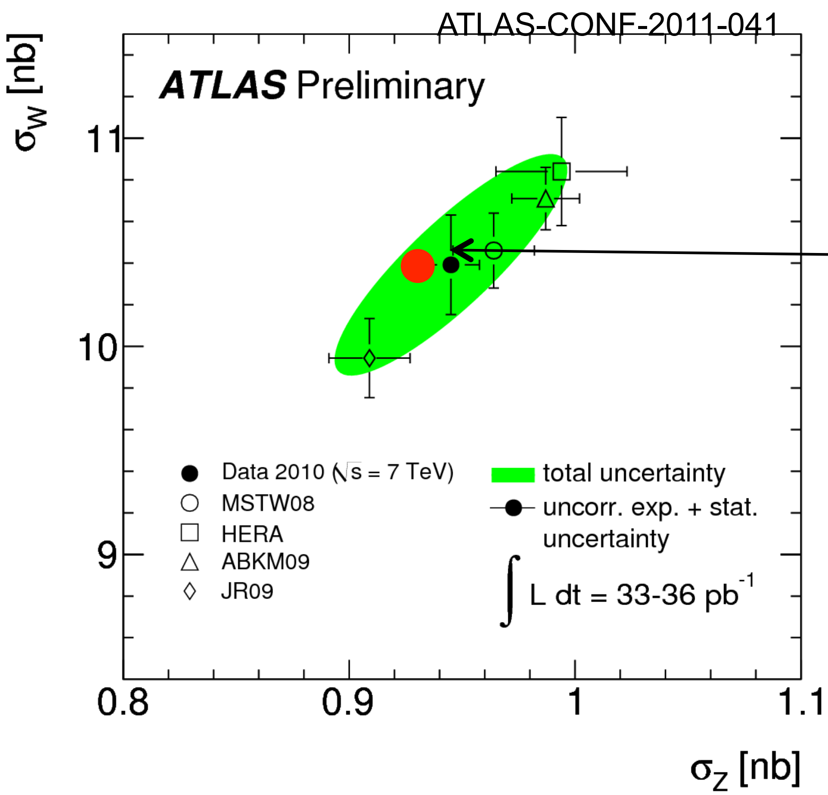

$\alpha_s$ decreases slightly at NNLO, has about the same PDF uncertainty as at NLO

Global world average =0.1184+/-0.0007 (includes NLO, NNLO, lattice input)

PDF4LHC used 0.118+/-0.002 (90%CL)

- NLO: $\alpha_s(M_Z) = 0.11964 \pm 0.0064$ at 90% c.l.
- NNLO: $\alpha_s(M_Z) = 0.118 \pm 0.005$

# LHC: W, Z cross sections

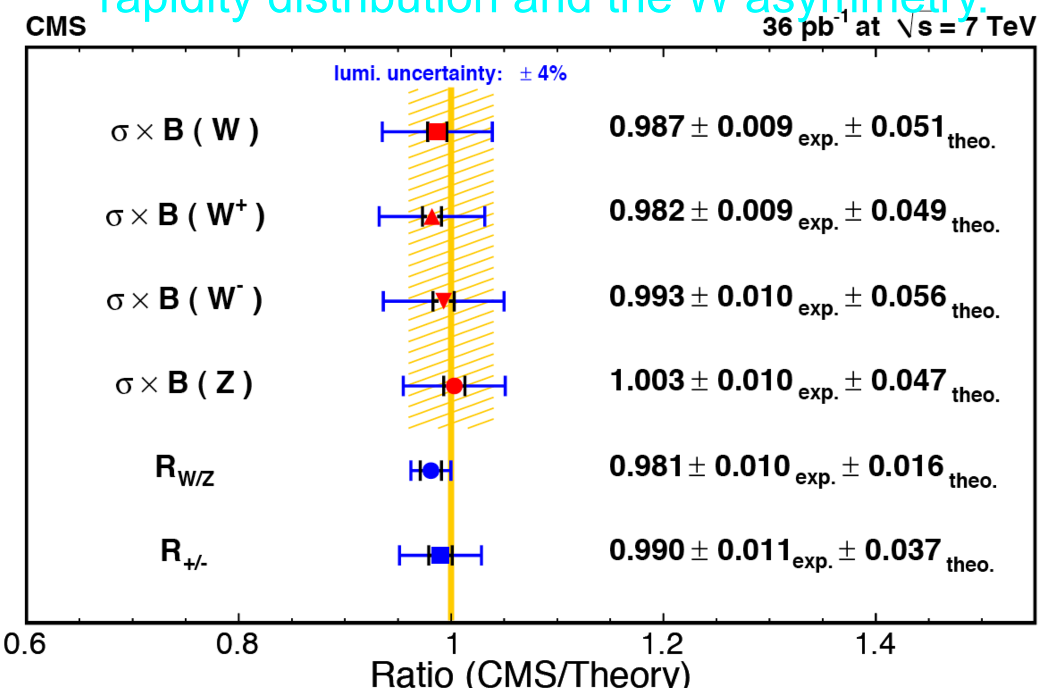



CT10.2 NNLO prediction

Many of the experimental/theory errors cancel with the ratio

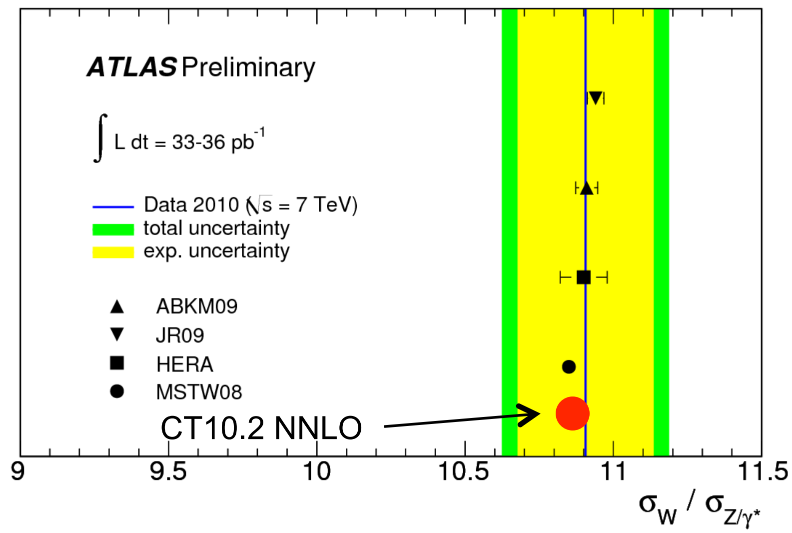
Of course, there is much additional informatic that will be used in PDF fits, such as the Z rapidity distribution and the W asymmetry.

