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QCD Sum Rules for KYN and $KY\Xi$ Coupling Constants

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New relations between QCD Borel sum rules for strong coupling constants of K-mesons to baryons are derived. It is shown that starting from the sum rule for the coupling constants $g_{\pi\Sigma\Sigma}$ and $g_{\pi\Sigma\Lambda}$ it is straightforward to obtain corresponding sum rules for the g_{KYN}, $g_{KY\Xi}$ couplings, $Y=\Sigma,\Lambda$.

Замиралов В.С.
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Получены новые соотношения между борелевскими правилами сумм в КХД для сильных констант связи барионов с K-мезонами. Показано, что, отправляясь от правил сумм для констант связи $g_{\pi\Sigma\Sigma}$ и $g_{\pi\Sigma\Lambda}$, можно непосредственно получить соответствующие правила сумм для констант связи g_{KYN} и $g_{KY\Xi}$, $Y=\Sigma,\Lambda$.

1 Introduction

Meson-baryon couplings were studied for years thoroughly either for pion-baryon couplings or kaon-baryon baryon ones as these couplings are important ingredients in the analysis of the baryon-baryon and meson-baryon scattering and meson production reactions. Experimentally rather unambigous results are obtained only for the coupling constant $g_{\pi NN}$. Other coupling constants, those involving K-meson in particular, require many phenomenology to be used in order to be extracted from experimental data. Since the advent of the $SU(3)$ symmetry all the meson-baryon coupling constants were expressed in terms of characteristic for baryon currents in $SU(3)$ constants F and D which gave possibility to construct a reliable phenomenological aproach. And indeed up to now it often forms a basis for constructing potential models for hyperon-nucleon interaction and meson-baryon scattering.

As soon as in [1] QCD sum rules (SR's) were proposed, they were used not only for baryon masses and magnetic moments starting from the works [2], [3] but also for baryon-meson coupling constants. Naturally, a pion-nucleon coupling attracted many attention (see, for example, [4], [5], [6]). Mostly two-point correlator function serves a basis of these calculations. Coupling constants of π^0- and η- mesons to baryons were intensively studied in various QCD SR approaches [7], [8], [9]. Recently we succeeded in writing QCD sum rule for the η coupling to the Λ hyperon [10] which was usually absent in such sum rules.

As for K-mesons they also were studied in the framework of the QCD sum rules, but more often basing on the three-point correlator function (see, e.g., [12], [13], [14]). Usually these sum rules are not related straightforwardly to those treating π and η couplings to baryons.

We would like to propose here QCD sume rules for all octet meson-baryon couplings through some universal $\mathcal{F}$ and $\mathcal{D}$ functions written in a unified manner. In order to be clear we choose as a basis for our reasoning $SU(3)$ symmetric QCD LC sum rules written by two of us with coauthors [9] and $SU(3)$ breaking QCD borel sum rules proposed in [7] (which is the most simple one in a series of sum rules obtained in [7],[8])

The plan of the paper is the following. First we reveal in what way one can obtain $\pi\Sigma\Lambda$ coupling from that of the $\pi^0\Sigma\Sigma$ one in the framework of a simple $SU(3)$ model. Then we show in this model how one could relate couplings of strange and non-strange mesons to baryons. Basing on this results we construct QCD sum rules which involve some generalized functions $\mathcal{F}$ and $\mathcal{D}$ which allows us to relate QCD sum rules for all meson-baryon couplings starting from some two-point correlation functions with two interpolating baryon fields sandwiched between the vacuum and meson states. We obtain as a result K- meson coupling constants to octet baryons which are discussed in the last section.

2 Relation between $\pi^0\Sigma\Sigma$ and $\pi\Sigma\Lambda$ constants in SU(3)

We begin as in [15], [16] from a simple example. In the unitary model all the pion-baryon coupling constants can be expressed in terms of F and D constants from the known unitary symmetry Lagrangian [17]

$$L = DSp\bar{B}\{P,B\} + FSp\bar{B}[P,B]. \tag{1}$$

where

$$B^\alpha_\beta = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}. \tag{2}$$

$$P^\alpha_\beta = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}. \tag{3}$$

wherefrom

$$g_{\pi NN} = F + D, \quad g_{\pi\Sigma\Sigma} = -\sqrt{2}F, \quad g_{\pi\Xi\Xi} = -F + D, \quad g_{\pi\Sigma\Lambda} = \sqrt{\frac{2}{3}}D,$$
$$g_{K\Xi\Sigma} = \sqrt{\frac{1}{2}}(F + D), \quad \sqrt{\frac{1}{6}}g_{K\Xi\Lambda} = (-3F + D),$$
$$g_{KN\Sigma} == \sqrt{\frac{1}{2}}(-F + D), \quad g_{KN\Lambda} = -\sqrt{\frac{1}{6}}(3F + D), \tag{4}$$

But coupling constants for π^0 meson can be written in a form similar to that found for Σ-like baryon magnetic moments in $SU(3)_f$ [15],[16]. Namely, let us write coupling constants of π^0 meson related in the quark model to currents

$$j^{\pi^0} = \frac{1}{\sqrt{2}}[\bar{u}\gamma_5 u - \bar{d}\gamma_5 d] \tag{5}$$

for Σ-like baryons $B(qq,q'), q,q' = u,d,s$ in the form

$$g(\pi^0 BB) == g_{\pi qq} 2F + g_{\pi q'q'}(F-D),$$

or, particle per particle:

$$g(\pi^0 pp) = g_{\pi uu} 2F + g_{\pi dd}(F-D) = \sqrt{\frac{1}{2}}(F+D);$$

$$g(\pi^0 \Sigma^+ \Sigma^+) = g_{\pi uu} 2F + g_{\pi ss}(F-D) = \sqrt{2}F;$$

$$g(\pi^0 \Xi^0 \Xi^0) = g_{\pi ss} 2F + g_{\pi uu}(F-D) = \sqrt{\frac{1}{2}}(F-D);$$

and so on, where $g_{\pi uu} = +\sqrt{\frac{1}{2}}$, $g_{\pi dd} = -\sqrt{\frac{1}{2}}$ and $g_{\pi ss} = 0$ can be just read off Eq.(5).

