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D1-82-921

OBSERVATION
OF A NARROW BARYON PRODUCED IN NEUTRON-CARBON INTERACTIONS

Submitted to "Physics Letters B"

1982

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We report here the observation of a narrow resonance with a mass of ~1960 MeV/c^2. It decays into $\Sigma^-(1385)K^+$. Unusual features of the resonance allow one to assume a possible five-quark structure. An indication of the existence of this resonance has been obtained in previous experiments /1/.

Our investigation is based on data of the charm search experiment in neutron-carbon interactions. This experiment has been performed at a neutral beam of the Serpukhov accelerator using the BIS-2 spectrometer. The momentum spectrum of the beam, consisting mainly of neutrons, is presented in Fig.1. A carbon target 6 g/cm^2 thick was used. The trigger requirement was four or more secondary charged particles passing through the whole spectrometer. No identification of charged particles was done. Details concerning the set-up and the procedures of data acquisition and analysis are described in refs. /1,2/. About 5.3×10^6, 1.7×10^6, and 4.4×10^6 events were recorded at each of three different configurations of the set-up, respectively. At the third configuration the target position and the polarity of the magnetic field were changed. The data obtained at this configuration (sample B) were analysed separately from those of the first and second configurations (sample A). The differences of these two samples allow possible systematic errors to be estimated.

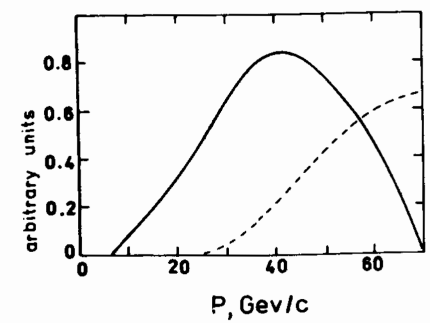

Fig.1. Momentum spectrum of the neutron beam (solid line) and momentum acceptance for events of the type (1) (dashed line).

We have searched for a process of the type:

$$n + C \longrightarrow \Sigma^-(1385)\,h^+ + \ldots \qquad (1)$$
$$\hookrightarrow \Lambda^\circ \pi^-$$

The BIS-2 spectrometer mainly accepted this type of events with both $\Sigma^-(1385)$ and charged positive hadron (h^+) produced in the

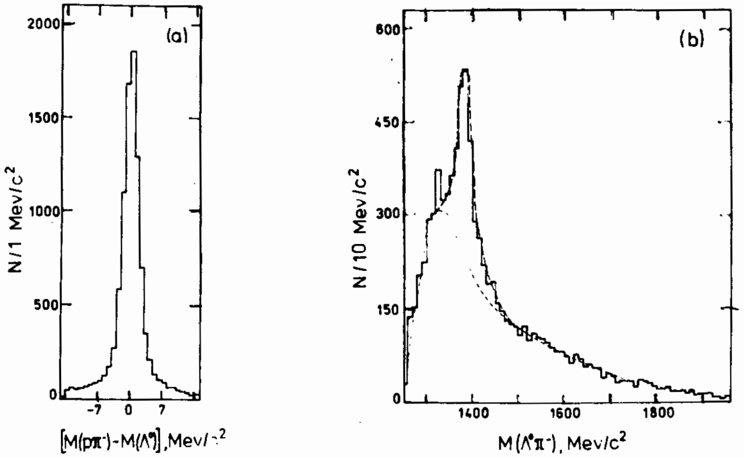

Fig.2. a) The $p\pi^-$ invariant mass spectrum of "Vees" around $M(\Lambda^\circ) = 1115.6$ MeV/c^2 for sample A. b) The $\Lambda^\circ\pi^-$ invariant mass spectrum for the same sample, fitted by a Breit-Wigner resonance plus a polynomial backgro- und (dashed curve). The production of $\Xi^-(1320)$ and $\Sigma^-(1385)$ is seen.

neutron beam fragmentation region. We selected events having a Λ° "Vee" with its vertex outside the target and only one positive (h^+) and one negative (π^-) particles emitted directly from the target. All three particles Λ°, π^-, and h^+ were requi- red to form a "good" vertex within the target region. The to- tal momentum of each event was also required to be greater than 28 GeV/c according to the acceptance of the spectrometer for the process (1) (dashed line in fig.1).

