Signals for strange quark contributions to the neutrino (antineutrino) scattering in quasi-elastic region

Myung-Ki Cheoun\textsuperscript{1)}, K. S. Kim\textsuperscript{2) *}

\textsuperscript{1)Department of Physics, Soongsil University, Seoul, 156-743, Korea}
\textsuperscript{2)School of Liberal Arts and Science, Korea Aerospace University, Koyang 412-791, Korea}

Strange quark contributions to the neutrino (antineutrino) scattering are investigated on the elastic neutrino-nucleon scattering and the neutrino-nucleus scattering for \textsuperscript{12}C target in the quasi-elastic region on the incident energy of 500 MeV, within the framework of a relativistic single particle model. For the neutrino-nucleus scattering, the effects of final state interaction for the knocked-out nucleon are included by a relativistic optical potential. In the cross sections we found some cancellations of the strange quark contributions between the knocked-out protons and neutrons. Consequently, the asymmetries between the incident neutrino and antineutrino which is the ratio of neutral current to charged current, and the difference between the asymmetries are shown to be able to yield more feasible quantities for the strangeness effects. In order to explicitly display importance of the cancellations, results of the exclusive reaction \textsuperscript{16}O(\nu, \nu' p) are additionally presented for detecting the strangeness effects.

PACS numbers: 25.30. Pt; 13.15.+g; 24.10.Jv

Since the exploration of a spin structure of proton at the EMC measurement \cite{1}, the deep-inelastic scattering of leptons from nucleons has played important roles for studying the distribution of quarks and gluons. In the quark parton model for the nucleon, the cross section of the scattering with polarized leptons on polarized nucleons is usually given by four structure functions, \( F_1(x), F_2(x), g_1(x), \) and \( g_2(x) \)

\[
F_2(x) = x \Sigma q e^2_q(x) = 2x F_1(x) , \quad g_1(x) = \frac{1}{2} \Sigma q e^2_q \Delta q(x)
\]

with \( x = Q^2/2p \cdot q \) and \( Q^2 = -(p' - p)^2 \) for the momentum \( p \) of the initial nucleon and

\* Corresponding author : kyungsik@hau.ac.kr
the momentum transfer $q$ from leptons. $e_q, q(x)$, and $\Delta q(x)$ denote a charge, a parton distribution and a polarized parton distribution function for quarks flavor $q$, respectively. In experimental aspect, the structure functions are usually measured as their integral forms because of their $Q^2$ dependence

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2) dx .$$

(2)

Available experimental data for the $\Gamma_1(Q^2)$ are located in $0.115 \sim 0.126$ depending on the region, $3 \leq Q^2 \leq 10.7$. If $\Delta q$ is defined as a difference of the total numbers of quarks and antiquarks in the nucleon with a helicity equal and opposite to the spin of the nucleon

$$\Delta q = \int_0^1 \sum_{r=\pm 1} r[q^{(r)}(x) + \bar{q}^{(r)}(x)] dx ,$$

(3)

$\Delta q$ stands for the contribution of $q$-quarks and $\bar{q}$-antiquarks to the spin of the nucleon. For example, in the infinite momentum frame (quark-parton model), $\Gamma_1(Q^2)$ is evaluated in terms of the $\Delta q$ with some constraints among them

\begin{equation}
\Gamma_1^p = \frac{1}{2} \left( \frac{4}{9} \Delta u + \frac{1}{9} \Delta d + \frac{1}{9} \Delta s \right) , \quad \Delta u + \Delta d - 2\Delta s = 3F - D , \quad \Delta u - \Delta d = g_A
\end{equation}

(4)

with $D$ and $F$ constants in SU(3) symmetry.

On the other hand, the axial form factors $G_A^q(Q^2)$ and the axial charges $g_A^q$ are given by the matrix elements and the diagonal matrix elements of the axial current

$$< p | \bar{q} \gamma_\mu \gamma_5 q | p > = \bar{u}(p') \gamma_\mu \gamma_5 G_A^q(Q^2) u(p) , \quad < p | \bar{q} \gamma_\mu q | p > = 2M s_\mu g_A^q ,$$

(5)

where $M$ and $s_\mu$ are respectively the mass and spin vector of the nucleon. In particular, for our primary interest, the axial coupling constant $g_A^s$ (or axial charge) induced by strangeness quark turned out to be equal to the $\Delta s$, which is related to the nucleon spin by the $s$ quark contribution. Though its value extracted from both experimental and/or theoretical results has not been fixed yet, several groups reported the value as $0.0 \pm 0.4$, $-0.08 \pm 0.06$, $-0.12 \pm 0.06$ and $-0.18 \pm 0.05$. Therefore, its value is allowed to vary in $0 < g_A^s < -0.19$ for further discussions of its effects in the elastic neutrino (antineutrino) $(\nu(\bar{\nu}))$ scattering.

