

Photon 2003

Organised by the Laboratori Nazionali di Frascati

Recent **QCD** Results from the Tevatron

Don Lincoln

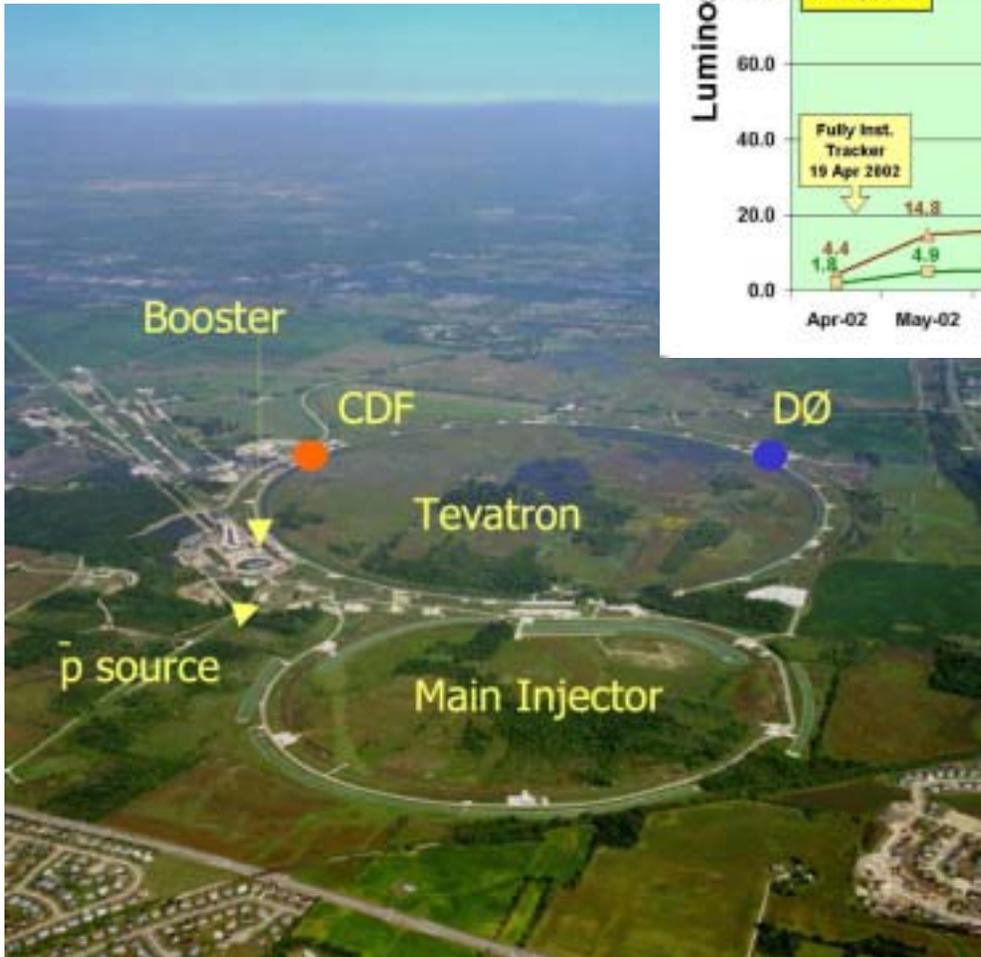
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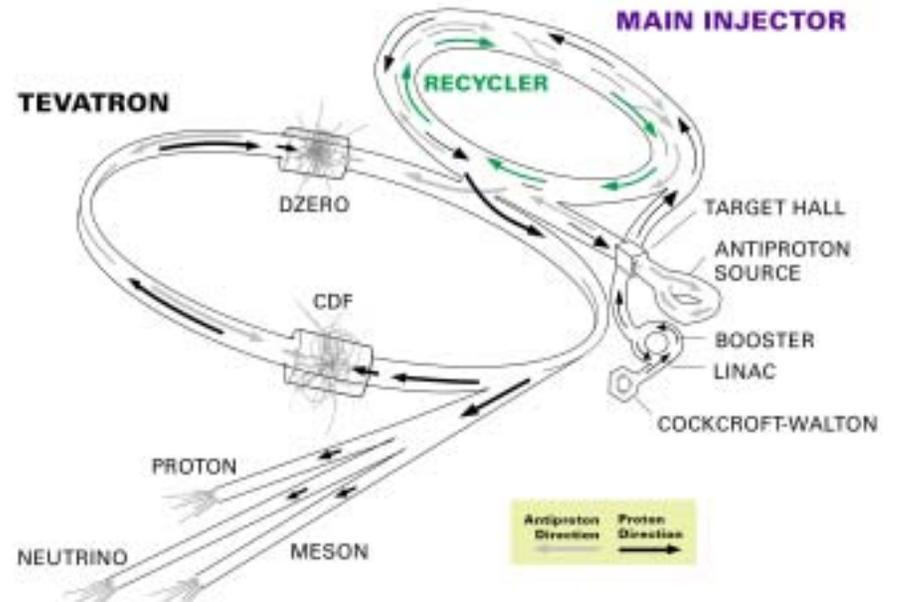
Fermilab

DØ Integrated Luminosity

19 April 2002 - 18 March 2003



FERMILAB'S ACCELERATOR CHAIN

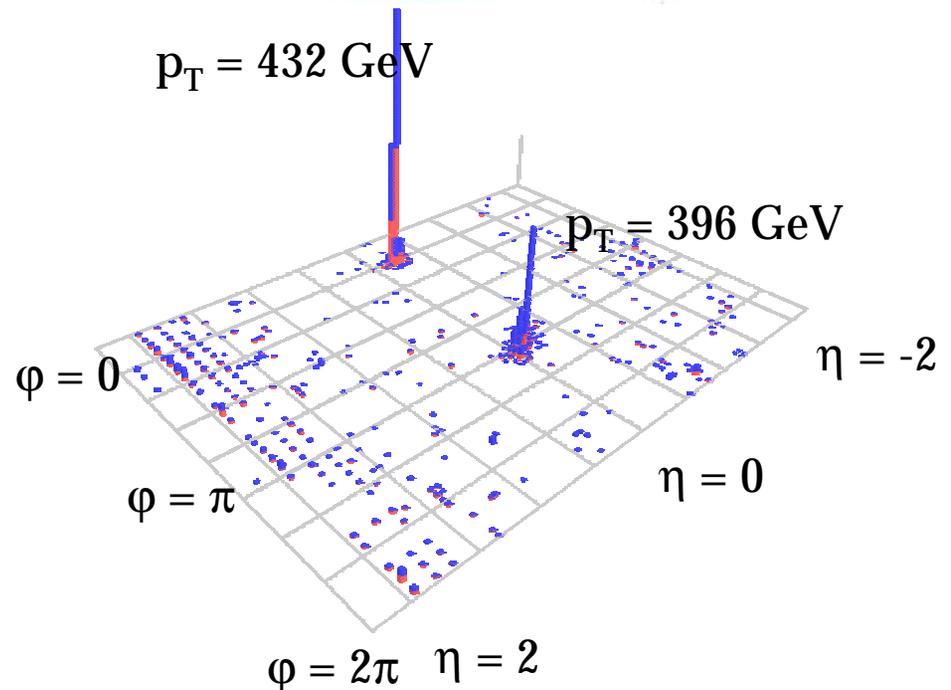
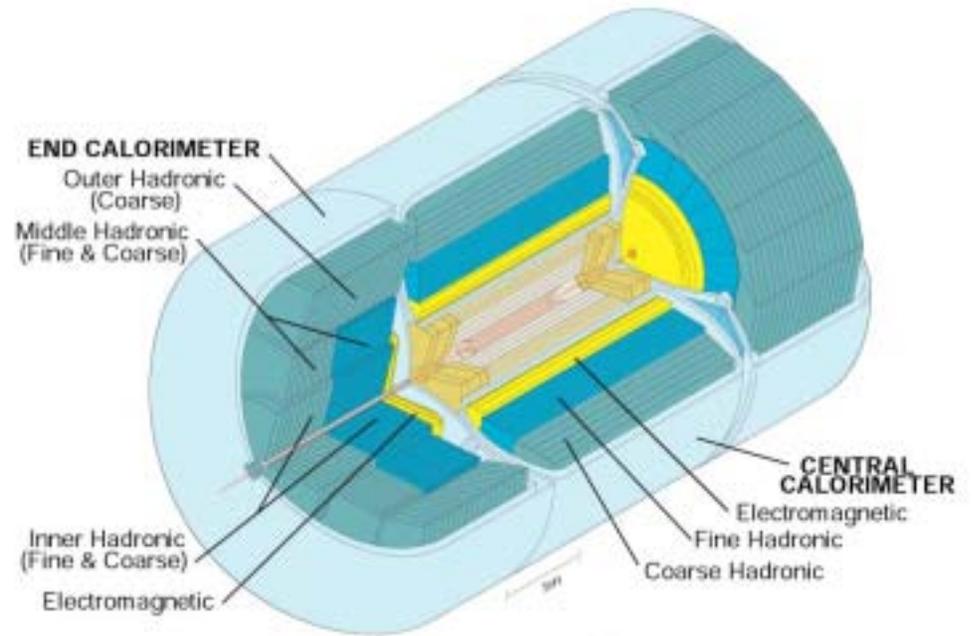


