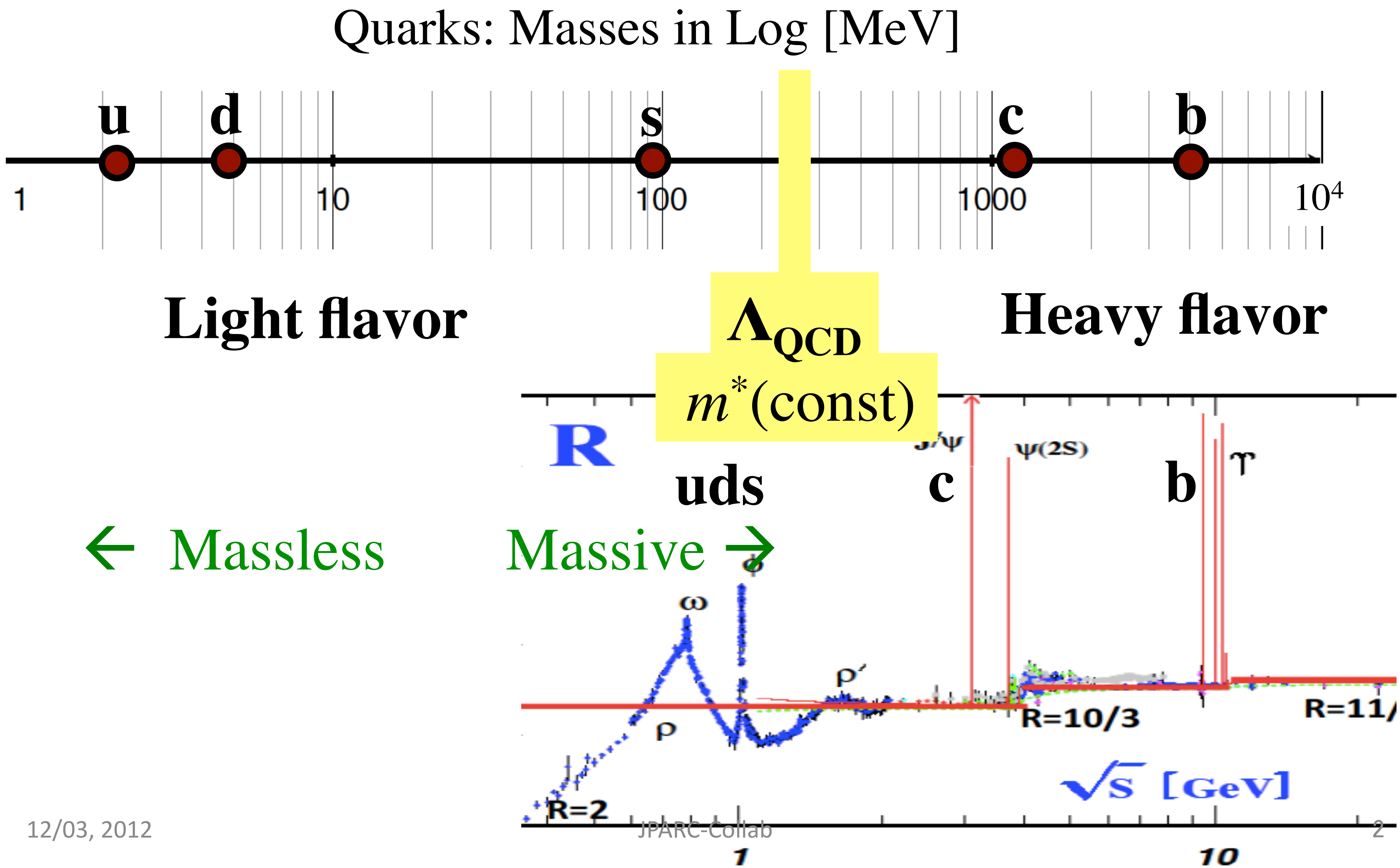
Heavy baryonで探るdiquark相関

保坂　淳　（阪大RCNP）

- はじめに
- ダイクォーク相関
- バリオン分光

はじめに

QCD, with ***invisible color*** and ***variety of flavors***



Heavy flavors

$m_c \sim 1.3$ GeV, $m_b \sim 4.6$ GeV

$E_{\mathrm{int}} \sim \Lambda_{\mathrm{QCD}} \sim 300$ MeV

➔

- $p \sim \sqrt{(2 m_c E_{\mathrm{int}})}$
  $\sim$ 0.7 (~1) GeV (charm)

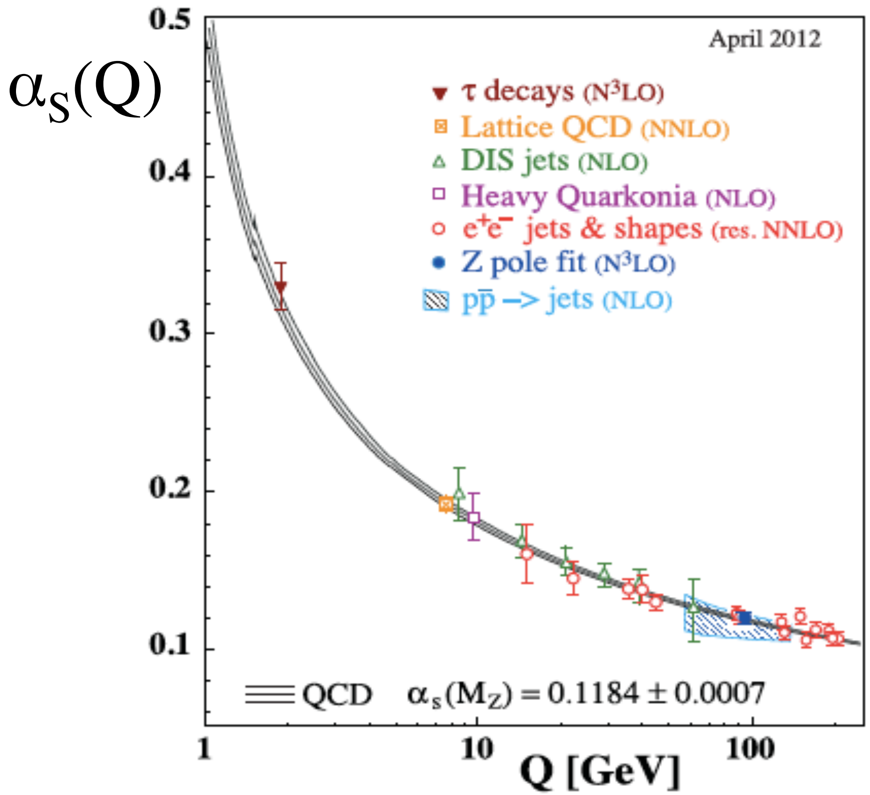
- $V \sim \alpha_S / r \sim 0.5/(0.2*\sqrt{6})$ [fm]
  ~ 200 MeV $<< m_c$

→ ~ Perturbative

- $v \sim p/M \sim 0.5$

→ Nonrel.

