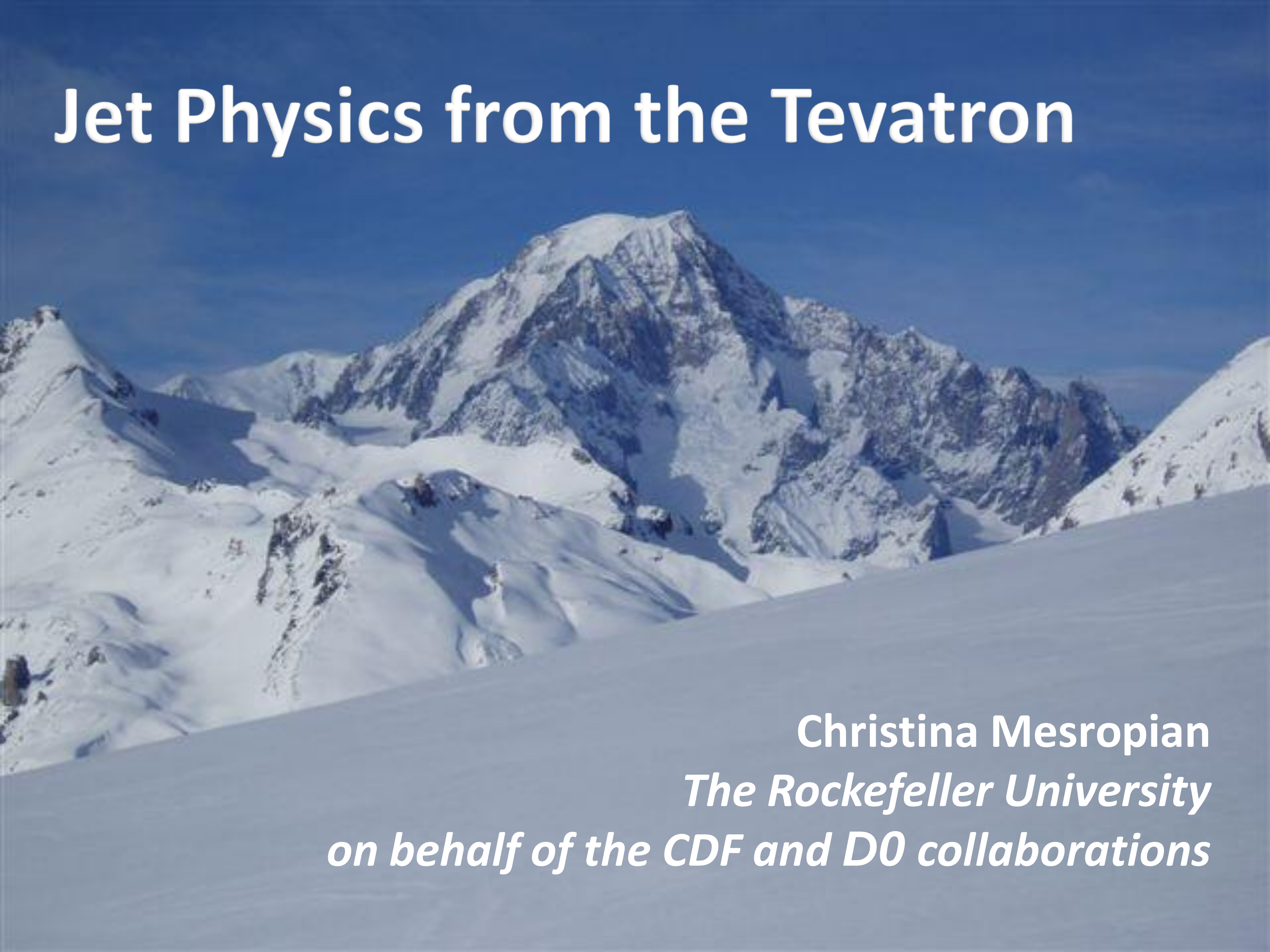
Jet Physics from the Tevatron



Christina Mesropian
The Rockefeller University
on behalf of the CDF and D0 collaborations

Contents

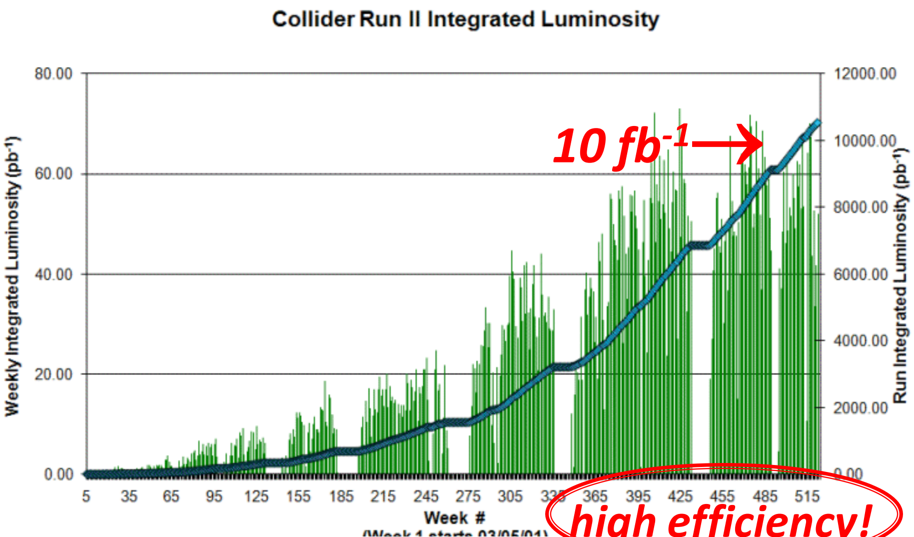
Very wide and varied QCD program
Many interesting results from both CDF and D0

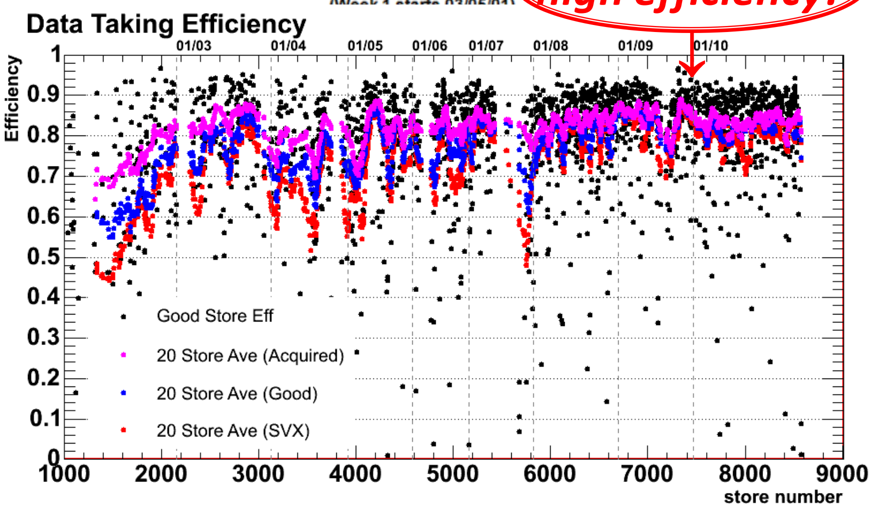
Hard QCD - jets, photons, bosons +jets
Soft QCD – UE studies, MinBias, diffraction

