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# Some Theoretical Uncertainties on Jet Production at the Tevatron

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# 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 and direct  $\gamma$  production
- Two major groups that provide semi-regular updates to parton distributions when new data/theory becomes available
  - ◆ MRS->MRST98->MRST99->MRST2001
  - ◆ CTEQ->CTEQ5->CTEQ5(1)->CTEQ6
- CTEQ6 is based on series of previous CTEQ distributions, but represents more than an evolutionary advance
  - ◆ update to new data sets
  - ◆ incorporation of correlated systematic errors for all experiments in the fit
  - ◆ new methodology enables full characterization of parton parametrization space in neighborhood of global minimum
    - ▲ Hessian method
    - ▲ Lagrange Multiplier
  - ◆ results available both in conventional formalism and in Les Houches accord format

# Uncertainties in pdf fits

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- 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

- ◆ 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

# Whats new/old since CTEQ5?

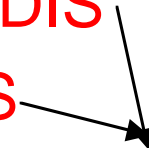
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## ● New Data

- ◆ new DIS data from H1/ZEUS
- ◆ jet cross sections from D0 as a function of  $\eta$
- ◆ updated E866 Drell-Yan deuteron/proton ratio
- ◆ re-analyzed CCFR  $F_2$

## ● Old data

- ◆ BCDMS DIS
- ◆ NMC DIS
- ◆ CCFR  $F_3$
- ◆ E665 DIS
- ◆ E605 DY
- ◆ CDF W asym
- ◆ CDF inclusive jets



now use measurements at separate energies with full correlation info

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~1800 data points: global  $\chi^2$  is 1950  
CTEQ5M  $\chi^2$  on same data is ~2500

# Nuts/bolts of fits

- Functional form used is:

- ◆  $xf(x, Q_0) = A_0 x^{A1} (1-x)^{A2} e^{A3x} (1 + A_4x)^{A5}$

- ▲  $Q_0 = 1$  GeV (below any data used in fit)

- easier to do forward evolution than backward

- ▲ functional form arrived at by adding a 1:1 Pade expansion to quantity  $d(\log xf)/dx$

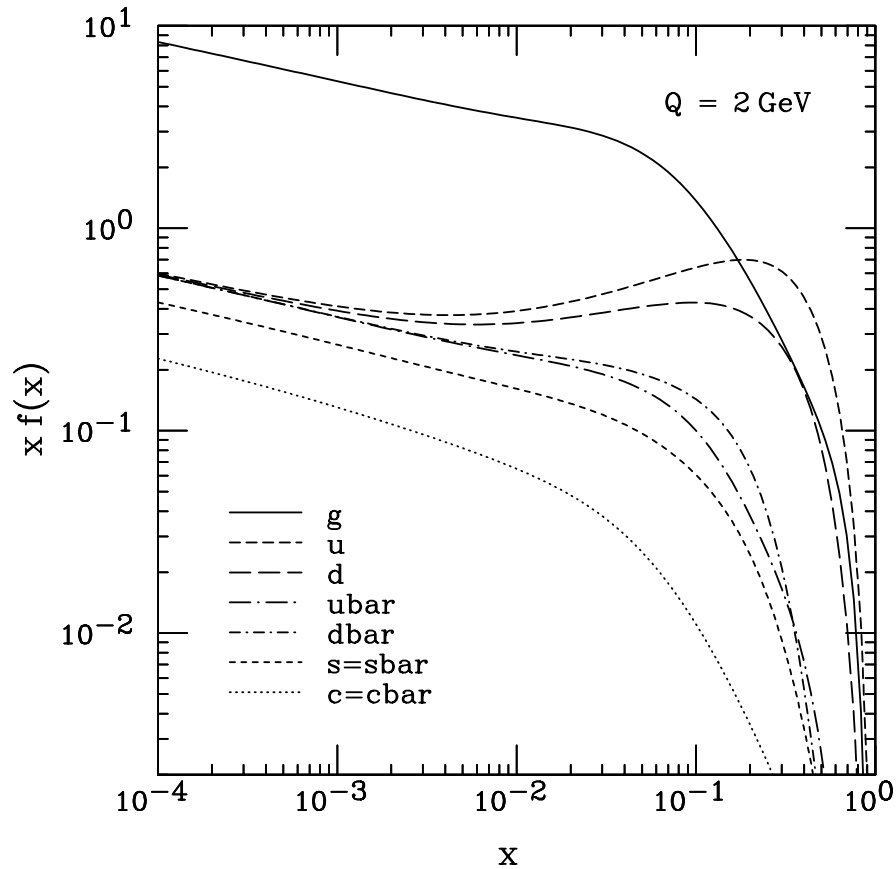
- ▲ more versatile than form used in CTEQ5 or MRST

- Light quarks treated as massless; evolution kernels of PDFs are mass-independent

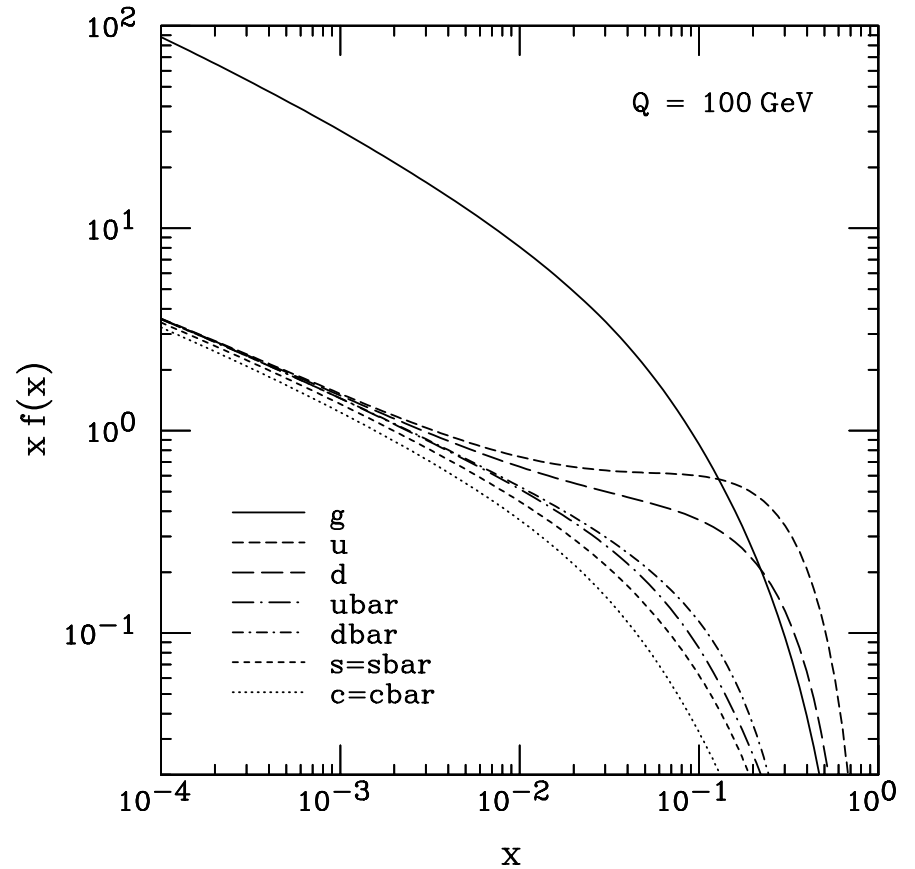
- Zero mass Wilson coefficients used in DIS structure functions