The only coupling which cannot be written immediately in this way is $\pi^0 \Sigma^0 \Lambda$. But we can overcome this difficulty. For that purpose let us write an expression also for $\pi^0 \Sigma^0 \Sigma^0$ coupling (which is equal to zero !):

$$g(\pi^0 \Sigma^0 \Sigma^0) = g_{\pi^0 uu} F + g_{\pi^0 dd} F + g_{\pi^0 ss}(F-D) = 0 \qquad (6)$$

and change $(d \leftrightarrow s)$ (which is generally speaking essentially nonlinear operation) to form an auxiliary quantity

$$g(\pi^0 \tilde{\Sigma}^{0,ds} \tilde{\Sigma}^{0,ds}) = g_{\pi^0 uu} F + g_{\pi^0 ss} F + g_{\pi^0 dd}(F-D) = \sqrt{\frac{1}{2}} D, \qquad (7)$$

and $(u \leftrightarrow s)$ to form one more auxiliary quantity

$$g(\pi^0 \tilde{\Sigma}^{0,us} \tilde{\Sigma}^{0,us}) = g_{\pi^0 dd} F + g_{\pi^0 ss} F + g_{\pi^0 uu}(F-D) = -\sqrt{\frac{1}{2}} D. \qquad (8)$$

The following relation holds:

$$g(\pi^0 \tilde{\Sigma}^{0,ds} \tilde{\Sigma}^{0,ds}) - g(\pi^0 \tilde{\Sigma}^{0,us} \tilde{\Sigma}^{0,us}) = \sqrt{3} g(\pi^0 \Sigma^0 \Lambda). \qquad (9)$$

The origin of this relation lies in the structure of baryon wave functions in the NRQM with isospin $I = 1, 0$ and $I_3 = 0$:

$$2\sqrt{3}|\Sigma^0(ud,s)\rangle_\uparrow = |2u_\uparrow d_\uparrow s_\downarrow + 2d_\uparrow u_\uparrow s_\downarrow - u_\uparrow s_\uparrow d_\downarrow - s_\uparrow u_\uparrow d_\downarrow - d_\uparrow s_\uparrow u_\downarrow - s_\uparrow d_\uparrow u_\downarrow\rangle,$$

$$2|\Lambda\rangle_\uparrow = |d_\uparrow s_\uparrow u_\downarrow + s_\uparrow d_\uparrow u_\downarrow - u_\uparrow s_\uparrow d_\downarrow - s_\uparrow u_\uparrow d_\downarrow\rangle,$$

where $q_\uparrow$ ($q_\downarrow$) means wave function of the quark q (here $q = u, d, s$) with the helicity $+1/2$ (-1/2). With the exchanges $d \leftrightarrow s$ and $u \leftrightarrow s$ one arrives at the corresponding U-spin and V-spin quantities, so $U = 1, 0$ and $U_3 = 0$ baryon wave functions are

$$-2|\tilde{\Sigma}^0_{d\leftrightarrow s}(us, d)\rangle = |\Sigma^0(ud, s) > +\sqrt{3}|\Lambda\rangle, \tag{10}$$

$$2|\tilde{\Lambda}_{d\leftrightarrow s}\rangle = -\sqrt{3}|\Sigma^0(ud, s) > +|\Lambda\rangle, \tag{11}$$

while $V = 1, V_3 = 0$ and $V = 0$ baryon wave functions are

$$-2|\tilde{\Sigma}^0_{u\leftrightarrow s}(ds, u)\rangle = |\Sigma^0(ud, s)\rangle - \sqrt{3}|\Lambda\rangle, \tag{12}$$

$$2|\tilde{\Lambda}_{u\leftrightarrow s}\rangle = \sqrt{3}|\Sigma^0(ud, s)\rangle + |\Lambda\rangle. \tag{13}$$

It is easy to show that the relation given by Eq.(9) immeaditely follows.

3 Relations between $K(\Sigma, \Lambda)N$, $K(\Sigma, \Lambda)\Xi$ and $\pi\Sigma\Lambda$ couplings in the SU(3)

Up to now we have considered couplings of baryons to π^0 meson. Now we try to consider also kaon and charged pion couplings to baryons. They are given by $SU(3)$ symmetry formulae but we want to rewrite it in a way suitable for derivation of the corresponding Borel sum rules.

Let us write formally the coupling of pion to Σ^+ and Λ_{ds} given by the Eq.(11):

$$2[g(\pi^-\Sigma^+\bar{\Lambda}_{ds})] = -\sqrt{3}g(\pi^-\Sigma^+\bar{\Sigma}^0) + g(\pi^-\Sigma^+\bar{\Lambda}) =$$

$$-\sqrt{3}(-\sqrt{2}F) + \sqrt{\frac{2}{3}}D = \sqrt{\frac{2}{3}}(3F + D).$$

Now we perform $d \leftrightarrow s$ exchange. Our auxiliary baryon Λ_{ds} returns obviously to its real form Λ while $\pi^-(\bar{d}u)$ changes to $K^-(\bar{s}u)$ and $\Sigma^+(uu, s)$ changes to $-p(uu, d)$, so we arrive at

$$2[g(\pi^-\Sigma^+\Lambda_{ds})]_{ds} = -2[g(K^-p\Lambda)] = \sqrt{\frac{2}{3}}(3F + D).$$

One can see that this is indeed the right expression for the coupling constant $g(K^-p\bar{\Lambda})$ from the Eq.(4).

Let us now write the formal coupling of pion to Σ^+ and Λ_{us} given by the Eq.(13):

$$2[g(\pi^-\Sigma^+\bar{\Lambda}_{us})] = \sqrt{3}g(\pi^-\Sigma^+\bar{\Sigma}^0) + g(\pi^-\Sigma^+\bar{\Lambda}) =$$

$$\sqrt{3}(-\sqrt{2}F) + \sqrt{\frac{2}{3}}D = -\sqrt{\frac{2}{3}}(3F - D).$$

Now we perform $u \leftrightarrow s$ exchange. Our formal baryon Λ_{us} returns to its real form Λ while $\pi^-(\bar{d}u)$ changes to $K^0(\bar{d}s)$ and $\Sigma^+(uu, s)$ changes to $-\Xi^0(ss, d)$:

$$2[g(\pi^-\Sigma^+\bar{\Lambda}_{us})]_{us} = 2[g(K^0\Xi^0\bar{\Lambda})] = -\sqrt{\frac{2}{3}}(3F - D).$$

One can prove that this is again the right expression for the coupling constant $g(K^0\Xi^0\bar{\Lambda})$.

