объединенный
институт
ядерных
исследований
дубна

E2-85-257

R.Lednický

ABOUT THE DETERMINATION OF Λ_c^+ POLARIZATION

Submitted to "ЯФ"

1985

A study of charmed baryon Λ_c^+ polarization in hadron fragmentation processes is of particular interest due to the observation of large hyperon polarizations in these processes over a wide range of energies (see, e.g., ref.[1]). In particular, in nucleon fragmentation reactions $N \to Y$, the hyperon polarizations, measured along the normal to the production plane $\hat{n} \parallel [\hat{p}_N \times \hat{p}_Y]$, achieve 20-30% at transverse momenta of ~ 1 GeV/c and approximately satisfy the following relations: $P_\Lambda = P_{\Xi^{-}_{0}} \approx -P_{\Sigma^\pm} < 0$. These data, as well as data on polarization asymmetry of hadrons produced in the fragmentation of polarized protons, can be explained, at least qualitatively, in terms of recombination quark models taking into account the possibility of polarization (polarization asymmetry) of hadron constituents[2-6]. Note that the Λ_c^+ and Λ polarizations are determined by the polarizations of c- and s-quarks, respectively, since the ud-diquark in the wave functions of these baryons has zero spin. Thus, if the c- and s-quark production mechanisms are similar, a negative Λ_c^+ polarization can be expected. Observation of a positive Λ_c^+ polarization could indicate[4] a noticeable contribution of the intrinsic charm to the nucleon wave function[7]. Comparison of the Λ_c^+ and Λ polarizations can also give some important information on the dependence of polarization on the quark mass. The polarization is expected to be proportional to the quark mass provided that the quark becomes polarized in scattering on a colour charge (as a consequence of vector quark-gluon coupling[8,9]). An opposite dependence can take place if the polarization is caused by the interaction with "external" confining field (e.g., in the case of spontaneous radiation polarization[10]). Decreasing the polarization with increasing the quark mass is expected also in the model based on the dynamical equation for scattering amplitude[11].

The Λ_c^+ polarization reveals itself in the asymmetry of the distribution of the cosine of angle θ between decay and production analyzers ζ and $\hat{z}$:

$$W \sim 1 + \alpha_c P_c \cos\theta, \qquad (1)$$

where P_c is the projection of the polarization vector on the z-axis and α_c is the asymmetry parameter*. Since the polarization vector is directed perpendicular to the production plane (parity conservation in the production process is assumed), the z-axis should be chosen along the normal $\hat{n}$ to this plane. The asymmetry parameter α_c is determined by the Λ_c^+ decay mechanism and depends on the choice of the decay analyzer $\hat{\zeta}$ ($|\alpha_c| \le 1$). We shall consider $\hat{\zeta}$ directed along the momentum of the decay baryon B (nucleon, hyperon or isobar) in the Λ_c^+ rest frame. In the case of a given spin-parity of the meson system M in the decay $\Lambda_c^+ \to BM$, the asymmetry parameter is connected with the helicity decay amplitudes $A_\mu^c(\lambda_1, \lambda_2)$ by the relation

$$\alpha_c = \sum_{\lambda_1 \lambda_2} |A^c_{+1/2}(\lambda_1, \lambda_2)|^2 - |A^c_{-1/2}(-\lambda_1, -\lambda_2)|^2 / \sum_{\lambda_1 \lambda_2} |A^c_\mu(\lambda_1, \lambda_2)|^2. \qquad (2)$$

Here λ_1 and λ_2 are the baryon and meson-state helicities, respectively; $\mu = \lambda_1 - \lambda_2$ is the Λ_c^+ spin projection on the decay analyzer $\hat{\zeta} = \hat{p}_B$. If the parity were conserved in a two-particle or quasi-two-particle Λ_c^+ decay, then α_c would be equal to 0. An indication for decay asymmetry of the Λ_c^+ baryons produced in nC interactions has been recently obtained by means of the JINR spectrometer BIS-2 at the Serpukhov accelerator [12]: the decays $\Lambda_c^+ \to \Lambda 3\pi$ and $\Lambda_c^+ \to p\bar{K}^- 2\pi$ have been detected and analyzed. These data indicate a non-zero polarization P_c, however, they do not allow one to determine either its magnitude or its sign, since the values of the asymmetry parameters α_c are unknown. Theoretical estimates of these parameters would be useful in this context. Consider first the simplest two-particle decays $\Lambda_c^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to p\bar{K}^\circ$. It is well-known that in the asymptotic limit $m_c \to \infty$, when the masses of light constituent quarks can be neglected in comparison with the c-quark mass m_c, these decays are described by the so-called spectator diagrams. It can be seen that the helicity of decay baryons is then mainly equal to $-1/2$, i.e., $\alpha_c = -1$. It should be taken into account that the decay baryon is formed by recombining a spectator scalar diquark $(ud)_0$ with a fast s(u)-quark which has helicity $-1/2$ due to the V-A structure of weak current responsible for the decay $c \to s(u) + \pi^+(\bar{K}^\circ)$. The asymmetry parameter α_c is approximate to -1 also in the

