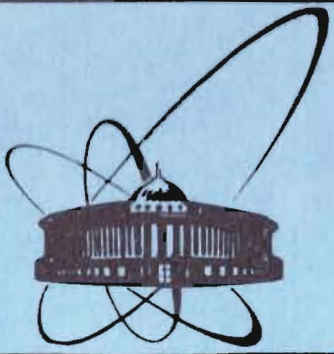

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E1-85-662

OBSERVATION OF $\bar{D}$-MESONS IN nC INTERACTIONS AT 40-70 GeV/c

BIS-2 Collaboration

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In this paper we report on the observation of $\bar{D}^0$ and D^- mesons produced in nC interactions at 40-70 GeV/c. Our result is the first direct observation of $\bar{D}$ mesons in hadronic processes at such low energies *).

We have already published the results on Λ_c^+ production detected via the decay modes $\Lambda_c^+ \to \bar{K}^0 p \pi^+ \pi^-$ and $\Lambda_c^+ \to \Lambda \pi^+ \pi^+ \pi^-$ /1/. Continuing the analysis of the same data sample we looked for signals of $D/\bar{D}$ mesons in the invariant mass spectra $M(K^0_S + m\pi)$ with $m = 1,2,3$. The channels with decays into $K(890)$, $K(1430)$ and $\varrho(770)$ were analysed as well. Significant signals of $\bar{D}$ mesons were observed in the mass spectra $M(K^+(890)\pi^-)$ and $M(K^+(890)\pi^-\pi^-)$. No indication of charge conjugated D^0 and D^+ mesons was found. The acceptance of the spectrometer allows one to detect $\bar{D}$ mesons in the kinematical region $x > 0.5$, where $x = p^*_L/p^*_{max}$ is the longitudinal fractional momentum in the center of mass system.

The experiment was performed with the spectrometer BIS-2 located in the neutral beam line 4N of the Serpukhov accelerator.

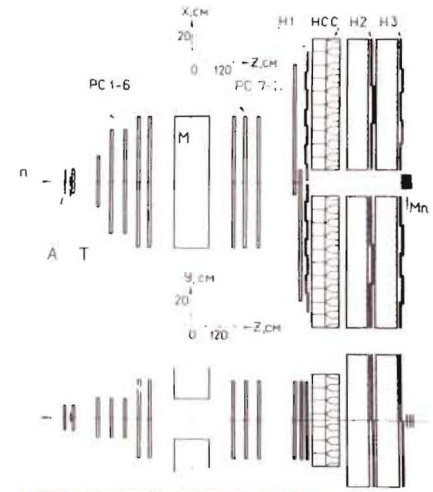


Fig.1. Schematic layout of the BIS-2 spectrometer: A - anticoincidence counter, T - carbon target, PC - multiwire proportional chambers, M - magnet, H1,2,3 - scintillation hodoscopes, HCC - lead glass Cherenkov counters, M_n - neutron beam monitor.

*) Short lived particles produced in hadronic interactions at 50-60 GeV/c have been seen in the emulsion experiment /9/.

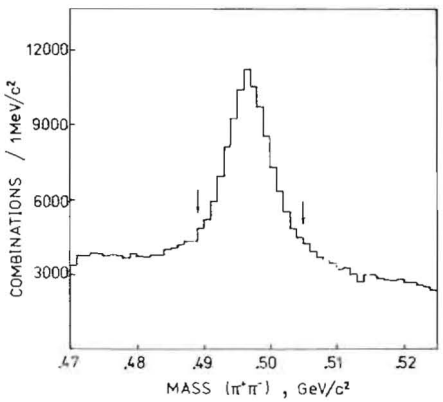


Fig.2. Invariant mass spectrum $M(\pi^+\pi^-)$ of K^o_s candidates.

