SCHDM2017 @ YITP

Theoretical study of $\Lambda(1405)$ in Ξ_b decay

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25 May 2017

Contents

Introduction : Λ(1405)

- **Λ(1405)** : I (J^P) = 0 ($1/2^-$), S=-1
  - **"exotic" candidate**

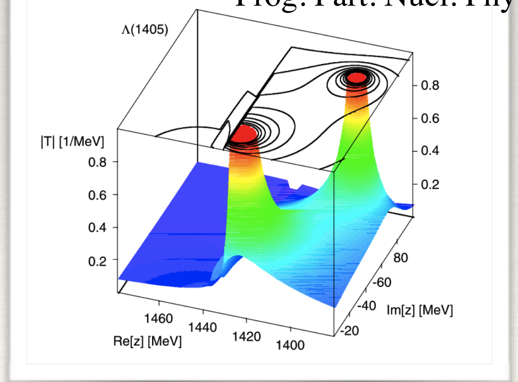
⇨ **doorway to K̄ nuclei** S. Ohnishi, et al., arXiv:1701.07589

  - **puzzle : pole structure**

Λ(1405) peak in spectrum ⟷ resonance pole

single pole or **double pole**

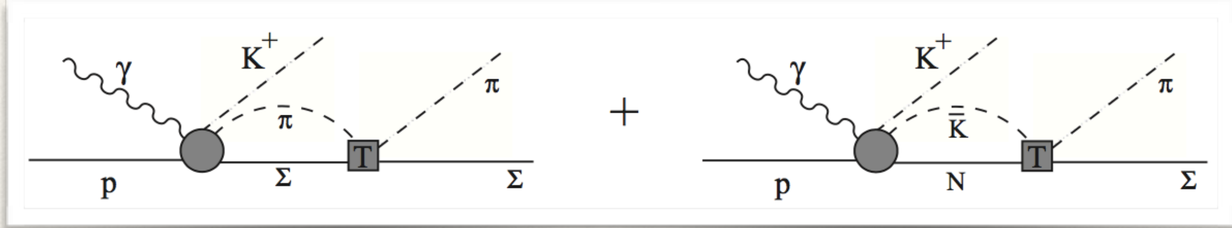
Hyodo and Jido,
Prog. Part. Nucl. Phys. 67, 55 (2012)



Λ(1405) is an interesting but mysterious state.

Introduction : Λ(1405) previous exp.

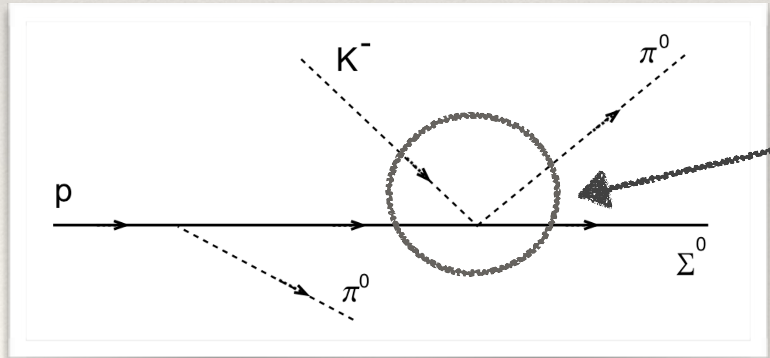
- **$\gamma p \to K^+(\pi\Sigma)$** exp.) LEPS : Niiyama et al., Phys. Rev. C78 (2008) 035202
  CLAS : Moriya et al., Phys. Rev. C87 (2013) 035206



Roca and Oset, Phys. Rev. C87 (2013) 055201

$$\frac{d\sigma}{dM_{\text{inv}}} \propto |b(W)G_{\pi\Sigma}T_{\pi\Sigma\to\pi\Sigma} + c(W)G_{\bar{K}N}T_{\bar{K}N\to\pi\Sigma}|^2$$

- **$K^- p \to \pi^0(\pi\Sigma)$** exp.) Crystal Ball : Prakhov et al., Phys. Rev. C70 (2004) 034605



$T_{\bar{K}N\to\pi\Sigma}$ is dominant

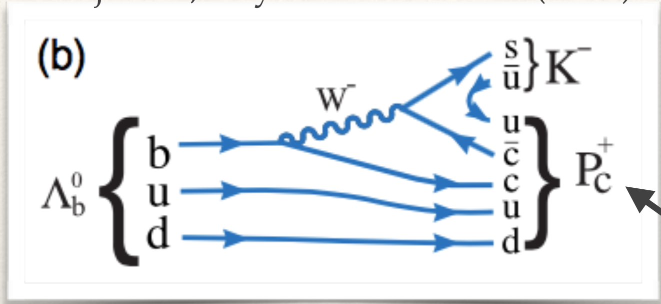
Magas, Oset, and Ramos, Phys. Rev. Lett. 95 (2005) 052301

$T_{\pi\Sigma\to\pi\Sigma}$ has not been measured.

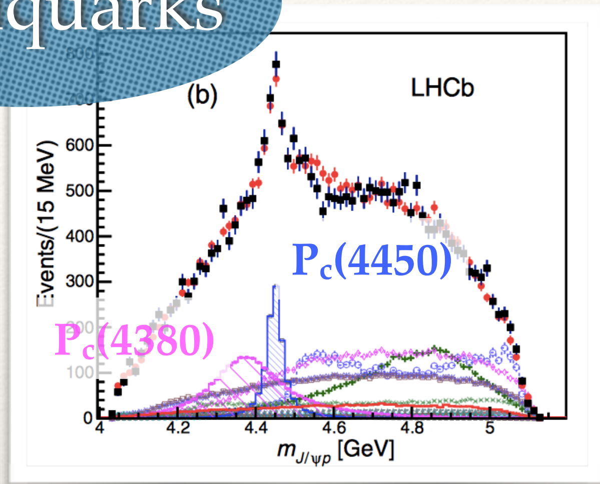
Introduction : heavy hadron decays

- **$\Lambda_b \to J/\psi\, K^- p$ decay** ⇨ pentaquarks

Aaij et al., Phys. Rev. Lett. 115 (2015) 072001

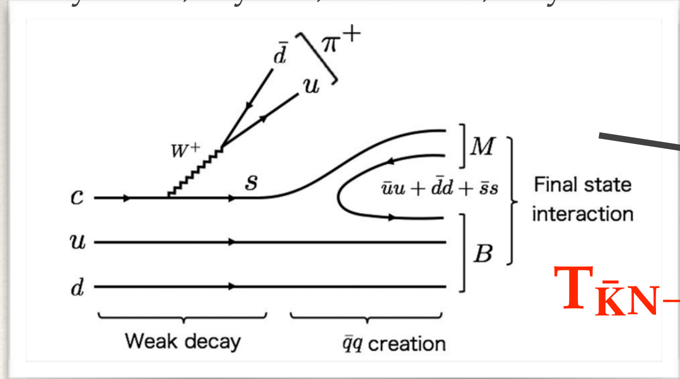


in $J/\psi\, p$ spectrum



- **$\Lambda_c^+ \to \pi^+ (\pi\Sigma)$ decay** ⇨ Λ(1405)

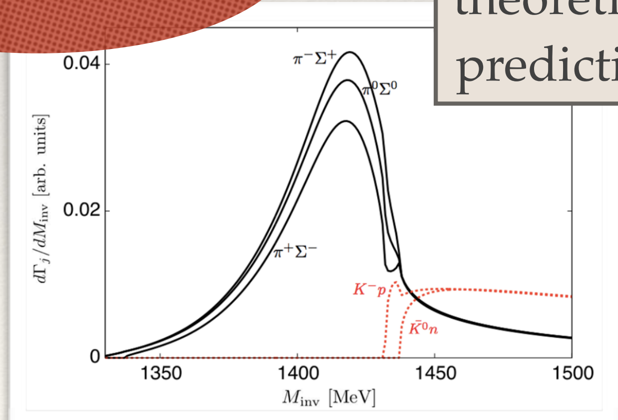
Miyahara, Hyodo, and Oset, Phys. Rev. C92 (2015) 055204



