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Charm production nearby threshold in pA-interactions at 70 GeV

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The results of the SERP-E-184 experiment at the U-70 accelerator (IHEP, Protvino) are presented. Interactions of the 70 GeV proton beam with C, Si and Pb targets were studied to detect decays of charmed D^0, $\overline{D}^0$, D^+, D^- mesons and Λ_c^+ baryon near their production threshold. Measurements of lifetimes and masses are shown a good agreement with PDG data. The inclusive cross sections of charm production and their A-dependencies were obtained. The yields of these particles are compared with the theoretical predictions and the data of other experiments. The measured cross section of the total open charm production ($\sigma_{\rm tot}(c\bar{c})$ = 7.1 $\pm$ 2.3(stat) $\pm$1.4(syst) μb/nucleon) at the collision c.m. energy $\sqrt{s}$ = 11.8 GeV is well above the QCD model predictions. The contributions of different species of charmed particles to the total cross section of the open charm production in proton-nucleus interactions vary with energy.

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1. Monte Carlo simulation and selection of events with the charmed particles

The SERP-E-184 experiment "Investigation of mechanisms of the production of charmed particles in pA- interactions at 70 GeV and their decays" at the U-70 accelerator (IHEP, Protvino) was carried out at the SVD-2 (Spectrometer with Vertex Detector) setup [1]. This setup was constructed to study the charmed particles production in pp- and pA-interactions by the SVD collaboration including IHEP (Protvino), JINR (Dubna) and SINP MSU (Moscow). The main elements of the setup are the high-precision micro-strip vertex detector (MSVD) with an active target (AT) and a magnetic spectrometer. The AT contains 5 silicon detectors each 300-μm thickness and 1-mm pitch strips, a Pb-plate (220 μm thick) and a C-plate (500 μm thick), placed as Si-Si-Pb-Si-C-Si-Si. The tracking part of MSVD consists of 10 Si-detectors: four XY pair and one XYUV quadruplet , U and V are the oblique planes. The angular acceptance of MSVD is $\pm$ 250 mrad. The spectrometer features allow one to get the effective mass resolution of σ = 4.4 MeV/c^2 for K^0_s and 1.6 MeV/c^2 for Λ^0_c masses.

Monte Carlo (MC) events were obtained with FRITIOF separately for interactions on C, Si, and Pb with the charm production. Decays of unstable particles happened later within GEANT code. Certain decay modes were imposed for charmed particles ($D^0 \to K^-\pi^+$, $\overline{D}^0 \to K^+\pi^-$, $D^+ \to K^-\pi^+\pi^+$, $D^- \to K^+\pi^-\pi^-$, $\Lambda^+_c \to pK^-\pi^+$). GEANT3.21 package was used to simulate registration of pA-interactions. We analysed the simulated events in order to work out the selection criteria [2] for $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$. The effective mass spectra of the $K\pi$ system after applying of all criteria were fitted by the sum of the straight line and the Gaussian function. It gives 1861 $\pm$ 7 MeV/c^2 for D^0 ($\overline{D}^0$) mass and the signal-to-noise ratio of (51$\pm$17)/(38$\pm$13). The detection efficiency of ($D^0/\overline{D}^0$) particles with taking into account of the efficiency of visual inspection is equal to $\varepsilon(D^0/\overline{D}^0) = 0.036$.

For reconstruction of the charged charmed mesons, we analysed the $K\pi\pi$-systems: $D^+ \to K^-\pi^+\pi^+$, $D^- \to K^+\pi^-\pi^-$. The charged charmed mesons were found by analysing of the events with a three-prong secondary vertexes (the selection procedure is described in [3]). After parametrisation of the spectrum as sum of the Gaussian function and polynomial we were got 15.5 $\pm$ 5.6 (15.0 $\pm$ 4.7) signal events from D^+ (D^-) meson decay over the background of 16.6 $\pm$ 6.0 (8.7 $\pm$ 2.7) events. Also, the mass of D^+: $M(D^+)$ = 1874 $\pm$ 5 MeV/c^2 (PDG $-$ 1869.6), $\varepsilon(D^+) = 0.014$ (efficiency of a signal extraction); the mass of D^-: $M(D^-)$= 1864 $\pm$ 8 MeV/c^2, $\varepsilon(D^-) = 0.008$.

The charmed Λ^+_c-baryon was analysed with the three-prong decay $\Lambda^+_c \to pK^-\pi^+$. Application of all the selection criteria [4] resulted in the effective mass spectrum with the signal-to-noise ratio: (21.6 $\pm$ 6.0)/(16.4 $\pm$ 4) and mass $M(\Lambda^+_c)$ = 2287 $\pm$ 4 MeV/c^2 (PDG $-$ 2286.5), $\varepsilon(\Lambda^+_c) = 0.011$.

