Modeling the underlying event: generating predictions for the LHC

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Abstract
This report presents tunings for PYTHIA version 6.416 and JIMMY version 4.3 to the underlying event. The MC generators are tuned to describe underlying event measurements made by CDF for p$\overline{\rm p}$ collisions at $\sqrt{s}$ = 1.8 TeV. LHC predictions for the underlying event generated by the tuned models are also compared in this report.

1 INTRODUCTION

Over the last few years, the Tevatron experiments CDF and D0 have managed to reduce uncertainties in various measurements to a level in which the corrections due to the underlying event (UE) have become yet more relevant than they were in Run I analyses. Studies in preparation for LHC collisions have also shown that an accurate description of the underlying event will be of great importance for reducing the uncertainties in virtually all measurements dependent on strong interaction processes. It is therefore very important to produce models for the underlying event in hadron collisions which can accurately describe Tevatron data and are also reliable to generate predictions for the LHC.

The Monte Carlo (MC) event generators PYTHIA [1] and HERWIG [2] are widely used for the simulation of hadron interactions by both Tevatron and LHC experiments. Both generators are designed to simulate the event activity produced as part of the underlying event in proton-antiproton (p$\overline{\rm p}$) and proton-proton (pp) events. In this report we focus on the fortran version of HERWIG. This needs to be linked to dedicated package, named "JIMMY" [3, 4], to produce the underlying event activity.

PYTHIA version 6.2 has been shown to describe both minimum bias and underlying event data reasonably well when appropriately tuned [5–7]. Major changes related to the description of minimum bias interactions and the underlying event have been introduced in PYTHIA version 6.4 [1]. There is a new, more sophisticated scenario for multiple interactions, new $p_{\rm T}$-ordered initial- and final-state showers (ISR and FSR) and a new treatment of beam remnants [1].

JIMMY [4] is a library of routines which should be linked to the HERWIG MC event generator [2] and is designed to generate multiple parton scattering events in hadron-hadron events. JIMMY implements ideas of the eikonal model which are discussed in more detail in Ref. [3, 4].

In this report we present a tuning for PYTHIA version 6.416 which has been obtained by comparing PYTHIA version 6.416 to the underlying event measurements done by CDF for p$\overline{\rm p}$ collisions at 1.8 TeV [8, 9]. We also compare the ATLAS tune for HERWIG version 6.510 with JIMMY version 4.3 to these data distributions [10].

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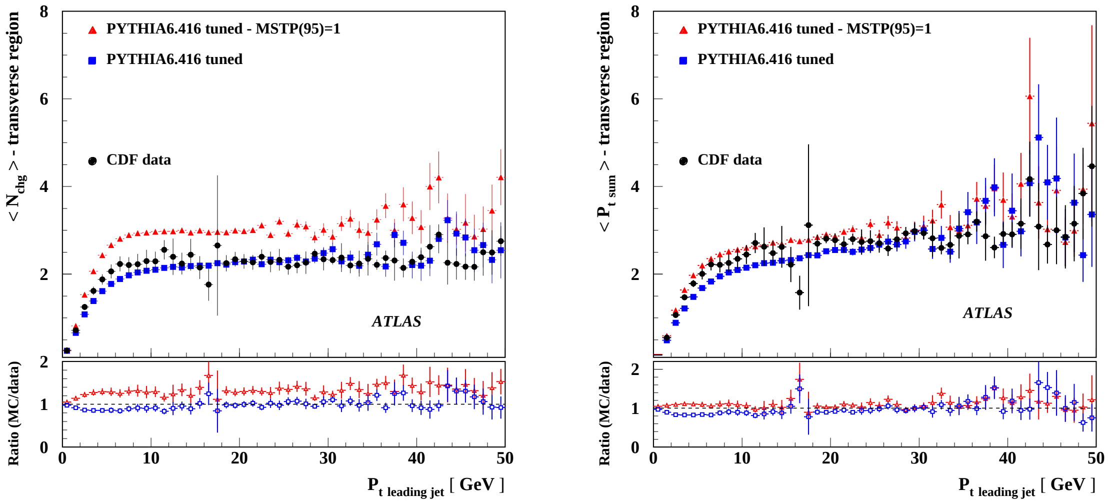
2 MC predictions vs. UE data

Based on the CDF analysis in Ref. [9], the underlying event is defined as the angular region in ϕ which is transverse to the leading charged particle jet.