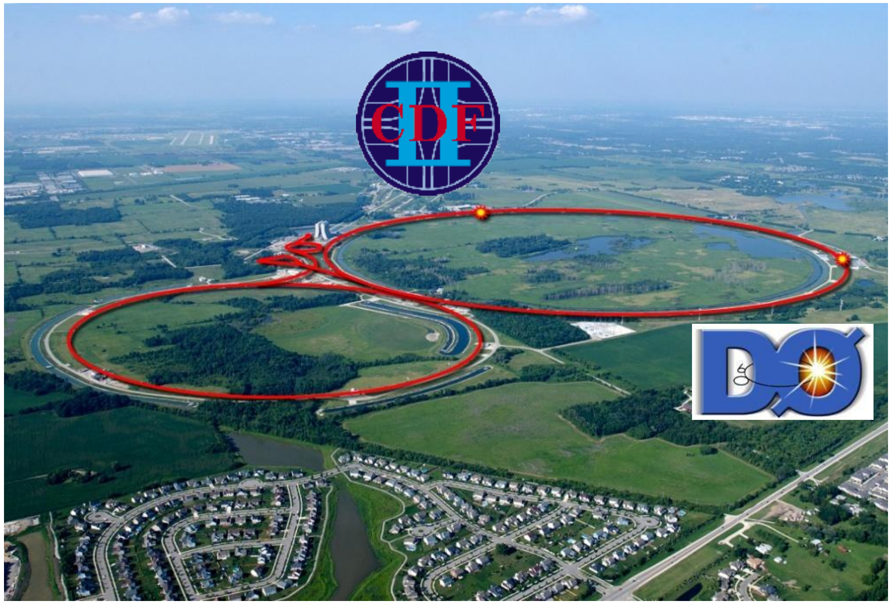
This talk covers **only jet production** results:
more Tevatron QCD talks:
Stefano Camarda on “W/Z+jets”

for complete list see:
http://www-cdf.fnal.gov/physics/new/qcd/QCD.html
http://www-d0.fnal.gov/Run2Physics/qcd/

Tevatron







Tevatron performing very well:

$10.3\ fb^{-1}$ delivered per experiment

$50\ pb^{-1}$ per week

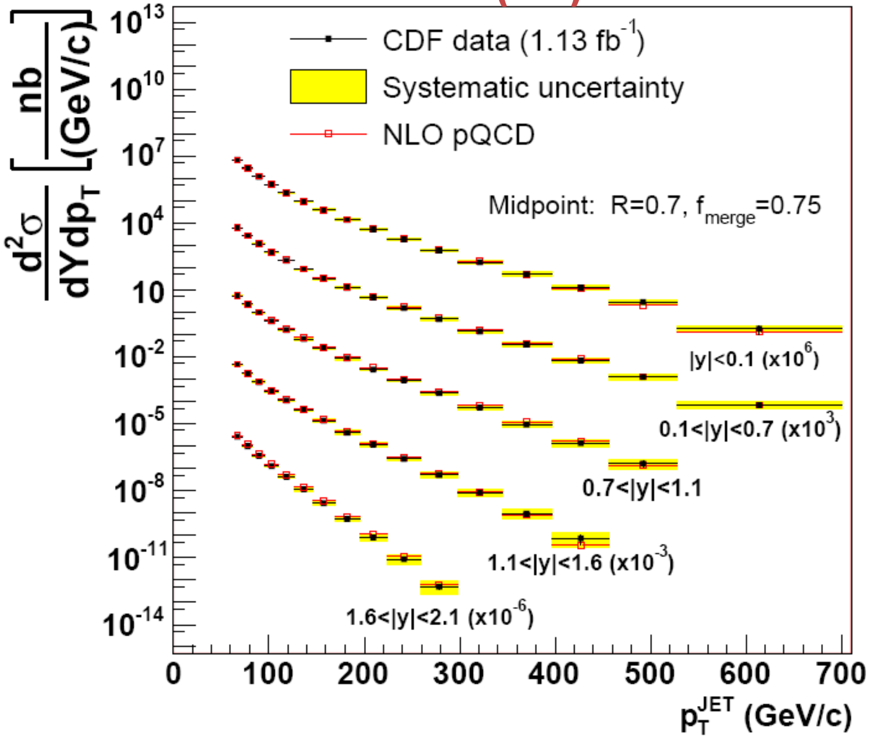
experiment efficiency ~90%

peak: $3.5 \times 10^{32}\ cm^{-2}s^{-1}$

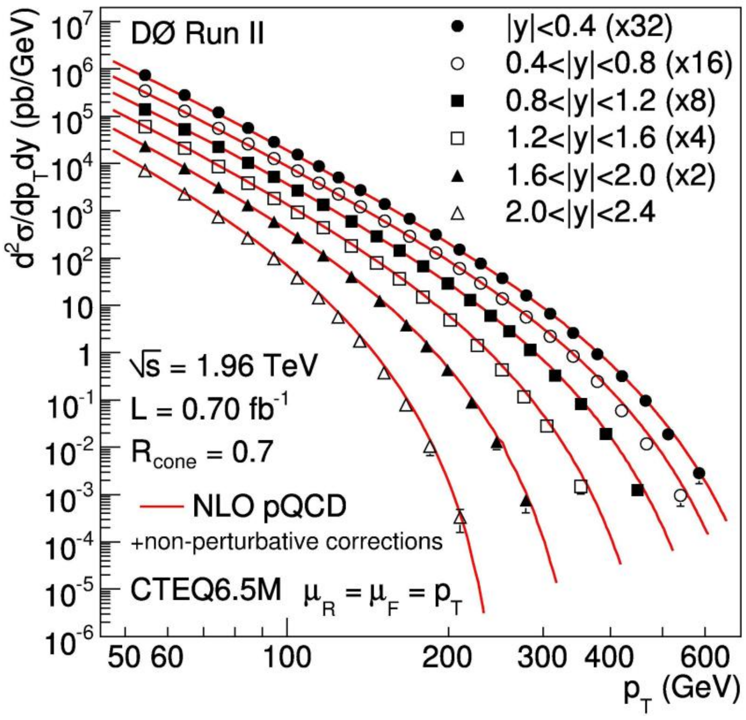
expecting $12 fb^{-1}$ by end of FY11

Inclusive Jet Cross Sections

PRD 78 052006 ('08)



PRL 101 062001 ('08)



- Test pQCD over 8 orders of magnitude
- Precise energy scale:

  1-2% D0

  2-3% CDF

- Different jet algorithms tested

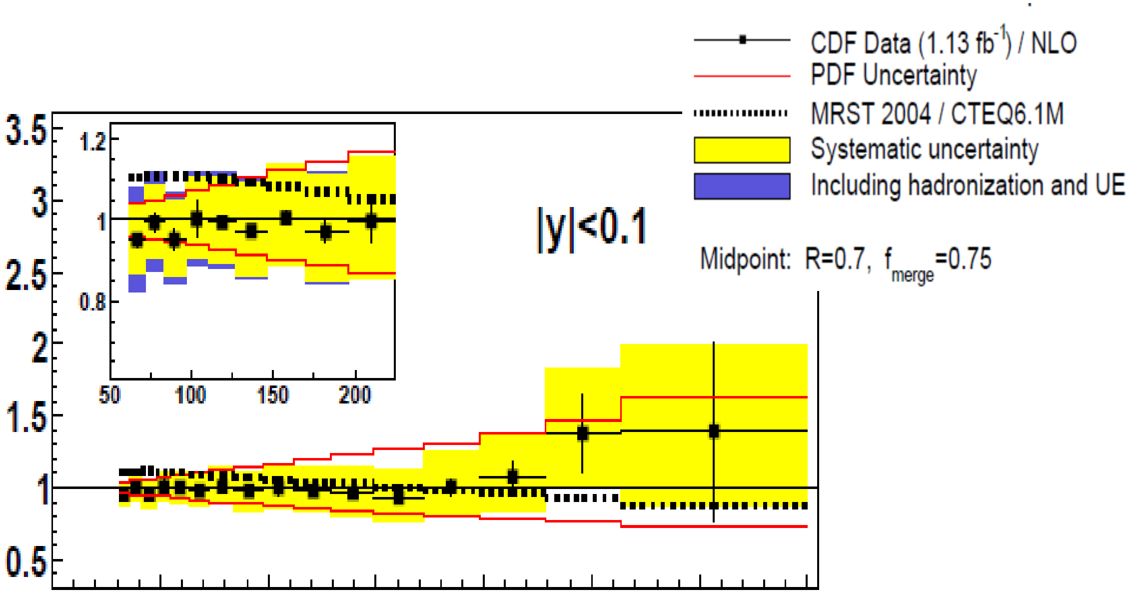
  Cone algorithm

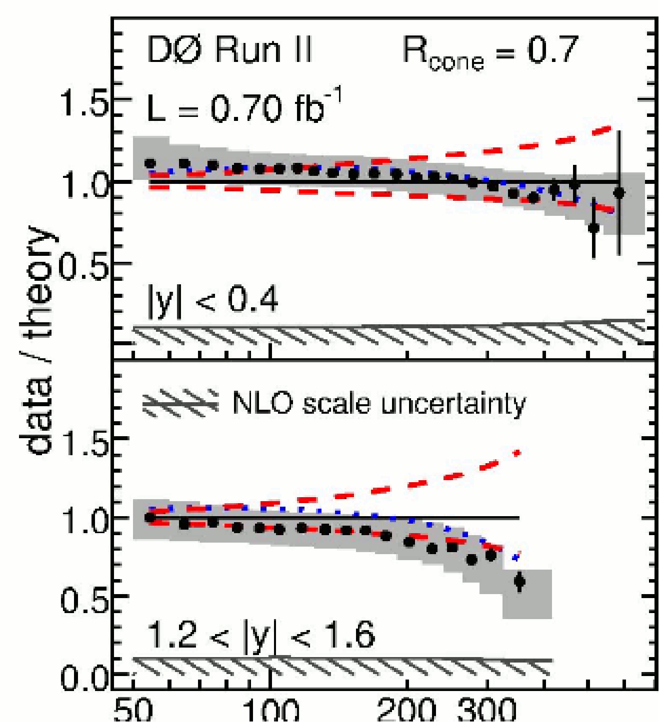
  k_T algorithm PRD 75, 092006 (2007)

- extended to forward rapidity |η|<2.4

Jet production –Precision regime

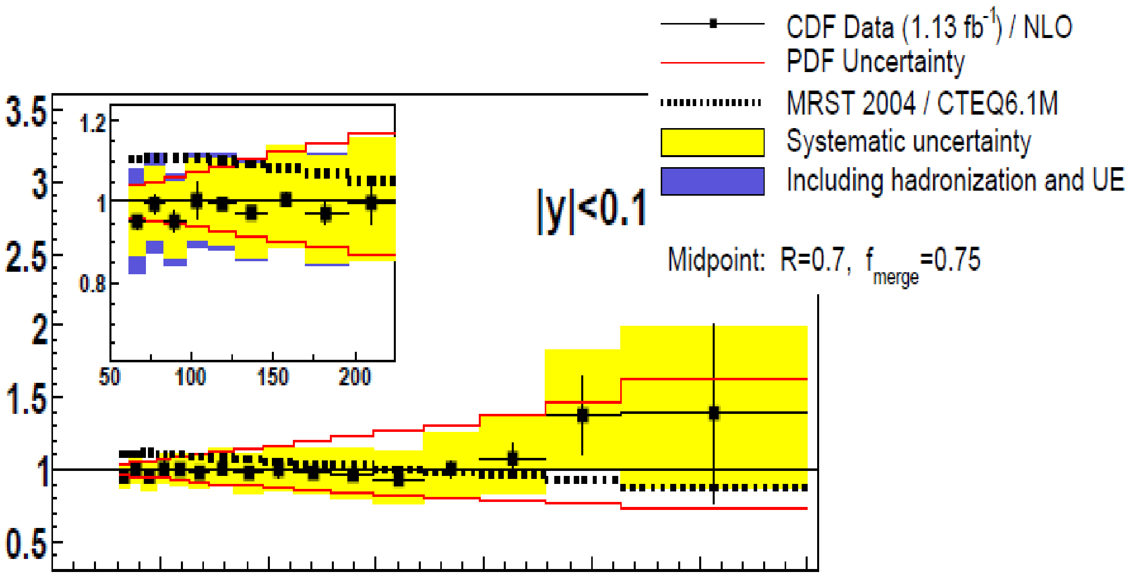
PDF input

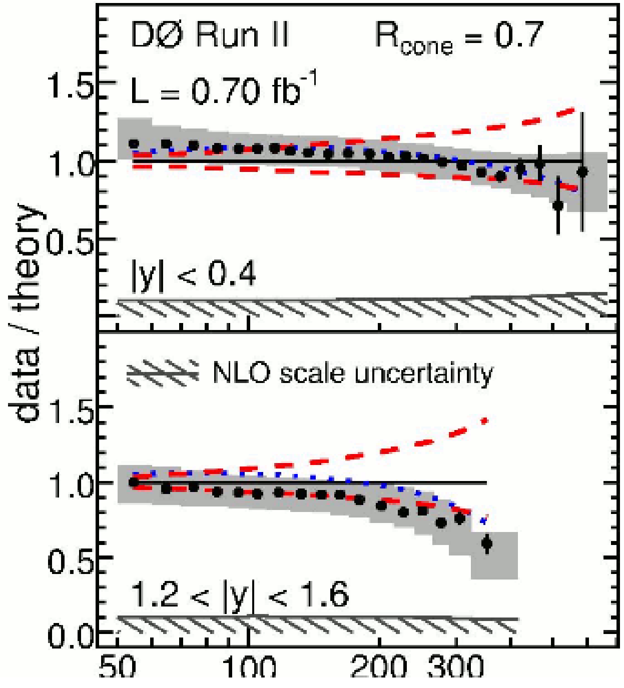




Jet production –Precision regime

PDF input





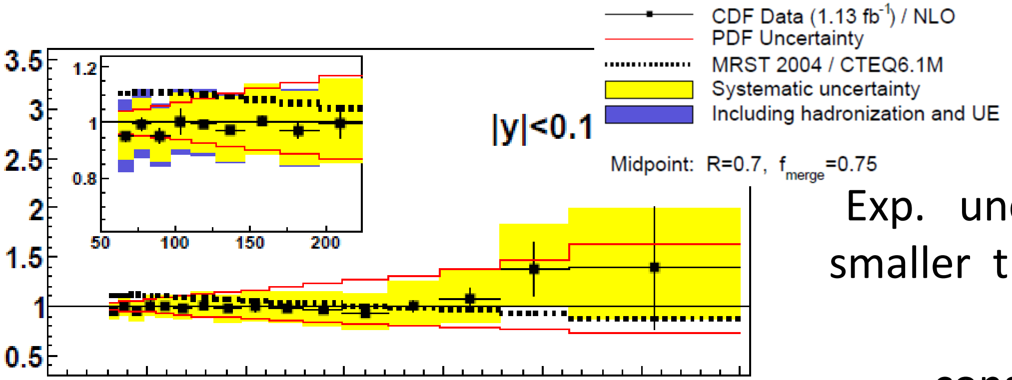
Exp. uncertainties are smaller than theoretical

