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SEARCH FOR A NONSTRANGE BARYONIUM DECAYING INTO STRANGE PARTICLES

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Collaboration

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A search for multiquark hadrons is of great importance for the investigation of the nature of strong interactions and the development of particle physics. In particular, the so-called baryoniums-mesons decaying into baryons and antibaryons belong to the multiquark hadrons. The question of their existence is connected with mutually inconsistent experimental data /1/ and still remains open. There exist theoretical prerequisites assuming that the presence of strange or heavy quarks in multiquark hadrons increases their stability, and they may appear as narrow meson resonances /2,3/. Thus, the experimental possibilities of their observation are improved. Recently, in two experiments performed in a hyperon beam of the CERN SPS /4/ and in a neutron beam of the Serpukhov accelerator /5/, the experimental indication of the existence of a narrow baryonium with nonzero strangeness has been obtained. In this case heavier narrow baryoniums with hidden strangeness are expected to exist. A pair of strange particles with opposite strangeness can be observed among the products of their decays.

Below the first results of the search for a candidate to a narrow baryonium with hidden strangeness are presented. The data were obtained by means of the BIS-2 spectrometer /6/ in the same experiment where the hadroproduction of charmed particles was investigated /7,8/, a narrow baryon resonance with hidden strangeness was detected /9/, and narrow states of the baryonium with non-zero strangeness were observed /5/.

The experiment was performed in a neutron beam of the Serpukhov accelerator. A layout of the main elements of the BIS-2 spectrometer is shown in Fig.1. The beam characterized by a mean momentum of ~40 GeV/c and an intensity of $\sim 3\cdot 10^6$ neutrons per spill was incident on a target (T) disposed in the head part of the spectrometer along its axis (OZ) coinciding with the beam axis. The transversal size of the interpolar gap of the spectrometric magnet was 100 x 29 cm^2. The centre of this gap in the experiment was taken for the origin of the "right" orthogonal coordinate system of the spectrometer (XYZ). The magnetic field in the gap, parallel and opposite to the OY axis, changed the transverse momentum of the charged particles, passing through it, by 0.64 GeV/c. The charged

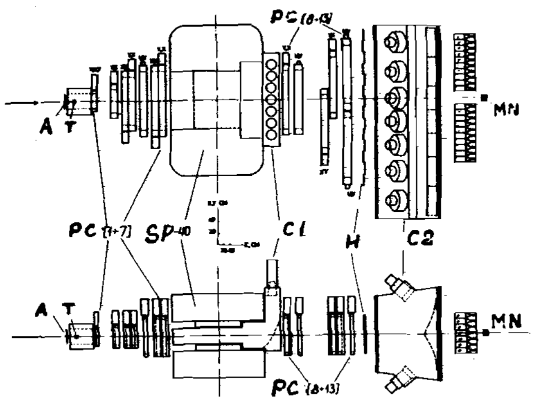


Fig. 1. Layout of the BIS-2 spectrometer.

particles were detected by means of the two-coordinate proportional chambers, with a 0.2 cm wire spacing, located upstream (PC1-7) and downstream (PC8-13) the magnet. Two multicell gas Cherenkov counters C1 and C2 placed, respectively, in the interpolar gap and at the end of the spectrometer, immediately after the hodoscope of the scintillation counters (H), were used to identify the charged particles. The 7-channel C1 was filled with air under atmospheric pressure with the following Cherenkov radiation momentum thresholds: 6 GeV/c for pions, 21 GeV/c for kaons and 40 CeV/c for protons. The corresponding thresholds for the 14-channel C2 filled with freon at atmospheric pressure, too, were 3, 11 and 20 CeV/c. To trigger the spectrometer, at least four charged particles passing through it were required. The triggering signal was formed by the fast logic analysing the signal in the hodoscope elements of the PC and H.

