Probing QCD with jets at the Tevatron

Mikołaj Ćwiok

University College Dublin, Ireland

on behalf of CDF & D0 Collaborations

VIIth Quark Confinement and Hadron Spectrum Conference

Ponta Delgada, St. Miguel, Azores, Portugal, 2-7 September 2006

Outline

0. Introduction to Tevatron, CDF & D0 ⇒ see my previous talk

1. Hadron-hadron collisions

2. Inclusive jet cross sections (CDF & D0)

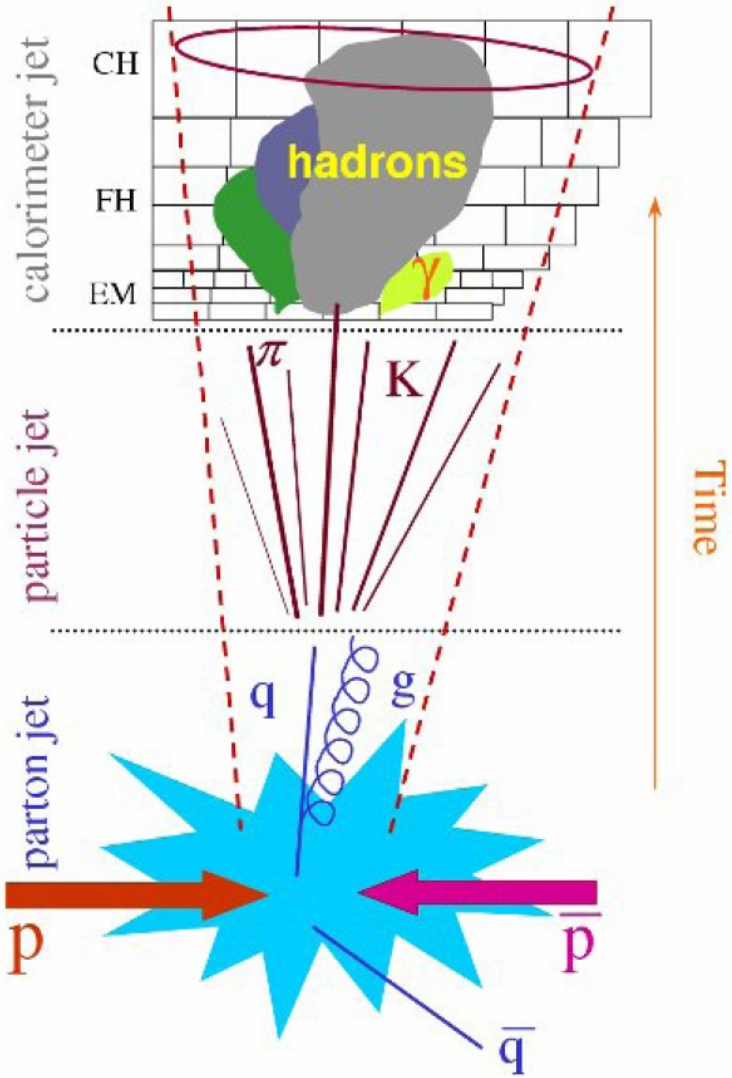
3. Inclusive Heavy Flavour jet cross section (CDF)

4. Dijet azimuthal decorrelation (D0)

5. Summary

Due to lack of time I <u>will not</u> talk about: **Vector Boson + Jets** and **Internal Jet Structure** results available from CDF/D0...

Hadron-Hadron Collisions



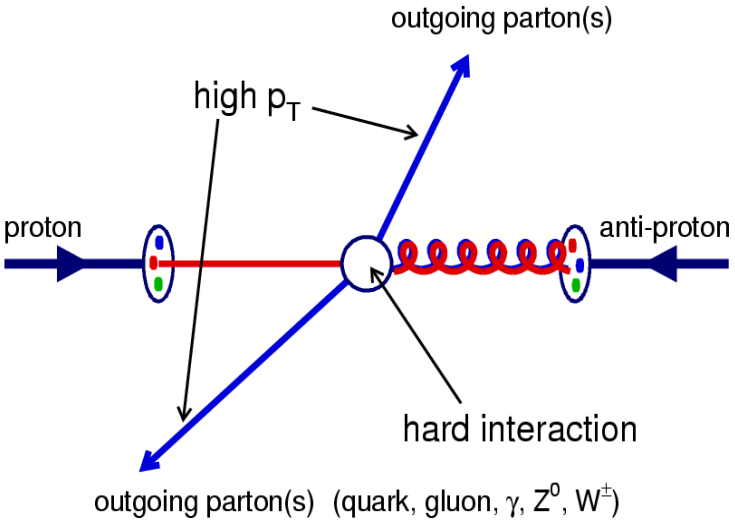
In hadron-hadron collisions:

- hard interactions of 2 partons (PDFs)
- soft initial state radiation (dijet azimuthal decorrelations)
- soft final state radiation (internal jet structure)
- hard radiation (multi-jets, W/Z+jets, γ+jets)
- hadronization/fragmentation (FFs, hadronization corr.)
- multi-parton interactions (underlying event)

Directly observed: energy deposits, tracks

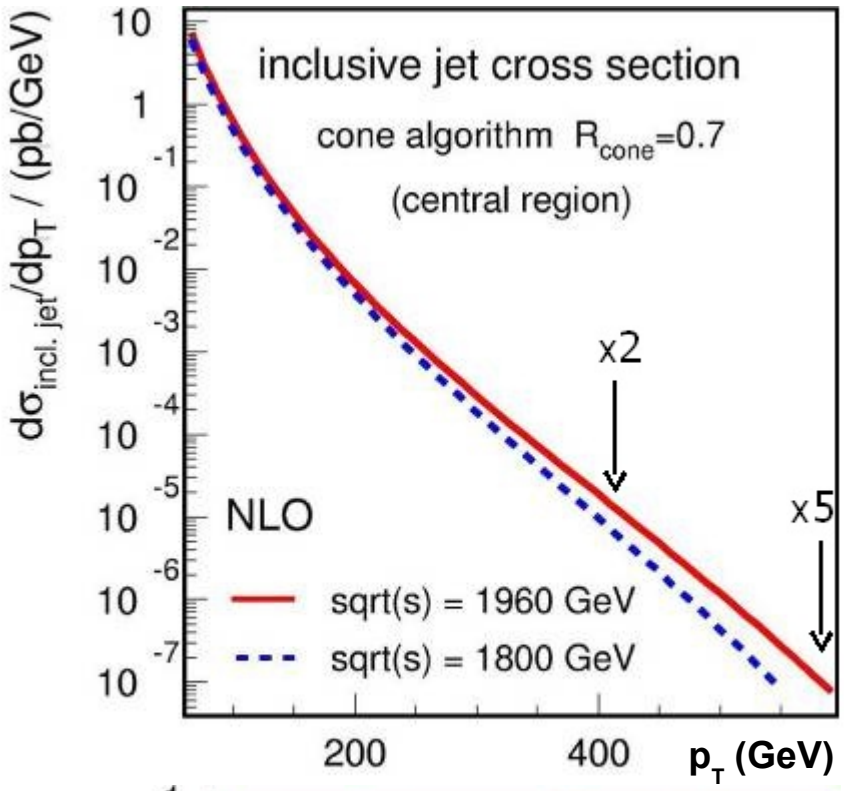
Jet definition relates observables defined on: parton-, particle- and detector level

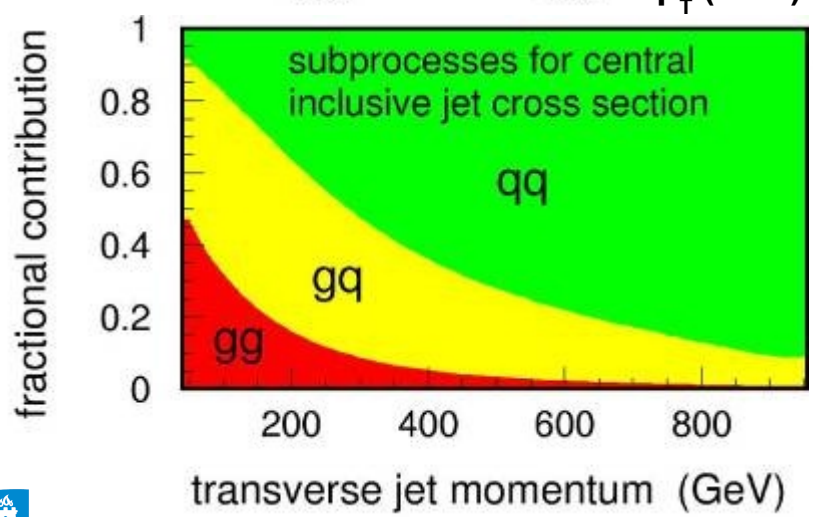
Jet algorithms should be infrared- & collinear safe



Jets not necessarily represent partons from the LO 2→n process

Inclusive Jets





High pT jets in Run II:

