Universality of the continuum limit for the H dibaryon

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University of Liverpool, UK

Toward (hyper)nuclear physics from LQCD

We are interested in baryon-baryon physics:

- Quark mass dependence of deuteron binding.
- Hyperon interactions $\longrightarrow$ neutron stars?
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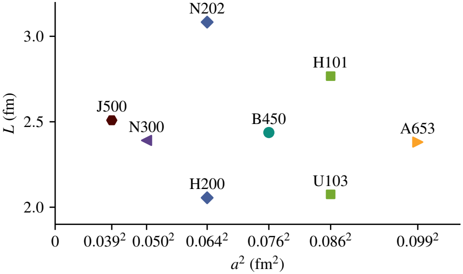
Need to control all systematics:

- Identification of spectrum.
- Finite-volume effects.
- Physical quark masses.
- **Discretization effects**.

Previous result

Weakly bound H dibaryon from SU(3)-flavor-symmetric QCD
JRG, A. D. Hanlon, P. M. Junnarkar, H. Wittig, Phys. Rev. Lett. **127**, 242003 (2021)



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

$m_\pi = m_K = m_\eta \approx 415$ MeV.

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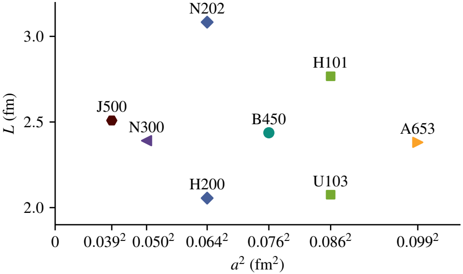

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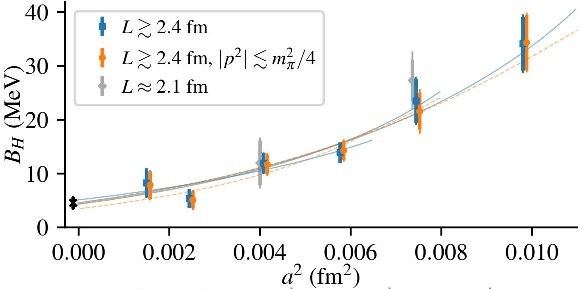

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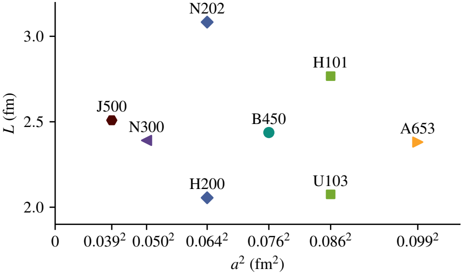

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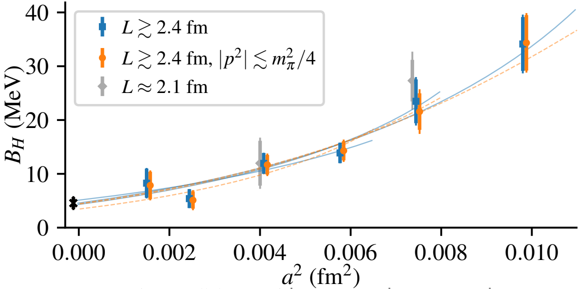

See also:
Takashi Inoue, EFB25, last summer
Robert Perry, Wednesday 11:35

Symanzik theory

With $O(a)$ improved action, corrections start at a^2:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{QCD}} + a^2 \sum_i \mathcal{O}_i + O(a^3).$$

Dimension-six operators $\mathcal{O}_i$ are gluonic, $\bar{q}q$, or $(\bar{q}q)^2$:

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We see percent-level effects on baryon-baryon energies
but O(100%) effects on scattering observables such as the scattering length.

Can we understand what is causing these large effects? Study using different actions.

Outline

1. Methods
2. Actions and ensembles
3. Spectrum
4. Binding energy and scattering parameters
5. Summary

Methodology

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Solve GEVP and extract energy differences $\Delta E = E_{BB} - E_B(\boldsymbol{p}_1) - E_B(\boldsymbol{p}_2)$ from correlator ratios.
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Use Lüscher quantization condition for S wave, fit to spectrum with model

$$p \cot \delta_0(p^2) = \sum_i c_i p^{2i}, \quad c_i = c_{i0} + c_{i1} a^2.$$

Bound state from pole condition $p \cot \delta_0(p^2) = -\sqrt{-p^2}$.

