Progress Towards Understanding the H-dibaryon from Lattice QCD

Andrew Hanlon

Helmholtz-Institut Mainz, Johannes Gutenberg-Universität

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Outline

- Motivation for studying the H-dibaryon
- Overview of recent results from the Mainz group
  - $N_f = 2$ CLS ensembles with quenched strange quark
  - Operator construction
  - Use of Distillation
- Preliminary results on $N_f = 2 + 1$ CLS ensembles
- Future work

Motivation

- In 1977, Jaffe predicts deeply bound dibaryon with quark content $uuddss$, $J = 0$, $I = 0$
- Conclusive experimental evidence for such a state is still lacking
- Early quenched calculations disagree on existence of such a bound state
- More recent results with dynamical quarks from NPLQCD and HAL QCD disagree on the binding energy for $m_\pi \approx 800\,\mathrm{MeV}$

The Mainz Dibaryon Project

- In collaboration with:

  A. Francis, J. Green, P. Junnarkar, H. Wittig

- Recent results on $N_f = 2$ CLS ensembles with quenched strange quark (arXiv:1805.03966)
  - Main focus on two ensembles with $a = 0.0658\,\text{fm}$ and $L = 2.1\,\text{fm}$
    - E1: $m_\pi = 960\,\text{MeV}$, quenched $m_s = m_{u,d}$
    - E5: $m_\pi = 440\,\text{MeV}$, quenched $m_s \approx m_s^{\text{phys}}$
  - Uses smeared point sources and Distillation
  - Finite volume analysis

- Recent extensions to $N_f = 3$

Interpolating Operators

- Hexaquark operators inspired by Jaffe's bag model prediction:

$$[rstuvw] = \epsilon_{ijk}\epsilon_{lmn}(s^i C\gamma_5 P_+ t^j)(v^l C\gamma_5 P_+ w^m)(r^k C\gamma_5 P_+ u^n)$$

  - Can form singlet H^1 and 27-plet H^{27} flavor combinations

- Two-baryon operators:
  - Momentum-projected single-baryon operators

$$B_\alpha(\boldsymbol{p}, t)[rst] = \sum_{\boldsymbol{x}} e^{-i\boldsymbol{p}\cdot\boldsymbol{x}}\epsilon_{abc}(s^a C\gamma_5 P_+ t^b)r^c_\alpha$$

  - Form spin-zero and spin-one operators

$$[B_1 B_2]_0(\boldsymbol{p}_1, \boldsymbol{p}_2) = B^{(1)}(\boldsymbol{p}_1)C\gamma_5 P_+ B^{(2)}(\boldsymbol{p}_2)$$
$$[B_1 B_2]_i(\boldsymbol{p}_1, \boldsymbol{p}_2) = B^{(1)}(\boldsymbol{p}_1)C\gamma_i P_+ B^{(2)}(\boldsymbol{p}_2)$$

  - Form $SU(3)$ flavor operators from $\Lambda\Lambda$, $\Sigma\Sigma$, and $N\Xi$

Rotational Properties of Operators

- Python package using SymPy libary to determine rotation properties
- Can very simply construct needed operators:

```
u = QuarkField.create('u')
a = ColorIdx('a')
i = DiracIdx('i')
...
Delta = Eijk(a,b,c) * u[a,i] * u[b,j] * u[c,k]
```

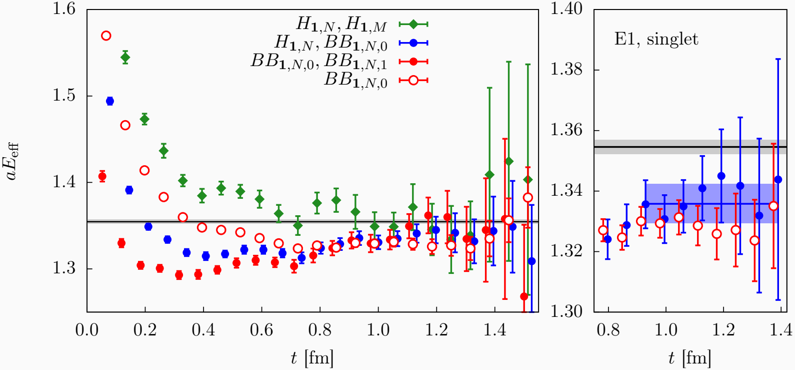
- Project to definite momentum, and determine Little Group

```
delta_ops = Operator(Delta, P([0,0,1]))
delta_op_rep = OperatorRepresentation(*delta_ops)
delta_op_rep.littleGroupContents()
# output: 6 G1 + 4 G2
```

- Supports multi-particle operators

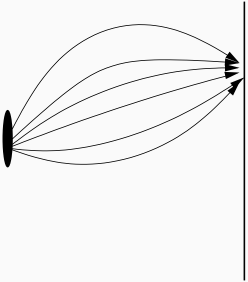
Ground State for Singlet Channel on $E1$ ($SU(3)$ Symmetric)

