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$\phi \to KK$ decay in light cone QCD

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Abstract. The coupling constant of $\phi \to KK$ decay is calculated by light cone QCD sum rules. The result obtained for $g_{\phi KK} = (4.9 \pm 0.8)$ is in good agreement with the existing experimental results.

1 Introduction

Light scalar mesons constitute a remarkable exception of the quark model systematization of the mesons, and their nature still needs to be unambiguously established [1].

Particularly, the nature of the $f_0(980)$ meson is under debate. According to the naive $\bar{q}q$ picture and strong coupling with the kaons, $f_0(980)$ can be interpreted as a pure $\bar{s}s$ state [2–4]. However, this interpretation does not explain the mass degeneracy between $f_0(980)$ and the isovector $a_0(980)$, which is interpreted as a $(\bar{u}u - \bar{d}d)/\sqrt{2}$ state. It is also interpreted as a four quark $\bar{q}q\bar{s}s$ [5] bound state of hadrons [6–8] and as a result of a process known as hadronic dressing [2, 9].

For understanding the content of the f_0 meson several alternatives have been suggested: For example, analysis of $\phi \to f_0\gamma$ decay [5–10] and investigation of the ratio $\Gamma(a_0 \to f_0\gamma)/\Gamma(\phi \to f_0\gamma)$ [7, 8] are believed to be the most promising ones for this purpose.

The $\phi \to f_0\gamma$ decay is a very efficient tool for this purpose, since the branching ratio is essentially dependent on the content of f_0. For example, if f_0 is a pure $\bar{s}s$ state, the branching ratio is $\sim 10^{-5}$, while if f_0 is composed of four quarks then the branching ratio is expected to be $\sim 10^{-4}$.

The strong coupling constants $g_{\phi K^+K^-}$ and $g_{f_0 K^+K^-}$ are among the important hadronic parameters entering the analysis involving ϕ and $f_0(980)$. Indeed, the kaon loop diagrams contributing $\phi \to f_0\gamma$ are expected to be in terms of $g_{f_0 K^+K^-}$ as well as $g_{\phi K^+K^-}$. The coupling constant $g_{f_0 K^+K^-}$ is studied in light cone QCD sum rules [10] (more about light cone QCD sum rules and their applications can be found in [11, 12]).

In the present work we calculate the strong coupling constant $g_{\phi K^+K^-}$ by the light cone QCD sum rules method. It should be noted that this constant can be obtained from the experimental data on ϕ meson decays. The goal of the present work is twofold. Firstly, we can ask: can we get new information about the quark content of the ϕ meson comparing experimental data with theoretical results? Secondly, how does light cone QCD work for the asymmetric case, i.e., with different Borel mass parameters corresponding to different mass channels?

This paper is organized as follows. In Sect. 2, we derive sum rules for the $g_{\phi K^+K^-}$ coupling constant. In Sect. 3, we present our numerical results and conclusion.

2 Sum rules for the $g_{\phi K^+K^-}$ coupling constant

In this section we calculate the strong coupling constant $g_{\phi K^+K^-}$ by light cone QCD sum rules. This coupling constant is defined by the following matrix element:

$$\langle K^-(q)\phi(p,\varepsilon)|K^+(p+q)\rangle \ , \qquad (1)$$

where the momentum assignment is specified in brackets and ε_μ is the polarization vector of the ϕ meson. In order to calculate the strong coupling constant $g_{\phi K^+K^-}$ we consider the following correlator function:

$$\Pi_{\mu\nu}(p,q) = \mathrm{i}\int \mathrm{d}^4x \mathrm{e}^{\mathrm{i}px} \left\langle K(q) \left| T\left\{ J_\nu^\phi(x) \bar{J}_\mu^K(0) \right\} \right| 0 \right\rangle \ , \qquad (2)$$

where the quark current $J_\mu^K = \bar{u}\gamma_\mu\gamma_5 s$ is the axial vector current and $J_\nu^\phi = \bar{s}\gamma_\mu s$ is the interpolating current for the ϕ meson.

