MINIMUM BIAS AND UNDERLYING EVENT AT CMS*

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The underlying event (UE), the softer component of the collision accompanying the hard scattering, accounts for a large fraction of the activity in terms of multiplicity and momentum of the observed particles. A brief review of the current status of the phenomenological studies, theoretical models and feasibility study for nominal CMS conditions at low luminosity is given.

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1. Introduction

1.1. The underlying event as observed in charged jet events

One can use the topological structure of hadron–hadron collisions to study the UE. looking only at the outgoing charged particles [1]. Jets are constructed from the charged particles using a simple clustering algorithm and then the direction of the leading charged particle jet is used to isolate regions of η–ϕ space that are sensitive to the UE. The transverse region to the charged particle jet direction, is almost perpendicular to the plane of the hard 2-to-2 scattering and is therefore very sensitive to the UE.

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Fig. 1 show the QCD Monte-Carlo models predictions for the average density of charged particles, $dN/d\eta d\phi$, and the average momentum density ($PT_{\rm sum}$), $dPT/d\eta d\phi$, respectively, in the transverse region *versus* the transverse momentum of the leading charged particle jet[1]. The charged jet $P_{\rm T}$

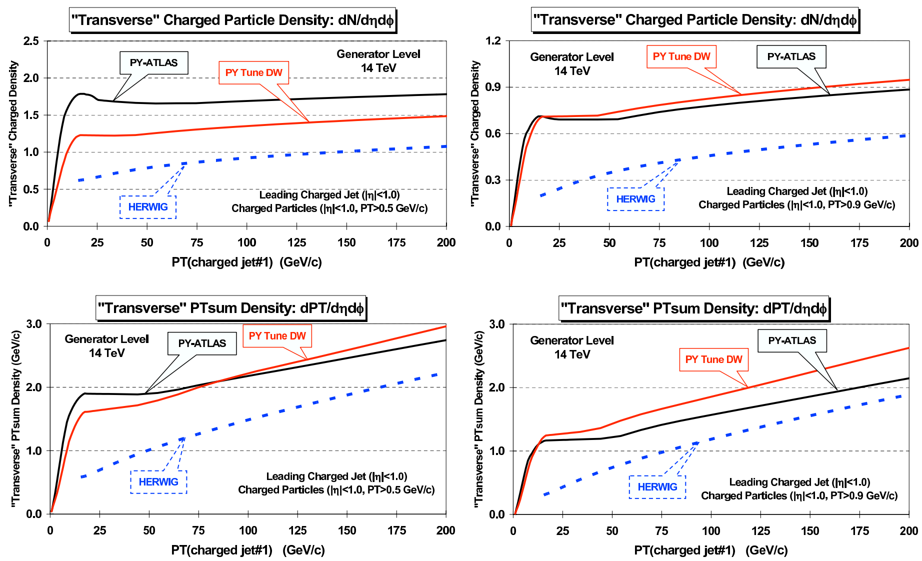

Fig. 1. Observables in the transverse region. Average density of charged particles (left), $dN/d\eta d\phi$, and average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$ (right) with $|\eta|<1$ and $p_{\rm T}>0.5\,{\rm GeV}/c$ (top) or $p_{\rm T}>0.9\,{\rm GeV}/c$ (bottom) *versus* the transverse momentum of the leading charged particle jet.

range 0 to 200 GeV/c shown in Fig. 1 is quite interesting. The two versions of PYTHIA (with Multiple Parton Interactions model) behave much differently than HERWIG (without MPI). Due to the MPI the PYTHIA tunes rise rapidly and then reach an approximately flat plateau region at $P_{\rm T}\sim 50$ GeV/c they begin to rise again due to initial and final state radiation which increases as the Q2 scale of the hard scattering increases.

1.2. The underlying event as observed in Drell–Yan muon-pair

Drell–Yan muon pair production provides an excellent way to study the UE. Here one studies the outgoing charged particles (excluding the $\mu^+\mu^-$ pair) as a function of the muon-pair invariant mass. After removing the

[1] The QCD models are HERWIG [2] and two versions of PYTHIA 6.2 [3]. One of the PYTHIA versions is the ATLAS tune [4] and the other (Tune DW) is similar to Tune A [5] but also fits the CDF Run 1 Z-boson transverse momentum distribution [6].

muon-pair everything else is the UE (*i.e.* initial-state radiation, beam–beam remnants, and MPI). As for the charged jet production, Fig. 2 shows predictions for the average density of charged particles, $dN/d\eta d\phi$, and the average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$, in the whole η–ϕ region.

