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CHARMED BARYON PRODUCTION AT THE CERN INTERSECTING STORAGE RINGS

ACCDHW Collaboration

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ABSTRACT

The production of Λ_c^+ charmed baryon has been observed in p-p collisions at the CERN ISR. A sharp peak at $2.26 \text{ GeV}/c^2$ was found in the decay mode $\Lambda_c^+ \rightarrow \overline{K}^{*0} p$ in events triggered with a forward K^- meson. Also the decay mode $\Lambda_c^+ \rightarrow K^- \Delta^{++}$ seems to be present. The estimation of the total cross section for Λ_c^+ production is given. However, the resulting value depends on the assumed form of the differential cross section. In addition, Λ_c^+ production in events triggered by the presence of a direct electron are discussed.

1. INTRODUCTION

In a recent publication [1] we reported the observation of charmed D mesons in pp interactions from the analysis of the $K^-\pi\pi$ mass spectra. Continuing the analysis of our experimental data, we studied the mass distributions of the $K^-\pi\pi$ system to search for evidence of charmed baryon [2,3] production.

2. EXPERIMENTAL PROCEDURE

The experiment was performed at the CERN Intersecting Storage Rings (ISR) using the Split Field Magnet detector (SFM). The results presented here come from data samples obtained with two different experimental set-ups. Details about the first set-up and procedures of data acquisition and analysis have been described previously [4,5].

The second experiment made use of the upgraded SFM detector, where both the acceptance and pattern recognition were improved. Furthermore, in set-up 2 other equipment was added to the detector. These were threshold Cerenkov counters, Multiwire Proportional Chambers (MWPC) with analog readout [6] ("dE/dx" chamber) at 90° to the beam and a time-of-flight system surrounding the horizontal plane of the detector.

In set-up 1 a sample of events was obtained at $\sqrt{s} = 52.5$ GeV by triggering on a negative particle emitted at a c.m.s. polar angle $\theta \approx 8^\circ$ with a transverse momentum larger than 0.5 GeV/c. A threshold Cerenkov counter covering the acceptance of the trigger allowed a separation into pion and non-pion samples. In the non-pion sample, about 80% of the trigger particles are K^- , 20% are $\bar{p}$, the pion contamination being negligible. A summary of the phase-space region covered by the trigger is given in table 1.

In set-up 2 a sample of events at $\sqrt{s} = 61.5$ GeV was obtained by triggering on electrons and positrons produced at $\theta \approx 90^\circ$. This was done by requiring two consecutive threshold Cerenkov counters to yield signals

in coincidence with signals from a road system in the MWPC selecting trajectory candidates. After track reconstruction, the pulse height information from the dE/dx chamber was used in addition to separate single electrons from electron pairs. Thus a sample of events was obtained with either an electron or a positron trigger. In table 2, we give the information on the phase-space region covered by the $e^\pm$ trigger. Pion and electron pair contaminations in the sample are less than 10% and 40% respectively.

3. CUTS AND SELECTION CRITERIA

Since in set-up 1 our data sample stems from triggering on a forward K^- with considerable longitudinal momentum, its parent system is expected to be produced rather diffractively. Hence, we applied cuts of such kind as to further select diffractive-like events (see also ref. [1]).

A. Multiplicity: events are accepted when $n_{\text{obs}} \leq 11$ (n_{obs} = number of observed particles). This selection reduces the combinatorial background in the $K\pi$ and $K\pi p$ spectra. The mean observed multiplicity is $\bar{n}_{\text{obs}} \approx 8$.

B. Leading system in the opposite direction: events are accepted only if $|x_{\text{opp}}| > 0.5$ or $|x_{\text{opp}}| < 0.1$, where x_{opp} is the total reduced longitudinal momentum seen in the hemisphere opposite to the longitudinal direction of the trigger. This cut selects those events in which a leading system is observed opposite in x to the trigger ($|x_{\text{opp}}| > 0.5$) or escapes detection ($|x_{\text{opp}}| < 0.1$).

C. Longitudinal momentum of K^- : the triggering K^- is required to have reduced longitudinal momentum $x_K > 0.3$ (equivalent to a p_T cut since the polar angle has a small accepted range).

D. Recoiling system in the same longitudinal direction: the "recoiling system" is defined as the set of particles emitted in the same longitudinal direction as the triggering K^- , but with a transverse component opposite to its transverse momentum p_{TK} . We define a quantity $p_{K\text{opp}}$

$$p_R = - \sum k_{Ti} = - \sum \vec{p}_i \cdot (\vec{p}_{TK} / |\vec{p}_{TK}|),$$

where the sum is extended over the particles in the recoiling system ($k_{Ti} < 0$ and $\vec{x}_K \cdot \vec{p}_{Li} > 0$). Events are accepted only when $p_R > 0.2$ GeV/c. This selection favours events where additional particles are produced close in phase-space to the Λ_c .

E. Transverse momentum of particle combination larger than 1 GeV/c.

In set-up 2, besides requiring the presence of an electron or positron and applying a modified cut $A'(n_{obs} \leq 14)$, some further specific conditions were imposed, as will be discussed below. In this sample, the mean observed multiplicity is $\bar{n}_{obs} \approx 15$.

