Opportunities in Hadron Physics with Hadron Beams: A Hadron Modeler's Perspective[a]

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[a] Physics with Secondary Hadron Beams in the 21st Century, GWU, Ashburn , VA, April 7th, 2012.

Outline

- States of QCD and Effective Degrees of Freedom
- Quark Models and Unflavored Baryons
- Hadron Beams I
- Quark Models and Flavored Baryons
- Hadron Beams II

Important question for hadron physicists (hadronists?):

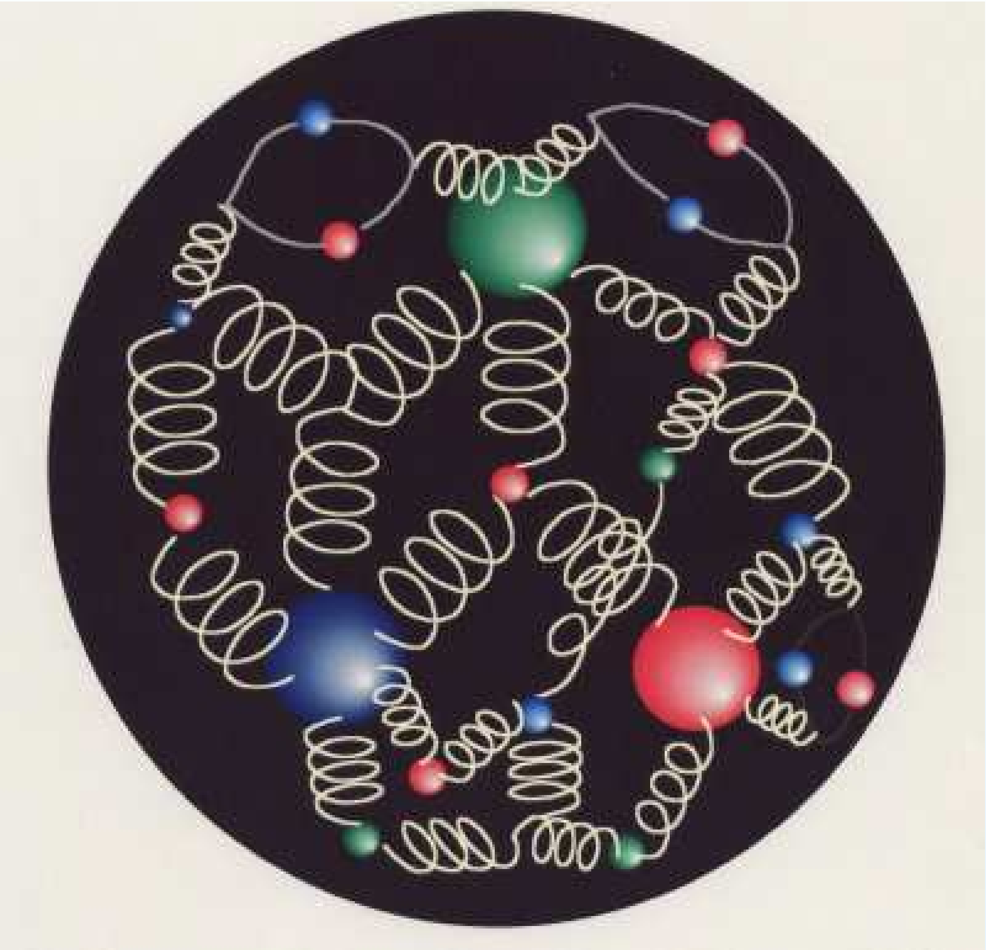
What are the states of QCD?

Certain: baryons, mesons;
less certain (no non-controversial examples yet exist): hybrids, glueballs, multiquarks.

Important question for hadron modelers:

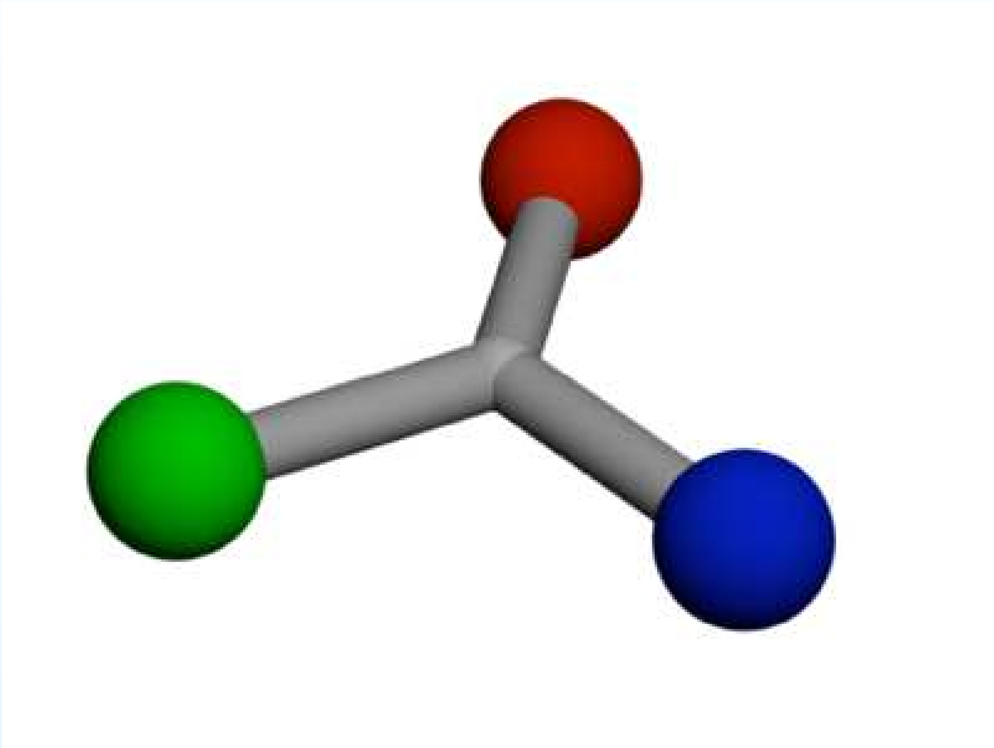
What are the effective degrees of freedom appropriate for understanding these states?

