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A New Measurement of the Masses and Widths of the Σ_c^{*++} and Σ_c^{*0} Charmed Baryons

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Abstract

Using data recorded by the CLEO III detector at CESR, we have made measurements of some properties of the Σ_c^{*++} and Σ_c^{*0} charmed baryons. In particular: $\Gamma(\Sigma_c^{*++}) = 14.4^{+1.6}_{-1.5} \pm 1.4$ MeV, $M(\Sigma_c^{*++}) - M(\Lambda_c^+) = 231.5 \pm 0.4 \pm 0.3$ MeV, $\Gamma(\Sigma_c^{*0}) = 16.6^{+1.9}_{-1.7} \pm 1.4$ MeV, $M(\Sigma_c^{*0}) - M(\Lambda_c^+) = 231.4 \pm 0.5 \pm 0.3$ MeV.

In 1997[1], the CLEO collaboration reported the observation of two states, decaying into $\Lambda_c^+\pi^+$ and $\Lambda_c^+\pi^-$. These states were identified as the Σ_c^{*++} and Σ_c^{*0}, the cuu and cdd quark combinations in a $J^P = \frac{3}{2}^+$ configuration. Although the spin and parity of the states have not been measured, it is generally assumed that this identification is correct. In 2001[2] CLEO showed the first evidence of the third member of the Σ_c^* iso-triplet, the Σ_c^{*+}, which because of the large background and low efficiency associated with the detection of a π^0, had a lower signal to noise ratio[1]. Although other experiments[3] have shown evidence for Σ_c^* baryons, there have been no further published measurements of their properties. Measurement of the masses of the Σ_c^{*++} and Σ_c^{*0} can be used to check models that predict the isospin mass splitting between these states, and measurements of their widths can be compared with the widths of the Σ_c baryons to check the predictions of Heavy Quark Symmetry.

Here we present new measurements of the natural widths of the Σ_c^{*++} and Σ_c^{*0} baryons, together with measurements of their masses with respect to the Λ_c^+ mass. These measurements are made using the CLEO III detector configuration[4]. The CLEO III Ring Imaging CHerenkov (RICH) detector enables a much superior separation of protons, kaon, and pions compared to previous versions of the CLEO detector. This in turn lowers the background for Λ_c^+ detection and allows us to measure the properties of particles decaying into Λ_c^+ baryons with greater precision than was previously possible.

The data presented here were taken at the Cornell Electron Storage Ring, corresponding to an integrated luminosity of 14 fb^{-1} in the energy range 9.4 to 11.5 GeV. This data set was acquired to study the decay products of the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, and $\Upsilon(4S)$ resonances as well as the $e^+e^- \to q\bar{q}$ continuum data in this energy range. The production mechanism of the charmed baryons is not under study here, but we note that our kinematic cuts exclude the decay products of B mesons. Thus, the majority of the charmed baryons we measure are produced from the $e^+e^- \to q\bar{q}$ continuum, and some may be the direct decay products of the Υ resonances.

We observe the Σ_c^* candidates by their decay $\Sigma_c^{*++/0} \to \Lambda_c^+\pi^{+/-}$. Charge conjugate modes are implicit throughout. For this measurement we use the two Λ_c^+ decay modes $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to p\overline{K^0}$. The CLEO III detector configuration detects charged particles using a cylindrical drift chamber system inside a solenoidal magnet. Particle identification of p, K, and π candidates is performed using specific ionization (dE/dx) measurements in the drift chamber, combined with information, when present, from the RICH counters. The technique for combining the two identification systems follows the method that was used to find the decay $\Xi_c^0 \to pK^-K^-\pi^+$, and is described elsewhere[5]. The $\overline{K^0}$ candidates are found from the detection of the vertices of $K_S^0 \to \pi^+\pi^-$ decays that are significantly displaced from the beam spot.