---

*Note that $P_c = \rho_{1/2\,1/2} - \rho_{-1/2\,-1/2}$, where ρ_{mm} are the diagonal elements of the Λ_c^+ spin density matrix. Similarly, $\alpha_c = w_{1/2} - w_{-1/2}$, where w_μ is the decay probability of Λ_c^+ with the spin projection on the $\hat{\zeta}$-axis equal to μ. This relation follows directly from (1); it should be taken into account that $w_{\pm 1/2}$ determines the probability of the configuration with $\cos\theta = \pm 1$ in the decay of Λ_c^+ completely polarized along the z-axis.

case when the $\pi^+(\bar{K}^\circ)$-meson is replaced by a meson system M with a small effective mass m. With increasing m, however, an essential decrease of $|\alpha_c|$ can be expected. There are several reasons for this: a spread of the decay quark directions of flight with respect to the baryon direction ($\hat{\zeta}$-axis) increases; the contribution of the meson state with helicity -1 may become important*; for the decay momentum comparable to the s(u)-quark mass, the helicity $+1/2$ quark production becomes essential. The spectator mechanism, however, does not explain experimental data on D-meson decays [13] and, apparently, on Λ_c^+-baryon decays as well [14-16]. Unfortunately, calculations of the decay amplitudes, taking into account non-spectator contributions, are highly model-dependent even in the case of the simplest two-particle decays $\Lambda_c^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to p\bar{K}^\circ$. So, the α_c value for the first decay calculated in ref. [17] turned out to be positive and for the second one - negative. Negative α_c values for both decays have been obtained in refs. [14,15]. Positive values of these parameters have been obtained in terms of the chiral Lagrangian model [18]. Thus, the theory at the present stage is unable to make a reliable conclusion even about signs of the asymmetry parameters of the simplest Λ_c^+-decays.

Let us discuss the possibility of simultaneous determination of the parameters α_c and P_c with the help of the analysis of angular distributions in cascade Λ_c^+-decays. To determine the parameter α_c in the case of Λ_c^+ decaying into a spin 1/2 baryon and a meson or a meson system with zero spin, it is enough to measure the polarization of the decay baryon. If this baryon is a hyperon, its weak decay $B \to B'\pi$ can be used for this, as for the determination of the asymmetry parameter in the decay $\Xi \to \Lambda\pi$ (see, e.g., ref. [19]). The angular distribution for the corresponding cascade decay is well known [20]. It can be written in the form:

$$W(\Omega, \Omega_1) \sim 1 + \alpha_B \alpha_c \cos\theta_1 + P_c [\alpha_c \cos\theta + \alpha_B \cos\theta \cos\theta_1 -$$
$$- \alpha_B \sqrt{1 - \alpha_c^2} \sin\theta \sin\theta_1 \cos(\phi_1 + \Phi_c)]. \qquad (3)$$

Here $\Omega_1 = (\phi_1, \theta_1)$ are the azimuthal and polar angles of the baryon B′ direction of flight in the baryon B rest frame in the helicity coordinate system: $\hat{z}_1 = \hat{p}_B$, $\hat{y}_1 \parallel [\hat{z} \times \hat{z}_1]$, $\hat{x}_1 = [\hat{y}_1 \times \hat{z}_1]$; α_B is the asymmetry parameter of the $B \to B'\pi$ decay and Φ_c is the phase difference of the decay amplitudes $A^c_{+1/2}(+1/2, 0)$ and

---

*Denoting this contribution by ϵ, we have $\alpha_c = -(1-\epsilon)/(1+\epsilon)$. It can be shown that $\epsilon = 2w_1 m^2/m_c^2$, where w_1 is the production probability of the meson state with mass m and spin 1 (note that only the meson system with spin 0 and 1 can be produced in the decay $c \to q + M$).

