PHENO 2006

Inclusive Jet Production in Run II at CDF.

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On behalf of the CDF Collaboration

Outline

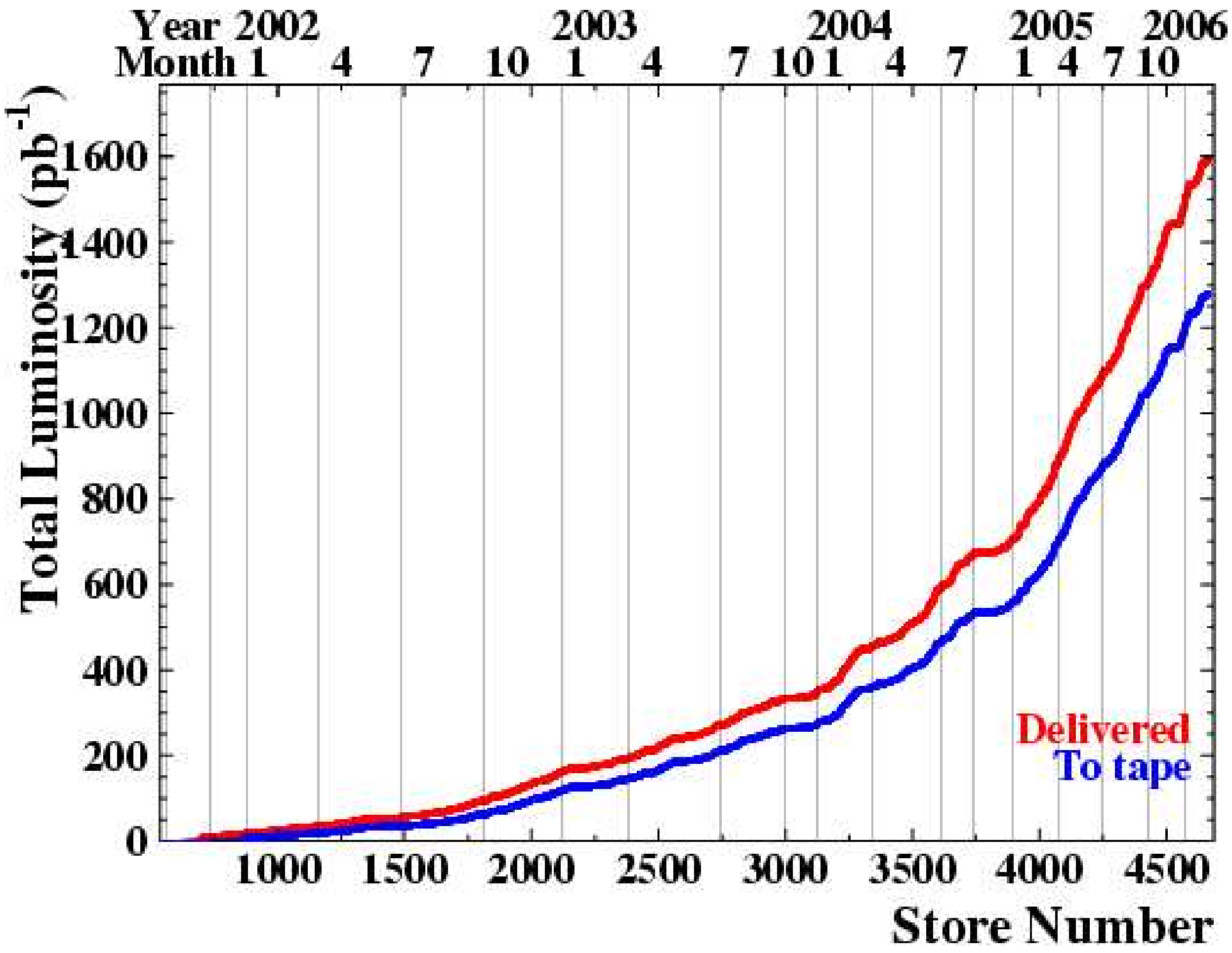
- FNAL, the Tevatron, and CDF
- Motivation
- Jet production at the Tevatron
- Jet algorithms
- Determination of the jet energy scale
- Jet corrections
- Recent inclusive jet cross section results

FNAL: Fermi National Accelerator Lab

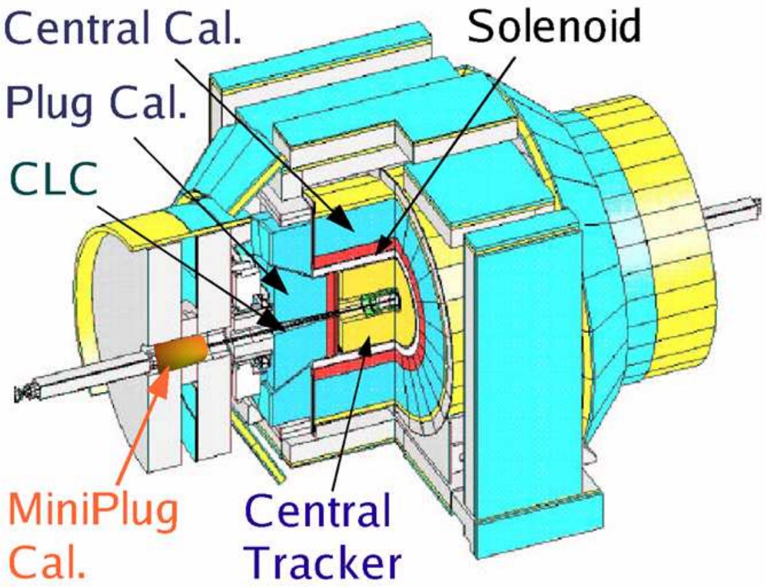
The Tevatron currently provides the highest energy proton-antiproton collisions in the world.

