Unanswered Questions in Charmed Baryon Physics

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Many conferences include:

1. Carefully justified experimental measurements, some of which are not explained by theorists
2. Theorists with models which cannot be tested experimentally

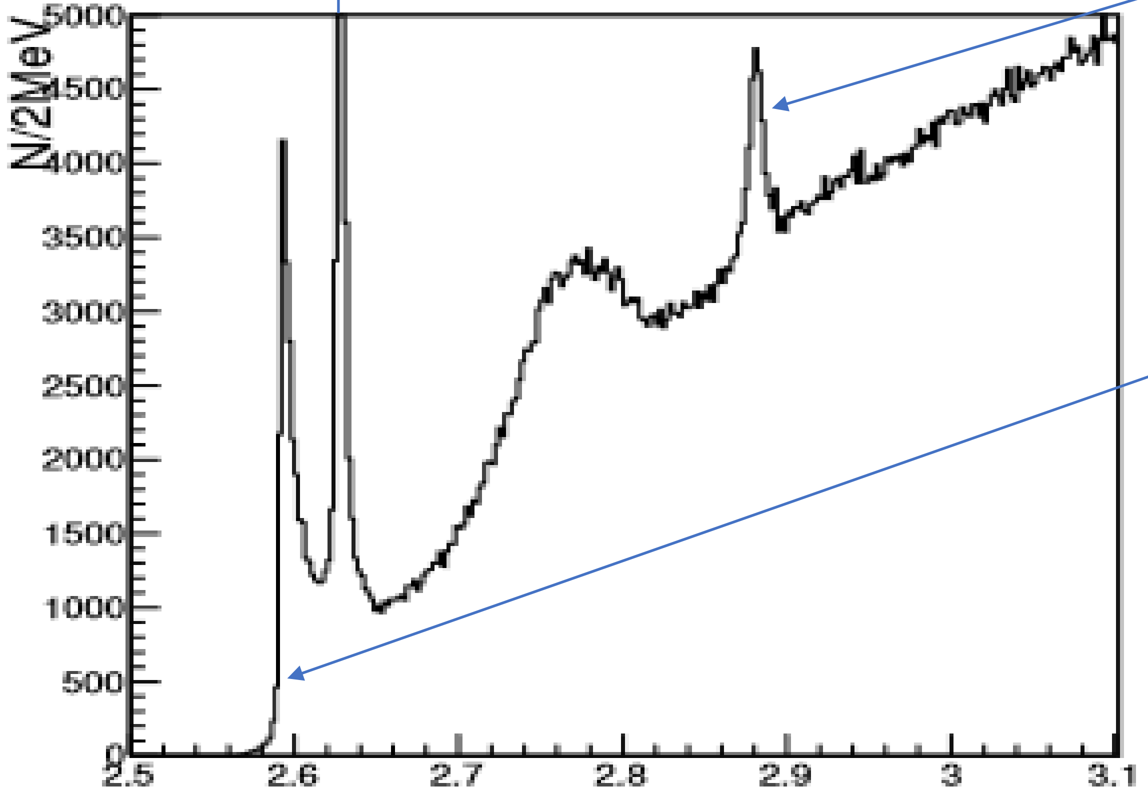
Sometimes there is a lack of overlap

I am experimentalist who will show some (public) data, but will ask questions which I have been interested in for many years, but no-one has answered to my satisfaction.

(Note I am representing only myself and not any experiment)

1. The $\Lambda_c^+\pi^+\pi^-$ spectrum shows lots of structure

$\Lambda_c^+(2625)$ goes much higher



$M(\Lambda_c^+\pi^+\pi^-)$ GeV/c^2

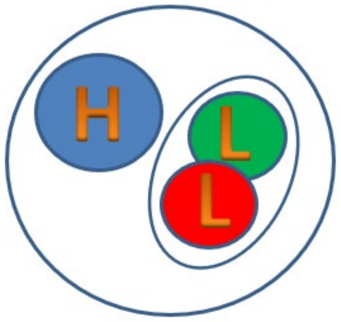
Belle data

$\Lambda_c^+(2880)$ is measured to be $J^P=5/2^+$ and to decay to $\Sigma_c(2455)\pi$ and a little to $\Sigma_c(2520)\pi$

But why doesn't it decay predominantly to $\Sigma_c(2520)\pi$?

