

# Diffractive Vector Meson Cross Sections from BK evolution with Impact Parameter

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The solution of the Balitsky-Kovchegov evolution equation with impact parameter dependence is used to compute cross sections for  $J/\Psi$ ,  $\rho$  and  $\phi$  vector meson production. These calculations are then compared with data from HERA and good agreement is found for the  $J/\Psi$  and  $\phi$  mesons while the  $\rho$  has a low normalization. The phenomenological corrections needed to bring the calculations into agreement with the data are discussed. The work presented here may be found in the publication [1].

## 1 Introduction

The Balitsky-Kovchegov (BK) equation [2, 3, 4, 5] is a non-linear evolution equation in Bjorken  $x$  (denoted  $x_{bj}$ ) whose solution describes the scattering of a color dipole ( $q\bar{q}$  pair) on a target. The BK equation has the form

$$\frac{\partial N_{\mathbf{x}_0\mathbf{x}_1}}{\partial Y} = \int \frac{d^2\mathbf{x}_2}{2\pi} \mathcal{K}(x_{01}, x_{12}, x_{02}; \alpha_s, m) [N_{\mathbf{x}_0\mathbf{x}_2} + N_{\mathbf{x}_2\mathbf{x}_1} - N_{\mathbf{x}_0\mathbf{x}_1} - N_{\mathbf{x}_0\mathbf{x}_2}N_{\mathbf{x}_2\mathbf{x}_1}] . \quad (1)$$

The scattering amplitude  $N_{\mathbf{x}_0\mathbf{x}_1}$  depends on the rapidity  $Y = \ln(1/x_{bj})$  and the coordinates of the color charges of the dipole  $\mathbf{x}_0$  and  $\mathbf{x}_1$ <sup>1</sup>. We shall not make the assumption that the scattering amplitude depends on only the dipole size  $x_{01} = |\mathbf{x}_0 - \mathbf{x}_1|$  but instead include the dependences on impact parameter  $b_{01} = |\mathbf{x}_0 + \mathbf{x}_1|/2$  and the angle  $\theta$  between the impact parameter and the dipole size. More details on the numerical solution are given in [6]. The kernel  $\mathcal{K}(x_{01}, x_{12}, x_{02}; \alpha_s, m)$  determines the dipole splitting and the form which behaves in a manner that best describes the  $F_2$  data [7] is

$$\mathcal{K} = \bar{\alpha}_s(x_{01}^2) \left[ \frac{1}{x_{02}^2} \left( \frac{\alpha_s(x_{02}^2)}{\alpha_s(x_{12}^2)} - 1 \right) + \frac{1}{x_{12}^2} \left( \frac{\alpha_s(x_{12}^2)}{\alpha_s(x_{02}^2)} - 1 \right) + \frac{x_{01}^2}{x_{12}^2 x_{02}^2} \right] \Theta\left(\frac{1}{m^2} - x_{02}^2\right) \Theta\left(\frac{1}{m^2} - x_{12}^2\right) . \quad (2)$$

In the above equation, we use  $\alpha_s(x^2) = \frac{1}{b \ln[\Lambda_{\text{QCD}}^{-2}(\frac{1}{x^2} + \mu^2)]}$  for the form of the running coupling with  $b = \frac{33-2n_f}{12\pi}$  and  $n_f$  is the number of active flavors. The  $\mu$  parameter effectively freezes the coupling at large dipole sizes and the massive parameter  $m$  cuts off large non-perturbative

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<sup>1</sup>A note on notation : bold-faced variables represent two-dimensional vectors, otherwise they are to be understood as magnitudes.

dipoles. The value of these parameters as well as others mentioned can be found in [1]. The initial condition of the evolution is described in [1] as well.

