QCD: Approaching True Precision

or, *Latest Jet Results from the TeVatron*

Presented by
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- Experimental Details
- SubJets and Event Quantities
- Cross Sections

Changing Paradigms in QCD

Inclusion of error estimates in the PDFs

calculation of virtual corrections → Progress toward NNLO predictions

covariance matrices → More rigorous treatment of experimental errors

jet algorithms workshop → More consistent E_T calculations between experiments

hope for better underlying event

Jet Definition

Iteration vs ratcheting

- Cone Definition
  $\mathcal{R}$=0.7 in η–φ
  merge/split

0.5 vs 0.75

Centroid found with
4-vector addition vs
Snowmass addition

- K_T Definition

  cells/clusters are combined if their relative k_T^2 is "small"
  (D=1.0 or 0.5 -- scaling parameter)

  For subjets, also define "large"
  (y_{cut}, =10^{-3})

$$d_{ij} = \min({}^{i}E_T^2,\ {}^{j}E_T^2)\,\frac{\Delta\mathcal{R}_{ij}^2}{D^2}$$

$$d_{ii} = {}^{i}E_T^2$$

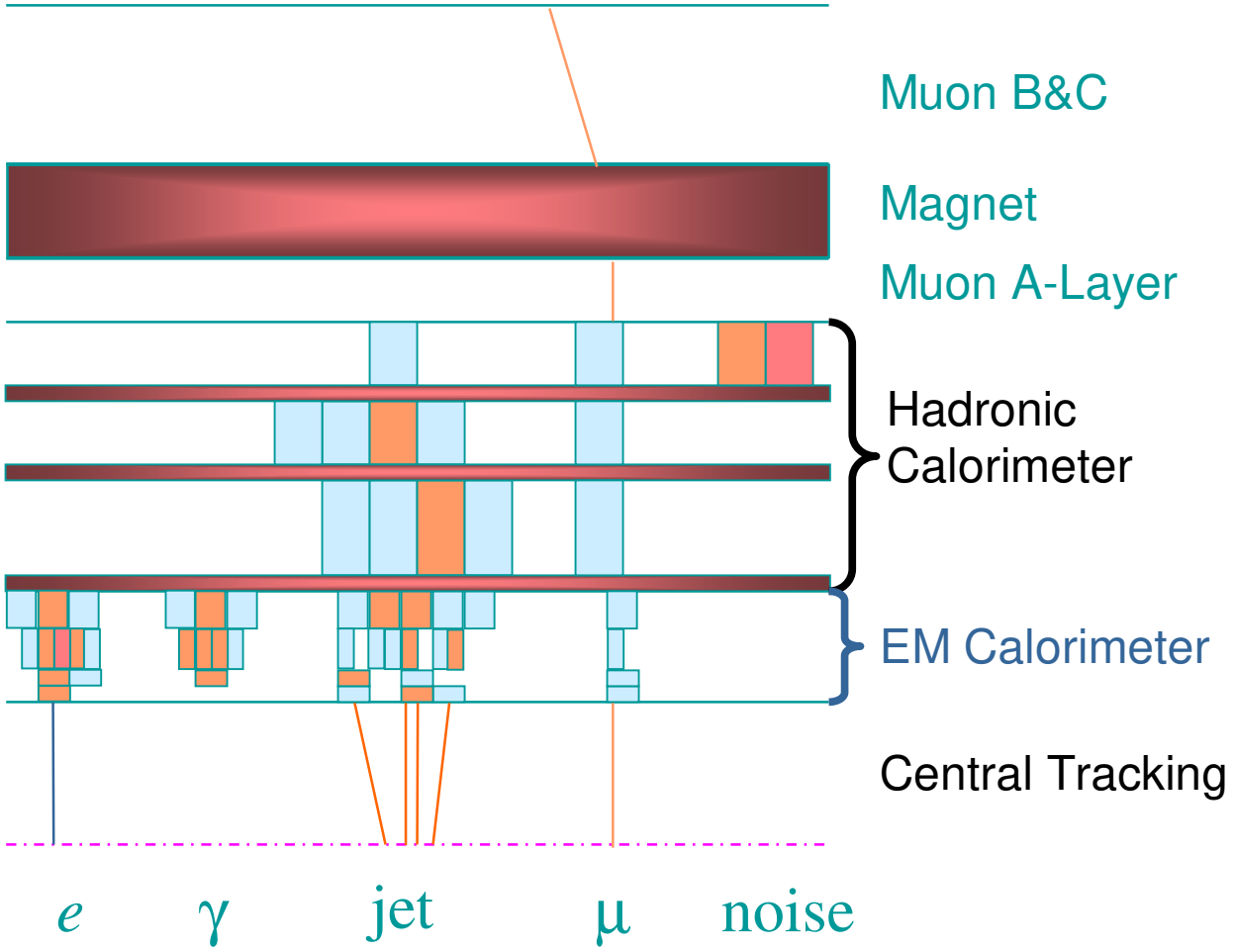
DØ uses Ellis and Soper's definition

Jet Cuts

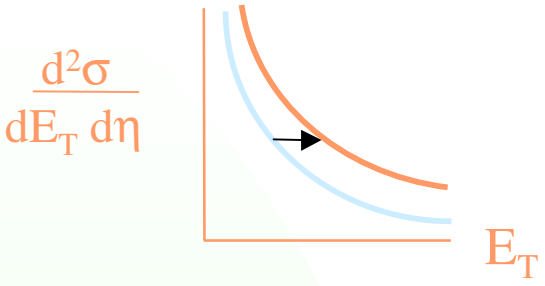
Typical cuts on
EM fraction,
hotcells,
missing E_T,
vertex position,
etc.

> 97% efficient

> 99% pure



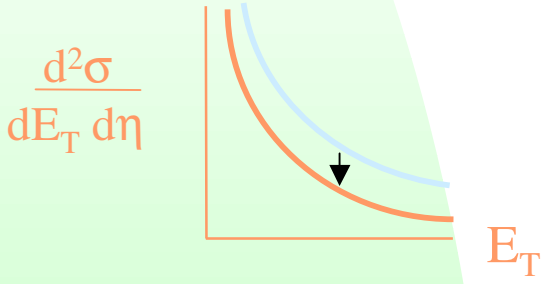
Jet Energy Corrections



- Response functions
- Noise and underlying event
- "Showering"

no distinction between jets of different kinds

the symmetric part



- Resolutions
  Estimated with dijet balancing or simulation

Jet and Event Quantities

- Subjet Multiplicity
- Underlying event structure

New !

