Production of $K\Lambda$ system in weak interactions with neutral currents

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Inequalities for the ratio of the cross sections of exclusive production of the $K\Lambda$ system in the reactions $\nu_\mu N \to \nu_\mu \Lambda K$ and $\nu_\mu n \to \mu^- \Lambda K^+$ are considered. Bounds on the cross section for the production of the $K\Lambda$ system by neutral currents are obtained within the framework of the Weinberg model.

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The discovery of neutral currents in exclusive weak interaction processes has raised interest in investigation of isotopic and SU_3 structure of neutral current. In particular, it is important to know the weight with which the strange quarks enter into this current. In this paper we start with the form of the central current in the Weinberg model[1]:

$$J_\alpha^{(o)} = J_\alpha^3 - 2\sin^2\theta_W J_\alpha^{em} , \qquad (1)$$

where J_α^3 is the third component of the isovector weak V–A current, J_α^{em} is the electromagnetic hadron current, and θ_w is the Weinberg angle. We consider the following exclusive processes of $K\Lambda$-system production:

$$\nu_\mu + p \to \nu_\mu + \Lambda + K^+ , \quad (2)$$

$$\nu_\mu + n \to \nu_\mu + \Lambda + K^\circ , \quad (3)$$

$$\nu_\mu + n \to \mu^- + \Lambda + K^+ . \quad (4)$$

The charged current causing the process (4) is of the form

$$J_\alpha^{(c)} = J_\alpha^1 + iJ_\alpha^2 , \quad (5)$$

where J_α^1, J_α^2, and J_α^3 are components of the same isovector weak current. We denote the cross sections of the processes (2)—(4) by σ_0^+, σ_0^0, and σ_-, respectively. Since $J_\alpha^{em} = J_\alpha^S + V_\alpha^3$, where J_α^S is the isoscalar part of the electromagnetic current and V_α^3 is the vector part of the isovector weak current $(J_\alpha^3 = V_\alpha^3 + A_\alpha^3)$, we can write these cross sections in the form

$$\sigma_\circ^+ = \frac{1}{3}\left|\sqrt{3}S - V\right|^2, \quad \sigma_\circ^\circ = \frac{1}{3}\left|\sqrt{3}S + V\right|^2, \quad \sigma_- = \frac{2}{3}|\tilde{V}|^2 . \quad (6)$$

Here S and V are the isoscalar and isovector contributions to the amplitudes of the processes (2)—(4). The quantity V is determined by the isovector part of the current (1), and $\tilde{V}$ by the current (5). For the sum of the cross sections of the processes (2) and (3) $\sigma_0 = \sigma_0^+ + \sigma_0^0$ the isoscalar-isovector interference vanishes, and the following inequality results:

$$R = \frac{\sigma_\circ}{\sigma_-} \geqslant 2\left|\frac{\langle \Lambda K^+ | J_\alpha^3 - 2\sin^2\theta_W V_\alpha^3 | p\rangle}{\langle \Lambda K^+ | J_\alpha^1 + iJ_\alpha^2 | n\rangle}\right|^2 = 2\left|\frac{\langle \Lambda K^\circ | J_\alpha^3 - 2\sin^2\theta_W V_\alpha^3 | n\rangle}{\langle \Lambda K^+ | J_\alpha^1 + iJ_\alpha^2 | n\rangle}\right|^2 . \quad (7)$$

It follows from the normalization condition that $|\langle \Lambda K^+ | J_\alpha^3 | p\rangle|^2 = (1/4)|\langle \Lambda K^+ | J_\alpha^1 + iJ_\alpha^2 | n\rangle|^2$. Taking into account the obvious inequality $|1-a|^2 \geq (1-|a|)^2$, we obtain

$$R \geqslant \frac{1}{2}\left[1 - 2\sin^2\theta_W\left(4|\langle \Lambda K^+ | V_\alpha^3 | p\rangle|^2/\sigma_-\right)^{1/2}\right]^2 . \quad (8)$$

If the expression of the square brackets is positive (as it certainly is at $\sin^2\theta_w < 1/2$, inasmuch as there is no V, A interference in the cross section integrated over the angles and $\sigma_- = 4\{|\langle V_\alpha^3\rangle|^2 + |\langle A_\alpha^3\rangle|^2\} \geq 4|\langle V_\alpha^3\rangle|^2$), then it is possible to make the inequality (8) stronger by replacing $2|\langle \Lambda K^+ | V_\alpha^3 | p\rangle^2$ by the large quantity $|\langle J_\alpha^{em}\rangle|^2$, which includes not only an isovector scalar contribution. For the sum of the cross sections on the protons and neutrons ($|\langle V_\alpha^3\rangle|$ is the same in both cases) we have

$$4|\langle \Lambda K^+ | V_\alpha^3 | p\rangle|^2 \leqslant V_{em} , \quad (9)$$

where V_{em} is expressed in terms of the sum of the electroproduction cross sections (V_{em} is introduced in the same manner as in[2])

$$V_{em} = \frac{G^2}{4\pi^2 a^2}\int q^4 \frac{d\sigma_{em}}{dq^2} dq^2 , \quad \frac{d\sigma_{em}}{dq^2} = \frac{d\sigma}{dq^2}(ep \to e\Lambda K^+) + \frac{d\sigma}{dq^2}(en \to e\Lambda K^\circ) , \quad (10)$$

and from (8) and (9) it follows that

$$R \geq \tfrac{1}{2}[1 - 2\sin^2\theta_W (V_{em}/\sigma_-)^{1/2}]^2 . \tag{11}$$

