Latest from Les Houches and CTEQ

J. Huston

Michigan State University

Les Houches

- Two workshops on “Physics at TeV Colliders” have been held so far, in 1999 and 2001 (May 21-June 1)
- Working groups on QCD/SM, Higgs, Beyond Standard Model
- See web page:

http://wwwlapp.in2p3.fr/conferences/LesHouches/Houches2001/

especially for links to writeups from 1999

- QCD writeup (hep-ph/0005114) is an excellent pedagogical review for many of the issues discussed here and at this SS

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Les Houches update

- Les Houches accord #1 (ME->MC)
  - accord implemented in Pythia 6.2
  - accord implemented in CompHEP
    - CDF top dilepton group has been generating ttbar events with CompHEP/Madgraph + Pythia
  - accord implemented in Wbbgen (not yet released)
  - accord implemented in Madgraph
    - MADCUP:http://pheno.physics.wisc.edu/Software/MadCUP/}.
    - MADGRAPH 2: within a few weeks
  - work proceeding on Herwig; in release 6.5 June 2002
  - work proceeding on Grace
  - In AcerMC:hep-ph/0201302
- Les Houches accord #2 (pdfs in ME/MC)
  - version of pdf interface has been developed
    - writeup available now; website will be publically available next week (http://pdf.fnal.gov)
  - commitment for being implemented in MCFM

Les Houches update

- Reminder: the big idea:
  - The Les Houches accords will be implemented in all ME/MC programs that CDF/D0 use
  - They will make it easy to generate the multi-parton final states crucial to much of the Run 2 physics program and to compare the results from different programs
  - CDF/D0/theorists can all share common MC *data sets*
  - They will make it possible to generate the pdf uncertainties for any cross sections measureable at the Tevatron

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Les Houches accord #2

- Using the interface is as easy as using PDFLIB (and much easier to update)
- First version will have CTEQ6M, CTEQ6L, all of CTEQ6 error pdfs and MRST2001 pdfs

- call InitiPDFset(*name*)
  - called once at the beginning of the code; *name* is the file name of external PDF file that defines PDF set
- call InitPDF(*mem*)
  - *mem* specifies individual member of pdf set
- call evolvePDF(*x*,*Q*,*f*)
  - returns pdf momentum densities for flavor *f* at momentum fraction *x* and scale *Q*

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Run 2 Monte Carlo Workshop

- Transparencies, video links to individual talks and links to programs can all be found at http://www-theory.fnal.gov/runiimc/

Signatures of New Physics

- W's, jets, γ's, b quarks, $\not{E}_T$
- …pretty much the same as signatures for SM physics
- How do we find new physics? By showing that it's not old physics.
  - can be modifications to the rate of production
  - …or modification to the kinematics, e.g.angular distributions
- Crucial to understand the QCD dynamics of both backgrounds to any new physics and to the new physics itself
- Some backgrounds can be measured in situ
  - …but may still want to predict in advance, e.g. QCD backgrounds to H->$\gamma\gamma$
- For some backgrounds, need to rely on theoretical calculations, e.g. ttbb backgrounds to ttH

Theoretical Predictions for New (Old) Physics

There are a variety of programs available for comparison of data to theory and/or predictions.

- Tree level
- Leading log Monte Carlo
- N^nLO
- Resummed

In general, agree quite well…but before you appeal to new physics, check the ME. (for example using Comphep) Can have ME corrections to MC or MC corrections to ME. (in CDF->HERPRT)

Perhaps biggest effort…include NLO ME corrections in Monte Carlo programs… correct normalizations. Correct shapes. N^nLO needed for precision physics.

Resummed description describes soft gluon effects (better than MC's)…has correct normalization (but need HO to get it); resummed predictions include non-perturbative effects correctly…may have to be put in by hand in MC's

threshold
dijet, direct γ

k_T
W,Z, Higgs

b space
(ResBos)

q_t space

Important to know strengths/weaknesses of each.

Where possible, normalize to existing data.

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…in addition, worry about pdf, fragmentation uncertainties

References for this talk

- LHC Guide to Parton Distributions and Cross Sections, J. Huston; http://www.pa.msu.edu/~huston/lhc/lhc_pdfnote.ps
- The QCD and Standard Model Working Group: Summary Report from Les Houches; hep-ph/0005114
- Parton Distributions Working Group, Tevatron Run 2 Workshop; hep-ph/0006300
- A QCD Analysis of HERA and fixed target structure functiondata, M. Botje; hep-ph/9912439
- Global fit to the charged leptons DIS data…, S. Alekhin; hep-ph/0011002
- Walter Giele's presentation to the QCD group on Jan. 12; http://www-cdf.fnal.gov/internal/physics/qcd/qcd99_internal_meetings.html
- Uncertainties of Predictions from Parton Distributions I: the Lagrange Multiplier Method, D. Stump, J. Huston et al.;hep-ph/0101051
- Uncertainties of Predictions from Parton Distributions II: the Hessian Method, J. Pumplin, J. Huston et al.; hep-ph/0101032
- Error Estimates on Parton Density Distributions, M. Botje; hep-ph/0110123
- **New Generation of Parton Distributions with Uncertainties from Global QCD Analysis (CTEQ6); hep-ph/0201195**

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 γ production
- Two major groups that provide semi-regular updates to parton distributions when new data/theory becomes available
  - MRS->MRST98->MRST99->MRST2001(central, lower α_s, higher α_s, better fit to jet data, LO)
    - **http://durpdg.dur.ac.uk/hepdata/mrs**
  - CTEQ->CTEQ5->CTEQ5(1)->CTEQ6 (cteq6m and cteq6l)
    - **http://www.phys.psu.edu/~cteq/#PDFs**
- 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
    - Largrange Multiplier
  - results available both in conventional formalism and in Les Houches accord format

Whats new/old since CTEQ5?

- New Data
  - new DIS data from H1/ZEUS
  - jet cross sections from D0 as a function of η
  - updated E866 Drell-Yan deuteron/proton ratio
  - re-analyzed CCFR F_2
- Old data
  - BCDMS DIS
  - NMC DIS

    (BCDMS DIS, NMC DIS →) now use measurements at separate energies with full correlation info
  - CCFR F_3
  - E665 DIS
  - E605 DY
  - CDF W asym
  - CDF inclusive jets

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  - $CCFR\ F_3$
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  - E605 DY
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  - CDF inclusive jets

now use measurements at separate energies with full correlation info

~1800 data points: global χ^2 is 1950
CTEQ5M χ^2 on same data is ~2500

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Nuts/bolts of fits

- Functional form used is:
  - $xf(x,Q_o) = A_o x^{A1} (1-x)^{A2} e^{A3x} (1 + A_4 x)^{A5}$
    - Q_o = 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

Nuts/bolts of fits

Previously, pdf fits minimized a χ^2 function that added stat and systematic errors in quadrature

$$\chi_0^2 = \sum_{\text{expt.}} \sum_{i=1}^{N} \frac{(D_i - T_i)^2}{\sigma_i'^2}$$

Most DIS experiments have published detailed list of their experimental errors. Best fit to data comes from minimizing a χ^2 function with systematic corrections

$$\chi^2 = \sum_{\text{expt.}} \left[\sum_{i=1}^{N} \frac{1}{\alpha_i^2} \left(D_i - T_i - \sum_{j=1}^{N} r_j \beta_{ji} \right)^2 + \sum_{j=1}^{N} r_j^2 \right]$$

r_j are systematic error corrections for each experiment

Minimization of χ^2 with respect to r_j can be done analytically

$$r_j = \sum_{j'=1}^{K} \left(A^{-1}\right)_{jj'} B_{j'};$$

ıponent vector,

$$B_j = \sum_{i=1}^{N} \frac{\beta_{ji}\,(D_i - T_i)}{\alpha_i^2},$$

$$A_{jj'} = \delta_{jj'} + \sum_{i=1}^{N} \frac{\beta_{ji}\beta_{j'i}}{\alpha_i^2}.$$

Substituting the best estimates (8) back into χ^2, we obtain a correlated χ^2 function,

$$\chi^2 = \sum_{\text{expt.}} \left\{ \sum_{i=1}^{N} \frac{(D_i - T_i)^2}{\alpha_i^2} - \sum_{j,j'=1}^{K} B_j \left(A^{-1}\right)_{jj'} B_{j'} \right\}.$$

can minimize χ^2 with respect to above correlated χ^2 function

Correct data with respect to systematic errors for χ^2 minimization

$$\longrightarrow D_i^{\text{corrected}} \equiv D_i - \sum_{j=1}^{K} r_j \beta_{ji}.$$

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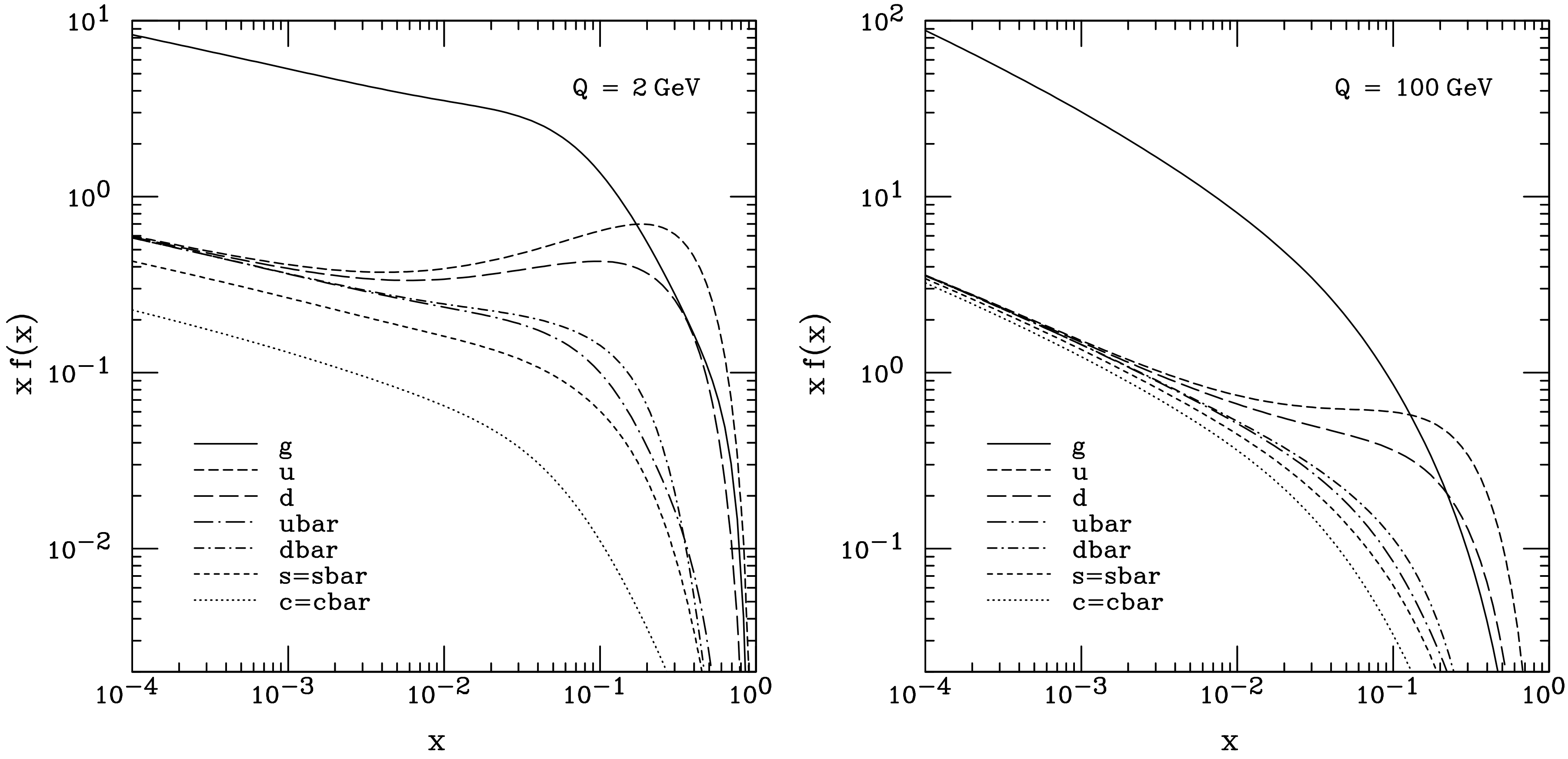
CTEQ6 pdfs

