Continuum limit of baryon-baryon scattering with SU(3) flavor symmetry

Jeremy R. Green

Theoretical Physics Department, CERN

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Zoom/Gather@MIT

H dibaryon

Conjectured 0^+, *uuddss* SU(3) singlet: $\Lambda\Lambda$ bound state. R. L. Jaffe, 1977

Experiments put upper limit $B_H < 7$ MeV

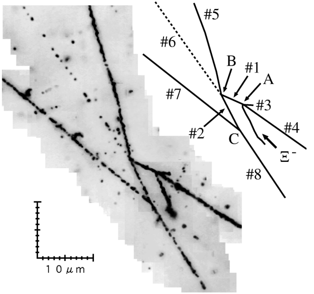
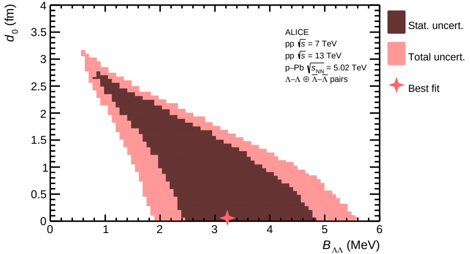


FIG. 2. Photograph and schematic drawing of NAGARA event. See text for detailed explanation.

KEK E373, PRL **87**, 212502 (2001)



ALICE, PLB **797**, 134822 (2019)

Hyperon-hyperon interactions difficult to study in experiment.
Important for understanding strangeness in neutron stars.

SU(3) singlet not accessible from strangeness 0 or −1.

Previous study

$N_f = 2$ CLS ensembles with quenched strange quark.

Lattice QCD study of the H dibaryon using hexaquark and two-baryon interpolators
A. Francis, JRG, P. M. Junnarkar, Ch. Miao, T. D. Rae, H. Wittig, Phys. Rev. D **99**, 074505 (2019)

- Comparison of interpolating operators

$$\text{Hexaquark: } \mathcal{O}_H \sim \sum_{\vec{x}} e^{-i\vec{p}\cdot\vec{x}} qqqqqq(x)$$

$$\text{Baryon-baryon: } \mathcal{O}_{BB} \sim \sum_{\vec{x}_1,\vec{x}_2} e^{-i\vec{p}_1\cdot\vec{x}_1} e^{-i\vec{p}_2\cdot\vec{x}_2} qqq(x_1)qqq(x_2)$$

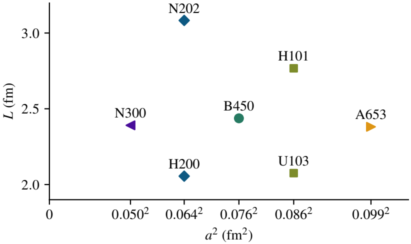
  → hexaquark less useful for isolating ground state

- Pioneering use of distillation for baryon-baryon operators.

Calculations with $N_f = 3$

Weakly bound H dibaryon from SU(3)-flavor-symmetric QCD
JRG, A. D. Hanlon, P. M. Junnarkar, H. Wittig, arXiv:2103.01054

Ensembles with $O(a)$ improved Wilson-clover fermions from CLS.



SU(3)-symmetric point with physical $m_u + m_d + m_s$.

$m_\pi = m_K = m_\eta \approx 420$ MeV.

Wide range of L and a.

Distillation and baryon-baryon interpolators used throughout.

Two octet baryons: $\mathbf{8} \otimes \mathbf{8} = (\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{27})_S \oplus (\mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}})_A$.
Initially focus on $\mathbf{1}$, ${}^1S_0$ for H dibaryon $\to A_1$ or A_1^+ little group irreps.

Fitting spectrum

In most frames, use 3×3 correlator matrix in GEVP.

Perform fits to ratio of diagonalized correlator,

$$R_n(t) \equiv \frac{\bar{C}_{nn}(t)}{C_\Lambda^{\vec{p}_1}(t)\, C_\Lambda^{\vec{p}_2}(t)},$$

yields energy difference from noninteracting level.

