Angular distribution and asymmetries in the decay of the polarized charmed baryon $Λ_c^+ → K^- ∆^{++} → K^- p \pi^+$

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Angular distribution of the final particles in the decay $Λ_c^+ → K^- ∆^{++}(1232) → K^- p \pi^+$ of the polarized charmed baryon is discussed. Asymmetries are proposed which allow for determination of the components of the $Λ_c^+\uparrow$ polarization vector. The precession angle of the polarization in the process of baryon channeling in a bent crystal is directly related to these asymmetries. The decay rate and asymmetry parameter for the $Λ_c^+ → K^- ∆^{++}(1232)$ decay are calculated in the pole model and compared with experiment.

Keywords: Charmed baryon decay; polarization; pole model

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1. Introduction

Measurement of polarization of the charm quark is important for the study of mechanisms of its production in the QCD processes and in the decays of new particles and, for example, the Higgs boson to the $c\bar{c}$ pair in order to determine the Lorentz structure and values of couplings. The polarization of the $c$ quark determines the polarization of the $Λ_c^+$ baryon and by investigating the angular distribution of the decay products of the polarized $Λ_c^+$ one can measure the value of its polarization, and thus the polarization of the $c$ quark. Note that the transverse polarization of $Λ_c^+$’s from QCD production has already been seen in the fixed-target experiments NA3[1, 2] and E791[3].

Another important aspect of the study of $Λ_c^+$ polarization is related to a possibility to measure its magnetic dipole moment (MDM) and electric dipole moment (EDM) using spin precession in a strong effective magnetic field inside bent crystals. The motivation here is comparison of experiment with various theoretical calculations of the MDM (see, e.g.,[4, 5] and references therein). Such measurements may also provide information on the MDM of the charm quark.

There are various modes of decay of the charmed $Λ_c^+$ baryon[6]. Our purpose is to investigate those modes for which measurement of angular distribution of the final

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particles is more expedient to determine the polarization of the initial \( \Lambda_c^+ \) baryon. Among these modes the hadronic decay \( \Lambda_c^+ \to K^- p \pi^+ \), which has the largest branching fraction, 6.28 \( \pm \) 0.32 \%, is of great interest. The first model-independent measurements of the absolute branching fraction of the \( \Lambda_c^+ \to K^- p \pi^+ \) decay have been performed by the Belle\(^\text{14}\) and BESIII\(^\text{15}\) collaborations. From theoretical point of view the nonleptonic decays of the charmed baryons is useful environment for studying the interplay between weak and strong interactions.

In the present paper we consider the decay \( \Lambda_c^+ \to K^- \Delta^{++}(1232) \) which contributes to the decay amplitude of \( \Lambda_c^+ \to K^- p \pi^+ \). Moreover, this process at the quark level arises due to mechanism of the \( W \)-exchange. Therefore, study of the decay \( \Lambda_c^+ \to K^- \Delta^{++}(1232) \) is important for the investigation of the \( W \)-exchange diagrams in the charmed-baryon sector.

In order to find the matrix element, which determines the decay width of \( \Lambda_c^+ \to K^- \Delta^{++}(1232) \) and asymmetry parameter, we apply the pole model developed in Refs.\(^\text{16,17}\) In general, calculation of matrix element of the non-leptonic decays of the charmed baryons with \( J^P = \frac{1}{2}^+ \) involves the factorization and non-factorization contributions\(^\text{13}\) The non-factorization contribution can be adequately described in the pole model\(^\text{16,17}\) Although for description of non-leptonic decay very often both factorization and non-factorization contributions are needed, there are cases in which only the pole contribution appears. The process \( \Lambda_c^+ \to K^- \Delta^{++} \) belongs to such decays.

