Fundamental composite 
Higgs dynamics on the lattice

Vincent Drach

CERN Theory Group Retreat, Les Houches

November 2015
Introduction

• Before CERN:
  • 2007-2010 : PhD, Grenoble, France
  • 2010-2013 : Postdoc, DESY-Zeuthen, Germany
  • 2013-2015 : Postdoc, CP3-Origins, Denmark

• Research Interests :
  • **Lattice QCD**:
    ★ Nucleon structure calculation
    ★ $\sigma$-terms, strangeness of the nucleon
    ★ Disconnected diagrams

  • **Lattice BSM**:
    ★ Extensions of the SM with strong dynamics ?
    ★ What are the key (lattice) observables ?
    ★ Use the lattice approach into a predictive machine for theories that are not observed in Nature.

→ Requires new ideas/techniques depending on the underlying theory

→ Poor signal-over-noise ratio, renormalisation issues
Unified Composite Higgs

- SU(2) gauge theory with $N_f = 2$ Dirac fermions in the fundamental representation.

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^a F^{a\mu\nu} + i \bar{U} \gamma^\mu D_\mu U + i \bar{D} \gamma^\mu D_\mu D + \frac{m}{2} Q^T (\sigma^2) C E Q + \frac{m}{2} (Q^T (\sigma^2) C E Q)^\dagger$$

- Pseudo-real irrep of SU(2): global flavour symmetry is upgraded to SU(4):

$$Q \equiv \begin{pmatrix} U_L \\ D_L \\ \tilde{U}_L \\ \tilde{D}_L \end{pmatrix} \equiv \begin{pmatrix} U_L \\ D_L \\ -i\sigma_2 C \tilde{u}_R^T \\ -i\sigma_2 C \tilde{d}_R^T \end{pmatrix}, \quad E = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

- Infinitesimal SU(4) transformation $Q \rightarrow \left(1 + i \sum_{n=1}^{15} \alpha^n T^n \right)$

- Generators that leaves the Lagrangian invariant satisfy: $ET^n + T^{nT} E = 0$

- Chiral symmetry breaking pattern: SU(4) breaks to SP(4) $\Rightarrow$ 5 Goldstone Bosons
Two interesting alignments of the condensate:

\[ \Sigma_H \equiv E = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} : \text{break EW symmetry} \]

\[ \Sigma_B \equiv \begin{pmatrix} i\sigma_2 & 0 \\ 0 & -i\sigma_2 \end{pmatrix} : \text{does not break EW} \]

General superposition: \[ \Sigma_0 = \cos \theta \Sigma_B + \sin \theta \Sigma_H \]

\[ Q_L = (U_L, D_L) : \text{SU(2)}_L \text{ doublet with hypercharge } 0 \]

\[ \tilde{U}_L, \tilde{D}_L : \text{SU(2)}_L \text{ singlet with hypercharge } \pm \frac{1}{2} \]

Electric charge matrix:

\[ Q = \text{diag} \left( \frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, \frac{1}{2} \right) \]

Two limit cases:

\[ \theta = 0 : \text{EW does not break : composite Higgs limit} \]

\[ \theta = \pi/2 : \text{EW breaks + DM candidate : technicolor limit} \]

Mixed case is natural: \( 0 < \theta < \pi/2 \)

\[ \Rightarrow \text{the model interpolate between TC and CH} \]
Scattering properties of the W are related to the scattering of the underlying GB. (Equivalence Theorem)

- **First step**: scattering length (done)
- **Then**: width of vector meson

Related to the decay rate into Ws of the new resonance

[Quigg & Thacker, PRD 1978]
The $\sigma$

- Higgs field: linear combination of GB fields and of the $\sigma$ field
- $m_\sigma$ can in principle be determined numerically in isolation

$\Rightarrow$ Large contribution from disconnected diagrams
$\Rightarrow$ Unstable in the chiral limit
$\Rightarrow$ Large correction from the SM
One interesting framework: *Unified Composite Higgs and Technicolor model*

- Estimation of new observables (scattering properties, $m_\sigma$)
- Investigate properties of the DM candidate in the TC limit (my contribution to lattice 2015)

**Outlook:**
- Vector resonance decay rate into Ws
- SM corrections? (four-fermion interaction on the lattice?)
- Suggestions …