# CTEQ6 pdfs

low Q

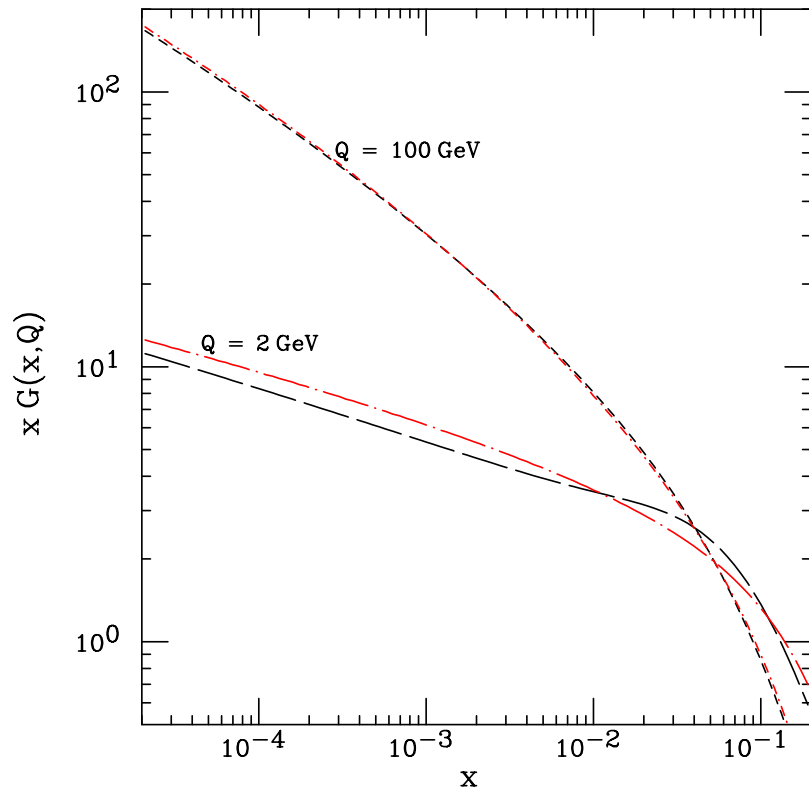


high Q

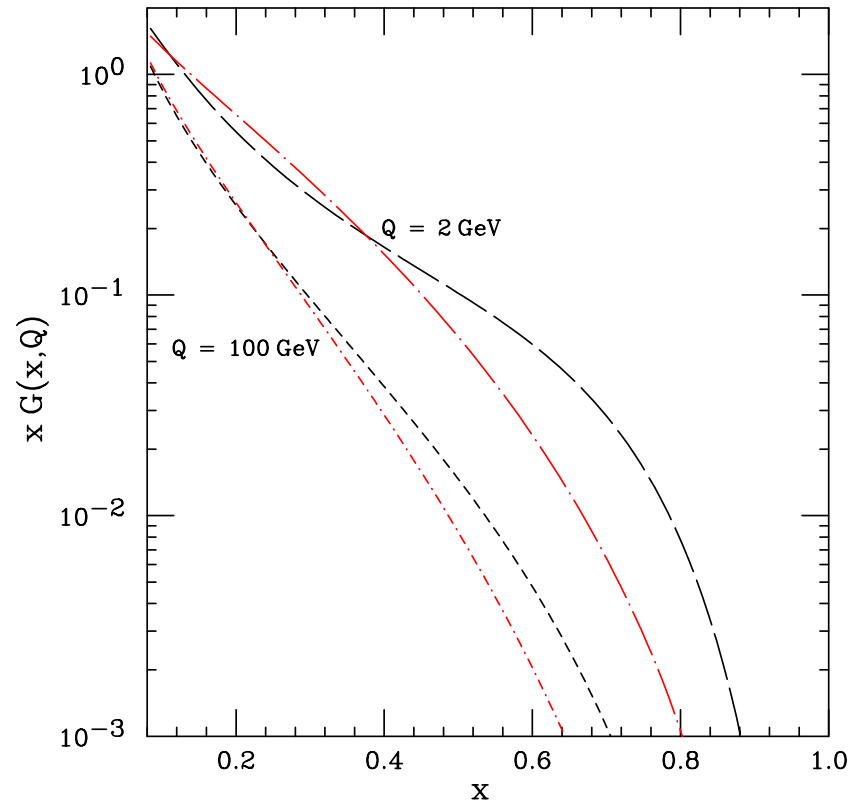


# Compare to CTEQ5

- Biggest change is in the gluon distribution; more momentum at high  $x$



low  $x$



high  $x$

# D0 jet cross section

- CTEQ4 and CTEQ5 had CDF and D0 central jet cross sections in fit
- Statistical power not great enough to strongly influence high  $x$  gluon
  - ◆ CTEQ4HJ/5HJ required a special emphasis to be given to high  $E_T$  data points
- Central fit for CTEQ6 is naturally *HJ-like*
- $\chi^2$  for CDF+D0 jet data is 113 for 123 data points
- Note the power of having search for new physics regions and control regions
  - ◆ pdf explanation should work for all regions
  - ◆ new physics should be central

