S=-2バリオン間相互作用のクォーク質量依存性

 

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H-dibaryon and ΛΛ interaction

H-dibaryon: uuddss bound state in quark model

R.L. Jaffe, Phys. Rev. Lett. 38, 195 (1977)

Experiments

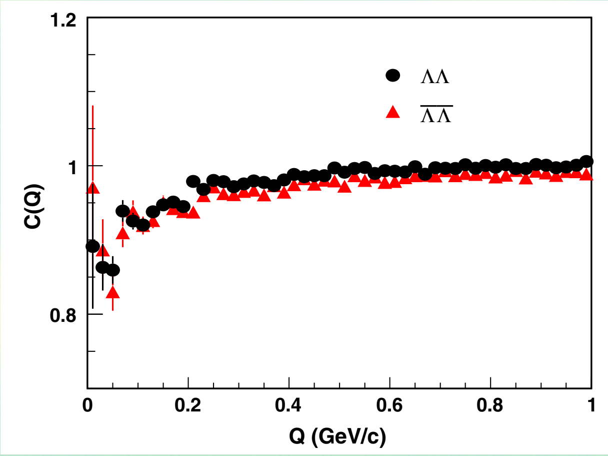
- Nagara event: no deeply bound H

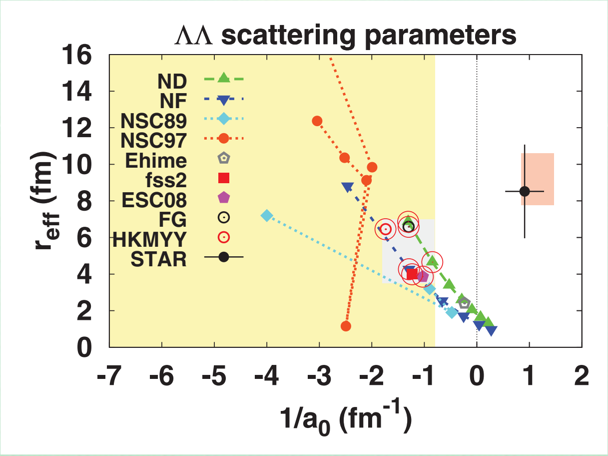
H. Takahashi, *et al.*, Phys. Rev. Lett. 87, 212502 (2001)

- RHIC-STAR: ΛΛ correlation —> scattering length

L. Adamczyk, *et al.*, Phys. Rev. Lett. 114, 022301 (2015)

K. Morita, T. Furumoto, A. Ohnishi, Phys. Rev. C 91, 024916 (2015)

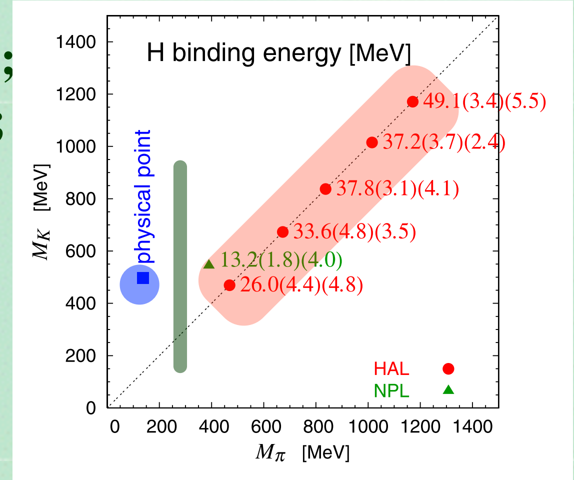




Lattice QCD and quark mass dependence

Bound H-dibaryon at unphysical quark masses

HAL QCD, T. Inoue *et al.*, Phys. Rev. Lett. 106, 162002 (2011);
NPLQCD, S. Beane *et al.*, Phys. Rev. Lett. 106, 162001 (2011);
HAL QCD, T. Inoue *et al.*, Nucl. Phys. A881, 28 (2012); …



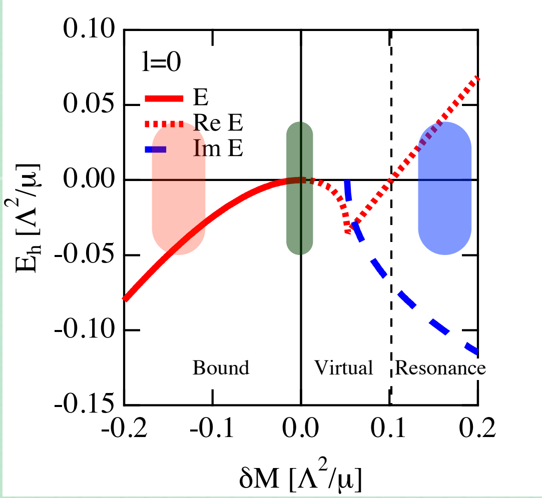
- Physical point simulation is ongoing.

