BSM on the lattice
Walking/conformal technicolor

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an aggressive presentation of data from

Luigi Del Debbio, Biagio Lucini, Claudio Pica, Antonio Rago
Phys.Rev.D80:074507,2009. arXiv:1004.3197. arXiv:1004.3206

Lattice QCD meets experiment in Flavour Physics
University of Glasgow
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Outline

1. Introduction
2. Hunting for technicolor models on the lattice
3. Lattice results
4. Conclusions

Technicolor

- Higgs sector replaced by a strongly interacting gauge theory (technicolor).
- χSB induces breaking of the electroweak symmetry.
- 3 technipions become the longitudinal modes for the massive $W^{\pm}$ and Z.

Original idea by S. Weinberg and L. Susskind, 1979.

- Rescaled QCD violates the SM precision tests.
- Conformal or walking technicolor. Deform QCD:
  - Many flavours.
  - Techniquarks in different representations of the technicolor group.
- General problems of technicolor:
  - Too many technipions.
  - No mass for the SM fermions.

Extended technicolor

- TC is embedded in an ETC. 4-fermion operators are effectively generated at low energy.

$$\Delta\mathcal{L}_{ETC} = \frac{a}{\Lambda_{ETC}^2}\langle\bar{\Psi}\Psi\rangle_{TC}\bar{\psi}\psi + \frac{b}{\Lambda_{ETC}^2}\langle\bar{\Psi}\Psi\rangle_{TC}\bar{\Psi}\Psi + \frac{c}{\Lambda_{ETC}^2}\bar{\psi}\psi\bar{\psi}\psi$$

  - Masses for SM fermions
  - Masses for extra technipions
  - Flavour changing neutral currents

- Lower bounds on Λ_{ETC} from neutral meson mixing.
  R. Sekhar Chivukula, Elizabeth H. Simmons, arXiv:1005.5727.

$$\begin{array}{ll} K^0 - \overline{K^0} & \Lambda_{ETC} > 1.0 \cdot 10^3 \text{ TeV} \\ D^0 - \overline{D^0} & \Lambda_{ETC} > 1.5 \cdot 10^3 \text{ TeV} \end{array}$$

- Problem of ETC:

$$\frac{a}{\Lambda_{ETC}^2}\langle\bar{\Psi}\Psi\rangle_{TC} \,,\; \frac{b}{\Lambda_{ETC}^2}\langle\bar{\Psi}\Psi\rangle_{TC} \gg \frac{c}{\Lambda_{ETC}^2}$$

Hunting for conformal/walking technicolor models

$SU(3)$ with $N_f = 8, 12, 16$ staggered fundamental fermions ($N_f^{cu} = 16.5$)

A. Deuzeman, M.P. Lombardo, E. Pallante.

- Phase structure of the bare-parameter space.

$N_f = 8$ confining, $N_f = 12$ conformal.

LSD collaboration T. Appelquist, G. T. Fleming, E. T. Neil., R. Brower

- SF running couplig.
- Lattice study of ChPT beyond QCD.

$N_f = 8$ confining, $N_f = 12$ conformal.

Z. Fodor, K. Holland, J. Kuti, D. Nogradi, C. Schroeder.

- Mesonic spectrum.
- Finite volume effects and ϵ-regime.
- WL running coupling.

$N_f = 8$ confining, $N_f = 12$ confining?, $N_f = 16$ conformal.

X. Jin, R. D. Mawhinney.

- Mesonic spectrum.
- Quark potential.
- Phase structure.

$N_f = 8$ confining, $N_f = 12$ controversial.

A. Hasenfratz.

- Montecarlo Renormalization Group.

$N_f = 8$ confining, $N_f = 12$ conformal.

Hunting for conformal/walking technicolor models

$SU(3)$ with $N_f = 2$ Wilson 2S fermions ($N_f^{cu} = 3.3$)

T. DeGrand, O. Machtey, Y. Shamir, B. Svetitsky.

- Finite-temperature phases.
- SF descrete beta function.

Conformal.

D.K. Sinclair, J.B. Kogut.

- Finite-temperature phases.

Confining.

Hunting for conformal/walking technicolor models

$SU(2)$ with $N_f = 2$ Wilson adjoint fermions ($N_f^{cu} = 2.75$)

A. Hietanen , T. Karavirta, A. Mykkanen, J. Rantaharju, K. Rummukainen, K. Tuominen.

- Spectrum.
- SF running coupling.

