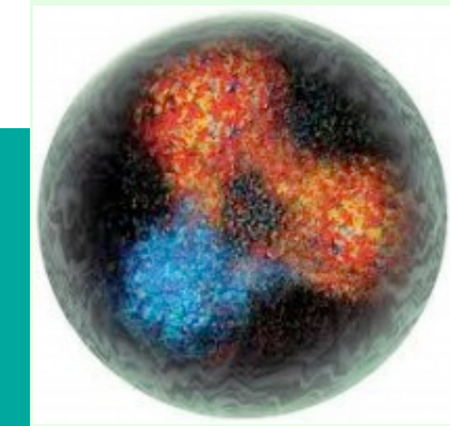
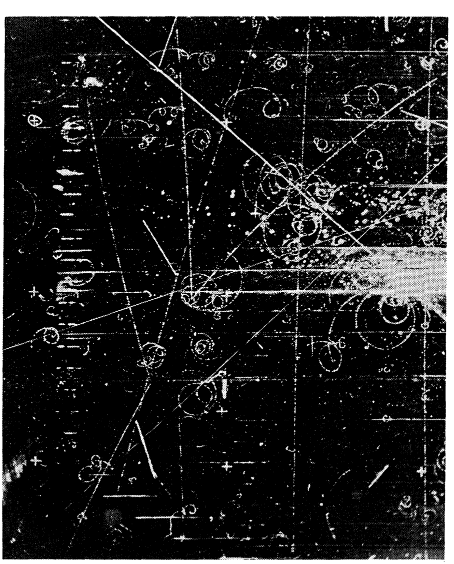


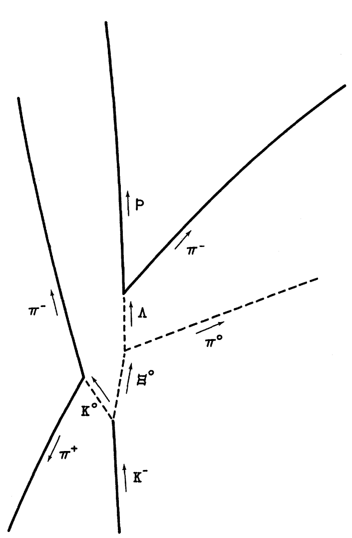
Perspectives in Excited Hyperons

Jose L. Goity

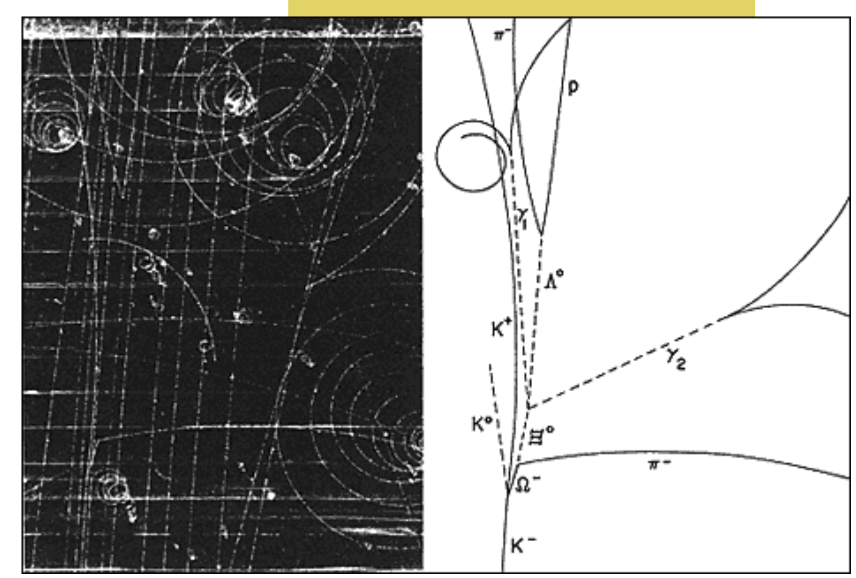
Hampton U and JLab

KLF Collaboration Meeting





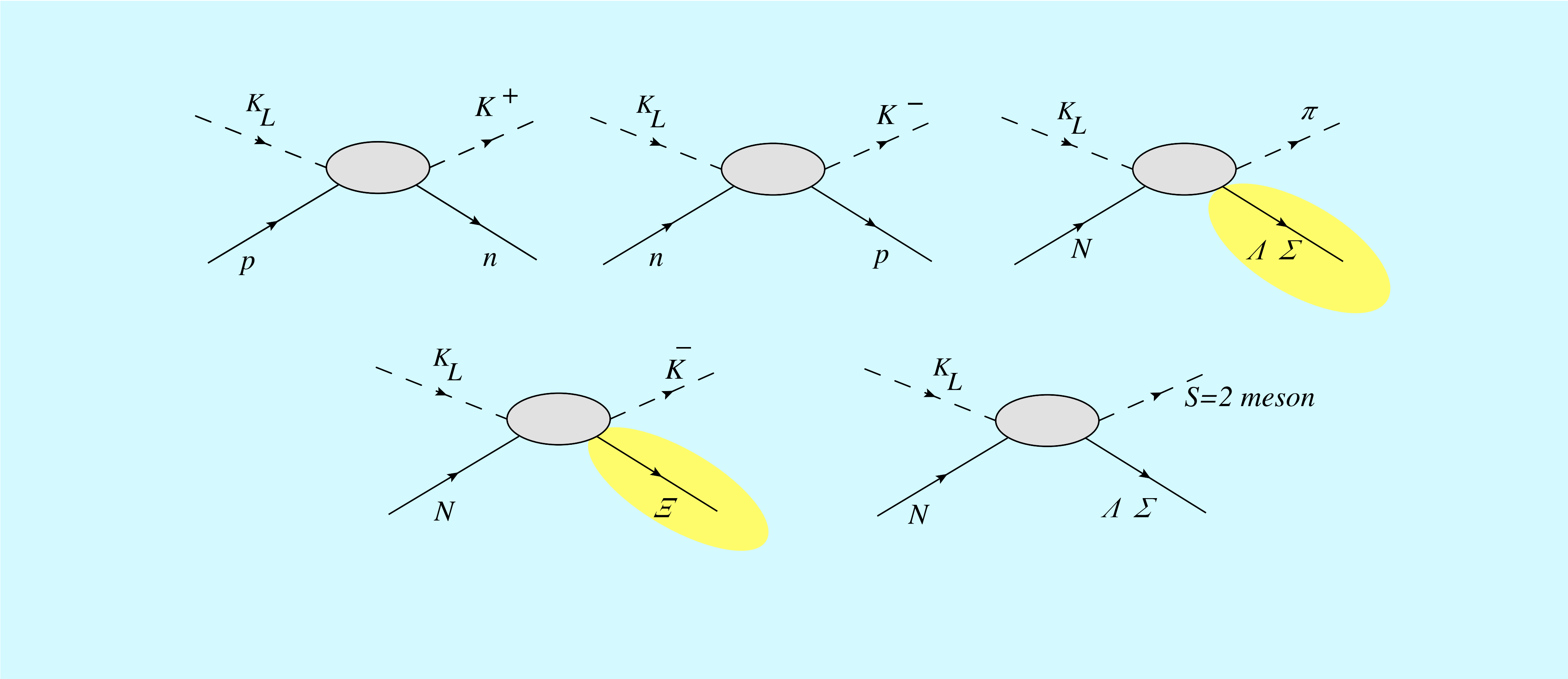
Feb. 12, 2020



The potentials of a KL beam

K_L: S=±1in one beam

- Study of electro-weak interactions with K mesons
- Production of excited K* mesons
- Production of strange baryons
- Search for exotic mesons and baryons



Outline

- Key questions on hyperons
- Missing hyperons
- The role of symmetries in excited baryons
- Excited baryon masses
- Partial decay widths
- Comments

Key questions

- Missing hyperon states: complete SU(3) multiplets in terms of isospin multiplets

	PDG
$\#\Sigma = \#\Xi = \#N + \#\Delta$	$26; 12; 49$
$\#\Omega = \#\Delta$	$4; 22$
$\#\Lambda = \#N + \#\text{singlets}$	$18; 29$

Hyperon	Missing Isospin multiplets
Λ	11
Σ	23
Ξ	37
Ω	18

- Should all observed hyperons belong into SU(3) multiplets?: true if SU(3) symmetry would be exact; in broken SU(3) dynamically generated resonances (pentaquarks) may not form multiplets due to the fine tuned dynamics needed to generate them

