Underlying Event Studies at CMS

Paolo Bartalini*and Livio Fanò†
on behalf of the CMS collaboration

November 12, 2011

Abstract

This paper summarizes the CMS Underlying Event studies in pp interactions up to highest centre of mass energies of 7 TeV. The Underlying Event in Drell-Yan and jet events is studied measuring the charged multiplicity density and the charged energy density in different regions which are defined considering the azimuthal distance of the reconstructed tracks with respect to the reconstructed boson and leading track-jet, respectively. Complementary measurements in the transverse region and a methodology using the jet median/area approach are also discussed. We compare our underlying event results with the predictions from different Monte Carlo event generators and tunes.

This contribution summarizes the Underlying Event (UE) measurements of the CMS collaboration using pp collision data up to highest energies of $\sqrt{s} = 7$ TeV.

In the presence of a hard process, characterized by the presence of particles or clusters of particles with a large transverse momentum p_T with respect to the beam direction, the final state of hadron-hadron interactions can be described as the superposition of several contributions: products of the partonic hard scattering with the highest scale, including initial and final state radiation; hadrons produced in additional "multiple parton interactions" (MPI); and "beam-beam remnants" (BBR) resulting from the hadronization of the partonic constituents that did not participate in other scatterings. Products of MPI and BBR form the "underlying event" (UE). The UE cannot be uniquely separated from initial and final state radiation.

A detailed description of the CMS detector is available in Ref. [1]. Generator level Monte Carlo (MC) predictions according to different simulations and tunes are compared to the data corrected with a bayesian unfolding technique taking into account the detector effects [2]. The PYTHIA 6 [3, 4] tune Z1 [5] adopts p_T ordering

*National Taiwan University
†INFN and Università degli Studi di Perugia

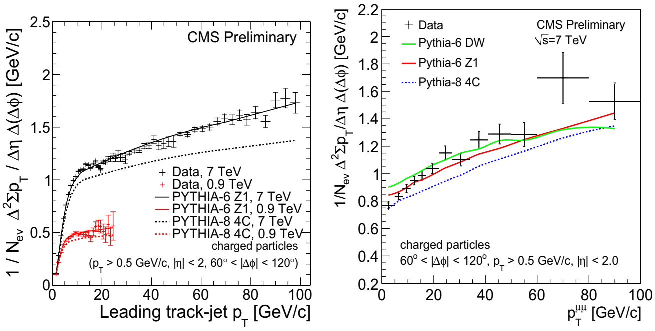

Figure 1: Average scalar $\sum p_T$ for tracks with a pseudorapidity $|\eta| < 2.0$ and $p_T > 0.5$ GeV/c in the transverse region as a function of the (left) leading track-jet p_T, for data at $\sqrt{s} = 0.9$ TeV and $\sqrt{s} = 7$ TeV; (right) $p_T^{\mu\mu}$, for data at $\sqrt{s} = 7$ TeV. Predictions from different PYTHIA 6 and PYTHIA 8 tunes are compared to the corrected data. The inner error bars indicate the statistical uncertainties affecting the measurements, the outer error bars thus represent the statistical uncertainties on the measurements and the systematic uncertainty affecting the MC predictions added in quadrature.

of parton showers and the new PYTHIA MPI model [6]. It includes the results of the Professor tunes [7] considering LEP fragmentation and the color reconnection parameters of the AMBT1 tune [8], while with the early CMS UE results have been used to tune the parameters governing the value and the $\sqrt{s}$ dependence of the cut-off transverse momentum that in PYTHIA regularizes the divergence of the leading order scattering amplitude as the final state parton transverse momentum $\hat{p}_T$ approaches 0. PYTHIA 8 [9, 10] also uses the new PYTHIA MPI model, which is interleaved with parton showering. The PYTHIA-8 tune 4C [11] which focuses on the description of the early LHC data, is adopted here.

The traditional CMS UE measurement in jet final staates [12] concentrates on the study of the transverse region, which is defined considering the azimuthal distance of the reconstructed tracks with respect to the leading track-jet of the event: $60^\circ < |\Delta\phi| < 120^\circ$. The jet reconstruction algorithm used in these studies is SisCone [13].

The centre-of-mass energy dependence of the hadronic activity in the transverse region is presented in Figure 1 (left) as a function of the p_T of the leading track-jet. The data points represent the average scalar track-p_T sum dependence, for $\sqrt{s} = 0.9$ TeV and $\sqrt{s} = 7$ TeV using tracks with a pseudorapidity $|\eta| < 2.0$ and $p_T > 0.5$ GeV/c. A significant growth of the UE activity of charged particles transverse to that of the leading track-jet is observed with increasing scale provided by the leading track-jet p_T, followed by saturation at large values of the scale. A significant growth of the activity in the transverse region is also observed, for the same value of the leading track-jet p_T, from $\sqrt{s} = 0.9$ TeV to $\sqrt{s} = 7$ TeV. These observations are consistent with the ones obtained at Tevatron [14]. The evolution with the hard scale of the ratio of the UE activity at 7 TeV and 0.9 TeV is remarkably well described by the Z1 tune. The trend is also reproduced by PYTHIA 8 Tune 4C. The strong growth of UE activity with charged particles is also striking in the comparison of the distributions of charged particle multiplicity, p_T and scalar p_T sum (not shown here) which corroborate the presence of a hard component in the UE hence the adoption of the MPI models.

