Strange form factors of the proton: a new analysis of the \( \nu (\bar{\nu}) \) data of the BNL–734 experiment

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Abstract

We consider ratios of elastic \( \nu (\bar{\nu}) \)–proton cross sections measured by the Brookhaven BNL–734 experiment and use them to obtain the neutral current (NC) over charged current (CC) neutrino–antineutrino asymmetry. We discuss the sensitivity of these ratios and of the asymmetry to the electric, magnetic and axial strange form factors of the nucleon and to the axial cutoff mass \( M_A \). We show that the effects of the nuclear structure and interactions on the asymmetry and, in general, on ratios of cross sections are negligible. We find some restrictions on the possible values of the parameters characterizing the strange form factors. We show that a precise measurement of the neutrino–antineutrino asymmetry would allow the extraction of the axial and vector magnetic strange form factors in a model independent way. The neutrino–antineutrino asymmetry turns out to be almost independent on the electric strange form factor and on the axial cutoff mass.

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I. INTRODUCTION

After the measurements of the polarized structure function of the proton, $g_1$, in deep inelastic scattering [1,2], it turned out, rather surprisingly, that the constant $g_s^A$, that characterizes the one–nucleon matrix element of the axial strange current, is of magnitude comparable with the corresponding $g_u^A$ and $g_d^A$ axial constants. A theoretical analysis of deep inelastic data [3] led to the following values for the axial constants:

$$g_s^A = -0.10 \pm 0.03, \quad g_u^A = 0.83 \pm 0.03, \quad g_d^A = -0.43 \pm 0.03.$$  

In a more recent analysis of the data [4], the value $g_s^A = -0.13 \pm 0.03$ was reported. Though it is subject to several assumptions (extrapolation of $g_1$ to the $x = 0$ point, SU(3)$_f$ symmetry, etc.), the rather large value of $g_s^A$ stimulated new experiments on the measurement of deep inelastic scattering of polarized leptons on polarized nucleons [5,6] and a lot of theoretical work on the subject (see for example ref. [7]).

Alternative approaches which allow to obtain the contribution of the strange quark current to the structure of the nucleon were also developed [8–10]. Among these, information on strange form factors of the nucleon can be obtained from NC scattering of $\nu(\bar{\nu})$ on nucleons and nuclei [11–14]. Up to now the most detailed investigation of NC $\nu(\bar{\nu})$ - proton scattering was done in the Brookhaven BNL–734 experiment. From the analysis of the data of this experiment a nonzero value of $g_s^A$ was found [11]. This result, however, strongly depends on the value of the axial cutoff mass $M_A$. For example, in the paper by Garvey et al. [12], from the fit of the BNL data it was found:

$$g_s^A = -0.21 \pm 0.10 \quad \text{and} \quad M_A = 1.032 \pm 0.036 \text{ GeV.}$$

This fit, however, shows up strong correlations between the values of $g_s^A$ and $M_A$: the data indeed are also compatible with $g_s^A = 0$, provided one assumes a slightly larger axial cutoff mass $M_A = 1.086 \pm 0.015 \text{ GeV,}$ which is in agreement with quasielastic neutrino-nucleon data. It is clear that new investigations of NC $\nu(\bar{\nu})$–nucleon scattering are necessary in order to draw definite conclusions about the value of $g_s^A$.

In this paper we calculate the contribution of the strange form factors of the nucleon to the NC over CC neutrino–antineutrino asymmetry and compare our results with the information on it, which one can extract from the data of the BNL–734 experiment.

In this experiment the following ratios of cross sections were obtained [11]:

$$R_\nu = \frac{\langle \sigma \rangle_{\nu p \rightarrow \nu p}}{\langle \sigma \rangle_{\nu n \rightarrow \mu^- p}} = 0.153 \pm 0.007 \pm 0.017 \quad (1)$$

$$R_\tau = \frac{\langle \sigma \rangle_{\tau p \rightarrow \tau p}}{\langle \sigma \rangle_{\tau p \rightarrow \mu^+ n}} = 0.218 \pm 0.012 \pm 0.023 \quad (2)$$

$$R = \frac{\langle \sigma \rangle_{\tau p \rightarrow \tau p}}{\langle \sigma \rangle_{\nu p \rightarrow \nu p}} = 0.302 \pm 0.019 \pm 0.037 \quad (3)$$

where $\langle \sigma \rangle_{\nu(\bar{\nu})}$ is a total cross section integrated over the incident neutrino (antineutrino) energy and weighted by the $\nu(\bar{\nu})$ flux in a way that will be specified below. The first error is statistical and the second is the systematic one.

