APPLICATIONS OF THE 1/Nc EXPANSION TO EXCITED BARYONS

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Exploring Hadrons with Electromagnetic Probes:
Structure, Excitations, Interactions
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OUTLINE

- Why is the 1/Nc expansion relevant
- 1/Nc expansion in baryons
- Applications to the baryon spectrum
- Partial decay widths
- Summary and comments

Why is the 1/Nc expansion relevant?

$$\underbrace{\texttt{QCD}}_{\text{Theory}} \rightarrow \underbrace{\texttt{Hadrons}}_{\text{Observables}}$$

Observables: determined by QCD non-perturbative dynamics

Non-perturbative dynamics encoded in different quantities:
LECs, Form factors, PDFs, GPDs, TMDs, etc

Fundamental QCD constraints on dynamics:
Unitarity and causality; Space-time symmetries;
Chiral and flavor approximate symmetries

Imply important relations:

- Hadron flavor multiplets
- Low energy Theorems
- Dispersion relations
- SU(3) broken symmetry relations

Additional tool: $1/N_c$ expansion

$$SU_c(3) \to SU_c(N_c)$$

- QCD can be expanded in $1/N_c$ throughout
- Expansion can be implemented at hadronic level
- Emergent dynamical symmetries:
  - Nonet symmetry in mesons
  - SU(6) spin-flavor symmetry in baryons
- Consistency with $1/N_c$ expansion improves BChPT
- OZI
- pQCD: planar expansion

Baryons: important facts

- GS **8** and **10** very well known
- Non-strange baryons up to 2.9 GeV listed in PDG
- Missing states:
  - No SU(3) excited baryon multiplet is complete
  - Large number of hyperons missing
  - Even more missing states vis-a-vis QM and LQCD
- Hadron resonance gas description of QCD thermodynamics indicates large number of missing baryon states

Missing hyperons

$SU(3)$	PDG
$\#\Sigma = \#\Xi = \#N + \#\Delta$	$26; 12; 49$
$\#\Omega = \#\Delta$	$4; 22$
$\#\Lambda = \#N + \#\text{singlets}$	$18; 29$

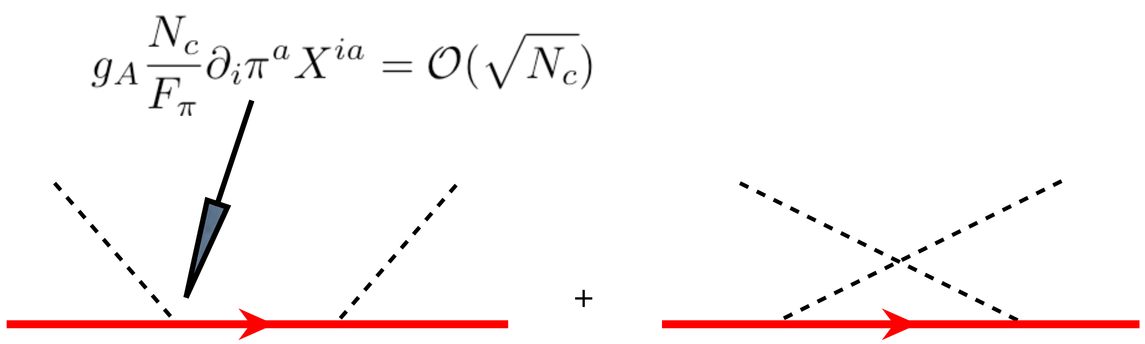
SU(3): $\#$ Y= 3($\#$ N+ $\#$ Δ)+singlets

- # Y > 147
- # Y in PDG $\sim$ 60

1/Nc expansion in baryons

- Additional model independent organizing tool for baryons
- Enhanced predictions, e.g., for missing states

Implementation



$$\propto \frac{k^i k'^j}{k_0} \frac{N_c^2}{F_\pi^2} \langle B' \mid [X^{ia}, X^{jb}] \mid B \rangle$$

Consistency requirement $[X^{ia}, X^{jb}] = \mathcal{O}(1/N_c)$

$\{T^a, S^i, X^{ia}\}$ contracted $SU(2N_f)$ spin-flavor symmetry

broken at subleading order in 1/Nc

Spin-flavor symmetry is the basis for implementing the $1/N_c$ expansion for baryons

Baryon states (resonances) should build spin-flavor multiplets

Effective theory

$$\langle B' \mid \underbrace{\Gamma}_{\texttt{QCD operator}} \mid B\rangle = \langle B' \mid \sum C_i \underbrace{O_i}_{\texttt{effective operators}} \mid B\rangle$$

