Vector-meson–baryon coupling constants in QCD sum rules

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The external-field quantum chromodynamics (QCD) sum rules method is used to evaluate the coupling constants of the vector mesons $\rho$ and $\omega$ to the nucleon and the $\Lambda$, $\Sigma$, and $\Xi$ baryons. It is shown that these coupling constants as calculated from QCD sum rules are consistent with SU(3)-flavor relations. By assuming ideal mixing, this leads to a determination of the $F/(F + D)$ ratio of the vector-meson octet: we find $a_+ = 1$ and $a_0 = 0.18$ for the vector and the magnetic $F/(F + D)$ ratios, respectively. The sensitivity of the results to the unknown vacuum susceptibility $\xi$ is discussed. The coupling constants with SU(3)-breaking effects taken into account are also calculated.

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I. INTRODUCTION

An important ingredient of the baryon–baryon interactions is the exchange of the members of vector-meson nonet ($\rho$, $\phi$, $\omega$, $K^*$). Vector mesons play also a special role in the electromagnetic interactions of hadrons. The vector-meson dominance (VMD) model [1] relates the hadronic electromagnetic interactions of hadrons. The vector-meson is the exchange of the members of vector-meson nonet mass. A spin-1/2 baryon is given by to compute from quantum chromodynamics (QCD). The Lagrangian density for the interaction of a vector meson with a spin-1/2 baryon is given by

$$\mathcal{L}_{VBB} = -ig_B^{\nu} \bar{\psi} \gamma_{\mu} \gamma_5 \psi V^{\mu} + \frac{f_B^{\nu}}{4m} \bar{\psi} \sigma_{\mu\nu} \psi (\partial^\mu V^\nu - \partial^\nu V^\mu).$$ (1)

where $\sigma_{\mu\nu} = i[\gamma_\mu, \gamma_\nu]/2$. The first term ($g_B^{\nu}$) is called the vector (electric) coupling and the second one ($f_B^{\nu}$) the tensor (magnetic) coupling; $m$ is a scaling mass to make $f_B^{\nu}$ dimensionless, conventionally taken to be equal to the proton mass.

The physical states $\psi$ and $\omega$ are mixtures of the unitary singlet and octet states. We assume ideal mixing with the mixing angle $\theta_0 = 35.3^\circ$, which is close to the experimental value $\theta_0 = 37.5^\circ$ [2]. This means that the $\phi$ meson is a pure $\bar{s}s$ state and hence does not couple to the nucleon (in the absence of a strangeness content). The couplings of the vector mesons to the baryon octet can be written in terms of the $NN\rho$ coupling constant and $a_{\rho,m}$ [3], where $a_\rho (a_m)$ is the $F/(F + D)$ ratio of the vector (magnetic) coupling constants. VMD predicts $a_\rho = 1$ via the universal coupling of the $\rho$ meson to the isospin current [4].

Our aim in this article is to calculate the vector and the tensor coupling constants of the vector mesons $\rho$ and $\omega$ to the $N$, $\Lambda$, $\Sigma$, and $\Xi$ baryons using the external-field QCD sum rules (QCDSR) [5], which is a powerful tool [6,7] to extract qualitative and quantitative information about hadron properties [8,9]. For this purpose, we assume a constant background tensor field $Z_{\mu\nu}$ and evaluate the vacuum-to-vacuum transition matrix element of the two-baryon interpolating fields to construct the sum rules. We define the external-vector-meson field as

$$Z_\mu = -\frac{1}{2} Z_{\mu\nu} x^\nu.$$ (2)

This background field can be decomposed into symmetric ($Z^S_{\mu\nu}$) and antisymmetric ($Z^A_{\mu\nu}$) parts. The antisymmetric part has been used to calculate the baryon magnetic moments [5,10–12], whereas the symmetric part was used in Ref. [13] to determine the vector-meson couplings $g_\rho^{\nu}$ and $f_\rho^{\nu}$. In this work, we use a similar method to calculate the vector-meson–baryon coupling constants. The sum rules for the antisymmetric part of the external field can be obtained from the sum rules for the baryon magnetic moments in Refs. [5,10–12], but the numerical results for the couplings cannot be obtained trivially, because they need an independent analysis that takes the sum rules for the symmetric part of the external field into account as well. This analysis was made in Ref. [13] with the aim to calculate the $NN\rho$ and $NN\omega$ couplings. We find it useful to revisit these calculations for a couple of reasons. First, we make a more systematic analysis of the sum rules that includes the single-pole contributions, which were not taken into account in Ref. [13]. Moreover, we extend the calculations to hyperons as well by calculating terms involving the quark mass in the sum rules. We compare our results with VMD and with a successful one-boson-exchange (OBE) model of the $NN$ and $YN$ interaction, the Nijmegen soft-core potential (NSC) [14–19], which was originally derived from Regge-pole theory. The coupling constants obtained from the external-field QCDSR method are defined at $t = 0$, and therefore the comparison to the OBE model is appropriate.

