Strange quark contributions to neutrino and antineutrino nucleus scattering via neutral current in quasi-elastic region

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Strange quark contributions to the neutral current reaction in neutrino(antineutrino) scattering are investigated on the nucleon level and extended to the $^{12}$C target nucleus through the neutrino-induced knocked-out nucleon process in the quasi-elastic region within the framework of a relativistic single particle model. The incident energy range between 500 MeV and 1.0 GeV is used for the scattering. Effects of final state interactions for the knocked-out nucleon are included by a relativistic optical potential. We found that there exist some cancellation mechanisms between strange quark contributions by protons and neutrons inside nuclei in inclusive reactions, $A(\nu (\bar{\nu}), \nu' (\bar{\nu}'))$. As a result, the sensitivity of the strange quark contents could be more salient on the asymmetry between neutrino and antineutrino scattering in knocked-out nucleon processes, $A(\nu (\bar{\nu}), \nu' (\bar{\nu}'))N$.

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Neutrino-nucleus ($\nu - A$) scattering has become to be widely interested in different fields of physics such as astrophysics, cosmology, particle, and nuclear physics. In particular, the scattering of neutrinos($\nu$) and antineutrinos($\bar{\nu}$) on nuclei enabled us to obtain some invaluable clues on the strangeness contents of the nucleon. Along this line, Brookhaven National Laboratory (BNL)\textsuperscript{[1]} reported that the value of a strange axial vector form factor of the nucleon does not have zero.

At intermediate $\nu (\bar{\nu})$ energies, there are many theoretical works\textsuperscript{[2, 3, 4, 5, 6, 7, 8, 9]} for the $\nu - A$ scattering, for example, relativistic Fermi gas (RFG) models\textsuperscript{[3, 4]}, the relativistic plane wave impulse approximation (RPWIA)\textsuperscript{[5]}, and non-relativistic nuclear shell models\textsuperscript{[6]}.

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One of recent developments is to extract model-independent and target-independent predictions for the $\nu - A$ scattering. For instance, ref. [10, 11] exploited the superscaling analysis (SuSA), which has been used for scaling analysis of inclusive electron scattering. They showed that the SuSA method yields predictions for neutrino scattering with the uncertainty about $15 \sim 20\%$ level compared with RFG models. Moreover it has been carried out not only in the quasi-elastic (QE) region but also in the $\Delta$ region.

Apart from the nuclear models, the final state interaction (FSI) of the knocked-out nucleon is one of important ingredients in relevant reactions. Usually two different methods, the complex optical potential [7] and the relativistic multiple scattering by the Glauber approximation [12], are exploited for the FSI. In particular, ref. [13] shows that the ratio of proton and neutron cross section in the QE region is sensitive to the strange quark axial form factor of the nucleon by using the Monte Carlo treatment of the rescattering.

In this paper, we investigate the strange quark contents on the nucleon by considering the neutral current (NC) scattering on the nucleon, and applying its results to the $\nu - A$ scattering in the QE region, where inelastic processes like pion production and $\Delta$ resonance are excluded. Beyond the QE region, of course, one has to include such inelastic processes. For example, ref. [14] showed that the contribution of $\Delta$ excitation is comparable to that of the QE scattering at the neutrino energies above 1 GeV.

Relativistic bound state wave functions for the nucleon are obtained from solving a Dirac equation in the presence of strong scalar and vector potentials based on the $\sigma - \omega$ model [15]. In order to include the FSI we take a relativistic optical potential [16]. Our nuclear model used here has been successfully applied to the $A(e,e')$ and $A(e,e'N)$ reactions [17, 18]. Incident neutrino (antineutrino) energies are concerned in intermediate ranges between 500 MeV and 1.0 GeV.