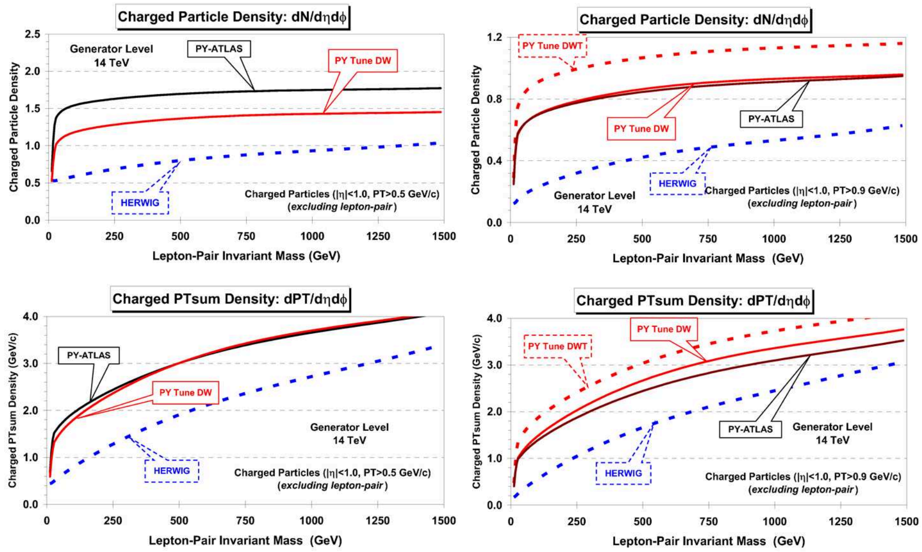

Fig. 2. Average charged particle density (top), $dN/d\eta d\phi$, and average charged $PT_{\rm sum}$ density (bottom), $dPT/d\eta d\phi$, with $p_{\rm T} > 0.5\,{\rm GeV}/c$ (left), $p_{\rm T} > 0.9\,{\rm GeV}/c$ (right) in $|\eta| < 1$ *versus* the muon-pair invariant mass for Tune DW, ATLAS, and HERWIG.

2. Feasibility studies

This studies are focused on the UE measurement that will be performed in nominal CMS conditions at low luminosity. All the studies presented in this section are obtained applying the official full simulation and reconstruction chain of the CMS experiment.

2.1. Measurement of the underlying event in jet events

The tracker-based measurement allows to keep an acceptable resolution for jet energies below 20 GeV, where the calorimetric measurement is dominated by large systematic uncertainties. In this study, a MB trigger is defined requiring at least a calorimetric jet of $P_{\rm T} > 20\,{\rm GeV}/c$. In order to combine the measurements performed at different leading charged jet scales two additional triggers are adopted: $P_{\rm T} > 60$ GeV/c and $P_{\rm T} > 120$ GeV/c (JET60 and JET120). These calorimetric jets are reconstructed with an iterative cone algorithm of radius 0.5 in the pseudorapidity-azimuth space. Fig. 3 reports $dN/d\eta d\phi$, and the average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$, with $p_{\rm T} > 0.9\,{\rm GeV}/c$ and $|\eta| < 1$ *versus* the azimuthal distance between charged tracks[2] and the leading charged jet for the data from the three different triggers introduced above. The enhanced activity due to the presence of the leading charged jet in the toward region (at 0 degrees) can be identified, along with the rise in the away region (± 180 degrees) which is due to the recoiling jet. The transverse region (centered at ± 90 degrees) is characterized by the lowest activity and flat distributions, as expected.