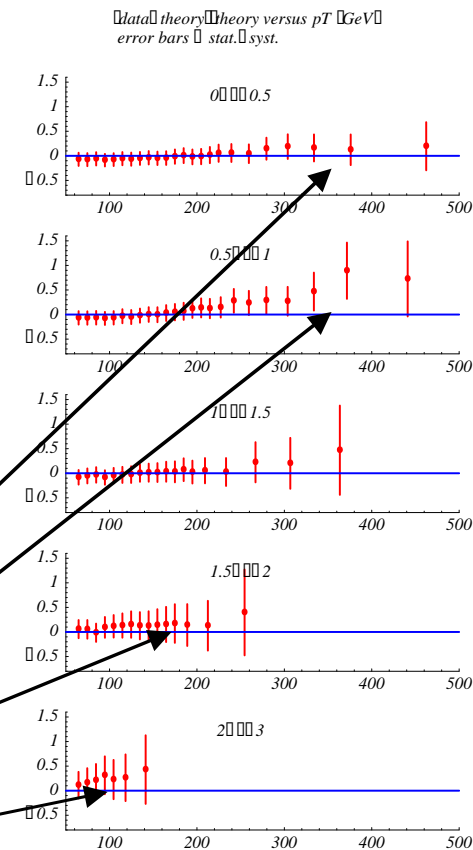
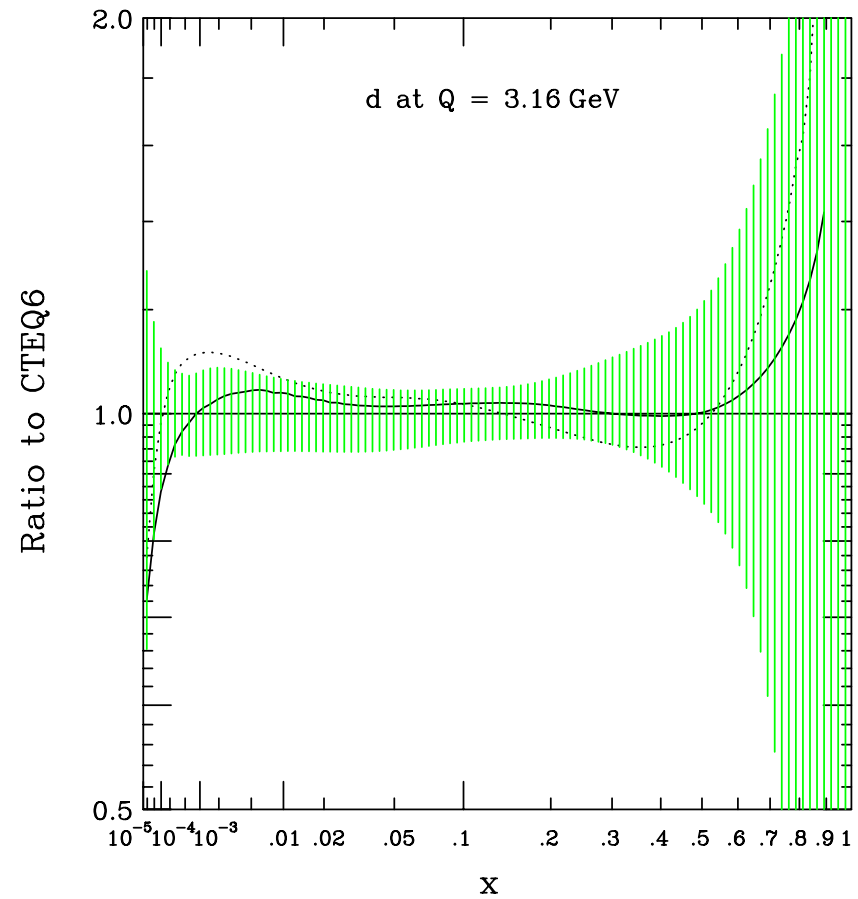
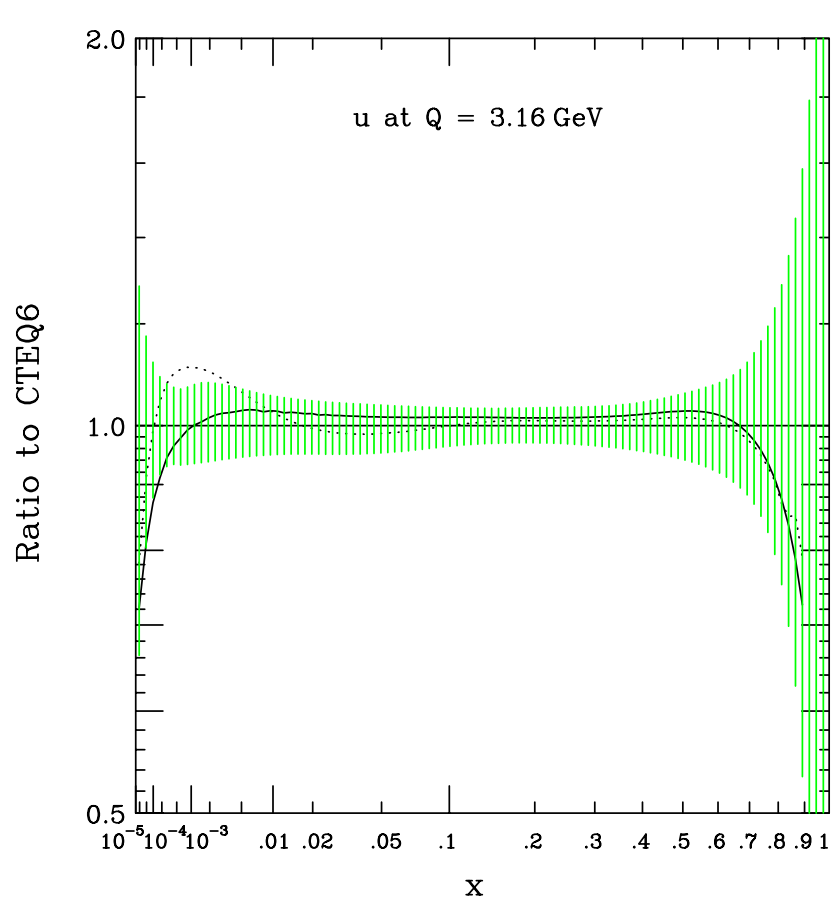


Figure 19: Comparison between theory and the D0 jet data. The error bars are statistical and systematic errors combined.

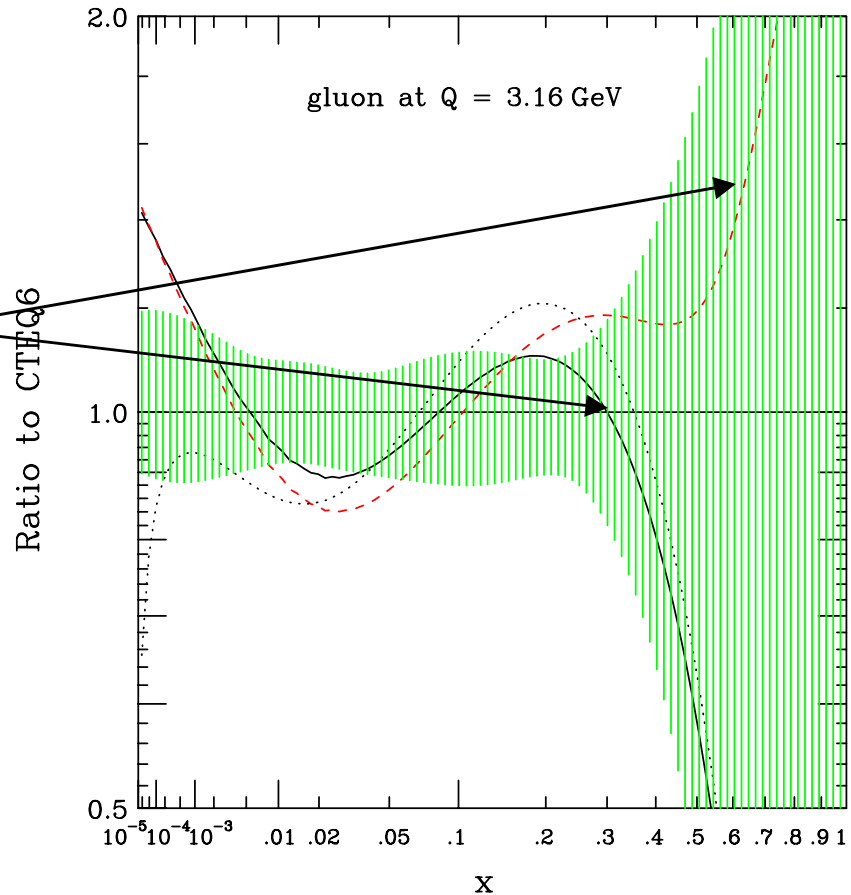
# PDF Uncertainties

- Use Hessian technique (T=10)

