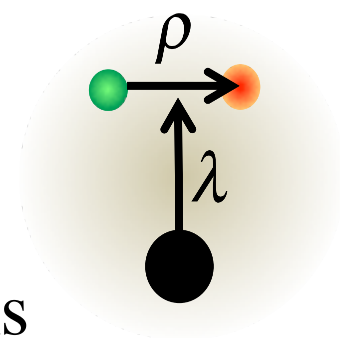
Charmed baryons - Structure, productions and decays -

Atsushi Hosaka, RCNP, Osaka
HHIQCD - symposium, YITP, Kyoto, 2/15-3/21

With Noumi, Shirotori, Kim, Sadato, Yoshida, Oka,
Hiyama, Yasui, Nagahiro
Prog. Theor. Exp. Phys. (2014) 103D01



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2. Charmed baryons: *to probe* ***ρλ modes*** ➔ **diquark**
3. Productions
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1. Introduction

Quark model and EXOTICS: Now 51 years old

A SCHEMATIC MODEL OF BARYONS AND MESONS

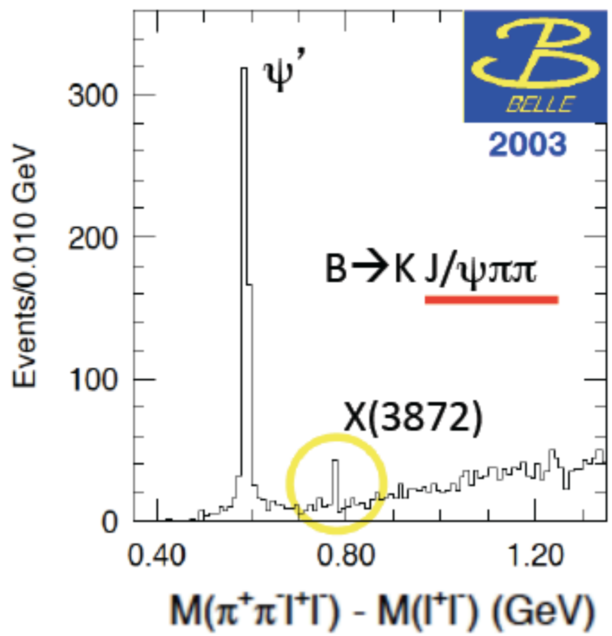
M. GELL-MANN
California Institute of Technology, Pasadena, California

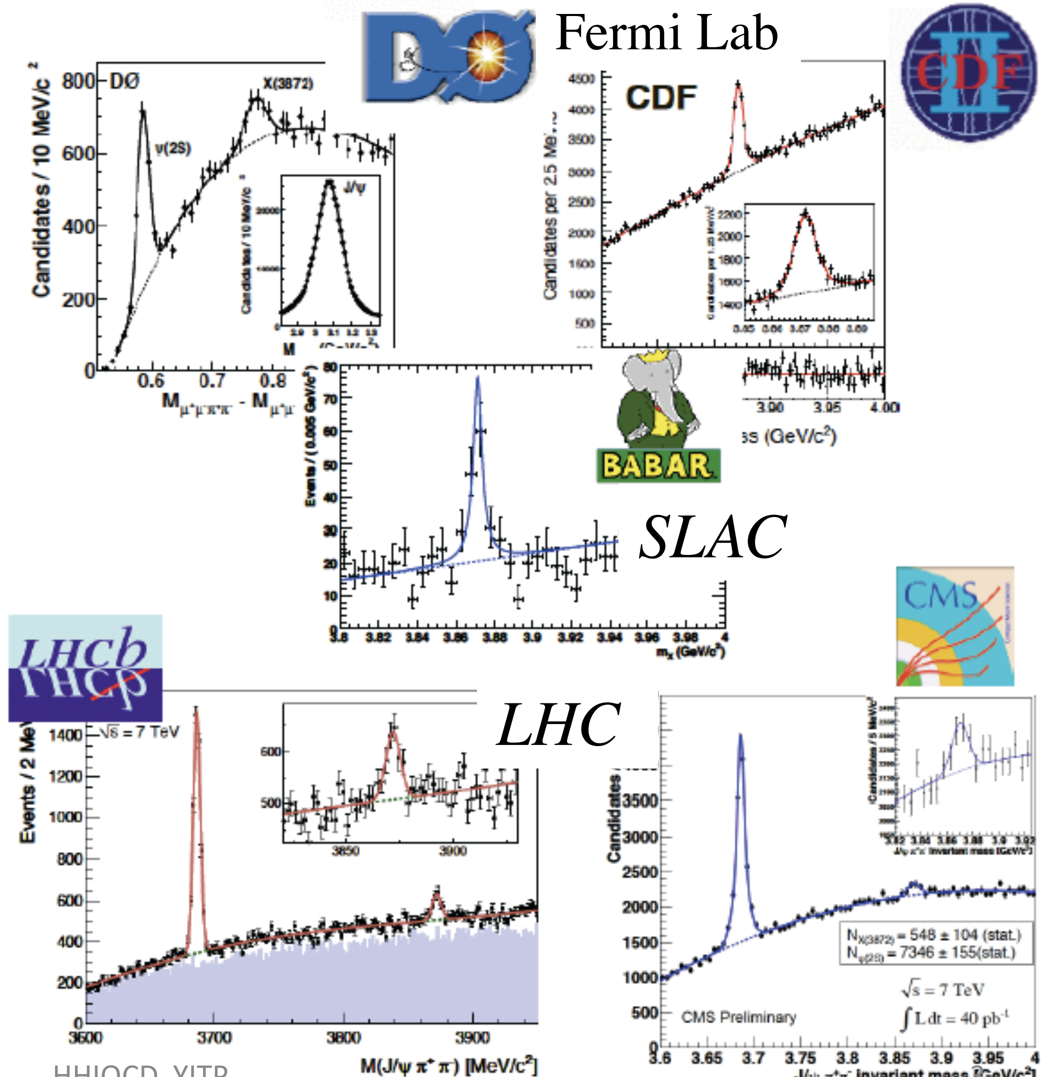
Received 4 January 1964

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**.

X (3872)

Discovery by Belle in 2003, followed by D0, CDF, BaBar.





And more recently also by LHCb, CMS

Quarks bonding differently at LHCb $Z^+(4430)$

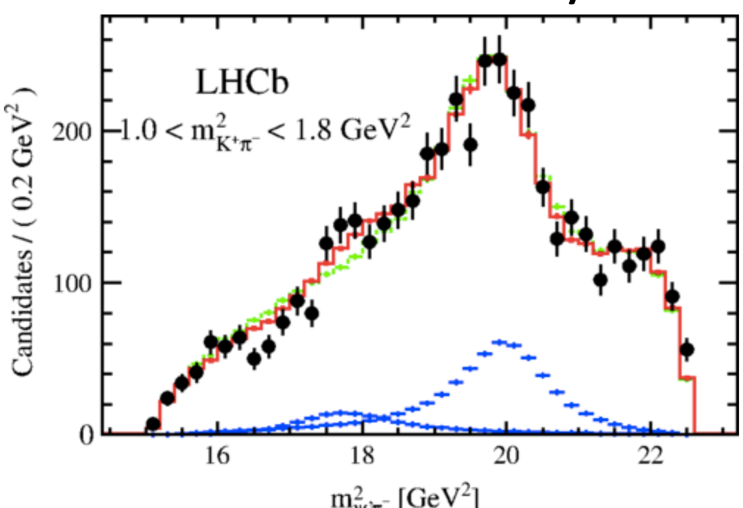
http://www.theguardian.com/science/life-and-physics/2014/apr/13/quarks-bonding-differently-at-lhcb

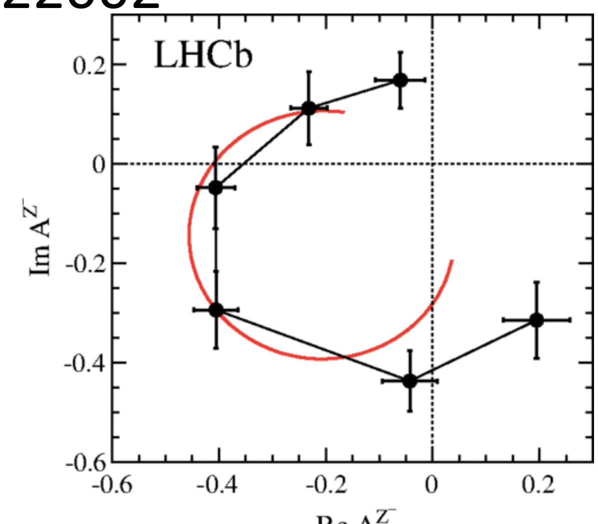
So until last week there were two known types of hadron.

......

LHCb has just confirmed what data from other experiments had already led us to suspect. There is a third way.

