Hyperon and charmed baryon productions with an instanton interaction

Sang-In Shim

RCNP, Osaka University

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Collaborated with Prof. Atsushi Hosaka and Prof. Hyun-Chul Kim

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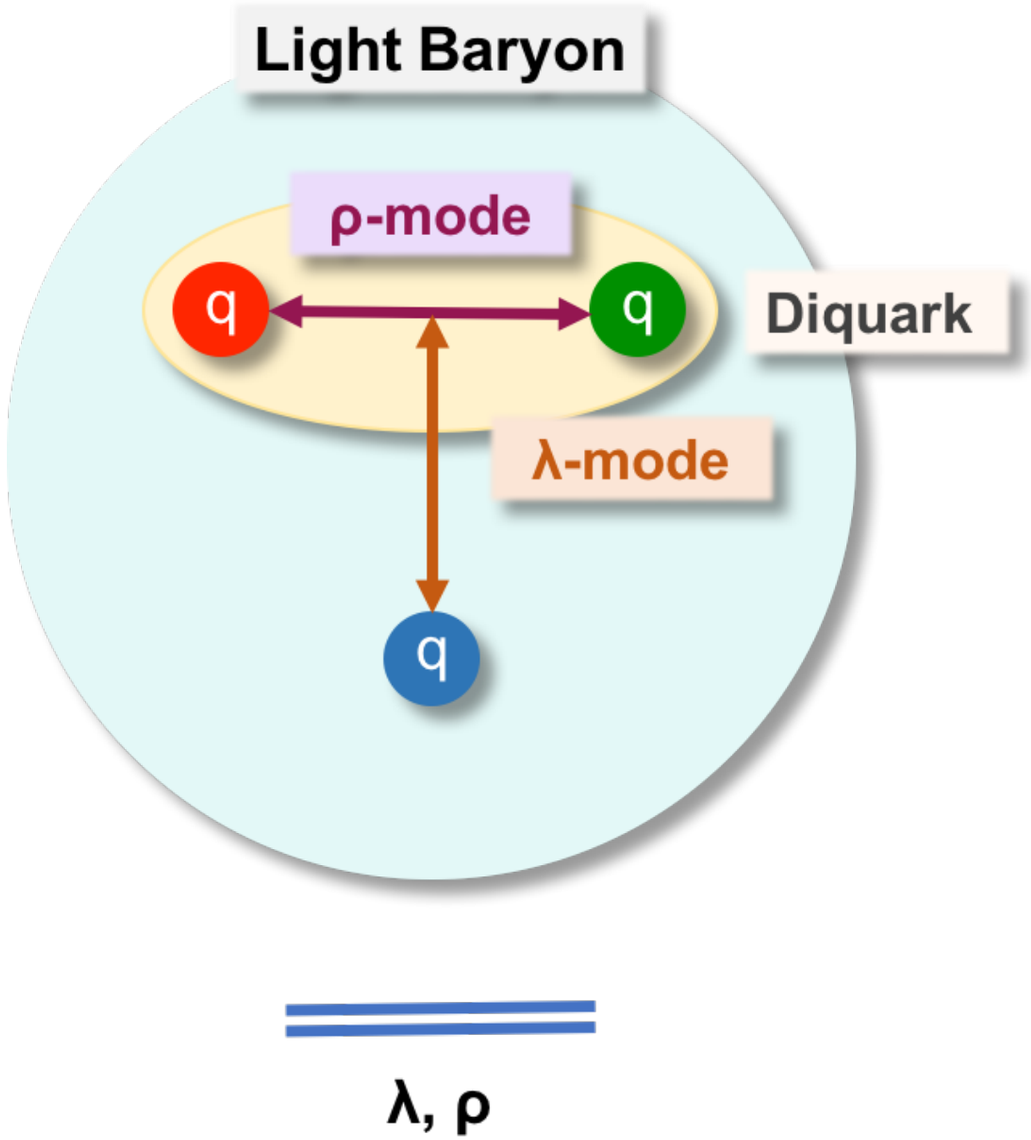
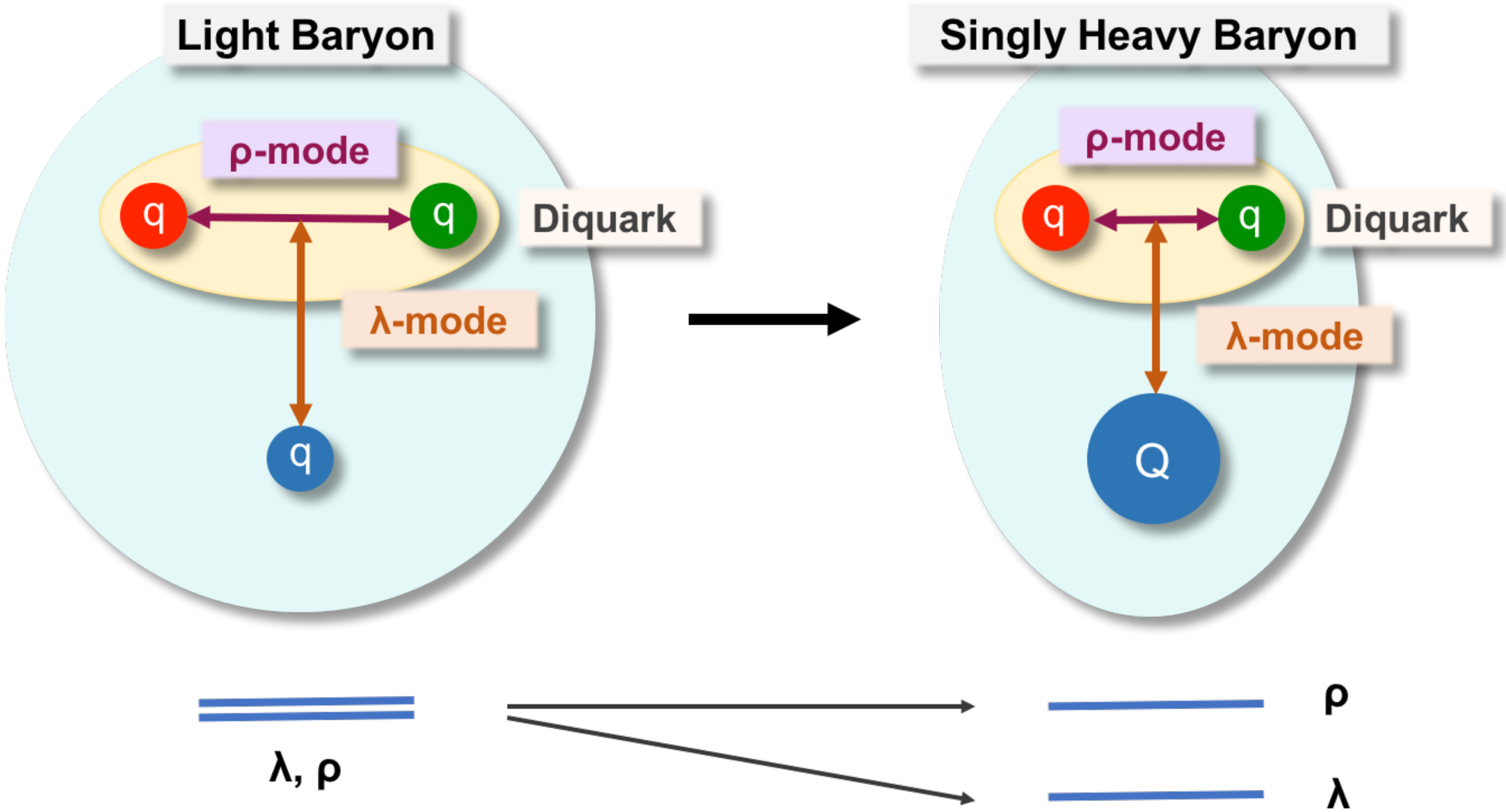
Diquarks and heavy baryons