Baryons: 3 valence quarks, innumerable sea quarks and antiquarks, gluons



Realm of DIS, PDFs, GPDs, etc.

For the modeler, a baryons consists of 3 valence quarks, with possible higher Fock components



What does this (simple) model yield?

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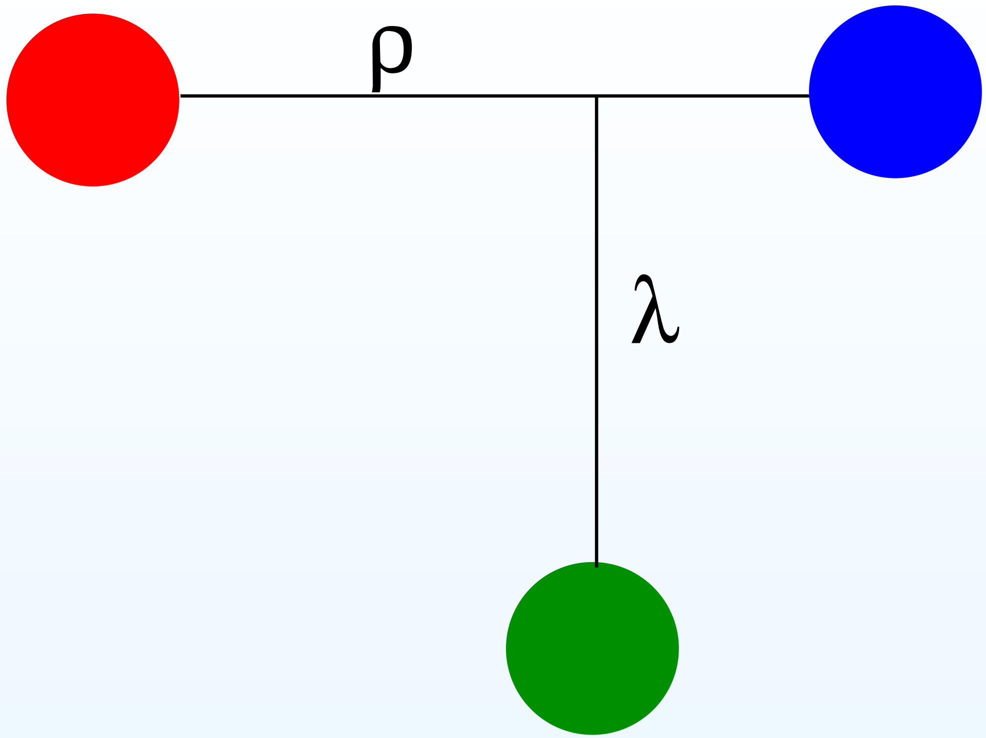

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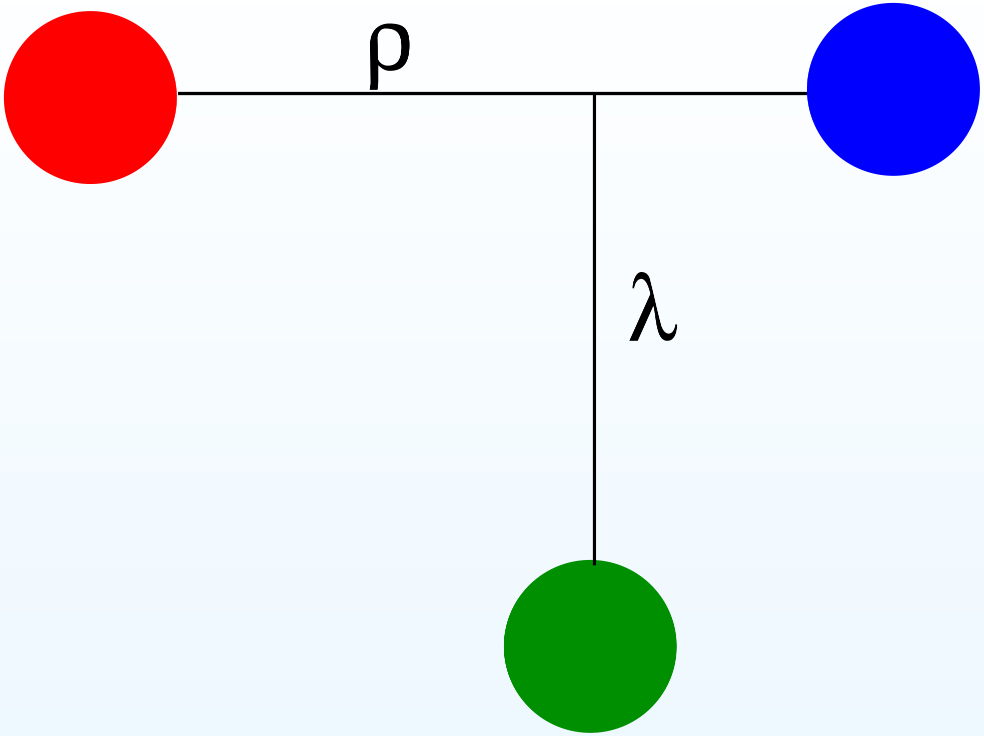

