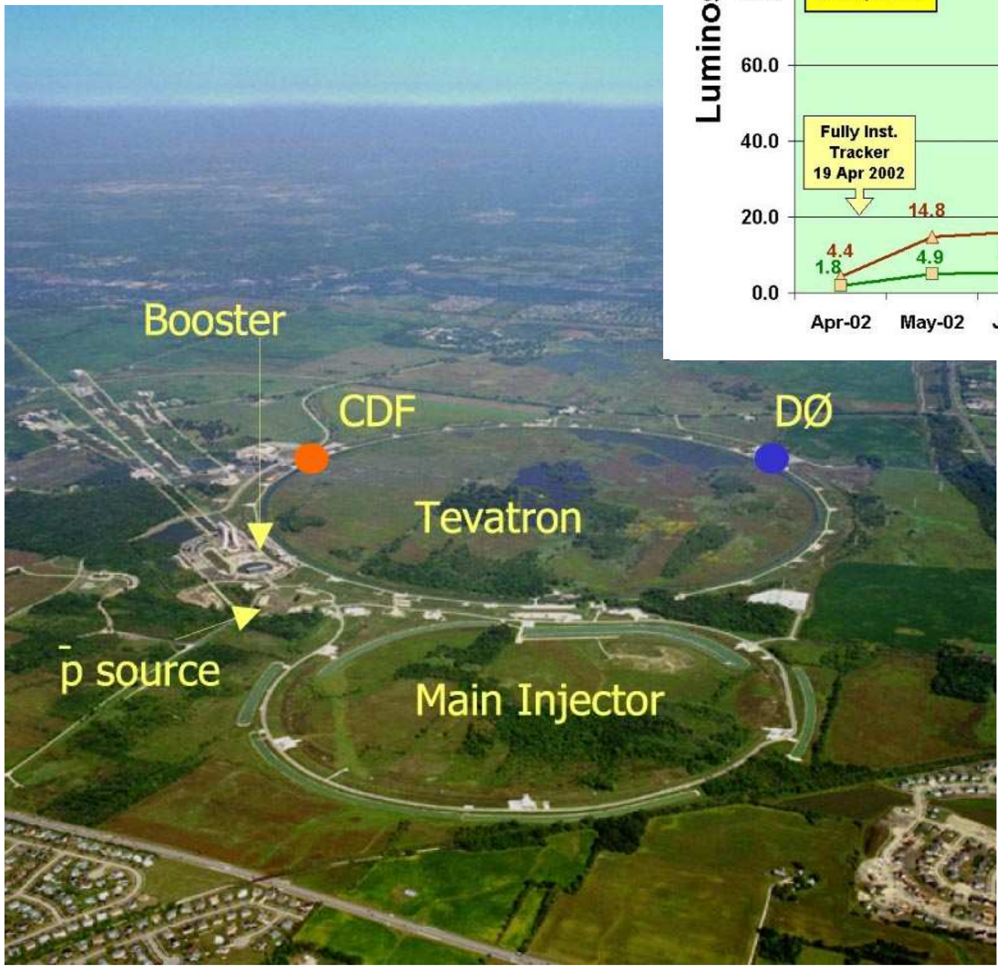
Photon 2003

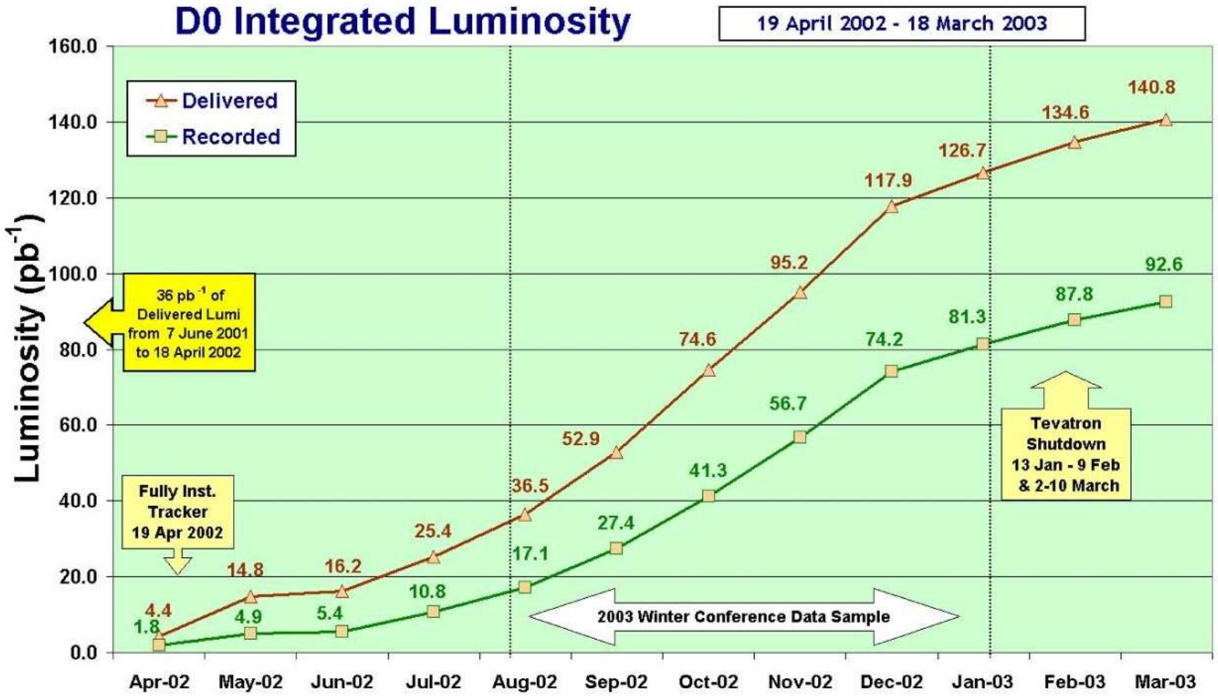
Organised by the Laboratori Nazionali di Frascati