(a) (b)

Fig. 1: PYTHIA version 6.416 predictions for the underlying event compared to the $< N_{\rm chg} >$ (a) and $< p_{\rm T}^{\rm sum} >$ (b).

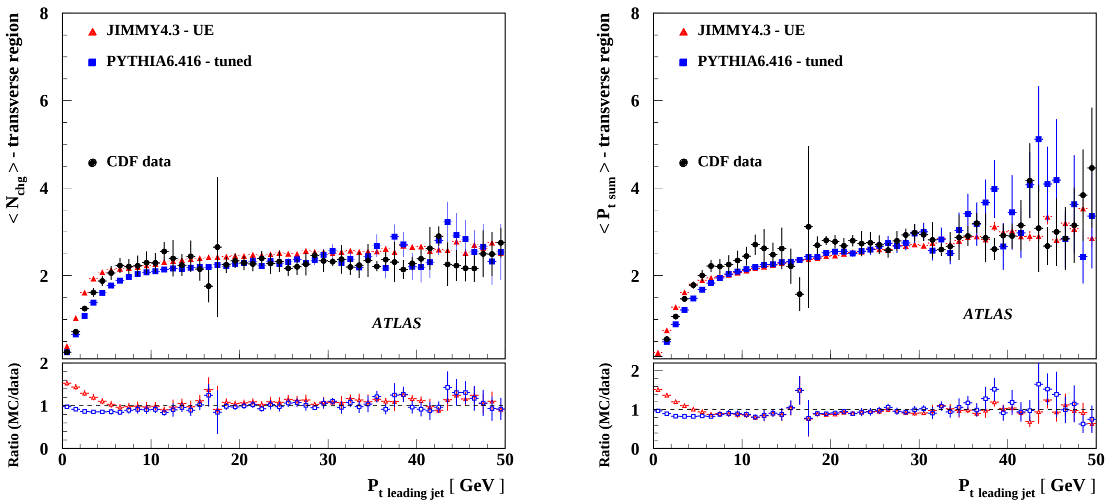
Figures 1(a) and 1(b) show PYTHIA version 6.416 predictions for the underlying event compared to the CDF data for the average charged particle multiplicity, $< N_{\rm chg} >$ (charged particles with $p_{\rm T} > 0.5$ GeV and $|\eta| < 1$) and average sum of charged particle's transverse momenta, $< p_{\rm T}^{\rm sum} >$ in the underlying event [9], respectively. Two MC generated distributions are compared to the data in these plots: one generated with all default settings in PYTHIA version 6.416 except for the explicit selection of the new multiple parton interaction and new parton shower model, which is switched on by setting MSTP(81)=21 [1], and a second distribution with a tuned set of parameters. This particular PYTHIA version 6.416 - tune was prepared for use in the 2008 production of simulated events for the ATLAS Collaboration. The list of tuned parameters is shown in Table 1.

The guiding principles to obtain the parameters listed in Table 1 were two: firstly the new multiple parton interaction model with interleaved showering and colour reconnection scheme was to be used and, secondly, changes to ISR and FSR parameters should be avoided if at all possible.

In order to obtain a tuning which could successfully reproduce the underlying event data, we have selected a combination of parameters that induce PYTHIA to preferably choose shorter strings to be drawn between the hard and the soft systems in the hadronic interaction. We have also increased the hadronic core radius compared to the tunings used in previous PYTHIA versions, such as the ones mentioned in Ref. [6,7]. As can be seen in Fig. 1 PYTHIA version 6.416 - tuned describes the data.

Table 1: PYTHIA version 6.416 - tuned parameter list for the underlying event.