$\Lambda_c^+(2593)$

Discovered in 1995 and immediately identified as the $J^P=1/2^-$ orbital excitation with one unit of angular momentum between the heavy quark and the light di-quark



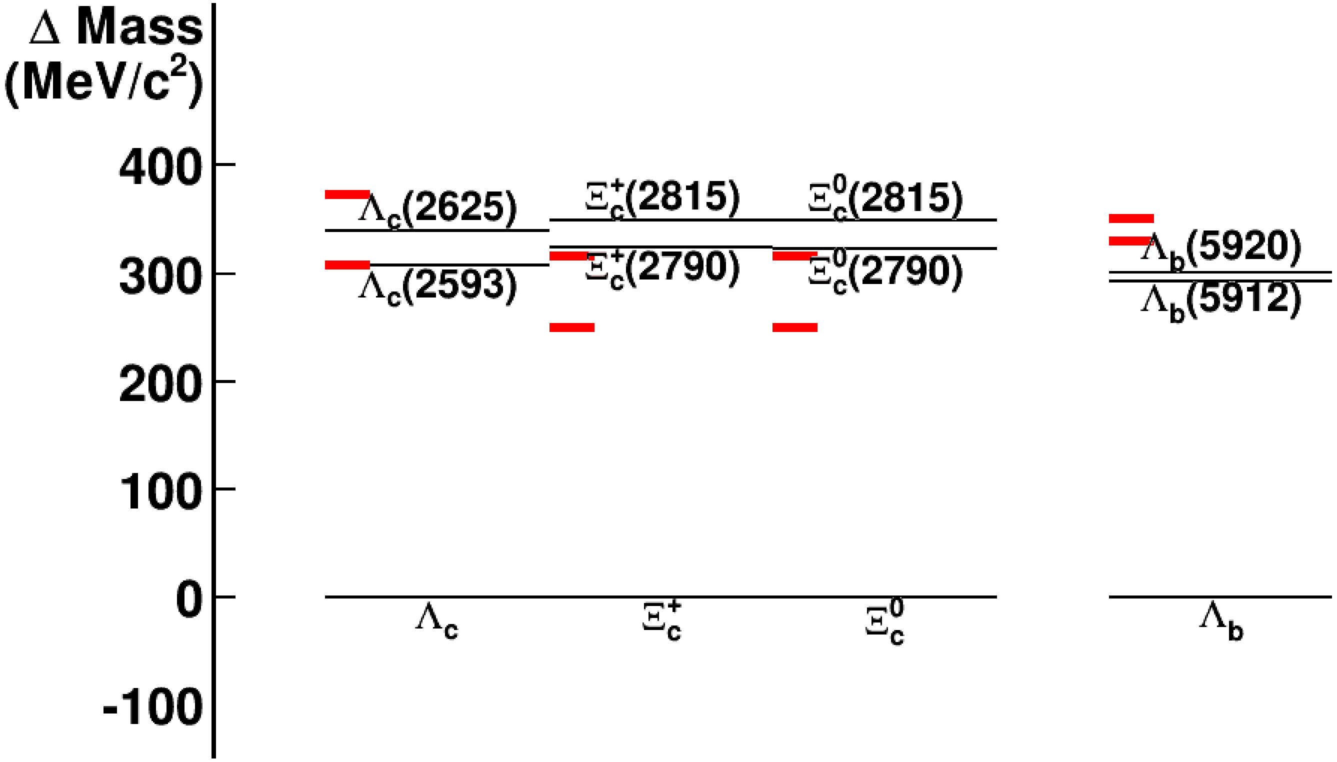
Based on this model of the Λ_c^+(2593), the approximate masses of 6 states were predicted, and subsequently these states have been found.

I also note that the production cross-section of the particles within the doublets are similar, which is what we would expect.

