

Properties of Baryon Resonances and Strong Decays

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Project P19035, Structure of Baryon Resonances

Collaborators:

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Outline

Introduction

Point-Form Spectator Model

Strong Decay Widths and Baryon Structure

Summary and Outlook

Determination of Baryon Resonances

- Lattice QCD
- Structure Models
 - Dyson-Schwinger, Constituent Quark Models (CQMs)...
- Hadronic Coupled-Channel Models (HCCM)
 - MAID, SAID, Sato-Lee, Giessen...

Connection of HCCMs and Lattice/Structure Models?

Attempts of Hybrid Approaches

$$QQQ - QQQ[m, g, Q\bar{Q}...]$$

Major Difficulties: Double-counting, off-shell, dressing...

Requirement: Self-consistent framework

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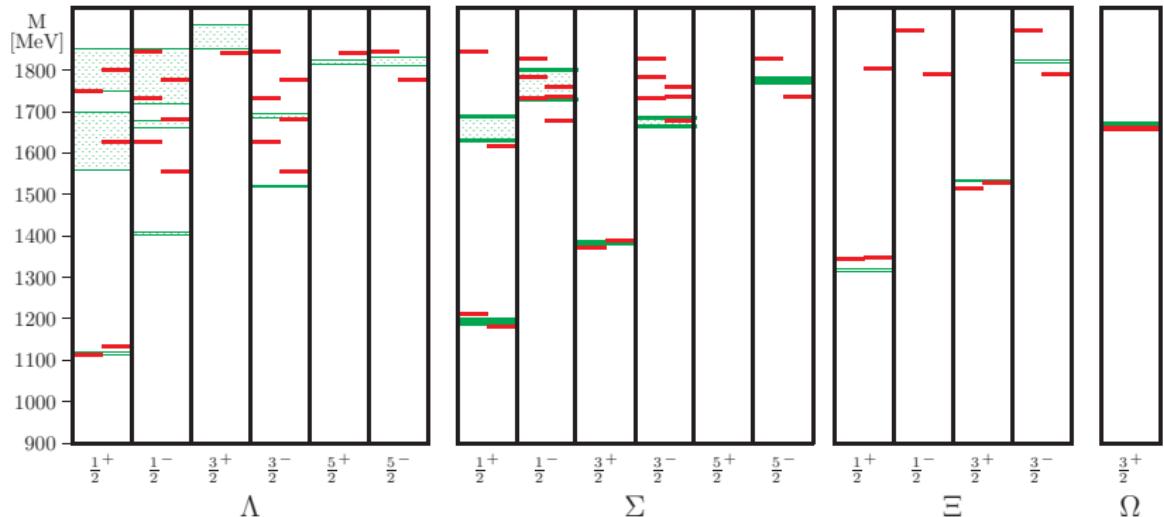
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In this talk we investigate relativistic CQMs

CQM Hyperon Spectra Comparison



Left Red: One-Gluon Exchange, Right Red: Goldstone-Boson Exchange,
Green: Experiment (PDG)

Is it possible to reproduce other baryon properties?

Point-Form Spectator Model (PFSM) in Relativistic Quantum Mechanics (RQM)

RQM: Hamiltonian → invariant mass operator

Point-Form: kinematic subgroup is Lorentz-group

Spectator Model:



- Meson couples to quark 1,
quarks 2 and 3 are
spectators

momentum transfer: $p_1^\mu - p_1'^\mu = \tilde{q}^\mu \neq q^\mu = P^\mu - P'^\mu$

→ PFSM is effective many-body operator!

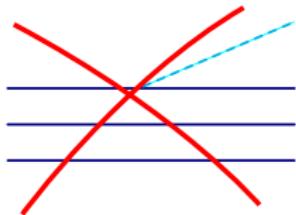
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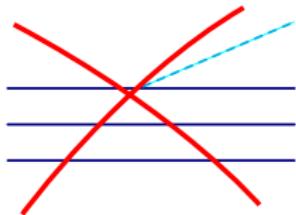
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Strategy to define PFSM

- Formal definition of vertex and spectator-constraints
- Adjust definition to satisfy global constraints and sensible limit-behaviours for transition amplitudes

T. Melde et al., to appear in Phys. Rev. D, nucl-th/0612013

→ Poincaré-invariance

Electromagnetic Results

- Nucleon electromagnetic properties
- Hyperon charge radii and magnetic moments

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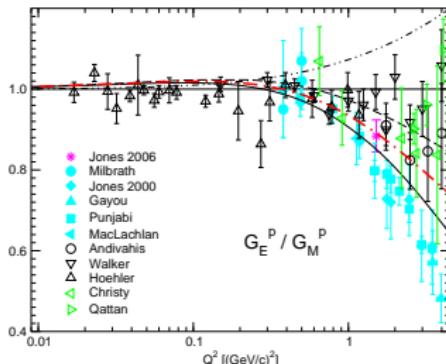
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Results for partial decay widths

- Relativistic decay predictions generally too small

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- Nonrelativistic approximations have severe effects (x-check)

"Call in the usual suspects!"

