Targeting the conformal window: 4+8 flavors

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What is the origin of the Higgs boson?

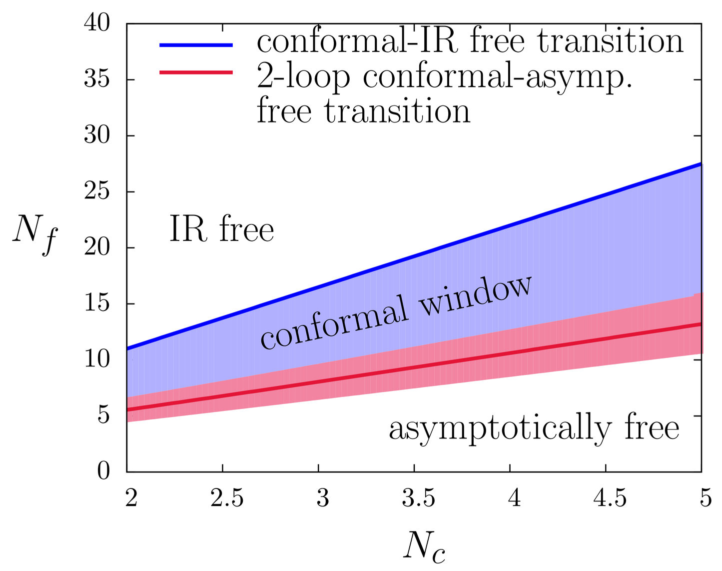
- LHC: Higgs is a relatively light, Standard-Model like scalar with mass ≈ 126 GeV
- Extra dimension? Fundamental scalar? Supersymmetry? Pseudo Nambu-Goldstone boson? Composite of strong dynamics?

The Higgs as a composite resonance

- A composite resonance is a natural mechanism, as e.g. in superconductivity
- Avoids fine-tuning of the scalar mass
- Likely requires a "walking" theory near a conformal infrared fixed point (IRFP)
  - → Light Higgs could be the dilaton of broken conformal symmetry
  - → Walking coupling leads to enhanced chiral condensate needed for precision EW constraints
- Strongly coupled model requires non-perturbative studies
  - → exploratory lattice results [1]

The conformal window

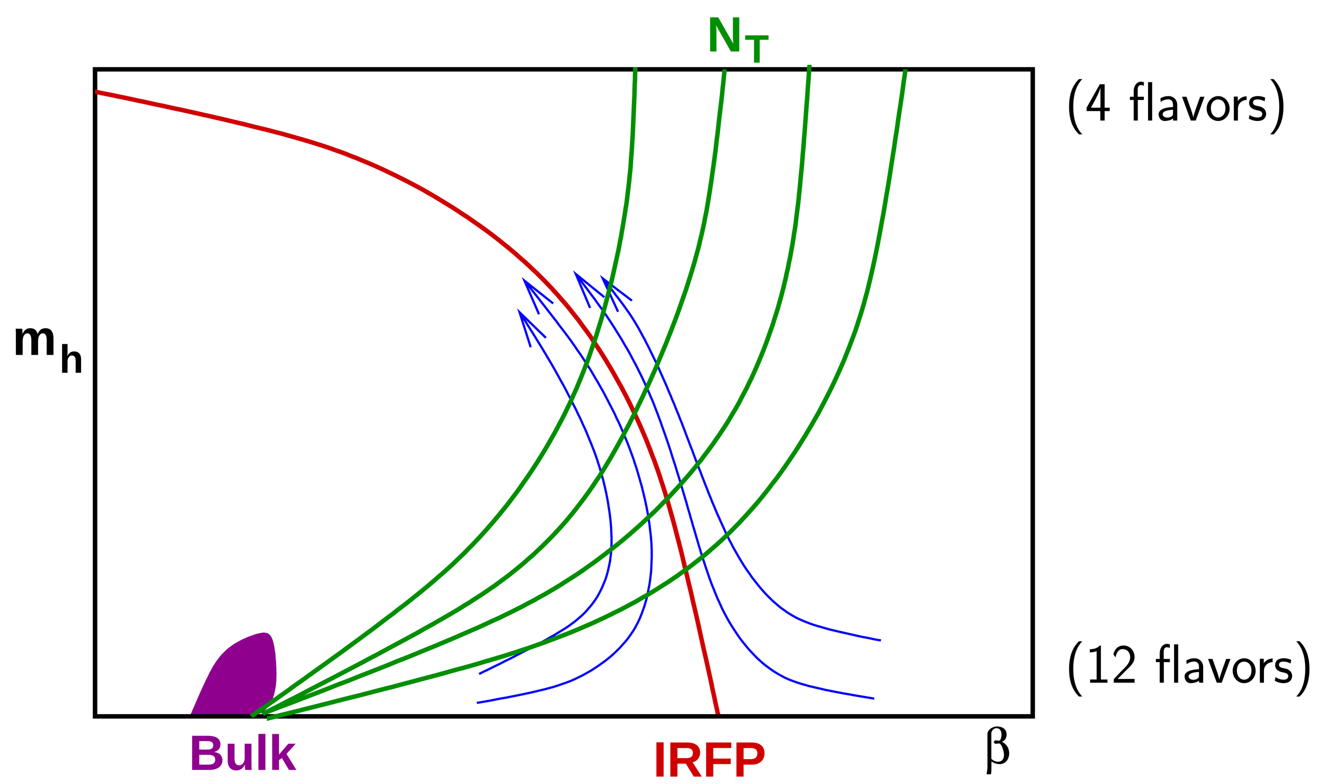
- No guarantee that any model close enough to the conformal window, but still in the chirally broken phase, shows desired walking behavior
- Even if such a model with integer flavor number exists, it may be hard to study
- Typical lattice methods are not suitable to investigate a system with a running gauge coupling changing very slowly with the scale