- Baryon excitations can be expressed as ρ- and λ-modes

Diquarks and heavy baryons



- Baryon excitations can be expressed as ρ- and λ-modes
- ρ- and λ-modes show distinct difference in heavy baryons

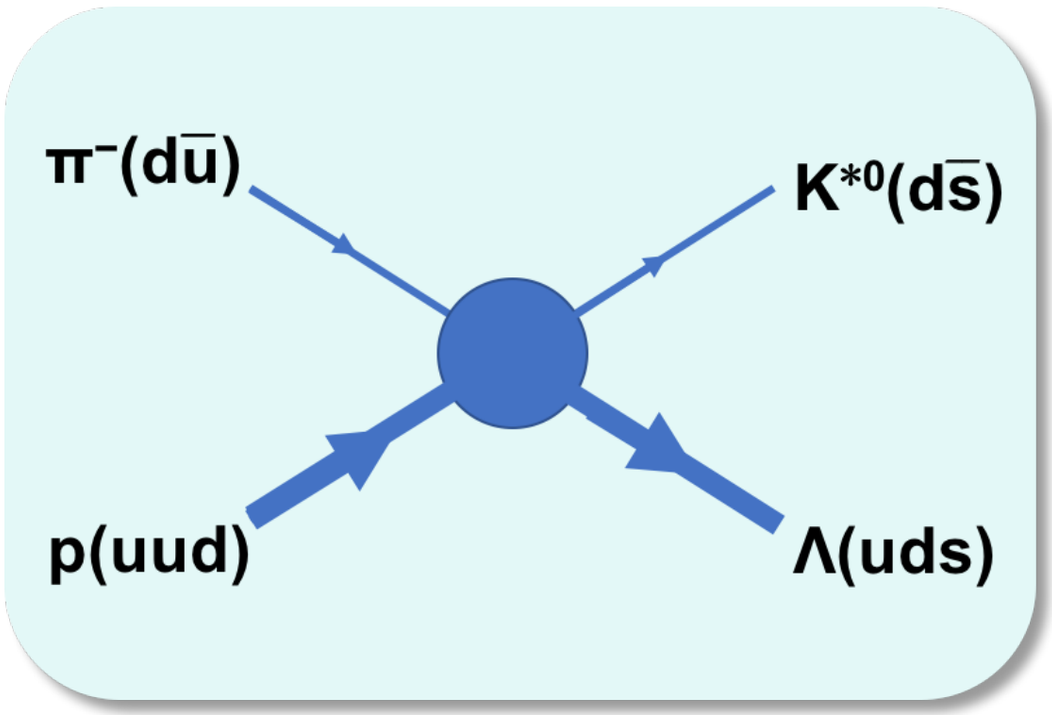
Researches on heavy baryon productions

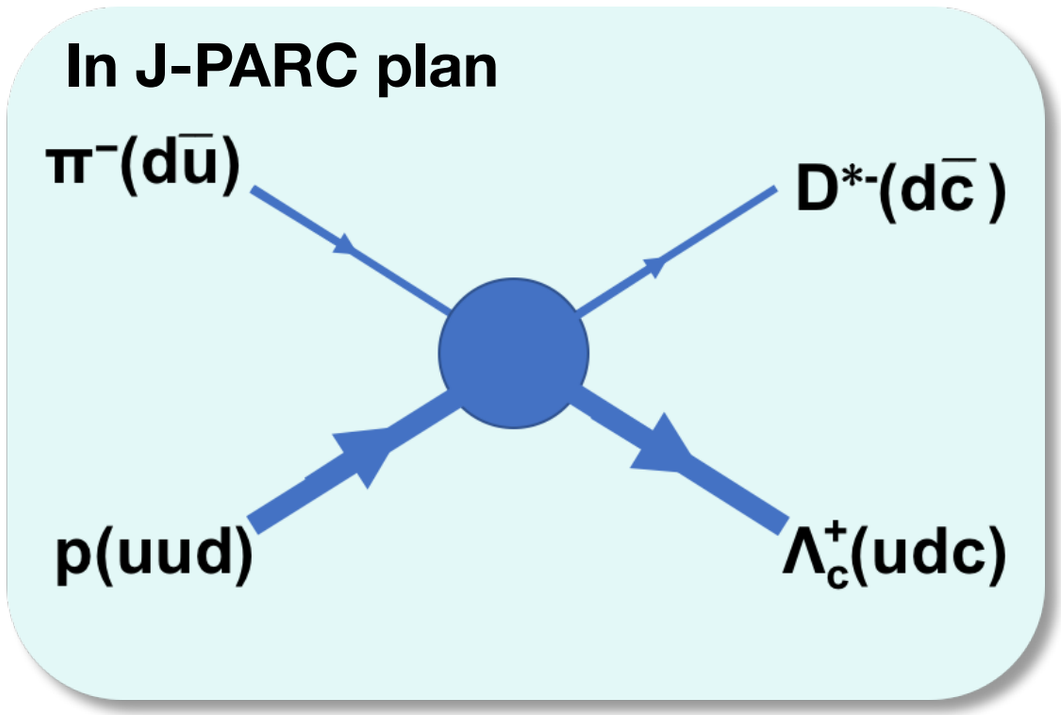
Early theoretical studies[1,2]

