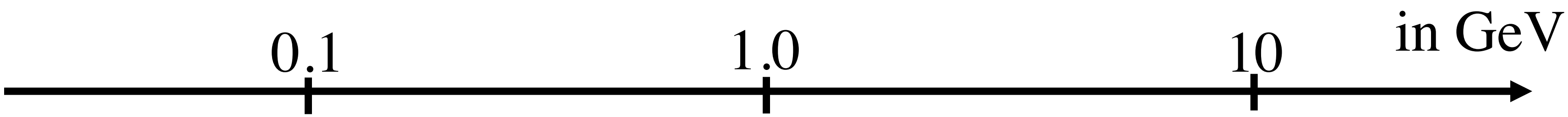
Charm hadron (baryon) spectroscopy

Atsushi Hosaka
RCNP, Osaka University

YITP workshop
Strangeness and charm in hadrons and dense matter
2017-05-15 — 2017-05-26

1. Heavy and Light flavors
2. Charmed baryons
3. Productions
4. Decays
5. Summary

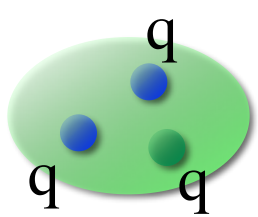
1. Light and heavy flavors



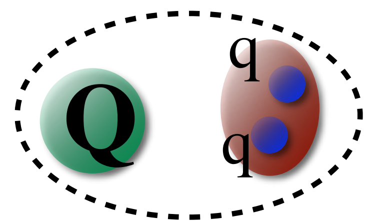
$m_u,\ m_d,\quad m_s \ll \Lambda_{QCD} \ll m_c,\quad m_b,\ \ldots$

m_Q

Light flavor
Chiral symmetry: SSB
Constituent quarks



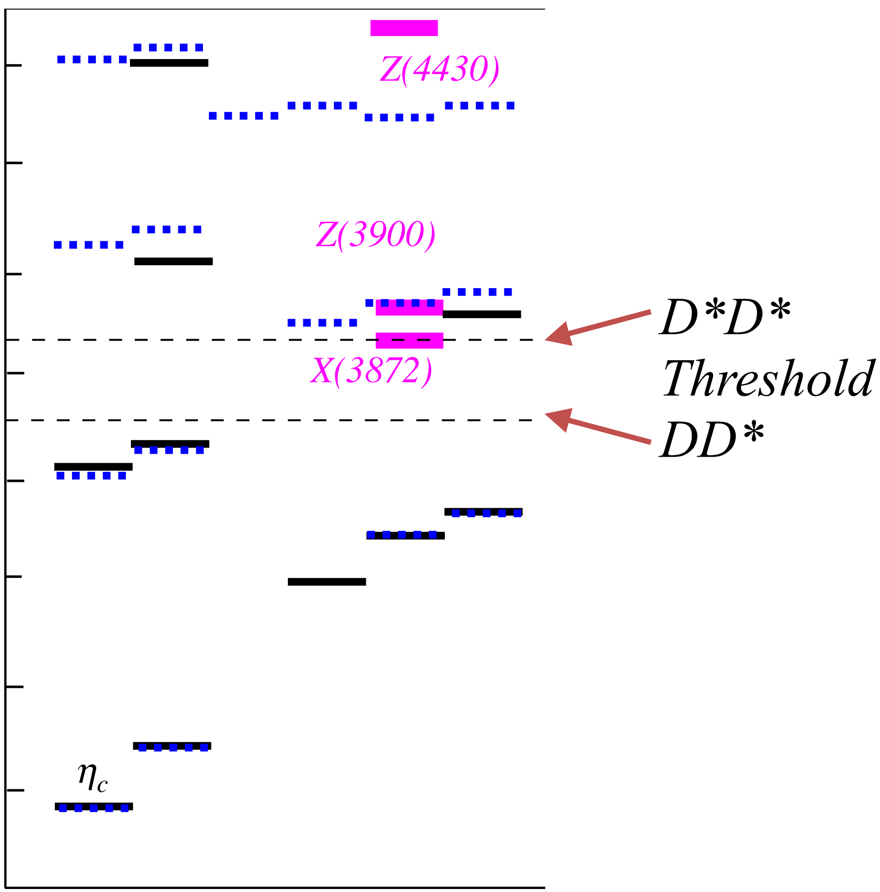
Heavy flavor
HQ spin multiplet
(Light) Brown muck



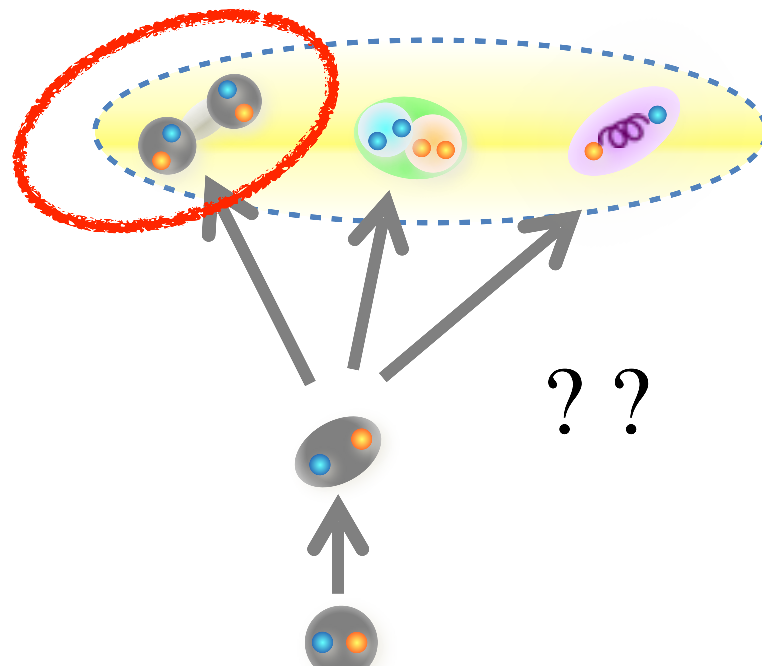
We expect to:
Study of dynamics of light (colored) d.o.f. by changing flavor

Exotic hadrons near thresholds

- Presence of light and heavy quarks, which rearrange into molecular, tetraquark, pentaquark, …
- Example: X(3872) is mostly a *DD* molecular like state*



Many unusual exotics appear near and above the thresholds



Difficulties in exotics are due to ignorance of heavy - (mostly) light complex systems

Charmed (bottom) baryon is one of simplest systems

Presently:
Not much is known (next slides)

These motivated us to study charmed baryons

Observed states

Ground states

- Λ_c^+ 2286 ****
- $\Lambda_c(2595)^+$ ***
- $\Lambda_c(2625)^+$ ***
- $\Lambda_c(2765)^+$ or $\Sigma_c(2765)$ *
- $\Lambda_c(2880)^+$ ***
- $\Lambda_c(2940)^+$ ***
- $\Sigma_c(2455)$
- $\Sigma_c(2520)$
- $\Sigma_c(2800)$ ***

Excited states

- Ξ_c^+ 2468 ***
- Ξ_c^0 2471 ***
- $\Xi_c'^+$ 2576 ***
- $\Xi_c'^0$ 2578 ***
- $\Xi_c(2645)$ ***
- $\Xi_c(2790)$ ***
- $\Xi_c(2815)$ ***
- $\Xi_c(2930)$ *
- $\Xi_c(2970)$ was $\Xi_c(2980)$ ***
- $\Xi_c(3055)$ ***
- $\Xi_c(3080)$ ***
- $\Xi_c(3123)$ *
- Ω_c^0 ***
- $\Omega_c(2770)^0$ ***

p
n

$N(1440)\ 1/2^+$
$N(1520)\ 3/2^-$
$N(1535)\ 1/2^-$
$N(1650)\ 1/2^-$
$N(1675)\ 5/2^-$
$N(1680)\ 5/2^+$
$N(1700)\ 3/2^-$
$N(1710)\ 1/2^+$
$N(1720)\ 3/2^+$
$N(1860)\ 5/2^+$
$N(1875)\ 3/2^-$
$N(1880)\ 1/2^+$
$N(1895)\ 1/2^-$
$N(1900)\ 3/2^+$
$N(1990)\ 7/2^+$
$N(2000)\ 5/2^+$
$N(2040)\ 3/2^+$
$N(2060)\ 5/2^-$
$N(2100)\ 1/2^+$
$N(2120)\ 3/2^-$
$N(2190)\ 7/2^-$
$N(2220)\ 9/2^+$
$N(2250)\ 9/2^-$
$N(2300)\ 1/2^+$
$N(2570)\ 5/2^-$
$N(2600)\ 11/2^-$
$N(2700)\ 13/2^+$

$\Delta(1232)\ 3/2^+$

$\Delta(1600)\ 3/2^+$
$\Delta(1620)\ 1/2^-$
$\Delta(1700)\ 3/2^-$
$\Delta(1750)\ 1/2^+$
$\Delta(1900)\ 1/2^-$
$\Delta(1905)\ 5/2^+$
$\Delta(1910)\ 1/2^+$
$\Delta(1920)\ 3/2^+$
$\Delta(1930)\ 5/2^-$
$\Delta(1940)\ 3/2^-$
$\Delta(1950)\ 7/2^+$
$\Delta(2000)\ 5/2^+$
$\Delta(2150)\ 1/2^-$
$\Delta(2200)\ 7/2^-$
$\Delta(2300)\ 9/2^+$
$\Delta(2350)\ 5/2^-$
$\Delta(2390)\ 7/2^+$
$\Delta(2400)\ 9/2^-$
$\Delta(2420)\ 11/2^+$
$\Delta(2750)\ 13/2^-$
$\Delta(2950)\ 15/2^+$

Λ

$\Lambda(1405)\ 1/2^-$
$\Lambda(1520)\ 3/2^-$
$\Lambda(1600)\ 1/2^+$
$\Lambda(1670)\ 1/2^-$
$\Lambda(1690)\ 3/2^-$
$\Lambda(1710)\ 1/2^+$
$\Lambda(1800)\ 1/2^-$
$\Lambda(1810)\ 1/2^+$
$\Lambda(1820)\ 5/2^+$
$\Lambda(1830)\ 5/2^-$
$\Lambda(1890)\ 3/2^+$
$\Lambda(2000)$
$\Lambda(2020)\ 7/2^+$
$\Lambda(2050)\ 3/2^-$
$\Lambda(2100)\ 7/2^-$
$\Lambda(2110)\ 5/2^+$
$\Lambda(2325)\ 3/2^-$
$\Lambda(2350)\ 9/2^+$
$\Lambda(2585)$ Bumps

Σ^+
Σ^0
Σ^-
$\Sigma(1385)\ 3/2^+$

$\Sigma(1480)$ Bumps
$\Sigma(1560)$ Bumps
$\Sigma(1580)\ 3/2^-$
$\Sigma(1620)\ 1/2^-$
$\Sigma(1620)$ Product
$\Sigma(1660)\ 1/2^+$
$\Sigma(1670)\ 3/2^-$
$\Sigma(1670)$ Bumps
$\Sigma(1690)$ Bumps
$\Sigma(1730)\ 3/2^+$
$\Sigma(1750)\ 1/2^-$
$\Sigma(1770)\ 1/2^+$
$\Sigma(1775)\ 5/2^-$
$\Sigma(1840)\ 3/2^+$
$\Sigma(1880)\ 1/2^+$
$\Sigma(1900)\ 1/2^-$
$\Sigma(1915)\ 5/2^+$
$\Sigma(1940)\ 3/2^+$
$\Sigma(1940)\ 3/2^-$
$\Sigma(2000)\ 1/2^-$
$\Sigma(2030)\ 7/2^+$
$\Sigma(2070)\ 5/2^+$
$\Sigma(2080)\ 3/2^+$
$\Sigma(2100)\ 7/2^-$
$\Sigma(2250)$
$\Sigma(2455)$ Bumps
$\Sigma(2620)$ Bumps
$\Sigma(3000)$ Bumps
$\Sigma(3170)$ Bumps

Ξ^0
Ξ^-
$\Xi(1530)\ 3/2^+$

$\Xi(1620)$
$\Xi(1690)$
$\Xi(1820)\ 3/2^-$
$\Xi(1950)$
$\Xi(2030)$
$\Xi(2120)$
$\Xi(2250)$
$\Xi(2370)$
$\Xi(2500)$

