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Measurement of the Underlying Event at LHC with the CMS detector

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Abstract

A study of *Underlying Events* (UE) at *Large Hadron Collider* (LHC) with CMS detector under nominal conditions is discussed. Using charged particle and charged particle jets, it will be possible to discriminate between various QCD models with different multiple parton interaction schemes, which correctly reproduce Tevatron data but give different predictions when extrapolated to the LHC energy. This will permit improving and tuning Monte Carlo models at LHC start-up, and opens prospects for exploring QCD dynamics in proton-proton collisions at 14TeV.

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1 Introduction

From a theoretical point of view, the underlying event (UE) in a hadron-hadron interaction is defined as all particle production accompanying the hard scattering component of the collision. From an experimental point of view, it is impossible to separate these two components. However, the topological structure of hadron-hadron collisions can be used to define physics observables which are sensitive to the UE. The ability to properly identify and calculate the UE activity, and in particular the contribution from Multiple Parton Interactions MPI [1], has direct implications for other measurements at the LHC. This work is devoted to the analysis of the sensitivity of UE observables, as measured by CMS[2], to different QCD models which describe well the Tevatron UE data but largely differ when extrapolated to the LHC energy. MPI are implemented in the PYTHIA simulations [3], for which the following tunes are considered: tune DW (reproducing the CDF Run-1 Z boson transverse momentum distribution [4]), tune DWT (with a different MPI energy dependence parametrization [5]) and tune S0 (which uses the new multiple interaction model implemented in PYTHIA [6]). In addition, an Herwig [7] simulation has also been performed, providing a useful reference to a model without multiple interactions.

2 Analysis strategy

Significant progress in the phenomenological study of the UE in jet events has been achieved by the CDF experiment at the Tevatron [8, 9]. In the present work, plans are discussed to study the topological structure of hadron-hadron collisions and the UE at the LHC, using only charged particle multiplicity and momentum densities in charged particle jets. A charged particle jet (referred to as a charged jet from now on) is defined using charged particles only, with no recourse to calorimeter information. The direction of the leading charged jet, which in most cases results from the hard scattering, is used to isolate different hadronic activity regions in the η-ϕ space and to study correlations in the azimuthal angle ϕ. The plane transverse to the jet direction is where the 2-to-2 hard scattering has the smallest influence and, therefore, where the UE contributions are easier to observe. In order to combine measurements with different leading charged jet energies, events are selected with a Minimum Bias (MB) trigger [10] and with three triggers based on the transverse momentum of the leading calorimetric jet ($P_T^{calo} >$ 20, 60 and 120 GeV/c). Charged jets are reconstructed with an iterative cone algorithm with radius R = 0.5, using charged particles emitted in the central detector region $|\eta| < 2$. Two variables allow evaluating charged jet performances: the distance $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ between the leading charged jet and the leading calorimetric jet, and the ratio of their transverse momenta P_T (transverse momenta are defined with respect to the beam axis). The transverse momentum of the leading charged jet is used to define the hard scale of the event.

Figure 1 presents, for the different trigger streams used , the density $dN/d\eta d\phi$ of the charged particle multiplicity and the density $dp_T^{sum}/d\eta d\phi$ of the total charged particle transverse momentum p_T^{sum} , as a function of the azimuthal distance to the leading charged jet. Enhanced activity is observed around the jet direction, in the ”toward” region ($\simeq$ 0 degrees from the jet direction), together with a corresponding rise in the ”away” region ($\simeq$ 180 degrees), due to the recoiling jet. The ”transverse” region ($\simeq \pm$ 90 degrees) is characterized by a lower activity and almost flat density distributions, as expected.

3 UE observable measurement

3.1 Tracking

Tracks of charged particles with $p_T >$ 0.9 GeV/c are reconstructed in CMS following the procedure described in [11]. The possibility to build the UE observables using tracks with $p_T >$ 0.5 GeV/c enhances sensitivity to the differences between the models. The standard CMS tracking algorithm was, thus, adapted to a 0.5 GeV/c threshold, by decreasing the p_T cut of the seeds and of the trajectory builder, and adapting other parameters of the trajectory reconstruction to optimize performance.

