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Recent measurement of underlying events

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Abstract

Recent measurements on the underlying events (UE) in the event topology of leading jet and leading track are presented. UE activities are quantified in term of particle and energy density. The UE observables are calculated in the transverse region with respect to the direction highest pT jet/track. These UE observables are measured as a as function of the pT of the leading track and jet.

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Recent measurement of underlying events

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A measurement of the underlying event (UE) activity is performed in proton-proton collisions at the centre-of-mass energy of 13 TeV . The measurement is performed using leading charged-particles as well as leading charged-particle jets as reference objects. A leading charged-particle or charged-particle jet is required to be produced in the central pseudorapidity region ($|\eta| < 2$) and with transverse momentum $p_t \geq 0.5$ ($p_t^{jet} \geq 1$) GeV for leading charged-particle (charged-particle jet) [1].

The data used in this analysis are selected from an unbiased sample of events whenever there is a beam crossing in the CMS detector. This corresponds to an integrated luminosity of 281 nb^{-1}. Events with exactly 1 primary vertex within 10 cm of the beamspot in the z-direction, 2 cm in the xy-plane ($\rho \leq 2$ cm), and at least 5 degrees of freedom ($dof > 4$) are chosen. Fake tracks from mis-reconstruction and secondary decays are removed by requiring the tracks to pass a selection based on a minimum fraction of consecutive hits and by requiring the impact parameter significance d_0/σ_{d_0} and the significance in the z-direction d_z/σ_{d_z} to each be less than 3. Only tracks with a relative uncertainty of $\sigma_{p_t}/p_t < 0.05$ are selected.

Jets are constructed by clustering reconstructed tracks/particles within the interval of $|\eta| < 2.5$ and with $p_t > 0.5$ GeV using the Seedless Infrared-Safe Cone (SISCone) jet algorithm [2] with a distance parameter of 0.5.

The UE activity is quantified in terms of the average multiplicity and scalar transverse momentum sum (Σp_t) densities of charged-particles (with $|\eta| < 2$ and $p_t \geq 0.5$ GeV) in the region orthogonal to the azimuthal direction of the leading charged-particle or jet, referred to as the transverse region. The densities of particles within an azimuthal opening angle of $60^\circ < |\Delta\phi| < 120^\circ$ with respect to the leading jet are defined as the transAVE densities.

The transverse region can be split into 2 halves depending on the sign of $\Delta\phi$. The transMAX (transMIN) densities are then defined as the densities in the transverse half with a higher (lower) activity. The transDIF density is then defined as the difference of transMAX and transMIN densities. The average Σp_t and particle densities are measured as function of the p_t of the leading particles and jets.

The measurement of the UE activity in terms of the transMAX, transMIN, and transDIF densities improves the differential power in the quantification of the activity coming from MPI. The transMIN activity is expected to largely contain radiation coming from MPI and the transDIF activity is more sensitive to initial- and final-state radiation. This differential power allows for improvements in the tuning of the model parameters describing the MPI.

Data correction is performed using a Bayesian unfolding method [3] which properly accounts for bin migration effects. The systematic uncertainty due to the model dependency (up to 8% in the lowest few bins in p_t^{jet}) of the correction method contributes the most to the total systematic uncertainty. The rest of the uncertainties come from PU (4%), fake mis-modelling (2%), impact parameter significance (0.8%), and vertex degree of freedom (1.5%). In general, the systematic uncertainties vary between the densities in the different regions (transAVE/transDIF/transMAX/transMIN), and as a function of p_t and p_t^{jet}.

The corrected distributions of the average particle and Σp_t densities as a function of the p_t of the leading jet/particle are compared with predictions by the Monte Carlo generator tunes PYTHIA8 (version 8.153) [4] CUETP8M1 and Monash [5], HERWIG++ (version 2.7.0) [6] CUETHS1, and EPOS (version 1.99) [7]. Generated events are passed through detector simulation using GEANT [8]. These various event generators differ in the treatment of initial- and final-state radiation, hadronisation, colour reconnections, and the regularisation of the infrared cross-section divergence (including that for MPI). PYTHIA uses the Lund string hadronisation model [9], EPOS uses a similar string fragmentation hadronisation model [10], while HERWIG uses a cluster hadronisation model [11]. Models for MPI are implemented assuming a Poissonian distribution of elementary partonic interactions, with an average number depending on the impact parameter of the hadronic collision [12, 13].

