Quark exchange & quark dynamics in diffractive electroproduction

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I briefly[1] discuss a covariant, quantum field theoretic quark-nucleon pomeron-exchange model[2] and describe two applications of this model to diffractive electroproduction. The model employs elements from studies of the Dyson-Schwinger equations of QCD, such as dressed-quark propagators which incorporate confinement, dynamical chiral symmetry breaking, and have the correct asymptotic behavior required by perturbative QCD[3]. The model provides an excellent description of diffractive processes and reveals some aspects of the interplay between perturbative and nonperturbative QCD. After a brief account of the role of the current-quark mass in determining the onset of the asymptotic-q^2 behavior of diffractive electroproduction, I describe how quark exchanges are included into the model, thereby providing a complete picture of the diffractive electroproduction of light-quark vector mesons over *all* energies and photon-momenta q^2.

The ρ-meson electroproduction current obtained in Ref. 2 is

$$J_\mu(q) = 2\, t_{\mu\alpha\nu}(q,p)\, \varepsilon_\nu(p;\lambda_\rho)\, \bar{u}_{m'}(p_2)\mathcal{G}_\alpha(W^2,t)u_m(p_1), \tag{1}$$

where $u_m(p_1)$ and $\bar{u}_{m'}(p_2)$ are the Dirac spinors for the nucleon, $\varepsilon_\nu(p;\lambda_\rho)$ is the polarization vector of the ρ meson, $\mathcal{G}_\alpha(W^2,t)$ (dashed box in Fig. 1) is the model quark-nucleon pomeron-exchange interaction, and $t_{\mu\alpha\nu}(q,p)$ is the photon-ρ-meson transition amplitude (represented by the quark loop in Fig. 1). The quark-nucleon interaction $\mathcal{G}_\alpha(s,t)$ is given in terms of the slope and intercept of the pomeron-exchange Regge trajectory and two coupling constants β_u and β_s for u- (or d-) and s-quarks. Their values are determined in an application to πN and KN elastic scattering[2]. Evaluation of $t_{\mu\alpha\nu}(q,p)$ requires explicit forms for the dressed-quark propagator $S_f(k)$, dressed quark-photon vertex $\Gamma_\mu(k,k')$, and vector-meson Bethe-Salpeter amplitude $V_\nu(k,p)$. These are taken from phenomenological studies of hadron observables based on the Dyson-Schwinger equations.

[1] For a longer version of this talk, see http://xxx.lanl.gov/abs/nucl-th/9806065.
[2] M.A. Pichowsky and T.-S.H. Lee, Phys. Rev. D**56** (1997) 1644.
[3] C.J. Burden, C.D. Roberts and M.J. Thomson, Phys. Lett. B**371** (1996) 163.

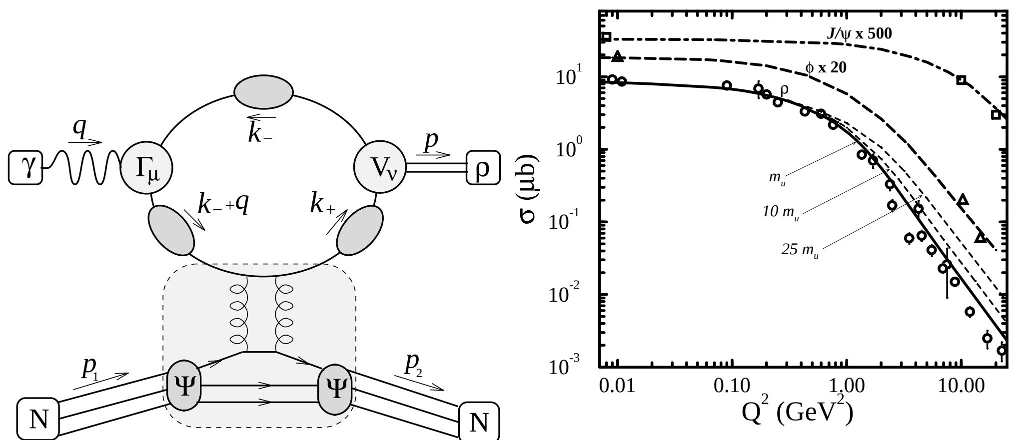

Figure 1: Left: The dashed box represents the quark-nucleon pomeron-exchange interaction $\mathcal{G}_\alpha(W^2,t)$. Shown within it is one of many possible multiple-gluon exchange diagrams that contributes. Right: The ρ^0-, ϕ-, and J/ψ-meson electroproduction cross sections at $W = 15$, 100 and 100 GeV, respectively. (Results and corresponding data are rescaled by amounts indicated.) Narrow dashed curves show ρ-meson results using fictitious current-quark masses of 10 and 25 times larger than $m_u = 5.5$ MeV.

