SURVIVAL PROBABILITY
OF LARGE RAPIDITY GAPS

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\textbf{Abstract:} We summarize the discussions on the value of the survival probabilities of the large rapidity gap (LRG) processes at Durham WS’98.

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1. When we calculate the cross sections with the LRG such as the diffractive (double diffractive (DD)) processes or two jets production with the LRG between them, we have to estimate the probability that rapidity gap corresponding to the Pomeron exchange will not be filled by secondaries from the scattering of a spectator partons or from the decay of bremsstrahlung gluons. This survival probability $< S^2 > \approx 1$ depends on the kinematics of each specific process and may violate the factorization (even for the cases where the factorization properties of diffractive amplitudes are satisfied at the initial stage).

2. To demonstrate the role of bremsstrahlung emission let us consider the exclusive Higgs boson DD production

$$ pp \rightarrow p + [LRG] + H + [LRG] + p $$

where the heavy boson $H$ is bounded by two rapidity gaps [1].

We start from the simplest Low-Nussinov (two gluon exchange) model for the Pomeron. The Higgs boson is produced in the central rapidity region by the gluon-gluon fusion ($gg \rightarrow H$) whilst a second t-channel gluon is needed to screen the colour flow. The amplitude is proportional to the integral over the gluon transverse momentum $q_t$

$$ A \sim \int_{q_0} d q_t^2 \frac{q_t^4}{q_t^2} $$

(2)

The infrared cutoff $q_0$ provided by confinement ($q_0 \sim 1/R$) is of the order of the inverse proton radius $R$. In this picture the two t-channel gluons form a colour dipole with size $r \sim 1/q_t$. When two such dipoles annihilate into the Higgs boson they normally emit bremsstrahlung gluons with $k_t > q_t$ (but with $k_t$ much less than Higgs mass $M_H$).

In the Double Log approximation the mean number of emitted gluons is

$$ n \approx \frac{N_c \alpha_s}{2 \pi} \ln^2 \frac{M_H^2}{4 q_t^2} $$

(3)

and the probability amplitude not to observe these extra gluons is

$$ < S^2 >_{\text{bremsstrahlung}} = e^{-n/2} . $$

We have to include this factor $< S^2 >$ in the integral (2). Now the low $q_t$ contribution is suppressed and the integral has a saddle point at rather large $q_t^2 = q_0^2$. In other words the Sudakov form factor $< S^2 >_{\text{bremsstrahlung}}$ plays a role of the survival probability and selects the small size components of the Pomeron wave function (that is the configurations which do not emit too many gluons). Of course the cross section becomes smaller for such a small size Pomeron; e.g. for $M_H \sim 200$ GeV reaction (1) is suppressed by more than 1000 (!) by the pure perturbative ($q_t^2 \sim q_0^2 \sim 15 \text{ GeV}^2$) effects.
For more a complicated process the effective form factor $< S^2 >$ depends on the specific kinematics (see [2] for the case of high $E_T$ dijet DD production) and clearly violates the factorization property of Pomeron exchange amplitudes.

3. The probability $< S^2 >_{\text{spectators}}$ to avoid/(not to observe) the rescattering of spectator partons may be estimated by extending "Pumplin" bound [3]: \[ \sigma^D \leq \frac{\sigma_{\text{tot}}}{2} \] (here $\sigma^D = \sigma_{\text{el}} + \sigma^{SD} + \sigma^{DD}$ is the sum of all diffractive cross sections – elastic, single and double diffractive dissociation).

Using the eikonal model for parton-parton rescattering, and averaging over the impact parameter $b_t$, one obtains the expression [4]

$$< S^2 >_{\text{spectators}} = \left( 1 - \frac{2\sigma^D}{\sigma_{\text{tot}}} \right)^2$$

which can be used for phenomenological estimates of the survival probability $< S^2 >_{\text{spectators}}$.

