The Run II Inclusive Jet Production Cross Section from DZERO

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Jets at DZERO

Motivation
Jet results from Tevatron Run I
Jet physics in Run II

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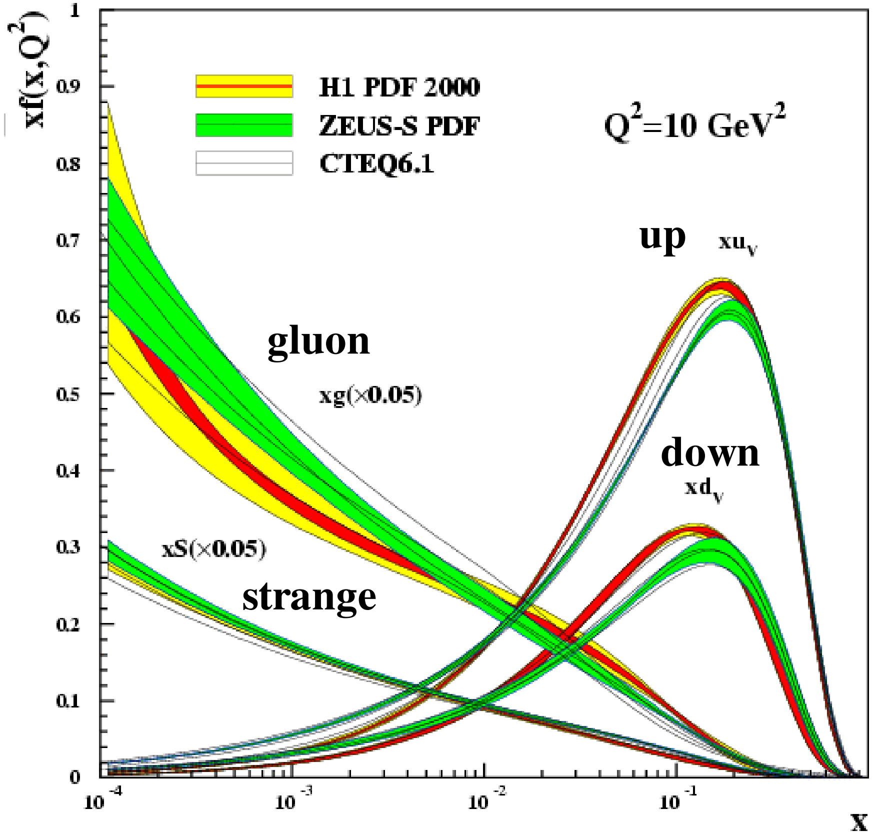
What can we learn?

- What can we learn by measuring jets?
  - Momentum distribution of constituents in protons and antiprotons; These constituents are called partons, and their momentum distributions are called parton distribution functions (PDFs)
  - The nature of the basic interaction between quarks and gluons
  - Hadronization (fragmentation), how partons materialize into jets
  - New physics like “quark compositeness”?

Proton parton distribution functions

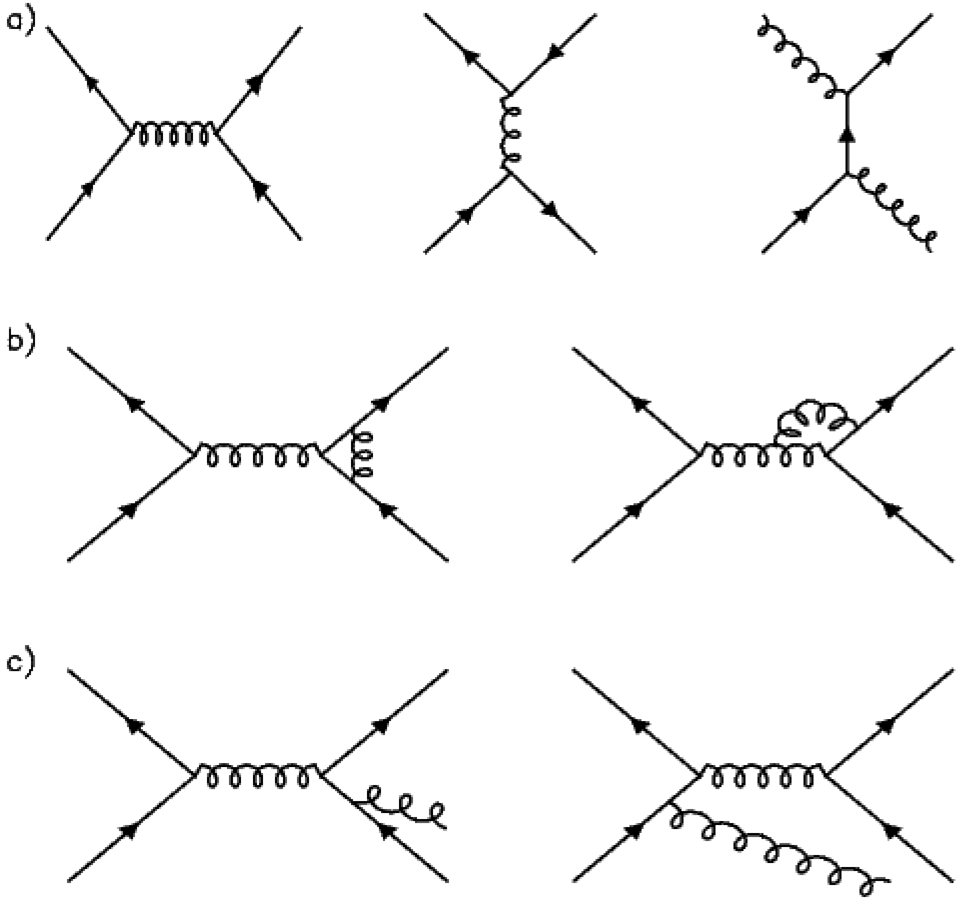


x: momentum fraction carried by individual parton
f(x,Q²): probability of finding parton with momentum fraction x in interval dx

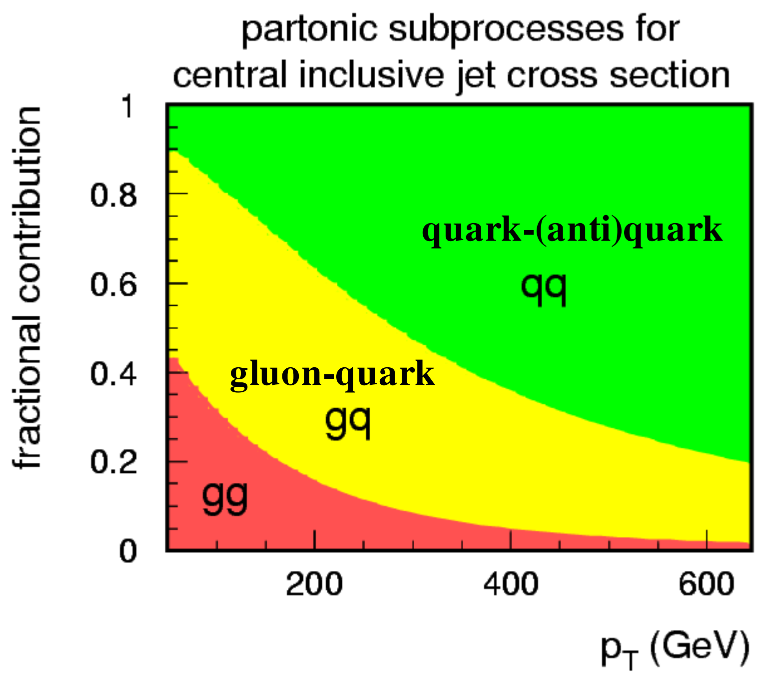
Data-Theory Comparison

- Comparison to analytic next-to-leading-order (NLO) calculation
- Theoretical physicists make predictions based on these diagrams using perturbation theory
- Motivation: better PDFs

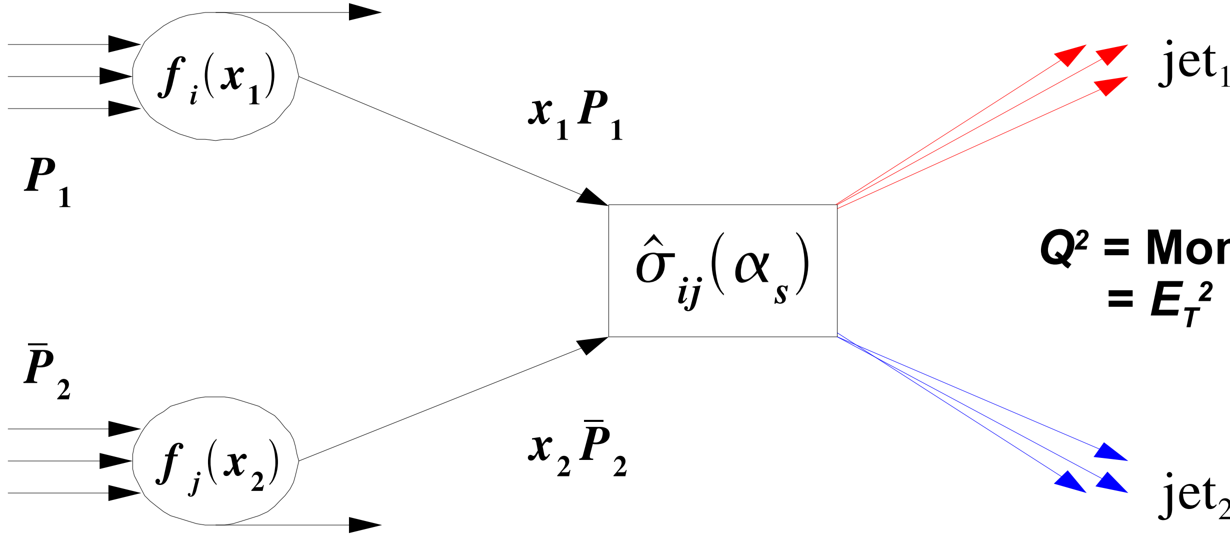
LO



NLO



The QCD calculation



Q^2 = Momentum Transfer
$= E_T^2$

$$\sigma = \sum_{ij} \int dx_1 dx_2 f_i(x_1, \mu_F^2) f_j(x_2, \mu_F^2) \hat{\sigma}_{ij}\left(\alpha_s^m(\mu_R^2), x_1 P_1, x_2 P_2, \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}\right)$$

