OBSERVATION OF THE CHARMED BARYON Σ_c IN e^+e^- ANNIHILATIONS

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Using the ARGUS detector at the DORIS II storage ring, we have observed the charmed baryons Σ_c^{++} and Σ_c^0, through their decays to $\Lambda_c^+\pi^\pm$. We have measured the mean Σ_c–Λ_c^+ mass difference as $167.6\pm0.3\pm1.6$ MeV/c^2. The isospin mass splitting between the Σ_c^{++} and the Σ_c^0 was found to be $1.2\pm0.7\pm0.3$ MeV/c^2. The rate of Λ_c^+ production from Σ_c decays was found to be $(36\pm12\pm11)$% of the total rate of Λ_c^+ production. The Σ_c x_p spectrum was observed to be similar to that of the Λ_c^+, with a Peterson function parameter ϵ of 0.29 ± 0.06.

In a previous publication [1] the ARGUS Collaboration has reported the observation of the charmed baryon Λ_c^+, the isospin singlet state of the lowest level charmed baryons. This paper [#1] reports the observation of two of the corresponding isospin triplet states, the Σ_c^{++} and the Σ_c^0. Measurements of the mass difference between the Σ_c and the Λ_c^+, and between the two observed Σ_c states provide useful tests of models for baryon spectroscopy. Determination of production characteristics of charmed baryons may assist in the understanding of the process of heavy quark fragmentation. To do this the x_p spectrum for Σ_c production was measured and the rate of Λ_c^+ production from Σ_c decays was determined.

The data used in this analysis were collected using the ARGUS detector at the DORIS II storage ring at DESY, and comprised an integrated luminosity of 219 pb^{-1} taken on the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(4S)$ resonances, and in the nearby continuum. The ARGUS detector and its particle identification capabilities are described in ref. [2].

The Σ_c states were observed by examining the Σ_c–Λ_c^+ mass difference spectrum, where the Σ_c was reconstructed from its decay to $\Lambda_c^+\pi^\pm$, and the Λ_c^+ was observed in decays to $pK^-\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, and $\bar{K}^0p$. The mass difference method exploits the fact that the Q value for the Σ_c decay is quite small and consequently the resolution of the mass difference is better than that of the mass of the Σ_c itself. Searches were made only for the Σ_c^{++} and Σ_c^0 states, as the Σ_c^+ would decay to $\Lambda_c^+\pi^0$, and studies involving neutral pions imply high levels of combinatorial backgrounds.

Λ_c^+ candidates were found using procedures similar to those described in ref. [1], with two differences. First, the likelihood ratio required for particle identification was 5% rather than 15%. A tight cut was required in the original Λ_c^+ analysis as D meson reflections proved to be a difficulty. In the Σ_c system, however, reflections of D* decays do not fall in the region of concern, and so the cut was relaxed. In addition, the requirement on the scaled momentum, x_p, of the Λ_c^+ candidate was dropped. Combinations from the different decay channels were used as Λ_c^+ candidates, if their masses were within 30 MeV/c^2 of the Λ_c^+ mass determined in ref. [1] for the $pK^-\pi^+$ and $\Lambda\pi^+\pi^-\pi^+$ channels, and 35 MeV/c^2 for the $\bar{K}^0p$ channel. To construct mass difference spectra, each selected Λ_c^+ candidate was combined with a π^+ for the Σ_c^{++} spectrum or a π^- for the Σ_c^0 spectrum. Two requirements were made on these $\Lambda_c^+\pi$ combinations. The scaled momentum x_p of the combination was required to be greater than 0.4, which greatly reduced the background. The quantity x_p is defined by $x_p=P(\Lambda_c^+\pi)/P(\Lambda_c^+\pi)_{max}$, where $P(\Lambda_c^+\pi)_{max}=\sqrt{E_{beam}^2-M^2(\Lambda_c^+\pi)}$. Furthermore, the cosine of the angle α between the π and the $(\Lambda_c^+\pi)$ boost direction, as measured in the $(\Lambda_c^+\pi)$ rest frame, was required to be greater than -0.8. The angle cut was motivated by the expectation that the angular distribution for pions originating from real, unpolarized Σ_c baryons, with spin $\frac{1}{2}$, would be isotropic in this frame, while background pions, particularly those from the opposite jet, would usually go backwards.