PDG 2012



Light flavors

$m_u \sim 2$ MeV, $m_d \sim 4.8$ MeV, $m_s \sim 95$ MeV
$E_{int} \sim \Lambda_{QCD} \sim 300$ MeV ~ *dynamically generated mass*
Quasiparicles for ΔE(excitations) < 1 GeV

Hierarchies

- Bare quarks → Const. massive quarks
  → Diqaurks …
- Hadrons → Multihadrons (nuclei)

Threshold

- Orbital excitations ~ qq^{bar} creation (~ real)

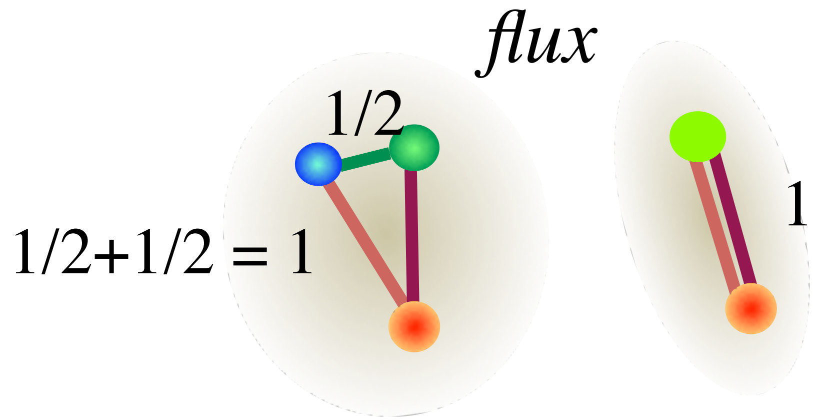
→ Multiquarks

Pions

- Present around light quarks
- Source of interactions between const. quarks
  → hadron interactions of light quarks

ダイクォーク相関

Selem-Wilczek: e-Print: [hep-ph/0602128](hep-ph/0602128)



- ee は斥力
- qqは引力を持つ
  SU(3)c :qq^{bar}の半分
  SU(2)c : qq^{bar}と同じ → Pauli-Gursey symmetry
  $q \sim q^{bar}$
  qq^{bar}力はカイラル対称性を破る
  質量の生成、パイオンのゼロ質量
- qq力は十分強い ~ 数百MeV

スピン、フレーバー依存

Color magnetic int.

$$\frac{\alpha}{m_i m_j}\frac{\lambda^a(i)}{2}\frac{\lambda^a(j)}{2}\vec{\sigma}(i)\cdot\vec{\sigma}(j)$$

qq	$(\bar{3}_C, 0_S)$ $-1/2$	$(\bar{3}_C, 1_S)$ $+1/6$	$(6_C, 0_S)$ $+1/4$	$(6_C, 1_S)$ $-1/12$
$\bar{q}q$	$(1_C, 0_S)$ -1	$(1_C, 1_S)$ $+1/3$	$(8_C, 0_S)$ $+1/8$	$(8_C, 1_S)$ $-1/24$

Good diquark ↑↓ Bad diquark ↑↑

- Σ-Λ (80 MeV), Σ_c-Λ_c (215 MeV) mass difference
- Λ, Σの生成比 (e+e-@10 GeV)

  $\Lambda : \Sigma = 0.08:0.023$, $\Lambda c : \Sigma c = 0.074:0.014$
- $\Delta I = ½$ rule
- $F_2^n/F_2^p \rightarrow ¼$
- Exoticsができにくい ← Good diquark間は斥力？

Chew-Frautsch systematics

Regge trajectory in a relativistic string connecting q-qq of finite mass

$$\mu^{3/2} = \mu_1^{3/2} + \mu_2^{3/2}$$

$$E \approx \sqrt{\sigma L} + \kappa L^{-\frac{1}{4}} \mu^{\frac{3}{2}}$$

$$\kappa \equiv \frac{2}{3} \frac{\pi^{\frac{1}{2}}}{\sigma^{\frac{1}{4}}}$$

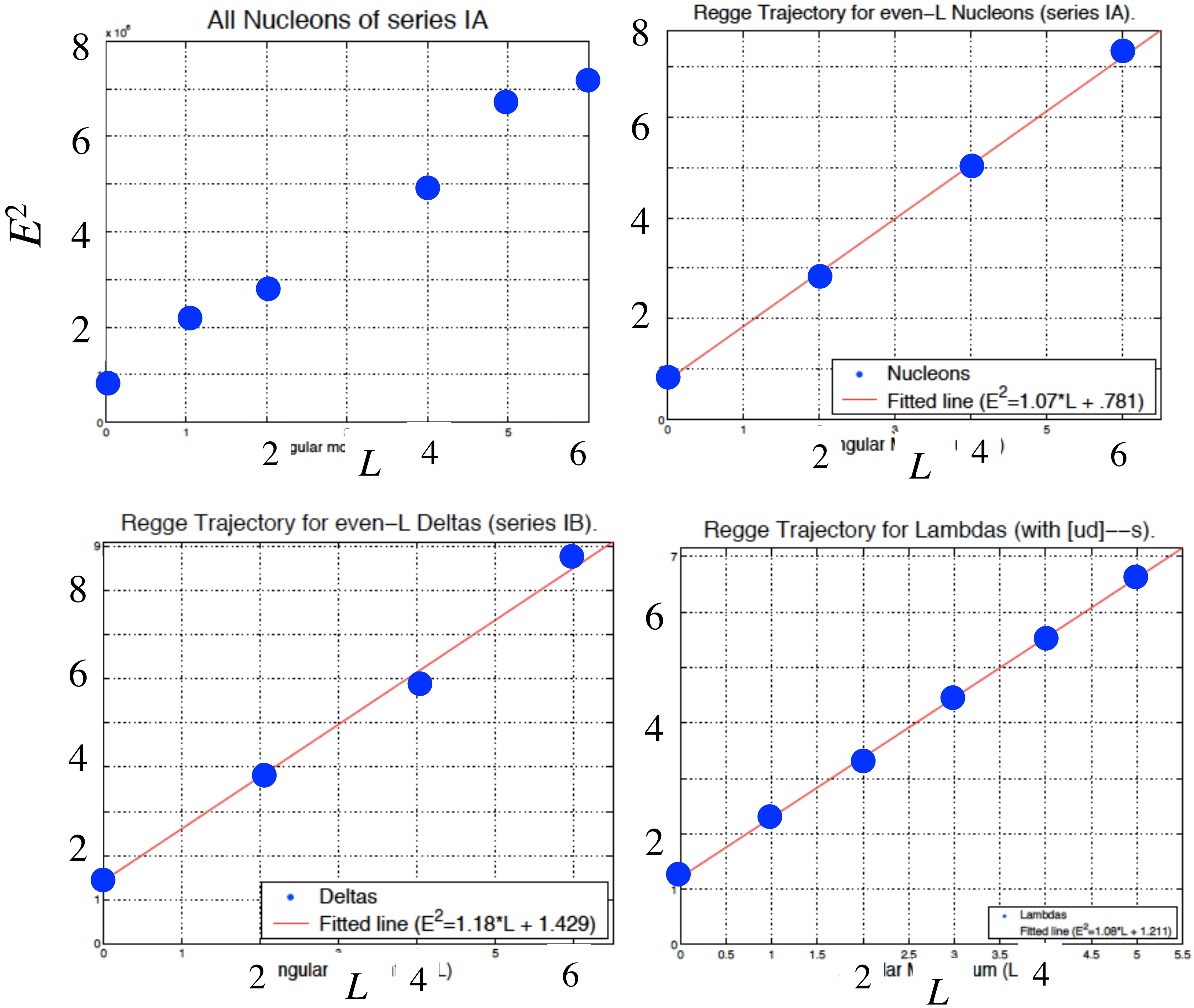
$$\mu \ll M$$

$$E - M = \sqrt{\frac{\sigma L}{2}} + 2^{\frac{1}{4}} \kappa L^{-\frac{1}{4}} \mu^{\frac{3}{2}}$$

$\sigma \sim 1.1$ GeV^2

N(1680)-Δ(1950) $$(ud)^{3/2} - [ud]^{3/2} = \frac{2^{1/4}}{\kappa}(1.950 - 1.680) = .28 \text{ GeV}^{3/2}$$

Σ(2030)-Σ(1915) $$(us)^{3/2} - [us]^{3/2} = \frac{2^{1/4}}{\kappa}(2.030 - 1.915) = .12 \text{ GeV}^{3/2}$$