Can we find a systematics to suggest improvement?

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Particle Data Group proposes multiplet classification
"All established baryons are 3-quark configurations"

$\frac{3}{2}^-$ octet baryon states $N(1520)$, $\Lambda(1690)$, $\Sigma(1670)$, $\Xi(1820)$

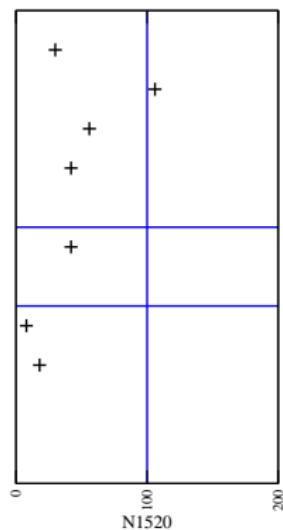
	Decay	Experiment	Relativistic		% of Exp. Width	
			GBE	OGE	GBE	OGE
$N(1520)$	$\rightarrow N\pi$	$(66 \pm 6)^{+9}_{-5}$	21	23	26 – 38	28 – 42
$\Lambda(1690)$	$\rightarrow \Sigma\pi$	$(18 \pm 6)^{+4}_{-2}$	19	25	68 – 190	89 – 250
$\Sigma(1670)$	$\rightarrow \Sigma\pi$	$(27 \pm 9)^{+12}_{-6}$	15	23	31 – 125	48 – 192
$\Sigma(1670)$	$\rightarrow \Lambda\pi$	$(6 \pm 3)^{+3}_{-1}$	2.5	2.0	21 – 125	17 – 100
$\Xi(1820)$	$\rightarrow \Xi\pi$	$\Gamma(14 - 39)$	0.4	1.6	$\Gamma(1 - 3)$	$\Gamma(4 - 11)$
$N(1520)$	$\rightarrow N\eta$	$(0.28 \pm 0.05)^{+0.03}_{-0.01}$	0.11	0.11	31 – 50	31 – 50
$\Lambda(1690)$	$\rightarrow \Lambda\eta$	$\Gamma(50 - 70)$		0.2		$\Gamma(\approx 0)$
$\Lambda(1690)$	$\rightarrow NK$	$(15 \pm 3)^{+3}_{-2}$	1.2	1.0	6 – 12	5 – 10
$\Sigma(1670)$	$\rightarrow NK$	$(6.0 \pm 1.8)^{+2.6}_{-1.4}$	1.1	1.0	11 – 39	10 – 36
$\Xi(1820)$	$\rightarrow \Lambda K$	$\Gamma(14 - 39)$	2.7	6.2	$\Gamma(7 - 19)$	$\Gamma(16 - 44)$
$\Xi(1820)$	$\rightarrow \Sigma K$	$\Gamma(14 - 39)$	4.1	9.3	$\Gamma(11 - 29)$	$\Gamma(24 - 66)$

Graphical Analysis

Spin- and Spatial-structure is also congruent

$\frac{3}{2}^-$ octet baryon states $N(1520)$, $\Lambda(1690)$, $\Sigma(1670)$, $\Xi(1820)$

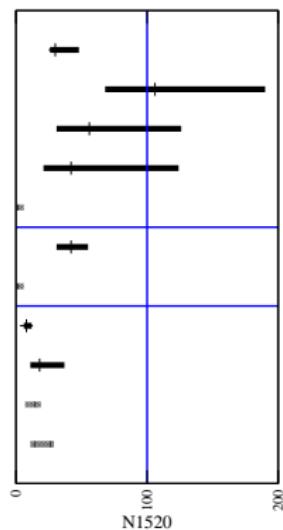
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Is the same systematics observed in the other multiplets?

Theoretical Results for the Decay Channel $\Sigma \rightarrow \Sigma\pi$

Decay $\rightarrow \Sigma\pi$	J^P	Experiment [MeV]	Relativistic		Nonrel. EEM	
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$\Sigma(1385)$	$\frac{3}{2}^+$	$(4.2 \pm 0.5)^{+0.7}_{-0.5}$	3.1	0.5	6.5	1.1
$\Sigma(1660)$	$\frac{1}{2}^+$	seen	10	24	2	15
$\Sigma(1670)$	$\frac{3}{2}^-$	$(27 \pm 9)^{+12}_{-6}$	15	23	21	32
$\Sigma(1750)^1$	$\frac{1}{2}^-$	$(3.6 \pm 3.6)^{+5.6}_{-0}$	58	102	480	1249
$\Sigma(1775)$	$\frac{5}{2}^-$	$(4.2 \pm 1.8)^{+0.8}_{-0.3}$	1.9	3.8	2.9	6.9
$\Sigma(1940)$	$\frac{3}{2}^-$	seen	2.2	3.7	0.5	1.1

$\Sigma(1750)^3$ is a flavor decuplet

→ different to PDG

What about the states $\Sigma(1750)^1$ and $\Sigma(1750)^2$?