Figure 2a illustrates the $p\pi^-$ invariant mass distribution of "Vees" from the sample A. The positive particle from "Vee" is assumed to be a proton; and the negative one, a pion. A clear signal of Λ° production is seen. "Vees" having $p\pi^-$ invariant mass within ± 7 MeV/c^2 from a value of $M(\Lambda^\circ) = 1115.6$ MeV/c^2 were identified as Λ° hyperons. 8697 and 7358 events containing a Λ° at a background level of 10% were selected from the two samples, respectively. The $\Lambda^\circ\pi^-$ invariant mass spectrum obtained from the A sample is presented in fig.2b. A clear signal is seen for $\Sigma^-(1385)$. The dashed curve represents the fit of a Breit-Wig- ner resonance plus a polynomial background to the spectrum. The mass and the width of the resonance obtained are in good agree- ment with other $\Sigma^-(1385)$ data[3]. To select the events containing $\Sigma^-(1385)$ the $\Lambda^\circ\pi^-$ invariant mass was required to be within ± 35 MeV/c^2 from the $\Sigma^-(1385)$ mass. Using this criterion, we have selected 2779 and 1711 events from the A and B samples, respec- tively.

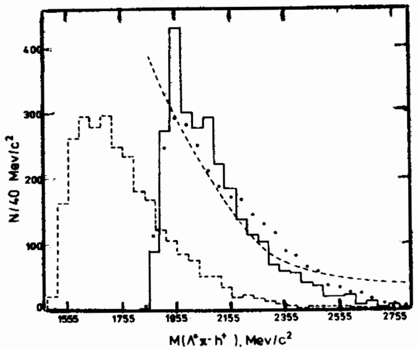

Fig.3. Invariant mass distribu- tion of the $\Sigma^-(1385)h^+$ system for sample A obtained under the assumption that h^+ is a kaon (solid line distribution), the background spectrum normalized to the same histogram (dotted distribution) and the accep- tance for the $\Sigma^-(1385)K^+$ system (dashed curve). Invariant mass distribution of the $\Sigma^-(1385)h^+$ system for the same sample ob- tained under the assumption that h^+ is a pion (dashed his- togram) is also shown.

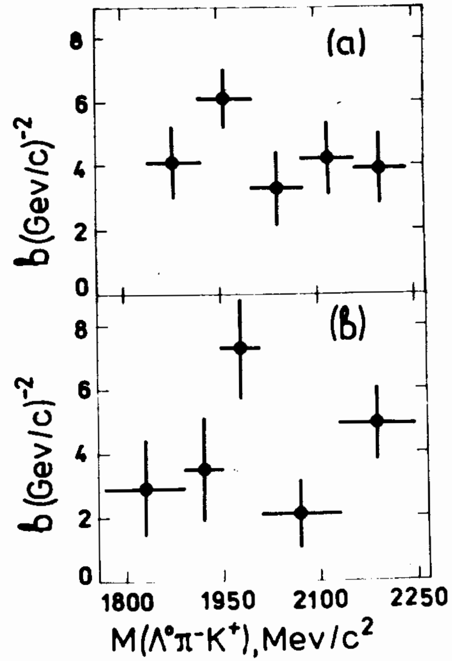

Fig.4. Slopes of the P_T^2 dis- tributions versus the $\Sigma^-(1385)K^+$ invariant mass plotted for (a) sample A and (b) sample B.

The $\Lambda^\circ\pi^-K^+$ invariant mass spectrum obtained from the sample A, assuming that h^+ is a K^+ meson, is presented in fig.3 (solid line distribution). A distinct peak is seen in a mass region of 1935÷1975 MeV/c^2. To rule out the possibility that the peak is due to the selection criteria, a background spectrum is shown in fig.3 as well (dotted distribution). This spectrum has been obtained by combining $\Sigma^-(1385)$ with K^+ from other events. Each combination satisfies all the above criteria. The background spectrum normalized to the original distribution (2779 events) describes satisfactorily the general features of the mass spect- rum, except for the peak region. The mass acceptance, calculated by the Monte-Carlo method (taking into account all experimental conditions and selection criteria) for the events (1), is a smooth curve (dashed curve in fig.3). Hence, the narrow peak in the in- variant mass spectrum of the $\Sigma^-(1385)K^+$ system cannot be attribu- ted to some inhomogeneity of the detection efficiency. The dashed distribution in fig.3 illustrates the $\Sigma^-(1385)h^+$ invariant mass spectrum obtained for the same events under the assumption that h^+ is a pion. There are no significant peaks in this spectrum. Consequently, the observed peak is not due to a kinematical reflection of any strange resonance. An enhancement is also observed for the close mass region in the invariant mass spectrum of the $\Sigma^-(1385)K^+$ system selected from the B sample.

