Polarization in hard diffractive electroproduction

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The approach to helicity amplitudes and spin-flip effects in diffractive electroproductionis discussed. It relies on the general twofold factorized structure of diffractive amplitudes and on the understanding of the helicity and angular dependences of the light-cone wave functions.

1. POLARIZATION EFFECTS

Detailed data analysis of the hard diffractive production of vector mesons have been presented at this workshop [1,2]. The effect of helicity flip has been observed in the distribution of light vector mesons versus the angle Φ between the electron scattering and the meson production planes. The interference of the helicity amplitudes M_{00} and $M_{\pm,0}$ (where the first index refers to the virtual photon and the second to the vector meson helicities) results in a term proportional to $\cos\Phi$. For negligible single-flip ampltudes $M_{\pm 0}$ this distribution would be flat.

Further, preliminary data on ρ produced diffractively from quasi-real photons seem to show at relatively large momentum transfer, $-t > 2\ GeV^2$, the interference contribution of the amplitudes M_{11} and M_{1-1} [3].

We have calculated the helicity amplitudes $M_{\lambda_\gamma \lambda_M}$ for diffractive electroproduction of vector mesons and estimated their dependence on Q^2 and t [4].

$$\frac{M_{11}}{M_{00}} \simeq \frac{m_\rho}{Q}\frac{1+\gamma}{\gamma},$$
$$\frac{M_{10}}{M_{00}} \simeq \frac{\sqrt{-t}}{Q}\frac{1}{\sqrt{2}\gamma}, \quad \frac{M_{01}}{M_{00}} \simeq -\frac{m_\rho\sqrt{-t}}{Q^2}\frac{\sqrt{2}}{\gamma},$$
$$\frac{M_{1-1}}{M_{00}} \simeq \frac{t}{Qm_\rho}R(x) \; - \; \frac{t\ m_\rho}{Q^3}\frac{2(\gamma+2)}{\gamma}. \qquad (1)$$

The parameter $\gamma < 1$ characterizes the scaling violation of the gluon density $xG(x, \overline{Q}^2)$ at small x. The latter cancels in the ratios in all contributions besides of one, where we have the x dependent ratio $R(x)$ of different types of gluon exchange contributions.

We have pointed out that the interference effect in Φ is large enough to be observable in experiment and estimated its magnitude for HERA conditions. Our prediction has been confirmed by experiment [1,2]. Recent calculations by other groups [5,6] are in agreement with ours.

The leading gluon exchange, i.e. the one responsible for hard diffraction, does not change the helicities of the scattering quarks or gluons. However it affects the angular momentum of the $q\overline{q}$ pair into which the incoming virtual photon dissociates before the interaction.

The observation of polarization effects provides more insight into details of the diffractive interaction. The progress in understanding these effects is in particular related to the progress in understanding the behavior of $\frac{\sigma_L}{\sigma_T}$.

2. AMPLITUDES OF HARD DIFFRACTION

Diffractive amplitudes have a twofold factorized structure. This can be read off from perturbative calculations, but is not tied to the applicability of perturbation theory and is not necessarily related to short distance factorization. Although there is no formal proof there are good arguments going back to ideas by Gribov [7] and Cheng and Wu [8] and a lot of experience from successful applications (cf. [9–14] and references

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therein).

The crossed channel partial wave of an diffractive amplitude $AB \leftrightarrow A'B'$ can be represented as a sum of factorized terms (usually with one term dominating) of the form

$$\Phi_{AA'}(\kappa_i) \otimes G_\omega(\kappa_i, \kappa'_j) \otimes \Phi_{BB'}(\kappa'_j). \qquad (2)$$

Here $\otimes$ stands for a convolution in the transverse momenta κ ($\sum \kappa_i = \sum \kappa'_j = q, q^2 = t$). G_ω describes the Regge exchange and the impact factors $\Phi_{AA'}, \Phi_{BB'}$ describe the coupling of the scattering particles to the exchange. For our case this is specified in Fig. 1 with the exchange approximated by two gluons. The impact factors in turn

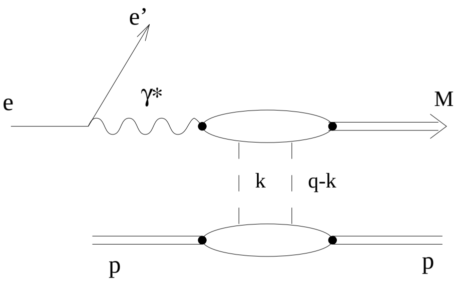

Figure 1. Factorization into impact factors and reggeon Green function.

are factorized as

$$\Psi_A(z, \ell_\perp) \otimes \Phi_{part}(z, \ell_\perp, \kappa_i) \otimes \Psi_{A'}(z, \ell_\perp), \qquad (3)$$

where now $\otimes$ denotes the convolution in the longitudinal momentum fraction z and the transverse momenta $\ell_\perp$ of the partons into which the incoming particle A dissociates far before the interaction and which recombine into the particle A' far after the interaction. $\Psi_{A(A')}$ stands for the light-cone wave function and Φ_{part} is the multi-parton impact factor. In the diffractive transition of a virtual photon to a vector meson the $q\bar{q}$ contribution (colour dipole) dominates. In this case the second kind of factorization is illustrated in Fig. 2. For the virtual photon wave function we can use

