Survival Probability in hadron-hadron interactions

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The values and energy dependence for the survival probability $< |S|^2 >$ of large rapidity gaps (LRG) are calculated in a three channel model. We find that $< |S|^2 >$ decreases with increasing energy, in line with recent results for LRG dijet production at the Tevatron.

1. DEFINITIONS AND GENERAL DISCUSSION

A LRG process[1] [2] is a multiparticle production process in which no particles are produced in a large window in rapidity. The typical process of this kind is the production of two jets with high transverse momenta (p_{1t} and p_{2t}) and large rapidity difference ($y_1 - y_2 \gg 1$) between them in which no hadrons are produced.

Bjorken advocated that LRG processes are a unique way to measure high energy asymptotics at short distances. This is known as the asymptotic exchange of the "hard" Pomeron, which we hope can be calculated in pQCD. The following observable was suggested [1] [2] to be measured experimentally (see Fig.1):

$$f_{gap} \; = \; \frac{\sigma(\; dijet \;\; production \;\; with \;\; LRG \;)}{\sigma_{inclusive}(\; dijet \;\; production \;)} \; . \quad (1)$$

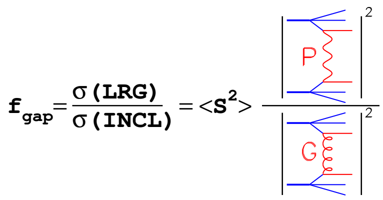

Figure 1. General expression for f_{gap}.

Unfortunately, the experimental observable f_{gap} does not measure the contribution of the "hard" Pomeron but has a factor[2] $< |S^2| >$ which is called the survival probability of LRG and which is the subject of this talk.

2. Data

We start to discuss the problem of the survival probability citing all experimental data on this subject given by D0[3] and CDF[4].

D0[3] find $f_{gap}(\sqrt{s} \; = \; 1800 \, GeV \,)$ 0.54 $\pm$ 0.17 % while CDF [4] have for the same quantity 1.13 $\pm$ 0.16 %, for $f_{gap}(\sqrt{s} \; = \; 640 \, GeV \,)$ D0 find 1.85 $\pm$ 0.38% and CDF measure 2.7 $\pm$ 0.9 %. For

$$R_{gap} \; = \; \frac{f_{gap}(\sqrt{s} \; = \; 630 \, GeV \,)}{f_{gap}(\sqrt{s} \; = \; 1800 \, GeV \,)}$$

D0 quote 3.4 $\pm$ 1.2 while CDF find 2.4 $\pm$ 0.9.

Another interesting quantity measured by D0 is

$$R_S \; = \; \frac{\langle | \; S \; |^2 \rangle (\sqrt{s} \; = \; 630 \, GeV \,)}{\langle | \; S \; |^2 \rangle (\sqrt{s} \; = \; 1800 \, GeV \,)} = 2.2 \, \pm \, 0.8.$$

We can learn two important properties of $\langle | \; S \; |^2 \rangle$: The value of $\langle | \; S \; |^2 \rangle$ is small ($\langle | \; S \; |^2 \rangle$ about 10%) because all estimates show that the ratio of "hard" Pomeron to inclusive dijet production is about 10 - 20% ;

$\langle | \; S \; |^2 \rangle$ decreases rapidly with energy. It is possible that the survival probability is to blame for the experimentally observed fast decreasing of f_{gap}, since the ratio of "hard" Pomeron to inclusive dijet production can only increase in pQCD.

It should be stressed that only the first data on f_{gap} in DIS [5] have appeared, this does not allow us to make any conclusions on the energy behaviour of $\langle | S |^2 \rangle$, but suggest that the value of the survival probability, is much higher ($\langle | S |^2 \rangle \approx 50 - 70\%$) than in hadron - hadron collisions.

3. SURVIVAL PROBABILITY IN THE EIKONAL MODEL

To understand the main features of the survival probability, we consider the simplest phenomenological model for the "soft" interaction - the Eikonal model.

