Spectroscopy of chimera baryons on Sp(4) lattice gauge theory

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Numerical calculations are accomplished by modifying the HiRep code.

arXiv:0805.2058

repository: https://github.com/sa2c/HiRep

Outline

- Introduction:
  - Sp(4) gauge theory: A Composite Higgs model
  - Chimera baryon operators
- Preliminary results
  - Projections
  - Mass hierarchy of chimera baryons
  - $m_{ps}^{(f)}$ massless limit
- Summary

Composite Higgs Models

Name	Gauge group	ψ	χ	Baryon type
M1	$SO(7)$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\psi\chi\chi$
M2	$SO(9)$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\psi\chi\chi$
M3	$SO(7)$	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M4	$SO(9)$	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M5	$Sp(4)$	$5 \times \mathbf{A}_2$	$6 \times \mathbf{F}$	$\psi\chi\chi$
M6	$SU(4)$	$5 \times \mathbf{A}_2$	$3 \times (\mathbf{F}, \overline{\mathbf{F}})$	$\psi\chi\chi$
M7	$SO(10)$	$5 \times \mathbf{F}$	$3 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$\psi\chi\chi$
M8	$Sp(4)$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$\psi\psi\chi$
M9	$SO(11)$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M10	$SO(10)$	$4 \times (\mathbf{Spin}, \mathbf{Spin})$	$6 \times \mathbf{F}$	$\psi\psi\chi$
M11	$SU(4)$	$4 \times (\mathbf{F}, \mathbf{F})$	$6 \times \mathbf{A}_2$	$\psi\psi\chi$
M12	$SU(5)$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{A}_2, \overline{\mathbf{A}_2})$	$\psi\psi\chi$, $\psi\chi\chi$

The minimal model

Barnard et al, arXiv:1311.6562

D. Franzosi and G. Ferretti, arXiv:1905.08273

Our choice of model

- Sp(4) gauge theory with 2F+3AS Dirac fermions
- Breaking pattern: ↓ 4F+6AS 2 component Weyl fermions

$$G/H = SU(4)\times SU(6) \,/\, Sp(4)\times SO(6)$$

Enhanced global symmetry due to the (pseudo-) reality

- $SU(4)/Sp(4)$ gives 5 goldstone bosons.
  - 4: SM Higgs doublet
  - 1: made heavy in model building
- SU(3) embedded in antisymmetric representation:

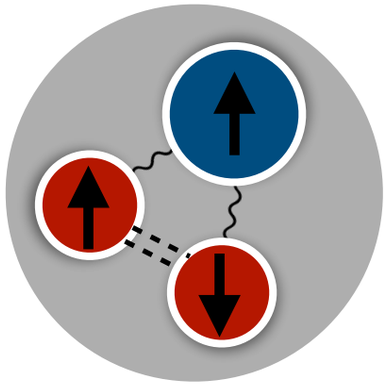
$$SU(6) \to SO(6) \supset SU(3)$$

↳ QCD colour SU(3)

Chimera Baryon

- Interpolating operators
  - Λ type: $\mathcal{O}_{\mathrm{CB},\gamma^5} = \left(\bar{\psi}^{1\,a}\gamma^5\psi^{2\,b}\right)\Omega_{bc}\chi^{k\,ca}$

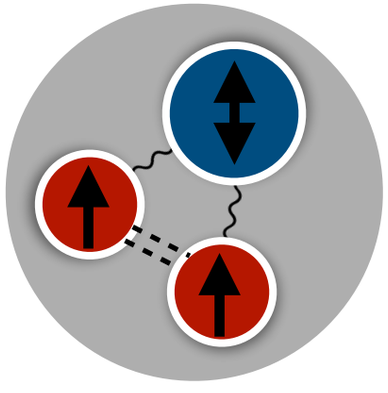
Carry QCD colour



$J = 1/2$

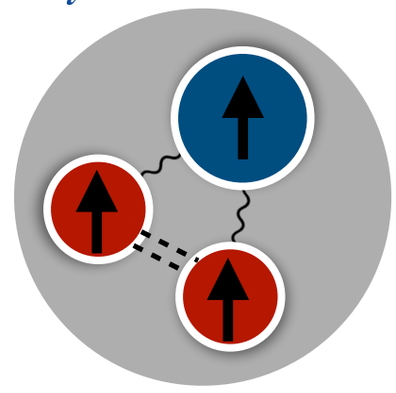
*top partner: mixing with top and generate m_t

  - Σ type: $\mathcal{O}_{\mathrm{CB},\gamma^\mu} = \left(\bar{\psi}^{1\,a}\gamma^\mu\psi^{2\,b}\right)\Omega_{bc}\chi^{k\,ca}$

