Vol. 33 (2002) ACTA PHYSICA POLONICA B No 11

DIFFRACTIVE VECTOR MESONS AT LARGE MOMENTUM TRANSFER FROM THE BFKL EQUATION*

R. Enberg[a], L. Motyka[a,c] and G. Poludniowski[b]

[a]High Energy Physics, Uppsala University, 75121 Uppsala, Sweden
[b]Department of Physics and Astronomy, University of Manchester
Manchester M13 9PL, UK
[c]M. Smoluchowski Institute of Physics, Jagellonian University
Reymonta 4, 30-059 Kraków, Poland

(Received July 1, 2002)

Diffractive vector meson photoproduction accompanied by proton dissociation is studied for large momentum transfer. The process is described by the non-forward BFKL equation, for which an analytical solution is found for all conformal spins, giving the scattering amplitude. Results are compared to HERA data on ρ production.

PACS numbers: 13.60.Le, 12.38.Bx

1. Introduction

Diffractive production of vector mesons in γp collisions at large momentum transfer, $\gamma p \to VX$, is an experimentally clean process. The signal consists of an isolated vector meson with large transverse momentum, separated from the remnant of the incoming proton by a large rapidity gap. There are recent measurements of cross-sections and helicity amplitudes for this process [1, 2].

The large momentum transfer involved makes it possible to describe the colour singlet exchange in terms of perturbative QCD. This is in contrast to vector meson production in diffractive processes with small momentum transfer, where the sensitivity to the infrared region is larger. The perturbative QCD description of hard colour singlet exchange across a large rapidity interval relies on the BFKL equation [3, 4], which resums leading powers of

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

the rapidity y to all orders in the perturbative expansion of the amplitude. The colour singlet system, or pomeron, is here a composite system of two reggeized gluons.

Let us mention that this process has been studied before; for heavy mesons in BFKL [5] using the Mueller–Tang [6] approximation, and for light mesons at the Born level [7]. The data on the cross-sections can be fitted with a BFKL calculation, but not by the fixed order formulae. The understanding of the helicity structure remains a challenge.

We have recently studied the production of heavy mesons in a BFKL framework [8], so here we concentrate on the case of light mesons.

2. The BFKL calculation

At large momentum transfer the pomeron couples predominantly to a single parton, (see Fig. 1), which means that the cross-section may be factorized into a convolution of the partonic cross-section with the parton distribution functions. We therefore calculate the amplitude for $\gamma q \to Vq$ (since $\gamma g \to Vg$ differs only by a colour factor).

In the BFKL framework the scattering amplitude is calculated as the convolution of three factors; schematically $\mathcal{A} = \Phi^{\gamma\to V} \otimes K_{\mathrm{BFKL}} \otimes \Phi^{q\to q}$, where Φ are the impact factors describing the coupling of the pomeron to the indicated vertices, and K_{BFKL} is the BFKL kernel describing the evolution of the gluon ladder.

The non-forward BFKL equation has a solution due to Lipatov [4]:

$$\mathcal{A} = \frac{1}{(2\pi)^6} \sum_n \int d\nu \, \frac{\nu^2 + \frac{n^2}{4}}{[\nu^2 + (\frac{n-1}{2})^2][\nu^2 + (\frac{n+1}{2})^2]} \mathrm{e}^{\omega_n(\nu) y} I^1_{n,\nu}(\boldsymbol{k},\boldsymbol{q})\, I^{2\,\star}_{n,\nu}(\boldsymbol{k}',\boldsymbol{q}). \tag{1}$$

This represents an expansion of the amplitude in the complete basis of eigenfunctions $E_{n,v}$ of the BFKL kernel. The functions $I^{1,2}_{n,\nu}$ are projections of the impact factors $\Phi^{1,2}(\boldsymbol{k},\boldsymbol{q})$ on these eigenfunctions, see [4, 8] for details.

