HYPERON 99

Excited Hyperons - Strange and Charming

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Uncovering the Amazing Regularities among Hyperon Resonances was a principal HEP activity for 25 years

- J^P analysis for 1-10 GeV/c K^-p scattering
- Scattering data from Polarized Targets
- Extensive phase shift analyses of large data sets showed mixture of narrow and wide states over wide range of masses
- Models for SU(3)-breaking effects

What insight did the data produce?

Table 1. The status of the Λ and Σ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

Particle	$L_{I \cdot 2J}$	Overall status	Status as seen in —			
			$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	P_{01}	****		F		$N\pi$(weakly)
$\Lambda(1405)$	S_{01}	****	****	o	****	
$\Lambda(1520)$	D_{03}	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	P_{01}	***	***	b	**	
$\Lambda(1670)$	S_{01}	****	****	i	****	$\Lambda\eta$
$\Lambda(1690)$	D_{03}	****	****	d	****	$\Lambda\pi\pi, \Sigma\pi\pi$
$\Lambda(1800)$	S_{01}	***	***	d	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(1810)$	P_{01}	***	***	e	**	$N\overline{K}^*$
$\Lambda(1820)$	F_{05}	****	****	n	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	D_{05}	****	***	F	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	P_{03}	****	****	o	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(2000)$		*		r	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2020)$	F_{07}	*	*	b	*	
$\Lambda(2100)$	G_{07}	****	****	i	***	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2110)$	F_{05}	***	**	d	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2325)$	D_{03}	*	*	d		$\Lambda\omega$
$\Lambda(2350)$		***	***	e	*	
$\Lambda(2585)$		**	**	n		

PDG 1998

$\Sigma(1193)$	P_{11}	****				$N\pi$(weakly)
$\Sigma(1385)$	P_{13}	****		****	****	
$\Sigma(1480)$		*	*	*	*	
$\Sigma(1560)$		**		**	**	
$\Sigma(1580)$	D_{13}	**	*	*		
$\Sigma(1620)$	S_{11}	**	**	*	*	
$\Sigma(1660)$	P_{11}	***	***	*	**	
$\Sigma(1670)$	D_{13}	****	****	****	****	several others
$\Sigma(1690)$		**	*	**	*	$\Lambda\pi\pi$
$\Sigma(1750)$	S_{11}	***	***	**	*	$\Sigma\eta$
$\Sigma(1770)$	P_{11}	*				
$\Sigma(1775)$	D_{15}	****	****	****	***	several others
$\Sigma(1840)$	P_{13}	*	*	**	*	
$\Sigma(1880)$	P_{11}	**	**	**		$N\overline{K}^*$
$\Sigma(1915)$	F_{15}	****	***	****	***	$\Sigma(1385)\pi$
$\Sigma(1940)$	D_{13}	***	*	***	**	quasi-2-body
$\Sigma(2000)$	S_{11}	*		*		$N\overline{K}^*, \Lambda(1520)\pi$
$\Sigma(2030)$	F_{17}	****	****	****	**	several others
$\Sigma(2070)$	F_{15}	*	*		*	
$\Sigma(2080)$	P_{13}	**		**		
$\Sigma(2100)$	G_{17}	*		*	*	
$\Sigma(2250)$		***	***	*	*	
$\Sigma(2455)$		**	*			
$\Sigma(2620)$		**	*			
$\Sigma(3000)$		*	*	*		
$\Sigma(3170)$		*				multi-body

PDG 1998

- Nobel Prize for Unitary Symmetry
- SU(3) relations for decays
- empirical mass relationships
- ... but no unifying theoretical structure for spectra, widths.

Still, the regularities are compelling - there IS a structure.