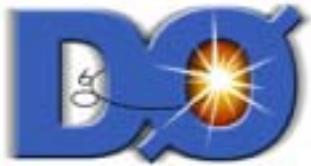
Don Lincoln, Fermilab



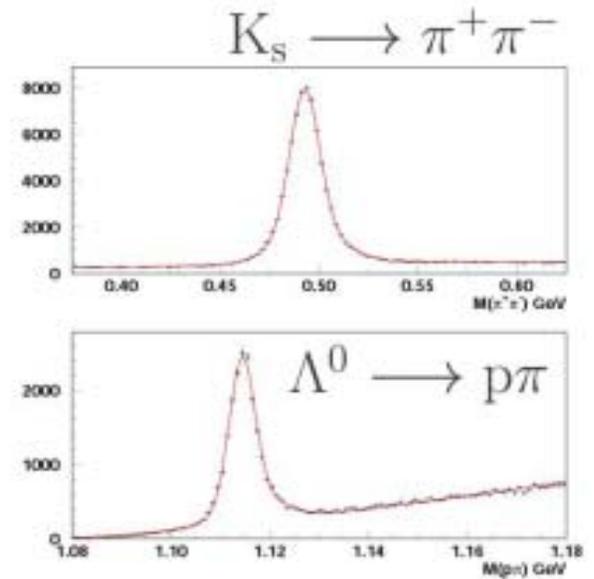
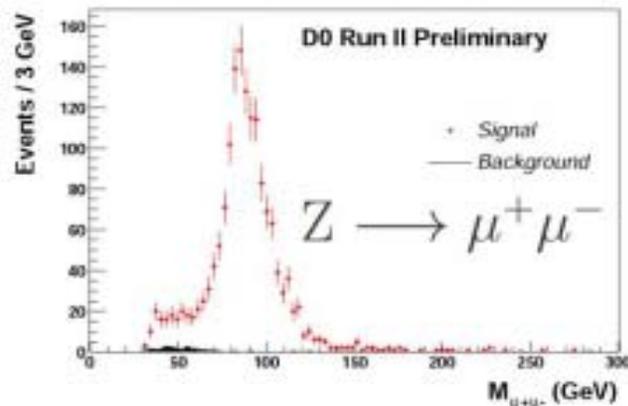
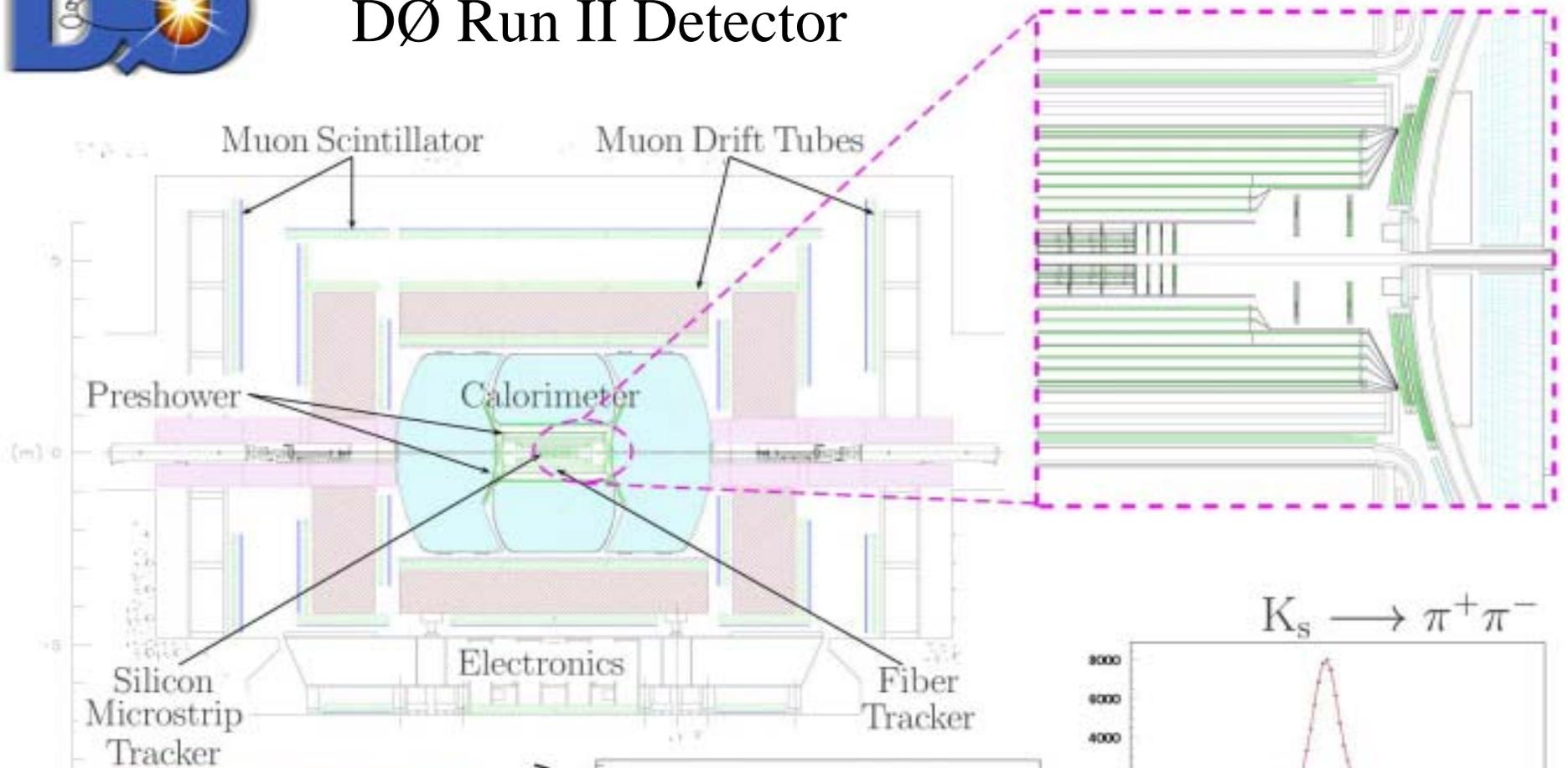
DØ Calorimeter

- Uranium-Liquid Argon Calorimeter
stable, uniform response, radiation hard
- Compensating: $e/\pi \approx 1$
- Uniform hermetic coverage
 $|\eta| \leq 4.2$, recall $\eta \equiv -\ln[\tan(\theta/2)]$
- Longitudinal Segmentation
 - 4 EM Layers (2,2,7,10) X_0
 - 4–5 Hadronic Layers (6λ)
- Transverse Segmentation
 - $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$ in EM_3
 - $\Delta\eta \times \Delta\phi = 0.10 \times 0.10$ otherwise





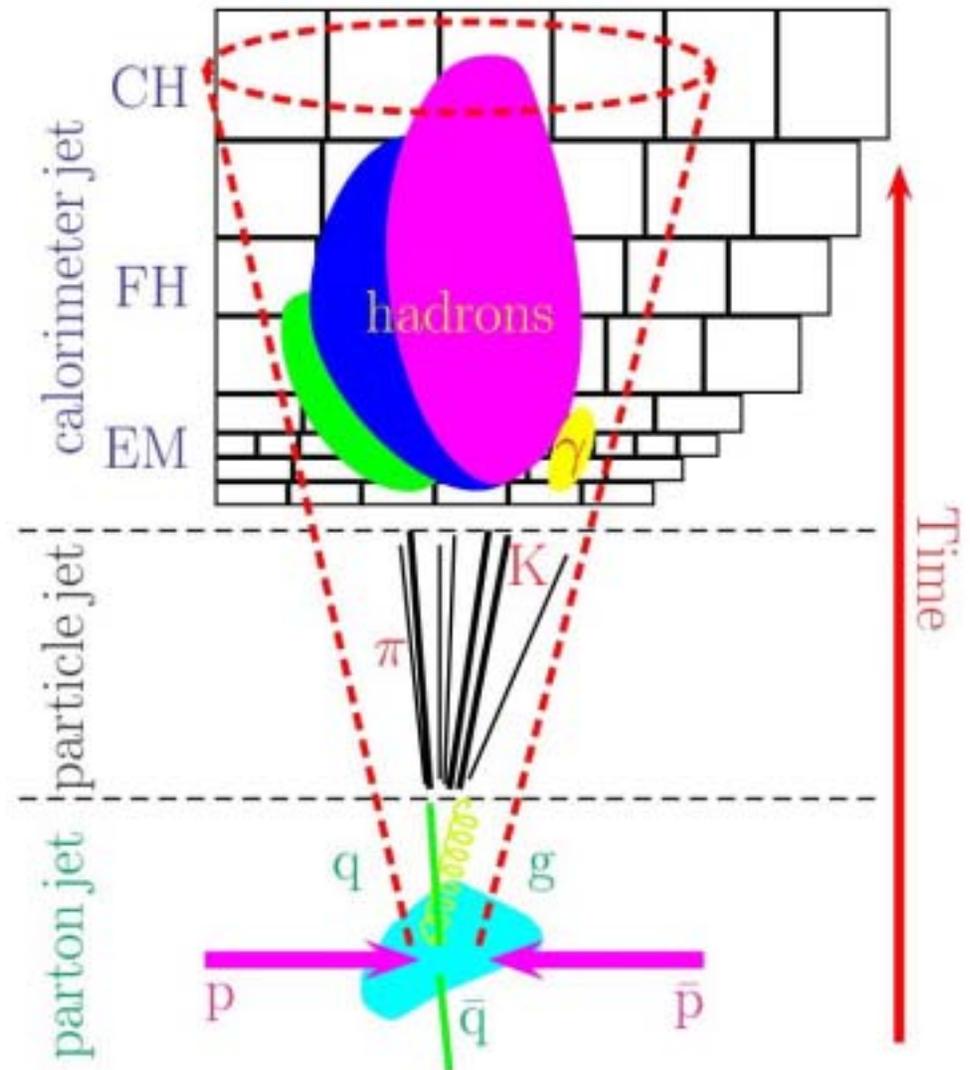
DØ Run II Detector





Cone Jet Definition

- $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
- Run I
 - Add up towers around a “seed”
 - Iterate, using “jets” as seeds, until stable
 - Jet quantities: E_{\perp} , η , ϕ
 - $E_{\perp}^{\text{jet}} = \sum_{R \leq 0.7} E_{\perp}^{\text{tower}}$
- Modifications for Run II
 - Use 4-vector scheme
 - p_{\perp} instead of E_{\perp}
 - Add midpoints between jets as additional seeds
 - Infrared safe
- Correct to particles





Jet Energy Scale

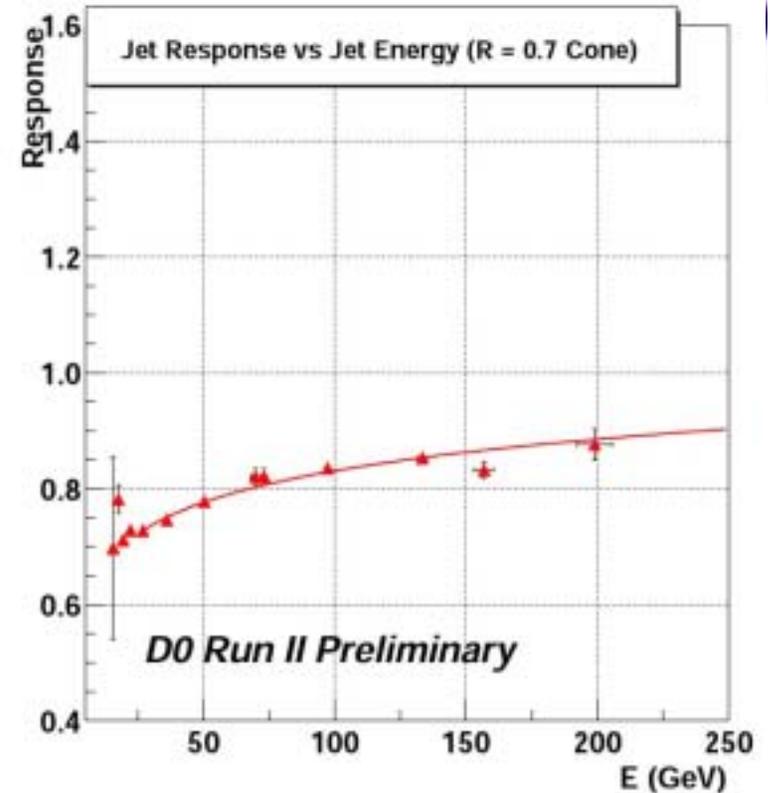
- Measured jet energy is corrected to particle level

$$E_{\text{corr}} = \frac{E_{\text{uncorr}} - O}{RS}$$

- O energy due to previous events, multiple interactions, noise, etc. (minimum bias, etc.)
- R calorimeter response to hadrons (includes non-linearities, dead material, etc.)