The integer n in (1) is known as the *conformal spin*. The terms in the sum with non-zero n are exponentially suppressed by the factor $e^{\omega_n(\nu)y}$, with $\omega_n(\nu) < 0$ for $n \neq 0$, and so the amplitude is usually approximated by the leading $n = 0$ term (the Mueller–Tang approximation [6]). This approximation, however, is only good for very large rapidities y. For moderate y the higher n terms can still be important, as was found in [9, 10]. We therefore calculate the amplitudes including all n.

3. Impact factors

The quark impact factor is given in Ref. [9] for all conformal spins, and we have to compute the vector meson impact factors. This is done separately for heavy [8] and light [11] mesons, using different approximations for the vector meson wave functions. In the heavy meson case, we used the non-relativistic approximation, where the constituent quarks are assumed to each carry half of the meson momentum. Our results can be found in [8].

Ivanov *et al.* [7] give the helicity amplitudes for light meson production, M_{++}, M_{+0} and M_{+-}, where the first index corresponds to the polarization of the incoming photon and the second to the vector meson. These are referred to as the no-flip, single-flip and double-flip amplitudes, respectively.

Their calculation assumes Born-level two-gluon exchange, and they use a relativistic approximation for the vector meson wave functions, with massless quarks. Note that the longitudinal and transverse degrees of freedom are factorized. For instance, taking $\boldsymbol{r}$ to be the transverse separation of the quarks in the vector meson, and u to be the lightcone momentum fraction of the quark, they give the single-flip amplitude as

$$M_{+0} = \int \frac{d^2\boldsymbol{k}}{\boldsymbol{k}^2(\boldsymbol{k}-\boldsymbol{q})^2}\left[C\,\alpha_{\mathrm{s}}^2 \int \frac{d^2\boldsymbol{r}\,du}{4\pi}\, f^{\mathrm{dipole}}\,\frac{\boldsymbol{r}\cdot\boldsymbol{e}^+}{r^2}\,\frac{f_\rho}{2}\,(1-2u)\phi_{\|}(u)\right], \tag{2}$$

where $\phi_{\|}(u)$ is the twist-2 vector meson wave function. Expressed in the impact factor picture, the factor in brackets is just the product of the impact factors $\Phi^{q\to q}$ and $\Phi_{+0}^{\gamma\to V}$. Thus, we calculate $I_{n,\nu}^{\gamma\to V}$ by projecting these expressions onto the BFKL eigenfunctions, and insert the result into (1).

The projection of the impact factor $I_{n,\nu}^{\gamma\to V}$ is then proportional to [11]

$$\begin{aligned}\mathcal{I} \;=\; & \sin\pi\,(1/2+\beta+\widetilde{\mu})\;\, B_+(\alpha,q^*,\xi^*)\;\widetilde{B}_+(\beta,q,\xi)\\ & -\sin\pi\,(1/2+\beta-\widetilde{\mu})\;\, B_-(\alpha,q^*,\xi^*)\;\widetilde{B}_-(\beta,q,\xi)\end{aligned} \tag{3}$$

for even n and zero for odd n. Here $\mu = n/2 - i\nu, \widetilde{\mu} = -n/2 - i\nu$, and we introduce the conformal blocks $B_\pm$

$$\begin{aligned}B_\pm(\alpha,q,\xi) \;=\; & \left(\frac{2i}{k}\right)^{\frac{3}{2}+\alpha}\left(\frac{iq}{4k}\right)^{\pm\mu}\frac{\Gamma(3/2+\alpha\pm\mu)}{\Gamma(1\pm\mu)}\\ & \times\; {}_2F_1\left(3/2+\alpha\pm\mu\,,\; 1/2\pm\mu\,;\; 1\pm 2\mu\,;\; 2/(1+\xi)\right),\end{aligned} \tag{4}$$

and $\widetilde{B}_\pm$ obtained by $\mu\to\widetilde{\mu}$. The constants α and β take different values for different helicity amplitudes.

