Minimum Bias and Underlying Event Developments in Herwig++

Stefan Gieseke, Simon Plätzer, Andrzej Siodmok, Christian Röhr*

Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

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We briefly review the status of the multiple partonic interaction model in Herwig++. We present a comparison of some model results to ATLAS data at 900 GeV. As a result we outline how small improvements in Herwig++ result in a very reasonable description of recent minimum bias data.

1 Introduction

The underlying event model in Herwig++ [1] is based on the observation that the hard inclusive cross section for partonic $2 \to 2$ scatters,

$$\sigma^{\rm inc}(s; p_t^{\rm min}) = \sum_{i,j} \int_{p_t^{\rm min\,2}} {\rm d}p_t^2 f_{i/h_1}(x_1, \mu^2) \otimes \frac{{\rm d}\hat{\sigma}_{i,j}}{{\rm d}p_t^2} \otimes f_{j/h_2}(x_2, \mu^2)\,, \tag{1}$$

calculated from the usual collinear factorization ansatz, eventually exceeds the total cross section, which is expected to follow the Donnachie–Landshoff (DL)parametrization [2]. The lower limit of allowed transverse momenta is chosen to be $p_t^{\rm min}$, which is one of the main parameters of the model. The simplest way out is the observation that the proton is a spatially extended object, allowing for independent multiple hard interactions, which are stricly all taken into account in the calculation of the inclusive cross section. Hence, one may calculate the average number of hard interactions from an eikonal ansatz as

$$\bar{n}(\vec{b}, s) = A(\vec{b}; \mu^2)\sigma^{\rm inc}(s; p_t^{\rm min})\ . \tag{2}$$

Here, the overlap function $A(\vec{b}; \mu^2)$ describes the spatial overlap of the two colliding hadrons (protons) as a function of the impact parameter $\vec{b}$. The parameter μ^2 characterizes the inverse radius of the proton. We assume a spatial distribution following the functional form deduced from the electromagnetic elastic form factor. We do allow for a different width of the distribution though, as the colour might be distributed differently than the electric charges.

The extension to soft scatterings is kept as simple as possible. First, the transverse momentum of scattered particles is extended to transverse momenta below $p_t^{\rm min}$. The additional soft contribution to the inclusive cross section is also eikonalized, such that we can as well calculate an average number of soft scatters from the resulting $\sigma^{\rm inc}_{\rm soft}$ and an overlap function $A_{\rm soft}(\vec{b})$ for

*Speaker

the soft scattering centers. The functional form $A_{\rm soft}(\vec{b})$ is assumed to be the same as for the hard scatters, but we allow for a different inverse radius, $\mu^2_{\rm soft}$.

We keep this model consistent with unitarity by fixing the two additional parameters $\sigma^{\rm inc}_{\rm soft}$ and $\mu^2_{\rm soft}$ from two constraints. First, we can calculate the total cross section from the eikonal model and fix it to be consistent with the DL parametrization. In addition, using the optical theorem, we can calculate the t–slope parameter from the eikonal model as well and fix it to a reasonable parametrization.

After in a first step only the model for hard multiple partonic interactions has been introduced [3] we also studied its implications from Tevatron data and total cross section data in a simplified version [4]. Finally, the extension of the model to include soft scatters has been implemented in Herwig++ and is now the default underlying event model since version 2.3. In [5] the consistency of the model predictions with current Tevatron data has been studied in detail.

2 Herwig++ against first LHC data

Equipped with the good description of the Tevatron data we can now take a first look at the ATLAS measurements made at the 900 GeV and 7 TeV runs at the LHC [6]. We anticipate the possibility that the assumptions made in order to extend the model into the soft region may be far too simple. Nevertheless, we have been able to accommodate the detailed underlying event analyses carried out at the Tevatron. There we have come up with regions in the two dimensional parameter plane of $p_t^{\rm min}$ and μ^2 were we obtain a similarly good overall χ^2 for the underlying event data and still are consistent with our constraints from the total cross section and the elastic slope parameter. This region roughly follows a line. We now had a first look at Minimum Bias data, particularly the relatively simple distribution of charged particles in pseudorapidity.

As a first step we have varied our model parameters and compared the results against the 900 GeV data. In Fig. 1 we see the bands that result from varying the Herwig++ parameters. The blue lines indicate a favourable set of parameters. This clearly shows that, despite covering the data in the plot, the shape of the pseudorapidity distribution in Herwig++ is by far too much peaked in the forward directions. In addition, there is not enough freedom in our parameter space to describe $\langle p_\perp \rangle(N_{ch})$.