Measured from E_{\perp} imbalance in $\gamma + \text{jet}$ events

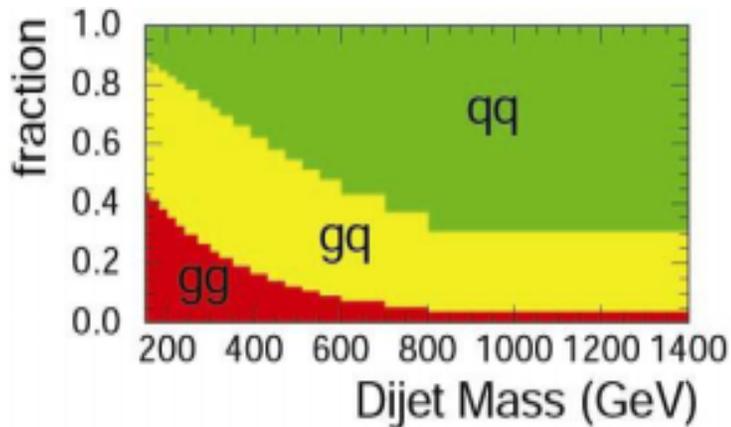
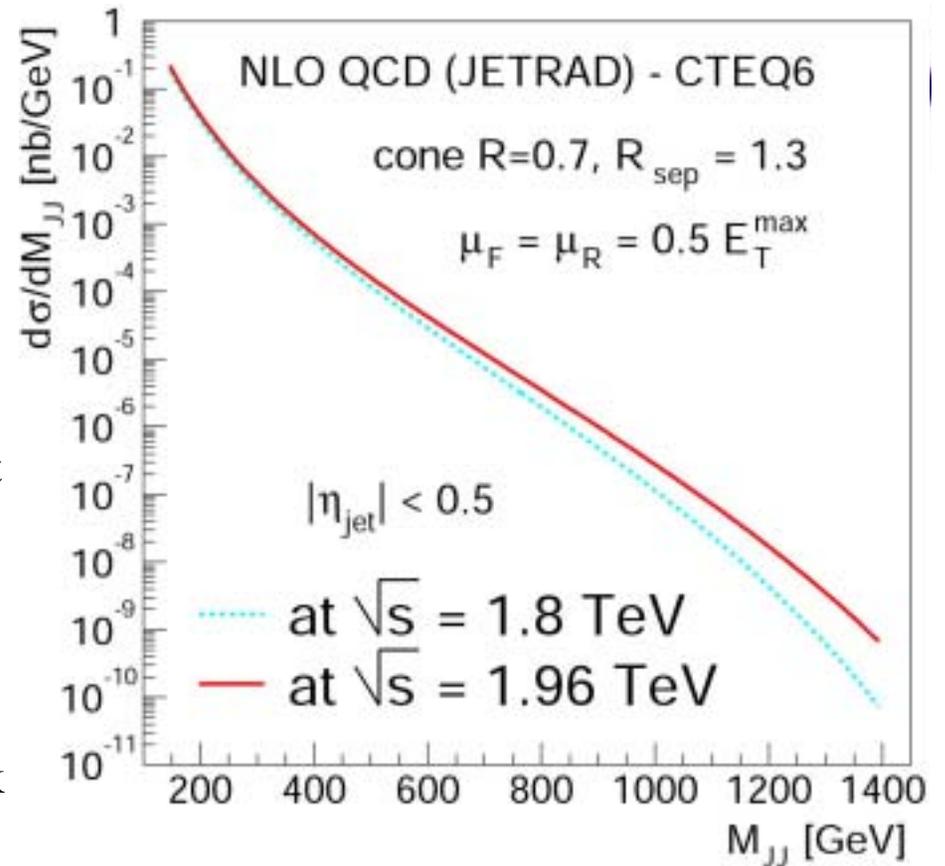
- S net fraction of particle-jet energy that remains inside jet cone after showering in calorimeter (jet transverse shapes)
- Large statistical uncertainties and substantial systematic uncertainties (increases with energy due to extrapolation)
- Current $\gamma + \text{jet}$ statistics extends only to about 200 GeV





Dijets in Run II

- Cross section at $E_{\text{CM}} = 1.96$ TeV is 2-5 times greater as compared to 1.8 TeV
- Higher statistics allow:
 - Better determination of proton structure at large x
 - Testing pQCD at a new level (resummation, NNLO theory, NLO event generators, etc.)
 - Improved searches for new physics (quark compositeness, resonances, etc.)



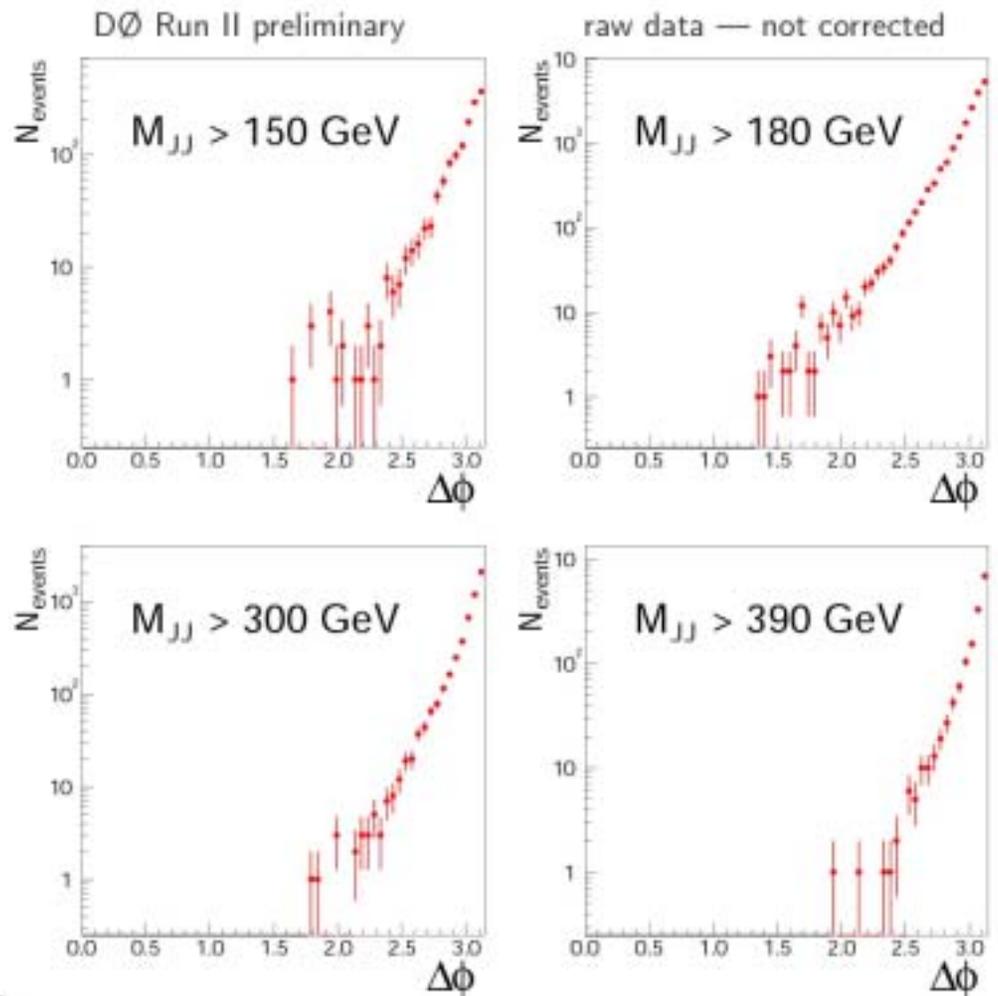
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QCD Results from the Tevatron



Dijet Sample Selection

- Selection criteria:
 - $N_{\text{jet}} \geq 2$
 - $|\eta_{\text{jet}}| < 0.5$
 - $\Delta R = 0.7$ cone jets
- Data sample
 - $\text{MET}/p_{\perp}^{\text{jet}} < 0.7$
 - Primary vertex:
 - $|Z_{\text{vertex}}| < 50$ cm
 - $N_{\text{tracks}} \geq 5$
 - Run selection based on hardware status, MET
 - Jet selection based on calorimeter characteristics to reduce fakes and noise (i.e. hot cells)



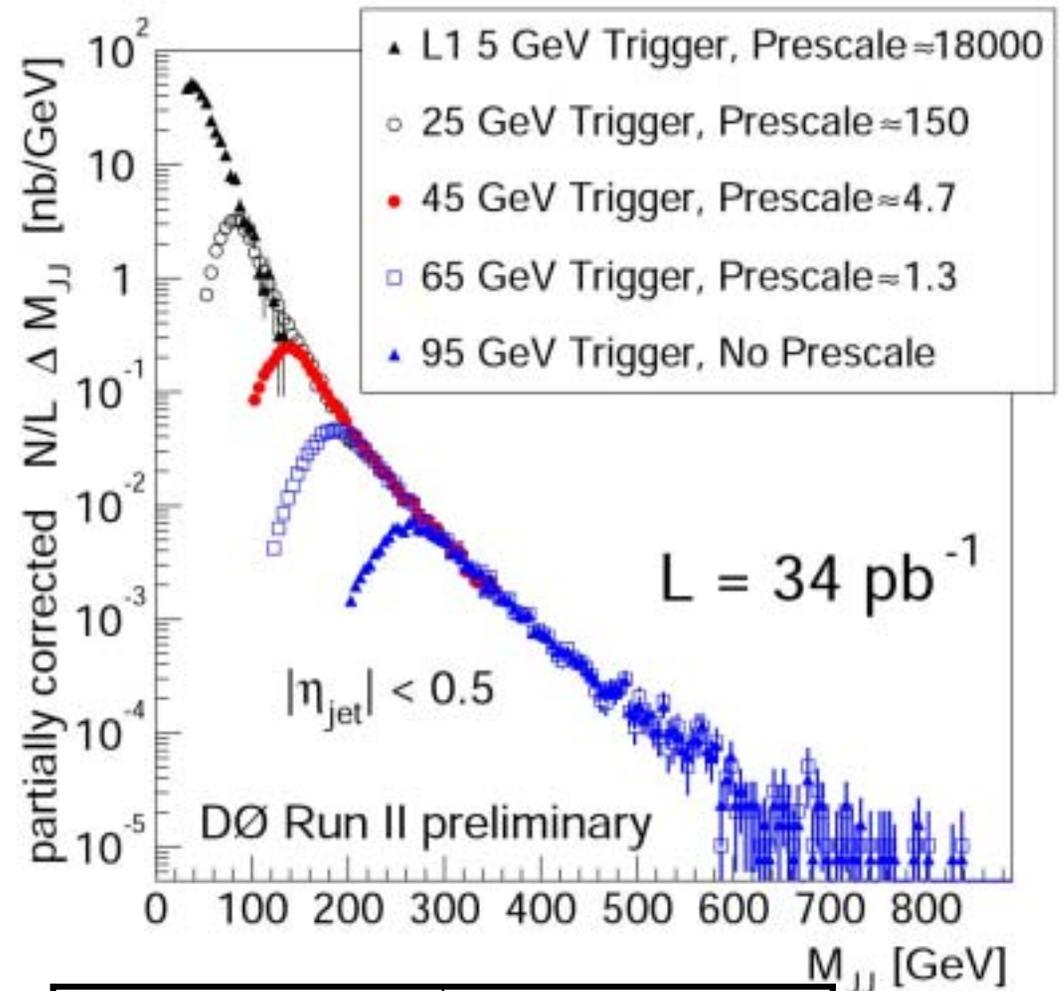
Integrated Luminosity: 34 pb^{-1}



Trigger Selection

- Level 1
 - Hardware trigger
 - Fast calorimeter readout
 - Multi-tower triggers
 - Coverage is $|\eta| < 2.4$
- Level 2
 - Software trigger with special hardware
 - Fast calorimeter readout
 - Simple jet clustering
- Level 3
 - Software trigger
 - Precision calorimeter readout
 - Simple cone algorithm with $\Delta R = 0.7$ (no splitting & merging)