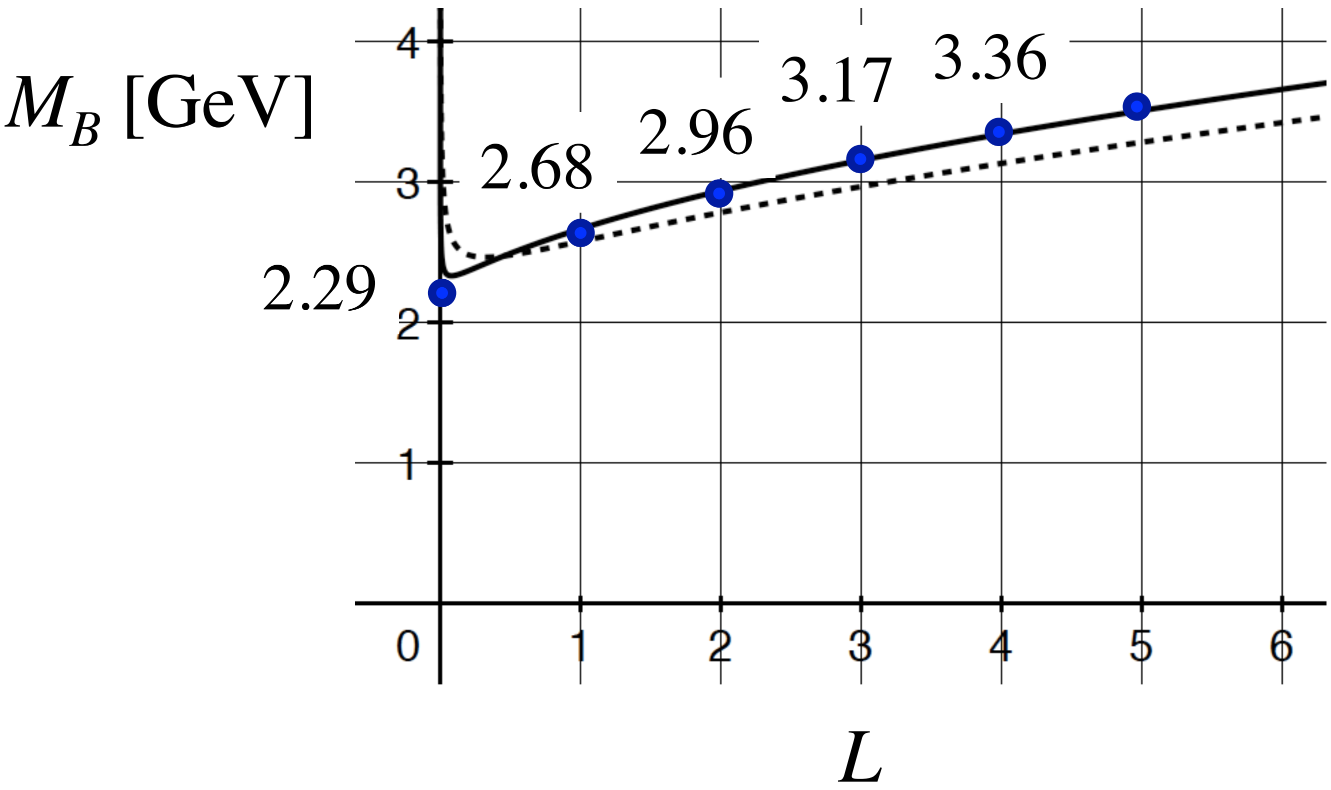

All Nucleons of series IA
E^2
L
Regge Trajectory for even–L Nucleons (series IA).
Nucleons
Fitted line (E^2=1.07*L + .781)
L
Regge Trajectory for even–L Deltas (series IB).
Deltas
Fitted line (E^2=1.18*L + 1.429)
L
Regge Trajectory for Lambdas (with [ud]––s).
L

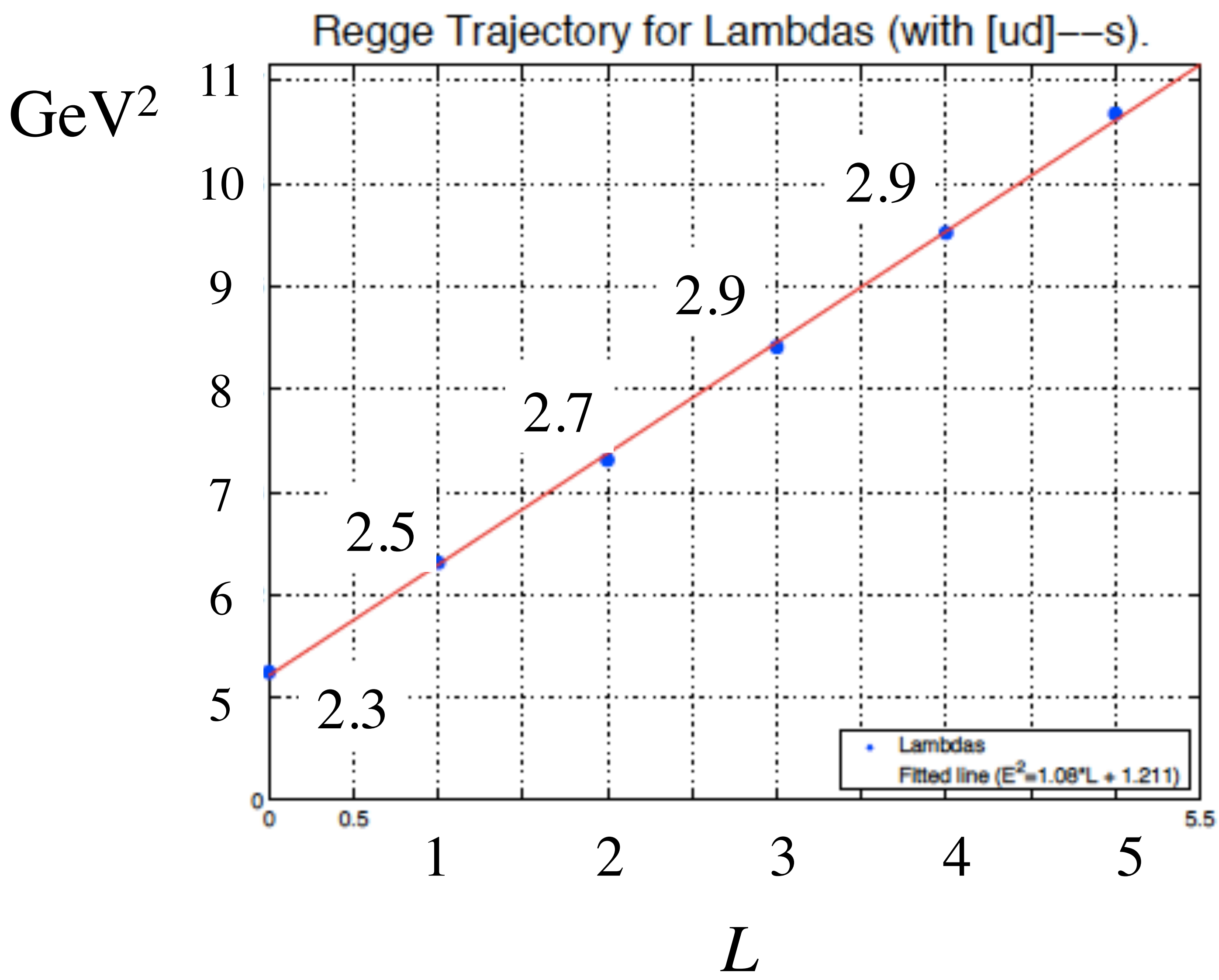
Selem-Wilczek

$$E - M = \sqrt{\frac{\sigma L}{2}} + 2^{\frac{1}{4}} \kappa L^{-\frac{1}{4}} \mu^{\frac{3}{2}}$$

$\mu = 0.3, M = 1.7$
$\mu = 0.6, M = 1.2$

Λc trajectory





Regge Trajectory for Lambdas (with [ud]−−s).
GeV²
11
10
9
8
7
6
5
0
0
0.5
5.5
1
2
3
4
5
L
2.3
2.5
2.7
2.9
2.9
Lambdas
Fitted line (E²=1.08*L + 1.211)

