Charmed Baryons and Their Interactions

Atsushi Hosaka
Research Center for Nuclear Physics (RCNP), Osaka University

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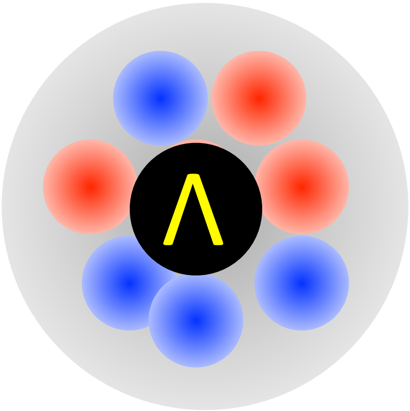
With Noumi, Shirotori, Kim, Sadato,
Yoshida, Oka, Hiyama, Nagahiro, Yasui

1. Introduction
2. Structure
3. Production
4. Decays

1. Introduction

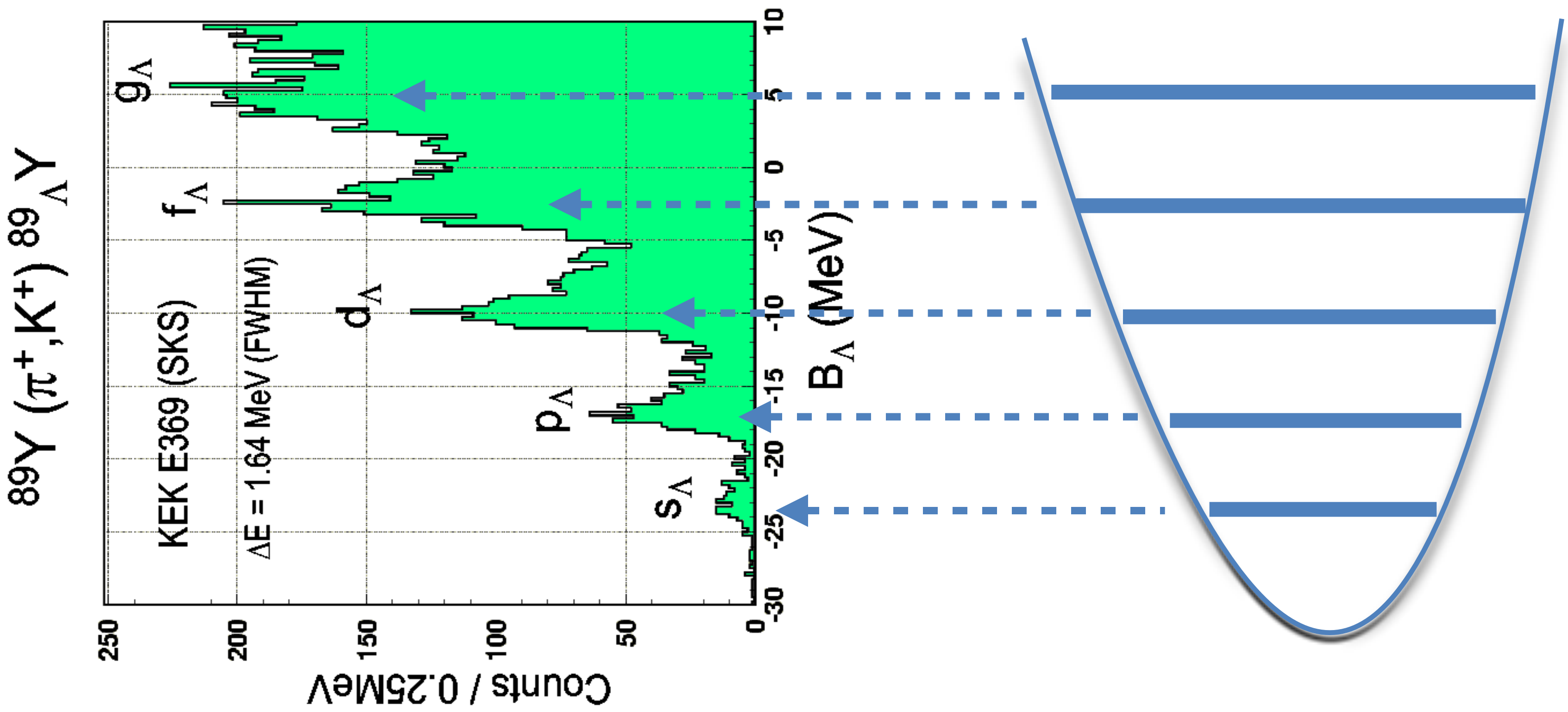
Hyper nuclei



Go into deep inside

Established shell structure

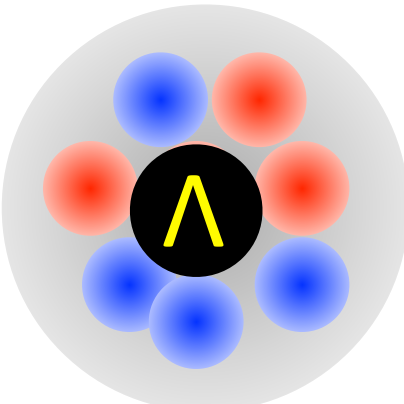
Single particle orbits



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

1. Introduction

Hyper nuclei



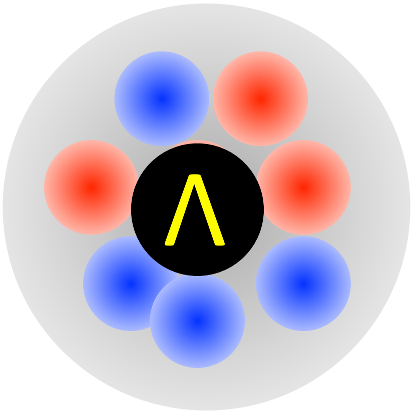
Go into deep inside
Established shell structure

Charmed baryons

What can we learn?

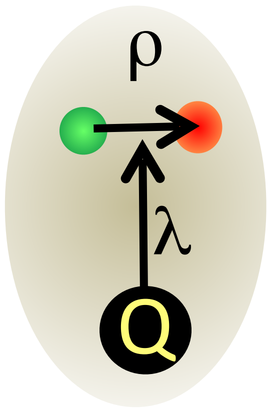
1. Introduction

Hyper nuclei



Go into deep inside
Established shell structure

Charmed baryons



Causes ***isotope-shift***
Will discriminates modes

Three or more particles
→ Baryons with ***ρ*** and ***λ*** modes

Exotics — Multiquarks

A SCHEMATIC MODEL OF BARYONS AND MESONS

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

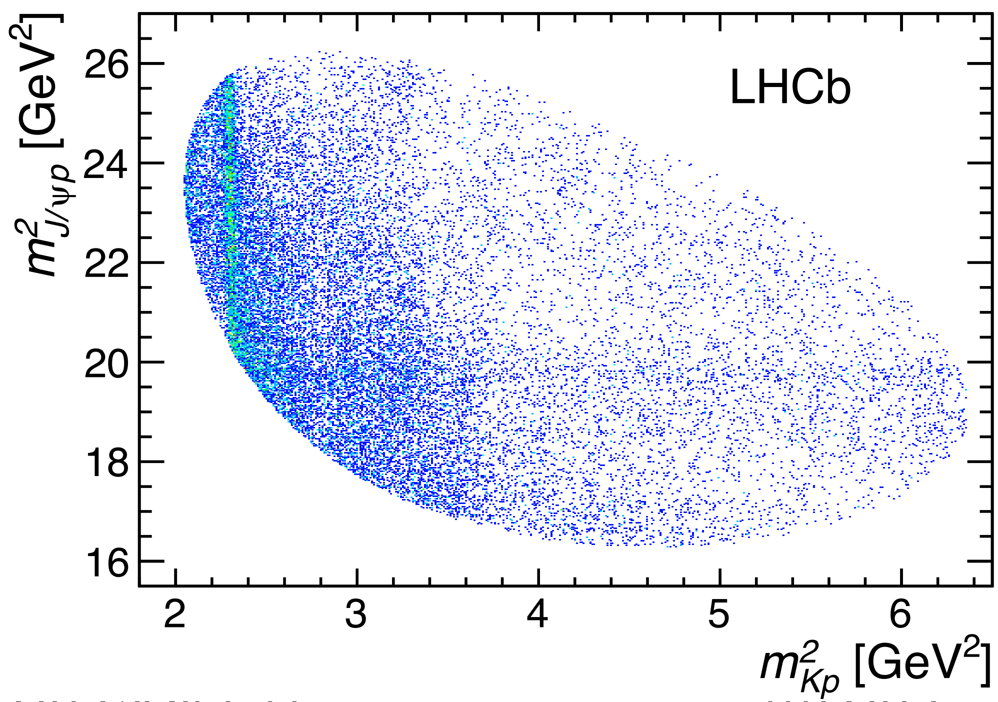
anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

