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Quarks vs. gluons in exclusive ρ electroproduction

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Abstract

We compare the contributions from quark and from gluon exchange to the exclusive process $\gamma^* p \to \rho^0 p$. We present evidence that the gluon contribution is substantial for values of the Bjorken variable x_B around 0.1.
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1. There is an ongoing experimental and theoretical effort to determine generalized parton distributions [1,2] from hard exclusive processes like deeply virtual Compton scattering and electroproduction of mesons. These distributions encode fundamental information about nucleon structure, in particular about the angular momentum carried by partons [2] and about their spatial distribution [3,4]. An important process is the production of ρ^0 mesons, well suited for experimental study because of its relatively high cross section and its clean final state signature from the decay $\rho^0 \to \pi^+\pi^-$. As pointed out in [5], the transverse target polarization asymmetry of this channel is sensitive to the nucleon spin-flip distribution E appearing in the angular momentum sum rule [2].

Quark and gluon distributions contribute to ρ production at the same order in α_s, as seen in Fig. 1. For the separation of quark and gluon degrees of freedom this channel is thus a valuable complement to deeply virtual Compton scattering, which offers the cleanest and most detailed access to generalized parton distributions [6,7], but is sensitive to gluons only at the level of α_s corrections. From the behavior of the usual quark and gluon densities one expects ρ production to be dominated by gluons at very small x_B and by quarks at very large x_B, and it is natural to ask where the transition between these two regimes takes place. In this Letter we present evidence that quarks and gluons contribute to the ρ cross section with comparable strength in the x_B region around 0.1, relevant for measurements

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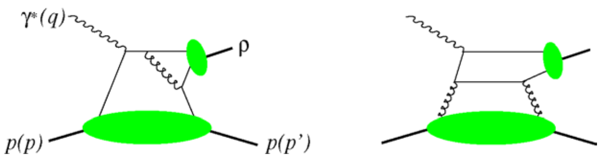

Fig. 1. Example graphs for $\gamma^* p \to \rho p$ with generalized quark and gluon distributions. Four-momenta are given in parentheses.

at HERMES [8]. Key ingredient in our argument is the measured cross section for ϕ electroproduction, where the gluon distribution should dominate.

2. We consider the exclusive processes $\gamma^* p \to \rho p$ and $\gamma^* p \to \phi p$ and use the standard kinematic variables $Q^2 = -q^2$, $W^2 = (p+q)^2$, $x_B = Q^2/(2pq)$ and $t = (p-p')^2$. In the limit of large Q^2 at fixed x_B and t the scattering amplitude factorizes into a hard-scattering kernel, generalized quark or gluon distributions, and the light-cone distribution amplitude of the produced meson [9]. We make the approximation that the normalization of the ρ and ϕ distribution amplitudes is related by $\langle \rho | \bar{u}\gamma^\mu u - \bar{d}\gamma^\mu d|0\rangle = \sqrt{2}\langle \phi|\bar{s}\gamma^\mu s|0\rangle$. This relation leads to a value of 9 : 2 for the ratio $(M_\rho \Gamma_{\rho\to e^+e^-}) : (M_\phi \Gamma_{\phi \to e^+e^-})$ of meson mass times partial leptonic width, which compares well with the value 9 : 2.1 from experiment [10]. We further assume that the ρ and ϕ distribution amplitudes have the same dependence on the quark momentum fraction. The ratio of production amplitudes for the two channels is then[1]

$$\mathcal{A}_\rho : \mathcal{A}_\phi = -\frac{1}{\sqrt{2}}\left(\frac{2}{3}\mathcal{F}^u + \frac{1}{3}\mathcal{F}^d + \frac{3}{4}\mathcal{F}^g\right) : \left(\frac{1}{3}\mathcal{F}^s + \frac{1}{4}\mathcal{F}^g\right) \tag{1}$$

to leading accuracy in $1/Q$ and in α_s. Here

$$\mathcal{F}^q = \int_0^1 dx \left[\frac{1}{\xi - x - i\varepsilon} - \frac{1}{\xi + x - i\varepsilon}\right] \times \left[F^q(x,\xi,t) - F^q(-x,\xi,t)\right] \quad (q = u,d,s),$$

$$\mathcal{F}^g = \int_0^1 dx \left[\frac{1}{\xi - x - i\varepsilon} - \frac{1}{\xi + x - i\varepsilon}\right] \frac{F^g(x,\xi,t)}{x} \tag{2}$$

with $\xi = x_B/(2-x_B)$ are the relevant integrals over quark and gluon matrix elements, parameterized by generalized parton distributions as

$$F^q(x,\xi,t) = \frac{1}{(p+p')^+}\left[H^q(x,\xi,t)\bar{u}(p')\gamma^+ u(p) + E^q(x,\xi,t)\bar{u}(p')\frac{i\sigma^{+\mu}(p'-p)_\mu}{2m}u(p)\right] \tag{3}$$

for quarks and in analogy for gluons. The distributions are normalized such that in the forward limit and for $x > 0$ one has $H^q(x,0,0) = q(x)$, $H^q(-x,0,0) = -\bar{q}(x)$ and $H^g(x,0,0) = xg(x)$, for explicit definitions see, e.g., [7]. It is understood that the distributions are to be taken at a factorization scale of order Q^2. We restrict our study to the Born level formulae (1) and (2) and note that at next-to-leading order in α_s the amplitudes depend in addition on the quark flavor singlet distribution $\sum_q [F^q(x,\xi,t) - F^q(-x,\xi,t)]$, which mixes with $F^g(x,\xi,t)$ under evolution [11].

3. The $\gamma^* p$ cross section on an unpolarized target involves the combination

$$\frac{1}{2}\sum_{s's}|\mathcal{F}_{s's}|^2 = \left(1-\xi^2\right)|\mathcal{H}|^2 - \left(\xi^2 + \frac{t}{4m^2}\right)|\mathcal{E}|^2 - 2\xi^2\,\mathrm{Re}\left(\mathcal{E}^*\mathcal{H}\right), \tag{4}$$

where s and s' respectively denote the polarization of the initial and final state proton, and where $\mathcal{F}$, $\mathcal{H}$ and $\mathcal{E}$ are the relevant linear combinations of integrals over quark and gluon distributions given in (1). In the following we will be interested in kinematics where ξ is below 0.1 and where the dominant values of $-t$ are

[1] We remark that there is a mistake in Eq. (284) of [7]: in all three terms with F^g the 8 in the prefactor should be replaced by 4.

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