Quark mass dependence of H-dibaryon

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in collaboration with

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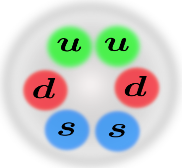
1. Introduction:H-dibaryon
2. Method: Pionless EFT
3. Numerical results
4. Summary



***H*-dibaryon?**

Outline

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2. Method: Pionless EFT
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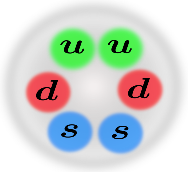
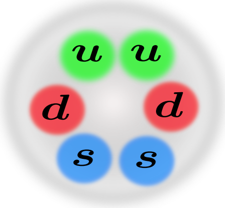


H-dibaryon?

H-dibaryon bound state?

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



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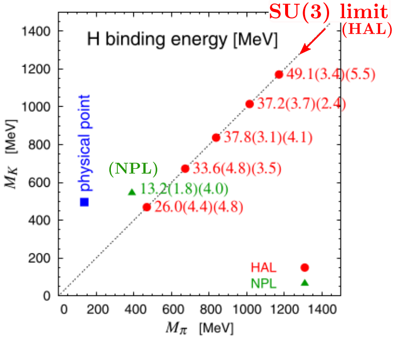

- HAL (SU(3)$_f$ **limit**)
  NPA**881**(2012)28
- NPL (SU(3)$_f$ **breaking**)
  $\Lambda\Lambda - N\Xi - \Sigma\Sigma$
  PRD**85**(2012)054511

Bound at large m_q regions!

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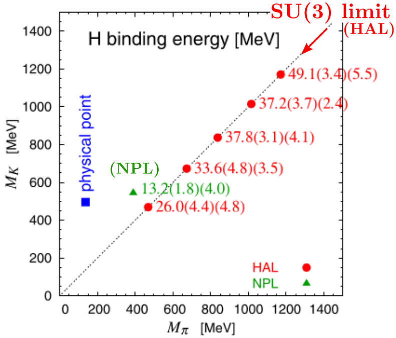

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⇓

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

- H-dibaryon has been studied by **Experiments**.

  ▷ Double Λ hypernuclei ${}^{6}_{\Lambda\Lambda}\mathrm{He}$

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

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

- Quark mass dependence of H-dibaryon

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

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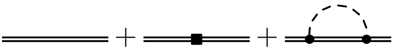

$$\Leftrightarrow m_0 + A_q m_q + B_q m_q^{3/2}$$

Results: **Unbound** at physical point

Large m_q (Lattice) $\to$ Physical point

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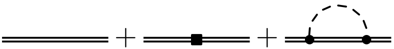

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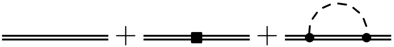

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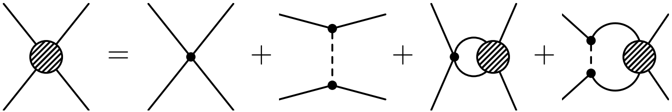
    J. Haidenbauer and U. G. Meissner, PLB**706**(2011)100, NPA**881**(2012)44



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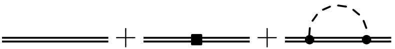

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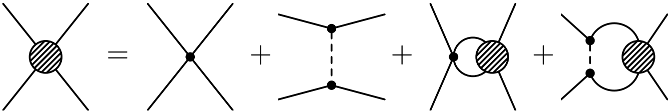

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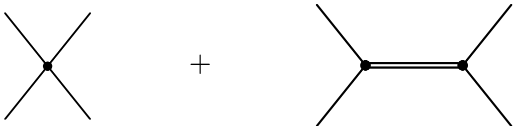
Purpose: Quark mass dependence of H-dibaryon is studied.

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

- Note: **Flavor singlet** is considered.
  8s,27 → Future work...
- Parameters are fitted by the Lattice QCD.

We will obtain

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

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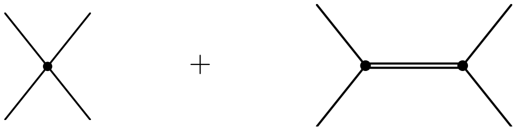

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We will obtain

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

Method: pionless EFT

▷ Compare Length scale $\boldsymbol{\ell_B}$ with Pion wavelength $\boldsymbol{\lambda_\pi}$

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**

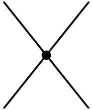

Table : ℓ_B vs λ_π on Lattice

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

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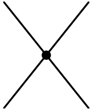

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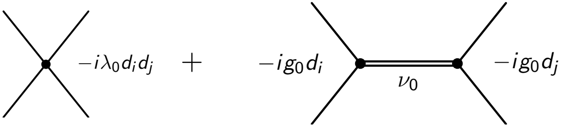
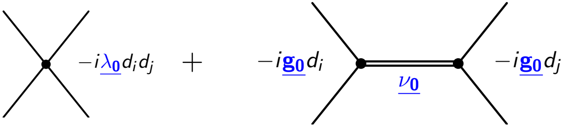
- Four baryon contact term and bare H-dibaryon field



Diagrams and Parameters
Method: pionless EFT

▷ Four baryon contact term and bare H-dibaryon field



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

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

- Coupling constants: $\boldsymbol{\lambda_0}$ and $\mathbf{g_0}$ (with d_i →flavor degeneracy of the two baryon states.)
- Mass difference $\nu_0 = M_H^{(0)} - 2M_\Lambda$ P. E. Shanahan *et al.*, PRL**107**(2011)092004.

