Excited Hyperons in the Quark Model

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Excited hyperons in the quark model

$SU(3)_f$ symmetry

- Corrections substantial

$SU(3)_f$ breaking in Λ and Σ baryons

Quark model predictions for spectrum and decays

What is special about Cascade baryons?

- Lightest excited Ξ^* states may have narrow widths, why?
- Configuration mixing weaker than in N/Δ

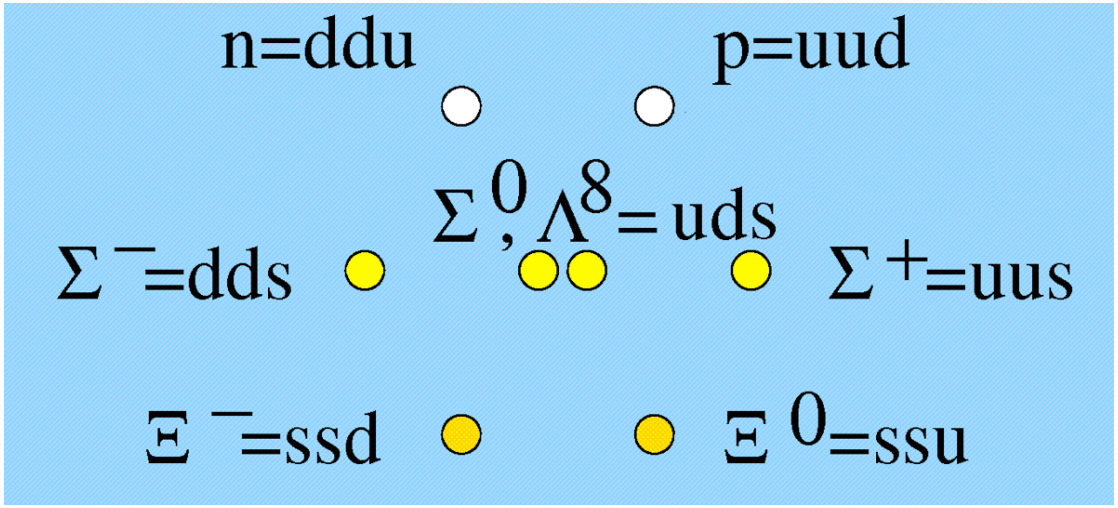
Excited hyperons at GlueX

$SU(3)_f$ octet baryons

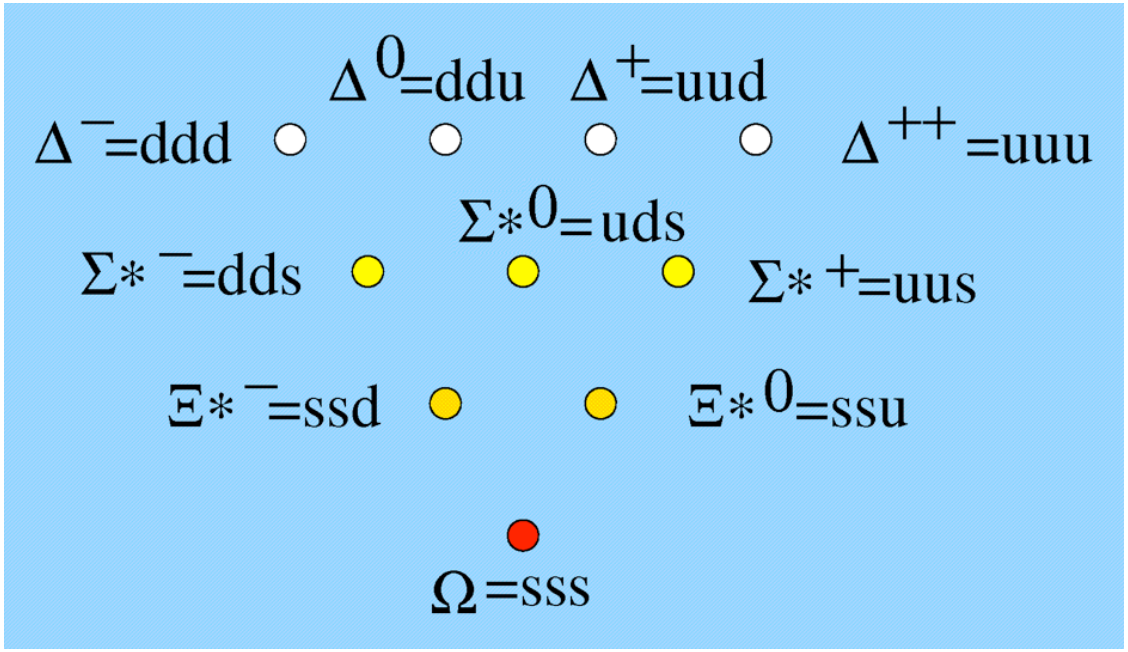
Three light (u,d,s) quarks have 27 possible flavor combinations

$3\times3\times3=3\times(3+6)=1+\bar{8}+8'+10$

(8,8′) has mixed flavor-exchange symmetry, spin-½ ground states



$SU(3)_f$ decuplet baryons



10 is flavor-exchange symmetric

- Ground states have spin 3/2 for total anti-symmetry
- All but Ω are higher-spin versions of octet states

$SU(3)_f$ symmetry

$SU(3)_f$ symmetry broken by the strange/light-quark mass difference

- Possible to describe strange baryons using an $SU(3)_f$ symmetric basis
- Not ideal, everything is strongly mixed
- Better choice is 'uds' basis where you (anti-)symmetrize only in u,d quark degrees of freedom
- Isospin much better symmetry than $SU(3)_f$

E.g.: $\phi_\Lambda = (ud-du)s/\sqrt{2}$

$\phi_\Sigma = uus, (ud+du)s/\sqrt{2}, dds$

- In Ξ symmetrize only in ss pair, $\phi_\Xi = ssu, ssd$

Σ / Λ mass difference

States with one strange quark are called $\Lambda\ (\mathrm{uds})$,
or $\Sigma^+\ (\mathrm{uus}),\ \Sigma^0\ (\mathrm{uds}),\ \Sigma^-\ (\mathrm{dds})$
with ground-state masses 1116 MeV and 1189 MeV

These are both S=−1, octet ground state baryons with $J^P=\frac{1}{2}^+$; they differ only by their isospin (Λ is an iso-singlet, Σ an iso-triplet)

Isospin-symmetry violating mass differences are generally small, of the order of a few MeV; is this an anomalously large isospin violation?