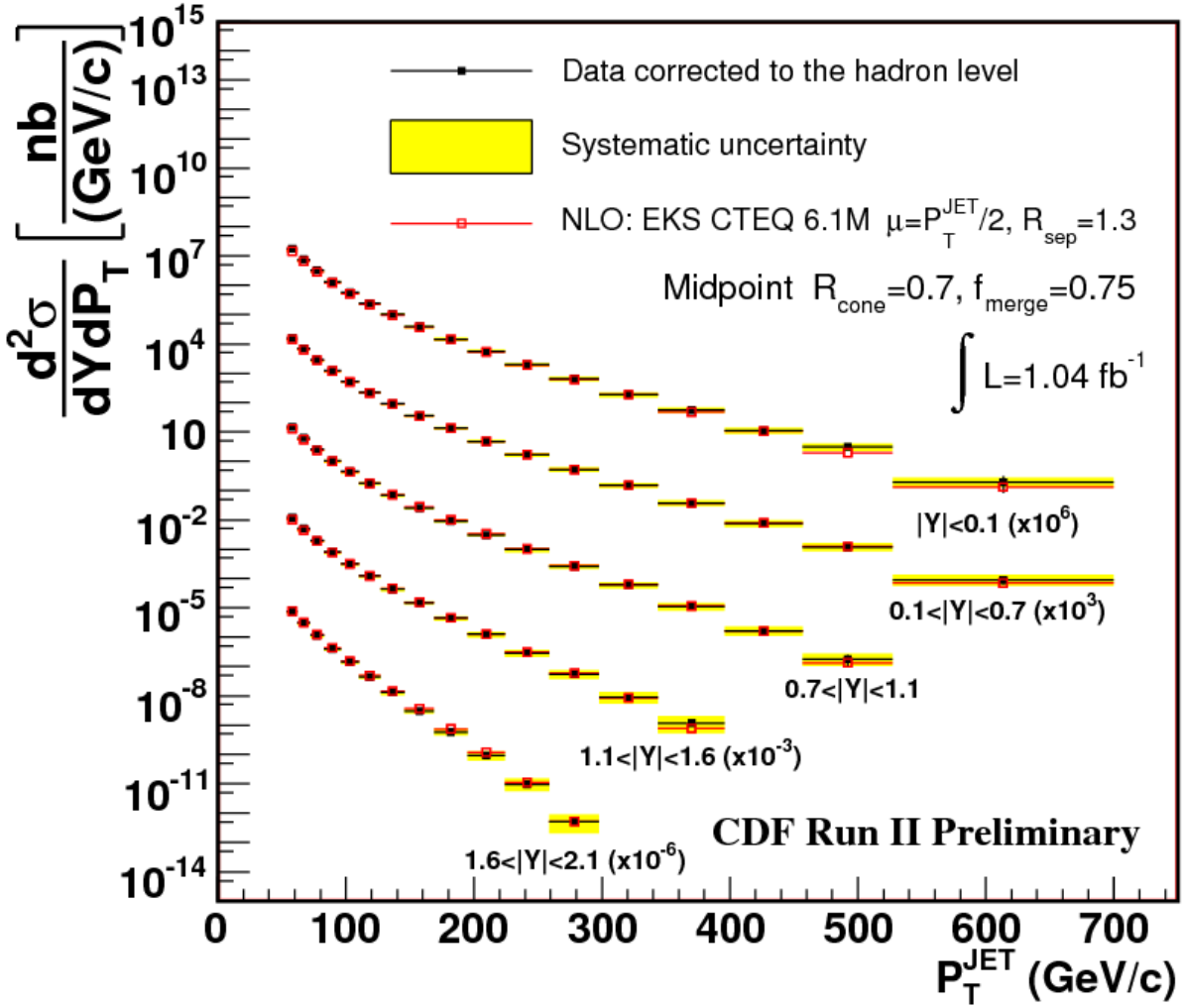
- higher instantaneous luminosity by a factor of ~10 than in Run I
- increased beam energy w.r.t. Run I
  ⇒ higher cross section by a factor of 5 at p_T=600 GeV⇒ better sensitivity to New Physics at high energies
- even at p_T=500 GeV quark-gluon scattering contributes to 30% of events
  ⇒ sensitivity to gluon PDF at high x region (x~0.5)

Improved jet algorithms in Run II:

- CDF: k_T algorithm, modified midpoint cone (but also legacy Run I cone)
- D0: midpoint cone algorithm

Inclusive Jets (CDF)

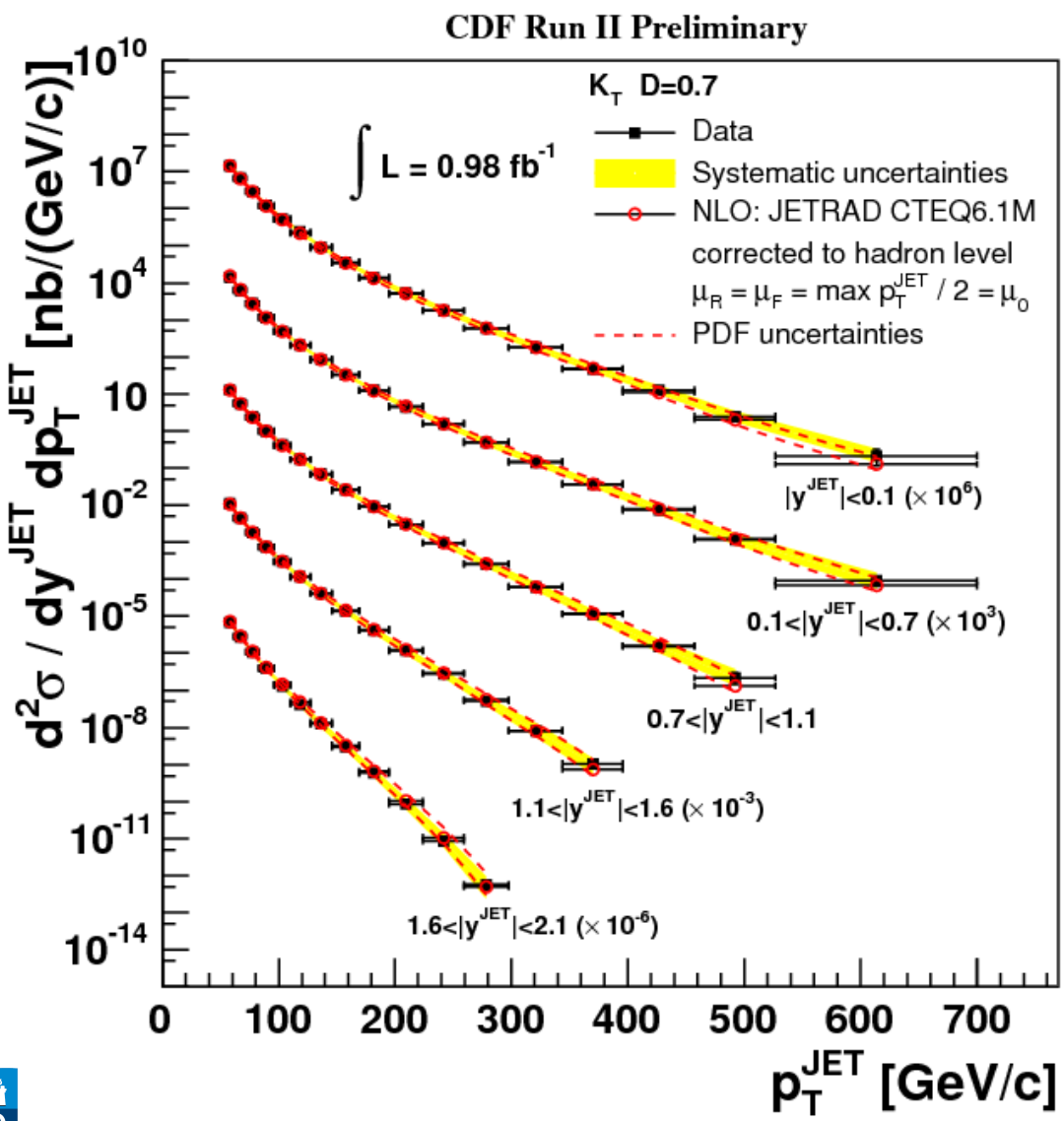
Midpoint searchcone algorithm (R=0.7)



- New improved jet cone algorithm with reduced infrared sensitivity
- **1 fb^{-1} data sample**
- Rapidity coverage up to |y|=2.1 using 5 rapidity bins
- P_T coverage up to 620 GeV for central rapidities
- Data corrected to the parton level for underlying events and hadronisation effects
- **NLO pQCD (EKS) well describes the data over entire phase space studied**