Λ(1405)
in πΣ spectrum

$T_{\bar{K}N\to\pi\Sigma}$ is dominant

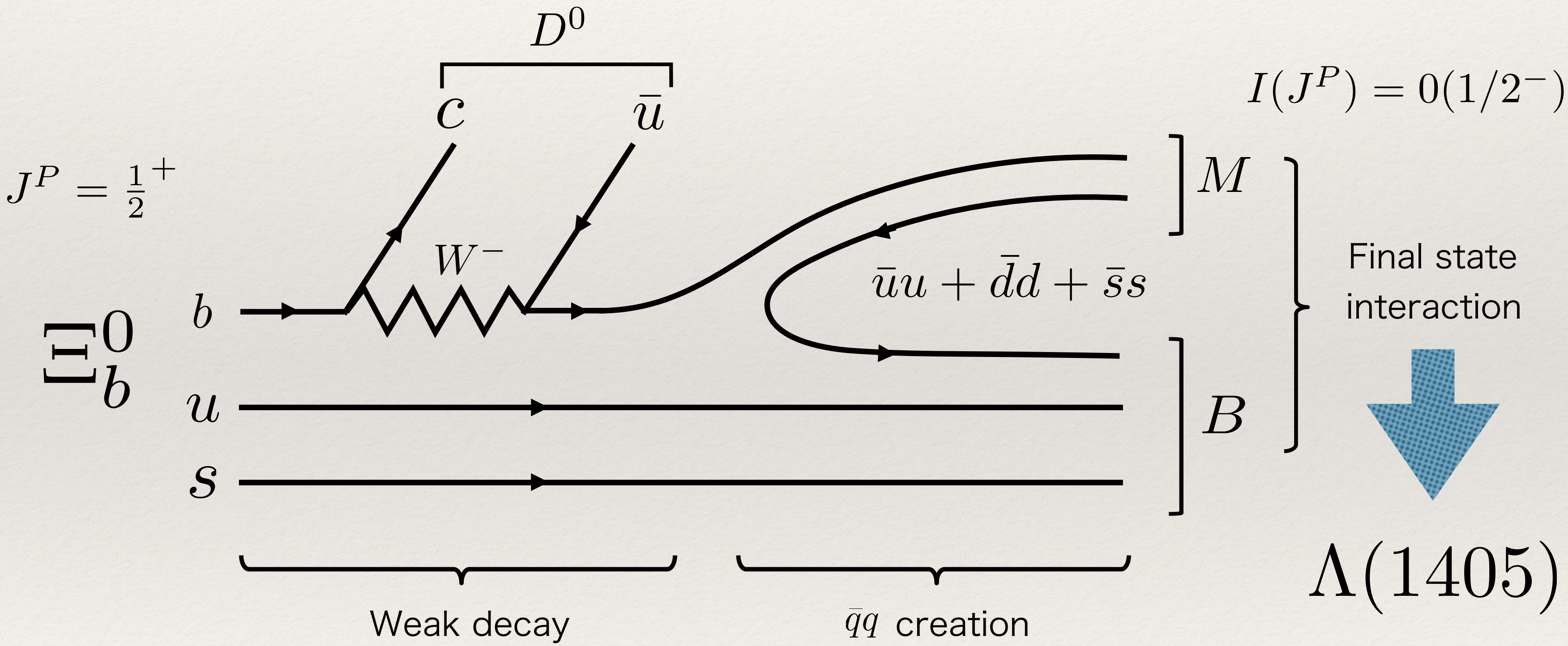
theoretical prediction



We search for decays dominated by $T_{\pi\Sigma\to\pi\Sigma}$.

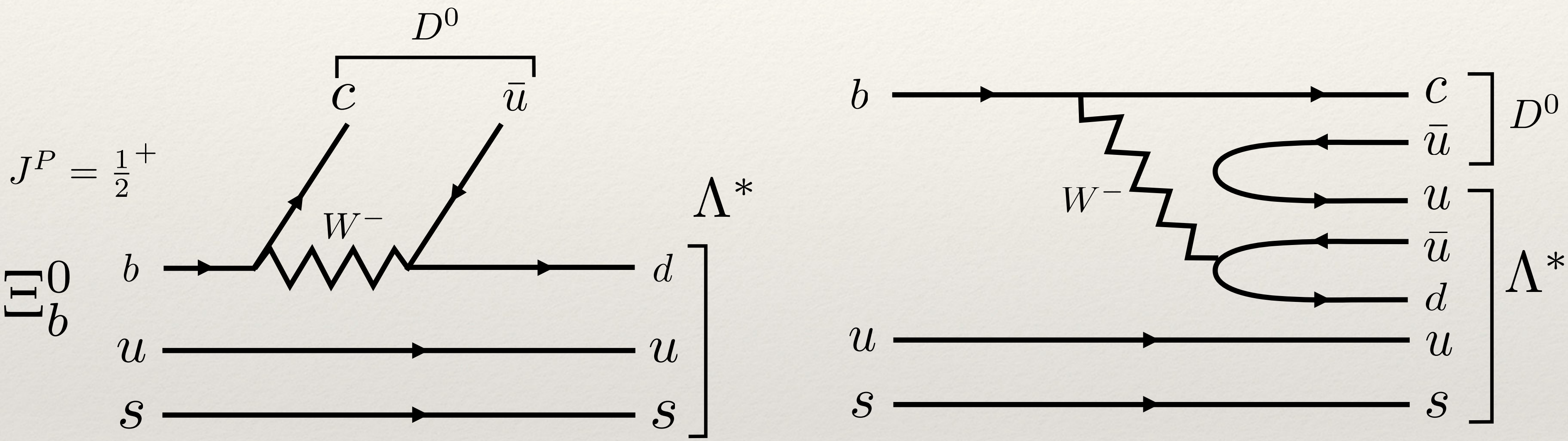
Formulation

Considering Cabibbo-Kobayashi-Maskawa matrix, kinematics, and diquark correlation, the following diagram is favored.