low Q

high Q



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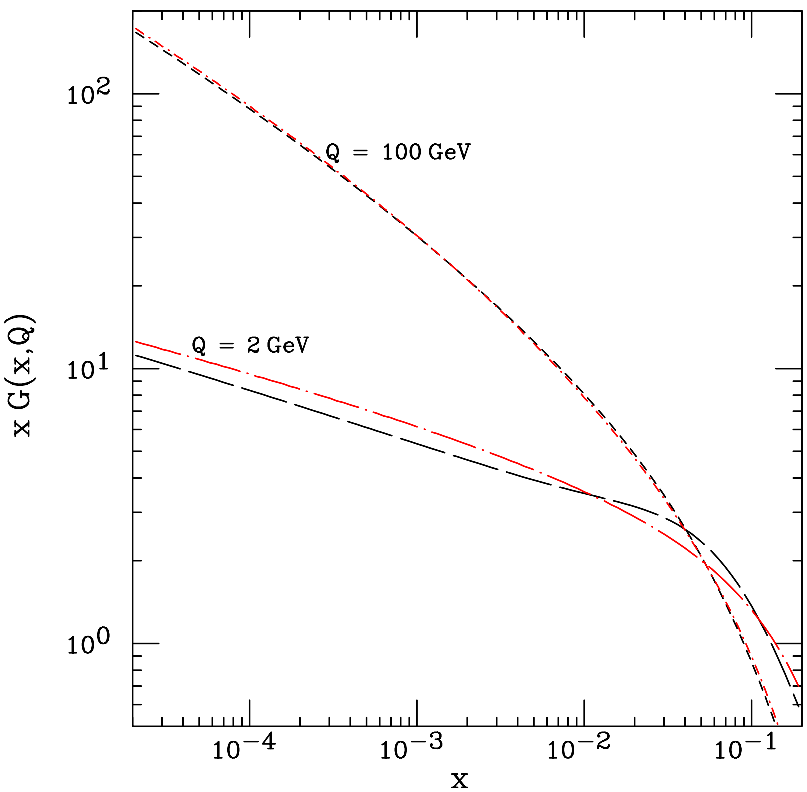
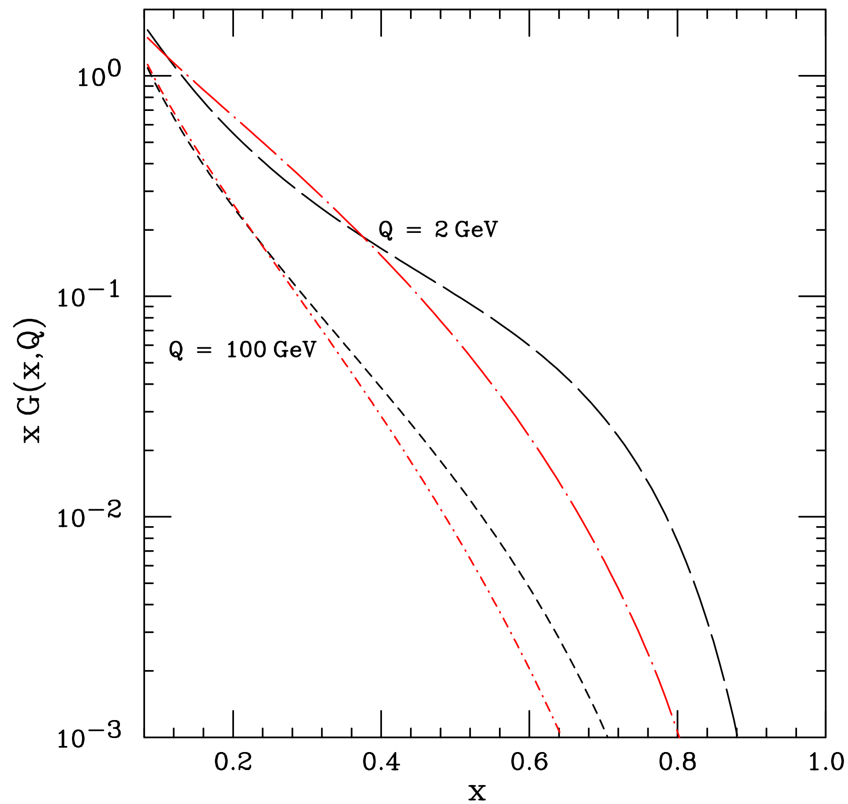
Compare to CTEQ5

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



low x



high x

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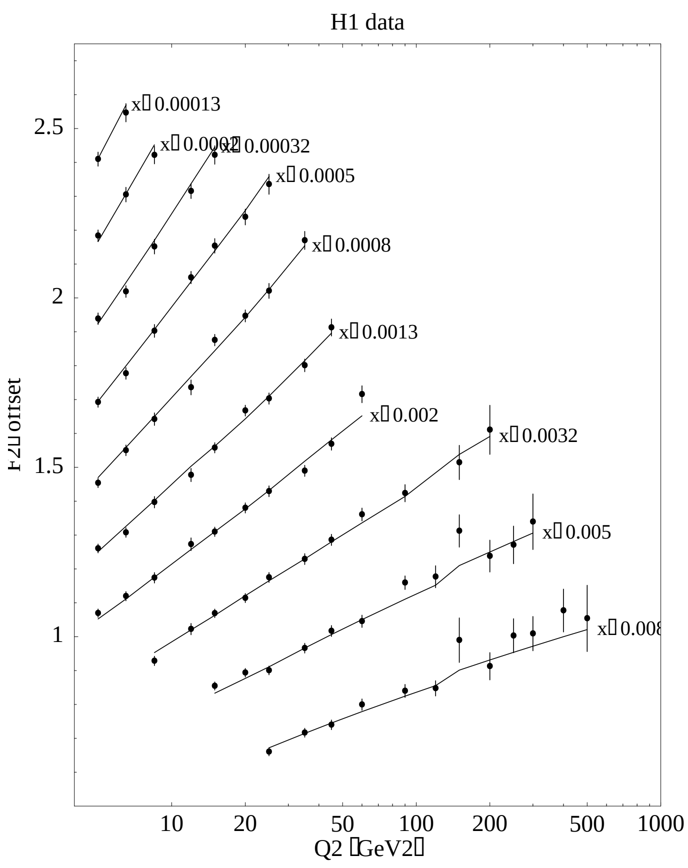
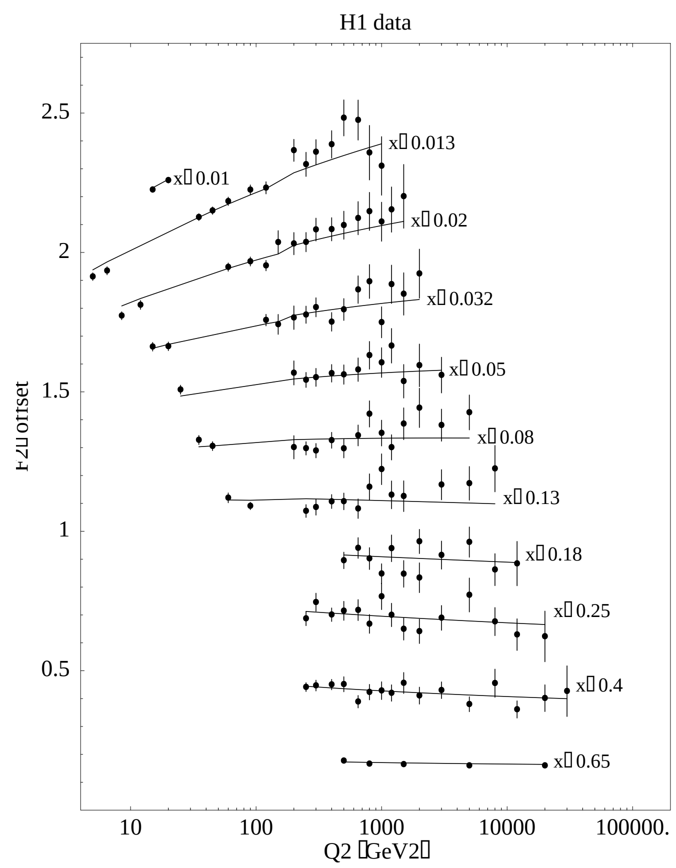
Comparisons to H1





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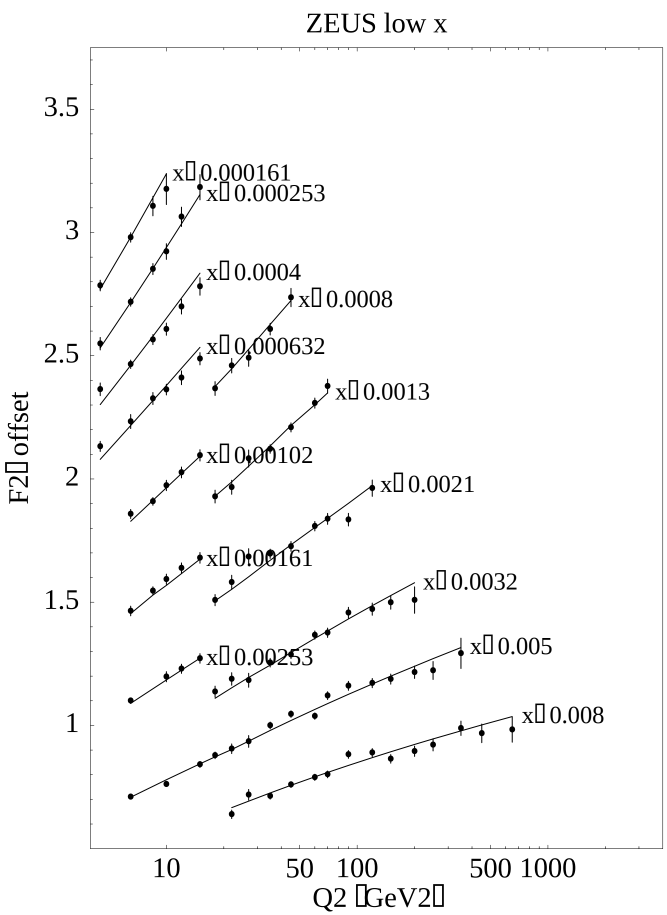
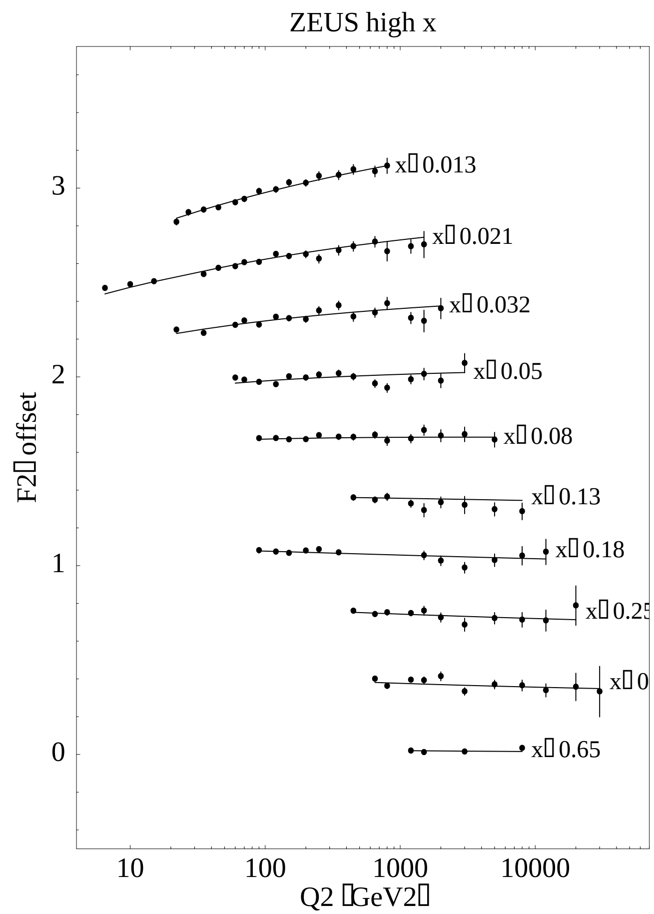
Comparisons to ZEUS





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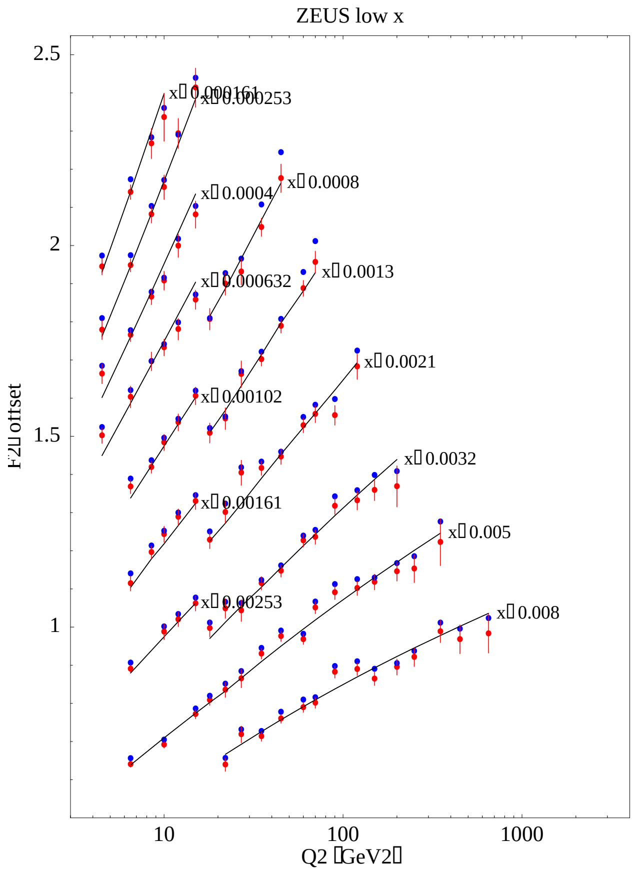
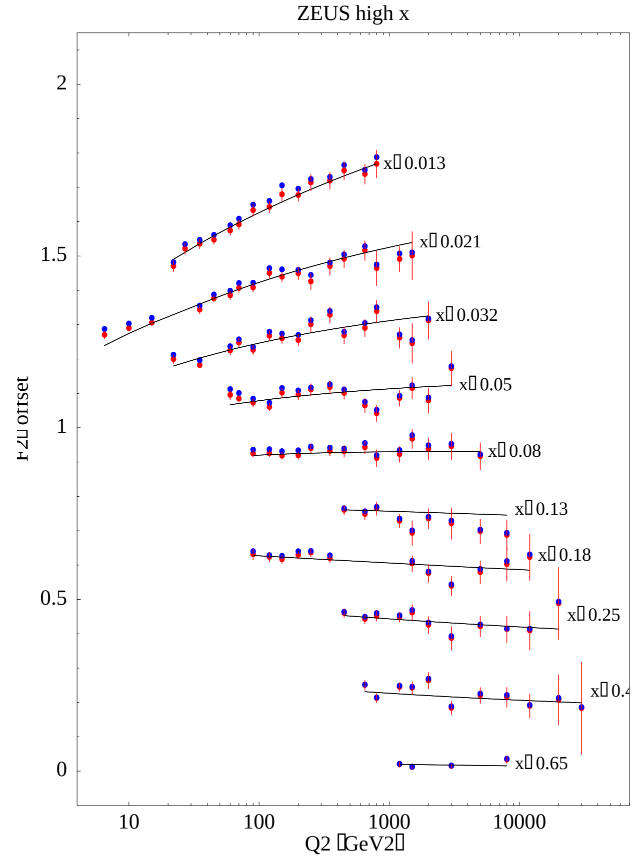
Effect of shifts of systematic errors