Ω^-

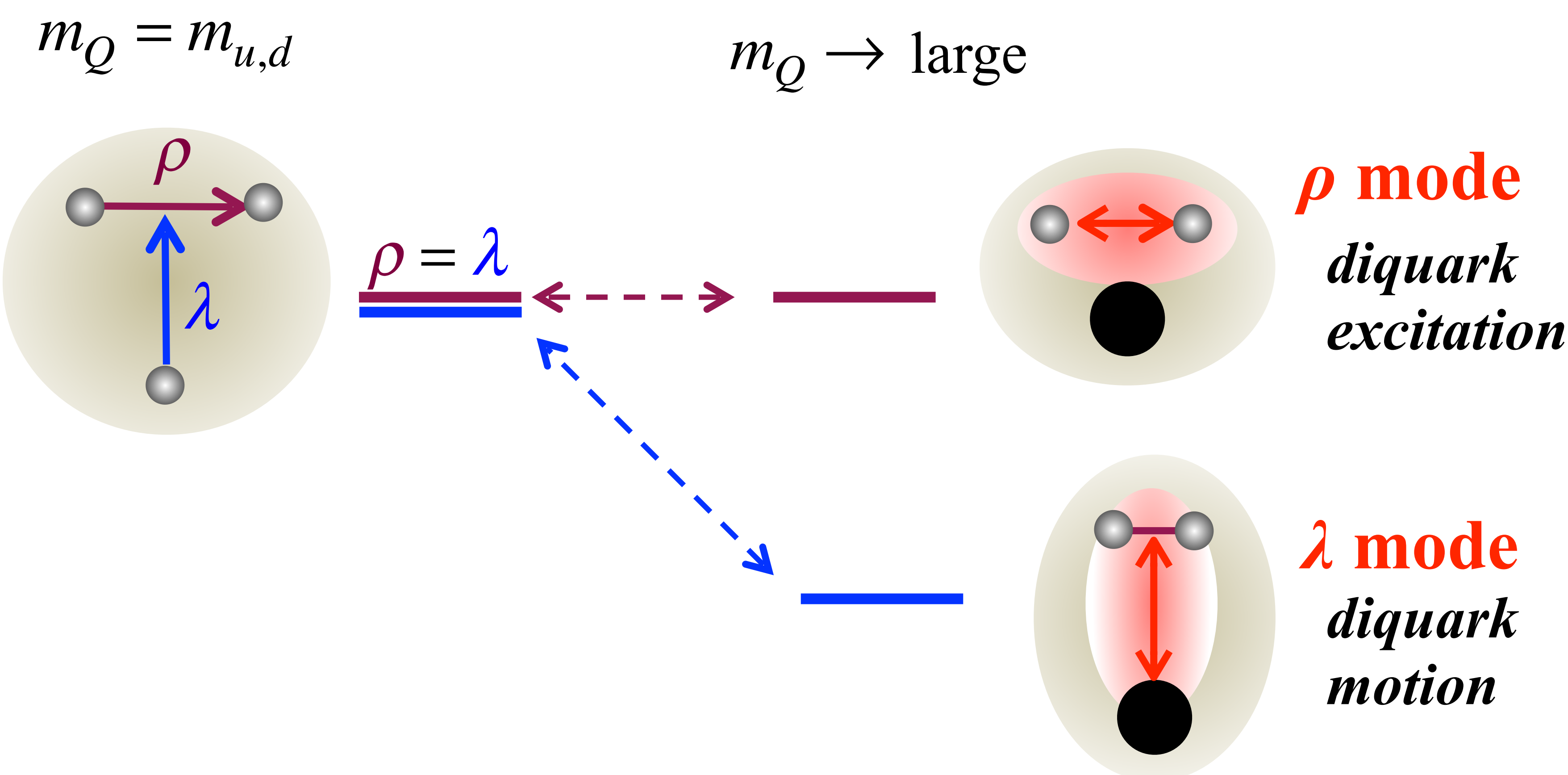
$\Omega(2250)^-$
$\Omega(2380)^-$
$\Omega(2470)^-$

Excited states

2. Charmed baryons

A heavy quark distinguishes the λ and ρ modes

Isotope-shift: Copley-Isgur-Karl, PRD20, 768 (1979)



These structures should be sensitive to reactions

Quark model 3-body calculation

Yoshida, Hiyama, Hosaka, Oka, Phys.Rev. D92 (2015) no.11, 114029

- Model Hamiltonian

$$H = \frac{p_1^2}{2m_q} + \frac{p_2^2}{2m_q} + \frac{p_3^2}{2M_Q} - \frac{P^2}{2M_{tot}}$$

$$+ V_{conf}(Linear\ or\ HO) + V_{spin-spin}(Color-magnetic) + \ldots$$

$$= H(\lambda) + H(\rho) + coupling$$

- Solved by the Gaussian expansion method

Structure of the basis wave functions

$J = 1/2,\ 3/2$: HQ doublet

$$\Lambda_c^*(1/2^-;\lambda\text{-mode}) = \underbrace{[[\psi_{0p}(\vec{\lambda})\psi_{0s}(\vec{\rho}),\, d^0]^1}_{\text{Brown muck}},\, \underbrace{\chi_c}_{\text{heavy quark}}]^J\ D^0 c$$

Brown muck

heavy quark

Quark model states

Example for Λ: *qq* is made isosinglet

$n = 0$

Ground states charmed baryons

$(n_\lambda, \ell_\lambda)$	(n_ρ, ℓ_ρ)	d^s	j^P	J^P	possible assignment
$(0,0)$	$(0,0)$	d^0	0^+	$1/2^+$	$\Lambda_c(2286)$
$(0,0)$	$(0,0)$	d^1	1^+	$(1/2, 3/2)^+$	$\Sigma_c(2455)$, $\Sigma_c^*(2520)$
				3	3

$n = 1$

Negative parity excited charmed baryons

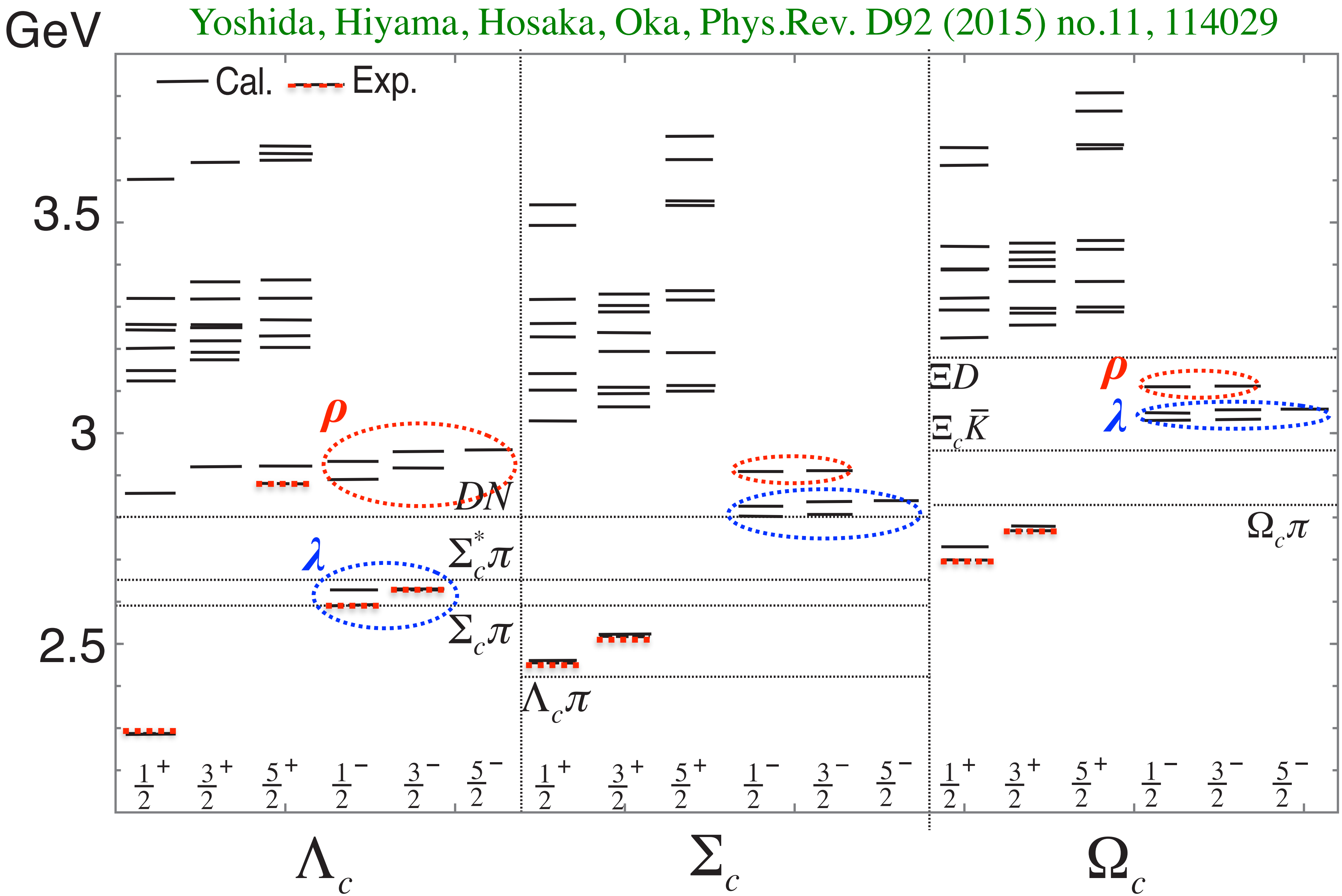
	$(n_\lambda, \ell_\lambda)$	(n_ρ, ℓ_ρ)	d^s	j^P	J^P	possible assignment
λ mode	$(0,1)$	$(0,0)$	d^0	1^-	$(1/2, 3/2)^-$	$\Lambda_c^*(2595)$, $\Lambda_c^*(2625)$
ρ mode	$(0,0)$	$(0,1)$	d^1	0^-	$1/2^-$	
				1^-	$(1/2, 3/2)^-$	
				2^-	$(3/2, 5/2)^-$	$\Lambda_c^*(2880)(?)$