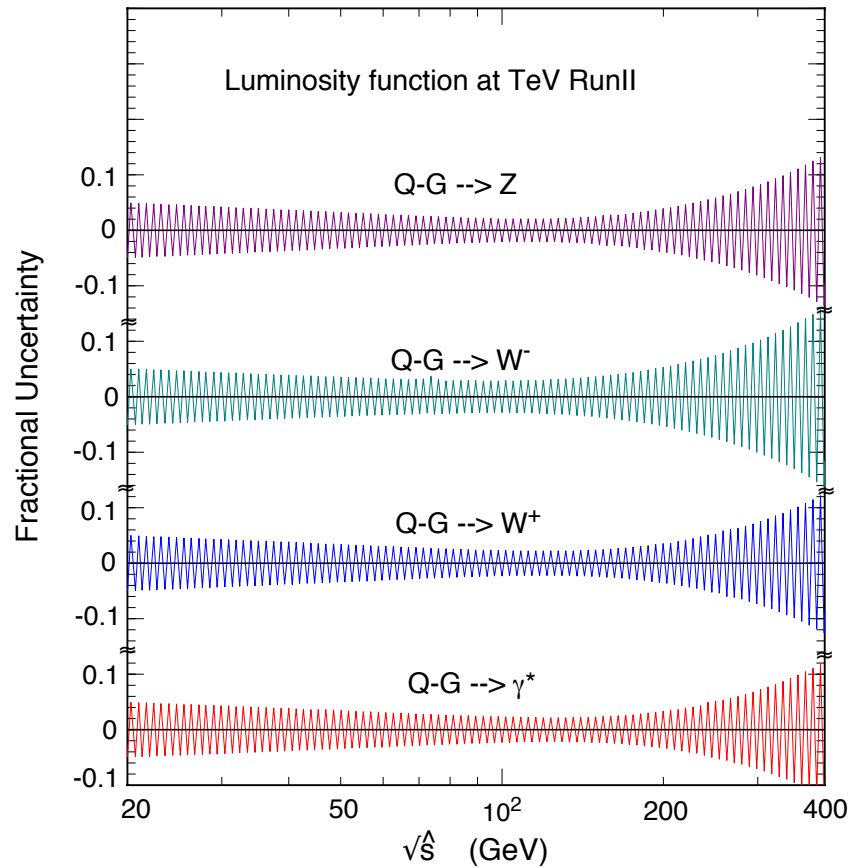
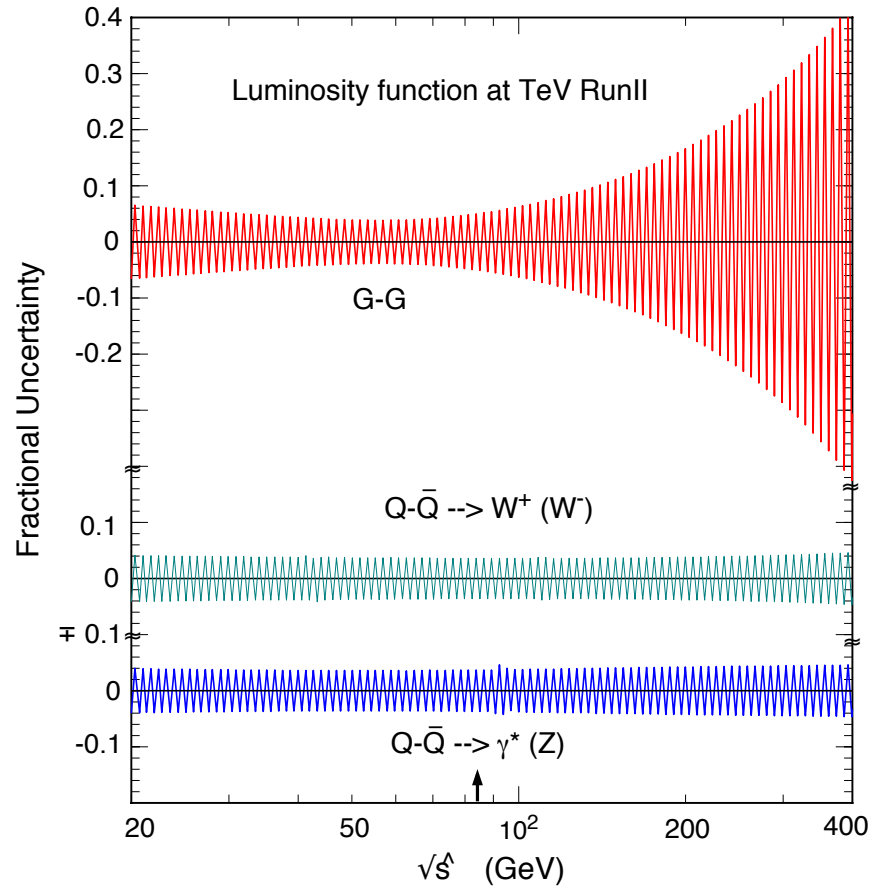


# Gluon Uncertainty

- Gluon is fairly well-constrained up to an  $x$ -value of 0.3
- New gluon is stiffer than CTEQ5M; not quite as stiff as CTEQ5HJ



