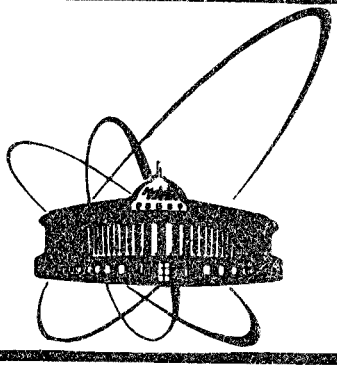

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E1-82-759

THE STUDY OF Λ_c^+ CHARM BARYON PRODUCTION IN ~58 GeV NEUTRON BEAM

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

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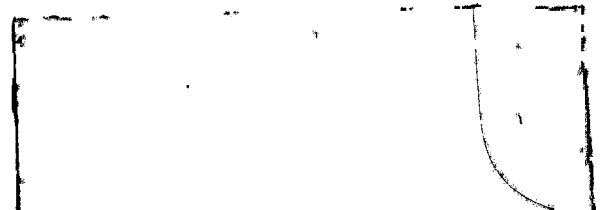

A search and a study of charm baryons Λ_c^+ in neutron carbon interactions at the Serpukhov accelerator [1,2] has prolonged using the spectrometer BIS-2 [2,3]. Seconrady charged particles are mainly registered from the fragmentation region of the neutron beam.

Narrow peaks have been observed in the effective mass spectra of $K_s^0 p\pi^+\pi^-$, $K_s^0 \to \pi^+\pi^-$ and $\Lambda^0\pi^+\pi^+\pi^-$ in the range of the charm baryon $\Lambda_c^+(2275)$ mass. The signal is about ten and four standard deviations, respectively. The partial cross sections are respectively $\sigma \cdot B(\Lambda_c^+ \to \bar{K}^0 p\pi^+\pi^-) = (33.5 \pm 5.2)$ and $\sigma \cdot B(\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-) = (4.5 \pm 1.1)\ \mu$b per carbon nucleus using the diffractive model for charm baryon production. Their ratio is 7.4 ± 2.2. Studying the invariant momentum distributions of Λ_c^+, we have used the approximations of the type $\exp[(-2.7 \pm 0.7) \cdot P_\perp]$ and $(1-X)^{(1.5 \pm 0.4)}$, where $P_\perp$ is the Λ_c^+ transverse momentum in GeV/c and $X = P_\parallel^*/P_{max}^*$ (here $P_\parallel^*$ and P_{max}^* are respectively the longitudinal and maximum longitudinal momenta of Λ_c^+ in the CMS of the incident neutron and the quasi-free nucleon of the carbon nucleus).

First results of the experiment have been published elsewhere [2].

1. BIS-2 SET-UP AND EXPERIMENTAL CONDITIONS

The BIS-2 spectrometer is placed on a neutral particle channel of the proton synchrotron at Serpukhov [4]. The angle of the channel is 11.3 mrad relative to the proton beam of the accelerator. The beam passes through a lead gamma-filter 10 cm thick, a cleaning magnet and a system of collimators. It consists mainly of neutrons with a small contamination of K_L^0 mesons (~1.5%) and charged particles (~2.5%). The maximum of the momentum spectrum of incident neutrons is about 40 GeV, and its spread is from 10 up to 70 GeV/c, but the useful energy range for the experiment is only above 40 GeV. A layout of the set-up is illustrated in Fig. 1. The magnetic field in MC changes the transversal component of the charged particle momentum by a value of 0.64 GeV/c. The spectrometer operates on-line with an EC-1040 computer.

To trigger the set-up, four charged particles passing through the spectrometer were required. Trigger conditions were

1. $(PC1 \text{ or } T)_{n\geq 1} \cdot (PC2)_{n\geq 2} \cdot (PC6)_{n\geq 3} \cdot (PC8)_{n\geq 4} \cdot (PC10+PC11)_{n\geq 4} (H1)_{n\geq 3} / A$, where n is the number of hitted regions in PC or H1 .

