Baryons from or with charm

available at *http://www.ipnl.in2p3.fr/perso/richard/SemConf/Talks.html*

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Introduction

Two different parts:

- Light baryons from charmonium decay,
- Heavy baryons.

Both probe light quark dynamics. In particular

- Level ordering of light-quark excitations,
- Relevance or not of diquark degree of freedom.

Additional issues for double or triple charm or beauty.

Baryons from charm: exclusive modes

$D_s \to p\,\bar{n}$ First stressed by X.Y. Pham (1980), seen by CLEO (2008). Test of PCAC, annihilation mechanism in weak decays.

$J/\psi \to$ baryon–antibaryon

Channel	BR (10^{-3})	BR/$p^{2\ell+1}$
$p\bar{p}$	2.12 ± 0.10	1.5
$n\bar{n}$	2.2 ± 0.4	1.5
$\Lambda\bar{\Lambda}$	1.30 ± 0.12	1.3
$\Sigma\bar{\Sigma}$	1.27 ± 0.17	1.3
$\Xi\bar{\Xi}$	0.9 ± 0.2	1.1
$\Delta\bar{\Delta}$	1.10 ± 0.29	1.2
$\Sigma^*\bar{\Sigma}^*$	0.52 ± 0.07	0.8

Baryons from charmonium: exclusive modes

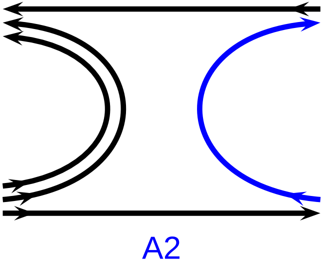
$\psi(2S) \to$ baryon–antibaryon

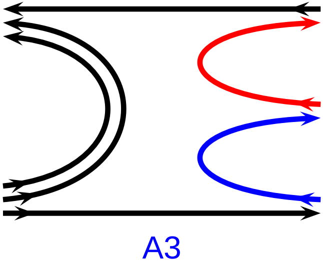
Channel	BES-I	CLEO-c
$p\bar{p}$	$2.16 \pm 0.15 \pm 0.36$	$2.87 \pm 0.12 \pm 0.15$
$\Lambda\bar{\Lambda}$	$1.81 \pm 0.20 \pm 0.27$	$3.28 \pm 0.23 \pm 0.25$
$\Sigma^0\bar{\Sigma}^0$	$1.2 \pm 0.4 \pm 0.4$	$2.63 \pm 0.35 \pm 0.21$
$\Xi^-\bar{\Xi}^+$	$0.94 \pm 0.27 \pm 0.15$	$2.38 \pm 0.30 \pm 0.21$

The parameter α of the angular distribution $\propto 1 + \alpha\cos^2\vartheta$ also measured.

Discussion: SU(3) symmetry

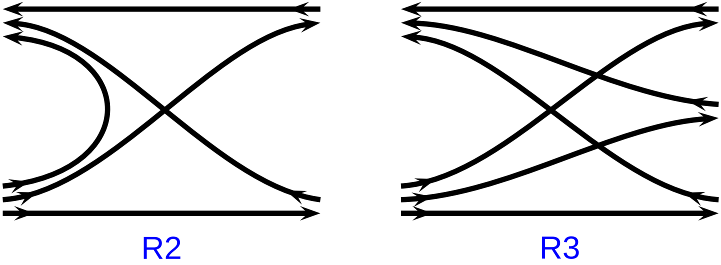
and even SU(6). No *strangeness suppression factor needed.*
This was discussed in a variety of contexts, e.g., $N\overline{N}$ annihilation: some claimed leading mechanisms require such a suppression, in particular the dominance of planar diagrams.





