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EVIDENCE FOR A NARROW BARYON AT 1.95 GeV/c^2

Dubna-Moscow-Prague-Sofia-Tbilisi Collaboration

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Submitted to ЯФ

The existence of narrow baryons is of particular interest because their small width is an indication of some nontrivial interdictions of their decays. Some theoretical models [1-4] hint at the possibility of narrow resonance production by diffractive processes, which are suitable for detection with up-to-date forward spectrometers. Diffractive production processes are essentially determined by the type of beam particles interacting with the target. Research on diffractive processes with high energy neutron beams is of considerable interest because they are rather badly studied.

In this work a search was made for new narrow baryon resonances, produced by neutrons on a carbon target and decaying into Λ° and two charged hadrons h^+ and h^-. The reaction studied is:

$$n + C \to \Lambda^\circ h^+ h^-, \quad \Lambda^\circ \to p\pi^- \qquad (1)$$

where the $\Lambda^\circ h^+ h^-$ system is generated with small transverse momentum $P_\perp$.

1. EXPERIMENTAL CONDITIONS

The experiment was performed by means of the BIS spectrometer [5] at the Serpukhov accelerator. The neutral beam parameters with a mean energy of about 40 GeV are presented in paper [5].

The spectrometer layout is shown in fig.1: M is an analysing magnet with magnetic field strength equivalent to a transverse momentum change of 0.64 GeV/c; SC 1-24 are 24 two-coordinate wire spark chambers with magnetostrictive read-out; DV is a decay volume about one meter long in which the Λ°-s had to decay; F1, G1, G11 are scintillation counter hodoscopes used to trigger the spectrometer, and MN is a neutron monitor. The centre of the carbon target (T) was located at $Z = -450$ cm. The target was a cylinder with a radius of $R_T = 2.5$ cm, and its length corresponded to 6 g/cm^2 of carbon. The trigger requirement was three or more charged particles. The spectrometer operated on-line with a BESM-3M computer. During the experi-

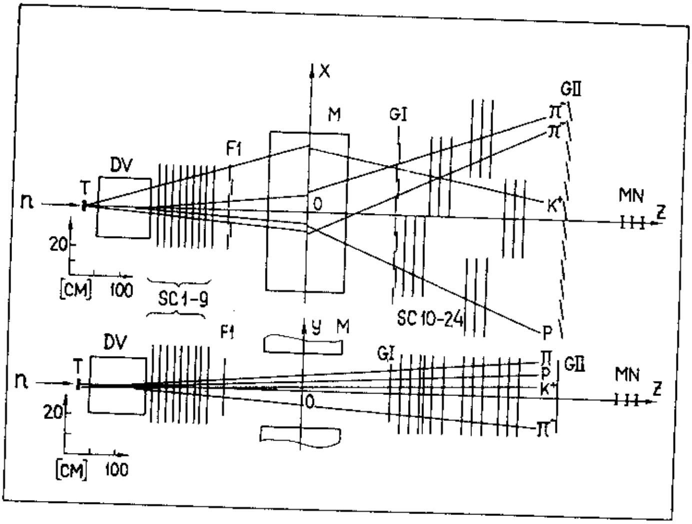

Fig.1. The BIS spectrometer and topology of a typical event $n + C \to \Lambda^0 h^+ h^-$.

ment the information on $2.5 \cdot 10^6$ interactions of neutrons was recorded on magnetic tapes. The neutron flux through the target corresponded to an integral luminosity of about 10^{34} neutrons$\cdot$cm^2.

2. EVENT SELECTION

About $6.7 \cdot 10^5$ events having two and more tracks were reconstructed using a geometric reconstruction program based on the algorithm /6/. The conditions of event selection were obtained after a statistical analysis of these events.