2. The hits of charged particles have to be presented simultaneously in PC10+PC11 and H1 , on the left and right from the axis of the spectrometer.

The kinematical region of registered charm baryons is mainly limited to the values of $P_\perp \lesssim 1$ GeV/c and $P_\parallel \geq 25$ GeV/c. The latter condition affects the fact that Λ_c^+ , produced by neutrons on the quasi-free nucleon of the carbon nucleus with energy lower than about 40 GeV or with $X \lesssim 0.4$, cannot be detected.

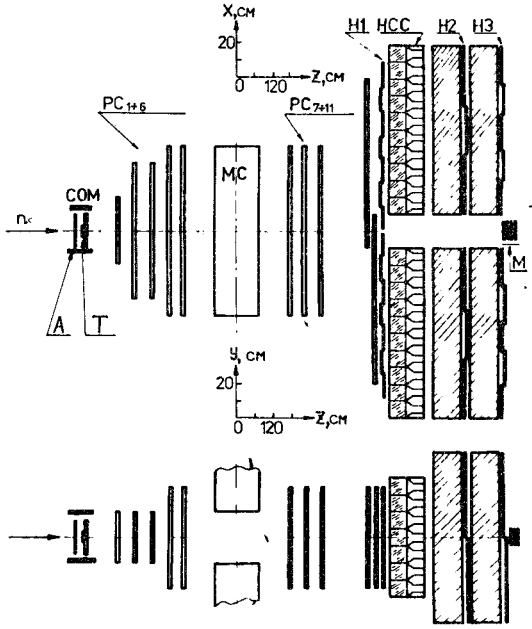

Fig.1. A scheme of the BIS-2 set-up on the neutron beam of the Serpukhov accelerator: A - scintillation counter; T - target, COM-counters surrounding the target, PC -two-coordinate multiwire proportional chambers, MC - spectrometric magnet, H - scintillation hodoscopes, HCC - lead glass walls, M - beam neutron monitor.

Our total statistics is about $25 \cdot 10^6$ events of neutron-carbon interactions, but we have used only about 40% of all events. The statistics has been obtained for two configurations which are different in the polarity of the magnetic field in MC , targets T and some geometric conditions of the set-up. This has been done in order to estimate possible systematic errors of the effective mass spectrum.

2. DATA ANALYSIS

Two independent programs of geometrical reconstruction were used to reconstruct the trajectories of charged particles[5]. The geometrical and kinematical characteristics of the particles were found, and the candidates for K_s° and Λ° sample were chosen according to their vertex position in the decay volume (between the target and PC4). Performing a statistical analysis of the data, we obtained the selection criteria for more complicated (multiparticle) events. In the data analysis the table mass was assigned to each of the charged particles.

We found sharp peaks in the effective mass spectra of $\pi^+\pi^-$ and $p\pi^-$ combinations in the range of K_s° and Λ° masses. The events from the interval of masses (488 ÷ 508) and (1108 ÷ 1123) MeV/c^2 were classified as K_s° and Λ°, respectively. This corresponds approximately to three full-widths of the observed peaks.

3. OBSERVATION OF NARROW PEAKS IN THE $K_s^\circ p\pi^+\pi^-$ AND $\Lambda^\circ\pi^+\pi^+\pi^-$. EFFECTIVE MASS SPECTRA

A total of $5.3 \cdot 10^6$ triggers were used in the first run. The corresponding beam flux of $1.85 \cdot 10^{11}$ neutrons was detected in the neutron monitor, and that of $2.52 \cdot 10^{11}$ was estimated using Monte-Carlo normalized to the total neutron-carbon cross section. Finally we used a value of $2.2 \cdot 10^{11}$ neutrons with a possible systematic error of 20%.