⬇

constrain PDF

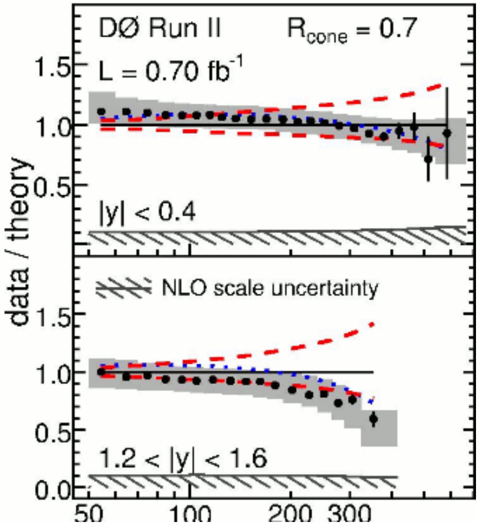
Jet production –Precision regime

PDF input



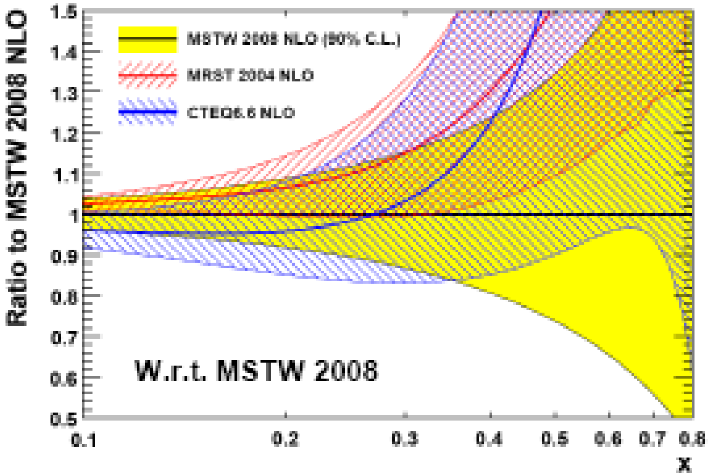
Exp. uncertainties are smaller than theoretical

constrain PDF



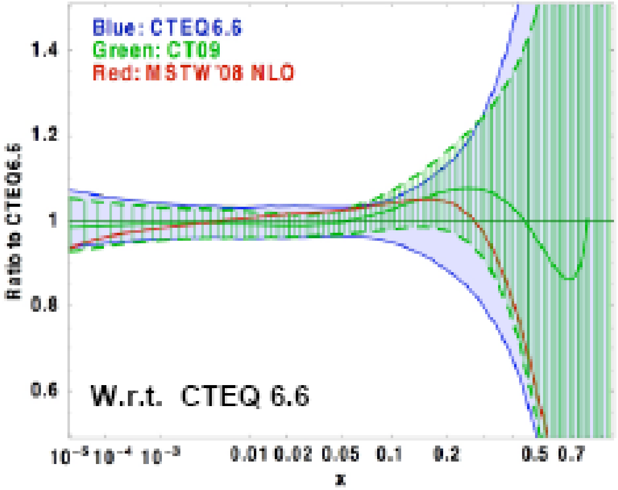
MSTW08: arXiv:0901.0002, Euro. Phys. J. C

Gluon distribution at $Q^2 = 10^4$ GeV^2



CT09: Phys.Rev.D80:014019,2009.

g at Q = 85 GeV

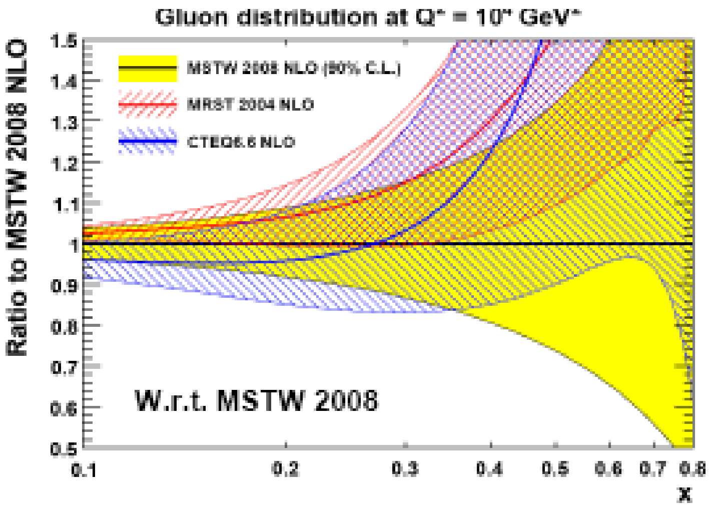


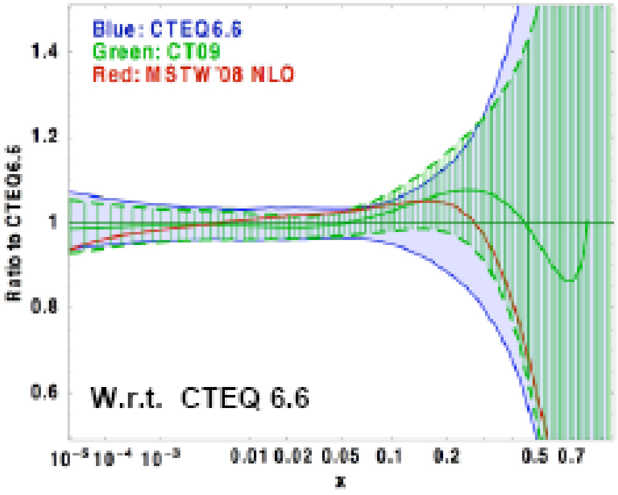
Jet production –Precision regime

PDF input

Conclusions from Les Houches QCD 2011:
“Tevatron jet data vital to pin down high-x gluon, giving smaller low-x gluon and therefore larger α_s in the global fit compared to a DIS-only fit.”

Expect Tevatron to dominate high- x gluon PDF for some years



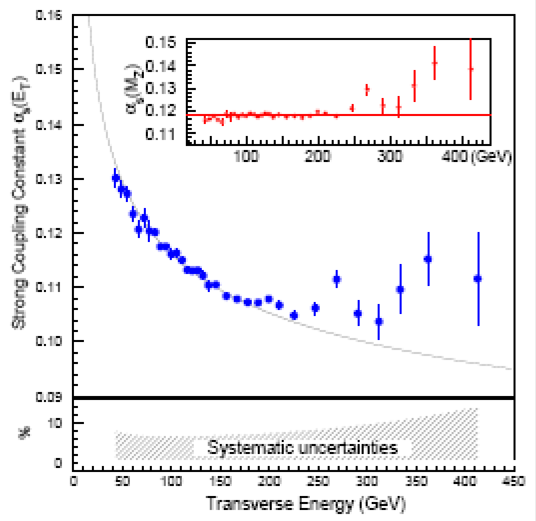


Jet production – Precision regime

α_s measurement

Historical note:

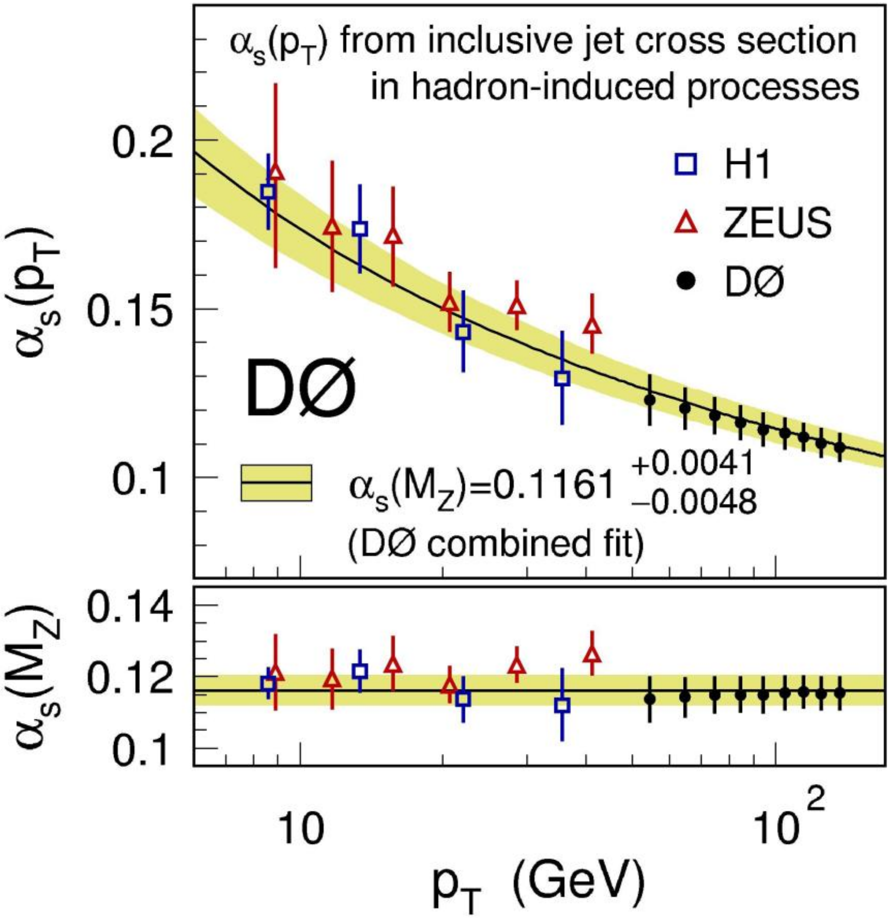
CDF Run I **Then** PRL 88:042001,2002



$\alpha_s(M_Z) = 0.1178 \pm 0.0001(\text{stat})^{+0.0081}_{-0.0095}(\text{syst})$

