In-medium modifications of the nucleon weak and electromagnetic form factors effects in neutrino interaction in dense matter

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4. Differential cross section
5. Mean Free Path
6. Conclusion and Outlook

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2. MATTER MODEL
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4. DIFFERENTIAL CROSS SECTION
5. MEAN FREE PATH
6. CONCLUSION AND OUTLOOK

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Motivation

- Previous study found that the neutrino mean free path (NMFP) of neutrino scattering (neutral current) is larger than that of the neutrino absorption (charged current) [1]
- Also they found that the propagation of neutrino in neutron matter is longer in medium than in vacuum.
- A few attempts were made to calculate neutrino differential cross section (DCRS) by consider weak magnetism (tensor part) and form factors in order to describe more realistic situation [2]. However they used free (vacuum) form factors of the nucleon
- From experimental side, such in-medium modification are strongly implied by several experiments [3]
- Therefore in this work we consider the medium modification of the weak and EM nucleon form factors in dense matter

[1] C. Shen, U. Lumbardo, N. V. Giai, and W. Zuo, PRC**68**, 055802 (2003)

[2] C. J. Horowitz, et al., PRD **65**, 043001 (2002) and reference therein

[3] S. Strauch [E93-049 Collaboration], et al., EPJA **19** (2004) and reference therein

To describe the constituents interaction in matter, here we use effective relativistic mean field (E-RMF) model. The effective Lagrangian density of E-RMF [4] [5] is defined as

$$\mathscr{L}_{E-RMF} = \mathscr{L}_N + \mathscr{L}_M \tag{1}$$

where for nucleons, the Lagrangian density is taken up to order $\nu = 3$, is defined by

$$\begin{aligned} \mathscr{L}_N &= \psi \left[i\gamma^\mu(\partial_\mu + i\bar{\nu}_\mu + ig_\rho \bar{b}_\mu + ig_\omega V_\mu) + g_A \gamma^\mu \gamma^5 \bar{a}_\mu - M + g_\sigma \sigma \right] \psi \\ &- \frac{f_\rho g_\rho \bar{\psi} \bar{b}_{\mu\nu} \sigma^{\mu\nu} \psi}{4M} \end{aligned} \tag{2}$$

[4] A.Sulaksono, P. H and T.Mart, PRC**72**, 065801 (2005)

[5] Furnstahl *et al.*, NPA**589**, 539 (1996)

where

$$\psi = \begin{pmatrix} p \\ n \end{pmatrix} \quad \bar{\nu} = -\frac{i}{2}\left(\bar{\xi}^{\dagger}\partial_{\mu}\bar{\xi} + \bar{\xi}\partial_{\mu}\bar{\xi}^{\dagger} = \bar{\nu}^{\dagger}\right)$$

$$\bar{a}_{\mu} = -\frac{i}{2}\left(\bar{\xi}^{\dagger}\partial_{\mu}\bar{\xi} - \bar{\xi}\partial_{\mu}\bar{\xi}^{\dagger}\right) = \bar{a}_{\mu}^{\dagger} \quad \text{where} \quad \bar{\xi} = \exp\left(i\bar{\pi}(x)/f_{\pi}\right)$$

$$\bar{\pi}(x) = \frac{1}{2}\vec{\tau}\cdot\vec{\pi}(x) \quad \bar{b}_{\mu\nu} = D_{\mu}\bar{b}_{\nu} - D_{\nu}\bar{b}_{\mu} + ig_{\rho}\left[\bar{b}_{\mu}, \bar{b}_{\nu}\right]$$

$$D_{\mu} = \partial_{\mu} + i\bar{\nu}_{\mu} \quad V_{\mu\nu} = \partial_{\mu}V_{\nu} - \partial_{\nu}V_{\mu} \quad \sigma^{\mu\nu} = \frac{1}{2}\left[\gamma^{\mu}, \gamma^{\nu}\right]$$

$$\nu = d + \frac{n}{2} + b \tag{3}$$

where ν is the power of fields and their derivatives, d, n and b are respectively the number of derivatives, the number of the nucleon fileds and the number of the Goldstone boson fields in the interaction.

For the meson Lagrangian is defined as

$$
\begin{aligned}
\mathcal{L}_M &= \frac{1}{4} f_\pi^2 \mathrm{Tr}\left[\partial_\mu \bar{U} \partial^\mu \bar{U}^\dagger\right] + \frac{1}{4} f_\pi^2 \mathrm{Tr}\left[\bar{U}\bar{U}^\dagger - 2\right] + \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma \\
&- \frac{1}{2}\mathrm{Tr}\left[\bar{b}_{\mu\nu}\bar{b}^{\mu\nu}\right] - \frac{1}{4} V_{\mu\nu} V^{\mu\nu} - g_{\rho\pi\pi}\frac{2 f_\pi^2}{m_\rho^2}\mathrm{Tr}\left[\bar{b}_{\mu\nu}\bar{\nu}^{\mu\nu}\right] \\
&+ \frac{1}{2}\left[1 + \eta_1 \frac{g_\sigma \sigma}{M} + \frac{\eta_2}{2}\frac{g_\sigma^2 \sigma^2}{M^2}\right] m_\omega^2 V_\mu V^\mu + \frac{1}{4!}\zeta_0 g_\omega^2 \left(V_\mu V^\mu\right)^2 \\
&+ \left[1 + \eta_\rho \frac{g_\sigma \sigma}{M} m_\rho^2\right] \mathrm{Tr}\left[\bar{b}_\mu \bar{b}^\mu\right] - m_\sigma^2 \sigma^2 \left[1 + \frac{\kappa_3}{3!}\frac{g_\sigma \sigma}{M} + \frac{\kappa_4}{4!}\frac{g_\sigma^2 \sigma^2}{M^2}\right]
\end{aligned}
\qquad (4)
$$