Sum over initial states

Parton Distributions

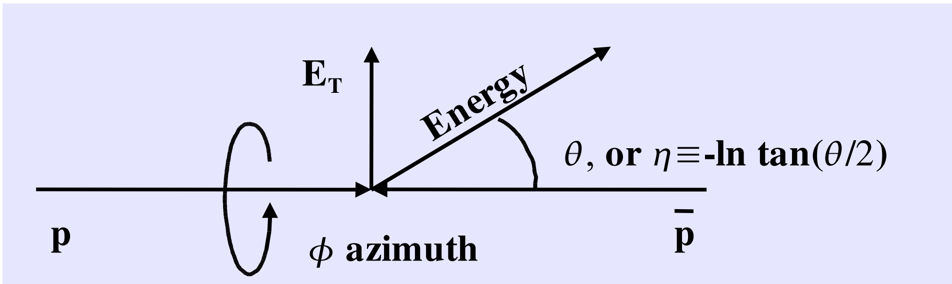
Factorization Scale

Point Cross Section

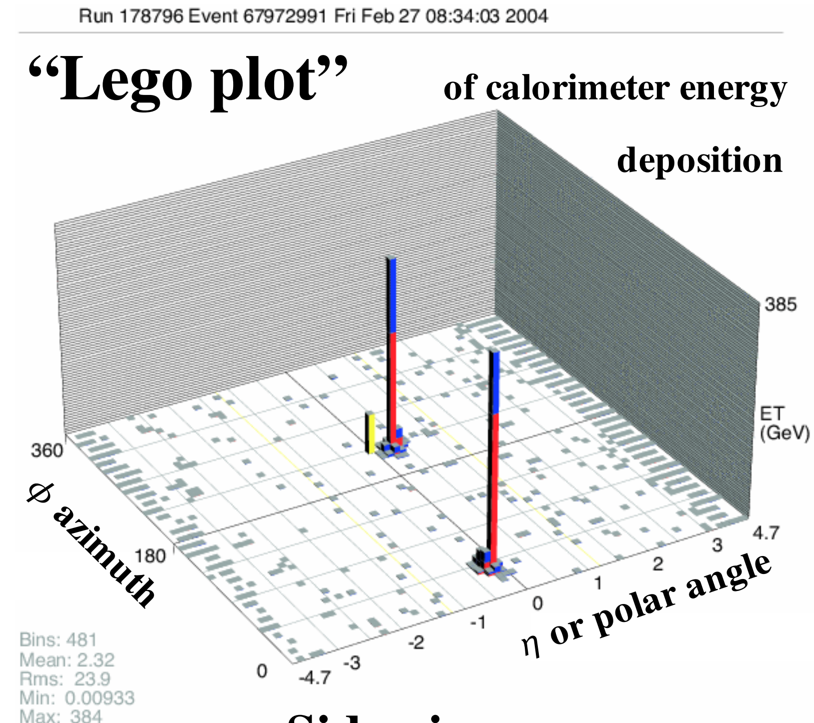
Order α_s^m

Renormalization Scale

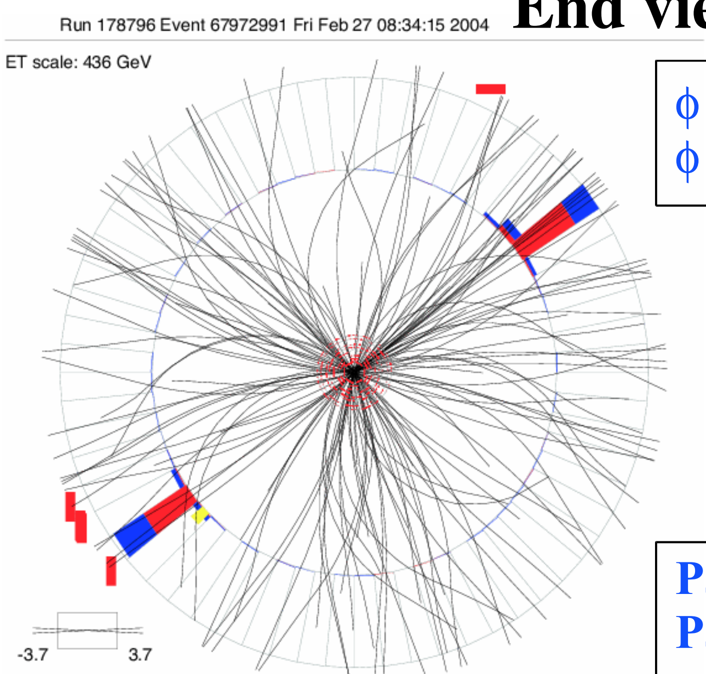
Highest energy DØ dijet event



$M_{jj} = 1206\ GeV/c^2$



End view

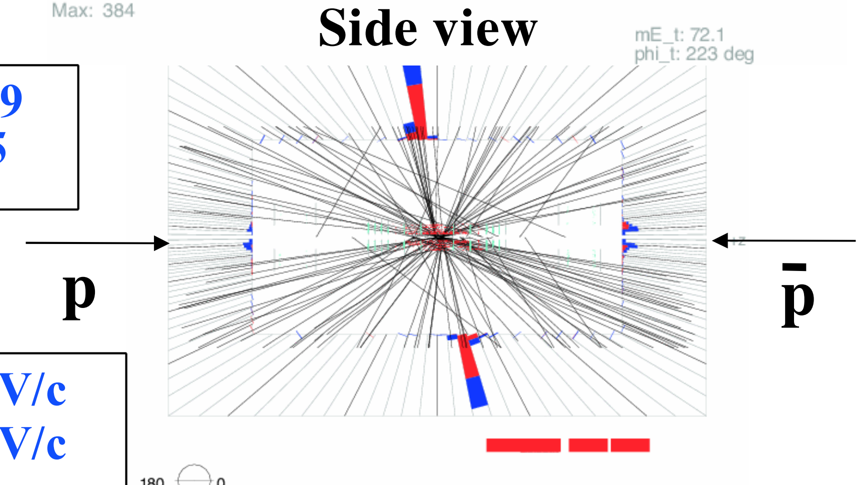


ϕ (Jet 1) = 0.65
ϕ (Jet 2) = 3.78

y (Jet 1) = -0.19
y (Jet 2) = 0.25

P_T (Jet 1) = 616 GeV/c
P_T (Jet 2) = 557 GeV/c

Side view

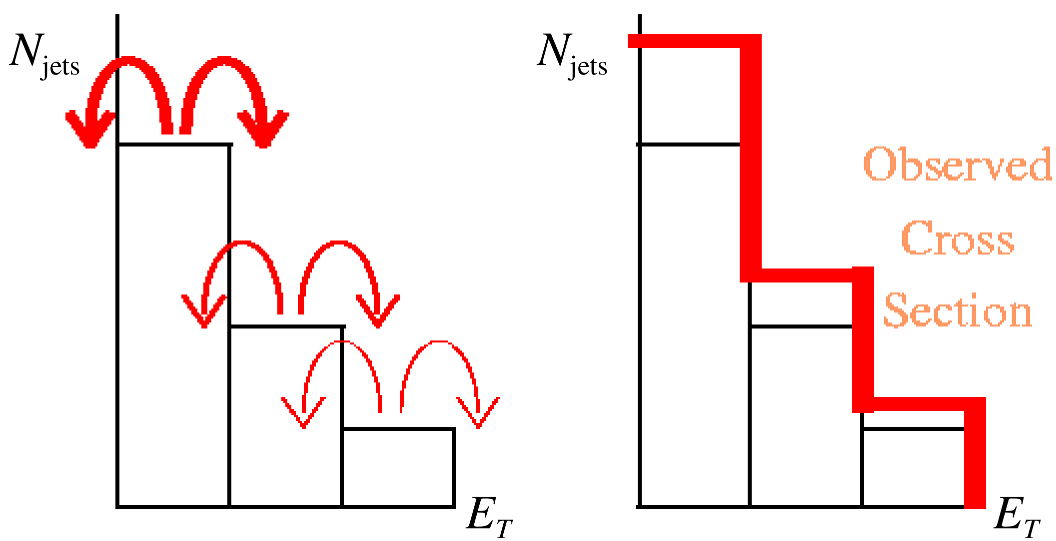


Steps of measurement

$$\frac{d^2\sigma}{dE_T d\eta} = \frac{N}{\epsilon L \Delta E_T \Delta\eta} \cdot C_{smear} \quad versus\ E_T$$

- Double differential cross section
- Number of jets
- JES
- Jet detection efficiency
- Integrated luminosity
- Bins of transverse energy and pseudorapidity

Events move in and out of E_T bins due to calorimeter energy resolution



John Krane

Jet results from Run I

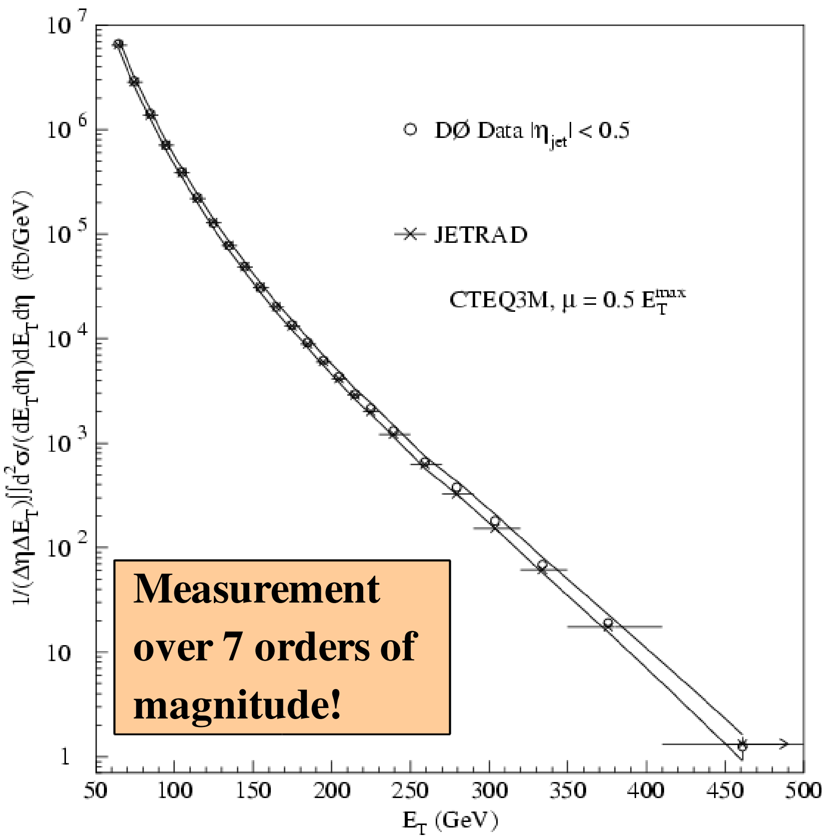
Jet results from Run I

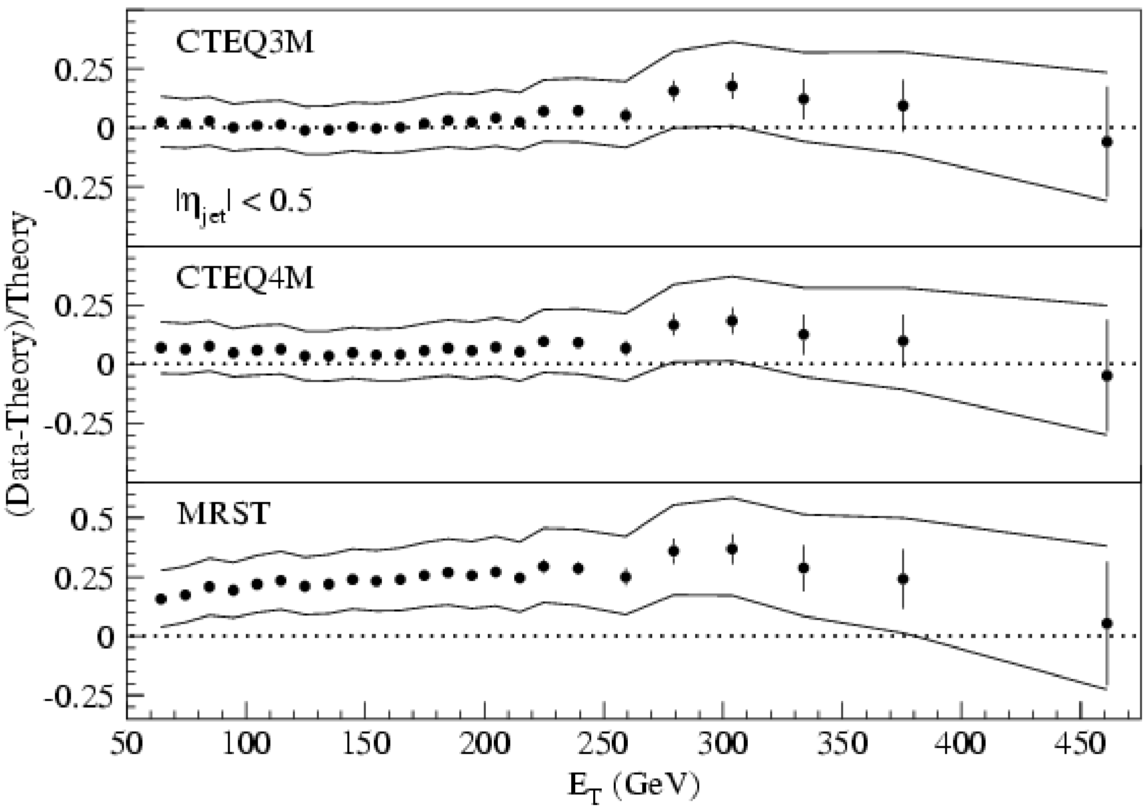
- The DØ inclusive jet cross section measurement from Run I was published in Phys. Rev. Lett. 82 in 1999
- Good agreement with NLO theory over a wide E_T range

Inclusive jet cross section

Phys. Rev. Lett. 82, p.2451 (1999); hep-ex/9807018

Good agreement with theory

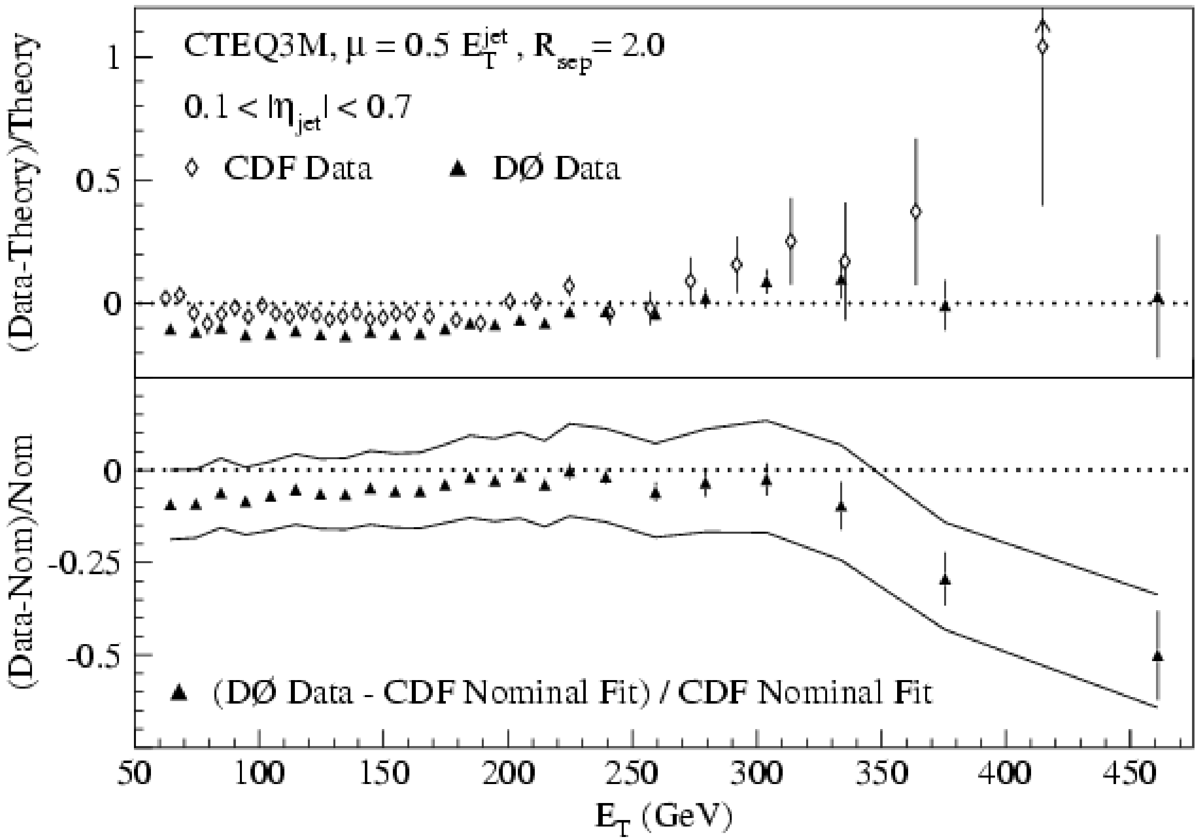




Inclusive jet cross section

- The inclusive jet cross section measurement caused a stir in Run I when CDF seemed to have an excess at high E_T
- Careful statistical analysis made at DØ showed that CDF excess was not significant and both experiments agreed within errors