7 = 2×λ + 5×ρ 3

This counting reversed for Σ and Ωc

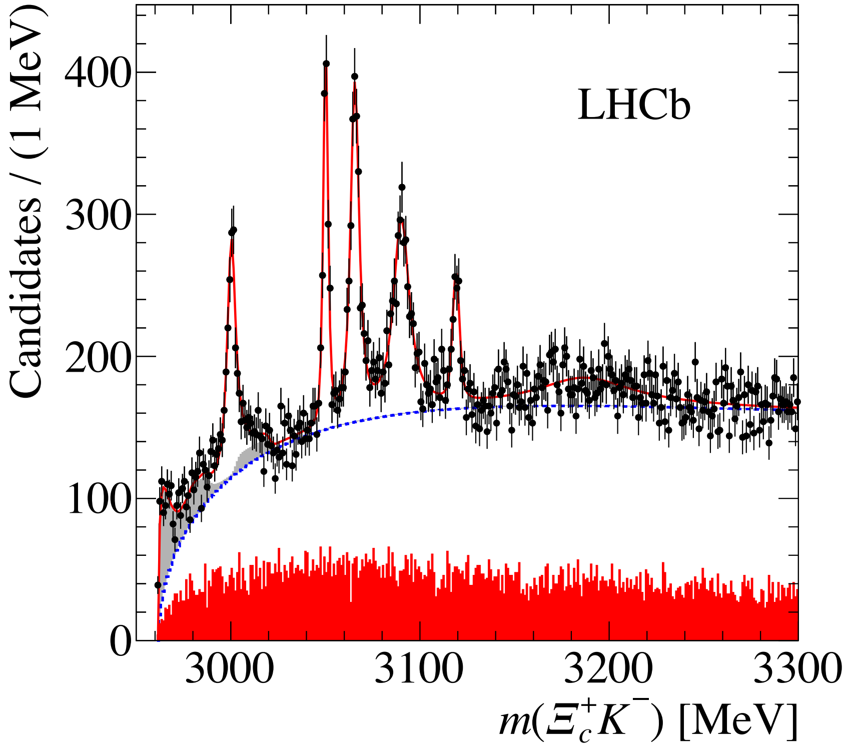
Masses

Yoshida, Hiyama, Hosaka, Oka, Phys.Rev. D92 (2015) no.11, 114029



Ωc from LHCb

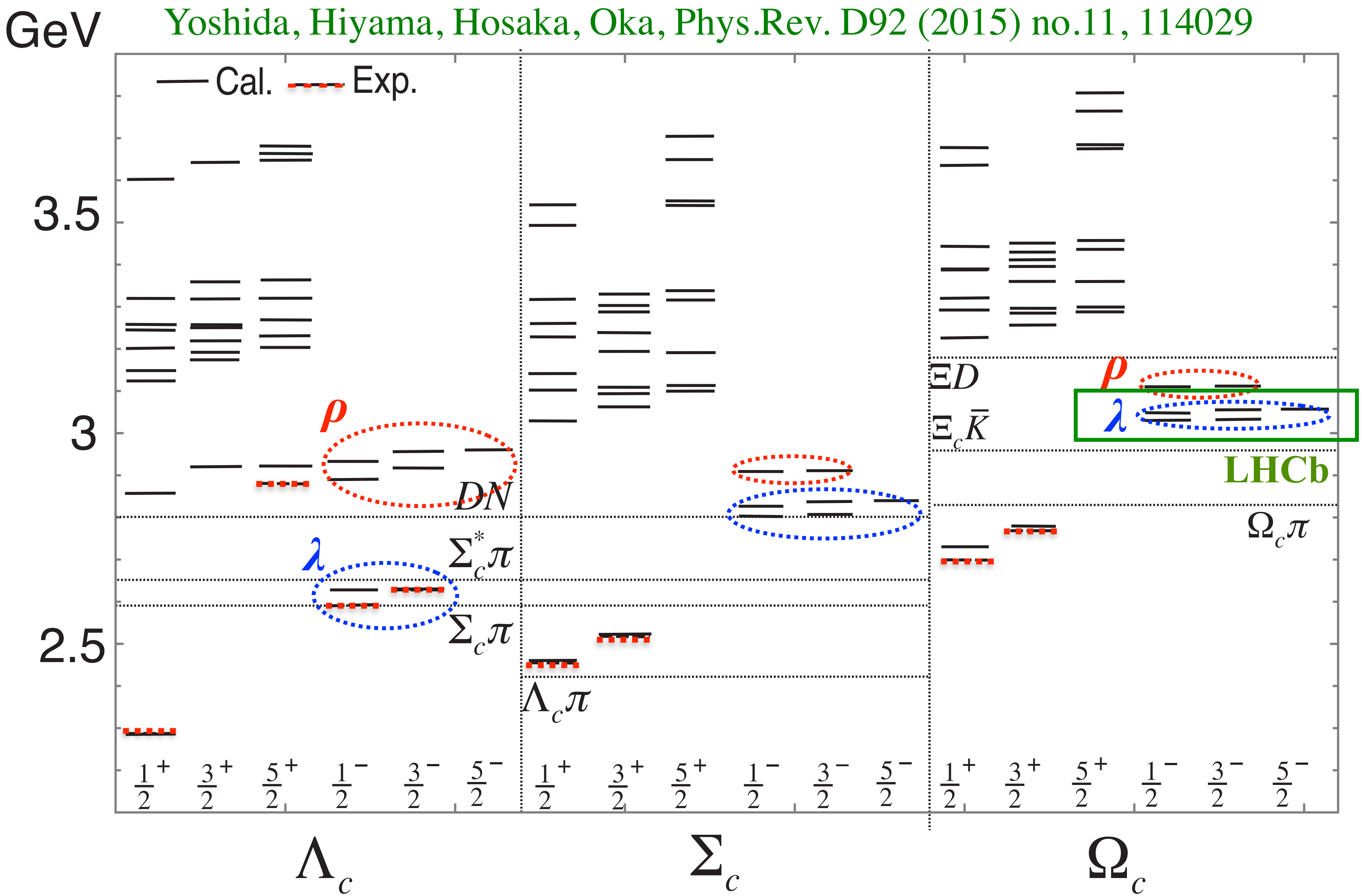
Phys.Rev.Lett. 118 (2017) no.18, 182001, arXiv:1703.04639



Five narrow peaks may correspond to ***five*** $\boldsymbol{\lambda}$ modes?

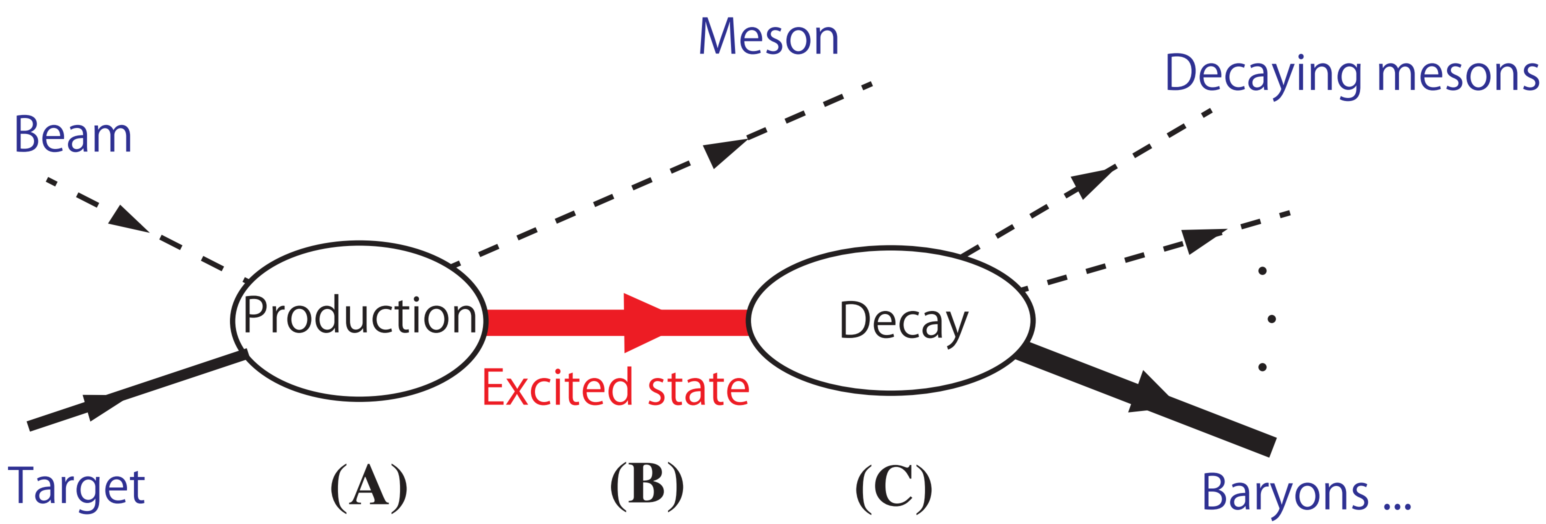
Masses

Yoshida, Hiyama, Hosaka, Oka, Phys.Rev. D92 (2015) no.11, 114029



How to study?

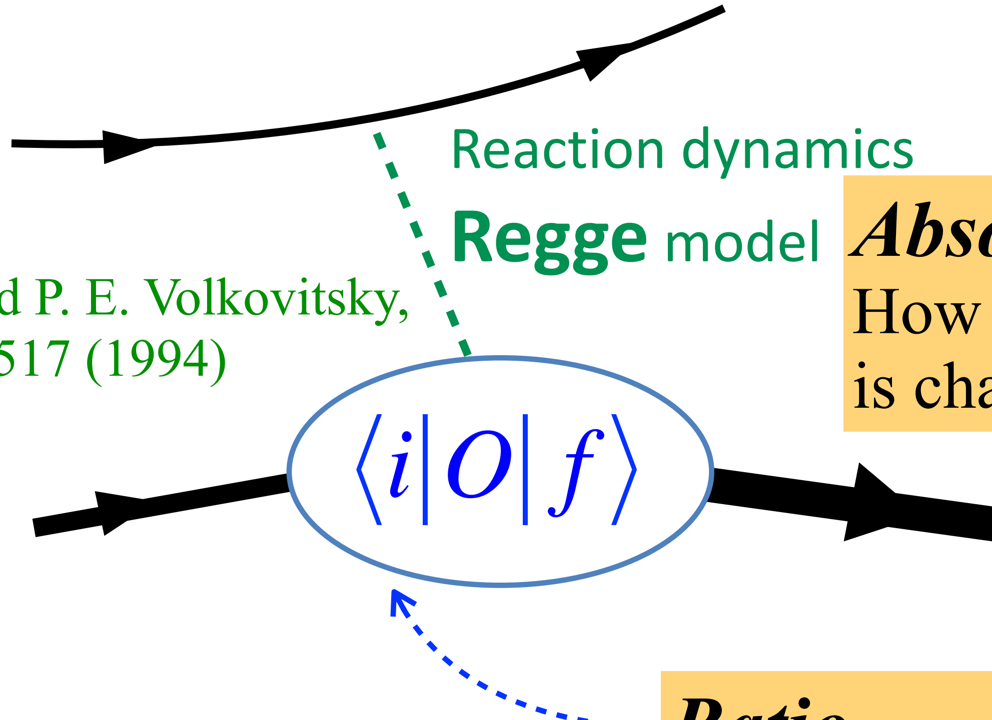
(A) Production
(B) Formation of resonances
(C) Decay of resonances



Reaction rates reflect the structure of excited states

3. Productions

$$\pi + N \rightarrow D^* + \Lambda_c$$



Reaction dynamics

Regge model

A. B. Kaidalov and P. E. Volkovitsky,
B. Z. Phys. C 63, 517 (1994)

Absolute values
How much
is charm produced?

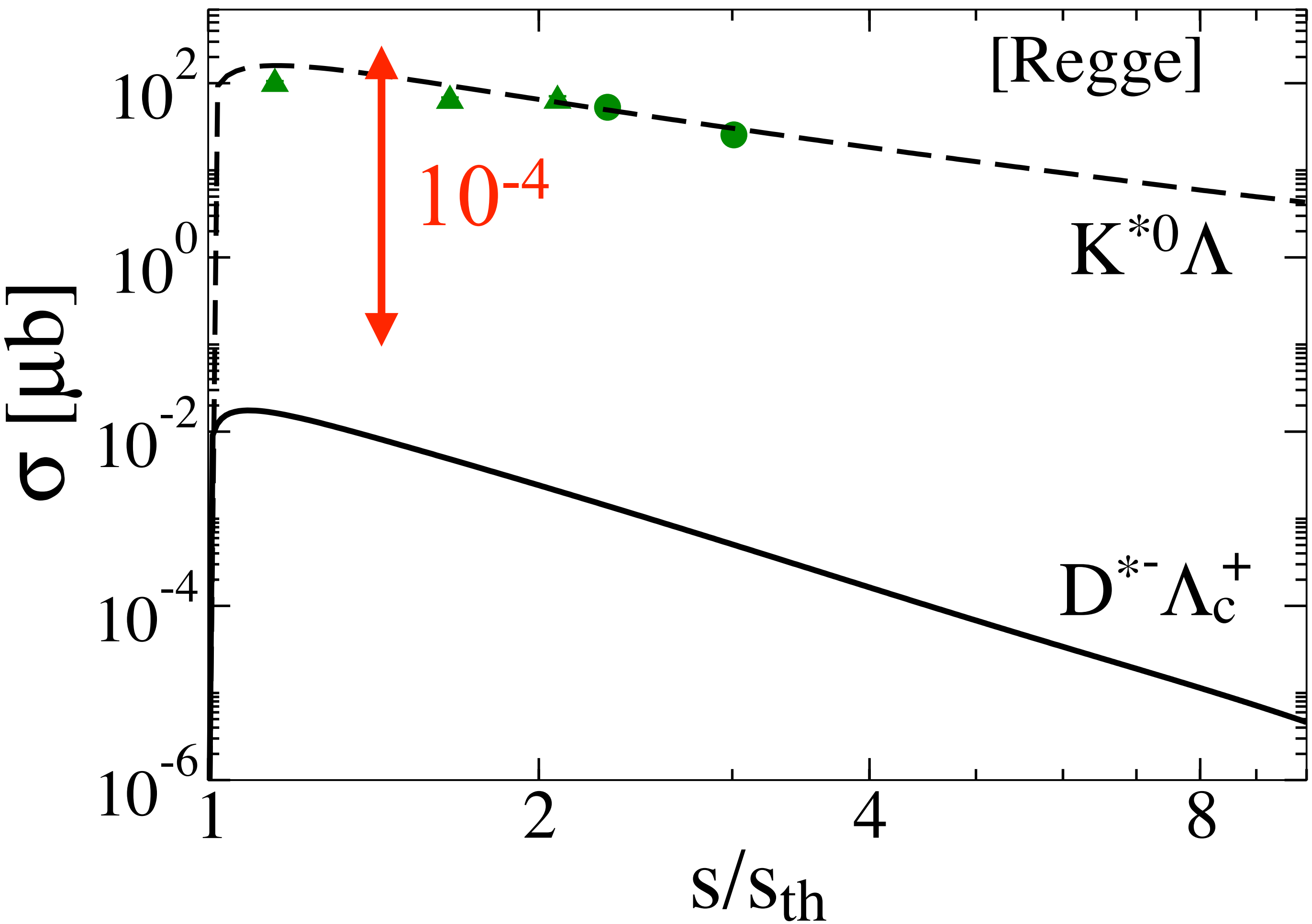
Ratio
How are they related to
internal structure?