$A^c_{-1/2}(-1/2,0)$ (values of the parameters α and Φ for hyperon decays can be found in tables of particle properties [21]). The distribution (3) yields 5 relations (moments) for 3 parameters α_c, P_c and Φ_c. To determine the parameters α_c and P_c, it is sufficient to analyze the angular distribution (3) integrated over the azimuthal angle ϕ_1, i.e., the moments $\langle\cos\theta\rangle = \alpha_c P_c/3$, $\langle\cos\theta_1\rangle = \alpha_B \alpha_c/3$ and $\langle\cos\theta\cos\theta_1\rangle = \alpha_B P_c/9$. In particular, the polarization P_c can be determined by the relations

$$P_c = \alpha_B \langle\cos\theta\rangle / \langle\cos\theta_1\rangle, \qquad P_c = 9\langle\cos\theta\cos\theta_1\rangle/\alpha_B. \tag{4}$$

Assuming the detection efficiency independent of decay angles, the statistical errors of the parameters α_c and P_c, in the limit $\alpha_c^2, P_c^2 \ll \alpha_B^2$, are equal to*

$$\sigma(\alpha_c) = \frac{\sqrt{3}}{\alpha_B}\delta, \qquad \sigma(P_c) = \frac{3}{\alpha_B}\delta. \tag{5}$$

Here $\delta = 1/a\sqrt{n}$ is the relative statistical error of the signal from the Λ_c^+-decay; n is the total number of candidates for this decay, (1-a) is the fraction of background events. If the meson system has spin $j_2 \geq 1$, the $\Lambda_c^+ \to BM$ decay is described by 4 amplitudes $A^c_\mu(\lambda_1,\lambda_2)$ with $\lambda_1, \lambda_2 = \pm 1,2,0; \pm 1/2, \pm 1$. In this case the measurement of the decay baryon polarization is insufficient to determine the asymmetry parameter α_c: a joint analysis of the baryon and meson spin states is required. We shall show that the angular distribution in the cascade decay $\Lambda_c^+ \to BM$, $B \to B'\pi$, $M \to ab\ldots$ yields sufficient information to determine α_c and P_c provided that the value $\alpha_B \neq 0$ is beforehand known. This distribution can be written in the form (see, e.g., refs. [22,23]):

$$W \sim \sum A^c_\mu(\lambda_1,\lambda_2) A^{c*}_{\mu'}(\lambda_1,\lambda_2)\,[\delta_{\mu\mu'} + \sqrt{3}P_c(\tfrac{1}{2}\mu' 1N|\tfrac{1}{2}\mu)\, d^1_{0N}(\theta)]\,\cdot$$
$$\cdot[\delta_{\lambda_1\lambda_1'} + \sqrt{3}\alpha_B(\tfrac{1}{2}\lambda_1' 1M_1|\tfrac{1}{2}\lambda_1) D^{1*}_{M_1 0}(\phi_1,\theta_1,0)]\,\cdot \tag{6}$$
$$\cdot\sum(2L_2+1)\langle T_{L_2N_2}\rangle (j_2\lambda_2' L_2M_2|j_2\lambda_2)\, D^{L_2 *}_{M_2N_2}(\phi_2,\theta_2,\psi_2).$$

Here ϕ_2, θ_2, ψ_2 are the Euler angles characterizing the orientation of the coordinate system $\{\xi_2\eta_2\zeta_2\}$, formed from the momenta of the particles from the meson-state decay, with respect to the helicity frame: $\hat{z}_2 = \hat{p}_M$, $\hat{y}_2 \| [\hat{z}\times\hat{z}_2]$, $\hat{x}_2 = [\hat{y}_2\times\hat{z}_2]$ (ϕ_2, θ_2 are the azimuthal and polar angles of the ζ_2-axis, $\pi-\psi_2$ is the azimuthal angle of the z_2-axis in the system $\{\xi_2\eta_2\zeta_2\}$). The functions

$$D^{L_2 *}_{M_2N_2}(\phi_2,\theta_2,\psi_2) = e^{iM_2\phi_2}\, d^{L_2}_{M_2N_2}(\theta_2)\, e^{iN_2\psi_2}$$

represent matrix elements of the corresponding rotation transformation $\{x_2y_2z_2\} \to \{\xi_2\eta_2\zeta_2\}$. The decay multipole parameters [23] $T_{L_2N_2}$ are the bilinear products of the helicity amplitudes in the $M \to ab\ldots$ decay:

$$T_{L_2N_2} = \sum_{\mu_2,\lambda_a,\lambda_b,\ldots} A_{\mu_2}(\lambda_a,\lambda_b,\ldots)\, A^*_{\mu_2'}(\lambda_a,\lambda_b,\ldots)\,(j_2\mu_2' L_2N_2|j_2\mu_2), \tag{7}$$

