Measurement of Charm Particle Lifetimes and Evidence for Charm Production in Hadron Collisions

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OBSERVATIONS OF CHARMED BARYON PRODUCTION AT THE CERN INTERSECTING STORAGE RINGS

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Recent experiments reporting charmed baryon production in pp interactions are reviewed. Charm cross section estimates are compared.

I. INTRODUCTION

The first evidence for production of the charmed baryon, Λ_c^+, in strong interactions has recently been reported from the CERN Intersecting Storage Rings. The evidence comes from three experiments which studied proton-proton interactions at cm energies of 53 GeV and 63 GeV [1-3]. The decay $\Lambda_c^+ \to K^- p \pi^+$ was seen in these experiments for the first time. Significantly Λ_c^+ is always observed at Feynman x greater than 0.3, suggesting a diffractive production mechanism. In some experiments the cross sections for Λ_c^+ and D^+ meson production are found to be surprisingly large.

II. THE EXPERIMENTS

1. Aachen-CERN-Harvard-Munich-Northwestern-Riverside Collaboration [1]

This experiment was specifically designed to look for charmed baryon production via leading particle fragmentation, since the cross section for strange baryon production was known to be substantial at large x [4].

The experimental setup (Fig. 1) was designed to trigger on the single diffraction dissociation reaction:

$$p + p \to p + X \quad (1)$$
$$\quad\quad\quad\quad \hookrightarrow \geq 6 \text{ charged particles.}$$

A large acceptance multiparticle detector, S1, in Arm 1, intercepted decay products of X within 40^o of beam 1. A precision small acceptance spectrometer in Arm 2 detected the quasi-elastic proton recoiling against X at 10-21 mrad from beam 2.

The Arm 1 detector consisted of two magnetic spectrometers covering the angular intervals 14^o-40^o and 1^o-6^o with respect to the beam 1 direction. For the outer spectrometer, $S1_a$, magnetic analysis was provided by a toroidal air-cored magnet with $\int Bd\ell \propto 1.6$ kG-m. The 12 coils are symmetrically distributed in azimuth, hence the name Lampshade Magnet (LSM). Particle trajectories through the LSM were determined by a 3360-channel drift chamber system [5]. The inner arm 1 spectrometer, $S1_b$ consisted of two identical septum magnets with $\int Bd\ell$ of 12.9 kG-m placed above and below the beam pipe. Particle trajectories were recorded with proportional wire chambers [6].

Cerenkov counters in the inner arm 1 spectrometer, $S1_a$ provided $\pi/K/p$ discrimination. Each septum magnet contained a 4-element gas Cerenkov counter, filled with freon 114 at atmospheric pressure, with threshold momenta of 2.7, 9.9 and 18.8 GeV/c for $\pi/K/p$.

Figure 2 shows the invariant mass distributions for (a) $K^- p \pi^+$ (18,600 events), and (b) $K^- p \pi^-$ (14,100 events). Identification of the K^- meson and proton was required in all events. The $K^- p \pi^+$ distribution has a peak at 2261 ± 8 MeV; the error includes systematic uncertainties. The peak is 5.3 standard deviations above background. On the basis of mass, width

