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Detection of D^\pm mesons production in pA-interactions at 70 GeV

VASILY RYADOVIKOV¹

ON BEHALF OF SVD-2 COLLABORATION

IHEP, Protvino, Moscow region, Russia

E-mail: riadovikov@ihep.ru

The results of analysis SERP-E-184 experiment [1] data, obtained with 70 GeV proton beam irradiation of active target with carbon, silicon and lead plates are presented. For 3-prongs charged charmed mesons decays, event selection criteria were developed and detection efficiency was calculated with detailed simulation using FRITIOF7.02 and GEANT3.21 programs. Signals of decays were found and charm production inclusive cross sections estimated at near threshold energy. The lifetimes and A-dependence of cross section were measured. Yields of D mesons and their ratios in comparison with data of other experiments and theoretical predictions are presented.

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1 Introduction

The open charm production cross section $\sigma(c\bar{c})$ at near threshold energy in pA-interactions was given in our earlier works [2, 3] on research of D^0 mesons characteristics with SVD-2 setup [4]. In this work the results of search and analysis of $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^- \rightarrow K^+\pi^-\pi^-$ decays in pA-interactions at 70 GeV are presented. Charged charm mesons production inclusive cross sections were estimated and their properties were measured. 52 million of inelastic events were detected with three nuclear targets and used in our analysis. Selection procedures for events with possible 3-prongs decays of charged D mesons were the following:

- Reconstruction of tracks and primary vertex using vertex detector data.
- Search of two prongs secondary vertices in track parameters space $\{\mathbf{a}, \mathbf{b}\}$ [5]. In this space each track is presented by a point and all points for tracks from the same vertex lie on a straight line.
- Spatial reconstruction of charged particles tracks in the magnetic spectrometer.
- Search of 3-prongs secondary vertices taking into account their charge signs and spatial association with primary vertex.

After primary selection there were 16320 events with $(K^-\pi^+\pi^+)$ decay hypothesis and 8439 with $(K^+\pi^-\pi^-)$ hypothesis. In fig. 1 raw experimental effective mass spectra of two systems are presented. Signals from D^\pm mesons can be observed over the large background. To diminish this background additional cuts and modeling were required.

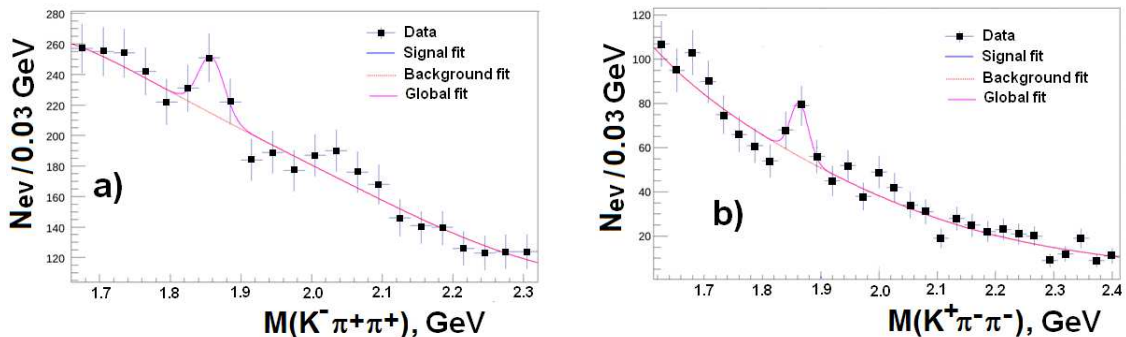


Figure 1: Raw experimental effective-mass spectra of $(K^-\pi^+\pi^+)$ (a) and $(K^+\pi^-\pi^-)$ systems (b).

