Weak interaction induced η-production off the nucleon

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Introduction

In this work we have studied the differential and total scattering cross section for the ν(anti-ν) induced production off the nucleon at low and intermediate energies for the ongoing and future neutrino oscillation experiments. The non-resonant terms are calculated using a microscopic model based on the SU(3) chiral Lagrangians[1]. We consider S11(1535) and S11(1650) resonances. The vector part of the N-S11 transition form factor has been obtained from the helicity amplitudes using MAID data [2], dipole form is taken for the axial form factor and the PCAC relation is used for the pseudoscalar form factor.

Formalism

Charged current ν(anti-ν) induced eta production

$$\nu_e(k) + N(p) \rightarrow e^-(k') + N'(p') + \eta(p_\eta)$$
$$\bar{\nu}_e(k) + N(p) \rightarrow e^+(k') + N'(p') + \eta(p_\eta)$$

The expression for the differential cross section in the laboratory (lab) frame for the above process is given by,

$$\frac{d^2\sigma}{dcos\theta_{\nu l} dp_l} = \int d\phi_\eta dp_\eta \frac{1}{32 M_N E_\nu (2\pi)^5} \frac{|\mathbf{k}'|^2 |\mathbf{p}_\eta|}{E_l E_\eta |\mathbf{q}|} \bar{\sum}\sum |\mathcal{M}|^2,$$

where the transition amplitude is written as

Here $$\mathcal{M} = \frac{G_F}{\sqrt{2}} j_\mu^{(L)} J^{\mu\,(H)} = \frac{g}{2\sqrt{2}} j_\mu^{(L)} \frac{1}{M_W^2} \frac{g}{2\sqrt{2}} J^{\mu\,(H)},$$

$$j_\mu^L = \bar{u}(k')\gamma^\mu(1-\gamma_5)\nu_l \quad ,$$

and we have obtained the hadronic current for s-channel and u-channel nucleon Born terms and s-channel and u-channel resonant S11(1535) and S11(1650) terms.

$$j^\mu{}_s = i\frac{D-3F}{2\sqrt{3}f_\pi} V_{ud}\bar{u}_p(p') \not{p}_\eta \gamma^5 \frac{\not{p}+\not{q}+M}{(p+q)^2-M^2} \mathcal{J}_N^\mu u_n(p)$$

$$j^\mu{}_u = i\frac{D-3F}{2\sqrt{3}f_\pi} V_{ud}\bar{u}_p(p') \mathcal{J}_N^\mu \frac{\not{p}-\not{p}_\eta+M}{(p-p_\eta)^2-M^2} \not{p}_\eta \gamma^5 u_n(p)$$

$$j_s^{\mu\ R} = i\frac{g_{\eta N S_{11}} V_{ud}}{f_\pi} \bar{u}_p(p') \frac{\not{p}+\not{q}+M_R}{(p+q)^2-M_R^2+i\Gamma_R M_R} \mathcal{J}_R^\mu \gamma^5 u_n(p)$$

$$j_u^{\mu\ R} = i\frac{g_{\eta N S_{11}} V_{ud}}{f_\pi} \bar{u}_p(p') \mathcal{J}_R^\mu \gamma^5 \frac{\not{p}-\not{p}_\eta+M_R}{(p-p_\eta)^2-M_R^2+i\Gamma_R M_R} u_n(p)$$

where

$$\mathcal{J}_N^\mu = f_1^V(Q^2)\gamma^\mu + f_2^V(Q^2)\, i\,\sigma^{\mu\rho}\frac{q_\rho}{2M_N} - \left(f^A(Q^2)\gamma^\mu + f^P(Q^2)q^\mu\right)\gamma^5$$

$$\mathcal{J}_R^\mu = \frac{F_1^V(Q^2)}{4M_N^2}(Q^2\gamma^\mu + \not{q}q^\mu) + \frac{F_2^V(Q^2)}{2M_N} i\sigma^{\mu\rho}q_\rho - \left(F^A(Q^2)\gamma^\mu - F^P(Q^2)q^\mu\right)\gamma^5$$