The correlator function, in general, can be written in terms of the following five independent invariant functions:

$$\Pi_{\mu\nu}(p,q) \qquad (3)$$
$$= \Pi_1 g_{\mu\nu} + \Pi_2 p_\mu p_\nu + \Pi_3 p_\mu q_\nu + \Pi_4 q_\mu p_\nu + \Pi_5 q_\mu q_\nu \ .$$

Therefore, our first problem is to choose the kinematical structure. For this aim, we consider the phenomenological part of the correlator function. This part can be written

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as

$$\Pi_{\mu\nu} = \sum \frac{\langle K^-(q)\phi(p)|K^+(p+q)\rangle\langle K^+(p+q)|J_\mu^K|0\rangle\langle 0|J_\nu^\phi|\phi(p)\rangle}{(p^2-m_\phi^2)[(p+q)^2-m_K^2]} \ . \quad (4)$$

The matrix elements entering (4) are defined by

$$\langle K^+(p+q)|J_\mu^K|0\rangle = f_K(p+q)_\mu \ ,$$
$$\langle 0|J_\nu^\phi|\phi(p)\rangle = m_\phi f_\phi \varepsilon_\nu \ . \quad (5)$$

Using (4) and (5), we get for the physical part

$$\Pi_{\mu\nu} = \frac{g_{\phi K^+K^-} f_K m_\phi f_\phi}{(p^2-m_\phi^2)[(p+q)^2-m_K^2]}(p_\mu+q_\mu)\left(q_\nu+\frac{1}{2}p_\nu\right). \quad (6)$$

It follows from this expression that the only the structures $p_\mu q_\nu$, $q_\mu q_\nu$, $q_\mu p_\nu$ and $p_\mu p_\nu$ give a contribution to the correlator function. In our further analysis, we will choose the structure $p_\mu q_\nu$ from which the corresponding invariant structure,

$$\Pi = \frac{g_{\phi K^+K^-} f_K m_\phi f_\phi}{(p^2-m_\phi^2)[(p+q)^2-m_K^2]} \ , \quad (7)$$

follows.

Our next task is the calculation of the correlator function from the QCD side. This calculation can be carried out by using the light cone operator product expansion method, in which we work with large momenta, i.e., $-p^2$ and $-(p+q)^2$ are both large. The correlator function, then, can be calculated as an expansion near to the light cone $x^2 \simeq 0$. The expansion involves matrix elements of the non-local operators between vacuum and the kaon states, i.e., in terms of kaon wave functions with increasing twist.

After lengthy calculations, we get the following expression for the invariant function which is proportional to the structure $p_\mu q_\nu$:

$$\begin{aligned}
&\Pi(p^2,(p+q)^2) \\
&= \mathrm{i}f_K \int_0^1 \mathrm{d}u \Bigg\{ \frac{4ug_2(u)}{\Delta^2} + \frac{\varphi_K(u)}{\Delta} \\
&\qquad - 4\frac{g_1(u)+G_2(u)}{\Delta^2}\left(1+\frac{2m_s^2}{\Delta}\right) \\
&\qquad + \frac{m_K^2}{3}\frac{\varphi_\sigma(u)}{\Delta^2}\Bigg\} \\
&+ \mathrm{i}f_K \int_0^1 \mathrm{d}u\, u \int \mathcal{D}\alpha_i \frac{2}{\Delta_2^2}[2\varphi_\perp(\alpha_i)+\varphi_\parallel+2\tilde{\varphi}_\perp(\alpha_i)] \\
&+ \mathrm{i}f_K \int_0^1 \mathrm{d}u \int_0^1 \mathrm{d}\alpha_3 \int_0^{1-\alpha_3} \mathrm{d}\alpha_1 \\
&\quad \times \frac{1}{\Delta_2^2}[2\varphi_\perp(\alpha_i)-\varphi_\parallel+2\tilde{\varphi}_\perp(\alpha_i)-\tilde{\varphi}_\parallel(\alpha_i)] \\
&+ 2\mathrm{i}f_K \Bigg\{ \int_0^1 \mathrm{d}u(u-1) \int_0^1 \mathrm{d}\alpha_3 \\
&\quad \times \frac{4\hat{F}(\alpha_3)\{pq+m_K^2[1+\alpha_3(u-1)]\}}{\Delta_1^3} \\
&+ \int_0^1 \mathrm{d}u \int_0^1 \mathrm{d}\alpha_3 \int_0^{1-\alpha_3} \mathrm{d}\alpha_1 \\
&\quad \times \frac{4F(\alpha_i)[pq+m_K^2(\alpha_1+u\alpha_3)]}{\Delta_2^3} \Bigg\} , \qquad (8)
\end{aligned}$$