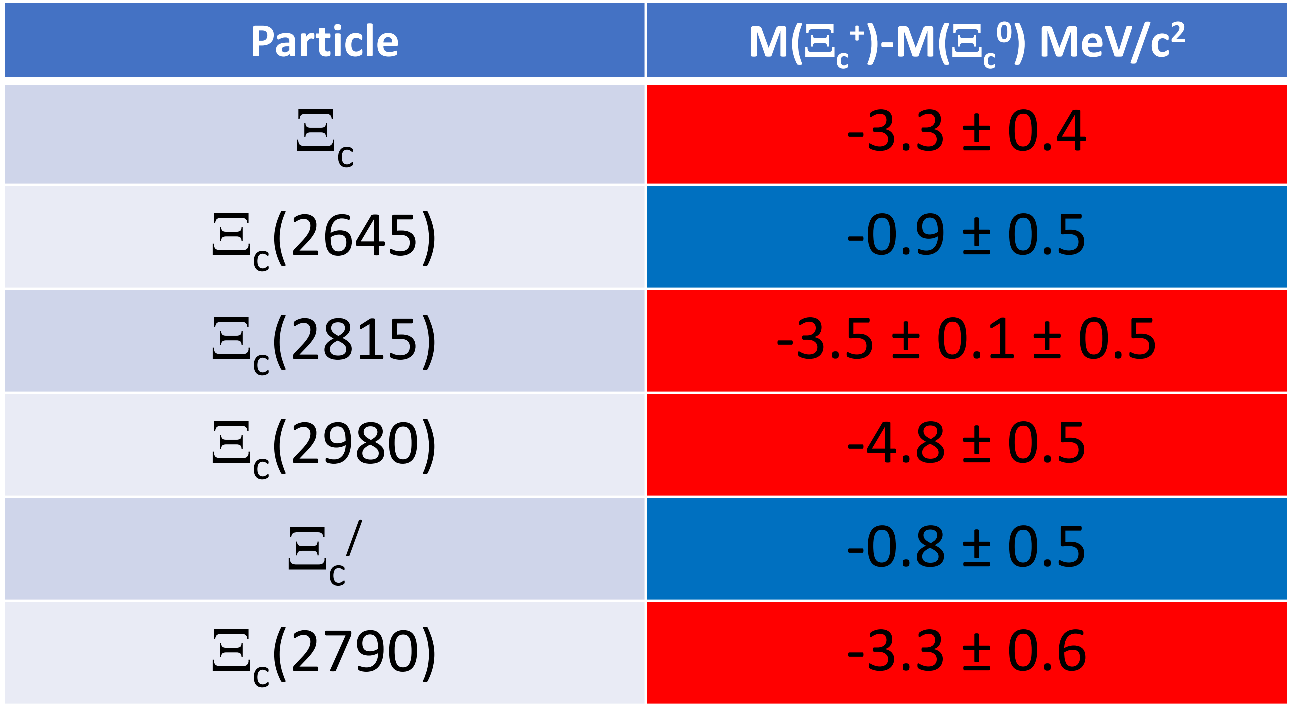
However, recent models tells me that my naïve picture is wrong and the Λ_c^+(2593) is a “molecular state” or a “dynamically generated resonance”.
If this is the case:

How come the previous model predicted 6 particles correctly?

How can I tell the difference between a heavy-quark light-diquark and some other model?



Let’s look at isospin splitting in the Ξ_c system   csu and csd



Particle	$M(\Xi_c^+)-M(\Xi_c^0)$ MeV/c^2
Ξ_c	-3.3 ± 0.4
$\Xi_c(2645)$	-0.9 ± 0.5
$\Xi_c(2815)$	-3.5 ± 0.1 ± 0.5
$\Xi_c(2980)$	-4.8 ± 0.5
$\Xi_c^{/}$	-0.8 ± 0.5
$\Xi_c(2790)$	-3.3 ± 0.6

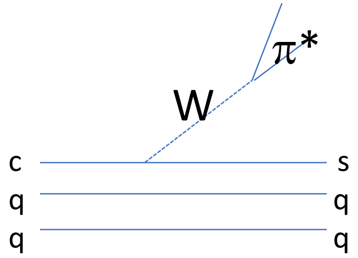
There seem to be two sets. In red, the isospin splitting is around -3.5 MeV/c^2, but in the blue it is much less
The red states all have the the two light quarks in a spin 0 configuration, whereas the blue states it is spin-1.

Is this a rule that can be extended to other excited states?