In the same way one can show that starting from the formal expressions for $g(\pi^-\Sigma^+\bar{\Sigma}^0_{ds})$ and $g(\pi^-\Sigma^+\bar{\Sigma}^0_{us})$ it is straightforward to arrive at kaon-baryon couplings $g(K^-p\bar{\Sigma}^0)$ and $g(K^0\Xi^0\bar{\Sigma}^0)$:

$$-2[g(\pi^-\Sigma^+\bar{\Sigma}^0_{ds})]_{ds} = [g(\pi^-\Sigma^+\bar{\Sigma}^0) + \sqrt{3}g(\pi^-\Sigma^+\bar{\Lambda})]_{ds} =$$

$$-\sqrt{2}F + \sqrt{3}(\sqrt{\frac{2}{3}}D) = 2[g(K^-p\bar{\Sigma}^0)] = \sqrt{2}(-F + D),$$

$$-2[g(\pi^-\Sigma^+\bar{\Sigma}^0_{us})]_{us} = [g(\pi^-\Sigma^+\bar{\Sigma}^0) - \sqrt{3}g(\pi^-\Sigma^+\bar{\Lambda})]_{us} =$$

$$-\sqrt{2}F - \sqrt{3}(\sqrt{\frac{2}{3}}D) = 2[g(K^0\Xi^0\bar{\Sigma}^0)] = -\sqrt{2}(F + D).$$

Derivation of these coupling constants indicates us the way to proceed in the formalism of QCD sum rules.

4 Light-Cone QCD sum rules for kaon-baryon couplings

We rewrite LC QCD SR's (Eq.(40) from [9]) for the $\mathcal{M} = \pi^0, \eta$ coupling to the baryon $BB(qq, q')$, in a way to make clear unitary symmetry pattern:

$$-\sqrt{\frac{1}{2}}M_B\lambda_B^2 g_{\mathcal{M}BB}e^{-M_B^2/M^2} = g_{\mathcal{M}qq}(\Pi_1^\gamma(M^2) - g_{\mathcal{M}q'q'}\Pi_2^\gamma(M^2), \tag{14}$$

wherefrom Eqs.(5-7) of [9] follows:

$$-M_N\lambda_N^2 g_{\pi^0 pp}e^{-(m_N^2/M^2)} =$$
$$\sqrt{2}(g_{\pi^0 uu}\Pi_1^\gamma(M^2) - g_{\pi^0 dd}\Pi_2^\gamma(M^2)) = \Pi_1^\gamma(M^2 + \Pi_2^\gamma(M^2);$$
$$-M_\Sigma\lambda_\Sigma^2 g_{\pi^0\Sigma^+\Sigma^+}e^{-(M_\Sigma^2/M^2)} = \sqrt{2}g_{\pi^0 uu}\Pi_1^\gamma(M^2) = \Pi_1^\gamma(M^2),$$
$$-M_\Xi\lambda_\Xi^2 g_{\pi^0\Xi^0\Xi^0}e^{-(M_\Xi^2/M^2)} = -\sqrt{2}g_{\pi^0 uu}\Pi_2^\gamma(M^2) = -\Pi_2^\gamma(M^2), \quad (15)$$

and so on, where $\Pi_{1,2}^\gamma(M^2)$ are given in [9] and can be redefined in terms of

$$\sqrt{2}F^\gamma(M^2) \equiv \Pi_1^\gamma(M^2), \quad \sqrt{2}D^\gamma(M^2) \equiv \Pi_1^\gamma(M^2) + 2\Pi_2^\gamma(M^2)$$

to see clearly $SU(3)$ pattern.

The LC QCD sum rules in [9] are flavour symmetric. Upon using this fact for the RHS of the LC QCD sum rules and following reasoning of the preceding section we can write

$$-\sqrt{3}g_{K^-p\Lambda}\frac{\lambda_\Lambda\lambda_N M^2}{(M_\Lambda^2 - M_N^2)}(M_N e^{-M_N^2/M^2} - M_\Lambda e^{-M_\Lambda^2/M^2}) =$$
$$-2\Pi_1^\gamma(M^2) - \Pi_2^\gamma(M^2) = -\sqrt{\frac{1}{2}}(D^\gamma(M^2) + 3F^\gamma(M^2))$$
$$-g_{K^-p\Sigma^0}\frac{\lambda_\Lambda\lambda_N M^2}{(M_\Sigma^2 - M_N^2)}(M_N e^{-M_N^2/M^2} - M_\Sigma e^{-M_\Sigma^2/M^2}) =$$
$$\Pi_2^\gamma(M^2) = \sqrt{\frac{1}{2}}(D^\gamma(M^2) - F^\gamma(M^2)),$$
$$-\sqrt{3}g_{K^0\Xi^0\Lambda}\frac{\lambda_\Lambda\lambda_\Xi M^2}{(M_\Xi^2 - M_\Lambda^2)}(M_\Lambda e^{-M_\Lambda^2/M^2} - M_\Xi e^{-M_\Xi^2/M^2}) =$$
$$\Pi_1^\gamma(M^2) - \Pi_2^\gamma(M^2) = -\sqrt{\frac{1}{2}}(D^\gamma(M^2) - 3F^\gamma(M^2)),$$
$$-g_{K^0\Xi^0\Sigma^0}\frac{\lambda_\Lambda\lambda_\Xi M^2}{(M_\Xi^2 - M_\Sigma^2)}(M_\Sigma e^{-M_\Sigma^2/M^2} - M_\Xi e^{-M_\Xi^2/M^2}) =$$
$$-\Pi_1^\gamma(M^2) - \Pi_2^\gamma(M^2) = -\sqrt{\frac{1}{2}}(D^\gamma(M^2) + F^\gamma(M^2)). \quad (16)$$

These expressions demonstrate a net $SU(3)$ pattern. But as we have in mind to expose some methodics we would prefer less complicated and not so lengthy expressions as in [9] and at the same time the case where unitary symmetry of quark masses and condensates is broken.

5 QCD sum rules

We use as the next example QCD sum rules based on the formalism developed in [7] where formules are more transparent and unitary symmetry is broken. Let us begin from the sum rule for the $\mathcal{M}\Sigma^0\Sigma^0$ coupling:

$$\frac{1}{\sqrt{2}}m_{\mathcal{M}}^2\lambda_\Sigma^2 g(\mathcal{M}\Sigma^0\Sigma^0)e^{-(m_\Sigma^2/M^2)}[1+A_\Sigma M^2] =$$
$$g_{\mathcal{M}ss}m_{\mathcal{M}}^2 M^4 E_0(x)[\frac{\langle\bar{s}s\rangle}{12\pi^2 f_{\mathcal{M}}}+\frac{3f_{3\mathcal{M}}}{4\sqrt{2}\pi^2}]$$
$$-g_{\mathcal{M}ss}\frac{1}{f_{\mathcal{M}}}M^2(m_d\langle\bar{u}u\rangle+m_u\langle\bar{d}d\rangle)\langle\bar{s}s\rangle$$
$$-g_{\mathcal{M}ss}\frac{m_{\mathcal{M}}^2}{72 f_{\mathcal{M}}}\langle\bar{s}s\rangle\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle$$
$$+\frac{1}{6f_{\mathcal{M}}}m_0^2[\langle\bar{s}s\rangle(m_d g_{\mathcal{M}uu}\langle\bar{u}u\rangle+m_u g_{\mathcal{M}dd}\langle\bar{d}d\rangle)$$
$$+m_s(g_{\mathcal{M}uu}+g_{\mathcal{M}dd})\langle\bar{u}u\rangle\langle\bar{d}d\rangle]. \quad (17)$$