4. Results

We will now go on to evaluate the obtained expressions, concentrating on the case of light mesons and referring to [8] for our results on heavy mesons.

ZEUS have measured the differential cross-section $d\sigma/dt$ for ρ and ϕ mesons for momentum transfers up to 8 GeV^2 [1]. In Fig. 1 we show a comparison of the data together with our calculation, including all conformal spins. Here we have chosen a fixed value of $\alpha_{\mathrm{s}} = 0.38$ in the prefactor (see (2)) and $\alpha_{\mathrm{s}} = 0.24$ in the eigenfunctions $\omega_n(\nu)$, defining the pomeron intercept. These choices of different α_{s} reflect the impact of non-leading corrections to the BFKL intercept. The rapidity is defined as $y = \ln(\hat{s}/m_\rho^2)$. Note that the turnover at $|t| \sim 2$ GeV^2 is due to the too restrictive infrared cut-off $u_{\min} = -m_\rho^2/t$ (taken from [7]) in the integration over u. Such a cut-off in u was required to regulate an unphysical divergence.

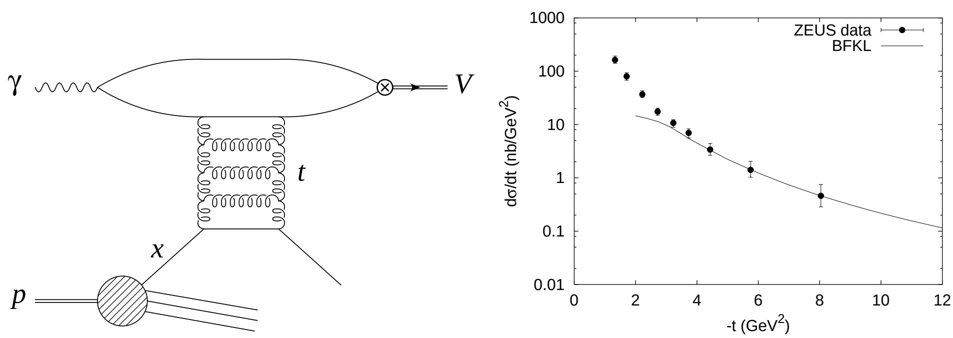

Fig. 1. Feynman graph and differential cross-section for the process $\gamma p \to \rho X$.

In addition, ZEUS have also measured the spin density matrix elements r_{ij}^{04} for the process. These parametrize the decay angular distributions of the mesons, and can be related to the helicity amplitudes M_{ij} (see *e.g.* [1]). Note, however, that both the no-flip and double-flip amplitudes processes lead to the same polarization states of the vector meson, and therefore they cannot be distinguished in unpolarized experiment. The r_{ij}^{04} contain interferences, though, so it can be inferred from the data that all three helicity amplitudes are non-zero for ρ and ϕ, while for J/Ψ, only the no-flip amplitude seems to be non-zero.

In Fig. 2, we show our BFKL predictions for r_{ij}^{04} compared to the ZEUS data. The qualitative features are well reproduced. The shapes of the curves depend somewhat on the choices of pomeron intercept and definition of the rapidity, but we find that (*i*) the $(+-)$ component of the amplitude dominates and (*ii*) the $(++)$ component is negative. The BFKL evolution thus changes the features from the fixed-order Born level results of [7].

