Cost of Survival for Large Rapidity Gaps

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In this note we report on calculations of the survival probability of the large rapidity gap (LRG) processes and its energy behaviour.

1. INTRODUCTION

In this note we consider reaction

\[ p + p \rightarrow X_1 + \text{jet}_1(y_1, p_1, t < \mu) + [LRG] + \text{jet}_2(p_2, t < \mu) + X_2, \]

where LRG denotes the large rapidity gap between produced particles and \( X \) corresponds to a system of hadrons with masses much smaller than the total energy.

The story of LRG processes started from Refs. [1, 2, 3], where it was noticed that these processes give us a unique way to measure high energy asymptotic at short distances. Indeed, at first sight the experimental observable

\[ f_{\text{gap}} = \frac{\sigma(LRG)}{\sigma(INCL)} = \langle |S|^2 \rangle \]

is directly related to the so called “hard” Pomeron exchange. However, this is not the case and the factor \( \langle |S|^2 \rangle \) appears between the “hard” Pomeron exchange and the experimental observable.

Actually, this factor \( \langle |S|^2 \rangle \) is a product of two survival probabilities

\[ \langle |S|^2 \rangle = \langle |S_{\text{bremsstrahlung}}(\Delta y = |y_1-y_2|)^2 \rangle \times \langle |S_{\text{spectators}}(s)|^2 \rangle \]

which have different meanings.

1. \( \langle |S_{\text{bremsstrahlung}}|^2 \rangle \) is probability that the LRG will not be filled by emission of bremsstrahlung gluons from partons, taking part in the “hard” interaction (see fig 1-a). This factor is certainly important and has been calculated in pQCD in Refs. [4, 5, 10]. We are not going to discuss it here.

2. \( \langle |S_{\text{spectators}}|^2 \rangle \) is related to probability that every parton with \( x_i > x_1 \) will have no inelastic interaction with any parton with \( x < x_2 \) (see fig. 1-b). The situation with our knowledge of this survival probability is the main goal of this paper.

2. Q & A

Q: Have we developed a theory for \( \langle |S_{\text{spectators}}(s)|^2 \rangle \)?

A: No, there are only models on the market (see Refs. [6, 7, 8, 9, 10]).

Q: Can we give a reliable estimates for the value of \( \langle |S_{\text{spectators}}|^2 \rangle \)?

A: No, we have only rough estimates based on the Eikonal - type models.

Q: Can we give a reliable estimates for the energy behaviour of \( \langle |S_{\text{spectators}}|^2 \rangle \)?

A: No, but we understood that \( \langle |S_{\text{spectators}}|^2 \rangle \) could steeply decreases with energy.

Q: Why are you talking about \( \langle |S_{\text{spectators}}|^2 \rangle \) if you can do nothing?

A: Because dealing with models we learned what questions we should ask experimentalists to improve
our estimate and what problems we need to solve theoretically to provide reliable estimates.

3. EIKONAL-TYPE MODELS

3.1. Eikonal model

In eikonal model we assumed that the correct degrees of freedom at high energies are hadrons, and, therefore, the scattering amplitude is diagonal in the hadron basis. Practically, it means \[ \sigma_{SD}/\sigma_{el}' \ll 1 \] that we assume that the ratio \( \sigma_{SD}/\sigma_{el}' \ll 1 \). In this model the unitarity constraint looks simple, namely,

\[
\text{Im} a_{el}(s, b) = |a_{el}(s, b)|^2 + G_{in}(s, b),
\]

which has solution in terms of arbitrary real function - opacity \( \Omega(s, b) \):

\[
a_{el} = i \left[ 1 - e^{-\Omega(s, b) \frac{R_{2}}{2}} \right] ; \quad \Omega(s, b) = \nu(s) e^{-\frac{b^2}{R_{2}^2}} ;
\]

where Eq. (6) is Pomeron-like parameterization that has been used for numerical estimates. The formula for survival probability looks as

\[
\langle |S|^2 \rangle = \frac{\int d^2 b e^{-\frac{b^2}{R_{H}^2}} e^{-\Omega(s, b)}}{\int d^2 b e^{-\frac{b^2}{R_{H}^2}}}
\]

where \( \chi^2 \) is radius for the hard processes. In Ref. \[ \right \] the values of \( R_{H}^2 \) and \( R_{2}^2(s) \) were discussed in details. The main observation is that the experimental value of the ration \( \sigma_{el}/\sigma_{tot} \) depends only on the value of \( \nu \). This gives us a way to find the value of \( \nu \) directly from the experimental data. The result is plotted in Fig.2 and shows both the small value of the survival probability and its sharp energy dependence.

3.2. Three channel model

The assumption that \( \sigma_{SD}/\sigma_{el}' \ll 1 \) is in contradiction with the experimental data, therefore, it is interesting to generalize the eikonal model to include processes of the diffractive dissociation. It was done in Ref. \[ \right \], where the rich diffractive final state was described by one wave function orthogonal to the hadron

\[
\Psi_{hadron} = \alpha \Psi_{1} + \beta \Psi_{2} ; \quad \Psi_{D} = -\beta \Psi_{1} + \alpha \Psi_{2} ,
\]

where \( \alpha^2 + \beta^2 = 1 \). The scattering amplitude is diagonal with respect functions \( \Psi_{1,2} \) and we used Eq. (6)-Eq. (8) -type parameterization to describe it. The result of our calculation is given in Fig.3.
4. CONCLUSIONS

The experimentally observed value of the survival probability appear naturally in these two models.

The parameters that have been used are in agreement with the more detailed fit of the experimental data.

It turns out that the scale of $\langle |S_{\text{spectator}}|^2 \rangle$ is given by ratios $R_{el} = \frac{\sigma_{el}}{\sigma_{\text{tot}}}$, $R_{SD} = \frac{\sigma_{SD}}{\sigma_{\text{tot}}}$, and $R_{DD} = \frac{\sigma_{DD}}{\sigma_{\text{tot}}}$, but not the ratio $R_{D} = \frac{\sigma_{el} + \sigma_{SD} + \sigma_{DD}}{\sigma_{\text{tot}}}$, which does not show any energy dependence.

The further measurement all ratios mentioned above will specify the model and will provide a better predictions for the survival probability. For example, new data on $R_{DD}$ [11] will specify the value of $\beta$ which will lead to more definite predictions for $\langle |S_{\text{spectator}}|^2 \rangle$ (see Fig. 3).

It is the most dangerous that we have no theoretical approach to calculation of the survival probability. I firmly believe that the theory of survival for large rapidity gaps in the region of high density QCD [12] will be very instructive and will give us new ideas for the physics of the large rapidity gap processes.

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Figure 3. The value of survival probability (Fig. 3-a), its energy dependence (Fig. 3-b) and prediction for the ratio of double diffraction dissociation to the total cross section (Fig. 3-c) versus $\beta$. 