Kim, Kim, Hosaka, Noumi, …
PTEP 2014 (2014) 10, 103D01,
PRD92 (2015) 9, 094021

Absolute values: Regge model

Kim, AH, Kim, Phys.Rev. D92 (2015) no.9, 094021

$\pi^- p \to (K^{*0}\Lambda \ \& \ D^{*-}\Lambda_c^+)$

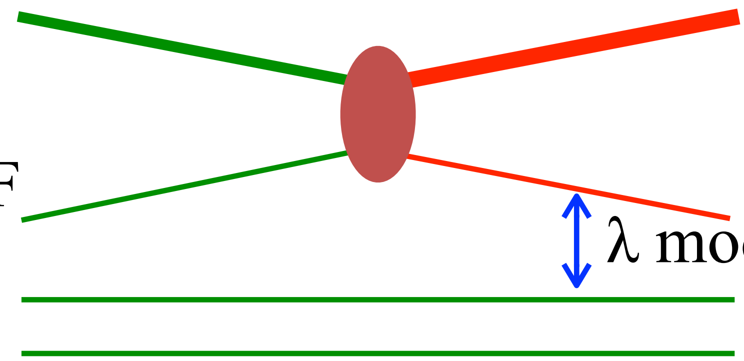


Strangeness
Fit the data

↓

Charm
Make prediction

Ratio: One-body process



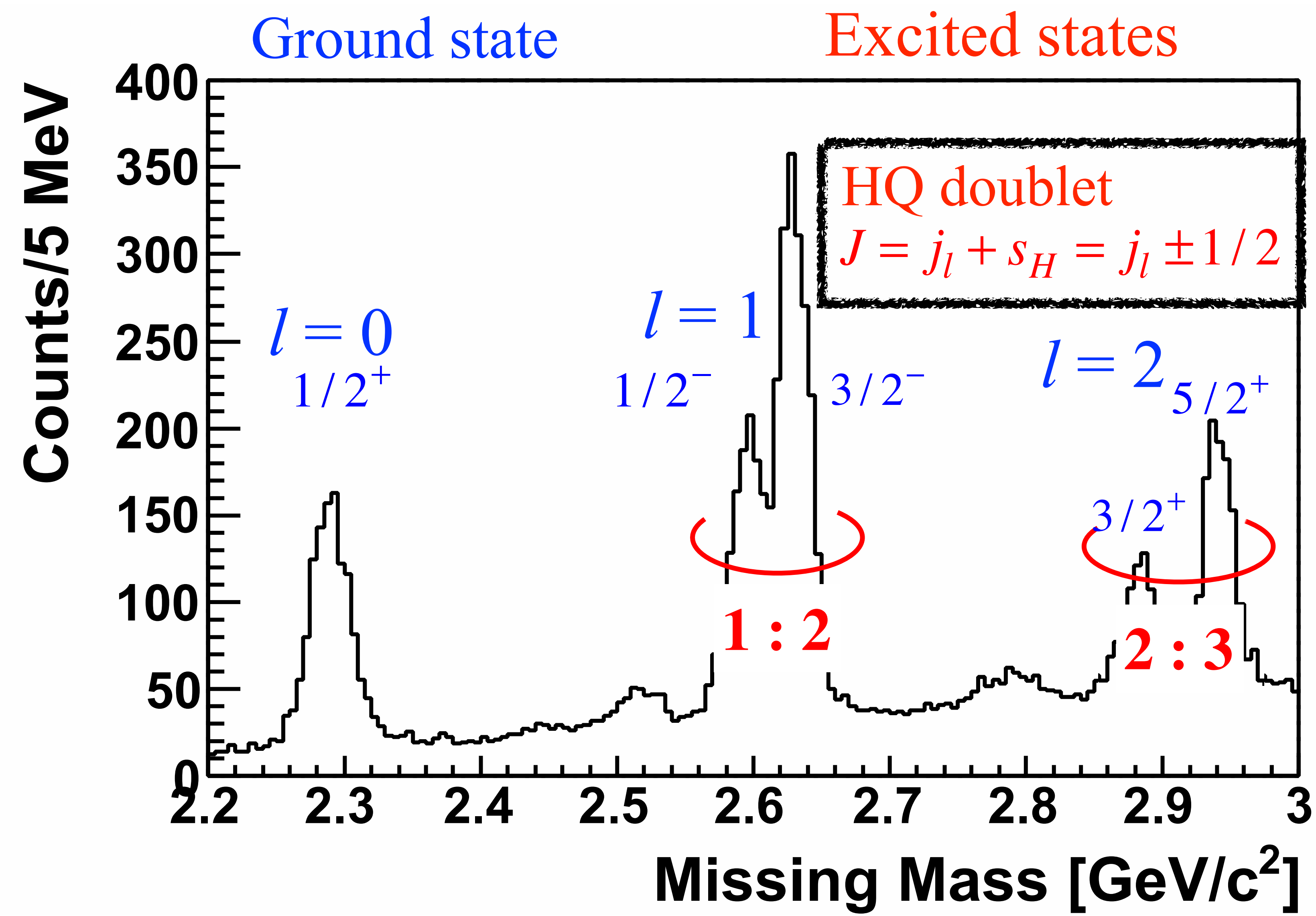
$$\langle B_c(\text{S-wave})|\vec{e}_\perp \cdot \vec{\sigma} e^{i\vec{q}_{eff}\cdot\vec{x}}|N(\text{S-wave})\rangle_{radial} \sim 1 \times \exp\left(-\frac{q_{eff}^2}{4A^2}\right)$$

$$\langle B_c(P\text{-wave})|\vec{e}_\perp \cdot \vec{\sigma} e^{i\vec{q}_{eff}\cdot\vec{x}}|N(\text{S-wave})\rangle_{radial} \sim \left(\frac{q_{eff}}{A}\right)^1 \times \exp\left(-\frac{q_{eff}^2}{4A^2}\right)$$

$$\langle B_c(D\text{-wave})|\vec{e}_\perp \cdot \vec{\sigma} e^{i\vec{q}_{eff}\cdot\vec{x}}|N(\text{S-wave})\rangle_{radial} \sim \left(\frac{q_{eff}}{A}\right)^2 \times \exp\left(-\frac{q_{eff}^2}{4A^2}\right)$$

Transitions to excited states are not suppressed

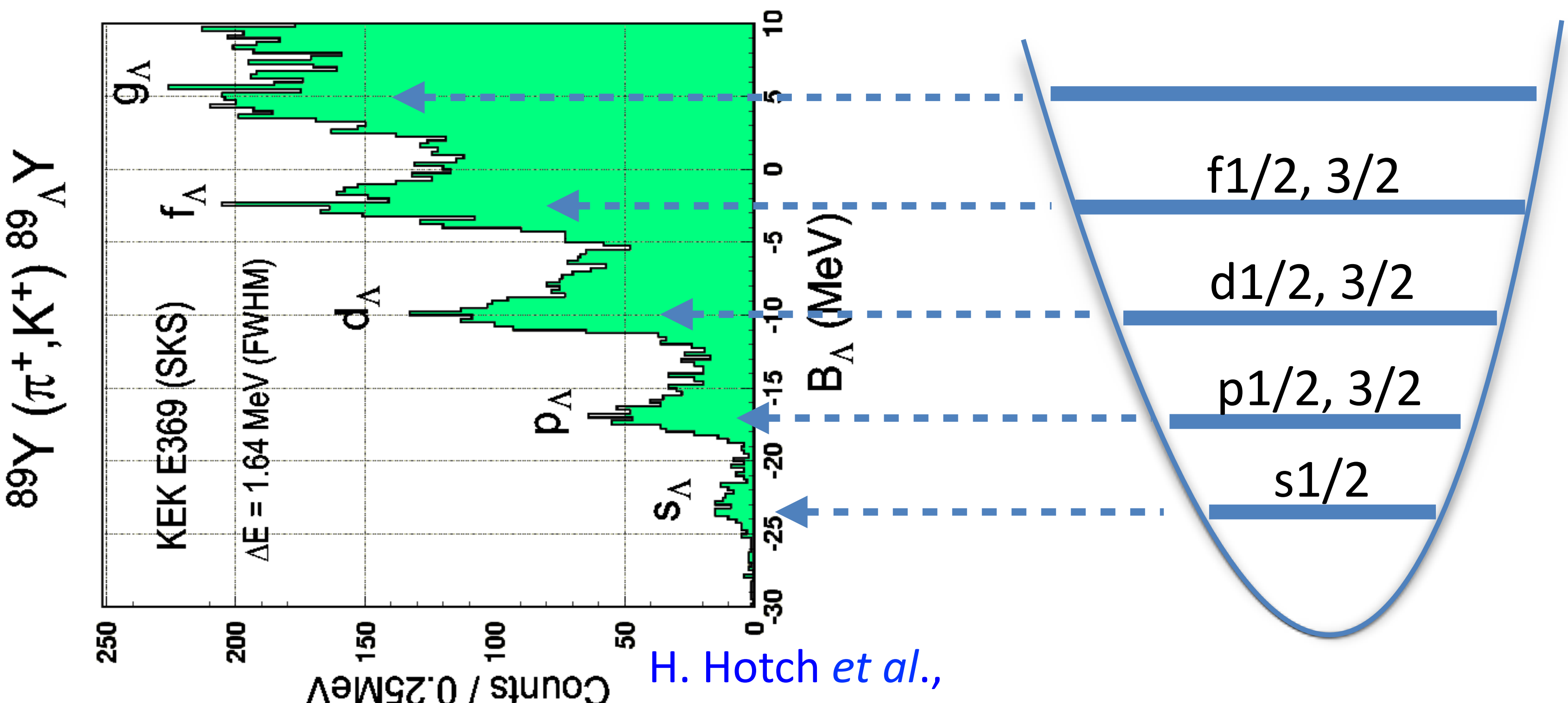
Spectrum simulation



Similarity with hyper nuclei

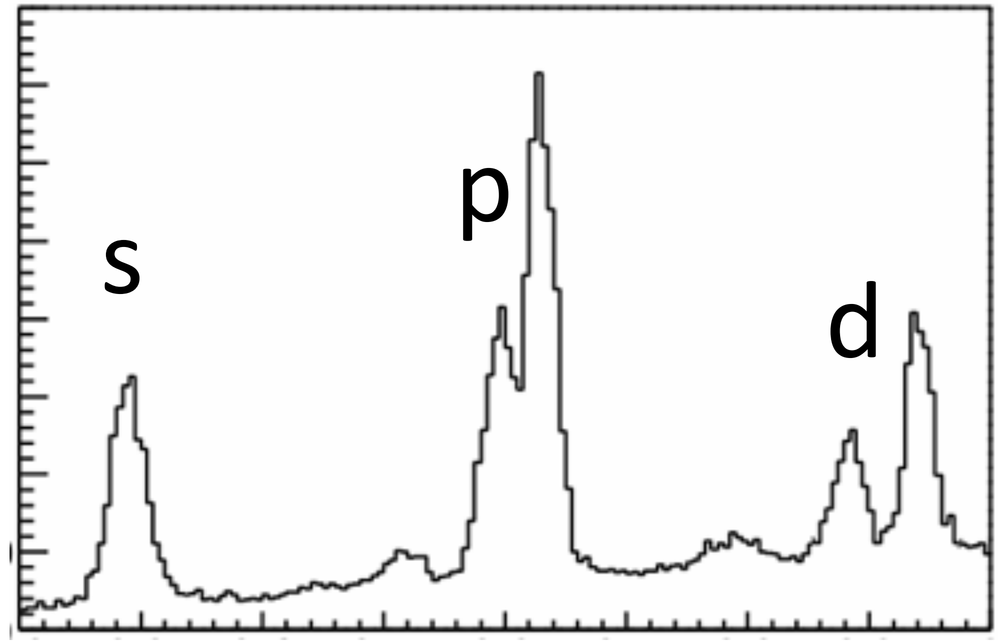
Establishing single particle orbits: ^{89}Y

