Inclusive Jet Production at the Tevatron

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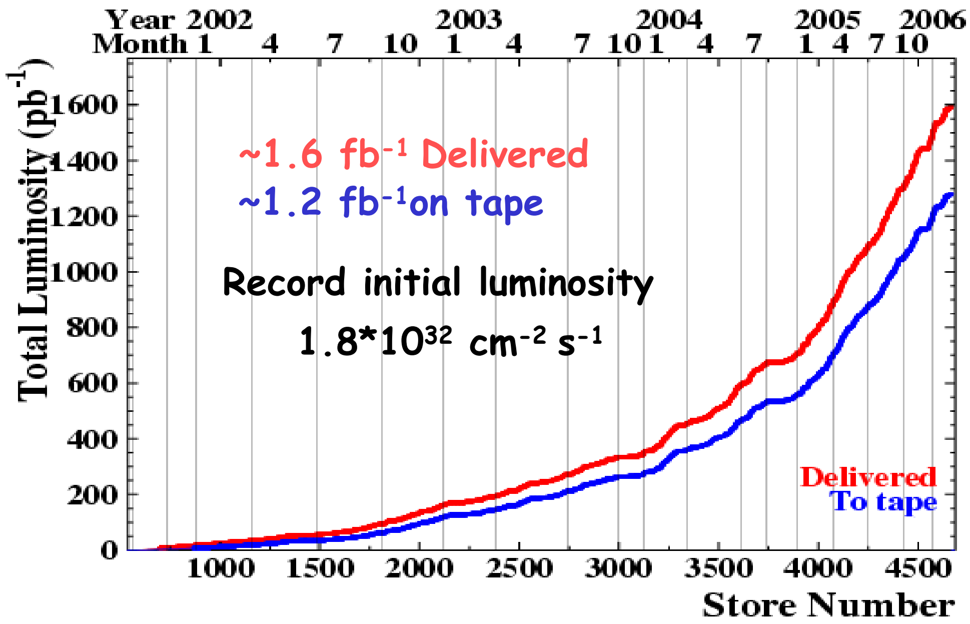
On behalf of the CDF Collaboration

Deep Inelastic Scattering Workshop 2006

Tevatron & CDF II

- → Proton - antiproton collider
- → $\sqrt{s}$ = 1.96 TeV (Run I → 1.8TeV)

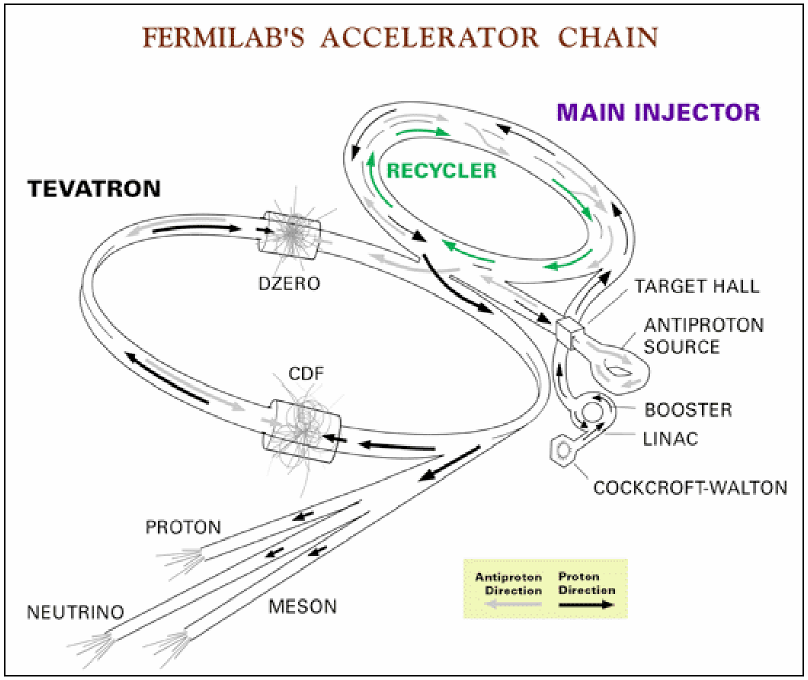


~1.6 fb^{-1} Delivered

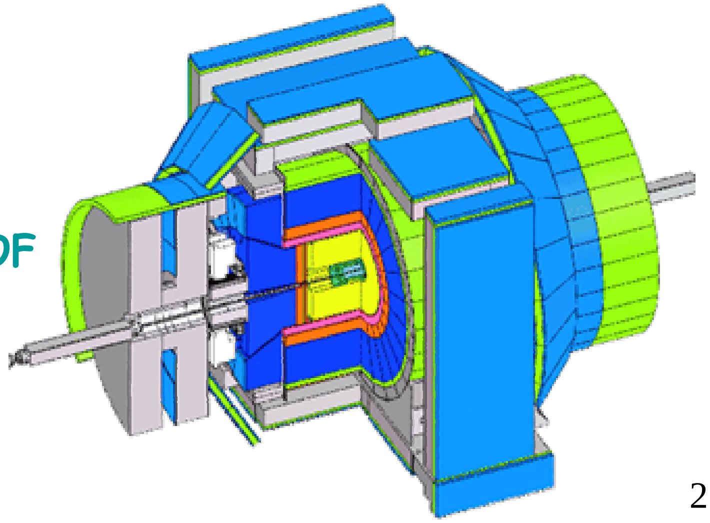
~1.2 fb^{-1}on tape

Record initial luminosity

$1.8*10^{32}$ cm^{-2} s^{-1}

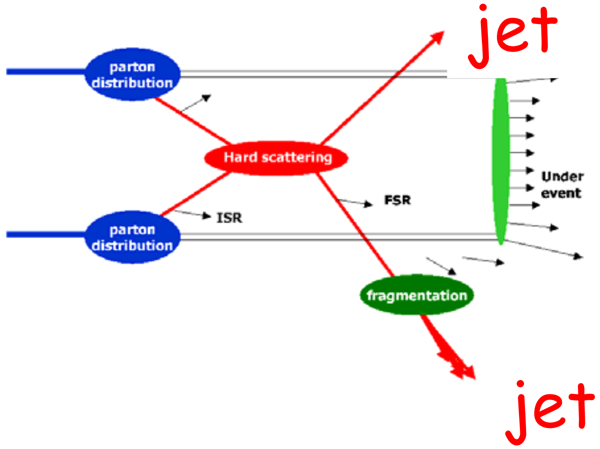


- → CDF detector was highly upgraded for Run II
  - New Silicon tracking, drift chamber and TOF
  - New Plug Calorimeters
  - Upgraded Muon system
  - New DAQ electronics & Trigger



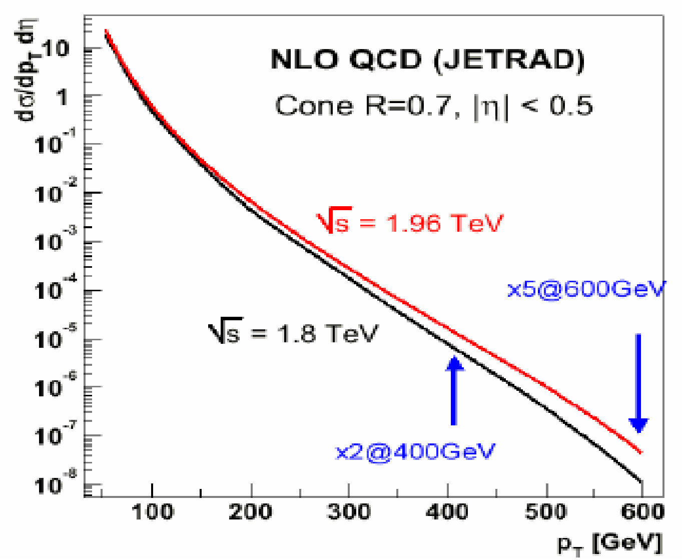
Jets @ Tevatron

Jet production



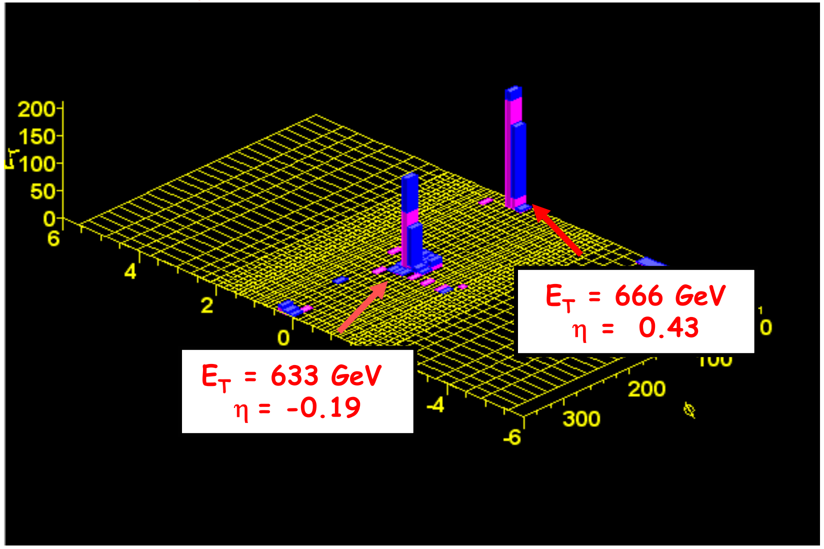
→ Stringent test of p-QCD
  - Over 9 order of magnitude
  - Sensitivity to distances ~ 10^{-19} m

→ Tail sensitive to new physics and PDFs

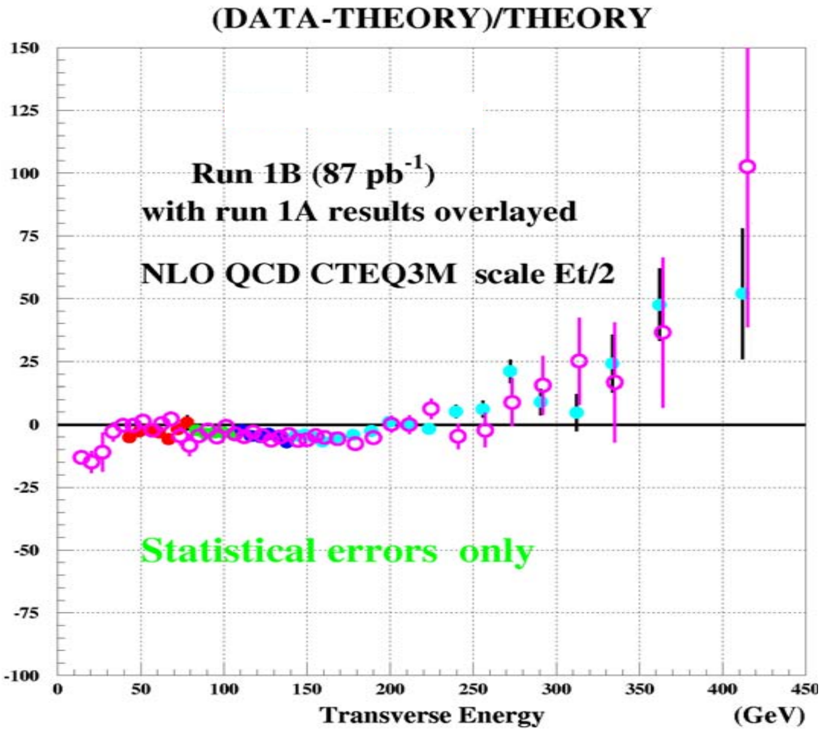


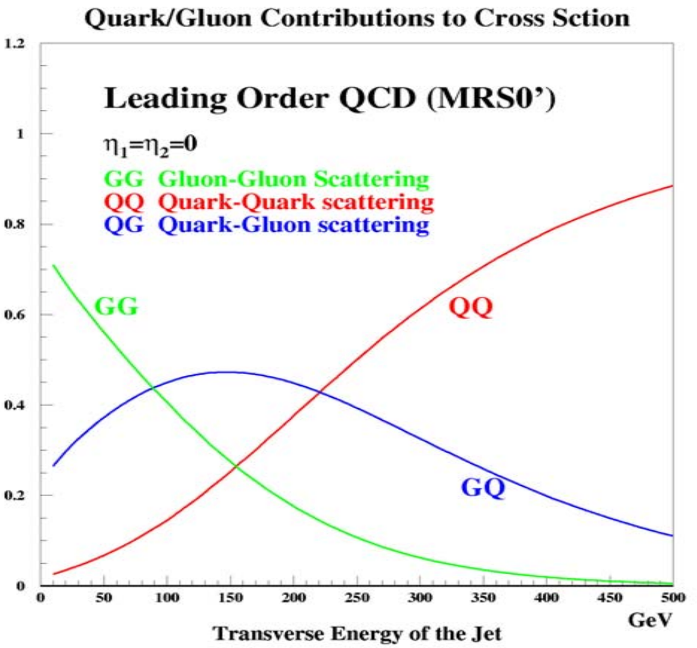
- Higher σ_{jet} with respect to RunI
- Increased p_T range for jet production