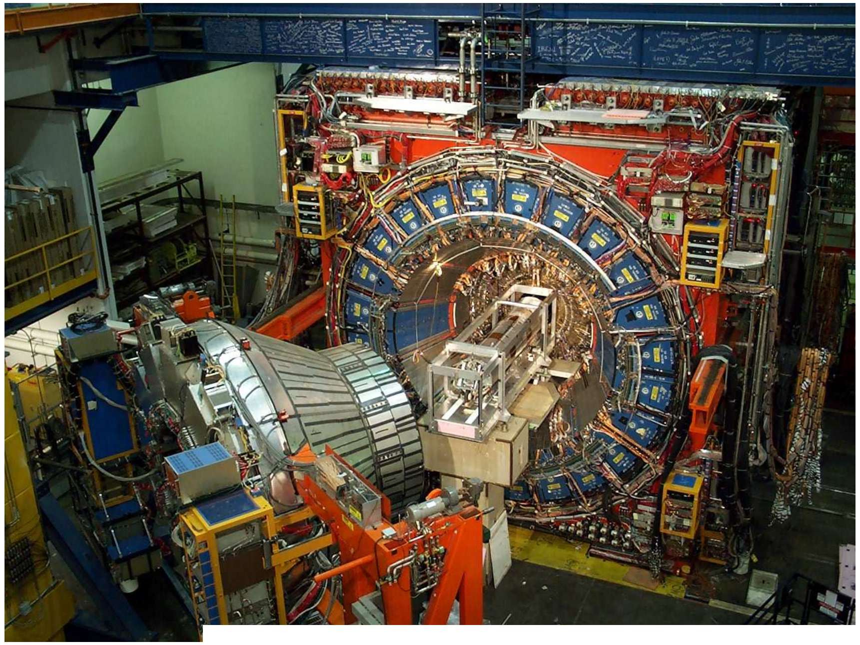
$$\sqrt{s} = 1.96 \text{ TeV}$$

The Tevatron at FNAL



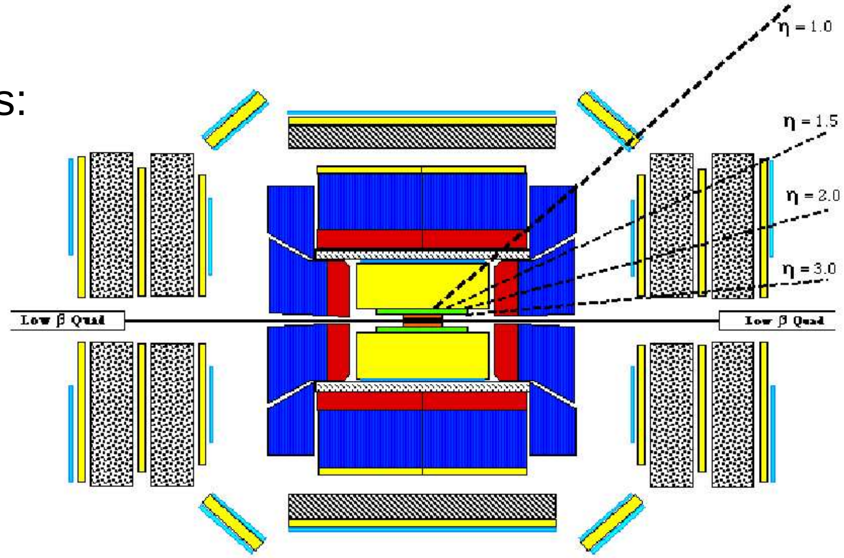
- The Tevatron at FNAL provides proton-antiproton collisions with a center of mass energy of 1.96 TeV.
- Approximately $1.2 fb^{-1}$ of integrated luminosity has been recorded to tape at CDF ($\sim 10\times$ the Run I integrated luminosity).



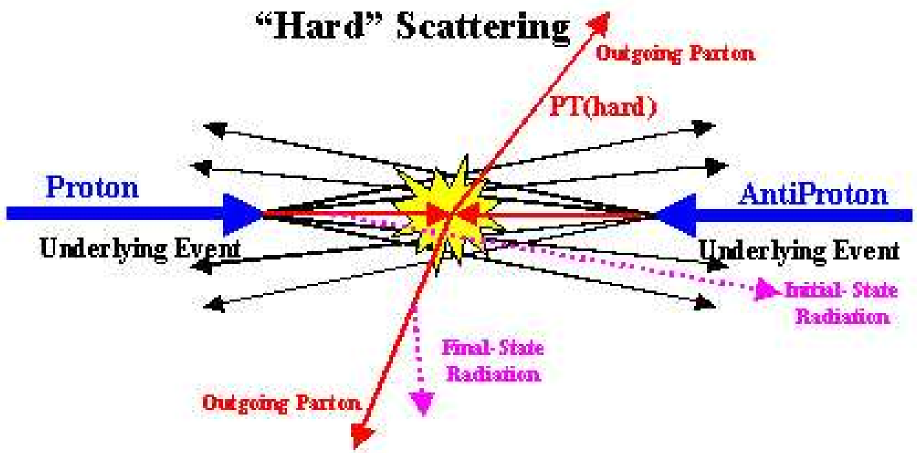


Jet measurements rely on several detector components:

- CLC: luminosity measurement
- COT: tracking for vertex reconstruction
- Electromagnetic Calorimeters: Jets, $e^{\pm}$, and γ
- Hadronic Calorimeters: Jets



∗ Components of a hadron collider event:

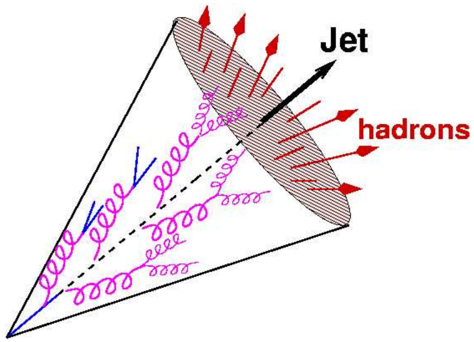


- 2$\longrightarrow$2 'hard' scattering
  - Described by perturbative QCD.
  - Dominated by dijet events.
- Initial and final state radiation (ISR and FSR)
- Underlying event (UE)
  - Beam-beam remnants
  - MPI (multiple parton interactions)

∗ Colored partons hadronize into color neutral hadrons.

∗ Particles from ISR, FSR, UE, and the 'hard' scattering are indistinguishable in the detector.

∗ Jet clustering algorithms combine particle energies from all of the components of the event to form jets.



Motivation: Inclusive Jet Cross Section

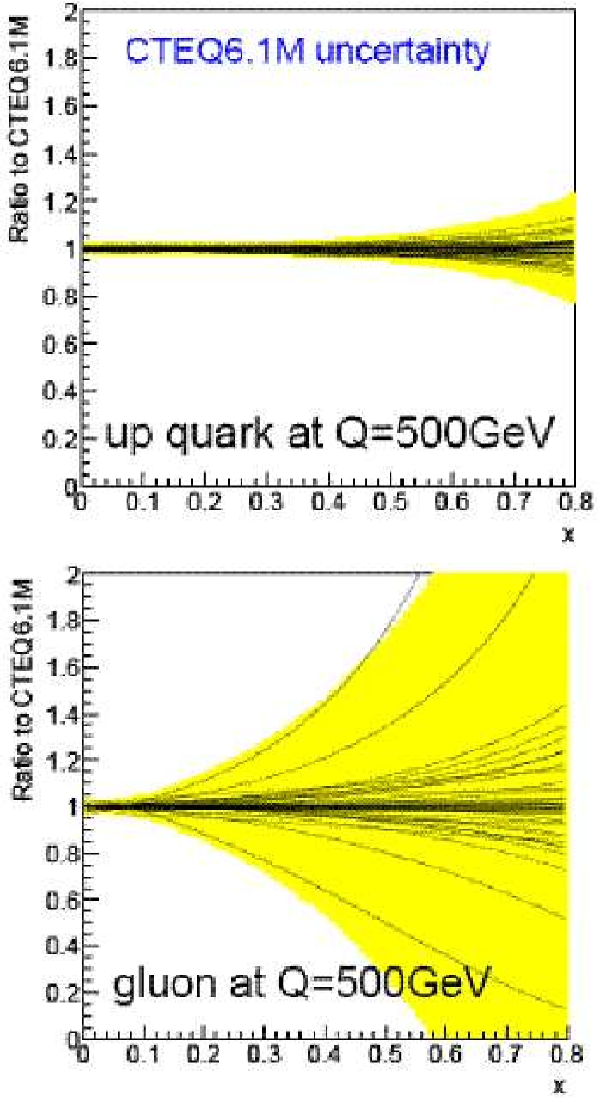
- Theoretically simple$\longrightarrow$ fundamental test of pQCD.
- Measurement over 8 orders of magnitude

in cross section.

- Wide P_T range $\longrightarrow$ probes running of α_s.
- Probe distance scale of order $10^{-19}m$.
- Sensitive to new physics $\longrightarrow$ quark substructure.
- Probe large x $\longrightarrow$ constrain gluon PDFs.
- Benefit of including the forward region:

$\longrightarrow$ Less sensitive to new physics.

$\longrightarrow$ Provides extra constraints on standard model (PDFs).



Jet Finding Algorithms

Need to define jet clustering algorithms that 'map' the final states onto jets.

(from QCD predictions and from data)

- Additional desired properties
  - Same algorithm at parton, hadron, and detector level
  - Infrared and collinear safe
  - Fully specified and easy to use
  - Independent of detector geometry/granularity
  - ...
- 2 types of algorithms employed at CDF
  - Cone algorithm: group particles based on separation in $Y - \phi$ space. (Midpoint algorithm)
  - K_T algorithm: group particles based on their relative transverse momenta (and separation in $Y - \phi$ space).

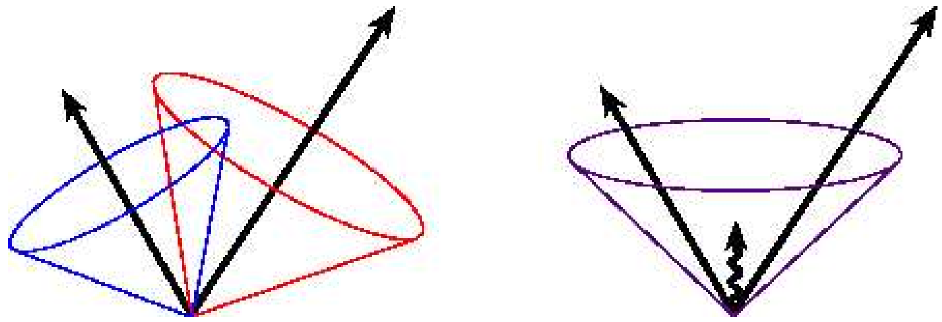
The Midpoint Jet Clustering Algorithm

A basic cone algorithm was used in Run I (JetClu):

- Start with *seed* towers.