- Extrapolation: unbound at phys. point

S. Shanahan, A. Thomas, R. Young, Phys. Rev. Lett. 107, 092004 (2011);
J. Haidenbauer, U.G. Meissner, Phys. Lett. B 706, 100 (2011)

Near-threshold scaling in s-wave

T. Hyodo, Phys. Rev. C90, 055208 (2014)



- virtual state

- unitary limit

Unitary limit at unphysical quark masses?

Effective Lagrangian

Large length scale compared with the interaction range

- HALQCD, SU(3) limit

HALQCD, T. Inoue *et al.*, Nucl. Phys. A881, 28 (2012)

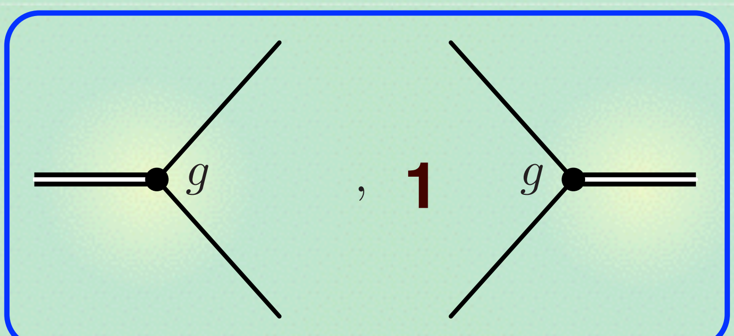
$$\{a_0, l_B = 1/\sqrt{MB}\} > \lambda_{\mathrm{int}} = 1/m_{NG}$$

Low energy effective Lagrangian with contact interactions

$$\mathcal{L}_{\mathrm{free}} = \sum_{a=1}^{4} \sum_{\sigma=\uparrow,\downarrow} B^{\dagger}_{a,\sigma} \left(i\frac{\partial}{\partial t} + \frac{\nabla^2}{2M_a} + \delta_a \right) B_{a,\sigma} + H^{\dagger} \left(i\frac{\partial}{\partial t} + \frac{\nabla^2}{2M_H} + \nu \right) H$$

$$\mathcal{L}_{\mathrm{int}} = \underline{-g[D^{(1)\dagger} H + H^{\dagger} D^{(1)}]} - \underline{\lambda^{(1)} D^{(1)\dagger} D^{(1)} - \lambda^{(8)} D^{(8)\dagger} D^{(8)} - \lambda^{(27)} D^{(27)\dagger} D^{(27)}}$$

$$D^{(F)} = [BB]^{(F)}_{J=0,S=-2,I=0}$$



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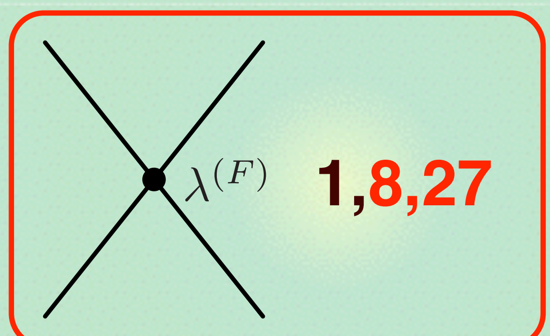
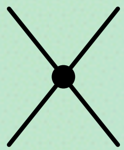
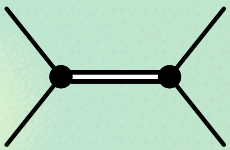


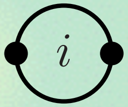
Low energy scattering amplitude

Coupled-channel scattering amplitude (i=ΛΛ, NΞ, ΣΣ)

$$f_{ii}(E) = \frac{\mu_i}{2\pi}\left[(\mathcal{A}^{\rm tree}(E))^{-1} + I(E)\right]^{-1}_{ii}$$