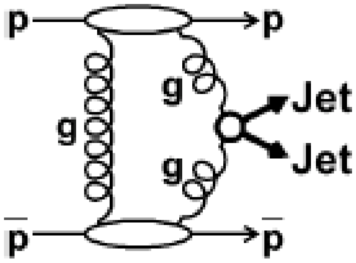
Now: $\alpha_s(M_Z) = 0.1173^{+0.0041}_{-0.0049}$

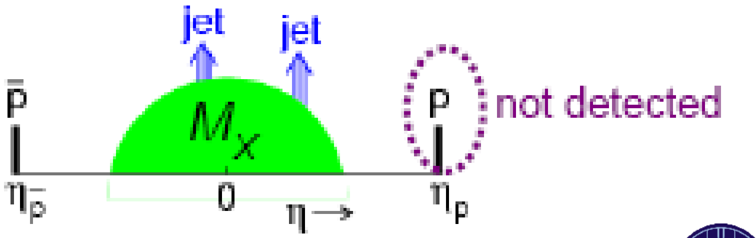
PRD 80, 111107 (2009)



- Theory: NLO+2-loop threshold corrections
- Significantly improved precision
- Running tested to very high Q^2 values

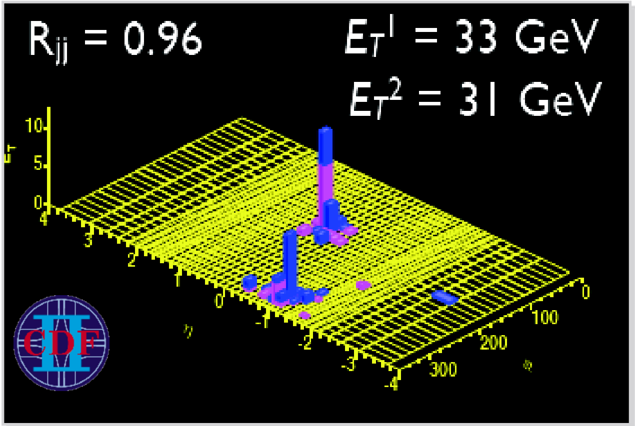
Exclusive Dijet Production



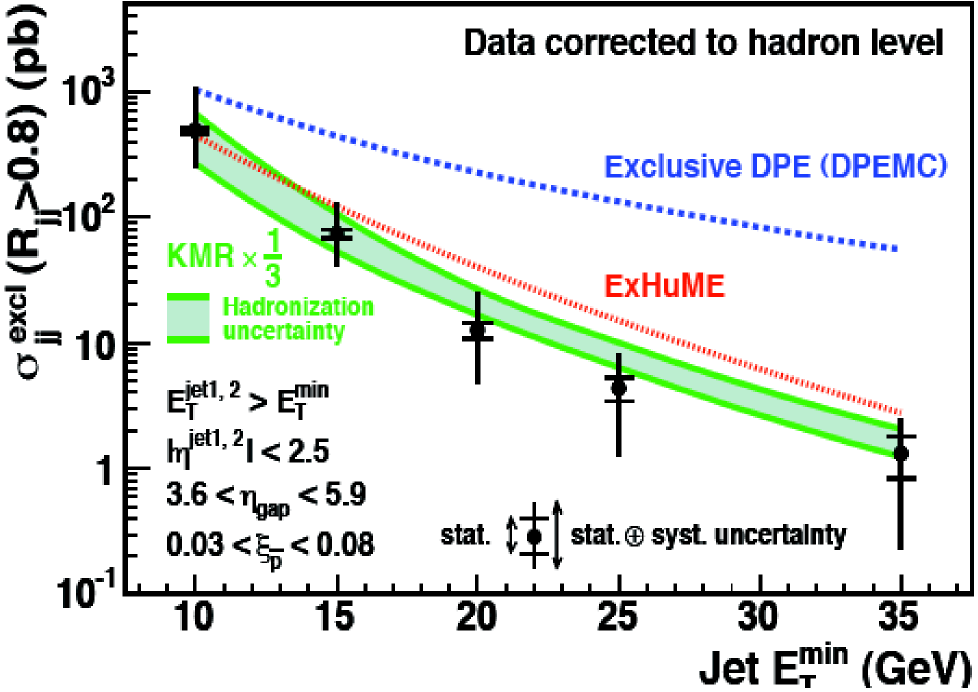


suppression at LO of the background sub-processes(J_z=0 selection rule)

“exclusive channel” →clean signal (no underlying event)

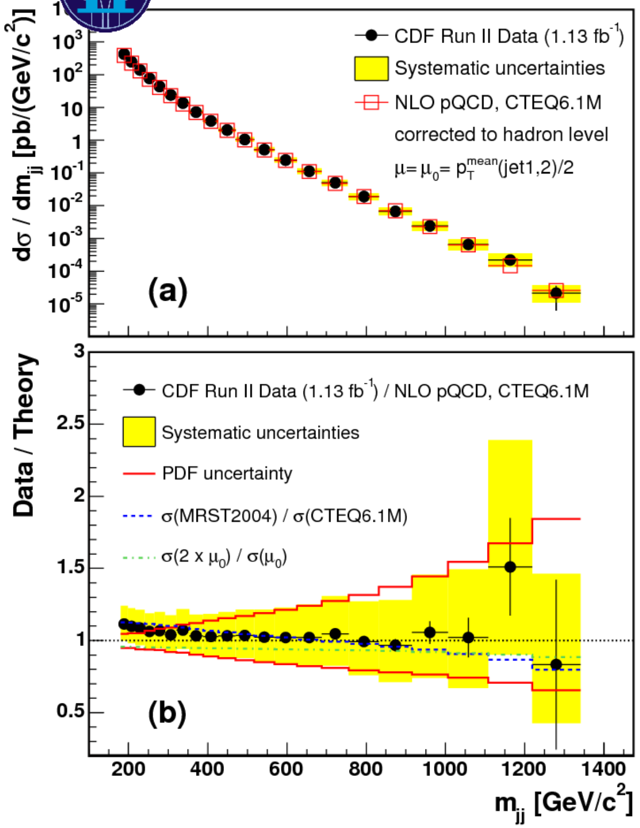


PRD 77, 052004 (2008)



Dijet Mass Measurements

PRD 79, 112002 (2009)