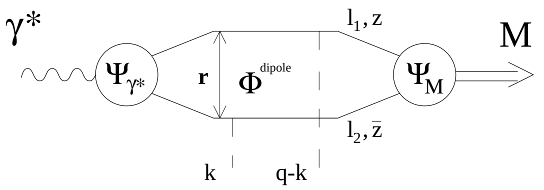

Figure 2. Factorization of the impact factor into wave functions and parton impact factor.

the expression derived from Feynman rules,

$$\Psi_\lambda^\gamma(Q^2; z, \ell_\perp) = \alpha_\lambda(z) e^{i\lambda\phi_\ell} \cdot \frac{\beta_\lambda}{[Q^2 + \frac{\ell_\perp^2}{z(1-z)}]} \qquad (4)$$

ϕ_ℓ is the polar angle of the transverse momentum $\ell_\perp$. $\alpha_0 = 1, \beta_0 = 2Q$ and $\alpha_\pm = \sqrt{z(1-z)} \cdot (z^{-1}$ or $(1-z)^{-1}$, depending on the quark helicity), $\beta_\pm = \frac{2\ell_\perp}{\sqrt{z(1-z)}}$. Note that $\frac{\ell_\perp}{\sqrt{z(1-z)}}$ is the invariant mass of the $q\bar{q}$ pair. We use also the Fourier transformed representation where $\ell_\perp$ is traded for the impact paramenter r, the dipole size. This is convenient because both r and z as well as the quark helicity are unchanged by the leading gluon exchange interaction.

3. THE VECTOR MESON WAVE FUNCTION

Obviously, for polarization effects the helicity and angular dependences of the wave functions are essential. One might think that the badly known meson wave function becomes a serious obstacle for deriving predictions. We shall argue however, that its essential features are fixed and that it has the form

$$\Psi_\lambda^M = f_M \ \alpha_\lambda(z) e^{i\lambda\phi_\ell} \cdot \Phi_\lambda(\frac{\ell_\perp^2}{z(1-z)}). \qquad (5)$$

Notice that now the transverse momentum $\ell_\perp$ refers to the meson momentum; Ψ_λ^M does not know about the incident virtual photon. The function Φ_λ of the invariant mass has to be chosen in a reasonable way, e.g. as an exponentially falling distribution with the slope determined by the meson mass. Its normalization does not depend on the helicity λ.

Formally, (5) can be obtained by applying to (4) the Borel transform with respect to Q^2 and replacing the Borel variable by the vector meson mass [15]. However it is not necessary to rely on this sum rule type argument. Indeed, the dependence on z beyond the one in the invariant mass is fixed because it follows from the decay angular distribution of the meson in a $q\overline{q}$ pair. In the rest frame the latter is given by $d^1_{\lambda_M \lambda_{qq}}(\theta)$. The rest frame angle θ between the quark momentum and the boost direction is related to the momentum fraction in the boosted frame by $z = \frac{1}{2}(1+\cos\theta)$. In this way, taking into account also the energy factor from the quark wave functions, the factor $\alpha_\lambda(z)$ is obtained in (5).

The angular integration (ϕ_ℓ) takes care of the angular momentum conservation in the upper impact factor. The intergration over the dipole size r (conjugate to $\ell_\perp$) is dominated by $r \sim \frac{1}{Q\sqrt{z(1-z)}}$. The integration over the momentum κ of the exchanged gluons turns out to be logarithmic in most cases but one (M_{1-1}). In these cases it is justified as a crude approximation to describe the gluon exchange interaction by the DGLAP gluon distribution in the proton.

It is important to notice that the scaling violation argument is $Q^2 z(1-z)$. Formally there appear end point singularities in z ($z = 0, 1$), if one would disregard the z dependence of the gluon exchange interaction. Following Ryskin et al. [10] we adopt the assumption that the gluon exchange vanishes at these end points.

4. DISCUSSION

The experimental observation of the helicity flip effects in agreement with the theoretical expectations has to be considered first of all as a further confirmation of the general structure of diffractive amplitudes outlined above. The improving accuracy expected in near future of the decay angular distribution data of different vector mesons produced diffractively by virtual photons together with the data on σ_L and σ_T will allow to extract information about the vector meson wave functions.

It would be interesting to see whether double-flip effects could be resolved in experiment (e.g. in the interference of M_{11} and M_{1-1}). The double-flip amplitude turns out to be more involved with two contributions of different twist estimated to be of the same order in the HERA kinematics.

The extension of the approach to the quasi-real photoproduction is possible, at least for relatively large t, by constructing the non-perturbative photon wave function in the same way as the meson wave function.

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