Tuning of the multiple parton interaction model in Herwig++ using early LHC data

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In this short note we present tunes of the Multiple Parton Interactions model in Herwig++ using the early LHC data. Measurements of the charged particle multiplicities and of the momentum flow in the underlying event in inelastic *pp* collisions are used to constrain the parameters of the model. The tunes aim to consistently describe both the new LHC measurements and pre-LHC data from the Tevatron and LEP.

1 Introduction

In recent years the LHC has collected data at an impressive rate which presents the opportunity to study physics not only at the new high-energy frontier but also with a higher precision. This means that QCD effects, both perturbative and non-perturbative can be studied in more detail. In particular, the first physics results from the LHC experiments were measurements of Minimum-Bias (MB) [1, 2] and Underlying Event (UE) characteristics [3] which are crucial to constrain and tune the parameters of multiple parton scattering models widely used in General Purpose Monte Carlo Generators [4–7]. In this short note we present tunes of the Multiple Parton Interactions (MPI) model in Herwig++ using these early LHC data sets.

2 Tuning of the model to the first LHC data

Before the LHC data was available, the two main parameters of the MPI model in Herwig++ [8–10], the inverse proton radius μ^2 and the minimum transverse momentum $p_\perp^{\rm min}$, were tuned by calculating the total χ^2 using the Tevatron UE data [11,12]. From this, we found a region in the two–dimensional parameter plane spanned by $p_\perp^{\rm min}$ and μ^2, where we obtain a similarly good overall χ^2 (deep blue area in Fig. 1(a)) and for which we get a truly satisfactory description of the data. As an example see Fig. 1(b).

Despite providing a very good description of the CDF UE data, it turned out that this model was too simple to describe the Minimum Bias ATLAS data collected at 900 GeV [1]. In particular, the model's results for the charged-particle multiplicity as a function of pseudorapidity and the average transverse momentum as a function of the particle multiplicity, $\langle p_\perp \rangle (N_{\rm ch})$ presented in Fig. 2, were highly unsatisfactory. The different colour lines in Fig. 2 represent

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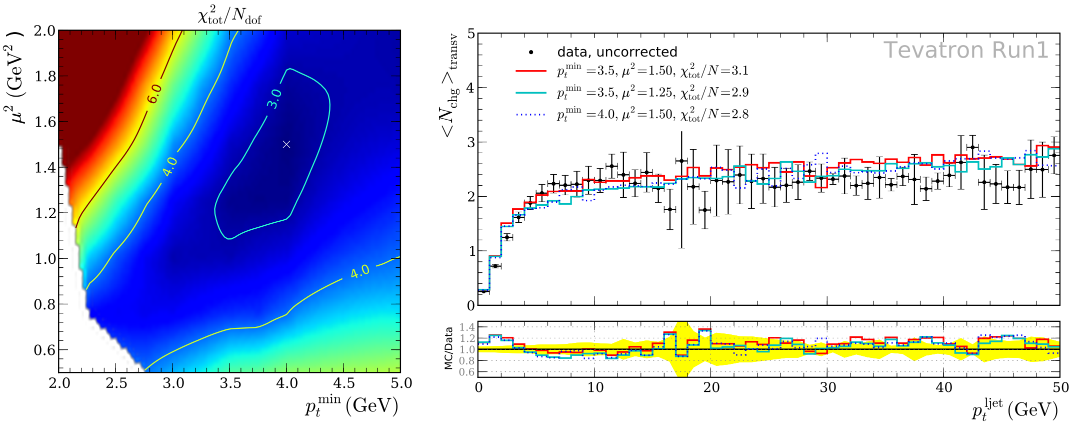

(a) (b)

Figure 1: Tuning the MPI model to pre-LHC data, plots taken from [10]. The left-hand plot shows contour plots for the χ^2 per degree of freedom for the fit to the CDF underlying event data. The cross indicates the location of Herwig++ preferred tune. In the right-side plot we see the multiplicity in the transverse region measured by CDF. The histograms show Herwig++ for three different MPI parameter sets.

different settings of the MPI model which give a satisfactory description of the Tevatron data for two different PDF sets: CTEQ6.1 [13] and MRST LO** [14]. As presented in more detail in [15–17], even a dedicated tuning of the MPI model parameters did not improve this description, which suggests that an important model detail is missing.

