Composite Higgs from mass-split models
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Motivation
- What is the nature of the Higgs boson?
- What is the origin of electro-weak symmetry breaking?
- Is there new physics below the Planck scale? How could it look like?

example

theory

Higgs is a light scalar with mass 125 GeV
- Standard Model is not UV complete
- No other resonances discovered so far
- Spectrum cannot be QCD-like

large separation of scales
e.g. strongly coupled conformal gauge theories
- → Higgs is a composite particle
- → Other resonances predicted in the few TeV range
- → Nonperturbative simulations using lattice field theory

Framework of composite Higgs models
- Start from Higgs-less Standard Model L_{SM}
- Add new strongly interacting gauge fermion system L_{SM} ∈ LD
- Add interactions between new sector and Standard Model L_{int}
- $L_{UV} \rightarrow L_{SM} + L_{SM} \rightarrow L_{SM} + \ldots$
- $L_{SM}$ triggers EW symmetry breaking and a light Higgs emerges
- Give mass to SM gauge fields and fermions (4-fermion interaction, partial compositeness, . . .)
- Effective ansatz: theory in the UV required to explain mass of $L_{SM}$ fermions

Mass-split models as candidates for $L_{SM}$
- Promising candidates are chirally broken in the IR but conformal in the UV [1]

UV
$\Lambda_{UV}$
fermion masses
Higgs dynamics
→ Conformal many flavor system in the UV
→ Allow some of the masses to decouple in the IR
→ Arrive at a chirally broken few-flavor system
e.g. SU(3) gauge theory with 12 or 10 flavors

IR
$\Lambda_{IR}$

→ Mass-split system are non-QCD-like:
- Chirally broken, but dimensional ratios show conformal hyperscaling, i.e. IRFP governs UV dynamics
- Physical quantities depend only on $m_h/m_A$
- Gauge coupling is irrelevant, takes the value of the IRFP
- For $m_H \rightarrow 0$, only $m_{\psi}$ is relevant, effective setting the scale
- The Higgs boson can emerge as dilaton-like particle or pseudo Nambu-Goldstone boson (pNGB)

Dilaton-like Higgs
- Ideal two massless flavors in the IR
- Possibility a light $0^+$ could emerge from conformal FP

Non-trivial vacuum alignment:
$F_{\psi} \equiv \langle \psi \psi \rangle / m_{\psi}^2 > 246$ GeV
- Ideal four massless flavors in the IR
- Mass emerges from its interactions
- Non-trivial vacuum alignment:
$F_{\psi} \equiv \langle \psi \psi \rangle / m_{\psi}^2 > 246$ GeV

pNGB Higgs
- Ideal two massless flavors in the IR
- No data points — possibly large systematic effects, low statistics, excited states, PV, etc.
- Identified promising parameters for numerical simulations
- First signs of hyperscaling, starting to push into the chiral regime

Summary
Mass-split models in the basin of attraction of an IRFP
- Exhibit a large scale separation
- Have a non-QCD-like spectrum
- Light $0^+$ is dilaton-like scalar
- Ratios show hyperscaling independent of coupling or heavy flavor mass
- Feature composite Higgs scenarios with a dilaton-like or pNGB Higgs boson
- Are highly predictive: at most one free parameter (due to hyperscaling)

References

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Example: 4+8 mass-split model [2]
- Plaquette gauge action with negative adjoint term and nHFP smeared staggered fermions [3]
- $g = 1.8$ and 4.4, $\bar{m}_h/l = -0.25$, $L^2 \times T^2 = 24^2 \times 48$, simulations performed using FUEL [4]
- $\bar{m}_{\psi}/m_{\psi} = 0.03, 0.05, 0.10, 0.15, 0.25, 0.35, m_{\psi} = 0.05, 0.06, 0.07, 0.08, 0.10$
- Connected spectrum from wall-sources and point-sinks, O(500) configurations
- Connected spectrum from stochastic sources with time-slice dilution, O(1000) configurations

Light-light spectrum
- Dimensionless ratio — no scale setting
- Lowest scaling $0^+$ is light, almost degenerate with the pion
- Ratios do not depend on heavy flavor mass $\bar{m}_H$ nor on gauge coupling $\beta$
- System exhibits hyperscaling

The light-light sector is chirally broken
- Using the same lattice units, $F_A$ shows hyperscaling and approaches a finite value
- $M_A$ in lattice units shows linear behavior for small $m_{\psi}$ (cf. QCD: $M_A/m_{\psi} = 4.7/86 \approx 0.05$)
- As in QCD like theories, $M_{\mu+}/M_A$ diverges for $m_{\psi} \rightarrow 0$

Hyperscaling in the light-light and heavy-heavy sector

Outlook: 4+6 mass-split model (Lattice Strong Dynamics collaboration)
- Tree-level improved Symanzik gauge action with stout-measured Wilson domain-wall fermions [5]
- Simulations performed with Grid-6 [6] or Irore [7] to utilize state-of-the-art supercomputers
- Domain-wall fermions feature continuum-like symmetries simplifying calculations
- Easier to calculate the Higgs potential, S-parameter, scattering processes, . . .
- Easier to investigate partial compositeness or four-fermion interactions
- Avoids issues of staggered fermions (e.g. rooting, symmetry breaking)
- Likely larger anomalous dimension if $N_F = 10$ is indeed conformal [8, 9, 10]