where m_q, $q=u,d,s$ are current quark masses, $f_{\mathcal{M}}$ is a $\mathcal{M}$-meson decay constant, $\mathcal{M}=\pi^0,\eta$, $\langle\bar{q}q\rangle$'s, $q=u,d,s$ are v.e.v.'s, taken as $-(2\pi)^2\langle\bar{u}u\rangle=-(2\pi)^2\langle\bar{d}d\rangle=-(2\pi)^2\langle\bar{q}q\rangle=0.55$ GeV^3, $\langle\bar{s}s\rangle/\langle\bar{d}d\rangle=0.8$, while $m_0^2=0.8$ GeV^2,

$$\langle\bar{q}q\rangle m_0^2=\langle\bar{g}_c q\sigma\cdot Gq\rangle.$$

$E_n(x)=(1-e^{-x}(1+x+...+x^n/n!))$ is a factor used to subtract the continuum contribution, $x=W^2/M^2$ [2]. Here $W^2=2.0$ GeV^2 is taken with the overlap amplitude $(2\pi)^4\lambda_\Sigma^2=1.88$ GeV^6. If we define $\mathcal{D}^{(0)}(\mathcal{M};M^2;u,d;s),\mathcal{F}^{(0)}(\mathcal{M};M^2;u,d;s)$ (this shorthanded notation means that these functions depend on M^2, all quark masses and all condensates: $\mathcal{D}^{(0)}(\mathcal{M};M^2;u,d;s)\equiv$
$\mathcal{D}^{(0)}(\mathcal{M};M^2;m_u,\langle\bar{u}u\rangle,...;m_d,\langle\bar{d}d\rangle,...;m_s,\langle\bar{s}s\rangle,...)$, similar for $\mathcal{F}$):

$$\mathcal{F}^{(0)}(\mathcal{M};M^2;u,d;s)=\frac{1}{6f_{\mathcal{M}}}m_0^2[\langle\bar{s}s\rangle(m_d\langle\bar{u}u\rangle+m_s\langle\bar{u}u\rangle\langle\bar{d}d\rangle],$$
$$\mathcal{D}^{(0)}(\mathcal{M};M^2;u,d;s)=$$
$$\mathcal{F}^{(0)}(\mathcal{M};M^2;u,d;s)-[m_{\mathcal{M}}^2 M^4 E_0(x)[\frac{\langle\bar{s}s\rangle}{12\pi^2 f_{\mathcal{M}}}+\frac{3f_{3\mathcal{M}}}{4\sqrt{2}\pi^2}]$$
$$-\frac{1}{f_{\mathcal{M}}}M^2(m_d\langle\bar{u}u\rangle+m_u\langle\bar{d}d\rangle)\langle\bar{s}s\rangle$$

$$-\frac{m_{\mathcal{M}}^2}{72 f_{\mathcal{M}}}\langle\bar{s}s\rangle\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle], \qquad (18)$$

The righthand side (RHS) of the Eq.(17) can be written in a form

$$\begin{aligned} RHS(\mathcal{M}\Sigma^0\Sigma^0) = (g_{\mathcal{M}uu} + \frac{1}{2}g_{\mathcal{M}ss})\mathcal{F}^0(\mathcal{M};M^2;u,d;s) + \\ (g_{\mathcal{M}dd} + \frac{1}{2}g_{\mathcal{M}ss})\mathcal{F}^0(\mathcal{M};M^2;d,u;s) - \\ \frac{1}{2}g_{\mathcal{M}ss}(\mathcal{D}^0(\mathcal{M};M^2;u,d;s) + \mathcal{D}^0(\mathcal{M};M^2;d,u;s)), \end{aligned} \qquad (19)$$

suitable for going to the exact $SU(3)$ limit. For this purpose we should put

$$\begin{aligned} m_u = m_d = m_s = m_q, \\ \langle\bar{u}u\rangle = \langle\bar{d}d\rangle = \langle\bar{s}s\rangle = \langle\bar{q}q\rangle, \\ D \equiv \mathcal{D}^{(0)}(\mathcal{M};M^2;q,q;q), F \equiv \mathcal{F}^{(0)}(\mathcal{M};M^2;q,q;q), \end{aligned} \qquad (20)$$

and take into account that

$$g_{\mathcal{M}uu} + g_{\mathcal{M}dd} + g_{\mathcal{M}ss} = 0, \quad \mathcal{M} = \pi^{(0)}, \eta. \qquad (21)$$

In the exact $SU(3)$ limit the RHS of the sum rule Eq.(19) yields

$$\begin{aligned} RHS(\mathcal{M}\Sigma^0\Sigma^0)_{SU(3)} = (g_{\mathcal{M}uu} + g_{\mathcal{M}dd} + g_{\mathcal{M}ss})\mathcal{F}^0(\mathcal{M};M^2;q,q;q) \\ -g_{\mathcal{M}ss}\mathcal{D}^0(\mathcal{M};M^2;q,q;q) = -g_{\mathcal{M}ss}D. \end{aligned} \qquad (22)$$

This sum rule yields zero $\pi^0\Sigma^0\bar{\Sigma}^0$ coupling as it should be but gives us a possibility to construct Borel sum rule for the $\pi^-\Sigma^+\bar{\Sigma}^0$ or $\pi^+\Sigma^-\bar{\Sigma}^0$. To illustrate transition from $\pi^0\Sigma^0\bar{\Sigma}^0$ coupling to that of $\pi^-\Sigma^+\bar{\Sigma}^0$ or $\pi^+\Sigma^-\bar{\Sigma}^0$ we expose two series of graphs (see Figs.1,2). (We should have shown also gluon lines due to v.e.v. related to m_0^2 but for the moment we ignore it for simplicity as these lines do not affect our reasoning.)

