Measurement of the Underlying Event in Jet Topologies using Charged Particle and Momentum Densities

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Abstract

A study of Underlying Events with the CMS detector under nominal and start-up conditions is discussed. Using charged particle densities in charged particle jets, it will be possible to discriminate between 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 14 TeV.

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, 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 [2], for which the following tunes are considered: tune DW (reproducing the CDF Run-1 Z boson transverse momentum distribution [3]), tune DWT (with a different MPI energy dependence parametrization [4]) and tune S0 (which uses the new multiple interaction model implemented in PYTHIA [5]). In addition, an Herwig [6] 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 [7, 8]. 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. Different integrated luminosity scenarios are considered: 1, 10 and 100 pb^{-1}. The foreseen start-up CMS tracker alignment precision is applied in the case of 1 pb^{-1}.

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 $\eta - \phi$ 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 [9] 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 four trigger streams, the density $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ of the charged particle multiplicity and the density $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ 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 Data samples

The data samples used for the present analysis are based on the DWT PYTHIA tune. MB and QCD dijet event samples, generated in bins of the transverse momentum $\hat{p}_T$ of the hard process, were reweighted according to their cross sections, the dijet events being merged into a single stream called hereafter JET. On that sample the calorimetric thresholds are applied in order to obtain the different trigger streams considered in the presented analysis The samples were reweighted according to the integrated luminosities corresponding to the different scenarios studied below, with consistent statistical precision in the relevant figures.

3.2 Tracking

Tracks of charged particles with $P_T > 0.9$ GeV/c are reconstructed in CMS following the procedure described in [10]. 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.

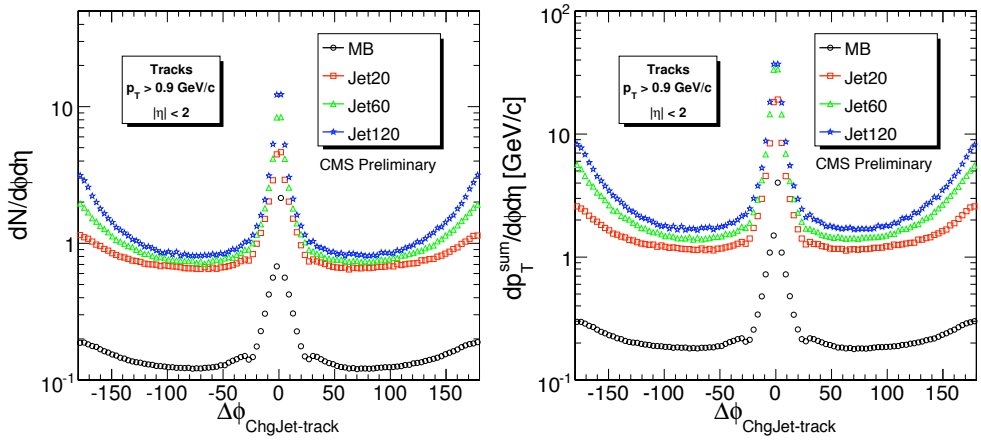

Fig. 1: Densities $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ of charged particle multiplicity (*left*) and $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ of total charged transverse momentum (*right*), as a function of the azimuthal distance to the leading charged jet direction.

3.3 Results on density measurements

The corrected densities $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ of charged particle multiplicity and $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ of charged tranverse momentum are presented in Figure 2 for the transverse region. The data, corresponding to an integrated luminosity of 10 pb^{-1}, are reported at the reconstruction level, using the DWT tune. The average corrections for both the P_T scale and the UE observables are found to be independent from the particular model used for the simulations.

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 former is due to the MPI contribution while the latter is due to initial and final state radiation, which keeps increasing with the hard scale of the event.

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.

With respect to the standard $0.9\,\mathrm{GeV/c}$ scenario, lowering the P_T threshold for track reconstruction to $0.5\,\mathrm{GeV/c}$ turns out to lead to an increase of about 50% of the charged particle multiplicity and of about 30% of the charged transverse momentum density, slightly enhancing the discrimination power between the different models in the charged jet P_T region below 40 GeV/c.