The Drell-Yan (DY) process with muonic final state, $q\bar{q} \to \mu^+\mu^-$, provides an excellent complementary way to study the underlying event. The CMS UE measurement [15] in DY events focuses on the di-muon invariant mass region between 60 and 120 GeV/c^2. The UE observables defined in the jet final states are extended to the DY case replacing the track-jet with the di-muon.

Figure 1 (right) shows the scalar track-p_T sum using tracks with a pseudorapidity $|\eta| < 2.0$ and $p_T > 0.5$ GeV/c in the transverse region. Since the minimum energy scale of the event in this analysis is set by the lower bound on $M_{\mu\mu}$, the MPI component turns out to be saturated, hence only a small but noticeable growth of the UE activity with increasing $p_T^{\mu\mu}$ can be observed which can be attributed to the radiative component. The UE measurement in DY events is extended to the regions along and opposite with respect to the di-muon direction (not shown here). Extrapolating to the point with minimal radiative and maximal MPI contribution, the UE activity in DY events turns out to be around 25% lower with respect to the jet case. In Ref. [16] this is interpreted in terms of the reduced transverse size of the gluons with respect to the quarks.

On top of the traditional approach, a new methodology to quote the UE adopting anti-k_T jets [17] and relying on the measurement of their area [18] is adopted for the first time by CMS using charged particles in pp collision data collected at $\sqrt{s} = 0.9$ TeV [19]. The new set of UE observables consider the whole pseudorapidity-azimuth plane instead of the transverse region and inherently take into account the leading jets of an event.

CMS also reports a measurement of the energy flow in the forward region [20, 21] for minimum bias, dijet and DY events. These measurements are connected to the central region UE ones as the basic philosophy is the same: they concentrate on the complementary activity of a pp interaction for different energy scales of the reconstructed leading objects.

In conclusion, a strong growth of the UE activity in jet final states is observed with increasing leading track-jet p_T for both $\sqrt{s} = 7$ TeV and $\sqrt{s} = 0.9$ TeV. In DY events the UE activity shows a much smaller growth with the increasing $p_T^{\mu\mu}$. Both these observations are compatible with a MPI component saturating at a rather modest energy scale. MPI are also corroborated by the observation of pronounced hard components in the UE. Complementary UE measurements in the forward region confirm the same pattern. CMS also presents a measurement of the UE using the jet-area/median approach.

References

[1] [CMS Collaboration], JINST **3** (2008) S08004.

[2] G. DAgostini, Nucl. Instrum. Meth. **A** 362 (1995) 487498.

[3] T. Sjostrand and M. van Zijl, Phys. Lett. B **188** 149 (1987).

[4] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **0605**, 026 (2006).

[5] R. Field, arXiv:hep-ph/1010.3558v1.

[6] P. Z. Skands and D. Wicke, Eur. Phys. J. **C** 52 (2007) 133.

[7] A. Buckley *et al.*, Eur. Phys. J. C **65**, 331 (2010).

[8] [ATLAS Collaboration], arXiv:hep-ex/1012.5104.

[9] T. Sjostrand, arXiv:hep-ph/0809.0303.

[10] R. Corke, arXiv:hep-ph/0901.2852.

[11] R. Corke and T. Sjostrand, arXiv:hep-ex/1011.1759.

[12] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1109**, 109 (2011).

[13] G. P. Salam and G. Soyez, JHEP **0705** (2007) 086.

[14] A. A. Affolder *et al.* [CDF Collaboration], Phys. Rev. D **65** (2002) 092002.

[15] [CMS Collaboration], CMS-PAS-QCD-10-040.

[16] L. Frankfurt, M. Strikman and C. Weiss, Phys. Rev. D **83**, 054012 (2011).

[17] M. Cacciari, G. P. Salam and G. Soyez, JHEP **0804**, 063 (2008).

[18] M. Cacciari, G. P. Salam and S. Sapeta, JHEP **1004** (2010) 065.

[19] [CMS Collaboration], CMS-PAS-QCD-10-005.

[20] [CMS Collaboration], CMS-PAS-FWD-10-008.

[21] S. Chatrchyan *et al.* [CMS Collaboration], arXiv:hep-ex/1110.0181.