We start from a weak current on the nucleon level, $J^\mu$, which represents the Fourier transform of the nucleon current density written as

$$J^\mu = \int \bar{\psi}_p \hat{J}_p^\mu \psi_b e^{i\textbf{q} \cdot \textbf{r}} \text{d}^3r,$$

where $\hat{J}_p^\mu$ is a free weak nucleon current operator, and $\psi_p$ and $\psi_b$ are wave functions of the knocked-out and the bound state nucleons, respectively. For a free nucleon, the NC operator comprises the weak vector and the axial vector form factors

$$\hat{J}_p^\mu = F_1^V(Q^2)\gamma^\mu + F_2^V(Q^2)\frac{i}{2M_N}\sigma^{\mu\nu}q_\nu + G_A(Q^2)\gamma^\mu\gamma^5 + \frac{1}{2M_N}G_P(Q^2)q^\mu\gamma^5.$$

(1)
By the conservation of the vector current (CVC) hypothesis with the inclusion of an isoscalar strange quark contribution, $F_i^s$, the vector form factors for protons and neutrons, $F_i^{V, p(n)}(Q^2)$, are expressed as

$$F_i^{V, p(n)}(Q^2) = \frac{1}{2} - 2\sin^2\theta_W F_i^{p(n)}(Q^2) - \frac{1}{2} F_i^{n(p)}(Q^2) - \frac{1}{2} F_i^s(Q^2),$$

where $\theta_W$ is the Weinberg angle given by $\sin^2\theta_W = 0.2224$. Strange vector form factors are given as

$$F_1^s(Q^2) = \frac{F_1^s Q^2}{(1 + \tau)(1 + Q^2/M_V^2)^2}, \quad F_2^s(Q^2) = \frac{F_2^s(0)}{(1 + \tau)(1 + Q^2/M_V^2)^2},$$

where $\tau = Q^2/(4M_N^2)$, $M_V = 0.843$ GeV, $F_1^s = -< r_s^2 > /6 = 0.53$ GeV$^{-2}$, and $F_2^s(0) = \mu_s$ is a strange magnetic moment given by $\mu_s = -0.4$. Here we exclude strange quark contributions to the electric form factor since their effects turned out to be very small. The axial form factor is given by

$$G_A(Q^2) = \frac{1}{2} (\pm g_A + g_A^s)/(1 + Q^2/M_A^2)^2,$$

where $g_A = 1.262$, $M_A = 1.032$ GeV. The $g_A^s = -0.19$ represents the strange quark contents in the nucleon. $-(+)$ coming from the isospin dependence denotes the knocked-out proton (neutron), respectively. Actually values of $F_i^s$ and $\mu_s$ have some ambiguity due to uncertainties persisting in the strange form factors. Physical parameters to the strangeness are used from ref. whose values are constrained to pertinent experimental data, while other constants are from ref. Since we take + sign for $G_A(Q^2)$ in eq.(2), the axial form factor in eq.(5) is just negative to the form factor elsewhere, for example, in ref.

The induced pseudoscalar form factor is parameterized by the Goldberger-Treiman relation

$$G_P(Q^2) = \frac{2M_N}{Q^2 + m_{\pi}^2} G_A(Q^2),$$

where $m_{\pi}$ is the pion mass. But the contribution of the pseudoscalar form factor vanishes for the NC reaction because of the negligible final lepton mass participating in this reaction.

The strange quark contributions are explicitly contained in $F_i^s$ and $g_A^s$. Since the first term in Eq. (3) rarely contributes due to the given Weinberg angle, the elastic cross section on the proton, $\sigma(\nu p \rightarrow \nu p)$, is sensitive mainly on the $F_i^s$ and $g_A$ values. But measuring of the cross section itself is not so easy experimentally task, so that one usually resorts to the cross section ratio between the proton and the neutron, $R_{p/n} = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \nu n)$. 
Measuring of this ratio has also some difficulties in the neutron detection. Therefore, 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 because the denominator, the charged current (CC) cross section, is relatively insensitive to the strangeness \[^{23}\] .

In this paper, we investigate an alternative way to search for the strangeness by using only NC reactions. It is an asymmetry on the neutrino and antineutrino cross section, 

$$A_{NC} = (\sigma_{NC}^\nu - \sigma_{NC}^\bar{\nu})/(\sigma_{NC}^\nu + \sigma_{NC}^\bar{\nu})$$

where $\sigma_{NC}^{\nu(\bar{\nu})}$ means differential cross sections by $\nu$ and $\bar{\nu}$. If we use Sachs form factors usually related by the nucleon form factors,

$$G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4M^2} F_2(Q^2), G_M(Q^2) = F_1(Q^2) + F_2(Q^2),$$