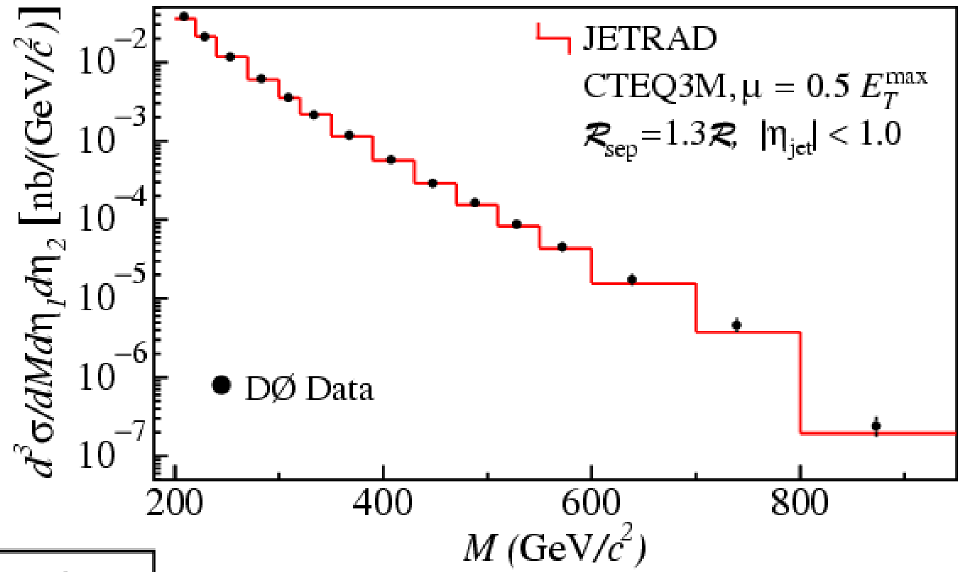
CDF to DØ comparison



Phys. Rev. Lett. 82, p.2451 (1999); hep-ex/9807018

Dijet mass cross section

- Complementary to inclusive jet cross section measurement
- Instead of inclusive (1,2,3...) jets use only dijets (2)
- Could show signs of quark compositeness
- Probes new particle resonances



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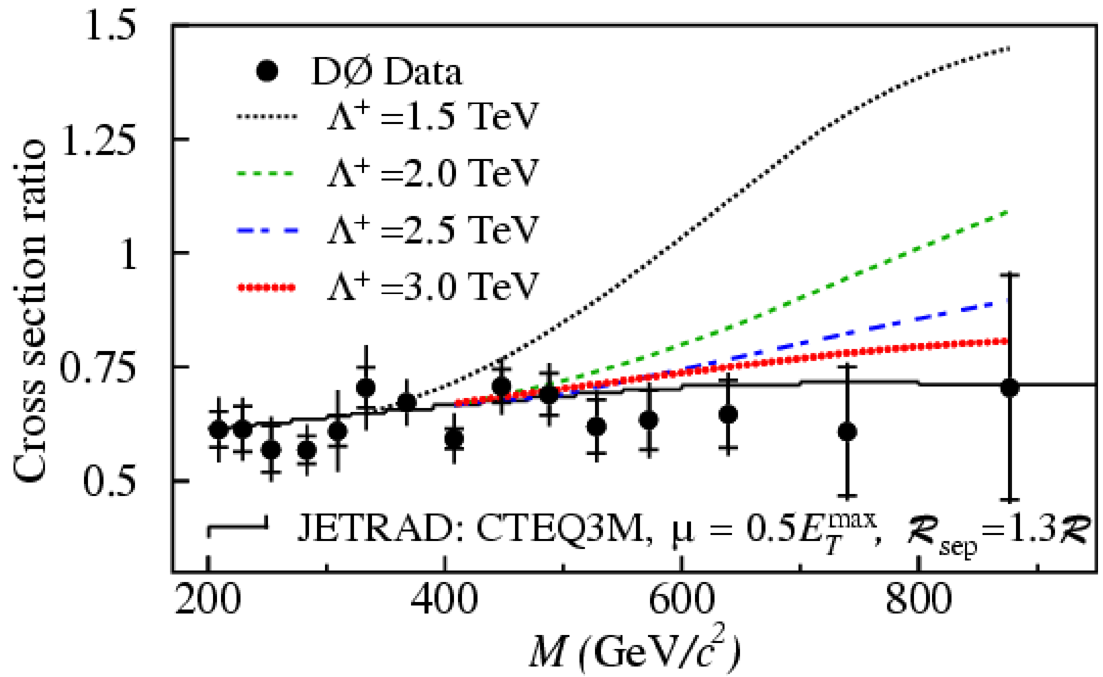
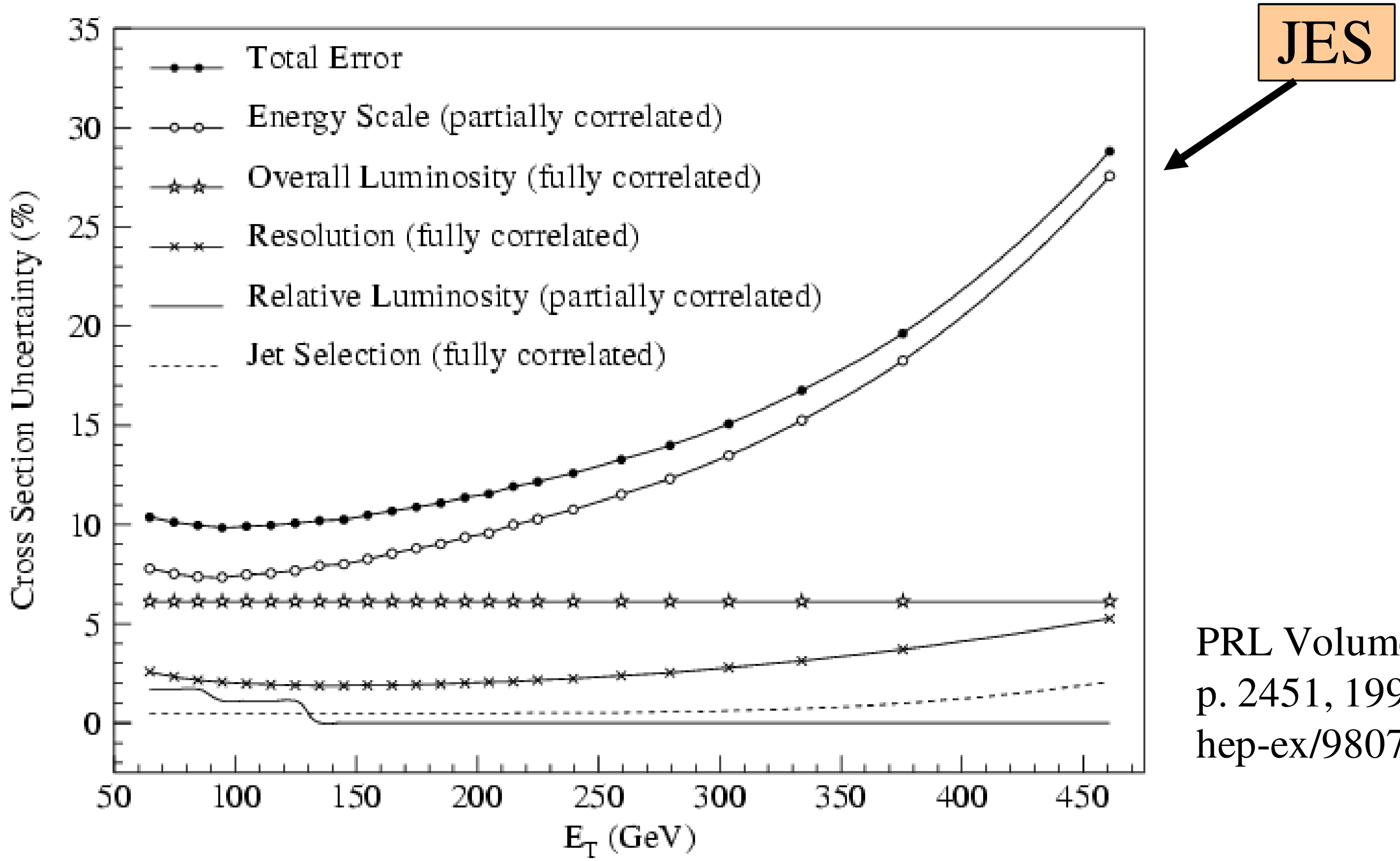


Dijet mass cross section ratio at two different rapidities is sensitive to contact interactions at quark compositeness scale Λ^+

Uncertainties in Run I

The leading uncertainty in inclusive jet cross section measurement (and in many others) was Jet Energy Scale (JES)

DØ systematics uncertainties



PRL Volume 82, p. 2451, 1999; hep-ex/9807018

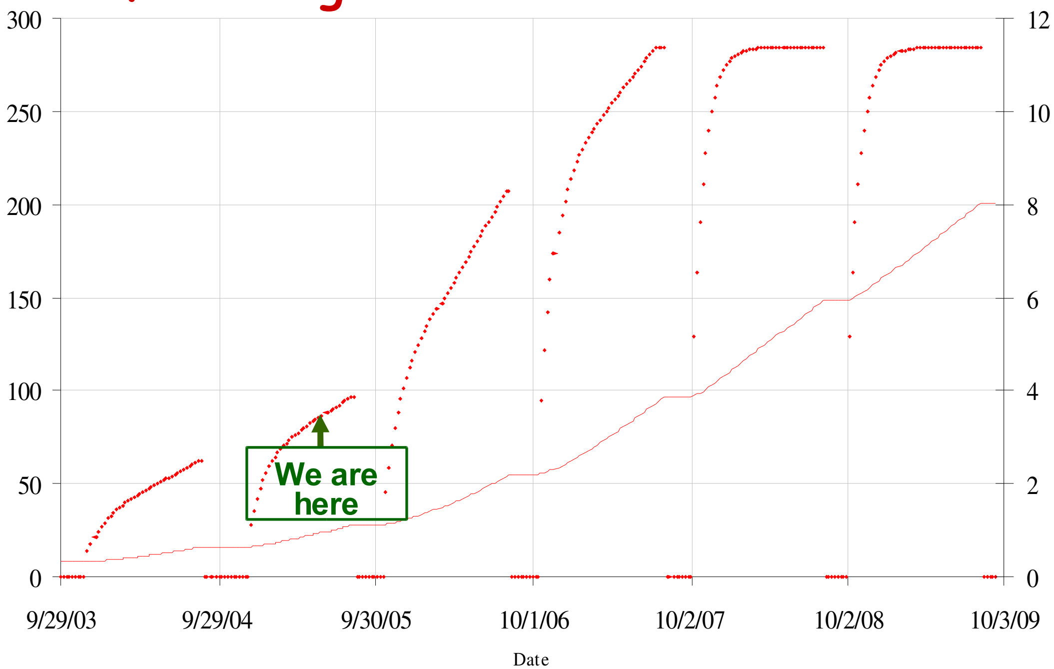
Jet physics from Run II

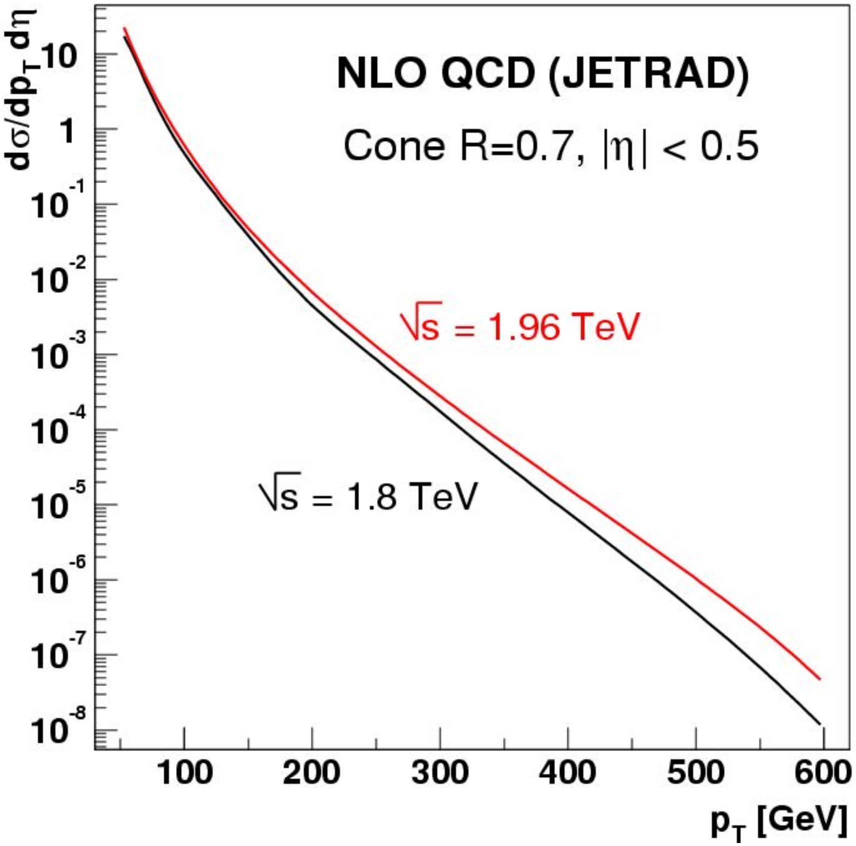
Why do this again?