## 2 Phenomenological corrections

Several corrections must be made in order to bring the calculation using the dipole scattering amplitude into agreement with the HERA data. One of these corrections is a skewed unintegrated gluon distribution. There is no gluon distribution in the formalism used for the evolution but it is present in the initial condition. Additionally the real part of the scattering amplitude is corrected for (this correction is much more modest compared to the large correction that the skewed gluon distribution gives). Both of these corrections are described in more depth in [1].

A correction to the photon wavefunction is also required. This correction has the form

$$|\Psi_\gamma|^2 \rightarrow |\Psi_\gamma|^2 \left( \frac{1 + B e^{-\omega^2(x_{01}-R)^2}}{1 + B e^{-\omega^2 R^2}} \right), \quad (3)$$

where  $B, R$  and  $\omega$  are parameters which are fit to the data. This correction gives an enhancement at small  $Q^2$ , which corresponds to large dipole sizes. This can be thought of as a contribution stemming from the photon having a hadronic component at these large sizes.

## 3 Comparison to vector meson cross sections

The differential cross section for exclusive vector meson production has been measured by H1 [8, 9, 10] and ZEUS [11, 12, 13, 14] collaborations at HERA. In computing the differential cross section the vector meson wavefunction used is known as the NNPDF prescription [15, 16].

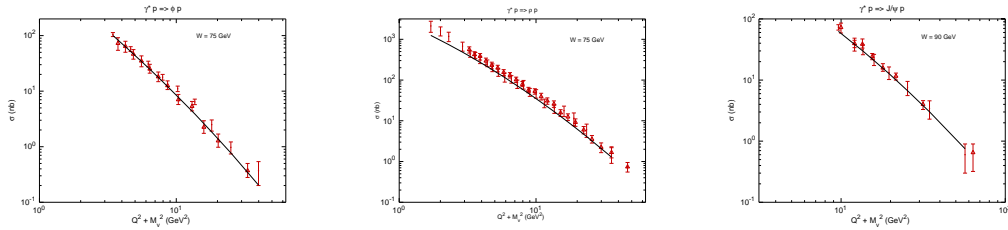


Figure 1:  $Q^2 + M_V^2$  dependence of the vector meson cross section for elastic production of  $J/\Psi, \rho$ , and  $\phi$ .

The integrated cross section is shown plotted in Fig 1 versus  $Q^2$  and in Fig 2 versus  $W^2$ . The data is well explained by our calculations in the case of both  $J/\Psi$  and  $\phi$  vector mesons. However the  $\rho$  vector meson has a normalization which is consistently low.

The dependence on the momentum transfer  $t$  is important in that it is conjugate to the impact parameter, so information on the measurement of the momentum transfer dependence also gives information about the dependence on the interaction on impact parameter. The differential cross section for  $J/\Psi$  versus the momentum transfer  $t$  and the energy  $W$  can be seen

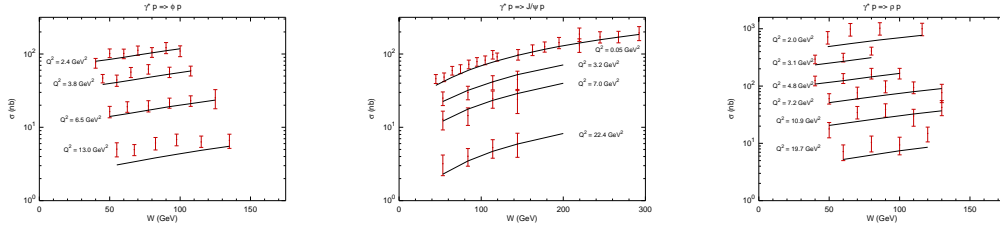


Figure 2:  $W$  dependence of the vector meson cross section for elastic production of  $J/\Psi$ ,  $\rho$ , and  $\phi$ .