2 Modeling and optimization of selection criteria

GEANT3.21 [6] program with the description of all SVD-2 components was used for modeling and optimization of selection criteria for D^\pm meson events. FRITIOF7.02

[7] program was used as the generator of pA-interactions. At first step the background under signals was simulated using 10 million Monte-Carlo (MC) events without charm. 3-prongs secondary vertices were found in some events because of detector noise and feature of procession algorithm. Distributions of some characteristics (decay length (L), momentum (P) and Feynman variable (X_F)) of 3-prongs systems for MC-events and experimental background in interval of D meson masses from fig. 1 ($M = 1.86 \pm 3 * 0.02$ (GeV)) were compared. The proper decay length L was calculated from the observed L_{lab} as $L = L_{lab} * M/P$. All distributions really reproduce experimental background conditions. Momenta of 3-prongs systems lie above 7 GeV.

A half of million MC-events with $D^+ \rightarrow K^- \pi^+ \pi^+$ decay were used for optimization of selection criteria. At the first the Dalitz-plot for $(K^- \pi^+ \pi^+)$ system was analyzed in $m_1 = m(K^- \pi_1^+)$ and $m_2 = m(K^- \pi_2^+)$ coordinates. All MC-events are grouped within an ellipse (fig. 2a). In fig. 2b mass plot for experimental events with MC-events ellipse is presented. For events in the ellipse, dependences of event densities on ϕ angle are shown in fig. 2c. From the analysis of fig. 2c the following selection criteria were taken: $\phi < 200^\circ$, or $\phi > 340^\circ$ and $R_{ell} < 1$.

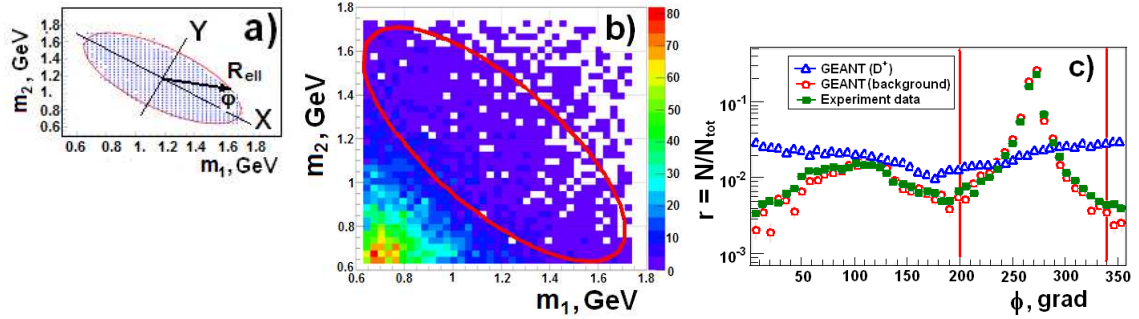


Figure 2: a) Dalitz-plot for $(K^- \pi^+ \pi^+)$ system. b) MC-ellipse imposed on experimental Dalitz-plot. c) Experimental and MC-events densities versus ϕ .

Another background occurs when charge track from primary vertex combined with K^0 decay vertex. To remove it another mass plot was considered: in the same 3-prongs secondary vertex K^- candidate was replaced with π^- candidate. In fig. 3a the plot with two pions mass hypotheses is presented. The K^0 background lies in the lower part of the plot. Events under the line $(M(\pi^+ \pi^-)_{H1} + M(\pi^+ \pi^-)_{H2} < C)$ have to be excluded. If N_{cut} is the number of the rejected events and N_{tot} total number of events, then the share of rejected events $W = N_{cut}/N_{tot}$ depends on C . From the analysis of distributions in fig. 3b the cut parameter $C = 1.2$ was taken for reduction of K^0 background. The K^0 background became practically unseen.

Distributions for MC-events with D^+ and for experimental events with 3-prongs secondary vertex vs. proper decay length L of $(K^- \pi^+ \pi^+)$ system were got. From the analysis of these distributions the $L > 0.12$ mm cut was introduced.