However, some times the correlations in the $b_t$-plane becomes important both for the value of the survival probability and its energy dependence [5] [6]. To illustrate this point we take the simple Eikonal model in which the survival probability $< S^2 >_{\text{spectators}}$ has a very transparent form [7] [5]:

$$< S^2 >_{\text{spectators}} = \int \frac{d^2b\Gamma_H(b)P(s,b)}{\int d^2b\Gamma_H(b)},$$

where the "hard" profile

$$\Gamma_H(b) = \frac{1}{\pi R_H^2(s)} e^{-\frac{b^2}{R_H^2(s)}}$$

where $R_H$ denotes the radius of interactions in the "hard" scattering process (for example, two jet production with high transverse momenta and LRG between them). $P(s,b) = e^{-\Omega(s,b)}$ is the probability that no inelastic interaction takes place at impact parameter $b$. Indeed, this meaning of $P(s,b)$ follows directly from the unitarity constraint which gives for the probability of all inelastic interaction $G_{\text{in}}(s,b)$:

$$G_{\text{in}}(s,b) = 1 - e^{-\Omega(s,b)},$$

where $\Omega(s,b)$ is an arbitrary real function called opacity.

Assuming the simplest $b$-profile for opacity:

$$\Omega(s,b) = \nu(s) e^{-\frac{b^2}{R_S^2(s)}},$$

with $R_S^2(s) = 2B_{el}(s)$ (i.e. $\frac{d\sigma}{dt} \sim e^{B_{el}(s)t}$), one can see [5][6] that the ratio $R = \frac{\sigma_{el}}{\sigma_{\text{tot}}}$ depends only on $\nu(s)$, namely:

$$R = \frac{\sigma_{el}}{\sigma_{\text{tot}}} = 1 - \frac{\ln(\nu) + C - Ei(-\nu)}{2[\ln(\nu/2) + C - Ei(-\nu/2)]}.$$
Eq. (9) allows us to find the value and energy dependence of parameter $\nu(s)$ using the experimental data for ratio $R$.

Using Eq. (9) we can calculate the survival probability due to possible interaction of spectator partons (see Eq. (5)):

$$<S^2>_{\text{spectators}} = \frac{a(s)\gamma[a(s),\nu(s)]}{[\nu(s)]^a(s)},$$

where $Ei(x) = \int_{-\infty}^{x} \frac{e^t}{t} dt$ is integral exponent, $\gamma(a, x) = \int_{0}^{x} z^{a-1} e^{-z} dz$ is the incomplete gamma function, $C=0.5773$ is the Euler constant and $a(s)$ is defined by

$$a(s) = \frac{R^2_{H}(s)}{R^2_{S}(s)}$$

In Ref. [6] the value of $R_H$ has been evaluated ($R^2_H = 8 GeV^{-2}$) using the experimental data on double parton cross section and on the $J/\Psi$ production in DIS. Fig. 1 shows the result of numerical calculations [6] which shows that this simple model can reproduce a small value of the survival probability and its energy dependence, namely:

$$\frac{<S^2>_{\sqrt{s}=630}}{<S^2>_{\sqrt{s}=1800}} = 2.2 \pm 0.2,$$

which is in a perfect agreement with the experimental data [8].

4. The resulting survival probability $<S^2> = <S^2(\Delta y)_{\text{bremsstrahlung}} \times <S^2(s)>_{\text{spectators}}$. The first factor depends mostly on the value of the LRG and can be estimated in the framework of pQCD, the second one depends mostly on the total energy and could be evaluated only in nonperturbative QCD. It means, practically, that we can have only models for its calculation. The Eikonal model with Gaussian impact parameter dependence is one of many, which has a obvious shortcoming since it takes into account only interaction of the fastest spectators. The only way to avoid uncertainties in calculations of $<S^2(s)>_{\text{spectators}}$ which we see at the moment is to measure the LRG processes in DIS [9]. In DIS $<S^2(s)>_{\text{spectators}}$ is about 0.7 - 0.8 and can be calculated in pQCD [9] [10]. For larger value of $Q^2 <S^2(s)>_{\text{spectators}} \rightarrow 1$ and it makes LRG processes in DIS is a good laboratory to measure $<S^2(\Delta y)_{\text{bremsstrahlung}}$.

References


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Figure 1: Contour plot of survival probability $< S^2 >_{spectators}$.