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Taking into account **two-star resonances** (as of PDG)

using masses, spatial-, spin- and flavour- properties
and theoretical decay widths

→ we suggest **classification**:

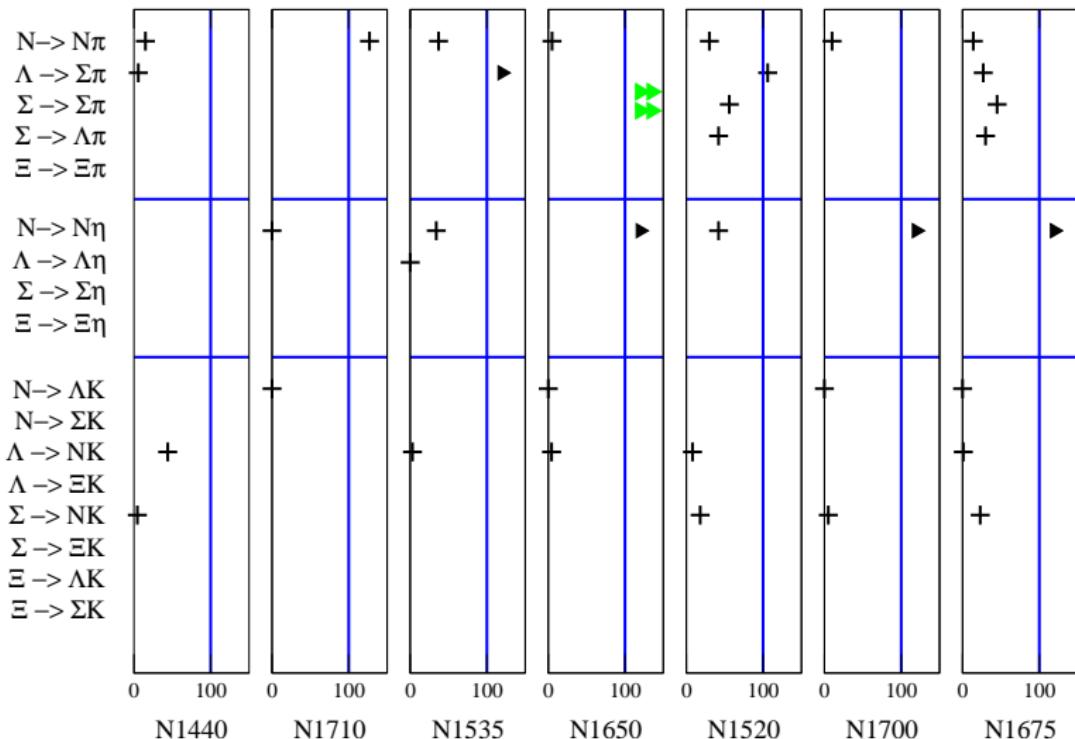
Multiplet Classification: Flavor Octet Baryons

$(LS)J^P$	#
$(0\frac{1}{2})\frac{1}{2}^+$ $N(939)^{100}$ $\Sigma(1193)^{100}$ $\Xi(1318)^{100}$ $\Lambda(1116)^{100}$	1
$(0\frac{1}{2})\frac{1}{2}^+$ $N(1440)^{100}$ $\Sigma(1660)^{100}$ $\Xi(\mathbf{1690})^{100}$ $\Lambda(1600)^{96}$	3
$(0\frac{1}{2})\frac{1}{2}^+$ $N(1710)^{100}$ $\Sigma(\mathbf{1880})^{99}$	4
$(1\frac{1}{2})\frac{1}{2}^-$ $N(1535)^{100}$ $\Sigma(\mathbf{1560})^{94}$	9
$(1\frac{3}{2})\frac{1}{2}^-$ $N(1650)^{100}$ $\Sigma(\mathbf{1620})^{100}$	14
$(1\frac{1}{2})\frac{3}{2}^-$ $N(1520)^{100}$ $\Sigma(1670)^{94}$ $\Xi(1820)^{97}$ $\Lambda(1690)^{72}$	8
$(1\frac{3}{2})\frac{3}{2}^-$ $N(1700)^{100}$ $\Sigma(1940)^{100}$	11
$(1\frac{3}{2})\frac{5}{2}^-$ $N(1675)^{100}$ $\Sigma(1775)^{100}$ $\Xi(\mathbf{1950})^{100}$ $\Lambda(1830)^{100}$	12

