Effect of SU(3) symmetry breaking in $\bar{\nu}_\mu + p \longrightarrow \mu^+ + \Lambda$

A. Fatima* and M. Sajjad Athar
Department of Physics, Aligarh Muslim University, Aligarh-202002, India

1. Introduction

In the few GeV energy region of antineutrinos, besides the conventional charged current quasielastic scattering process ($\bar{\nu}_l + N \longrightarrow l^+ + N'; N, N' = p$ or n), strangeness changing ($|\Delta S| = 1$) single hyperon production process ($\bar{\nu}_l + N \longrightarrow l^+ + Y; N = p$ or n and $Y = \Lambda$ or Σ) is also possible, which is forbidden for ν_l induced process due to $\Delta S = \Delta Q$ rule. The hyperons having a finite lifetime (*e.g.*, $\tau_\Lambda = 263\ ps$, $\tau_{\Sigma^+} = 80\ ps$, etc.) decay to a nucleon and a pion. The pions produced in such processes are, in addition, to the pions coming from the resonant and non-resonant channels in ~ 1 GeV energy region. It has been shown by us [1, 2] that these pions contribute $\approx 40 - 50\%$ of the total 1π events in the energy region of 0.8–1 GeV, when the interaction takes place with the nucleons bound inside a nuclear target like ^{12}C, ^{16}O, ^{40}Ar, ^{208}Pb, etc., which are presently being used in the (anti)neutrino experiments like NOvA, T2K, MicroBooNE, etc., or are planned to be used in experiments like DUNE and HyperK.

The study of single hyperon production is important both theoretically as well as experimentally as the production cross section has large error bars and there is significant model dependence (Fig. 1). The state-of-art imaging detectors like LArTPC (liquid argon time projection chamber) are capable of detecting events through particle tracks like the DUNE experiment is well capable of observing Λ production events. Thus, it would be possible to understand Λ production cross section in the few GeV energy region. We have studied the effect of different vector and axial vector form factors on the production cross section

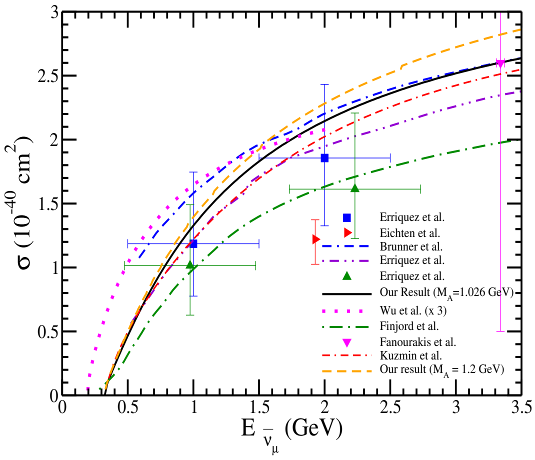

FIG. 1: σ vs. $E_{\bar{\nu}_\mu}$ for the Λ production cross section with SU(3) symmetry. For lines and points, please see Fig. 3 of Ref. [2].

of single hyperons induced by the antineutrinos [1, 2, 3]. In this work, we have studied SU(3) symmetry breaking effects using various models, which modify the vector and axial vector transition current resulting in a modified cross section to the results obtained when SU(3) symmetry is assumed.

2. Formalism

The transition matrix element for the process

$$\bar{\nu}_\mu(k) + p(p) \longrightarrow \mu^+(k') + \Lambda(p'), \quad (1)$$

is written as

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} \sin\theta_c \; l^\mu J_\mu, \quad (2)$$

where the quantities in the brackets of Eq. (1) represent the four momenta of the particles, G_F is the Fermi coupling constant, and θ_c (= 13.1°) is the Cabibbo mixing angle. The leptonic current l^μ is given by

$$l^\mu = \bar{u}(k')\gamma^\mu(1+\gamma_5)u(k). \quad (3)$$

*Electronic address: atikafatima1706@gmail.com

TABLE I: Values of the parameters a and b given in Eq. (5).