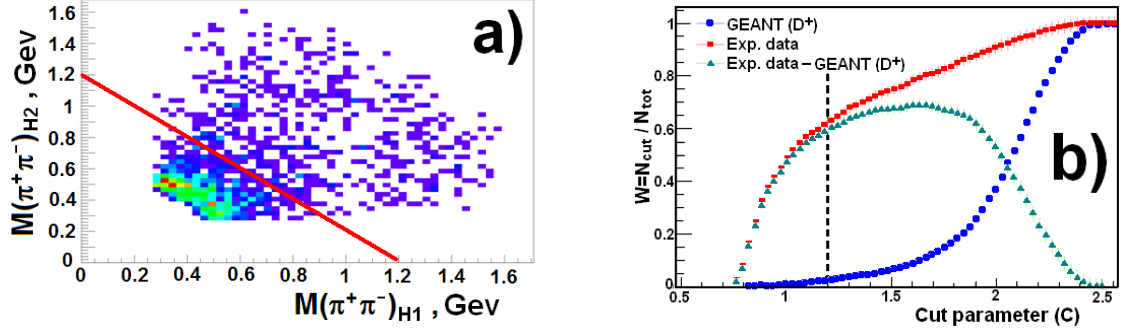


Figure 3: a) The plot for $(\pi\pi\pi)$ system. b) Dependence of W value on parameter C .

3 The analysis of experimental events

As a result of simulation the selection criteria for D^+ decays with the minimum background were taken: 1) $\phi(K^-\pi^+) < 200^\circ$, or $\phi(K^-\pi^+) > 340^\circ$ and $R_{ell} < 1$; 2) $M(\pi^+\pi^-)_{H1} + M(\pi^+\pi^-)_{H2} < 1.2$ GeV; 3) $L(K^-\pi^+\pi^+) > 0.12$ mm. The D^+ detection efficiency obtained after application of these criteria to 500000 MC-events is 1.4%. The same criteria were applied to 500000 MC-events with D^- decays. Detection efficiency for D^- is 0.8%. In figs. 4a and 4b the experimental mass spectra of $(K^-\pi^+\pi^+)$ and $(K^+\pi^-\pi^-)$ systems are presented. Signals of D mesons were fitted by the sum of Gaussian function and 6-order polynomial background. The parameters of the fits for D^+ were: $\chi^2/\text{NDF} = 7.4 / 12$, prob = 0.8; signal from $D^+ = 15.4$ events; background under the signal = 16.6 events; D^+ mass = 1873 ± 5 MeV; standard deviation = 12 MeV. For D^- : $\chi^2/\text{NDF} = 2.7 / 11$, prob = 0.99; signal from $D^- = 15.3$ events; background under the signal = 8.7 events; D^- mass = 1863 ± 8 MeV; standard deviation = 22 MeV. The measured values of charged D mesons masses are near to PDG value (1869.6 MeV) within the errors. In the mass interval of D mesons a K^0 background was not found.

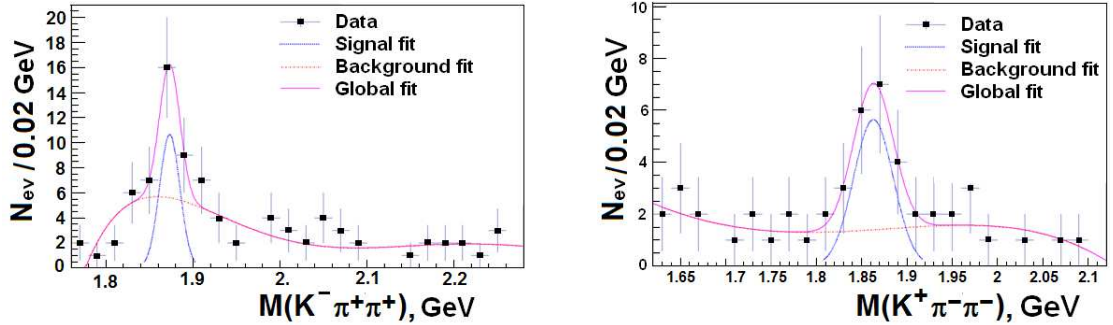


Figure 4: Effective-mass spectra of $(K^-\pi^+\pi^+)$ (a) and of $(K^+\pi^-\pi^-)$ (b) systems.