- *Main assumptions:*
- Only the fastest parton interacts with "wee" partons
- Hadrons are correct degrees of freedom at high energy
- $\frac{\sigma_{SD}+\sigma_{DD}}{\sigma_{el}} \ll 1$
- Oversimplified final state
- *Simple form of unitarity:*

$$2\, Im a_{el}(s,b) = | a_{el}(s,b) |^2 + G_{in}(s,b). \qquad (2)$$

- *Solution:*

$$a_{el} = i\,[\,1 - e^{-\frac{\Omega(s,b)}{2}}\,]\,; \qquad (3)$$
$$G_{in}(s,b) = 1 - e^{-\Omega(s,b)}\,; \qquad (4)$$

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

- *Simple parameterization :*

$$\Omega(s,b) = \frac{\sigma_0}{\pi R^2(s)}\,(\frac{s}{s_0})^{\Delta_P}\, e^{-\frac{b^2}{R^2(s)}} \qquad (5)$$
$$= \nu(s)\, e^{-\frac{b^2}{R^2(s)}}$$

- *Analytical formulae for "soft" observable:*

$$\sigma_{tot} = 2\int d^2b(1 - e^{-\Omega(s,b)/2}) \qquad (6)$$
$$= 2\pi R^2(s)\,[\,ln(\frac{\nu(s)}{2}) + C - Ei(-\frac{\nu(s)}{2})\,]\,;$$
$$\sigma_{in} = \int d^2b(1 - e^{-\Omega(s,b)}) \qquad (7)$$
$$= \pi R^2(s)\,[\,ln(\nu(s)) + C - Ei(-\nu(s))$$
$$\sigma_{el} = \sigma_{tot} - \sigma_{in} = \pi R^2(s)\,[\,ln(\frac{\nu(s)}{4}) + C +$$
$$Ei(-\nu(s)) - 2Ei(-\frac{\nu(s)}{2}) \qquad (8)$$

- *A simple formula for survival probability:*

$$<| S_{spectator} |^2> = \frac{\int d^2b \Gamma_H(b) P(s,b)}{\int d^2b \Gamma_H(b)}\,, \qquad (9)$$

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

- *Analitycal form of* $<| S_{spectator} |^2>$ *:*

$$<| S_{spectator} |^2> = \frac{a(s)\gamma[a(s),\nu(s)]}{[\nu(s)]^{a(s)}} \qquad (10)$$

with $a(s) = \frac{R_S^2(s)}{R_H^2}$.

4. SURVIVAL PROBABILITY IN THE EIKONAL MODEL (COMPARISON WITH EXPERIMENT)

To get more reliable estimates for the value and energy dependence of $<| S_{spectator} |^2>$ we tried to extract all parameters directly from the experimental data [8]. The first observation (see Eqs.(7) - (9)) is that the ratio

$$R_{el}(\nu) = \frac{\sigma_{el}}{\sigma_{tot}} \qquad (11)$$

is a function of the only parameter ν. Therefore, we can use the experimental data on R_{el} to fix ν at particular value of energy (see Fig.2).

To fix the value of $a(s)$ we used the data on J/Ψ production[9] which shows two different slopes in t-dependence for elastic and inelastic processes (

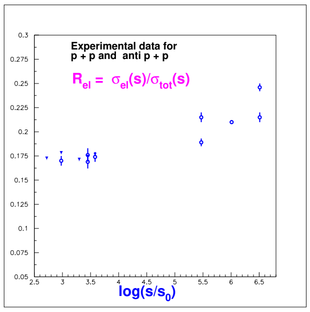

Figure 2-a

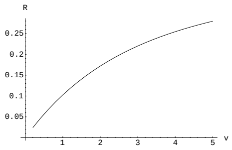
Figure 2-b

Figure 2. Experimental data (Fig.2-a) and the Eikonal model predictions (Fig.2-b) for $R_{el} = \frac{\sigma_{el}}{\sigma_{tot}}$.

see Fig. 3-a). These data can be used to extract the value of $R^2_H = 8\, GeV^{-2}$ (see Ref. [8]).

Using "soft" phenomenology for $R^2(s)$ [8] we obtain a prediction for the survival probability given in Fig.6. One can see that the Eikonal model reproduces both the experimental value and the energy dependence of the survival probability.

