Quark mass dependence of H-dibaryon

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in collaboration with

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ストレンジネス・ハドロン合同研究会

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Outline

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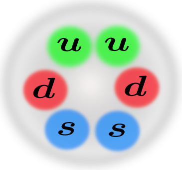
1. Introduction:H-dibaryon
2. Method: Pionless EFT
3. Numerical results
4. Summary



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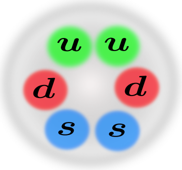
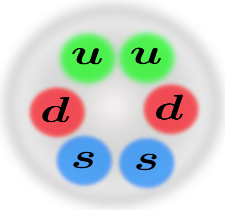


H-dibaryon?

H-dibaryon bound state?

Introduction:H-dibaryon

- H-dibaryon: R.L.Jaffe (Bag model) PRL**38**(1977)195
  - ▷ Flavor-singlet dihyperon with $J^P = 0^+$.
  - ▷ Attractive color magnetic int. $\to M_H = 2150$ MeV.
    ($\sim$80 MeV below $\Lambda\Lambda$)



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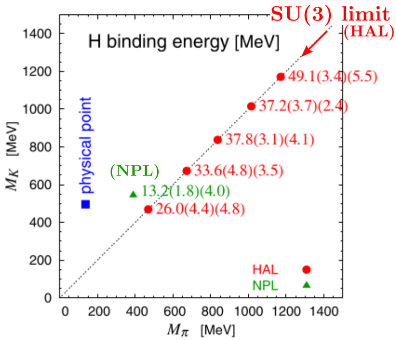
- H-dibaryon from Lattice QCD **(Large quark mass region)**



- HAL ($SU(3)_f$ **limit**) NPA**881**(2012)28
- NPL ($SU(3)_f$ **breaking**) $\Lambda\Lambda - N\Xi - \Sigma\Sigma$ PRD**85**(2012)054511

Bound at large m_q regions!

HALQCD collaboration, NPA**881**(2012)28.

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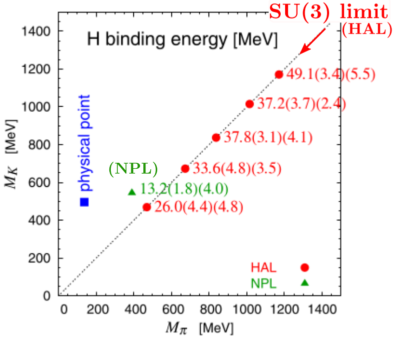

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Bound at large m_q regions!

⇓

(Un)Bound at **Physical point**?

- H-dibaryon has been studied by :**Experiments**.
  - ▷ NAGARA event: double Λ hypernuclei ${}^{6}_{\Lambda\Lambda}\mathrm{He}$

    H.Takahashi *et al.*,PRL**87**(2001)212502

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  - Belle: $\Upsilon(1S)$ and $\Upsilon(2S)$ decays

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    ⇒ **Negative scattering length** of ΛΛ (→**No Bound state**)

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No H bound state at the physical point...?
Virtual state? Resonance?

- Quark mass dependence of H-dibaryon

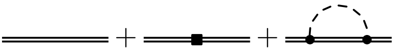
Large m_q (Lattice) $\rightarrow$ Physical point

Introduction: H-dibaryon

▷ Quark mass dependence of H-dibaryon

- Bare H-state ($6q$ state) by evaluating the NG boson loop

  P. E. Shanahan *et al.*, PRL**107**(2011)092004, JPS Conf.Proc.**1**(2014)013028

 $\Leftrightarrow m_0 + A_q m_q + B_q m_q^{3/2}$

Results: **Unbound** at physical point

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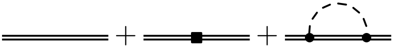

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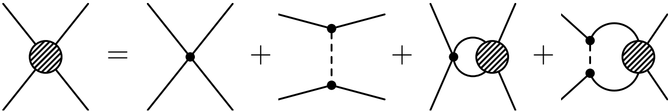
Results: **Unbound** at physical point

  - Chiral effective field theory $\cdots$ BB scattering

    J. Haidenbauer and U. G. Meissner, PLB**706**(2011)100, NPA**881**(2012)44



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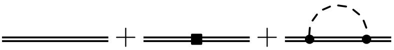

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Results: **Unbound** at physical point

→ **But,** couplings to **BB channels** are not considered.

