Multiplicities and the Underlying Event

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Abstract

CDF Run II data for minimum bias collisions and the underlying event associated with Drell-Yan lepton pair production are presented and how these measurements can give us better insights into the relative importance of the different contributing subprocesses to the 'softer' physics are discussed.

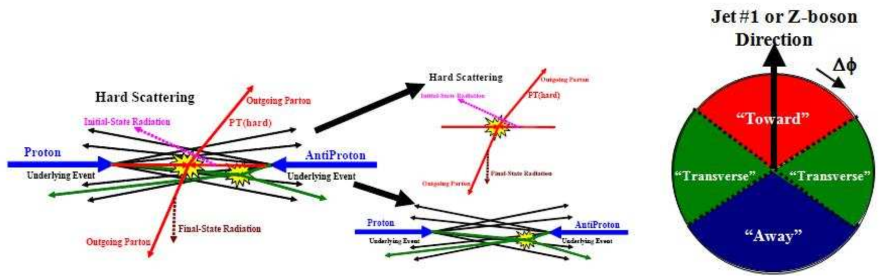
1 Introduction: Minimum Bias Events and the Underlying Event

In order to find 'new' physics at a hadron-hadron collider it is essential to understand and simulate accurately the 'ordinary' QCD hard-scattering events, so that we can discriminate new physics from the complicated background. To do this one must not only have a good model of the hard scattering part of the process, but also of the theoretically poorly understood softer part.

A typical 2-to-2 hard scattering event is a proton-antiproton collision at the hadron colliders as shown in the Figure 1(a), all happening inside the radius of a proton. In addition to the two hard scattered outgoing partons, which fragment into jets - there is initial and final state radiation (caused by bremsstrahlung and gluon emission), multiple parton interaction (additional 2-to-2 scattering within the same event), 'beam beam remnants' (particles that come from the breakup of the proton and antiproton, from the partons not participating in the primary hard scatter). We define the 'underlying event' [1] as everything except the hard scattered components, which includes the 'beam-beam remnants' (or the BBR) plus the multiple parton interaction (or the MPI). However, it is not possible on an event-by-event basis to be certain which particles came from the underlying event and, which particles originated from the hard scattering. The 'underlying event' (*i.e.* BBR plus MPI) is an unavoidable background to most collider observables. For example, at the Tevatron both the inclusive jet cross section and the b-jet cross section, as well as isolation cuts and the measurement of missing energy depend sensitively on the underlying event. A good understanding of it will lead to more precise measurements at the Tevatron and the LHC.

For Drell-Yan lepton pair production, we have the outgoing lepton anti-lepton pair in the final state and there would be no colored final state radiation. Hence it provides a very clean way to study the underlying event.

'Minimum bias event', although different from the underlying event, is another excellent place to look at the 'softer' physics. One selects (*i.e.* 'triggers' on) certain events to store onto tape. Minimum bias (or 'min-bias') is a generic term which refers to events that are selected with a 'loose' trigger. All triggers produce some bias and the term min-bias is meaningless until one specifies the precise trigger used to collect the data. The CDF 'min-bias' trigger consists of requiring at least one charged particle in the forward region $3.2 < \eta < 5.9$ and simultaneously



(a) (b)

Fig. 1: A typical 2-2 hard scattering process and dividing the central region

at least one charged particle in the backward region $-5.9 < \eta < -3.2$. In principle it contains all types of interactions proportionally to their natural production rate.

2 Comparing data with QCD Monte Carlo Models

2.1 Minimum Bias Events

Two of the observables that are experimentally accessible in the minimum bias (or MB) final state are presented here. They are the inclusive charged particle transverse momentum differential cross section $d^3\sigma/p_T dp_T dy d\phi$ and the event transverse energy sum differential cross section $d^3\sigma/dE_T d\eta d\phi$, in the range $p_T > 0.4\ GeV/c$ and $|\eta| < 1$. These two measurements provide some of the basic features of the inelastic inclusive particle production spectra. The measurement of the event transverse energy sum is new to the field and represents a first attempt at describing the full final state including neutral particles. In this regard, it is complementary to the charged particle measurement in describing the global features of the inelastic $p\overline{p}$ cross section.