Highest dijet mass so far: Mass ≅1.3 TeV



Run I cross section

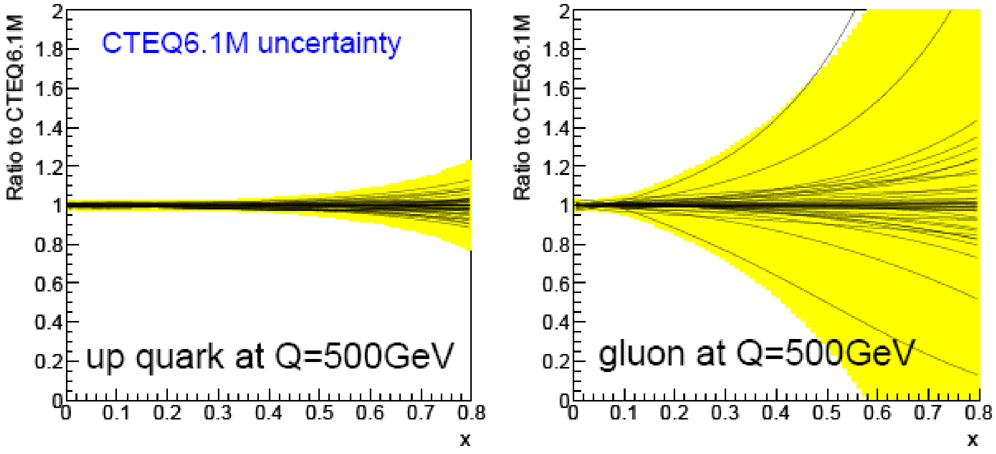




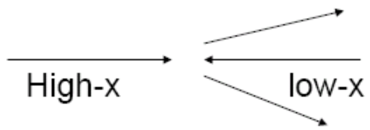
- Excess at high-E_T → new physics?

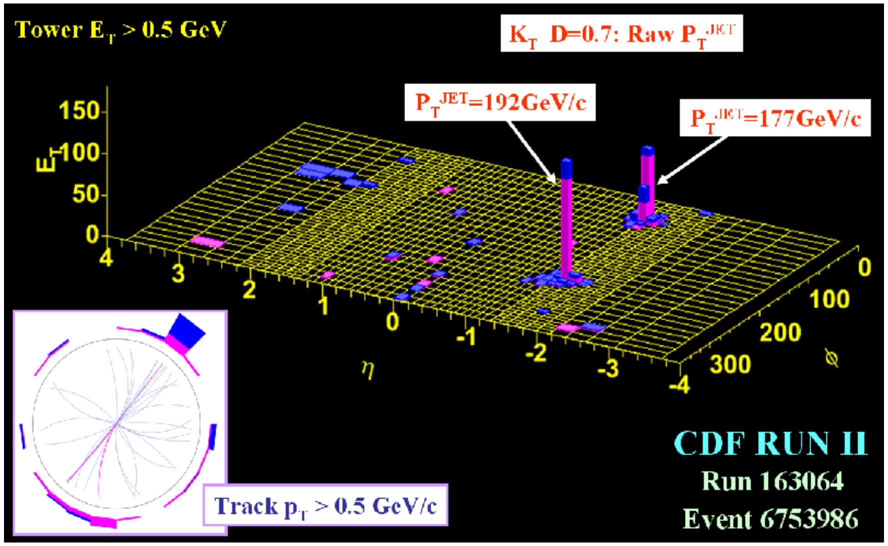
- Important gluon-gluon and gluon-quark contributions at high-E_T

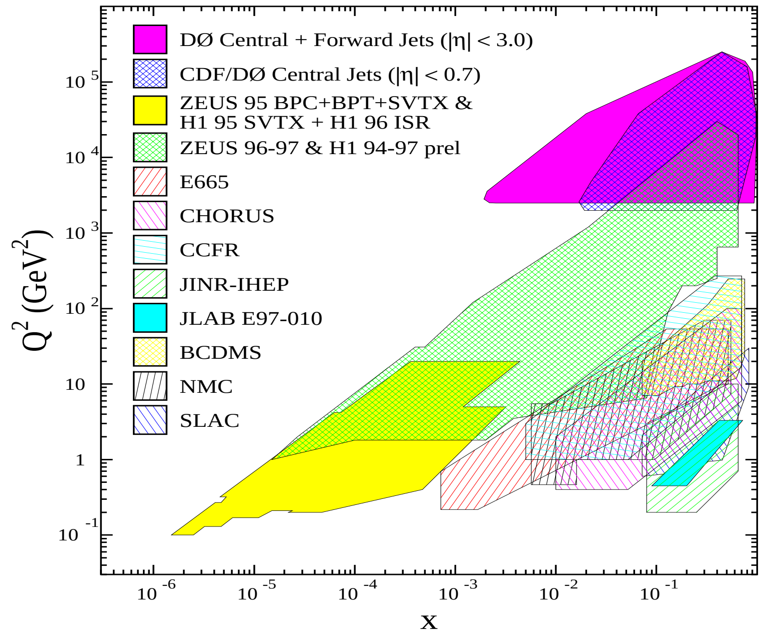
- Gluon pdf at high-x not well known

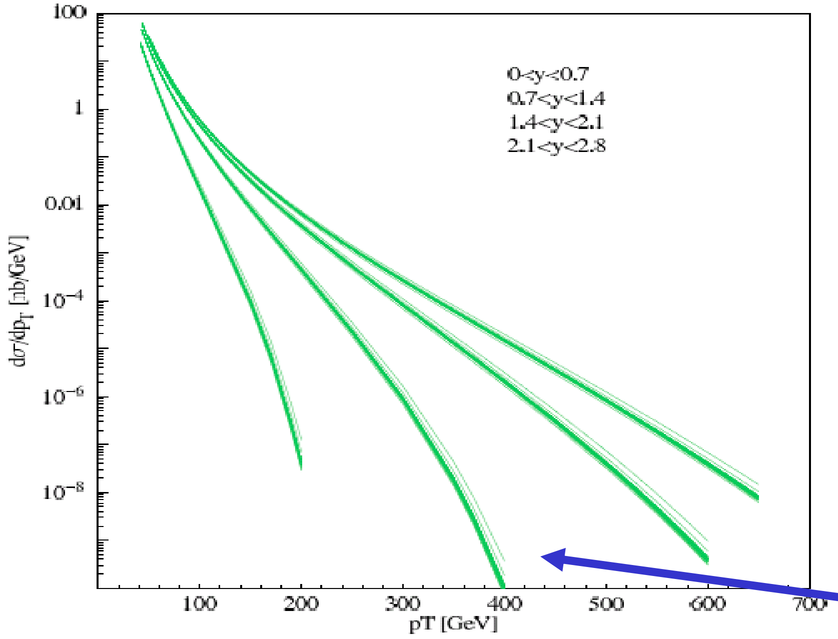


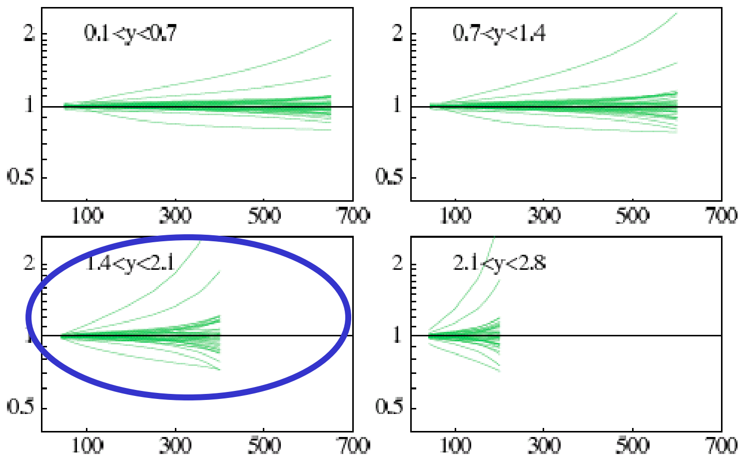
Cross section vs η









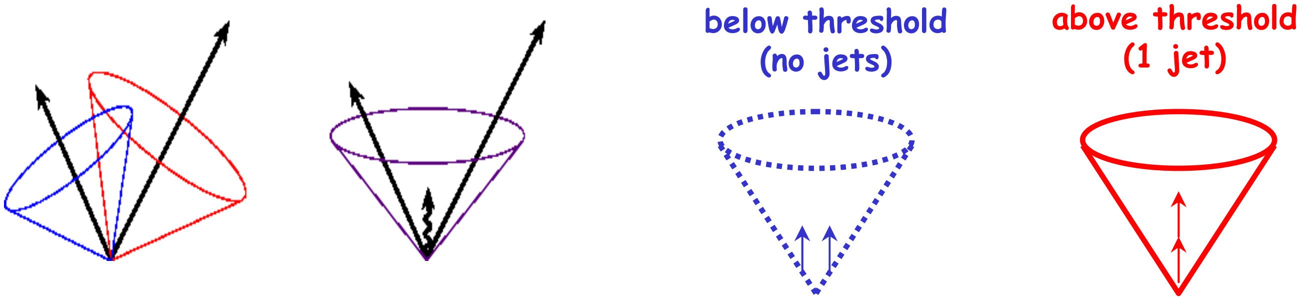


Measurements in the **forward region** allow to constrain the gluon distribution

Jet Measurement: Cone algorithms

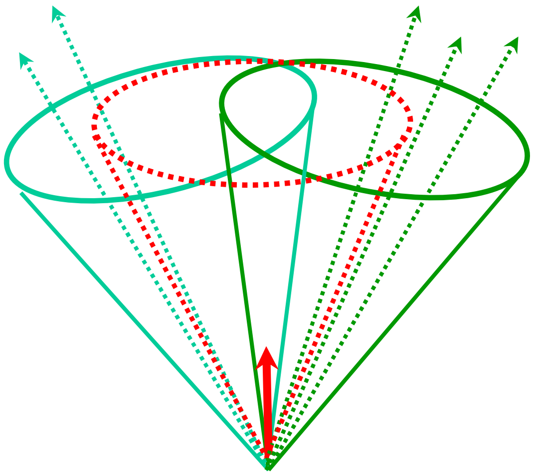
Precise jet search algorithm necessary to compare with theory

→ Run I cone-based algorithm is not infrared/collinear safe to all orders in p-QCD



