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Yu.L.Kalinovsky [1], W.Kallies, K.R.Nasriddinov [2], N.A.Sarikov [2]

WEAK MANY-BODY DECAYS OF THE Λ_c^+-BARYON

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[1] GPI, Gomel, USSR.
[2] INP, Tashkent, AS UzSSR.

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At present, the data on two-, three-, and four-body nonleptonic weak decays of charmed baryons are available [1]. The description of nonleptonic decays of that sort, in particular of the Λ_c^+-baryon, in quark models [2] has a typical difficulty, namely, a complicated calculation is needed if one considers the many-body character of the final state.

In this paper, we propose to use the generalized phenomenological chiral-Lagrangian method (PCLM), including the spin-1 meson and baryon interactions (the so-called "hard"-meson method [3]), to find reliable though rough branching-ratio estimates and to give different distributions of the decay products for some Λ_c^+ decays. The "hard"-meson method allowed us to take into account the q^2-dependence of the form factors through the pole contributions of the spin-1 mesons. In this very briefly described scheme we consider the two-, three-, and four-body decays of Λ_c^+ in the "tree" approximation.

In the generalized PCLM the strong interactions of the 15-plets of pseudoscalar and spin-1 mesons and the 20-plet of $1/2^+$- baryons are described by the following SU(4) x SU(4) --chiral invariant Lagrangians [3] :

$$L_S = \frac{F_\pi^2}{2} D_\mu \xi_i D_\mu \xi_i + \begin{pmatrix} g_A \\ -g \\ -g g_A \end{pmatrix} \left\{ \begin{pmatrix} \alpha \\ \beta \\ \alpha \end{pmatrix} \left[\bar{B} \gamma_\mu \begin{pmatrix} A_i \\ V_i \\ A_i \end{pmatrix} B \right]_d + \begin{pmatrix} 1-\alpha \\ 1-\beta \\ 1-\alpha \end{pmatrix} \left[\bar{B} \gamma_\mu \begin{pmatrix} A_i \\ V_i \\ A_i \end{pmatrix} B \right]_f \right\} \begin{pmatrix} \partial_\mu \xi_i \\ \vartheta_\mu^i \\ a_\mu^i \end{pmatrix}, \quad i = 1 \div 15. \tag{1}$$

Here

$$\left[\bar{B} V_i B \right]_{d(f)} \equiv \frac{1}{2} \bar{B}^{k}_{[mn]} (V_i)_k^{\ell} B_\ell^{[mn]} +(-) \bar{B}^{m}_{[\ell n]} (V_i)_k^{\ell} B_m^{[kn]},$$

$$(k, \ell, m, n = 1 \div 4)$$

$$F_\pi = 93\,MeV;\quad g_A = 1.25;\quad g^2/4\pi \approx 3;$$
$$A_i \equiv V_i\gamma_5;\quad V_i \equiv \frac{\lambda_i}{2} I,$$

and λ_i are the Gell-Mann matrices; $\alpha = \frac{2}{3}$ and $\beta = \frac{3}{4}$ are the mixing parameters of the d- and f-couplings; $\zeta_i \equiv \varphi_i/F_\pi$; $B \equiv B_e^{[i+k]}$, φ_i, ϑ_μ^i and a_μ^i represent the fields of the $1/2^+$-baryons, 0^-, 1^-- and 1^+ - mesons, respectively.

The weak interaction Lagrangian has the form [4] :

$$L_W^{\Delta C=1}(\theta_7,\theta_{10}) = \frac{G_F}{\sqrt{2}}\Big[h_1 J_\mu^{1-i2} J_\mu^{13-i14} - h_2 J_\mu^{6+i7} J_\mu^{9-i10} + h_3 J_\mu^{1-i2} \tilde{J}_\mu^{11-i12} - h_4 J_\mu^{4-i5} J_\mu^{13-i14} + h_5\left(J_\mu^3 - \sqrt{3} J_\mu^8\right) J_\mu^{9-i10} + h_6 J_\mu^{6-i7} J_\mu^{9-i10} - h_7 J_\mu^{4-i5} \tilde{J}_\mu^{11-i12} + h.c.\Big], \qquad (2)$$

