Physical spectrum of a partially Higgsed gauge theory

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Motivation

- Summarizing situation in SM: [Talk by A. Maas]
  - ★ FMS mechanism: [Fröhlich *et al.*, PL **B97** (1980) and NP **B190** (1981)]
    Spectrum of physical states (bound states) and elementary states (W/Z, Higgs, etc.) coincide
  - ★ Multiplet structure of gauge sector traded for multiplet structure of custodial symmetry
  - ★ Gauge group = custodial group
    $\Rightarrow$ Same degeneration pattern
- Applicability of FMS mechanism relies on:
  - ★ Special structure of SM: Local = global multiplet
  - ★ Smallness of Higgs fluctuations
- Does it also work in BSM scenarios?

  [Maas, 1502.02421 / Törek and Maas, 1509.06497]

Partially Higgsed gauge theory

- Aim is to construct a counter-example:
  - ★ GUT inspired theories:
    Gauge group larger than global symmetry group
  - ★ Local $\neq$ global multiplet
- Toy model: $SU(3)$ gauge group with fundamental Higgs ϕ

$$\mathcal{L} = \left(D_\mu \phi\right)^\dagger \left(D_\mu \phi\right) + \mu^2 \phi^\dagger \phi - \frac{\mu^2}{2v^2}\left(\phi^\dagger \phi\right)^2 + \frac{1}{2}\mathrm{tr}\left[W_{\mu\nu}^2\right]$$

- Perturbative construction: $SU(3) \xrightarrow{\langle\phi\rangle} SU(2)$
- Perturbative spectrum:
  - ★ $4 + 1$ massive and 3 massless gauge bosons
  - ★ 1 massive Higgs boson

$J^P = 1^-$ singlet channel

- Conflict expected in vector channel [Törek and Maas, 1509.06497]
- FMS mechanism: [Fröhlich *et al.*, PL **B97** (1980) and NP **B190** (1981)]
  - ★ Composite gauge-invariant operator:

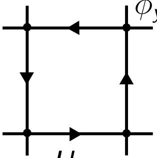
$$O_\mu(x) = i\left(\phi^\dagger D_\mu \phi\right)(x)$$

  - ★ Fix to gauge with non-vanishing vev (minimal 't Hooft-Landau gauge)
  - ★ Expand Higgs around vev: $\phi_i(x) = v\delta_{i,3} + \eta_i(x)$

$$\langle O_\mu(x) O_\mu^\dagger(y)\rangle = v^4 \langle W_\mu^8(x) W_\mu^8(y)\rangle + \mathcal{O}(\eta W / v)$$

- Correlators have same mass poles $\Rightarrow$ same mass
- Only a single massive particle is predicted
  $\Rightarrow$ Contradiction to perturbative spectrum

Lattice studies: Basic setup



- Lattice action: $U_{x,\mu} = e^{iW_{x,\mu}} \in SU(3)$

$$S[U,\phi] = \frac{\beta}{3}\sum_{\square} \text{Re tr}[U_{\square}] + \sum_x \Big[\phi_x^\dagger \phi_x + \lambda(\phi_x^\dagger \phi_x - 1)^2 - \\ - \kappa \sum_\mu (\phi_x^\dagger\ U_{x,\mu}\ \phi_{x+\hat{\mu}} + c.c.)\Big]$$

- Generating configurations: Multi-hit Metropolis algorithm
- To study elementary fields: Gauge fixing required
  - ★ Local gauge fixing: Minimal Landau gauge $\partial_\mu W_\mu(x) = 0$
  - ★ Global gauge fixing: Rotate Higgs field into $\phi \propto (0,0,1)$

Phase diagram: QLR vs. HLR

- Depending on β, κ and λ different expectations:
  - ★ Non-Abelian gauge theory: QCD-like region (QLR)
  - ★ Higgs sector: Higgs-like region (HLR)
- Quantity to measure polarization: $\overline{\phi} = \frac{1}{V} \sum_x \phi_x$