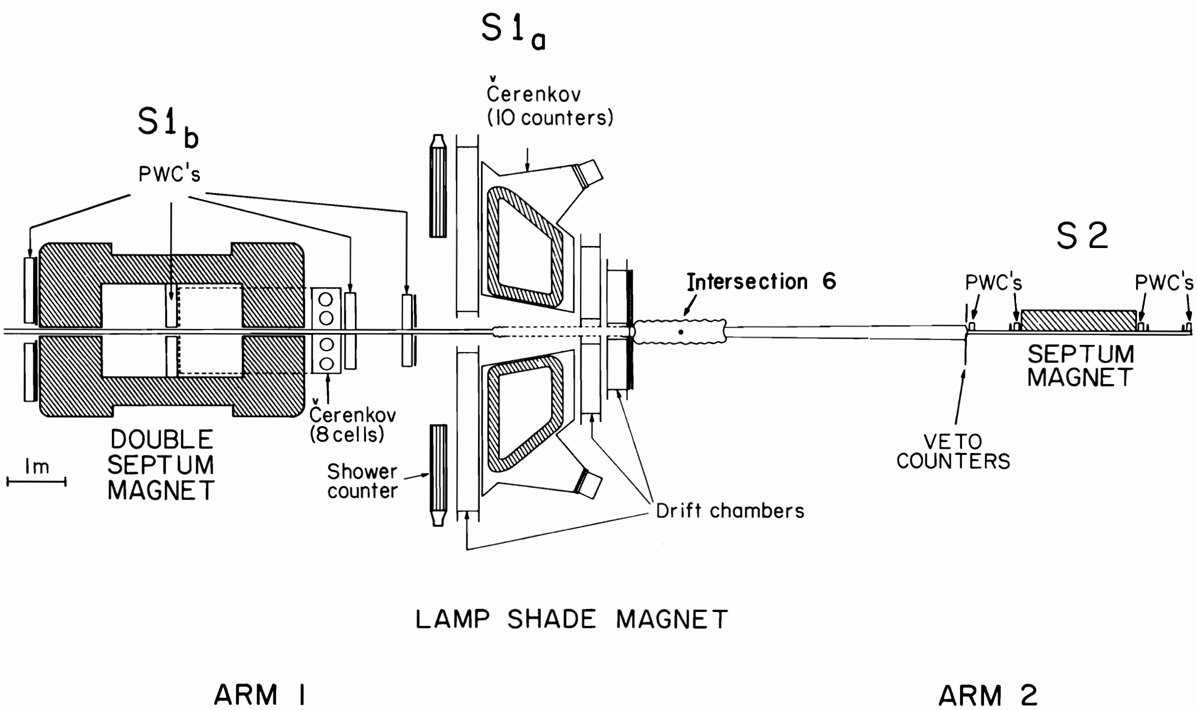


Fig. 1. Experimental setup for the ACHMNR experiment.

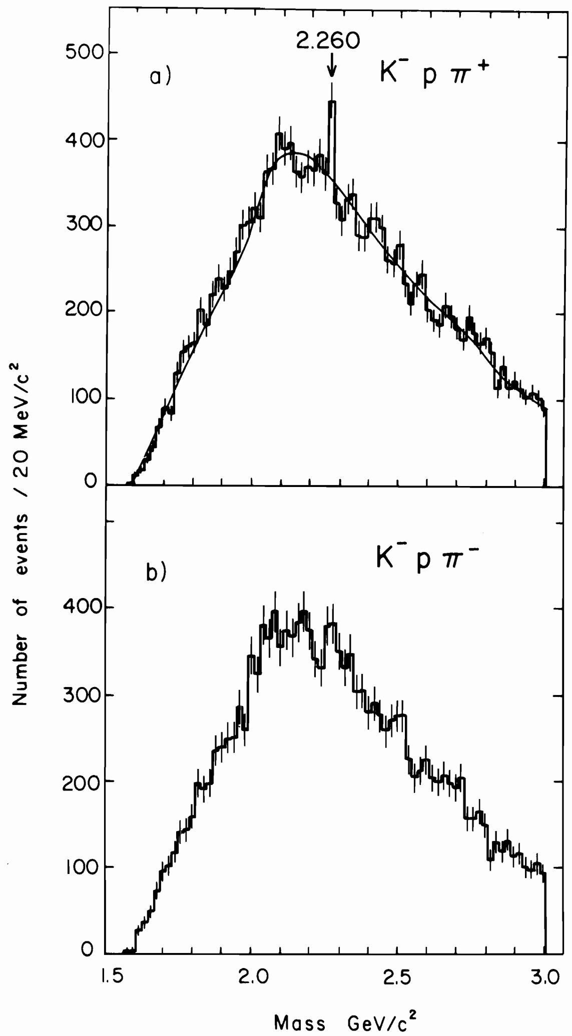


Fig. 2. Invariant mass plots for (a) $K^-p\pi^+$ and (b) $K^-p\pi^-$ in 20 MeV/c^2 bins. The continuous line in (a) is the smoothed $K^-p\pi^-$ distribution normalized to the total number of $K^-p\pi^+$ events. (Ref. 1).