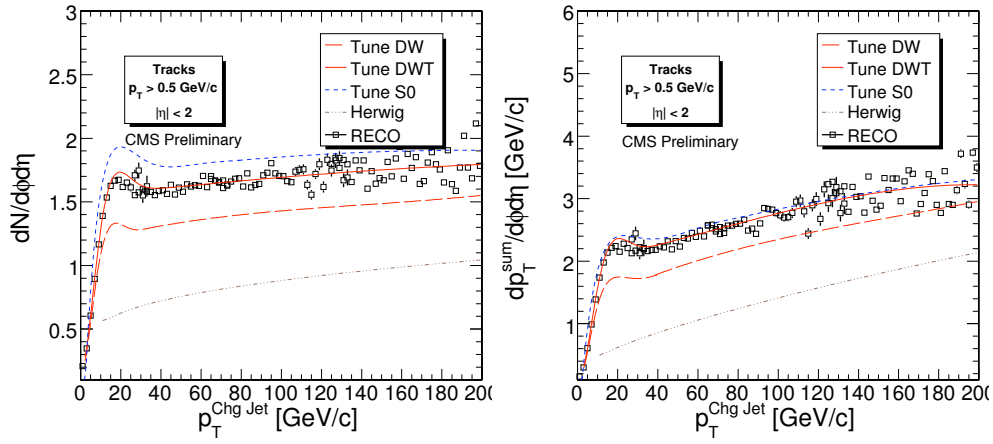

Fig. 2: Densities $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ (*left*) and $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ (*right*) for tracks with $p_t > 0.5$ GeV/c, as a function of the leading charged jet P_T, in the transverse region, for an integrated luminosity of 100 pb^{-1} (corrected distributions).

3.4 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 3, 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 Start-up conditions

The CMS tracking performance at the LHC start-up, with an integrated luminosity of the order of 1 pb^{-1}, will be affected by imperfect knowledge of detector element alignment. This additional error to the reconstructed positions of charged particle hits in the tracker system is taken into account by the *alignment position error* (APE) tool [11] [12] [13].

Figure 4 compares the tracker performance between the case of an ideally aligned detector and the case of a misaligned detector, before and after using the APE tool. The track reconstruction efficiency is seriously degraded by the mis-alignment, but it can be completely recovered using the APE tool, thanks to an increase in the spatial window used to find compatible hits during the trajectory building. The larger search window recovers many good hits which would otherwise be lost, at the expense of significantly increasing the rate of fake tracks. The relative

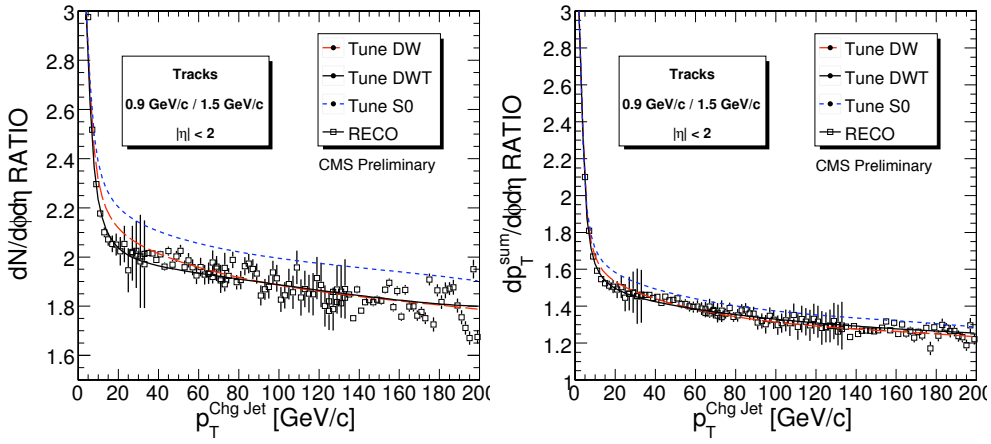

Fig. 3: Ratio of the UE event observables, computed with track transverse momenta $p_T > 1.5$ GeV/c and $p_T > 0.9$ GeV/c: densities $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ (*left*) and $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ (*right*), as a function of the leading charged jet P_T, in the transverse region, for an integrated luminosity of 100 pb^{-1} (uncorrected distributions).

p_T resolution, also shown in Figure 4, is seen to be almost fully recovered after correcting the misalignment.

5 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 $\mathrm{d}N/\mathrm{d}\eta\mathrm{d}\phi$ of charged particle multiplicity and $\mathrm{d}p_T^{sum}/\mathrm{d}\eta\mathrm{d}\phi$ 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.