Alternative model: 4+8 flavors

- Study SU(3) with $N_l + N_h$ flavors: N_l massless (light) and N_h heavy flavors of mass m_h
- In the infrared: for $m_h \to \infty$ the system is chirally broken (4 light flavors);
  for $m_h \to 0$ the system is chirally symmetric (12 light flavors) [2]
- Tuning the mass m_h allows us to interpolate between chirally symmetric and broken phases
- In the ultraviolet (UV) this model exhibits chirally symmetric behavior that appears as walking

The phase diagram

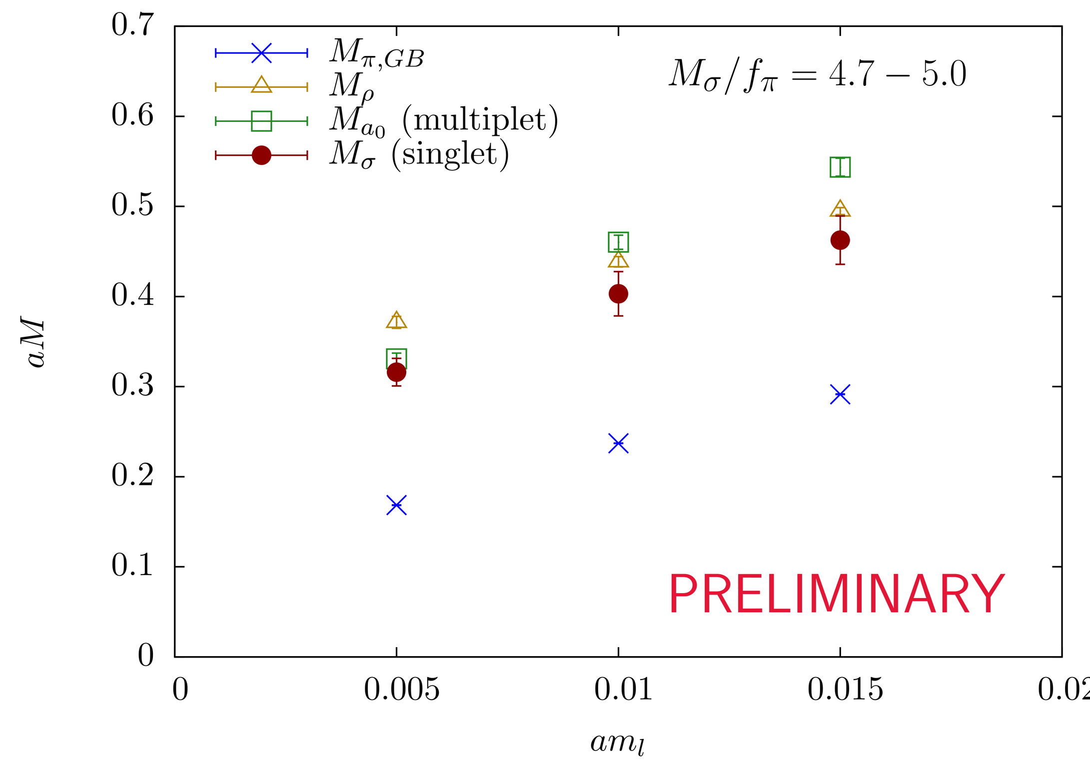