where $\bar{U} = \bar{\xi}^2$ and $\bar{\nu}_{\mu\nu} = \partial_\mu \bar{\nu}_\nu - \partial_\nu \bar{\nu}_\mu + i\left[\bar{\nu}_\mu, \bar{\nu}_\nu\right] = -i\left[\bar{a}_\mu, \bar{a}_\nu\right]$.

Parameter set used in the E-RMF model

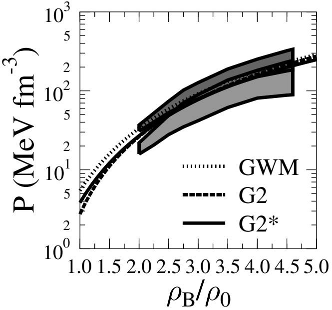
In this calculation we used the GWM parameter set [6]. By taking η_1, η_2, ζ_0, η_ρ and f_ρ equal to zero, we obtain the same EOM as in standard RMF models.

Parameters	*GWM*
m_σ/M_N	0.554
$(g_\sigma/m_\sigma)^2$	9.148 fm^2
$(g_\omega/m_\omega)^2$	4.820 fm^2
$(g_\rho/m_\rho)^2$	4.791 fm^2
κ_3	0
κ_4	0
ζ_0	0
η_1	0
η_2	0
η_ρ	0

[6] M. Chiapparini, H. Rodrigues and S. B. Duarte, PRC**54**, 936-941 (1996)

EOS prediction of the E-RMF model

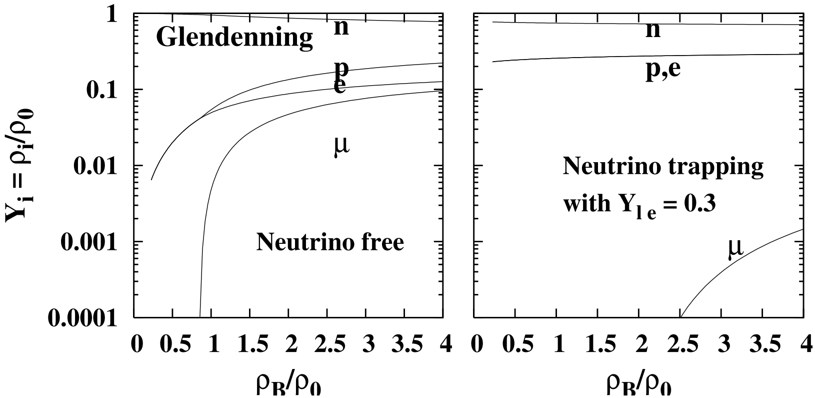
Pressure, $E_B = 16.30$MeV, Effective mass $M^*/M = 0.77$, saturation density $\rho_0 = 0.15$ fm^3, compression modulus $K = 219$ MeV which has an excellent agreement with the experimental data $K = 210 \pm 30$ [7]and symmetry coefficient = 36.8 MeV



[7] J. P. Blaizot, Phys. Rept. **64**, 171 (1980)

Fraction of matter

Here we show the fraction of matter with/without neutrino trapping



This result is similar as obtained in Ref. [6].

The interaction neutrino with matter can be described by the Lagrangian density, that is [8]

$$\mathcal{L}^j_{int} = \frac{G_F}{\sqrt{2}} \left(\bar{\nu}\Gamma^\mu_W \nu\right)\left(\bar{\psi} J^{Wj}_a \psi\right) + \frac{4\pi\alpha}{q^2}\left(\bar{\nu}\Gamma^\mu_{EM}\nu\right)\left(\bar{\psi} J^{EMj}_a \psi\right) \quad (5)$$

where

$$\begin{aligned}
\Gamma^\mu_W &= \gamma^\mu(1-\gamma^5) \\
\Gamma^\mu_{EM} &= f_{\mu\nu}\gamma^\mu + g_{1\nu}\gamma^\mu\gamma^5 - \left(f_{1\nu} + i g_{2\nu}\gamma^5\right)\frac{P^\mu}{2m_e^2} \\
J^{Wj}_\mu &= F^{Qj}_1 \gamma_\mu - G^j_A \gamma_\mu \gamma^5 + i F^{Wj}_2 \frac{\sigma_{\mu\nu} q^\mu}{2M} \\
J^{EMj}_\mu &= F^{EMj}_1 \gamma_\mu + i F^{EMj}_2 \frac{\sigma_{\mu\nu} q^\mu}{2M}
\end{aligned} \quad (6)$$

