mLO-PDFs

Modified Leading Order Parton Distribution Functions for Event Generators

work in progress with
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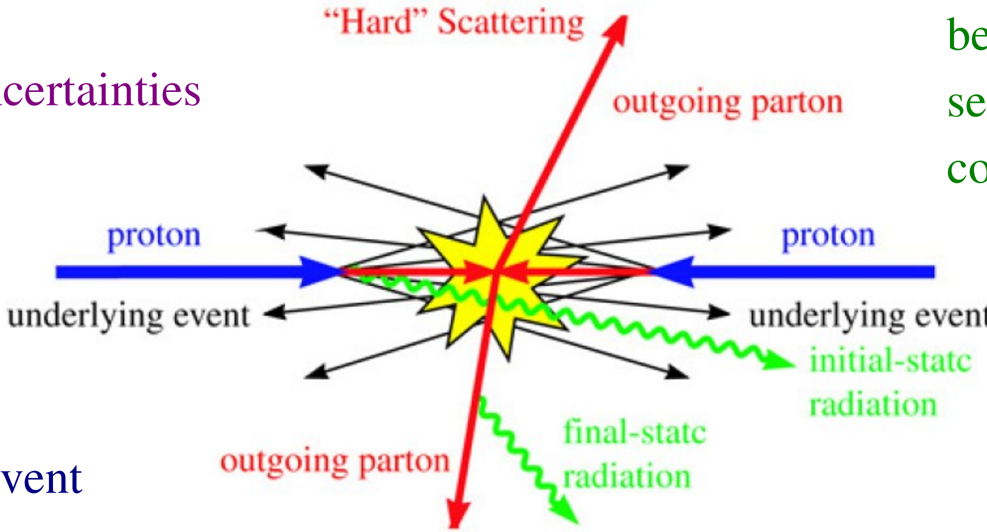
Understanding Cross Sections at the LHC

LO, NLO and NNLO calculations

K-factors

PDFs with uncertainties

benchmark cross sections and pdf correlations



underlying event and minimum bias events

Sudakov form factors

jet algorithms and jet reconstruction

Modern PDFs

- Important pheno. inputs
  - Sets rates, kinematics: $Y_{boson} = \frac{1}{2} \ln(\frac{x_1}{x_2})$
- Ensembles, including errors
  - 41 = 1 + 20 +/- sigmas
  - $f = x^A (1-x)^B (1+C x)^D$
  - Good fits require NLO, which changes Y_{boson}

Event Generators use PDFs for:

- Setting kinematics at high Q
- Backwards evolution ISR
  - Transverse evolution: $P_{T\,,\,boson}$
- Underlying Event (semi-hard QCD at low x)
  - Important for modeling: triggering, track occupancy, jet energy, isolation, etc.

Modified LO pdf's (LO*)

- What about PDFs for parton shower Monte Carlos?
  - standard has been to use LO PDFs, most commonly CTEQ5L/CTEQ6L, in Pythia, Herwig, Sherpa, ALPGEN/Madgraph+…
- …but
  - LO PDFs can create LHC cross sections/acceptances that differ in both shape and normalization from NLO
    - due to influence of HERA data
    - and lack of ln(1/x) and ln(1-x) terms in LO PDFs and evolution
  - …and are often outside NLO error bands

Modified LO pdf's (LO*)

- …but
  - NLO error PDFs are used in combination with the central LO PDF even with this mis-match
    - causes an error in PDF re-weighting due to non-matching of Sudakov form factors
  - predictions for *inclusive* observables from LO matrix elements for many of the collider processes that we want to calculate are not so different from those from NLO matrix elements (aside from a reasonably constant K-factor)

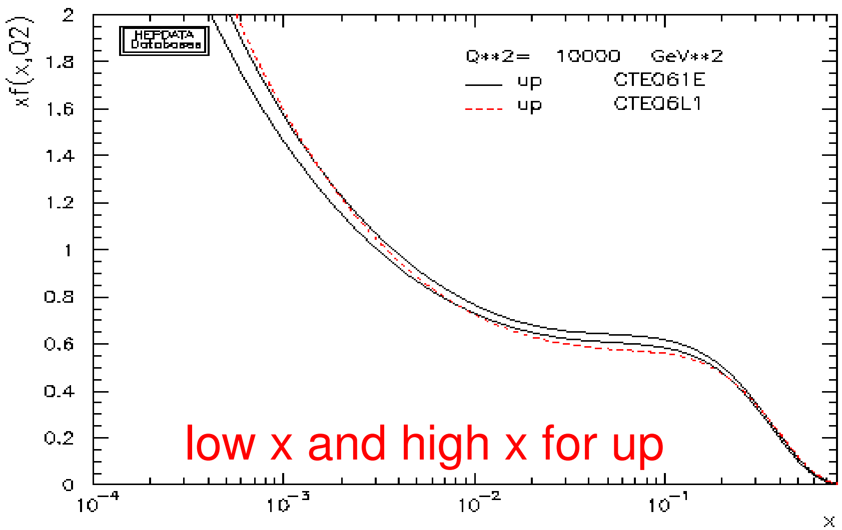
Modified LO pdf's (LO*)

