Strange Magnetic Moment and Isospin Symmetry Breaking

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Abstract

The small mass difference $m_n - m_p = 1.3$ MeV between the proton and neutron leads to an excess of $n = \pi^- p$ over $p = \pi^+ n$ fluctuations which can be calculated by using a light-cone meson-baryon fluctuation model of intrinsic quark-antiquark pairs of the nucleon sea. The Gottfried sum rule violation may partially be explained by isospin symmetry breaking between the proton and neutron and the same effect introduces correction terms to the anomalous magnetic moments and the anomalous weak magnetic moments of the proton and neutron. We also evaluated the strange magnetic moment of the nucleon from the lowest strangeness $K\Lambda$ fluctuation and found a non-trivial influence due to isospin symmetry breaking in the experimental measurements of the strange magnetic moment of the nucleon.

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1 Introduction

There have been considerable theoretical investigations and experimental activities on the strange content of the nucleon in recent years. The strange content of the nucleon arises from the non-valence sea quarks and provides a direct window into the nonperturbative QCD nature of the quark sea in the quantum bound-state structure of the hadronic wavefunctions [1, 2, 3, 4]. There have been several novel and unexpected features or discoveries related to the strange content of the nucleon, such as the significant strangeness content stemming from the pion-nucleon sigma term [5], the anti-polarized strange quark sea in the proton from the Ellis-Jaffe sum rule violation [6], and the strange quark-antiquark asymmetry in the nucleon sea from two different determinations of the strange quark distributions in the nucleon [4, 7]. Recently, the strange magnetic moment of the nucleon has also received extensive attention both theoretically and experimentally.

The strange magnetic moment is closely related to the sea quark-antiquark asymmetry of the nucleon: A non-zero strange magnetic moment is a direct reflection of the strange-antistrange asymmetry in the nucleon sea [7, 8]. Experimental measurements of the strange magnetic moment by means of parity-violating electron scattering have been suggested [9, 10] and the first measurement by the SAMPLE Collaboration [11] found

\[ G_s^M(Q^2 = 0.1\text{GeV}^2) = +0.23 \pm 0.37 \pm 0.15 \pm 0.19 \text{ n.m.} \]

In many earlier theoretical discussions, the strange magnetic moment was predicted to have a large negative value, for example, of the order \(-0.3 \text{ n.m.} [12]\). However, there have been recent discussions about the possibility of a small negative or even positive strange magnetic moment [13], influenced by the progress of experimental measurements.

The purpose of this paper is to investigate possible uncertainties in the experimental measurements of the strange magnetic moment. We will show that there are terms due to isospin symmetry breaking in the anomalous magnetic moments and the anomalous weak magnetic moments of the proton and neutron obtained by tak-
ing into account the small mass difference \( m_n - m_p = 1.3 \text{ MeV} \) in the non-perturbative meson-baryon fluctuations from the intrinsic quark-antiquark pairs of the nucleon sea. Such terms are related to the Gottfried sum rule violation which may partially be explained by isospin symmetry breaking between the proton sea and the neutron sea \([14, 15]\) and the size of these terms will be estimated by using a light-cone model of nonperturbative meson-baryon fluctuations \([4]\). It will be shown that these correction terms have a non-trivial influence on the extraction of the strange magnetic moment of the nucleon from experimental measurements.

2 The strange magnetic moment measurements

The analyses of experimental measurements of the strange magnetic moment are based on the following equations: the anomalous magnetic moments of the proton and neutron

\[
G_{M}^{p} = \frac{2}{3} G_{M}^{u} - \frac{1}{3} G_{M}^{d} - \frac{1}{3} G_{M}^{s}, (1)
\]

\[
G_{M}^{n} = \frac{2}{3} G_{M}^{d} - \frac{1}{3} G_{M}^{u} - \frac{1}{3} G_{M}^{s}, (2)
\]

and the anomalous weak magnetic moments (via the neutral weak vector current matrix elements) of the proton and neutron