- The renormalized trajectory (RT) emerging from the IRFP of the 12-flavor system at $m_h = 0$ runs to the trivial $\beta = 0$ point at $m_h = \infty$
- For $am_h \ll 1$ the RG flow lines approach this IRFP and hover around it for a while before running to the trivial FP along the renormalized trajectory
- As long as the original gauge coupling is close to the RT the IR behavior of the system can be characterized by m_h i.e. we can investigate the system as a function of m_h with β fixed
- The chiral condensate $\langle\psi\bar{\psi}\rangle_l$ serves as order parameter

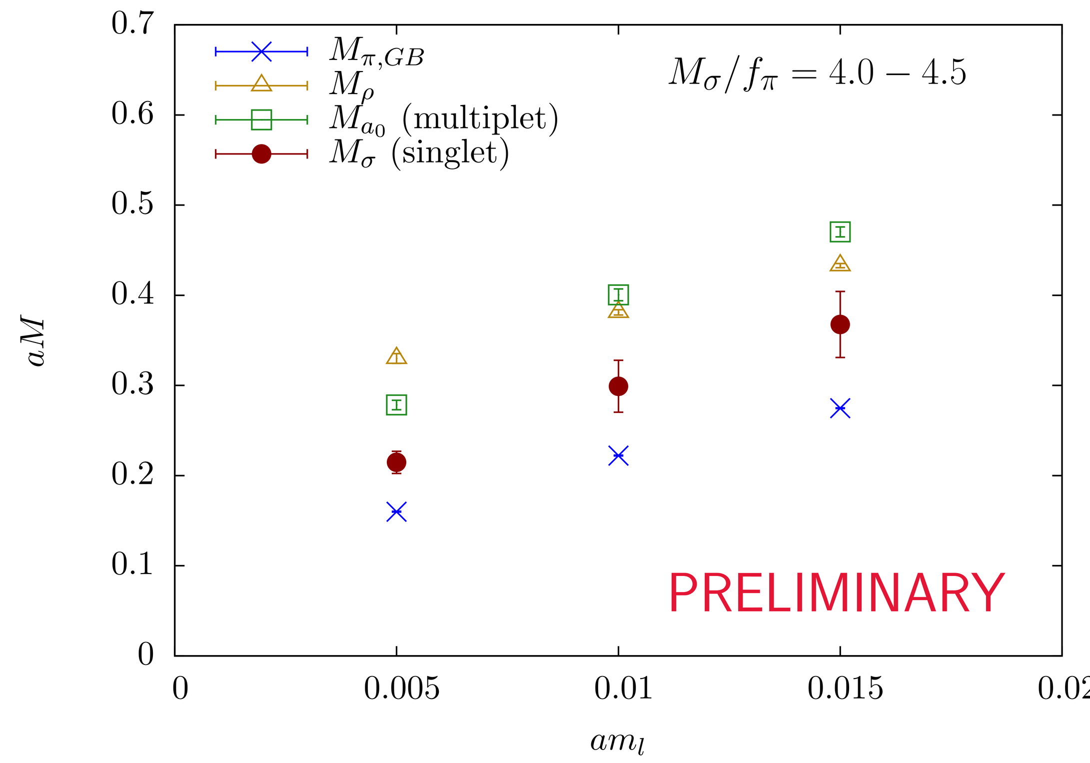
Measuring the 0^{++} from light fermion sources