This triggered new developments of the MPI model to include non-perturbative colour reconnections (CR). They are described in more detail in a separate contribution to this workshop [18]. Currently two different colour reconnection implementations are available in Herwig++: a rather simple and plain model (pCR) and a statistical model (sCR). In this contribution we focus on the plain model, but at the end we also show some comparisons with the statistical model. Both CR models can be regarded as an extension of the cluster model [19], which is used for hadronization in Herwig++. Therefore, in principle both models require a re-tuning of the hadronization model, which is a difficult and time consuming process. The difficulty is due to the fact that the large number of hadronization parameters in Herwig++ have to be tuned to a wide range of experimental data, primarily from LEP. However, because the colour structure of the LEP final states is well-defined by the perturbative parton shower evolution, by construction of the CR model we do not expect that it will change this structure significantly. This was confirmed by comparison of Herwig++ results with and without CR against LEP data. For the case of the pCR model, an example is shown in Fig. 3. The full set of plots showing that the LEP data description in Herwig++ with and without CR is of the same quality can be found on the Herwig++ web page [20]. These results allowed us to factorize the tuning procedure and to keep using the well-tested default Herwig++ tune for parton shower and hadronization parameters, and tune only parameters of the CR and MPI models. In the case of the MPI model with plain CR, there are only two parameters steering the colour structure of the multiple interactions, $p_{\rm disrupt}$ and $p_{\rm reco}$, which we included in the tuning procedure along with $p_\perp^{\rm min}$ and μ^2. The Professor package was applied to produce a four-

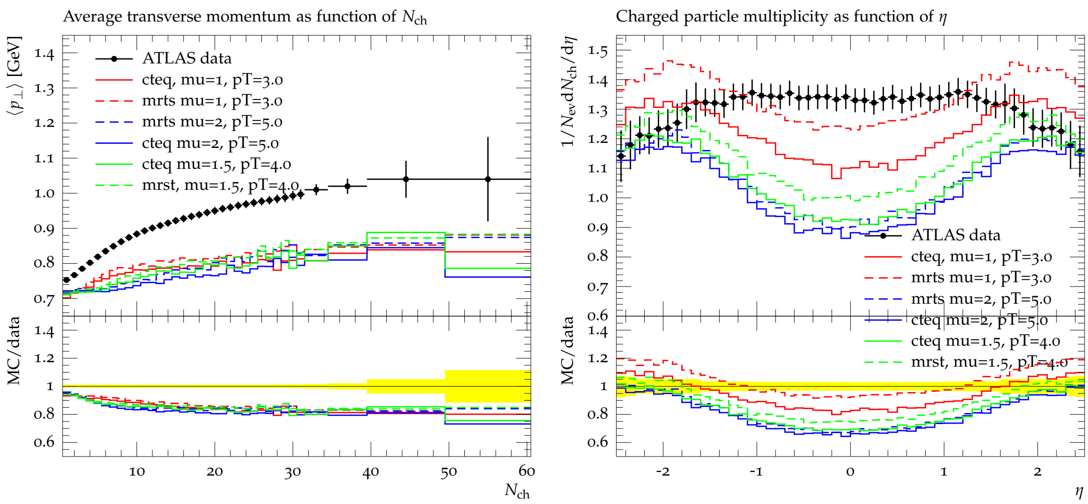

Figure 2: Comparison of Herwig++ 2.4.2 (without CR) to ATLAS minimum-bias distributions at $\sqrt{s} = 0.9$ TeV with $N_{ch} \geq 2$, $p_\perp > 500$ MeV and $|\eta| < 2.5$. The different colour lines represent different settings of the MPI model which give a satisfactory description of the Tevatron data for two different PDF sets CTEQ6.1 and MRST LO**.