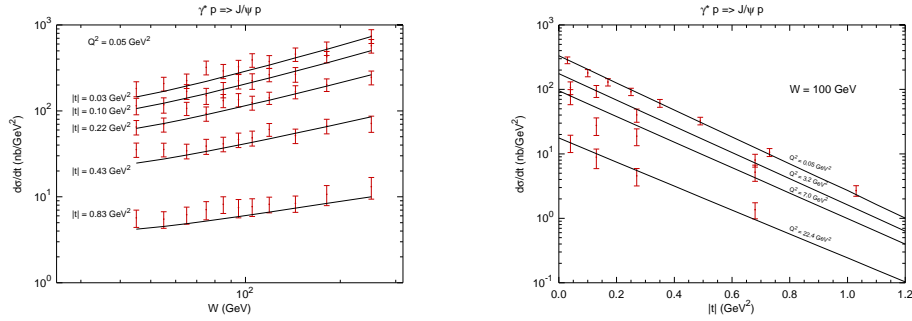


Figure 3: Differential cross section plots of  $J/\Psi$  production

in Fig 3. The differential cross section is well explained by the calculation. On a logarithmic plot the differential cross section versus  $t$  falls along linear paths which suggests a parameterization of  $d\sigma/dt \sim \exp(-B_D|t|)$  where  $B_D$  is a slope parameter.

The plots for  $B_D$  versus both  $Q^2 + M^2$  and  $W$  can be found in Fig 4 for  $J/\Psi$  production. The slope  $B_D$  describes the interaction area in impact parameter space and it was found that there is a slope in  $B_D$  versus  $W$ . This feature is not present in other models and arises naturally from the inclusion of impact parameter in our calculation. The rise of the slope with energy corresponds to the diffusion of the interaction region in impact parameter space. The slope  $B_D$  is sensitive to the initial distribution size in impact parameter, which determines the intercept, as well as the mass cutoff in the kernel (2) determining the slope.

## 4 Conclusions

The BK equation with impact parameter dependence describes well the data for exclusive vector meson production for  $J/\Psi$  and  $\phi$  mesons. The  $\rho$  meson has a chronic low normalization which is possibly due to an additional soft correction. The effects of the phenomenological corrections is large and cannot be neglected, especially the skewed gluon distribution. The photon wavefunction correction (3) is a universal correction and does not only apply to vector

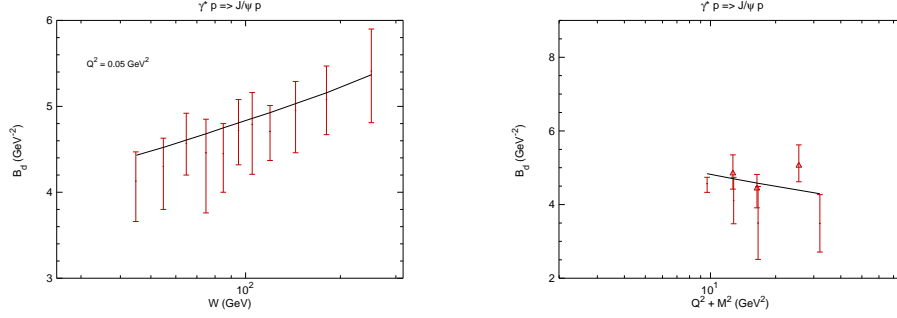


Figure 4: Dependence of the slope parameter  $B_D$  versus  $W$  and  $Q^2 + M_V^2$  for  $J/\Psi$  production.

meson production but inclusive measurements as well. It was found that the  $F_2$  structure function did not find good agreement with the data, while the trends of the data were described the normalization was, in general, too large. This indicates that the photon wavefunction correction is too large, however lowering it worsens the vector meson fits, implying there is more to be done with the vector meson wavefunctions or that there is a soft correction which affects only the vector mesons which is not taken into account. Despite the fact that there are some normalization issues in fitting both inclusive and exclusive data simultaneously the solution to the BK equation with impact parameter does describe the trends of the data, as well as producing an energy dependence of  $B_D$  which arises purely from the impact parameter dependence of our model.

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