Measuring D mesons lifetime we can get another proof of observing charm particles. Events from signal slice ($M(D) \pm 2.5 * \sigma$) were selected. The decay length distributions were constructed for them taking into account detection efficiency. The distributions were fitted by exponent. The background under a signal was estimated with help of distributions for MC-events. The measured values of the $c\tau$ parameters were $291 \pm 75 \mu\text{m}$ for D^+ meson and $341 \pm 88 \mu\text{m}$ for D^- meson. They coincide with PDG value ($311.8 \mu\text{m}$) within the errors. Only statistical errors are here. The lifetime for events outside of signal areas considerably differ from these values.

4 Inclusive cross sections and A-dependence

The formula for calculation of cross sections was taken as:

$$N_s = [N_0(\sigma_D A^\alpha)/(\sigma_{pp} A^{0.7})] \times [(B\varepsilon)/K_{tr}], \text{ where}$$

N_s – number of events in a signal; N_0 – number of events with pA-interactions in a target; σ_D – charm cross section; A – nuclear weight of target material (C, Si, Pb); α – parameter of A-dependence for charm cross section ($= 0.7$ for background); σ_{pp} – inelastic pp-interactions cross section at 70 GeV ($= 31440 \text{ mb}$); B – branching ratio of $D^\pm \rightarrow K\pi\pi$ decay ($= 0.094$); ε – detection efficiency for D mesons ($\varepsilon(D^+) = 0.014$, $\varepsilon(D^-) = 0.008$); $K_{tr} = 0.57$ (trigger efficiency [2] after specification);

With the expressions: $C_D = [N_0/(\sigma_{pp} A^{0.7})] \times [(B\varepsilon)/K_{tr}]$ and $\ln(N_s/C_D) = \alpha \times \ln(A) + \ln(\sigma_D)$ A-dependence of cross sections was received. The slope parameters of linear fits are: 1.02 ± 0.26 for D^+ and 1.04 ± 0.27 for D^- . The average values of inclusive cross sections (weighed on target materials) are:

$$\begin{aligned} \sigma(D^+) &= 1.2 \pm 0.4(\text{stat.}) \pm 0.2(\text{syst.}) \ (\mu\text{b/nucleon}), \\ \sigma(D^-) &= 1.9 \pm 0.6(\text{stat.}) \pm 0.4(\text{syst.}) \ (\mu\text{b/nucleon}). \end{aligned}$$

The relative errors of the cross sections are: near 30% from statistics and near 15% from uncertainty of detection efficiency and of trigger factor calculations.

5 The ratios of charm meson yields

In earlier paper [2] the estimation of open charm total cross section neutral D mesons observations in pA-interactions at 70 GeV was obtained as:

$$\sigma(c\bar{c}) = 7.1 \pm 2.4(\text{stat.}) \pm 1.4(\text{syst.}) \ (\mu\text{b/nucleon}).$$

The cross sections of neutral charm mesons and anti-mesons were estimated as:

$$\begin{aligned} \sigma(D^0) &= 2.5 \pm 0.8(\text{stat.}) \pm 0.5(\text{syst.}) \ (\mu\text{b/nucleon}), \\ \sigma(\bar{D}^0) &= 4.6 \pm 1.6(\text{stat.}) \pm 0.9(\text{syst.}) \ (\mu\text{b/nucleon}). \end{aligned}$$

Table 1. Yields of D mesons and their ratios.