- Plaquette gauge action with negative adjoint term and nHYP smeared staggered fermions [3]
- $\beta = 4.0$, $\beta_a/\beta = -0.25$, $L^3 \times T = 24^3 \times 48$, simulations performed using FUEL [4]
- Connected spectrum from wall-sources and point-sinks, $O(500)$ configurations
- Disconnected spectrum from stochastic sources with time-slice dilution, $O(1000)$ configurations
- Finite volume effects are small: connected spectrum gives consistent results on $32^3 \times 64$

$am_h = 0.100$:



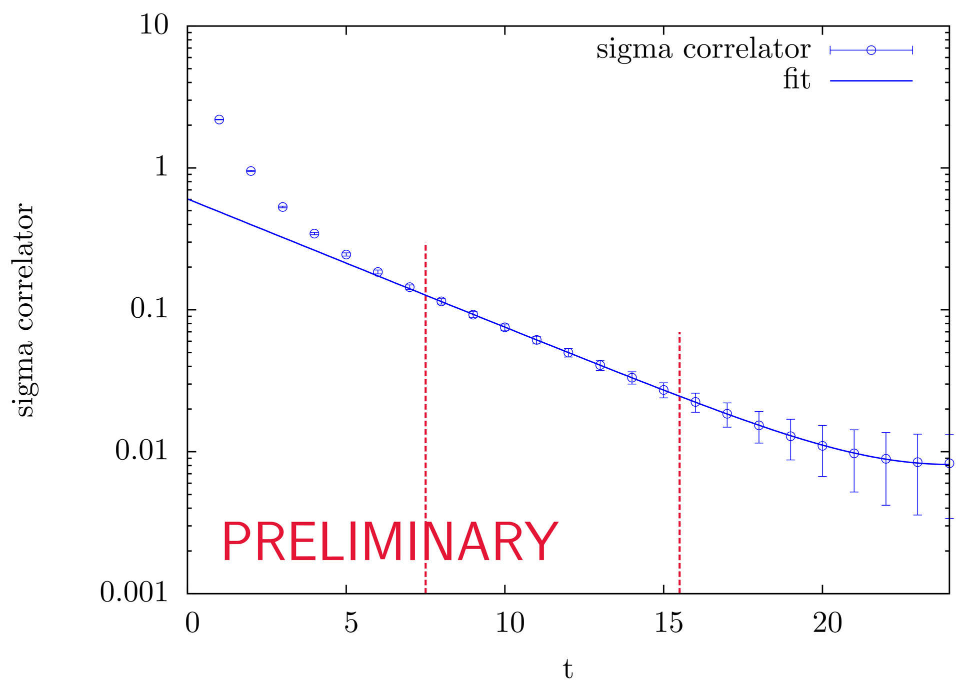
$am_h = 0.080$:



- $m_h = 0.100$: M_σ, M_ρ, and M_{a_0} are of similar magnitude (QCD-like spectrum)
- $m_h = 0.080$: M_σ is 20-30% lighter than M_ρ and M_{a_0}
- $m_h = 0.060$: Hope to find M_σ much lighter than M_ρ and M_{a_0} (in progress)
- M_σ/f_π decreases from $am_h = 0.100$ to $am_h = 0.080$

Technical details

- Consider only light fermion states, ignore mixing with heavy flavors
- Sigma correlator obtained from $D_+(t) - C_+(t)$ after vev subtraction
  - → Valid for any value of the masses M_σ and M_{a_0}
- Sample correlator plot for $m_l = 0.005$ and $m_h = 0.080$