where $G_F = 10^{-5}/m_p^2$ and

$$\begin{aligned}
h_1 &\equiv \tilde c^2 c^2 + \tilde c\tilde s(cs - c^2 + s^2) + \tilde s^2 s^2 = 0.895 \\
h_2 &\equiv \tilde c^2 c^2 + \tilde c\tilde s(c^2 - s^2) + \tilde s^2 s^2 = 0.968 \\
h_3 &\equiv \tilde c^2 cs - \tilde c\tilde s(c^2 + 2cs) - \tilde s^2 cs = 0.186 \\
h_4 &\equiv \tilde c^2 cs + \tilde c\tilde s(s^2 - 2cs) - \tilde s^2 cs = 0.236 \\
h_5 &\equiv \tilde c^2 cs + 2\tilde c\tilde s cs - \tilde s^2 cs = 0.285 \\
h_6 &\equiv \tilde c^2 s^2 - \tilde c\tilde s(c^2 - s^2) + \tilde s^2 c^2 = 0.032 \\
h_7 &\equiv \tilde c^2 s^2 + \tilde c\tilde s(-cs + c^2 - s^2) + \tilde s^2 c^2 = 0.105 \\
c &\equiv \cos\theta_7,\ s \equiv \sin\theta_7,\ \tilde c \equiv \cos\theta_{10},\ \tilde s \equiv \sin\theta_{10}
\end{aligned} \qquad (3)$$

$\theta_c = \theta_7 - \theta_{10}$, θ_c is the Cabibbo angle. The given weak Lagrangian in the case $\theta_7 = \theta_{10} = 0$ strictly satisfies the $|\Delta T| = 1$ selection rule ("20-plet-dominance").

For taking into account the baryon pole contributions we need the phenomenological Lagrangian describing the two-body baryon weak interactions [5] :

$$L_W^{\Delta C=1} = G_{BB}\Big[\frac{1}{\sqrt{6}}\left(\bar\Xi^0 \Xi_c^0 + \bar\Lambda \Sigma_c^0 + \bar\Sigma^+ \Lambda_c^+ + 2\bar\Xi_c^+ \Xi_{cc}^+\right) + \frac{1}{\sqrt{2}}\left(\bar\Xi^0 \Xi_c^{\prime 0} - \bar\Sigma^0 \Sigma_c^0 + \bar\Sigma^+ \Sigma_c^+\right) + h.c.\Big] + O(\Delta T \neq 1). \qquad (4)$$

where $G_{BB} = -4.45\ 10^{-8}$ GeV was fixed from the experiment [5].

The decay amplitudes for the decays $\Lambda_c^+ \to \frac{1}{2}^+ + 0^-$, $\Lambda_c^+ \to \frac{1}{2}^+ + 1^-$, $\Lambda_c^+ \to \frac{1}{2}^+ + 0^- + 0^-$ and $\Lambda_c^+ \to \frac{1}{2}^+ + 0^- + 0^- + 0^-$ can be written as:

$$\begin{aligned}
M\left(\tfrac{1}{2}^+ 0^-\right) &= G_F \bar u_B (S + P\gamma_5) u_{\Lambda_c}; \\
M\left(\tfrac{1}{2}^+ 1^-\right) &= G_F \varepsilon_\mu^\lambda \bar u_B \gamma_\mu (A + B\gamma_5) u_{\Lambda_c}; \\
M\left(\tfrac{1}{2}^+ 0^- 0^-\right) &= G_F \bar u_B\left[f_1 + g_1\gamma_5 + \hat K_1(f_2 + g_2\gamma_5) + \hat K_2(f_3 + g_3\gamma_5)\right] u_{\Lambda_c}; \\
M\left(\tfrac{1}{2}^+ 0^- 0^- 0^-\right) &= G_F \bar u_B\Big[f_1 + g_1\gamma_5 + \hat u(f_2 + g_2\gamma_5) + \hat\vartheta(f_3 + g_3\gamma_5) + \\
&\quad + \hat u\hat\vartheta(f_4 + g_4\gamma_5) + i\varepsilon_{\mu\nu\alpha\beta}\, q_\nu \vartheta_\alpha u_\beta \gamma_\mu (f_5 + g_5\gamma_5)\Big] u_{\Lambda_c},
\end{aligned} \qquad (5)$$

where S, P, A, B, f_n, g_n are form factors; $q \equiv P_{\Lambda_c^+} - P_B$, $u \equiv K_3 + K_4$, $\vartheta \equiv K_3 - K_4$, $K_1 \dots K_4$ are the 4-momenta of the mesons ($\hat K \equiv K_\mu \gamma^\mu$); ε_μ^λ is the polarisation vector of the 1^+-mesons. The calculated amplitudes for the two-body decays (S, P, A and B) are listed in tables 1,2 (in addition, in (3) there are given values of the parameters $h_1 \dots h_7$). The calculated three- and four-body partial widths (see Table 3) and

Table 1. The amplitudes (S, P) and the partial widths (in $10^{11} s^{-1}$) for the decays $\Lambda_c^+ \to \frac{1}{2}^+ + 0^-$. In columns I ans II, respectively, the results without and with the spin-1 meson contributions are listed.