- Improved luminosity means more statistics, ~100 pb^{-1} in Run I, 4-8 fb^{-1}(= 4000-8000 pb^{-1}) expected for Run II
- Higher center of mass energy, 1960 GeV versus 1800 GeV, means about three times larger cross section at 600 GeV
- Outstanding questions from Run I (e.g. CDF visual excess at high E_T)

~2.8e32 peak

~8 fb^{-1} integrated





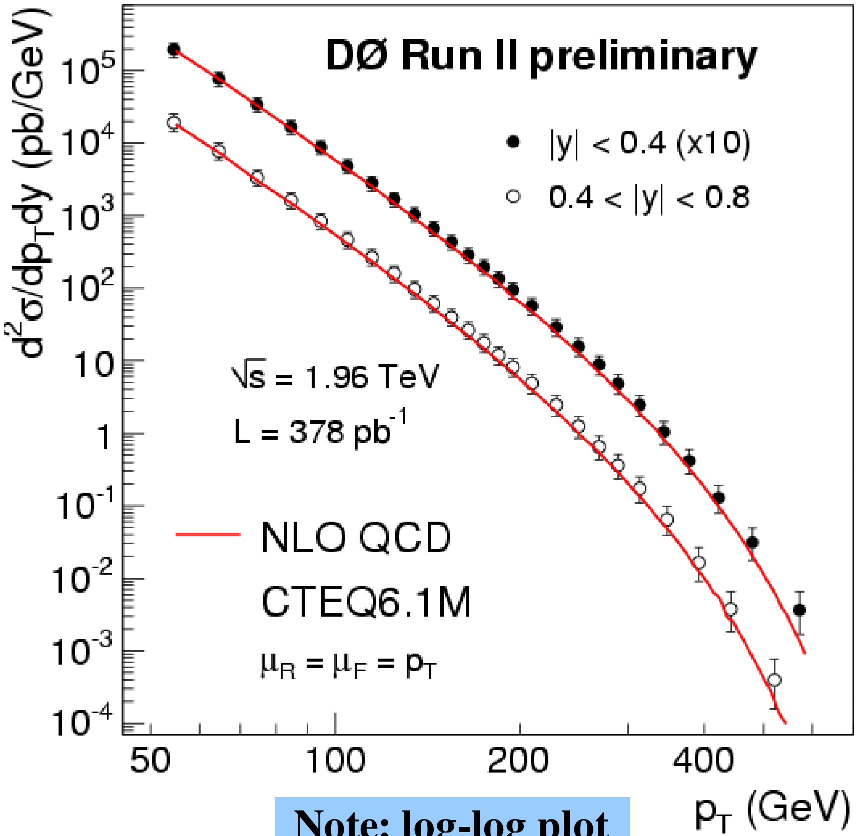
Run II preliminary

- Preliminary results from Run II presented at the Moriond conference this spring
- *"A good agreement between NLO perturbative QCD and data is found"*

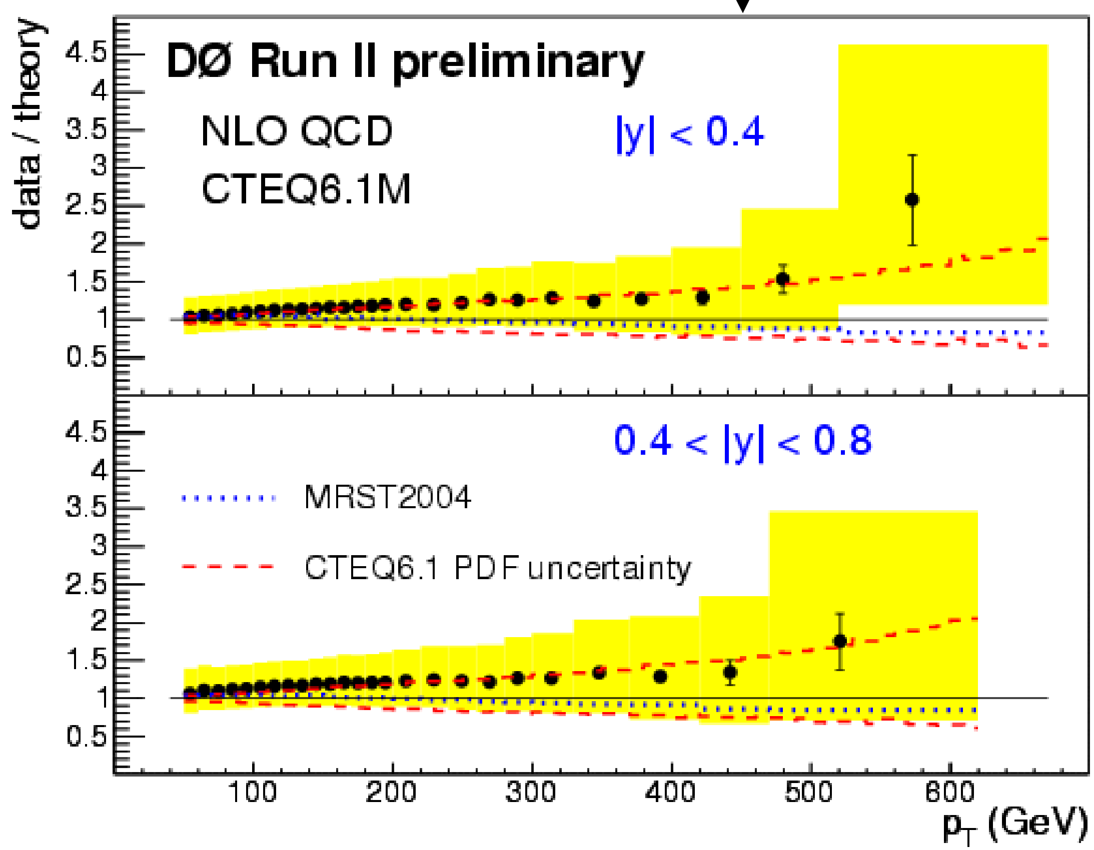
Measurement over 8 orders of magnitude!

Inclusive jet cross section

Run I highest 460 GeV



Note: log-log plot



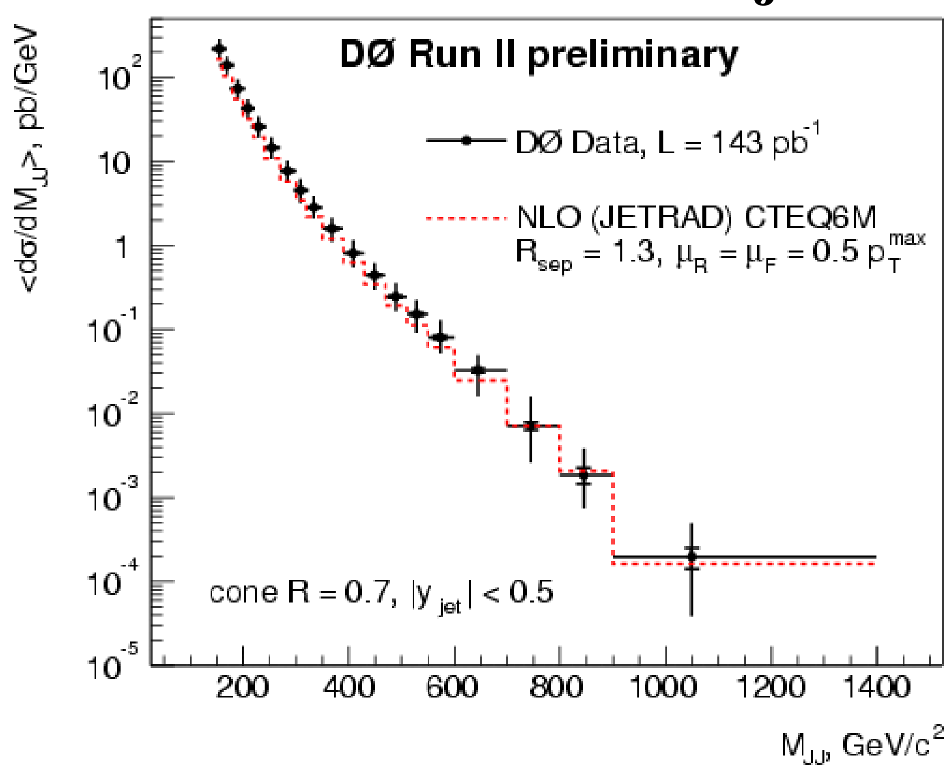
Dijet mass cross section

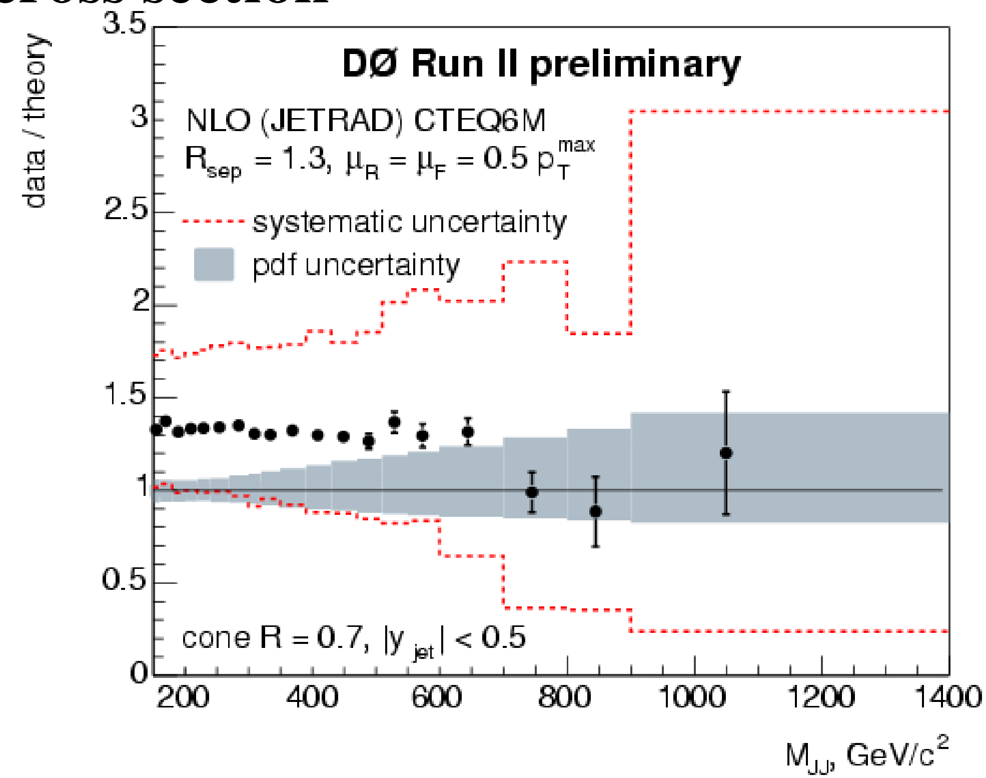
- Complementary to inclusive jet cross section
- Instead of inclusive (1,2,3...) jets use only dijets (2)
- Could show signs of quark compositeness
- Probes new particle resonances

Good agreement between data and NLO theory

Dijet mass cross section

Results from 2004





Outlook for Run II jet physics

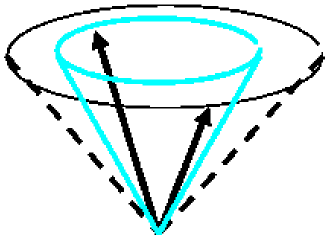
- Why Run II measurement still worse than Run I?
  - Detector changed, more material in front of calorimeter: large systematic uncertainties
  - Integrated luminosity only recently surpassed Run I total
- Much work needed to improve systematics, but:
  - Increased statistics can be used to do better calibrations with physics objects: gamma+jet, dijet calibration, calorimeter eta-phi intercalibration with jets, Z mass peak...
  - Can benefit from Run I experience
- Run II integrated luminosity by 2007 should be ~30 times that of Run I

Backup slides

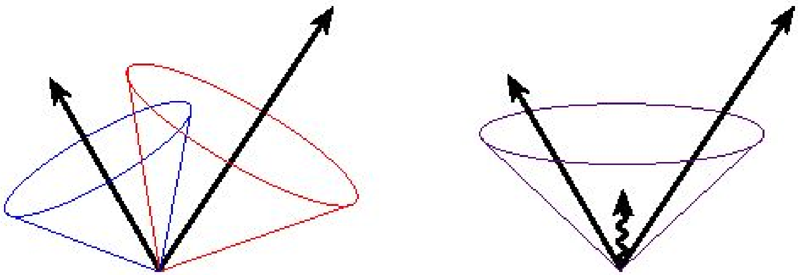
The “Run II cone algorithm”

“particle = {experiment: calorimeter towers / MC: stable particles / pQCD: partons}

three parameters: Rcone = 0.7, pTmin = 8 GeV, overlap fraction f = 50%



- Use all particles as **seeds**
  - make cone of radius DeltaR = sqrt(Deltay2+DeltaPhi2) < Rcone around seed direction
  - proto jet: add particles within cone in the “E-scheme” (adding four-vectors)
  - iterate until stable solution is found with: cone axis = jet-axis
- Use all **midpoints** between pairs of jets as **additional seeds** => infrared safety!!!!
  - (repeat procedure as described above)
- Take all solution from the first two steps:
  - remove identical solutions
  - remove proto-jets with pTjet < pTmin



- Look for jes with **overlapping cones**:
  - merge jets, if more than a fraction f of pTjet is contained in the overlap region
  - otherwise split jets: assign the particles in the overlap region to the nearest jet (→ and recompute jet-axes)

Differences between Run I and Run II

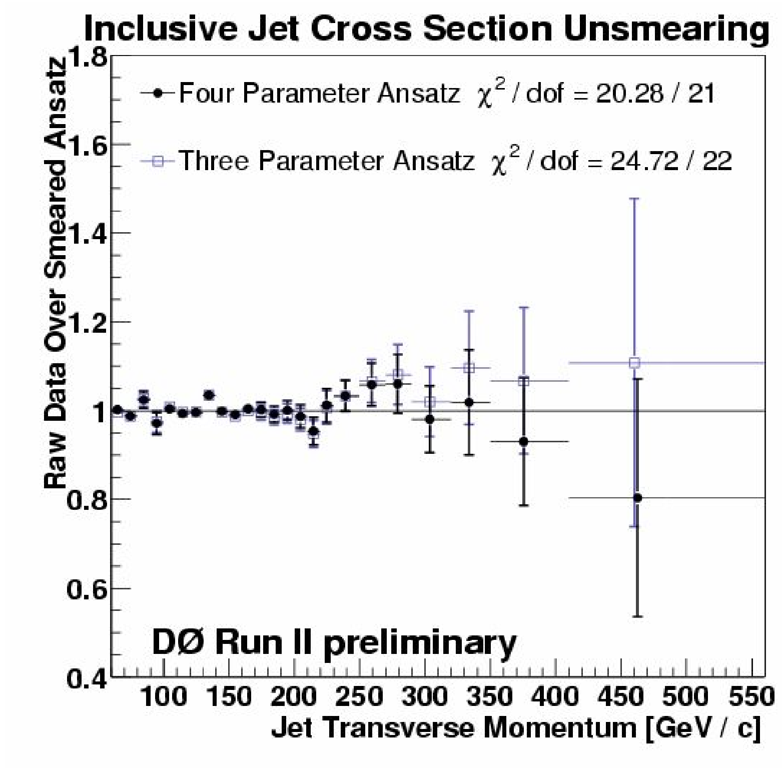
The cone algorithm used by DØ Run I differed in the following ways:

- Particles were combined in the "E_T-scheme" ("snowmass convention") instead of the "E-scheme" (adding four-vectors)
  - ⇒ in Run I by definition jet four-vectors were massless
  - → pseudorapidity η was used instead of rapidity y
  - → transverse energy $E_T = E \cdot \sin\theta$ was used instead of transverse momentum p_T

  Please note: $E_T^{E_T\text{-scheme}} > p_T^{E\text{-scheme}}$ and $M_{dijet}^{E_T\text{-scheme}} < M_{dijet}^{E\text{-scheme}}$

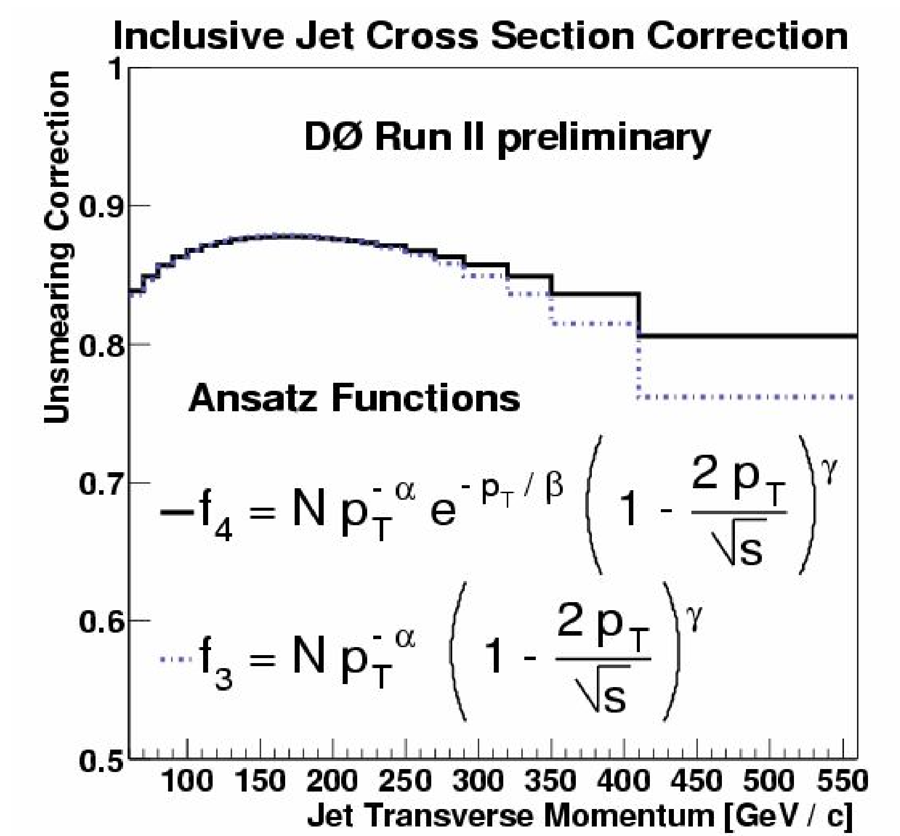
- No midpoints were used as additional seeds
  - ⇒ procedure not infrared safe ⇒ no predictions from perturbative QCD possible

Smearing correction



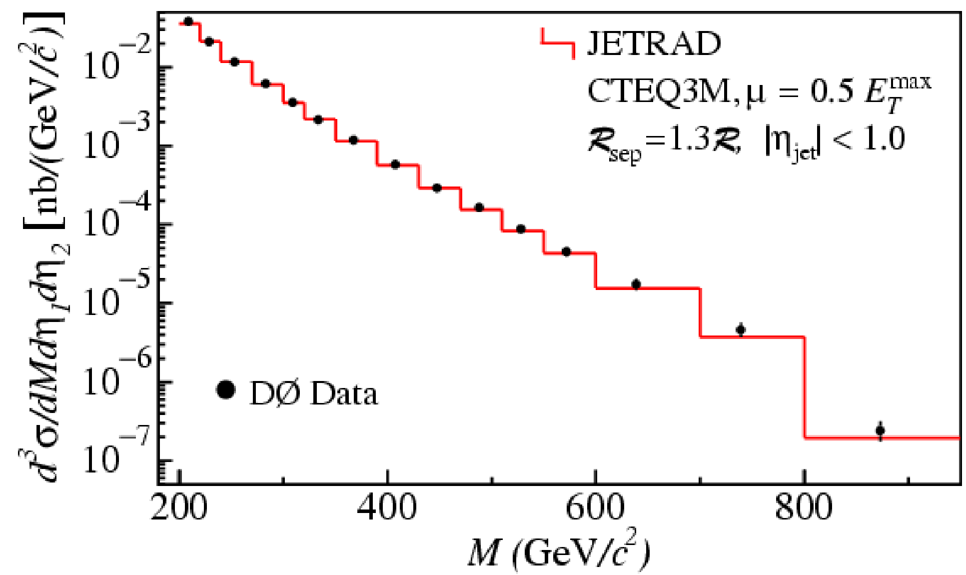
Ansatz functions compared to the data after smearing with jet resolution and fitting

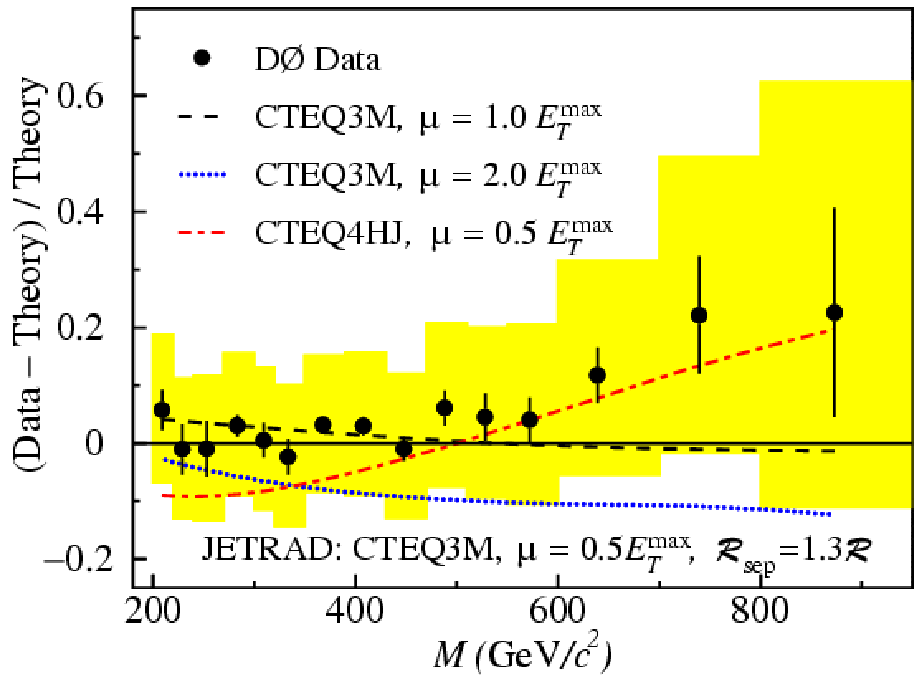
Unsmearing corrections

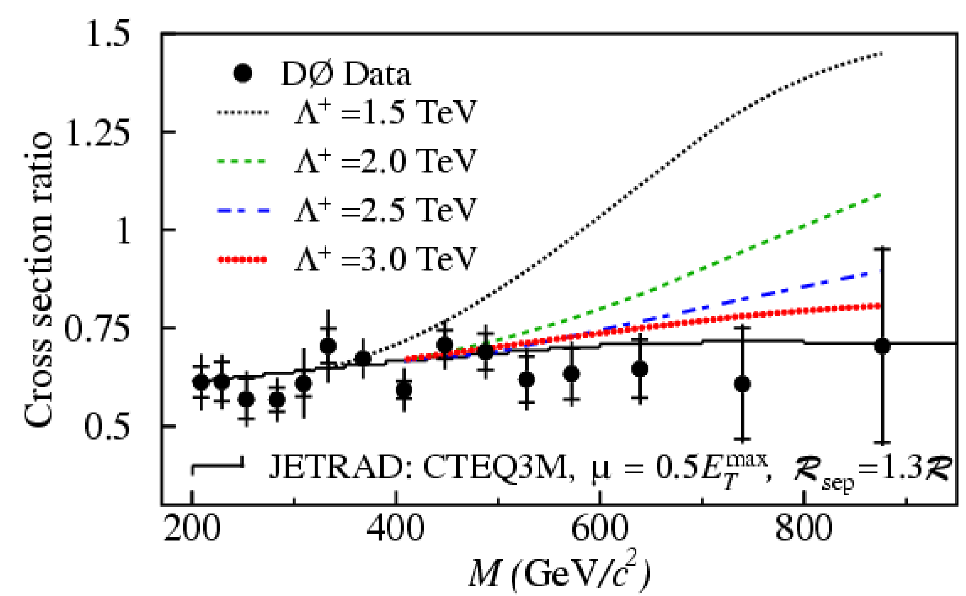


Dijet mass cross section

- Very similar to inclusive jet cross section measurement
- Instead of inclusive (1,2,3...) jets use only dijets (2)
- Back-to-back, E_T balance, probes Q^2
- Could show signs of quark compositeness

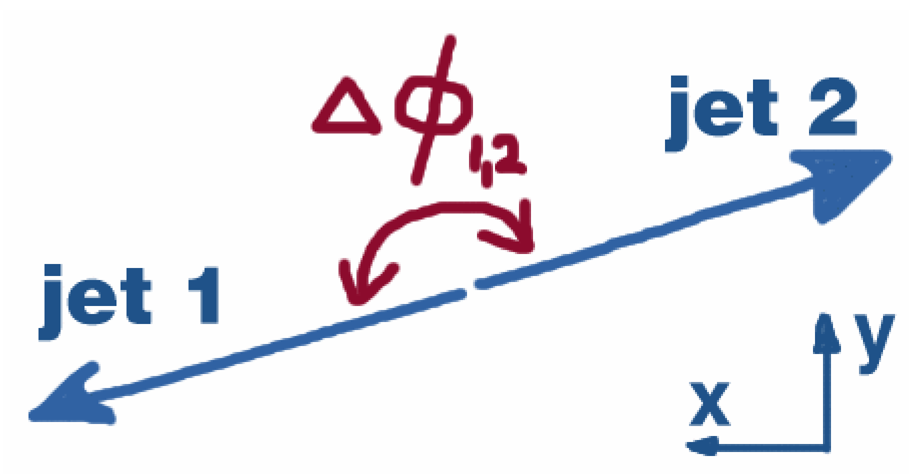


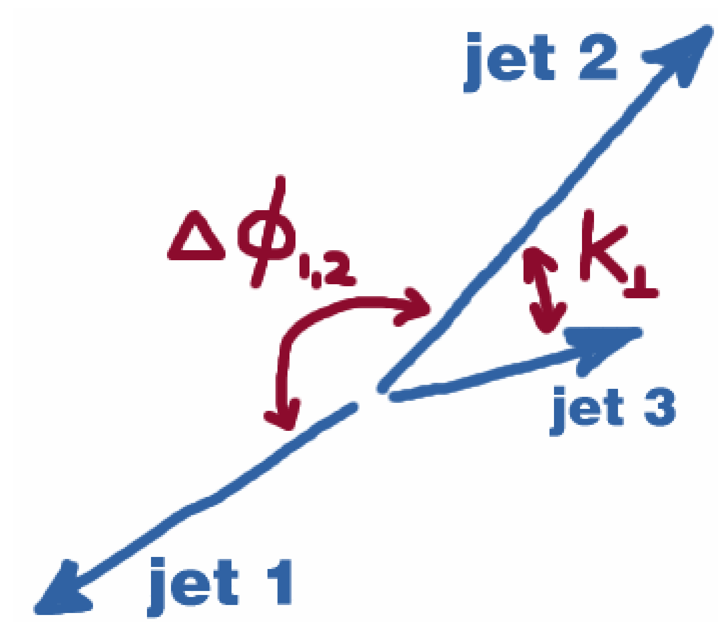




Azimuthal decorrelations

- Dijet cross section as a function of the azimuthal angle between the two leading jets ($\Delta\phi$)