The present paper is organized as follows. In Sec.\(^\text{2}\) definitions and results for \( \Lambda_c^+ \to K^- \Delta^{++} \to K^- p \pi^+ \) decay are presented. In particular, in Subsec.\(^\text{2.1}\) amplitudes and angular distributions are given, and in Subsec.\(^\text{2.2}\) asymmetries are defined which determine components of the \( \Lambda_c^+ \) polarization. In Subsec.\(^\text{2.3}\) the rotation angle of the \( \Lambda_c^+ \) polarization vector after baryon passing through a bent crystal is expressed through the asymmetries in the \( \Lambda_c^+ \to K^- \Delta^{++} \to K^- p \pi^+ \) decay. In Sec.\(^\text{3}\) the pole model for \( \Lambda_c^+ \to K^- \Delta^{++} \) is described. Parameters of the model and theoretical uncertainties are discussed in Subsec.\(^\text{3.1}\) Branching ratio and asymmetry parameter are calculated and compared with experiment. As a test of the model, in Subsec.\(^\text{3.2}\) we estimate the rate of the weak decay of the strange baryon, \( \Omega^- \to K^- \Lambda \). Concluding remarks are given in Sec.\(^\text{4}\).

2. Amplitudes and angular distributions in the decay
\( \Lambda_c^+ \to K^- \Delta^{++} \to K^- p \pi^+ \)

2.1. Differential decay rate

The decay

\[
\Lambda_c^+(p) \to K^-(p_2) + \Delta^{++}(p'),
\]

where \( p(p') \) and \( p_2 \) are the four-momenta of \( \Lambda_c^+ \) (\( \Delta^{++}(1232) \)) baryon and \( K^- \) meson, respectively, corresponds to the class of transitions \( \frac{1}{2}^+ \to \frac{3}{2}^+ + 0^- \). Note that throughout this paper integers and fractions with a superscript + or − will
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represent $J^P$. The most general form of the transition amplitude is

$$\mathcal{M} = \bar{u}_\mu(p') (B - A \gamma_5)p^\mu_2 u(p),$$  

(2)

where $u(p)$ is the Dirac spinor, $u_\mu(p')$ is the Rarita-Schwinger vector-spinor, such that $p'_\mu u'(p') = 0$ and $\gamma_\mu u'(p') = 0$, $A$ and $B$ are the Lorentz invariant amplitudes which have dimension GeV$^{-1}$. The amplitude $B$ describes the parity conserving transition ($P$-wave), while $A$ – parity violating one ($D$-wave).

In the rest frame of the $\Lambda_c^+$ baryon the helicity amplitudes of the decay $\Lambda_c^+(p, \lambda) \to K^-(p_2) + \Delta^{++}(p', \lambda')$ are defined by the expression

$$F_{0\lambda\lambda'} = -k \sqrt{\frac{2s}{3s'}} \exp(i\lambda\phi_K) u^\lambda_{\lambda'}(\theta_K) a_{\lambda'},$$  

(3)

where $s = (p_2 + p')^2$ and $s' = p'^2$. Here $\lambda$ is the projection of the $\Lambda_c^+$ spin on the axis $OZ$. The polar angle $\theta_K$ and azimuthal angle $\phi_K$ define the direction of the $K^-$ meson. Further, $k$ is the momentum of the $K^-$ meson, $k \equiv |\vec{p}_2| = (4s)^{-1/2} \lambda^{1/2}(s, s', m_2^2)$, $m_2$ is the mass of $K^-$, $\lambda(a, b, c)$ is the triangle function, which is symmetrical with respect to all three variables, $\lambda(a, b, c) = a^2 + b^2 + c^2 - 2a b - 2a c - 2b c$. Finally, $\lambda'$ is the helicity of the $\Delta^{++}(1232)$ isobar.

The helicity amplitudes $a_{\lambda'}$ are related to the invariant amplitudes $A$ and $B$:

$$a_{\pm 3/2} = 0, \quad a_{1/2} = k_+ B + k_- A, \quad a_{-1/2} = k_+ B - k_- A,$$

(4)

where

$$k_\pm \equiv [(s^{1/2} \pm s'^{1/2})^2 - m_2^2]^{1/2}.$$

The partial probability $\Gamma(\Lambda_c^+ \to K^- \Delta^{++})$ for the unpolarized $\Lambda_c^+$ baryon is

$$m_{\Lambda_c} \Gamma(\Lambda_c^+ \to K^- \Delta^{++}) = \frac{k^3}{12\pi s'} \left( k^2 |B|^2 + k^2 |A|^2 \right),$$  

