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Алеев, А.Н.

ПОИСК АСИММЕТРИИ В РАСПАДАХ ОЧАРОВАННО-СТРАННОГО БАРИОНА Ξ_c^+

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A.N.Aleev, V.P.Balandin, A.S.Chvyrov, I.I.Evsikov, I.M.Geshkov, T.S.Grigalashvili, I.M.Ivanchenko, A.M.Kalinin, A.F.Kamburyan, M.N.Kapishin, N.N.Karpenko, V.D.Kekelidze, D.A.Kirillov, I.G.Kosarev, N.A.Kuz'min, G.A.Kvirikashvili, M.F.Likhachov, A.L.Lyubimov, P.V.Moisenz, A.N.Morozov, A.K.Odishvili, V.V.Pal'chik, A.V.Pose, Yu.K.Potrebenikov, T.B.Progulova, A.Prokes, V.A.Sashin, V.E.Simonov, L.A.Slepets, V.N.Spaskov, G.T.Tatishvili, A.I.Zinchenko, P.Z.Hristov
Joint Institute for Nuclear Research, Dubna

G.A.Aralbaeva, A.A.Loktionov
Institute of High Energy Physics of the Rep. Kaz. Academy of Sciences, Alma-Ata

M.V.Belov, E.G.Devitsin, V.A.Kozlov, S.Yu.Potashov, M.V.Zavertyaev
Lebedev Physical Institute of the Russian Academy of Sciences, Moscow

E.A.Chudakov
Institute of Nuclear Physics, Moscow State University

V.D.Cholakov
Hilendarski University of Plovdiv

J.Hladky, M.Novak, M.Smizanska, M.Vetsko
Institute of Physics of the Czecho-Slovak Academy of Sciences, Prague

V.I.Zayachky
Higher Chemical-Technological Institute, Sofia

D.T.Burilkov, P.K.Markov, P.T.Todorov, R.K.Trayanov
Institute of Nuclear Research and Nuclear Energetics of the Bulgarian Academy of Sciences, Sofia

L.N.Abesalashvili, N.S.Amaglobeli, R.A.Kvatadze, M.V.Kopadze, N.L.Lomidze, M.D.Mosidze, G.I.Nikobadze, T.G.Pitskhelauri, M.S.Chargeishvili, R.G.Shanidze
Institute of High Energy Physics, Tbilisi State University

The investigation of polarization phenomenon in production and decay processes of strange and charmed baryons, has made it possible to follow up this phenomenon using flavor tagged quarks (s, c) and estimate the dependence of these phenomena on the mass of quarks. The observation of Λ – hyperon polarization in inclusive processes [1–8] has stimulated intensive theoretical and experimental research on polarization of various hyperons produced in different processes [9–26].

In the BIS–2 experiment the polarization of Λ – hyperons produced in neutron-nucleus interactions, has been measured depending on their transverse momenta and atomic weights of target nuclei [27,28]. The data obtained in the same experiment indicate the polarization of charmed baryons Λ_C^+ [29,30]. The polarization of Λ_C^+ produced in *pp*–interactions, has been also observed at the ISR [31].

The first results indicating charmed strange baryon Ξ_C^+ polarization, are presented in this paper.

The experiment was carried out in the neutron beam of the Serpukhov accelerator with the BIS–2 spectrometer [32]. The neutral channel $4N$ [33] was oriented at 11.3 mrad to the circulating proton beam. The internal beryllium target was 2 mm in diameter and 20 mm in length. The total length of the channel from the internal target to the center of the spectrometer magnet, was 65 m.

A layout of the main elements of the BIS–2 spectrometer is presented in fig.1. The beam with the mean momentum of $\approx$ 40 GeV/c and intensity of $\approx 3{\cdot}10^6$ neutrons per spill, was interacting with target ($T1$) located in front of the setup. Liquid hydrogen, carbon, aluminum and copper were used as the targets. The lengths of the targets were 2,1 g/cm^2 for liquid hydrogen and $3.4{\cdot}A^{1/3}$ g/cm^2 for the other nuclei where A is the atomic weight. The solid targets were changed after each (40–50)$\cdot10^3$ nA interactions recorded on magnetic tapes. The gap of the analyzing magnet (M) was (100x29) cm^2. The center of the magnet gap was considered as the origin of the "right" orthogonal coordinate system (XYZ) of the spectrometer. The magnetic field in M was directed along the OY axis and caused a 0.64 GeV/c change of the transverse momentum of the charged particles crossing the field region. The charged particles were detected with 2-coordinate proportional chambers with 0.2 cm wire spacing, disposed upstream (PC 1–7) and downstream (PC 8–13) the magnet. Two multicell threshold gas Cherenkov counters C1 and C2 [34,35], placed respectively in the