格子QCD

ダイクォーク相関関数

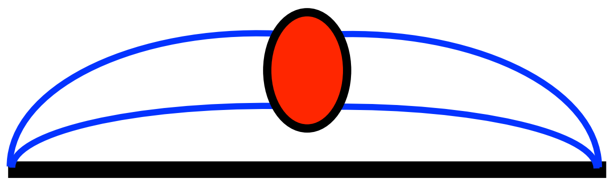
$$C(\boldsymbol{r}_u,\boldsymbol{r}_d;t)=\langle 0|J_\Gamma(0,2t)\rho_u(\boldsymbol{r}_u,t)\rho_d(\boldsymbol{r}_d,t)J_\Gamma^\dagger(0,0)|0\rangle$$

$$\rho(\boldsymbol{r},t)=\bar{q}_f\gamma_0 q_f,\quad f=u,d$$

$$J_\Gamma(x)=\varepsilon^{abc}[u_a^T(x)C\Gamma d_b(x)\pm d_a^T(x)C\Gamma u_b(x)]s_c(x)$$

ud-diquark　　Static heavy quark

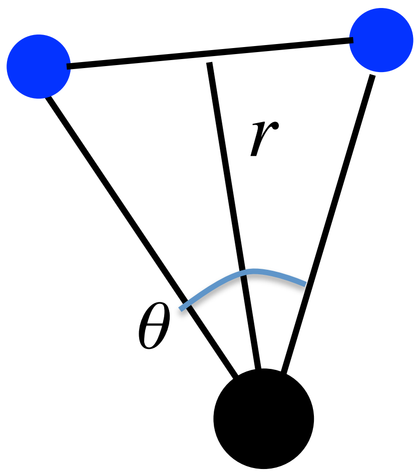
$\rho_u(\boldsymbol{r}_u,t)\rho_d(\boldsymbol{r}_d,t)$

$2t$  $t=0$

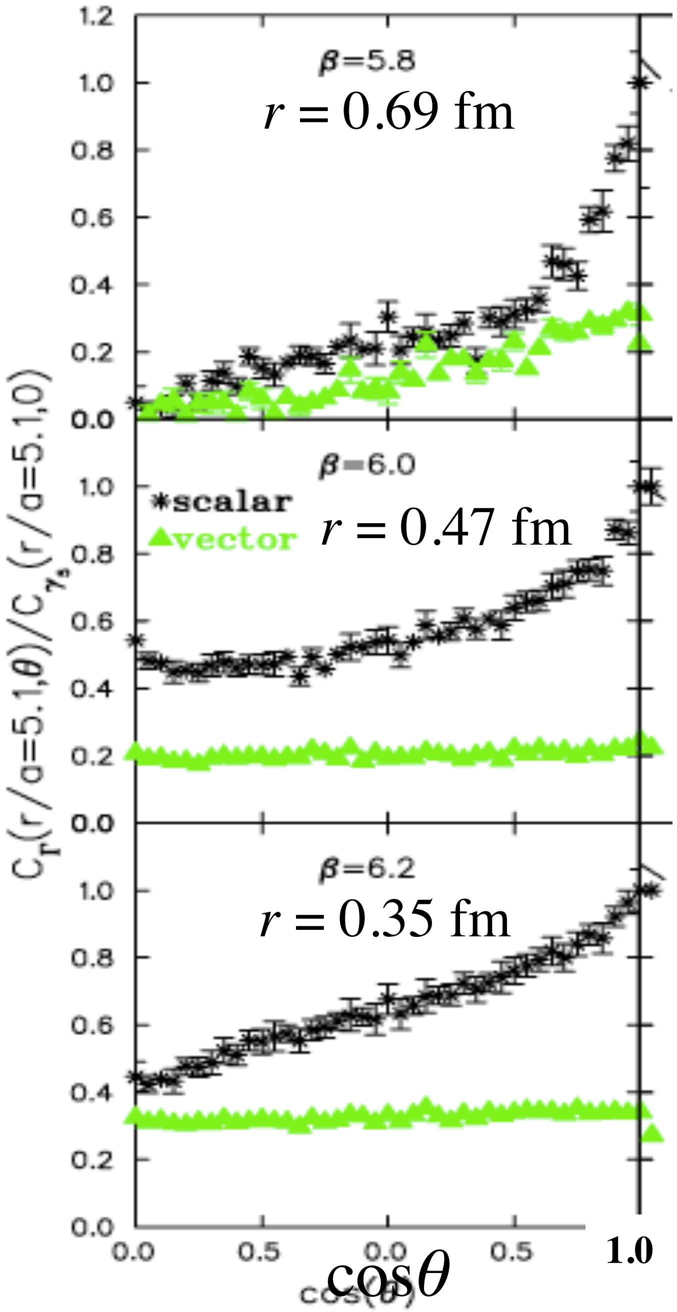
t

Density correlations

Alexandrou, deForcrand, Lucini
PRL 97, 222002 (2006)