Like the p,n (and other baryon) magnetic moments, this is easily explained in the quark model

Σ / Λ mass difference

Switch to 'uds' basis where don't symmetrize flavor wave function in heavier s quark (results independent of basis used)

$$\phi_{\Lambda^0} = \frac{1}{\sqrt{2}}(ud - du)s, \;\; \Psi_{\Lambda^0} = C_A \phi_{\Lambda^0} \chi^{\rho}_{\frac{1}{2}}$$

$$\phi_{\Sigma^0} = \frac{1}{\sqrt{2}}(ud + du)s, \;\; \Psi_{\Sigma^0} = C_A \phi_{\Sigma^0} \chi^{\lambda}_{\frac{1}{2}}$$

Assume a short-distance potential between the quarks proportional to $\sum_{i<j} f(r_{ij}) \frac{\mathbf{S}_i \cdot \mathbf{S}_j}{m_i m_j}, \; r_{ij} := |\mathbf{r}_i - \mathbf{r}_j|$

Need to evaluate this potential in the Λ and Σ to see if there is a difference in its expectation value

Σ / Λ mass difference

Examine the Λ spin expectation value

$$\chi^{\rho\,\dagger}_{\frac{1}{2}} \sum_{i<j} \frac{\mathbf{S}_i \cdot \mathbf{S}_j}{m_i m_j} \chi^{\rho}_{\frac{1}{2}} = \frac{1}{\sqrt{2}} \langle (\uparrow\downarrow - \downarrow\uparrow) \uparrow | \left(\frac{\mathbf{S}_1 \cdot \mathbf{S}_2}{m_{u,d}^2} + 2 \frac{\mathbf{S}_1 \cdot \mathbf{S}_3}{m_{u,d} m_s} \right) \frac{1}{\sqrt{2}} | (\uparrow\downarrow - \downarrow\uparrow) \uparrow \rangle$$

Evaluate the $\mathbf{S}_1 \cdot \mathbf{S}_2$ term first

$$\frac{1}{2m_{u,d}^2} \langle (\uparrow\downarrow - \downarrow\uparrow) \uparrow | \left(\frac{S_{1+}S_{2-} + S_{1-}S_{2+}}{2} + S_{1z}S_{2z} \right) | (\uparrow\downarrow - \downarrow\uparrow) \uparrow \rangle$$

$$= \frac{1}{2m_{u,d}^2} \left(-\frac{1}{2} - \frac{1}{2} - \frac{1}{4} - \frac{1}{4} \right)$$

$$= \frac{1}{2m_{u,d}^2} \left(-\frac{3}{2} \right) = -\frac{3}{4m_{u,d}^2}$$

Σ / Λ mass difference

$$\chi^{\rho\,\dagger}_{\frac{1}{2}} \sum_{i<j} \frac{\mathbf{S}_i \cdot \mathbf{S}_j}{m_i m_j} \chi^{\rho}_{\frac{1}{2}} = \frac{1}{\sqrt{2}} \langle (\uparrow\downarrow - \downarrow\uparrow) \uparrow | \left(\frac{\mathbf{S}_1 \cdot \mathbf{S}_2}{m_{u,d}^2} + 2 \frac{\mathbf{S}_1 \cdot \mathbf{S}_3}{m_{u,d} m_s} \right) \frac{1}{\sqrt{2}} | (\uparrow\downarrow - \downarrow\uparrow) \uparrow \rangle$$

Then the $2\mathbf{S}_1 \cdot \mathbf{S}_3$ term

$$\frac{2}{2 m_{u,d} m_s} \langle (\uparrow\downarrow - \downarrow\uparrow) \uparrow | \left(\frac{S_{1+} S_{3-} + S_{1-} S_{3+}}{2} + S_{1z} S_{3z} \right) | (\uparrow\downarrow - \downarrow\uparrow) \uparrow \rangle$$
$$= \frac{1}{2 m_{u,d}^2} \left(0 + 0 - \frac{1}{4} + \frac{1}{4} \right) = 0$$

Then for the Λ

$$\chi^{\rho\,\dagger}_{\frac{1}{2}} \sum_{i<j} \frac{\mathbf{S}_i \cdot \mathbf{S}_j}{m_i m_j} \chi^{\rho}_{\frac{1}{2}} = -\frac{3}{4 m_{u,d}^2}$$

The strange quark in Λ does not have an attractive spin-spin interaction with the spin-zero light-quark pair

Σ / Λ mass difference

Then if we assume that for the Λ and Σ the expectation value of r_{ij} is the same, independent of {i,j}, i.e., SU(3)f symmetry of the spatial wave function, then

$$\langle\Lambda|\sum_{i<j} f(r_{ij})\frac{\mathbf{S}_i\cdot\mathbf{S}_j}{m_i m_j}|\Lambda\rangle = \langle\psi_{\Lambda,\Sigma}|f(r_{ij})|\psi_{\Lambda,\Sigma}\rangle\left(-\frac{3}{4m_{u,d}^2}\right)$$

$$\langle\Sigma|\sum_{i<j} f(r_{ij})\frac{\mathbf{S}_i\cdot\mathbf{S}_j}{m_i m_j}|\Sigma\rangle = \langle\psi_{\Lambda,\Sigma}|f(r_{ij})|\psi_{\Lambda,\Sigma}\rangle\left(\frac{1}{4m_{u,d}^2}-\frac{1}{m_{u,d}m_s}\right)$$

So we see that the Λ can be lighter than the Σ if m_s is heavier than $m_{u,d}$

$$m_\Sigma - m_\Lambda = \langle\psi|f(r_{ij})|\psi\rangle\left(\frac{1}{m_{u,d}^2}-\frac{1}{m_{u,d}m_s}\right) = \langle\psi|f(r_{ij})|\psi\rangle\frac{1}{m_{u,d}^2}\left(1-\frac{m_{u,d}}{m_s}\right)$$

We can estimate *how much* lighter by comparing with the Δ − N splitting

Σ / Λ mass difference related to Δ / N

When all the masses are the same we can use

$$\langle|2\sum_{i<j}\mathbf{S}_i\cdot\mathbf{S}_j|\rangle = \langle|S^2 - s_1^2 - s_2^2 - s_3^2|\rangle = S(S+1) - 3/4 - 3/4 - 3/4$$

$$\langle\Delta|2\sum_{i<j}\mathbf{S}_i\cdot\mathbf{S}_j|\Delta\rangle = \left[\frac{3}{2}\left(\frac{5}{2}\right) - \frac{9}{4}\right] = \frac{3}{2}$$

$$\langle N|2\sum_{i<j}\mathbf{S}_i\cdot\mathbf{S}_j|N\rangle = \left[\frac{1}{2}\left(\frac{3}{2}\right) - \frac{9}{4}\right] = -\frac{3}{2}$$

So $\langle\Delta|\sum_{i<j} f(r_{ij})\frac{\mathbf{S}_i\cdot\mathbf{S}_j}{m_i m_j}|\Delta\rangle = \langle\psi_\Delta|f(r_{ij})|\psi_\Delta\rangle\left(+\frac{3}{4m_{u,d}^2}\right)$

$$\langle N|\sum_{i<j} f(r_{ij})\frac{\mathbf{S}_i\cdot\mathbf{S}_j}{m_i m_j}|N\rangle = \langle\psi_N|f(r_{ij})|\psi_N\rangle\left(-\frac{3}{4m_{u,d}^2}\right)$$

and $m_\Delta - m_N = \langle\psi|f(r_{ij})|\psi\rangle\left(\frac{3}{2m_{u,d}^2}\right)$

Σ / Λ mass difference related to Δ − N

Putting this all together, and assuming $SU(3)_f$ symmetry in the spatial wave functions, we have

$$
\begin{aligned}
m_\Sigma - m_\Lambda &= \langle\psi|f(r_{ij})|\psi\rangle \frac{1}{m_{u,d}^2}\left(1 - \frac{m_{u,d}}{m_s}\right) \\
&= \frac{2}{3}\left(m_\Delta - m_N\right)\left[1 - \frac{m_{u,d}}{m_s}\right] \\
&= \frac{2}{3}\left(293\ \mathrm{MeV}\right)\left[1 - \frac{m_{u,d}}{m_s}\right]
\end{aligned}
$$

