Studying the flavor dependence of SU(3) gauge theory with lattice simulations

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That big old tube and the Matryoshka theory
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That big old tube:
LHC
Geneva
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The Matryoshka theory
Small worlds inside small worlds
Technicolor, take 2

Massless SU(2) Gauge fields
\[ A_1 \quad A_2 \quad A_3 \]

A new strong force
Techni-quarks
Techni-gluons

Massless particle fermion fields
\[ \Psi_e, \Psi_\mu, \ldots \]

Spontaneous chiral symmetry breaking by the strong dynamics

\[ W^+ \quad Z^0 \quad W^- \]
\[ \pi^+ \quad \pi^0 \quad \pi^- \]
\[ m_\pi = 0 \]
\[ \langle \bar{T}T \rangle \neq 0 \]

\[ m_{W,Z} \sim F^{tc}_\pi \]

TC

\[ m_e \sim \langle \bar{T}T \rangle, \ldots \]

ETC

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The virtues of TC/ETC

✓ Dynamical explanation of EWS breaking
✓ Asymptotically free:
  no unnatural fine tuning needed
  no hierarchy problem (breaking scale naturally much smaller than cutoff)
  it is not trivial
✓ ETC provides insights to flavor physics

The problems of TC/ETC

o Flavor changing neutral currents (ETC)
o Precision electroweak measurements (TC)
o Large top quark mass
Precision EW constraints

The $S$ parameter of Peskin & Takeuchi assumes a scaled version of QCD with $N_f$ and $N_c$

$$S_{\text{techni}} \approx 0.25 \frac{N_F}{2} \frac{N_c}{3} \sim \frac{m_{a_1}^2 - m_{\rho}^2}{m_{a_1}^2}$$

$1\,\sigma$ constraints

$$S_{\text{exp}} < S_{\text{techni}}$$
Flavor changing neutral currents

- Fermion masses need new interactions at scale \( M >> \Lambda_{TC} \)

- At scales well below \( M \rightarrow \bar{\Psi}\Psi \bar{T}T \rightarrow m_f \sim \frac{<\bar{T}T>}{M^2} \)

- But also have \( \bar{\Psi}\Psi \bar{\Psi}\Psi \)

- Flavor changing neutral currents: no known suppression mechanism

- Must keep the scale M very high \( \sim 1,000 \text{ TeV} \)

- But then the quark and lepton masses become too small
Not so fast

- Scaling QCD with the number of flavors and colors is not correct.

- QCD with many light flavors is a very different theory than QCD with 2 light flavors

\[ L \frac{\partial}{\partial L} g(L) = \beta(g) g^{g \sim 0} b_0 g^3 + b_1 g^5 + b_2 g^7 + \cdots \]

\[ b_0 = -\frac{1}{(4\pi)^2} \left( \frac{11}{3} N_c - \frac{2}{3} N_f \right), \quad b_1 = -\frac{1}{(4\pi)^4} \left[ \frac{34}{3} N_c^2 - \left( \frac{13}{3} N_c - \frac{1}{N_c} \right) N_f \right]. \]

Perturbative beta function

Walking

Low end of conformal window

\[ 8 \leq N_{f_c} \leq 12 \]

Possible effects of walking and the Lattice

- \( \frac{m_{a1}^2 - m_{\rho}^2}{m_{a1}^2} \sim S \) may be smaller

- Coupling stays strong at larger scales:
  could enhance condensate relative to \( \Lambda_{TC} \)

- Need a true first principles calculation => Need the Lattice.
Something old is new again. Why now?
The Lattice Strong Dynamics collaboration

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First principles simulations

- How do SU($N_c$) gauge theories behave as we increase $N_f$ to the IRFP?
- Does walking produce enhanced condensates?
- Is the S parameter smaller than expected from QCD?
- What does the spectrum look like?
- How much is the mass of the lowest vector?
- Are there any other non-perturbative mechanisms at work?
Higher demands

- Computing cost increases as $N_f^{3/2}$

- The lattice must have cutoff much larger than the CS breaking scale in order to accommodate slower running. Larger lattices are needed as we approach the IRFP.
Work in progress

Simulations of SU(3) with 4 and 6 flavors in the fundamental rep. with DWF on \(16^3 \times 32, \ 32^3 \times 64\)
Large $N_p$
104 racks at LLNL

\[ N_p = 212,992 \text{ CPUs} \]

600 TeraFlops
Large scale simulations at the LLNL BG/L

- Since September we have used more than 50 million core hours
- After first publications we plan to share our lattices with the community
Conclusions
… nature would avail itself of all the opportunities offered by the equations of valid theories. If nuclei could exist in doughnut shapes, I felt, that some of them would exist in such shapes. We physicists should think about where such extreme behavior might occur, and look for it.