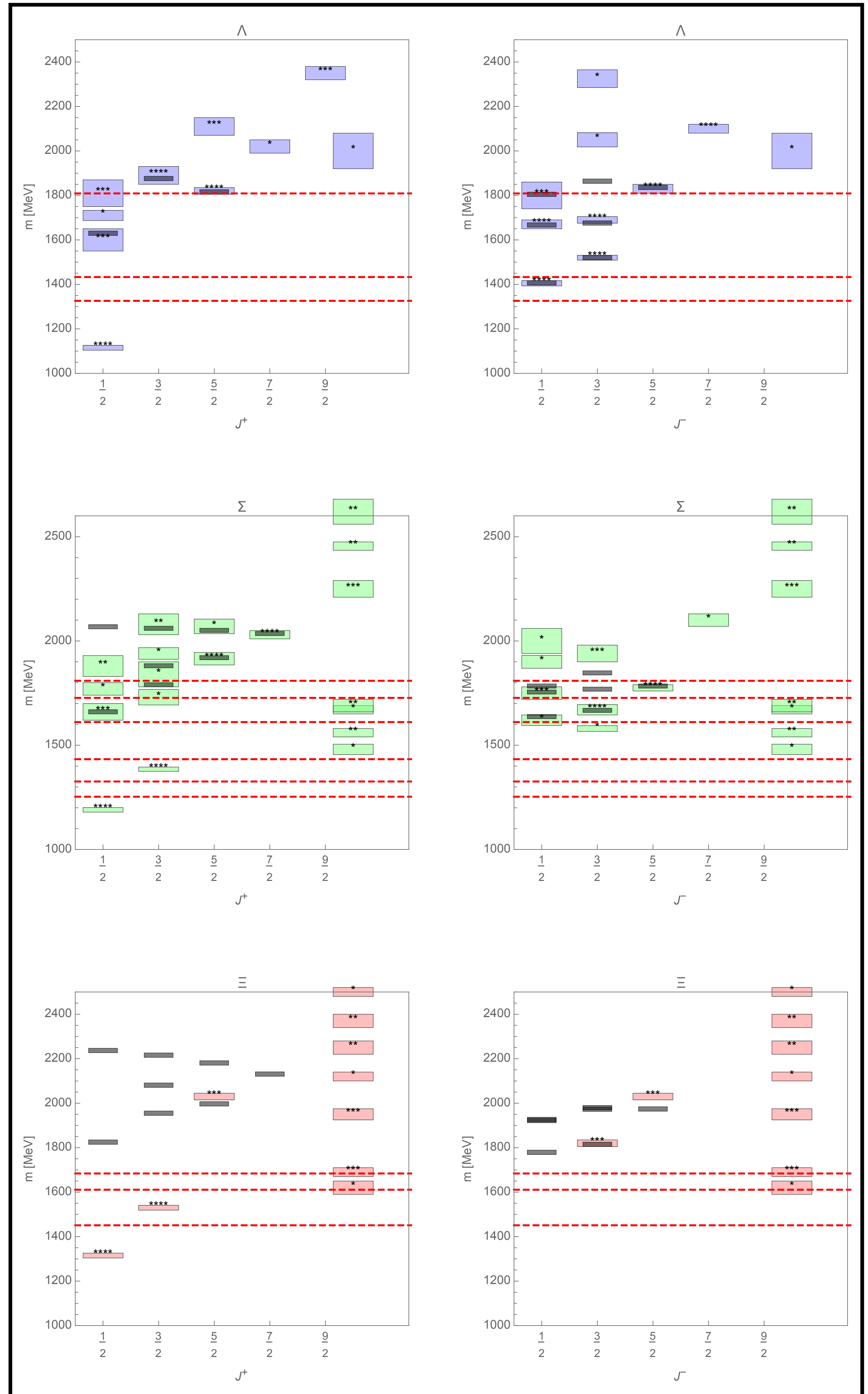
- Should baryons filling SU(3) multiplets also fill SU(6) multiplets?: probably yes — demanded for large Nc QCD

- Sufficient inputs and theoretical tools to make some predictions: quark models, 1/Nc expansion, Lattice QCD (talk by David Richards)

Present status of hyperons from PDG

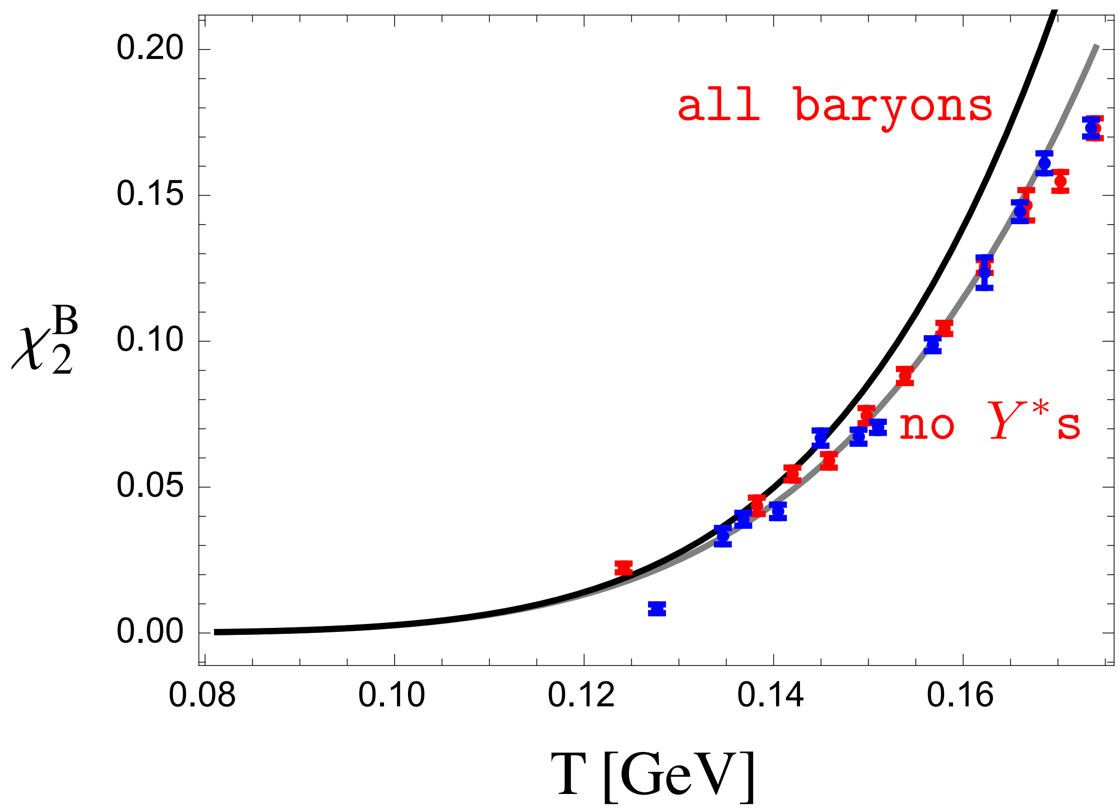
SU(6) spin-flavor and 1/Nc baryon mass formulas
Including only up to second resonance level

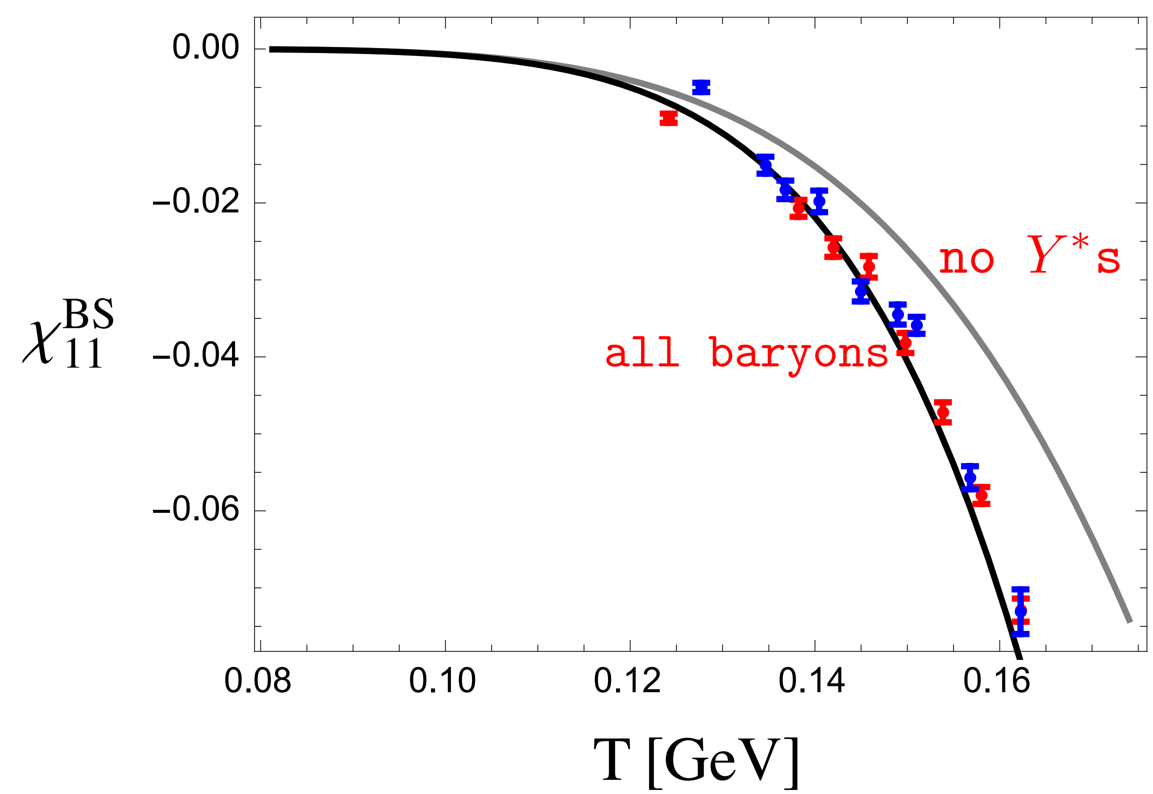
Meson-baryon thresholds



Another possible indication of missing hyperons: QCD Thermodynamics

$$\chi_2^{ij} = \frac{1}{T^2}\frac{\partial^2 p}{\partial\mu_i\partial\mu_j} \qquad i,j:\quad Q,\ S,\ B$$





Calculations using the Hadron Resonance Gas Model

`LQCD results:  Bazavov et al.`

Can give only a very global indication that states are missing: little predictivity otherwise

What is needed for believable prediction on missing hyperons

Framework at hadronic level that fulfills fundamental strictures of QCD

- SU(3) approximate symmetry; expansion in quark masses
- A consistent expansion in 1/Nc which leads to approximate SU(6) spin-flavor sym
- Implementation of unitarity and analyticity

First two are straightforward to implement;

last one is much more difficult to implement for

the purpose of predictions but there are some models

such as unitary ChPT

Following discussion implements the constraints of broken SU(6) consistent with perturbative expansion in quark masses and 1/Nc

Symmetry approach to excited baryons

Flavor SU(3): broken by $m_s >> m_{u,d}$

It should be a good approximate symmetry because

$$m_s << \text{hadronic scales}$$

Expect baryons to fill SU(3) multiplets: 8s, 10s and 1s.
GS baryon multiplets (low lying 8 and 10) are complete
What about others? -- only one is complete in PDG!

