Evidence for no shrinkage in elastic photoproduction of $J/\Psi$

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Abstract

The differential cross section $d\sigma/dt$ of elastic photoproduction of $J/\Psi$ at different $\gamma p$ center of mass energies $W$ are used to determine the properties of the exchanged trajectory in the reaction $\gamma p \rightarrow J/\Psi p$. In the region $|t| < 1 \text{ GeV}^2$, the resulting trajectory is $\alpha(t) = (1.153 \pm 0.027) + (-0.001 \pm 0.072)t$. The vanishing value of the slope of the trajectory is an experimental evidence for no shrinkage and thus for the perturbative nature of the exchange.
1 Introduction

High energy interactions are a combination of soft and hard interactions. It is however not completely clear how to quantify these regions. Hard interactions are usually thought of as those which can be completely calculated by perturbative QCD. The soft ones are in the nonperturbative domain and usually need some experimental/phenomenological input to carry out calculations. In most cases one is in a situation where there is interplay between soft and hard processes [1].

A particular case where this interplay is present are diffractive processes and one discusses soft and hard diffraction. The soft diffraction is characterized as a process in which one exchanges a Pomeron trajectory with the properties of having an intercept $\alpha_0$ of about 1.08 and a slope $\alpha'$ of 0.25 GeV$^{-2}$. This trajectory is also sometimes referred to as the 'soft Pomeron' or the 'nonperturbative Pomeron'.

The hard diffractive processes seen e.g. in deep inelastic scattering reactions, seem to be described by a trajectory with a larger intercept than that of the 'soft Pomeron'. One calls such a trajectory 'hard Pomeron'. Although clearly there is just one Pomeron and it is the one invented by Gribov to describe the rise of the total hadron–hadron cross section, we will nevertheless use the notions of 'soft Pomeron' and 'hard Pomeron' for the sake of clarity. The expectations of the 'hard Pomeron' trajectory are to have a larger intercept than that of the 'soft Pomeron' and a smaller slope. The reason for the smaller slope is connected to Gribov diffusion [2] and will be elaborated on later.

A very clean diffractive reaction in which only a Pomeron can be exchanged is the elastic photoproduction of $J/\Psi$

$$\gamma p \rightarrow J/\Psi p.$$  \hspace{1cm} (1)

The cross section for this reaction rises faster than expected from a 'soft' diffractive reaction. While the cross section of elastic photoproduction of the three lightest vector mesons $\rho^0$, $\omega$ and $\phi$ rises like $W^{0.22}$ [3], that of the $J/\Psi$ rises like $W^{0.64\pm0.13}$ [4] or $W^{0.92\pm0.14}$ [5]. This indicates that the intercept of the exchanged 'object' in the latter reaction is larger than 1.08 but in order to measure this intercept from the cross section behaviour one needs information also on the slope $\alpha'$.

How can one get information on $\alpha'$? One way is by looking for the shrinkage of the diffractive peak with increasing energy. This is done by assuming a functional form of the differential cross section $d\sigma/dt$, for example a single exponential $\exp(bt)$, and then studying the dependence of the exponential slope $b$ on $W$,

$$b = b_0 + 4\alpha' \ln W.$$  \hspace{1cm} (2)

A more direct way is by measuring the whole trajectory directly. This is done by studying the $W$ dependence of $d\sigma/dt$ at fixed $t$ values,

$$\frac{d\sigma}{dt} = f(t)(W^2)^{(2\alpha(t)-2)},$$  \hspace{1cm} (3)

where $f(t)$ is a function of $t$ only. Thus one can determine $\alpha(t)$ at each $t$ value and by fitting a linear form to the trajectory,

$$\alpha(t) = \alpha_0 + \alpha't,$$  \hspace{1cm} (4)
one finally determines the intercept and the slope of the trajectory.