ATLAS W/Z cross section ratio in good agreement with NNLO predictions from the PDF groups shown

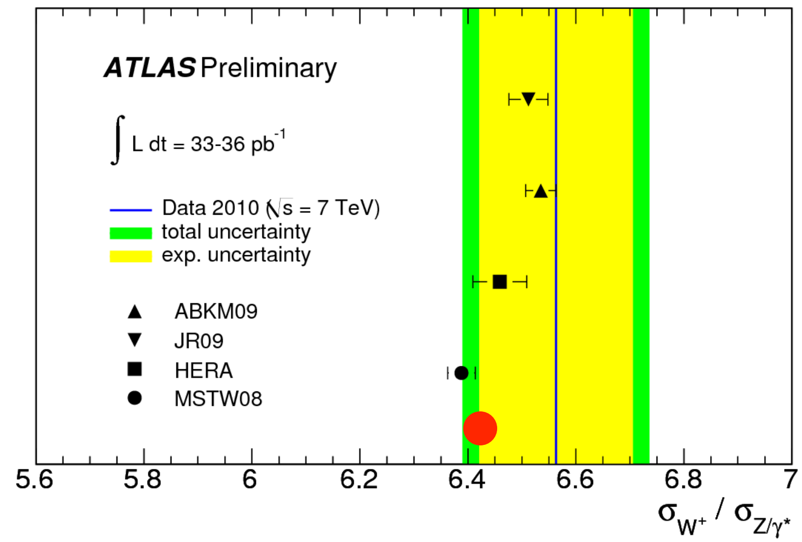


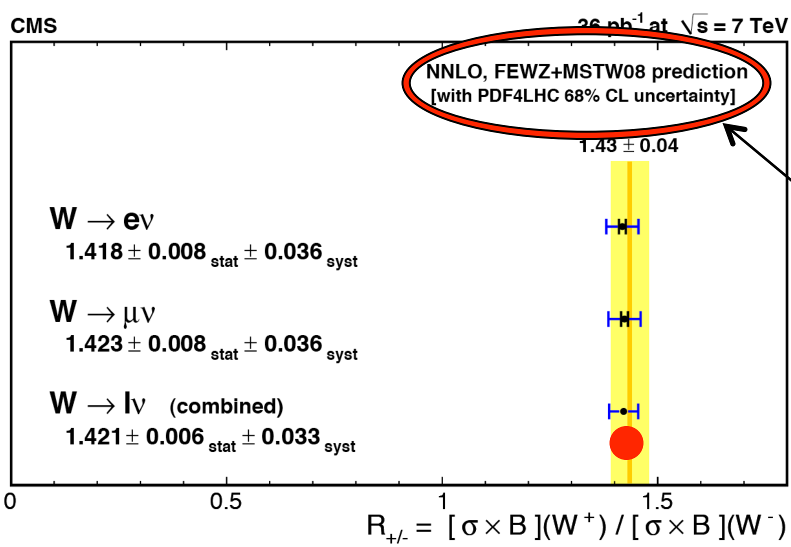

PDF4LHC CMS PAS EWK-10-005

# LHC: W/Z ratios

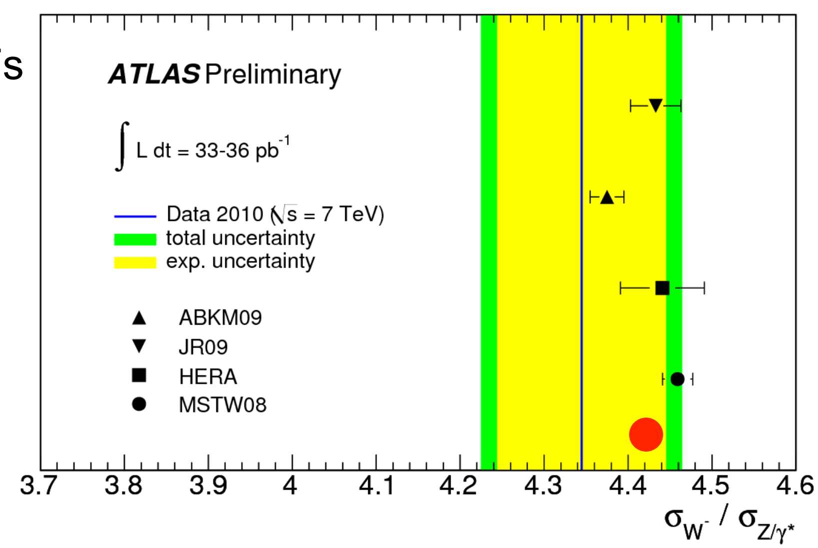



Total W/Z ratio from ATLAS in good agreement with theory, but separate $W^+/Z$ and $W^-/Z$ ratios show some differences (at 1 sigma level) for some of PDFs



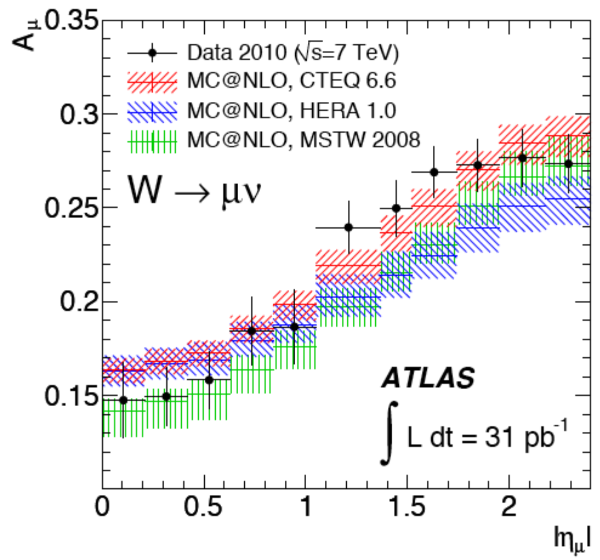

CMS results for W,Z use PDF4LHC recipe for NNLO; good agreement with theory



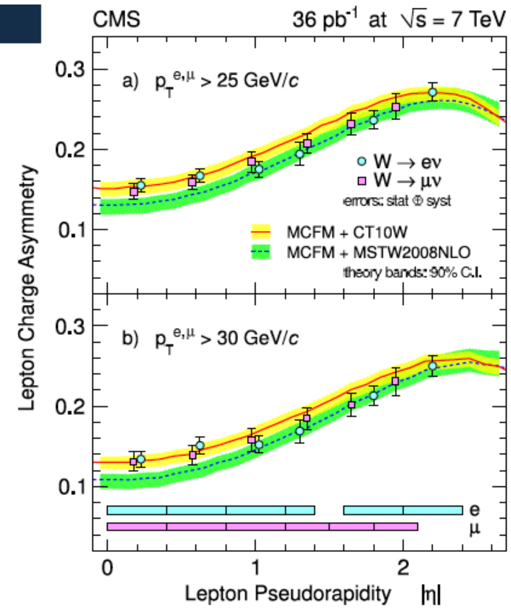
# W lepton asymmetry

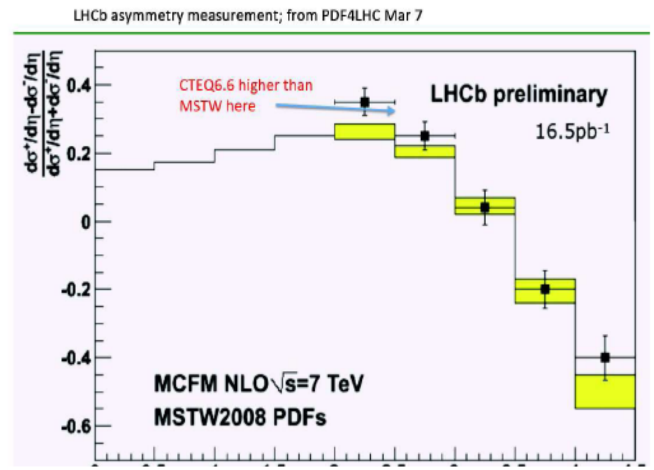
- Potentially has quickest PDF impact; somewhat different between ATLAS and CMS; LHCb adds kinematic extension

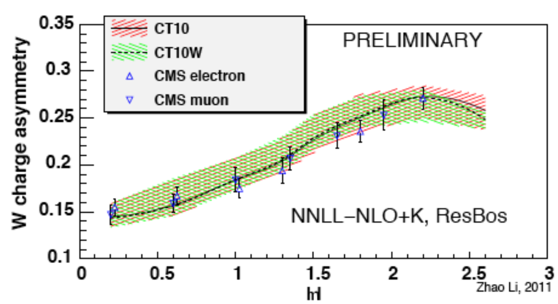
## CT10(W) vs. $A_\ell$ at the LHC

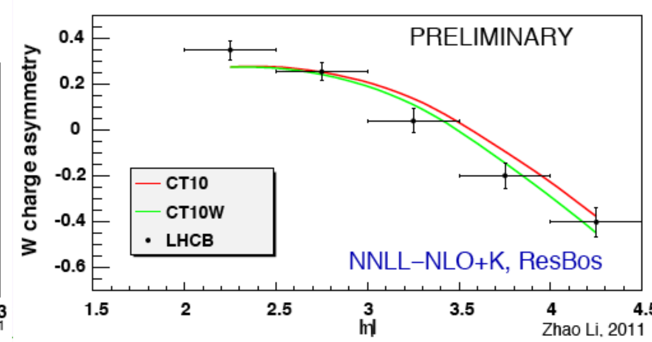



CT10(W) agrees well with the LHC $A_\ell$; some differences between NLO and NNLL+NLO




…so should use programs like ResBos/MC@NLO for comparisons/inclusion in fits

# ATLAS: inclusive jets

- Important to carry predictions out over wide rapidity range. New physics tends to be central. Old physics (PDFs) has an impact on all rapidity regions. This data (or higher statistics version can be fed back into global PDF fits and can/will have impact, especially on high x gluon.