$N_{3/2^-}$	1532
$\Lambda_{3/2^-}$	1676
$\Sigma_{3/2^-}$	1667
$\Xi_{3/2^-}$	1815

GMO relation

$$2(N_{3/2}+\Xi_{3/2})-3\Lambda_{3/2}-\Sigma_{3/2}=-19\pm 26\ MeV$$

Excellent check!

Additional symmetries in baryons

QCD observables admit expansions in $m_{u,d,s}$ and in $1/N_c$

Consequence of the $1/N_c$ expansion for baryons: approximate spin-flavor $SU(2N_f) = SU(6)$ symmetry violated at order $1/N_c$ or higher.

How good is $SU(6)$?: a check with mass relations

GS mass relations: Gursey-Radicati with $1/N_c$ power counting included

$$M_{GS} = c_1\,N_c + \frac{c_{HF}}{N_c}\,(S^2 - \frac{3}{4}N_c) - c_{\mathcal{S}}\frac{m_s - m_{u,d}}{\Lambda}\,\mathcal{S} + \mathcal{O}(1/N_c^2; m_s/N_c)$$

	$\Sigma - \Lambda = \mathcal{O}(m_s/N_c)$	74 MeV
GMO	$\Xi_8 - \Sigma_8 = \frac{1}{2}(3\Lambda - \Sigma_8) - N$	128 vs 141 MeV
ES	$\Sigma_{10} - \Delta = \Xi_{10} - \Sigma_{10}$	153 vs 145
”	$\Omega^- - \Xi_{10} = \Xi_{10} - \Sigma_{10}$	142 vs 145
8-10	$\Sigma_{10} - \Sigma_8 = \Xi_{10} - \Xi_8$	212 vs 195

deviation is $\mathcal{O}((m_s - m_{u,d})^2/N_c)$

deviation is $\mathcal{O}(1/N_c^2)$

A test with the N & Δ axial couplings

large N_c prediction $g_A^{NN} = g_A^{N\Delta} = g_A^{\Delta\Delta}$

	g_A^{NN}	$g_A^{N\Delta}$	$g_A^{\Delta\Delta}$
Exp	1.27	1.24	–
Lattice QCD (ETM)	1.17	1.07	0.98

deviations are $\mathcal{O}(1/N_c^2) \sim 10\%$: OK!

Many other tests with the octet and decuplet axial couplings

SU(6) broken according to 1/Nc power counting works remarkably well in the GS 8 and 10

SU(6) plays a key role in baryon ChPT for improving the chiral expansion as well

Excited baryons

$$SU(6) \times O(3) \to \text{Large } N_c \text{ QCD} \to SU(6)$$

Observed fact: in all analyzed observables (masses, partial widths, photocouplings) operators involving factors of $SU(6)$ and $O(3)$ operators have small coefficients:

$\mathcal{O}(1/N_c)$ suppressed in transition and in $SU(6)$ symmetric states (56-plet)
$\mathcal{O}(1/N_c^0)$ in $SU(6)$ mixed-symmetric states (70-plet)

Expansion in $1/N_c$ and if necessary in "spin-orbit" couplings

Mass formulas

$$M(R(SU(6)), L, J, R(SU(3)), Y) = M_0(R(SU(6)), L) + \delta M(R(SU(6)), L, J, R(SU(3)), Y)$$

$$R(SU(6)) = 56,\ 70,\ 20?, \qquad R(SU(3)) = 1,\ 8,\ 10$$

δM expanded in $m_s - m_{u,d}$ and in $1/N_c$

More predictivity: through additional mass relations

$[56,2^+]$ mass relations

JLG, Schat & Scoccola

Basis of mass operators

Operator	Coefficient (MeV)
$O_1 = N_c\, \mathbf{1}$	$c_1 = 541 \pm 4$
$O_2 = \frac{1}{N_c} l_i\, S_i$	$c_2 = 18 \pm 16$
$O_3 = \frac{1}{N_c} S_i S_i$	$c_3 = 241 \pm 14$
$\bar{B}_1 = -\mathcal{S}$	$b_1 = 206 \pm 18$
$\bar{B}_2 = \frac{1}{N_c} l_i G_{i8} - \frac{1}{2\sqrt{3}} O_2$	$b_2 = 104 \pm 64$
$\bar{B}_3 = \frac{1}{N_c} S_i G_{i8} - \frac{1}{2\sqrt{3}} O_3$	$b_3 = 223 \pm 68$

	$\mathcal{O}(\Lambda/N_c^2)$		$Exp[MeV]$
	$\frac{1}{2}(\Delta_{5/2} - \Delta_{3/2} - N_{5/2} + N_{3/2})$	$=$	-12 ± 33
	$\sqrt{\frac{2}{53}}(\Delta_{7/2} - \Delta_{5/2} - \frac{7}{5}(N_{5/2} - N_{3/2}))$	$=$	15 ± 15
	$\frac{1}{2\sqrt{5}}(\Delta_{7/2} - \Delta_{1/2} - 3(N_{5/2} - N_{3/2}))$	$=$	24 ± 34
	$\frac{1}{2\sqrt{3}}(\Lambda_{5/2} - \Lambda_{3/2} + \Sigma_{5/2} - \Sigma_{3/2} - 2(\Sigma'_{5/2} - \Sigma'_{3/2})$	$=$	11 ± 36
	$\frac{1}{\sqrt{218}}(7\,\Sigma'_{3/2} + 5\,\Sigma_{7/2} - 12\,\Sigma'_{5/2})$	$=$	-7 ± 38
	$\frac{1}{\sqrt{57}}(4\,\Sigma_{1/2} + \Sigma_{7/2} - 5\,\Sigma'_{3/2})$		
	$\mathcal{O}(m_s/N_c^2)$		$Exp[MeV]$
	$\frac{1}{\sqrt{3346}}(8\Lambda_{3/2} - 8N_{3/2} + 37\Lambda_{5/2} - 22N_{5/2} - 15\Sigma_{5/2} - 30\Sigma_{7/2} + 30\Delta_{7/2})$	$=$	8.5 ± 12
	$\frac{1}{2\sqrt{13}}(\Lambda_{5/2} - \Lambda_{3/2} + 3(\Sigma_{5/2} - \Sigma_{3/2}) - 4(N_{5/2} - N_{3/2}))$	$=$	34 ± 34
(GMO)	$2(N + \Xi)$	$=$	$3\,\Lambda + \Sigma$
(EQS)	$\Sigma - \Delta$	$=$	$\Xi - \Sigma = \Omega - \Xi$

$[56,2^+]$	$masses$	$[MeV]$
$State$	$1/N_c$	PDG
$N_{3/2}$	1674 ± 15	1700 ± 50
$\Lambda_{3/2}$	1876 ± 39	1880 ± 30
$\Sigma_{3/2}$	1881 ± 25	(1840)
$\Xi_{3/2}$	2081 ± 57	
$N_{5/2}$	1689 ± 14	1683 ± 8
$\Lambda_{5/2}$	1816 ± 33	1820 ± 5
$\Sigma_{5/2}$	1920 ± 24	1918 ± 18
$\Xi_{5/2}$	1997 ± 49	
$\Delta_{1/2}$	1897 ± 32	1895 ± 25
$\Sigma_{1/2}$	2068 ± 52	
$\Xi_{1/2}$	2237 ± 88	
$\Omega_{1/2}$	2408 ± 127	
$\Delta_{3/2}$	1906 ± 27	1935 ± 35
$\Sigma'_{3/2}$	2061 ± 44	(2080)
$\Xi'_{3/2}$	2216 ± 76	
$\Omega_{3/2}$	2373 ± 110	
$\Delta_{5/2}$	1921 ± 21	1895 ± 25
$\Sigma'_{5/2}$	2051 ± 37	(2070)
$\Xi'_{5/2}$	2181 ± 64	
$\Omega_{5/2}$	2313 ± 94	
$\Delta_{7/2}$	1942 ± 27	1950 ± 10
$\Sigma_{7/2}$	2036 ± 44	2033 ± 8
$\Xi_{7/2}$	2131 ± 76	
$\Omega_{7/2}$	2229 ± 110	

$[70, 1^-]$ mass relations

Masses [MeV]		
State	*Exp*	*Large N_c*
$N_{1/2}$	1538 ± 18	1541
$\Lambda_{1/2}$	1670 ± 10	1667
$\Sigma_{1/2}$	(1620)	1637
$\Xi_{1/2}$	(1690)	1779
$N_{3/2}$	1523 ± 8	1532
$\Lambda_{3/2}$	1690 ± 5	1676
$\Sigma_{3/2}$	1675 ± 10	1667
$\Xi_{3/2}$	1823 ± 5	1815
$N'_{1/2}$	1660 ± 20	1660
$\Lambda'_{1/2}$	1785 ± 65	1806
$\Sigma'_{1/2}$	1765 ± 35	1755
$\Xi'_{1/2}$		1927
$N'_{3/2}$	1700 ± 50	1699
$\Lambda'_{3/2}$		1864
$\Sigma'_{3/2}$		1769
$\Xi'_{3/2}$		1980
$N_{5/2}$	1678 ± 8	1671
$\Lambda_{5/2}$	1820 ± 10	1836
$\Sigma_{5/2}$	1775 ± 5	1784
$\Xi_{5/2}$		1974
$\Delta_{1/2}$	1645 ± 30	1645
$\Sigma''_{1/2}$		1784
$\Xi''_{1/2}$		1922
$\Omega_{1/2}$		2061
$\Delta_{3/2}$	1720 ± 50	1720
$\Sigma''_{3/2}$		1847
$\Xi''_{3/2}$		1973
$\Omega_{3/2}$		2100
$\Lambda''_{1/2}$	1407 ± 4	1407
$\Lambda''_{3/2}$	1520 ± 1	1520