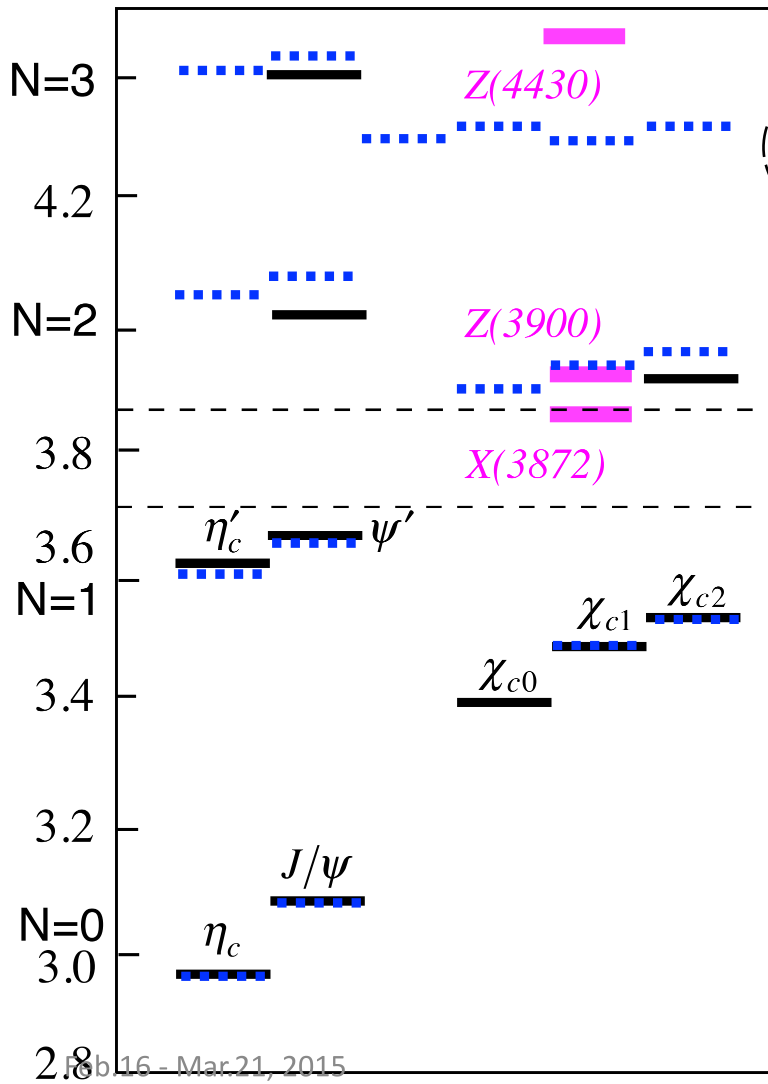
Phys. Rev. Lett. **112**, 222002

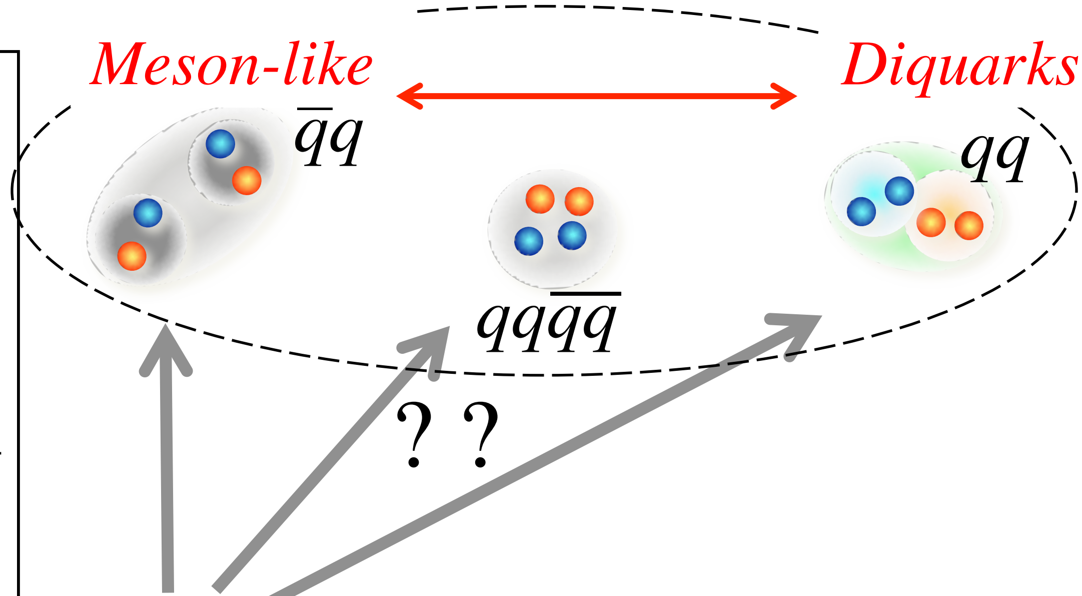




EXOTIC threshold (and above)

$q\bar{q}$ creation and rearrangement of multiquarks

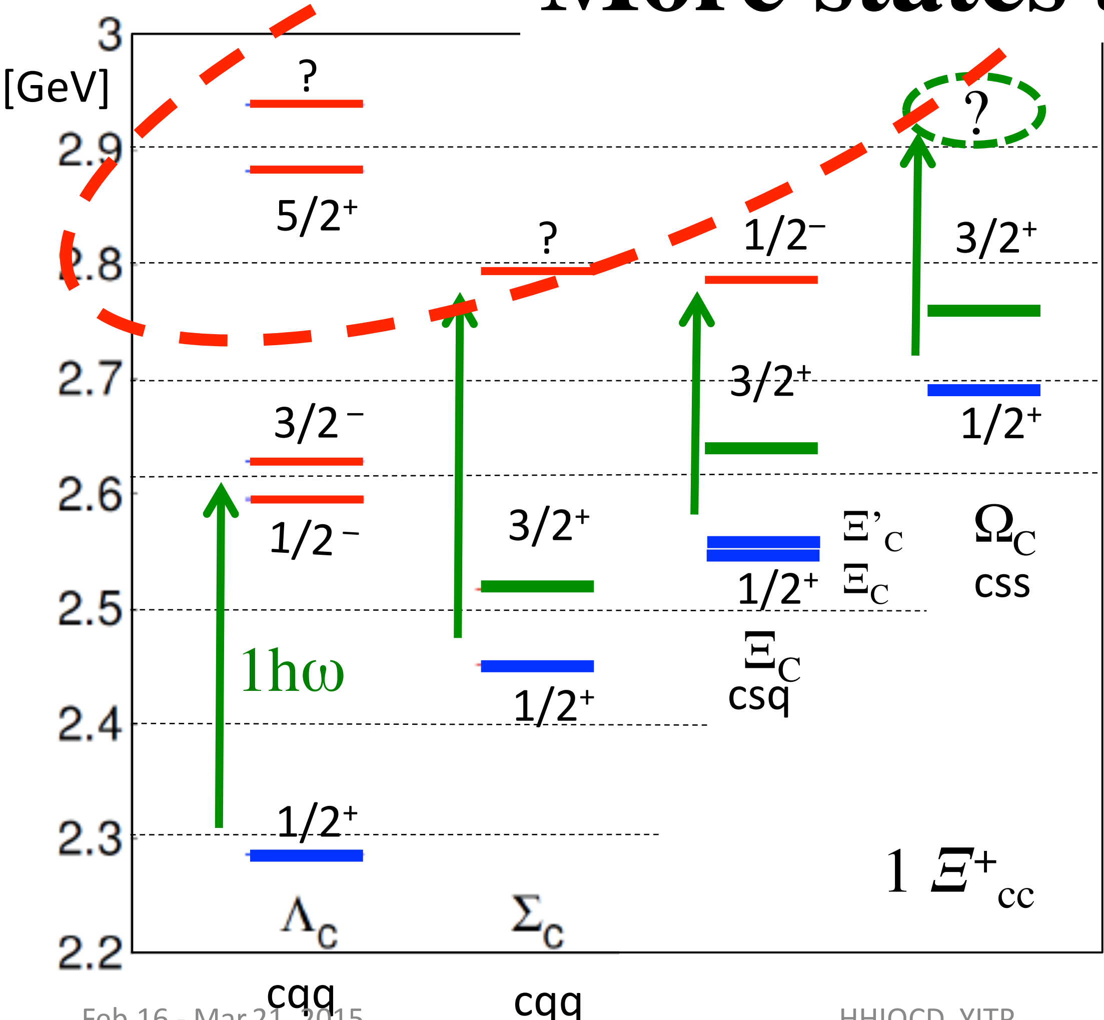




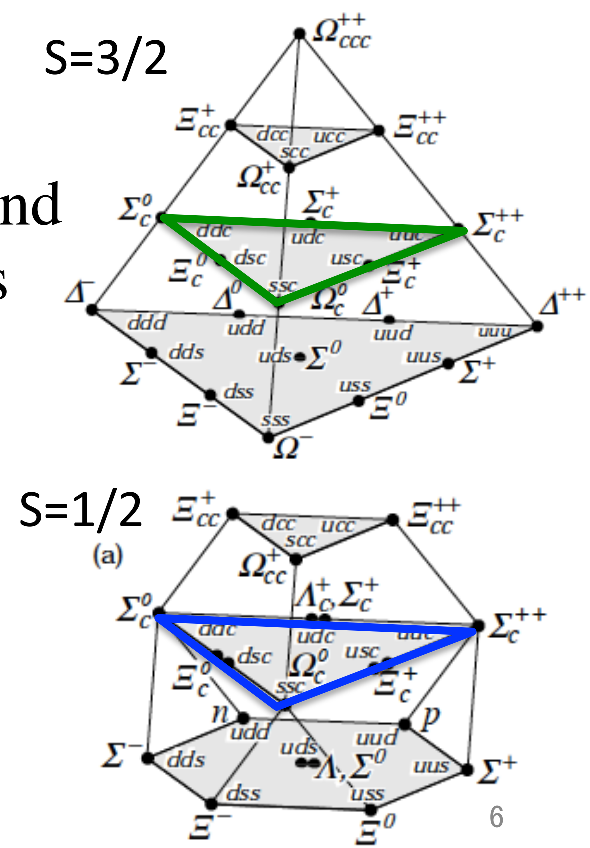
- What governs them ?
- Are heavy quarks useful to know it?
- Constituent quarks, mesons, diquarks ...