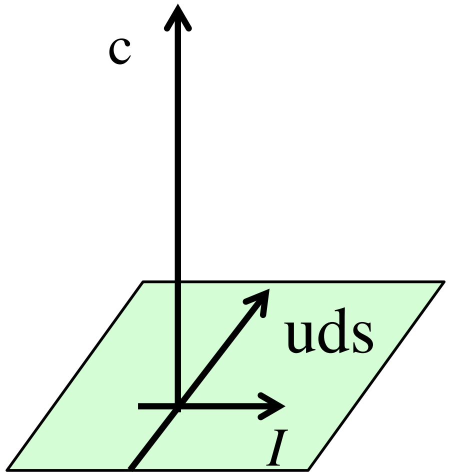
Good diquark
Bad diquark

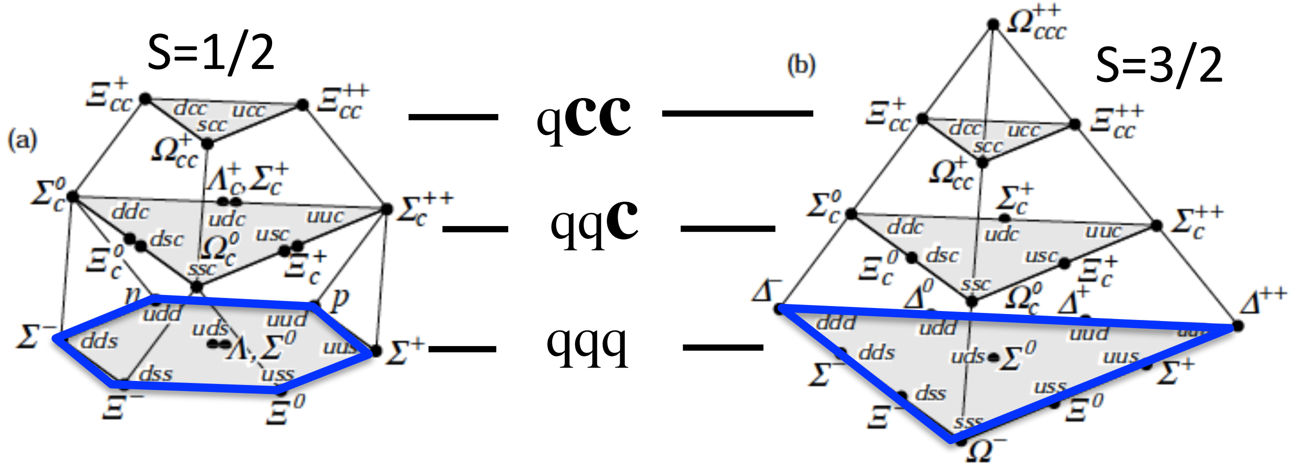


Indicates significant attraction
between quarks in good diquark pair

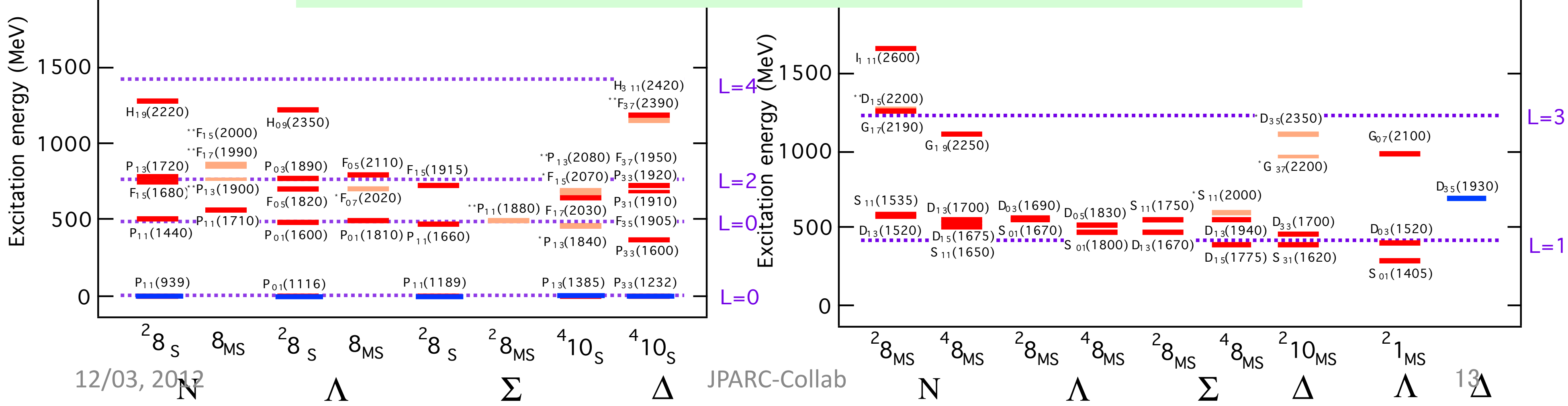
バリオン分光

軽いクォーク(uds)のバリオン



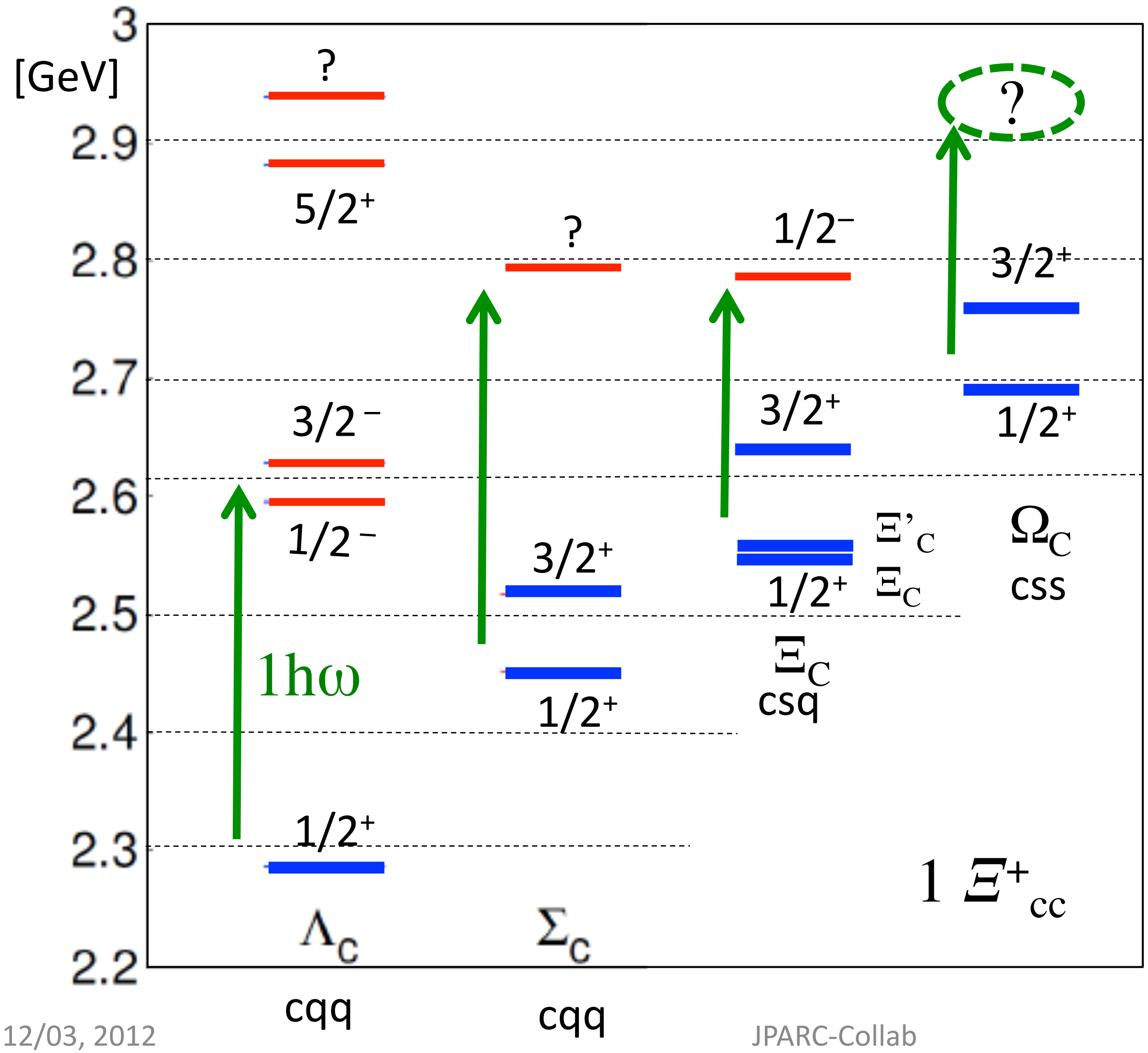


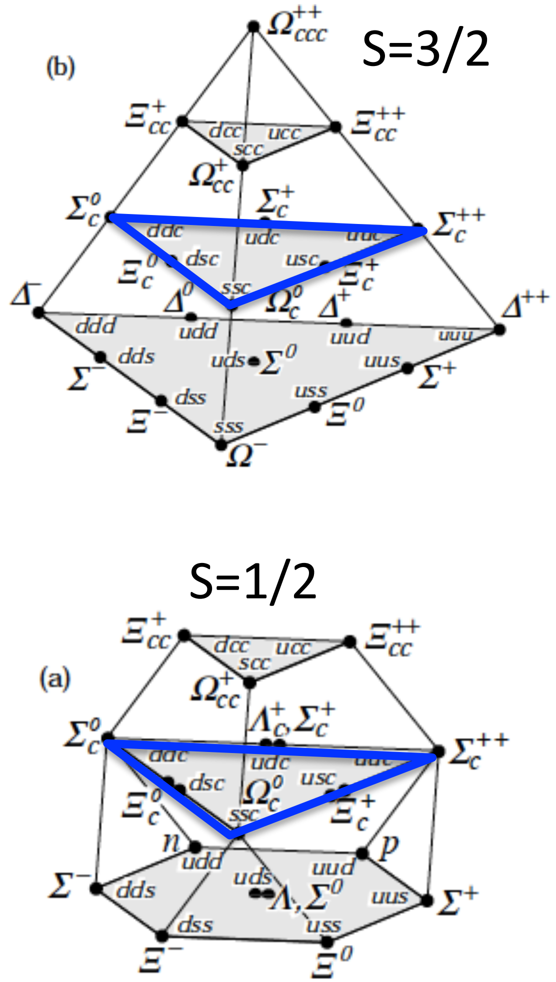
基底状態 8 + 10 と励起状態 ~ 80 個が観測