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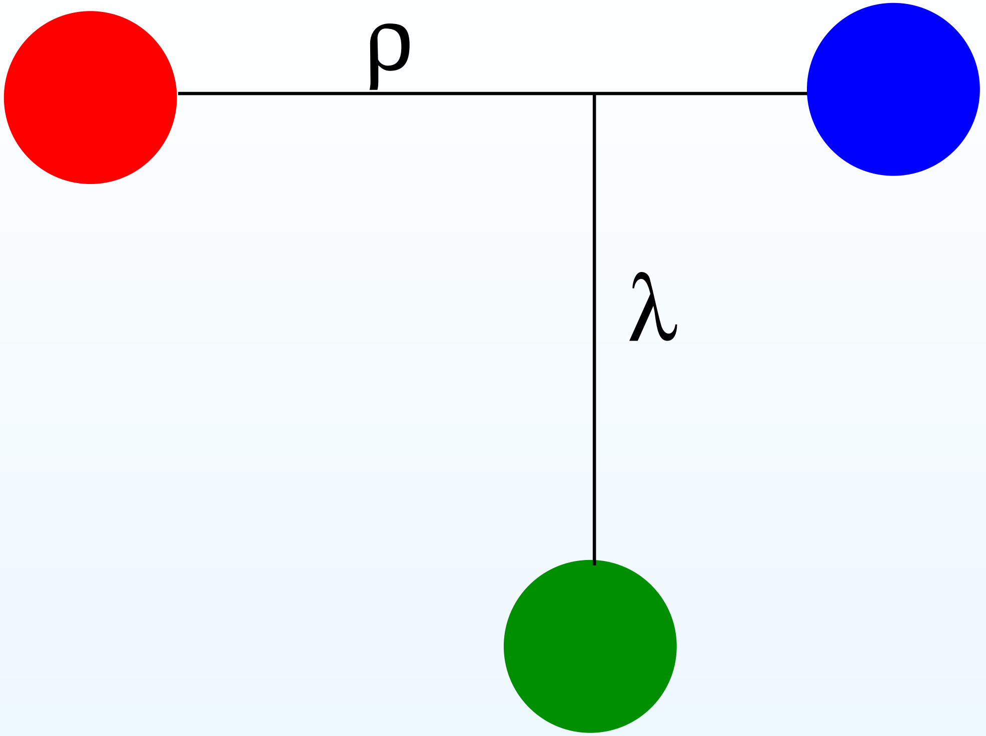

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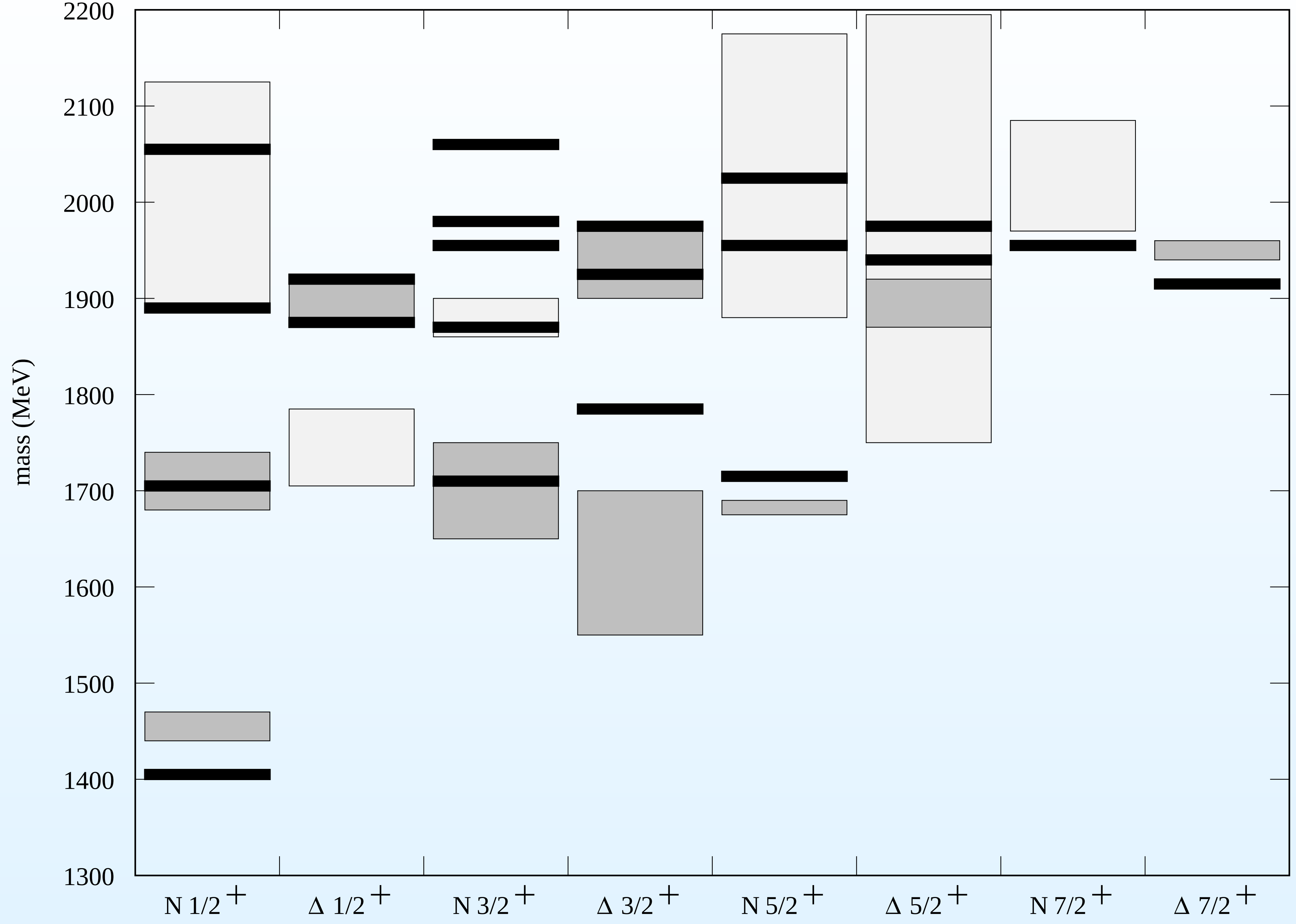
For baryons comprised of only u and d quarks, this model leads to more states than have been seen experimentally (states that have been extracted from partial wave analyses). This is the so-called 'missing (expected) baryon' problem.


mass (MeV)
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1400
1300
N 1/2 +
Δ 1/2 +
N 3/2 +
Δ 3/2 +
N 5/2 +
Δ 5/2 +
N 7/2 +
Δ 7/2 +