(6)

where $m_{\Lambda_c}$ is the mass of the $\Lambda_c^+$ while the angular distribution for the polarized $\Lambda_c^+$ baryon reads

$$\frac{1}{\Gamma(\Lambda_c^+ \to K^- \Delta^{++})} \frac{d^2\Gamma}{d\cos\theta_K d\phi_K} = \frac{1}{4\pi} \left( 1 - \alpha \vec{P} \cdot \hat{\vec{p}}_2 \right),$$

(7)

where $\vec{P}$ is the polarization vector of $\Lambda_c^+$, and $\alpha$ is the asymmetry parameter

$$\alpha = \frac{|a_{1/2}|^2 - |a_{-1/2}|^2}{|a_{1/2}|^2 + |a_{-1/2}|^2} = \frac{2k_+ k_- \text{Re}(AB^*)}{k^2_+ |B|^2 + k^2_- |A|^2}.$$

(8)

Here $\hat{\vec{p}}_2 \equiv \vec{p}_2 / |\vec{p}_2|$ is the unit vector chosen along the momentum of $K^-$ meson. The sign minus in (7) is related to our choice of the unit vector along the momentum of the $K^-$ meson.

In the rest frame of $\Lambda_c^+$, the differential probability of the decay of the polarized $\Lambda_c^+$

$$\Lambda_c^+(p) \to K^-(p_2) + \Delta^{++}(p') \to K^-(p_2) + p(p_1) + \pi^+(p_3),$$

(9)
with \( p_1 (p_3) \) being the four-momentum of the proton (\( \pi^+ \) meson), is determined by

\[
d^4 \Gamma \frac{d^4 \Gamma}{d \cos \theta_K d \phi_K d \cos \theta_p ds} = (1 - \alpha \vec{P} \cdot \vec{p}_2) (1 + 3 \cos^2 \theta_p)
\]

\[
\times \frac{m_\Delta \Gamma_\Delta(s')}{(s' - m_\Delta^2)^2 - m_\Delta^2 \Gamma_\Delta^2(s')} \Gamma(\Lambda_c^+ \to K^- \Delta^{++}) \frac{16 \pi^2}{m_\Delta^2 (1 + k^2(m_\Delta^2) r_\Delta^2)},
\]

(10)

where \( m_\Delta \) is the mass of the \( \Delta^{++}(1232) \) isobar, \( s' = (p_1 + p_3)^2 \) is the invariant mass squared of the \( p \pi^+ \) system. In the rest frame of the \( \Delta^{++}(1232) \), \( \theta_p \) is the angle between the proton momentum and the direction opposite to the momentum of \( \Lambda_c^+ \) baryon, and \( \Gamma_\Delta(s') \) is the mass dependent \( \Delta^{++}(1232) \) width given by

\[
\Gamma_\Delta(s') = \Gamma_\Delta(m_\Delta^2) \left( \frac{k'(s')}{k'(m_\Delta^2)} \right)^3 \left( \frac{k_\lambda(s')}{k_\lambda(m_\Delta^2)} \right)^2 \frac{m_\Delta}{\sqrt{s'}} \frac{1 + k^2(m_\Delta^2) r_\Delta^2}{1 + k^2(s') r_\Delta^2},
\]

(11)

where \( \Gamma_\Delta(m_\Delta^2) \) is the width of the resonance, \( k'(s') = (4 s')^{-1/2} \lambda^{1/2}(s', m_1^2, m_\Delta^2) \) is the momentum in the \( p \pi^+ \) center-of-mass frame, \( k_\lambda(s') = ((s')^{1/2} + m_1^2 - m_\Delta^2)^{1/2} \), \( m_1 (m_3) \) is the mass of the proton \( p \) (\( \pi^+ \) meson), and \( k'(m_\Delta^2) (k_\lambda(m_\Delta^2)) \) is \( k'(s') \) (\( k_\lambda(s') \)) evaluated at the resonance mass.