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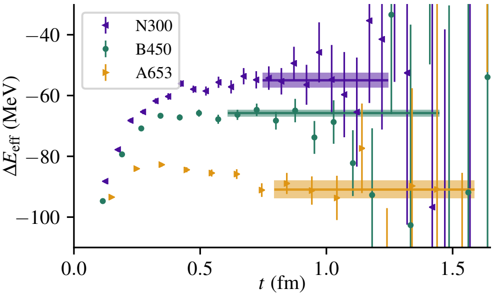
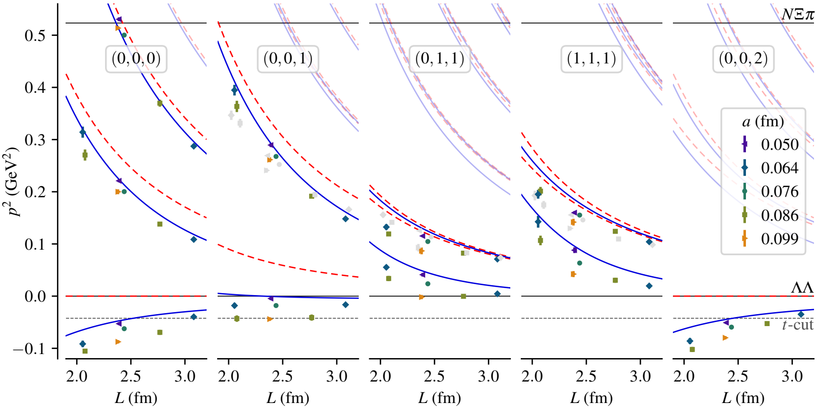


Effective energy difference: ground state in $(0, 0, 1)$ (closest to pole location).

Three ensembles with similar L, different a.

Spectrum summary

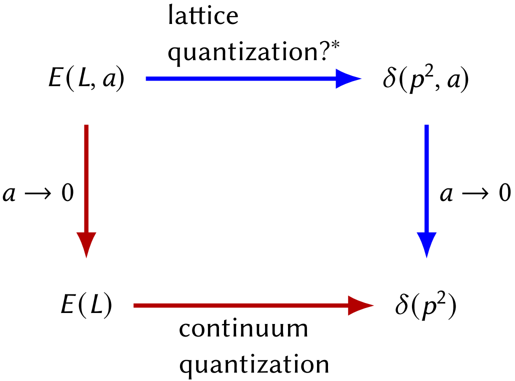


Points: lattice energy levels.

Red dashed curves: noninteracting levels.

Blue curves: interacting levels in continuum.

Two paths to continuum phase shift



*finite-volume quantization at nonzero lattice spacing was studied for a contact interaction in C. Körber, E. Berkowitz, T. Luu, 1912.04425

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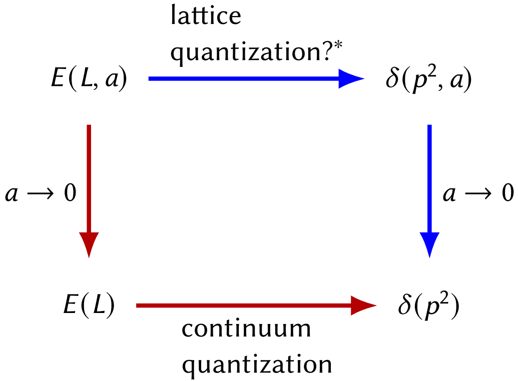

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Our strategy: apply continuum quantization conditions to $E(L,a)$, i.e. follow blue path neglecting artifacts in quantization condition.

