SIMULATIONS OF MINIMUM BIAS EVENTS AND THE UNDERLYING EVENT, MC TUNING AND PREDICTIONS FOR THE LHC*

C.M. Buttar, D. Clements, I. Dawson and A. Moraes

Department of Physics and Astronomy, University of Sheffield
Hicks Building, Hounsfield Road, Sheffield S3 7RH, UK

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Minimum bias and underlying event data from the $Sp\bar{p}S$ and the Tevatron have been compared to PYTHIA and PHOJET simulations. The data have been used to tune the PYTHIA multiparton model and good agreement is found. PHOJET also gives good agreement. Predictions are made for the multiplicities in minimum bias and the underlying events at the LHC. PYTHIA predicts increases by factors of order two to three from Tevatron energies, while PHOJET predicts more modest increases by a factor of 1.5. The effect of different levels of underlying event activity on the central jet veto used in Higgs searches in the vector boson fusion channel is investigated.

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1. Introduction

In $p(\bar{p})p$ collisions at hadron colliders such as the Tevatron or in the future at the LHC, an increasing number of parton interactions occur in a single pp interaction. Multiparton interactions have been observed experimentally; indirectly in charged multiplicity distributions in minimum bias events where the multiparton events result in high multiplicity tails that break KNO scaling [1] and in the comparison of low E_{T} jet cross-sections with QCD [2]. Multiparton scattering has also been seen indirectly in the underlying event associated with jets [3]. Multiparton events have also been directly observed in hard scattering processes [4].

Multiparton scattering increases the number of soft (p_{T} ~few GeV) particles either in a so-called minimum bias event or in the underlying event associated with high p_{T} jets or leptons. Therefore, for the LHC it is important

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to have an accurate model of multiparton scattering to help develop robust reconstruction algorithms and physics analyses. In this report a tuning of the PYTHIA [5] multiparton model [6] is presented based on minimum bias data from UA5 at 200, 546 and 900 GeV [7], E735 at 1.8 TeV [8] and CDF [9] at 1.8 TeV, and underlying event data from CDF at 1.8 TeV [3]. All of these data have been used in the tuning, although only a few representative plots will be shown. As both minimum bias events and the underlying event are low p_{T} physics processes we have developed a single tuning to describe both. This tuning is then used to evaluate the effect of the underlying event on the central jet veto used in the search for a low mass Higgs in vector boson production [11]. A comparison with PHOJET has also been made.

2. The PYTHIA model

The multiparton model in PYTHIA (version 6.2) has a number of different physical parameters. The basic parameter is the lower limit of the transverse momentum, p_{T}-min, used in the calculation of the QCD $2 \rightarrow 2$ 'hard' cross-section. In the so-called simple model the hard cross-section is calculated using a minimum p_{T} that corresponds to the low p_{T} limit in the QCD calculation. In the complex model the minimum p_{T} is used as a regulating parameter. This results in a hard cross-section that is effectively calculated down to $p_{\mathrm{T}} = 0$, resulting in a greater number of multiparton interactions compared with the simple model. Associated with each model is a different set of matter distributions. In the simple model, a uniform matter distribution is used. In the complex model in addition to the uniform matter distribution, a single or double Gaussian matter distribution can be used. The Gaussian matter distributions introduce fluctuations in the multiplicity distributions particularly at large multiplicities.

The p_{T}-min parameter in the simple and complex model controls the number of multiparton interactions and can therefore be tuned using the mean charged multiplicity and the height of the rapidity plateau. The matter distribution controls the fluctuations in multiplicity and this can be tuned using the charged multiplicity distributions.

The simple scenario can be excluded by the charged multiplicity distributions as the predicted spectrum is too narrow, as was pointed out when the model was first developed [6]. We will not investigate tuning the simple scenario further, but note that this is the PYTHIA default setting.

As minimum bias events are defined by experimental triggers and include a component of double diffractive events, we have simulated minimum bias events using both non-diffractive inelastic scattering and double diffractive scattering. For the underlying event we have only used non-diffractive inelastic scattering.

3. Comparison to data

Figure 1 shows the charged multiplicity distribution from UA5 at 546 GeV, compared to the uniform, single Gaussian and double Gaussian matter distributions using the PYTHIA default settings. The uniform matter distribution gives rise to a Poisson distribution which cannot reproduce the shape of the high multiplicity tail. Both the single and double Gaussian distributions are able to describe the high multiplicity tail. The value of p_T-min can be determined by looking at the rapidity distributions. Figure 1 also shows a comparison between PYTHIA predictions and data from CDF. A value of 1.9 GeV is favoured, and this also reproduces the UA5 distributions at 200 and 900 GeV.