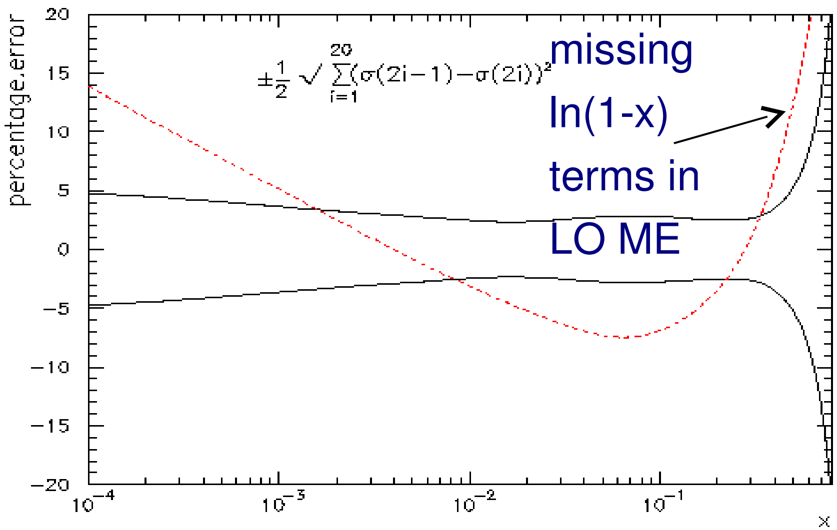
- …but
  - the low x behavior of LO PDFs are used in models of the underlying event (UE) at the Tevatron and its extrapolation to the LHC
  - Also used for calculating low x cross sections at the LHC
- => motivation for modified LO PDFs

CTEQ Approach

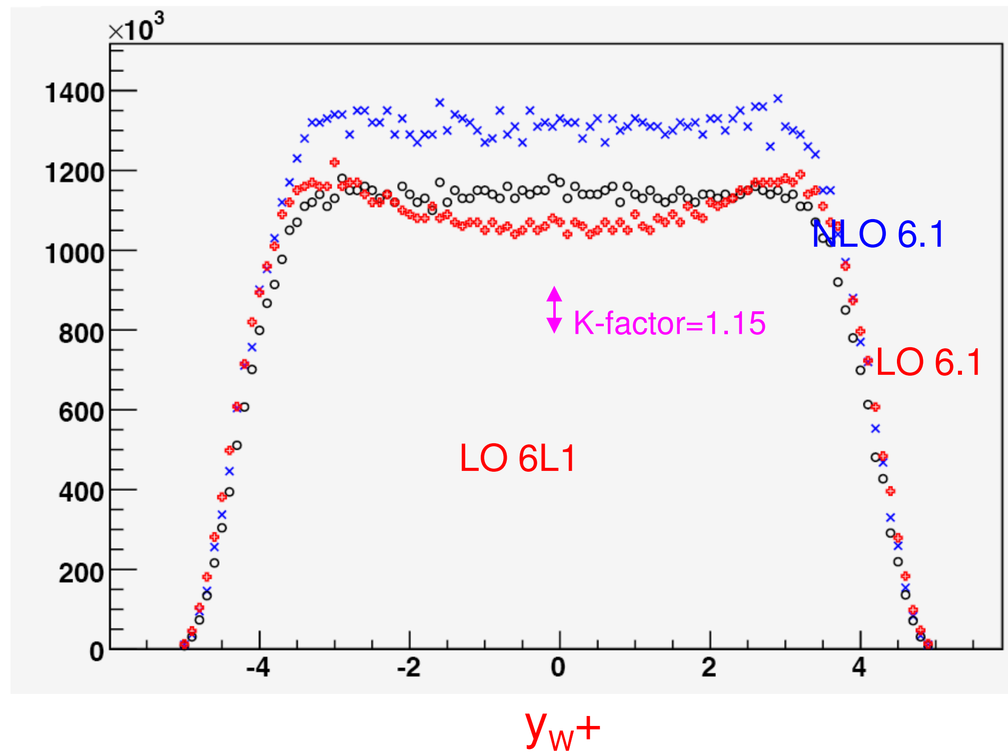
- LO* PDFs should behave as LO as x->0; as close to NLO as possible as x->1
- LO* PDFs should be universal and produce reasonable results out of the box
- It should be possible to produce error PDFs:
  - similar Sudakov form factors
  - similar UE
  - so PDF re-weighting makes sense
- LO* PDFs should describe UE at Tevatron with a tune similar to CTEQ6L (for convenience) and extrapolate to a *reasonable* UE at the LHC

Where are the differences between LO and NLO partons?



