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Electromagnetic form factors for spin-1 particles with the light-front

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Abstract

This work is dedicate to investigate the spin-1 electromagnetic form factors with the light-front quantum field theory approach. All prescriptions with the light-front approach are contamined by the zero-modes contribuitions to the electromagnetic matrix elements of the electromagnetic current with the plus component of the current; however, the Inna Grach prescriptions it is immune for the zero modes contribuitions. We show numerically the contribution of zero-modes for the electromagnetic current in the case of the vector particles in the light-front quantum field theory. Also the electromagnetic observables, like electromagnetic form factors, radius and the decay constant are presented.

Keywords: Spin-1 particles, Electomagnetic current, Light-Front, Electromagnetic form factors, Quark Model

1. Introduction

The structure of the hadrons have stimulate much interest in the recently works with differents approaches [1, 2, 3, 4, 5, 6, 7], since hadronic electromagnetic form factors provide an window to the understanding the bound states QCD at low and intermediate momentum transfer.

However, the spin-1 hadronic structure has received less studies [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20], because from the experimental side, spin-1 particles are very difficult to measure the eletromagnetic proprieties [11].

The light-front model are helpfull to describe the hadronic structure in exclusive processes, in addition to the simplicity, have the correct kinematical boots properties of the corresponding amplitudes [21, 22]. But, in the another side, the light-front description in a truncated Fock space breaks the rotational symmetry as the associated transformation corresponds to a dynamical boost [2, 23, 24].

Therefore, an analysis with covariant analytical models, can be useful to pin down the main missing features in a truncated light-front Fock space description of the composite system. In this respect, the rotational symmetry breaking of the plus component of the electromagnetic current, in the Drell-Yan frame, was studied within an analytical model for the spin-1 vertex of a composite two-fermion bound state [2, 23].

In the last years, was shown, if pair terms or zero-modes contributions are ignored in the computation of the matrix elements of the electromagnetic current, the covariance of the electromagnetic form factors is violated [2, 10, 23, 24, 25, 26]. The complete restoration of covariance in the form factor calculation is found only when pair terms or zero modes contributions to the matrix elements of the current are take account [10, 23, 24, 25, 26, 27].

The extraction of the electromagnetic form factors of a spin-1 composite particle from the microscopic matrix elements of the plus component of the current ($J^+ = J^0 + J^3$) in the Drell-Yan frame (momentum transfer $q^+ = q^0 + q^3 = 0$), based only on the valence component of the wave function, presents ambiguities due

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to the lacking of the rotational invariance of the current model [28, 29].

In the Breit-frame with momentum transfers along the transverse direction (the Drell-Yan condition is satisfied) the current J^+ has four independent matrix elements, although only three form factors exist due to the constraints of covariance and current conservation. Therefore, the four matrix elements satisfy an identity, known as the angular condition [28] which is violated when the Fock space is truncated.

Several extraction schemes for evaluating the form factors were proposed, and in particular we consider the suggestion made in Ref. [28]. It was found in a numerical calculation of the ρ-meson electromagnetic form factors considering only the valence contribution [2], that the prescription proposed by [28] to evaluate the form factors, produced results in agreement with the covariant calculations. In Ref. [2], it was used an analytical form of the ρ-quark-antiquark vertex. Later, in Ref. [26], it was shown that the above prescription eliminates the pair diagram contributions to the form factors, using a simplified form of the model, when the matrix elements of the current were evaluated for spin-1 light-cone polarization states. This nice result was thought to be due to the use of the particular light-cone polarization states.

Our aim, is to expose in a simple and detailed form, how the pair terms appear in the matrix elements of the current evaluated between instant form polarization states, and their cancelation in the form factors using the correct prescription. Therefore, we conclude that this property is more general than realized before.

The matrix elements of the plus component of the current computed in the light-front helicity basis are free from zero-modes contributions excepting the $0 \to 0$ one. Our results goes beyond previous findings and generalizes finding in the reference [26].

