Time reversal invariance and polarization observables in weak electron-nucleon scattering

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In view of the recent interest in the polarization observables in the neutrino reactions [1], we have recently studied the polarization observables in the weak electron scattering from nucleons assuming TRI [2]. In the absence of TRI, some of the form factors in the transition matrix element are allowed to be complex leading to a component of polarization vector in a direction perpendicular to the plane of reaction. Such a polarization component has not been observed so far in the neutrino reactions but similar efforts can be made to measure them in weak electron scattering [3].

With the availability of high luminosity electron beam at the accelerators like JLab and MAMI there exists a possibility of studying weak quasielastic production of neutrons and hyperons off the proton, *i.e.,*

$$\begin{aligned} e^- + p &\longrightarrow \nu_e + n \\ e^- + p &\longrightarrow \nu_e + \Lambda^0 \\ e^- + p &\longrightarrow \nu_e + \Sigma^0 \end{aligned} \quad (1)$$

The observation of the final hadron polarization is quite difficult for neutron as it requires a double scattering experiment [4] but the observation of hyperon polarization is facilitated by its decay into pions. The asymmetry in the angular distribution of pions with respect to a chosen axis of quantization in a direction lying in the plane of reaction or perpendicular to it gives information about the polarization component with or without TRI.

In this work, we have studied the total cross section, differential cross section and the polarization observables of the final hyperons and neutron produced in the reaction

$$e^-(k) + p(p) \longrightarrow \nu_e(k') + X(p'), \quad (2)$$

where $X = n, \Lambda^0, \Sigma^0$ and the quantities in the brackets represent the four momentum of the corresponding particles. The general expression of the differential cross section corresponding to the process given in Eq. (2) may be written as

$$\begin{aligned} d\sigma &= \frac{1}{(2\pi)^2}\frac{1}{4E_e M_N}\delta^4(k+p-k'-p') \\ &\times \frac{d^3k'}{2E_{k'}}\frac{d^3p'}{2E_{p'}}\overline{\sum}\sum|\mathcal{M}|^2, \end{aligned} \quad (3)$$

where E_e is the electron energy, M_N is the nucleon mass and the transition matrix element squared is defined as:

$$\overline{\sum}\sum|\mathcal{M}|^2 = \frac{G_F^2 a^2}{2}\mathcal{J}^{\alpha\beta}\mathcal{L}_{\alpha\beta} \quad (4)$$

where G_F is the Fermi coupling constant, a $= \sin\theta_c$ for Λ^0 and Σ^0 productions, a $= \cos\theta_c$ for neutron production where θ_c is the Cabibbo mixing angle. The hadronic and leptonic tensors are given by

$$\mathcal{J}_{\alpha\beta} = \frac{1}{2}\mathrm{Tr}\left[\Lambda(\not{p}')J_\alpha\Lambda(\not{p})\tilde{J}_\beta\right] \quad (5)$$

$$\mathcal{L}^{\alpha\beta} = \frac{1}{2}\mathrm{Tr}\left[\gamma^\alpha(1-\gamma_5)(\not{k}+m_e)\gamma^\beta(1-\gamma_5)\not{k}'\right], \quad (6)$$

with $\Lambda(p) = (\not{p} + M_N)$ and $\tilde{J}_\beta = \gamma^0 J_\beta^\dagger \gamma^0$. J_α is the hadronic current operator given by

$$\begin{aligned} J_\alpha &= \gamma_\alpha f_1^{NX}(Q^2) + i\sigma_{\alpha\beta}\frac{q^\beta}{M_N+M_X}f_2^{NX}(Q^2) \\ &+ \frac{q_\alpha}{M_N+M_X}f_3^{NX}(Q^2) \\ &- \left[i\sigma_{\alpha\beta}\gamma_5\frac{q^\beta}{M_N+M_X}g_2^{NX}(Q^2)\right. \\ &+ \left.\gamma_\alpha\gamma_5 g_1^{NX}(Q^2) + \frac{q_\alpha}{M_N+M_X}g_3^{NX}(Q^2)\gamma_5\right]. \end{aligned} \quad (7)$$