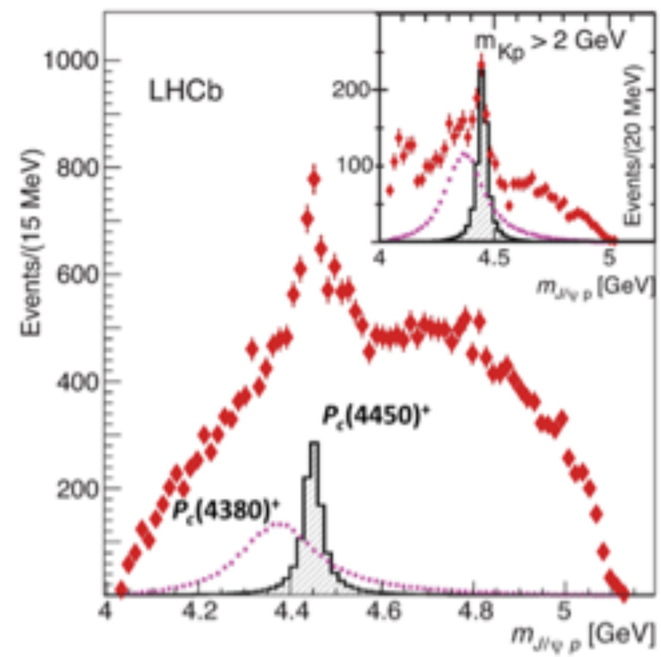
LHCb found Pentaquarks

http://arxiv.org/abs/1507.03414

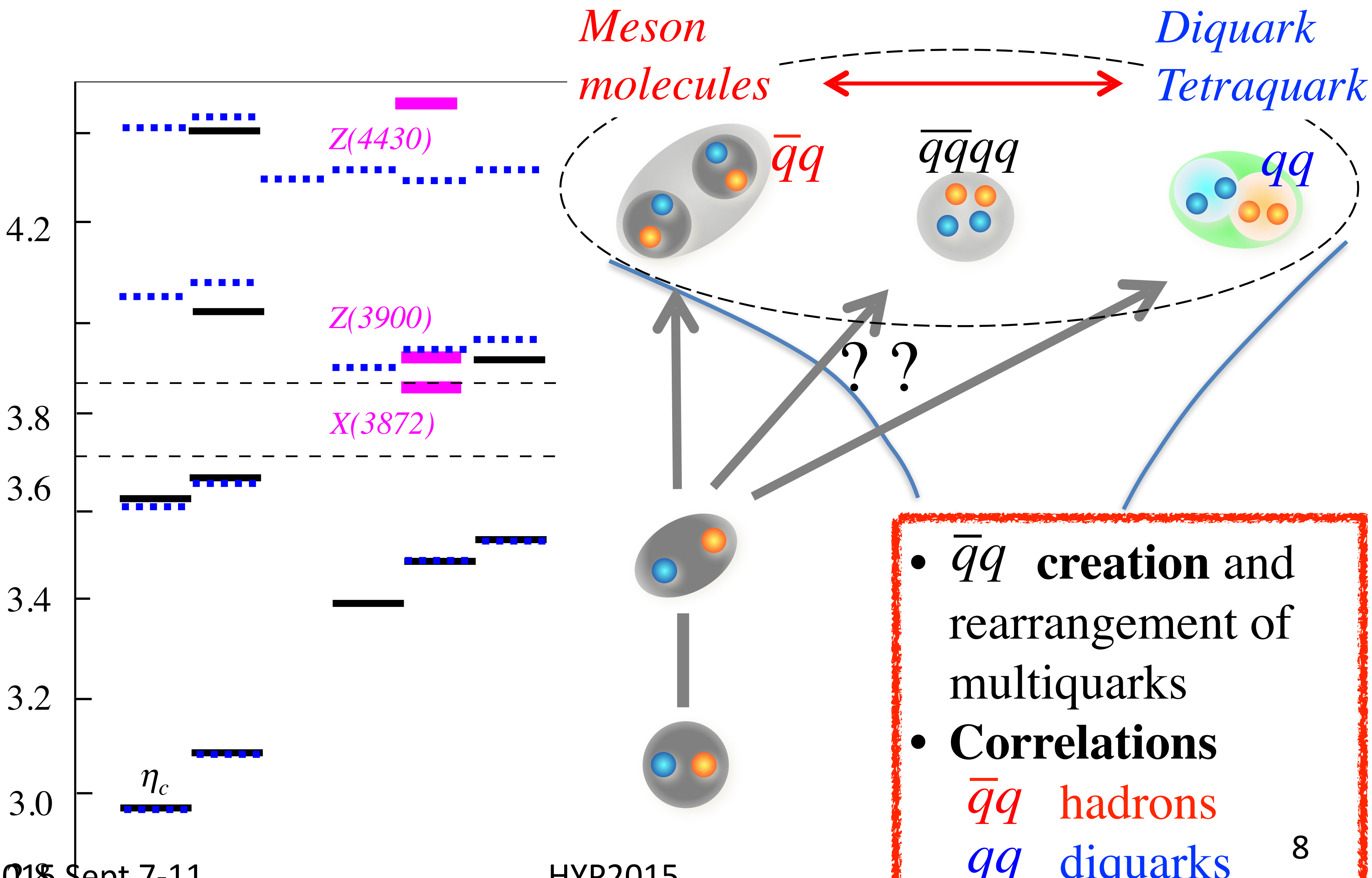
7-8 TeV pp collision —> Λ_b

$$\Lambda_b \longrightarrow J/\psi, p, K^-$$





Near and above the threshold



- $\bar{q}q$ **creation** and rearrangement of multiquarks
- **Correlations**
  $\bar{q}q$ hadrons
  qq diquarks