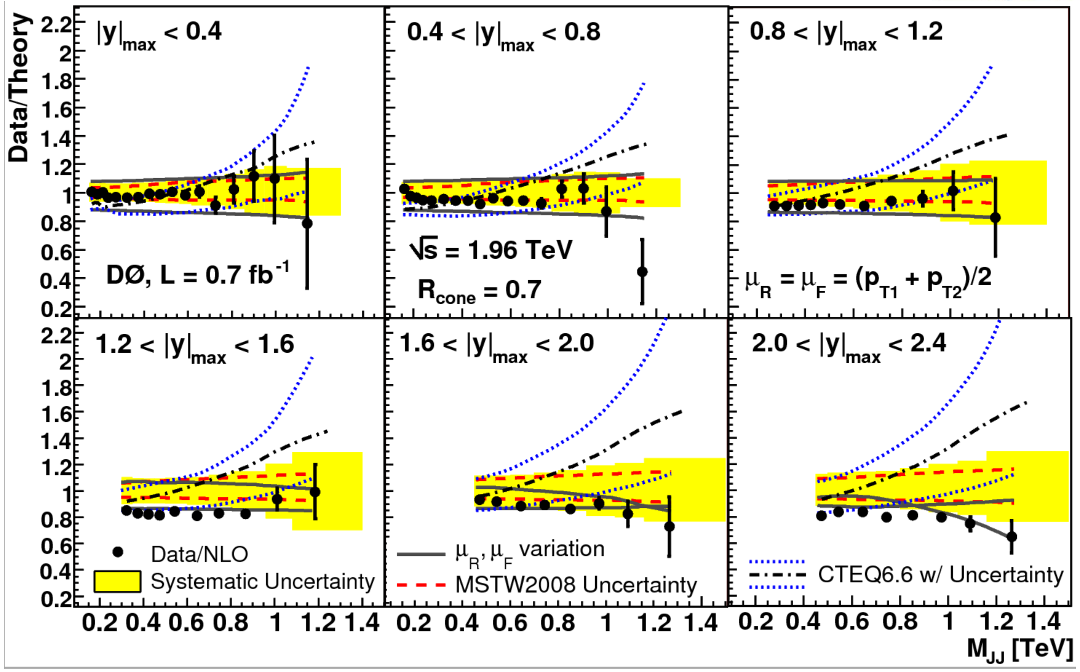
Study dijet events in |y|<1.0

NLO pQCD fits to data: χ^2/ndf = 21/21

Measurement of dijet mass in six rapidity bins, $|y|_{max}$ = max(|y1|, |y2|)

Comparison to NLO pQCD with MSTW2008 and CTEQ6.6M NLO PDFs,

PLB 693, 531 (2010)



Three Jet Mass Cross Section

Differential measurements of 3-jet mass:

$p_T^{\text{lead}}>150$ GeV, $p_T^{\text{3rd}} >40$ GeV; $\Delta R_{jj}>1.4$

- Studies Invariant masses > 1 TeV !
- Measurement is done in 3 rapidity and p_T intervals of 3rd jet.
- Three-jet calculation available @NLO

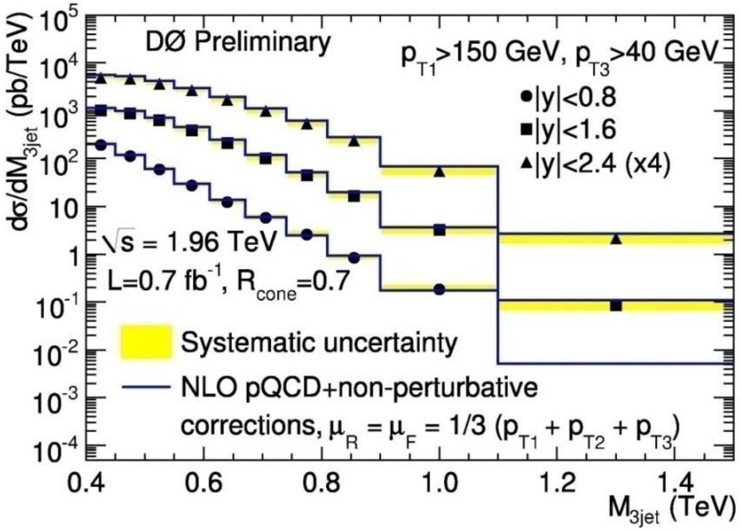
  Used NLOJET++ with MSTW2008

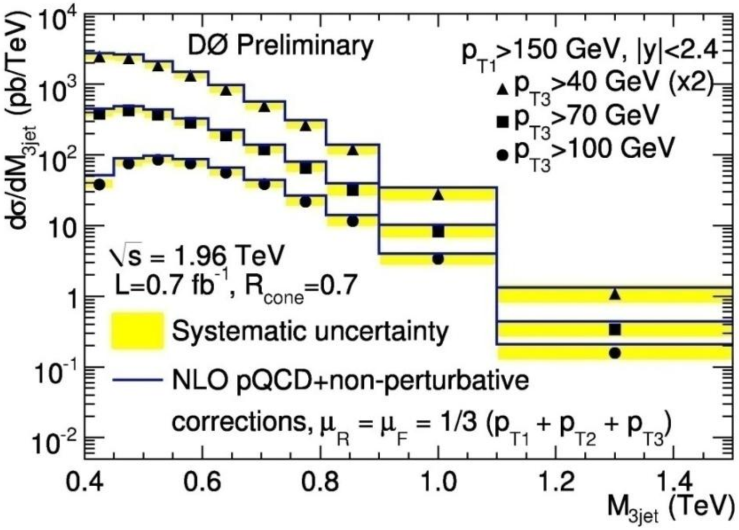
  Default scale $\mu = 1/3(p_{T1}+p_{T2}+p_{T3})$

NLO non-perturbative corr.: -3%,+6%

Total systematic uncertainty: 20-30%

(dominated by JES, p_T resolution and lum.)





R3/2 Jet Production

Many experimental uncertainties cancel in the ratio R3/2

- Measure as a function of two momentum R3/2(p_{Tmax}, p_{Tmin})= P(3rd jet | 2 jets):

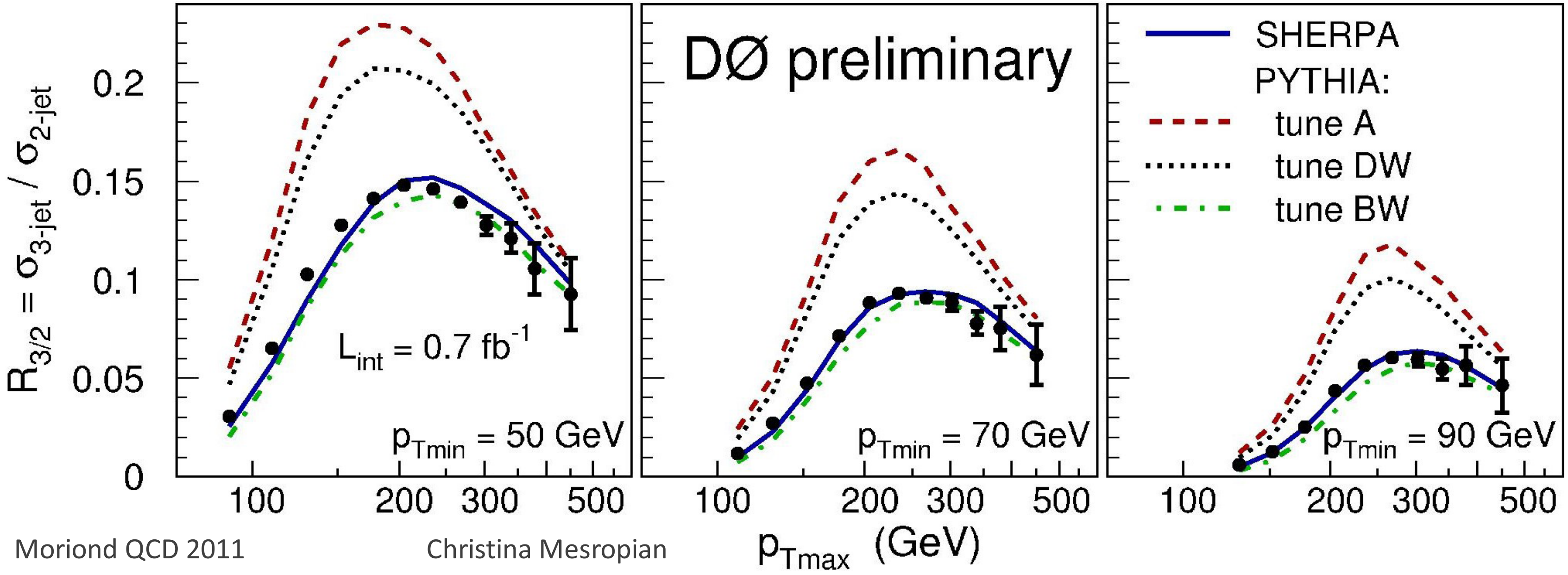
  p_{Tmax} – leading jet pT (common between 2- and 3-jet productions)

  p_{Tmin} – scale at which other 1-2 jets resolved

- Excellent agreement to Sherpa 1.1.3 (MSTW2008 LO)

