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PROBING TRANSVERSITY IN ELECTROPRODUCTION OF TWO VECTOR MESONS

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Electroproduction of two vector mesons with a large rapidity gap between them provides the first feasible selective access to chiral-odd GPDs [1]. The scattering amplitude of the process $\gamma^* N \to \rho_L^0 \rho_T^+ N'$ may be represented as a convolution of an impact factor describing the $\gamma^* \to \rho_L^0$ transition and an amplitude describing the $N \to \rho_T^+ N'$ transition, analogously to deeply exclusive electroproduction of a meson, the virtual photon being replaced by a Pomeron. The production of a transversely polarized vector meson ρ_T^+ selects a chiral-odd GPD in the proton.

Показано, что электророждение двух векторных мезонов с большой разностью быстрот дает первую возможность измерения кирально-нечетных обобщенных партонных распределений [1]. Амплитуда рассеяния процесса $\gamma^* N \to \rho_L^0 \rho_T^+ N'$ представима в виде свертки импакт-фактора, описывающего переход $\gamma^* \to \rho_L^0$, и амплитуды, описывающей переход $N \to \rho_T^+ N'$, аналогично эксклюзивному образованию мезона с заменой виртуального фотона помероном. Образование поперечно-поляризованного мезона ρ_T^+ отбирает кирально-нечетные ОПР протона.

The study of transversity [2] is of fundamental interest for understanding the spin structure of nucleons. Generalized Parton Distributions (GPDs) are the nonperturbative objects encoding the information about the quark and gluon proton structure in the most complete way [3]. While the chiral even GPD may be probed in various hard exclusive processes, no single one has yet been proven to be sensitive to transverse spin-dependent chiral-odd GPDs [4, 5].

In the massless quark limit, the chiral-odd functions may appear only in pairs in a nonvanishing scattering amplitude, so that chirality flip encoded in one of them is compensated by another. The natural probe for the forward chiral-odd distributions is the Drell–Yan process, containing the convolution of chiral-odd distributions of quark and antiquark [6]. Its nonforward analog is provided by the hard exclusive production of a transversely polarized vector meson, where the quark transversity distribution in the nucleon is substituted by the chiral-odd GPD. The generalized (skewed) transversity distribution in nucleon target $F_\zeta^T(x)$ described by the polarization vector n^μ is defined by the formula

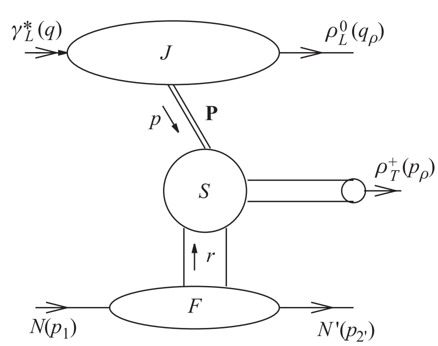
$$\langle N(p_{2'},n)|\bar{q}(0)\sigma^{\mu\,\nu}q(y)|N(p_2,n)\rangle = \bar{u}(p_{2'},n)\sigma^{\mu\,\nu}u(p_2,n)\times \\ \times\int\limits_0^1 d\,x_1\,\left[\mathrm{e}^{-ix_1(p_2 y)}F_\zeta^{T\,q}(x_1) - \mathrm{e}^{ix_2(p_2 y)}F_\zeta^{T\,\bar{q}}(x_1)\right], \quad (1)$$

where $\sigma^{\mu\,\nu} = i/2[\gamma^\mu\,,\gamma^\nu],\ x_2 = x_1 - \zeta$.

However, the simplest realization of this idea, namely the hard exclusive electroproduction of a transversely polarized vector meson, results in a zero contribution [7, 8]. We suggest another process which allows one to access the chiral-odd GPD's by «substituting» to the virtual photon a hard two gluon exchange, i.e., a perturbative Pomeron ($\mathcal{P}$) in the lowest order, coming from a virtual photon → meson transition. Let us consider the specific process

$$\gamma_L^*(q)N(p_2) \to \rho_L^0 e(q_\rho)\rho_T^+ e(p_\rho)N'(p_{2'}), \quad (2)$$

shown in the figure, of scattering of a virtual photon on a nucleon N, which leads via two gluon exchange to the production of two vector mesons separated by a large rapidity gap and the scattered nucleon N'. We choose a charged vector meson ρ^+ to select quark-antiquark exchange with the nucleon line. We consider the kinematical region where the rapidity gap between ρ^+ and N' is much smaller than the one between ρ^0 and ρ^+, that is the energy of the system ($\rho^+ - N'$) is smaller than the energy of the system ($\rho^0 - \rho^+$) but still large enough to justify our approach (in particular much larger than baryonic resonance masses).



