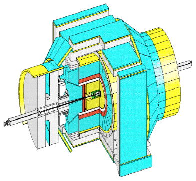


PDF Uncertainties in Run 2 and application to jet and top physics

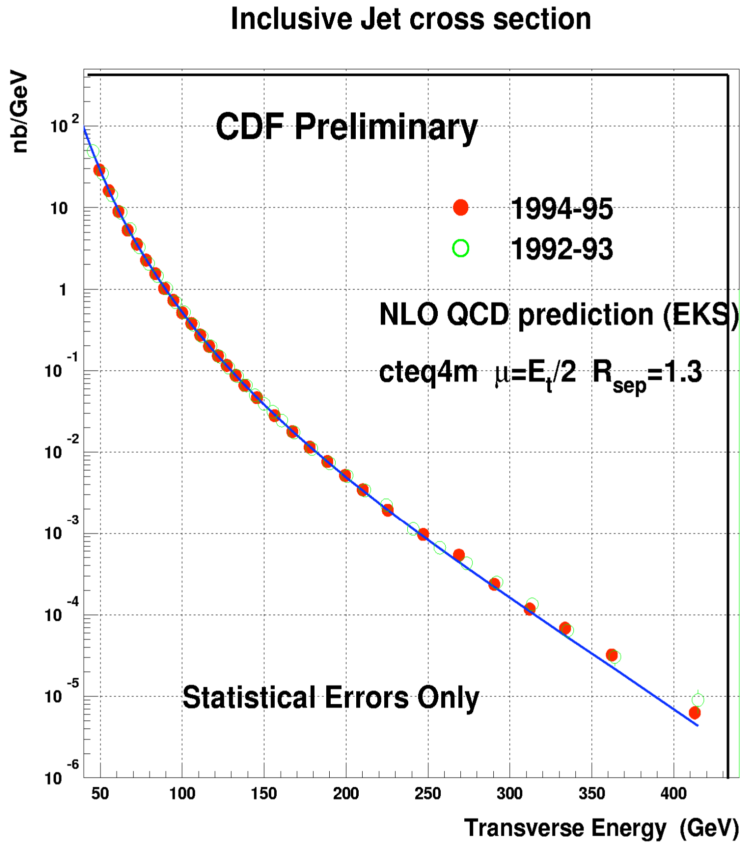
J. Huston

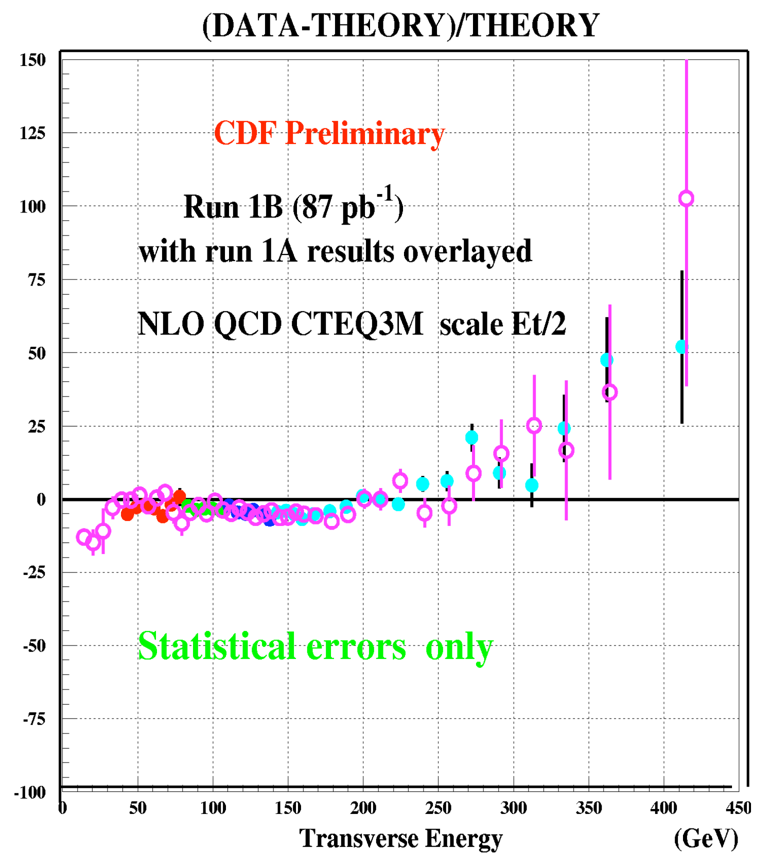
Michigan State University

Let’s back-track to some Run 1 results

- The Tevatron Collider serves as arena for precision tests of QCD with photons, W/Z’s, jets
  - Highest Q^2 scales currently achievable (sensitivity for new physics at small distance scales)
  - Sensitivity to parton distributions over wide kinematic range
- Dynamics of any new physics will be from QCD; backgrounds to any new physics will be from QCD processes

A jet excess observed in both Run 1A and 1B?





Exotic explanations

Possible Explanations of High E_T Excess

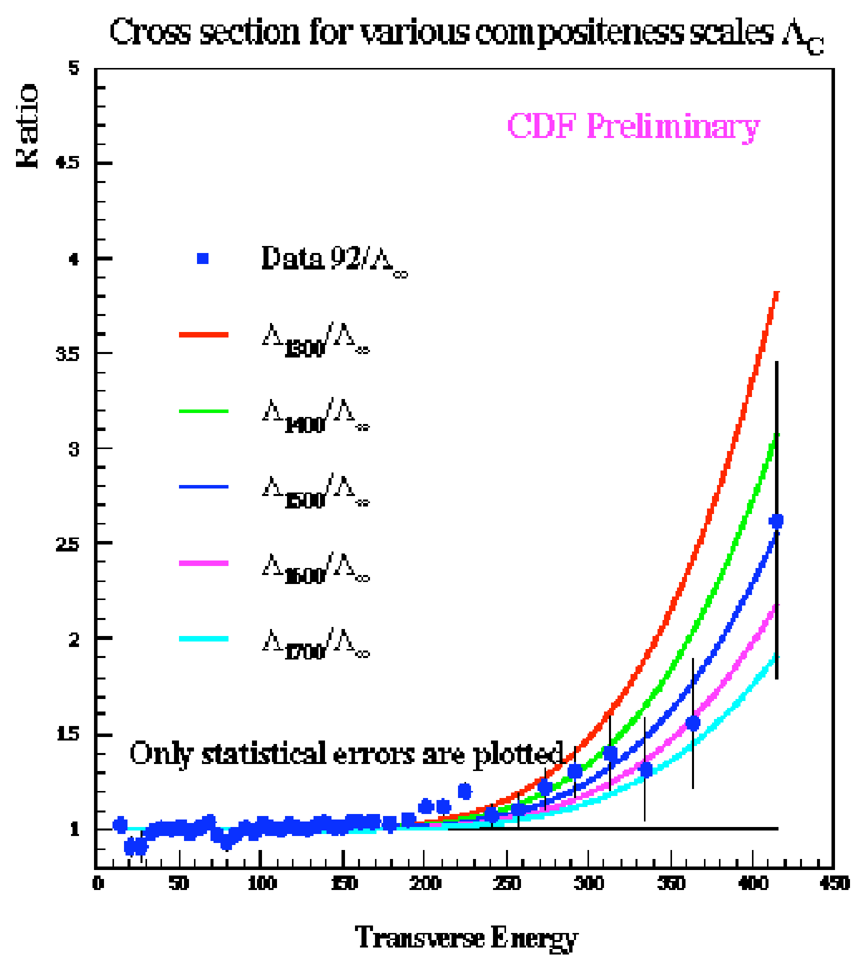
Until uncertainties within the realm of QCD are better understood any claim of NEW PHYSICS is INDEFENSIBLE!

However, the new physics possibilities include:

Composite quarks: Eichten, Lane and Peskin, PRL 50 811 (1983)
a contact term is added to LO QCD Lagrangian
→ increased cross section for high E_T jets

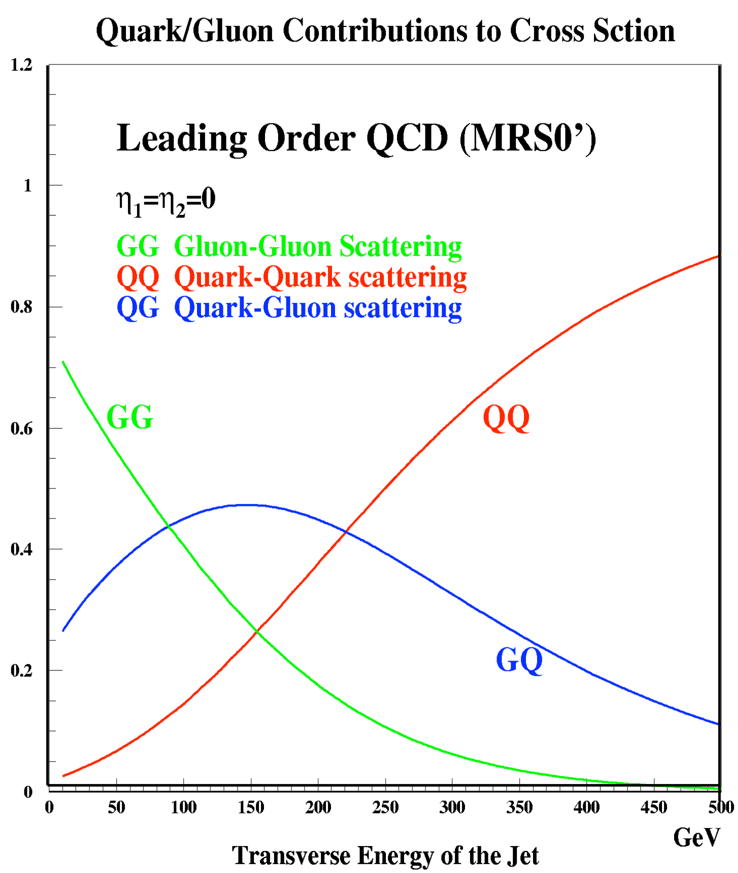
α_s stops running: possible conspiracy between new particles Susy (hep-ph9512325, hep-ph9601279), color sextet (Alan White ANL)