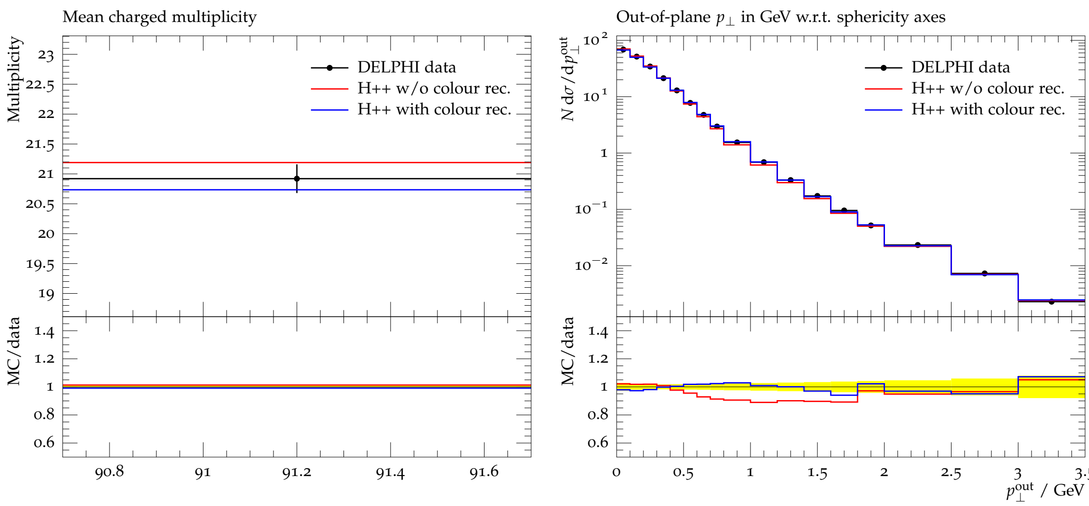

Figure 3: An example of comparison of Herwig++ with pCR (blue line) and without pCR (red line) to the measurements from DELPHI detector at LEP.

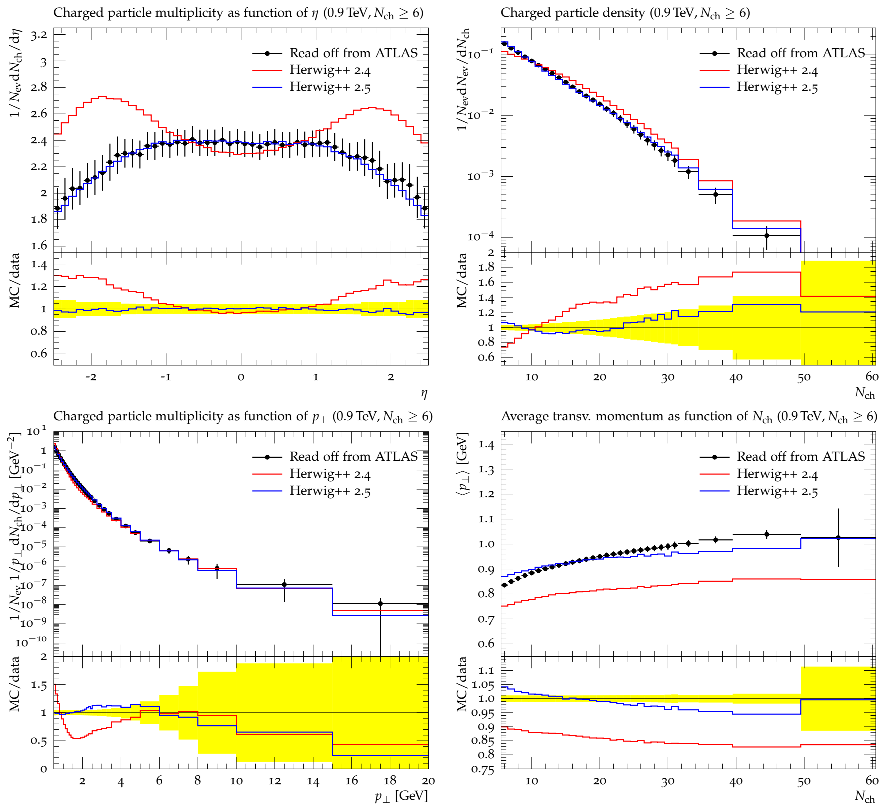

Figure 4: Comparison of Herwig++ 2.4.2 without CR model and Herwig++ 2.5 with pCR model to ATLAS minimum-bias distributions at $\sqrt{s} = 0.9$ TeV with $N_{\rm ch} \geq 6$, $p_\perp > 500$ MeV and $|\eta| < 2.5$. The ATLAS data was taken from plots published in Ref. [2].