Get 73 MeV with *constituent* quark masses $m_{u,d} / m_s = 0.63$

Λ is lighter than Σ because the attractive spin-spin interaction involves the strange quark in Σ but not in Λ, and this attraction is weaker than that between two light quarks (inversely proportional to quark mass)

$SU(3)_f$ breaking in decay amplitudes

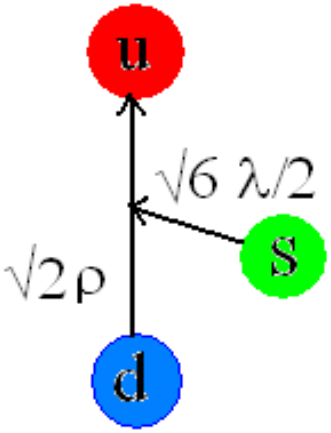
Examine 'stretched' ($|\mathbf{J}|=|\mathbf{L}|+|\mathbf{S}|$) Λ and Σ excited states

$\Lambda\ 5/2^- = C_A\ [(ud-du)s/\sqrt{2}]\ \chi^S_{3/2}\ \Psi^\rho_{11}$

$\Sigma\ 5/2^- = C_A\ [(ud+du)s/\sqrt{2}]\ \chi^S_{3/2}\ \Psi^\lambda_{11}$

$\Psi^\rho_{11} = \alpha_\rho \rho_+\ \Psi_{00}, \quad \Psi^\lambda_{11} = \alpha_\lambda \lambda_+\ \Psi_{00}$

$\Psi_{00} = [\alpha_\rho^{3/2}\alpha_\lambda^{3/2}/\pi^{3/2}]\ \exp\{-(\alpha_\rho^2\rho^2+\alpha_\lambda^2\lambda^2)/2\}$



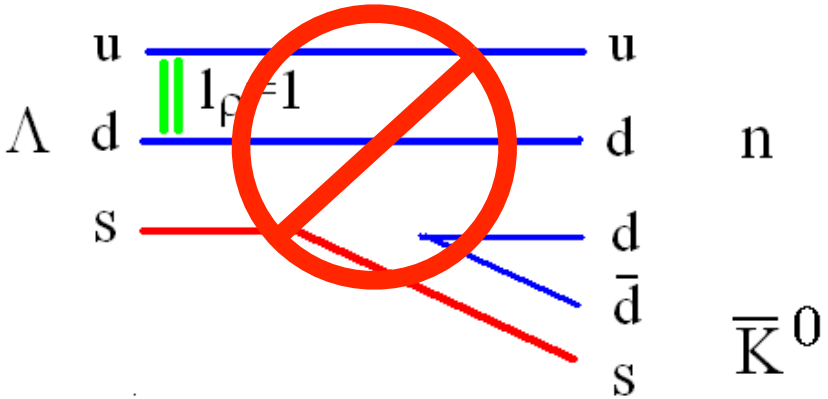
s quark heavier, so $\omega_\rho > \omega_\lambda$ and so $m_{\Lambda\ 5/2^-} > m_{\Sigma\ 5/2^-}$

Expt: $\Lambda(1830)D_{05} > \Sigma(1775)D_{15}$

Decoupling mechanism…

ρ-type spatial excitations in Λ should largely decouple from the NK state:

$\Lambda(1830)D_{05}$ has 3-10% BR to NK



λ-type excitations should couple:

$\Sigma(1775)D_{15}$ has 37-43% branch to NK

Relativized model

Variational calculation in large H.O. basis (SC, N. Isgur)

- Flux-tube confinement, plus associated spin-orbit
- Include OGE Coulomb, contact, tensor, spin-orbit
- Relativistic KE, relativistic corrections in potentials, e.g.

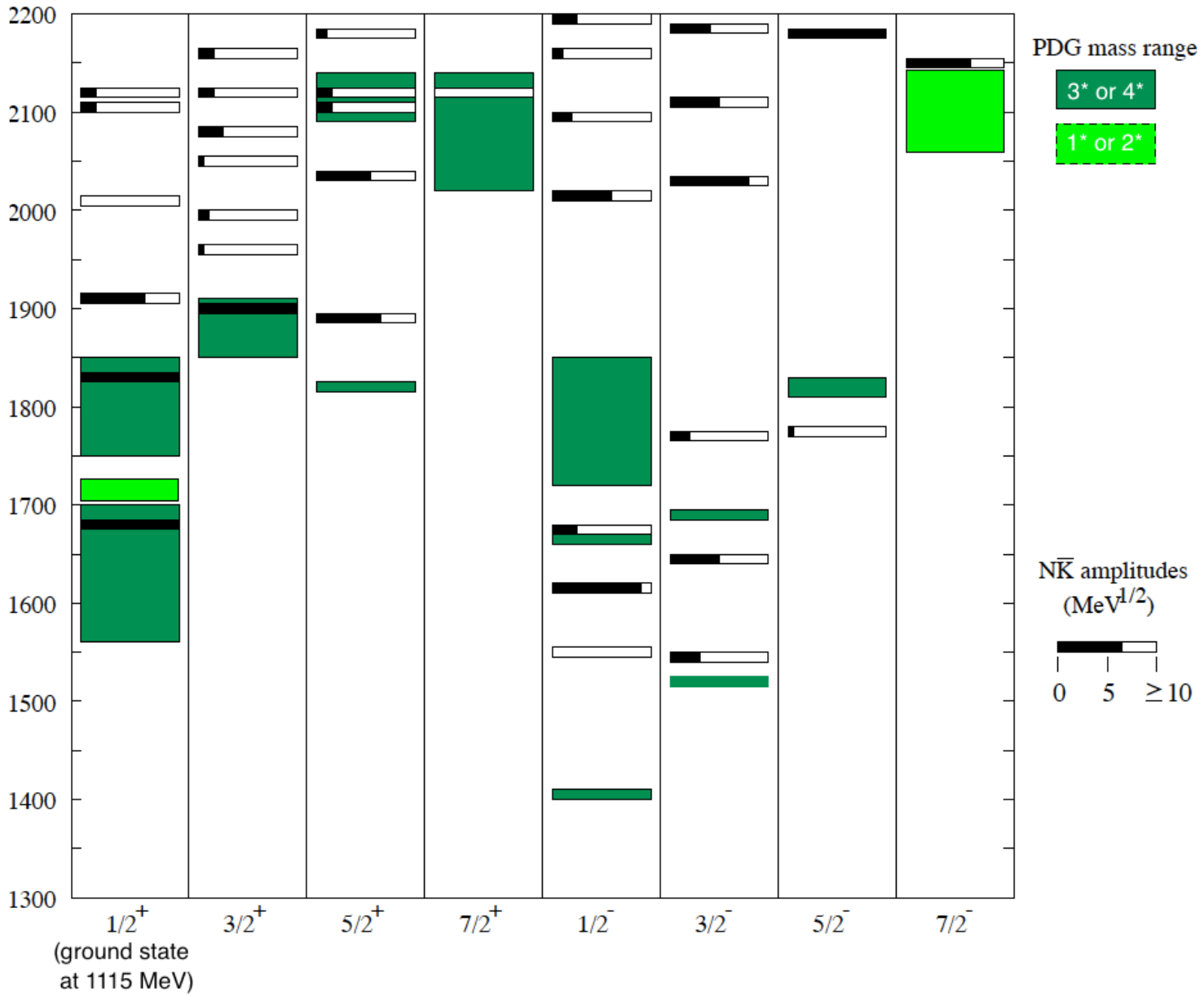
$$\left(\frac{m_i m_j}{E_i E_j}\right)^{\frac{1}{2}+\epsilon_{\rm cont}} \frac{8\pi}{3}\alpha_s(r_{ij})\frac{2}{3}\frac{\mathbf{S}_i\cdot\mathbf{S}_j}{m_i m_j}\left[\frac{\sigma_{ij}^3}{\pi^{\frac{3}{2}}}e^{-\sigma_{ij}^2 r_{ij}^2}\right]\left(\frac{m_i m_j}{E_i E_j}\right)^{\frac{1}{2}+\epsilon_{\rm cont}}$$