- Low E_T Multijet studies

Subjet Multiplicity

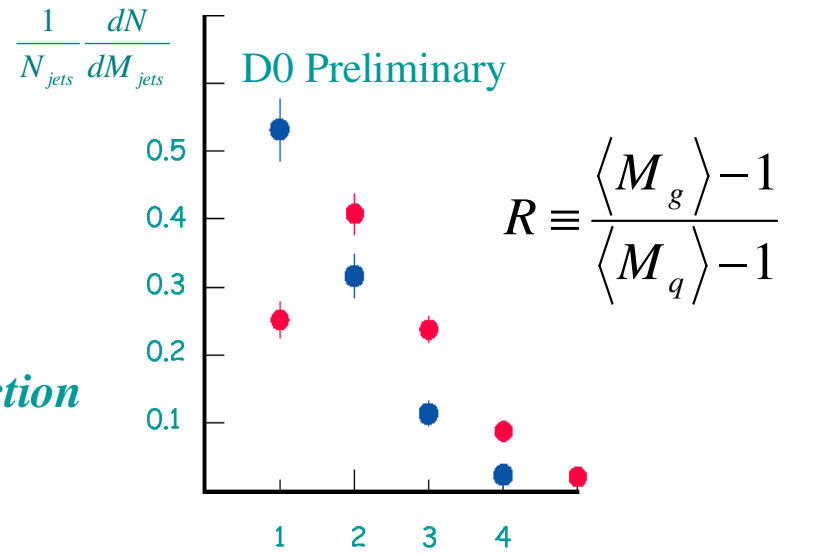
Using the k_T algorithm

- Linear Combination:

Mean Jet Multiplicity

$$\langle M \rangle = f_g M_g + (1-f_g) M_Q$$

Gluon Jet Fraction *Quark Jet Fraction*



- Assume M_g, M_Q independent of $\sqrt{s}$
- Measure M at two $\sqrt{s}$ energies and extract the g and Q components
- Largest uncertainty comes from the gluon fractions in the PDFs

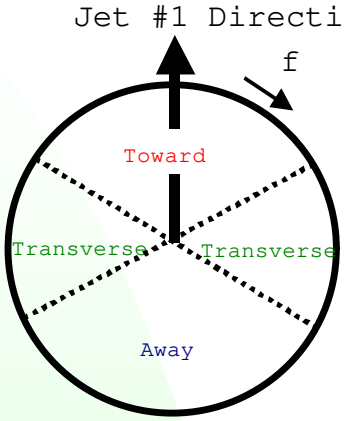
no attempt to develop a likelihood function

Coming soon as a PRD

$$R = 1.91 \pm 0.04\,(\text{stat}) \pm {}^{0.23}_{0.19}\,(\text{sys})$$

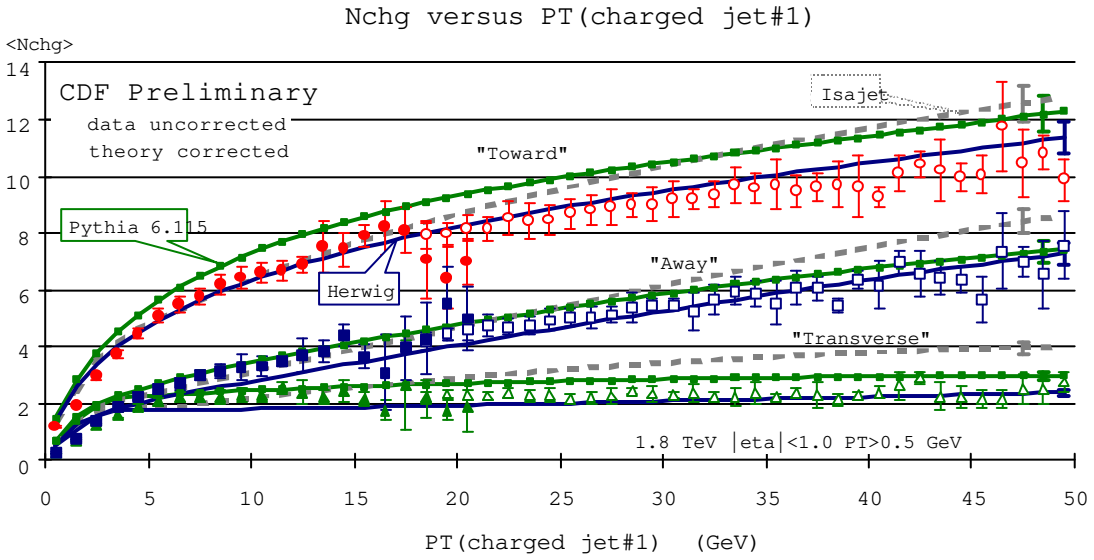
HEWIG prediction =1.86±0.08(stat)