($\Gamma \simeq$ 20 MeV) and absence from the $K^-p\pi^-$ plot, this structure is identified as the charmed baryon Λ_c^+ previously observed in weak [7] and electromagnetic [8] interactions. The continuous line in Fig. 2a is the smoothed $K^-p\pi^-$ distribution normalized to the total number of $K^-p\pi^+$ events.

The detector acceptance for $\Lambda_c^+ \rightarrow K^-p\pi^+$ covered the kinematic range $0.3 < x < 1$ and $p_T < 1$ GeV/c^2. No events were observed for $x > 0.8$. The suppression of large x events is associated with the trigger multiplicity condition which introduced a threshold of 10 GeV/c^2 for the mass of X in reaction (1).

In this experiment $\sigma \cdot B$ $(K^-p\pi^+)$ is estimated to lie in the range 0.7-1.8 μb for Λ_c produced at $0.3<|x|<0.8$ in the single diffraction dissociation process.

A narrow structure ($\Gamma \simeq$ 30 MeV) is also seen at 2.255 GeV/c^2 in the $\Lambda^0\pi^+\pi^+\pi^-$ channel, (Fig. 3), with statistical significance $\leq 3\sigma$. Details of selection criteria for $\Lambda^0 3\pi$ studies are given by Dibitonto [9].

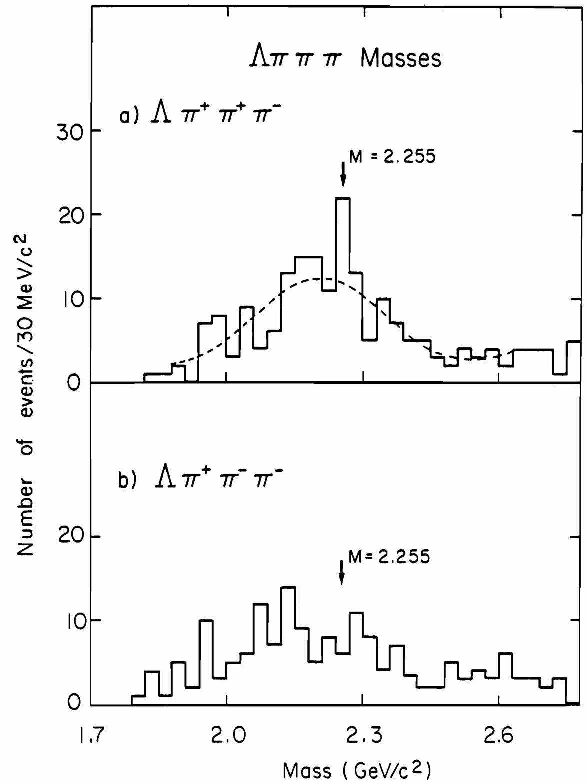


Fig. 3. Invariant mass plots for (a) $\Lambda^0\pi^+\pi^+\pi^-$ and (b) $\Lambda^0\pi^+\pi^-\pi^-$ in 30 MeV/c^2 bins. (Ref. 1).

2. CERN-College de France-Dortmund-Heidelberg-LAPP-Warsaw Collaboration [2]

This group used the Split Field Magnet (SFM) detector, which has almost full acceptance in cm polar angle Θ [10]. The trigger, which was designed for high p_T studies, required a negative particle at $\Theta \sim 8^0$ with $p_T > 0.5$ GeV/c. Trigger particles were identified by a threshold Cerenkov counter.

The search for $\Lambda_c^+ \rightarrow K^-p\pi^+$ was done with K^- trigger events; no Cerenkov information was available for the positive tracks. Data was then selected which satisfied the following criteria:

(1) K^{*0} production, i.e. $M(K^-\pi^+) = 890 \pm 40$ MeV/c^2;

(2) number of charged particles per event ≤ 11;

(3) "diffractive" configuration in the hemisphere opposite to the K^-, $\Sigma x_{opp} > 0.5$ or $\Sigma x_{opp} < 0.1$;

(4) $x_k > 0.3$;

(5) transverse momentum of K^- balanced by $\geq$0.2 GeV/c in the same hemisphere;

(6) $p_T(K^-p\pi^+) > 1$ GeV/c.