2. Cross sections for charmed particle production and their A- dependence

We have calculated inclusive cross sections for charmed particle i ($i = D^0, \overline{D}^0, D^\pm$ or Λ^+_c) using the relation:

$N_s(i) = (N_0\ \sigma(i)\ \mathrm{A}^\alpha/(\sigma_{\mathrm{pp}}\ \mathrm{A}^{0.7}))(B(i)\ \varepsilon(i))/K_{\mathrm{tr}}$ or $ln(N_{\mathrm{s}}(i)/C(i)) = \alpha \times ln(\mathrm{A}) + ln\sigma(i)$, where $C(i) = [N_0/(\sigma_{pp} \times A^{0.7})] \times [(B(i) \times \varepsilon(i))/K_{tr}]$, $N_s(i)$ determines the number of events in the signal for the i-charmed particle produced in the given target, N_0 $-$ the number of inelastic interactions in this target, $\sigma(i)$ $-$ the cross section for charmed particle production at a single nucleon of the

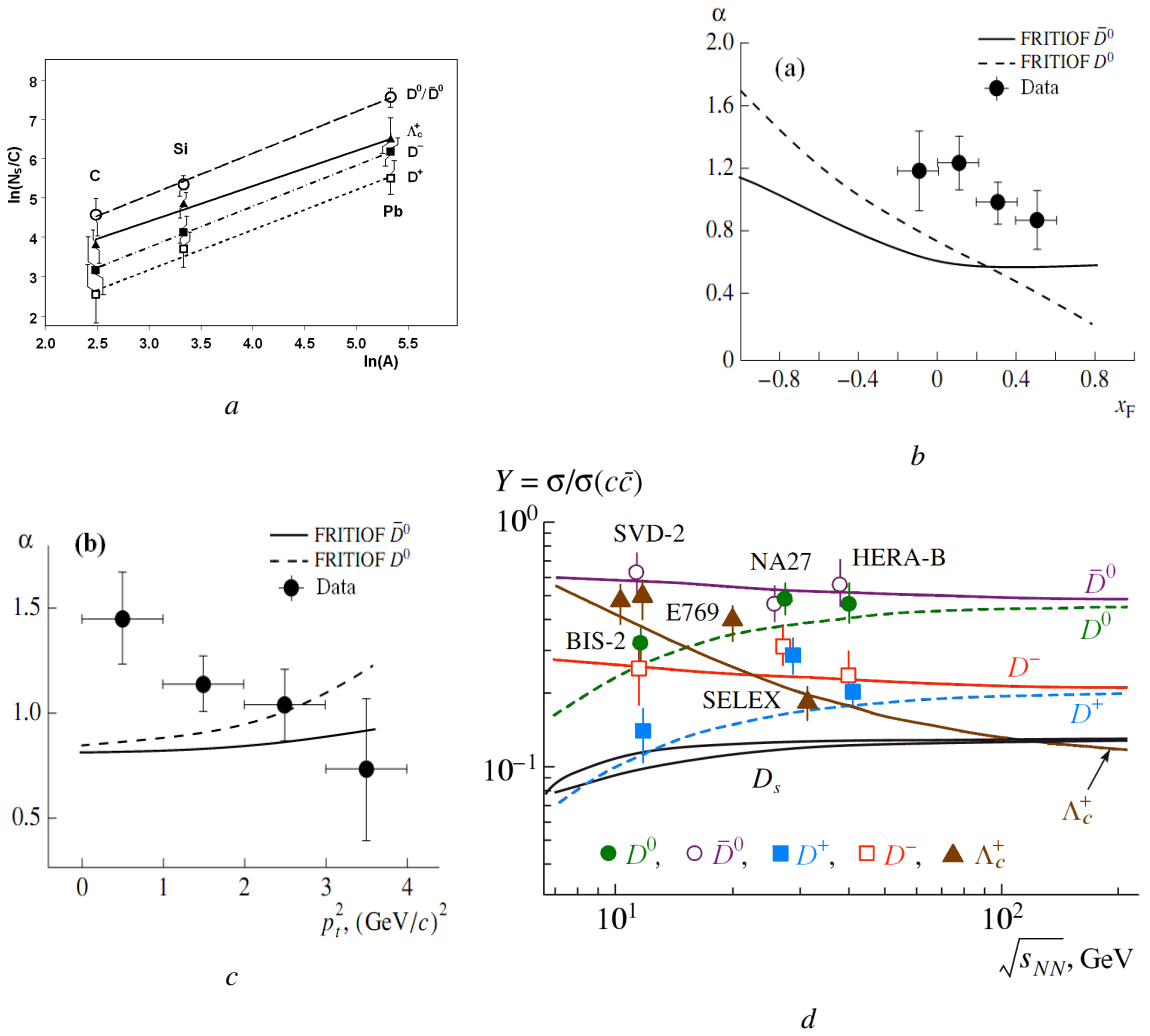

Figure 1: (*a*) the A-dependence of cross sections for the charmed particles production in pA-interactions; the α-parameter as a function of (*b*) x_F and (*c*) p_T^2 for ($D^0/\overline{D}^0$) particle, the lines describe MC events (FRITIOF); (*d*) relative yields of charmed particles: • – D^0, ○ – $\overline{D}^0$, ■ – D^+, □ – D^+, ▲ – Λ_c^+ [2, 3, 4], the theoretical curves (with designation of a particle) are taken from [6] .