Strong decays calculated in pair creation ($^3P_0$) model (SC, W. Roberts)

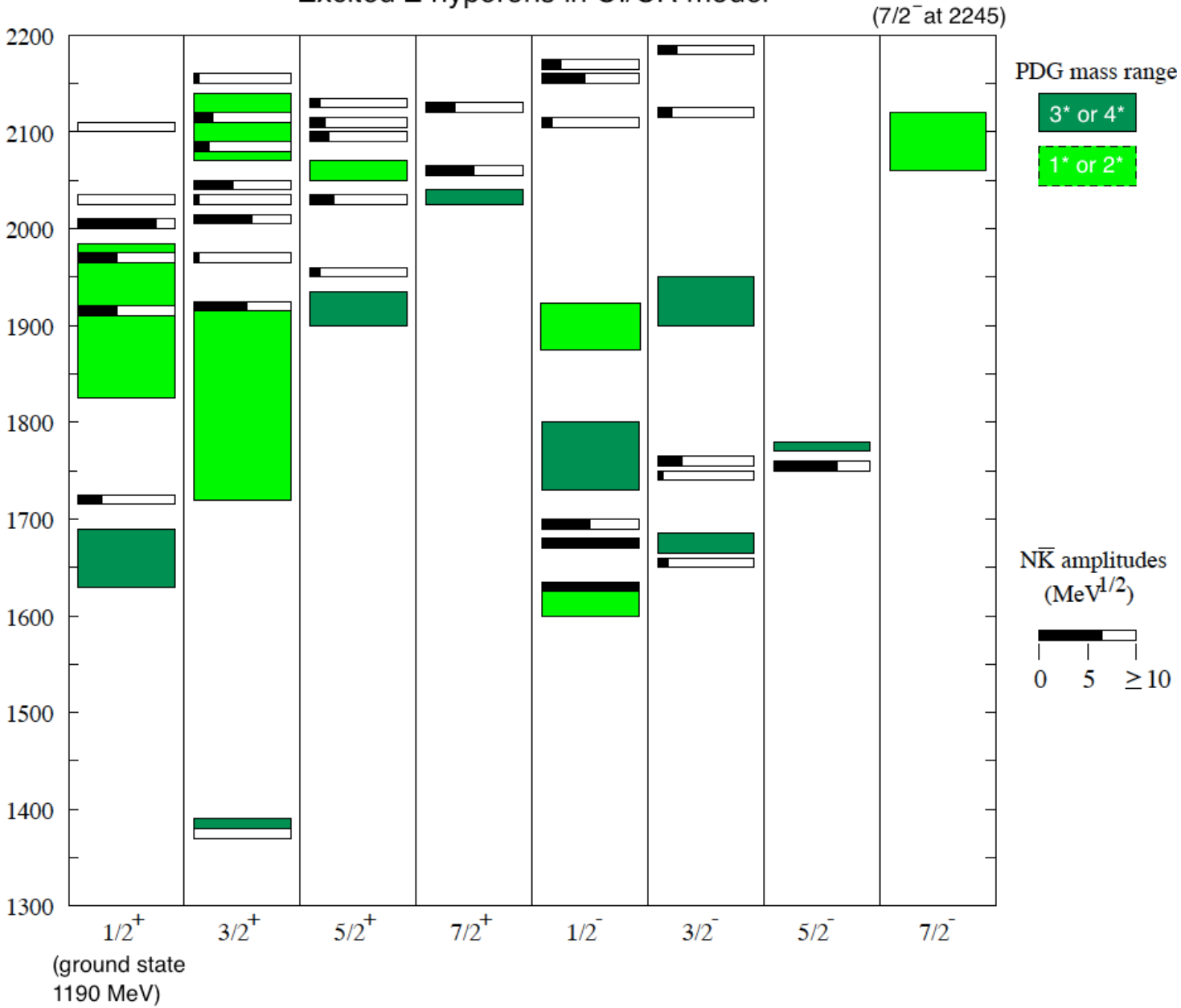
- $^3P_0$ is popular phenomenological decay model
- Emitted mesons have structure
- Correlates many decays with very few parameters

Same set of parameters for all baryons

Excited Λ hyperons in CI/CR model



Excited Σ hyperons in CI/CR model



What is special about Cascades?

Decays $\Xi^* \rightarrow \Xi\,\pi$ are suppressed relative to $N, \Delta \rightarrow N\,\pi$

- Other channels involve K, which cuts down the available phase space
- Leads to the possibility of narrow excited states

Why are some Cascades narrow?

Example:

$\Delta(1232)^+ \rightarrow p\pi^0$ has width 120±5 MeV

But $\Xi^{*0}(1530) \rightarrow \Xi^0\pi^0$ has width 9-10 MeV

Some of this is phase space:

227 MeV decay momentum for $\Delta \rightarrow N\pi$ (P-wave)

152 MeV for $\Xi^*(1530) \rightarrow \Xi\pi$ (also P-wave)

SU(6) (flavor-spin) decay coefficients

P. Zenczykowski, Ann. Phys. **169**, 453, 1986

No $SU(3)_f$ breaking in baryon/meson structure

Square of spin-flavor coupling constants (no phase space differences):

A \ BP	$N\pi$	$\Delta\pi$	ΣK	ΛK	$\Sigma^* K$	$N\eta$	$N\eta'$	$\Delta\eta$	$\Delta\eta'$
N	$\frac{25}{6}$	$\frac{16}{3}$	$\frac{1}{6}$	$\frac{3}{2}$	$\frac{4}{3}$	$\frac{1}{3}\left(\frac{c}{\sqrt{2}}-s\right)^2$	$\frac{1}{3}\left(c+\frac{s}{\sqrt{2}}\right)^2$	0	0
Δ	$\frac{4}{3}$	$\frac{25}{6}$	$\frac{4}{3}$	0	$\frac{5}{3}$	0	0	$\frac{5}{3}\left(\frac{c}{\sqrt{2}}-s\right)^2$	$\frac{5}{3}\left(c+\frac{s}{\sqrt{2}}\right)^2$