- Legend indicates sink operators
- Hexaquark operators noisier and slower ground-state saturation

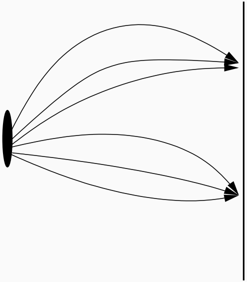


Adding Distillation to the Mix

- Use of point sources requires local operators at the source
- Leads to non-Hermitian correlator matrices



$\langle H(t) H^\dagger(0) \rangle$

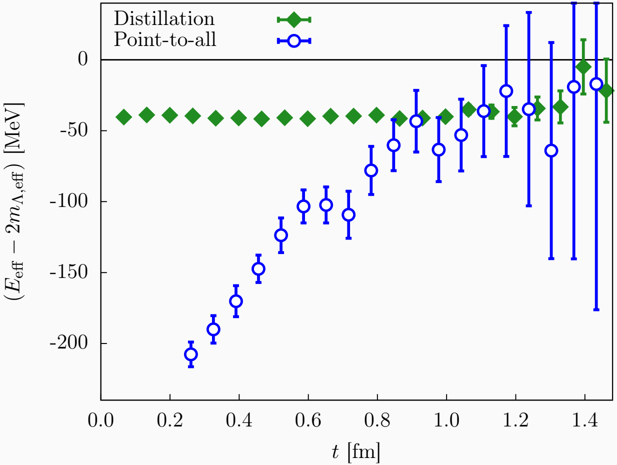


$\langle BB(t) H^\dagger(0) \rangle$

- Add use of timeslice-to-all method

Distillation vs. Smeared Point Sources

- Ensemble E1, ground state in singlet channel
- Better quality data at lower cost



Finite Volume Analysis - Lüscher Method

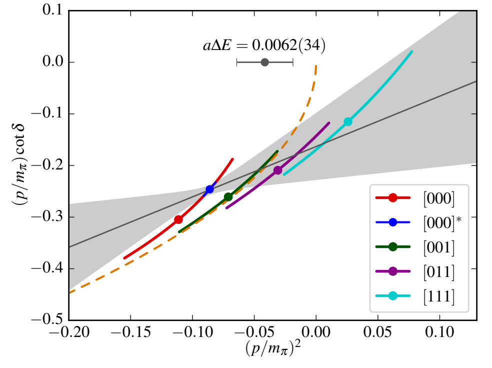
- S-wave scattering phase shift:

$$p \cot \delta_0(p) = \frac{2}{\sqrt{\pi} L \gamma} \mathcal{Z}_{00}^{\boldsymbol{P}}(1, q^2), \qquad q = \frac{pL}{2\pi}, \qquad p^2 = \frac{1}{4}(E^2 - \boldsymbol{P}^2) - m_\Lambda^2$$

- Pole below threshold indicates a bound state

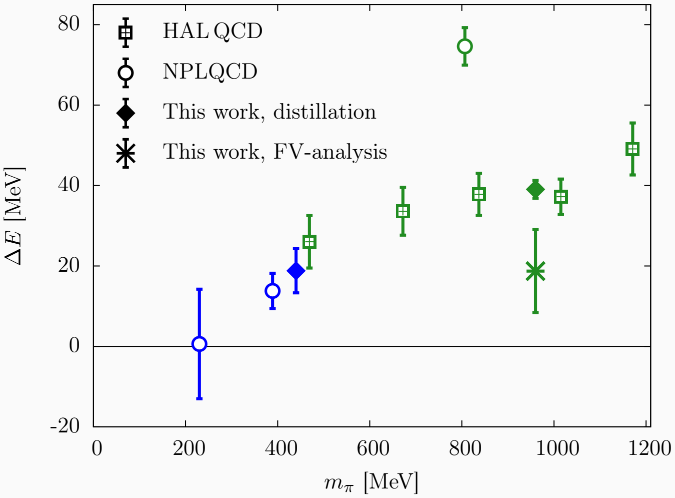
$$\mathcal{A} \propto \frac{1}{p \cot \delta_0(p) - ip}$$