In this paper, although the strangeness effects in vectorial parts can be studied by parity not only violating (or polarized electron scattering) but $\nu$ scattering, we focus on the strangeness $g_A^s$ effect in the axial part by studying the $\nu(\bar{\nu})$ scattering on the quasi-elastic (QE) region, where inelastic processes like pion production and delta resonance are excluded.
Before going further, we briefly summarize the present status for signals of the strangeness effects in the $\nu(\bar{\nu})$ scattering. Since the vectorial parts are rarely contributed due to the given Weinberg angle in the reaction, the elastic cross section on the proton $\sigma(\nu p \rightarrow \nu p)$ mediated by a neutral current (NC) reaction is sensitive mainly on the $g_A^s$ value. But the measurement of the cross section is not experimentally easy, so that one usually resorts to the ratio of proton to neutron cross sections $R_{p/n} = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \nu n)$ [3]. The measurement of this ratio has also some difficulties in the neutron detection. Since the charged current (CC) cross section is relatively insensitive to the strangeness, the ratio $R_{NC/CC} = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \mu^- p)$ is suggested as a plausible signal for the nucleon strangeness although the signal goes down by a factor 2 [6]. In this paper, more precise analysis for those quantities are carried out in searching other feasible quantities for the strangeness effects in the $\nu(\bar{\nu})$-scattering.

The elastic neutrino-nucleon ($\nu(\bar{\nu}) - N$) cross section by the NC reaction is expressed in terms of the Sachs (vector and axial) form factors [2, 7]

$$
\frac{d\sigma}{dQ^2}^{NC}_{\nu(\bar{\nu})} = \frac{G^2_F}{2\pi} \left[ \frac{1}{2} y^2 (G^V_M)^2 + (1 - y - \frac{M}{2E_\nu} y) (G^V_E)^2 + \frac{E_\nu}{2M} y (G^V_M)^2 \right] + \left( \frac{1}{2} y^2 + 1 - y + \frac{M}{2E_\nu} y \right) (G^A_M)^2 + h2y(1 - \frac{1}{2} y) G^V_M G^A_A .
$$

(6)

Here, $E_\nu$ is the incident $\nu(\bar{\nu})$ energy in the laboratory frame, and $y = p \cdot q/p \cdot k = Q^2/2p \cdot k$ with initial four momenta $k$ of $\nu(\bar{\nu})$, target nucleon $p$, and four momentum transfer $q$ to the nucleon, respectively. $G_F \simeq 1.16639 \times 10^{-11}$ MeV$^{-2}$ is the Fermi constant. Vectorial Sachs form factors are written as electric and magnetic form factors of the nucleon

$$
G^V_{M,E}(Q^2) = \left( \frac{1}{2} - 2\sin^2 \theta_W \right) G^p_{M,E}(Q^2) - \frac{1}{2} G^n_{M,E}(Q^2) - \frac{1}{2} G^s_{M,E}(Q^2) \quad \text{for NC}
$$

$$
G^s_M(Q^2) = \frac{Q^2 F^s_1 + \mu_s}{(1 + \tau)(1 + Q^2/M^2_A)}^2, \quad G^V_E(Q^2) = \frac{Q^2 F^s_1 - \mu_s \tau}{(1 + \tau)(1 + Q^2/M^2_A)}^2 ,
$$

(7)

where $\mu_s = G^s_M(0)$ is a strange magnetic moment. The axial form factor is usually presumed as a dipole form

$$
G^{NC}_A(Q^2) = \frac{1}{2} (g_A + g_A^s)/(1 + Q^2/M^2_A)^2 \quad \text{for NC}
$$

$$
G^{CC}_A(Q^2) = -g_A/(1 + Q^2/M^2_A)^2 \quad \text{for CC},
$$

(8)

where $g_A = 1.262$ and $M_A$ are the axial coupling constant and the axial cut off mass, respectively. $-(+)$ coming from the isospin dependence denotes the knocked-out proton.
(neutron), respectively. The $g_A^s$ appeared explicitly in Eq.(8) represents the strange quark contents in the nucleon. Of course, the strangeness effects could contribute to other form factors, but their effects turned out to contribute only a few % to those physical quantities.