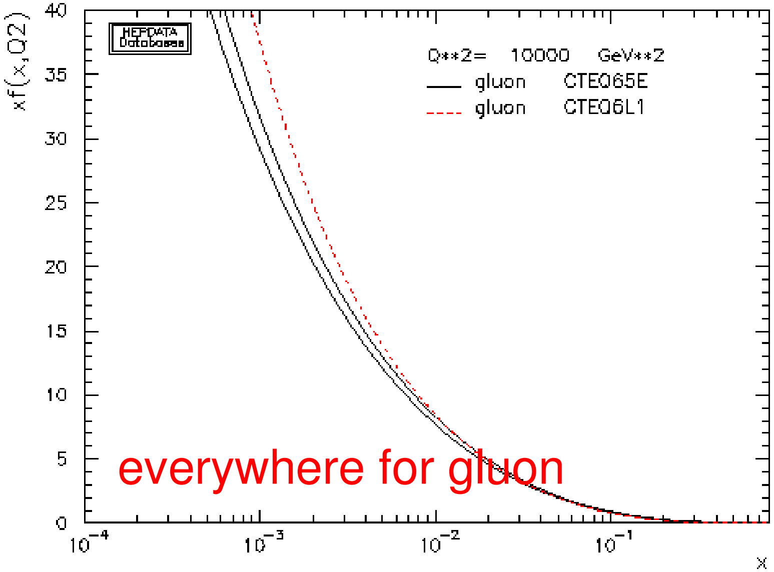


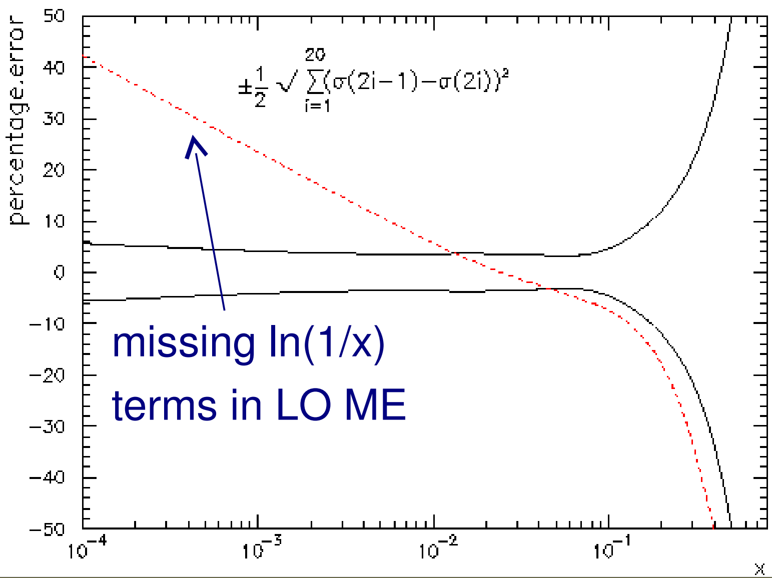
W+ rapidity distribution at LHC



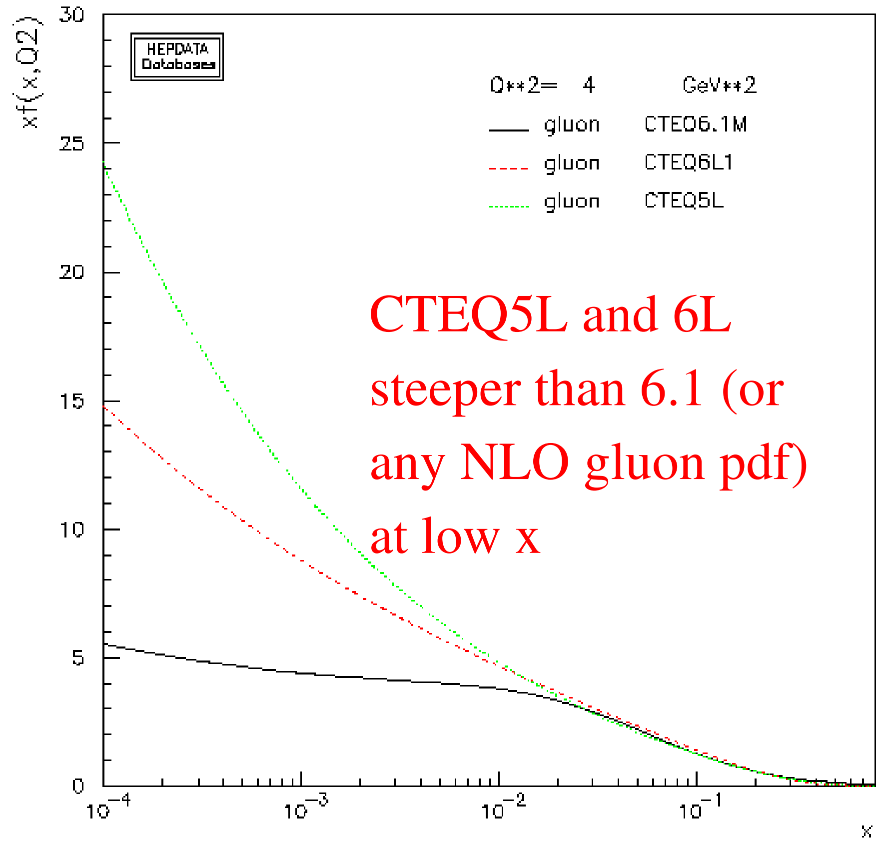
Shape of the W^+ rapidity distribution is significantly different than the NLO result if the LO pdf is used, but very similar if the NLO pdf is used.

Where are the differences?