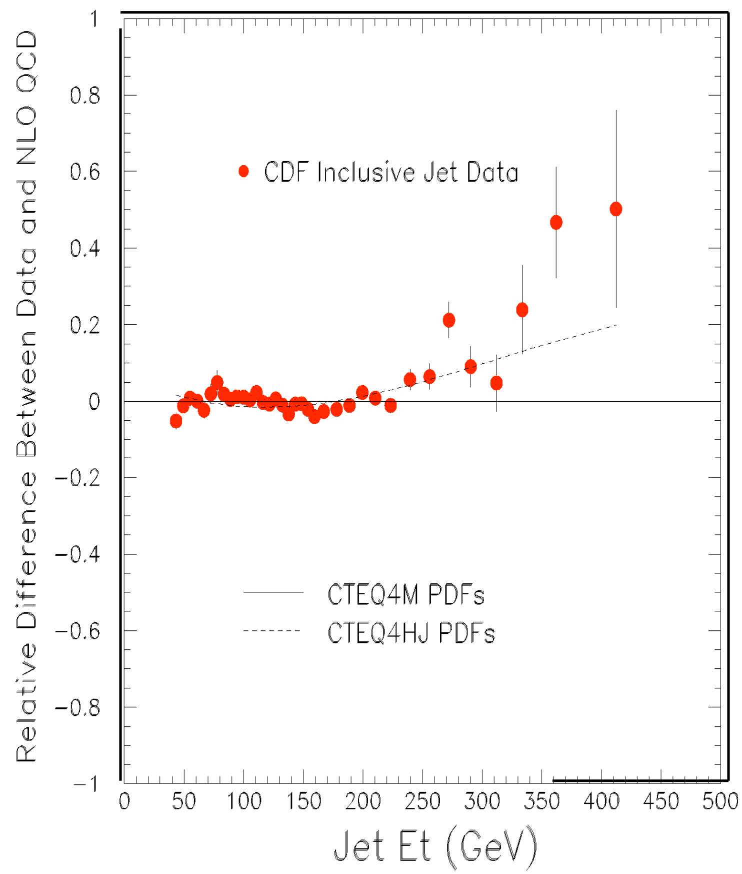
New Particle Z' : leptophobic Z', this could also possibly explain the charm/bottom problem at LEP (hep-ph/9601324)



Non-exotic explanations

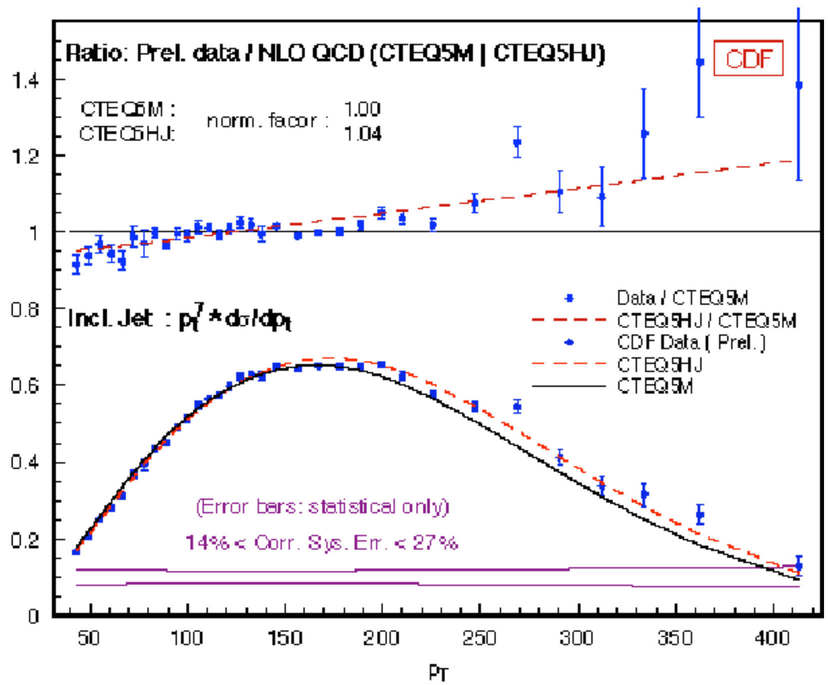
Modify the gluon distribution at high x

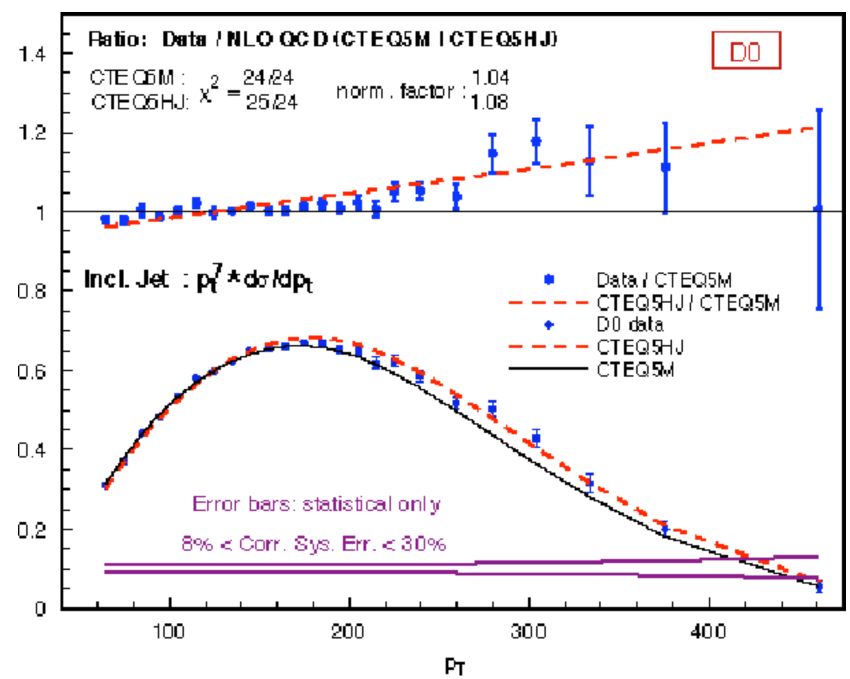




Tevatron Jets and the high x gluon

- Best fit to CDF and D0 central jet cross sections provided by CTEQ5HJ pdf's
- …but this is not the central fit; extra weight given to high E_T data points; need a more powerful sample

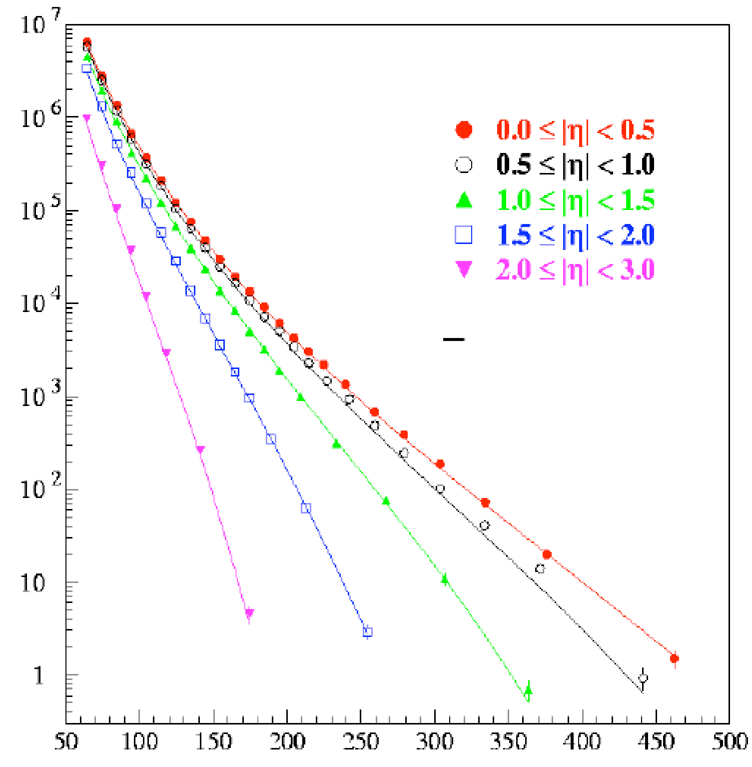




Chisquares for recent pdf’s

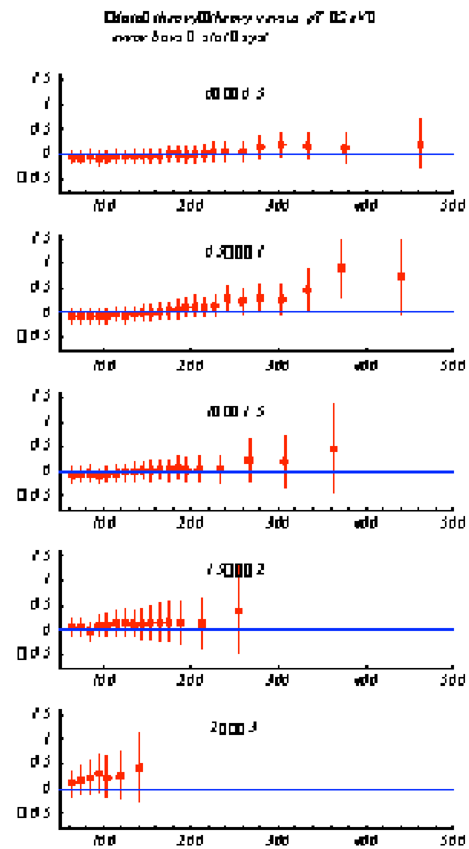
- CTEQ4HJ (with enhanced gluon) provides best description of D0 jet data
- Implies that new fit including this data will have a natural HJ-like behavior

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



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



So is this the end of the story?