Discussion: SU(3) symmetry

in contrast to "rearrangement" diagrams



Baryon–antibaryon–meson(s) decays

Consider $J/\psi \to B\,\overline{B}\,m$. From Dalitz plot contains much information, in particular:

- baryon–antibaryon mass distribution. Interesting enhancements, due to attraction in the baryon–antibaryon interaction. Speculations about baryonium!
- baryon–meson or c.c. mass distribution: baryon excitation spectrum from a *clean* initial state in a limited mass range.
- In particular,$p\,\bar{p}\,\eta$ S11(1535) and S11(1650) recovered (P-states excitations in the quark model)
- $p\,\bar{n}\,\pi^- + \text{c.c.}$, peaks observed, at about 1360 MeV/c^2 and 2030 MeV/c^2.
- First peak seemingly $N^\star(1440)$ (Roper resonance). In the quark model, this is a radial excitation. Surprisingly it lies below the orbital excitations. In a any reasonable static potential, the radial excitation are *above*, as in the 2-body systems using a similar interaction.

Baryon–antibaryon–meson(s) decays

- Resonance at 2030 MeV/c^2, with preferred QN $(1/2)^+$ or $(3/2)^+$. Several “missing states” there, as compared to the symmetric quark model.
- lowest state with 3-body character has $\ell_x = \ell_y = 1$ in each Jacobi variable, with an antisymmetric coupling to an overall $L = 1$, e.g., factor $\vec{x} \times \vec{y}$ in the specific HO model.
  Can be associated to an antisymmetric spin–isospin wave function with $I = 1/2$ and $s = 1/2$.
  Thus $J^P = (1/2)^+$ or $(3/2)^+$ after recoupling $\vec{L}$ and $\vec{s}$.
- Not confirmed in other modes, or from $\psi(2S)$.

The diquark issue

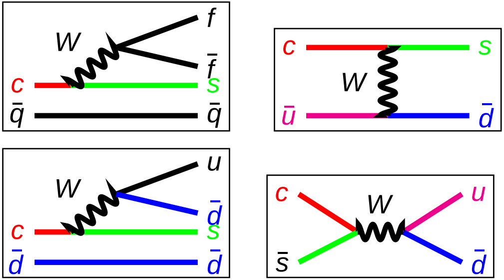
- Diquarks introduced early, see Lichtenberg's review at Torino,
- Often rediscovered,
- Simplified picture of baryons as quark–diquark,
- However, if taken seriously, low-mass diquarks lead to a proliferation of exotics: diquark–antidiquarks, 3-diquark states = dibaryons, etc., see Frederikson' demon deuteron,
- Some models explaining new charmonium states as $(cs) - (\bar{c}\bar{s})$ should check their $(cs\,cs\,cs)$ sector against $(ccc) + (sss)$
- the issue remains open in the light quark sector. Are "missing states" (predicted in $(q\,q\,q)$, not in $(q\,[qq])$) simply not coupled to usual production channels, or really missing?

Hybrid baryon

- In principle on the same footing as hybrid mesons,
- But not leading to exotic quantum numbers,
- No need for additional states from the present data,
- Still hybrid baryons regularly proposed to solve specific questions, e.g., $\Lambda(1405)$ (Kisslinger & Henley), or the Roper resonance.

Weak decays

- A major issue. When it was discovered that $\tau(D^0) \ll \tau(D^+)$, this was a shock! (Exaggerated in the first date, ratio ~ 4 instead of 2.5)
- Charm does not ignore its surrounding while decaying,
- $W - exchange$, annihilation, and interferences



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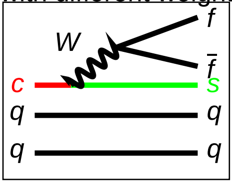
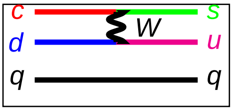
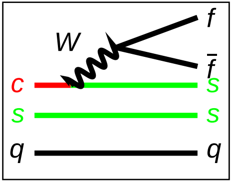
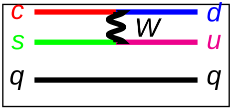
Weak decays-2

Predictions made for baryons (Ruckl, Guberina, . . .). Same mechanisms, with different weights.