The parameter \( r_\Delta \) is the so-called interaction radius, value of which depends on parametrization of \( \Gamma_\Delta(s') \). If, for example,

\[
\Gamma_\Delta(s') = \Gamma_\Delta(m_\Delta^2) \left( \frac{k'(s')}{k'(m_\Delta^2)} \right)^3 \frac{1 + k^2(m_\Delta^2) r_\Delta^2}{1 + k^2(s') r_\Delta^2},
\]

(12)

then \( r_\Delta = 1.11 \pm 0.02 \text{ fm} \). Another parametrization of \( \Gamma_\Delta(s') \) was suggested in:\n
\[
\Gamma_\Delta(s') = \Gamma_\Delta(m_\Delta^2) \left( \frac{k'(s')}{k'(m_\Delta^2)} \right)^3 \frac{1 + k^2(m_\Delta^2) r_\Delta^2}{1 + k^2(s') r_\Delta^2} \frac{m_\Delta}{\sqrt{s'}}.
\]

(13)

In this case \( r_\Delta \) changes to \( 1.03 \pm 0.02 \text{ fm} \). We note that Ref. \([20]\) gives a few reasons for neglecting the multipler \( k_\lambda^2 \) in Eq. \([13]\). At the same time it is also stressed that these reasons are not quite convincing.

The fully differential angular distribution for the 3-body decay \([9]\) is given by

\[
W(\theta_K, \phi_K, \theta_p) = \frac{d^4 \Gamma}{d \cos \theta_K d \phi_K d \cos \theta_p ds} / d \Gamma / ds = \frac{1}{16 \pi} (1 - \alpha \vec{P} \cdot \vec{p}_2) (1 + 3 \cos^2 \theta_p),
\]

(14)

where the distribution over the \( \Delta \) invariant mass is

\[
\frac{d \Gamma}{ds} = \frac{1}{\pi (s' - m_\Delta^2)^2 - m_\Delta^2 \Gamma_\Delta^2(s')} \Gamma(\Lambda_c^+ \to K^- \Delta^{++}).
\]

(15)
2.2. One-dimensional angular distributions and asymmetries

The one-dimensional angular distributions in \( \cos \theta_K \) and \( \phi_K \) are simply

\[
W_{\theta_K}(\cos \theta_K) \equiv \frac{d^2 \Gamma}{d \cos \theta_K ds'} / \frac{d \Gamma}{ds'} = \frac{1}{2} \left( 1 - \alpha P_z \cos \theta_K \right)
\]

and

\[
W_{\phi_K}(\phi_K) \equiv \frac{d^2 \Gamma}{d \phi_K ds'} / \frac{d \Gamma}{ds'} = \frac{1}{2\pi} - \frac{\alpha}{8} \left( P_x \cos \phi_K + P_y \sin \phi_K \right).
\]

Study of the distribution (16) allows one to measure the product \( \alpha P_z \). Indeed, we can define the forward-backward asymmetry of the \( K^- \) mesons

\[
A_{FB} = \frac{F - B}{F + B},
\]

where

\[
F \equiv \int_0^1 W_{\theta_K}(\cos \theta_K) d \cos \theta_K, \quad B \equiv \int_{-1}^0 W_{\theta_K}(\cos \theta_K) d \cos \theta_K.
\]

This asymmetry is equal to

\[
A_{FB} = -\frac{\alpha}{2} P_z,
\]

and its measurement allows one to find the \( z \) component \( P_z \) of the polarization vector once the value of \( \alpha \) is known.

Measurement of the angular distribution in the azimuthal angle \( \phi_K \) (17) allows one to determine the components \( P_x \) and \( P_y \):

\[
A_x \equiv \int_0^{\pi/2} d \phi_K - \int_{\pi/2}^{3\pi/2} d \phi_K + \int_{3\pi/2}^{2\pi} d \phi_K W_{\phi_K}(\phi_K) = -\frac{\alpha}{2} P_x,
\]

\[
A_y \equiv \int_0^{\pi} d \phi_K - \int_{\pi}^{2\pi} d \phi_K W_{\phi_K}(\phi_K) = -\frac{\alpha}{2} P_y.
\]

2.3. Application to precession of the \( \Lambda_c^+ \) polarization in bent crystals

In general case for measurement of the polarization components one has to know the asymmetry parameter \( \alpha \) and magnitude of polarization \( P \). However, for measurement of the magnetic dipole moment (MDM) and electric dipole moment (EDM) of a short-lived fermion using technique of the bent crystals (see Refs. 6, 7, 21) it is sufficient to determine only the rotation angles of the polarization vector. We will show that in this case one can directly use the asymmetries introduced in Subsec. 2.2 without knowledge of parameter \( \alpha \) and magnitude of polarization.