\[
G_{M}^{Zp} = e_{u}^{Z} G_{M}^{u} + e_{d}^{Z} G_{M}^{d} + e_{s}^{Z} G_{M}^{s}, (3)
\]

\[
G_{M}^{Zn} = e_{u}^{Z} G_{M}^{d} + e_{d}^{Z} G_{M}^{u} + e_{s}^{Z} G_{M}^{s}, (4)
\]

where \( e_{u}^{Z} = (\frac{1}{4} - \frac{2}{3} \sin^2 \theta_{W}) \) and \( e_{d}^{Z} = e_{s}^{Z} = (-\frac{1}{4} + \frac{1}{3} \sin^2 \theta_{W}) \).

Combining Eqs.(1), (2) and (3), one has

\[
G_{M}^{Zp} = (\frac{1}{4} - \sin^2 \theta_{W}) G_{M}^{p} - \frac{1}{4} G_{M}^{n} - \frac{1}{4} G_{M}^{s}, (5)
\]

from which one can extract the strange magnetic moment \( G_{M}^{s} \) from the measurable \( G_{M}^{Zp} \) and the known experimental data of \( G_{M}^{p} \) and \( G_{M}^{n} \).

One important and strong assumption in the above equations is the isospin symmetry between the proton and neutron. Thus a source of isospin symmetry breaking between the proton and neutron may introduce uncertainties in the extracted value of the strange magnetic moment \( G_{M}^{s} \) based on the above equations.
3 Isospin symmetry breaking

The discovery of the Gottfried sum rule (GSR) [16] violation by the New Muon Collaboration (NMC) [17] motivated studies on the flavor content of the nucleon sea [4, 14, 18, 19]. It is commonly taken for granted that this violation is due to the flavor asymmetry between the $u$ and $d$ quark pairs in the nucleon sea while still preserving the isospin symmetry between the proton and the neutron [18, 19]. Nevertheless, it has been suggested [14] that the GSR violation could alternatively be explained by the isospin symmetry breaking between the proton and the neutron while preserving the flavor distribution symmetry in the nucleon sea. The flavor asymmetry between the $u$ and $d$ sea quarks is likely the main source by the excess of the intrinsic $d\bar{d}$ pairs over $u\bar{u}$ pairs in the proton sea through $p(\bar{u}ud) = \pi^+(ud)n(udd)$ over $p(\bar{u}ud) = \pi^-(d\bar{u})\Delta^{++}(uud)$ meson-baryon fluctuations [4, 19]. But one can not exclude the possibility that the isospin symmetry breaking partially contributes to the GSR violation and suggestions have been made [14, 15] as to how to distinguish between the two possible explanations.

We will show in the following that the same mechanism leading to the excess of $d\bar{d}$ pairs over $u\bar{u}$ pairs in the proton sea could also lead to a small excess of the lowest meson-baryon fluctuation $n(udd) = \pi^-(d\bar{u})p(\bar{u}ud)$ for the neutron over $p(\bar{u}ud) = \pi^+(ud)n(udd)$ for the proton within a light-cone model of energetically-favored meson-baryon fluctuations [4]. In a strict sense, we still lack a basic theory to produce the probabilities of fluctuations due the the non-perturbative nature of those fluctuations. However, the probabilities for such fluctuations can be inferred from experimental measurements of physical quantities related to those fluctuations. For example, the amplitude of the lowest fluctuation state $p = \pi^+n$ for the proton is of the order 15% as estimated from the measured Gottfried sum [4] and the amplitude of lowest strangeness fluctuation state $p = K^+\Lambda$ is of the order 5% from re-producing empirical measurements related to the strange content of the nucleon [4, 20].