3.2 Results on density measurements

The densities $dN/d\eta d\phi$ of charged particle multiplicity and $dp_T^{sum}/d\eta d\phi$ of charged p_T^{sum} are presented in Figure2 for the toward region and in Figure3 for the transverse region. The data, corresponding to an integrated luminosity of 10 pb^{-1} , are presented at the reconstruction level, using the DWT tune. In the toward region, the expected strong correlation between the transverse momentum of the charged jet and the charged p_T^{sum} density is clearly visible. In the transverse region, two contributions to the hadronic activity can be identified: a fast saturation of the UE densities for charged jets with $P_T <$ 20 GeV/c, and a smooth rise for $P_T >$ 40 GeV/c. The latter is due to initial and final state radiation, which increases with the hard scale of the event. In Figure 4, the ratio between generated and reconstructed UE observables is presented as a function of the charged jet P_T , for simulations performed with the PYTHIA DWT tune and the $p_T > 0.9$ GeV/c tracking reconstruction parameter set. The average corrections for both the P_T scale and the UE observables are found to be independent of the particular model used for the simulations. Figure 5 presents the predictions for the transverse activity, as obtained using the PYTHIA DWT tune and corrected following the results of Figure 4. The statistical precision and the alignment conditions correspond to those achieved with an integrated luminosity of 100 pb^{-1} . The curves represent the predictions of the different PYTHIA (DW, DWT and S0 tunes) and HERWIG simulations. Lowering the pT threshold for track reconstruction to 0.5 GeV/c leads to an increase of about 50% of the charged particle multiplicity and of about 30% of the charged transverse momentum density. As shown in Figure 6, this enhances the discrimination power between the different models in the charged jet P_T region below 40 GeV/c, where the differences between models are expected to be the largest. This is particularly clear when comparing the DWT and S0 tunes.

3.3 Results using observable ratios

The ratios between (uncorrected) UE density observables in the transverse region, for charged particles with $p_T >$ 0.9 GeV/c and with $p_T >$ 1.5 GeV/c, are presented in Figure 7, for an integrated luminosity of 100 pb^{-1} . Ratios are shown here as obtained after track reconstruction, without applying additional reconstruction corrections; given the uniform performance of track reconstruction, the ratios presented here at detector level are similar to those at generator level. These ratios show a significant sensitivity to differences between different MPI models, thus providing a feasible (and original) investigation method.

4 Conclusions

The predictions on the amount of hadronic activity in the region transverse to the jets produced in proton-proton interactions at the LHC energies are based on extrapolations from lower energy data (mostly from the Tevatron). These extrapolations are uncertain and predictions differ significantly among model parameterisations. It is thus important to measure the UE activity at the LHC as soon as possible, and to compare those measurements with Tevatron data. This will lead to a better understanding of the QCD dynamics and to improvements of QCD based Monte Carlo models aimed at describing ordinary events at the LHC, an extremely important ingredient for new physics searches. Variables well suited for studying the UE structure and to discriminate between models are the densities $dN/d\eta d\phi$ of charged particle multiplicity and $dp_T^{sum}/d\eta d\phi$ of total charged particle transverse momentum p_T^{sum} , in charged particle jets. An original approach is proposed, by taking the ratio of these variables for different charged particle p_T thresholds. With 10 pb^{-1} and a partially calibrated detector, it will be possible to control systematic uncertainties on the UE observables, to keep them at the level of the statistical errors and to perform a first discrimination between UE models. Extending the statistics to 100 pb^{-1} and exploiting the uniform performance of track reconstruction for $p_T > 1.5$ GeV/c and $p_T > 0.9$ GeV/c, the ratio of observables will probe more subtle differences between models.