The transMAX and transMIN particle densities are shown in figure 1 as a function of p_t and p_t^{jet}. The transAVE and transDIF distributions are not shown as they can be obtained from the transMAX and transMIN densities. The agreement between the measurements and the simulations is quantified by the ratio plots shown in the bottom panels. The measurements are better described by the Monash tune of PYTHIA8. The PYTHIA8 CUETP8M1 describe the measurements within 10–20%. The predictions by the CUETHS1 tune of HERWIG fails in the low p_t region. EPOS describes the low p_t rising region well but fails to describe the plateau region by 20%. The amount of agreement between the simulations and the measured transAVE and transDIF densities, is similar to that of the average particle densities as described above. Distributions for the average Σp_t densities (not shown) also reveal similar behaviour.

In all plots, the densities increase sharply up to 5 (12–15) GeV and then rise slowly with increasing p_t (p_t^{jet}). The transMIN densities are flatter compared to the transMAX and transDIF (not shown) densities, whereas the transMAX and transDIF densities show a similar trend in the plateau region. Simulations describe the qualitative behavior of the measurements, i.e. the sharp rise and the flattening of the UE activity, and a larger rise in transMAX and transDIF in the plateau region. The level of agreement between simulations and the measurements falls within 10–20% in the plateau region but differs in the low p_t region. The sharp rise with p_t is interpreted in the MC models as due to an increase in the MPI contribution which reaches a plateau at high