# Luminosity function uncertainties at the Tevatron



# Remaining questions/discussion

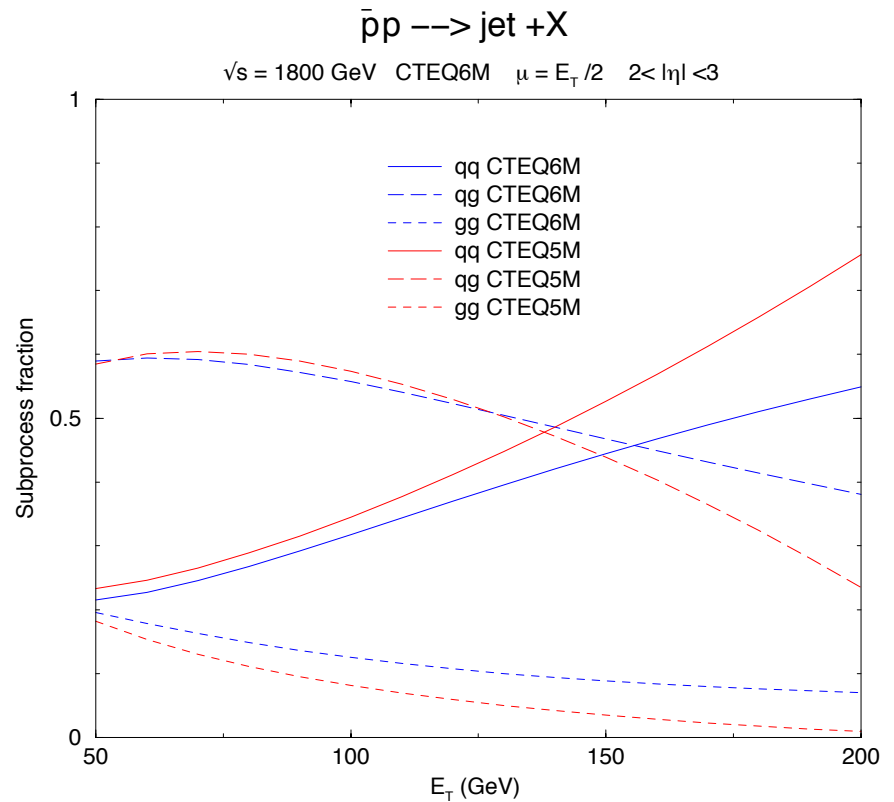
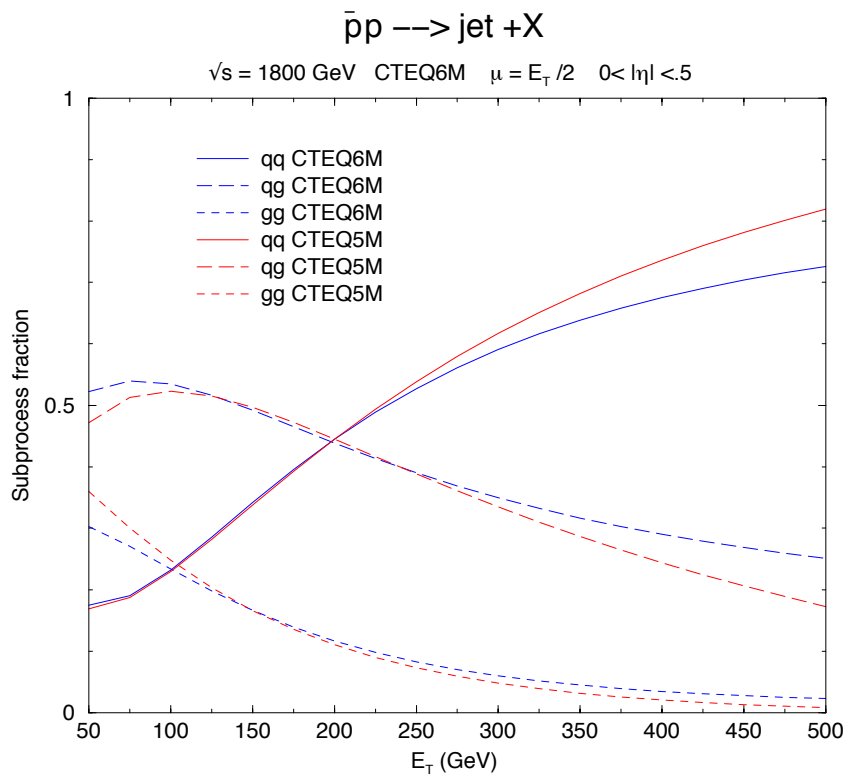
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- HJ-like behavior for gluon motivated to describe CDF Run 1 data now seems a natural consequence of global fitting
- ...but need to be careful not to hide any possible new physics in the gluon uncertainty
- How much room is left over for new physics in Run 1 data?
- What is uncertainty on Run 2 jet cross sections?
- Is NLO QCD valid for description of jet cross sections in full range of  $E_T/p_T$  and rapidity, for both Run 1 and Run 2?
- These and other questions to be answered in CTEQ paper in preparation
- Here are a few excerpts

# Subprocess plots

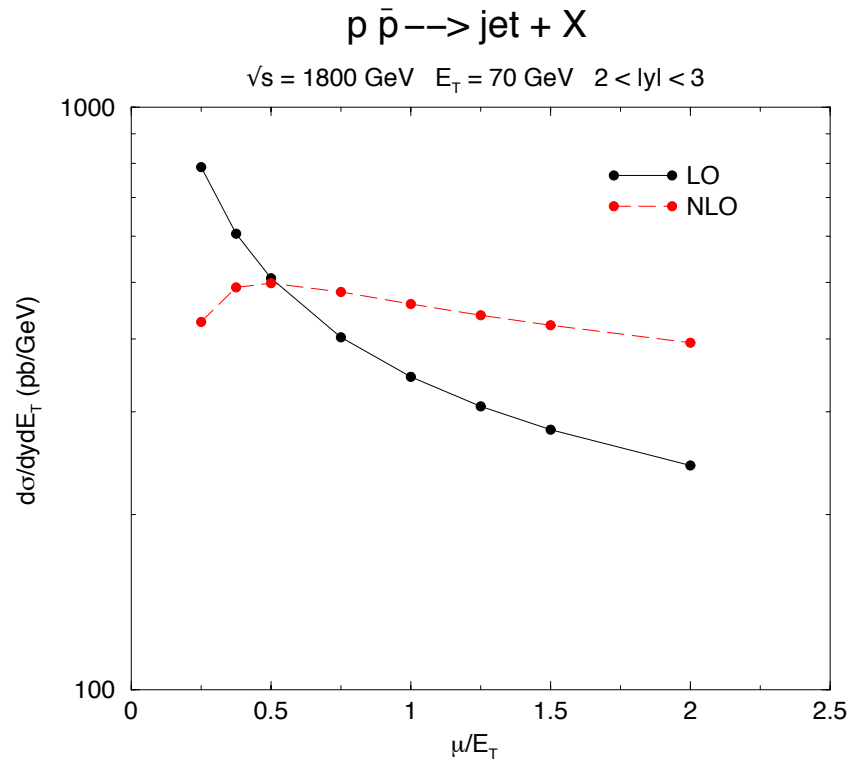
- Enhanced gluon-quark scattering in CTEQ6