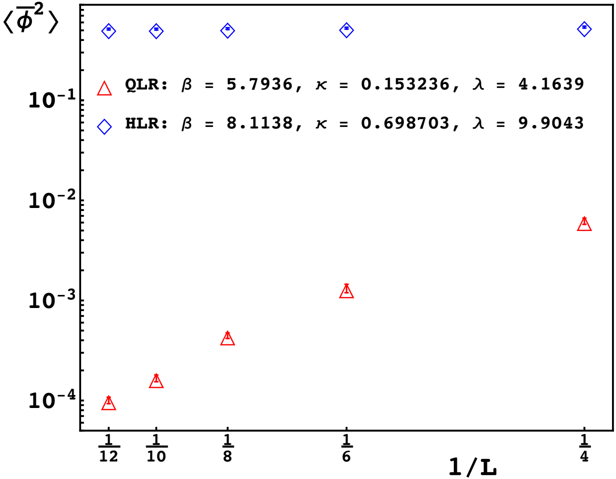
  [Caudy and Greensite, PR **D78** (2008) / Langfeld, (2002)]

- Quantity to distinguish the regions:

$$\langle \overline{\phi}^2 \rangle = \left\langle \left| \frac{1}{V} \sum_x \phi_x \right|^2 \right\rangle \approx \frac{\xi}{V}$$

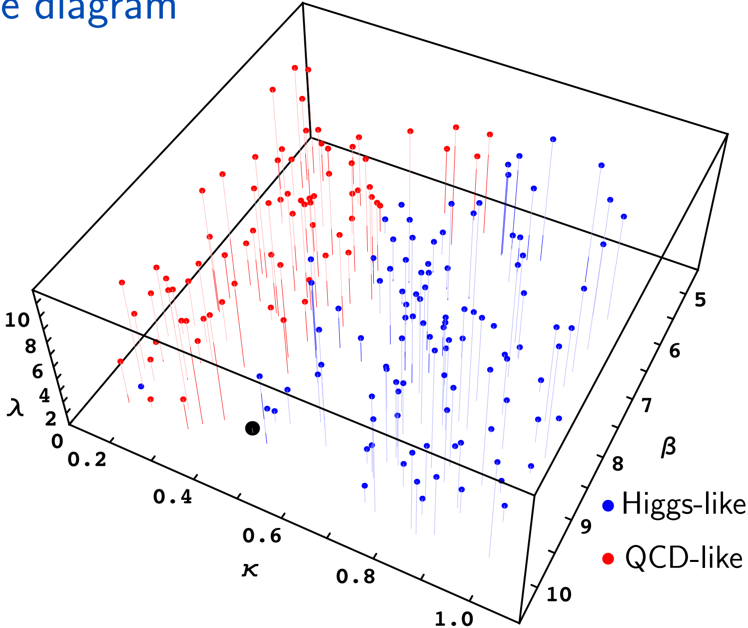
- QLR: $\langle \overline{\phi}^2 \rangle \xrightarrow{V \to \infty} 0$ for ξ finite
- HLR: $\langle \overline{\phi}^2 \rangle \xrightarrow{V \to \infty} \mathit{const.} > 0$ for ξ infinite

Phase diagram: QLR vs. HLR



- Large values of $\kappa \Leftrightarrow$ large negative tree-level masses $\Rightarrow$ BEH effect in this gauge (depends also on β, λ)
- Small values of $\kappa \Rightarrow$ No BEH effect