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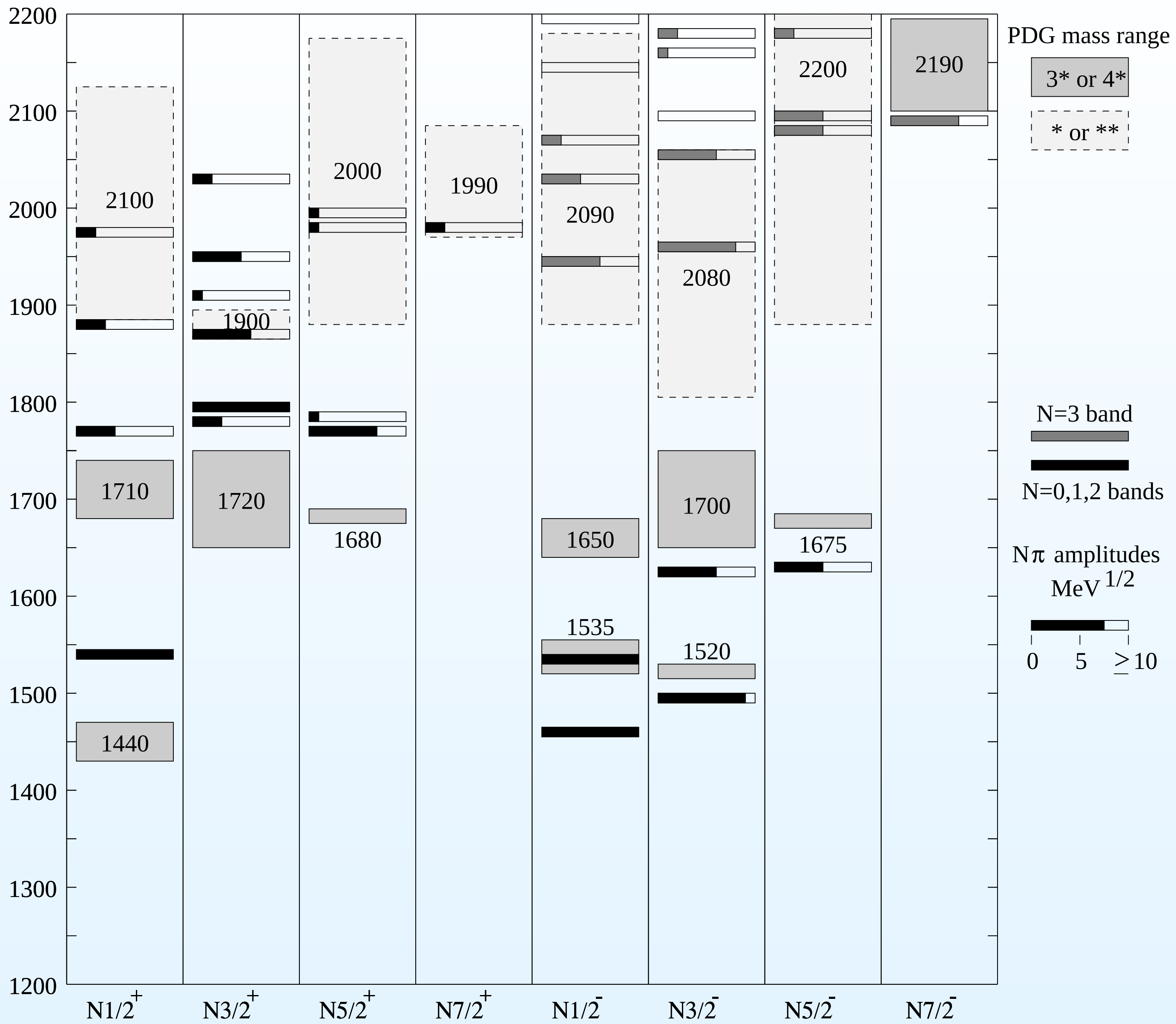
States coupling weakly to $N\pi$ will be difficult to produce in $N\pi$ scattering experiments. Construct model ($^3P_0$), check this hypothesis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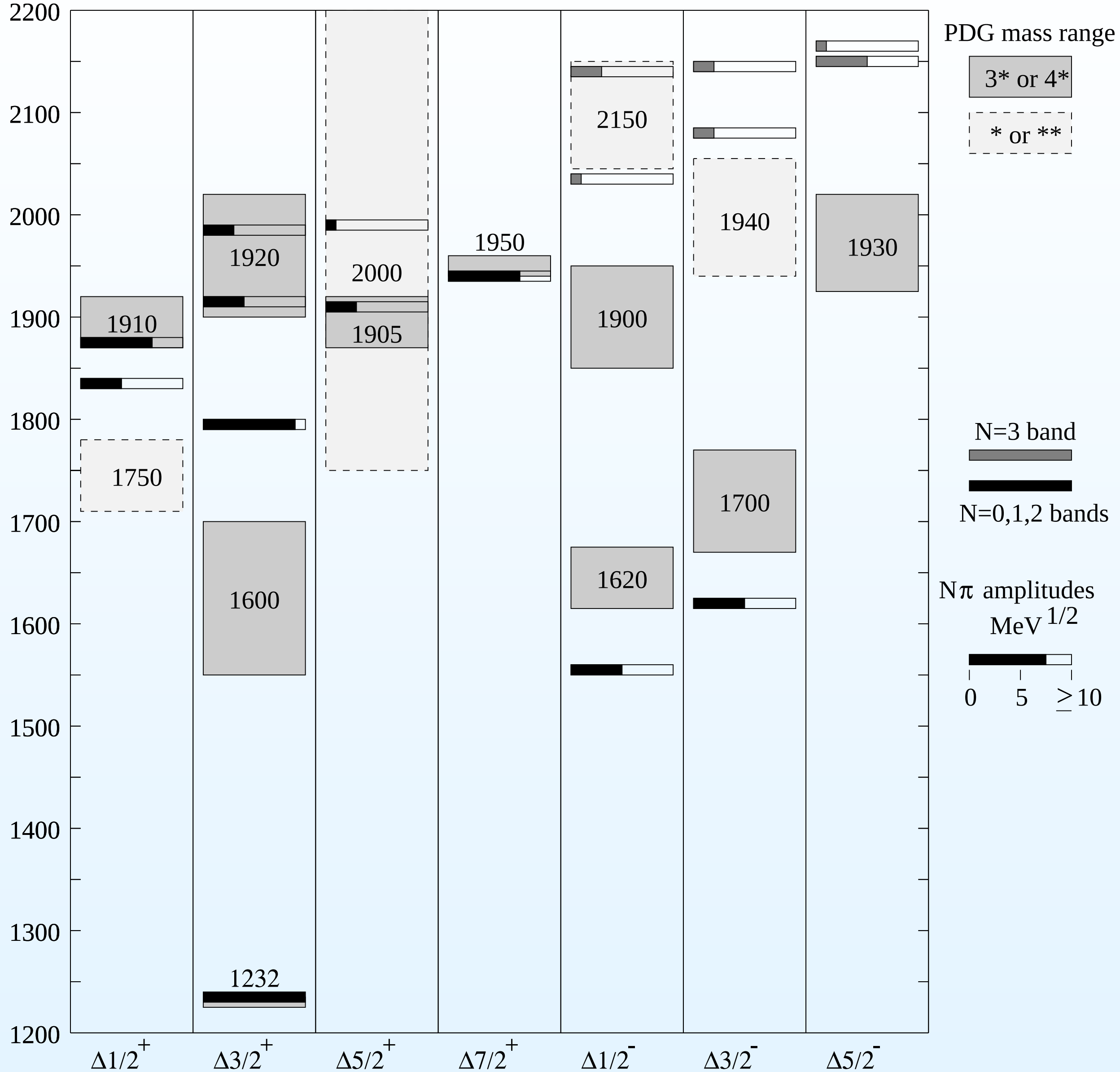
1700
1520
2200
1675
2190
N1/2+
N3/2+
N5/2+
N7/2+
N1/2-
N3/2-
N5/2-
N7/2-
PDG mass range
3* or 4*
* or **
N=3 band
N=0,1,2 bands
Nπ amplitudes
MeV 1/2
0
5
≥10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1620
1940
1700
1930
Δ1/2+
Δ3/2+
Δ5/2+
Δ7/2+
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PDG mass range
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≥10