where $\lambda_a, \lambda_b \ldots$ are the decay particle helicities, μ_2 is the projection of the spin j_2 on the axis ζ_2; $\langle T_{L_2N_2}\rangle$ denotes the result of averaging over the variables characterizing internal orientation of the particles from the meson-state decay (in the case of 3-particle decay, they are Dalitz plot variables). In the case of 2-particle decay, the ζ_2-axis is uniquely fixed by the relative momentum of the decay particles in their rest frame; the directions of the axes ξ_2 and η_2 are nonessential. Consequently, $N_2 = 0$ and we can put $\psi_2 = 0$ in (6). In the case of 3-particle decay, we direct the ζ_2-axis along the normal to the decay plane and the axis ξ_2 along the momentum of one of the decay particles in their rest frame. For such a choice of the coordinate system $\{\xi_2\eta_2\zeta_2\}$, parity conservation forbids odd N_2-values but, unlike the case of 2-particle decay, in general, it allows odd L_2-values**. To determine α_c and P_c, it is enough to analyze the angular distribution (6) integrated over the azimuthal angles, i.e.,

$$W \sim \sum_{L_2=0,2,\ldots}(2L_2+1)\langle T_{L_20}\rangle d^{L_2}_{00}(\theta_2)\{(j_20L_20|j_20)[a_+(1+P_c\cos\theta)(1+\alpha_B\cos\theta_1) +$$
$$+ a_-(1-P_c\cos\theta)(1-\alpha_B\cos\theta_1)] + (j_21L_20|j_21)[b_+(1+P_c\cos\theta)(1-\alpha_B\cos\theta_1) + \tag{8}$$
$$+ b_-(1-P_c\cos\theta)(1+\alpha_B\cos\theta_1)]\} - \sum_{L_2=1,3,\ldots}(2L_2+1)\langle T_{L_20}\rangle d^{L_2}_{00}(\theta_2)(j_21L_20|j_21)\times$$
$$\times[b_+(1+P_c\cos\theta)(1-\alpha_B\cos\theta_1) - b_-(1-P_c\cos\theta)(1+\alpha_B\cos\theta_1)],$$

---

* These errors get smaller with increasing P_c^2 and α_c^2. For example, the error $\sigma(\alpha_c)$ is reduced by a factor of $\sqrt{2}$ at $P_c^2 \simeq \alpha_B^2 + 3\alpha_c^2$; for the same reduction of $\sigma(P_c)$, $\alpha_c^2 \simeq \frac{1}{3}(\alpha_B^2 + P_c^2)$ is required.

** $\langle T_{L_2N_2}\rangle = 0$ for odd L_2-values provided that two of the decay particles are identical or they are in a state with a given isospin [24].

where $a_{\pm} = |A^{c}_{\pm 1/2}(\pm 1/2, 0)|^2$, $b_{\pm} = |A^{c}_{\pm 1/2}(\mp 1/2, \mp 1)|^2$. After integration over $\cos\theta_1$ and $\cos\theta_2$ in (8), we obtain the distribution (1) with the asymmetry parameter $\alpha_c = (a_+ - a_- + b_+ - b_-)/(a_+ + a_- + b_+ + b_-)$. For each L_2 -value, the distribution (8) allows the determination of 4 moments $\langle d^{L_2}_{00}(\theta_2)\rangle$, $\langle \cos\theta\, d^{L_2}_{00}(\theta_2)\rangle$, $\langle \cos\theta_1 d^{L_2}_{00}(\theta_2)\rangle$ and $\langle \cos\theta \cos\theta_1 d^{L_2}_{00}(\theta_2)\rangle$ which can be expressed through unknown parameters $a_{\pm}$, $b_{\pm}$, $\langle T_{L_2 0}\rangle$ and polarization P_c. It can be shown that the corresponding system of equations is overdetermined provided that the parameter $\alpha_B \neq 0$ is known. If the baryon B does not decay or parity is conserved in its decay ($\alpha_B = 0$), the asymmetry parameter α_c and polarization P_c, in general, cannot be determined by analyzing the angular distribution (6) only. The exception is the case when the parameter $\langle T_{L_2 0}\rangle \neq 0$ for an odd value of L_2 *. If, however, the sign of this parameter is beforehand unknown, only absolute values of α_c and P_c can be determined. It is seen well, e.g., in the case of distribution (3) which is insensitive to simultaneous change of the signs of the parameters P_c, α_c and $\alpha_B = \sqrt{3}T^{B}_{10}/T^{B}_{00}$. A meson-state decay into spinless particles is of practical interest. A decay into two spinless particles is described by the only amplitude A_0, and the decay multipole parameters, in accordance with (7), are uniquely determined: $T_{L_2 0} = (j_2 0 L_2 0 | j_2 0)\, T_{00}$. This circumstance and also the fact that the $T_{L_2 0}$ -values are maximal lead to the smallest possible errors of the parameters α_c and P_c at given $j_2 > 0$. The maximal errors of these parameters, however, are higher than in the case of the meson system with zero spin. For example, for $j_2 = 1$, they are 1.5 times larger than the values given in (5)**. Generally speaking, the parameters $\langle T_{L_2 0}\rangle$ for a decay into three spinless particles are not uniquely determined. Parity conservation, however, decreases essentially the number of independent parameters. So, only even values of the spin j_2 projection μ_2 on the normal to the decay plane are allowed in the case when the meson-state parity coincides with the product of parities of the decay particles, while only odd values are allowed in the opposite case. For example,