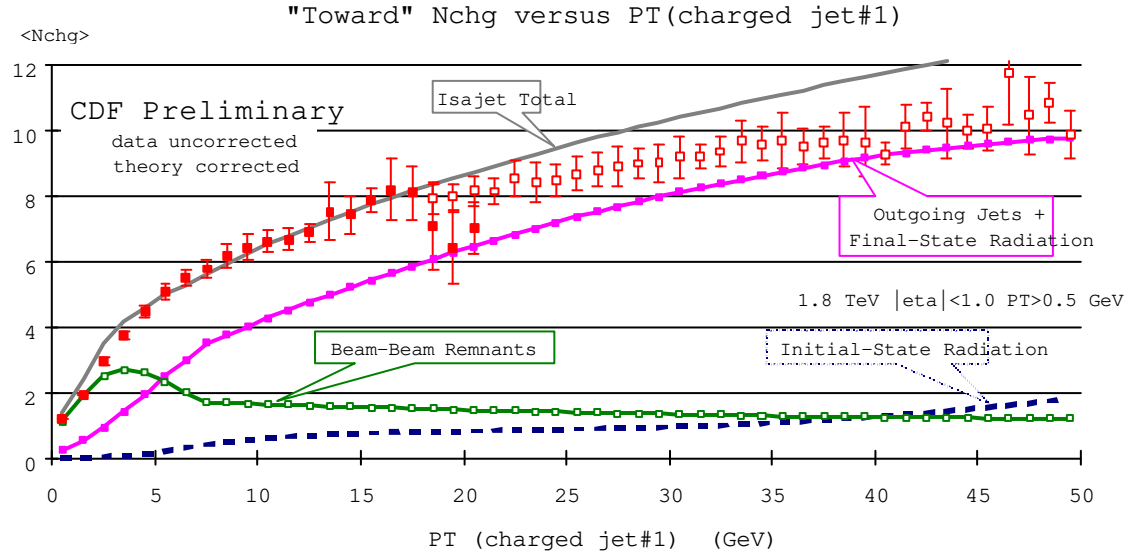
Underlying event structure



Counting charged particles in azimuthal sectors

Improve modeling of underlying event





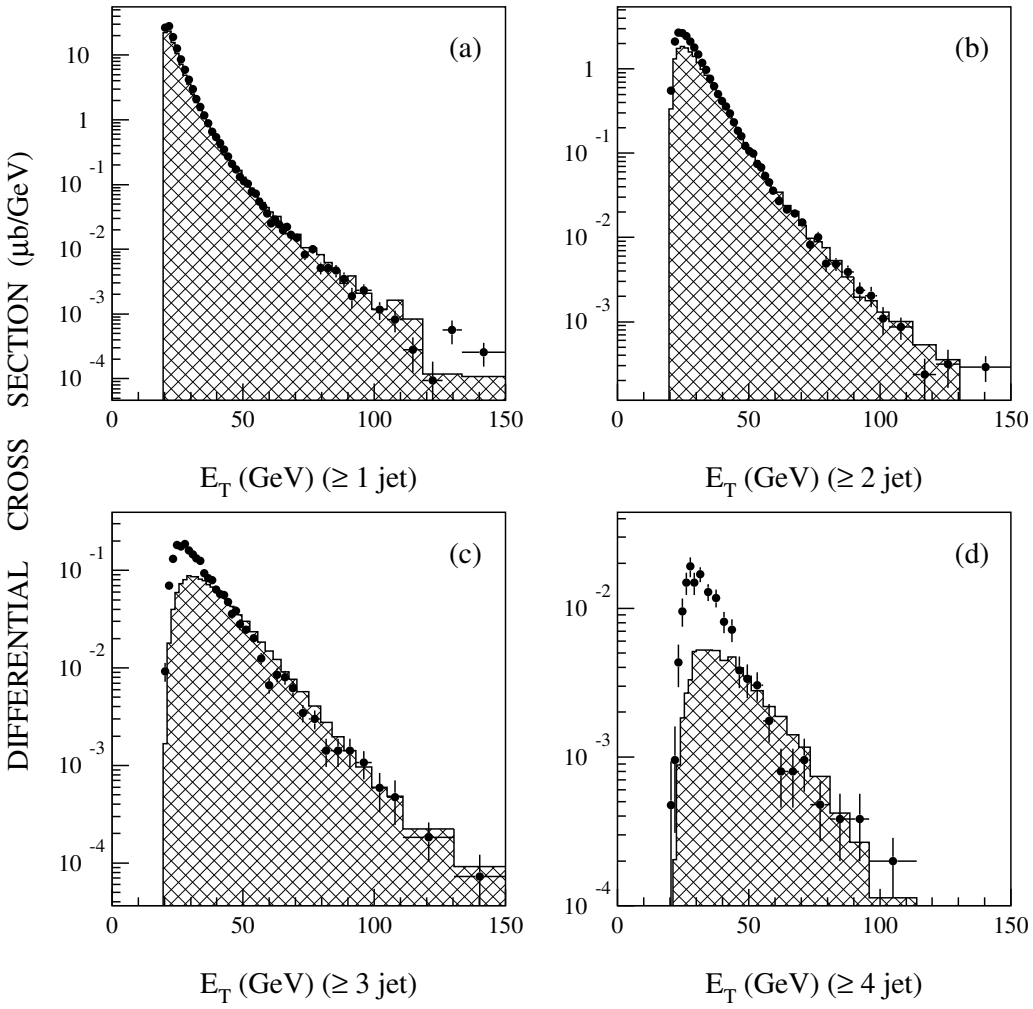
Low E_T Multijet events

At high-E_T, QCD does quite well.

But try counting jets at low-E_T…compare to Pythia

Each jet's E_T>20 GeV.

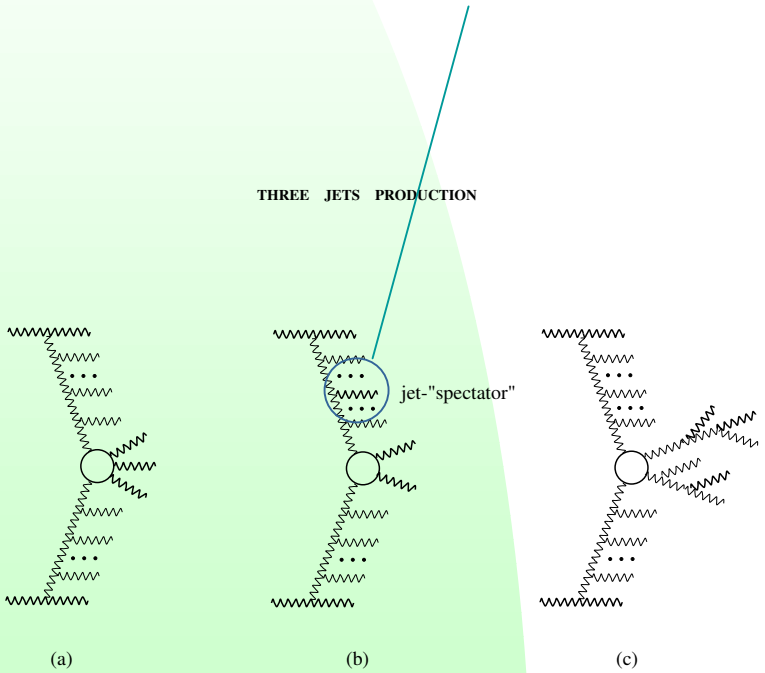
For 2 jets or more, normalization is off, so correct to >40 GeV spectrum.

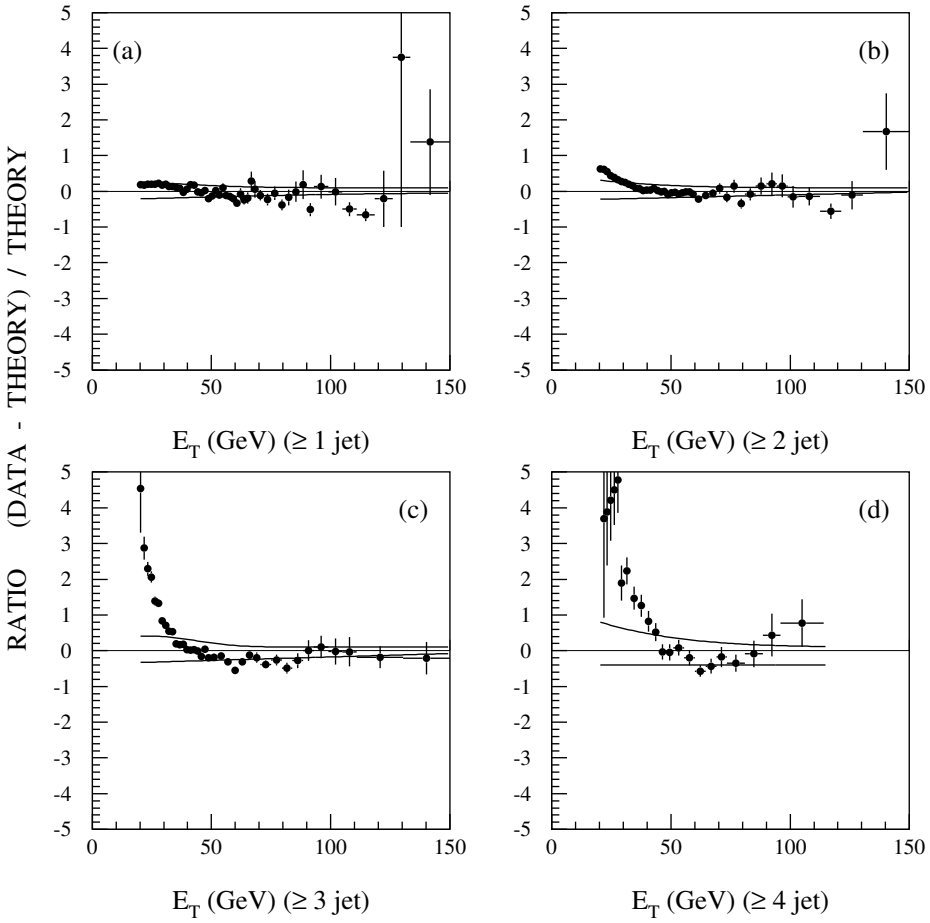


Low E_T Multijet events

Strong p_T ordering in DGLAP suppresses "spectator jets"