The high-energy ρ-meson electroproduction cross section calculated from this model (solid curve in Fig. 1) is in excellent agreement with the data for all q^2. One important feature of the quark-nucleon interaction $\mathcal{G}_\alpha(W^2,t)$ in Eq. (1) is that it is independent of q^2. Hence, the correct q^2 dependence of the diffractive cross sections arises from having employed quark propagators that describe low-energy meson observables, such as the π- and K-meson electromagnetic form factors.

The role of the current-quark mass m_u in determining the q^2 dependence of electroproduction is explored in Ref. 2 by using fictitious current quark masses m_f that are 10 and 25 times greater than $m_u = 5.5$ MeV to recalculate the ρ-meson electroproduction cross section. A comparison of these curves to the result obtained using the correct value of $m_u = 5.5$ MeV, reveals that all three curves converge in the photoproduction limit of $q^2 \to 0$, but diverge significantly for larger values of q^2, but do ultimately exhibit the same q^{-4} behavior. The onset of this asymptotic behavior is *determined* by the magnitude of m_u; that is, a larger current-quark mass for the quark and antiquark inside the produced vector meson postpones the onset of the asymptotic power-law behavior until a larger value of q^2. The results for ϕ and J/ψ electroproduction obtained from the model are shown in Fig 1.

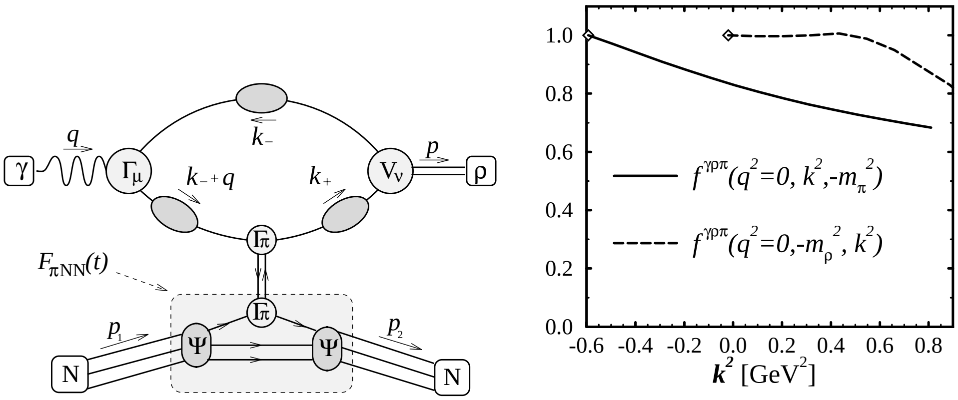

Figure 2: Left: t-channel effective-π exchange in ρ-meson electroproduction. Right: The off-shell $\gamma\rho\pi$ transition form factor. Diamonds indicate the "on-shell point."

Both the model calculation and experimental data exhibit the anticipated behavior.

The energy at which pomeron exchange and effective-meson exchanges each contribute about a half of the photoproduction cross section is $W \approx$ 6 GeV for ρ mesons and $W \approx 3$ GeV for ϕ mesons (see Fig. 3). These are incorporated into the pomeron-exchange model by a reorganization of the nonlocal interactions between quarks into sums of exchanges of effective fields with mesonic quantum numbers, referred to as effective-meson fields.

