Charm Baryon Working Group Report

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Charm baryons has been singled out as a separate study group for a good reason. Most of what we have learned on charm physics comes from the study of charm mesons, because there are much more data for charm mesons than for charm baryons. The standard dogma is that this will continue to be true in the future. However, significant experimental progress has been made recently for charm baryons, and this has been slowly followed by more theoretical interest [1]. The charge of this working group was to determine how much the study of charm baryons can increase our knowledge of charm physics; what physics can be studied more easily with charm baryons than with charm mesons; and how to boost the production and reconstruction efficiency for charm baryons. We start our discussion with a list of physics topics.

1. LIFETIMES. A systematic study of the lifetimes of the weakly decaying charm baryons can give us information on the different roles of spectator decay, W-exchange, and interference. A number of circumstances make the study of charm baryon lifetimes extremely important in their own right and also complementary to what can be learned from charm meson lifetimes. The four weakly decaying (singly) charm baryons, when added to the three charm mesons, more than doubles the amount of possible lifetime measurements and makes a comparison of lifetime ratios with theory much more practical. Since W-exchange is not helicity suppressed in Cabibbo-favored charm baryon decays, and since there are more interference possibilities in charm baryon decays, charm baryon lifetimes are more sensitive to W-exchange and interference contributions. This neatly complements the study of charm meson decays.

   Although there have been recent improvements in the lifetime measurements of a number of different charm particles, improvements in the reliability of theoretical predictions have not followed. It can be seen from some older work on charm baryon lifetimes [2], that the absolute lifetimes are difficult to predict reliably but the ratios of lifetimes can be more reliably calculated. It has even been said that the QCD-based 'inclusive' approach adopted in these calculations will never become fully quantitative [3], however, measurements of the lifetimes will still be informative [4]. So on the theoretical side one needs to improve the reliablity of calculations for the absolute lifetimes and also set out a procedure whereby one can extract useful information on the various decay contributions from the different lifetime measurements. On the experimental side, the precision of lifetime measurements of the D mesons are now at the 1% level. One may expect similar precision to be reached for the Λ_c^+ and Ξ_c^+, but the short lifetimes of the Ξ_c^0 and Ω_c^0 are almost comparable to the current experimental resolution of 0.05–0.07 ps, which limits the precision of lifetime measurements. Improvements in the longitudinal vertex resolution are required in the future. This will also improve signal-to-noise and produce a more uniform acceptance with lifetime.

2. HADRONIC DECAYS. We can surely learn more about W-exchange from the study of charm baryons, since this is not helicity or color suppressed as in charm meson decays, but can we learn more about final state interactions and interference effects? Also, two-body decays appear quite dominant in charm meson decays; is this true for charm baryons? Maybe W-exchange can play a role in the resonant structure of charm decays? It is difficult to answer these questions at present due to both the lack of data on charm baryon exclusive hadronic decays and the corresponding lack of theoretical knowledge. There are several older and more recent theoretical analyses of charm baryon hadronic decays [5]. A desirable theoretical work would be a compilation of specific charm baryon decays from which one can extract useful information on W-exchange and Final State Interactions.

   Traditional Dalitz plot analyses would be useful, but no Dalitz plot analysis on charm baryon decays has yet been done that correctly handles the spin effects. Some theoretical work on this would be helpful. Resonant analyses greatly benefit from large signal-to-noise, but in the past this has been difficult to achieve with large efficiency, mainly due to the short lifetime of charm baryons and background from the more adundant charm meson decays. Another area of charm baryons that could be greatly improved is the number of different fully reconstructed decay modes. Not many have so far been seen, and for a good reason: the decay baryon has to be reconstructed. These consist of: protons, which must be identified with good efficiency to eliminate abundant pions and kaons; neutrons, which are difficult to reconstruct and cannot be used in vertexing; Λ^0, which normally cannot be used in vertexing and some are lost due to its relatively long lifetime; $\Sigma^{\pm,0}$, difficult to reconstruct due to neutral particles in their decay modes, and some are lost due to their relatively long lifetimes; and $\Xi^{-,0}$ and Ω^-, which require the reconstruction of a Λ^0 (and π^0 for the Ξ^0) and some of which are lost due to two relatively long-lived decays. To compete with charm meson decays, one has to increase the acceptance and efficiency for reconstruction of these baryons relative to what has been achieved so far.

3. ABSOLUTE BRANCHING RATIOS. To aid in comparisons with theory where (normally) absolute rates are calculated, one requires the absolute branching ratios, as well as lifetimes. We could not think of any particularly good methods of obtaining absolute branching ratios for the $\Xi_c^{+,0}$ and Ω_c^0 charm baryons. Methods already exist for extract-

ing the absolute branching ratio for Λ_c^+ [6, 7]. Using theoretical predictions of exclusive semileptonic decays one may be able to relate the Λ_c^+ decays to the $\Xi_c^{+,0}$ and Ω_c^0 decays, but one still needs more knowledge of their production. Probably a specialized experiment is needed for a measurement of the absolute branching ratio of the $\Xi_c^{+,0}$ and Ω_c^0 charm baryons.

