Gravitational form factors of kaon in light-cone quark model

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Introduction

Understanding the structure of hadron in terms of its constituents is an interesting issue. The generalized parton distributions (GPDs) [1] are the one to reveal the 3-D structure of hadron. The form factors can be evaluated by taking the x moments of GPDs and are accessible through the exclusive processes. The electromagnetic form factors (EFFs) [2] explains the spatial distribution of charge inside the hadron whereas the gravitational form factors (GFFs) can be explained by the second Mellin moments GPDs without any real gravitational scattering [3]. By taking the two dimensional fourier transformation of GFFs, one can get the distribution of longitudinal momentum in the hadron. The pseudoscalar mesons are the most interesting particles to understand. The electromagnetic form factors of pion and kaon have been studied in Ref. [4, 5]. The kaon is a composite of two quarks like pion with the exception that the kaon composites have different quark masses. In the present work, the light-cone formalism [6, 7] is used to explain the gravitational form factors of the charged kaon (K^+). We use the overlap representation of light-cone wave functions for kaon to evaluate the GFFs from the energy-momentum tensor ($T^{\mu\nu}$).

Light-cone quark model

The light-cone spin wave functions for kaon in terms of the light-front form spin states of two spin-1/2 partons ($\chi^{\lambda_1}_{1(F)}$ and $\chi^{\lambda_2}_{2(F)}$) are written as [5]

$$\chi^K(x,\mathbf{k}_\perp) = \sum_{\lambda_1,\lambda_2} C^F_0(x,\mathbf{k}_\perp,\lambda_1,\lambda_2)\chi^{\lambda_1}_{1(F)}\chi^{\lambda_2}_{2(F)}. \quad (1)$$

The component coefficients $C^F_{J=0}(x,\mathbf{k}_\perp,\lambda_1,\lambda_2)$ are written as

$$\begin{aligned}
&C^F_0(x,\mathbf{k}_\perp,\uparrow,\downarrow) = \\
&\quad \omega_1\omega_2[(q_1^+ + m_1)(q_2^+ + m_2) - q_\perp^2]/\sqrt{2}, \\
&C^F_0(x,\mathbf{k}_\perp,\downarrow,\uparrow) = \\
&\quad -\omega_1\omega_2[(q_1^+ + m_1)(q_2^+ + m_2) - q_\perp^2]/\sqrt{2}, \\
&C^F_0(x,\mathbf{k}_\perp,\uparrow,\uparrow) = \\
&\quad \omega_1\omega_2[(q_1^+ + m_1)q_2^L - (q_2^+ + m_2)q_1^L]/\sqrt{2}, \\
&C^F_0(x,\mathbf{k}_\perp,\downarrow,\downarrow) = \\
&\quad \omega_1\omega_2[(q_1^+ + m_1)q_2^R - (q_2^+ + m_2)q_1^R]/\sqrt{2},
\end{aligned} \quad (2)$$

where $\omega_i = [2q_i^+(q_i^0 + m_i)]^{-1/2}$, $q_i^{R,L} = q_i^1 \pm q_i^2$ with $i = 1$ or 2.

We have

$$\begin{aligned}
q_1^+ &= x\mathcal{M}, \\
q_2^+ &= (1-x)\mathcal{M},
\end{aligned} \quad (3)$$

with

$$\mathcal{M} = \frac{m_1^2 + \mathbf{k}_\perp^2}{x} + \frac{m_2^2 + \mathbf{k}_\perp^2}{1-x}. \quad (4)$$

Eq. (2) must satisfy the relation

$$\sum_{\lambda_1,\lambda_2} C^F_0(x,\mathbf{k}_\perp,\lambda_1,\lambda_2)^* C^F_0(x,\mathbf{k}_\perp,\lambda_1,\lambda_2) = 1. \quad (5)$$

The Brodsky-Huang-Lepage (BHL) prescription [7] is used to get the space wavefuction for kaon, we have

$$\varphi_{\rm BHL} = A_0 \exp\left[-\frac{\frac{\mathbf{k}_\perp^2 + m_1^2}{x} + \frac{\mathbf{k}_\perp^2 + m_2^2}{1-x}}{8\beta^2} - \frac{(m_1^2 - m_2^2)^2}{8\beta^2(\frac{\mathbf{k}_\perp^2 + m_1^2)}{x} + \frac{\mathbf{k}_\perp^2 + m_2^2)}{1-x}} \right]. \quad (6)$$