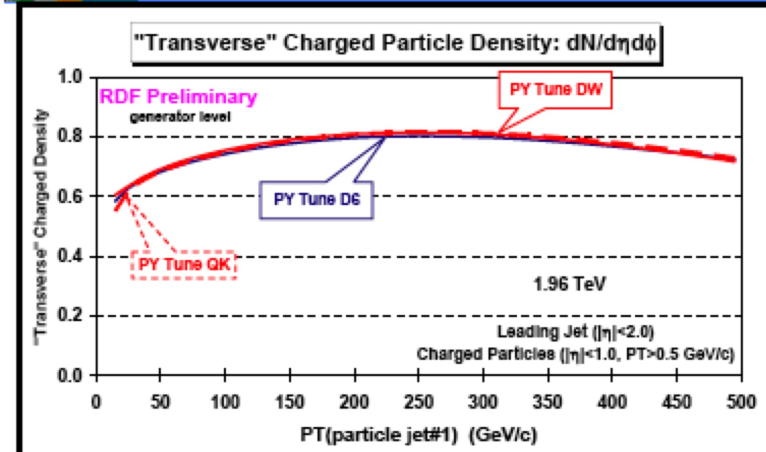


- at low Q

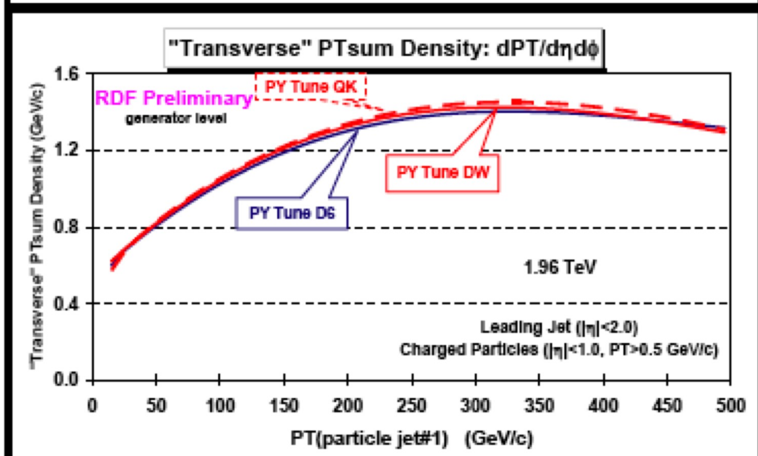


Tunes with CTEQ6L

New PYTHIA 6.2 Tunes



	1.96 TeV		14 TeV	
	P_{T0}(MPI) GeV	σ(MPI) mb	P_{T0}(MPI) GeV	σ(MPI) mb
Tune DW	1.9409	351.7	3.1730	549.2
Tune DWT	1.9409	351.7	2.6091	829.1
ATLAS	2.0046	324.5	2.7457	768.0
Tune D6	1.8387	306.3	3.0059	546.1
Tune D6T	1.8387	306.3	2.5184	786.5
Tune QK	1.9409	259.5	3.1730	422.0
Tune QKT	1.9409	259.5	2.6091	588.0



- **Average charged particle density and PTsum density in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus P_T(jet#1) at 1.96 TeV for PY Tune DW, Tune D6, and Tune QK.**

CTEQ techniques

- Include in LO* fit (weighted) **pseudo-data** for characteristic LHC processes produced using CTEQ6.6 NLO pdf's with NLO matrix elements (using MCFM), along with full CTEQ6.6 dataset (2885 points)
  - low mass bB
    - fix low x gluon for UE
  - tT over full mass range
    - higher x gluon
  - W^+, W^-, Z^0 rapidity distributions
    - quark distributions
  - gg->H (120 GeV) rapidity distribution

CTEQ techniques

Choices

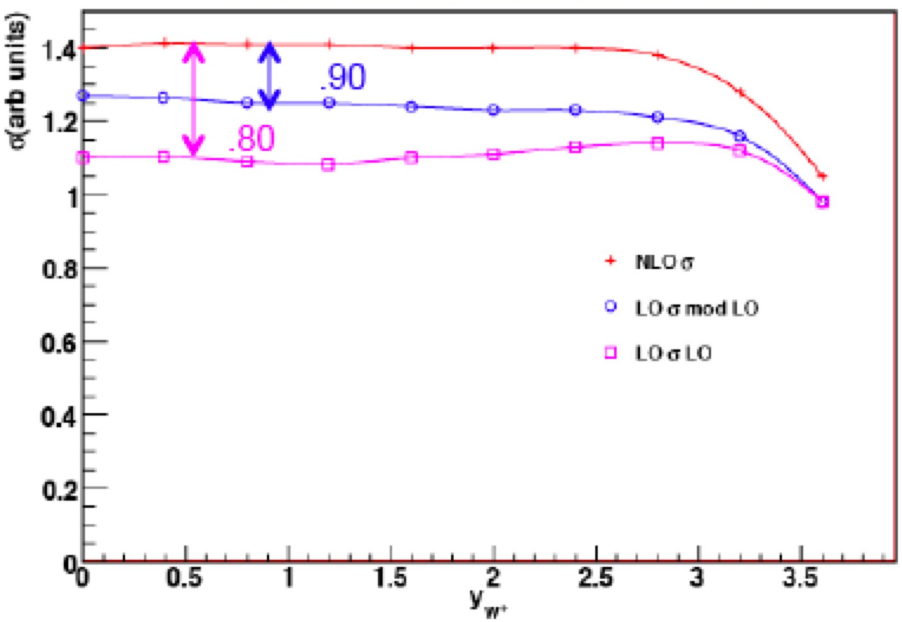
- Use of 2-loop or 1-loop α_s
  - Herwig preference for 2-loop
  - Pythia preference for 1-loop
- Fixed momentum sum rule, or not
  - re-arrange momentum within proton and/or add extra momentum
  - extra momentum appreciated by some of pseudo-data sets but not others and may lose some useful correlations
- Fix pseudo-data normalizations to K-factors expected from higher order corrections, or let float
- Scale variation within reasonable range for fine-tuning of agreement with pseudo-data
  - e.g., let vector boson scale vary from 0.5 m_B to 2.0 m_B