We follow an analysis similar to the one in our earlier work on scalar-meson–baryon coupling constants [20,21]. We first

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We present the formulation of QCDSR with an external tensor field and construct the relevant sum rules. In Sec. III we give the numerical analysis of the sum rules and discuss the results. Finally, in Sec. IV, we arrive at our conclusions for this chapter.

II. CONSTRUCTION OF THE SUM RULES

We start with the correlation function of the baryon interpolating fields in the presence of a constant background tensor field $Z_{lm\nu}$ defined by

$$i \int d^4x \ e^{i q \cdot x} \langle 0 | T [ \eta_B(x) \bar{\eta}_B(0) ] | 0 \rangle_Z = \Pi(p) + g^V_{\mu \nu} Z_{\mu \nu} \Pi^V_{\mu \nu}(p),$$

where $g^V_{\mu \nu}$ is the vector-meson–quark coupling constant and $\Pi^V_{\mu \nu}(p)$ is the baryon interpolating fields that are chosen as [8]

$$\eta_N = \epsilon_{abc} [(u_T^T C y u_b) y y y^* d_c],$$

$$\eta_S = \epsilon_{abc} [(s_T^T C y s_b) y y y^* u_c],$$

$$\eta_S^* = (2/3)^{1/2} \epsilon_{abc} [(u_T^T C y u_b) y y y^* s_c],$$

$$\eta_A = (2/3)^{1/2} \epsilon_{abc} [(u_T^T C y u_b) y y y^* s_c] - (d_T^T C y d_b) y y y^* u_c.$$  

for $N, S, \Sigma$, and $\Lambda$, respectively; $a, b, c$ are color indices, and $T$ and $C$ denote transposition and charge conjugation, respectively.

The external field contributes to the correlation function in Eq. (3) in two ways: first, it directly couples to the quark field in the baryon current. Second, it induces the following vacuum condensates:

$$\langle \bar{q} \sigma_{\mu \nu} q \rangle_Z = g^V_{\mu \nu} Z^A_{\mu \nu} \langle \bar{q} q \rangle,$$

$$g_{\epsilon_{\mu \nu \rho \delta}} \langle \bar{q} G_{\mu \nu} q \rangle_Z = g^V_{\mu \nu} \epsilon_{\mu \nu \rho \delta} Z^A_{\rho \delta} \langle \bar{q} q \rangle,$$

$$g_{\epsilon_{\mu \nu \rho \delta}} \langle \bar{q} G_{\mu \nu} q \rangle_Z = i g_{\epsilon_{\mu \nu \rho \delta}} Z^A_{\rho \delta} \langle \bar{q} q \rangle.$$

The second term in Eq. (3) is obtained from the third term in Eq. (11).

where $S_q$ represents the quark propagator in the presence of the external field and we use the quark propagator given in Ref. [13].

Lorentz covariance and parity conservation implies that the correlation function can be written in terms of different Lorentz-Dirac structures, viz.

$$g^V_{\mu \nu}(p) = \Pi^A_{\mu \nu}(p_{\mu} y_{\nu} + p_{\nu} y_{\mu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu} + \Pi^A_{\mu \nu} p_{\mu} p_{\nu}
part of the external field, we construct the sum rules at the structure $\hat{p}\sigma_{\mu\nu} + \sigma_{\mu\nu}\hat{p}$, which have also been used for the determination of the baryon magnetic moments [5,10–12]. For the symmetric part of the external field, we construct the sum rules at the structures $p_{\mu}Y_{\nu} + p_{\nu}Y_{\mu}$ (hereafter structure I) and $\hat{p}p_{\mu}p_{\nu}$ (hereafter structure II), for reasons that will become clear below.

