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A STUDY OF THE Λ_c^+ PRODUCED IN nC INTERACTIONS AT ~58 GeV

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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:

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

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

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 7.8 and 6. g/cm^2 carbon targets (T) were 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.

The results are based on the data obtained at 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. $5.3 \cdot 10^6$, $1.7 \cdot 10^6$, and $4.4 \cdot 10^6$ events were recorded at each of the configurations, respectively. These events corresponded to the integral neutron flux $M_n \cong 6 \cdot 10^{11}$ through the target.

We searched for inclusive Λ_c^+ production in the process

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

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

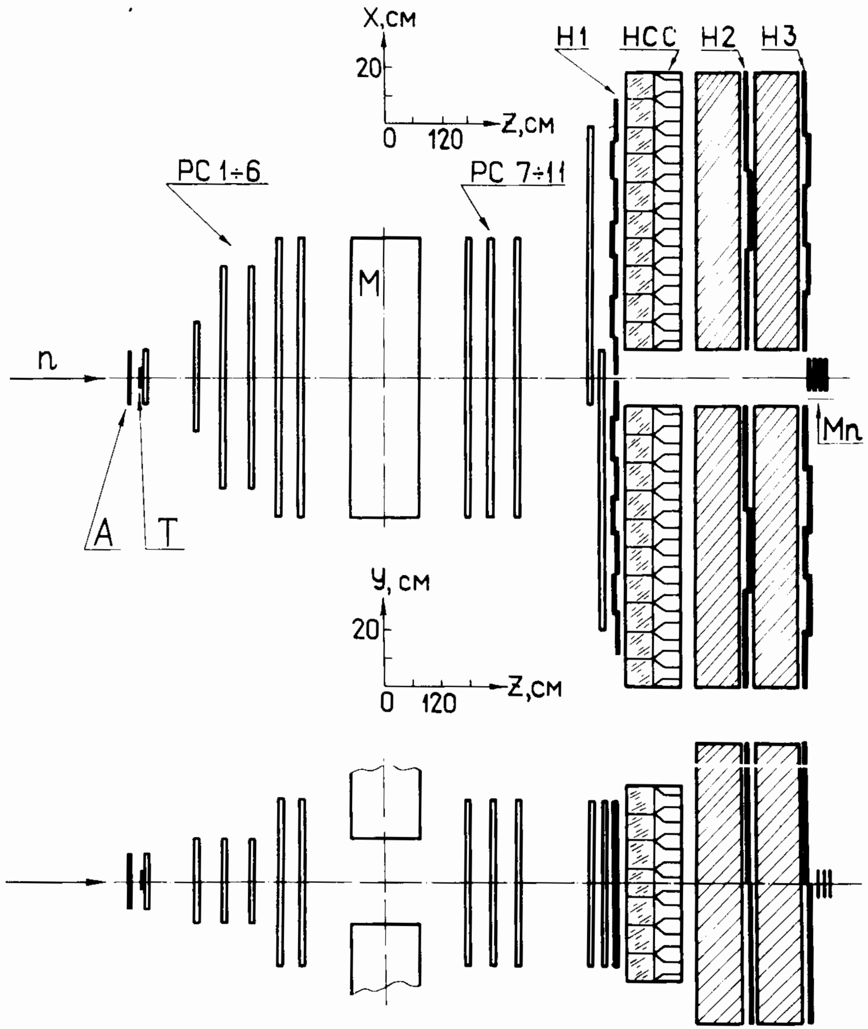

Fig.1. A scheme of the BIS-2 set up: M - magnet; PC - two-coordinate multiwire proportional chambers; A - scintillation anticoincidence counter; T - carbon target; H1 - scintillation hodoscope; M_n - neutron beam monitor; H2 and H3 - μ detector hodoscopes; HCC - lead glass walls. No information from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

more than 15 cm downstream the centre of the target. Figure 3 illustrates the "Vee" invariant mass spectra for K^o_S and Λ^o. We identified the "Vee", having the invariant mass of a two-