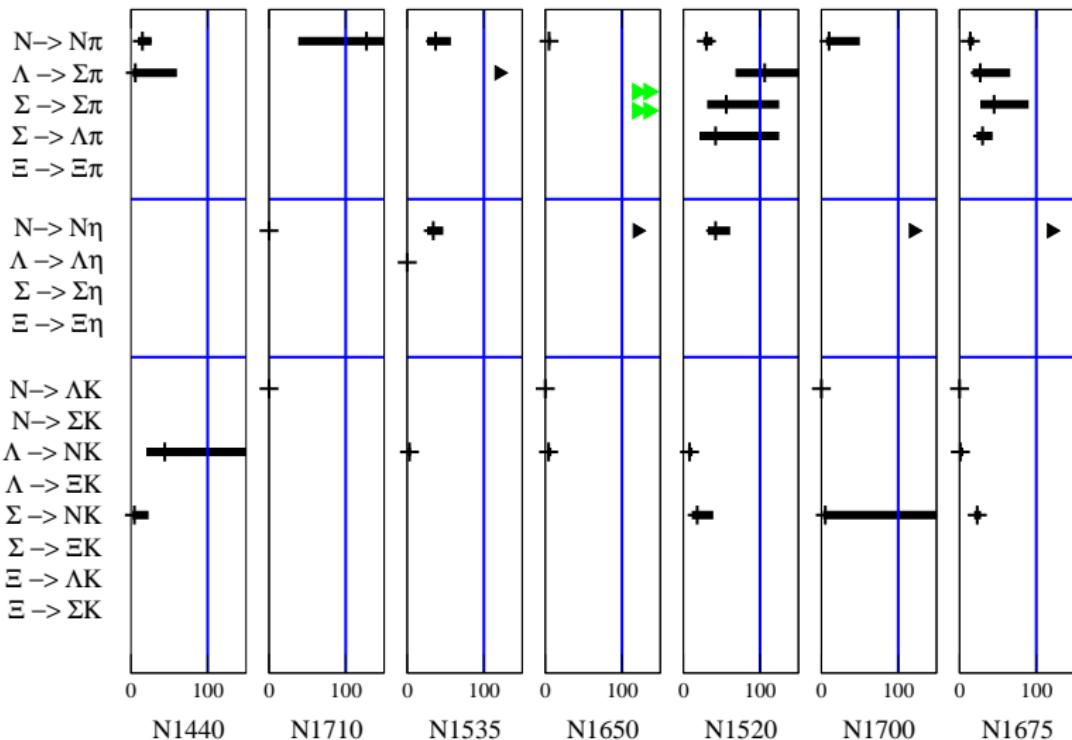
... classification according to Guzey and Polyakov

[hep-ph/0512355 (2005)]

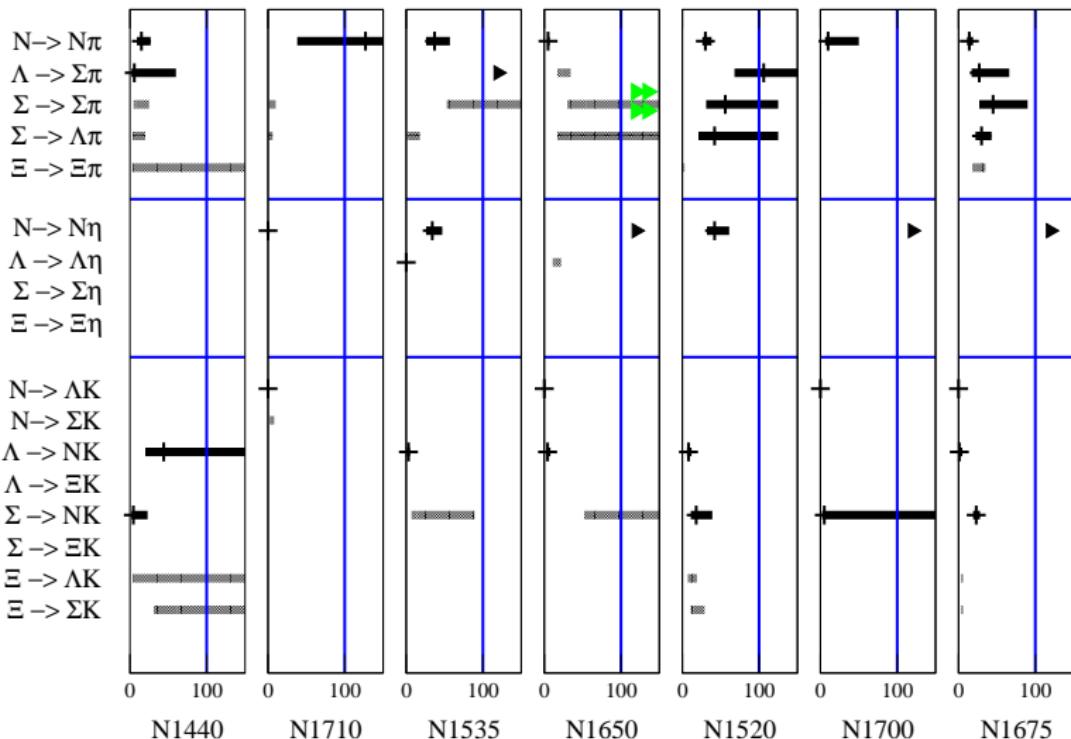
Octet Decays (GBE CQM)