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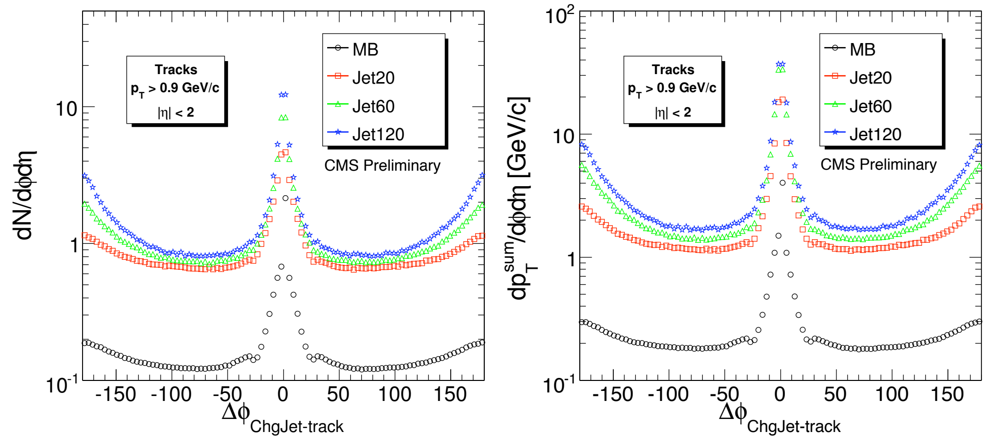

Figure 1: Densities $dN/d\eta d\phi$ of charged particle multiplicity (left) and $dp_T^{sum}/d\eta d\phi$ of total charged transverse momentum (right), as a function of the azimuthal distance to the leading charged jet direction..

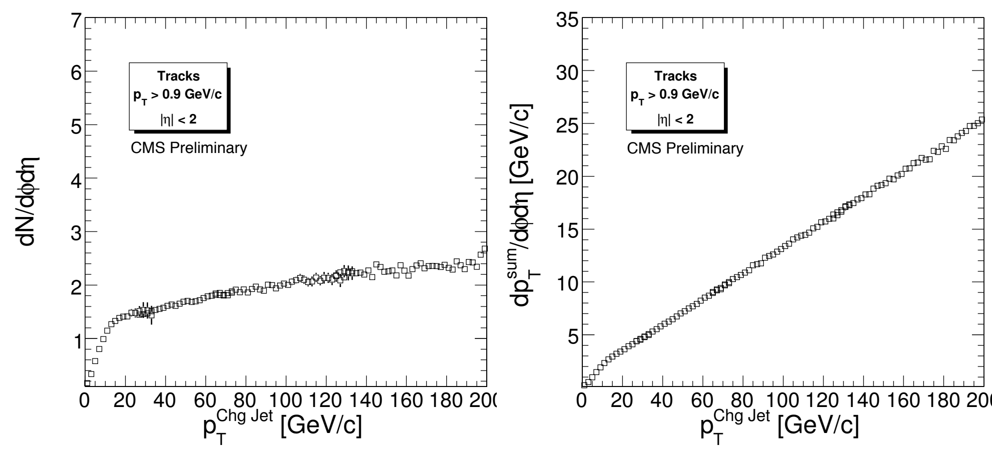

Figure 2: Densities $dN/d\eta d\phi$ of charged particle multiplicity (left) and $dp_T^{sum}/d\eta d\phi$ of total charged transverse momentum (right), as a function of the leading charged jet P_T, in the toward region, for an integrated luminosity of 10 pb^{-1} (uncorrected distributions).