$q_\mu (= k_\mu - k'_\mu = p'_\mu - p_\mu)$ is the four momentum transfer with $Q^2 = -q^2$, M_X represents the

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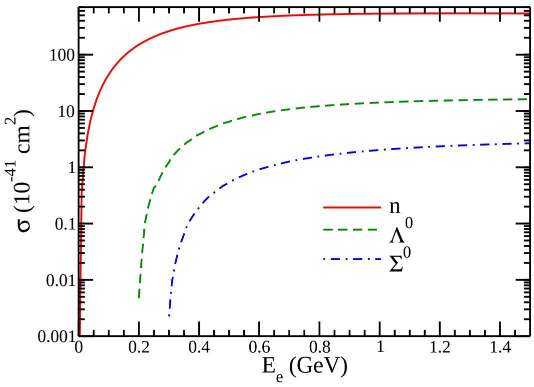

FIG. 1: σ *vs* E_e for n(solid line), Λ^0(dashed line) and Σ^0 (dashed-dotted line) productions.

mass of the final baryon and the form factors $f_i^{NX}(Q^2)$ and $g_i^{NX}(Q^2)$ are discussed in detail in Ref. [2].

The polarization 4-vector (ξ^τ) of the final baryon produced in reaction (2) is written as:

$$\xi^\tau = \left(g^{\tau\sigma} - \frac{p'^\tau p'^\sigma}{M_X^2}\right) \times \frac{\mathcal{L}^{\alpha\beta}\mathrm{Tr}\left[\gamma_\sigma\gamma_5\Lambda(p')J_\alpha\Lambda(p)\tilde{J}_\beta\right]}{\mathcal{L}^{\alpha\beta}\mathrm{Tr}\left[\Lambda(p')J_\alpha\Lambda(p)\tilde{J}_\beta\right]} \quad (8)$$

with

$$\frac{d\sigma}{dQ^2} = \frac{1}{64\pi M_N^2 {E_e}^2}\overline{\sum}\sum|\mathcal{M}|^2. \quad (9)$$

One may write the polarization vector as

$$\boldsymbol{\xi} = \xi_P \boldsymbol{e_P} + \xi_L \boldsymbol{e_L} + +\xi_T \boldsymbol{e_T}, \quad (10)$$

where $\boldsymbol{e_P}$, $\boldsymbol{e_L}$ and $\boldsymbol{e_T}$ are the unit vectors corresponding to the perpendicular, longitudinal and transverse directions along the momentum of the baryon and are given as

$$\boldsymbol{e_L} = \frac{\boldsymbol{p'}}{|\boldsymbol{p'}|}, \qquad \boldsymbol{e_P} = \boldsymbol{e_L} \times \boldsymbol{e_T}, \quad (11)$$

where

$$\boldsymbol{e_T} = \frac{\boldsymbol{p'} \times \boldsymbol{k}}{|\boldsymbol{p'} \times \boldsymbol{k}|}. \quad (12)$$

Using the above expressions one may write the perpendicular, longitudinal and transverse components of the polarization vector $\boldsymbol{\xi}$ as

$$\xi_{P,L,T}(Q^2) = \boldsymbol{\xi} \cdot \boldsymbol{e_{P,L,T}}\ , \quad (13)$$

which leads to the perpendicular $P_P(Q^2)$, longitudinal $P_L(Q^2)$ and transverse $P_T(Q^2)$ components of the polarization vector as:

$$P_L(Q^2) = \frac{M_X}{E_{p'}}\xi_L(Q^2),$$
$$P_P(Q^2) = \xi_P(Q^2),$$
$$P_T(Q^2) = \xi_T(Q^2), \quad (14)$$

where $\frac{M_X}{E_{p'}}$ is the Lorentz boost factor along $\mathbf{p}'$.

In Fig. 1, we have presented the results of the total cross section versus the energy of the incoming electron for n, Λ^0 and Σ^0 productions.

We shall present the results of the components of the polarization vector of the final baryons with and without TRI.

References

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