Hard Exclusive Photoproduction of Φ and J/Ψ Mesons

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Abstract

We calculate the leading-order perturbative contribution to $\gamma\, p \to M_V\, p$, with M_V being a Φ or J/Ψ meson, in the kinematic region of large energy and scattering angle.

The theoretical basis of our investigation is the ERBL factorization scheme for hard exclusive hadronic reactions (see Refs. [1, 2]). This scheme results from an asymptotic analysis, which is undoubtedly valid for infinitely large momentum transfer, but it strongly depends on the particular reaction whether it can be applied to kinematic situations accessible in experiments. Only if competing (non-perturbative) mechanisms play a minor role for one or the other reason, the ERBL contribution has a fair chance to provide a substantial part of the cross section even at moderately large momentum transfer. This could be the case for the Φ and J/Ψ photoproduction channels, since vector-meson-dominance as well as handbag-type mechanisms are suppressed if a heavy quark-antiquark pair has to be produced. This is our main motivation to concentrate on the particular photoproduction channels.

According to the ERBL factorization scheme a hadronic scattering amplitude M at large momentum transfer can be written as a convolution integral of a hard scattering amplitude T_{H}, describing the scattering of the hadronic constituents, and hadronic distribution amplitudes (DAs) ϕ_{H}, parameterizing their bound state dynamics:

$$M_{\gamma p \to M_V p}\,(s,t) = \int_0^1 [dx] \int_0^1 [dy] \int_0^1 [dz]\, \phi_V^\dagger\,(z_i)\, \phi_p^\dagger\,(y_i)\, T_{\mathrm{H}}\left(x_i, y_i, z_i; \hat{s}, \hat{t}\right) \phi_p\,(x_i)\,. \tag{1}$$

The elementary scattering process takes place on the quark-gluon level. Hadrons are replaced by their valence (anti-)quarks which are assumed to move collinear to their parent hadron with longitudinal momentum fractions x_i, y_i, z_i, respectively. The internal redistribution of the large transferred momentum is accomplished by introducing hard gluons connecting all the quark lines. Thus, the hard scattering amplitude T_{H} is a process dependent, coherent sum of Feynman tree diagrams. For T_{H} we have two generic classes of diagrams: one in which the photon couples to the vector meson (class I) and one in which it couples to the proton (class II). Class I diagrams can be considered as the remnant of a vector-meson-dominance mechanism, in which the γ fluctuates into the vector meson which then goes on-shell by exchanging hard gluons with the proton. Class II diagrams represent a Compton-like mechanism. The arguments $\hat{s}$ and $\hat{t}$ of T_{H} indicate that all quark masses, apart of the charm-quark mass, are neglected when calculating T_{H}. The DAs are probability amplitudes for the momentum fractions. In our actual calculation we have chosen the "asymptotic" DA for the proton, i.e. $\phi_p \propto x_1 x_2 x_3$, and the "non-relativistic" DA $\phi_V \propto \delta\,(z_1 - 1/2)$ for the vector mesons. For the strong coupling α_{S} we have used the one-loop expression with $\Lambda_{\mathrm{QCD}} = 200$ MeV. As argument we have taken the average virtuality of that hard gluon which provides a particular α_{S}. If $|t|$ is large enough, α_{S} should be small enough to

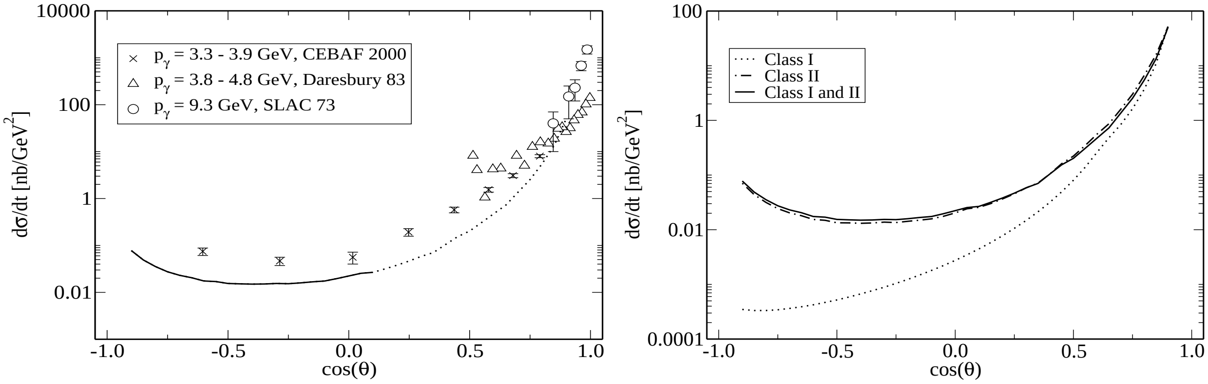

Figure 1: Leading-order perturbative prediction for $d\sigma_{\gamma p\to\Phi p}/dt$ at $p_\gamma^{\rm lab} = 9.3$ GeV in comparison with data [3, 4, 5] (left figure). Data from Refs. [4, 5] are appropriately scaled up to $p_\gamma^{\rm lab} = 9.3$ GeV. Results are shown for the asymptotic proton DA and the non-relativistic DA for the Φ. The solid part of the curve corresponds to $\alpha_{\rm S} \leq 0.5$, the remaining part to $0.5 < \alpha_{\rm S} \leq 0.7$. The right figure exhibits the contributions of class I and class II diagrams.

justify a perturbative treatment. In order to extrapolate our predictions to small $|t|$ values (where data exist), we apply a cutoff such that $\alpha_{\rm S}$ does not exceed a value of 0.7.

Fig.1 (left) shows our predictions for the unpolarized Φ-production cross section at 9.3 GeV photon lab energy in comparison with experimental data taken at SLAC [3], Daresbury [4] and JLab [5]. 9.3 GeV is the highest energy for which data up to reasonably large scattering angles exist. To increase our data base we have scaled those data, which were taken at lower energies but larger scattering angles, such that they smoothly extrapolate the SLAC data. The angular dependence of the (scaled) data is well reproduced. The absolute magnitude is a factor of 3-4 too small, but not orders of magnitude away as in other photoproduction channels. An increase of magnitude is even to be expected if one takes the asymptotic DA for the Φ ($\phi_V \propto z_1 z_2$) instead of the non-relativistic one. Since we have neglected all quark masses for Φ production, the proton helicity is conserved and the Φ must be polarized longitudinally. The right plot shows how the differential cross section is composed of class I and class II contributions. One observes that class II diagrams are by far dominant. This is somewhat unexpected, since class I graphs resemble the common picture of vector-meson photoproduction.

Our investigation of J/Ψ-photoproduction revealed that it is crucial to take into account the c-quark mass. The finite c-quark mass gives rise to the production of transversely polarized J/Ψs. For reasonably large energies and momentum transfers, which could be reached, e.g., by an upgrade of CEBAF, the corresponding amplitudes even dominate nearly over the whole angular range.

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