Study of meson spectroscopy of a lattice SU(4) gauge BSM model.

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TaCo collaboration

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Hierarchy problem

Unaesthetic features of SM

- Higgs potential introduced for SSB.
- Higgs is light ($\sim$ 100GeV) compared to Λ_{Planck} .
- Higgs is a scalar.

Higgs mass Hierarchy problem

- Higgs mass $\sim \Lambda_{EW}$.
- Any coupling to the Higgs introduces corrections $O(\Lambda_{UV}^2)$ to Higgs mass, due to radiative corrections.
- At higher scales, parameters have to be fine-tuned to get observed Higgs mass.

Is Higgs a composite pNGB in a new strong sector?

Composite Higgs [2]

- Introduce a new strong sector (Hypercolor).
- Induce chiral symmetry breaking to get pNGBs one of which is the Higgs.
- Symmetry breaking $G \to H$, with Higgs doublet in the G/H coset.
- Weak sector $SU(2)_L \times U(1)_Y \subset H$.
- Higgs potential generated dynamically by coupling to SM fields.

Partial compositeness [1]

- Linear couplings of top quark to a baryon in the new sector gives fermion mass.

Ferretti-Karateev in 2014 classified UV completions.

[2] Dugan, Georgi, Kaplan, Nucl. Phys. B254, 299 (1985)

[1] Kaplan, Nuclear Physics B365, (1991)

Ferretti's model(1404.7137)

- UV completion with partial compositness.
- SU(4) gauge theory with 2 representations.

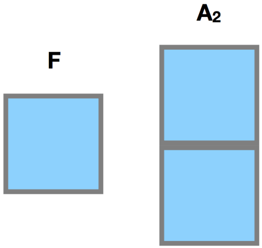
Fermion content

- 5 sextet(A_2) Majorana fermions.
- 6 fundamental(F) Weyl fermions.

Symmetry breaking

- $SU(5)/SO(5)$ in A_2 rep.
- $(SU(3)_L \times SU(3)_R)\ /SU(3)$ in F rep.

The Higgs doublet lives in the $SU(5)/SO(5)$ coset.



Our Lattice model

SU(4) gauge theory with modified fermion content

- 2 flavors of sextet A_2 Dirac fermions.
- 2 flavors of fundamental F Dirac fermions.

Symmetry breaking

- $SU(4)/SO(4)$ in A_2 rep.
- $(SU(2)_L \times SU(2)_R)\ /SU(2)$ in F rep.

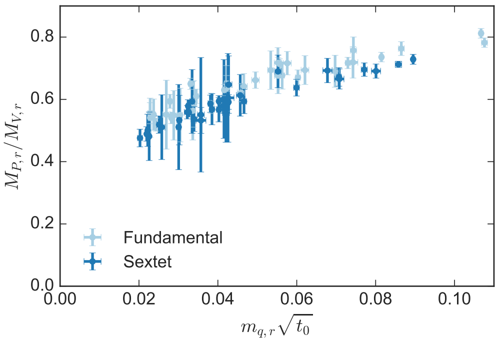
- 3 coupling constants : $\beta,\ \kappa_4,\ \kappa_6$.
- Expected to capture qualitative features of Ferretti's model.

Lattice details

- Simulations on lattice sizes $16^3 \times 32$ and $16^3 \times 18$.
- About 40 ensembles.
- Multi-rep MILC code by Yigal Shamir
- Studied Pseudo-scalar and vector mesons.
- Extract meson masses using two-point correlation functions.
- Using Wilson flow method to set the scale.

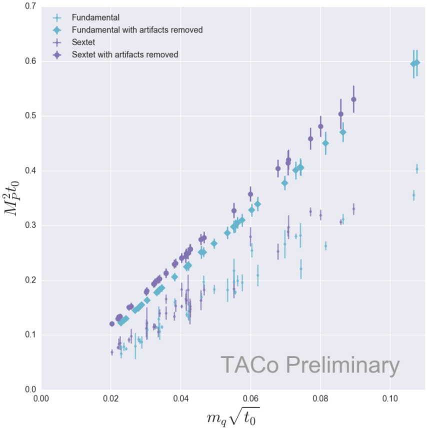
Ensemble overview

- Lattice results obtained in terms of lattice spacing a.
- Using Wilson flow scale t_0 to remove a dependence.
- Look at M_P/M_V vs m_q.
- Quark mass m_q obtained using Axial Ward identity.
- Relatively heavy mesons.
- Similar behavior for both representations.



Leading order ChiPt

- Upto leading order in ChiPt, $M_{pi}^2 \sim m_q$.
- Removed lattice artifacts obtained using Wilson ChiPt.
- Linear behavior for both reps.