BFKL has diffusion in $\log(p_T)$





Looking also at Jetrad and Herwig

Cross Sections

$$\frac{d^2\sigma}{dE_T d\eta} = \frac{N}{\varepsilon \cdot L \cdot \Delta E_T \cdot \Delta\eta} \cdot C_{smear}$$

$$versus \quad E_T$$

Published! ■ R32

Published! ■ 630/1800 ratio of jet cross sections

Published! ■ Forward cross sections

Submitted ■ Two PRDs

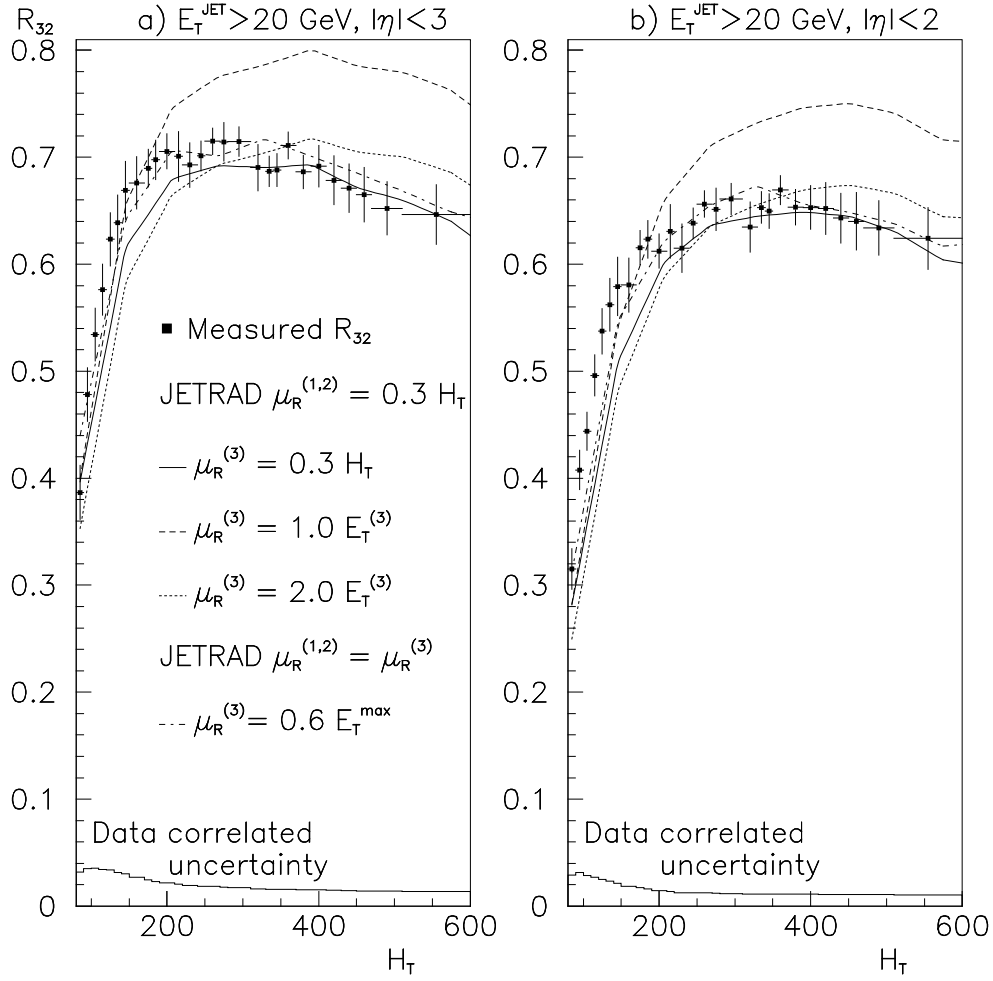
New ! ■ K_T central inclusive

χ^2 analysis

Inclusive R32

$$\frac{\sigma_{3+\text{ Jets}}}{\sigma_{2+\text{ Jets}}} \quad vs \quad H_T$$

- A study of soft jet emission rate
- Ratios exploit error correlations
- We observe lack of PDF sensitivity
- Investigate μ_R scale sensitivity with Jetrad



Inclusive R32

several formulae for μ_R

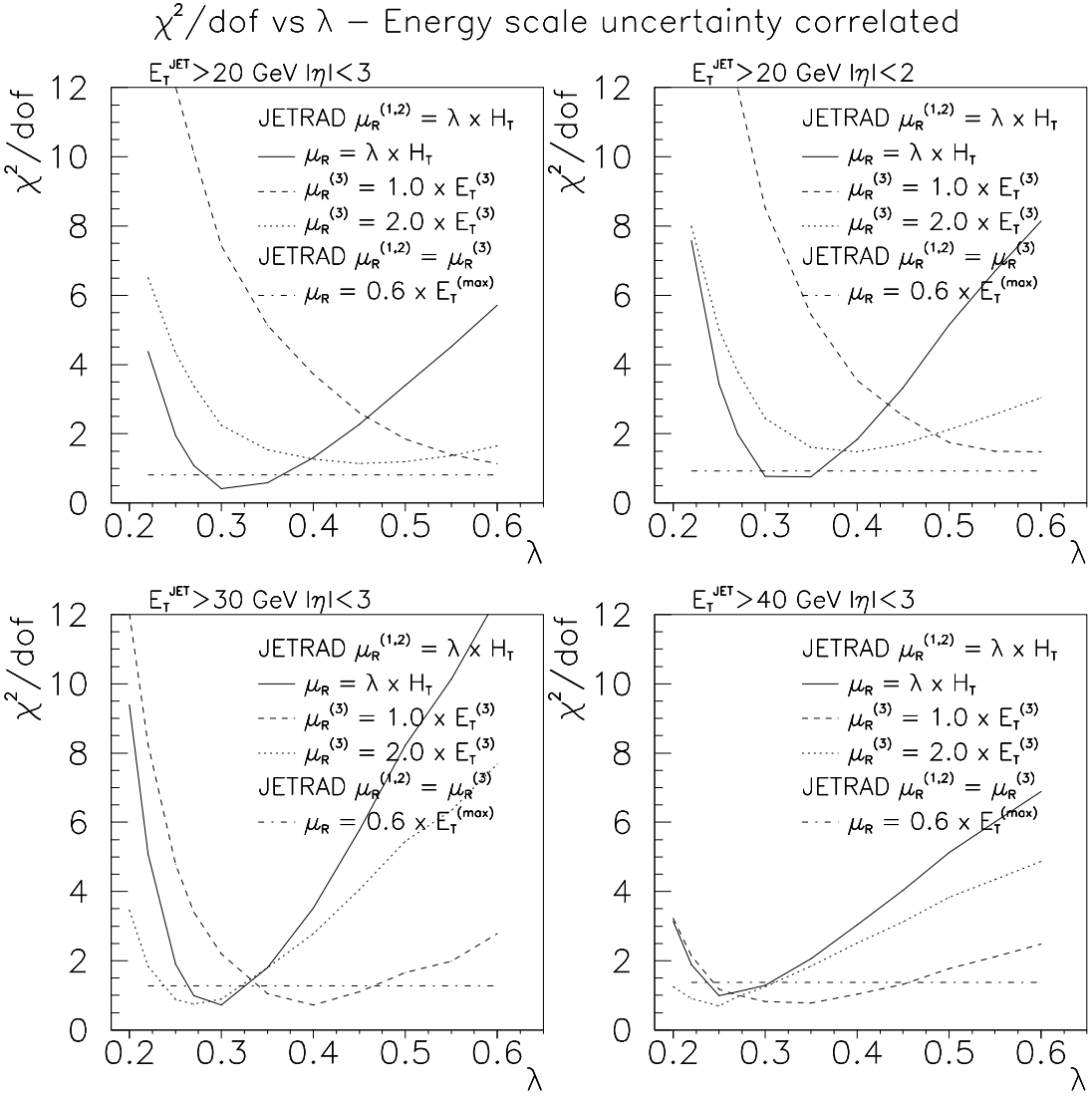
μ_R not always same for jets in the same event (yet agreement not improved)