---

* Due to parity conservation in the meson-state decay, this is possible only in the case of decay into more than two particles, e.g., $\bar{Q} \to \bar{K}^{\circ} 2\pi$.

** The error $\sigma(P_c)$ depends on a relative contribution of the amplitudes with $\lambda_2 = \pm 1$ and 0. It is maximal at $(b_+ + b_-)/(a_+ + a_-) = 4/3$ and minimal (two times less) at $b_+ + b_- = 0$.

a 1^-- state decay into three pseudoscalar mesons, as well as the decay into two spinless particles, is described by the only amplitude A_0, i.e., $T_{10} = 0$ and $T_{20} = -\sqrt{\frac{2}{5}}T_{00}$. A 1^+- state decay into three 0^- mesons is described by two amplitudes $A_{\pm 1}$, so that $T_{10} = \frac{1}{\sqrt{2}}(|A_1|^2 - |A_{-1}|^2)$ and $T_{20} = \frac{1}{\sqrt{10}}T_{00}$.

A decay $\Lambda^+_c \to B^* M$ is also of practical interest, where B^* is an isobar with spin-parity $3/2^+$ decaying into a $1/2^+$ baryon and a pseudoscalar meson (e.g., $\Sigma^* \to \Lambda\pi$, $\Delta \to N\pi$). The angular distribution in such a cascade decay takes the form analogous to (6):

$$W \sim \sum A^{c}_{\mu}(\lambda_1,\lambda_2)\, A^{c*}_{\mu'}(\lambda'_1,\lambda'_2)\, [\delta_{\mu\mu'} + \sqrt{3}\, P_c (\tfrac{1}{2}\mu' 1N | \tfrac{1}{2}\mu)\, d^{1}_{0N}(\theta)]\, [\delta_{\lambda_1\lambda'_1} - \sqrt{5}(\tfrac{3}{2}\lambda'_1 2M_1 | \tfrac{3}{2}\lambda_1)\, D^{2*}_{M_1 0}(\phi_1, \theta_1, 0)] \times \tag{9}$$

$$\times \sum (2L_2+1) \langle T_{L_2 N_2}\rangle (j_2\lambda'_2 L_2 M_2 | j_2\lambda_2)\, D^{L_2 *}_{M_2 N_2}(\phi_2, \theta_2, \psi_2).$$

After integration over the azimuthal angles, it contains parameters P_c, $\langle T_{L_2 0}\rangle$ and, in the general case, 6 parameters $a_{\pm} = |A^{c}_{\pm 1/2}(\pm 1/2, 0)|^2$, $b_{\pm} = |A^{c}_{\pm 1/2}(\mp 1/2, \mp 1)|^2$ and $c_{\pm} = |A^{c}_{\pm 1/2}(\pm 3/2, \pm 1)|^2$. As in the previous case when $\alpha_B = 0$, this distribution allows the parameters α_c and P_c to be determined providing the sign of the parameter $\langle T_{L_2 0}\rangle \neq 0$ at an odd L_2 - value is beforehand known. If such a condition is not fulfilled, but the baryon B is a hyperon, asymmetry of its weak decay $B \to B'\pi$ can be used to determine α_c and P_c. Instead of (9), we then have

$$W \sim \sum A^{c}_{\mu}(\lambda_1,\lambda_2)\, A^{c*}_{\mu'}(\lambda'_1,\lambda'_2)\, [\delta_{\mu\mu'} + \sqrt{3}\, P_c (\tfrac{1}{2}\mu' 1N | \tfrac{1}{2}\mu)\, d^{1}_{0N}(\theta)]\, [\delta_{\lambda_B\lambda'_B} + \sqrt{3}\alpha_B \times$$

$$\times (\tfrac{1}{2}\lambda'_B 1N_1 | \tfrac{1}{2}\lambda_B)\, D^{1*}_{N_1 0}(\phi'_1, \theta'_1, 0)] \cdot \sum (2L_1+1)(\tfrac{3}{2}\lambda'_1 L_1 M_1 | \tfrac{3}{2}\lambda_1) \times$$

