T-invariance in weak interaction induced processes

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1. Introduction

It is well established that parity(P) as well as the combined operation of parity and charge conjugation(C) are violated in weak interactions, while CPT is conserved which imply the violation of time reversal(T). Keeping this in mind, in this thesis, we have studied T-invariance and violation in the antineutrino and electron induced single hyperon production through the polarization measurements of hyperons. The hyperons decay predominantly into pions i.e. $\Lambda(\Sigma^0) \to p\pi^-$ or $n\pi^0$, and $\Sigma^- \to n\pi^-$ and the asymmetry in the angular distribution of pions determines the polarization of hyperon. The measurement of the transverse component of the polarization, perpendicular to the reaction plane, gives information about the weak electric form factor which is forbidden by the T-invariance. Such a measurement will, thus, provide an opportunity to study the underlying physics of T-violation in the weak interactions. The details of these calculations are given in Refs. [1–4]. The present and future neutrino experiments like MicroBooNE and DUNE, which are using or plan to use liquid argon time projection chamber (LArTPC) detectors give the three dimensional track of the interaction. Thus, it is possible to perform the polarization measurements with LArTPC detectors.

2. Formalism

The expression of the differential scattering cross section for the processes

$$\bar{\nu}_\mu(k) + N(p) \to \mu^+(k') + Y(p'), \quad (1)$$
$$e^-(k) + N(p) \to \nu_e(k') + Y(p'), \quad (2)$$

where $N = p, n$ and $Y = \Lambda, \Sigma^0, \Sigma^-$, in the laboratory frame, is written as [1–4]

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2 a^2 \sin^2\theta_C}{8\pi M^2 E^2} \mathcal{J}^{\mu\nu} \mathcal{L}_{\mu\nu}, \quad (3)$$

where $E = E_{\bar{\nu}_\mu}$ (E_e) is the incoming antineutrino (electron) energy and $a = 1(\frac{1}{2})$ for the antineutrino (electron) induced processes. The hadronic $(\mathcal{J}^{\mu\nu})$ and the leptonic $(\mathcal{L}_{\mu\nu})$ tensors are obtained as

$$\mathcal{J}_{\mu\nu} = \overline{\sum}\sum J_\mu J_\nu^\dagger = \mathrm{Tr}\left[\Lambda(p')\Gamma_\mu\Lambda(p)\tilde{\Gamma}_\nu\right], \quad (4)$$
$$\mathcal{L}^{\mu\nu} = \overline{\sum}\sum l_\mu l_\nu^\dagger = \mathrm{Tr}\left[l^\mu\Lambda(k')l^\nu\Lambda(k)\right], \quad (5)$$

with $\tilde{\Gamma}_\nu = \gamma^0\Gamma_\nu^\dagger\gamma^0$. The leptonic current (l^μ) and the hadronic current (j^μ) are given in Ref. [1–4].

The polarization 4-vector(ξ^τ) of the final hyperon in reactions (1) and (2) is given by:

$$\xi^\tau = \left(g^{\tau\sigma} - \frac{p'^\tau p'^\sigma}{M'^2}\right)\frac{\mathcal{L}^{\alpha\beta}\mathrm{Tr}\left[\gamma_\sigma\gamma_5\Lambda(p')\Gamma_\alpha\Lambda(p)\tilde{\Gamma}_\beta\right]}{\mathcal{L}^{\alpha\beta}\mathrm{Tr}\left[\Lambda(p')\Gamma_\alpha\Lambda(p)\tilde{\Gamma}_\beta\right]},$$

where ξ^τ is manifestly orthogonal to p'^τ, *i.e.* $p'\cdot\xi = 0$. In the laboratory frame where the initial nucleon is at rest, the polarization vector $\vec{\xi}$ is given as

$$\vec{\xi} = \left[A(Q^2)\vec{k} + B(Q^2)\vec{p}\,' + C(Q^2)M(\vec{k}\times\vec{p}\,')\right].$$

The expressions of $A(Q^2)$, $B(Q^2)$ and $C(Q^2)$ as well as the explicit relations of the longitudinal $(P_L(Q^2))$, perpendicular $(P_P(Q^2))$ and transverse $(P_T(Q^2))$ components of the polarization are given in Refs. [1–3].