To construct the hadronic side, we saturate the correlator in Eq. (3) with baryon states, $u^\dagger \nu$,$\ldots B_{\mu\nu}\langle B|0\rangle = 2\frac{m_B}{N_B}(21)$, and define the vector-meson-baryon interaction by the following vertices:

$$\Gamma_{\rho BB} \equiv \langle B|\rho B\rangle = \bar{\nu} \left( g_{\rho}^{\mu}Y_{\mu} + \frac{f_{B}}{2m_B}\sigma_{\mu\nu}q^{\nu} \right)\nu \cdot \rho^\mu,$$

(22)

where $q^{\nu}$ is the meson four-momentum and $\nu$ is the Dirac spinor for the baryon, which is normalized as $\bar{\nu}\nu = 2m_B$. In Eq. (21) we defined the overlap amplitude of the baryons as $A_B = \langle \bar{B}^{\dagger}B_{\mu\nu}\rangle$. The sum rules are obtained by matching the operator product expansion (OPE) side with the hadronic side and applying the Borel transformation. The sum rules for $N$, $\Sigma$, $\Xi$, and $\Lambda$ are given as follows at structure I:

$$\begin{aligned}
M^6 E_0^N L^{-4/9} \left( 2g^{\nu}_a + g^{\nu}_d \right) + \frac{8M^4}{3} E_0^N L^{2/9} \xi a_q \left( 4g^{\nu}_a + g^{\nu}_d \right) \\
+ \frac{4}{3} a_q^2 L^{-4/9} \left( 2g^{\nu}_a + g^{\nu}_d \right) \frac{e^{m_{\rho}\mu}/M^2}{\zeta_N} = g^{\nu}_N + C_N M^2,
\end{aligned}
$$

(24)

$$\begin{aligned}
g^{\nu}_a \left[ 2M^6 E_0^\Sigma L^{-4/9} + \frac{32M^4}{3} E_0^\Sigma L^{2/9} \xi a_q g^{\nu}_a + \frac{8}{3} a_q^2 L^{4/9} \\
- 4m_s(f + 1) a_q M^2 \right] \frac{e^{m_{\rho}\mu}/M^2}{\zeta_\Sigma} = g^{\nu}_\Sigma + C_\Sigma M^2,
\end{aligned}
$$

(25)

$$\begin{aligned}
g^{\nu}_d \left[ M^6 E_0^\Xi L^{-4/9} + \frac{8M^4}{3} E_0^\Xi L^{2/9} \xi a_q g^{\nu}_d \\
+ \frac{4}{3} (f + 1) a_q^2 L^{4/9} \right] \frac{e^{m_{\rho}\mu}/M^2}{\zeta_\Xi} = g^{\nu}_\Xi + C_\Xi M^2,
\end{aligned}
$$

(26)

and at structure II:

$$\begin{aligned}
\left( g^{\nu}_a + g^{\nu}_d \right) \left[ M^6 E_0^\Lambda L^{-4/9} + \frac{32}{9} M^4 E_0^\Lambda L^{2/9} \xi a_q \\
+ \frac{4}{9} (4f + 3) a_q^2 L^{4/9} + \frac{2}{3} m_s (1 - 3f) a_q M^2 \right] \times \frac{e^{m_{\rho}\mu}/M^2}{\zeta_\Lambda} = g^{\nu}_\Lambda + C_\Lambda M^2,
\end{aligned}
$$

(27)

where $a_q = -(2\pi)^2\langle \bar{q}q \rangle, M$ is the Borel mass, and we incorporated the effects of the anomalous dimensions of various operators through the factor $L = \ln(M^2/\Lambda^2_{\text{QCD}})/\ln(\mu^2/\Lambda^2_{\text{QCD}})$, where $\mu$ is the renormalization scale and $\Lambda_{\text{QCD}}$ is the QCD scale parameter. We have defined $f = \langle \bar{q}q \rangle/\langle \bar{s}s \rangle - 1$, which is a parameter that quantifies SU(3) breaking in the vacuum condensates. We use these sum rules for the determination of the vector couplings, $g$.