$$(\tfrac{3}{2}\lambda'_B L_1 N_1 | \tfrac{3}{2}\lambda_B)\, D^{L_1 *}_{M_1 N_1}(\phi_1, \theta_1, 0) \cdot \sum (2L_2+1) \langle T_{L_2 N_2}\rangle (j_2\lambda'_2 L_2 M_2 | j_2\lambda_2) \times$$

$$\times D^{L_2 *}_{M_2 N_2}(\phi_2, \theta_2, \psi_2), \tag{10}$$

where ϕ'_1, θ'_1 are the azimuthal and polar angles of the baryon B' momentum in the B rest frame in the helicity coordinate system: $\hat{z}_1' = \hat{p}_B$, $\hat{y}_1' \parallel [\hat{z}_1 \times \hat{z}_1']$, $\hat{x}_1' = \hat{y}_1' \times \hat{z}_1'$ ($\hat{p}_B$ is the unit vector directed along the baryon B momentum in the rest frame of the isobar B*). After integration in (10) over the azimuthal angles ϕ_1 , ϕ_2 and ψ_2, we obtain

$$
\begin{aligned}
W \sim & \sum_{L_2=0,2\ldots} (2L_2+1) \langle T_{L_2 0} \rangle d^{L_2}_{00}(\theta_2) \{ (j_2 0 L_2 0 | j_2 0) [a_+ (1+P_c \cos\theta)(1+d^2_{00}(\theta_1)+\alpha_B Z) + \\
& + a_-(1-P_c \cos\theta)(1+d^2_{00}(\theta_1)-\alpha_B Z)] + (j_2 1 L_2 0 | j_2 1) [b_+(1+P_c \cos\theta)(1+d^2_{00}(\theta_1)-\alpha_B Z) + \\
& + b_-(1-P_c \cos\theta)(1+d^2_{00}(\theta_1)+\alpha_B Z) + c_+(1+P_c \cos\theta)(1-d^2_{00}(\theta_1)+\alpha_B \tilde{Z}) + \\
& + c_-(1-P_c \cos\theta)(1-d^2_{00}(\theta_1)-\alpha_B \tilde{Z})] - \sum_{L_2=1,3,\ldots} (2L_2+1) \langle T_{L_2 0} \rangle d^{L_2}_{00}(\theta_2)(j_2 1 L_2 0 | j_2 1) \qquad (11) \\
& \times [b_+(1+P_c \cos\theta)(1+d^2_{00}(\theta_1)-\alpha_B Z) - b_-(1-P_c \cos\theta)(1+d^2_{00}(\theta_1)+\alpha_B Z) + \\
& + c_+(1+P_c \cos\theta)(1-d^2_{00}(\theta_1)+\alpha_B \tilde{Z}) - c_-(1-P_c \cos\theta)(1-d^2_{00}(\theta_1)-\alpha_B \tilde{Z})].
\end{aligned}
$$

Here Z , $\tilde{Z}$ are the functions of the decay angles ϕ_1' , θ_1' and θ_1 :

$$
\begin{aligned}
& Z = Z_1 + 3Z_3 , \quad \tilde{Z} = 3Z_1 - Z_3 , \quad Z_1 = \frac{1}{5}(\cos\theta_1' \cos\theta_1 - 2 \sin\theta_1' \sin\theta_1 \cos\phi_1') , \\
& Z_3 = \frac{1}{5} [3 \cos\theta_1' d^3_{00}(\theta_1) + 2\sqrt{3} \sin\theta_1' d^3_{10}(\theta_1) \cos\phi_1'] . \qquad (12)
\end{aligned}
$$

The distribution (11) leads to an overdetermined system of equations for the parameters $\langle T_{L_2 0} \rangle$, $a_\pm$, $b_\pm$, $c_\pm$ and P_c provided that $\alpha_B \neq 0$ is known. If, e.g., the meson state M has spin $j_2=0$, then $b_\pm = c_\pm = 0$ and $T_{L_2 0} = 0$ at $L_2 \neq 0$. In this case the angular distribution (11) contains 11 orthogonal functions; their contributions (moments) are determined by only two parameters P_c and $\alpha_c = (a_+ - a_-)/(a_+ + a_-)$. Despite the large number of moments, the errors of these parameters (in the limit α_c^2 , $P_c^2 \ll \alpha_B^2$) turned out to be 2.3 times larger than the values given in (5). However, as α_c^2 and P_c^2 increase, they get smaller more rapidly as compared to the case of Λ_c^+ decay into a hyperon and a zero spin meson*.