Figure 4 shows the invariant mass distribution of $K^-p\pi^+$ events satisfying criteria up to (3), (4) in (a) and up to (6) in (b). A peak centered at 2.26 GeV/c^2 appears when the condition $x_k > 0.3$ is applied. The peak in Fig. 4b is 6.5 standard deviations above the background, with width 40 MeV/c^2 consistent with the experimental resolution.

In the same experiment a less significant peak is seen at 2.26 GeV/c^2 in the $K^-\Delta^{++}$ invariant mass distribution (Fig. 5).

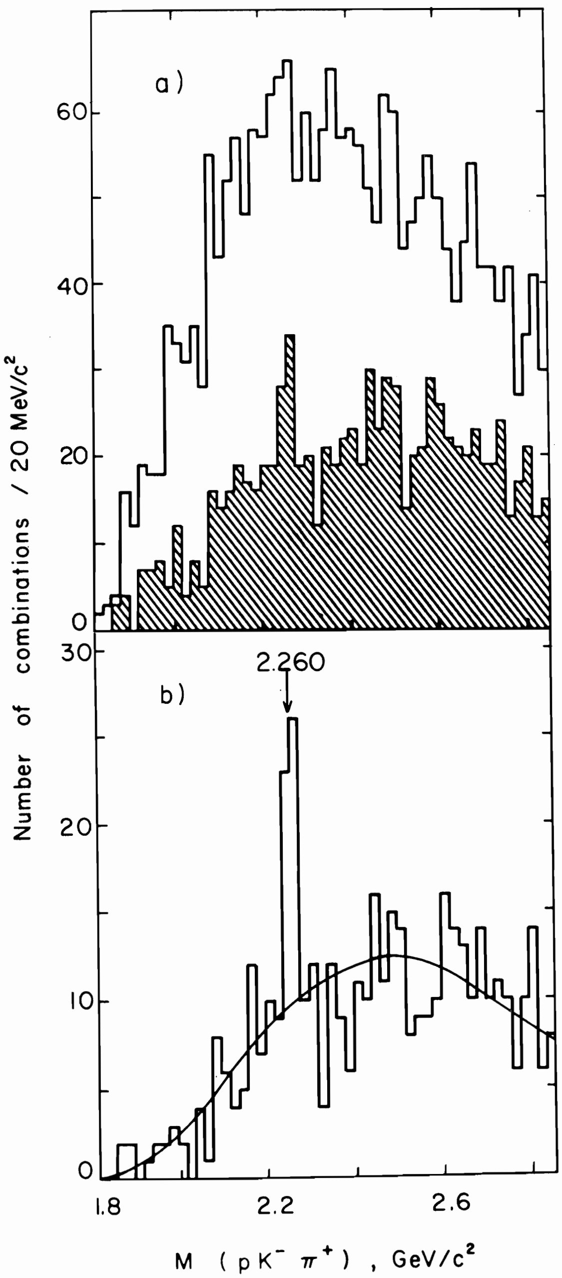


Fig. 4. Invariant mass plots in 20 MeV/c^2 bins for $K^{*o}p$ for (a) cuts 1-3, 1-4 (hatched), and (b) cuts 1-6. (Ref. 2).

In this experiment the detector acceptance for Λ_c covers the range $x > 0.3$ and $p_T > 1.0$ GeV/c^2. Table 1 gives the cross section estimates for inclusive Λ_c production at $x > 0.3$; detection inefficiency in p_T has been corrected assuming that $\sigma \propto f(y)\exp(-2p_T)$.

Table 1

$\sigma \cdot B$ for inclusive Λ_c^+ production measured by Drijard et al. [2]. Errors are ~50%.