A total of 2379 events of $K_s^\circ h^+h^+h^-$ and 1814 events of $K_s^\circ h^+h^-h^-$ combinations were found. Here $h^\pm$ means charged particles with a given charge. The effective mass spectra were reconstructed under the assumption that h^+ is a proton and other h^- are pions.

As was shown[2], there was a sharp narrow peak in the effective mass spectrum of the combinations with the total positive charge. It coorresponds to six standard deviations from the background level in a mass range of 2260 MeV/c^2 . On the contrary, in the mass spectrum of the combinations, having the total negative charge, no significant peak was seen. Figure 2 shows[2] the case of positive combinations, in which the positive particle with larger (Fig. 2a) and smaller (fig. 2b) momentum was classified as a proton. In the latter spectrum one cannot see any significant maximum compared to Fig. 2a, where a narrow peak is in a mass interval of 2240 - 2270 MeV/c^2 . There are 244 combinations from 224 events, and the peak contains 83 combinations upon 161 backgrouns combinations. The average peak mass is (2259±15) MeV/c^2 .

In a further analysis of the real and simulated data, the following kinematical criteria, depressing the background level, were supplemented:

1. The projection of the proton momentum in the rest system of $\bar{K}^\circ p\pi^+\pi^-$ onto the neutron beam direction should have a negative value and, in contrast, a positive value for the positive pion. This criterion is mainly in agreement with the conditions of the experiment and, in practice, it is similar to the criterion $1 < P_p/P_{\pi^+} < 2.3$ used in the laboratory system.

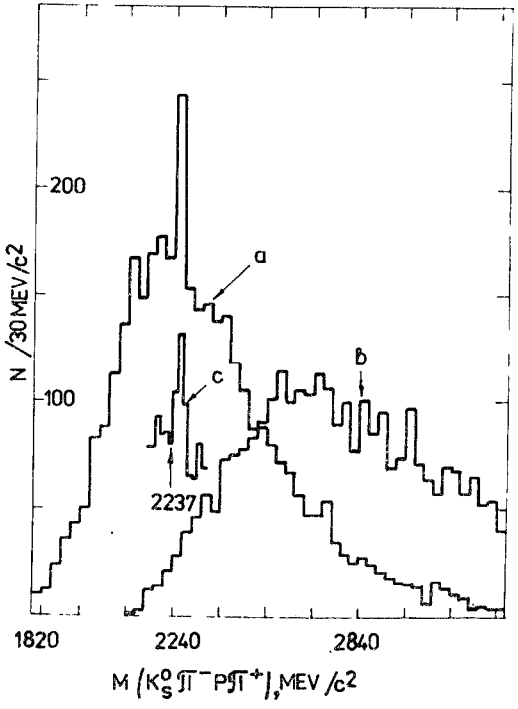

Fig. 2. The effective mass spectrum of $K^{\circ}_{s}p\pi^{+}\pi^{-}(K^{\circ}_{s}\to\pi^{+}\pi^{-})$ combinations (first run): a) the case, when the positive particle with greater momentum is classified as proton, b) the case, when the positive particle with smaller momentum is classifies as proton, c) the same case as a) but the binning is 15 MeV/c^2.

2. The solid angle between the proton and both pions should be greater than 3.14 ster. The criterion is independent of the geometrical conditions. It is probably close to the production and decay characteristics of Λ^{+}_{c}.

Figure 3 illustrates the spectrum of $K^{\circ}_{s}p\pi^{+}\pi^{-}$ reconstructed under these supplementary criteria. A sharp peak contains 68 events upon 68 backgrouns combinations. Comparing Figs. 2a and 3a, one can see the backgorunds depressing the power of the above criteria. The average Λ^{+}_{c} mass is (2258±15) MeV/c^2.