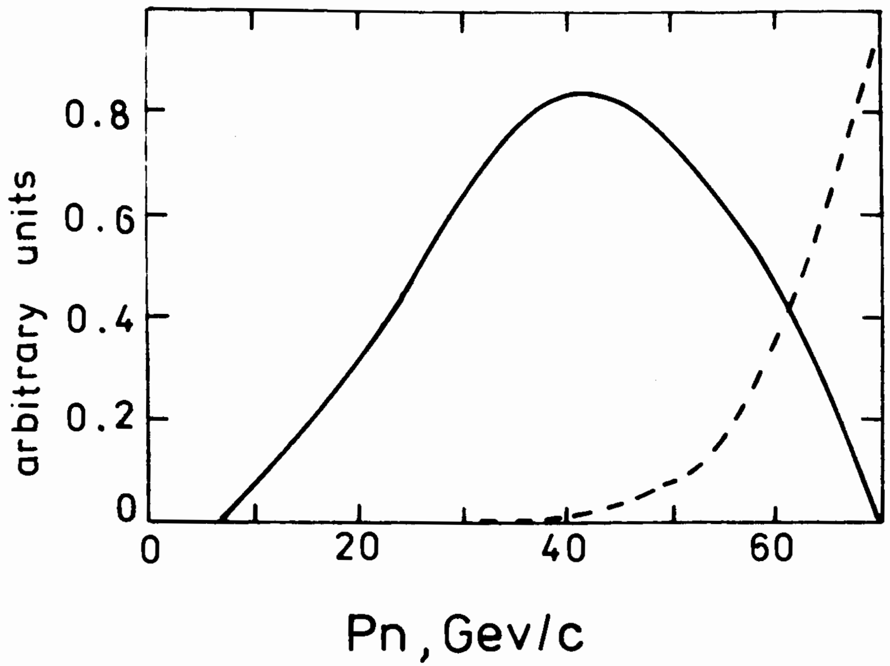

Fig.2. Neutron beam momentum spectrum (solid curve) and neutron momentum acceptance for Λ^+_c (dashed curve).

pion system $M(\pi^+\pi^-)$ with ± 10 MeV/c^2 from $M(K^o_S)$ = 497.67 MeV/c^2 with K^o_S, and the "Vee" having the invariant mass of a system of a proton and negative pion $M(p\pi^-)$ with ± 7 MeV/c^2 from $M(\Lambda^o)$ = 1115.6 MeV/c^2 with Λ^o.

We have selected events containing at least one $K^o_S h^+ h^+ h^-$ or $\Lambda^o h^+ h^+ h^-$ conbination. The $M(K^o_S p\pi^+\pi^-)$ invariant mass distribution for $K^o_S h^+ h^+ h^-$ combinations, assuming that the largest momentum of the positive particles belongs to the proton, is presented in fig.4a (solid line distribution). The width of the bins (= 20 MeV/c^2) was chosen equal to ~2 times the experimental resolution. Figure 4b (solid line distribution) presents the invariant mass $M(\Lambda^o\pi^+\pi^+\pi^-)$ distribution for $\Lambda^o h^+ h^+ h^-$ combinations. The width of the bins (= 30 MeV/c^2) is ~4 times the experimental resolution for this invariant mass. Explicit peaks are seen in both distributions in the mass region of the charmed baryon Λ^+_c. To estimate the number of events in the peaks a polynomial background, was fitted to these distributions (dotted distributions in fig.4). 130 ± 18 and 57 ± 14 events above the background correspond to ~10 and ~5 standard deviations. We consider these peaks as a baryon state with the width less than 30 MeV/c^2. If the observed baryon is a hyperon resonance,

