The Underlying Event in Herwig++

Stefan Gieseke[1], *Christian Röhr*[1,*], *Andrzej Siódmok*[1,2]

[1]Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany
[2]The University of Manchester, Manchester, United Kingdom

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We review the modelling of multiple interactions in the event generator Herwig++ and study implications of recent tuning efforts to LHC data. A crucial ingredient to a successful description of minimum-bias and underlying-event observables is a model for colour reconnection. Improvements to this model, inspired by statistical physics, are presented.

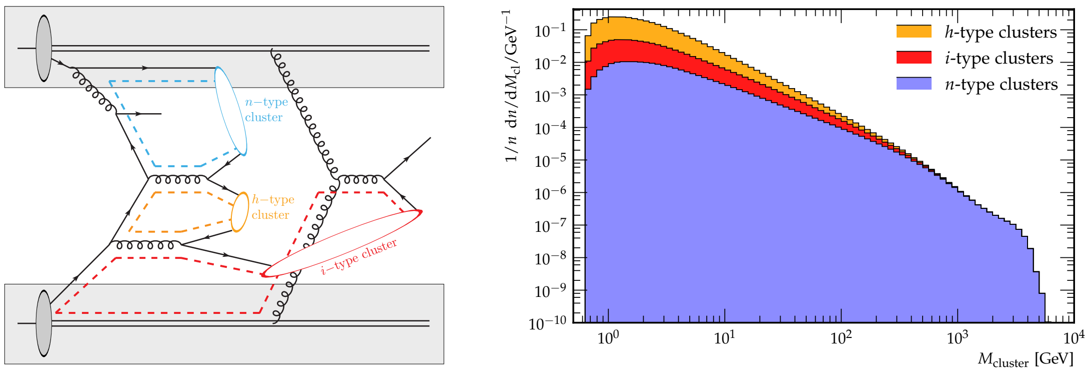
1 Introduction

Multiple partonic interactions (MPI) are vital for a successful description of the underlying event (UE) in hard hadronic collisions and of minimum-bias (MB) data from the Tevatron and the Large Hadron Collider (LHC). A model of independent multiple partonic interactions was first implemented in Pythia [1], where its relevance for a description of hadron collider data was immediately shown. Meanwhile, all major event generators for LHC physics, Herwig [2], Pythia [3, 4] and Sherpa [5], contain MPI models. The core MPI model in Herwig++, which is similar to the Jimmy add-on [6] to the Fortran version of Herwig, was introduced in Ref. [7]. Additional hard parton-parton scatters unitarize the hard jet cross section. Also the jet-like structure of the underlying event is reproduced by this model. With soft components in multiple parton interactions included, which is described in Ref. [8], this model is sufficient to describe the UE data collected at the Tevatron. First MB data from ATLAS [9], however, e.g. the pseudorapidity distribution of charged particles, cannot be reproduced with the core MPI model discussed so far.

As shown in Ref. [10], which we summarize in this work, we can significantly improve the description of MB and UE data from the LHC if we include a model for colour reconnections (CR). The idea of CR is based on colour preconfinement [11], which implies that parton jets emerging from different partonic interactions are colour-connected if they overlap in momentum space. As the core MPI model does not take that into account, those colour connections have to be adapted afterwards by means of a CR procedure.

The colour connections between partons define colour singlet objects, the clusters. The cluster hadronization model [12], which is implemented in Herwig++, generates hadronic final states based on clusters. Figure 1a shows that in events with multiple parton scatters clusters can be discriminated by the origin of their partonic constituents. We define three classes of clusters. h-type clusters consist of partons generated perturbatively in a single partonic subprocess. The second type of clusters are the subprocesses-interconnecting ones, which

*Speaker



(a) Sketch of cluster classes in a simple pp event. The classes are defined in the text.

(b) Contributions of the cluster classes to the invariant cluster mass distribution in soft-inclusive pp collisions at 7 TeV.

Figure 1: Classification of clusters in hadron collision events.

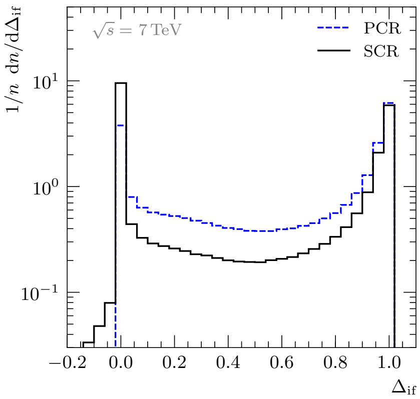
combine partons generated perturbatively in different subprocesses. These clusters are labelled as i-type. The remaining clusters, which we call n-type, contain one parton which was created non-perturbatively, i.e. during the extraction of partons from the hadrons or in soft scatters. Using this classification, we see in Fig. 1b that n-type clusters contribute most to the high-mass tail in the invariant mass distribution of the clusters. This observation is easily interpreted: The non-perturbative extraction of the partons from the protons, denoted by the grey-shaded area in Fig. 1a, may yield colour connections between partons which are distant in momentum space and thus have large invariant masses. To restore the physical picture of preconfinement, a colour reconnection model must be applied which helps to avoid these heavy clusters.