dimensional tuning of parameters by a combination of response parametrization and numerical fit optimization as described in [21]. The Rivet package [22] was used to analyse the generated events and compare results against the experimental data. Initially we wanted to determine whether the new model would be able to improve the description of the MB data, therefore we started by tuning to ATLAS MB data. Because currently there is no model for soft diffractive physics in Herwig++ we use diffraction-reduced ATLAS MB analysis with an additional cut on the number of charged particles: $N_{\rm ch} \geq 6$. All four available MB observables were used without additional weightings to any observable. The results of this tune are shown by the blue lines in Fig. 4. In the top–left of this figure we can see that colour reconnection helps to achieve a better description of $\langle p_T \rangle (N_{\rm ch})$. The other three distributions are now well described giving the impression that the CR was the missing piece of the MPI model in Herwig++. The next very important question was whether the new model would be able to describe the UE data collected by ATLAS [3] at 7 TeV. As before we used the Professor tool to tune the parameters of the model. This time we used two observables for the tune, the mean number of stable charged particles per unit of η-ϕ, $\langle {\rm d}^2 N_{\rm ch}/{\rm d}\eta\, {\rm d}\phi \rangle$, and the mean scalar $p_\perp$ sum of stable particles per

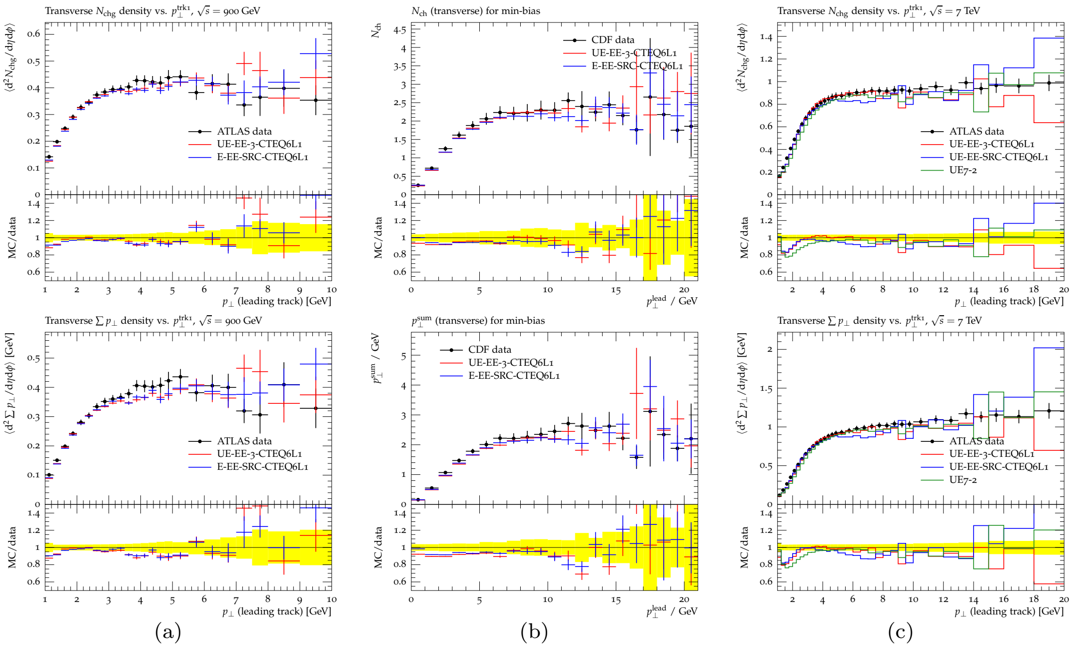

Figure 5: ATLAS data at 900 GeV (1st column), CDF data at 1800 GeV (2nd column) and ATLAS data at 7 TeV (3rd column), showing the density and $\sum p_\perp$ of the charged particles in the transverse area as a function of $p_\perp^{\rm lead}$. The data is compared with UE-EE-3, UE-7 and UE-EE-sCR tunes.