$f_{1,2}^V$ are isovector form factors for the nucleons which are expressed in terms of Dirac and Pauli form factors, which in turn are expressed in terms of electric and magnetic Sach's form factors. We have taken BBBA05 parametrisation[3]

$$f_1^V(Q^2) = f_1^p(Q^2) - f_1^n(Q^2); \qquad f_2^V(Q^2) = f_2^p(Q^2) - f_2^n(Q^2)$$
$$f^A(Q^2) = \frac{f^A(0)}{(1+\frac{Q^2}{M_A^2})^2}; \qquad f^P(Q^2) = \frac{2M}{m_\pi^2+Q^2} f^A(Q^2)$$
$$F_1^V(Q^2) = F_1^p(Q^2) - F_1^n(Q^2); \qquad F_2^V(Q^2) = F_2^p(Q^2) - F_2^n(Q^2)$$
$$F^A(Q^2) = \frac{F^A(0)}{(1+\frac{Q^2}{M_A^2})^2}; \qquad F^P(Q^2) = \frac{M_R - M_N}{m_\pi^2+Q^2} F^A(Q^2)$$
$$f^A(0) = 1.26, \quad F^A(0) = 2g_\pi^* \ \text{where } g_\pi^* \sim 0.106$$

The total width is taken as,

$$\Gamma_R(1535) = 0.42\,\Gamma_{N^*\rightarrow N\eta} + 0.46\,\Gamma_{N^*\rightarrow N\pi} + 0.12\,\Gamma_{N^*\rightarrow X}$$
$$\Gamma_R(1650) = 0.10\,\Gamma_{N^*\rightarrow N\eta} + 0.70\,\Gamma_{N^*\rightarrow N\pi} + 0.20\,\Gamma_{N^*\rightarrow X}$$

We have taken the following form of S-wave decay width

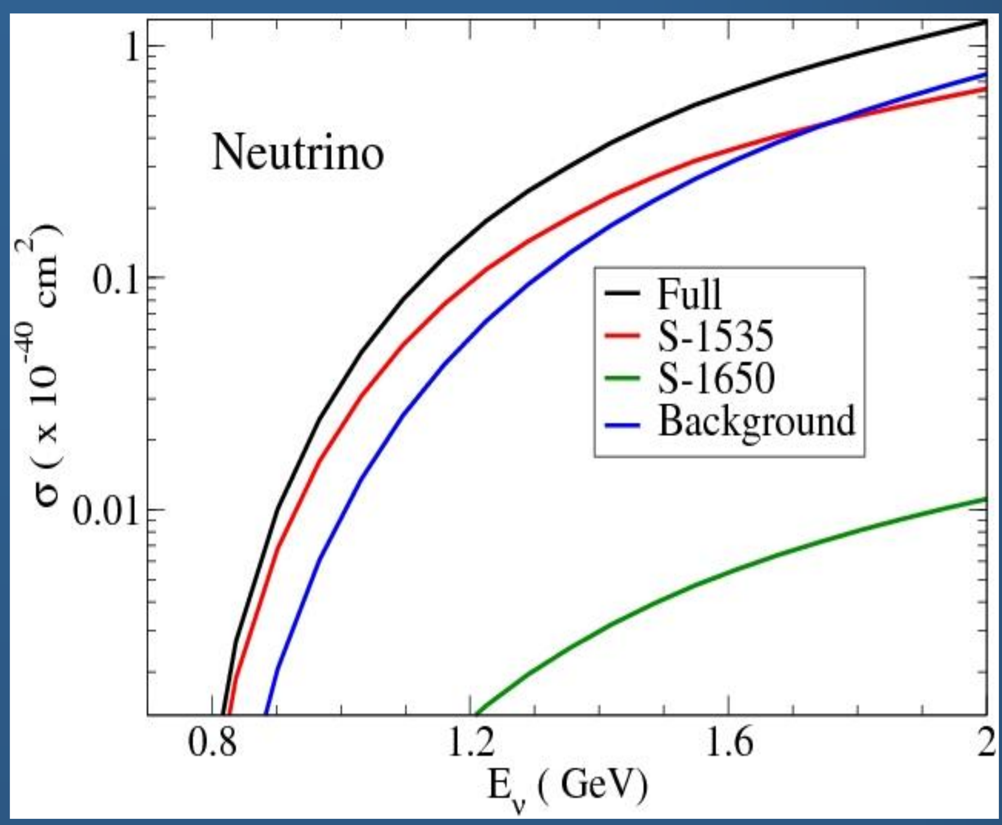
$$\Gamma_R(S11 \rightarrow Nm) = \frac{g_m^2 p_m^{CM}}{8\pi f_\pi^2} \frac{(W^2-M^2)^2 - m^2(2M_R^2+M^2-W^2-2MM_R)}{W^2}$$
$$p_m^{CM} = \frac{\sqrt{\lambda(W^2, m^2, M_N^2)}}{2W}$$

