

objective: minimal realization of light composite Higgs

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USQCD Collaboration Meeting

May 1-2, 2015, Fermilab

What is our composite Higgs terminology? *H* = rr minology? IIposite i ligga terminolog What is our composite Higgs terminology?

gauge group. The Higgs Lagrangian is replaced by a suitable new fermion sector $\mathcal{L}_{\mathcal{A}}$

1, 2, 3. The hypercharge generator is taken to be the third generator of *SU*(2)R. The

 $\frac{1}{2}$ $\frac{1000}{800}$ do as let there switched o, an *SU*(2)L ⇤ *SU*(2)R symmetry. The full symmetry group can be made the Higgs doublet field fid $\overline{1}$

$$
H = \frac{1}{\sqrt{2}} \begin{pmatrix} \pi_2 + i \pi_1 \\ \sigma - i \pi_3 \end{pmatrix} \qquad \qquad \frac{1}{\sqrt{2}} (\sigma + i \vec{\tau} \cdot \vec{\pi}) \equiv M
$$

 τ^a $D_\mu M = \partial_\mu M - i\,g\,W_\mu M + i\,g'\,M\,B_\mu$, with $W_\mu = W_\mu^a \frac{1}{2}$, $B_\mu = B_\mu \frac{1}{2}$ μ T_{M} T_{M} T_{M} T_{M} T_{M} T_{M} with T_{M} T_{M} $D_{\mu}NI = \partial_{\mu}NI - i g VV_{\mu}NI + i g NI B_{\mu}$, With $VV_{\mu} = VV_{\mu} - i g V_{\mu} = B_{\mu} - i g V_{\mu}$ $D_{\mu}M = \partial_{\mu}M - i g W_{\mu}M + i g'MB_{\mu}$, with $W_{\mu} = W_{\mu}^{a}$ ⇧*a* $\frac{c}{2}$, $B_{\mu} = B_{\mu}$ τ^3 $D_{\mu}M = \partial_{\mu}M - i g W_{\mu}M + i g'MB_{\mu}$, with $W_{\mu} = W_{\mu}^{a} \frac{d}{2}$, $B_{\mu} = B_{\mu} \frac{d}{2}$ ⇧*a* $- v v_{\mu} \frac{1}{2}$, 1 $\sum_{i,j}$ $\mu - D\mu \overline{2}$

tile
1 2 The Higgs Lagrangian is The Higgs Lagrangian is to:

southaneous symmetry breaking spontaneous symmetry breaking Higgs mechanism

At this point one *assumes* that the mass squared of the Higgs field is negative and this

$$
\mathcal{L} = \frac{1}{2} \text{Tr} \left[D_{\mu} M^{\dagger} D^{\mu} M \right] - \frac{m_{M}^{2}}{2} \text{Tr} \left[M^{\dagger} M \right] - \frac{\lambda}{4} \text{Tr} \left[M^{\dagger} M \right]^{2}
$$

interacting strongly coupled gauge interaction (technically: $\frac{1}{2}$. Matters in $\frac{1}{2}$. Matters in $\frac{1}{2}$. Matters in $\frac{1}{2}$. Strongly: coupled gauge $\mathcal{L}_{Higgs} \rightarrow -$ 1 4 $F_{\mu\nu}F^{\mu\nu} + i\bar{Q}\gamma_{\mu}D^{\mu}Q + \dots$ where, the best we have left underlying the unit $\frac{1}{2}$ gauge group and the associated technifermion (*Q*) representation. The dots represent *M* ⌃ *gLMg*† *^R* and *gL*/*^R SU*(2)L/^R . (1.3) \vert . $\frac{1}{4}$. $v^{\mu\nu}$ + = (*i* ⇧2*H*⌅ , 0) . (1.4) The *SU*(2)L symmetry is gauged by introducing the weak gauge bosons *W^a* with *a* = 1 + ⇧³⇥ $\overline{}$ d gauge theory $\sum_{Higgs} \rightarrow -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{Q}\gamma_{\mu}D^{\mu}Q + \ldots$ $\frac{4}{2}$ is the havetack? ordinary covariant derivative acting on the Higgs, in the present notation, is: leads to the electroweak symmetry breaking. Except for the Higgs mass term the other strongly coupled gauge theory and the SM operators meaning that the SM operators have dimensionless means of the SM operators \mathbb{R}^n $\frac{1}{1 - \frac{1}{1 - \frac{$ $\mathcal{L}_{\text{Higgs}} \rightarrow -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \mathcal{Q} \gamma_{\mu} D^{\mu} \mathcal{Q} + \dots$ description of the chiral symmetry breaking in the haystack? 1The mass of the haystacks? with α since the associated renormalization group invariant scale must be fixed to an hadronic must be fixed to an α leads to the electroweak symmetry breaking. Except for the Higgs mass term the other and the Higgs mass mass mass mass in the Higgs mass is that the Higgs Lagrangian has a familiar of \mathbb{R}^n mass \mathbb{R}^n $f_{Higgs} \rightarrow -\frac{1}{2} F_{\mu\nu} F^{\mu\nu} + i \bar{O} \nu_{\mu} D^{\mu} O + \ldots$ $4 \frac{\mu}{\sqrt{2}}$ $\frac{1}{\sqrt{1-\frac{1$ or, just one of the haystacks?