The spectrometer is depicted in fig.1. It consists of multiwire proportional chambers and other detectors in front of and behind the momentum analyzing magnet. The trigger conditions required four or more charged particles detected behind the magnet. For three different spectrometer configurations (target position and length, position of MWPCs, magnetic field polarity) 11.4×10^6 events were recorded corresponding to an integral luminosity of $(1.9 \pm 0.5) \times 10^{35}$ cm^{-2}. The mean beam momentum for the detected $\bar{D}$ mesons is about 60 GeV/c. A more detailed description of the spectrometer BIS-2 and the experimental conditions is given elsewhere /2/.

The spectrometer had no detector for identification of hadrons and all charged particles were assumed to be pions. The K^o_s was identified by the decays into two charged pions. The invariant mass spectrum $M(\pi^+\pi^-)$ of all K^o_s candidates is shown in fig.2. For a further analysis 119000 K^o_s candidates from a mass interval 489 MeV/c^2 to 505 MeV/c^2 were selected.

First, the production of $D/\bar{D}$ was searched for in the decay modes $D^\pm \to \bar{K}^o \pi^\pm$, $\bar{D}^o \to \bar{K}^o \pi^+\pi^-$ and $D^\pm \to \bar{K}^o \pi^+\pi^-\pi^\pm$. The mass spectra $M(K^o_s \pi^\pm)$ contain only a few events in the $D/\bar{D}$ mass region because the detection efficiency is small. The mass spectra $M(K^o_s \pi^+\pi^-)$ and $M(K^o_s \pi^+\pi^-\pi^\pm)$ are shown in fig.3. No signals are seen in the $D/\bar{D}$ mass region.

Next we analyzed the $D/\bar{D}$ decay modes into $K^\pm(890)$ and pions. The $K^\pm(890)$ are defined by $(K^o_s \pi^\pm)$ combinations with invariant mass from 840 MeV/c^2 to 940 MeV/c^2. The mass spectrum $M(K^o_s \pi^+)$ with a signal of about 4000 $K^+(890)$ is plotted in fig.4. A similar mass spectrum was obtained for $M(K^o_s \pi^-)$. The mass spectra $M(K^+(890)\pi^-)$ and $M(K^+(890)\pi^-\pi^-)$ are shown in fig.5. Clear peaks of (21 ± 6) and (32 ± 7) combinations are visible in the $\bar{D}^o$ and D^- mass regions, respectively. The solid lines in fig.5 are the fits parame-

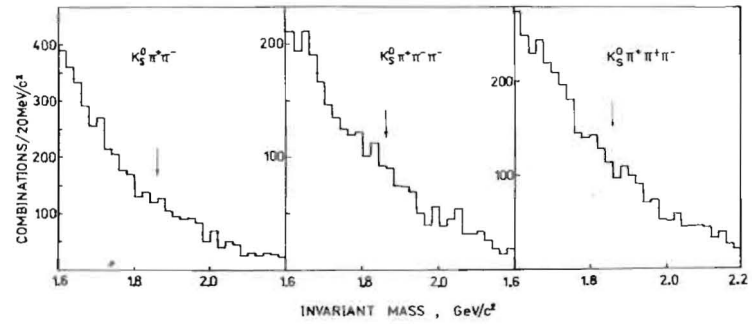


Fig.3. Invariant mass spectra $M(K^o_s \pi^+\pi^-)$ and $M(K^o_s \pi^+\pi^-\pi^\pm)$. The arrows show the expected location of the $D/\bar{D}$ signals.

trizing the mass spectra by an exponential background and a Gaussian. The central mass values of the peaks, $M_{\bar{D}^o} = (1867 \pm 7)$ MeV/c^2 and $M_{D^-} = (1871 \pm 7)$ MeV/c^2, are in good agreement with the masses of the charmed mesons $\bar{D}^o$ and D^- /3/. The widths of the peaks, $\Gamma_{\bar{D}^o} = (34 \pm 12)$ MeV/c^2 and $\Gamma_{D^-} = (40 \pm 12)$ MeV/c^2, are compatible with the expected mass resolution. For mass scale calibration the position of the $K^+(890)$ signal was used. The mass values and narrow widths of the peaks allow one to conclude that the observed signals arise from weak decays of the charmed mesons $\bar{D}^o$ and D^-. The same arguments exclude an interpretation of the signals as a K^* resonance. The observed signals of $\bar{D}^o$ and D^- have a statistical significance of 5 and 7 standard deviations, respectively. The combination-to-event ratios in the $\bar{D}^o$ and D^- mass intervals are 1.2 and 1.4, respectively.

