Inclusive Jet Production @ CDF

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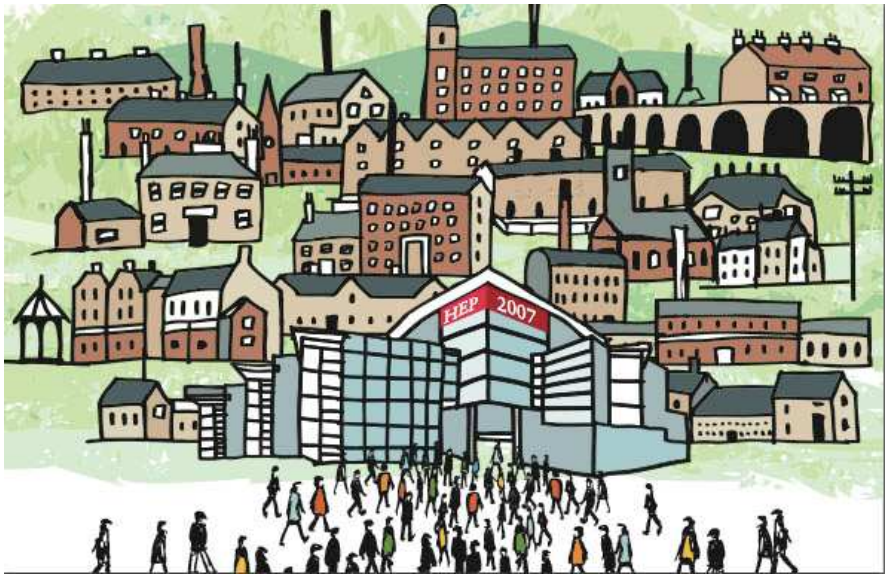
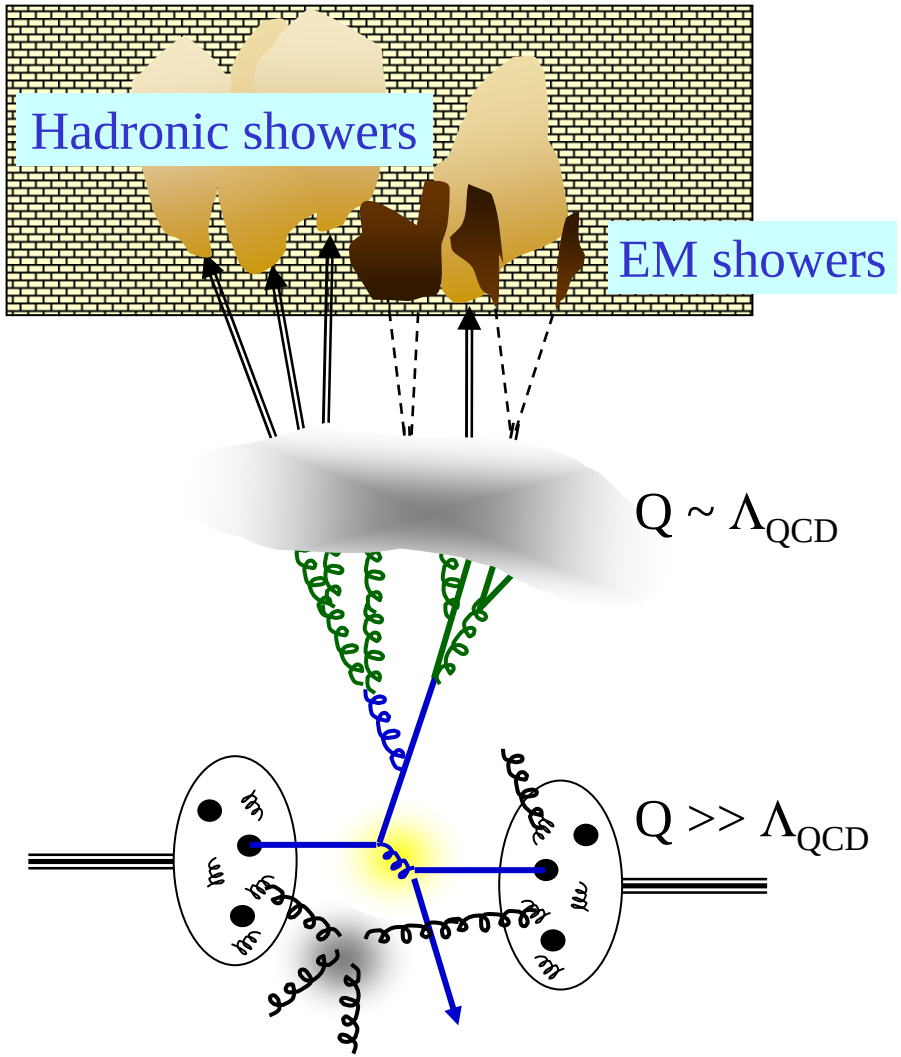


European Physical Society
HEP 2007

Jet Production Measurements

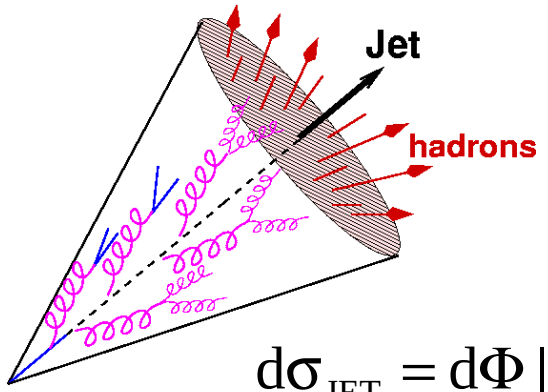


Unfold measurements to hadron level

↳ Correct for efficiency, smearing

Correct theory (pQCD) for non-perturbative effects

↳ Underlying Event, Fragmentation



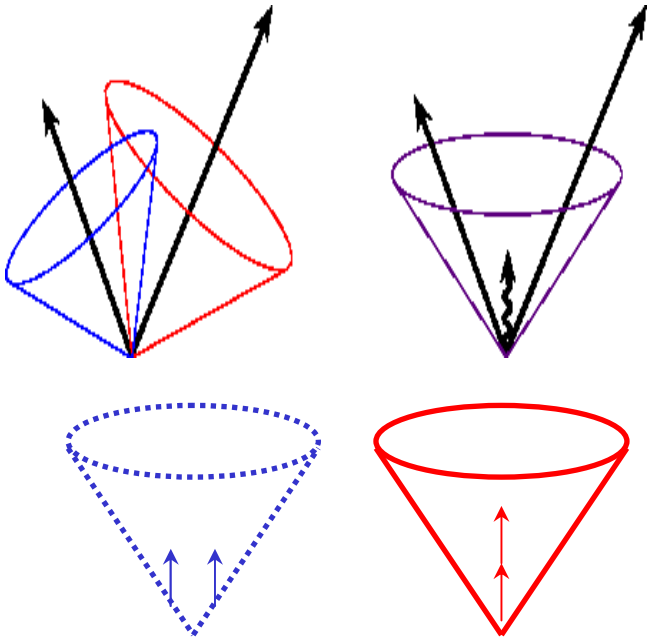
$$d\sigma_{JET} = d\Phi \, |M|^2 \, F_{JET}$$

Well defined jet algorithm required

↳ At calorimeter, hadron and parton levels

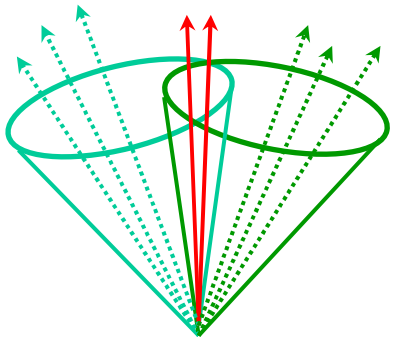
Cone Jet Algorithms and pQCD

- Iterative cone algorithms
  - Staring from seeds, iteratively cluster particles in cones of radius R_{CONE} and look for stable cones (geometrical center = p_T-weighted centroid)
- Infrared and Collinear Safety
  - Fixed order pQCD contains not fully cancelled infrared divergences
    - Inclusive jet cross section affected at NNLO
  - Tevatron Run II Cone Algorithm: Midpoint
    - Uses midpoints between pairs of proto-jets as additional seeds $\rightarrow$ Infrared and collinear safety restored
- Merging/Splitting
  - Emulated in NLO pQCD calculation by merging 2 partons only if they are within $R' = R_{CONE} \times R_{SEP}$ of each other
    - Arbitrary parameter R_{SEP}: prescription $R_{SEP} = 1.3$ (based on parton level approximate arguments)

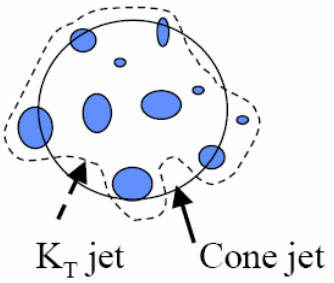


below threshold (no jets)