Outline

Near-conformal SCGT?

light scalar close to conformal window effective theory? scale setting and spectroscopy systematics and mixed action

Chiral Higgs condensate

 GMOR and mode number epsilon regime and RMT large mass anomalous dimension?

Scale dependent renormalized coupling matching scale dependent coupling from

form UV to IR with chiSB

Early universe EW phase transition, sextet baryon, and dark matter

Summary

minimal realization

The LHC will probe the mechanism of electroweak symmetry breaking. A very attractive QCD intuition for near-conformal alternative to the standard mechanism, with fundamental scalars, involves new strongly-

Technicolor thought to be scaled up QCD with scalars such as trivialized and fine-tuning. Chiral symmetry motivation of the project: composite Higgs-like scalar close to the electroweak symmetry. Although this duplication of \sim conformal window

Fight $0++$ scalar and spectrum and 14 48 noise vectors on each gauge configuration [60]. The correlator Cconn(t) on the left plot and the light 0++ scalar and spectrum 2013-14 testing

⁰ ⁵ ¹⁰ ¹⁵ ²⁰ ²⁵ [−]¹

test of scalar technology: The right plot were assembled from the stochastic fermion on the stochastic fermion

12 14 16 18 20 22

 $C(t) = \sum [A_n e^{-m_n(\Gamma_S \otimes \Gamma_T)t} + (-1)^t B_n e^{-m_n(\gamma_4 \gamma_5 \Gamma_S \otimes \gamma_4 \gamma_5 \Gamma_T)t}]$ n

staggered correlator

*F*2

0.4

⌅ *^d*(*R*TC) *^m*²

 β =3.20 (with PCA analysis) 40³x80 m=0.004

, (5) and (5)

TC , *^v*² ⁼ *^N*TD *^F*²

*F*2

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⌅ *^d*(*R*TC) *^m*²

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, (5) and (5)

TC , *^v*² ⁼ *^N*TD *^F*²

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Search for a new resonance decaying to a *W* or *Z* boson and a Higgs boson in the $\ell\ell/\ell\nu/\nu + b\bar{b}$ final states with the ATLAS Detector

The ATLAS Collaboration

Abstract

A search for a new resonance decaying to a *W* or *Z* boson and a Higgs boson in the $\ell\ell/\ell\nu/\nu+$ *bb* final states is performed using 20.3 fb⁻¹ of *pp* collision data recorded at $\sqrt{s} = 8$ TeV with the ATLAS detector at the Large Hadron Collider. The search is conducted by examining the *WH*/*ZH* invariant mass distribution for a localized excess. No significant deviation from the Standard Model background prediction is observed. The results are interpreted in terms of constraints on the Minimal Walking Technicolor model and on a simplified approach based on a phenomenological Lagrangian of Heavy Vector Triplets.

 m_{R1^0} [GeV]

from the SM couplings of 20% when MA ' 2 TeV. This is reflected in the small deviations of the Higgs branching $\frac{1400}{1600}$ 1800 1800 10

 10^{-3}

 10^{-3}

400 600 800 1000 1200 1400 1600 1800

(b) $R_1^{\pm}(V'^{\pm}) \rightarrow WH, H \rightarrow b\bar{b}$

400 600 800 1000 1200 1400 1600 1800

 $m_{R1^{\pm}}$ [GeV]

invariant masses will be reconstructed from leptons and $\frac{1}{2}$ jets in the final state with a s
The final state with a state with $\frac{1}{4000}$ $\frac{1}{400}$ $\frac{1}{400}$ $\frac{1}{4000}$ $\frac{1}{4000}$ $\frac{1200}{m}$. The signal remains into a count leptonic lept $r_{\rm R1}$ ratios of the two Z-bosons and the hadronic state hadronic state hadronic state hadronic state hadronic state $r_{\rm R1}$

 \overrightarrow{A} \overrightarrow{A} \overrightarrow{A}

 R_1 and R_2 couplings:

 \hat{g} is the coupling in SU(4) vector boson

systematics and mixed action taste breaking to improve

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idea:

- use the gauge configurations generated with sea fermions
- taste breaking makes chiPT analysis unnecessarily complicated
- in the analysis use valence Dirac operator with gauge links on the gradient flow
- taste symmetry is restored in valence spectrum
- Mixed Action analysis should agree with original standard analysis when cutoff is removed: cross check

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sextet mixed action at flow time t=2 F_{π} (rwall pion channel)

taste breaking and mixed action

epsilon regime, p regime to epsilon regime crossover, valence pqChiPT with Mixed Action:

new analysis in crossover and **consider** ϵ **are given the orientation** RMT regime opens up with mixed action on gradient flow

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Have BEE External EXPLEM FEE EXPLEMENT regime opens up with <u>1</u> 10−2 × 10−3 × 10−3 × 10−3 × 10−3 × 10−3.1 × 10

The chiral condensate full spectrum new method

- nf=2 sextet example illustrates results from the Chebyshev expansion
- full spectrum with 6,000 Chebyshev polynomials in the expansion
- the integrated spectral density counts the sum of all eigenmodes correctly
- Jackknife errors are so small that they are not visible in the plots.