QCD-inspired models were quite successful in organizing spectra

Capstick and Isgur (1986)

- color-string model
- constituent quark masses incorporate glue effects, set from **meson** spectroscopy
- relativistic corrections to potential model

The GOOD NEWS

- same model fits all meson and baryon spectra
- hyperfine splits in mesons, baryons arise from same physics and have same size
- spin-orbit effects are suppressed, as observed

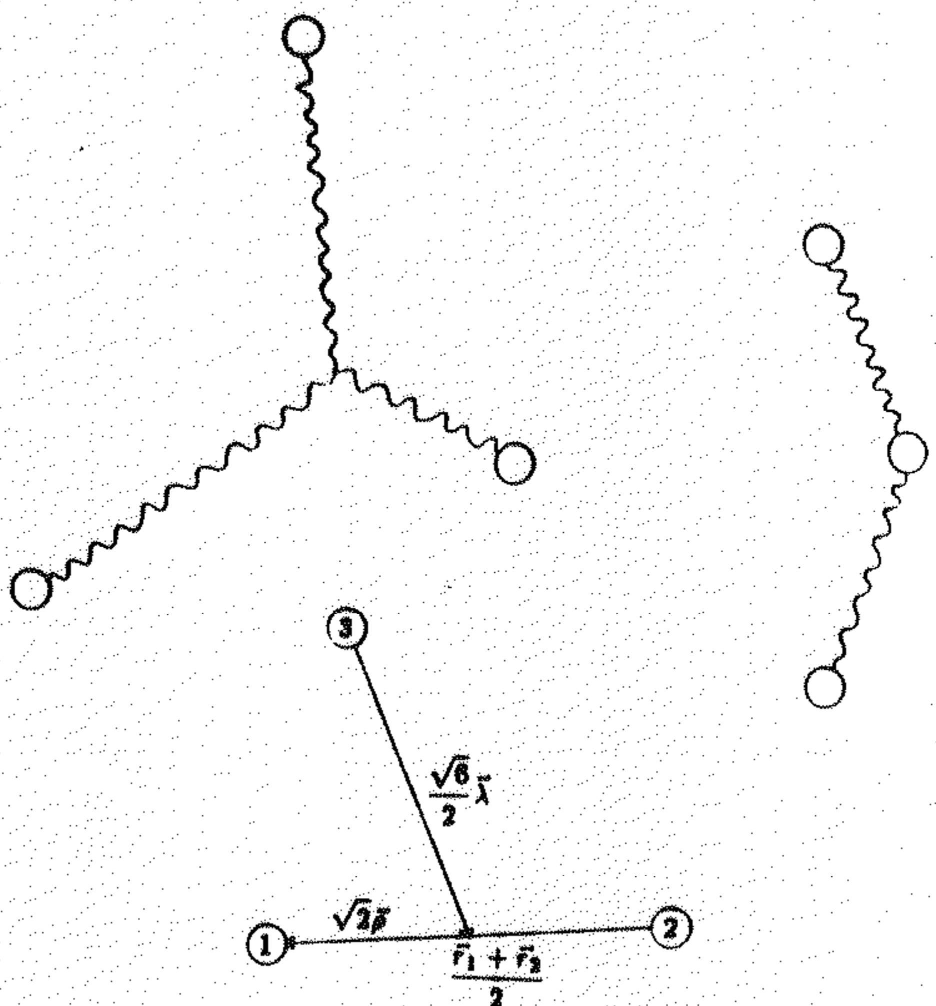


FIG. 1. The gauge-invariant string configurations and the relative coordinates ρ and λ.

... but the BAD NEWS

- far more states than particles. (selection rule missing?)
- a model, not full QCD calculation
- the $\Lambda(1405)$ problem persists (is it really a sud state?)

Where are we now?

There are no new results at all on Λ and Σ resonances. The field remains at a standstill ....

PDG - Hyperon Resonance
section of Baryon Listings

IF sqq baryons are static, cqq baryons are very much alive.

Is cross-fertilization possible between cqq and sqq spectroscopy?