Formulation : Weak decay

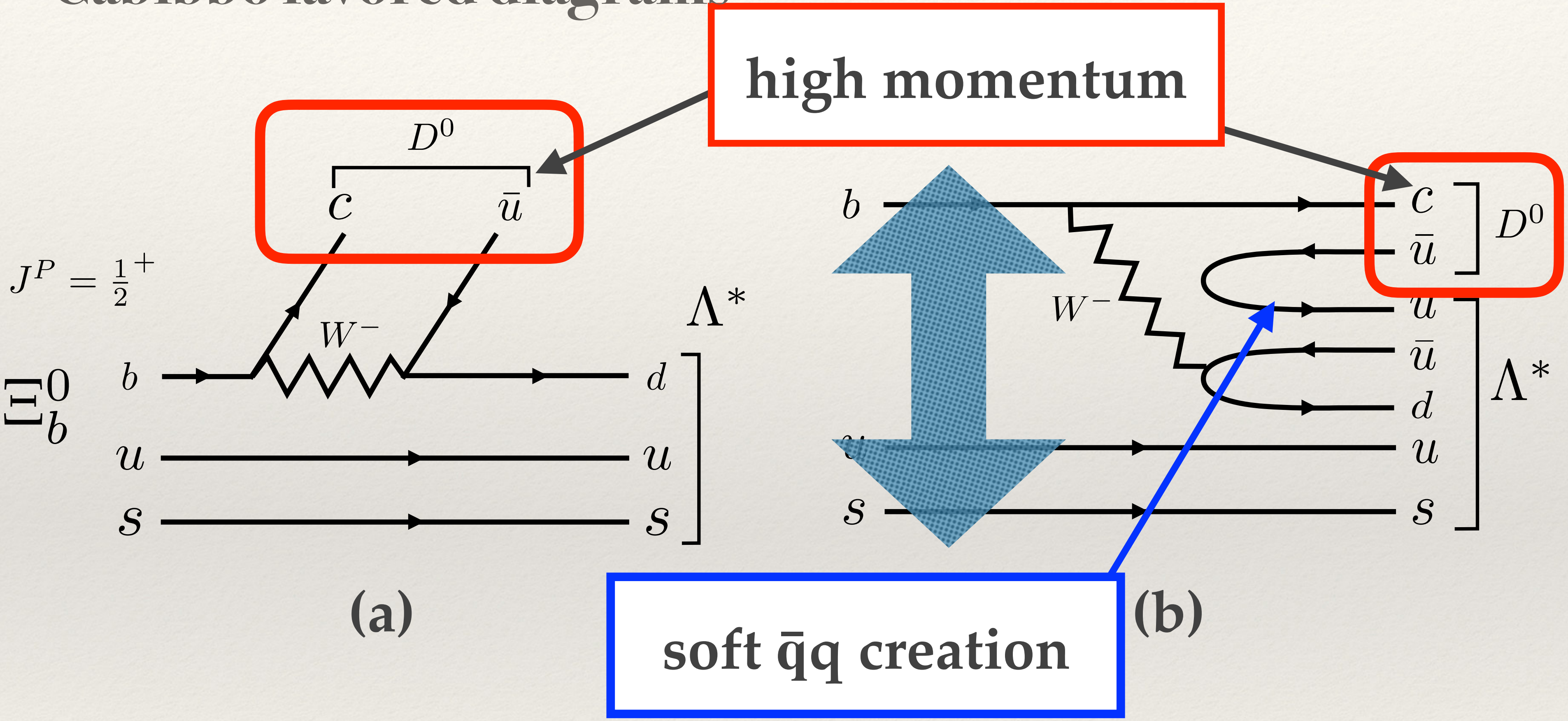
- **Cabibbo favored diagrams**



(a) **(b)**

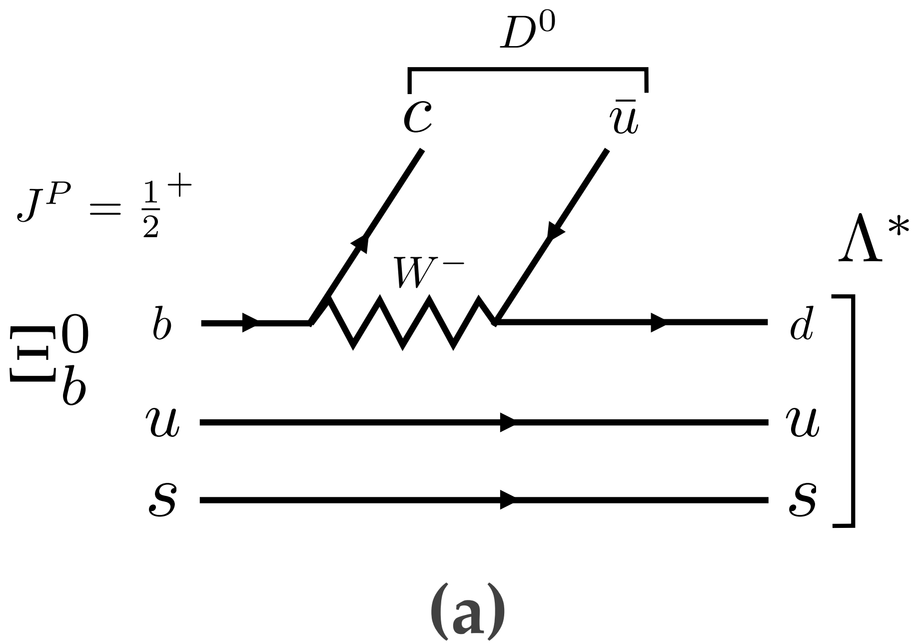
Formulation : Weak decay

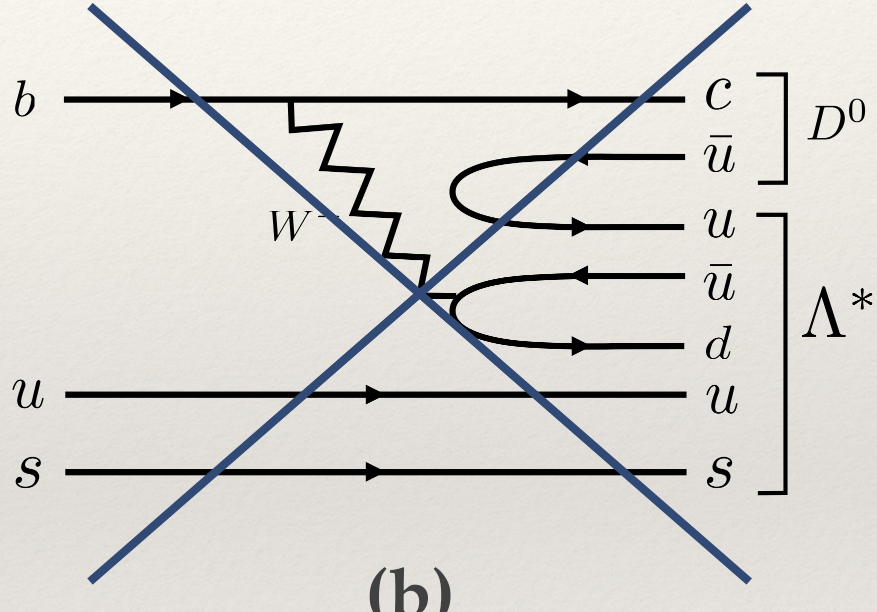
- Cabibbo favored diagrams



Formulation : Weak decay

- **Cabibbo favored diagrams**





for momentum mismatch

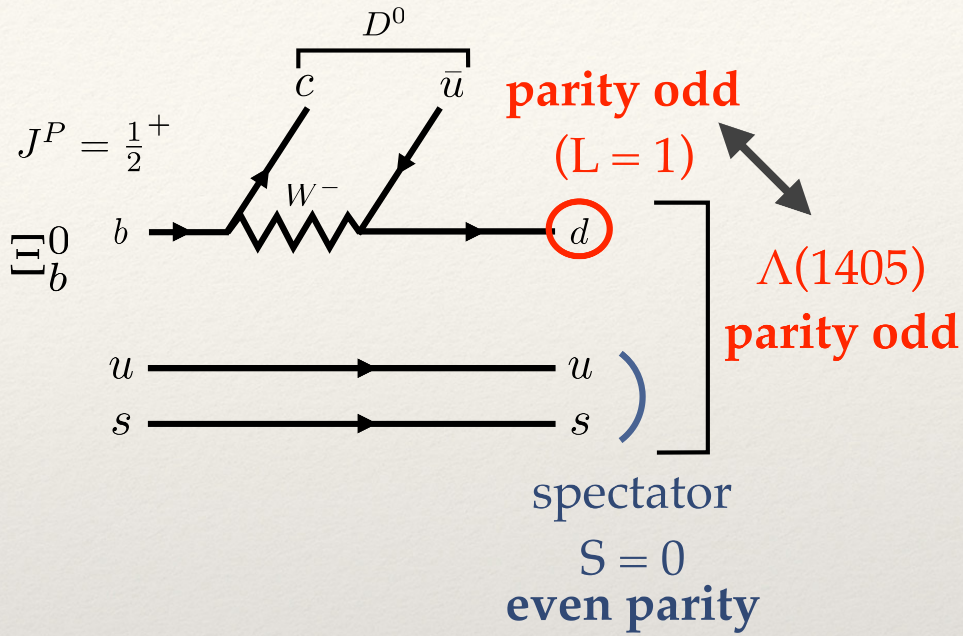
Diagram (a) is most favored.