Factorization of the process $\gamma_L^*(q)N(p_2) \to \rho_1 e(q_\rho)\ \rho_2^+ e(p_\rho)N'(p_{2'})$ in the asymmetric kinematics discussed in the text. $\mathbf{P}$ is the hard Pomeron

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

$$
\begin{aligned}
&q^\mu = p_1^\mu - \frac{Q^2}{s} p_2^\mu\,, \quad q^2 = -Q^2\,, \quad s = 2(p_1 p_2), \\
&q_\rho^\mu = \alpha p_1^\mu + \frac{\mathbf{p}^{\,2}}{\alpha s} p_2^\mu + p_\perp^\mu, \quad p_\perp^2 = -\mathbf{p}^{\,2}, \\
&p_\rho^\mu = \bar\alpha p_1^\mu + \frac{\mathbf{p}^{\,2}}{\bar\alpha s} p_2^\mu - p_\perp^\mu, \quad \bar\alpha \equiv 1-\alpha, \\
&p_{2'}^\mu = p_2^\mu (1-\zeta),
\end{aligned}
\tag{3}
$$

where ζ is the skewedness parameter which can be written in terms of the two meson invariant mass

$$
s_1 = (q_\rho + p_\rho)^2 = \frac{\mathbf{p}^{\,2}}{\alpha\bar\alpha} \tag{4}
$$

and the photon virtuality Q^2 as

$$
\zeta = \frac{1}{s}(Q^2 + s_1). \tag{5}
$$

The $\rho^+(p_\rho)$-meson-target invariant mass equals

$$
s_2 = (p_\rho + p_{2'})^2 = s\bar\alpha(1-\zeta). \tag{6}
$$

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, being of the order of s

$$
s_1 = s\,\zeta\,, \quad s_1 \gg Q^2,\ \mathbf{p}^{\,2}, \tag{7}
$$

whereas s_2 is kept constant but large enough to justify the use of perturbation theory in the collinear subprocess $\mathcal{P}N \to \rho_T^+ N'$ and the application of the GPD framework

$$
s_2 \to \frac{\mathbf{p}^{\,2}}{\zeta}\ (1-\zeta) = \text{const}. \tag{8}
$$

In terms of the longitudinal fraction α the limit with a large rapidity gap corresponds to taking the limits

$$
\alpha \to 1, \quad \bar\alpha s_1 \to \mathbf{p}^{\,2}, \quad \zeta \sim 1. \tag{9}
$$

We have shown [1] that in such a kinematical circumstance, the Born term for this process is calculable consistently within the collinear factorization method. The final result is represented as an integral (over the longitudinal momentum fractions of the quarks) of the product of two amplitudes: the first one describing the transition $\gamma^* \to \rho^0_L$ via two gluon exchange and the second one describing the subprocess $\mathcal{P}N \to \rho^+ N'$ which is closely related to the electroproduction process $\gamma^* N \to \rho^+ N'$, where collinear factorization theorems allow one to separate the long-distance dynamics expressed through the GPDs from a perturbatively calculable coefficient function. The case of transversally polarized vector meson ρ^+_T involves the chiral-odd GPD. The hard scale appearing in this process is supplied by the relatively large momentum transfer p^2 in the two gluon channel, i.e., by the virtuality of the Pomeron.

Such a process is a representative of a new class of hard reactions whose QCD description within the collinear factorization scheme involves in the described above kinematics the impact factor J appearing naturally in the Regge-type perturbative description based on the BFKL evolution and the collinear distributions whose evolutions are governed by DGLAP–ERBL equations.

We have choosen the kinematics so that the nucleon gets no transverse momentum in the process. Let us however note that in principle one may allow a finite momentum transfer, small with respect to $|\mathbf{p}|$. This case will involve additional GPDs in the expressions to follow.

We have shown that the collinear factorization holds at least in the Born approximation. The resulting scattering amplitude has a very compact form and it reads:

$$\mathcal{M}^{\gamma^* p \to \rho^0_L \rho^+_T n} = -i \sin\theta\, 8\pi^2 \zeta s \alpha_s f_T \sqrt{1-\zeta} \frac{C_F}{N\,(\mathbf{p}^{\,2})^2} \times \\ \times \int\limits_0^1 \frac{du\,\phi_\perp(u)}{u^2 \bar{u}^2} J^{\gamma^*_L \to \rho^0_L}(u\mathbf{p}, \bar{u}\mathbf{p}) \left[F^{Tu}_\zeta(u\zeta) - F^{T\bar{d}}_\zeta(u\zeta) \right], \quad (10)$$

where θ is the angle between the transverse polarization vector of the target $\mathbf{n}$ and the polarization vector $\boldsymbol{\epsilon}_T$ of the produced ρ^+_T-meson.