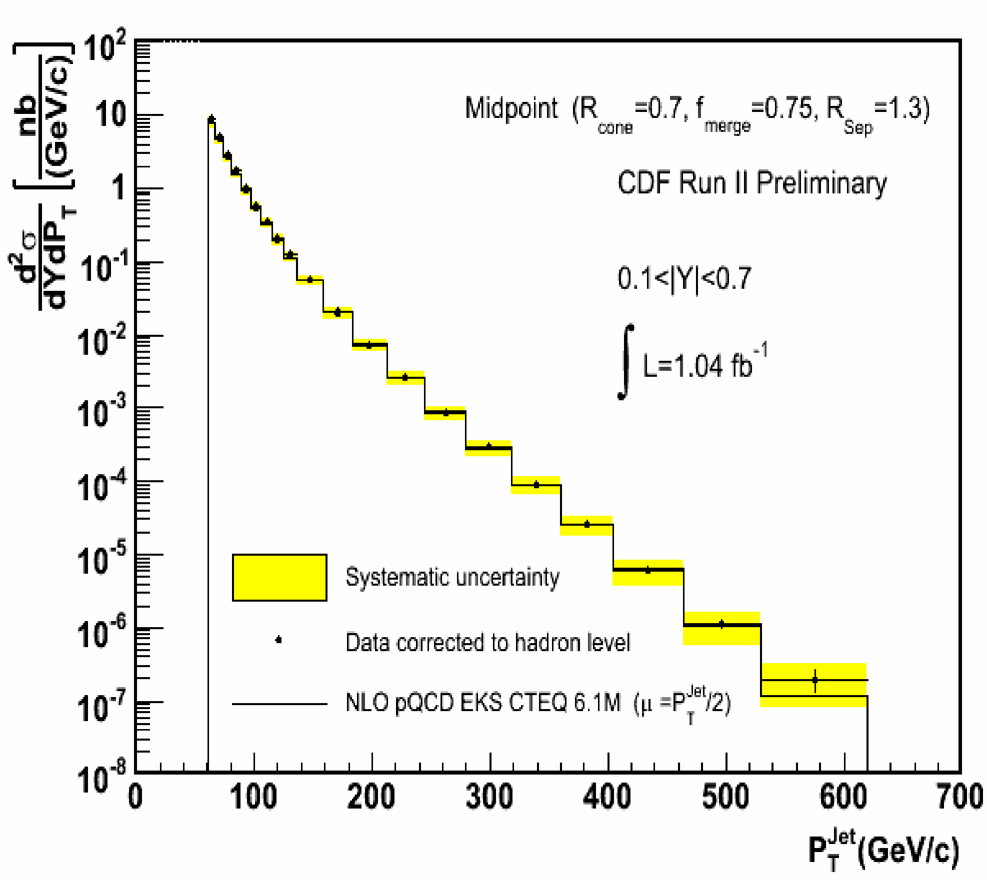
→ Run II ⇒ new cone-based algorithm: MidPoint

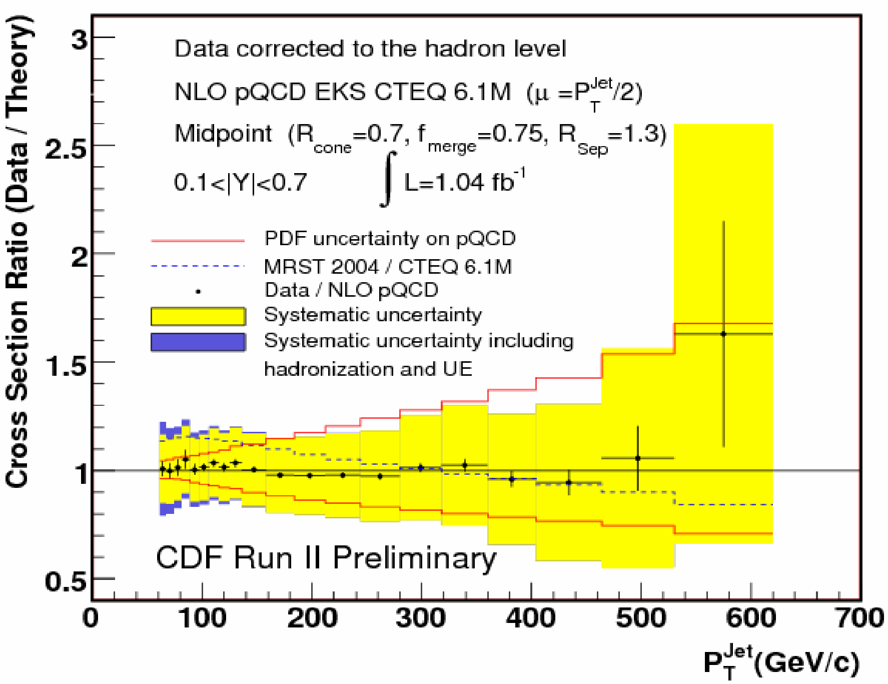
1. Draw a cone of radius R around each seed (CAL tower with E > 1GeV) and form "proto-jet"
2. Draw new cones around "proto-jets" and iterate until stable cone
3. Put seed in Midpoint (η-ϕ) for each pair of proto-jets separated by less than 2R and iterate for stable jet
4. Merging/Splitting



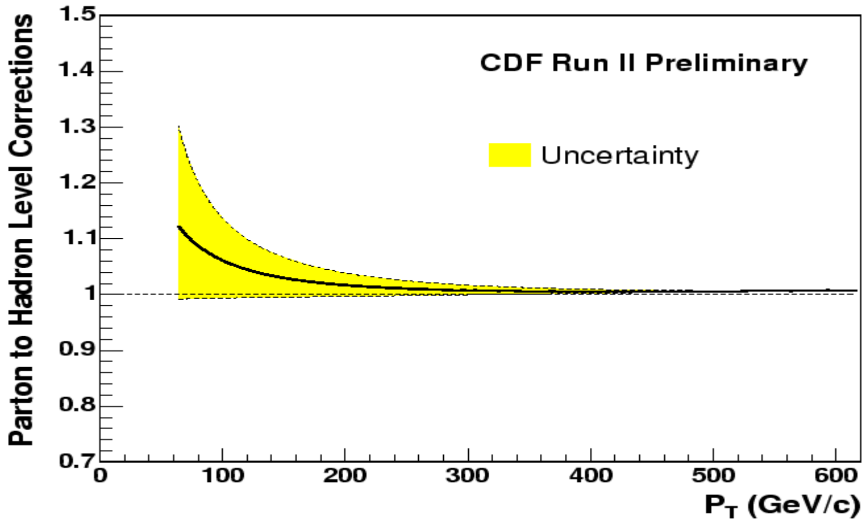
Jets cross sections using MidPoint(~ 1fb^{-1})

Results   0.1 <|Y^{Jet} | <0.7



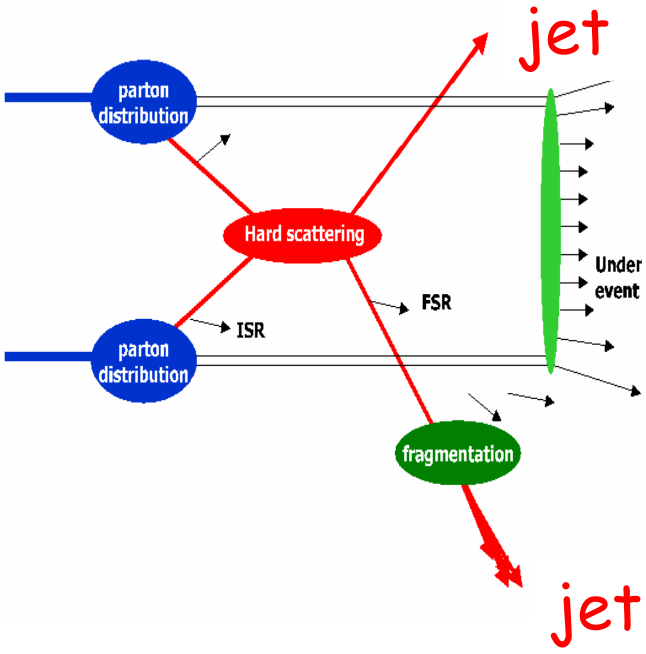


Good agreement with NLO

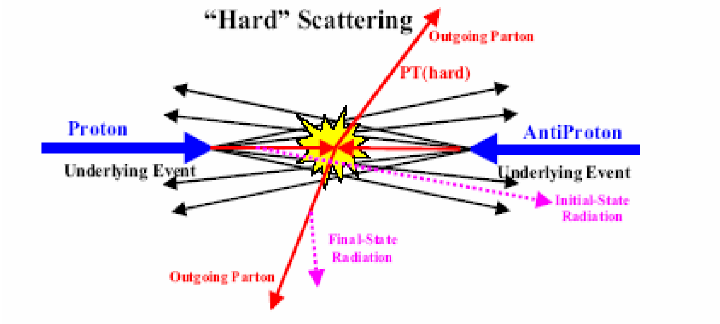


NLO corrections

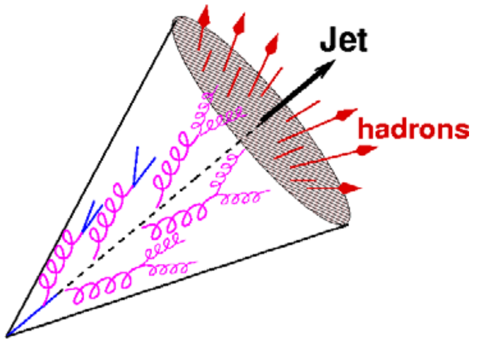
For comparison to NLO pQCD calculations corrections have to be applied for Underlying event and Hadronization effect (model dependent)



Underlying event



Hadronization

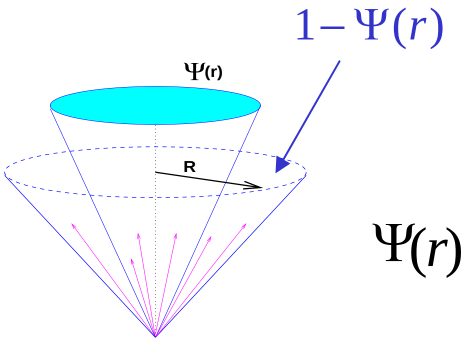


- Correction parton-hadron level based on PYTHIA Tune A MC

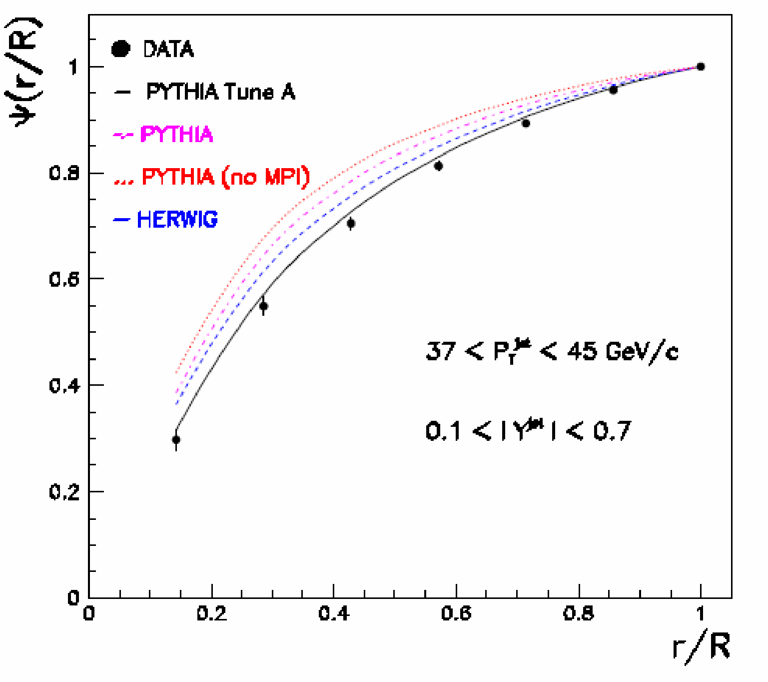
MC modeling

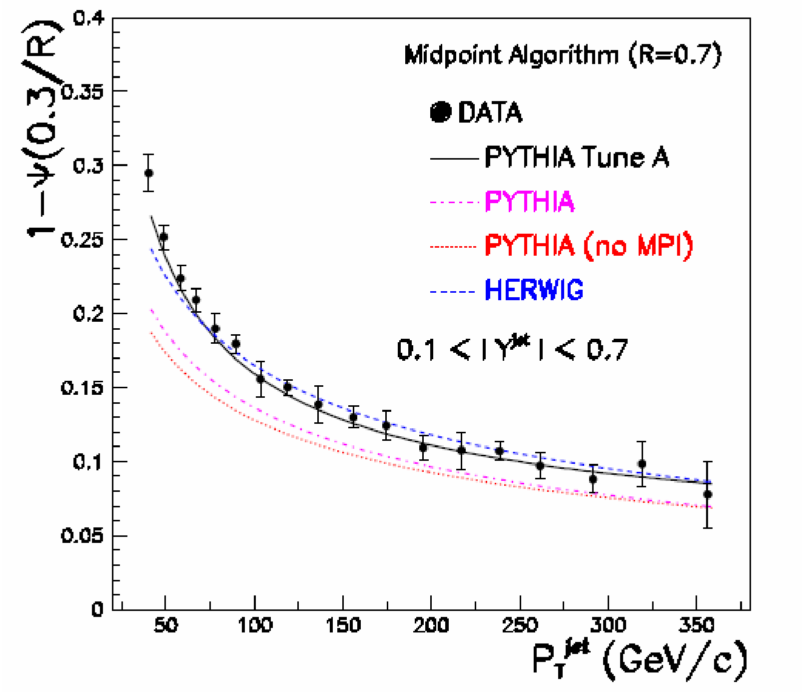
→ Jet Shape measurements

- **Test of** **parton shower** **models**
- **Sensitive to the** **underlying event**