Recent QCD Results from the Tevatron

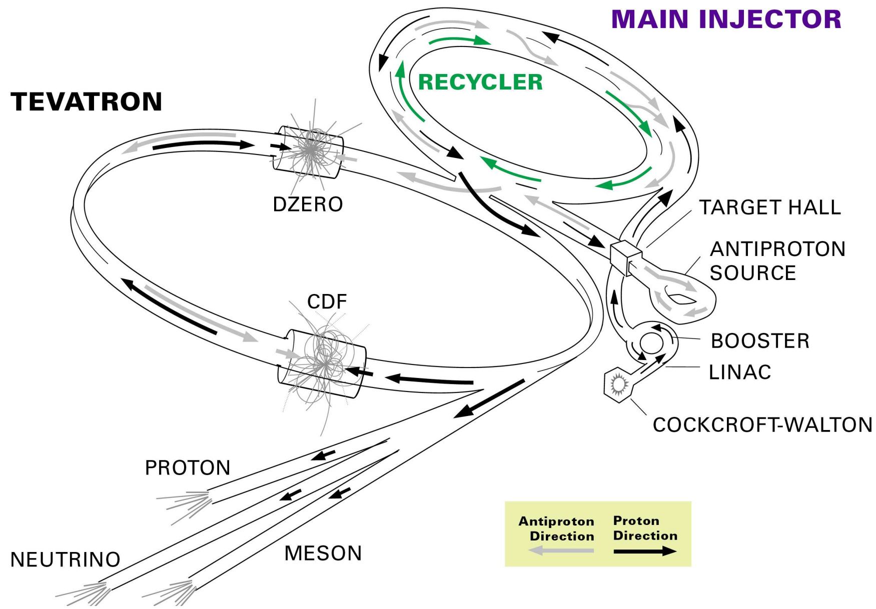
Don Lincoln

Fermilab





FERMILAB'S ACCELERATOR CHAIN



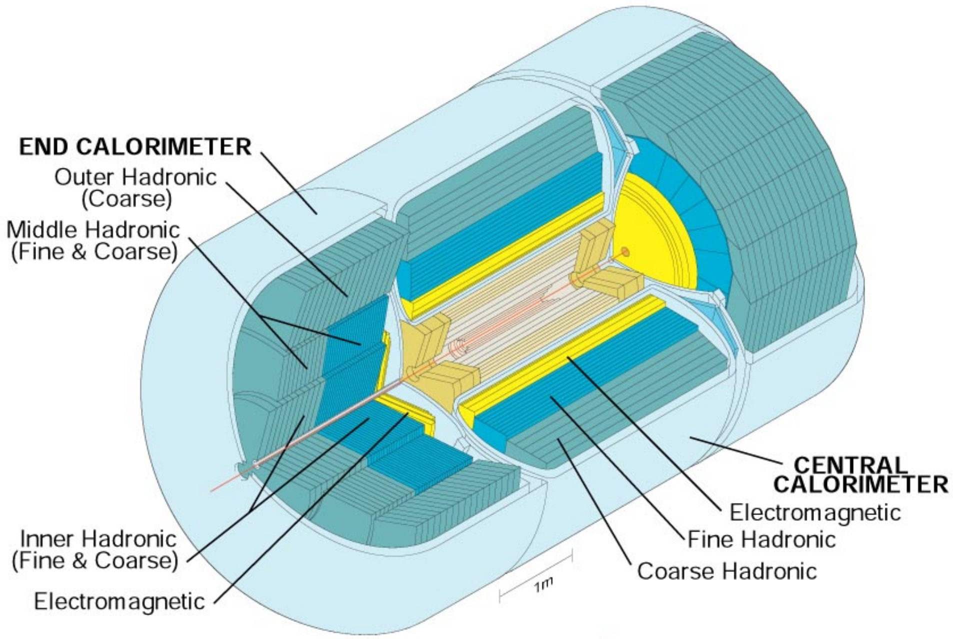
Don Lincoln, Fermilab

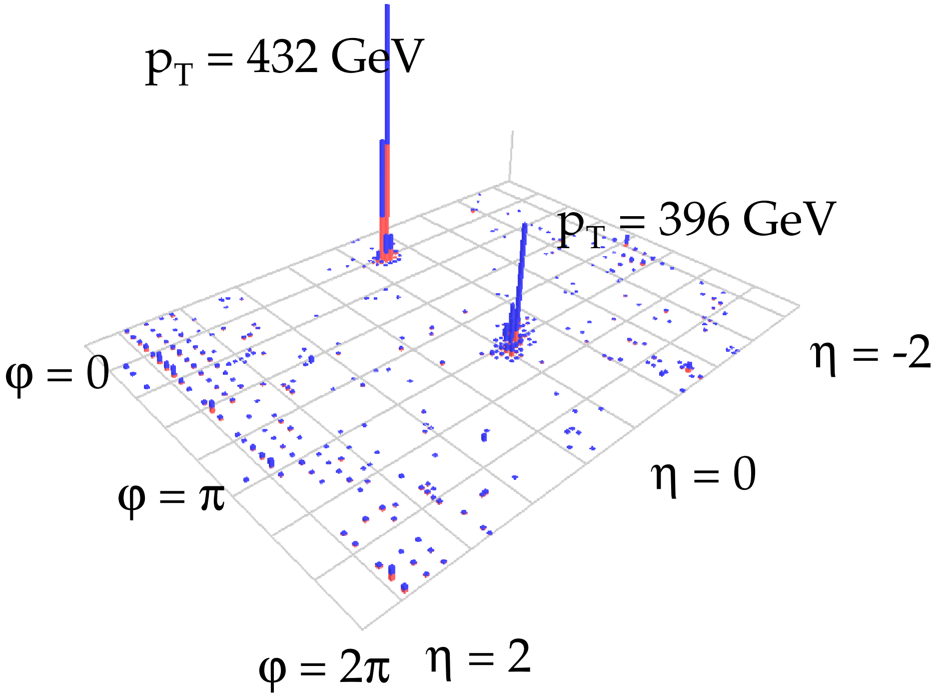
DØ Calorimeter

- 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_o
  - 4–5 Hadronic Layers (6λ)
- Transverse Segmentation

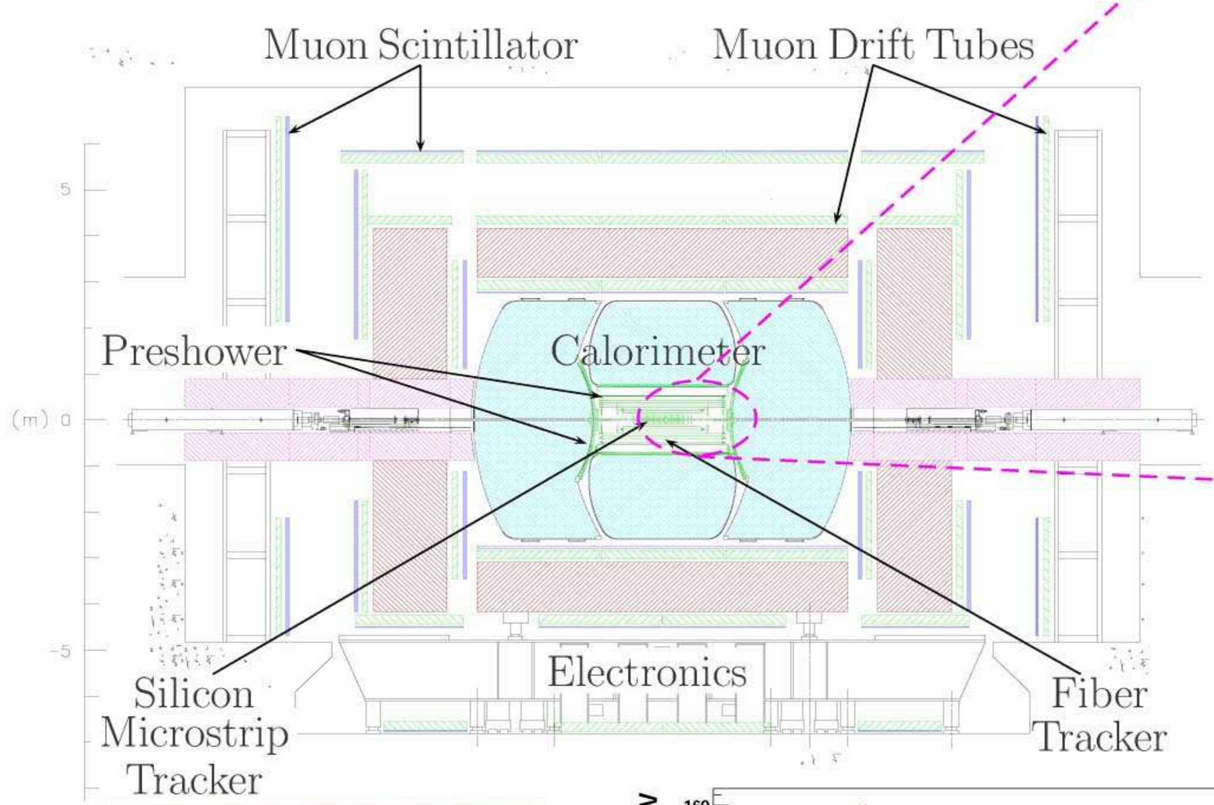
  $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$ in EM_3

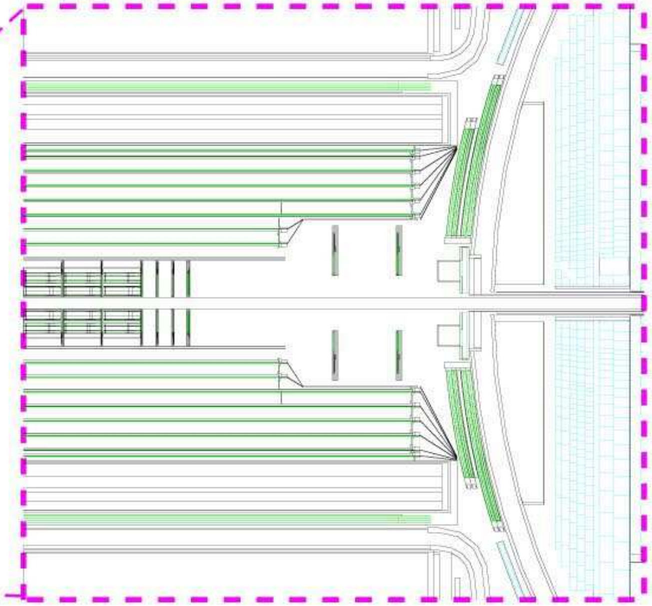
  $\Delta\eta \times \Delta\phi = 0.10 \times 0.10$ otherwise

