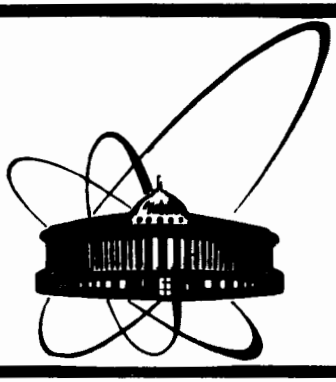

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CHARMED BARYON Λ_c^+ PRODUCTION BY ~58 GeV NEUTRONS ON CARBON

BIS-2 Collaboration: Berlin - Budapest - Dubna - Moscow - Prague - Sofia - Tbilisi

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Here we report the result of a search for inclusive Λ_c^+ production by ~58 GeV neutrons on carbon at the Serpukhov accelerator using the spectrometer BIS-2[1]. We have observed the following decay modes:

$$\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-, \quad (1)$$

$$\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-. \quad (2)$$

Our result is a first statistically significant direct observation of charmed particle production in strong interactions at these low energies. A previous stage of this investigation has been reported in[2,3].

The layout of the BIS-2 spectrometer (fig.1) allows the registration of secondary particles mainly produced in the high energy fragmentation region of the neutron beam. The momentum spectrum of the neutron beam is shown in fig.2. A 6 g/cm^2 carbon target (T) was used. The magnet (M) changed the transverse momentum of charged particles by 0.64 GeV/c. To trigger the spectrometer, four or more charged particles were required to pass the whole spectrometer. The spectrometer operated on-line with an EC-1040 computer.

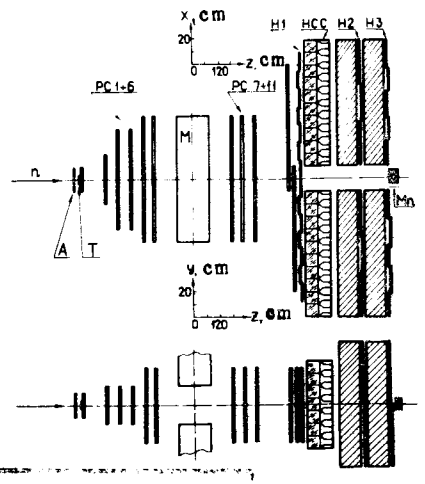

Fig.1. A scheme of the BIS-2 set-up: M - magnet; PC - two-coordinate multiwire proportional chambers; A - scintillation anticoincidence counter; T - carbon target; H1 - scintillation hodoscope; M_n - neutron beam monitor; H2 and H3 - μ detector hodoscopes; HCC - lead glass walls. No information from H2, H3 and HCC have been used in data analysis presented.

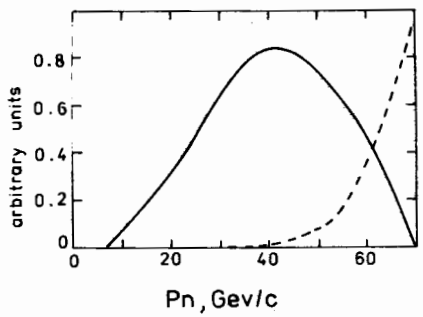

Fig.2. Neutron beam momentum spectrum (solid curve) and neutron momentum acceptance for Λ_c^+ (dashed curve).

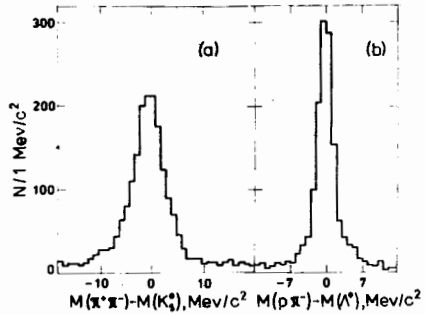

Fig.3. "Vees" invariant mass spectra illustrating K_S° and Λ° detection at the third configuration: (a) is the $M(\pi^+\pi^-)$ spectrum in a mass region around $M(K_s^\circ) = 497.67$ MeV/c^2; (b) is the $M(p\pi^-)$ spectrum in a mass region around $M(\Lambda^\circ) = 1115.6$ MeV/c^2.

The results are based on the data of three different configurations of the spectrometer. Main differences were the polarity of the magnetic field in the magnet, positions of the target, and some geometrical parameters of the proportional chambers (PC). All the changes of the experimental conditions allowed us to estimate possible systematic errors. $5.3\cdot10^6$, $1.7\cdot10^6$, and $4.4\cdot10^6$ events were recorded at each of the configurations, respectively. These events corresponded to the integral neutron flux $M_n \simeq 4.75\cdot10^{11}$ through the target.

