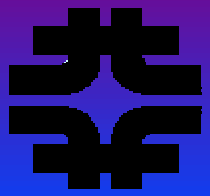


QCD Physics at the Tevatron

Giuseppe Latino

(University of New Mexico)

for the CDF and DØ Collaborations

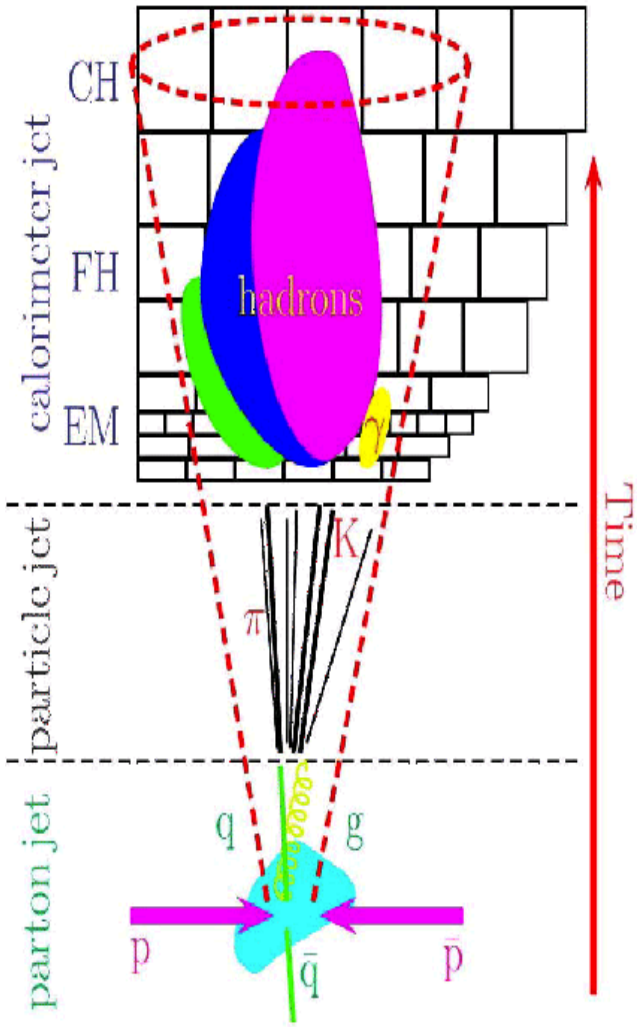
Highlights on Run II Results:

- Inclusive Jet Cross Section
- DiJet Mass Cross Section
- W + Jets Production
- Underlying Event Studies

QCD Studies @ Tevatron

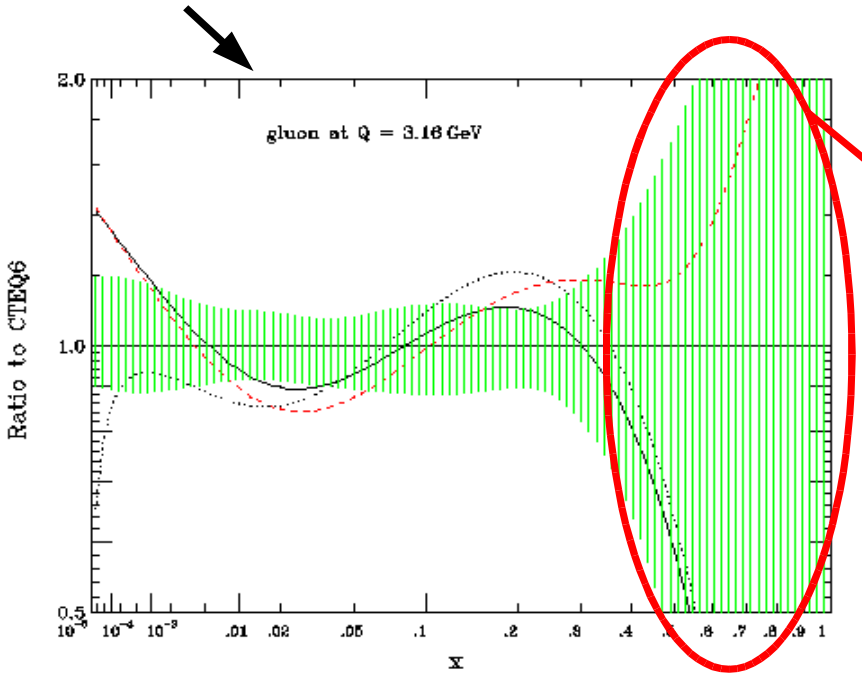
Tevatron: *ppb*ar collider at the highest √s ever reached

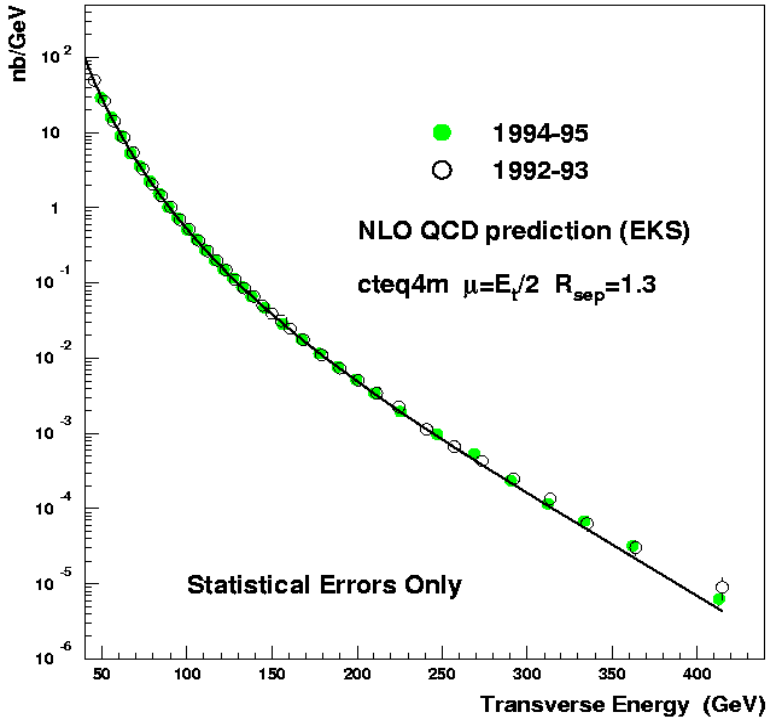
- All production processes are QCD related: optimal understanding basic for all analyses
  - Fundamental parameters (ex.: high x gluon PDFs)
  - background for each process of interest (ex.: W+Jets for *top* and *Higgs* production)
  - Phenomenology on non-perturbative regime (ex.: Underlying Event modeling)
- Highest Q^2 probed ($\lambda \sim 10^{-17}$ cm)
  - Precise test of pQCD at NLO
  - Check for deviations ⇒ look for new physics
- Other studies of interest: diffraction, heavy flavor, hadron spectroscopy



Legacy from Run I Incl. Jet Cross Section

- Great interest about high E_T excess
- SM explanation: increased high *x* contribution in gluon PDF
- New PDFs from global fit including CDF/DØ high E_T data:
  CTEQ6 and MRST01





Great residual uncertainty for gluon PDF at high *x* :

- Green band: all PDFs fitting data
- Lines: ratio to CTEQ5M/HJ, MRST01

New Run II high E_T measurement expected to improve constraint

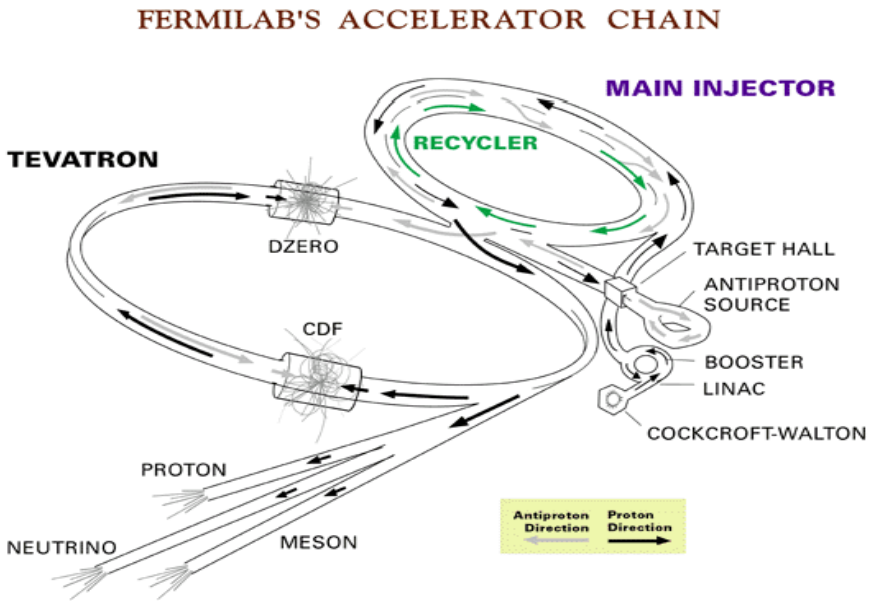
Tevatron in Run II

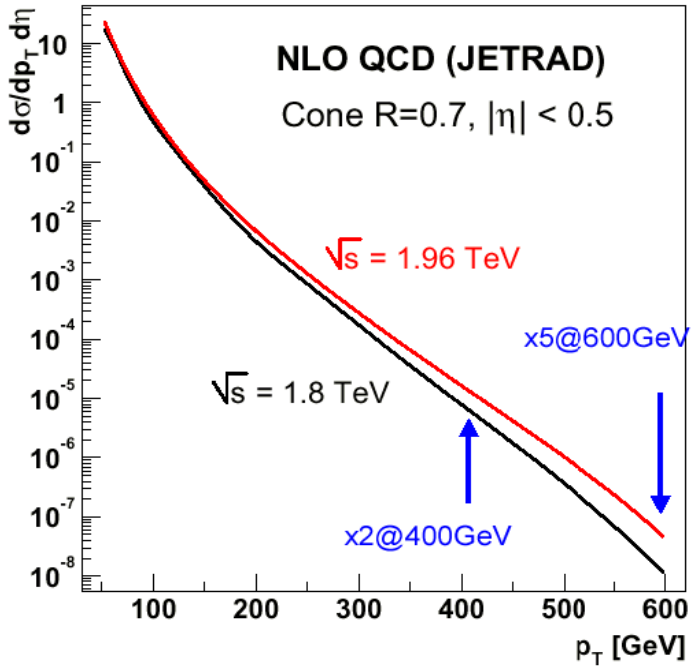
Performances (Feb. 2004):