New times produce new tools

HQET and $1/N_c$

Problem: too many degrees of freedom in $\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3}$ and masses are too light for perturbative QCD

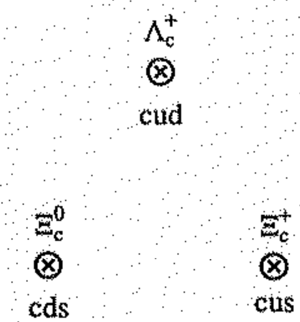
Observed regularities in hyperon spectra suggest selection rules

Look in places where there is even more symmetry for insight

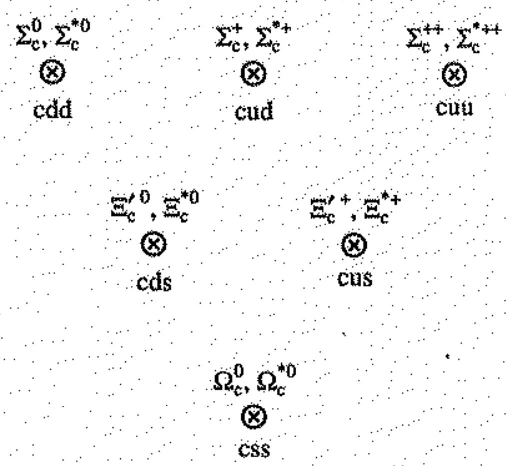
HQET - Qqq system separates heavy quark degrees of freedom from qq

- extended symmetry imposes new selection rules
- qq system has spin-flavor symmetry that restricts states
- meson-baryon structure identity for qq in $[\bar{\mathbf{3}}]$

... BUT ... HQET is a relational theory



Flavor $SU(3)$ weight diagram for the $\bar{\mathbf{3}}$ spin-1/2 $c\,[qq]$ baryons. The corresponding $b\,[qq]$ baryons are the Λ_b^0, Ξ_b^- and Ξ_b^0. The vertical direction is hypercharge, and the horizontal direction is I_3, the third component of isospin.



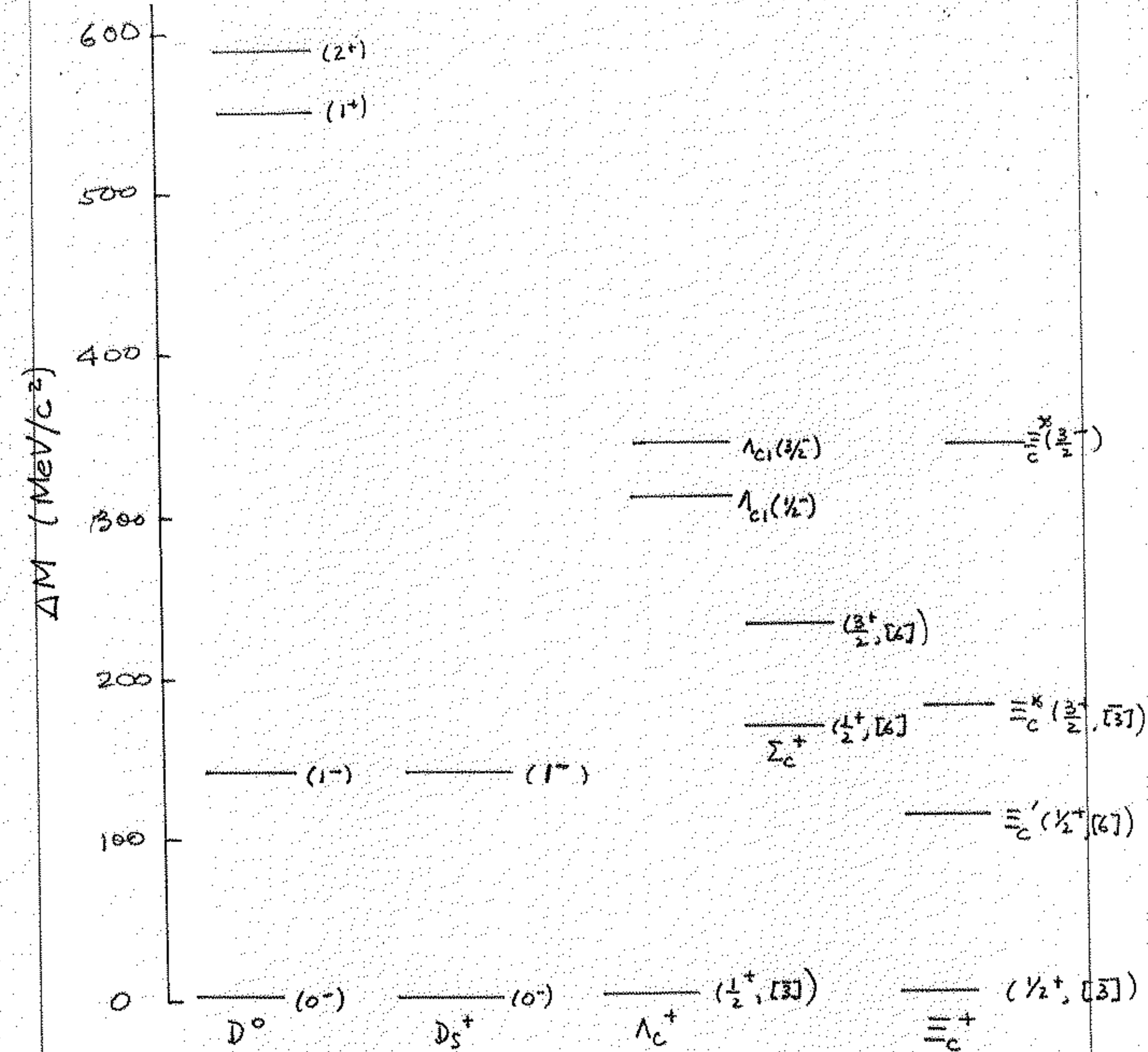
Flavor $SU(3)$ weight diagram for the $\mathbf{6}$ spin-1/2 and spin-3/2 $c\,(qq)$ baryons. The corresponding $b\,(qq)$ baryons are the spin-1/2 $\Sigma_b^{-,0,+}$, $\Xi_b^{\prime -,0}$ and Ω_b^-, and their spin-3/2 partners. The vertical direction is hypercharge, and the horizontal direction is I_3, the third component of isospin.