We searched for inclusive Λ_c^+ production in the process

$$n + C \to \Lambda_c^+ + \ldots \qquad (3)$$
$$\Lambda_c^+ \to \Lambda^\circ(\bar{K}^\circ)\, h^+h^+h^-$$

This process possesses the topology with a $\Lambda^\circ(K_s^\circ)$ "Vee", having its vertex outside the target, and with three charged particles (h^+, $h^+$and h^-) emitted directly from it. The "Vee" vertex was required to have the closest approach less than 1 cm and to lie more than 15 cm downstream the centre of the target. Figure 3 illustrates the "Vee" invariant mass spectra for K_s° and Λ° detected at the third configuration. We identified the "Vee", having the invariant mass of a two-pion system $M(\pi^+\pi^-)$ within ±10 MeV/c^2 from $M(K_s^\circ)$=497.67 MeV/c^2 with K_s°, and the "Vee" having the invariant mass of a system of a proton and a negative pion $M(p\pi^-)$ within ±7 MeV/c^2 from $(\Lambda^\circ) = 1115.6$ MeV/c^2 with Λ°.

In accordance with the acceptance for Λ_c^+, each combination of events corresponding to reaction (3) was required to have the total momentum greater than 25 GeV/c (except configuration one).

2379, 513 and 1350 events of $K_s^\circ h^+h^+h^-$ combinations were selected at the three configurations, respectively. Figure 4 presents the invariant mass $M(K_s^\circ p\pi^+\pi^-)$ distributions for these events assuming that the largest momentum of both positive particles belongs to the proton. The widths of the bins were chosen close to the experimental resolutions. Sharp peaks are seen for the mass region of charmed baryon Λ_c^+. The number of combinations per event in each bin is smaller than 1.1. To estimate the number of events in peaks, a polynomial background (dotted curves in fig.4) was fitted to the distributions. The statistical significances of these peaks are ~6, ~5, and ~5 standard deviations from the background, respectively. If the observed peaks are due to hyperon resonances, in the neutron fragmentation region one can observe, with a higher probability, the isotopically conjugated negative state (as, for example, the $\Sigma(1385)$ production [4]). No significant peaks are seen in the invariant mass of the $K_s^\circ p\pi^-\pi^-$ system selected similar to $K_s^\circ p\pi^+\pi^-$ (the dashed distribution in fig.4). So, we are led to identify the observed peaks with the charmed baryon Λ_c^+.

In the sample of events containing a Λ° we searched for the decay (2). 2150, 360, and 1161 events of $\Lambda^\circ h^+h^+h^-$ combinations were selected at the three configurations, respectively. The invariant mass $M(\Lambda^\circ\pi^+\pi^+\pi^-)$ spectra for these events, assuming that all $h^\pm$ are pions, are presented in fig.5. The number of combinations per event in each bin is smaller than 1.05. A polynomial background was fitted (dotted curves) like for the distributions in fig.4. Peaks are seen for the Λ_c^+ mass region in each spectrum. Thus, we observe the decay mode (2) of the charmed baryon Λ_c^+, which has been detected elsewhere [5].

The partial cross section is given by $\sigma\cdot B = NA/(N_A T M_n B_0 \xi)$, where N is the number of Λ_c^+ decays observed; A is the atomic number of the carbon nucleus; N_A is the Avogadro number; T is the target length; M_n is the neutron flux; B_0 is the decay ratio of $\bar{K}^\circ(\Lambda^\circ)$ observed; B is the decay ratio of Λ_c^+ observed; ξ is the detection efficiency of Λ_c^+ obtained by the Monte-Carlo simulation taking into account all experimental and data processing conditions. The Λ_c^+ decays (1) and (2) were simulated according to the phase space of four particles. The dashed line in fig.2 represents the beam momentum acceptance for Λ_c^+. The momentum of neutrons having produced Λ_c^+ registered is greater than 40 GeV/c (the mean value is about 58 GeV/c). The Λ_c^+ observed have the following transverse and longitudinal momentum ranges: $P_T \lesssim 1$ GeV/c and Feynman x-variable greater than 0.4. To estimate the partial cross section in the complete region ($x > 0$) we apply a variety of models for Λ_c^+ production in neut-