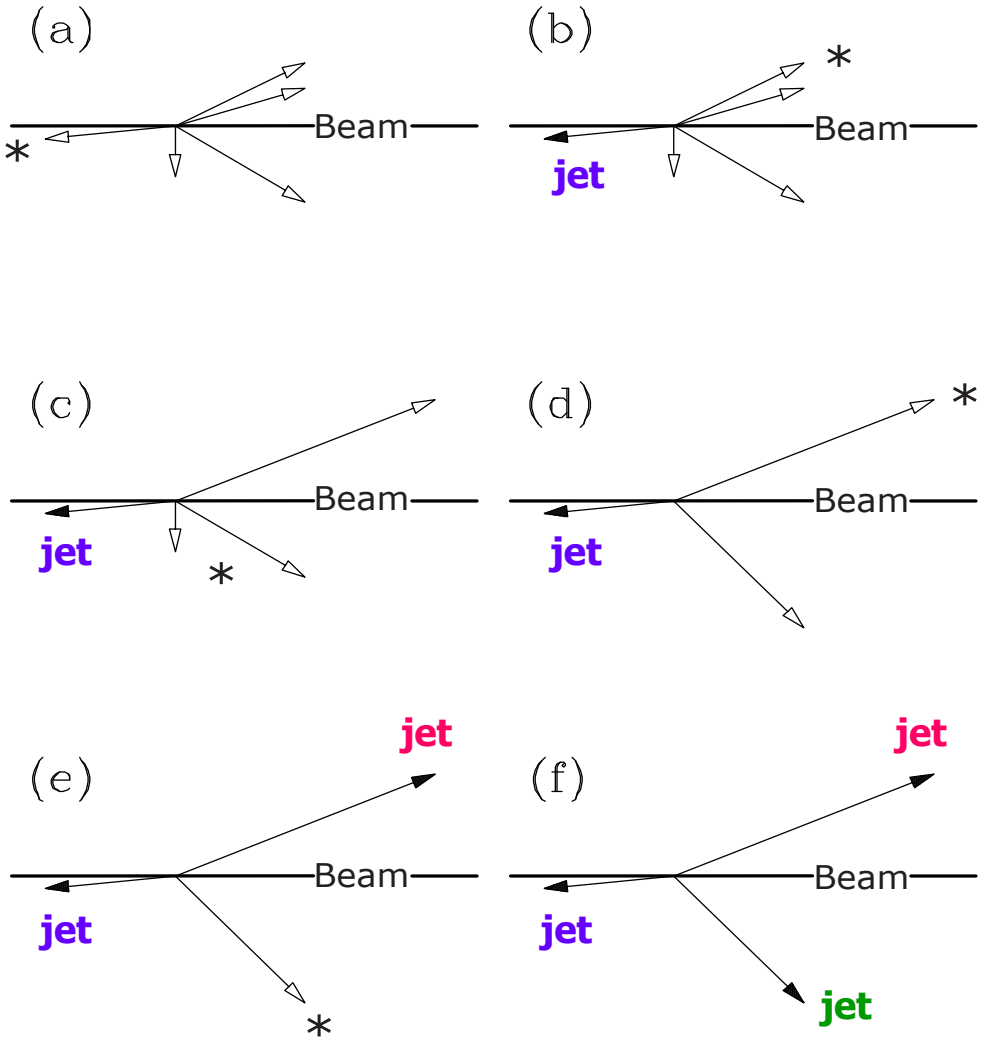
above threshold (1 jet)



k_T Algorithm

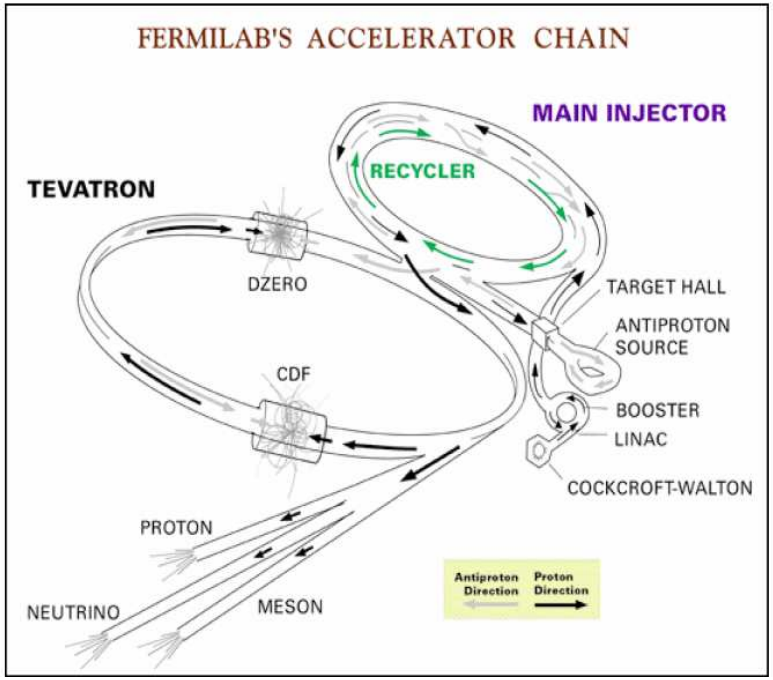


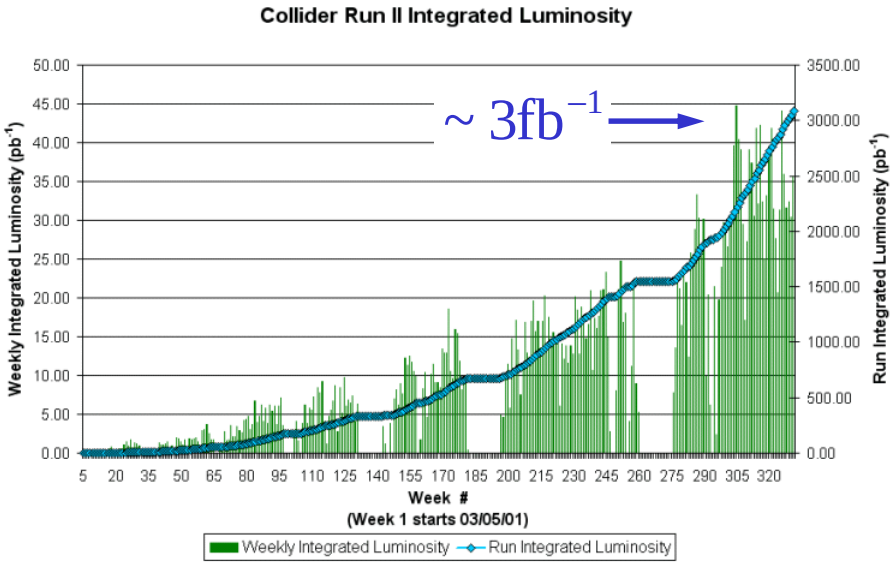
- Inclusive k_T algorithm
  - Merging pairs of nearby particles in order of increasing relative p_T
    - $d_{ij} = \min(p_{T,i}^2, p_{T,j}^2)\ \dfrac{\Delta R^2}{D^2}$
    - $d_{ii} = p_{T,i}^2$
  - D parameter controls merging termination and characterizes size of resulting jets
- p_T classification inspired by pQCD gluon emissions
  - Infrared and Collinear safe to all orders in pQCD
  - No merging/splitting
    - No R_{SEP} issue comparing to pQCD

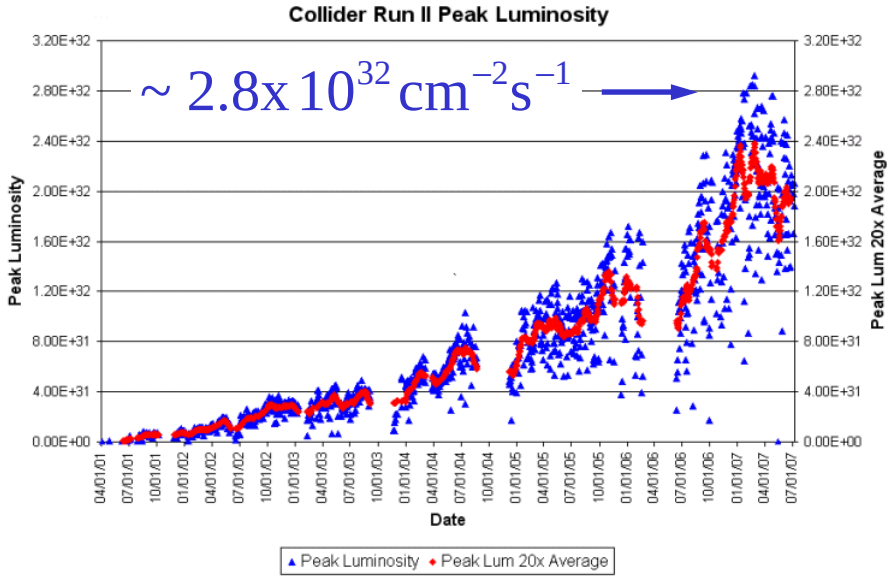


The Tevatron

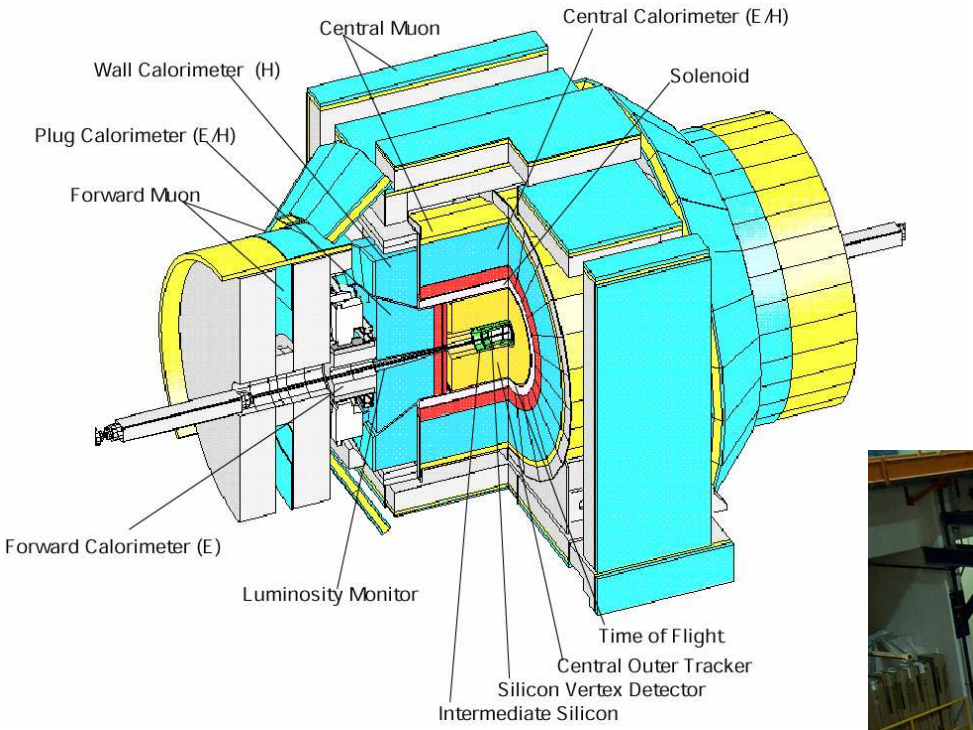
- Proton-antiproton collisions
- $\sqrt{s}$ = 1.96 TeV
- 36 bunches: crossing time = 396 ns
- ☺ Delivered ~ 1.5 fb^{-1} since 06/2006
- Current extrapolation ~ 6 fb^{-1} by 2009
  - 8 fb^{-1} still the goal
    - Need increased antiproton staking rates