Hadron	Mass (MeV)	Quark Content	J^P	s_ℓ
D^+	1869.3 ± 0.5	$c\bar{d}$	0^-	$1/2$
D^{*+}	2010.0 ± 0.5		1^-	
D^0	1864.5 ± 0.5	$c\bar{u}$	0^-	$1/2$
D^{*0}	2006.7 ± 0.5		1^-	
D_s^+	1968.5 ± 0.6	$c\bar{s}$	0^-	$1/2$
D_s^{*+}	2112.4 ± 0.7		1^-	
D_0^*		$c\bar{q}$	0^+	$1/2$
D_1^*			1^+	
D_1	2422 ± 2	$c\bar{q}$	1^+	$3/2$
D_2^*	2459 ± 2		2^+	

TABLES

Name	Mass (MeV)	J^P	J_ℓ^P	"s_ℓ"	"L_ℓ"	I	S	Dominant Decay
Λ_c^+	2284.9 ± 0.6	$\frac{1}{2}^+$	0^+	0	0	0	0	weak
Σ_c^0	2452.1 ± 0.7	$\frac{1}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^-\,(P)$
Σ_c^+	2453.5 ± 0.9	$\frac{1}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^0\,(P)$
Σ_c^{++}	2452.9 ± 0.6	$\frac{1}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^+\,(P)$
Σ_c^{*0}	2517.5 ± 1.6	$\frac{3}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^-\,(P)$
Σ_c^{*+}	?	$\frac{3}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^0\,(P)$
Σ_c^{*++}	2519.4 ± 1.6	$\frac{3}{2}^+$	1^+	1	0	1	0	$\Lambda_c^+\pi^+\,(P)$
$\Lambda_{c1}(\frac{1}{2})^+$	2593.6 ± 1.0	$\frac{1}{2}^-$	1^-	0	1	0	0	$\Sigma_c\pi\,(S)$
$\Lambda_{c1}(\frac{3}{2})^+$	2626.4 ± 0.9	$\frac{3}{2}^-$	1^-	0	1	0	0	$\Lambda_c^+\pi\pi\,(S,P)$
Ξ_c^0	2470.3 ± 1.8	$\frac{1}{2}^+$	0^+	0	0	$\frac{1}{2}$	-1	weak
Ξ_c^+	2465.6 ± 1.4	$\frac{1}{2}^+$	0^+	0	0	$\frac{1}{2}$	-1	weak
$\Xi_c^{\prime 0,+}$	~ 2580 (?)	$\frac{1}{2}^+$	1^+	1	0	$\frac{1}{2}$	-1	$\Xi_c\gamma$
Ξ_c^{*0}	2643.8 ± 1.8	$\frac{3}{2}^+$	1^+	1	0	$\frac{1}{2}$	-1	$\Xi_c\pi\,(P)$
Ξ_c^{*+}	2644.6 ± 2.1	$\frac{3}{2}^+$	1^+	1	0	$\frac{1}{2}$	-1	$\Xi_c\pi\,(P)$
$\Xi_{c1}(\frac{1}{2})^{0,+}$	?	$\frac{1}{2}^-$	1^-	0	1	$\frac{1}{2}$	-1	$\Xi_c'\pi\,(S)$
$\Xi_{c1}(\frac{3}{2})^0$	?	$\frac{3}{2}^-$	1^-	0	1	$\frac{1}{2}$	-1	$\Xi_c^*\pi\,(S)$
$\Xi_{c1}(\frac{3}{2})^+$	2815.0 ± 1.9	$\frac{3}{2}^-$	1^-	0	1	$\frac{1}{2}$	-1	$\Xi_c^*\pi\,(S)$
Ω_c^0	2704 ± 4	$\frac{1}{2}^+$	1^+	1	0	0	-2	weak
Ω_c^{*0}	?	$\frac{3}{2}^+$	1^+	1	0	0	-2	$\Omega_c\gamma$