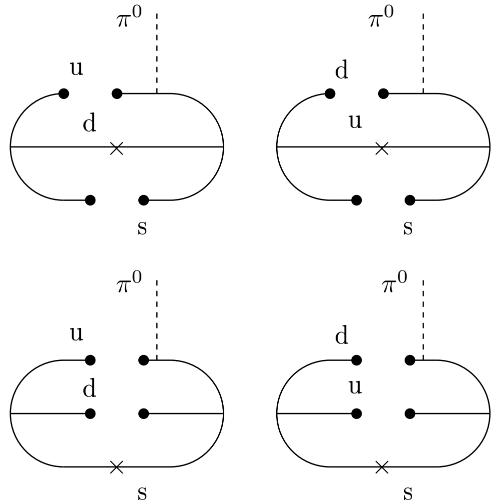

Fig.1

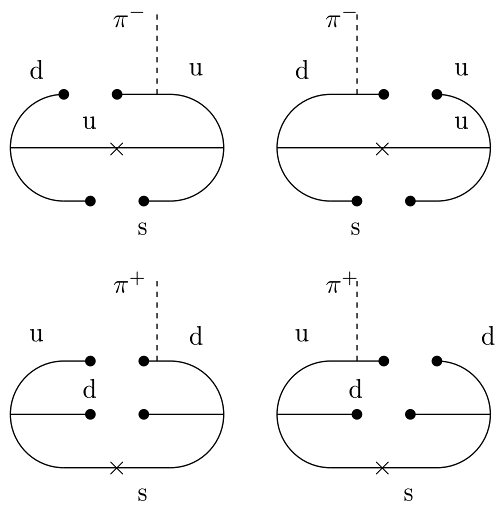

Fig.2

The sum rule for the $\pi^-\Sigma^+\bar{\Sigma}^0$ coupling reads

$$-m_\pi^2 \lambda_\Sigma^2 g(\pi^-\Sigma^+\Sigma^0) e^{-(m_\Sigma^2/M^2)}[1 + A_\Sigma M^2] =$$

$$\frac{m_0^2}{6f_\pi}[(m_u\langle\bar{s}s\rangle + m_s\langle\bar{u}u\rangle)(\langle\bar{u}u\rangle + \langle\bar{d}d\rangle)] \equiv \sqrt{2}\mathcal{F}^{(-)}(\pi^-; M^2; u, d; s) \quad (23)$$

and a similar sum rule for $\pi^+\Sigma^-\Sigma^0$ coupling (upon $u \leftrightarrow d$) to compare with the $\pi^0\Sigma^+\bar{\Sigma}^+$ coupling sum rule [7]

$$m_\pi^2 \lambda_\Sigma^2 g(\pi^0\Sigma^+\Sigma^+) e^{-(m_\Sigma^2/M^2)}[1 + A_\Sigma M^2] =$$
$$\frac{m_0^2}{3f_\pi}[(m_u\langle\bar{s}s\rangle + m_s\langle\bar{u}u\rangle)\langle\bar{u}u\rangle] = \sqrt{2}\mathcal{F}^{(0)}(\pi^0; M^2; u, u; s). \quad (24)$$

Upon using our relation between the correlation functions for Σ and Λ hyperons [15] we have constructed recently QCD borel sum rule for $\pi^0\Sigma\Lambda$ coupling [11]

$$\sqrt{3}m_\pi^2 \lambda_\Lambda \lambda_\Sigma g(\pi^0\Sigma^0\Lambda)$$
$$\frac{M^2}{M_\Sigma^2 - M_\Lambda^2}(e^{-M_\Lambda^2/M^2} - e^{-M_\Sigma^2/M^2})[1 + A_{\Sigma\Lambda}M^2] =$$
$$-m_\pi^2 M^4 E_0(x)[\frac{\langle\bar{d}d\rangle + \langle\bar{u}u\rangle}{12\pi^2 f_\pi} + \frac{3f_{3\pi}}{4\sqrt{2}\pi^2}] + \frac{m_\pi^2}{72f_\pi}[\langle\bar{d}d\rangle + \langle\bar{u}u\rangle]\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle$$
$$+\frac{1}{6f_\pi}(6M^2 + m_0^2)[(m_s\langle\bar{u}u\rangle + m_u\langle\bar{s}s\rangle)\langle\bar{d}d\rangle + (m_d\langle\bar{s}s\rangle + m_s\langle\bar{d}d\rangle)\langle\bar{u}u\rangle] \quad (25)$$

The RHS of it we present as

$$RHS(\pi^0\Sigma^0\Lambda) = \frac{1}{2\sqrt{2}}[\mathcal{D}^{(0)}(\pi^0; M^2; s, d; u) + \mathcal{D}^{(0)}(\pi^0; M^2; s, u; d) +$$
$$\mathcal{D}^{(0)}(\pi^0; M^2; u, s; d) + \mathcal{D}^{(0)}(\pi^0; M^2; d, s; u)] +$$
$$\frac{1}{2\sqrt{2}}[\mathcal{F}^{(0)}(\pi^0; M^2; u, s; d) + \mathcal{F}^{(0)}(\pi^0; M^2; d, s; u) -$$
$$\mathcal{F}^{(0)}(\pi^0; M^2; s, u; d) - \mathcal{F}^{(0)}(\pi^0; M^2; s, d; u)] \rightarrow |_{exact \quad SU(3)} \quad \sqrt{2}D. \quad (26)$$

For the left hand side (LHS) of the Eq.(25) we can use safely instead of masses Σ and Λ some effective mass $M_{\Sigma\Lambda} = (M_\Sigma + M_\Lambda)/2$ to simplify a little the final expression (see below) From the sum rule for the $\pi^0\Sigma^0\Lambda$ coupling Eq.(25) [11] we can just deduce upon using isotopic invariance the corresponding expression for the $\pi^-\Sigma^+\bar{\Lambda}$ one (see also Fig.1-4). It reads as

$$\sqrt{3}m_\pi^2 \lambda_\Lambda \lambda_\Sigma g(\pi^-\Sigma^+\bar{\Lambda}) e^{-(M_{\Sigma\Lambda}^2/M^2)}[1 + A_{\Sigma\Lambda}M^2] =$$
$$= [-m_\pi^2 M^4 E_0(x)[\frac{(\langle\bar{u}u\rangle + \langle\bar{d}d\rangle)}{12\pi^2 f_\pi} + \frac{3f_{3\pi}}{4\sqrt{2}\pi^2}] +$$
$$\frac{(m_0^2 + 6M^2)}{6f_\pi}[(m_u\langle\bar{s}s\rangle + m_s\langle\bar{u}u\rangle)(\langle\bar{u}u\rangle + \langle\bar{d}d\rangle)] +$$

$$+\frac{m_\pi^2}{72 f_\pi}(\langle \bar{u}u\rangle + \langle \bar{d}d\rangle)\langle \frac{\alpha_s}{\pi}\mathcal{G}^2\rangle] \equiv$$

$$\sqrt{2}\mathcal{D}^{(-)}(\pi^-; M^2; s, d; u) \rightarrow |_{exact \quad SU(3)} \quad \sqrt{2}D. \tag{27}$$