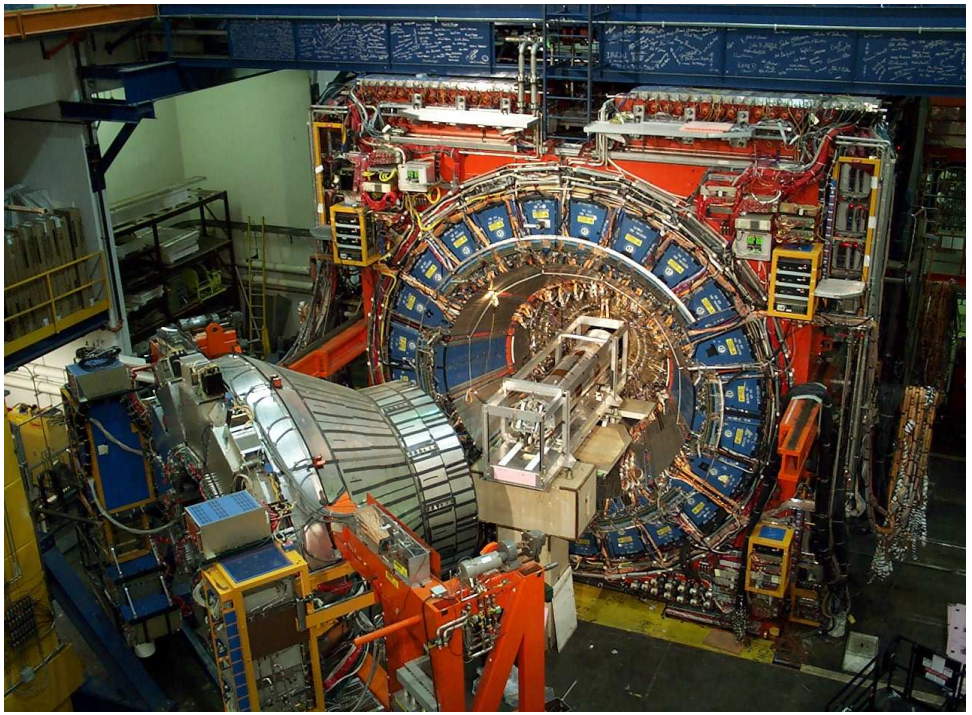
CDF



Highly upgraded for run II

- New silicon tracking
- New drift chamber
- Upgraded muon chambers
- New plug calorimeters
- New TOF

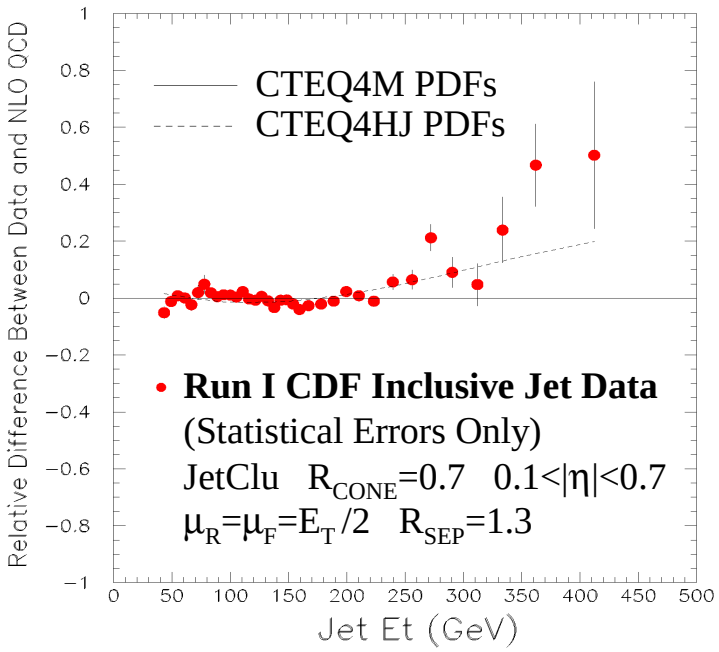
…

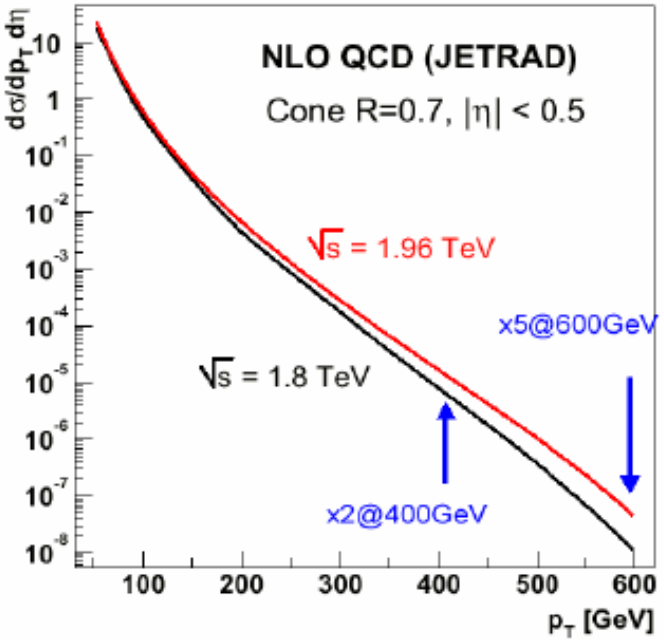


- Data taking efficiency ~ 85 %
- About 2.6 fb^{-1} on tape
  - Results based on 1 to 1.13 fb^{-1}

Inclusive Jets @ the Tevatron

- Legacy from Run I
  - Great interest on apparent excess at high E_T
  - SM explanation
    - Gluon PDF increased at high x
    - Recent PDFs from global fit include CDF and D0 jet data from Run I (CTEQ6, MRST2001)

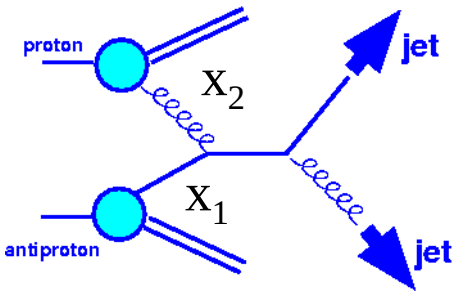


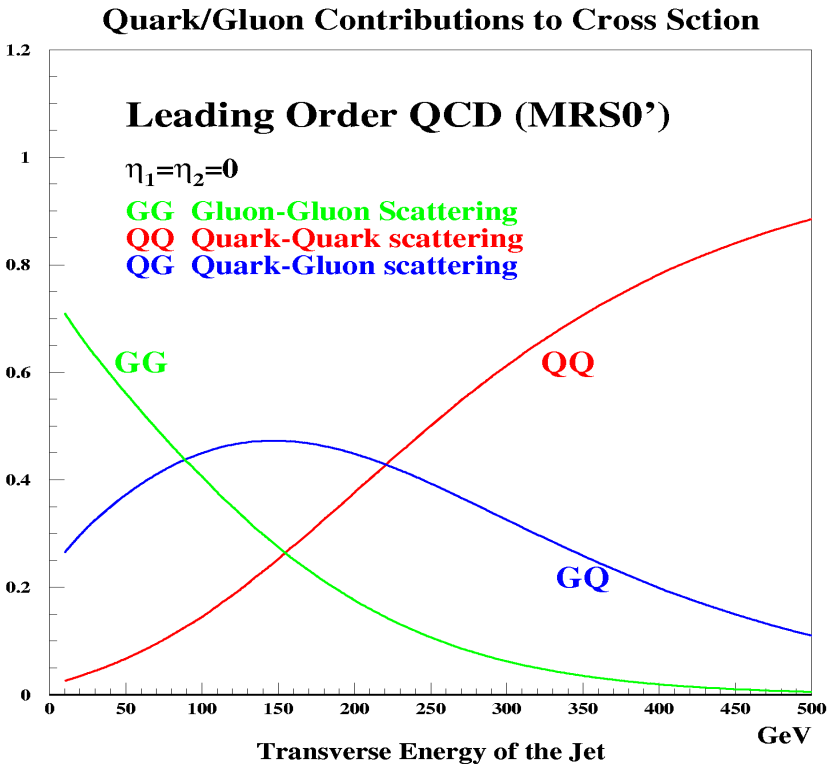


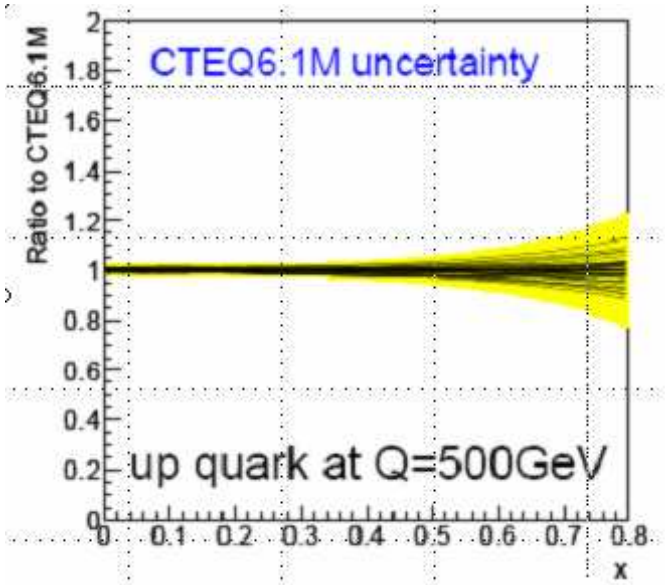
- Stringent test of pQCD
  - Over ~ 8 orders of magnitude
- Tail sensitive to New Physics
  - Probing distances ~ 10^{-19} m
  - Production enhanced at high p_T thanks to new $\sqrt{s}$
- PDFs at high Q^2 & high x

