Jet Physics and Underlying Event Studies at CDF

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Presented are recent results on the measurements of inclusive jet cross sections and dijet mass differential cross sections, which allow us to test QCD at short distance scales and constrain parton distribution functions in the proton. Results on the underlying event in jet and Drell-Yan production and comparisons with Monte Carlo predictions are also presented.

1 Inclusive jets and dijets

The differential inclusive jet cross section and dijet cross section at the Tevatron test QCD at the shortest distances currently attainable in accelerator experiments. The measurements provide a fundamental test of perturbative QCD calculations and a constraint on the parton distribution functions (PDFs) of the proton. The dijet mass spectrum is also sensitive to the presence of new particles that decay into two jets.

CDF has made inclusive jet cross section measurements using the k_T algorithm [1] and Midpoint cone clustering algorithm [2]. The recent measurements using these algorithms are based on 1.0 and 1.13 fb^{-1} of data, respectively, and cover the rapidity region up to $|y_{jet}| = 2.1$ which is much wider than $0.1 < |y_{jet}| < 0.7$ in the previous measurements. The k_T measurement was published in [3] and the results from the Midpoint measurement [4] with the cone radius $R_{cone} = 0.7$ are shown in Fig. 1.

In the measurements, the energy of each jet is corrected for the calorimeter response and multiple $p\bar{p}$ interactions. Then, the jet p_T spectra are formed, and they are corrected for for event selection efficiencies and energy smearing due to finite calorimeter energy resolution on a bin-by-bin basis. The dominant systematic uncertainties in the measurements arise from the uncertainty in the jet energy scale determination.

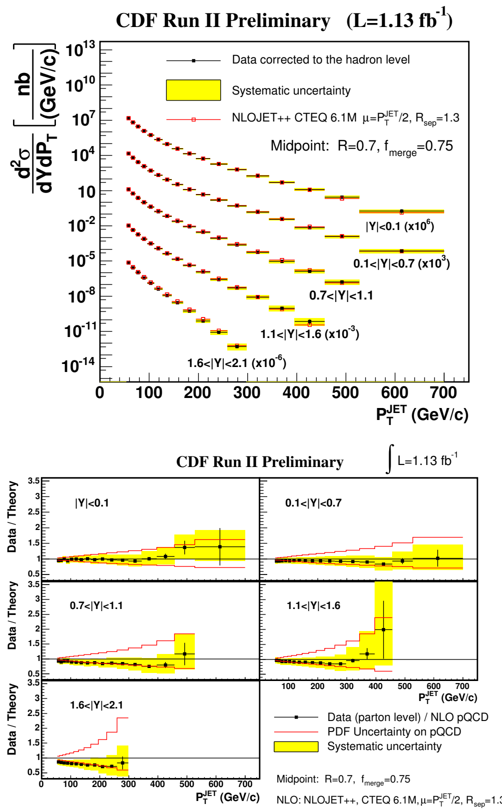

Figure 1: *(top)* Measured inclusive jet differential cross sections compared to NLO pQCD predictions; *(bottom)* Ratios of the measured cross sections over the NLO pQCD predictions.

The measured cross sections are in agreement with next-to-leading order (NLO) perturbative QCD (pQCD) predictions based on CTEQ6.1M PDF. The measurements in the forward region show that the experimental uncertainties are somewhat smaller than the PDF uncertainties, and this measurement is expected to further constrain the PDFs.

The dijet mass differential cross section was also measured in 1.13 fb^{-1} of data [5] using jets reconstructed by the Midpoint algorithm with the cone radius $R_{cone} = 0.7$ in the rapidity region of $|y_{jet1,2}| < 1$. For this measurement, a strategy similar to the one used for the inclusive jet cross section measurements is adopted, *i.e.*, jet energies are corrected on a jet-by-jet basis, then a dijet mass spectrum is formed from the corrected jets, and the spectrum is corrected for event selection efficiencies and dijet mass measurement resolution effects on a bin-by-bin basis. The measured dijet mass spectrum was found to be in good agreement with NLO pQCD predictions within the uncertainties as shown in Fig. 2. Limits on the cross sections for new particles decaying into two jets have been obtained based on this measurement [5].

