A Review of Charmed Baryon Experimental Data

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1 Introduction

This is a review of the experimental results on charmed baryons, with the accent on those reported most recently.

2 Motivation

The charmed baryon sector is the richest quark spectroscopy available for study. Compared with mesons there are *more* states as there are more possibilities for orbital excitations. More importantly, the extra mass associated with these excitations is less (because it is inversely proportional to a measure of the center-of-mass), leading to less phase space for decays and *narrower* states. The charm quark is sufficiently massive for the states to be described as a combination of a heavy quark and a light di-quark - this picture does not work well for strange baryons. The charmed baryon sector is much easier to study experimentally than the B baryon sector. It also offers a good laboratory for studying weak decays as there are four weakly decaying singly charmed baryons.

3 Techniques

There are two main techniques that have been used in recent years for charmed baryons studies. Fixed target experiments, such as FOCUS, SELEX and E-791 at Fermilab, have a long pathlength for charm decays which can be used as a tag, and also can yield accurate lifetime measurements. Spectroscopy has tended to be easier at e^+e^- machines operating at around 10 GeV (notably CLEO, now joined by BELLE). In the e^+e^- continuum, around 40% of events are charm. Running at the Λ_c^+ threshold has not been done for a long time but there is hope that CLEO_c will do this in the future.

4 The Greek Alphabet of Charmed Baryons

We always consider a charmed baryon as the combination of a (heavy) charm quark and a light di-quark, which has its own well-defined quantum numbers J^P_{LIGHT}. This combines with the charm quark to give the overall J^P of the state. If the two light quarks are u and/or d then the particle is either a Λ_c or a Σ_c. The former are anti-symmetric under interchange of the two light quarks and are iso-scalars, the latter are symmetric under interchange and are iso-triplets. When one of the two light quarks is a strange quark the baryons are called Ξ_c states, and if both light quarks are strange it is an Ω_c.

5 The Λ_c^+ Ground State

More than thirty decay modes of the Λ_c^+ have been measured. A recent contribution comes from BELLE[1] who have measured a series of comparatively rare decays that are either Cabibbo-suppressed (such as the first observation of ΛK^+) or unambiguously due to W-exchange diagrams. There have also been two recent measurements of the Λ_c^+ lifetime, from SELEX[2] ($\tau(\Lambda_c^+) = 198.1 \pm 7.0 \pm 5.6$ fs) and FOCUS ($\tau(\Lambda_c^+) = 204.6 \pm 3.4 \pm 2.4$ fs [3]). The PDG 2001[4] number of of 188 ± 7 seems to be edging up. This is of course a short lifetime by charm standards, presumably because W-exchange is an allowed method for Λ_c^+ decays, as has been shown directly.

6 Recent Σ_c and Σ_c^* Results

The doubly charged and neutral Σ_c states are relatively easy to observe as they decay with a charged pion to the Λ_c^+ ground state. The masses of all three Σ_c states have been well measured. Two recent measurements from CLEO[5] and FOCUS[6] measure the natural widths, with all results being around 2 MeV. The singly charged states decay via a π^0 decay which is usually harder to detect experimentally. There are fewer measurements of the Σ_c^* states because their large natural widths cause complications. The singly charged state was only recently reported by CLEO[7]. Looking at all the results, we can note that a) there is little isospin splitting, but the singly charged state may be a little lighter than the others in line with predictions[8], b) the width of the $\frac{3}{2}$ states is around seven times that of the $\frac{1}{2}$ states - this is in line with predictions that this ratio depends only on a few simple numerical factors plus phase-space[9], and c) a very naive quark model which predicts that the mass splitting between the spin-weighted average of the Σ^*-Σ system and the ground state should be independent of the heavy quark mass, and the splitting between the $\frac{3}{2}$ and $\frac{1}{2}$ states is inversely proportional to heavy quark mass. The strange and charmed $\Sigma - \Lambda$ system obeys this scaling law very well. I expect it to do so in the B-system also.

7 Higher States

Allowing orbital angular momentum into the picture produces a large number of predicted states. Some of these can be expected to be narrow and some very wide. With the $L = 1$ between the heavy quark and the light di-quark, there should be 2 Λ_{c1} states (well known and well measured) and no fewer than 5 iso-triplets of Σ_c states. Most people use a numerical subscript to denote the spin of the light diquark. Alternatively, having $L = 1$ between the two light quarks produced 5 Λ_c states and 2 iso-triplets of Σ_c's. All these particles (except maybe some above pD threshold), will cascade down via (multi-)pion decays to the ground-state Λ_c. CLEO have found two bumps in $\Lambda_c^+\pi^+\pi^-$[10]. One is wide, and they like the identification as the first two Σ_{c1} states. The second is more interesting as it is fairly narrow, and they identify it as the first of the second generation of orbitally excited Λ_c particles. This particular state has no allowed single pion decay available. These observations have yet to pique the theorists interest. Figure 1 shows a guess of the spectroscopy of the $\Lambda_c - \Sigma_c$ states, based upon a very simple potential model. The states that CLEO guesses correspond to their bumps are denoted by bold lines.