the NC elastic neutrino(antineutrino) cross section on the nucleon level is expressed in terms of the Sachs form factors \[^{24}\],

$$\frac{d\sigma}{dQ^2}^{NC}_\nu - \frac{d\sigma}{dQ^2}^{NC}_{\bar{\nu}} = -\frac{G_E^2}{2\pi} 4y(1 - \frac{1}{2}y)G_MG_A,$$

and the sum of the cross sections are simply summarized as

$$\frac{d\sigma}{dQ^2}^{NC}_\nu + \frac{d\sigma}{dQ^2}^{NC}_{\bar{\nu}} = \frac{G_E^2}{\pi} \left[ \frac{1}{2}y^2(G_M)^2 + (1 - y - \frac{M}{2E_\nu}y)(G_E)^2 + \frac{E_\nu}{2M}y(G_M)^2 \right] + (\frac{1}{2}y^2 + 1 - y + \frac{M}{2E_\nu}y)(G_A)^2 \right].$$

Here $E_\nu$ is the energy of incident $\nu(\bar{\nu})$ in the laboratory frame, and $y = p \cdot q / p \cdot k = Q^2/2p \cdot k$ with $k, p$ and $q$, initial 4 momenta of $\nu(\bar{\nu})$ and target nucleon, and 4 momentum transfer to the nucleon, respectively. $\mp$ corresponds to the cases of the $\nu$ and $\bar{\nu}$. Therefore the difference and the sum of the cross sections are simply summarized as

$$\frac{d\sigma}{dQ^2}^{NC}_\nu - \frac{d\sigma}{dQ^2}^{NC}_{\bar{\nu}} = -\frac{G_E^2}{2\pi} 4y(1 - \frac{1}{2}y)G_MG_A,$$

$$\frac{d\sigma}{dQ^2}^{NC}_\nu + \frac{d\sigma}{dQ^2}^{NC}_{\bar{\nu}} = \frac{G_E^2}{\pi} \left[ \frac{1}{2}y^2(G_M)^2 + (1 - y - \frac{M}{2E_\nu}y)(G_E)^2 + \frac{E_\nu}{2M}y(G_M)^2 \right] + (\frac{1}{2}y^2 + 1 - y + \frac{M}{2E_\nu}y)(G_A)^2 \right].$$

Here eq.(9), which is the numerator in the $A_{NC}$, is proportional to $G_A$. Since the $y$ variable is given as $Q^2/2E_\nu M$ in the nucleon rest frame, $y$ is always positive, but less than 1 for the energy region, $E_\nu < 1$ GeV and $Q^2 < 1$ GeV$^2$, considered here. It means that the asymmetry $A_{NC}$ could be very sensitive on the $g_A^s$ value because $A_{NC}$ is approximated as $2yG_MG_A/(1 - y)(G_E^2 + G_A^2)$ if $O(y^2)$ and $\frac{E_\nu}{2M}O(y)$ terms are neglected. Moreover, the eq.(9) has a positive sign irrespective of the proton and the neutron. Consequently, $\nu$ cross section is always larger than that of $\bar{\nu}$ on the nucleon level.
Detailed results on the nucleon level are shown in fig. 1 and 2, where the results for $g_A^* = -0.19$ and 0.0 are presented on the proton (fig.1) and the neutron (fig.2). The cross sections by the incident $\nu(\bar{\nu})$ on the proton are usually enhanced in the whole $Q^2$ region by the $g_A$, while they are reduced on the neutron. But the asymmetry on the proton is maximally decreased in the $Q^2 \sim 0.6$ GeV$^2$ region about 15%, while on the neutron it is maximally increased in that region. The ratio, $R_{\bar{\nu}/\nu}$, on the contrary, shows reversed behaviors. Therefore, the $g_A^*$ effects can be detected in the asymmetry $A_{NC}$ around the $Q^2 \sim 0.6$ GeV$^2$ region, more clearly than the cross sections.

