H-dibaryon spectroscopy with Distillation

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Outline

• Introduction
  • Status of experimental and Lattice results.
    • Challenges in Lattice spectroscopy of multi-baryon systems.
  • Overview of current methodology for multi-baryon systems.
  • H-dibaryon results with point sources.
  • Distillation methodology and results.
• Conclusions
The H-dibaryon

Predicted by Jaffe in 1977 using MIT bag model as a deeply bound state:

\[ J = I = 0, \ S = -2 \]

\[ m_H < 2m_\Lambda \sim -80 \text{ MeV} \]

A flavor singlet in SU(3),

\[ BB^1 = -\sqrt{\frac{1}{8}}(\Lambda\Lambda) + \sqrt{\frac{3}{8}}(\Sigma\Sigma) + \sqrt{\frac{4}{8}}(N\Xi) \]

Decades of theoretical and experimental investigations provide no conclusive evidence on the fate of the H....
Bound H-dibaryon?

Experimentally a deeply bound state ruled out.

Observation of a $\Lambda\Lambda^6$He Double Hypernucleus

Nagara Event : Emulsion study $B_{\Lambda\Lambda} = 7.13 \pm 0.87$ MeV

Search for an $H$-Dibaryon with a Mass near $2m_\Lambda$ in $Y(1S)$ and $Y(2S)$ Decays

KEK Belle Detector : No signature of bound state.
Challenges in multi-baryon Lattice spectroscopy

Lattice techniques offer first principle calculation of QCD observables!

1. Unphysical quarks, finite lattice spacing and volume.
3. Non-trivial contractions.
4. Non-trivial finite volume effects.
5. Reliable determination of ground state.

Courtesy: USQCD
Current methodology for multi-baryon spectroscopy

- Compute quark propagators by inverting Dirac matrix on point sources.

- Smear the source fields and/or the quark propagators to improve overlap onto the ground state.

- Construct hadronic states with the interested quantum numbers.

- Compute expectation values of operators and determine the ground state at large $t$...

$$\langle 0| \mathcal{O}(\vec{x}, t) \mathcal{O}^\dagger(0)|0\rangle \xrightarrow{t \rightarrow \infty} A e^{-M_\pi t}$$
Variational method provides reliable determination of ground state

Compute a correlator matrix of two point functions as,

\[ C_{ij} = \sum_x \langle O_i(t_0 + t, x) O_j^\dagger(t_0, x_0) \rangle, \]

and solve the generalised eigenvalue problem as,

\[ C_{ij}(t + \Delta t) v_j(t) = \lambda(t) C_{ij}(t) v_j(t) \]

Effective masses are obtained from eigenvalues as,

\[ m_{\text{eff}} = \frac{-\log \lambda(t)}{\Delta t} \]
H-dibaryon operator set up

Local six quark interpolating operators at source and sink:

\[
[abcde\ell] = \varepsilon^{ijk}\varepsilon^{lmn}(b^T_i C\gamma_5 P + c_j)(e^T_l C\gamma_5 P + f_m)(a^T_k C\gamma_5 P + d_n)
\]

\[
H^1 = \frac{1}{48}(\text{sudsud} - \text{udusds} - \text{dudsus})
\]

\[
H^{27} = \frac{1}{48\sqrt{3}}(2\text{sudsud} + \text{udusds} + \text{dudsus})
\]

Two-baryon interpolating operators at sink:

\[
B_\alpha = [abc]_\alpha = \varepsilon^{ijk}(b^T_i C\gamma_5 P + c_j)a_k\alpha
\]

\[
B_1 B_2(\vec{p}_1, \vec{p}_2) = \sum_{\vec{x}, \vec{y}} e^{ip_1 \cdot \vec{x}} e^{ip_2 \cdot \vec{y}} B_1^T(\vec{x}) C\gamma_5 P + B_2(\vec{y})
\]

Operators belong to 1, 8, and 27 of SU(3).
1. SU(3) symmetric ensemble E1: $m_\pi = 960$ MeV
   a.) 1 and 27 operators of SU(3) are decoupled.
   b.) 2 smearings at source and sink.
   c.) 2 source operators and 10 sink operators.

2. Ensemble E5 (Broken SU(3) symmetry): $m_\pi = 450$ MeV
   a.) 1 and 27 operators of SU(3) are now mixed.
   b.) No 8 operator present at source.
   c.) 4 source operators and 28 sink operators.
H-dibaryon results with point sources

Results on Ensemble E1 $m_{\pi} = 960$ MeV

$BB_0^1 = BB_{(0,0),(0,0,0)}$, $BB_1^1 = BB_{(1,0),(0,0)}$, $BB_2^1 = BB_{(1,0),(0,0,0)}$
H-dibaryon results with point sources

Results on Ensemble E5 $m_{\pi} = 440$ MeV

$H^0 (N) H^1 (N) H^3 (M) H^{GT} (M)$

$H^0 (N) H^{GT} (N) BB_1^0 (N) BB_2^0 (N)$

$H^1 (N) H^{GT} (N) BB_1^1 (N) BB_2^2 (N)$
Enter Distillation

Distillation is a smearing scheme enabling timeslice-to-all propagator computation.

Compute N low eigenvectors of spatial lattice laplacian,

\[ \Delta(t) \ V(t) = \lambda(t) \ V(t) \]

Employ a smeared diluted noise source and invert the Dirac matrix on it,

\[ \tilde{\rho}(t_0) = V(t_0) P(t_0) \rho(t_0) \quad \tau(t) = V^\dagger(t) D^{-1}(t', t_0) \tilde{\rho}(t_0) \]

A stochastic estimate of the Quark propagator is then given by,

\[ \phi(t) = V(t) \tau(t) \quad D^{-1}(t', t_0) \sim E\left( \phi(t) \tilde{\rho}^\dagger(t_0) \right) \]

M. Peardon et.al, Phys Rev D80 (2009) 054506
J. Bulava, et.al, Phys Rev D83 (2011) 114505
Baryons in Distillation

Compute color singlets in distillation space. Use 1 overall Noise vector.
Results on single Lambda

Distillation results compatible with point sources for single baryons

Ensemble E1 $m_\pi = 960$ MeV
Dibaryon contractions

Use baryons objects to construct dibaryons.

Construct $N^2$ baryon blocks and contract them.
Preliminary Dibaryon results

Flavor basis

SU(3) basis

Ensemble E1 $m_\pi = 960$ MeV

$M_{H,3}$ vs. $t$
Effective binding energies \( \Delta E(t) = \log \left( \frac{C_H(t)}{C_{\Lambda\Lambda}^2(t + J)} \right)/J \)
Comparison with point sources

**Ensemble E1** $m_\pi = 960$ MeV

**Ensemble E5** $m_\pi = 440$ MeV
Summary

1. First application of distillation method to multi-baryon systems shows promising results.

2. The solution of the GEVP on non-hermitian correlator matrices yields true ground state at large source-sink separation.

3. Work on moving frames currently under way!

4. A detailed finite volume study is planned in the near future.
The End.