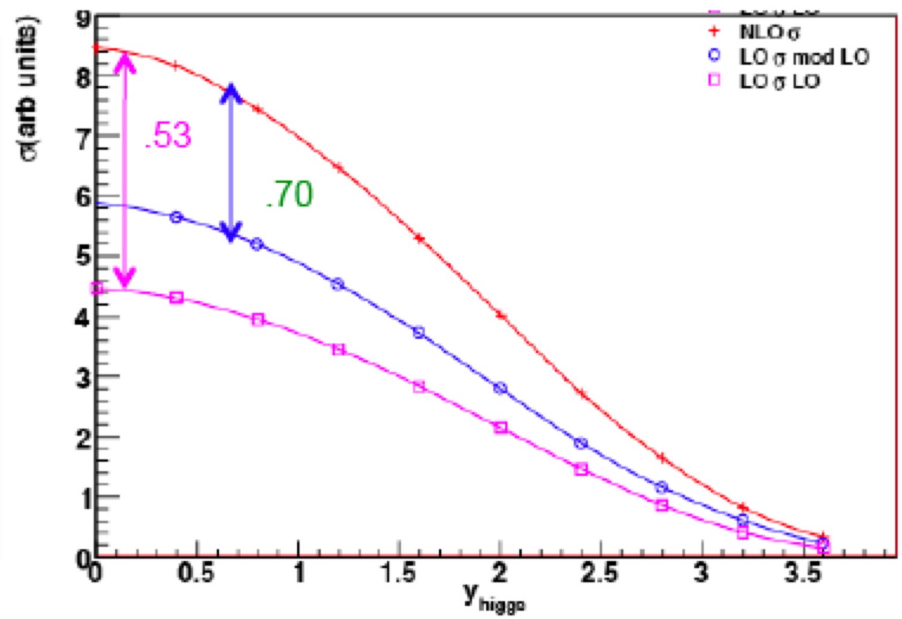
Some results

- Pseudo-data has conflicts with global data set
  - Part of the original problem
- Requiring better fit to pseudo-data increases chisquare of LO fit to global data set
  - χ^2 improves with α_s free in fit
    - no real preference for 1-loop or 2-loop α_s
  - χ^2 improves with momentum sum rule free
    - prefers more momentum (~1.05)
    - normalization of pseudo-data (needed K-factor) gets closer to 1 (since the chisquare gets better if that happens)
    - still some conflicts with DIS data

Some results (2-loop α_s)

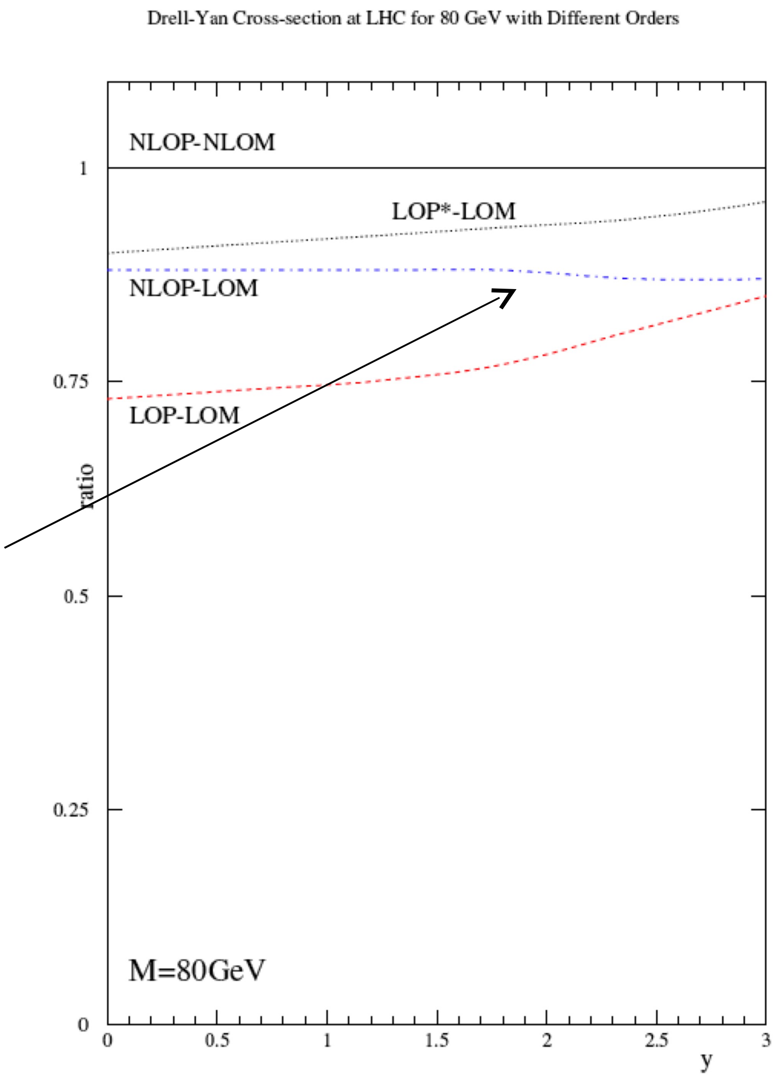
- Rapidity distributions for W^+ and Higgs from pure NLO, LO with LO pdf, LO with CTEQ modified LO pdf
- Momentum sum=1.06 for CTEQ modified LO pdf
  - why so much less than mod MSTW?
- $\alpha_s(m_Z)$=0.124 for CTEQ modified LO pdf
- tT normalization is 0.76