After applying these requirements, signals were seen in the mass difference distributions as shown in fig.

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[#1] In this paper references to a specific charge state should be taken to imply the charge-conjugate state also.

1. The mass difference spectra were fitted with a background function consisting of a third order polynomial, and a gaussian of fixed width to represent the signal. The width of the gaussian was fixed to the expected detector resolution of 1.8 MeV/c^2, as determined from Monte Carlo studies. For the $\Lambda_c^+\pi^+$ mass difference distribution, the fitted signal contained 92±19 events with a mass difference value of 168.2±0.5 MeV/c^2, while for the $\Lambda_c^+\pi^-$ mass difference distribution the signal contained 70±19 events at a mass difference of 167.0±0.5 MeV/c^2.

The average of the Σ_c^{++} and Σ_c^0 to Λ_c^+ mass differences was 167.6±0.3±1.6 MeV/c^2. The systematic error contains contributions from the uncertainty in the momentum scale calibration, and the effects due to difference between the Λ_c^+ mass as measured in its different decay modes [1]. This result is consistent with most previous attempts to measure the mass difference (see ref. [3]), but more accurate.

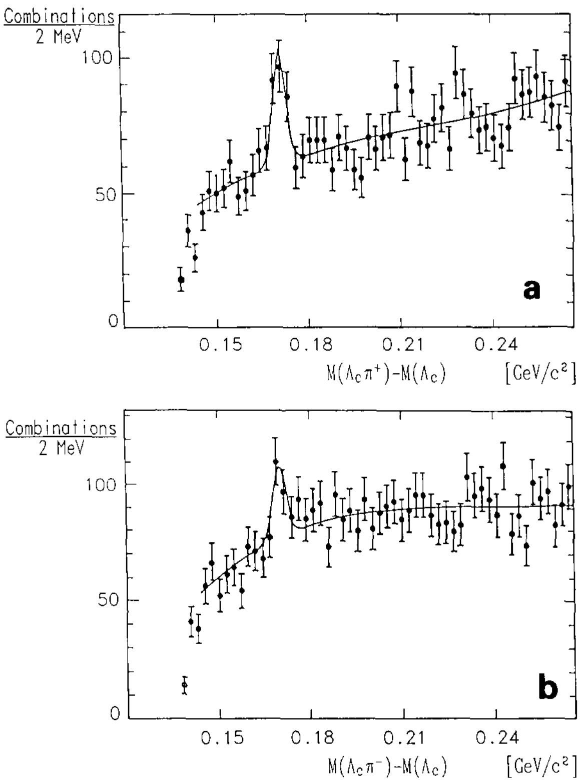

Fig. 1 (a) Mass difference spectrum for $\Lambda_c^+\pi^+-\Lambda_c^+$, using Λ_c^+ candidates from the decay modes $pK^-\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, and $\bar{K}^0p$. The solid line shows the best fit to a polynomial background and a gaussian signal shape. (b) Mass difference spectrum for $\Lambda_c^+\pi^--\Lambda_c^+$, using Λ_c^+ candidates from the decay modes $pK^-\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, and $\bar{K}^0p$. The solid line shows the best fit to a polynomial background and a gaussian signal shape.

The isospin mass splitting between the Σ_c^{++} and Σ_c^0 states is 1.2±0.7±0.3 MeV/c^2. In this case the systematic error is due to variations in the mass difference upon changing the background parametrization. This value is in major disagreement with the recent result reported by Diesburg et al. [4] of −10.8±2.9 MeV/c^2. While the two measurements report consistent values of the mass difference between the Σ_c^{++} and Λ_c^+, we see no indication of an enhancement in the region of the $\Sigma_c^0-\Lambda_c^+$ spectrum which corresponds to the mass difference as reported in ref. [4].