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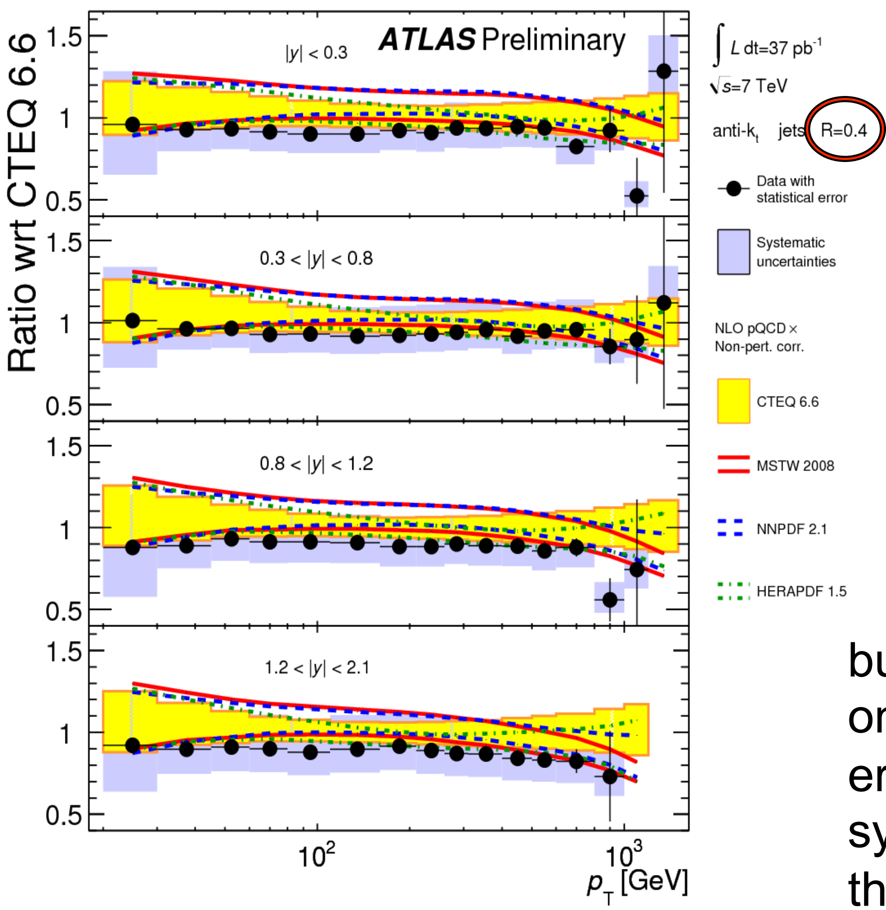
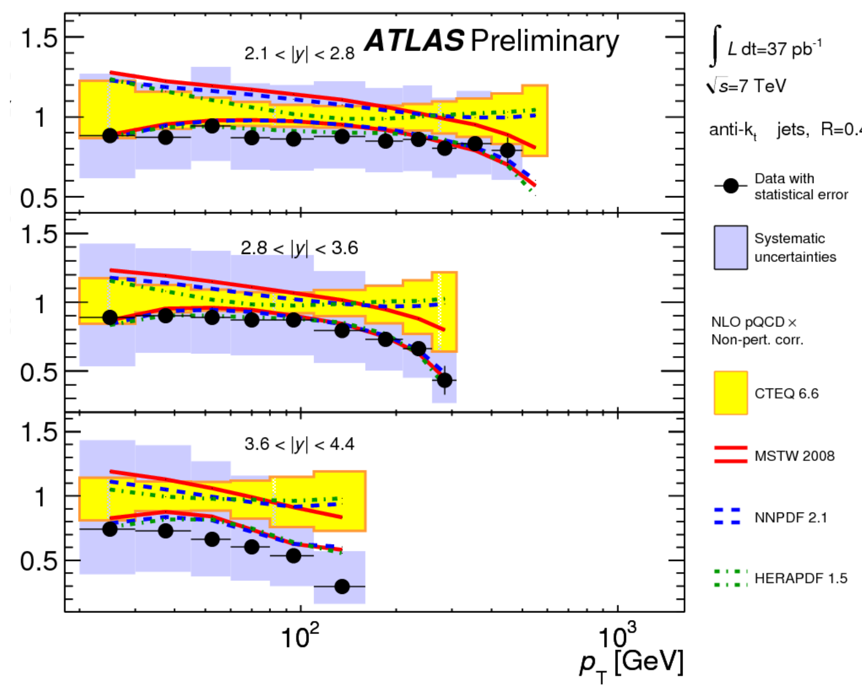
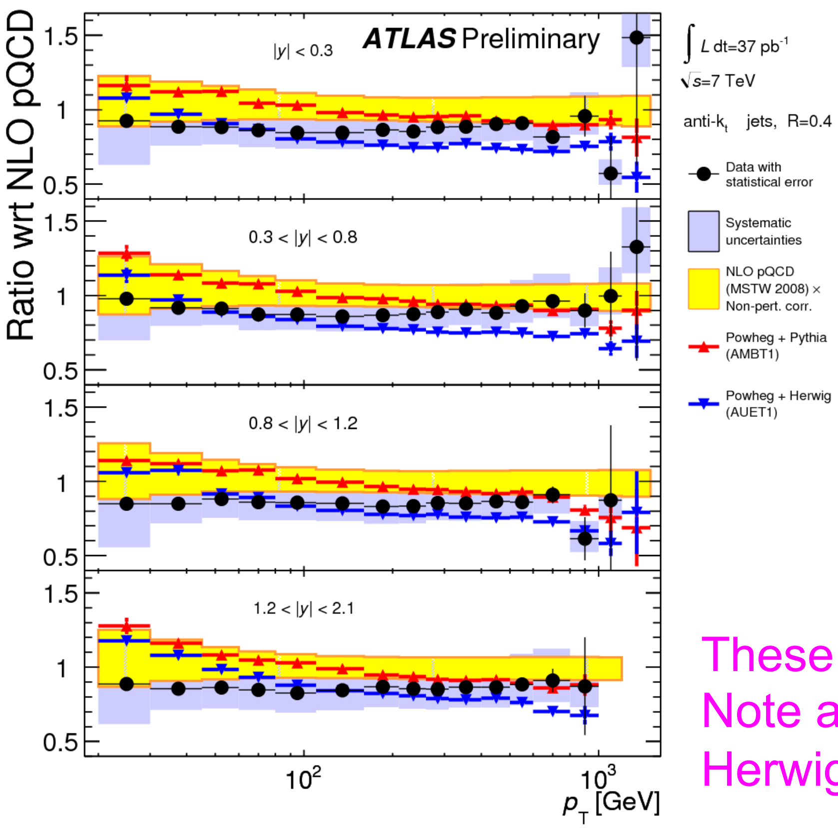