$\mathcal{A}^{\rm tree}_{ij}(E) =$ i  j + i  j

$$= -\left(V_{ij} + \frac{g^2 d_i^\dagger d_j}{E-\nu+i0^+}\right), \quad V = U^{-1}\begin{pmatrix}\lambda^{(1)} & & \\ & \lambda^{(8)} & \\ & & \lambda^{(27)}\end{pmatrix}U, \quad d = \begin{pmatrix}-\sqrt{\frac{1}{8}} \\ -\sqrt{\frac{1}{2}} \\ \sqrt{\frac{3}{8}}\end{pmatrix}$$

$I_i(E) =$ 

$$= \frac{\mu_i}{\pi^2}\left(-\Lambda + k_i \,\mathrm{artanh}\frac{\Lambda}{k_i}\right), \quad k_i = \sqrt{2\mu_i(E-\Delta_i)}$$

EFT describes the low energy scattering for a given (m_l, m_s).

- **scattering length, bound state pole, …**
- **Quark mass dep. —> baryon masses and couplings λ**

Modeling quark mass dependence

"Quark masses" via GMOR relation

$$B_0 m_l = \frac{m_\pi^2}{2}, \quad B_0 m_s = m_K^2 - \frac{m_\pi^2}{2}$$

Baryon masses <— Exp./lattice

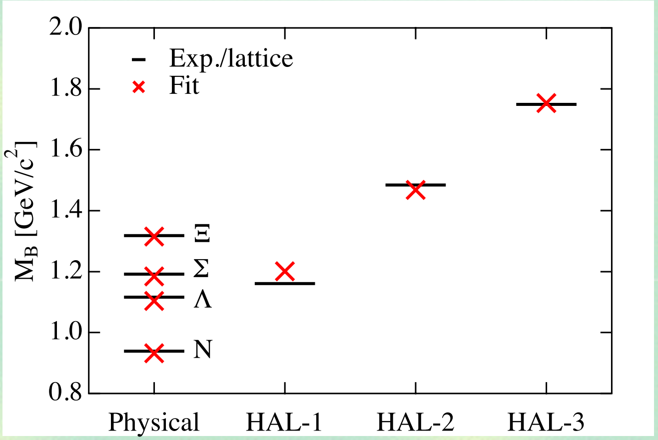
HALQCD, T. Inoue *et al.*, Nucl. Phys. A881, 28 (2012)

$$M_N(m_l, m_s) = M_0 - (2\alpha + 2\beta + 4\sigma) B_0 m_l - 2\sigma B_0 m_s,$$

$$M_\Lambda(m_l, m_s) = M_0 - (\alpha + 2\beta + 4\sigma) B_0 m_l - (\alpha + 2\sigma) B_0 m_s,$$

$$M_\Sigma(m_l, m_s) = M_0 - \left(\frac{5}{3}\alpha + \frac{2}{3}\beta + 4\sigma\right) B_0 m_l - \left(\frac{1}{3}\alpha + \frac{4}{3}\beta + 2\sigma\right) B_0 m_s,$$

$$M_\Xi(m_l, m_s) = M_0 - \left(\frac{1}{3}\alpha + \frac{4}{3}\beta + 4\sigma\right) B_0 m_l - \left(\frac{5}{3}\alpha + \frac{2}{3}\beta + 2\sigma\right) B_0 m_s$$