Formulation : q̄q creation

- **quark d.o.f. $\rightarrow$ hadron d.o.f.**

$$|\Xi_b^0\rangle = \frac{1}{\sqrt{2}}|b(su - us)\rangle$$

$$\xrightarrow{\text{weak decay}} \frac{1}{\sqrt{2}}|d(su - us)\rangle$$



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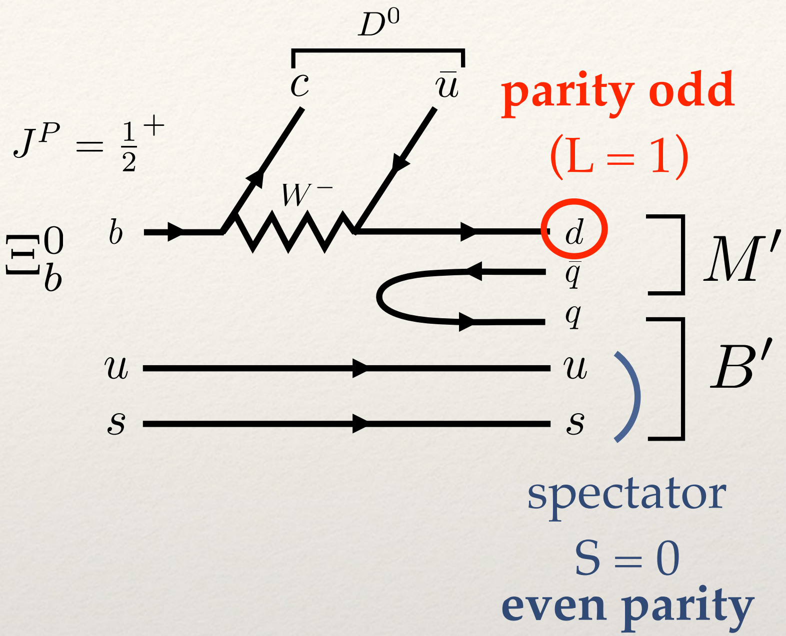
$$\xrightarrow{\text{weak decay}} \frac{1}{\sqrt{2}}|d(su-us)\rangle$$

$$\xrightarrow{\bar{q}q\text{ creation}} \frac{1}{\sqrt{2}}\sum_{i=u,d,s}|\underbrace{d\bar{q}_i}_{M'}\underbrace{q_i(su-us)}_{B'}\rangle$$



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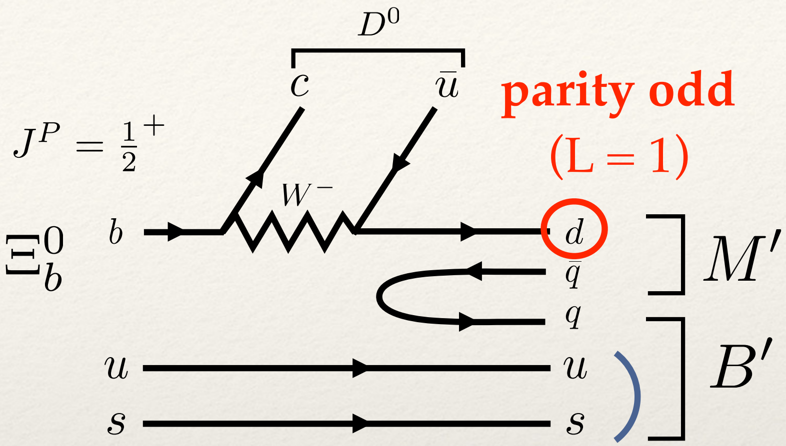


considering SU(3) transformation,

$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix} = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \frac{2\eta'}{\sqrt{6}} \end{pmatrix}$$

q̄ : 3̄ → 3̄ diquark

used in Chiral EFT

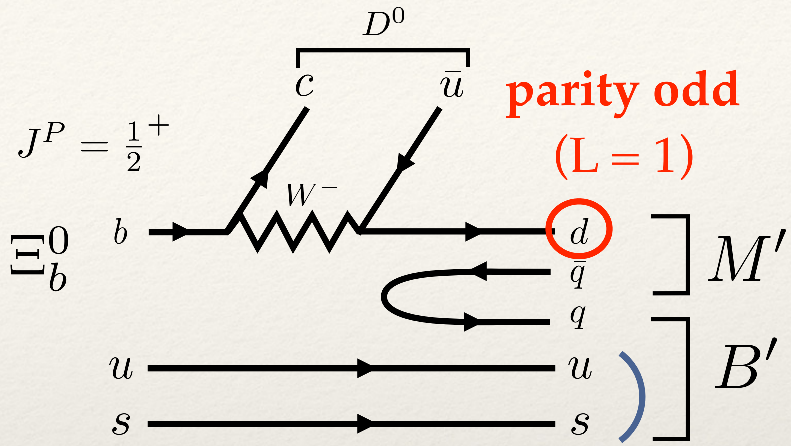
$$B = \begin{pmatrix} \quad \end{pmatrix} = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} + \frac{\Lambda_1}{\sqrt{3}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} + \frac{\Lambda_1}{\sqrt{3}} & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda + \frac{\Lambda_1}{\sqrt{3}} \end{pmatrix}$$

Formulation : q̄q creation

- **quark d.o.f. ⟶ hadron d.o.f.**

$$|\Xi_b^0\rangle = \frac{1}{\sqrt{2}}|b(su-us)\rangle$$

$$\xrightarrow{\text{weak decay}} \frac{1}{\sqrt{2}}|d(su-us)\rangle$$



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q̄ : $\bar{3} \to \bar{3}$ diquark

used in Chiral EFT

$$B = \frac{1}{\sqrt{2}} \begin{pmatrix} u(ds-sd) & u(su-us) & u(ud-du) \\ d(ds-sd) & d(su-us) & d(ud-du) \\ s(ds-sd) & s(su-us) & s(ud-du) \end{pmatrix} = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} + \frac{\Lambda_1}{\sqrt{3}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} + \frac{\Lambda_1}{\sqrt{3}} & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda + \frac{\Lambda_1}{\sqrt{3}} \end{pmatrix}$$

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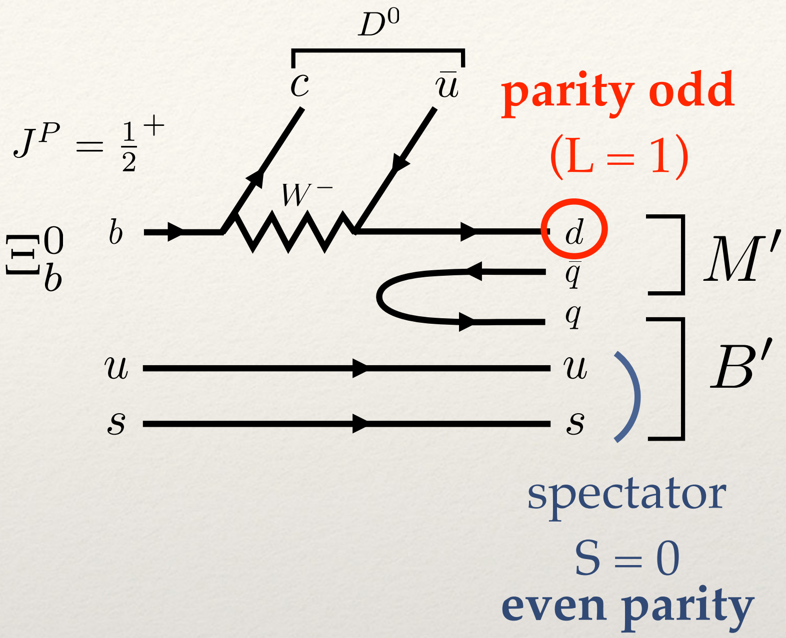
$$\xrightarrow{\bar{q}q\text{ creation}} \frac{1}{\sqrt{2}}\sum_{i=u,d,s}|\underbrace{d\bar{q}_i}_{M'}\underbrace{q_i(su-us)}_{B'}\rangle$$



$$|MB'\rangle = -\frac{1}{2\sqrt{3}}|\pi^0\Lambda\rangle + \frac{1}{2}|\pi^0\Sigma^0\rangle + |\pi^-\Sigma^+\rangle + \frac{1}{3\sqrt{2}}|\eta\Lambda\rangle - \frac{1}{\sqrt{6}}|\eta\Sigma^0\rangle + |K^0\Xi^0\rangle$$