Consider the ρ-meson electroproduction current due to the t-channel exchange of an effective "π meson":

$$J_\mu(q) = \Lambda_{\mu\nu}(q,p)\,\varepsilon_\nu(p;\lambda_\rho)(m_\pi^2 - t)^{-1}\,\bar{u}_{m'}(p_2)\;\gamma_5 F_{\pi NN}(t)\;u_m(p_1), \qquad (2)$$

where $\Lambda_{\mu\nu}(q,p)$ is the photon-ρ-meson transition amplitude due to the exchange of an effective π meson (denoted in Fig. 2 by a quark loop) and $F_{\pi NN}(t) = (1 - t/\Lambda^2)^{-1}$ with $\Lambda \approx 1$ GeV is the effective-π-NN form factor. The amplitude is written as

$$\Lambda_{\mu\nu}(q,p) = (e_0/m_\rho)\; g_{\gamma\rho\pi}\; \epsilon_{\mu\nu\alpha\beta} q_\alpha p_\beta\; f^{\gamma\rho\pi}(q^2, p^2, -t), \qquad (3)$$

where $g_{\gamma\rho\pi}$ is the $\rho \to \gamma\pi$ decay constant, $\epsilon_{\mu\nu\alpha\beta}$ is the usual Levi-Cevita tensor, and $f^{\gamma\rho\pi}(q^2, p^2, -t)$ is the $\gamma\rho\pi$-transition form factor, defined so that when all three particles are on their mass shell, $f^{\gamma\rho\pi}(0, -m_\rho^2, -m_\pi^2) = 1$. All of the elements required to calculate Eq. (2) are known from phenomenological and numerical studies of the Dyson-Schwinger equations. The resulting

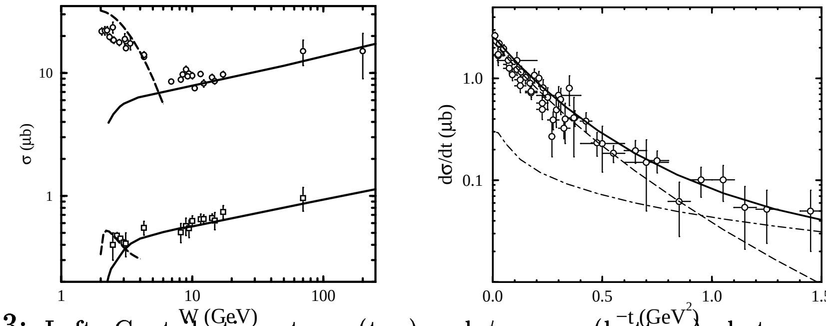

Figure 3: Left: Contributions to ρ- (top) and ϕ-meson (bottom) photoproduction from pomeron exchange (solid) and meson exchanges (dashed). Right: Differential cross section for ϕ-meson photoproduction due to pomeron exchange (dashed), π and η exchanges (dot-dashed) and their sum (solid) at $W = 3$ GeV.

photo-ρ-meson transition form factor is shown in Fig. 2 for a range of off-shell π- and ρ-meson momenta.

With these meson-transition form factors, one can use the quark-nucleon pomeron-exchange model to calculate ρ- and ϕ-meson electroproduction at all energies and q^2. The energy dependence of the ρ and ϕ-meson cross sections are shown in the left of Fig. 3 with $f^{\gamma\rho\pi}(q^2 = 0, p^2 = -m_\rho^2, -t) = 1$; hence, these predictions should overestimate the contributions from meson exchanges. In the right of Fig. 3 are results for the ϕ-meson differential cross section at $W = 3$ GeV. At moderate t, the meson-exchange contributions (from π and η exchange) overwhelm that of pomeron exchange. At lower energies, meson exchanges become increasingly important and one must include them (and their respective transition form factors) to obtain good agreement with the data.

I have given a brief outline of how quark dynamics and correlated-quark exchanges may be explored in diffractive electroproduction using a quantum field theoretic framework based on the Dyson-Schwinger equations of QCD.

In numerical studies of the Dyson-Schwinger equations, both perturbative and nonperturbative aspects of QCD are manifest in the solutions obtained for the elementary Schwinger functions, such as the dressed-quark propagator and meson Bethe-Salpeter amplitudes. In phenomenological applications, such as the one described here, one explores the consequences of employing such dressed Schwinger functions and their effect on experimental observables. In this way, one is able to probe the underlying dyamics of quarks and gluons involved in exclusive processes and further improve our understanding of QCD.