Operator	Coefficient
$O_0 = N_c \, 1$	$c_0 = 449 \pm 2$
$O_1 = N_c \, t^a T^a_c - \frac{1}{2\sqrt{3}N_c} O_0$	$c_1 = -81 \pm 36$
$O_2 = l_h \, s_h$	$c_2 = 52 \pm 15$
$O_3 = \frac{3}{N_c} \, l^{(2)}_{hk} \, g_{ha} \, G^c_{ka}$	$c_3 = 116 \pm 44$
$O_4 = \frac{4}{N_c+1} \, l_h \, t_a \, G^c_{ha}$	$c_4 = 110 \pm 16$
$O_5 = \frac{1}{N_c} \, l_h \, S^c_h$	$c_5 = 74 \pm 30$
$O_6 = \frac{1}{N_c} \, S^c_h \, S^c_h$	$c_6 = 480 \pm 15$
$O_7 = \frac{1}{N_c} \, s_h \, S^c_h$	$c_7 = -159 \pm 50$
$O_8 = \frac{1}{N_c} \, l^{(2)}_{hk} s_h \, S^c_k$	$c_8 = 6 \pm 110$
$O_9 = \frac{1}{N_c^2} \, l_h \, g_{ka}\{S^c_k, G^c_{ha}\}$	$c_9 = 213 \pm 153$
$O_{10} = \frac{1}{N_c^2} t_a \{S^c_h, G^c_{ha}\}$	$c_{10} = -168 \pm 56$
$O_{11} = \frac{1}{N_c^2} \, l_h \, g_{ha}\{S^c_k, G^c_{ka}\}$	$c_{11} = -133 \pm 130$
$\bar{B}_1 = T^c_8 - \frac{N_c - 1}{2\sqrt{3}N_c} O_1$	$d_2 = -194 \pm 17$
$\bar{B}_2 = \frac{1}{N_c} \, d_{8ab} \, g_{ha} \, G^c_{hb} + \frac{N_c^2 - 9}{16\sqrt{3}N_c^2(N_c-1)} O_0 + \frac{1}{4\sqrt{3}(N_c-1)} O_6 + \frac{1}{12\sqrt{3}} O_7$	$d_3 = -150 \pm 301$
$\bar{B}_3 = l_h \, g_{h8} - \frac{1}{2\sqrt{3}} O_2$	$d_4 = -82 \pm 57$

GMO, ES & 15 1-8-10 relations

$$\mathcal{O}(m_s/N_c^2; m_s^2)$$

$$\frac{1}{\sqrt{16930}} \left(14(\tilde{\Lambda}_{3/2} + \tilde{\Lambda}'_{3/2}) + 63\tilde{\Lambda}_{5/2} + 36(\tilde{\Sigma}_{1/2} + \tilde{\Sigma}'_{1/2}) - 68(\tilde{\Lambda}_{1/2} + \tilde{\Lambda}'_{1/2}) - 27\tilde{\Sigma}_{5/2}\right)$$

$$\frac{1}{\sqrt{1570}} \left(14(\tilde{\Sigma}_{3/2} + \tilde{\Sigma}'_{3/2}) + 21\tilde{\Lambda}_{5/2} - 9\tilde{\Sigma}_{5/2} - 18(\tilde{\Lambda}_{1/2} + \tilde{\Lambda}'_{1/2}) - 2(\tilde{\Sigma}_{1/2} + \tilde{\Sigma}'_{1/2})\right)$$

$$\frac{1}{\sqrt{8066}} \left(14\tilde{\Sigma}''_{1/2} + 49\tilde{\Lambda}_{5/2} + 23(\tilde{\Sigma}_{1/2} + \tilde{\Sigma}'_{1/2}) - 45(\tilde{\Lambda}_{1/2} + \tilde{\Lambda}'_{1/2}) - 19\tilde{\Sigma}_{5/2}\right)$$

$$\frac{1}{2\sqrt{695}} \left(14\tilde{\Sigma}''_{3/2} + 28\tilde{\Lambda}_{5/2} + 11(\tilde{\Sigma}_{1/2} + \tilde{\Sigma}'_{1/2}) - 27(\tilde{\Lambda}_{1/2} + \tilde{\Lambda}'_{1/2}) - 10\tilde{\Sigma}_{5/2}\right)$$

PDG identified states are sufficient to predict masses of missing states up to higher order terms in 1/Nc and SU(3) breaking

JLG, Schat & Scoccola

Only a reduced number of possible mass operators are important after fitting to the known masses

Checks with Lattice QCD

HSC R. Edwards et al (2013)

Fernando & JLG

$[56, 0^+]$

Relation	M_π[MeV] 391	524
$2(N+\Xi)-(3\Lambda+\Sigma)=0$	179±180	106±155
$\Sigma''-\Delta=\Xi''-\Sigma''=\Omega''-\Xi''$	13±45	-27±26
	84±40	41±49
	48±42	41±57
$\frac{1}{3}(\Sigma+2\Sigma'')-\Lambda-(\frac{2}{3}(\Delta-N))=0$	51±65	29±41
$\Sigma''-\Sigma=\Xi''-\Xi$	58±63	77±80
$3\Lambda+\Sigma-2(N+\Xi)+(\Omega''-\Xi''-\Sigma''+\Delta)=0$	144±189	174±170
$\Sigma''-\Delta+\Omega''-\Xi''-2(\Xi^*-\Sigma'')=0$	107±110	67±147

$[70, 1^-]$

Relation	M_π [MeV] 391	524
$14(S_{\Lambda_{3/2}}+S_{\Lambda'_{3/2}})+63S_{\Lambda_{5/2}}+36(S_{\Sigma_{1/2}}+S_{\Sigma'_{1/2}})$		
$-68(S_{\Lambda_{1/2}}+S_{\Lambda'_{1/2}})-27S_{\Sigma_{5/2}}=0$	9.4±40	0.96±34
$14(S_{\Sigma_{3/2}}+S_{\Sigma'_{3/2}})+21S_{\Lambda_{5/2}}-9S_{\Sigma_{5/2}}$		
$-18(S_{\Lambda_{1/2}}+S_{\Lambda'_{1/2}})-2(S_{\Sigma_{1/2}}+S_{\Sigma'_{1/2}})=0$	37±45	5.4±38
$14\,S_{\Sigma''_{1/2}}+49S_{\Lambda_{5/2}}+23(S_{\Sigma_{1/2}}+S_{\Sigma'_{1/2}})$		
$-45(S_{\Lambda_{1/2}}+S_{\Lambda'_{1/2}})-19S_{\Sigma_{5/2}}=0$	9.4±40	0.7±34
$14\,S_{\Sigma''_{3/2}}+28S_{\Lambda_{5/2}}+11(S_{\Sigma_{1/2}}+S_{\Sigma'_{1/2}})$		
$-27(S_{\Lambda_{1/2}}+S_{\Lambda'_{1/2}})-10S_{\Sigma_{5/2}}=0$	0.8±40	0.1±33

$[56, 2^+]$

Relation	M_π[MeV] 391	524	702
$2(N_{3/2}+\Xi_{3/2})-(3\Lambda_{3/2}+\Sigma_{3/2})=0$	98±126	49±173	0
$2(N_{5/2}+\Xi_{5/2})-(3\Lambda_{5/2}+\Sigma_{5/2})=0$	40±98	55±65	0
$\Sigma''_{1/2}-\Delta_{1/2}=\Xi''_{1/2}-\Sigma''_{1/2}=\Omega_{1/2}-\Xi''_{1/2}$	-13±110	36±33	0
	23±44	43±22	0
	85±54	35±19	0
$\Sigma''_{3/2}-\Delta_{3/2}=\Xi''_{3/2}-\Sigma''_{3/2}=\Omega_{3/2}-\Xi''_{1/2}$	48±46	36±23	0
	56±29	30±16	0
	45±31	41±15	0
$\Sigma''_{5/2}-\Delta_{5/2}=\Xi''_{5/2}-\Sigma''_{5/2}=\Omega_{5/2}-\Xi''_{5/2}$	35±40	34±26	0
	62±31	26±23	0
	57±34	52±18	0
$\Sigma''_{7/2}-\Delta_{7/2}=\Xi''_{7/2}-\Sigma''_{7/2}=\Omega_{7/2}-\Xi''_{7/2}$	38±38	35±25	0
	67±31	36±20	0
	59±31	22±18	0
$\Delta_{5/2}-\Delta_{3/2}-(N_{5/2}-N_{3/2})=0$	70±68	4±68	44±33
$(\Delta_{7/2}-\Delta_{5/2})-\frac{7}{5}(N_{5/2}-N_{3/2})=0$	68±78	2.5±92	75±41
$\Delta_{7/2}-\Delta_{1/2}-3(N_{5/2}-N_{3/2})=0$	129±175	13±192	133±74
$\frac{8}{15}(\Lambda_{3/2}-N_{3/2})+\frac{22}{15}(\Lambda_{5/2}-N_{5/2})$			
$-(\Sigma_{5/2}-\Lambda_{5/2})-2(\Sigma''_{7/2}-\Delta_{7/2})=0$	91±100	29±75	0
$\Lambda_{5/2}-\Lambda_{3/2}+3(\Sigma_{5/2}-\Sigma_{3/2})-4(N_{5/2}-N_{3/2})=0$	10±207	10±272	0
$\Lambda_{5/2}-\Lambda_{3/2}+\Sigma_{5/2}-\Sigma_{3/2}-2(\Sigma''_{5/2}-\Sigma''_{3/2})=0$	111±81	12±72	87±59
$7(\Sigma''_{3/2}-\Sigma''_{7/2})-12(\Sigma''_{5/2}-\Sigma''_{7/2})=0$	44±319	39±268	67±266
$4(\Sigma''_{1/2}-\Sigma''_{7/2})-5(\Sigma''_{3/2}-\Sigma''_{7/2})=0$	83±170	87±104	58±161