  (calorimeter towers with energy above given threshold)

- Cluster towers within the cone radius.
- Iterate to find stable cone.
- Sensitive to 'soft' radiation.



Midpoint algorithm replaced JetClu as the cone algorithm in CDF for Run II

- Add extra *seeds* at the midpoint between all stable cones.
- Check for an additional stable cone at the midpoint between all stable cones.
- Less sensitive to 'soft' radiation.
- Need R_{sep} parameter at the parton level (NLO) to approximate the split-merge step.

The K_T Algorithm

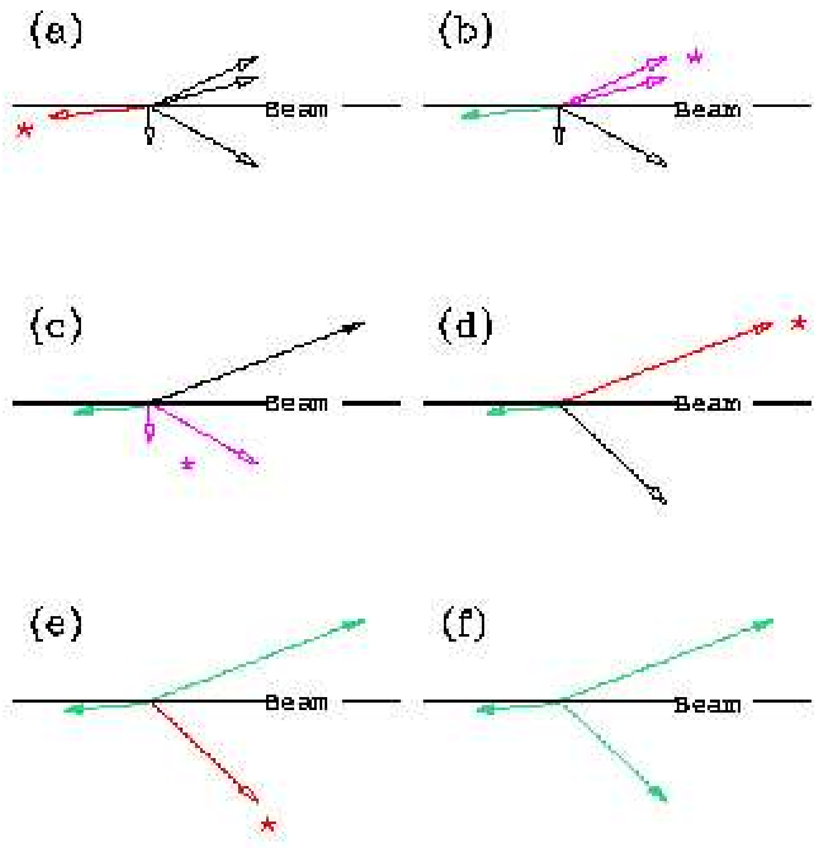
1) Construct for each particle and pair of particles:

$d_{ij} \equiv min(P_{T\,i}^2, P_{T\,j}^2) \times \frac{\Delta R^2}{D^2}$ and $d_i \equiv P_{T\,i}^2$

2) Start with $min(d_{ij}, d_i)$:

- If a d_i is the smallest, promote it to a jet.
- If a d_{ij} is the smallest, combine particles.

3) Iterate until all particles are in a jet.



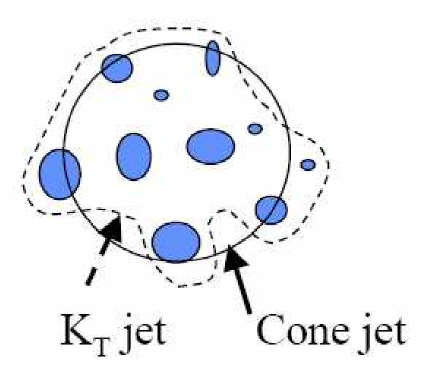
K_T Algorithm is theoretically preferred.

- Infrared/collinear safe to all orders in pQCD.
- No merging/splitting parameter needed.