From the uncertainty principle, we can also estimate the relative probabilities of two meson-baryon states by comparing their off-shell light-cone energies with the static nucleon bound state. For example, we can use the light-cone Gaussian type
where $\mathcal{M}^2 = \sum_{i=1}^{2} \frac{k_i^2 + m_i^2}{x_i}$ is the invariant mass for the meson-baryon state, $m_N$ is the physical mass of the nucleon, and $\alpha$ sets the characteristic internal momentum scale, with the same normalization constant $A_{\text{Gaussian}}$ to evaluate the relative probabilities of two meson-baryon fluctuation states. With the parameter value $\alpha = 330$ MeV as previously adopted \[4\], and with the physical masses $m_p = 938.27$, $m_n = 939.57$, and $m_\pi = 139.57$ MeV for the proton, neutron, and charged pion \[22\], we find the ratio of the fluctuation probabilities

$$r_{p/n}^\pi = P(p = \pi^+ n)/P(n = \pi^- p) = 0.986,$$

which is equivalent to an excess of 0.2% of $n = \pi^- p$ over $p = \pi^+ n$ fluctuations assuming $P(p = \pi^+ n) \approx P(n = \pi^- p) \approx 0.15$. There are still uncertainties in the evaluation of the ratio $r_{p/n}^\pi$. For example, the parameter $\alpha$ reflects the relative internal motions of the pions around the baryon and might be smaller, e.g. $\alpha \approx 200$ MeV, compared to $\alpha = 330$ MeV due to the small pion mass $m_\pi$, and the Coulomb attraction between $\pi^-$ and $p$ in the $n = \pi^- p$ state may cause slightly larger relative motions of pions (e.g. $\alpha = 205$ MeV) than that in the $p = \pi^+ n$ state (e.g. $\alpha = 200$ MeV) from the uncertainty principle. With the parameters $\alpha = 205$ MeV for the neutron and $\alpha = 200$ MeV for the proton, we find the ratio $r_{p/n}^\pi = 0.820$, which is equivalent to an excess of 3% of $n = \pi^- p$ over $p = \pi^+ n$ fluctuations. In a strict sense, there is no reason to assume a single value for the normalization constant $A_{\text{Gaussian}}$ and this may introduce further uncertainties about the amplitude of isospin symmetry breaking. Therefore the excess of $n = \pi^- p$ over $p = \pi^+ n$ fluctuation probabilities lies in the range

$$\delta P^\pi = P(n = \pi^- p) - P(p = \pi^+ n) = 0.002 \rightarrow 0.03$$

from a crude model estimation.

There are also neutral fluctuations (i.e., the fluctuation of chargeless mesons $\pi^0$ et al.) in the nucleons but the isospin symmetry breaking arising from those neutral...
fluctuations can be shown to be negligibly small by using similar estimations to those above. The ratio of the strangeness fluctuations

\[ r_{p/n}^K = \frac{P(p = K^+\Lambda)}{P(n = K^0\Lambda)} = 1.02, \tag{9} \]

which is equivalent to an excess of 0.1% of \( p = K^+\Lambda \) over \( n = K^0\Lambda \) fluctuations assuming \( P(p = K^+\Lambda) \approx P(n = K^0\Lambda) \approx 0.05 \). Thus we can neglect the isospin symmetry breaking from the strangeness fluctuations. We also ignore here the possible isospin symmetry breaking in the valence quarks between the proton and neutron \[23\]. Thus the excess of \( n = \pi^- p \) over \( p = \pi^+ n \) fluctuation states due to the small mass difference \( m_n - m_p = 1.3 \text{ MeV} \) seems to be an important source for the isospin symmetry breaking between the proton and the neutron. If the GSR violation is entirely due to isospin symmetry breaking between the proton and the neutron, then the NMC measurement \( S_G = \frac{1}{3} + \frac{10}{9} \int_0^1 \text{d}x[O_q^p(x) - O_q^n(x)] = 0.235 \pm 0.026 \tag{7} \) implies

\[ \int_0^1 \text{d}x[O_q^n(x) - O_q^p(x)] = \frac{3}{10} - \frac{9}{10} S_G = 0.088 \pm 0.023, \tag{10} \]

which can be considered as the excess of quark-antiquark pairs in the neutron over those in the proton \[14, 15\]. Eq. (8) means that the isospin symmetry breaking between the proton and the neutron contributes only a small part of the GSR violation or the sea of the pion also contributes some part to the GSR violation.