A \ BV	$N\rho$	$\Delta\rho$	ΣK^*	ΛK^*	$\Sigma^* K^*$	$N\omega$	$N\varphi$	$\Delta\omega$	$\Delta\varphi$
N	$\frac{59}{6}$	$\frac{32}{3}$	$\frac{11}{6}$	$\frac{9}{2}$	$\frac{8}{3}$	$\frac{11}{2}$	0	0	0
Δ	$\frac{8}{3}$	$\frac{85}{6}$	$\frac{8}{3}$	0	$\frac{19}{3}$	0	0	$\frac{19}{2}$	0

SU(6) (flavor-spin) decay coefficients

A \ BP	ΣK	$\Sigma^* K$	ΛK	$\Xi\pi$	$\Xi^*\pi$	ΩK	$\Xi\eta$	$\Xi\eta'$	$\Xi^*\eta$	$\Xi^*\eta'$
Ξ	$\frac{25}{6}$	$\frac{4}{3}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{4}{3}$	$\frac{8}{3}$	$\frac{1}{3}\left(s+\frac{3c}{\sqrt{12}}\right)^2$	$\frac{1}{3}\left(c-\frac{3s}{\sqrt{12}}\right)^2$	$\frac{4}{3}c^2$	$\frac{4}{3}s^2$
Ξ^*	$\frac{2}{3}$	$\frac{10}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{5}{6}$	$\frac{5}{3}$	$\frac{2}{3}c^2$	$\frac{2}{3}s^2$	$\frac{5}{3}\left(s+\frac{c}{\sqrt{12}}\right)^2$	$\frac{5}{3}\left(c-\frac{s}{\sqrt{12}}\right)^2$

A \ BV	ΣK^*	$\Sigma^* K^*$	ΛK^*	$\Xi\rho$	$\Xi^*\rho$	ΩK^*	$\Xi\omega$	$\Xi\varphi$	$\Xi^*\omega$	$\Xi^*\varphi$
Ξ	$\frac{59}{6}$	$\frac{8}{3}$	$\frac{11}{6}$	$\frac{11}{6}$	$\frac{8}{3}$	$\frac{16}{3}$	$\frac{11}{18}$	$\frac{68}{9}$	$\frac{8}{9}$	$\frac{16}{9}$
Ξ^*	$\frac{4}{3}$	$\frac{38}{3}$	$\frac{4}{3}$	$\frac{4}{3}$	$\frac{19}{6}$	$\frac{19}{3}$	$\frac{4}{9}$	$\frac{8}{9}$	$\frac{19}{18}$	$\frac{76}{9}$

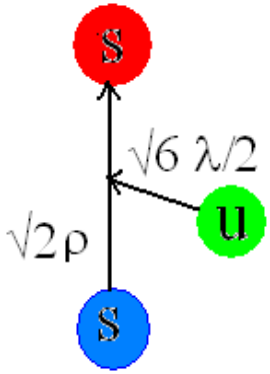
Fewer degeneracies

Three-body system has two 3-D relative coordinates

$\rho = (\mathbf{r}_1 - \mathbf{r}_2)/\sqrt{2}$

$\lambda = (\mathbf{r}_1 + \mathbf{r}_2 - 2\mathbf{r}_3)/\sqrt{6}$

If all quark masses equal (N, Δ, Ω), excitation costs same energy for both



Exchange symmetry requires two strange quarks at ends of ρ coordinate in Ξ states

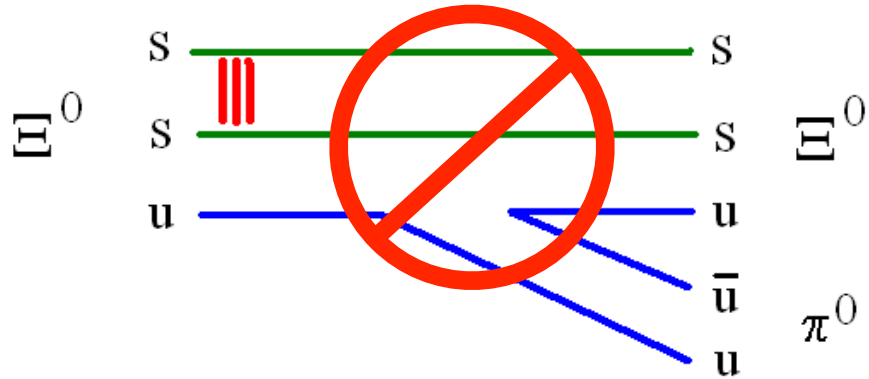
Excitation of ρ costs less energy than λ **if** confinement potential is flavor independent

E.g. in 3-D harmonic oscillator: $\omega^2 = 3K/\mu$, so $\omega_\rho < \omega_\lambda$

Decay selection rules

Ground state Ξ has $n_\rho = l_\rho = 0$ (= $n_\lambda = l_\lambda$)

If two strange quarks are spectators in a strong decay, like $\Xi^* \rightarrow \Xi\,\pi$:



Exited state can't have n_ρ or l_ρ different from ground state (no overlap)

Lightest Ξ^* states have ρ excited, should decouple from $\Xi\pi$, which has the largest phase space

Spoiled by hyperfine mixing, but this is smaller in Ξ

Weaker hyperfine interactions

Assume flavor-dependent short-range (contact) interactions

E.g. one-gluon exchange (DeRujula, Georgi, Glashow)

$$M = \sum_{i=1}^{3} m_i + \frac{2\alpha_s}{3}\frac{8\pi}{3}\langle\delta^3(\mathbf{r})\rangle \sum_{i<j=1}^{3} \frac{\mathbf{S}_i \cdot \mathbf{S}_j}{m_i m_j}$$

Hyperfine interactions progressively weaker because of explicit flavor dependence (seen in meson and baryon spectrum):