Default [1]	**PYTHIA6.416 - tuned**	**Comments**
MSTP(51)=7 CTEQ5L	MSTP(51)=10042 MSTP(52)=2 CTEQ6L (from LHAPDF)	PDF set
MSTP(81)=1 (old MPI model)	MSTP(81)=21 (new MPI model)	multiple interaction model
MSTP(95)=1	MSTP(95)=2	method for colour reconnection
PARP(78)=0.025	PARP(78)=0.3	regulates the number of attempted colour reconnections
PARP(82)=2.0	PARP(82)=2.1	$p_{\mathrm{T_{min}}}$ parameter
PARP(83)=0.5	PARP(83)=0.8	fraction of matter in hadronic core
PARP(84)=0.4	PARP(84)=0.7	hadronic core radius



(a) (b)

Fig. 2: PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE predictions for the underlying event compared to the $< N_{\mathrm{chg}} >$ (a) and $< p_{\mathrm{T}}^{\mathrm{sum}} >$ (b).

Figures 2(a) and 2(b) show PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE [10] predictions for the underlying event compared to the CDF data for $< N_{\mathrm{chg}} >$ and $< p_{\mathrm{T}}^{\mathrm{sum}} >$, respectively. Both models describe the data reasonably well. However, as shown in

Fig. 3, the ratio $< p_{\rm T}^{\rm sum} >/< N_{\rm chg} >$ is better described by PYTHIA version 6.416 - tuned. This indicates that charged particles generated by JIMMY version 4.3 - UE are generally softer than the data and also softer than those generated by PYTHIA version 6.416 - tuned.

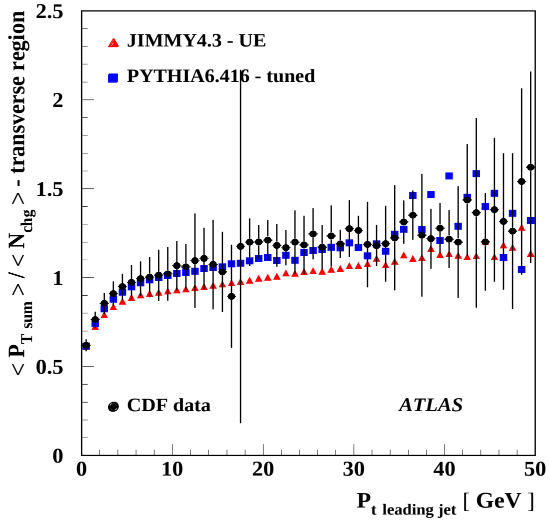


Fig. 3: PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE predictions for the underlying event in $\rm p\bar{p}$ collisions at 1.8 TeV compared to the ratio $< p_{\rm T}^{\rm sum} >/< N_{\rm chg} >$.

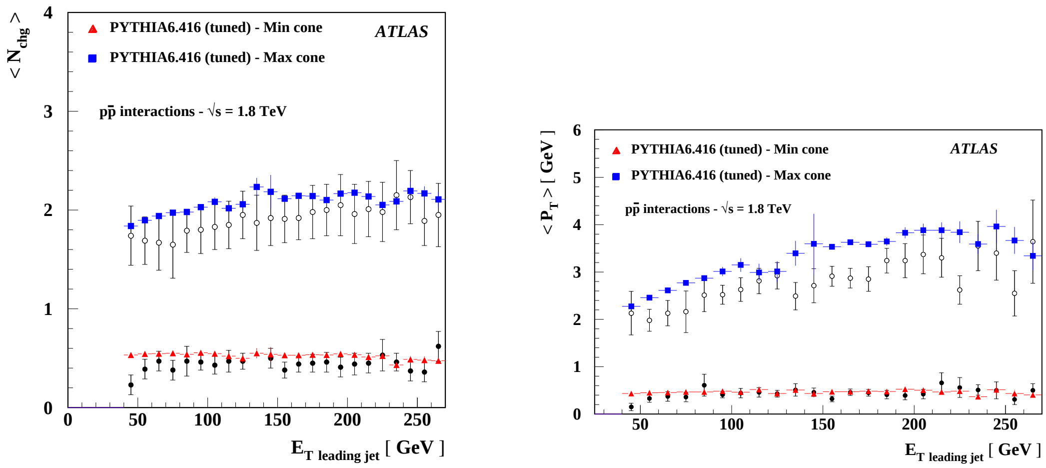
Another CDF measurement of the underlying event was made by defining two cones in $\eta - \phi$ space, at the same pseudorapidity η as the leading $E_{\rm T}$ jet (calorimeter jet) and $\pm\pi/2$ in the azimuthal direction, ϕ [8]. The total charged track transverse momentum inside each of the two cones was then measured and the higher of the two values used to define the "MAX" cone, with the remaining cone being labelled "MIN" cone.

