Light scalar resonance from lattice simulation of SU(3) gauge theory with eight light fermions†

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Studying the properties of strongly-coupled gauge theories with a large number of fermions has been an area of active research using lattice gauge theory techniques in recent years[1]. The screening of the gauge force by the presence of N_f light fermions is known to trigger a phase transition as N_f increases, with confinement and chiral symmetry breaking disappearing as the theory becomes scale invariant at long distances. Near the transition, such a theory can be confining (and therefore a useful candidate for the construction of composite Higgs models), but exhibit novel dynamical features associated with the onset of scale invariance.

Lattice gauge theory provides an ideal method to study these non-perturbative theories numerically. We consider an SU(3) gauge theory with $N_f = 8$ degenerate light fermions, charged under the fundamental representation. An earlier study of this same theory by the LatKMI collaboration[2] revealed evidence for a very light scalar resonance with $J^{PC} = 0^{++}$ quantum numbers. This is qualitatively different from QCD, where the lightest scalar resonance is heavy enough to decay into two pions.

Our lattice simulations are carried out with an nHYP-smeared staggered fermion action, and a plaquette gauge action which includes an adjoint plaquette term to reduce lattice artifacts associated with a lattice phase transition.[3] We use standard lattice spectroscopy techniques to calculate the resonance masses and decay constants. For the 0^{++} meson state, the fermion-line-disconnected contribution to the two-point correlation function is important, for which we employ the method of dilution with $U(1)$ stochastic sources. We simulate the theory at relatively light fermion masses, with the ratio $M_\rho/M_\pi \approx 2.1$ at our lightest point shown, requiring a $64^3 \times 128$ lattice volume in order to control finite-volume systematic effects.

One of the main results of our simulation is shown in figure 1, which gives the resonance masses as a function of the input fermion mass am. Over a wide range of input masses, the 0^{++} resonance is seen to be nearly degenerate with the pion, and both resonances are becoming light compared to the ρ and other heavier states seen in the spectrum. This confirms the LatKMI result[2] and demonstrates that the degeneracy between the 0^{++} and π states persists even to rather light fermion masses, approaching the chiral limit of the theory.

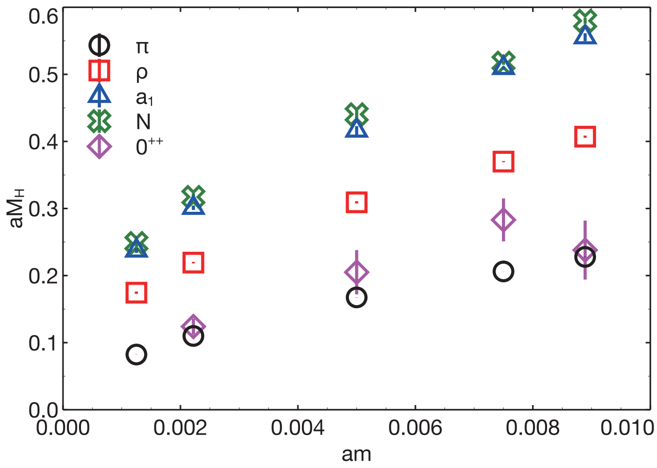

Fig. 1. Spectrum of the SU(3) $N_f = 8$ theory in lattice units, obtained from our simulations. The states shown are the lightest resonance in the pseudoscalar (π), scalar (0^{++}), vector (ρ), axial vector (a_1), and nucleon (N) channels. Error bars are shown for all results, but are often smaller than the size of the symbols used. The 0^{++} and π states are seen to be near-degenerate over a wide range of input fermion masses am and well-separated from the rest of the spectrum.

The separation of the 0^{++} and π states relative to the rest of the spectrum, which stands in stark contrast to the familiar case of QCD, raises the question of whether there is an effective field theory (EFT) containing both the 0^{++} and π degrees of freedom which can describe the low-energy dynamics of the $N_f = 8$ system. Identifying a novel EFT that contains a light scalar degree of freedom could provide a completely new approach to the construction of composite Higgs models, and might help to deepen our understanding of the confining-conformal transition in many-fermion gauge theories as well. As a next step in our study of this theory, lattice calculations of $\pi - \pi$ scattering are now underway, which will help to distinguish the possible EFT descriptions of this intriguing system.

References

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