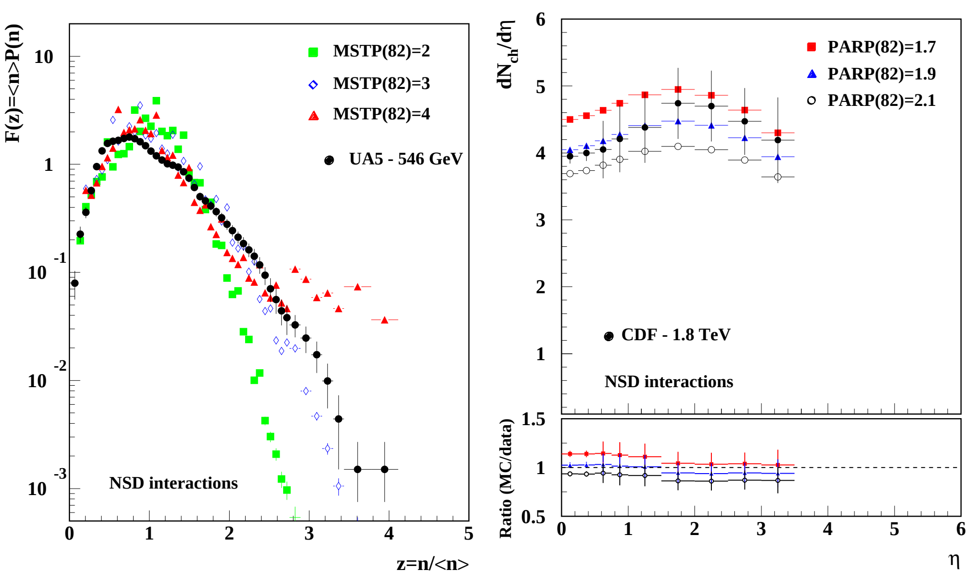

Fig. 1. Left figure: charged multiplicity distribution measured by UA5 at 546 GeV (circles) compared to the prediction of the PYTHIA complex scenario with uniform (squares), single Gaussian (diamonds) and double Gaussian (triangles) matter distributions Right figure: Rapidity distribution measured by CDF at 1.8 TeV (crosses) compared to to the prediction of PYTHIA for three different values of p_T-min: 1.7 GeV (squares), 1.9 GeV (triangles) and 2.1 GeV (circles)

The CDF underlying event data is shown in figure 2 and compared to the predictions of the PYTHIA model for a large range of p_T-min, the best agreement being for a value 2.1 GeV. This is considerably larger than the value indicated by the central rapidity plateau in minimum bias events and would lead to a lower plateau compared to the data, as shown in figure 1. Figure 2 also shows the predictions of the PYTHIA model using a fixed p_{T}-min but for a number of different core sizes in the double Gaussian model. The default core-size of 0.2 results in too much activity in the underlying event, 0.5 gives the best agreement with the data and 0.8 predicts too little activity. Either the p_{T}-min and core size parameters can be tuned to

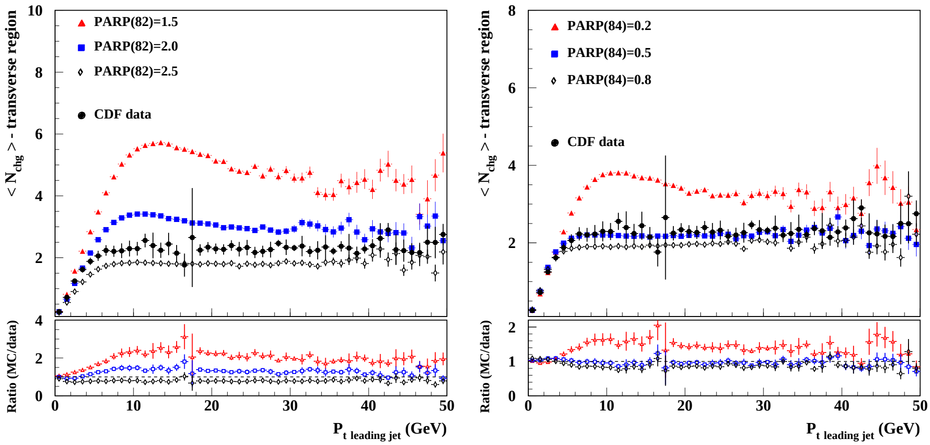

Fig. 2. Comparison of PYTHIA predictions with underlying event data from CDF. Left shows a comparison with PYTHIA generated for a wide range of p_{T}-min values 1.5 GeV (triangles), 2.0 GeV (squares) and 2.5 GeV (diamonds), using the double Gaussian model with default core-size of 0.2. Right shows a comparison with PYTHIA generated using a range of core sizes for the double Gaussian model 0.2 (triangles), 0.5 (squares) and 0.8 (diamonds) for the default p_{T}-min of 1.9 GeV.