$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T(0,R)}$$





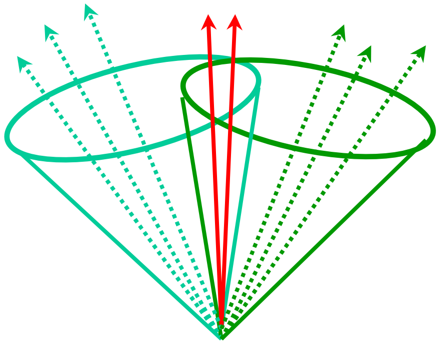
CDF publication: Phys. Rev. D71, 112002 (2005)

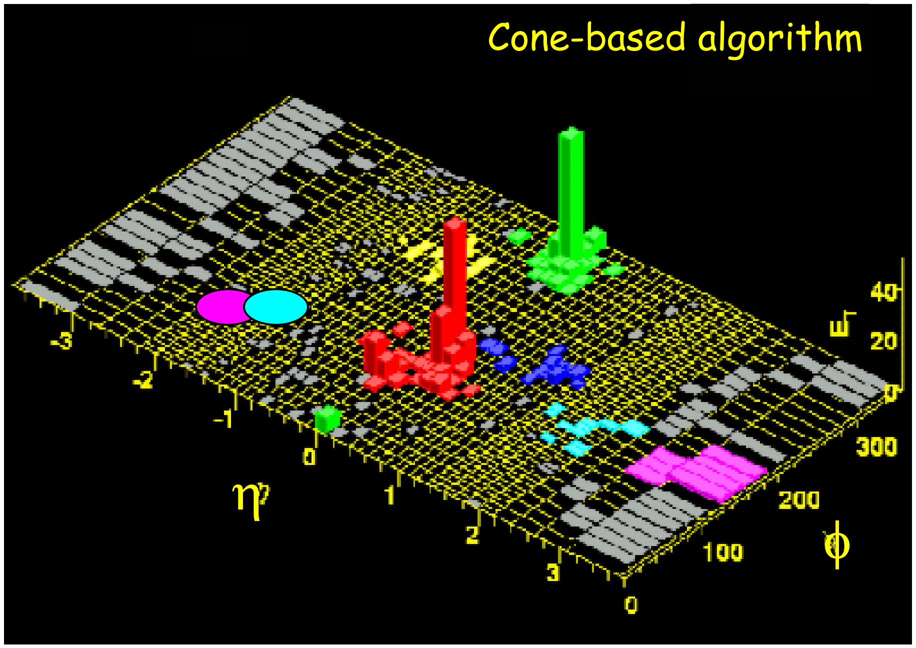
- PYTHIA Tune A provides a proper modeling of the underlying event contributions

MidPoint algorithm: merging/splitting

→ Look for possible overlap

- **Cone-based jet algorithms include an "experimental" prescription to resolve situations with overlapping cones**

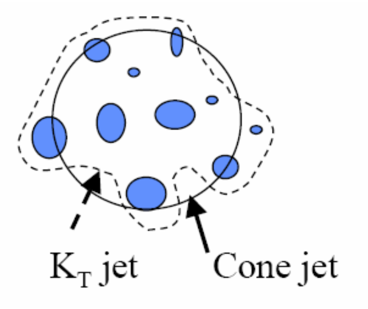




merged if common E is more than 75 % of smallest jet ← **This is emulated in pQCD theoretical calculations by an arbitrary increase of the cone size : R → R' = R * R_{sep}**

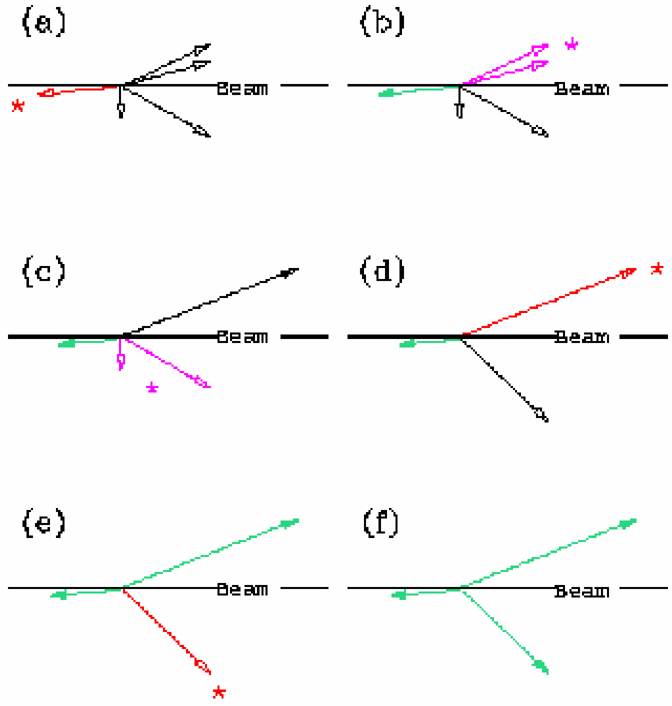
- Theory suggests to separate jets according to their relative transverse momentum

K_T algorithm



→ K_T Algorithm preferred by theorists

- Separate jets according to their relative transverse momentum



1. **Compute for each pair (i,j) and for each particle (i) the quantities:**

$$d_{ij} = \min(P^2_{T,i}, P^2_{T,j})\frac{\Delta R^2}{D^2} \qquad d_i = (P_{T,i})^2$$

2. **Starting from smallest $\{d_{ij}, d_i\}$:**

   - If it is a d_i then it is called a jet and is removed from the list

   - If it is a d_{ij} the particles are combined in "proto-jets" (E scheme)

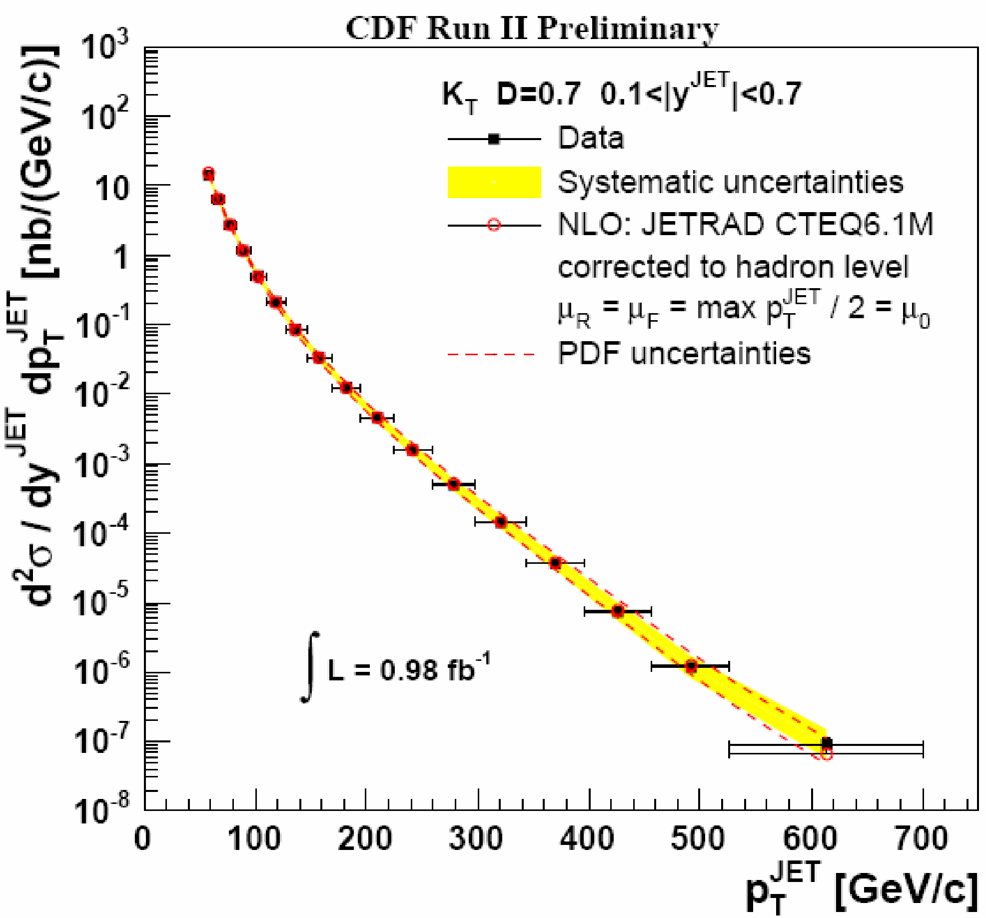
3. **Iterate until all particles are in jets**

- Infrared/collinear safe to all order in p-QCD (relevant for NNLO)
- No merging/splitting parameter needed

Successfully used at LEP and HERA but its is relatively new in hadron colliders ⇨ more difficult environment (Underlying Event, Multiple pp interactions)

Jets cross sections using K_T (~ $1 fb^{-1}$)