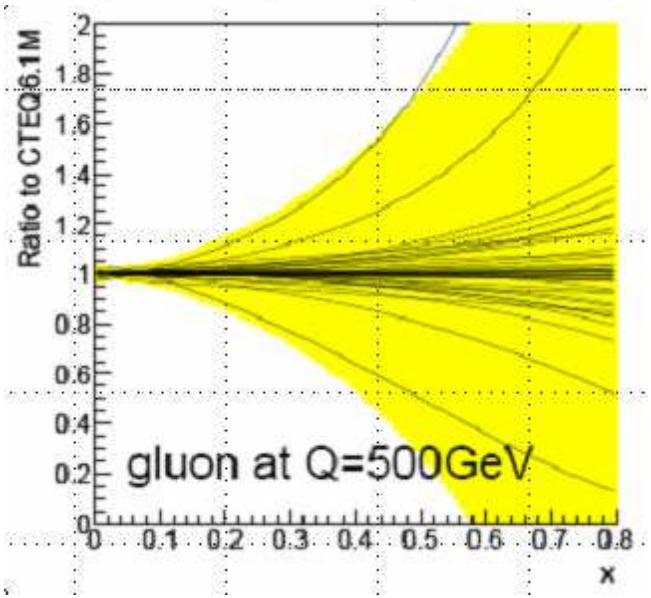
Gluon PDF at high x

$$\sigma_{GQ}^{total} = \sum \int dx_1 dx_2 f_q(x_1, Q^2) f_g(x_{2,} Q^2) \hat{\sigma}^{parton}$$





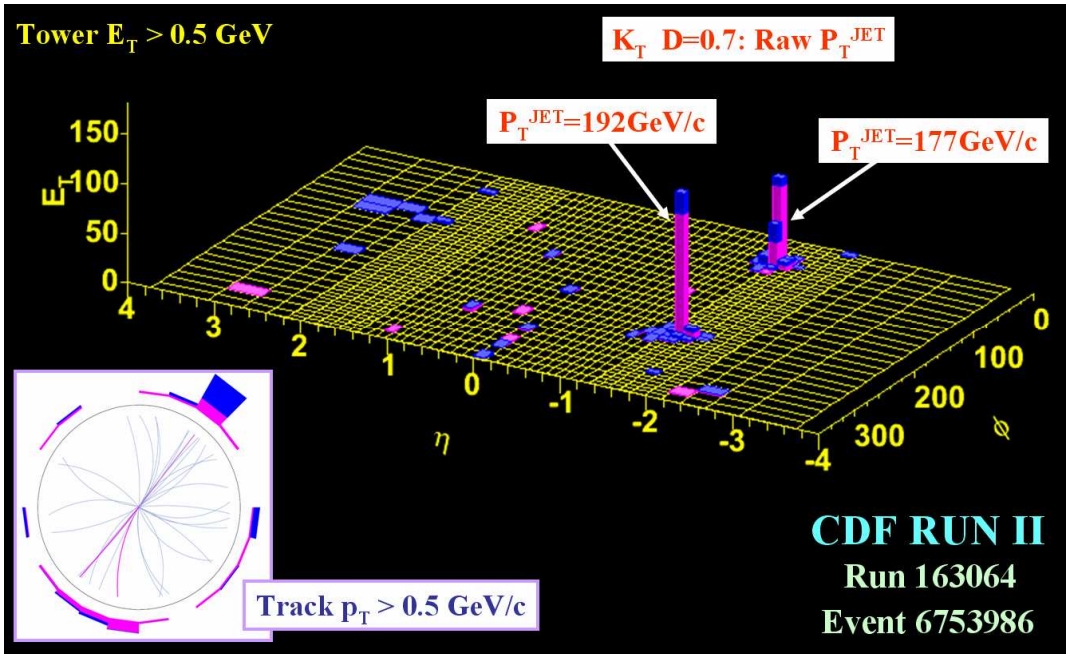


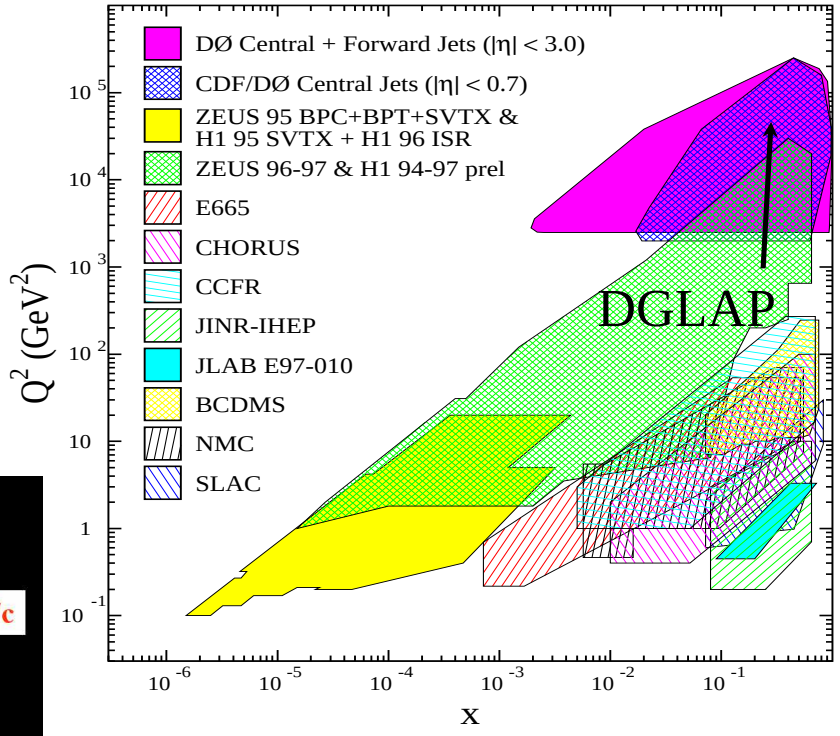


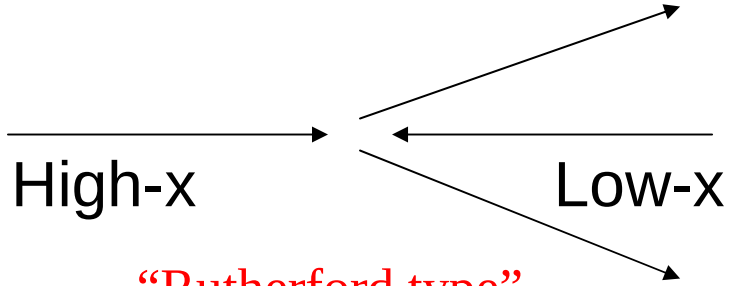
Important GG and GQ contributions

Forward Jets

- Essentials to pin down PDFs vs. eventual New Physics at higher Q^2 in central region
  - DGLAP gives Q^2 evolution
- Expend x range toward low x