In order to calculate the $\nu(\bar{\nu})$-nucleus ($\nu - A$) scattering, we choose the nucleus fixed frame where the target nucleus is seated at the origin of the coordinate system. The four-momenta of the incident and outgoing neutrinos (antineutrinos), the target nucleus, the residual nucleus, and the knocked-out nucleon are labelled $p_i^\mu$, $p_f^\mu$, $p_A$, $p_{A-1}^\mu$, and $p^\mu$, respectively. In the laboratory frame, the inclusive cross section, which does not detect the outgoing $\nu (\bar{\nu})$, is given by the contraction between lepton and hadron tensors

$$d\sigma = 4\pi^2 M_N M_{A-1}^\nu (2\pi)^3 M_A \int \sin \theta_l d\theta_l \int \sin \theta_p d\theta_p p f_{\text{rec}}^{-1} \sigma_M^{Z,W\pm} [v_L R_L + v_T R_T + h v_T' R_T'] , \quad (9)$$

where $\theta_l$ denotes the scattering angle of the lepton. $\sigma_Z^{W\pm}$ for NC and CC is defined by

$$\sigma_Z^{W\pm} = \left( \frac{G_F \cos(\theta_l/2) E_f M_Z^2}{\sqrt{2} \pi (Q^2 + M_Z^2)} \right)^2 , \quad (10)$$

where $M_Z$ and $M_W$ are the rest mass of $Z$-boson and $W$-boson, respectively. $\theta_C$ denotes the Cabibbo angle given by $\cos^2 \theta_C \simeq 0.9749$. The recoil factor $f_{\text{rec}}$ is given as

$$f_{\text{rec}} = \frac{E_{A-1}}{M_A} \left[ 1 + \frac{E_p}{E_{A-1}} \left[ 1 - \frac{q \cdot p}{p^2} \right] \right] . \quad (11)$$

Nuclear response functions to the weak current are denoted as $R_L$, $R_T$ and $R_T'$, whose detailed forms are referred from Ref. [8].

Detailed results of the cross sections on the proton and the neutron target for $g_A^s = -0.19$ and 0.0 are shown in the upper parts of Fig. Cross sections by the incident $\nu(\bar{\nu})$ on the proton are usually enhanced in the whole $Q^2$ region by the $g_A^s$, 15% maximally, while they are reduced on the neutron. Other quantities related to these cross sections, such as asymmetries and ratios between $\nu$ and $\bar{\nu}$ in the NC reaction, also show similar effects [7]. Therefore the strangeness effect is not large enough to be discernible in the cross sections, asymmetries, and ratios if we recollect the persisting experimental error bars in the BNL data [3].

The lowest part of Fig. exhibits the strange quark contributions to the cross section on $^{12}$C($\nu(\bar{\nu}), \nu'(\bar{\nu}')$) reaction. For directly comparing with the nucleon case, we present them in terms of outgoing nucleon kinetic energy $T_N$ because $Q^2 = 2MT_p$ would hold on the
free nucleon inside nuclei. Thick and thin curves are the results for $g_A^s = -0.19$ and $0.0$, respectively. Note that a relativistic optical potential for the final nucleon is taken into account for the FSI \cite{12}. Detailed discussions about the FSI are done at Ref. \cite{13}. Peak positions for $^{12}\text{C}$ nuclei, which does not show up in the nucleon case, just come from the binding energy of nucleons inside nuclei.

To analyze cross sections (solid curves) for the $\nu-^{12}\text{C}$ scattering, we present separately each contribution via final neutrons (dotted curves) and final protons (dashed curves) in the figure. The effect of $g_A^s$ for the proton is increased by about 30%, but for the neutron it is decreased by 30%, maximally, independently of the incident energy. These individual $g_A^s$ effects on each nucleon resemble exactly those of each nucleon in the upper parts of Fig.\cite{11} that is, the $g_A^s$ effect enhances the cross section by protons and decreases that by neutrons.