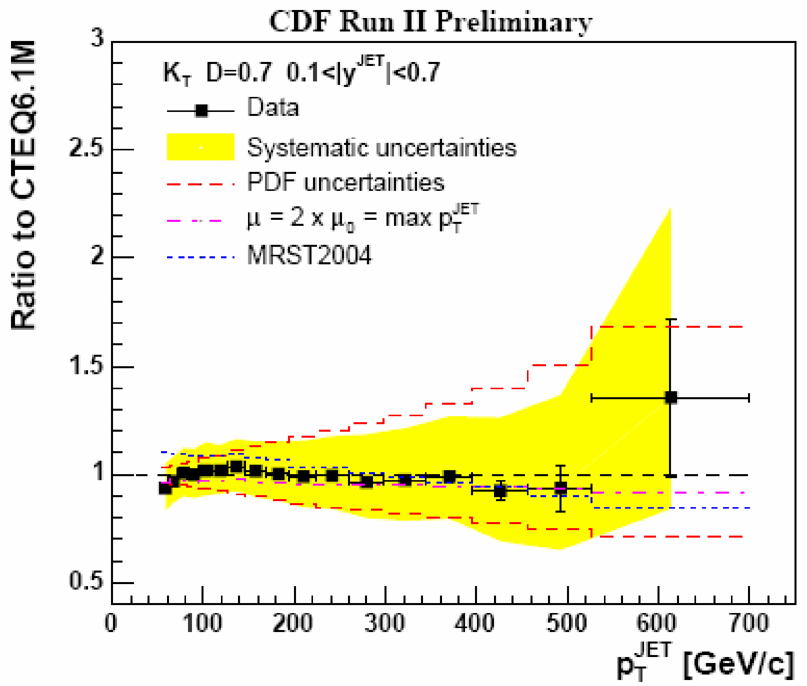
Results 0.1 <|y^{Jet} | <0.7

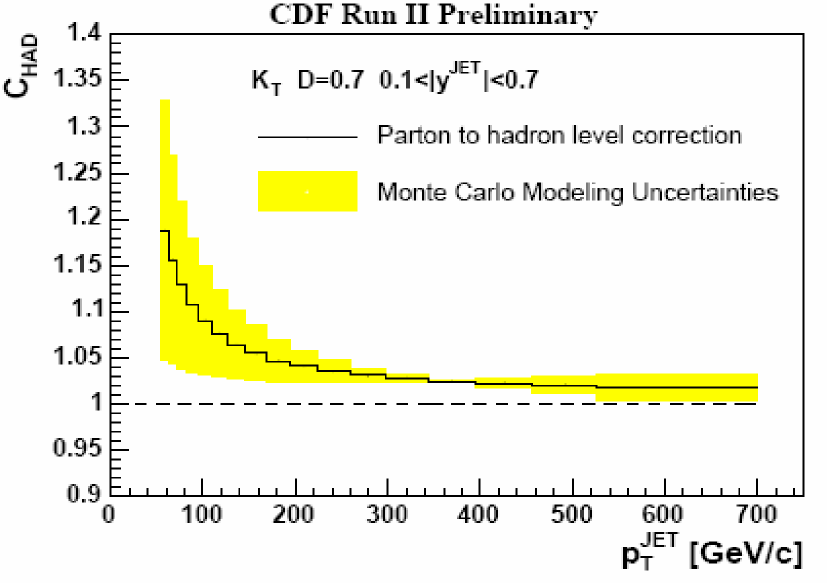


Good agreement with NLO

Recent CDF publication with 385 pb^{-1}

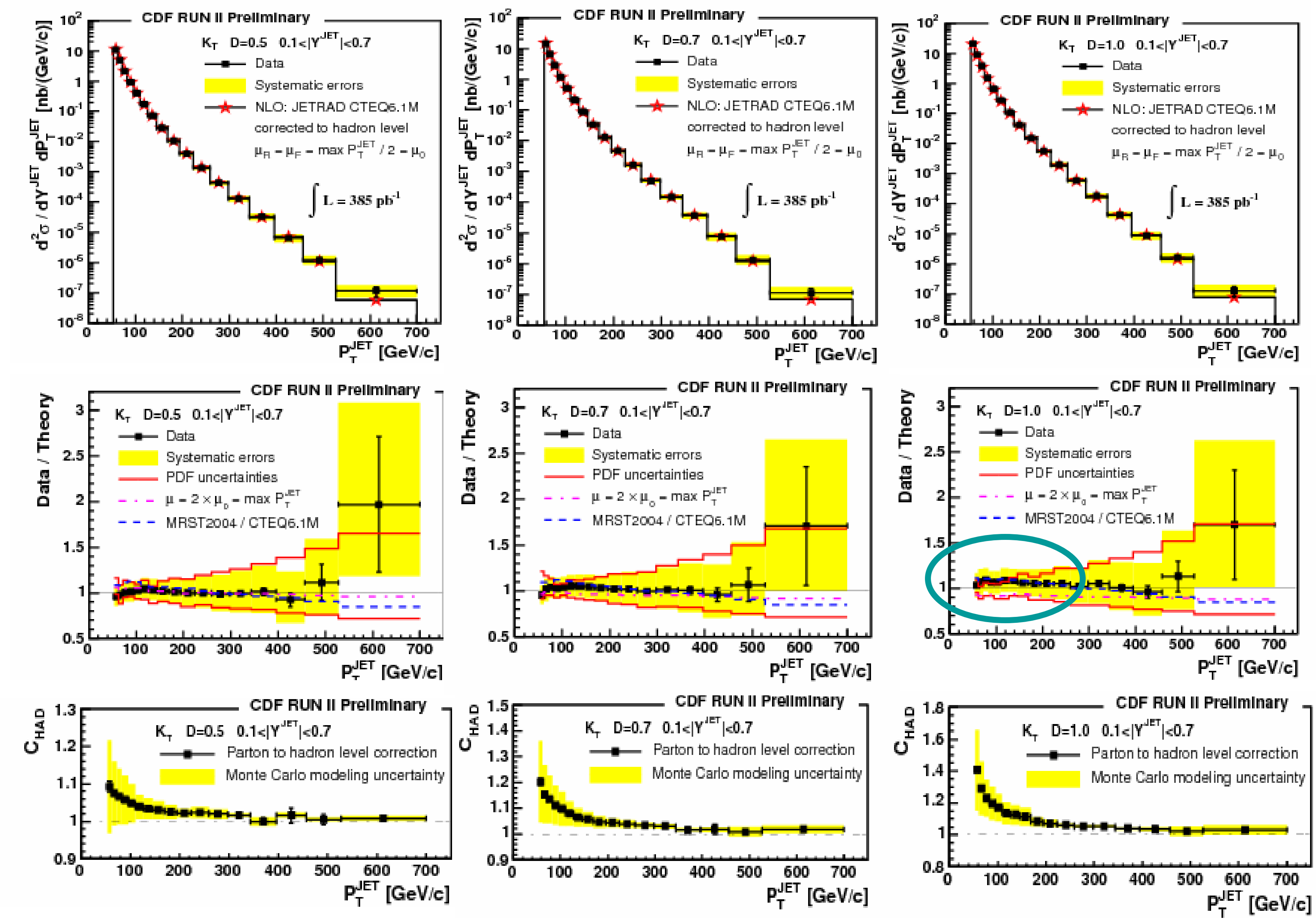
Phys. Rev. Lett.96, 122001 (2006)





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

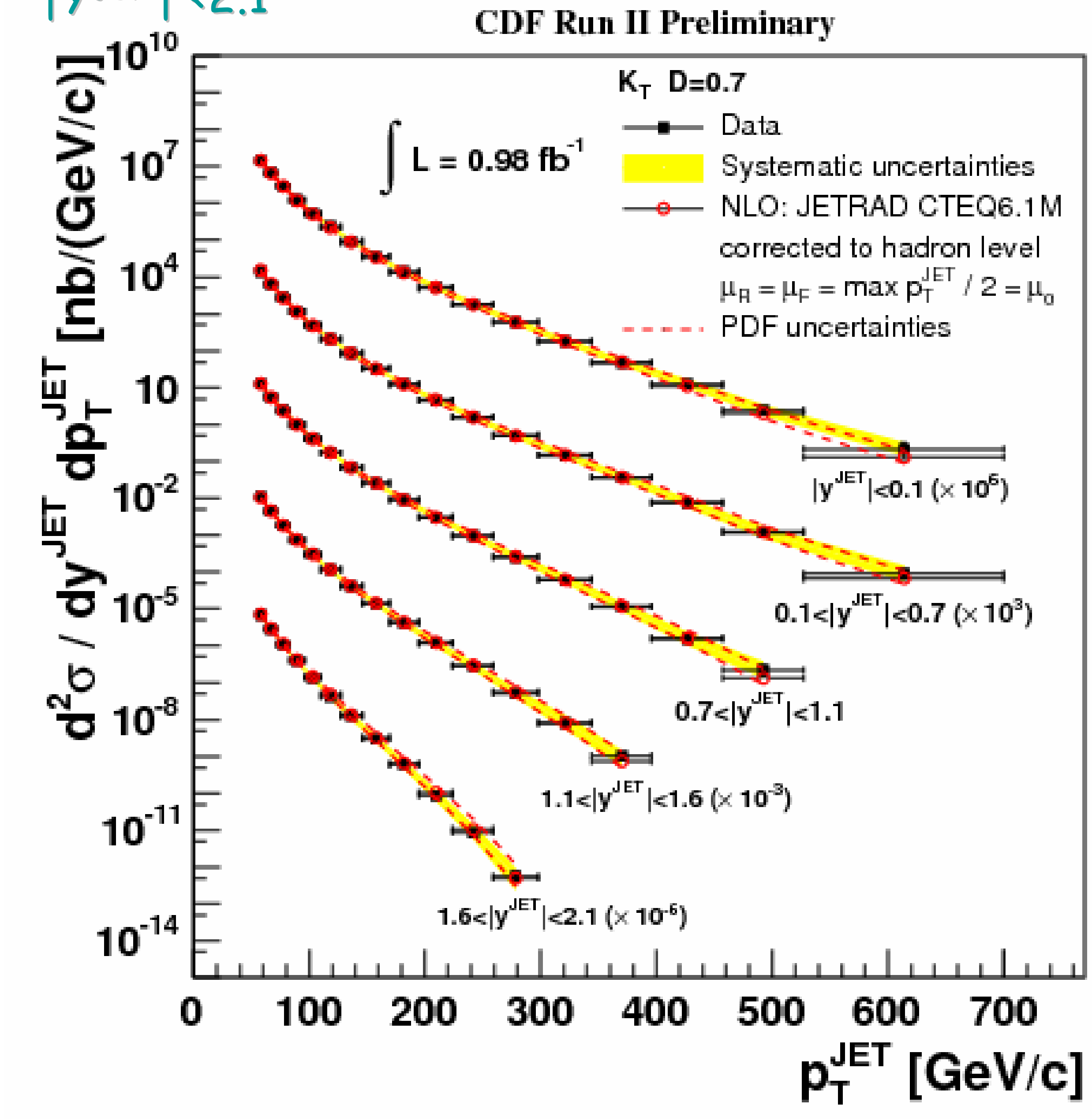
K_T Jets vs D



- Parton-hadron corrections are important at low P_T → they are under control

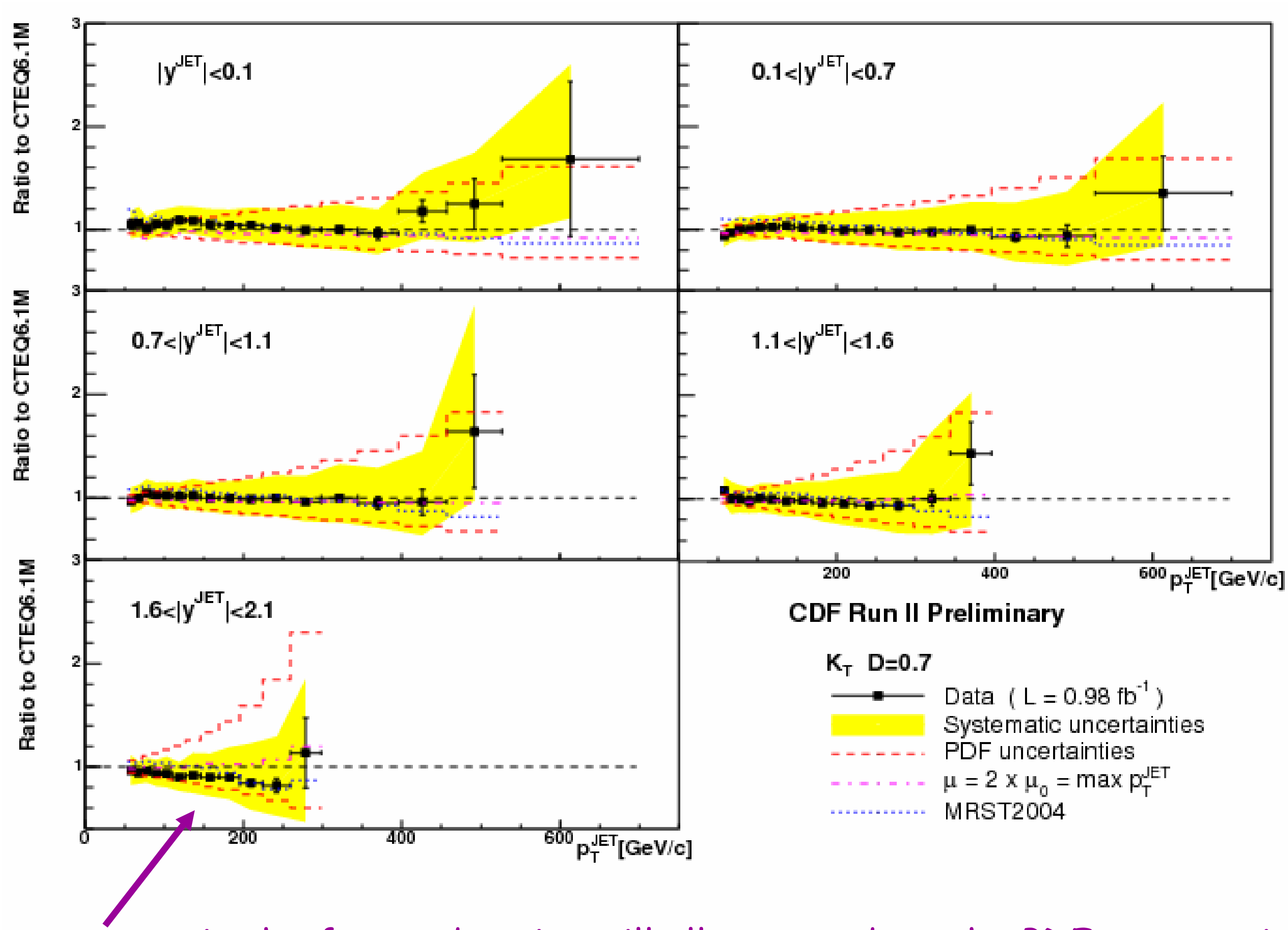
Jets cross sections using K_T (~ $1 fb^{-1}$)