2. Structure: *what do we expect to study?*

A heavy quark distinguish the fundamental modes

λ and ***ρ***

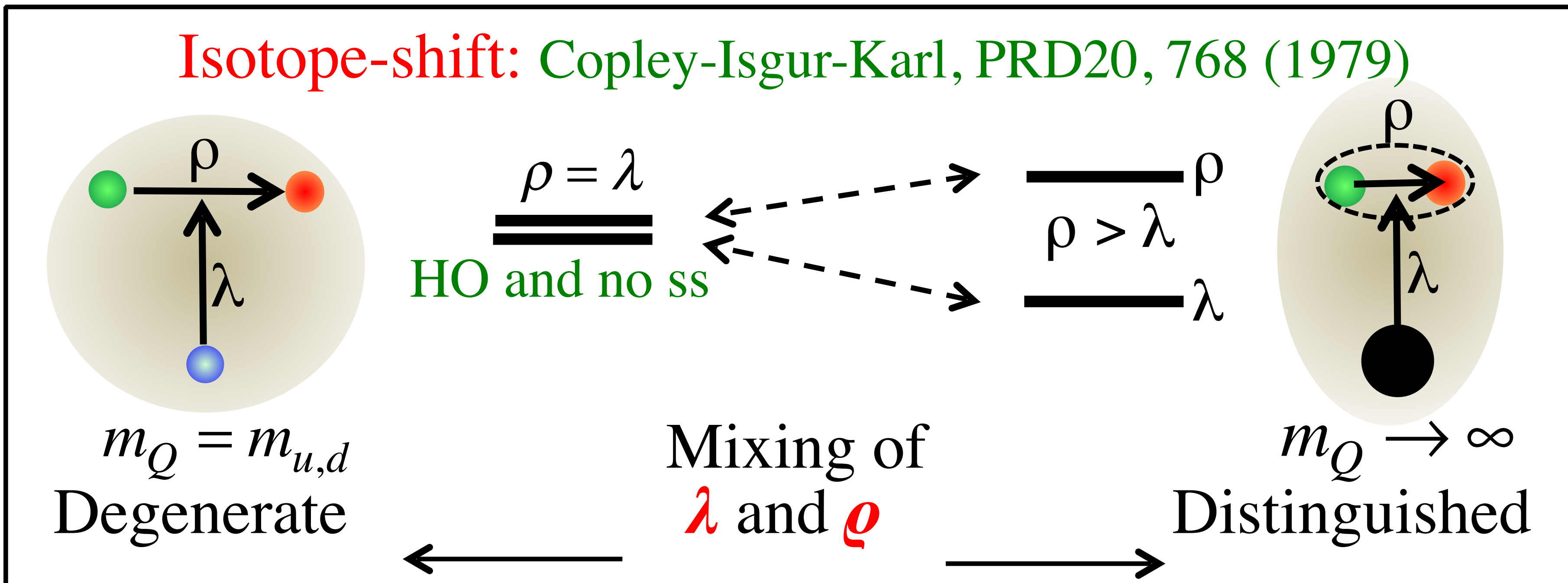
Place to look at ***qq*** dynamics

2. Structure: *what do we expect to study?*

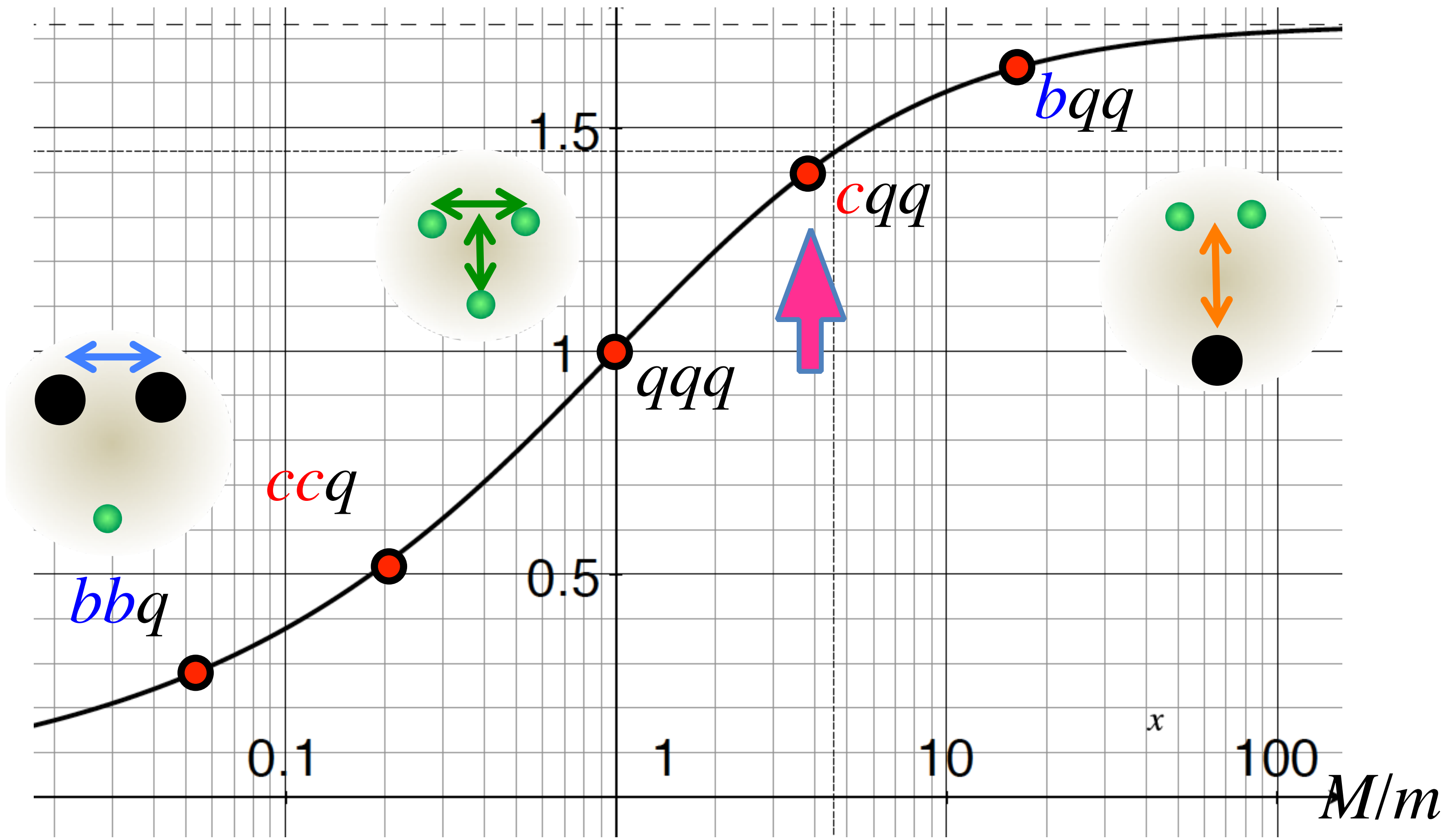
A heavy quark distinguish the fundamental modes