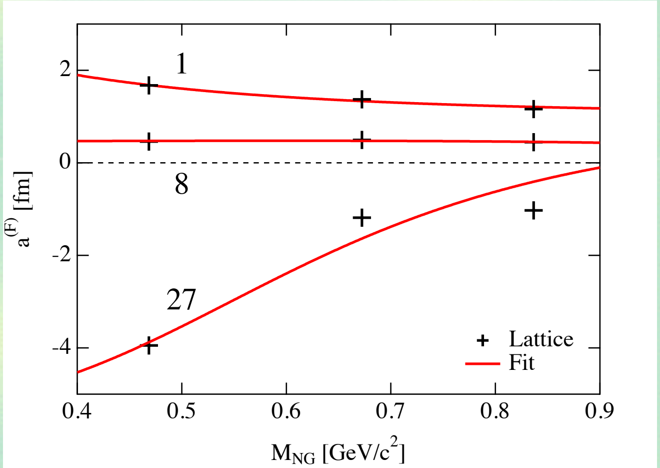


Couplings <— scattering length

- 1: bound, 8: repulsive, 27: attractive

$$\lambda^{(F)}(m_l, m_s) = \lambda_0^{(F)} + \lambda_1^{(F)} B_0 (2m_l + m_s)$$

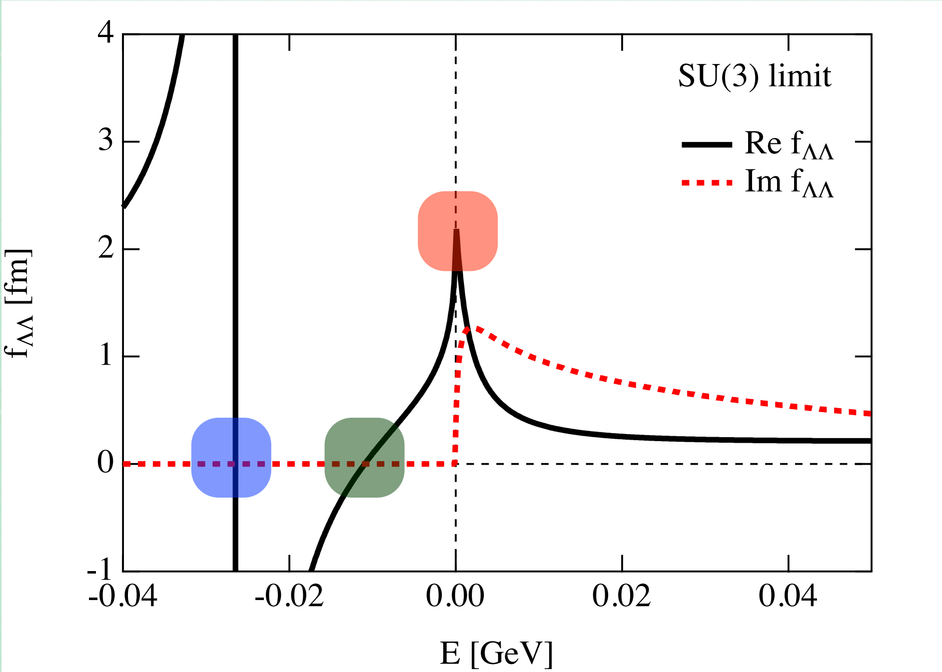
$$g(m_l, m_s) = 0$$

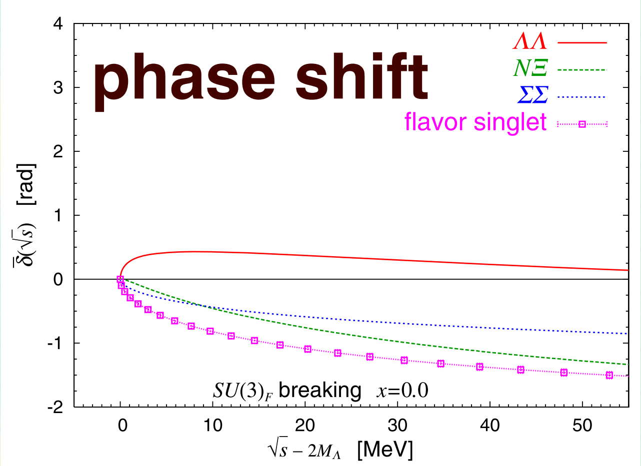


- This talk: g=0, no bare H

SU(3) limit

ΛΛ scattering amplitude in the SU(3) limit





c.f. HALQCD, T. Inoue *et al.*, Nucl. Phys. A881, 28 (2012)