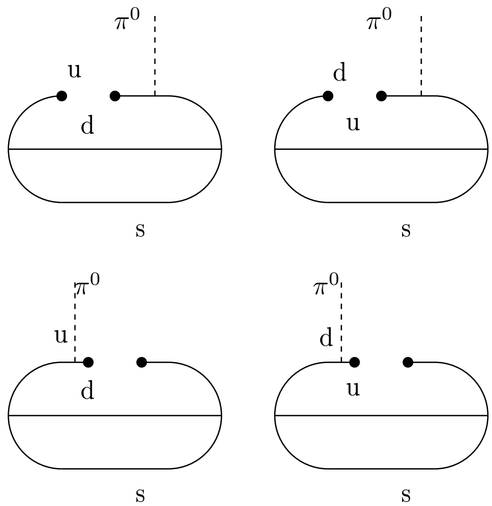

Fig.3

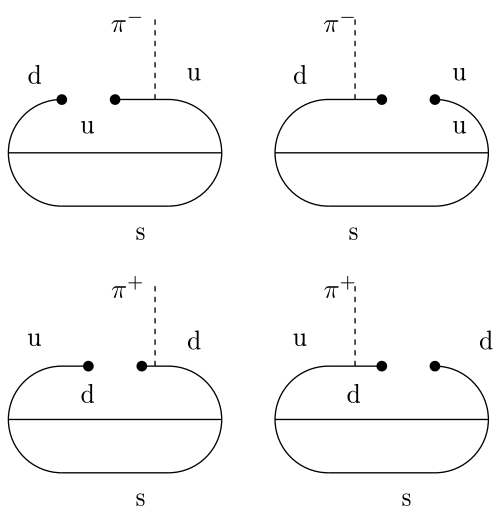

Fig.4

And now we are able to derive Borel sum rules for K-meson couplings to octet baryons starting from those for $\pi\Sigma\Lambda$ and $\pi\Sigma\Sigma$ couplings given by the Eqs.(23,27). We shall form auxiliary couplings upon using quantities $\Lambda_{ds}, \Sigma^0_{ds}$ and $\Lambda_{us}, \Sigma^0_{us}$ given by the Eqs. (10-13), and then return to those usual ones performing transformations $d \leftrightarrow s$ and $u \leftrightarrow s$. First we construct a formal sum rule for the case where Λ is changed to Λ_{ds} just by using Eq.(11), and we retain for a moment only RHS of the corresponding sum rules:

$$RHS(\pi^-\Sigma^+\bar{\Lambda}_{ds}) = -\frac{\sqrt{3}}{2}RHS(\pi^-\Sigma^+\bar{\Sigma}^0) + \frac{1}{2}RHS(\pi^-\Sigma^+\bar{\Lambda}) = \sqrt{\frac{1}{6}}(3\mathcal{F}^{(-)}(\pi^-;M^2;u,d;s) + \mathcal{D}^{(-)}(\pi^-;M^2;s,d;u)). \quad (28)$$

Performing to it the transformation $(d \leftrightarrow s)$ we should change in fact π^- to K^-, Σ^+ to $-p$ to obtain:

$$RHS((g(\pi^-\Sigma^+\bar{\Lambda}_{ds})_{ds}) = -RHS(g(K^-p\bar{\Lambda}) = \sqrt{\frac{1}{6}}(3\mathcal{F}^{(-)}(K^-;M^2;u,s;d) + \mathcal{D}^{(-)}(K^-;M^2;d,s;u)) \to |_{exact \quad SU(3)} \quad \sqrt{\frac{1}{6}}(3F + D), \quad (29)$$

or in full notation

$$m_K^2 g_{K^-p\bar{\Lambda}} \frac{\lambda_\Lambda \lambda_N M^2}{(M_\Lambda^2 - M_N^2)}(e^{-M_N^2/M^2} - e^{-M_\Lambda^2/M^2})(1 + A_{\Lambda N}M^2) = -\frac{1}{2\sqrt{3}}[-m_K^2 M^4 E_0(x)[\frac{(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)}{12\pi^2 f_K} + \frac{3f_{3K}}{4\sqrt{2}\pi^2}] + \frac{(2m_0^2 + 3M^2)}{3f_K}[(m_u\langle\bar{d}d\rangle + m_d\langle\bar{u}u\rangle)(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)] + \frac{m_K^2}{72f_K}(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle]. \quad (30)$$

Interchanging in this sum rule $(u \leftrightarrow d)$ one transforms it into the sum rule for the coupling constant $g_{K^0n\bar{\Lambda}}$.

In a similar way constructing a formal sum rule for the case where Λ in Eq.(27) is changed to Λ_{us} upon using Eqs.(13,2322,9) and performing the transformation $(u \leftrightarrow s)$ we obtain:

$$-RHS((g(\pi^-\Sigma^+\bar{\Lambda}_{us})_{us}) = RHS(\bar{K}^0\Xi^0\bar{\Lambda}) =$$

$$\sqrt{\frac{1}{6}}(3\mathcal{F}^{(-)}(K^0;M^2;s,d;u) - \mathcal{D}^{(-)}(K^0;M^2;u,d;s))$$
$$\to |_{exact \quad SU(3)} \quad \sqrt{\frac{1}{6}}(3F - D), \qquad (31)$$

or full notation,

$$m_K^2 g_{\bar{K}^0\Xi^0\bar{\Lambda}} \frac{\lambda_\Lambda \lambda_\Xi M^2}{(M_\Xi^2 - M_\Lambda^2)}(e^{-M_\Lambda^2/M^2} - e^{-M_\Xi^2/M^2})(1 + A_{\Lambda\Xi}M^2)$$
$$= -\frac{1}{2\sqrt{3}}[-m_K^2 M^4 E_0(x)[\frac{(\langle\bar{d}d\rangle + \langle\bar{s}s\rangle)}{12\pi^2 f_K} + \frac{3f_{3K}}{4\sqrt{2}\pi^2}] +$$
$$\frac{(-m_0^2 + 3M^2)}{3f_K}[(m_u\langle\bar{s}s\rangle + m_s\langle\bar{u}u\rangle)(\langle\bar{d}d\rangle + \langle\bar{s}s\rangle)]$$
$$+\frac{m_K^2}{72f_K}(\langle\bar{d}d\rangle + \langle\bar{s}s\rangle)\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle]. \qquad (32)$$