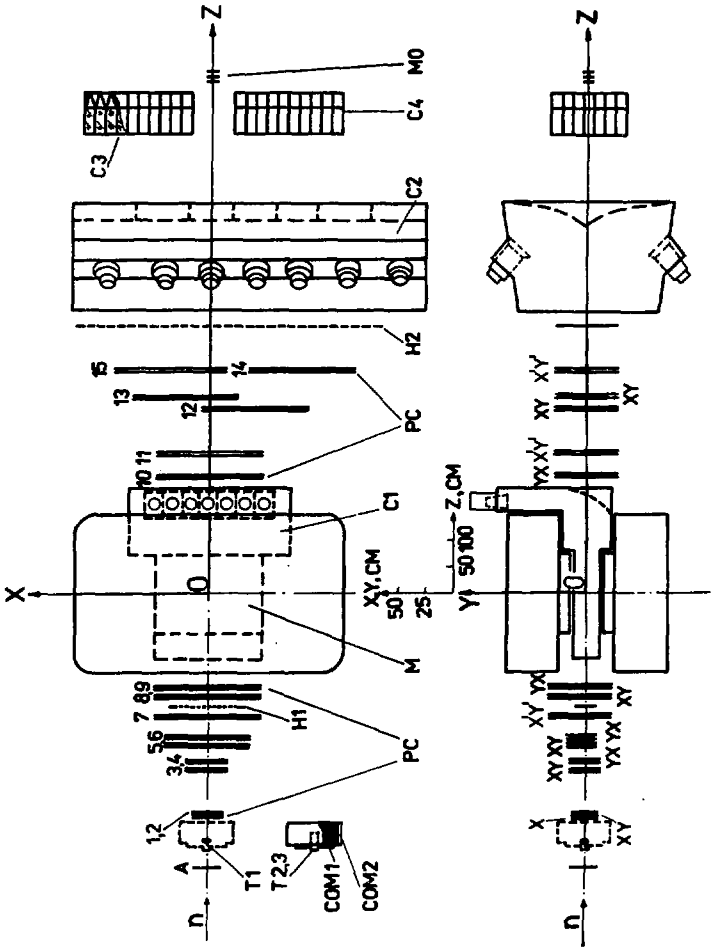

Fig.1. Arrangement of the BIS–2 spectrometer elements in the 4N beam of the Serpukhov accelerator

magnet gap and behind the hodoscope of scintillation counters (H). were used to identify charged hadrons. Characteristics of Cherenkov counters are listed in table 1.

Table 1

Cherenkov counter	Number of channels	Gas (atm. pressure)	The threshold momentum of Cherenkov radiation, GeV/c		
			$\pi^{\pm}$	$K^{\pm}$	$p(\bar{p})$
(C1)	7	Air	6.0	21.2	40.3
(C2)	14	Fr_{12}	3.1	10.8	20.5

The trigger requirement was at least four charged particles to pass through the spectrometer. To form trigger signal, fast logic circuits analyzed the number of channels in PC and H hodoscopes hit by the charged particles.

In all $\approx 64 \cdot 10^6$ neutron–nucleus interactions detected during 4 runs of the accelerator operation in 1982–1985, have been analyzed.

The Ξ_C^+ were searched for via their decays into

$$K_S^0 p K^- \pi^+ . \tag{1}$$

To search for charmed strange baryons Ξ_C^+ only the events containing K_S^0 and at least three charged particles, have been analyzed.

The effective mass resolution for this state estimated by Monte Carlo simulation, was ≈ 10 MeV/c^2. Due to such resolution and low multiplicity of the secondary particles at these energies, the combinatorial background was insignificant in the effective mass spectrum of the final states (1). Therefore, it was possible to search for charmed particles without a vertex detector which enables one to distinguish the production and decay vertices.