The experiment was performed in two runs of the accelerator operation (~ 250 hours each). A liquid hydrogen target was used in the first run, and ~ 10^7 neutron-proton interactions were detected. In the second run carbon, aluminium and copper nuclear targets, alternated after ~ 5 x 10^4 detected neutron-nuclear interactions, were used. Altogether ~ 1.2 x 10^7 interactions were detected during the second run. All the targets were 6 cm in diameter. The thickness along the beam was 2.1 g/cm^2 for the liquid-hydrogen target and 3.4 x $A^{1/3}$ for the nuclear targets, where A is the atomic weight of target nuclei.

Narrow resonances with zero strangeness decaying into baryons and strange particles were searched. The decays containing Λ°, $\bar\Lambda^\circ$ or K°s as one of the strange particles were chosen from all possible decay modes. These particles were identified via the decays:

$$\Lambda^\circ \to p\pi^-, \quad (1a)$$

$$\bar\Lambda^\circ \to \bar p\pi^+, \quad (1b)$$

$$K^\circ_S \to \pi^+\pi^- \quad (1c)$$

and this allowed the background to be reduced essentially among the states searched for.

Altogether, ~ 1.5 x 10^5 events with Λ°, ~1.1 x 10^5 events with K°s and ~1.5 x 10^3 events with $\bar\Lambda^\circ$ were detected in the experiment.

The desired resonances may appear as narrow peaks in the invariant mass spectra of the final states. The conditions of the given experiment allowed one to reconstruct the invariant mass spectra of the following states

$$\Lambda^\circ \bar p K^+, \quad (2a)$$

$$\bar\Lambda^\circ p K^-, \quad (2b)$$

$$\Lambda^\circ \bar p K^+ \pi^\pm, \quad (3a)$$

$$\bar\Lambda^\circ p K^- \pi^\pm \quad (3b)$$

and

$$K^\circ_S p \bar p K^\pm. \quad (3c)$$

The above-mentioned eight final states exhausted all three- and four-particle decays of the sought resonances which could be detected by the spectrometer. Five-particle final states and double-charged states among them were not analyzed because of their much lower detection efficiency as compared with the considered ones.

To plot the invariant mass spectra of states (2-3), the events were selected in which the neutral vertex (V°), corresponding to one of the decays (1), was reconstructed, and also at least two oppositely charged particles emitted from the target were detected. For the V° selection, it was required that the minimum distance between its trajectories to be less than 0.9 cm (a three-fold value of the experimental resolution of this parameter) and the V° vertex; to be down stream the target. The minimum distance between the edge of the target and the V° vertex, equal to 0 cm for hydrogen exposure and 8 cm for nuclear target exposure, was chosen as a result of signal optimization for Λ°, $\bar\Lambda^\circ$ and K°s to the corresponding background. To reconstruct the topology of the whole event, the trajectories of the secondary charged particles were expected to cross the spectrometer and to have a common vertex in the target region. The point, the root-mean-square distan-

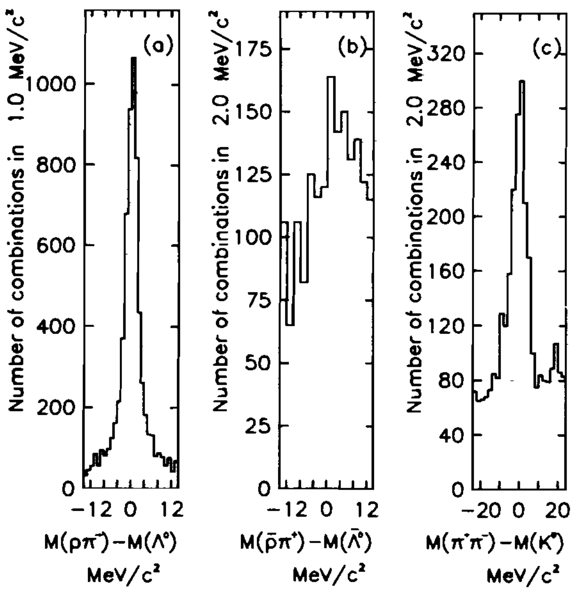


Fig.2. Invariant mass distributions of $V°$: a) for the $p\pi^-$ system in the $M(\Lambda°)$ region of the $\Lambda°$ table mass; b) for the $\bar{p}\pi^+$ system in the $M(\bar{\Lambda}°)$ region; c) for the $\pi^+\pi^-$ system in the $M(K^\circ_S)$ region of the K°_S table mass.

ce of which from the considered trajectories including the reconstructed $V°$ to be less than 2.0 cm, was chosen as the common vertex.