O_i : basis of operators ordered in powers of $1/N_c$
built with products of generators of SU(6)
C_i : coefficients parameterizing the QCD dynamics

1/N_c power counting for n-body operator $\left(\frac{1}{N_c}\right)^{n-1-\kappa}$

Examples

1-body

	1	S^i	T^a	G^{ia}
κ :	1	0	0	1

2-body

	$\frac{1}{N_c}S^iS^j$	$\frac{1}{N_c}S^iG^{ja}$	$\frac{1}{N_c}T^aT^b$	$\frac{1}{N_c}G^{ia}T^b$	$\frac{1}{N_c}G^{ia}G^{jb}$
κ :	0	1	0	1	2

a couple of (confidence building) tests of spin-flavor symmetry

SU(4)

$g_A^N = 1.267 \pm 0.004; \quad g_A^\Delta = 1.235 \pm 0.011$ from Δ width + GTR

SU(6)

$$\text{LO in } 1/N_c: \quad \frac{F}{D} = \frac{2}{3} \; vs \; \text{phen}: \begin{cases} 0.51 & \text{LO ChPT} \\ 0.66 \pm 0.06 & \text{NLO ChPT} \end{cases}$$

Baryon masses and widths

Rigorous approach: S-matrix poles in complex energy-plane
Define a mass and a width
Less rigorous: Breit-Wigner mass and width

If SU(3) and spin-flavor are good approximate symms
quantities related by them and breaking
can be expanded in $m_s - m_{u,d}$ and $1/N_c$

Application to the baryon spectrum

$SU(6) \times O(3)$ multiplets

$[56, 0+]$ (Roper); $[56, 2^+]$; $[70, 1^-]$

sufficient number of known states for useful applications

Multiplet	Baryon	Name, status	Exp. (MeV)
$[\mathbf{56}, 0^+]$ 8 states 4 missing	$N_{1/2}$	$N(1440)****$	1440 ± 20
	$\Delta_{3/2}$	$\Delta(1600)***$	1600 ± 75
	$\Lambda_{1/2}$	$\Lambda(1600)***$	1600 ± 75
	$\Sigma_{1/2}$	$\Sigma(1660)***$	1660 ± 30
$[\mathbf{56}, 2^+]$	$N_{3/2}$	$N(1720)****$	1700 ± 50
	$\Lambda_{3/2}$	$\Lambda(1890)****$	1880 ± 30
	$N_{5/2}$	$N(1680)****$	1683 ± 8
24 states	$\Lambda_{5/2}$	$\Lambda(1820)****$	1820 ± 5
14 missing	${}^8\Sigma_{5/2}$	$\Sigma(1915)****$	1918 ± 18
	$\Delta_{1/2}$	$\Delta(1910)****$	1895 ± 25
	$\Delta_{3/2}$	$\Delta(1920)***$	1935 ± 35
	$\Delta_{5/2}$	$\Delta(1905)****$	1895 ± 25
	$\Delta_{7/2}$	$\Delta(1950)****$	1950 ± 10
	${}^{10}\Sigma_{7/2}$	$\Sigma(2030)****$	2033 ± 8

Multiplet	Baryon	Name, status	Exp. (MeV)
$[\mathbf{70}, 1^-]$	$\mathrm{N}_{1/2}$	N(1535)****	1538 ± 18
	${}^8\Lambda_{1/2}$	Λ(1670)****	1670 ± 10
	$\mathrm{N}_{3/2}$	N(1520)****	1523 ± 8
	${}^8\Lambda_{3/2}$	Λ(1690)****	1690 ± 5
	${}^8\Sigma_{3/2}$	Σ(1670)****	1675 ± 10
	${}^8\Xi_{3/2}$	Ξ(1820)***	1823 ± 5
	$\mathrm{N}'_{1/2}$	N(1650)****	1660 ± 20
	${}^8\Lambda'_{1/2}$	Λ(1800)***	1785 ± 65
30 states	${}^8\Sigma'_{1/2}$	Σ(1750)***	1765 ± 35
13 missing	$\mathrm{N}'_{3/2}$	N(1700)***	1700 ± 50
	$\mathrm{N}'_{5/2}$	N(1675)****	1678 ± 8
	${}^8\Lambda'_{5/2}$	Λ(1830)****	1820 ± 10
	${}^8\Sigma'_{5/2}$	Σ(1775)****	1775 ± 5
	$\Delta_{1/2}$	Δ(1620)****	1645 ± 30
	$\Delta_{3/2}$	Δ(1700)****	1720 ± 50
	${}^1\Lambda_{1/2}$	Λ(1405)****	1407 ± 4
	${}^1\Lambda_{3/2}$	Λ(1520)****	1520 ± 1