- You need to be careful that you are not mistaking old physics for new physics
- …but you also have to be careful that you are not labelling potential new physics as old physics
- We need to be able to quantify the uncertainty for parton distribution functions and the resultant predicted cross sections

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 □ production
- Two major groups that provide semi-regular updates to parton distributions when new data/theory becomes available
  - MRS->MRST98->MRST99->MRST2001->MRST2002
  - CTEQ->CTEQ5->CTEQ5(1)->CTEQ6->CTEQ6.1(new)
- 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 (more on this later)

Uncertainties in pdf's

- 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 (±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

Uncertainties in pdf fits

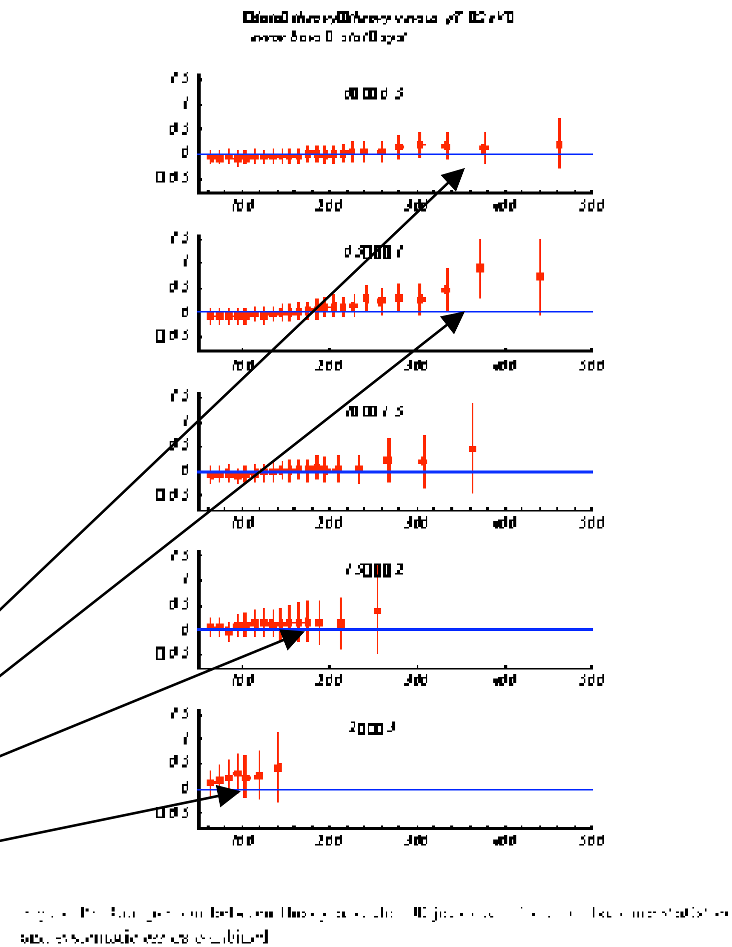
- Two sources
  - Experimental errors
    - Hessian/Lagrange multiplier techniques designed to address estimate of these effects
      - question is what $\Delta\chi^2$ change best represents estimate of uncertainty (we use $\Delta\chi^2$ of 100 (out of 2000))
  - Theoretical
    - higher twist/non-perturbative effects
      - choose Q^2 and W cuts to try to avoid
    - higher order effects
      - is NNLO necessary yet?
    - edge of phase space effects

Nuts/bolts of fits

- Functional form used is:
  - $xf(x,Q_o) = A_o x^{A1} (1-x)^{A2} e^{A3x} (1 + A_4x)^{A5}$
    - 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
    - there are 20 free parameters used in the global fit
- Light quarks treated as massless; evolution kernels of PDFs are mass-independent
- Zero mass Wilson coefficients used in DIS structure functions

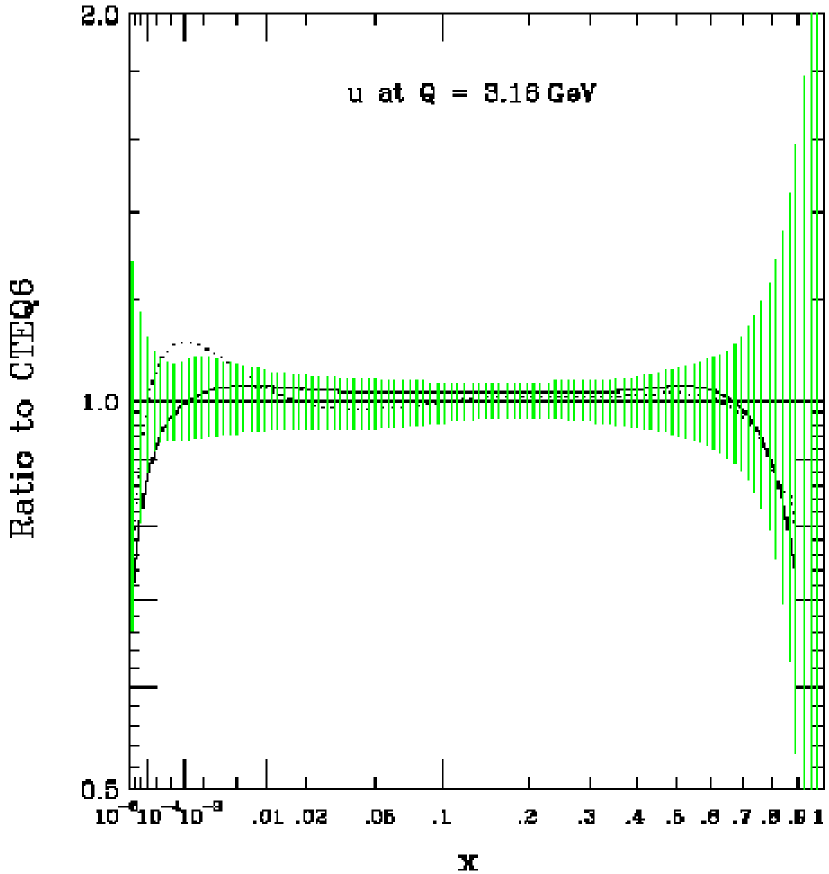
D0 jet cross section

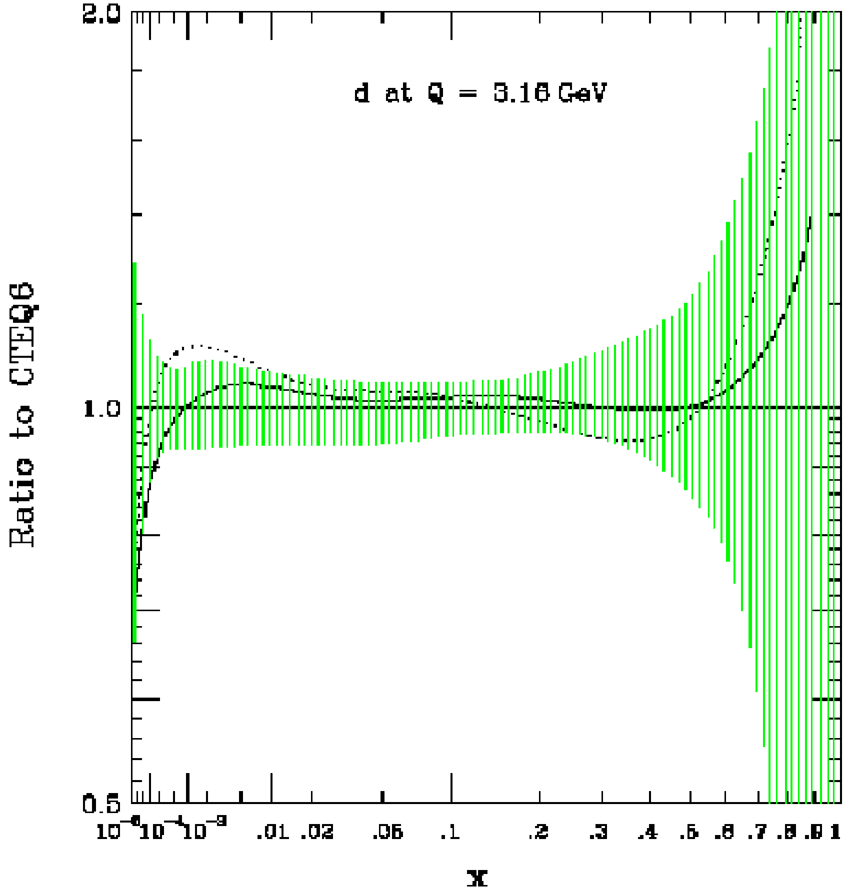
- CTEQ4 and CTEQ5 had CDF and D0 central jet cross sections in fit
- Statistical power not great enough to strongly influence high x gluon
  - CTEQ4HJ/5HJ required a special emphasis to be given to high E_T data points
- Central fit for CTEQ6 is naturally *HJ-like*
- χ^2 for CDF+D0 jet data is 113 for 123 data points
- 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