- The cross sections and production rates of heavy baryons were predicted
- Only λ-modes are considered

Experimental plan[3]

- Experiment for charmed baryon productions are planed at J-PARC





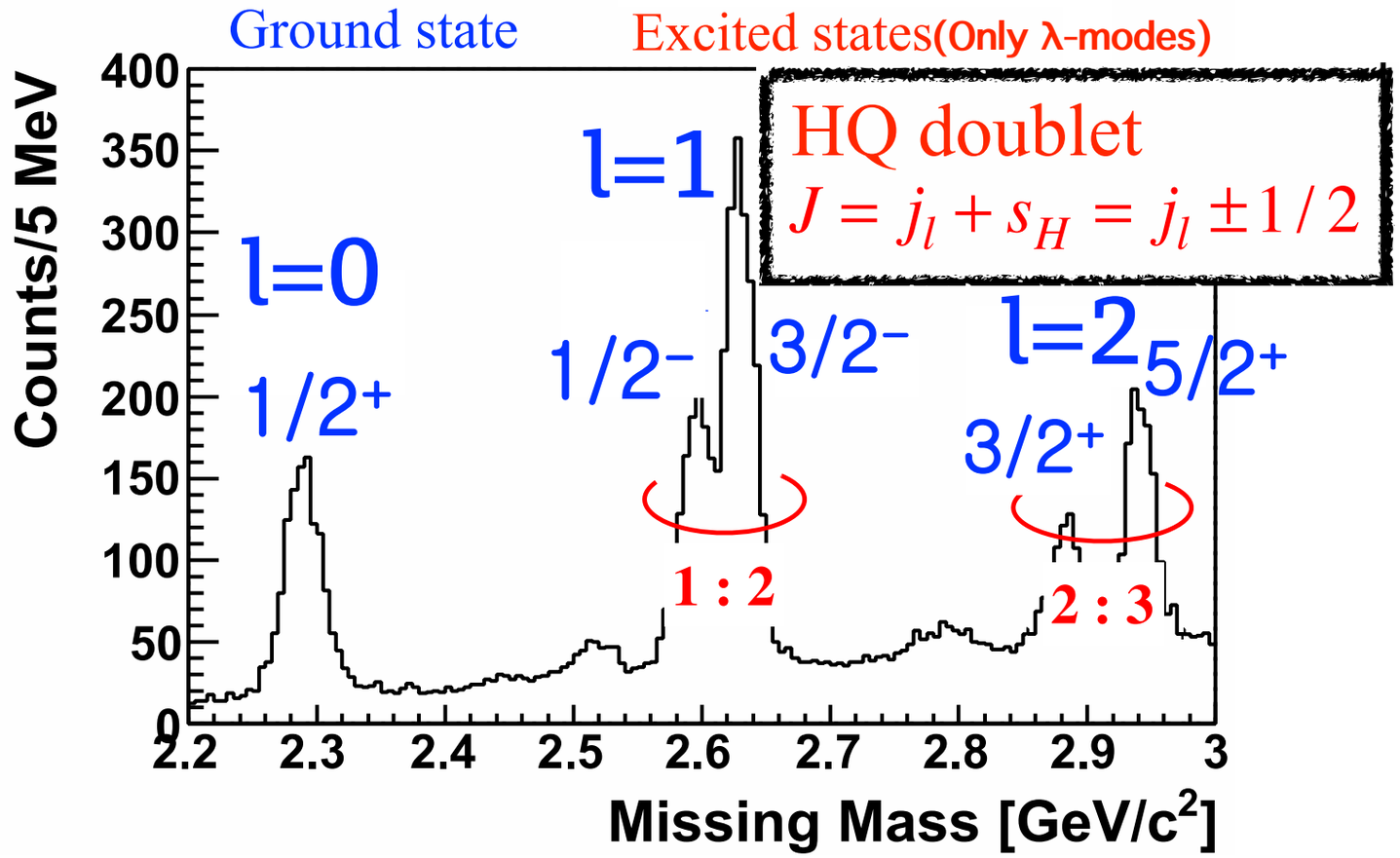
[1] S.-H.Kim, A.Hosaka, H.-Ch.Kim, H.Noumi and K.Shirotori, PTEP(2014)no.10, 103D01.
[2] S.-H.Kim, A.Hosaka, H.-Ch.Kim, H.Noumi, PRD92(2014)no.9, 094021.
[3] Charmed baryon spectroscopy via the (π, D^{*-}) reaction (2012). J-PARC P50 proposal.