Let us assume that in front of the bent crystal the initial polarization vector is oriented along \( OX \) axis, and \( \Lambda_c^+ \) baryon moves along \( OZ \) axis (see Fig. 1 in
Ref. [6], and the averaged electric field in the crystal is directed along OX axis. Thus the three-vectors of initial polarization, baryon velocity and electric field have the components

\[ \vec{P}_{in} = (P, 0, 0), \quad \vec{v} = (0, 0, v), \quad \vec{E} = (-E, 0, 0). \]  \hfill (23)

In general the magnetic dipole moment (MDM) and electric dipole moment (EDM) of the baryon are written as

\[ \vec{\mu} = \frac{q}{2mc} \vec{S}, \quad \vec{d} = \frac{\eta q}{2mc} \vec{S}, \]  \hfill (24)

where \( q \) is the electric charge of the baryon with the mass \( m \), \( \vec{S} = \frac{\hbar}{2} \vec{\sigma} \) is its spin, \( g \) is the gyromagnetic factor (\( g \)-factor) and \( \eta \) is the similar factor for the EDM.

After passing the crystal the spin, or the polarization vector \( \vec{P} = 2\hbar \langle \vec{S} \rangle \), rotates around the axis which is determined by the equations for the spin precession in external electric and magnetic fields [22–26]. In particular, for the electric field in (23), which is orthogonal to the velocity at any moment of time, \( \vec{E} \vec{v} = 0 \), one finds the angular velocity of the polarization rotation

\[ \vec{\Omega} = (\omega', -\omega, 0), \]  \hfill (25)

\[ \omega = \gamma \omega_v \left( a - \frac{\eta}{2\gamma^2} + \frac{1}{\gamma} \right), \quad \omega' = \gamma \omega_v \frac{\eta v}{2c}. \]

Here \( a = \frac{1}{2}(g - 2) \) is the anomalous magnetic moment of the baryon, \( \gamma = (1 - \frac{v^2}{c^2})^{-1/2} \) is the Lorentz factor, and the angular velocity of the momentum rotation \( \vec{\omega}_v \) is defined through

\[ \vec{\omega}_v = (0, -\omega_v, 0), \quad \omega_v = \frac{qE}{m\gamma v} = \frac{v}{R}, \]  \hfill (26)

where \( R \) is curvature of the crystal.

Integration of Eq. (25) over time assuming constant velocity leads to relations

\[ \vec{\Phi} = (\theta', -\theta, 0), \]  \hfill (27)

\[ \theta = \gamma \theta_v \left( a - \frac{\eta}{2\gamma^2} + \frac{1}{\gamma} \right), \quad \theta' = \gamma \theta_v \frac{\eta v}{2c}, \]

\[ \vec{\theta}_v = (0, -\theta_v, 0), \quad \theta_v = \frac{L}{R}, \]

where \( L \) is the arc length that baryon passes in the channeling regime. The crystal length and crystal curvature for the \( \Lambda_c^+ \) baryon have been analyzed and optimized in Refs. [6,9].

Eqs. (27) imply that the polarization vector rotates around the unit vector \( \vec{n} \) by the angle \( \Phi \) which are defined as follows

\[ \vec{n} = \left( \frac{\theta'}{\Phi}, -\frac{\theta}{\Phi}, 0 \right), \quad \Phi = \sqrt{\theta^2 + \theta'^2}. \]  \hfill (28)
Then the components of the baryon polarization vector after passing the crystal are

\[ \vec{P}_{\text{fin}} = (P_x, P_y, P_z), \]

\[ P_x = P \frac{1}{\Phi^2} (\theta^2 \cos \Phi + \theta'^2), \]

\[ P_y = P \theta' \Phi^2 (\cos \Phi - 1), \]

\[ P_z = P \frac{\theta}{\Phi} \sin \Phi. \]  

(29)