Alternative actions

OpenLat: $N_f = 3$ exponentiated clover

$$4 + m_0 + c_{\mathrm{SW}} \frac{i}{4} \sigma_{\mu\nu} \hat{F}_{\mu\nu} \longrightarrow (4 + m_0) \exp\left(\frac{c_{\mathrm{SW}}}{4 + m_0} \frac{i}{4} \sigma_{\mu\nu} \hat{F}_{\mu\nu} \right)$$

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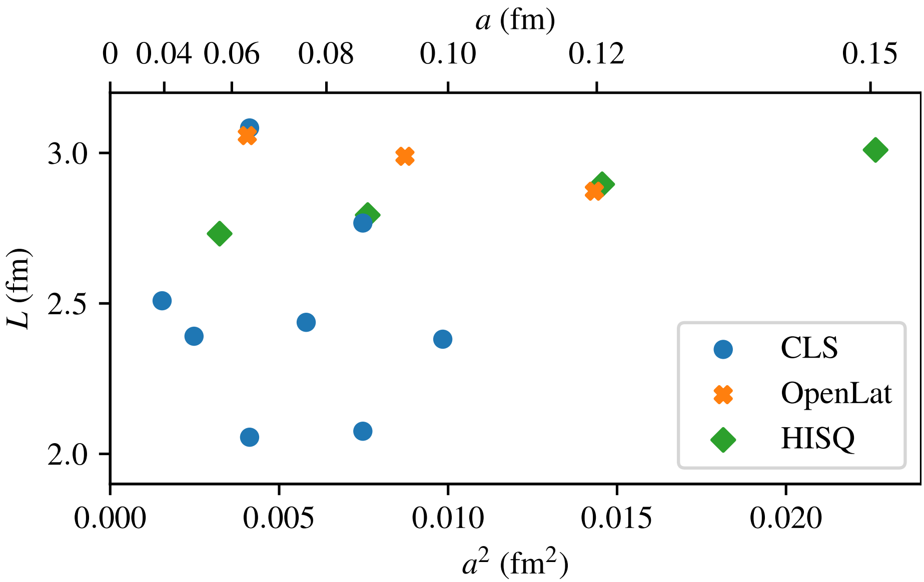
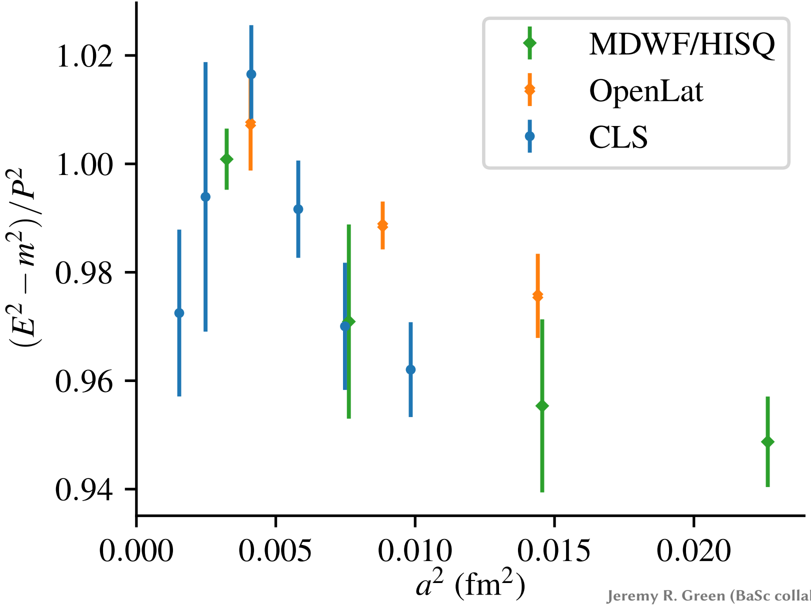
MDWF/HISQ: tadpole-improved one-loop improved gauge action,
$N_f = 3 + 1$ rooted improved staggered sea fermions coupled to smeared links incl. 3-link term,
Möbius domain wall valence fermions coupled to flowed ($t/a^2 = 1$) gauge field.

Ensembles



a (fm)
0
0.04
0.06
0.08
0.10
0.12
0.15
L (fm)
3.0
2.5
2.0
0.000
0.005
0.010
0.015
0.020
a² (fm²)
CLS
OpenLat
HISQ

Octet baryon dispersion relation



Average over lowest few nonzero momenta.