To illustrate the good statistics and signal to noise ratio of the Λ_c^+ signals, we reduce the combinatorial background, which is worse for Λ_c^+ candidates with low momentum, by applying a cut on the scaled momentum, x_p. We define $x_p \equiv p_{baryon}/p_{max}$, where $p_{max} \equiv \sqrt{E_{beam}^2 - M_{baryon}^2}$. We fit the invariant mass distributions for these modes to a sum of a Gaussian signal and a low-order polynomial background. Figure 1 shows the plot for the $\Lambda_c^+ \to pK^-\pi^+$ signal; the signal yield is approximately 45,000. The decay mode $\Lambda_c^+ \to p\overline{K^0}$, which has superior signal to noise ratio, augments the number of candidates by 15%.

[1] The Σ_c^{*+} is not again addressed in this paper. The signal to background ratio in the new data set is no better than in the old.

Releasing the $x_p(\Lambda_c^+)$ cut, Λ_c^+ candidates within 2.0 σ of the peak mass in each decay mode were combined with each remaining charged π track in the event. A cut of $x_p > 0.5$ was made on the $\Lambda_c^+\pi$ combination, and the mass difference $\Delta(M) = M(\Lambda_c^+\pi) - M(\Lambda_c^+)$ was calculated.

The mass difference spectra, shown in Figure 2, are plotted in the mass range 178-298 MeV. The lower bound of this plot is chosen to avoid the contribution of $\Sigma_c^{++/0} \to \Lambda_c^+\pi^{+/-}$ decays. The upper bound is chosen to approximately center the Σ_c^* peaks.

The fits to the signal spectra in Figure 2 each have three components as follows. Firstly, the excesses in the region below 204 MeV due to $\Lambda_{c1}^+(2625)$ production are accommodated by functions found using the $\Lambda_c^+\pi$ spectrum from reconstructed $\Lambda_{c1}^+(2625)$ decays, with the normalization corrected using a Monte Carlo program. Secondly, we use a background shape of a first order polynomial. Lastly, we use signal functions of spin-1 Breit-Wigners convolved with a Gaussian resolution function of standard deviation, $\sigma = 1.61$ MeV. This resolution was calculated using a GEANT-based Monte Carlo simulation program[6] for a peak in the region under scrutiny.

In the case of $\Lambda_c^+\pi^+$ we obtain a signal of 1330 ± 110 events, with a width of $\Gamma = 14.4^{+1.6}_{-1.5}$ MeV, and a mass difference of $\Delta(M) = 231.5 \pm 0.4$ MeV. For the $\Lambda_c^+\pi^-$, we obtain a signal of 1350 ± 120 events, with a width of $\Gamma = 16.6^{+1.9}_{-1.7}$ MeV, and a mass difference of $\Delta(M) = 231.4 \pm 0.5$ MeV.

We have checked that consistent widths and mass differences are extracted if the data are restricted to particles or anti-particles, and if the data are restricted to data taken at the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ (resonances where the signal to background ratio is not as high), or in the $\Upsilon(4S)$ and non-resonant regions.

The parameters of the extracted signals depend on the exact method of fitting used. We have tried many variations of the background functions and fitting range. These include using a second-order Chebychev polynomial for the background function, allowing the $\Lambda_{c1}(2625)$ contribution to float, and extending the fitting range to much higher values of $\Delta(M)$. The systematic uncertainties in the measurements due to the fitting procedures are taken as being the maximum range of parameters obtained using different reasonable fits of these types. This is the dominating systematic uncertainty for the width measurements. The results of the Monte Carlo simulation program that predicts the detector resolution have been checked using a series of narrow states in our data. Based on the agreement of the simulation and the results of analyzing these peaks, we assign a systematic uncertainty of ± 0.13 MeV to the value of the detector resolution for the Σ_c^* states. As the resolution is an order of magnitude less than the intrinsic widths that we measure, this uncertainty produces a modest uncertainty (≈ 0.14 MeV) in the measurements of the widths, which is negligible compared with the uncertainty due to the fitting technique.