Mass operators: example with $[\mathbf{56}, \mathbf{2}^+]$

	operator	order in $1/N_c$
SU(6) singlet	$N_c \mathbf{1}$	-1
SU(3) singlet	$\frac{1}{N_c} \vec{L} \cdot \vec{S}$	1
	$\frac{1}{N_c} \vec{S}^2$	1
SU(3) octet	N_s	0
	$\frac{1}{N_c}(L^i G^{i8} - \frac{1}{\sqrt{12}} \vec{L} \cdot \vec{S})$	1
	$\frac{1}{N_c}(S^i G^{i8} - \frac{1}{\sqrt{12}} \vec{S}^2)$	1

Mass relations 2 GMOs, 9 ES, 8 new

$$\Delta_{5/2} - \Delta_{3/2} - (N_{5/2} - N_{3/2}) = 0 \qquad -23 \pm 66 \text{ MeV}$$
$$(\Delta_{7/2} - \Delta_{5/2}) - \tfrac{7}{5}(N_{5/2} - N_{3/2}) = 0 \qquad 79 \pm 76 \text{ MeV}$$
$$\Delta_{7/2} - \Delta_{1/2} - 3(N_{5/2} - N_{3/2}) = 0 \qquad 106 \pm 155 \text{ MeV}$$
$$\tfrac{8}{15}(\Lambda_{3/2} - N_{3/2}) + \tfrac{22}{15}(\Lambda_{5/2} - N_{5/2}) - (\Sigma_{5/2} - \Lambda_{5/2}) - 2(\Sigma_{7/2}'' - \Delta_{7/2}) = 0 \qquad 33 \pm 47 \text{ MeV}$$
$$\Lambda_{5/2} - \Lambda_{3/2} + 3(\Sigma_{5/2} - \Sigma_{3/2}) - 4(N_{5/2} - N_{3/2}) = 0 \qquad 242 \pm 367 \text{ MeV}$$
$$\Lambda_{5/2} - \Lambda_{3/2} + \Sigma_{5/2} - \Sigma_{3/2} - 2(\Sigma_{5/2}'' - \Sigma_{3/2}'') = 0 \qquad 38 \pm 302 \text{ MeV}$$
$$7(\Sigma''_{3/2} - \Sigma''_{7/2}) - 12(\Sigma''_{5/2} - \Sigma''_{7/2}) = 0$$
$$4(\Sigma''_{1/2} - \Sigma''_{7/2}) - 5(\Sigma''_{3/2} - \Sigma''_{7/2}) = 0$$

- masses of missing $[56,2^+]$ (all hyperons) predicted
- mass relations tested with masses calculated in LQCD [JLab LQCD: Edwards et al]

Missing states	Fitted mass [MeV]	Mass listed in PDG [MeV]
$\Sigma_{3/2}$	1889	$\Sigma(1840)(3/2^+)^*$ with mass $\sim$ 1840
$\Xi_{3/2}$	2074	$\Xi(2120)^*(?^?)$: 2130±7
$\Xi_{5/2}$	2000	$\Xi(2030)^{***}(S \geqslant 5/2^+)$ with 2025±5
$\Sigma''_{1/2}$	2059.5	...
$\Xi''_{1/2}$	2221	$\Xi(2250)^{**}(?^?)$: 2214±5
$\Omega_{1/2}$	2382	...
$\Sigma''_{3/2}$	2059.35	$\Sigma(2080)^{**}(3/2^+)$: 2120±40
$\Xi''_{3/2}$	2211.8	...
$\Omega_{3/2}$	2350	...
$\Sigma''_{5/2}$	2053	$\Sigma(2070)^*(5/2^+)$: 2070±10
$\Xi''_{5/2}$	2178	...
$\Omega_{5/2}$	2297	...
$\Xi''_{7/2}$	2129	$\Xi(2120)^*(?^?)$: 2130±7
$\Omega_{7/2}$	2222	...