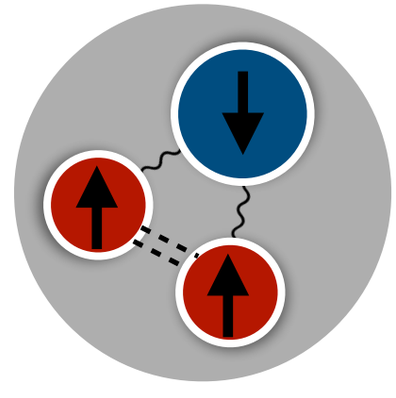


Spin projection

$J = 3/2$: Σ^*



$J = 1/2$: Σ



Chimera Baryon

- Spin projector for Σ-type baryon:

$$\left(P^{3/2}\right)^{ij} = \delta^{ij} - \frac{1}{3}\gamma^i\gamma^j$$

$$\left(P^{1/2}\right)^{ij} = \frac{1}{3}\gamma^i\gamma^j$$

- Two-point function

$$C_{ij}(t) = \sum_{\vec{x}} \left\langle \mathcal{O}^i_{\mathrm{CB}}(x)\bar{\mathcal{O}}^j{}_{\mathrm{CB}}(0) \right\rangle \text{ with } \mathcal{O}^i_{CB} = \left(\bar{\psi}\gamma^i\psi\right)\chi$$

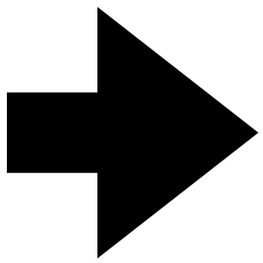
$$\rightarrow C_\Sigma^{1/2}(t) = \mathrm{Tr}\left[\left(P^{1/2}\right)^{ij} C_{jk}(t)\right]$$

Chimera Baryon

- Parity projection

$$C_{\mathrm{CB}}(t) = \sum_{\vec{x}} \left\langle \mathcal{O}_{\mathrm{CB}}(x) \bar{\mathcal{O}}_{\mathrm{CB}}(0) \right\rangle$$

$$\rightarrow P_e \left[c_e e^{-m_e t} + c_o e^{-m_o (T-t)} \right] - P_o \left[c_o e^{-m_o t} + c_e e^{-m_e (T-t)} \right]$$



Projector:

$$P_{eo} = \frac{1}{2}(1 \pm \gamma^0)$$

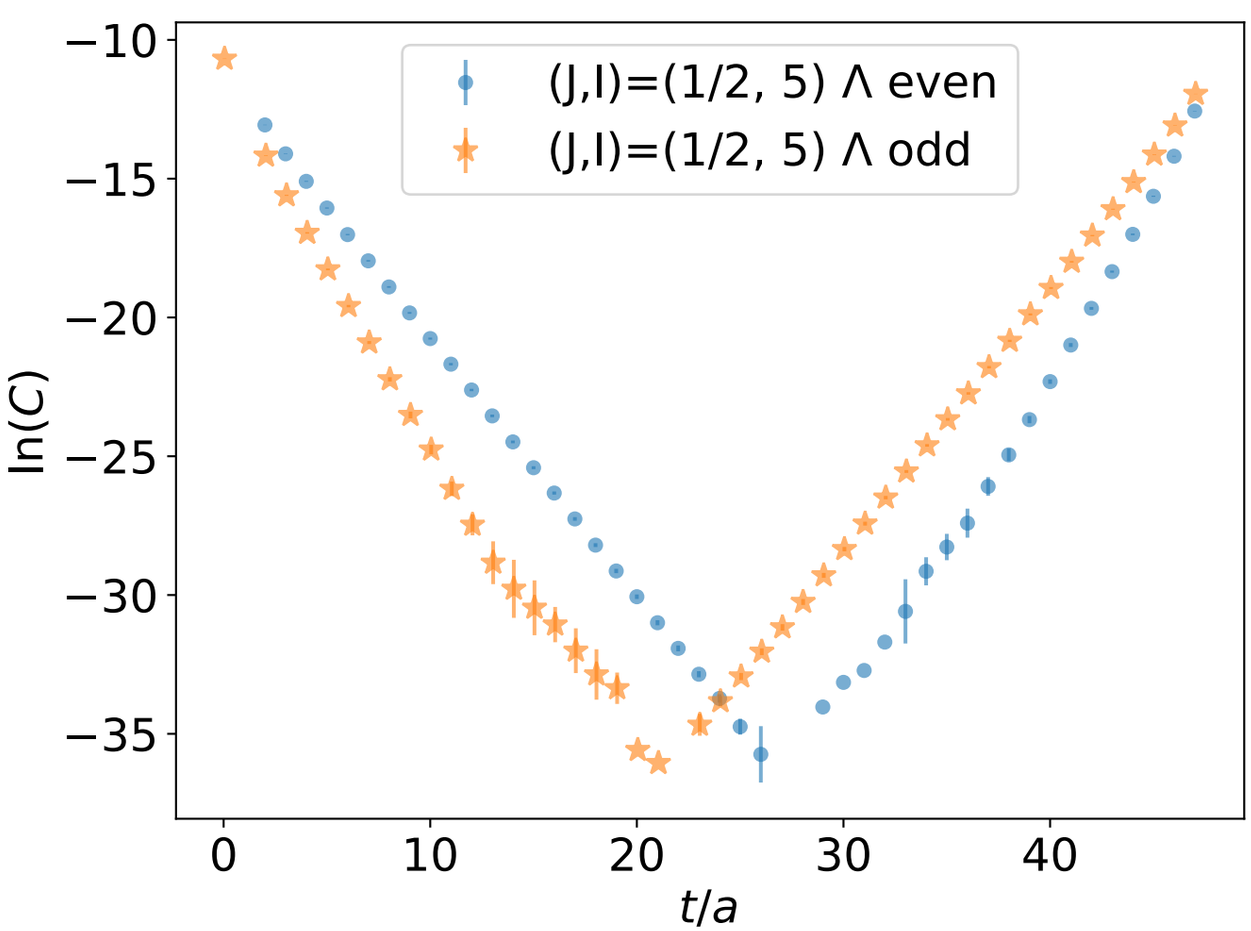
Study Plan

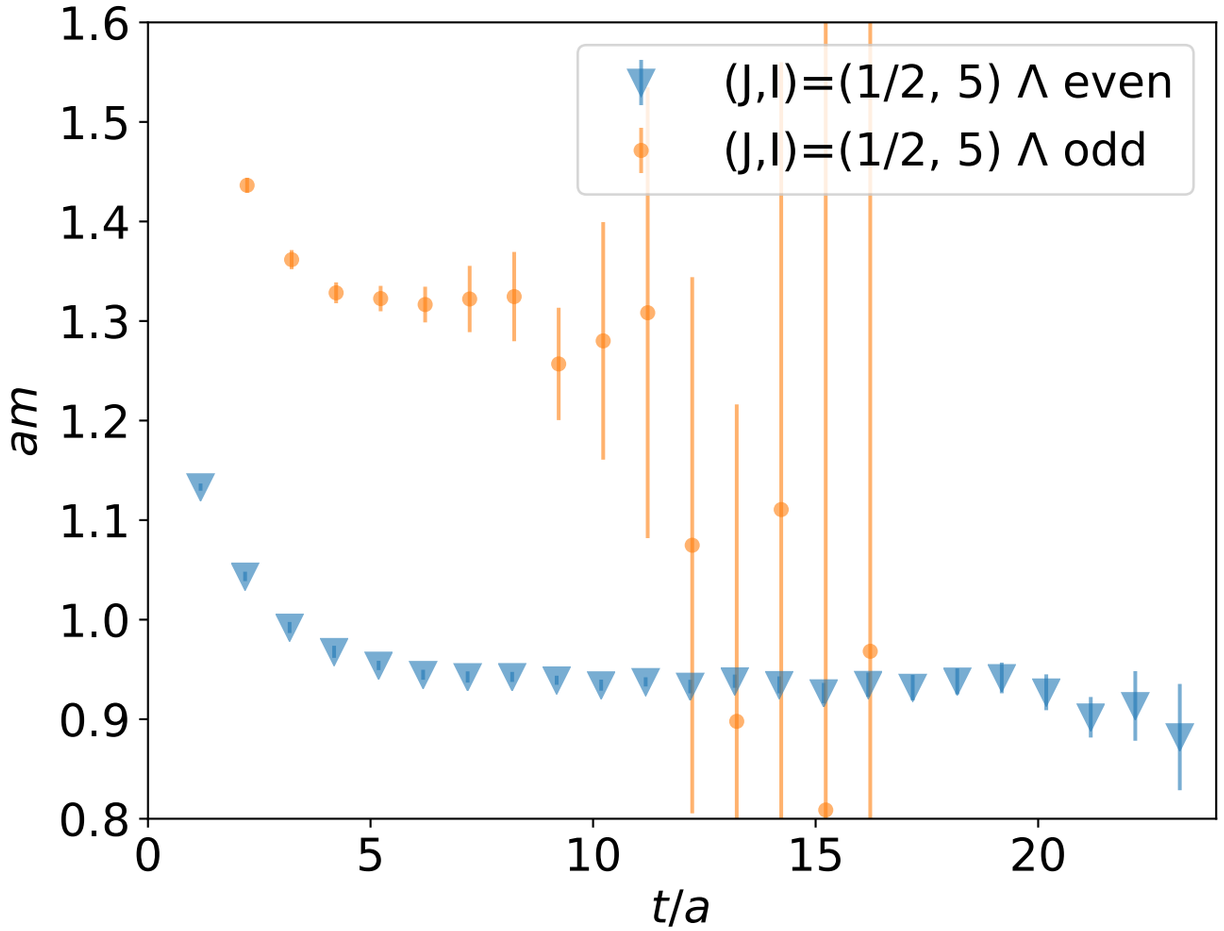
- Quenched fundamental and antisymmetric fermions arXiv:1912.06505
- $N_f = 2$ dynamical fundamental fermions arXiv:1909.12662
- $n_f = 3$ dynamical antisymmetric fermions (Ongoing)
- Fully dynamical 2F + 3AS fermions arXiv:2202.05516
  - Chimera baryon (quenched studies first)
  - 4-fermion operator matrix elements (relevant to generating Higgs mass)