The angles \( \theta \) and \( \theta' \) are determined from ratios of the asymmetries in Eqs. (20)-(22):

\[ A_x = \frac{\theta^2 \cos \Phi + \theta'^2}{\theta \Phi \sin \Phi}, \quad A_y = \frac{\theta' (\cos \Phi - 1)}{\Phi \sin \Phi}. \]  

(30)

It is seen that the parameter \( \alpha \) and the magnitude of the polarization \( P \) do not enter these equations. The angles \( \theta \) and \( \theta' \), and correspondingly the anomalous magnetic moment \( a \) and electric dipole moment \( \eta \), can be directly found from ratios of the asymmetries in Eqs. (30).

Under the assumption that the angle \( \theta' \) is small compared to the angle \( \theta \) one has \( \Phi \approx \theta \) and Eqs. (30) simplify:

\[ \frac{A_x}{A_{FB}} = \cot \theta, \quad \frac{A_y}{A_{FB}} = \frac{\theta' (\cos \theta - 1)}{\theta \sin \theta}. \]  

(31)

and it is seen, in particular, that the asymmetry \( A_y \) is not zero only if baryon has a nonzero EDM.

Eqs. (30) and (31) may be useful in measurements of MDM and EDM of the short-lived baryons using bent crystals at CERN.

3. Model calculation of decay rate and asymmetry

3.1. Pole model for the decay \( \Lambda_c^+ \rightarrow K^- \Delta^{++} \) (1232)

In the pole model the charmed baryon \( \Lambda_c^+ (udc) \) due to the weak interaction mediated by the W-boson exchange transforms into the intermediate baryons \( \Sigma^+ (uus) \) or \( \Sigma^+ (uus) \). Further the strong interaction induces the decay of the \( \Sigma^+ (uus) \) to the state \( K^- (s\bar{u}) + \Delta^{++} (uuu) \) (see Fig. 1). This two-step mechanism on the hadronic level can be described by the s-pole amplitude in Fig. 2.

To describe the transition \( \Sigma^+ (\frac{1}{2}^+) \rightarrow K^- \Delta^{++} \) one can use the following interaction Lagrangians

\[ \mathcal{L}_{\Sigma^+ (\frac{1}{2}^+), K^- \Delta^{++}} = g_\perp (\bar{\Delta} \bar{\partial}_\perp \Sigma) \partial_\mu K + \text{H.c.}. \]  

(32)

with \( \vartheta_+ = 1 \) and \( \vartheta_- = \gamma_5 \).
Fig. 1. Diagram of the process $\Lambda_c^+ \to K^- \Delta^{++}$ on the quark level.

For the matrix element of the weak effective Hamiltonian $H_W$ between the states of $\Lambda_c^+$ and $\Sigma^+(1/2^\pm)$ one can write following:

\begin{align}
\langle \Sigma^+(1/2^+) | H_W | \Lambda_c^+ \rangle &= h_+ \bar{u}_{\Sigma^+ (1/2^+)} u_{\Lambda_c^+}, \\
\langle \Sigma^+(1/2^-) | H_W | \Lambda_c^+ \rangle &= h_- \bar{u}_{\Sigma^+ (1/2^-)} u_{\Lambda_c^+}.
\end{align}

In Eqs. (33) and (34) we used the shorthanded notation

$$g_{\pm} \equiv g_{\Delta^{++}K^-\Sigma^+(1/2^\pm)}, \quad h_{\pm} \equiv h_{\Sigma^+(1/2^\pm)\Lambda_c^+}$$

Using the above definitions we find the amplitudes $B$ and $A$ in (35):

\begin{align}
B &= \sum_{k=1}^{4} \frac{h_{+,k} g_{+,k}}{\sqrt{s - M_{\Sigma^+(1/2^+)}} + \frac{i}{2} \Gamma_{\Sigma^+(1/2^+)}}; \\
A &= \sum_{k=1}^{4} \frac{h_{-,k} g_{-,k}}{\sqrt{s - M_{\Sigma^+(1/2^-)}} + \frac{i}{2} \Gamma_{\Sigma^+(1/2^-)}}
\end{align}

in terms of the masses and the total decay widths of the intermediate baryons $\Sigma^+_k (1/2^\pm)$. The sums run over contributing states.