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L3 p_{\perp} Threshold	Offline M_{JJ} Cut
25 GeV	150 GeV
45 GeV	180 GeV
65 GeV	300 GeV
95 GeV	390 GeV



Unsmearing Correction

- Jet Energy Resolution

- Use the data dijet sample
- Asymmetry measurement

$$A = \frac{p_t^{jet1} - p_t^{jet2}}{p_t^{jet1} + p_t^{jet2}}$$

$$\sigma_{pt} = \sqrt{2}\sigma A$$

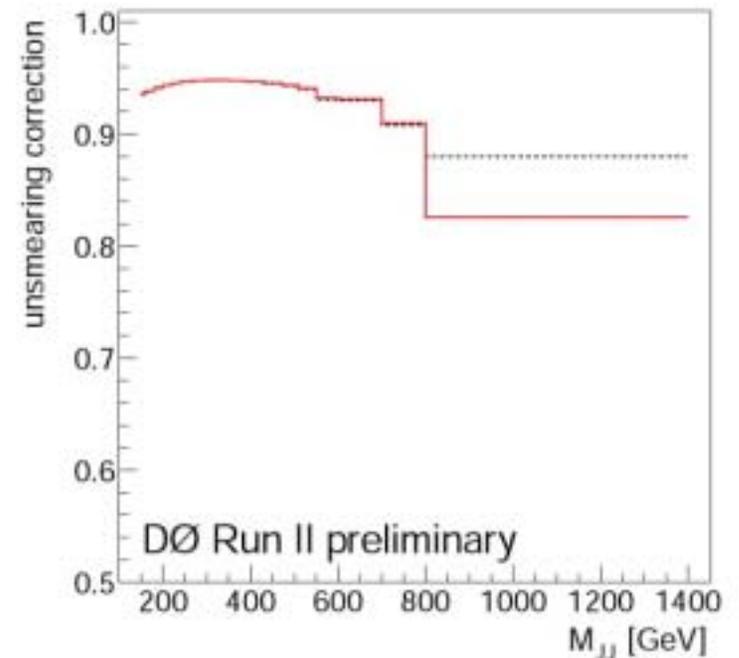
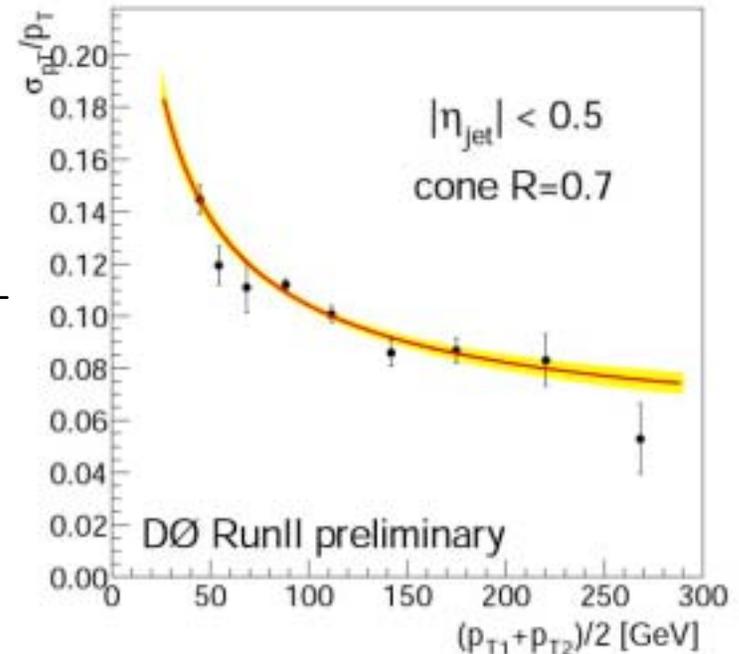
- Correct for third jets and particle jet resolution

- Dijet Mass resolution unsmearing

- Smear PYTHIA events in mass bins
- Gaussian fit to $\Delta M_{jj}/M_{jj}$ in each bin

- Fit to
$$\frac{\sigma(M_{JJ})}{M_{JJ}} = \sqrt{\frac{N^2}{M_{JJ}^2} + \frac{N^2}{M_{JJ}^2} + C^2}$$

- Determine unsmearing correction

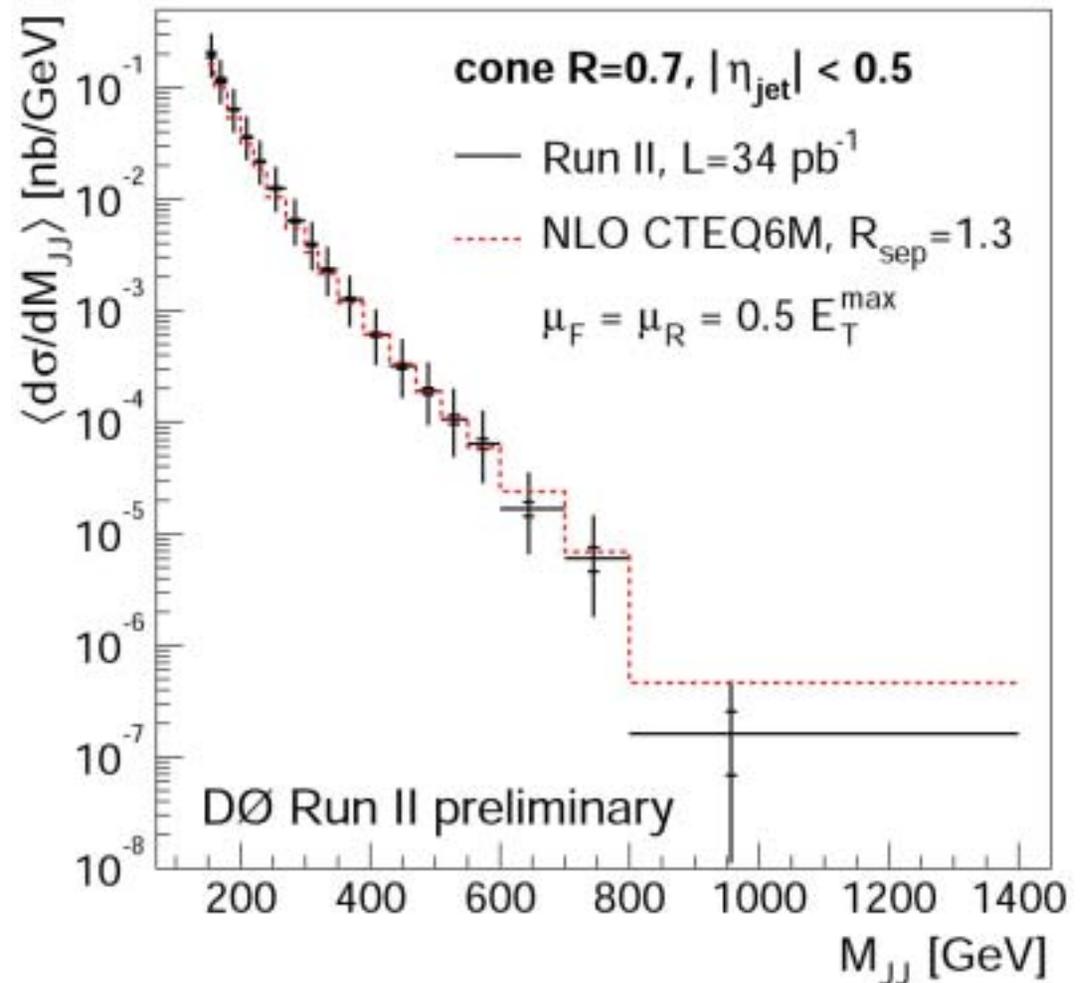




Dijet Mass Cross Section

$$\left\langle \frac{d\sigma}{dM_{JJ}} \right\rangle = \frac{N_{event}}{L} \frac{1}{\Delta M_{JJ}} \frac{C_{unsmear}}{\epsilon_{eff}}$$