Since the neutrino energy was not known exactly at the BNL experiments, one usually defines the flux averaged cross section

$$<\sigma> = \left< \frac{d\sigma}{dQ^2} \right>_{\nu(\bar{\nu})} = \frac{\int dE_{\nu(\bar{\nu})}(d\sigma/dQ^2)^{NC}_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})})}{\int dE_{\nu(\bar{\nu})}\Phi_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})})},$$

(11)

where $\Phi_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})})$ is neutrino and antineutrino energy spectra. The experimental result at BNL, $R_{\bar{\nu}/\nu}^{BNL} = <\sigma(\bar{\nu}p \rightarrow \bar{\nu}p)>/<\sigma(\nu p \rightarrow \nu p)>$, turned out to be about 0.32 [1, 24]. Therefore, the flux averaged asymmetry $<A_{NC}> = (<\sigma_{NC}^\nu>-<\sigma_{NC}^\bar{\nu}>)/(<\sigma_{NC}^\nu>+<\sigma_{NC}^\bar{\nu}>)$ is 0.5 on the nucleon level. This value is approximately consistent with our $A_{NC}$ values in fig. 1 and 2, if they are averaged by $Q^2$.

Now, we investigate whether these asymmetry phenomena still hold in nuclei or not, and the sensitivity of the cross sections and the asymmetry in the nucleus on the $g_A^*$ value. For the application to the $\nu - A$ scattering, we briefly summarize the formula exploited in this paper [25].

The four-momenta of the incident and the outgoing neutrinos (antineutrinos) are labelled $k_i^\mu = (E_i, k_i)$, $k_f^\mu = (E_f, k_f)$. We choose the nucleus fixed frame where the target nucleus is seated at the origin of the coordinate system. $p_A^\mu = (E_A, p_A)$, $p_{A-1}^\mu = (E_{A-1}, p_{A-1})$, and $p^\mu = (E_p, p)$ represent the four-momenta of the target nucleus, the residual nucleus, and the knocked-out nucleon, respectively. In the laboratory frame, the inclusive cross section is given by the contraction between the lepton tensor and the hadron tensor [8]

$$\frac{d\sigma}{dE_f} = 4\pi^2\frac{M_NS_{\nu L}R_L + \nu_TR_T + hv_TR'_T}{(2\pi)^3M_A}\int \sin \theta_L d\theta_L \int \sin \theta_p d\theta_p pf_{\text{rec}}^{-1}\sigma_M^Z[v_LR_L + \nu_TR_T + hv_TR'_T],$$

(12)

where $M_N$ is the nucleon mass, $\theta_L$ denotes the scattering angle of the lepton, and $h = -1$ ($h = +1$) corresponds to the helicity of the incident neutrino (antineutrino). The squared four-momentum transfer is given by $Q^2 = q^2 - \omega^2$. $\sigma_M^Z$ is defined by

$$\sigma_M^Z = \left( \frac{G_F \cos(\theta_L/2)E_M^2}{\sqrt{2\pi}(Q^2 + M_N^2)} \right),$$

(13)
where \( G_F \) is the Fermi constant given by \( G_F \approx 1.16639 \times 10^{-11} \) MeV\(^{-1} \) and \( M_Z \) is the rest mass of \( Z \)-boson. The recoil factor \( f_{\text{rec}} \) is given by

\[
f_{\text{rec}} = \frac{E_{A-1}}{M_A} \left[ 1 + \frac{E_p}{E_{A-1}} \left[ 1 - \frac{q \cdot p}{p^2} \right] \right].
\] (14)

For the NC reaction, the coefficients \( v \) in eq.(12) are given by

\[
v_L = 1, \quad v_T = \tan^2 \frac{\theta_L}{2} + \frac{Q^2}{2q^2}, \quad v'_T = \tan^2 \frac{\theta_L}{2} \left[ \tan^2 \frac{\theta_L}{2} + \frac{Q^2}{q^2} \right]^{1/2}.
\] (15)

The corresponding response functions are given by

\[
R_L = \left| J^0 - \frac{\omega}{q} J_z \right|^2, \quad R_T = |J^x|^2 + |J^y|^2, \quad R'_T = 2\text{Im}(J^x J^{y*}).
\] (16)

Here the \( R'_T \), which is a transverse response function for a target nuclei, just corresponds to the last term in the Eq.(8) on the nucleon level. We calculate the NC \( \nu(\bar{\nu}) \) scattering on the target \( ^{12}\text{C} \) nucleus in the QE region for two incident energies, 500 MeV and 1.0 GeV.