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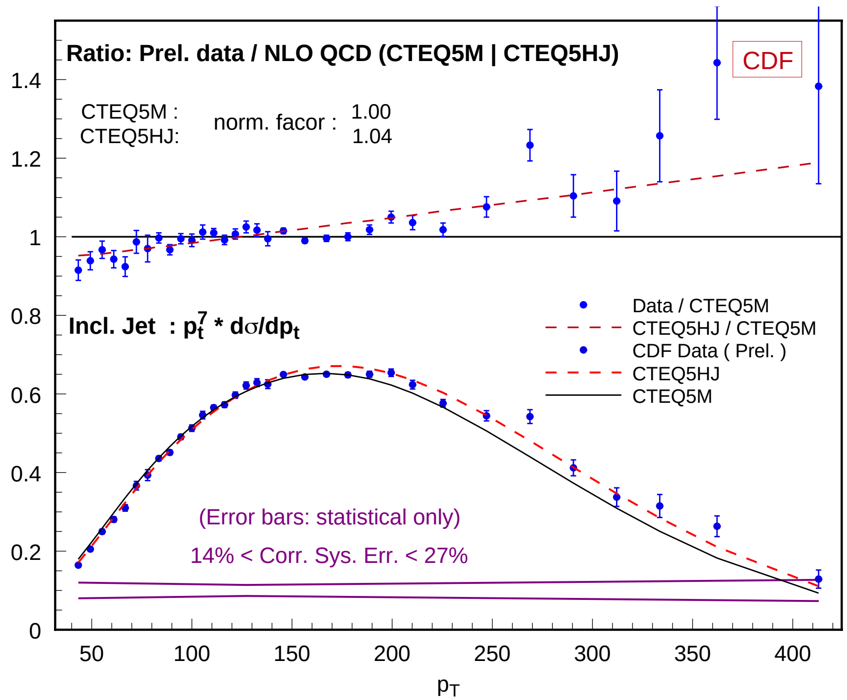
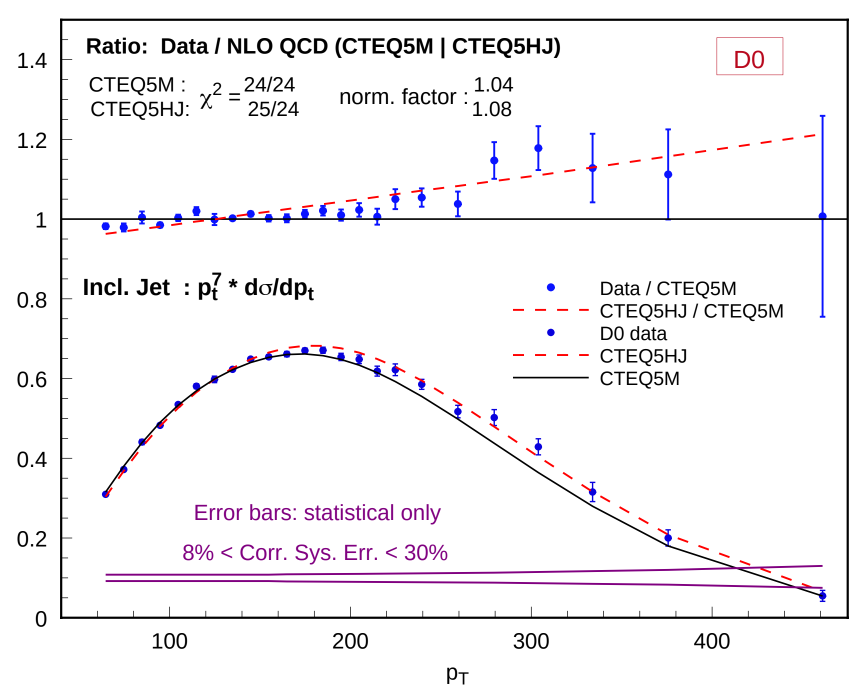
Jets at the Tevatron and the high x gluon

Best fit to CDF and D0 central jet cross sections provided by CTEQ5HJ pdf’s





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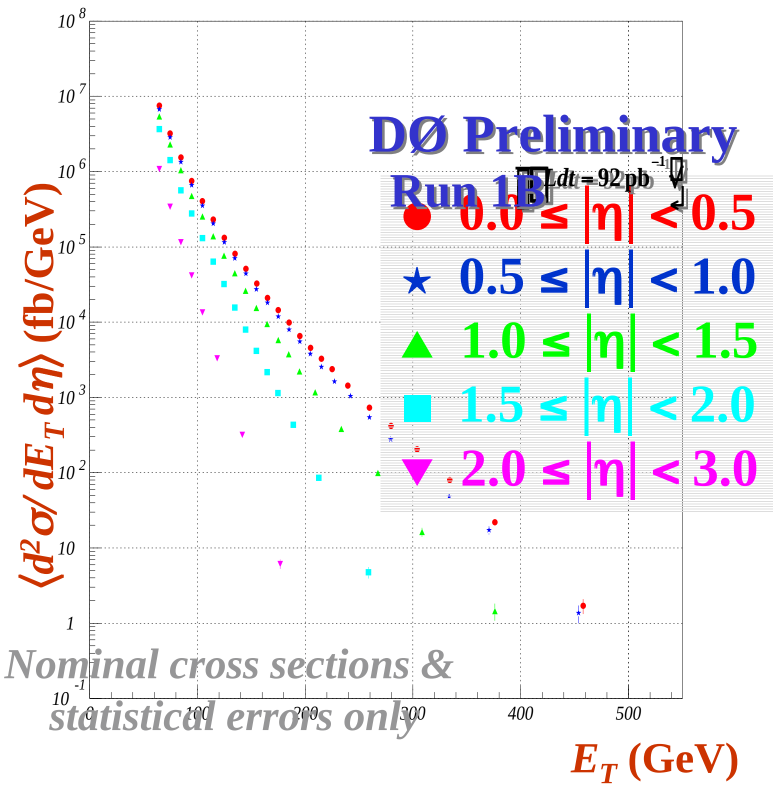
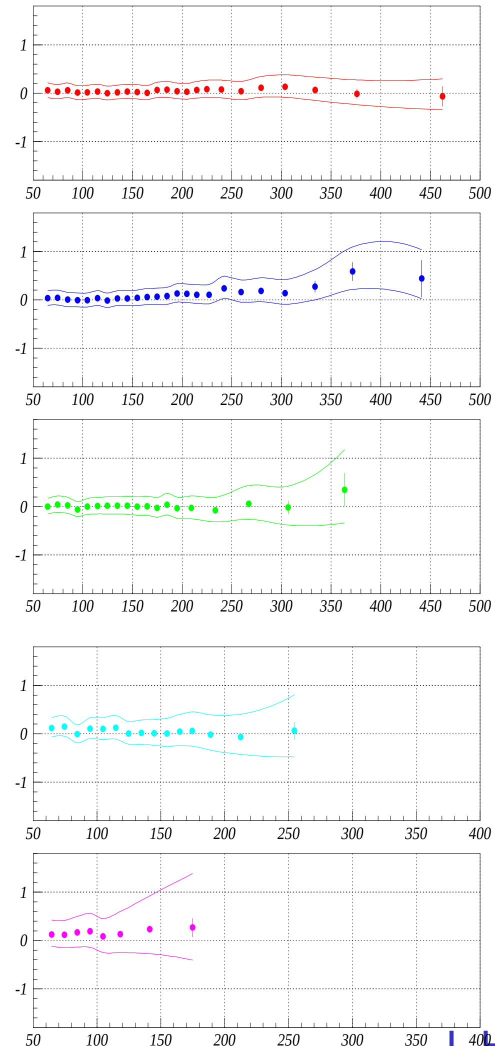
CTEQ4HJ(5HJ) provides best description of D0 jet cross sections



PDF	χ^2	χ^2/dof	Prob
CTEQ3M	121.56	1.35	0.01
CTEQ4M	92.46	1.03	0.41
CTEQ4HJ	59.38	0.66	0.99
MRST	113.78	1.26	0.05
MRSTgD	155.52	1.73	<0.01
MRSTgU	85.09	0.95	0.63



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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*
- χ^2 for CDF+D0 jet data is 113 for 123 data points

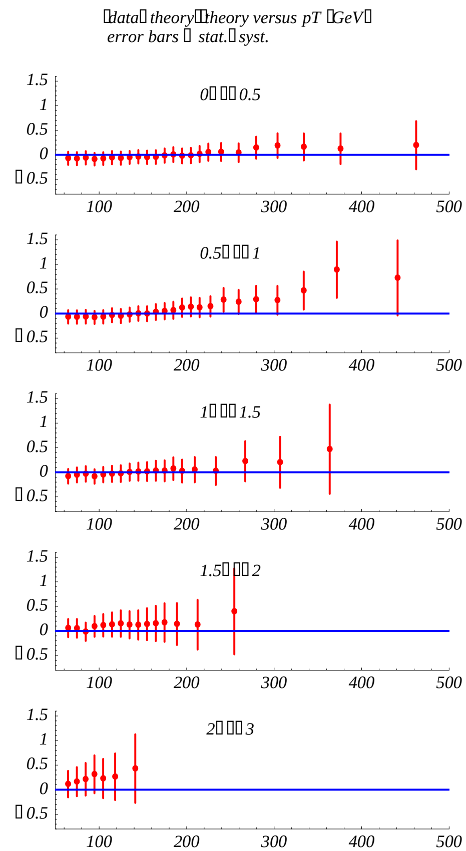

Figure 19: Comparison between theory and the D0 jet data. The error bars are statistical and systematic errors combined.

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PDF Uncertainties

- What's unknown about PDF's
  - the gluon distribution
  - strange and anti-strange quarks
  - details in the {u,d} quark sector; up/down differences and ratios
  - heavy quark distributions

- Σ of quark distributions (q + qbar) is well-determined over wide range of x and Q^2
  - Quark distributions primarily determined from DIS and DY data sets which have large statistics and systematic errors in few percent range ($\pm 3\%$ for $10^{-4}<x<0.75$)
  - Individual quark flavors, though may have uncertainties larger than that on the sum; important, for example, for W asymmetry
- information on dbar and ubar comes at small x from HERA and at medium x from fixed target DY production on H_2 and D_2 targets
  - Note dbar≠ubar
- strange quark sea determined from dimuon production in ν DIS (CCFR)
- d/u at large x comes from FT DY production on H_2 and D_2 and lepton asymmetry in W production

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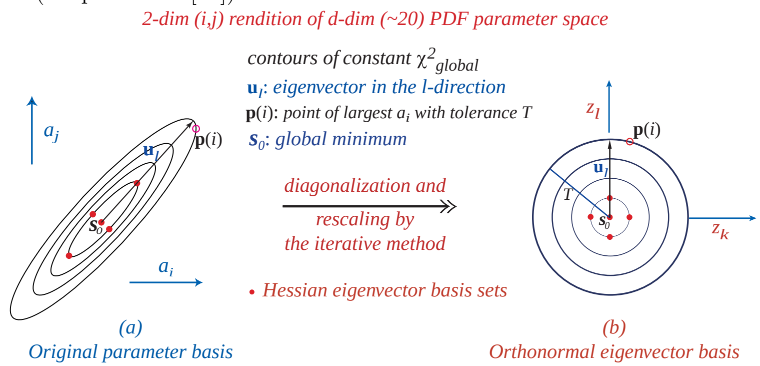
PDF Uncertainties

theoretical model with many parameters, as well as its own sources of inherent uncertainties.

In [9, 10, 11], we formulated two methods, the Hessian and the Lagrange, which enable the systematic characterization of the *neighborhood* of the global minimum of the χ^2 function. These allow a systematic way of assessing the compatibility of the data sets in the framework of the theoretical (PQCD) model [36], as well as of estimating the uncertainties of the PDFs and their physical predictions if the experimental inputs are assumed to be compatible, within certain practical tolerance. The basic ideas are summarized in the accompanying illustration (adapted from [10]):



The behavior of the global χ^2 function in the neighborhood of the global minimum in the PDF parameter space is encapsulated in $2N_p$ sets of eigenvector PDFs (with $N_p \sim 20$ being the number of initial PDF parameters), obtained by an iterative procedure to diagonalize the Hessian matrix and to adjust the step sizes of the numerical calculation to match the natural physical scales. This procedure efficiently overcomes a number of critical obstacles[4] encountered when applying standard tools to perform error propagation in the global χ^2 minimization approach. Details are given in [9, 10]

The analysis done in this work make full use of this method. The resulting $2N_p + 1$ PDF sets, consisting of the best fit and the eigenvector basis sets, allow us to calculate the best estimate, and the range of uncertainty, of the PDF themselves as well as any physical

[3]For our analysis, there are ~ 2000 data points from ~ 16 different experiments of very different systematics and a wide range of precision.

[4]These are due to difficulties in calculating physically meaningful error matrices, by finite differences, in the face of: (i) vastly different scales ($\sim 10^{6-7}$) in different, a priori unknown, directions in the high dimension parameter space; and (ii) numerical fluctuations due to integration errors in the theoretical (PQCD) model calculation, as well as round-offs.