$\boldsymbol{\lambda}$ and $\boldsymbol{\varrho}$

Place to look at ***qq*** dynamics



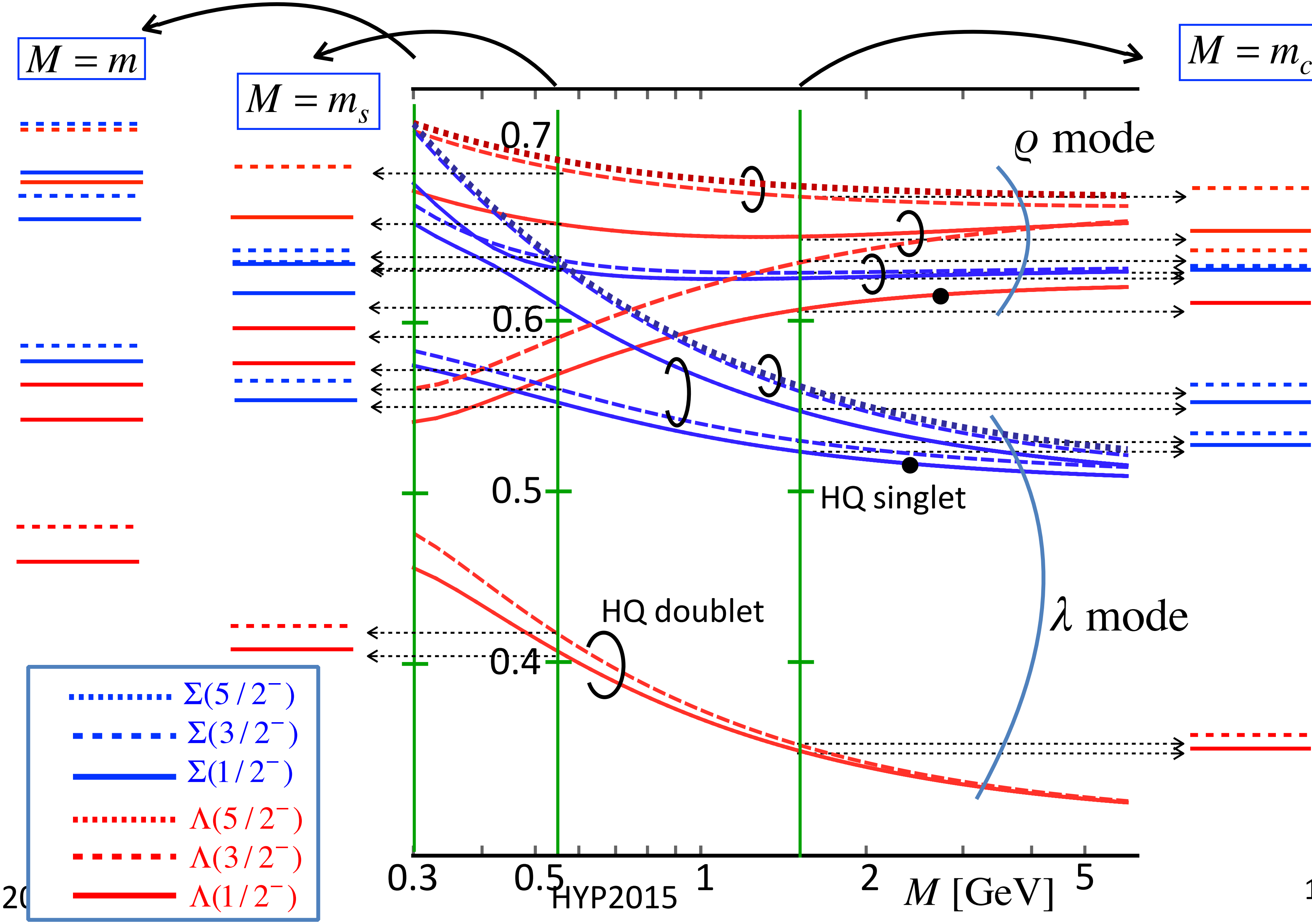
$$\frac{\omega_\rho}{\omega_\lambda} = \left[\frac{1}{3}\left(1+\frac{2m}{M}\right)\right]^{1/2} = \left[\frac{1}{3}(1+2x)\right]^{1/2}$$



Negative parity states — p-wave excitations - $1/2^-$, $3/2^-$

Quark model 3-body calculation by Yoshida & Sadato

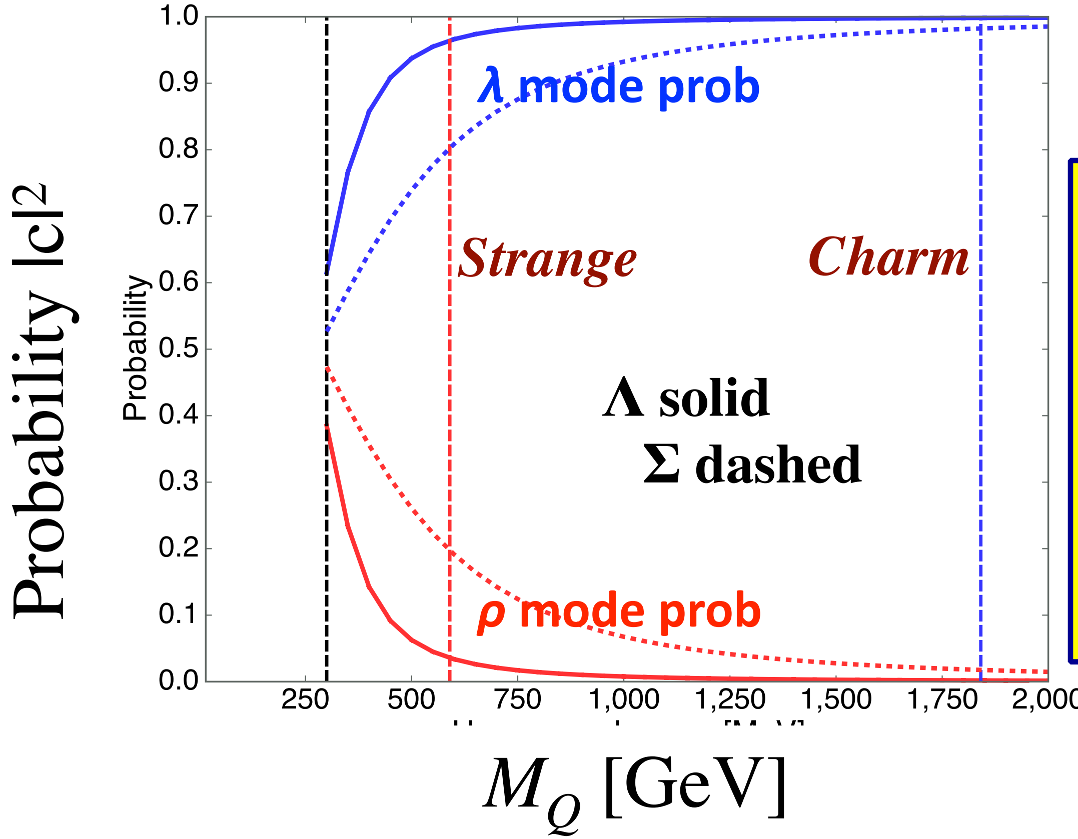
Excitation energies — p-wave states —



Wave function

Mixing of $\Lambda(\text{phys}) = c_\lambda \Lambda(^2\lambda) + c_\rho \Lambda(^2\rho)$

e.g. λ-mode dominant state: How much the other mode mixes?

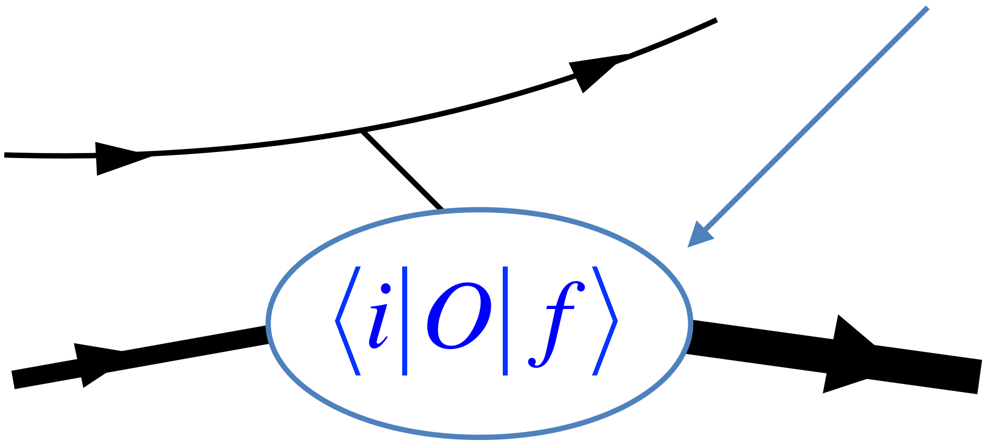


$\Lambda_c{}^*$ is almost pure ***λ*** mode
➔
Reflect more ***qq*** nature

SU(3) ⟷ Heavy quark

3. Productions

Production rates reflect structure



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

Cross sections (Y_c/Y_s) and Ratios (Y_c^*/Y_c)

Strategy:

Forward peak (high energy) → t-channel dominant

We look at:

(1) Absolute values

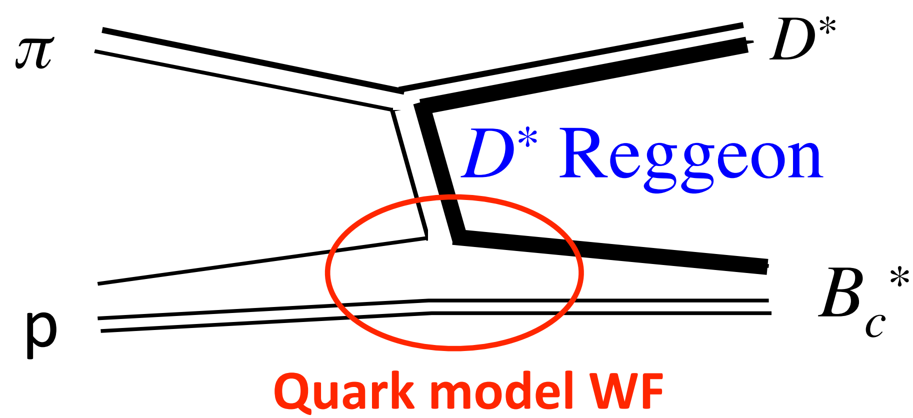
by (Λ_c/Λ_s) by the Regge model, ***K^*, D^* Vector-Reggeon***