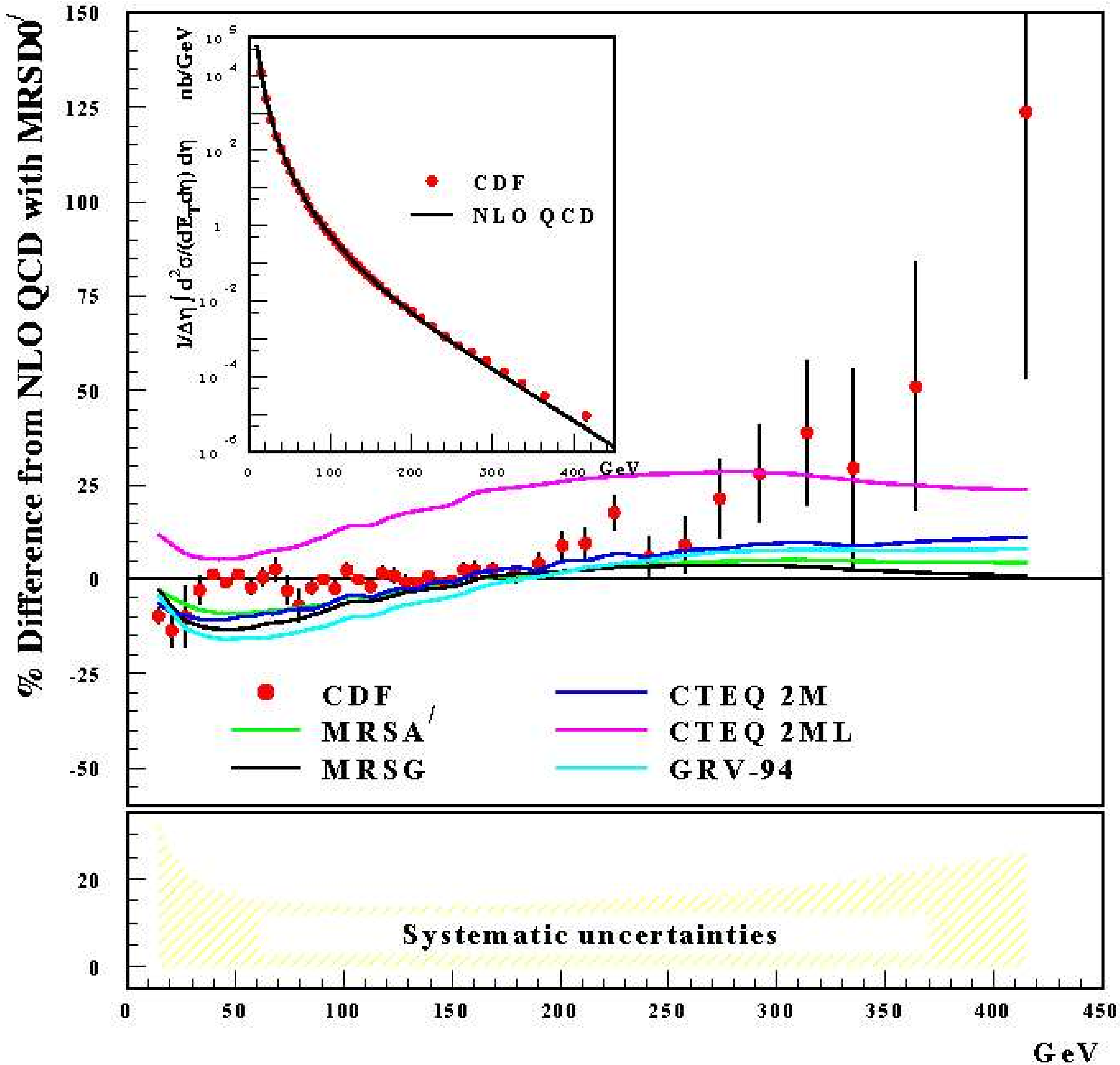
K_T has been used

successfully at e+e- and ep colliders, but is relatively

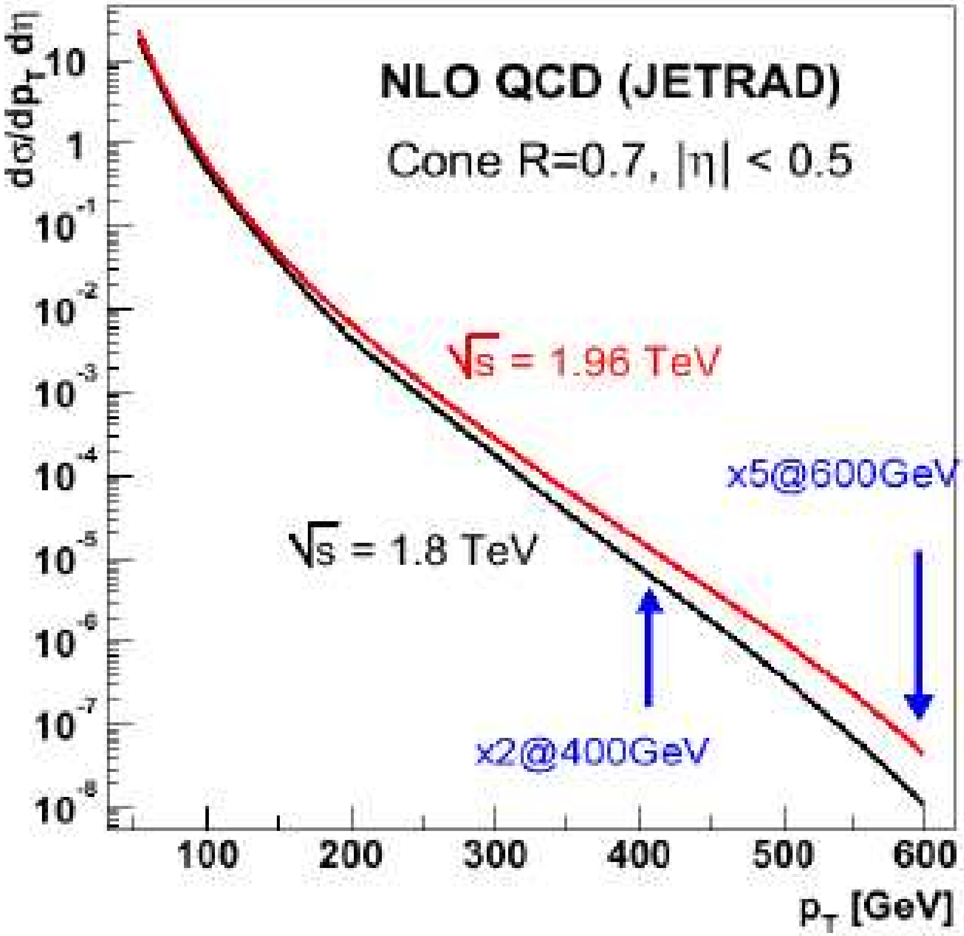
new to the hadron-hadron collider environment.



CDF Run 1a Inclusive Cross Section (1996)



Run I and Run II predictions



NOTE: CDF did not make a measurement in the forward region in Run I. Upgrades to the calorimeter and tracking system help make this possible in Run II.

Jet Energy Correction Strategy

∗ Based on Data:

- Correct for “pileup”.

  ⟶ Correct for extra energy due to multiple proton-antiproton collisions in the event.

∗ Based on PYTHIA MC:

- Cal⟶Had: Correct for energy scale (absolute) and resolution (bin-by-bin).

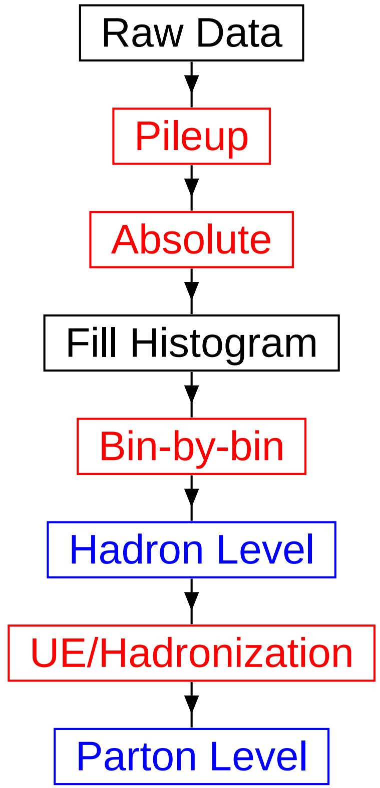
  ⟶ Average energy loss of jets due to non-compensating nature of the calorimeter.

  ⟶ Smearing effect due to the jet energy resolution (10-20%).

- Had⟶Par: Correct for UE and Hadronization.

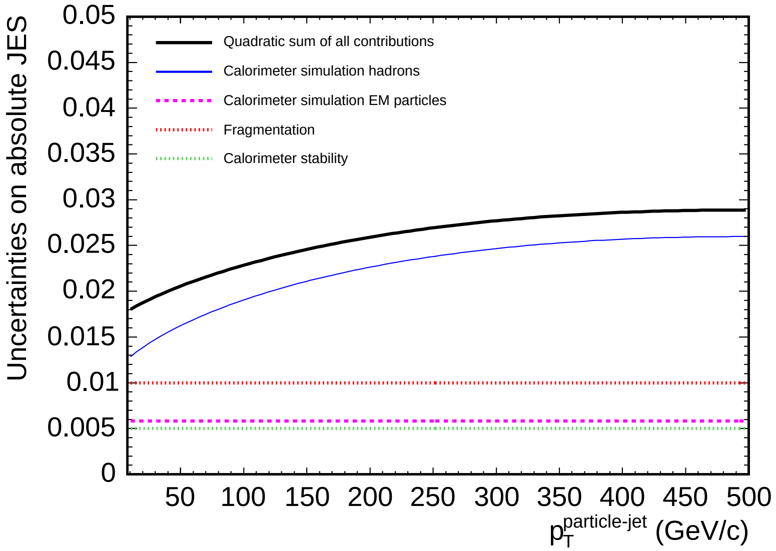
  ⟶ Extra energy from UE.

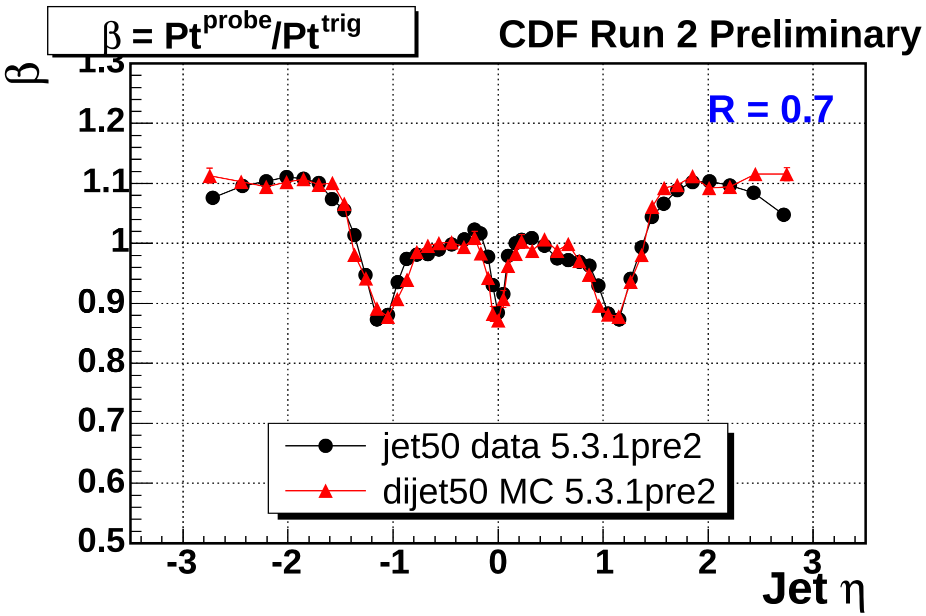
  ⟶ Energy loss ‘out of cone’ due to hadronization.