Researches on heavy baryon productions

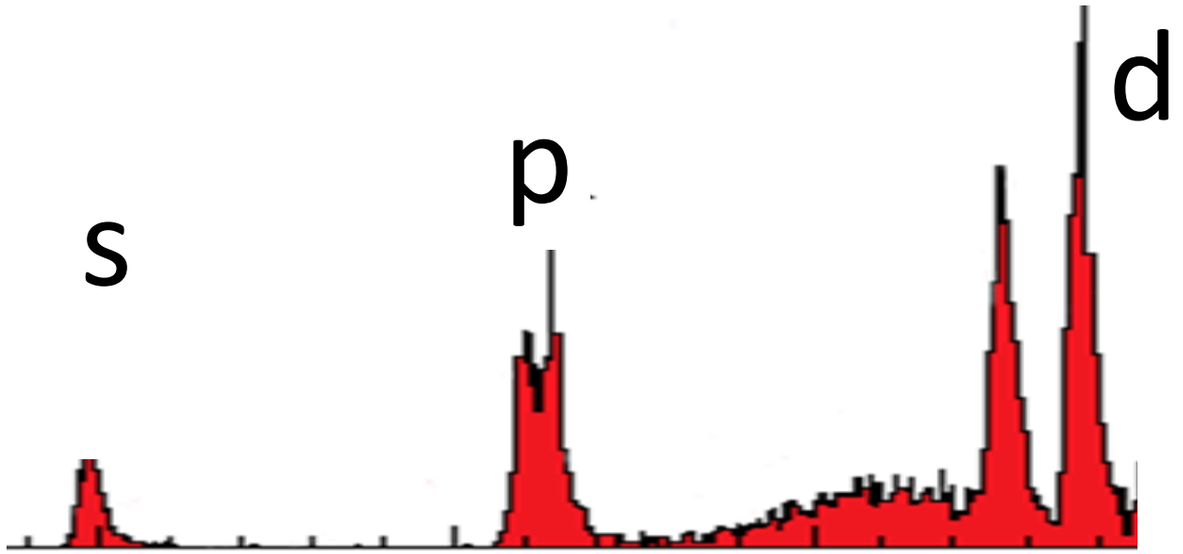
Similarity with hypernucleus productions

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

(Kim, Hosaka, Kim, Noumi, 2015)