The straight-line parts of the tracks before and after the magnet, reconstructed separately in two projections XOZ and YOZ, are described by the equation $X, Y = a + b \cdot Z$ with two parameters a and b. The experimental resolutions obtained for these parameters are respectively: $\sigma_a = 0.2$ cm and $\sigma_b = 0.001$. To exclude false tracks generated by the program, of each two tracks in an event having close parameters (a and a′, b and b′), satisfying the inequalities $(\frac{a-a'}{3\sigma_a})^2 + (\frac{b-b'}{3\sigma_b})^2 < 2$ for XOZ or $(\frac{a-a'}{\sigma_a})^2 + (\frac{b-b'}{\sigma_b})^2 < 2$ for YOZ, there remained one with larger number of sparks. 14980 events with two or more positive and two or more negative tracks were selected.

Figure 1 presents the two projections of typical event (1) geometry. All types of combinations of two pairs of oppositely charged tracks were constructed for topology reconstruction of such an event. It was required that the vertex of the track pair corresponding to the $\Lambda^{\circ} \to p\pi^{-}$ decay should be within the decay volume:

$$-30 < X_{\Lambda} < 30 \text{ cm}, \quad -15 < Y_{\Lambda} < 15 \text{ cm}, \quad \text{and} \quad -440 < Z_{\Lambda} < -290 \text{ cm} \qquad (2)$$

and that the nearest distance d_{Λ} between the tracks should be less than 0.3 cm. For analogous parameters of the track pairs corresponding to h^{+} and h^{-} hadrons the following conditions should be required:

$$X_v^2 + Y_v^2 < R_T^2, \quad -465 < Z_v < -435 \text{ cm}, \quad \text{and} \quad d_v < 0.45 \text{ cm}. \qquad (3)$$

The precision of determination of Z in the target region was 10 cm. The d_{Λ} and d_v distributions are plotted in figs.2a and 2b. The widths of the corresponding distributions are $\sigma_{\Lambda} = 0.1$ cm and $\sigma_v = 0.15$ cm. Each pair of oppositely charged tracks is characterized by:

$$W_{\Lambda,v} = \left(\frac{d_{\Lambda,v}}{\sigma_{d_{\Lambda,v}}}\right)^2 + \Lambda_1^2 + \Lambda_2^2 , \qquad (4)$$

where $\Lambda_{1,2}$ are distances between the track parts before and after the magnet in plane $Z=0$ normalized to their dispersions. Each event combination is characterized by the parameter:

$$\chi^2 = \left(\frac{dd}{\sigma_{dd}}\right)^2 + W_{\Lambda} + W_v , \qquad (5)$$

where dd is a distance between the vertex of the h^{+} and h^{-} track pair and the sum of momentum vectors of the track pair from the decay volume. The dd distribution (fig.2c) has a dispersion of $\sigma_{dd}^2 = 0.09 \text{ cm}^2$. From all combinations of events only one was selected having the smallest χ^2. The distribution of this parameter is plotted in fig.2d.

The following conditions should be required for all the events:

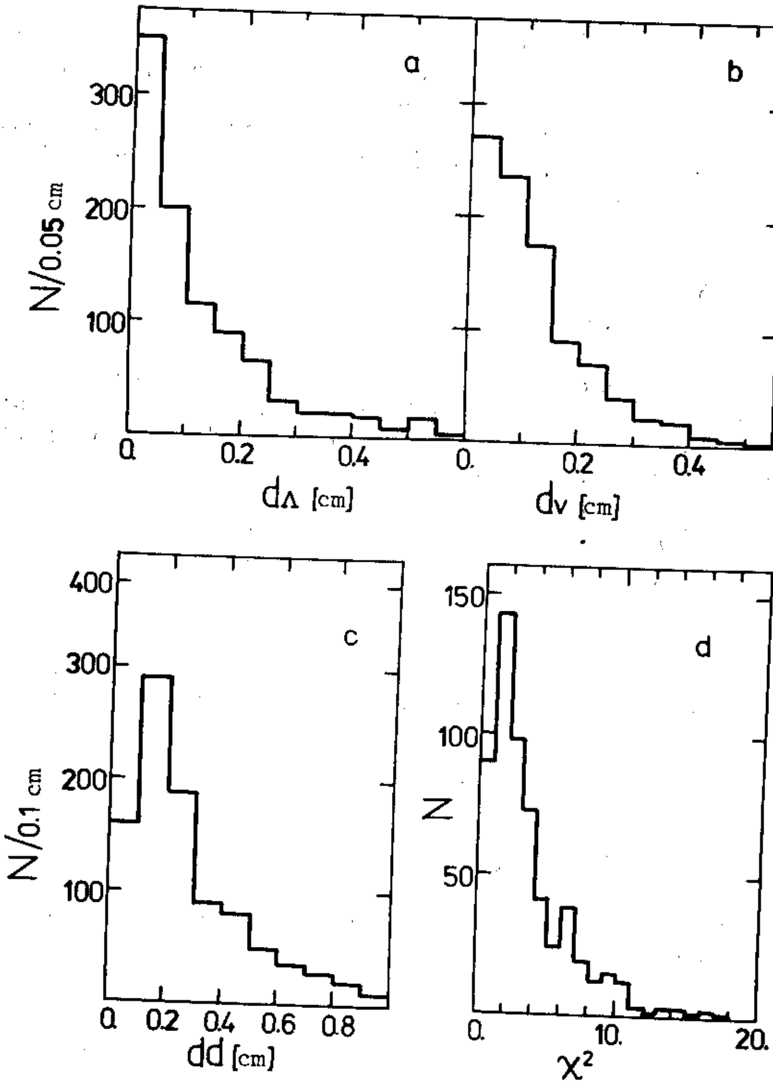

Fig.2. a) Distribution over d_Λ, the nearest distance between the p and π^- tracks from the $\Lambda°$ decay. b) Distribution over d_v, the nearest distance between the hadron tracks from the target. c) Distribution over dd, the nearest distance between the vector-momentum of $\Lambda°$ and the hadron vertex in the target. d) χ^2 distribution (5).

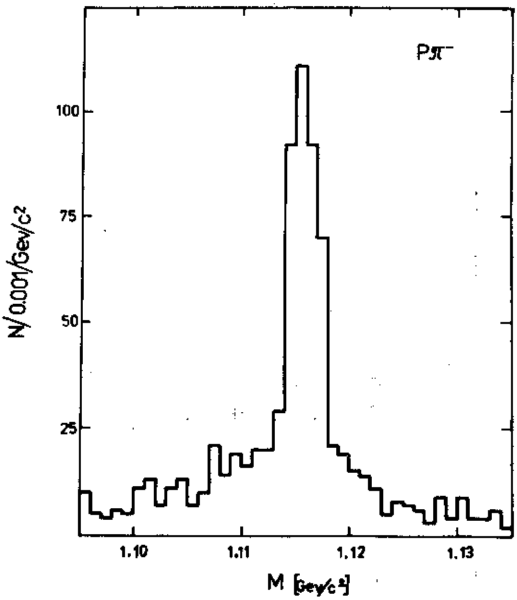

Fig.3. Invariant mass distribution of the $p\pi^-$ system for events (1).

$$dd < 0.8 \text{ cm},$$
$$\chi^2 < 20,$$
$$2 < \vec{P}_+ < 22 \text{ GeV/c}, \qquad (6)$$
$$1 < \vec{P}_- < 13 \text{ GeV/c},$$
$$9 < \vec{P}_\Lambda \lesssim 36 \text{ GeV/c, and}$$
$$20 < \vec{P}_\Lambda + \vec{P}_+ + \vec{P}_- < 65 \text{ GeV/c}.$$