The Ω_c (css) lifetime saga demonstrated how little we know about the Ω_c decays

(In order to measure the Ω_c lifetime you need first convince people you have seen the Ω_c)

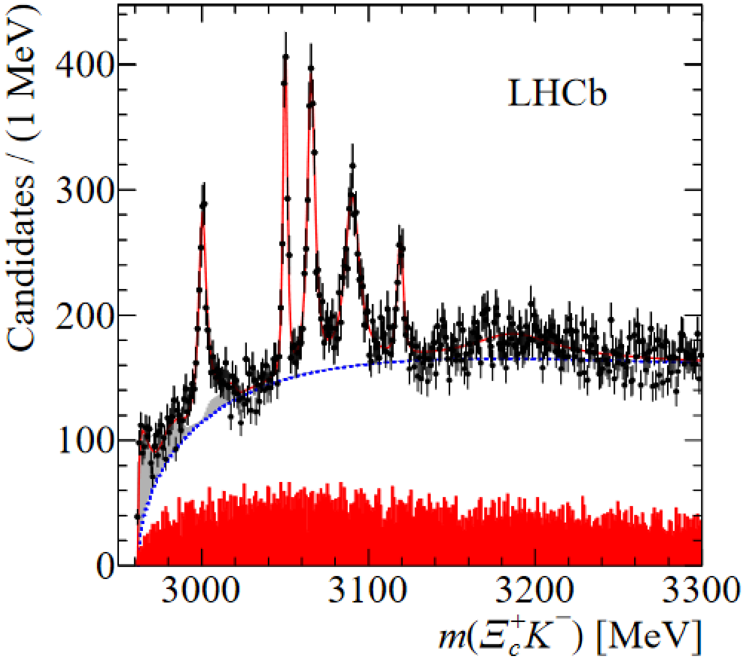
If simple spectator diagram dominated the decays, the weakly-decaying charmed hadrons would all have similar branching ratios to (1, 2 and 3 pions) + stable particle.



Ω_c PDG	**Λ_c^+ PDG**	**Ξ_c^0 PDG**	**Ξ_c^+ PDG**
$\Omega^-\pi^+\pi^0/\Omega^-\pi^+$	$\Lambda\pi^+\pi^0/\Lambda\pi^+$	$\Xi^-\pi^+\pi^0/\Xi^-\pi^+$	$\Xi^0\pi^+\pi^0/\Xi^0\pi^+$
1.97±0.17	5.46±0.42	Not Measured	4.2±1.5
$\Omega^-\pi^+\pi^-\pi^+/\Omega^-\pi^+$	$\Lambda\pi^+\pi^-\pi^+/\Lambda\pi^+$	$\Xi^-\pi^+\pi^-\pi^+/\Xi^-\pi^+$	$\Xi^0\pi^+\pi^-\pi^+/\Xi^0\pi^+$
0.29±0.04	2.84±0.34	3.3±0.5	3.1±1.0

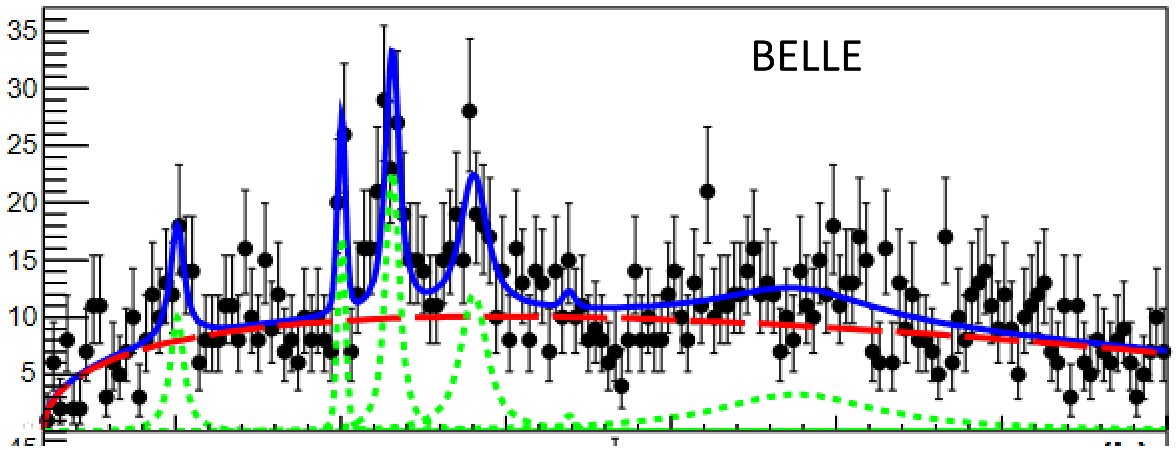
Why is this ratio so low?