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



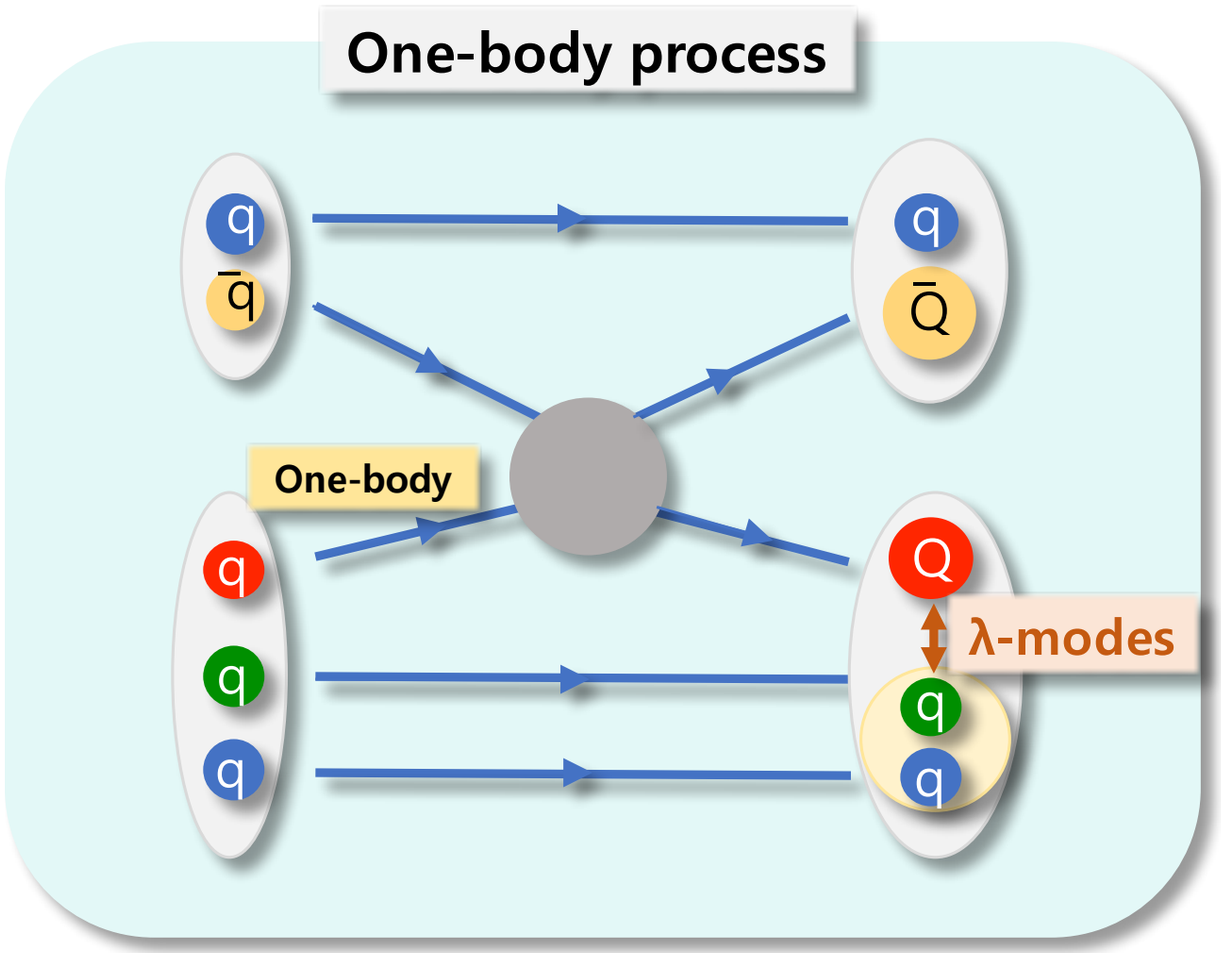
Motivation

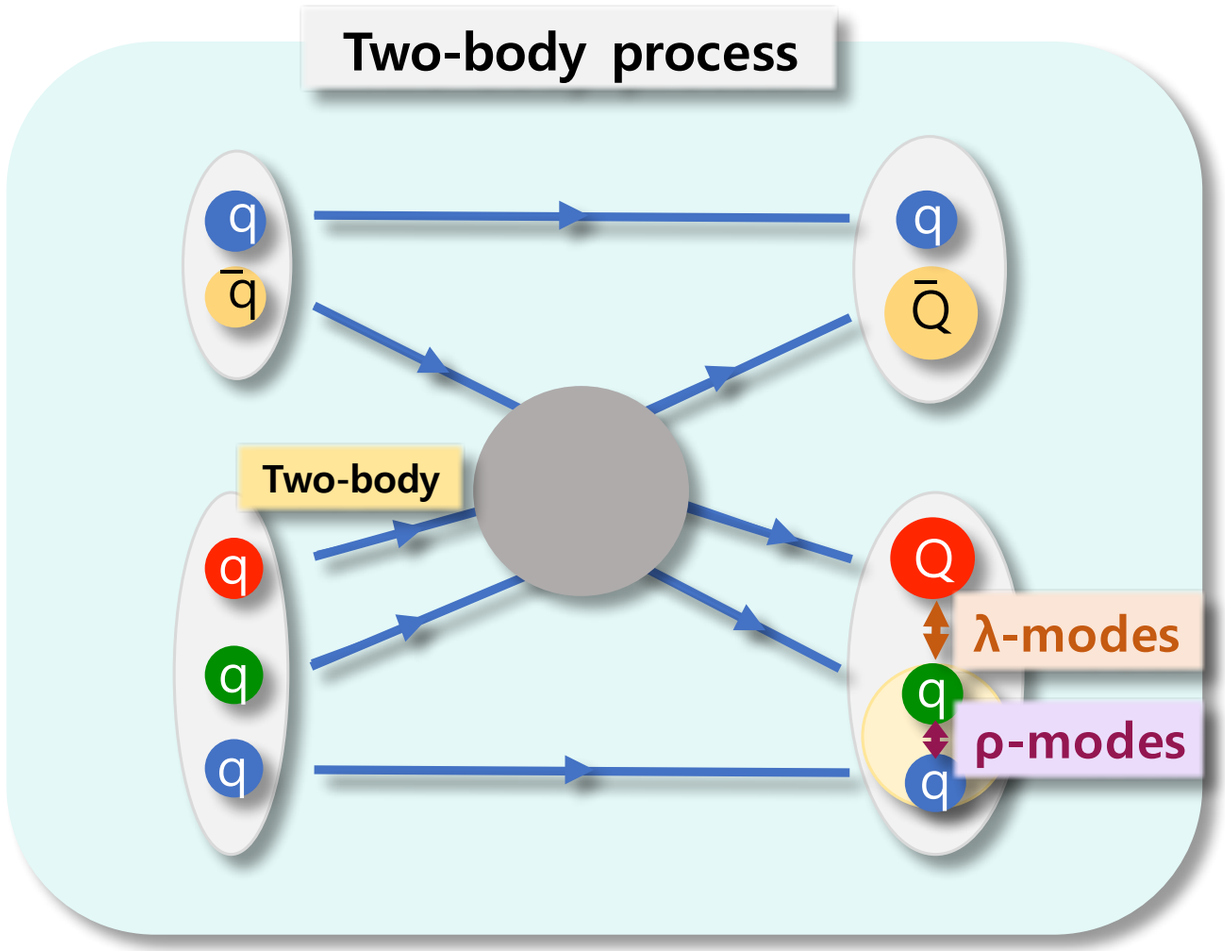
- ρ- and λ-modes can be clarified in heavy baryons
  (They are hard to distinguish in light baryons)

- Diquark properties can be studied
  by identifying ρ- and λ-modes of heavy baryons

- Observables such as cross sections can be obtained
  from proper description of processes
  and heavy baryon structures can be studied

