MASSES OF HEAVY FLAVOURED HADRONS

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ABSTRACT

We make predictions for the $B_s$ and $B_c$ masses. We discuss the mass and the spectrum of the $\phi cc$ baryon.

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I shall not come back on the predictions on the masses of beautiful baryons on which I have lectures many years ago here in Erice and more recently in San Miniato.

First I would like to speak of something relevant to the B-\bar{B} factories which is the masses of the B_s and B^0_s. A very successful fit of s\bar{s}, c\bar{c}, c\bar{c} and b\bar{b} bound states is given by the non-relativistic effective quark antiquark central potential

\[ V = 8.064 + 6.870 \, r^{0.1} \]  

when units are powers of GeV, with effective quark masses

\[ m_s = 0.518 \text{ GeV}, \quad m_c = 1.8 \text{ GeV}, \quad m_b = 5.174 \text{ GeV}. \]

One also needs a phenomenological hyperfine splitting

\[ \frac{\sqrt{\hat{t}_1 \hat{t}_2}}{m_1 m_2} \ll 3(\bar{t}_1 - \bar{t}_2) \]  

where C is fitted to the J/\psi - \eta_c mass difference.

With this potential one finds

\[ m_{D_s} = 1.99, \quad m_{D_s}^* = 2.11 \]  

(4)

to be compared to the experimental values

\[ m_{D_s} = 1.97 \]

and

\[ m_{D_s}^* - m_{D_s} = 0.140 \text{ GeV}. \]
Therefore we expect deviations of at most 20 MeV. However, the $D_s^*-D_s$ separation is wrong by 15%. Our model predicts

\[ M(b\bar{s})_0^- = 5354 \text{ MeV} \]
\[ M(b\bar{s})_1^- = 5408 \text{ MeV} \]  
\[ \text{and also} \]
\[ M(b\bar{c})_0^- = 6250 \text{ MeV} \]
\[ M(b\bar{c})_1^- = 6318 \text{ MeV} \]

Concerning the $B_s$'s our predictions mean that with a mass 10868 MeV for the $T_{sB}$ state (according to Dan Coffman, this conference), the decays

\[ T_{sB} \rightarrow B_s B_s^* \]
\[ B_s B_s^* \rightarrow B_s B_s^* \]
\[ B_s B_s^* \]

are allowed (the latter with a very small phase space).

One might wish to correct the model to account for the experimental hyperfine splitting $D_s^*-D_s$. If one does so one finds slightly higher masses

\[ M_{B_s} = 5374 \text{ MeV} \]
\[ M_{B_s^*} = 5410 \text{ MeV}. \]  
\[ \text{This, however, does not alter the previous conclusions.} \]

It is amusing to notice that the $B_s-B_u$ mass difference is therefore about 100 MeV, much less than what is believed to be the $m_s-m_u$ mass difference between constituent quarks, about 200 MeV, so that flavour SU(3) symmetry is restored in these heavy mesons.

I would like to remind $B\bar{B}$ factory builders not to forget the $B_c$ mesons. They are only 900 MeV higher and would be very interesting to see. Their production rate could be small.

Now I turn to a different and very interesting animal, the ccc baryon, the analogue of the $Q^-$, with charmed quarks replacing strange quarks. This baryon has already been seriously studied by Bjorken. My remarks will be somewhat complementary to those of B.J. In a way if, as some people say, the cC system is the hydrogen atom of particle physics,
the ccc baryon, with spin 3/2 naturally, is the Helium or Lithium atom. It is a stable particle with respect to strong interactions with a lifetime of \(1 \times 10^{-13}\) seconds and it produces a doubly ionizing track. Bjorken has tried to estimate its production rate and found that it is not unfeasible.

Now, what is the expected mass of the ground state? First of all, there is the rule of Nussinov

\[
M_{QQQ} > \frac{3}{2} M_{Q}\tag{8}
\]

which gives

\[
M_{ccc} > \frac{3}{2} M_{\psi} = 4.65\text{ GeV}\tag{9}
\]

Looking at

\[
M_{Q} = 1.665\text{ GeV compared to } 3/2 M_{\psi} = 1530
\]

\[
M_{\Delta} = 1.232\text{ GeV compared to } 3/2 M_{\Delta} = 1135
\]

I would expect something around 4.8 GeV. One could make a calculation of the mass using the potential (1) and the rule

\[
V_{QQ} = \frac{1}{2} V_{QQ}\tag{10}
\]

which is very reasonable, produces automatically the Nussinov inequality (8), and is, as shown by J.-M. Richard, very successful in the case of the \(Q^-\).

It is important to know the precise mass of the ccc, because for instance, if \(M_{ccc}\) is less than 4.773 GeV the \((ccc)\) antiparticle cannot annihilate in matter. Indeed, then

\[
M_{ccc} + M_{\bar{Q}} < 2M_{H^+} + M_{H}\tag{8}
\]

If, on the other hand,

\[
4.773 < M_{ccc} < 4.903
\]

the only annihilation mode is \(2H^+ + H\) and this is a complicated rearrangement collisions.

The spectrum of the ccc system is also very interesting. If we believe that potential (1) is a good potential both for sss and ccc, then the spectrum is the same for both systems with a rescaling of the level spacing:

\[
\frac{\Delta E_{ccc}}{\Delta E_{sss}} = \left(\frac{m_{ccc}}{m_{sss}}\right)^{1/21} = 0.942
\]

For a first guess we can use the \(Q^-\) spectrum calculated in the Chao, Isgur, Kari model and rescale it. We find that the spacing between the first 3/2+ excited state and the 3/2+ ground state is 360 MeV so that there is a very little phase space for a decay \((ccc)^* + ccc+2\pi\), less that for the transition \(\psi' + 3/\psi+\pi\). We expect therefore that \((ccc)^* + \pi_0\) will be narrow (less than 50 KeV). The same applies to the lowest 1/2- and 3/2- states. The other possible decays, when allowed by quantum numbers, are \((ccc)^* + ccc + \gamma\) and \((ccc)^* + \pi_0\) which is isospin violating. The
strong decay \((ccc)^* + (c\bar{c}) + (ccd)\) occurs only for excitations above 
\(2M_D - J/\psi = 640\) MeV, according to J.-M. Richard.

In conclusion the ccc spectrum is very interesting. Decay widths are 
very small. The observation of the levels would constitute an excellent 
test of non-relativistic calculations and of the rule (10).

I would like to remind to those who think that it is unrealistic to 
believe that the production and study of ccc states are possible that, in 
the particle physics of our times, an experiment impossible at time T is 
possible at time T+10 (in years!) Who would have thought twenty years ago 
that antiprotons could be produced and accumulated so abundantly?

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