DIFFRACTIVE ELECTROPRODUCTION OF TWO MESONS SEPARATED BY A LARGE RAPIDITY GAP

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We consider the process $\gamma^* N \to M_1 M_2 N'$ with a large rapidity gap between the two mesons $M_1$ and $M_2$. Within the QCD collinear approximation, the scattering amplitude may be written as a convolution of an impact factor describing the $\gamma^* \to M_1$ transition and an amplitude describing the $N \to M_2 N'$ collinear process.

1 The Process

Let us consider [1] the process $AN \to M_1 M_2 N'$ shown in Fig. 1 of scattering of a particle $A$, e.g. being a virtual or real photon, on a nucleon $N$, which leads via two gluon exchange to the production of particle $M_1$ (meson or pair of mesons) separated by a large rapidity gap from another produced meson $M_2$ and the scattered nucleon $N'$. We consider the kinematical region where the rapidity gap between $M_2$ and $N'$ is much smaller than the one between $M_1$ and $M_2$, that is the energy of the system ($M_2 - N'$) is smaller than the energy of the system ($M_1 - M_2$) but still large enough to justify our approach (in particular much larger than baryonic resonance masses).

Such a process is a representative of a new class of hard reactions whose QCD description involves at the same time the impact factor appearing naturally in Regge-type perturbative description based on the BFKL evolution [2] and the collinear distributions which have been introduced for describing

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deeply virtual Compton scattering [3] and whose evolutions are governed by DGLAP-ERBL equations.

In order to make our discussion clear let us consider a reference process with all longitudinally polarized vector particles

\[ \gamma^*_{L}(q_{\gamma^*}) N(p_2) \rightarrow \rho^+_L(q_{\rho}) \rho^+_L(p_\rho) N'(p_{2'}) , \]

which involves the emission of two gluons in the $\gamma^*_{L} \rightarrow \rho_L$ transition and which is more founded theoretically from the point of view of the collinear factorization. We choose a charged vector meson $\rho^+$ to select quark antiquark exchange with the nucleon.

2 Kinematics

Let us summarize the kinematics of the process (1). We introduce two light-like Sudakov vectors $p_{1/2}$. The momenta are parametrized as follows:

\[ q^\mu = p^\mu_1 - \frac{Q^2}{s} p^\mu_2 , \quad q^2 = -Q^2 , \quad s = 2(p_1p_2) , \]

\[ q^\mu_{\rho} = \alpha p^\mu_1 + \frac{\vec{p}^2}{\alpha s} p^\perp_2 + p^\mu_\perp , \quad p^2_\perp = -\vec{p}^2 , \]

\[ p^\mu_{\rho} = \bar{\alpha} p^\mu_1 + \frac{\vec{p}^2}{\bar{\alpha} s} p^\perp_2 - p^\mu_\perp , \quad \bar{\alpha} \equiv 1 - \alpha , \]

\[ p^\mu_{2'} = p^\mu_2 (1 - \zeta) , \]

Figure 1: Factorization of the process $A N \rightarrow M_1 M_2 N'$ in the asymmetric kinematics discussed in the text. $P$ is the hard Pomeron.
where $\zeta$ is the skewedness parameter which can be written as

$$\zeta = \frac{1}{s} \left( Q^2 + s_1 \right),$$

(3)

and where $s_1$ is the two meson invariant mass $s_1 = (q_p + p_p)^2 = \vec{p}_1^2 / \alpha \bar{\alpha}$.

The $\rho^+(p_p)$-meson - target invariant mass equals $s_2 = (p_p + p_{2'})^2 = s \bar{\alpha} (1 - \zeta)$. The kinematical limit with a large rapidity gap between the two mesons in the final state is obtained by demanding that $s_1$ is very large

$$s_1 = s \zeta, \quad s_1 \gg Q^2, \vec{p}_2^2,$$

(4)

whereas $s_2$ is kept constant but large enough to justify the use of perturbation theory in the collinear subprocess $\mathcal{P}N \rightarrow \rho_L^0 N'$ and the application of the GPD framework [3]. In terms of the longitudinal fraction $\alpha$ the kinematics with a large rapidity gap corresponds to taking the limits $\alpha \rightarrow 1, \quad \bar{\alpha} s_1 \rightarrow \vec{p}_2^2, \quad \zeta \sim 1$. We consider the case when the scattered nucleon gets no transverse momentum in the process, but one may allow a finite momentum transfer, small with respect to $|\vec{p}_2|$, with slight modifications of the formulae.

