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PHOTOPRODUCTION OF THE Λ_c CHARMED BARYON

M.P. Alvarez[2], R. Barate[3b], D. Bloch[9], P. Bonamy[7], P. Borgeaud[7], M. Burchell[4], H. Burmeister[3], J.M. Brunet[6], F. Calvino[2a], M. Cattaneo[4], J.M. Crespo[2], B. d'Almagne[5], M. David[7], L. DiCiaccio[3c], J. Dixon[4], P. Druet[5], A. Duane[4], J.P. Engel[9], A. Ferrer[3d], T.A. Filippas[1], E. Fokitis[1], R.W. Forty[4], P. Foucault[9], E.N. Gazis[1], J.P. Gerber[9], Y. Giomataris[3], T. Hofmokl[10], E.C. Katsoufis[1], M. Koratzinos[3,4,5], C. Krafft[5], B. Lefievre[6], Y. Lemoigne[7], A. Lopez[3,5*], W.K. Lui[8], C. Magneville[7], A. Maltezos[1], J.G. McEwen[8], Th. Papadopoulou[1], B. Pattison[3], D. Poutot[6], M. Primout[7], H. Rahmani[1], P. Roudeau[5], C. Seez[4], J. Six[5], R. Strub[9], D. Treille[3], P. Triscos[6], G. Tristram[6], G. Villet[7], A. Volte[6], M. Wayne[5], D.M. Websdale[4], G. Wormser[5] and Y. Zolnierowski[3]

(The NA14/2 Collaboration)

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1) National Technical University, Athens, Greece.
2) Universidad Autónoma de Barcelona, Bellaterra, Spain.
3) CERN, Geneva, Switzerland.
4) Blackett Lab., Imperial College, London, UK.
5) LAL, IN2P3–CNRS and Univ. Paris-Sud, Orsay, France.
6) Collège de France, Paris, France.
7) DPhPE, CEN–Saclay, Gif-sur-Yvette, France.
8) Univ. of Southampton, Southampton, UK.
9) CRN, IN2P3–CNRS and Univ. L. Pasteur, Strasburg, France.
10) Univ. of Warsaw, Warsaw, Poland.
a) Univ. Politecnica de Catalunya, ETSEIB–DEN, Barcelona, Spain.
b) Univ. J. Fourier and ISN, Grenoble, France.
c) Univ. di Roma II, 'Tor Vergata', Rome, Italy.
d) Univ. de Valencia, IFIC, Valencia, Spain.
*) On leave from Fac. de Ciencias Fisicas, Univ. Complutense, Madrid, Spain.

ABSTRACT

In a photoproduction experiment using a mean photon energy of 100 GeV we have observed 29±8 Λ_c ($\overline{\Lambda}_c$) charmed-baryon and antibaryon decays in the $pK^-\pi^+$ ($\bar{p}K^+\pi^-$) final state. Quasi two-body final states do not contribute significantly to this channel. The mass of the Λ_c was measured to be $2281.7 \pm 2.7 \pm 2.6$ MeV/c^2 and its lifetime $0.18 \pm 0.03 \pm 0.03$ ps.

The ratio of Λ_c/D production, measured in this experiment, is significantly greater than that predicted by photon–gluon fusion and using a Lund model to describe the hadronization. This excess cannot be completely accounted for in this model, even using a Λ_c branching fraction in $pK\pi$ as high as 5%.

1. INTRODUCTION

Although precision measurements of the Λ_c*) mass and lifetime have recently been published [1], much less is known of the characteristics of the production and decay of charmed baryons compared with those of the charmed mesons.

This paper reports results obtained with a sample of photoproduced Λ_c reconstructed from 17 million triggers in the NA14/2 experiment. The experiment uses a large-acceptance spectrometer, combined with Cherenkov counters, and a silicon vertex detector that comprises an active target and microstrips. The apparatus is described elsewhere [2].

2. Λ_c SELECTION IN THE pKπ CHANNEL

The 17 million recorded events were obtained using a simple hadronic interaction trigger that required at least two charged particles to emerge from the interaction of the photon beam (mean energy 100 GeV) in the target.

All events were passed through a fast filter which reconstructed charged tracks and, where possible, identified them in the air Cherenkov counter (protons in the momentum range 21–38 GeV/c and kaons in the range 7–20 GeV/c). Events containing an identified pKπ combination were selected. When all three tracks were reconstructed in the microstrip detector a decay vertex fit was performed.