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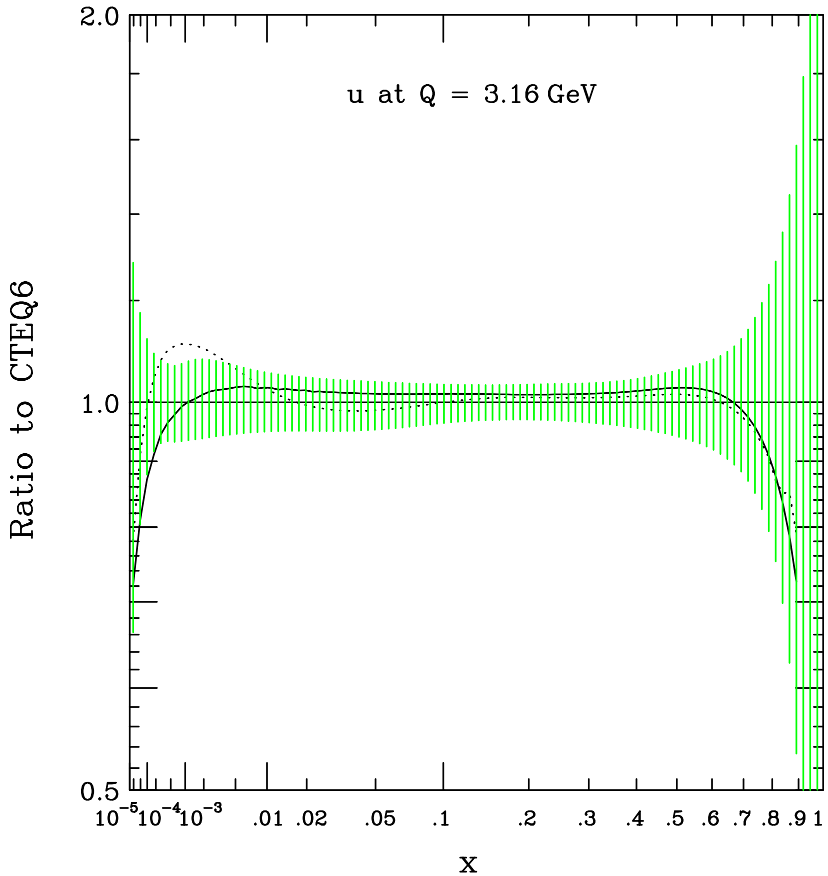
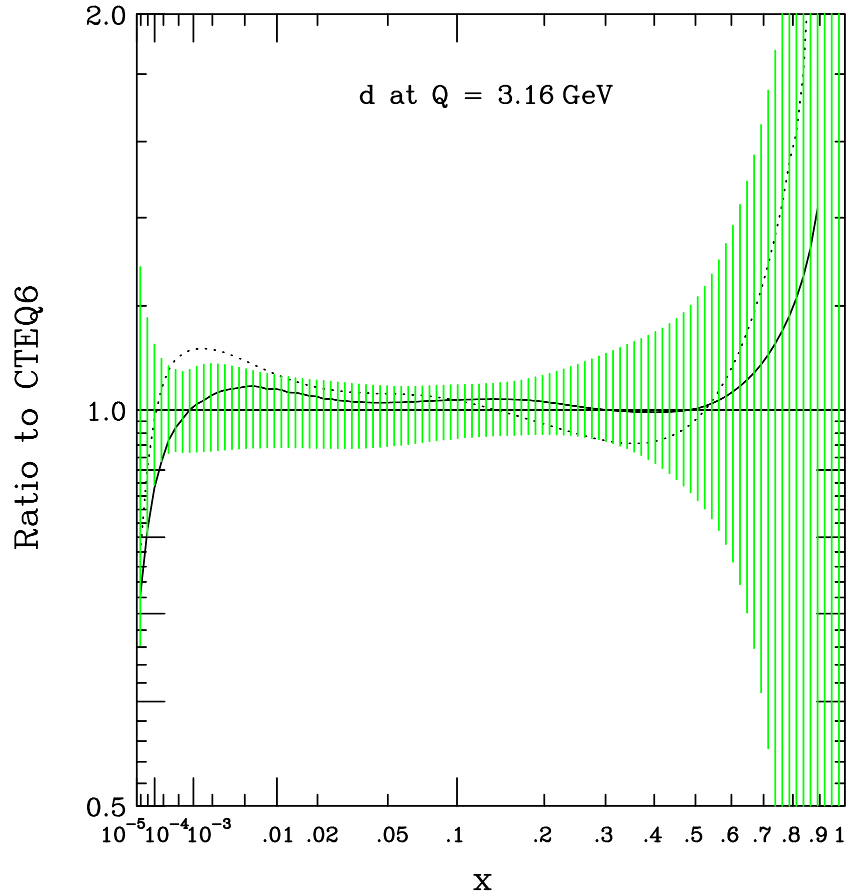
PDF Uncertainties

- Use Hessian technique (T=10)





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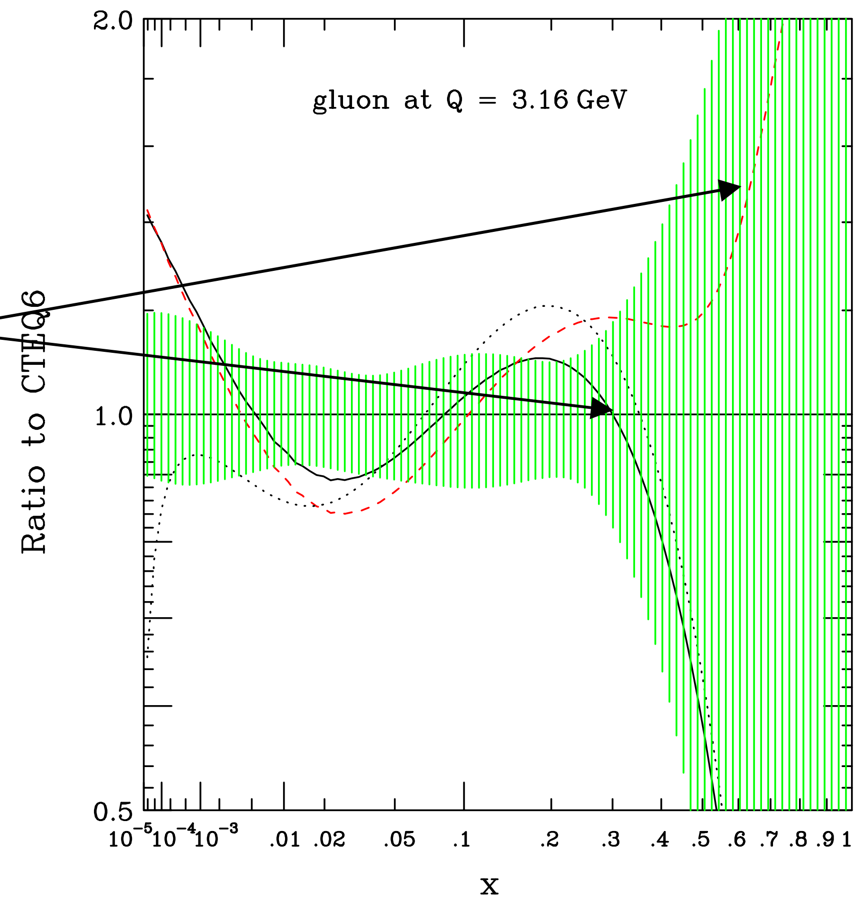
Gluon Uncertainty

- 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



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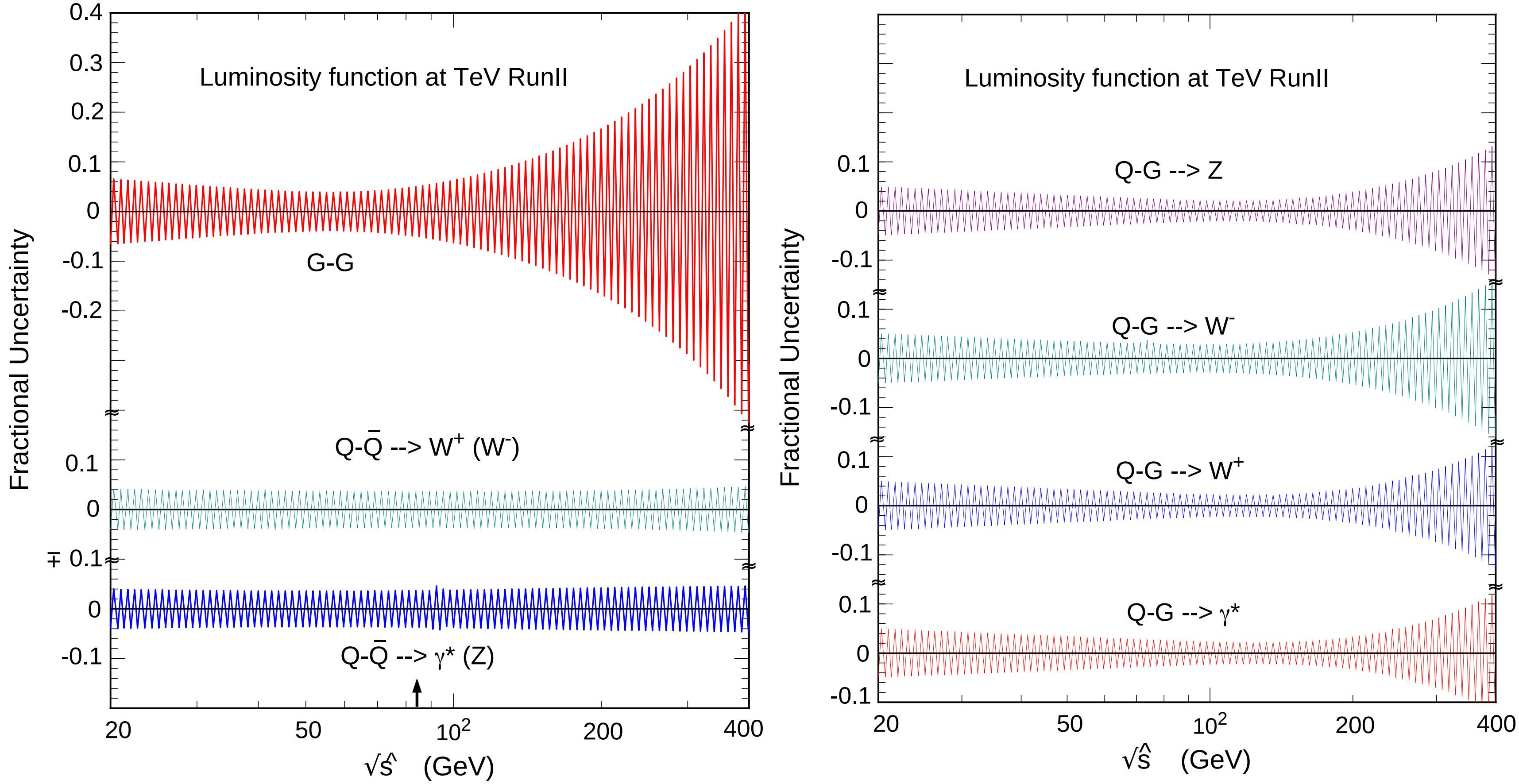
Luminosity function uncertainties at the Tevatron



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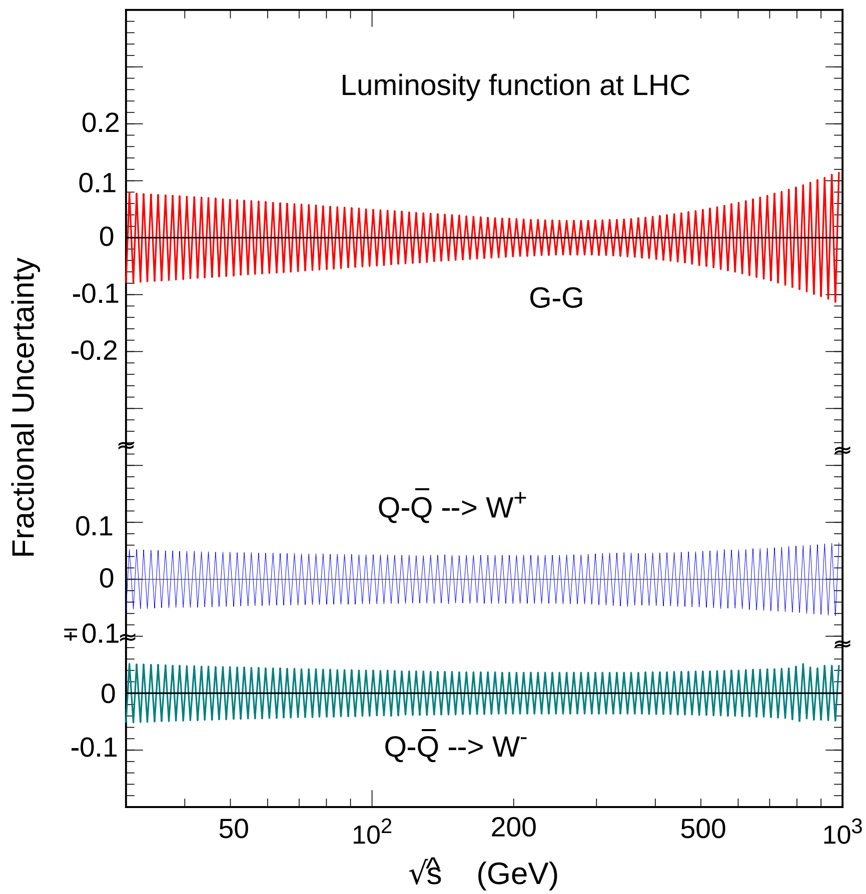
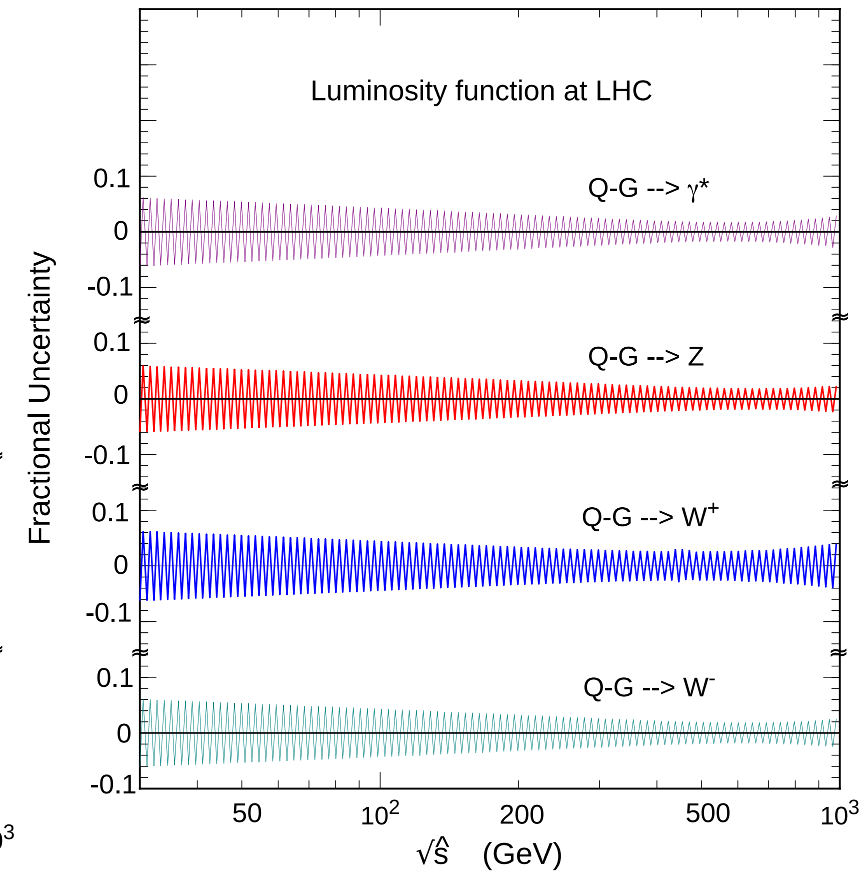
Luminosity Function Uncertainties at the LHC