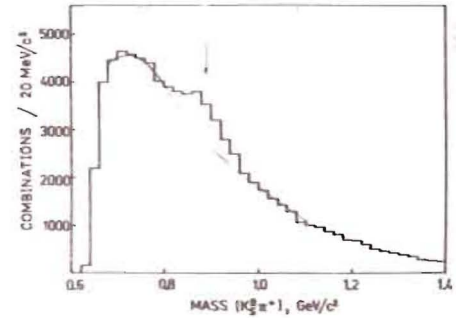


Fig.4. Invariant mass spectrum $M(K^o_s \pi^+)$.

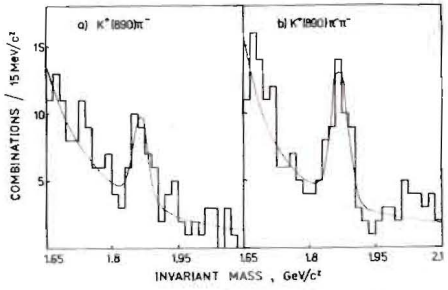


Fig.5. Invariant mass spectra $M(K^+(890)\pi^-)$ and $M(K^+(890)\pi^-\pi^-)$ showing the signals of $\bar{D}^0$ and D^- mesons.

No signals of the charge conjugated states of D^0 and D^+ decaying into $K^-(890)$ are observed. The mass spectra $M(K^-(890)\pi^+)$ and $M(K^-(890)\pi^+\pi^+)$ are shown in fig.6. We have also analyzed the $D/\bar{D}$ decay modes into $K(1430)$ and $\varrho(770)$ but have not found any indication of a $D/\bar{D}$ signal.

The absence of any D signal has to be interpreted by charm production properties. As mentioned above, the same data sample exhibits a strong signal of the charmed baryon Λ_c^+. Neglecting $\Lambda_c^+\,\bar{\Lambda}_c^+$ pair production, the observed Λ_c^+ baryons have to be accompanied by $\bar{D}$ mesons. Another argument in favour of the more abundant production of $\bar{D}$ in comparison with D mesons in the beam fragmentation region is based on the quark structure of these particles. The $\bar{D}$ mesons have one valence quark in common with the beam particle and can be produced in the forward direction whereas D mesons and the beam particle have no common valence quark.

For an estimation of cross sections the detection efficiency was determined using Monte-Carlo techniques. The simulation included the momentum distribution of the neutron beam, geometrical apertures, trigger conditions, chamber inefficiency, decay of particles in the spectrometer, multiple scattering, and reconstruction efficiencies. Two different models were considered: the diffractive production of a $\bar{D}\,\Lambda_c^+$ system and the inclusive production of $\bar{D}$ mesons with the further assumption that the Λ_c^+ is produced with a mean gap of

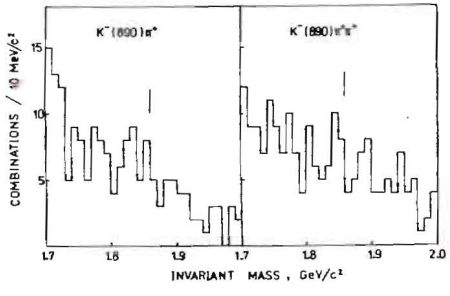


Fig.6. Invariant mass spectra $M(K^-(890)\pi^+)$ and $M(K^-(890)\pi^+\pi^+)$ in the D^0/D^+ mass region.

