MPI and Monte Carlo event generators

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This contribution summarizes recent developments in modeling multiple parton interactions within Monte Carlo event generators. We will review few selected topics driving current research in the field and address open questions.

1 Introduction

Monte Carlo event generators are indispensable tools for describing fully exclusive final states at collider experiments. In hadron collisions, multiple parton interactions not only play a crucial role in driving phenomena such as the underlying event, but are the key ingredient to modeling the 'average' (inelastic) hadron collision, commonly referred to as minimum bias physics.

Besides being of interest on its own, the underlying event impacts on all final states observed at the LHC and thus requires a sound understanding to identify the hard physics of interest; an accurate modeling of minimum bias physics is needed to simulate pile-up, multiple collisions during one bunch crossing.

Starting from simple parameterizations of the underlying event activity as measured by the UA5 experiment, more sophisticated models based on eikonalized cross sections have been developed. These models have received tremendous improvements over recent years, particularly towards the inclusion of soft underlying event activity, taking into account correlations between longitudinal and transverse structure inside the colliding hadrons, as well as an equivalent reformulation in terms of secondary scatters competing with initial state radiation.

Diffractive contributions to inelastic scattering have so far been treated mostly independent, but efforts are now underway to setup a unified framework including cut and uncut chain contributions on equal footing.

Besides these traditional models, independent approaches have set out to describe underlying event and minimum bias physics motivated by BFKL evolution. Most prominently, event generators are available incorporating CCFM evolution of initial state partons, as well as the dipole formulation of BFKL.

In this summary, we will first focus on developments within the class of eikonal models, as presented at this workshop and then briefly address BFKL motivated approaches. We will close with a selection of open questions before drawing general conclusions.

2 Eikonal approaches

Most of the established models for the description of inimum bias and underlying event physics are based on the eikonal ansatz of unitarized total cross sections. These approaches have been implemented in a variety of different model assumptions in all of the multi-purpose event generators used at LHC and previous hadron collider experiments.

Within the eikonal approaches of multiple partonic interactions, the connection to hadronization models seems to be crucial. Particularly, the color structure assigned to a sequence of several scatterings including subsequent radiation by parton showering does typically not seem to generate final states minimizing the energy of hadron progenitors, *i.e.* string pieces or clusters. The effect of these configurations can readily be recognized in predicting too much and mostly too forward hadronic activity. Most eikonal models are thus supplemented by a model of color reconnection, describing nonperturbative exchange of color charge such as to minimize the overall string length or sum of cluster masses. Driven by few parameters which need to be tuned to data, very reasonable descriptions of underlying event and minimum bias data can be achieved by including these models. Recent developements in this area, particularly statistical models for colour reconnection, have been discussed by Stefan Gieseke and Peter Skands. Tuning efforts which are required to fix the parameters of these models from data, showing the huge impact of colour reconnection on a sensible description of minimum bias and underlying event data have been presented by Deepak Kar and Andrzej Siodmok.

A crucial ingredient to all eikonal models of multiple parton interactions is the assumption on the quark and gluon distribution in the proton as a function of transverse degrees of freedom (impact parameter) and the longitudinal momentum fraction carried by each parton. The basic assumption is that the distribution factorizes into a transverse and a longitudinal contribution. This simple assumption does indeed seem to work very well, though there is no first-principle mechanism which would ensure its validity. Indeed, on very general grounds, it is expected that the width of the transverse distribution of partons will grow logarithmically with smaller momentum fractions. A model along these lines and its implementation in Pythia has been outlined by Peter Skands.

Closely connected to the modelling of the matter overlap of two colliding hadrons are potential explanations of the so-called ridge effect. CMS has reported the measurement of two-particle correlations as a function of the event multiplicity and track transverse momenta. Besides the known behavior of the measured correlation function, a new feature of long-range (in rapidity), near-side (in azimuth) correlations has been observed in events with high multiplicity and moderate $p_\perp \sim 2$GeV. A similar behavior has been observed in heavy ion collisions at RHIC, but not so far in pp collisions. The effect is not reproduced by any Monte Carlo simulation available so far. Sara Alderweireldt has presented a possible solution to explain this effect within the framework of multiple interactions. In a modified version of Pythia, additional azimuthal correlations have been introduced as a function of impact parameter, where a preferred plane is emerging in more peripheral collisions. A new tune has been required to still give an acceptable description of minimum bias and underlying event data, and the model indeed reproduces the 'ridge effect' at least qualitatively.