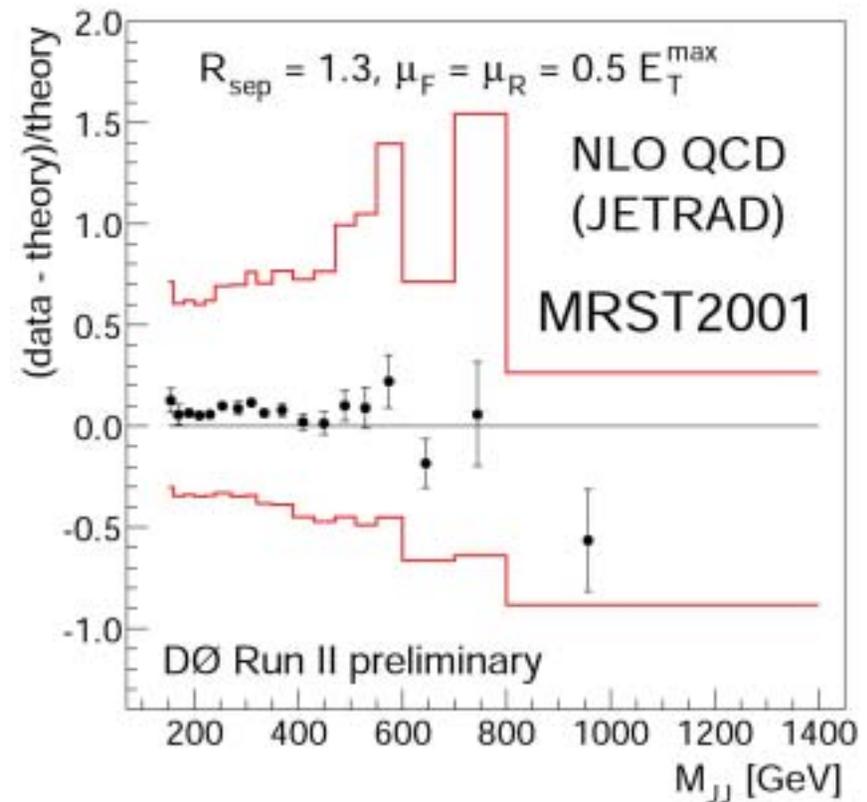
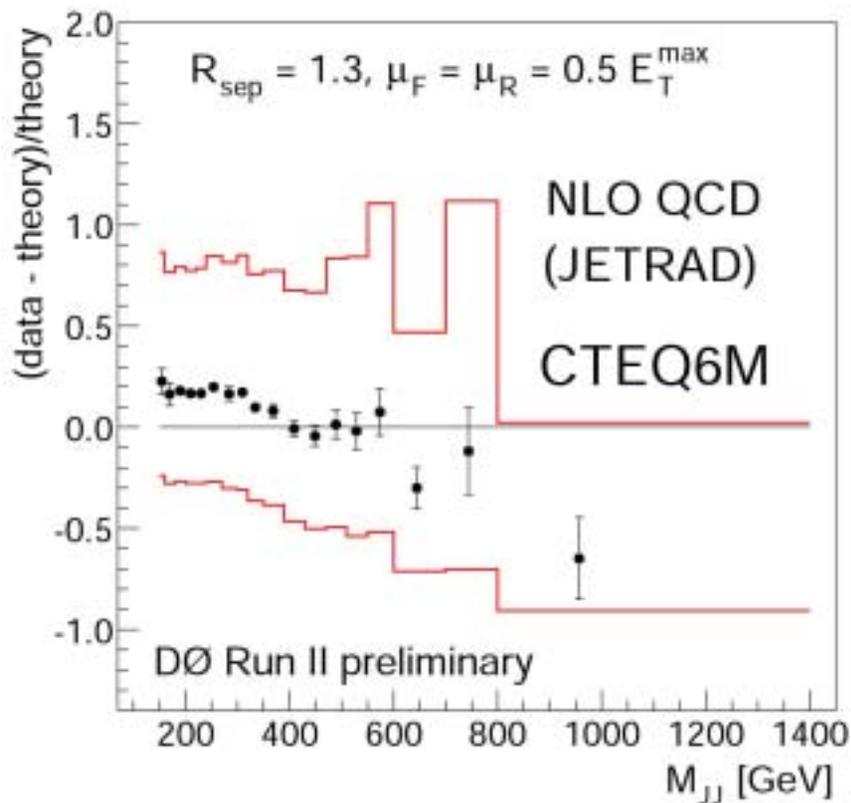
- Efficiencies
 - Estimated from data
 - Vertex quality: ~78%
 - Jet quality: ~94%
- 10% normalization uncertainty not shown (luminosity)
- NLO pQCD JETRAD compared to data
 - All scales set equal
 - $R_{sep} = 1.3$





Theory Comparison

- Main uncertainties: jet energy scale, p_{\perp} resolution, jet quality cuts. **(Dominated by jet energy scale.)**
- 10% normalization uncertainty not shown.

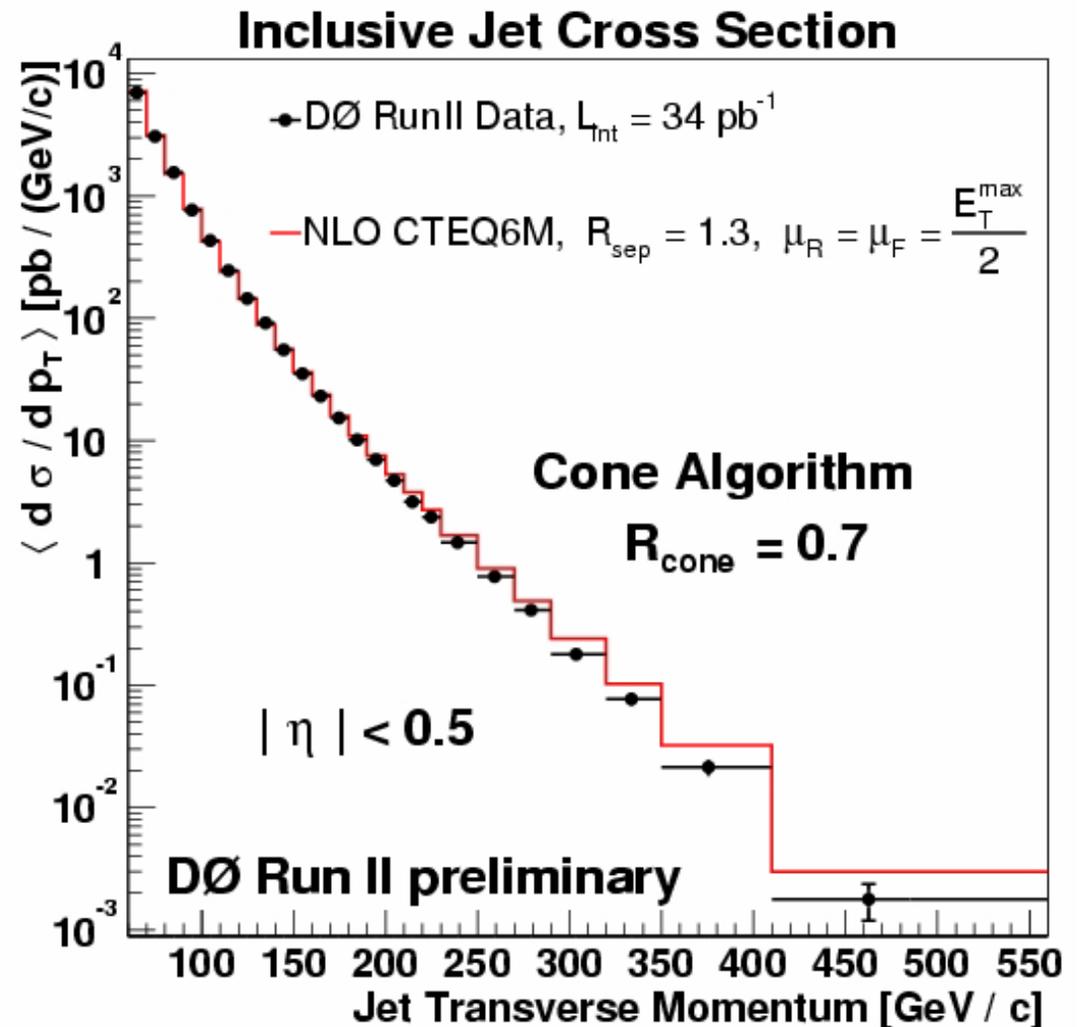




Inclusive Jet Cross Section

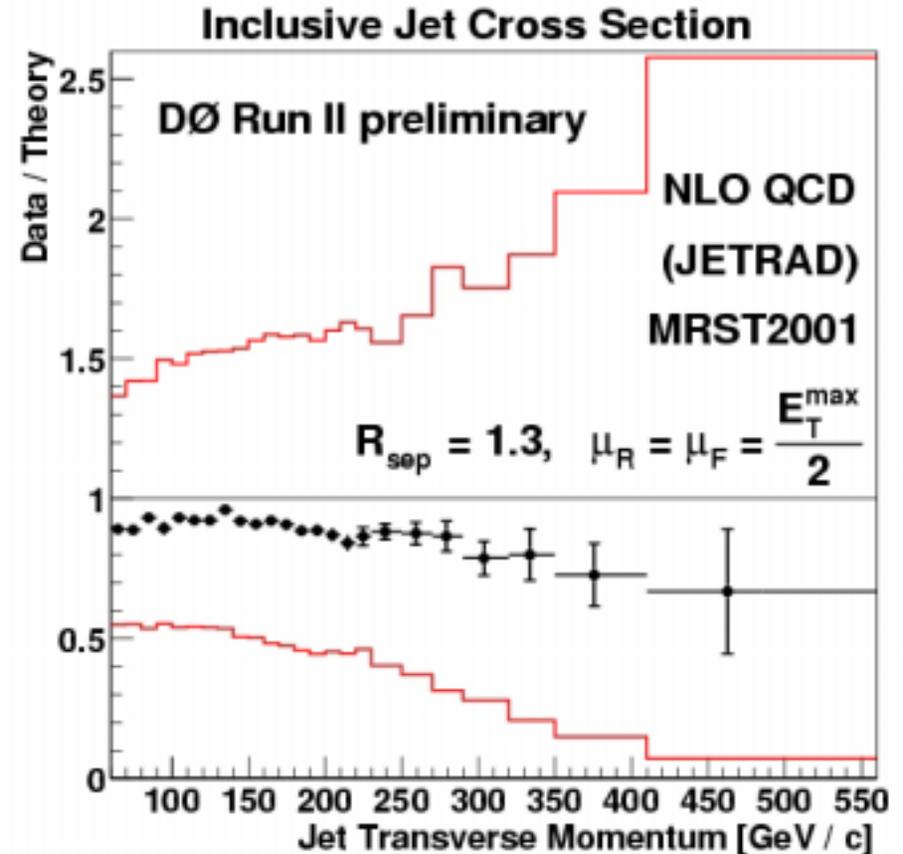
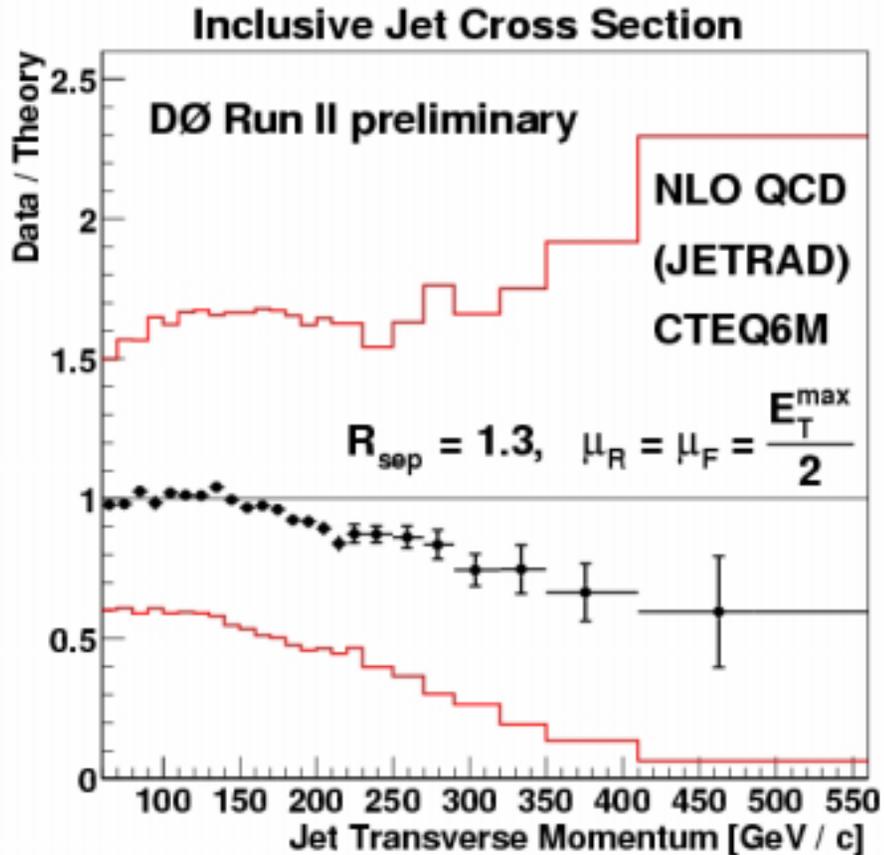
$$\left\langle \frac{d\sigma}{dp_t} \right\rangle = \frac{N_{event}}{L \cdot \Delta p_T} \times \frac{C_{unsmear}}{\epsilon_{eff}}$$