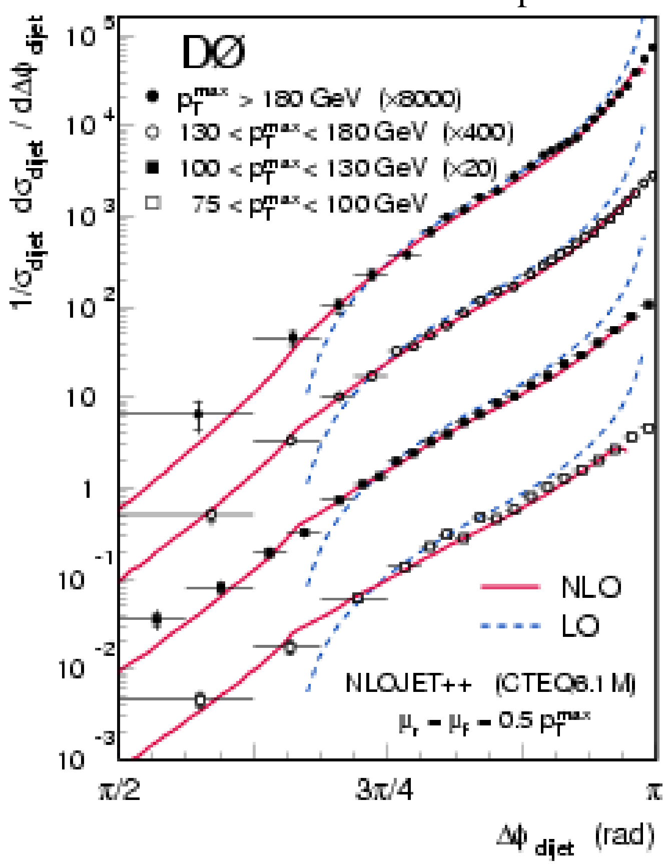
Azimuthal decorrelations

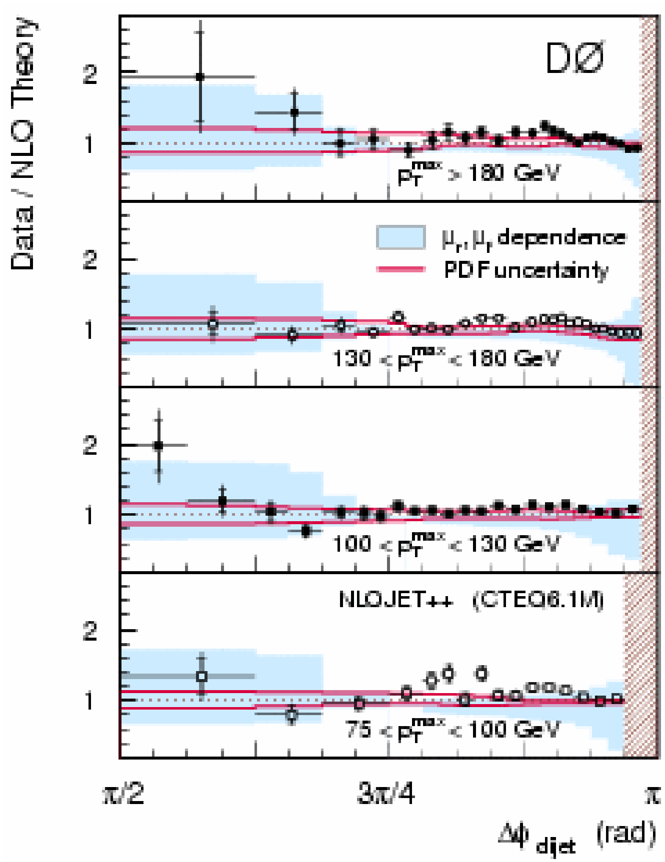
- Dijet cross section as a function of the azimuthal angle between the two leading jets ($\Delta\phi$)
- First Run II QCD paper (submitted to PRL)

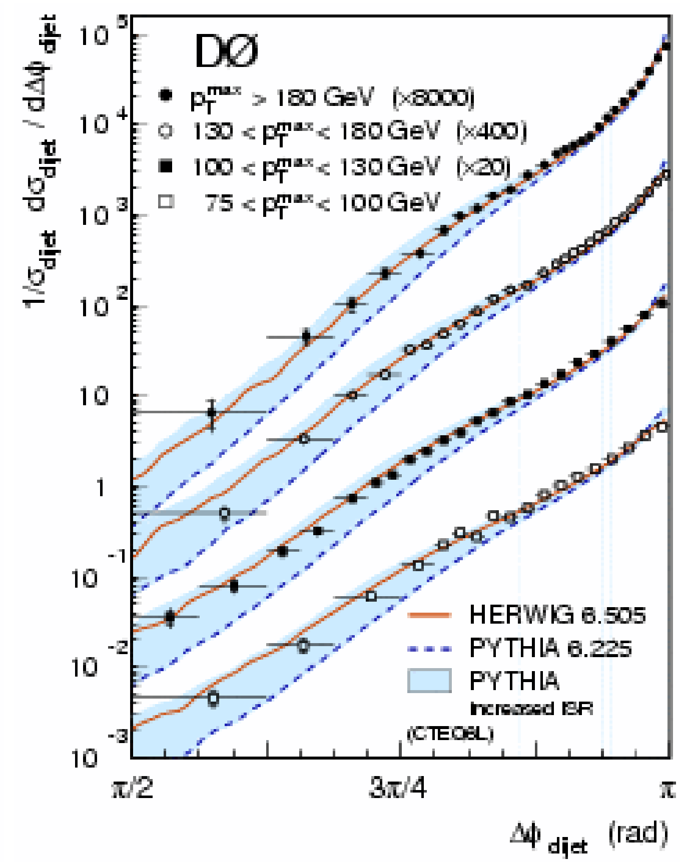
Herwig and **Pythia** are **Monte Carlo** event generators

Azimuthal decorrelations

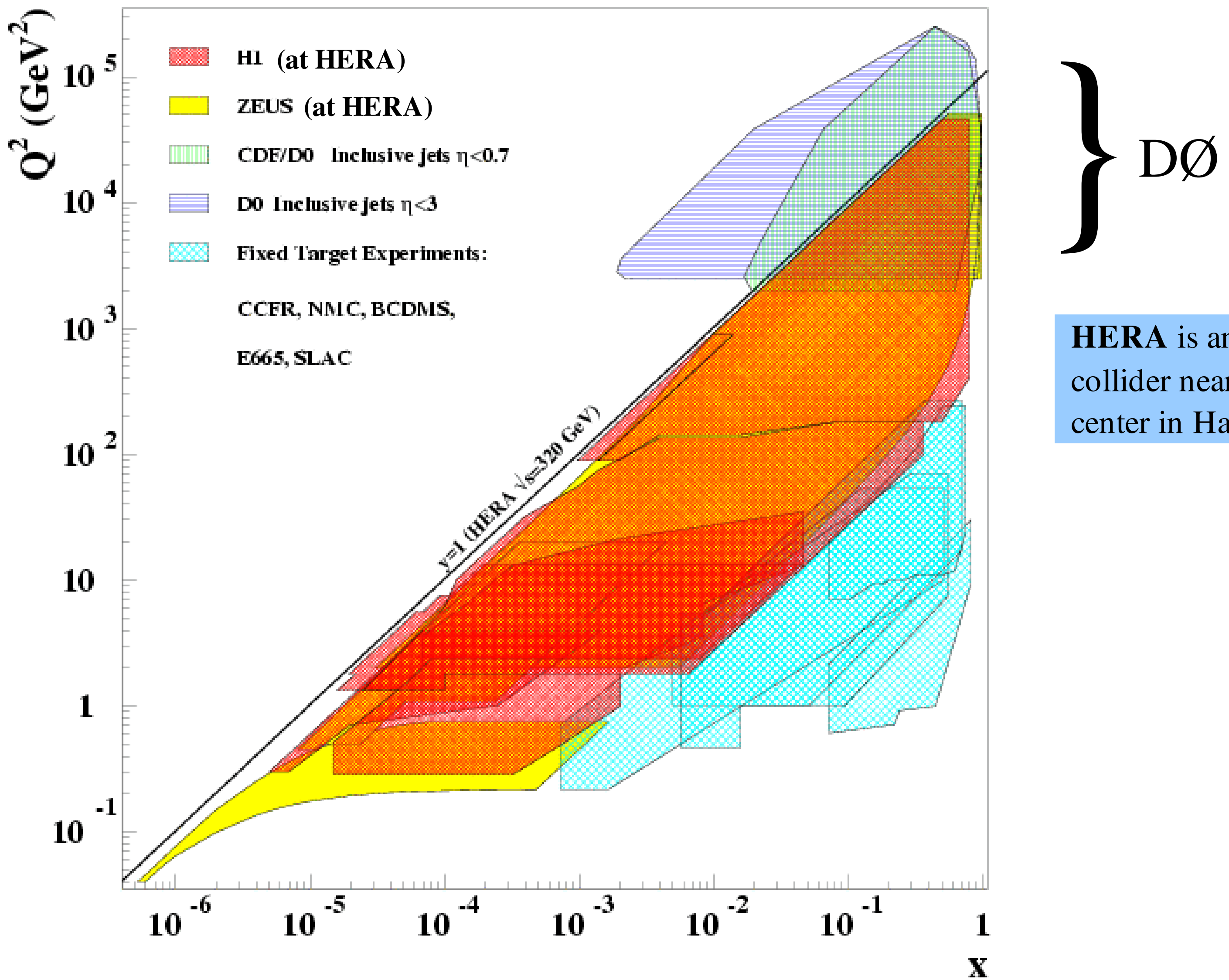
hep-ex0409040







DØ kinematic range

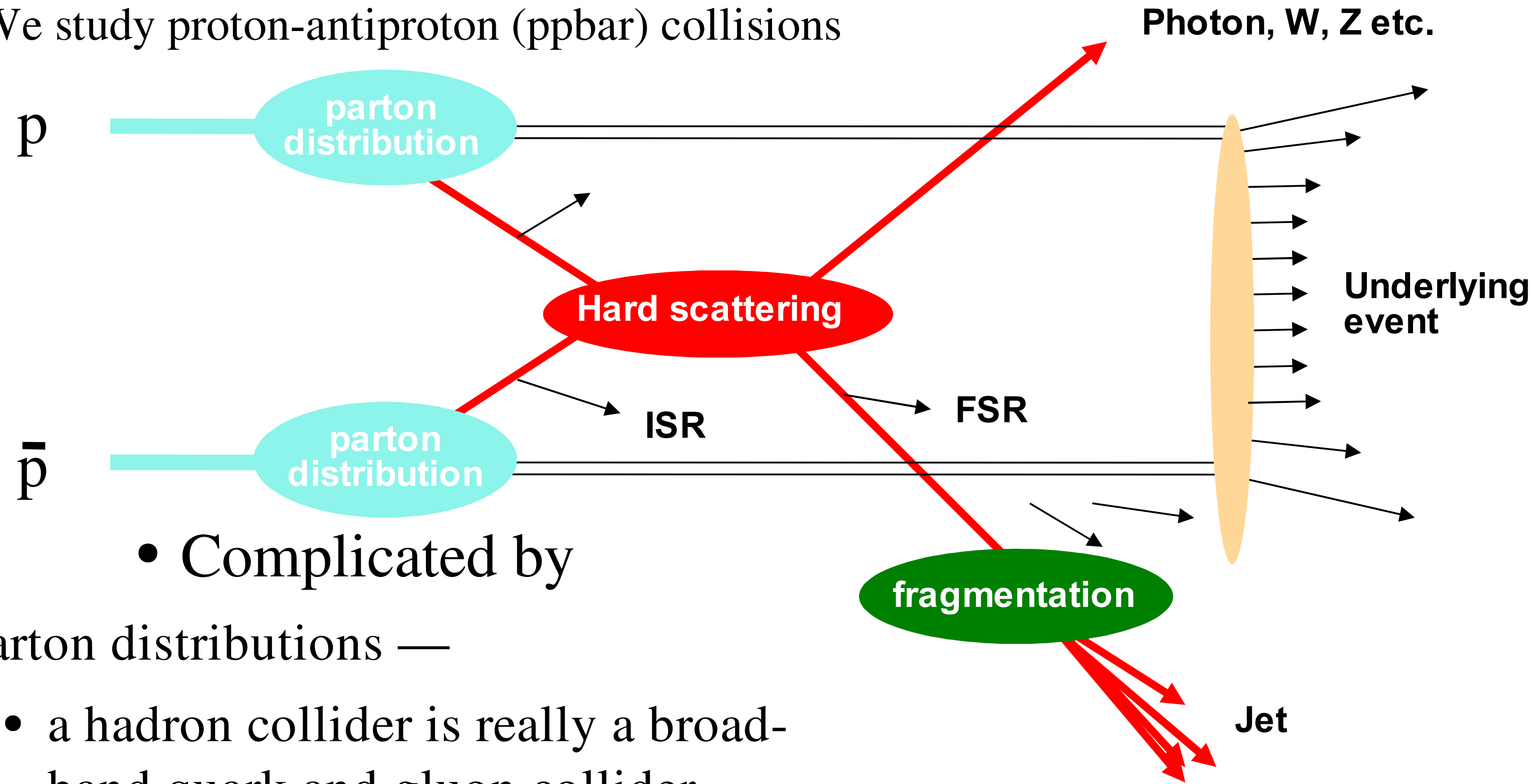


HERA is an electron-proton collider near DESY research center in Hamburg, Germany

What is a jet?

Jet is a spray of particles coming from a hard interaction

- Jets are formed by collisions of partons (quarks and gluons) from individual particles
- We study proton-antiproton (ppbar) collisions



- Complicated by

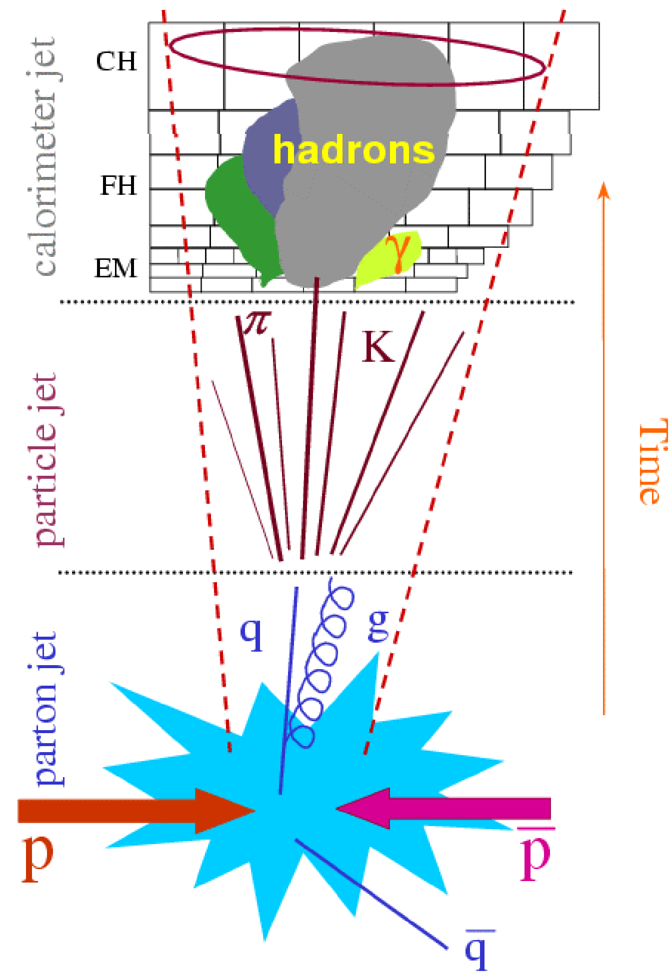
– parton distributions —

- a hadron collider is really a broad-band quark and gluon collider
- both the initial and final states can be colored and can radiate gluons