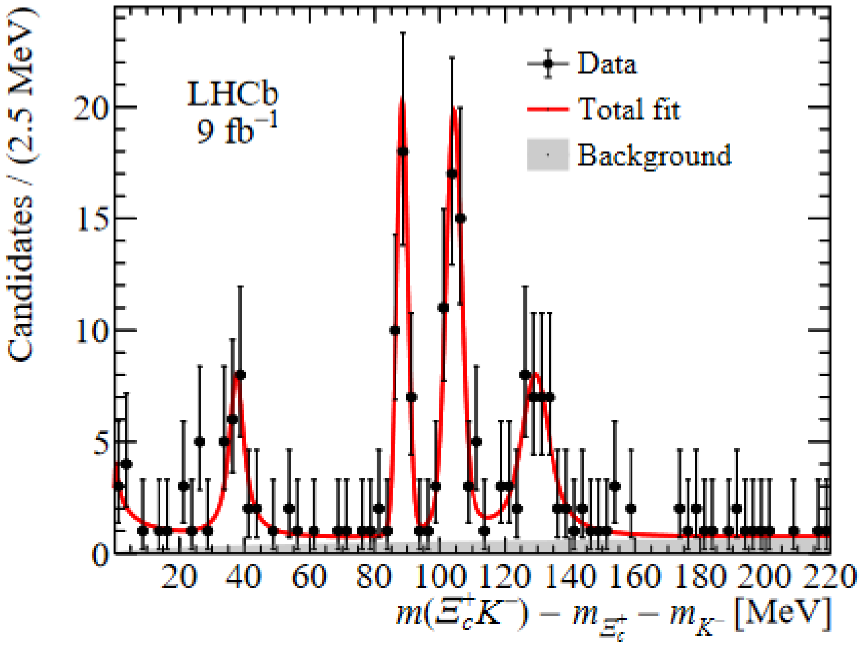
One subject which has TOO MANY answers, is what are the excited Ω_c 5 (or 6) particles?



5 narrow peaks, one possible wide one

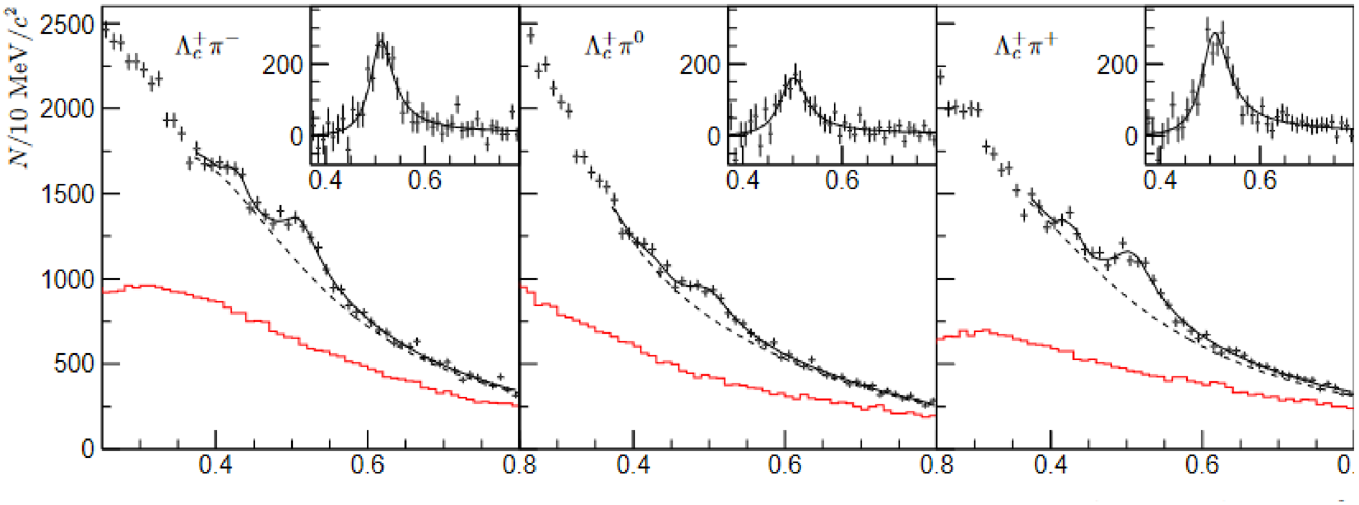
Explanations need to take into account the production cross-section as well as the mass, width and decay properties