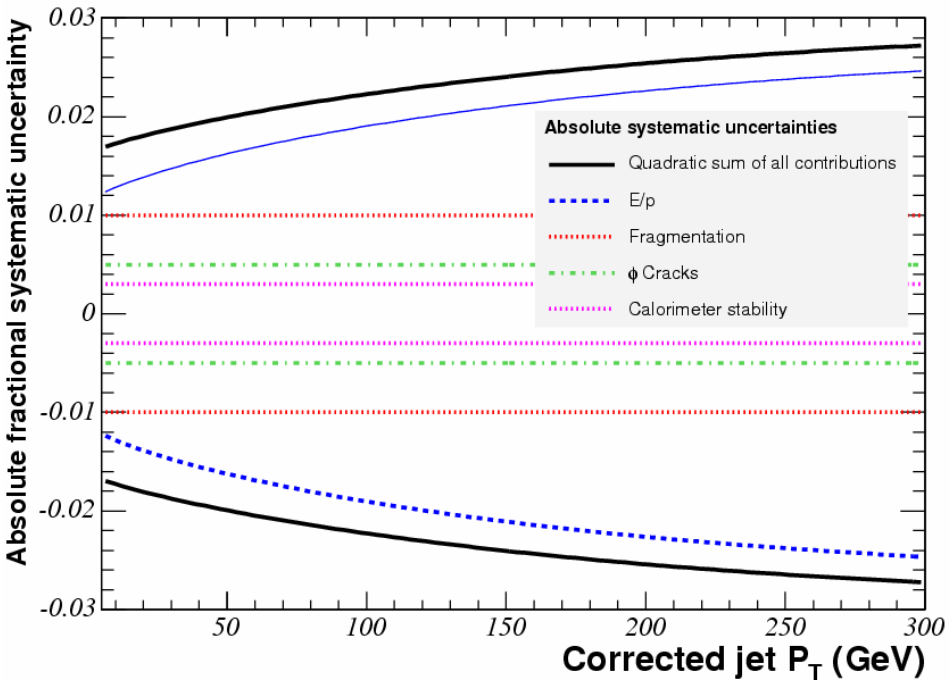




"Rutherford type" parton backscattering

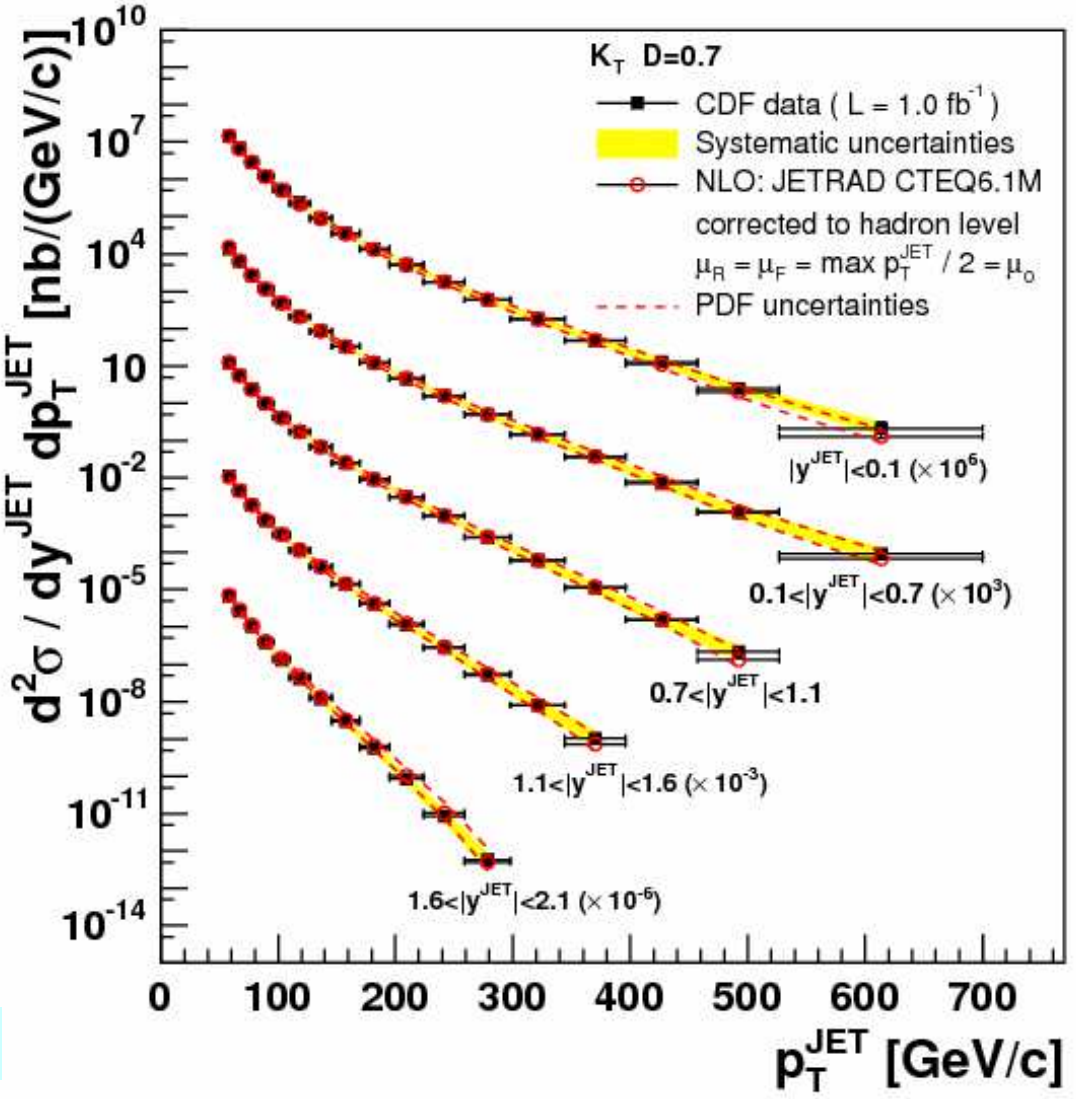
Jet Energy Scale

- Absolute Calibration: central calorimeter response very well reproduced by the simulation
  - E/p of isolated tracks used to tune the showering simulation (G-Flash)
    - ⇨ Residual discrepancies taken as systematic uncertainties
  - Reasonable simulation of the p_T spectrum of the particles within a jet by PYTHIA and HERWIG fragmentation models
    - ⇨ Induced difference on Jet Energy Scale < 1%
  - Photon-jet balance
    - ⇨ Data and Simulation agree at 1% to 2% level
- Non uniformity versus η
  - Dijet balance
- Resolution
  - Bisector method



Inclusive Jet Production with k_T

- 5 rapidity ranges
  - Up to $|y^{JET}| = 2.1$
- D = 0.7
- L = 1.0 fb^{-1}
- Good description by NLO QCD
  - Experimental uncertainties dominated by Jet Energy Scale (2 to 3%)
  - Theoretical uncertainties dominated by PDF (gluon at high x)



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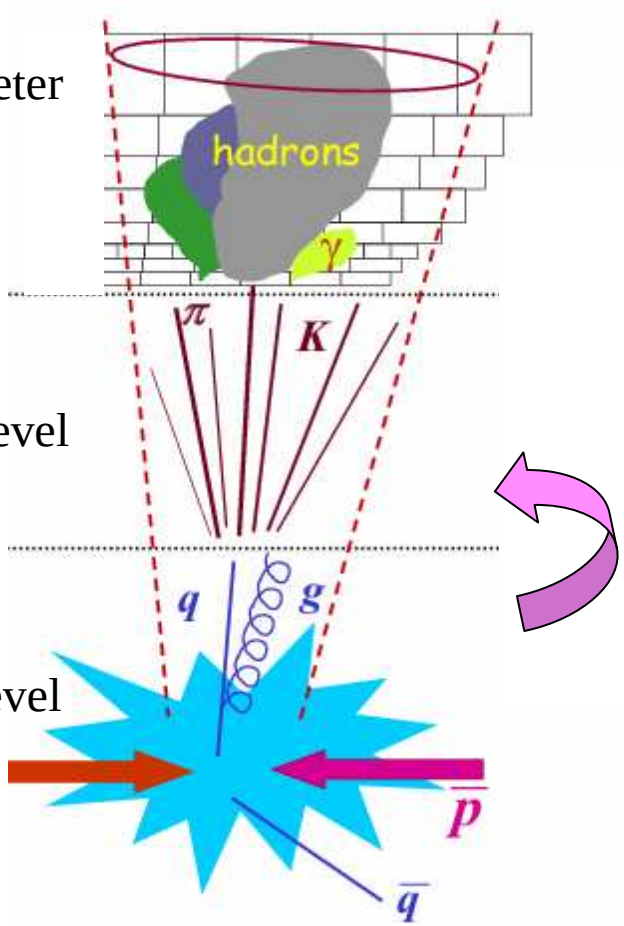
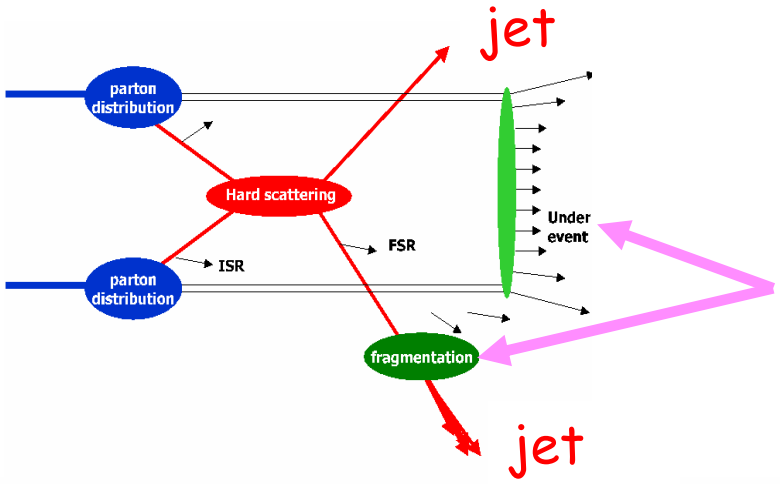
Underlying Event & Hadronization Correction