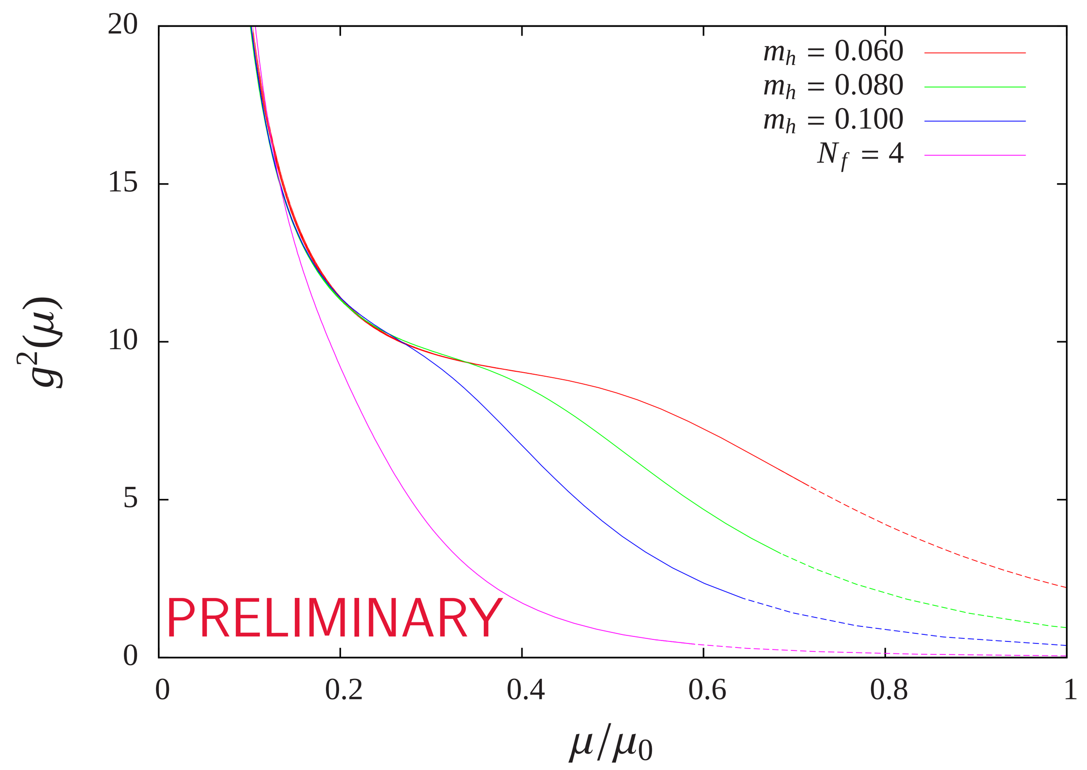
Signals of "walking"

- Tuning m_h controls the energy dependence of the gauge coupling
- Use gradient flow to define a renormalized coupling [5] and study its scale dependence

$$g^2_{GF}(\mu = \frac{1}{\sqrt{8t}}; m_h) \propto t^2 \langle E \rangle, \qquad E = \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu}$$

- → Control finite volume effects by restricting $\sqrt{8t}/a \le 0.2L$, $L = 24, 32$
- → Control cut-off effects by restricting $\sqrt{8t}/a > \mathcal{O}(1)$ (needs further study)
- → Define the lattice scale $\sqrt{8t_0}/a$ via $t^2\langle E \rangle|_{t=t_0} = 0.3$

Compare different am_h at $\beta = 4.0$ in the $am_l \to 0$ limit



- We show $am_h = 0.060$, 0.080, and 0.100 and use $\mu_0 = 1/\sqrt{8t_0}$ at $am_h = 0.080$
  - → $am_h = \infty$ ($N_f = 4$): QCD-like running coupling
  - → $am_h = 0.100$ shows very little "walking" (again almost QCD-like)
  - → $am_h = 0.080$ shows the emergence of "walking"
  - → $am_h = 0.060$ and below should have extended "walking" range: Numerical measurements need larger volumes ($32^3 \times 64$ in progress)

Summary and Outlook

- The first results are promising and follow expectations:
  - → The coupling shows signs of "walking" as $m_h \to 0$
  - → The 0^{++} scalar M_σ decreases as $m_h \to 0$
- The $4 + 8$ flavor system presents new challenges:
  - → The phase diagram is complicated and the continuum limit requires $m_h \to 0$ in addition to $\beta \to \infty$
  - → The isosinglet scalar is a mixture of the light and heavy flavors
  - → Extracting M_σ becomes easier as it gets lighter
- Future plans:
  - → Numerical exploration of the finite temperature phase diagram
  - → Computation of the gradient flow step scaling function
  - → Improving the 0^{++} measurement using better statistics, smaller m_h, larger volumes

References

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