- $L_{ins} \sim 6 \times 10^{31}\ cm^{-2}s^{-1}$
- $L_{int} \sim 400\ pb^{-1}$ (delivered)

Long term goal (end 2009):

- $L_{ins} \sim 2 \times 10^{32}\ cm^{-2}s^{-1}$
- $L_{int} \sim 4.4 - 8.5\ fb^{-1}$





$\sqrt{s}$: 1.8 TeV $\Rightarrow$ 1.96 TeV

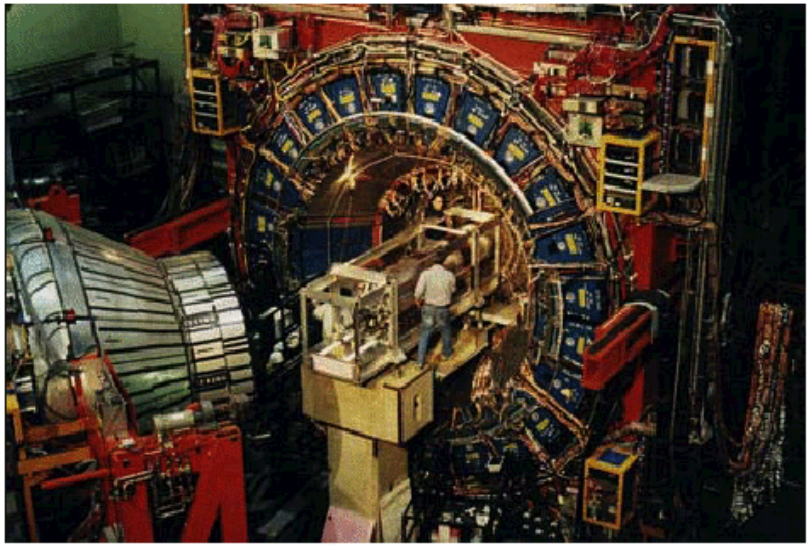
- Higher σ_{jet} ($\sim \times 5$ for $P_T \sim 600$ GeV)
- Increased kinematic range for jet production

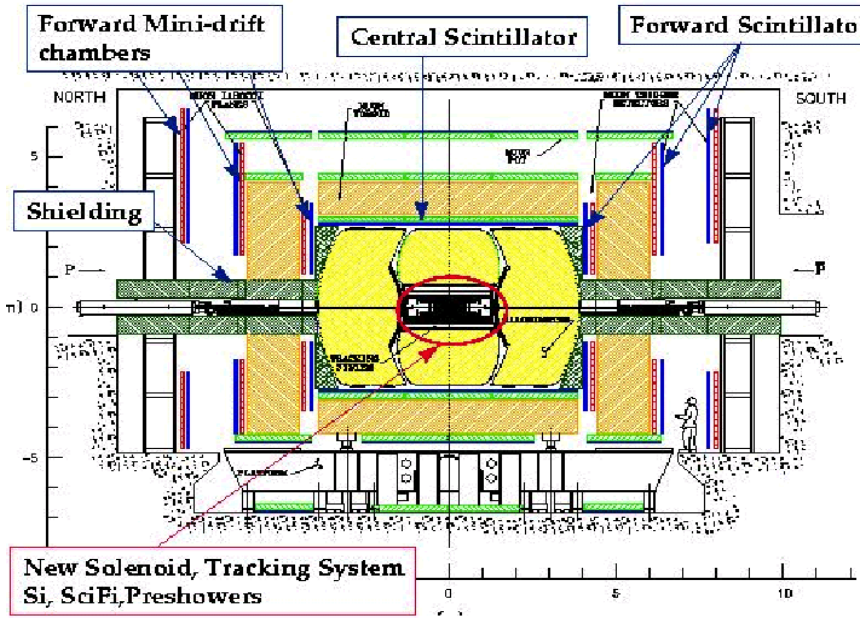
Sensible improvement over Run I Results

CDF & DØ in Run II

CDF Upgrades:

- Si detector & Tracking
- Time of Flight detector
- "Plug" Calorimeters (up to $|\eta| = 3.6$)
- Forward detectors
- Muon system
- DAQ electronics & Trigger





DØ Upgrades:

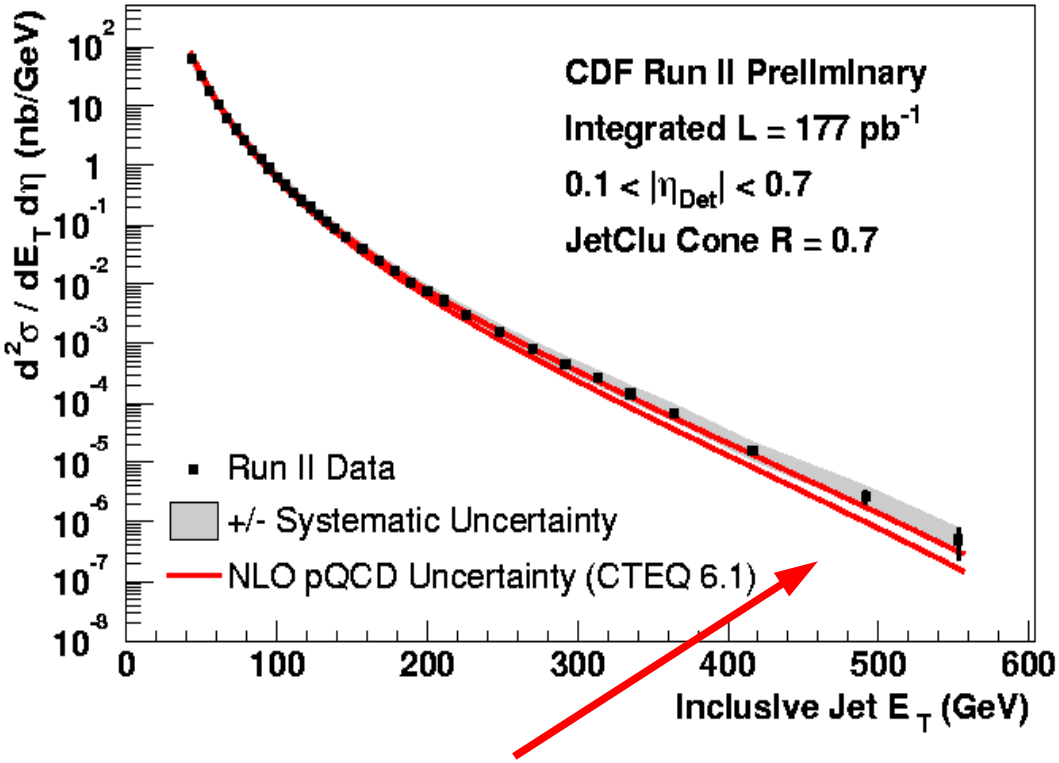
- Si detector & Tracking
- Solenoid
- Preshower detector
- Forward detectors
- DAQ electronics & Trigger

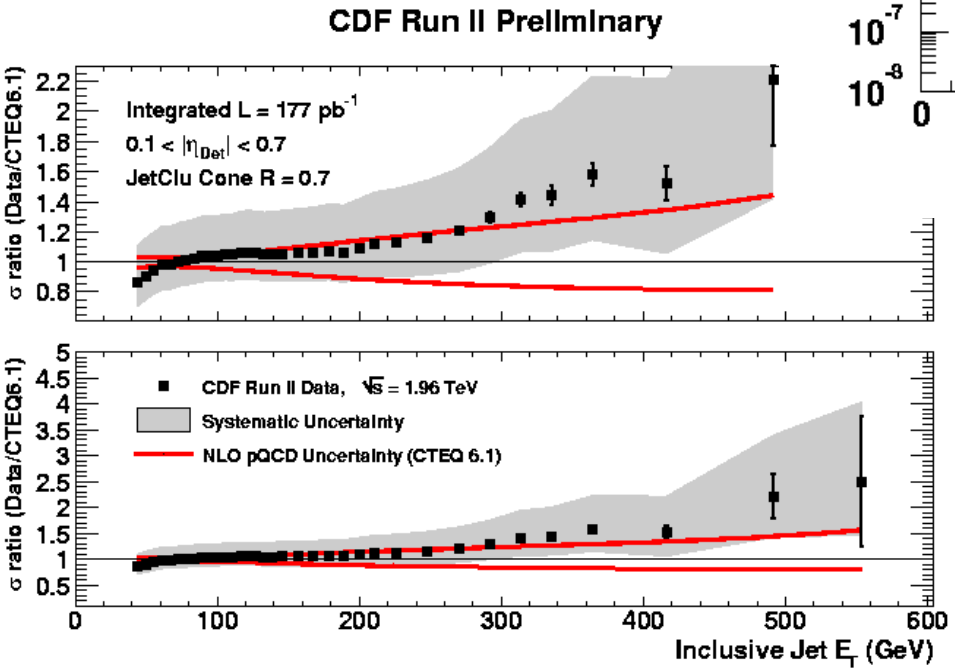
U/LAr Calorimeters : linear, $e/\pi \sim 1$,
hermetic coverage in Ω up to $|\eta| = 4.2$

Inclusive Jet Cross Section

CDF

- NLO pQCD: **EKS** ($\mu = E_T/2$), $R_{sep} = 1.3$, CTEQ6.1 PDFs
- Experimental uncertainty dominated by E scale
- Largest theoretical error from PDFs (high *x* gluon)