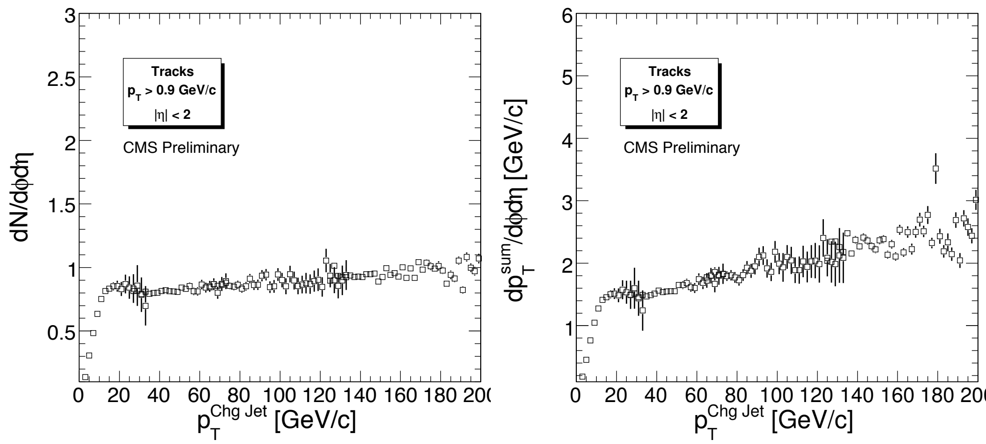

Figure 3: Same as in Figure 2 but in the transverse region.

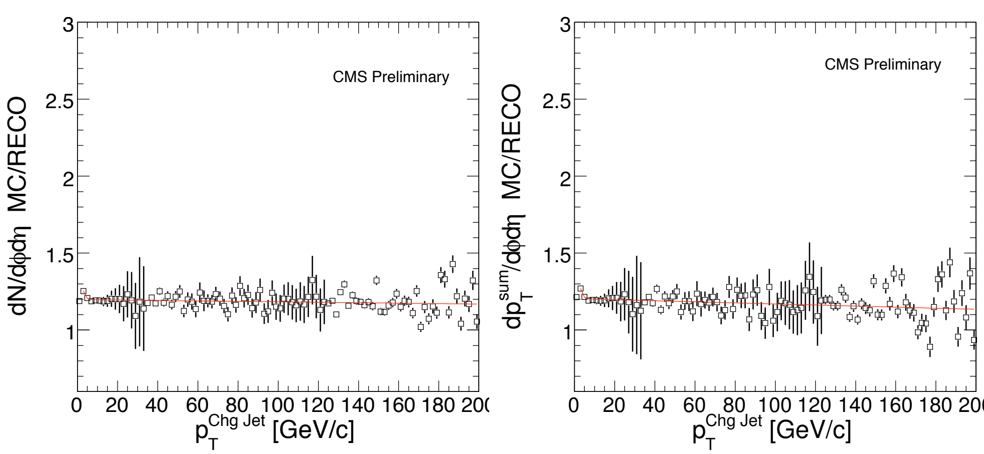

Figure 4: Ratio between generator (MC) and reconstructed (RECO) level predictions from the PYTHIA DWT tune, for the $dN/d\eta d\phi$ (left) and $dp_T^{sum}/d\eta d\phi$ (right) densities, as a function of the leading charged jet P_T, for an integrated luminosity of 10 pb^{-1}.

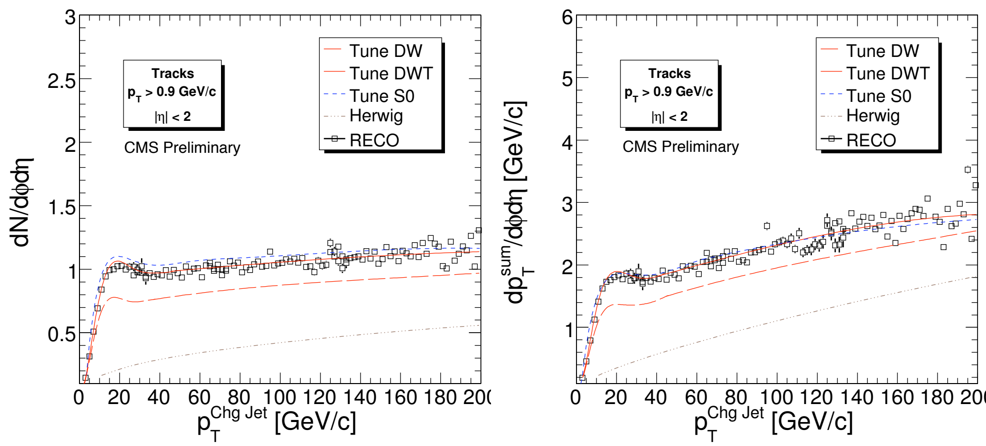

Figure 5: Densities $dN/d\eta d\phi$ (left) and $dp_T^{sum}/d\eta d\phi$ (right) for tracks with $p_T > 0.9$ GeV/c, as a function of the leading charged jet P_T, in the transverse region, for an integrated luminosity of 100 pb^{-1} (corrected distributions).