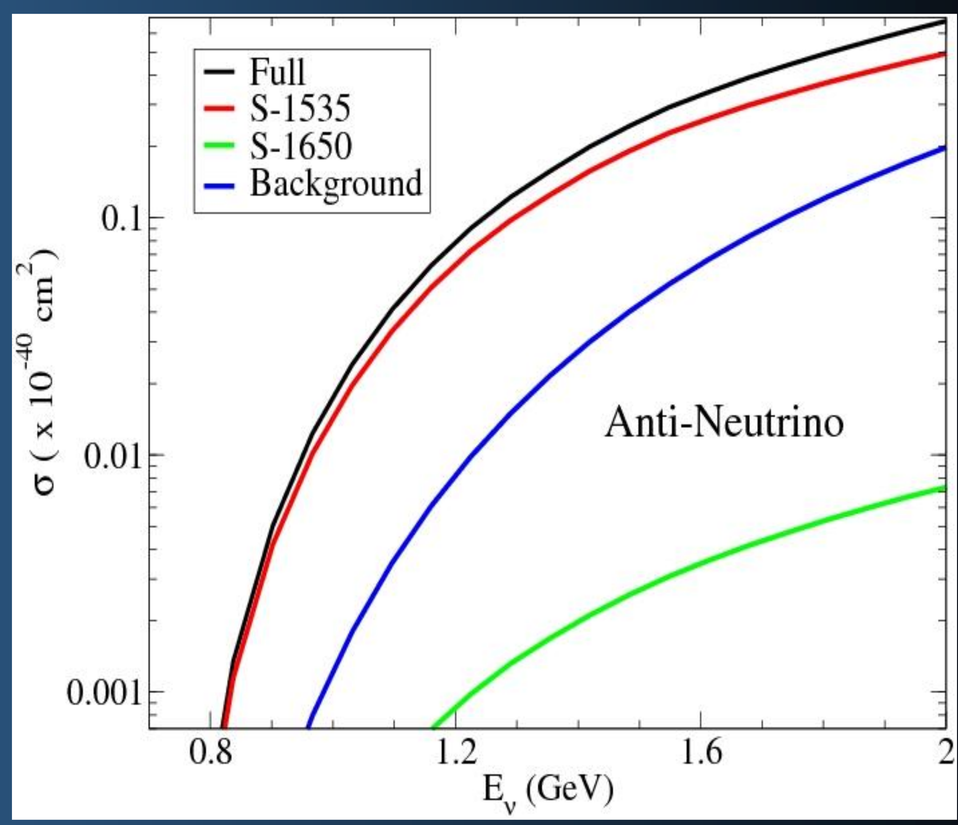
For S11-1535, $g_{\eta N S_{11}} = 0.286$ and for S11-1650, $g_{\eta N S_{11}} = 0.0867$

