Soft QCD and the Underlying Event at CDF

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We present recent studies of soft QCD in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The observables studied are the transverse thrust and thrust minor. Data are compared to dedicated theoretical predictions and subsequently to Pythia Monte Carlo with and without multiple parton interactions. We also present study of the event topology in Drell-Yan lepton-pair production in proton-antiproton collisions. The data are corrected to the particle level and then compared with the PYTHIA Tune AW. The goal is to improve our understanding and modeling of the high energy collider events.

1 Event Shapes Studies

Event shapes describe geometric properties of the energy flow in QCD final states by encoding information about the energy flow of an event in a continuous fashion. A single parameter can describe, see Fig. 1, the transition between a configuration with all particles flowing along a single axis, and a configuration where the energy is distributed uniformly over solid angle.

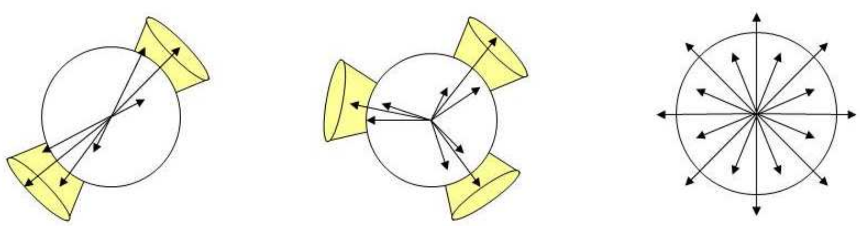

Figure 1: Schematic representation of energy flow in an event.

Event shapes have been studied extensively in e^+e^- and DIS experiments. However at hadron colliders they have received far less attention, primarily due to the difficulties in the theoretical description associated with the environment. From a theoretical point of view, a description over the full range of an event shape observable at a hadron collider requires not only perturbative QCD calculations but also the inclusion a phenomenological model of the underlying event. Only recently, there were developments which allowed to produce full perturbative QCD predictions at next-to-leading-order matched to next-to-leading-log (NLO+NLL) [1]. However, the simple model of beam remnants is yet to be incorporated in the theoretical predictions.

The event shape variables which are studied are following: thrust, $\tau_\perp$, which is defined as

$$1 - \max_{\vec{n_T}} \frac{\sum_{i=0}^{n} \mid \vec{q}_{\perp i} \cdot \vec{n}_T \mid}{\sum_{i=0}^{n} \mid \vec{q}_{\perp i \mid}},$$

where the sum runs over all particles in the final state and the thrust axis, $\vec{n}_T$, is defined as the unit vector in the transverse plane which maximizes the second part of this expression, thus for a perfectly *pencil-like* event, Fig. 1(left), with only 2 outgoing particles $\tau_\perp$=0, and for isotropic event, see Fig.1(right) right, $\tau_\perp = 1 - 2/\pi$. The second variable used, is the transverse thrust minor,

$$T_{min} = \frac{\sum_{\imath=0}^{n} \mid \vec{q}_{\perp\imath} \cdot \vec{n}_m \mid}{\sum_{\imath=0}^{n} \mid \vec{q}_{\perp\imath|}}, \vec{n}_m = \vec{n}_T \times \hat{z},$$

where $\hat{z}$ is the beam direction, which together with $\vec{n}_T$ define the event plane in which the primary hard scattering occurs. This way, thrust minor can be viewed as a measure of the out-of-plane transverse momentum.