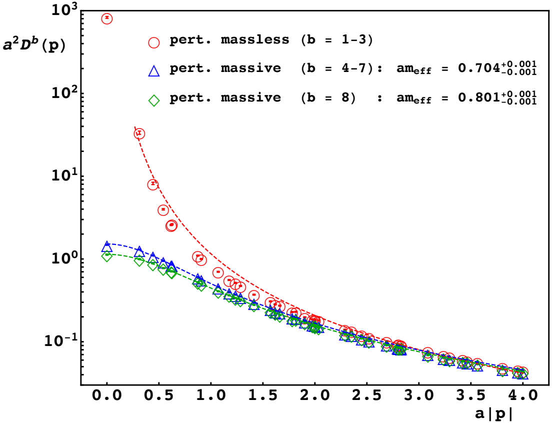
Phase diagram



Propagators

- Good agreement with tree-level perturbation theory

$V = 20^4$, $\beta = 9.59055$, $\kappa = 0.444462$, $\lambda = 0.4118$

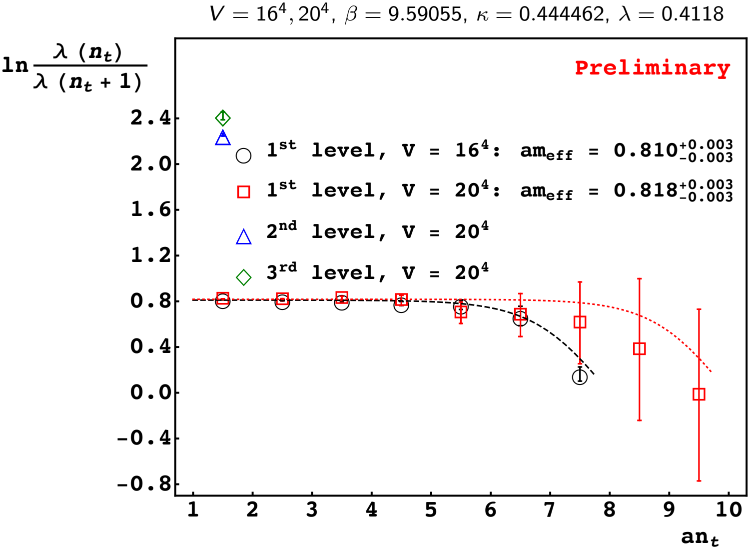


- Dashed lines: Fits to Z/p^2 and $Z/(p^2 + (am_{\text{eff}})^2)$

Spectroscopy in 1^- channel - Setup

- Variational analysis with operator set:
  (larger operator basis is work in progress)
  $$O_\mu = \mathrm{Re}\Big(i\ \mathrm{tr}\Big[\phi_i^\dagger U_\mu^{ij} \phi_j\Big]\Big) \text{ and } O_\nu O_\nu O_\mu$$
- Links stout-smeared and Higgs APE-smeared
- Total operator set consists of 3-times and 4-times smeared O
  $\Rightarrow$ Crosscorrelation matrix $C(n_t)$
- Generalized eigenvalue problem: $C(n_t)\vec{v} = \lambda(n_t) C(n_0)\vec{v}$
  $\Rightarrow \lambda^{(k)}(n_t) \propto e^{-n_t E_k}\Big(1 + \mathcal{O}(e^{-n_t \Delta E_k})\Big)$
- Energy levels: E_k from $\ln \frac{\lambda^{(k)}(n_t)}{\lambda^{(k)}(n_t+1)} \Rightarrow E_0 \equiv m_{\mathrm{eff}}$

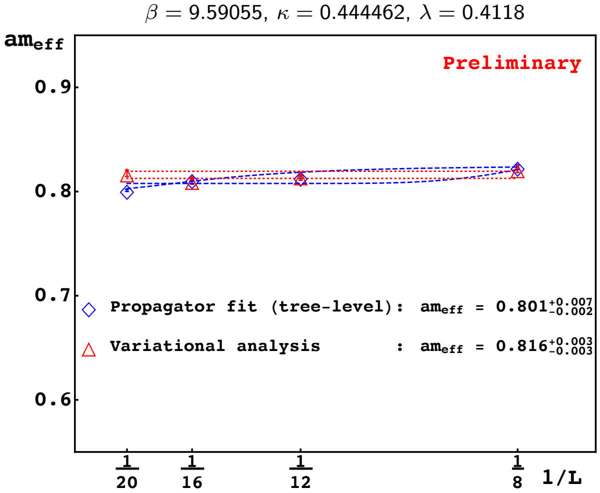
Spectroscopy in 1^- channel - Results



- Dashed/dotted lines:
  Results of fit $\lambda(n_t) = A\cosh\left(am_{\text{eff}}\left(n_t - L/2\right)\right)$

Volume dependency of m_{eff}

- Single massive ground state with mass of W^8
- Exactly like FMS mechanism predicts



- Dashed/dotted lines: Fits of am_{eff} to $A + B\ e^{-cV}$

Conclusions [1607.05860]

- $SU(3)$ gauge theory with fundamental Higgs
- Perturbative framework: 4+1 massive and 3 massless gauge bosons
- Perturbative description works well for propagators
- FMS mechanism: Single massive state in 1^- channel
- Lattice results support FMS prediction