$$A_{\frac{1}{2}}^{p,n} = \sqrt{\frac{2\pi\alpha}{M_N}\frac{(M_R+M_N)^2+Q^2}{M_R^2-M_N^2}} \left(\frac{Q^2}{4M_N^2}F_1^{p,n}(Q^2) + \frac{M_R-M_N}{2M_N}F_2^{p,n}(Q^2)\right)$$
$$S_{\frac{1}{2}}^{p,n} = \sqrt{\frac{\pi\alpha}{M_N}\frac{(M_R-M_N)^2+Q^2}{M_R^2-M_N^2}} \frac{(M_R-M_N)^2+Q^2}{4M_R M_N} \left(\frac{M_R-M_N}{2M_N}F_1^{p,n}(Q^2) - F_2^{p,n}(Q^2)\right)$$

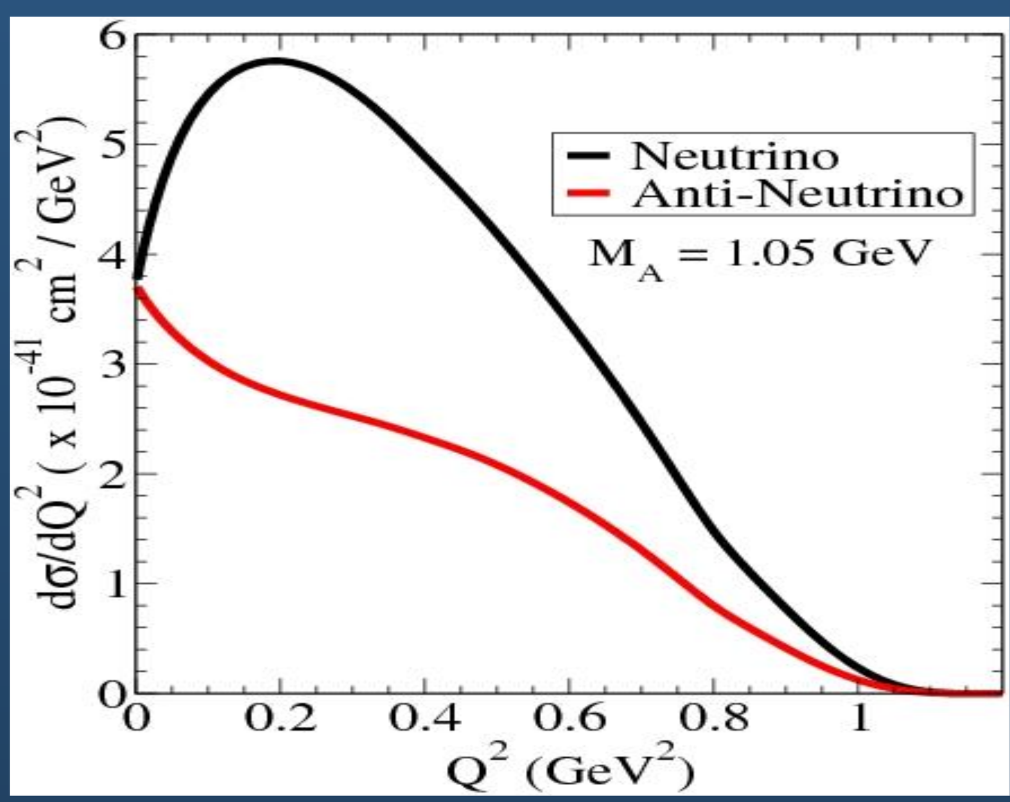
Results and Discussion

Total scattering cross section

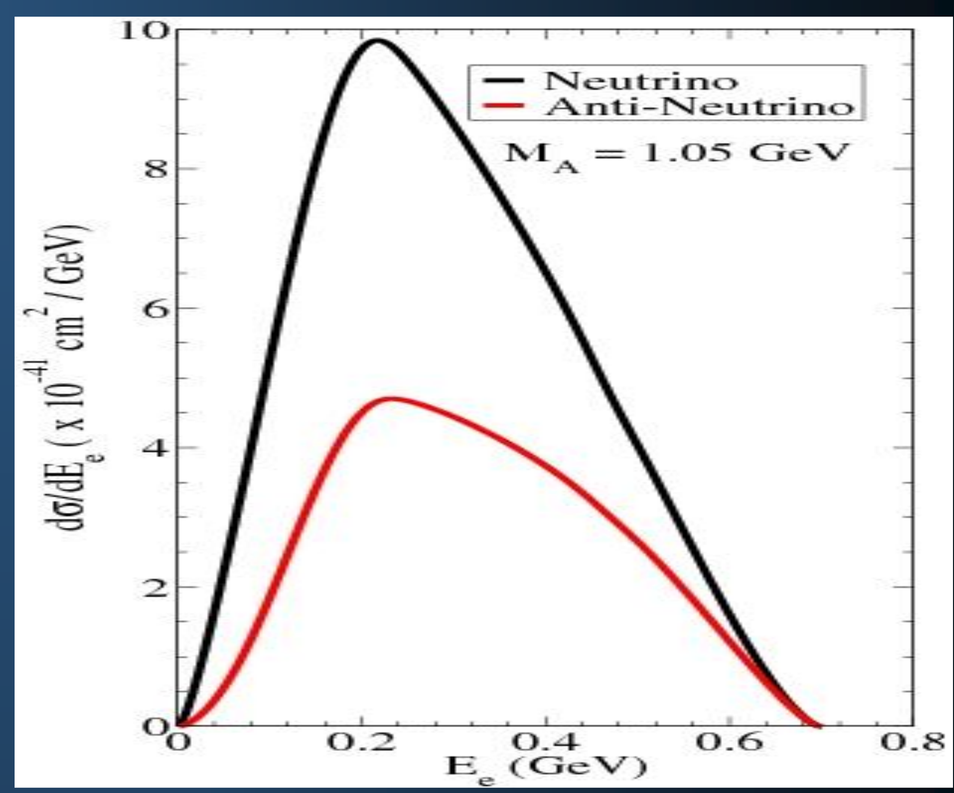