Figs.2(a), (b) and (c) present the invariant mass spectra for the systems $p\pi^-$, $\bar{p}\pi^+$ and $\pi^+\pi^-$ reconstructed for the $V°$ of the selected events. In two spectra (Fig.2(a) and (c)) the peaks are seen with their centres at the table masses of $\Lambda°$ and $K°$s which indicates the presence of the decays (1(a) and (c)) among the selected events. The FWHM values characterizing an experimental resolution of the reconstructed events are equal to 4.5 and 6 MeV/c^2 respectively*. To select the events containing $\Lambda°$, it was required that the corresponding invariant mass of the $V°$ differed from the table mass of $\Lambda°$ by no more than 7 MeV/c^2 and for $\bar{\Lambda}°$ and $K°$s selection by no more than 10 MeV/c^2.

Taking the above conditions into account, 26453, 1868 and 16217 events, containing, respectively, $\Lambda°$, $\bar{\Lambda}°$ and $K°$s and at least two oppositely charged particles emitted from the target, were selected. For the selection of the combinations corresponding to the final states (2-3) among these events, it was necessary to identify the charged particles by means of the C1/C2 [10]. The momenta of the particles, candidates to protons or antiprotons, were from 3 to 12 GeV/c what was below the Cherenkov radiation threshoulds of the C1/C2 even

*The parameters of $\bar{\Lambda}°$ signal could not be determained due to low statistic of considered events.

for kaons. Therefore, for the identification of protons and antiprotons it was only required that the particles were not unambiguously identified as pions.

The efficiency of charged particle identification depends both on their momenta and on the total number of charged particles detected in the event. Therefore, the criteria, determining the same suppression factors for background pions, can differ for the identification of protons (antiprotons) or kaons in the events with different final states (2)-(3)*. Two methods were used because of the absence of an independent way for the optimization of these criteria. In the first method the criteria, determining the degree of pion suppression, were chosen according to the conditions for charged particle identification in the selection of the known decays: $\phi \to K^+K^+$, $\Lambda° \to \bar{p}\pi^+$ and so on. In the general case such criteria are not optimal to search for the cought signals. In the second method the criteria were chosen independently for each final state and also for two samples (for the hydrogen and nuclear targets) and were optimized by a maximum significance of the signals.

Fig.3(a) illustrates the invariant mass spectra of the neutral final state (2a) obtained for 4087 combinations, which were selected by the first method of antiproton and kaon identification. The histogram binning (20 MeV/c^2) is chosen

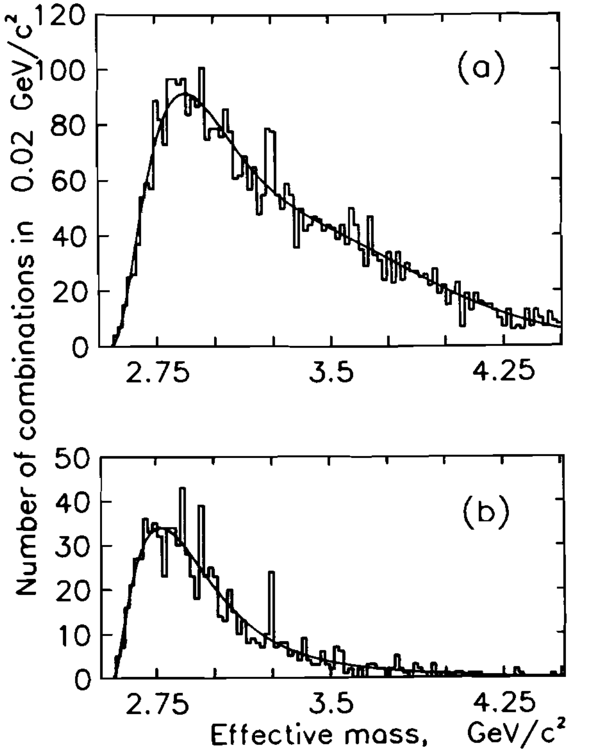


Fig.3. Invariant mass distributions of the final states of $\Lambda°\bar{p}K^+$ (a) and $\bar{\Lambda}°pK^-$ (b).