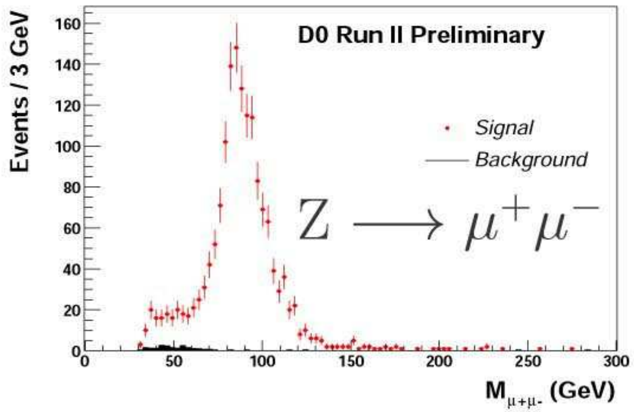


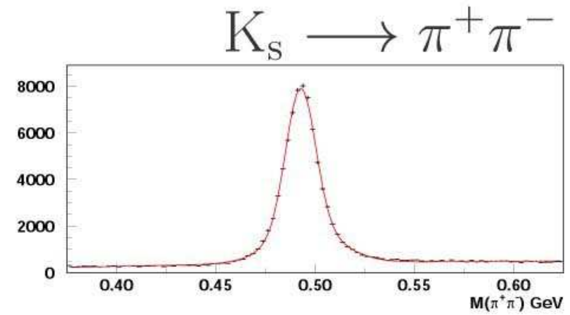


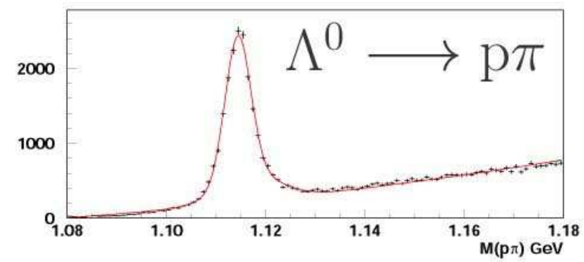
DØ Run II Detector





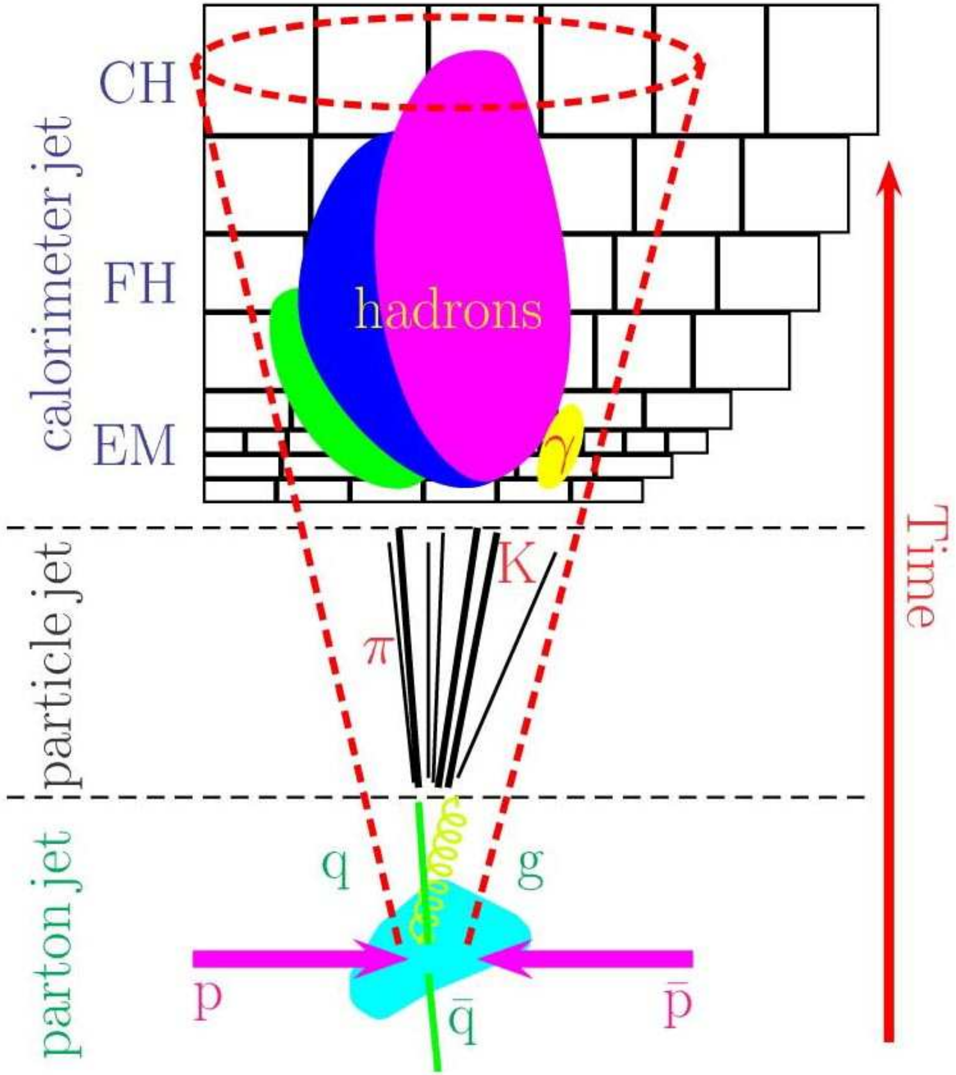






Cone Jet Definition

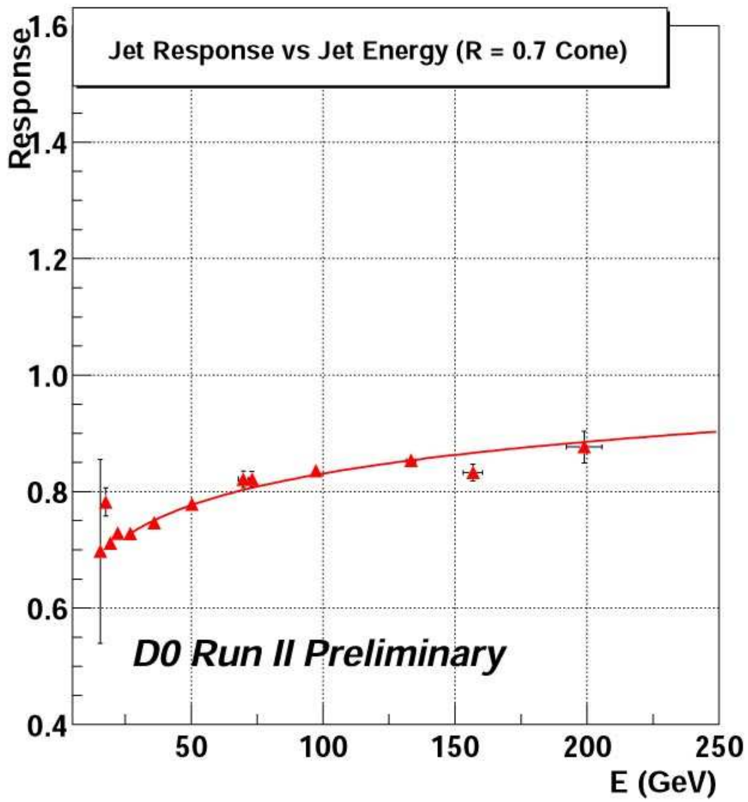
- $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
- Run I
  - Add up towers around a “seed”
  - Iterate, using “jets” as seeds, unt stable
  - Jet quantities: $E_\perp$, η, ϕ
  - $E_\perp^{jet} = \sum_{R \le 0.7} E_\perp^{tower}$
- Modifications for Run II
  - Use 4-vector scheme
  - $p_\perp$ instead 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.)

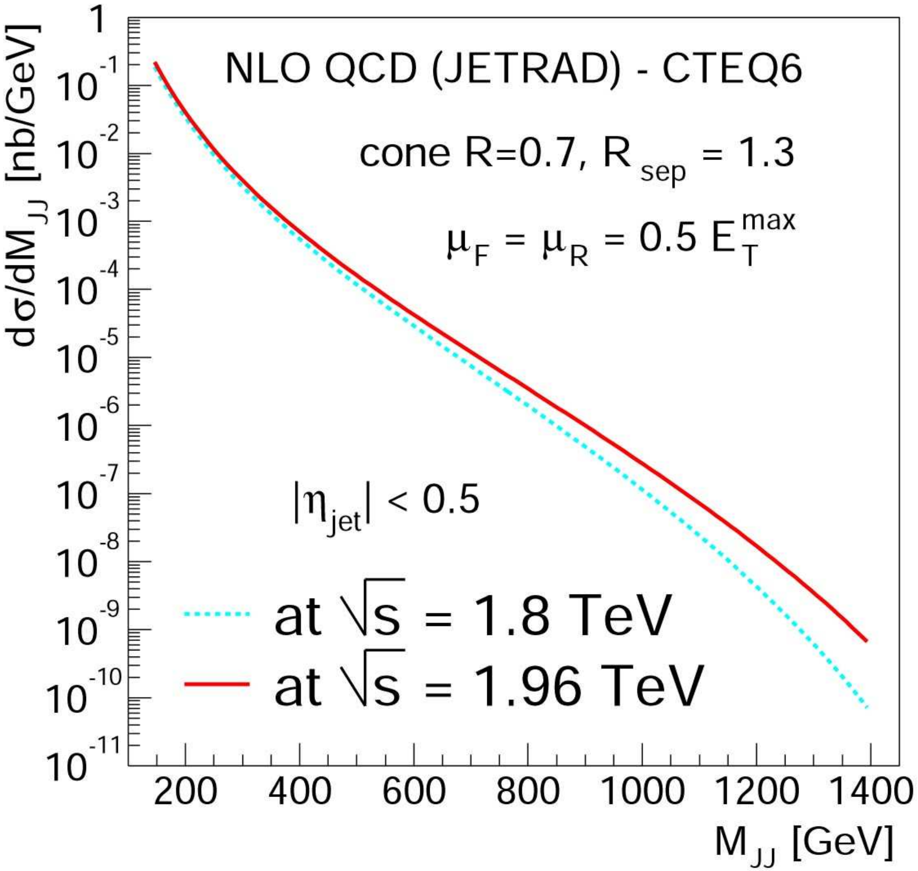
Measured from $E_{\perp}$ imbalance in γ + jet events

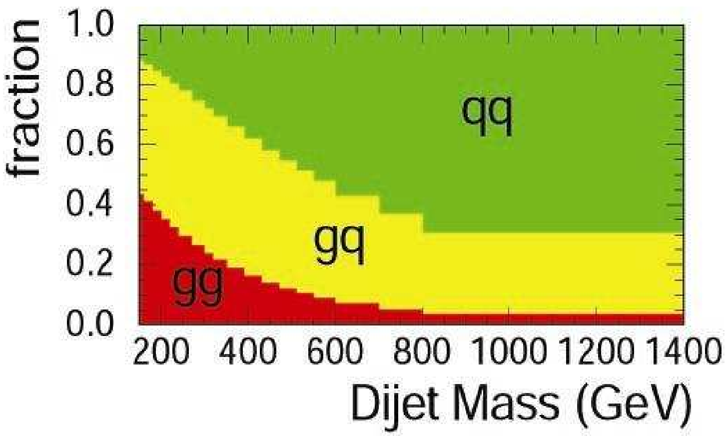
- S net fraction of particle-jet energy that remains inside jet cone after showering in calorimeter (jet transverse shapes)

- Large statistical uncertainties and substantial systematic uncertainties (increases with energy due to extrapolation)
- Current γ + jet statistics extends only to about 200 GeV

Dijets in Run II

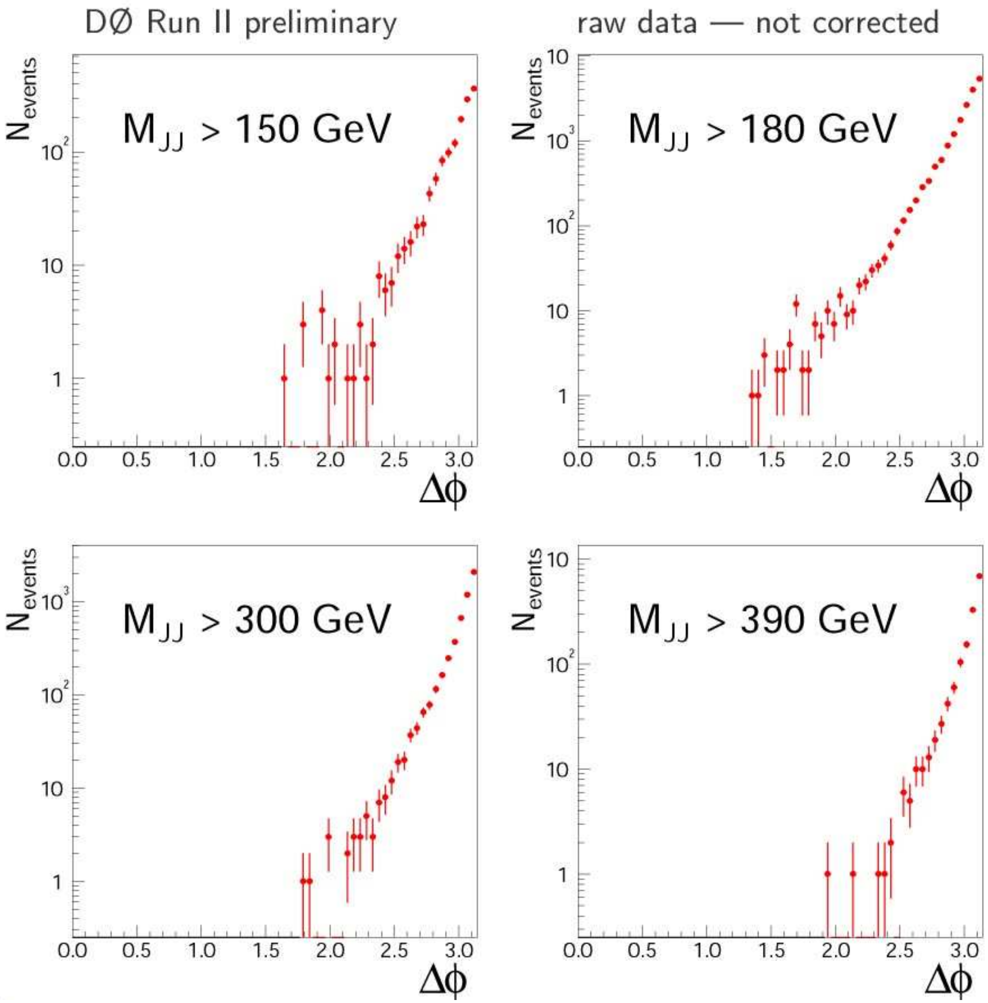
- Cross section at E_{CM} = 1.96 TeV is 2-5 times greater as compared to 1.8 TeV
- Higher statistics allow:
  - Better determination of proton structure at large x
  - Testing pQCD at a new level (resummation, NNLO theory, NLO event generators, etc.)
  - Improved searches for new physics (quark compositeness,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