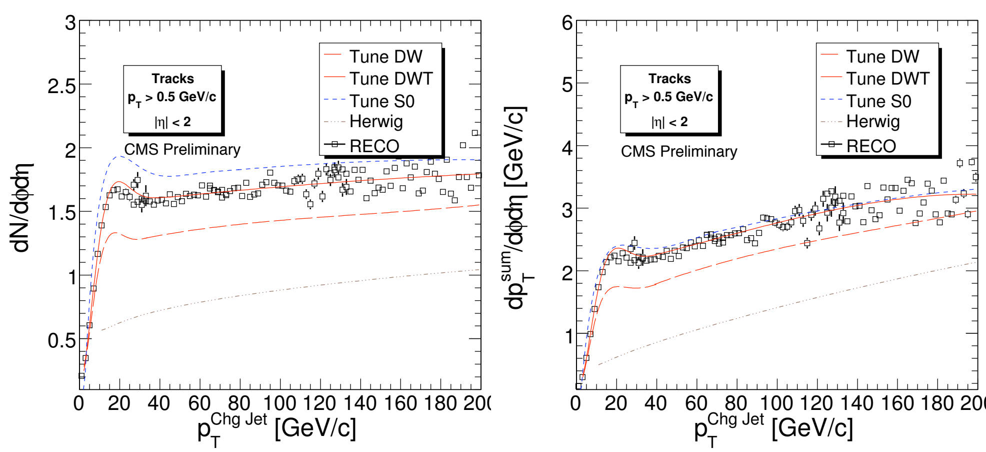

Figure 6: Same as in Figure 5 but using tracks with $p_T > 0.5$ GeV/c.

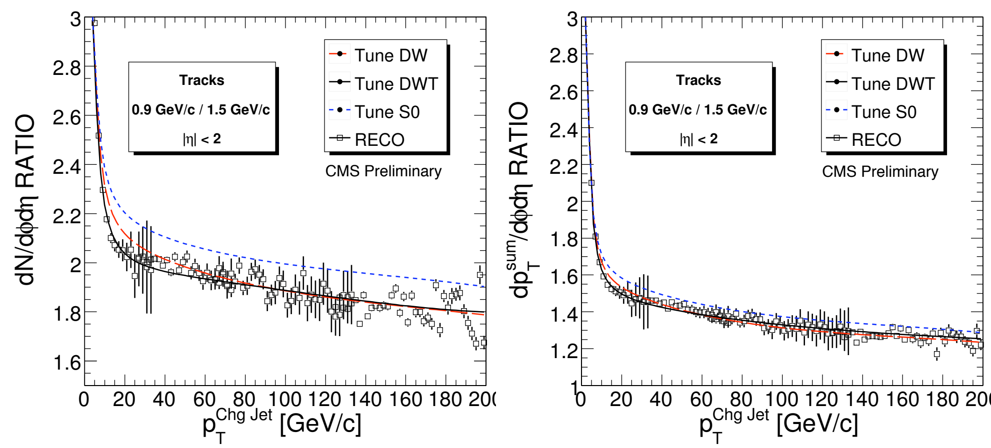

Figure 7: Ratio of the UE event observables, computed with track transverse momenta p_T >1.5 GeV/c and p_T >0.9 GeV/c: densities $dN/d\eta d\phi$ (left) and $dp_T^{sum}/d\eta d\phi$ (right), as a function of the leading charged jet P_T, in the transverse region, for an integrated luminosity of 100 pb^{-1}(uncorrected distributions).