reproduce the underlying event data. However, if we choose to tune using the p_{T}-min parameter then we will have to use a value larger than used to reproduce minimum bias distributions. As both minimum bias and the underlying event are products of soft physics then the PYTHIA model should be able to reproduce both sets of data using the same tuning. We have therefore chosen to tune the model to the underlying event by increasing the core-size.

Figure 3 shows how the rapidity plateau varies for a fixed p_{T}-min for three different core sizes. This shows that varying the core size does not have a significant effect on the minimum bias events. In figure 3 predictions using the three different core sizes are compared to E735 data, showing that a core-size of 0.5 actually improves the agreement with the data. The charged multiplicity distribution produced using a core-size of 0.8 falls too quickly to describe the high multiplicity tail. This shows that increasing the core size above 0.5 leads to worse agreement with data. Taking this to the limit of a core-size of 1.0 would lead to the single Gaussian model, therefore we can also say that the double Gaussian model gives a better description of the data than the single Gaussian model.

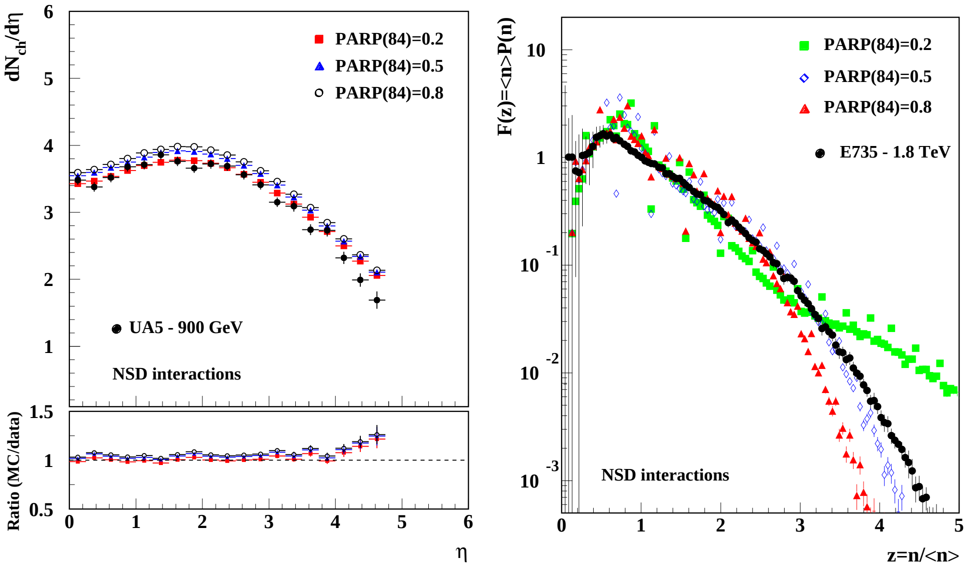

Fig. 3. Left figure shows a comparison between CDF data and PYTHIA predictions for different core sizes. Right figure shows a comparison of E735 charged multiplicity distribution with the PYTHIA predictions for core sizes of 0.2 (squares), 0.5 (diamonds) and 0.8 (triangles)

The final tuning of the PYTHIA multiparton model uses the complex scenario with a double Gaussian matter distribution (MSTP(82) = 4) with a core-size (PARP(84)) of 0.5, compared to the default of 0.2 and a slightly lower $p_{\rm T}$-min (PARP(82)) of 1.8 GeV compared to the default of 1.9 GeV.

4. Predictions for the LHC

Having obtained a set of parameters, we present the predictions for the LHC in figure 4. There is an increase in the pseudo-rapidity plateau, going from 4.1 at the Tevatron to 7.0 at the LHC representing nearly a two-fold increase in the multiplicity in minimum bias events. Similarly, the multiplicity in the underlying event accompanying a leading jet of $p_{\rm T} = 20$ GeV increases from 2.3 at the Tevatron to 7.0 at the LHC, a three-fold increase. There is an apparent difference between the increase in multiplicities in minimum bias events and that in the underlying event. This is possibly due to there being some radiation from the hard process leaking into the underlying event.