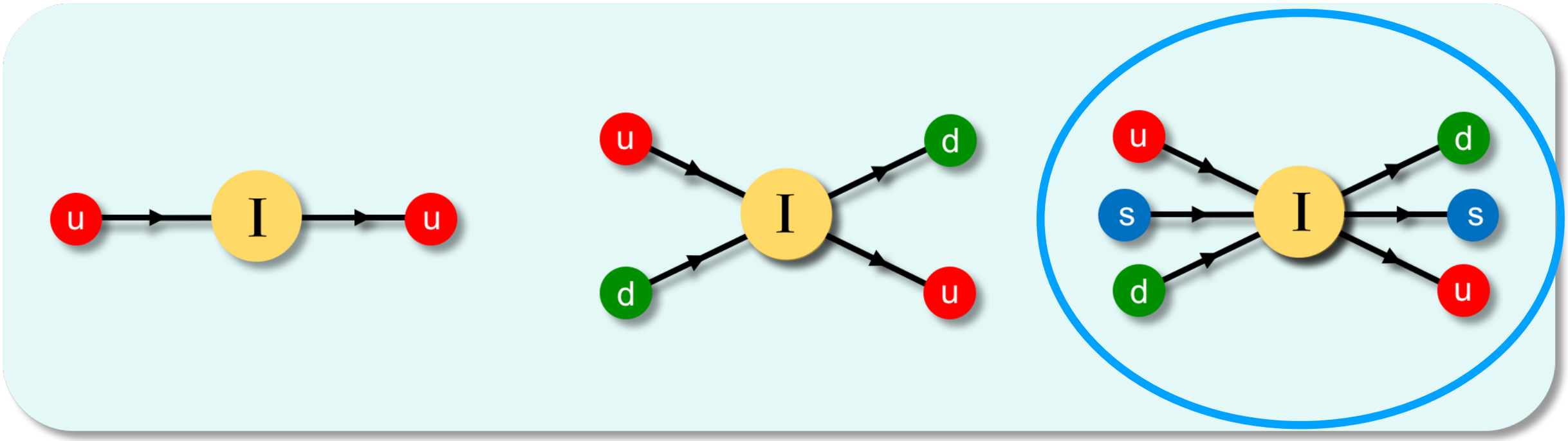
One- and two-body processes





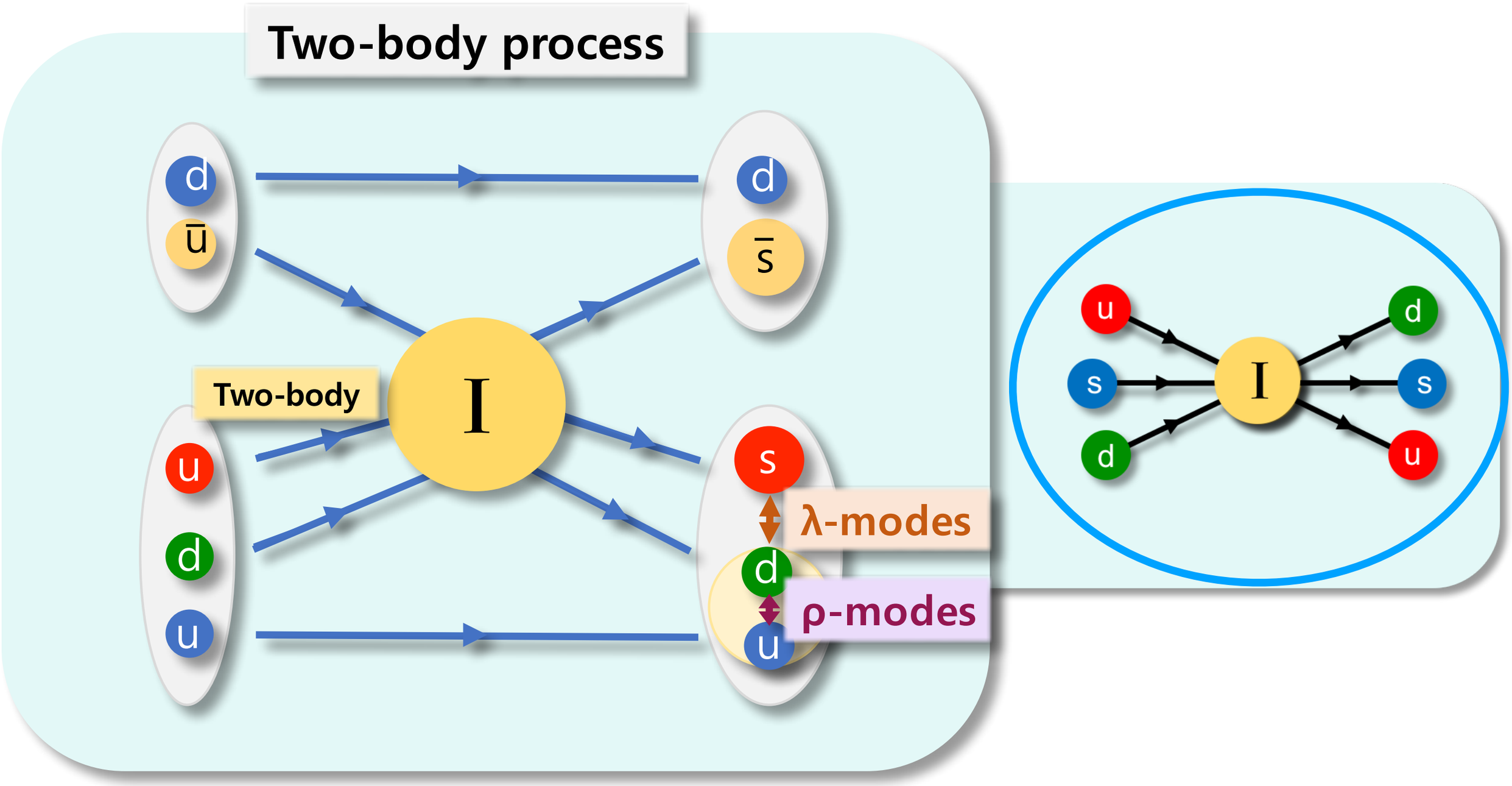
- One-body process
  - One quark in the baryon is involved in the reaction
  - The heavy baryon can be excited only to λ-modes
- Two-body process
  - Both ρ- and λ-modes can be found
  - Need to consider 3-quark interactions

Quark interactions in the instanton model (’t Hooft interaction)



- Quarks interact with each others via instantons
- Hyperon productions can be described by using ’t Hooft interactions

Quark interactions in the instanton model ('t Hooft interaction)



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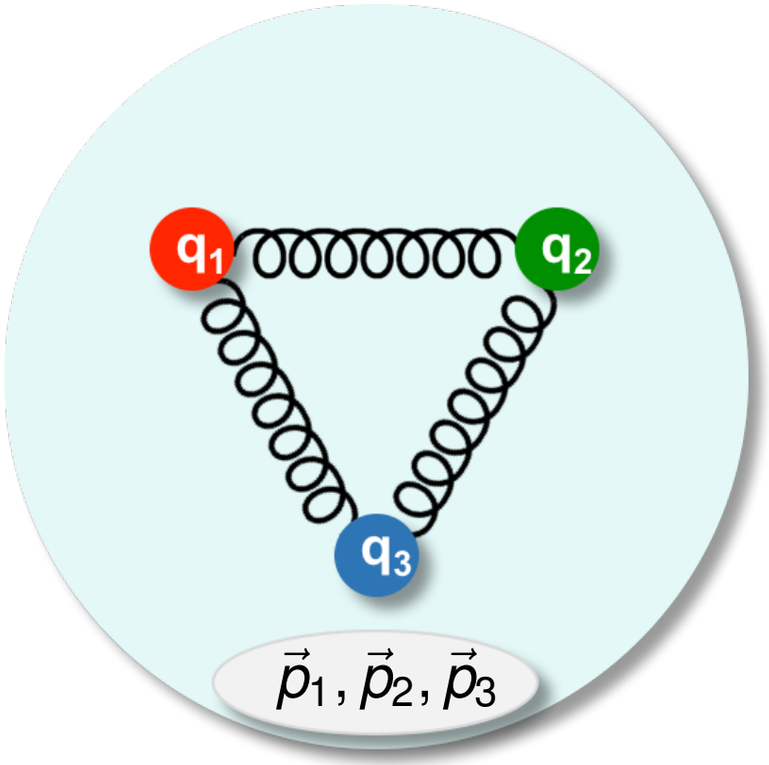
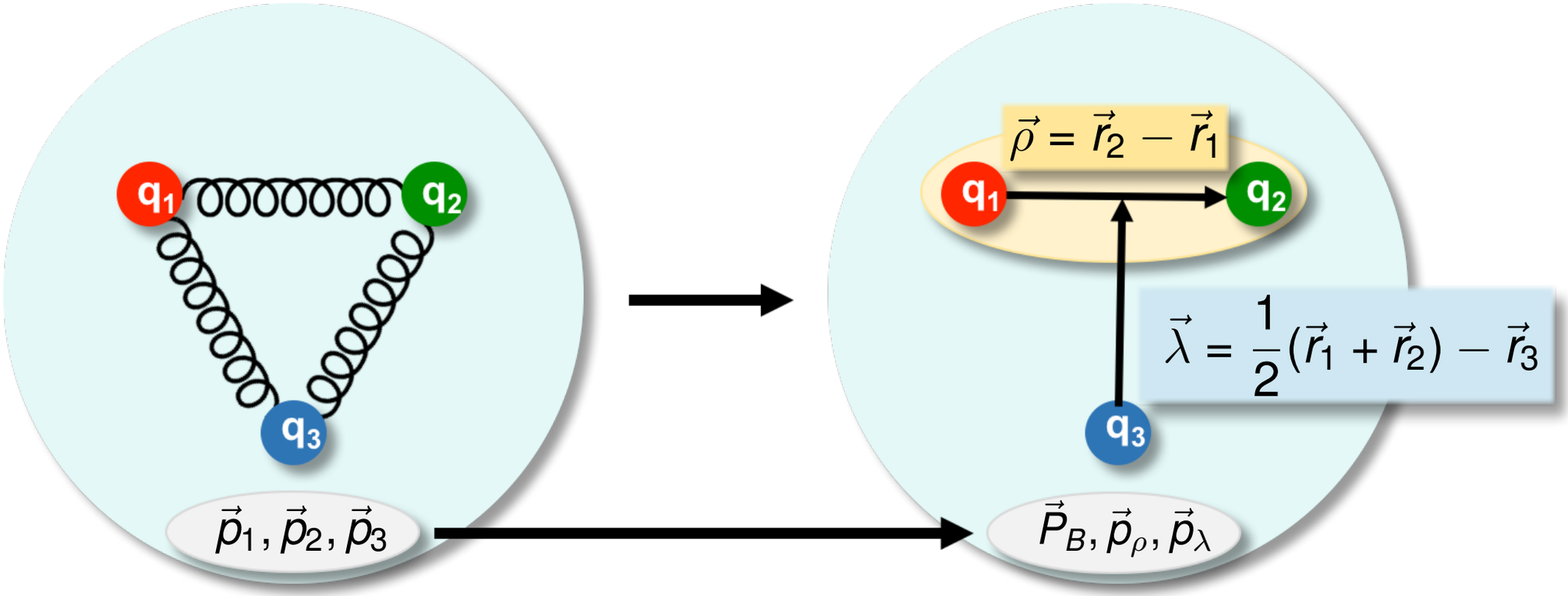
Baryon wave functions ($m_1 = m_2 = m_q$)