PDF Uncertainties

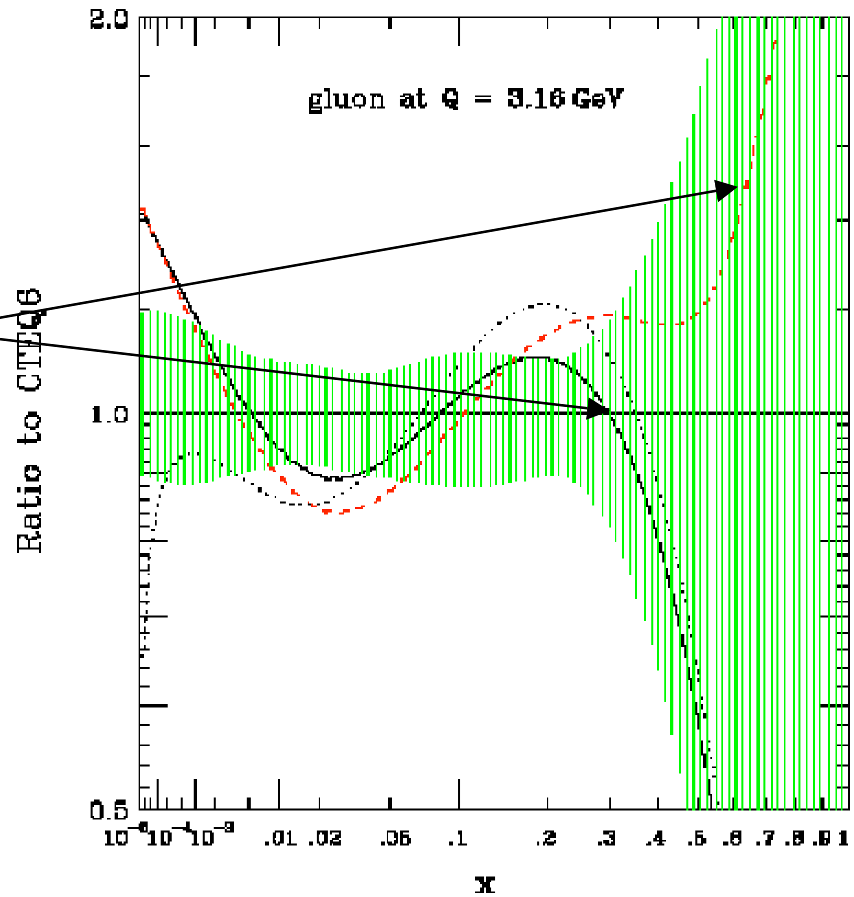
- Use Hessian technique (T=10)