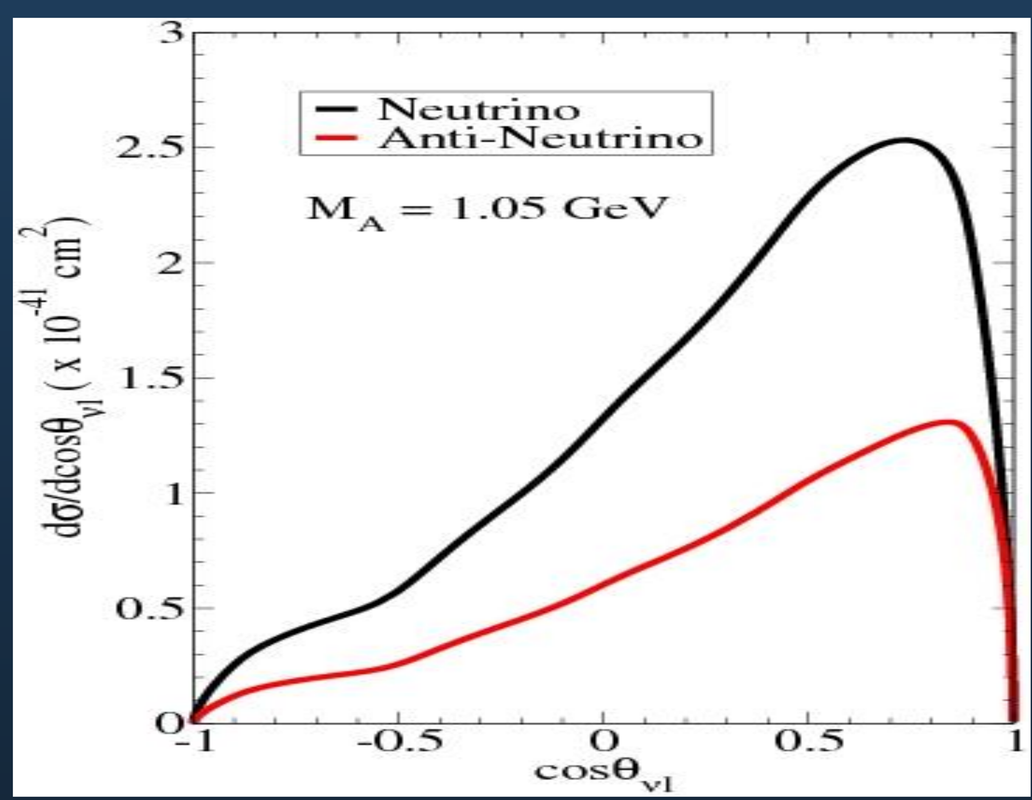
Q² distribution E=1.4 GeV



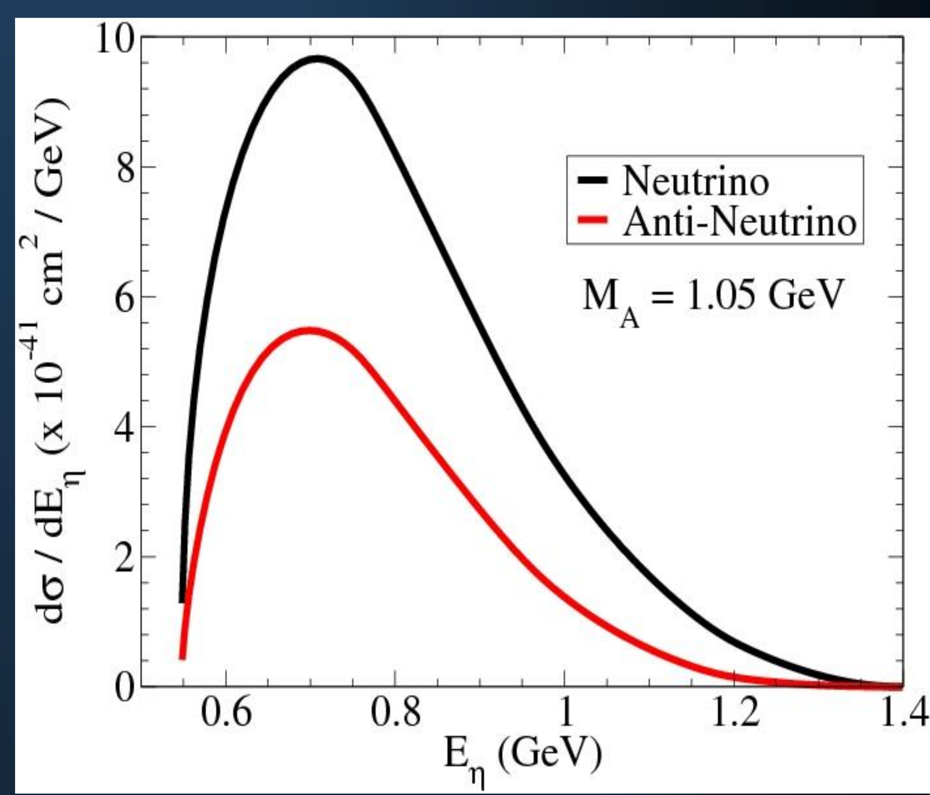
Lepton energy distribution



Angular distribution



Eta energy distribution



We find that the contribution of S11(1535) is large at low energies in the case of neutrino induced process, while at intermediate energies contribution from Born terms becomes almost equal to S11(1535) contribution. This is unlike the case of electromagnetic interaction where S11(1535) dominates. The contribution of S11(1650) is very small(<1%).

In the case of antineutrinos the contribution of S11(1535) dominates at low as well as intermediate energies.

Q^2 distribution is sharply peaked in the case of neutrino, while in the case of antineutrino due to the interference terms of S1535 and nucleon Born terms occurring with the opposite sign, Q^2 distribution is not peaked .

References

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3. R. Bradford, A Bodek, H. Budd and J Arrington, Nucl. Phys. B(Proc. Suppl.) 159(2006)127.