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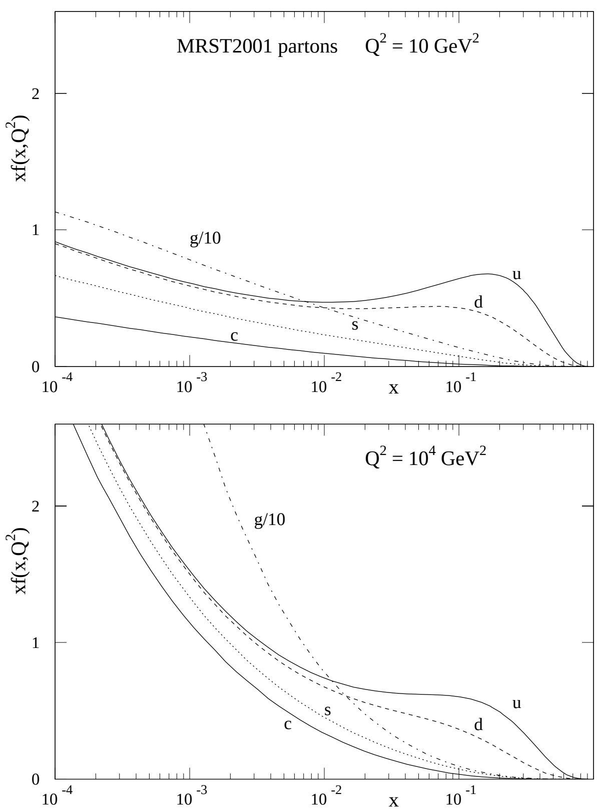
Effective use of pdf uncertainties

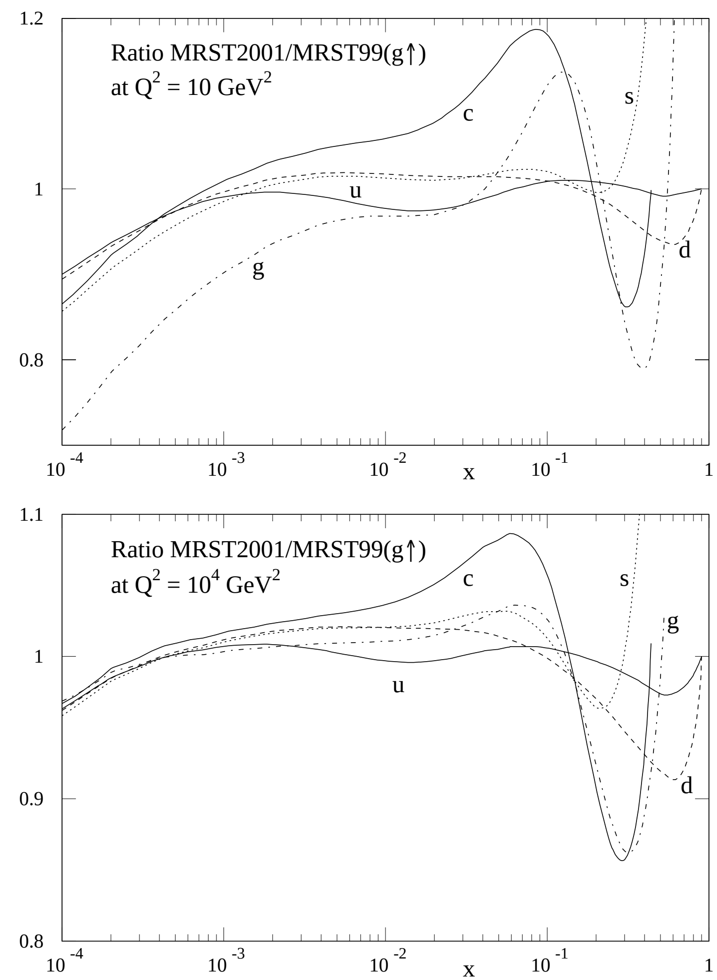
- PDF uncertainties are important both for precision measurements (W/Z cross sections) as well as for studies of potential new physics (a la jet cross sections at high E_T)
- Most Monte Carlo/matrix element programs have "central" pdf's built in, or can easily interface to PDFLIB
- Determining the pdf uncertainty for a particular cross section/distribution might require the use of many pdf's
  - CTEQ Hessian pdf errors require using 33 pdf's
  - GKK on the order of 100
- Too clumsy to attempt to includes grids for calculation of all of these pdf's with the MC programs
- **->Les Houches accord #2**
  - Each pdf can be specified by a few lines of information, if MC programs can perform the evolution
  - Fast evolution routine will be included in new releases to construct grids for each pdf

MRST2001 pdfs

- Similar data sets to CTEQ6 but no correlated error info
  - plus use SLAC DIS and HERA charm data



Comparison of MRST2001 partons with MRST99 partons



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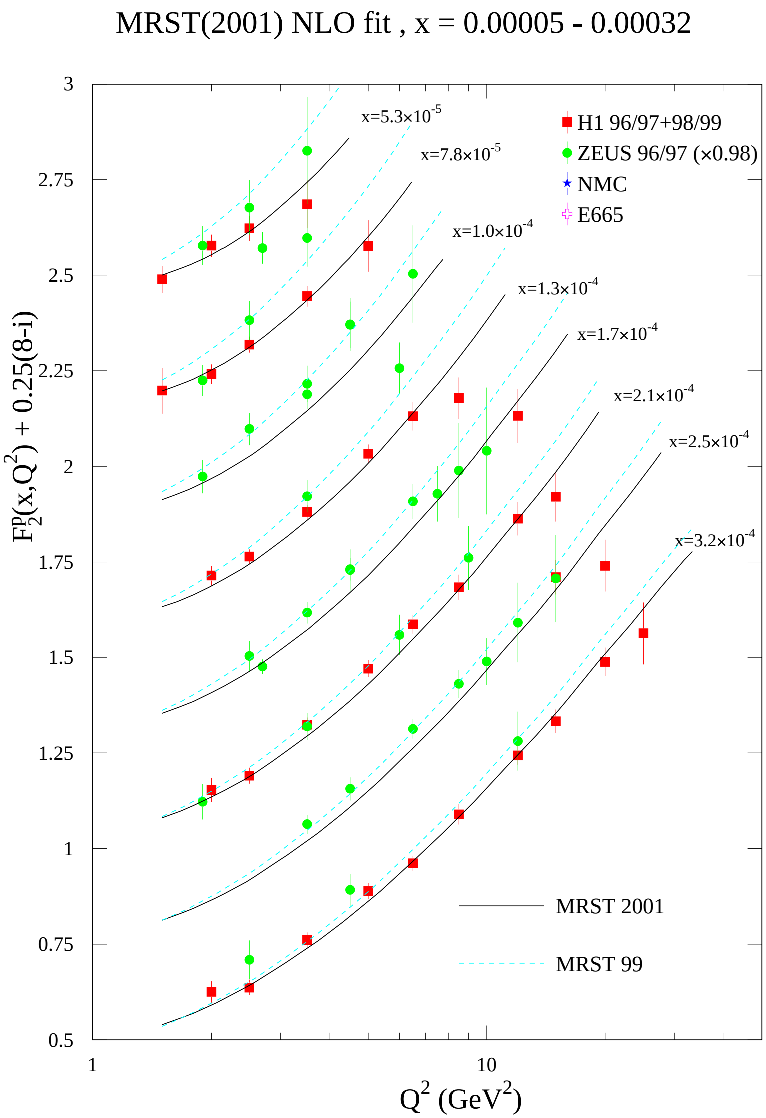
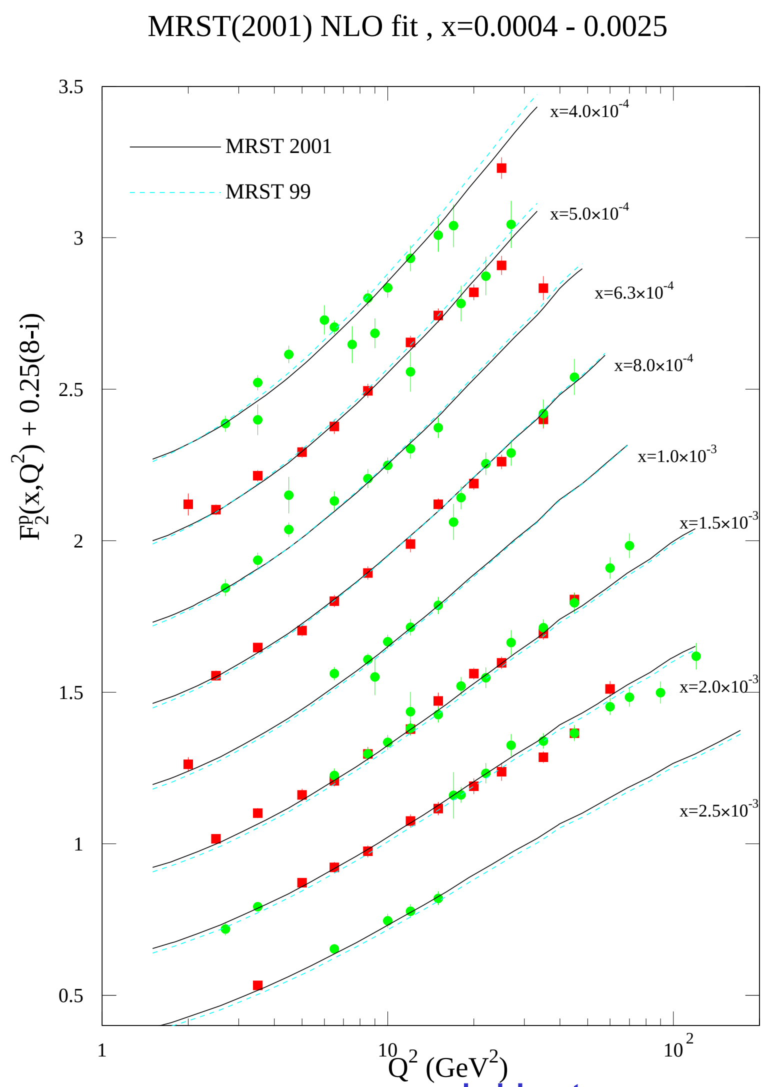
Comparison to DIS





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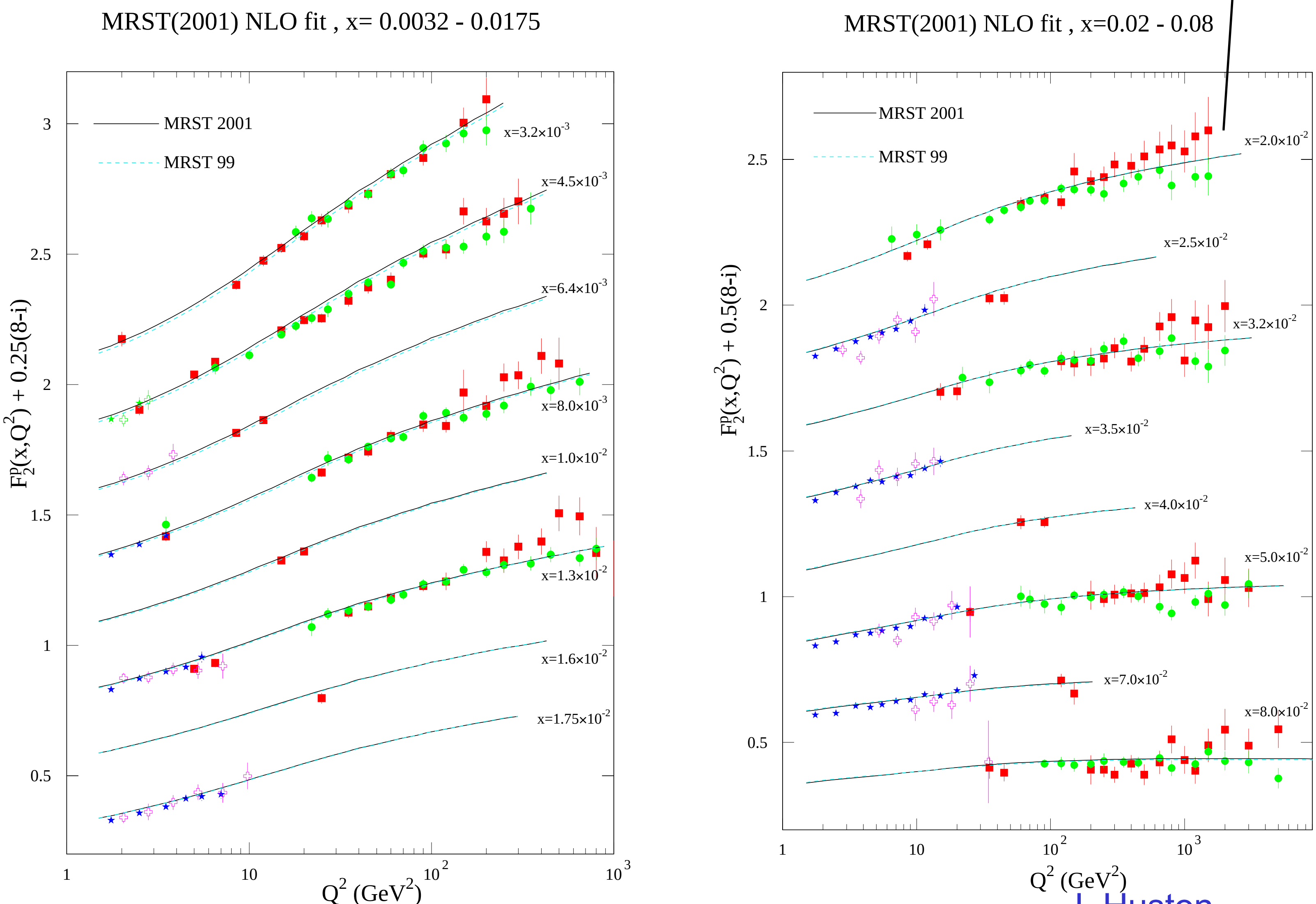
Comparison to DIS