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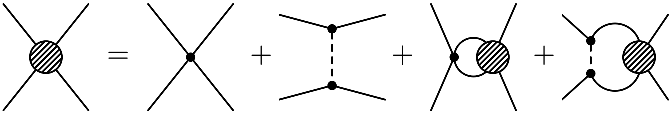

Results: **Unbound** at physical point

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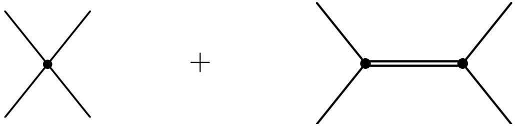
Our work

Purpose: Quark mass dependence of H-dibaryon is studied.

Method: the pionless effective field theory (EFT) with **two baryon channels** and **bare H-dibaryon field**.



D. B. Kaplan, NPB **494**(1997)471,E.Braaten,*et al.*,Annals,Phys.**323**(2008)1770

- Parameters are fitted by the Lattice QCD.

We will obtain

- Binding energy
- Structure of H-dibaryon
- BB interaction
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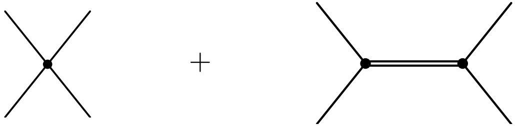

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- Parameters are fitted by the Lattice QCD.

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- Binding energy → Scattering length **(Today's talk)**
- Structure of H-dibaryon
- BB interaction
- ...

We report our current status.

Method: pionless EFT

▷ Compare Length scale ℓ_B with Pion wavelength λ_π

If $\ell_B = (2\mu B)^{-1/2} \gg \lambda_\pi = 1/m_\pi$, **short range forces** are not relevant for the bound states.

⇒ BB interaction → **Contact term**

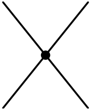

Table : ℓ_B vs λ_π on Lattice

Data	ℓ_B	λ_π	λ_π/ℓ_B
HAL-1	0.59	0.17	0.29
HAL-2	0.72	0.19	0.27
HAL-3	0.77	0.24	0.31
HAL-4	0.88	0.29	0.33
HAL-5	1.14	0.42	0.37
NPL	1.55	0.51	0.33

Method: pionless EFT

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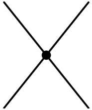
$\Rightarrow$ BB interaction $\to$ **Contact term**



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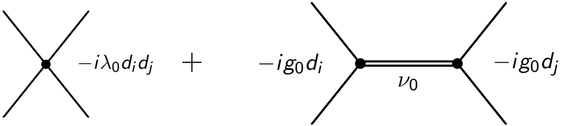
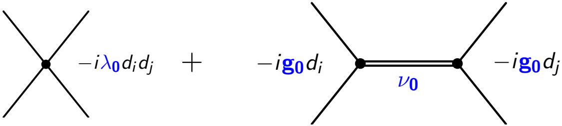
- Four baryon contact term and bare H-dibaryon field



Diagrams and Parameters

Method: pionless EFT

▷ Four baryon contact term and bare H-dibaryon field



- Coupling constants: $\boldsymbol{\lambda_0}$ and $\mathbf{g_0}$ (with d_i →flavor degeneracy of the two baryon states.)

$$i, j = 1, 2, 3 = \Lambda\Lambda,\ \ N\Xi,\ \ \Sigma\Sigma$$

$$d_1 = \frac{1}{\sqrt{8}},\ d_2 = \frac{2}{\sqrt{8}},\ d_3 = \sqrt{\frac{3}{8}},\quad \sum_{i=1}^{3} d_i^2 = 1$$