Preliminary results

Preliminary results

Projection-Parity

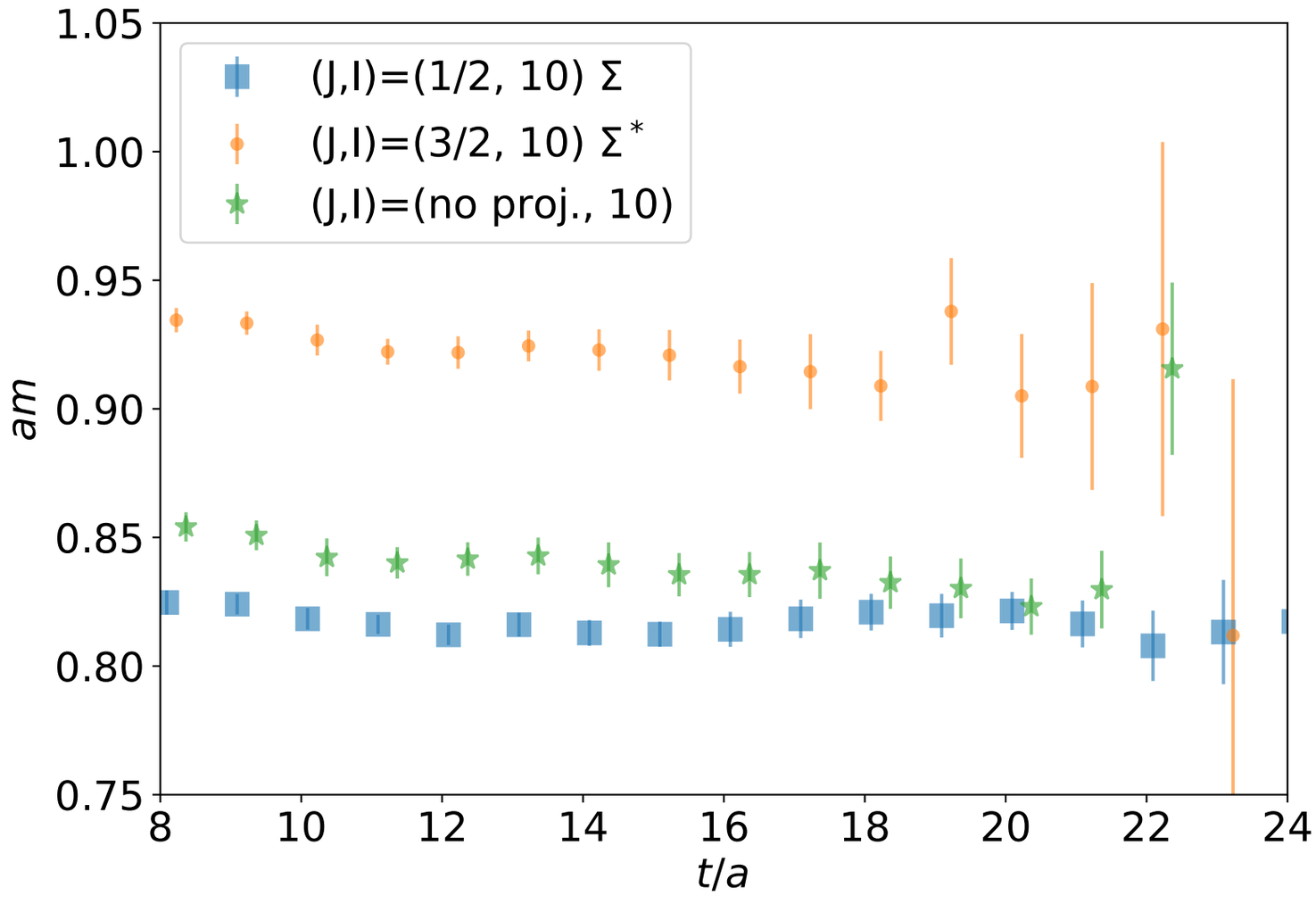




The log plot of the chimera baryon correlators (left) and their effective mass plot (right) with the parity projection obtained with quenched approximation.