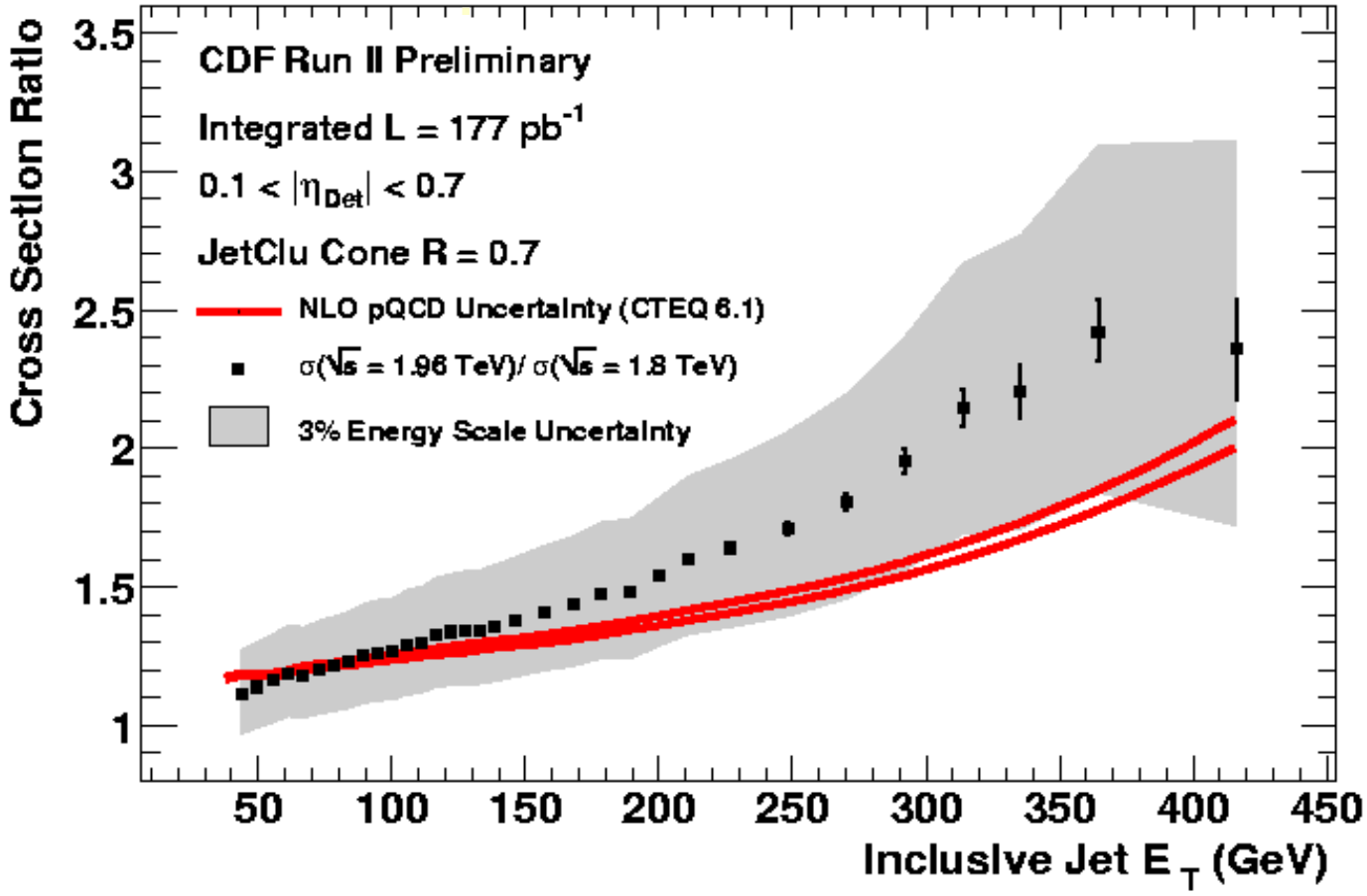
Extending Run I reach by ~ 150 GeV !

Reasonable data-theory agreement within errors

Ongoing: reduce systematics, MidPoint/K_T, forward jets

Inclusive Jet Cross Section (2)

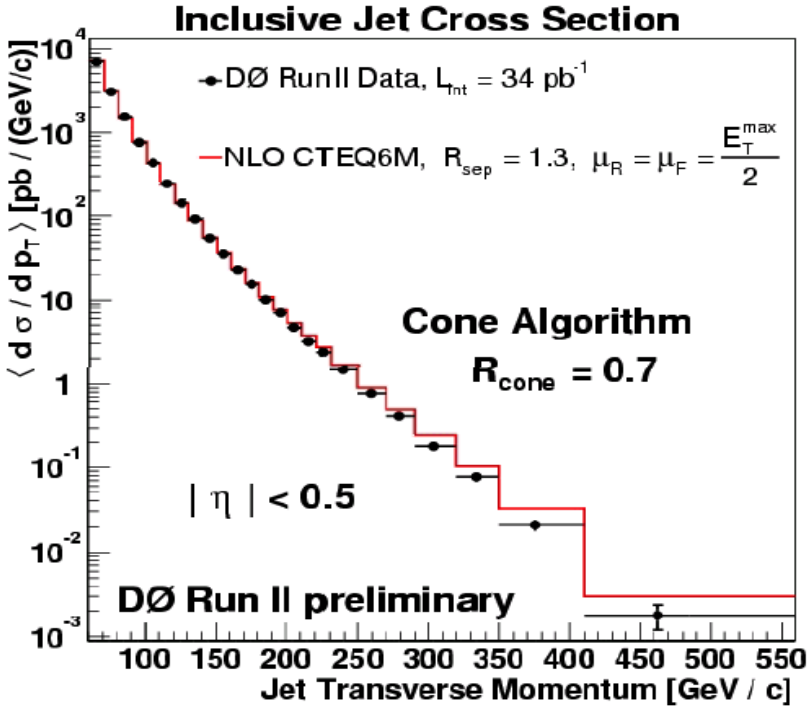
σ(Run II) / σ(Run I)



Higher σ in Run II from $\sqrt{s}$ = 1.8 TeV $\Rightarrow$ 1.96 TeV

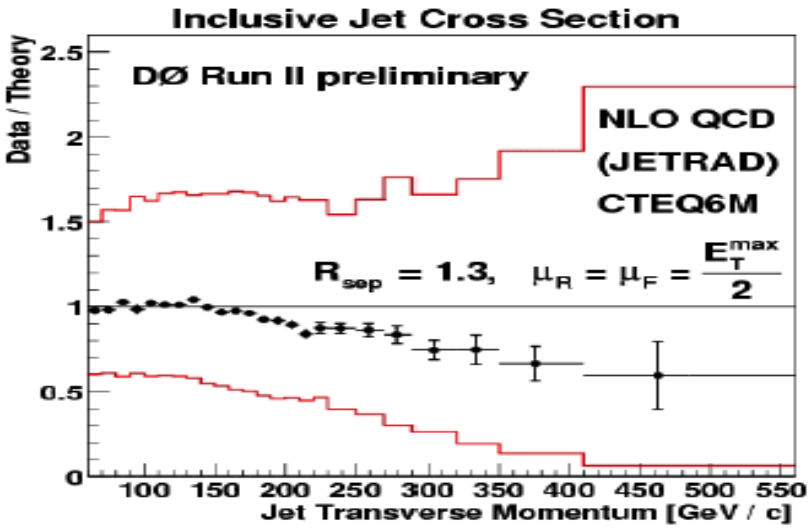
Data and theory in reasonable agreement within errors

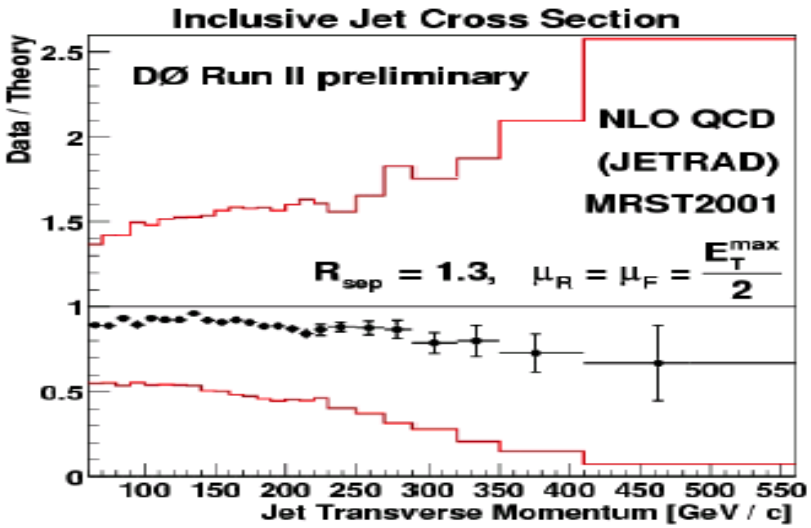
Inclusive Jet Cross Section (3)



DØ

- "Optimized-cone" algorithm (MidPoint)
- NLO pQCD: **JETRAD** ($\mu = E_T^{max}/2$), CTEQ6M & MRST01 PDFs
- Results differ with PDFs, both consistent with measurement
- Reasonable data-theory agreement within errors dominated by E scale
- Ongoing: reduce errors, K_T, forward jets