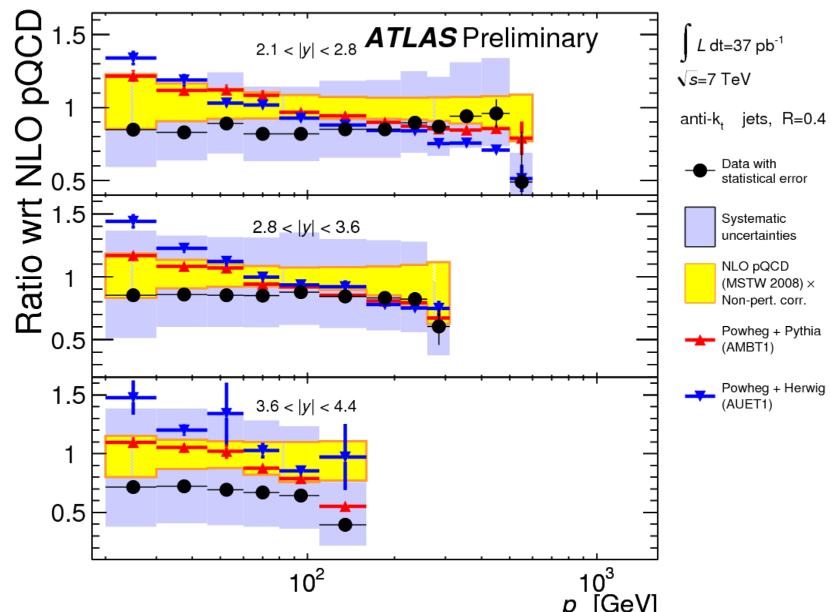




but the use in global PDF fits is possible only once detailed correlated systematic error information is made available. For jets, systematic errors are much more important than statistical errors.

# Inclusive jets: Powheg

- Powheg is a method for the inclusion of NLO matrix element corrections into parton shower Monte Carlos
- Experimentalists were ecstatic when inclusive jet production was added
- Note that Powheg predictions have a somewhat different shape than fixed order perturbative predictions (NLOJET++). This is something that must be understood, and investigation is currently underway. **This would be a good topic for this workshop.**




These differences will affect the global PDF fits. Note also differences between Pythia and Herwig showering.

# Issue not new: from my talk at March PDF4LHC meeting

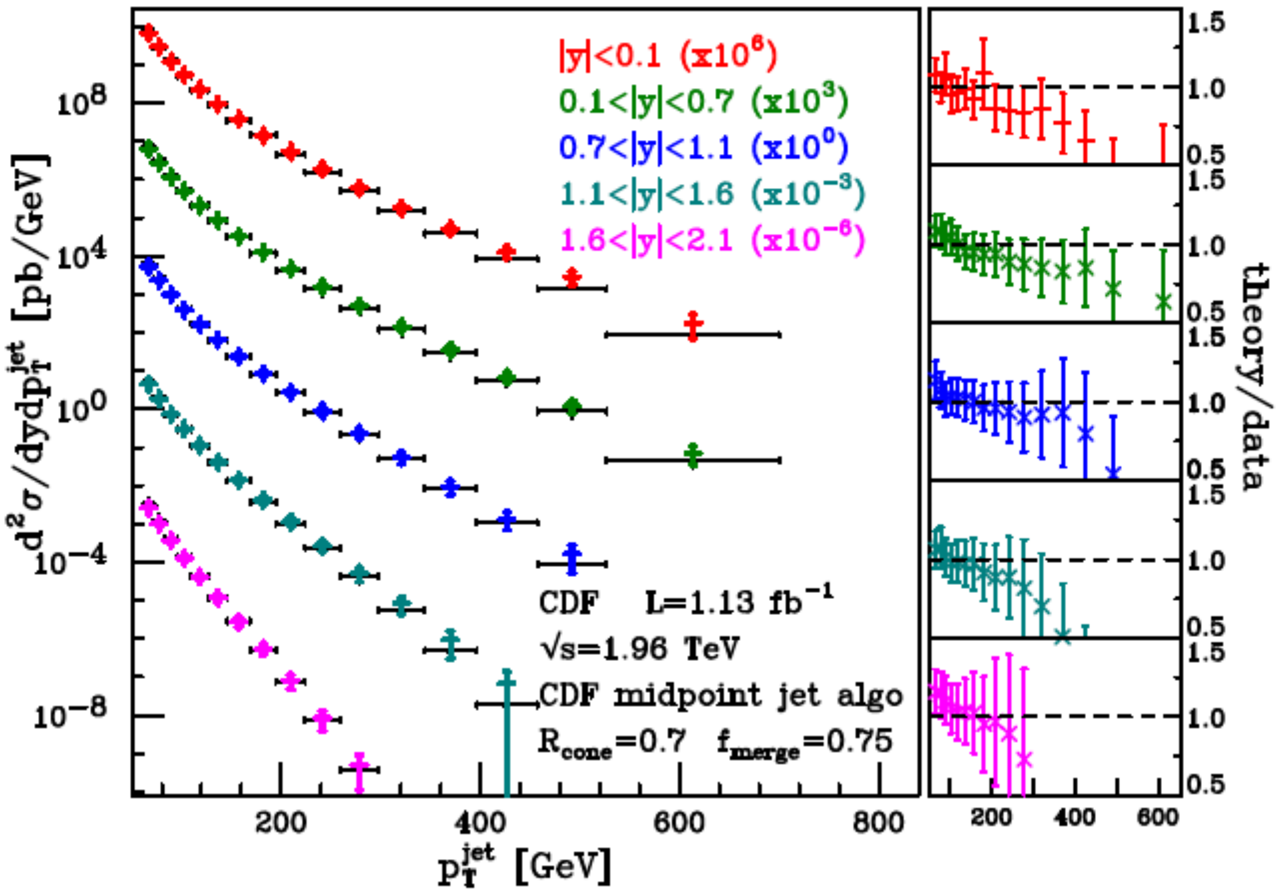



Figure 20: Predictions and experimental results for the double-differential inclusive jet cross section as a function of the transverse momentum of the jet $p_T^{jet}$, for different bins of jet rapidity, $y$, as measured by the CDF Collaboration, using the cone-based midpoint jet algorithm. Black lines are the POWHEG+PYTHIA results (error bars are drawn too, even if almost invisible on the plot scale), while coloured bars are the experimental data (with errors represented as vertical bars) [30]. Data are shown from top to bottom in order of increasing rapidity.