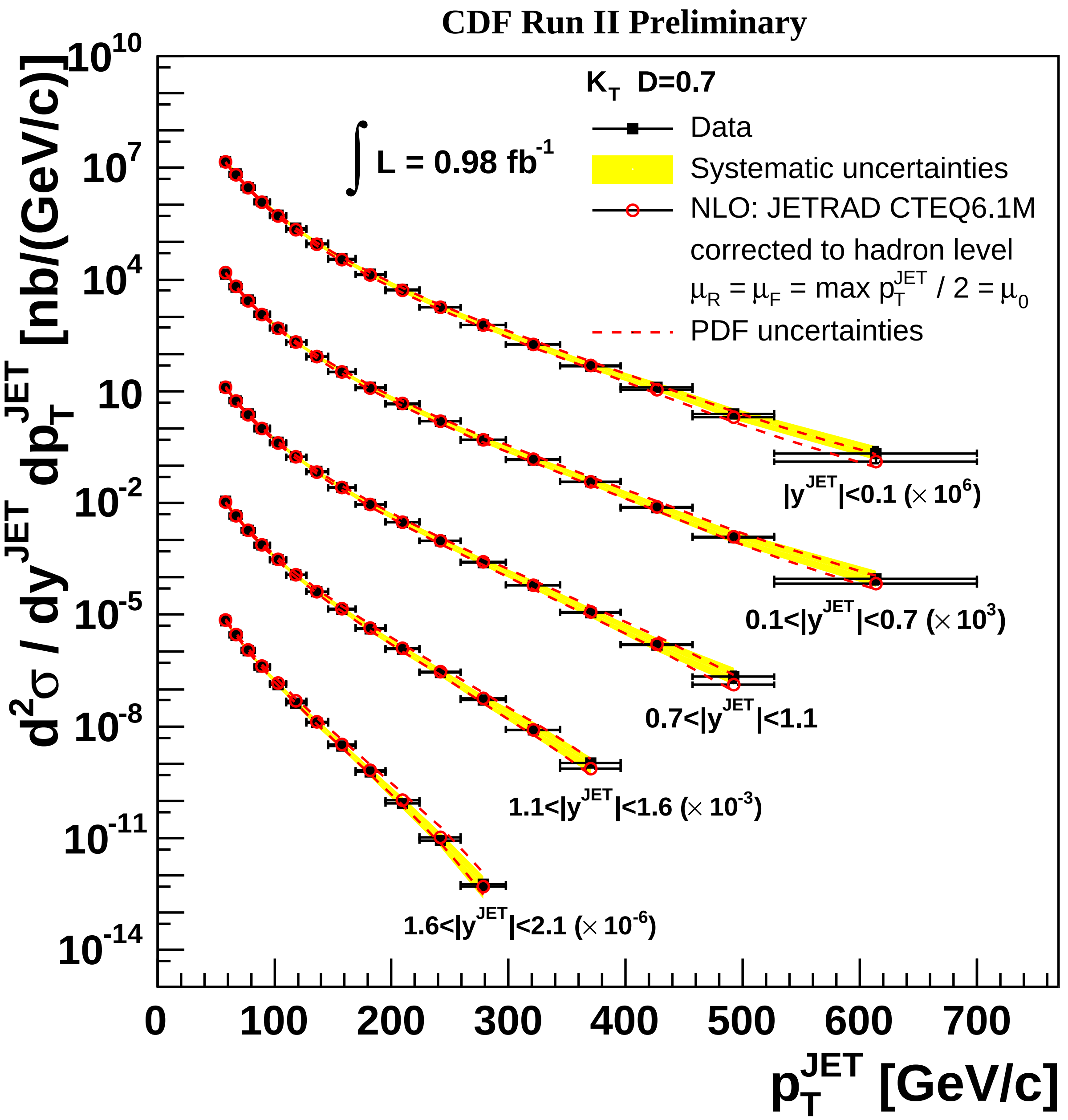
Jet Energy Scale at CDF

- In the central region, the jet energy scale (JES) is determined based on the detector simulation and jet fragmentation model.
- The detector simulation is tuned to reproduce the single particle response measured in-situ and in the test beam.
- Outside the central region, the jet energy scale is determined based on the relative differences to the central region observed in dijet Pt balance.
- Because of the steeply falling spectrum, a small uncertainty in the JES translates to a large uncertainty in the cross section measurement.