Upon interchange ($u \leftrightarrow d$) one get the sum rule for the coupling constant $\bar{K}^-\Xi^-\bar{\Lambda}$. Analogous sum rules can be constructed for Σ^0 coupling with kaon. First using Eq.(10) and Eqs.(23,27) we construct sum rule for the formal quantity involving Σ^0_{ds}:

$$-2 \cdot RHS(\pi^-\Sigma^+\bar{\Sigma}^0_{ds}) = RHS(\pi^-\Sigma^+\bar{\Sigma}^0) + \sqrt{3}RHS(\pi^-\Sigma^+\bar{\Lambda})$$
$$-\sqrt{2}\mathcal{F}^{(-)}(\pi^-;M^2;u,d;s) + \sqrt{2}\mathcal{D}^{(-)}(\pi^-;M^2;s,d;u) \qquad (33)$$

and then return to real Σ^0 with the 2nd application of the transformation ($d \leftrightarrow s$) changing also Σ^+ to $-p$ and π^- to K^-:

$$-2 \cdot RHS((\pi^-\Sigma^+\bar{\Sigma}^0_{ds})_{ds}) = 2 \cdot RHS(K^-p\bar{\Sigma}^0) =$$
$$-\sqrt{2}\mathcal{F}^{(-)}(K^-;M^2;u,s;d) + \sqrt{2}\mathcal{D}^{(-)}(K^-;M^2;d,s;u)$$
$$\to |_{exact \quad SU(3)} \quad -\sqrt{2}(F - D), \qquad (34)$$

or, in full notation,

$$2m_K^2 g_{K^-p\bar{\Sigma}^0} \frac{\lambda_\Sigma \lambda_N M^2}{(M_\Sigma^2 - M_N^2)}(e^{-M_N^2/M^2} - e^{-M_\Sigma^2/M^2})(1 + A_{\Sigma N}M^2) =$$
$$-m_K^2 M^4 E_0(x)[\frac{(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)}{12\pi^2 f_K} + \frac{3f_{3K}}{4\sqrt{2}\pi^2}] +$$
$$\frac{M^2}{f_K}(m_u\langle\bar{d}d\rangle + m_d\langle\bar{u}u\rangle)(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)$$
$$+\frac{m_K^2}{72f_K}(\langle\bar{u}u\rangle + \langle\bar{s}s\rangle)\langle\frac{\alpha_s}{\pi}\mathcal{G}^2\rangle. \qquad (35)$$

Invoking isotopic invariance it is easy to obtain from the Eq.(34) sum rules for the coupling constants $g_{\bar{K}^0 n \bar{\Sigma}^0}$ (upon interchange $(u \leftrightarrow d)$), $g_{K^- n\bar{\Sigma}^+}$, $g_{K^0 p\bar{\Sigma}^+}$ and $g_{K^- n\bar{\Sigma}^+}$ (upon interchange $(d \leftrightarrow u)$). As the last one we construct sum rule for the formal quantity involving Σ^0_{us} using Eq.(1212) and Eqs.(23,27):

$$-2 \cdot RHS(\pi^- \Sigma^+ \bar{\Sigma}^0_{us}) = RHS(\pi^- \Sigma^+ \bar{\Sigma}^0) - \sqrt{3} \cdot RHS(\pi^- \Sigma^+ \bar{\Lambda}) =$$
$$-\sqrt{2}\mathcal{F}^{(-)}(\pi^-; M^2; u, d; s) - \sqrt{2}\mathcal{D}^{(-)}(\pi^-; M^2; s, d; u) \quad (36)$$

and then return to real Σ^0 with the transformation $(u \leftrightarrow s)$ changing also Σ^+ to $-\Xi^0$ and π^- to K^0:

$$-2 \cdot RHS((\pi^- \Sigma^+ \bar{\Sigma}^0_{us})_{us}) = 2 \cdot RHS(K^0 \Xi^0 \bar{\Sigma}^0) =$$
$$-\sqrt{2}\mathcal{F}^{(-)}(K^0; M^2; s, d; u) - \sqrt{2}\mathcal{D}^{(-)}(K^0; M^2; u, d; s)$$
$$\to |_{exact \quad SU(3)} \quad -\sqrt{2}(F + D), \quad (37)$$

or, in full notation,

$$2m_K^2 g_{\bar{K}^0 \Xi^0 \bar{\Sigma}^0} \frac{\lambda_\Sigma \lambda_\Xi M^2}{(M_\Xi^2 - M_\Sigma^2)}(e^{-M_\Sigma^2/M^2} - e^{-M_\Xi^2/M^2})(1 + A_{\Sigma\Xi} M^2)$$
$$= m_K^2 M^4 E_0(x)[\frac{(\langle \bar{d}d\rangle + \langle \bar{s}s\rangle)}{12\pi^2 f_K} + \frac{3f_{3K}}{4\sqrt{2}\pi^2}]$$
$$-\frac{m_0^2 + 3M^2}{3f_K}[(m_u\langle \bar{s}s\rangle + m_s\langle \bar{u}u\rangle)(\langle \bar{d}d\rangle + \langle \bar{s}s\rangle)]$$
$$-\frac{m_K^2}{72 f_K}(\langle \bar{d}d\rangle + \langle \bar{s}s\rangle)\langle \frac{\alpha_s}{\pi}\mathcal{G}^2\rangle. \quad (38)$$

Isotopic invariance allows us to obtain from the Eq.(37) sum rules for coupling constants $g_{\bar{K}^- \Xi^- \bar{\Sigma}^0}$, $g_{\bar{K}^- \Xi^0 \bar{\Sigma}^+}$ and $g_{\bar{K}^0 \Xi^- \bar{\Sigma}^-}$.

6 Discussion

Thus we have constructed QCD sum rules with the Lorenz structure $i\gamma 5 q$ for all the K meson - baryon coupling constants $g(K\Xi\Sigma)$, $g(K\Xi\Lambda)$, $g(KN\Sigma)$, $g(KN\Lambda)$.

We have calculated RHS's of our sum rules and multiplying them with exponential and other factors from the LHS's, have obtained products $\lambda \cdot g_{\mathcal{M}BB}$ and upon assuming the form $\lambda_B^2 \sim C M_B^6$ from [7] have extracted coupling constants of K-mesons to octet baryons. The results are presented in the Tables 1,2 with $C = 5.48 \times 10^{-4}$. In order to control our results we recalculate sum rules for π couplings to baryons in the strict $SU(3)$ limit of [7] obtaining values close to it.