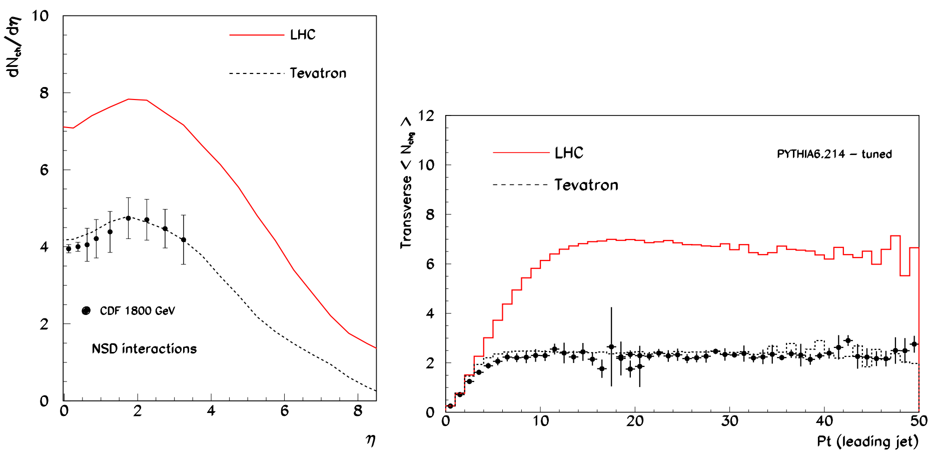

Fig. 4. The figure shows the Tevatron data and the PYTHIA prediction for LHC energies of the pseudo-rapidity (left figure) and particle multiplicity in the underlying event (right figure)

5. Comparison with PHOJET

We have also compared the underlying event data to PHOJET [10] and find that it gives a good description of both the minimum bias data and the underlying event data (figure 5). We have used the default values (PHOJET 1.12) and not made any attempt to tune the model.

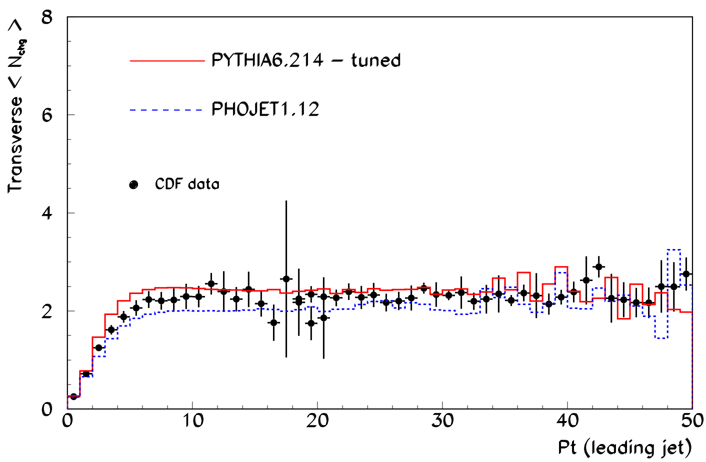

Fig. 5. Comparison of CDF underlying event multiplicities with the tuned PYTHIA model and PHOJET

However, a large discrepancy between the PHOJET prediction and the PYTHIA prediction at LHC energies is found. The PHOJET prediction for the central rapidity plateau appears to follow the extrapolations from UA5 and CDF data [9], while the PYTHIA prediction is considerably higher. There is also a large discrepancy between the PHOJET and PYTHIA predictions for the underlying event, with PHOJET predicting an increase of around 1.5 compared with the much larger increase predicted by PYTHIA of a factor of 3. The energy extrapolation is not well constrained so we can take the difference between PHOJET and PYTHIA as a measure of the theoretical uncertainty on predictions of soft physics at the LHC.