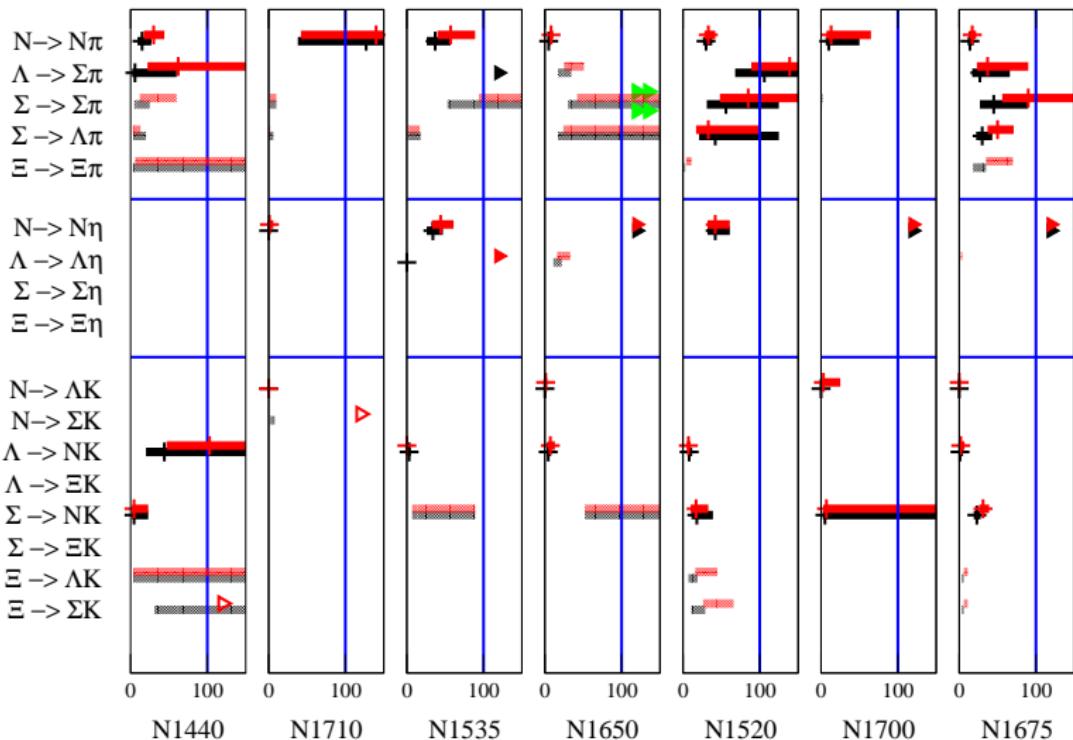
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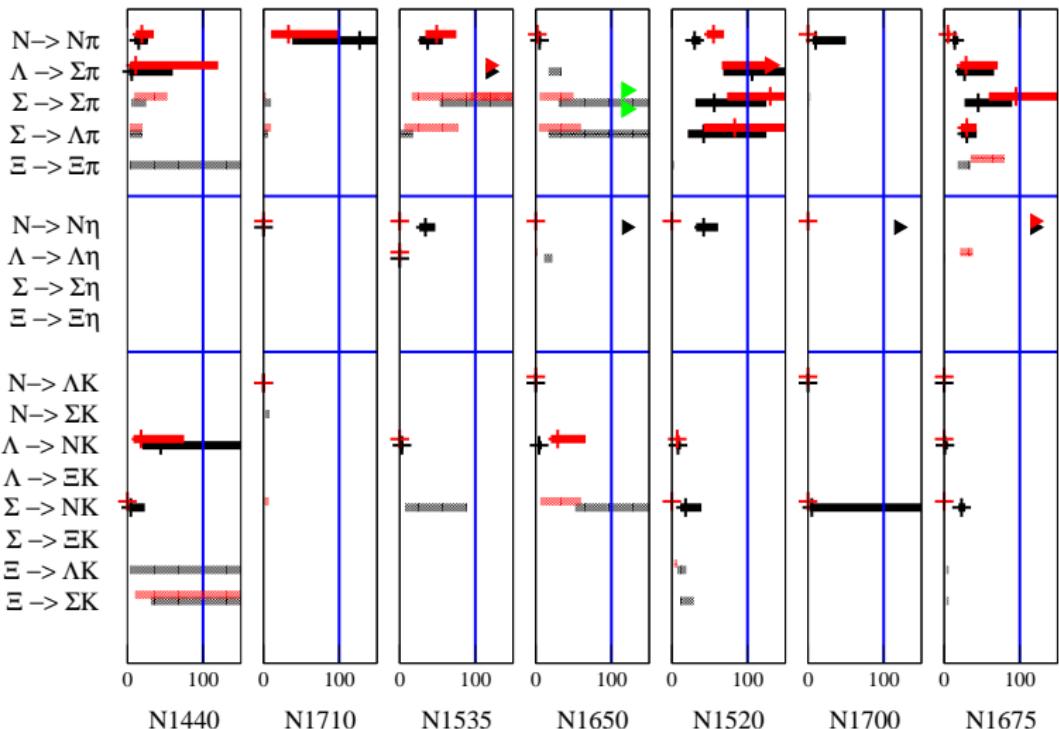
Octet Decays (GBE CQM)