Combined phase shift fits

S-wave quantization condition:

$$p \cot \delta(p) = \frac{2}{\sqrt{\pi L \gamma}} Z_{00}^{\vec{P}L/(2\pi)}\left(1, \left(\frac{pL}{2\pi}\right)^2\right)$$

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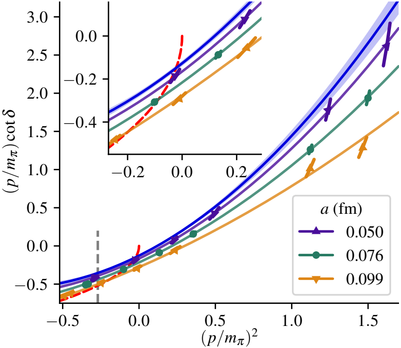
Fit ansatz:

$$p \cot \delta(p) = \sum_{i=0}^{N-1} c_i p^{2i}, \qquad c_i = c_{i0} + c_{i1} a^2.$$



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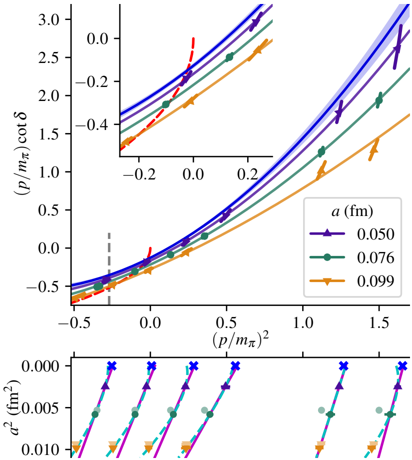
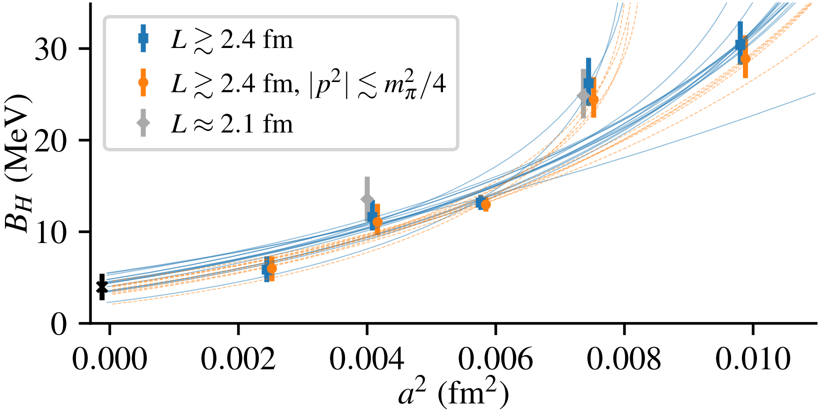
Cross check: extrapolate energies at fixed volume.



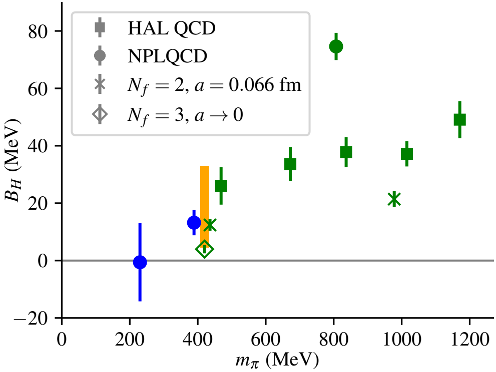
Binding energy versus a



Fits to spectrum of different subsets of ensembles.

Strong dependence on lattice spacing.