Preliminary results

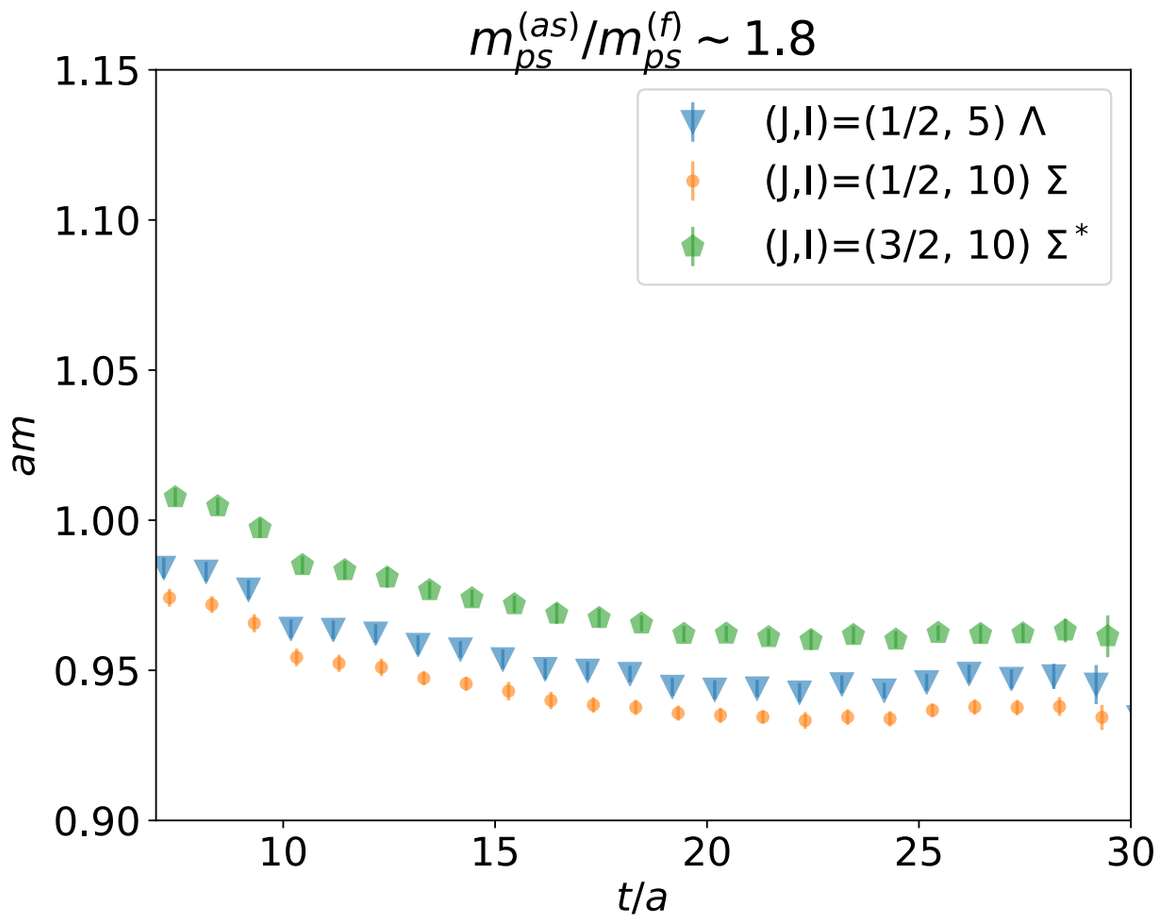
Projection-Spin

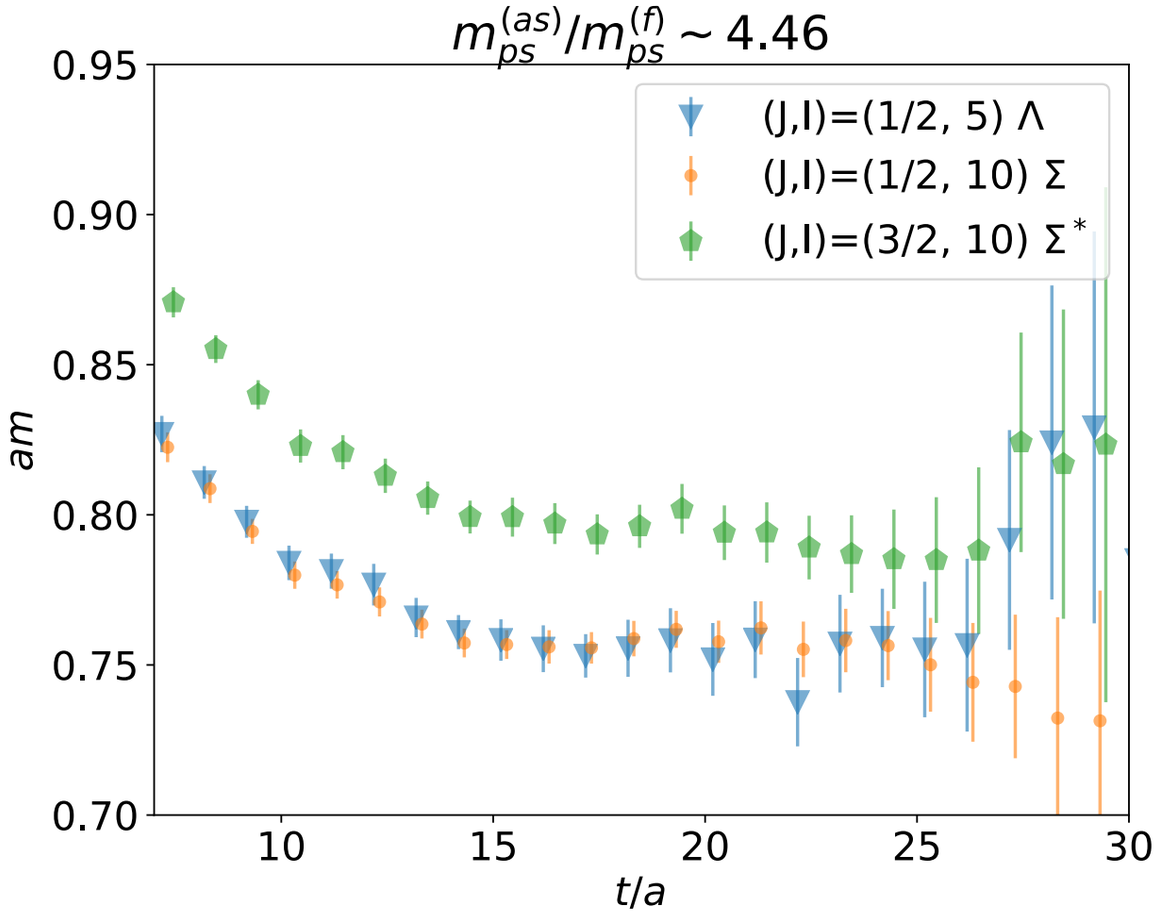


Comparison of effective mass plot between two spin projected states and the state without spin projection.

