Jet Physics and Underlying Event Studies at CDF

Andrew Mehta

University of Liverpool

for the CDF Collaboration

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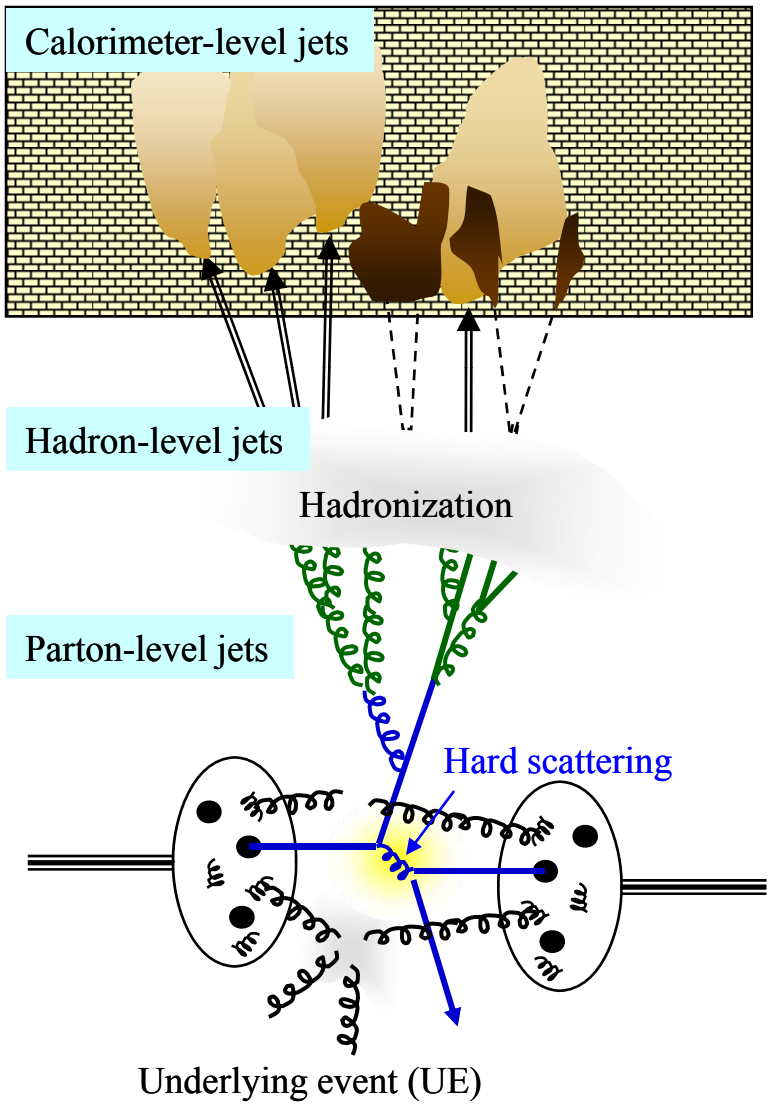
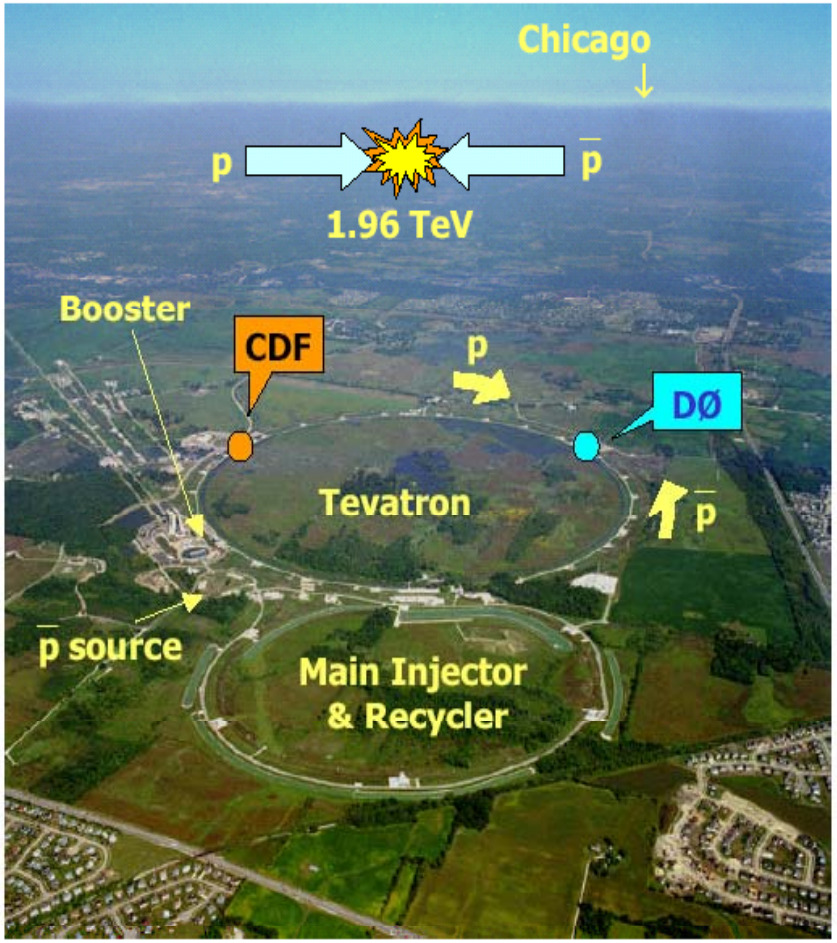
Jet Production in Hadron-Hadron Collisions



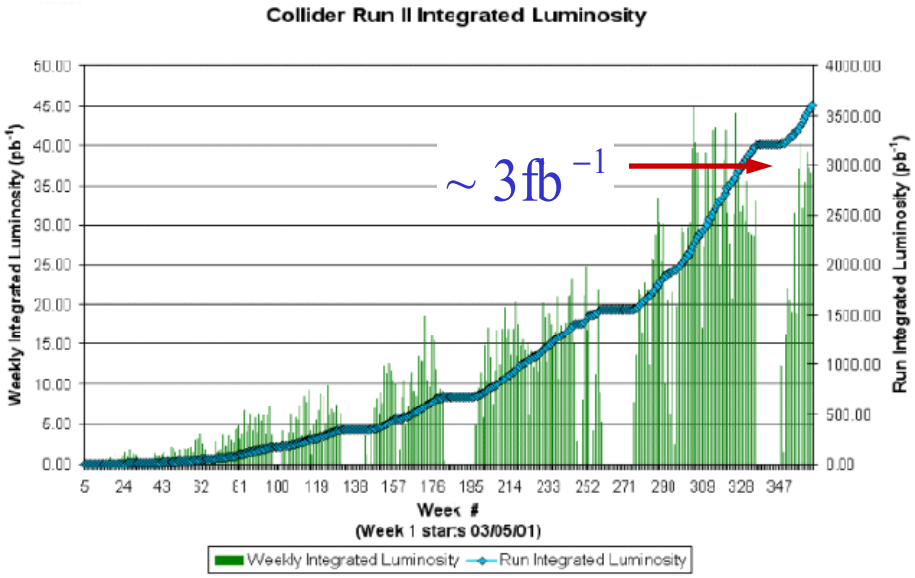
- Perturbative (hard) QCD components
  - 2→2 hard scattering
  - Initial & final state radiation, parton-showers
- Non-perturbative (soft) QCD contributions
  - Underlying event
    - Beam-beam remnants
    - Multiple parton interactions
  - Hadronization

- Jets are collimated spray of hadrons originating from hard-scattered partons
  - experimental probes of hard scattering!
- Need to understand soft QCD contributions to jets (study of underlying event essential!)