note data a little steeper



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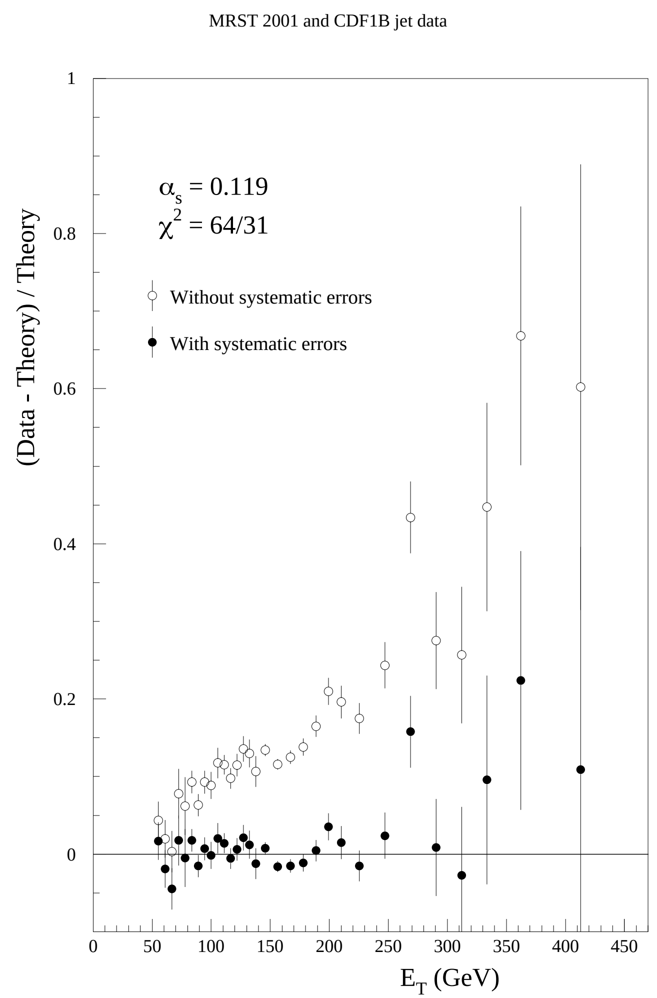
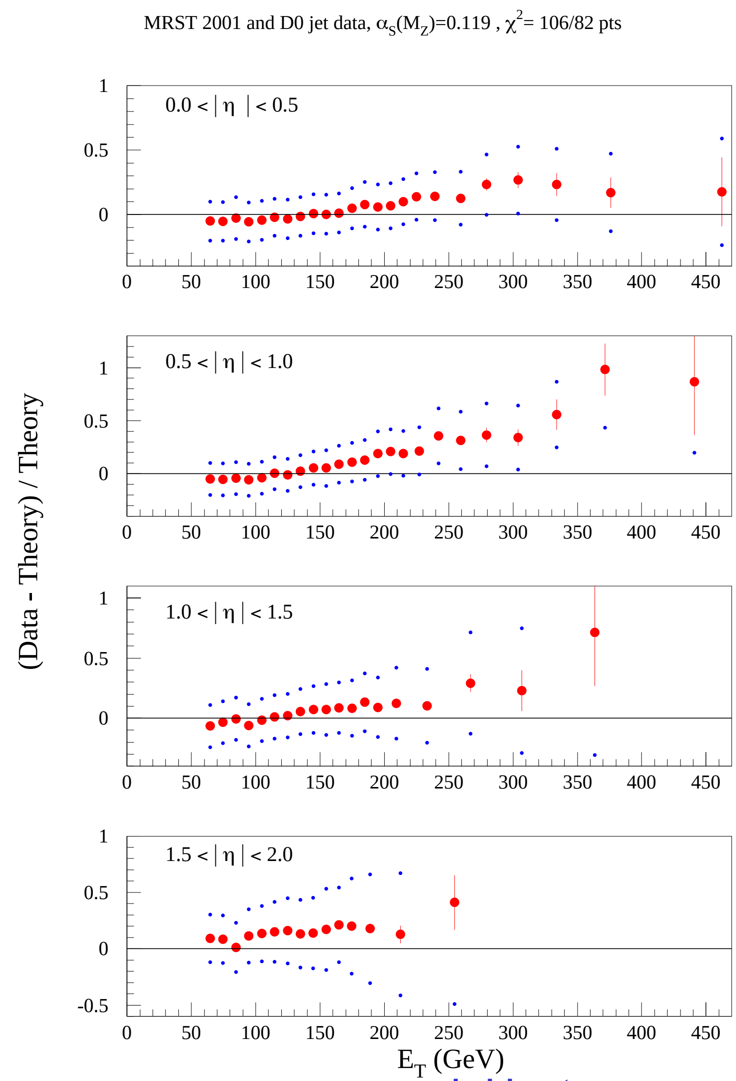
MRST2001: Comparisons to CDF/D0 jets

- χ^2 = 170/113 points





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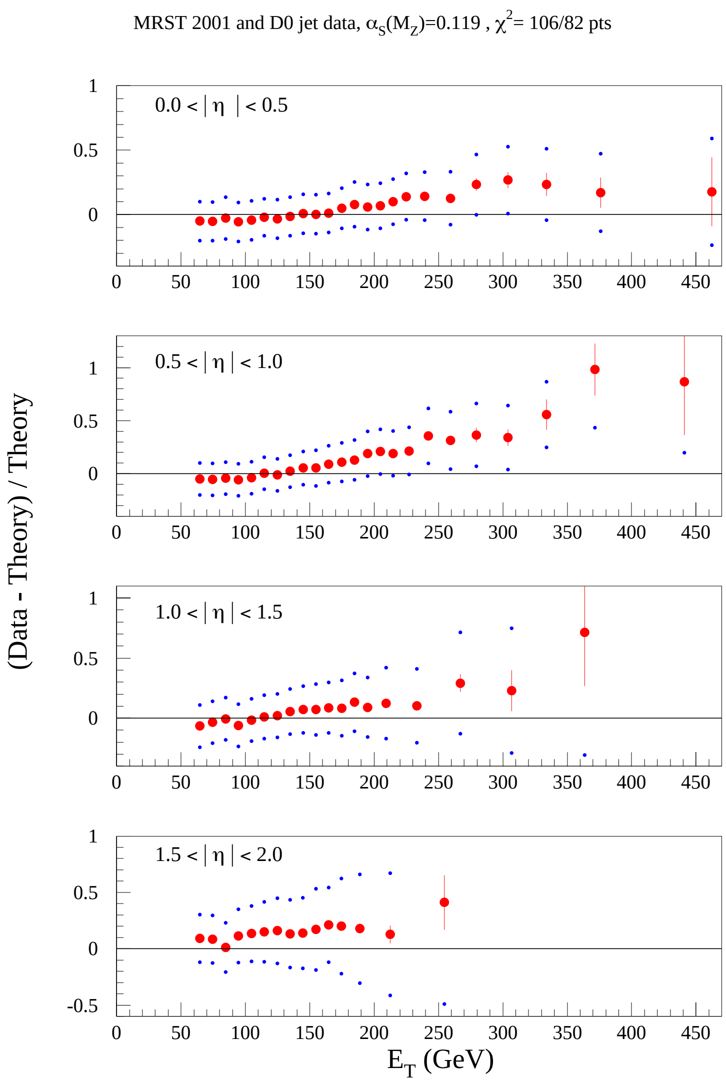
MRST2001/CTEQ6M comparison for D0 jets



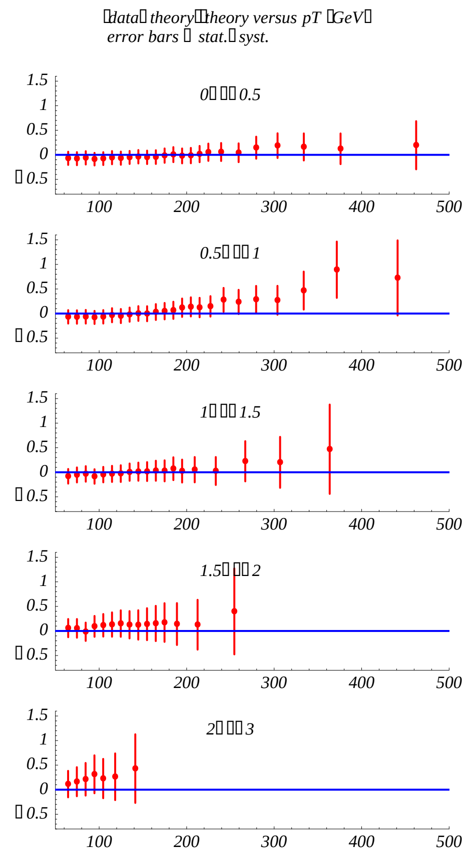


Figure 19: Comparison between theory and the D0 jet data. The error bars are statistical and systematic errors combined.

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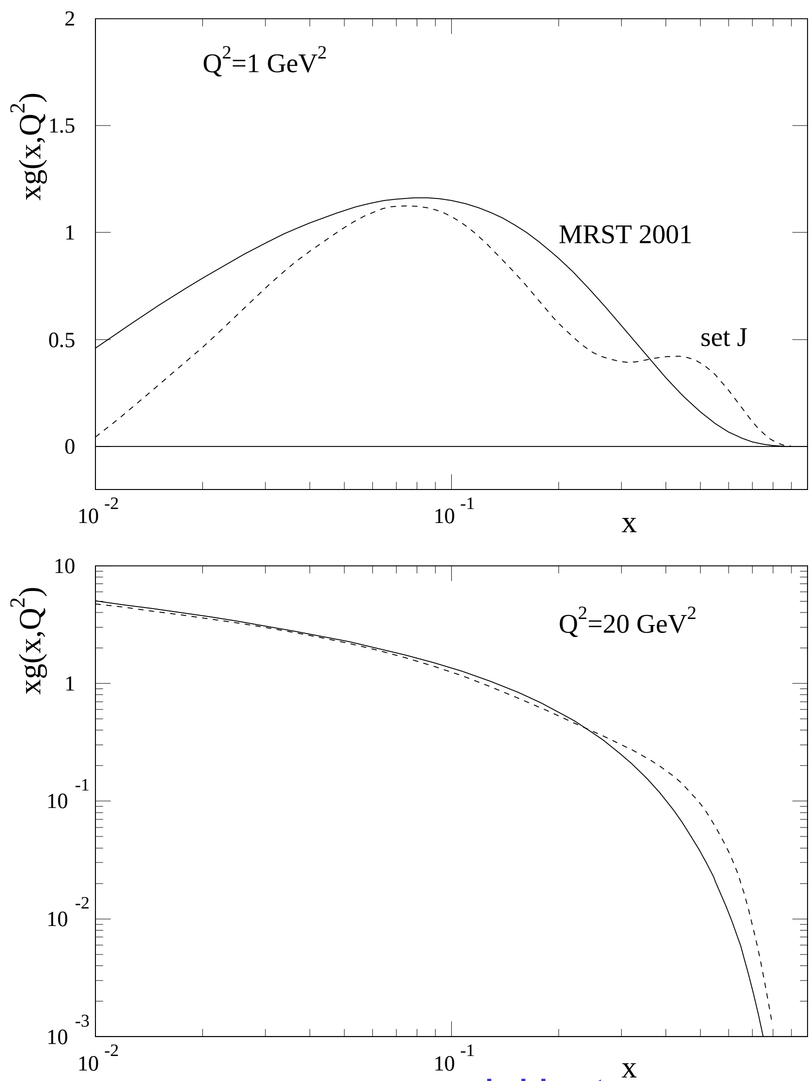
MRST2001J

- Fit to the jet data gives a χ^2 of 118 (for 113 points) compared to 170
- α_s = .121
- But gluon has a *kink* at low Q, leading to a *shoulder* at higher Q
- Fit rejected
- But an artifact of too strict a parametrization?
- We get a kink in CTEQ6 gluon if we use MRST parametrization