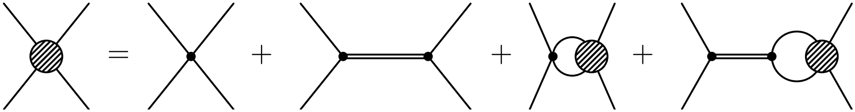
- Mass difference $\nu_0 = M_H^{(0)} - 2M_B = \nu_0^{\mathbf{a}} + \nu_0^{\mathbf{b}}\mathbf{M_B}$

$$M_B = \frac{1}{8}(2M_N + M_\Lambda + 3M_\Sigma + 2M_\Xi)$$

Parameters $\boldsymbol{\lambda_0}$, $\mathbf{g_0}$ and $\boldsymbol{\nu_0^{a,b}}$ are fitted by the Lattice data.

Scattering amplitudes
Method: pionless EFT

- Lippmann-Schwinger eq. for flavor-singlet $\Lambda\Lambda - N\Xi - \Sigma\Sigma$



$\Rightarrow$ Scattering amplitude $(\mathrm{SU}(3)_f$ breaking)

$$f_{ii}(E) = -\frac{\mu_i}{4\pi} d_i^2 \left[\left(\lambda_0 + \frac{g_0^2}{E - \nu_0 + i0^+} \right)^{-1} + \sum_{\ell=1}^{3} d_\ell^2 \frac{\mu_\ell}{\pi^2} \left(\Lambda - \kappa_\ell \tan^{-1} \frac{\Lambda}{\kappa_\ell} \right) \right]^{-1}$$

μ_i = reduced mass, $\quad \kappa_\ell = \sqrt{-2\mu_\ell (E - \Delta_\ell)}$,

$\Delta_1 = 0, \quad \Delta_2 = M_N + M_\Xi - 2M_\Lambda, \quad \Delta_3 = 2M_\Sigma - 2M_\Lambda$

Momentum cutoff $\quad \Lambda \sim 400\,\mathrm{MeV}\ (m_\pi)$

$\Rightarrow$ Binding energy is obtained as **poles of the amplitudes**.

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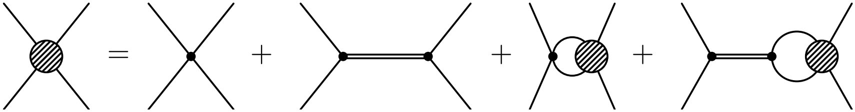

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- Parameters λ_0, g_0 and $\nu_0^{a,b}$ are fitted by **the Lattice data**.

Table. H-dibaryon binding energy from Lattice.

	Data	$B(\sigma_{\rm sta})(\sigma_{\rm sys})$ [MeV]	M_Λ [MeV]
SU(3)$_f$ limit	HAL-1	49.1 (3.4)(5.5)	2274
	HAL-2	37.2 (3.7)(2.4)	2031
	HAL-3	37.8 (3.1)(4.2)	1749
	HAL-4	33.6 (4.8)(3.5)	1484
	HAL-5	26.0 (4.4)(4.8)	1161
SU(3)$_f$ breaking	NPL	13.2 (1.8)(4.0)	1170
Physical point	(Sasaki-san)	???	1116

HAL NPA**881**(2012)28, NPL PRD**85**(2012)054511

- Parameters which minimize χ^2

$$\chi^2 = \sum_i \frac{[B_i^{Lattice} - B_i(\lambda, g^2, \nu^a, \nu^b)]^2}{\sigma_{{\rm sta},i}^2 + \sigma_{{\rm sys},i}^2}$$

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Summary

Subject: Quark mass dependence of the H-dibaryon

⇓

- Baryon-baryon scattering ($\Lambda\Lambda - N\Xi - \Sigma\Sigma$) is discussed by the pionless EFT.
- The scattering amplitude described by the four baryon contact term and the coupling to the bare H-dibaryon is studied.
- The coupling constants of the EFT is fitted by the Lattice QCD results.
- The negative scattering length at the physical point is obtained.

Thank you for your kind attention.