single-scales seem better than mixed-scales,

$0.3*H_T$ is most robust

(As minimum E_T threshold climbs, the "hardness" of the event is less well-represented by E_T^{max}?)

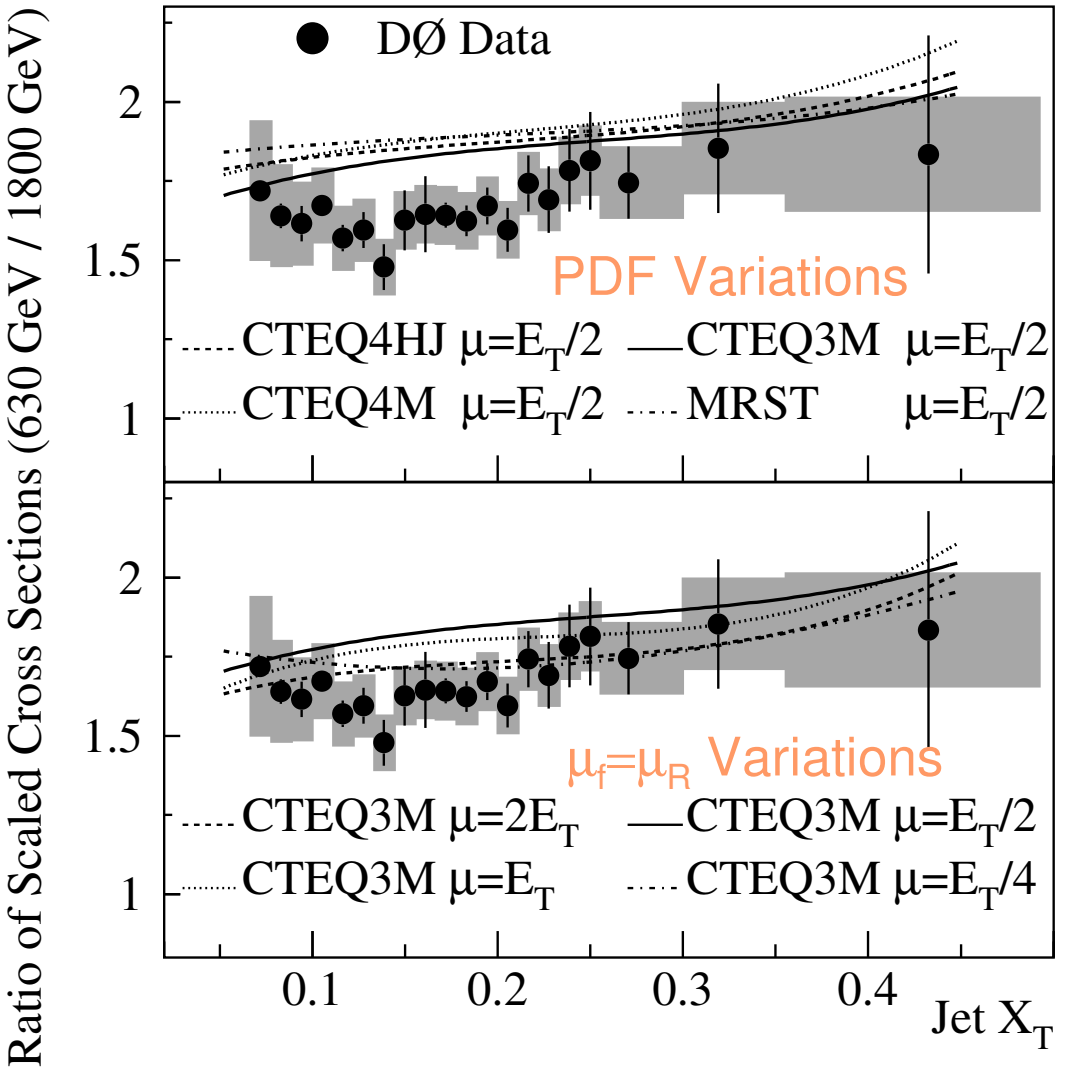
PRL 86, 1955 (2001)