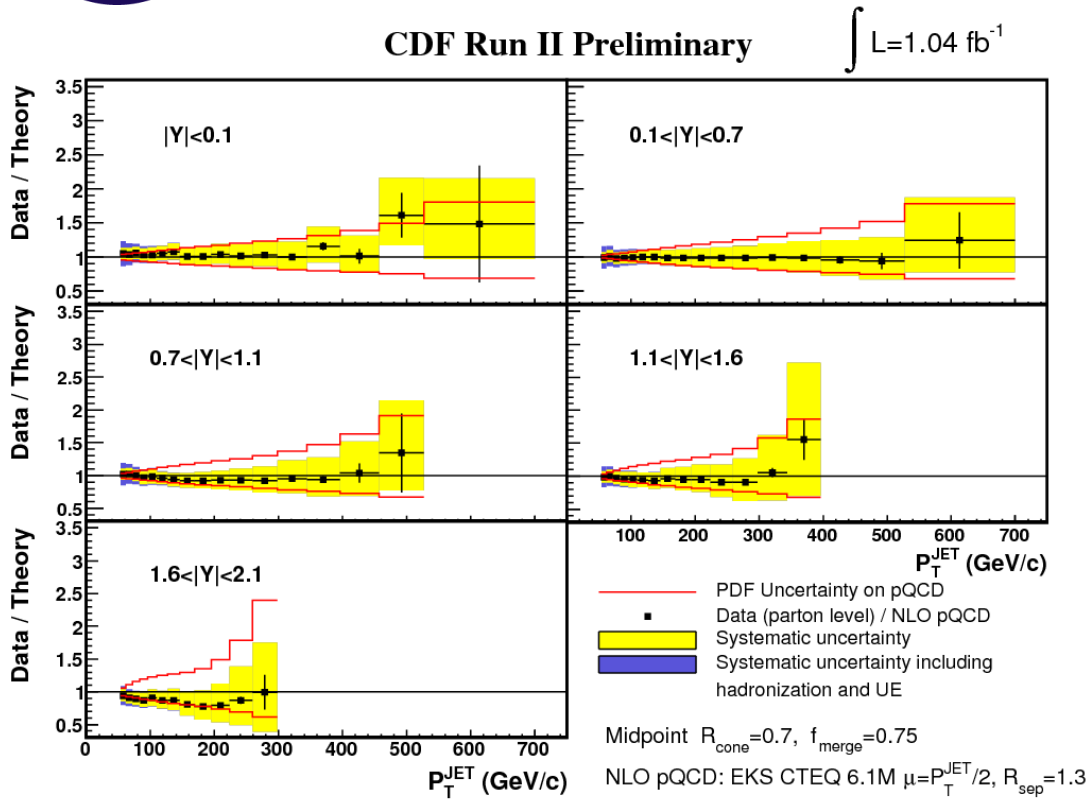
Inclusive Jets (CDF)

K_T algorithm (D=0.7)

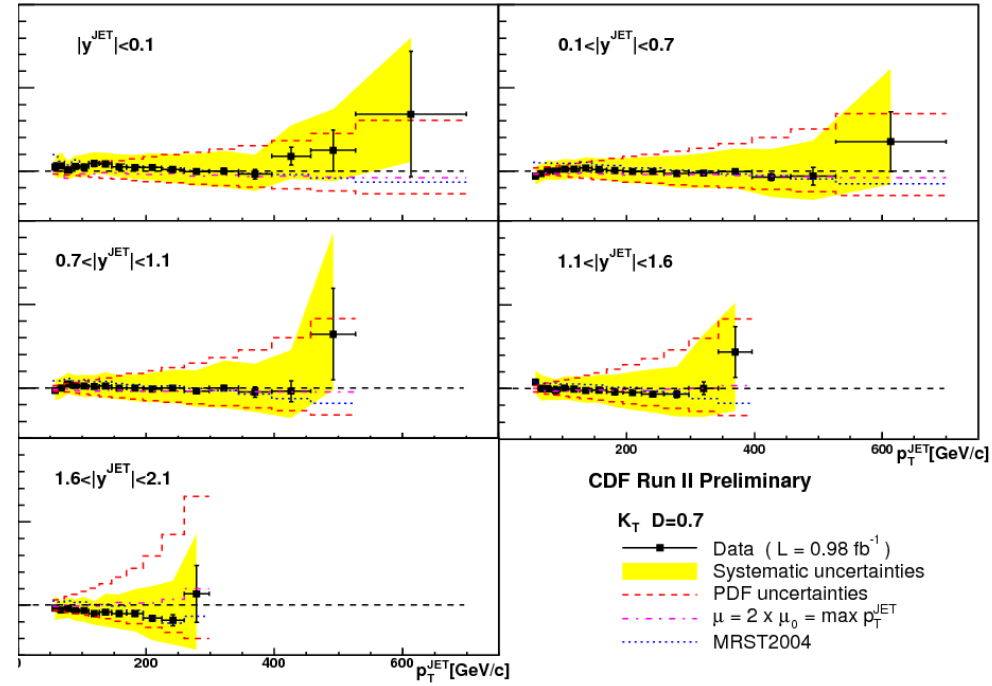


- Infrared and collinear safe k_T algorithm
- **1 fb^{-1} data sample**
- Rapidity coverage up to $|y|=2.1$ using 5 rapidity bins
- NLO QCD calculations corrected to the hadron level for underlying events and hadronizarion effects
- **NLO pQCD (JETRAD) well describes the data over entire phase space studied**
- In very good agreement with measurement based on cone algorithm

Inclusive Jets (CDF)



Midpoint searchcone algorithm

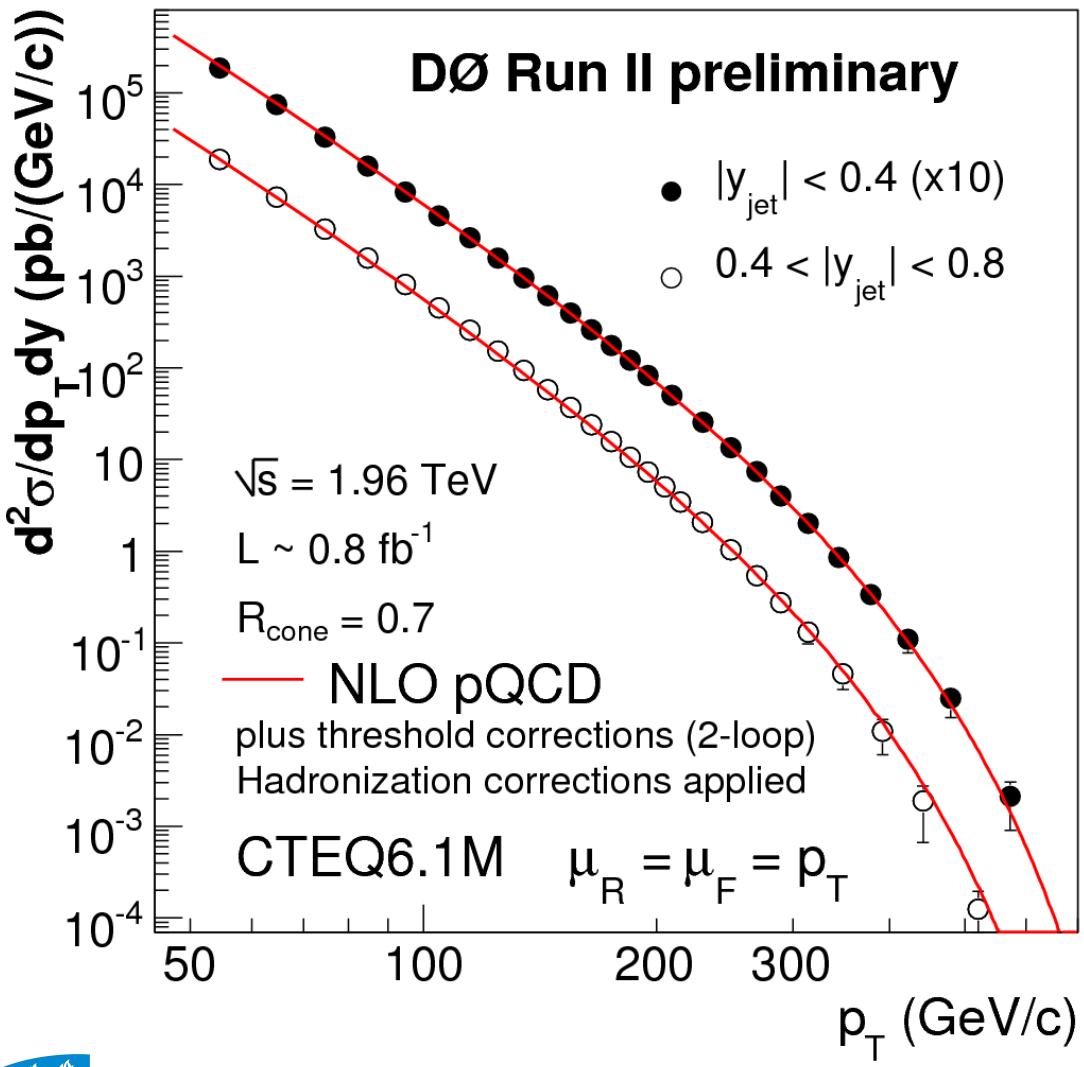


kT algorithm

- Leading systematics is due to Jet Energy Scale at high p_T (10-60%)
- Hadronization corrections are of the order of 10% at low p_T
- Exp. errors are comparable with theoretical ones due to uncertainty of PDF
- Data can be used to further constrain PDFs using high rapidity bins