  Pythia tunes – virtuality-ordered parton showers

  A and DW does not describe the R3/2 data; Tune BW works



R3/2 Jet Production

Many experimental uncertainties cancel in the ratio R3/2

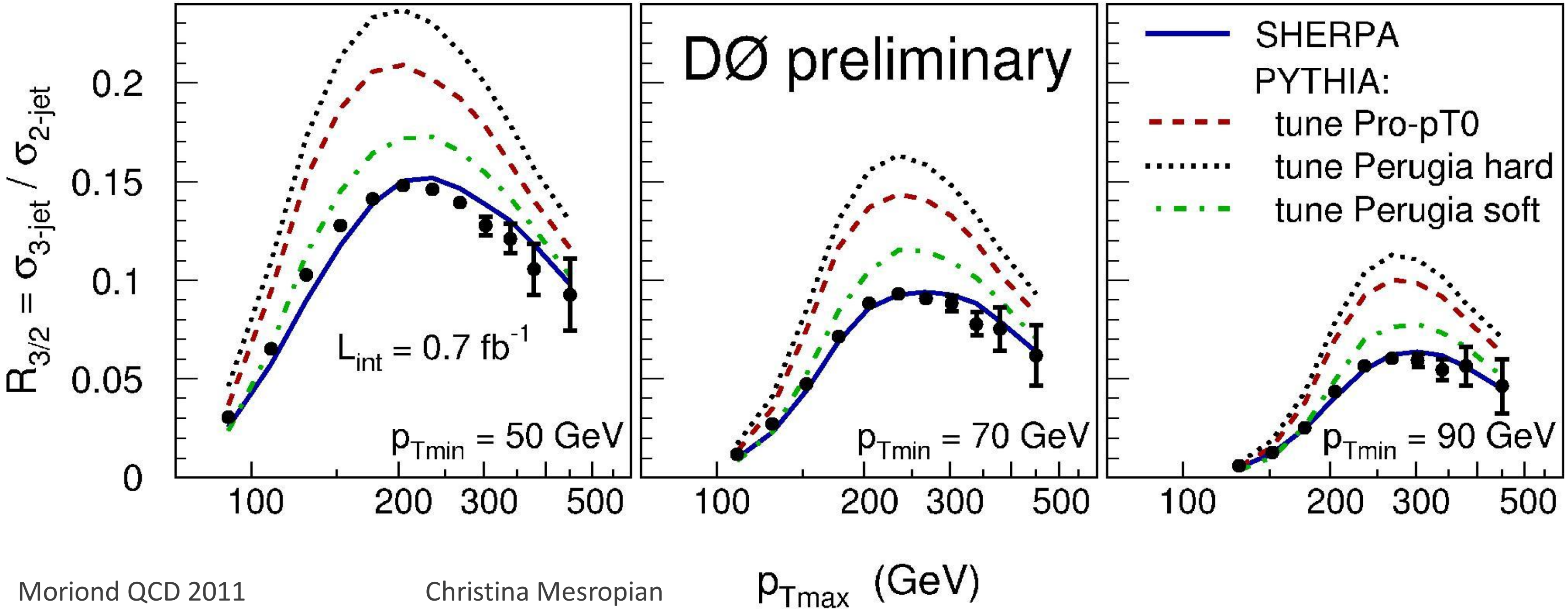
- Measure as a function of two momentum R3/2(p_{Tmax}, p_{Tmin})= P(3rd jet | 2 jets):

  p_{Tmax} – leading jet pT (common between 2- and 3-jet productions)

  p_{Tmin} – scale at which other 1-2 jets resolved

- Excellent agreement to Sherpa 1.1.3 (MSTW2008 LO)

  Pythia tunes Perugia – p_T - ordered parton showers don't work that well



Jet Substructure
Jet Mass

MOTIVATION : Mass of high-pT jets - important property, but only theor. studies:

o High mass:

QCD NLO predictions for jet mass

Ellis et al, 0712.2447

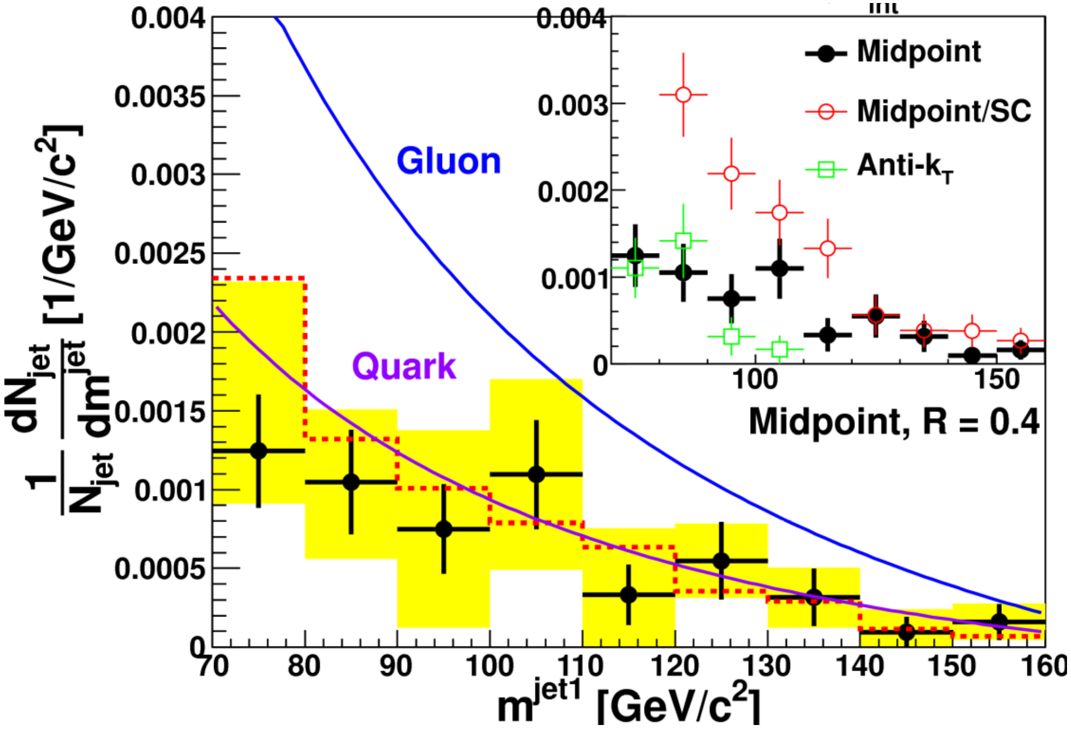
Alemeida, et al. 0810.0934

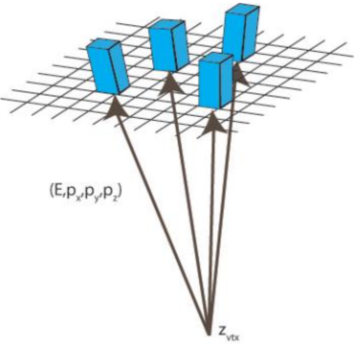
Such jets form significant background to new physics signals

Examples: high p_T tops, Higgs, neutralino …

Use standard “e-scheme” for mass calculation

CDF Run II Preliminary, L_{int}=6fb^{-1}





- o 4-vector sum over towers in jet
- o Each tower is a particle with m = 0
- o Four vector sum gives (E,p_x,p_y,p_z)