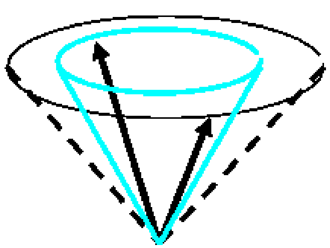
– underlying event from proton remnants

Detecting jets

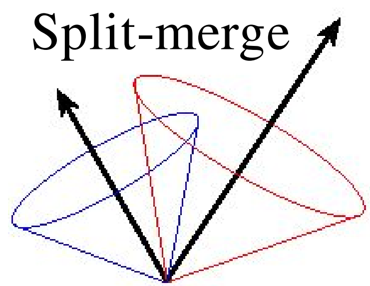
- Experimentally jets are clusters of calorimeter energy
- Experimental difficulties:
  - Jets come in varying shapes
  - Jets may overlap
  - Event may contain soft radiation outside the jet “cone”
- Jet algorithm needs to address these issues to successfully relate data to theory:
  - Fixed cone size or k_T
  - Split-merge procedures
  - Infrared safety (results stable with soft radiation)
- Run II cone algorithm, Run I cone algorithm, k_T jets



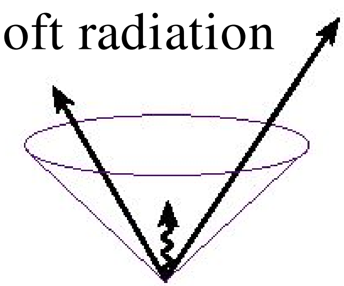
Cone size



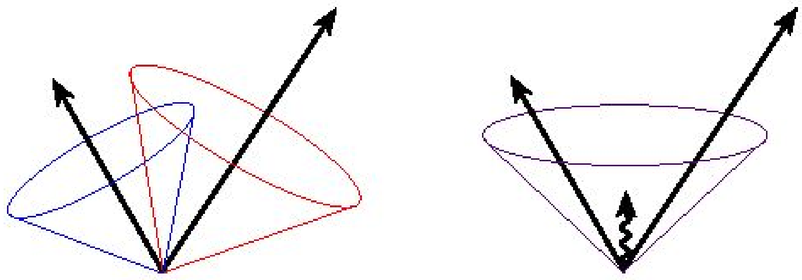
Split-merge



Soft radiation



Jet algorithms



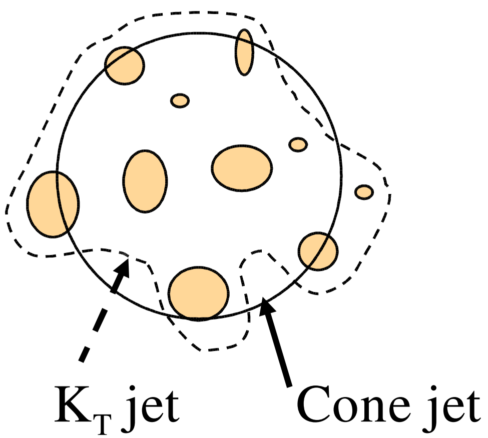
Run I Legacy Cone:

- 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

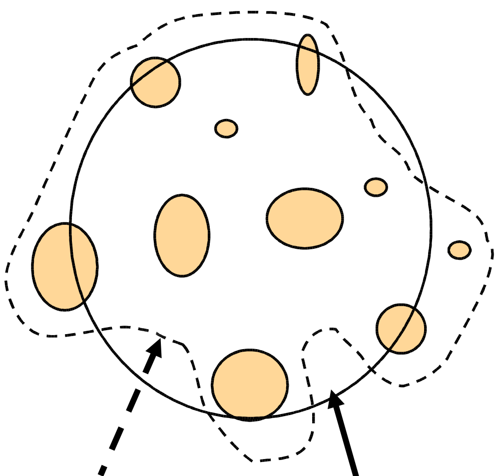
Future: k_T algorithm?

- So far we have been using only cone algorithms
  - Improvements over time make them more stable against soft radiation/collinear partons
    - Still, ambiguity when 2 cone jets overlap
      - Experimental prescription for "split/merge"
      - In theory, arbitrary parameter introduced to handle this
        - Not ideal
- Combining particles by their relative transverse momentum (k_T) is much more robust between data and theory

k_T: (some D0 Run I/new CDF runII)

Uses relative momentum of particles

Infrared/collinear safe (in principle)
Fewer split/merge ambiguities



$$d_{ij} = \min(P_{T,i}^2, P_{T,j}^2) \frac{\Delta R_{ij}^2}{D^2}$$

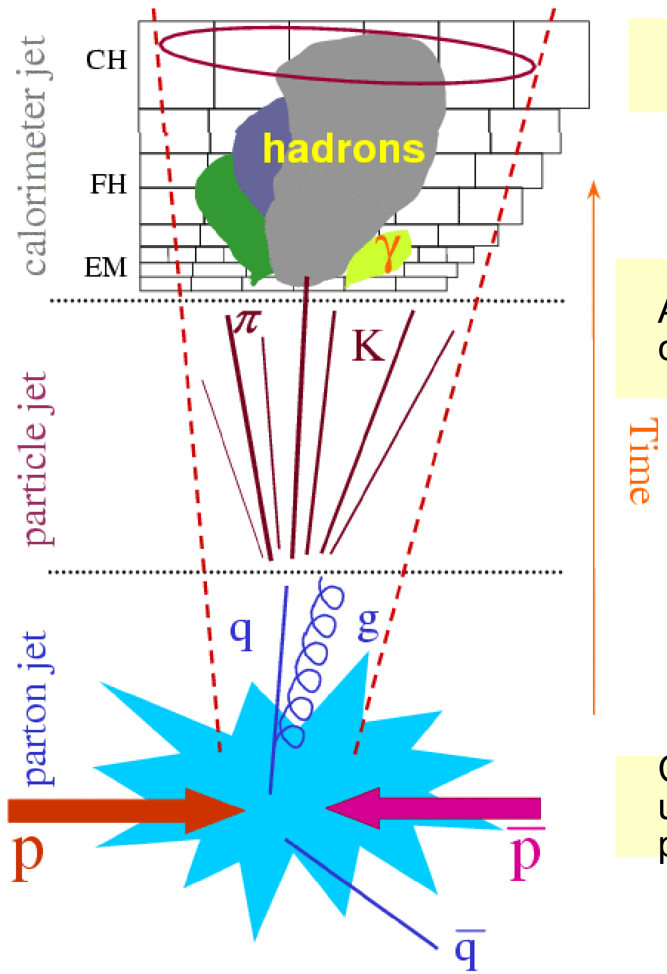
$$R_{ij} = \sqrt{\Delta \eta_{ij}^2 + \Delta \phi_{ij}^2}$$

(*D* is a "distance" parameter)

V. O'Dell

Jet Energy Scale

Leading uncertainty



Complex detector properties

Algorithms with complex behavior

Complex underlying physics

Need to correct for detector, algorithm and physics effects to obtain the true energy of the jets:
Jet Energy Scale (JES)

$$E_{jet}^{particle} = \frac{E_{jet}^{calor} - E_{offset}}{R_{jet} \cdot F_S}$$

Measured jet energy (as measured in calorimeter)

Offset Correction (for energy not associated with hard scatter)

Corrected jet energy (to particle level)

Jet response

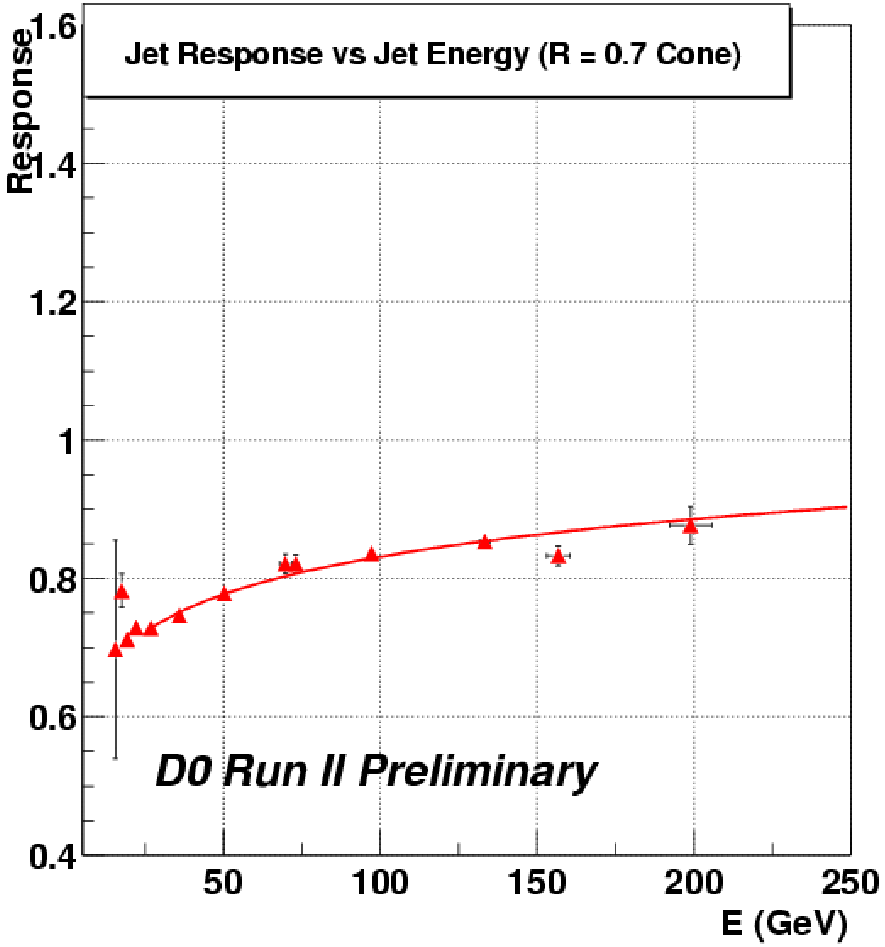
Showering Correction (for energy leaking in/out of cone)

Jet resolution

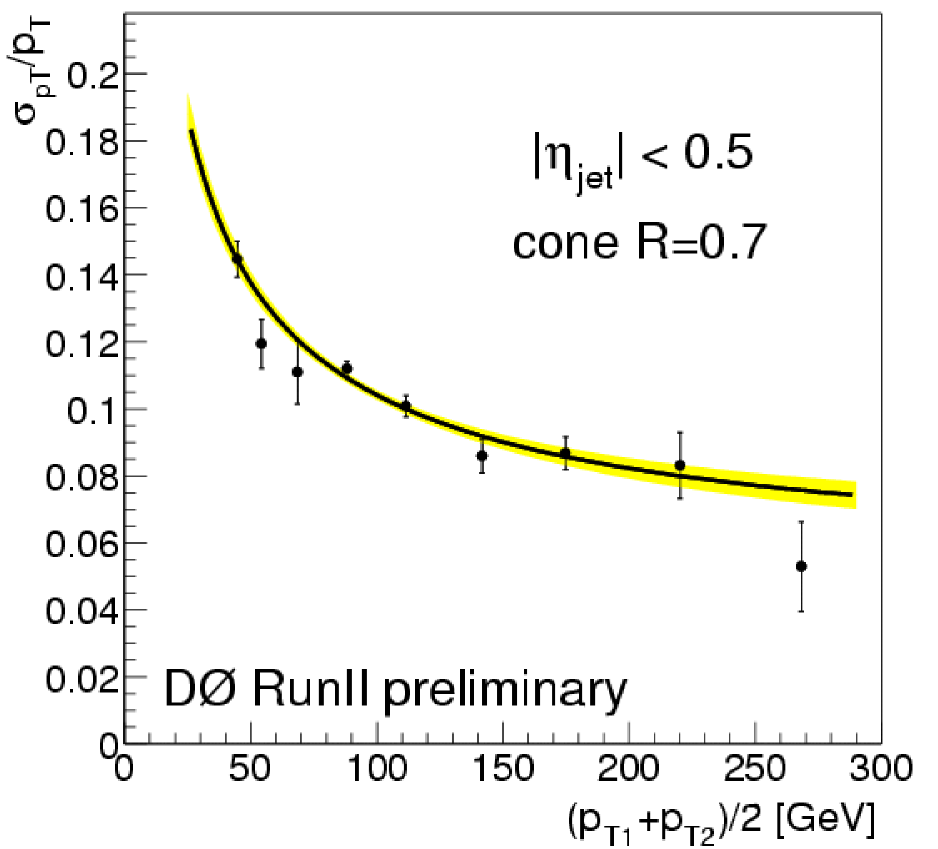
- Resolution needed for unsmearing
- JES is also important for other physics results (e.g. top mass in lepton+jets)

Jet response $R \equiv E_{meas}/E_{particle}$

Resolution $\frac{\sigma}{p_T} = \sqrt{\frac{N^2}{p_T^2} + \frac{S^2}{p_T} + C^2}$



Jet resolution



Krane's Thesis (1998)