(2) Ratios of B_c^*(λ modes) / B_c

by a one step process of *Qd* picture for λ-mode

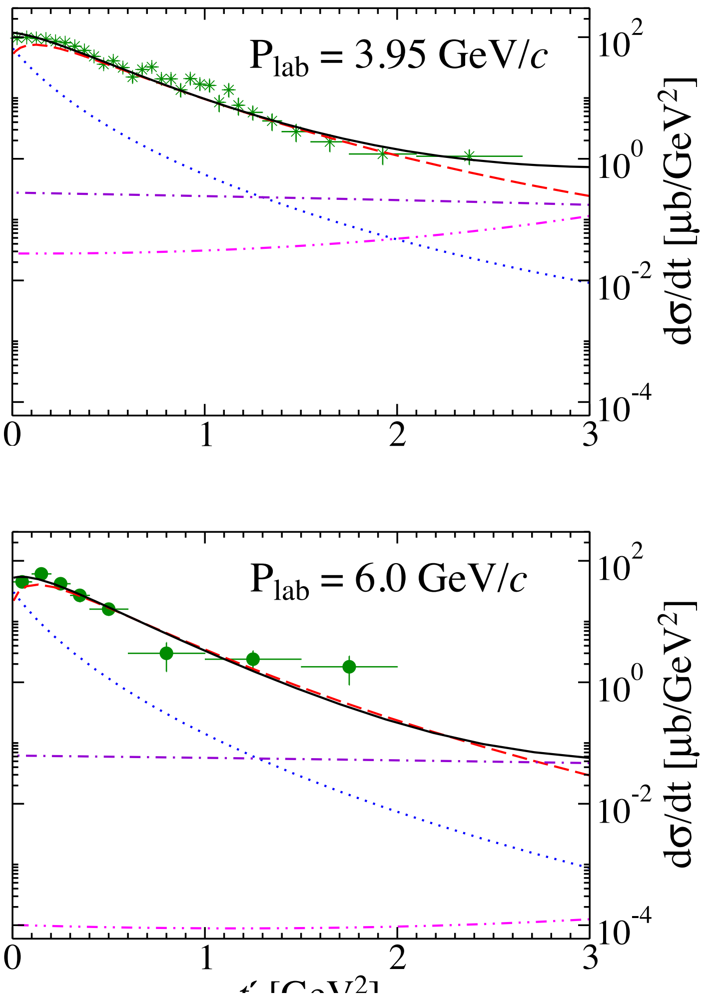
Pion-induced reaction

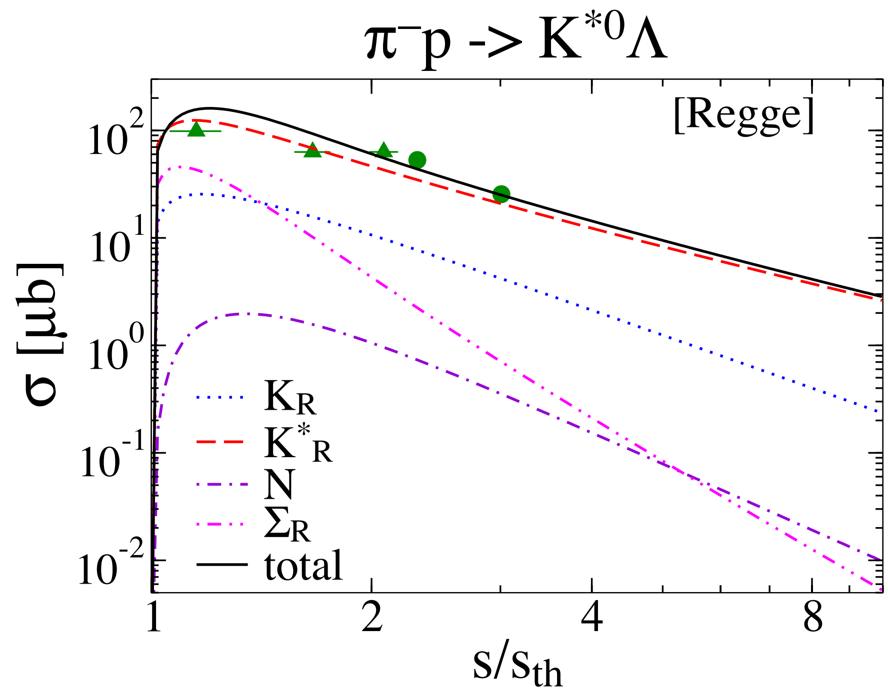
$\pi + p \rightarrow D^* + B_c^*$



Vector Reggeon dominance

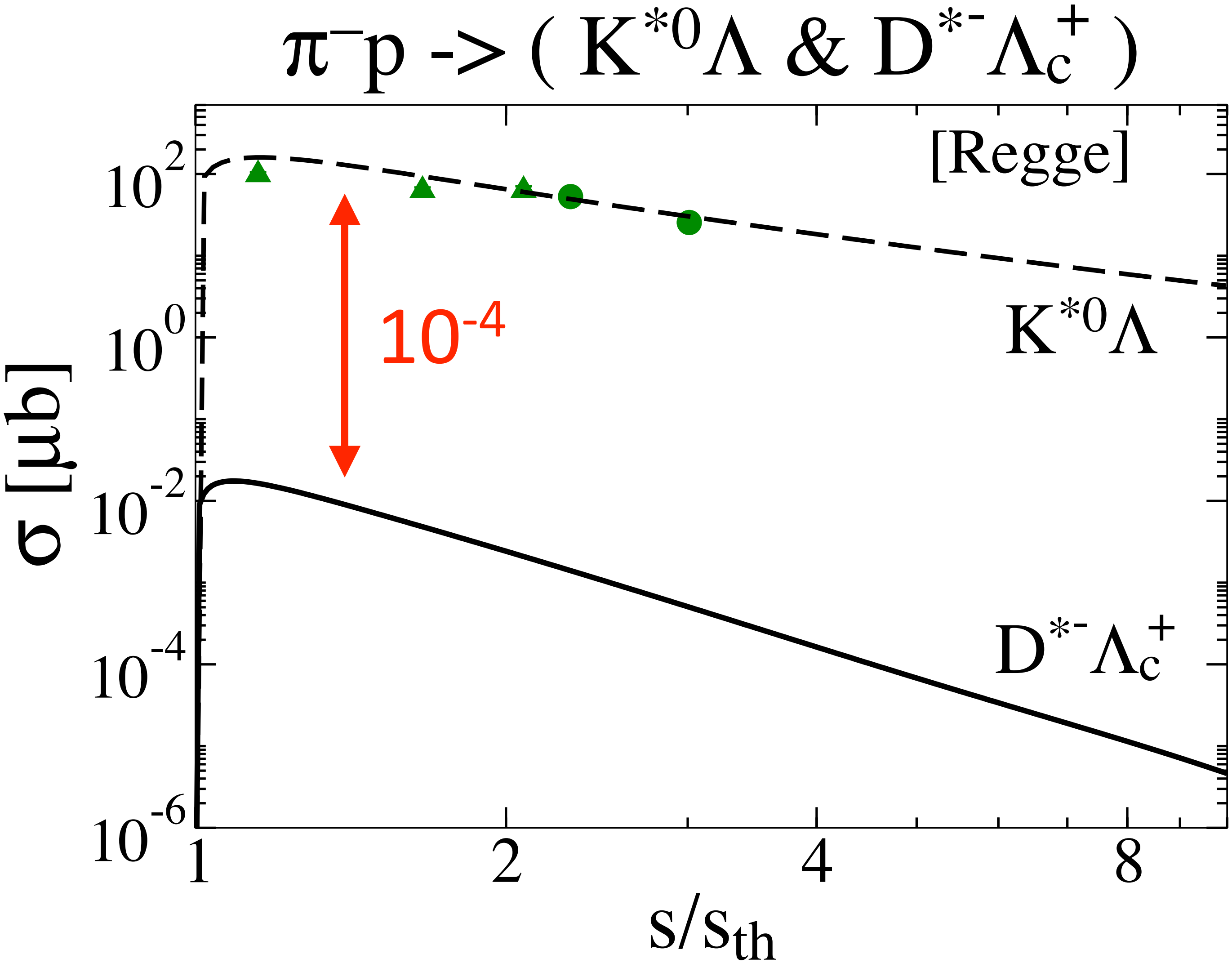
Sang-Ho Kim, in preparation



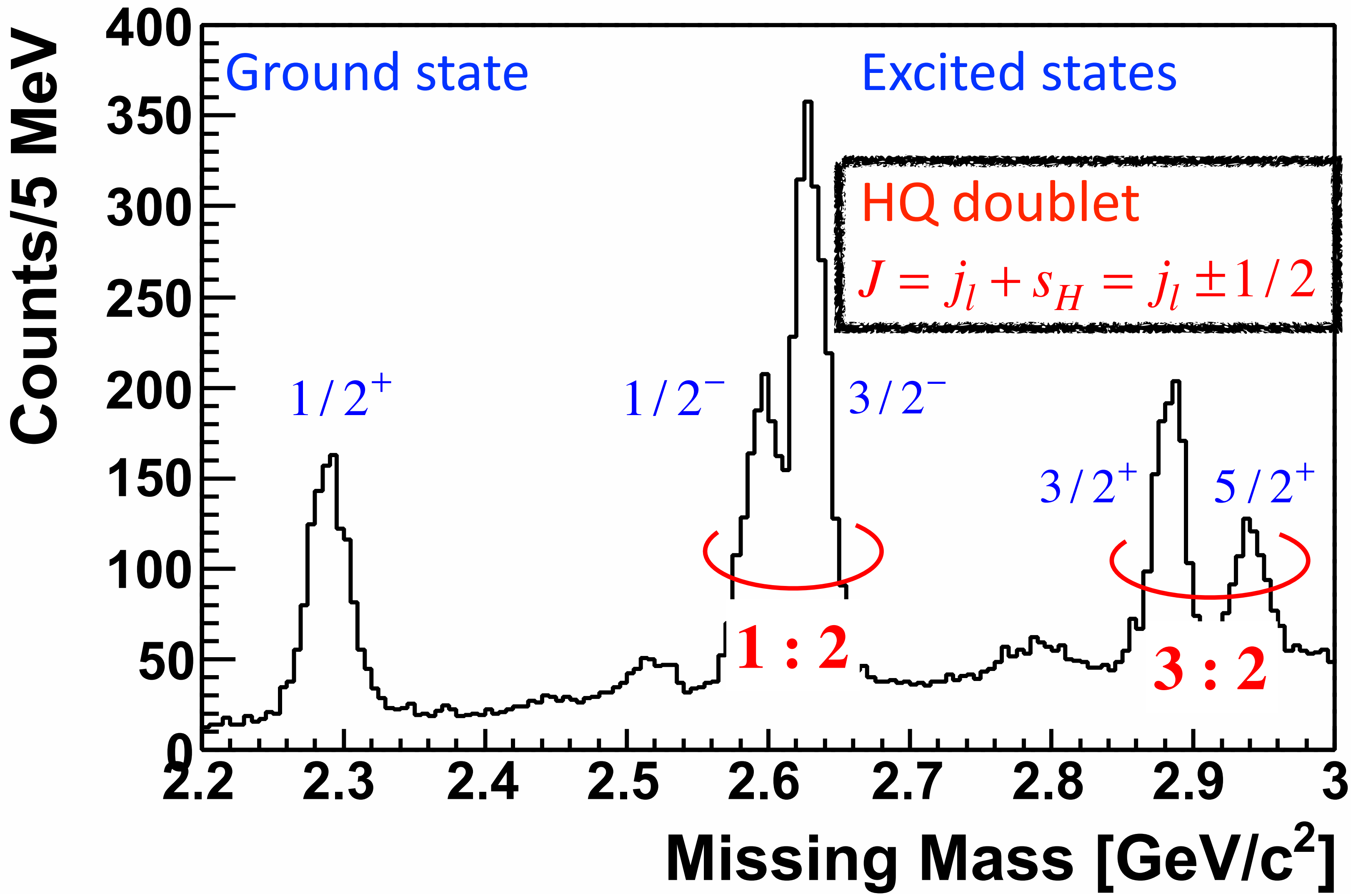


- Vector-Reggeon dominance with some pseudoscalar
- Energy dependence is also well produced