2. Charmed baryons

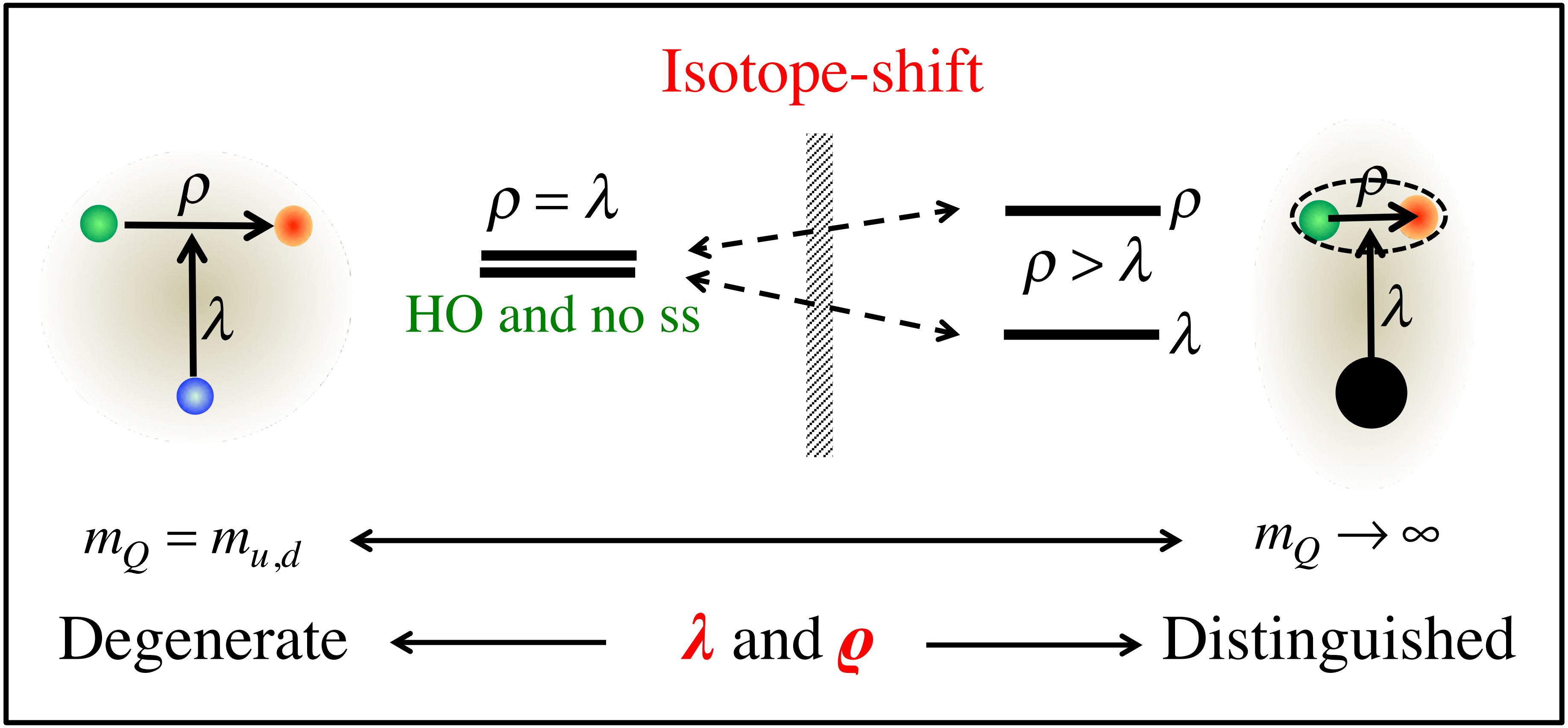
More states at J-PARC



Ground states



Qqq distinguishes the fundamental modes λ and ρ ➔ place to look at diquarks



Quark model calculation

Yoshida, Sadato, Hiyama, Oka, Hosaka

- Model Hamiltonian

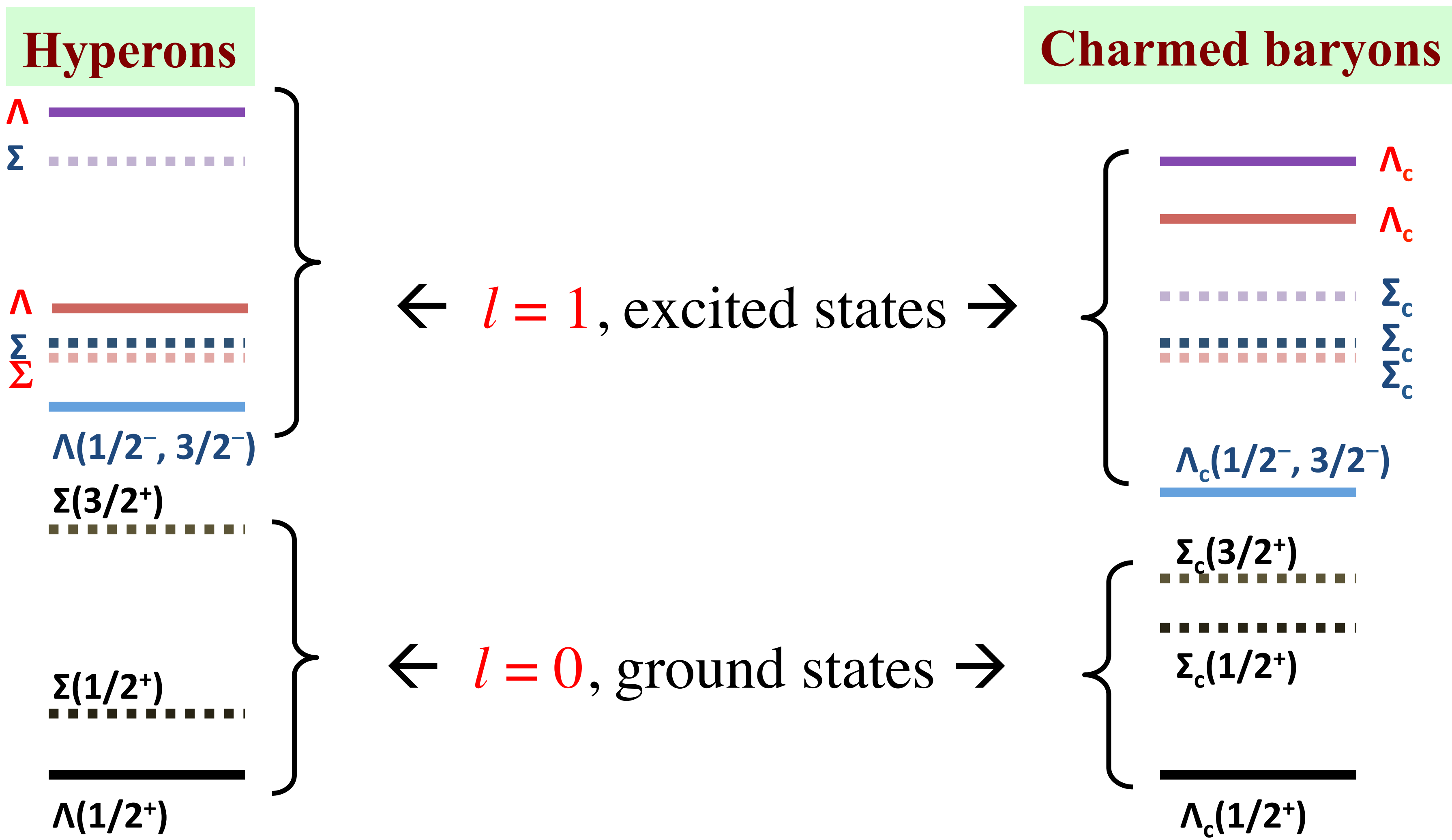
$$H = \frac{p_1^2}{2m_q} + \frac{p_2^2}{2m_q} + \frac{p_3^2}{2M_Q} - \frac{P^2}{2M_{tot}}$$

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

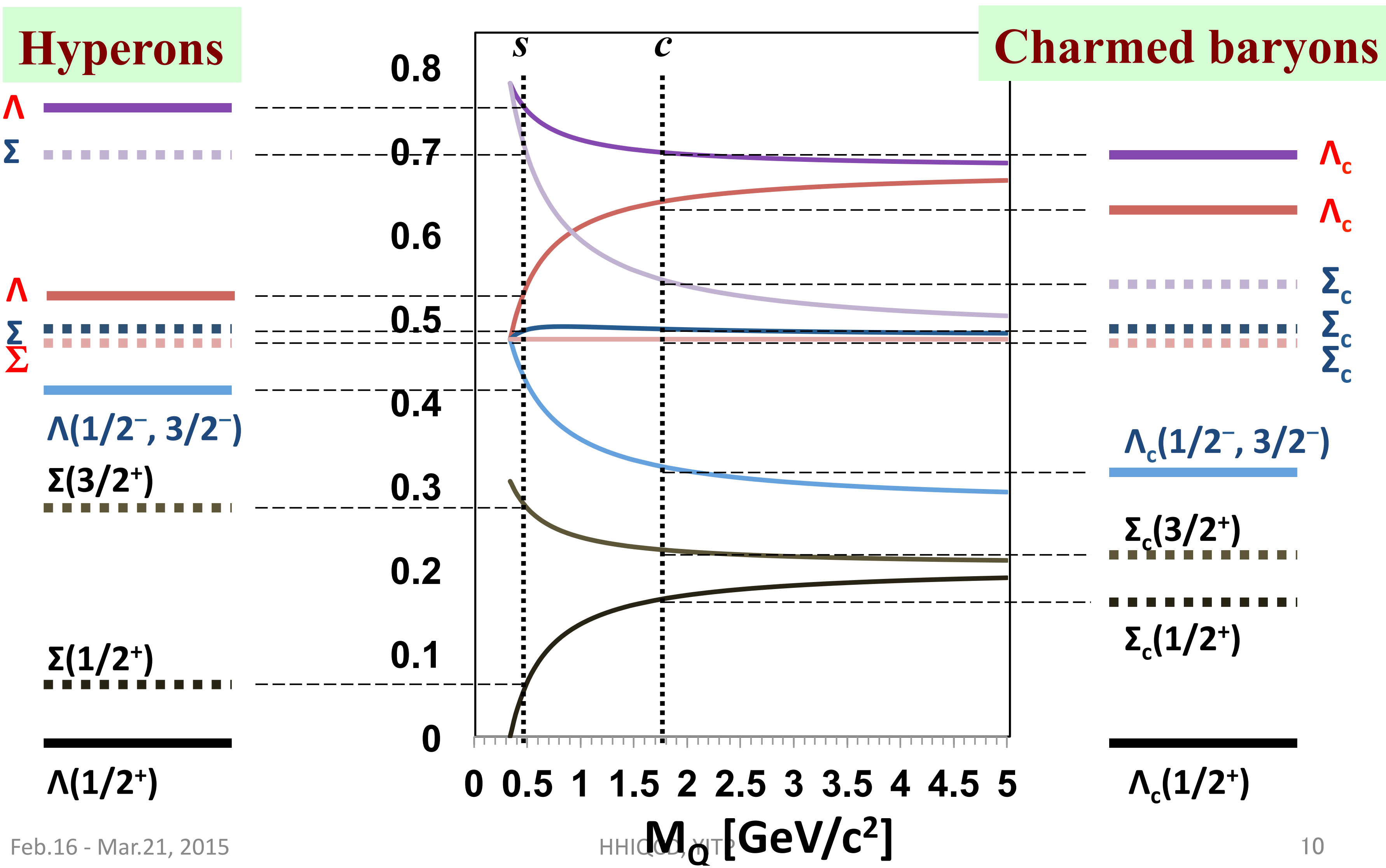
- Solved by the Gaussian expansion method