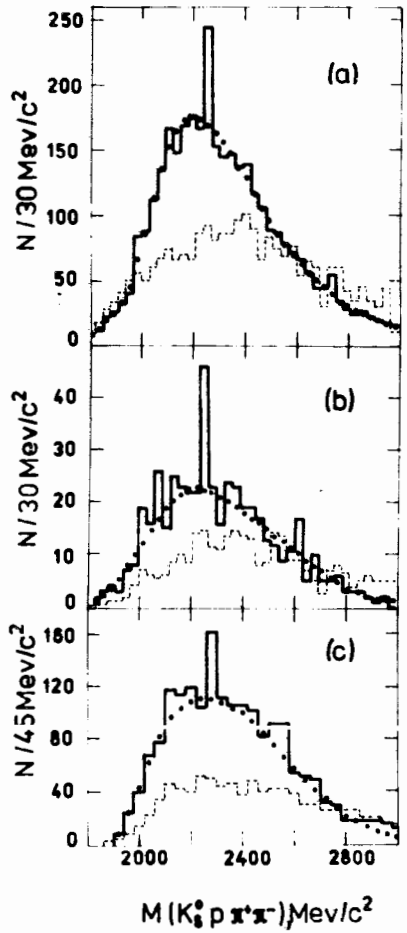

Fig.4. Invariant mass $M(K^0_s p\pi^+\pi^-)$ spectra for the events selected at the first (a), second (b) and third (c) configurations of the experiment (the dotted curves are the background fit); the dashed distributions are the invariant mass $M(K^0_s p\pi^-\pi^-)$ spectra.

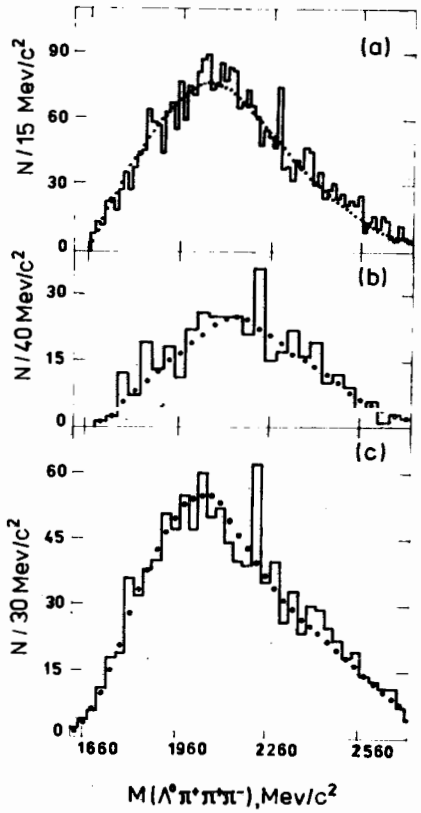

Fig.5. Invariant mass $M(\Lambda^0\pi^+\pi^+\pi^-)$ spectra for the events selected at the first (a), second (b) and third (c) configurations of the experiment; the dotted curves are the background fit.

ron-nucleon interactions. Some of them (A and B) imply the invariant inclusive cross section in the form:

$$Ed^3\sigma/dP^3 \sim \exp(-b \cdot P_T) \cdot f(x), \qquad (4)$$

where $f(x)$ is the x distribution function, which was varied, and $b = 2.5$ $(GeV/c)^{-1}$ /3/. The latter value is also in accordance with the experiment /6/.

The A model: $f(x)$ has the same shape as for inclusive production of Λ^0 hyperons by 69 GeV protons in pp interactions /7/. This should be expected from the quark model for hadron fragmentation /8/ and has been also confirmed by an ISR experiment /9/.

The B model: $f(x) = (1-x)^{1.5}$. The result obtained under this assumption can give us the upper limit for σB. The $f(x)$ spectrum is unlikely to be "softer". The latter is confirmed by some experimental /3,9/ and theoretical /10,11,12/ results.

The C model: the system R is produced by diffraction dissociation of neutrons on quasifree nucleons in the carbon nucleus according to the invariant cross section $Ed^3\sigma/dP^3 \sim 1/M_R^2 \cdot \exp(-\beta \cdot t)$, where M_R is the invariant mass of the R system, $\beta = (GeV/c)^{-2}$. The R system decays into $\Lambda_c^+ D^-$ with Gottfried-Jackson angle distributions as calculated in /13/ for the diffraction dissociation $p \to \Lambda^0 K^+$. Results close to this model are obtained for Λ_c^+ inclusive production using the cross section (4) with a flat distribution for $f(x)$ or calculated in /10,11/. If we assume a flat distribution of the Gottfried-Jackson angles, the value of σB is the same as in the A model.