In ref. [9] we have shown that the measurement of neutrino–antineutrino asymmetry
\[ A_p(Q^2) = \frac{\frac{d\sigma}{dQ^2}_{\nu p \to \nu p} - \frac{d\sigma}{dQ^2}_{\nu p \to \bar{\nu} p}}{\frac{d\sigma}{dQ^2}_{\nu n \to \mu^- p} - \frac{d\sigma}{dQ^2}_{\bar{\nu} p \to \mu^+ n}} \]  

will allow to obtain direct model independent information on the axial \((F_A^s)\) and magnetic \((G_M^s)\) strange form factors of the nucleon. Indeed (4) can be rewritten as

\[ A_p(Q^2) = \frac{1}{4|V_{ud}|^2} \left( 1 - \frac{F_A^s}{F_A} \right) \left( 1 - 2 \sin^2 \theta_W \frac{G_M^p}{G_M^3} - \frac{G_M^s}{2G_M^3} \right), \]  

where \(F_A\) is the CC axial form factor and \(G_M^3 = (G_M^p - G_M^n)/2\) the isovector magnetic form factor of the nucleon.

Here we will use the ratios (1)–(3) to obtain an experimental information on the integral asymmetry. In the next Section we will compare this asymmetry with our theoretical calculation, which includes the contribution of the strange nucleon form factors.

The Brookhaven experiment was performed using wide band neutrino and antineutrino beams, with an average energy of about 1.3 GeV. Almost 80% of the events were due to quasielastic proton knockout from \(^{12}\)C nuclei and the remaining 20% of events were due to elastic neutrino (antineutrino) scattering on free protons. In order to compare theoretical calculations with the BNL data, one must take into account the energy spectrum of the neutrinos \([\phi_\nu(\epsilon_\nu)]\) and antineutrinos \([\phi_{\bar{\nu}}(\epsilon_{\bar{\nu}})]\). In the case of elastic scattering, we define a folded differential cross section by:

\[ \langle \frac{d\sigma}{dQ^2} \rangle_{\nu(\bar{\nu})p} = \frac{1}{\Phi_{\nu(\bar{\nu})}} \int_{0.2 \text{ GeV}}^{5 \text{ GeV}} d\epsilon_{\nu(\bar{\nu})} \frac{d\sigma}{dQ^2} \phi_{\nu(\bar{\nu})}(\epsilon_{\nu(\bar{\nu})}) \]  

where \(\Phi_{\nu(\bar{\nu})}\) is the total neutrino (antineutrino) flux and the limits on \(\epsilon_{\nu(\bar{\nu})}\) correspond to the experimental conditions.

The differential cross sections are given as a function of the squared momentum transfer, \(Q^2\), which in the case of free protons is directly obtained from the final proton kinetic energy in the laboratory system by the relation \(Q^2 = 2MT_p\) (\(M\) being the proton mass). For scattering off \(^{12}\)C the authors of ref. [11] obtained the equivalent “free scattering data” by correcting for the Fermi motion and binding energy of the hit nucleon: in this case the \(Q^2\) given by the above relation must be regarded as an effective momentum transfer squared, around which the quasielastic \(\nu(\bar{\nu})\) scattering on \(^{12}\)C occurs.

A proper interpretation of the results in terms of scattering on the free nucleon requires a reliable understanding of the effects associated with the nuclear, many–body dynamics in both the initial and final states, as well as with the final state interactions (FSI) between the ejected nucleon and the residual nucleus. We have shown [15,16] that for neutrino (antineutrino) energies of about 1 GeV and larger these effects are within percentage range for ratios of cross sections. Note, however, that FSI sizeably reduce (~50%) the separated cross sections with respect to the plane wave impulse approximation (PWIA): indeed FSI take into account the existence of other reaction channels besides the quasielastic one and just approximately 50% of the reaction events correspond to elastic proton knockout.
Therefore, when applied to the individual cross sections, the interpretation of the BNL data as corresponding to elastic scattering on “free” protons is not free from ambiguities.