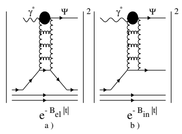
Figure 3-a

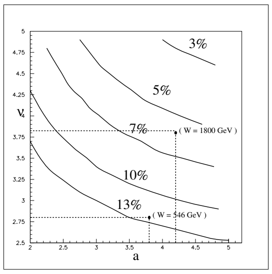

Figure 3-b

Figure 3. it J/Psi production (Fig.3-a) and the survival probability $<|\ S_{spectator}\ |^2>$ in the Eikonal model (Fig.3-b)

5. A MORE GENERAL APPROACH TO CALCULATE $<|\ S_{spectator}\ |^2>$

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In Ref. [10] a more general approach has been developed to calculation of $<|\ S_{spectator}\ |^2>$ which based on the following assumptions:

- Only the fastest parton interacts with the target ;
- Hadrons are not correct degrees of freedom ;
- $\frac{\sigma_{DD}(\,M > M_0\,)}{\sigma_{el}} \ll 1$;
- Oversimplified final state: central production (uniform in rapidity) and elastic + diffractive production with small masses.

One can see that all the above assumptions are very close to the Eikonal model, and the difference is only in the way how the diffractive production processes are treated. In the model of Ref. [10] we assume that the correct degrees of freedom at high energy are not hadrons, but some different states which are described by wave functions Ψ_1 and Ψ_2. Our interaction matrix is diagonal

$$<\Psi_n \times \Psi_m|\mathbf{T}|\Psi_{n'} \times \Psi_{m'}>= A_{n,m}(s,b_t)\,\delta_{nn'}\,\delta_{mm'} \quad (12)$$

and only for $A_{n,m}$ (not for hadrons) unitarity has a form:

$$2 Im A_{n,m}(s,b_t) = |A^2_{n,m}(s,b_t)|^2 + G^{in}_{n,m}(s,b_t). \quad (13)$$

Produced hadron and a diffractive state have the following wave functions:

$$\Psi_{hadron} \;=\; \alpha\,\Psi_1 \;+\; \beta\,\Psi_2\;; \quad (14)$$

$$\Psi_D \;=\; -\beta\,\Psi_1 \;+\; \alpha\,\Psi_2\,. \quad (15)$$

Therefore, three channels are taken into account in this model, namely, elastic scattering, single and double diffractive production while only elastic rescatterings were included in the Eikonal model.

Using the Eikonal - like parameterization, the three channel model leads to the prediction for the value and energy dependence of $\langle|\ S_{spectator}\ |^2$

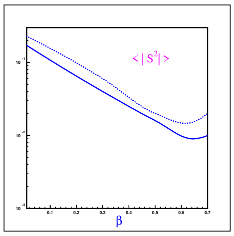

Figure 4-a

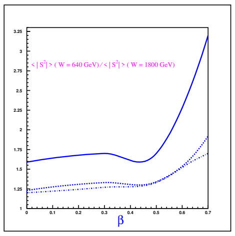

Figure 4-b

Figure 4. The value (Fig.4-a) of survival probability $<| S_{spectator} |^2>$ at $\sqrt{s} = W = 1800\,GeV$ and the ratio $<| S(W = 640\,GeV) |^2> / <| S(W = 1800\,GeV) |^2$ (Fig.4-b) versus β in the three channel model.

$\rangle$ given in Fig.4. One can see that this model can reproduce the experimental data including the energy dependence.

Summarizing the experience dealing with three channel model, we can conclude that:

- Accuracy of the three channel model, in principle, is much better than in the Eikonal Model, but still one does not know what to do with diffraction in the region of large mass ($M \approx s$) ;

- The scale of SC is not given by $R_D = \frac{\sigma_{el} + \sigma_{SD} + \sigma_{DD}}{\sigma_{tot}}$, but rather by the separate ratios
  $R_{el} = \frac{\sigma_{el}}{\sigma_{tot}} \quad R_{SD} = \frac{\sigma_{SD}}{\sigma_{tot}} \quad R_{DD} = \frac{\sigma_{DD}}{\sigma_{tot}}$

- The small value of the survival probability as well as its strong energy dependence appear naturally in this approach ;

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

6. CONCLUSIONS

We can estimate the survival probability in hadron - hadron collisions only in rather primitive models, which reproduces the trends of the experimental data.

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