K_S^0 were identified via their decays into $\pi^+\pi^-$. These decays have a topology of neutral Vee (V^0) – a pair of the opposite charged particles with the distance between their tracks less than four–fold value of the experimental resolution (0.1–0.2 cm). It was also required that vertices of V^0's should be disposed downstream the liquid hydrogen target and 10 cm beyond the solid targets along the beam.

$6.18{\cdot}10^5$ events with K_S^0 candidates have been selected in accordance with the above criteria. Among these candidates only those have been identified with K^0 which had the effective mass of $\pi^+\pi^-$ system differing from the K^0 mass less than 10 MeV/c^2 (the experimental resolution for this mass is $\approx$ 4 MeV/c^2).

K_S^0 and charged hadrons $h^\pm$ were required to have a common interaction vertex. This point should have the minimum root–mean–square distance from all the trajectories in the event. The maximum allowed distance was taken equal to the four–fold value of the experimental resolution for this parameter. This resolution varied between 0.1 and 0.3 cm in different target exposures. The mean path of the charmed particles before their decays accepted in the experiment, was of the order 1 mm. The decay and common interaction vertices cannot be distinguished within the experimental resolution. Thus, the reconstructed decay vertex was required to be inside the target.

The effective mass spectrum of the final states (1) has been obtained under the assumption that a positive particle with the largest momentum in the event, is a proton. This allowed one to reduce the combinatorial background.

The information obtained from C1 and C2 was used to reduce the background caused by the misidentification of charged particles. Relative probabilities $W(i)$ of each charged particle to be identified with the i–th type of particle ($i = \pi^+$, K^-, p), have been evaluated. For this purpose the signals in different C1 and C2 channels were compared with the estimated distribution of Cherenkov light and corresponding numbers of photoelectrons emitted by the charged particles over these channels. The relative probabilities $W(i)$ have been normalized in such a way that their sum for each detected charged particle would be $W(\pi)+W(K)+W(p) = 3$. Thus, the value $W(i)$=3 means 100% reliability of the particle identification as the i–th type. The condition $W(\pi) = W(K) = W(p) = 1$ means a completely unidentified particle, etc. Some ambiguities of the charged particle identification were caused by Cherenkov light of one particle spreading over several channels. The calculated efficiency of particle identification shows the dependences on the charged particle momentum and total number of particles accepted in the event. The charged particles identification method is described in detail in [35].

To search for the charmed strange baryon Ξ_C^+ in the final states (1) the identification of K^- and p, was required. The selection criterion used to identify K^-, was: $W(K^-) \geq 1.1$. This enables one to exclude such combinations where either K^- could be identified as π^- with high probability, or π^-, K^- and $\bar{p}$ are not distinguished. Almost 90% of π^- among K^- candidates have been excluded under this condition. The efficiency of K^- identification in the final states (1) was close to 70%. To select p in the final states (1) it was required that $W(p) \geq 1.4$. The identification efficiency in this case was also around 70%. All the particles h^+ not identified as protons, were considered pions due to their vast majority Such identification criteria lead to the efficiency of the final states (1) selection close to 50%.

2452 combinations of the final states (1) have been selected using all the criteria mentioned above.

Fig.2 shows the effective mass spectrum of the final states (1). According to the Monte–Carlo calculation the acceptance is a smooth and decreasing function of the effective mass. Thus, the effective mass spectrum has been fitted by a smooth background curve derived as the product of the degree and exponential functions. The obtained ratio of χ^2 to the degrees of freedom, is 0.94. At the Ξ_C^+ mass region there is a signal significantly exceeding the combination numbers above the background level. The numbers of combinations in the peak – N_S and background level – B are:

$$N_S = 58 \pm 14$$

and (2)

$$B = 144 \pm 12.$$

The statistical significance of the signal is ≈ 5 standard deviations from the background. This signal at the mean mass of 2475 $\pm$ 5 (stat.) $\pm$ 20 (syst.) MeV/c^2, can be interpreted as Cabibbo–allowed decay of the charmed strange baryon Ξ_C^+.