1.5 rapidity units relative to the $\bar{D}$. The diffractive cross section was assumed to follow the law: $d^2\sigma/dM^2dt \propto 1/M^2 \cdot \exp(-6t)$, where M is the mass of the $\bar{D}\,\Lambda_c^+$ system and t is the squared momentum transfer. The inclusive $\bar{D}$ cross section was parametrized as follows: $E/\sqrt{s}\; d^2\sigma/dx\,dp_T^2 \propto (1-x)^1 \exp(-1.5p_T^2)$. The Monte-Carlo simulation was performed for each bin of the two-dimensional (p_L, p_T)-distribution. The efficiency versus (p_L, p_T) is nearly model-independent and we used the average of both models. The integral efficiencies in a region of 30 GeV/c $< p_L <$ 60 GeV/c and $p_T <$ 1 GeV/c are $(5.6 \pm 0.6)\cdot 10^{-4}$ for $\bar{D}^0$ and $(3.4 \pm 0.4)\cdot 10^{-4}$ for D^-. In order to minimize the model dependence of the resulting cross sections the experimental momentum spectra were taken into account in the calculation of the integral efficiency.

The longitudinal and transverse momentum spectra of detected $\bar{D}^0$ and D^- mesons are shown in fig.7. The background was subtracted by estimation of the signal in the mass spectrum of each momentum bin. The invariant longitudinal momentum spectra corrected for the acceptance are displayed in fig.8. To determine the dependence of the invariant cross section on x, an ansatz $F(x) \propto (1-x)^N$ has been fitted to the momentum spectra. The fit yields $N_{\bar{D}^0} = 1.1 \pm 0.5$ (stat.) $\pm$ $\pm$ 0.4(syst.) and $N_{D^-} = 0.8 \pm 0.4 \pm 0.4$. The systematic error reflects the uncertainty of the beam spectrum shape. The lines drawn in fig.8 correspond to the fitted functions $F(x)$. Predictions of power law for the structure functions $F(x)$ are given by the quark counting rules [4]. The minimum value of $N = 3$ is predicted for $\bar{D}$ mesons produced by incoming neutrons assuming a gluon exchange mechanism with point-like sea quark pair production [5]. This value is in disagreement with our data. Deviation from the counting rule predictions in the very forward region were also observed in other reactions [6]. The flatter slopes in the high x region points to the contribution of diffraction-like processes.

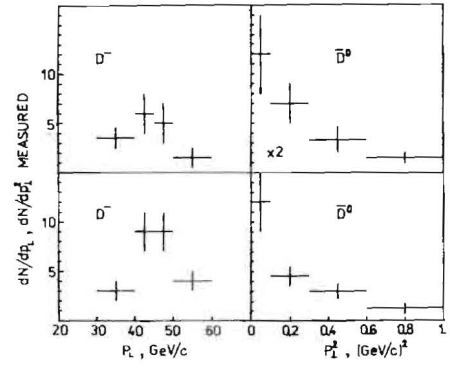


Fig.7. Longitudinal and transverse momentum spectra of detected $\bar{D}^0$ and D^- mesons after background subtraction.

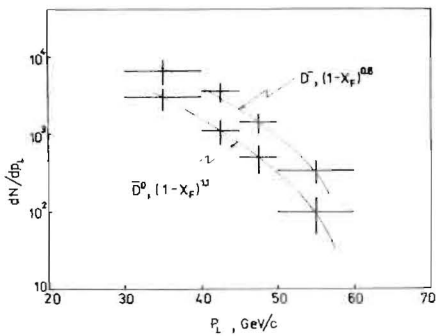


Fig.8. Invariant longitudinal momentum spectra of $\bar{D}^0$ and D^- mesons corrected for acceptance. Also shown are the fits of the power law dependence $(1-x)^N$.