In order to use such a direct determination of the Pomeron trajectory, one needs to study a reaction which is driven only by a Pomeron exchange. The best examples of such reactions are either \( \gamma p \to \phi p \) or \( \gamma p \to J/\Psi p \). Since the \( \phi \) and the \( J/\Psi \) are pure \( s\bar{s} \) and \( c\bar{c} \) states, respectively, the reactions can only proceed via a Pomeron exchange, even at low \( W \) values, as the exchange of secondary trajectories is suppressed in these cases.

In the present note we report on the results of a study of the energy dependence of the differential cross section for elastic photoproduction of \( J/\Psi \) in order to measure \( \alpha(t) \) using equation (3). Using these values and equation (4) we want to check in particular whether the data used here are from EMC [6] at an average energy of \( W = 16.2 \) GeV. The data used in the present analysis come from four different experiments. The lowest energy data used is a cut of \( z \geq 0.95 \), where \( z \) is the fraction of the photon carried by the \( J/\Psi \), corrected for coherence at low \( p_T^2 \). A sum of two exponentials were fit to the data yielding \( d\sigma/dp_T^2 = (89 \pm 15) \exp[(-5.2 \pm 0.6)p_T^2] + (2.3 \pm 0.9) \exp[(-0.66 \pm 0.14)p_T^2] \). This expression was used for \( p_T^2 < 1 \) GeV\(^2\) since in this region the approximation \( |t| \approx p_T^2 \) is a good one. Also for \( p_T^2 < 1 \) GeV\(^2\) the contamination of events where the nucleon dissociates is small in the elastic sample.

The second data set is taken from the E401 experiment [7] where \( d\sigma/dt \) has been measured at \( W = 16.8 \) GeV for the elastic process in the region \( |t| < 1 \) GeV\(^2\). This experiment was performed with real photons enabling a direct measurement of \( t \). A careful study was performed to isolate the elastic events. An exponential in \( t \) and \( t^2 \) was fit to the data resulting in \( d\sigma/dt = (80 \pm 13) \exp[(5.6 \pm 1.2)t + (2.9 \pm 1.3)t^2] \).

The H1 collaboration [4] measured \( d\sigma/dp_T^2 \) for the elastic channel at \( W = 85 \) GeV and for \( p_T^2 < 1 \) GeV\(^2\) the data can be represented by a single exponential \( \exp(-bp_T^2) \) with a slope of \( b = (4.0 \pm 0.2 \pm 0.2) \) GeV\(^{-2}\). The effects of using \( p_T^2 \) instead of \( |t| \) are small and accounted for in the systematic error on the slope.

The highest energy point used in this analysis, \( W = 90 \) GeV, is from the ZEUS experiment [5] which measured \( d\sigma/dt \) for the elastic channel. Also these data can be described for \( |t| < 1 \) GeV\(^2\) by a single exponential in \( t \), yielding a slope of \( b = 4.6 \pm 0.4\) GeV\(^{-2}\).

2 The data

The data used in the present analysis come from four different experiments. The lowest energy data used here are from EMC [3] at an average energy of \( W = 16.2 \) GeV. The data are presented as \( d\sigma/dp_T^2 \) for a cut of \( z \geq 0.95 \), where \( z \) is the fraction of the photon carried by the \( J/\Psi \), corrected for coherence at low \( p_T^2 \). A sum of two exponentials were fit to the data yielding \( d\sigma/dp_T^2 = (89 \pm 15) \exp[(-5.2 \pm 0.6)p_T^2] + (2.3 \pm 0.9) \exp[(-0.66 \pm 0.14)p_T^2] \). This expression was used for \( p_T^2 < 1 \) GeV\(^2\) since in this region the approximation \( |t| \approx p_T^2 \) is a good one. Also for \( p_T^2 < 1 \) GeV\(^2\) the contamination of events where the nucleon dissociates is small in the elastic sample.