This inequality follows from (8) and the condition that the expression in the square brackets in (8) and (11) is positive. By a somewhat different method we can show that (11) is valid for any sign of the expression in the square brackets. Inequalities similar to (11) were obtained earlier in[2] for the processes $\nu_\mu N \to \nu_\mu N\pi$ and $\nu_\mu N \to \mu^- N\pi$, and in[3] for the inclusive cross sections. It is easily seen that the bound on σ_0 from the inequality (11) takes the form

$$\frac{4V_{em} R \sin^4\theta_W}{(1+\sqrt{2R})^2} \leqslant \sigma_0 \leqslant \frac{4V_{em} R \sin^4\theta_W}{(1-\sqrt{2R})^2} . \tag{12}$$

The upper bound holds in this case only if $R < 1/2$.

Instead of the inequality for σ_0 we can write relations for $\sin^2\theta_W$

$$\frac{1}{2}\sqrt{\frac{\sigma_-}{V_{em}}}(1-\sqrt{2R}) \leqslant \sin^2\theta_W \leqslant \frac{1}{2}\sqrt{\frac{\sigma_-}{V_{em}}}(1+\sqrt{2R}) . \tag{13}$$

The lower bound is of interest here only at $R < 1/2$.

The inequalities (12) and (13) can be useful because by virtue of a number of kinematic limitations it is much easier to measure the ratio R of the cross sections with neutral and charge currents than the cross sections separately.

To obtain from (12) and (13) quantitative limitations on σ_0 and $\sin^2\theta_W$ it is necessary to know V_{em} and R. Starting from the results of[4] for $K\Lambda$ electroproduction, which were obtained on the basis of a Regge analysis and agree well with the experimental data,[5] we can find V_{em} in the formula (10). (We assume that in analogy with the known quark-parton relation between the inclusive cross sections, we have

$$\frac{d\sigma}{dq^2}(en \to e\Lambda K^0) \approx \frac{2}{3}\frac{d\sigma}{dq^2}(ep \to e\Lambda K^+)).$$

Assuming the energy of the initial electron to be of the order of 2 GeV, we obtain $V_{em} = (2 \pm 1) \times 10^{-40}$ cm^2. The error is connected here with the uncertainty of the experimental data and with the error of the extrapolation. The value $R = 2.25 \pm 2$, obtained by the Argonne group[7] at $E_\nu \approx 2$ GeV for the processes (2)—(4), is subject to a large error and is based on insufficient statistics. An analogous ratio, obtained at CERN[8] for quasi-inclusive processes that differ from (2)—(4) by the possible presence of arbitrary nonstrange hadrons in the final state, is equal to $0.34^{+0.17}_{-0.09}$. This last value seems more reasonable, since it is close to the inclusive value $R_\nu = \sigma(\nu_\mu N \to \nu_\mu X)/\sigma(\nu_\mu N \to \mu^- X) = 0.217 \pm 0.026$.[9] Therefore, assuming $R \approx 0.3$, $V_{em} = (2 \pm 1) \times 10^{-40}$ cm^2, and $\sin^2\theta_W \approx 1/3$,[10] we obtain from (12) the bounds of σ_0:

$$(6 \pm 3) \times 10^{-41}\,\text{cm}^2 \leqslant \sigma_0 \leqslant (44 \pm 22) \times 10^{-41}\,\text{cm}^2. \tag{14}$$

If we assume the experimental value $\sigma_- = (4 \pm 3) \times 10^{-40}$ cm^2,[6] then the value $\sigma_0 = R\sigma_- = (12 \pm 9) \times 10^{-41}$ cm^2 agrees with the inequalities (4). On the other hand, using the experimental value of σ_- indicated above and $R \approx 0.3$ we can obtain, in accordance with (13), and inequality for the Weinberg angle

$$0.16 \pm 0.07 \leqslant \sin^2\theta_W \leqslant 1.24 \pm 0.58 , \tag{15}$$

in which, however, the errors are still very large.

We note in conclusion that in addition to reactions (2)—(4) we can consider analogous processes of production of other hadrons. For their cross sections there are also inequalities of the type (11). This question will be the subject of a more detailed article .

[1] S. Weinberg, Phys. Rev. **D5**, 1412 (1972).
[2] C.H. Albright, B.W. Lee, E.A. Paschos, and L. Wolfenstein, Phys. Rev. **D7**, 2220 (1973).
[3] E.A. Paschos and L. Wolfenstein, Phys. Rev. **D7**, 91 (1973).
[4] A. Bartl and W. Majerotto, Nucl. Phys. **B90**, 285 (1975).
[5] T. Azemoon *et al.*, Nucl. Phys. **B95**, 77 (1975).
[6] S. J. Barish *et al.*, Phys. Rev. Lett. **33**, 1446 (1974).
[7] L. Hyman, La Physique du Neutrino a Haute Energie, Ecole Polytechnique, Paris, 1975, p.183.
[8] H. Deden *et al.*, Phys. Lett. **B58**, 361 (1975).
[9] A. Pullia, Proc. Eighteenth Intern. Conf. on High Energy Physics, London, 1974, IV-114.
[10] CERN-Gargamelle Collaboration, Paper presented to the Intern. Symposium on Electron and Photon Interactions at High Energies, Stanford, 1975.