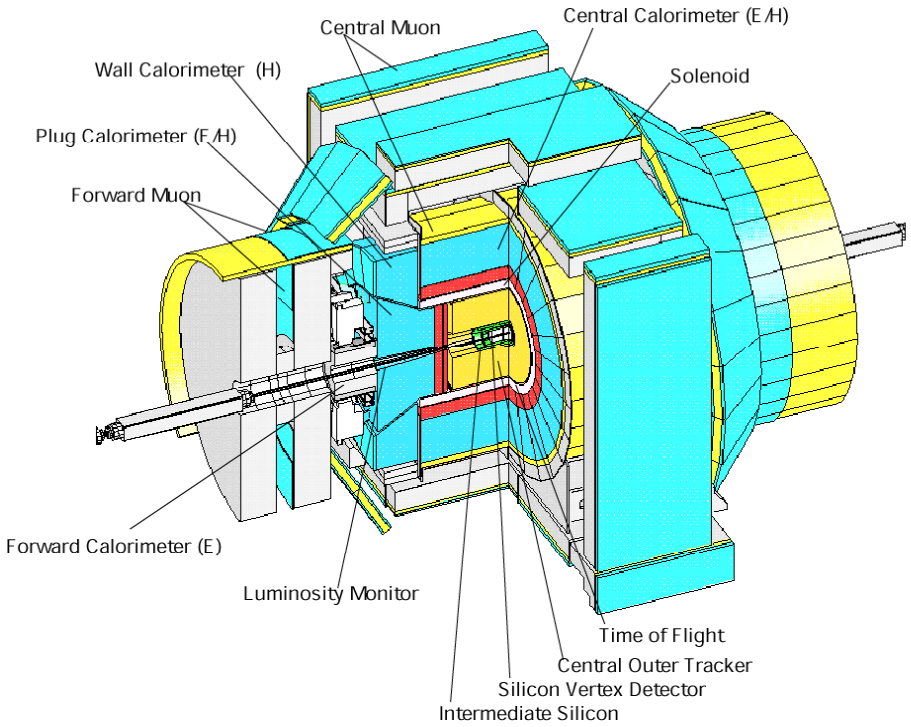
Fermilab Tevatron in Run II



- Proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV
- Run II started in March 2001
- Delivered luminosity now >3 fb^{-1}
- Projection ~ 6 - 8 fb^{-1} by 2009

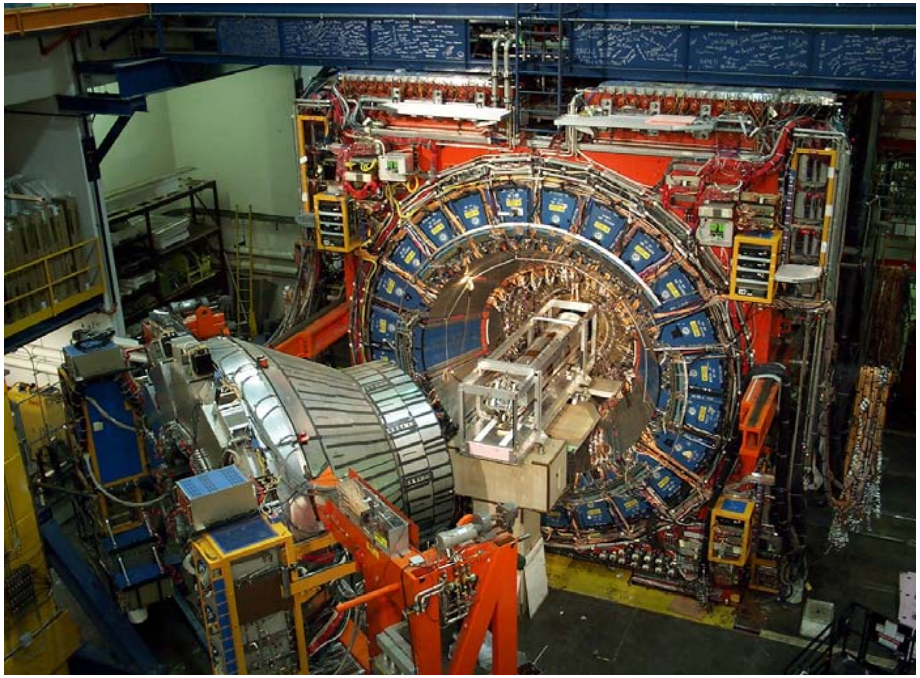


Collider Detector at Fermilab (CDF)



Multi-purpose detectors

- Silicon vertex detector
- Central drift chamber (COT)
- Solenoid magnet
- EM and hadron calorimeters
- Muon chambers

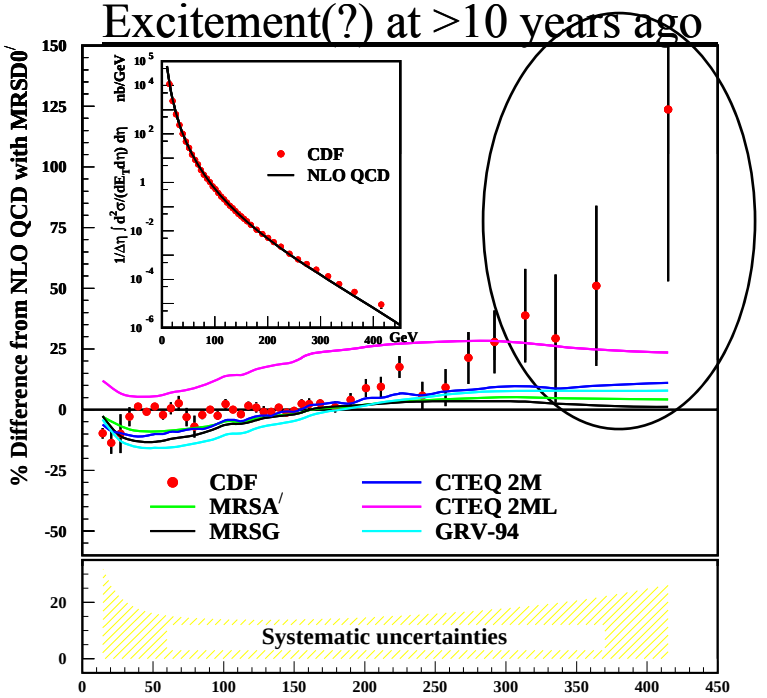


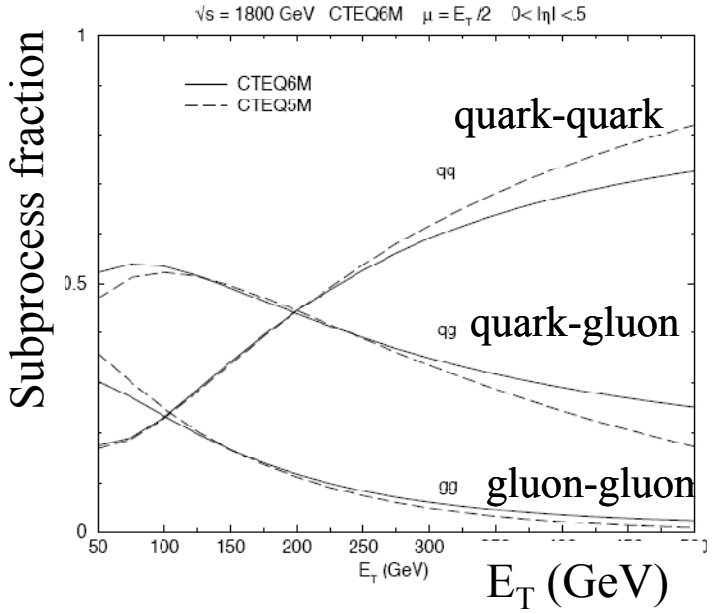
- Data taking efficiency ~ 85 %
- About 2.7 fb^{-1} on tape

