How Can We Find the Exotics?*

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A search is proposed for dibaryonic systems with non-zero charm and beauty quantum numbers which are more suitable for unambiguous identification. An estimate of the production cross sections for the dibaryonic systems H_c, H_b and H_{bs} is presented.

Searches for exotic states like the glueball and multiquark hadronic states have not yielded any conclusive evidence so far. Part of the difficulty lies in the fact that the states that have been searched for have the same quantum numbers as the conventional mesonic and baryonic resonances and therefore are difficult to distinguish from the same. In this paper we make a case for looking for specific dibaryonic states which are more suitable for unambiguous identification though they may be more difficult to produce or detect.

Table 1 displays a few selected dibaryonic states [1] in the SU(3), SU(4), and SU(5) flavor sectors with their masses and other quantum numbers and the hadronic particle channels to which they can communicate.

The masses were calculated using the MIT bag model. Consider the dibaryons $_{-1}^{0}H_{5/2}$ and $_{-3}^{1}H_{3/2}$. We use the notation $_{s}^{J}H_{I}$ for a dibaryon with spin, strangeness and isospin quantum numbers J, s, and I. From the table it can be seen that in all the possible decay modes only strangeness -1 dibaryon $_{-1}^{0}H_{5/2}$ has a decay mode with a final state whose threshold energy is less than the mass of the dibaryon. But this mode will also be suppressed since parity conservation demands that it be at least a p-wave transition, and further it violates flavor symmetry. Thus it is reasonable to expect that these states are much longer lived and more likely to decay by weak interactions, thereby becoming more amenable to unambiguous identification.

Table 1. Selected dibaryonic states.

Dibaryon	J	I	s	c	b	Mass	Particle channel
$_{-1}^{0}H_{5/2}$	0	5/2	-1	0	0	2.332	$N\Lambda\pi\pi$ (2.335), $\Sigma N\pi$ (2.273)
$_{-3}^{1}H_{3/2}$	1	3/2	-3	0	0	2.496	$\Xi\Lambda\pi$ (2.573), $\Xi\Sigma$ (2.511)
H_c	1	3/2	0	1	0	3.275	$\Sigma_c N$ (3.36), $\Lambda_c N\pi$ (3.34)
H_b	1	1/2	0	0	-1	6.308	$\Lambda_b N$ (6.408)
H_{bs}	1	0	-1	0	-1	6.373	$\Lambda_b N$ (6.581)

The production of the dibaryons discussed above in pp and $\bar{K}d$ collisions is, however, much more difficult that those that have already been studied, since they require the transfer of either a large amount of strangeness or isospin or both. Further, the threshold energies for these processes are very large and the cross sections are likely to be rather small. In the SU(4) and SU(5) sectors we find that the lightest dibaryon states are:

H_c: with $B = 2$, $I = 3/2$, $J = 1$, $s = 0$, $c = 1$, $b = 0$;
$$m = 3.275 \text{ GeV},$$

H_b: with $B = 2$, $I = 1/2$, $J = 1$, $s = 0$, $c = 0$, $b = -1$;
$$m = 6.308 \text{ GeV} \quad \text{and}$$

H_{bs}: with $B = 2$, $I = 1$, $J = 1$, $s = -1$, $c = 0$, $b = -1$;
$$m = 6.373 \text{ GeV}.$$

From Table 1 it can be seen that all the lowest threshold final states have energies much greater than the masses of the corresponding dibaryons, which are therefore expected to decay only by weak interactions. We now proceed to estimate the production cross sections for these states. The H_c, H_b and H_{bs} dibaryons can be produced by the reaction process $M_i + d \rightarrow H_j + \pi$, where M_i stands for the mesons D,
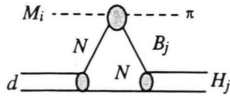
Fig. 1 a

Fig. 1 b

Fig. 1 a. Dibaryon production.