Formulation : q̄q creation

- **quark d.o.f. $\rightarrow$ hadron d.o.f.**

$$|\Xi_b^0\rangle = \frac{1}{\sqrt{2}}|b(su-us)\rangle$$

$$\xrightarrow{\text{weak decay}} \frac{1}{\sqrt{2}}|d(su-us)\rangle$$

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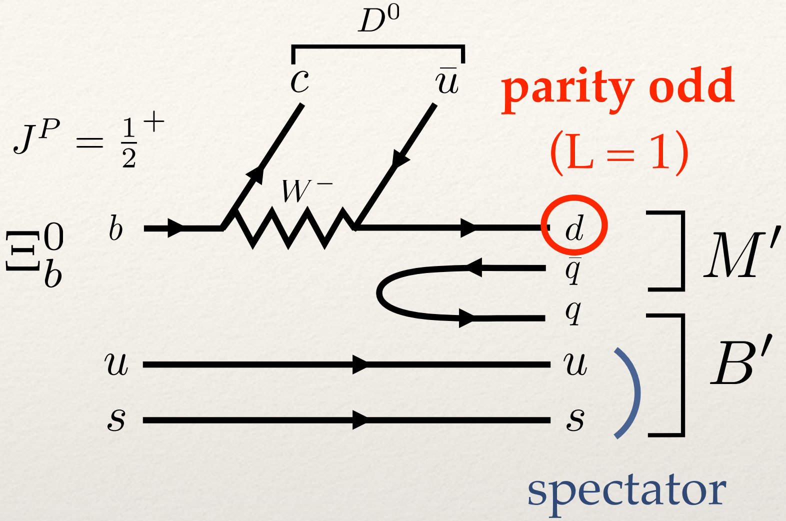
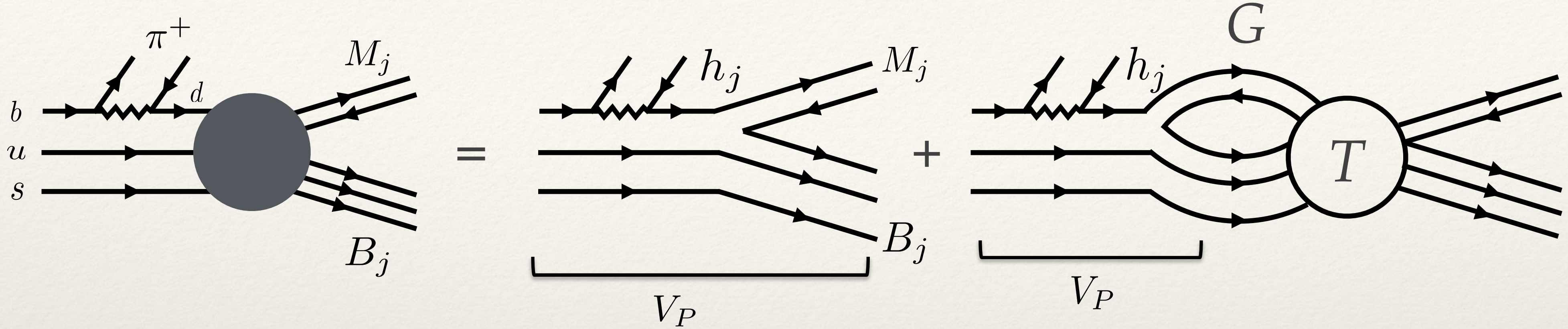


no K̄N state !!

$T_{\pi\Sigma\to\pi\Sigma}$ is dominant

$$|MB'\rangle = -\frac{1}{2\sqrt{3}}|\pi^0\Lambda\rangle + \frac{1}{2}|\pi^0\Sigma^0\rangle + |\pi^-\Sigma^+\rangle + \frac{1}{3\sqrt{2}}|\eta\Lambda\rangle - \frac{1}{\sqrt{6}}|\eta\Sigma^0\rangle + |K^0\Xi^0\rangle$$

Formulation : Final State Interaction



$$\mathscr{M}_j = V_P \left(h_j + \sum_i h_i G_i(M_{\rm inv}) T_{ij}(M_{\rm inv}) \right)$$

$$\frac{{\rm d}\Gamma_j}{{\rm d}M_{\rm inv}} = \frac{1}{(2\pi)^3} \frac{p_{D^0} \tilde{p}_j M_{\Xi_b^0} M_j}{M_{\Xi_b^0}^2} |\mathscr{M}_j|^2$$

coefficients can be determined from $|MB'\rangle$

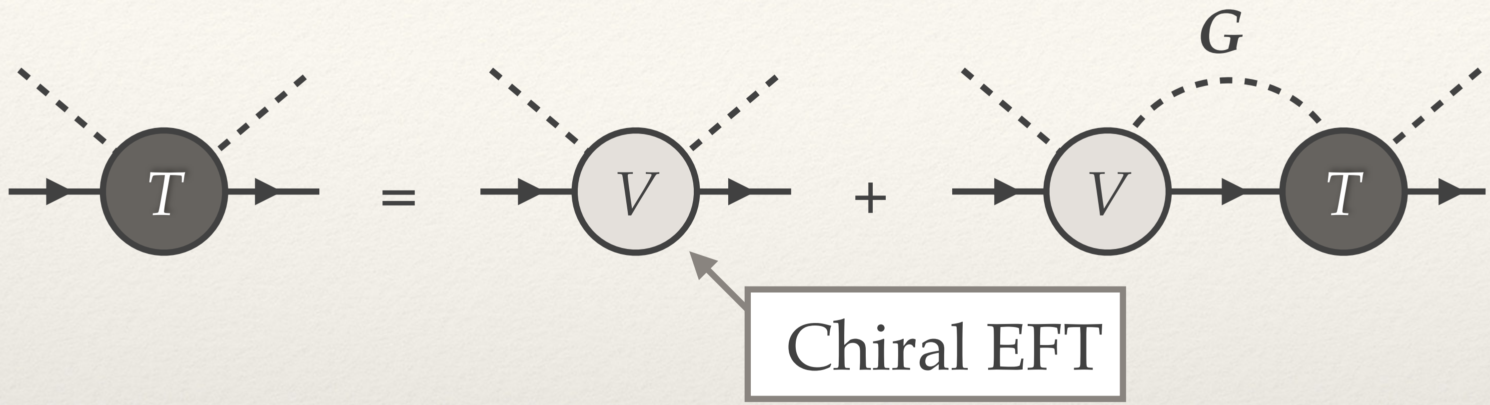
$$h_{\pi^0\Lambda^0} = -\frac{1}{2\sqrt{3}},$$
$$h_{\pi^0\Sigma^0} = \frac{1}{2},\ h_{\pi^-\Sigma^+} = 1,\ h_{\pi^+\Sigma^-} = 0,$$
$$h_{K^-p} = h_{\bar{K}^0 n} = 0,$$
$$h_{\eta\Lambda} = \frac{1}{3\sqrt{2}},\ h_{\eta\Sigma^0} = 0,\ h_{K^0\Xi^0} = 1,\ h_{K^+\Xi^-} = 0$$

G_i : **meson-baryon loop function,** T_{ij} : **meson-baryon scattering matrix**