Conformal.

S. Catterall, J. Giedt, F. Sannino, J. Schneible.

- Mesonic spectrum.
- Volume scaling with the bare fermion mass.

Conformal.

L. Del Debbio, B. Lucini, AP, C. Pica, A. Rago

- Mesonic and gluonic spectrum.
- Finite-size scaling.

Conformal.

F. Bursa, L. Del Debbio, L. Kegaan, C. Pica, T. Pickup

- SF running coupling.

Conformal.

Minimal Walking Techincolor

- $SU(2)$ technicolor group
- 2 techniquarks in the adjoint representation ot the technicolor group
- Spontaneous χSB pattern

$$SU(4) \to SO(4)$$

- 9 technipions = 3 longitudinal modes for W/Z + 6 extra light states

Minimal Walking Techincolor

- Spontaneous χSB is an essential ingredient for technicolor. However in our simulations the pion is quite heavy ($M_{PS} > 5F_{PS}$).

  MWT does not break χS. As it is, it cannot be used for technicolor.

  Conformal technicolor: a deformation of the theory along a relevant direction will induce χSB.

  More work for model builders.

- Some measured physical quantities are quite independent of the techniquark mass.

  Assume that they will not be modified when MWT is opportunely deformed.

  Disclaimer: the main goal of this talk is not to give precise predictions, but rather to discuss what kind of quantities can be measured with lattice techniques.

Technicolor scale

Chiral effective Lagrangian for technipions $S = e^{2i\pi/F_{PS}} \in SU(N_f)$ (at the LO).

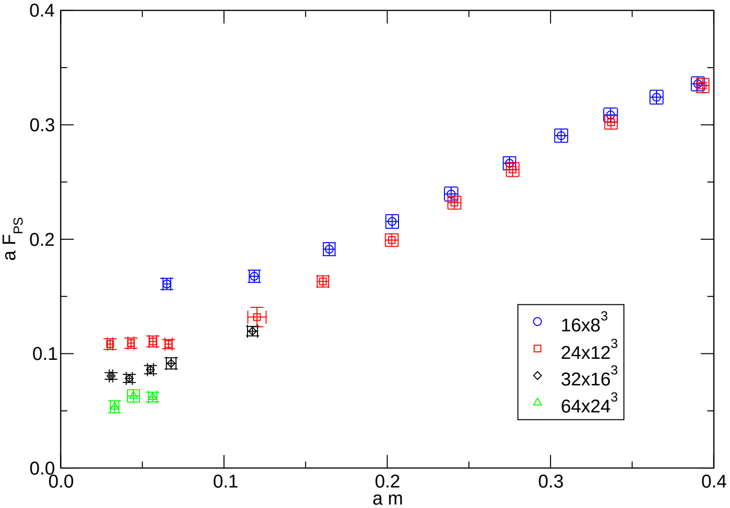
$$\mathcal{L} = \mathcal{L}_{SM} + \frac{F_{PS}^2}{4} \mathrm{tr}\, |\partial S + i(gWS - g'SB)|^2$$

Mass for W/Z:

$$M_W = \frac{v}{2} g \quad \Rightarrow \quad M_W = \frac{F_{PS}}{2} g$$

$$F_{PS} = 246 \text{ GeV}$$

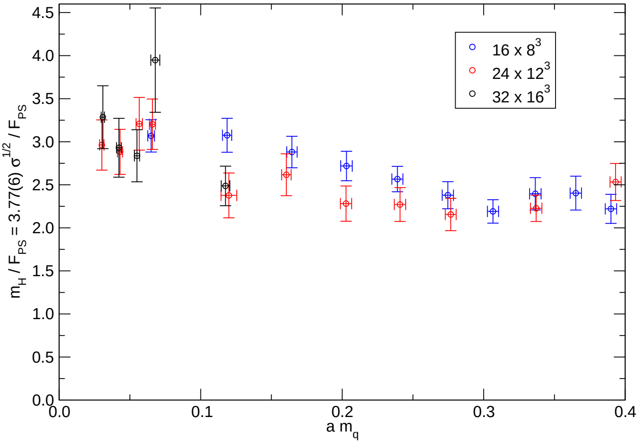
Technicolor scale



F_{PS} is used to set the value of the lattice spacing.