Preliminary results

Mass hierarchy

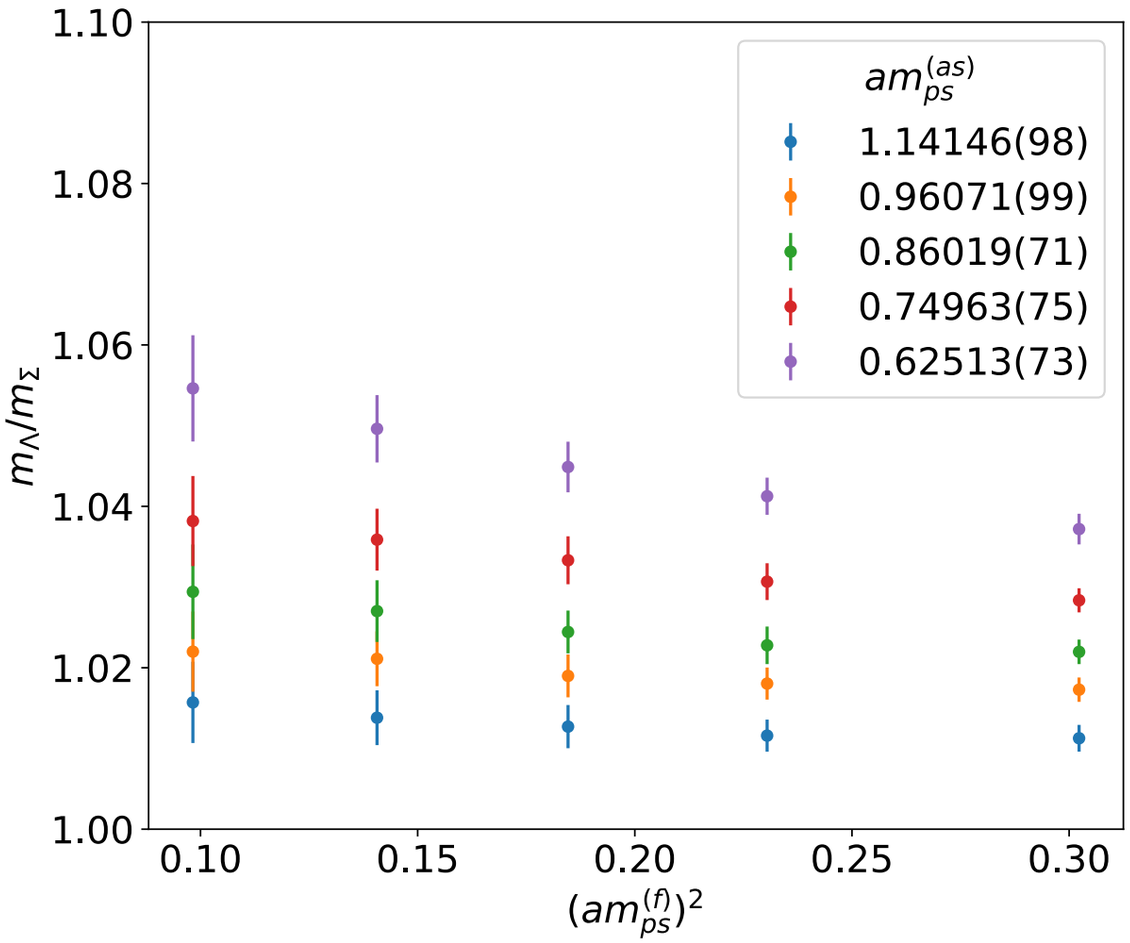


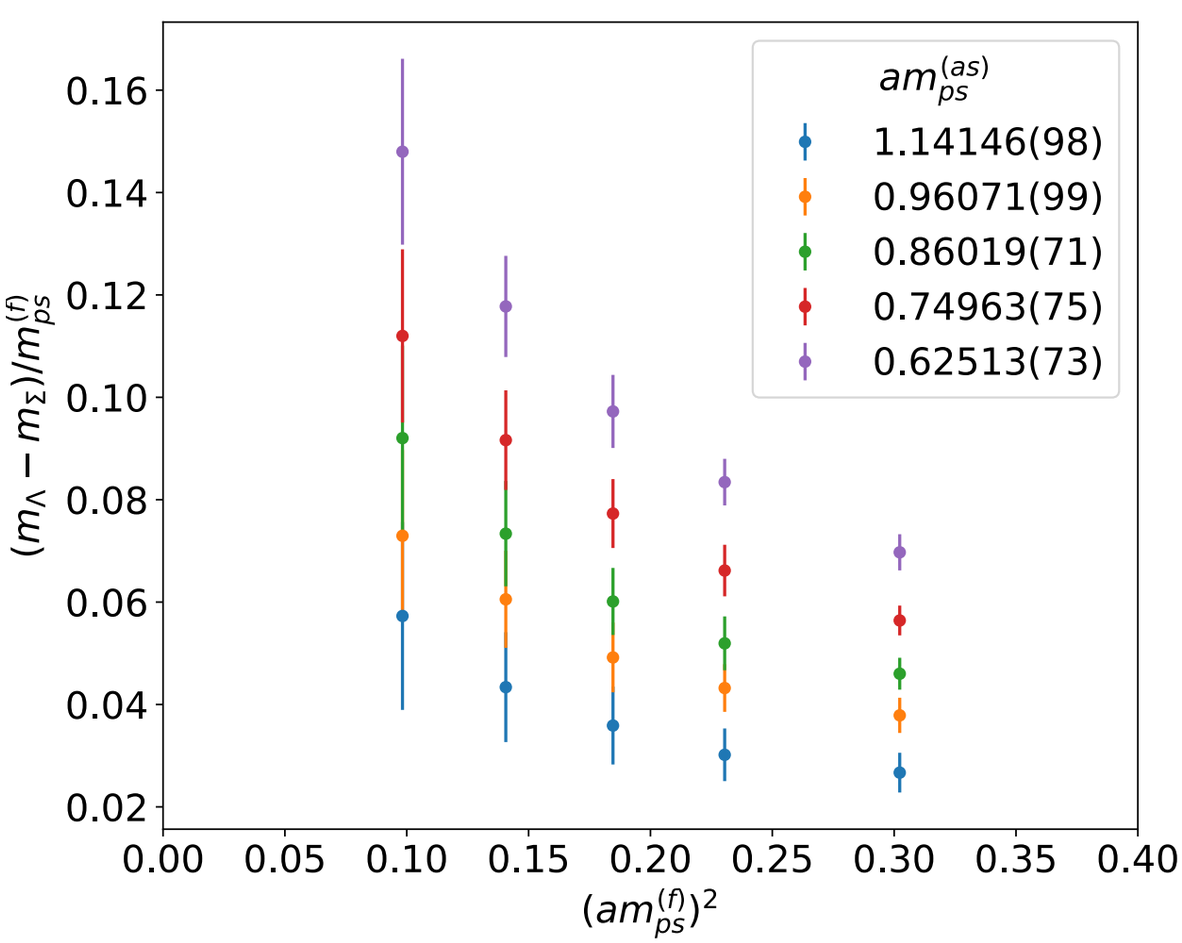


Effective mass plot of chimera baryons calculated with different F bare masses $m_0^{(f)} = -0.6$ (left) and $m_0^{(f)} = -0.69$ (right) at fixed AS bare mass $m_0^{(as)} = -0.81$.
The lattice size is 60×48^3 with $\beta = 8.0$.