$$\implies p \cot \delta_0(p) = -\sqrt{-p^2}$$



Comparison to Other Collaborations

- Green are $SU(3)$-symmetric, and blue are $SU(3)$ broken

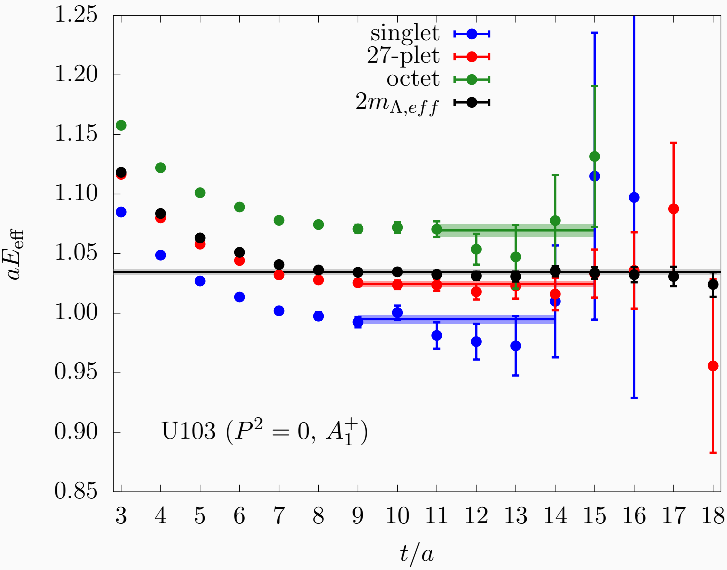


$N_f = 2 + 1$ CLS Ensembles

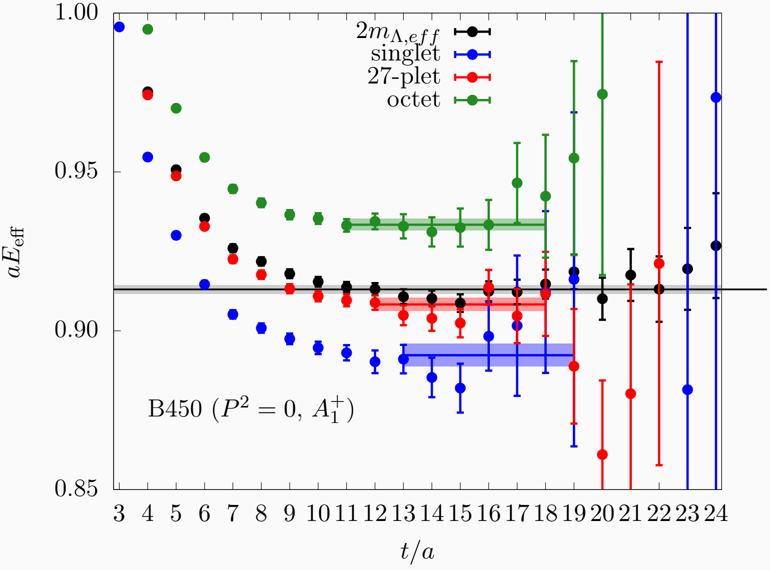
- Beginning extensions to CLS ensembles with $N_f = 2 + 1$ $O(a)$-improved Wilson fermions

- Initial results for the $SU(3)$-symmetric point, $m_\pi = m_K \approx 420\,\mathrm{MeV}$
  - U103 - $\beta = 3.40$, $24^3 \times 128$, open BCs
  - H101 - $\beta = 3.40$, $32^3 \times 96$, open BCs
  - B450 - $\beta = 3.46$, $32^3 \times 64$, periodic BCs

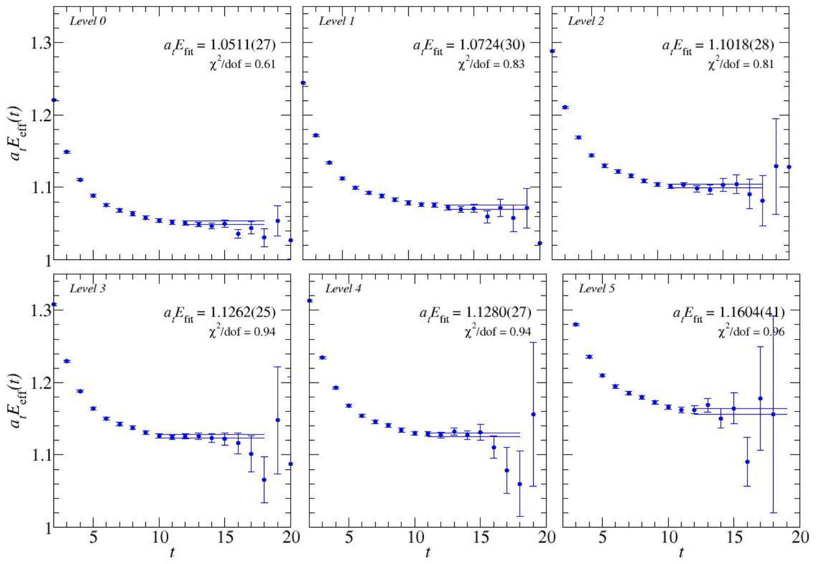
U103: $P^2 = 0$, A_1^+ irrep



B450: $P^2 = 0$, A_1^+ irrep



H101: $SU(3)$ octet, $P^2 = 1$, A_1 irrep



Summary and Outlook

- Results for $N_f = 2$ ensembles shown
- Distillation substantially improves quality of data

Future Work

- Finalize $N_f = 3$ results
- Include $SU(3)$ broken ensembles
  - Coupled channels ($\Lambda\Lambda$, $N\Xi$, $\Sigma\Sigma$)
- Extensions to more ensembles
  - Cost scales as N_{LapH}^4
  - N_{LapH} scales as L^3 for constant smearing radius
  - Investigate stochastic LapH

Questions?