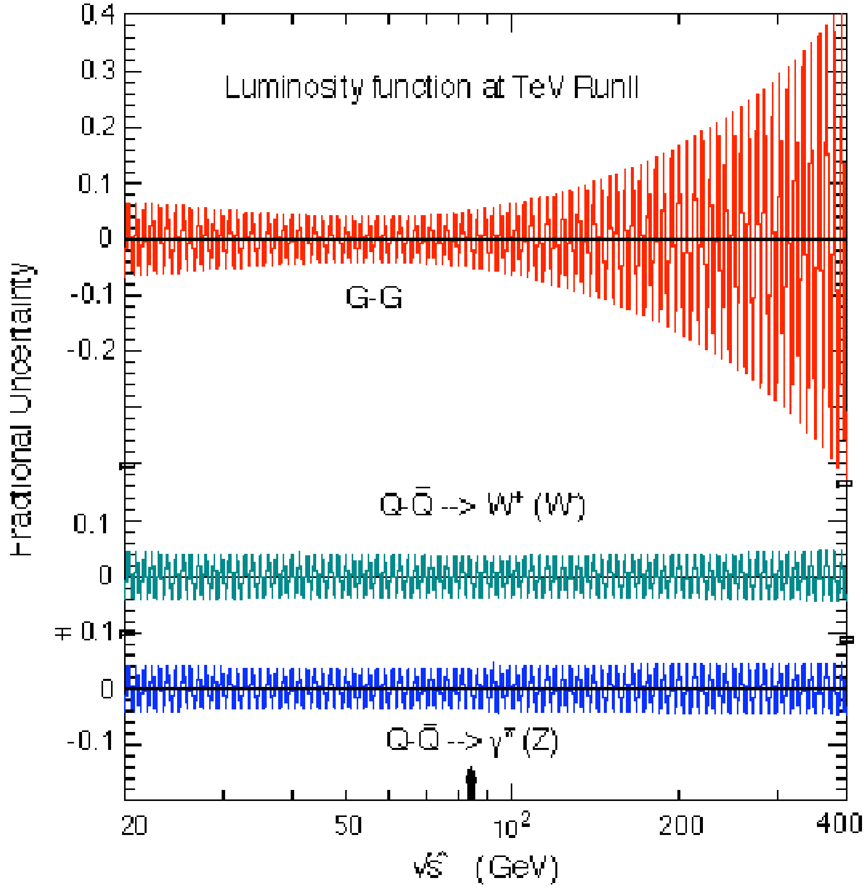


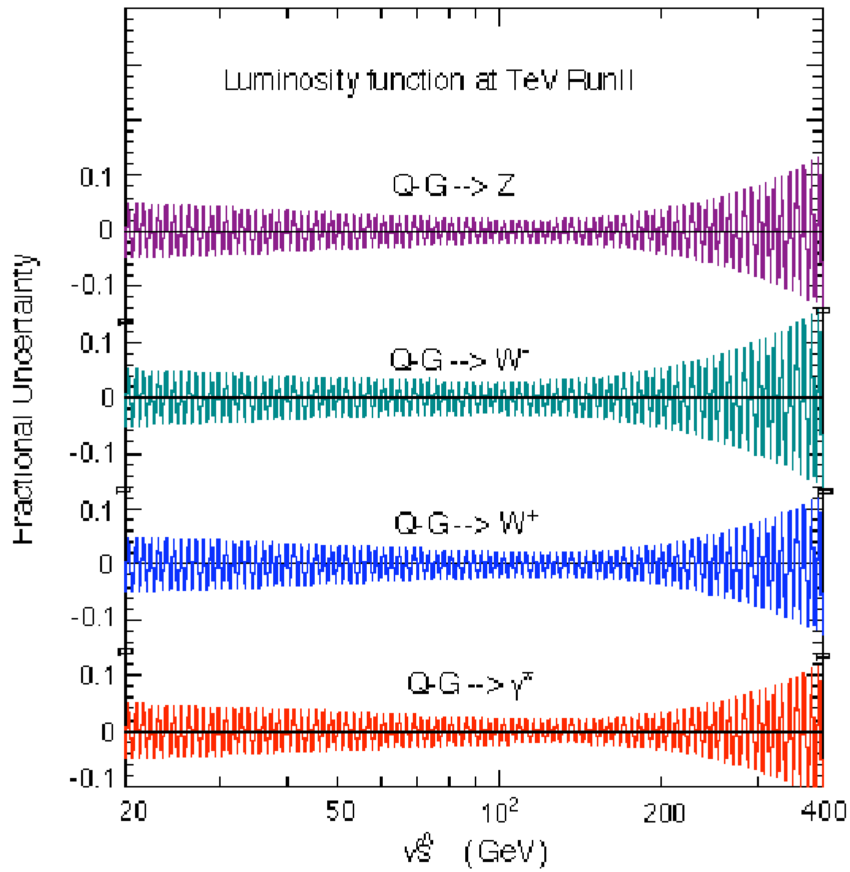
Gluon Uncertainty

- 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





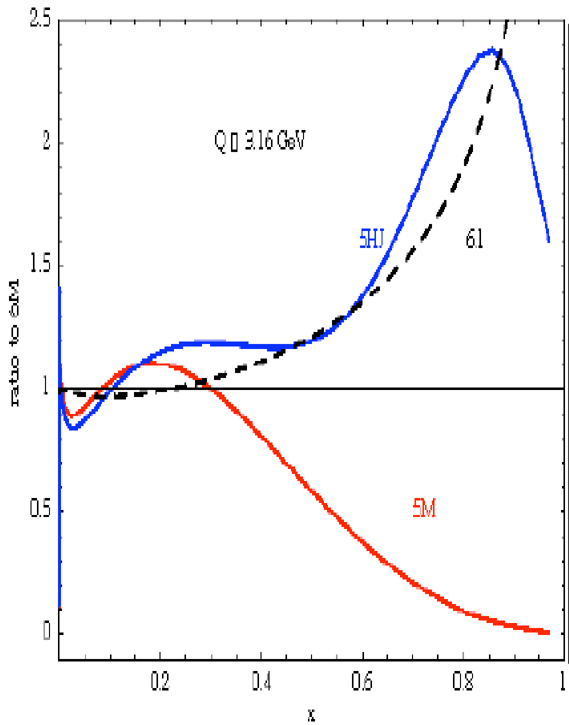
Remaining questions/discussion

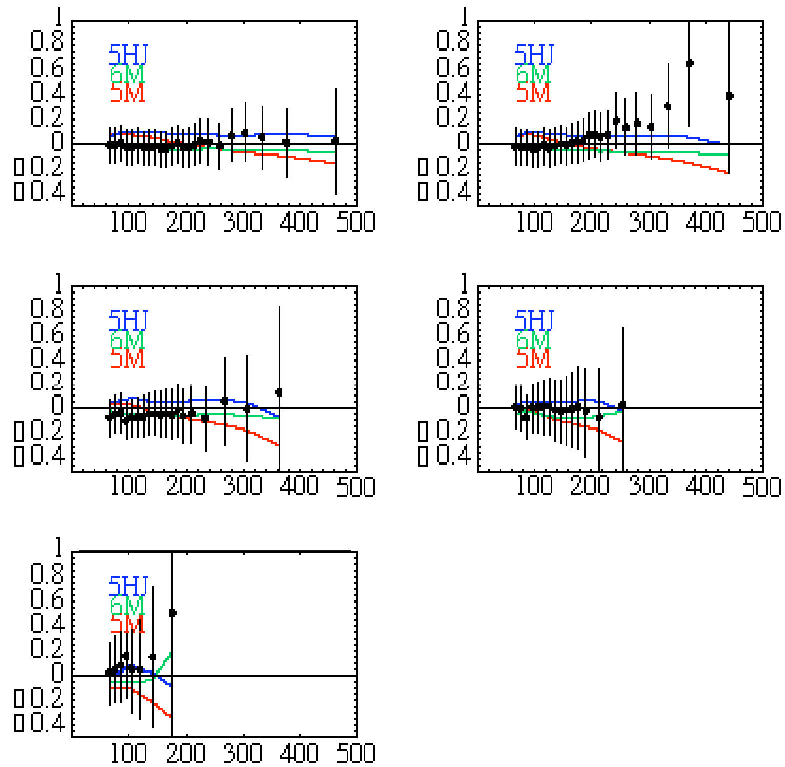
- HJ-like behavior for gluon motivated to describe CDF Run 1 data now seems a natural consequence of global fitting
- …but need to be careful not to hide any possible new physics in the gluon uncertainty
- How much room is left over for new physics in Run 1 data?
- What is uncertainty on Run 2 jet cross 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 are answered in
  - hep-ph/0303013 Inclusive Jet Production, Parton Distributions, and the Search for New Physics
  - Authors: Daniel Stump, Joey Huston, Jon Pumplin, Wu-Ki Tung, H. L. Lai, Steve Kuhlmann, J. F. Owens
- Here are a few excerpts

6.1 gluon compared to 5M/5HJ/6M

- In the course of investigations for this paper, some improvements to the analysis were made that changed the gluon distribution: cteq6m->cteq6.1

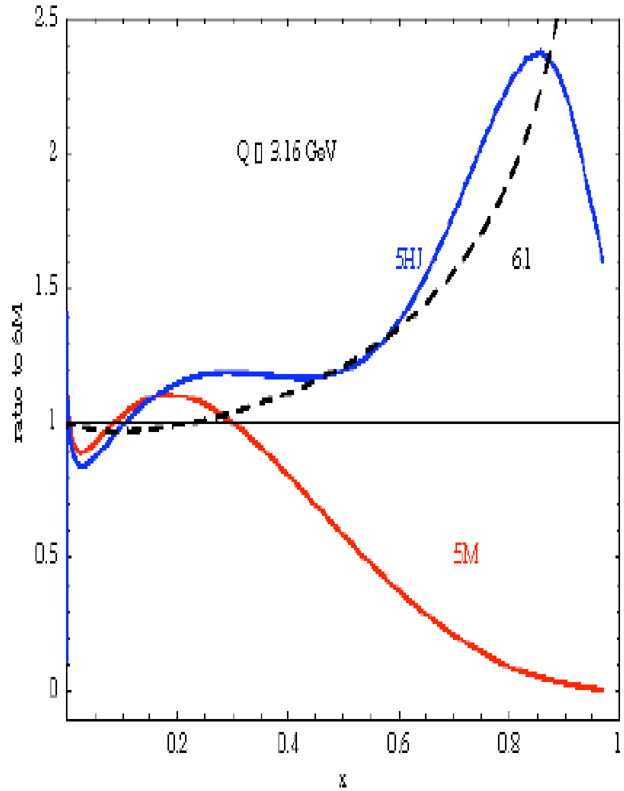
•small changes in jet cross sections, as for example the D0 jet cross section below

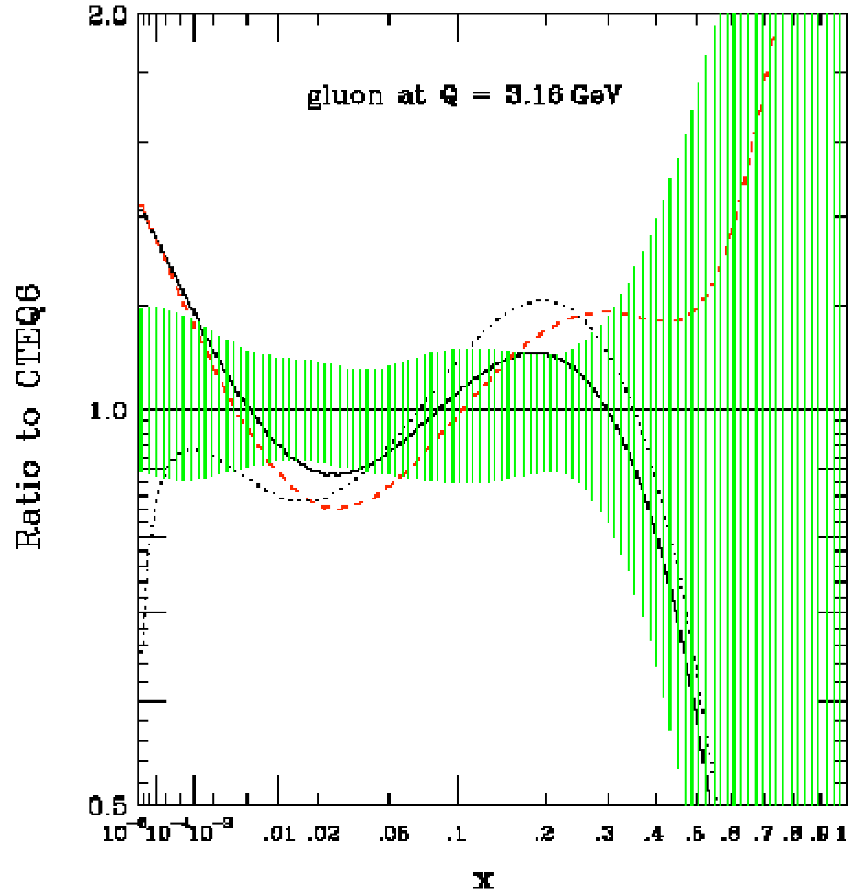




Remaining gluon uncertainties

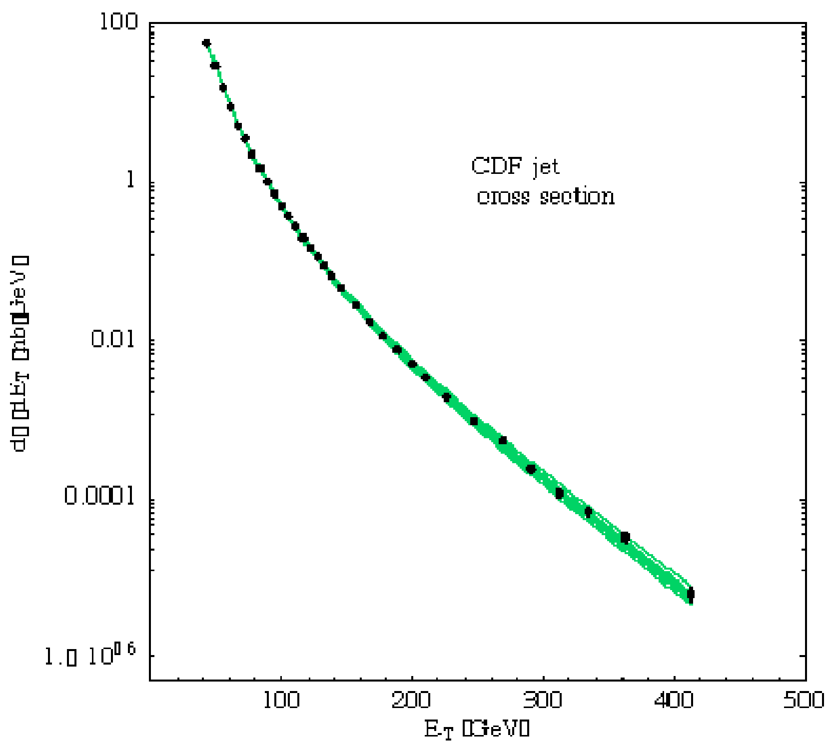
New cteq6.1 well within uncertainty
band for gluon distribution