$$H = \sum_i \frac{\vec{p}_i^{\,2}}{2m_i} + \sum_{i<j} \frac{k}{2} |\vec{r}_i - \vec{r}_j|^2$$

Baryon wave functions ($m_1 = m_2 = m_q$)



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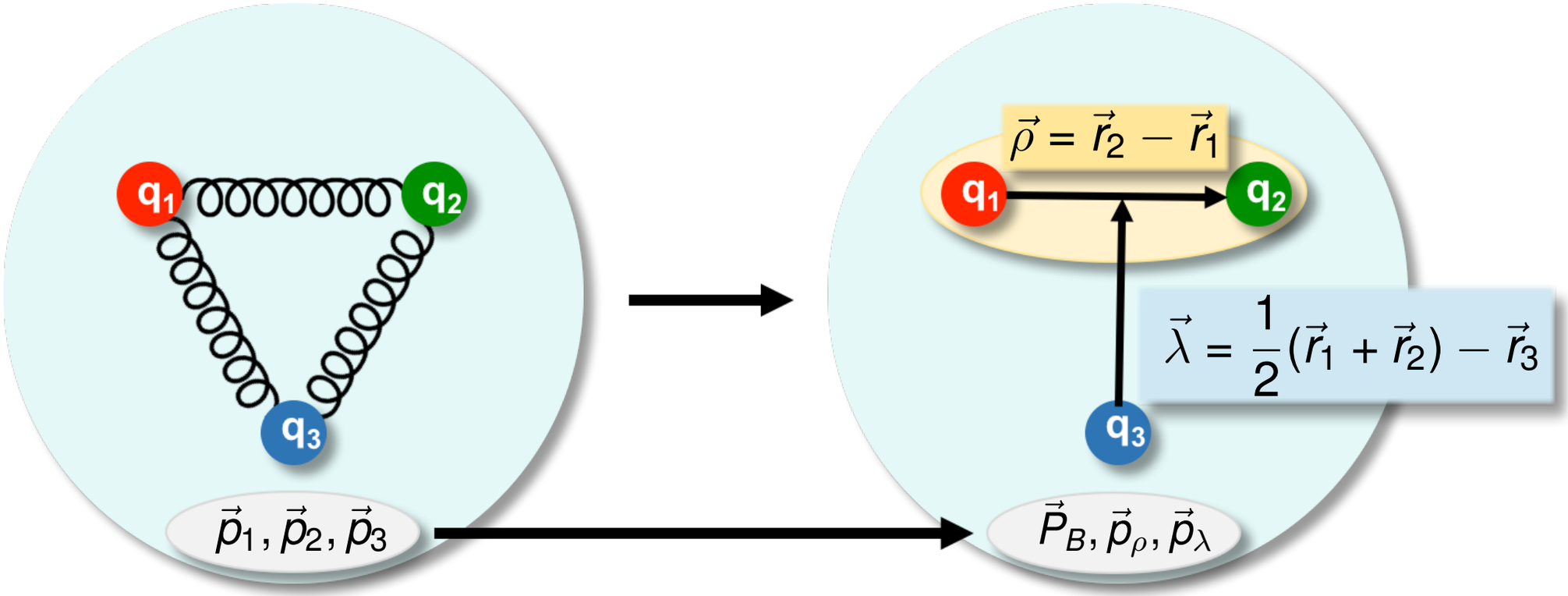


$$H = \sum_i \frac{\vec{p}_i^2}{2m_i} + \sum_{i<j} \frac{k}{2}|\vec{r}_i - \vec{r}_j|^2$$

$$= \frac{\vec{P}_B^2}{2M_B} + \frac{\vec{p}_\rho^2}{2m_\rho} + \frac{\vec{p}_\lambda^2}{2m_\lambda} + \frac{1}{2}m_\rho\omega_\rho^2\vec{\rho}^2 + \frac{1}{2}m_\lambda\omega_\lambda^2\vec{\lambda}^2$$