A first hint towards the possible improvement of the description is given in Fig. 2. We vary the probability that any of the additional soft scatters gets disconnected in colour space from the rest of the event and the beam remnants in particular. The value `cD` $= 1$ was used as a default, saying that the soft scatters have always been disconnected. Physically this means that there are no colour strings build up between the beam remnants and the soft particles produced in the soft underlying event. When they are build up more and more as we see when we vary the parameter towards the other extreme value 0 (always connected) we find that we produce many additional soft particles, building up an evenly filled plateau in rapidity. Having checked also other parameters, such as parton distribution functions and their behaviour at small x values we found that the effect of the colour disruption parameter was most important.

A second hint is given by the unability to describe $\langle p_\perp \rangle(N_{ch})$ which is considered to be very sensitive to the presence of non perturbative colour reconnections. So, as final additional we have considered a newly implemented model for soft colour reconnections in Herwig++. We find that only with the two latter modifications we can give a sensible description of minmum bias events.

In order to clearify this situation quantitatively we have to take into account that there currently is no model for diffractive physics in Herwig++. In order to exclude the contribution from diffractive events, ATLAS have imposed an additional cut on the number of charged particles in a minimum bias event, $N_{\rm ch} \geq 6$ [7]. The results have been presented at this conference but are not yet publicly available. We have read off the results of this preliminary study from the available plots[1] and compared to the simulation with Herwig++ in Fig. 3. Here, we have included the variation of the colour disruption parameter and the colour reconnection model. The figure shows that a good description of minimum bias observables is indeed possible. A final version of the colour reconnection model will be available with the next release of Herwig++. In order to release the model, further consistency checks against LEP data have to be completed as this data may as well be sensitive to the colour reconnection model.

3 Conclusion

We have tested the generation of minimum bias events in Herwig++ against first data from ATLAS and found that significant improvements in the colour treatment of the Herwig++ model are needed. Taking colour reconnections and stronger colour correlations of soft scatters with the beam remnants into account we find a very good description of non–diffractive minimum bias events.

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[1] which is possible to sufficiently high accuracy

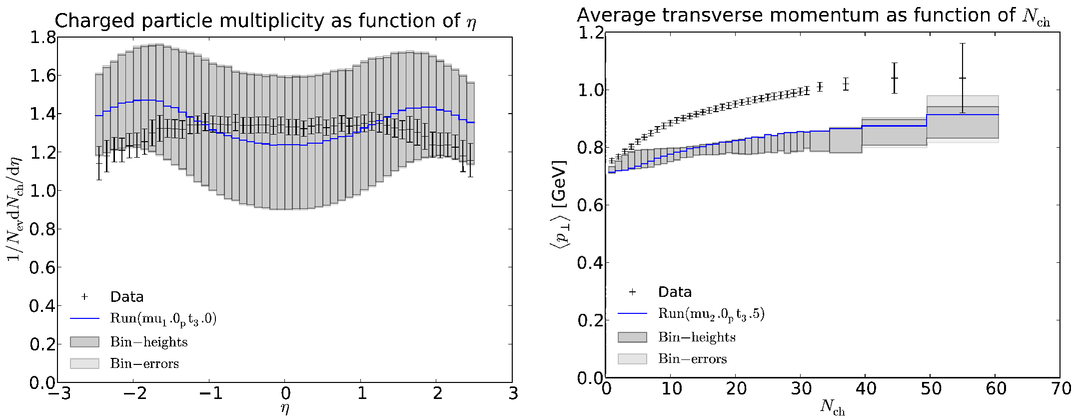

Figure 1: Pseudorapidity distribution of charged particles at 900 GeV compared to data (upper plot). $\langle p_\perp \rangle (N_{ch})$ at 900 GeV compared to ATLAS data. The grey bands indicate the variation from the unfixed parameters in Herwig++. The blue lines are some favourable choice of parameters.