$J^{\gamma^*_L \to \rho^0_L}$ is the impact factor

$$J^{\gamma^*_L \to \rho^0_L}(\mathbf{k}_1, \mathbf{k}_2) = -f_\rho \frac{e\alpha_s 2\pi Q}{N_c \sqrt{2}} \int\limits_0^1 dz\; z\bar{z} \phi_{||}(z) P(\mathbf{k}_1, \mathbf{k}_2), \quad (11)$$

with

$$P(\mathbf{k}_1, \mathbf{k}_2 = \mathbf{p} - \mathbf{k}_1) = \frac{1}{z^2 \mathbf{p}^{\,2} + m_q^2 + Q^2 z\bar{z}} + \frac{1}{\bar{z}^2 \mathbf{p}^{\,2} + m_q^2 + Q^2 z\bar{z}} - \\ - \frac{1}{(\mathbf{k}_1 - z\mathbf{p})^2 + m_q^2 + Q^2 z\bar{z}} - \frac{1}{(\mathbf{k}_1 - \bar{z}\mathbf{p})^2 + m_q^2 + Q^2 z\bar{z}}. \quad (12)$$

The transversely polarized ρ-meson is described by means of its chiral-odd light-cone distribution amplitude [9] defined by the matrix element

$$\langle \rho_T(p_\rho, T) \mid \bar{q}(x)\sigma^{\mu\nu} q(-x) \mid 0\rangle = = i f_T \left(p_\rho^\mu \epsilon_T^{*\nu} - p_\rho^\nu \epsilon_T^{*\mu}\right) \int\limits_0^1 du\, \mathrm{e}^{-i(2u-1)(p_\rho x)}\, \phi_\perp(u), \quad (13)$$

where $\phi_\perp(u) = 6u\bar{u}$ and $f_T(\mu) = 160 \pm 10$ MeV at the scale $\mu = 1$ GeV.

Another example is the process with ρ^0 replaced by heavy J/Ψ-meson. One could study either $\gamma_L^* N \to J/\Psi_L \rho_T^+ N'$ involving the impact factor

$$J^{\gamma_L^* \to J/\Psi_L}(\mathbf{k}_1, \mathbf{k}_2 = \mathbf{p} - \mathbf{k}_1) = = -\frac{8\pi\, e\, \alpha_s\, Q\, f_{J/\Psi}}{3N} \left(\frac{1}{\mathbf{p}^{\,2} + Q^2 + 4m_c^2} - \frac{1}{(2\mathbf{k}_1 - \mathbf{p})^2 + Q^2 + 4m_c^2}\right), \quad (14)$$

or the process $\gamma_T^* N \to J/\Psi_T \rho_T^+ N'$ for which the impact factor $J^{\gamma_T^* \to J/\Psi_T}$ has the form

$$J^{\gamma_T^* \to J/\Psi_T}(\mathbf{k}_1, \mathbf{k}_2 = \mathbf{p} - \mathbf{k}_1) = \frac{4e\alpha_s \pi m_c f_{J/\Psi}}{3N} (\boldsymbol{\varepsilon}\boldsymbol{\epsilon}^*) \times \times \left(\frac{1}{\mathbf{p}^{\,2} + Q^2 + 4m_c^2} - \frac{1}{(2\mathbf{k}_1 - \mathbf{p})^2 + Q^2 + 4m_c^2}\right). \quad (15)$$

These impact factors are obtained from the corresponding ones for light quarks by applying a standard nonrelativistic approximation for the J/Ψ-meson vertex, i.e., by approximating the distribution amplitude by $\phi_{j/\Psi}(z) = \delta(z - 1/2)$. The coupling constant $f_{J/\Psi}^2 = \dfrac{27 m_{J/\Psi} \Gamma_{J/\Psi \to e^+ e^-}}{16\pi \alpha_{em}^2}$ is expressed in terms of the width $\Gamma_{J/\Psi \to e^+ e^-}$ and $\alpha_{em} = e^2/4\pi$. This last process (15) can be of course also studied for both virtual and real photon.

One can also study the transversity in the inelastic DVCS: $\gamma_{L/T}^* N \to \gamma \rho_T^+ N'$. The expressions for the corresponding impact factors $J^{\gamma_T^* \to \gamma_{T'}}$ and $J^{\gamma_L^* \to \gamma_{T'}}$ are also known and can be found, e.g., in [10] (Eqs. (11) and (12), respectively).

The case with $Q^2 = 0$, i.e., the photoproduction at large momentrum transfer is more complicated and may require to take into account both the perturbative and the hadronic (nonperturbative) contributions (see, e.g., [11]).

In conclusion, the chiral-odd GPD may now be accessed in a feasible reaction, namely $\gamma^* p \to \rho_L^0\, \rho_T^+ n$ which can be described consistently within the collinear factorization approach in the specific kinematics, where the two mesons are produced with a large rapidity gap. Higher order studies are necessary to establish the validity of this factorization property beyond the Born order. An estimate of the cross section of this reaction requires a knowledge of the chiral-odd GPD. No model has been proposed yet for this quantity. Further improvement of the theoretical understanding of hadronic impact factors may help us to access this chiral-odd GPD also in hadronic diffractive reactions at RHIC and LHC.

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