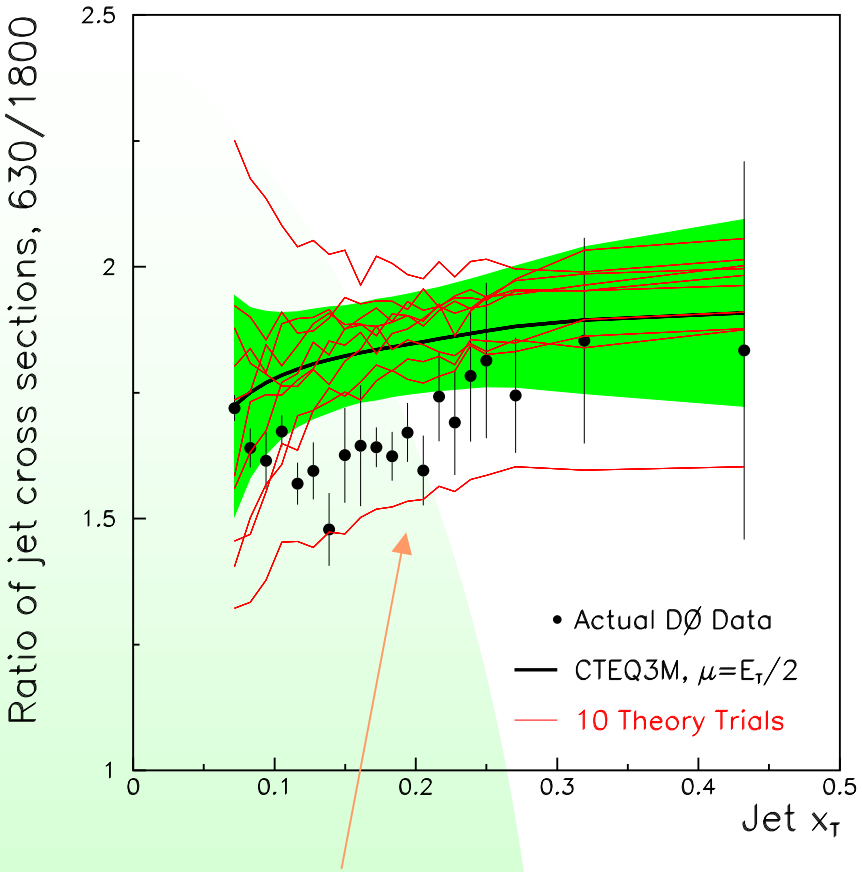
Inclusive Ratio $\frac{630}{1800}$

$$\frac{(E_T)^3}{2\pi}\cdot\frac{d^2\sigma}{dE_T d\eta} \quad versus \quad x_T = \frac{E_T}{\sqrt{s}/2}$$

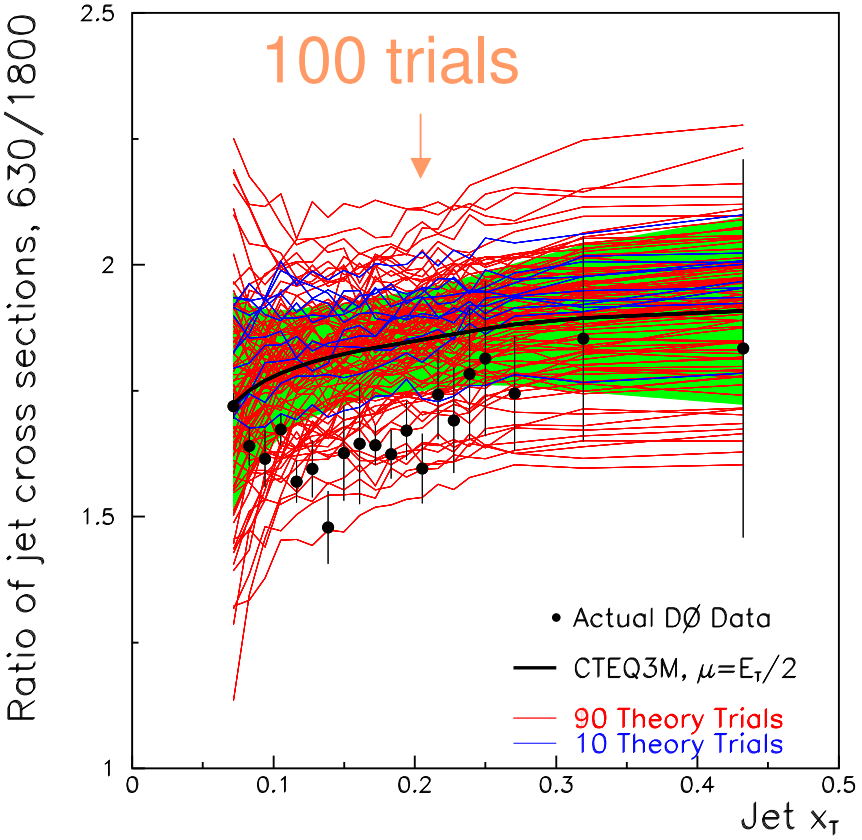
- Published yesterday in PRL
- χ^2 probabilities fall between 30% and 60%
- DØ has tried a "normalization-only" test, which yields generally poor agreement (<1%), except for $2*E_T$ (7%) and $0.25*E_T$ (23%).



A few words on χ^2



10 MC simulations of systematic errors



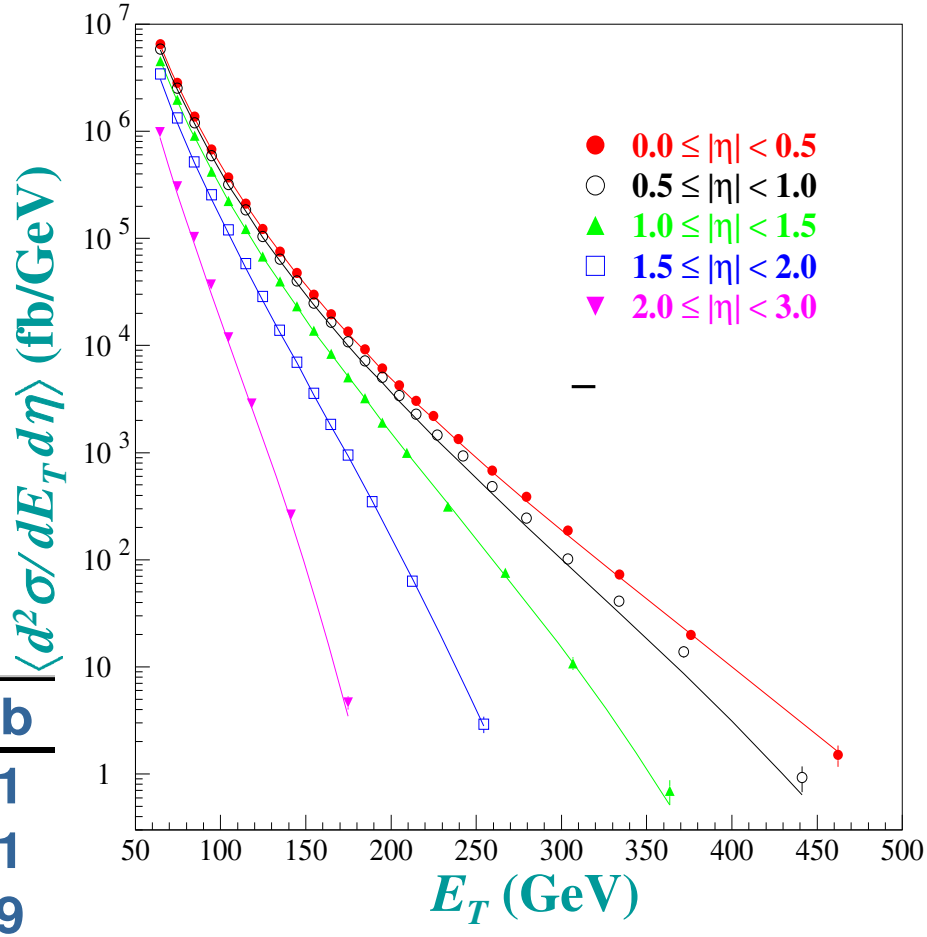
The calculations work great, root-diagonal elements alone not sufficient for plots

Rapidity-dependent Inclusive

DØ's most complete cross section measurement

Uncertainty in theory is larger than uncertainty is data!