- Event and jet efficiencies are estimated from data
- 10% normalization uncertainty from luminosity is not shown
- The theory is NLO pQCD calculated with JETRAD





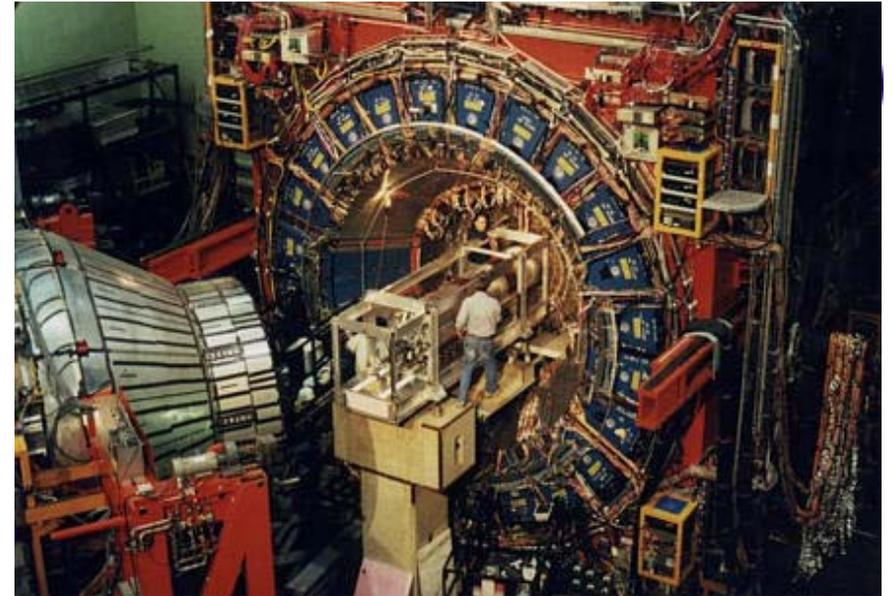
Inclusive Jet Cross Section



— Systematic error band, dominated by energy scale
(10% luminosity normalization not included)

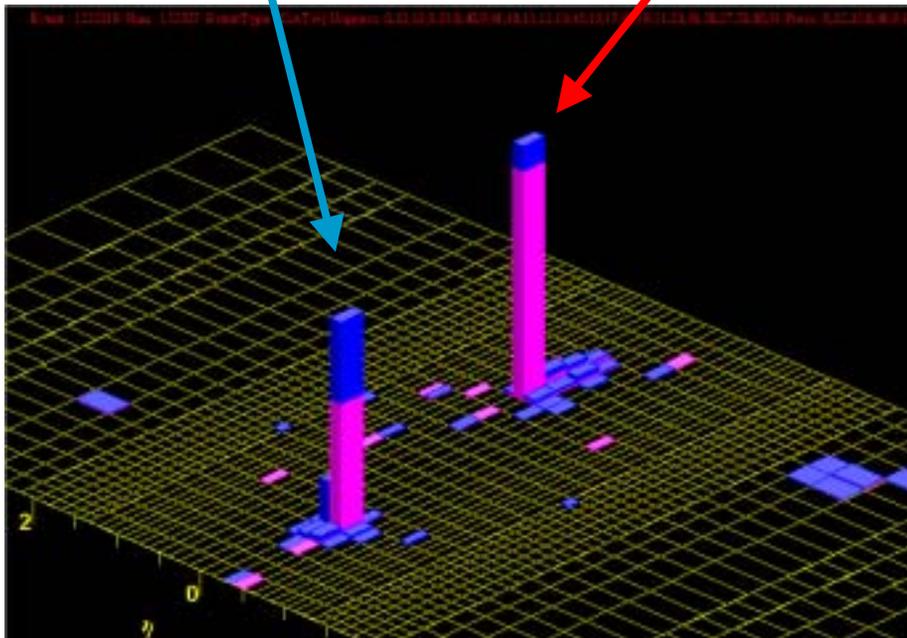


CDF



Jet 2
 $E_T = 546 \text{ GeV (raw)}$
 $\eta_{det} = -0.30$

Jet 1
 $E_T = 583 \text{ GeV (raw)}$
 $\eta_{det} = 0.31$



Collider Detector at Fermilab (CDF)

- New plug calorimeter ($1.1 < |\eta| < 3.6$)
- New tracking system
- Upgraded trigger

CDF Run II Preliminary

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QCD Results from the Tevatron

Inclusive Jet Cross Section



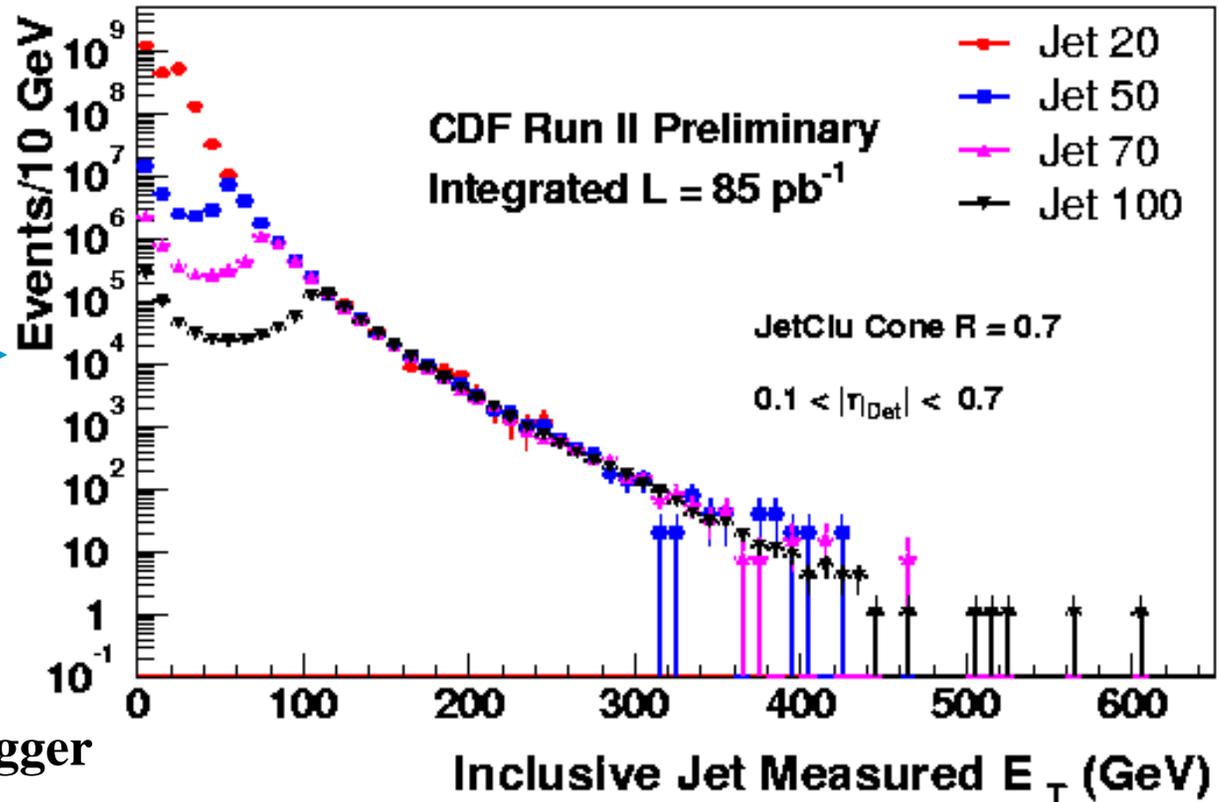
- Repeat Run I analyses

- Use CDF cone jet algorithm with $R = 0.7$ (JetClu)

- Event selection cuts

- $|z_{\text{vertex}}| < 60 \text{ cm}$
- $\sum E_T < 1500 \text{ GeV}$
- $E_T^{\text{missing}} / \sqrt{\sum E_T} < 2 \text{ to } 7$