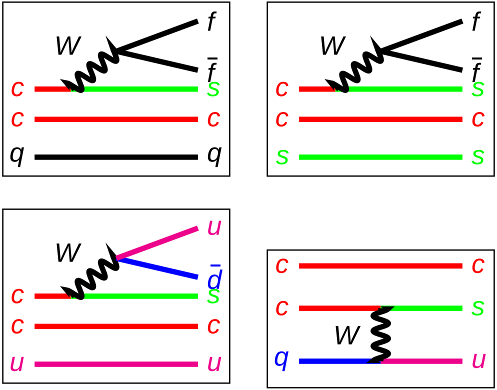






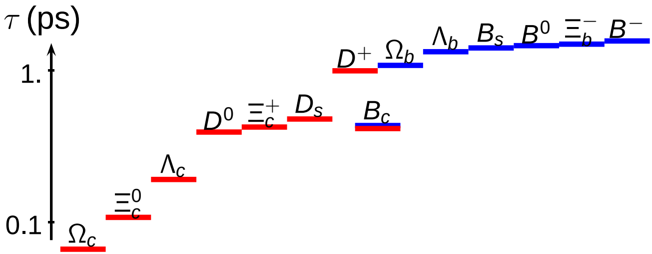
Weak-decays-3

For double charm



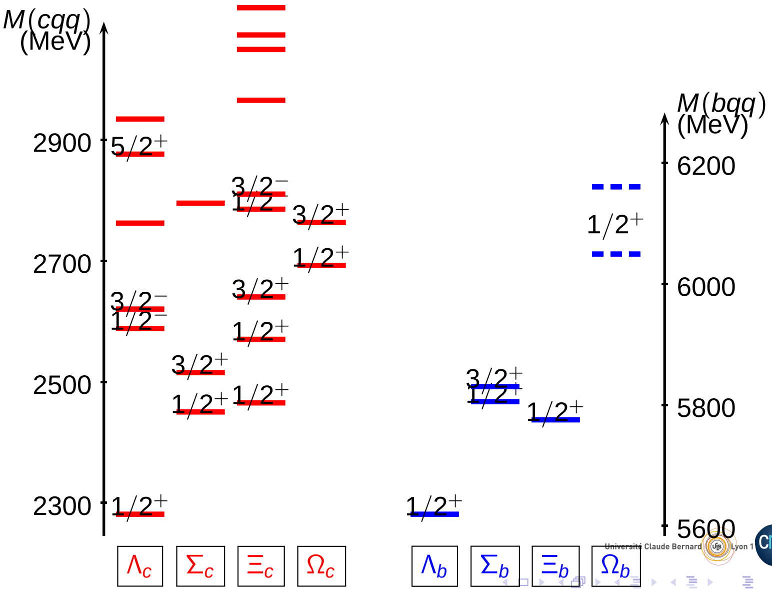
Lifetime: Results

Hierarchy as predicted. But more pronounced spread.



Double and triple charm welcome!

Spectroscopy: single heavy flavour



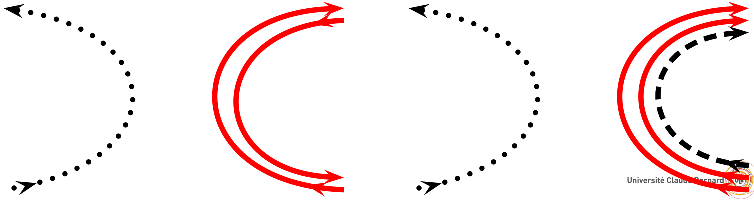
Spectroscopy: single heavy flavour-2

- Almost perfect $b \leftrightarrow c$ correspondence, and anticipated changes, such a $\Sigma_b^* - \Sigma_b < \Sigma_c^* - \Sigma_c$,
- The highest candidate for Ω_b (from $D0$) less likely than the lowest one (CDF).
- For Λ_c, first excitation seemingly with negative parity. Where is the Roper?
- Same observation for Ξ_c
- Isospin breaking: Regularly revisited. Difficulties for the Σ_c in the conventional approach (Varga et al., Fritsch). More recently, Gua et al. found a better description of the data using chiral perturbation theory.

