

A charge-conjugation-invariance constrained Pomeron-quark coupling

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The commonly used γ_μ Pomeron-quark coupling changes its sign under charge conjugation, in contradiction to the property of Pomeron. I show that the Pomeron-quark coupling is tensorial and is invariant under the charge conjugation.

1. Introduction

High-energy diffractive processes have been extensively modeled with Pomeron(**P**) exchange. It was shown [1] that the **P**-proton coupling to a very good approximation is given by the sum of individual **P**-quark coupling and that in the two-gluon model of the Pomeron the **P**-quark coupling is proportional to γ_μ , similar to that of C=1 isoscalar photon. As noted in Ref. [2], the model has a dubious aspect because γ_μ is odd under charge conjugation, \mathcal{C} , while the Pomeron should be even under \mathcal{C} . In spite of this, the γ_μ -model has been extensively employed [2]-[4].

In this work, I use the nonperturbative nature of the multigluon exchange and treat the Pomeron as a bound state of the gluons. As a result, a tensorial **P**-quark coupling emerges, which has the correct charge-conjugation property. My study also shed light on why the γ_μ coupling can be successful inspite of its intrinsic inadequacy.

2. Doorway-state model for **P** $q\bar{q}$ coupling

The doorway model for the s -channel qq scattering and the corresponding t -channel $q\bar{q}$ scattering is illustrated in Fig.1, where the doorway-state (shaded rectangle) is required to possess the quantum numbers of a Pomeron. At small t 's the Pomeron trajectory is linear: $\alpha(t) = \alpha_0 + \alpha' t$. The spins of the Pomerons are given by $J = \mathcal{R}e[\alpha(t)] = \alpha_0 + \mathcal{R}e[\alpha'] t$, where $\alpha_0 = 1.08$ and $\mathcal{R}e[\alpha'] = 0.20 \pm 0.02$ [5],[6], and 0.25 [3]. The spins compatible with the general properties of the Pomeron are $J = 2, 4, 6, \dots$. For definiteness, I will discuss the case with $J = 2$. The inclusion of higher J in the theory is straightforward.

It suffices to analyze the lower **P** $q\bar{q}$ vertex in Fig.1(b), where $p_2^{(t)} = -p_1'$ and $p_1'^{(t)} = -p_2$ are the momenta of the \bar{q} . The LSZ reduction gives the vertex function

$$X^{(t)} \propto \bar{u}(p_2', s') \Omega_{\rho\sigma}^{(t)} v(p_1'^{(t)}, s^{(t)}) e^{\rho\sigma}(P, \Lambda), \quad (1)$$

where $e^{\rho\sigma}$ is the spin-2 tensor spinor.

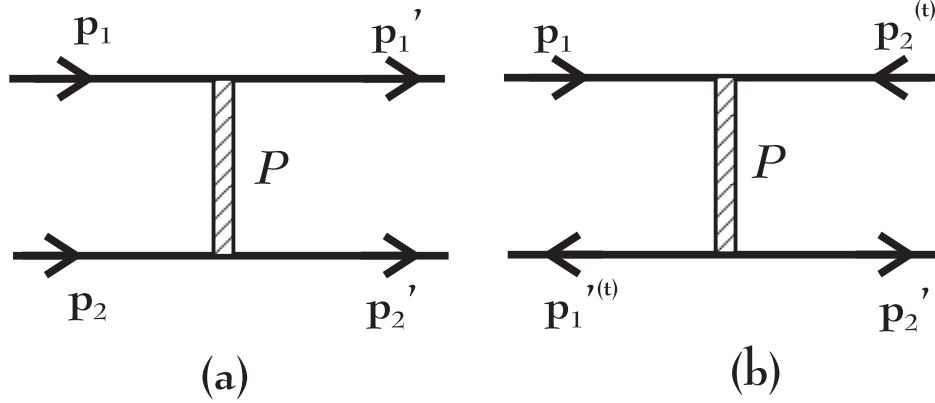


Figure 1. Doorway model. The solid lines and the shaded bar denote, respectively, the q or \bar{q} and the Pomeron: (a) s -channel qq scattering; (b) t -channel $q\bar{q}$ scattering.

Since $e^{\rho\sigma}$ is a symmetric tensor and $\bar{u}v$ is scalar, it follows that $\Omega_{\rho\sigma}^{(t)}$ is a symmetric tensor. The most general expansion of $\Omega_{\rho\sigma}^{(t)}$ is

$$\Omega_{\rho\sigma}^{(t)} = a_{(\rho)} g_{\rho\sigma} + h_{\rho\sigma} + (b_{\rho}\gamma_{\sigma} + b_{\sigma}\gamma_{\rho}) + c \sigma_{\rho\sigma} + (d_{\rho}\gamma_{\sigma} + d_{\sigma}\gamma_{\rho})\gamma_5 + f_{\rho\sigma}\gamma_5 \quad (2)$$