In addition to the above differential cross sections, one can define the total folded cross sections by integrating (6) over the (effective) momentum transfer $Q^2$:

$$\langle \sigma \rangle_{\nu(\bar{\nu})p} = \int_{0.5 \text{ GeV}^2}^{1 \text{ GeV}^2} dQ^2 \langle d\sigma / dQ^2 \rangle_{\nu(\bar{\nu})p},$$

the limits of integration being taken from ref. 11.

The neutrino–antineutrino folded integral asymmetry, $\langle A_p \rangle$, is obtained from the neutral current to charge current ratio of the differences between the total folded neutrino and antineutrino cross sections [9,15]:

$$\langle A_p \rangle = \frac{\langle \sigma \rangle_{\nu(p \rightarrow p \nu)} - \langle \sigma \rangle_{\bar{\nu}(p \rightarrow p \bar{\nu})}}{\langle \sigma \rangle_{\nu(p \rightarrow p \mu^-)} - \langle \sigma \rangle_{\bar{\nu}(p \rightarrow p \mu^+)} .}$$

This quantity can be written in terms of the ratios (1)–(3) as follows:

$$\langle A_p \rangle = \frac{R_{\nu}(1 - R)}{1 - RR_{\nu}/R_{\bar{\nu}}},$$

and from the experimental data we found

$$\langle A_p \rangle = 0.136 \pm 0.008 \text{(stat)} \pm 0.019 \text{(syst)}$$

where the statistical error has been estimated using the standard quadratic error propagation theory, while for the systematic error we take into account the positive correlation coefficient $\rho = 0.5$ between systematic errors for $\nu$ and $\bar{\nu}$ cross sections [11].

**II. RESULTS AND DISCUSSION**

In this Section we shall compare the experimental values for the ratios (1)–(3) and for the asymmetry (4) with their theoretical evaluation. We shall discuss the influence of the strange form factors of the nucleon; moreover, for data obtained from scattering of $\nu(\bar{\nu})$ on nuclei, the influence of the nuclear medium will be shortly examined.

Let us first discuss the sensitivity of the integral asymmetry to different assumptions. First of all we have considered the effect of folding the elastic $\nu(\bar{\nu})$ cross sections with the corresponding fluxes. In Fig. 1 we show the integral asymmetry as a function of the axial strange constant, $g_A$. The electric and magnetic strange form factors have been taken to be zero. In the case of elastic neutrino (antineutrino)–proton scattering the folded integral asymmetry (solid line) is compared with the “unfolded” integral asymmetry evaluated at a fixed $\nu(\bar{\nu})$ energy $\epsilon_{\nu(\bar{\nu})} = 1 \text{ GeV}$ (empty dots). The difference between the two curves is less
than 2%, a result which one could have expected from the similarity between the neutrino and antineutrino spectra in the BNL-734 experiment. 

Next we compare the results obtained for elastic scattering on protons to the ones obtained in the impulse approximation (IA) for quasielastic $\nu(\bar{\nu})$ scattering on $^{12}\text{C}$. Three different approximations are used to describe the nuclear dynamics: first we consider a relativistic Fermi gas (RFG) within the PWIA, namely without distortion of the ejected nucleon wave. For the RFG we show in Fig. 1 both the folded (dashed line) and the unfolded (dotted line) asymmetry. Further we use a relativistic shell model (RSM), both within PWIA (dot–dashed line) and with inclusion of the FSI of the observed nucleon (three–dot–dashed line); the latter is taken into account through a relativistic optical potential (ROP), which is employed together with the RSM (see refs. [13] and [17] for details of these models). Due to the small effect of the folding procedure, which can be argued from the elastic and the RFG cases, for the RSM (without and with the final state interaction) only the unfolded asymmetry is shown, again at $\epsilon_{\nu(\bar{\nu})} = 1$ GeV. We notice that the quasielastic $\nu(\bar{\nu})$–nucleus scattering, treated within the RFG and RSM (in PWIA) gives results almost identical to the case of elastic $\nu(\bar{\nu})$–proton scattering. The effect of FSI, instead, shows up in a reduction of the asymmetry of at most 2%, mainly due to Coulomb effects, as pointed out in ref. [15]. Nevertheless the effect of the axial strange constant $g_A^s$ on the integral asymmetry remains larger (for $-g_A^s \geq 0.05$) than the effects associated with nuclear models (including FSI) and/or with the folding over the $\nu(\bar{\nu})$ spectra. This result justifies previous analyses of the BNL quasielastic data in terms of a Fermi Gas model when ratios of cross sections and/or asymmetries are concerned; indeed for quasielastic processes, ratios of cross sections are basically the same as for the corresponding elastic $\nu(\bar{\nu})$–proton processes. However we remind that FSI are not negligible for the single cross sections [15,18,19].