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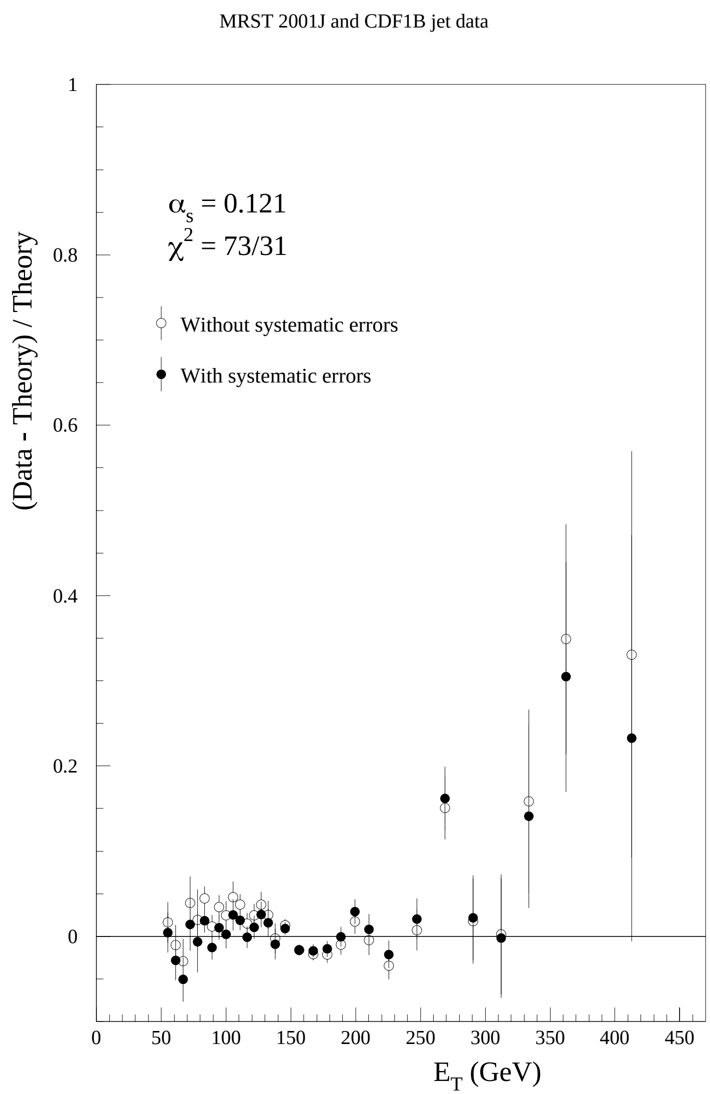
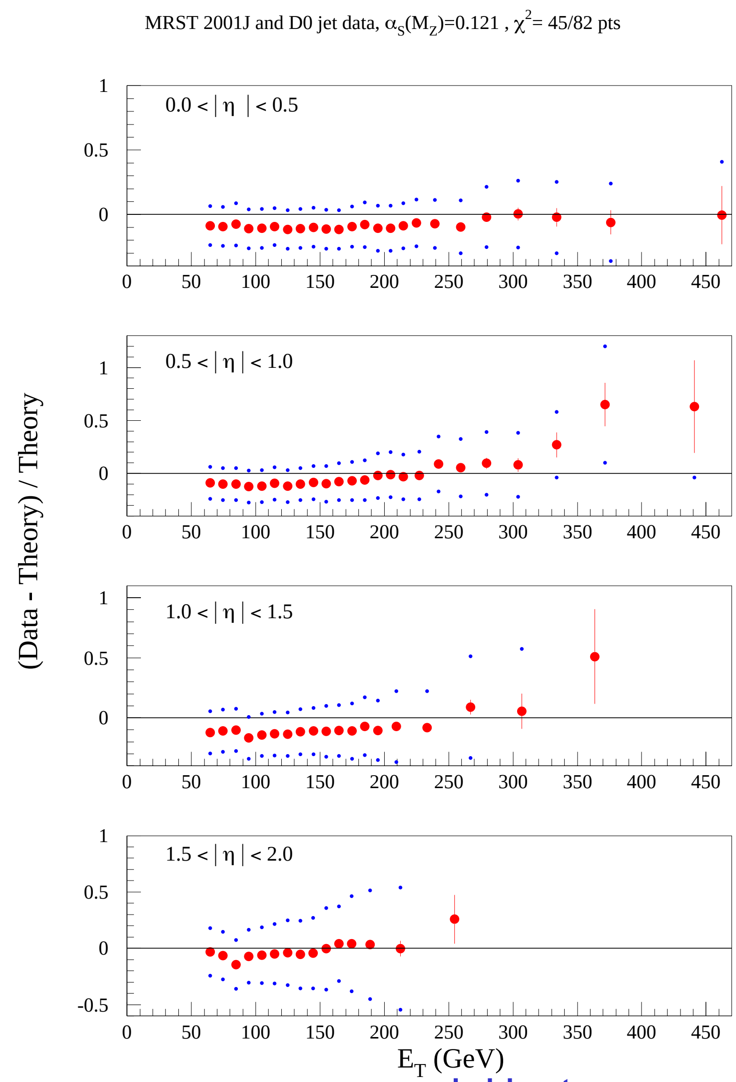
MRST2001J: Comparison to CDF/D0 jets





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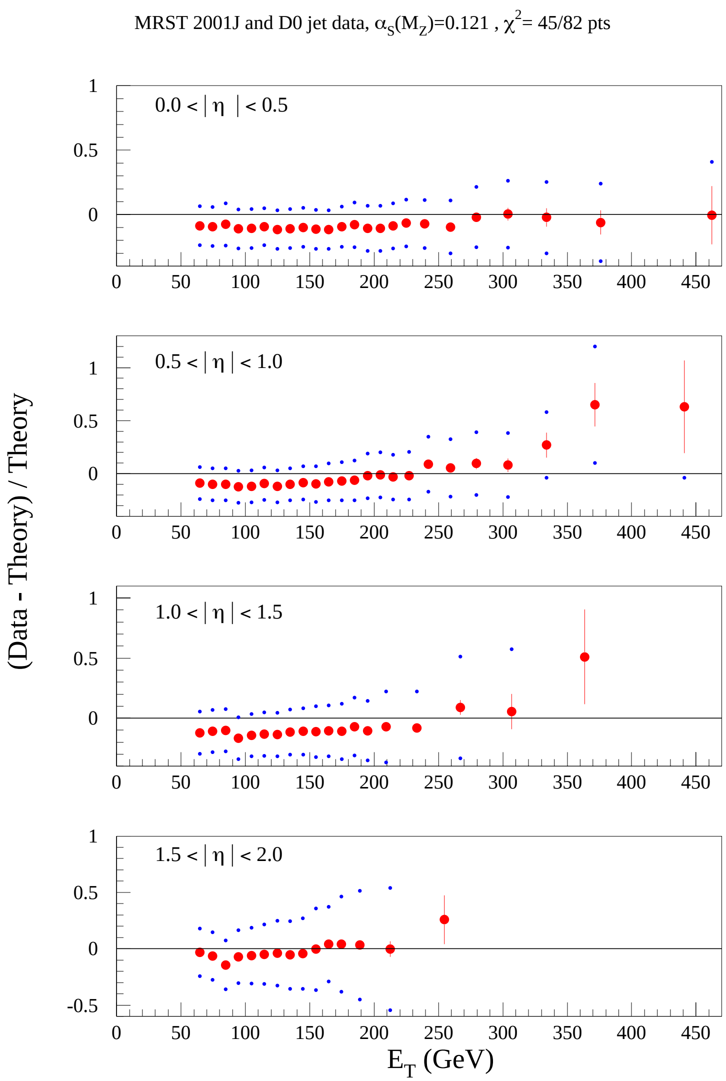
MRST2001J/CTEQ6M Comparisons



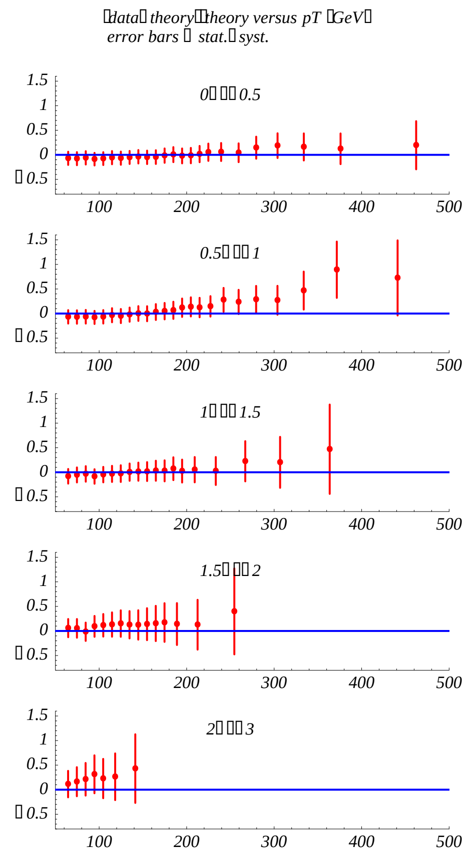


Figure 19: Comparison between theory and the D0 jet data. The error bars are statistical and systematic errors combined.

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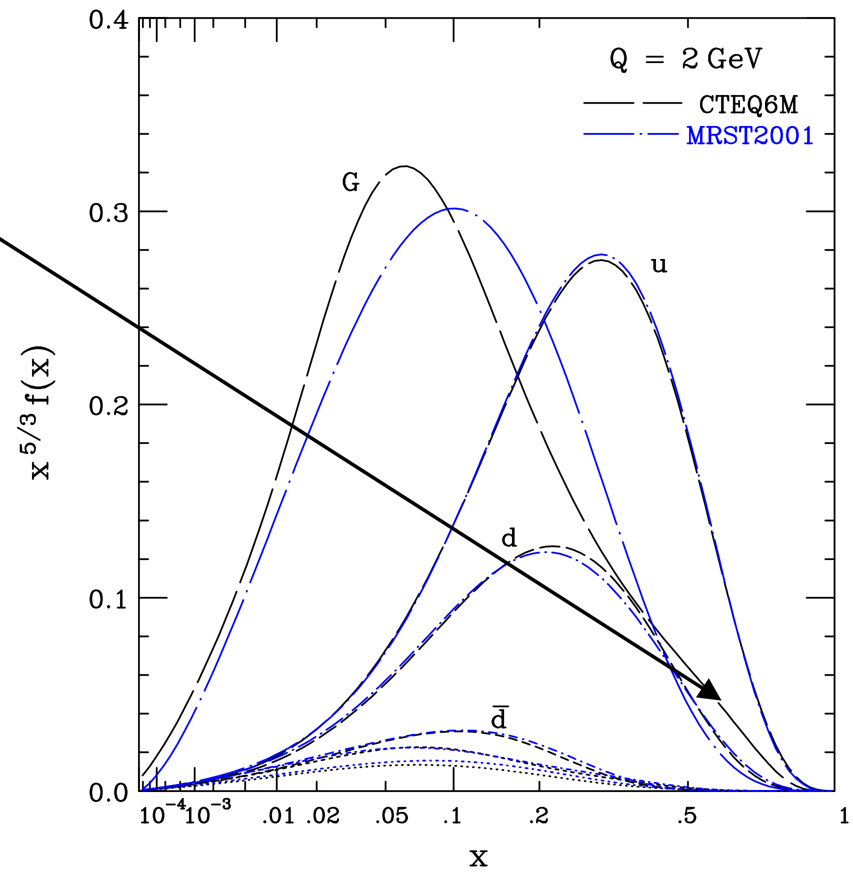
Compare CTEQ6 to MRST

- Main difference is the gluon at high x



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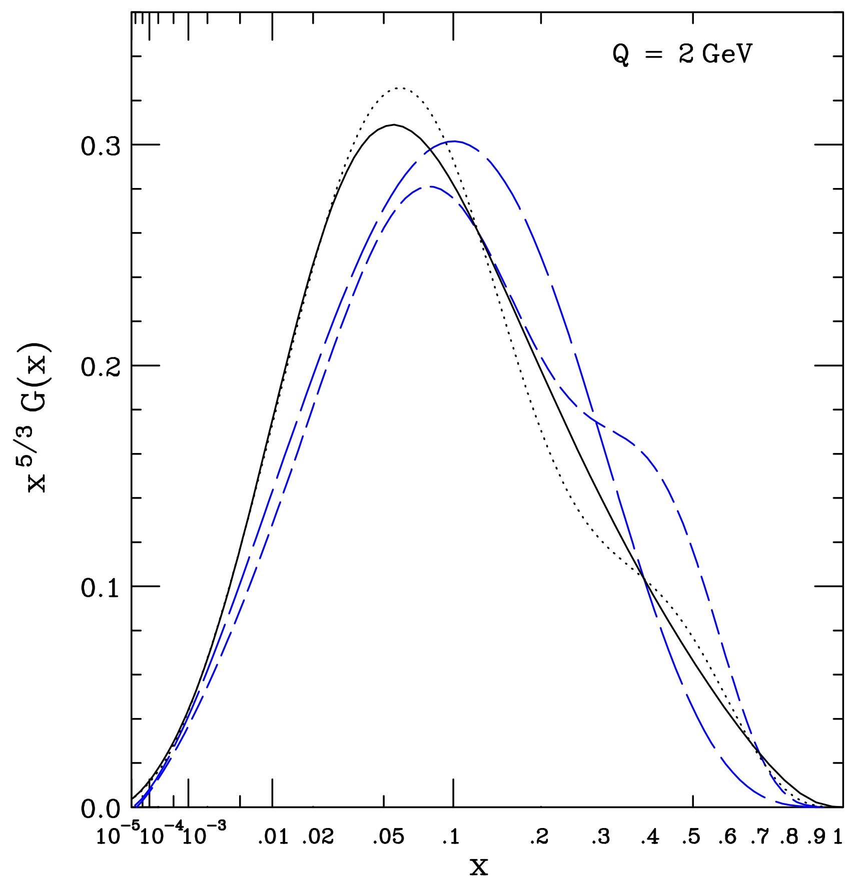
Compare CTEQ6 to MRST

- Solid: CTEQ6M
- Long-dashed: MRST2001
- Short-dashed: MRST2001J
- Dotted: MRST-like fit