2-body decay channels	$\sigma \cdot B$(2-body) (μb)	$\frac{B(\text{2-body})}{B(K^-p\pi^+)}$ [11]	$\sigma \cdot B(K^-p\pi^+)$ (μb)
$K^{*o}(K^-\pi^+)p$	1.05	0.12 ± 0.07	8.8
$\Delta^{++}K^-$	1.16	0.17 ± 0.07	6.8

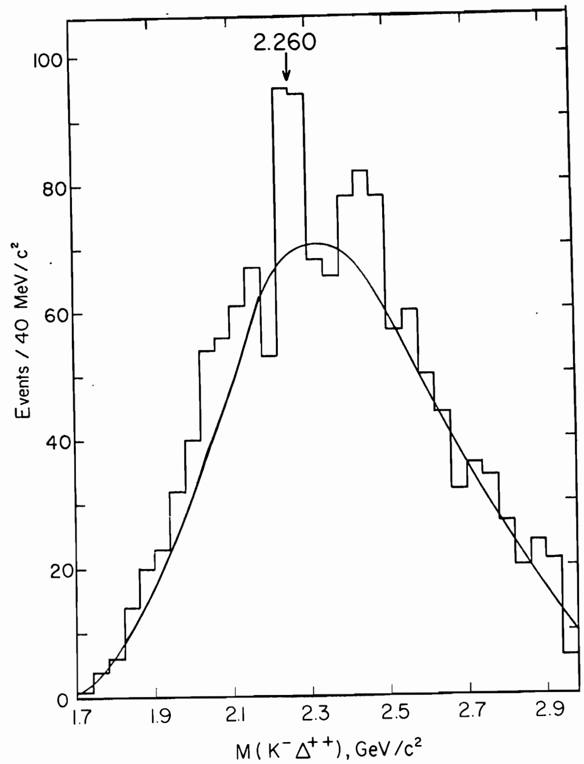


Fig. 5. Invariant mass plots in 40 MeV/c^2 bins for $K^-\Delta^{++}$. The line is a background estimate normalized to the histogram for mass values above 2.5 GeV/c^2. (Ref. 2).

3. UCLA-Saclay Collaboration [3].

The double septum magnetic spectrometer ($S1_b$ in Fig. 1) was used for this study. The angular coverage of the spectrometer, $- 15 < \Theta < 100$ mrad -, limited the acceptance for Λ_c to $x \geq 0.7$. The data was obtained with an inclusive n-particle ($n \geq 2$) trigger. K^- mesons were identified with Cerenkov counters having a threshold for $\pi/K/p$ of 3.5/12.5/23.6 GeV/c. A minimum momentum of 5 GeV/c was imposed for K^- identification.

Figure 6 shows (a) $K^-p\pi^\pm$ and (b) $\Lambda^o\pi^+\pi^-\pi^\pm$ invariant mass plots for the x range 0.75-0.90. From the structures around 2.290 GeV/c^2 in both mass plots cross section estimates of $\sigma \cdot B = 2.3 \pm 0.3$ μb and 2.8 ± 1.0 μb are obtained for Λ_c, decaying to $K^-p\pi^+$ and $\Lambda^o\pi^+\pi^+\pi^-$ respectively. Clearly the magnitude and statistical significance of these cross sections depend strongly on background estimates.

The excess of positive charge over negative charge states in Fig. 6 is a predictable feature of large x particle production in pp interactions [12].

III. CROSS SECTIONS

The cross section for Λ_c^+ production is calculated from the measured values of $\sigma \cdot B(K^-p\pi^+)$ using the branching fraction $B(K^-p\pi^+) = 0.017 \pm 0.010$ reported by V. Luth at this conference [13]. Table 2 lists σ and $\Delta\sigma/\Delta x$ for each experiment; in general errors are dominated by the uncertainty in $B(K^-p\pi^+)$.