$^{89}Y\ (\pi^+, K^+)\ ^{89}{}_{\Lambda}Y$

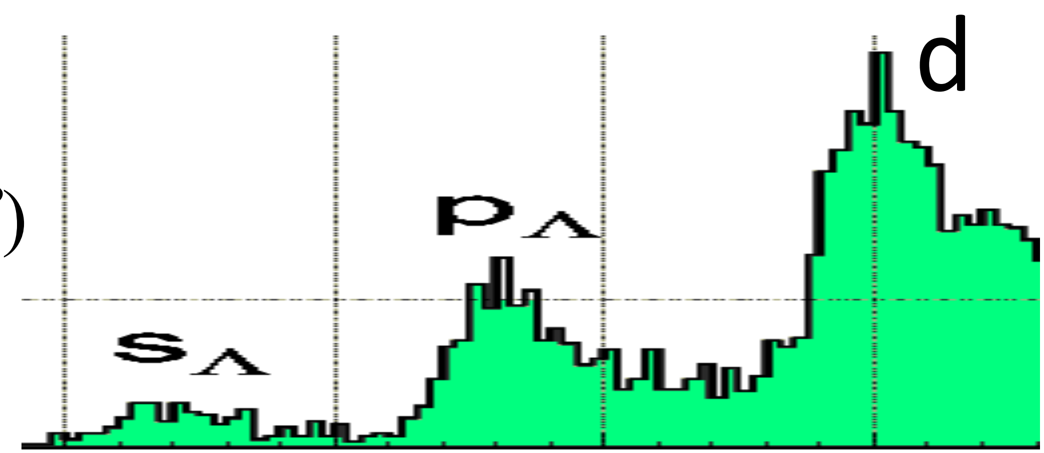


H. Hotch *et al.*,
Phys. Rev. C64, 044302(2001)

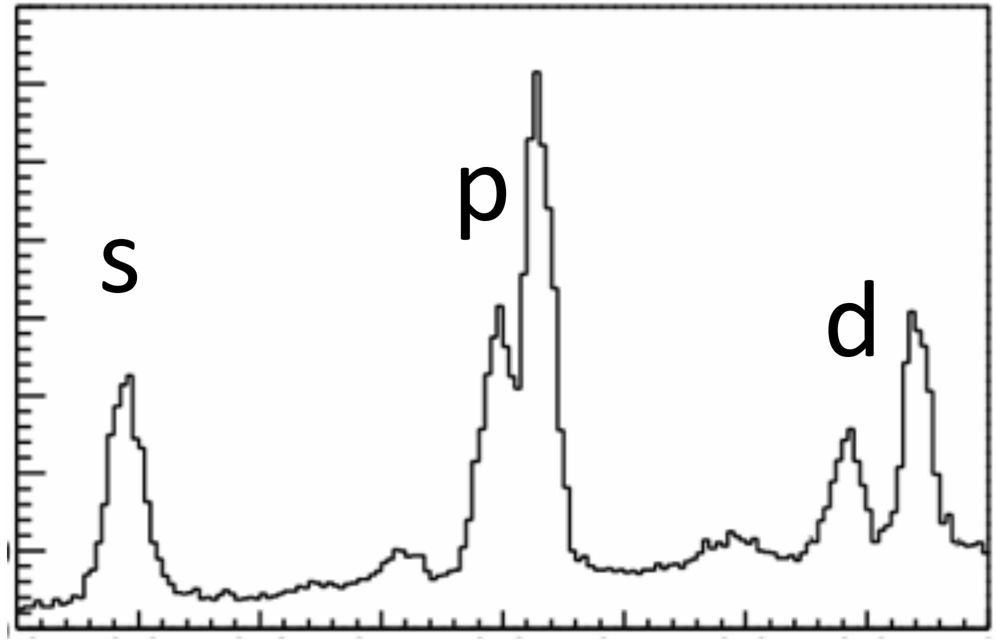
$\pi + p$
$\rightarrow D^* + B_c^*(J^P)$



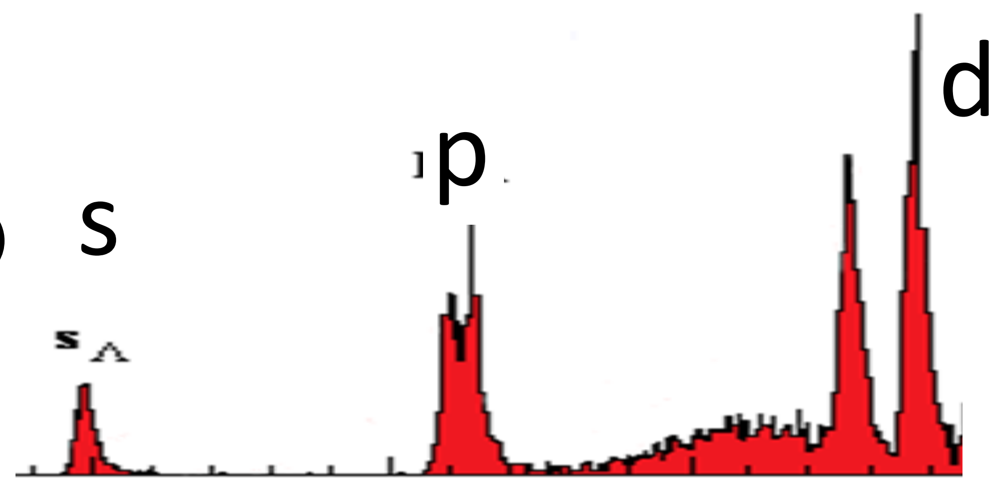
$\pi^+ + {}^{89}\mathrm{Y}$
$\rightarrow \mathrm{K}^+ + {}^{89}{}_{\Lambda}\mathrm{Y}(J^P)$



$\pi + p$
$\rightarrow D^* + B_c{}^*(J^P)$

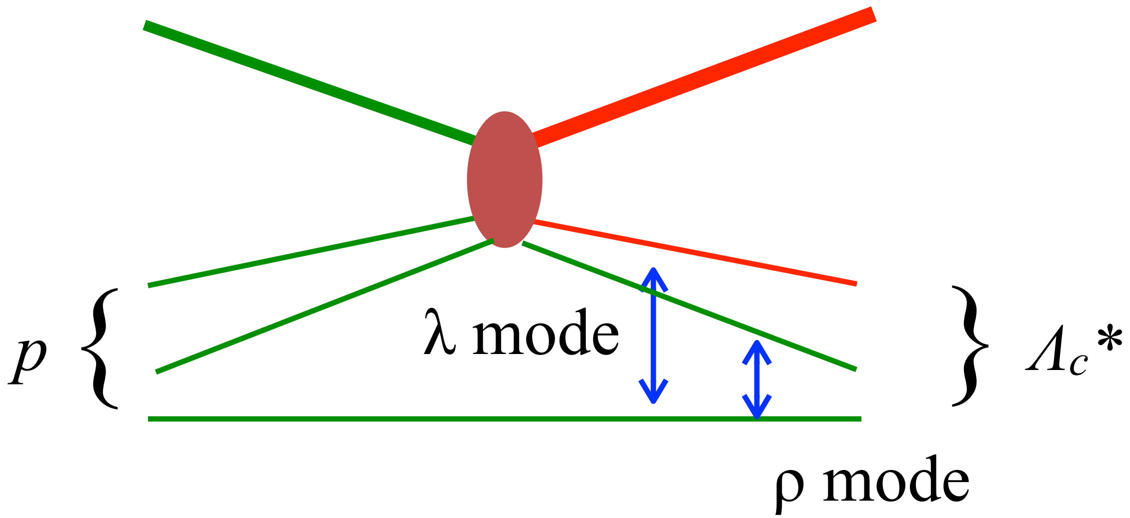


$\pi^+ + {}^{89}\mathrm{Y}$
$\rightarrow \mathrm{K}^+ + {}^{89}{}_{\Lambda}\mathrm{Y}(J^P)$



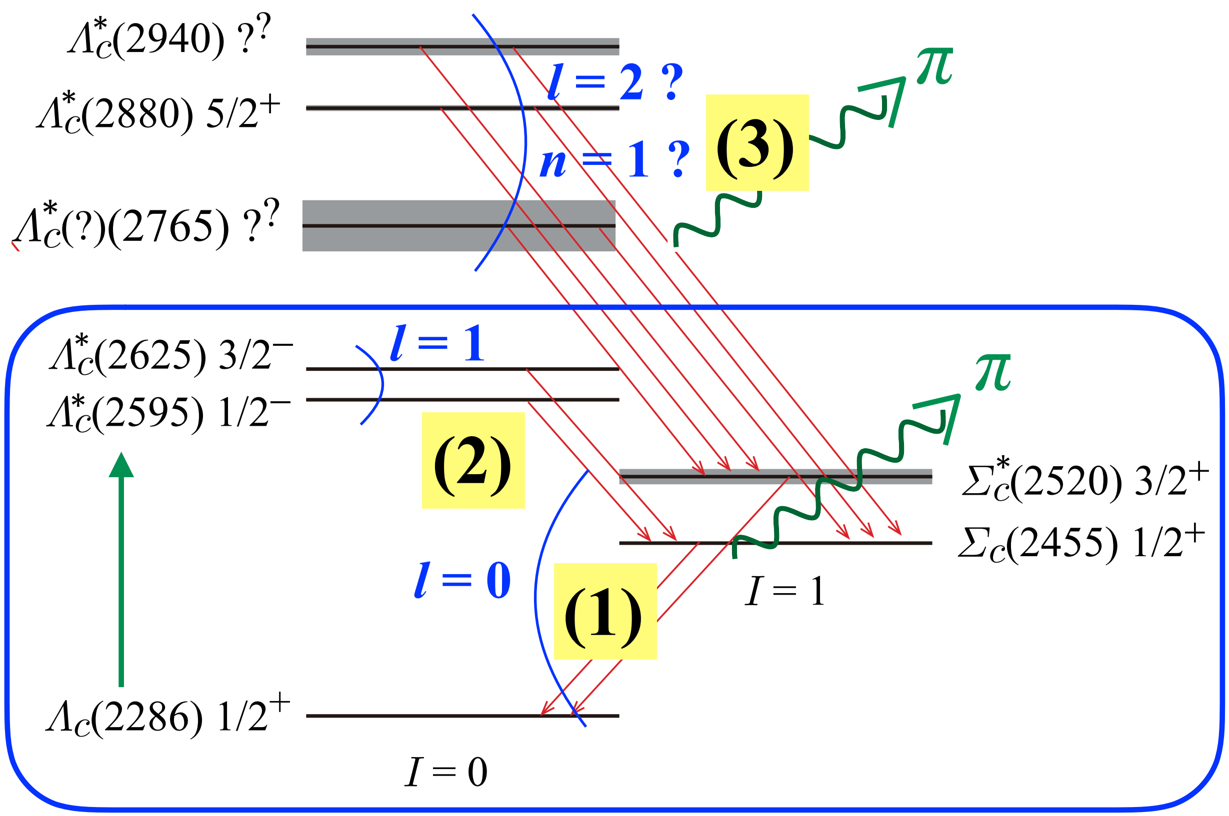
Two body process to be done

S.I. Shim and AH



4. Decays —Pion emission—

Nagahiro et al, Phys.Rev. D95 (2017) no.1, 014023 arXiv:1609.01085
Arifi, Nagahiro, AH, arXiv:1704.00464