Let us discuss values of the model parameters. These parameters were suggested in Ref.17; here we update these values using the present experimental information.19

For the contribution from the lowest-mass positive parity $\Sigma^+$ baryon we need the constants $g_{\Delta^{++}K^-\Sigma^+(1/2^+)}$ and $h_{\Sigma^+(1/2^+)\Lambda_c^+}$. To find the former, one can apply the $SU(3)$ symmetry relations for the product of constants $g_{BP_B f_P}$, where $f_P$ is the constant of the weak decay of the pseudoscalar meson $P$, baryon $B$ belongs to the $SU(3)$ octet $1/2^+$ and $B'$ to the $SU(3)$ decuplet $3/2^+$. The generalized Goldberger-Treiman relation for the axial-vector current form factor and the $SU(3)$ symmetry
the couplings $B(3)$ relating the baryons of decuplet next octet $1$ and octet $0$.

Experimental information on the rates of $\Lambda_c^+ \rightarrow K^- \Delta^{++}$ is kinematically forbidden but one can again use the $SU(3)$ relations for the couplings

$$g_{\Delta^{++}K^-\Sigma^+(1/2^+)} f_K = g_{\Delta^{++}\pi^-N^+(1535)} f_\pi = \sqrt{3} g_{\Xi^0K^-\Sigma^+(1620)} f_K = \ldots$$

relating the baryons of decuplet $7^+$ and octet $3^-$. Similar relations hold for the next octet $3^-$ containing $\Sigma^+(1750)$ and $N^+(1650)$.

Experimental information on the rates of $N^+(1535) \rightarrow \pi\Delta$ and $N^+(1650) \rightarrow \pi\Delta$ decays exists, however, the branching fractions are not very precise: $B(N^+(1535) \rightarrow \pi\Delta) = 1 - 4\%$ and $B(N^+(1650) \rightarrow \pi\Delta) = 6 - 18\%$. We can write $B(N^+(1535) \rightarrow \pi\Delta) = 2.5 \pm 1.5\%$ and $B(N^+(1650) \rightarrow \pi\Delta) = 12 \pm 6\%$

calculate the needed couplings and their errors using Eq. (40)

$$g_{\Delta^{++}K^-\Sigma^+(1620)} f_K = 8.98 \pm 2.69 \text{ GeV}^{-1},$$

$$g_{\Delta^{++}K^-\Sigma^+(1750)} = 6.89 \pm 1.72 \text{ GeV}^{-1}.$$  

The values of constants $h_{\Sigma^+(1620)\Lambda_c^+} = 0.32 \times 10^{-7}$ GeV and $h_{\Sigma^+(1750)\Lambda_c^+} = 0.79 \times 10^{-7}$ GeV are taken from [17].

| $A$     | $\Gamma_0 / \text{GeV}$ | $\Gamma_{\text{exp}} / \text{GeV}$ | $\alpha_{\text{exp}} / \text{GeV}$ |
|---------|--------------------------|-------------------------------|------------------------------------|
| $A_1 + A_2$ | $6.38 \pm 1.08$ | $5.2$ | $5.4 \pm 1.26$ |
| $A_1 - A_2$ | $5.03 \pm 0.90$ | $5.0$ | $-0.67 \pm 0.30$ |

Results of our calculation of the $\Lambda_c^+ \rightarrow K^- \Delta^{++}$ decay rate [11] and asymmetry parameter [5] are presented in Table 1. In calculation we set $\sqrt{s} = m_{\Lambda_c}$ and
\( \sqrt{s} = m_\Delta \). The errors on the calculated decay width and asymmetry are induced by the errors on the coupling constants \( g_{\Delta^+ K^- \Sigma^+} \) and \( g_{\Delta^+ K^- \Pi^0(1232)} \). The largest uncertainty of calculations comes from the relative sign of amplitudes \( A_1 \) and \( A_2 \), corresponding to the \( \Lambda^+_c \rightarrow K^- \Sigma^+(1620) \rightarrow K^- \pi^+ \) transition, respectively, in Eq. (37). Negative sign between these amplitudes gives rise to decay width and asymmetry parameter, which are in a reasonable agreement with experiment. Note that the experimental value of asymmetry parameter in Table 1 was calculated in Ref. [7], where the measured amplitudes from [3] were used.