TABLE I. The lowest lying charmed baryons [9–12]. The spin and orbital angular momentum quantum numbers s_ℓ and L_ℓ are only defined in the quark model, and are included here for guidance. Isospin and strangeness are denoted respectively by I and S. The angular momentum of the π emitted in a strong decay is indicated. For simplicity, we give estimated errors on baryon masses themselves, rather than reporting the (more accurately measured) mass differences.



HQET PREDICTION : $\Xi_c^{*+}(3/2^-) \not\to \Xi_c^+ \pi^+\pi^-$

$\to \Xi_c^*(3/2^+)\, \pi$

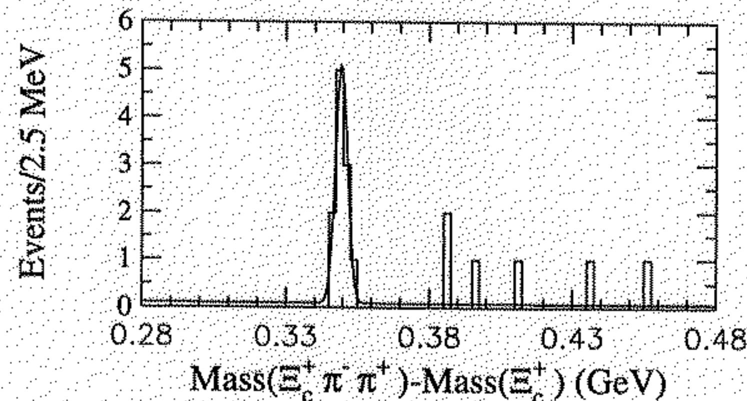


FIG. 3. The mass difference $M(\Xi_c^+\pi^+\pi^-) - M(\Xi_c^+)$ for combinations that lie in the Ξ_c^{*0} band. combinations, an x_p cut of 0.7 applied.