How can the ‘expected’ states be produced and detected? New channels, including photoproduction of final states like $N\pi\pi$, $N\pi\eta$ (from $\Delta\eta$), $N\eta$, $N\omega$, etc.: significant portion of CLAS program at JLab

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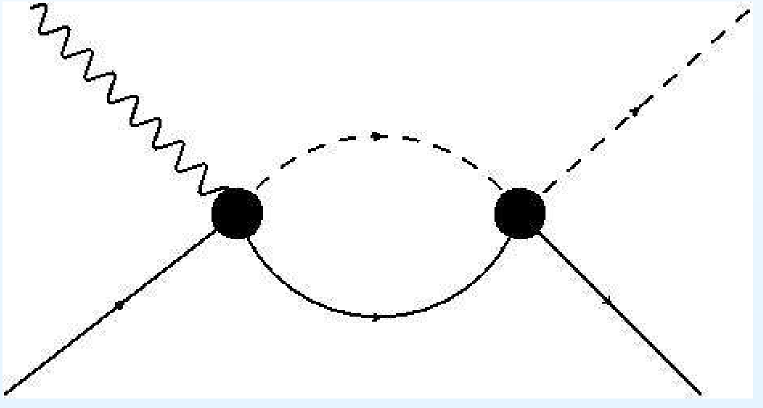
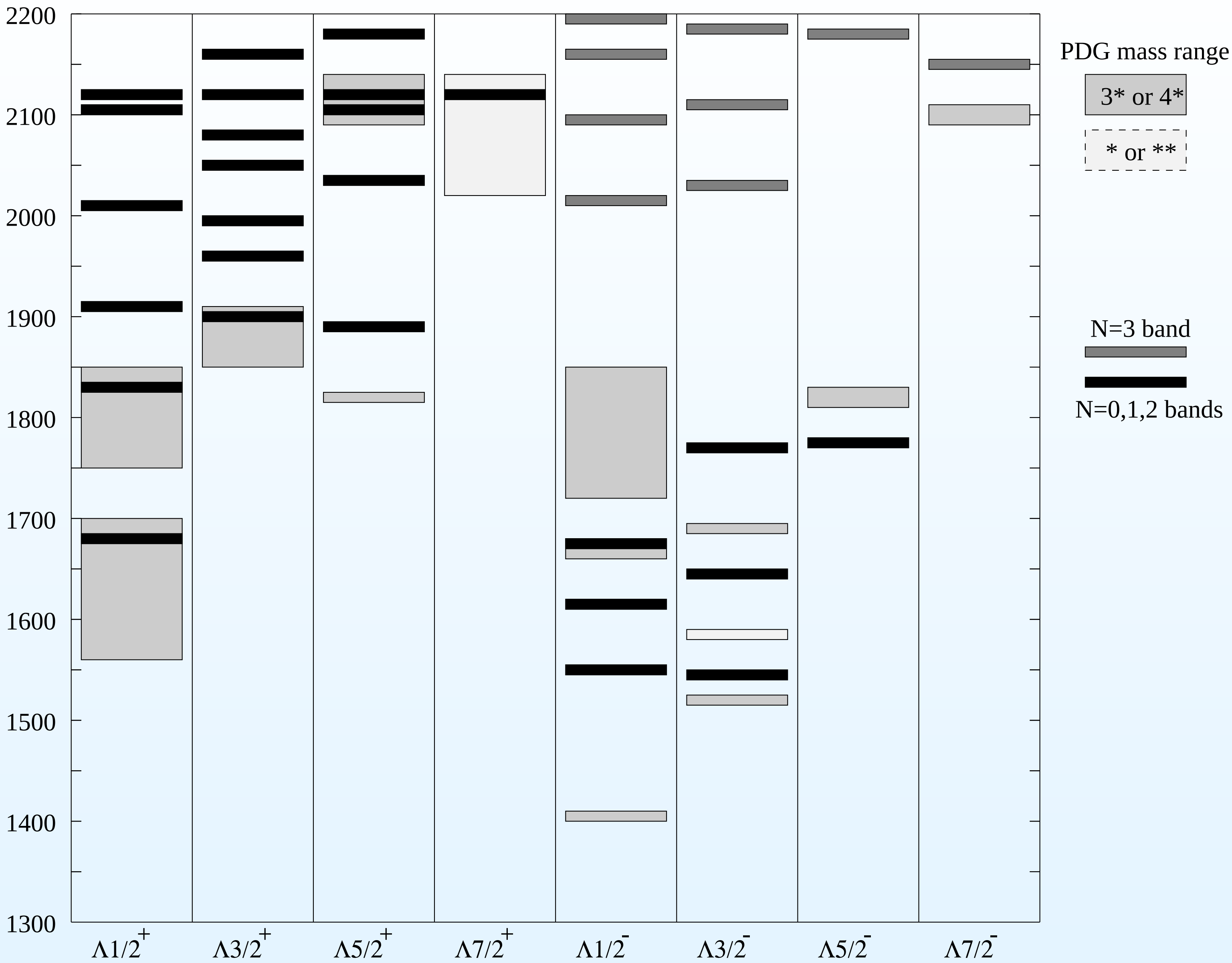


Among hyperons, similar pattern, but even fewer of the predicted states have been observed.