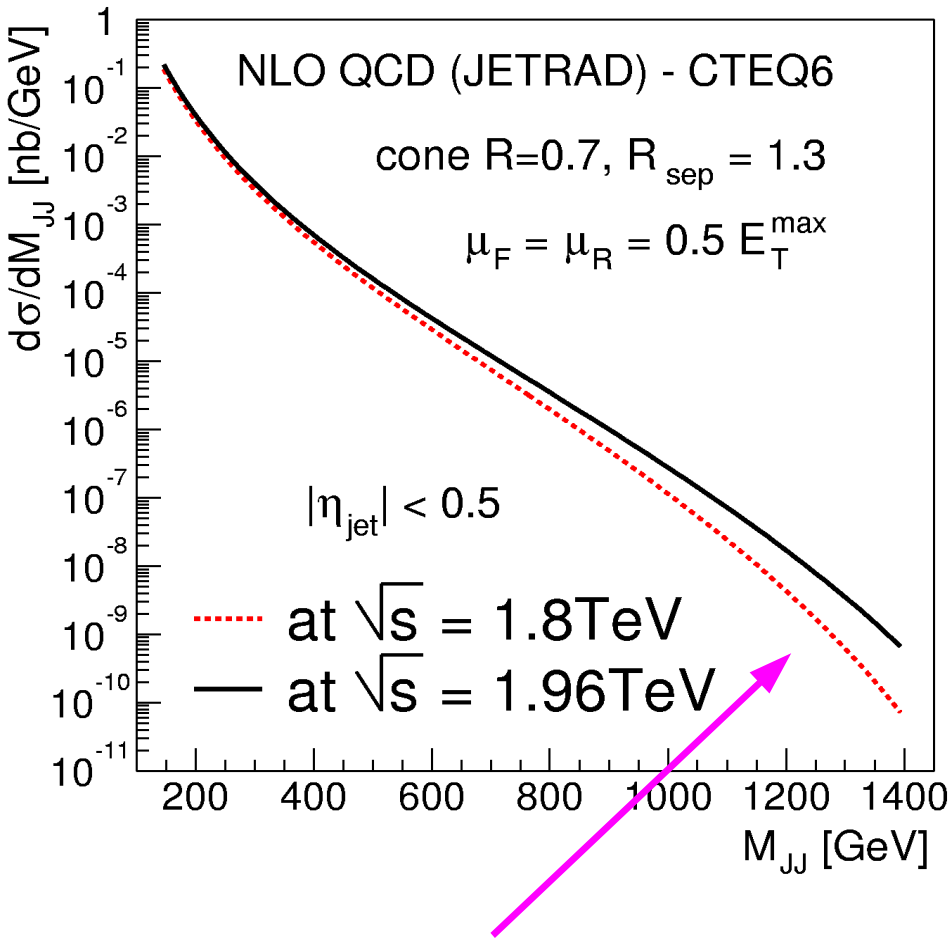
Dijet Mass Cross Section

- Test of pQCD complementary to inclusive jet cross section analysis
- Great sensitivity to new physics
- Limits on theoretical parameters: Λ_c , M (new particles)

Preliminary measurements using similar analysis strategies as for σ_J:

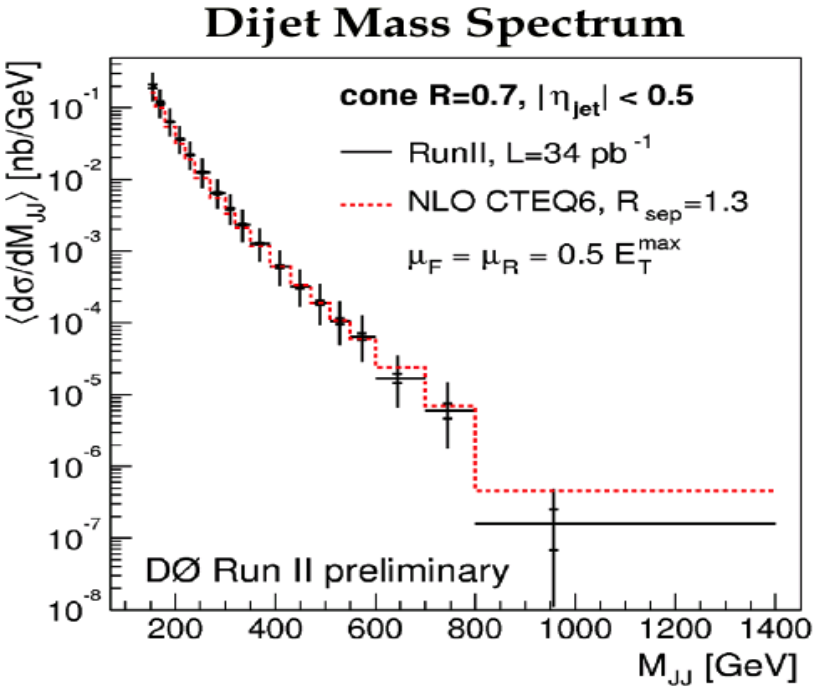
- CDF: comparing with Run I results (JetClu $R = 0.7$, $|\eta| < 2.0$, jet corr.)
- DØ: using new techniques (MidPoint $R = 0.7$, $|\eta| < 0.5$, jet cal.)

Experimental uncertainty dominated by energy scale



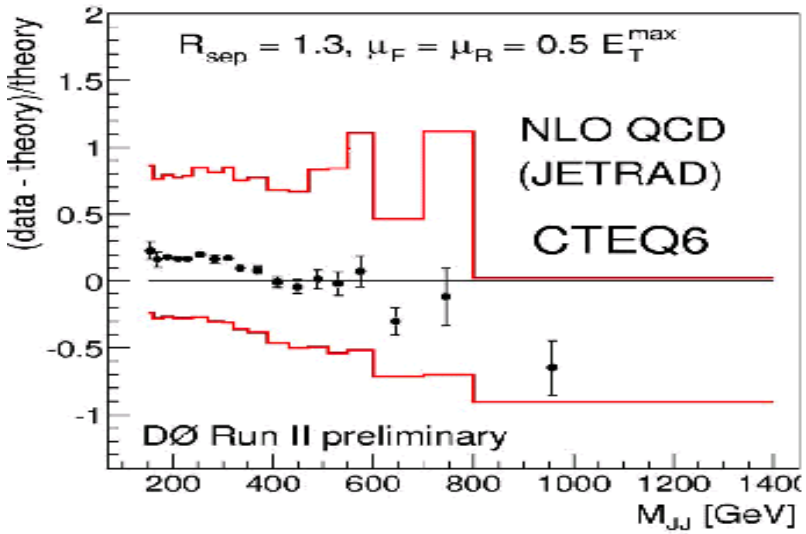
Increased √s in Run II extending Run I results

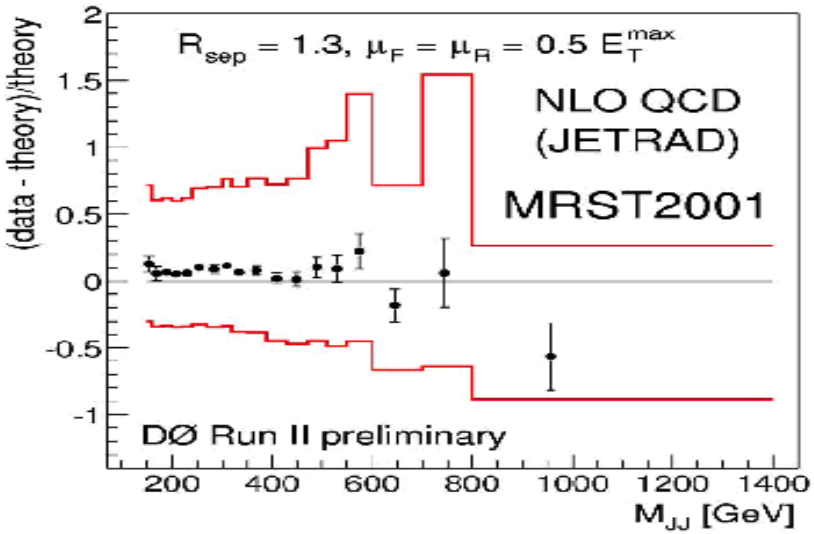
Dijet Mass Cross Section (2)



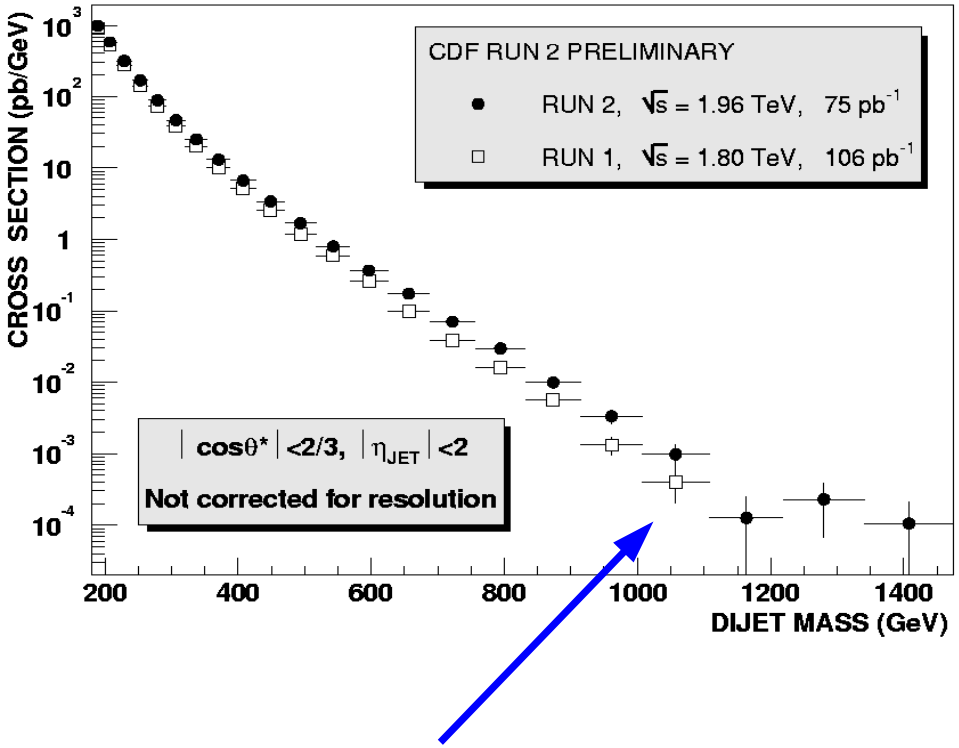
DØ

- NLO pQCD: **JETRAD** ($\mu = E_T^{max}/2$), CTEQ6M & MRST01 PDFs
- Differences from PDFs, both consistent with measurement
- Reasonable data-theory agreement within errors (E-scale dominated)
- Ongoing: reduce energy scale uncertainty