*The background conditions were also different in runs with different targets.

to be equal to the two-fold experimental resolution. The level of a non-resonant background obtained from the spectrum approximation by a smooth analytical function is denoted by the curve. The peak is seen in a mass region of 3250 MeV/c ^{2}. The two bins of the signal contain 48 combinations over the background curve. This corresponds to more than four standard deviations. Optimization of the signal using the second method of identification practically does not improve the signal. The observed bump might be considered as an indication of the sought resonance.

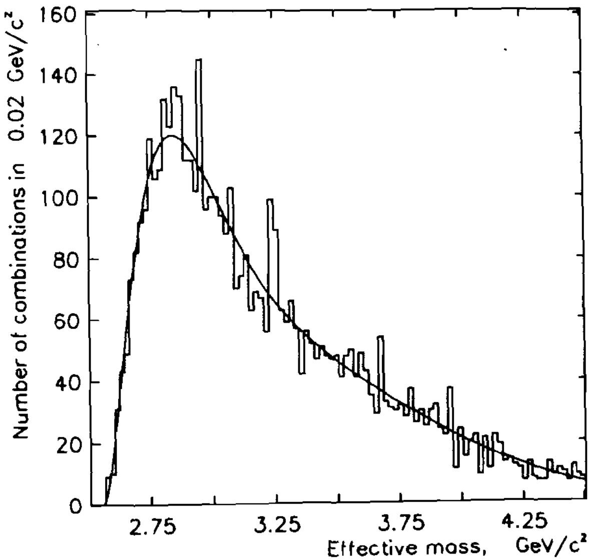
In a 3250 MeV/c ^{2} mass region no peculiarity is seen in the invariant mass spectra for another neutral state (2b) obtained according to the same identification criteria for protons, antiprotons and kaons (the first method). A small peak is seen at the same mass as in Fig.3a in the invariant mass spectra of the state (2b) shown in Fig.3(b), which has been obtained for 860 combinations selected by optimization of charged particle identification (the second method). The peak contains about ~ 17 events over the smooth background curve. If the peaks observed in both spectra are due to the existence of the narrow meson resonance, the branching ratio of its decay modes (2a) and (2b) must be equal because of the C invariance of strong interactions. The acceptance for the states (2b) and (3b) is lower than that for the (2a) and (3a) states due to the spectrometer asymmetry in the XOZ plane. The acceptance corrected ratio of the branching ratio (2a) to (2b) obtained for the number of events selected by the second method is equal to 1.4 ± 0.5*.

Fig.4. shows the summarized invariant mass spectrum for both neutral final states (2a) and (2b). A peak is seen in the two bins centered at 3245 MeV/c ^{2}. There are (55±13) combinations in the peak over the background (smooth curve) expected in this mass region (about 130 combinations). Statistical significance of such a signal corresponds to about five standard deviations.

The sum of the invariant mass spectra of all the charged final states (3a)-(3b) is shown in Fig.5. The identification criteria for protons, antiprotons and kaons, chosen in the frame of the first method are similar for each of the considered final states in this distribution of the selected

In the calculation of the acceptance the conditions of charged particle identification were not taken into account.

Fig.4. Summary invariant mass spectrum of the $\Lambda^\circ \bar{p} K^+$ and $\bar{\Lambda}^\circ p K^-$ system.