[8] A. Sulaksono, PTPH and T. Mart, PRC**72**, 065801 (2005)

The electromagnetic properties of Dirac Neutrinos are described in terms of four form factors $f_{1\nu}$, $g_{1\nu}$, $f_{2\nu}$ and $g_{2\nu}$ (Dirac, anapole, magnetic and electric form factors, respectively :

$$\Gamma^{\mu}_{EM} = f_{1m\nu}\gamma^{\mu} + g_{1\nu}\gamma^{\mu}\gamma^{5} - \left(f_{2\nu} + ig_{2\nu}\gamma^{5}\right)\frac{P^{\mu}}{2m_e} \quad (7)$$

where m_ν and m_e are the neutrino and electron masses, respectively.

$$f_{m\nu} = f_{1\nu} + \left(\frac{m_\nu}{m_e}\right) f_{2\nu} \quad P^{\mu} = k^{\mu} + k^{\mu'} \quad (8)$$

NOTE : In this work, we calculate the general formulation for neutrino interaction in matter by considering the neutrino form factors.

In the static limit, the reduced Dirac form factor, $f_{1\nu}$ and the neutrino anapole form factor $g_{1\nu}$ are related to the vector and axial charge radii $\langle r_V^2 \rangle$ and $\langle r_A^2 \rangle$:

$$f_{1\nu}(q^2) = \frac{1}{6}\langle r_V^2 \rangle q^2 \qquad g_{1\nu}(q^2) = \frac{1}{6}\langle r_A^2 \rangle q^2 \tag{9}$$

where the neutrino charges radius is defined as

$$r^2 = \langle r_V^2 \rangle + \langle r_A^2 \rangle \tag{10}$$

In the limit of $q^2 \to 0$, $f_{2\nu}$ and $g_{2\nu}$ define respectively the neutrino magnetic moment and the *Charge Parity* (CP) violating electric dipole moment:

$$\begin{aligned} \mu_\nu^m &= f_{2\nu}(0)\mu_B \quad \text{and} \quad \mu_\nu^e = g_{2\nu}(0)\mu_B \\ \mu_\nu^2 &= \mu_\nu^{m2} + \mu_\nu^{e2} \end{aligned} \tag{11}$$

Weak form factors in the limit of $q^2 \to 0$. Here we use
$\sin\theta_W = 0.231$, $g_A = 1.260$, $\mu_p = 1.793$ and $\mu_n = -1.913$ [9]

Reaction	F_1^W	G_A	F_2^W
$\nu_i n \to \nu_i n$	-0.5	- $g_A/2$	- $(\mu_p - \mu_n)/2$ - 2 $\sin^2\theta_W \mu_n$
$\nu_i p \to \nu_i p$	0.5 -2 $\sin^2\theta_W$	$g_A/2$	$(\mu_p - \mu_n)/2$ - 2 $\sin^2\theta_W \mu_p$
$\nu_e e \to \nu_e e$	0.5 + 2 $\sin^2\theta_W$	1/2	0
$\nu_\mu \mu \to \nu_\mu \mu$	0.5 + 2 $\sin^2\theta_W$	1/2	0
$\nu_{\mu\tau} e \to \nu_{\mu\tau} e$	-0.5 + 2 $\sin^2\theta_W$	-1/2	0
$\nu_{\mu\tau} \mu \to \nu_{\mu\tau} \mu$	-0.5 + 2 $\sin^2\theta_W$	-1/2	0

For anti-neutrinos, we replace $G_A^j \to -G_A^j$
In Medium modification, $G_A \to G_A^*$, $F_{2p,n} \to F_{2p,n}^*$ and $F_2^W \to F_2^*$.

[9] C.J.Horowitz and M.A.P.Garcia, PRC**68**, 025803 (2003)

Target Particles Electromagnetic Form Factor in vacuum

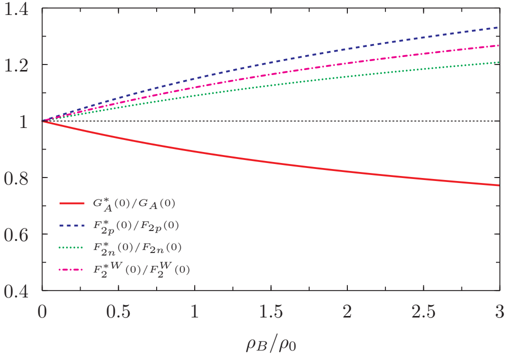
Electromagnetic Form Factor in the limit $q^2 \to 0$ [10]

Target	F_1^{EM}	F_2^{EM}
n	0	μ_n
p	1	μ_p
e	1	0
μ	1	0

[10] P. Vogel and J. Engel, PRD**39**, 3378 (1989)