where

$$\begin{aligned}
\Delta &= m_s^2 - (p+qu)^2 \ , \\
\Delta_1 &= m_s^2 - [p+q(1+(u-1)\alpha_3]^2 \ , \\
\Delta_2 &= m_s^2 - [p+q(\alpha_1+u\alpha_3)]^2 \ , \qquad (9)
\end{aligned}$$

and

$$\hat{F}(\alpha_3) = -\int_0^{\alpha_3} \mathrm{d}t \int_0^{1-t} \mathrm{d}\alpha_1 \Phi(\alpha_1, 1-\alpha_1-t, t) \ , \quad (10)$$

$$F(\alpha_i) = -\int_0^{\alpha_1} \mathrm{d}t \Phi(t, 1-\alpha_3-t, \alpha_3) \ , \quad (11)$$

$$\Phi(\alpha_i) = \varphi_\parallel(\alpha_i)+\varphi_\perp(\alpha_i)+\tilde{\varphi}_\parallel(\alpha_i)+\tilde{\varphi}_\perp(\alpha_i) \ . \quad (12)$$

The functions in (8) are defined by

$$\begin{aligned}
&\langle K(q)|\bar{u}(x)\gamma_\mu\gamma_5 s(0)|0\rangle \\
&= -\mathrm{i}f_K q_\mu \int_0^1 \mathrm{d}u \mathrm{e}^{\mathrm{i}uqx}[\varphi_K(u)+x^2 g_1(u)] \\
&+ f_K\left(x_\mu - \frac{q_\mu x^2}{qx}\right)\int_0^1 \mathrm{d}u \mathrm{e}^{\mathrm{i}uqx} g_2(u) \ , \qquad (13) \\
&\langle K(q)|\bar{u}(x)\sigma_{\mu\nu}\gamma_5 s(0)|0\rangle \\
&= \mathrm{i}(q_\mu x_\nu - q_\nu x_\mu)\frac{f_K m_K^2}{6m_s}\int_0^1 \mathrm{d}u \mathrm{e}^{\mathrm{i}uqx}\varphi_\sigma(u) \ , \qquad (14)
\end{aligned}$$

and

$$G(u) = -\int_0^u g_2(u)\mathrm{d}v \ . \quad (15)$$

The matrix elements involving the quark–gluon field are determined by

$$\begin{aligned}
&\langle K(q)|\bar{u}(x)\gamma_\mu\gamma_5 g_s G_{\alpha\beta}(ux)s(0)|0\rangle \\
&= f_K\left[q_\beta\left(g_{\alpha\mu}-\frac{x_\alpha q_\mu}{qx}\right) - q_\alpha\left(g_{\beta\mu}-\frac{x_\beta q_\mu}{qx}\right)\right] \\
&\quad \times \int \mathcal{D}\alpha_i \varphi_\perp(\alpha_i)\mathrm{e}^{\mathrm{i}qx(\alpha_1+u\alpha_3)} \qquad (16) \\
&+ f_K\frac{q_\mu}{qx}(q_\alpha x_\beta - q_\beta x_\alpha)\int \mathcal{D}\alpha_i \varphi_\parallel(\alpha_i)\mathrm{e}^{\mathrm{i}qx(\alpha_1+u\alpha_3)}
\end{aligned}$$