where $a_{(\rho)}$ and c are scalars, $h_{\rho\sigma}$ a symmetric tensor, b_{ρ} and b_{σ} 4-vectors, d_{ρ} and d_{σ} pseudo 4-vectors, and $f_{\rho\sigma}$ a pseudo tensor. Only two of the three 4-vectors in Eq.(1) are independent. Because it is not possible to construct either a pseudoscalar or a pseudovector, or a pseudotensor from two 4-vectors, it follows that $d_{\rho} = d_{\sigma} = 0$ and $f_{\rho\sigma} = 0$. Furthermore, since the Pomeron has no charge and since $\bar{u}v$ is invariant under \mathcal{C} , it follows that $\Omega_{\rho\sigma}^{(t)}$ is also invariant with respect to \mathcal{C} . Because $\gamma_{\rho}, \sigma_{\rho\sigma}$ are both odd under \mathcal{C} , hence $b_{\rho} = b_{\sigma} = 0$ and $c = 0$. The final result is

$$\Omega_{\rho\sigma}^{(t)} = a_{(\rho)} g_{\rho\sigma} + h_{\rho\sigma} . \quad (3)$$

One can write $h_{\rho\sigma} = p_{1\rho}'^{(t)} p_{2\sigma}'^{(t)} + p_{2\rho}'^{(t)} p_{1\sigma}'^{(t)}$. In the c.m. of the t -channel, $p_1'^{(t)} = (E(\kappa), -\vec{\kappa})$ and $p_2'^{(t)} = (E(\kappa), +\vec{\kappa})$. Thus, $h_{00} = 2E^2$, $h_{0j} = h_{j0} = 0$, $h_{ij} = h_{ji} = -2\kappa_i\kappa_j$.

The absence of γ_{μ} in Eq.(3) is due to the spin-2 tensor spinor of the Pomeron which makes $\Omega_{\rho\sigma}^{(t)}$ invariant under the \mathcal{C} operation. One should note that in Ref.[1] no definite spin and parity were projected out from the two-gluon state. As a result, the two-gluon model led to a γ_{μ} coupling. In other words, it is the spin-parity of the Pomeron that constrains the symmetry property of the vertex. Of course, obtaining a bound state starting with multigluons is still an unsolved nonperturbative dynamics. Our doorway approach represents an alternative solution.

3. The $q\bar{q}$ amplitude

The amplitude is equal to $\sum_{\rho\sigma\mu\nu} \Omega_{\rho\sigma}^{(t)} \Pi^{\rho\sigma,\mu\nu}(P) \Omega_{\mu\nu}^{(t)\dagger} \equiv \mathcal{I}_{q\bar{q}}$, where $\Pi^{\rho\sigma,\mu\nu}$ is the spin-2 projector. In the rest frame of the \mathbf{P} , $P = (M, \vec{0})$. Hence, $\Pi^{\rho\sigma,\mu\nu}(P)$ reduces to

$\Pi^{ij,mn} = (\delta_{im}\delta_{jn} + \delta_{jm}\delta_{in})/2 - \delta_{ij}\delta_{mn}/3$ ($i, j, m, n = 1, 2, 3$). If $a_{(\rho)} = a$, then

$$\mathcal{I}_{q\bar{q}} = \sum_{ijmn} \Omega_{ij}^{(t)} \Pi^{ij,mn} \Omega_{mn}^{(t)\dagger} = \frac{8}{3} |\vec{\kappa}|^4 \equiv G^2. \quad (4)$$

The effective interaction Lagrangian density of the doorway model is

$$\mathcal{L}_I = \frac{f}{M} \theta_{\mu\nu} \Phi^{\mu\nu} + g \bar{\psi} \gamma_\mu \psi A_\mu + h.c. \quad (5)$$

where M and $\Phi^{\mu\nu}$ are the mass and the tensor field of the 2^{++} Pomeron, ψ the quark field, A_μ the gluon field, and f, g the coupling constants. The color index is omitted but understood. The gauge invariant gluonic current is [7] $\theta_{\rho\sigma} = -G_\rho^\epsilon G_{\epsilon\sigma} + \frac{1}{4} g_{\rho\sigma} G_{\delta\xi} G^{\delta\xi}$. In the abelian approximation $G_{\epsilon\sigma} = \partial_\epsilon A_\sigma - \partial_\sigma A_\epsilon$ and $G_\rho^\epsilon = \partial_\rho A^\epsilon - \partial^\epsilon A_\rho$. The leading-order diagrams are shown in Fig.2. Detailed evaluation of these diagrams supports the ansatz $a_{(\rho)} = a$ that led to Eq.(4).