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Λ1/2+
Λ3/2+
Λ5/2+
Λ7/2+
Λ1/2-
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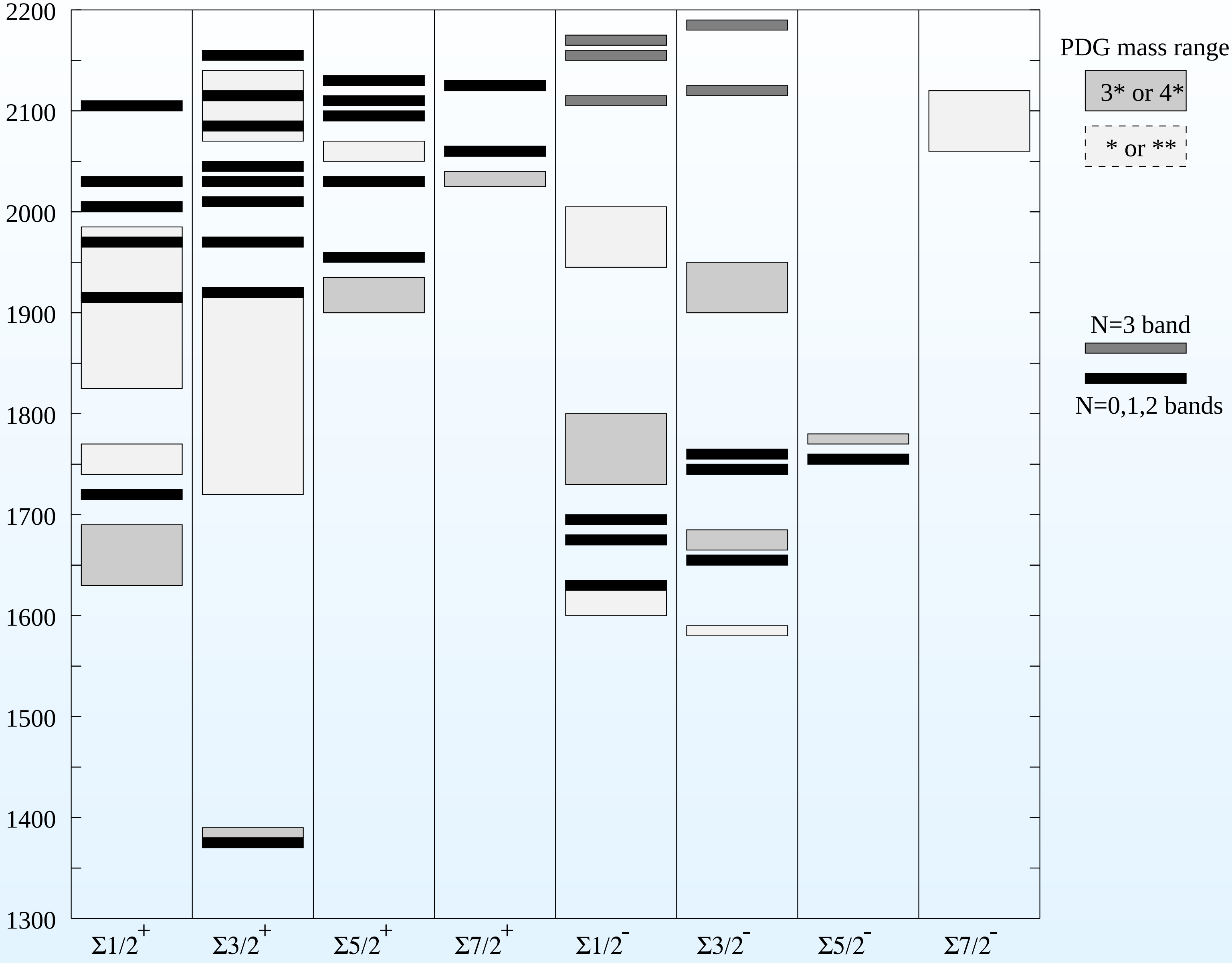
PDG mass range
3* or 4*
* or **
N=3 band
N=0,1,2 bands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Experiment	J^P	PDG rating	Experiment	J^P	PDG rating
$\Xi(1317)$	$1/2^+$ (expected)	****	$\Omega(1672)$	$3/2^+$	****
$\Xi(1530)$	$3/2^+$ (favored by data)	****	$\Omega(2250)$	$?^?$	***
$\Xi(1823)$	$3/2^-$	***	$\Omega(2380)$	$?^?$	**
$\Xi(1690)$	$?^?$	***	$\Omega(2470)$	$?^?$	**
$\Xi(1950)$	$?^?$	***			
$\Xi(2030)$	$\geq 5/2^?$	***			
$\Xi(2250)$	$?^?$	**			
$\Xi(2370)$	$?^?$	**			
$\Xi(1620)$	$?^?$	*			
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Hadron beams, particularly kaon beams (coupled with the precision that may be achievable with secondary beams at Jlab), can provide the data needed to understand the spectrum of flavored baryons.