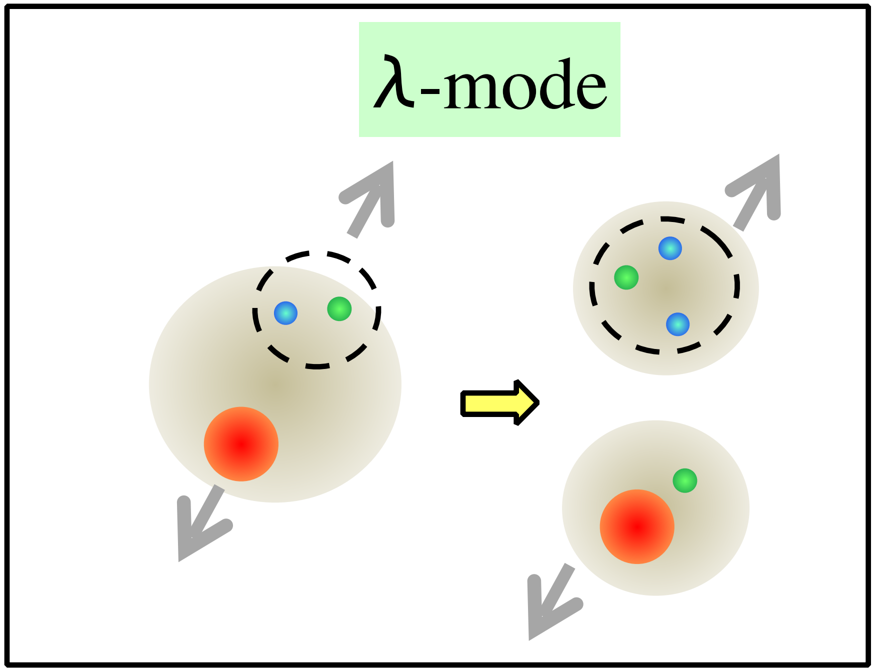
D* meson productions

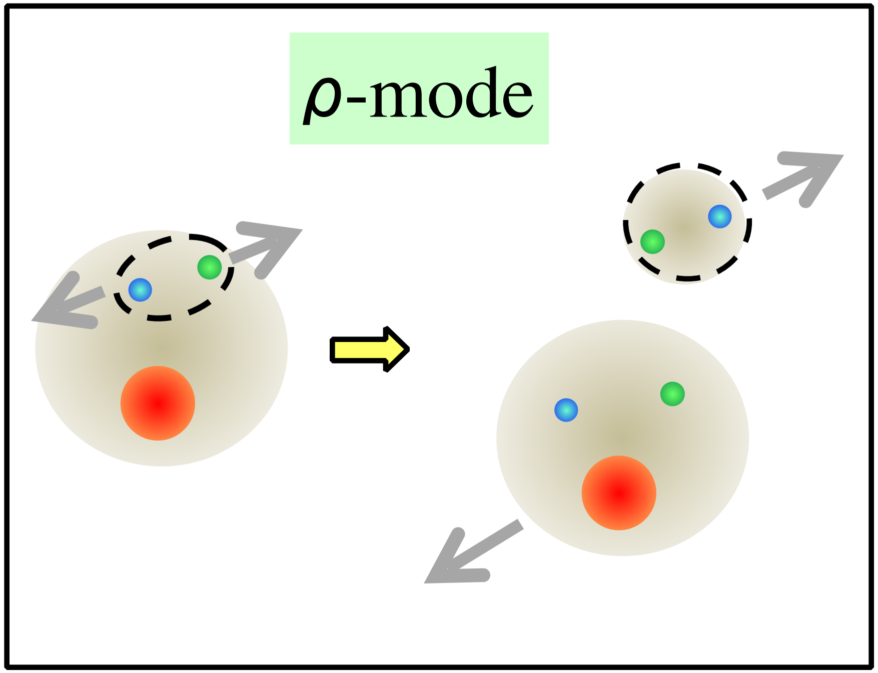


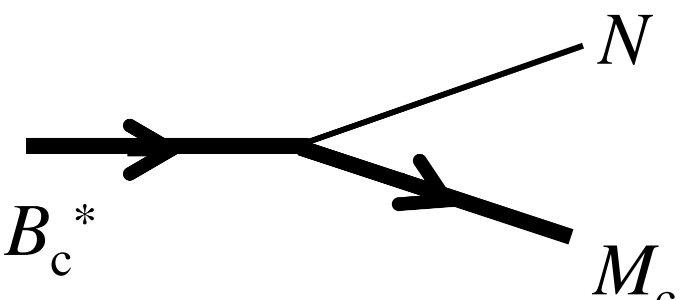
Charm production spectrum

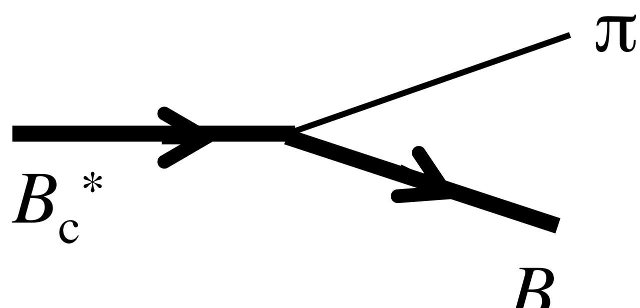


4. Decays





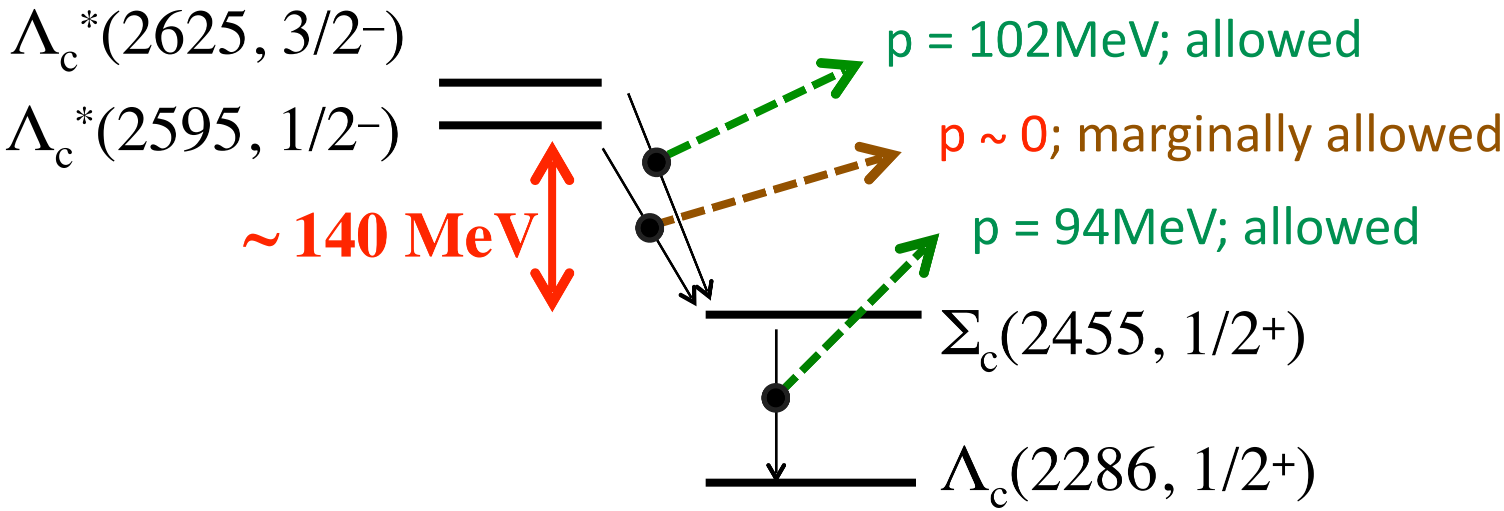




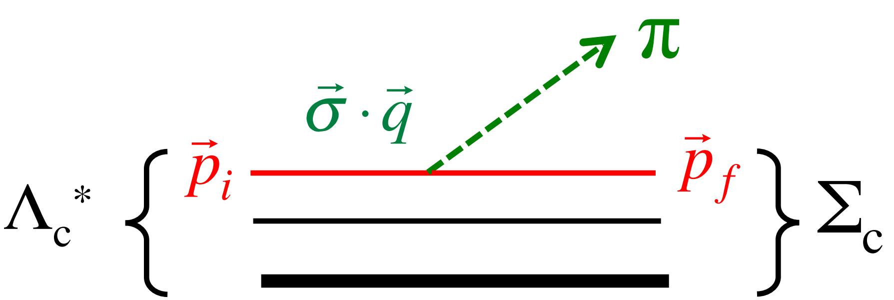
4. Decays —Pion emission—

On going, Nagahiro and Yasui

- Unique feature ~ **very near the threshold**



- Place to look at the ***two independent*** operators



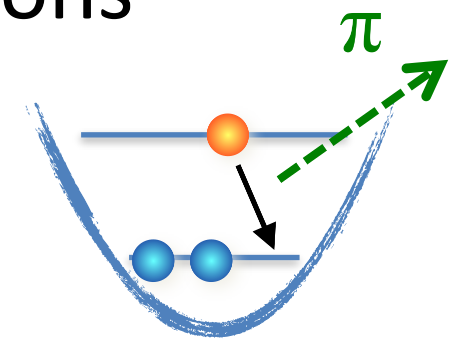
$\vec{\sigma}\cdot\vec{p}_i,\ \vec{\sigma}\cdot\vec{p}_f$

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

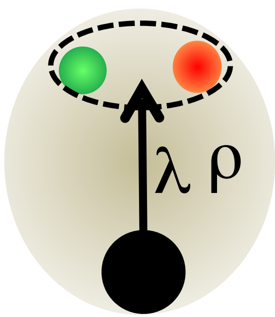
Actual computations

Λ_c^* (*P-wave excitations, J^P*)