The obtained values of coupling constants are not very impressive, but one should take in mind that we have based our results for methodical reasons on one of the simpliest series of sum rules from [7] which do not pretend to account for real quantities too much [8].

These sum rules confirm a known result that usual formulation of the constants in terms of the D and F constants is not suitable here due to large symmetry breaking. But all these sum rules when expressed in terms of the generalized functions $\mathcal{F}$ and $\mathcal{D}$ reveal indeed a simple $SU(3)_f$ pattern, and this is one of the main results we present here. The relations given by Eqs.(30,32, 34,37) indicate in what way one can change and use the concept of the unitary symmetry in the framework of QCD sum rules.

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Table 1.

The best-fitted values of the coupling constants g_{KNY}, $g_{K\Xi Y}$ and corresponding values of A_{NY}, $A_{\Xi Y}$ are given together with the Borel windows(BW) for each sum rule, $Y = \Lambda, \Sigma$.

Coupling	BW, M^2, GeV^2	g	Ag, GeV^{-2}	A, GeV^{-2}
$\pi^0 pp$	1.0-1.4	$13.4/\sqrt{2}$	5.75	0.62
$K^- p\Lambda$	1.0-2.0	0.77	1.73	2.25
$\bar{K}^0 \Xi^0 \Lambda$	1.3-2.3	-1.35	0.8	-0.59
$K^- p\Sigma^0$	1.1-2.1	1.18	2.53	2.14
$\bar{K}^0 \Xi^0 \Sigma^0$	1.5-2.5	-3.09	-0.94	0.30

Table 2

The values of the coupling constants g_{KNY}, $g_{K\Xi Y}$, $Y = \Lambda, \Sigma$, of this work as well as of several recent works are given.

Coupling	$\|g\|$ [14]	g [12],[13]	g, this work
$\pi^0 pp$	-	-	$13.4/\sqrt{2}$(input)
$KN\Lambda$	2.37±0.09	-3.47	0.77
$\bar{K}\Xi\Lambda$	-	-	-1.35
$KN\Sigma$	0.025±0.015	1.17	1.18
$K\Xi\Sigma$	-	7.02	-3.09

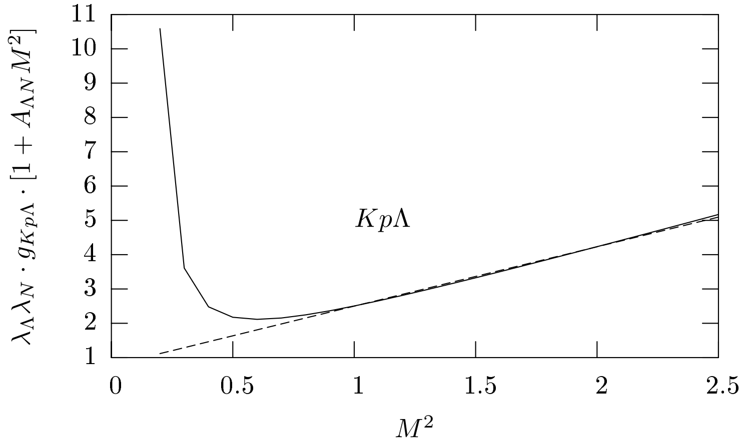

Fig 1. The Borel curve is given by Eq.(30)

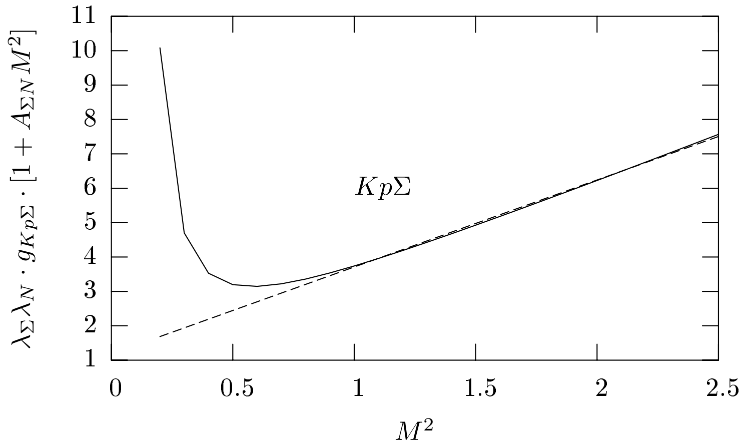

Fig 2. The Borel curve is given by Eq.(35)

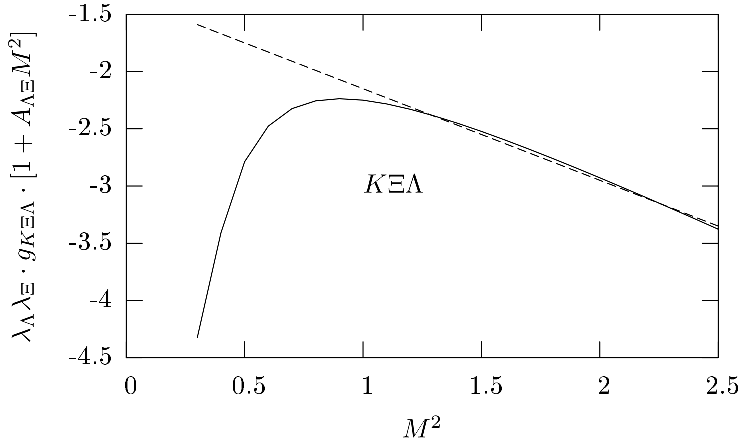

Fig 3. The Borel curve is given by Eq.(32)

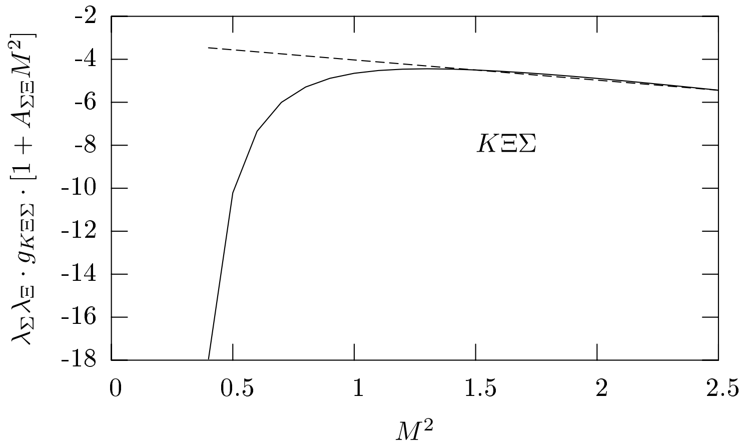

Fig 4. The Borel curve is given by Eq.(38)

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