Decay mode	R_i	I S	I P	I Γ	II S	II P	II Γ
$\Lambda_c^+ \to \Lambda\pi^+$	R_1	-0.1	0.2	1.8	-0.2	0.3	2.8
$\Lambda_c^+ \to p\bar{K}^0$	R_2	-0.05	0.4	2.9	-0.1	0.6	5
$\Lambda_c^+ \to \Lambda K^+$	R_4	0.03	-0.06	0.1	0.04	-0.1	3.2
$\Lambda_c^+ \to p\pi^0$	R_5	0.01	-0.07	0.1	0.03	-0.1	0.3
$\Lambda_c^+ \to p\eta$	R_5	-0.02	0.2	0.7	-0.05	0.03	1
$\Lambda_c^+ \to pK^0$	R_6	0.006	-0.04	0.04	0.009	-0.05	0.04
$\Lambda_c^+ \to n\pi^+$	R_3	0.009	-0.07	0.1	0.03	-0.1	0.3
$\Lambda_c^+ \to nK^+$	R_7	-0.005	0.04	0.04	-0.02	0.08	0.09
$\Lambda_c^+ \to \Sigma^0\pi^+$		0	-0.02	$0.7\ 10^{-2}$	0	-0.02	$1.7\ 10^{-2}$

corresponding mass distributions (see, as examples, figs. 1,2,3) **are obtained with a computer by using the subroutine** TWIST/6/, **in which the integration of squared matrix element over** the phase space of final states has been performed with the help of the Monte-Carlo method and Kopylov's procedure.

Comparison of the calculated results (in brackets) and available experimental data [1] gives:

$$R_1 \equiv \frac{\Gamma(\Lambda_c^+ \to p\bar{K}^{*0})}{\Gamma(\Lambda_c^+ \to pK^-\pi^+)} = \begin{cases} 0.18 \pm 0.1 \\ 0.42 \pm 0.24 \end{cases} \qquad (0.6)$$

$$R_2 \equiv \frac{\Gamma(\Lambda_c^+ \to p\bar{K}^0)}{\Gamma(\Lambda_c^+ \to pK^-\pi^+)} = 0.5 \pm 0.25 \qquad (0.3)$$

$$R_3 \equiv \frac{\Gamma(\Lambda_c^+ \to \Lambda\pi^+)}{\Gamma(\Lambda_c^+ \to p\bar{K}^0)} = \begin{cases} 0.67 \pm 0.78 \\ 0.51 \pm 0.62 \end{cases} \qquad (0.56)$$

$$R_4 \equiv \frac{\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-)}{\Gamma(\Lambda_c^+ \to pK^-\pi^+)} < 1.4 \qquad (0.2)$$

$$R_5 \equiv \frac{\Gamma(\Lambda_c^+ \to p\bar{K}^0\pi^-\pi^+)}{\Gamma(\Lambda_c^+ \to p\bar{K}^0)} < 3.3 \qquad (0.5)$$

Table 2. The amplitudes (A, B) and partial widths (in $10^{11} s^{-1}$) for the decays $\Lambda_c^+ \to \frac{1}{2}^+ + 1^-$

Decay mode	R_i	A	B	Γ
$\Lambda_c^+ \to p\bar{K}^{*0}$	R_2	-0.2	-0.4	11
$\Lambda_c^+ \to pK^{*0}$	R_6	0.007	0.02	0.01
$\Lambda_c^+ \to \Lambda\rho^+$	R_1	-0.2	-0.2	3
$\Lambda_c^+ \to \Sigma\rho^+$	—	-0.005	0	$0.4\ 10^{-3}$
$\Lambda_c^+ \to \Xi^0 K^{*+}$	—	-0.02	0	$0.4\ 10^{-3}$
$\Lambda_c^+ \to \Sigma^+\rho^0$	—	0.005	0	$0.4\ 10^{-3}$
$\Lambda_c^+ \to \Sigma^+\omega$	—	0.008	0	$0.9\ 10^{-3}$
$\Lambda_c^+ \to \Sigma^+\varphi$	—	0.004	0	$0.3\ 10^{-4}$