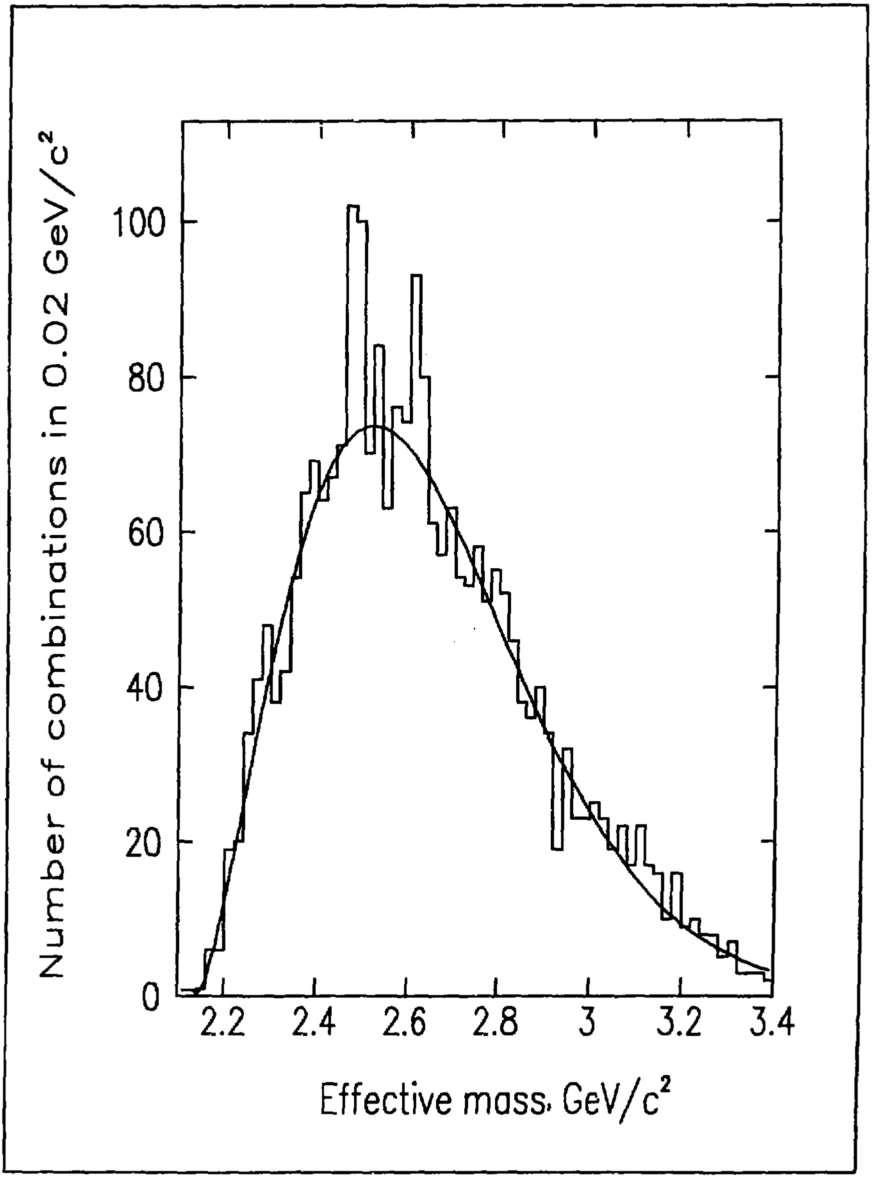

Fig.2. Effective mass spectrum of the final states $K^0_S p K^- \pi^+$

As soon as the Ξ_C^+ production is a parity–conserving process, a possible Ξ_C^+ polarization vector should be perpendicular to the production plane. Therefore the normal to the production plane has been adopted as an analyzing axis and defined:

$$\vec{N} = [\vec{n} \times \vec{\Xi}_C^+], \tag{3}$$

where $\vec{n}$ and $\vec{\Xi}_C^+$ are the momenta of incident neutron and Ξ_C^+, respectively, both in the laboratory system.

The definition of the beam direction depends on the internal Be target disposition and the point of interaction in the target T (Fig.1). Coordinates of the internal Be target were determined by the reconstruction of the total momenta of all the particles in the events for each of the experimental runs independently. The errors in X and Y coordinate reconstructions of the target position, were estimated as ± 5 cm. The errors in Z coordinate reconstruction have almost no influence on the definition of $\vec{n}$.