unit of η-ϕ, $\langle \mathrm{d}^2 \sum p_\perp / \mathrm{d}\eta\, \mathrm{d}\phi \rangle$, both as a function of $p_\perp^{\rm lead}$ in the kinematic range $p_\perp > 500$ MeV and $|\eta| < 2.5$. The resulting tune, named UE7-2, gives very satisfactory results for not only the tuned observables but also all other observables provided by ATLAS in Ref. [3]. In Fig 5(c) we present two selected examples: $\langle \mathrm{d}^2 N_{\rm ch} / \mathrm{d}\eta\, \mathrm{d}\phi \rangle$ and $\langle \mathrm{d}^2 \sum p_\perp / \mathrm{d}\eta\, \mathrm{d}\phi \rangle$ as a function of $p_\perp^{\rm lead}$ for the lower $p_\perp$ cut ($p_\perp > 500$ MeV) in the transverse region (which is the most sensitive region with respect to multiple interactions) compared to the Herwig++ UE7-2 results (green line). The full comparison with all ATLAS UE and MB data sets is available on the Herwig++ tune page [20]. We repeated the tuning process for the UE data collected by ATLAS at 900 GeV and CDF at 1800 GeV and obtained as good results as for 7 TeV. It is worth mentioning that the ATLAS UE observables with the lower $p_\perp$ cut, were not available during the preparation of the UE7-2 tune but are also very well described by the tune, see [20]. These results can therefore be treated as a prediction of the model. At this stage different UE tunes were mandatory for different hadronic centre-of-mass energies $\sqrt{s}$. In the next section we address the question of whether an energy-independent UE tune can be obtained using the present model.

3 Centre-of-mass energy dependence of UE tunes

To study the energy dependence of the parameters properly, we need to define a set of observables measured at different collider energies, for which description is sensitive to the MPI model parameters. The experimental data should be measured at all energies in similar phase-

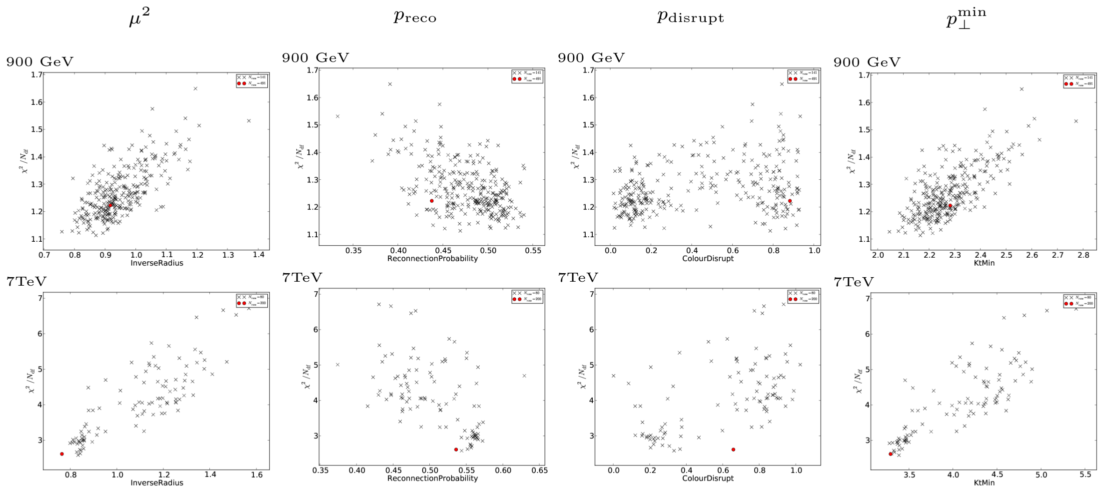

Figure 6: The spread of UE-EE tuning results for the μ^2, $p_{\rm reco}$, $p_{\rm disrupt}$ and $p_\perp^{\rm min}$ tunes, using cubic generator response parameterizations with all generator runs (red circles) and with subsets of generator runs (black crosses). The first row shows results for tunes to the data at 900 GeV and the second at 7 TeV.

space regions and under not too different trigger conditions. These conditions were met by two UE observables, $\langle {\rm d}^2 N_{\rm ch}/{\rm d}\eta\,{\rm d}\phi\rangle$ and $\langle {\rm d}^2 \sum p_\perp/{\rm d}\eta\,{\rm d}\phi\rangle$ measured as a function of $p_\perp^{\rm lead}$ (with $p_\perp^{\rm lead} < 20$ GeV) by ATLAS at 900 GeV and 7000 GeV (with $p_\perp > 500$ MeV) and CDF at 1800 GeV, therefore we used them for this task. For each hadronic centre-of-mass energy we preformed independent four-dimensional tunings.