Dijet Mass Cross Section (3)

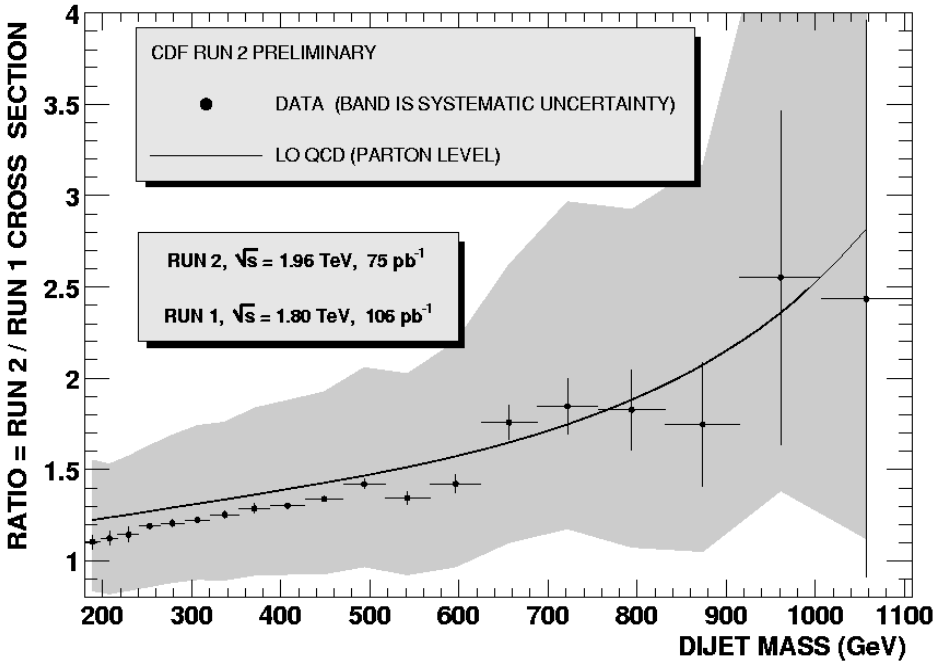


- Run I results already extended by ~ 350 GeV !
- Ongoing: MidPoint, improved jet corrections

CDF

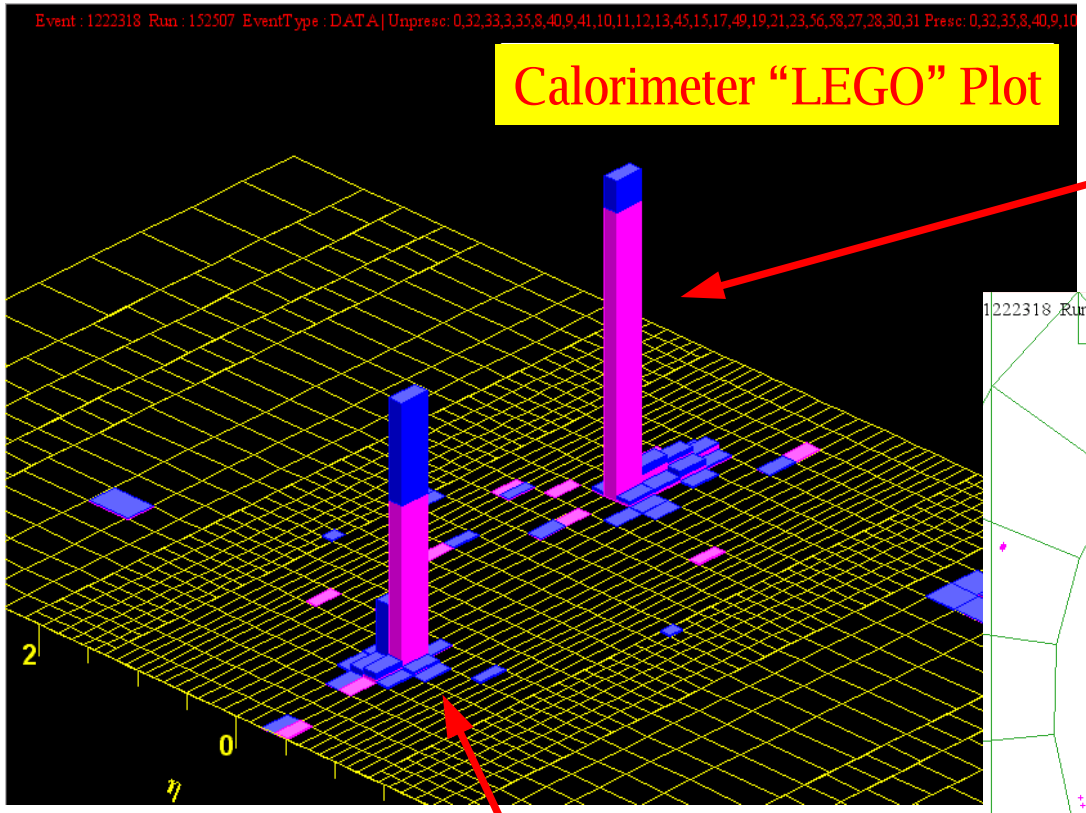
- Higher Run II $\sigma_{M_{JJ}}$ from higher $\sqrt{s}$
- Data and theory (LO) in reasonable agreement within errors
- Consistency with σ_J results

σ(Run II)/σ(Run I)