---

* For example $\sigma(P_c)$ is reduced by a factor of $\sqrt{2}$ at $\alpha_c^2 \simeq (\alpha_B^2 + 6.4 P_c^2)/19.2$.

We have assumed until now that the meson state M has a given spin-parity. Now we discuss the situation when the spin-parity of this state is not defined. As an example we choose the $\Lambda_c^+ \to \Lambda 3\pi$ decay and suppose the 3π system to be produced mainly in the lowest 0^- and 1^+ states. Note that suppression of a contribution of higher orbital excitations $\ell_{\pi\pi}$, ℓ_π = 1,1; 1,2;... can be strengthened by selecting a low mass 3π system. In such a case, the decay angular distribution, integrated over the azimuthal angles, represents a superposition of the distributions (8) with $j_2=0$ and 1. It should be taken into account that the terms corresponding to the interference of the 0^- and 1^+ states vanish after integration over ψ_2 and that $T_{20}^{1^+} = -\frac{1}{\sqrt{10}} T_{00}^{1^+}$, $\langle T_{10}^{1^+} \rangle = 0$ and $b_\pm^{0^-} = 0$. This distribution leads to 8 relations for 7 parameters $a_\pm^{0^-} \langle T_{00}^{0^-} \rangle$, $a_\pm^{1^+} \langle T_{00}^{1^+} \rangle$ and P_c . It is easy to show that these relations form an overdetermined system of equations; e.g., the polarization P_c is given by two equations

$$
\begin{aligned}
& P_c = \alpha_\Lambda [\langle \cos\theta \rangle - 10 \langle \cos\theta \, d^2_{00}(\theta_2) \rangle] / [\langle \cos\theta_1 \rangle - 10 \langle \cos\theta_1 d^2_{00}(\theta_2) \rangle] , \\
& P_c = \frac{9}{\alpha_\Lambda} [\langle \cos\theta \cos\theta_1 \rangle - 10 \langle \cos\theta \cos\theta_1 d^2_{00}(\theta_2) \rangle] / [1 - 10 \langle d^2_{00}(\theta_2) \rangle] , \qquad (13)
\end{aligned}
$$

which represent generalization of the relations (4). The error of P_c is maximal in the case of a dominant contribution of the 0^- state and α_c^2 , $P_c^2 \ll \alpha_B^2$. It is 4.6 times larger than in the case when the zero spin of the meson state is known beforehand (see (5))*. In the limit of small α_c^2 , P_c^2 the error $\sigma(P_c)$ is minimal provided that the contribution of the 1^+ state dominates and $b_\pm = 0$. In such a case, it is 1.5 times larger than the value given in (5). Concerning the error of the parameter α_c , in the limit α_c^2 , $P_c^2 \ll \alpha_B^2$ it is maximal and equal to $\sigma(\alpha_c)$ = = $1.7\,\delta/P_c$ independent of a relative contribution of the 0^- and 1^+ states.

Conclusions:

– The measurement of the Λ_c^+ polarization P_c and the asymmetry parameters α_c of the Λ_c^+ decays is important to clarify the mechanisms of quark production and hadronization. In particular, the difference of the asymmetries of the decay nucleon and Λ -

---

* The useful information can give a Dalitz plot analysis of the 3π system.

hyperon angular distributions measures the contribution of the non-spectator diagrams which are sensitive to the quark interactions at large distances.

– Since the asymmetry parameters α_c are unknown and at the present stage the theory cannot give a reliable conclusion even about the signs of these parameters, the measurement of the Λ_c^+-decay asymmetries is sufficient to determine only the lower limit for $|P_c|$ corresponding to the condition $|\alpha_c| = 1$;

– The Λ_c^+ polarization can be determined by an analysis of the angular distributions in the Λ_c^+ cascade decays provided that the asymmetry parameter, or another odd multipole parameter, characterizing the secondary decay (e.g., $\Lambda \to p\pi$, $\bar{Q} \to \bar{K}2\pi$) is beforehand known.

– Two particle or quasi-two-particle Λ_c^+-decays (e.g., $\Lambda_c^+ \to \Lambda\pi$, $\Lambda\rho$, $\Lambda\omega$, $\Lambda_c^+ \to \Sigma^*\pi$, $\Sigma^* \to \Lambda\pi$) are the most suitable to measure the Λ_c^+-polarization. The error of the polarization in the case of the decays into three or more particles or resonances turns out to be larger since a part of the information is spent to determine the partial wave contributions.

– Realistic statistics (at the level of several hundreds of Λ_c^+ decays in separate decay channels) achievable in the near future will allow a reliable determination of the signs of the asymmetry parameters α_c and the polarization P_c if only $|\alpha_c|$ and $|P_c| \gtrsim 0.5$.