Results $|y^{Jet}| < 2.1$



Good agreement with NLO

Results with K_T: Data/NLO



Measurements in the forward region will allow to reduce the PDFs uncertainties

Summary & Conclusions

→ Inclusive jet cross section measured using ~1fb^{-1} of CDF Run II data in five rapidity regions (up to $|y^{Jet}| < 2.1$)

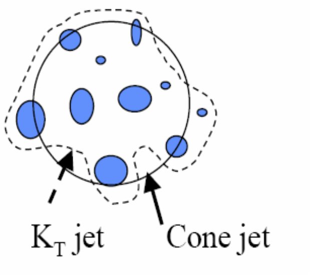
- Using the K_T algorithm and MidPoint algorithms
- Fully corrected to the hadron level
- Good agreement with theory (corrected for UE / Hadronization)

→ The K_T algorithm works fine in hadron colliders

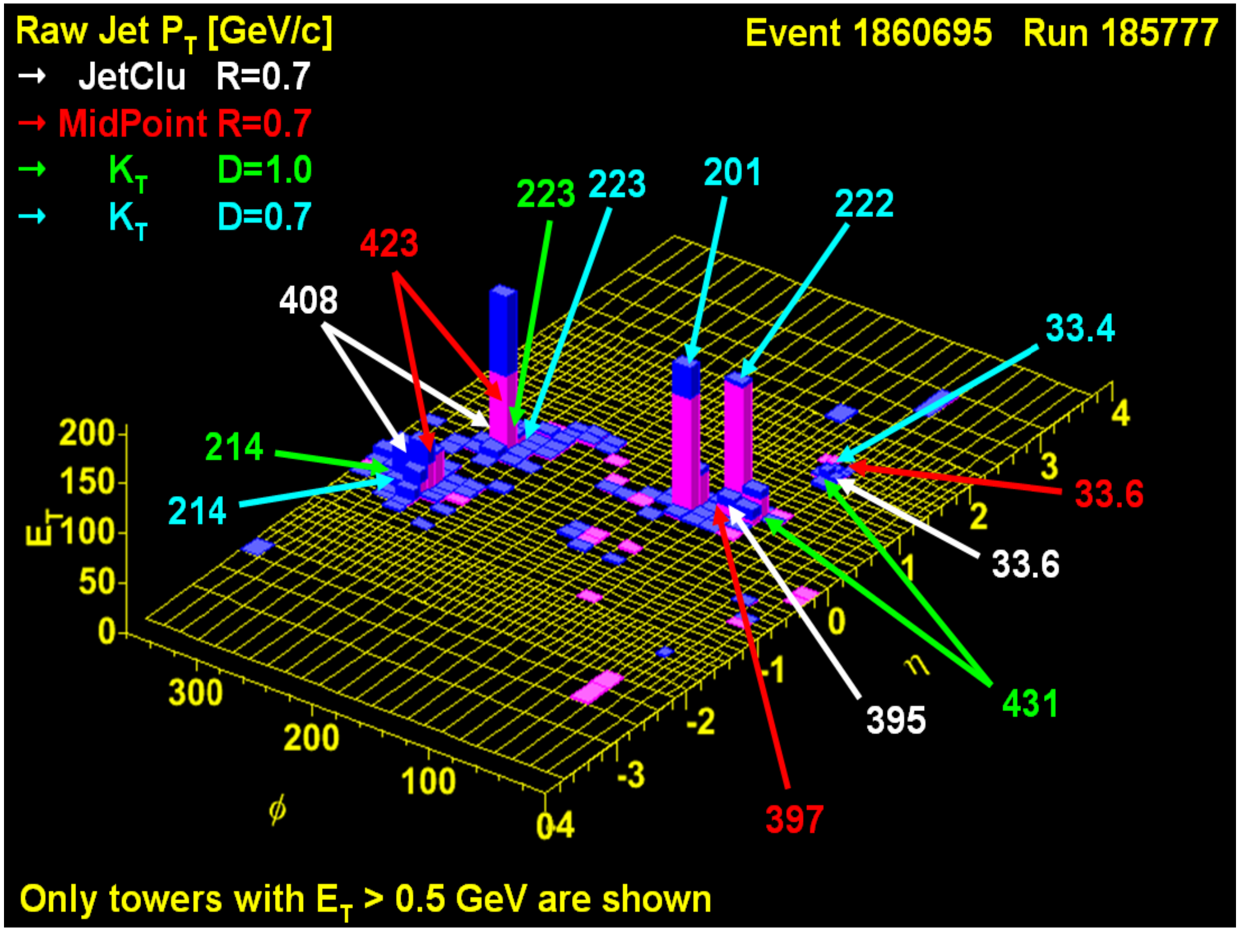
→We hope these measurements will be used to further constrain the PDFs (gluon at high x)

Back Up

MidPoint vs K_T algorithm



→ An example:



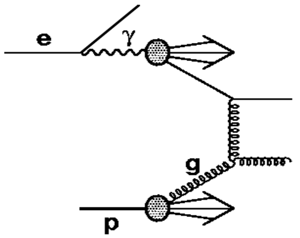
Differences in the number of jets, the jet E_T ...

Different Cross section measurement

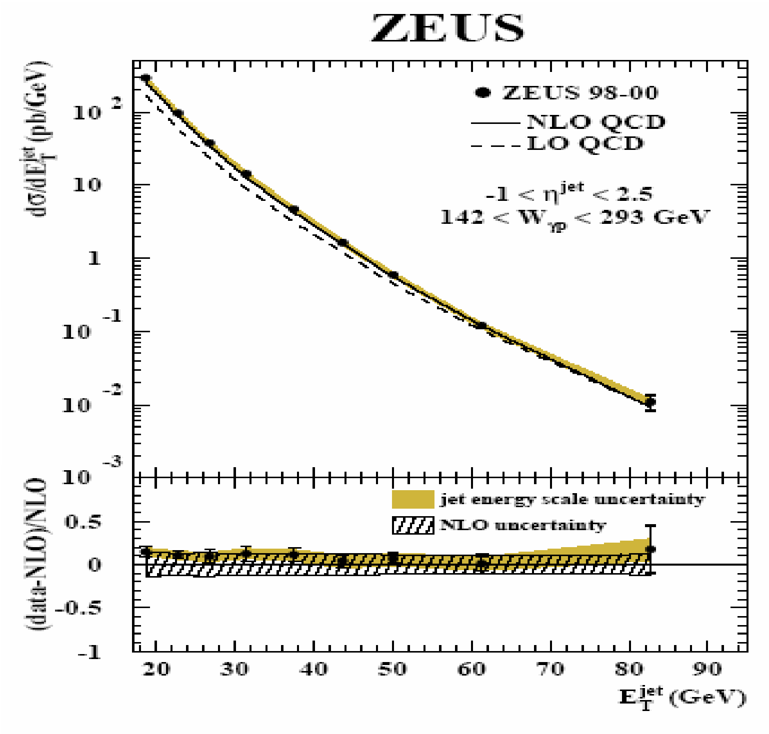
Previous results with K_T algorithm

→ Successfully used at LEP and HERA

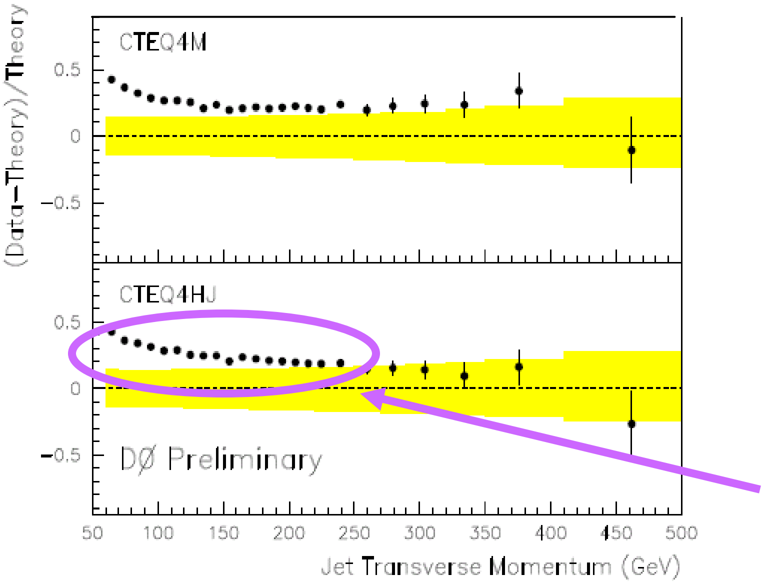
Photoproduction at HERA



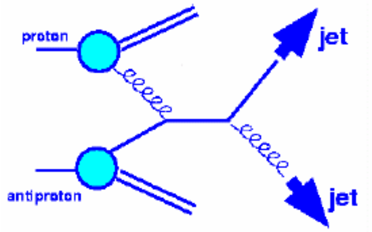
jet
jet



→ Relatively new in hadron colliders



Inclusive Jet Cross Section at Tevatron (RunI)



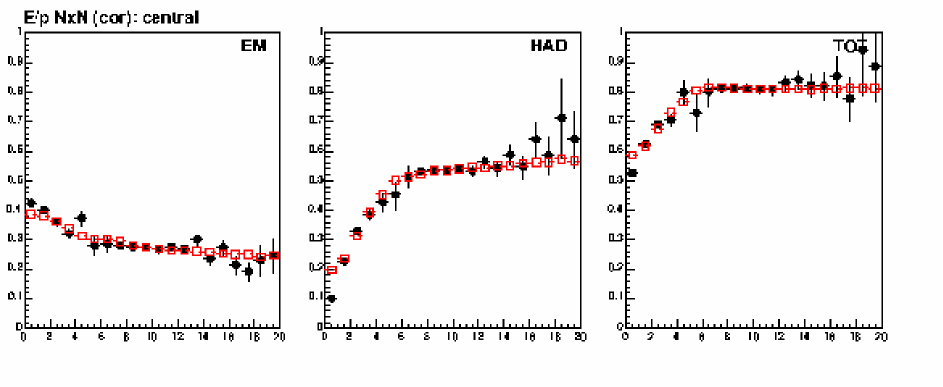
more difficult environment
(underlying Event, Multiple $p\bar{p}$ interactions)