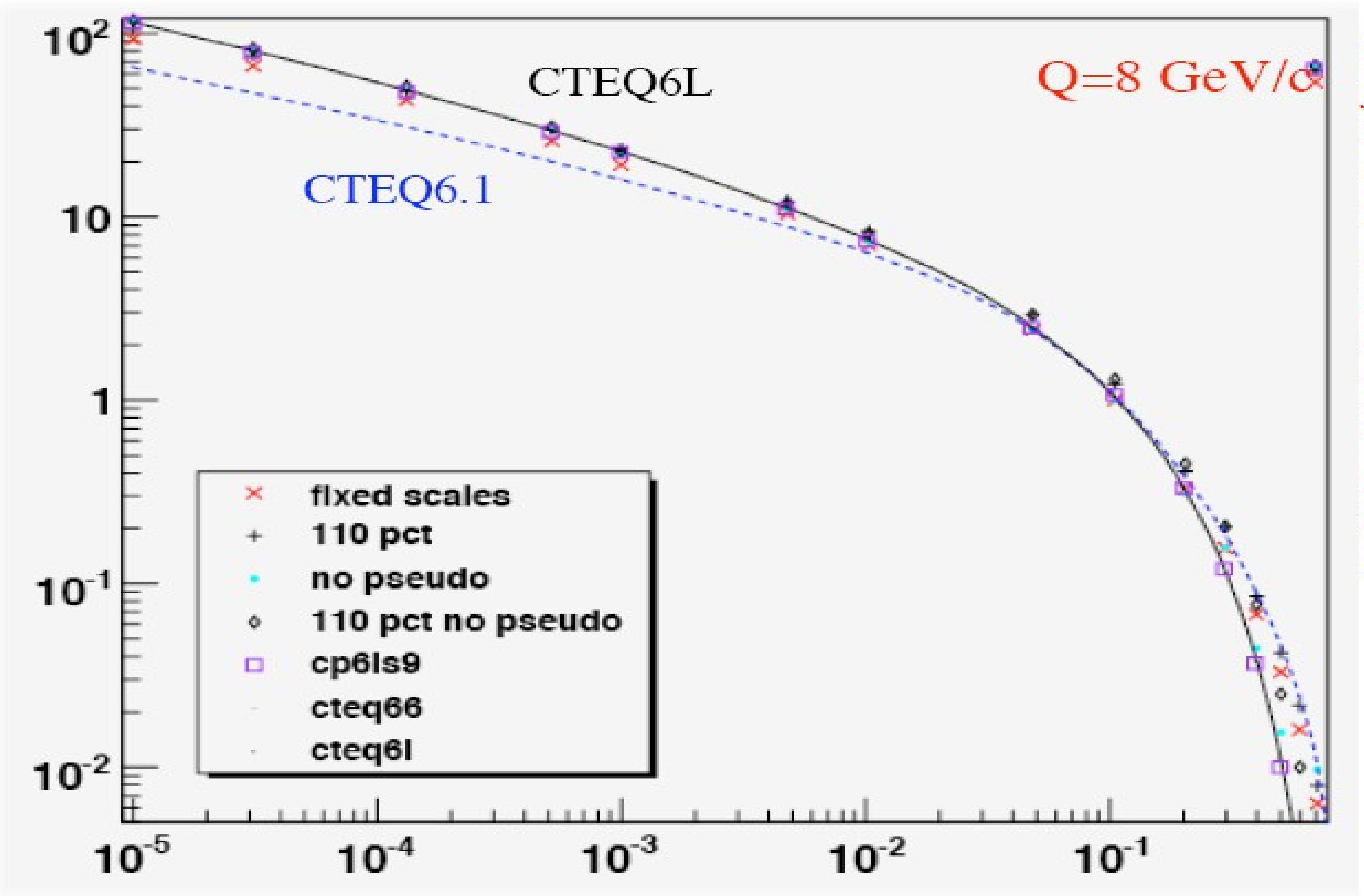


MRSTLO*

- The MRST group has a modified LO pdf that tries to incorporate many of the points mentioned on the previous slides
- They relax the momentum sum rule (114%) and achieve a better agreement (than MRST LO pdf's) with some important LHC benchmark cross sections
- Available in LHAPDF