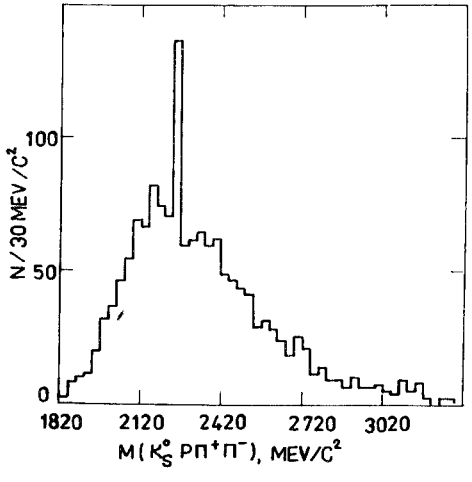

Fig. 3. The effective mass spectrum of $K^{\circ}_{s}p\pi^{+}\pi^{-}$ combinations (first run) using the kinematical selection criteria (see text).

In order to select $\Lambda^{+}_{c}\to\Lambda^{\circ}\pi^{+}\pi^{+}\pi^{-}$ events, conventional geometrical criteria were used together with the criterion No. 2. This means that only the events were selected, in which the solid angle between the momenta of Λ° and two positive pions in the rest system of $\Lambda^{\circ}\pi^{+}\pi^{+}\pi^{-}$ was greater than 3.5 ster.

Figure 4 shows the effective mass spectrum of $\Lambda^{\circ}\pi^{+}\pi^{+}\pi^{-}$ reconstructed under this condition. A narrow peak at a mass of (2277.5±7.5) MeV/c^2 contains (21±5) events. Again, there is no significant peak in the Λ^{+}_{c} region in the mass spectrum of $\Lambda^{\circ}\pi^{+}\pi^{-}\pi^{-}$ events reconstructed under similar criteria.

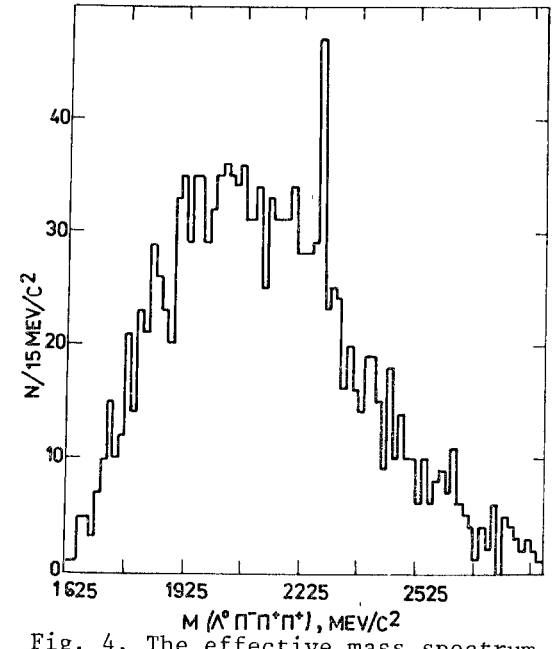

Fig. 4. The effective mass spectrum of $\Lambda^{\circ}\pi^{+}\pi^{+}\pi^{-}$ combinations.

About 4.6 millions of triggers were used in the recent analysis of the second run. Selecting the events, the same kinematical criteria were used as in the first run, and the geometrical criteria were changed in correspondence to the experimental conditions of the run. Figure 5 shows the effective mass spectrum of the $K^{\circ}_{s}p\pi^{+}\pi^{-}$ system. The sharp narrow peak of (51±9) events corresponds to a Λ^{+}_{c} mass of (2288±17) MeV/c^2. The average mass, using both runs, is (2275±6) MeV/c^2. This value is in accordance with the average Λ^{+}_{c} mass given in paper [6].