Figure 3 and 4 exhibit the strange quark contributions to the cross section by \( \nu(\bar{\nu}) \) scattering on the \( ^{12}\text{C} \) target nuclei, \( i.e. \) \( ^{12}\text{C}(\nu(\bar{\nu})^{\prime},\nu(\bar{\nu})^{\prime}) \). 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 knocked-out nucleon [16] is taken into account for the FSI. Detailed discussions about the FSI are presented at our previous paper [25].

To analyze cross sections for \( \nu - ^{12}\text{C} \) (solid curves) in fig.3, we present each contribution by the neutron (dotted curves) and the proton (dashed curves), which includes knocked-out or excited states of the corresponding nucleon by the incident \( \nu \). The effect of \( g_A^s \) for the protons is increased by 30\% for 500 MeV and 31\% for 1.0 GeV, but for the knocked-out neutrons it is decreased by 30\% for 500 MeV and 29\% for 1.0 GeV, maximally. These individual \( g_A^s \) effects on each nucleon resemble exactly those of each nucleon in fig. 1 and 2, \( i.e. \), the \( g_A^s \) effects by protons increase the cross section and decreases those of neutrons. These phenomena are quite natural because the knocked-out nucleons are scattered by the QE processes and they are main contributions in the inclusive reaction.

However, total net \( g_A^s \) effects may severely depend on the competition between the proton and neutron processes. In the case of \( ^{12}\text{C} \), the enhancement due to the \( g_A^s \) by the proton is nearly compensated by the neutron process, so that the net effect of \( g_A^s \) increases the cross sections only by about 3\% for 500 MeV and 2\% for 1.0 GeV, maximally. These values are much smaller than those on the elementary process.
For the incident $\bar{\nu}$ in fig.4, the $g_A^s$ effect enhances the results by 21% for 500 MeV and by 19% for 1.0 GeV on the knocked-out protons, but reduces them by 20% for 500 MeV and 18% for 1.0 GeV for the neutrons, maximally. The reduction by the neutron is nearly balanced by the enhancement due to the proton. Consequently, the net effect of the strange quark reduces the total cross sections only by 1% for 500 MeV and 2% for 1.0 GeV, maximally, similarly to the $\nu$ case. In specific, in the $\nu$ case of fig.3, the net effect is nearly indiscernible.

From these results, in the $\nu - A$ cross sections, the $g_A^s$ effect turned out to contribute more positively to the protons while it does negatively to the magnitude of the cross sections for the neutrons. Total net effects in nuclei due to the $g_A^s$ come from the competition of the two knocked-out nucleon processes in the QE region, whose detailed competition may depend severely on the target nuclei. In the case of $^{12}C$, the strange quark effects reduce the cross sections for the $\nu$ and the $\bar{\nu}$, although the resultant effects are only within a few % by the cancellation. Therefore, the $g_A^s$ effect in nuclei is too small to be deduced from the $A(\nu,\nu')$ cross section itself.

The asymmetry between the $\nu -$ and $\bar{\nu} - A$ scattering processes is hinged on the third term in Eq. (12), $R_T'$, due to its helicity dependence. Using the helicities, the asymmetry between $\nu$ and $\bar{\nu}$ is written as

$$A_{NC} = \frac{\sigma(h = -1) - \sigma(h = +1)}{\sigma(h = -1) + \sigma(h = +1)},$$

where $\sigma$ denotes the differential cross section in Eq. (12) and $h = -1$ ($h = +1$) represents the helicity of the incident $\nu(\bar{\nu})$. Our results for the asymmetry $A_{NC}$ in the $^{12}C(\nu(\bar{\nu}),\nu'(\bar{\nu}'))$ reaction are shown in fig.5. For $E_\nu = 500MeV$ case, in the region $T_\nu = 250 \sim 300$ MeV region, which just corresponds to $Q^2(\sim 2MT_\nu) \sim 0.6$ GeV$^2$ region, the $g_A^s$ effects appear maximally as expected from the elementary processes. But the amounts of the $g_A^s$ effects, i.e. the gaps in solid and dashed curves, are much smaller than the 15 % on the nucleon level. It is also remarkable that the $A_{NC}$ value averaged by $T_\nu$ is as large as that of the nucleon level, about 0.5 because the $A_{NC}$ averaged by $T_\nu$ corresponds to that of $A_{NC}$ averaged by $Q^2$ on the elementary processes. Therefore $g_A^s$ effects in $A_{NC}$ do not show any drastic effects in nucleus just like cross sections (the solid lines in fig. 3 and 4). But, likewise nucleon level, positive values of $A_{NC}$ indicate that cross sections by $\nu$ is always larger than that of $\bar{\nu}$, at least the QE region considered here, even in nuclei.