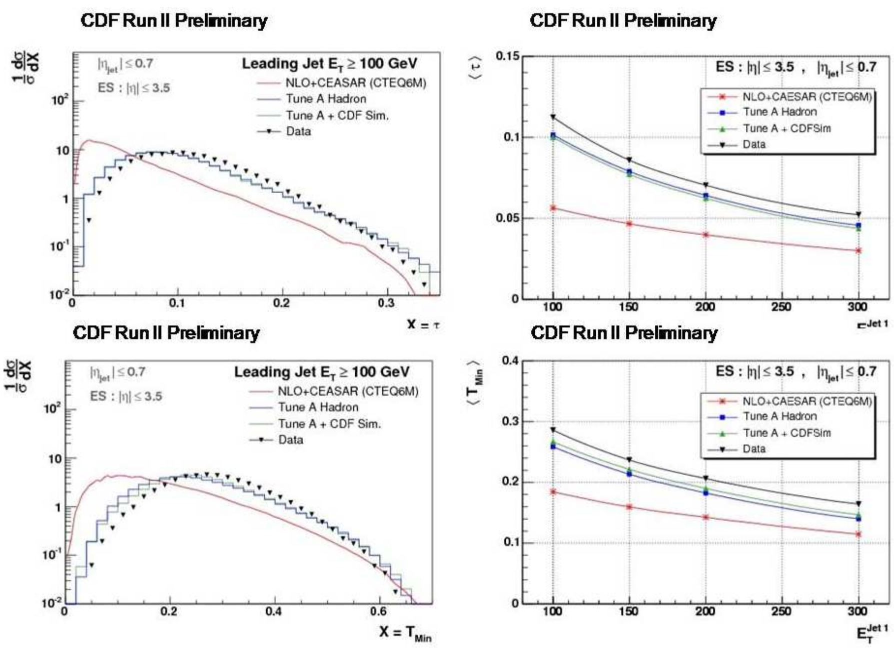

Figure 2: Distributions of $\tau_\perp$ and T_{min} for leading jet energy of 100 GeV (left). Evolution of the mean values of $\tau_\perp$ and T_{min} as a function of the leading jet energy (right).

Currently, the theoretical restriction of any fully NLL resummations is that the observable must be *global*, sensitive to emissions in all direction. This requirement is in direct conflict with the experimental realities, namely the limited detector coverage in the forward region. However, the two observables discussed above, are defined exclusively over the transverse plane, therefore for sufficiently large values of maximum accessible pseudo-rapidity the contribution from the excluded region should not be significant.

As we mentioned above, the experimental data cannot be directly compared to the theoretical predictions, since they do not include description of the underlying event (UE). However, by taking a weighted difference between the mean values of the $\tau_\perp$ and T_{min}, we can construct a quantity which is independent of the UE. The evolution of this quantity as a function of the leading jet energies of 100, 150, 200, and 300 GeV will allow us to have meaningful comparison between data and the theoretical predictions. The data sample is collected using single jet triggers with respective E_T thresholds of 50, 70, and 100 GeV. The following selection criteria were applied: events are required to have only 1 primary reconstructed vertex, and at least 2 jets with $| \eta_{jet}^{1,2} |<0.7$. Figure 2(left, top and bottom) shows a comparison of the $\tau_\perp$ and T_{min} distributions, uncorrected for the detectors effects, for the leading jet energies greater than 100 GeV with the theoretical predictions, labeled *NLO+CAESAR*, and PYTHIA MC predictions. The distributions in data are shifted by roughly a constant amount relative to the distributions in PYTHIA Tune A after detector simulations, however, the overall shape is well reproduced by the MC. Both data and PYTHIA Tune A show significant differences in shape relative to the CAESAR+NLO theoretical predictions, since later do not include the underlying event. The evolution of the mean values of these two observables is presented in Fig. 2(right, top and bottom). These plots demonstrate the relatively small detector effects in the measurement of the transverse thrust and thrust minor as well as comparatively larger, but approximately constant offset between data and simulation. Finally, Fig. 3 shows the

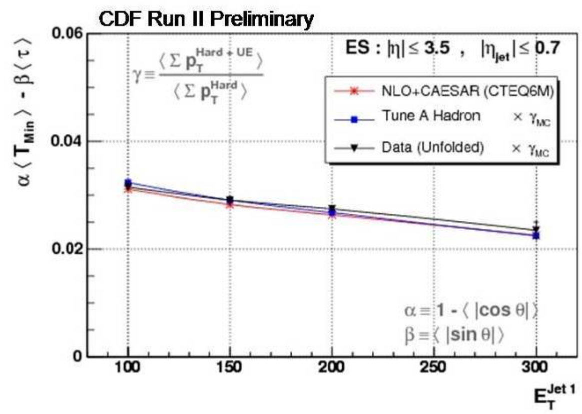

Figure 3: The weighted difference of the mean values of $\tau_\perp$ and T_{min} as a function of the leading jet energy for CAESAR+NLO, PYTHIA Tune A at the hadron level; and experimental data unfolded to the particle level. The smaller error bars correspond to statistical uncertainty only, while the larger bars correspond to statistical and systematic uncertainties added in quadrature.

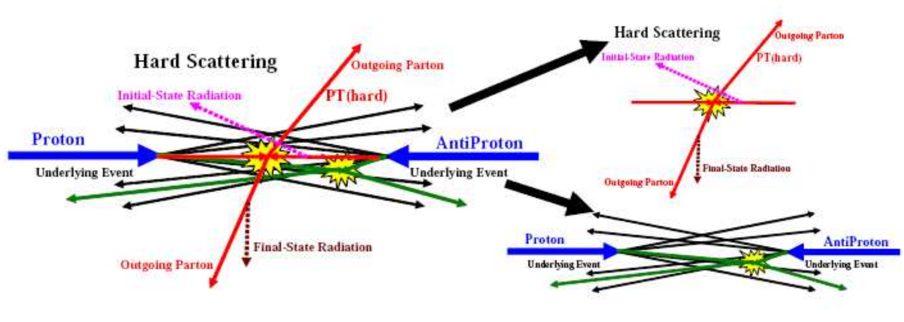

Figure 4: Illustration of the way QCD Monte Carlo models simulate a $p\bar{p}$ collision. The *underlying event* consists of particles that arise from the *beam-beam remnants* and from multiple parton interactions.