Larger contribution for forward rapidities



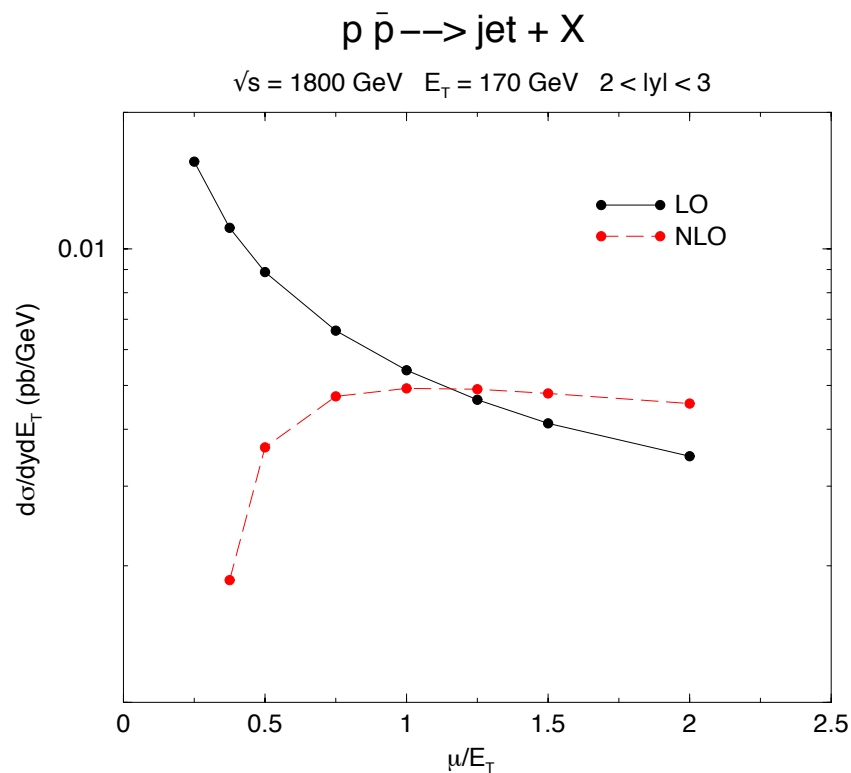
# Reliability of NLO QCD

- One way of looking for possible effects of higher order terms is to examine the scale dependence of the jet cross section
- Also, look at the K-factor (NLO/LO) at scale cross section evaluated at
- For  $\mu/E_T=0.5$ , K-factor is of the order of 1 for most of Tevatron jet data
- Is NLO QCD reliable for all data taken in Run 1?



# NLO and LO scale dependence

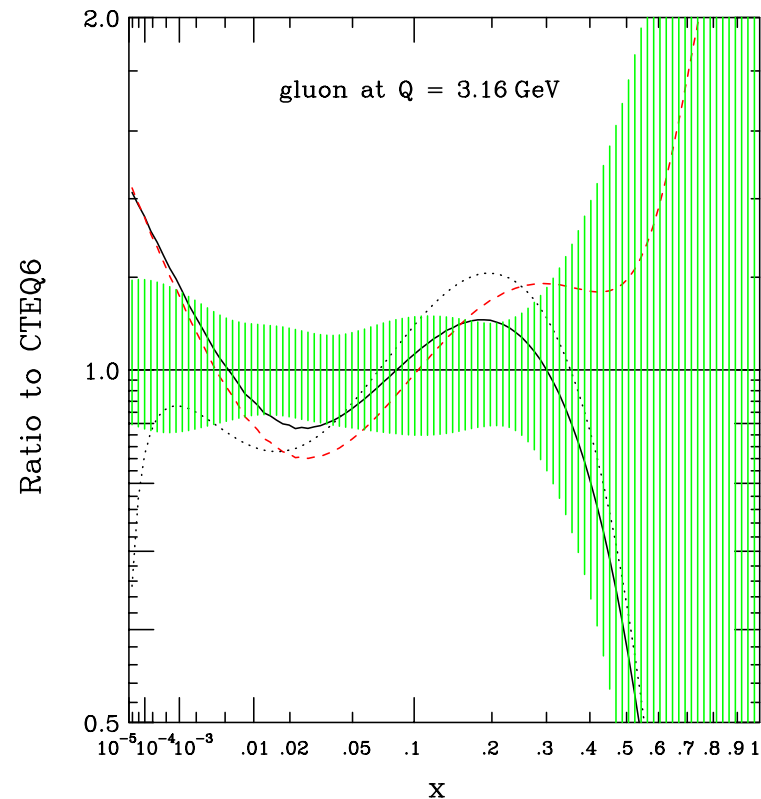
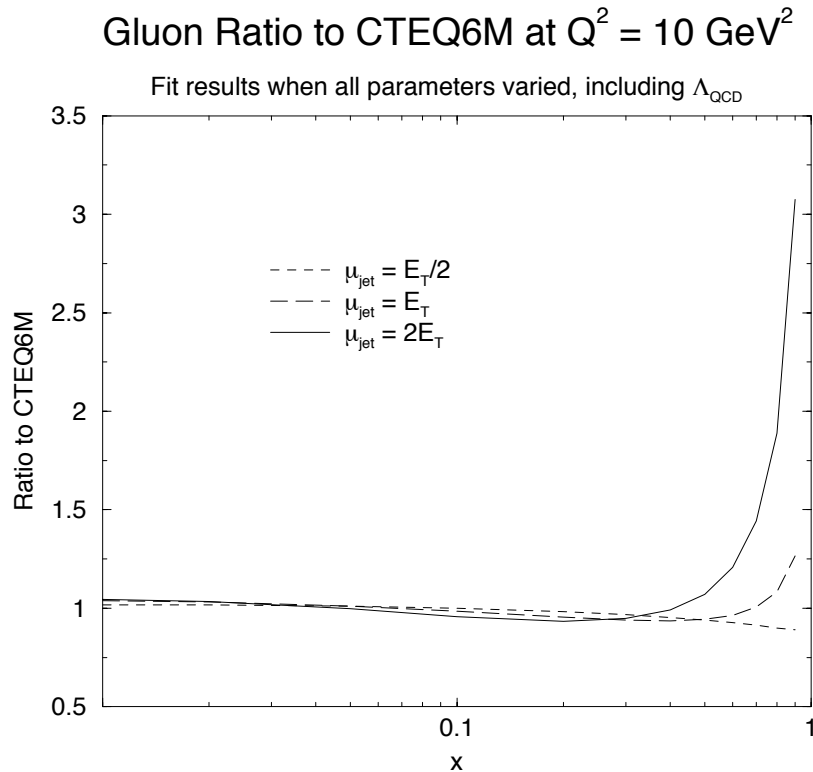
- Leading log calculations of the jet cross section at high  $E_T$  generally decrease as renorm/factorization scales are increased
- At NLO, scale dependence is reduced and cross section typically has parabolic shape as function of scale
- For large  $y$ , high  $E_T$ , point where NLO curve crosses LO curve moves out in  $\mu/E_T$ , due to kinematic reasons
- So, K-factor at  $\mu/E_T$  can be significantly less than 1
- Not a cause for alarm per se, but scale dependence of cross section does become steep at scales lower than  $0.5 E_T$



# Scale dependent fits

- Repeat CTEQ6 fit using scales of  $E_T$ ,  $2E_T$  for jet cross section
- Compare gluon distribution to CTEQ6M ( $\mu=E_T/2$ )