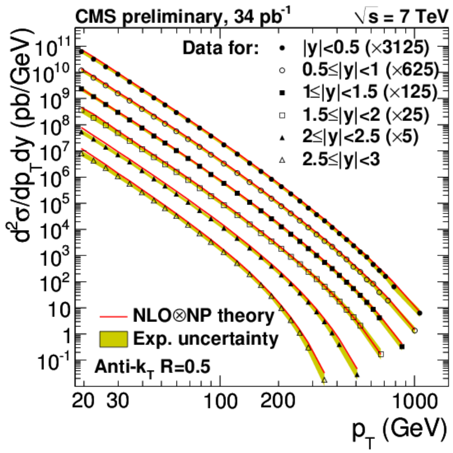
…from *Jet Pair Production in Powheg*, arXiv:1012.3380

note that theory/data has a slope not evident with fixed order comparisons (NLO corrected by UE/hadronization)

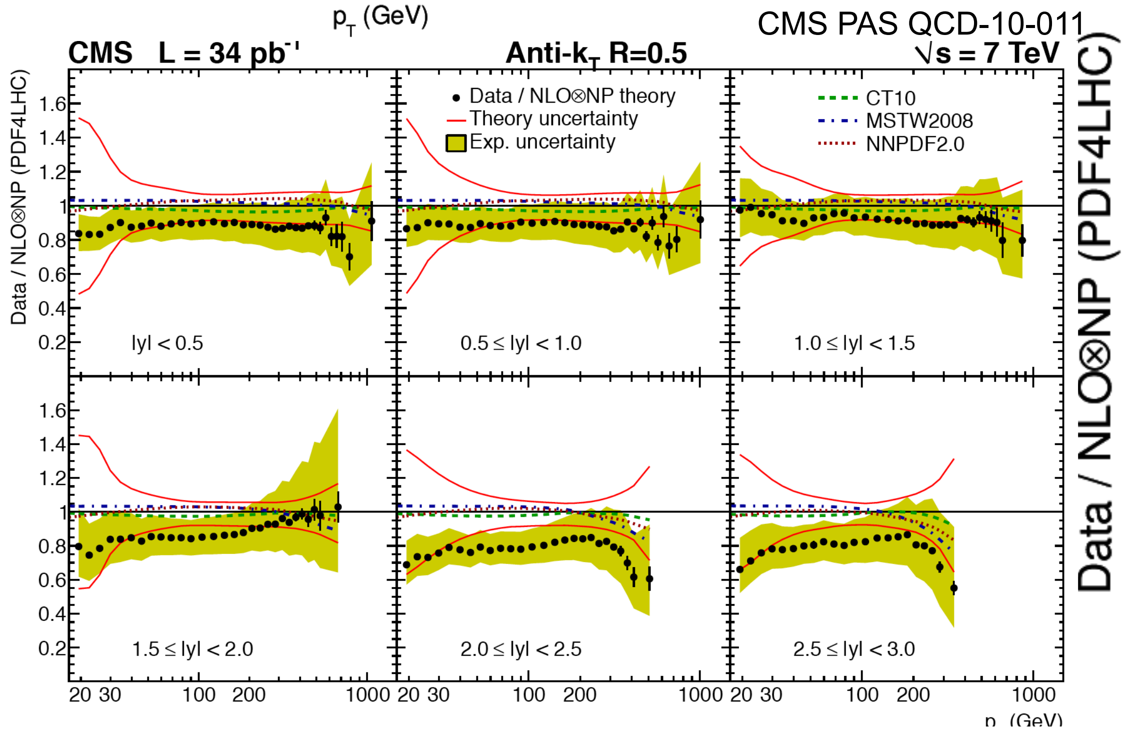
also observed in ATLAS comparisons (but can't show them here)

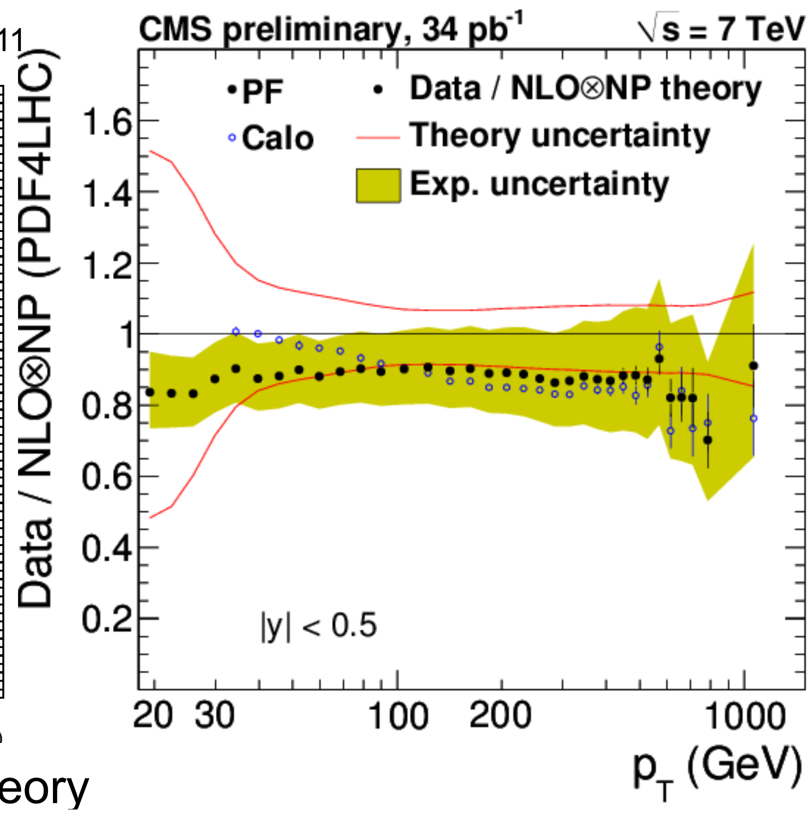
an effect we need to understand

# CMS: inclusive jets



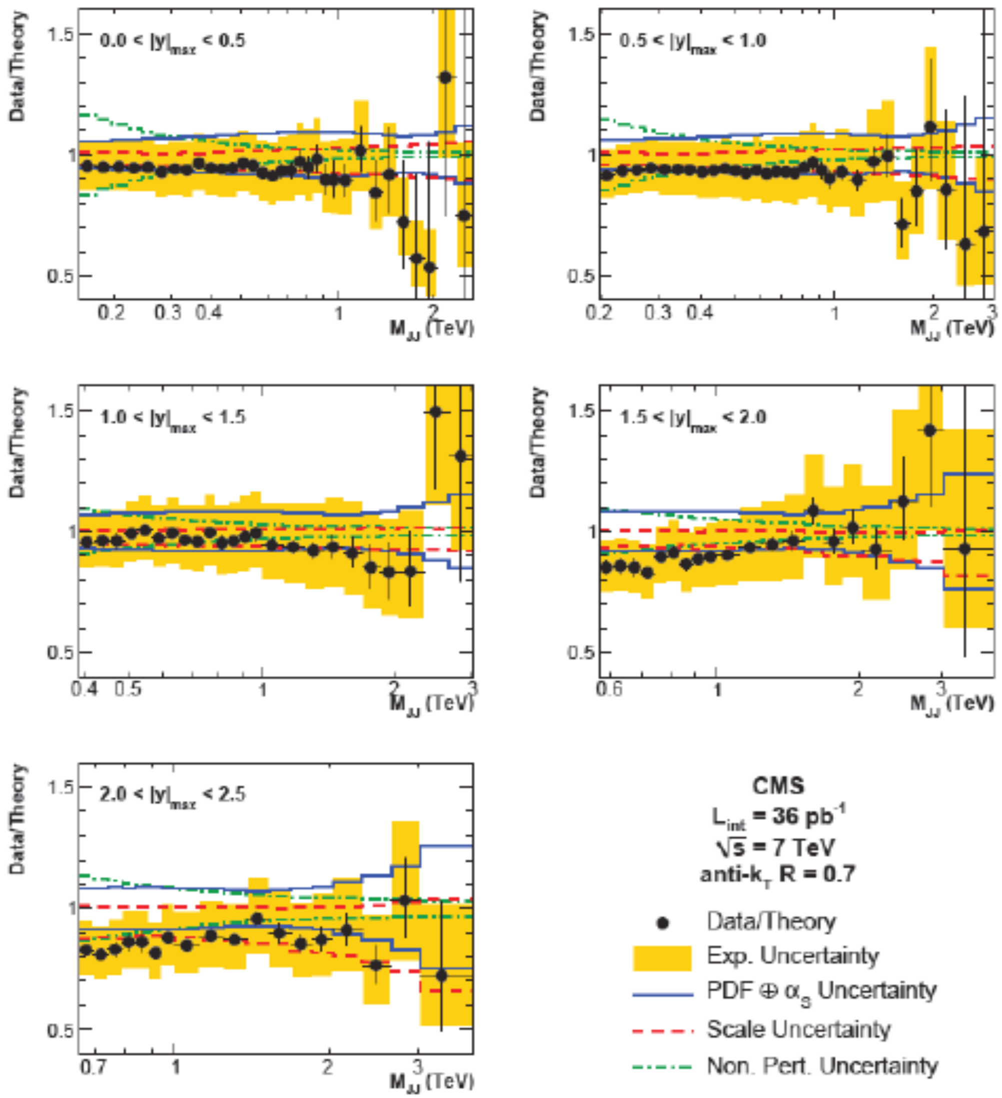

Here the comparison is to predictions using the midpoint of CT10, MSTW2008 and NNPDF2.0, with the error band given by the envelope (i.e. the PDF4LHC prescription). The theory error also includes the scale choice and NP uncertainties.