mass relations implied by SU(6) broken at order 1/Nc hold remarkably well

Excited hyperons: mass predictions and puzzles

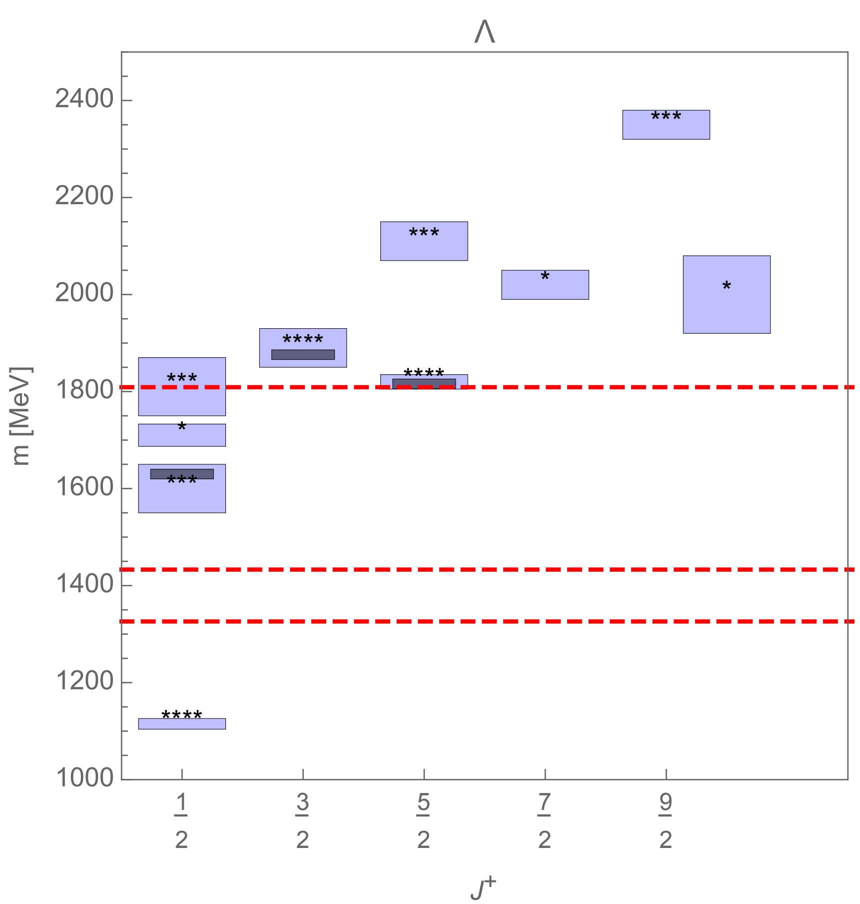
Mass predictions based on SU(6)xO(3)

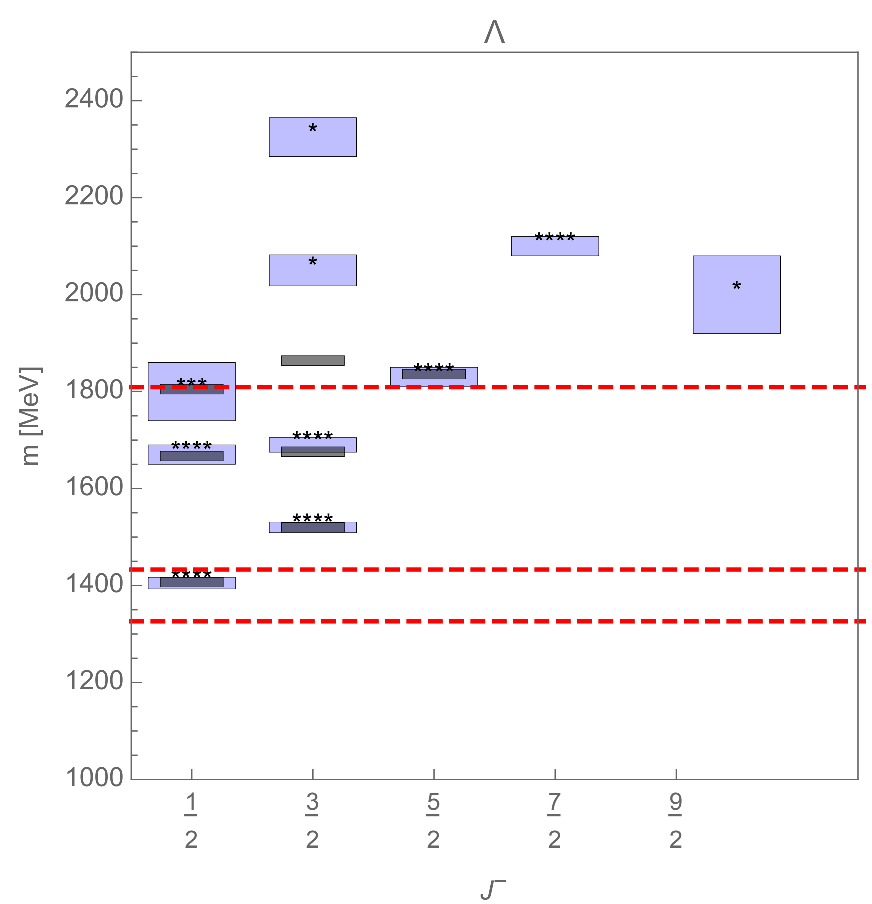
Λs

- One missing state in the $[70, 1^-]$:
  prediction: $\Lambda_{3/2^-}(1830)$

- PDG: $\Lambda_{1/2^+}(1810)$ a bit too light to fit into higher excited multiplets such as $[70, 0^+]$ or $[70, 2^+]$ Matagne & Stancu
  sits exactly at the ΞK threshold

- Heavier states poorly established or need higher excited spin-flavor multiplets: too sparse for predictions





Σs

- Positive parity predicted masses:

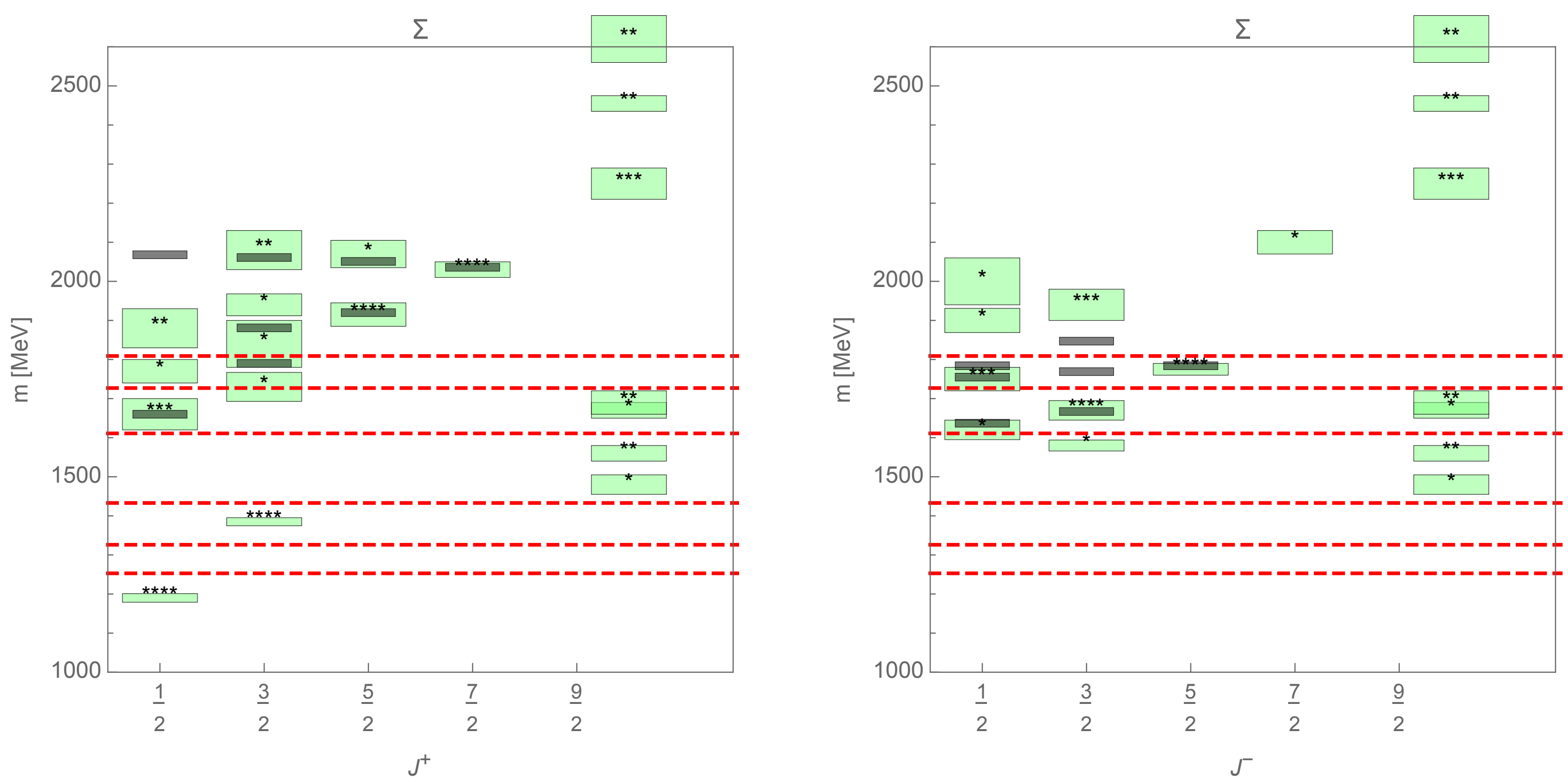
$\Sigma_{1/2^+}(1790)$ in a decuplet in $[56, 0^+]$
$\Sigma_{1/2^+}(2068)$ in a decuplet in $[56, 2^+]$
$\Sigma_{3/2^+}(1880)$ in an octet in $[56, 2^+]$
$\Sigma_{3/2^+}(2060)$ in a decuplet in $[56, 2^+]$
$\Sigma_{5/2^+}(2050)$ in a decuplet in $[56, 2^+]$