The author is grateful to S.B.Gerasimov, J.Hladky, I.M.Gramenitsky, W.Kallies, V.D.Kekelidze, M.F.Likhachev, A.L.Lyubimov, V.N.Pervushin and A.Prokes for their interest in this work and useful discussions.

REFERENCES

1. High Energy Spin Physics – 1982. AIP Conf.Proc., No.95, Part. and Fields. Subseries No.28. Amer.Inst.of Phys., New York, 1983, p.77.
2. Heller K. et al. Phys.Rev.Lett., 1978, 41, p.607.
3. Andersson B. et al. Phys.Lett., 1979, 85B, p.417; LU TP 82-13, Lund, 1982; Gustafson G. High Energy Spin Physics-1982, p.355.
4. De Grand T.A., Miettinen H.I. Phys.Rev., 1981, D24, p.2419.
5. Struminsky B.V. YaF, 1981, 34, p.1954.
6. Lednicky R. Czech.J.Phys., 1983, B33, p.1177; Z.Phys., 1985, C26, p.531.
7. Brodsky S. et al. Phys.Lett., 1980, 93B, p.451.

8. Kane G., Yao Y.P. Nucl.Phys., 1978, B137, p.313.
9. Szwed J. Phys.Lett., 1981, 105B, p.403.
10. Batyunya B.V. et al. Czech.J.Phys., 1981, B31, p.11.
11. Troshin S.M., Tyurin N.E. YaF, 1983, 38, p.1065.
12. Aleev A.N. et al. In: JINR Rapid Communications, No.1-84, Dubna, 1984, p.13.
13. Klanner R. In: Proc. of the XXII Int.Conf. on High Energy Physics. Leipzig, 1984, vol.II, p.201.
14. Ebert D., Kallies W. Phys.Lett., 1983, 131B, p.183; Kallies W., Ebert D. YaF, 1984, 40, p.1250.
15. Hussian F., Scadron M.D. Nuovo Cim., 1984, 79A, p.248.
16. Shifman M.A., Voloshin M.B. ITEP-62, Moscow, 1984.
17. Körner J.G. et al. Z.Phys., 1979, C2, p.117.
18. Pervushin V.N., Sarikov N.A. JINR, E2-84-620, Dubna, 1984.
19. Baltay C. et al. Phys.Rev., 1974, D9, p.49.
20. Lee T.D., Yang C.N. Phys.Rev., 1957, 108, p.1645.
21. Wohl C.G. et al. Rev.Mod.Phys., 1984, 56, No.2, part 2.
22. Chung S.U. CERN 71-8, Geneva, 1971.
23. Lednicky R. JINR, E2-10567, Dubna, 1977.
24. Berman S.M., Jacob M. Phys.Rev., 1965, 139, p.B1023.

Received by Publishing Department
on April 11, 1985.

В Объединенном институте ядерных исследований начал выходить сборник *"Краткие сообщения ОИЯИ"*. В нем будут помещаться статьи, содержащие оригинальные научные, научно-технические, методические и прикладные результаты, требующие срочной публикации. Будучи частью "Сообщений ОИЯИ", статьи, вошедшие в сборник, имеют, как и другие издания ОИЯИ, статус официальных публикаций.

Сборник "Краткие сообщения ОИЯИ" будет выходить регулярно.

The Joint Institute for Nuclear Research begins publishing a collection of papers entitled *JINR Rapid Communications* which is a section of the JINR Communications and is intended for the accelerated publication of important results on the following subjects:

Physics of elementary particles and atomic nuclei.
Theoretical physics.
Experimental techniques and methods.
Accelerators.
Cryogenics.
Computing mathematics and methods.
Solid state physics. Liquids.
Theory of condensed matter.
Applied researches.

Being a part of the JINR Communications, the articles of new collection like all other publications of the Joint Institute for Nuclear Research have the status of official publications.

JINR Rapid Communications will be issued regularly.

Ледницки Р. E2-85-257

Об определении поляризации очарованного бариона Λ_c^+

Получены формулы для угловых распределений в различных каскадных распадах Λ_c^+-бариона, позволяющие определить его поляризацию и соответствующие параметры асимметрии. Оценены ошибки этих параметров. Указывается на важность поляризационных измерений для изучения кварковых взаимодействий на "больших" расстояниях.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1985

Lednický R. E2-85-257

About the Determination of Λ_c^+ Polarization

Formulae for angular distributions for various Λ_c^+ cascade decays, allowing the determination of its polarization and asymmetry parameters, are obtained. Errors of these parameters are estimated. The importance of polarization measurements for studying quark interactions at "large" distances is stressed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1985