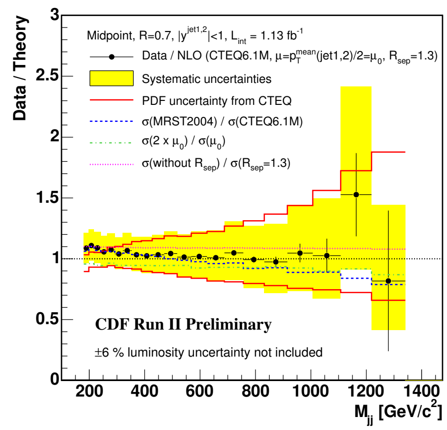

Figure 2: Ratios of the measured dijet mass differential cross sections over the NLO pQCD predictions.

2 Underlying event in jet and Drell-Yan events

Many of the important observables at a hadron collider, including jets, are sensitive to the underlying event (UE), so a good understanding of UE is needed for precision measurements. A series of studies have been made on the UE by CDF in Run I [6, 7] and Run II [8, 9].

These studies have made use of the topological structure of hadron-hadron collisions to study the UE. The geometry is illustrated in Fig. 3, where the transverse, towards and away regions have been defined with respect to the direction of the leading jet. In jet events, measurements on event activities in the transverse region with respect to the jet axis have been made, because this region is most sensitive to the UE. In order to better

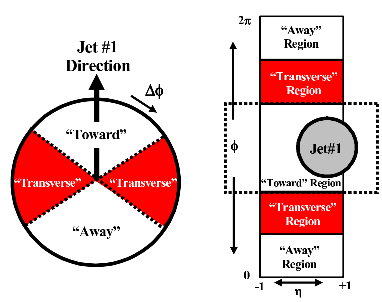

Figure 3: Definitions of the toward, away and transverse regions. The angle $\Delta\phi = \phi - \phi_{jet1}$ is the relative azimuthal angle between charged particles and the direction of the leading jet. The transverse region is defined by $60^\circ < |\Delta\phi| < 120^\circ$ and $|\eta| < 1$.

separate the hard components from the UE, the transMAX and transMIN regions are also used, which refer to the transverse regions containing the highest and lowest scalar p_T sum of charged particles, respectively.

The p_T densities carried by charged particles with $p_T > 0.5$ GeV/c, $dp_T/d\eta d\phi$, in both transMAX and transMIN are shown in Fig. 4 as a function of the leading jet p_T. We expect that the transMAX region will pick up the hardest initial state radiation or final state radiation, and thus the transMIN region will be more sensitive to the underlying event, which is indicated in Fig. 4; $dp_T/d\eta d\phi$ in transMAX increases with increasing leading jet p_T in leading jet events but, on the other hand, $dp_T/d\eta d\phi$ in transMIN stays rather flat with leading jet p_T.

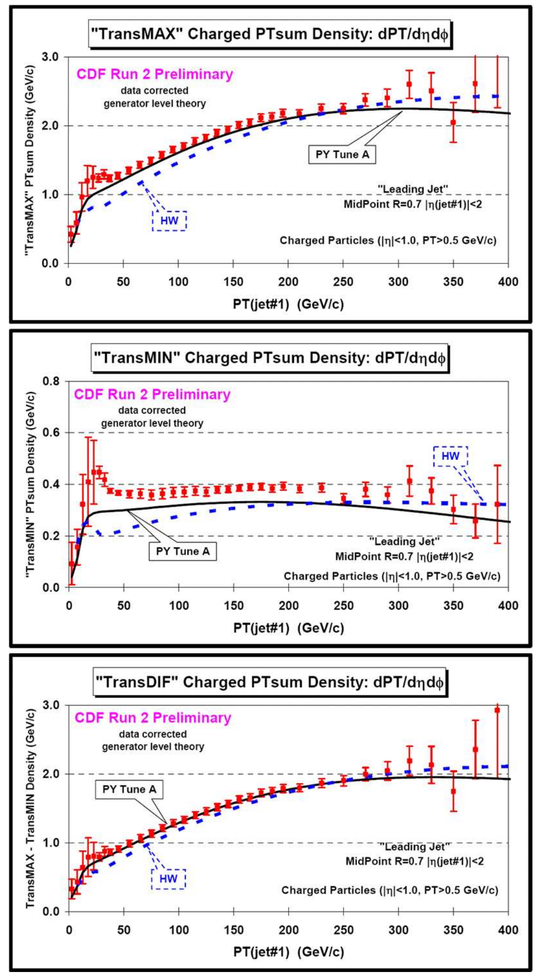

Figure 4: The sum p_T of charged particles for the transMAX region (*top*), transMIN region (*middle*), and transDIF (*i.e.*, TransMAX–TransMIN) (*bottom*) as functions of the leading jet p_T in data, PYTHIA Tune A and HERWIG (without multiple parton interactions).