Double charm baryons

Experimental situation

- Rather embarrassing. The SELEX collaboration at Fermilab has claimed to see the Ξ_{cc}^{+} in two modes, one with the remaining charm in a baryon (PRL), another in a meson (PLB). Some candidates (not published but shown at Conferences) for isospin or spin partners.
- Unfortunately, not seen in other experiments. In particular FOCUS at Fermilab.
- Not seen also in B-factories. See,
- The paradox



Double charm baryons

Theory

- More and more papers. First by Lee et al.
- QCD sum rules, Zhang (Hunan), Wang (North China E. P.), Narison et al., etc.
- Lattice QCD (Flynn et al., ,Liu et al.)
- Constituent-quark estimates, with or without refinements.
- Quark–diquark limit often stressed: in (QQq) $\langle r(QQ)\rangle \ll \langle (r(Qq)\rangle$. But this is not very much informative.
- As for $H_2{}^+$ in atomic physics, a *Born–Openheimer* is more fruitful, that gives the ground state and the first excitations (Fleck et al.), and opens the door for an improved treatment, where the effective QQ potential is estimated on lattice and then used in a Schrödinger equation for QQ.
- The (QQq) combines in a single object two limits: the quasi-static motion of two heavy quarks, as in quarkonium and the ultra-relativistic motion of a light quark around a coloured source, as in D or B mesons.

Triple charm baryons

- A new deal for baryon spectroscopy (Bjorken).
- Not yet accessible experimentally.
- Studies in constituent models, where it becomes rather simple, as compared to other baryons.
- Already in 1980, using a potential inspired by an adiabatic version of the bag model, suited for heavy quarks (Hasenfratz et al., Aerts et al.)
- Recently, Ω_{bbb} estimated on the Lattice (Meinel). Earlier, but with less advanced lattice technique, this was for the case for (ccc) (Chiu).

Triple charm

The static potential

- Hasenfratz et al., Aerts et al., 1980:, 3-body potential. Also anticipated by many authors (Artru, Merkuriev, Dosch, Kogut, etc.), Now supported by lattice QCD.
- $$V = \lambda \min_J (\|JA_1\| + \|JA_2\| + \|JA_3\|) \; ,$$
- An old problem of Fermat and Torricelli

- Not much change for the baryon spectrum.
- Extension to multiquarks: dramatic changes.

Conclusions

- Clean approach to light baryons from quarkonium decay
- To be extended to $(b\bar{b})$ and B decay
- Dramatic progress in (Qqq) spectroscopy
- Production and identification of (QQq) remain puzzling
- (QQQ) is an interesting limit of QCD

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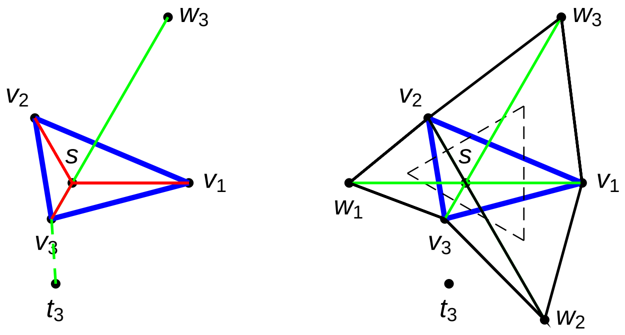
THE END

EXTRA SLIDE

Steiner tree: baryons



$$\min_s \|sv_1\| + \|sv_2\| + \|sv_3\| = \max\{\|v_3w_3\| + \|v_3t_3\|\}$$