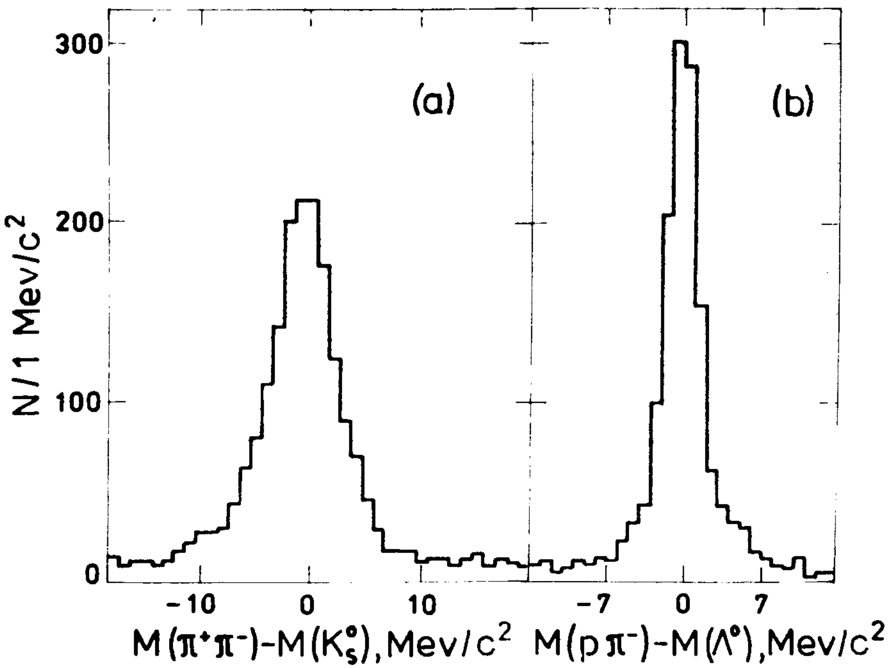

Fig.3. "Vees" invariant mass spectra illustrating K°_S and Λ° detection at the part of the statistics. (a) is the $M(\pi^+\pi^-)$ spectrum in a mass region around $M(K^\circ_S)$ = 497.67 MeV/c^2; (b) is the $M(p\pi^-)$ spectrum in a mass region around $M(\Lambda^\circ)$ = 1115.6 MeV/c^2.

in the neutron beam fragmentation region one could observe,with a higher probability,the isotopically conjugated negative state (as,for example,the production of the Σ^-(1385)[4]).But no significant peaks are seen in the invariant mass distributions for $K^\circ_S p\pi^-\pi^-$ and $\Lambda^\circ\pi^+\pi^-\pi^-$ systems selected similarly to $K^\circ_S p\pi^+\pi^-$ and $\Lambda^\circ\pi^+\pi^+\pi^-$ (the crossline distributions in fig.4). So, we are led to identify the observed peaks with the Cabibbo favoured charmed baryon Λ_c^+ decays (1) and (2). The latter decay mode has been detected elsewhere[5].

The partial cross section is given by $\sigma B = NA/(N_A T M_n B_0 \epsilon)$, 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; ϵ 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) simulated according to the phase space of four particles. The dashed line