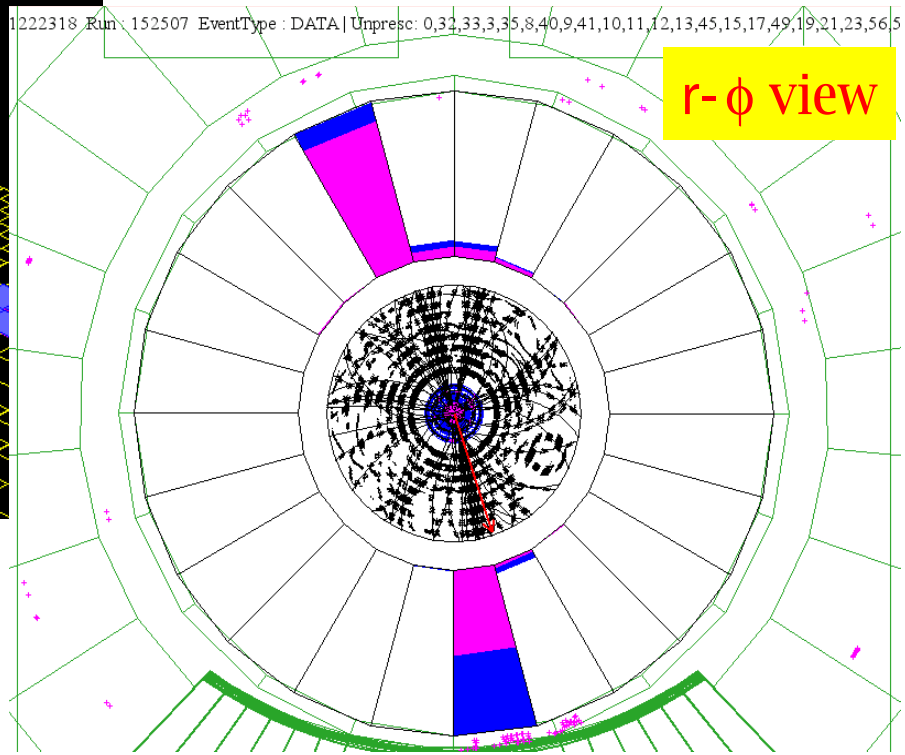


Run II Highest E_T Jets

Highest mass dijet event ever (so far...): M_{JJ} = 1364 GeV

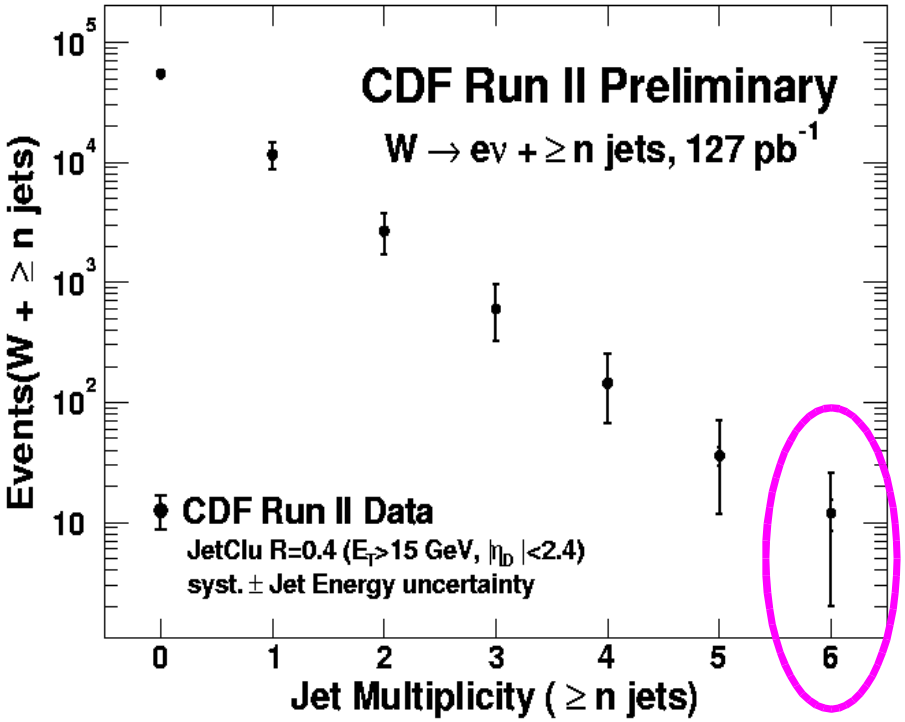


E_T = 666 GeV
η = 0.43



E_T = 633 GeV
η = - 0.19

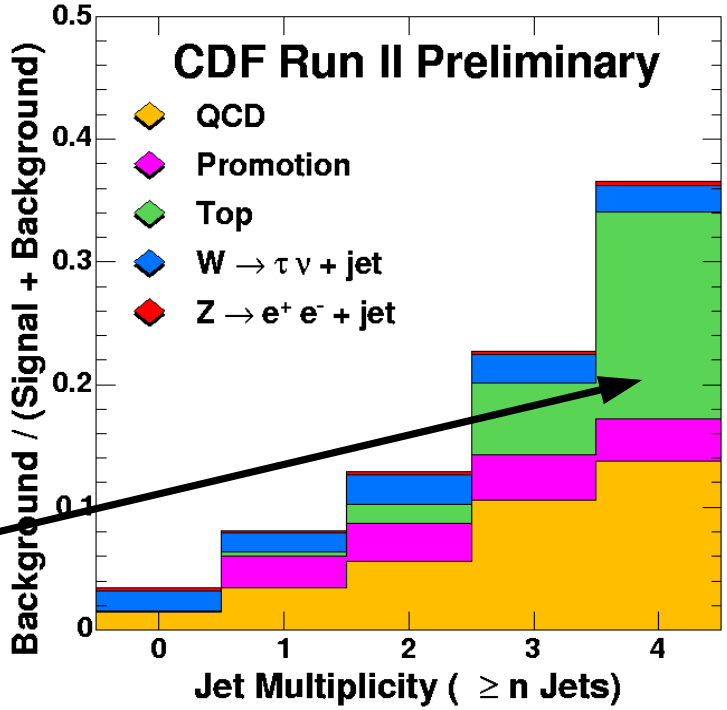
W + Jets Production



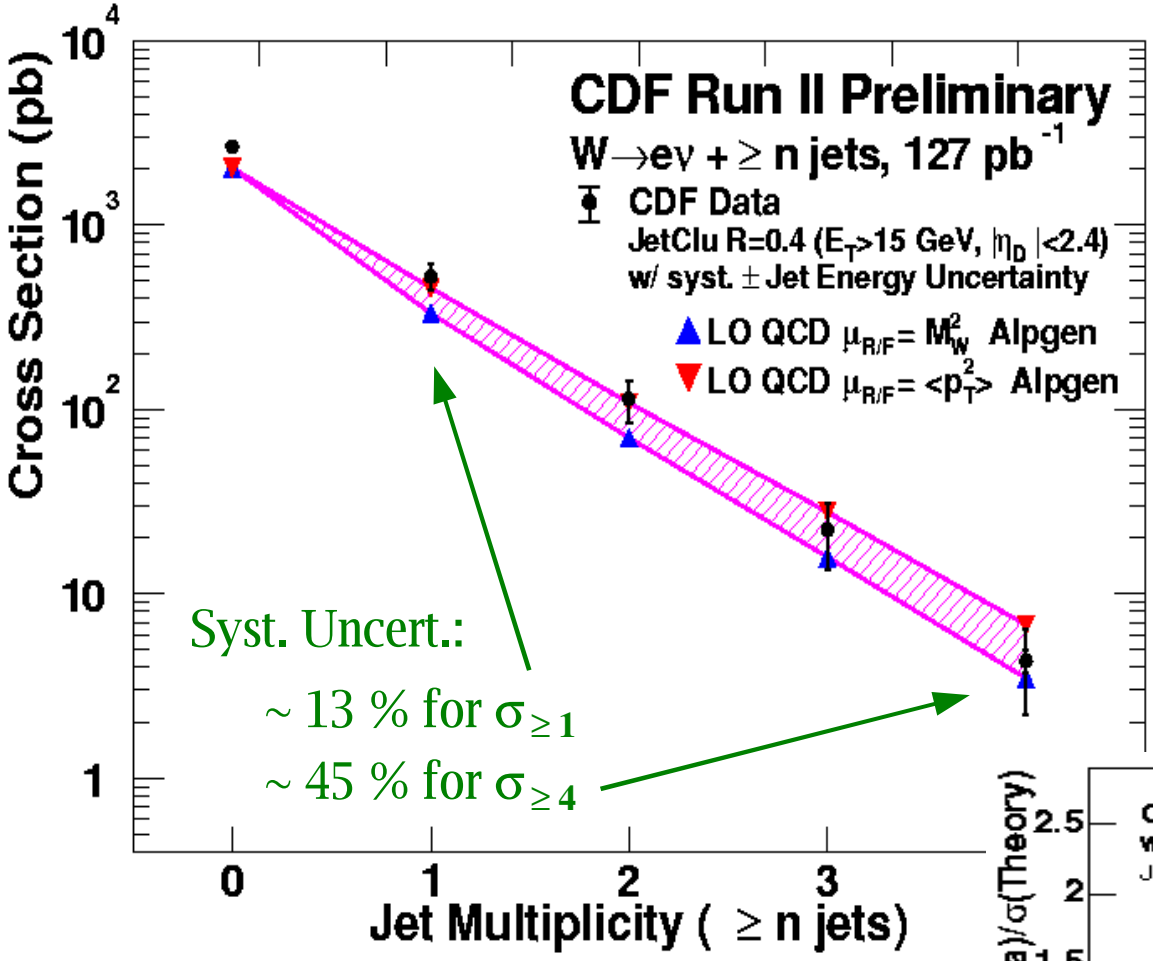
- $W^{\pm} \rightarrow e^{\pm} \nu$: clean signature
- RunII: up to n jets = 6 !
- Backgrounds:
  - QCD important in all bins
  - *top* dominant at higher multiplicity

Measurement dominated by jet E uncertainty

- Test pQCD at high Q^2 ($\geq M_W$)
- Fundamental channel for SM and new physics processes:
  - *top* quark measurements
  - Higgs and Susy searches



$W^{\pm} \rightarrow e^{\pm}\nu + \geq n$ Jet Cross Section



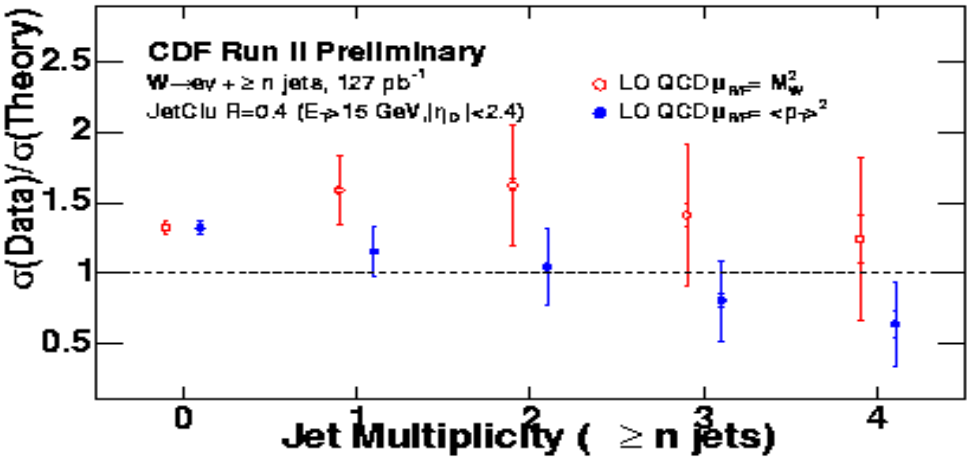
Syst. Uncert.:

~ 13 % for $\sigma_{\geq 1}$

~ 45 % for $\sigma_{\geq 4}$

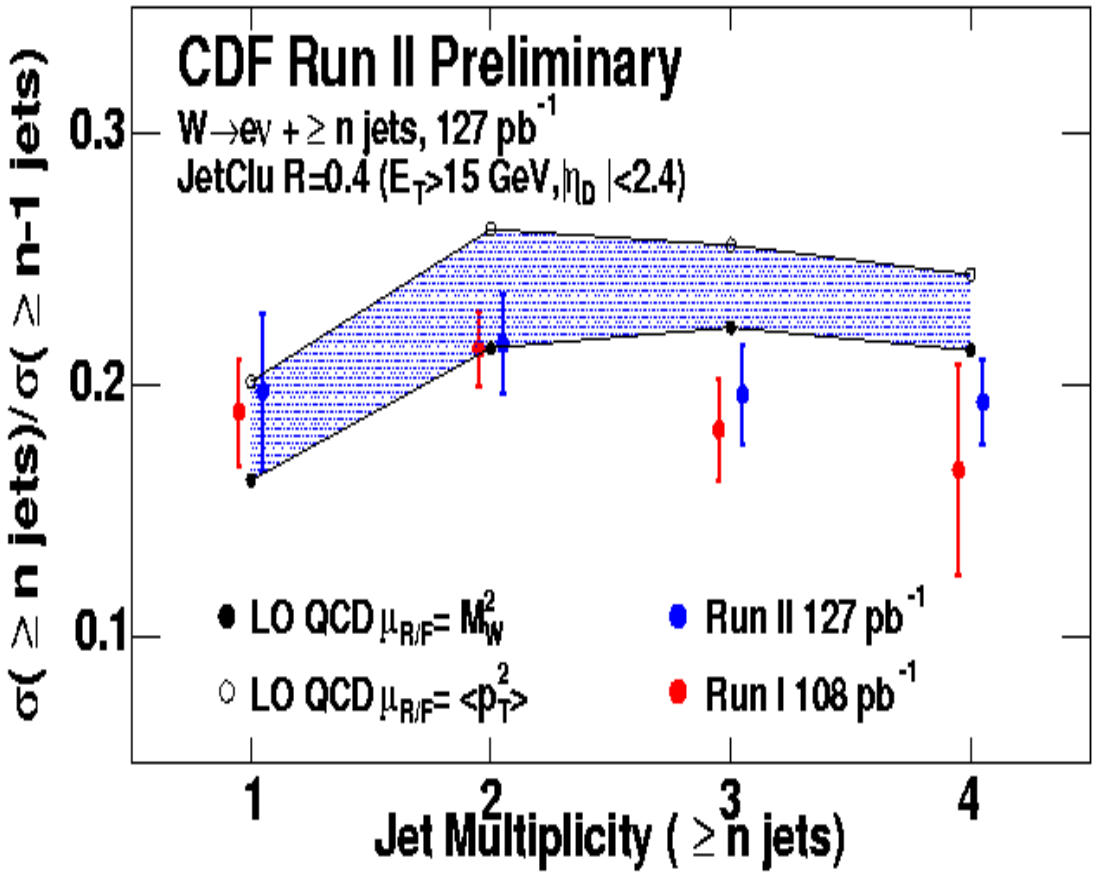
$$\sigma_{\geq n}(W) \times BR = (N_n - B_n)/(\varepsilon_n \cdot L)$$