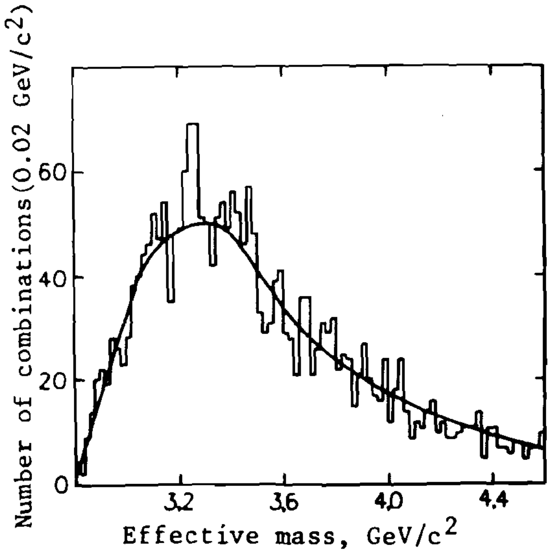


Fig.5. Summary invariant mass spectrum of the charged states $\Lambda^\circ \bar{p} K^+ \pi^\pm$, $\bar{\Lambda}^\circ p K^- \pi^\pm$ and $K^\circ_S p \bar{p} K^\pm$ selected according to the criteria of charged particle identification.

2538 combinations. The histogram binning is equal to 20 MeV/c ^{2}. The smooth curve denotes a non-resonant background obtained from the spectrum approximation by the smooth analytical function. A peak is seen in this distribution in the same mass region as in the invariant mass spectrum of the neutral states (Figs.3 and 4). In three bins the peak contains ~53 com-

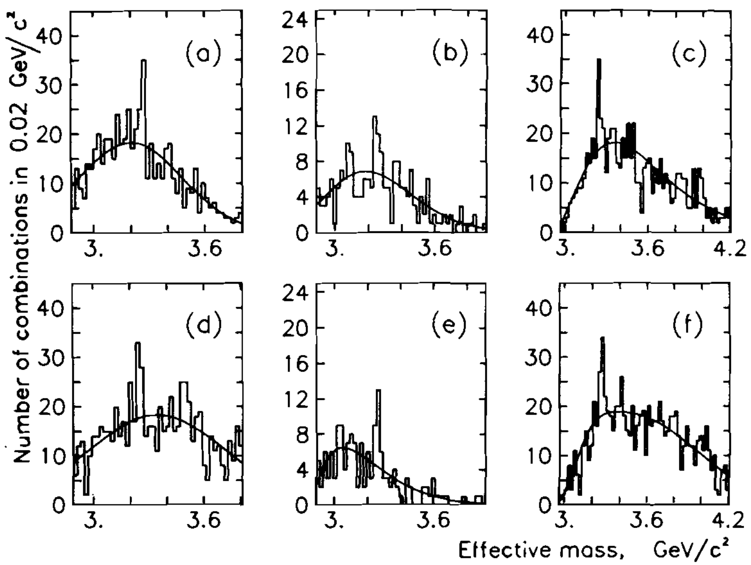


Fig.6. Invariant mass distributions of the final states: a) $\Lambda^\circ \bar{p} K^+ \pi^-$, b) $\Lambda^\circ \bar{p} K^+ \pi^+$, c) $\bar{\Lambda}^\circ p K^- \pi^-$, d) $\bar{\Lambda}^\circ p K^- \pi^+$, e) $K^\circ_S p \bar{p} K^-$, and f) $K^\circ_S p \bar{p} K^+$.

binations over the background curve. This corresponds to about four standard deviations. As the given distribution is obtained for the events selected by the first method (the identification criteria are not optimized), the observed peak allows one to estimate the lower limit of its statistical significance.

Another estimation is obtained in the analysis of the events selected by the second methos of the identification of charged particles. The invariant mass spectra of the charged states (3a-3c) obtained by this method are shown in Figs.6(a-f). These spectra contain respectively, 521, 230, 768, 756, 162 and 989 events, candidates to the analyzed final states. The results of approximating the spectra by the background curve are also presented in these figures. The peaks are seen in each of these six spectra in two-three bins centered at ~3260 MeV/c^2. As in the case of the neutral states (2a) and (2b), the probabilities of narrow peak production in the states (3a) and (3b) obtained in view of the acceptance do not differ within the experimental errors.