Most match with existing PDG entries

- Negative parity predicted masses:

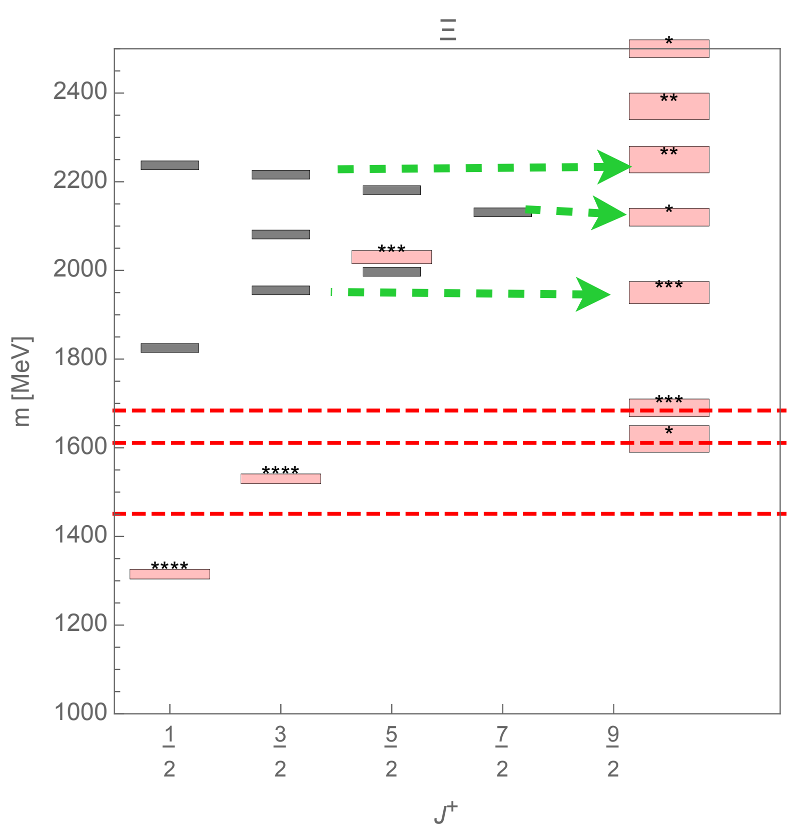
$\Sigma_{1/2^-}(1637)$ in an octet in $[70, 1^-]$
$\Sigma_{3/2^-}(1770)$ in an octet in $[70, 1^-]$
$\Sigma_{1/2^-}(1785)$ in a decuplet in $[70, 1^-]$
$\Sigma_{3/2^-}(1847)$ in a decuplet in $[70, 1^-]$

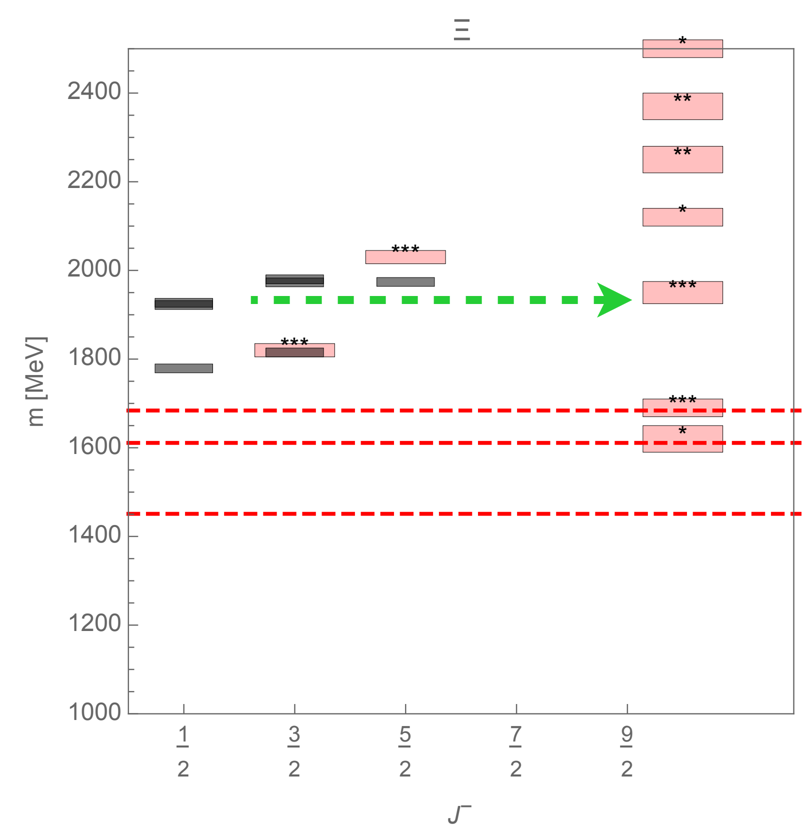
- Puzzles: several * and ** PDG entries seem too light to fit in any multiplet



Ξs

- Lightest PDG entries coincide with thresholds. Cannot be described within any multiplet.
- Several possible identifications of predictions with PDG listings
- $\Xi_{5/2}(2030)$ *** is best identified with a state in the $[56, 2^+]$
- 12 predictions and a few possible matchings with listed PDG states
- Two remaining mass states should be in other multiplets.





Other observables: partial decay widths

$[70,1^-]$ decay relations: LO=exact SU(4) limit

$\tilde{\Gamma}$: reduced widths: phase space factors removed

S-wave

$$\frac{\tilde{\Gamma}(N(1535)\to N\pi)-\tilde{\Gamma}(N(1650)\to N\pi)}{\tilde{\Gamma}(N(1535)\to N\pi)+\tilde{\Gamma}(N(1650)\to N\pi)}=\frac{1}{5}(3\cos 2\theta_{N_1}-4\sin 2\theta_{N_1}) \to \theta_{N_1}=0.46(10)\ or\ 1.76(10)$$

$$\frac{\tilde{\Gamma}(N(1535)\to N\eta)-\tilde{\Gamma}(N(1650)\to N\eta)}{\tilde{\Gamma}(N(1535)\to N\eta)+\tilde{\Gamma}(N(1650)\to N\eta)}=\sin 2\theta_{N_1} \to \theta_{N_1}=0.51(27)$$

$$\tilde{\Gamma}(N(1535)\to N\pi)+\tilde{\Gamma}(N(1650)\to N\pi)=\tilde{\Gamma}(\Delta(1535)\to \Delta\pi) \quad 51(10)\ (th)\ vs\ 31(15)\ (exp)$$

$$\frac{\tilde{\Gamma}(\Delta(1620)\to N\pi)}{\tilde{\Gamma}(\Delta(1700)\to \Delta\pi)}= \quad 0.1\ (th) \quad vs \quad 0.29(15)\ (exp)$$

D-wave

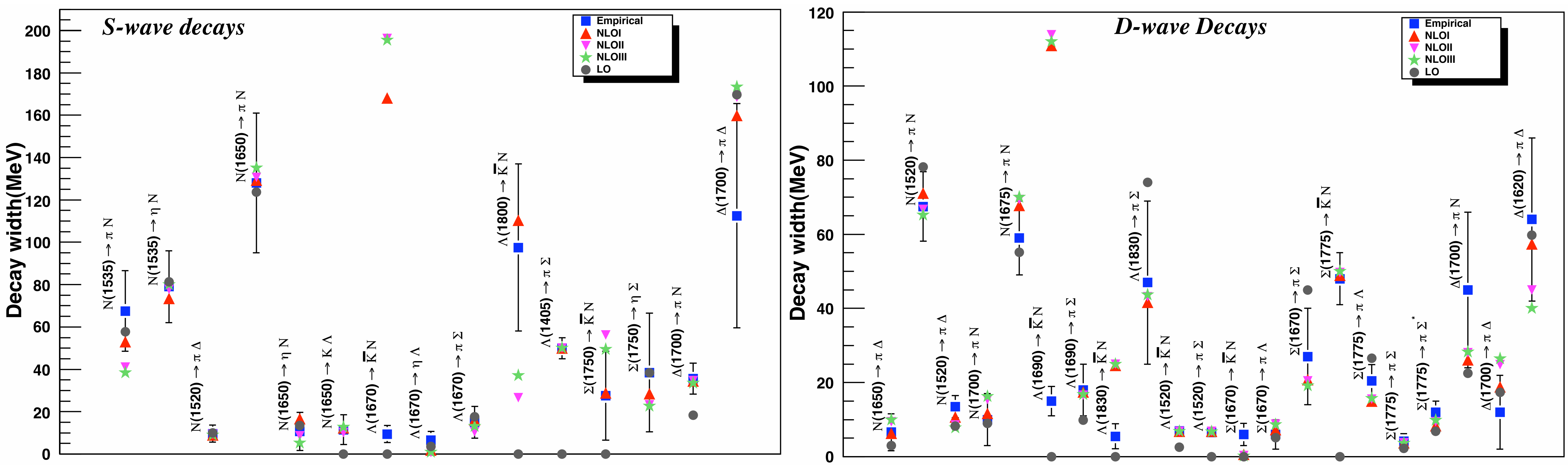
$$2\tilde{\Gamma}(\Delta(1620)\to\Delta\pi)+\tilde{\Gamma}(\Delta(1700)\to\Delta\pi)=15\tilde{\Gamma}(\Delta(1620)\to N\pi)+32\tilde{\Gamma}(\Delta(1700)\to N\pi)$$