Dijet Sample Selection

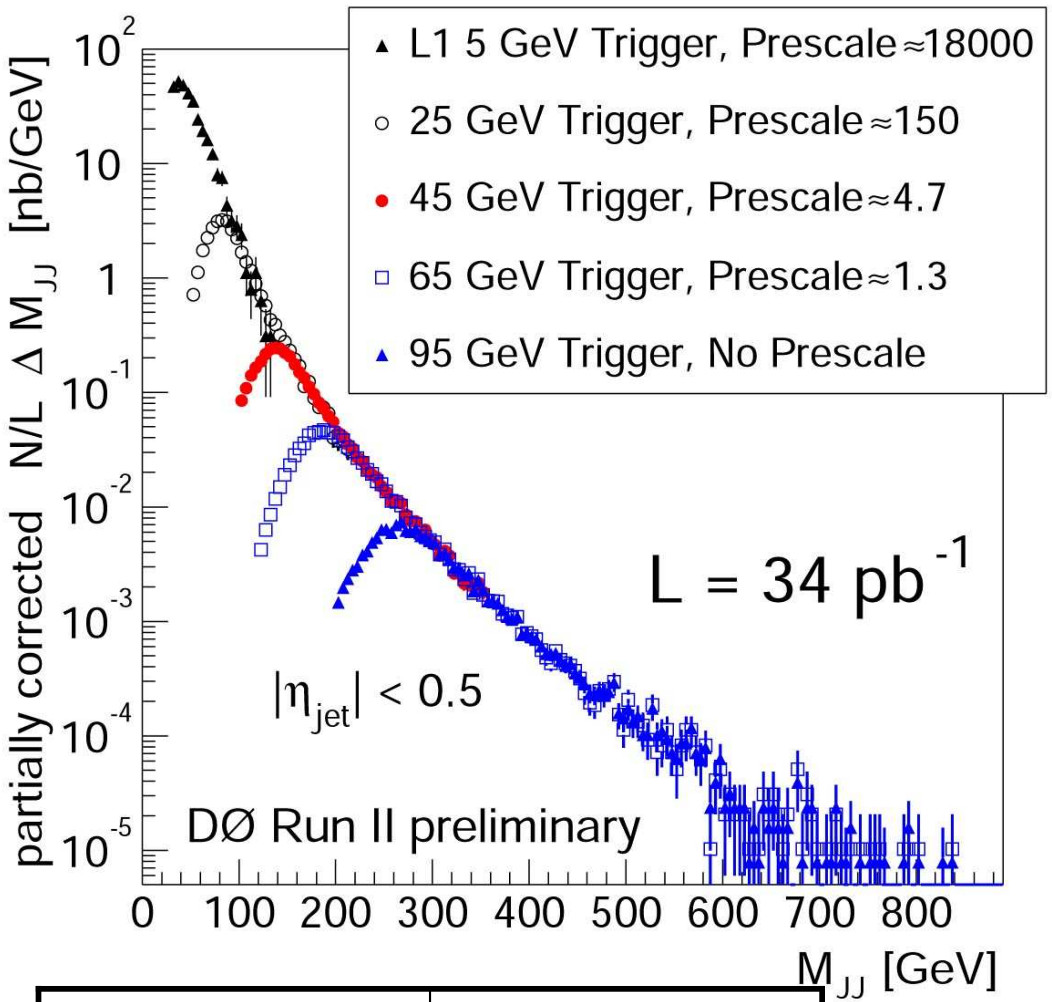
- Selection criteria:
  - $N_{jet} \geq 2$
  - $|\eta_{jet}| < 0.5$
  - $\Delta R = 0.7$ cone jets
- Data sample
  - $MET/p_{\perp}^{jet} < 0.7$
  - Primary vertex:
    - $|Z_{vertex}| < 50$ cm
    - Ntracks ≥ 5
  - Run selection based on hardware status, MET
  - Jet selection based on calorimeter characteristics 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)



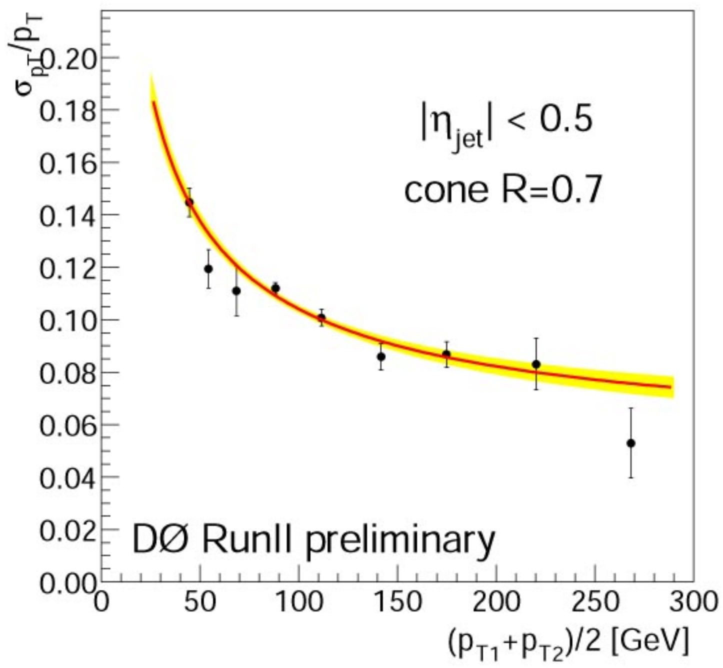
L3 $p_\perp$ Threshold	Offline M_{JJ} Cut
25 GeV	150 GeV
45 GeV	180 GeV
65 GeV	300 GeV
95 GeV	390 GeV

Unsmearing Correction

- Jet Energy Resolution
  - Use the data dijet sample
  - Asymmetry measurement

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

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

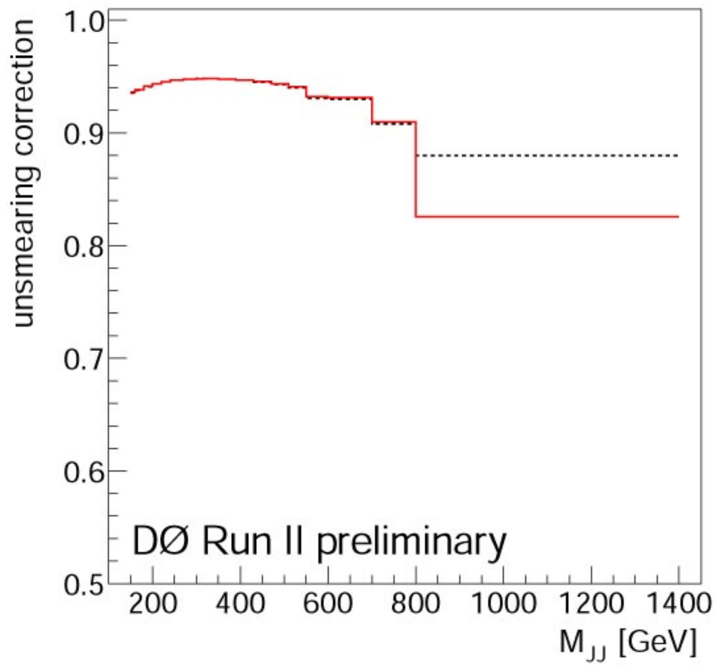


  - Correct for third jets and particle jet resolution

- Dijet Mass resolution unsmearing
  - Smear PYTHIA events in mass bins
  - Gaussian fit to ΔMjj/Mjj in each bin
  - Fit to