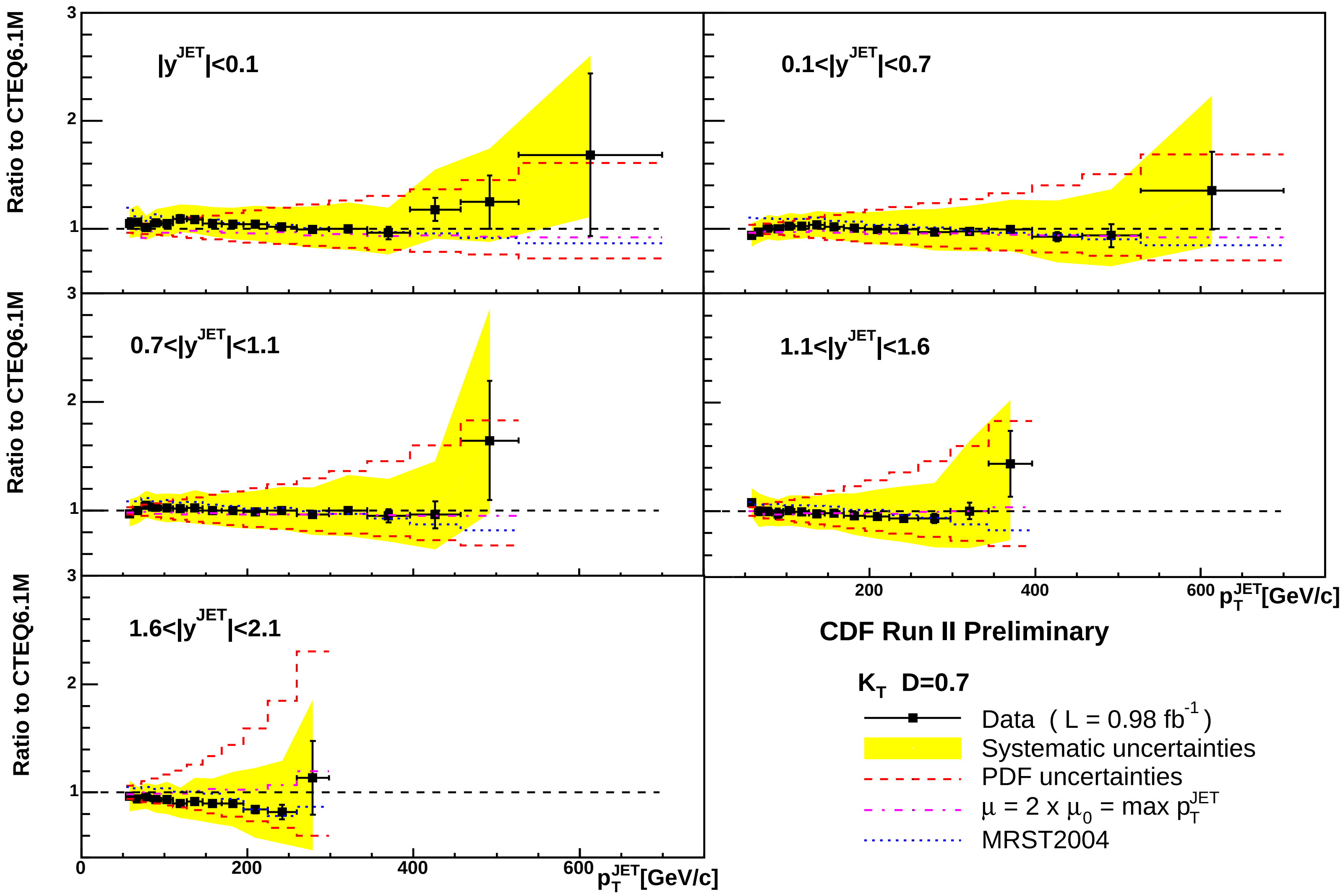




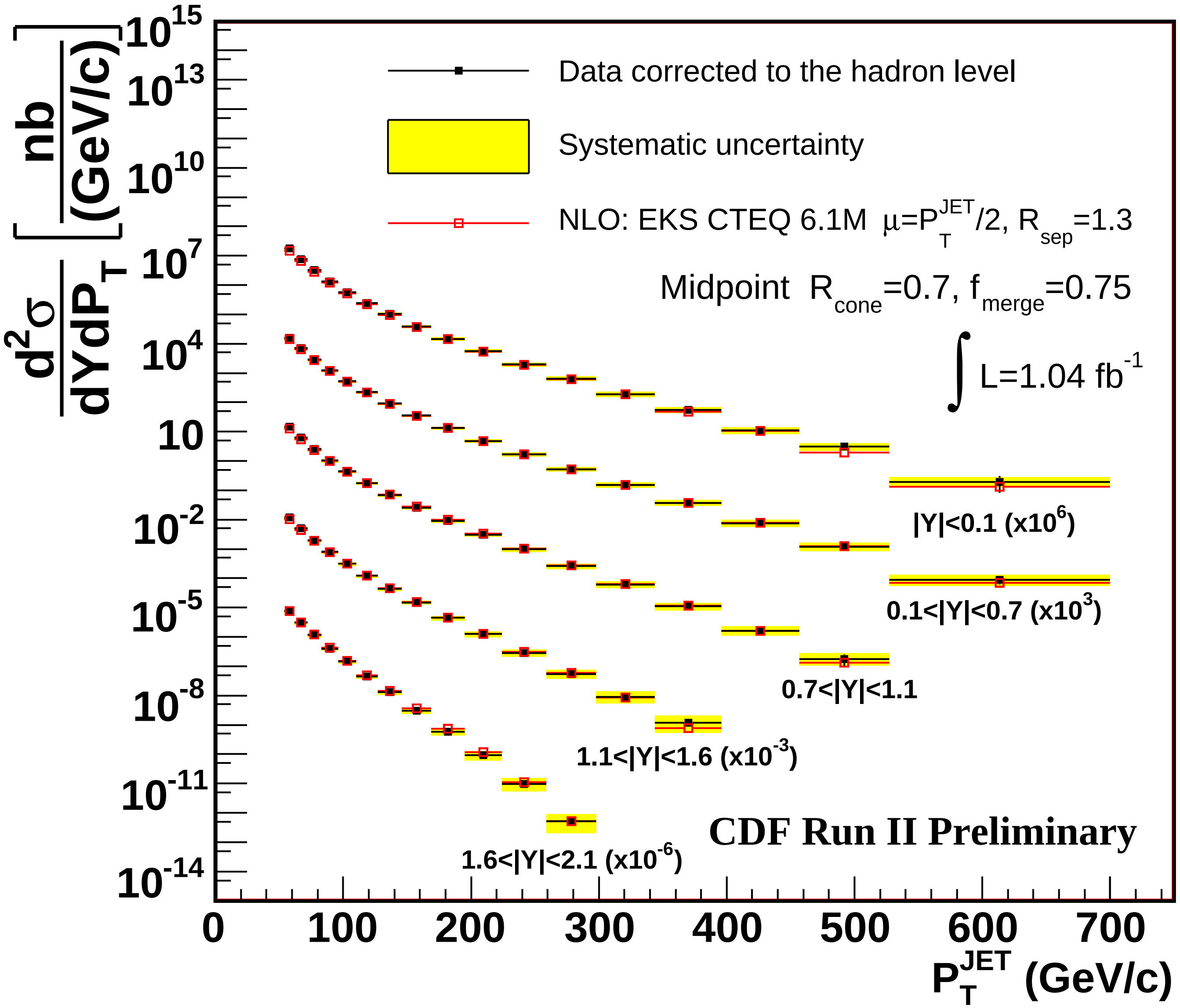
K_T Results: Cross Section Distributions