All the events registered have the squared transversal momentum $P_T^2 \leq 1.0$ $(GeV/c)^2$. We plotted the P_T^2 distributions for different $M(\Lambda^\circ\pi^-K^+)$ regions and fitted an exponential $\sim \exp(-b \cdot P_T^2)$ to them. Figures 4a and 4b show the obtained slope parameters as a function of the $\Sigma^-(1385)K^+$ invariant mass for the A and B samples, respectively. The increase of the slope parameter in the peak mass region is seen on these plots. Thus, one can conclude that the events responsible for the peak are produced at low P_T^2. To obtain the slope parameter for these events, the $\Sigma^-(1385)K^+$ invariant mass spectra were plotted for different P_T^2 regions. We have estimated the number of events responsible for the peak and the background level under the peak, for each spectrum. Using the estimated numbers, the P_T^2 spectra were plotted for peak and background events (combining both samples). These spectra corrected for acceptance were fitted by the exponential. For background events the slope was obtained to be $3.4 \pm 0.2 (GeV/c)^{-2}$. For peak events $b = 9.8 \pm 2.5$ $(GeV/c)^{-2}$. The latter parameter is close to the value expected for the diffraction dissociation of neutron on nucleon /4/. So, we conclude that peak events are produced by the diffraction-like process of neutrons on quasi-free nucleons of carbon nuclei. This conclusion is also supported by the absence of any significant peaks in the $\Sigma^-(1385)K^+$ invariant mass spectrum for events having more than three (Λ° , π^- and h^+) detected particles.

To increase the signal-to-background ratio of peak events, we have selected 1725 events from the A sample under the condition $P_T^2 < 0.24$ $(GeV/c)^2$ and 584 events from the B sample satisfying the condition $P_T^2 < 0.15$ $(GeV/c)^2$. The $\Sigma^-(1385)K^+$ invariant mass distributions for these events are shown in Fig.5a,b. The circles show the mass spectra corrected for acceptance. Significant peaks are seen at ~1960 MeV/c^2 in both distributions. The numbers of events in the peaks were estimated by fitting a polynomial background to these distributions (dashed lines). The statistical significances of the peaks were obtained to be about 7.0 and 5.5 standard deviations from the background level for the A and B samples, respectively.

The observation of these peaks in both event samples has led us to the conclusion that there should be a narrow resonance. The features of the resonance observed are summarized in the table. We estimated the systematical error for a resonance mean mass M of about 10 MeV/c. The width Γ of

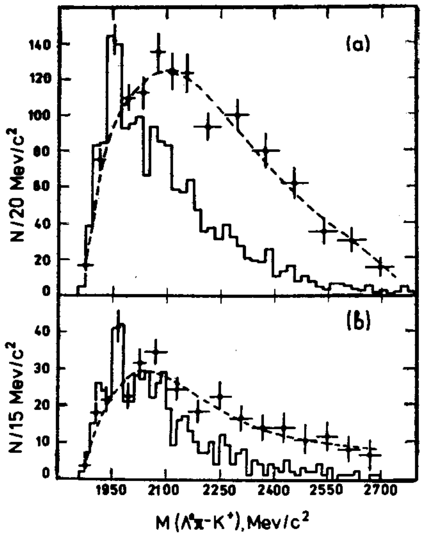

Fig.5. Invariant mass distributions of the $\Sigma^-(1385)K^+$ system: (a) selected from sample A under the condition $P_T^2 < 0.24$ $(GeV/c)^2$ and (b) selected from sample B under the condition $P_T^2 < 0.15 (GeV/c)^2$. The same mass spectra corrected for acceptance (black circles) and fitted by polynomial background (dashed lines) are also shown.

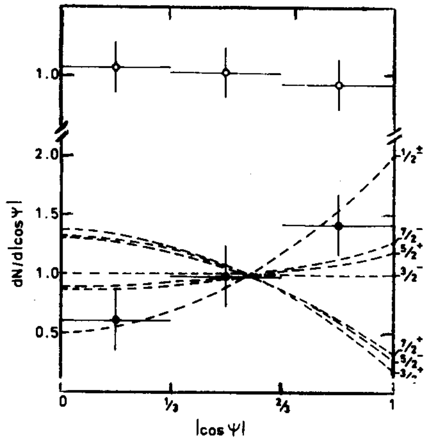

Fig.6. The $|\cos\psi|$ spectra for resonance (black circles) and background (open circles) events. The dashed lines are the expected spectra for different spin-parities.