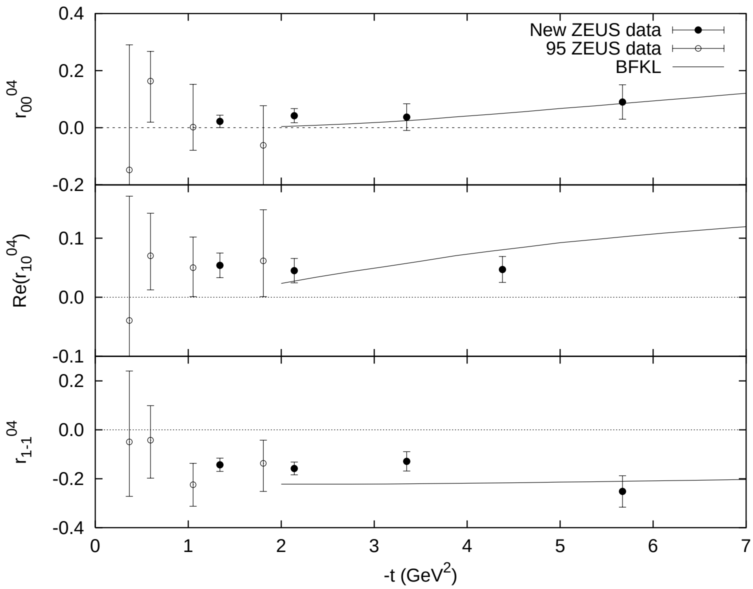

Fig. 2. Spin density matrix elements for ρ meson production.

These results should be interpreted with some care, however, because of some uncertainties. We have not included the chiral-odd components of the photon wave function of [7], but believe that these may be small [11]. Also, the endpoints in the u-integration have to be treated carefully and may change the results. Furthermore, the approximations used, with massless quarks and a factorized meson wave function, have to be understood.

5. Conclusions

In conclusion, we have studied the process $\gamma p \to VX$ in a BFKL framework, obtaining exact solutions of the BFKL equation. Comparing the calculations to ZEUS data shows good agreement with both the differential cross-section and the spin density matrix elements for diffractive ρ production.

We thank Jeff Forshaw for useful discussions. This study was supported in part by the Swedish Natural Science Research Council and by the Polish State Committee for Scientific Research (KBN) under grant no. 5P03B 14420.

REFERENCES

[1] K. Klimek, *Acta Phys. Pol.* **B33**, 3541 (2002), these proceedings; S. Chekanov *et al.* [ZEUS Collaboration], `hep-ex/0205081`, *Eur. Phys. J.* **C**, in press.

[2] D.P. Brown, *Acta Phys. Pol.* **B33**, 3535 (2002), these proceedings.

[3] L.N. Lipatov, *Sov. J. Nucl. Phys.* **23**, 338 (1976); E.A. Kuraev, L.N. Lipatov, V.S. Fadin, *Sov. Phys. JETP* **44**, 443 (1976); *Sov. Phys. JETP* **45**, 199 (1977); I.I. Balitsky, L.N. Lipatov, *Sov. J. Nucl. Phys.* **28**, 822 (1978).

[4] L.N. Lipatov, *Sov. Phys. JETP* **63**, 904 (1986); *Phys. Rep.* **286**, 131 (1997).

[5] J.R. Forshaw, M.G. Ryskin, *Z. Phys.* **C68**, 137 (1995); J. Bartels, J.R. Forshaw, H. Lotter, M. Wüsthoff, *Phys. Lett.* **B375**, 301 (1996); J.R. Forshaw, G. Poludniowski, *Eur. Phys. J.* **C** in press, `hep-ph/0107068`.

[6] A.H. Mueller, W.-K. Tang, *Phys. Lett.* **B284**, 123 (1992).

[7] D.Y. Ivanov *et al. Phys. Lett.* **B478**, 101 (2000); *Phys. Lett.* **B498**, 295 (2001).

[8] R. Enberg, L. Motyka, G. Poludniowski, to appear shortly.

[9] L. Motyka, A.D. Martin, M.G. Ryskin, *Phys. Lett.* **B524**, 107 (2002).

[10] R. Enberg, G. Ingelman, L. Motyka, *Phys. Lett.* **B524**, 273 (2002).

[11] R. Enberg, J. Forshaw, L. Motyka, G. Poludniowski, in preparation.