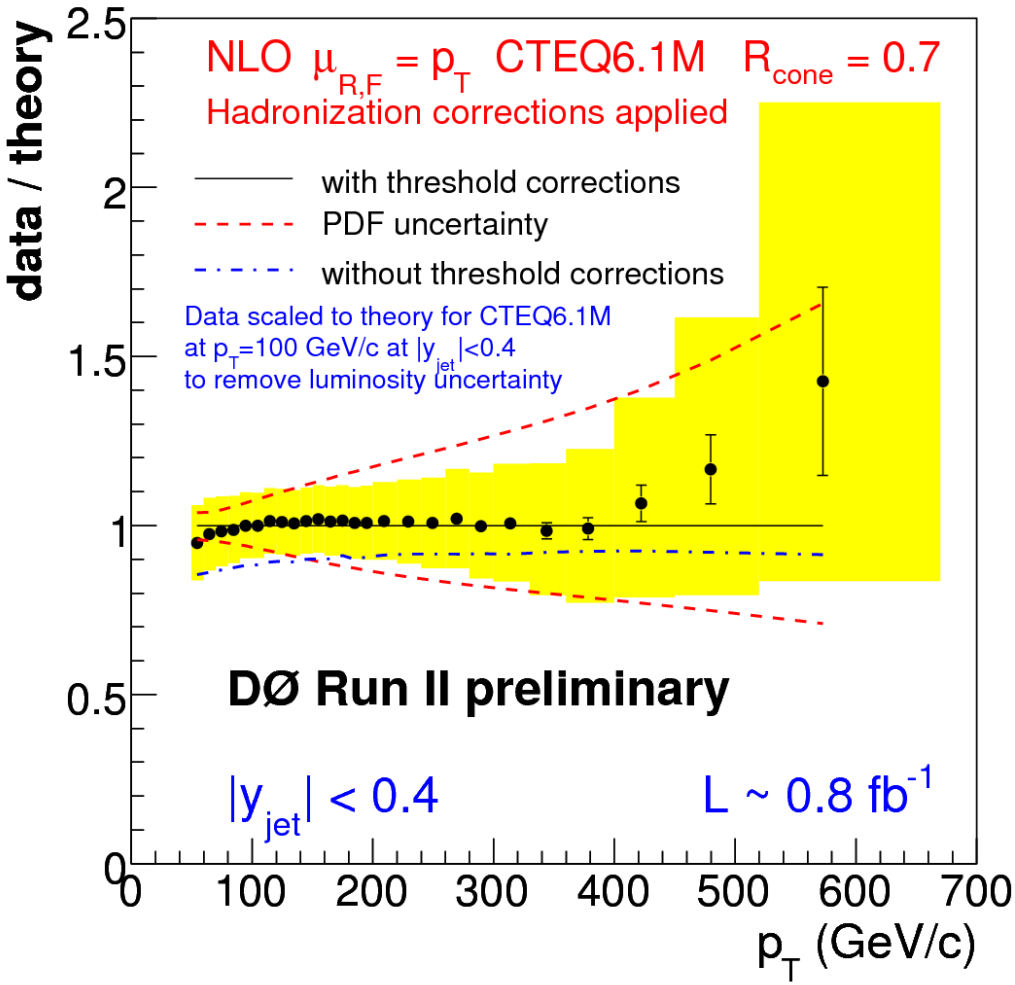
Inclusive Jets (D0)

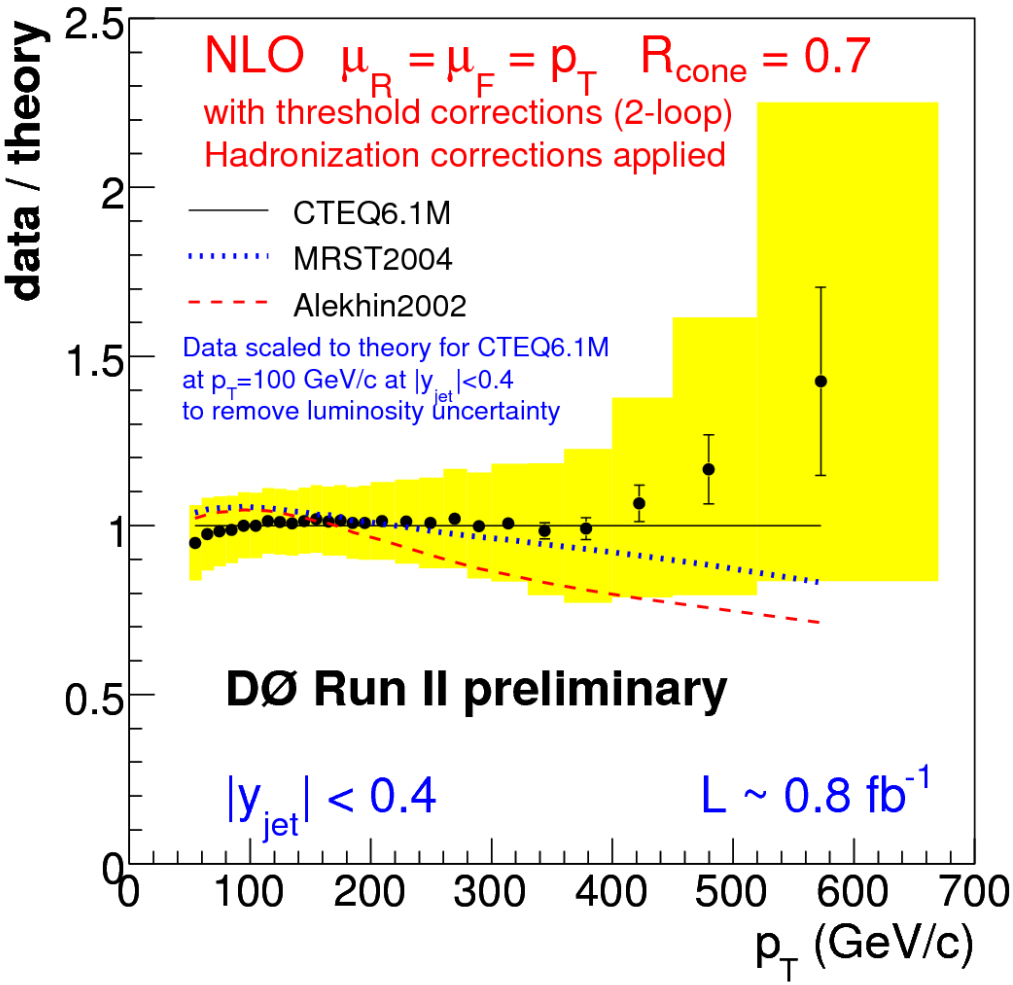
RunII midpoint cone algorithm (R=0.7)



- **0.8 fb^{-1} data sample**
- 2 central rapidity bins
- Data compared to NLO pQCD prediction by NLOJET++ (using CTEQ6.1M) with:
  - 2-loop NNLO-NNL corrections using threshold resummation techniques (Kidonakis et al.)
  - Hadronization corrections
- Data scaled to NNLO-NNL predictions at p_T=100 GeV and $|y|<0.4$ (to remove luminosity uncertainty)
- **Good agreement with pQCD**

Inclusive Jets (D0)