Here $\vec{P}^+$ and $\vec{P}^-$ are momenta-vectors of hadrons h^+ and h^-. 970 events were selected under the above criteria for a further analysis. In fig.3 is plotted the invariant mass ($M_{p\pi^-}$) distribution of the track pair with the vertex in the decay volume assuming that positive particle is a proton and negative one is a pion. The condition was required that the invariant mass obtained on the assumption that both particles are pions, $M_{\pi\pi}$, should have its magnitude outside the kaon mass (M_{K°) region ($|M_{K^\circ}-M_{\pi\pi}|>0$ >0.015 GeV/c^2), and the momentum of positive particle should be three or more times greater than the momentum of negative one. A narrow peak in the Λ° mass (M_{Λ°) region corresponds to an experimental resolution of 0.0018 GeV/c^2. Under the condition

$$|M_\Lambda - M_{p\pi^-}| < 0.0075 \text{ GeV/c}^2 \qquad (7)$$

578 events were selected for which the background of incorrectly identified Λ° is about 11%, and for 413 events of reaction (1) selected providing

$$|M_\Lambda - M_{p\pi^-}| < 0.0025 \text{ GeV/c}^2 \qquad (8)$$

the background was less than 5%.

3. ANALYSIS OF THE EVENTS SELECTED

The high mass resolution of the spectrometer allows one to detect narrow resonances without identification of all decay products, since a narrow peak is the effective mass

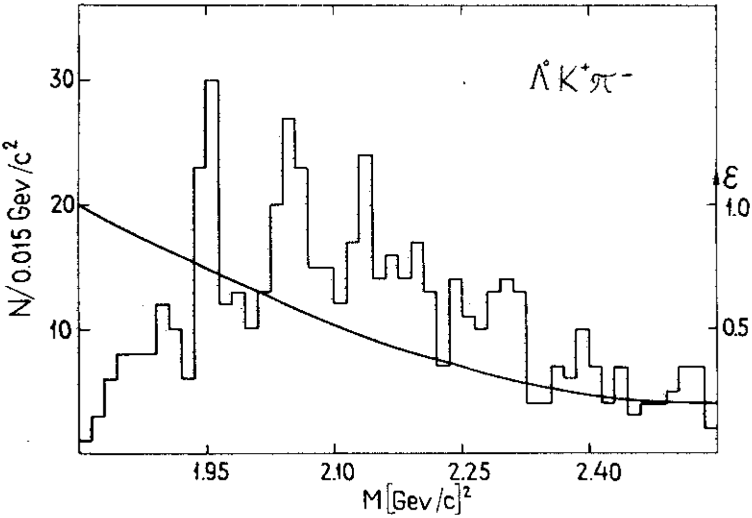

Fig.4. Invariant mass distribution of the $\Lambda^{\circ}K^{+}\pi^{-}$ system provided $|M_{p\pi^-} - M_{\Lambda}| < 0.0075$ GeV/c². The smooth curve is the detection efficiency for the mode (10) versus invariant mass (arbitrary units).

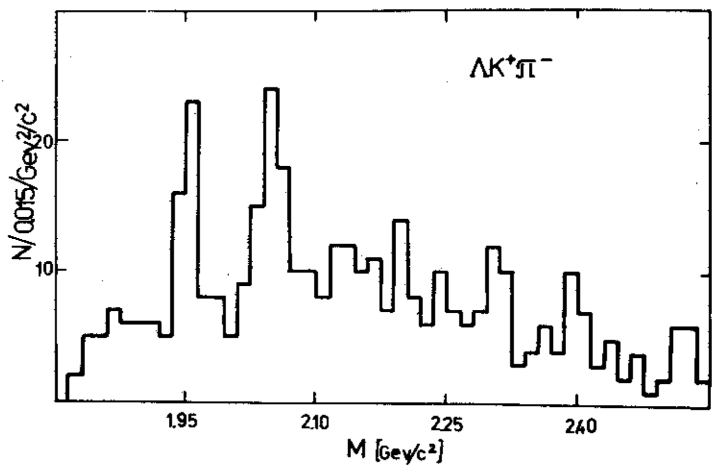

Fig.5. Invariant mass distribution of the $\Lambda^{\circ}K^{+}\pi^{-}$ system provided $|M_{p\pi^-} - M_{\Lambda}| < 0.0025$ GeV/c .