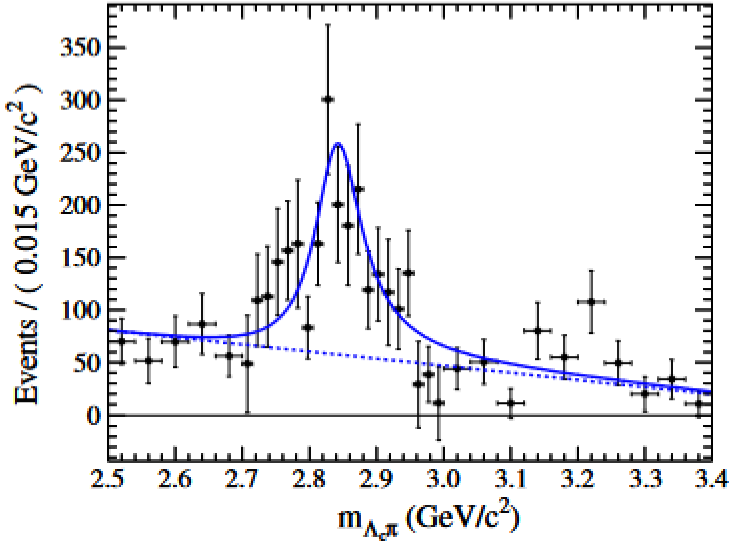


The fifth narrow peak is missing

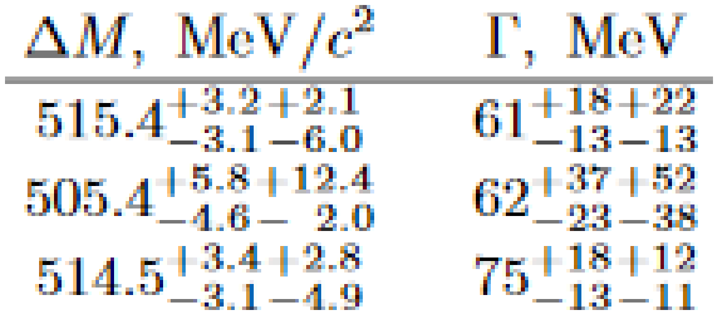
What is the $\Sigma_c(2800)$?



Belle, in continuum production



BaBar in B decay



ΔM, MeV/c^2	Γ, MeV
$515.4^{+3.2+2.1}_{-3.1-6.0}$	61^{+18+22}_{-13-13}
$505.4^{+5.8+12.4}_{-4.6-\ 2.0}$	62^{+37+52}_{-23-38}
$514.5^{+3.4+2.8}_{-3.1-4.9}$	75^{+18+12}_{-13-11}

$\Delta M = 560 \pm 8 \pm 10\ \mathrm{MeV}/c^2$

$\Gamma = (86^{+33}_{-22})\ \mathrm{MeV}$

What is this peak? If you think it is an orbitally excited Σ_c, then why is there only one peak in each?
HQET predicts that three of the states decay to $\Lambda_c\pi$, the other two to $\Sigma_c\pi$, where are they?

My unanswered questions

Why does the $\Lambda_c^+(2880)$ not decay “quickly” to $\Sigma_c(2520)\pi$?

If the $\Lambda_c^+(2593)$ is not an L = 1 heavy-quark/light diquark combination, how come that model has successfully predicted the mass and properties of 6 similar states?
What experimental data would differentiate between the models?

Why does the Ω_c^0 decay to $\Omega^- \pi^+$ rather than $\Omega^- \pi^+ \pi^- \pi^+$?

We still don’t know what the Ω_c^{*0} spectrum means, but how do we take into account the production cross-sections?

If the $\Sigma_c(2800)$ is an L=1 Σ_c, where are the others? The first orbital excitations should be a quintuplet of states