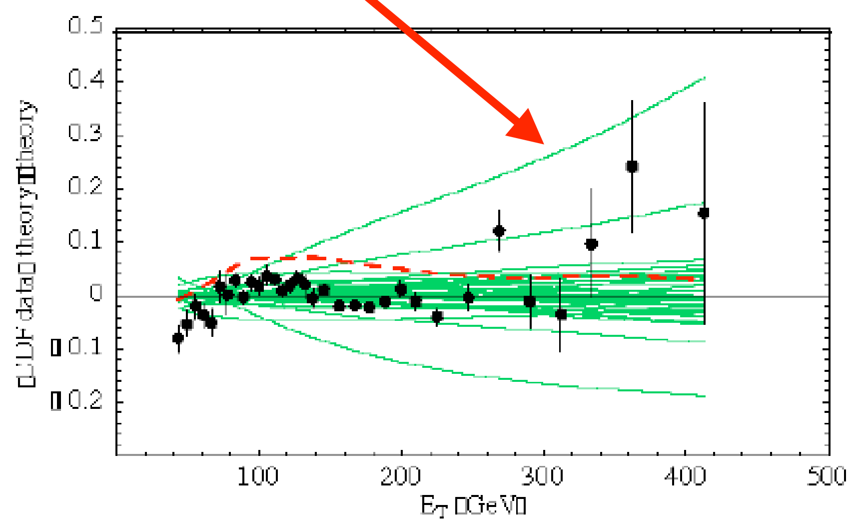
PDF uncertainties for Run 1 cross section

- 20 free parameters in the fit
- In the Hessian method, a 20X20 matrix is diagonalized and 20 orthogonal eigenvector directions in parameter space are determined



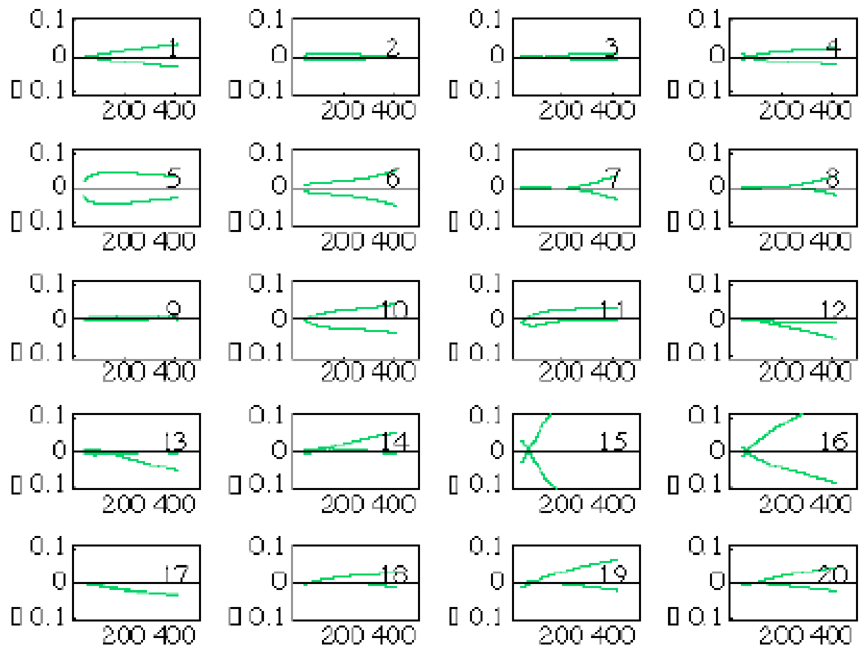
•Each eigenvector direction corresponds to some linear combination of pdf parameters
•Large eigenvalues correspond to highly determined directions (e.g. valence quarks)
•Small eigenvalues correspond to poorly determined directions (high x gluon)
•Result is 40 pdf's (go along + and - direction $\Delta\chi^2$ of 100 for each eigenvalue)

Note 1 eigenvector(15+) leads to noticeably larger prediction than the others



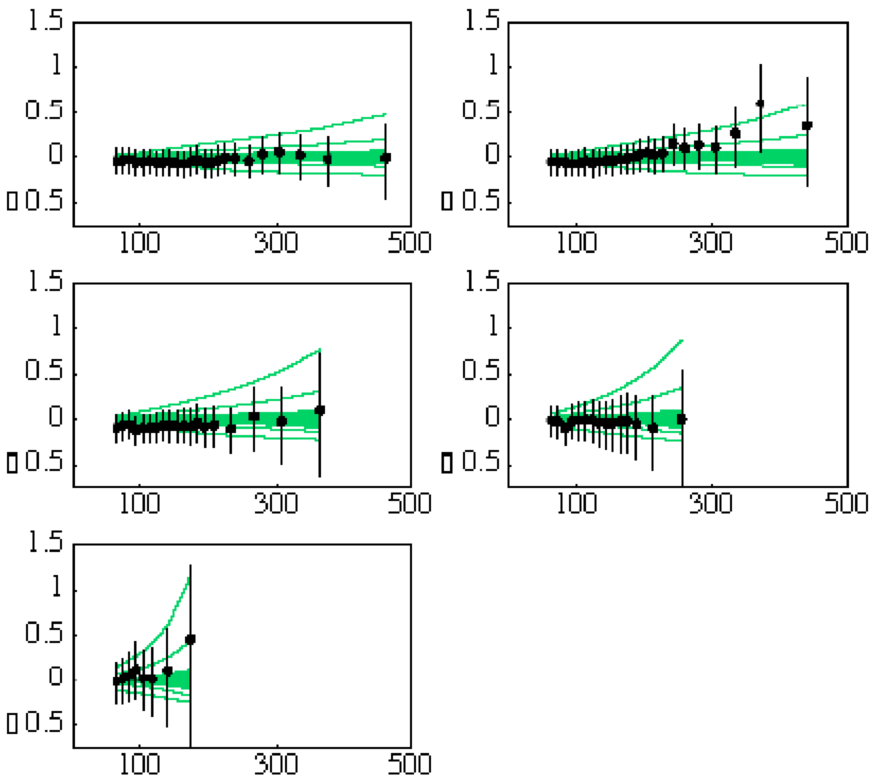
CDF jet cross section uncertainties

- On the right are shown the uncertainties for the CDF jet cross section along each eigenvector ($\Delta\chi^2 = 100$)
  - jet cross section most sensitive to eigenvector 15
    - which mainly contains parameters relating to behavior of high x gluon