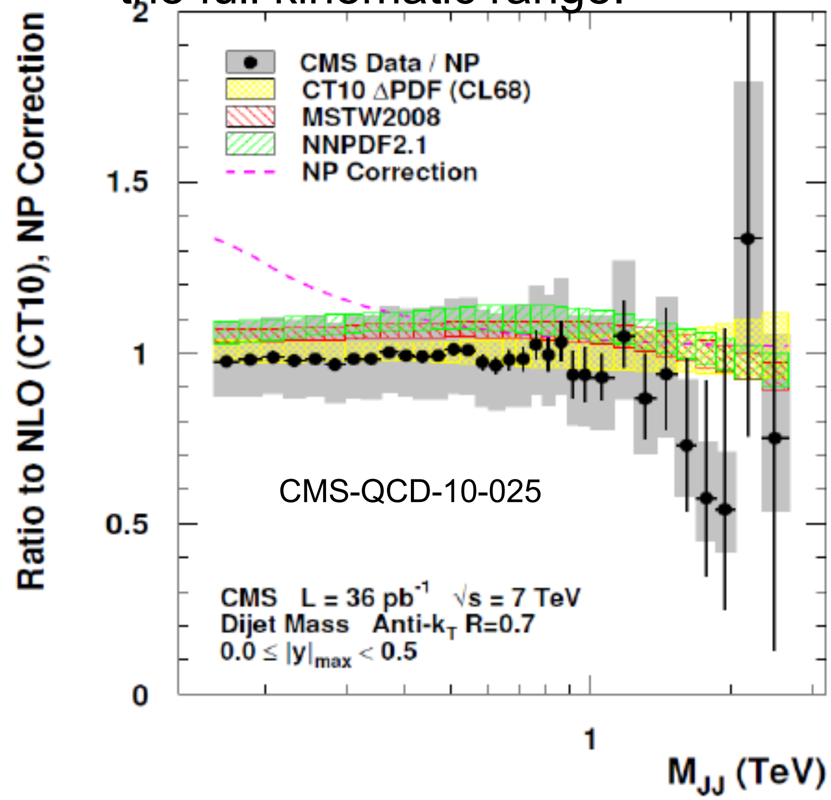




…agreement but data a bit low compared to theory

# CMS: dijets



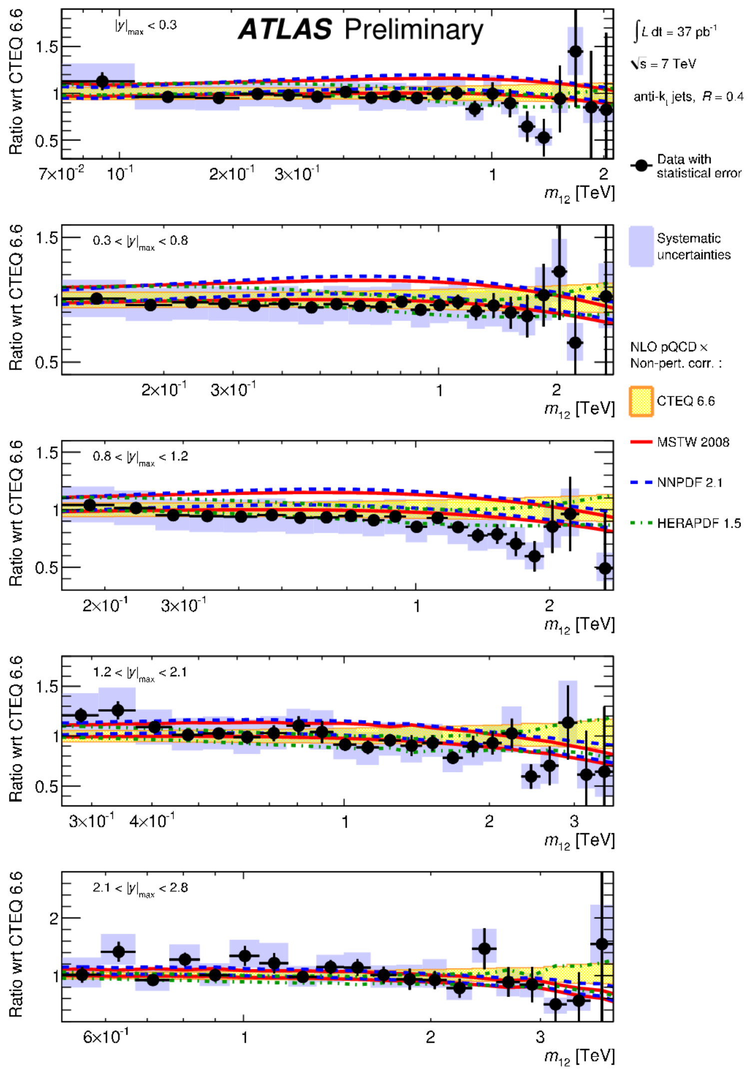

Here, the results (plotted vs $y_{max}$, the maximum rapidity of the two leading jets, are in reasonable agreement with the NLO predictions (using CT10) over the full kinematic range.



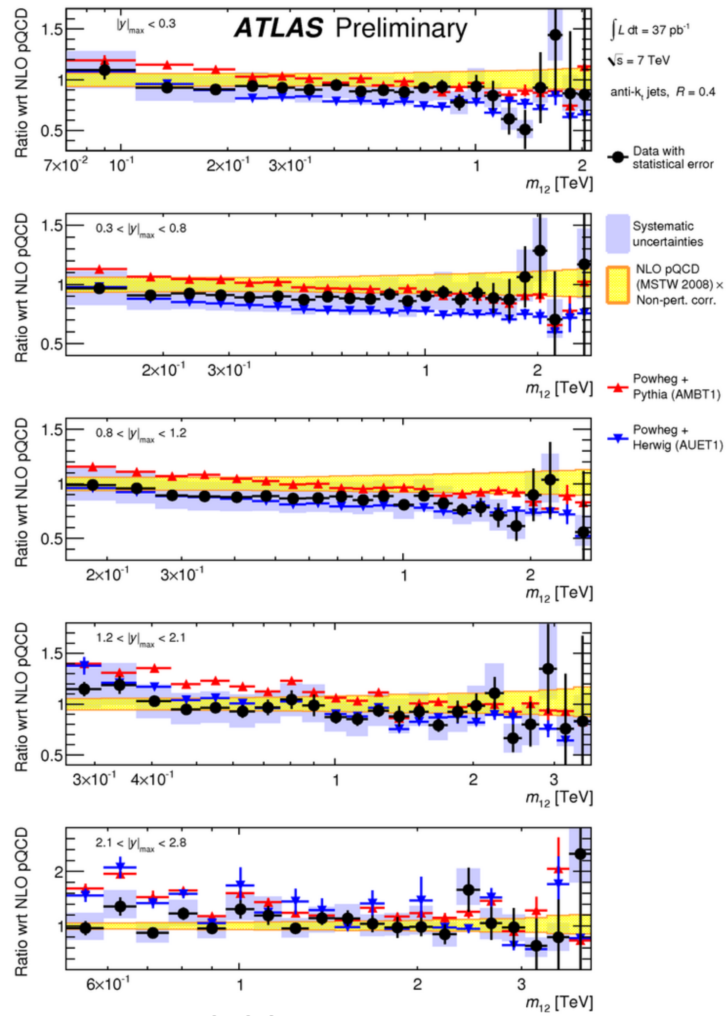
# ATLAS: dijets

Plot the cross section as a function of $|y_{max}|$.