On the basis of the previous discussion, in what follows we just consider ratios of folded cross sections for elastic scattering on free protons. In Fig. 2 we demonstrate the effects of strangeness for the ratios (1)–(3) and the integral asymmetry (8). The experimental values for the various quantities are indicated by the shadowed regions: the error band corresponds to one standard deviation, calculated from quadratic propagation of the statistical and systematical errors. We have assumed the usual dipole parameterization both for non–strange and strange form factors, the latter being $F_A^s(Q^2) = g_A^s G_D^A(Q^2)$, $G_M^s(Q^2) = \mu_s G_V^A(Q^2)$ and $G_E^s(Q^2) = \rho_s \tau G_D^A(Q^2)$ ($\tau = Q^2/4M^2$), where $G_D^A(Q^2) = (1 + Q^2/M^2_{V(A)})^{-2}$ and we keep the strengths $g_A^s$, $\mu_s$ and $\rho_s$ as free parameters. We assume the same values for the strange cutoff masses as for the non–strange vector (axial) form factors. We do not discuss here other parameterizations for the $Q^2$-dependence of the strange form factors, about which practically nothing is known (see refs. [20][21]). A decrease of $G_M^s$ and $F_A^s$ stronger than dipole at high $Q^2$ (as suggested by the quark counting rule) would obviously reduce the global effect of strangeness. However

\footnote{One could notice that the average energy of the neutrino (antineutrino) spectra of the BNL experiment is about $\epsilon_{\nu(\bar{\nu})} \simeq 1.3$ GeV; however between 1 and 2 GeV the unfolded asymmetry varies at most by 0.3%, which makes irrelevant the fixed value of $\epsilon_{\nu(\bar{\nu})}$ that we utilize for the unfolded asymmetry.}
it was shown in previous works [3,13] that the effect of different parameterizations of the strange form factors is very small in the BNL $Q^2$ region, of the order of $\sim 1 - 2\%$.

In Fig. 2(a) we show the ratios $R_\nu$ and $R_\bar{\nu}$ versus $\mu_s$ for two values of the axial–strange constant: $g^s_A = 0, -0.15$ and three values of the electric strange constant: $\rho_s = 0, \pm 2$. For the axial cutoff mass we use the value $M_A = 1.032$ GeV [12]. Both observables are much more sensitive to the axial strange constant $g^s_A$, than to $\rho_s$: the former gives an effect of the order of $\sim 15\%$ for $R_\nu$ and $\sim 27\%$ for $R_\bar{\nu}$. The influence of the magnetic and electric strange form factors, instead, amount, respectively, to $\sim 8\%$ ($R_\nu$), $\sim 7\%$ ($R_\bar{\nu}$) for $\mu_s$ and to $\sim 4\%$ ($R_\nu$), $\sim 7\%$ ($R_\bar{\nu}$) for $\rho_s$. Note that the role played by the electric and magnetic strange form factors is similar in the case of antineutrinos, whereas for neutrinos the dependence upon $\mu_s$ is clearly stronger. This agrees with the discussion presented in ref. [16]. As it is seen from Fig. 2(a), within the present assumptions for the form factor parameterization and for $M_A$, in the rather large range of $\mu_s$ and $\rho_s$ considered here, a value of the strange axial constant $g^s_A$ as large as $-0.15$ is not favoured by the BNL–734 data.