$$\begin{aligned}
&\langle K(q)|\bar{u}(x)\gamma_\mu g_s \tilde{G}_{\alpha\beta}(ux)s(0)|0\rangle \\
&= \mathrm{i} f_K \left[q_\beta \left(g_{\alpha\mu} - \frac{x_\alpha q_\mu}{qx} \right) - q_\alpha \left(g_{\beta\mu} - \frac{x_\beta q_\mu}{qx} \right) \right] \\
&\quad \times \int \mathcal{D}\alpha_i \tilde{\varphi}_\perp(\alpha_i) \mathrm{e}^{\mathrm{i}qx(\alpha_1 + u\alpha_3)} \qquad (17) \\
&+ \mathrm{i} f_K \frac{q_\mu}{qx} (q_\alpha x_\beta - q_\beta x_\alpha) \int \mathcal{D}\alpha_i \tilde{\varphi}_\parallel(\alpha_i) \mathrm{e}^{\mathrm{i}qx(\alpha_1 + u\alpha_3)} ,
\end{aligned}$$

where $\tilde{G}_{\alpha\beta} = \frac{1}{2}\epsilon_{\alpha\beta\rho\sigma}G^{\rho\sigma}$, $\mathcal{D}\alpha_i = \mathrm{d}\alpha_1 \mathrm{d}\alpha_2 \mathrm{d}\alpha_3 \delta(1 - \alpha_1 - \alpha_2 - \alpha_3)$.

The sum rule for $g_{\phi K^+K^-}$ is obtained by equating the phenomenological and the theoretical parts, (7) and (8).

In order to suppress the contributions of the continuum and higher states, we perform a double Borel transformation over the variables $-p^2$ and $-(p+q)^2$ on both sides of (7) and (8), and obtain the following expression for the correlator function:

$$\begin{aligned}
&f_K m_\phi f_\phi g_{\phi KK} \mathrm{e}^{-m_\phi^2/M_1^2} \mathrm{e}^{-m_K^2/M_2^2} \\
&= f_K \mathrm{e}^{-m_0^2/M^2} \Bigg\{ M^2 \varphi_K(u_0) + 4u_0 g_2(u_0) \\
&- 4[g_1(u_0) + G_2(u_0)] + \frac{m_K^2}{3}\varphi_\sigma(u_0) \\
&- 4\frac{m_s^2}{M^2}[g_1(u_0) + G_2(u_0)] \\
&+ \left(\int_0^{1-u_0} \mathrm{d}\alpha_3 \int_{u_0-\alpha_3}^{u_0} \mathrm{d}\alpha_1 \right. \\
&\quad \left. + \int_{1-u_0}^1 \mathrm{d}\alpha_3 \int_{u_0-\alpha_3}^{1-\alpha_3} \mathrm{d}\alpha_1 - \int_{u_0}^1 \mathrm{d}\alpha_3 \int_{u_0-\alpha_3}^0 \mathrm{d}\alpha_1 \right) \\
&\times \left(2\frac{u_0 - \alpha_1}{\alpha_3} \frac{2\varphi_\perp(\alpha_i) + \varphi_\parallel(\alpha_i) + 2\tilde{\varphi}_\perp(\alpha_i)}{\alpha_3} \right. \\
&\quad \left. + \frac{\Phi(\alpha_i)}{\alpha_3} - \frac{2}{\alpha_3}\frac{\mathrm{d}F(\alpha_i)}{\mathrm{d}\alpha_1} \right) \qquad (18) \\
&- 2\int_{1-u_0}^1 \frac{\hat{F}'(\alpha_3)}{\alpha_3}\mathrm{d}\alpha_3 - 2\int_{1-u_0}^1 \mathrm{d}\alpha_3 \frac{F(1-\alpha_3, 0, \alpha_3)}{\alpha_3} \Bigg\} ,
\end{aligned}$$