The sum rules involving the antisymmetric part of the external field can easily be derived from the magnetic-moment sum rules in Refs. [5,10–12]. We use Eqs. (13)–(15) with the sum rules at the structure $\hat{p}\sigma_{\mu\nu} + \sigma_{\mu\nu}\hat{p}$, which were also used for the determination of the magnetic moments. We obtain:

$$\begin{aligned}
\left[ 4M^6 E_0^N L^{-4/9} g^{\mu}_a + \frac{4}{9} a_q^2 L^{4/9} \right] - \left( 2g^{\nu}_a + 3g^{\nu}_d \right) \\
+ g^{\nu}_a \left( 2\kappa - \xi \right) + \frac{b}{6} M^2 L^{-4/9} \left( 4g^{\nu}_a + g^{\nu}_d \right) - \frac{8}{3} \chi a_q^2 L^{-4/9} \\
\times g^{\nu}_d \left( M^2 - \frac{m_B^2 L^{-4/9}}{8} \right) \frac{e^{m_{\rho}\mu}/M^2}{\zeta_N} = \left( g^{\nu}_N + f^{\nu}_N \right) + C_N M^2,
\end{aligned}
$$

(32)
For the gluon condensate, we use the value
\[ b = 0.47 \text{ GeV}^4, \] (40)
as determined from the charmonium sum rules [6,7]. The value of the parameter \( m_\pi^2 \) has been taken in early baryon sum rules [24,25] and heavy-light quark system analyses [26] as
\[ m_\pi^2 = 0.8 \text{ GeV}^2. \] (41)

The commonly accepted value of the overlap amplitude of the nucleon as \( \hat{\Lambda}_N^2 = 2.1 \text{ GeV}^6 \) is taken from Ref. [5] and the continuum threshold for the nucleon case is taken in the region \( 2.0 \text{ GeV}^2 \leq s_0^N \leq 2.5 \text{ GeV}^2 \). The values of the susceptibilities have been estimated in early magnetic-moment calculations [5,10]. In this work, we adopt the average values of these susceptibilities as \( \chi = -4.5 \text{ GeV}^{-2}, \kappa = 0.4, \) and \( \xi = -0.8 \) [27]. Finally, we use \( \mu = 0.5 \text{ GeV} \) for the renormalization scale and \( \Lambda_{\text{QCD}} = 0.1 \text{ GeV} \) for the QCD scale parameter.

We first consider the sum rules in the SU(3)-flavor symmetric limit, where we take \( m_q = m_\pi = 0 \) and \( f = 0 \). In this limit we also set the physical parameters of all the baryons equal to the ones of the nucleon: \( m_B = m_N = 0.94 \text{ GeV}, \hat{\Lambda}_B^2 = \hat{\Lambda}_N^2 = \hat{\Lambda} \), \( s_0^B = s_0^N \). In this SU(3) limit we choose the Borel window \( 0.8 \text{ GeV}^2 < M^2 < 1.4 \text{ GeV}^2 \), which is commonly identified as the fiducial region for the nucleon mass sum rules. For the vector-meson–quark coupling constant we adopt the value
\[ g^V_q = g^q = 3.7, \] (42)
as estimated from Nambu-Jona-Lasinio model of Ref. [28], which was used to successfully reproduce the \( \rho \pi \pi \) coupling constant.

To determine the values of the vector couplings from the sum rules in Eqs. (24)–(31), one needs to know the value of the susceptibility \( \xi \), which is unknown. We note, however, that if \( \xi \) is negligibly small, then the sum rules at structures I and II are consistent with each other and have the nice feature that \( g^V_N / g^V_N = 1/3 \), which agrees well with the OBE potential model [29] and the VMD model [1] results. Therefore, we first analyze the sum rules for \( \xi = 0 \) and then discuss the deviations for arbitrary \( \xi \) values. We present the Borel mass dependence of vector and tensor coupling constants of \( \rho \) and \( \omega \) to the nucleon in Fig. 1 and to the hyperons in Fig. 2, for the average values of the vacuum parameters. The single-pole contributions (cf. the slopes in Figs. 1 and 2) are quite important, especially in the case of the sum rules for the tensor couplings. Taking into account the uncertainties in \( s_0^N \) and \( a_q \), the predicted values for the coupling constants of the \( \rho \) and \( \omega \) mesons to the baryons read:

\[ g^O_N = 7.2 \pm 1.8, \quad g^O_N = g^O_B \equiv g^O_A = 4.8 \pm 1.2, \]
\[ g^O_N = g^O_B \equiv g^O_A = 2.4 \pm 0.6, \quad g^O_A \equiv f_A^\rho = 0, \]
\[ f_A^\rho = 7.7 \pm 1.9, \quad f_A^\rho = -2.2 \pm 0.6, \quad f_A^\rho = f_A^\rho = 2.3 \pm 0.4, \]
\[ f_A^\rho = f_A^\rho = -5.0 \pm 1.0, \quad f_A^\rho = -5.7 \pm 1.0. \] (43)
TABLE I. The vector-meson–baryon coupling constants in the SU(3) limit for the average values of the vacuum parameters.

<table>
<thead>
<tr>
<th>M</th>
<th>NN</th>
<th>ΛΛ</th>
<th>ΣΣ</th>
<th>ΣΣM</th>
<th>ΛΣM</th>
<th>ΣNM</th>
<th>ΛNM</th>
<th>ΛΛM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ω  g</td>
<td>6.9</td>
<td>4.6</td>
<td>2.3</td>
<td>4.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>-2.2</td>
<td>-5.7</td>
<td>-4.9</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ  g</td>
<td>0</td>
<td>-3.3</td>
<td>-6.5</td>
<td>-3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>0</td>
<td>-4.8</td>
<td>-3.8</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ρ  g</td>
<td>2.3</td>
<td>2.3</td>
<td>4.6</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>7.6</td>
<td>-4.9</td>
<td>2.7</td>
<td>6.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K  g</td>
<td>-2.3</td>
<td>-4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>4.9</td>
<td>-5.9</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

is justified by the zero strangeness content of the nucleon and by the ideal-mixing scheme. In Table I we give all the vector-meson–baryon coupling constants, obtained from these relations.

In Fig. 3, we present the dependence of $\alpha_v = F/(F + D)$ on the susceptibility $\xi$ for the sum rules at structures I and II, at $M^2 = 1$ GeV$^2$ and for the average values of the other vacuum parameters. The sum rules are rather sensitive to a change in the value of $\xi$, because it appears in the coefficient of a dimension-3 operator. The sum rule at structure I shows a more reliable behavior. In Fig. 4, the dependence of $g_N^p/g_N^p$ on the susceptibility $\xi$ for the sum rules at structures I and II is given. For $|\xi| > 1$, the terms in the sum rules involving $\xi$ dominate. To avoid the pole in $\alpha_v$ (for structure I) on the negative $\xi$ plane, we concentrate on the region $0 < \xi < 1$ GeV$^{-1}$, where we obtain $5.2 < g_N^p < 12.7$ and $1.7 < g_N^p < 5.2$. This implies that away from $\xi = 0$, $g_N^p/g_N^p$ tends to increase for the sum rules at structure I and gets as high as 0.5, whereas the value of $\alpha_v$ gets as low as 0.8. These results disagree with those from the OBE potential model [9] and the VMD model [1], which give $g_N^p/g_N^p = 1/3$ and $\alpha_v = 1$.

Next, we turn to the effect of SU(3)-flavor breaking, where we allow $s = -0.15$ GeV and $f = -0.2$, keeping $m_u = m_d = 0$. We also restore the physical values for the masses and the
other parameters of the baryons [30,31]:

\[ E_A^0 = 3.3 \text{ GeV}^2, \quad E_S^0 = 4.6 \text{ GeV}^2, \quad E_Y^0 = 3.3 \text{ GeV}^2, \]
\[ s_0^A = 3.1 \pm 0.3 \text{ GeV}^2, \quad s_0^S = 3.6 \pm 0.4 \text{ GeV}^2, \]
\[ s_0^Y = 3.2 \pm 0.3 \text{ GeV}^2. \]

The corresponding Borel windows are chosen as follows:

- for \( \Lambda \), \( 1.0 \text{ GeV}^2 < M^2 < 1.4 \text{ GeV}^2 \),
- for \( \Sigma \), \( 1.5 \text{ GeV}^2 < M^2 < 1.9 \text{ GeV}^2 \),
- for \( \Sigma \), \( 1.2 \text{ GeV}^2 < M^2 < 1.6 \text{ GeV}^2 \).