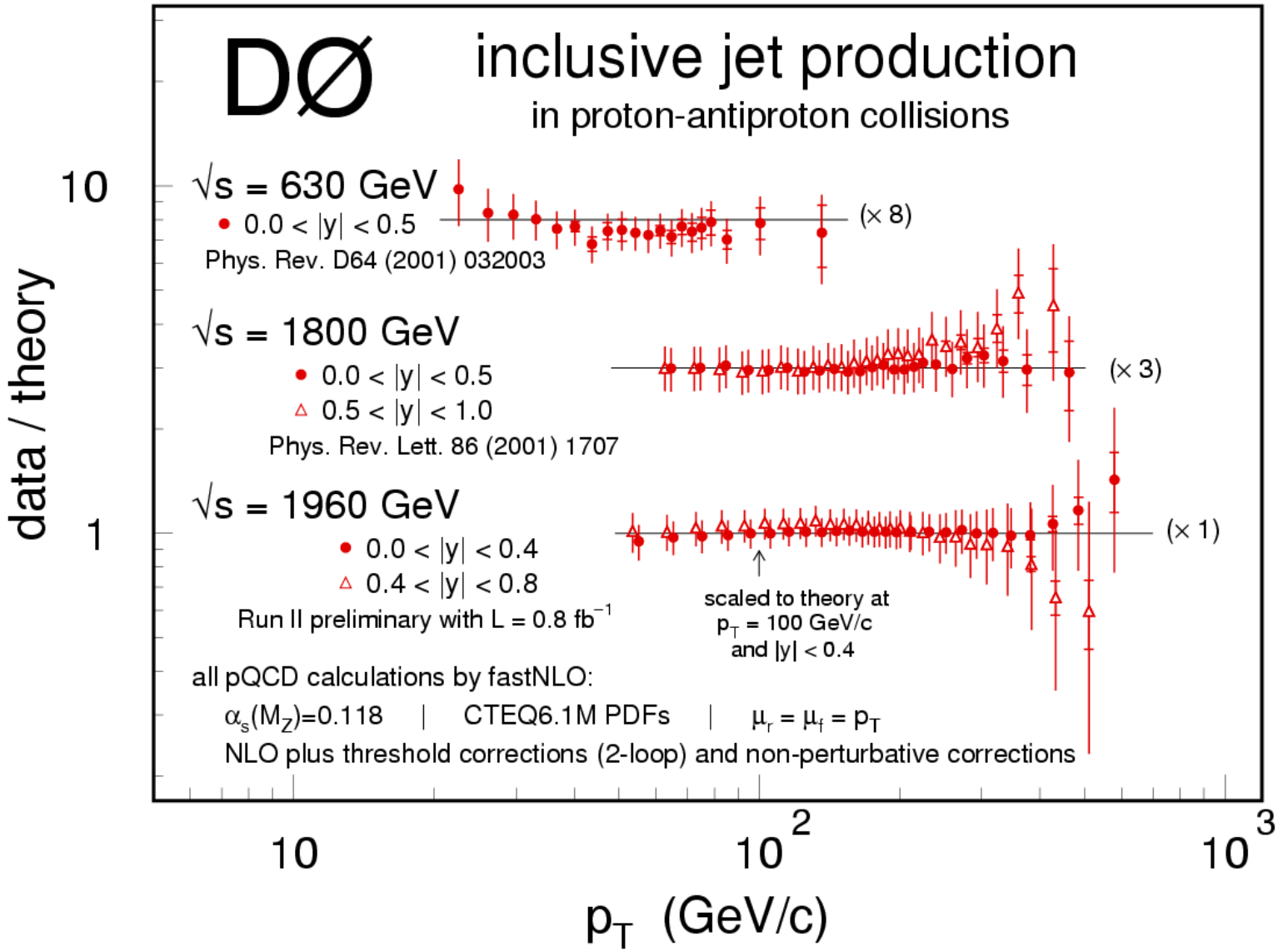




- 2-loop corrections reduced the scale sensitivity
- Systematic exp. errors dominated by Jet Energy Scale at high p_T
- Exp. uncertainties comparable with PDF ones from CTEQ ⇒ further constrain PDFs
- Potential sensitivity w.r.t. MRST and Alekhin PDF sets

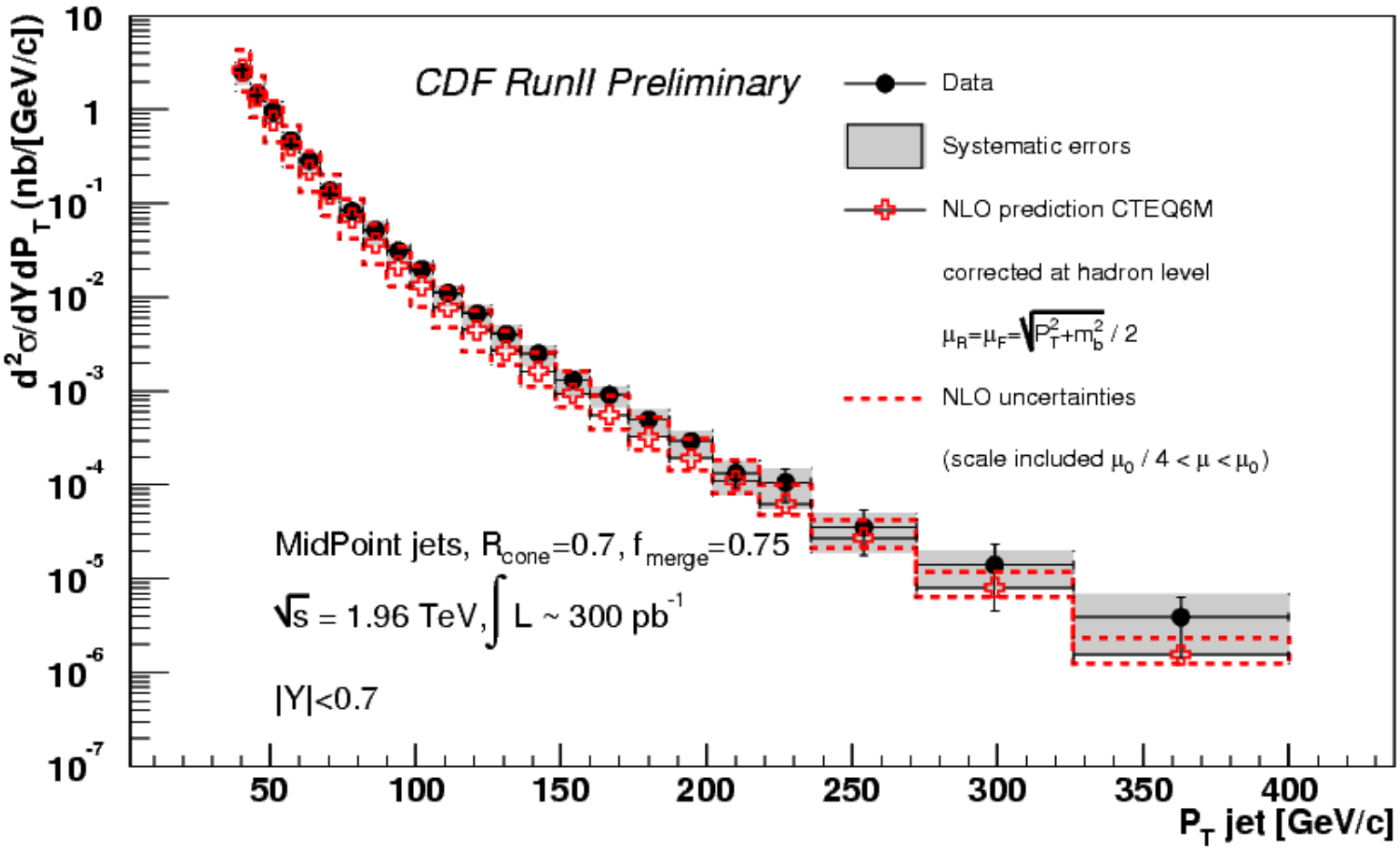
Inclusive Jets (D0)

Good agreement of theory and data over p_T range: 20-700 GeV



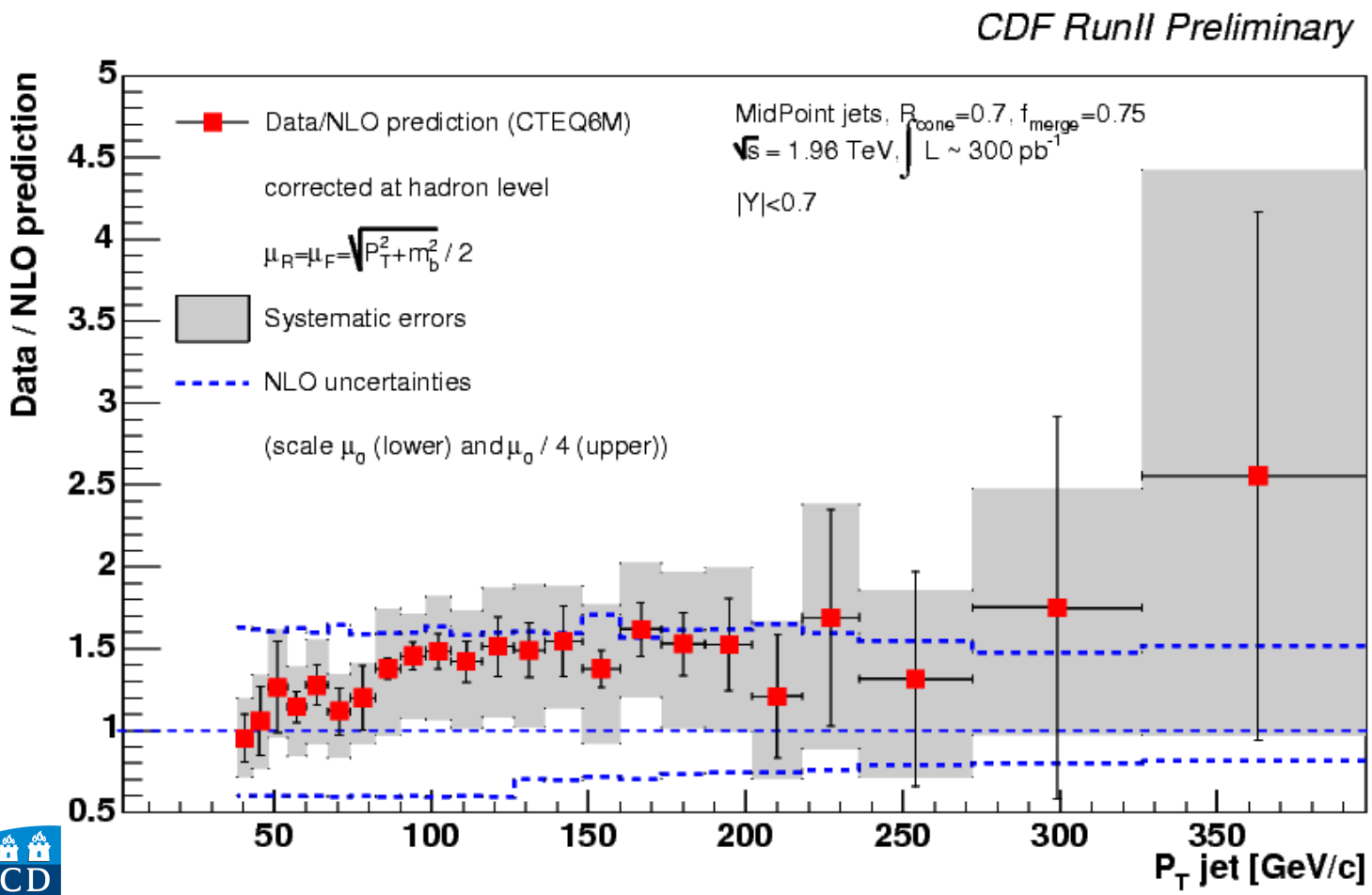
Inclusive b-jet cross section (CDF)