4. SPECTROSCOPY. Recently there has been a lot of interest in excited D mesons (D^{**}). The spectroscopy of excited charm baryon states should be much "richer" just because there are more of them; these should complement our studies of excited D mesons although they are theoretically more difficult to handle [8]. The large number of mass splittings that can be studied should provide an excellent testing ground for theory, but an experimental analysis will require excellent photon and π^0 reconstruction efficiency, as well as very efficient reconstruction of the ground-state charm baryons. In order to measure narrow natural widths, it is anticipated that one would require better mass resolution than is typical of charm experiments so far. Since most resonances are expected to decay strongly, there would be an advantage to having a primary vertex which is relatively clean of pions, as in photoproduction.

5. SPIN DEPENDENT DECAYS. It is possible that charm baryons could be produced polarized in hadroproduction, as has been observed for strange baryons [9]. Charm baryons offer another experimental ground for this study and a spin analysis should be easily achievable as long as we have excellent signal-to-noise [10].

6. CHARM BARYON PRODUCTION. Almost all the experimental results on charm production have come from J/ψ and D studies. Charm baryon production will complement this study, and also enables investigation of other features of charm production like associated production. We know of no recent theoretical work on charm baryon production. A theoretical analysis may motivate more enthusiasm for future experimental studies [11]. We expect many new results from Fermilab experiment E791 and upcoming experiment E781 on charm baryon hadroproduction. Results on charm baryon photoproduction should come from the upcoming Fermilab E831 experiment.

7. DOUBLY CHARM BARYONS. The physics interest of the doubly charm baryons *ccd*, *ccu* and *ccs* is covered in an article by Jean-Marc Richard in these Proceedings. We did not come up with a method to calculate reliably the production of these baryons, but a back-of-the-envelope calculation shows that it is quite possible that a few could be seen in the next generation of charm experiments (Fermilab E831 and E781). These are expected to decay weakly with reasonably charm-like lifetimes into D mesons plus baryons or into charm baryons, mainly Ξ_c [12]. Reconstruction of these doubly charm states require excellent reconstruction efficiency for Ξ_c. It is not known how the production of these doubly charm baryons could be enhanced.

8. RARE/EXOTIC DECAYS. We cannot normally hope to compete with charm meson studies in the search for rare or exotic decays, and we could not think of any phenomena that would affect uniquely charm baryon decays but not charm mesons.

9. SEMILEPTONIC DECAYS. The inclusive semileptonic partial widths for D^0 and D^+ are observed to be the same. It would be interesting to study whether this is true for the charm baryons. This would not be true if interference effects are important for one charm baryon and not another. Information on the inclusive semileptonic partial widths may be helpful in determining the charm baryon lifetimes if one has a reliable theoretical model for what fraction of the total width is semileptonic. A determination of the inclusive semileptonic width is experimentally difficult due to large backgrounds unless one can produce a particular charm baryon cleanly or can find a clean tag. Exclusive semileptonic charm baryon decays should be easier to reconstruct. It would be interesting to study whether these decays are saturated by pure 3-body decays (one hadron and the lepton and neutrino) as in the case of the D mesons. These studies would also complement our studies using charm mesons of form factors and CKM matrix elements. Measurement of the exclusive semileptonic charm baryon decays may be helpful in extracting absolute branching ratios for the charm baryons.

It is clear to this working group that the study of charm baryons can provide unique physics and also information complementary to that gained from a study of charm mesons. It is also clear that in the majority of past experiments, the focus of beam considerations, triggering conditions and detector elements have been on charm mesons. It was felt by this group that to gain significantly in our knowledge of charm physics through the study of charm baryons, one has to focus on the special requirements of charm baryons: enhancing their production and improving their reconstruction. The reconstruction needs improvement in vertex resolution, due to the short lifetimes of the charm baryons; in momentum/mass resolution to improve the signal-to-noise and measure natural widths; in acceptance of the relatively long lived hyperons that have to be reconstructed; and in particle identification to improve signal-to-noise. These considerations were taken into account for CERN experiment WA89 and the upcoming Fermilab experiment E781, which have been designed to study charm-strange baryons. The upcoming Fermilab experiment E831, which is a "normal charm meson" experiment, is expected to fully reconstruct 20,000 $\Lambda_c^+ \rightarrow pK^-\pi^+$ and one million charm mesons. A future CHARM 2000 "normal charm meson" experiment that reconstructs 100 million charm mesons may be expected to reconstruct one million $\Lambda_c^+ \rightarrow pK^-\pi^+$ and 10,000 each of Ξ_c^+, Ξ_c^0 and Ω_c^0. Obviously the impact of such an experiment will depend on whether E781 can achieve their goal of fully reconstructing 100,000 $\Lambda_c^+ \rightarrow pK^-\pi^+$, 150,000 each of Ξ_c^+ and Ξ_c^0, and 5,000 Ω_c^0 [13]. If so, we believe a specialized charm baryon experiment will be required to significantly improve on that.

References

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