Octet Decays (GBE-OGE CQM)



Octet Decays (GBE-II CQM)



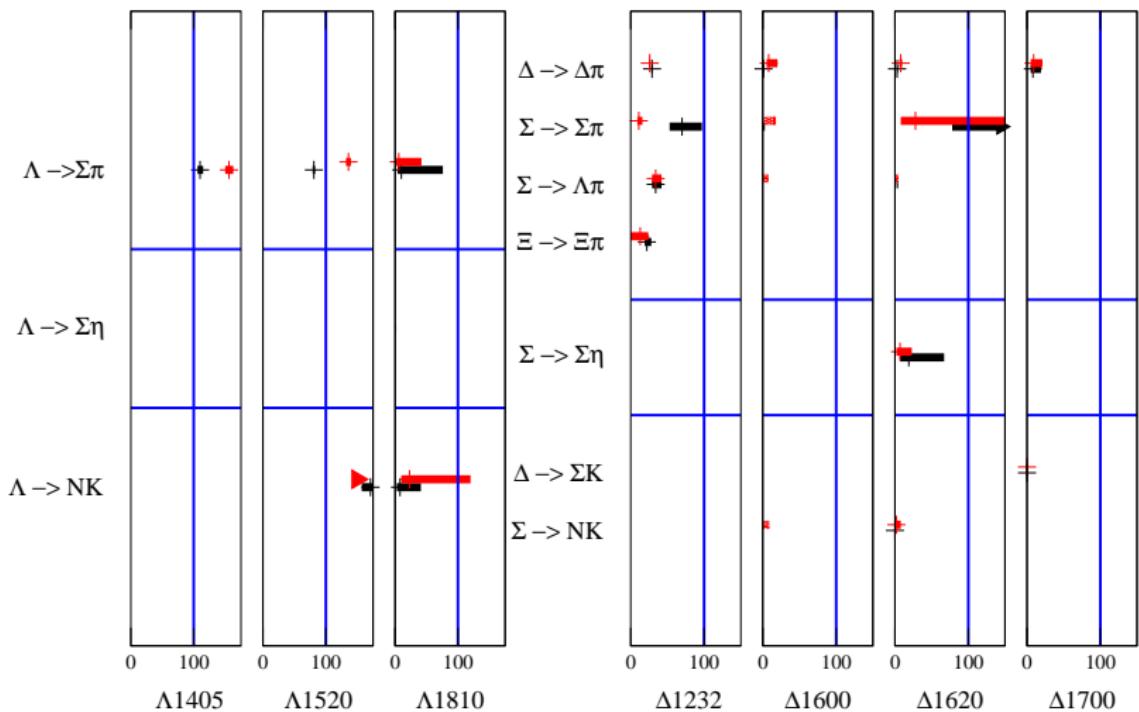
Flavor Singlet Baryons

$(LS)J^P$	#
$(0\frac{1}{2})\frac{1}{2}^+$ $\Lambda(1810)^{92}$	4
$(1\frac{1}{2})\frac{1}{2}^-$ $\Lambda(1405)^{71}$	6
$(1\frac{1}{2})\frac{3}{2}^-$ $\Lambda(1520)^{71}$	7