Target particles Form Factor in the Medium

In medium modifications, $G_A \to G_A^*$, $F_{2p,n} \to F_{2p,n}^*$ and $F_2^W \to F_2^*$. This results are calculated using the Quark-Meson Coupling (QMC) model [11]. [Next talks of Kazuo and Javier]



This in-medium modified nucleon form factors will be used as an INPUT to ~~neutrino interaction with matter.~~

[11] K. Saito, K. Tsushima and A. Thomas, PPNP**58**, 1-167 (2007)

Using the Lagrangian density, the differential cross section is obtained as

$$\left(\frac{1}{V}\frac{d^3\sigma}{d^2\Omega dE_\nu^{'}}\right) = -\frac{1}{16\pi^2}\frac{E_\nu^{'}}{E_\nu}[\left(\frac{G_F}{\sqrt{2}}\right)\left(L_\nu^{\mu\nu}\Pi_{\mu\nu}^{Im}\right)^{(W)} + \left(\frac{4\pi\alpha}{q^2}\right)^2 (L_\nu^{\mu\nu}\Pi_{\mu\nu}^{Im})^{(EM)} + \frac{8G_F\pi\alpha}{q^2\sqrt{2}}\left(L_\nu^{\mu\nu}\Pi_{\mu\nu}^{Im}\right)^{(INT)}] \quad (12)$$

where the weak coupling, $G_F = 1.023 \times 10^{-5}/M^2$, where M is the nucleon mass.

Weak, EM and INT Contribution

The neutrino tensors for the weak contribution is given by

$$L_{\nu}^{\mu\nu(W)} = 8\left[2k^{\mu}k^{\nu} - (k^{\mu}q^{\nu} + k^{\nu}q^{\mu}) + g^{\mu\nu}(k.q) - i\epsilon^{\alpha\mu\beta\nu}k_{\alpha}k_{\beta}^{'}\right] \tag{13}$$

$$\begin{aligned} L_{\nu}^{\mu\nu(EM)} &= 4(f_{m\nu}^2 + g_{1\nu})[2k^{\mu}k^{\nu} - (k^{\mu}q^{\nu} + k^{\nu}q^{\mu}) + g^{\mu\nu}(k.q)] \\ &- 8if_{m\nu}g_{1\nu}\epsilon^{\alpha\mu\beta\nu}(k_{\alpha}k_{\beta}^{'}) \\ &- \frac{f_{2\nu}^2 + g_{2\nu}^2}{m_e^2}(k.q)[4k^{\mu}k^{\nu} - 2(k^{\mu}q^{\nu} + q^{\mu}k^{\nu}) + q^{\mu}q^{\nu}] \end{aligned} \tag{14}$$

and for the interference contribution:

$$\begin{aligned} L_{\nu}^{\mu\nu(INT)} &= 4(f_{m\nu} + g_{1\nu})[2k^{\mu}k^{\nu} - (k^{\mu}k^{\nu} + k^{\nu}q^{\mu}) + g^{\mu\nu}(k.q) \\ &- i\epsilon^{\alpha\mu\beta\nu}k_{\alpha}k_{\beta}^{'}] \end{aligned} \tag{15}$$

The Polarization Tensors

The polarization tensors $\Pi^{\mu\nu}$ for the weak (W) , electromagnetic (EM) and interference (INT) terms, which define the target particles, can be written as

$$\begin{aligned}
\Pi^{Im(W)j}_{\mu\nu} &= (F_1^{Wj2} + G_A^{j2})\Pi^{Vj}_{\mu\nu} \\
&+ \left(G_A^{j2} + \frac{q^2}{2mM}F_1^{Wj}F_2^{Wj}\right)\Pi^{Aj}g_{\mu\nu} \\
&- 2\left(F_1^{Wj}G_A^j + \frac{m}{M}F_2^{Wj}G_A^j\right)\Pi^{V-Aj}_{\mu\nu} \\
&+ \frac{F_2^{Wj2}}{M^2}\left[(m^2 + \frac{q^2}{4})(q^2 g_{\mu\nu} - q_\mu q_\nu) - \frac{q^2}{8}\Pi^{Vj}_{\mu\nu}\right] \qquad (16)
\end{aligned}$$

The polarization tensors $\Pi^{\mu\nu}$ for the electromagnetic (EM) can be written as

$$\begin{aligned}\Pi^{Im(EM)j}_{\mu\nu} &= F_1^{EMj2}\Pi^{Vj}_{\mu\nu} \\ &+ \frac{q^2}{2mM}F_1^{EMj}F_2^{EMj}\Pi^{Aj}g_{\mu\nu} \\ &+ \frac{F_2^{EMj2}}{M^2}\left[(m^2+\frac{q^2}{4})(q^2 g_{\mu\nu}-q_\mu q_\nu)-\frac{q^2}{8}\Pi^{Vj}_{\mu\nu}\right]\end{aligned} \tag{17}$$

