Progress on Multiple Interactions
Modelling the underlying event in hadron–hadron collisions

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Abstract. We report on the development of a new model for the underlying event in hadron–hadron collisions. The model includes parton showers for all interactions, as well as non-trivial flavour, momentum, and colour correlations between interaction initiators and beam remnant partons.

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1 Introduction

A simple consequence of the composite nature of hadrons is the possibility to have hadron–hadron collisions in which several distinct pairs of partons collide with each other (multiple interactions). In fact, simple perturbative calculations can be used to show [1] that most inelastic events in high–energy hadronic collisions should contain several perturbatively calculable interactions, in addition to whatever nonperturbative phenomena may be present.

Although most of this activity is not hard enough to play a significant role in the description of high–\(p_{\perp}\) jet physics, it can be responsible for a large fraction of the total multiplicity (and large fluctuations in it), for semi-hard (mini-)jets in the event, for the details of jet profiles and for the jet pedestal effect, leading to random as well as systematic shifts in the jet energy scale. Thus, a good understanding of multiple interactions would seem prerequisite to carrying out precision studies involving jets and/or the underlying event in hadronic collisions.

In an earlier study [1], it was argued that all the underlying event activity could be explained by the multiple interactions mechanism alone. However, while the origin of underlying events is thus assumed to be perturbative, many nonperturbative aspects still force their entrance on the stage. This in particular relates to the structure of beam remnants and to the correlations in flavour, colour, and momentum between the partons involved. In [1], only very simple beam remnant structures could technically be dealt with, hence substantial simplifications had to be imposed.

In recent years, the physics of the underlying event has come to attract more attention. Simple parameterizations can be tuned to describe the average underlying activity, but are inadequate to fully describe correlations and fluctuations. The increased interest and the new data now prompts us to develop a more realistic framework for multiple interactions than the one in ref. [1], while making use of many of the same underlying ideas.

One new aspect was the augmentation in [2] of the standard Lund string fragmentation framework [3] to include the hadronization of colour topologies containing non-zero baryon number. In the context of multiple interactions, this improvement means that almost arbitrarily complicated baryon beam remnants may now be dealt with, hence many of the restrictions present in the old model are no longer necessary.

Here, we present a model for how flavours, colours, and momenta are correlated between all the partons involved in a hadron–hadron collision, both those that undergo interactions and those constituting the beam remnants. However, all aspects of the model cannot be treated within the limits of this format, hence some aspects have been left out; we concentrate exclusively on baryon beams and neither the dependence on impact parameter nor the assignment of ‘primordial \(k_{\perp}\)’ to parton shower initiators is addressed here. More complete descriptions may be found in [4,5].

This article is organized as follows. In Section 2 the main work on flavour and momentum space correlations is presented and in 3 the very thorny issue of colour correlations. Finally, Section 4 provides a brief summary.

2 Towards a Realistic Model

Consider a hadron undergoing multiple interactions in a collision. Such an object should be described by multiparton densities, giving the joint probability of simultaneously finding \(n\) partons with flavours \(f_1, \ldots, f_n\), carrying momentum fractions \(x_1, \ldots, x_n\) inside the hadron,
when probed by interactions at scales $Q^2_1, \ldots, Q^2_n$. However, we are nowhere near having sufficient experimental information to pin down such distributions. Therefore, and wishing to make maximal use of the information that we do have, namely the standard one-parton-inclusive parton densities, we propose the following strategy.

As described in [1], the interactions may be generated in an ordered sequence of falling $p_t$. For the hardest interaction, all smaller $p_t$ scales may be effectively integrated out of the (unknown) fully correlated distributions, leaving an object described by the standard one-parton distributions, by definition. For the second and subsequent interactions, again all lower $p_t$ scales can be integrated out, but the correlations with the first cannot, and so on.

Thus, we introduce modified parton densities, that correlate the $i$th interaction and its shower evolution to what happened in the $i-1$ previous ones.

The first and most trivial observation is that each interaction $i$ removes a momentum fraction $x_i$ from the hadron remnant. Already in [1] this momentum loss was happened in the $i$th interaction and its shower evolution to what coming from this perturbative ansatz, and neglecting other contributions, by definition. For the second and subsequent interactions, all smaller $p_t$ scales can be integrated out of the (unknown) fully correlated distributions, leaving an object described by the standard one-parton distributions, by definition. For the second and subsequent interactions, again all lower $p_t$ scales can be integrated out, but the correlations with the first cannot, and so on.

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After the perturbative interactions have taken each their share of longitudinal momentum, the question arises how the remaining momentum is shared between the beam remnant partons. Here, valence quarks receive an $x$ picked at random according to a small–$Q^2$ valence-like parton density, while sea quarks must be companions of one of the initiator quarks, and hence should have an $x$ picked according to the $q_c(x; x_s)$ distribution introduced above. In the rare case that no valence quarks remain and no sea quarks need be added for flavour conservation, the beam remnant is represented by a gluon, carrying all of the beam remnant longitudinal momentum.

Further aspects of the model include the possible formation of composite objects in the beam remnants (e.g. diquarks) and the addition of non-zero primordial $k_\perp$ values to the parton shower initiators. Especially the latter introduces some complications, to obtain consistent kinematics. Details on these aspects will be presented in [5].

3 Colour Correlations

The initial state of a baryon may be represented by three valence quarks connected antisymmetrically in colour via a central ‘string junction’, $J$. b) Example of how a given set of parton shower initiators could have been radiated off the initial configuration, in the case of the ‘purely random’ correlations discussed in the text.

4 Conclusion

The development of a new model for the underlying event in hadron–hadron collisions has been reported. This model extends the multiple interactions mechanism proposed in [1] with the possibility of non-trivial flavour and momentum correlations, parton showers for all initiator and final state partons, and several options for colour correlations between initiator and beam remnant partons. Many of these improvements rely on the development of junction fragmentation in [2].

The issue of colour correlations is still actively under study.

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