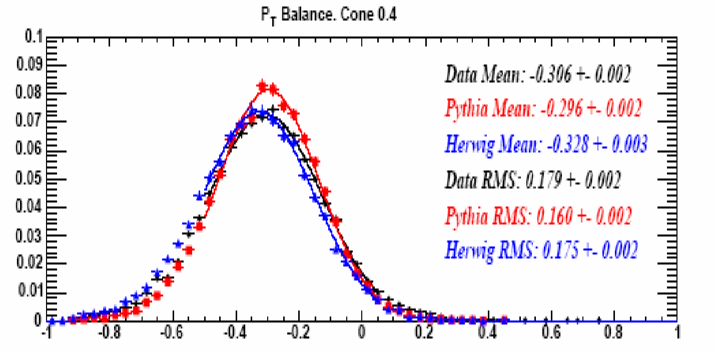
Jet Energy scale

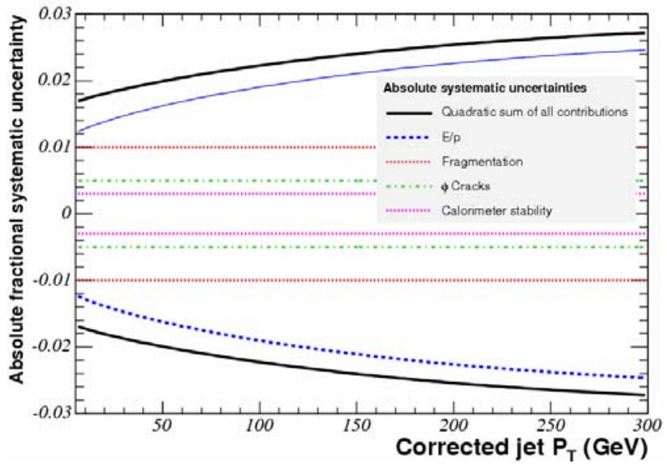
- Measured E/p using single particles
  - Charged pions, μ's (J/Psi and W decays)
  - Z->ee mass is used to set absolute EM scale
- E/p used to tune the simulation
  ⇨ GFLASH parameterization of the showering in the calorimeter
- γ-jet balance used to check the jet energy scale

→ Systematic uncertainties

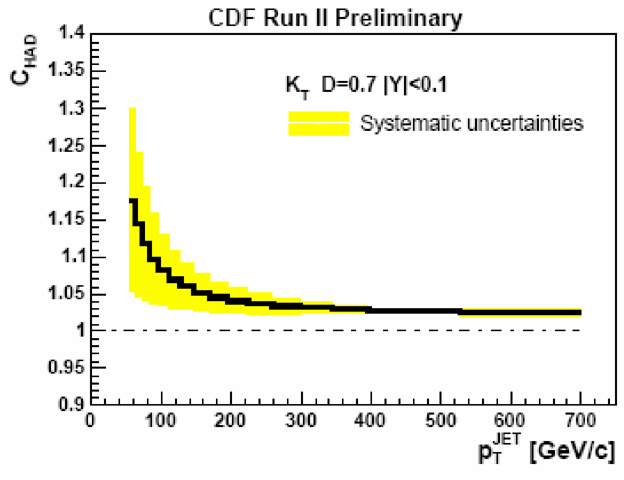
- Calorimeter simulation
  - Residual differences between data and simulation in the response of the calorimeter to single particles (E/p)
- Fragmentation
  - Spectra of the particles inside jets
- Stability
  - Calibration fluctuation with time