The acceptance-corrected transverse momentum spectra over the range $p_T < 1$ GeV/c are shown in fig.9. The spectra are compatible with an exponential decrease. Fitting the function $d\sigma/dp_T^2 \propto \exp(Bp_T^2)$ to the spectra, one obtains the slopes $B_{\bar{D}^0} = (1.4 \pm 0.7)$ $(GeV/c)^{-2}$ and $B_{D^-} = (1.7 \pm 0.8)$ $(GeV/c)^{-2}$. The mean transverse momentum of both spectra is about 0.7 GeV/c assuming the fitted p_T-dependence also for $p_T > 1$ GeV/c.

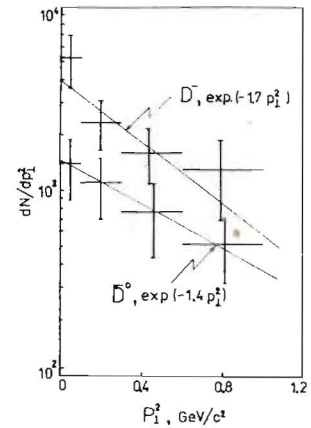
Taking into account the detection efficiency, the signals in the kinematical region $30\ GeV/c < p_L < 60\ GeV/c$, $p_T < 1$ GeV/c correspond to the cross sections times branching ratio

$\sigma_{\bar{D}^0} \cdot BR_1 = (0.9 \pm 0.3)\ \mu b$ and $\sigma_{D^-} \cdot BR_2 = (2.1 \pm 0.7)\ \mu b$.

The definition of $K^+(890)$ candidates includes a large fraction of nonresonant $(K^0_S \pi^+)$ combinations. For this reason one cannot exclude all contributions from the nonresonant decay modes $\bar{D}^0 \to K^0 \pi^+ \pi^-$ and $D^- \to K^0 \pi^+ \pi^- \pi^-$ to the selected sample. The branching ratios BR_1, BR_2 have to be values between the ratios of the decay modes $\bar{D}^0 \to K^0 \pi^+ \pi^-$, $D^- \to K^0 \pi^+ \pi^- \pi^-$ and the resonant subchannels with $K^+(890)$. The branching ratios have been measured [4] for the decays $\bar{D}^0 \to K^+(890)\pi^-(3.4 \pm 1.4)\%$, $\bar{D}^0 \to K^0 \pi^+ \pi^-(4.2 \pm 0.8)\%$ and $D^- \to K^0 \pi^+ \pi^- \pi^-(8.4 \pm 3.5)\%$.

To calculate the cross sections per nucleon we have to know the atomic weight dependence of the cross section. This dependence is generally described by a factor A^α, where A is the atomic weight number. The parameter α is unknown for open charm production, and we have used $\alpha = 2/3$. This value seems to be favoured for the region $x > 0.5$ if α varies with x as observed for non-charmed particles [7].

Fig.9. Acceptance-corrected transverse momentum spectra of $\bar{D}^0$ and D^- mesons. The lines represent fits of the exponential function $\exp(-Bp_T^2)$.



Next we estimate the inclusive cross sections per nucleon in the kinematical region $30\ GeV/c < p_L < 60\ GeV/c$ and $p_T < 1$ GeV/c. For $\bar{D}^0$ production we obtain values in the interval $2\ \mu b/nucleon < \sigma_{\bar{D}^0} < 11\ \mu b/nucleon$ using the extreme values of the partial cross section $0.6\ \mu b < \sigma_{\bar{D}^0} \cdot BR_1 < 1.2\ \mu b$, and of the branching ratio $2.0\% < BR_1 < 5.0\%$. As a consequence of the unknown branching ratio $BR(D^- \to K^+(890)\pi^-\pi^-)$ only a lower limit of the inclusive D^- cross section can be calculated. We obtain $\sigma_{D^-} > 2\ \mu b/nucleon$ using the limits of the partial cross section $\sigma_{D^-} \cdot BR_2 > 1.4\ \mu b$ and of the branching ratio $BR_2 < 11.9\%$.