We follow a procedure similar to the one in the SU(3)-flavor conserving case and fit the LHS’s of the sum rules to the function in Eq. (37) in the Borel windows specified in Eq. (48). Taking into account the uncertainties in \( s_0^B \) and \( a_q \), the predicted values for the coupling constants of the \( \rho \) and \( \omega \) mesons to \( \Lambda \), \( \Sigma \), and \( \Sigma \) with the SU(3)-flavor breaking effects read:

\[ g_0^e = 2.9 \pm 1.1, \quad g_0^e = g_0^e = 1.1 \pm 0.7, \]
\[ g_0^e = g_0^e = 3.1 \pm 1.2, \quad f_0^e = -4.0 \pm 0.8, \]
\[ f_0^e = g_0^e = 2.4 \pm 0.6, \quad f_0^e = g_0^e = 7.0 \pm 1.6. \]

We observe that the SU(3)-breaking effects modify the couplings by 30%–50%, which indicates a large breaking. Although the \( \Sigma \Sigma \omega \) and \( \Sigma \Sigma \rho \) coupling constants increase with SU(3)-breaking effects, the other coupling constants tend to decrease.

IV. DISCUSSION AND CONCLUSIONS

In this work, we have calculated the vector-meson–baryon coupling constants, which are important quantities in OBE models of the \( \Lambda N \) and \( YY \) interactions, employing the external-field QCDSR method. The main uncertainties in the results stem from the undetermined QCD parameters. Although the values of the susceptibilities \( \chi, \xi, \) and \( \kappa \) are relatively better known from magnetic-moment calculations, \( \xi \) is undetermined. We have first made the analysis by taking \( \xi \) negligibly small, which produces couplings in agreement with the ones from the literature. Then, we have analyzed the sum rules for arbitrary \( \xi \) and observed that the results are sensitive to a change in this susceptibility. In this respect, an independent determination of the susceptibility \( \xi \) is desirable.

The coupling constants can be determined in terms of vector-meson–quark coupling constant in this method. To compare our results with the others in the literature and to remain as model-independent as possible, we find it useful to give the following ratios of the coupling constants in the SU(3) limit for the average values of the vacuum parameters,

\[ \frac{f_N^s}{g_N^s} = 3.8, \quad \frac{f_N^s}{g_N^s} = -0.3, \]

which compares well with the results from VMD,

\[ \frac{f_N^s}{g_N^s} = F_1^e = 3.3, \quad \frac{f_N^s}{g_N^s} = F_1^e = -0.1, \]

where \( F_1^e(F_1^e) \) and \( F_2^s(F_2^s) \) are the isoscalar (isovector) electric and magnetic form factors of the nucleon, respectively, at zero momentum transfer. This result is not totally surprising, because a similar scheme to the one of electromagnetic coupling has been assumed for vector-meson–baryon interaction. These ratios are close to the ones from the NSC NN potential model [29], which are \( f_N^e/g_N^s = 4.2 \) and \( f_N^s/g_N^s = 0.3 \). Our value for the vector NN\( \rho \) coupling constant, with the choice of the quark\( \rho \) coupling constant in Eq. (42), agrees with the one from the recent Nijmegen extended-soft-core (ESC) potential model [19], which is \( g_N^s = 2.8 \). The ESC model gives \( g_N^e/g_N^s = 1/4 \), a value for the \( NN\omega \) coupling constant larger than what we have obtained from QCDSR. From SU(3) symmetry, ideal mixing, and \( \alpha_s = 1 \) it follows that

\[ g_N^e + \sqrt{2} g_N^s = 3g_N^s. \]

the main reason for this is the sizable \( NN\phi \) coupling in NSC potential models, which is simply \( g_N^s = 0 \) in the QCDSR. Such a large value for the \( NN\omega \) coupling constant as in the ESC or \( 3 P_0 \) models [19] requires a quark\( \omega \) coupling constant that is about 50% larger than what we have adopted in Eq. (42). Our value of the \( F/(F + D) \) ratio for the vector coupling, which is \( \alpha_s = 1 \), agrees with the value given in NSC89 [17]. Our value for \( \alpha_m \), which is \( \alpha_m = 0.18 \), is about half of the values obtained in NSCa-f [18] and NSC89 [17], which are 0.37 \( \leq \alpha_m \leq 0.45 \) and \( \alpha_m = 0.28 \), respectively.