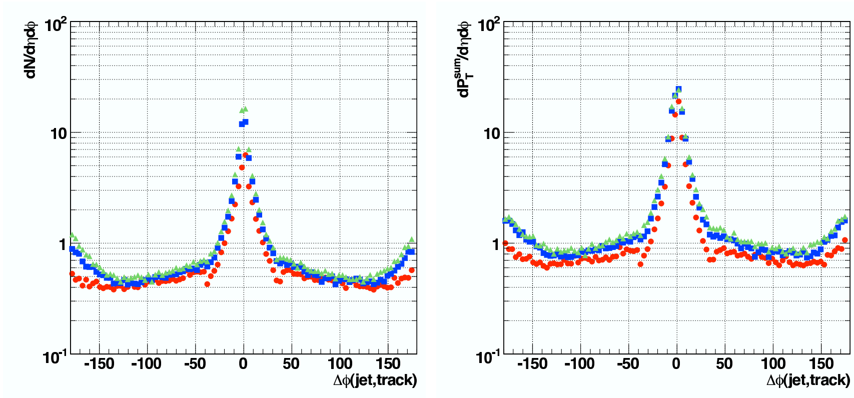

Fig. 3. Charged jet production at 14 TeV. Density of charged particles, $dN/d\eta d\phi$ (left) and average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$ (right), with $p_{\rm T} > 0.9\,{\rm GeV}/c$ and $|\eta| < 1$ *versus* the azimuthal distance between charged tracks and leading charged jet. Data from different triggers collected for an arbitrary integrated luminosity are superimposed: (circles) = Minimum Bias; (squares) = JET60; (triangles) = JET120. All the distributions are at reconstruction level and uncorrected.

The density of charged particles, $dN/d\eta d\phi$, and the average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$, in the transverse regions are reported in Figs. 4[3]. The shapes of uncorrected reconstruction level distributions basically agree with the corresponding generator level ones. The difference in absolute scale (about -20% for both $dN/d\eta d\phi$ and $dPT/d\eta d\phi$) turns out to be compatible with charged jet energy calibration, charged track inefficiencies and charged track fake rates [7].

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[2] Tracks arising from the piled-up interactions are suppressed requiring the extrapolated coordinate along the beam axis to be inside 1 mm with respect to the primary vertex associated to the leading charged jet.

[3] $2\,{\rm GeV}/c$ bins are used up to P_T(chgjet1) $= 20\,{\rm GeV}/c$, $10\,{\rm GeV}/c$ bins above such threshold.