NLOJET++




Powheg

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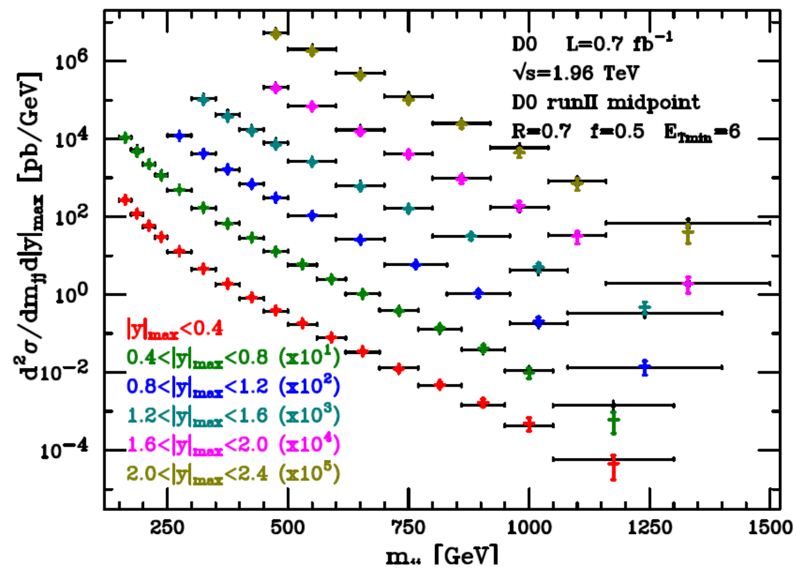
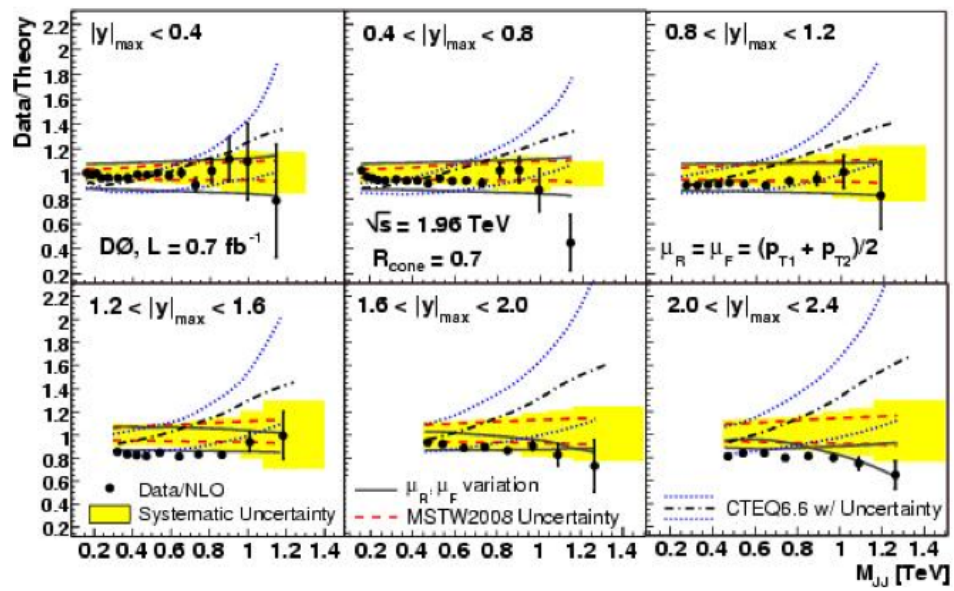
again, as for inclusive jet production, we see that there are some shape differences between fixed order and Powheg that need to be understood, especially in the forward region.

# Older result:D0 dijet cross section

- Powheg predictions (black lines), using CTEQ6 PDFs, in very good agreement with the D0 data
- Not seen (without systematic error shifts) for fixed order predictions



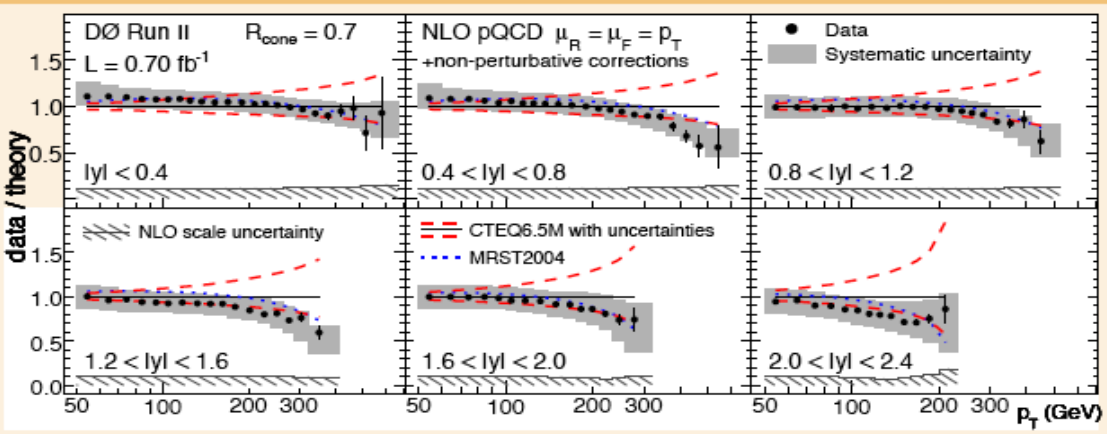
# Jet data: systematic errors crucial

- CDF Run 2 jets
  - CT10: $\chi^2$/npt= 112.3/72 with $R^2$=16.5
  - CT10.1: 119.5/72 with $R^2$=20.0
  - MSTW08: 118.2/72 with $R^2$=22.8

$R^2$=contributions of systematic error shifts to $\chi^2$; contribution should be on order of 1 per syst error; no >>1 error shifts for any error

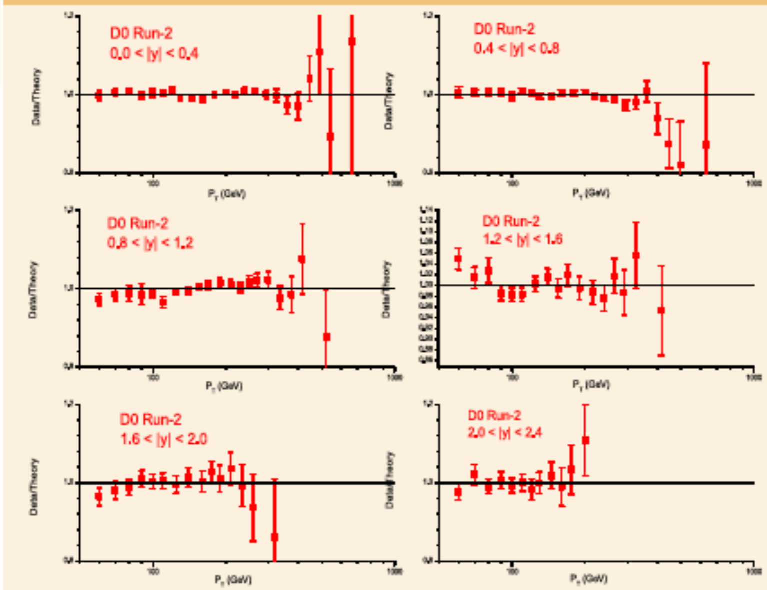
- D0 Run 2 jets
  - CT10: $\chi^2$/npt= 125.6/110 with $R^2$=19.8
  - CT10.1: 122.9/110 with $R^2$=22.3
  - MSTW08: 120.7 with $R^2$=16.1

**D0 Coll., arXiv:0802.2400 (700 $pb^{-1}$)**




"Discrepancy"?