Charmed baryons $14_c + 1_{cc} \ll 80_{uds}$ 個

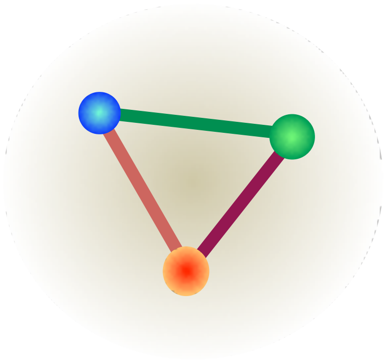
$(6_{excited})$



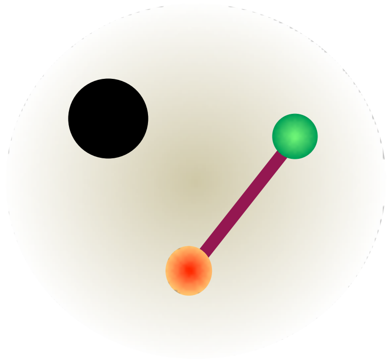


重いハドロンを使う利点

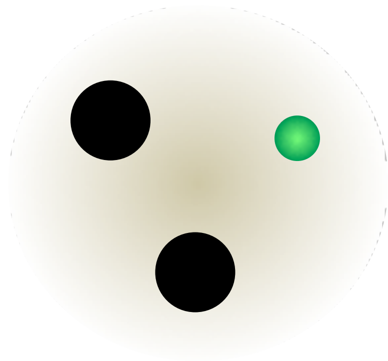
- モードを差別化する



バリオン



ダイクォーク
重いクォーク

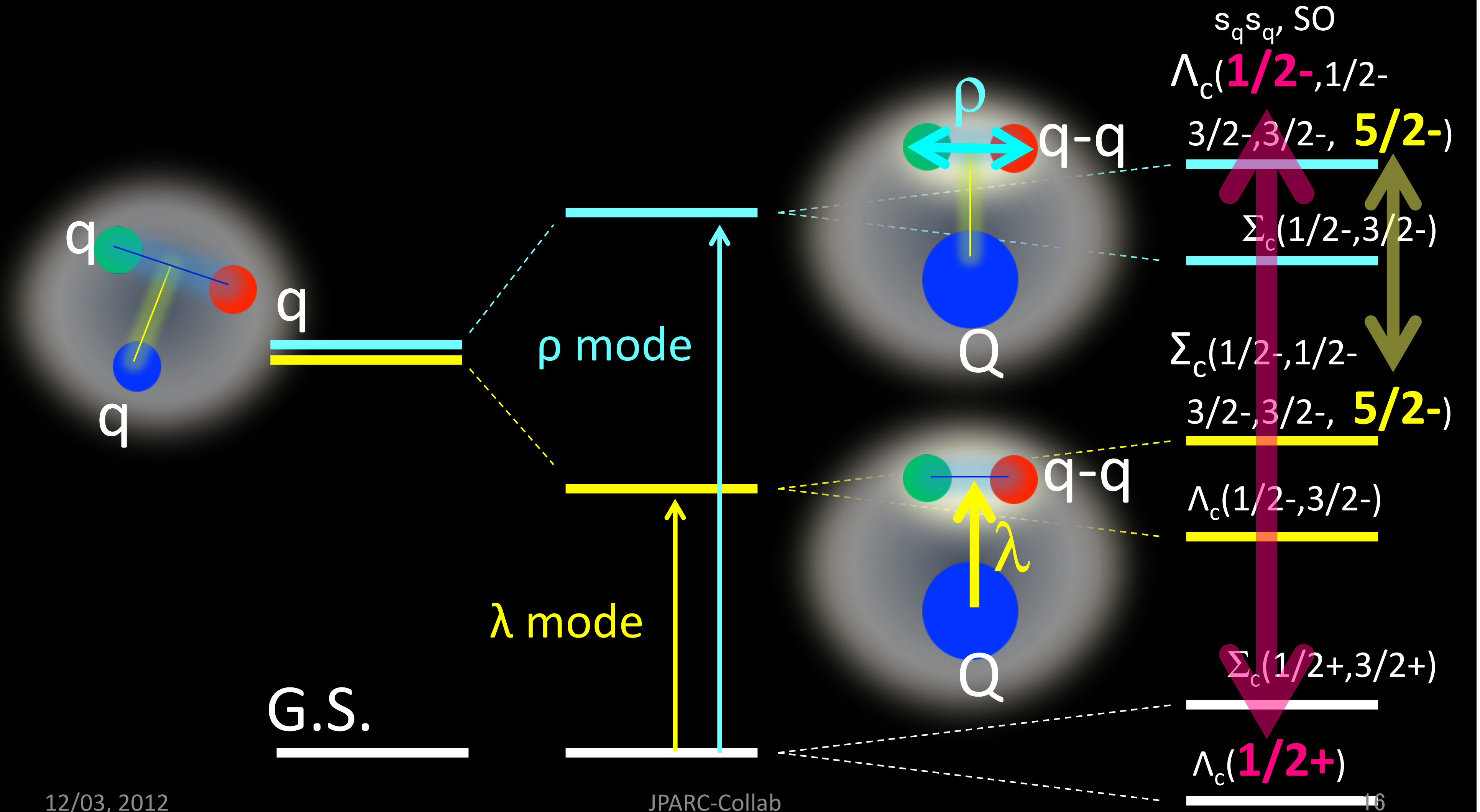


構成クォーク
重いダイクォーク

- 予想されるスペクトラム、崩壊、生成比を実験で検証

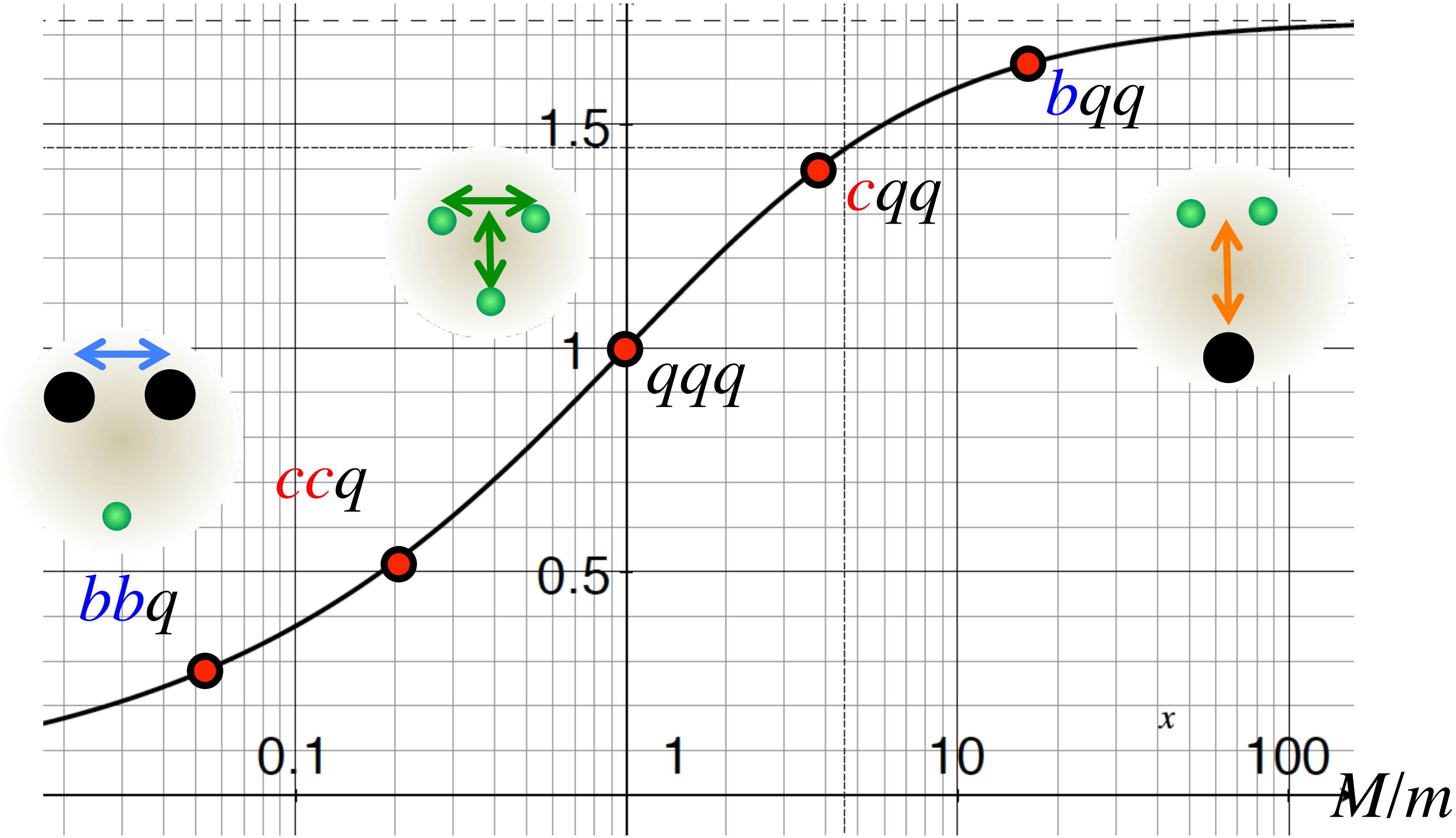
“Q” may isolate “qq”