where $M^2 = \frac{M_1^2 M_2^2}{M_1^2 + M_2^2}$, $u_0 = \frac{M_1^2}{M_1^2 + M_2^2}$ and $m_0^2 = m_s^2 + m_K^2 u_0(1-u_0)$. Subtraction of the continuum and higher states is carried out by employing the quark–hadron duality, i.e., the continuum contribution, which is represented in terms of the spectral density obtained from the QCD side, by equating it to the one obtained from the QCD side, but starting from some given threshold. The prescription for subtraction of the contribution of the continuum in the light cone version of the sum rule is proposed in [13] (see also [14]). In [13] and in many other works, the symmetric point $M_1^2 = M_2^2 = 2M^2$ (i.e., $u_0 = 1/2$) is considered, and then the continuum subtraction is implemented by means of the simple substitution

$$\mathrm{e}^{-m^2/M^2} \to \mathrm{e}^{-m^2/M^2} - \mathrm{e}^{-s_0/M^2}$$

in the leading twist term (in our case the leading twist term is the wave function $\varphi_K(u)$). But this prescription is not adequate in our case, where the Borel parameters and masses of different channels are not equal. In the present work we will follow the analysis given in [10], where the prescription for the continuum subtraction through use of the Borel parameters with different masses in the respective channels is proposed, and properties of the wave functions are exploited. Namely, the leading twist-2 wave function can be exploited as a power series:

$$\varphi_K(u) = \sum_k b_k (1-u)^k ,$$

in order to calculate its contribution in the duality region. Here we will neglect the continuum subtraction in the higher twist terms altogether, due to their small contribution to the theoretical part of the sum rules. Also, we will neglect the continuum subtraction in all higher twist terms, due to their small contribution to the theoretical part of the sum rules.

The final result for the $g_{\phi KK}$ coupling is given by

$$\begin{aligned}
&g_{\phi KK} = \frac{1}{m_\phi f_\phi} \mathrm{e}^{m_\phi^2/M_1^2} \mathrm{e}^{m_K^2/M_2^2} \mathrm{e}^{-m_0^2/M^2} \\
&\times \Bigg\{ M^2 \sum_k b_k \left(\frac{M^2}{M_1^2} \right)^k \\
&\times \left[1 - \mathrm{e}^{-(s_0 - m_s^2)/M^2} \sum_{i=0}^k \frac{1}{i!} \left(\frac{s_0 - m_s^2}{M^2} \right)^i \right. \\
&\left. + \mathrm{e}^{-(s_0 - m_s^2)/M^2} \frac{m_K^2 M^2}{M_1^2 M_2^2} \frac{1}{(k+1)!} \left(\frac{s_0 - m_s^2}{M^2} \right)^{k+1} \right] \\
&+ 4u_0 g_2(u_0) - 4[g_1(u_0) + G_2(u_0)] \\
&+ \frac{m_K^2}{3}\varphi_\sigma(u_0) - 4\frac{m_s^2}{M^2}[g_1(u_0) + G_2(u_0)] \\
&+ \left(\int_0^{1-u_0} \mathrm{d}\alpha_3 \int_0^{u_0} \mathrm{d}\alpha_1 + \int_{1-u_0}^1 \mathrm{d}\alpha_3 \int_{u_0-\alpha_3}^{1-\alpha_3} \mathrm{d}\alpha_1 \right. \\
&\quad \left. - \int_{u_0}^1 \mathrm{d}\alpha_3 \int_{u_0-\alpha_3}^0 \mathrm{d}\alpha_1 \right) \\
&\times \left[2\frac{u_0 - \alpha_1}{\alpha_3^2} (2\varphi_\perp(\alpha_i) + \varphi_\parallel(\alpha_i) + 2\tilde{\varphi}_\perp(\alpha_i)) \right. \\
&\quad \left. + \frac{\Phi(\alpha_i)}{\alpha_3} - \frac{2}{\alpha_3}\frac{\mathrm{d}F(\alpha_i)}{\mathrm{d}\alpha_1} \right] \\
&- 2\int_{1-u_0}^1 \mathrm{d}\alpha_3 \frac{\hat{F}'(\alpha_3)}{\alpha_3} - 2\int_{1-u_0}^1 \mathrm{d}\alpha_3 \frac{F(1-\alpha_3, 0, \alpha_3)}{\alpha_3} \Bigg\},
\end{aligned}$$

where s_0 is the smallest continuum contribution.