Preliminary results

Mass hierarchy

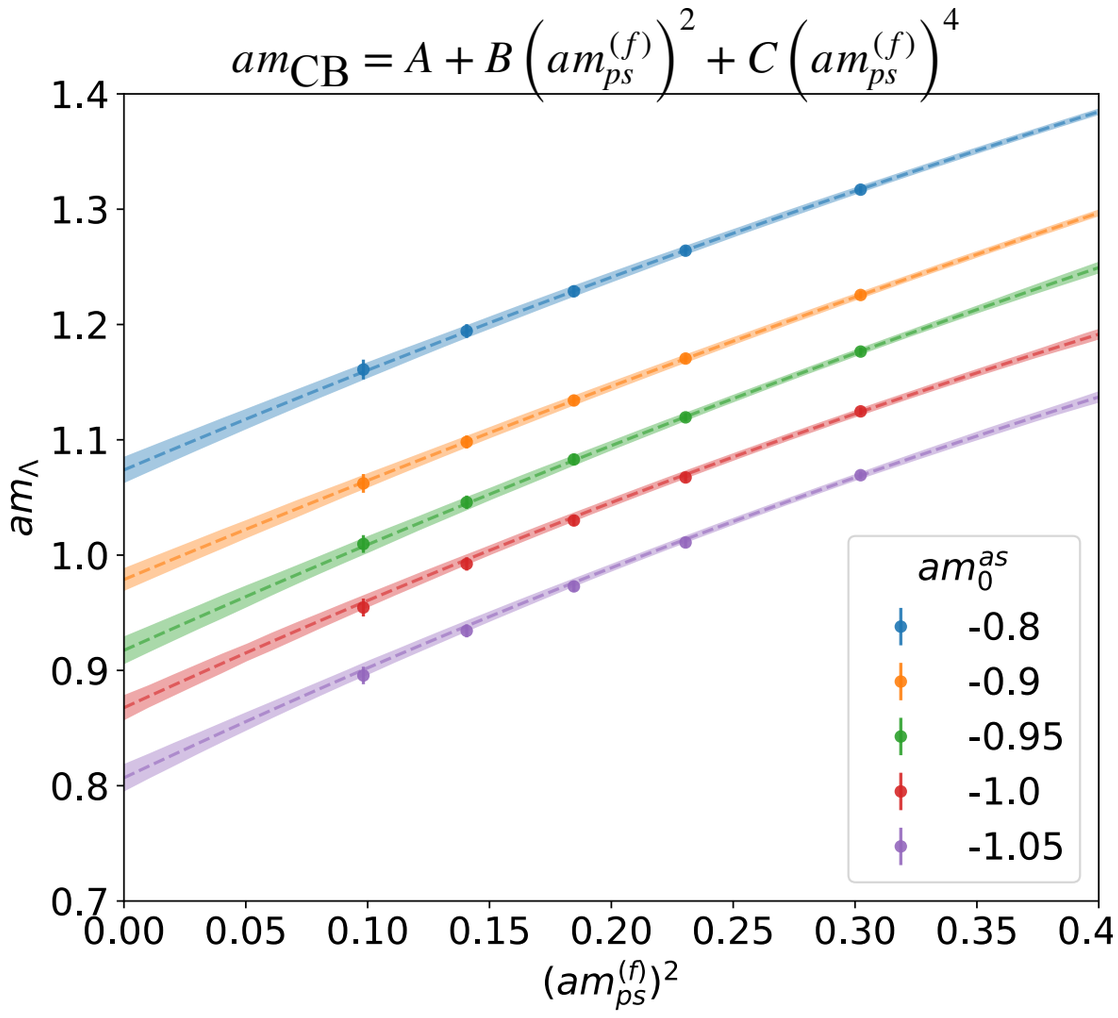


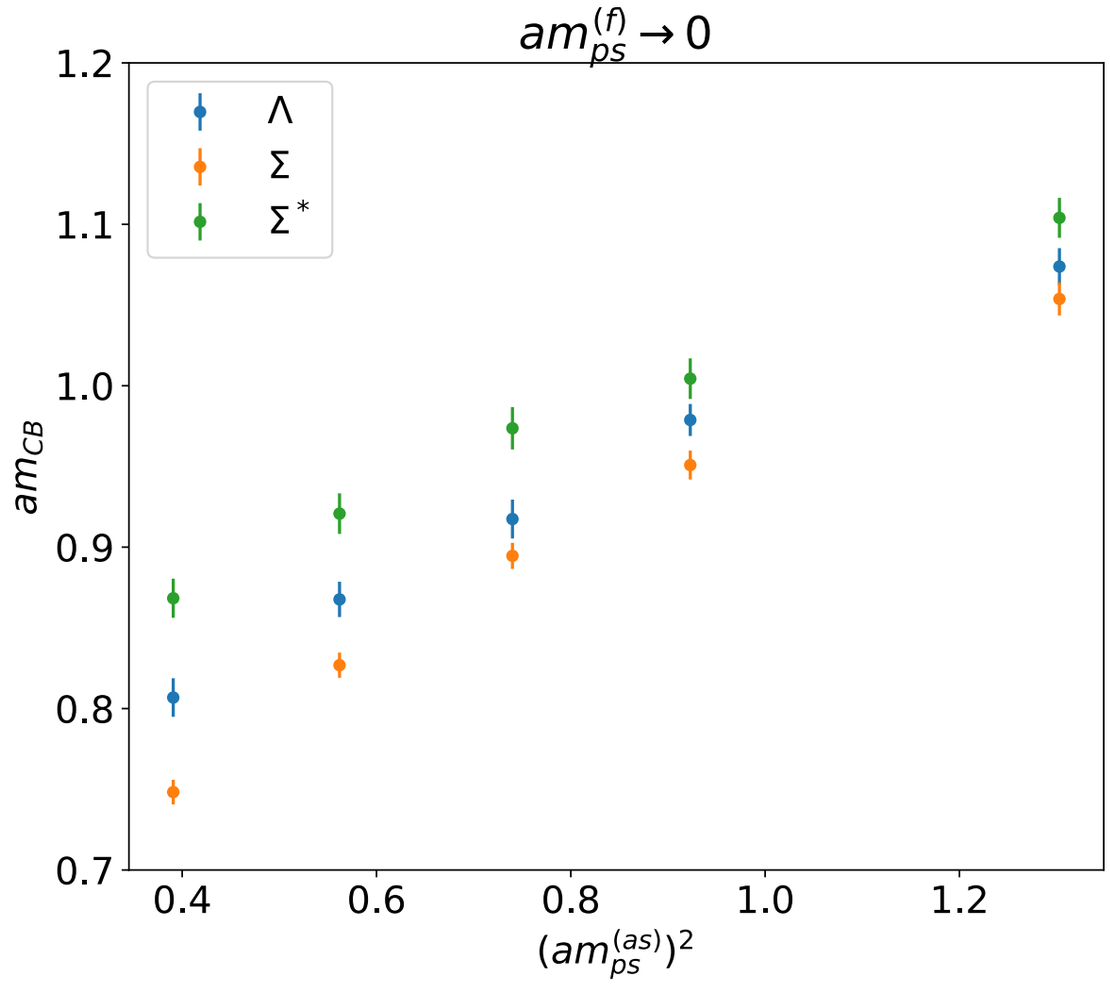


Mass ratios calculated with different bare masses on a 48×24^3 and $\beta = 7.62$ lattice.

Preliminary results

$m_{ps}^{(f)}$ Massless limit





$\mathbf{am_0}$	**-0.8**	**-0.9**	**-0.95**	**-1.0**	**-1.05**
χ^2/d.o.f.	0.12	0.03	0.36	0.97	1.2

Summary

- Chimera baryons
  - Λ: Top partner in composite Higgs model
  - Σ and Σ^* with different spin
- Projection
  - Spin
  - Parity
- The mass hierarchy of chimera baryons —— model building
- Exploratory spectrum of chimera baryon at the $m_{ps}^{(f)}$ massless limit as a guide for fully dynamical study.

END