The masses of the signals are insensitive to the fitting technique, and the different fits produce a maximum range of ± 0.2 MeV for the measurements. We allow for a systematic uncertainty of 0.2 MeV from possible analysis biasses. An uncertainty in the CLEO magnetic field strength of 0.1%, which is bounded by measurements of particles of known mass, corresponds to an uncertainty of 0.13 MeV in the mass difference measurements. These three sources of uncertainty add in quadrature to give a total systematic uncertainty in the mass difference measurements of 0.3 MeV. These last two uncertainties do not contribute to the systematic uncertainty in the isospin mass splitting between the two states.

Our measurements of the Σ_c^* masses and widths are consistent with the previously published CLEO numbers[1]. However, the splitting between the two states $M(\Sigma_c^{*++}) - M(\Sigma_c^{*0})$,

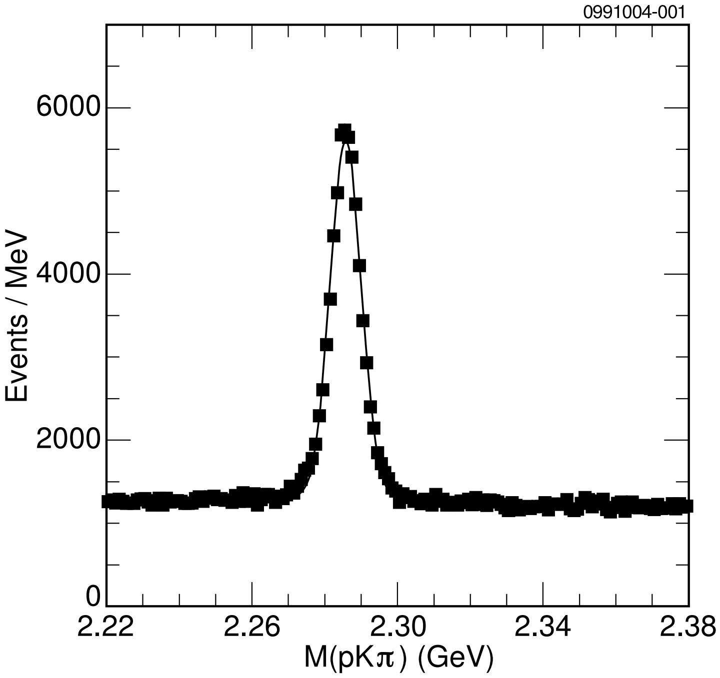

FIG. 1: Invariant mass plot for $pK^-\pi^+$ combinations with $x_p(pK^-\pi^+) > 0.45$

is now measured to be $-0.1 \pm 0.8 \pm 0.3$ MeV, whereas previously it was $+1.9 \pm 2.0$ MeV. This isospin splitting is expected to be small and negative[7]. The difference in the widths of the two states is expected to be negligible. By Heavy Quark Symmetry[8] the ratio $\Gamma(\Sigma_c^*)/\Gamma(\Sigma_c)$ should equal $(M_{\Sigma_c}/M_{\Sigma_c^*}) \times (p_\pi(\Sigma_c^*)^3/p_\pi(\Sigma_c)^3)$, where p_π is the momentum of the π in the parent's rest frame. The isospin mass splitting of the states is very small, and for both the doubly charged and neutral states this latter quantity equals 7.5 ± 0.1. Using our new values of the Σ_c^* widths, and world average values of the Σ_c states[9], we obtain $\Gamma(\Sigma_c^{*++})/\Gamma(\Sigma_c^{++}) = 6.5 \pm 1.3$ and $\Gamma(\Sigma_c^{*0})/\Gamma(\Sigma_c^0) = 7.5 \pm 1.7$, in excellent agreement with expectation.

In conclusion, we present new measurements of the properties of the Σ_c^{*++} and Σ_c^{*0} baryons. For the doubly charged state $M(\Sigma_c^*) - M(\Lambda_c^+)$ is measured to be $231.5 \pm 0.4 \pm 0.3$ MeV and $\Gamma = 14.4^{+1.6}_{-1.5} \pm 1.4$ MeV, and for the neutral state $M(\Sigma_c^*) - M(\Lambda_c^+)$ is measured to be $231.4 \pm 0.5 \pm 0.3$ MeV and $\Gamma = 16.6^{+1.9}_{-1.7} \pm 1.4$ MeV.