Additional mixed actions

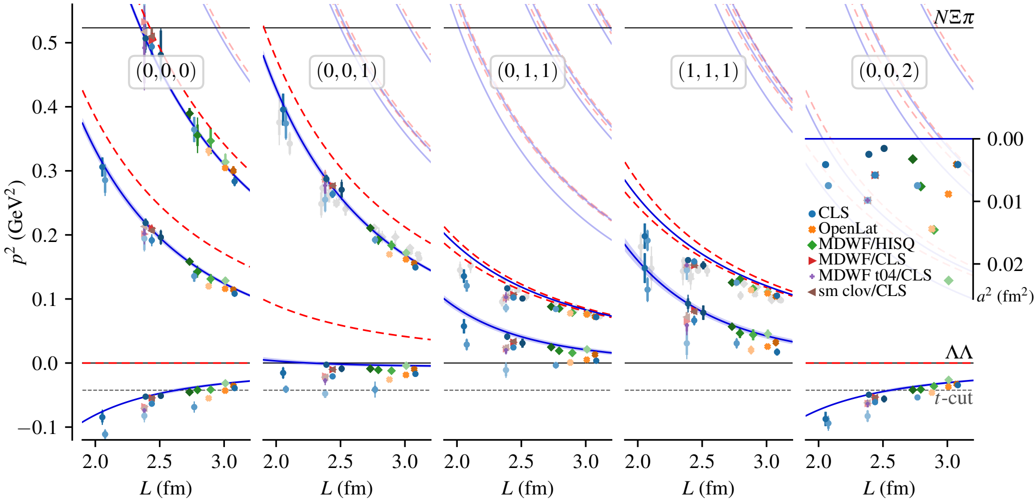
Step-by-step change between CLS and MDWF/HISQ:

- Clover valence on flowed ($t/a^2 = 1$) CLS.
- MDWF on flowed ($t/a^2 = 1$) CLS.

Try less smearing:

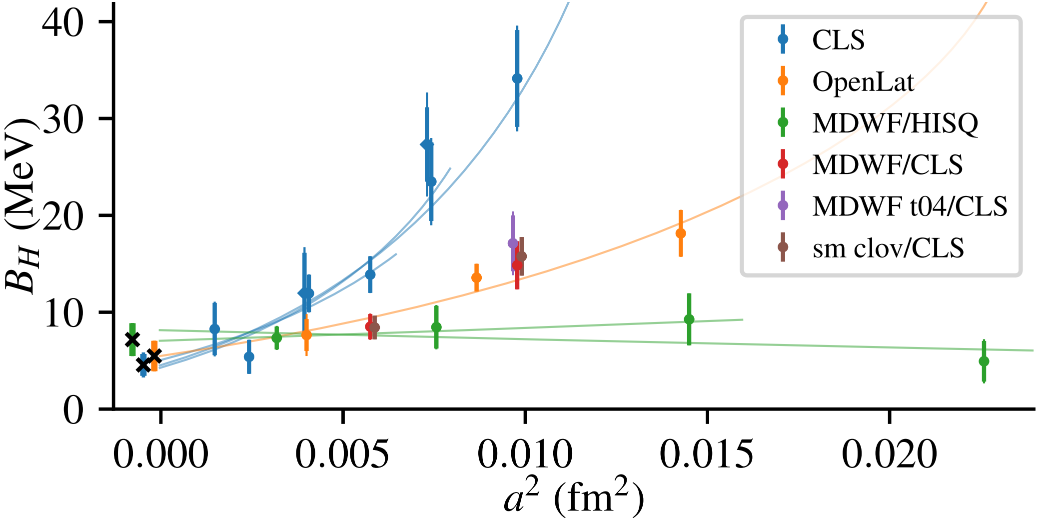
- MDWF on flowed ($t/a^2 = 0.4$) CLS.

Spectrum



Points: lattice levels. Red dashed: noninteracting levels. Blue: continuum (published).