$$\frac{d\sigma}{dE_T} = \frac{N}{\varepsilon L \Delta E_T \Delta \eta}$$



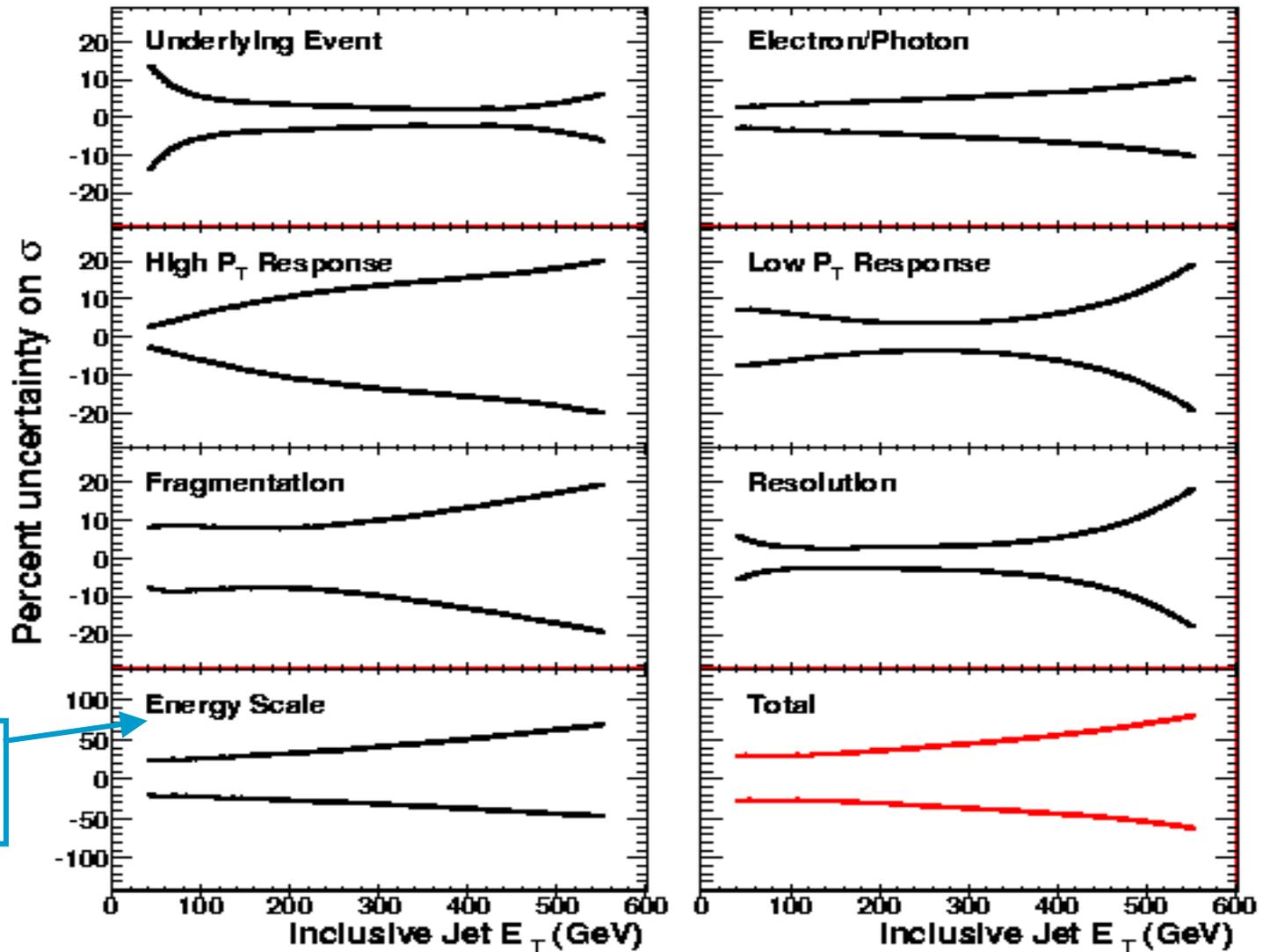
- Require fully efficient trigger
- Apply jet energy corrections (same as in Run I)

Systematic Uncertainties

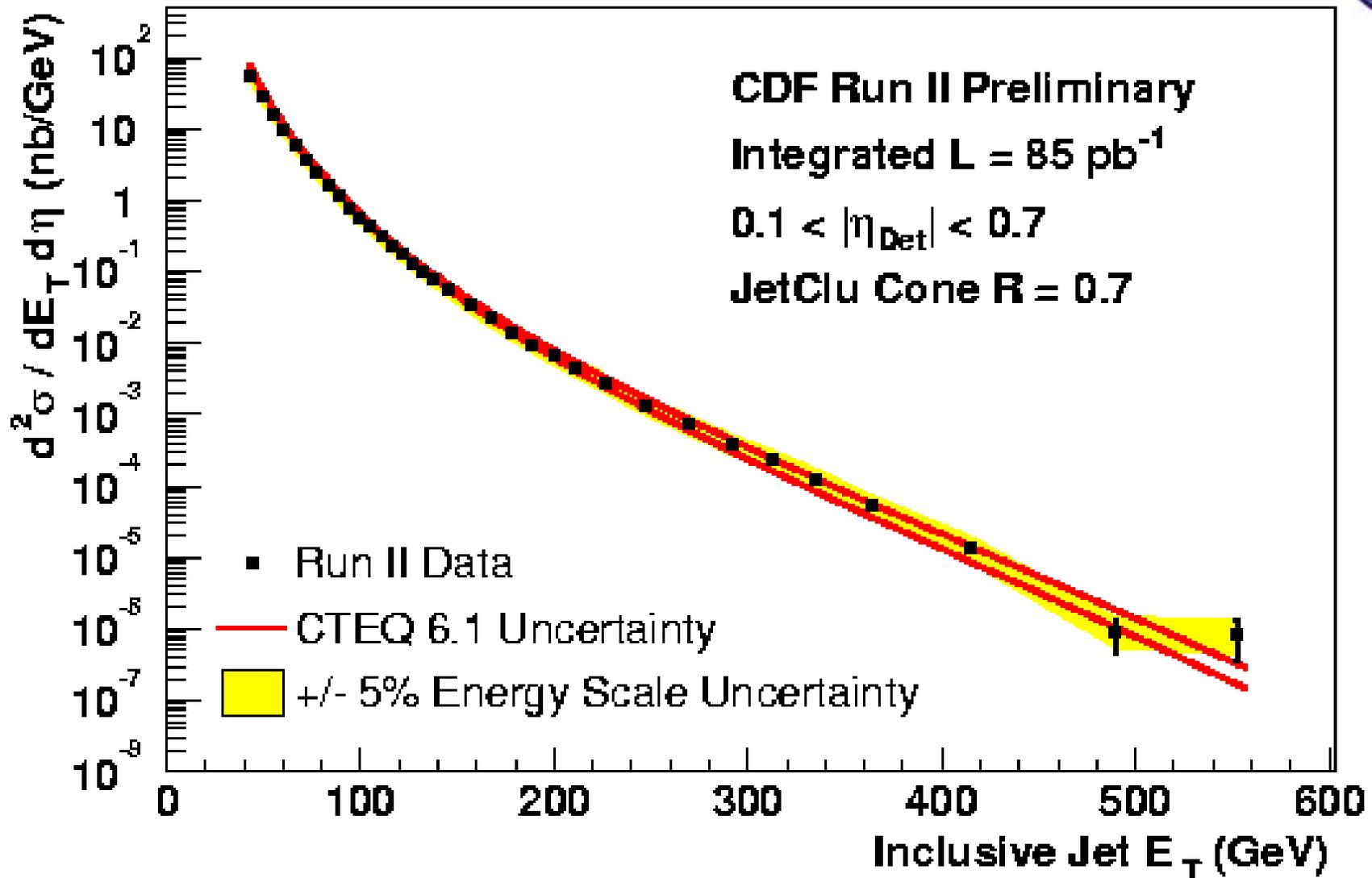


Luminosity uncertainty = 6%

CDF Run II Preliminary



Corrected: Log



• **8 orders of magnitude!**

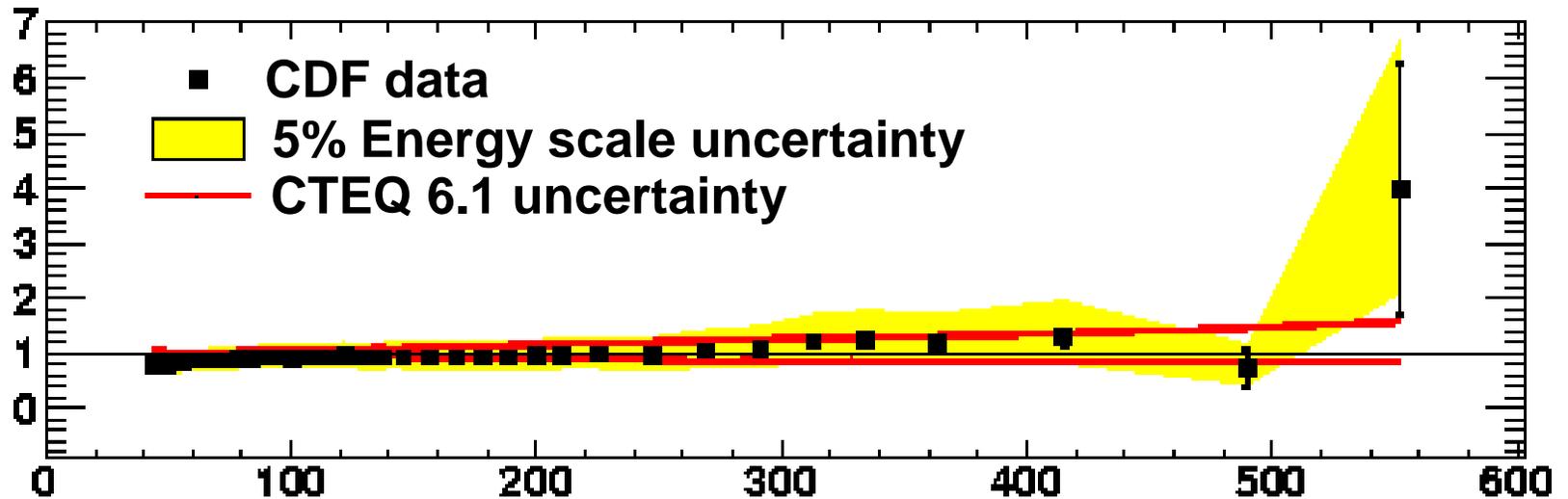
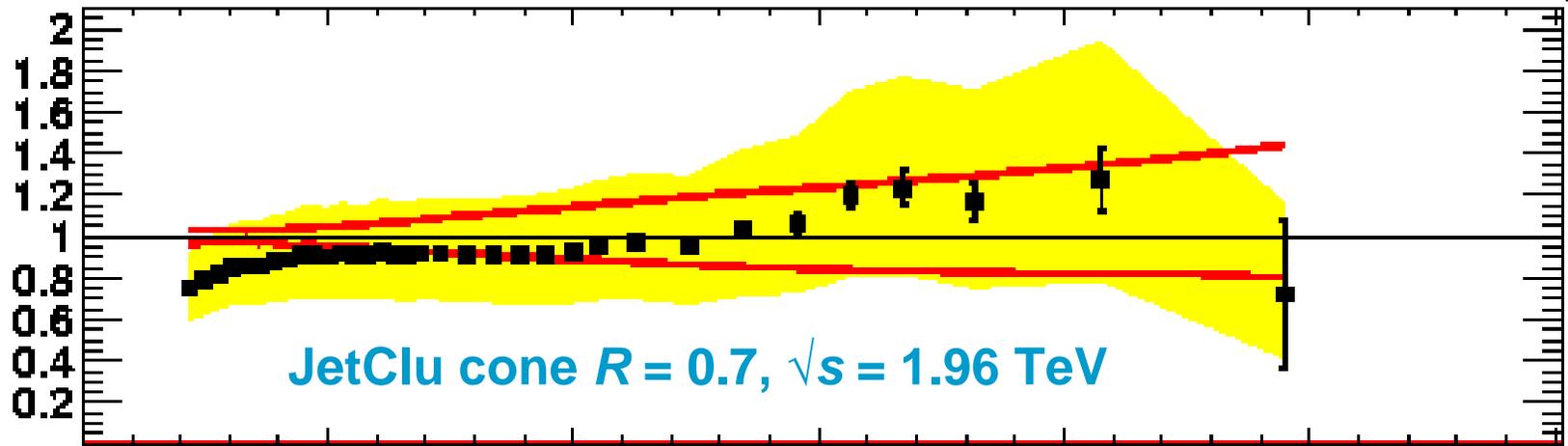
CTEQ 6.1: hep-ph/0303013