3 Numerical analysis

In this section we present our numerical calculation of the $g_{\phi KK}$ coupling constant. It follows from (19) that the main input parameters are the kaon wave functions. The theoretical framework for their determination is based on an expansion in terms of the matrix elements of the conformal operators [15]. In particular, for the leading twist-2 wave function $\varphi_K(u)$ defined in (13), the expansion goes over into Gegenbauer polynomials:

$$\varphi_K(u,\mu^2) = 6u(1-u) \times \left[1 + \sum_{n=1}^{\infty} a_{2n}(\mu^2) C_{2n}^{3/2}(2u-1)\right] , \tag{19}$$

where $a_2(1\,\mathrm{GeV}) = 0.2$ [16].

Analogously φ_σ is defined as

$$\varphi_\sigma(u) = 6u(1-u) \times \left[1 + \left(5\eta_3 - \frac{1}{2}\eta_3 w_3 - \frac{7}{20}\rho^2 - \frac{3}{5}\rho^2 \tilde{a}_2\right) C_2^{3/2}(2u-1) + \cdots\right] , \tag{20}$$

where at the $\mu = 1\,\mathrm{GeV}$ scale $\eta_3 = 0.015$, $w_3 = -3$, and $\tilde{a}_2 = 0.2$. Here, the factor $\rho = m_s^2/m_K^2$ takes into account the boson mass corrections [17]. The twist-4 wave functions $\varphi_\parallel(\alpha_i)$, $\varphi_\perp(\alpha_i)$, $\tilde{\varphi}_\parallel(\alpha_i)$ and $\tilde{\varphi}_\perp(\alpha_i)$, including the meson mass corrections are given as [15, 17]

$$\begin{aligned}
\varphi_\perp(\alpha_i) &= 30 m_K^2 \alpha_3^2 (2\alpha_1 - 1 - \alpha_3) \\
&\times \left[h_{00} + h_{01}\alpha_3 + \frac{h_{10}}{2}(5\alpha_3 - 3) + \cdots\right] \\
\varphi_\perp(\alpha_i) &= 120 m_K^2 \alpha_1 (1 - \alpha_1 - \alpha_3) \\
&\times \alpha_3 [a_{10}(1 - 2\alpha_1 - \alpha_3) + \cdots] , \\
\tilde{\varphi}_\perp(\alpha_i) &= -30 m_K^2 \alpha_3^2 \\
&\times \left\{h_{00}(1-\alpha_3) + h_{01}[\alpha_3(1-\alpha_3) + 6\alpha_1(1-\alpha_1-\alpha_3)\right. \\
&\left. + h_{10}[\alpha_3(1-\alpha_3) - \frac{3}{2}[\alpha_1^2 + (1-\alpha_1-\alpha_3)^2] + \cdots\right\} , \\
\tilde{\varphi}_\perp(\alpha_i) &= 120 m_K^2 \alpha_1 (1 - \alpha_1 - \alpha_3) \\
&\times \alpha_3 [v_{00} + v_{10}(3\alpha_3 - 1) + \cdots] ,
\end{aligned}$$

where

$$\begin{aligned}
h_{00} = v_{00} &= -\frac{1}{3}\eta_4 , \\
h_{01} &= \frac{7}{4}\eta_4 w_4 - \frac{3}{20} a_2 , \\
h_{10} &= \frac{7}{2}\eta_4 w_4 + \frac{3}{20} a_2 , \\
v_{10} &= \frac{21}{8}\eta_4 w_4 , \\
a_{10} &= \frac{21}{8}\eta_4 w_4 - \frac{9}{20} a_2 ,
\end{aligned}$$

with $\eta_4(\mu = 1\,\mathrm{GeV}) = 0.6$ and $w_4(\mu = 1\,\mathrm{GeV}) = 0.2$ [15, 17].

