EXCLUSIVE $J/\Psi$ PRODUCTION IN $PP$ AND $P\bar{P}$ COLLISIONS AND THE QCD ODDERON

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We briefly present the QCD based calculation of exclusive $J/\psi$ production via pomeron-odderon fusion in proton-antiproton collision. For the Tevatron energy the differential cross section $d\sigma/dy(y = 0)$ is estimated to be around 1 nb.

1 Introduction

The color neutral gluon systems, exchanged at high energy scattering processes, can be classified with respect to their $C$ parity. The most important one is $C$-even system with quantum numbers of vacuum i.e. the pomeron. In perturbative QCD the lowest order prototype of the pomeron is the color neutral system of two gluons. The odderon is the $C$-odd partner of the pomeron. The hard odderon skeleton consists of three gluons in a color neutral state. It is quite obvious that the effects of the odderon exchanges are less important than those due to the pomeron (one would naively expect a suppression by a power of the coupling constant $\alpha_s$ for the additional gluon). It is not clear, however, why the contribution of the odderon is so small that it has not been definitely observed by any experiment.

The concept of the odderon was introduced a long time ago $^1$. To this day the best, but still weak, experimental evidence for the odderon was found as a difference between the differential cross sections for elastic $pp$ and $p\bar{p}$ scattering at $\sqrt{s} = 53$ GeV at CERN ISR $^2$. A natural difficulty in detecting odderon effects is the fact that, in general, the odderon and the pomeron contribute to the scattering amplitude at the same time. For a detailed review of the phenomenological and theoretical status of the odderon we refer the reader to $^3$.

Recently more attention has been given to exclusive production processes in which the odderon is the only possible exchange. In the present paper we concentrate on exclusive $J/\psi$ meson production in $p\bar{p}$ collisions: $p\bar{p} \rightarrow p + J/\psi + \bar{p}$ where ”+” means rapidity gap. This process occurs via pure odderon exchange without any pomeron mixing. The odderon is here in competition only with the photon which is under good theoretical control.

2 Exclusive $J/\psi$ production in perturbative QCD

Diffractive production of $J/\psi$ meson in proton-(anti)proton collisions via pomeron-odderon fusion was investigated in ref. $^4$ in the framework of Regge theory. The potential contribution of the $\omega$ reggeon to this process is expected to be strongly suppressed due to the Zweig rule. It was

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estimated that for $p\bar{p}$ collisions at $\sqrt{s} = 2$ TeV a total cross section is of the order $\sigma_{tot} = 75$ nb.\(^6\) This result is quite encouraging, however, it should be treated rather as an order of magnitude estimate.

There is another very attractive theoretical feature of this process, that is a presence of relatively large scale $m_{J/\psi}^2$ that, with a bit of optimism, justifies the use of perturbative QCD.

Now let us step by step explain the main points of our calculation.

The Born amplitude\(^c\) (multiplied by 2!) of exclusive $J/\psi$ production in quark-(anti)quark collision is described by the sum of sixteen diagrams shown in Fig. 1 and Fig. 2 (the quark line with a cross is put on shell).

![Diagrams](image)

Figure 1: Sixteen (see Fig. 2) diagrams contributing to the amplitude of the process of exclusive $J/\psi$ meson production via pomeron-odderon and pomeron-photon fusion in quark-(anti)quark collision.

The shaded area in Fig. 1 denotes a sum of four diagrams shown in Fig. 2 (and analogous for the $\gamma gg \rightarrow J/\psi$ subprocess).

![Diagrams](image)

Figure 2: The shaded area in Fig. 1 represents a sum of four diagrams contributing to the subprocess $3g \rightarrow J/\psi$.

Here some comments are to be in order.

1. The coupling of the pomeron and the odderon to the proton. The model we adopt was formulated by Fukugita and Kwieciński.\(^5\) Shortly speaking, we consider the proton as a system of three valence quarks with totally antisymmetric wave function in the color space. The strong coupling constant is taken to be 1, however, the real value may be as small as 0.3\(^6\). It is the main source of uncertainties in our calculation.