See how systems change as M_Q is varied

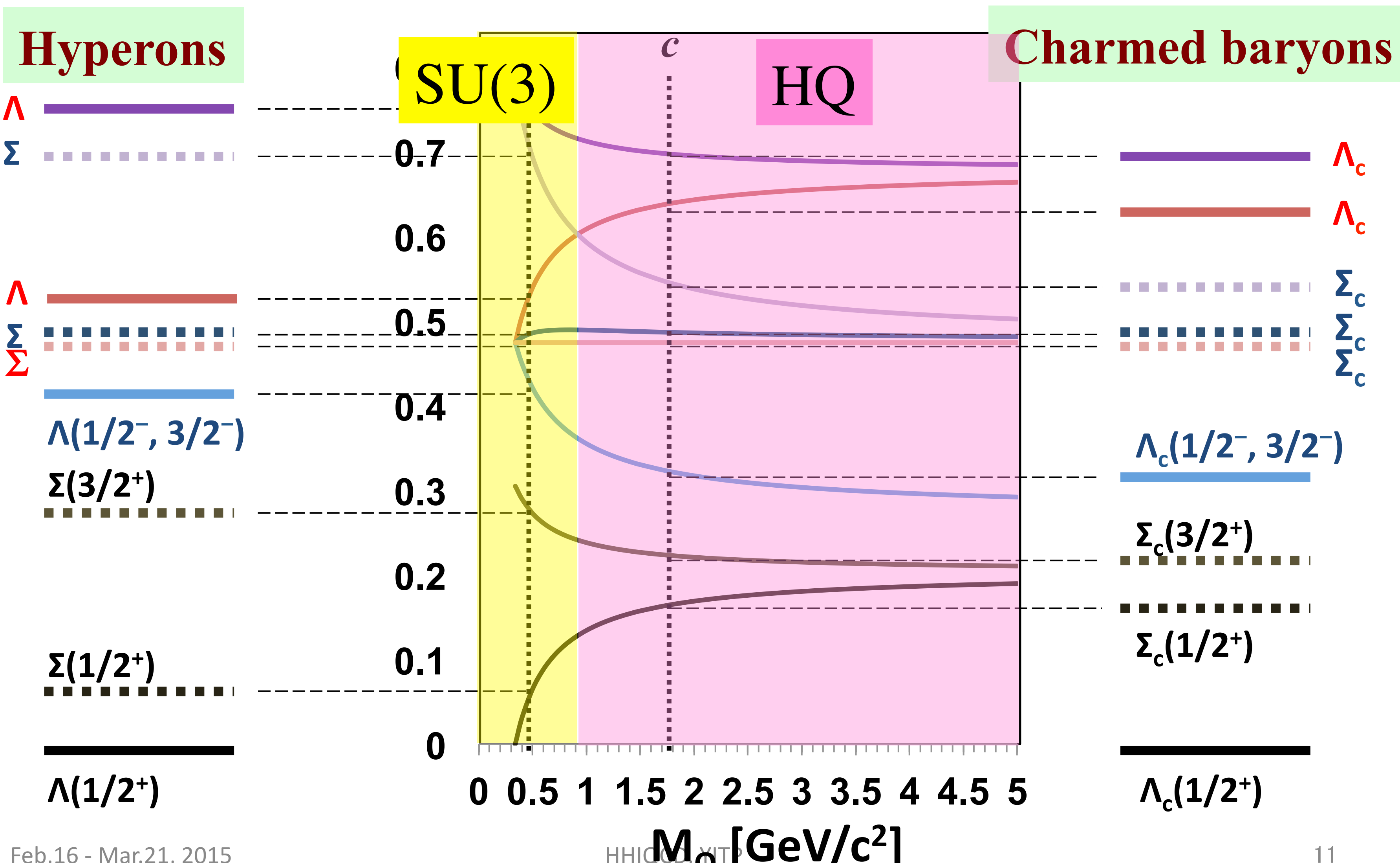
Excitation spectrum



Excitation spectrum



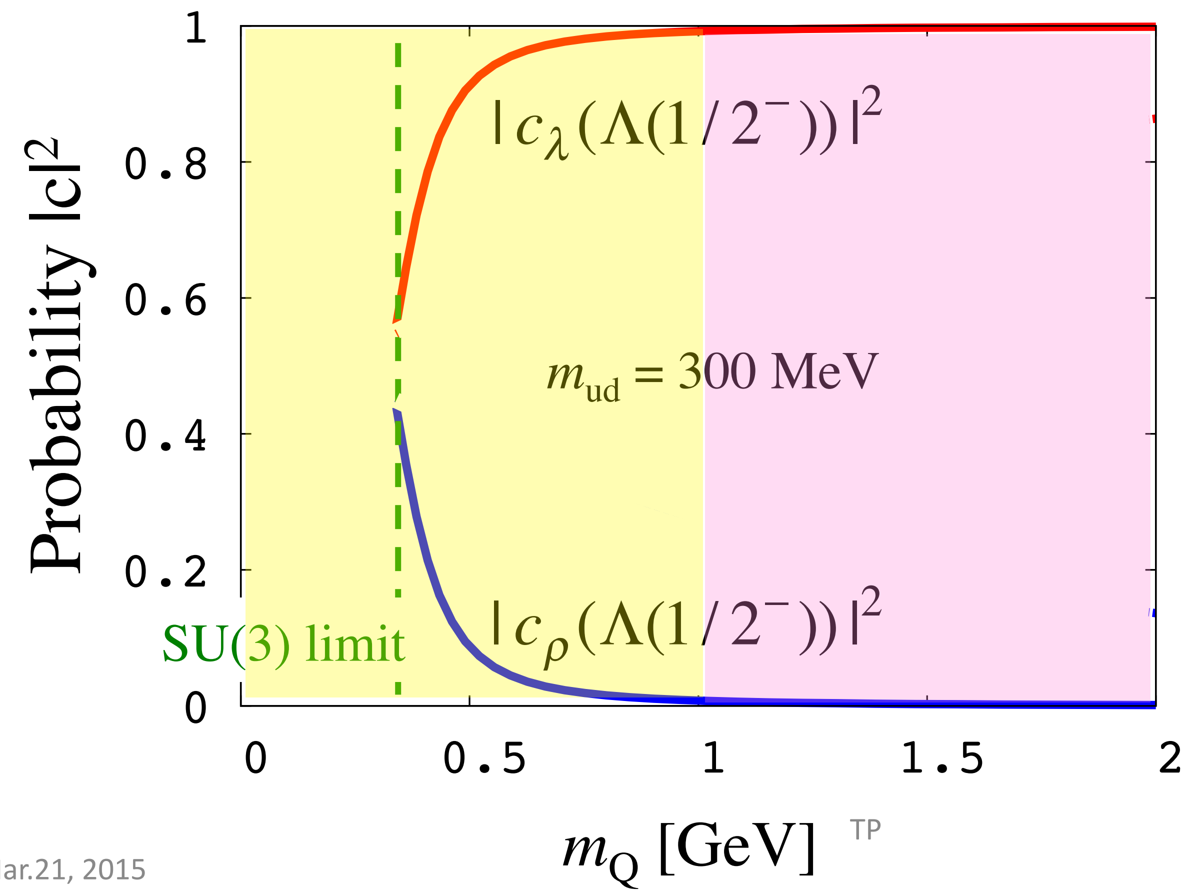
Excitation spectrum



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?



TP

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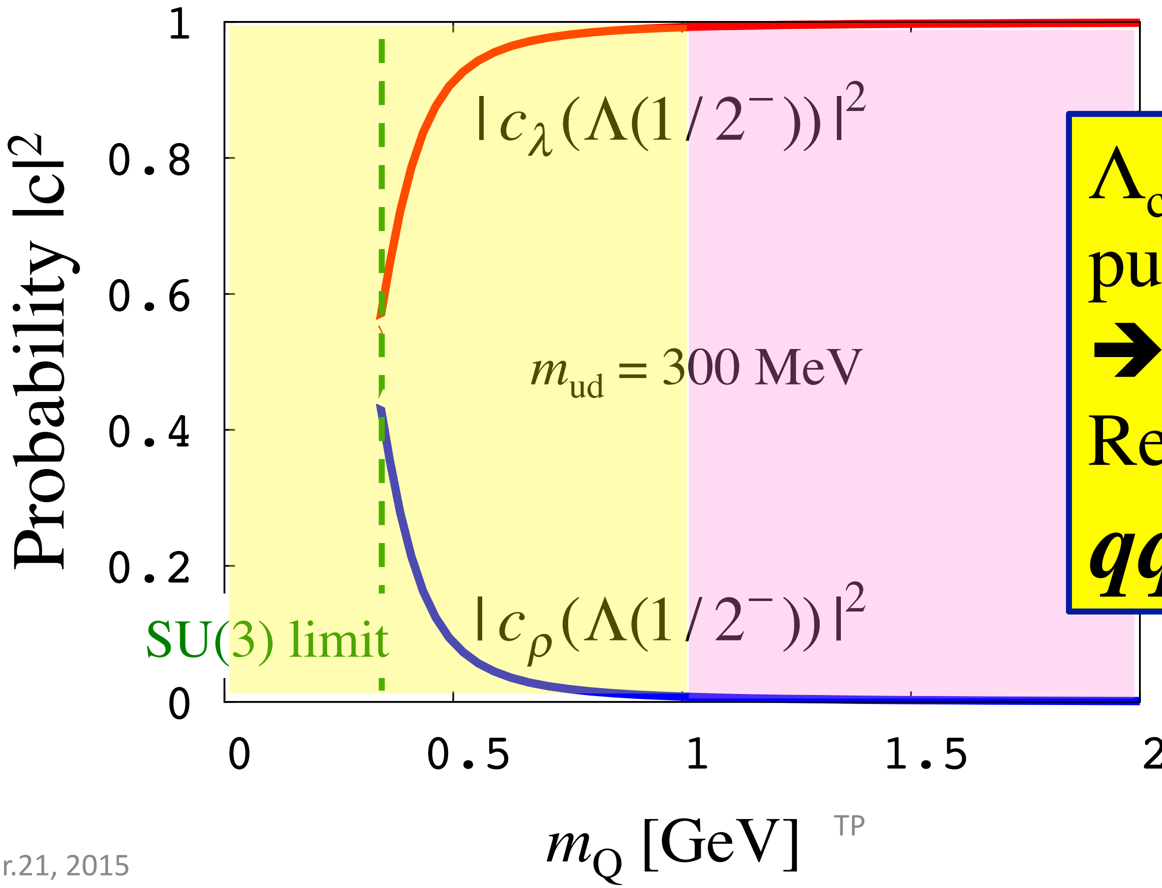