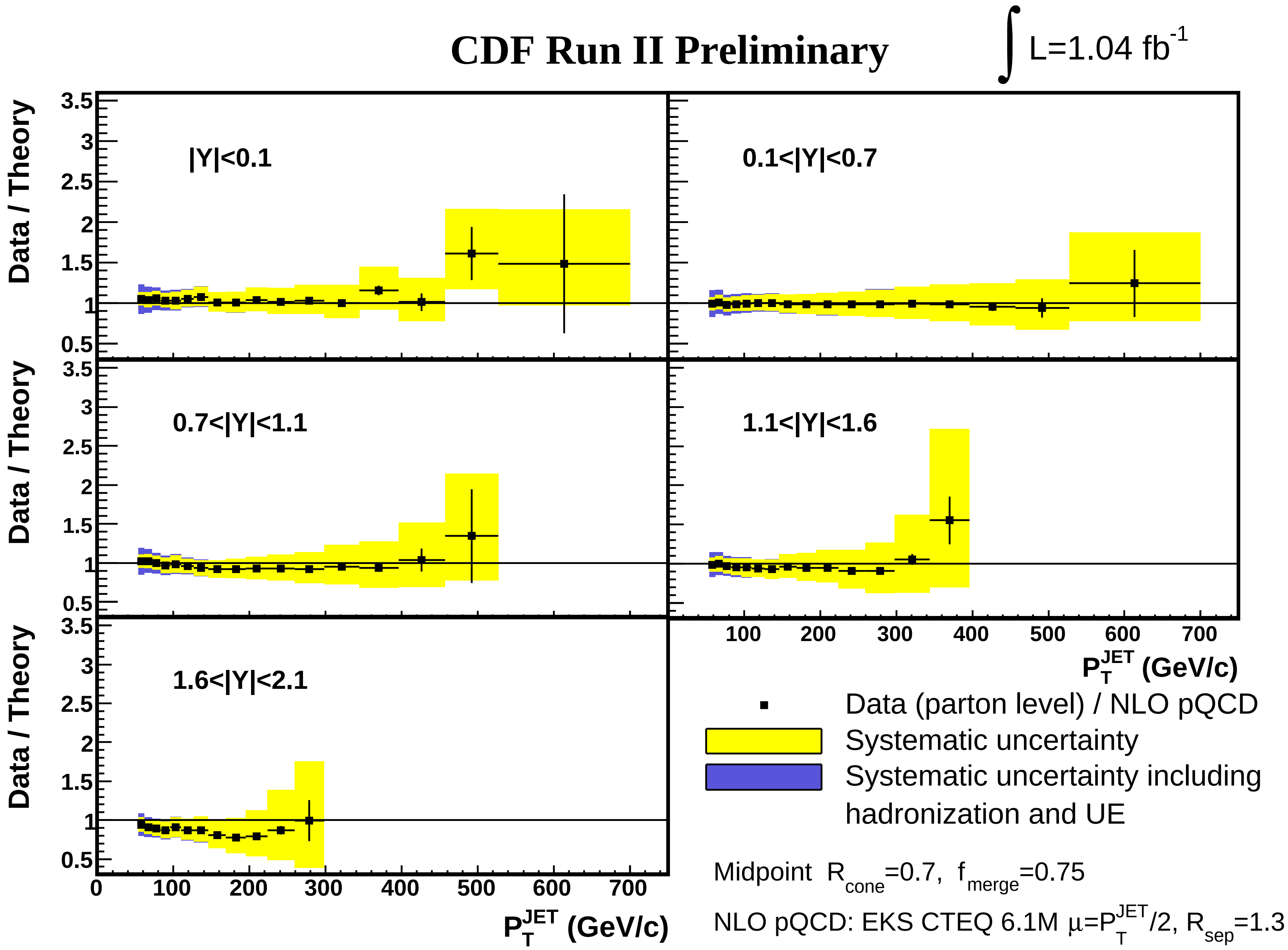
K_T Results: Ratio to NLO pQCD



Midpoint Results: Cross Section Distributions



Midpoint Results: Ratio to NLO pQCD

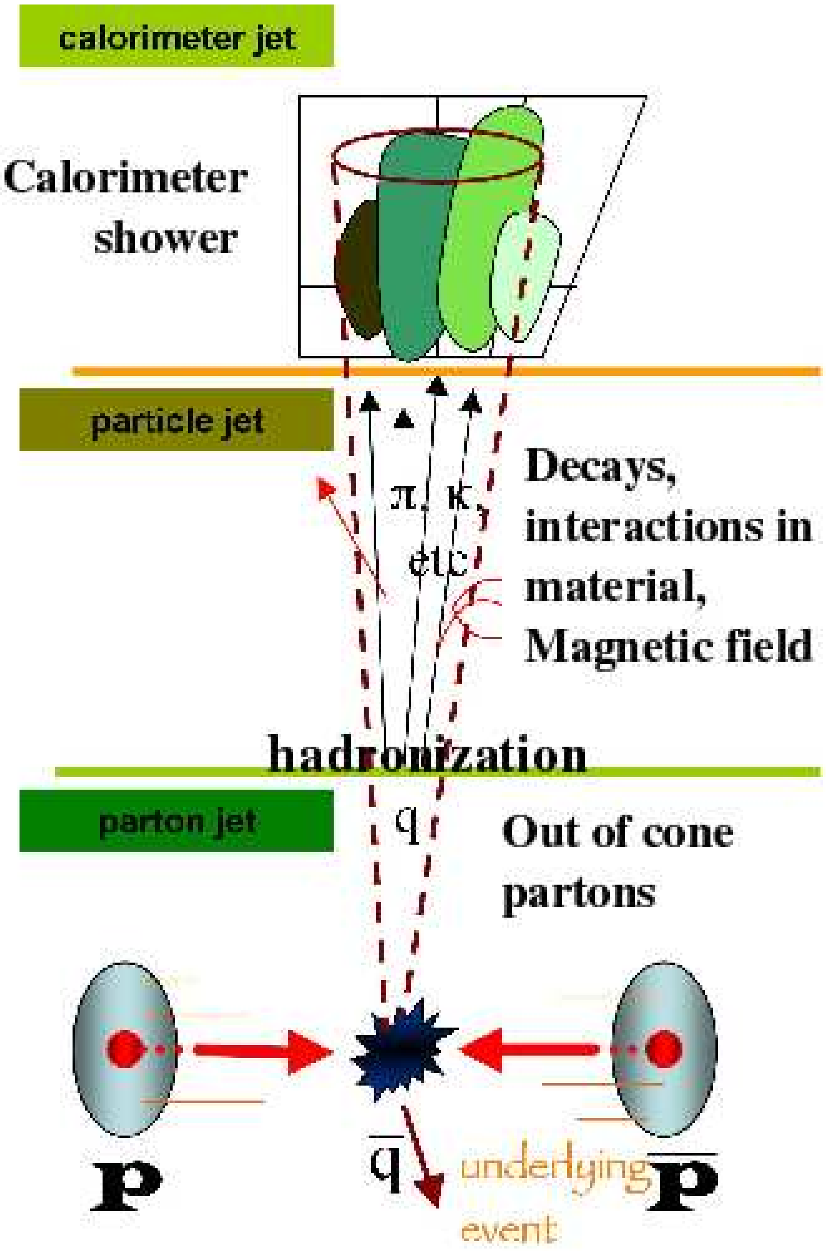


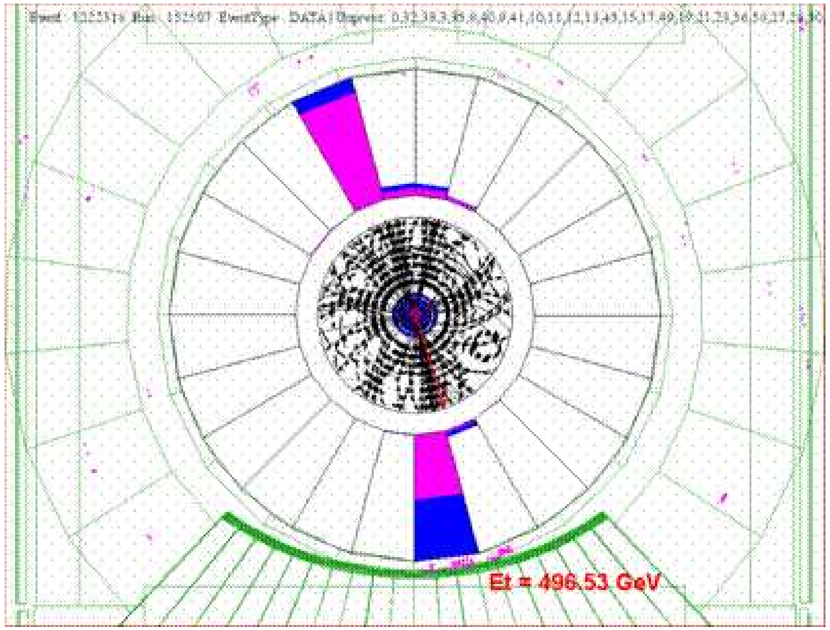
Summary and Conclusions

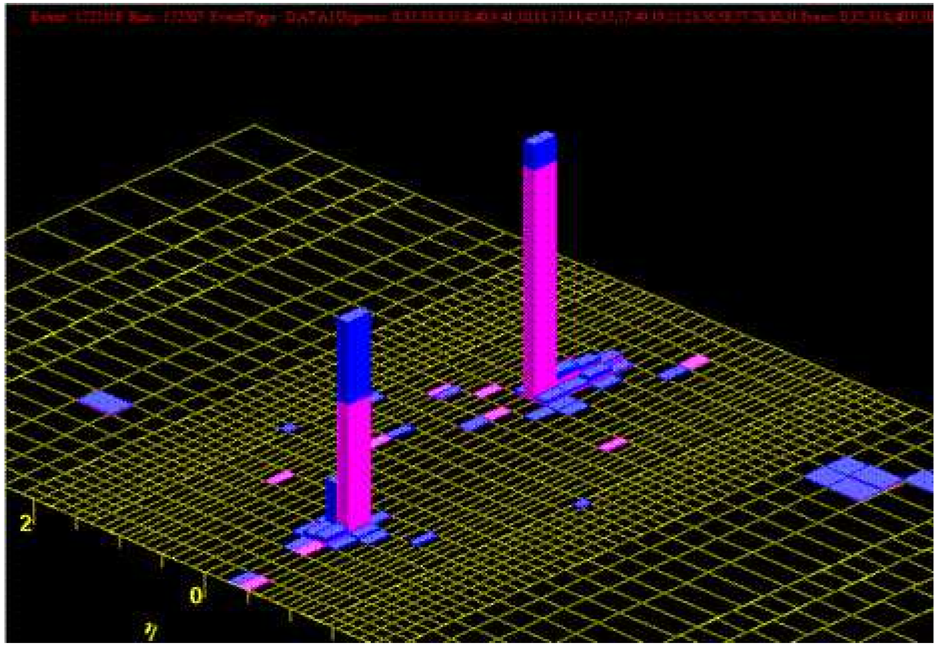
- Updated results on the inclusive jet cross section from CDF are presented:
  - Jets clustered by the Midpoint and K_T jet algorithms
  - Over $1fb^{-1}$ of data
  - Measurements extend to the forward region (up to $|Y| = 2.1$)
- Measured cross sections agree well with NLO pQCD predictions.
- Measurement is consistent between the $Midpoint$ and the K_T algorithm.
- K_T seems to work well in the hadron collider 'messy' environment.
- These results provide very important constraints on PDFs
  (especially the gluon densities at high x).