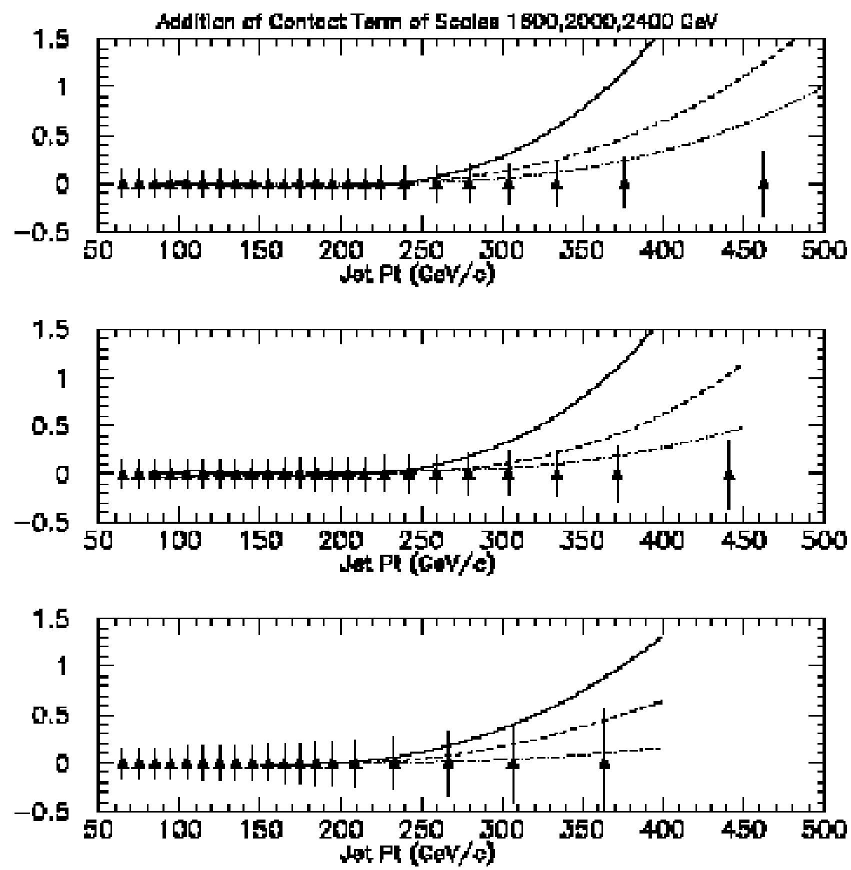


Room for new physics

- Uncertainties for D0 Run 1 jet cross section as a function of rapidity

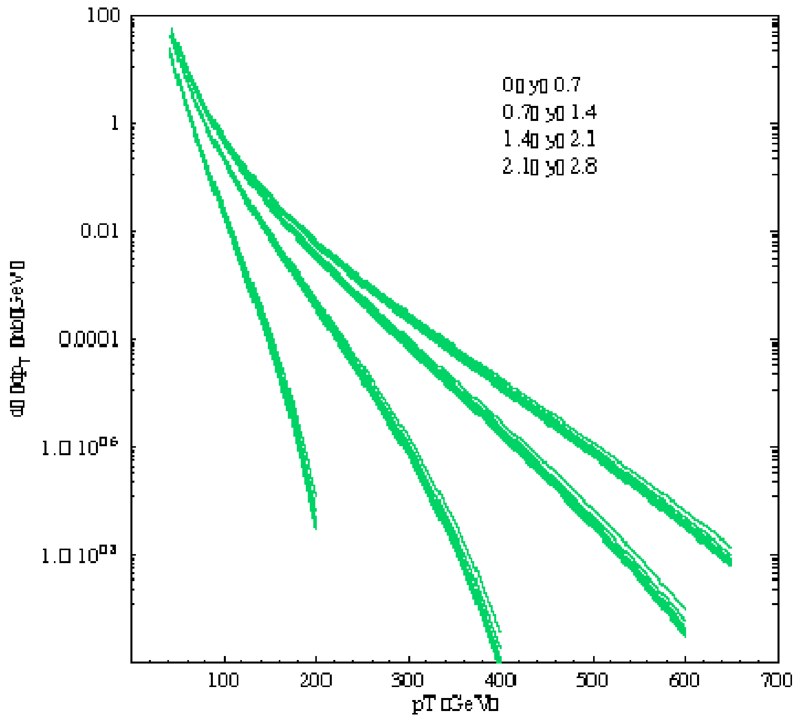


Effect of new physics (compositeness) for the first 3 rapidity bins (effects on last bins are negligible)

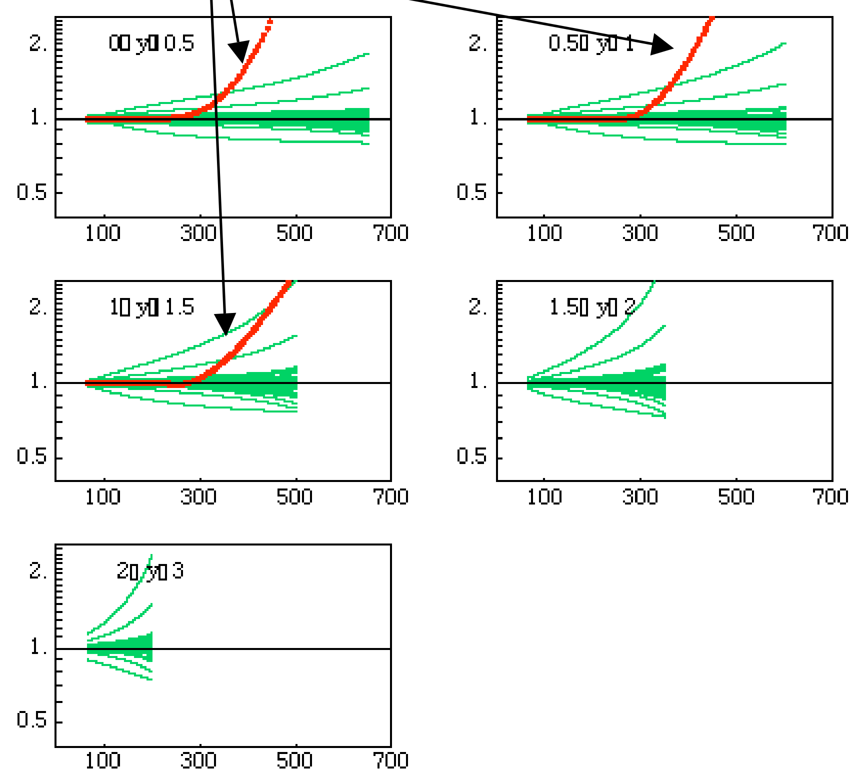


Uncertainties on Run 2 predictions for CDF

- CDF will measure the inclusive jet cross section in the forward regions as well

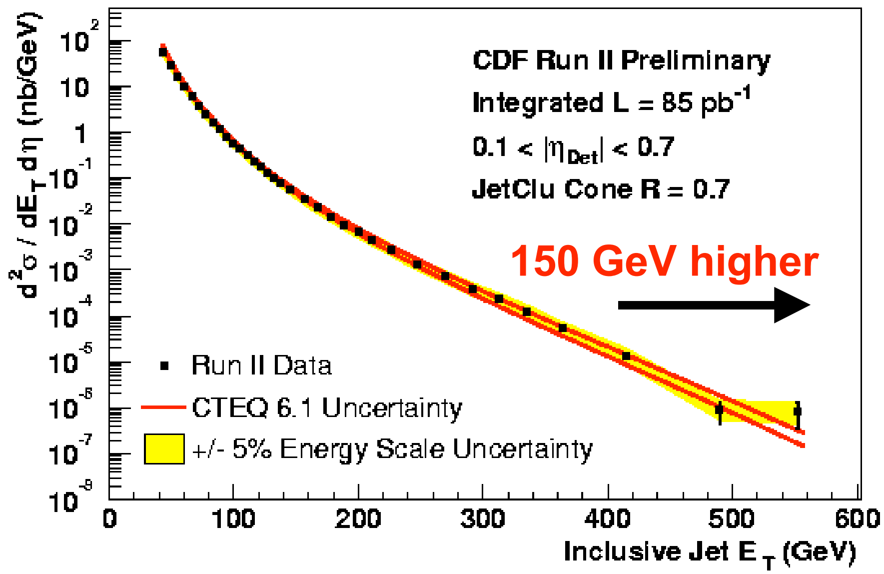


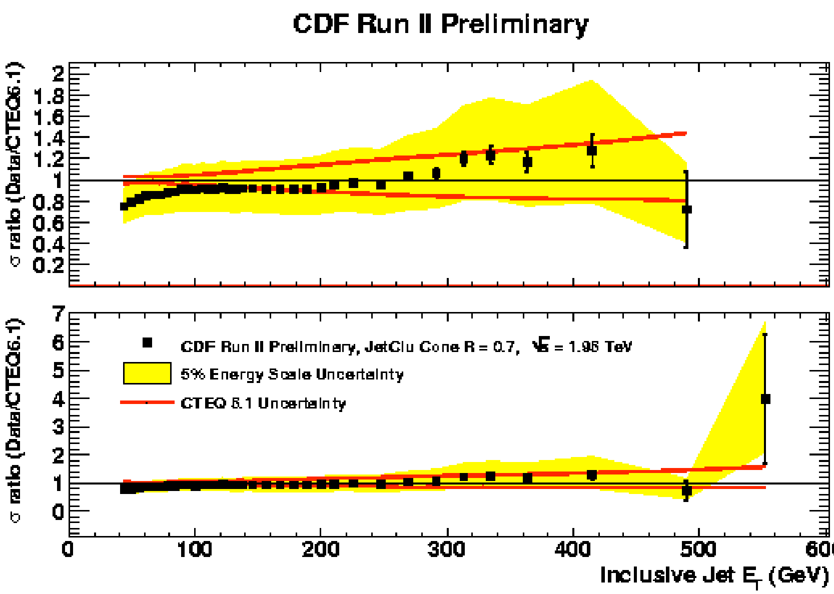
effect of a compositeness term of 2.4 TeV (destructive interference)



Similar predictions for D0

Run 2 so far



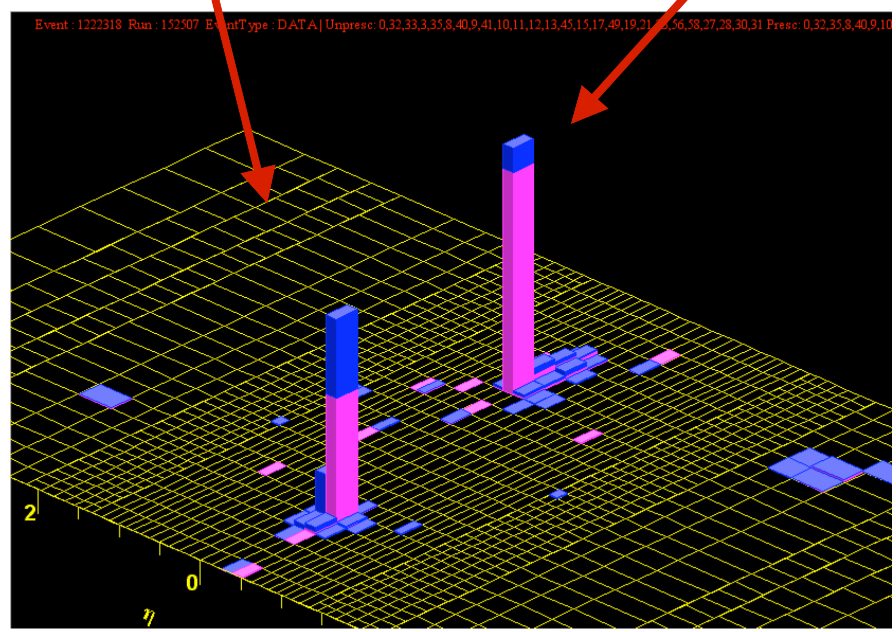


Run 152507 event 1222318

Dijet Mass = 1364 GeV (corr)