$\Lambda_c{}^*$ is almost pure ***λ*** mode
➔
Reflect more ***qq*** nature

TP

3. Charmed baryon Productions

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

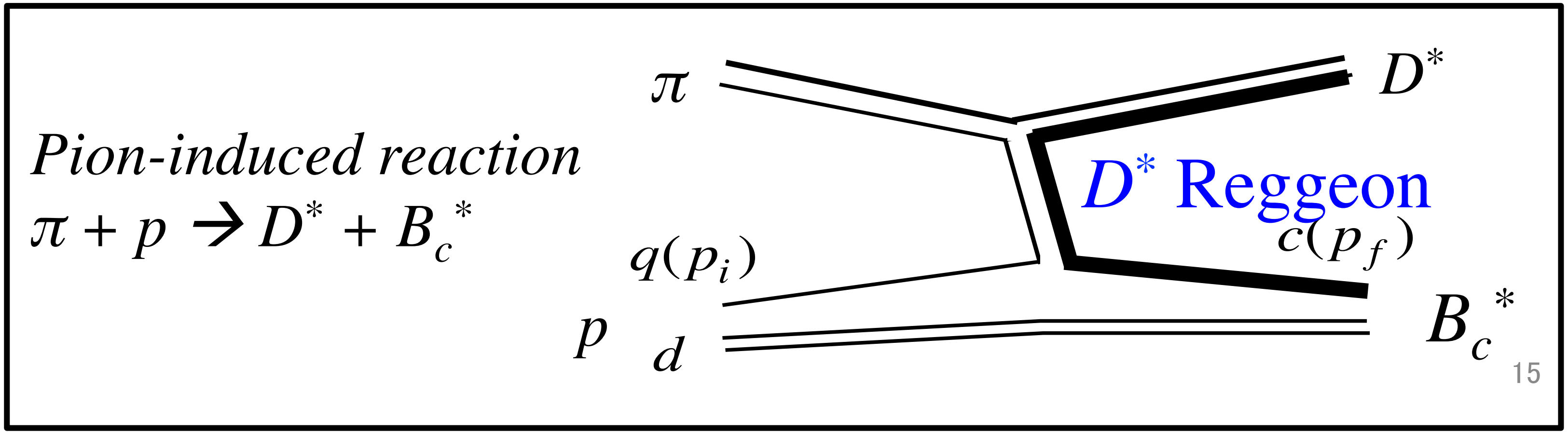
Production rate (Λ_c/Λ) and Ratios (B_c^*/B_c)

Strategy:

Forward peak (high energy) → t-channel dominant

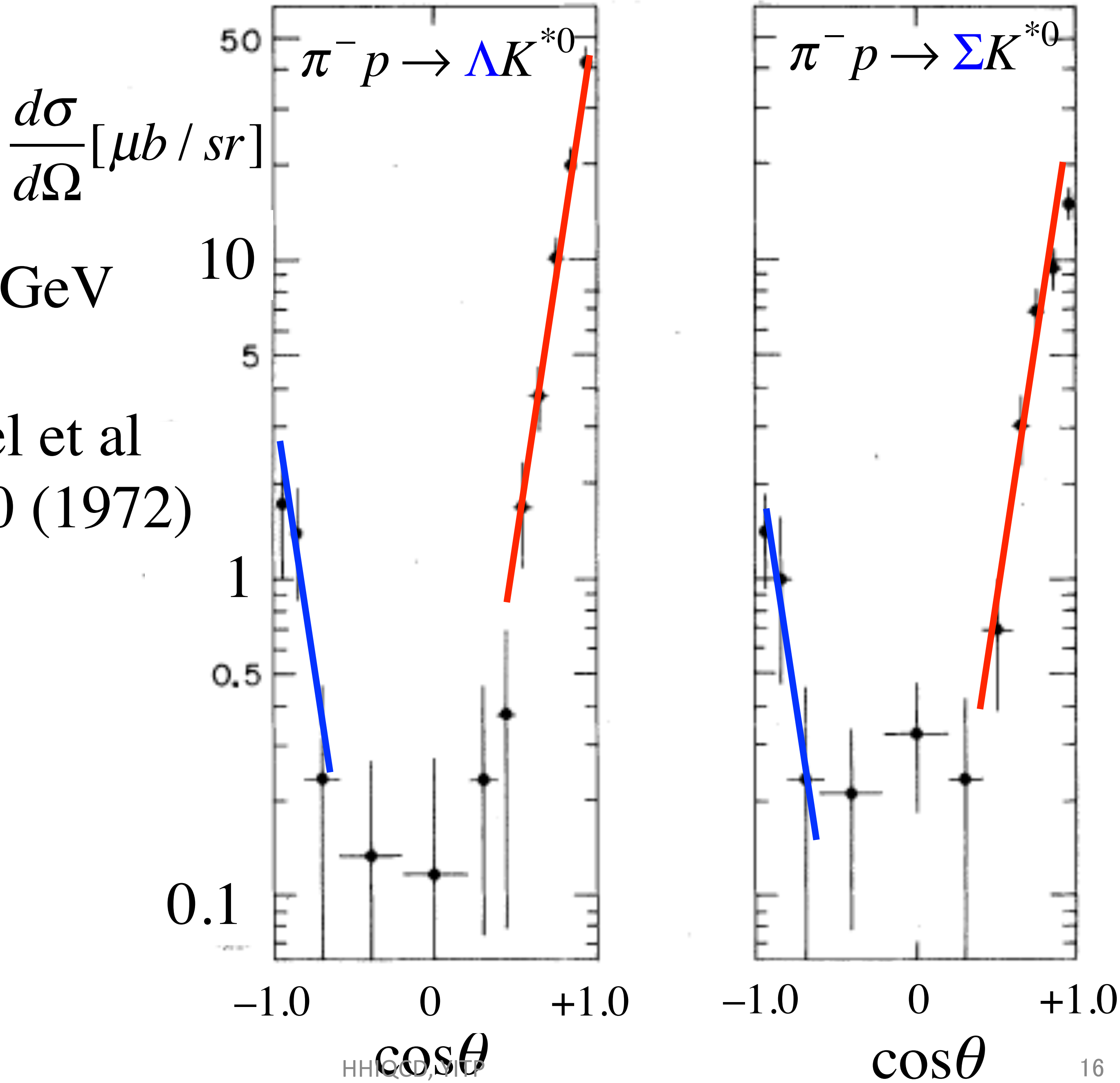
We look at:

- Rates (Λ_c/Λ) by the Regge model, D^* Reggeon
- Relative ratios of $B_c{}^*$(λ modes) / B_c by a one step process of *Qd* picture for λ-mode



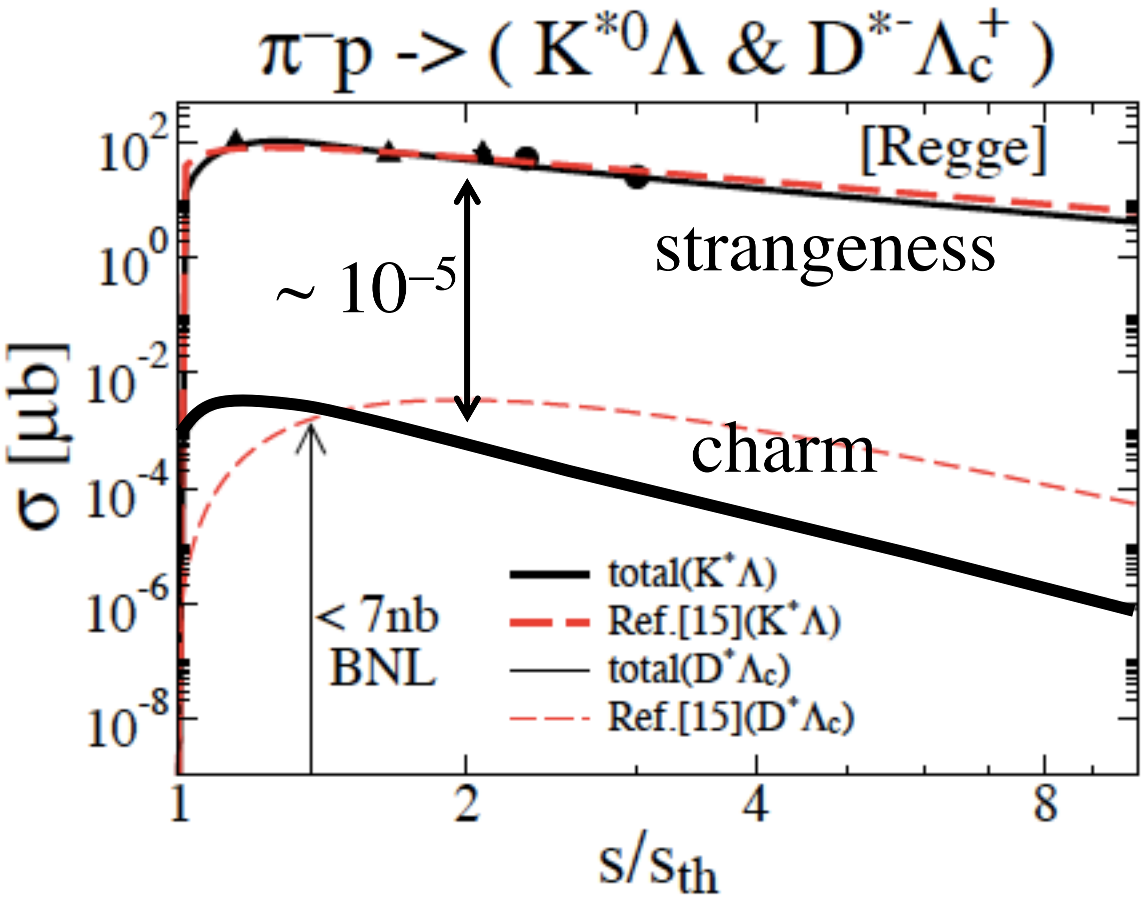
$p_{\pi,\,\mathrm{Lab}} = 4.5\ \mathrm{GeV}$