Binding energy: comparison with literature



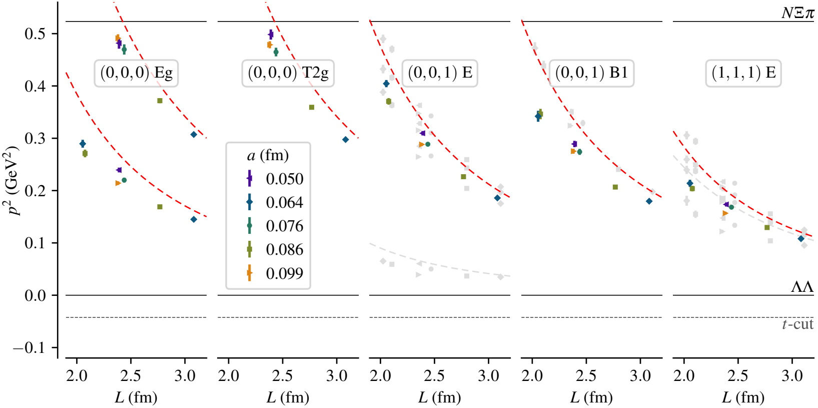
green: $m_s = m_{ud}$

blue: $m_s = m_s^{\text{phys}} > m_{ud}$

H dibaryon: current status

- Analysis being revised in response to referee comments.
  $\to$ more conservative errors on spectrum.
- Additional ensemble providing sixth lattice spacing
  $a = 0.039$ fm.
- Main conclusions unchanged:
  - large discretization effects
  - small continuum binding energy

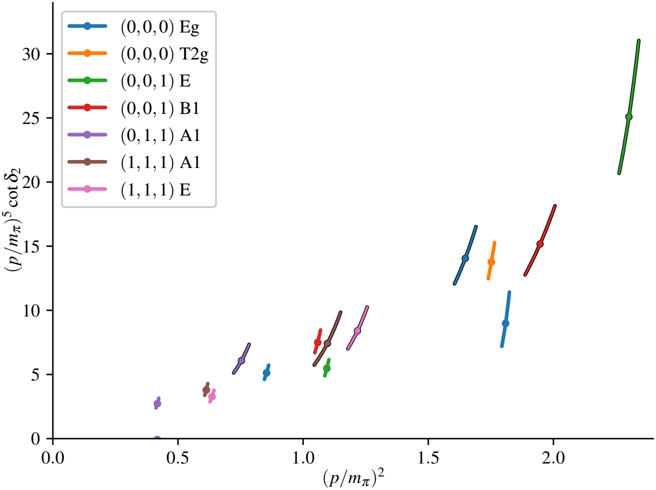
PRELIMINARY: singlet spectrum in nontrivial irreps



Focus on spin zero for ${}^1D_2$.

Many spin-one levels (gray) discarded: relevant for ${}^3P_1$, ${}^3P_2$–${}^3F_2$, etc.
Omitted irreps have only spin-one levels.

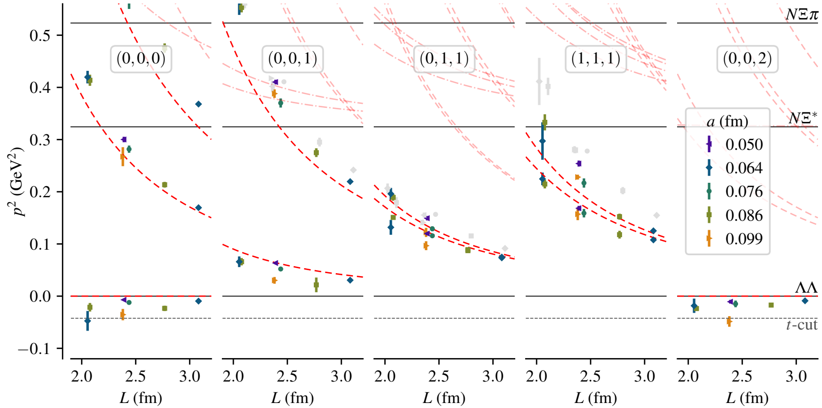
PRELIMINARY: singlet ${}^1D_2$



Ensembles H200 and N202: $a = 0.064$ fm, $L = 2.1$ and 3.1 fm.

Finite-volume matrix in quantization condition computed using TwoHadronsInBox,
C. Morningstar *et al.*, Nucl. Phys. B **964**, 477–507 (2017)

PRELIMINARY: 27-plet spectrum in trivial irreps



27 includes NN $I = 1$.

δ_0 passes through zero. Fit rational functions to $p \cot \delta_0$?

Dineutron is probably a virtual bound state.

Conclusions / outlook

- Distillation works well for the baryon-baryon spectum.
- H dibaryon is weakly bound at SU(3) point.
- Discretization effects can be very large!

Looking forward:

- Much more physics to be extracted from symmetric-point data.
- Next talk goes away from SU(3) point.