- ε_n: from data and MC studies
- LO pQCD: **ALPGEN** (CTEQ5L, $\mu = M_W^2, < P_T^2 >$) + Herwig + detector simul.
- Theoretical errors dominated by dependence on μ



Data-theory agreement within errors

$W^{\pm} \rightarrow e^{\pm}\nu + \geq n$ Jet Cross Section (2)



Ratio $\sigma_{\geq n} / \sigma_{\geq n-1}$:

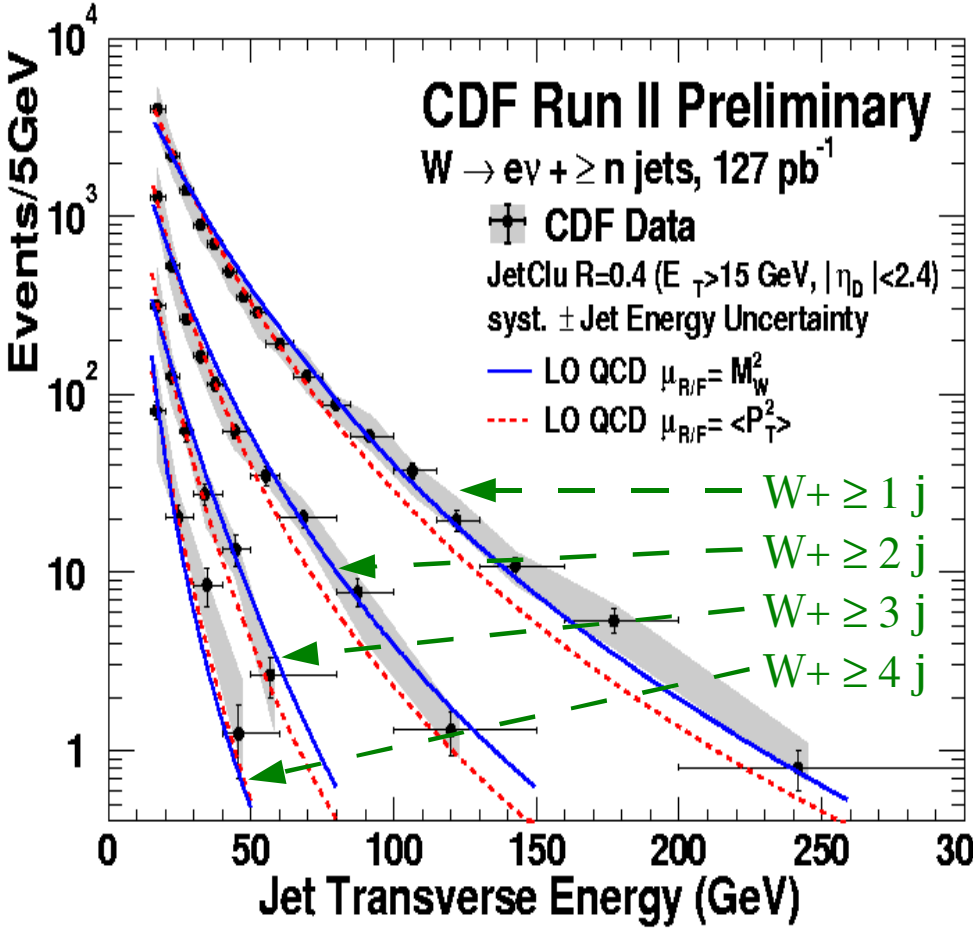
- Measure decrease in cross section for each additional jet
- Related to α_s value
- Reduced systematics

Run II vrs. Run I:

$\sigma_{\geq n}$ (Run II) / $\sigma_{\geq n}$ (Run I) > 1 with big uncertainties

Results in agreement with theory within errors

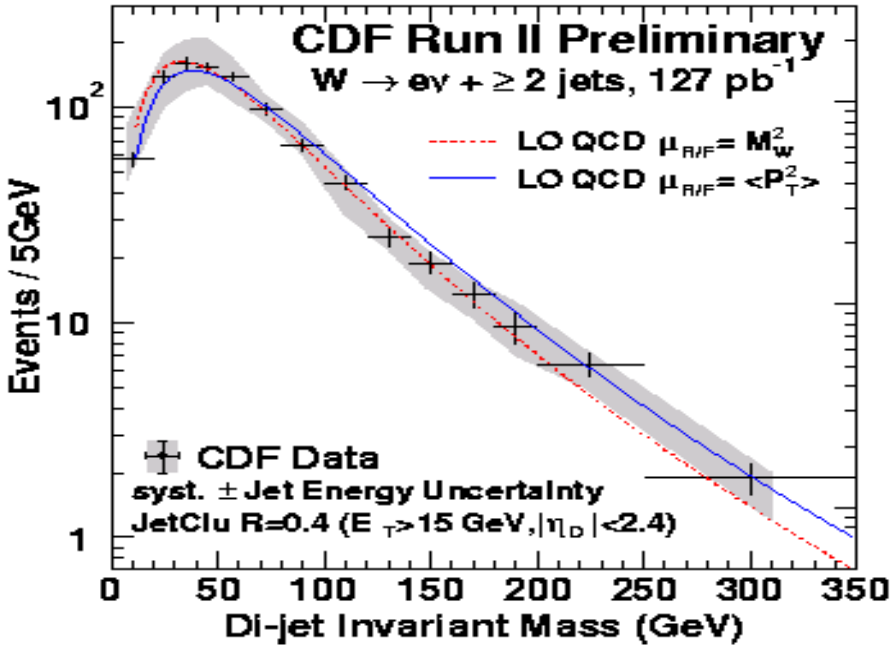
$W^{\pm} \rightarrow e^{\pm}\nu + \geq n$ Jet Cross Section (3)



Fair data-theory agreement

Kinematic distributions:

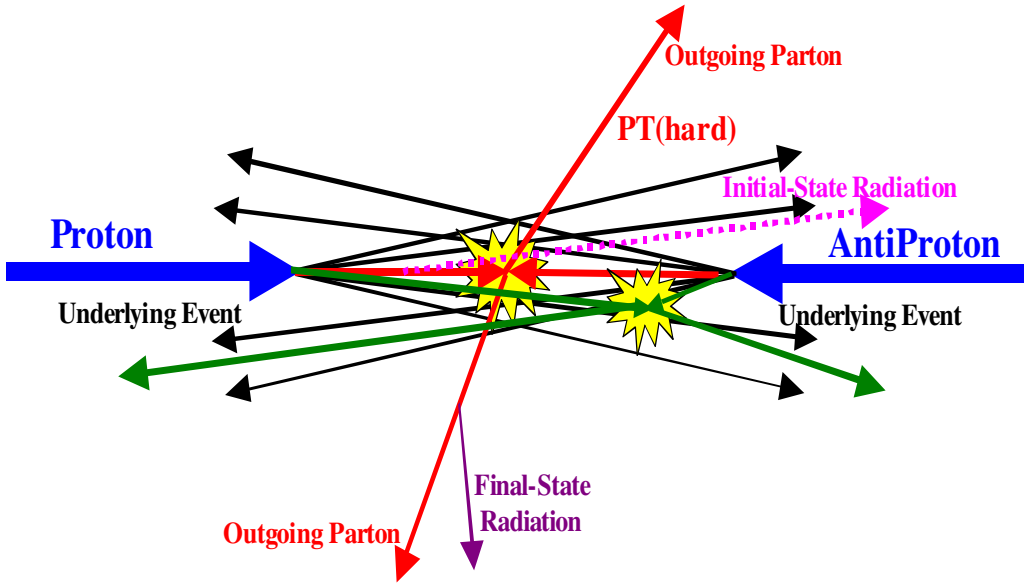
- Diff. cross sec. vrs. E_T for n-th highest E_T jet in W+ ≥ n jets: reduced dependence on μ
- Dijet invariant mass and angular separation: sensitive to soft/collinear jet prod.