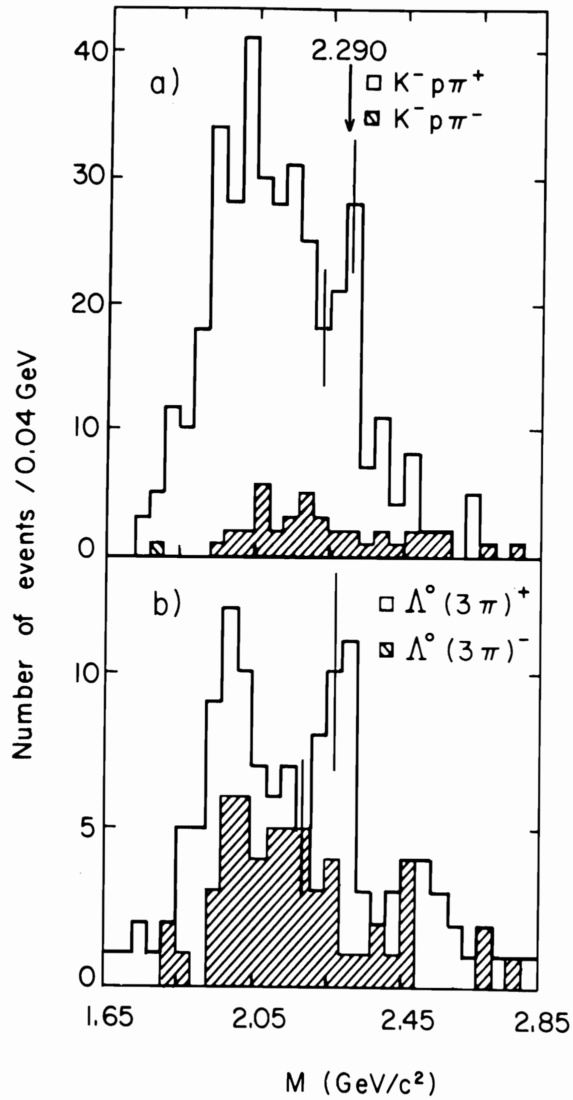


Fig. 6. Invariant mass plots with 40 MeV/c^2 bins for (a) $K^-p\pi^+$ and $K^-p\pi^-$ and (b) $\Lambda^0\pi^+\pi^+\pi^-$ and $\Lambda^0\pi^+\pi^-\pi^-$ (Ref. 3).

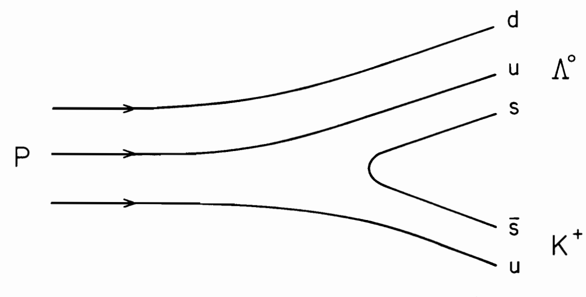
Table 2

σ and $\Delta\sigma/\Delta x$ for Λ_c^+ production measured at the CERN ISR

Experiment	$\sqrt{s}$ (GeV)	x Range	$\sigma \cdot B(K^-p\pi^+)$ (μb)	σ (μb)	$\Delta\sigma/\Delta x$ (mb)
ACHMNR	63	0.3-0.8	0.3-0.9	35	0.070
CCDHLW*	53	0.3-1.0	8.8±4.4	515	0.74
UCLA-SACLAY	53,63	0.75-0.9	2.3±0.3	135	0.90

*cross section estimate based on $K^{*0}p$ peak.

It is instructive to compare the data in Table 2 with strange particle production cross sections. Fig. 7 shows the x dependence of the invariant cross sections for inclusive Λ^0 [14] and $K^\pm$ [15] production in pp collisions at $\sqrt{s}$ of 53 GeV/c and p_T of 0.55 GeV/c. The data in Fig. 7 are most readily interpreted in terms of signficant Λ^0 and K^+ production by beam fragmentation as shown:



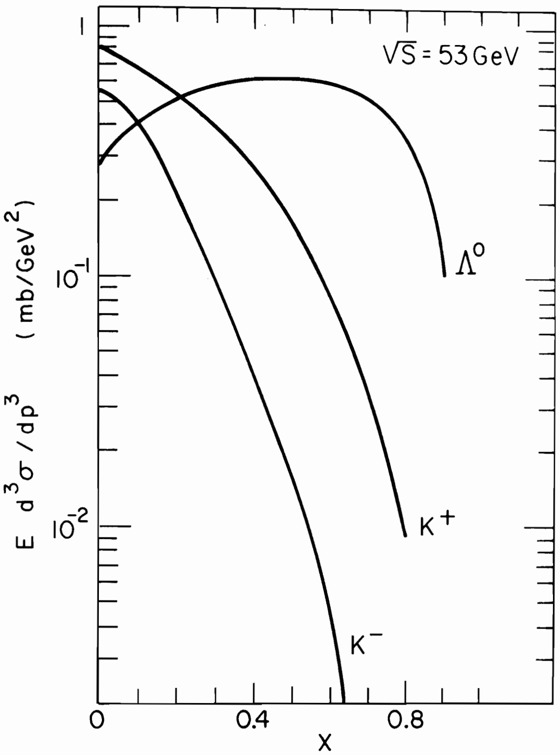


Fig. 7. Invariant cross sections versus Feynman x for inclusive Λ^0 [14] and $K^\pm$ [15] production at p_T = 0.55 GeV/c in pp interactions at $\sqrt{s}$ of 53 GeV.

Gustafson and Peterson [16] have calculated that a similar mechanism could give rise to diffractive production of Λ_c^+ at the level of ∿2% of Λ^0 production, that is ∿100 μb at $\sqrt{s}$ of 53 GeV. In Fig. 8 $\Delta\sigma/\Delta|x|$ from Table 2 is compared with $d\sigma/d|x|$ for Λ^0 production at $\sqrt{s}$ of 53 GeV [14]. Only the ACHMNR charm cross section appears compatible with the prediction of Ref. 16 that Λ_c^+/Λ_0 be ∿2%.

Recently the cross sections for D^+ production at x > 0.3 [17] and $D\bar{D}$ production at x = 0 [18] have been measured at $\sqrt{s}$ of 53, 63 GeV at the CERN ISR. In Fig. 9 the measured $\bar{D}$ cross sections are compared with K^- (strange analogue of D^+) cross sections over the same x range.* The ratios D^+/K^- differs by about two orders of magnitude for the two measurements.

*For D^+ production at x > 0.3 the smallest estimate of the cross section has been taken and averaged over 0.3 < x < 0.5.