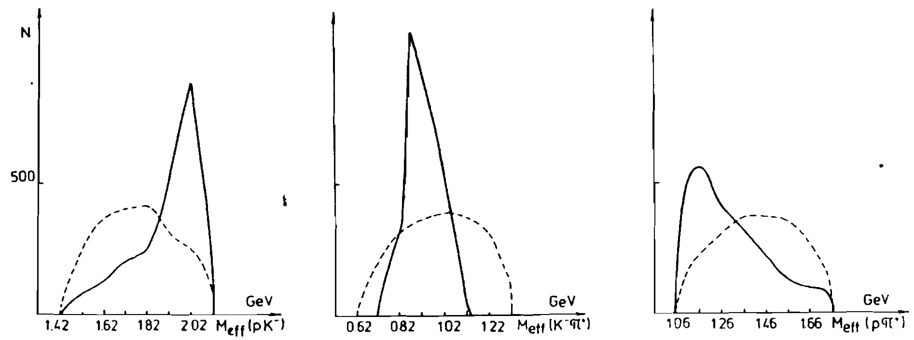

Fig. 1. The distributions of the decay products $\Lambda_c^+ \to pK^-\pi^+$. The dashed lines corresponds to the distributions with phase space corrections added.

The calculated results for R_{1+5} are obtained in the "hard"-meson method (see Tables 1,3).

Table 3. The partial widths (in $10^{11}s^{-1}$) of the decays $\Lambda_c^+ \to \frac{1}{2}^+ + 0^- + 0^-$, $\Lambda_c^+ \to \frac{1}{2}^+ + 0^- + 0^- + 0^-$ without (I) and with (II) the spin-1 meson pole contributions

Decay mode	Γ		Decay mode	Γ	
	I	II		I	II
$\Lambda_c^+ \to pK^-\pi^+$	8.7	17.9	$\Lambda_c^+ \to \Lambda K^+\eta$	0.1 10^{-3}	0.5 10^{-3}
$\Lambda_c^+ \to p\bar{K}^0\pi^0$	0.4	11.8	$\Lambda_c^+ \to p\pi^-\pi^+$	0.2	0.6
$\Lambda_c^+ \to n\bar{K}^0\pi^+$	9	12.7	$\Lambda_c^+ \to p\bar{K}^0K^0$	0.8 10^{-2}	0.2 10^{-1}
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	1.6	8.5	$\Lambda_c^+ \to pK^+\pi^-$	0.9 10^{-3}	0.02
$\Lambda_c^+ \to \Lambda K^+\bar{K}^0$	0.6 10^{-2}	0.2 10^{-2}	$\Lambda_c^+ \to pK^0\pi^0$	0.4 10^{-3}	0.9 10^{-2}
$\Lambda_c^+ \to p\bar{K}^0\pi^0$	0.7	0.3	$\Lambda_c^+ \to pK^0\eta$	0.4 10^{-4}	0.2 10^{-3}
$\Lambda_c^+ \to n\pi^+\pi^0$	0.2	0.6	$\Lambda_c^+ \to nK^0\pi^+$	0.9 10^{-2}	0.2
$\Lambda_c^+ \to nK^+\bar{K}^0$	0.3 10^{-2}	0.7 10^{-2}	$\Lambda_c^+ \to nK^+\pi^0$	0.5 10^{-2}	0.9 10^{-1}
$\Lambda_c^+ \to \Lambda K^0\pi^+$	0.1 10^{-1}	0.4	$\Lambda_c^+ \to nK^+\eta$	0.5 10^{-3}	0.2 10^{-2}
$\Lambda_c^+ \to \Lambda K^+\pi^0$	0.7 10^{-1}	1.9			
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	0.06	0.4			
$\Lambda_c^+ \to p\bar{K}^0\pi^+\pi^-$	0.4	2.5			

In Figs. 1, 2 and 3 are shown the mass distributions of the decay products for the Cabibbo-allowed modes $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to p\bar{K}^0\pi^+\pi^-$ and $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, and we can conclude that the pole contributions of vector mesons play an important role.

One sees that the calculated and experimental ratios of the partial widths with a different number of final mesons are in a comparatively good agreement. This fact may be considered as a signal that in Λ_c^+ decay processes the chiral symmetry

plays a role, and we really can use the generalized PCLM to find reliable branching-ratio estimates for a more effective measurement and analysis of experiments.