The description of diffractive contributions has so far been treated mostly independent of the eikonal models for multiple partonic interactions. Diffractive event generation is up to now rooted in the Ingelmann-Schlein model, assigning a partonic substructure to a pomeron along with appropriate parton distribution functions, which have been obtained from *e.g.* diffractive events measured at HERA. Additional gap survival factors need to be included to arrive at a reasonable description of diffractive events. Physically, the different diffractive, non-diffractive and elastic contributions can and should be treated on equal footing, though: they correspond to different cuts of diagrams contributing to the total cross section. Frank Krauss presented first steps towards a minimum bias simulation based on this motivation, more precisely on the model of Khoze, Martin and Ryskin. While there are many open issues until this simulation can be regarded a full-fledged model including the underlying event physics, first comparisons to minimum bias data look promising.

Event generators which are based on a Regge-physics picture right from the start are mainly used in the description of cosmic ray physics, but now receive increasing attention for hadron colliders, as well. Within this context, recent improvements to the DPMJET generator have been discussed by Fritz Bopp.

3 BFKL motivated approaches

At high energies, where the parton densities become large and where multiparton interactions can be expected, the longitudinal momentum fractions x at which the hard processes occur, can reach very small values, and deviations from the collinear DGLAP type evolution can be expected. The amount of multiparton interaction, which is needed to describe experimental measurements depends on the amount of activity from a single interaction and on the size of the parton distribution function. Thus one can expect, that a small x improved parton shower would imply a different contribution from multiparton interactions. This has been discussed in the contribution of F. Hautmann. The inclusive jet production at Tevatron and LHC energies is reasonably well described using unintegrated gluon distributions together with the $g^*g^* \to g$ process as discussed by V. Saleev. A reasonable description of also low p_t particle production at LHC energies is obtained by a gluon density which includes saturation effects (G. Lykasov). The small x behavior of the parton distribution is studied in a analytical way by A. Kotikov.

Not only a different parton evolution might play a role at highest energies, also parton recombination and saturation effects as well as diffractive interactions must appear, as predicted and described by the AGK rules (see the contribution by J. Bartels). The small x BFKL evolution can be described by the dipole picture of A. Mueller, which allows an extension to include also recombination effects (swing) as well as color singlet exchanges (diffraction), as described by the Lund Dipole Model and its Monte Carlo implementation DIPSI. This approach is successful describing diffractive processes from HERA as well as minimum bias and multiparton interaction processes at LHC, as discussed in the contribution by L. Lönnblad.

4 Open questions

The implementation of multiparton interactions in Monte Carlo event generators does not yet include small x improved parton showering, nor does it include saturation and recombination effect. However, using the DGLAP based collinear parton shower with the concept of multiparton interactions gives a surprisingly good description of experimental measurements.

- Can effects expected from small x evolution, like the energy and rapidity dependence of forward-backward jets (Mueller Navelet jets) be mimicked by multiparton interactions ? Is there a way to tell the difference ?

- Where is the signal from (soft as well as hard) diffractive processes, which must be present in multiparton interactions, seen ? Is the so-called "gap-survival" probability just a consequence of multiparton interactions ? Where do diffractive parton densities, as measured at HERA, play a role ?

- Is there a difference in the hadronic final state from a scenario with a BFKL like parton density, which needs saturation, compared to a parton density which has a less steep energy dependence ?
- Where is a signal from interfering multiparton ladders, apart from a schematic description of the Ridge effect in pp ?
- Where is the tension between a description of min-bias data and a description of the underlying event data coming from ? Does this indicate limitations of the present models of multiparton interactions ?
- How is the color distributed between different multiparton ladders ? Is color reconnection a effective parameterization of diffraction ?
- etc.

5 Conclusions

Many new and interesting measurements from LHC, HERA and Tevatron have been presented, which are in general reasonably well described by adjusting free parameters in the models of multiparton interactions. However, several questions on the consistency of the multiparton interaction approach have been raised. The measurements at LHC have reached a level of precision, that more fundamental questions can be addressed. The measurements and the model description has already after 2 years of LHC running reached a level comparable to what was achieved at the Tevatron. The much larger energy and the much larger fiducial coverage of the LHC detectors allow further measurements which can constrain the models much better and eventually lead to a understanding of the high energy behavior of hadronic interactions. The high energy behavior of hadronic cross sections is of fundamental importance: without multiparton interaction, saturation and diffraction, the hadronic cross section would increase to fast, leading to unitarization problems, similar to what happens with the longitudinal part of WW scattering without a Higgs. However, the unitarization problem of hadronic interactions is of much higher relevance, as the hadronic cross section domiates the interaction with matter.