The values of the other input parameters appearing in (19) are $m_s = 0.14\,\mathrm{GeV}$ [18], $m_K = 0.4937\,\mathrm{GeV}$ and $m_\phi = 1.02\,\mathrm{GeV}$. The leptonic decay constant of the ϕ meson, $f_\phi = 0.234\,\mathrm{GeV}$, follows from the experimental result of the $\phi \to \ell^+\ell^-$ decay [19]. The threshold s_0 which is varied around the value $s_0 = 1.1\,\mathrm{GeV}^2$, is determined from the analysis of two-point function sum rules for f_K [20].

Having all input parameters, we now proceed by carrying out a numerical calculation. The dependence of $g_{\phi KK}$ on the Borel masses M_1^2 and M_2^2 at two fixed values of $s_0 = 1.1\,\mathrm{GeV}^2$ and $s_0 = 1.2\,\mathrm{GeV}^2$ is presented in Figs. 1 and 2, respectively. According to the QCD sum rule method, ranges of the auxiliary Borel parameters M_i^2 should be

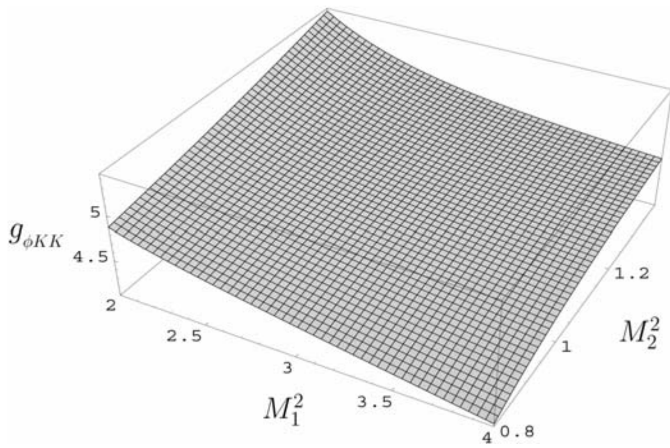

Fig. 1. The dependence of the coupling constant $g_{\phi KK}$ on the Borel parameters M_1^2 and M_2^2, at the fixed value $s_0 = 1.1\,\mathrm{GeV}^2$ of the continuum threshold

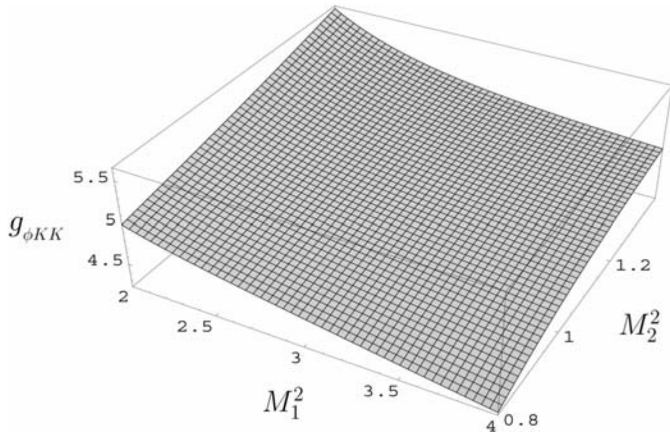

Fig. 2. The same as Fig. 1, but at the fixed value $s_0 = 1.2\,\mathrm{GeV}^2$ of the continuum threshold

found such that the result for $g_{\phi KK}$ be practically independent of them.