- **b-jet cross section measured in central region ($|y|<0.7$) for $40<p_T<400$ GeV**
- Reconstruct secondary vertex from B hadron decays
- Midpoint cone jets used
- **0.3 fb^{-1} data sample**



Inclusive b-jet cross section (CDF)

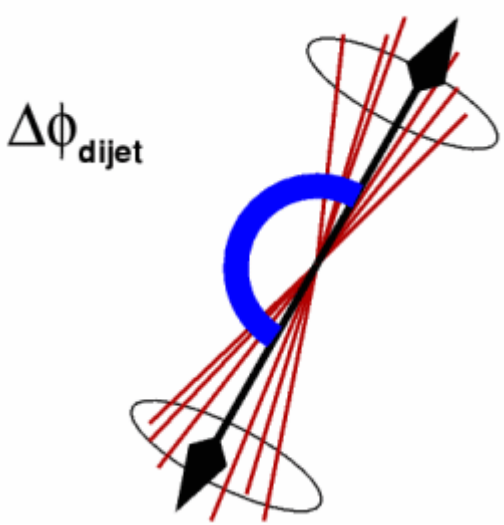
- Dominant syst. uncertainties: jet energy calibration, purity of tagged b-jet
- Data compared to NLO pQCD prediction (Mangano and Frixione) using CTEQ6M
- Large theoretical uncertainties due to renormalization and factorization scales at NLO (40-50% for p_T < 150 GeV)
- PYTHIA and HERWIG (not shown here) are too low by a factor of: 1.5 – 2



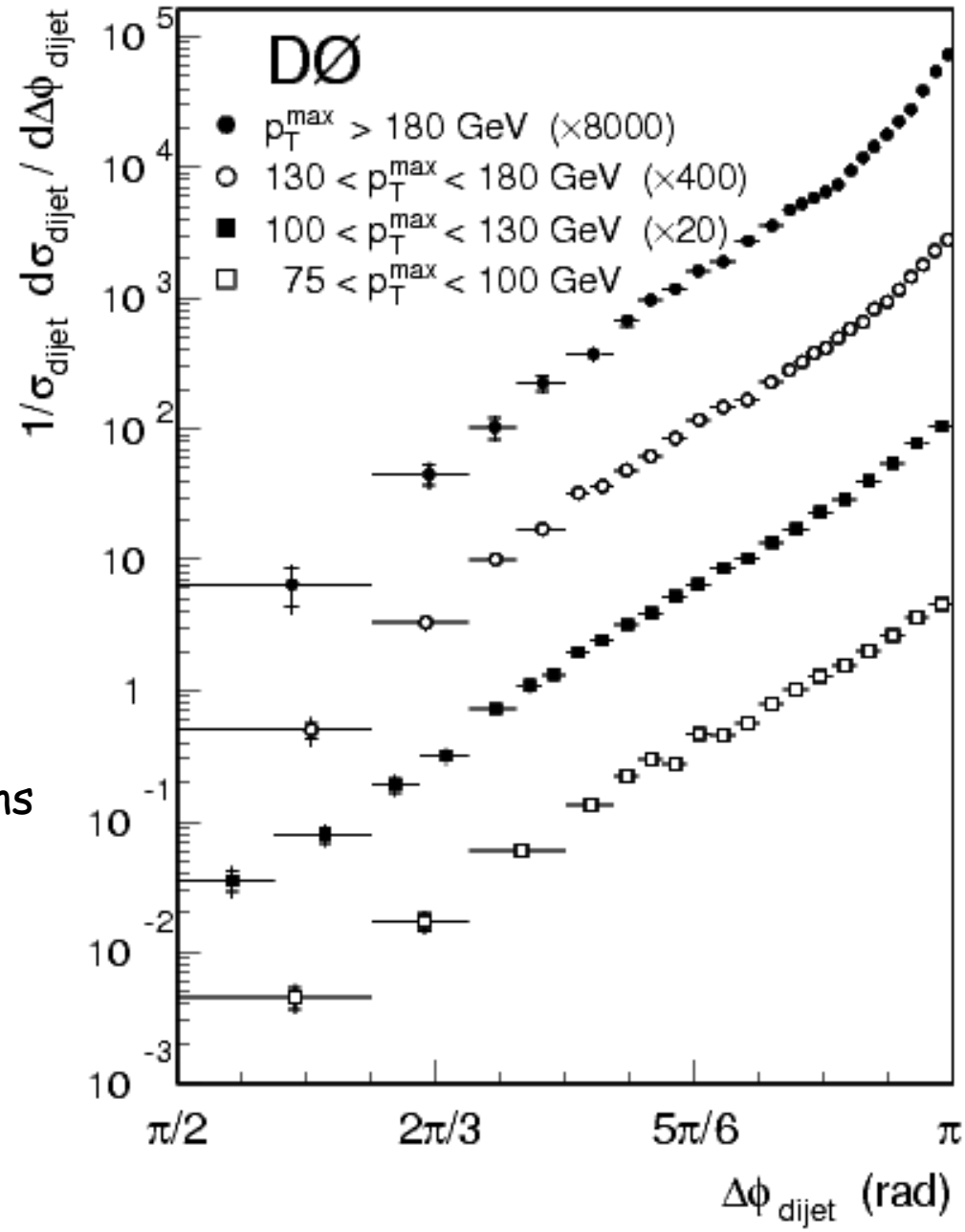
Data agree with NLO theory within errors

Dijet Azimuthal Decorrelation (D0)

- Dijet cross section as a function of the azimuthal angle between the two leading jets ($\Delta\phi$) in the central rapidity region
- $\Delta\phi$ is sensitive to Soft and Hard parton emissions:
  - Events with $\Delta\phi$ close to π are strongly affected by soft QCD effects ⇒ testing parton-showers
  - Events deviating from back-to-back topology are due to hard parton emissions ⇒ testing 3-jet NLO



- Four p_T^{max} bins
- **150 pb^{-1} data sample**

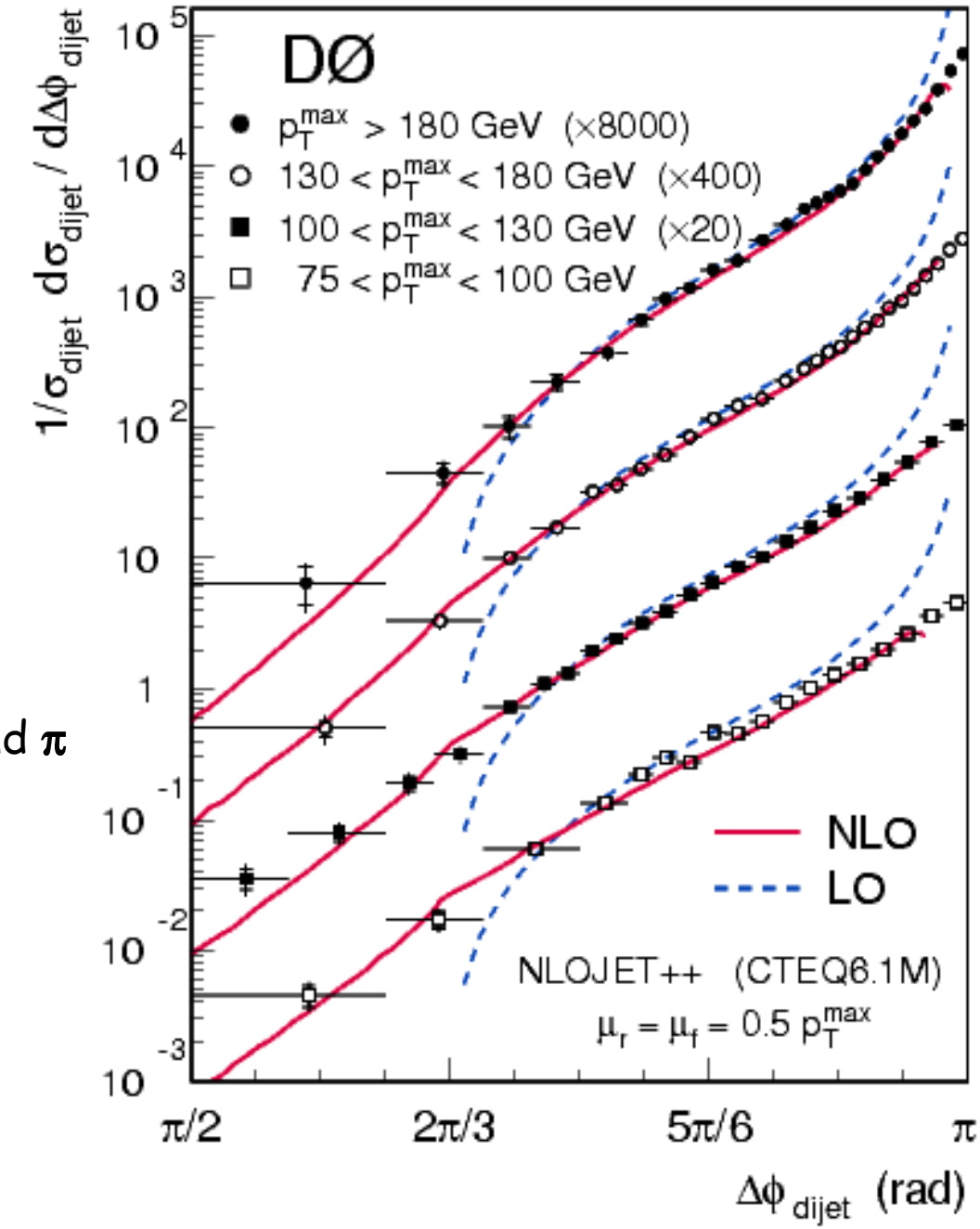


Dijet Azimuthal Decorrelation (D0)