Corrected: Linear



CDF Run II Preliminary

σ ratio: Data / CTEQ6.1

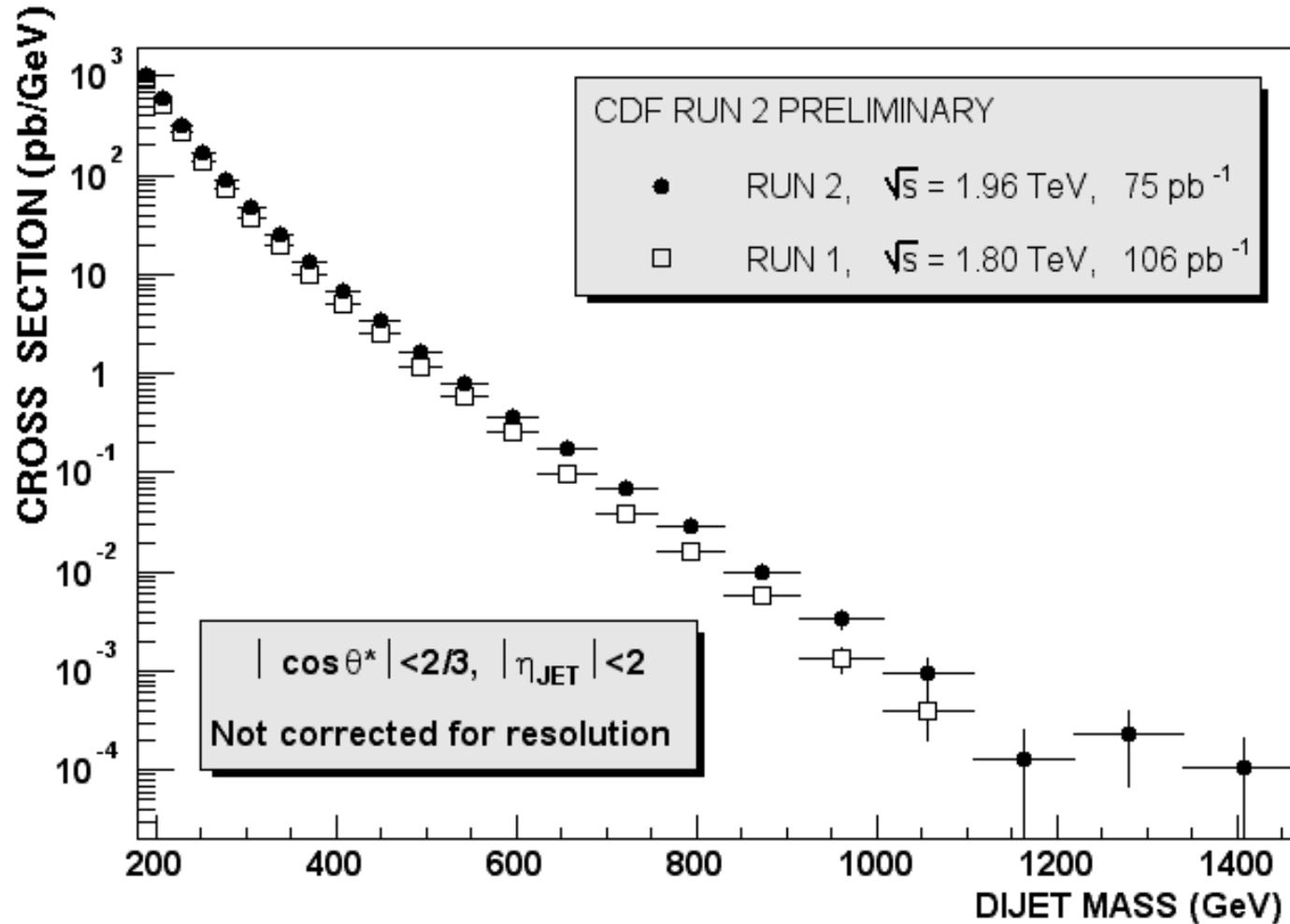


Good agreement (within uncertainties)

Inclusive jet E_T (GeV)



Dijet Mass



- Higher σ in Run II due to higher \sqrt{s}
- 3 more bins at high dijet mass



Summary

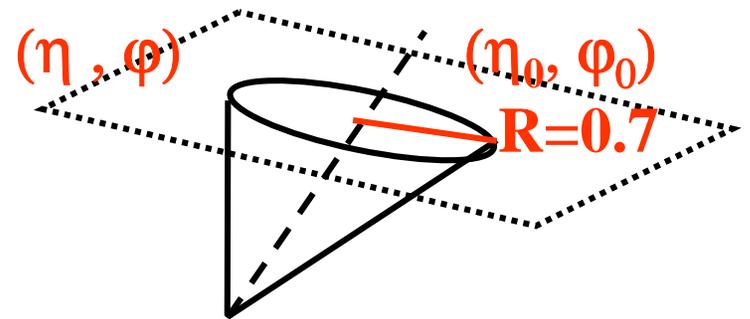


- We have made significant progress on two important QCD measurements
 - Inclusive jet cross-section
 - Di-jet mass cross section
- Data/theory agreement excellent, although errors in this preliminary measurement are larger than our published results.
- Improved statistics for calibration will yield a measurement competitive with published results by summer, with superior results following.
- Analysis efforts ongoing, including a rich diffractive physics effort.



Our Jet Algorithm

- We use a four vector cone algorithm with a radius of 0.7 in η - ϕ space
 - Identify seed tower in the calorimeter
 - Using the event's vertex, assign a four vector to that seed
 - Add all other other four vectors inside R to generate the jet's four vector
 - If the jet's four vector does not line up with the seed's repeat using the new jet four vector as the seed.
- Changes from Tevatron Run I
 - We use the midpoints between jets as seeds for new jets
 - We use four vectors instead of scalar quantites



The Jet Definition

$$p^J = (E^J, \vec{p}^J) = \sum_{i \in J} (E^i, p_x^i, p_y^i, p_z^i)$$

The Jet's Properties

$$p_T^J = \sqrt{(p_x^J)^2 + (p_y^J)^2}$$

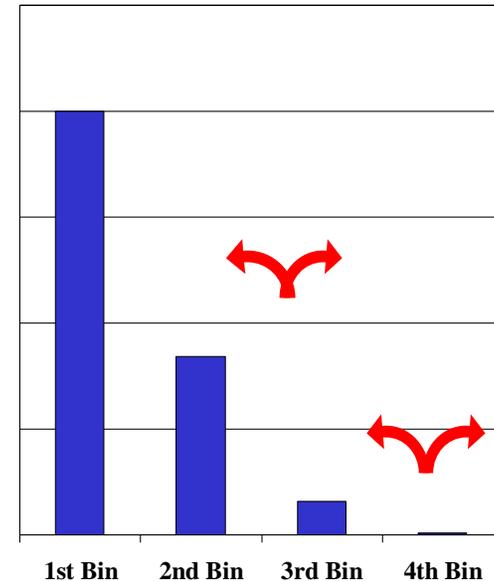
$$y^J = \frac{1}{2} \ln \left(\frac{E^J + p_z^J}{E^J - p_z^J} \right) \quad \phi^J = \arctan \left(\frac{p_y^J}{p_x^J} \right)$$



Unsmearing

Steeply Falling Spectrum

- The steeply falling cross section means that we get more jets migrating into a bin from its left than its right
- To unsmear this, we guess an ansatz function for the true cross section and smear it with our jet resolution
- We vary the ansatz's parameters to get the best possible fit
- Lastly, we multiply our data by the same amount that the ansatz is multiplied by to get the smeared ansatz that matches the data

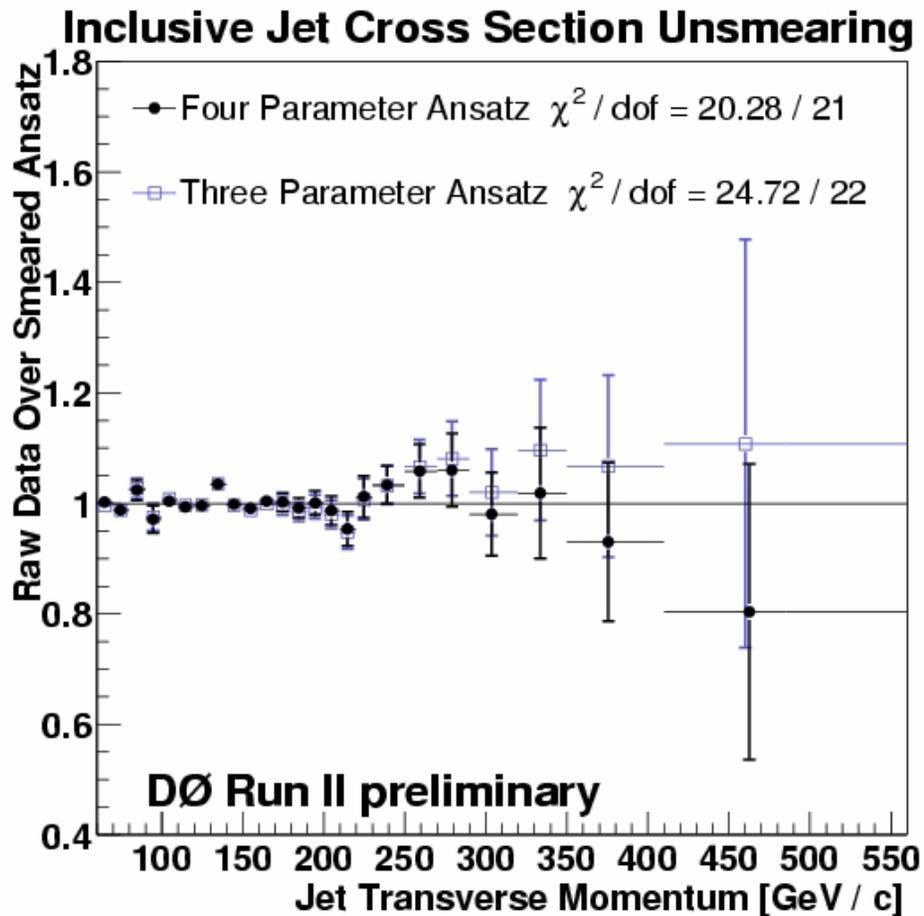


$$F(M_{JJ}) = \int_0^{\sqrt{s}} dM'_{JJ} f(M'_{JJ}) G(M'_{JJ} - M_{JJ}, M'_{JJ})$$



Unsmearing the Cross Sections

- Because the cross section is steeply falling, imperfect jet resolution causes the cross section to shift to the right.



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