Inclusive Jet Production

- Test perturbative QCD predictions over ~8 orders of magnitude in cross section
- Constrain QCD parameters (PDF, α_s)
- Potentially sensitive to new physics
  - Probing distances ~ 10^{-19} m

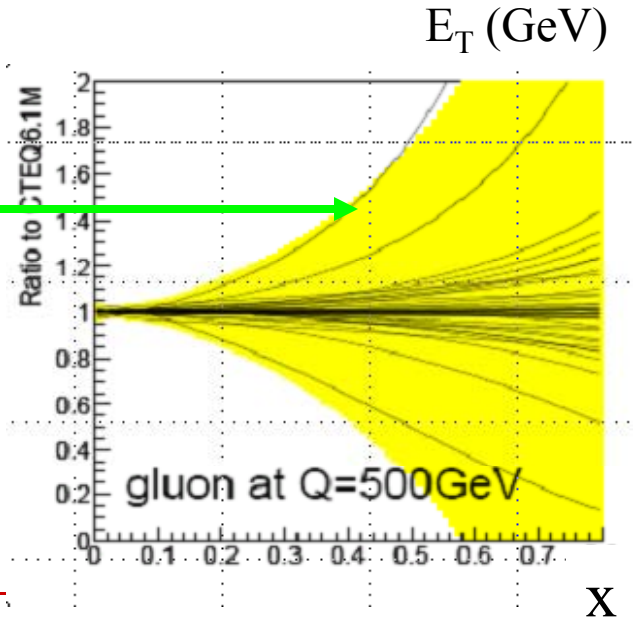
Excitement(?) at >10 years ago





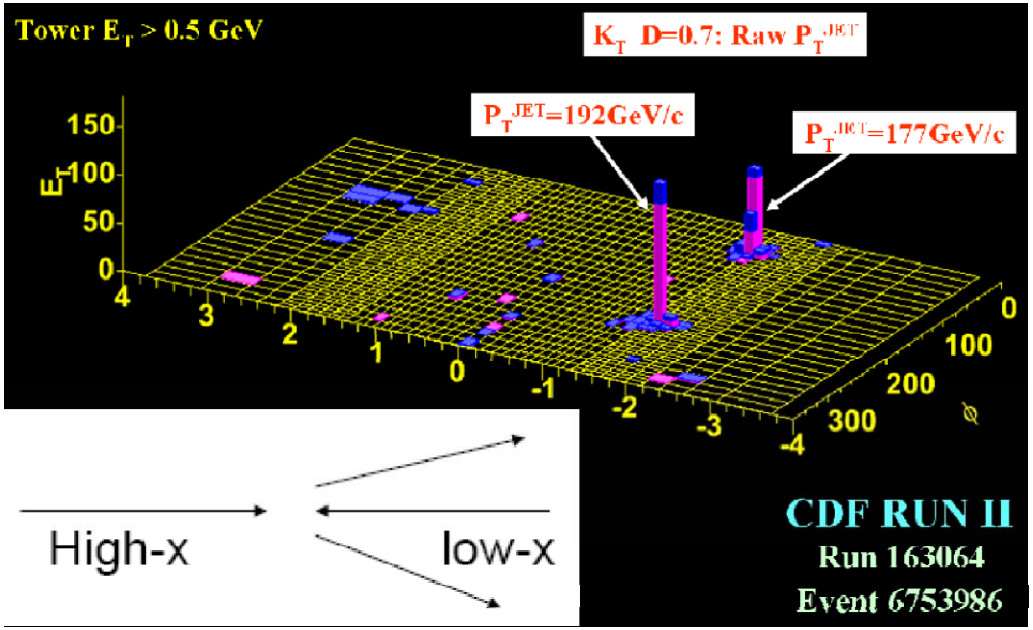
- Sizable cross section from quark-gluon sub-process
- High-x gluon not well known

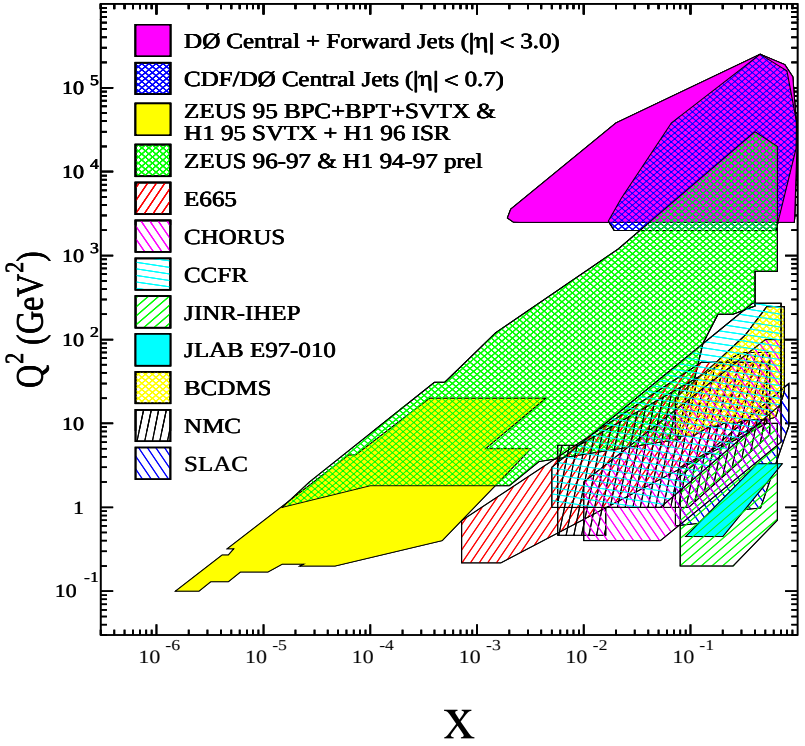
…can be accommodated in the Standard Model



Forward Jet Measurement

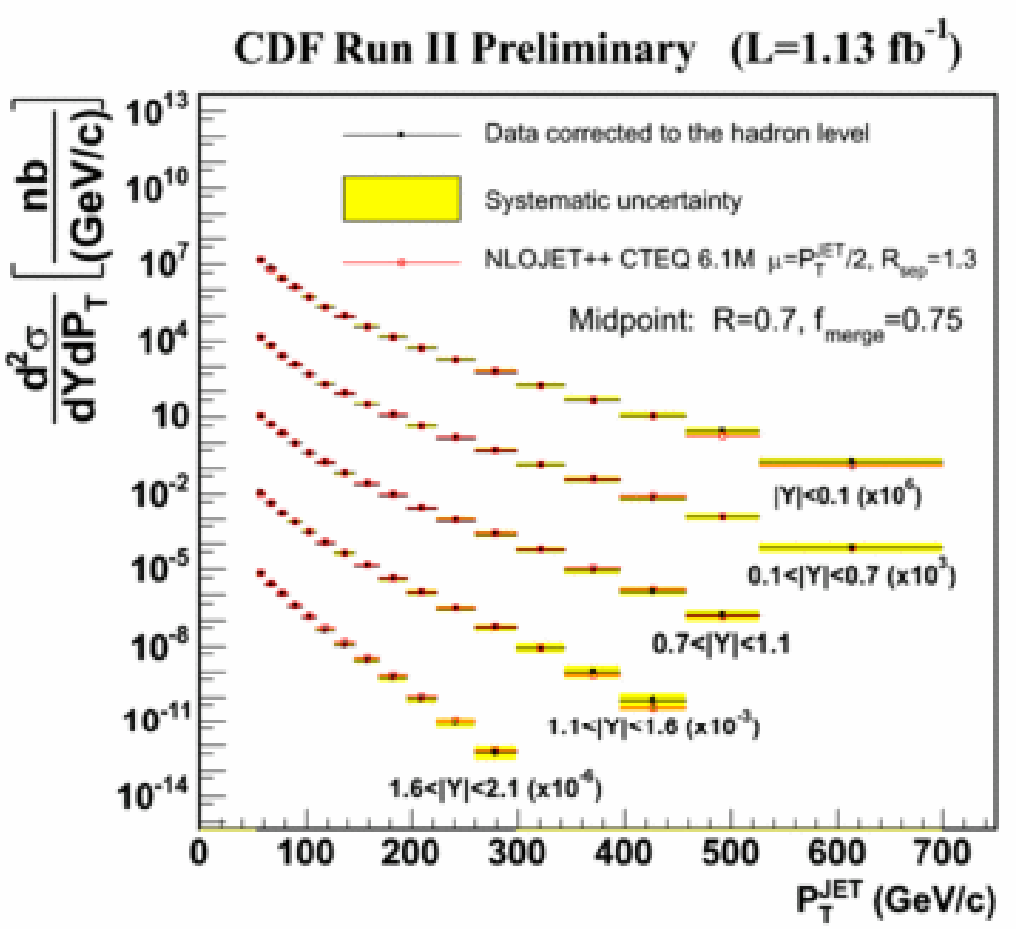
- Forward jets probe high-x at lower Q^2 (= $-q^2$) than central jets
  - Q^2 evolution given by DGLAP
  - Essential to distinguish PDF and possible new physics at higher Q^2
- Also, extend the sensitivity to lower x