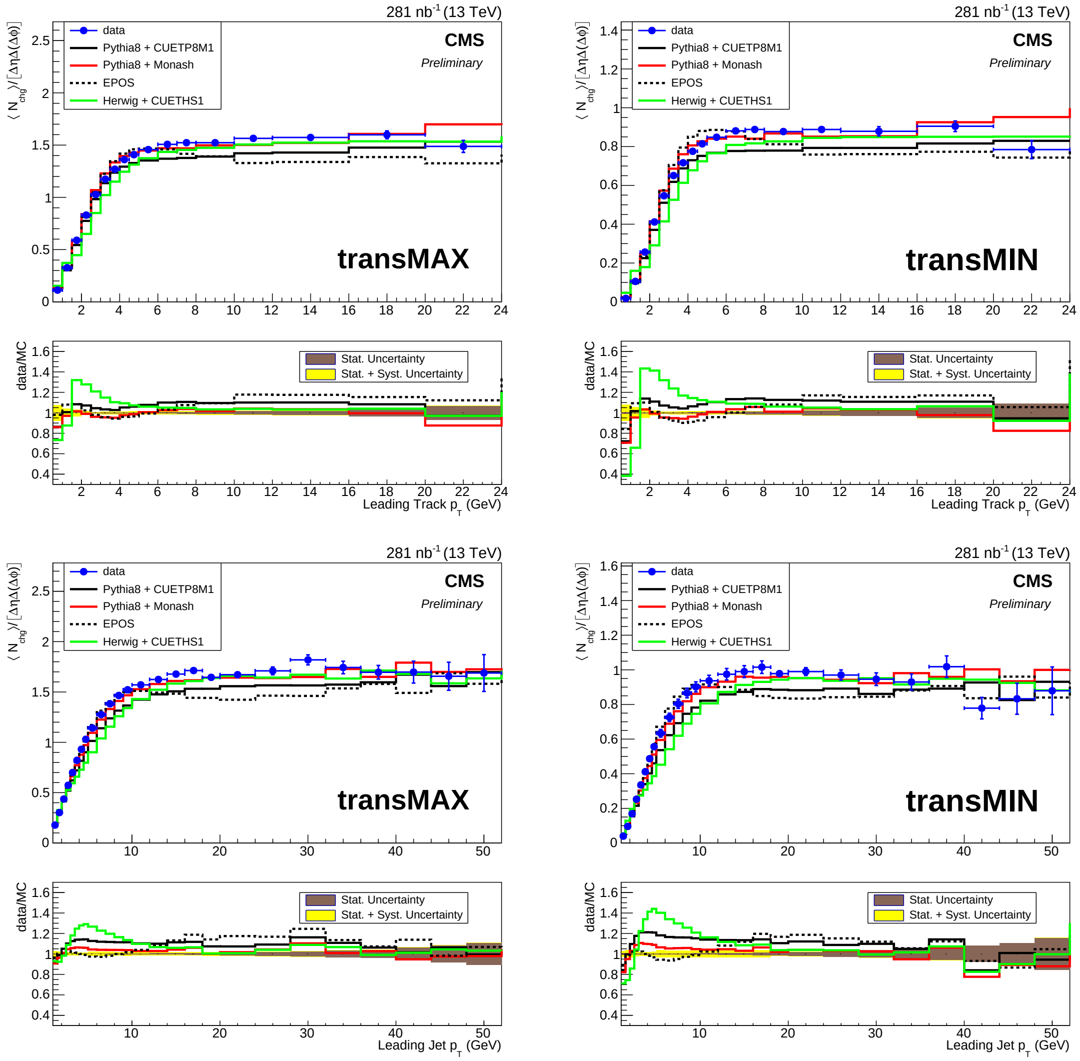

Figure 1: Comparisons of corrected (left column) transMAX and (right column) transMIN average particle densities with the various simulations as a function of (top row) p_t and (bottom row) p_t^{jet}. The error bar represents the statistical and systematic uncertainties added in quadrature. Bottom panels show the ratio of the simulation with the measurements. The brown band in the bottom plot represents the statistical uncertainty in the corrected data whereas the total uncertainty is shown in the yellow band.

p_t. A slow increase in large p_t region is mainly due to the increase in the initial- and final- state radiation contribution. As MPI activity is expected to be uniform in the whole phase-space, the transMIN densities capture mainly the activity coming from MPI whereas transDIF densities give the evolution of the radiation with p_t of the reference object.

Comparisons between various MC simulated samples and data across centre-of-mass energies of 0.9, 2.76, 7, and 13 TeV are made for transAVE as a function of p_t^{jet} as shown in figure 2. There is a strong rise in the UE activity as a function of the centre-of-mass energy as predicted by the MC tunes. This is attributed to an increase in the of number partons with smaller fractional momenta $x \sim 2p_t/\sqrt{s}$. The transMIN (not shown) densities exhibit a stronger $\sqrt{s}$ dependence than the transDIF (not shown) density, indicating that the activity coming from MPI grows more with $\sqrt{s}$ than that from ISR and FSR.

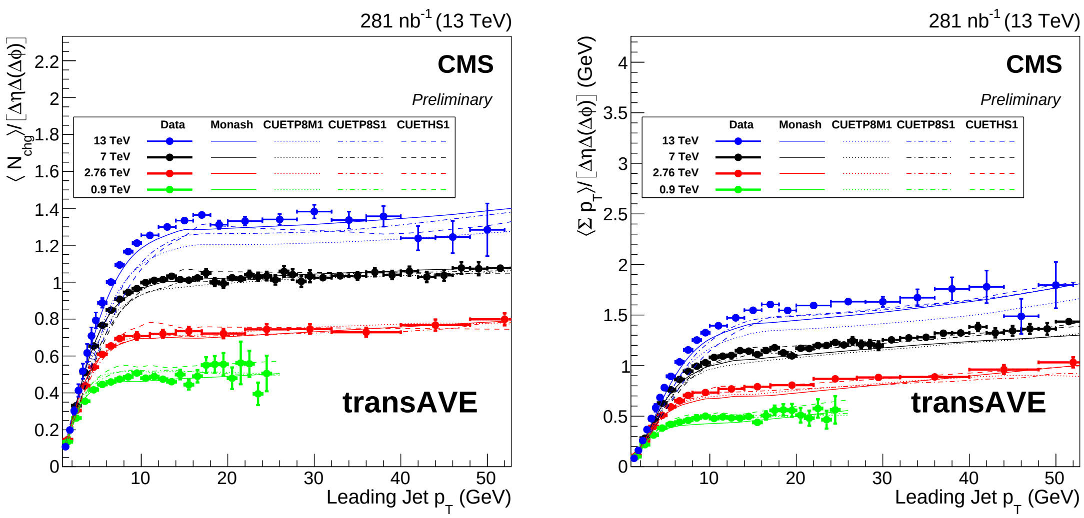

Figure 2: Comparisons of corrected transAVE (left) particle and (right) Σp_t densities with various simulations at $\sqrt{s} = 0.9$, 2.76, 7, and 13 TeV as a function of p_t^{jet}.

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