Results of the calculation of the ratio $R$ and the integral asymmetry $\langle A_p \rangle$ are shown in Fig. 2(b): the maximum relative change in the ratio $R$, obtained in the ranges of strange parameters considered here, amounts to $\sim 10\%$ for $g^s_A$, $\sim 13\%$ for $\mu_s$ and $\sim 5\%$ for $\rho_s$. Both for $R$ and $\langle A_p \rangle$ the effects induced by the axial and magnetic strange form factors are similar. These effects are clearly larger (in $R$) than the ones due to the electric strange form factor. Moreover it is worth noticing that the integral asymmetry does not depend at all upon the electric strange form factor, a result already obtained in ref. [9] for the unfolded asymmetry $A_p(Q^2)$. The maximum relative change in $\langle A_p \rangle$, obtained in the ranges of the strange parameters considered here, is fairly sizeable and amounts to $\sim 12\%$ (for $g^s_A$) and $\sim 14\%$ (for $\mu_s$). All the considered values of the strange parameters are compatible with the asymmetry $\langle A_p \rangle$ within the experimental errors. However for values of $g^s_A$ as large as $-0.15$ the experimental value of $R$ favours $\mu_s \lesssim 0$.

The experimental relative errors for the various ratios and the asymmetry are: $\sim 12\%$ ($R_\nu$ and $R_\bar{\nu}$), $\sim 14\%$ ($R$) and $\sim 16\%$ ($\langle A_p \rangle$). Thus the experimental uncertainties are of the same order as the effects of the strange form factors of the nucleon. At present the error bands are clearly too large to allow any definite conclusion on the strangeness content of the nucleon: as already pointed out in ref. [12,13], one needs to considerably reduce the experimental errors. Nevertheless, the results shown in Fig. 2 give indications that may help in the analysis and interpretation of the present and, in our auspices, future data. As we have already noticed, the comparison between the theoretical calculations and the experimental data for the ratio $R_\bar{\nu}$ (fig. 2a) shows that values of $-g^s_A \geq 0.15$ are clearly disfavoured: moreover a value $g^s_A = -0.10$ (see ref. [3]) seems to require negative values of $\mu_s$, of the order of $-0.2$. Yet the analysis of the other observables is not conclusive, mainly because of the width of the experimental bands, which are compatible with many different choices of the strangeness parameters, $g^s_A$, $\mu_s$, $\rho_s$, including the one which sets all of them to zero. Keeping this in mind and without any claim for a definitive evidence, the results seem to favour negative values of the magnetic strange parameter, $\mu_s$, if $-g^s_A$ is relatively large, in agreement with the findings of ref. [12].

We remind here that a value of the strange magnetic form factor of the nucleon has been recently measured at BATES [22], with the result $G_M^s(0.1\text{GeV}^2) = 0.23 \pm 0.37 \pm 0.15 \pm 0.19$. This value is affected by large experimental and theoretical uncertainties (the last error refers
to the estimate of radiative corrections), but it is centered around a positive $\mu_s$, although it is still compatible with zero or negative values of $\mu_s$. At present neutrino scattering and parity violating electron scattering experiments appear to be not conclusive for what concerns $\mu_s$. We also notice that, if the P–odd asymmetry measured in the scattering of polarized electrons on nucleons will provide a more stringent information on the strange magnetic form factor, then future, precise experiments combining the measurement of $\nu$ and $\bar{\nu}$–proton scattering could allow a determination of the axial strange form factor and of the electric one $^{[10]}$. The effect of the latter is clearly smaller than the one associated to the axial and magnetic strange form factors. This is especially true for $R_\nu$, whereas $R_\rho$ shows a non–negligible sensitivity to $\rho_s$.

Concerning the asymmetry [lower part of Fig. 2(b)], it is obviously insensitive to the electric strange form factor, according to its definition [see formula(5)]; it is, instead, rather sensitive to $g_A^s$ and $\mu_s$, but, for the time being, the experimental error band does not allow us to discriminate among the various possible choices for $g_A^s$, $\mu_s$ values.

Finally let us discuss the role played by the axial cutoff mass $M_A$. For this purpose we show in Fig. 3(a) and 3(b) the various observables, $R_\nu$, $R_\tau$, $R$ and $\langle A_\rho \rangle$, versus the axial strange constant $g_A^s$ for three different choices of $M_A$: $M_A = 0.996,1.032$ and $1.068$ GeV, which are, within $1 \sigma$, the values obtained in fit number IV of ref. $^{[12]}$. The values of the magnetic and electric strange parameters, $\mu_s$, $\rho_s$ have been fixed to zero. In Fig. 3 we compare the theoretical predictions with the ratios (1)–(3) measured in BNL–734 experiment, and with the asymmetry $^{[8]}$, with the same error bands shown in Fig. 2.