At LHC start-up, the first pb^{-1} of collected data will be mainly intended to calibrate the analysis tools. Even with such a low integrated luminosity, it will be possible to perform a first measurement of the UE activity in charged jet events. With 10 pb^{-1} and a partially calibrated de-

tector, 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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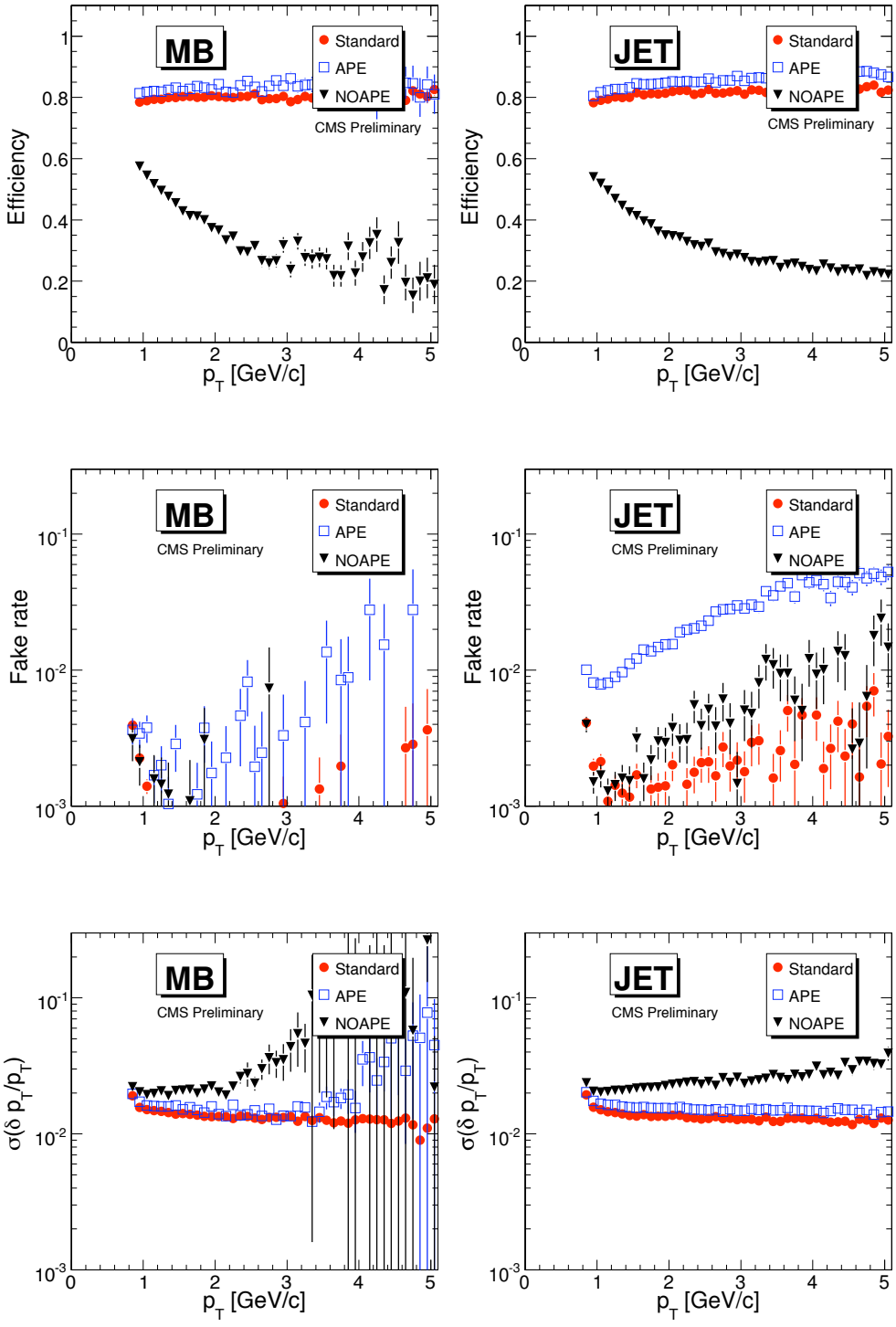

Fig. 4: Tracking performance for an ideal tracker (*circles*), for a misaligned tracker as expected at start-up (*triangles*) and for a misaligned tracker with use of the APE tool (*squares*), for charged particles with $p_T > 0.9$ GeV/c from the MB (*left*) and JET (*right*) samples: track reconstruction efficiency, fake track rate and relative p_T resolution, as a function of the leading charged jet P_T.