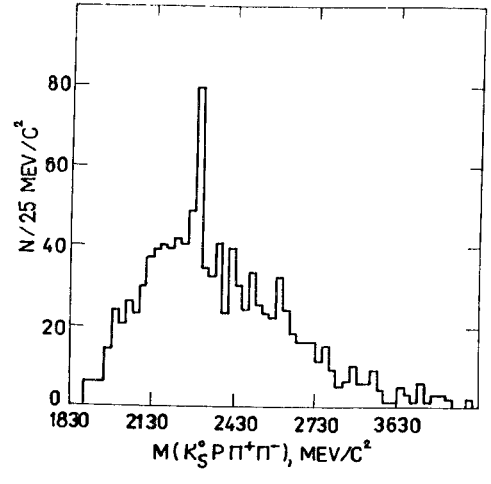

Fig. 5. The effective mass spectrum of $K^{\circ}_{s}p\pi^{+}\pi^{-}$ combinations (second run) using the kinematical selection criteria (see text).

4. ESTIMATION OF THE PARTIAL CROSS SECTIONS, RELATIVE BRANCHING RATIOS AND MOMENTUM DISTRIBUTION APPROXIMATION

To estimate the partial cross section $\sigma(nC \to \Lambda_c^+ + X) \cdot B(\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-)$ and $\sigma(nC \to \Lambda_c^+ + X) \cdot B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-)$, the data of only the first run were used. Two independent Monte-Carlo calculations of the Λ_c^+ production process, where Λ_c^+ is expected to have a large relative longitudinal momentum, were performed: a) Diffractive production of the system $R \to \Lambda_c^+ D^-$ induced by neutrons on quasi-free nucleons of the carbon nucleus: $d^2\sigma/(dt \cdot dM^2) \sim 1/M^2 \cdot \exp(\beta t)$, where M is the mass of system R, t is the neutron momentum transfer squared to R and $\beta = 6\ (GeV/c)^2$. The R, Λ_c^+, D^- were supposed to decay isotropically according to the phase-space. b) The X distribution of Λ_c^+ production was supposed to be the same as for Λ^0 /7/, and the transverse momentum distribution is $d\sigma/dP_\perp^2 \sim \exp(-3.1 P_\perp^2)$. The momentum and energy conservation laws were taken into account. A similar assumption as in case a) was used for the decay of Λ_c^+.

To calculate the registration efficiency of Λ_c^+, we took into account: the neutron beam momentum distribution, the geometry of the set-up, the Coulomb scattering in the spectrometer, the detection efficiency of the proportional chambers, the decay of particles in the spectrometer, the trigger conditions and the efficiency of all off-line programs used in our analysis.

The results of both calculations were in good agreement. We used an average efficiency of $\sim 1 \cdot 10^{-4}$ with a systematic error of about 30%.

The partial cross sections are given using the relation:

$$\sigma \cdot B = A \cdot N / (T \cdot N_A \cdot M_n \cdot \epsilon \cdot B_1), \qquad (1)$$

where A is the atomic number of carbon, N is the number of Λ_c^+ events observed in our experiment, T is the target thickness in g/cm^2, N_A is the Avogadro number, ϵ is the total registration efficiency of Λ_c^+, M_n is the total neutron beam flux, and B_1 are the partial widths of $\bar{K}^0 \to K_S^0 \to \pi^+\pi^-$ or $\Lambda^0 \to p\pi^-$ decays.

The estimated values of the partial cross sections are: $\sigma \cdot B(\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-) = (33.5 \pm 5.2)$ and $\sigma \cdot B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-) = (4.5 \pm 1.1)\ \mu b$ per carbon nucleus with a possible systematic error of 50%. The ratio of $B(\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-)$ to $B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-)$ is 7.4±2.2.

Assuming that $B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-) = (1 \div 2)\%$ /6,8/, the inclusive cross sections of Λ_c^+ production in neutron-carbon interactions at an average effective neutron energy of (58±2) GeV are (100÷36) and (44÷16) μb per nucleon for $A^{2/3}$ and A dependences, respectively. The systematic error is about 50%.