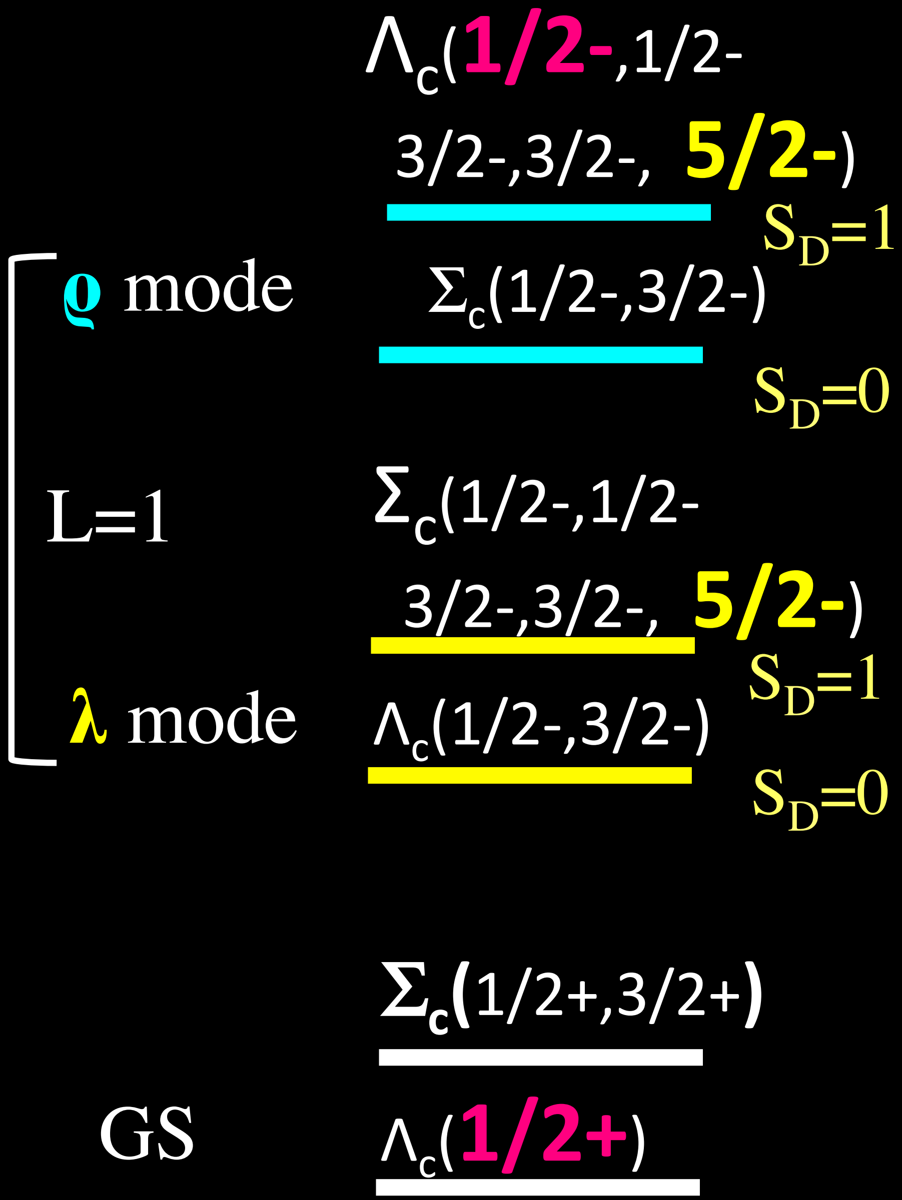
- λ and ρ motions split → known as ***isotope shift***



Spectrum

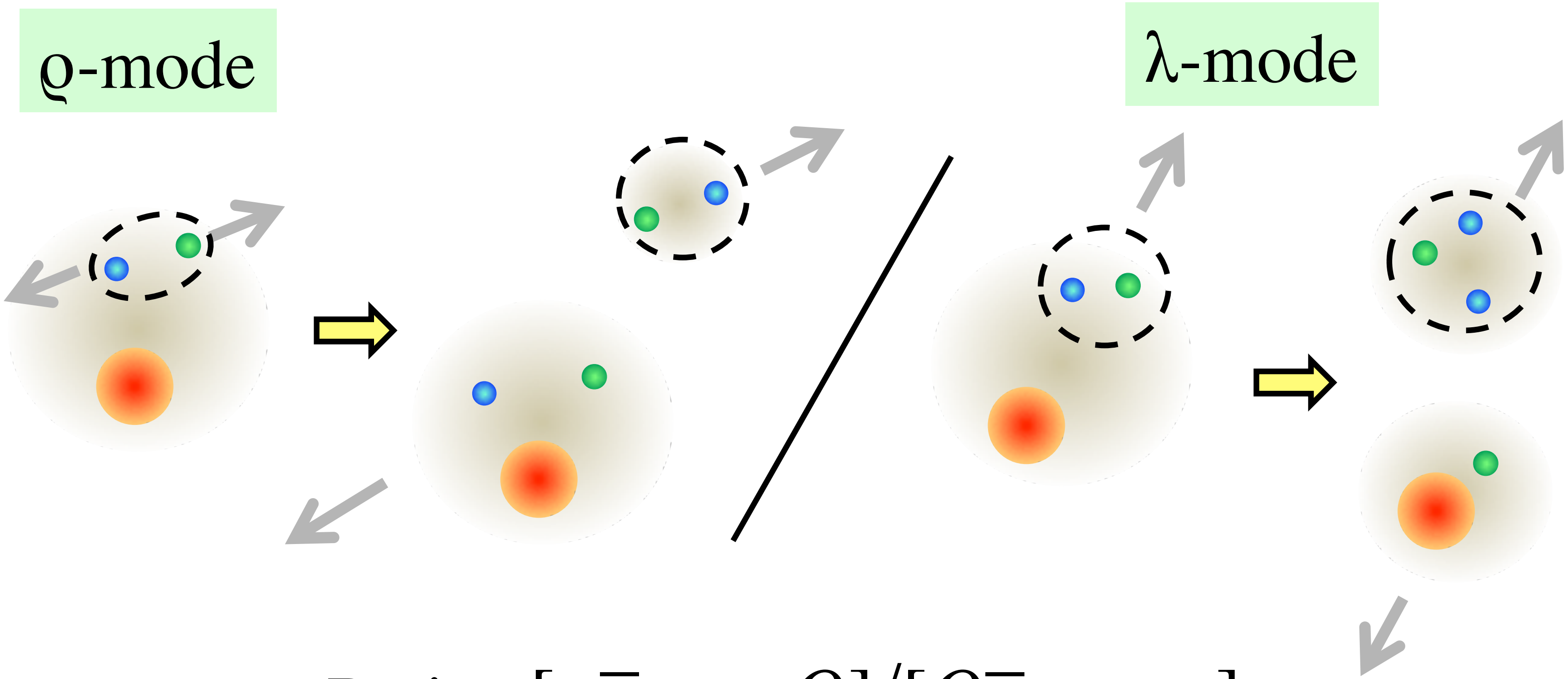
$$\frac{\omega_\lambda}{\omega_\rho} = \left[\frac{1}{3}\left(1+\frac{2m}{M}\right)\right]^{1/2} = \left[\frac{1}{3}(1+2x)\right]^{1/2}$$





- ***Isotope shift***
  5/2- provides cleanest configuration
  - *Indication in strange baryons*
    $\Lambda_{5/2-}(1830) > \Sigma_{5/2-}(1775)$
    (ρ) (λ)
- ***Chiral partner*** of diquarks
  $0^+(^1S_0)$ and $0^-(^3P_0)$
  just as
  π and σ