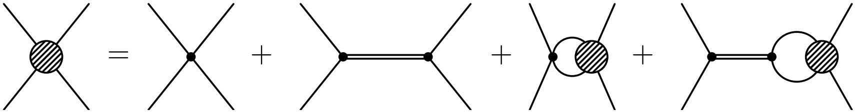
$$M_H^{(0)} = \mathbf{M_H} - \boldsymbol{\sigma_H}(m_\pi^2/2 + m_K^2)$$

Parameters ($\boldsymbol{\lambda_0}$, $\mathbf{g_0}$, $\mathbf{M_H}$, $\boldsymbol{\sigma_H}$) 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

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

$\mu_i =$ 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 $\quad \Lambda \sim 300\,\text{MeV}$

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

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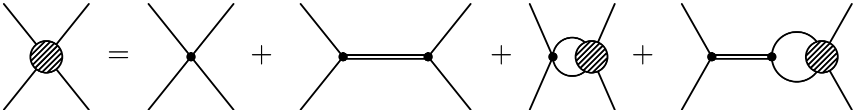

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Parameter fitting
Numerical results

- Parameters (λ_0, g_0, M_H, σ_H) are fitted by **the binding energies** from the Lattice data.

Table. H-dibaryon binding energy from Lattice.

	Data	B [MeV]	M_Λ [MeV]
SU(3)$_f$ limit	HAL-1	49.1	2274
	HAL-2	37.2	2031
	HAL-3	37.8	1749
	HAL-4	33.6	1484
	HAL-5	26.0	1161
SU(3)$_f$ breaking	NPL	13.2	1170
Physical point		**???**	1116

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

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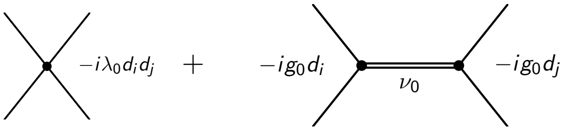

- Parameter fitting by **HAL3-5 data**

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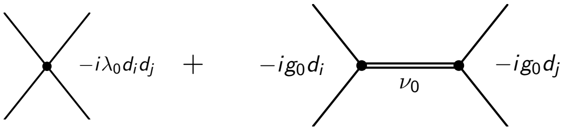

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λ_0 [MeV^{-2}]	g_0^2 [MeV^{-1}]	M_H [MeV]	σ_H [MeV^{-1}]
-1.3×10^{-5}	2.4	19783	-1.5×10^{-3}

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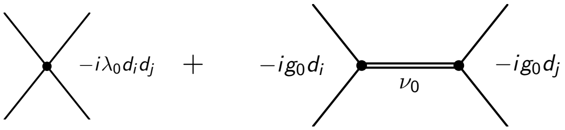

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▷ $\lambda_0 < 0$: Contact term is attractive.

▷ **Large M_H:** Bare field is not important.

- From the EFT with fitting parameters, Scattering lengths (a) are obtained.

		HAL3-5	Lattice
SU(3) limit	$a_{\mathrm{HAL3}}(M_B = 1749)$ [fm]	1.40	(Bound)
(a of BB singlet)	$a_{\mathrm{HAL4}}(M_B = 1484)$ [fm]	1.49	(Bound)
	$a_{\mathrm{HAL5}}(M_B = 1161)$ [fm]	1.71	(Bound)
SU(3) breaking	$a_{\mathrm{NPL}}(M_\Lambda = 1170)$ [fm]	-6.52	(Bound)
(a of $\Lambda\Lambda$)	$a_{\mathrm{Phys}}(M_\Lambda = 1116)$ [fm]	-3.77	—

(Definition: $a > 0 \rightarrow$ repulsive, $a < 0 \rightarrow$ attractive)

Scattering length (fitting by HAL data)

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- **Inconsistency** between our result and Lattice (NPL)
  - ▷ Our result: Negative a_{NPL} $\Leftrightarrow$ NPL:Bound state
    (no Bound state) ($E_B = 13.2$ MeV)

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- Phys. point: Negative a_{Phys} $\Rightarrow$ No bound state

Parameter fitting (HAL + NPL)

- Parameters fitting by HAL3-5 + NPL

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  $\Rightarrow$ no small χ^2 solution...

- Why...?

Parameter fitting (HAL + NPL)

Numerical results

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  $\Rightarrow$ no small χ^2 solution...

- Why...?

▷ Our model
  (i) 8s and 27 components are needed.
  (ii) Quark mass dependence of coupling constant.
  $\Rightarrow$ Future work

▷ Inconsistency between HAL and NPL...?

K. Sasaki [HAL QCD Collaboration], Nucl. Phys. A **914**, 231 (2013).

	$(m_\pi, m_K)[MeV]$	state
HAL	(411,635)	Resonance(below $N\Xi$ threshold)
NPL	(390,544)	Bound ($E_B = 13.2$ MeV)

The inconsistency will be resolved in future lattice studied.

Summary

Subject: Quark mass dependence of the H-dibaryon

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- 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.
- We obtain the scattering length at the Lattice data point and the physical point.

Future work

- 8s and 27 components will be included.
- Quark mass dependence of coupling constants.

Thank you for your kind attention.