The direction of flight of the i–th particle of the final state (1) in the Ξ_C^+ rest frame relative to the normal $\vec{N}$ is defined with the relation:

$$\cos\ \Theta_i = (\vec{N} \cdot \vec{P}_i) \ / \ |\vec{N}| \cdot |\vec{P}_i|, \tag{4}$$

where $\vec{P}_i$ is the momentum of i–th particle in the Ξ_C^+ rest frame. If $\cos\ \Theta_i > 0$, the i–th particle is emitted into the "up" hemisphere of the Ξ_C^+ production plane, and if $\cos\ \Theta_i < 0$ – into the "down" one. The polarization of Ξ_C^+ can be estimated via the corresponding asymmetry of the decay:

$$A_i = (N_i(\mathrm{up}) - N_i(\mathrm{down}))\ /\ (N_i(\mathrm{up}) + N_i(\mathrm{down})). \tag{5}$$

Here $N_i(\mathrm{up})/N_i(\mathrm{down})$ are the numbers of observed Ξ_C^+ decays, where i–th particle is emitted respectively into the "up"/"down" hemisphere.

The registration efficiency of the final states (1) obtained with the Monte–Carlo simulation, is invariant over "up"/"down" directions of the particle emissions. In the absence of the systematic errors the background distribution should be symmetrical on the directions of the secondary particle emissions. Then the equation (5) can be represented as

$$A_i = \Delta N_i \;/\; (N - B), \tag{6}$$

where ΔN_i is the difference of the numbers of the observed combinations with the i–th particle emitted "up" and "down", and $N = N_S + B$ is the overall number of combinations of the final states (1) in the Ξ_C^+ mass region (fig.2).

It has been measured that K^- and π^+ have the largest asymmetry among all the particles in the final states (1). Fig.3 shows the effective mass spectrum of the events containing K^- emitted "up" (Fig.3(a)) and "down" (Fig.3(b)) to the Ξ_C^+ production plane. These spectra contain 1216 and 1236 combinations, respectively.

Asymmetries (6) obtained for each particle of the final states (1), are presented in table 2. Asymmetries of the background events obtained for the combinations outside the region of Ξ_C^+ signal in the mass spectrum (1), are also presented.

Table 2

Analyzing particle	Asymmetry	
	Signal	Background
K_S^0	-0,10 ± 0,25	+0,00 ± 0,02
p	+0,35 ± 0,25	+0,01 ± 0,02
K^-	+0,52 ± 0,26	-0,01 ± 0,02
π^+	-0,62 ± 0,27	-0,01 ± 0,02