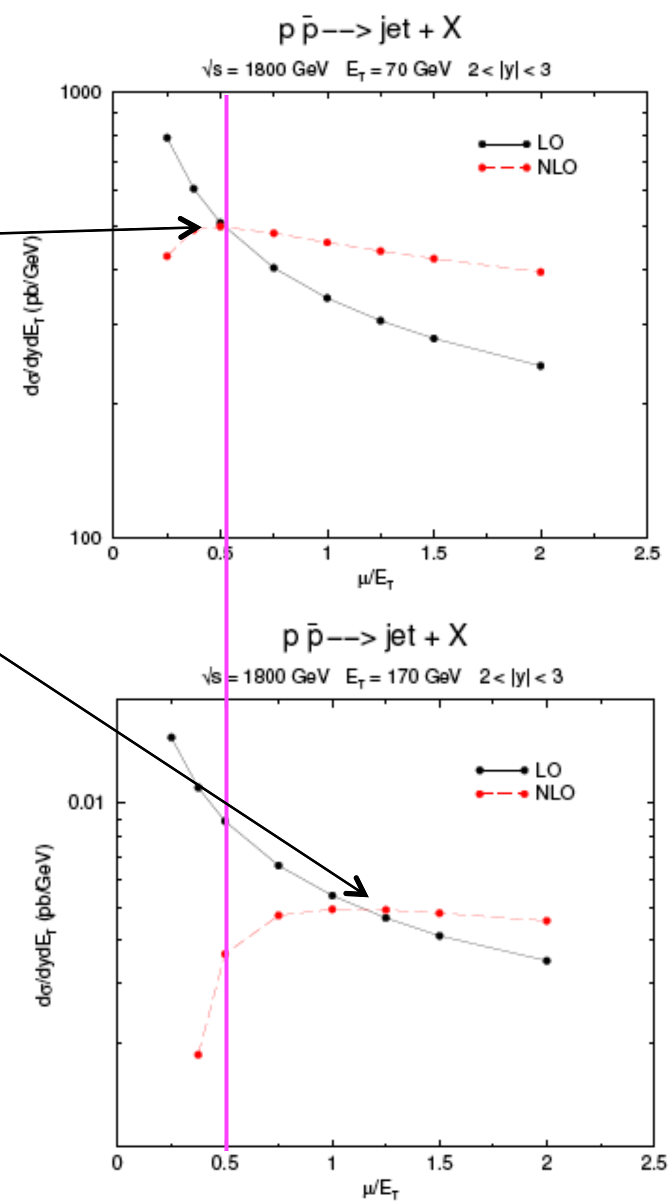
**(Shifted D0-Run 2 data)/CT09**




Good agreement

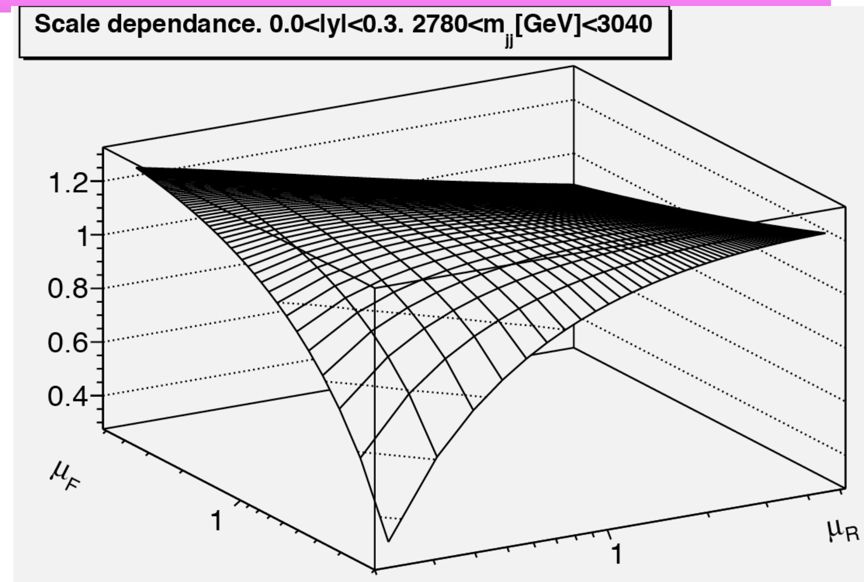
# Scale choices

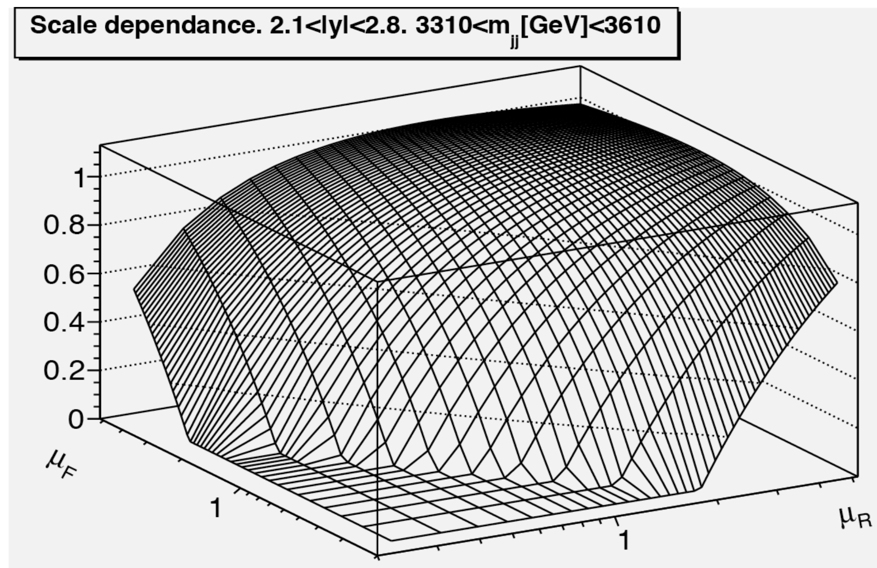
- CTEQ PDFs have used a scale of $p_T^{jet}/2$ for fitting inclusive jet cross sections
  - typically near peak of cross section for central kinematics
  - original suggestion of Ellis-Kunzst-Soper
- For high $y/p_T$, jet cross sections peak at higher scales
  - if PDFs are fit with scale $p_T/2$, and scale of $p_T$ is used for comparison by experimentalists, then effective cross section increases in these regions
- A scale of $p_T^{jet}$ is in many cases more appropriate at the LHC, so we have now switched to that
  - that scale, however, is not large enough for high $y/p_T$ at the LHC, where cross sections with scale $p_T^{jet}$ can be negative (for NLOJET ++, not Powheg)



# Scale dependence

- Top shows scale dependence for central kinematics
  - saddle point around $p_T^{jet}$
- Bottom shows scale dependence for forward kinematics
- For latter case, cross section is positive (and relatively constant) for higher scales (~$3*p_T^{jet}$)



# Summary

- Newest generations of CTEQ-TEA PDFs will be CT10.1 (NLO), CT10.2 (NNLO)
- Still many issues relating to cross sections at the Tevatron/LHC that have to be addressed for PDF fits