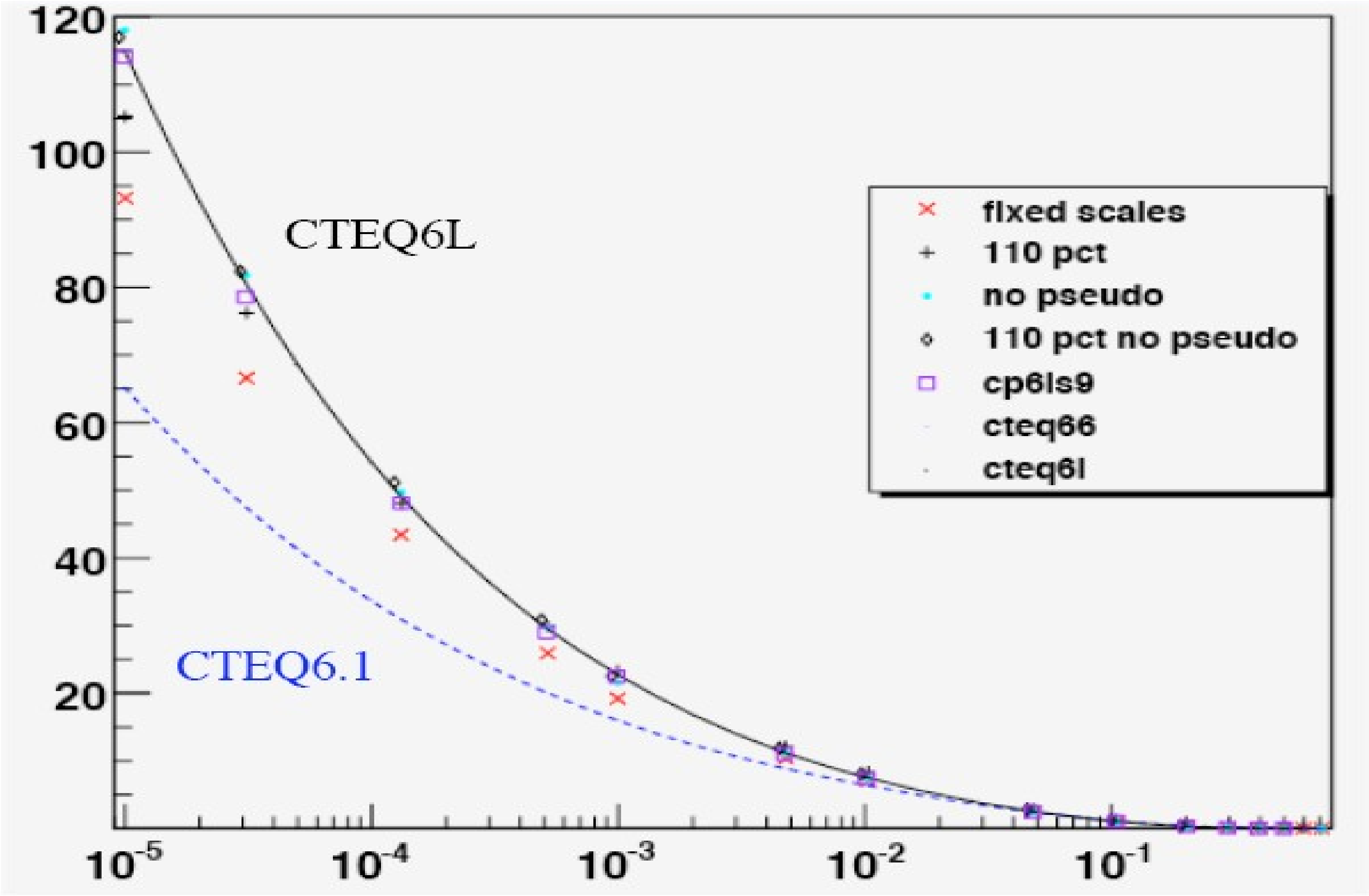


Results: gluon distribution



- Candidate pdf titled *fixed scales* tries to fit pseudo-data
- Larger than CTEQ6L at high **x**, but smaller at low **x**
- With *110%* momentum in proton, gluon is larger at high **x**
- Including the pseudo-data in the fit increases the high **x** gluon even more

Focus on small-x



Error PDFs

- To be truly useful, there should be accompanying error PDFs of a similar character as the LO* PDFs
  - We will not mix the NLO error PDFs with a central LO PDF
    - Damage limited in gluon radiation if same α_s used
    - Still a problem for UE if low x gluons are different
- Error PDFs imply a level of precision that is inherent to NLO
  - at NLO, we can construct an orthonormal set of eigenvectors accompanying a level of precision corresponding to a given change of $\Delta\chi^2$ in the global fit
  - that level of $\Delta\chi^2$, that variation, less well defined for LO fits

Inclusive jet cross section in Run2

new physics tends to be central

pdf explanations are universal

crucial to measure over a wide rapidity interval

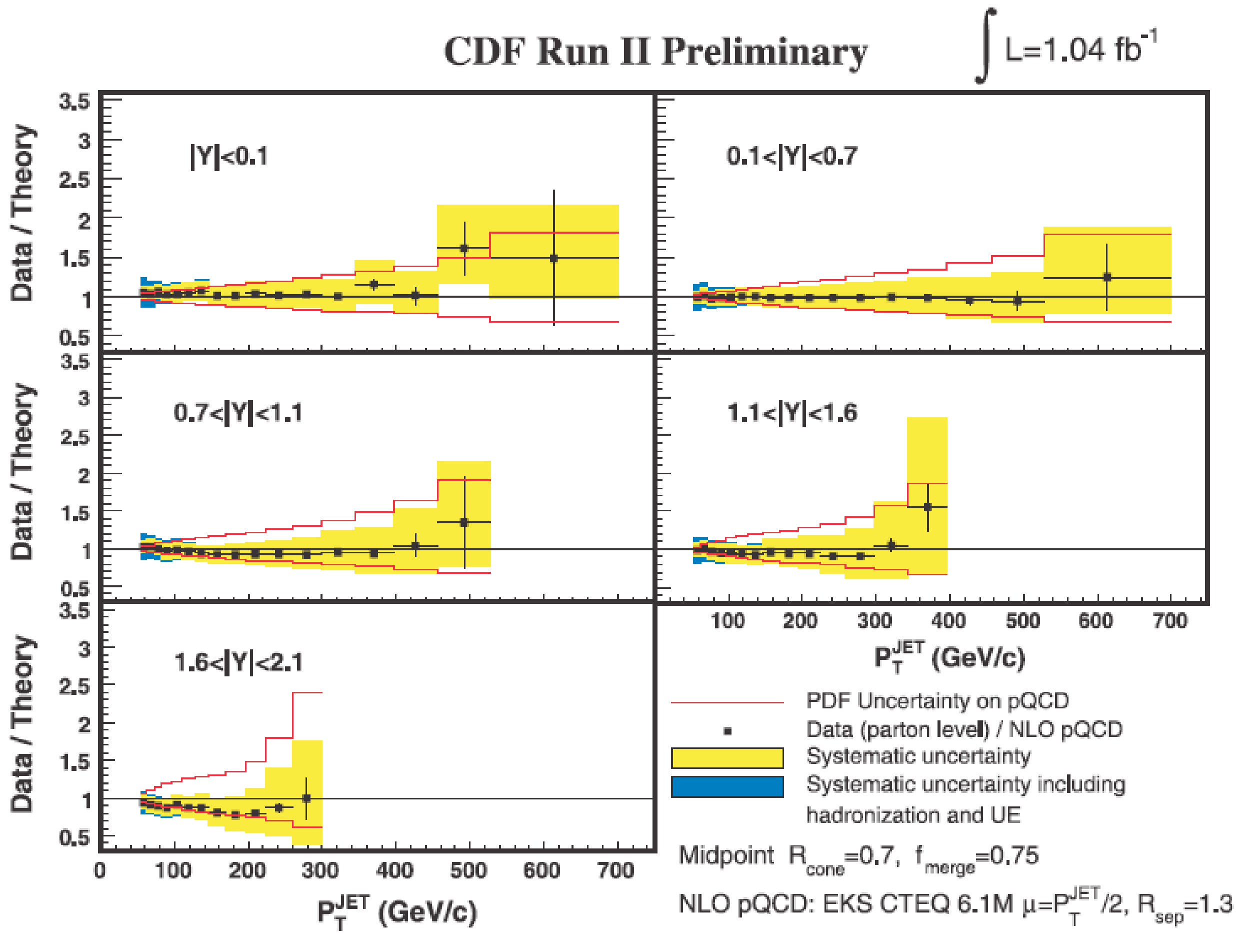


Figure 50. The inclusive jet cross section from CDF in Run 2, for several rapidity intervals using the midpoint cone algorithm, compared on a linear scale to NLO theoretical predictions using CTEQ6.1 pdfs.

