The underlying event in pp collisions at 900 GeV in CMS

Giuseppe B. Cerati for the CMS Collaboration

DOI: http://dx.doi.org/10.3204/DESY-PROC-2010-01/273

The underlying event in pp interactions at $\sqrt{s} = 900$ GeV is studied measuring the charged multiplicity density and the charged energy density in a region perpendicular to the plane of the hard 2-to-2 scattering. Two different methodologies are adopted to identify the direction and the energy scale of the hard scattering in Minimum Bias events that rely on the leading charged track and on the leading charged jet. The study allows to discriminate between various QCD Monte Carlo tunes with different multiple parton interaction schemes which correctly reproduce Tevatron underlying event data but give different predictions when extrapolated to different energies.

1 Introduction

The hard scattering in proton-proton collisions can be thought of as the sum of the hard 2-to-2 parton collision, including the initial and final state radiation, and of the underlying event (UE), given by beam-beam remnants (BBR) and multiple parton interactions (MPI). Characterising the UE is an unavoidable step towards an accurate tuning of Monte Carlo (MC) models which is crucial for the precise measurement of Standard Model processes and, consequently, for the search for physics beyond the SM. Using $\sqrt{s} = 900$ GeV collisions collected by the CMS detector [1] late 2009, UE properties at LHC energies can be compared to the predictions of several MC tunes which have been studied at Tevatron energies and inferences about MPI models can be drawn.

1.1 PHYTHIA tunes

In the work presented at this conference [2], several PYTHIA tunes are considered; they are all compatible with Tevatron data but differ in the description of parton fragmentation and multiple parton interaction. From the UE perspective, the main difference between the tunes is the value of two parameters, $p_T^0(\sqrt{s_0})$ at a reference energy $\sqrt{s_0}$ and ϵ, used by PYTHIA to regularize the $1/{p_T}^4$ divergence for final state parton $p_T \to 0$. The first is a cut-off parameter, used both for hard-scattering and MPI, while the second controls the energy dependence of the cut-off:

$$p_T^0(\sqrt{s}) = p_T^0(\sqrt{s_0}) \cdot (\sqrt{s}/\sqrt{s_0})^{\epsilon} \tag{1}$$

Among the considered tunes, *D6T* ($p_T^0(1.8\ TeV)$=1.8 GeV/c, ϵ=0.16) has the smallest ϵ value (obtained fitting UA5 Minimum Bias data at $Sp\bar{p}S$) and it is the only tune exploiting CTEQ6L pdfs; *DW* ($p_T^0(1.8\ TeV)$=1.9 GeV/c, ϵ=0.25) can be considered as the "best fit" of Tevatron data since it is compatible with the Drell-Yan p_T spectrum from CDF and with the D0 di-jet $\Delta\phi$ distribution; both *Pro-Q20* ($p_T^0(1.8\ TeV)$=1.9 GeV/c, ϵ=0.22) and *P0* ($p_T^0(1.8\ TeV)$=2 GeV/c, ϵ=0.26) tunes make use of the Professor fit program, which exploits LEP data for the tuning of the fragmentation functions, while only P0 implements the new PYTHIA MPI model with p_T-ordered showers; the last tune, *CW*, ($p_T^0(1.8\ TeV)$=1.8 GeV/c, ϵ=0.3), was created for the sake of the present study and is intended to maximize the MPI contribution at $\sqrt{s} = 900$ GeV while still being compatible with Tevatron data.

2 Data Analysis

The predictions of these tunes after full detector simulation are compared to CMS data. Events are characterised as a function of the scale of the hard interaction, defined either by the leading track or by the leading tracker-jet; the two methods define two complementary analysis approaches. The direction of the hard interaction in the plane orthogonal to the beam direction allows to identify three equally-sized regions (Fig. 1(a)): Toward ($|\Delta\phi| < 60°$), Away ($|\Delta\phi| > 120°$) and Transverse ($60 \leq |\Delta\phi| \leq 120°$), where $\Delta\phi$ is the azimuthal angle difference between a reconstructed track and the leading object in the event. The transverse region, less sensitive to hard-scattering components and to final state radiation products, is the most convenient region to characterise the UE properties. The analysis is performed on data collected during the 2009 LHC runs at $\sqrt{s} = 900$ GeV, consisting of 250k selected events and 4.8M tracks.