However, total net $g_A^s$ effects severely depend on the competition between the protons and neutrons processes because of the summation of all nucleons. In the case of $^{12}\text{C}$, the enhancement by the proton is nearly compensated by the neutron process, so that the net effect increases the cross section only below 3% for the given $E_\nu$.

For the $\bar{\nu}-^{12}\text{C}$ process, the $g_A^s$ effect enhances the cross section by about 20% on the protons, but reduces them by 20% the neutrons. The reduction by neutrons is nearly balanced by the enhancement due to protons. Consequently, the net effect of the strange quark reduces also the cross section only below 2% for the given $E_{\bar{\nu}}$, similarly to the $\nu$ case.

From these results, in the $\nu - A$ cross sections, the $g_A^s$ effect contributes more positively to the proton while it does negatively to the neutron, and is cancelled out finally. In the case of $^{12}\text{C}$, the resultant effects are only within a few % by the cancellation between the final protons and neutrons. Therefore, the $g_A^s$ effect in nuclei is too small to be deduced from the $A(\nu, \nu')$ cross section.

On the other hand, the cross section for the CC scattering is given with the following replacement into the NC cross sections of Eqs. (6) and (9)

$$
\left(\frac{d\sigma}{dQ^2}\right)^{CC}_{\nu(\bar{\nu})} = \left(\frac{d\sigma}{dQ^2}\right)^{NC}_{\nu(\bar{\nu})} \left( G_E^V \to G_E^{CC}, G_M^V \to G_M^{CC}, G_A \to G_A^{CC} \right),
$$

with $G_E^{CC} = G_E^p(Q^2) - G_E^n(Q^2)$, $G_M^{CC} = G_M^p(Q^2) - G_M^n(Q^2)$. Since the relevant form factors are expressed only by the electro-magnetic form factors the CC scattering is not nearly influenced by the strangeness in the form factors. Therefore, the ratios of the NC and CC
reactions given by
\[ R_{NC/CC} = \frac{\sigma(\nu, \nu'p)}{\sigma(\nu, \mu^-p)} = \frac{\sigma^{\nu p}_{NC}}{\sigma^{\nu p}_{CC}}, \quad \bar{R}_{NC/CC} = \frac{\sigma(\bar{\nu}, \bar{\nu}'n)}{\sigma(\bar{\nu}, \mu^+n)} = \frac{\sigma^{\bar{\nu} p}_{NC}}{\sigma^{\bar{\nu} p}_{CC}}, \]  
\hspace{1cm} (13)

have been suggested for probing the strangeness on the nucleon or nuclei. Moreover any possible nuclear structure effects in these reactions are expected to be cancelled out. Since these ratios are focused on the knocked-out nucleon, we introduce another definition of the ratios by focusing on the nucleon inside the target nucleus as follows
\[ R'_{NC/CC} = \frac{\sigma(\nu, \nu'n)}{\sigma(\nu, \mu^-p)} = \frac{\sigma^{\nu n}_{NC}}{\sigma^{\nu n}_{CC}}, \quad \bar{R}'_{NC/CC} = \frac{\sigma(\bar{\nu}, \bar{\nu}'n)}{\sigma(\bar{\nu}, \mu^+n)} = \frac{\sigma^{\bar{\nu} n}_{NC}}{\sigma^{\bar{\nu} n}_{CC}}. \]  
\hspace{1cm} (14)

Since the charge exchange is not included, these \( R' \) and \( \bar{R}' \) quantities have the same meaning as \( R_{NC/CC} = \sigma(\nu n \rightarrow \nu n)/\sigma(\nu n \rightarrow \mu^-p), \bar{R}_{NC/CC} = \sigma(\bar{\nu}p \rightarrow \bar{\nu}p)/\sigma(\bar{\nu}p \rightarrow \mu^+n) \) on nucleon level, namely, \( R' \) and \( \bar{R}' \) mean the ratios on the nucleon inside nuclei bombarded by incident \( \nu(\bar{\nu}) \). Results and relevant discussions for the ratios on the \( ^{12}\text{C} \) target are given at Fig. 2. The strangeness effects are not so large than those of the cross sections at Fig. 1. Divergence of high \( T_P \) is associated with the effect of outgoing lepton mass in the CC reaction [2].