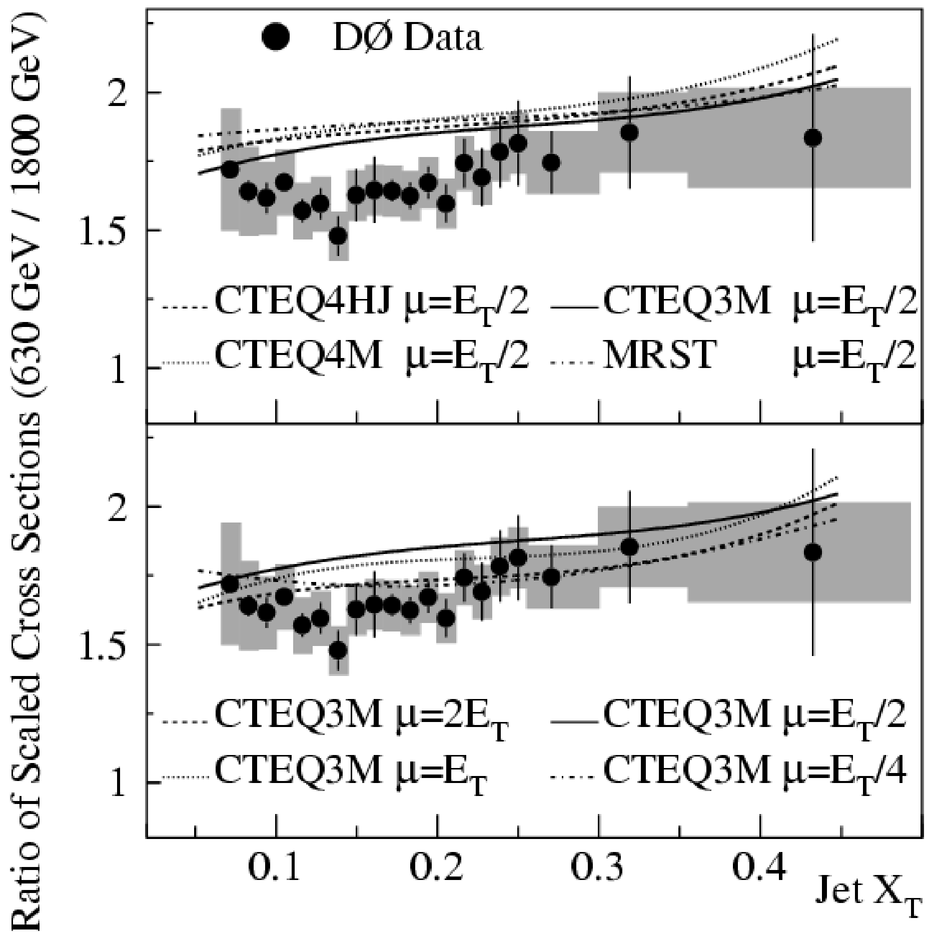
JES (leading systematic uncertainty) will cancel in the ratio of cross sections at different √s

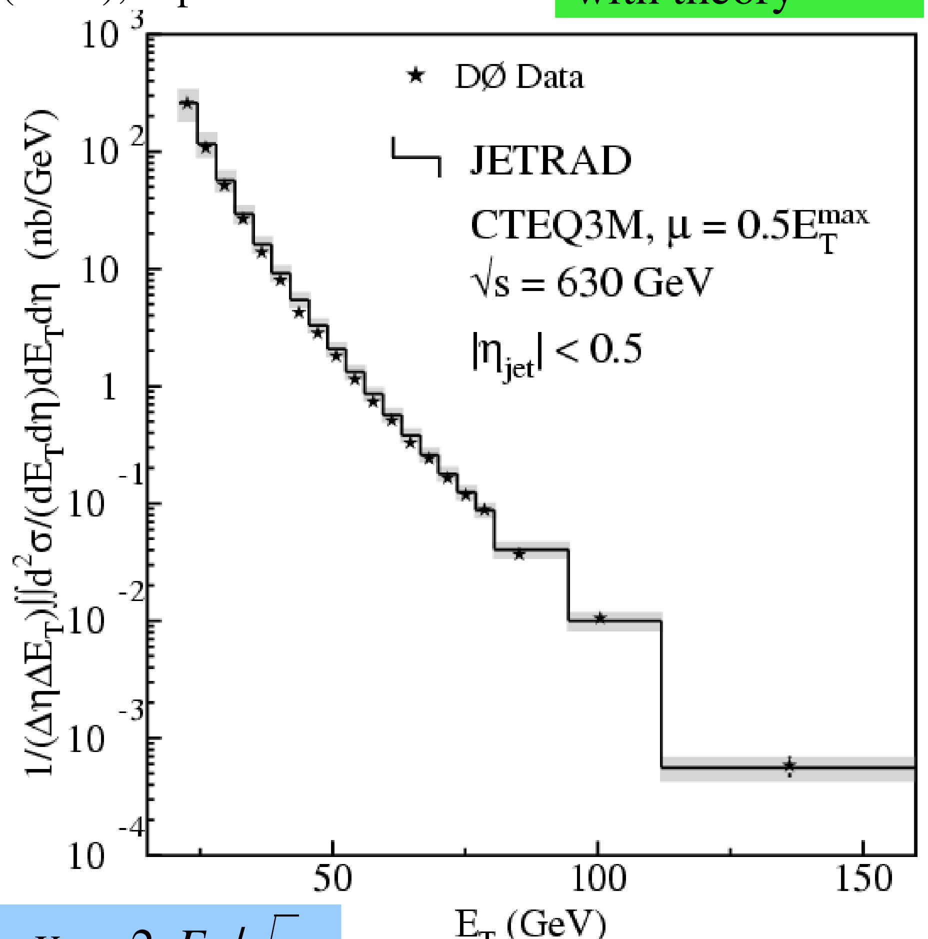
Agreement with theory

Ratio of scaled cross sections at 630 GeV / 1800 GeV

Phys. Rev. Lett. 86, p.2523 (2001); hep-ex/0008072

Good agreement with theory



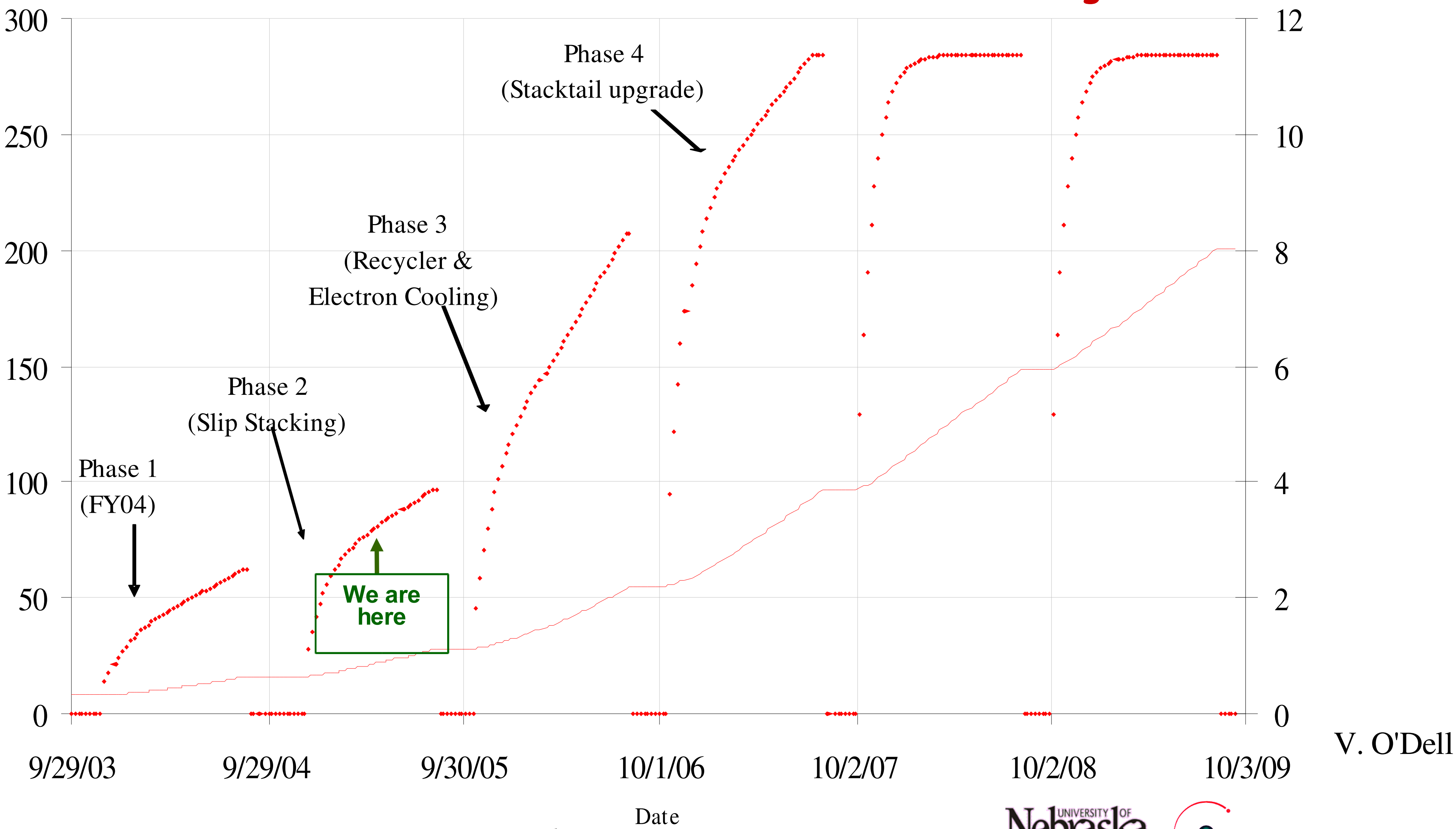


Jet X_T: $2 \cdot E_T / \sqrt{s}$

Run II luminosity projections

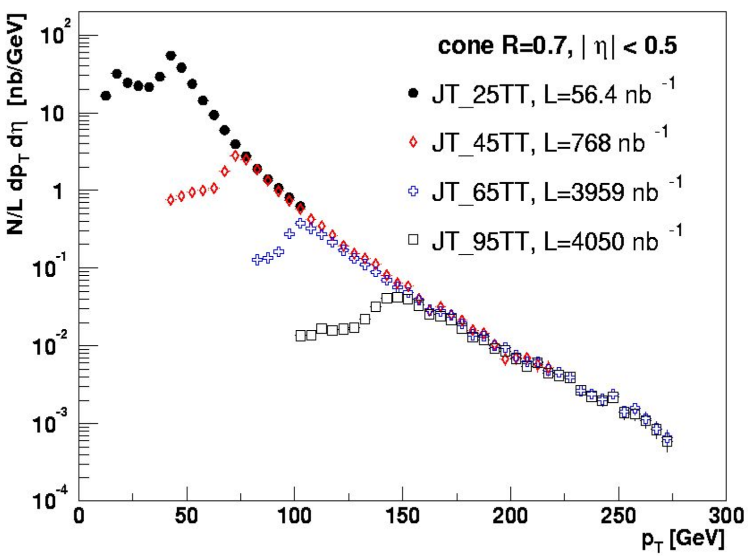
Luminosity just keeps on coming!
(note "base goal" is 4fb^{-1} integrated)

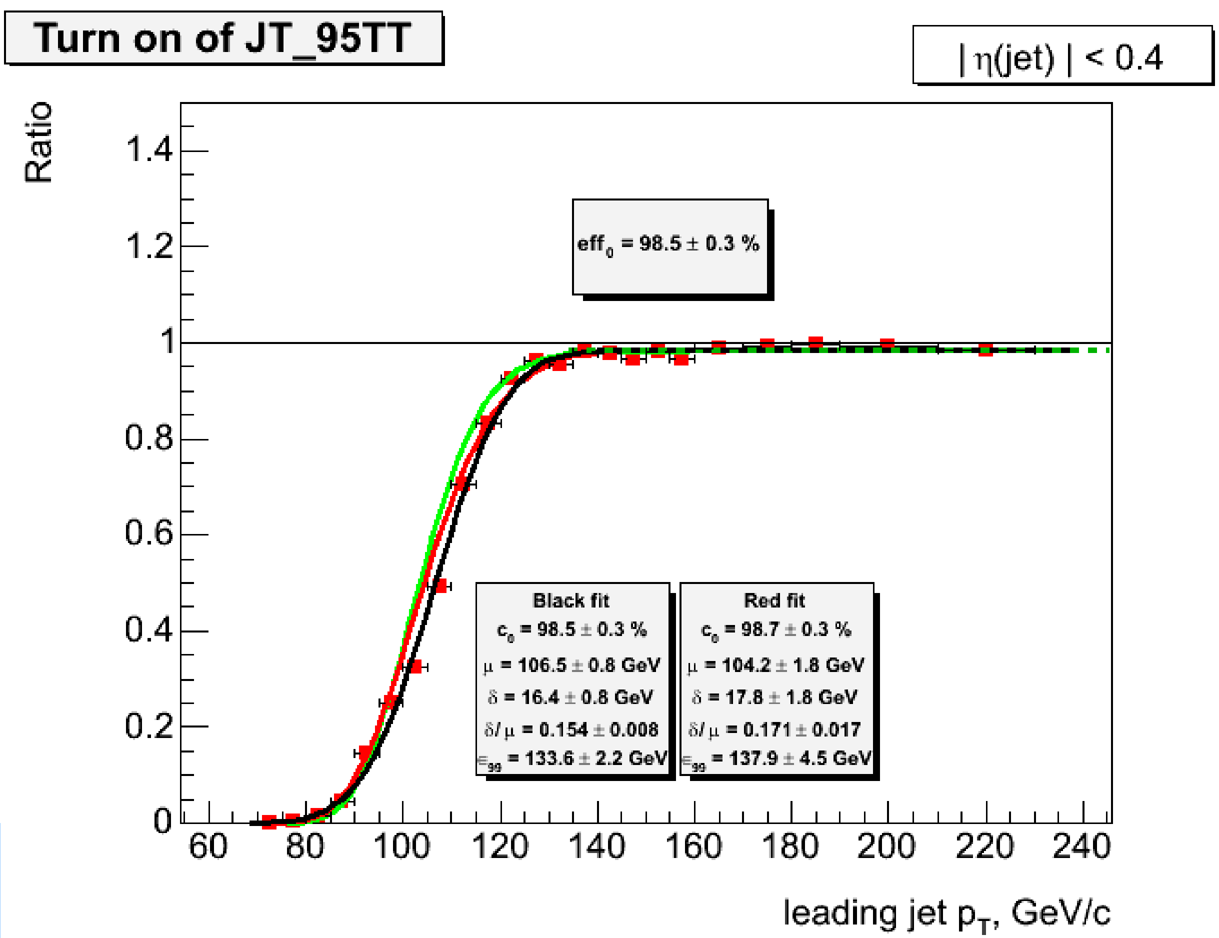
~2.8e32 peak
~8 fb^{-1} integrated



Jet trigger efficiencies

- Absolute jet trigger efficiencies: formerly trigger efficiencies studied relative two each other, poor knowledge of absolute efficiency
- Muon triggered events used to check efficiency





Ratio of number of jets triggered by JT_95TT compared to JT_65TT etc.