The primary vertex reconstruction is not straightforward owing to the presence of tracks from the decay of the second charmed particle; the method chosen was optimized using a Monte Carlo simulation. In the accessible Λ_c energy range, 30–80 GeV, the mean flight path is about 700 μm, barely twice the standard error in the separation of vertices reconstructed with the microstrip detector. Since the reconstructed Λ_c must originate from the primary vertex, only tracks intersecting the Λ_c trajectory were used in the fit. The most probable primary vertex was selected using geometrical and kinematical criteria, which were tuned using the Monte Carlo simulation.

The charmed-particle signal was selected by imposing a cut on either the proper lifetime of the decay or the separation of the production and decay vertices divided by the error on this distance (N_σ). This cut defines a minimum observable decay time, $t_{\min}$, for each event.

3. MASS SPECTRA

A clear signal of 29 ± 8 events over a low background was obtained in the pKπ mass distribution (fig. 1). A possible misidentification of a π or a K as a proton would allow D^+ or D_s decay to simulate that of Λ_c. Five events were compatible with these hypotheses, but removing them has no significant effect on the mass and lifetime estimates.

The Λ_c mass is measured as 2281.7 ± 2.7 ± 2.6 MeV/c^2. Two-body decays via resonant states ($\Delta\overline{K}$) and ($p\overline{K}^{*0}$) were investigated. No clear peaks were observed corresponding to the $\Delta^{++}(1232)$ and the $\overline{K}^{*0}(890)$. The numbers of events found in these mass regions yield branching ratios (relative to pKπ) that are compatible with other reported measurements [3].

*) Charge-conjugate states are implicitly included, except when distinguished in the text.

4. LIFETIME MEASUREMENT

Figure 2 shows the proper-time distribution for the selected sample. In the range of proper time considered (0.22–0.8 ps) the experimental acceptance on the Λ_c sample is practically uniform. The lifetime was determined [4] using a maximum likelihood method. The value obtained is $\tau = 0.18 \pm 0.03 \pm 0.03$ ps, in agreement with previous measurements [1, 3].

5. PRODUCTION MECHANISM AND CROSS-SECTION

Photoproduction of Λ_c ($\overline{\Lambda}_c$) is generally considered to result from the association of a c ($\bar{c}$) quark with a Q ($\overline{Q}$) diquark [5]. At high incident photon energies $Q\overline{Q}$ pairs are easily produced in mesonic or baryonic strings (fig. 3) and $\Lambda_c/\overline{\Lambda}_c$ production is symmetric (figs. 4a and 4b). At low energies (below about 50 GeV), insufficient phase space is available for $Q\overline{Q}$ production but the c quark can still form Λ_c through association with a spectator diquark Q from the nucleon (fig. 4c). Thus Λ_c production is favoured compared with $\overline{\Lambda}_c$. A Monte Carlo simulation [6], which includes both mechanisms and is based on the Lund model, has been performed for the photon energies relevant to the NA14 experiment. The excess of Λ_c over $\overline{\Lambda}_c$ is concentrated at low x_F; taking into account the experimental acceptance the model yields a $\overline{\Lambda}_c/\Lambda_c$ ratio of 0.9. The value for this ratio measured in our experiment is 0.6 ± 0.3.

The sum of the Λ_c and $\overline{\Lambda}_c$ cross-sections can be estimated from the total hadronic photoproduction cross-section and the Λ_c branching fraction $\mathrm{Br}(\Lambda_c \to pK\pi)$. Corrections have to be applied for experimental acceptance, and for trigger and analysis efficiencies. Since the Λ_c identification is limited by the Cherenkov detector to the 30–80 GeV range we quote the result

$$\sigma_{\Lambda_c}(E > 30\ \mathrm{GeV}) \cdot \mathrm{Br}(\Lambda_c \to pK\pi) = 2.5 \pm 0.7 \pm 0.7\ \mathrm{nb}.$$

A Monte Carlo extrapolation that includes all Λ_c energies, but with large model-dependent uncertainties, gives

$$\sigma_{\Lambda_c} \cdot \mathrm{BR} = 8 \pm 5\ \mathrm{nb}\ .$$

The Lund model for hadronization [7] predicts the charmed-baryon production relative to charmed-meson production. For one specific set of cuts we observed 500 $D^0 \to K\pi$ and 425 $D^+ \to K\pi\pi$ decays [4]. The Monte Carlo leads to an expectation of 2–3 Λ_c with a proper lifetime exceeding 0.4 ps. The number of Λ_c observed is six times this prediction.