The Polarization tensors

The polarization tensors for the interference contribution can be written as

$$\begin{aligned}\Pi^{Im(INT)j}_{\mu\nu} &= (F_1^{Wj}F_1^{EMj} + \frac{q^2}{4M^2}F_2^{Wj}F_2^{EMj})\Pi^{Vj}_{\mu\nu} \\ &+ \left[\frac{F_2^{Wj}F_2^{EMj}}{4M^2}(1+\frac{q^2}{4m^2} - \frac{(F_1^{Wj}F_2^{EMj} + F_2^{Wj}F_1^{EMj})}{4mM}\right] \\ &\times (q^2 g_{\mu\nu} - q_\mu q_\nu)\Pi^{Aj} + \left(\frac{m}{M}F_2^{EMj}G_A^j - F_1^{EMj}G_A^j\right)\Pi^{V-Aj}_{\mu\nu}\end{aligned} \tag{18}$$

where $j = n, p$ (nucleons), M is equal to M^* and M is the nucleon mass, while for $j = e^-, \mu^-$ (leptons), m is the lepton mass.

Due to the current conversations and translational invariance, the vector polarization $\Pi^{ImV}_{\mu\nu}$ of every contribution consists of two independent components which we choose to be in the frame of $q^{\mu} \equiv (q_0, \mid \vec{q} \mid, 0, 0)$. The explicit forms of Π_T, Π_L, Π_{VA} and Π_A for nucleons [12]are

$$\begin{aligned}\Pi_T &= \frac{1}{4\pi \mid \vec{q} \mid}[\left(M^{*2} + \frac{q^4}{4 \mid \vec{q} \mid^2} + \frac{q^2}{2}\right)(E_F - E^*) \\ &+ \frac{q_0 q^2}{2 \mid \vec{q} \mid^2}(E_F^2 - E^{*2}) + \frac{q^2}{3 \mid \vec{q} \mid^2}(E_F^3 - E^{*3})]\end{aligned} \tag{19}$$

This result is similar as obtained in Ref.[12].

[12] C.J.Horowitz and J.Piekarewicz, PRL **86**, 5647 (2001)

The polarization tensors

For the Longitudinal and vector-axial and axial polarization tensors:

$$
\begin{aligned}
\Pi_L &= \frac{q^2}{2\pi \mid \vec{q} \mid^3} \left[\frac{1}{4}(E_F - E^*) q^2 + \frac{q_0}{2}(E_F^2 - E^{*2}) + \frac{1}{3}(E_F^3 - E^{*3}) \right] \\
\Pi_{VA} &= \frac{iq^2}{8\pi \mid \vec{q} \mid^3} \left[(E_F^2 - E^{*2}) + q_0 (E_F - E^*) \right] \\
\Pi_A &= \frac{i}{2\pi \mid \vec{q} \mid} M^{*2} (E_F - E^*)
\end{aligned} \tag{20}
$$

This result is similar as obtained in Ref.[12].

The contraction of every polarization and neutrino tensors couple $L^{\mu\nu}\Pi_{\mu\nu}$ are [13]

$$
\begin{aligned}
(L^{\mu\nu}_{\nu}\Pi^{Im}_{\mu\nu})^{(W)} &= -8q^2 \sum_{j=n,p,e^-,\mu^-} [A^j_W(\Pi^j_L + \Pi^j_T) + B^j_{1W}\Pi^j_T \\
&+ B^j_{2W}\Pi^j_A + C^j_W\Pi^j_{VA}] \\
\left(L^{\mu\nu}_{\nu}\Pi^{Im}_{\mu\nu}\right)^{(EM)} &= q^2 \sum_{j=n,p,e^-,\mu^-} [A^j_{EM}\left(\Pi^j_L + \Pi^j_T\right) \\
&+ B^j_{1EM}\Pi^j_T + B^j_{2EM}\Pi^J_A] \\
\left(L^{\mu\nu}_{\nu}\Pi^{Im}_{\mu\nu}\right)^{(INT)} &= -4q^2 \sum_{j=n,p,e^-,\mu^-} [A^i_{INT}\left(\Pi^j_L + \Pi^j_T\right) \\
&+ B^j_{1INT}\Pi^j_T + B^j_{2INT}\Pi^J_A + C^j_{INT}\Pi^j_{VA}]
\end{aligned} \tag{21}
$$

[13] PTPH, A. Sulaksono and T. Mart, NPA**782**, 400 (2007)

For weak contribution, the function in front of every polarization terms in Eq. (21) are given by

$$
\begin{aligned}
A^j_W &= \left(\frac{2E(E-q_0)+\frac{1}{2}q^2}{|\vec{q}|^2}\right)\left[F_1^{Wj2}+G_A^{j2}-\frac{F_2^{Wj2}q^2}{4M_N^2}\right] \\
B^j_{1W} &= \left[F_1^{Wj2}+G_A^{j2}-\frac{F_2^{Wj2}q^2}{4M_N^2}\right] \\
B^j_{2W} &= -\left[G_A^{j2}+\frac{q^2}{2mM_N}F_1^{Wj}F_2^{Wj}-\frac{F_2^{Wj2}q^2}{4M_N^2\left(1+\frac{q^2}{4m^2}\right)}\right] \\
C^j_W &= -2\left(2E-q_0\right)\left[F_1^{Wj}G_A^{Wj}+\frac{m}{M_N}F_2^{Wj}G_A^j\right],
\end{aligned}
\tag{22}
$$