Let us stress that the role of the hard scale in the process under discussion is played by the virtuality $p^2 = -\vec{p}_1^2$, or by the large momentum transfer in the two-gluon exchange channel. If additionally the incoming photon has non zero, sufficiently large virtuality $Q^2$, then the theoretical description of the processes simplifies even more, as we can neglect within our approximation the contribution of the hadronic component of the photon.

3 Amplitude

We have shown that the scattering amplitude $\mathcal{M}$ of the process (1) may be calculated in the collinear factorization approach. The final result is represented as a convolution (an integral over the longitudinal momentum fractions of the quarks) of the two amplitudes: the first one describing the transition $A \rightarrow M_1$ via two gluon exchange and the second one describing the subprocess $\mathcal{P} N \rightarrow M_2 N'$ which is closely related to the electroproduction process $\gamma^* N \rightarrow M_2 N'$ where collinear factorization theorems [4] allow to separate the long distance dynamics expressed through GPDs from a perturbatively calculable coefficient function. The hard scale appearing in the process $\mathcal{P}N \rightarrow M_2 N'$ is supplied
by the relatively large momentum transfer $p^2$ in the two gluon channel, i.e. by the virtuality of the Pomeron $P$.

The scattering amplitude reads:

$$\mathcal{M} = \sum_{p=q,q} \int_0^1 dz \int_0^1 du \int_0^1 dx_1 T_H^p(x_1, u, z) F_p^p(x_1) \phi_{\rho^+}(u) \phi_{\rho^0}(z).$$

(5)

Here $F_p^p(x_1)$ is the generalized parton $p$ distribution in the target at zero momentum transfer; $x_1$ and $x_2 = x_1 - \zeta$ are the momentum fractions of the emitted and absorbed partons (quarks) of the target, respectively (as usual the case $x_2 < 0$ is interpreted as an emitted antiquark). $\phi_{\rho^+}(u)$ and $\phi_{\rho^0}(z)$ are the distribution amplitudes of the $\rho^+$—meson and $\rho^0$—meson, respectively. $T_H^p(x_1, u, z)$ is the hard scattering amplitude (the coefficient function). For clarity of notation we omit in Eq. (5) the factorization scale dependence of $T_H^p$, $F_p^p$, $\phi_{\rho^0}$ and $\phi_{\rho^+}$.

Eq. (5) describes the amplitude in the leading twist. Within this approximation one neglects (in the physical gauge) the contributions of the higher Fock states in the meson wave functions and the many parton correlations (higher twist GPD’s) in the proton. Moreover, one can neglect in the hard scattering amplitude the relative (with respect to a meson momentum) transverse momenta of partons (the collinear approximation). This results in the appearance in the factorization formula (5) of the distribution amplitudes$^1$, i.e. the light-cone wave functions depending on the relative transverse momenta of constituents integrated over these momenta up to the collinear factorization scale.

In the Born approximation the scattering amplitude $T_H^q(x_1, u, z)$ for the quark $q$ target is described by six diagrams. They are calculated for the on-mass-shell quarks carrying the collinear momenta $x_1, 2p_2$. The on-mass-shell quark (resp. antiquark) entering the $\rho$—mesons distribution amplitudes $\phi_{\rho^+}(u)$ and $\phi_{\rho^0}(z)$ carry fractions $u$ (resp. $1 - u$) and $z$ (resp. $1 - z$) of the momentum of a corresponding outgoing meson, $q_\rho$ and $p_\rho$, respectively. Moreover, we shown that the scattering amplitude $T_H^q(x_1, u, z)$ turns out to be proportional to $J^{\gamma^L \rightarrow \rho^}_L (up, \bar{u}\bar{p})$, i.e. to the impact factor for $\gamma^L \rightarrow \rho^0_L$ transition via the two gluon (Pomeron) exchange.

$^1$or a generalized distribution amplitude [5] if $M_1$ is a pair of mesons
We found that the integrals over $x_1, u$ and $z$ in the amplitude (5) are convergent which justifies the validity of the factorization formula. Gauge invariance plays here a crucial role by guaranteeing that the impact factor vanishes when $u, \bar{u} \to 0$.

All steps of the derivation can be immediately applied to the description of a whole family of processes, in particular those involving the chiral-odd GPD [6], e.g. for
\[
\gamma_1^L(q) \to \rho_2^L(q_\rho) \to \rho_1^\perp(p_\rho)N'(p_{2'}) ,
\]
which has been the main motivation for the present studies. The scattering amplitude for the process (6) has the same general structure as for the reference process (1); it involves the $\rho^\perp$-meson distribution amplitude and the generalized transversity distribution in the target.

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