Inclusive jet production at the LHC

- pdf uncertainty is sizeable at the highest transverse momenta, as at Tevatron

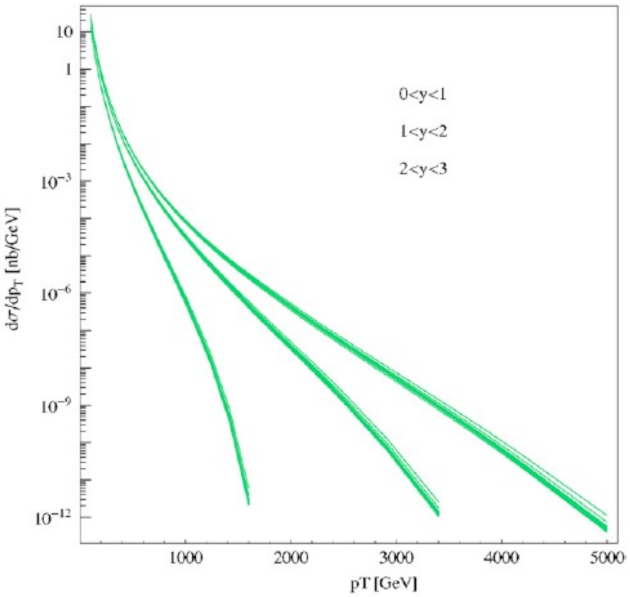


Figure 104. Inclusive jet cross section predictions for the LHC using the CTEQ6.1 central pdf and the 40 error pdfs.

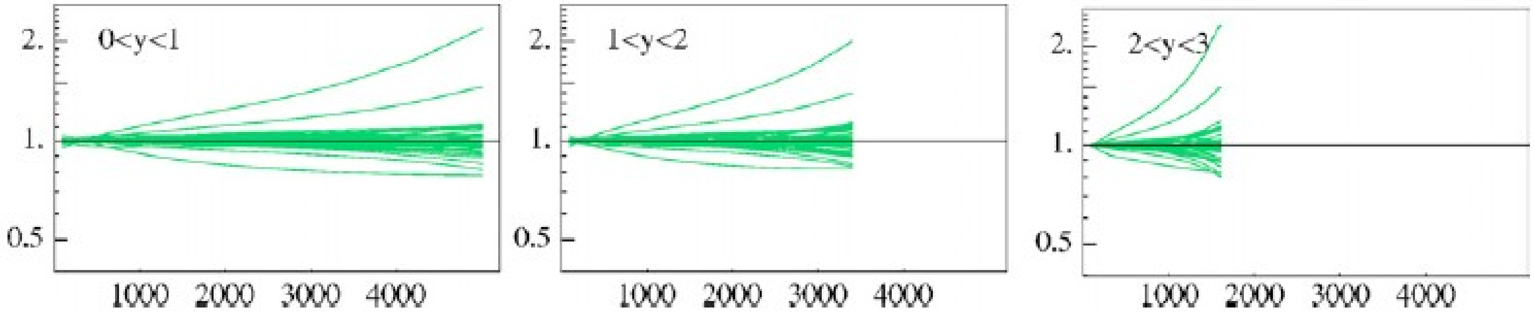


Figure 105. The ratios of the jet cross section predictions for the LHC using the CTEQ6.1 error pdfs to the prediction using the central pdf. The extremes are produced by eigenvector 15.

Comment on K-factors

Sometimes it is useful to define a K-factor (NLO/LO). Note the value of the K-factor depends critically on its definition. K-factors at LHC (mostly) similar to those at Tevatron.

CHS

Table 1. K-factors for various processes at the Tevatron and the LHC, calculated using a selection of input parameters. In all cases, the CTEQ6M PDF set is used at NLO. $\mathcal{K}$ uses the CTEQ6L1 set at leading order, whilst $\mathcal{K}'$ uses the same set, CTEQ6M, as at NLO. Jets satisfy the requirements $p_T > 15$ GeV and $|\eta| < 2.5$ (5.0) at the Tevatron (LHC). In the $W+2$ jet process the jets are separated by $\Delta R > 0.52$, whilst the weak boson fusion (WBF) calculations are performed for a Higgs of mass 120 GeV.

	Typical scales		Tevatron K-factor			LHC K-factor		
Process	μ_0	μ_1	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
$W+1$ jet	m_W	$\langle p_T^{\text{jet}}\rangle$	1.42	1.20	1.43	1.21	1.32	1.42
$W+2$ jets	m_W	$\langle p_T^{\text{jet}}\rangle$	1.16	0.91	1.29	0.89	0.88	1.10
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs via WBF	m_H	$\langle p_T^{\text{jet}}\rangle$	1.07	0.97	1.07	1.23	1.34	1.09
Higgs + 1 jet						1.42		
Higgs + 2 jets						1.15		
tT + 1 jet			1.19	1.37	1.26	0.97	1.29	1.10

K-factors may differ from unity because of new subprocesses/ contributions at higher order **and/or differences between LO and NLO pdf's**

Conclusions

- New pheno. tools will be needed to confront data at the LHC
- PDFs impact many aspects of modeling high energy collisions
- We (CTEQ) are addressing inconsistencies
- Public results will be available soon, including modified error PDFs