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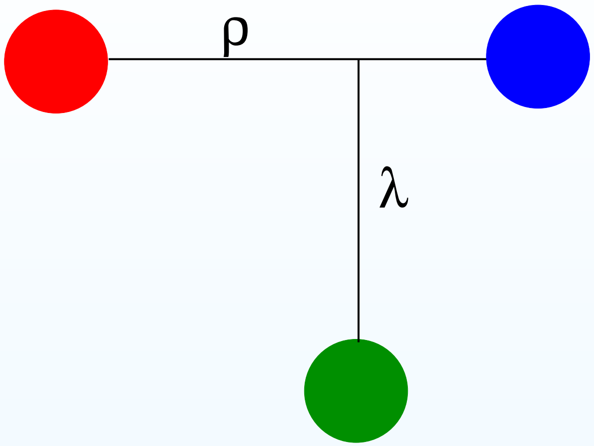

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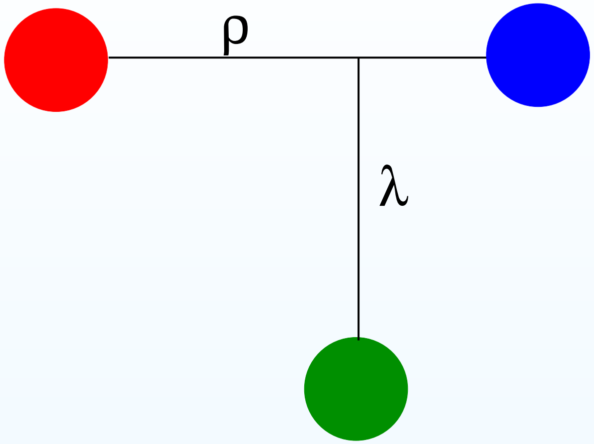

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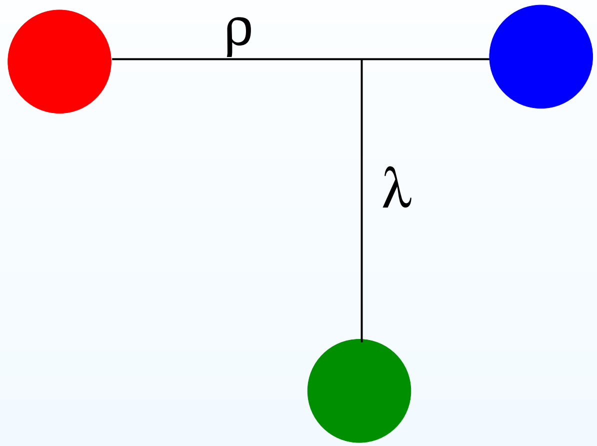

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$L = 1$ excitations, for instance, are built from the SU(3) wave functions

$$\left|N^4P_M\left(\frac{1}{2}^-,\frac{3}{2}^-,\frac{5}{2}^-\right)\right\rangle = \chi^S_{\frac{3}{2}}\frac{1}{\sqrt{2}}\left(\phi^\rho_N\psi_1^{M_\rho}+\phi^\lambda_N\psi_1^{M_\lambda}\right),$$

$$\left|N^2P_M\left(\frac{1}{2}^-,\frac{3}{2}^-\right)\right\rangle = \frac{1}{2}\left[\phi^\rho_N\left(\psi_1^{M_\rho}\chi^\lambda_{\frac{1}{2}}+\psi_1^{M_\lambda}\chi^\rho_{\frac{1}{2}}\right)+\phi^\lambda_N\left(\psi_1^{M_\rho}\chi^\rho_{\frac{1}{2}}-\psi_1^{M_\lambda}\chi^\lambda_{\frac{1}{2}}\right)\right]$$

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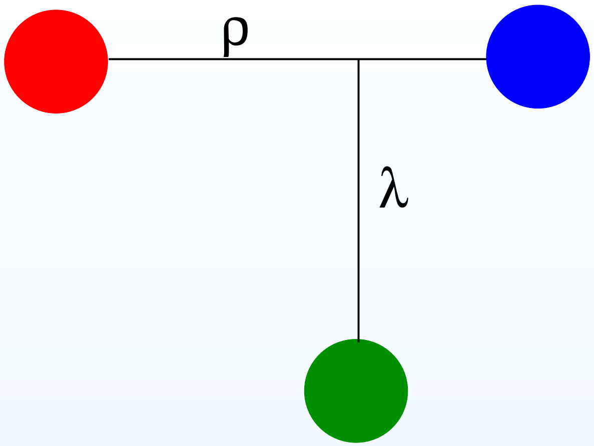

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$\Longrightarrow$ interpretation of phenomenology is complicated.