$$5.9(1.9) \quad vs \quad 8.3(2.3)$$

$$\tilde{\Gamma}(N(1535)\to\Delta\pi)+\tilde{\Gamma}(N(1650)\to\Delta\pi)+11\tilde{\Gamma}(\Delta(1620)\to\Delta\pi)=132\tilde{\Gamma}(\Delta(1700)\to N\pi)+90\tilde{\Gamma}(N(1675)\to N\pi)$$

$$32(11) \quad vs \quad 41(10)$$

70-plet baryon's partial decay widths



Gonzalez, Jayalath, Scoccola & JLG

need to give the resulting widths for the missing states

Known hyperons partial decay widths in the 70-plet

	$\Lambda(1670)$				$\Lambda(1690)$				
	$\bar{K}N$	$\eta\Lambda$	$\pi\Sigma$	$\pi\Sigma^*$	$\pi\Sigma^*$		$\bar{K}N$	$\eta\Lambda$	$\pi\Sigma$
PW	S	S	S	D	S	D	D	D	D
LO	113(24)	0.11(0.12)	1.8(2.0)	0.16(0.09)	7.3(3.5)	9(1)	60(6)	~ 0	9.0(0.9)
NLO	9(15)	6.1(4.3)	15(11)	0.04(0.10)	114(49)	2.1(1.5)	16(5)	~ 0	5.3(2.9)
Exp	9.4(3.6)	6.6(3.6)	15(7.5)				15(4)		18(6.7)

	$\Sigma(1670)$				
	$\pi\Sigma^*$		$\bar{K}N$	$\pi\Lambda$	$\pi\Sigma$
PW	S	D	D	D	D
LO	1.5(0.7)	1.5(0.2)	2.1(0.5)	4.8(0.5)	46(5)
NLO	4(11)	1.5(0.9)	2.5(1.4)	7.0(2.9)	28(11)
Exp			6(2.7)	6(3.6)	27(12.7)

	$\Lambda(1800)$				$\Lambda(1830)$				
	$\bar{K}N$	$\eta\Lambda$	$\pi\Sigma$	$\pi\Sigma^*$	$\bar{K}N$	$\eta\Lambda$	$\pi\Sigma$	$K\Xi$	$\pi\Sigma^*$
PW	S	S	S	D	D	D	D	D	D
LO	43(13)	30(4)	150(20)	3.0(1.6)	3.0(1.6)	3.5(0.3)	69(6)	~ 0	54(7)
NLO	100(73)	94(47)	109(25)	5.9(5.2)	12(4)	9.6(2.5)	38(11)	~ 0	57(18)
Exp	98(40)				5.5(3.4)		46.7(22)		

	$\Sigma(1750)$					
	$\bar{K}N$	$\pi\Lambda$	$\pi\Sigma$	$\eta\Sigma$	$\bar{K}\Delta$	$\pi\Sigma^*$
PW	S	S	S	S	D	D
LO	45(8)	51(7)	6.2(5.3)	14(2)	0.07(0.04)	0.5(0.3)
NLO	30(34)	38(12)	4.2(7.6)	53(28)	0.4(0.2)	0.4(0.5)
Exp	27.5(21)		4.4(4.4)	38.5(28)		

	$\Lambda(1405)$	$\Lambda(1520)$	
	$\pi\Sigma$	$\bar{K}N$	$\pi\Sigma$
PW	S	D	D
LO	50(19)	2.7(0.4)	8.2(1.3)
NLO	50(9)	6.7(1.1)	6.9(1.8)
Exp	50(5)	7(0.5)	6.5(0.5)

	$\Sigma(1775)$					
	$\bar{K}N$	$\pi\Lambda$	$\pi\Sigma$	$\eta\Sigma$	$\bar{K}\Delta$	$\pi\Sigma^*$
PW	D	D	D	D	D	D
LO	39(3)	27(3)	3.0(1.2)	0.08(0.01)	1.6(0.2)	7(1)
NLO	55(12)	14(4)	0.6(0.8)	0.22(0.06)	3.9(0.8)	7.4(2.3)
Exp	48(7)	20.4(4.4)	4.2(2)			12(2.8)

	$\Xi(1820)$				
	$\pi\Xi^*$		$\bar{K}\Lambda$	$\bar{K}\Sigma$	$\pi\Xi$
PW	S	D	D	D	D
LO	2.3(0.6)	2.6(0.3)	10(1)	14(1)	4.2(0.9)
NLO	2.4(2.2)	3.2(0.6)	18(3)	29(4)	0.3(0.6)
Exp					

$$\chi^2_{\rm dof} \sim 1.2$$

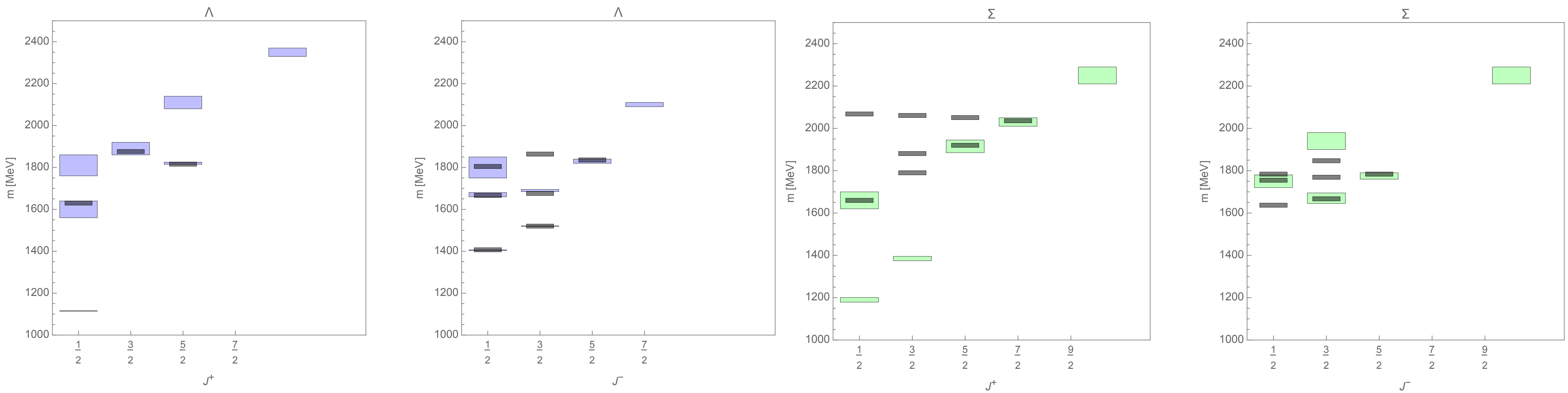
S-wave: 14 PDG PW inputs fitted with 7 parameters
D-wave: 25 “ 8 “

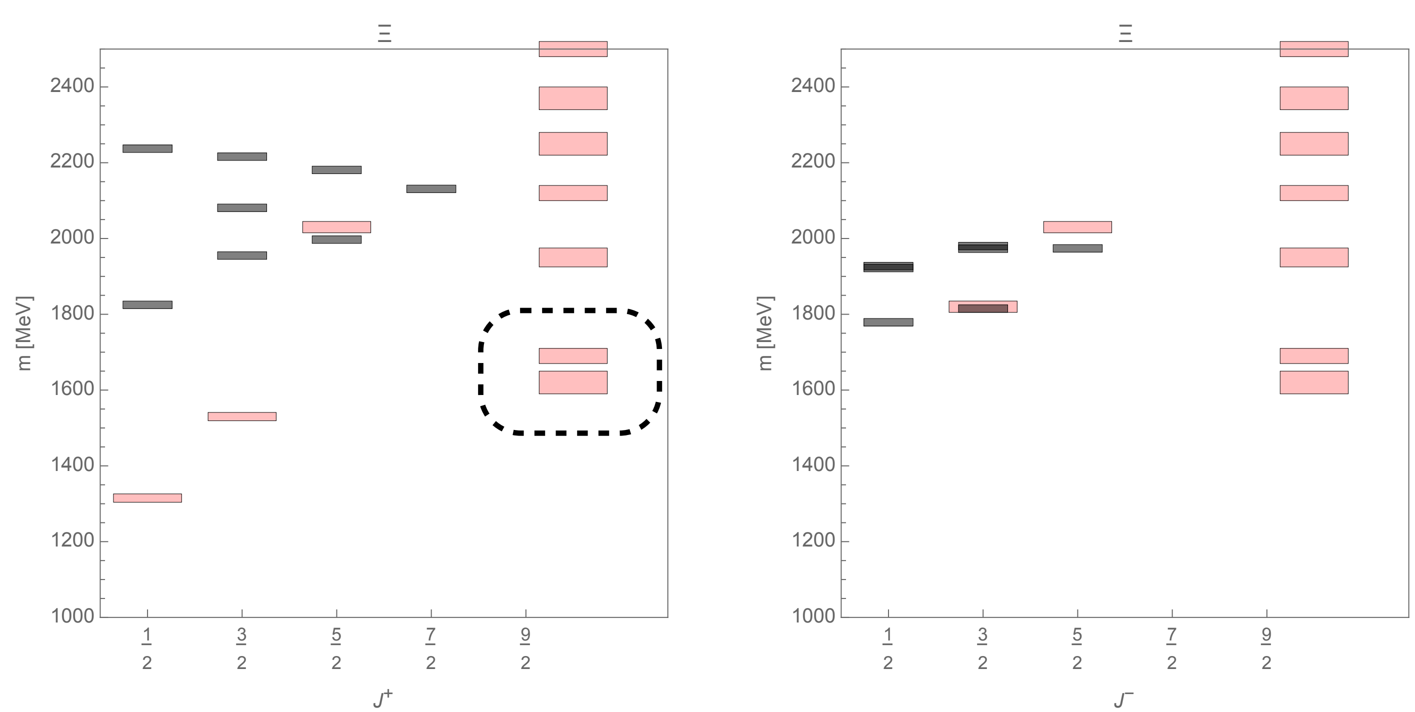
PW predictions for unobserved states in 70-plet are possible with these same calculations: to be done