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

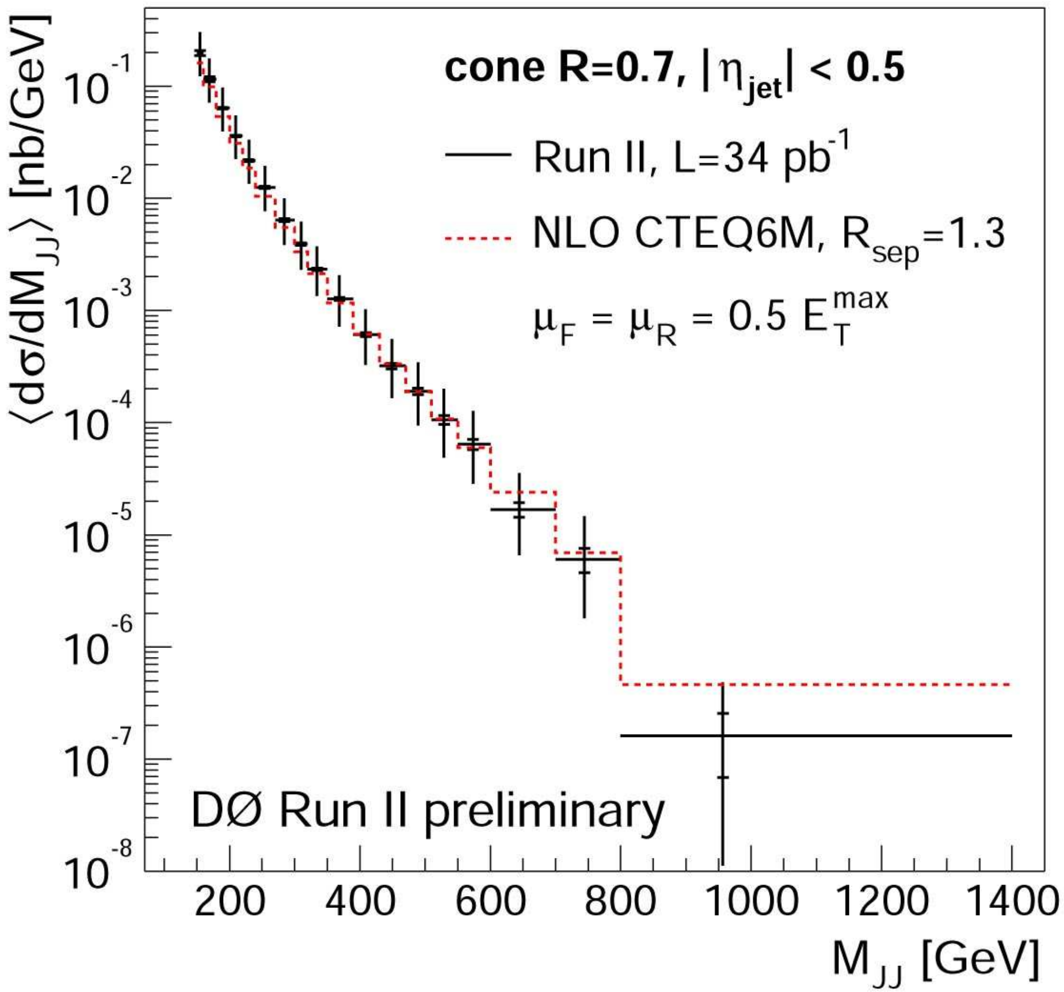
  - Determine unsmearing correction



Dijet Mass Cross Section

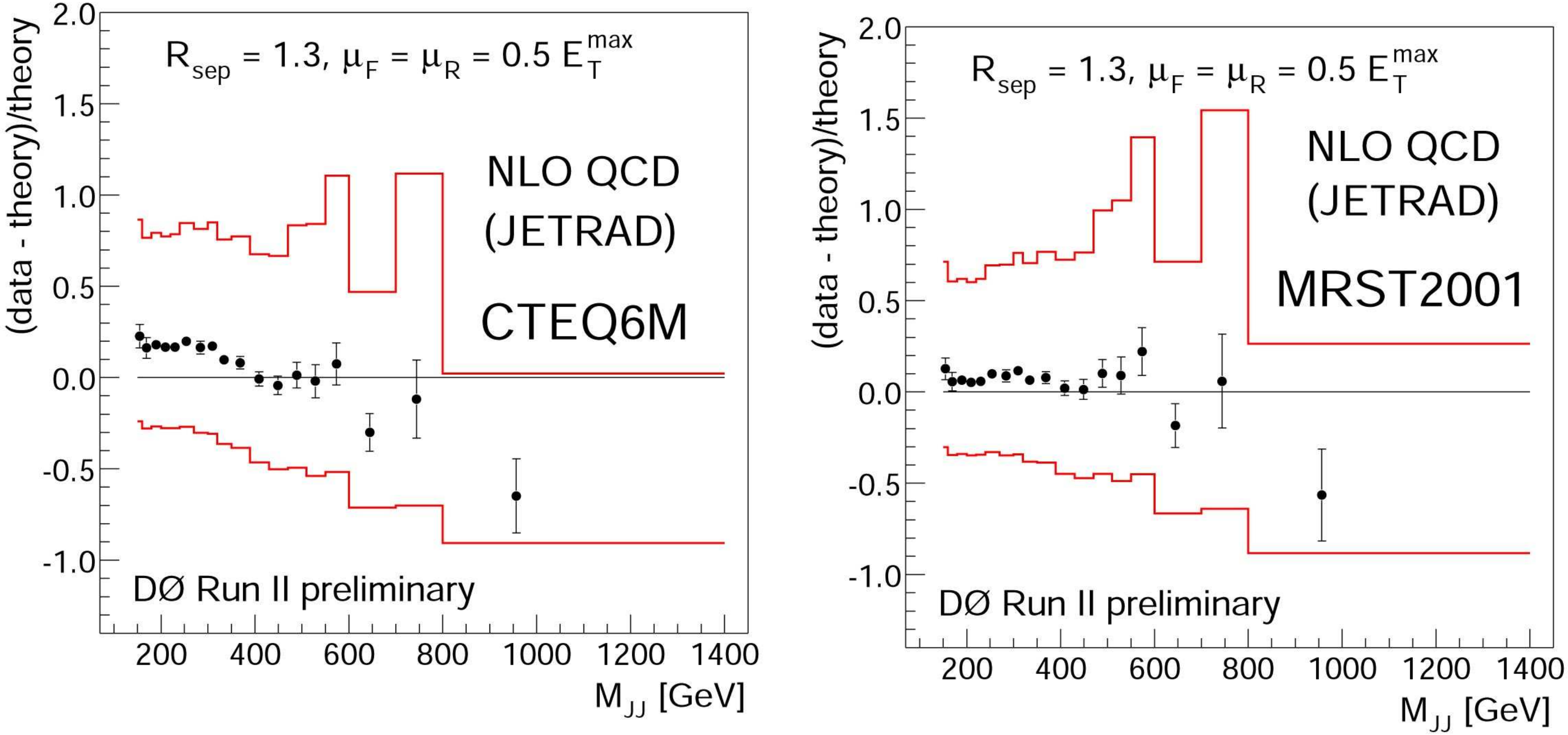
$$\left\langle \frac{d\sigma}{dM_{JJ}} \right\rangle = \frac{N_{event}}{L} \frac{1}{\Delta M_{JJ}} \frac{C_{unsmear}}{\varepsilon_{eff}}$$

- 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

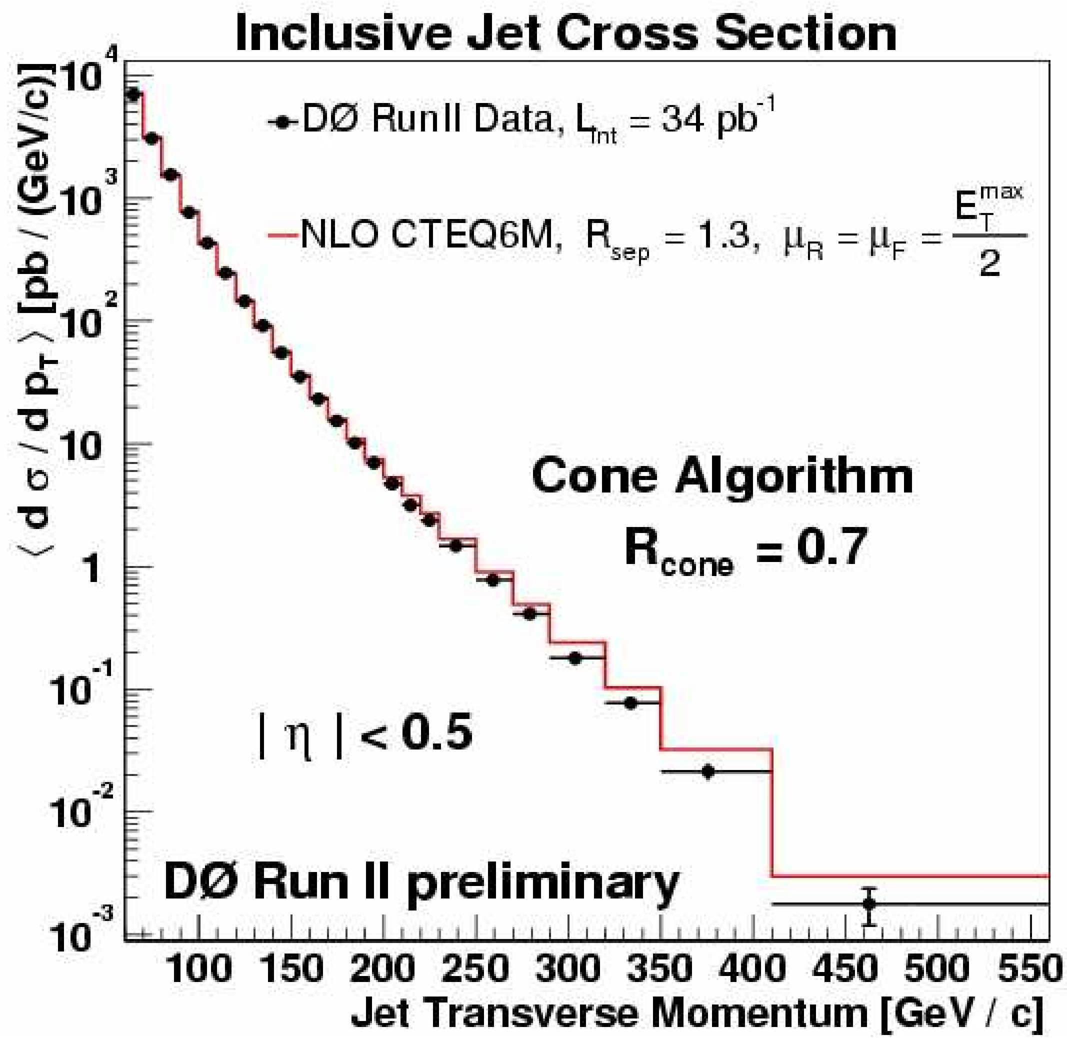
- Main uncertainties: jet energy scale, $p_\perp$ resolution, jet quality cuts. (Dominated by jet energy scale.)
- 10% normalization uncertainty not shown.