decay spectrum ⟺ **two-body amplitude** T

Results : chiral unitary approach

- **model for two-body T matrix**



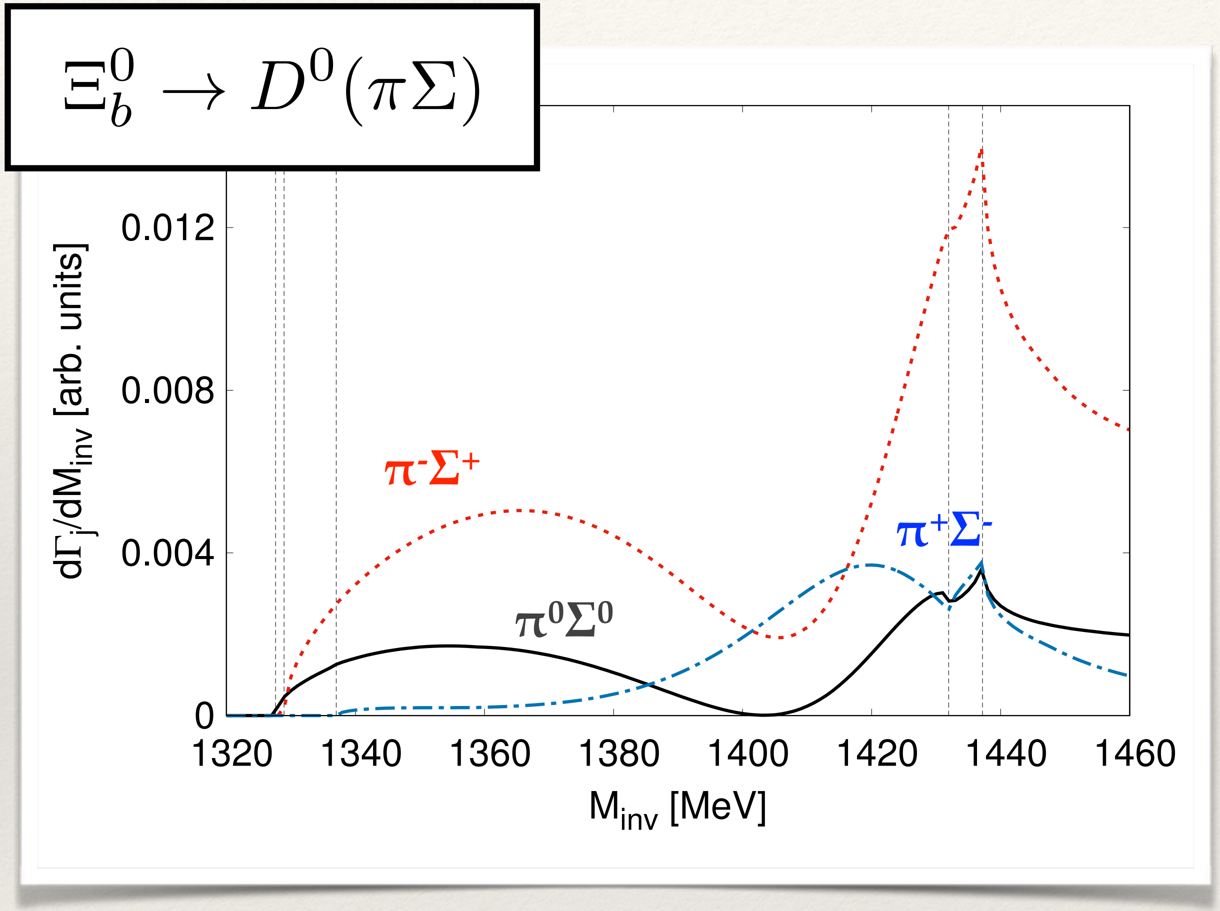
$$T = V + VGT = V + VGV + VGVGV + \cdots$$
$$= (V^{-1} - G)^{-1}$$

Ikeda, Hyodo and Weise, Nucl. Phys. A881, 98 (2012)

IHW model

- fit near the $\bar{\mathrm{K}}\mathrm{N}$ threshold including new exp. data
- s-wave meson-baryon scattering with NLO term
- with isospin breaking

Results : invariant mass distribution



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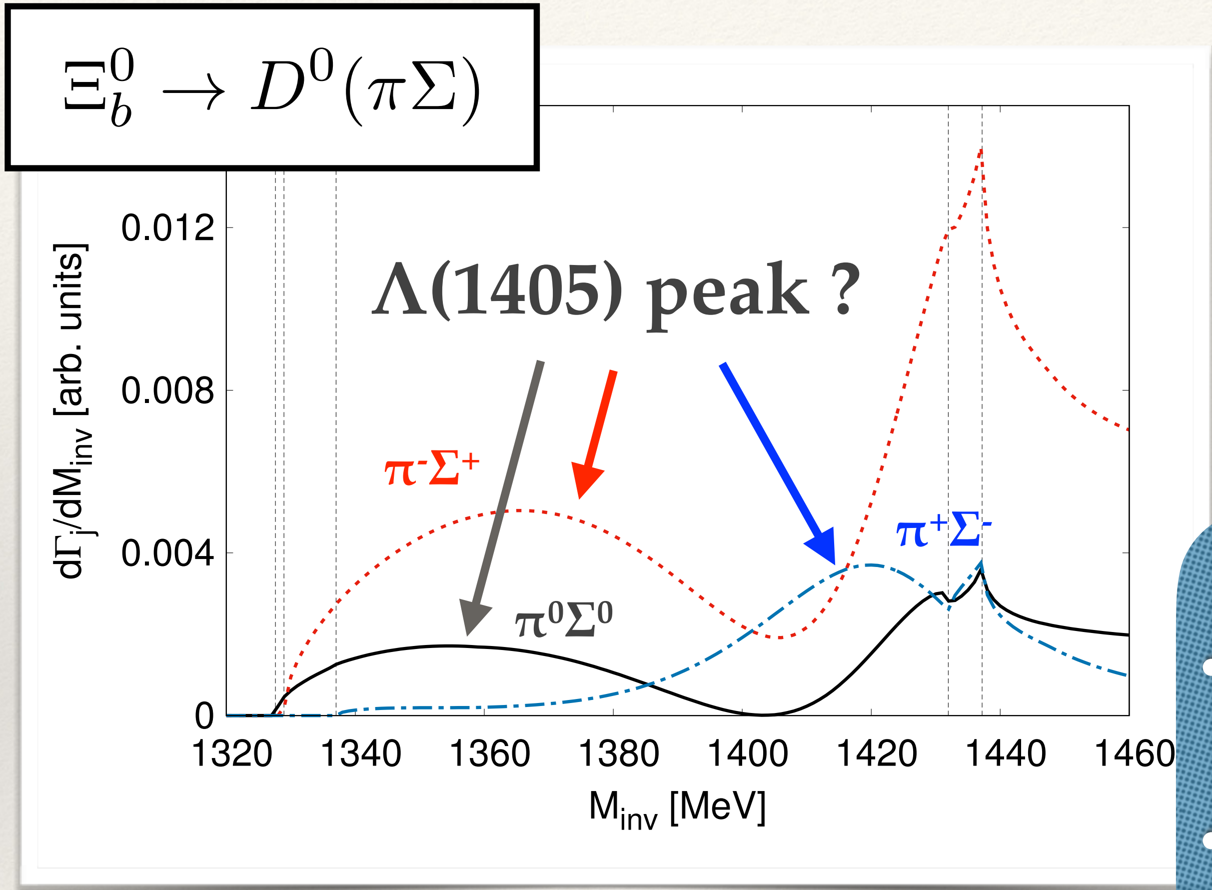
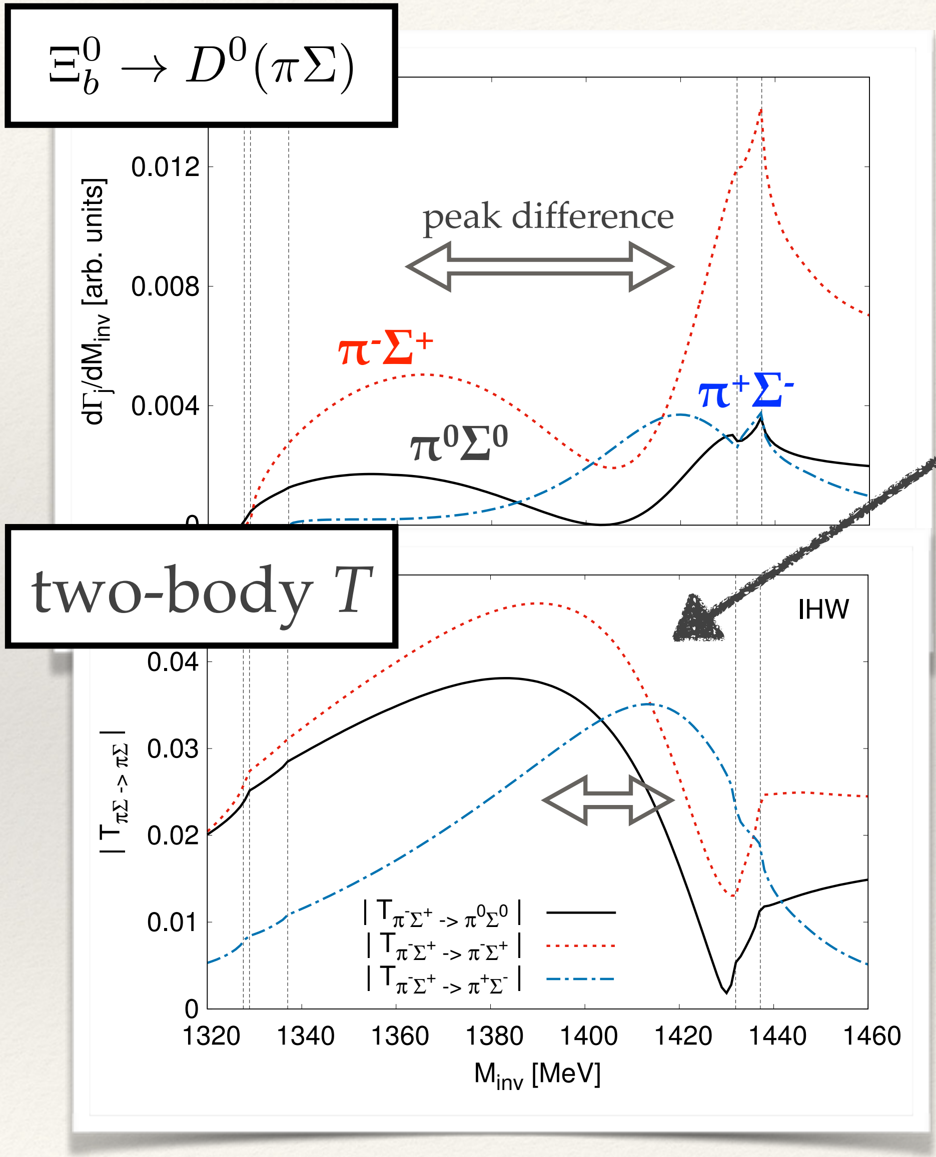