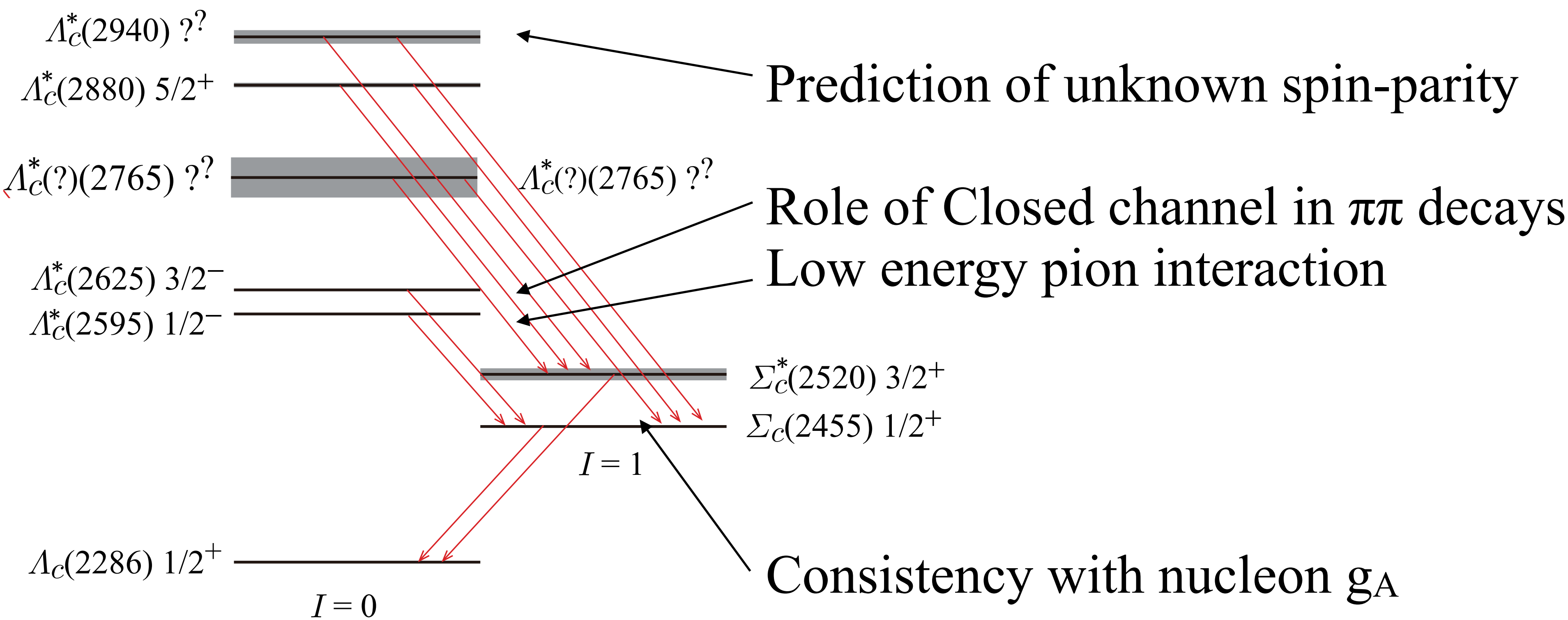
(1) $\Sigma \xrightarrow{\pi} \Lambda$
- 0hω ⟶ 0hω
- One π

(2) $\Lambda^* \xrightarrow{\pi} \Sigma \xrightarrow{\pi} \Lambda$
- 1hω ⟶ 0hω
- Two π

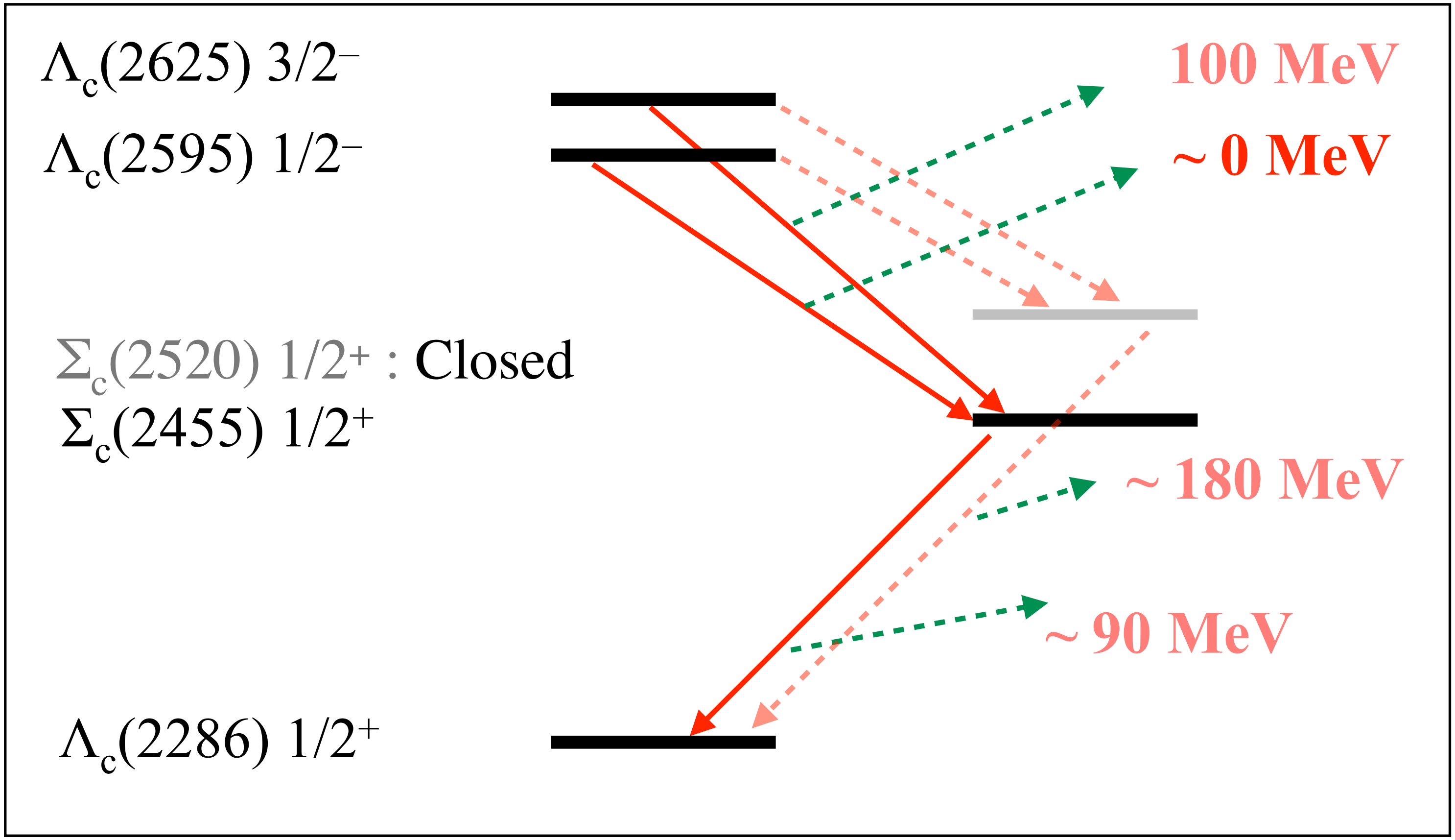
(3) $\Lambda^* \xrightarrow{\pi} \Sigma \xrightarrow{\pi} \Lambda$
- 2hω ⟶ 0hω
- Two π, D, …

4. Decays —Pion emission—

Nagahiro et al, Phys.Rev. D95 (2017) no.1, 014023 arXiv:1609.01085
Arifi, Nagahiro, AH, arXiv:1704.00464



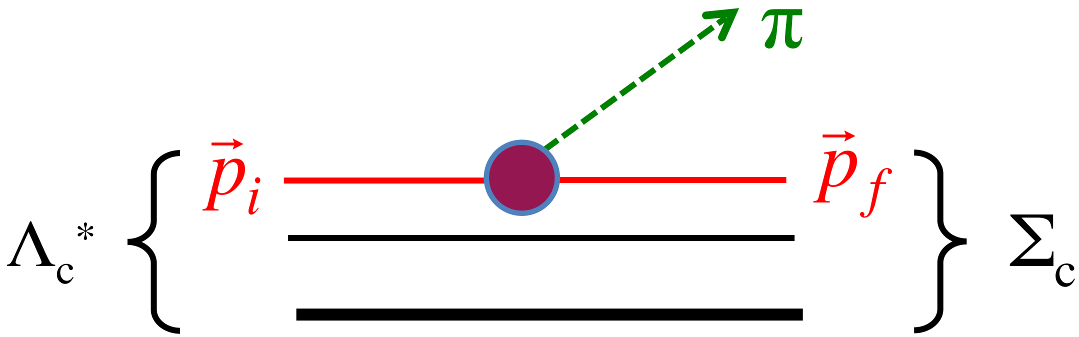
Low lying decays with small p_π (MeV)



To compare with $\Delta \to \pi N$ at $p_\pi \sim 230$ MeV

Low energy pion dynamics can be better tested

Low energy πqq interaction



Non-relativistic $\vec{\sigma}\cdot\vec{p}_i,\ \vec{\sigma}\cdot\vec{p}_f$

Relativistic $\bar{q}\gamma_5 q\phi_\pi,\ \bar{q}\gamma^\mu\gamma_5 q\,\partial_\mu\phi_\pi$

PS *PV: preferable*

$$\mathcal{L}_{\pi qq}(x) = \frac{g_A^q}{2f_\pi}\bar{q}(x)\gamma_\mu\gamma_5\vec{\tau}q(x)\cdot\partial^\mu\vec{\pi}(x)$$

$g^q{}_A \sim 1$: Quark axial coupling

$\Lambda_c(2595)\ 1/2^-$

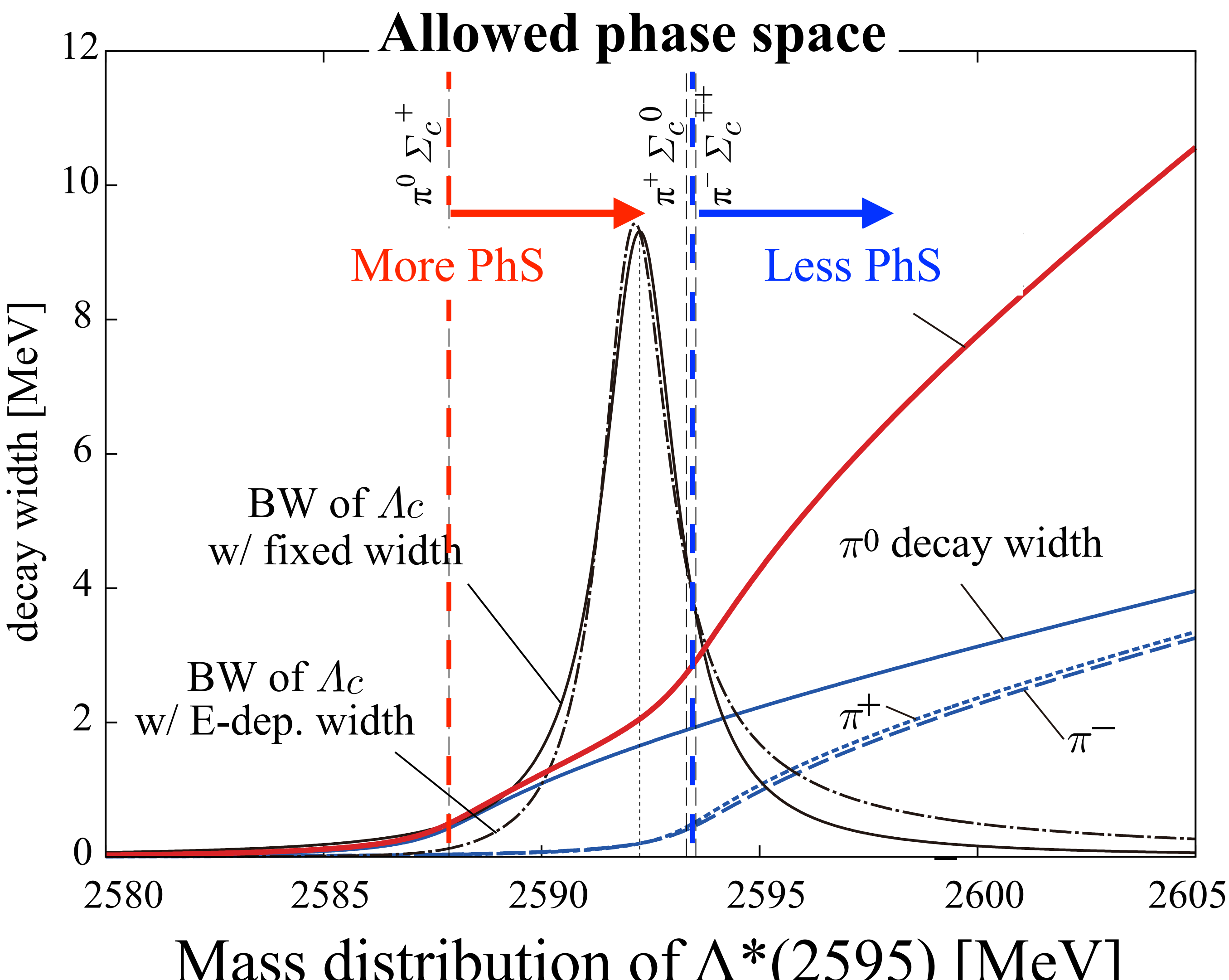
Nagahiro et al, Phys.Rev. D95 (2017) no.1, 014023 arXiv:1609.01085