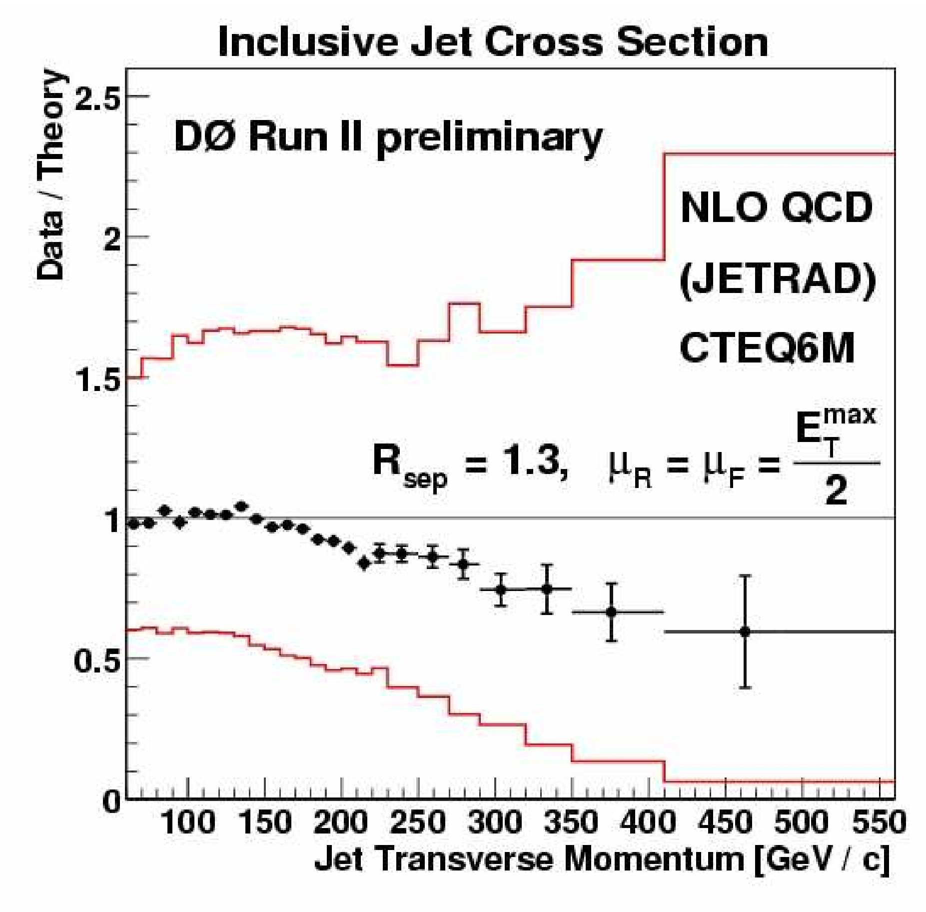
Inclusive Jet Cross Section

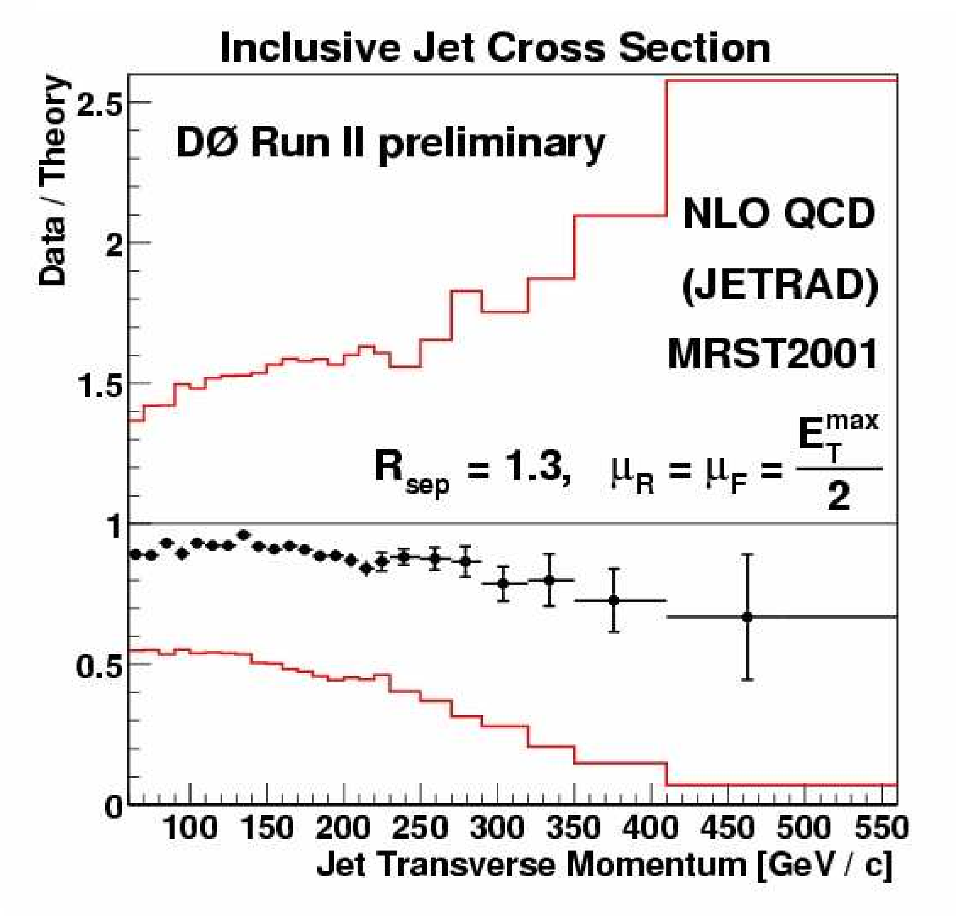
$$\left\langle \frac{d\sigma}{dp_t} \right\rangle = \frac{N_{event}}{L \cdot \Delta p_T} \times \frac{C_{unsmear}}{\varepsilon_{eff}}$$

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



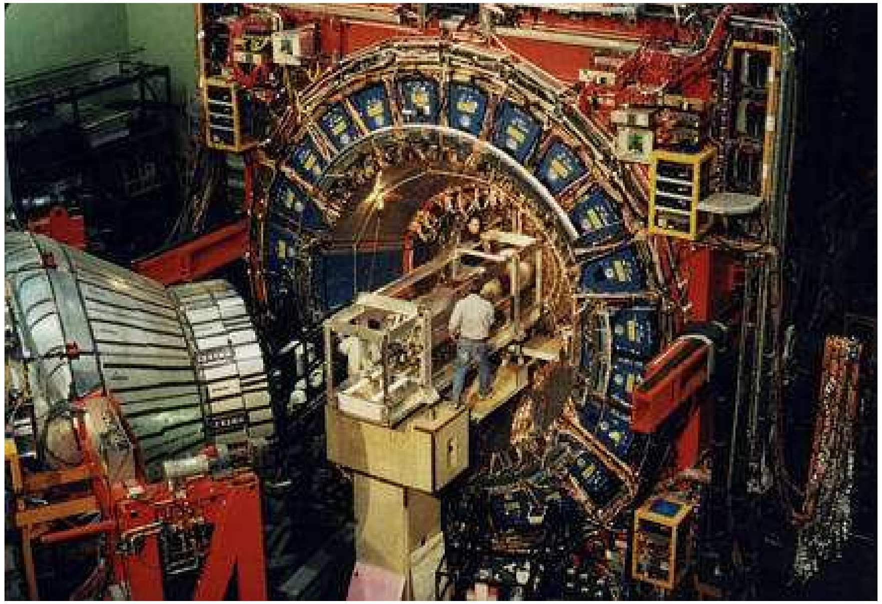
Inclusive Jet Cross Section





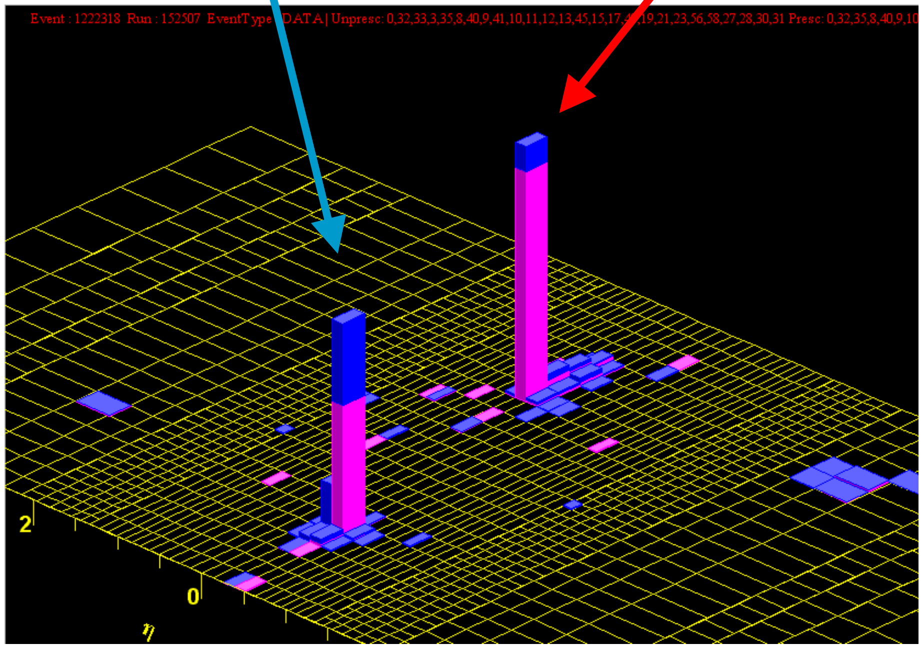
Systematic error band, dominated by energy scale
(10% luminosity normalization not included)

CDF



Jet 2
E_T = 546 GeV (raw)
η_{det} = -0.30

Jet 1
E_T = 583 GeV (raw)
η_{det} = 0.31



CDF Run II Preliminary

Collider Detector at Fermilab (CDF)