High values for the Λ_c/D production ratio are implied from results reported in other recent experiments [8]. Part of the explanation could be an underestimate of the branching fraction $\mathrm{Br}(\Lambda_c \to pK\pi)$, and a recent analysis of data [9] yields a value about a factor of 2 higher than the world average (2.6±0.9% [3]). Figure 5 presents a comparison of experimental and theoretical Λ_c/D production ratios using $\mathrm{Br}(\Lambda_c \to pK\pi) = 5\%$. The error bars reflect only the statistical uncertainty of the measurements. Systematic experimental errors cancel to a large extent in each ratio, and uncertainties due to branching ratios are common to all experiments. Uncertainties due to the Lund model have not been included. We have used the default value 0.1 (which reproduces proton and Λ production) for the ratio of diquark production relative to quark production. The size of the discrepancy indicates a failing in the application of the Lund model to photoproduction, and probably also to e^+e^- production, of charmed baryons.

6. ANALYSIS USING THE FREON CHERENKOV COUNTER

For the last 4.3 million recorded events, a second Cherenkov counter with Freon was operational, which allowed extension of the identification of protons to the momentum range 13–20 GeV/c. A selection was made of Λ_c candidates using these protons.

The results of the fits for the Λ_c mass and lifetime are consistent with those found for the full sample. However, owing to the selection of events with low-energy protons, the Λ_c of this sample have a momentum range 20–35 GeV and were not included in the general analysis. The value measured for the $\overline{\Lambda}_c/\Lambda_c$ ratio is 0.7 ± 0.5.

7. CONCLUSIONS

We have measured, with low background, a clear signal of 29 ± 8 Λ_c decays. The mass and lifetime measurements agree with values obtained in other experiments. No evidence is observed for dominant two-body decays involving $K^*(890)$ or $\Delta^{++}(1232)$. The high Λ_c/D ratio found in this experiment exceeds the Lund model prediction even if the branching fraction is as high as 5%. Thus the analysis of Λ_c production in e^+e^- annihilation and photoproduction indicates that the Lund Monte Carlo program is unable to reproduce the high Λ_c yield.

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Figure captions

Fig. 1 The pKπ effective mass distribution.

Fig. 2 Proper-time distribution (the broken line applies to background events).

Fig. 3 Charmed-quark hadronization.

Fig. 4 The Λ_c and $\overline{\Lambda}_c$ production: symmetric production at high energy of Λ_c (a) and $\overline{\Lambda}_c$ (b); production of Λ_c from a target diquark (c).

Fig. 5 Comparison of ratios of observed and predicted relative production of Λ_c/D in different experiments [8] [assuming a branching fraction $Br(\Lambda_c \to pK\pi) = 5\%$].