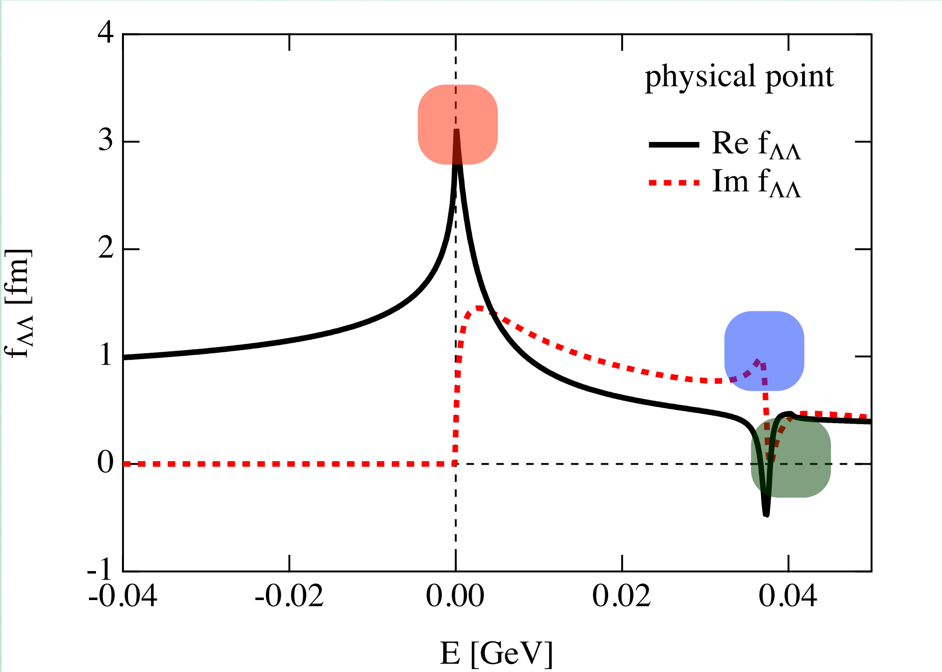
- bound H <— bound state in 1
- attractive scattering length <— attraction in 27

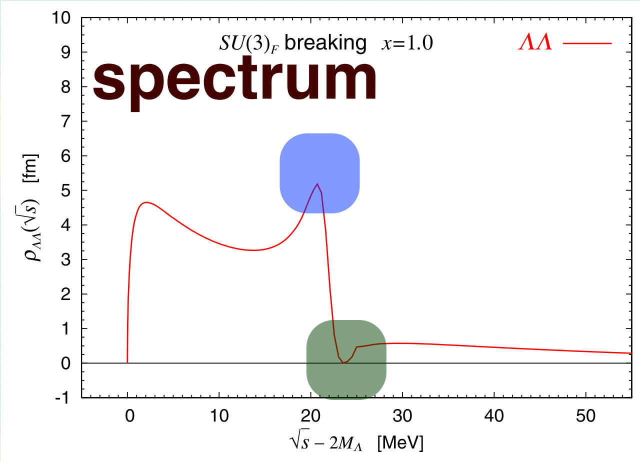
$$f_{\Lambda\Lambda}(E) = \frac{1}{8}f^{(1)}(E) + \frac{1}{5}f^{(8)}(E) + \frac{27}{40}f^{(27)}(E)$$

- CDD pole below threshold: f(E)=0 —> ERE breaks down.

Physical point

ΛΛ scattering amplitude at the physical point





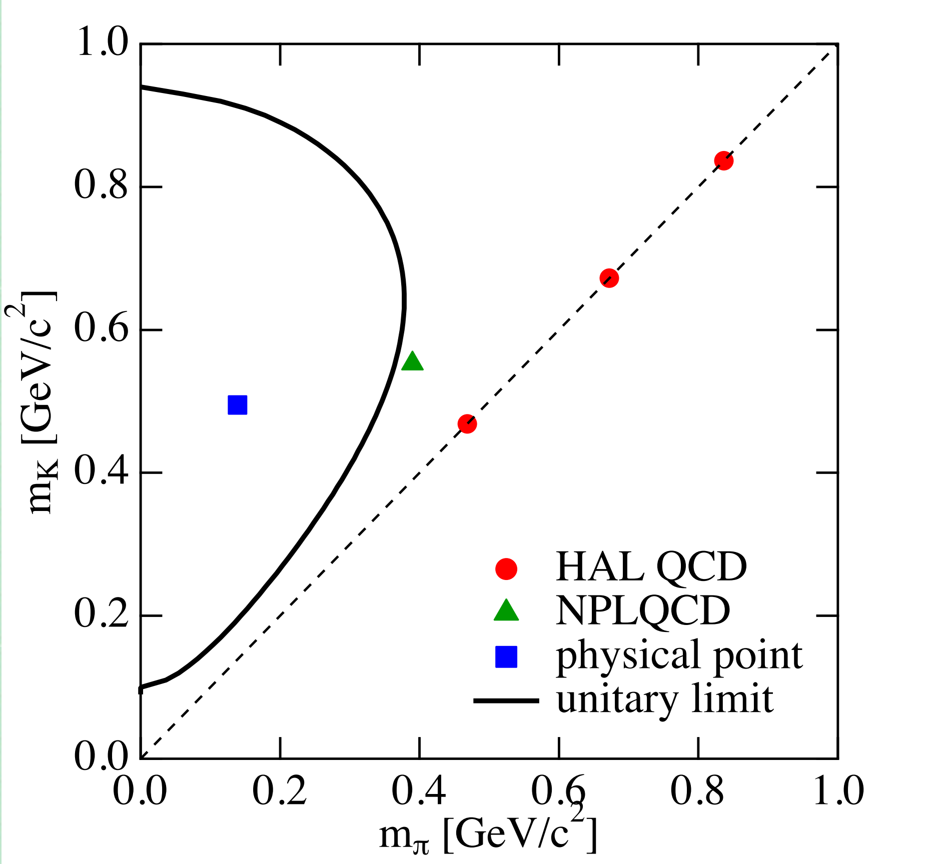
c.f. HALQCD, T. Inoue *et al.*, Nucl. Phys. A881, 28 (2012)