Table

Features of the resonance observed. Systematical error of M and statistical errors for $\sigma \cdot B$ are given only

Sample	Number of events	M MeV/c^2	Γ MeV/c^2	$\sigma \cdot B$ μb per carbon nucleus
A	97± 17	1955	35±10	0.79± 0.13
B	38± 9	1965	22±7	0.75± 0.17
Complete	135± 19	1960±10	26±6	0.78±0.10

the resonance was determined taking into account an experimental mass resolution of ~20 MeV/c^2 . The partial cross sections times the branching ratio $\sigma \cdot B$ are presented with the statistical errors only. The systematical error of $\sigma \cdot B$ is mainly due to the errors in measuring the neutron flux and in calculating the resonance detection efficiency. This error was estimated to be less than 40%.

To estimate the spin-parity J^P of the resonance observed, we have used the method described in ref.[5]. This method can be successfully applicable to the case of two-body decays into $3/2^+$ and 0^- particles with low angular momentum. In our case the latter condition seems to be satisfied due to a small free energy of the decay. We have constructed the $|\cos\psi|$ spectra for resonance and background events similarly to the P_T^2 spectra, where ψ is the angle between the $\Sigma^-(1385)$ momentum in the resonance rest frame and the Λ^0 momentum in the $\Sigma^-(1385)$ rest frame. Figure 6 presents these spectra corrected for acceptance for both combined event samples. The dashed lines represent the expected spectra for different J^P. The spectrum for the resonance events (black circles) satisfies the hypotheses of spin-parity: $1/2^\pm$, $3/2^-$, $5/2^+$, or $7/2^-$ and excludes the others. Otherwise the Gribov-Morrison rule[6] for diffraction dissociation processes excludes the same spin-parities as that in the above analysis. This rule demands $\Delta P = (-1)^{\Delta J}$ for the change in parity ΔP and spin ΔJ between the initial particle and the dissociated system.

In conclusion 135 ± 19 events of the narrow baryon decaying into $\Sigma^-(1385)$ and K^+ have been found.

The mass of this resonance is 1960 MeV/c^2 with a systematic error of ~10 MeV/c^2 and the width is 26±6 MeV/c^2. The possible spin-parities of the resonance are $1/2^\pm$, $3/2^-$, $5/2^+$, or $7/2^-$.

The resonance is produced by neutrons in diffraction-like processes with partial cross section:

$$\sigma \cdot B = 0.8 \pm 0.1 \ \mu b \text{ per carbon nucleus},$$

and with the slope of the differential cross section:

$$b = 9.8 \pm 2.5 \ (\text{GeV}/c)^{-2}.$$

This resonance cannot be identified with the known resonance $\Delta(1950)$[3,7] because the width (0.2-0.3 GeV/c^2) and the spin-parity ($7/2^+$) of the latter are excluded in our case.

The narrow width of the observed resonance and its decay into strange particles suggest the existence of a new five-quark ($udds\bar{s}$) baryon state. The possible existence of such systems as a narrow baryon resonance has been discussed in a series of papers, e.g., refs.[8].

The authors are deeply indebted to A.M.Baldin, E.I.Mal´tsev, I.A.Savin and I.S.Zlatev for their support of the experiments and permanent interest in this investigation. We also thank A.O.Chkheidze, V.G.Kadyshevsky, A.B.Kaidalov, A.P.Kobushkin, V.A.Matveev, and T.Toohig for useful discussions.

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Received by Publishing Department
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Алеев А.Н. и др. Д1-82-921

Наблюдение узкого барионного резонанса, рожденного в нейтрон-углеродных взаимодействиях

Наблюдается рождение узкого резонанса, распадающегося на $\Sigma^-(1385)$ и K^+. Масса резонанса равна 1960 ± 10 МэВ/c^2, а его ширина - 26 ± 6 МэВ/c^2. Резонанс рождается в дифракционных процессах при взаимодействии нейтронов с углеродной мишенью. Произведение сечения его рождения на вероятность его распада по наблюдаемому каналу равно $0,8\pm0,1$ мкб/ядро углерода. Возможные значения спин-четности резонанса: $1/2^{\pm}$, $3/2^-$, $5/2^+$, $7/2^-$.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1982

Aleev A.N. et al. D1-82-921

Observation of a Narrow Baryon Produced in Neutron-Carbon Interactions

A narrow resonance decaying into $\Sigma^-(1385)$ and K^+ is observed. The mass of the resonance is 1960 ± 10 MeV/c^2 and its width is 26 ± 6 MeV/c^2. The resonance is produced by neutrons in a diffraction-like process. The partial cross section $\sigma\cdot B$ is 0.8 ± 0.1 μb per carbon nucleus. Possible spin-parities of the resonance are: $1/2^{\pm}$, $3/2^-$, $5/2^+$, $7/2^-$.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1982