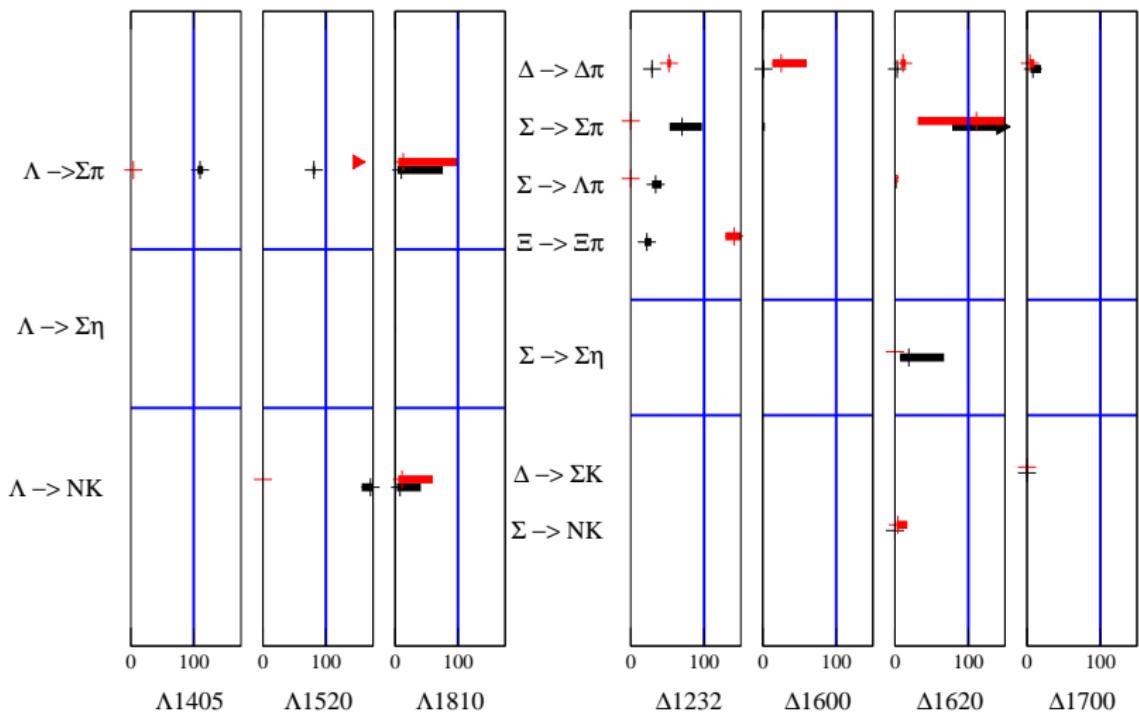
Flavor Decuplet Baryons

$(LS)J^P$	#
$(0\frac{3}{2})\frac{3}{2}^+$ $\Delta(1232)^{100}$ $\Sigma(1385)^{100}$ $\Xi(1530)^{100}$ $\Omega(1672)^{100}$	2
$(0\frac{3}{2})\frac{3}{2}^+$ $\Delta(1600)^{100}$ $\Sigma(1690)^{99}$	5
$(1\frac{1}{2})\frac{1}{2}^-$ $\Delta(1620)^{100}$ $\Sigma(1750)^{94}$	10
$(1\frac{1}{2})\frac{3}{2}^-$ $\Delta(1700)^{100}$	13

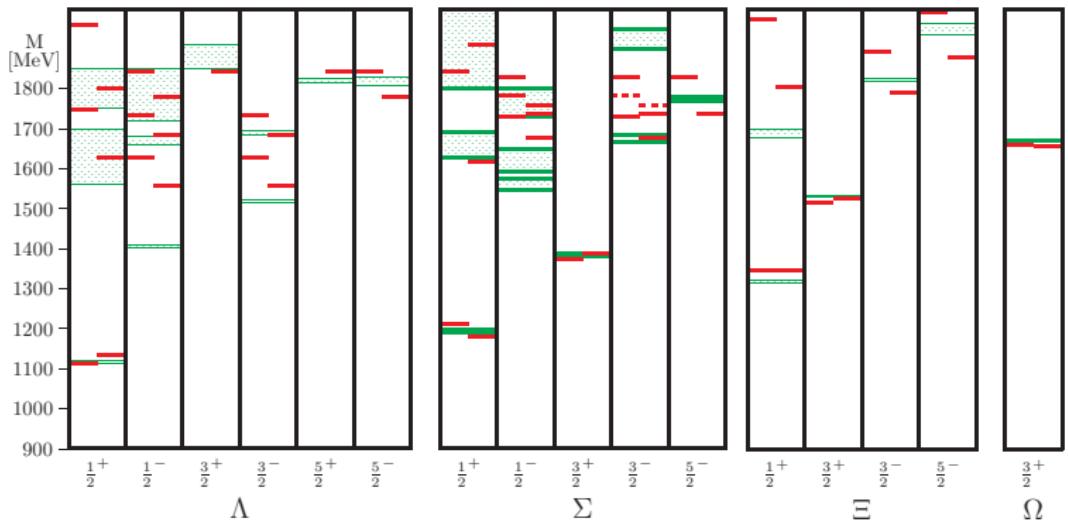
Singlet and Decuplet Decays (GBE-OGE)



Singlet and Decuplet Decays (GBE-II)



Hyperon Spectra Including 2-star Resonances



Left Red: One-Gluon Exchange, Right Red: Goldstone-Boson Exchange, Green: PDG

Summary

- Poincaré-invariant calculations for strong baryon decays
(In concordance with Bonn results)
- **Caution:** non-relativistic approximation *considerable!* effect
- **Systematics** leads to **multiplet classification**:
Inclusion of (non-established) baryons in RCQMs

RCQM consistent structure model for (bare) baryon states

Careful: CQMs do not directly yield resonance masses!