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Comparison with NLO ChiPT

- Useful to compare lattice results to NLO ChiPT.
- Multirep NLO ChiPT worked out by DeGrand, Goltermann, Neil, Shamir (1605.07738).
- $M_{P4}, F_{P4}, M_{P6}, F_{P6}$ depend on a set of low energy constants(LECs).
- Simultaneous fit to all four quantities.
- Find a good fit ($\chi^2/DOF \sim 0.5$)

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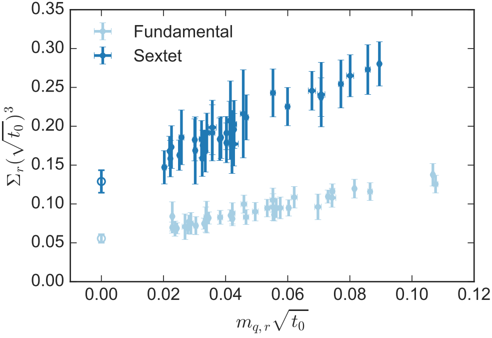
Condensates

- Two condensates, one for each representation.
- Compute it indirectly using $\hat{\Sigma}_r = \frac{M^2_{P,r}\ F^2_{P,r}}{2m_{q,r}}$
- Chiral limit values computed using ChiPt.
- Condensate ratio Σ_6/Σ_4
  - Lattice calc $\rightarrow$ 2.2
  - Large N scaling $\rightarrow \frac{dim(A_2)}{dim(F)} \sim \frac{N^2/2}{N} \sim 2.$



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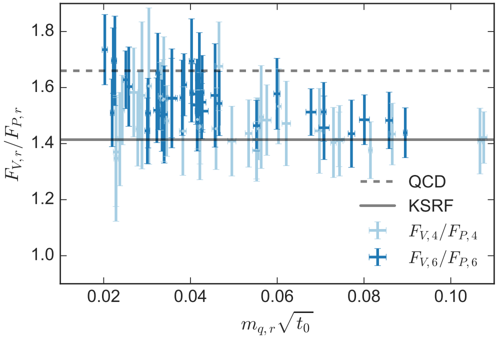
Decay constants

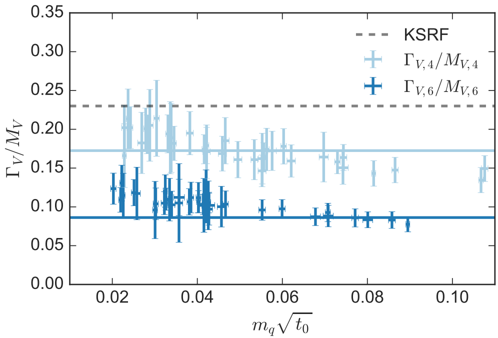
- KSRF [3,4] related F_V and F_P using current algebra and vector meson dominance. $F_V = \sqrt{2} F_P$.
- Can compare F_V and F_P in a fixed representation.
- QCD experiment: $F_V / F_P = 216 MeV / 130 MeV = 1.66$.
- For both reps, our results similar to QCD.



[3] Kawarabayashi and Suzuki, PRL 16, 255 (1966).
[4] Riyazuddin and Fayyazuddin, PRL 147, 1071 (1966).

Decay widths

- KSRF also predicted coupling strength $g_{VPP} = \frac{M_V}{F_P}$.
- Allows tree-level estimation of vector decay width: $\Gamma_V = g_{VPP}^2 M_V / 48\pi$.
- KSRF prediction $\frac{\Gamma_V}{M_V} \sim \frac{M_V^2}{48\pi F_P^2}$.
- $\frac{\Gamma_V}{M_V}_{QCD} = 0.19$.
- Our states narrower than QCD.
- $\frac{\Gamma_{V6}}{M_{V6}} = 0.13$, $\frac{\Gamma_{V4}}{M_{V4}} = 0.18$.



Conclusions and Outlook

Conclusions

- Zero temperature study of lattice SU(4) gauge theory BSM model with fermions in multiple reps.
- Meson spectroscopy data consistent with ChiPT.
- KSRF relations hold similar to QCD.
- Theory appears QCD-like.

Future direction

- Baryon spectroscopy.
- Coupling between the two irreps.
  - LECs unconstrained.
  - Greater precision might help constrain these.
- Existence of exotic pNGB ζ meson.
  - Theory has non-anomalous $U(1)_A$
  - SSB $\implies$ scalar, singlet ζ meson.

THANK YOU

Back-up slides

Wilson flow to set the scale

- Wilson flow: a smearing technique to smooth-out configurations.
- Also, a method to set the scale[5],.
- $t_0\langle E(t_0)\rangle = M(N)$, where $E(t) = \frac{1}{4}G_{t,\mu\nu}G_{t,\mu\nu}$.
- For QCD (N=3), M = 0.3, corresponding to $\sqrt{(}t_0) = 0.14fm$.
- For SU(4), $t_0\langle E(t_0)\rangle = 0.3 \times \frac{4}{3} = 0.4$,

[6] M. Luscher, JHEP 08, 071 (2010)