Comments

- K_L beam: only neutral light meson beam that can be available
- K_L beam opens new opportunities to research hyperon physics at JLab: search for missing states, more data on established states
- Predictions grounded on symmetries can be made once a sufficient number of states in a given multiplet can be identified. Numerous predictions already available. Experiment should have the last word!
- Interesting puzzles exist for PDG listed excited hyperons which do not fit into any of the low lying excited multiplets: they need to be further revisited and investigated.
- Excited Ξs are very poorly known. Establishing and discovering new states is important for establishing the multiplet structure of excited baryons in particular.
- A source of predictions becoming increasingly important is Lattice QCD. (David Richards talk)

Present status of excited hyperons (PDG)



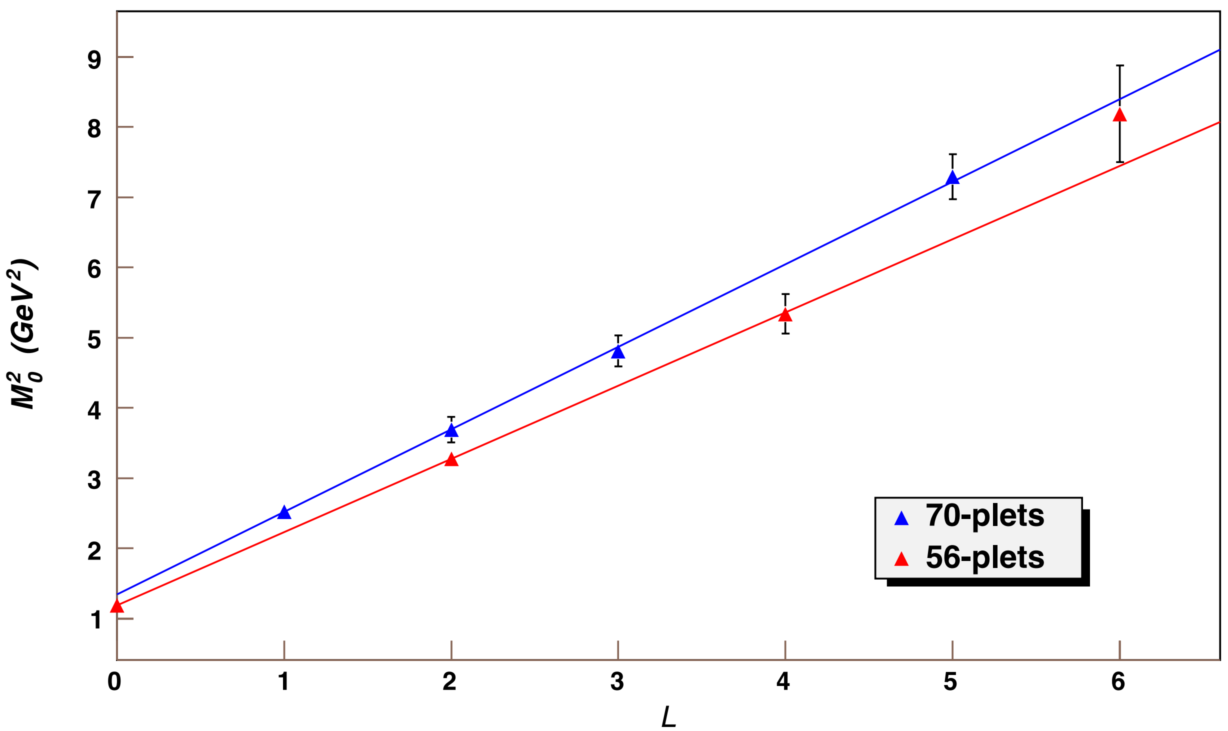


1/Nc baryon mass formulas

Chew-Frautschi for spin-flavor singlet piece of baryon masses

$$[\mathbf{56}, 0^+]_{GS},\ [\mathbf{56}, (2^+, 4^+, 6^+)],\ [\mathbf{70}, (1^-, 2^+, 3^-, 5^-)]$$

+ a grain of salt



JLG & N. Matagne

- $M_0^2[\mathbf{56}, \ell] = [(1.18 \pm 0.003) + (1.05 \pm 0.01)\,\ell]\ \mathrm{GeV}^2$
- $M_0^2[\mathbf{70}, \ell] = [(1.13 \pm 0.02) + (1.18 \pm 0.02)\,\ell]\ \mathrm{GeV}^2$
- $(M_0[\mathbf{70}, \ell] - M_0[\mathbf{56}, \ell])^2 \simeq (5.7 + 4.2\,\ell) \times 10^{-4}\ \mathrm{GeV}^2$
- Splitting between trajectories $\mathcal{O}(N_c^0)$: due to exchange interaction. In magnitude smaller than expected.
- Regge trajectories with physical masses include contributions which do not have linear behavior.
- Strong indication of small **56**-**70** configuration mixings and good approximate $O(3)$ symmetry

$1/N_c$ predictions for Ξ masses

Ξ State	Mass [MeV]	Width [MeV]	J^P	PDG Status
$\Xi^0(1314)$	1314.83 ± 0.20	-	$\frac{1}{2}^+$	****
$\Xi^-(1320)$	1321.31 ± 0.13	-	$\frac{1}{2}^+$	****
$\Xi^0(1530)$	1531.80 ± 0.32	9.1 ± 0.5	$\frac{3}{2}^+$	****
$\Xi^-(1535)$	1535.0 ± 0.6	9.9 ± 1.8	$\frac{3}{2}^+$	****
$\Xi(1620)$	~ 1620	20-40	$?^?$	*
$\Xi(1690)$	1690 ± 10	< 30	$?^?$	***
$\Xi(1820)$	1823 ± 5	24^{+15}_{-10}	$\frac{3}{2}^-$	***
$\Xi(1950)$	1950 ± 15	60 ± 20	$?^?$	***
$\Xi(2030)$	2025 ± 5	20^{+15}_{-5}	$\geq \frac{5}{2}^?$	***
$\Xi(2120)$	~ 2120	~ 25	$?^?$	*
$\Xi(2250)$	~ 2250	50 ± 30	$?^?$	**
$\Xi(2370)$	~ 2370	~ 80	$?^?$	**
$\Xi(2500)$	~ 2500	?	$?^?$	*

Excited Ξs in $O(3) \times SU(6)$ Multiplets

$[\ell = 0, 56]^+$ Carlson & Carone			$[\ell = 1, 70]^-$ Schat, Scoccola & JLG			$[\ell = 2, 56]^+$ Schat, Scoccola & JLG			$[\ell = 4, 56]^+$ Matagne & Stancu		
State	$1/N_c$	Exp	State	$1/N_c$	Exp	State	$1/N_c$	Exp	State	$1/N_c$	Exp
$\Xi^8_{1/2}$	1825 ± 98	-	$\Xi^8_{1/2}$	1780 ± 20	-	$\Xi^8_{3/2}$	2081 ± 57	-	$\Xi^8_{7/2}$	2460 ± 166	-
$\Xi^{10}_{3/2}$	1955 ± 196	-	$\Xi^8_{3/2}$	1815 ± 20	1823 ± 5	$\Xi^8_{5/2}$	1997 ± 50	-	$\Xi^8_{9/2}$	2465 ± 165	-
			$\Xi^8_{1/2}$	1927 ± 20	-	$\Xi^{10}_{1/2}$	2237 ± 90	-	$\Xi^{10}_{5/2}$	2700 ± 266	-
			$\Xi^8_{3/2}$	1980 ± 20	-	$\Xi^{10}_{3/2}$	2216 ± 80	-	$\Xi^{10}_{7/2}$	2592 ± 203	-
			$\Xi^8_{5/2}$	1974 ± 20	-	$\Xi^{10}_{5/2}$	2181 ± 65	-	$\Xi^{10}_{9/2}$	2598 ± 250	-
			$\Xi^{10}_{1/2}$	1922 ± 20	-	$\Xi^{10}_{7/2}$	2131 ± 80	-	$\Xi^{10}_{11/2}$	2715 ± 260	-
			$\Xi^{10}_{3/2}$	1973 ± 20	-						

70-plet:

- 7 masses in range 1750-2000 MeV
- Two pairs of same J states nearly degenerate
- Most significant predictions of $1/N_c$ analysis

	Masses [MeV]	Spin-flavor content			
State	$1/N_c$	$^2 1$	$^2 8$	$^4 8$	$^2 10$
$\Xi_{1/2}$	1779		0.85	0.44	0.29
$\Xi_{3/2}$	1815		-0.98	0.03	-0.19
$\Xi'_{1/2}$	1927		-0.46	0.87	0.18
$\Xi'_{3/2}$	1980		-0.02	(-0.57)	(-0.82)
$\Xi_{5/2}$	1974			1.00	
$\Xi''_{1/2}$	1922		-0.14	-0.31	0.94
$\Xi''_{3/2}$	1973		-0.19	(-0.80)	(0.57)

L=2 56-plet:

- 6 masses in range 2000-2250 MeV
- Same J states separated by >140 MeV
- Larger errors in predictions than in 70-plet
- Parameter free mass relations rather well tested.