N, Δ: $1/(m_{u,d}\, m_{u,d})$ for all three quark pairs

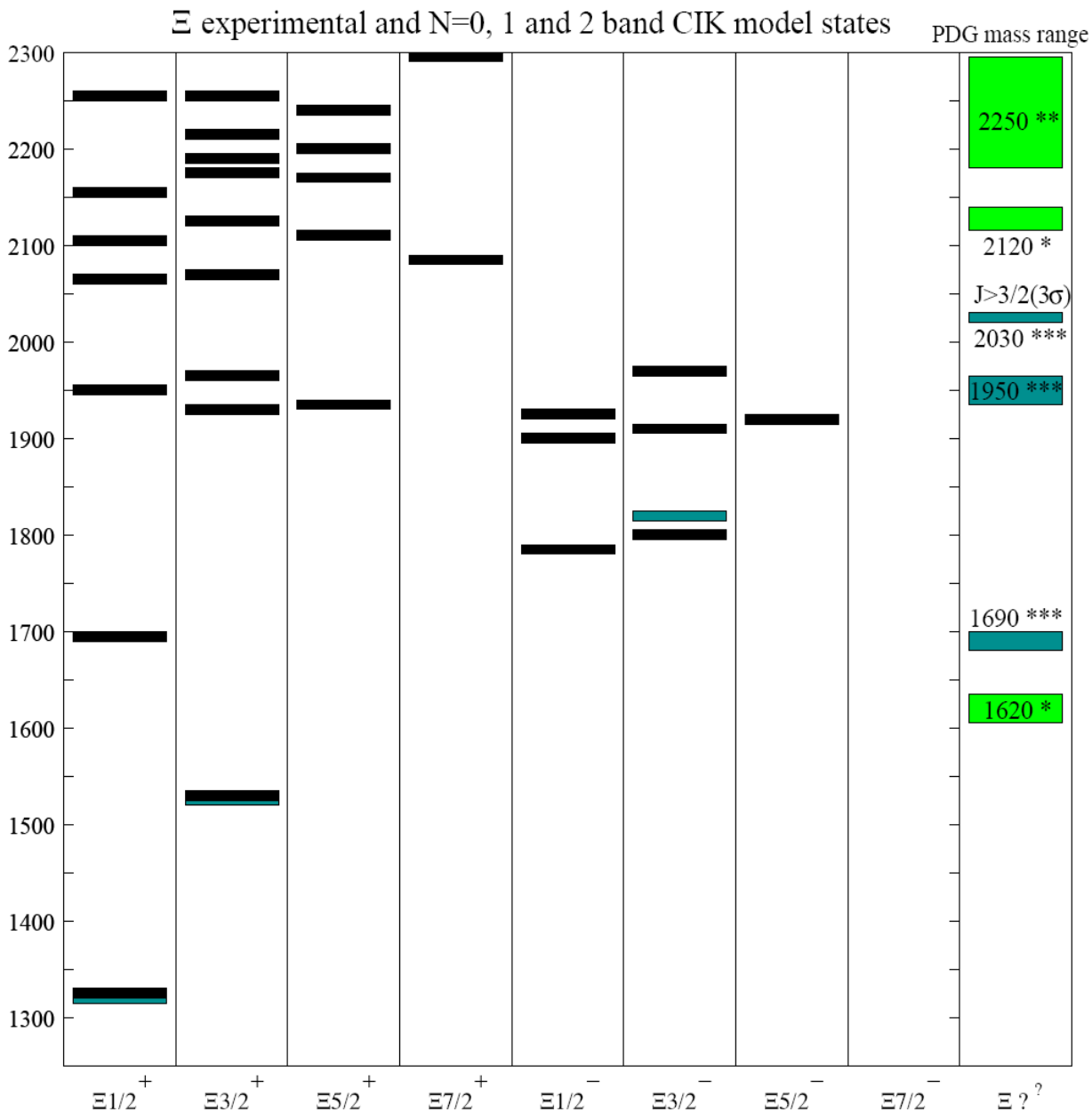
Λ,Σ: $1/(m_{u,d}\, m_s)$ for 2 pairs, $1/(m_{u,d}\, m_{u,d})$ for 1 pair

Ξ: $1/(m_s\, m_s)$ for 1 pair, $1/(m_{u,d}\, m_s)$ for 2 pairs

Non-relativistic one-gluon exchange model

Chao, Isgur and Karl, PRD **23**, 155 (1981):

- Use H.O. basis to N=2
- First order perturbation theory in an-harmonic terms (linear, Coulomb) in spin-independent potential
- NR kinetic energy
- First order perturbation theory in:
  - Hyperfine (spin-dipole/spin-dipole) interaction:
    - Contact term (splits Δ-N, Σ-Λ, Σ^*-Σ, Ξ^*-Ξ,…)
    - Tensor term (important mixings)
    - (Spin-orbit term calculated, but too large; neglected)


Ξ experimental and N=0, 1 and 2 band CIK model states
PDG mass range
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
2250 **
2120 *
J>3/2(3σ)
2030 ***
1950 ***
1690 ***
1620 *
Ξ1/2+
Ξ3/2+
Ξ5/2+
Ξ7/2+
Ξ1/2−
Ξ3/2−
Ξ5/2−
Ξ7/2−
Ξ ??

Patterns in Ξ^* spectrum and decays

E.g. lightest $J^P = 7/2^+$ Ξ^* states (F_{17}):

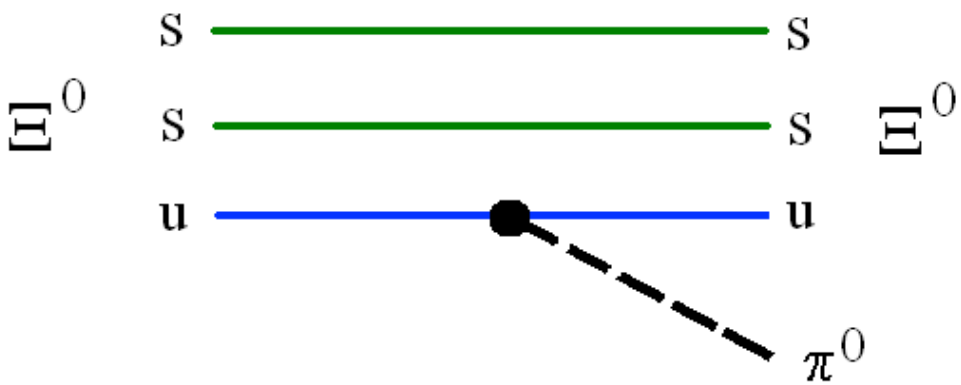
- Either L=2 from l_ρ=2 ($D_{\rho\rho}$) or from l_λ=2 ($D_{\lambda\lambda}$)
- Lightest state should be l_ρ=2 ($\omega_\rho < \omega_\lambda$)
- Splitting should be substantial

Lightest state should decouple from $\Xi\pi$, and so have small width

Chao, Isgur and Karl strong decays

Use elementary-meson emission model

- Pseudoscalar mesons emitted directly from quark lines
- Parameters fixed by fit to N, Δ, Λ, Σ strong decays



Chao Isgur and Karl Ξ states (expt.)

mass	state	J^P	wvfn.	$\lvert A_{\Xi\pi}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Lambda K}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Sigma K}\rvert$ $MeV^{\frac{1}{2}}$	$\Sigma\lvert A_i\rvert^2$ MeV
1695	$[P_{11}]_2$	$1/2^+$	mixed	1.0	0.7	0.2	1.5
1950	$[P_{11}]_3$	$1/2^+$	mixed	1.8	2.6	3.4	22
1530	Ξ^*	$3/2^+$		4.5 3.2			20 10
1930	$[P_{13}]_2$	$3/2^+$	$^2D_{\rho\rho}$	0.1	2.1	4.3	23
1965	$[P_{13}]_3$	$3/2^+$	$\sim {}^2S_{\rho\rho}$	1.6	3.0	4.1	57
1935	$[F_{15}]_1$	$5/2^+$	$^2D_{\rho\rho}$	0.5	1.9	4.9	28
2110	$[F_{15}]_2$	$5/2^+$	$^4D_{\rho\rho}$	0.8	3.0	2.5	16
2085	$[F_{17}]_1$	$7/2^+$	$^4D_{\rho\rho}$	1.0	5.4	4.2	48
2195	$[F_{17}]_2$	$7/2^+$	$^4D_{\lambda\lambda}$	8.6	1.1	1.0	76

Chao Isgur and Karl Ξ states (expt.)