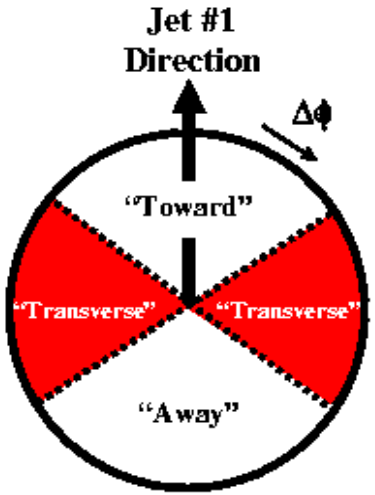


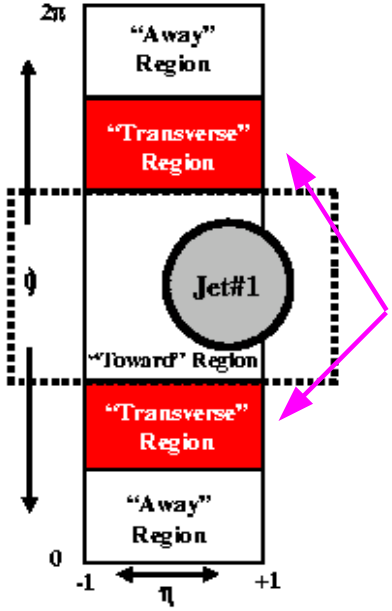
Underlying Event Studies

Underlying Event:

- Everything except the two outgoing hard scattered jets:
  - hard initial/final state radiation
  - beam-beam remnants
  - multiple parton interactions
- Unavoidable background NOT well defined/modeled theoretically



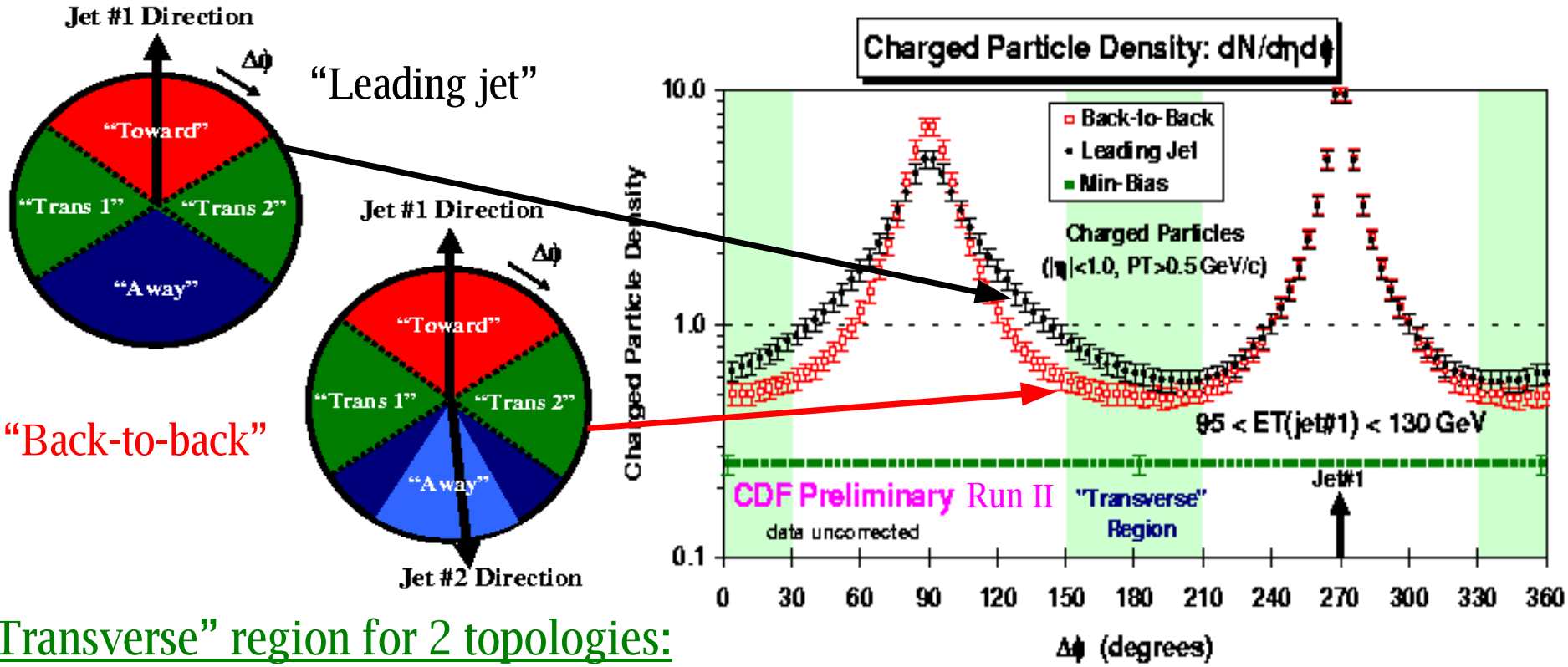




Phenomenological studies:

- Leading calorimeter jet (JetClu $R = 0.7$, $|\eta| < 2$) defines 3 regions of same size in η-ϕ space
- "Transverse" region very sensitive to U.E.
- Charged particle ($p_T > 0.5$ GeV/c, $|\eta| < 1$) $\Delta\phi$ correlations with respect to jet #1
- Min-bias & jet data vrs. Pythia and Herwig

Underlying Event Studies (2)



"Transverse" region for 2 topologies:

- "Leading jet":
  no prescription on jet #2
- "Back-to-back":
  $\Delta\phi_{12} > 150^{o}$, $E_T^{j2}/E_T^{j1} > 0.8$
  $\Rightarrow$ hard ISR and FSR suppressed

Charged particle density vrs Δφ:

- "leading jet": ISR/FSR E_T^{j1} dependent
- "back-to-back": stable versus E_T^{j1}
- lower density in "min-bias" events

Similar results for scalar P_TSum density

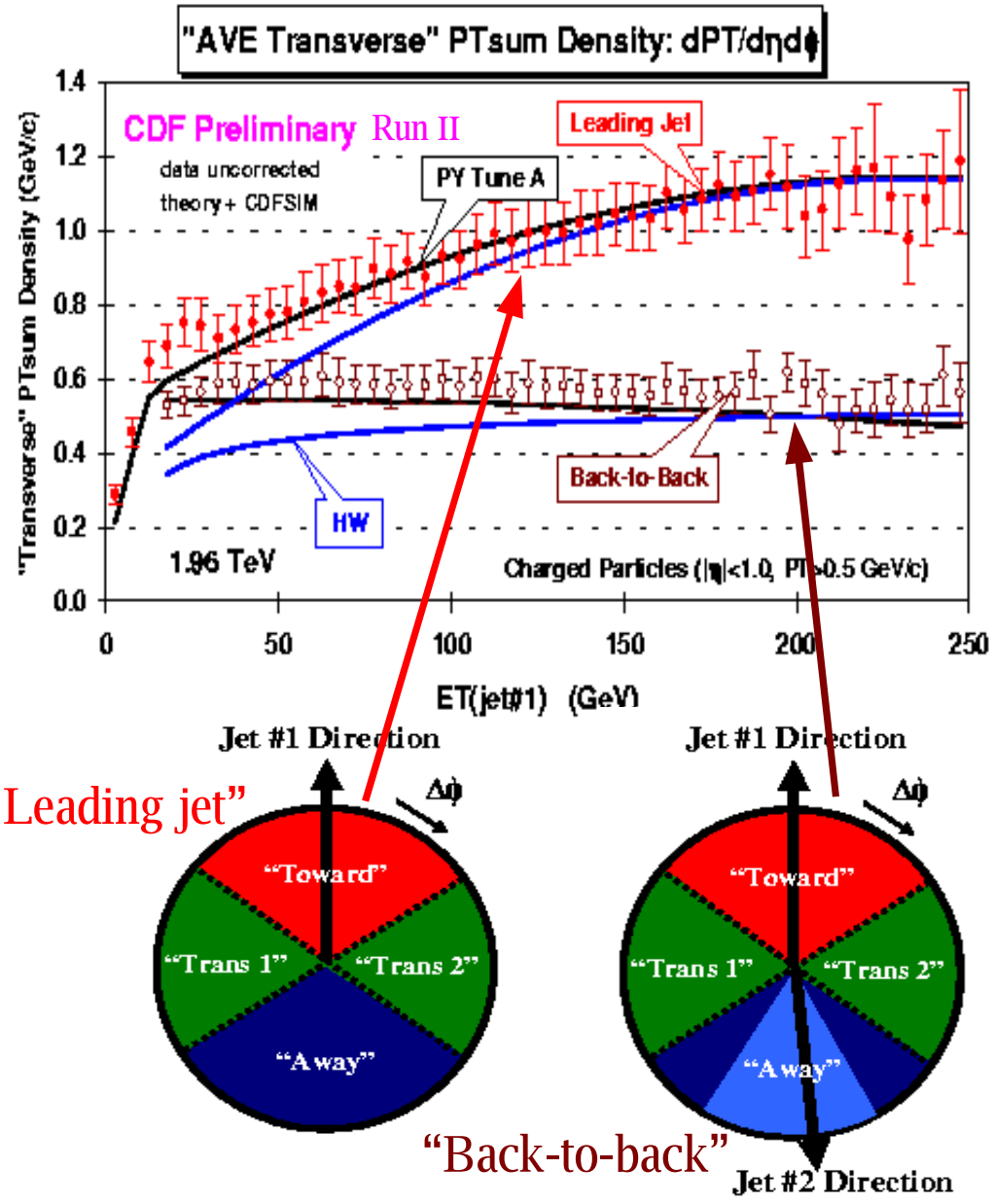
Underlying Event Studies (3)

Involving non-pQCD physics:

- Data not well reproduced by current MC with default parameters
- Pythia (6.206) tuned on Run I data with multi-parton interactions

Comparing data with Pythia & Herwig:

- Consider average charged particle and scalar P_TSum density in the "transverse" region versus E_T^{j1} in events "leading jet" and "back-to-back"
- Compare data with MC dijet events after detector simulation
- Pythia (tuned on Run I data) in good agreement with Run II data
- Herwig (no multi-parton interaction) works only at high E_t^{j1}



Conclusions

- A very exciting and important QCD physics program is ongoing at the Tevatron with the increased $\sqrt{s}$ and higher statistics of Run II extending measurements at high Q^2
- Some Preliminary results:
  - measured inclusive jet and dijet mass cross sections in reasonable agreement with NLO pQCD + CTEQ6.1/MRST01; jet E scale (high x gluon PDF) uncertainty dominant error for data (theory)
  - W + jets production fairly described by LO MC (Alpgen) + Herwig
  - Underlying Event well described by Pythia (tuned on Run I data)