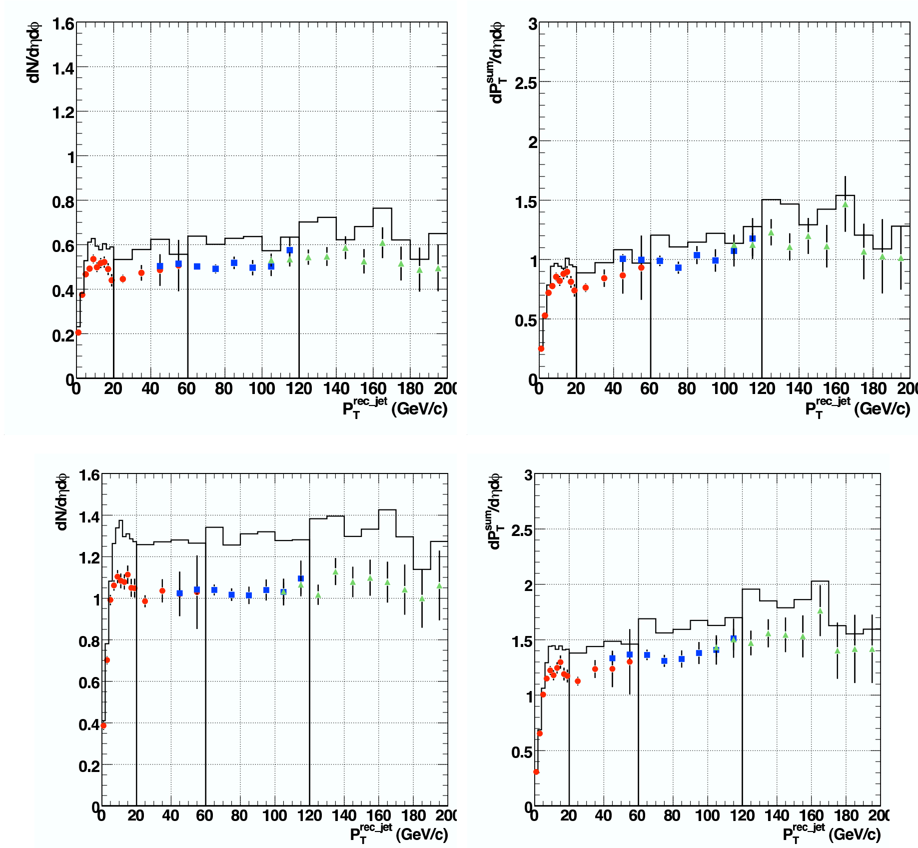

Fig. 4. Charged jet production at 14 TeV. Density of charged particles, $dN/d\eta d\phi$ (left) and average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$ (right), with $p_{\rm T} > 0.9\,{\rm GeV}/c$ (top), $p_{\rm T} > 0.5\,{\rm GeV}/c$ (bottom) and $|\eta| < 1$ in the transverse region *versus* the transverse momentum of the leading charged particle jet.

2.2. The underlying event in muon-pair events

The scale of the Drell–Yan process can be quantified using the invariant mass or the $p_{\rm T}$ of the two muons, whose measurement relies on both muon and tracker detectors. Single muon and muon-pair CMS triggers assure high efficiencies for the studied process[4].

In our study, "isolated muons" are required not to have charged tracks with $p_{\rm T} > 0.9\,{\rm GeV}/c$ in a cone of radius 0.3 in the η–ϕ space around the muon. Selecting isolated muons reduce the QCD background to negligi-

[4] Tracks arising from the piled-up interactions are suppressed by requiring the extrapolated coordinate along the beam axis to be inside $1mm$ with respect to the primary vertex associated to the leading muons.

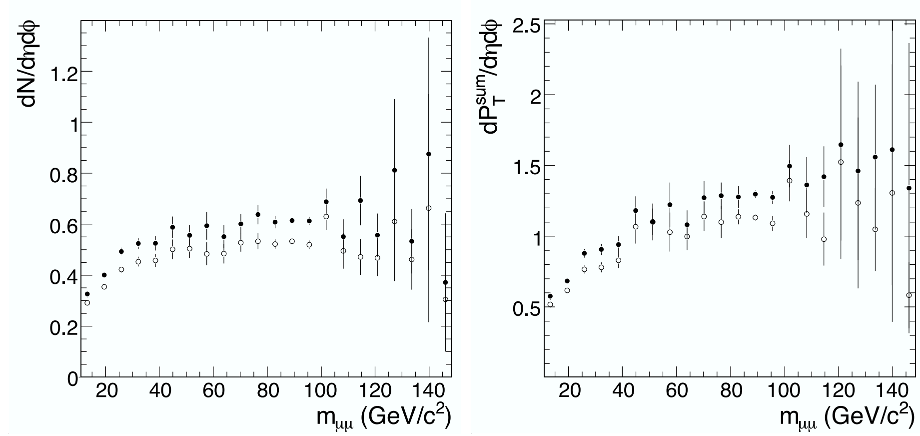

Fig. 5. Muon-pair production at 14 TeV with two isolated muons. Density of charged particles, $dN/d\eta d\phi$ (left) and average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$ (right), with $p_{\rm T} > 0.9\,{\rm GeV}/c$ and $|\eta| < 1$ *versus* the muon-pair invariant mass. Empty circles correspond to the raw (uncorrected) reconstruction level profiles; full circles correspond to the generator level profiles for the events passing the reconstruction level selection. Tracks arising from the piled-up interactions are suppressed requiring the extrapolated coordinate along the beam axis to be inside 1 mm with respect to the primary vertex associated to the leading muons.

ble levels for $p_{\rm T}$ >15 GeV/c, while keeping an efficiency of 76.9%. The charged particle density, $dN/d\eta d\phi$, and the average charged $PT_{\rm sum}$ density, $dPT/d\eta d\phi$ in muon-pair production with isolated muons *versus* the muon-pair invariant mass are reported in Fig. 5. The sensitive decrease of both these observables depends on the correlations between isolation and underlying event activity [8].

3. Conclusions

Predictions on the amount of activity in UE at the LHC based on extrapolations from lower energy data differ greatly. Reference UE measurements at CMS under nominal conditions are feasible, allowing predictions of different models to be tested. The UE is studied by examining charged particles in the transverse region in charged particle jet production and in the central region of Drell–Yan muon-pair production (after removing the muon-pair).

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