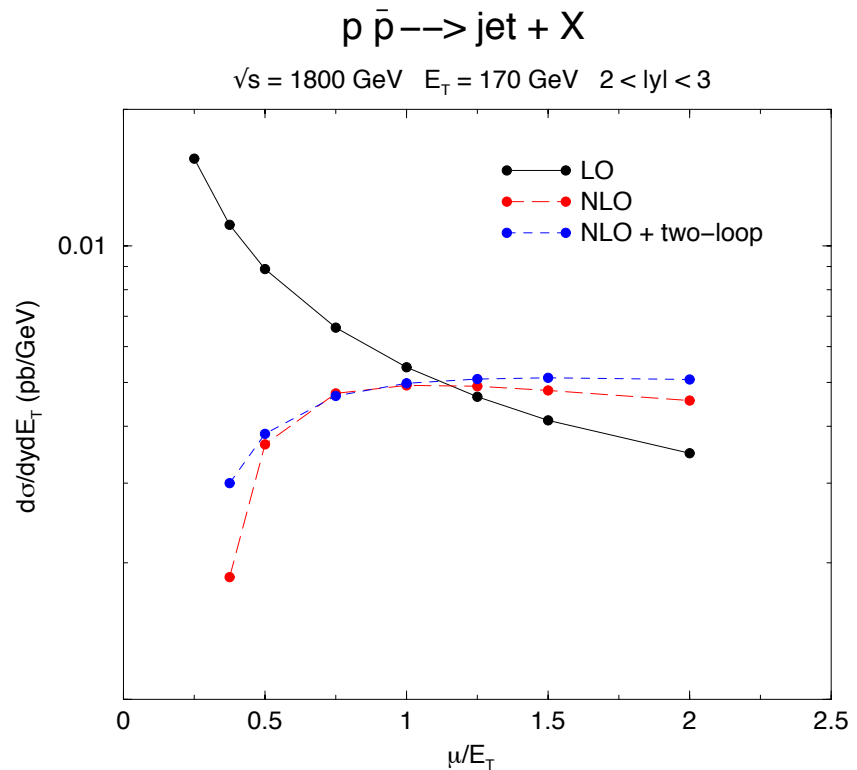
Variations within CTEQ6 pdf uncertainty band



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CDF/D0 Jet Meeting

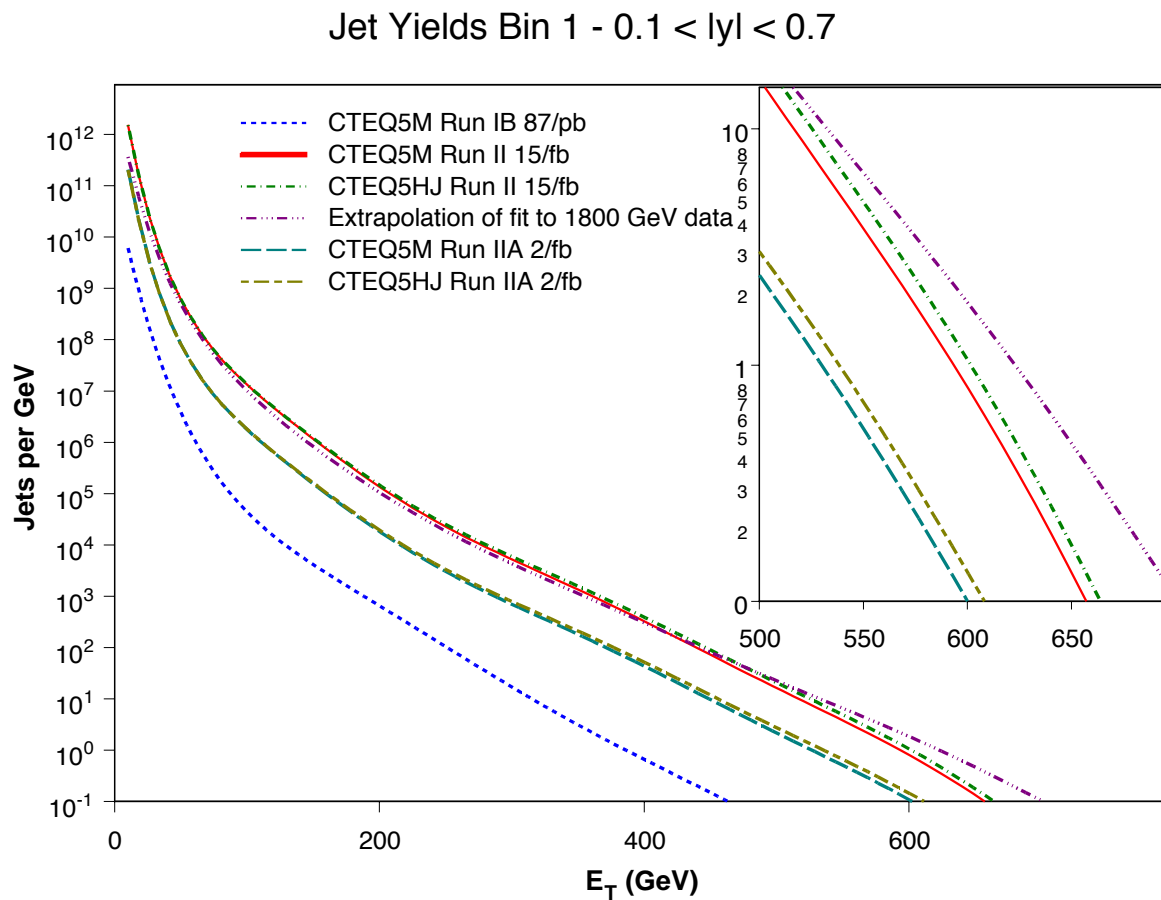
# Edge of phase space

- Potentially significant problems from phase space limitations at large  $E_T$  and rapidity
- Such corrections can be treated by threshold resummation techniques
- Estimated at two loop level and found to be small for central rapidity region
- Repeated for forward rapidity region and again are not significant at scale used in fit