D.J. Krennel et al
PRD6, 1220 (1972)



Absolute values

Regge model (Sang-Ho Kim, in preparation)



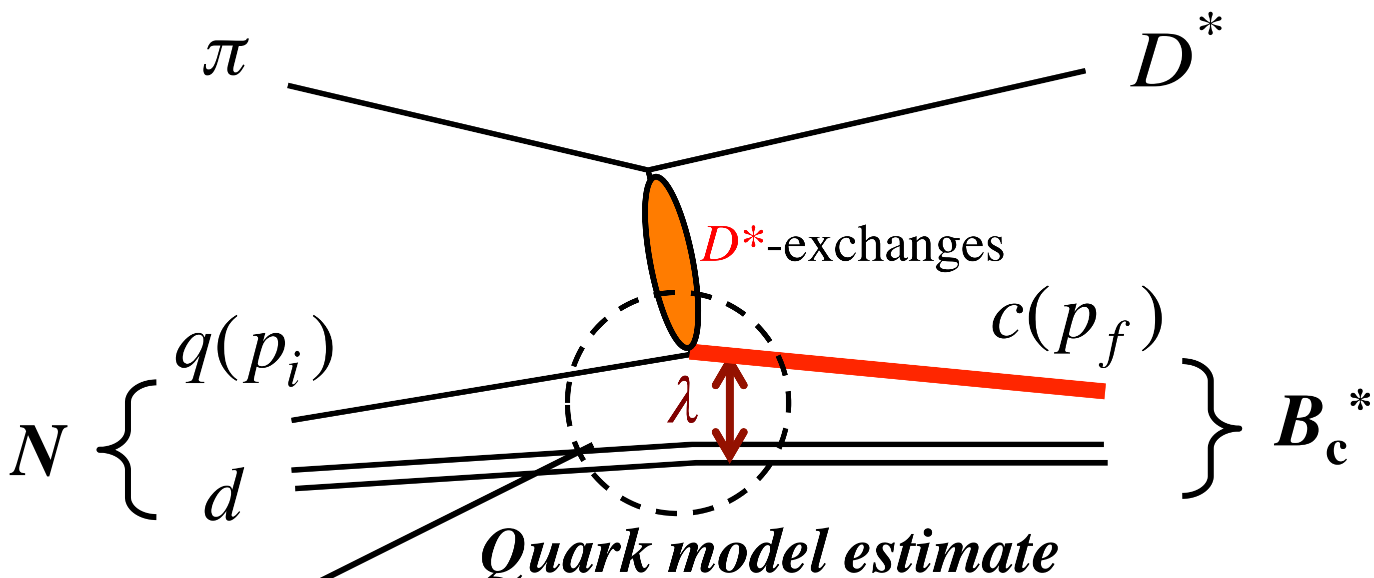
We have examined:

- K^*(strange) productions
- D and D^* Reggeon
- Angular dependence
- u-channels
  - ~ Baryon Regge
- Normalizations

Charm/strangeness ratio: $10^{-4} \sim 10^{-6}$
➔ several nb near the threshold

Relative rates of (B_c^*/B_c)

One step process for Qd λ-mode



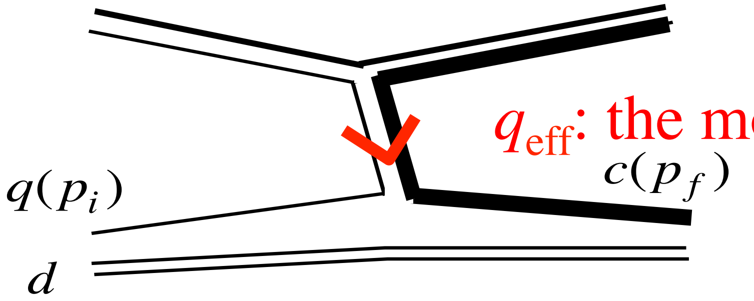
$$t_{fi} \sim \vec{k}_\pi \times \vec{e} \cdot \vec{J}_{fi}$$

$$\sim \left\langle B_c^* \middle| \vec{e}_\perp \cdot \vec{\sigma} e^{i\vec{q}_{eff} \cdot \vec{x}} \middle| N \right\rangle = \text{(Geometric)} \times \text{(Dynamic)}$$

D^* ~ Transverse

CG coefficients

Dynamical part ~ radial integral



$q_{\rm eff}$: the momentum transfer ~ Large

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

Excited states

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

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

Transitions to excited states are not suppressed

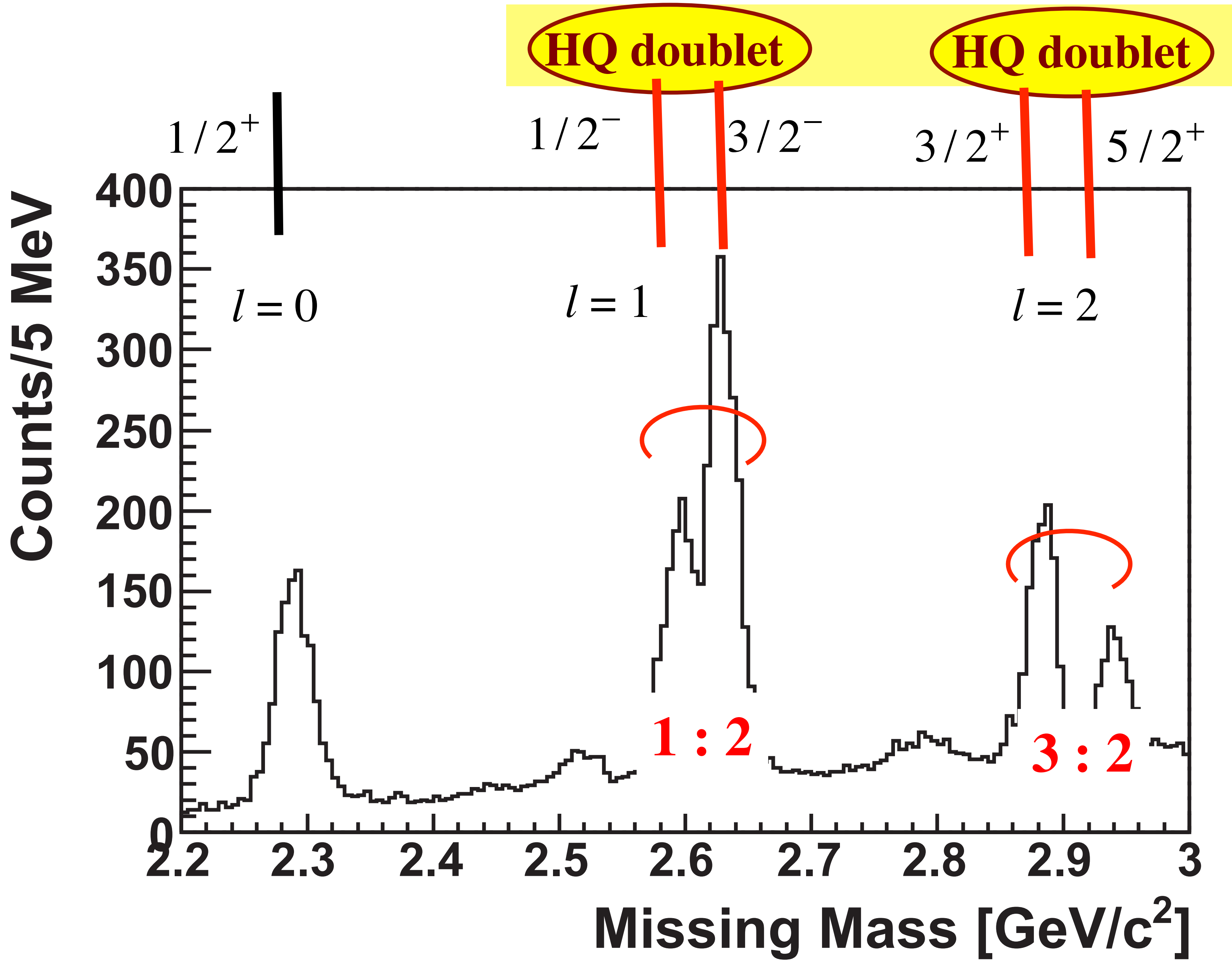
Results

Charm $k_{\pi}^{CM} = 2.71$ [GeV] , $k_{\pi}^{Lab} = 16$ [GeV]

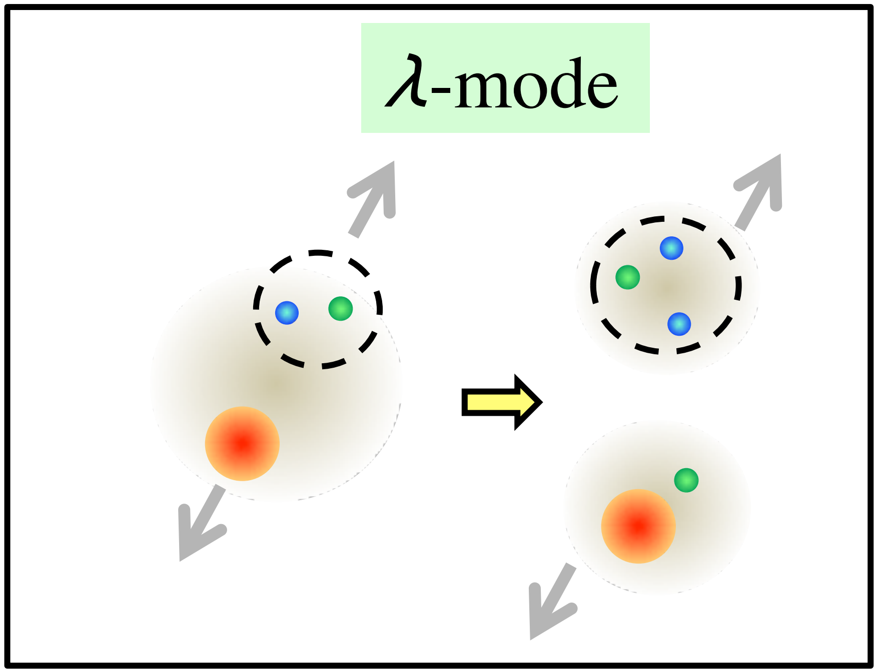
$l = 0$	$\Lambda_c(\frac{1}{2}^+)$	$\Sigma_c(\frac{1}{2}^+)$	$\Sigma_c(\frac{3}{2}^+)$					
	1.00	0.02	0.16					
$l = 1$	$\Lambda_c(\frac{1}{2}^-)$	$\Lambda_c(\frac{3}{2}^-)$	$\Sigma_c(\frac{1}{2}^-)$	$\Sigma_c(\frac{3}{2}^-)$	$\Sigma'_c(\frac{1}{2}^-)$	$\Sigma'_c(\frac{3}{2}^-)$	$\Sigma'_c(\frac{5}{2}^-)$	
	0.90	1.70	0.02	0.03	0.04	0.19	0.18	
$l = 2$	$\Lambda_c(\frac{3}{2}^+)$	$\Lambda_c(\frac{5}{2}^+ -)$	$\Sigma_c(\frac{3}{2}^+)$	$\Sigma_c(\frac{5}{2}^+)$	$\Sigma'_c(\frac{1}{2}^+)$	$\Sigma'_c(\frac{3}{2}^+)$	$\Sigma'_c(\frac{5}{2}^+)$	$\Sigma'_c(\frac{5}{2}^+)$
	0.50	0.88	0.02	0.02	0.01	0.03	0.07	0.07