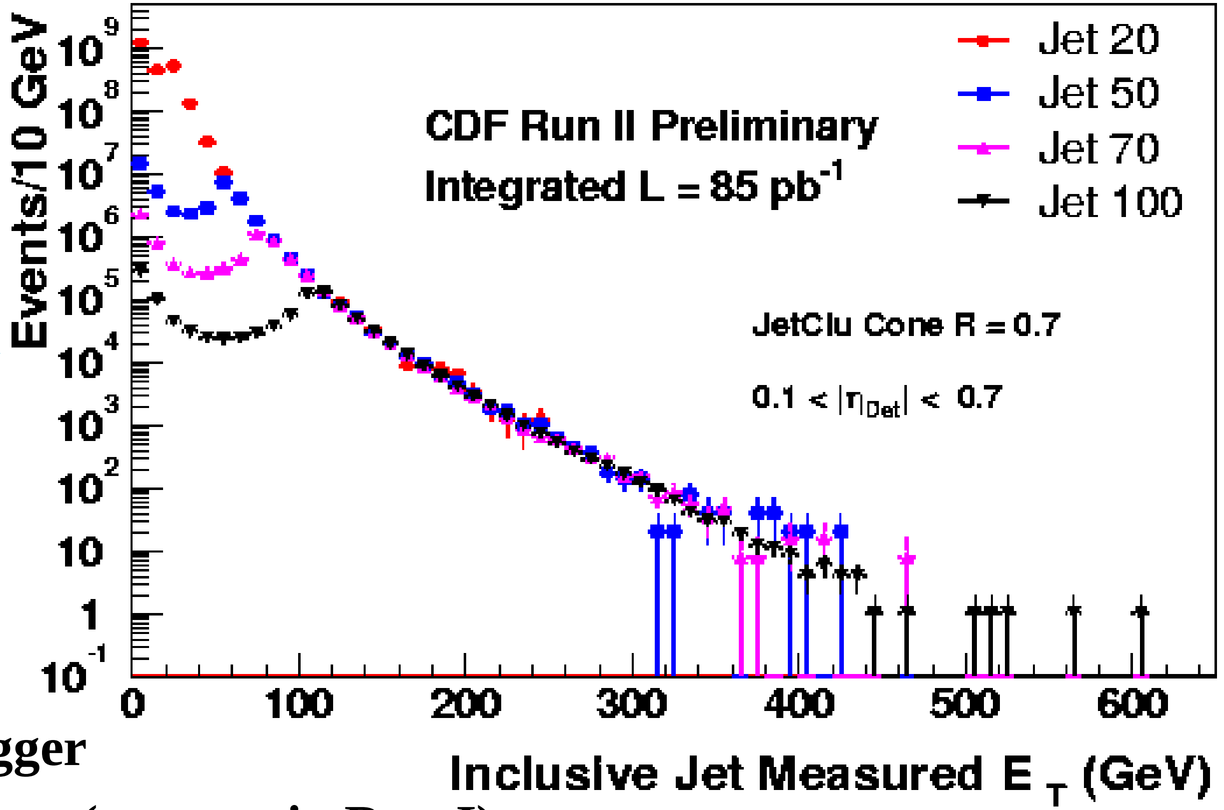
- New plug calorimeter (1.1 < | η | < 3.6)
- New tracking system
- Upgraded trigger

Inclusive Jet Cross Section

- **Repeat Run I analyses**
  - **Use CDF cone jet algorithm with R = 0.7 (JetClu)**

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

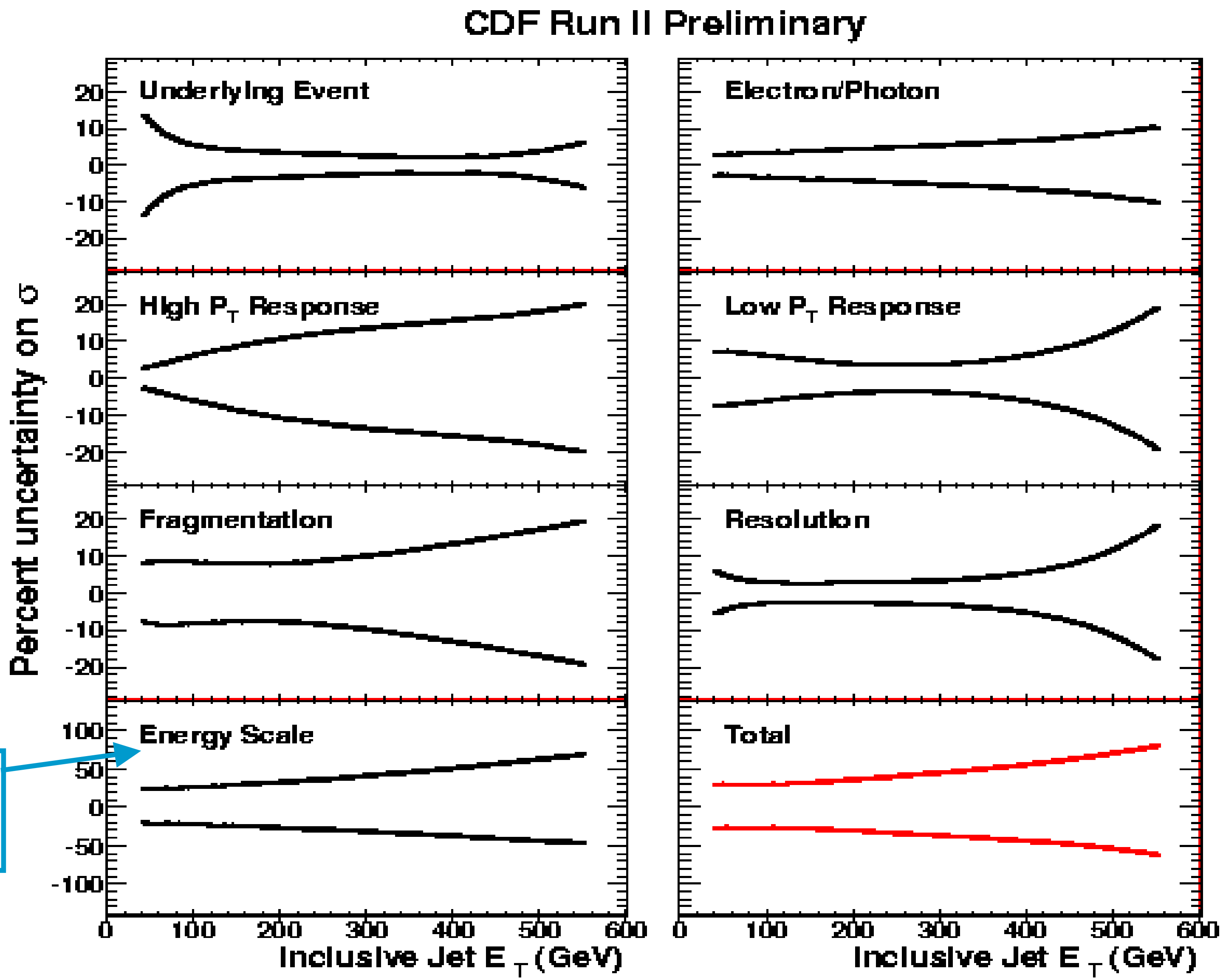
$$\frac{d\sigma}{dE_T} = \frac{N}{\varepsilon L \, \Delta E_T \, \Delta\eta}$$