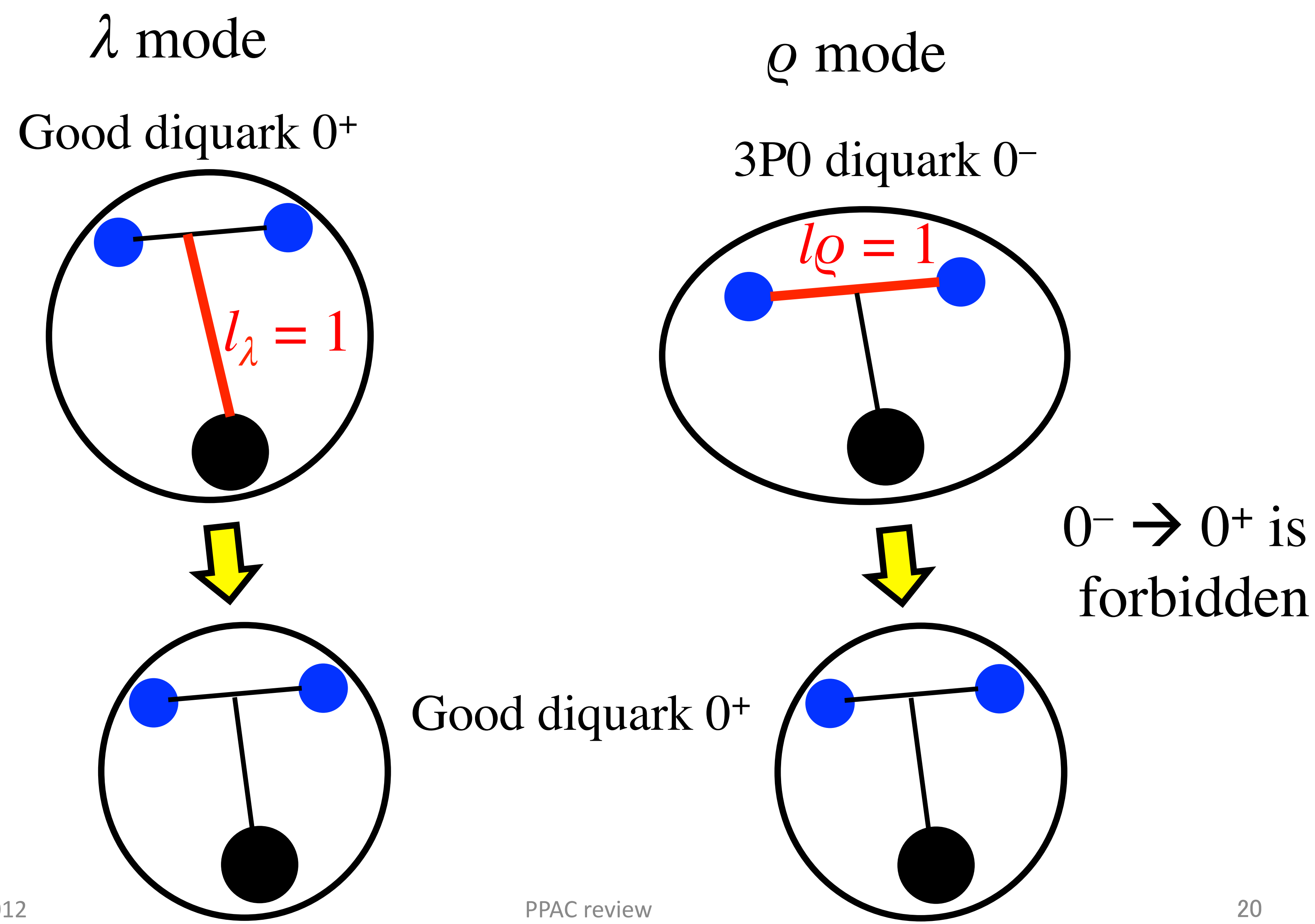
Decays



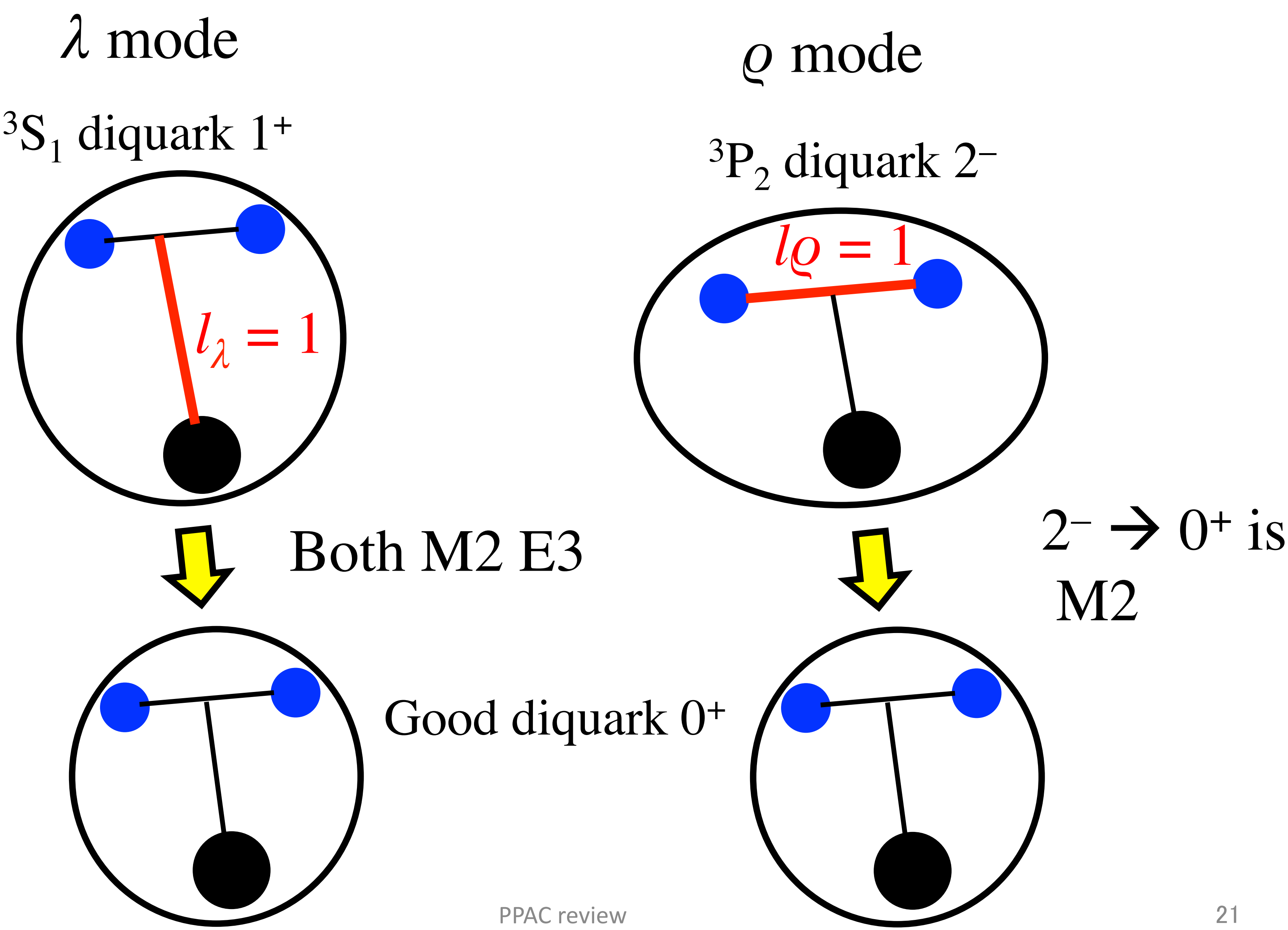
Ratio: $[q\bar{q} + qqQ]/[Q\bar{q} + qqq]$

ϱ-modeバリオンは軽い中間子と重いバリオンに
λ-mode　　　　　　　重い　　　　　　軽い　　　　　に崩壊

$1/2^- \rightarrow 1/2^+$ E1 transition



$5/2^- \rightarrow 1/2^+$ M2, E3 transition



重いクォークの役割

- 2体相関を見る
- スペクトラムの系統性
  λ-ϱモードの分離、Good, bad diquark
- 崩壊パターン、ダイクォーク相関による選択則
- ダイクォークの分布