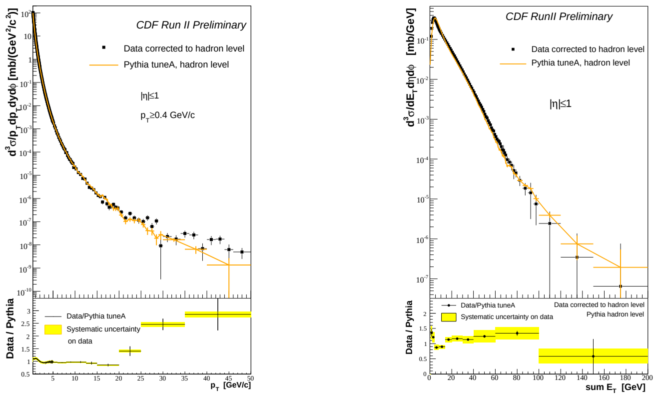
In Fig. 2(a), we show the track p_T differential cross section. PYTHIA tune A [2, 3] was the first model that comes close to describing a wide range of MB experimental distributions. It reproduces the data for inclusive charged particle p_T distribution within 10% up to $p_T > 20$ GeV/c but the data are above the prediction at high p_T. This implies that the tune probably does not have exactly the right fraction of hard 2-to-2 parton-parton scattering and, also, that there is more soft energy in the data than predicted.

In Fig. 2(b), we show the ΣE_T cross-section spectrum. The transverse energy is measured in the central region only as the sum of the E_T of each calorimeter tower in $|\eta| < 1$. This plot shows the fully corrected distribution. The MC generators tuned to reproduce charged particle production fail to reproduce this variable, especially at higher energy ($\Sigma E_T > 50$ GeV). This might be related to the observation that there is an excess of energy in the underlying event in high transverse momentum jet production over the prediction of PYTHIA tune A.

The lower plots show the ratio of data to simulation in each case.

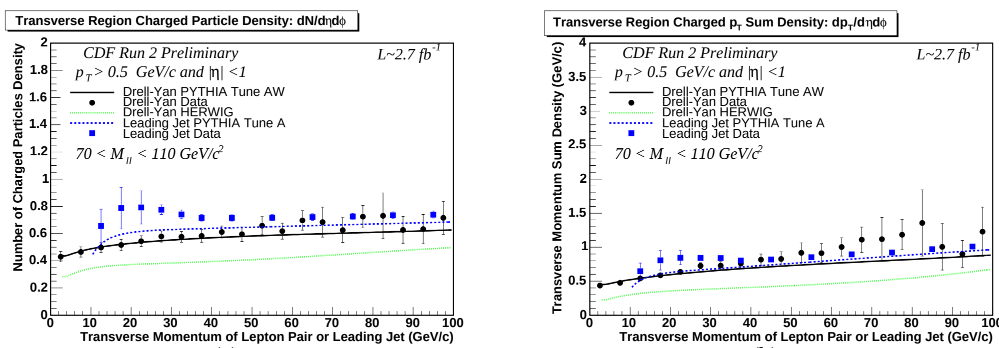
2.2 The Underlying Event with Drell-Yan

Here we study charged particles in the range $p_T > 0.5\ GeV/c$ and $|\eta| < 1$, at the region of Z-boson, defined as $70\ GeV/c^2 < M_{ll} < 110\ GeV/c^2$, in the 'toward', 'away' and 'transverse'



(a) (b)

Fig. 2: Min-bias plots, the track p_T differential cross section at the left and the ΣE_T cross-section on the right



(a) (b)

Fig. 3: Drell-Yan underlying event plots, charged particle multliplicity on the left and the charged p_T sum on the right

regions, as defined in Fig. 1(b). The underlying event observables are found to be reasonably flat with the increasing lepton pair transverse momentum in the transverse and toward regions, but goes up in the away region to balance the lepton pairs. In Fig. 3(a) and Fig. 3(b), we looked at the 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 and AW [3, 4], HERWIG [5] without MPI and a previous CDF analysis on leading jet underlying event results. We mostly observed very good agreements with PYTHIA tune AW Monte Carlo predictions (HERWIG produces much less activity), although the agreement between theory and data is not perfect. We also compared them with leading jet underlying event results and observed reasonably close agreement - which may indicate the universality of underlying event modeling.