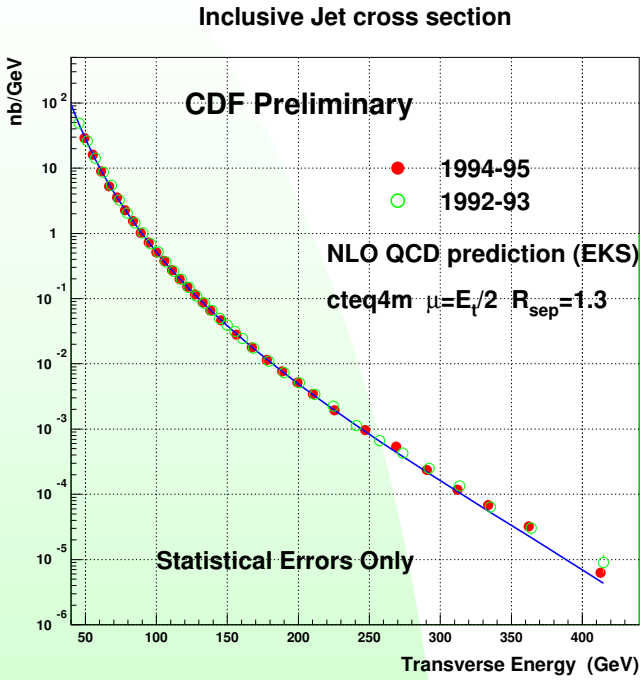
PDF	χ^2	χ^2/dof	Prob
CTEQ3M	121.56	1.35	0.01
CTEQ4M	92.46	1.03	0.41
CTEQ4HJ	59.38	0.66	0.99
MRST	113.78	1.26	0.05
MRSTgD	155.52	1.73	<0.01
MRSTgU	85.09	0.95	0.63



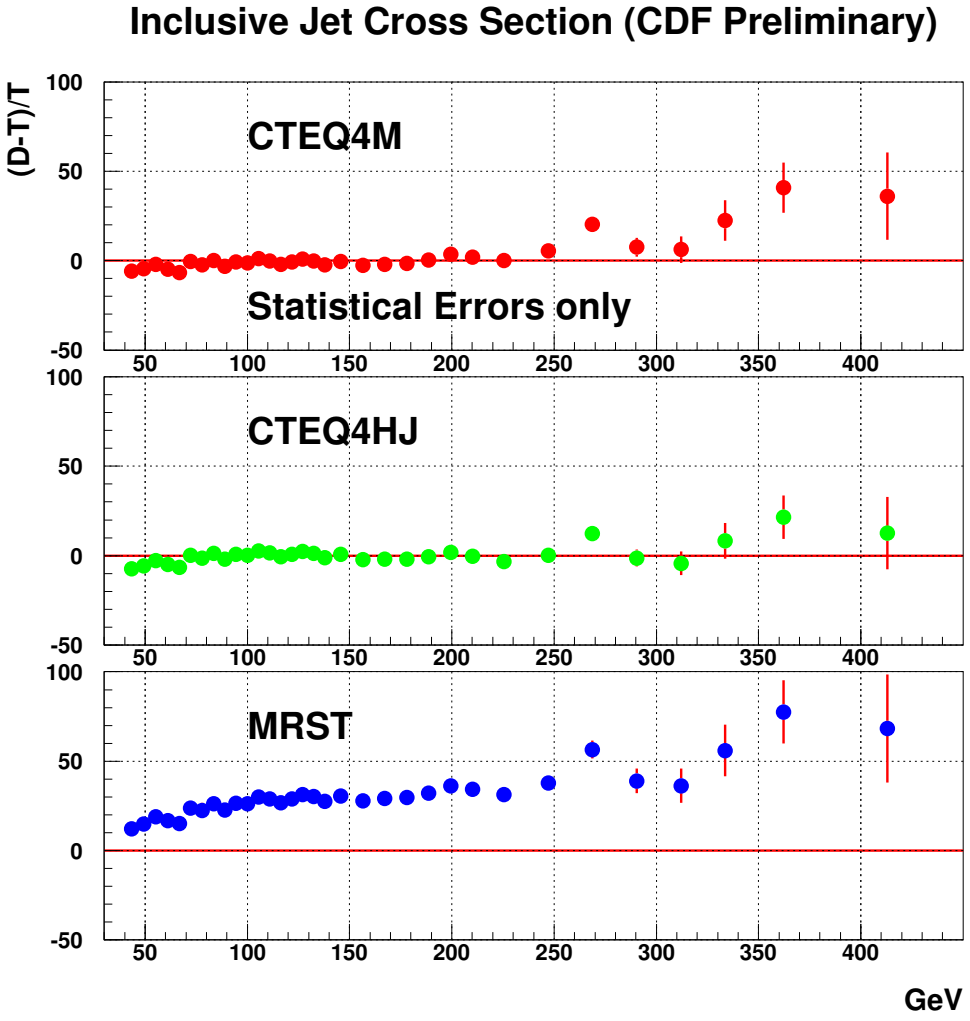
PRL 86, 1707 (2001)

Jets PRD #1: CDF's Run 1b inclusive jet

Has discussion of $\Delta\chi^2$ technique.



Includes comparisons to Run 1a data DØ's run 1b data



Jets PRD #2:

DØ's Run 1b jet results

Tour de Force:

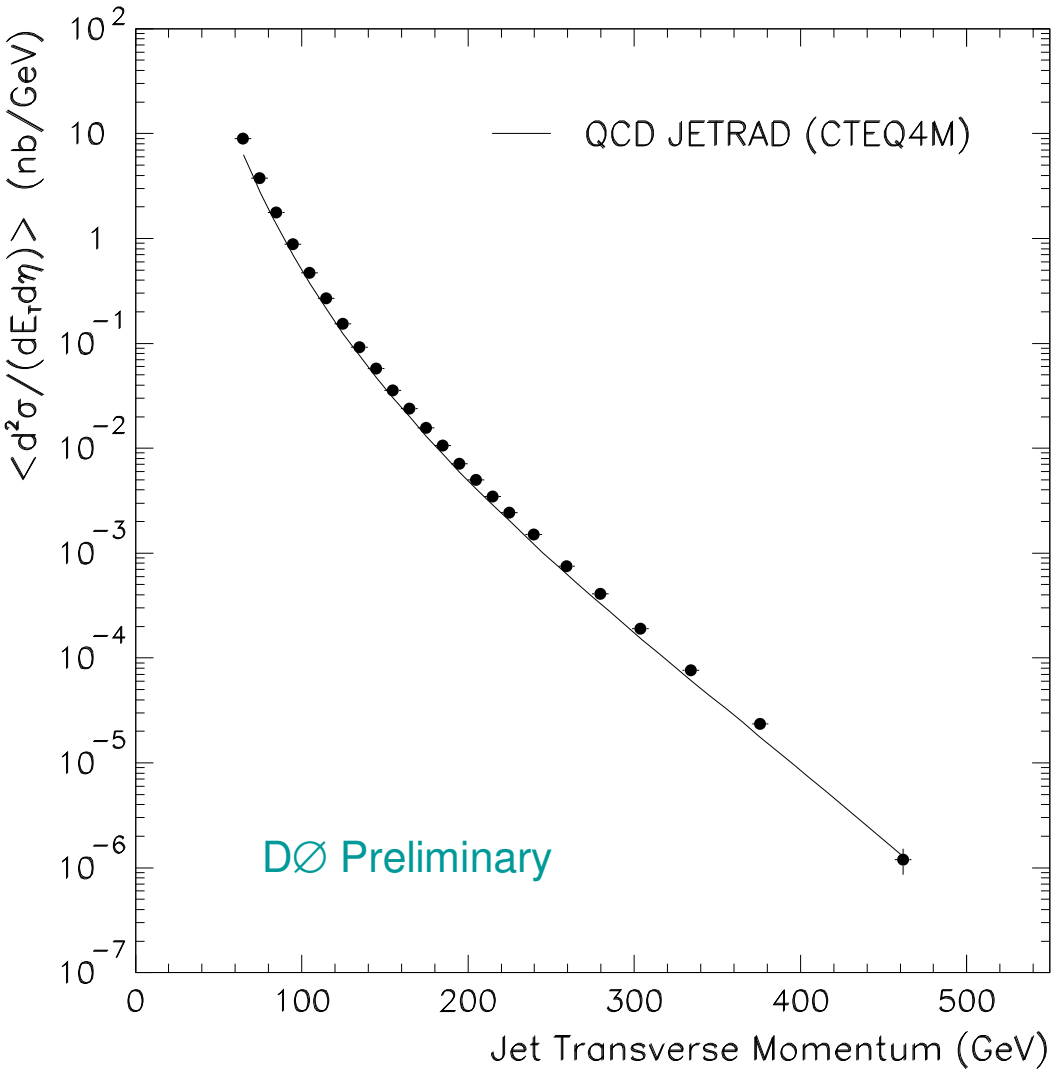
1800 central inclusive,
dijet mass,
dijet angular distribution,
630/1800 inclusive ratio

K_T Inclusive Jet Cross Section

$-0.5 < \eta < 0.5$

D = 1.0

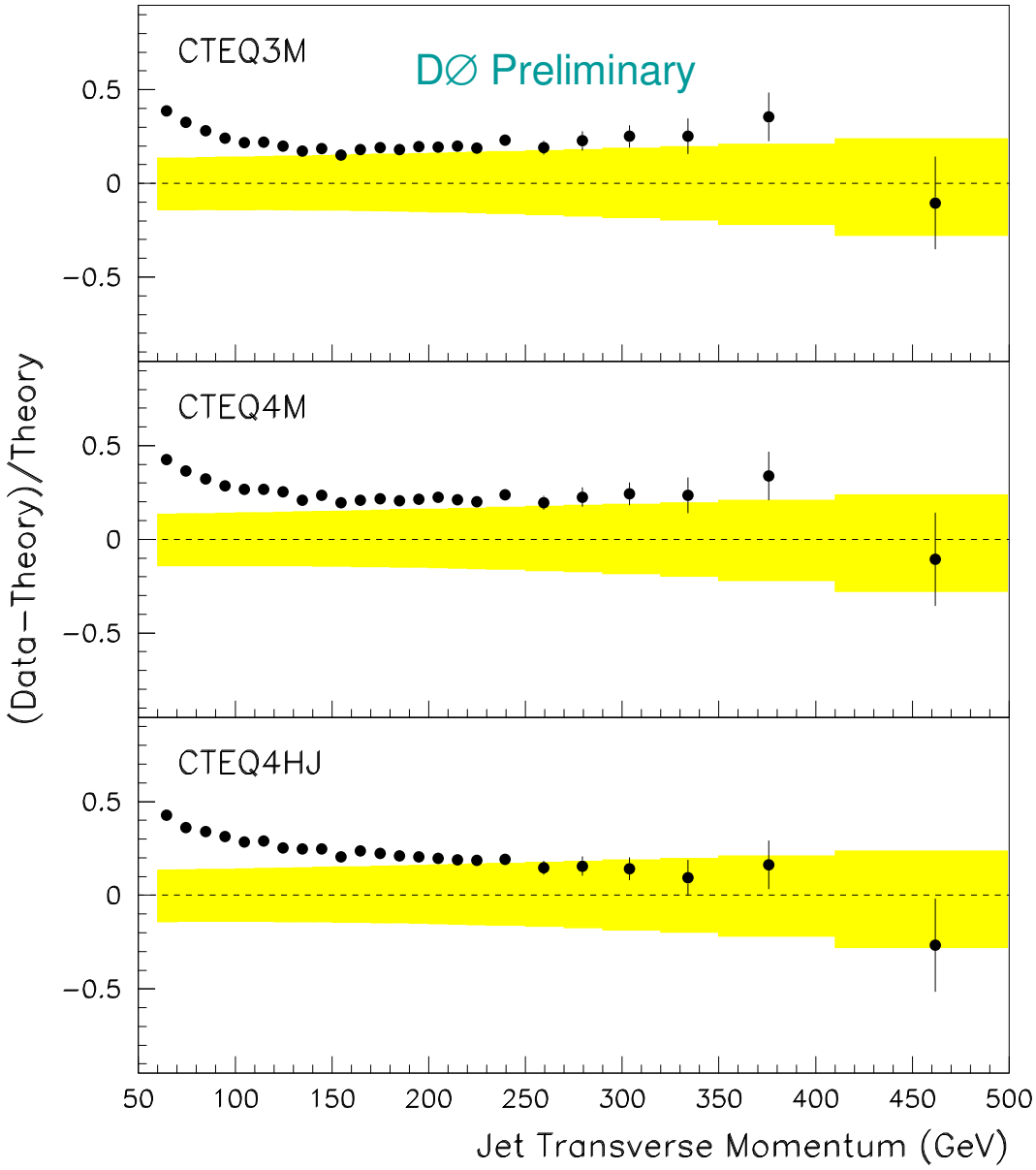
- Predictions IR and UV safe
- Merging behavior well-defined for both exp. and theory



K_T Comparison

- Normalization differs by 20% or more
- p_T dependence
- DØ has an error matrix expect χ^2 numbers soon

"No significant deviations of predictions from data"



Summary

- TeVatron stopped running in 1996
  but several results are still in the queue
  - Jet substructure
  - Event structure
  - Cross sections
- Growing sophistication in results
  - Greater consistency between experiments
  - Error matrices
  - Better corrections