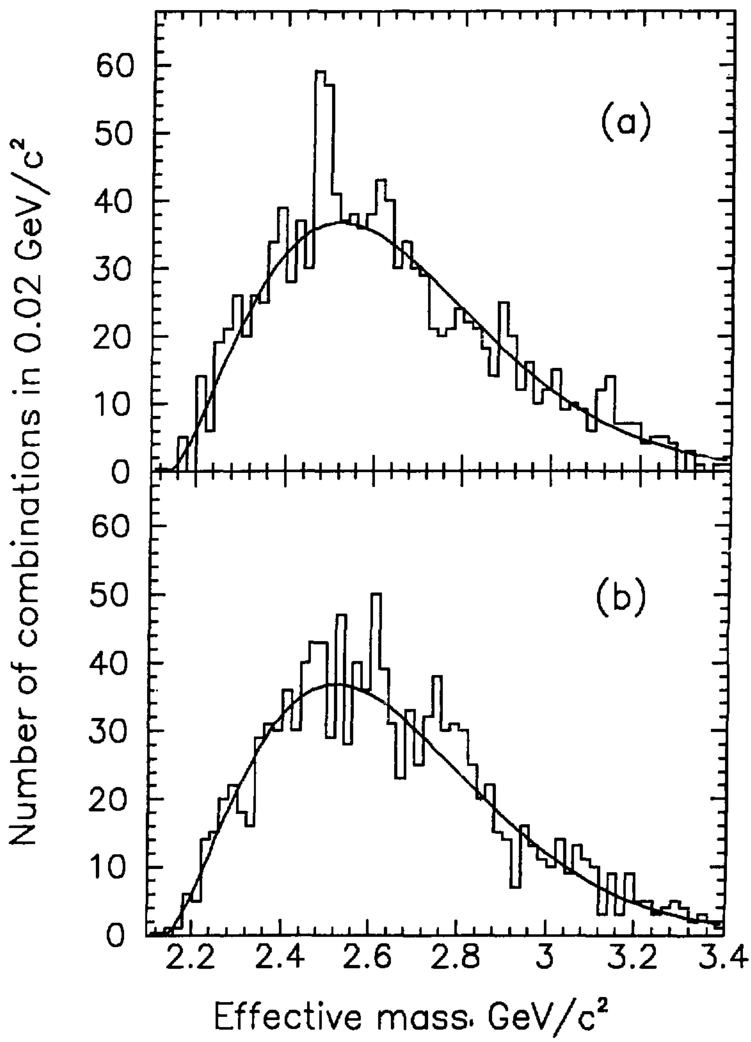

Fig.3. $K_S^0 p K^- \pi^+$ effective mass spectra for the events containing K^-, emitted into "up" (a) and "down" (b) hemispheres

The background events decay symmetrically in respect to the Ξ_C^+ production plane, as was expected. The distribution of the background events from different regions of mass, has been estimated in a more detailed way, analyzing K^- emission into the "up"/"down" hemisphere. The spectra (figs. 3(a) and 3(b)) have been compared with the same smooth background curve obtained by fitting the overall spectrum (fig.2). But the normalization factor of 0.5 has been used. The ratio of χ^2 to the number of degrees of freedom obtained for figs. 3(a) and 3(b), is 0.90 and 1.31, respectively. So one could conclude that the background is rather symmetrical in different regions of mass.

A systematic error could be caused by the restricted accuracy ($\pm$ 5 cm) of the coordinate definitions of the internal Be target. This leads to an error while determining the normal (3). This error causes the possible "up"/"down" asymmetry of the secondary particle emissions. To estimate this systematic error the values of K^- emission asymmetries for events causing the Ξ_C^+ signal and background (all the events outside the region of Ξ_C^+ signal), have been plotted in respect to the Y-coordinate [1] of the internal Be target (fig.4). Y-coordinate was varied from -20 to +20 cm with a step of 5 cm. As fig.4 shows, the asymmetry of the signal remains positive for whole region while the asymmetry of background reverses its sign. In the range of $\pm$5 cm the distinction of the signal asymmetries from the asimmetry value at Y=0, is -0.09/+0.20. This may be considered as the acceptable systematic error caused by the accuracy the neutron vector is determined.

Another possible systematic error could be caused by distinction between registration efficiencies for different channels of C2 [2]. To estimate this error, the asymmetry of K^- emission for the events of the Ξ_C^+ signal and background, has been calculated for two cases. In the first one the analyzed particle falls only into the upper ($Y > 0$) row of the C2 channels and in the second case - into the lower ($Y < 0$) one. The background asymmetry calculated in these two marginal cases, differs slightly from zero. Taking into account that the background

[1] It was gained that the normal (3) averaged over all the events, is perpendicular to the $X0Z$ plane. And the result is that the asymmetry of decay products depends slightly on X-coordinate of the internal target. Therefore, when compared to Y-dependence, the X-coordinate dependence can be neglected.

[2] Since all the channels of C1 are arranged in a line, its registration efficiency is independent of Y-coordinate of the trajectory in counter planes and, consequently, cannot be affected by the measurements of A value.