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[1] G. Brandenberg *et al.,* Phys. Rev. Lett. **78**, 2304 (1997).

[2] R. Ammar *et al.,* Phys. Rev. Lett. **86**, 1167 (2001).

[3] N. Gabtshev *et al.,* Phys. Rev. **D66**:091102 (2002).

[4] Y. Kubota *et al.,* Nucl. Instr. Meth. **A320**, 66 (1992), G. Viehauser *et al.,* Nucl. Instr. Meth.

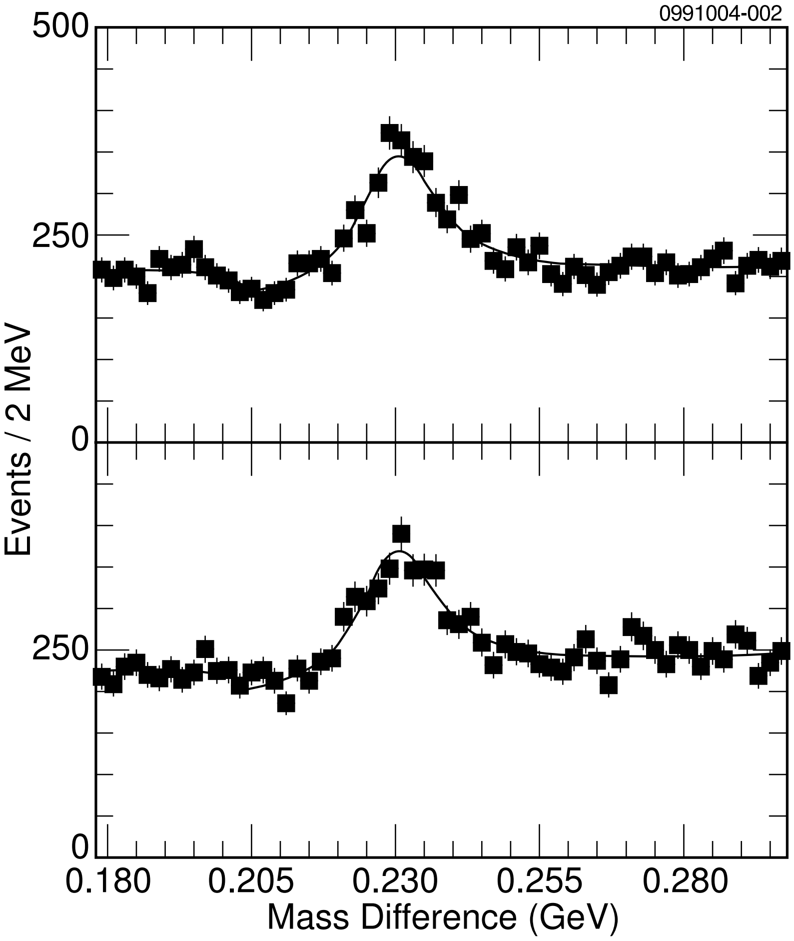

FIG. 2: $M(\Lambda_c^+\pi) - M(\Lambda_c^+)$ mass differences for (upper) π^+ and (lower) π^- combinations

A462, 146 (2001), D. Peterson *et al.,* Nucl. Instr. Meth. **A478**, 142 (2002), M. Artuso *et al.,* Nucl. Instr. Meth. **A502**, 1991 (2003).

[5] I. Danko *et al.,* Phys. Rev. **D69**:052004 (2004).

[6] R. Brun et al., CERN/DD/EE/84-11.

[7] S. Capstick, Phys. Rev. **D36**, 2800 (1987), W. Y. P. Hwang and D. Lichtenberg, Phys. Rev. **D35**, 3526 (1987), R. E. Cutkosky and P. Geiger, Phys Rev. **D48**, 1315 (1993).

[8] D. Pirjol and T-M. Yan, Phys. Rev. **D56**:5483 (1997).

[9] M. Artuso *et al.,* Phys. Rev. **D65**:071101 (2002), J. Link *et al.,* Phys. Lett. B525, 205 (2002).