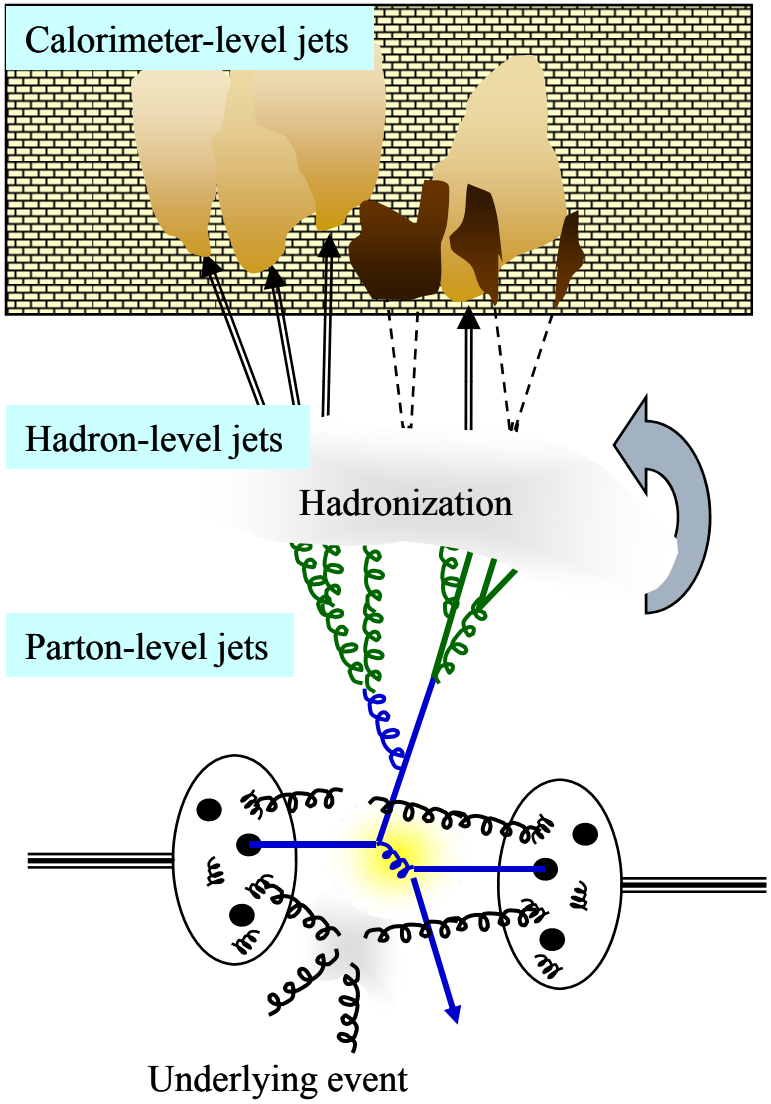
Inclusive Jet Cross Sections

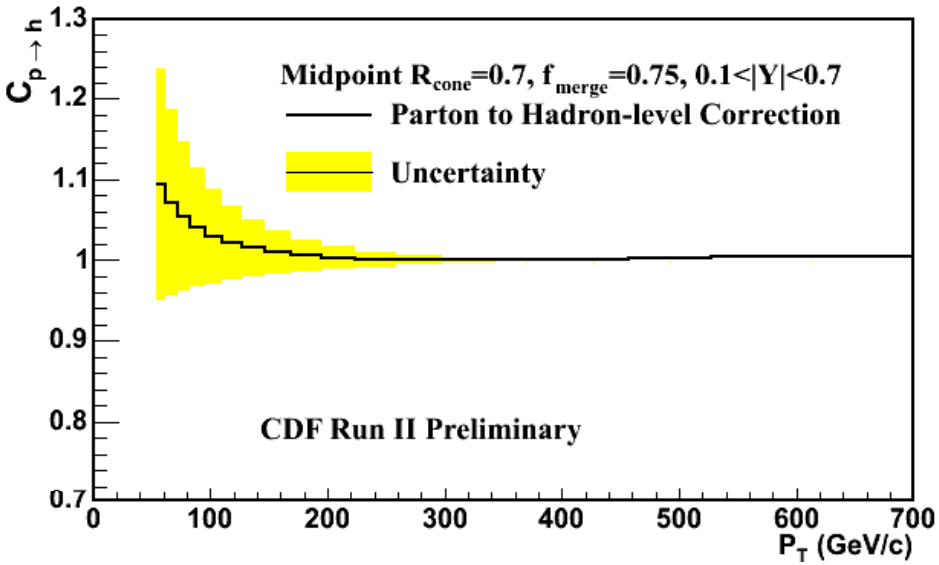
- L = 1.1 fb^{-1}
- Jets reconstructed with Midpoint algorithm, R = 0.7
- Consistent with NLO pQCD predictions
  - Experimental uncertainties dominated by jet energy scale (2-3%)
  - Theoretical uncertainties mainly from PDF (gluon at high x)