	decay channel	full	$[\Sigma_c\pi]^+$	$\Sigma_c^{++}\pi^-$	$\Sigma_c^0\pi^+$	$\Sigma_c^+\pi^0$
Experiments	(MeV) [5]	2.6 ± 0.6	-	0.624 (24%)	0.624 (24%)	-
Momentum	q (MeV/c)	-	-	†	†	29
$(n_\lambda, \ell_\lambda),\ (n_\rho, \ell_\rho)$	$J_\Lambda(j)^P$					
$(0,1),\ (0,0)$	$1/2(1)^-$		1.5–2.9	0.13–0.25	0.15–0.28	1.2–2.4
$(0,0),\ (0,1)$	$1/2(0)^-$		0	0	isospin violated	
	$1/2(1)^-$		6.5–11.9	0.57–1.04	0.63–1.15	5.3–9.7

- 80 % of the decay of is explained with strong isospin breaking
- λ-mode results consistent, ρ-mode results overestimate

Isospin breaking between $\pi^0\Sigma_c^+$ and $\pi^+\Sigma_c^0$, $\pi^-\Sigma_c^{++}$

Mass distribution of Λ*(2595) and different phase space



$\Lambda_c(2625)\ 3/2^-$

Possible decay to $\Sigma c(2455)\pi$ is via D-wave

decay channel	full	$\Sigma_c^{++}\pi^-$
Experimental value Γ (MeV) [5]	< 0.97	$< 0.05 (< 5\%)$
momentum of final particle q (MeV/c)	-	101

this work	$(n_\lambda, \ell_\lambda), (n_\rho, \ell_\rho)$	$J_\Lambda(j)^P$	
Γ	$(0,1), (0,0)$	$1/2(1)^-$	5.4–10.7
(MeV)		$3/2(1)^-$	0.024–0.039
	$(0,0), (0,1)$	$1/2(0)^-$	0

D-wave decay

- Only a small part of the decay width is from the two-body
- The remaining is considered by three-body decay

Σc(2455), Σc(2520)

$B_i J^P$ (MeV)	$\Gamma^{\rm full}_{\rm exp}(\Gamma_i)$ (MeV)	q (MeV)	$\Gamma_{\rm th}(\Sigma_c(J^+)^{++} \to \Lambda_c^{gs}(1/2^+; 2286)^+\pi^+)$ (MeV)
$\Sigma_c(2455)\ 1/2^+$ (2453.98) ($\omega_\pi = 0$ limit)	2.26 (2.26) (2.26)	89	4.27–4.33
$\Sigma_c(2520)\ 3/2^+$ (2517.9) ($\omega_\pi = 0$ limit)	14.9 (14.9)	176	30.0–31.2

Factor 2 difference, which is due to …

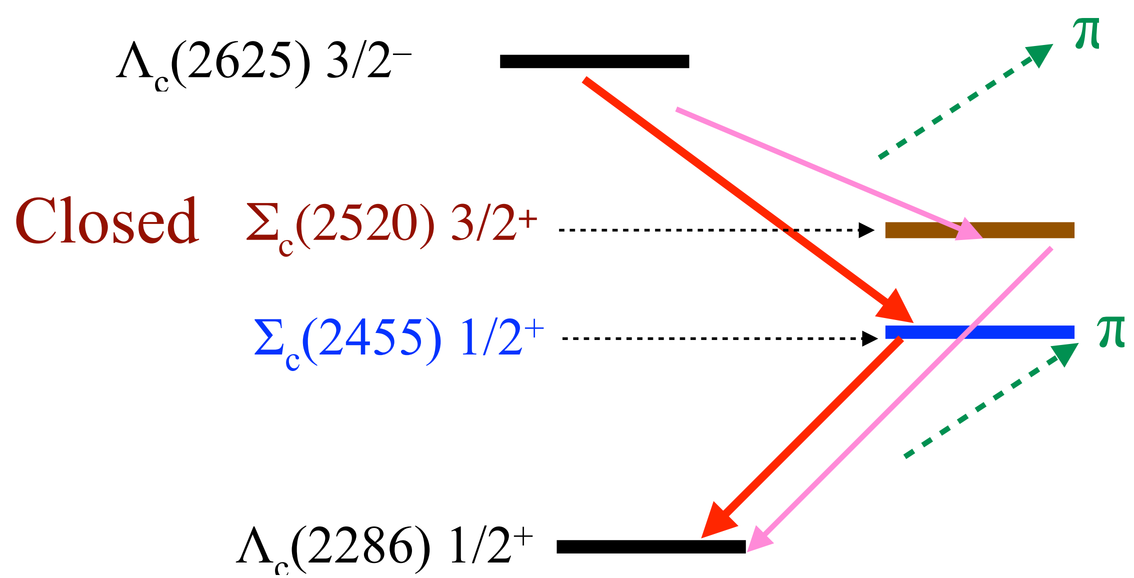
$$g_A{}^q = 1 \quad \to \quad g_A{}^N = 5/3 \ > \ 1.25_{\rm exp}$$

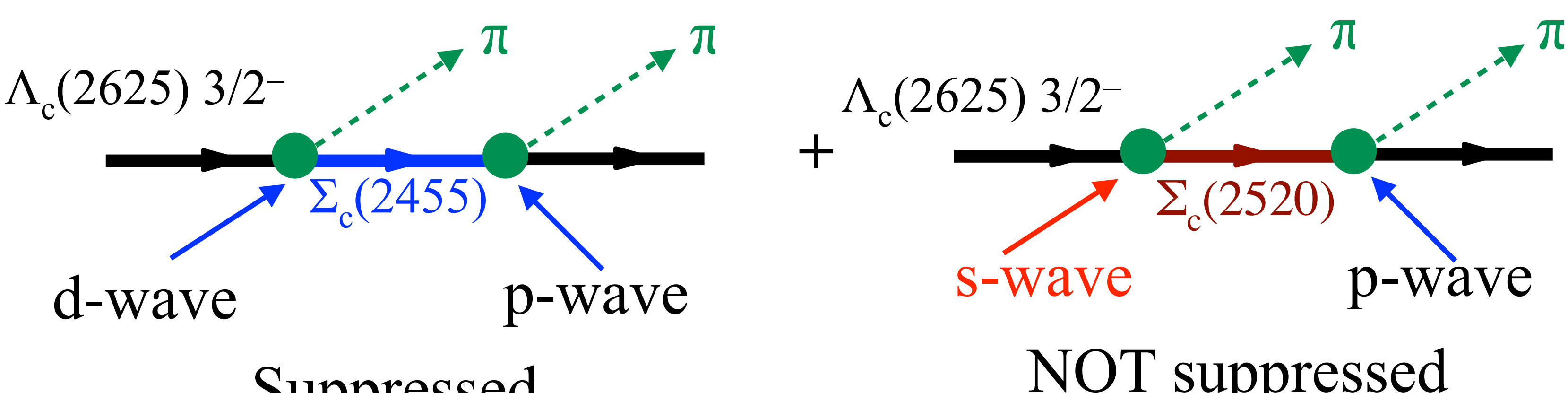
$\Lambda_c(2625)\ 3/2^-$

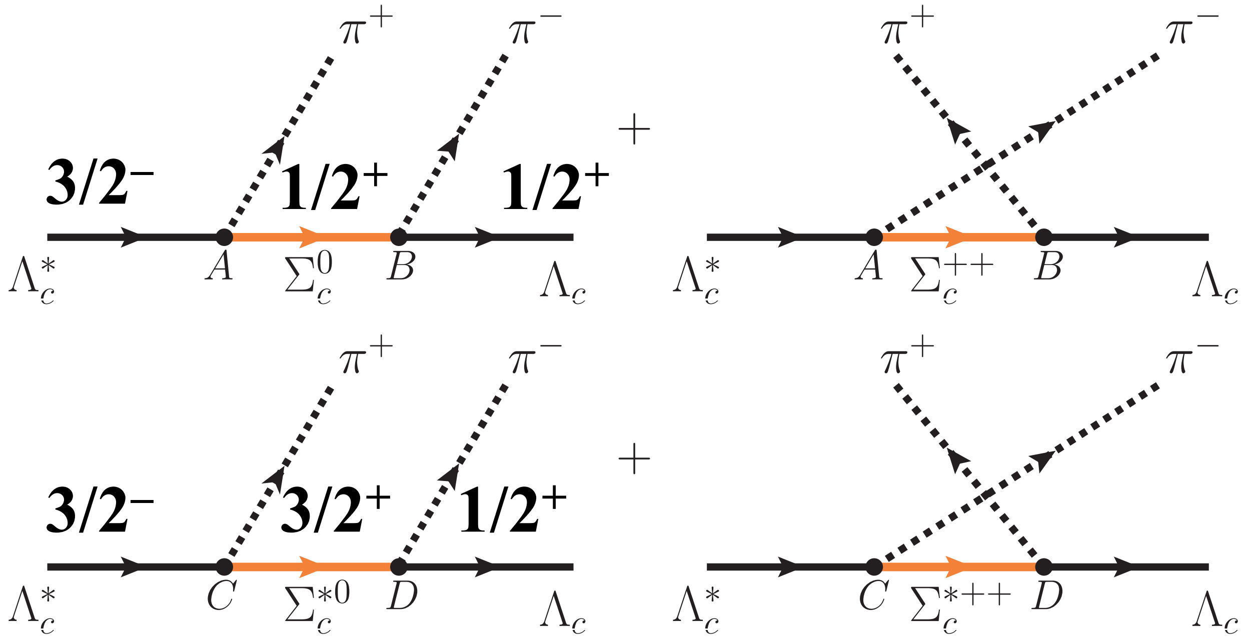
Three-body decay

Role of the closed channel in $\Lambda_c(2625)\ 3/2^- \to \pi\pi\Lambda_c(2286)\ 1/2^+$

Sequential decays







$$\mathcal{L}_A = f_a \vec{\psi}^{\dagger}_{\Sigma_c} \left(\vec{\sigma} \cdot \vec{\nabla} \vec{S} \cdot \vec{\nabla} - \frac{1}{3} \vec{\sigma} \cdot \vec{S} \vec{\nabla}^2 \right) \psi_{\Lambda_c^*} \cdot \vec{\pi} + h.c,$$

$$\mathcal{L}_B = f_b \psi^{\dagger}_{\Lambda_c} \left(\vec{\sigma} \cdot \vec{\nabla} \right) \vec{\psi}_{\Sigma_c} \cdot \vec{\pi} + h.c,$$

$$\mathcal{L}_C^s = f_c \vec{\psi}^{\dagger}_{\Sigma_c^*} \psi_{\Lambda_c^*} \cdot \vec{\pi} + h.c,$$

$$\mathcal{L}_C^d = f_c' \vec{\psi}^{\dagger}_{\Sigma_c^*} \left(\vec{\Sigma} \cdot \vec{\nabla} \vec{\Sigma} \cdot \vec{\nabla} - \frac{1}{3} \vec{\Sigma} \cdot \vec{\Sigma} \vec{\nabla}^2 \right) \psi_{\Lambda_c^*} \cdot \vec{\pi} + h.c,$$

$$\mathcal{L}_D = f_d \psi^{\dagger}_{\Lambda_c} \left(\vec{S} \cdot \vec{\nabla} \right) \vec{\psi}_{\Sigma_c^*} \cdot \vec{\pi} + h.c. \qquad ($$