LQCD, JLab: [R. Edwards et al. PRD 87 (2013)]

Relation	M_π[MeV]		
	391	524	702
$\Delta_{5/2}-\Delta_{3/2}-(N_{5/2}-N_{3/2})=0$	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

Similar situation for the 70-plet

LQCD calculations with $M_K \sim 700\text{MeV}$ and $M_\pi > 390\text{MeV}$

M_π dependency of coefficients in mass operators

[I. Fernando & JLG]

Mixing angles of nucleons in 70-plet

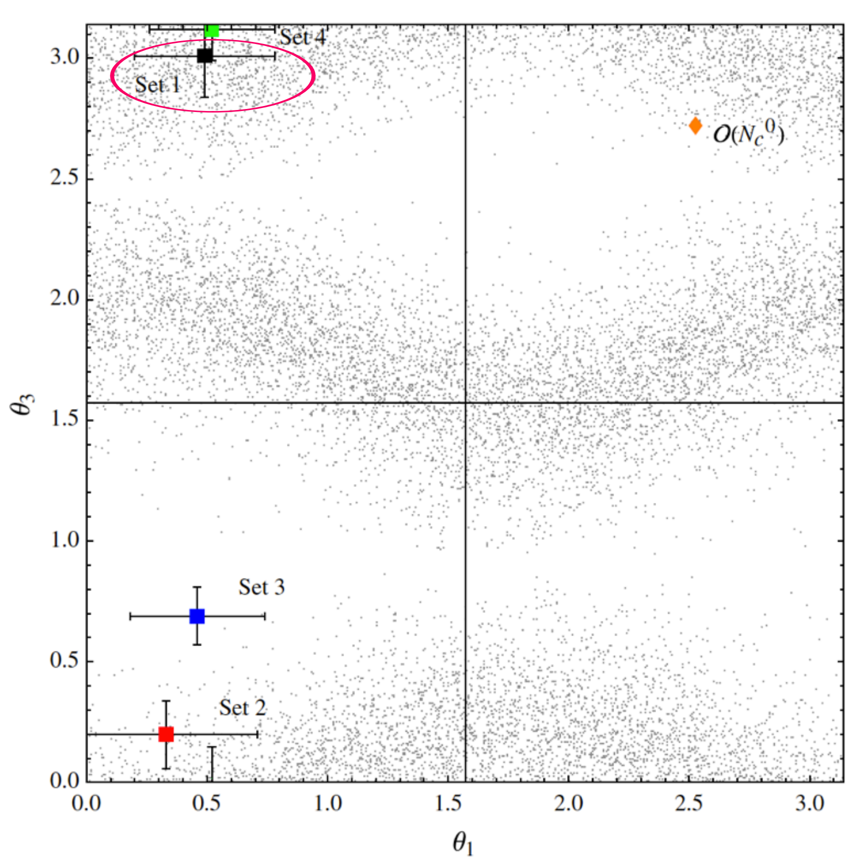
$$J^P = \frac{1}{2}^- : \quad \begin{pmatrix} N(1535) \\ N(1650) \end{pmatrix}; \quad J^P = \frac{3}{2}^- : \quad \begin{pmatrix} N(1650) \\ N(1700) \end{pmatrix}$$

$$\begin{pmatrix} N_J \\ N'_J \end{pmatrix} = \begin{pmatrix} \cos\theta_{2J} & \sin\theta_{2J} \\ -\sin\theta_{2J} & \cos\theta_{2J} \end{pmatrix} \begin{pmatrix} {}^2N^*_J \\ {}^4N^*_J \end{pmatrix}$$

Mixings fixed @LO $\quad \theta_1 = 2.52 \quad \theta_3 = 2.72$

NLO relation @ $\mathcal{O}(1/N_c)$

$$3(M_{N_{\frac{1}{2}}} + M_{N'_{\frac{1}{2}}} - 4M_{N_{\frac{3}{2}}} - 4M_{N'_{\frac{3}{2}}} + 6M_{N_{\frac{5}{2}}} + 8M_{\Delta_{\frac{1}{2}}} - 8M_{\Delta_{\frac{3}{2}}})$$
$$= (M_{N'_{\frac{1}{2}}} - M_{N_{\frac{1}{2}}})(13\cos(2\theta_1) + \sqrt{32}\sin(2\theta_1)) - 4(M_{N'_{\frac{3}{2}}} - M_{N_{\frac{3}{2}}})(\cos(2\theta_3) - \sqrt{20}\sin(2\theta_3))$$



Cases 1,...,4: fits to masses only
Case 1: fit to masses, decays & photo-couplings

[Gonzalez de Urreta, Scoccola JLG]