2.1 Event and Track Selection

Events are selected requiring a Minimum Bias trigger [2] defined as the coincidence of both Beam Pick-up Timing for experiments with a hit in the Beam Scintillator Counters and requiring a primary vertex with at least three associated tracks. In addition, events must contain a leading object with a p_T above threshold: threshold values are 0.5, 1.0 or 2.0 GeV/c for the leading track analysis and 1.0 or 3.0 GeV/c for the leading tracker-jet. Tracks are first selected according to basic kinematic cuts tuned to obtain homogeneous tracking performance: $p_T > 0.5$ GeV/c and $|\eta| < 2$; the primary vertex compatibility is verified by requiring longitudinal and transverse impact parameter significances less than 5; finally, good quality tracks are selected demanding a p_T error less than 5% and the "highPurity" flag [2]. Both event- and track-level cut efficiencies show a good data-MC matching, with agreement at the percent level.

2.2 Systematic Uncertainties

A complete study of systematic uncertainties is carried out investigating all possible sources of data-MC disagreement. MC samples with altered descriptions of beam spot, tracker alignment, dead channels and material are analyzed and the corresponding effects evaluated. In addition, the underestimation of the rates of secondary particles in MC is accounted for and the uncertainty due to the chosen track selection is evaluated exploiting alternative sets of selection criteria. Also, the trigger uncertainty is cross-checked with the complementary forward hadron calorimeter trigger. In summary, all results are quite stable, leading to a total uncertainty O(2%) and proving that the CMS simulation is very accurate and the reconstruction algorithms very robust.

2.3 Results

The average multiplicity of charged particles per unit of pseudorapidity shows that the tunes describe the features of data within 10-15%, but none of the tunes is in satisfactory agreement. The total multiplicity depends on the interaction scale, increasing with the p_T of the leading object. As far as the shape is concerned, the best description is provided by Pro-Q20 and P0 tunes; CW is too high in normalization, D6T, P0 and Pro-Q20 are too low, while DW is high at large pseudorapidities $|\eta|$ and low at small $|\eta|$. Figure 1(b) shows the average scalar sum of charged particles transverse momenta as a function of $\Delta\phi$. In the Toward region all tunes but P0 are above data, while in the Away region only DW and CW overshoot the data. The data in the transverse region lie between the CW and DW tunes; since this region is the most sensitive to UE properties, the following results focus on this region only.

The charged multiplicity and charged energy densities as a function of the interaction scale show the same features in data and MC: a fast rise due to MPI at low p_T is followed by a slower increase due to radiation above $\sim$3 GeV/c and $\sim$5 GeV/c for leading track and jet analyses respectively. The probability distribution of track multiplicity in the transverse region is shown for events with a tracker-jet with p_T>3 GeV/c (Fig. 4): data and all tunes show a steep decrease for track multiplicity N_{ch}>2; D6T and Pro-Q20 diverge, predicting too many low multiplicity events. The track p_T distribution in the transverse region is characterised by an almost exponential spectrum, with the P0 tune close to data at high p_T and showing a flat ratio in the whole p_T range.

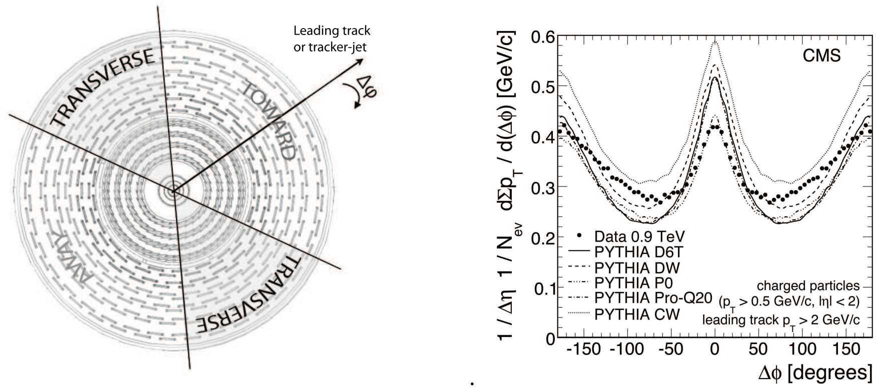
3 A Different Approach to the UE: Jet Area/Median