For EM contribution, the function in front of every polarization terms in Eq. (21) are given by

$$
\begin{aligned}
A^j_{EM} &= \left[\left(\frac{2E\,(E-q_0)+\frac{1}{2}q^2}{|\,\vec{q}\,|^2}\left(bq^2-a\right)+\frac{1}{2}bq^2\right)\right] \\
&\times\left[F_1^{EMj2}-\frac{F_2^{EM2j}q^2}{4M_N^2}\right] \\
B^j_{1EM} &= -\frac{1}{2}\left(bq^2+a\right)\left[F_1^{EMj2}-\frac{F_2^{EMj2}q^2}{4M_N^2}\right] \\
B^j_{2EM} &= \frac{1}{2}\left(bq^2+a\right)\left[\frac{q^2}{2mM_N}F_1^{EMj}F_2^{EMj}-\frac{F_2^{EMj2}q^2}{4M_N^2}\left(1+\frac{q^2}{4m^2}\right)\right], \qquad (23)
\end{aligned}
$$

where $a = 4(f^2_{\mu\nu}+g^2_{1\nu})$, $b = \frac{f^2_{2\nu}+g^2_{2\nu}}{m_e^2}$ and $c = f_{\mu\nu}+g_{1\nu}$

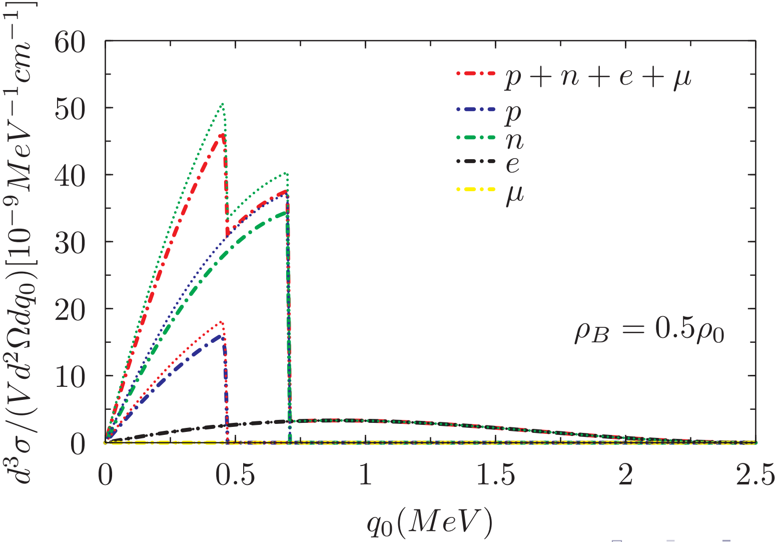
For INT contribution, the function in front of every polarization terms in Eq. (21) are given by

$$\begin{aligned}
A^j_{INT} &= c\left(\frac{2E\left(E-q_0\right)+\frac{1}{2}q^2}{\mid \vec{q}\mid^2}\right)\left[F_1^{Wj}F_1^{EMj}+\frac{q^2}{4M_N^2}F_2^{Wj}F_2^{EMj}\right]\\
B^j_{1INT} &= c\left[F_1^{Wj}F_1^{EMj}+\frac{q^2}{4M_N^2}F_2^{Wj}F_2^{EMj}\right]\\
B^j_{2INT} &= -cq^2\left[\frac{F_2^{Wj}F_2^{EMj}}{4M_N^2}\left(1+\frac{q^2}{4m^2}\right)-\frac{\left(F_1^{Wj}F_2^{EMj}+F_2^{Wj}F_1^{EMj}\right)}{4mM_N}\right]\\
C^j_{INT} &= c\left(2E-q_0\right)\left[\frac{m}{M_N}F_2^{EMj}G^j_A-F_1^{EMj}G^j_A\right]
\end{aligned} \tag{24}$$

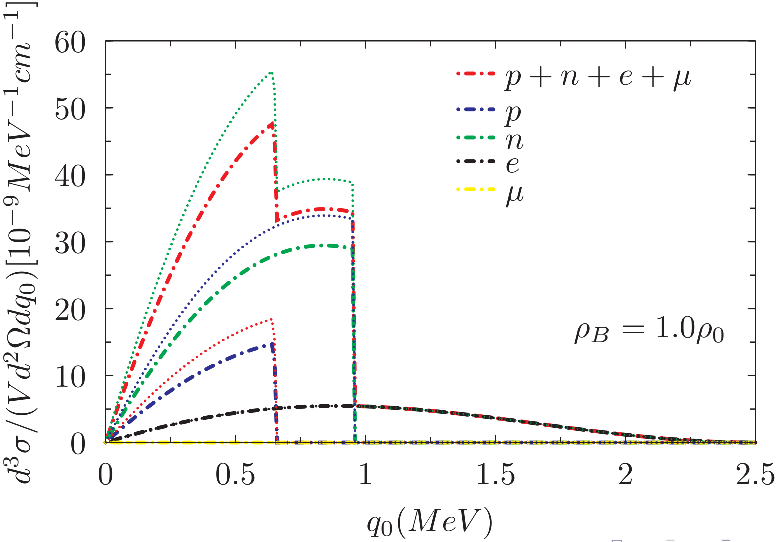
where $a=4(f^2_{\mu\nu}+g^2_{1\nu})$, $b=\frac{f^2_{2\nu}+g^2_{2\nu}}{m_e^2}$ and $c=f_{\mu\nu}+g_{1\nu}$

Results of the DCRS

The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter for ρ_B = 0.5 ρ_0.