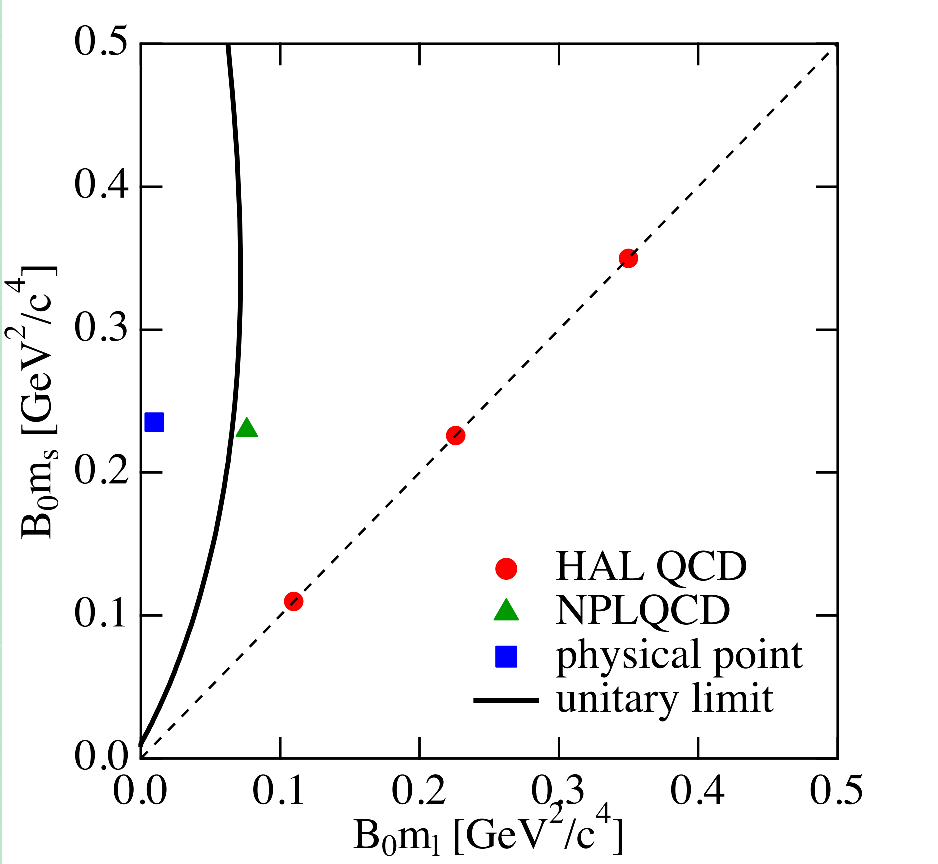
- no bound H, but a resonance
- attractive scattering length: $a_{\Lambda\Lambda} = -3.2$ fm
- Ramsauer-Townsend effect near resonance : $\delta=\pi$ -> $f(E)=0$
  <— remnant of the CDD pole

Extrapolation and unitary limit

Extrapolation in the NGboson/quark mass plane

$$B_0 m_l = \frac{m_\pi^2}{2}, \quad B_0 m_s = m_K^2 - \frac{m_\pi^2}{2}$$





- unitary limit between SU(3) limit and physical point

Summary

- We study the quark mass dependence of the H-dibaryon and the $\Lambda\Lambda$ interaction using EFT.
- SU(3) limit: bound H with attractive scattering length <— CDD pole below the threshold.
- Physical point: Ramsauer-Townsend effect near resonance as a remnant of the CDD pole.
- Unitary limit of the $\Lambda\Lambda$ scattering exists between SU(3) limit and physical point.

Y. Yamaguchi, T. Hyodo, in preparation.