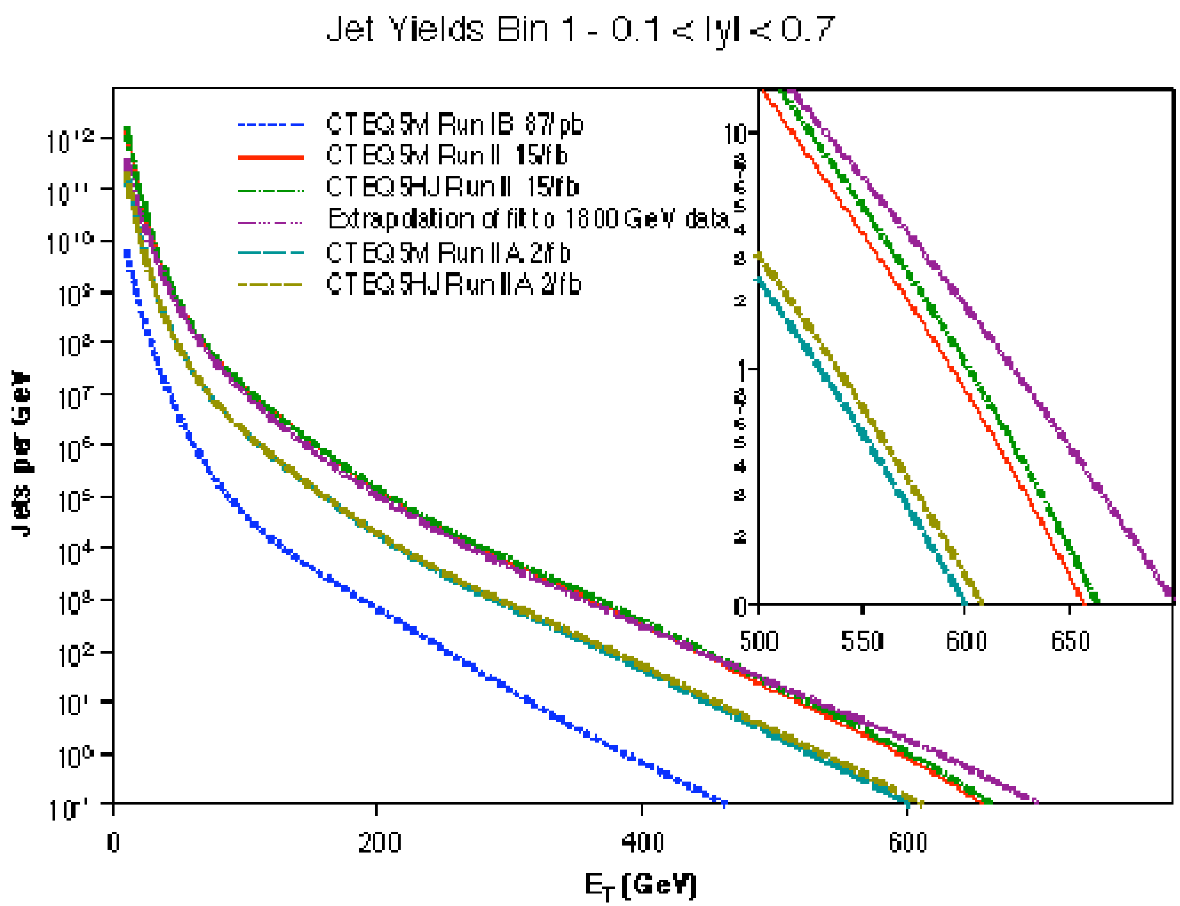
Jet 2
E_T = 633 GeV (corr)
η_{det} = - 0.30

Jet 1
E_T = 666 GeV (corr)
η_{det} = 0.31



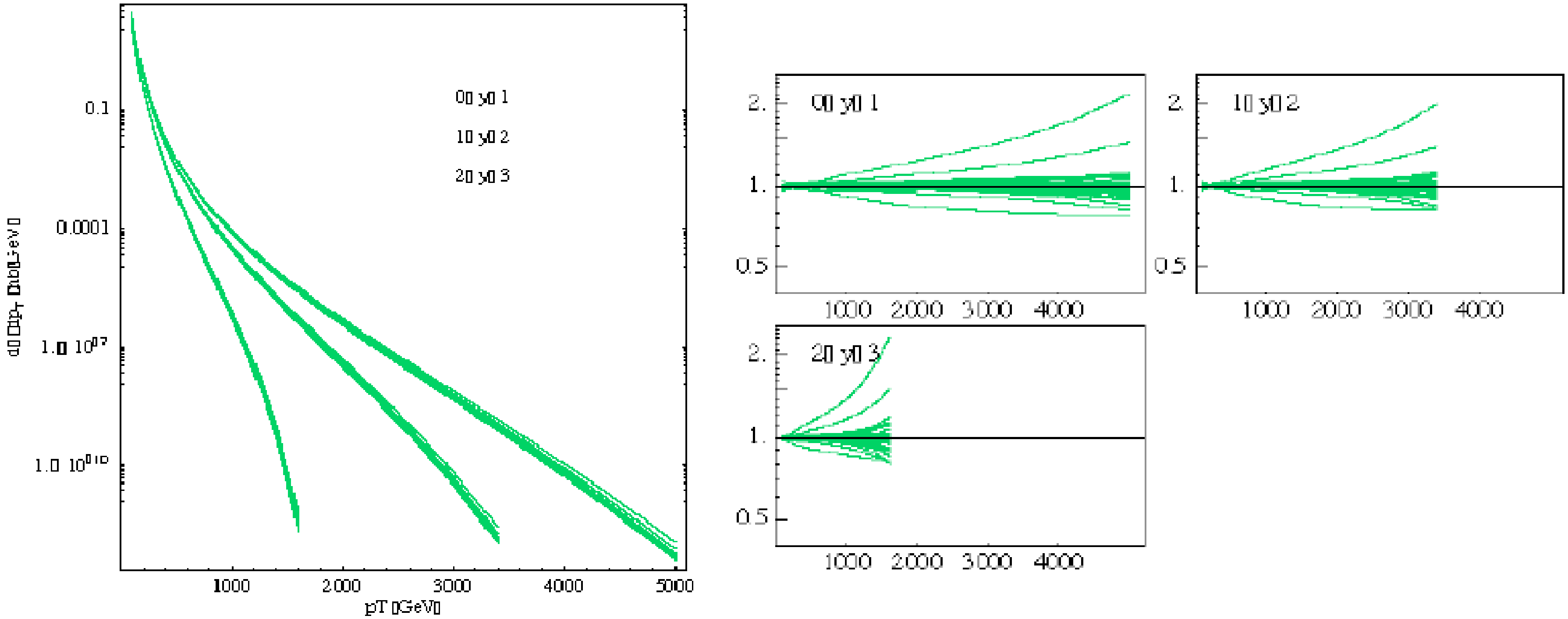
Jet Yields in Run II(from Steve Ellis)

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



Jet cross sections at the LHC

- Apply the same exercise to the LHC



Top cross sections at the Tevatron

- hep-ph/0303085
  - The t-tbar cross-section at 1.8 and 1.96 TeV: a study of the systematics due to parton densities and scale dependence
  - Authors: M. Cacciari, S. Frixione, M.L. Mangano, P. Nason, G. Ridolfi
- MLM and collaborators used the CTEQ6 (and MRST) error pdf's to explore the range of uncertainty for top cross section predictions
- CTEQ6 error pdf's also being used by CDF to determine pdf uncertainty for top mass

$\sqrt{S}$	m_{top}	μ_0	$\sigma_{t\bar{t}}$(6M)	$\Delta\sigma$
1800	170	0.5	6.22	0.4[illegible]
1800	170	1	6.10	0.40
1800	170	2	5.85	0.37
1800	175	0.5	5.26	0.35
1800	175	1	5.19	0.34
1800	175	2	4.81	0.31
1800	180	0.5	4.62	0.29
1800	180	1	4.47	0.28
1800	180	2	4.11	0.26
1960	170	0.5	7.97	0.57
1960	170	1	7.68	0.5[illegible]
1960	170	2	7.29	0.51
1960	175	0.5	6.83	[illegible]
1960	175	1	6.70	0.45
1960	175	2	6.28	0.42
1960	180	0.5	5.8[illegible]	0.41
1960	180	1	5.77	0.38
1960	180	2	[illegible]	0.36

Table 2: Range of cross-section predictions (in pb) for the CTEQ6 family of PDFs at a fixed scale $\mu_0 = \mu/m_{top}$ [illegible] relative to the central value using the 6M set, and $\Delta\sigma$ is the error, as defined in eq. ([illegible]).

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 40 pdf’s
  - GKK on the order of 100
  - **New: MRST2002->30 pdfs**
- 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

Les Houches accord #2

- Using the interface is as easy as using PDFLIB (and much easier to update)
- First version has CTEQ6M, CTEQ6L, all of CTEQ6 error pdfs and MRST2001 pdfs
- See pdf.fnal.gov and Lynn Garren's talk next
  - LHAPDF will be made into an official Fermilab product
- Ultimately, Durham has agreed to take over the maintenance of the LHAPDF

- 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*

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