The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter for ρ_B = 1.0 ρ_0.



Results of the DCRS

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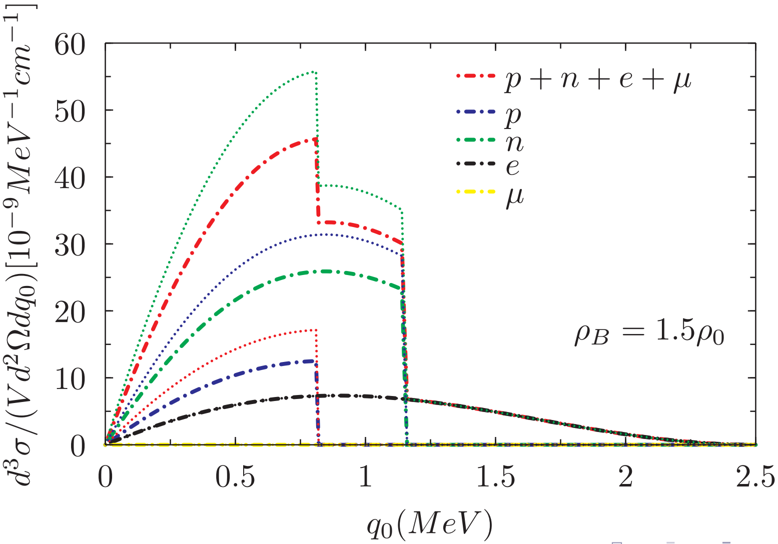
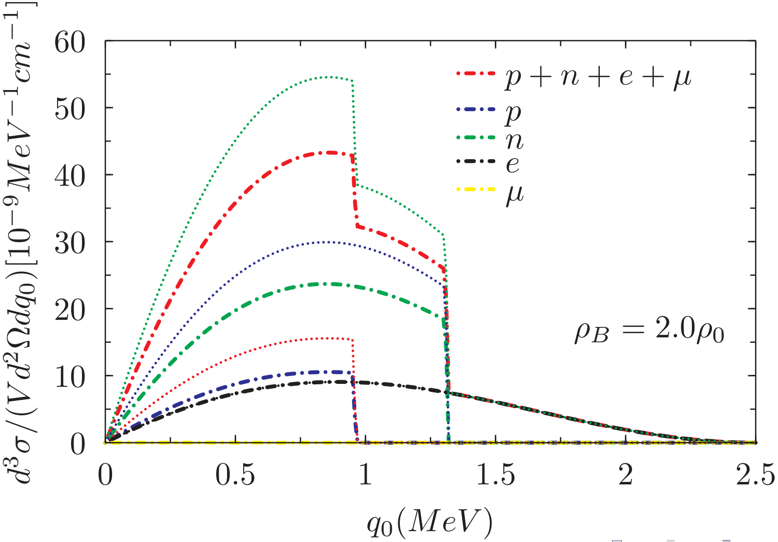


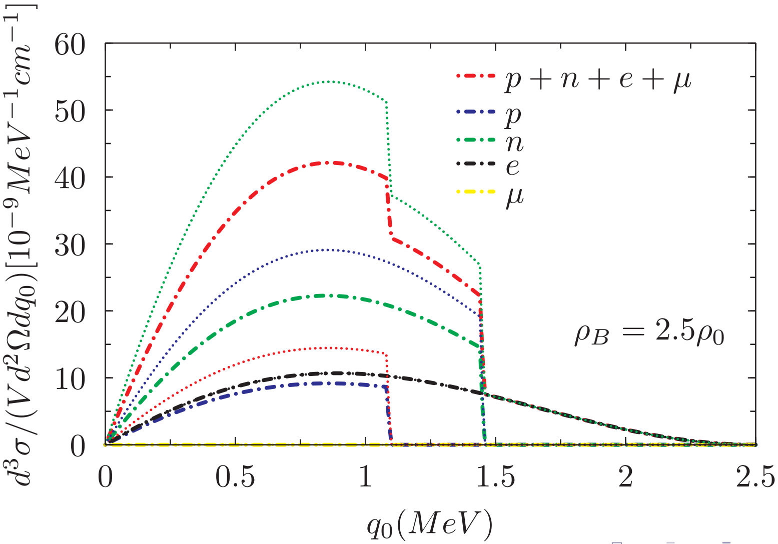
Results of the DCRS

The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter for ρ_B = 2.0 ρ_0.