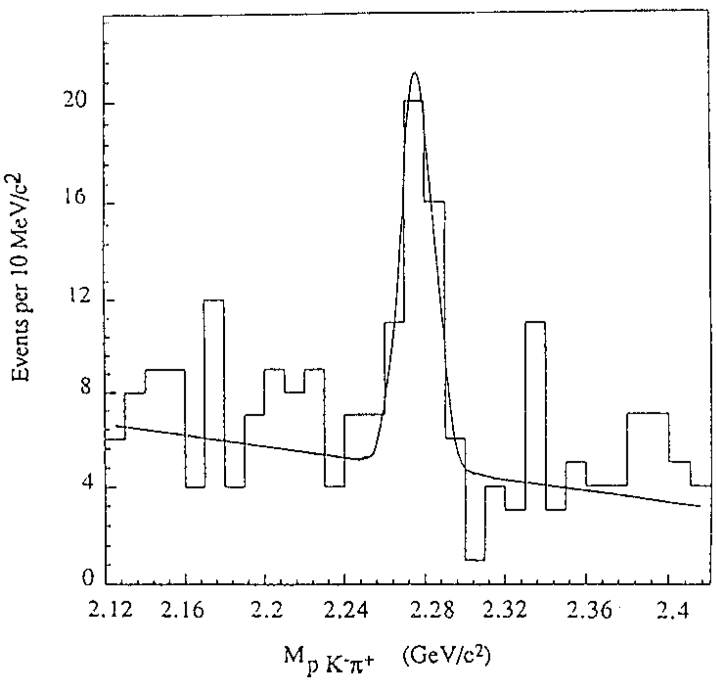

Figure 1

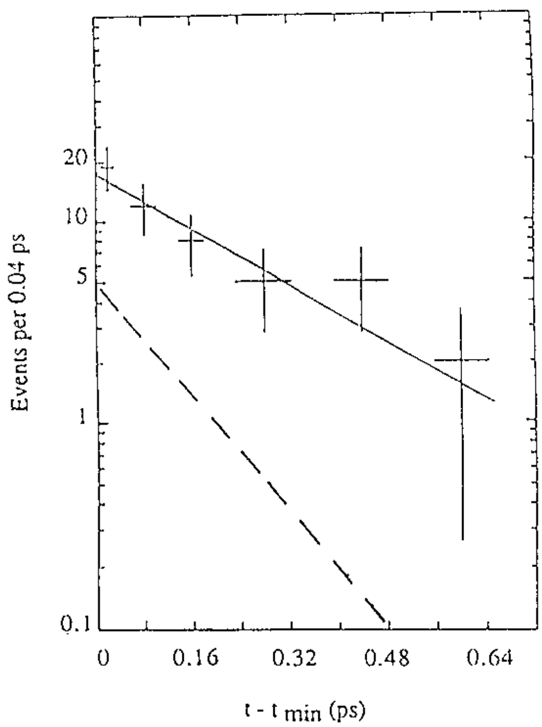

Figure 2

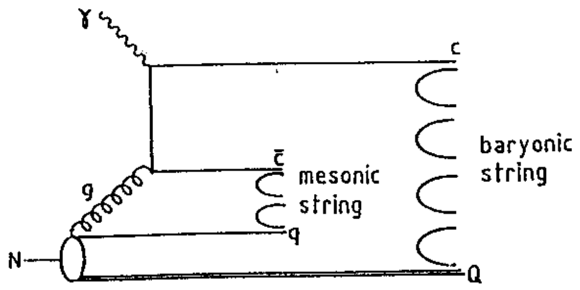

Figure 3

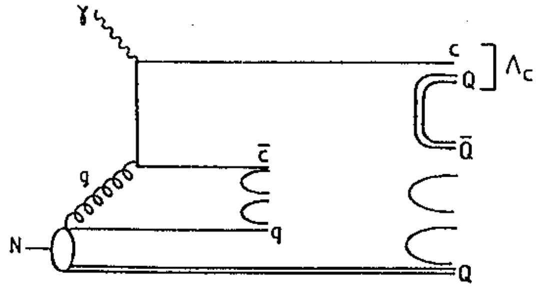

Figure 4 a

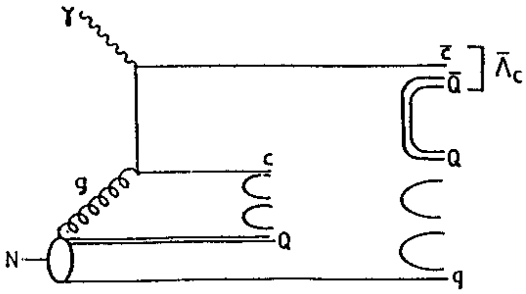

Figure 4 b

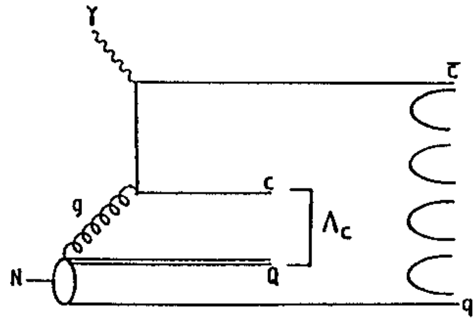

Figure 4 c

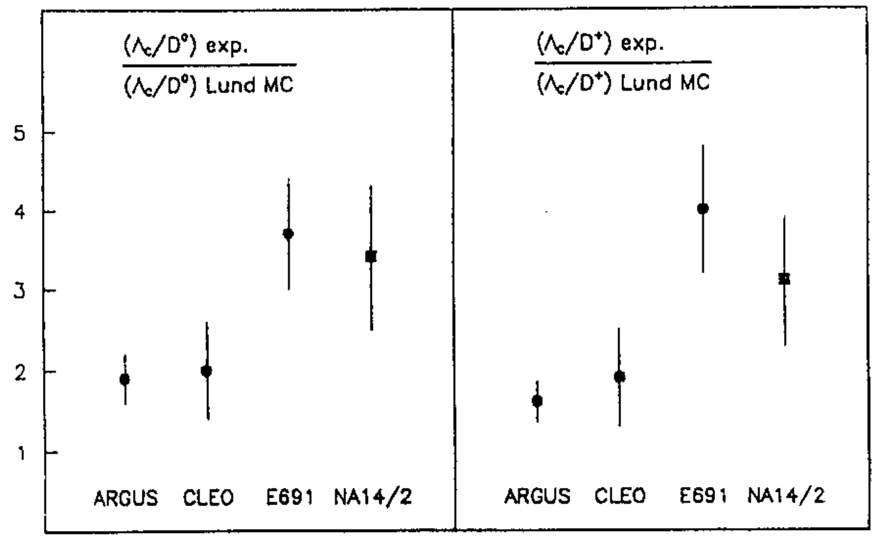

Figure 5