mass	state	J^P	wvfn.	$\lvert A_{\Xi\pi}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Lambda K}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Sigma K}\rvert$ $MeV^{\frac{1}{2}}$	$\Sigma\lvert A_i\rvert^2$ MeV
1785	$[S_{11}]_1$	$1/2^-$	$^2P_\rho$	3.6	4.2	3.7	44
1890	$[S_{11}]_2$	$1/2^-$	$^4P_\lambda$	5.5	0.8	2.2	36
1925	$[S_{11}]_3$	$1/2^-$	$^2P_\lambda$	1.5	1.4	5.4	33
1800 1820	$[D_{13}]_1$	$3/2^-$	$^2P_\rho$	1.6 1.5	3.6 2.7	3.9 2.7	31 24
1910	$[D_{13}]_2$	$3/2^-$	$^2P_\lambda$	4.3	0.9	4.6	40
1970	$[D_{13}]_3$	$3/2^-$	$^4P_\lambda$	3.7	1.8	3.2	27
1920	$[D_{15}]_1$	$5/2^-$	$^4P_\lambda$	9.8	4.7	3.4	130

Chao Isgur and Karl Ξ states…

Recall:

Roper at 1440, width ~350 MeV

N(1710), width ~100 MeV

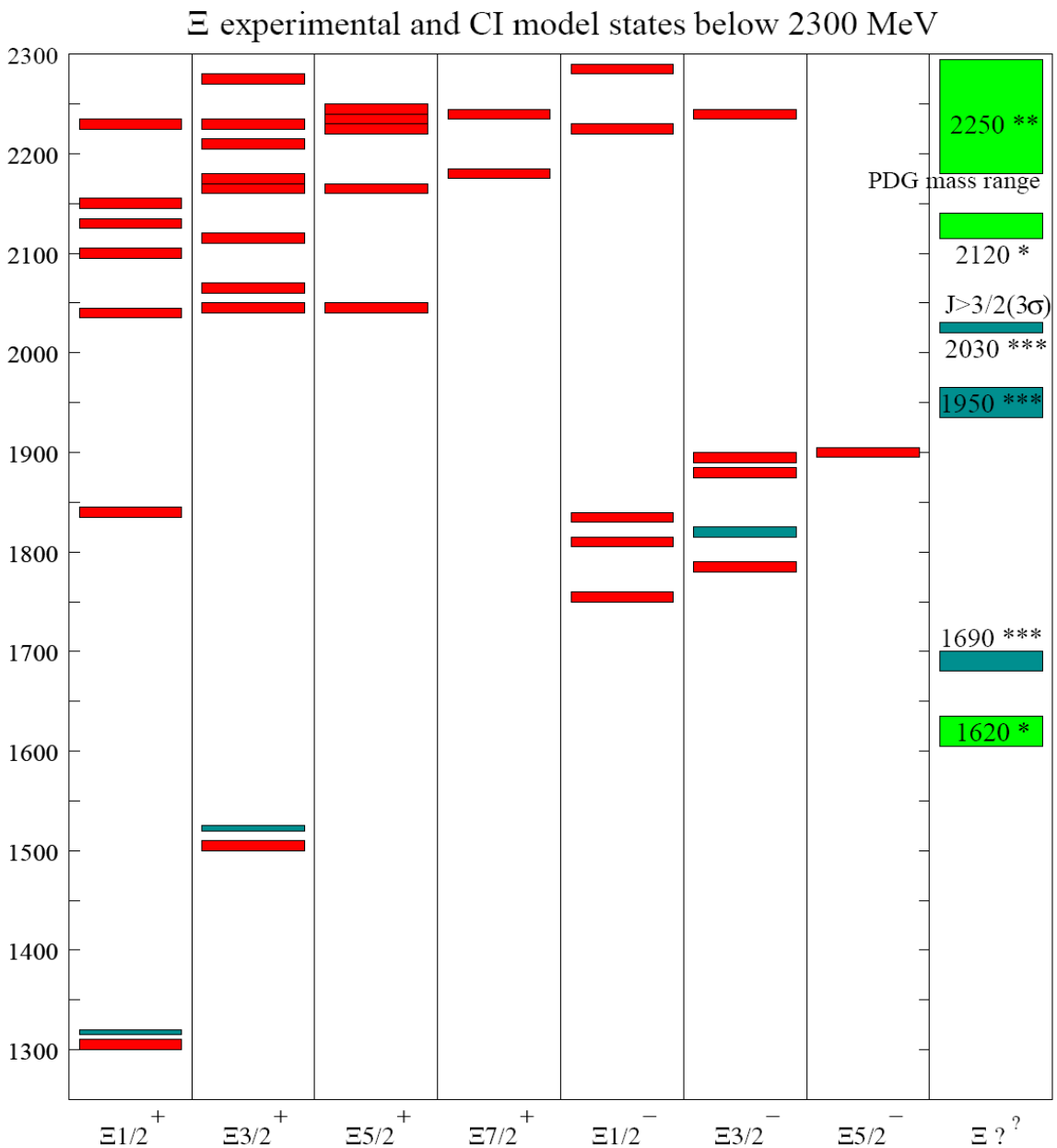
Exciting prospect:

Roper-resonance equivalent state $\Xi[P_{11}]_2$ at ~1700 MeV

Isolated from negative-parity states at ~1800-1900 MeV, which have Γ = 25-50 MeV

Widely separated from its $\Xi[P_{11}]_3$ partner at ~1950 MeV (width ~ 25 MeV)

Width of a few MeV (phase space; also $\Xi\pi\pi$ contribution small)


Ξ experimental and CI model states below 2300 MeV
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
2250 **
PDG mass range
2120 *
J>3/2(3σ)
2030 ***
1950 ***
1690 ***
1620 *
Ξ1/2+
Ξ3/2+
Ξ5/2+
Ξ7/2+
Ξ1/2−
Ξ3/2−
Ξ5/2−
Ξ ?

CI/CR Ξ states/decays (expt.)

mass	state	J^P	$\lvert A_{\Xi\pi}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Lambda K}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Sigma K}\rvert$ $MeV^{\frac{1}{2}}$	$\Sigma\lvert Ai\rvert^2$ MeV
1840	$[P_{11}]_2$	$1/2^+$	1.9	2.8	2.1	16
2040	$[P_{11}]_3$	$1/2^+$	5.2	5.3	5.1	81
1530	$[\Xi]^*$	$3/2^+$	3.2 3.2			10 10
2045	$[P_{13}]_2$	$3/2^+$	4.9	7.6	6.7	127
2065	$[P_{13}]_3$	$3/2^+$	1.7	5.1	10.5	110
2045	$[F_{15}]_1$	$5/2^+$	0.3	0.9	2.6	8
2165	$[F_{15}]_2$	$5/2^+$	1.4	2.1	0.2	6
2180	$[F_{17}]_1$	$7/2^+$	1.5	3.1	2.3	17
2240	$[F_{17}]_2$	$7/2^+$	5.0	0.2	0.0	25

CI/CR Ξ states/decays (expt.)

mass	state	J^P	$\lvert A_{\Xi\pi}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Lambda K}\rvert$ $MeV^{\frac{1}{2}}$	$\lvert A_{\Sigma K}\rvert$ $MeV^{\frac{1}{2}}$	$\Sigma\lvert A_i\rvert^2$ MeV
1755	$[S_{11}]_1$	$1/2^-$	9.3	13.6	15.3	506
1810	$[S_{11}]_2$	$1/2^-$	15.1	4.0	10.0	344
1835	$[S_{11}]_3$	$1/2^-$	2.7	4.7	12.5	186
1785	$[D_{13}]_1$	$3/2^-$	1.5 1.5	3.1 2.7	3.3 2.7	23 24
1880	$[D_{13}]_2$	$3/2^-$	2.3	1.7	2.3	13
1895	$[D_{13}]_3$	$3/2^-$	2.7	2.0	3.0	20
1900	$[D_{15}]_1$	$5/2^-$	6.5	3.3	2.7	60