From these figures we see that such regions indeed do exist. When M_1^2 and M_2^2 are varied in the regions $2\,\mathrm{GeV}^2 \le M_1^2 \le 4\,\mathrm{GeV}^2$ and $0.8\,\mathrm{GeV}^2 \le M_2^2 \le 1.4\,\mathrm{GeV}^2$, the result for $g_{\phi KK}$ seems to be independent of the Borel parameters. It should be noted here that the result changes slightly when the continuum threshold is fixed at the value $s_0 = 1.2\,\mathrm{GeV}^2$. The final result for $g_{\phi KK}$ is

$$g_{\phi KK} = 4.9 \pm 0.8 \ . \tag{21}$$

At this point, let us discuss the sources of the uncertainties. The $SU_f(3)$ breaking effects in kaon distribution amplitudes which we neglected can play an essential role, since we can explore a wide range of u and hence smoothen the effects of the shape of the wave function. An additional uncertainty arises from the value of m_s. All these factors can cause an uncertainty of about 5–10%. Moreover, the errors coming from the variations in the continuum threshold and Borel masses change the result by about 10%. If all these uncertainties are taken into account, the resulting error is about 20%, which is quoted in (21).

Finally, we would comment that existing experimental results on $\phi \to KK$ decay predict $g_{\phi KK} = 4.8$. So, obviously, we see that our result is quite close to the experimental value. Therefore we conclude that the quark content of ϕ is $\bar{s}s$, and for channels with different masses and different Borel parameters, the light cone QCD sum rules work quite well.

References

1. L. Montanet, Rept. Prog. Phys. **46**, 337 (1983); F.E. Close, Rept. Prog. Phys. **51**, 833 (1988); N.N. Achasov, Nucl. Phys. Proc. Suppl. **21**, 180 (1991); T. Barnes, prep. hep-ph/0001326 (2000); V.V. Anisovich, AIP Conference Proceedings **619**, 197 (2002)
2. N.A. Tornqvist, Phys. Rev. Lett. **49**, 624 (1982); Z. Phys. C **68**, 647 (1995)
3. N.A. Tornqvist, M. Roos, Phys. Rev. Lett. **76**, 1575 (1996)
4. E. Van Beveren et al., Z. Phys. C **30**, 615 (1986); M.D. Scadron, Phys. Rev. D **26**, 239 (1982); E. Van Beveren, G. Rupp, M.D. Scadron, Phys. Lett. B **495**, 300 (2000); Erratum, B **509**, 365 (2001)
5. R.I. Jaffe, Phys. Rev. D **15**, 267 (1977); Phys. Rev. D **17**, 1444 (1978)
6. J.D. Weinstein, N. Isgur, Phys. Rev. Lett. **48**, 659 (1982); Phys. Rev. D **41**, 2236 (1990)
7. M. Brown, F.E. Close, in the DAΦNE physics Handbook, edited by L. Maiani, G. Pancheri, N. Paver (INFN, Frascati 1995), p. 447
8. F.E. Close, N. Isgur, S. Kumano, Nucl. Phys. B **389**, 513 (1993)
9. F. De Fazio, M.R. Pennington, Phys. Lett. B **521**, 15 (2001)
10. P. Colangelo, F. De Fazio, Phys. Lett. B **559**, 49 (2003)
11. V.M. Braun, Progress on Heavy Quark Physics, Proceedings Rostock 1997, p. 105, hep-ph/9801222
12. P. Colangelo, A. Khodjamirian, in At the Frontier of Particle Physics/Handbook of QCD, edited by M. Shifman (World Scientific, Singapore 2001), Vol. 3, p. 1495
13. V.M. Belyaev, V.M. Braun, A. Khodjamirian, R. Rückl, Phys. Rev. D **51**, 6177 (1995)
14. T.M. Aliev, A. Özpineci, M. Savcı, Nucl. Phys. A **678**, 443 (2000); Phys. Rev. D **64**, 034001 (2001); D **62**, 053012 (2000)
15. V.M. Braun, I.E. Filyanov, Z. Phys. C **44**, 157 (1989)
16. P. Ball, JHEP **9809**, 005 (1998)
17. P. Ball, JHEP **9901**, 010 (1999)
18. P. Colangelo, F. De Fazio, G. Nardulli, N. Paver, Phys. Lett. B **408**, 340 (1997)
19. K. Hagiwara et al., Phys. Rev. D **66**, 010001 (2002)
20. A.A. Ovchinnikov, A. Pivovarov, Phys. Lett. B **163**, 231 (1985)