In table 1 we summarize the numbers of Λ_c^+ decays (1) and (2) observed at the three configurations, the mean mass value $M(\Lambda_c^+)$ of Λ_c^+ obtained in our experiment and σB calculated under the assumptions of model A. We have estimated that the systematic error of $M(\Lambda_c^+)$ is ~12 Mev/c^2. The values of σB obtained at the three different configurations agree well within the errors (only statistical errors are shown). The systematic error of σB is mainly due to the error of the neutron beam flux and the momentum spectrum measurements. We estimate that this error does not exceed 45%.

In conclusion we summarize the results obtained. We have found 212 ± 25 Λ_c^+ baryons. Their average mass is 2266 MeV/c^2 with a systematic error of ~12 MeV/c^2. Our mass value is in good agreement with the values obtained in other experiments /14/.

The ratio of the branching ratios $B(\bar{K}^0 p\pi^+\pi^-)/B(\Lambda^0\pi^+\pi^+\pi^-)$ is 4.5 ± 1.0.

The partial cross sections σB for Λ_c^+ production by ~58 GeV neutrons on carbon calculated within the framework of the three models are presented in table 2. We consider as the most probable the results of the A model. We could not obtain lower values of σB than the results of the C model taking into account all considered models. Using the result of the C-model and the upper limit for the branching ratio of $B(\Lambda^0\pi^+\pi^+\pi^-) < 3.1\%$ (obtained from the Λ_c^+ data in /14/), we estimate the lower limit for the inclusive Λ_c^+ production cross section $\sigma > 100$ μb per carbon nucleus (90% confidence level).

Table 1

Features of the charmed baryon Λ_c^+ observed. The systematic errors of $M(\Lambda_c^+)$ are shown. The σB values are obtained using the A model (only statistical errors are shown)

Configuration	1	2	3	complete
	$\Lambda_c^+ \to \bar{K}^0 p\pi^+\pi^-$			
Number of events	79 ± 15	23 ± 7	48 ± 13	150 ± 21
$M(\Lambda_c^+)$, MeV/c^2	2255	2250	2283	2268± 15
σB, μb/nucleus	34 ± 6	40 ± 12	25 ± 7	31 ± 4
	$\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-$			
Number of events	25 ± 9	13 ± 6	24 ± 8	62 ± 13
$M(\Lambda_c^+)$, MeV/c^2	2278	2240	2244	2262± 20
σB, μb/nucleus	6 ± 2	10 ± 4	7 ± 2	6.9 ± 1.3

Table 2

Partial cross sections σB (μb per carbon nucleus) obtained under different assumptions of Λ_c^+ production. Only statistical errors are shown

Model	A $\exp(-2.5\cdot P_T)$ $f_{\nu^0}(x)$	B $\exp(-2.5\cdot P_T)$ $(1-x)^{1.5}$	C $1/M_R^2\cdot\exp(-6\cdot t)$
$B(\bar{K}^0 p\pi^+\pi^-)$	31± 4	93±13	12±2
$B(\Lambda^0\pi^+\pi^+\pi^-)$	6.9±1.3	21±5	3.5±1.0

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Рождение очарованных барионов Λ_c^+ в нейтрон-углеродных взаимодействиях при энергии нейтронов ~58 ГэВ

В реакции взаимодействия нейтронов со средней энергией около 58 ГэВ с ядрами углерода наблюдается рождение очарованных барионов Λ_c^+. Зарегистрированы их распады по каналам: $\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-$ и $\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-$. Произведения модельно-зависимого сечения рождения Λ_c^+ на вероятности его распадов по этим каналам равны соответственно 31 ± 4 и $6,9 \pm 1,3$ мкб/ядро углерода. Нижняя граница сечения инклюзивного ($x>0$) рождения Λ_c^+, полученная с учетом рассмотренных моделей, равна ~100 мкб на ядро углерода при 90%-ном уровне достоверности. Систематические ошибки составляют ~45%.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1982

Aleev A.N. et al. D1-82-895

Charmed Baryon Λ_c^+ Production by ~58 GeV Neutrons on Carbon

The production of the charmed baryon Λ_c^+ by ~58 GeV neutrons on carbon is observed. The decay modes detected are: $\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-$ and $\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-$. The model-dependent partial cross section times branching ratios are 31 ± 4 μb and 6.9 ± 1.3 μb per carbon nucleus, respectively. A lower limit for the inclusive cross section of Λ_c^+ production (taking into account all models considered) at $x > 0$ is found to be about 100 μb per carbon nucleus at a 90% confidence level. The systematic errors are ~45%.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1982