In order to find more feasible \( g_A^s \) signals, the difference of the cross sections between incident \( \nu \) and \( \bar{\nu} \) is suggested as a candidate for the effects [2, 8]. Since \( h = -1 \) (\( h = +1 \)) in Eqs.(6) and (9) corresponds to the helicity of the incident \( \nu(\bar{\nu}) \), a difference of the cross sections is summarized as a simple form. For instance, for the \( \nu-N \) scattering, the difference of the cross section is given as
\[ \frac{d\sigma}{dQ^2}^{NC}_\nu - \frac{d\sigma}{dQ^2}^{NC}_{\bar{\nu}} = -\frac{G_F^2}{2\pi} 4y(1 - \frac{1}{2}y)G_M^V G_A^A. \]  
\hspace{1cm} (15)

Similar conjectures can be done for the \( \nu-A \) scattering from Eq. (9).

Since the difference of the cross sections between \( \nu \) and \( \bar{\nu} \) can be expressed only by a few form factors, more efficient observable are possible if we consider asymmetries between \( \nu \) and \( \bar{\nu} \) relative to the CC reactions. Moreover it enables us to distinguish each strangeness contribution in the two strangeness effects, i.e. vectorial and axial strangeness parts at small \( Q^2 \) region
\[ A_{NC/CC}^p = \frac{\sigma^{\nu p}_{NC} - \sigma^{\bar{\nu} p}_{NC}}{(\sigma^{\nu p}_{CC} - \sigma^{\bar{\nu} p}_{CC})} = 0.12 - 0.12\frac{g_A^s}{g_A} - 0.13\frac{G_M^s}{G_M^3}, \]  
\hspace{1cm} (16)
\[ A_{NC/CC}^n = \frac{\sigma^{\nu n}_{NC} - \sigma^{\bar{\nu} n}_{NC}}{(\sigma^{\nu n}_{CC} - \sigma^{\bar{\nu} n}_{CC})} = 0.16 + 0.16\frac{g_A^s}{g_A} + 0.13\frac{G_M^s}{G_M^3}, \]  
\hspace{1cm} (16)
where the third terms with $G_M^s(Q^2 = 0) = \mu_s$, $G_M^3 = (G_M^p - G_M^n)/2$, $\mu_p = 2.79$, and $\mu_n = -1.91$ come from the vectorial part. Since $|G_M^s/G_M^3|$ and $|g_A^s/g_A|$ are approximately 0.2, the strangeness effects from the vector and axial parts are comparable, in principle. It could be questioned if Eq.(16) still holds even in the case of a nucleus. But, we assume that it holds because the outgoing nucleon can be described as quasi-freely bombarded by the incident $\nu(\bar{\nu})$.

Here two interesting remarks are possible. One is that $A_{NC/CC}^{p(n)}$ could be a constant if there would be no strangeness effects. The second point is related to the $\mu_s$ sign. If $g_A^s$ and $G_M^s$ have different ($\pm$) sign, the values of $A_{NC/CC}^p$ and $A_{NC/CC}^n$ become constants 0.12 and 0.16, respectively, because the last two terms in Eq. (16) are nearly cancelled out. Any deviations from these constants would imply that both signs are same. For instance, we presented the case of $g_A^s = -0.19$ and $\mu_s = -0.4$ showing such a tendency at the upper panels in Fig. 3. Both nucleon and nuclei cases show nearly the same trend. It means that $g_A^s$ effect is nearly evadable from any observable suggested until now. Divergence of high $T_P$ in the nuclear case of Fig. 3 also comes from the CC reaction in the denominator.

As another way to study the strangeness, we introduce the difference and the sum of asymmetries

$$DA_{NC/CC} = A_{NC/CC}^p - A_{NC/CC}^n \simeq -0.04 - 0.28\left(\frac{g_A^s}{g_A} + \frac{G_M^s}{G_M^3}\right), \quad (17)$$