Outlook

- Variation of vertex-couplings
- Generalization of RCQM

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Poincaré Invariant Mesonic Decays

Decay Width

$$\Gamma_{i \rightarrow f} = \frac{|\mathbf{q}|}{4M^2} \frac{1}{2\Sigma+1} \frac{1}{2T+1} \sum_{M_\Sigma, M_{\Sigma'}} M_{T, M_{T'}, M_{T_m}} |F_{i \rightarrow f}|^2$$

↑ phase-space factor transition amplitude ↑

Transition Amplitude

$$F_{i \rightarrow f} = \langle M', \mathbf{V}', \Sigma', M_\Sigma', T', M_T' | \hat{D}_{rd}^m | M, \mathbf{V}, \Sigma, M_\Sigma, T, M_T \rangle$$

↑
mesonic decay operator

Poincaré Invariant Transition Amplitude

$$\langle V', M', J', \Sigma' | \hat{O} | V, M, J, \Sigma \rangle = \frac{2}{MM'} \sum_{\sigma_i \sigma'_i} \sum_{\mu_i \mu'_i} \int d^3 \vec{k}_2 d^3 \vec{k}_3 d^3 \vec{k}'_2 d^3 \vec{k}'_3$$

$$\sqrt{\frac{(\omega_1 + \omega_2 + \omega_3)^3}{2\omega_1 2\omega_2 2\omega_3}} \sqrt{\frac{(\omega'_1 + \omega'_2 + \omega'_3)^3}{2\omega'_1 2\omega'_2 2\omega'_3}}$$

$$\Psi_{M' J' \Sigma'}^* \left(\vec{k}'_i; \mu'_i \right) \prod_{\sigma'_i} D_{\sigma'_i \mu'_i}^{\star \frac{1}{2}} \left\{ R_W [k'_i; B(V')] \right\}$$

$$\langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3 | \hat{O}_{\text{rd}} | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle$$

$$\prod_{\sigma_i} D_{\sigma_i \mu_i}^{\frac{1}{2}} \left\{ R_W [k_i; B(V)] \right\} \Psi_{MJ\Sigma} \left(\vec{k}_i; \mu_i \right)$$

$$2MV_0\delta^3 \left(M\vec{V} - M'\vec{V}' - \vec{Q} \right)$$

Point-Form Spectator Model

$$\begin{aligned} & \langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3 | \hat{D}_{rd}^{\text{pv}, m} | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle \\ &= -3\mathcal{N} \frac{i g_{qqm}}{m_1 + m'_1} \frac{1}{\sqrt{2\pi}} \bar{u}(p'_1, \sigma'_1) \gamma_5 \gamma^\mu \mathcal{F}^m u(p_1, \sigma_1) q_\mu \\ & \quad \times 2p_{20} \delta^3(\mathbf{p}_2 - \mathbf{p}'_2) \delta_{\sigma_2 \sigma'_2} 2p_{30} \delta^3(\mathbf{p}_3 - \mathbf{p}'_3) \delta_{\sigma_3 \sigma'_3} \\ & \quad \text{pv} \cdots \text{pseudovector coupling} \end{aligned}$$

- Meson couples to quark 1, quarks 2 and 3 are **spectators**
- Spectator conditions together with overall momentum conservation determine **momentum transfer**
 $\tilde{q}^\mu = p_1^\mu - p'_1{}^\mu \neq q^\mu$ to meson-emitting quark
- PFSM provides effective many-body operator!

multiplet	$(LS)J^P$				
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octet	$(0\frac{1}{2})\frac{1}{2}^+$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	Ξ
octet	$(0\frac{1}{2})\frac{1}{2}^+$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	Ξ
singlet	$(1\frac{1}{2})\frac{1}{2}^-$	-	$\Lambda(1405)$	-	-
singlet	$(1\frac{1}{2})\frac{3}{2}^-$	-	$\Lambda(1520)$	-	-
octet	$(1\frac{1}{2})\frac{3}{2}^-$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$
octet	$(1\frac{1}{2})\frac{1}{2}^-$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	Ξ
decuplet	$(1\frac{1}{2})\frac{1}{2}^-$	$\Delta(1620)$	-	Σ	Ξ
octet	$(1\frac{3}{2})\frac{3}{2}^-$	$N(1700)$	Λ	Σ	Ξ
octet	$(1\frac{3}{2})\frac{5}{2}^-$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	Ξ
decuplet	$(1\frac{1}{2})\frac{3}{2}^-$	$\Delta(1700)$	-	Σ	Ξ
octet	$(1\frac{3}{2})\frac{1}{2}^-$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	Ξ