Model	I [5]	II [5]	III [6]	IV [7]	V [7]	VI [7]	VII [7]	VIII [7]	IX [7]	X [7]	XI [7]	XII [8]
a	−1.258	−1.3275	–	−1.188	−1.2088	−1.195	−1.249	−1.258	−1.306	−1.155	−1.226	–
b	–	–	−0.84	–	–	–	–	–	–	–	–	−0.879

The hadronic current J_μ, in the absence of second class current, is expressed as:

$$J_\mu = \bar{u}(p') \left[\gamma_\mu f_1(Q^2) + i\sigma_{\mu\nu} \frac{q^\nu}{M + M_\Lambda} f_2(Q^2) - \gamma_\mu \gamma_5 g_1(Q^2) - \frac{2\, q_\mu}{M + M_\Lambda} g_3(Q^2) \gamma_5 \right] u(p), \quad (4)$$

where M and M_Λ are the masses of proton and Λ, $q_\mu (= k_\mu - k'_\mu = p'_\mu - p_\mu)$ is the four momentum transfer with $Q^2 = -q^2, Q^2 > 0$. $f_1(Q^2)$, $f_2(Q^2)$, $g_1(Q^2)$ and $g_3(Q^2)$ are the vector, weak magnetic, axial vector and induced pseudoscalar form factors, respectively, which are determined using the various symmetry properties of the weak hadronic currents discussed in detail in Refs. [1, 2, 3]. For completeness, here, we give the general expressions of the form factors used in the numerical calculations:

$$f_1(Q^2) = a f_1^p(Q^2), f_2(Q^2) = -\sqrt{\frac{3}{2}} f_2^p(Q^2),$$
$$g_1(Q^2) = b \frac{g_A}{\left(1 + \frac{Q^2}{M_A^2}\right)^2},$$
$$g_3(Q^2) = \frac{(M + M_\Lambda)^2}{2(m_K^2 + Q^2)} g_1(Q^2), \quad (5)$$

where $f_{1,2}^p$ are the electromagnetic proton form factors, $g_A = 1.267$ is the axial charge, M_A is the axial dipole mass, m_K is the mass of kaon, a and b are the vector and axial vector couplings, which contain both the SU(3) symmetric and breaking terms. In the SU(3) symmetry, these values are: $a = -1.225$, and $b = -0.895$. We assume same Q^2 dependence for the SU(3) symmetric and breaking terms. Using the different models of the SU(3) symmetry breaking [4, 5, 6, 7, 8], we have parameterized $f_1(Q^2)$ and $g_1(Q^2)$ in terms of a and b, which are tabulated in Table I.

3. Results and discussion

In Fig. 2, we have shown the results of the Λ production cross section with and without (dashed line) SU(3) symmetry breaking effect. The band corresponds to the variation in the results of the cross section when the different values of a and b are taken. It may be realised that the variation in the cross section is $1.35^{+0.16}_{-0.10}$, $2.14^{+0.24}_{-0.16}$ and $2.49^{+0.27}_{-0.17} \times 10^{-40}$ cm^2 at 1, 2 and 3 GeV, respectively. These results will be discussed in the forthcoming symposium.

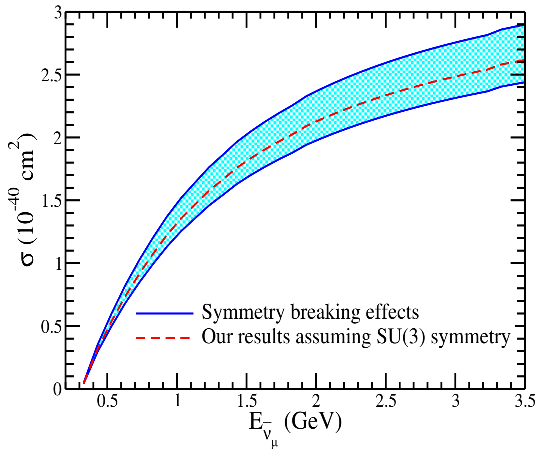

FIG. 2: σ vs. $E_{\bar{\nu}_\mu}$ for the Λ production cross section. Dashed line represents the present results assuming SU(3) symmetry. The shaded region represents the effect of SU(3) symmetry breaking obtained using the values of a and b given in Table I.

References

[1] A. Fatima, M. Sajjad Athar and S. K. Singh, doi:10.1140/epjs/s11734-021-00272-0 [arXiv:2106.14590 [hep-ph]].
[2] A. Fatima, M. Sajjad Athar and S. K. Singh, Front. in Phys. **7**, 13 (2019).
[3] A. Fatima, M. Sajjad Athar and S. K. Singh, Phys. Rev. D **98**, 033005 (2018).
[4] A. Faessler *et al.*, Phys. Rev. D **78**, 094005 (2008).
[5] G. Villadoro, Phys. Rev. D **74**, 014018 (2006).
[6] T. Ledwig, A. Silva, H. C. Kim and K. Goeke, JHEP **07**, 132 (2008).
[7] S. Sasaki, Phys. Rev. D **86**, 114502 (2012).
[8] G. S. Yang and H. C. Kim, Phys. Rev. C **92**, 035206 (2015).