Fig. 4 also shows $dp_T/d\eta d\phi$ of transDIF which is the difference between the transMAX and transMIN regions. The PYTHIA Tune A [10] predictions are close to but somewhat below the data points in transMAX and transMIN; however, it is in reasonable agreement with data in transDIF. HERWIG does not describe the data as well as PYTHIA Tune A. The densities of charged particles, $dN_{ch}/d\eta d\phi$, and the E_T densities of all particles, $dE_T/d\eta d\phi$ are also measured, and the comparisons between the data, PYTHIA Tune A, and HERWIG show the similar trend in these observables as well. This indicates that the slight excess activity seen in the data over PYTHIA Tune A arises from the soft component of the underlying event (*i.e.*, beam-beam remnants and/or multiple parton interactions) that contributes equally to both transMAX and transMIN.

CDF recently made similar measurements also in Drell-Yan production [9]. In Drell-Yan events, the transverse, toward, and away regions are defined with respect to the direction of the lepton pairs. Drell-Yan events provide a clean environment to study the UE, as we can identify and remove leptons from the toward and transverse regions to study the UE. The data samples are collected by selecting events with two high p_T electron and muon pairs ($p_T > 18$ GeV/c), and only events with the lepton pair invariant mass in the Z boson mass region, *i.e.*, $70 - 110$ GeV/c^2 are used.

The $dp_T/d\eta d\phi$ in the toward and transverse regions in Drell-Yan events is shown as a function of the lepton pair p_T in Fig. 5. The distributions are found to be rather flat with the increasing lepton pair p_T in the toward and transverse regions, but goes up in the away region to balance lepton pairs. These features are reasonably well described by PYTHIA with Tune AW [10], which is similar to Tune A but is also tuned to fit the measured Z p_T distribution.

In Fig. 5, $dp_T/d\eta d\phi$ in the transverse region in Drell-Yan and jet events are compared as a function of lepton pair or leading jet p_T. At low p_T, Drell-Yan events still have large invariant mass lepton-pairs, whereas we only get minimum-bias events in a jet event sample in that region. So, dijet and Drell-Yan events have distinct topologies, nevertheless, the two distributions show a similar trend.

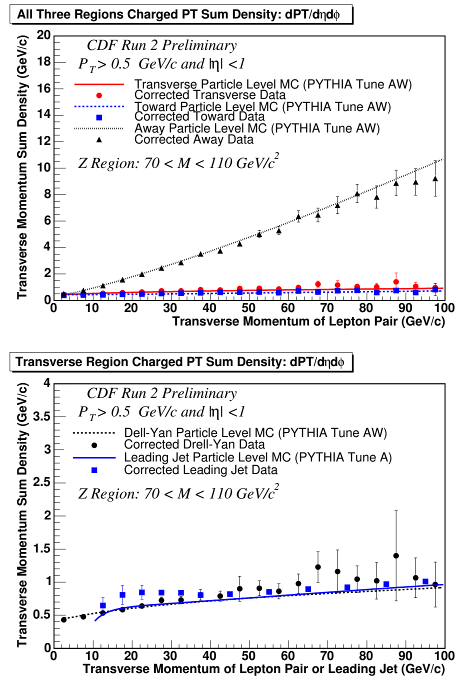

Figure 5: *(left)* $dp_T/d\eta d\phi$; *(right)* ratios of the measured cross sections over the NLO pQCD predictions.

3 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.

CDF has been also making measurements of the observables that are sensitive to the UE for better understanding and improved modeling of UE. Tuned PYTHIA appears to describe data reasonably well. Having good modeling of UE is important for many physics analyses. It will be very important to measure the underlying event at the LHC and tune the MC models at the beginning of the LHC.

References

[1] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. Lett. **96**, 122001 (2006).

[2] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. D **74**, 071103(R) (2006).

[3] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. D **75**, 092006 (2007).

[4] CDF Collaboration, CDF public note 8928.

[5] CDF Collaboration, CDF public note 9246.

[6] A. Affolder *et al.* (CDF Collaboration), Phys. Rev. D **65**, 092002 (2002).

[7] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. D **70**, 072002 (2004).

[8] R. D. Field (CDF Collaboration), FERMILAB-CONF-06-409-E.

[9] CDF Collaboration, CDF public note 9351.

[10] R. D. Field (CDF Collaboration), FERMILAB-PUB-06-408-E.