6. Effect of the underlying event on central jet veto

As an example of an application, we have looked at the effect of varying the PYTHIA model for the underlying event on the efficiency of the central jet veto in Higgs VBF analysis for $H \to WW \to ll + p_{\mathrm{T}}$-miss [11]. Figure 6 shows the p_{T} spectrum of non-tag jets produced using ATLFAST simulation [12] for three different PYTHIA models of the underlying event: default model, default double Gaussian and tuned model, the respective central-jet

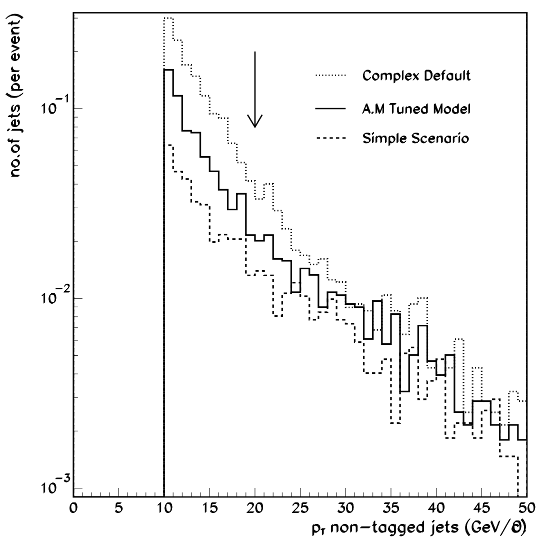

Fig. 6. p_{T} spectrum on non-tag jets in Higgs events produced by vector boson fusion ($M_{\mathrm{H}} = 160$ GeV) using PYTHIA and reconstructing the jets with a cone-finder in ATLFAST, for three different underlying event models: PYTHIA default, default double Gaussian and the tuned model described above (the arrow represents the 20 GeV cut applied in the Higgs analysis

veto efficiencies are found to be 82%, 71% and 76%. There is a significant increase in the activity of the underlying event, but it is sufficiently soft that it does not lead to a significant increase in jets with $P_{\rm T} > 20$ GeV, the cut applied in the analysis.

7. Summary and conclusions

Using a range of minimum bias and underlying event data from $p\bar{p}$ across an energy range from 200 GeV to 1.8 TeV, we have developed a tuning for the PYTHIA multiparton model that is used to describe minimum bias and underlying event data. The data shows that the default PYTHIA model does not generate sufficient activity in the pseudo-rapidity distributions, the underlying event multiplicity or reproduce high multiplicity tails observed in charged multiplicity distributions. To describe the data a $p_{\rm T}$-min of 1.8 GeV (compared to the default value of 1.9 GeV) must be used together with a double Gaussian matter distribution using a core-size of 0.5 (compared with the default value of 0.2). This tuning uses the default PYTHIA pdf of CTEQ5L and if this is changed, the model will require re-tuning. Using the tuned model, predictions for minimum bias events and the underlying event have been made for the LHC energy of 14 TeV. The increase in multiplicity compared to that measured at the Tevatron is two-fold for minimum bias events and three-fold for the underlying event. The difference in the increase is likely to be due to radiation from the hard process being measured as part of the underlying event. We have also compared PHOJET to the data and found that it gives a good description without requiring tuning. However when extrapolating to the LHC, the PYTHIA and PHOJET predictions diverge, with the PHOJET predictions being less than those of PYTHIA. Thus, there is still considerable uncertainty due to the lack of understanding as to how to extrapolate soft processes to higher energies. We have looked at the effect of using different underlying event models to simulate the central jet veto in Higgs produced by vector boson fusion. Although the low $p_{\rm T}$ jet rates increases due to the enhanced activity in the underlying event, this is not significant above the jet cut of 20 GeV.

REFERENCES

[1] S.G. Matinyan, W.D. Walker, *Phys. Rev.* **D59**, 034022 (1999).

[2] D0 Collaboration, *Phys. Rev.* **D67**, 0520001 (2003).

[3] CDF Collaboration, *Phys. Rev.* **D65**, 092002 (2002).

[4] CDF Collaboration, *Phys. Rev.* **D65**, 3811 (1997).

[5] T. Sjostrand *et al.*, *Comput. Phys. Commun.* **135**, 238 (2001).

[6] T. Sjostrand, M. van Zijl, *Phys. Rev.* **D36**, 2019 (1987).

[7] UA5 Collaboration, *Phys. Rep.* **154**, 247 (1987); *Z. Phys.* **C37**, 191 (1988); *Z. Phys.* **C43**, 357 (1989).

[8] E735 Collaboration, *Phys. Lett.* **B435**, 453 (1998).

[9] CDF Collaboration, *Phys. Rev.* **D41**, 2330 (1990).

[10] R. Engel, *Z. Phys.* **C66**, 203 (1995); R. Engel, J. Ranft, *Phys. Rev.* **D54**, 4244 (1996).

[11] S. Asai *et al.*, *Eur. Phys. J. C Direct* (2003).

[12] E. Richter-Was, D. Froidevaux, L. Poggioli, ATLAS internal note ATL-PHYS-98-131 (1998).