4 The measured “strange magnetic moment”

If we take into account the correction due to isospin symmetry breaking, the anomalous magnetic moment of the neutron should be written as

\[ G_M^m = \frac{2}{3} G_M^d - \frac{1}{3} G_M^u - \frac{1}{3} G_M^s + \delta G_M^m. \tag{11} \]

Combining Eqs.(1), (3) and (11), one has

\[ G_M^{Zp} = \left( \frac{1}{4} - \sin^2 \theta_W \right) G_M^p - \frac{1}{4} (G_M^m - \delta G_M^m) - \frac{1}{4} G_M^s \]

\[ = \left( \frac{1}{4} - \sin^2 \theta_W \right) G_M^p - \frac{1}{4} G_M^m - \frac{1}{4} \hat{G}_M^s. \tag{12} \]
from which we know that the “strange magnetic moment” measured from Eq. (5) is actually

\[
\hat{G}_M^s = G_M^s - \delta G_M^n. \tag{13}
\]

We now roughly estimate the correction term due to isospin symmetry breaking in the neutron anomalous magnetic moment. In the light-cone meson-baryon fluctuation model [4], the total angular momentum space wavefunction of the energetically most favored intermediate \( N = MB \) state in the center-of-mass reference frame should be

\[
\left| J = \frac{1}{2}, J_z = \frac{1}{2} \right> = \sqrt{\frac{2}{3}} \left| L = 1, L_z = 1 \right> \left| S^B = \frac{1}{2}, S^B_z = -\frac{1}{2} \right> - \sqrt{\frac{1}{3}} \left| L = 1, L_z = 0 \right> \left| S^B = \frac{1}{2}, S^B_z = \frac{1}{2} \right>. \tag{14}
\]

After taking into account the contributions from the baryon spin and the orbital motions of the meson and baryon, we have the magnetic moment of the meson-baryon state

\[
\mu_{MB}^N = \left< 2S^B_z \right> \mu_B + e_B \left< L^B_z \right> \mu^B_L + e_M \left< L^M_z \right> \mu^M_L, \tag{15}
\]

where \( \mu_B \) is the baryon magnetic moment, \( \left< 2S^B_z \right> = -\frac{1}{3} \) is the fractional spin contribution to the nucleon from the baryon, \( e_B \) and \( e_M \) are the electric charges of the baryon and meson, \( \left< L^B_z \right> = \frac{m_M}{m_M + m_B} \left< L_z \right> \) and \( \left< L^M_z \right> = \frac{m_B}{m_M + m_B} \left< L_z \right> \) are the orbital angular momenta of the baryon and meson with \( \left< L_z \right> = \frac{2}{3}, \mu^B_L = \frac{m_B}{m_B + m_M} \mu_N \) and \( \mu^M_L = \frac{m_M}{m_M + m_N} \mu_N \) are the contributions from the orbital motions of the baryon and meson with unit charge and unit orbital angular momentum. For the \( n = \pi^- p \) state, we have

\[
\mu_{n-p}^\pi = -\frac{1}{3} \mu_p + \left< L^p_z \right> \mu^p_L - \left< L^\pi_z \right> \mu^\pi_L. \tag{16}
\]

Thus the correction term due to isospin symmetry breaking to the neutron anomalous magnetic moment is

\[
\delta G_M^n = \delta P^\pi (\mu_{n-p}^\pi - \mu_n'), \tag{17}
\]

where \( \mu_n' = \mu_n - \delta G_M^n \) is the neutron magnetic moment without isospin symmetry breaking, but as an approximation, we may first use the physical \( \mu_n \) instead. By using the experimental data \( \mu_p = 2.793 \) and \( \mu_n = -1.913 \) n.m. [22], we have

\[
\delta G_M^n \approx -0.006 \rightarrow -0.088 \text{ n.m.} \tag{18}
\]
corresponding to $\delta P^z \approx 0.2 \rightarrow 3\%$