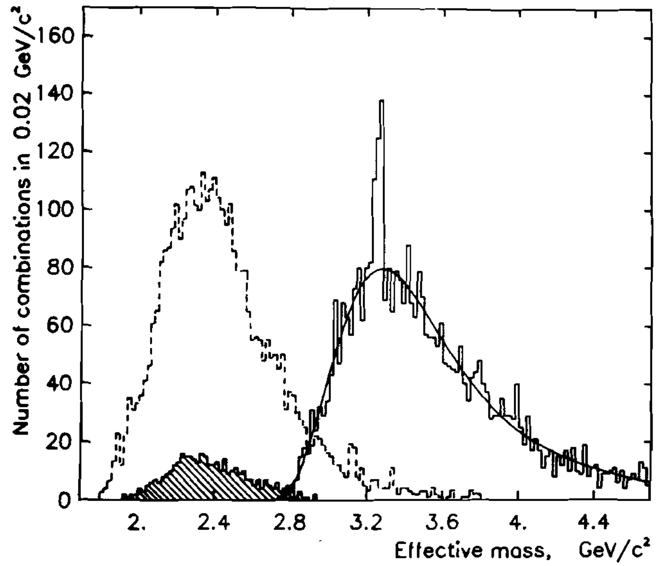


Fig.7. Full-line histogram-summary invariant mass spectrum for the charged states: $\Lambda^\circ \bar{p} K^+ \pi^\pm$, $\bar{\Lambda}^\circ p K^- \pi^\pm$ and $K^\circ_S p \bar{p} K^\pm$. Dotted histogram - the invariant mass spectrum obtained for the same events by the replacement of the proton (antiproton) mass on pion mass; shaded histogramm - the events from the M_ϕ peak region obtained after the same replacement.

The summarized spectrum of the six spectra (Fig.6(a) - (f)) of the charged states is presented by the solid-line histogram in Fig.7. The curve in this figure corresponds to the non-resonant background level. In a narrow peak with a central mass of 3256 MeV/c^2 in the three bins there are (117 ± 18) over 250 combinations of the background level what corresponds to seven standard deviations.

Thus, the peaks are seen in all analyzed invariant mass spectra of the final states (2)-(3) in a ~3250 MeV/c^2 mass region. Even for the non-optimal selection criteria of particles (the first method of the charged particle identification) the peaks remain in most spectra. This shows evidence that these peaks are physical signals but not statistical fluctuations. They cannot be a consequence of the kinematic reflection of some resonances due to an incorrect identification of the decay products since they are present in different final states. Independently, this fact was confirmed by the invariant mass spectra obtained for the same events by imputing to the secondary particles other wrong masses. All spectra constructed in such a way have a smooth form without any statistically significant peaks. The example of one of these spectra is presented in Fig.7 by a dotted histogram.

Thus, the observed signals could be considered as an indication for the existence of the narrow meson resonance with zero strangeness in the three charged states (neutral, positive and negative). The width of the resonance is no more than 30 MeV/c^2. The mass of the charged states is equal to (3255 ± ± 30) MeV/c^2, and that of the neutral state is ~ 10 MeV/c^2 lower. The error is an estimation of the tolerable systematic uncertainty in the calculated invariant masses for the considered configurations. Further we denote this resonance as M_ϕ.*

It was obtained that the branching ratio (3a) or (3b) is close to the branching ratio (3c).

As it follows from the analysis of the inclusive spectra of the longitudinal (P_L) and squared transversal (P_T^2) momentum components of the observed M_ϕ, they are detected in a kinematical region of ($20 \le P_L \le 60$) GeV/c and $P_T^2 \le 0.8$(GeV/c)^2. This corresponds to the values of the Feynman variable: $x > 0.2$. The dependence of the M_ϕ production cross section on the atomic weight (A) in this kinematical region agrees with the expression $A^{2/3}$. In accordance with this dependence, the resonance production cross section on different nuclei were recalculated for the cross section per nucleon. In the considered kinematic region the production cross section times the branching ratios of one of the observed modes (2a) or (2b) for the neutral state, at a 90% confidence level, is determined within the limits:

$$0.4 \div 3.0 \ \mu b/\text{nucleon}. \tag{4}$$

The production cross section times the branching ratio for the charged states decaying via the mode (3a) or (2b), at the same confidence level, is limited by the values:

$$0.5 \div 7.0 \ \mu b/\text{nucleon}. \tag{5}$$

The wide ranges of (4) and (5) are due to the systematic errors connected with inaccuracies of the monitoring and uncertainty