Figure 4 shows PYTHIA version 6.416 - tuned predictions for the underlying event in $\rm p\bar{p}$ collisions at $\sqrt{\rm s}$ = 1.8 TeV compared to CDF data [8] for $< N_{\rm chg} >$ and $< P_{\rm T} >$ of charged particles in the MAX and MIN cones. PYTHIA version 6.416 - tuned describes the data reasonably well. However, we notice that the $< P_{\rm T} >$ in the MAX cone is slightly harder than the data.

3 LHC predictions for the UE

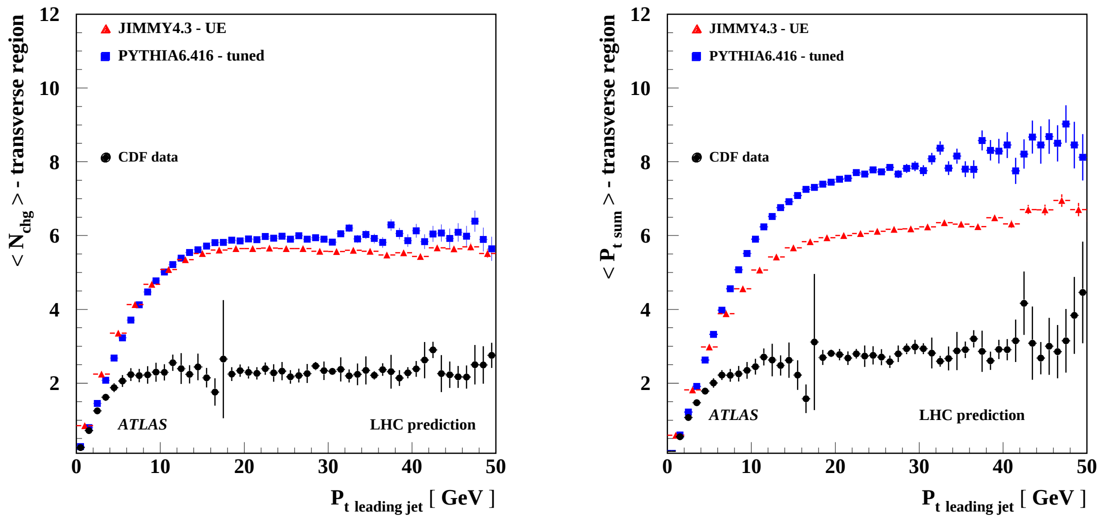
Predictions for the underlying event in LHC collisions (pp collisions at $\sqrt{\rm s}$ = 14 TeV) have been generated with PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE. Figures 5(a) and 5(b) show $< N_{\rm chg} >$ and $< p_{\rm T}^{\rm sum} >$ distributions for the region transverse to the leading jet (charged particles with $p_{\rm T} > 0.5$ GeV and $|\eta| < 1$), as generated by PYTHIA version 6.416 - tuned (Table 1) and JIMMY version 4.3 - UE [10], respectively. The CDF data ($\rm p\bar{p}$ collisions at $\sqrt{\rm s}$ = 1.8 TeV) for the underlying event is also included in Fig. 5 for comparison.

A close inspection of predictions for the $< N_{\rm chg} >$ in the underlying event given in



(a) (b)

Fig. 4: (a) Average charged particle multiplicity, $< N_{\rm chg} >$, in MAX (top distributions) and MIN (bottom distributions) cones; (b) average total $P_{\rm T}$ of charged particles in MAX and MIN cones.