8 The Ξ_c Spectrum

The *csu* and *csd* quark combinations are referred to as Ξ_c^+ and Ξ_c^0 respectively. Their spectroscopy follows the lines of the $\Lambda_c - \Sigma_c$ pattern, except that it comprises only iso-doublets, rather than iso-singlet and iso-triplets. The first 10 states (analagous to the those up to and including the $\Lambda_{c1}(2630)$) have been reported. Nine of these first observations were by CLEO[11] and many of them have yet to be confirmed. The Ξ_c^+ groundstate has been known since the eighties (although first sightings[12] were controversial), and its lifetime has been measured several times with a PDG (2001)[4] average of 330^{+60}_{-40} fs. Since then have been two more measurements of this lifetime. The CLEO II.V detector selects a clean sample of Ξ_c^+ decays, but its pathlength resolution is comparable to the individual pathlengths. It finds $503 \pm 47 \pm 18$ fs[13]. FOCUS has more events[14], worse signal-to-noise, but much better lifetime resolution. It obtains $439 \pm 22 \pm 9$ fs. It seems that the Ξ_c^+ lifetime is creeping up.

9 The Ω_c

The $\Omega_c(css)$ combination was reported many times over the last two decades, but we can safely say now that most have been shown to be incorrect on mass and/or cross-section grounds. The E-687 peak in $\Sigma^+K^-K^-\pi^+$ is the one that still looks impressive[15]. In 2001 CLEO[16] found a good looking peak using the sum of 5 "expected" decay modes (not including $\Sigma^+K^-K^-\pi^+$). Now BELLE[17] has (prelimi-

nary) results shoding an extremely clean peak in $\Omega^-\pi^+$. Their mass ($2693.7 \pm 1.3^{+1.1}_{-1.0}$ MeV) agrees well with the CLEO number ($2694.6 \pm 2.6 \pm 1.9$ MeV). There is no doubt that the Ω_c has been discovered.

A recent analysis by CLEO finds semi-leptonic decays of the Ω_c. They reconstruct $760 \pm 32\ \Omega^-$ baryons (it is clearly tough to produce an sss state in e^+e^- annihilations). They then look for correlations with correctly charged electrons. After subtraction of backgrounds, they find an excess of 11.4 ± 3.8 events that are attributable to $\Omega_c \to \Omega^- e^+ \nu$ events. The ratio of the simplese hadronic decay mode $\Omega^-\pi^+$ to this semi-leptonic mode is $0.41 \pm 0.19 \pm 0.04$. This is similar to analagous ratios in Ξ_c^0 and Λ_c^+ decays.

10 Doubly charmed baryons

Theorists have always enjoyed predicting the masses of the doubly charmed baryons Ξ_{cc}^{++} (ccu) and $\Xi_c c^+$ (ccd). SELEX have shown[18] peak (of only 3 σ significance and definitely preliminary) in the decay mode $\Lambda_c^+ K^-\pi^+\pi^+$. The mass is 3.79 GeV. I do not understand what processes must be involved to produce enough of them so that an individual decay mode of one of the states will make around 1% of the Λ_c^+ candidates in their sample.

11 Conclusion

There have been 22 charmed baryon states reported in the literature, though many of them need to be confirmed. They display a spectroscopy that is complex, yet orderly and comprehensible. There remains more work to be done on spectroscopy, and work is still active in understanding decay mechanisms. In the future, BELLE and BaBar are the experiments best placed for new discoveries, and CLEO_c operating at Λ_c^+ threshold could also make complementary contributions.

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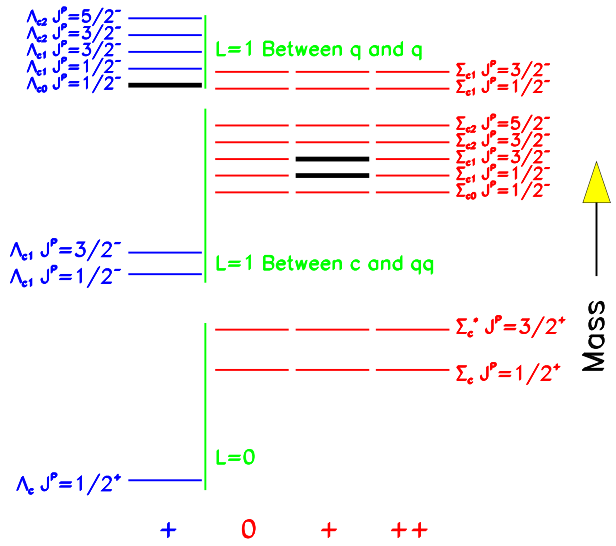

Figure 1: The author's view of the expected mass spectrum of singly-charmed baryons.

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