Comparison with theory (NLOJET++ using CTEQ6.1M):

LO: limitated to $\Delta\phi > 2\pi/3$
diverges near $\sim\pi$

NLO: good down to $\pi/2$
becomes better toward π
resummation is needed around π



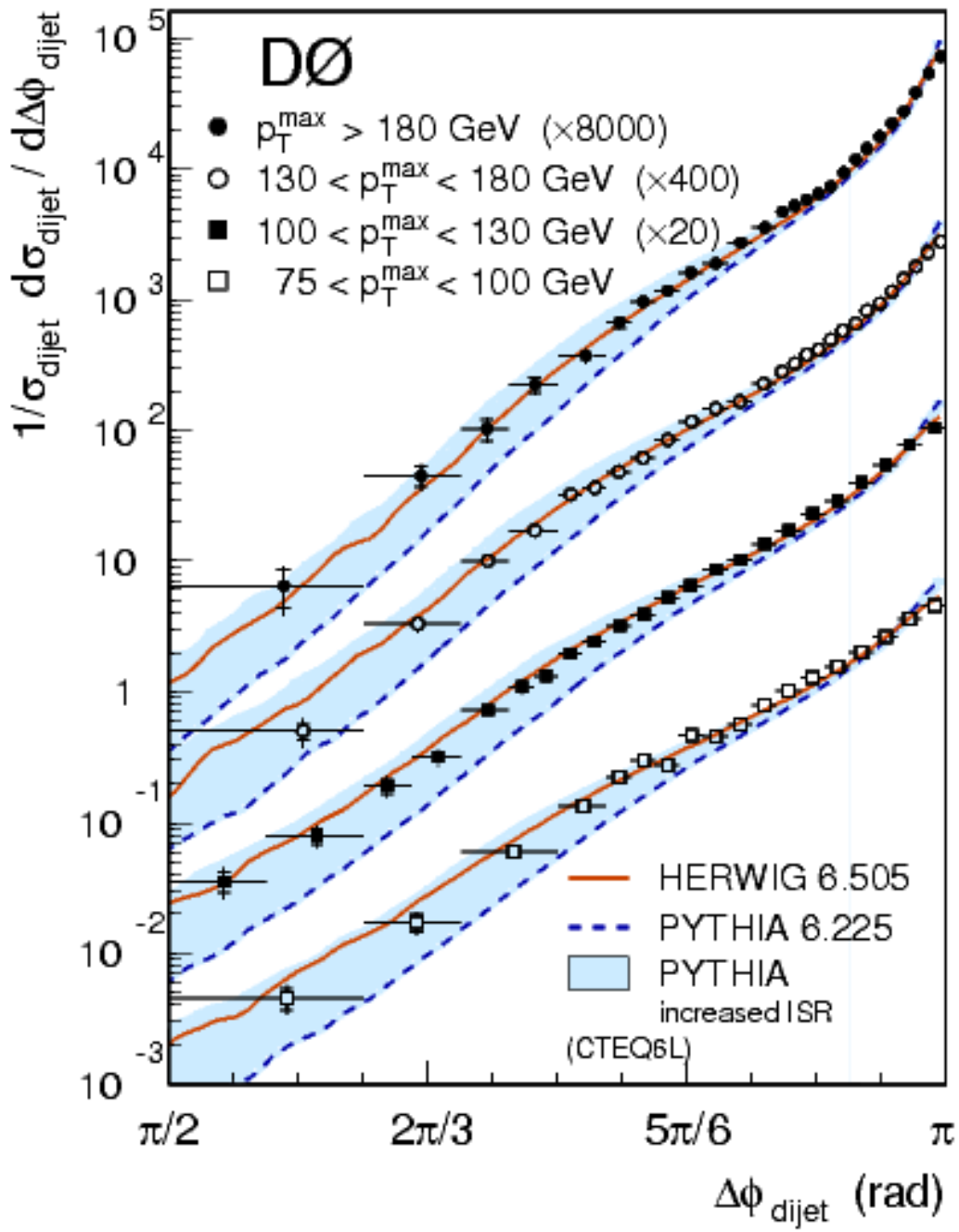
Dijet Azimuthal Decorrelation (D0)

Comparison with theory:
(using CTEQ6L):

HERWIG: very good agreement "out-of-the-box"

Data agree very well with **SHERPA** and **ALPGEN** predictions too (not shown in the figure)

PYTHIA: too low at smaller $\Delta\phi$ (can be tuned by increasing ISR)



Summary

New measurements based on ~1 fb^{-1} are available / in progress
Expect more statistics within next 2 years (~8 fb^{-1} by 2009)

New jet algorithms are being used (midpoint cone, k_T) having better theoretical behaviour than in Run I

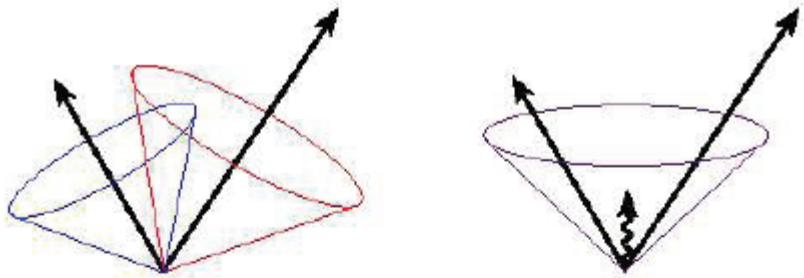
Improved understanding of jet energy calibration in Run II

Experimental errors are comparable with theoretical errors from PDF uncertainties; data can be used to better constrain q and g densities in proton.

Various NLO QCD approximations tested successfully

BACKUP slides

Jet Algorithms (1)



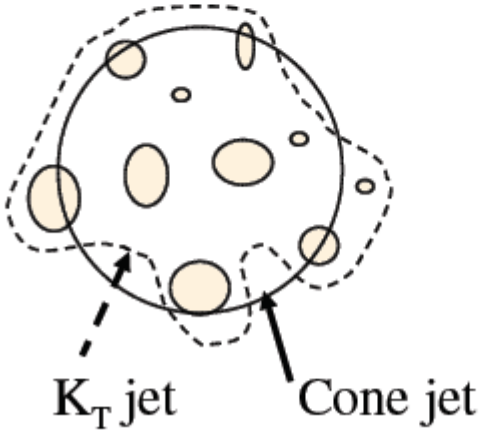
Run I Legacy Cone:

- Draw a cone of fixed size in $\eta-\phi$ space around a seed
- Compute jet axis from E_T-weighted mean and jet E_T from ΣE_T's
- Draw a new cone around the new jet axis and recalculate axis and new E_T
- Iterate until stable
- Algorithm is sensitive to soft radiation

Improved Run II Cone : "Joint Jet Working Group"

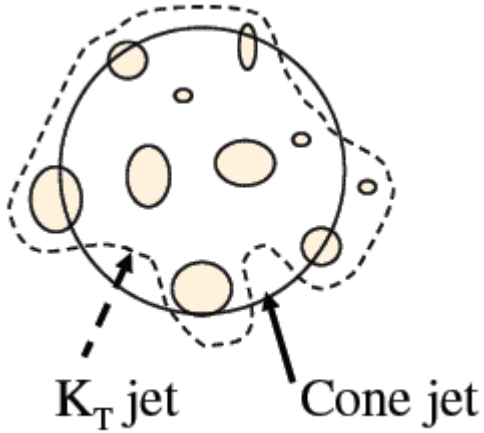
- Use 4-vectors instead of E_T
- Add additional midpoint seeds between pairs of close jets
- Split/merge after stable protojets found
- Improved infrared safety at NLO

(D0 Run II/CDF MIDPOINT)



V. O'Dell

Jet Algorithms (2)



CDF k_T algorithm in Run II:

- Iterative procedure
- Closest pair are recombined into one until the mutual distance is lower then some cut
- No fixed geometrical shape
- No splitting or merging
- Infrared/collinear safe