The x_p spectrum of the Σ_c was measured, after excluding data taken in the energy region of the $\Upsilon(4S)$ in order to eliminate possible contamination from the decay of B mesons to the Σ_c. The signals were divided into four bins of x_p, and a gaussian was fitted to each distribution with its width fixed to the Monte Carlo value for the resolution, and the mass fixed to the overall measured value in the particular charge state. The numbers were corrected for detector acceptance, in each x_p bin, using the weighted mean of the acceptance for the Σ_c^{++} and the Σ_c^0. The procedure was further complicated because the acceptance differs for each of the Λ_c^+ decay modes. For each Λ_c^+ channel the acceptance was determined by Monte Carlo simulation and weighted by the branching fraction of that particular Λ_c^+ mode relative to the decay to $pK^-\pi^+$. These ratios have been determined in ref. [1]. This procedure results in the acceptance normalized to the branching ratio of $\Lambda_c^+\to pK^-\pi^+$ as given by the expression

$$\frac{\eta(\Sigma_c)}{Br(\Lambda_c^+\to pK^-\pi^+)}=\sum_X\frac{Br(\Lambda_c^+\to X)}{Br(\Lambda_c^+\to pK^-\pi^+)}\cdot\eta(X),$$

where the sum X is over the modes $pK^-\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, and $\bar{K}^0p$. The result has a ±20% error due to the uncertainties in the relative branching fractions. Following this procedure the x_p spectrum shown in fig. 2 was obtained. This was fitted with the well known Peterson function [5], giving a value for the parameter ϵ of 0.29±0.06, which is close to that measured for the x_p spectrum of the Λ_c^+, which has a Peterson ϵ of 0.24±0.04.

The rate of Λ_c^+ production from Σ_c decays was de-

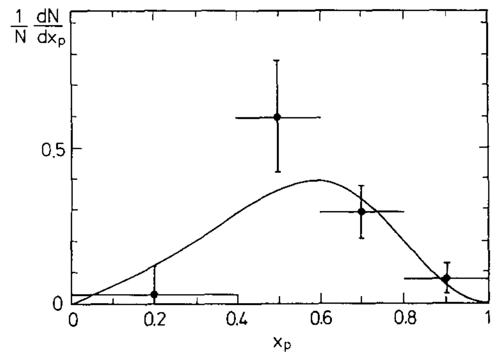

Fig. 2. Combined Σ_c^{++} and Σ_c^0 x_p spectrum.The solid line shows the results of a fit with the Peterson splitting function.

termined by making use of the above equation. The number of events in the entire x_p spectrum was determined by integrating the Peterson function derived from the fit, and dividing this by the number of Λ_c^+ baryons observed in the $pK^-\pi^+$ decay mode. This gives the fraction of Λ_c^+ baryons originating from the decay of each charge state of the Σ_c to be 0.12 ± 0.04. Assuming isospin invariance, for three Σ_c states, the total fraction of Λ_c^+ baryons produced from Σ_c decays is $0.36\pm0.12\pm0.11$. The systematic error contains contributions from the uncertainty in the acceptance weighting procedure, and the dependence of the number of fitted events on variation of the background parametrization.

In summary, we have observed two of the Σ_c states and found a mean mass difference between the Σ_c and the Λ_c^+ of $167.6\pm0.3\pm1.6$ MeV/c^2. We observe an isospin splitting between the Σ_c^{++} and Σ_c^0 states of $1.2\pm0.7\pm0.3$ MeV/c^2. These results should provide more precise tests of models for baryon spectroscopy. We have measured the rate of Λ_c^+ production from the decay of the Σ_c to be $0.36\pm0.12\pm0.11$ of total Λ_c^+ production.

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References

[1] ARGUS Collab., H. Albrecht et al., DESY preprint DESY 88-011, submitted to Phys. Lett. B.
[2] M. Danilov et al., Nucl. Instrum. Methods 217 (1983) 153;
R. Heller et al., Nucl. Instrum. Methods A 235 (1985) 26;
A. Drescher et al., Nucl. Instrum. Methods 205 (1983) 125; 216 (1983) 35;
A. Ariefiev et al., DESY preprint DESY 83-025 (1983);
K. Edwards et al., Nucl. Instrum. Methods A 252 (1986) 384.
[3] Particle Data Group, M. Aguilar-Benitez et al., Review of particle properties, Phys. Lett. B 170 (1986) 1, and references therein;
R.G. Ammar et al., JETP Lett. 43 (1986) 515.
[4] M. Diesburg et al., Phys. Rev. Lett. 59 (1987) 2711.
[5] C. Peterson et al., Phys. Rev. D 27 (1983) 105.