SCREENING CORRECTIONS IN SIMULATING HEAVY ION COLLISIONS

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One year ago, we presented a new approach to treat hadronic interactions for the initial stage of nuclear collisions. It is an effective theory based on the Gribov-Regge formalism, where the internal structure of the Pomerons at high energies is governed by perturbative parton evolution, therefore the name “Parton-Based Gribov-Regge Theory”. The main improvement compared to models used so-far is the appropriate treatment of the energy sharing between the different elementary interactions in case of multiple scattering. It is clear that the above formalism is not yet complete. At high energies (RHIC, LHC), the multiple elementary interactions (Pomerons) can not be purely parallel, they interact. So we introduce multiple Pomeron vertices into the theory.

1 Introduction

The most sophisticated approach to high energy hadronic interactions is the so-called Gribov-Regge theory. This is an effective field theory, which allows multiple interactions to happen “in parallel”, with phenomenological objects called Pomerons representing elementary interactions. Using the general rules of field theory, one may express cross sections in terms of a couple of parameters characterizing the Pomeron. Interference terms are crucial, as they assure the unitarity of the theory.

A big disadvantage of GRT implementations so far is the fact that cross sections and particle production are not calculated consistently: the fact that energy needs to be shared between many Pomerons in case of multiple scattering is well taken into account when considering particle production (in particular in Monte Carlo applications), but not for cross sections.

Another problem is the fact that at high energies, one also needs a consistent approach to include both soft and hard processes. The latter ones are usually treated in the framework of the parton model, which only allows the calculation of inclusive cross sections.

We recently presented a completely new approach for hadronic interactions and the initial stage of nuclear collisions, which is able to solve several of the above-mentioned problems.
We provide a rigorous treatment of the multiple scattering aspect, such that questions of energy conservation are clearly determined by the rules of field theory, both for cross section and particle production calculations. In both (!) cases, energy is properly shared between the different interactions happening in parallel. This is the most important new aspect of our approach, which we consider a first necessary step to construct a consistent model for high energy nuclear scattering.

Let us consider nucleus-nucleus (\(AB\)) scattering. The nucleus-nucleus scattering amplitude is defined by the sum of contributions of diagrams, corresponding to multiple elementary scattering processes between parton constituents of projectile and target nucleons. These elementary scatterings are the sum of soft, semi-hard, and hard contributions: \(T_{2 \rightarrow 2} = T_{\text{soft}} + T_{\text{semi}} + T_{\text{hard}}\). A corresponding relation holds for the inelastic amplitude \(T_{2 \rightarrow X}\). We introduce “cut elementary diagrams” as being the sum over squared inelastic amplitudes, \(\sum_X (T_{2 \rightarrow X})(T_{2 \rightarrow X})^*\), which are graphically represented by vertical dashed lines, whereas the elastic amplitudes are represented by unbroken lines:

\[
\begin{align*}
T_{2 \rightarrow 2} &= \sum_X (T_{2 \rightarrow X})(T_{2 \rightarrow X})^*.
\end{align*}
\]

This is very handy for treating the nuclear scattering model. We define the model via the elastic scattering amplitude \(T_{AB \rightarrow AB}\) which is assumed to consist of purely parallel elementary interactions between partonic constituents, described by \(T_{2 \rightarrow 2}\). The amplitude is therefore a sum of many terms. Having defined elastic scattering and inelastic scattering, particle production is practically given, if one employs a quantum mechanically self-consistent picture. Let us now consider inelastic scattering: one has of course the same parallel structure, just some of the elementary interactions may be inelastic, some elastic. The inelastic amplitude being a sum over many terms \(- T_{AB \rightarrow X} = \sum_i T_{AB \rightarrow X}^{(i)}\) has to be squared and summed over final states in order to get the inelastic cross section, which provides interference terms \(\sum_X (T_{AB \rightarrow X}^{(i)})(T_{AB \rightarrow X}^{(j)})^*\). These can be conveniently expressed in terms of the cut and uncut elementary diagrams, as shown in fig. 1.

![Figure 1: Examples of cut multiple scattering diagrams, with cut (dashed lines) and uncut (full lines) elementary diagrams (Pomerons).](image-url)
One has to be careful about energy conservation: all the partonic constituents (lines) leaving a nucleon (blob) have to share the momentum of the nucleon. So, in the explicit formula one has an integration over momentum fractions of the partons, taking care of momentum conservation. This formula is the master formula of the approach, allowing calculations of cross sections as well as particle production.\footnote{1}

So far we described only the basic version of the model. In reality we also consider multiple Pomeron vertices, i.e. enhanced diagrams, which lead to take into account screening corrections (next section) and shadowing for nuclear scattering (work in progress).

2 Enhanced Diagrams

2.1 Presentation

We saw in section \footnote{1} that a Pomeron is an elementary interaction. If those Pomerons interact each other, then they give another type of interaction called \textit{enhanced diagram}. There are many types of enhanced diagrams depending on the number of Pomeron for each vertices and on the number of vertices. In our model, effective first order of triple and 4-Pomeron vertices (Y and X diagrams see fig. \footnote{3}) are enough to be self-consistent.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Y uncut and cut diagrams with triple Pomeron vertex and X uncut diagram (and some cut ones) with 4-Pomeron vertex.}
\end{figure}

Enhanced diagrams can be cut by different ways (fig. \footnote{3}). Each of those cut diagrams has a different share to the cross section. For instance, Y diagrams are negative contributions, called screening corrections, which lead to a slower increase of the total cross section depending on the energy. On the other hand, X diagrams are positive contributions to the cross section, i.e. anti-screening. Likewise, diagrams do not give the same multiplicity depending on the way they are cut, which leads to an increase of the fluctuations.

2.2 Results for proton-proton scattering

For the moment, not all enhanced diagrams are included in the \textsc{neXus} model. As a consequence, following results are calculated only with triple Pomeron diagrams (Y diagrams) with an effective coupling constant for pp scattering.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Deceleration of the growth of the cross section.}
\end{figure}

One can observe on the left plot of the fig. \footnote{3} a deceleration of the growth of the cross section. That means that the interaction’s probability of proton’s components is decreased by screening corrections. On the other hand, another consequence of the introduction of enhanced diagrams is quite visible on the right plot of fig. \footnote{3} (probability of producing N charged particles). It is noted that the probability of obtaining great multiplicities is 5 times larger if one includes triple Pomerons in the model. Indeed there are three types of cut triple Pomerons producing a very different number of new particles. As they are not always the same ones which take place event-by-event, the fluctuations are increased (sometimes few produced particles, sometimes much). And thus, on average, it arrives more often than a lot of particles are produced compared to the basic model.
3 Conclusion

The thorough study of the reaction’s mechanism of a proton-proton collision thus showed us that the exchange in parallel of elementary interactions called Pomerons with energy conservation was not enough to get a self-consistent theory at high energies. Indeed it is also necessary to consider the interactions between those Pomerons to have a model which includes the screening corrections. One then obtains a more realistic description of the concerned processes. Moreover, the introduction of this type of interaction into a nuclear scattering model allows also to take into account nuclear effects, such as shadowing effect, which play a major role in this type of reaction. We thus obtain a realistic and consistent model which describes the initial stage of ultra-relativistic heavy ions collisions and provides the initial conditions necessary to the description of the following stages of the reaction, as an hydrodynamic evolution of a QGP.

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