Relativized-model Ξ states…

$^3P_0$ model tends to overestimate S-wave decay amplitudes (OK for P, F, D…)

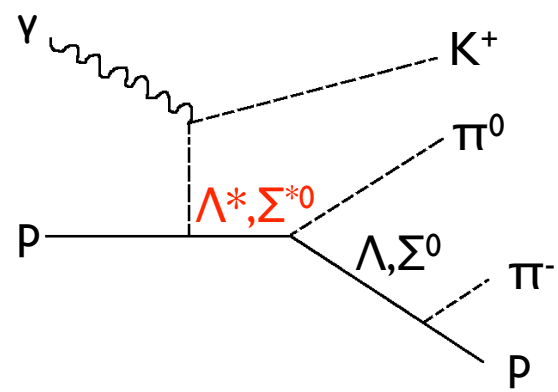
- Need to calculate $\Xi^*\pi$ (i.e. $\Xi\pi\pi$) widths

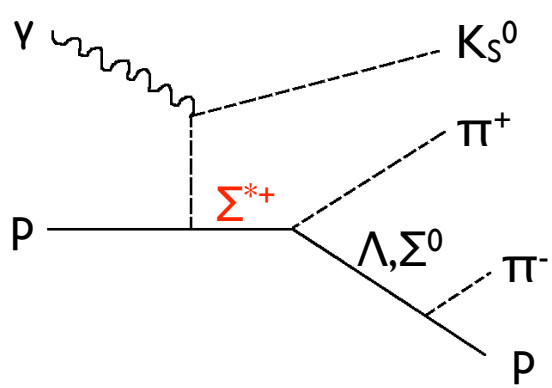
Roper-like state $\Xi[P_{11}]_2$ likely at ~ 1700-1800 MeV

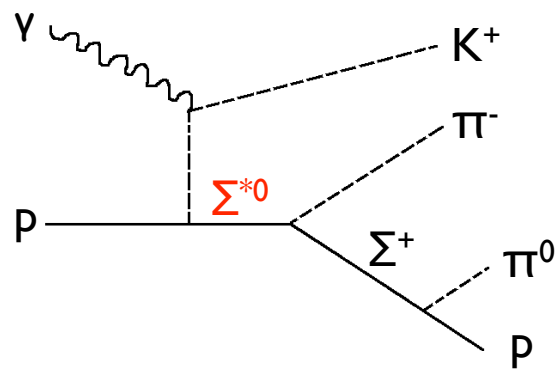
- May be close to lightest negative-parity states at ~1800-1900 MeV, lightest of which are still likely to have Γ = 25-50 MeV
- Widely separated (~200 MeV) from its $\Xi[P_{11}]_3$ partner at ~1990 MeV (width ~ 80 MeV)
- Narrow: width 10-15 MeV

Λ and Σ baryons at GlueX

Without K_L beam, primary mechanism for photo-production of hyperons at GlueX is peripheral kaon production followed by strong decay of the baryon

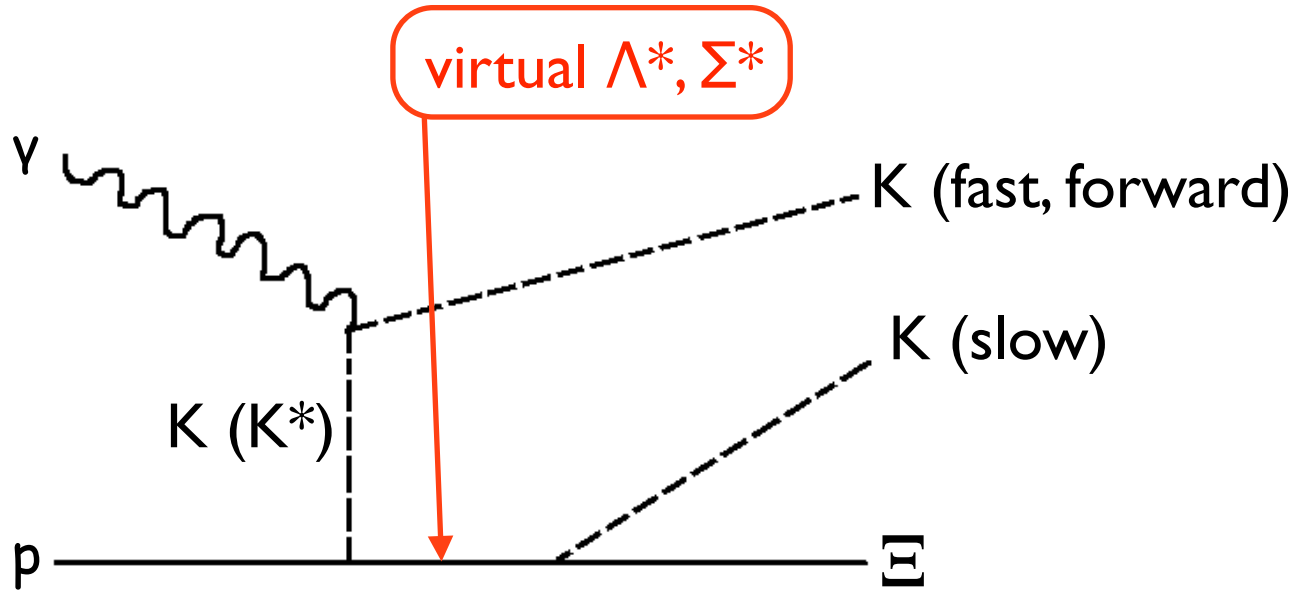






Ξ baryons at GlueX

Cascades produced when produced hyperon decays to Ξ K



Can GlueX see *excited* hyperons this way?

Λ and Σ baryons at GlueX

With K_L beam, *form* hyperons at GlueX in s-, t-, and u-channel elastic and inelastic scattering processes

See Mark Manley's talk:

Formation using (elastic) $K_L^0\, p \rightarrow K_S^0\, p$ needs hyperon to couple in initial *and* final state to $\bar{K}N$

Better to look in $K_L^0\, p \rightarrow \pi^+ (\Lambda, \Sigma^0)$

$$K_L^0\, p \rightarrow \pi^0\, \Sigma^0, \quad K_L^0\, p \rightarrow K^+\, \Xi^0$$

The formed resonance needs to couple to $\bar{K}N$ in the initial state, and model states missing in old (charged) kaon elastic scattering experiments couple weakly to K^-N

Conclusions and outlook

Masses and decays of hyperons with varying strangeness probe the flavor dependence of the short-range interaction between quarks

It is likely that there are several excited Ξ baryons that are relatively narrow

It would be very interesting to see the lightest excited states in certain partial waves decouple from the $\Xi\pi$ channel

Confirm flavor independence of confinement suggested in decays (spectrum) of excited Λ and Σ baryons

New data for Λ^*, Σ^* and Ξ^* baryons will vastly improve our understanding of baryon physics