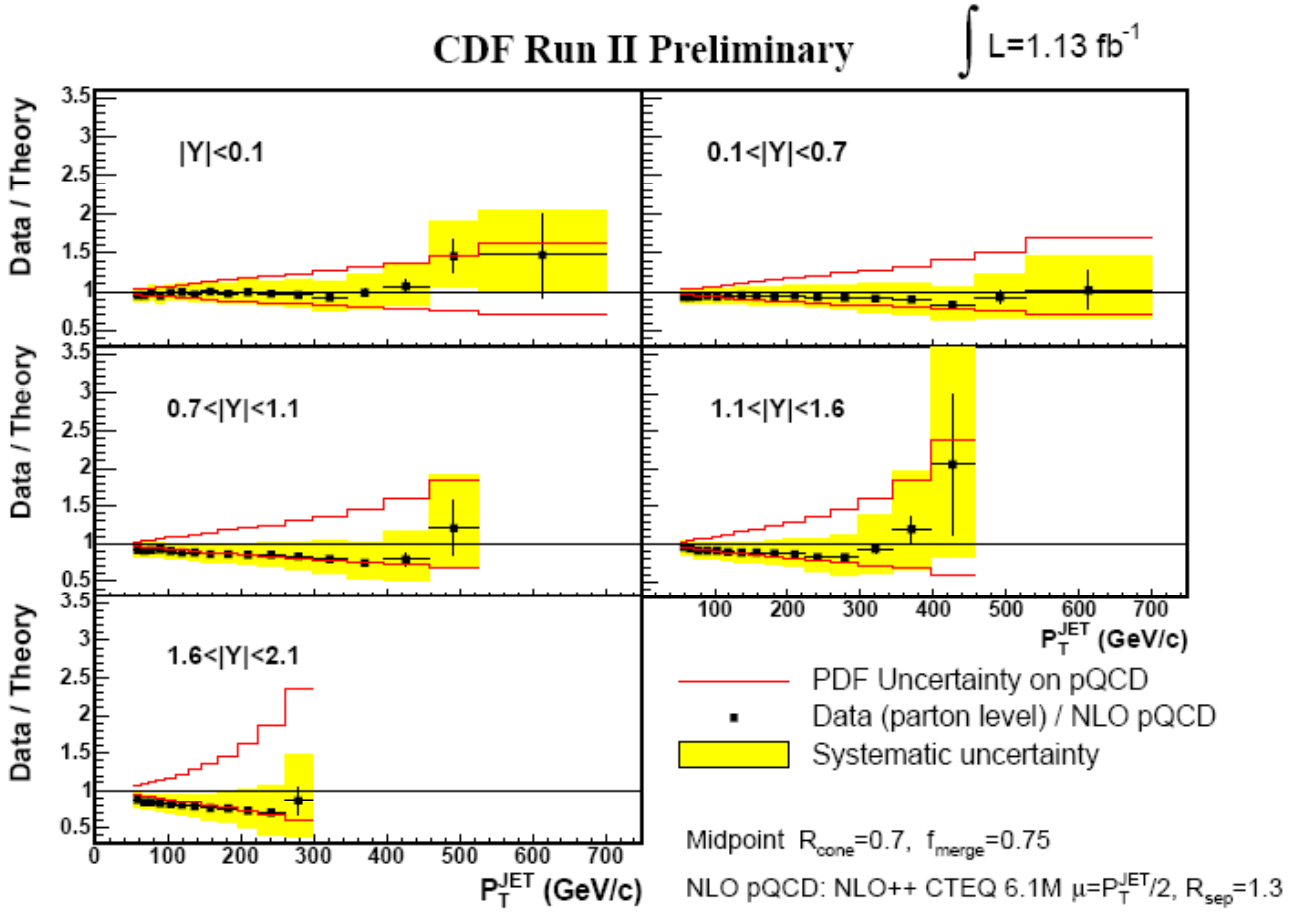
(6% luminosity uncertainty not included)

Underlying Event & Hadronization Correction





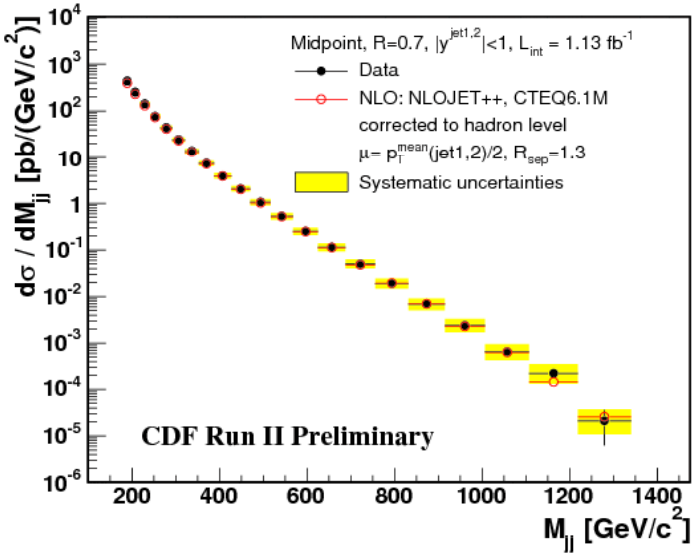
Inclusive Jet Cross Sections vs Theory

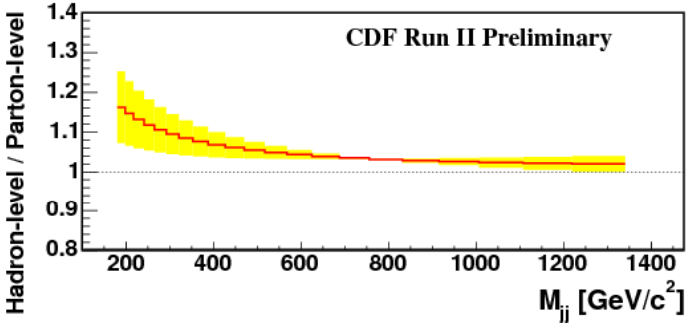


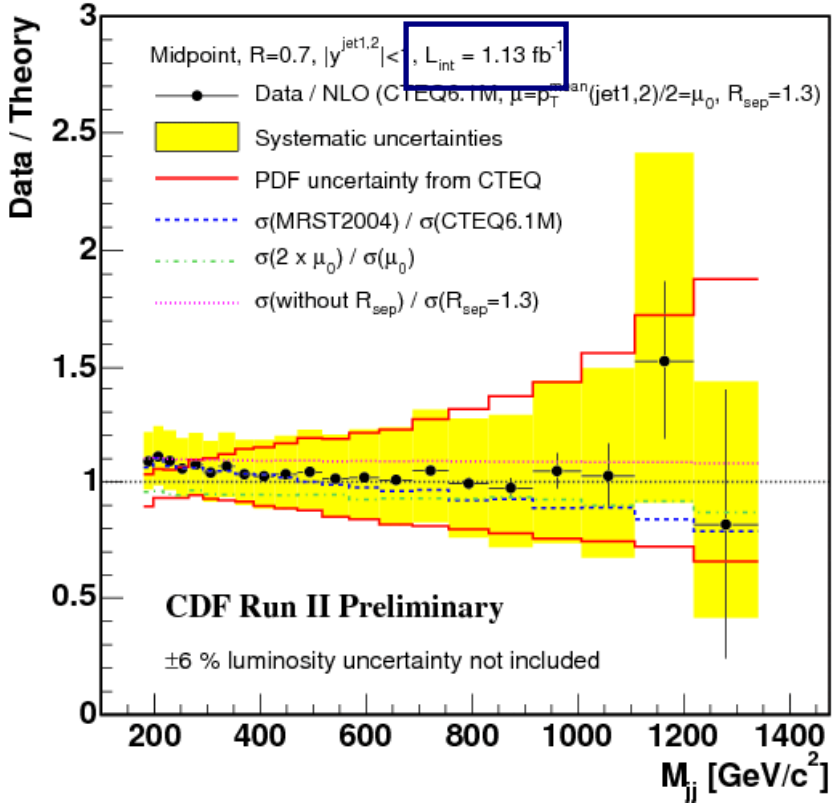
- Data consistent with NLO pQCD predictions in all rapidity region
- Experimental uncertainty in the forward region smaller than the PDF
  → will contribute to further constrain PDFs

Dijet Production

- Test of pQCD predictions
- Sensitive to new physics: decays of massive particles,