2 Colour reconnection models

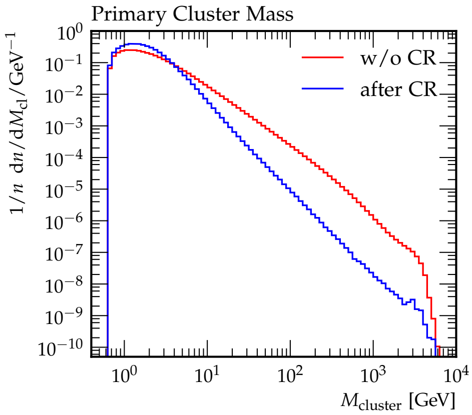
A colour reconnection model has been included in HERWIG++ as of version 2.5 [13]. This model iterates over all cluster pairs in a random order. Whenever a swap of colours is preferable, i.e. when the new cluster masses are smaller, this is done with a given probability, which is the only model parameter. This *plain* model has shown to give the desired results. As the clusters are presented to the model only in a given sequence, though, it is hard to assess which clusters are affected and to what extent the sequence is physically relevant.

For these reasons, we implemented another CR model, which adopts the Metropolis [14] and the Simulated-Annealing algorithm [15]. The *statistical* colour reconnection model has been implemented as of HERWIG++ 2.6 [16] and is discussed in detail in Ref. [10]. The new CR model reduces the colour length $\lambda \equiv \sum_{i=1}^{N_{\rm cl}} m_i^2$ statistically, where $N_{\rm cl}$ is the number of clusters in an event and m_i is the invariant mass of cluster i.

For both the plain and the statistical CR model we observe an extreme drop in the colour length, $\Delta_{\rm if} \equiv 1 - \lambda_{\rm final}/\lambda_{\rm init}$, as shown in Fig. 2a. Here, $\lambda_{\rm init}$ and $\lambda_{\rm final}$ denote the colour length λ before and after the colour reconnection procedure, respectively. The change in the cluster mass spectrum is directly visible in Fig. 2b. For these plots, a set of typical values for the model parameters was used, which we obtained from tunes to experimental data.



(a) Colour length drop in soft-inclusive *pp* collisions. PCR denotes the plain CR model, whereas SCR stands for the statistical model.



(b) Effect of colour reconnection on the cluster mass spectrum.

Figure 2: Impact of colour reconnection on the colour length and the cluster mass spectrum.

3 Results

We find that CR improves the description of MB data from ATLAS. As an example, we show in Fig. 3a the pseudorapidity distribution of charged particles at $\sqrt{s} = 900$ GeV, compared to ATLAS data from [17]. This analysis suppresses contributions from diffractive events by cutting on the transverse momentum of the charged particles, $p_\perp > 500$ MeV, and on the charged-particle multiplicity, $N_{ch} \geq 6$. As Herwig++ contains no model for soft diffraction, a comparison to samples with looser cuts, $p_\perp > 100$ MeV and $N_{ch} \geq 1$, which contain diffractive contributions, yields less agreement. We expand on this in more detail in [10].

The model also enables a good description of the underlying event. In Fig. 3b we see, as an example, the charged-particle multiplicity density at $\sqrt{s} = 7$ TeV, in a region *transverse* to the leading track in azimuth, $60° < |\Delta\phi| < 120°$, which is most sensitive to underlying-event activity. The model results are compared to ATLAS data from [18].

4 Conclusions

We have summarized the latest developments in the MPI model in Herwig++ and expanded on the motivation and modelling of colour reconnection. Furthermore, we have shown that (sufficiently diffraction-suppressed) minimum-bias data from the LHC and underlying-event observables are well described by the present model.

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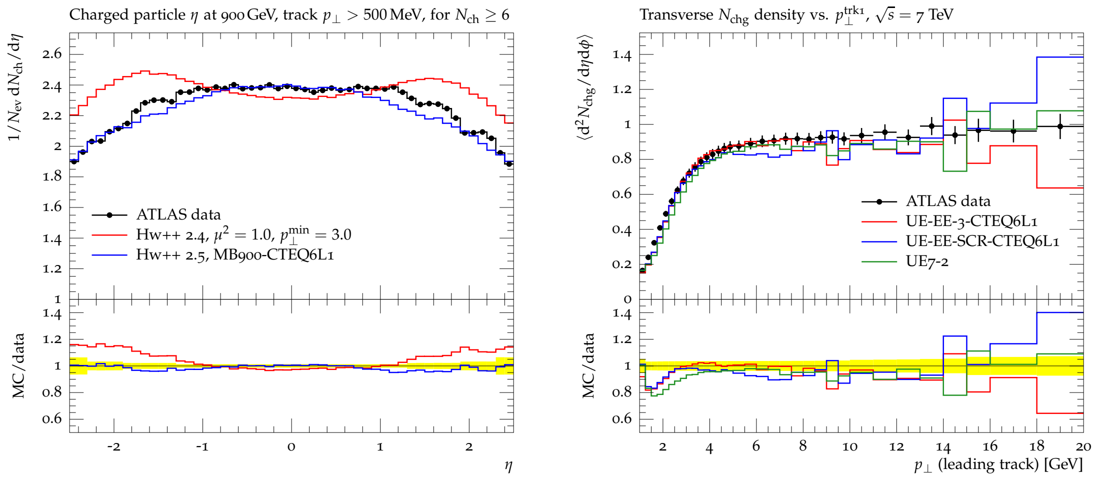

(a) Pseudorapidity distribution of charged particles. The HERWIG 2.4 model contains no CR. MB900-CTEQ6L1 is a dedicated tune of the model with PCR to 900 GeV MB data.

(b) Charged-particle multiplicity density in the transverse area as a function of the $p_\perp$ of the leading track. All histograms show HERWIG UE tunes including CR.

Figure 3: HERWIG results compared to ATLAS data.

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