target. A-dependence of the charmed particle production in pA-interactions at the AT (C, Si and Pb) is close to 1 for all charmed particles [4] as shown in Fig. 1, *a*. For the largest number of the reconstructed mesons ($D^0/\overline{D}^0$) the dependences of $\alpha-$parameter on x_F and p_T^2 is shown in Fig. 1, b and c, respectively. The lines describe MC events (FRITIOF). Relative yields of charmed particles are shown in Fig. 1, *d* where • – D^0, ○ – $\overline{D}^0$, ■ – D^+, □ – D^+, ▲ – Λ_c^+ [2, 3, 4] are the experimental points, the theoretical curves (with designation of a particle) are taken from [6].

The total cross section of the charmed particle production in pp at 70 GeV/c is estimated as $\sigma_{tot}(c\bar{c}) = 7.1 \pm 2.3$ (stat) $\pm$ 1.4 (syst) μb/nucleon [4].

3. Conclusion

Our basic results of study of the charmed particle production are careful measurements of

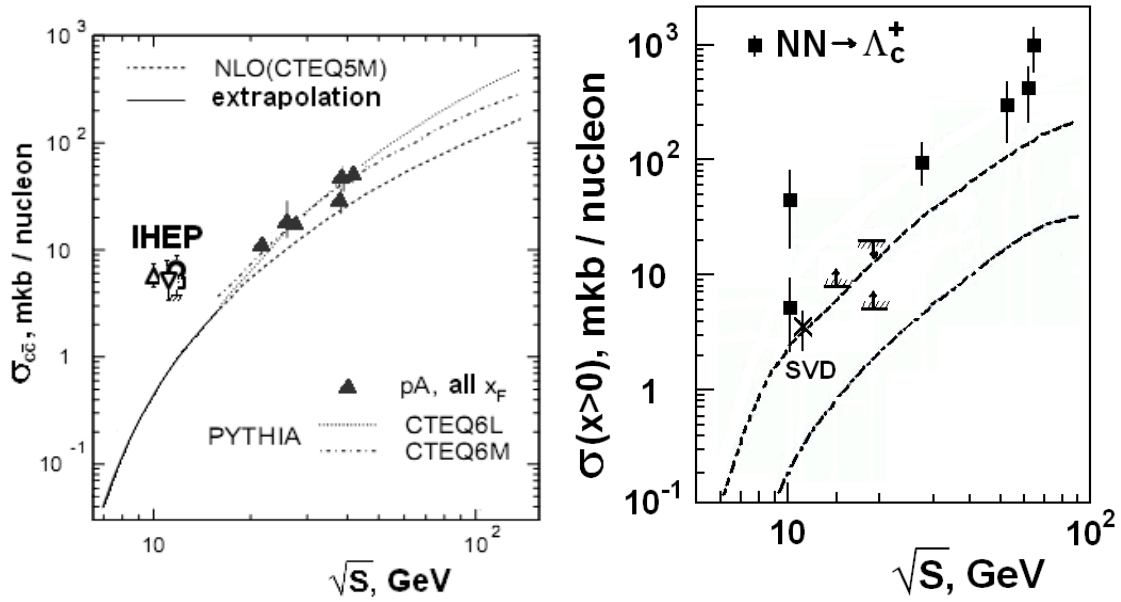

Figure 2: Left panel: $\sigma_{\rm tot}$ ($c\bar{c}$) in pA-interactions. Extrapolation is solid line. Experiments: $\circ$ – SVD-2, $\square$ – SCAT bubble chamber, $\triangledown$ – beam-dump, $\triangle$ – BIS-2 spectrometer [6], other lines are taken from various models (see refs. in [4]. Right panel: $\sigma(\Lambda_c^+)$ at $x_{\rm F} > 0$, where $\blacksquare$ – world data, X – the result of our experiment, lines - the model predictions based on QCD [5].

$\star$ $\sigma_{\rm tot}(c\bar{c})$ = 7.1 $\pm$ 2.3 (stat) $\pm$ 1.4 (syst) μb/nucleon at c.m. energy $\sqrt{s}$ = 11.8 GeV that is much above the QCD model predictions (Fig. 2, the left panel);

$\star$ the contributions of $\sigma(i)$, where $i = D^0, \overline{D}^0, D^+, D^-$ and Λ_c^+ into the total cross section $\sigma(c\bar{c})$ vary at lower collision energies (Fig. 1, *d*);

$\star$ the cross section for Λ_c^+ production at $\sqrt{s} > 30$ GeV contradicts $\sigma(c\bar{c})$ for the open charm production cross section (Fig. 2, the right panel). $\sigma(\Lambda_c^+)$ are extraordinarily large in this area.

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