Leptoproduction of Polarized Vector Mesons

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Abstract

We present a status report on a study of vector meson leptoproduction for the HERA energy range on the basis of the generalized handbag approach for which the amplitudes factorize in the parton subprocess $\gamma^* g \rightarrow V g$ and generalized parton distributions (full report in [1]). In contrast to the leading twist approach transverse degrees of freedom as well as Sudakov suppressions are taken into account in the subprocess. First results for the cross section of the reaction $\gamma^*_L p \rightarrow \rho^0_L p$ are found to be in fair agreement with experiment.

We are going to investigate vector meson leptoproduction off protons at high energies, large virtuality, $Q^2$, of the exchanged photon and small invariant momentum transfer, $t$, from the initial to the final proton. In the kinematical region we are interested in, the process factorizes into a hard subprocess - meson leptoproduction off partons - and a soft proton matrix element which represents a generalized or skewed parton distribution (GPD) [2, 3]. It can be shown that the cross section is dominated by longitudinally polarized photons for $Q^2 \rightarrow \infty$; the cross section for transversely polarized photons is suppressed by $1/Q^2$.

The only application of the GPD approach for the reaction has been performed by Mankiewicz et al. [4]. It turns out however that the cross section comes out to large by order of magnitude. This is similar to the two–gluon exchange approach of Brodsky et al. [5] which can be understood as a LO $\alpha_s \log(Q^2/LQCD)$ calculation, as shown by Frankfurt et al. [6]. The latter authors argue that transverse momentum effects in the photon wave function lead to a suppression factor multiplying the leading twist amplitude which leads then to agreement with experiment. Motivated by experience with meson form factors [7, 8] we include transverse degrees of freedom as well as Sudakov suppressions in the subprocess. By these effects contributions from the end-point regions, in which one of the partons entering the meson wave function becomes soft and where factorization breaks down, are suppressed. A similar idea has been advocated by Vanderhaeghen et al. [9] for the quark subprocess, however both approaches differ in detail.

The kinematics of the process are depicted in figure 1. The lower blob represents the soft hadron part, which is parametrized by a GPD $H(x, \xi, t)$ in case of unpolarized gluons and $H(x, \xi, t)$ in case of polarized gluons, whereas the upper blob contains the hard scattering amplitude and the soft meson production.

Considering the factorization of the process, we will now discuss the different components of the amplitude of leptoproduction of polarized vector mesons. For the GPD we

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1Throughout this paper we will use Ji’s notation for GPDs [10].
2The GPDs $H(x, \xi, t)$ and $\tilde{H}(x, \xi, t)$ are universal functions and may also be accessed e.g. in deeply virtual compton scattering.
Figure 1: The handbag-type diagram for leptoproduction of mesons. The large blob represents a sum over all spectator configuration. $k$ and $k'$ denote the momenta of the active partons. The small blob stands for meson leptoproduction off partons.

use a double distribution ansatz \cite{11} where a normal parton distribution is convoluted with a profile function for which we choose $h(x, y) = 6y(1 - x - y)$. The meson production is described by a convolution of the distribution amplitude, for which we took the asymptotic form, and the hard scattering part. The hard amplitude was calculated considering only gluonic contributions since the ZEUS data — with which we compared our calculations — are at high enough energies to neglect quark contributions.

Furthermore, according to the modified perturbative approach \cite{7, 8} we retain the quark transverse degrees of freedom and take into account Sudakov suppression\footnote{It has been shown in \cite{7, 8} that factorization is still valid in the modified perturbative approach.}. The inclusion of these effects leads to suppression of the contributions from the soft end–point regions which results in an overall smaller cross section for the $\gamma^* p \rightarrow V_L p$ process.

The final expression for the amplitude in this approach is

$$M_{0+0+}^{V(g)} = -\frac{2e}{\sqrt{N_c}} \sqrt{1 - \xi^2 (1 + \xi)} Q \int dx d\tau \tau \bar{\tau} H^g(x, \xi, t)$$

$$\times \int d^2b \hat{\Psi}(\tau, -b) \hat{T}_g(\tau, Q, b) \alpha_s(\mu_R) \exp \left[-S(\tau, b, Q)\right],$$

with

$$\hat{\Psi}(\tau, b) = 2\pi \frac{f_V}{\sqrt{2N_c}} \frac{6}{\sqrt{\tau b}} \exp \left[-\frac{\tau b}{4a_V^2}\right],$$

$$S(\tau, b, Q) = s(\tau, b, Q) + s(\bar{\tau}, b, Q) - \frac{4}{\beta_0} \ln \frac{\ln (\mu_R/\Lambda_{QCD})}{\ln (1/b\Lambda_{QCD})},$$

$$s(\beta, b, Q) = \frac{8}{3\beta_0} \left( \hat{q} \ln \left( \frac{\hat{q}}{\hat{b}} \right) - \hat{q} + \hat{b} \right) + \text{NLL terms \cite{12}},$$

and the hard scattering amplitude is denoted by $\hat{T}_g(\tau, Q, b)$.

As can be seen in figure 2, our calculation describes experimental data quite well. Without the inclusion of transverse quark momenta and sudakov suppression the curves
Figure 2: The cross section $s(\gamma^* L p \to \rho^0 L p)$ in nbarn as a function of the energy $W$ in GeV. Plotted are ZEUS [13] datapoints at $Q^2 = 9, 13, 17, 27$ GeV$^2$ where the topmost curve has the lowest $Q^2$. The calculated cross sections are in good agreement with experimental data.

would be approximately an order of magnitude above the data. The modified perturbative approach therefore is needed to correctly reproduce the data.

Due to the uncertainties, the cross section of vector meson photoproduction is not well suited to obtain informations on the GPDs, in this context the measurement of asymmetries seems more promising. Especially the measurement of the double–spin asymmetry in vector meson production — a task, for which newer experiments like HERMES are well suited — may provide interesting insights concerning the polarized gluon GPDs.

In the future it is planned to calculate all $\gamma^*_L \to V_L$ amplitudes — $\gamma^*_L \to V_L$ is already available — to examine spin–dependent effects by e.g. calculating the spin density matrix elements of the $\rho$–meson. In this context it is worthwhile to note that the mechanism which we propose for the suppression of the cross section also serves to regularize the infrared divergences, which appear in the calculation of the $\gamma^*_L \to V_L$ amplitudes.

The interest in the $\gamma^*_L \to V_L$ transitions bases not only in possible measurements of spin-dependent observables, e.g. at COMPASS, but some information on these amplitudes is already available from the H1 [14] and ZEUS [13] measurements of the decay density matrix elements in leptoproduction of $\rho$-mesons. The analysis of these matrix elements demonstrates that both the $\gamma^*_L \to V_L$ and the $\gamma^*_L \to V_L$ transition amplitudes are non-negligible even at photon virtualities as large as 10GeV$^2$. It is common to analyse the density matrix elements under the assumption of small relative phases between the amplitudes as is characteristic of Pomeron-type models [16]. In this case the $\gamma^*_L \to V_L$ transition amplitudes amount to about 20% of the dominant $\gamma^*_L \to V_L$ amplitude [14] [15].
and, hence, s-channel helicity conservation seems to hold with a fairly high precision.

Also of interest is the application of our method to the calculation of the $\Phi$ and $J/\Psi$ photoproduction cross sections which we intend to do in the near future.

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