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

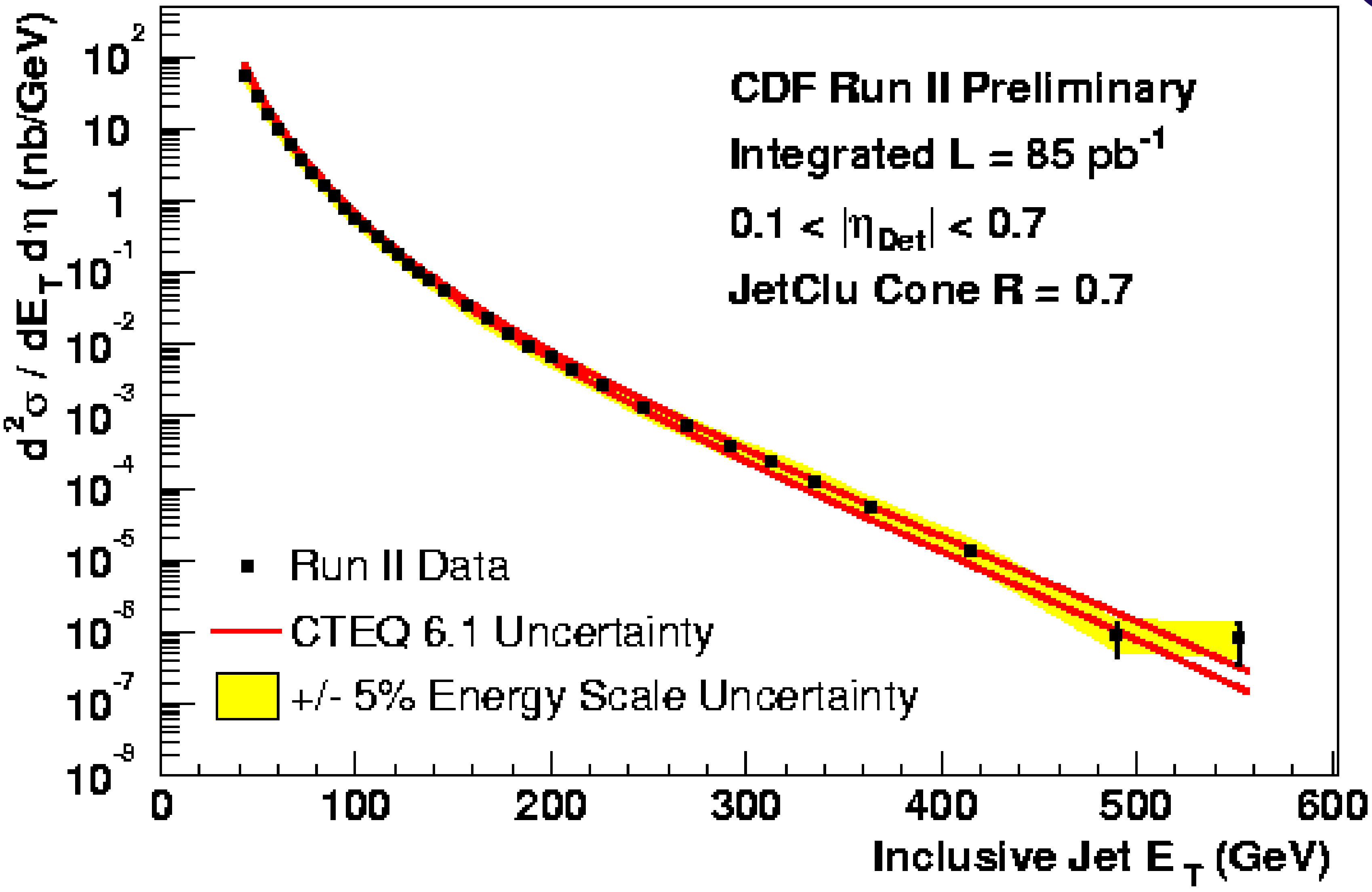
Systematic Uncertainties

Luminosity uncertainty = 6%



Largest uncertainty

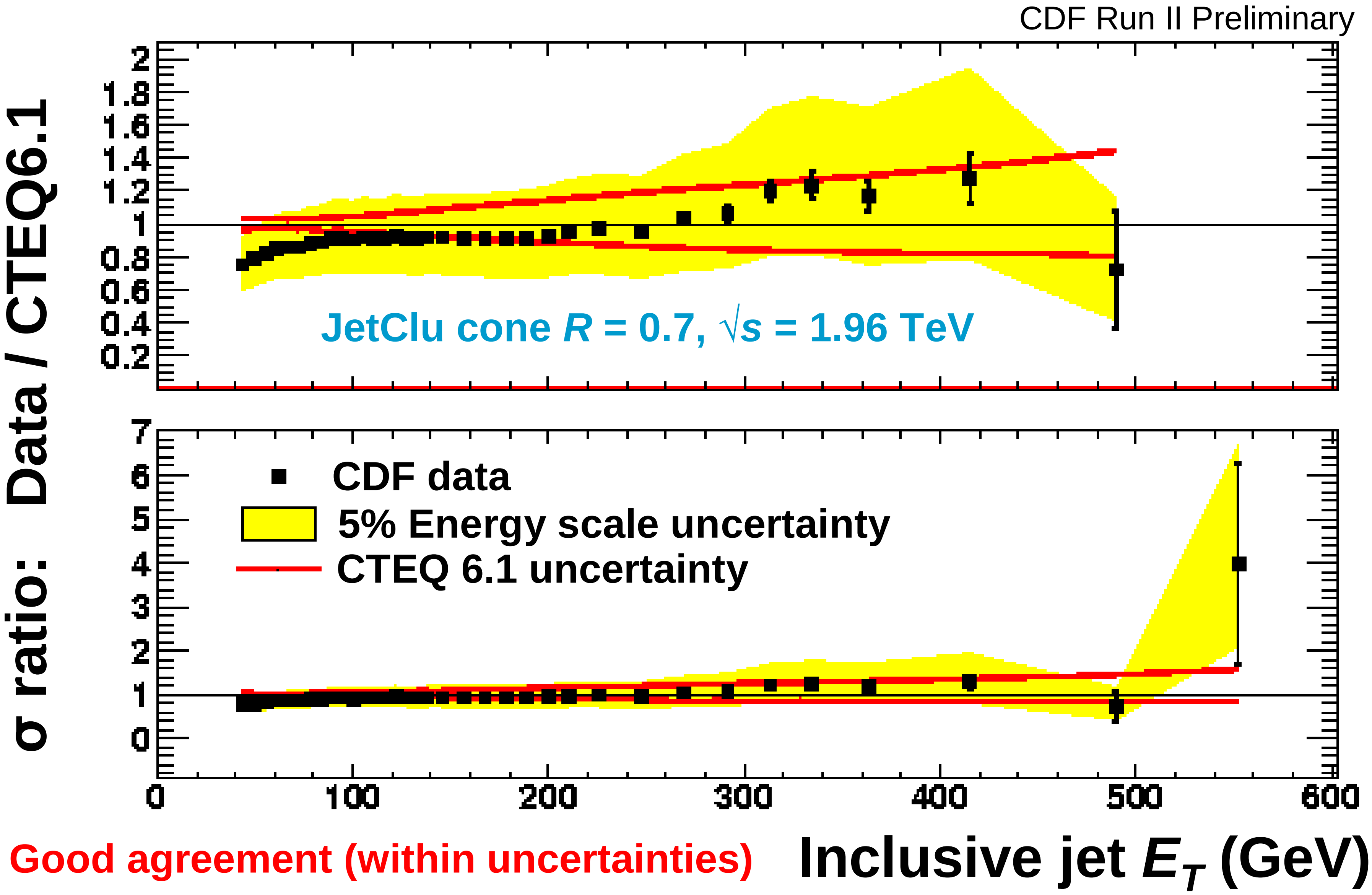
Corrected: Log



- 8 orders of magnitude!

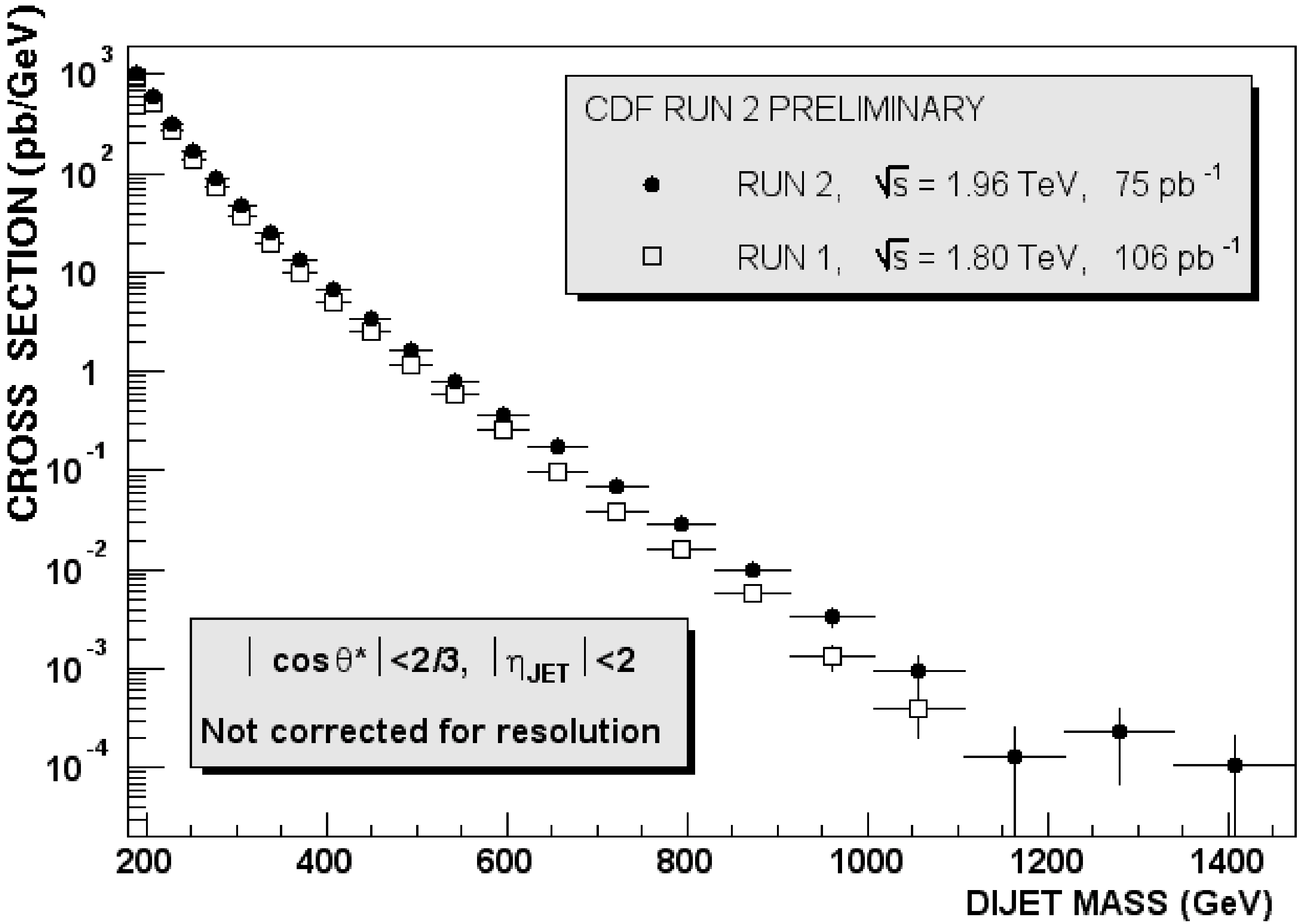
CTEQ 6.1: hep-ph/0303013

Corrected: Linear



Good agreement (within uncertainties)

Dijet Mass



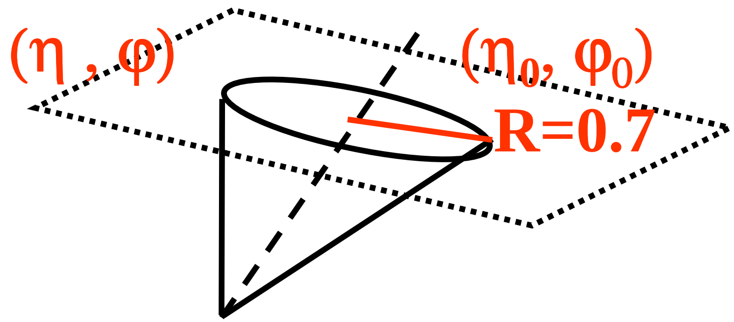
- **Higher σ in Run II due to higher $\sqrt{s}$**
- **3 more bins at high dijet mass**

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

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

The Jet's Properties

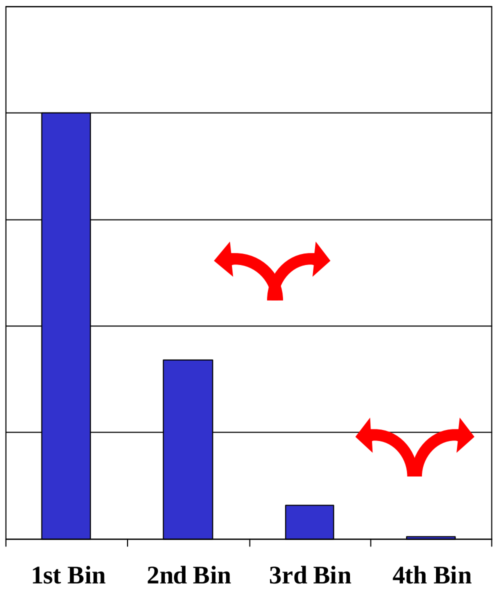
$$p_T^J = \sqrt{\left(p_x^J\right)^2 + \left(p_y^J\right)^2}$$

$$y^j = \frac{1}{2} \ln\left(\frac{E^J + p_z^j}{E^J - p_z^j}\right) \qquad \varphi^J = \arctan\left(p_y^J \big/ p_x^J \right)$$

Unsmearing

- 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

Steeply Falling Spectrum



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

Unsmearing the Cross Sections

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