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3 Results

Figure 1 shows the differential cross section for the elastic process \( \gamma p \to J/\Psi p \), as function of the \( \gamma p \) center of mass energy \( W \), for five fixed \( t \) values, \( |t| = 0.1, 0.3, 0.5, 0.7 \) and \( 0.9 \) GeV\(^2\). For each of the five \( t \) values a fit of the form,

\[
\frac{d\sigma}{dt} = f(t)W^{[4\alpha(t)-4]}, \tag{5}
\]
was performed and the value of \( \alpha(t) \) was determined. These values are plotted in figure 2 as function of \( t \) and seem to be independent of \( t \). A linear fit of the form \( \alpha(t) = \alpha_0 + \alpha' t \) yields

\[
\alpha_0 = 1.153 \pm 0.027, \quad (6)
\]

\[
\alpha' = -0.001 \pm 0.072 \text{ GeV}^{-2}. \quad (7)
\]

For comparison, the trajectory of the Donnachie–Landshoff 'soft' Pomeron \(^8\) is also shown in the figure as a dashed line.

If one assumes that \( f(t) \) is due to the electromagnetic form factor of the proton, one can fit all 20 data points to the form

\[
\frac{d\sigma}{dt} = \frac{C}{(1 + \frac{t}{m^2})^4} W^{(4\alpha_0 + 4\alpha't - 4)}. \quad (8)
\]

A very good fit to the data is obtained with the following results

\[
\alpha_0 = 1.161 \pm 0.023, \quad (9)
\]

\[
\alpha' = -0.029 \pm 0.054 \text{ GeV}^{-2}. \quad (10)
\]

The value of the scale parameter from the fit is \( m^2 = 0.72 \pm 0.23 \text{ GeV}^2 \), consistent with the accepted value of 0.71 GeV\(^2\) used to describe the electromagnetic form factor. The value of the parameter \( C \) is 14 \( \pm \) 6, with units such that \( d\sigma/dt \) is given in nb/GeV\(^2\).

### 4 Discussion and conclusions

The resulting value of \( \alpha' \approx 0 \) is evidence to the fact that there is no shrinkage of \( d\sigma/dt \) in the process \( \gamma p \rightarrow J/\Psi p \). Shrinkage is a characteristic behaviour of diffractive processes dominated by 'soft' Pomeron exchange. The value of \( \alpha' \) is connected to the inverse value of the average \( k_T \) of the partons involved in the exchange. A process can start at the photon in a small configuration with a high \( k_T \) value but as a result of Gribov diffusion \(^2\) the partons interacting with those of the proton become 'soft' due to their random diffusion and thus the value of \( \alpha' \) is non zero, leading to shrinkage. The fact that no shrinkage is observed in elastic photoproduction of \( J/\Psi \) indicates that Gribov diffusion is unimportant in this process at the presently available \( W \) values, and the average \( k_T \) remains large. Such a behaviour is expected \(^9\) from processes governed by the 'perturbative Pomeron' whose values of \( \alpha(t) \) are expected to remain larger than 1. This makes the process a 'hard' one, fully calculable in perturbative QCD.

In conclusion, the trajectory of the 'object' exchanged in the process \( \gamma p \rightarrow J/\Psi p \) was determined to be \( \alpha(t) = (1.153 \pm 0.027) + (-0.001 \pm 0.072)t \), giving evidence for no shrinkage in the process. This can be interpreted as indication that for the reaction \( \gamma p \rightarrow J/\Psi p \) diffusion from small to large size configuration is only a small correction up to \( W = 90 \text{ GeV} \). Thus the process is 'hard' and fully calculable in perturbative QCD.
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Figure 1: The differential cross section $d\sigma/dt$ of the reaction $\gamma p \rightarrow J/\psi p$ as function of $W$ for fixed values of $t$, as indicated in the figures. The line is the result of a fit of the form $d\sigma/dt = A(t)W^{[a(t)-4]}$ to the data.
Figure 2: The values $\alpha(t)$ of the exchanged trajectory in the reaction $\gamma p \rightarrow J/\psi p$ as function of $t$. The solid line is the result of a fit of the form $\alpha(t) = \alpha_0 + \alpha' t$ to the data. The dashed line is the trajectory of the Donnachie–Landshoff (DL) Pomeron.