$\longrightarrow \Sigma_c(2455, 1/2^+) + \pi$



Quark model (H.O.) wave functions



$S_d = 0, 1$, $l_{\lambda,\rho} = 1$ } $J_{\text{Light}} = 0,1,2$

$S_Q = 1/2$

} $J_{\text{Total}} = 1/2, 3/2, 5/2$

HQ singlet ($1/2$); HQ doublet ($3/2$, $5/2$)

$$\left.\begin{array}{l} m = 0.4\ \text{GeV}, \quad M = 1.5\ \text{GeV} \\ k = 0.03\ \text{GeV}^3 \end{array}\right\} \rightarrow \langle R^2 \rangle^{1/2} = 0.5\ \text{fm}$$

$$g_A^{(q)} = 1, \quad f_\pi = 93\ \text{MeV} \qquad \leftarrow \quad L_{\pi qq} = \frac{g_A^{(q)}}{f_\pi} \bar{q} \gamma^\mu \gamma_5 q \partial_\mu \phi_\pi$$

Initial baryons Λ_c^*	Γ_{exp}(full) [MeV] p [MeV]	$\Gamma_{calc}(\Lambda_c^* \longrightarrow \Sigma_c(2455)\,\pi)$ [MeV]						
		λ-mode, l_λ=1		ρ-mode, l_ρ=1				
		Doublet $d(^1S_0)\,[l_\lambda, c]^{1/2,\,3/2}$		Singlet $[d(^3P_0)]^{1/2}$	Doublet $[d(^3P_1)\,c]^{1/2,\,3/2}$		Doublet $[d(^3P_2)\,c]^{3/2,\,5/2}$	
		$1/2^-$	$3/2^-$	$1/2^-$	$1/2^-$	$3/2^-$	$3/2^-$	$5/2^-$
$\Lambda_c(2595)$ 2592.25	2.6	1.7*	*	*	*	*	*	*
$\Lambda_c(2625)$ 2628.11	< 0.97 (102)	18	0.1	0**	81	0.04	0.08	0.03
$\Lambda_c(2765)$ Σ_c?, 2766.6	50 (262)	76	8	0**	390	4.5	7.8	3.6
$\Lambda_c(2880)$ 2881.63	5.8 (376)	107	37	0**	624	21	37.5	17
$\Lambda_c(2940)$ 2939.3	17 (427)	110	66	0**	700	38	64	29

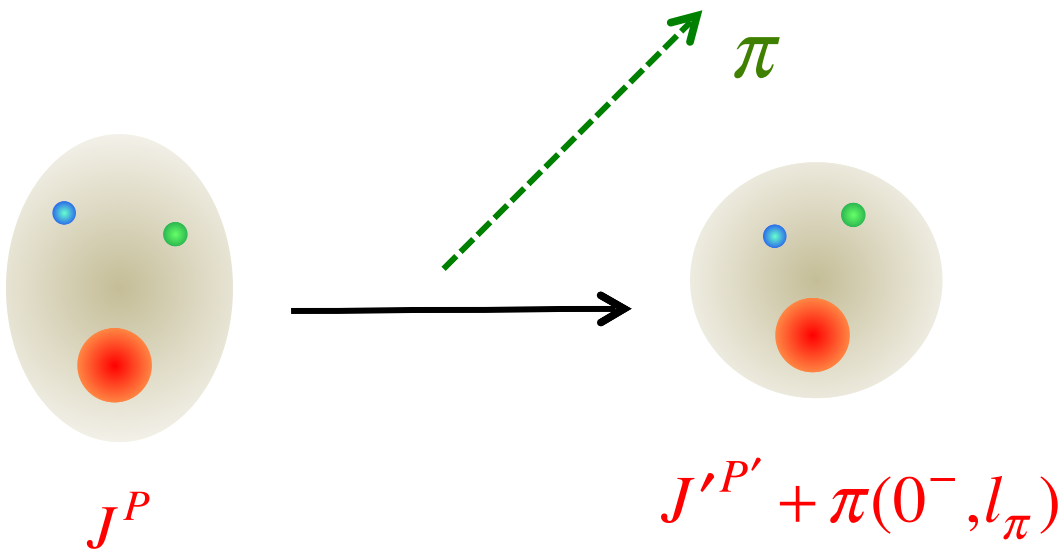
* Almost threshold – carefully studied, ** Forbidden (selection rule)

- $1/2^-$: s-wave $\pi\Sigma$ decay
- $3/2^-$, $5/2^+$: d, f-wave $\pi\Sigma$ decay ⟶ suppressed by power $(q/a)^{4,\,6}$
- $\Lambda_c(2880)$ and $\Lambda_c(2940)$ could be higher spin states?

Possible selection rules

ρ-modes

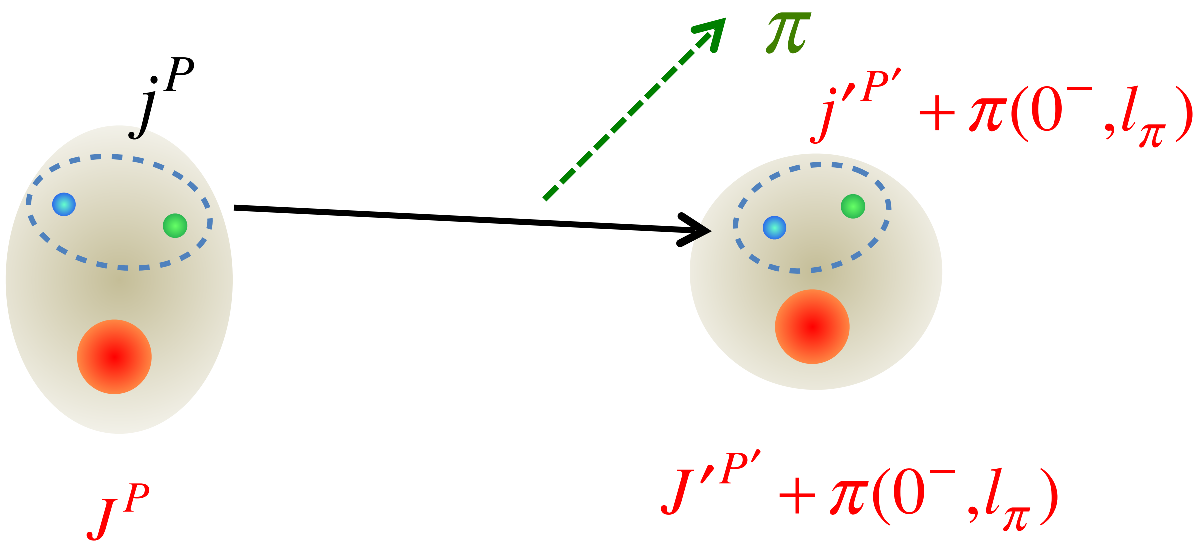
Decays of baryons



Possible selection rules

ρ-modes

Decays of baryons = of diquarks



Two conditions must be satisfied for baryons and for diquarks

$$\Lambda_c(1/2^-, \rho) \to \Sigma_c(1/2^+, GS) + \pi$$
$$d(^3P_0) \to d(^3S_1) + \pi$$

is not allowed

Summary

- Heavy quarks identify and disentangle essential modes of hadrons, ρ and λ modes.
- Productions are useful to
- Charm baryons are abundantly produced
- Decays are useful to further understand the structure

- Model Hamiltonian

$$H = \frac{p_1^2}{2m_q} + \frac{p_2^2}{2m_q} + \frac{p_3^2}{2M_Q} - \frac{P^2}{2M_{tot}}$$
$$+ V_{conf}(HO) + V_{spin-spin}(Color - magnetic) + \ldots$$

- Solved by the Gaussian expansion method