In addition, we note that the proposed method gives, in comparison with other known approaches [2] based on different quark models, not only an easy way to calculate the probability ratios for many-body decays of hadrons with a minimal

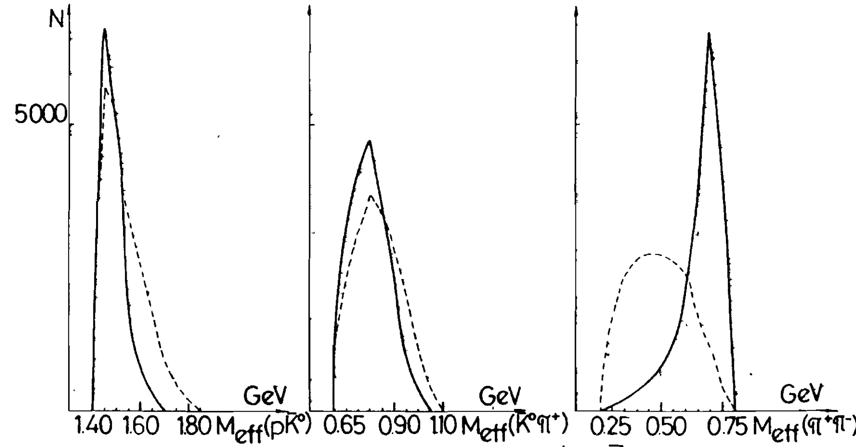

Fig. 2. The distributions for $\Lambda_c^+ \to p\bar{K}^0\pi^+\pi^-$.

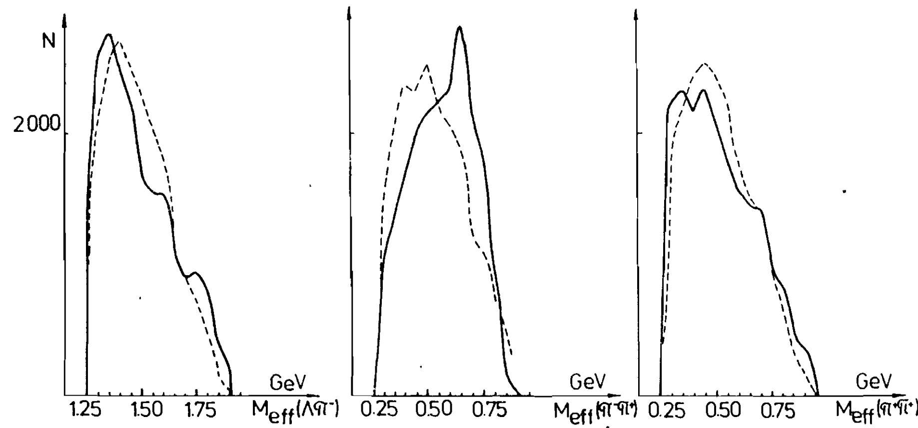

Fig. 3. The distributions for $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$.

number of phenomenological parameters, but provides the correct description of the relative probability (R_3) of the modes $\Lambda_c^+ \to \Lambda \pi^+$ and $\Lambda_c^+ \to p \bar{K}^0$, too. It is known that quark models predict different values which, as a rule, strongly differ from the experimentally measured value [5].

Thus, we can say that the PCLM with the "hardness" of mesons is a good approach for many-body nonleptonic weak decays of Λ_c^+.

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Калиновский Ю.Л. и др. E2-87-863
Многочастичные слабые распады очарованного Λ_c^+-бариона

В рамках метода "жестких" киральных лагранжианов /обобщенных путем введения взаимодействий псевдоскалярных, векторных мезонов с $1/2^+$ барионами/ вычислены двух-, трех- и четырехчастичные слабые нелептонные распады Λ_c^+-бариона. Показано, что теоретические и экспериментальные значения отношений вероятностей мод распадов находятся в удовлетворительном согласии.

Работа выполнена в Лаборатории теоретической физики, ОИЯИ.

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Kalinovsky Yu.L. et al. E2-87-863
Weak Many-Body Desays of the Λ_c^+-Baryon

The generalized "hard"-meson chiral-Lagrangian method, including pseudoscalar and spin-1 meson interactions with $1/2^+$-baryons, is used to calculate two-, three-, and four-body nonleptonic weak decays of Λ_c^+. It is shown that the theoretical and experimental ratios of the decay modes are in fair agreement.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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