BACKUP

Jet Production at the Tevatron



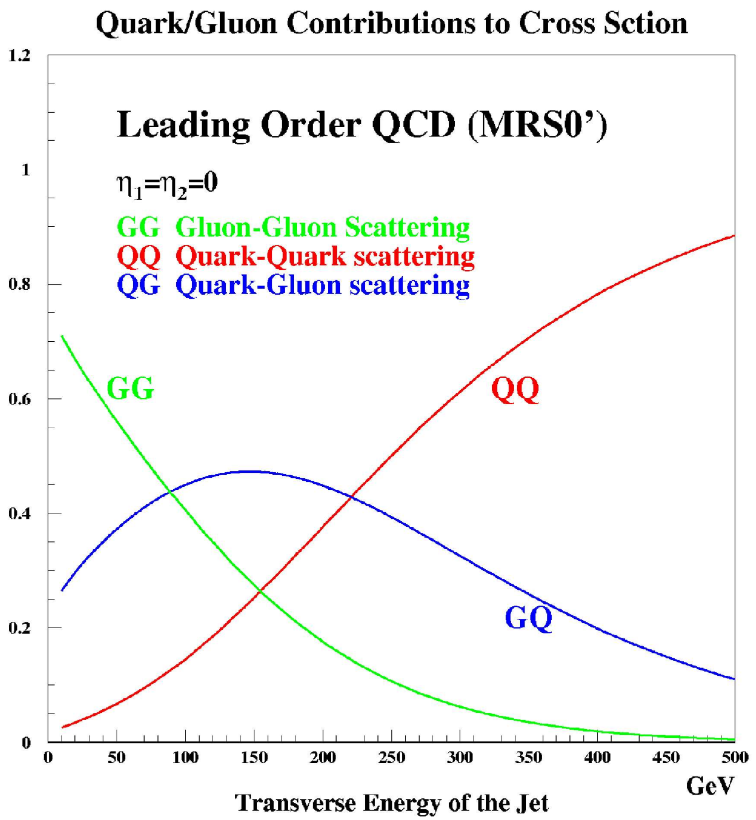


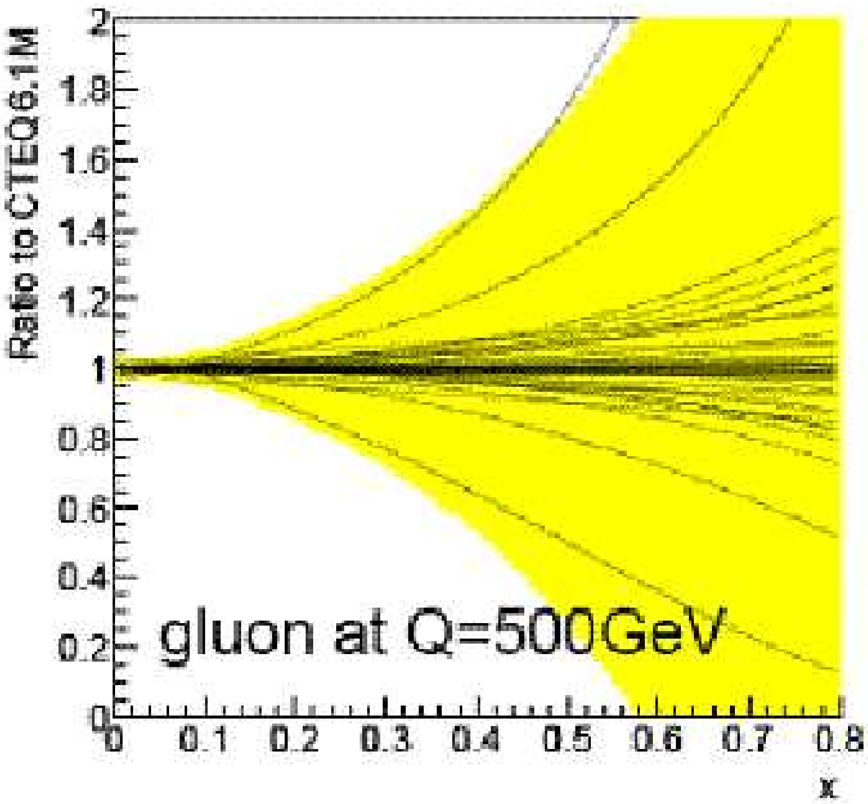


Highest energy dijet event measured so far at CDF.

$$(P_T^{Raw} \sim 580 GeV)$$

Gluon contributions at high x





Inclusive Jet Data Selection

- 4 jet triggers: jet20, jet50, jet70, and jet100.
- Use data set only when trigger efficiency is $>$ 0.995.

- Event selection
  - Missing E$_T$ significance cut ($\widetilde{\not{E}_T} = \not{E}_T/\sqrt{\sum E_T}$)

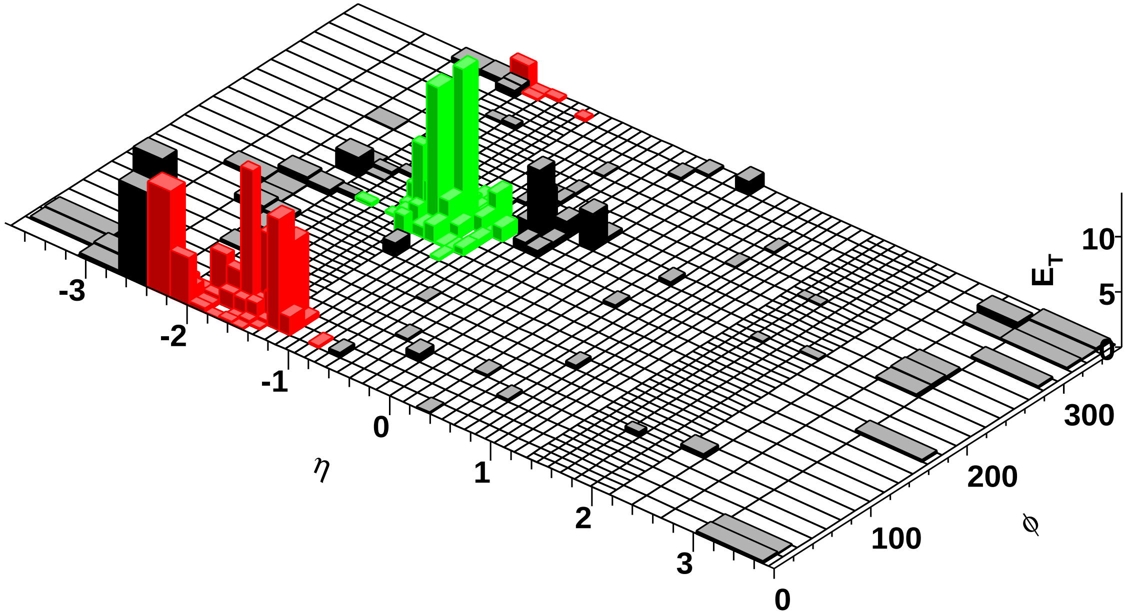
    Cut is sample dependent (4,5,5,6).
  - $|Z_{vert}| \leq 60cm$ ($\sim 5\%$ correction to the cross section for the efficiency of this cut).
  - At least 1 jet $|Y| < 2.1$. Split into 5 bins:
    - $0.0 < |Y| < 0.1$
    - $0.1 < |Y| < 0.7$
    - $0.7 < |Y| < 1.1$
    - $1.0 < |Y| < 1.6$
    - $1.6 < |Y| < 2.1$

MC Checks and Corrections

Before the MC and detector simulation can be used to correct the data it must be checked that CDF detector simulation is accurately describing the real CDF detector.

- Bisector Method: Used to compare jet resolution in the CDF simulation and the data.
  - Central region agrees well between data and MC
  - $0.7 < |Y| < 1.1$ and $1.6 < |Y| < 2.1$ under smear jet energy
  - $|Y| < 0.1$ and $1.1 < |Y| < 1.6$ over smear jet energy
  - Hadron level study is used to derive bin corrections for the resolution.
- Dijet Balance: Used to compare central/non-central relative calorimeter response in the CDF simulation and the data.
  - Results are used to correct MC.
  - There is a large systematic uncertainty from this correction at high P_T.
- PYTHIA re-weighting : Force the shape of PYTHIA cross section to agree with data so that unfolding corrections are not biased.
  - Difference in shape may be due to PDF
  - Weight events $\longrightarrow$ modified unfolding factors.

The Search Cone.



- CDF observed “dark” towers in some events.
- To improve the match between parton, hadron, and detector level jets the search cone was added to minimize this effect. Search for stable cone with $R_{cone} = \frac{R}{2}$ then expand to $R_{cone} = R$.
- Results in a 5% increase of the jet cross section.