spectrum of the system registered is observed only in the case when all products of the decaying resonance are correctly identified. In our case only Λ° was reliably identified, and the h^+ and h^- hadrons were ascribed the K^+ and π^- masses. Figures 4 and 5 present the effective mass distributions $M_{\Lambda^\circ K^+\pi^-}$ of the $\Lambda^\circ K^+\pi^-$ system for 578 events selected under condition (7) and 413 events satisfying condition (8), respectively. Two narrow peaks are seen in these distributions at 1.95 and 2.05 GeV/c^2 in accordance with preliminary results/7/. The number of events in mass intervals of 1.935 ÷ 1.965 GeV/c^2 and 2.025-2.070 GeV/c^2 is respectively seven and three standard deviations above the level obtained by averaging over each four bins of the histogram. All possible mass distributions were plotted for events in these mass intervals, where the masses of all stable mesons and baryons were ascribed to the h^+ and h^- hadrons. None of these distributions shows any concentration of events in a narrow mass interval. Therefore one can conclude that the peaks of the $\Lambda^\circ K^+\pi^-$ system at 1.95 and 2.05 GeV/c^2 are not kinematical reflections of some known resonances the decay products of which are wrongly identified.

The invariant mass distribution of the $\Lambda^\circ\pi^-$ subsystem for all 578 events is shown in fig.6. The narrow peak at 1.32 GeV/c^2 corresponds to about 20 recorded decays $\Xi^-\to\Lambda^\circ\pi^-$, the broad peak centeres at 1.39 GeV/c^2 - to decays $\Sigma^{-*}_{1385}\to\Lambda^\circ\pi^-$. The shaded histogram in fig.6 is the same distribution for 42 events from a peak region of $1.94 < M_{\Lambda^\circ K^+\pi^-} < 1.96$ GeV/c^2.

The substantial part of these events has a $\Lambda^\circ\pi^-$ mass near the resonance Σ^{-*}_{1385}. Figure 7 shows the invariant mass ($M_{\Lambda^\circ K^+\pi^-}$) spectrum for events satisfying the following additional condition:

$$|M_{\Lambda^\circ\pi^-} - 1{,}385| < 0.04 \text{ GeV}/c^2. \qquad (9)$$

Here, as in figs. 4 and 5, a narrow peak is seen at 1.95 GeV/c^2. The number of events in this peak decreases in accordance with decreasing Σ^{-*}_{1385} statistics under condition (9). A possible interpretation of the peak is the existence of a narrow baryon resonance with a mass of 1.95 GeV/c^2, which has a decay mode

$$N^* \to \Sigma^{-*}_{1385} + K^+ . \qquad (10)$$

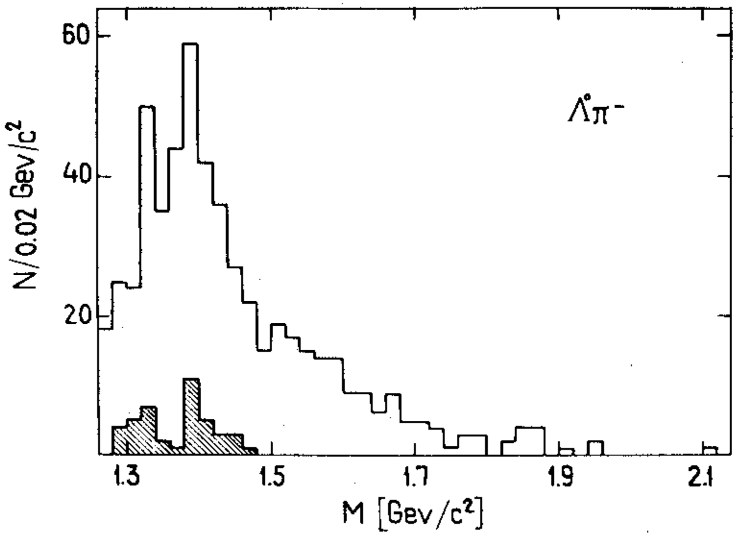

Fig.6. Invariant mass distribution of the $\Lambda^{\circ}\pi^{-}$ system. The shaded part is plotted on condition that $1.94 < M_{\Lambda^{\circ}K^{+}\pi^{-}} < 1.96$ GeV/c^{2}.