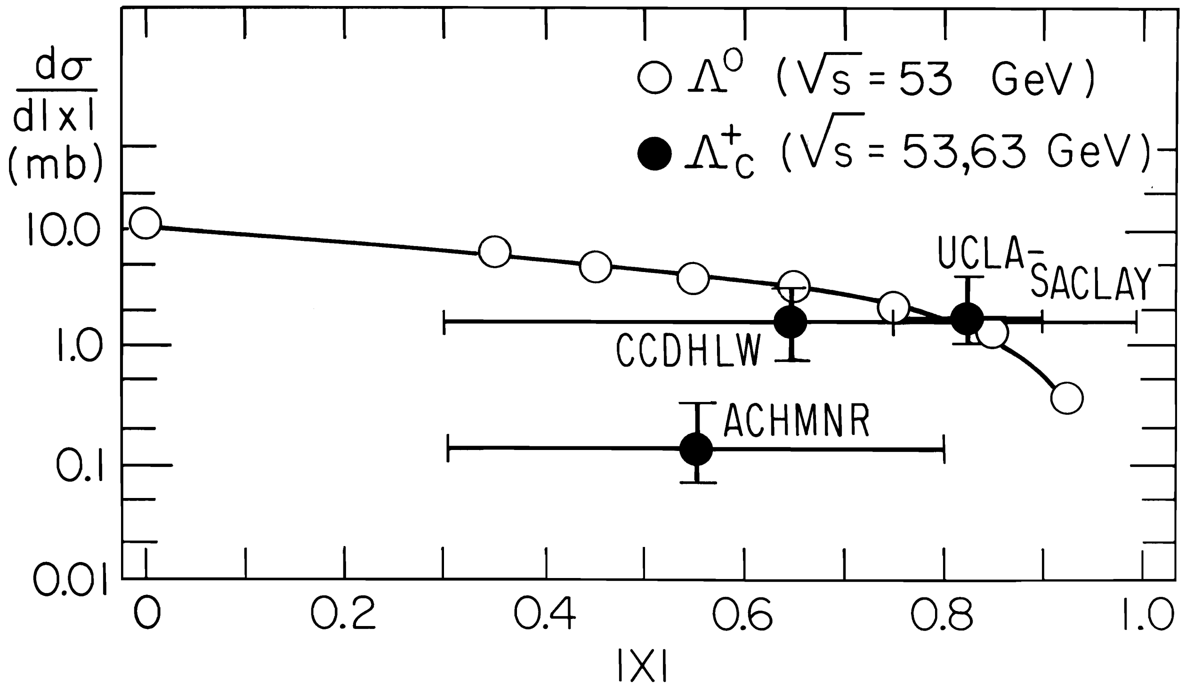


Fig. 8. $d\sigma/d|x|$ for Λ^0 at 53 GeV and Λ_c at 53 and 63 GeV. The smooth curve is a fit to the Λ^0 points. The cross sections from Table 2 have been multiplied by 2 to include negative x values.

IV. MASS OF Λ_c^+

The mass measured by ACHMNR is 2262 ± 10 MeV where the uncertainty includes systematic errors.* The peaks observed by CCDHLW are centered around 2260 MeV, - no error is quoted. The UCLA-Saclay collaboration find a mass near 2280 in the $\Lambda^0\pi^+\pi^+\pi^-$ channel and near 2290 in the $K^-\pi^+p$ channel, but state that "clear uncertainties in the precise shape of this background under the enhancement make a reliable determination of the mass of the state impossible with the present statistics."

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*Revised from the value given in Ref. 1.

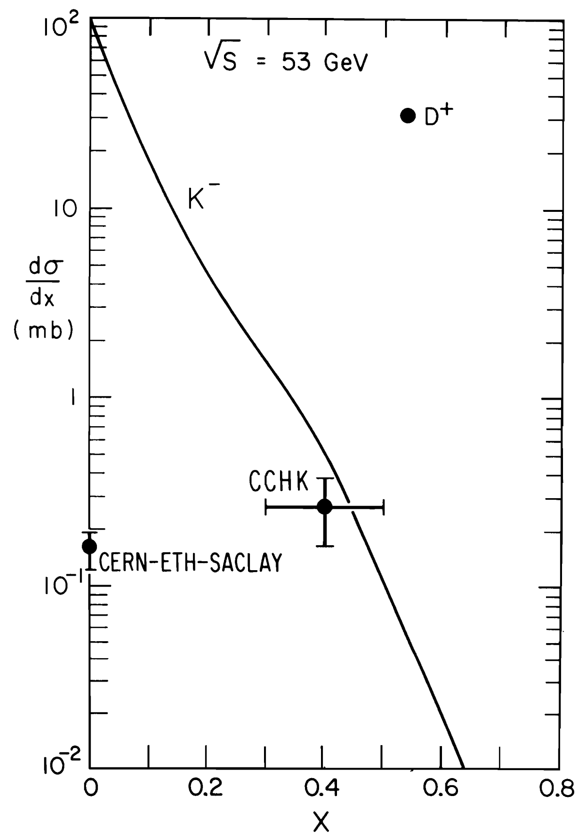

Fig. 9. The smooth curve is a compilation of $d\sigma/dx$ for inclusive K^- production at $\sqrt{s}$ of 53 GeV [15]. The solid circles are D^+ cross sections from Refs. 17 and 18.

DISCUSSION

Q. (Luth, SLAC) What do you know about the masses of the Λ_C?

A. The ACHMNR and the Split Field Magnet experiment both find a mass of 2.26. The UCLA-Saclay experiment finds a mass around 2280 or 2290.

Q. What are the errors on those numbers?

A. The statistical errors are around 5 MeV but I think it's fairly obvious if we compared these numbers with the SPEAR numbers that some experiment has systematic errors.