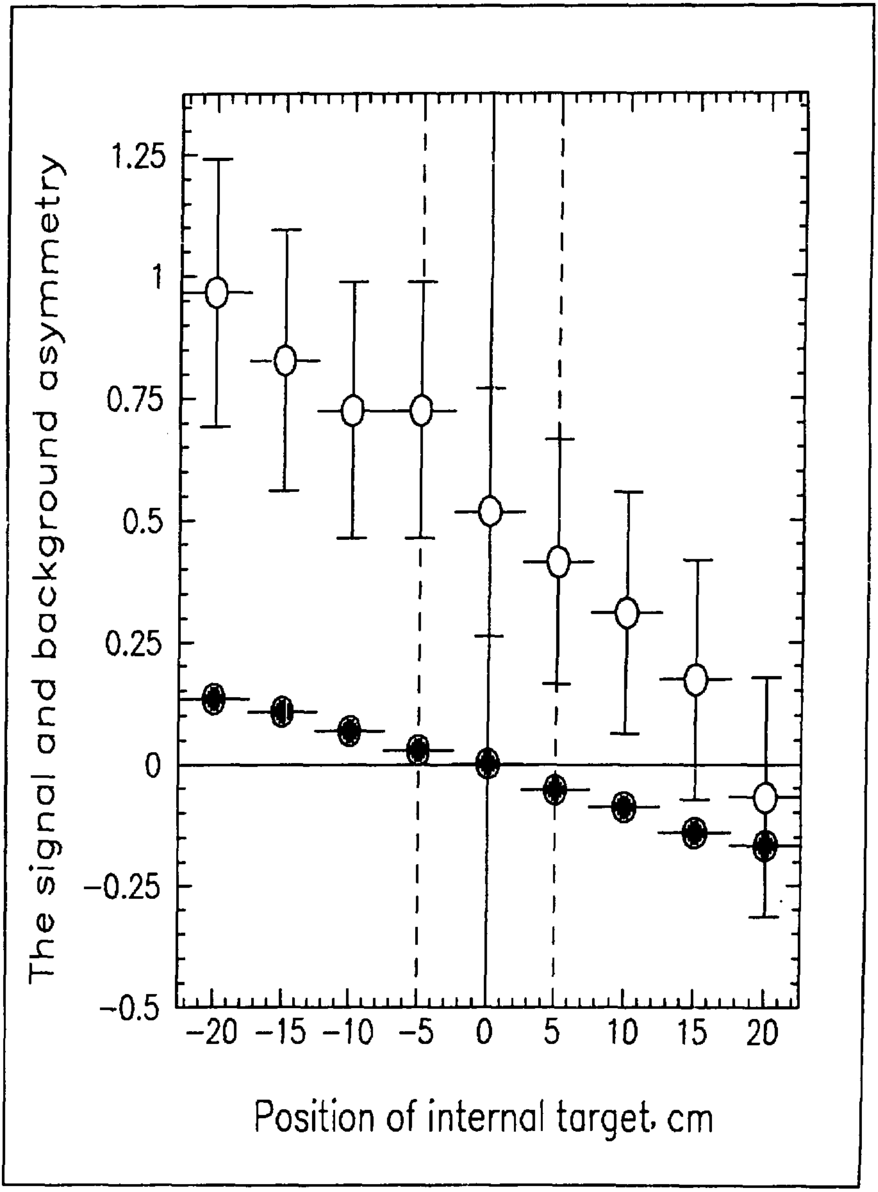

Fig.4. The asymmetry dependence on the Y–coordinate of the internal *Be* target position obtained for the Ξ_C^+ signal (light circles) and background (black circles)

asymmetry must be equal to zero, the correction factors leading to the symmetry of the background, have been obtained. The values of Ξ_C^+ signal asymmetry recalculated with these correction factors, differ from the Ξ_C^+ signal asymmetry ($A(K^-)$=0.52) by +0.13 and −0.06 for the two limiting cases of K^- emission, into the upper or lower C2 rows, respectively.

Taking into consideration the both possible sources of systematic errors, it was obtained that:

$$A(K^-)=0.52\pm0.26\ (\mathrm{st.})^{+0.24}_{-0.11}(\mathrm{syst.}). \tag{7}$$

The asymmetry of the decay product distribution relative to the Ξ_C^+ production plane, is connected with possible polarization $\wp$ of the decaying particle by the following relation:

$$\wp \ = \ 2{\cdot}A \ / \ (\textstyle\sum_j \alpha_j \ \cdot w_j), \tag{8}$$

where α_j ($\leq$ 1) is the decay parameters and w_j – weight of the j–th mode of decay. Using (5) and taking into account that $w_j \leq 1$ and, thus, $\sum_j \alpha_j \ \cdot w_j \leq 1$, the following limitation for the Ξ_C^+ polarization has been obtained:

$$\wp \ \geq 0.1\ (90\%\ \mathrm{C.L.}). \tag{9}$$

CONCLUSION:

The asymmetry of the charmed strange baryon Ξ_C^+ decays into $K_S^0 pK^-\pi^+$ has been observed for the first time. This asymmetry indicates possible polarization of Ξ_C^+ ($\wp \ \geq 0.1$) produced in neutron–nucleus interactions at the Serpukhov energies.

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