4. MASS SPECTRA

In the following we are going to discuss mass distributions of the $K\pi$ system obtained in the two different experimental set-ups. In particular, spectra for the $\overline{K}^{*0}p$ and the $K^- \Delta^{++}$ systems are presented as studied in set-up 1 and those for the systems $K^- p \pi^+$ and $K^+ p \pi^-$ as seen with the upgraded detector of set-up 2.

(a) For the data sample of set-up 1, we have observed a $K^*(890)$ signal in the $K^- \pi^+$ mass spectrum [1]. In fig. 1 we display the mass distribution $\overline{K}^{*0}p$ with $K^- \pi^+$ in the $K^*(890)$ region (of full width 80 MeV/c² around the K^* mass). In this plot all combinations have been entered where the additional positive particle is in the same rapidity hemisphere as the K^* . To all these the proton mass has been tentatively assigned. The mass spectrum of fig. 1 shows a narrow peak at a mass value around 2.26 GeV/c², the mass region [2] of the Λ_c^+ charmed baryon. The width of the peak is compatible with the experimental resolution. Although the particle combination under discussion does not possess "exotic" quantum numbers, the narrow width of the observed peak renders a possible interpretation as a Y^* unlikely. To rule out the possibility that the signal is due to kinematics and/or acceptance, a background

spectrum is also shown in fig. 1, obtained by combining the triggering K^- with secondaries from other events. Using this background, we estimate the significance of the signal to be larger than six standard deviations.

The same sample of events was used to analyze the channel $K^- \Delta^{++}$. In contrast to the case of $\bar{K}^{*0} p$, we do not apply cut $C(x_K > 0.3)$, but we take only positive particles with $x > 0.3$ as proton candidates. In fig. 2 we show the mass distribution $p\pi^+$, where both particles are required to be in the same rapidity hemisphere as the trigger. A peak at the position of the $\Delta^{++}(1236)$ is observed. By selecting events in the region of the $\Delta^{++}(\pm 0.1 \text{ GeV}/c^2)$ one also clearly improves the identification of positive particles as protons. The cuts applied to obtain fig. 2 were A, B and D', where D' means $p_R > 0.1 \text{ GeV}/c$ in the notation discussed above. This cut was chosen instead of $p_R > 0.2 \text{ GeV}/c$ since by omitting cut C the average p_T of the triggering K^- is lowered.

If one now combines the $p\pi^+$ system in the region of Δ^{++} with the triggering K^- , a $K^- \Delta^{++}$ mass spectrum is obtained as shown in fig. 3. Again a peak is seen centred at a mass value of $2.26 \text{ GeV}/c$. The observed width is larger than that one of the $\bar{K}^{*0} p$ channel, in agreement with our experimental resolution^(*). In contrast to the case of $\bar{K}^{*0} p$ mass distribution, the background obtained by combining K^- with Δ^{++} from other events does not describe appropriately the mass distribution outside the peak. In fact, another structure seems to be present in our data.

Other background estimates, e.g. obtained by assigning a K^- mass to the triggering π^- in the pion sample and the mass distribution $K^- p\pi^-$, with $p\pi^-$ fulfilling the Δ cut, show no statistically significant enhancements.

We have checked that the signals which we observe are not due to trivial reflections. In particular there are practically no common parts between the 3 samples of events defined by mass windows about the 3 peaks, $(K^- \pi^+) p$ in fig. 1, $K^- (\pi^+ p)$ in fig. 3 and $(K^- \pi^+) \pi^+$ in ref. [1] respectively.

(*) The channels $\bar{K}^{*0} p$ and $K^- \Delta^{++}$ are not observed in the same part of the detector, which explains the different resolutions. In the case of the D^+ charmed meson [1], another phase-space region is observed but, in addition, the larger Q-value results in a larger experimental width.

(b) We now turn to the presentation of mass spectra obtained in set-up 2, i.e. by triggering on electron. Since the lowest lying charmed particles are expected to have a fair branching fraction into leptons, this trigger should highly enrich events of charm production. Due to the fact that hadroproduction yields pairs of charmed particles, we expect a particle with $C = +1$ to be produced with that one which yielded an electron in its semi-leptonic decay. On the other hand, triggering on a positron, an accompanying $C = -1$ state is expected.

Thus, in fig. 4 we display the mass distribution of the $pK^-\pi^+$ system from the reaction $pp \rightarrow e^- K^-\pi^+ pX$. Once more, a peak at the position of the charmed baryon Λ_c is observed.

It should be pointed out, however, that with the exception of the triggering electron, the other particles involved are not identified. Mass values are simply attributed and all combinations entered into the plot. Some reasonable conditions were imposed, however. Again a multiplicity cut $n_{obs} \leq 14$ was made. Both the longitudinal momenta of the K^- and of the proton were required to be larger than the one of the π^+ . The resulting combination was required to be opposite in azimuth to the trigger electron and to have a rapidity $|y| > 0.5$. For the system opposite in rapidity condition B was again imposed.