Selection: > 1 jet
p_T>400 GeV/c
0.1<|η|<0.7

Jet Substructure
Angularity and Planar Flow

Jet substructure variables that are insensitive to soft radiation at high jet mass:

Angularity :

$$\tau_a(R, p_T) = \frac{1}{m_J} \sum_{i \in jet} \omega_i \sin^a \vartheta_i [1 - \cos \vartheta_i]^{1-a}$$

- **Emphasizes cone-edge radiation**
- **For large $m^{jet,}$ has analytic approximation**

Planar flow:

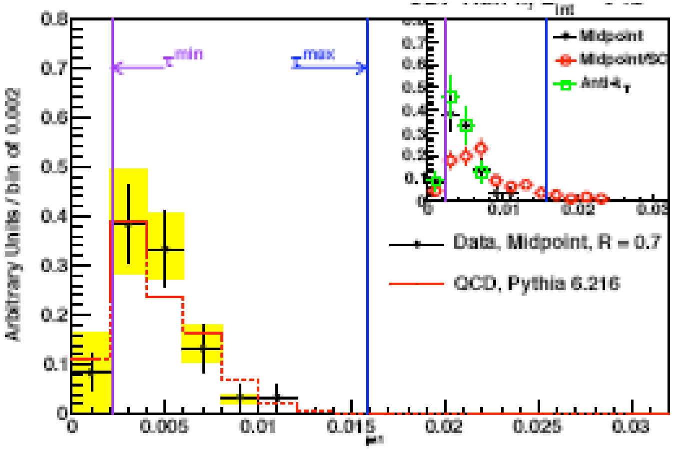
$$I_w^{kl} = \frac{1}{m_{jet}} \sum_i \frac{p_{i,k}}{w_i} \frac{p_{i,l}}{w_i};$$

- ***w_i - energy of particle I***
- **λ_1, λ_2 are eigenvalues**

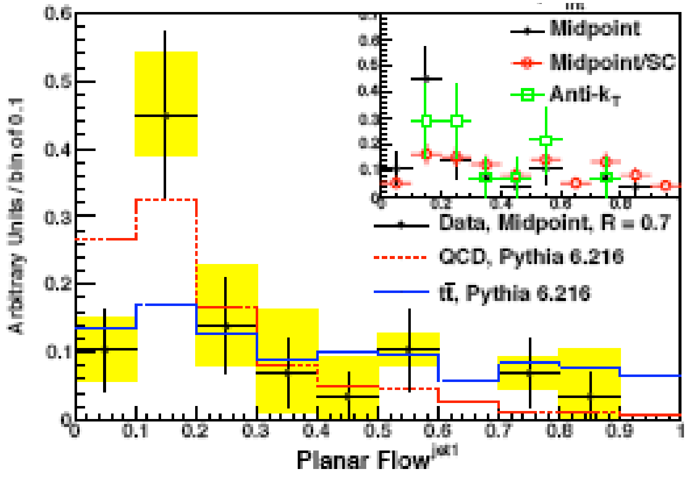
$$Pf \equiv \frac{4\lambda_1\lambda_2}{(\lambda_1 + \lambda_2)^2}$$

Selection: > 1 jet
p_T>400 GeV/c 0.1<|η|<0.7
anti-top requirements

CDF Run II Preliminary, L_{int}=6fb^{-1}



CDF Run II Preliminary, L_{int}=6fb^{-1}



Conclusions

- Understanding of jet identification, JES, and systematics leads (in many cases) to experimental systematic uncertainties smaller than theoretical uncertainties

  extended measurement to forward rapidities and high pT values
  improving our knowledge of PDF, particularly high-x gluons
  measurements of the strong coupling constant

- Next level of measurements
  3 jet studies
  measurements of jet substructure variables
  validating phenomenological models for diffraction

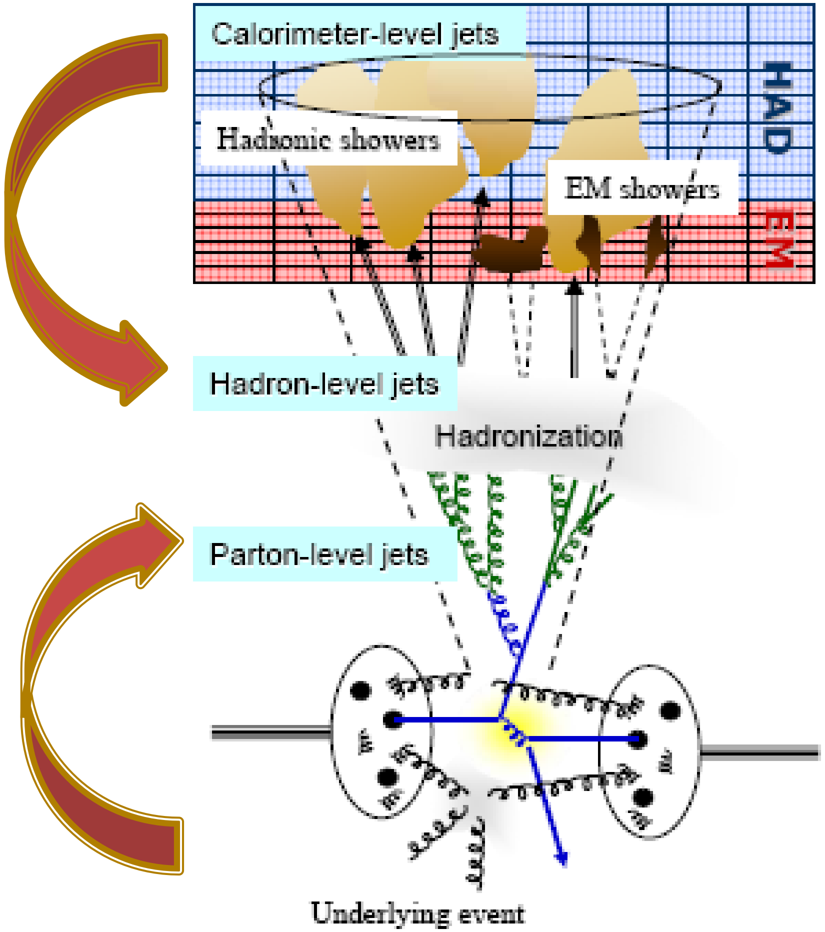
- Results shown today use only half of the data sample
  More to come from the QCD program at the Tevatron

Backup

Jet Measurements

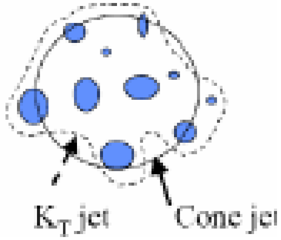
- ❑ Unfold measurements to the hadron (particle) level

- ❑ Correct parton-level theory for non-perturbative effects (hadronization & UE)



Jet Algorithms

Two main categories of jet algorithms



- Cone Algorithms
  - E.g. Midpoint Algo.: Extensive use at Tevatron in Run II (as suggested in Run II workshop in 1999, hep-ex/0005012)
  - Cluster objects based on their proximity in $y(\eta)$-ϕ space
  - Identify "stable" cones (kinematic direction = geometric center)
  - Pros: simpler for underlying-event and pileup corrections
    Cons: infrared-unsafe in high order pQCD & overlapping stable cones.
- Successive Combination Algorithms
  - E.g. Kt Algorithm: Extensive use at HERA. A few Tevatron analyses.
  - Cluster objects based on a certain metric. Relative Kt for Kt algorithm.
  - Pros: Infrared-safe in all order of perturbative QCD calculations.
    Cons: Jet geometry can be complicated. Complex corrections.

A lot of developments in recent years.

- SISCone, Cambridge-Aachen, Anti-Kt, etc.
- Extensively studied in LHC experiments. Will benefit future studies.