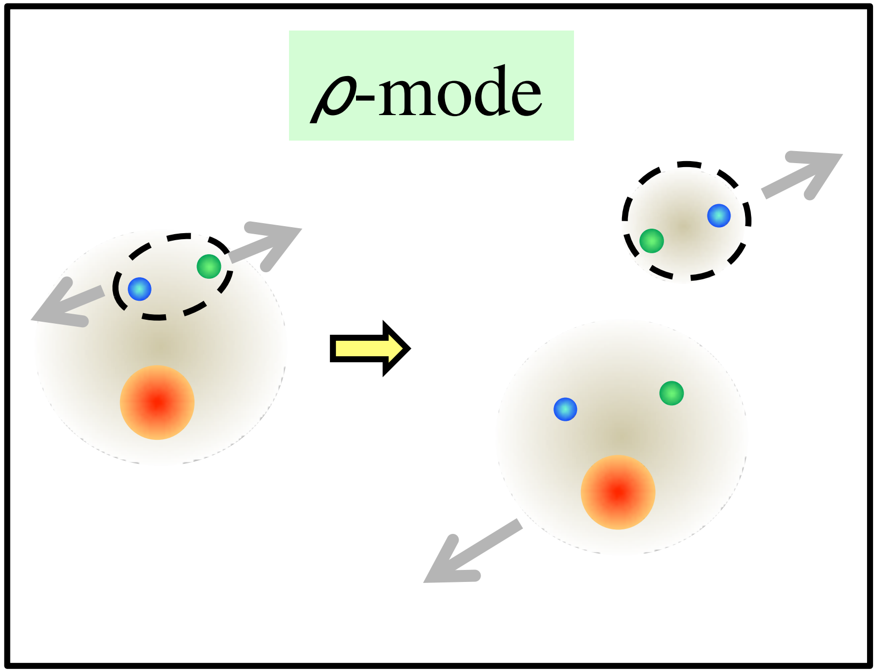
Strange $k_{\pi}^{CM} = 1.59$ [GeV], $k_{\pi}^{Lab} = 5.8$ [GeV]

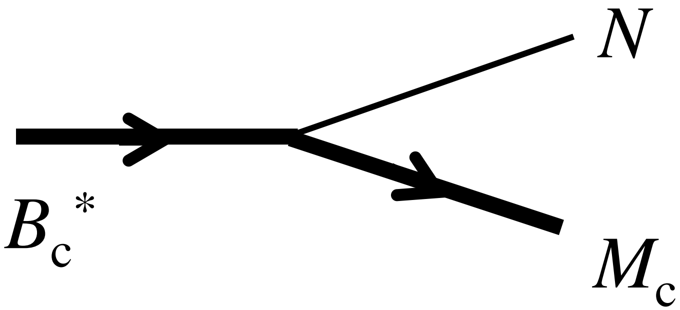
$l = 0$	$\Lambda(\frac{1}{2}^+)$	$\Sigma(\frac{1}{2}^+)$	$\Sigma(\frac{3}{2}^+)$					
	1.00	0.067	0.44					
$l = 1$	$\Lambda(\frac{1}{2}^-)$	$\Lambda(\frac{3}{2}^-)$	$\Sigma(\frac{1}{2}^-)$	$\Sigma(\frac{3}{2}^-)$	$\Sigma'(\frac{1}{2}^-)$	$\Sigma'(\frac{3}{2}^-)$	$\Sigma'(\frac{5}{2}^-)$	
	0.11	0.23	0.007	0.01	0.01	0.07	0.067	
$l = 2$	$\Lambda(\frac{3}{2}^+)$	$\Lambda_c(\frac{5}{2}^+ -)$	$\Sigma(\frac{3}{2}^+)$	$\Sigma(\frac{5}{2}^+)$	$\Sigma'(\frac{1}{2}^+)$	$\Sigma'(\frac{3}{2}^+)$	$\Sigma'(\frac{5}{2}^+)$	$\Sigma'(\frac{5}{2}^+)$
	0.13	0.20	0.007	0.01	0.004	0.02	0.038	0.04

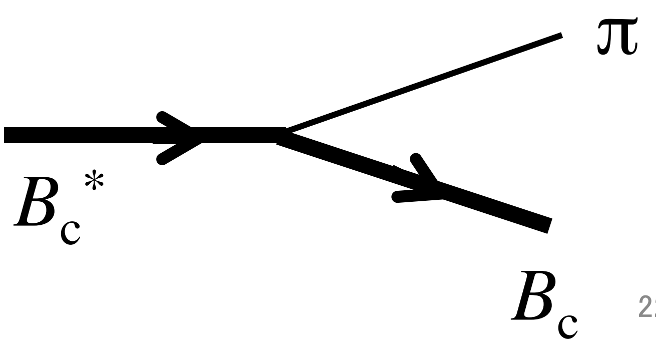

HQ doublet
HQ doublet
1/2+
1/2−
3/2−
3/2+
5/2+
l = 0
l = 1
l = 2
1 : 2
3 : 2
Counts/5 MeV
400
350
300
250
200
150
100
50
0
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Missing Mass [GeV/c2]

4. Decays









Pion emission – quark model --on going

Things to be looked at:

- Pion emission ~ **very near the threshold**
- D-meson emission ~ The coupling of *D*-meson to *cq*

Pion emission – quark model --on going

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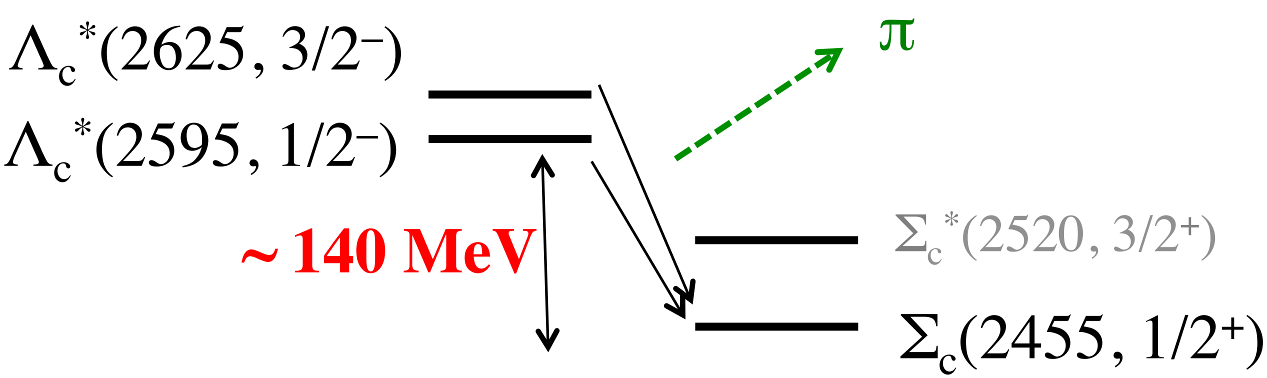
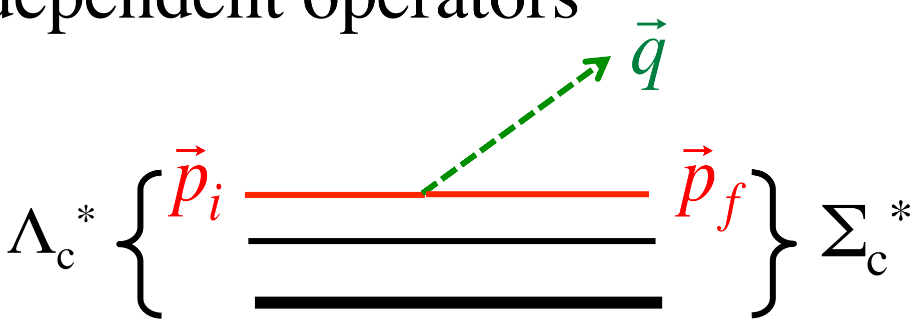
- Pion emission ~ **very near the threshold**



Place to look at the two independent operators

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

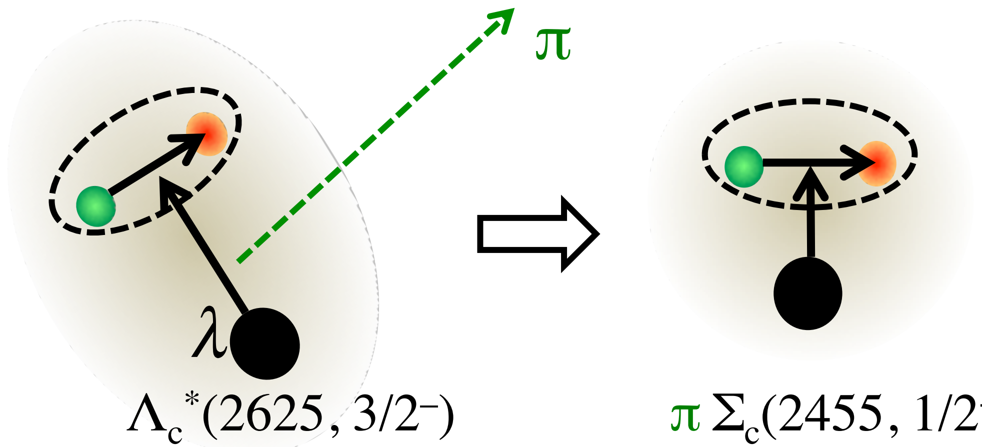
$\vec{\sigma}\cdot\vec{p}_i, \ \vec{\sigma}\cdot\vec{p}_f \ (\vec{\sigma}\cdot\vec{q})$