2. The $J/\psi$ vertex. As the binding energy of $s$ wave $c\bar{c}$ quarks for $J/\psi$ system is small (much less than the charm quark mass), we can follow\(^7\,^8\) and use nonrelativistic colinear approximation. The coupling constant may be expressed in terms of the electronic width $\Gamma_{J/\psi}^{e^-e^+}$ of $J/\psi \rightarrow e^-e^+$ decay. It was suggested in\(^9\) to implement relativistic corrections by redefining the mass of the c quark to be half of the $J/\psi$ mass.

3. Gap survival factor. We also must take the gap survival effect into account i.e. the probability $S_{gap}^2$ of the gaps not to be populated by secondaries produced in the soft rescattering. It is not a universal number but it depends on the initial energy and the particular final state. In our calculations we take for the Tevatron energy for pomeron-odderon fusion contribution $S_{gap}^2 = 0.05\(^10\)$. Here we assume that the soft rescattering in exclusive $J/\psi$ production via\(^5\) This result does not take the pomeron-photon fusion contribution into account

\(^c\)The details of our calculations will be presented in a forthcoming paper
pomeron-odderon fusion is the same as in the reaction of exclusive double pomeron exchange $\chi_c$ production (actually it is the best we can do). For the pomeron-photon fusion contribution we take $S_{gap}^2 = 1$.

4.BFKL evolution. For the Tevatron energy we expect enhancement by a factor about 3.

5.BKP evolution. At leading order the intercept of the odderon trajectory is predicted to be very close to $1$. From this point of view bare three gluons in color neutral state appear as a normal model for the odderon.

3 Results and discussion

Now we are ready to show our predictions for exclusive $J/\psi$ meson production in proton-(anti)proton collisions.

Let us start from some general remarks. The cross section in proton-proton collisions is smaller than in proton-antiproton collisions. The differential cross section $d\sigma/dy$ weakly depends on the rapidity $y$ of the produced $J/\psi$. It is presumably a reflection of lack of BFKL and BKP evolution. Another interesting observation is that the odderon and photon contributions do not interfere (complex phase). It allows us to discuss these contributions separately.

In Table 1 predictions for the Tevatron energy are shown. As can be seen the pomeron-odderon contribution to the differential cross section for exclusive $J/\psi$ meson production is of comparable size as the contribution coming from pomeron-photon fusion. It should be noted, however, that the odderon coupling to proton is the most serious uncertainty of our calculations and the result presented in Table 1 for pomeron-odderon contribution should be regarded only as an order of magnitude estimate.

| $\sqrt{s} = 2$ TeV | odderon | photon |
|-------------------|---------|--------|
| $d\sigma/dy(y = 0)$ | 0.5 – 3 nb | 2.5 nb |

Table 1: The results for exclusive $J/\psi$ production at the Tevatron energy in proton-antiproton collisions based on Fukugita-Kwieciński model. The main uncertainty comes from unknown odderon-proton coupling.

The situation looks much better if we impose the following cuts: $|t_1^2|, |t_2^2| > 0.25$ GeV$^2$ (or appropriate cuts for one hadron and transverse momentum of $J/\psi$). Then, the pomeron-odderon fusion contribution decreases about an order of magnitude, being still visible, and the pomeron-photon fusion contribution decreases about two to three orders of magnitude, being completely negligible.

At the end one thing should be emphasized. The cross section of $\gamma p \rightarrow J/\psi + p$ subprocess may be calculated perturbatively (as we did), see for example or taken from extrapolations of the HERA data. It allows us to calculate the pomeron-photon fusion contribution in a model independent way. Performing appropriate calculations we obtain the value to be about 3 nb, what is in good agreement with our perturbative calculation. For details of this approach see where this problem is thoroughly studied. We believe that it allows to estimate this contribution with an accuracy up to 15%.

In summary, our recipe for the odderon looks like follows: take the data for exclusive $J/\psi$ production, throw away the pomeron-photon contribution being under quite good control, and if there remains something, and we suggest that this will be indeed the case, it is the odderon.

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Note that the branching fraction for the decay $J/\psi \rightarrow \mu^+ \mu^-$ is not included.

In this reference the authors also estimate the pomeron-odderon contribution. However, they use different diagrams – the whole odderon is coupled to $c$ quark
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