Solid lines correspond to results for $M_A = 1.032$ GeV, dashed lines to $M_A = 1.068$ GeV and dot–dashed to $M_A = 0.996$ GeV. One can see that by varying $M_A$ in the considered range, the ratio $R_\tau$ is changed by $\sim 18 \%$, $R$ by $\sim 10 \%$ and $R_\nu$ by $\sim 5 \%$; therefore these ratios rather strongly depend on the precise value of $M_A$, particularly in the case of antineutrinos. This observation was already pointed out in ref. $^{[10]}$ and stands out more clearly here. Moreover the comparison with the experimental data clearly shows, as in ref. $^{[12]}$, a strong correlation between $g_A^s$ and $M_A$, which is particularly evident in $R_\tau$: keeping in mind that here the vector strange form factors are set to zero, the results obtained for $R_\tau$ would disfavour, within one standard deviation, a wide range of values for $g_A^s$. In particular $M_A = 1.068$ GeV is only compatible with $g_A^s$–values such that $-g_A^s \lesssim 0.05$, $M_A = 1.032$ GeV with $-g_A^s \lesssim 0.1$, whereas $M_A = 0.996$ GeV extends the range of allowed $g_A^s$–values to $-g_A^s \lesssim 0.15$. It is worth noticing that the other quantities shown in Fig. 3 are much less restrictive on the chosen values for these parameters.

In contrast with the ratios (1)–(3), we have found that the neutrino–antineutrino asymmetry is practically independent on the value of the axial cutoff mass $M_A$; this fact makes this quantity more suited to determine $g_A^s$ independently from the $Q^2$ behaviour of the axial form factors $^{[3]}$.

In conclusion, we have thoroughly re–examined the data of the elastic $\nu(\bar{\nu})$–proton scattering BNL–734 experiment. We have checked that the effects of the nuclear structure and interactions on the ratios of cross sections and on the asymmetry considered here are negligible. This is an important prerequisite to draw reliable conclusions on the nuclear strange form factors from this type of experiments.

Although our results go in the same direction as some authors have claimed before, we can state here that the experimental uncertainty is still too large to be conclusive about specific
values of the strange form factors of the nucleon. A rather wide range of values for the strange parameters, $g_A^s$, $\mu_s$ and $\rho_s$, is compatible with the BNL–734 data and more precise measurements are thus needed in order to determine simultaneously the electric, magnetic and axial strange form factors of the nucleon. A crucial uncertainty for this determination comes from the existing errors on the axial cutoff mass $M_A^2$.

Our investigation indicates that one can extract the strange form factors of the nucleon from ratios like $R_\nu$ only if the axial cutoff mass will be known with much better accuracy than at present. On the contrary, a high precision measurement of the neutrino–antineutrino asymmetry $A_\nu$ could allow to determine the axial and vector strange form factors even without the knowledge of the precise value of $M_A$.

We can conclude that the uncertainty of the available data does not allow to set stringent limits on the strange vector and axial–vector parameters, but future, more precise measurements could make their determination possible in a model independent way.

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\[ \text{Notice that from quasielastic } \nu(\bar{\nu}) \text{ scattering the value } M_A = 1.09 \pm 0.03 \pm 0.02 \text{ was found.} \]
REFERENCES