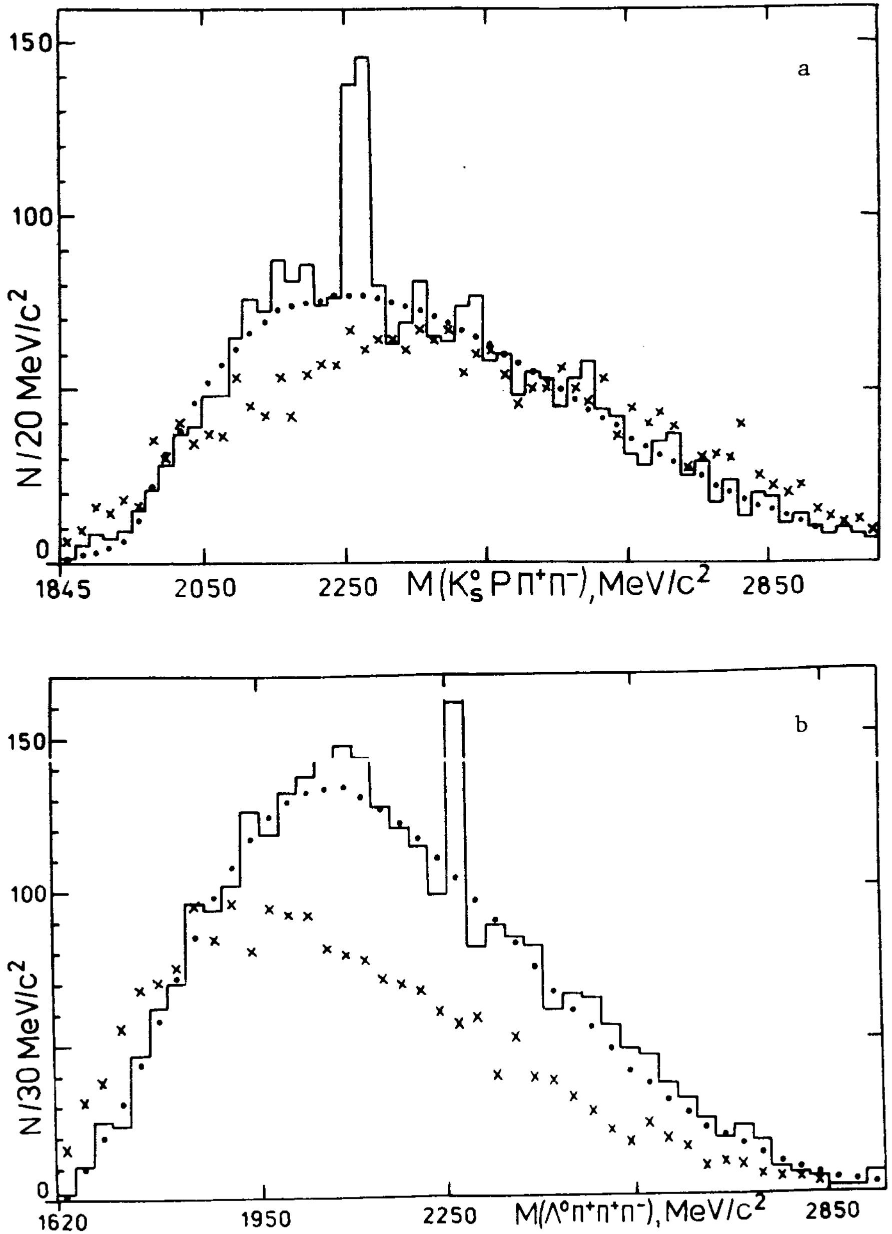

Fig.4. The invariant mass distributions: (a) for $K^\circ_S p\pi^+\pi^-$ (solid line) and $K^\circ_S p\pi^-\pi^-$ (cross-line) systems; (b) for $\Lambda^\circ\pi^+\pi^+\pi^-$ (solid line) and $\Lambda^\circ\pi^+\pi^-\pi^-$ (cross-line) systems. The dotted lines show the result of the polynomial fit to these distributions.

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: $P_\perp \leq 1$ GeV/c and Feynman x-variable greater than ~0.5.

We have obtained the partial cross section of Λ_c^+ production for $X_F > 0.5$ times the branching ratios of the decay (1) B_1

$$\sigma(X_F > 0.5) B_1 = (6.2 \pm 1.3)\mu b \quad \text{per carbon nucleus}$$

and of the decay (2) B_2

$$\sigma(X_F > 0.5) B_2 = (2.0 \pm 0.6)\mu b \quad \text{per carbon nucleus.}$$

To estimate the partial cross section in the complete region ($X_F > 0$) we apply a variety of models for Λ_c^+ production in neutron-nucleon interactions.

The A model imply the invariant inclusive cross section in the form:

$$E d^3\sigma / d\vec{p}^3 \sim \exp(-b \cdot P_\perp) \cdot f(X_F), \tag{4}$$

where $f(X_F)$ is the X_F distribution function and $b = 2.5 (\text{GeV/c})^{-1}$ /3/. The latter value is also in accordance with the experiment /6,2/. $f(X_F)$ has the same shape as for inclusive production of Λ° 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: the system R is produced by diffraction dissociation of neutrons on quasifree nucleons in the carbon nucleus according to the invariant cross section $E d^3\sigma / d\vec{p}^3 \sim 1/M_R^2 \cdot \exp(-\beta \cdot t)$, where M_R is the invariant mass of the R system, $\beta = 6 (\text{GeV/c})^{-2}$. The R system decays into $\Lambda_c^+ D^-$ with Gottfried-Jackson angle distributions as calculated in /10/ for the diffraction dissociation $p \to \Lambda^\circ K^+$.

Results close to the model B are obtained for Λ_c^+ inclusive production using the cross section (4) with a distribution for $f(X_F)$ calculated in /11-13/. If using the B model we assume a flat distribution of the Gottfried-Jackson angles, the value of $\sigma \cdot B$ is close to the same value in the A model.