The kaon light-cone wave function has the form

$$\psi = \varphi_{\mathrm{BHL}}\ \chi^K(x, \mathbf{k}_\perp). \tag{7}$$

Gravitational form factors (GFFs)

The relation between the GFFs and the matrix element of energy-momentum tensor ($T^{\mu\nu}$) is given in Ref. [8]. In case of kaon, only one GFF labelled as $A_K(Q^2)$ is non-zero. Using the overlap representation of kaon LFWFs, the GFF $A_K(Q^2)$ for quark is defined as

$$A_K^u(Q^2) = \sum_{\lambda_1,\lambda_2} \int x\ [dx][d^2\mathbf{k}_\perp] \times \psi^*(x, \mathbf{k}''_\perp, \lambda_1, \lambda_2)\psi(x, \mathbf{k}'_\perp, \lambda_1, \lambda_2), \tag{8}$$

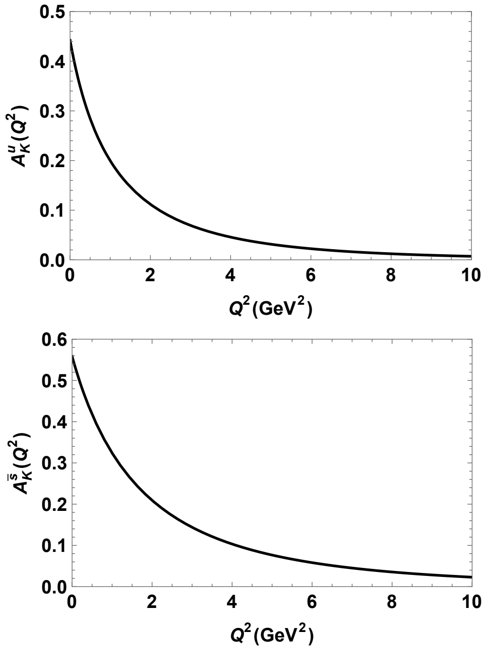
and for anti-quark, $A_K(Q^2)$ is defined as

$$A_K^{\bar{s}}(Q^2) = \sum_{\lambda_1,\lambda_2} \int (1-x)\ [dx][d^2\mathbf{k}_\perp] \times \psi^*(x, \mathbf{k}''_\perp, \lambda_1, \lambda_2)\psi(x, \mathbf{k}'_\perp, \lambda_1, \lambda_2), \tag{9}$$

where in the symmteric frame, initial and final state momenta are $\mathbf{k}'_\perp = \mathbf{k}_\perp + (1-x)\frac{\mathbf{q}_\perp}{2}$ and $\mathbf{k}''_\perp = \mathbf{k}_\perp - (1-x)\frac{\mathbf{q}_\perp}{2}$ respectively.

Results and Discussion

The explicit expressions of gravitational form factor for quark and antiquark have been evaluated by using the Eqs. (2 and 6) in Eq. (8) and Eq. (9) respectively. In Fig. 1(a) and 1(b), we plot the kaon gravitational form factor as a function of momentum transferred Q^2, for quark $A_K^u(Q^2)$ and antiquark $A_K^{\bar{s}}(Q^2)$ respectively. In both cases, we see that the GFF decreases with increasing Q^2. The curve is more sharp in case of $A_K^u(Q^2)$ than $A_K^{\bar{s}}(Q^2)$. At zero momentum transfer ($Q^2 = 0$), the values of GFF for both quark and antiquark are shown in Table I. We observe that the sum rule $A_K(0) = A_K^u(0) + A_K^{\bar{s}} \simeq 1.00$ is successfully satisfied.



(a)

(b)

FIG. 1: Plots of gravitational form factor of kaon (a) for quark $A_K^u(Q^2)$ and (b) for antiquark $A_K^{\bar{s}}(Q^2)$.

$A_K^u(0)$	0.4421
$A_K^{\bar{s}}(0)$	0.5583

TABLE I: The values of gravitational form factor for quark and antiquark at $Q^2 = 0$.

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