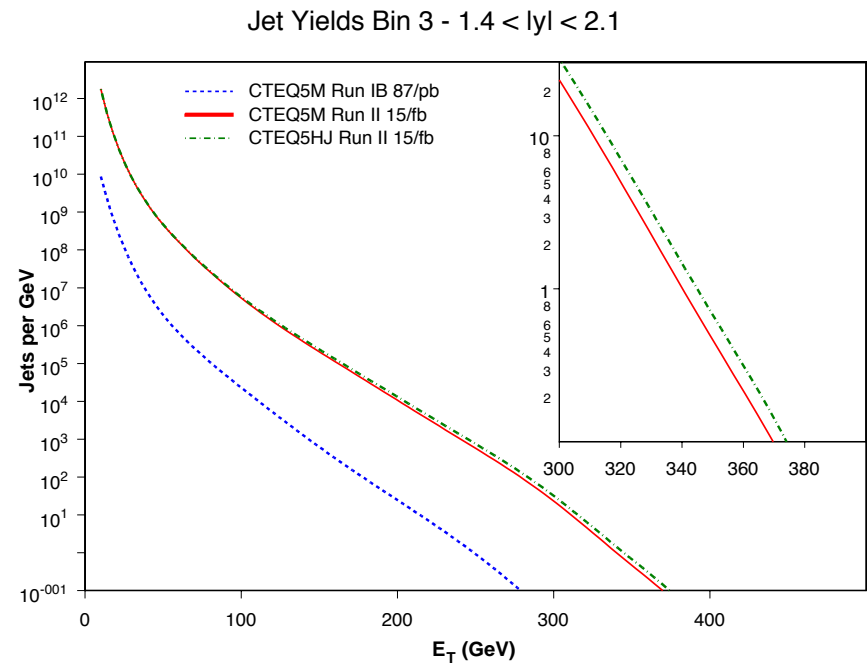
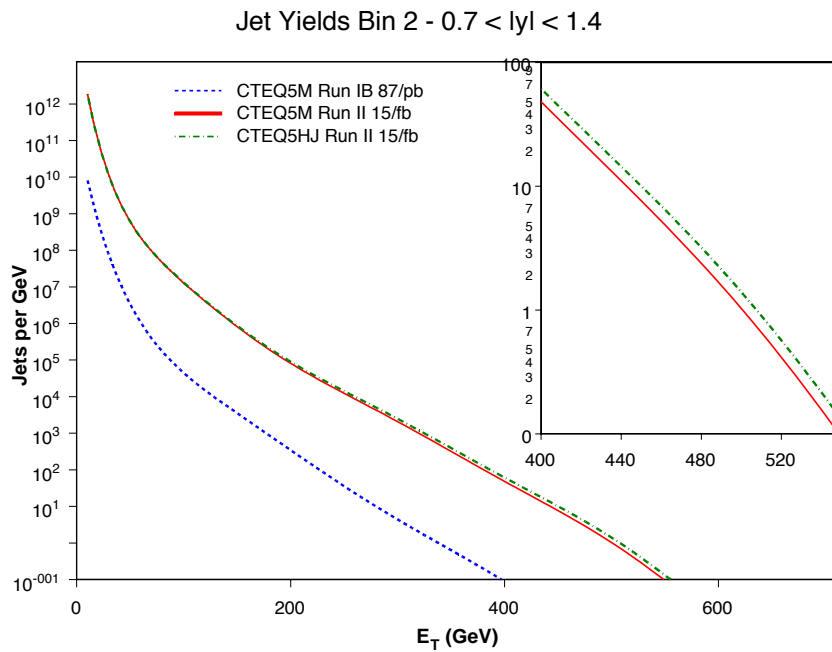
# Jet Yields in Run II (from Steve Ellis)

See [http://www.pa.msu.edu/~huston/run2btdr\\_qcd/tdr.ps](http://www.pa.msu.edu/~huston/run2btdr_qcd/tdr.ps) .



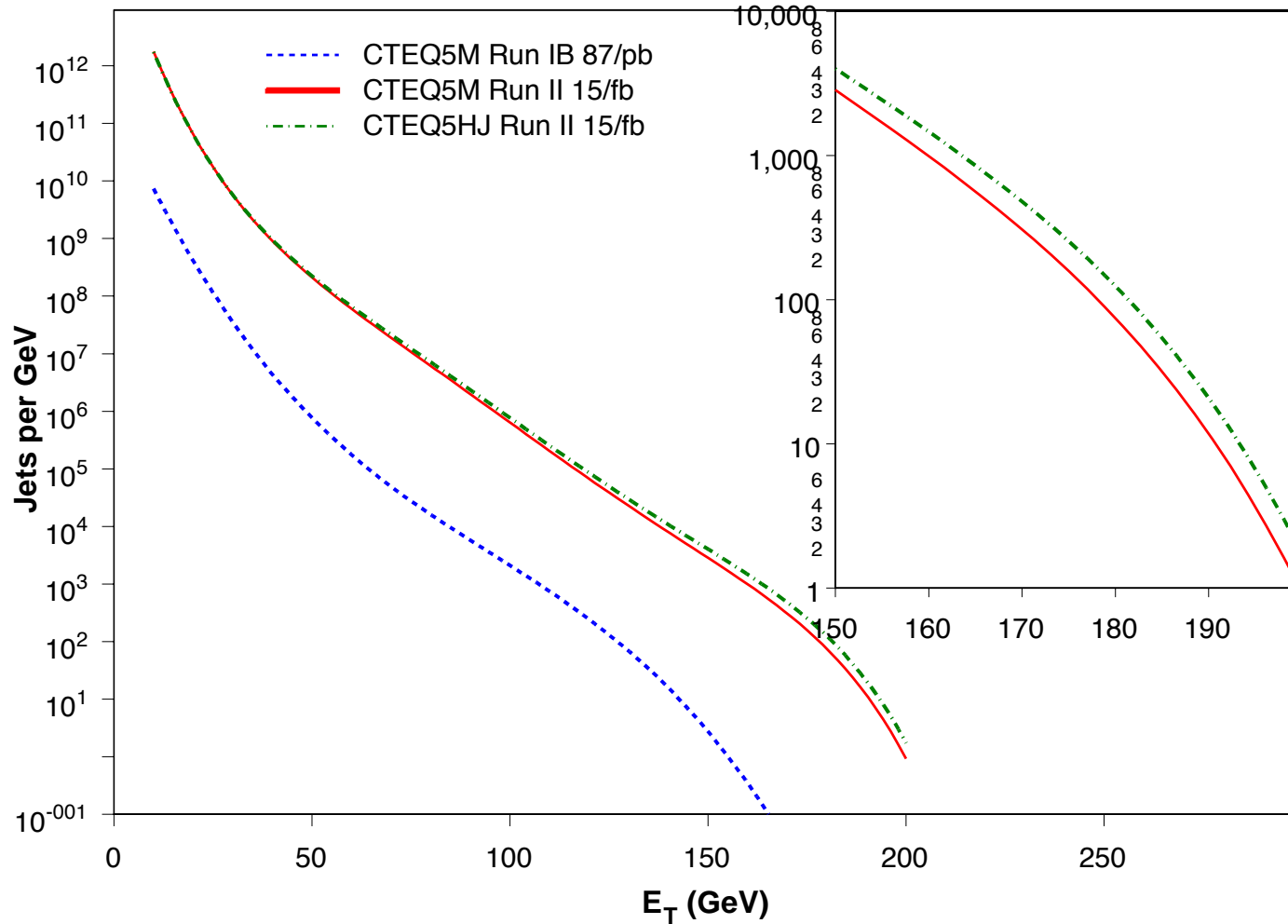
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# Forward Jet Yields



# Forward Jet Yields

Jet Yields Bin 4 -  $2.1 < |\eta| < 3.0$



# Conclusions

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- Paper should be finished in  $<1$  month
  - ◆ uncertainties on jet cross sections in both Run 1 and Run 2
  - ◆ room for new physics in both