The following approximations of the invariant momentum spectra were used: $1/P_\perp \cdot dN/dP_\perp \sim \exp(-bP_\perp)$ and $F(P_\parallel) \sim \int (1-X)^k \cdot W(S)\, dS$,

where W(S) is the neutron spectrum versus the energy squared in the CMS(nN). It was found that $b = 2.7 \pm 0.7$ and $k = 1.5 \pm 0.4$ ($P_\perp$ is in GeV/c).

In conclusion we report here on the first observation of the open-charm particle Λ_c^+ at the Serpukhov accelerator in nC interactions at an average neutron effective energy of 58 GeV. The decays observed are: $\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-$ (21 events) and $\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-$ (134 events).

The average Λ_c^+ mass is (2275±6) MeV/c^2.

The ratio of branching ratio $B(\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-)/B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-)$ is 7.4±2.2. The decays Λ_c^+ include the contributions of possible resonant states as $\bar{K}^0 \pi^+ \Lambda^0$, $K^{*-} p \pi^+$, etc.

The partial cross sections $\sigma \cdot B(\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-) = (33.5 \pm 5.2)$ and $\sigma \cdot B(\Lambda_c^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-) = (4.5 \pm 1.1)\ \mu b$ per carbon nucleus have been estimated. Using the last value and calculating the Λ_c^+ partial cross section per nucleon, one can see that the value is comparable to the one of papers /8/ studying the Λ_c^+ diffractive production on ISR.

The Λ_c^+ invariant perpendicular and longitudinal momenta distributions have been fitted by $\exp[(-2.7 \pm 0.7) P_\perp]$ and $(1-X)^{1.5 \pm 0.4}$, respectively. The parameters found are close to the values of paper /9/ from ISR.

The values of our cross sections seem to be in reasonable agreements with the model /10/.

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Исследование очарованных барионов Λ_c^+, рожденных в нейтрон-углеродных взаимодействиях при ~ 58 ГэВ

Приводятся новые результаты исследования очарованных барионов Λ_c^+, рожденных нейтронами на ядрах углерода. Эксперимент выполнен с помощью спектрометра БИС-2, действующего на серпуховском ускорителе. Обнаружено рождение Λ_c^+, распадающихся по каналам $\bar{K}^0 p \pi^+\pi^-$ и $\Lambda^0\pi^+\pi^+\pi^-$. Найдено, что масса $M(\Lambda_c^+) = (2275 \pm 6)$ МэВ/c^2. Модельно зависимые произведения сечений взаимодействия на вероятность распада по изучаемым каналам равны $(33,5 \pm 5,2)$ мкб и $(4,5 \pm 1,1)$ мкб на ядро углерода соответственно, а их отношение равно $7,4 \pm 2,2$. Инвариантные импульсные распределения аппроксимируются функциями $\exp(-(2,7 \pm 0,7)P_\perp)$ и $(1-X)^{1,5 \pm 0,4}$.

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Препринт Объединенного института ядерных исследований. Дубна 1982

Aleev A.N. et al. E1-82-759

The Study of Λ_c^+ Charm Baryon Production in ~58 GeV Neutron Beam

The production of charm baryons Λ_c^+ has been observed using the spectrometer BIS-2 on a neutron beam of the Serpukhov accelerator. The charm baryons decay into $\bar{K}^0 p \pi^+\pi^-$ and $\Lambda^0\pi^+\pi^+\pi^-$ with confidence levels of ~10 and ~ 4 standard deviations from background, respectively. The average mass $M(\Lambda_c^+) = (2275 \pm 6)$ MeV/c^2. The estimates of the partial cross sections are, respectively, $(33.5 \pm 5.2)\mu$b and $(4.5 \pm 1.1)\mu$b per carbon nucleus, and their ratio is (7.4 ± 2.2). The invariant momentum distributions have been approximated by the functions of the type $\exp(-bP_\perp)$ and $(1-X)^k$, where $b = 2.7 \pm 0.7$ and $k = 1.5 \pm 0.4$ ($P_\perp$ is in GeV/c).

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1982