Fig. 1 b. Background process.
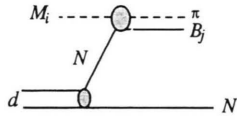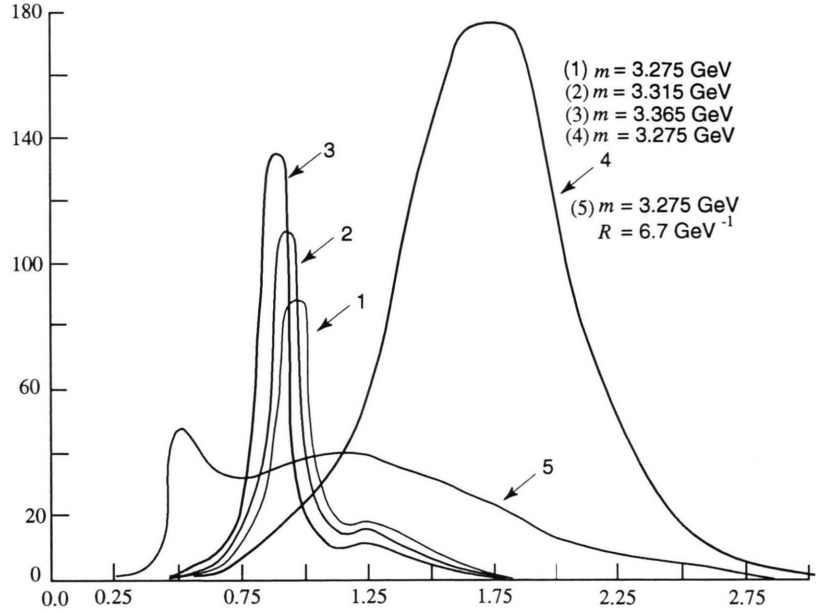
Fig. 2. H_c production and background process cross section variation.
(1) $m = 3.275$ GeV, (2) $m = 3.315$ GeV, (3) $m = 3.365$ GeV, (4) $m = 3.275$ GeV,
(5) $m = 3.275$ GeV, $R = 6.7$ GeV.

B, and F, and H_j stands correspondingly for H_c, H_b and H_{bs}.

The diagrammatic representation of the lowest order process for the above reactions and the associated background processes are shown in Figs. 1 a and 1 b.

The cross sections for the two processes can be calculated [2] in terms of the deuteron dissociation matrix element, the dibaryon fusion matrix element and the transition matrix element of the third vertex in the case of the dibaryon production and the deuteron dissociation matrix element and the transition matrix element for the back ground process. The differential cross section with respect to the invariant mass of a two body subsystem in the three-body process can also be obtained using the standard relationships. The resulting cross sections are functions of the radius parameters of the baryons and the dibaryon and their masses. The transition matrix element occurring in the dibaryon production diagram was deduced from the measured differential cross section of the process $\bar{K} + p \rightarrow \Xi + K$, assuming unbroken SU(4) symmetry.

Similarly the differential and total cross sections can be calculated for the production processes of the beauty flavored dibaryons H_b, H_{bs}.

The variation of the differential cross section for H production (curves 1, 2, 3) and the background process (curve 4) with the incident momentum k is shown in Figure 2. Of the two peaks in curves 1, 2, and 3 the lower one arises due to the phase space factor, whereas the broader one at the higher momentum corresponds to the enhancement due to the H_c production. Further, the magnitude of this peak is 21 μb compared to 0.04 μb for the $S = -2$, H dibaryon for $R_H = 4.21$ GeV^{-1}. The differential cross sections are dependent on the radius parameter R_{Hj}. We have presented here the curves (1 and 5) for the same mass of H_c for two values of the parameter R_{Hc}, 4.21 GeV^{-1} and 6.7 GeV^{-1}. The former corresponds to the value used for a strange dibaryon, and the latter corresponds to the value used in the bag model to obtain the mass of the H_c. It can be seen that the general trend of the curves is the same but the position shape and the height of the peaks vary.