Strong decays

partial wave decay widths for single meson emission

$$\Gamma^{[\ell,I]}(B^* \to B) = \frac{k^{2\ell+1}}{8\pi^2\Lambda^{2\ell}} \frac{M_B}{M_{B^*}} \frac{|\sum_n C_n^{[\ell,I]} \langle B||\mathcal{B}_n(\ell,I)||B^*\rangle|^2}{(2J^*+1)(2I^*+1)}$$

Basis of operators $\{\mathcal{B}_n(\ell, I)\}$ describing the decay amplitude

$[\mathbf{70}, \mathbf{1}^-]$ to $\mathcal{O}(1/N_c)$ and 1st order in SU(3) breaking

[Ch. Jayalath et al]

- basis of operators for S and D wave decays
- fits to PDG provided partial decay widths
- predictions for 70-plet hyperon decays
- determinations of mixing angles in 70-plet (up to some ambiguities)

Important example: 70-plet nucleons

	$N(1535)$			$N(1520)$			
	πN	ηN	$\pi\Delta$	$\pi\Delta$		πN	ηN
PW	S	S	D	S	D	D	D
LO	57(17)	33(6)	0.3(0.2)	8.9(4.3)	8.1(1.0)	77(7)	0.09(0.01)
NLO	57(19)	73(44)	0.9(0.7)	9(11)	10(2)	72(11)	0.26(0.07)
Exp	68(19)	79(17)	0.8(0.8)	9.6(4.1)	13.6(2.7)	69(10)	0.26(0.05)

	$N(1650)$				$N(1700)$					
	πN	ηN	$K\Lambda$	$\pi\Delta$	$\pi\Delta$		πN	ηN	$K\Lambda$	$K\Sigma$
PW	S	S	S	D	S	D	D	D	D	D
LO	143(26)	2.5(1.6)	9.8(2.9)	4.8(2.6)	215(57)	2.9(2.4)	11.4(8.5)	0.52(0.25)	0.13(0.08)	~ 0
NLO	133(33)	12.5(11.0)	11.5(6.4)	5.1(5.8)	297(111)	0.3(2.0)	12(13)	≤ 0.15	≤ 0.03	~ 0
Exp	128(33)	10.7(5.9)	11.5(6.7)	6.6(5)			10(7)		1.5(1.5)	

From fit to PDG masses and partial decay widths

State mixings fixed (up to an ambiguity) by the fit

LO result is already quite satisfactory!

Summary and comments

- Symmetries and the 1/Nc expansion give fundamental connections between hadrons and QCD

- They not only serve to organize our understanding, but they also give quantitative predictions

- Discovering missing hyperons and understanding their properties is essential for a consistent picture of baryon resonances: perhaps one of the most important problems in excited baryon physics

- Interplay with current LQCD efforts to calculate the baryon spectrum should be most clarifying for testing the 1/Nc expansion in baryons, and in turn help understand or organize the LQCD results

- The 1/Nc expansion plays also a direct role in dynamics: BChPT is significantly improved when it is made consistent with the 1/Nc expansion

Non-strange baryons

Particle	J^P	overall	$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	****	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	****	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1700)$	$3/2^-$	***	**	***	*			*	*	*	***
$N(1710)$	$1/2^+$	****	****	****	***		**	****	**	*	**
$N(1720)$	$3/2^+$	****	****	****	***			**	**	**	*
$N(1860)$	$5/2^+$	**		**						*	*
$N(1875)$	$3/2^-$	***	***	*			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	**	*	**			**	*		
$N(1900)$	$3/2^+$	***	***	**	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	**	*	**			**	*	**	
$N(2040)$	$3/2^+$	*		*							
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*		*							
$N(2120)$	$3/2^-$	**	**	**				*	*		
$N(2190)$	$7/2^-$	****	***	****			*	**		*	
$N(2220)$	$9/2^+$	****		****							
$N(2250)$	$9/2^-$	****		****							
$N(2300)$	$1/2^+$	**		**							
$N(2570)$	$5/2^-$	**		**							
$N(2600)$	$11/2^-$	***		***							
$N(2700)$	$13/2^+$	**		**							