A Monte-Carlo simulation of the decay (10) and the detection of its decay products by the set-up were done. The N* was assumed to be produced diffractively in the interaction of neutrons with nucleons of the target. The momentum spectrum of the $\Lambda^{\circ}h^{+}h^{-}$ system was adjusted to the corresponding experimental distribution.

In calculating the detection efficiency, the following factors were taken into account: set-up geometry, Coulomb scattering of charged particles, space resolution and efficiency of the spark chambers, triggering conditions, algorithm of geometrical recostruction program and all criteria of event selection. To obtain the dependence of the detection efficiency of events (1) on the value of $M_{\Lambda^{\circ}K^{+}\pi^{-}}$, the baryon mass was generated uniformly in the whole interval of the masses recorded. This dependence is a smooth curve (see fig.4). Therefore the narrow peaks in the invariant mass spectrum of $M_{\Lambda^{\circ}K^{+}\pi^{-}}$ cannot be attributed to possible inhomogeneities of the detection efficiency. The experimental resolution of the mass of baryon N* decaying via the mode (10) is found to be 0.015 GeV/c^{2}. The efficiency for detecting this decay mode

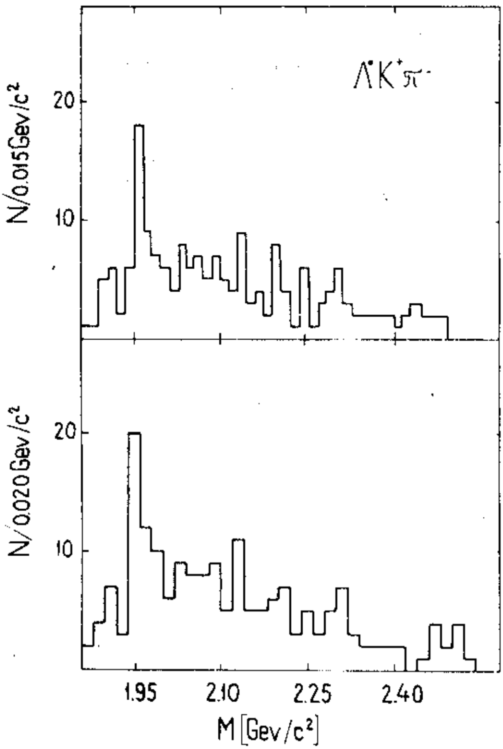

Fig.7. Invariant mass distribution of the $\Lambda^0 K^+\pi^-$ system providing $1.345 < M_{\Lambda^0\pi^-} < 1.425$ GeV/c^2.

depends on $P_\perp^2$ as

$$\epsilon(P_\perp^2) \sim e^{-P_\perp^2}. \qquad (11)$$

The integrated efficiency for detecting the baryon N*, diffractively produced and decaying via (10), is obtained to be:

$$\epsilon_I = (4 \pm 1) \times 10^{-3}. \qquad (12)$$

The errors in this value come from variation of the parameters for the diffractive production of N*.

4. RESULTS

There is an evidence for a new narrow baryon. This resonance is produced in the interactions of neutrons having a medium energy of 40 GeV/c with a carbon target and decays into Σ^{-*}_{1385} and K^+. The resonance mass is 1.95 GeV/c^2 and its width does not exceed the experimental mass resolution, i.e., 0.015 GeV/c^2. Assuming diffractive production, we obtain for the cross section (σ) times the branching ratio (B) of the decay (10) the value:

$$\sigma \times B = (0.6 \pm 0.5)\ \mu b.$$

The errors of this value come mainly from uncertainties of the neutron monitor and efficiency errors (12).

The resonance has a substantially smaller width than the Λ_{1950} resonance which possesses the same decay mode[8]. We have not observed the Λ_{1950} in our experiment. This can be explained because the production of the Λ_{1950} resonance in a neutron beam is not diffractive, therefore its production cross section must decrease rapidly with increasing energy [9,10]. As our spectrometer detects mainly systems with small $P_{\perp}^2$ (11), the integrated efficiency for recording the Λ_{1950} is much lower than for N^*.

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