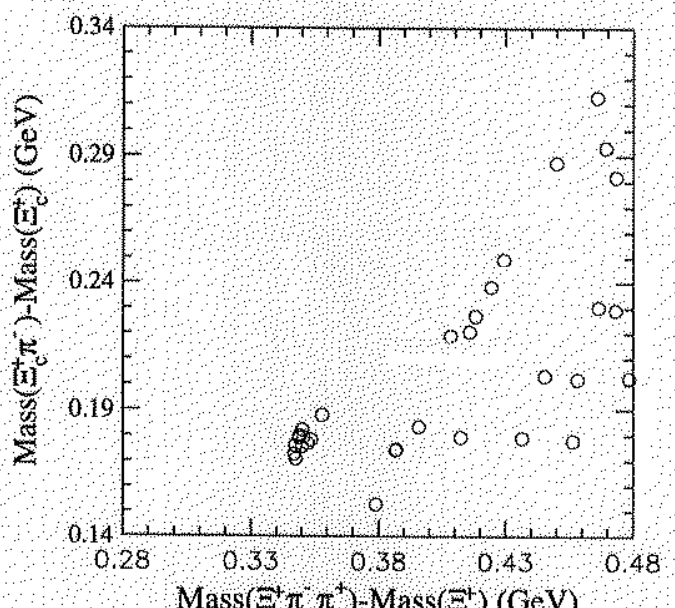


FIG. 4. Scatter plot of $M(\Xi_c^+\pi^- - M(\Xi_c^+)$ versus $M(\Xi_c^+\pi^-\pi^+) - M(\Xi_c^+)$. The signal is the small cluster in the bottom left hand corner.

- HQET does not define masses or splittings - quark model is required to determine order of qq multiplets in [$\bar{\mathbf{3}}$] or [$\mathbf{6}$]
- HQET does not relate relative transition strengths for different J_ℓ^P
- HQET corrections of order $1/m_Q$ can mix states of different J_ℓ^P (affects widths, for example)

Learn from experiment - excitations are $\sim m_\pi$

Introduce ideas of chiral symmetry for low-energy pion transitions

GOAL: relate observed splittings, widths and selection rules

How well does it do for cq mesons and cqq baryons?

HQET combined with chiral perturbation theory relates widths to light-quark quantum numbers

... BUT

- relates pure states of different flavor only in terms of common chiral form factor
- subject to problems due to mixing from $1/m_c$ corrections
- chiral scale limit on $[E_\pi]_{max}$ OK for ℓ=1 [**6**] states?

... AND

- J^P assignments for states based on quark model, <u>not</u> <u>measurement</u>
- Where are the [**6**] states?
- Where are the missing s-wave states for D?
- What about Ω_c states?
- How much mixing is there between states due to corrections?

IS ANY OF THIS RELATED TO HYPERON SPECTROSCOPY?

Capstick-Isgur model shows striking interdependence

- fix charm constituent quark mass from D meson mass
- use all other parameters from non-charm MESON model
- find $m_{\Lambda_c^+} = 2265 \pm 20$ MeV
- find baryon excitations in rather good agreement with data

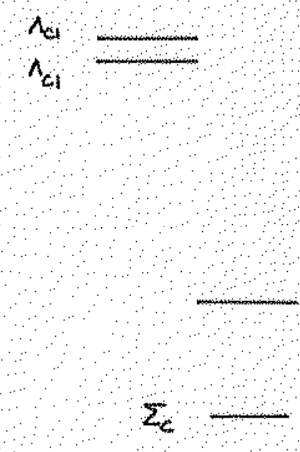
Correlation between qqq and cqq fits?

