CMS Underlying Event and Double Parton Scattering Monte Carlo Tunes

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Abstract

Three new PYTHIA 8 underlying event (UE) tunes are presented, one using the CTEQ6L1 parton distribution function (PDF), one using HERAPDF1.5LO, and one using the NNPDF2.3LO PDF; two new PYTHIA 6 UE tunes, one for the CTEQ6L1 PDF and one for the HERAPDF1.5LO, and one new HERWIG++ UE tune for the CTEQ6L1 PDF are also available. Simultaneous fits to CDF UE data at center-of-mass energies of 0.3, 0.9, and 1.96 TeV, together with CMS UE data at 7 TeV, check the UE models and constrain their parameters, providing thereby more precise predictions for proton-proton collisions at 13 TeV. In addition, several new double parton scattering (DPS) tunes are examined in order to investigate if the values of the parameters from fits to UE observables are consistent with the values determined from fitting DPS-sensitive observables. It is also examined how well the new UE tunes predict minimum bias (MB) events, jet, and Drell-Yan observables, as well as MB and UE observables at 13 TeV.

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1 Introduction

It is essential to have reliable predictions for the completely new and unexplored energy scenario of which LHC recently reaches up to 13 TeV center-of-mass energy. The underlying event, consisting of beam-beam remnants as well as the particles coming from the multiple partonic interactions (MPI), in a hadron-hadron collision is simulated in QCD Monte Carlo models. The partonic cross section of the hard scatterings can be perturbatively calculable. The non-perturbative interactions are modeled with the use of experimental data. Double parton scattering (DPS) [1–3] where two hard scattering partons can occur within the same hadron-hadron collision is described with an effective cross section parameter, $\sigma_{\text{eff}}$, which is a non-directly observed parton level quantity. Measurements of $\sigma_{\text{eff}}$ were performed in $pp$ collision at $\sqrt{s} = 7$ TeV, by the CMS [4] and ATLAS [5] collaborations in a W+dijet final state. Although various experimental measurements were performed, no evidence of an energy dependence of $\sigma_{\text{eff}}$ has been observed yet.

2 CMS underlying event tunes

The charged particle with largest transverse momentum $p_T^{\text{max}}$ in the event is selected and named as the “leading object”. In order to characterize the UE activity, the charged particles with $p_T > 0.5$ GeV and $|\eta| < 0.8$ are used. The transverse plane is divided in different regions by taking into account the azimuthal angle $\phi$ and pseudorapidity $\eta$ of the leading jet. The regions are called “toward” ($|\Delta \phi| < \pi/3, |\eta| < 0.8$) and “away” ($\Delta \phi < 2\pi/3, |\eta| < 0.8$). The charged-particle density and the scalar transverse momentum $p_T$ sum density in the transverse region are evaluated as the sum of the contribution in the two regions: “Transverse-1” ($\pi/3 < -\Delta \phi < 2\pi/3, |\eta| < 0.8$) and “Transverse-2” ($\pi/3 < \Delta \phi < 2\pi/3, |\eta| < 0.8$). Further separation is used for the transverse region. The one with bigger activity in terms of $p_T$ of the charged particles is defined as “TransMAX” region whereas the “TransMIN” region is the one with less activity. The average of the TransMIN and TransMAX regions are labelled “TransAVE”. This additional subdivision of the transverse
region allows a better separation of the MPI and PS components. The TransMAX region might contain a third jet which can be produced by PS. However, TransMIN region does not contain the third jet but can have contribution from MPI. The TransMIN region has sensitivity to the components of the UE such as beam-beam remnants and MPI.

The software tool, Robust Independent Validation of Experiment and Theory (RIVET) [6], is used for generating MC predictions with a different choice of parameters related to the UE simulation. The PROFESSOR [7] framework which provided the generator response parameters and set of tuned parameters best fits to the measurement is then utilized to include the MC predictions.

CDF data at $\sqrt{s} = 0.9$ and 1.96 TeV [8] for charged-particle density in the TransMIN region as a function of $p_T^{\text{max}}$ is shown in Figure 1. The data are compared to predictions obtained with the PYTHIA 8 Tune 4C and with the new CMS tunes: CUETP8M1-CTEQ6L1, CUETP8M1-HERAPDF1.5LO, and CUETP8M1 [9]. Predictions from the new CMS tunes describe CDF data. The new CMS tunes significantly provides a better description than the PYTHIA 8 Tune 4C. This can be explained with the better choice of parameters used in the MPI energy dependence and the obtaining of the color reconnection in the retuning.

![Figure 1: The particle density for charged particles with $p_T > 0.5$ GeV and $|\eta| < 0.8$ in the TransMIN region as a function of the transverse momentum of the leading charged particle $p_T^{\text{max}}$ shown for CDF data $\sqrt{s} = 0.9$ TeV (left) and for $\sqrt{s} = 1.96$ TeV (right). The ratio of MC to CDF data is given at the bottom panel of each figure. Total experimental uncertainty is represented with green band.](image)

DPS-sensitive observable, the azimuthal angle between the two selected pairs of hard probes, $\Delta S$, is measured in four-jet production at $\sqrt{s} = 7$ TeV with the CMS detector [10]. The comparison of CMS data and predictions using CUETP8M1 and CUETHpp51 is shown in Figure 2 (left). Figure 2 (right) shows the comparison of predictions and the charged particle density with $p_T > 0.5$ GeV and $|\eta| < 2$ in the TransAVE region measured by ATLAS at $\sqrt{s} = 7$ TeV [11]. CUETP8M1 reproduces reasonably well the DPS-sensitive observable, $\Delta S$, but prediction using
CDPSTP8S2-4j does not describe the UE data.

Figure 2: Comparison of $\Delta S$ observable measured in CMS with predictions of PYTHIA8 using CUETP8M1 and HERWIG++ with CUETHppS1 (left), the charged particle density with $p_T > 0.5$ GeV and $|\eta| < 2$ in the TransAVE region measured by ATLAS at $\sqrt{s} = 7$ TeV (right).

3 Conclusion

In conclusion, CMS has produced new tunes of PYTHIA 6 [12], PYTHIA 8 [13] and HERWIG++ [14] event generators by using the UE data measured at various center-of-mass energies by the CDF and CMS experiments. The UE parameters were constrained by testing the UE models. The new CMS tunes at different collision energies provide an improved description of UE data. The new DPS-based tunes, two W+dijet DPS tunes and two four-jet DPS tunes, were constructed for testing the dependence of the DPS-sensitive observables on the MPI parameter. Predictions of the new CMS tunes were also compared to several other data distributions, such as the energy flow and charged particle spectra in the toward and the away regions measured by various experiments and results were found to be very accurate. The new CMS tunes will have an important role on the new LHC data as well as the predictions at the higher collision energies such as 13 or 14 TeV.

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References