Jet Energy Calibration

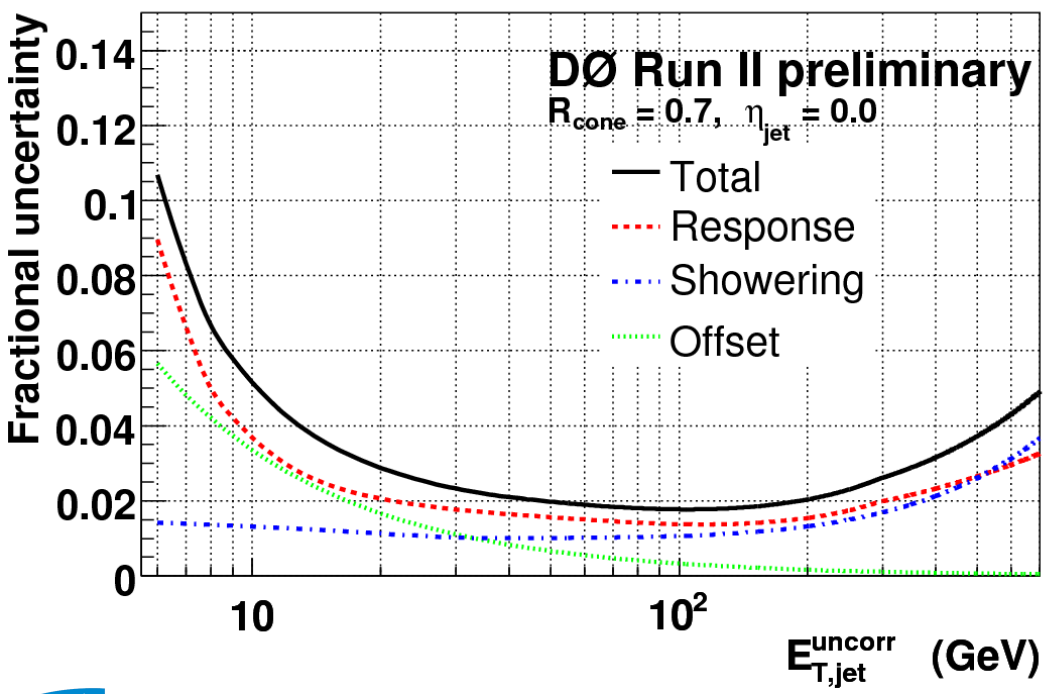
DØ:

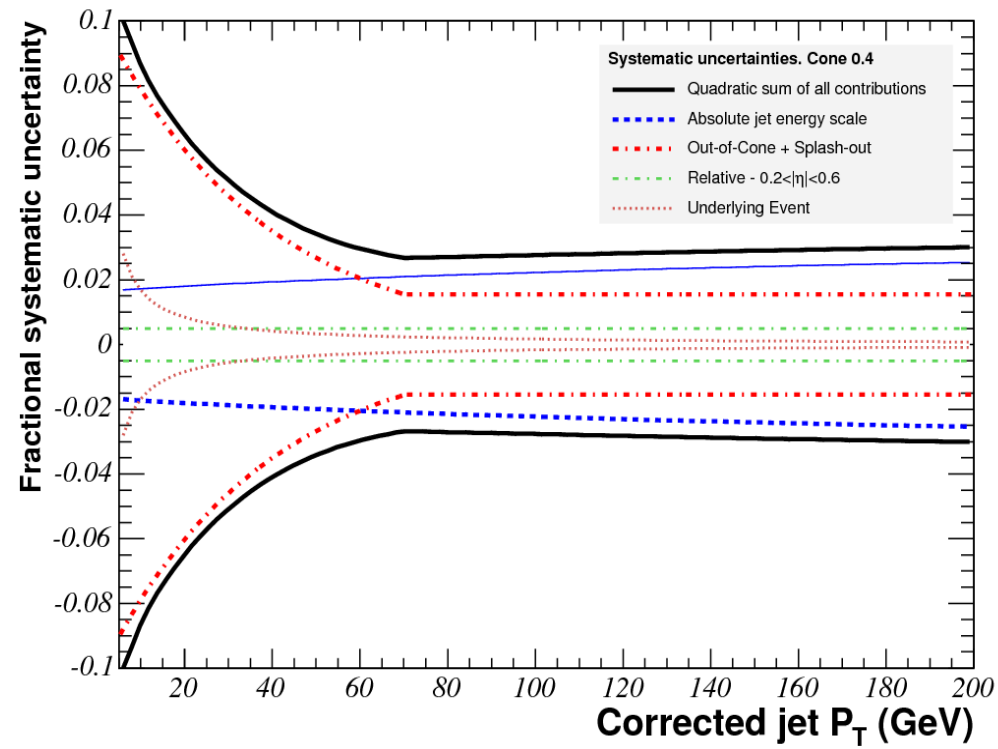
- In-situ calibration From p_T imbalance in γ+jet events
- Precision of Run I reached for p_T<200 GeV

  preliminary version used only ~10% of available γ+jet statistics

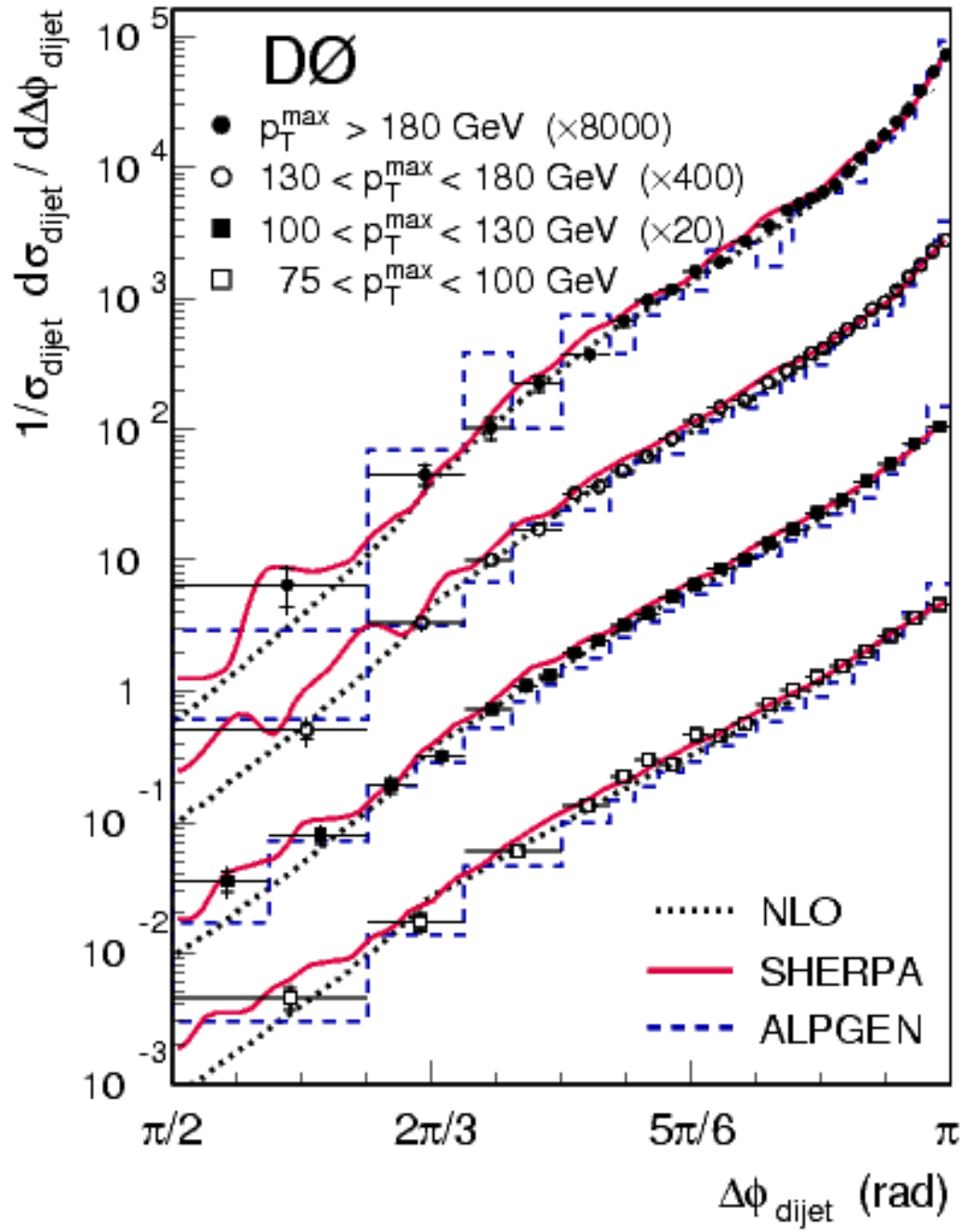
CDF:

- Calibration based on MC simulation
- MC single particle response and fragmentation is tuned on data
- Precision better than in Run I *especially in the forward region*





Dijet Azimuthal Decorrelations (D0)

150 pb^{-1} data sample compared with prediction by:

- NLO
- SHERPA
- ALPGEN