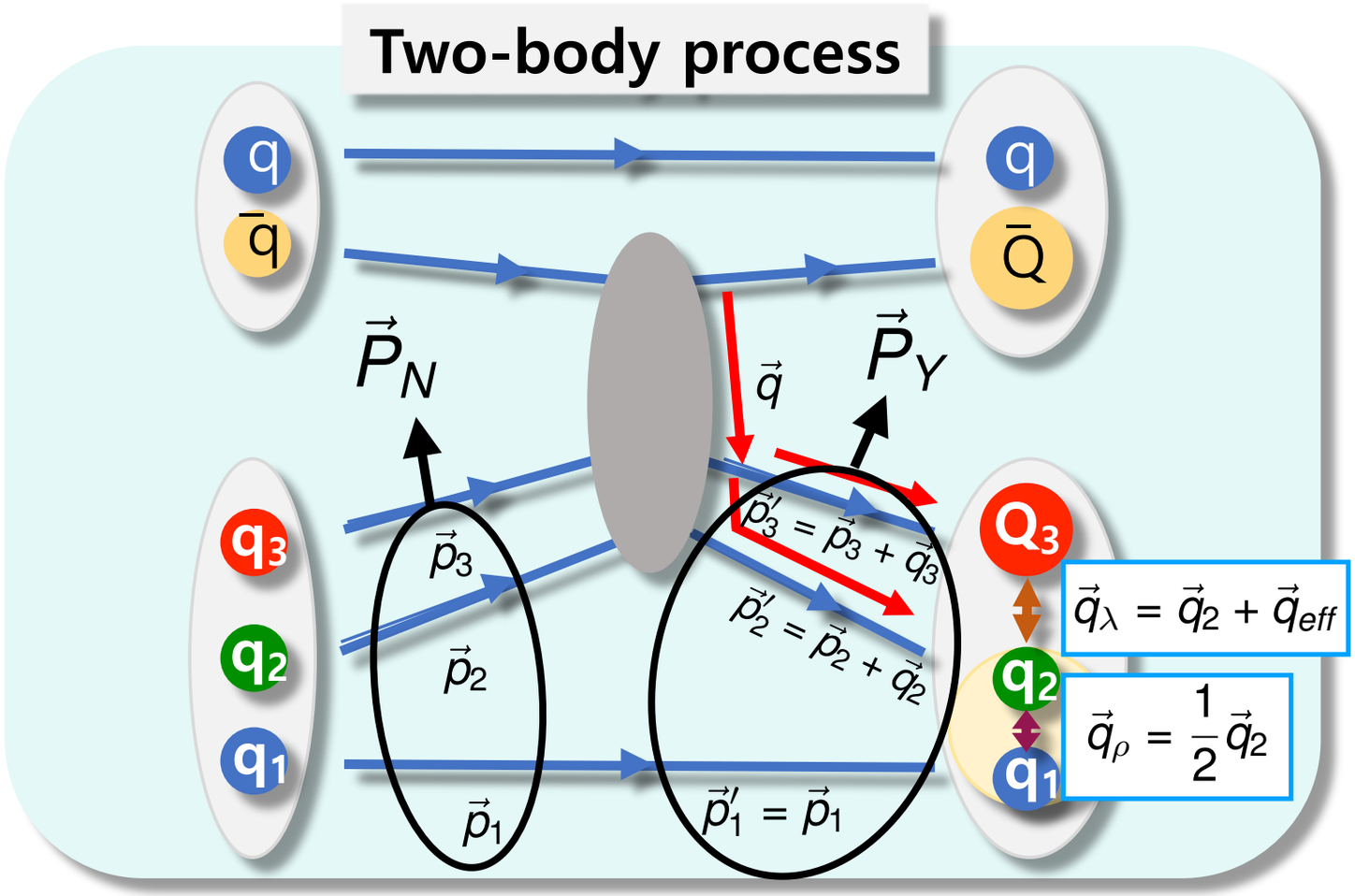
$$m_\rho = \frac{m_q}{2} \qquad \omega_\rho^2 = \frac{3k}{2m_\rho}$$

$$m_\lambda = \frac{2m_q m_3}{2m_q + m_3} \qquad \omega_\lambda^2 = \frac{2k}{m_\lambda}$$

3D Harmonic oscillators of $\vec{\rho}$ and $\vec{\lambda}$

$$\vec{p}_\rho = \frac{1}{2}(\vec{p}_2 - \vec{p}_1), \quad \vec{p}_\lambda = \frac{m_3}{2m_q + m_3}(\vec{p}_1 + \vec{p}_2) - \frac{2m_q}{2m_q + m_3}\vec{p}_3$$

Transition amplitudes for two-body processes



$$\langle Y(Y_c), K(D)|\mathcal{L}_{tH}|p,\pi\rangle \sim \boxed{\begin{aligned} &C_{Y(Yc)K(D)}\,\delta^{(3)}\left(\vec{p}_Y - \vec{p}_p - \vec{q}\right)\int d^3q_2\; d^3q_3\;\delta^{(3)}\left(\vec{q} - \vec{q}_2 - \vec{q}_3\right) \\ &\times \int d^3\rho\; e^{i\vec{q}_\rho\cdot\vec{\rho}}\psi^{\rho *}_{l_\rho}(\vec{\rho})\psi^{\rho}_{0}(\vec{\rho}) \int d^3\lambda\; e^{i\vec{q}_\lambda\cdot\vec{\lambda}}\psi^{\lambda' *}_{l_\lambda}(\vec{\lambda})\psi^{\lambda}_{0}(\vec{\lambda}) \end{aligned}}$$

$\vec{q}_{eff}$: Effective momentum transfer, $\vec{q}_{eff} = \frac{2}{3}\vec{p}_p - \frac{2m_q}{2m_q+m_Q}\vec{p}_{Y(Y_c)}$

$\mathcal{L}_{tH}$: Interaction Lagrangian for the 3-quark interaction

$\psi_l^{\rho \text{ or } \lambda(*)}$: Wave function for ρ- or λ- modes of the initial(final) state baryon

Summary and Outlook

- Productions of hyperon are being studied and the results show some similarities with one-body processes

- Not only λ- but also ρ-mode transition amplitudes are found by using two-body processes
(it cannot be done with one-body processes)

- Calculations of production rates
and extension for charmed baryons are planed

Thank you
for your attention!