$$SA_{NC/CC} = A_{NC/CC}^p + A_{NC/CC}^n = 0.28 + 0.04\frac{g_A^s}{g_A}.\quad \text{The sum of asymmetry in Eq. (17) is given only in terms of the axial part. But the second term is very small by the factor 0.04, so that the SA is nearly independent of the strangeness, but the DA depends strongly on the axial strangeness. Figure 4 represents the calculation for the difference and the summation of the asymmetries. On the summation, the $g_A^s$ effect is negligible, so that the summation of the asymmetry behaves a constant about 0.28 at low and middle kinetic energies, independently of free or bound nucleons. On the difference, the $g_A^s$ effects clearly appear to be larger than any other observable. If the values of $g_A^s$ and $\mu_s$ have different signs, the DA would be constant, but it depends on $Q^2$ if they have same signs as in Fig. 4.}\n
Finally, we consider the exclusive $\nu - A$ scattering i.e. $A(\nu, \nu'N)$ because we expect that the strangeness effects via each nucleon process can be survived in the exclusive reaction without mutual cancellations. Our terminology for the exclusive reaction is based on the
concept in the electron scattering [15].

In the laboratory frame, the exclusive differential cross section is given by the contraction between the lepton tensor and the hadron tensor [11, 15]

\[
d^5\sigma/dE_f d\Omega_f d\Omega_p = K[v_L R_L + v_T R_T + v_{TT} R_{TT} \cos 2\phi_p + v_{LT} R_{LT} \cos \phi_p
\]

\[
+ h(v_{LT}' R_{LT}' + v_{LT} R_{LT} \sin \phi_p)],
\]

where \(\phi_p\) denotes the azimuthal angle of the knocked-out proton as measured with respect to the incident \(\nu\) scattering plane (\(x - z\) plane). \(R_L, R_T, R_{TT}, R_{LT}, R_{LT}'\), and \(R_{LT}'\) are called the longitudinal, transverse, transverse-transverse, longitudinal-transverse, polarized transverse, and polarized longitudinal-transverse response functions, respectively. The kinematics factor \(K\) is given by

\[
K = \frac{M_N}{(2\pi)^3 M_A} f_{\text{rel}}^{-1} \sigma_Z.
\]

Our results in Fig. 5 where incident \(E_\nu = 2.4\) GeV is adopted as a JLAB type’s electron energy, show clearly the strangeness effects, as expected. However, in the experimental side, this reaction may have actual difficulties in detecting incident and outgoing neutrinos. However, if one integrates the scattering angle and averages over the neutrino energies, the five folded cross section in Eq. (18) becomes a two folded form, that is, the cross section is going to be the angular distribution of the knocked-out nucleon by detecting only solid angles of the knocked-out nucleon.

In conclusion, the \(g_A^s\) effect in the elastic \(\nu(\bar{\nu}) - N\) scattering for the NC reaction enhances the cross section for the proton, but reduces it for the neutron. But for the \(\nu - A\) scattering in the QE region, the contributions of both protons and neutrons compensate each other in the cross section because of the summation over all nucleons, so that the net effects on the cross sections are nearly indiscernible due to the possible cancellations. However the asymmetries between incident \(\nu\) and \(\bar{\nu}\) divided by the CC reaction could be a prominent signal for the strangeness effect. In specific, differences of the asymmetries could be a feasible quantity for the signal.

Finally the exclusive reaction like \(^{12}\text{C}(\nu(\bar{\nu}), \nu'(\bar{\nu}'))N\) could be more efficient tests for the effect rather than the inclusive reaction \(^{12}\text{C}(\nu(\bar{\nu}), \nu'(\bar{\nu}'))\), because there are no competitions of the \(g_A^s\) effects for the knocked-out protons and neutrons in the exclusive reaction. Our results for the exclusive reaction justify clearly this conjecture.
Acknowledgements

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (R01-2007-000-20569) and one of author, Cheoun, was supported by the Soongsil University Research Fund.