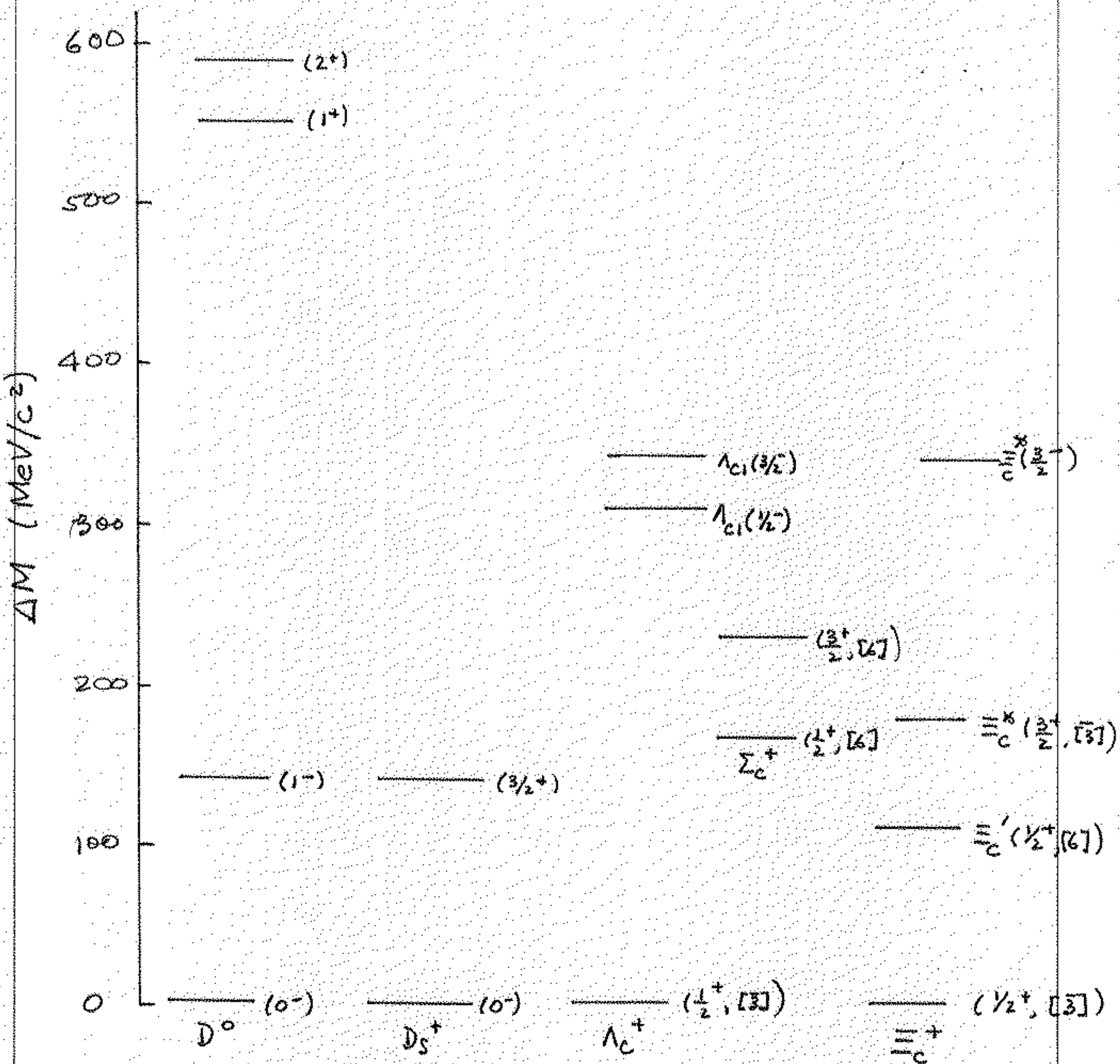
This is only a model. Better theory for qqq systems?

RECENT PROGRESS WITH $1/N_c$ MASS RELATIONS

- Jenkins and co-workers study chiral- and $\mathrm{SU(3)_F}$- breaking effects by ordering in N_c expansion
- re-establish empirical mass relations to leading order in $1/N_c$
- calculate hierarchy of comparisons and tests of flavor symmetry with good results

CAPSTICK & ISGUR (1986)





HQET PREDICTION : $\Xi_c^{*+}(3/2^-) \not\rightarrow \Xi_c^+ \pi^+ \pi^-$

$\rightarrow \Xi_c^*(3/2^+)\,\pi$

HOPEFUL SIGN FOR FUTURE OF THEORY

WHAT ABOUT EXPERIMENT?

- What about the $\Lambda(1405)$?
  - doesn't fit in Capstick-Isgur scheme
  - is $\Lambda(1405)$ the analog of $\Lambda_c^+(2594)$ or is it a mixture with KN bound state hadronic amplitude?
  - Compare HQET-violating decays $\Lambda_c^+ \to \Lambda(1405) + e^+ + \nu$ and $\Lambda_c^+ \to \Lambda(1520) + e^+ + \nu$
  - Make similar studies in Λ_b decays
  - Do high-sensitivity Dalitz plot analyses of $\Lambda_c^+ \to \Sigma\pi\pi$ and $\Xi_c^+ \to \Sigma K\pi$. Is $\Lambda(1405)$ seen?
- Learn to measure quantum numbers of charmed or beauty baryon excitations to check theory

All this work requires extensive supply of charm (or beauty) baryons.

Job for charm hunting at b-factories