weighted difference between the mean values of the transverse thrust and thrust minor as a function of the leading jet E_T. This observable ultimately allows for a direct comparison between data and the dedicated theoretical predictions (CAESAR + NLO) which do not incorporate an underlying event. The detector effects have been accounted for. The figure shows good general agreement between theoretical predictions, Pythia Tune A, and data.

2 The Underlying Event with Drell-Yan

The existence of Monte Carlo models that simulate accurately QCD hard-scattering events is essential for all *new* physics searches at the hadron-hadron colliders. To achieve mentioned accuracy one should be able not only to have a good model of the hard scattering part of the process, but also of the beam-beam remnants (BBR) and the multiple parton interactions (MPI), see Fig. 4, an unavoidable background to most collider observables. For Drell-Yan lepton pair production, the final state includes lepton anti-lepton pair, and there is no colored final state radiation, thus providing a clean way to study the underlying event. The methodology of presented study is similar to previous CDF UE studies, [2] by considering *toward*, *away*, and *transverse* regions as defined in Fig. 5. We study charged particles with p_T >0.5 GeV/c and $\mid \eta \mid$<1 in the above mentioned regions. For high p_T jet production we require that the leading jet in the event, reconstructed with MidPoint algorithm (R=0.7, f_{merge}=0.75) will have $\mid \eta_{jet} \mid$<2. For Drell-Yan production we require the invariant mass of the lepton-pair be in the mass region of the Z-boson, 70< M_{pair} <110 GeV/c^2, with $\mid \eta_{pair} \mid$<6. The underlying event observables are found to be reasonably flat with the increasing lepton pair transverse momentum in the *transverse* and *toward* regions, but distributions go up in the *away* region to balance lepton pairs. In Fig. 6(a) and (b), we plot two observables corresponding to the underlying event: the number of charged particle density and the charged transverse momentum sum density in the transverse region compared with PYTHIA Tunes A *leading jet* and AW*Drell-Yan* [3]-[4], HERWIG [5] without MPI and a previous results of CDF analysis of underlying events with the leading jet. There is very good agreement with PYTHIA tune AW MC predictions, while HERWIG produces much less activity. The comparison with leading jet underlying event results show close agreement, which indicates the universality of underlying event modeling.

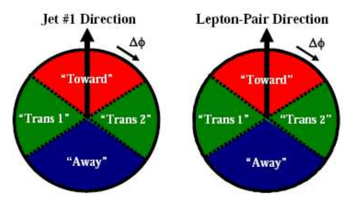

Figure 5: Illustration of correlations in azimuthal angle $\Delta\phi$ relative to (left) the direction of the leading jet in the event, or (right) the direction of the lepton-pair in Drell-Yan production. The angle $\Delta\phi = \phi - \phi_{jet1pair}$.

3 Conclusions

CDF collaboration continues extensive program of underlying event studies. In these proceedings we presented the comparison of UE observables in leading jet and Drell-Yan lepton pair productions. The underlying event is similar for both types of events. These results provide data that can be used to test and improve the QCD Monte-Carlo models of the underlying event that are used to simulate hadron-hadron collisions. We also discussed event shapes studies at CDF and introduced new quantity, weighted difference between the

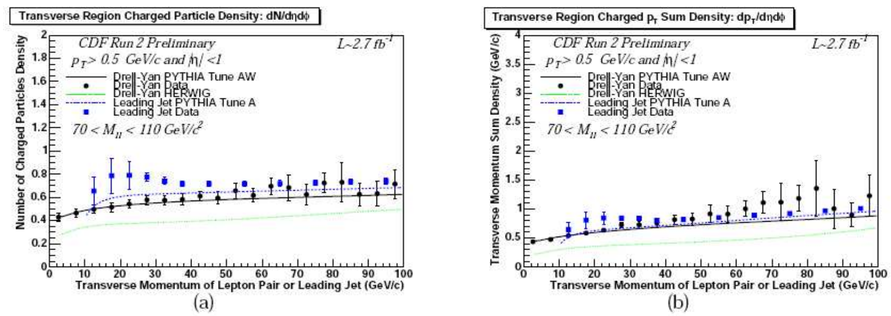

Figure 6: The underlying event observables in Drell-Yan production.

mean values of the transverse thrust and thrust minor, which allows to directly compare theoretical predictions with the experimental data.

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