As we have shown above, the strangeness fluctuations do not introduce isospin symmetry breaking correction terms to the magnetic moments for the proton and neutron. We also consider only the lowest non-neutral strangeness fluctuation $K\Lambda$ state, since higher fluctuations might be suppressed due to larger off-shellness \cite{4}. In the constituent quark model, the spin of $\Lambda$ is provided by its strange quark and the expectation value of the spin of the antistrange quark in the $K$ is zero. This introduces a quark-antiquark asymmetry in the spin and momentum distributions between the strange and antistrange quarks \cite{2, 3, 4}. Since the strange quark is responsible for the magnetic moment of the $\Lambda$, the strangeness contribution to the magnetic moment comes from the strange quark in the $\Lambda$ component and the orbital motions of the strange quark in the $\Lambda$ and anti-strange quark in the $K$ components:

$$\mu_s = [\langle 2S^A_z \rangle \mu_A + c_s \langle L^A_z \rangle \mu_L^A + c_T \langle L^K_z \rangle \mu_L^K]P_{\Lambda K},$$ \hspace{1cm} (19)

where $\mu_A = -0.613 \pm 0.004 \text{n.m.}$ is the $\Lambda$ magnetic moment and $P_{\Lambda K}$ is the probability of finding the $\Lambda K$ state in the nucleon and is of the order of 5%. Thus the strange magnetic moment $G^s_M$ is

$$G^s_M = \mu_s / (-1/3) = [\mu_A + \langle L^A_z \rangle \mu_L^A - \langle L^K_z \rangle \mu_L^K]P_{\Lambda K} \approx -0.066 \text{n.m.},$$ \hspace{1cm} (20)

which is with much smaller magnitude than most earlier theoretical predictions \cite{12}. We also note that considerations of higher strangeness fluctuations in some models could reduce the strange magnetic moment to smaller negative or even positive values \cite{13}. The isospin symmetry breaking term $\delta G^s_M$ in Eq. (13) causes an increase of the order

$$- \delta G^s_M \approx 0.006 \rightarrow 0.088 \text{n.m.}$$ \hspace{1cm} (21)

to the actual strange magnetic moment $G^s_M$ and has a non-trivial influence on the experimental measurements of $G^s_M$. Therefore the measured $G^s_M$ could range from a small negative to even a positive value within our simple estimation.

We turn our attention to the isospin symmetry breaking terms in the anomalous weak magnetic moment $G^Z_M$. If there are no isospin symmetry breaking terms,
combining Eqs. (1), (2) and (4) we have

\[ G^Z_M = \left(\frac{1}{4} - \sin^2 \theta_W\right) G^n_M - \frac{1}{4} G^p_M - \frac{1}{4} G^s_M, \] (22)

which is similar to Eq. (5). We can use this to extract the strange magnetic moment \( G^s_M \) from the measurable \( G^Z_M \) and the known experimental data of \( G^p_M \) and \( G^n_M \). By taking into account the corrections due to isospin symmetry breaking, Eq. (22) should be changed to

\[ G^Z_M = \left(\frac{1}{4} - \sin^2 \theta_W\right) G^n_M - \frac{1}{4} G^p_M - \frac{1}{4} G^s_M + \delta G^Z_M \]

where the “strange magnetic moment” measured from Eq. (22) is actually

\[ \tilde{G}^s_M = G^s_M + (1 - 4 \sin^2 \theta_W) \delta G^n_M - 4 \delta G^Z_M. \] (23)