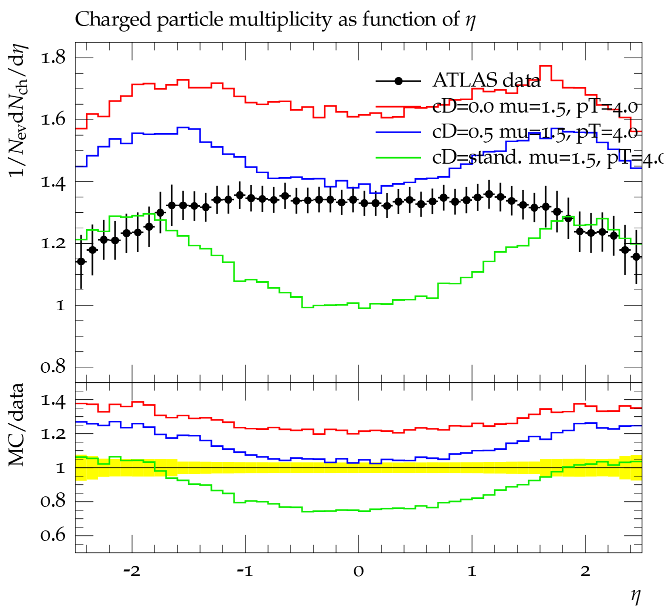

Figure 2: Pseudorapidity distribution of charged particles at 900 GeV compared to data. The lines show the sensitivity to the soft colour disruption parameter in Herwig++.

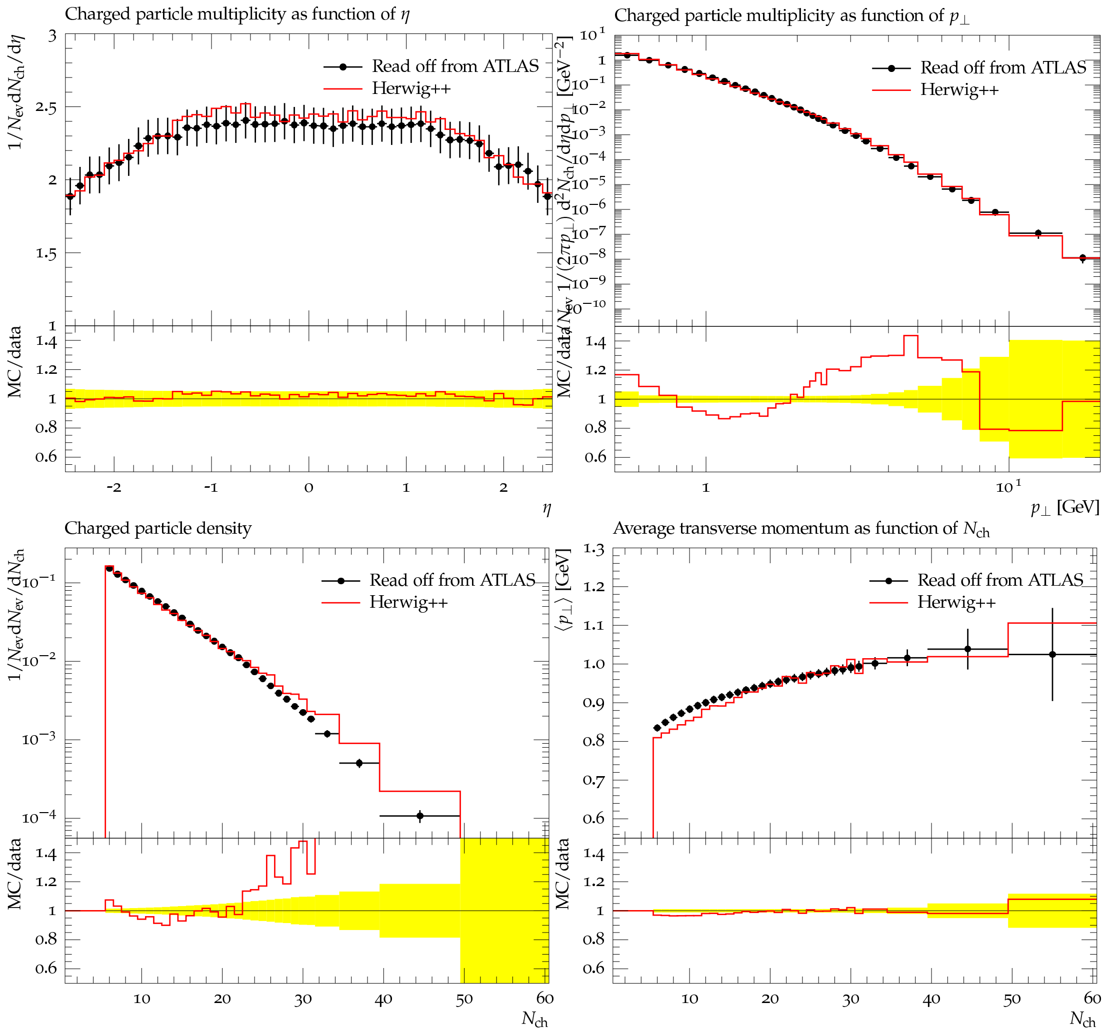

Figure 3: Various observables from the ATLAS $N_{\text{ch}} \geq 6$ analysis compared to Herwig++. The data points are read off preliminary, but publically available, ATLAS figures.