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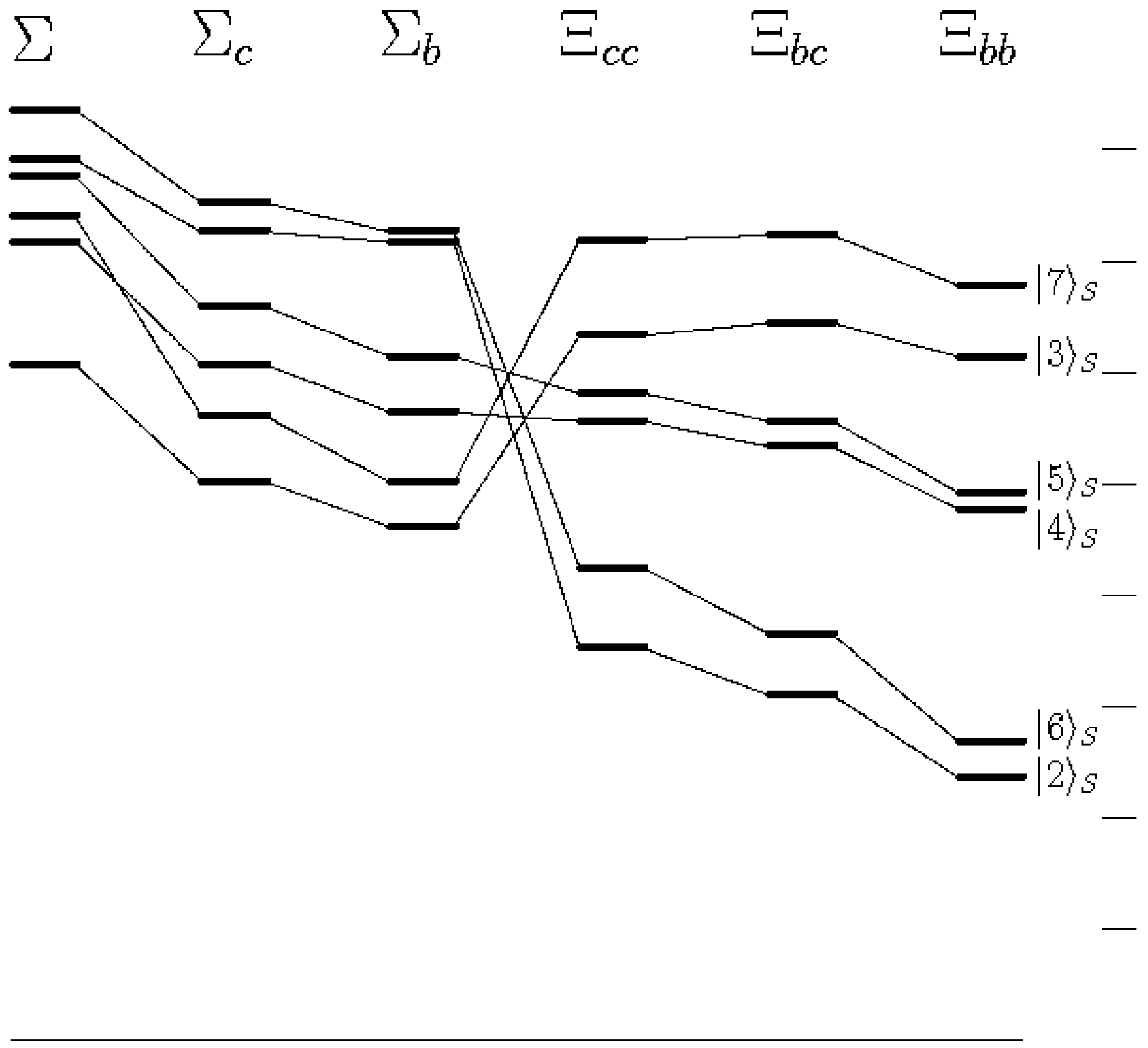
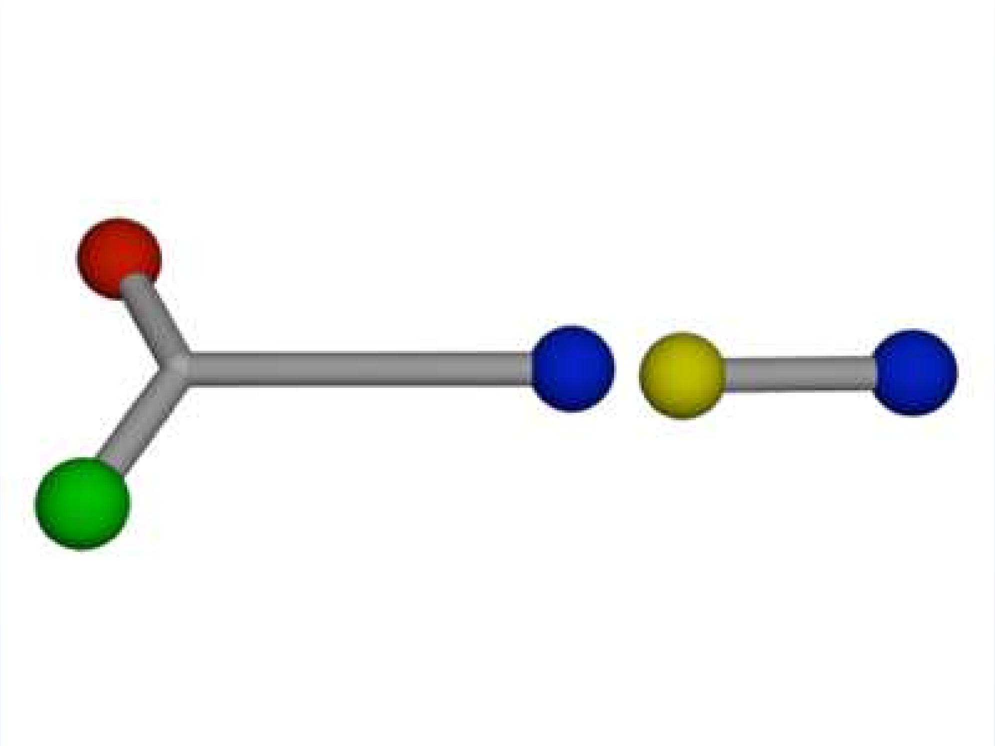
If quarks 1 and 2 are heavier than quark 3 (such as in Ξ), excitations in the ρ coordinate cost less energy

J^P	Ξ		Ω	
	Experiment	Model	Experiment	Model
$1/2^+$	1.317$\pm$ 0.001	1.325	-	2.175
	-	1.891	-	2.191
	-	2.014	-	-
$3/2^+$	1.532$\pm$ 0.001	1.520	1.672	1.656
	-	1.934	-	2.170
	-	2.020	-	2.182
$5/2^+$	1.950$\pm$ 0.015	1.936	-	2.178
	-	2.025	-	2.210
$7/2^+$	2.025$\pm$ 0.005	2.035	-	2.183
		2.148	-	-
$1/2^-$	1.690$\pm$ 0.010	1.725	-	1.923
	-	1.811	-	-
$3/2^-$	-	1.759	-	1.953
	1.823$\pm$ 0.005	1.826	-	-
$5/2^-$	-	1.883	-	-


Σ
Σ_c
Σ_b
Ξ_{cc}
Ξ_{bc}
Ξ_{bb}
$|7\rangle_S$
$|3\rangle_S$
$|5\rangle_S$
$|4\rangle_S$
$|6\rangle_S$
$|2\rangle_S$



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Data from as many decay channels as possible are necessary for insights into spectrum, and data from experiments with hadron beams have a crucial role to play

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If a dedicated production experiment using hadron beams fails to 'see a signal' for any of these 'expected' states, it probably doesn't exist, and indicates that we have the degrees of freedom wrong

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Precision studies of properties of antibaryons (as LEAR did for $\overline{\Lambda}$)

Conclusions

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A vast array of hadron phenomenology, crucial for further insight into nonperturbative QCD, can be probed