- different "Λ(1405) peak" positions ?
- quite low positions ($\pi^-\Sigma^+$ & $\pi^0\Sigma^0$) ?

Results : invariant mass distribution



- **I=1 interference**

$$|\pi^0\Sigma^0\rangle \sim -\frac{1}{\sqrt{3}}|\pi\Sigma\rangle^{I=0}$$

$$|\pi^-\Sigma^+\rangle \sim -\frac{1}{\sqrt{3}}|\pi\Sigma\rangle^{I=0} - \frac{1}{\sqrt{2}}|\pi\Sigma\rangle^{I=1}$$

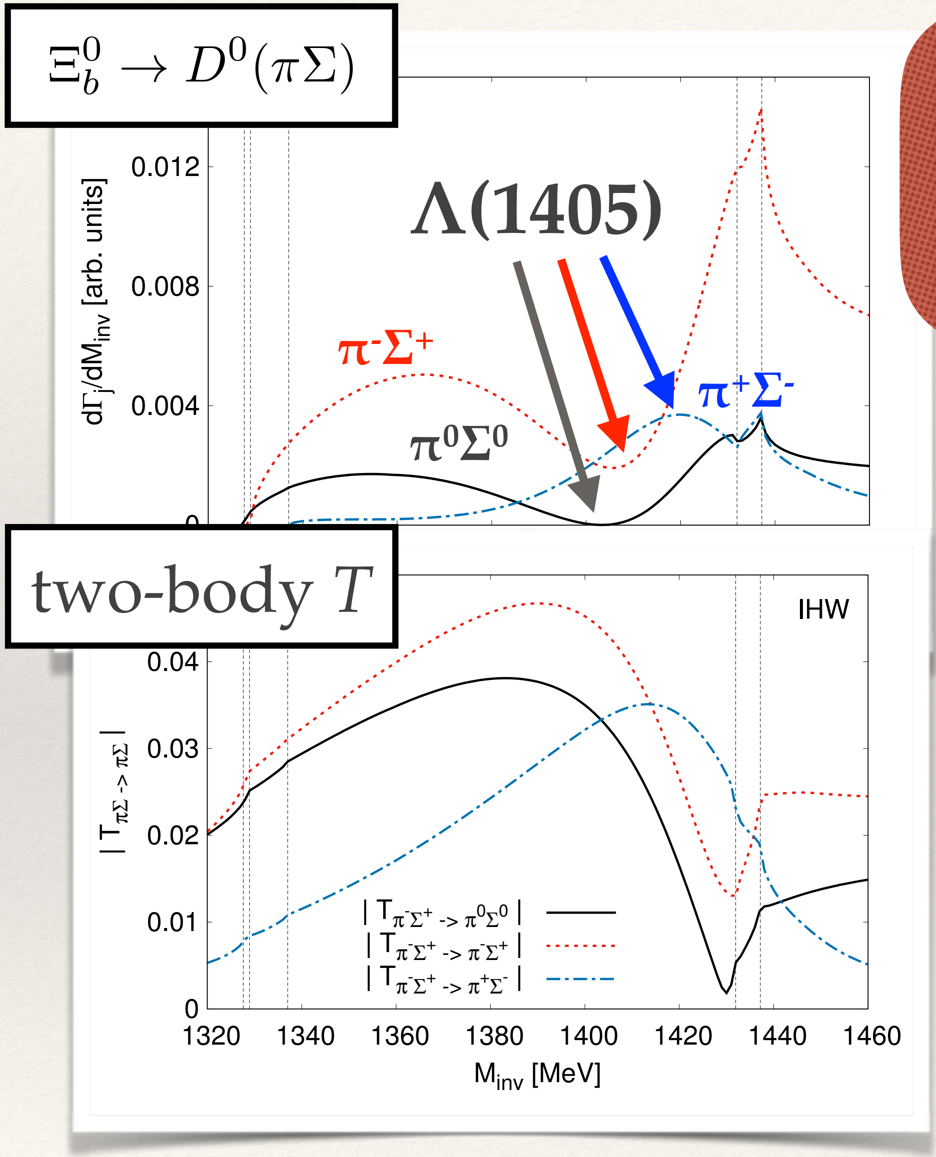
$$|\pi^+\Sigma^-\rangle \sim -\frac{1}{\sqrt{3}}|\pi\Sigma\rangle^{I=0} + \frac{1}{\sqrt{2}}|\pi\Sigma\rangle^{I=1}$$

⇨ **small peak difference in T**

⇕

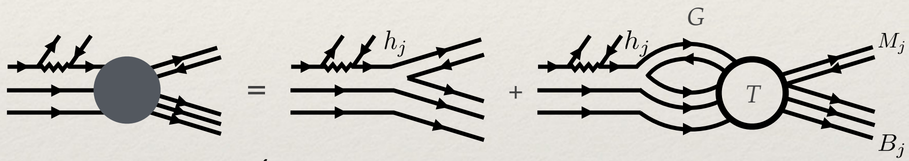
difference in Ξ_b^0 is much larger

Results : invariant mass distribution



"dips" in $\pi^0\Sigma^0$ and $\pi^-\Sigma^+$ correspond to Λ(1405) in T.

- **"dip" origin**



$$\mathscr{M}_j = V_P \left(h_j + \sum_i h_i G_i(M_{\rm inv}) T_{ij}(M_{\rm inv}) \right)$$

interference between "tree" and "rescattering"

(h_j=0 in $\pi^+\Sigma^-$ → ~~dip~~ peak appears)

Λ(1405) in $T_{\pi\Sigma\to\pi\Sigma}$ can be extracted from Ξ_b^0 decay.