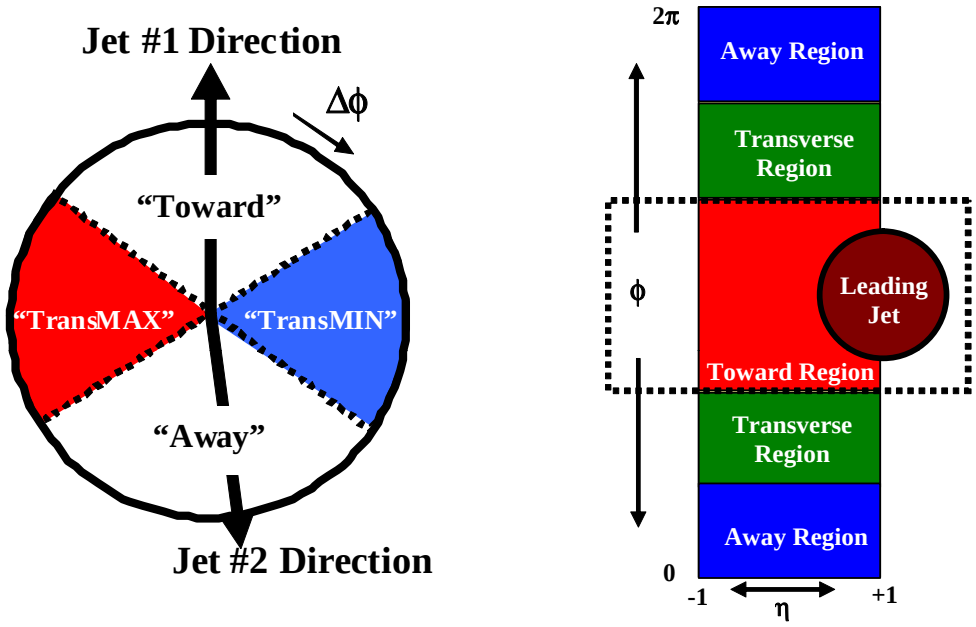






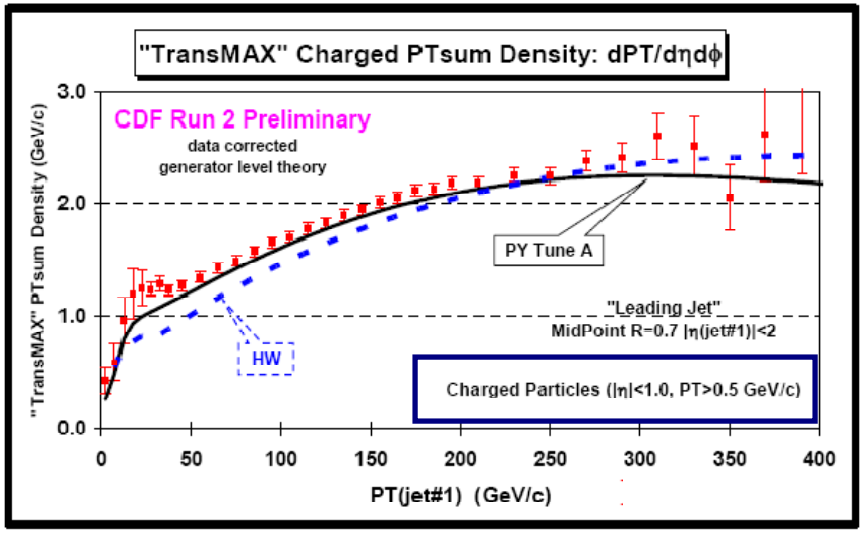
- Consistent with NLO pQCD predictions
  - Experimental uncertainties comparable to PDF uncertainties
- No significant evidence for a resonance found.
  - Limits on new particles decaying into dijets are set (see C Magass's talk in EWK&BSM session)

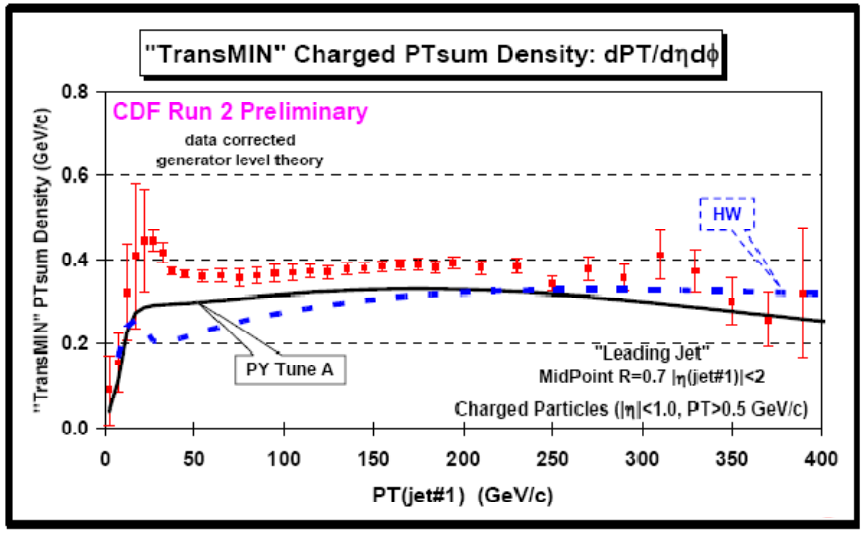
Underlying Event (UE) Studies



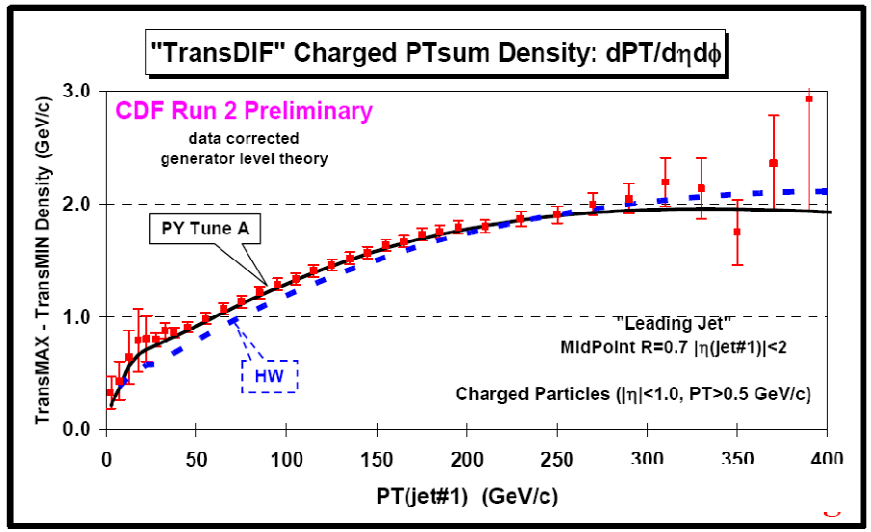
- Define (1) toward, (2) away, and (3) transverse regions based on the leading jet in the event. The transverse region is most sensitive to UE.
- The two transverse regions, TransMAX and TransMIN, defined event-by-event to further separate soft and semi-hard components of UE.