Similarly to Eq. (15), we can write the weak magnetic moment of the meson-baryon state

\[ \mu^Z_{MB} = \left\langle 2S_z \right\rangle \mu^Z_B + e^Z_B \left\langle L_z^B \right\rangle \mu^B_L + e^Z_M \left\langle L_z^M \right\rangle \mu^M_L, \] (25)

where \( e^Z_B = 2e^Z_u + e^Z_d \) for p and \( e^Z_M = e^Z_d - e^Z_u \) for \( \pi^- (a\bar{u}) \). Similarly to Eq. (17), the correction term to the anomalous weak magnetic moment of the neutron due to isospin symmetry breaking is

\[ \delta G^Z_M = (\mu^Z_{\pi^- p} - \mu^Z_n) \delta P^\pi \]

\[ = \delta P^\pi \left[ -\frac{1}{3} \mu^Z_p + \left(\frac{1}{4} - \sin^2 \theta_W\right) \langle L^p_z \rangle \mu^p_L - \left(\frac{1}{2} - \sin^2 \theta_W\right) \langle L^\pi_z \rangle \mu^\pi_L - \mu^Z_n \right], \] (26)

where \( \mu^Z_n \) would be \( \mu^Z_n \) without isospin symmetry breaking and \( \sin^2 \theta_w = 0.2315 \) \cite{22}. After some calculation we find

\[ \delta G^Z_M \approx -0.001 \rightarrow -0.015 \text{ n.m.} \] (27)

corresponding to \( \delta P^\pi \approx 0.2 \rightarrow 3\% \). Therefore the correction term in Eq. (24) causes an increase of the measured “strange magnetic moment” \( \tilde{G}^s_M \) in a range

\[ (1 - 4 \sin^2 \theta_W) \delta G^n_M - 4 \delta G^Z_M \approx 0.004 \rightarrow 0.054 \text{ n.m.} \] (28)
compared to the actual strange magnetic moment $G_M^s$.

In a strict sense, it is difficult to have a model-independent measurement of the strange magnetic moment $G_M^s$ without isospin symmetry breaking corrections from the anomalous magnetic moments and the anomalous weak magnetic moments of the proton and neutron if other measurements of physical quantities related to the hadronic vector matrix elements are not involved. However, with the help of model-dependent theoretical connection between $\delta G_M^n$ and $\delta G_M^p$ we may extract the strange magnetic moment $G_M^s$ from the measured $\hat{G}_M^s$ and $\tilde{G}_M^s$. For example, combining Eqs. (1), (3), (13), and (24), supplied with Eqs. (17) and (26), one could constrain the uncertainties caused by $\delta G_M^n$ and $\delta G_M^p$ and determine the quark matrix elements $G_M^u, G_M^d, and G_M^s$. Other measurements of the strange vector form factors have also been suggested [24]. Thus the experimental measurements of the neutral weak vector matrix elements of nucleons, both undertaken and proposed, will play an important role in deepening our understanding concerning the strange content of the nucleon.

5 Conclusion

We have shown that there are terms due to isospin symmetry breaking in the anomalous magnetic moments and the anomalous weak magnetic moments of the proton and neutron as estimated their size by using a light-cone meson-baryon fluctuation model of the intrinsic sea quark-antiquark pairs. Such terms are related to the Gottfried sum rule violation of isospin symmetry breaking between the proton sea and the neutron sea and the same effect might cause a non-negligible correction to the actual strange magnetic moment derived from the measurements. Further theoretical and experimental work is needed to constrain the uncertainties in the experimental measurements of the strange magnetic moment of the nucleon.

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References

[1] S.J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B 93 (1980) 451; S.J. Brodsky, C. Peterson, and N. Sakai, Phys. Rev. D 23 (1981) 2745.

[2] A.I. Signal and A.W. Thomas, Phys. Lett. B 191 (1987) 205.

[3] M. Burkardt and B.J. Warr, Phys. Rev. D 45 (1992) 958.

[4] S.J. Brodsky and B.-Q. Ma, Phys. Lett. B 381 (1996) 317.

[5] T.P. Cheng and R.F. Dashen, Phys. Rev. Lett. 26 (1971) 594; T.P. Cheng, Phys. Rev. D 13 (1976) 2161; C.A. Dominguez and P. Langacker, Phys. Rev. D 24 (1981) 1905.