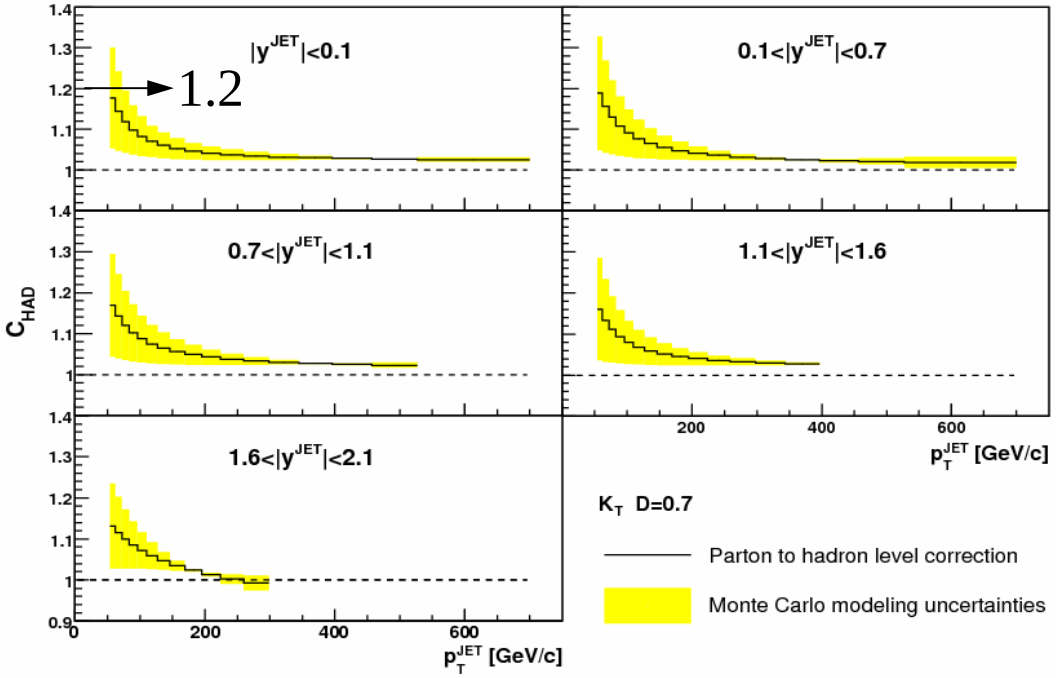
Calorimeter level

Hadron level

Parton level

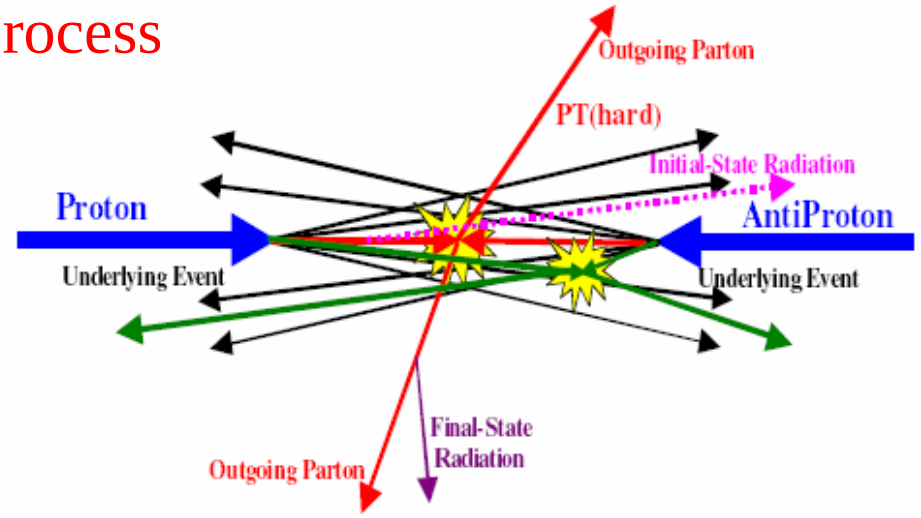


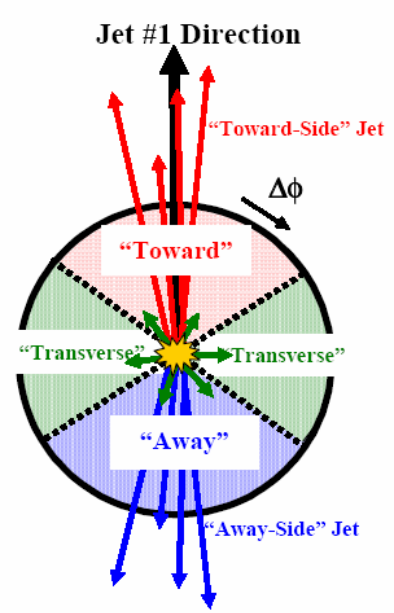


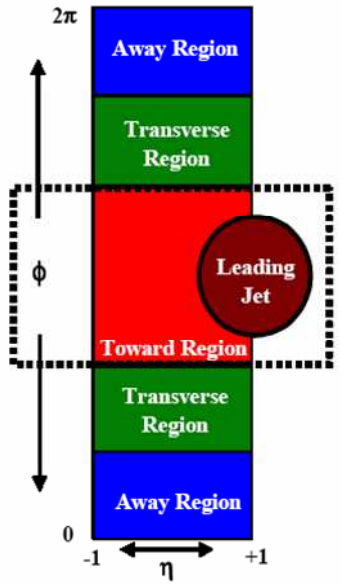


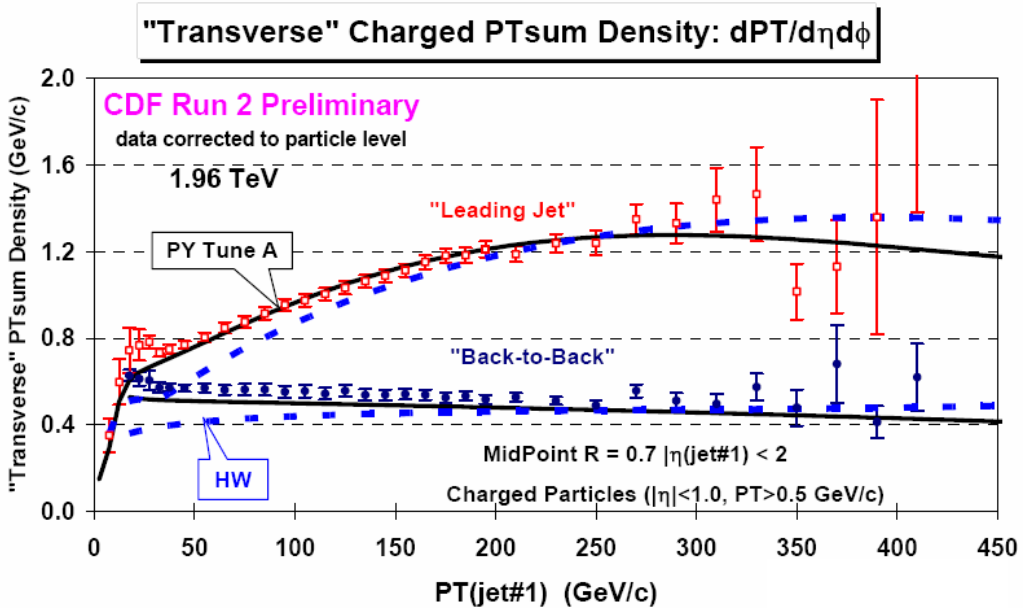
Underlying Event

- Everything but the hard scattering process
  - Initial state soft radiations
  - Beam-beam remnants
  - Multiple Parton Interactions (MPI)
- Studied in the transverse region
  - Leading jet sample
  - Back-to-back sample





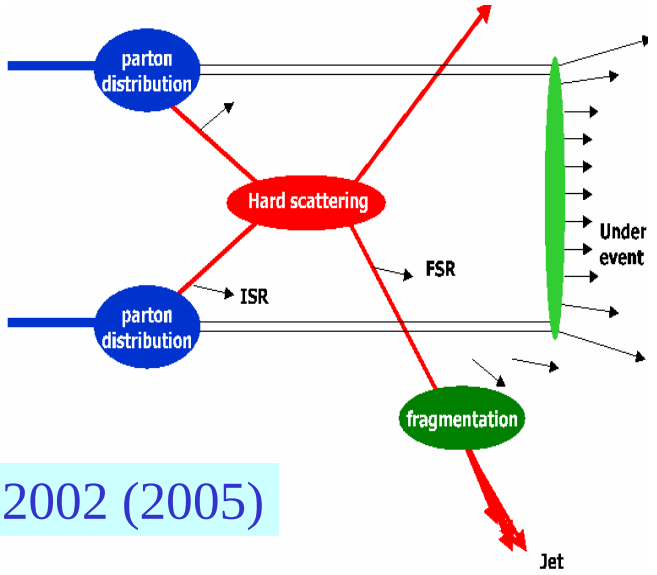




Energy Flow Inside Jets

Jet shapes governed by multi-gluon emission from primary parton

- Test of parton shower models
- Sensitive to underlying event structure
- Sensitive to quark and gluon mixture in the final state



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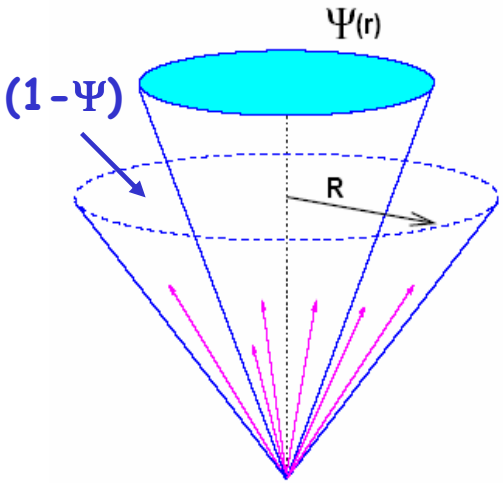
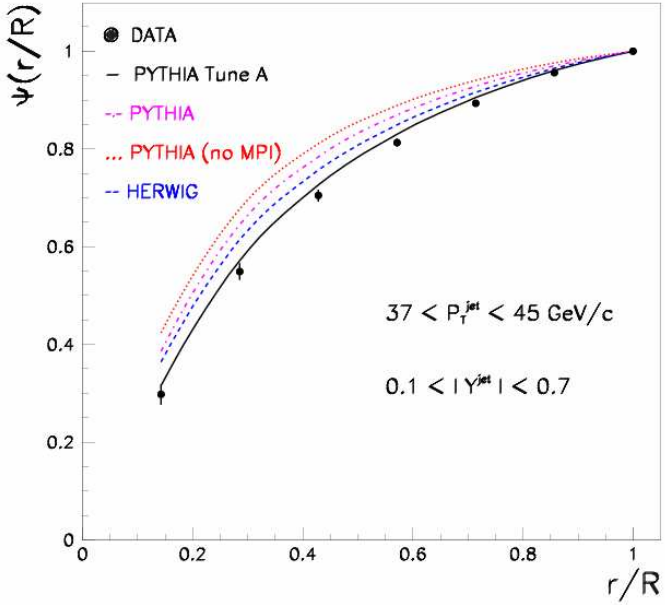
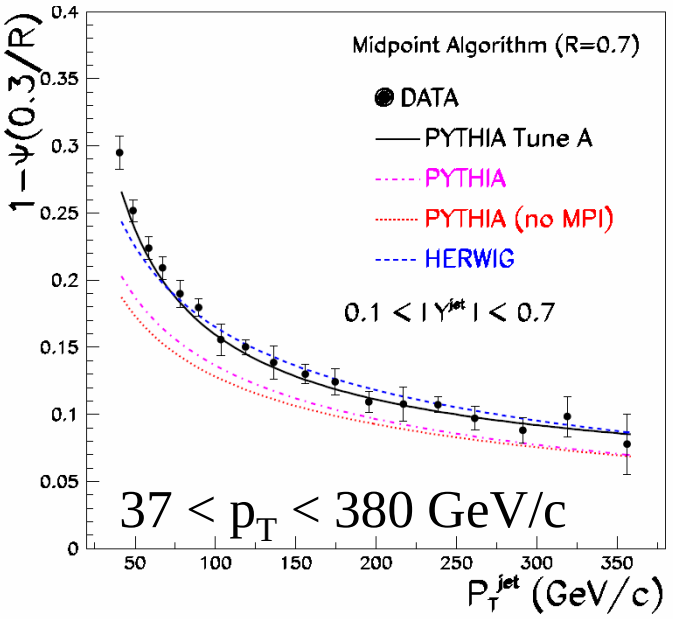
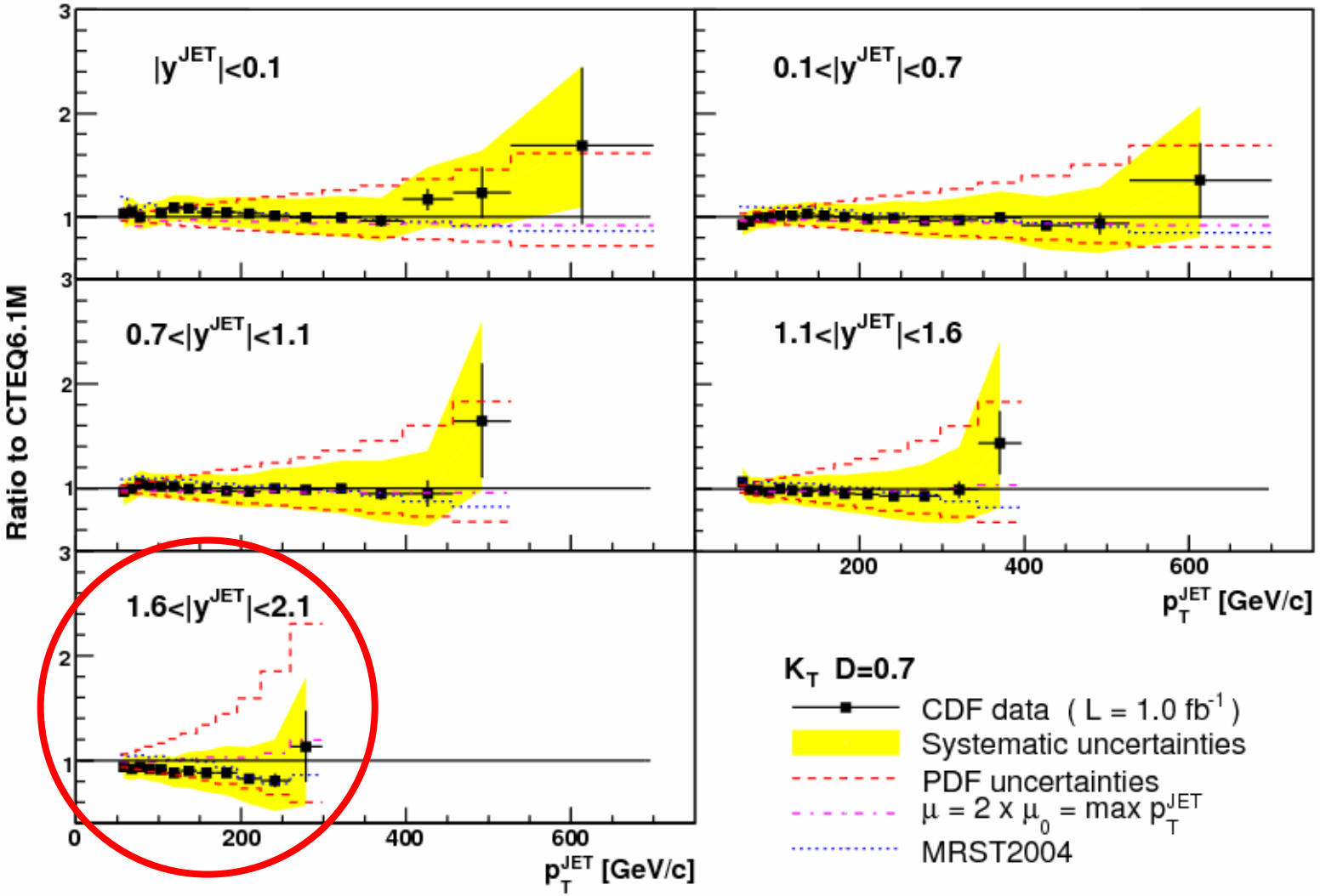
$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T(0,R)}$$