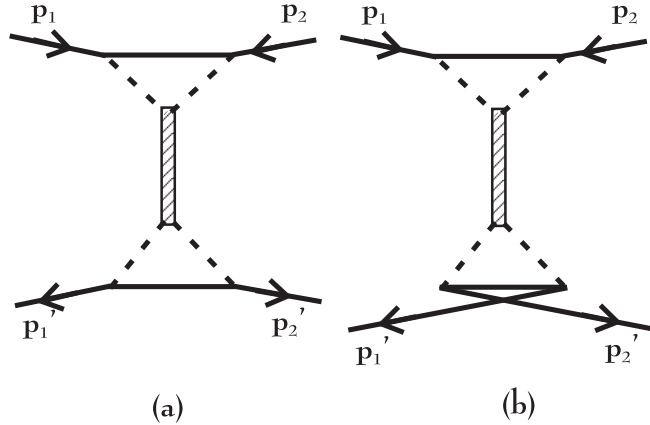


Figure 2. Leading-order diagrams of $q_{p_1} \bar{q}_{p_2} \rightarrow q_{p_1'} \bar{q}_{p_2'}$. The dashed lines denote the intermediate gluons. There are two additional diagrams (not shown) corresponding, respectively, to having the q and \bar{q} lines crossed in the upper vertex of (a) and (b).

The determination of the tensor-coupling vertex from the pp scattering data by means of Regge theory can be found in Ref.[8] where for the first time a singularity-free, crossing symmetric, invariant form factor has been formulated and applied with success. The results obtained from fitting pp total and differential cross sections at \sqrt{s} between 30 and 60 GeV/c with the use of $\alpha' = 0.20; J = 2$ are: $\Lambda_s = 0.65-0.66$; $\Lambda_t = 1.95-1.96$; $g_1 = 1.03-1.04$; $g_3 = 3.48-3.52$ (all in GeV/c). (The dimensions and values of g_1 and g_3 differ from those in [8] because of using a new parametrization of the amplitude, namely, (a) $M_{new} \equiv (k_s/\sqrt{s}) M_{\lambda_2 \lambda_4; \lambda_1 \lambda_3}$ and (b) in $M_{\lambda_2 \lambda_4; \lambda_1 \lambda_3}$ the factor $4m^2$ is absorbed into $G_\lambda G_{\lambda'}$. See eqs.(1) and (2) of [8]-1 for the notation.) The form factor is illustrated in Fig.3.

4. Conclusion

The spin and parity of the Pomeron leads to a \mathcal{C} -invariant tensor-coupling $\mathbf{P}q\bar{q}$ vertex and to a $q\bar{q}$ amplitude proportional to G^2 , a scalar. One notes that the γ_μ coupling gives

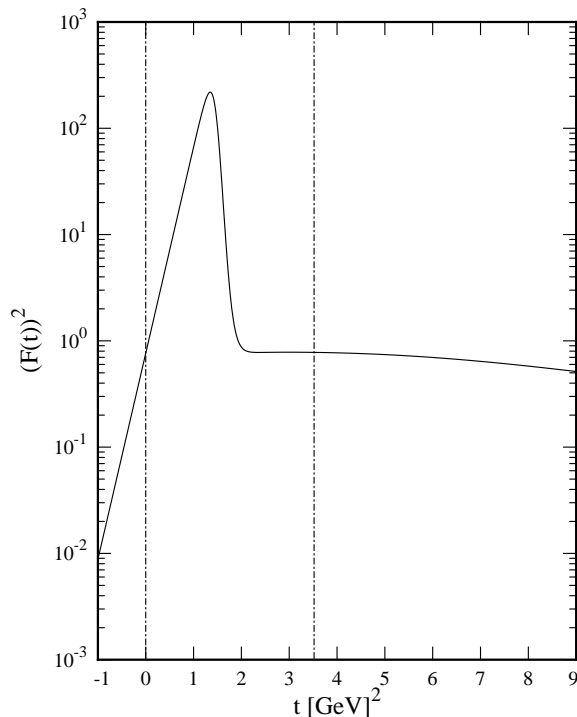


Figure 3. The t -dependence of the square of the angular-momentum-independent part of the singularity-free and crossing-symmetric form factor. The physical domains of the s - and t -channels correspond to $t \leq 0$ and $t \geq 4m_p^2 = 3.52[\text{GeV}/c]^2$, respectively.

an amplitude $\propto \gamma_\mu \otimes \gamma^\mu$ which also gives a scalar number[1]. This could be the reason that the γ_μ model can describe the pp scattering data inspite of its inconsistency with the Pomeron property. The tensor coupling should be used because of its transformation property under the charge conjugation. Study of diffractive processes involving more than two Pomeron vertices would differentiate the predictive powers of the γ_μ and tensor couplings.

REFERENCES

1. P.V. Landshoff and O. Nachtmann, Z. Phys. C 35 (1987) 45.
2. M.A. Pichowsky and T.-S.H. Lee, Phys. Rev. D 56 (1997) 1644.
3. A. Donnachie and P.V. Landshoff, Phys. Lett. B 185 (1987) 403.
4. J.-M. Laget and R. Mendez-Galain, Nucl. Phys. A 581 (1995) 397.
5. P.D.B. Collins, *An Introduction to Regge Theory and High Energy Physics*, Cambridge Univ. Press, 1977; see Section 6.8e for α' .
6. M.A. Block, K. Kang, and A.R. White, Int. J. Mod. Phys. A 7 (1992) 4449.
7. S. Narison, Nucl. Phys. B509 (1998) 312.
8. L.C. Liu and Wei-hsing Ma, J. Phys. G 26 (2000) L59; L.C. Liu, Phys. Lett. B 529 (2002) 65.