(a) (b)

Fig. 5: PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE predictions for the underlying event in pp collisions at $\sqrt{s}$ = 14TeV for $< N_{\rm chg} >$ (a) and $< p_{\rm T}^{\rm sum} >$ (b).

Fig.5(a), shows that the average charged particle multiplicity for events with leading jets with $P_{\rm T_{ljet}} > 15$ GeV reaches a plateau at ~ 5.5 charged particles according to both PYTHIA version 6.416 - tuned and JIMMY version 4.3-UE. This corresponds to a rise of a factor of ~ 2 in the plateau of $< N_{\rm chg} >$ as the colliding energy is increased from $\sqrt{\rm s}$ = 1.8 TeV to $\sqrt{\rm s}$ = 14 TeV.

The $< p_{\rm T}^{\rm sum} >$ distributions in Fig. 5(b) show that PYTHIA version 6.416 - tuned generates harder particles in the underlying event compared to JIMMY version 4.3-UE. This is in agreement with the results shown in Fig. 3, although for the LHC prediction the discrepancy between the two models is considerably larger than the observed at the Tevatron energy.

The difference between the predictions for the charged particle's $p_{\rm T}$ in the underlying event is a direct result of the tuning of the colour reconnection parameters in the new PYTHIA version 6.4 model. This component of the PYTHIA model has been specifically tuned to produce harder particles, whereas in JIMMY version 4.3 - UE this mechanism (or an alternative option) is not yet available.

4 CONCLUSIONS

In this report we have compared tunings for PYTHIA version 6.416 (Table 1) and JIMMY version 4.3 [10] to the underlying event. Both models have shown that, when appropriately tuned, they can describe the data.

In order to obtain the parameters for PYTHIA version 6.416 - tuned, we have deliberately selected a combination of parameters that generate shorter strings between the hard and the soft systems in the hadronic interaction. We have also increased the hadronic core radius compared to the tunings used in previous PYTHIA versions (see Refs. [6, 7] for example).

We have noticed that PYTHIA version 6.416 - tuned and JIMMY version 4.3 - UE generate approximately the same densities of charged particles in the underlying event. This is observed for the underlying event predictions at the Tevatron and LHC energies alike.

However, there is a considerable disagreement between these tuned models in their predictions for the $p_{\rm T}$ spectrum in the underlying event, as can be seen in Figs. 3 and 5(b). PYTHIA version 6.416 - tuned has been calibrated to describe the ratio $< p_{\rm T}^{\rm sum} >$/$< N_{\rm chg} >$, which has been possible through the tuning of the colour reconnection parameters in PYTHIA. JIMMY version 4.3 - UE has not been tuned to this ratio.

As a final point, we would like to mention that this is an "*ongoing*" study. At the moment these are the best parameters we have found to describe the data, but as the models are better understood, the tunings could be improved in the near future.

References

[1] T. Sjostrand, S. Mrenna, and P. Skands, JHEP **05**, 026 (2006).

[2] G. Corcella *et al.*, JHEP **01**, 010 (2001). `hep-ph/0210213`.

[3] J. M. Butterworth, J. R. Forshaw, and M. H. Seymour, Z. Phys. C **72**, 637 (1996). `hep-ph/9601371`.

[4] J. M. Butterworth and M. H. Seymour, *JIMMY4: Multiparton Interactions in Herwig for the LHC*, October 2004.

[5] T. Sjostrand and M. van Zijl, Phys. Rev. D **36**, 2019 (1987).

[6] A. Moraes, C. Buttar, and I. Dawson, Eur. Phys. J. C **50**, 435 (2007).

[7] R. Field, *Min-Bias and the Underlying Event at the Tevatron and the LHC*, October 2002. (talk presented at the Fermilab ME/MC Tuning Workshop, Fermilab).

[8] D. Acosta *et al.*, Phys. Rev. **D70**, 072002 (2004).

[9] T. Affolder *et al.*, Phys. Rev. **D65**, 092002 (2002).

[10] C. Buttar *et al.*, *Physics at Tev Colliders 2005 - QCD, EW and Higgs Working Group: Summary Report*, April 2006.