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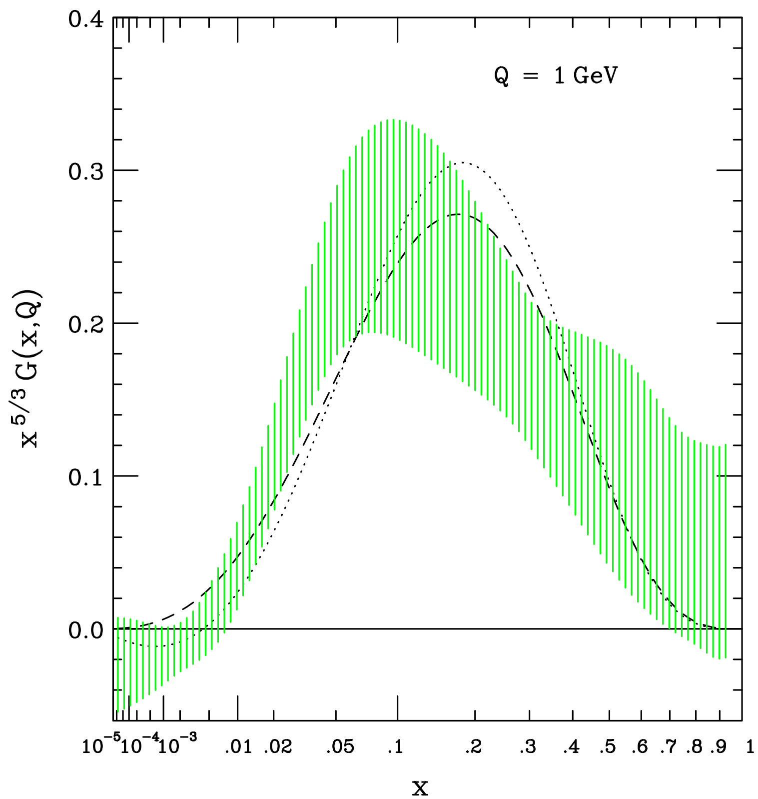
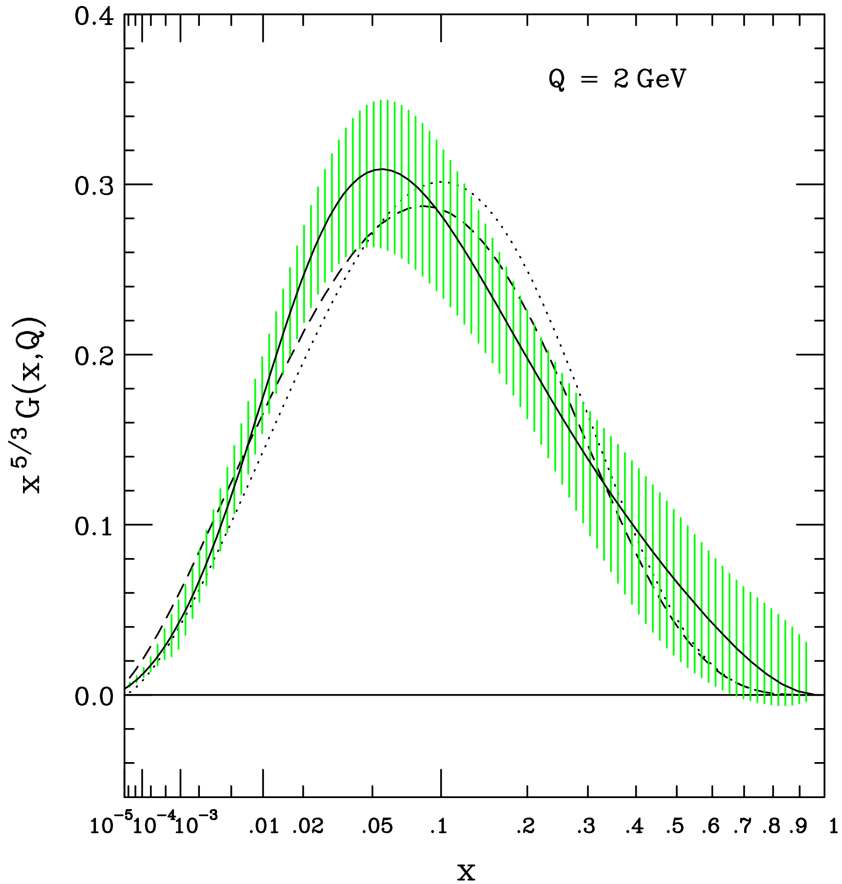
Uncertainty in gluon at small Q

- Note gluon can be negative at small x and **large x**

Evolves to positive by ~1.3 GeV





Dashed: CTEQ5M
Dotted: MRST2001
Solid: CTEQ6M

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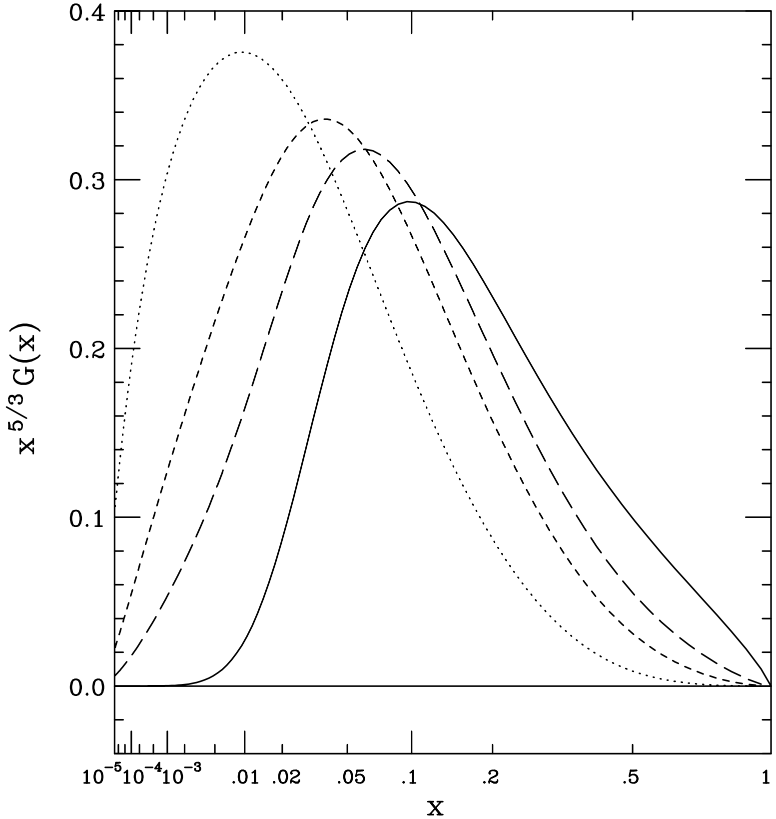
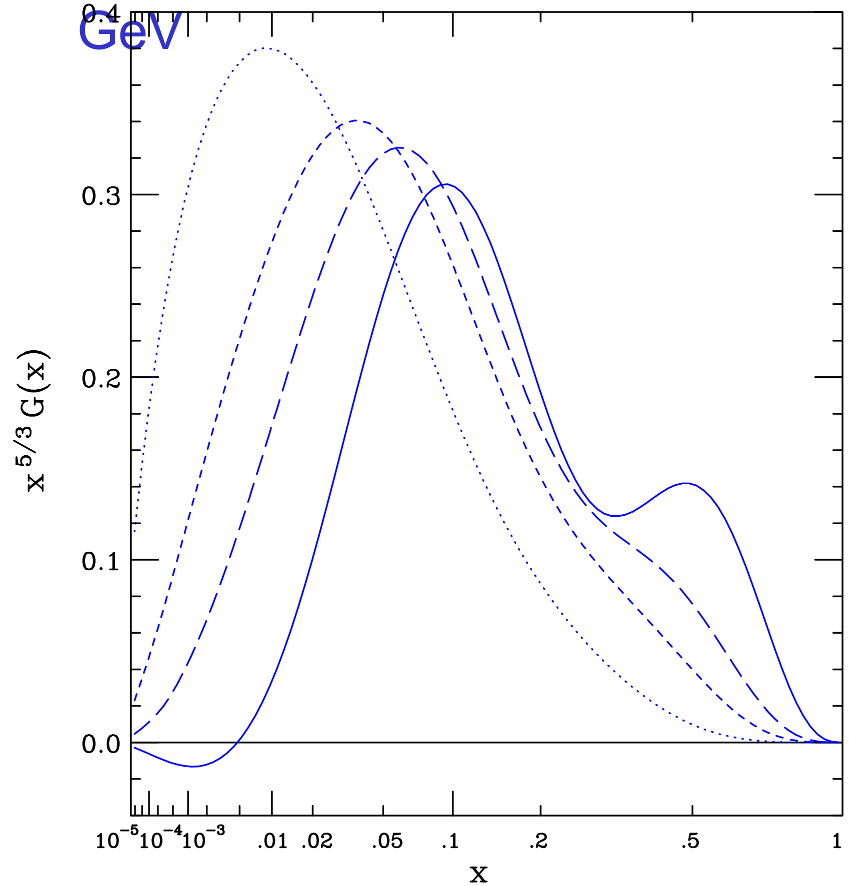
Gluon evolution

- CTEQ6M-like gluon at Q=1,2,5,100 GeV



MRST-like gluon at Q=1,2,5,100 GeV



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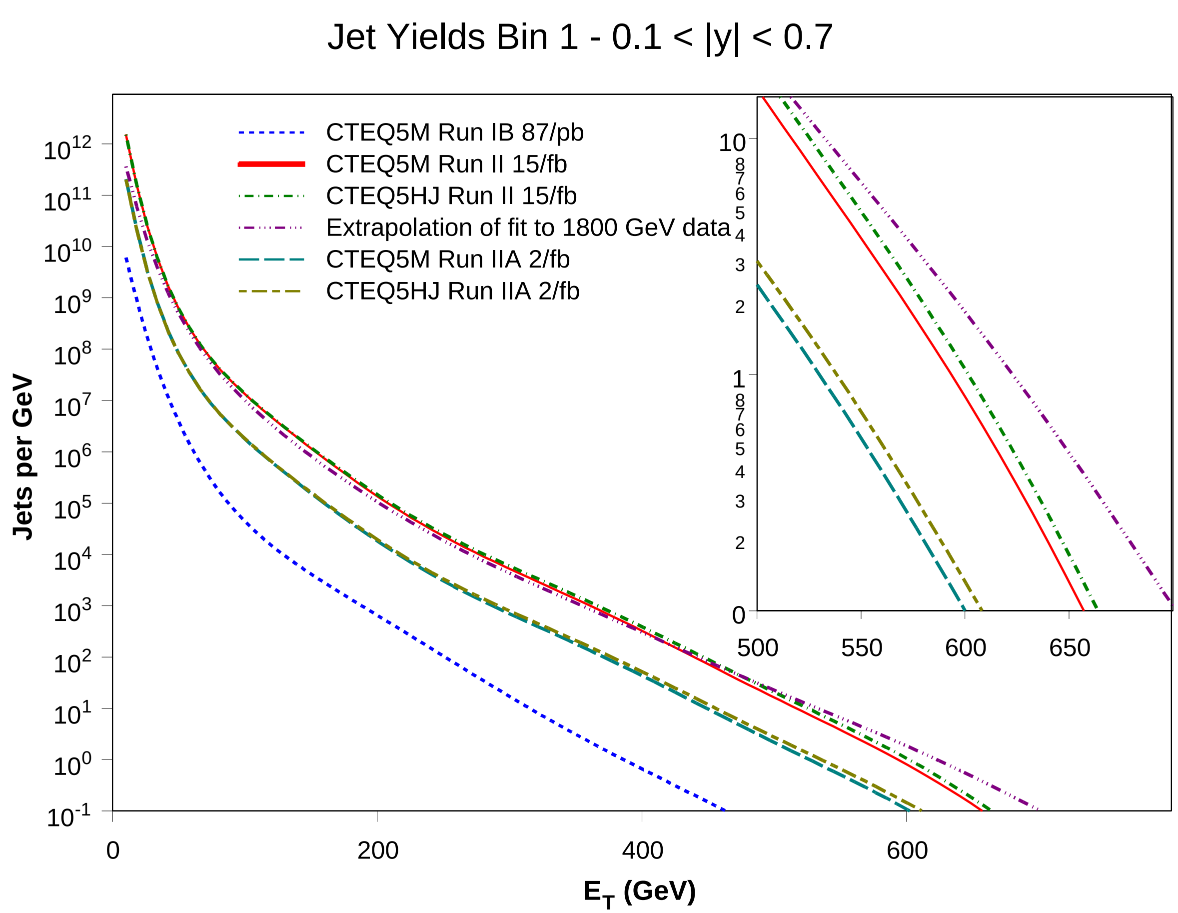
Conclusions: CTEQ6

- CTEQ6 now public
  - most up-to-date set of pdfs for Run II
- PDF’s available in Les Houches format soon
  - Easy to include new pdf’s
  - Easy to calculate pdf uncertainties on any cross section
- Run 2 MCs should use (1) CTEQ6 (2) MRST2001 pdfs

Some extra slides

Jet Yields in Run II

See http://www.pa.msu.edu/~huston/run2btdr_qcd/tdr.ps .



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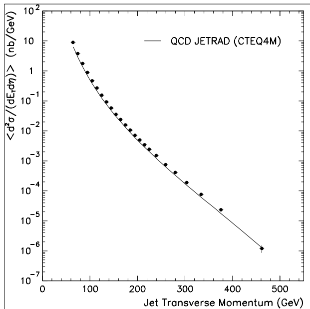
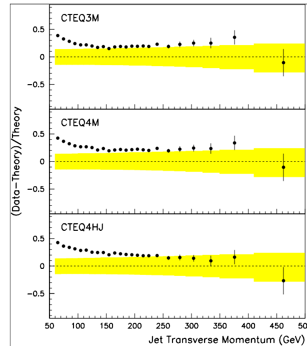
D0 jet cross section using k_T algorithm

- $|\eta| < 0.5$; D = 1.0
- Expect hadronization effects to be less than with cone algorithm

Normalization differs by 20%





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