Underlying Event in Jet Events

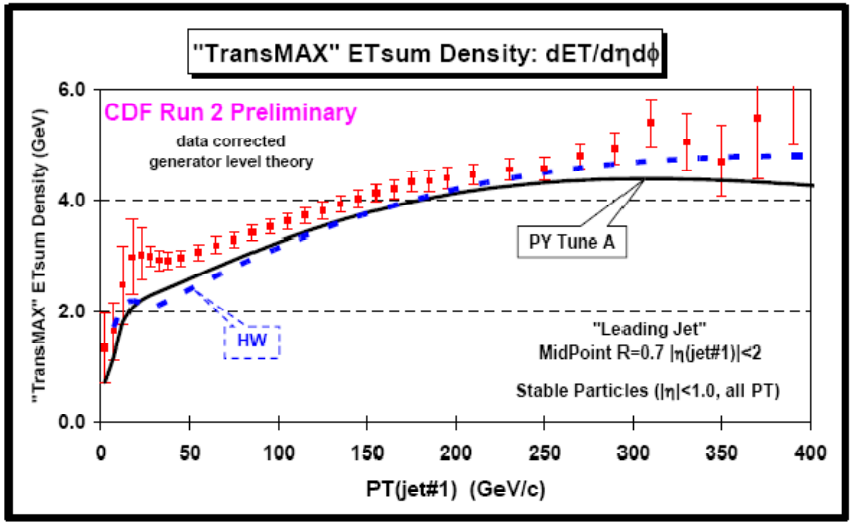


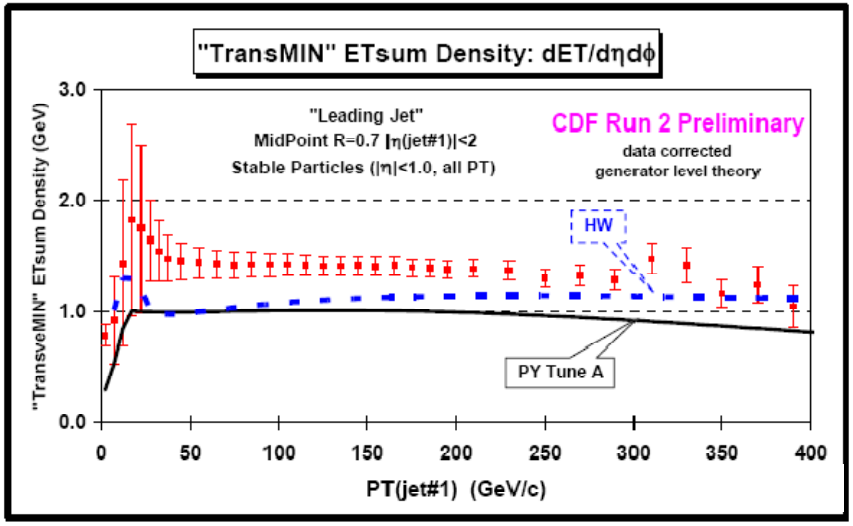


- Tuned PYTHIA (Tune A) doing reasonable job but not quite perfect
- TransDIF = TransMAX-TransMIN is sensitive to the semi-hard component of UE. Well described by Tuned PYTHIA (w/ multiple parton interactions)

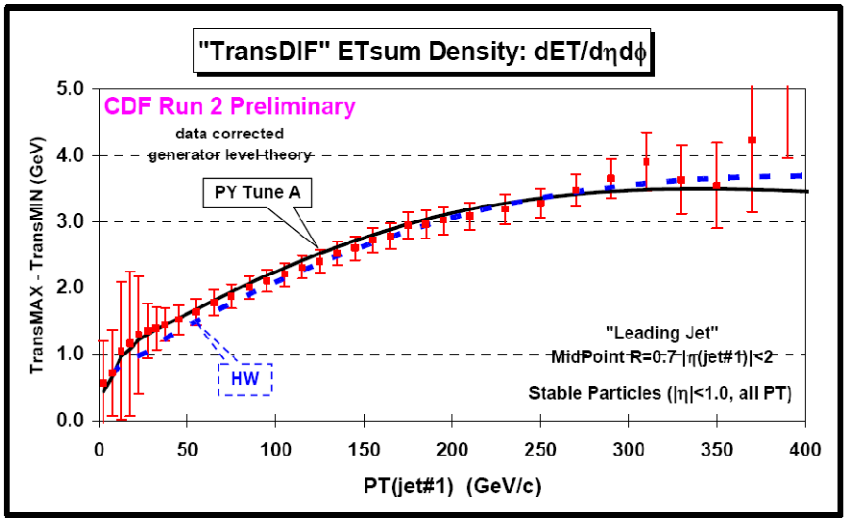


Underlying Event in Jet Events

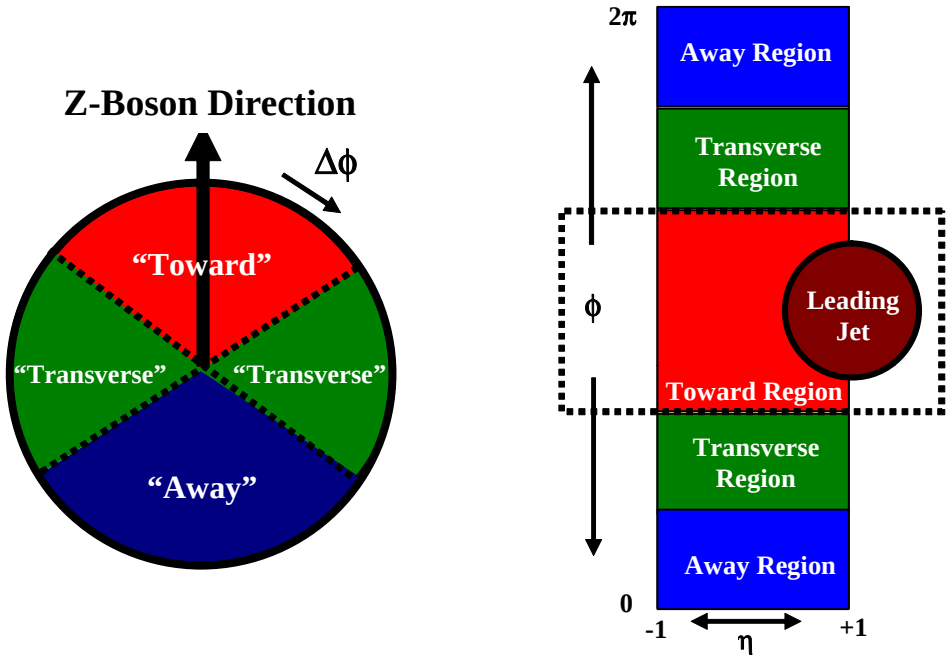




- Now, looking at all particles including neutrals (instead of charged particles only with p_T>0.5 GeV/c)
- Similar trend observed