Results : "peak" v.s. "dip" against $\bar{K}N$ fraction

"dip" is characteristic of $\mathbf{T}_{\pi\Sigma\to\pi\Sigma}$ dominated reaction

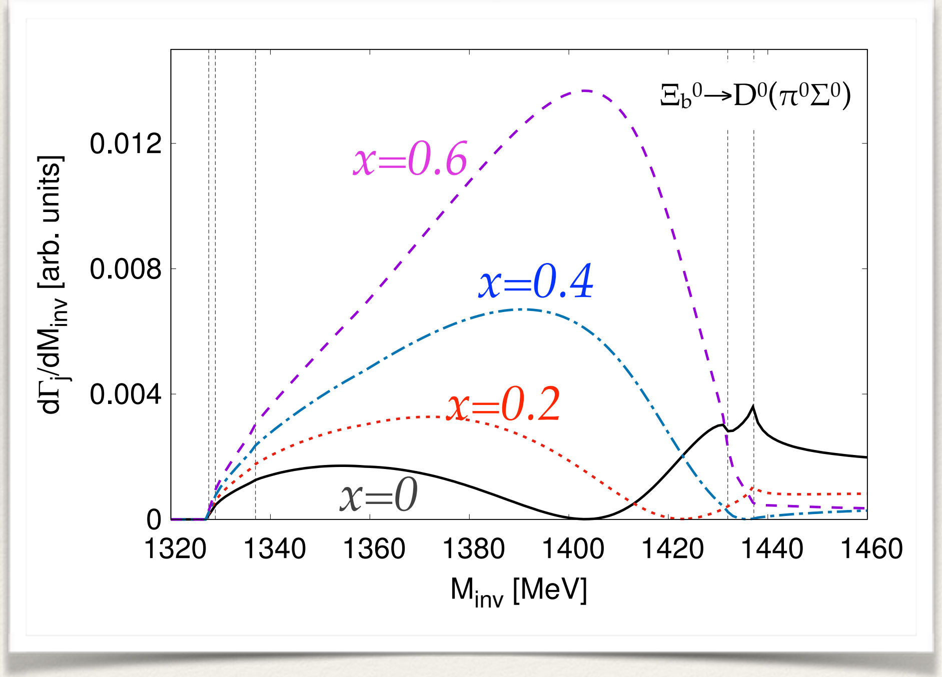
weaker coupling to Λ(1405)

⟷ existing $\mathbf{T}_{\bar{K}N\to\pi\Sigma}$ dominated reactions reveal "peak"

strong coupling to Λ(1405)

$$|MB'\rangle = -\frac{1}{2\sqrt{3}}|\pi^0\Lambda\rangle + \frac{1}{2}|\pi^0\Sigma^0\rangle + |\pi^-\Sigma^+\rangle + \frac{1}{3\sqrt{2}}|\eta\Lambda\rangle - \frac{1}{\sqrt{6}}|\eta\Sigma^0\rangle + |K^0\Xi^0\rangle$$

$$x\ (|K^-p\rangle + |\bar{K}^0 n\rangle)$$



When *x* < *0.5*, "dip" would appear.

Results : "peak" v.s. "dip" against $\bar{\mathrm{K}}$N fraction

"dip" is characteristic of $\mathbf{T}_{\pi\Sigma\to\pi\Sigma}$ dominated reaction

weaker coupling to $\Lambda(1405)$

⟷ existing $\mathbf{T}_{\bar{K}N\to\pi\Sigma}$ dominated reactions reveal "peak"

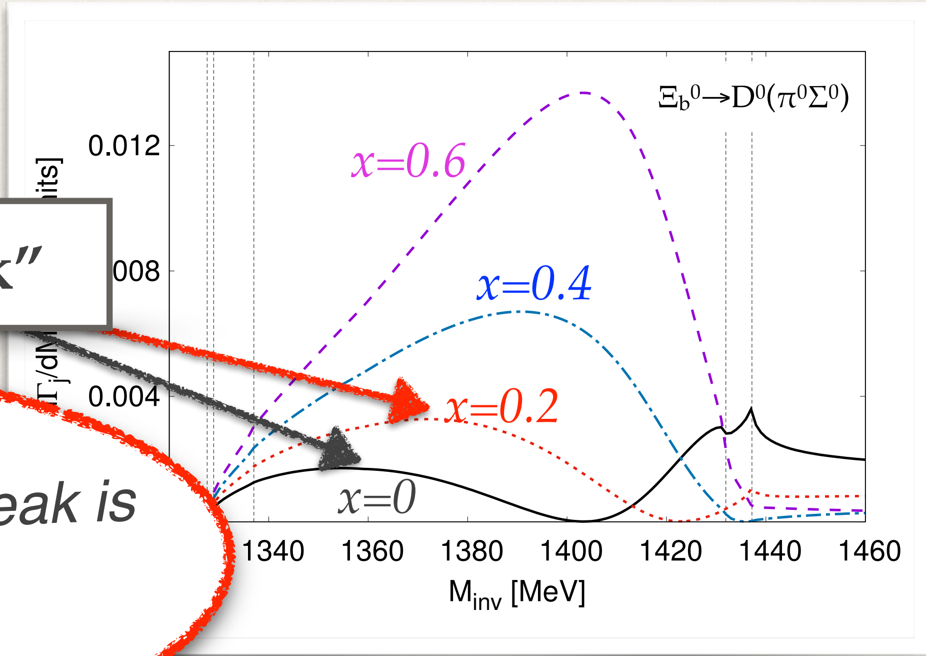
strong coupling to $\Lambda(1405)$

$$|MB'\rangle = -\frac{1}{2\sqrt{3}}|\pi^0\Lambda\rangle + \frac{1}{2}|\pi^0\Sigma^0\rangle + |\pi^-\Sigma^+\rangle$$

$+$

$x\ (|K^-p\rangle + |\bar{K}^0$

"dip" ⟷ "fake peak"



We have to note whether the peak is

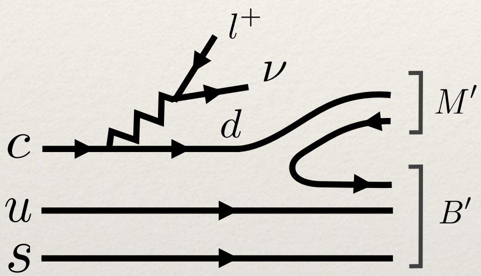
"real" or "fake".

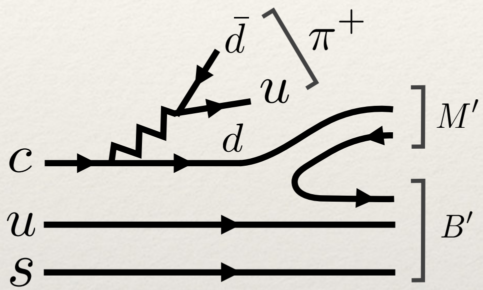
When $x < 0.5$, "dip" would appear.

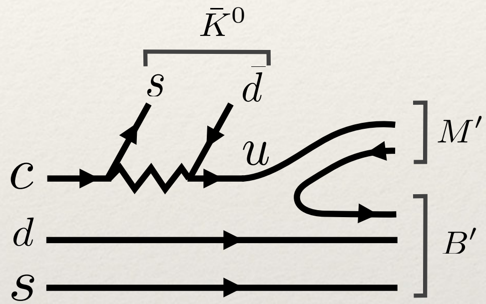
Other diagrams

- **reactions dominated by $T_{\pi\Sigma\to\pi\Sigma}$**

$\Xi_c^+ \to \nu_l l^+ (\pi\Sigma)$	$\Xi_c^+ \to \pi^+ (\pi\Sigma)$	$\Xi_c^0 \to \bar{K}^0 (\pi\Sigma)$







○ only one diagram

○ no contribution from other hadron interactions

× neutrino cannot be measured

× many other diagrams

× π^+M, π^+B interaction may contribute in some channels

○ all final state can be caught

× many other diagrams

× $\bar{K}^0M$, $\bar{K}^0B$ interaction may contribute in some channels

○ all final state can be caught

○ Cabibbo favored

Summary

- We have studied the $\Xi_b^0 \to D^0(\pi\Sigma)$ decay.
- Respecting the SU(3) sym., we have connected the quark d.o.f. and hadron d.o.f.
- From the CKM matrix and kinematics, it turns out that the Ξ_b^0 decay is dominated by $T_{\pi\Sigma\to\pi\Sigma}$.
- $\Lambda(1405)$ signal is seen as a peak in $\pi^+\Sigma^-$, and a "dip" in $\pi^0\Sigma^0$ and $\pi^-\Sigma^+$ due to the interference between tree and rescattering diagrams.

  $\longrightarrow$ "fake peak" may appear when the $\bar{K}N$ fraction is small.