In order to more clearly understand these results, the $g_A^s$ effects on the asymmetry via
the proton and the neutron knockout processes are separately investigated in fig. 6 and 7. Solid and dashed curves represent the results with $g_A^s = -0.19$ and $g_A^s = 0.0$, respectively. The $g_A^s$ effects in $A_{NC}$ show a tendency nearly same as those of nucleons in fig. 1 and 2, i.e. the proton knockout case is decreased contrary to the neutron knockout case which is increased by $g_A^s$ effects. The relatively small effects in fig. 5 turned out to stem from some cancellation between reduction by protons and enhancement by neutrons in this inclusive reaction.

If one wants to search for the $g_A^s$ effects in nuclei, therefore, the asymmetries in the exclusive reactions, $^{12}\text{C}(\nu(\bar{\nu}),\nu'(\bar{\nu}')\text{N})$ detecting knocked-out nucleon, are more efficient tools rather than the inclusive reactions. In specific, the asymmetry in the $T_p = 200 \sim 250$ MeV region for the knocked-out nucleon in the reaction, could be more efficient tests on searches of the $g_A^s$ effect.

In conclusion, the $g_A^s$ effect in the NC $\nu(\bar{\nu})$ scattering on the nucleon enhances the cross section for the proton, but reduces it for the neutron. But in the $\nu - A$ scattering on the QE region both protons’ and neutrons’ contributions compensate each other in the cross section, so that the net effects are sensitive, sometimes nearly indiscernible, on the nuclear structure because of the possible cancellations. The effects in the asymmetry between $\nu$ and $\bar{\nu}$ scattering also show a similar competing mechanism between knocked-out protons and neutrons. It means that exclusive reactions detecting knocked-out nucleon, such as $A(\nu(\bar{\nu}),\nu'(\bar{\nu}')\text{N})$, could be more plausible tests for the effect rather than inclusive reactions, $A(\nu(\bar{\nu}),\nu'(\bar{\nu}'))$, because there are no competitions of the $g_A^s$ effects between the processes via the knockout protons and the knockout neutrons in the exclusive reaction.

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FIG. 1: $d\sigma/dQ$\textsuperscript{2} for $\nu (\bar{\nu}) p \rightarrow \nu (\bar{\nu}) p$ by the neutral current in an arbitrary unit (upper part), asymmetry, and ratio $R$ for $\bar{\nu}/\nu$ on the proton as a function of the incident energy $E = 500$ MeV, They are calculated for $g_s A = -0.19$ and 0.0 cases, respectively.
FIG. 2: The same as figure 1, but for the neutron target.
FIG. 3: Neutral current $^{12}\text{C}(\nu, \nu')$ cross section as a function of the knocked out nucleon kinetic energy $T_p$ at incident neutrino energy $E = 500$ MeV. 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 $g_A^p = -0.19$ and $g_A^n = 0$. The optical potential of the knocked-out nucleon is used for the final state interaction.
FIG. 4: The same as Fig. 3 but for the antineutrino.
FIG. 5: The asymmetry as a function of the kinetic energy of the knocked-out nucleon. Solid and dashed curves represent the results with $g_A^s = -0.19$ and $g_A^s = 0$, respectively.
FIG. 6: The asymmetry as a function of the kinetic energy of the knocked-out proton with the same kinematics as Fig. 5. Solid and dashed curves represent the results with $g_A^s = -0.19$ and $g_A^s = 0$, respectively.
FIG. 7: The asymmetry as a function of the kinetic energy of the knocked-out neutron with the same kinematics as Fig. 5. Solid and dashed curves represent the results with $g_A^s = -0.19$ and $g_A^s = 0$, respectively. In the case of neutron, the asymmetry seems to be increased, but the absolute values are decreased consistently with the neutron case in Fig. 2. The difference in 1.0 GeV case is nearly indiscernible.