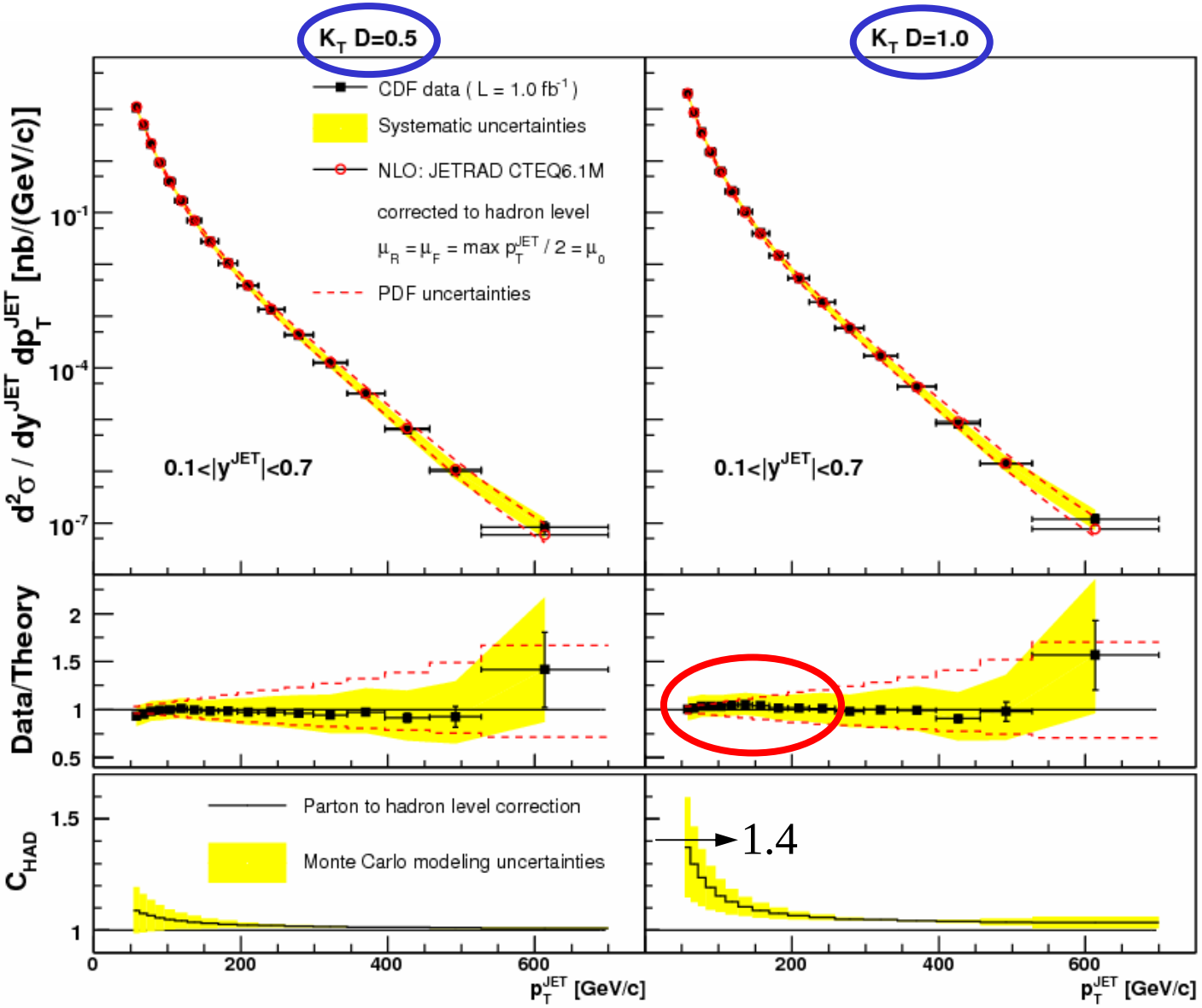




Data / Theory


|y^JET|<0.1
0.1<|y^JET|<0.7
0.7<|y^JET|<1.1
1.1<|y^JET|<1.6
1.6<|y^JET|<2.1
Ratio to CTEQ6.1M
p_T^JET [GeV/c]
K_T D=0.7
CDF data (L = 1.0 fb^-1)
Systematic uncertainties
PDF uncertainties
μ = 2 x μ_0 = max p_T^JET
MRST2004

k_T jets vs. D


K_T D=0.5
K_T D=1.0
CDF data (L = 1.0 fb^-1)
Systematic uncertainties
NLO: JETRAD CTEQ6.1M
corrected to hadron level
μ_R = μ_F = max p_T^JET / 2 = μ_0
PDF uncertainties
d²σ / dy^JET dp_T^JET [nb/(GeV/c)]
0.1<|y^JET|<0.7
Data/Theory
C_HAD
Parton to hadron level correction
Monte Carlo modeling uncertainties
1.4
p_T^JET [GeV/c]

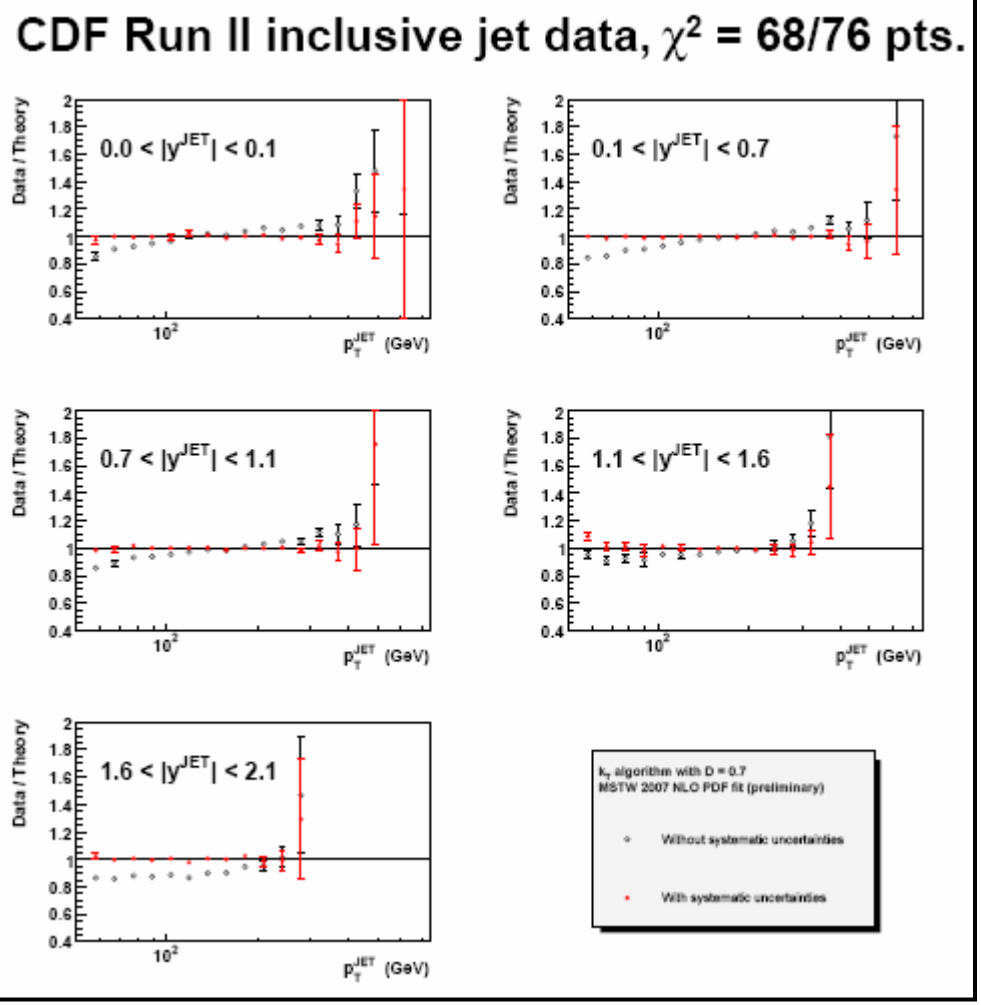
Being used in new QCD global fits

See e.g. Robert Thorne's presentation at the 3rd HERA - LHC Workshop (March 2007): "Update on MRST (MSTW) fits"

Now also include CDF Run II inclusive jet data in different rapidity bins using k_T jet algorithm (mid-point cone algorithm data seems very similar, but numbers not yet available).