Higgs mass

The Higgs is replaced by the lightest isosinglet scalar meson (analog of f_0/σ resonance).



$$m_H \simeq 3.0(5) F_{PS} \simeq 615 \;-\; 861 \text{ GeV} \qquad (H \to ZZ)$$

S-parameter

- Deform the W/Z/γ propagator

$$\Pi_{W^3B}(q) = \Pi^{SM}_{W^3B}(q) + \Pi^{Higgs}_{W^3B}(q) + \frac{g'}{g}\hat{S}q^2 + \dots$$

  - 1-loop propagation of W/Z, quarks, leptons
  - 1-loop propagation of the Higgs
  - new physics

- Fit the experimental data using:
  • the 1-loop SM formulae
  • the deformation due to the $\hat{S}$ parameters
  • the assumption $m_H < 1$ TeV
  and you get $\hat{S} < 3 \cdot 10^{-3}$

S-parameter

- QCD/Technicolor

$$\hat{S} = \frac{\pi\alpha}{\sin^2\theta_W}\sum_n\left(\frac{F^2_{V,n}}{M^2_{V,n}} - \frac{F^2_{A,n}}{M^2_{A,n}}\right)$$

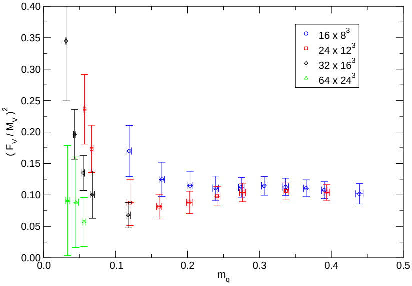
- QCD (ρ dominance)

$$\hat{S} \simeq \frac{\pi\alpha}{\sin^2\theta_W}\left(\frac{F^2_{\rho}}{M^2_{\rho}} - \frac{F^2_{a_1}}{M^2_{a_1}}\right) \simeq 0.095(0.023 - 0.003) \simeq 2\cdot 10^{-3}$$

M. E. Peskin and T. Takeuchi, Phys. Rev. D **46**, 381 (1992).

S-parameter

- Is the V dominance valid for MWT?



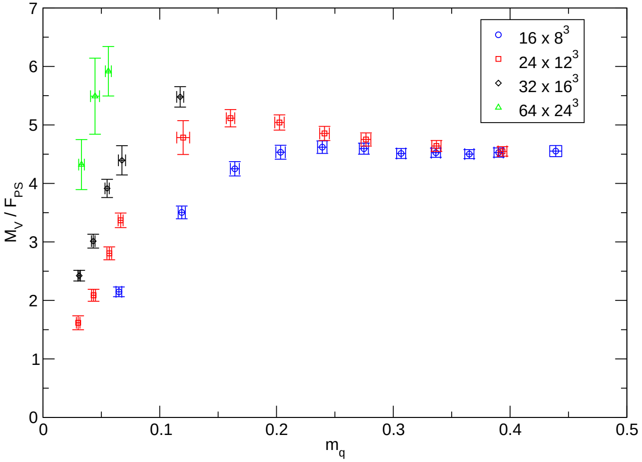
$\hat{S} \simeq 10^{-2}$

- MWT seems to be very different from QCD (less χSB, cancellation between V and A states).

$$\hat{S} = \frac{\pi\alpha}{\sin^2\theta_W} \sum_n \left(\frac{F^2_{V,n}}{M^2_{V,n}} - \frac{F^2_{A,n}}{M^2_{A,n}} \right)$$

- The S-parameter must be computed from first principles. For QCD...
P. A. Boyle, L. Del Debbio, J. Wennekers and J. M. Zanotti, Phys. Rev. D **81**, 014504 (2010). [arXiv:0909.4931 [hep-lat]].

Techirho



$$M_V \simeq 6(1)F_{PS} \simeq 1.2 \ - \ 1.7 \ \mathrm{TeV} \qquad (\rho \to \ell\ell \ , \ \rho \to WW)$$

Conclusions

- Technicolor provides a mechanism for electroweak symmetry breaking, which is alternative to the Higgs boson with Mexican-hat potential.
- In order to satisfy the constraints from the electroweak precision tests, the technicolor theory must be very different from QCD. A large variety of theories is being scrutinised.
- Due to their strongly coupled nature, technicolor models can be investigated by lattice simulations (but also by gauge/gravity correspondence...)
- MWT can be used as building block for a conformal technicolor model (so don't trust the results in these slides too much!).
- What we measured and we will measure in the future:
  - Higgs mass
  - Technirho mass
  - S-parameter
  - Chiral condensate