An alternative approach to studying the UE [3] is by measuring, for each jet in an event, the ratio of the jet transverse momentum and the area covered by this jet in the pseudorapidity versus azimuthal angle plane. In each event, there are hard jets that have large values of p_T/A, while most have small values and are sensitive to UE and pile up effects. The parameter $\rho = median(p_T/A)$ can be used to describe the UE activity since the median is less sensitive to the outlying hard jets.

The CMS analysis based on this method [4] makes use of track jets reconstructed with the kT algorithm with R=0.6 and defines a modified version of the ρ parameter to account for the very low detector occupancy in 900 GeV events. This analysis uses similar selections and systematic uncertainty estimation as described in the previus sections. Results comparing data with several PYTHIA tunes are compatible with those obtained with the traditional approach.

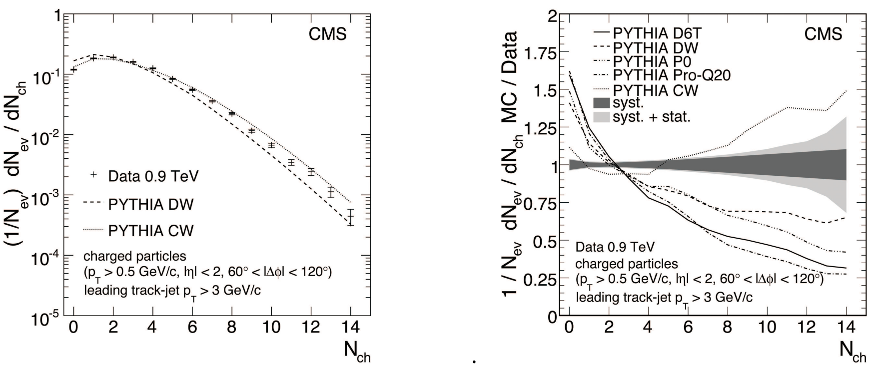
4 Conclusions

The first study of hadron production with $\sqrt{s}$ = 900 GeV LHC data at a scale provided by the leading track or the leading tracker-jet is presented. Predictions of several PYTHIA tunes, after full detector simulation, are compared to data with particular interest in the transverse region. The tunes describe CMS data within 10-15%, but, with the exception of CW, they predict too little hadronic activity in the transverse region. Data favor an energy dependence of the cut-off parameter like DW (ϵ = 0.25) or even stronger (ϵ = 0.30 as CW). Lower values are disfavored (i.e. D6T: ϵ = 0.16). A new approach, based on the jet area, was developed and leads to complementary results. New results, including more tunes and generator-level variables both at 0.9 and 7 TeV, are being produced and will become public in the next months.



(a) (b)

Figure 1: Representation of the three regions in the the x-y view of the CMS tracker (a). Average scalar p_T sum of tracks with $p_T > 0.5$ GeV/c and $|\eta| < 2$ per unit of pseudorapidity and per radian, as a function of $\Delta\phi$; the leading track is excluded (b).



(a) (b)

Figure 2: Track multiplicity probability in the transverse region for events with a tracker-jet with p_T>3 GeV/c. (a) shows the distribution for data, DW and CW tunes; (b) shows the ratio between all tunes and data.

References

[1] CMS Collaboration, "The CMS experiment at the CERN LHC", JINST 3:S08004,2008.

[2] CMS Collaboration, "First Measurement of the Underlying Event Activity at the LHC with $\sqrt{s} = 0.9$ TeV" CMS-QCD-10-001 (2010) [arXiv:1006.2083], Submitted to the European Physical Journal C.

[3] M. Cacciari, G. P. Salam, and S. Sapeta, "On the characterisation of the underlying event", JHEP 04 (2010) 065 [arXiv:0912.4926].

[4] CMS Collaboration "Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV," CMS-PAS-QCD-10-005 (2010).