*Denotion is chosen in accordance with the suggestion /1/ to mark the open or hidden strangeness by an index.

of the M_ϕ inclusive characteristics (mainly, in the x spectrum) from which the acceptance calculation is dependent on.

The meson resonance M_ϕ would be a baryonium since there is a baryon and an antibaryon among the products of its decay. Its mass is 180-200 MeV/c^2 greater than the one of the strange baryonium. Different charged states of this baryonium, (M_s^0, M_s^+, M_s^- and M_s^{--}) have been observed earlinear in the same experiment /5/, and its main characteristics correspond to the resonance U(3100) /4/ observed at the CERN SPS. Due to the unusual isotopic spin, U/M_s can be attributed to exotic mesons containing at least four quarks*. The mass difference between the considered M_s and M_ϕ baryoniums is close to typical splitting between the levels in the SU(3) multiplets of the baryons /1/ which differ in one hypercharge unit. Since the M_ϕ decays into strange particles, it can be regarded as a candidate to the baryonium with hidden strangeness, a representative of the same SU(3) multiplet of exotic mesons as M_s.

The presented data on a search for baryoniums, decaying into strange particles, have been obtained as a result of the analysis of ~ 40% of the statistical information detected by means of the BIS-2 spectrometer.

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Алеев А.Н. и др. Д1-88-194
Поиск нестранного барионня,
распадающегося на странные частицы

В эксперименте, проведенном на нейтронном пучке серпуховского ускорителя с помощью спетрометра БИС-2, в инклюзивном подходе искался нестранный барионий, распадающийся на странные частицы. Исследовались конечные состояния, характеризующиеся нулевыми значениями барионного числа и странности, но содержащие странные частицы и частицы с отличным от нуля барионным числом. Проанализированы спектры инвариантных масс состояний: $\Lambda^{\circ}\bar{p}K^{+}$, $\bar{\Lambda}^{\circ}pK^{-}$, $\Lambda^{\circ}\bar{p}K^{+}\pi^{\pm}$, $\bar{\Lambda}^{\circ}pK^{-}\pi^{\pm}$ и $K^{\circ}p\bar{p}K^{\pm}$. В указанных спектрах в области массы 3250 МэВ/c^2 наблюдаются узкие выбросы с шириной ~30 МэВ/c^2, что соответствует величине экспериментального разрешения. Полученные данные являются указанием на существование узкого мезонного резонанса со скрытыми квантовыми числами: барионным зарядом и странностью.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1988

Aleev A.N. et al. D1-88-194
Search for a Nonstrange Baryonium Decaying
into Strange Particles

Inclusive production of a nonstrange baryonium decaying into strange particles has been searched for in the experiment performed in a neutron beam of the Serpukhov accelerator by means of the BIS-2 spectrometer. Final state characterized by a zero baryon number and strangeness, but containing strange particles and particles with a non-zero baryon number, have been studied. The invariant mass spectra: $\Lambda^{\circ}\bar{p}K^{+}$, $\bar{\Lambda}^{\circ}pK^{-}$, $\Lambda^{\circ}\bar{p}K^{+}\pi^{\pm}$, $\bar{\Lambda}^{\circ}pK^{-}\pi^{\pm}$ and $K^{\circ}p\bar{p}K^{\pm}$ have been analysed. In mentioned spectra narrow peaks ~30 MeV/c^2 in width, which is close to the corresponding experimental resolution, are seen in a mass region of 3250 MeV/c^2. The obtained data indicate the existence of a narrow meson resonance with hidden quantum numbers: baryon number and strangeness.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1988