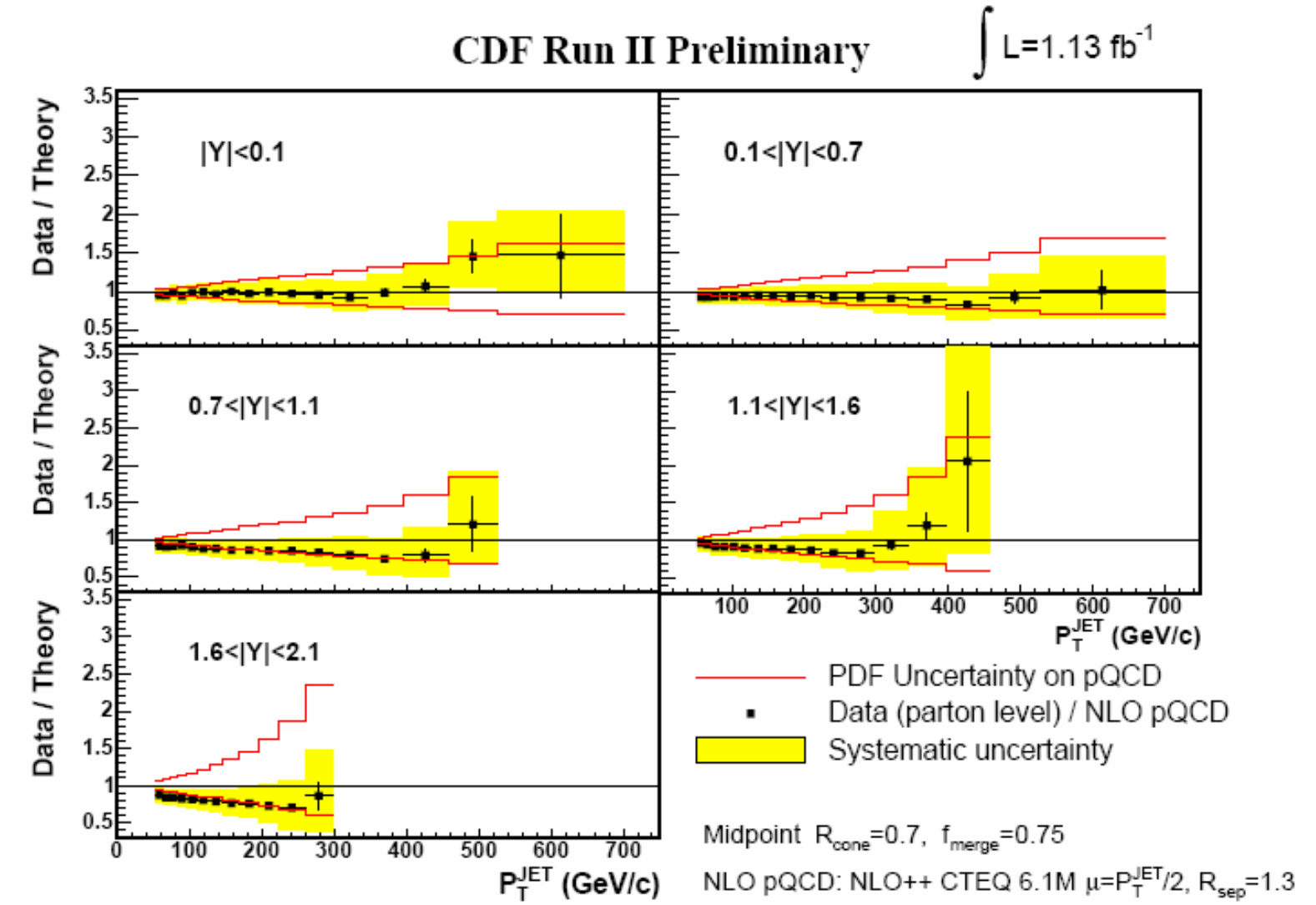
Very good fit – $\sigma^2 = 68/76$.

Full use of correlated systematic errors required for any sensible result.



Inclusive Jet Production with Midpoint

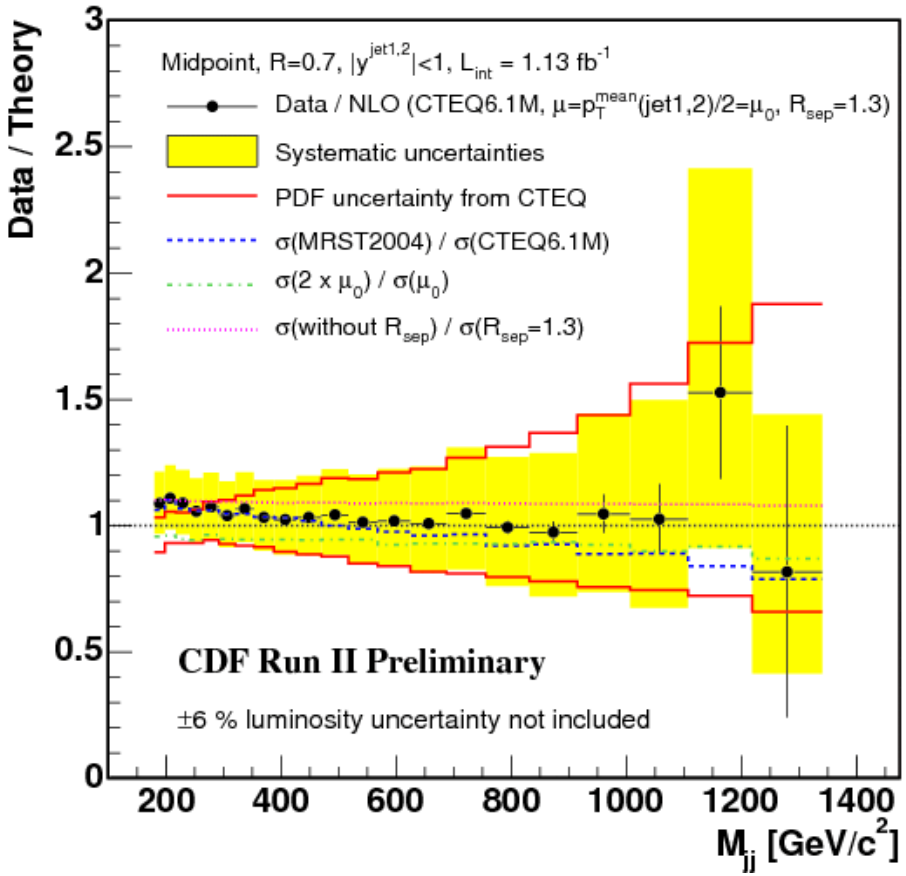
R = 0.7 (no search cone step) L = 1.13 fb^{-1}

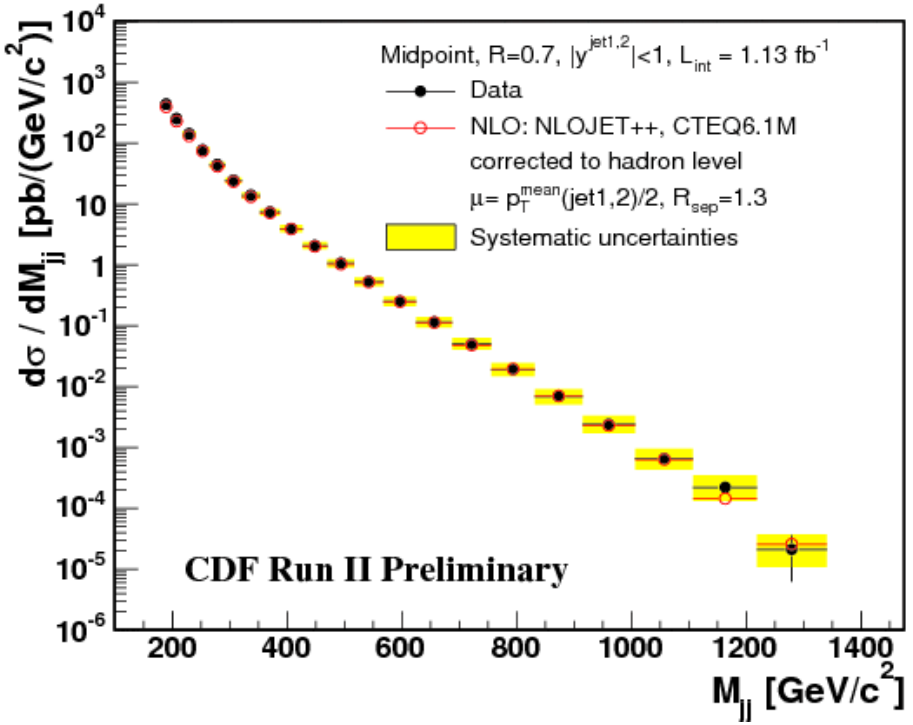


Dijet Production

Midpoint R = 0.7

- $|y^{JET1,2}| < 1$
- $L = 1.1\ fb^{-1}$





- Consistent with NLO pQCD
  - Experimental uncertainties comparable to PDF ones
- Sensitive to New Physics
  - Heavy resonances, Compositeness
  - Limits being worked out…

Conclusions

- Good agreement with pQCD using both k_T and Midpoint
  - Important test of pQCD over ~ 8 orders of magnitude
  - p_T reach extended by ~ 150 GeV/c with respect to Run I
- Careful treatment of non perturbative effects
  - Underlying Event studies
  - Jet shape measurements
- Inclusive jet data being used in new QCD global fits to better constrain the gluon PDF at high x
- Limits on new physics from dijet production being evaluated

Backup Slides

Results from ZEUS / D0 Run I