As we see the $\bar{D}$ cross section is of the same magnitude as the Λ_c^+ cross section obtained in this experiment [1]. Our results suggest that charm is more copiously produced in hadronic interactions even at energies close to the threshold than was so far predicted on the basis of perturbative QCD calculations [8]. The most likely interpretation of our results is the associative production of $\bar{D}$ mesons and Λ_c^+ baryons by incoming neutrons in diffraction-like processes.

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Алеев А.Н. и др. E1-85-662
Наблюдение $\bar{D}$-мезонов в nC-взаимодействиях при 40-70 ГэВ/с

В нейтрон-углеродных взаимодействиях при импульсах пучка нейтронов 40-70 ГэВ/с наблюдалось рождение очарованных мезонов $\bar{D}^0$ и D^-. Эксперимент выполнен с помощью спектрометра БИС-2, расположенного на пучке нейтронов 4Н серпуховского ускорителя. Сигналы $\bar{D}$-мезонов наблюдаются в спектрах эффективных масс $(K^+(890)\pi^-)$ и $(K^+(890)\pi^-\pi^-)$. Кинематическая область регистрации $\bar{D}$-мезонов - 30 ГэВ/с $< P_L <$ 60 ГэВ/с и $P_T <$ 1 ГэВ/с. Для этой области определены парциальные сечения $\sigma(nC \to \bar{D}^0 + X) \cdot {}^T BR$ = /0,9±0,3/ мкб и $\sigma(nC \to D^- + X) \cdot BR$ = /2,1±0,7/ мкб. Спектр продольных импульсов для фейнмановской переменной $X > 0,5$ описывается зависимостью $F(x) \propto (1-x)^N$, при $N_{\bar{D}^0}$ = 1,1±0,5±0,4 и N_{D^-} = 0,8±0,4±0,4. Спектр поперечных импульсов параметризуется экспоненциальной функцией $d\sigma/dP_T^2 \propto \exp(-BP_T^2)$, при $B_{\bar{D}^0}$ = /1,4±0,7/ /ГэВ/с/$^{-2}$ и B_{D^-} = /1,7±0,8/ /ГэВ/с/$^{-2}$.

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Препринт Объединенного института ядерных исследований. Дубна 1985

Aleev A.N. et al. E1-85-662
Observation of $\bar{D}$-Mesons in nC - Interactions at 40-70 GeV/c

The production of $\bar{D}^0$ and D^- mesons has been observed in neutron carbon interactions at 40-70 GeV/c. The experiment was performed with the spectrometer BIS-2 located in the neutron beam 4H of the Serpukhov accelerator. The signals of $\bar{D}$ mesons were detected in the effective mass spectra $M(K^+(890)\pi^-)$ and $M(K^+(890)\pi^-\pi^-)$. The kinematical region of the detected $\bar{D}$ mesons is 30 GeV/c $< P_L <$ 60 GeV/c and $P_T <$ 1 GeV/c. For this region the partial cross sections are $\sigma(nC \to \bar{D}^0 + X) \cdot {}^T BR$ = (0.9±0.3) μb and $\sigma(nC \to D^- + X) \cdot BR$ = (2.1±0.7) μb. The longitudinal momentum spectrum in the region $x > 0.5$ can be described by $F(x) = (1-x)^N$ with $N_{\bar{D}^0}$ = 1.1±0.5±0.4 and N_{D^-} = 0.8±0.4±0.4. The transverse momentum spectra were parametrized by the exponential function $d\sigma/dp_T^2 = \exp(-Bp_T^2)$ with $B_{\bar{D}^0}$ = (1.4±0.7) (GeV/c)$^{-2}$ and B_{D^-} = (1.7±0.8) (GeV/c)$^{-2}$.

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

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