Pion emission – quark model --on going

Diquark correlation may suppress pion emission

λ-mode decay



overlap vanishes
with strong correlation

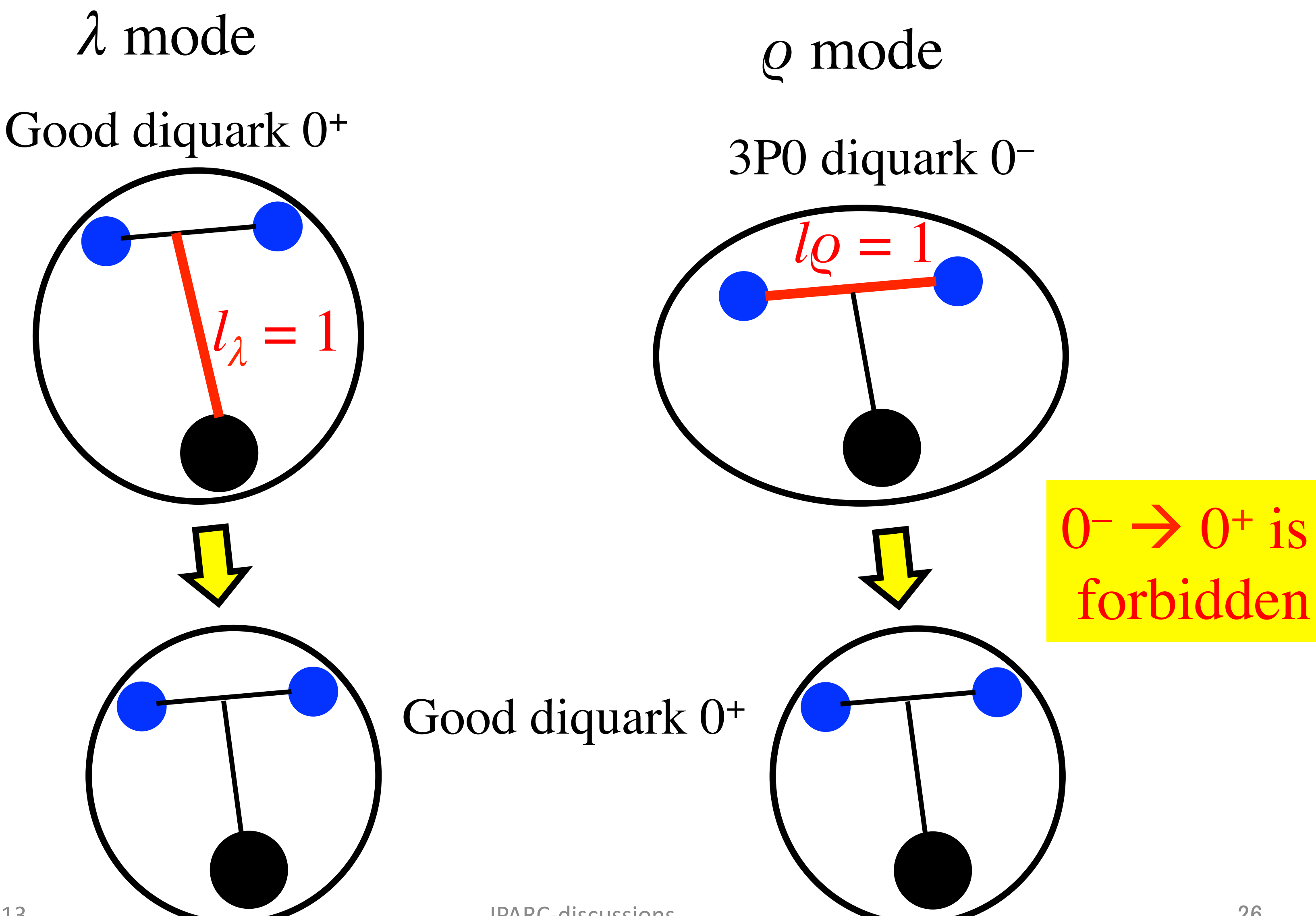
$$A_h = \frac{q}{m}\int d^3X e^{-i(P-q-k)X} \times \int d^3\rho e^{-i\vec{q}_\rho\cdot\vec{\rho}}\langle\psi_0'(\vec{\rho})|\psi_0(\vec{\rho})\rangle$$

$$\times \int d^3\lambda \langle [[\psi_0(\vec{\lambda}), d^1]^1, \chi^c]_h^{J_f} | e^{-i\vec{q}_\lambda\cdot\vec{\lambda}}\sigma_3 | [[\psi_1(\vec{\lambda}), d^0]^1, \chi^c]_h^{J_i}\rangle$$

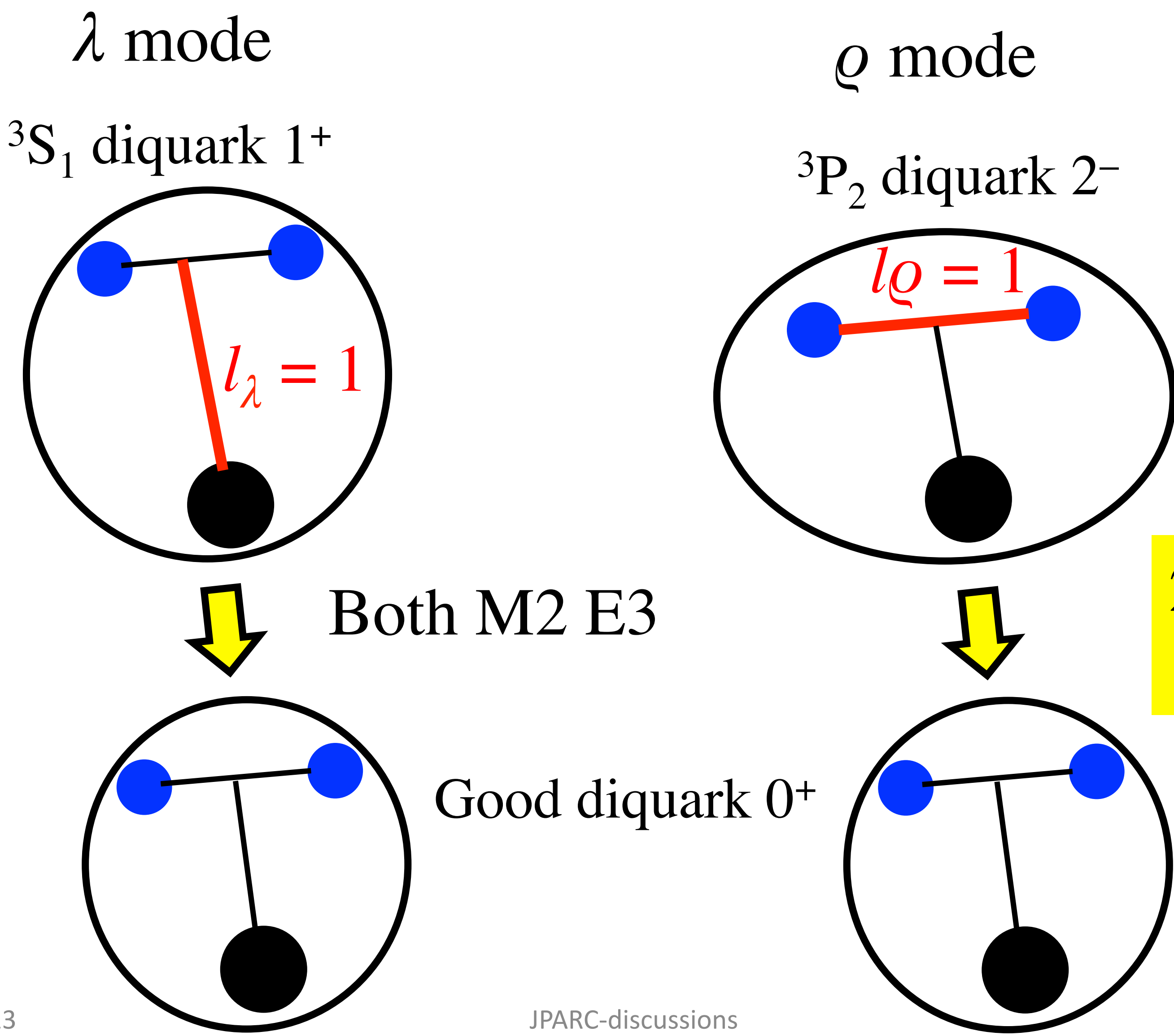
$\Sigma_c(2455, 1/2^+)$ + π ← $\Lambda_c^*(2625, 3/2^-)$

Pion emission by the λ motion

Radiative decay: $1/2^- \rightarrow 1/2^+$ E1



Radiative decay: $5/2^- \rightarrow 1/2^+$ M2, E3



$2^- \rightarrow 0^+$ is only M2

Summary

- Charmed baryons: yet unexplored states
- J-PARC plans to observe them
- ρ and λ modes are distinct (Isotope shift)
  better chance to look at in Λ* than in Σ* → diquarks
- Systematic study in strangeness is important
- Higher excited (Λ) states may be produced a lot
- Pion decay provides unique opportunity
- Radiative decay selection rules are also helpful

The 10th International Workshop on the Physics of Excited Nucleons

NSTAR 2015

- Complete experiments of meson-photoproduction reactions for N*
- Reaction models and PWA for resonance parameters
- Dynamical models and coupled channel analysis
- Baryon (hadron) structure, form factors, and transition amplitudes
- Chiral symmetry and baryon resonances
- Baryons (hadrons) from lattice QCD and new approaches
- Facilities and future projects
- Other topics related to N* physics