2. Spin-1 Electromagnetic Current

In the impulse approximation, the electromagnetic current, J^{μ}_{ji} is writing below [2], and, here it is assumed the constituent quark as a Dirac point-like particle:

$$J^{\mu}_{ji} = \imath \int \frac{d^4k}{(2\pi)^4} \Lambda(k,p_f)\Lambda(k,p_i) \times \frac{Tr[\epsilon^{'\alpha}_j \Gamma_\alpha(k,k-p_f)(\not k-\not p_f+m)\gamma^\mu(\not k-\not p_i+m)\epsilon^\beta_i \Gamma_\beta(k,k-p_i)(\not k+m)]}{((k-p_i)^2-m^2+\imath\epsilon)(k^2-m^2+\imath\epsilon)((k-p_f)^2-m^2+\imath\epsilon)}, \quad (1)$$

where J^{μ}_{ji} is written in the cartesian instant form spin basis. The *vector*-meson four-momentum in the Breit-frame are, $p^\mu_i = (p^0, -q_x/2, 0, 0)$ for the initial state and the final four-momentum is $p^\mu_f = (p^0, q_x/2, 0, 0)$. Here, the plus component of the electromagnetic current, $\mu = +$ is utlized and $\gamma^+ = \gamma^0 + \gamma^3$. For the ϵ^β_i initial polarization we have:

$$\begin{aligned} \epsilon^\mu_x &= (-\sqrt{\eta}, \sqrt{1+\eta}, 0, 0), \epsilon^\mu_y = (0,0,1,0), \\ \epsilon^\mu_z &= (0,0,0,1), \end{aligned}$$

and, the final polarizations are:

$$\begin{aligned} \epsilon^{'\mu}_x &= (\sqrt{\eta}, \sqrt{1+\eta}, 0, 0), \epsilon^{'\mu}_y = \epsilon^\mu_y, \\ \epsilon^{'\mu}_z &= \epsilon^\mu_z, \end{aligned}$$

here, $\eta = q^2/4m_v^2$; the subscripts i and j, stand for x, y and z. The function $\Lambda(k,p)$ is a regularization function, in order to make the electromagnetic current, Eq.(1), finite, $\Lambda(k,p) = N/((p-k)^2 - m_R + \imath\epsilon)^2$; the normalization constant is found with the condition for charge electromagnetic form factor $G_0(0) = 1$. The matrix elements of the electromagnetic current in the instant form basis J^+_{ji} and the matrix elements of the current in the light-front basis $I^+_{m'm}$, are related with the unitary transformation between these spin basis by the Melosh rotation [30, 31]:

$$\begin{aligned} I^+_{11} &= \frac{J^+_{xx} + (1+\eta)J^+_{yy} - \eta J^+_{zz} - 2\sqrt{\eta}J^+_{zx}}{2(1+\eta)}, \\ I^+_{10} &= \frac{\sqrt{\eta}J^+_{xx} + \sqrt{\eta}J^+_{zz} - (\eta-1)J^+_{zx}}{\sqrt{2}(1+\eta)}, \\ I^+_{1-1} &= \frac{(1+\eta)J^+_{yy} - J^+_{xx} + \eta J^+_{zz} + 2\sqrt{\eta}J^+_{zx}}{2(1+\eta)}, \\ I^+_{00} &= \frac{J^+_{zz} - \eta J^+_{xx} - 2\sqrt{\eta}J^+_{zx}}{(1+\eta)}, \end{aligned} \quad (2)$$

For the plus component of the electromagnetic current, with the Breit frame, $q^+ = 0$, the angular condition satisfied by the matrix elements of the electromagnetic current is [18, 28, 29]:

$$\begin{aligned} \Delta(q^2) &= (1+2\eta)I^+_{11} + I^+_{1-1} - \sqrt{8\eta}I^+_{10} - I^+_{00} \\ &= \left(J^+_{yy} - J^+_{zz}\right)(1+\eta) = 0\,. \end{aligned} \quad (3)$$

With the instant form basis, (IF), the angular condition, Eq.(3), take a very simple form, $J^+_{yy} = J^+_{zz}$. But, in the case of the spin-1 particles, the electromagnetic current in the light-front approach, besides the valence component, we have the non-valence contribuitions with the consequence $\Delta(q^2) \neq 0$ [2, 10, 18, 27]. In addition the valence component, the electromagnetic current, need added the non-valence component in order to restore the covariance [4, 18, 23, 26, 27]. In this work,