[1] D. Adams et al., Phys. Lett. B329, 399 (1994).
[2] K. Abe et al., Phys. Rev. Lett. 74, 346 (1995).
[3] J. Ellis and M. Karliner, Phys. Lett. B341, 397 (1995).
[4] A. Magnon, plenary talk at INPC98, Paris, August 1998; The Spin Muon Collaboration, Phys. Rev. D58, 112002 (1998).
[5] D. Adams et al., (SM Collab.) Phys. Rev. D56, 5330 (1997).
[6] K. Abe et al., (E143 Collab.) Phys. Rev. Lett. 75, 25 (1995).
[7] B. Lampe and E. Reya, preprint hep-ph/9810270 (Oct. 1998).
[8] D.B. Kaplan and A. Manohar, Nucl. Phys. B310, 527 (1988).
[9] W.M. Alberico, S.M. Bilenky, C. Giunti and C. Maieron, Z. f"ur Physik C70, 463 (1996).
[10] see, for example: M.J. Musolf et al., Phys. Rep. 239, 1 (1994)
[11] L.A. Ahrens, et. al., Phys. Rev. D35, 785 (1987).
[12] G.T. Garvey, W.C. Louis and D.H. White, Phys. Rev. C48, 761 (1993).
[13] C.J. Horowitz, H. Kim, D.P. Murdock and S. Pollock, Phys. Rev. C48, 3078 (1993).
[14] M.B. Barbaro, A. De Pace, T.W. Donnelly, A. Molinari and M.J. Musolf, Phys. Rev. C54, 1554 (1996).
[15] W.M. Alberico, M.B. Barbaro, S.M. Bilenky, J.A. Caballero, C. Giunti, C. Maieron, E. Moya de Guerra and J.M. Udias, Nucl. Phys. A623, 471 (1997).
[16] W.M. Alberico, M.B. Barbaro, S.M. Bilenky, J.A. Caballero, C. Giunti, C. Maieron, E. Moya de Guerra and J.M. Udias, Phys. Lett. B438, 9 (1998).
[17] J.M. Udías, P. Sarriguren, E. Moya de Guerra and J.A. Caballero, Phys. Rev. C53, R1488 (1996); ibid. C48, 2731 (1993).
[18] G.T. Garvey, S. Krewald, E. Kolbe and K. Langanke, Phys. Lett. B289, 249 (1992).
[19] G.T. Garvey, E. Kolbe, K. Langanke and S. Krewald, Phys. Rev. C48, 1919 (1993).
[20] E.Kolbe, S.Krewald and H.Weigel, Z. für Physik A358, 445 (1997).
[21] H. Forkel et al., Phys. Rev. C 50, 3108 (1994); H.C. Kim, T. Watabe and K. Goeke, Nucl. Phys. A 616, 606 (1997); M. Kirchbach and D. Arenhövel, Proceedings, Physics with GeV–particle beams, 414 (1994) (hep-ph/9409293).
[22] B. Mueller et al., SAMPLE Collaboration, Phys. Rev. Lett. 78, 3824 (1997).
[23] L.A. Ahrens et al., Phys. Lett. B202, 284 (1988).
FIG. 1. The integral asymmetry \( A_p \) versus \( g_A^q \). The magnetic and electric strange form factors have been fixed to zero. The solid line corresponds to the folded \( \nu(\overline{\nu}) \)-proton elastic scattering asymmetry, the empty dots to elastic scattering without folding at \( \epsilon_{\nu(\overline{\nu})} = 1 \text{ GeV} \). Results for the quasi-elastic asymmetry on \(^{12}\text{C}\) are shown by the following curves: dashed line (RFG, with folding), dotted line (RFG, unfolded), dot-dashed line (RSM, unfolded) and three-dot-dashed line (RSM+ROP, unfolded); all unfolded curves are evaluated at \( \epsilon_{\nu(\overline{\nu})} = 1 \text{ GeV} \).
FIG. 2. The ratios $R_\nu$ and $R_\bar{\nu}$ (a), and $R$ and $\langle A_p \rangle$ (b), as a function of $\mu_s$: all curves correspond to $\nu(\bar{\nu})$-p elastic scattering. Results are shown for $g_A^s = 0$ and $g_A^s = -0.15$. In both cases we have chosen $\rho_s$ to be: $\rho_s = 0$ (solid line), $\rho_s = -2$ (dot–dashed line) and $\rho_s = +2$ (dashed line). The shadowed regions correspond to the experimental data measured at BNL-734 experiment [eqs. (5-7,9)].
FIG. 3. The ratios $R_\nu$ and $R_\rho$ (a), and $R$ and $\langle A_p \rangle$ (b), as a function of $g_A^s$: all curves correspond to elastic scattering and the electric and magnetic strange parameters have been taken $\mu_s = \rho_s = 0$. Results are shown for three different values of the axial mass cutoff: $M_A = 1.032$ GeV (solid lines), $M_A = 1.068$ GeV (dashed lines) and $M_A = 0.996$ GeV (dot–dashed lines).