Mesons	PYTHIA	FRITIOF			SVD-2	Other experiments	
	pp-int.	pA-interactions			pA-int.	pA-interactions	
		C	Si	Pb		NA-27 [8]	HERA-B [9]
D^0	0.28	0.48	0.51	0.55	0.35 ± 0.16	0.57 ± 0.08	0.44 ± 0.18
\bar{D}^0	0.74	0.60	0.59	0.58	0.65 ± 0.31	0.43 ± 0.09	0.54 ± 0.23
D^+	0.13	0.28	0.29	0.29	0.16 ± 0.07	0.31 ± 0.06	0.19 ± 0.08
D^-	0.24	0.28	0.27	0.28	0.27 ± 0.17	0.34 ± 0.06	0.25 ± 0.11
D^0/\bar{D}^0	0.38	0.80	0.86	0.95	0.54 ± 0.25	1.33 ± 0.25	0.81 ± 0.23
D^+/D^-	0.54	1.0	1.1	1.0	0.59 ± 0.20	0.92 ± 0.21	0.76 ± 0.22
$D^\pm / (D^0 + \bar{D}^0)$	0.36	0.51	0.51	0.5	0.44 ± 0.24	0.65 ± 0.21	0.46 ± 0.18
D^+/D^0	0.18	0.56	0.52	0.46	0.59 ± 0.21	0.54 ± 0.11	0.44 ± 0.12
D^-/\bar{D}^-	0.32	0.47	0.46	0.48	0.42 ± 0.26	0.78 ± 0.19	0.47 ± 0.14

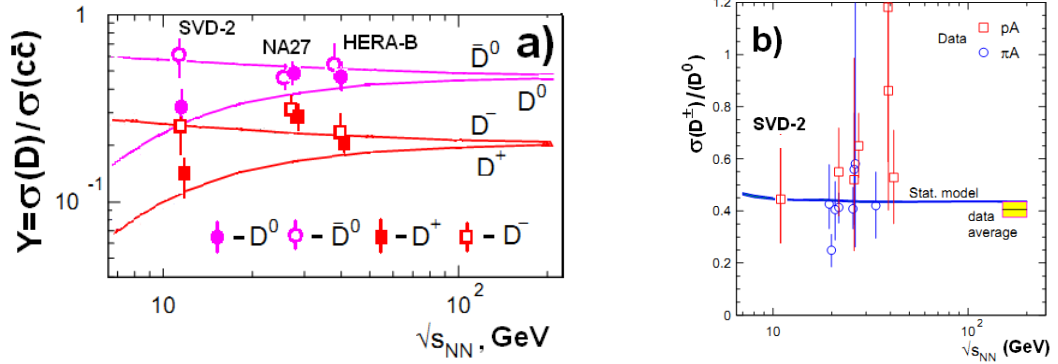


Figure 5: a) Yields of D-mesons. b) Ratios of $(D^+ + D^-)$ and $(D^0 + \bar{D}^0)$ cross sections.

In table 1 yields of D mesons and their ratios using SVD-2 results and data of other experiments for pA-interactions are presented. The yields received from the PYTHIA and FRITIOF programs at our energy are also given. Fig. 5a shows that yields of mesons are decreasing with drop of energy, but yields of anti-mesons are increasing. The difference in the yields of particles and antiparticles was observed for the first time in a nA-interactions at average neutron beam energy 43 GeV in BIS-2 experiment [10]. In this experiment the decays of antiparticles (\bar{D}^0 and D^-) were detected, but the decays of particles (D^0 and D^+) were not found. Cross sections of particles production might appear below the sensitivity threshold in this experiment. In fig. 5b the ratios of cross sections of charged and neutral D mesons from paper [11] and the present result are shown. The results are compared to the predictions of statistical hadronization model [12].

6 Conclusion

In SERP-E-184 experiment at SVD-2 setup (Protvino, Russia) D^\pm mesons signals were obtained in effective-mass spectra of 3-prongs ($K\pi\pi$) systems in pA-interactions at 70 GeV. The selection criteria of events with open charm production were optimized using detailed simulation with FRITIOF7.02 and GEANT3.21 programs. Inclusive cross sections of D^\pm mesons production were estimated at near threshold energy. The SVD-2 active target with plates of different materials (C, Si, Pb) allowed to measure the A-dependence parameters of cross sections for D^\pm mesons production. The yields of D mesons and their ratios in comparison with data of other experiments and theoretical predictions were estimated. Experimental data showed the changes in D mesons yields with a decrease of pA-interaction energy. These results are close to the predictions of a statistical hadronization model.

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