In order to estimate the background, protons from other events were combined with the K^- and π^+ . The resulting curve is also indicated in fig. 4. The insert in the figure is a $K^-\pi^+$ mass distribution obtained in the same way but from the sample of events with a positron trigger. We do not observe any signal here. Neither do we see any $\bar{\Lambda}_c$ production if we analyze the positron trigger sample the same way as the electron sample by assuming the reaction $pp \rightarrow e^+ K^+\pi^-\bar{p}X$.

For a fraction of the events obtained in set-up 2, a particle identification was possible yielding events with identified kaons and protons. No special conditions were applied to this sample except those automatically imposed by the acceptance and resolution of the time-of-flight system. The resulting effect was that the $Kp\pi$ system populates mostly the phase-space region opposite in azimuth to the trigger and at low rapidity values, $|y| < 1.0$. In particular, we have studied the $K^+\pi^-\bar{p}$ mass combinations where both K^+ and $\bar{p}$ have been identified.

In fig. 5, we show the $K^+ \pi^- \bar{p}$ mass spectrum for a sample of events with a positron trigger. In this case we observe a signal at the $\bar{\Lambda}_c$ mass in the case of the antibaryon combination with the positron trigger. Here again the background is estimated by combining particles from different events, as indicated by the broken line in the figure, and by obtaining the $K^+ \pi^- \bar{p}$ mass spectrum from the e^- trigger sample. In the same figure, we show the $K^{*0} \bar{p}$ mass spectrum for the subset of events where the $K^+ \pi^-$ is in the $K^*(890)$ region.

5. CROSS SECTIONS

Inclusive cross sections for $\bar{\Lambda}_c$ production have been calculated for the decay channels $\bar{K}^{*0} \bar{p}$ and $K^- \Delta^{++}$ from set-up 1 (sect. 4(a)). The Monte-Carlo method used has been described in ref. [1]. For the invariant inclusive $\bar{\Lambda}_c$ cross section, we assume scaling and factorization in the form

$$E \frac{d^3\sigma}{d^3p} \sim f(y/y_{\max}) e^{-Ap_T}$$

with $A = 2 \text{ (GeV/c)}^{-1}$.

Two different parametrizations of the longitudinal momentum dependence have been investigated:

- (a) uniform in rapidity, $d\sigma/dy = \text{const.}$
- (b) uniform in x , $d\sigma/dx = \text{const.}$

Under these assumptions, we obtain the following total inclusive cross sections:

	$\bar{\Lambda}_c \rightarrow \bar{K}^{*0} \bar{p}$	$\bar{\Lambda}_c \rightarrow K^- \Delta^{++}$
model (a)	$B \cdot \sigma = 6.2 \text{ } \mu\text{b}$	$6.7 \text{ } \mu\text{b}$
model (b)	$B \cdot \sigma = 3.0 \text{ } \mu\text{b}$	$3.3 \text{ } \mu\text{b}$

The error on these quantities has been estimated to be $\sim 50\%$.

If we fix the corresponding branching fractions to about 10% [7], the observed signals yield a total inclusive Λ_c cross section of 65 μb in model (a) and 31 μb in model (b).

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TABLE 1

Kinematic range of K^- trigger

Variable	Range	Mean	FWHM	r.m.s
x	0.2 - 0.6	0.31	0.09	0.04
y	2 - 3	2.65	0.38	0.15
p_T (GeV/c)	> 0.5	1.5	0.55	0.27
θ	$5^\circ - 13^\circ$	8.0°	3.1°	1.28°
ϕ	$144^\circ - 168^\circ$	158°	10.4°	3.9°
	$174^\circ - 216^\circ$	193°	21.2°	7.4°

TABLE 2

Kinematic range of $e^\pm$ trigger

Variable	Range e^-	Range e^+	Mean e^-	Mean e^+
x	± 0.012	± 0.012	0	0
y	± 0.3	± 0.4	0	0
p_T (GeV/c)	0.3 - 2.0	0.3 - 2.0	0.695	0.672

FIGURE CAPTIONS

- Fig. 1 $K^- p \pi^+$ mass distribution under the condition that the combination $K^- \pi^+$ has a mass in the $K^*(890)$ region. The broken line represents an estimate of the background.
- Fig. 2 The $p \pi^+$ mass distribution for events fulfilling cuts ABD'.
- Fig. 3 The $K^- p \pi^+$ mass distribution with $p \pi^+$ in the $\Delta^{++}(1236)$ region. The line is an estimate of the background normalized to the histogram for mass values $> 2.5 \text{ GeV}/c^2$.
- Fig. 4 The $K^- p \pi^+$ mass distribution from events with an electron trigger. The broken line is an estimate of the background. The insert shows the $K^- p \pi^+$ mass distribution from events with a positron trigger.
- Fig. 5 The $K^+ \bar{p} \pi^-$ mass distribution for positron triggered events with the K^+ and $\bar{p}$ identified in the time-of-flight system. The broken line represents an estimate of the background. The subset $K^{*0} \bar{p}$ is represented separately.

Fig. 1

Fig. 2

Fig.3

Fig 4

Fig.5