[6] S.J. Brodsky, J. Ellis, and M. Karliner, Phys. Lett. B 206 (1988) 309; J. Ellis and M. Karliner, Phys. Lett. B 213 (1988) 73.

[7] S.J. Brodsky and B.-Q. Ma, Phys. Lett. B 392 (1997) 452; in the caption of Fig. 1 of this paper, also in Eq. (3) of [4], exp(−M^2/2α^2) in the Gaussian type wavefunction should be exp(−M^2/8α^2).

[8] X. Ji and J. Tang, Phys. Lett. B 362 (1995) 182.

[9] R.D. McKeown, Phys. Lett. B 219 (1989) 140; D.H. Beck, Phys. Rev. D 39 (1989) 3248.

[10] MIT-Bates Proposal No. 89-06, R.D. McKeown and D. H. Beck, spokespersons; MIT-Bates Proposal No. 94-11, M. Pitt and E.J. Beise, spokespersons; CEBAF Proposal No. PR-91-004, E.J. Beise, spokesperson; CEBAF Proposal No. PR-91-010, J.M. Finn and P.A. Souder, spokespersons; CEBAF Proposal No. PR-91-017, D.H. Beck, spokesperson; Mainz Proposal A4/1-93 94-11, D. von Harrach, spokesperson.
[11] SAMPLE Collab., B. Mueller et al., Phys. Rev. Lett. 78 (1997) 3824.

[12] See, e.g., H. Forkel, M. Nielsen, X. Jin, and T.D. Cohen, Phys. Rev. C 50 (1994) 3108, and references therein.

[13] See, e.g., R.D. McKeown, MAP-202, hep-ph/9607340; E. Kolbe, S. Krewald, and H. Weigel, nucl-th/9610001, Z. Phys. A (1997) in press; W. Melnitchouk and M. Malheiro, Phys. Rev. C 55 (1997) 431; P. Geiger and N. Isgur, Phys. Rev. D 55 (1997) 299.

[14] B.-Q. Ma, Phys. Lett. B 274 (1992) 111.

[15] B.-Q. Ma, A. Schäfer, and W. Greiner, Phys. Rev. D 47 (1993) 51; J. Phys. G 20 (1994) 719.

[16] K. Gottfried, Phys. Rev. Lett. 18 (1967) 1174.

[17] NM Collab., P. Amaudruz et al., Phys. Rev. Lett. 66 (1991) 2712; M. Arneodo et al., Phys. Rev. D 50 (1994) R1.

[18] G. Preparata, P.G. Ratcliffe, and J. Soffer, Phys. Rev. Lett. 66 (1991) 687.

[19] E.M. Henley and G.A. Miller, Phys. Lett. B 251 (1990) 453; S. Kumano, Phys. Rev. D 43 (1991) 59; D 43 (1991) 3067; A. Signal, A.W. Schreiber, and A.W. Thomas, Mod. Phys. Lett. A 6 (1991) 271. For a review, see, e.g., S. Kumano, hep-ph/9702367, submitted to Phys. Rep..

[20] X. Song, J.S. McCarthy, and H.J. Weber, Phys. Rev. D 55 (1997) 2624; H.J. Weber, X. Song, and M. Kirchback, INPP-UVA-96-07, hep-ph/9701266, Mod. Phys. Lett. A (1997) in press.

[21] S.J. Brodsky, T. Huang, and G.P. Lepage, in: Particles and Fields, eds. A.Z. Capri and A.N. Kamal (Plenum, New York, 1983), p. 143.
[22] Particle Data Group, R.M. Barnett et al., Phys. Rev. D 54 (1996) 1.

[23] E. Sather, Phys. Lett. B 274 (1992) 433;
    J.T. Londergan, A. Pang, and A.W. Thomas, Phys. Rev. D 54 (1996) 3154;
    C.J. Benesh and T. Goldman, Phys. Rev. C 55 (1997) 441.

[24] W.M. Alberico, S.M. Bilenky, C. Giunti, and C. Maieron, Z. Phys. C 70 (1996) 463.