The bag model estimates for the masses of hadrons have to be corrected for the center of mass motion and the fact that they correspond to the poles of the P matrix [3] rather than the S matrix. The two corrections tend to cancel each other. It can be seen from the graph that as the mass of H_c increases the kinematic

enhancement gets more pronounced whereas the dynamic enhancement is suppressed. However this effect is not appreciable unless the mass is very near the threshold for the two-body decay where the phase space effect dominates. From Fig. 2 we see that, while the background cross section is higher than the H_c production cross section at its peak value, the ratio is only one order of magnitude and at very low incident momenta the H_c production cross section is in fact larger than the background process. The signal to noise ratio for the production of H_c is of order 10. This is much more favourable than those for the $S = -1$ and $S = -2$ dibaryons, which are 10^{-2} and 10^{-1}, respectively. Experimental searches are already going on for the latter dibaryons.

So far we have not discussed the possibility of the background process where the two intermediate baryons interact to form a deuteron like bound state with binding energies of the order of a few MeV. The cross section for such a process turns out to be negligibly small compared to the H_c production cross section. Further we note that a cutoff in the outgoing pion momentum can lead to an enhancement in the signal to noise ratio.

The missing mass plot against the invariant mass of the (Σ_c, N) two particle subsystem of the background process is shown in Figure 3. The histogram for the two-body H_c production is shown here to have a width, though it is intrinsically zero since the experimental resolution will be a finite quantity. Even though the peak of the three-body final state is greater by an order of magnitude, the two peaks are well separated so that the signature of the H_c production is unambiguous. This again is in contrast with the case of the $S = -1$ dibaryon where the peak due to the production of the dibaryon is between the thresholds for two of the background processes, making its detection more difficult.

In the foregoing analysis we have considered only the forward direction, i.e. $\cos(\theta) = 1$ since all the differential cross sections are peaked in the forward direction, a reflection of the fact that we are considering s wave transitions. In the non-forward directions similar analysis can be made, but the cross sections decrease rapidly. Finally we remark that one of the added advantages in searching for the charm
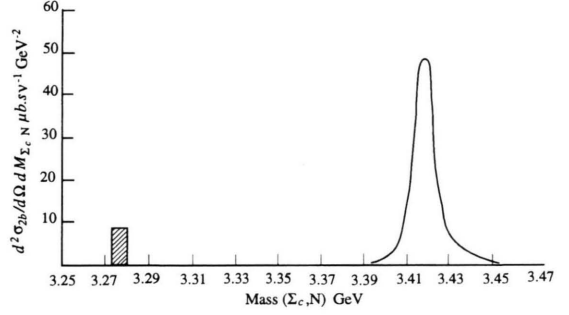

Fig. 3. Missing mass plot of the subsystem $(\Sigma_c N)$.

dibaryon is that one of the systems is triply charged, namely, H_c^{+++}. This can be produced by the reaction $D^+ + d \rightarrow H_c^{+++} + \pi^-$. Even though the cross section for this process is suppressed by a factor of three compared to the other charge states, we believe that the possibility of the unambiguous identification of this state may far outweigh the problem of statistics.

Similar estimates for the systems with $b \neq 0$ show that, even though the production cross section of the dibaryons is comparable to their respective background processes, the kinematic and the dynamic enhancements in these cases are no longer well separated and the shapes of the curves are no longer clearly distinguishable from the background processes. The only significant effect is the large enhancement due to phase space effects on the dibaryon production at an incident momentum approximately equal to 0.8 GeV so that the cross section is much higher than that of the background process.

The invariant mass plots of the two dibaryon systems H_b and H_{bs} and their background two-body sub systems show that in both cases the peaks corresponding to the particle production and the background process are well separated and further are of the same order of magnitude. In view of the fact that there are proposals to build b-factories, it would perhaps be feasible to look for dibaryons with beauty. A detailed analysis of the production of these and other dibaryonic systems is reported in [4].

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