[1] J. Ashman et al., EMC Collaboration, Nucl. Phys. B 328, 1 (1989).
[2] W. M. Alberico, S. M. Bilenky, and C. Maieron, Phys. Rep. 358, 227, (2002).
[3] G. T. Garvey, S. Krewald, E. Kolbe, and K. Langanke, Phys. Rev. C 48, 1919 (1993); Phys. Lett. B 289, 249 (1992).
[4] R. D. Young, J. Roche, R. D. Carlini, and A. W Thomas, Phys. Rev. Lett., 97, 102002, (2006).
[5] Stephen F. Pate, Eur. Phys. J. A 24, s2, 67, (2005).
[6] B. I. S. van der Ventel, and J. Piekarewicz, Phys. Rev. C 69, 035501, (2004).
[7] Myung-Ki Cheoun and K. S. Kim, J. Phys. G 35, 065107, (2008).
[8] K. S. Kim, Myung Ki Cheoun, and B. G. Yu, to be appeared, Phys. Rev C, arXiv:0707.2767 (2008).
[9] Y. Umino, J. M. Udias, Phys. Rev. C 52, 3399 (1995); Y. Umino, J. M. Udias, and P. J. Mulders, Phys. Rev. Lett. 74, 4993 (1995).
[10] Andrea Meucci, Carlotta Giusti, and Franco Davide Pacati, Nucl. Phys. A739, 277 (2004); Nucl. Phys. A744, 307 (2004); Nucl. Phys. A773, 250 (2006).
[11] M. C. Martinez, P. Lava, N. Jahowicz, J. Rynkebusch, K, Vantournhout, and J. M. Udias, Phys. Rev. C 73, 024607 (2006).
[12] E. D. Cooper, S. Hama, B. C. Clark, and R. L. Mercer, Phys. Rev. C 47, 297 (1993).
[13] K. S. Kim, B. G. Yu, M. K. Cheoun, T. K. Choi, and M. T. Cheon, J. Phys. G 34, 2643 (2007).
[14] J. M. Udias, P. Sarriguren, E. Moya de Guerra, E. Garrido, and J. A. Caballero, Phys. Rev. C 53, R1488 (1996).
[15] K. S. Kim, Myung Ki Cheoun, Yeungun Chung, and Hyung Joo Nam, Eur. Phys. J. A 11, 147 (2001).
FIG. 1: (Color online) Upper 4 figures are differential cross sections by the NC scattering on proton (left) and neutron (right), Eq. (6), in a unit ($G_F^2 / 9 \simeq 6.05 \times 10^{-39} \text{[cm}^2/\text{(GeV/c)}^2]$), as a function of $Q^2$ for $E_{\nu(\bar{\nu})} = 500$ MeV. They are calculated for $g_A^s = -0.19$ and 0.0 cases, respectively. The lowest panel is for $^{12}$C$(\nu(\bar{\nu}), \nu(\bar{\nu}))$ cross section, Eq.(9), as a function of the knocked out nucleon kinetic energy $T_p$ at $E_{\nu(\bar{\nu})} = 500$ MeV, where left (right) panel is for the $\nu$ ($\bar{\nu}$) scattering, respectively. Solid curves are the results for the cross sections, dashed and dotted lines are the contributions of the proton and the neutron, respectively. Thick and thin lines are calculations with $g_A^s = -0.19$ and $g_A^s = 0.0$. 
FIG. 2: (Color online) Ratios of the NC to the CC cross sections of the $\nu - A$ scattering for $^{12}C$ as a function of the knocked-out nucleon kinetic energy. For the NC reaction, solid (red) curves represent the results with $g_A^s = 0.0$, dashed (black) lines are with $g_A^s = -0.19$. 
FIG. 3: (Color online) Asymmetries $A_{NC/CC}^p$ and $A_{NC/CC}^n$, Eq.(16), between the NC and CC reactions for an incident $E_{\nu(\bar{\nu})} = 500$ MeV. They are calculated for $g_A^s = -0.19$ (dashed curve) and 0.0 cases (solid curve), respectively. Upper panel is for the nucleon, while lower panel is for $^{12}C$. 
FIG. 4: (Color online) The differences and summations of the asymmetries between the NC and CC cross sections of $\nu - N$ (upper part) and $\nu - A$ scattering for $^{12}$C target (lower parts) as a function of the knocked-out nucleon kinetic energy. Solid (red) curves represent the results with $g_A^s = 0.0$, dashed (black) lines are with $g_A^s = -0.19$. 
FIG. 5: (Color online) Neutral current $^{16}\text{O}(\nu, \nu'p)$ cross sections as a function of the missing momentum at $E_{\nu} = 2.4$ GeV. Solid (red) curves are the results for $g_A^s = 0.0$ and dashed (black) lines are for $g_A^s = -0.19$, respectively. Thick and thin lines are the results for the incident $\nu$ and $\bar{\nu}$. States of the outgoing nucleon, $p_{1/2}$ and $p_{3/2}$, are indicated, respectively.