Fig. 6 shows the spread of the tuning results for each parameter against Professor's heuristic χ^2. In the first row we present results for 900 GeV and in the second row for 7000 GeV. Each point is from a separate tune, made using various combinations of generator runs at points in the parameter space. We see that the parameters are not well constrained and are sensitive to the input MC runs. This is due to what we have already seen at the beginning of section 2 during the tuning of the MPI model without CR to the Tevatron data, namely the strong and constant correlation between $p_\perp^{\rm min}$ and μ^2 (represented by a dark blue area of Fig. 1(a)). This reflects the fact that a smaller hadron radius will always balance against a larger $p_\perp$ cutoff as far as the underlying-event activity is concerned. When we fix one of these two parameters, the rest of the parameters are much less sensitive to the input MC runs. The most important information we can see on these figures is that the experimental data for the two different energies (900 GeV and 7 TeV) can not be described by the same set of model parameters. More precisely, the experimental data prefers different $p_\perp^{\rm min}$ values for different hadronic centre-of-mass energies $\sqrt{s}$, while the rest of the parameters can remain independent of the energy. This observation led us to the creation of energy-extrapolated UE tunes, named UE-EE-3, in which all parameters are fixed except $p_\perp^{\rm min}$, which varies with energy. The parameter values for the UE-EE-3 tune for two different PDF sets, CTEQ6L1 and MRST LO**, are given in Table 1. As before we only present a selection of example observables for the UE-EE-3 tunes using the CTEQ6L1 PDF set. In Fig. 5 we show $\langle {\rm d}^2 N_{\rm ch}/{\rm d}\eta\,{\rm d}\phi\rangle$ and $\langle {\rm d}^2 \sum p_\perp/{\rm d}\eta\,{\rm d}\phi\rangle$ as a function of $p_\perp^{\rm lead}$ for lower $p_\perp$ cut ($p_\perp > 500$ MeV). We can see that the quality of the data description

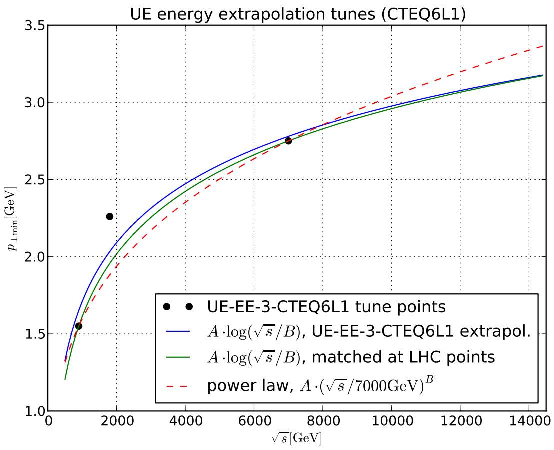

Figure 7: Example $p_\perp^{\min}$ energy extrapolation for UE-EE-3 CTEQ6L1 tune.

For PDF $\sqrt{s}$ [GeV]	CTEQ6L1 $p_\perp^{\min}$ [GeV]	MRST LO** $p_\perp^{\min}$ [GeV]
900	1.55	1.86
1800	2.26	2.55
2760	2.33	2.62
7000	2.75	3.06
8000	2.85	3.21
14000	3.16	3.53
For PDF	CTEQ6L1	MRST LO**
μ^2	1.35	1.11
p_{reco}	0.61	0.54
p_{CD}	0.75	0.80

Table 1: Parameters values from UE-EE-3 tunes for two different PDF sets.