3 Correlation Studies

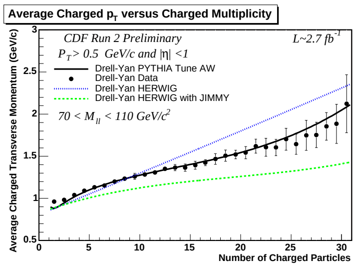
The rate of change of $< p_T >$ versus charged multiplicity is a measure of the amount of hard versus soft processes contributing to collisions and it is sensitive to the modeling of the multiple parton interactions [6]. This variable is one of the most sensitive to the combination of the physical effects present in MB collisions and is also the most poorly reproduced variable by the available Monte Carlo generators. If only the soft beam-beam remnants contributed to min-bias collisions then $< p_T >$ would not depend on charged multiplicity. If one has two processes contributing, one soft (beam-beam remnants) and one hard (hard 2-to-2 parton-parton scattering), then demanding large multiplicity would preferentially select the hard process and lead to a high $< p_T >$. However, we see that with only these two processes $< p_T >$ increases much too rapidly as a function of multiplicity. Multiple-parton interactions provides another mechanism for producing large multiplicities that are harder than the beam-beam remnants, but not as hard as the primary 2-to-2 hard scattering.

Fig. 4(a) shows the data corrected to the particle level on the average p_T of charged particles versus the multiplicity for charged particles with $p_T > 0.5\ GeV/c$ and $|\eta| < 1$ for Z-boson events from this analysis. HERWIG (without MPI) predicts the $< p_T >$ to rise too rapidly as the multiplicity increases. For HERWIG (without MPI) large multiplicities come from events with a high p_T Z-boson and hence a large p_T 'away-side' jet. This can be seen clearly in Fig. 4(b) which shows the average p_T of the Z-boson versus the charged multiplicity. Without MPI the only way of getting large multiplicity is with high p_T(Z) events. For the models with MPI one can get large multiplicity either from high p_T(Z) events or from MPI and hence $< p_T(Z) >$ does not rise as sharply with multiplicity in accord with the data. PYTHIA tune AW describes the Z-boson data fairly well.

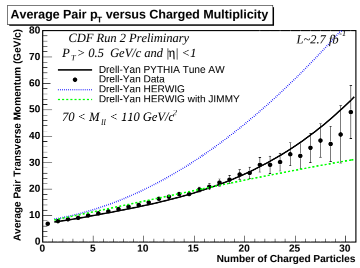
Fig. 4(d) shows the data corrected to the particle level on the average p_T of charged particles versus the multiplicity for charged particles with $p_T > 0.5\ GeV/c$ and $|\eta| < 1$ for Z-boson events in which $p_T(Z) < 10\ GeV/c$ and Fig. 4(c) shows the same distribution for minimum bias events, compared to some PYTHIA Min-Bias production tunings. Regardless of all the improvements in the comprehension of low-p_T production, the models are still unable to reproduce second order quantities such as final state particle correlations. We see that $< p_T >$ still increases as the multiplicity increases although not as fast. If we require $p_T(Z) < 10\ GeV/c$, then HERWIG (without MPI) predicts that the $< p_T >$ decreases slightly as the multiplicity increases. This is because without MPI and without the high p_T 'away-side' jet which is suppressed by requiring low $p_T(Z)$, large multiplicities come from events with a lot of initial-state radiation and the particles coming from initial-state radiation are 'soft'. PYTHIA tune AW describes the behavior of $< p_T >$ versus the multiplicity fairly well even when we select $p_T(Z) < 10\ GeV/c$. This strongly suggests that MPI are playing an important role in both these processes.

4 Summary and Conclusions

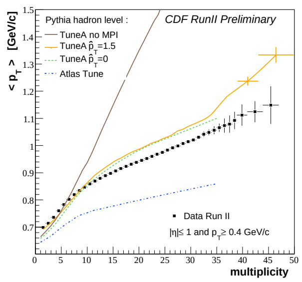
We are making good progress in understanding and modeling the softer physics. CDF tunes A and AW describe the data very well, although we still do not yet have a perfect fit to all the features of the CDF underlying event and min-bias data. Future studies should focus on tuning the



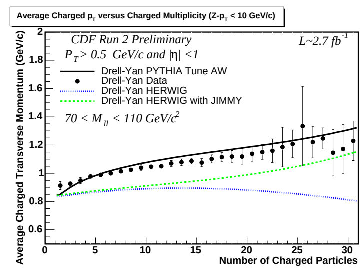
(a)



(b)



(c)



(d)

Fig. 4: Charged multiplicity against charged transverse momentum average correlation plots. While (a), (b) and (d) show Drell-Yan data, (c) comes from minimum-bias studies.

energy dependence for the event activity in both minimum bias and the underlying event, which at the moment seems to be one of the least understood aspects of all the models. The underlying event is expected to be much more active in LHC and it is critical to have sensible underlying event models containing our best physical knowledge and intuition, tuned to all relevant available data.

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