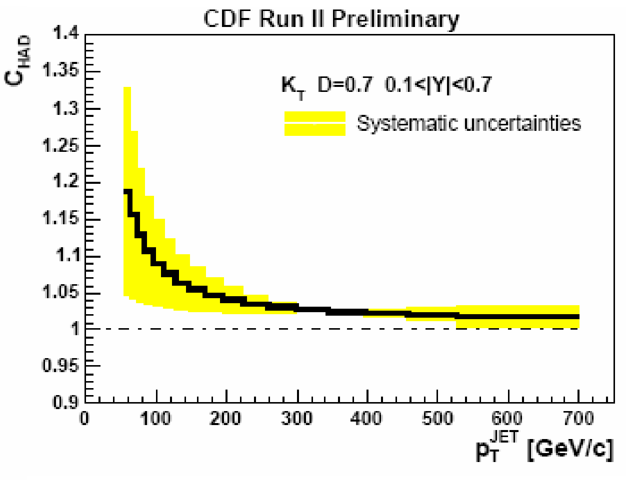


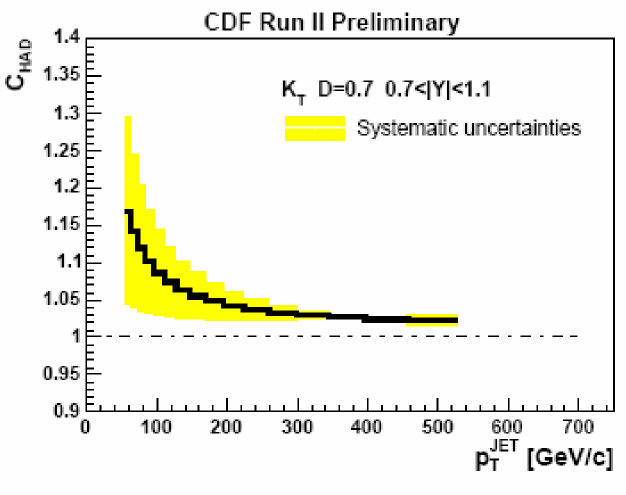


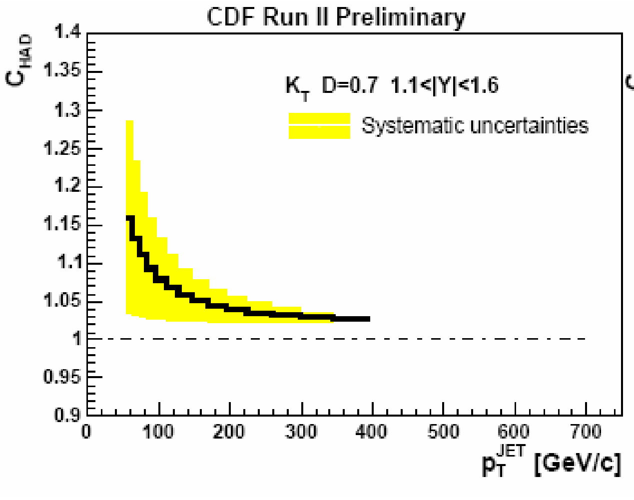


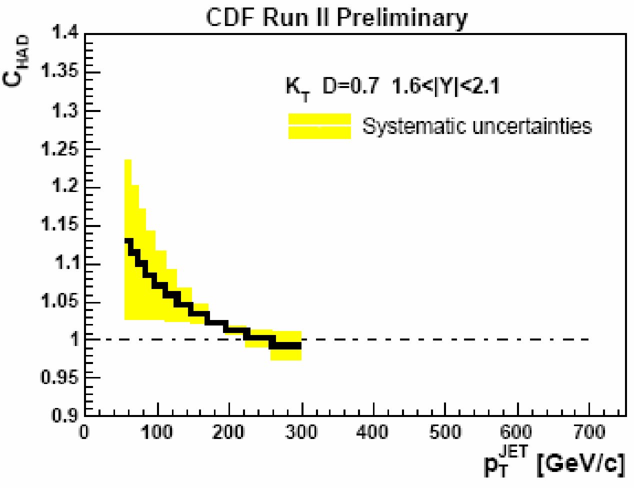
UE/Hadronization corrections











NLO calculations

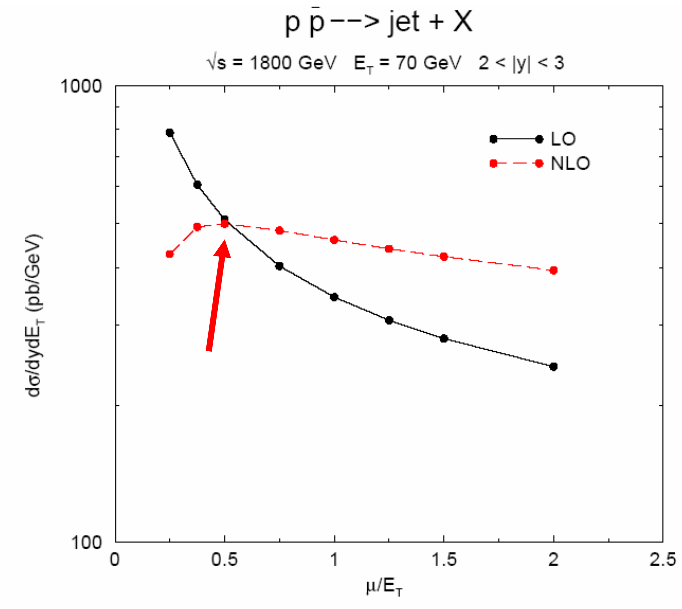
→ JETRAD CTEQ61 package

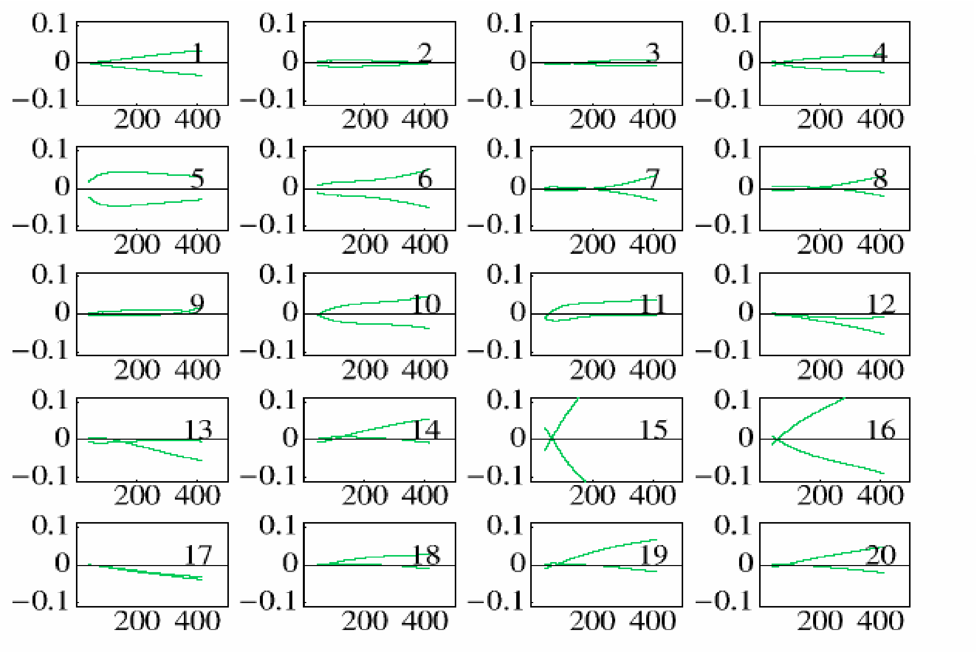
- $\mu_R = \mu_F =$ Maximum Jet $P_T/2$

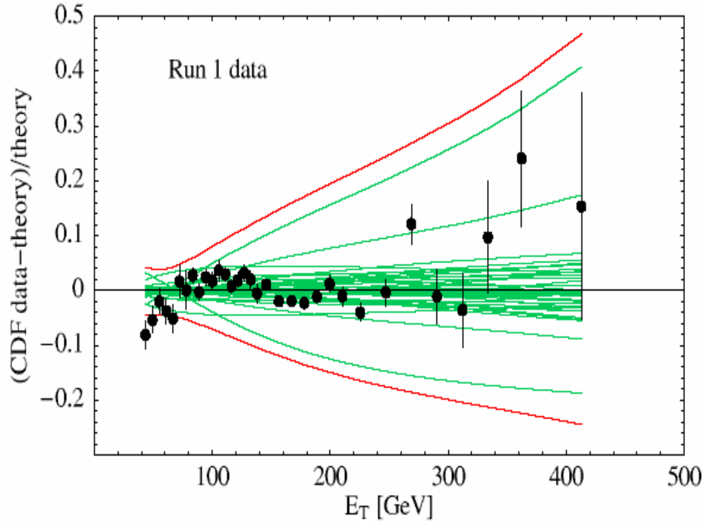
→ NLO uncertainties

- uncertainties associated to the PDFs

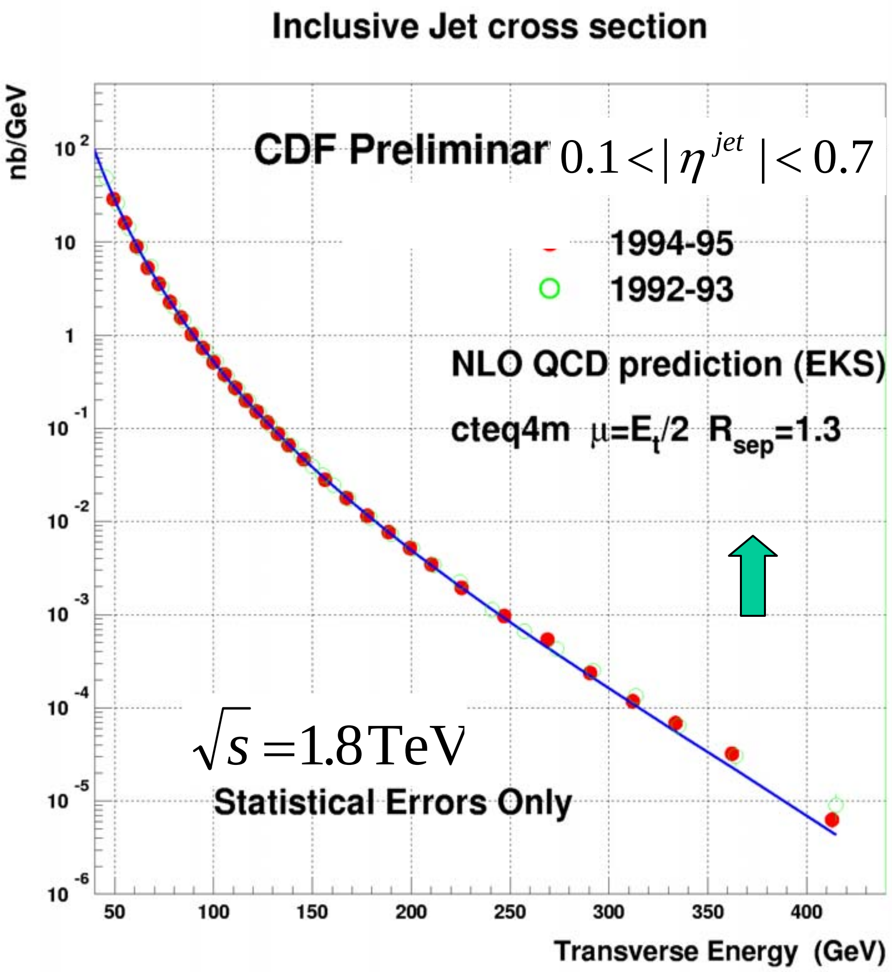
Use the 40 sets corresponding to plus and minus deviations of the 20 eigenvectors



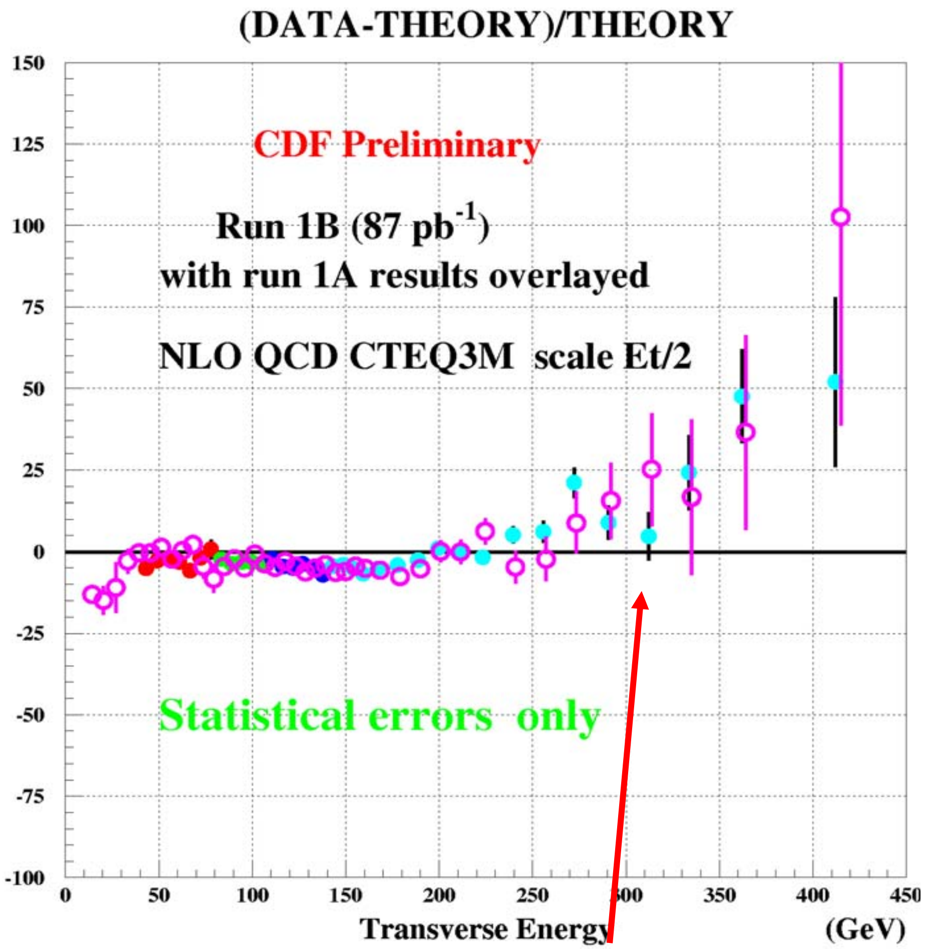




Run I Results

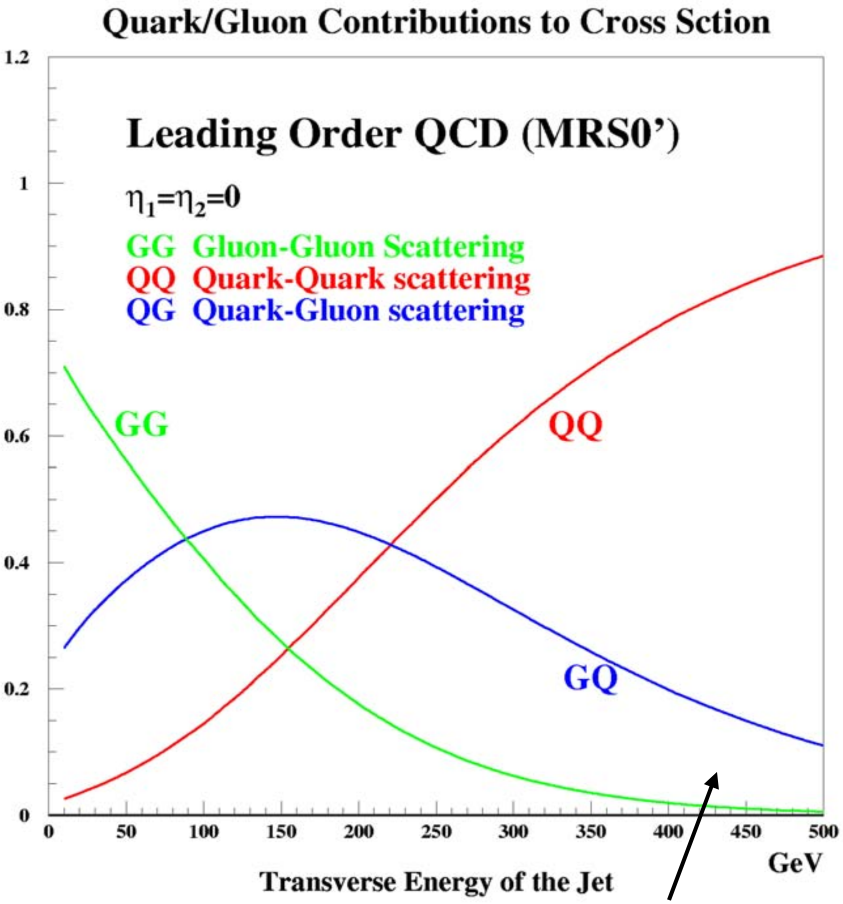


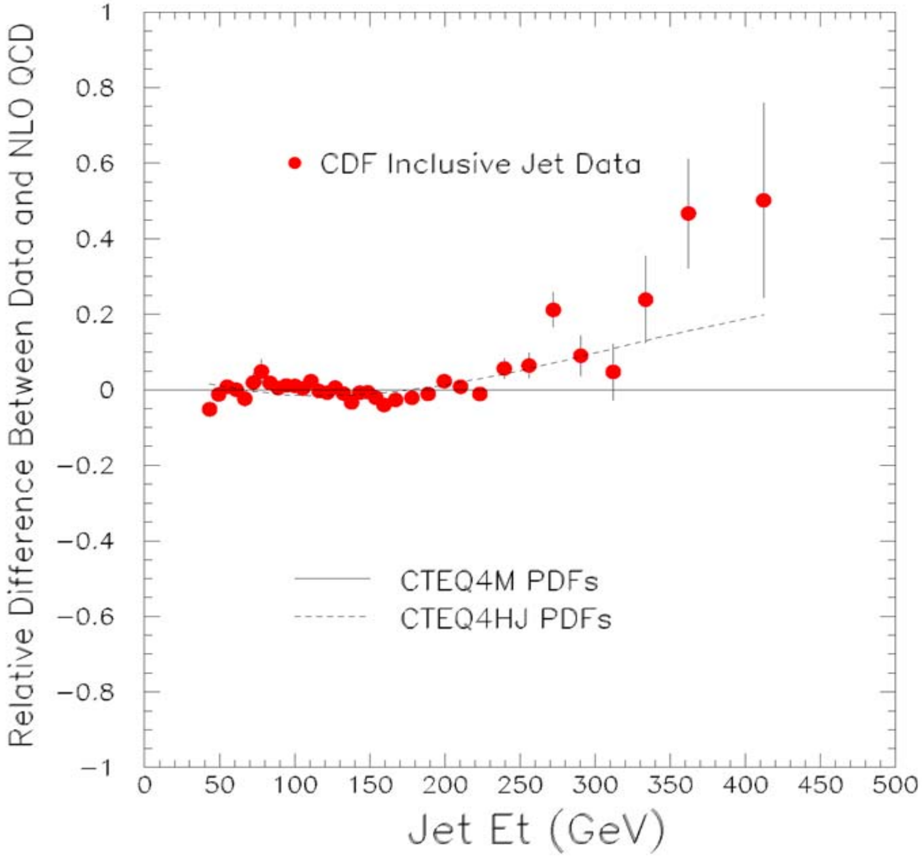
Run I data compared to pQCD NLO



Observed deviation in tail ……..
was this a sign of new physics ?

gluon density at high-x





Important gluon-gluon and gluon-quark contributions at high-E_T

Gluon pdf at high-x not well known
…room for SM explanation….

Pythia - Tune A

- Smoothed out probability of Multi-Parton Interaction (MPI) vs impact
- Enhanced Initial State Radiation
- MPIs are more likely to produce gluons than quark-antiquark pairs and MPI gluons are more likely to have color connection to p-pbar remmants

PYTHIA 6.206 Tune Set A (CTEQ5L)

Parameter	**Default**	**Tune**	**Description**
PARP(67)	1.0	**4.0**	Scale factor that governs the amount of initial-state radiation.
MSTP(81)	1	**1**	Turns on multiple parton interactions (MPI).
MSTP(82)	1	**4**	Double Gaussian matter distribution.
PARP(82)	1.9	**2.0**	Cut-off for multiple parton interactions, P_{T0}.
PARP(83)	0.5	**0.5**	Warm Core: 50% of matter in radius 0.4.
PARP(84)	0.2	**0.4**	Warm Core: 50% of matter in radius 0.4.
PARP(85)	0.33	**0.9**	Probability that the MPI produces two gluons with color connections to the "nearest neighbors".
PARP(86)	0.66	**0.95**	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.
PARP(89)	1,000.0	**1,800.0**	Determines the reference energy E_0.
PARP(90)	0.16	**0.25**	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(Ecm) = P_{T0}(Ecm/E0)^{PARP(90)}$.