by the UE7-2 tune and the energy-dependent tunes is on the same level. Because we do not know of any convincing physics argument how $p_\perp^{\min}$ should depend on the energy, in order to provide predictions for different energies we fit a function of the form $A \cdot log(\sqrt(s)/B)$, where A and B are free fit parameters, to the three $p_\perp^{\min}$ values obtained in the UE-EE-3 tuning. Some examples of possible fits are shown in Fig. 7. Based on this, we provide $p_\perp^{\min}$ values (see Table 1) for three different energies (2760, 8000 and 14000 GeV), for which in the future the LHC should provide experimental data, which then in turn can be confronted with the model predictions. Finally, although we do not present the details of how we obtained the tunes for the sCR model, we compare its results to the pCR for the observables included in Fig. 5. The results for both CR models give very similar results. The sCR model, however, allows for a much deeper understanding of the mechanism of colour reconnections, as is described in the already mentioned separate contribution to this workshop [18].

4 Conclusions and outlook

We have shown that by tuning the MPI model with CR, we can obtain a proper description of non-diffractive MB ATLAS observables. We present for the very first time the energy-extrapolated tune UE-EE-3, which is an important step towards the understanding of the energy dependence of the model. News concerning Herwig++ tunes are available on the tune wiki page [20].

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References

[1] G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **688** (2010) 21 (arXiv:1003.3124 [hep-ex]).

[2] G. Aad *et al.* [ATLAS Collaboration], New J. Phys. **13** (2011) 053033 (arXiv:1012.5104 [hep-ex]).

[3] G. Aad *et al.* [Atlas Collaboration], Phys. Rev. D **83** (2011) 112001 (arXiv:1012.0791 [hep-ex]).

[4] M. Bahr *et al.*, Eur. Phys. J. C **58** (2008) 639 (arXiv:0803.0883 [hep-ph]).

[5] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **0605** (2006) 026 (arXiv:hep-ph/0603175).

[6] T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. **178** (2008) 852 (arXiv:0710.3820 [hep-ph]).

[7] T. Gleisberg, S. Hoeche, F. Krauss, M. Schonherr, S. Schumann, F. Siegert and J. Winter, JHEP **0902** (2009) 007 (arXiv:0811.4622 [hep-ph]).

[8] M. Bahr, S. Gieseke and M. H. Seymour, JHEP **0807** (2008) 076 (arXiv:0803.3633 [hep-ph]).

[9] M. Bahr, J. M. Butterworth and M. H. Seymour, JHEP **0901** (2009) 065 (arXiv:0806.2949 [hep-ph]).

[10] M. Bahr, J. M. Butterworth, S. Gieseke and M. H. Seymour, arXiv:0905.4671 [hep-ph].

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

[12] D. Acosta *et al.* [CDF Collaboration], Phys. Rev. D **70** (2004) 072002 (arXiv:hep-ex/0404004).

[13] J. Pumplin, D. R. Stump, J. Huston, H. L. Lai, P. M. Nadolsky and W. K. Tung, JHEP **0207** (2002) 012 (arXiv:hep-ph/0201195).

[14] A. Sherstnev and R. S. Thorne, Eur. Phys. J. C **55** (2008) 553 (arXiv:0711.2473 [hep-ph]).

[15] S. Gieseke, S. Platzer, A. Siodmok and C. Rohr, DESY-PROC-2010-01.

[16] S. Gieseke, C. A. Rohr and A. Siodmok, arXiv:1110.2675 [hep-ph].

[17] P. Bartalini, E. L. Berger, B. Blok, G. Calucci, R. Corke, M. Diehl, Y. Dokshitzer, L. Fano *et al.*, arXiv:1111.0469 [hep-ph].

[18] S. Gieseke, C. Rohr and A. Siodmok "Multiparton Interactions in Herwig++," these proceedings.

[19] B. R. Webber, Nucl. Phys. B **238** (1984) 492.

[20] Herwig++ Collaboration (`http://herwig.hepforge.org/`), "Minimum Bias and Underlying Event tune", `http://projects.hepforge.org/herwig/trac/wiki/MB\_UE\_tunes`.

[21] A. Buckley, H. Hoeth, H. Lacker, H. Schulz and J. E. von Seggern, Eur. Phys. J. C **65** (2010) 331 (arXiv:0907.2973 [hep-ph]).

[22] A. Buckley *et al.*, arXiv:1003.0694 [hep-ph].