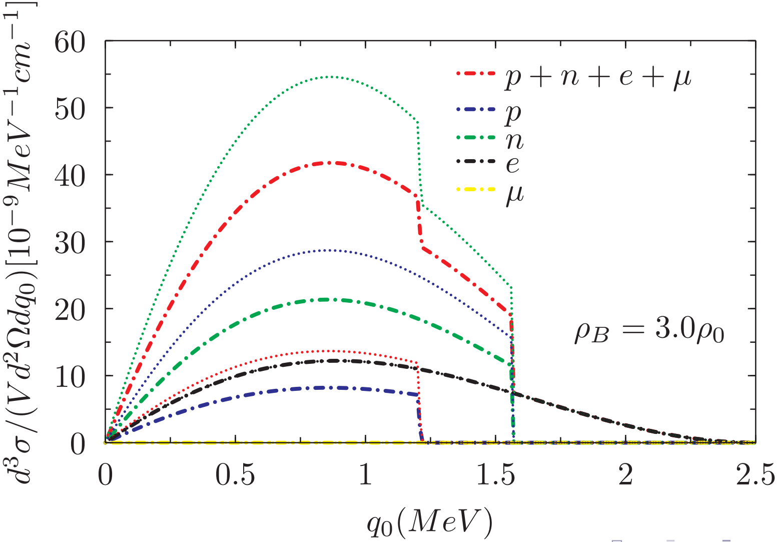


Results of the DCRS

The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter for ρ_B = 2.5 ρ_0.



The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter for ρ_B = 3.0 ρ_0.



Neutrino Mean Free Path

We consider only neutrino mean free path (NMFP) of the neutrino scattering, but not the NMFP of absorption. This is because the NMFP of neutrino scattering is larger than the NMFP of the neutrino absorption. The inverse mean free path of the neutrino is straightforwardly obtained by integrating the differential cross section over the energy transfer q_0 and the three-momentum transfer $\mid \vec{q} \mid$. The final expression for the NMFP as a function of the initial energy at a fixed baryon density can be written as,

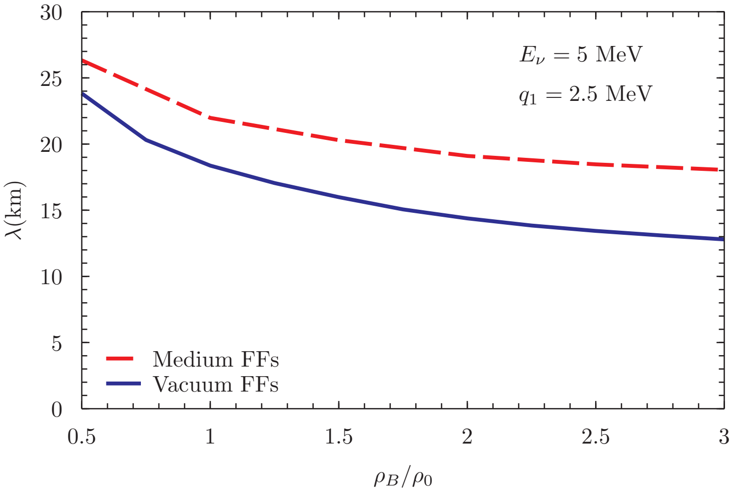
$$\frac{1}{\lambda(E_\nu)} = \int_{q_0}^{2E_\nu - q_0} d \mid \vec{q} \mid \int_0^{2E_\nu} dq_0 \frac{\mid \vec{q} \mid}{E'_\nu E_\nu} 2\pi \frac{1}{V} \frac{d^3\sigma}{d^2\Omega' dE'_\nu}, \tag{25}$$

where E_ν, $E'_\nu = E + q_0$ are the initial and final neutrino energy, respectively. More detailed explanations for the determination of the lower and upper integral limits [14].

[14] S. Reddy, M. Prakash and J. M. Lattimer, PRD**58**, 013009 (1998)

Results of Mean Free Path

The q_1 = 2.5 MeV, E_ν = 5 MeV in neutrino-less matter.



Conclusion and outlook

- We have studied the impact of in-medium modification of the weak and EM form factor of the nucleon on the neutrino scattering
- The in-medium nucleon form factors are estimated by the quark-meson coupling (QMC) model that in based on the quark degrees of freedom nucleon
- The DCRS of the neutrino scattering with the constituents of cold matter were found slowly decrease with increasing baryon density, which results in the increase of the NMFP. This feature is sensitive to the in-medium modifications of the nucleon weak and electromagnetic form factors (in particular, that of the axial-vector form factor)
- We found that the effects of medium modification of the nucleon weak and EM form factors on the cross section are more pronounced at higher densities

Conclusion and outlook

- The impact of the in-medium modified of the nucleon form factors is more clear on the neutrino mean free path
- With increasing baryon density, this would be interesting to include more matter constituent such as Λ and Σ or other baryons with medium modification form factors of baryons.

THANK YOU VERY MUCH FOR ATTENTION !!