The invariant production cross section for $X_F > 0.5$ is described by

$$E d^3\sigma / d\vec{p}^3 \sim (1 - X_F)^{(0.9 \pm 0.5)} \cdot \exp[-(2.5 \pm 0.6) \cdot P_\perp] \; .$$

In conclusion we summarize the results obtained. We have found ~190 Λ_c^+ baryons. Their average mass is (2266 ± 4) MeV/c^2. Our mass value is in good agreement with the values obtained in other experiments /14/.

The ratio of the branching ratios $B_1(\bar{K}^\circ p \pi^+ \pi^-)/B_2(\Lambda^\circ \pi^+ \pi^+ \pi^-)$ is 3.1 ± 1.0.

The partial cross sections $\sigma \cdot B$ for Λ_c^+ production by ~58 GeV neutrons on carbon for $X_F > 0.5$ and calculated for $X_F > 0$ within the framework of the models A and B are presented in the table. The possible systematic errors of $\sigma \cdot B$ are mainly due to the error of the momentum spectrum measurements. We estimate that this error does not exceed 35%. We could not obtain values of $\sigma \cdot B$ lower than the results of the B-model taking into account all considered models. Using the result of the B-model and the upper limit for the branching ratio of $B_2(\Lambda^\circ \pi^+ \pi^+ \pi^-)$ 3.1% /14/ (90% confidence level), we estimate the inclusive production cross section $\sigma \geq (70 \pm 20)$ μb per carbon nucleus for $X_F > 0$.

Table

Partial cross sections of Λ_c^+ production times branching ratios $\sigma \cdot B$ (per carbon nucleus)

$\sigma \cdot B$, μb per carbon nucleus			
Decay	$X_F > 0.5$	$X_F > 0$	
		model A	model B
$\bar{K}^\circ p \pi^+ \pi^-$	6.2 ± 1.3	18.3 ± 3.7	6.7 ± 1.4
$\Lambda^\circ \pi^+ \pi^+ \pi^-$	2.0 ± 0.6	6.0 ± 2.0	2.2 ± 0.7

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Алеев А.Н. и др. E1-83-417

Изучение Λ_c^+, рожденных в nC взаимодействиях при ~58 ГэВ

Наблюдается рождение очарованного бариона Λ_c^+ в процессе $n + C \to \Lambda_c^+ + \ldots$ Эксперимент выполнен в нейтронном пучке серпуховского ускорителя с помощью спектрометра БИС-2. В распределениях по эффективным массам систем $K_S^\circ p\pi^+\pi^-$ и $\Lambda^\circ\pi^+\pi^+\pi^-$ около значения массы 2270 МэВ/c^2 наблюдаются узкие пики 10 и 5 стандартных отклонений от уровня фона соответственно. Найдено, что масса $M(\Lambda_c^+) = 2266 \pm 4$ МэВ/c^2. Произведения сечения рождения на вероятность распада по наблюденным каналам, определенные для $X_F > 0,5$, равны /6,2±1,3/ и /2,0±0,6/ мб на ядро углерода соответственно, а их отношение равно 3,1±1,0. Инвариантное сечение рождения Λ_c^+ описывается выражением:

$$E\frac{d^2\sigma}{P_\perp dp_\perp dp_\parallel} \sim (1-X_F)^{(0.9\pm0.5)} \exp[(-2.5\pm0.6)P_\perp].$$

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A Study of the Λ_c^+ Produced in nC Interactions at ~58 GeV

The production of the charm baryon Λ_c^+ has been observed in the reaction $n + C \to \Lambda_c^+ + \ldots$ The experiment has been performed in a neutron beam of the Serpukhov accelerator, using the spectrometer BIS-2. The effective mass distributions of the $(K_S^\circ p\pi^+\pi^-)$ and $(\Lambda^\circ\pi^+\pi^+\pi^-)$ systems show a narrow peak of ~10 and ~5 standard deviations above the background level, respectively, at an average mass value $M(\Lambda_c^+) = 2266 \pm 4$ MeV/c^2. The cross sections times the branching ratios measured for $X_F > 0.5$, for each Λ_c^+ decay channel, are equal to (6.2±1.3) and (2.0±0.6) μb per carbon nucleus, respectively, and their ratio is 3.1±1.0. The invariant production cross section for $X_F > 0.5$ is described by:

$$E\frac{d^3\sigma}{d\vec{p}^3} \sim (1 - X_F)^{(0.9\pm0.5)} \cdot \exp[-(2.5\pm0.6)P_\perp].$$

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

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