Underlying Event in Jet and DY Production

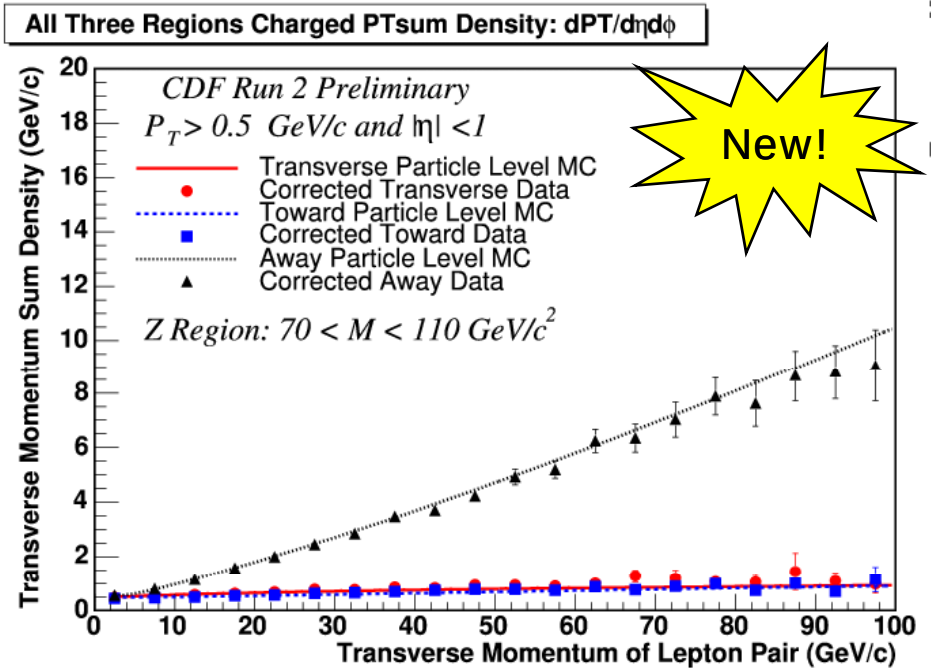


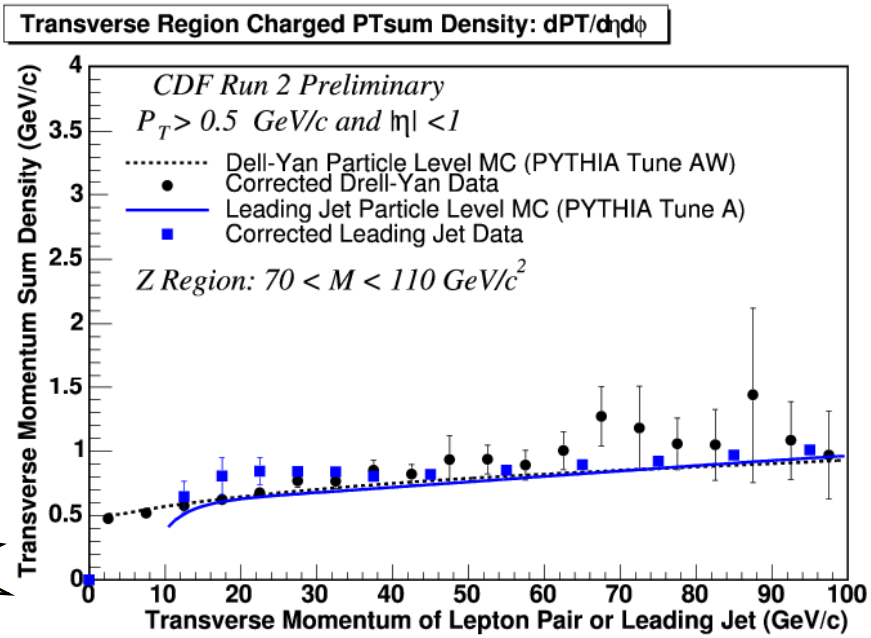
- Drell-Yan (DY) events provide clean environment for studying UE
- In DY events, the transverse and toward region (excluding the lepton-pairs) are both sensitive to underlying event, while the away region is largely affected by the recoils

Underlying Event in DY and Jet Production

Comparisons of three regions

- Away region p_T density goes up with lepton-pair p_T, while the transverse and toward region p_T density is mostly flat with lepton-pair p_T





Comparisons of the transverse region between jet and DY events

- Similar trend in jet and DY events
- Tuned Pythia describe data reasonably well.

Summary

- CDF has been making measurements of inclusive jet and dijet cross sections.
  - The measurements are consistent with NLO pQCD predictions based on recent PDFs
  - The inclusive jet cross section measurements will contribute to further constrain PDFs
  - The dijet mass spectrum measurement is providing useful limits on new physics

- CDF is making good progress toward understanding the underlying event (UE), tuning the UE model on our own, and at the same time making many distributions sensitive to underlying event publicly-available so that any theorist can tune UE model
  - Tuned PYTHIA seems to describe data reasonably well though not perfect so far
  - Having good modelling of UE is important for many physics analyses (e.g. inclusive and dijet cross section measurements)

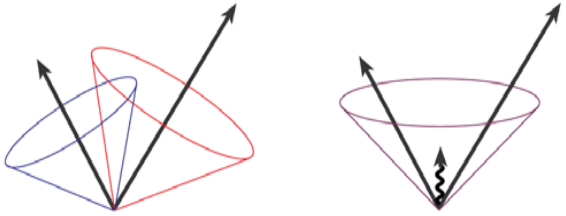
  It will be very important to measurement the underlying event at the LHC and tune the MC models at the beginning of the LHC

Backups

Jet "Definitions" - Algorithms at CDF

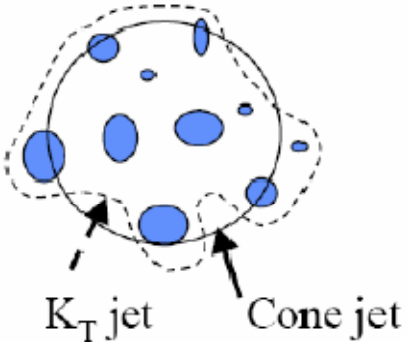
- Cone algorithms (JetClu, Midpoint)
  - Cluster objects based on their proximity in $y(\eta)$-ϕ space
  - Starting from seeds (calor. towers/particles above threshold), find stable cones (p_T-weighted centroid = geometric center).

Infrared unsafety:
soft parton emission changes jet clustering



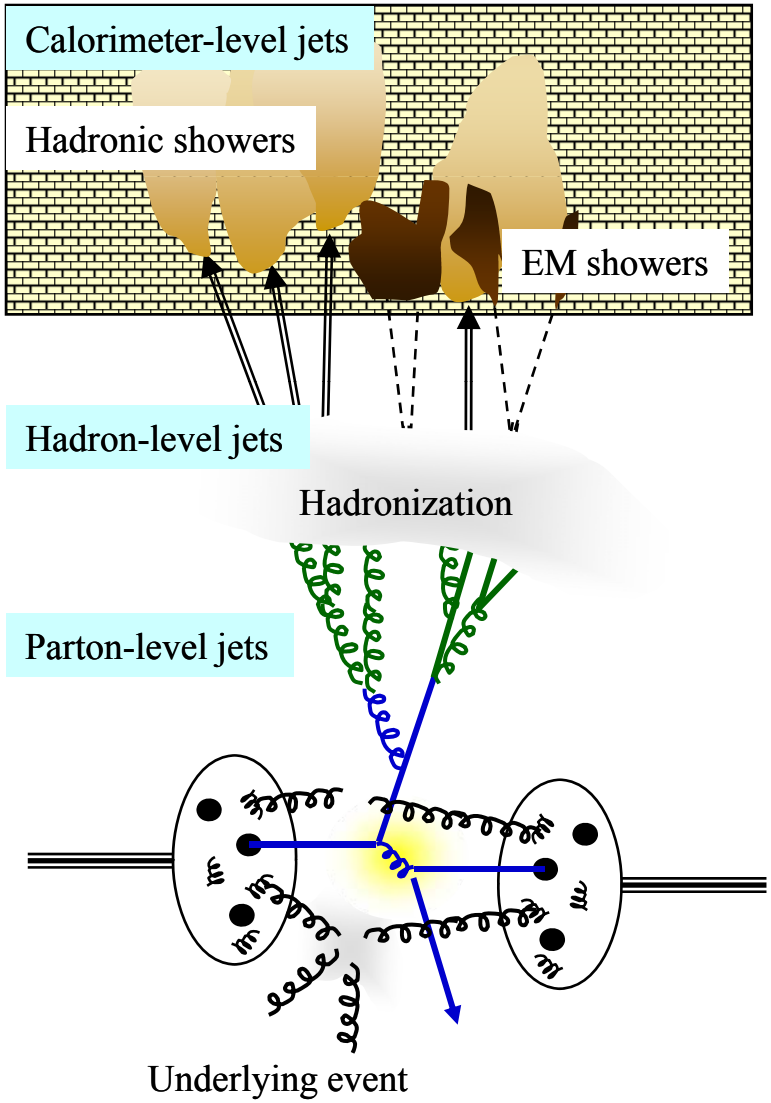
  - In Run II QCD studies, often use "Midpoint" algorithm, i.e. look for stable cones from middle points between stable cones → Infrared safe to NNLO
  - Stable cones sometime overlaps → merge cones when overlap > 75%

- k_T algorithm
  - Cluster objects based on their relative transverse momentum (k_T)
  - Iteratively cluster pairs of close objects until all objects become part of jets



  - No issue of splitting/merging. Infrared and collinear safe to all orders of QCD.
  - Successful at LEP & HERA, but relatively new at the hadron colliders
    - More difficult environment (underlying event, multiple $p\bar{p}$ interactions…)

Jet Energy Corrections



Measure calorimeter-level jets. Then, correct for:

- Energy from additional $p\bar{p}$ collisions
- Calorimeter non-uniformity
- Average energy loss and smearing effect in calorimeter energy measurement
  - Shower simulation tuned to data
- Hadron-level jet cross section

To make fair comparisons with parton-level pQCD predictions, need to account for:

- Underlying event
- Hadronization

Effects evaluated from simulated jet events.
Underlying event in MC is tuned to data.