The chiral condensate GMOR test in far IR <u>is late</u> columnal condensate given test in

1

GMOR relation (nf=2): $2BF^2 = \Sigma$ (Σ is the chiral condensate) infinite-volume result. As shown on the left in Figure 4, we find the data can be described quite data can be d
The data can be described quite data can be described quite data can be described quite data can be described UMOR relation (nt=2): $2BF = 2$ (2 is the chiral condensate)

F: decay constant of Goldstone pion $M_{\pi}^2 = 2B \cdot m$ in LO χ PT $\mathcal{L}^{\mathcal{L}}$ relation. We can also compare the fermion in the fermion in the fermion mass from chiral mass from chir

from chiral perturbation theory of the condensate in the p-regime: $\Sigma_{\rm eff}$ $\frac{\epsilon_{\text{eff}}}{\Sigma} = 1 +$ \sum $32\pi^3N_F F^4$ $\sqrt{ }$ $2N_F^2 |\Lambda|$ arctan $\frac{|\Lambda|}{m} - 4\pi |\Lambda| - N_F^2$ $\frac{m^2}{\mu^2}$ *m* log $\frac{|\Lambda|}{\mu^2}$ – 4*m* log $\frac{|\Lambda|}{\mu}$

Improved determination of the chiral condensate Σ compared from Dirac spectra and the Chebyshev expansion.

With the additive NLO cutoff term separated from B and new fit to F, the improved result on Σ eliminates previous discrepancies in the GMOR relation.

The chiral condensate mass anomalous dimension

Boulder group pioneered fitting procedure

 $V_R(M_R, m_R) = V(M,m) \approx const \cdot M^{1+\gamma_m(M)},$ 4 or equivalently, $v(M,m) \approx const \cdot \lambda$ 4 ^{1+γ_m(λ)}, with $\gamma_m(\lambda)$ fitted

How to match λ scale and g^2 ?

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How to match λ scale and g^2 ?

scale-dependent coupling matching IR to UV

the running coupling and the β function finite volume

monotonic increase of g2 with scale is consistent with:

- mass deformed spectroscopy at low fermion mass
- chiral condensate
- mass anomalous dimension
- connection with $g^2(t,m)$ in bulk with chiSB

lattice step functions: 12➞**18, 16**➞**24, 20**➞**30, 24**➞**36 last two step functions are critical in the analysis: SSC vs. WSC are consistent at large flow times which requires the large volumes**

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Early universe

Kogut-Sinclair work consistent with χSB EW phase transition Relevance in early cosmology (order of the phase transition?) LatHC is doing a new analysis using different methods

- Nf=2 Qu=2/3 Qd = -1/3 fundamental rep udd neutral dark matter candidate
- dark matter candidate sextet Nf=2 electroweak active in the application
- 1/2 unit of electric charge (anomalies)
- rather subtle sextet baryon construction (symmetric in color)
- charged relics not expected?

Three *SU*(3) sextet fermions can give rise to a color singlet. The tensor product $6\otimes 6\otimes 6$ can be decomposed into irreducible representations of *SU*(3) as,

 $6\otimes 6\otimes 6=1\oplus 2\times 8\oplus 10\oplus 10\oplus 3\times 27\oplus 28\oplus 2\times 35$

where irreps are denoted by their dimensions and $\overline{10}$ is the complex conjugate of 10.

Fermions in the 6-representation carry 2 indices, ψ_{ab} , and transform as

$$
\psi_{aa'} \longrightarrow U_{ab} \ U_{a'b'} \ \psi_{bb'}
$$

and the singlet can be constructed explicitly as

 ϵ_{abc} $\epsilon_{a'b'c'}$ $\psi_{aa'}$ $\psi_{bb'}$ $\psi_{cc'}$.

Kieran Holland, Julius Kuti, Santanu Mondal, Daniel Nogradi, Chik \blacksquare

Summary: simplest composite scalar is probably very light (near conformality)

- successful knock on LHC door **ATLAS analysis and CMS plan**
-
- light scalar (dilaton-like?) emerging close to conformal window
-
-
-
- **•** Electroweak phase transition and baryon intriguing

• very efficient staggered BG/Q code 30-40 percent CG efficiency sextet Janos **•• spectroscopy ••• spectroscopy •••• spectroscopy •••• emerging resonance spectrum** \sim **2-3 TeV •** chiral condensate, large $\gamma(\lambda)$ new method is very promising **•** scale-dependent coupling difficult, Gradient Flow is huge improvement