### 3.2. Test of the model for decay \( \Omega^- \rightarrow K^- \Lambda \)

Following [14] we test the pole model for the weak decay of the strange baryon, \( \Omega^- \rightarrow K^- \Lambda \). The latter decay has some similarities with the \( \Lambda^+_c \rightarrow K^- \Delta^{++} \) decay. Indeed, in framework of the pole model, \( \Omega^- \rightarrow K^- \Lambda \) proceeds via the strong-interaction process \( \Omega^- (ssss) \rightarrow K^- (s\bar{u}) \Xi^0 (uss) \) followed by the conversion \( \Xi^0 (uss) \rightarrow \Lambda (dus) \) due to the W-exchange. This mechanism corresponds to the strong-interaction process \( \Lambda^+_c \rightarrow K^- \Delta^{++} \) in the pole model.

The parity conserving amplitude \( B \) has the form

\[
B = \frac{h_{\Lambda \Xi^0}}{M_\Lambda - M_{\Xi^0}},
\]

where we keep contribution from the lowest-mass baryon \( \Xi^0 (\frac{1}{2}^+) \). The contribution from the parity violating amplitude \( A \) for \( \Omega^- \rightarrow K^- \Lambda \) is suppressed because of the smallness of the corresponding factor \( k_- \) in Eqs. (5) and (6).

The coupling \( g_{\Omega^- K^- \Xi^0} = g_{\Delta^+ K^- \Sigma^+} \) due to the SU(3) relations (38), and is given in [39]. The value of the constant \( h_{\Lambda \Xi^0} \) is calculated from Eqs. (22) in Ref. [27]. It turns out to be \( h_{\Lambda \Xi^0} = -0.88 \times 10^{-7} \text{ GeV} \).

The decay width calculated using Eq. (43) is \( \Gamma(\Omega^- \rightarrow K^- \Lambda) = (7.64 \pm 1.39) \times 10^9 \text{ s}^{-1} \). This result can be compared with the data [13]: \( \Gamma(\Omega^- \rightarrow K^- \Lambda)_{\text{exp}} = (8.26 \pm 0.14) \times 10^9 \text{ s}^{-1} \). The calculated asymmetry parameter \( \alpha \) vanishes since we neglected the amplitude \( A \), while the experiment [14] gives \( \alpha = 0.0154 \pm 0.0020 \) which is very small. It is seen that the calculation in this simple model does not contradict the experiment. This gives confidence in the predictive power of the pole model.

### 4. Conclusions

In summary, we have derived angular distribution of the final particles in the nonleptonic decay of the polarized charmed baryon \( \Lambda^+_c \), namely \( \Lambda^+_c \rightarrow K^- \Delta^{++}(1232) \rightarrow K^- p \pi^+ \). Several asymmetries have been proposed which are convenient for experimental determination of the components of the \( \Lambda^+_c \) polarization vector. These asymmetries can be useful in the future measurements of magnetic and electric
Angular distribution and asymmetries

The dipole moments of the charmed baryon $\Lambda_c^+$ at the SPS and the LHC using technique of channeling of charged particles in bent crystals. This is part of the Physics Beyond Colliders project with a fixed-target setup at CERN.

We show that the precession angles of the baryon polarization $\vec{P}$ after passing of the baryon through the bent crystal are related to ratios of asymmetries. In these ratios the magnitude of polarization $P$ and asymmetry parameter $\alpha$ do not enter, which is convenient for measurement of the precession angles and thereby the magnetic and electric dipole moments of $\Lambda_c^+$.

Further, we have calculated the decay rate and asymmetry parameter for $\Lambda_c^+ \rightarrow K^- \Delta^{++}(1232)$ in the pole model of Refs. The parameters of the model have been updated using the present experimental information. Results of calculation are in reasonable agreement with available data. As an additional test of the pole model, the rate of the strange baryon decay $\Omega^- \rightarrow K^- \Lambda$ has been estimated and compared with experiment.

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