3. Results and discussion

In Fig. 1, we show the dependence of the cross section on the axial dipole mass M_A with or without the presence of $g_2^R(0)$. It may be observed from the figure that a higher value of $\sigma(E_{\bar{\nu}_\mu})$ may be obtained by either taking a non-zero value of $g_2^{np}(0)$ or increasing the value of M_A. Furthermore, the cross section measurements may give information only about the non-zero value of $g_2^{np}(0)$ irrespective of the nature of the second class current (SCC) i.e. with or without T-invariance. One may

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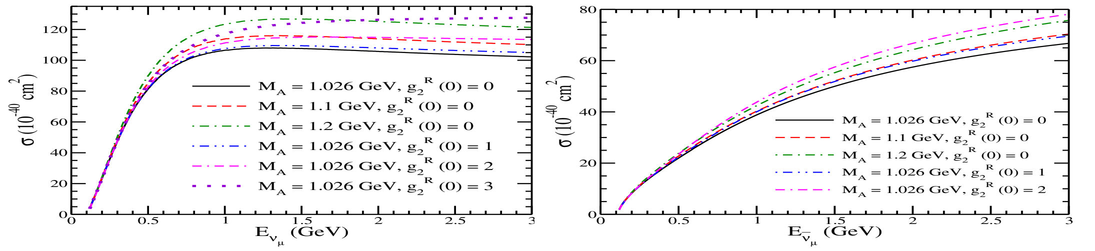

FIG. 1: σ *vs.* $E_{\nu_\mu(\bar{\nu}_\mu)}$ for the process $\nu_\mu + n \rightarrow \mu^- + p$ (left panel) and $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$ (right panel) for the different combinations of M_A, and $g_2^R(0)$.

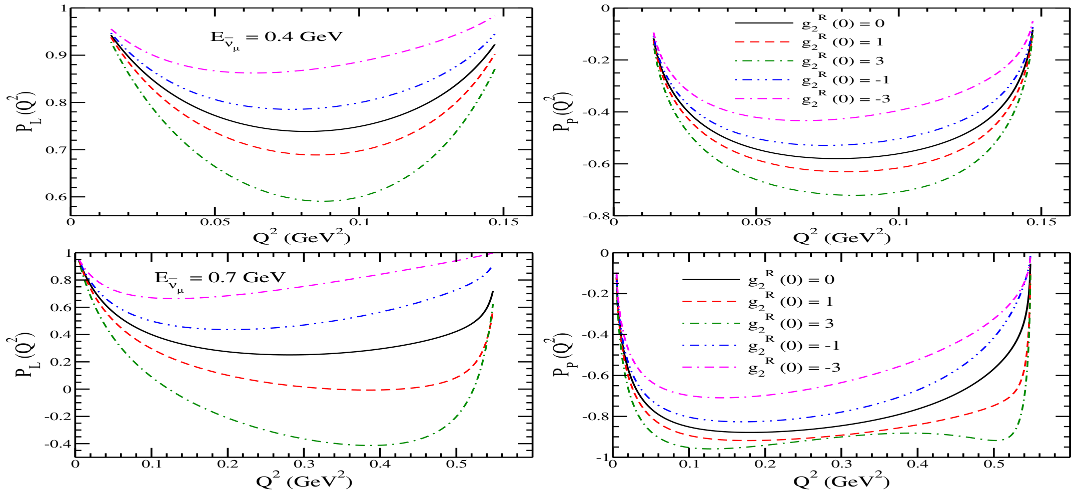

FIG. 2: $P_L(Q^2)$ (left panel) and $P_P(Q^2)$ (right panel) for the process $\bar{\nu}_\mu + p \rightarrow \mu^+ + \Lambda$ at $E_{\bar{\nu}_\mu} = 0.4$ GeV (upper panel) and 0.7 GeV (lower panel) with different values of $g_2^R(0)$.

obtain the nature of the SCC by measuring the polarization observables which gives different results with real and imaginary values of $g_2^{np}(0)$ corresponding to the SCC with or without T-invariance.

We have studied the dependence of the polarization components on the second class currents with T-invariance for the process $\bar{\nu}_\mu + p \rightarrow \mu^+ + \Lambda$ and presented the results for $P_L(Q^2)$ and $P_P(Q^2)$ as a function of Q^2 in Fig. 2. We find that $P_L(Q^2)$ shows large variations as we change $|g_2^R(0)|$ from 0 to 3 at high antineutrino energies, $E_{\bar{\nu}_\mu}$ (say 0.7 GeV) in comparison to the lower energies (say 0.4 GeV). In the case of $P_P(Q^2)$ also, the Q^2 dependence is quite strong and similar to that of $P_L(Q^2)$.

Recently we have also studied photon induced associated particle production form the proton target [5], some of the results of which have also been presented in this symposium.

In the era of precision experiments with electron, neutrino and antineutrino beams, it is possible to get information on the second class current with and without T-invariance in the quasielastic reactions specially in the strangeness sector.

References

[1] A. Fatima *et al.*, Phys. Rev. D **98**,033005 (2018).

[2] F. Akbar, M. Sajjad Athar, A. Fatima and S. K. Singh, Eur. Phys. J. A **53**, 154 (2017).

[3] A. Fatima *et al.*, Eur. Phys. J. A **54**, 95 (2018).

[4] A. Fatima *et al.*, Front. in Phys. **7**, 13 (2019)

[5] A. Fatima *et al.*, Phys. Rev. D (in submission), 2019.