Particle	J^P	overall	$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
$\Delta(1232)$	$3/2^+$	****	****	****	F						
$\Delta(1600)$	$3/2^+$	***	***	***	o					*	***
$\Delta(1620)$	$1/2^-$	****	***	****		r				***	***
$\Delta(1700)$	$3/2^-$	****	****	****		b				**	***
$\Delta(1750)$	$1/2^+$	*		*			i				
$\Delta(1900)$	$1/2^-$	**	**	**			d		**	**	**
$\Delta(1905)$	$5/2^+$	****	****	****			d		***	**	**
$\Delta(1910)$	$1/2^+$	****	**	****				e	*	*	**
$\Delta(1920)$	$3/2^+$	***	**	***				n	***		**
$\Delta(1930)$	$5/2^-$	***		***							
$\Delta(1940)$	$3/2^-$	**	**	*	F						
$\Delta(1950)$	$7/2^+$	****	****	****	o				***	*	***
$\Delta(2000)$	$5/2^+$	**				r					**
$\Delta(2150)$	$1/2^-$	*		*		b					
$\Delta(2200)$	$7/2^-$	*		*			i				
$\Delta(2300)$	$9/2^+$	**		**			d				
$\Delta(2350)$	$5/2^-$	*		*			d				
$\Delta(2390)$	$7/2^+$	*		*				e			
$\Delta(2400)$	$9/2^-$	**		**				n			
$\Delta(2420)$	$11/2^+$	****	*	****							
$\Delta(2750)$	$13/2^-$	**		**							
$\Delta(2950)$	$15/2^+$	**		**							

Hyperons

Particle	J^P	Overall status	$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	1/2+	****		F		$N\pi$(weakly)
$\Lambda(1405)$	1/2−	****	****	o	****	
$\Lambda(1520)$	3/2−	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	1/2+	***	***	b	**	
$\Lambda(1670)$	1/2−	****	****	i	****	$\Lambda\eta$
$\Lambda(1690)$	3/2−	****	****	d	****	$\Lambda\pi\pi, \Sigma\pi\pi$
$\Lambda(1800)$	1/2−	***	***	d	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(1810)$	1/2+	***	***	e	**	$N\overline{K}^*$
$\Lambda(1820)$	5/2+	****	****	n	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	5/2−	****	***	F	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	3/2+	****	****	o	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(2000)$		*		r	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2020)$	7/2+	*	*	b	*	
$\Lambda(2100)$	7/2−	****	****	i	***	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2110)$	5/2+	***	**	d	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2325)$	3/2−	*	*	d		$\Lambda\omega$
$\Lambda(2350)$		***	***	e	*	
$\Lambda(2585)$		**	**	n		

Particle	J^P	Overall status	$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Sigma(1193)$	1/2+	****				$N\pi$(weakly)
$\Sigma(1385)$	3/2+	****		****	****	
$\Sigma(1480)$		*	*	*	*	
$\Sigma(1560)$		**		**	**	
$\Sigma(1580)$	3/2−	*	*	*		
$\Sigma(1620)$	1/2−	**	**	*	*	
$\Sigma(1660)$	1/2+	***	***	*	**	
$\Sigma(1670)$	3/2−	****	****	****	****	several others
$\Sigma(1690)$		**	*	**	*	$\Lambda\pi\pi$
$\Sigma(1750)$	1/2−	***	***	**	*	$\Sigma\eta$
$\Sigma(1770)$	1/2+	*				
$\Sigma(1775)$	5/2−	****	****	****	***	several others
$\Sigma(1840)$	3/2+	*	*	**	*	
$\Sigma(1880)$	1/2+	**	**	**		$N\overline{K}^*$
$\Sigma(1915)$	5/2+	****	***	****	***	$\Sigma(1385)\pi$
$\Sigma(1940)$	3/2−	***	*	***	**	quasi-2-body
$\Sigma(2000)$	1/2−	*		*		$N\overline{K}^*, \Lambda(1520)\pi$
$\Sigma(2030)$	7/2+	****	****	****	**	several others
$\Sigma(2070)$	5/2+	*	*		*	
$\Sigma(2080)$	3/2+	**		**		
$\Sigma(2100)$	7/2−	*		*	*	
$\Sigma(2250)$		***	***	*	*	
$\Sigma(2455)$		**	*			
$\Sigma(2620)$		**	*			
$\Sigma(3000)$		*	*	*		
$\Sigma(3170)$		*				multi-body

Particle	J^P	Overall status	$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$		*	*				
$\Xi(1690)$		***		***	**		
$\Xi(1820)$	3/2−	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

$SU(3)$	PDG
$\#\Sigma = \#\Xi = \#N + \#\Delta$	$26; 12; 49$
$\#\Omega = \#\Delta$	$4; 22$
$\#\Lambda = \#N + \#\text{singlets}$	$18; 29$

SU(3): # Y= 3(# N+ # Δ)+singlets