$\Lambda_c(2625) \to \Sigma_c^{(*)} + \pi \to \Lambda + \pi + \pi$

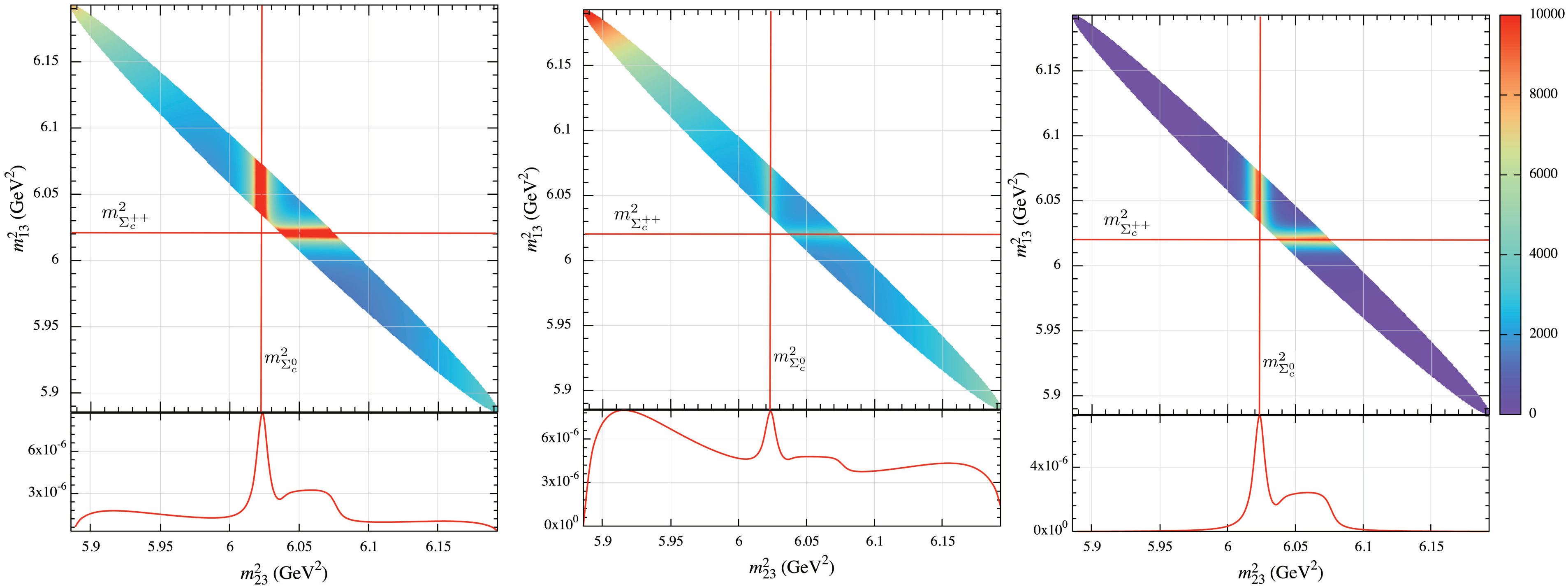
	Intermediate state	λ-mode $j=1$	ρ1 $j=1$	ρ2 $j=2$		Exp.[12]
$\Sigma_c(2455)\ 1/2^+$	$\Sigma_c^{++}\pi^-$	0.037	0.018	0.033		<0.05 (<5%)
	$\Sigma_c^{0}\pi^+$	0.031	0.016	0.030		<0.05 (<5%)
	$\Sigma_c^{+}\pi^0$	0.053	0.027	0.049		-
					3-body	(large)
$\Sigma_c^*(2520)\ 3/2^+$ closed	$\Sigma_c^{*++}\pi^-$	0.044	0.190	0		-
	$\Sigma_c^{*0}\pi^+$	0.064	0.285	0		-
	$\Sigma_c^{*+}\pi^0$	0.071	0.306	0		-
	Γ_{total}	0.300	0.842	0.112		< 0.97
	R	0.61	0.93	0		0.54 ± 0.14

$$R = \frac{\Gamma(\Lambda_c^* \to \Lambda_c \pi^+ \pi^- (\text{non-resonant}))}{\Gamma(\Lambda_c^* \to \Lambda_c \pi^+ \pi^- (\text{total}))}$$

- The two body decay of $\Lambda_c(2625)$ is minor
- The contribution of closed (virtual) $\Sigma_c(2520)$ is large due to S-wave nature
- The ratio prefers the λ mode

➡ λ mode is consistent with data, but more study is needed

Dalitz plot



λ mode	ρ1 mode	ρ2 mode
R = 0.61	0.91	0.00

$$R = \frac{\Gamma(\Lambda_c^* \to \Lambda_c \pi^+ \pi^- (\text{non-resonant}))}{\Gamma(\Lambda_c^* \to \Lambda_c \pi^+ \pi^- (\text{total}))}$$

Summary

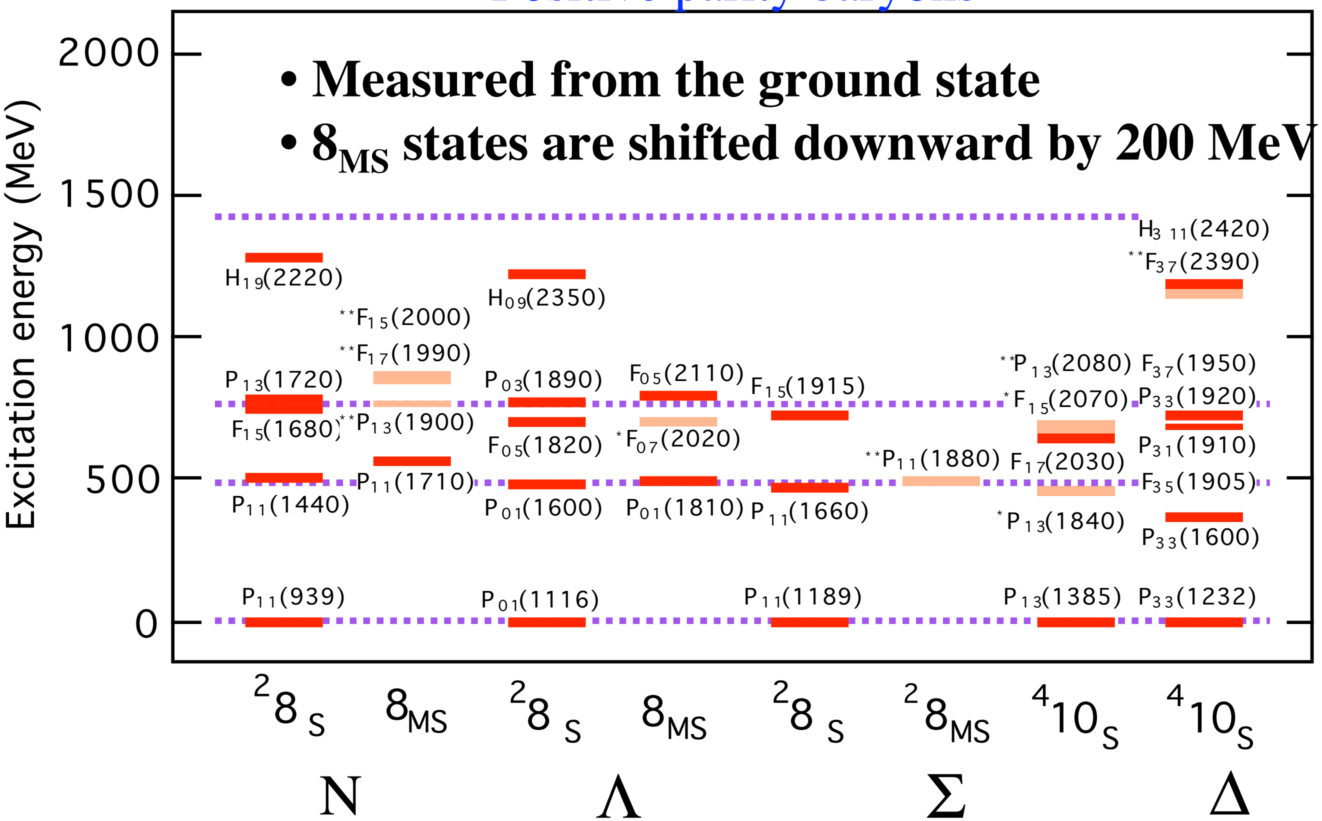
- We have discussed charmed (one-heavy quark) baryons.
- Distinction of λ-ρ mode should be tested.
- Reaction rates/ratios are useful

Questions and problems

- So far $1h\omega$ (likely to be λ mode), what about ρ modes
- Higher excited states, $2h\omega$
- D (heavy) meson emission and decay width
- Nature of monopole (Roper) excitation of 1/2+
- Similar or even lower than 1/2–
- ΔE(1/2+) ~ 500 MeV, independent of flavors

- Production mechanism (quantitatively)

Positive parity baryons



Candidate for charmed baryon

Λ_c^+ 2286
$\Lambda_c(2595)^+$
$\Lambda_c(2625)^+$
$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$
$\Lambda_c(2880)^+$
$\Lambda_c(2940)^+$
$\Sigma_c(2455)$
$\Sigma_c(2520)$
$\Sigma_c(2800)$

Heavy Baryons and their Exotics from Instantons in Holographic QCD

arXiv:1704.03412

Yizhuang Liu* and Ismail Zahed†
Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794-3800, USA
(Dated: April 28, 2017)

$$M_{NQ} = +M_0 + N_Q m_H + \left(\frac{(l+1)^2}{6} + \frac{2}{15}N_c^2\left(1 - \frac{15N_Q}{4N_c} + \frac{5N_Q^2}{3N_c^2}\right)\right)^{\frac{1}{2}} M_{KK} + \frac{2(n_\rho + n_z) + 2}{\sqrt{6}} M_{KK} \quad (42)$$

Radial excitation of diquark soliton positive parity

Excitations into 5th dim diquark internal? negative parity

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Baryons from Instantons in Holographic QCD

Hiroyuki Hata,[1,*)] Tadakatsu Sakai,[2,**)] Shigeki Sugimoto[3,***)] and Shinichiro Yamato[1,†)]

$\Lambda_c(2880)\ 5/2^+$

	decay channel	full	$[\Sigma_c^{(*)}\pi]_{total}$	$[\Sigma_c\pi]^+$	$[\Sigma_c^*\pi]^+$	R
Experimental value Γ_{exp} (MeV)		5.8 ± 1.1 [24]				0.225 [40]
ıtum of final particle q (MeV/c)				375	315	
$(n_\lambda, \ell_\lambda), (n_\rho, \ell_\rho)$	$J_\Lambda(j)^P$					
(0, 2), (0, 0)	$5/2(2)^+$		11.2–26.1	1.2–2.8	9.9–23.3	8.1–8.4
(0, 0), (0, 2)	$5/2(2)^+$		27.8–52.2	1.4–2.6	26.4–49.5	18.7–18.9
(0, 1), (0, 1)	$5/2(2)_2^+$		51.7–109.6	1.8–3.5	49.9–106.1	27.5–30.1
	$5/2(2)_1^+$		0.63–1.68	0	0.63–1.68	(∞)
	$5/2(3)_2^+$		2.9–5.8	2.1–4.0	0.85–1.73	0.41–0.43

- Both absolute values and R ratio are sensitive to configurations
- Brown muck of $j = 3$ seems preferred.
- This implies that $\Lambda_c(2940)$ could be $7/2^+$

$$R = \frac{\Gamma(\Sigma_c^*(3/2^+)\pi)}{\Gamma(\Sigma_c(1/2^+)\pi)}$$