Binding energy of H dibaryon



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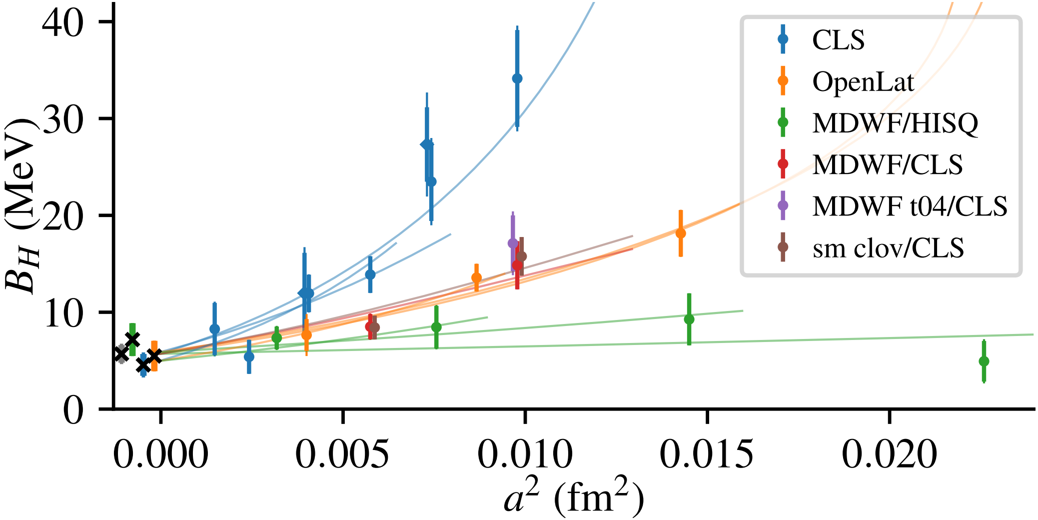
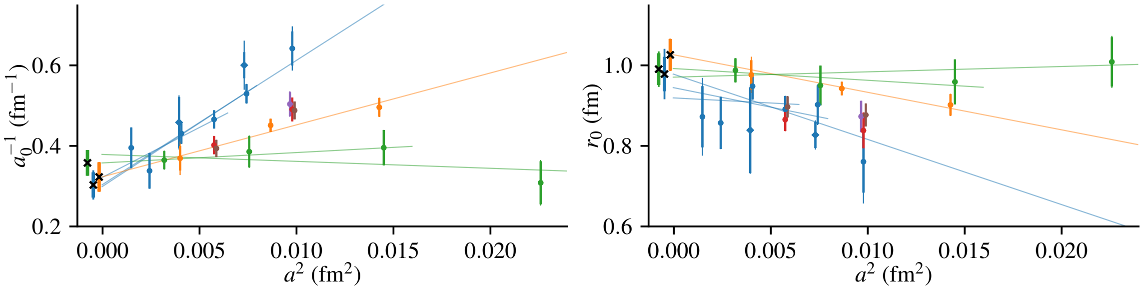


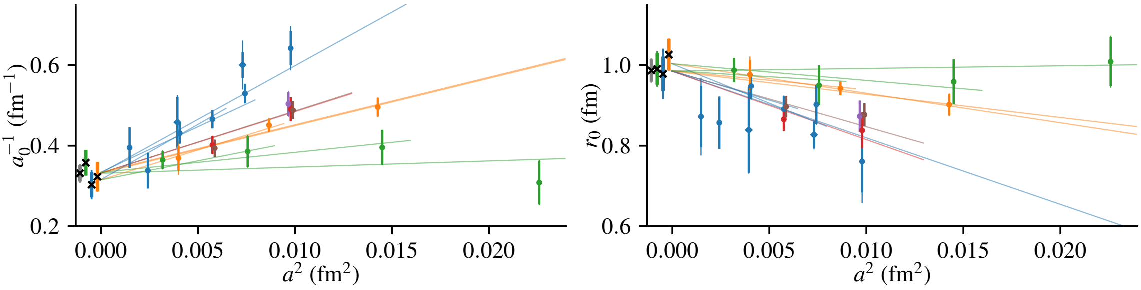
Good fit quality for each action separately or all combined.



$$p \cot \delta_0(p) = -\frac{1}{a_0} + \frac{1}{2} r_0 p^2 + O(p^4)$$

Stronger discretization effects in a_0^{-1}.

Scattering parameters



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Summary

- $B_H \approx 6$ MeV at $m_\pi = m_K \approx 415$ MeV obtained from three independent continuum extrapolations. Charm sea has negligible effect.
- Size of discretization effects varies significantly among different actions.
- Exponentiated clover term yields smaller lattice artifacts.
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Controlling discretization effects is important!

MDWF on HISQ: tuning