Strong Dynamics at the LHC?

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I will focus on pedestrian (4D) new strong dynamics (ETC, Walking TC, Top Color, LSTC ...)

- Implications of Early LHC results
- Some Suggested Signatures?
Implications of early LHC Results

- Excess in the 125 GeV region: Is it the SM higgs?
  - Both ATLAS and CMS see $5\sigma$ excess
  - spin and parity: $0^+$ or $0^-$ (or $2^+$)? Measure angular correlations. First Critical Issue
    - $ZZ^* \rightarrow 4$ leptons; $WW^* \rightarrow$ lepton + $E_T$ (missing) + 2jets angular correlations.
    - LHC experiments likely will determine by end of this run 2012
  - If not $0^+$, then not the Higgs and likely new strong dynamics responsible for EWSB
    - This is difficult because a $0^-$ state couples gauge bosons only through loops.
    - Highly suppressed vector boson fusion and associated production contributions to production of a pseudoscalar.
    - Rate for $WW^*$ and $ZZ^*$ decays of the 125 state would be highly suppressed.
  - How close to SM values are the $WW/ZZ$ couplings? Second Critical Issue

ATLAS: $m_H$ (peak) = 126.5 GeV/c²

CMS: $m_H$ (peak) = 125.3 GeV/c²
Implications of early LHC Results

- Measure couplings to distinguish SM Higgs from BSM scalars

\[ \Gamma(h(125)) = 4.03 \text{ MeV} \]

- Within large present errors, ATLAS and CMS results consistent with SM Higgs couplings. **Third Critical Issue**

- But might still be consistent with a fine tuned pseudoscalar interpretation. [E.E., K. Lane, A. Martin]
Strong Dynamics Possibilities

- Perturbative
  - SM, 2HDM (SUSY)

- Higgs
  - more scalars
  - composite higgs, dilaton
  - technipions

- Strong Dynamics
  - ETC, WalkingTC, LSTC, Composite Higgs, ...

- Many spin zero states

- SM
  - non SM
couplings
No evidence for new physics beyond the Standard Model (BSM) to date:

- ATLAS limits

\[
\text{CMS limits}
\]

However there must be new physics!!! WHY? All the usual reasons. Incomplete and theoretically problematic (unnatural ala 'tHooft).
Signals for Strong Dynamics

- New $V, A$ states: (Detailed studies in the LSTC model)
  [E. E., K. Lane, A. Martin, E. Pilon arXiv:1206.0186]
  - $\rho_T, a_T \rightarrow W \pi_T \rightarrow l \nu j j$ - Signal at CDF (not seen at D0), LHC studies ongoing

CDF

Excess stable w.r.t. changes in selection, despite change in big shape at low mass

Eichten, Lane, Martin

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Particle level, no detector simulation

D0 limits to be compared with CDF $\sigma(pp \rightarrow WX) = 3.0 \pm 0.7$ pb
difference w.r.t. D0 $2.5\sigma$

Figure 7: The CMS $M_{jj}$ distributions for 4.7 fb$^{-1}$ of $W \rightarrow \mu\nu\nu$ plus two or three jets data at $\sqrt{s} = 7$ TeV before (top left) and after (top right) the background subtraction summarized in the text; from Ref. [43]. On the bottom left is our $M_{jj}$ distribution for the $\rho_T, a_T \rightarrow W\pi_T \rightarrow l\nu jj$ signal and backgrounds at the LHC for 5 fb$^{-1}$. Augmented ATLAS-like cuts as described in the text were used. The open red histograms are the $\rho_T$ and $a_T$ signals times 10.
Signals for Strong Dynamics

- $\rho \tau, a_T \rightarrow Z \pi \pi \rightarrow l^+ l^- j j$ - Best channel for LHC

- $\rho \tau, a_T \rightarrow W Z \rightarrow l l l j j$ - Unavoidable channel with possibly small branching rate

• Other states expected but model dependent: New fermions and technipions
Summary

• Early results from the LHC are encouraging for a strong dynamical explanation (ala technicolor) of Electroweak Symmetry Breaking:
  - No SUSY (yet)
  - No signs of Extra Dimensions (yet)

• New Strong Dynamics must explain:
  - $S$ parameter -> not like QCD
  - quark masses and limits on flavor changing neutral currents -> Extended TC, walking TC, ...
  - top quark mass -> can not treat TC in isolation, ETC, walkingTC, TC2, ...

• No complete model. Look at possible low energy signals
  - CDF $Wjj$ signal -> $Zjj$ and improved cuts
  - LHC tests -> $Zjj$, dileptons, $W/Z/\gamma + X$, $WW$, $WZ$, ...

• Very exciting times - the LHC will provide a clearer picture of the new physics within the next year. Observation (or limits) on new pseudoscalar particles [color octets, triplets (leptoquarks) and color singlets] and spin one particles [$\rho_T, \eta_T, \omega_T, A_T, ...$] will provide valuable clues to possible new strong dynamics.
Brief History
A New Strong Dynamics

- Technicolor provides a natural solution to the origin of EWSB without elementary scalars BUT:
  - Precision measurements of $S$ and $T$ parameters rule out QCD-like model.
  - One technifermion doublet $\Delta S = N_{TC}/(6\pi)$

$$S = 4\pi \int \frac{dm^2}{m^4} \left[ \sigma^3_V(m^2) - \sigma^3_A(m^2) \right]^{\text{new}}$$

- New strong dynamics not QCD-like

- No masses for quarks and leptons generated
  - There are no couplings between technifermions and ordinary fermions.
  - Effective Yukawa couplings are all zero.

- Requires Extended Technicolor (ETC) (Dimopoulos and Susskind (1979); Eichten and Lane (1980))
  - Contains fermions and technifermions in same representation of ETC gauge interactions
  - When the gauge group $G_{ETC}$ breaks to $G_{TC}$, some ETC gauge bosons acquire masses: $\sim g_{ETC} \Lambda_{ETC}$
ETC Interactions

- Form of the effective lagrangian below ETC scale:
  - preserves $SU_L(2) \times U(1)$ EW symmetry
  - when EWSB occurs these terms generates masses for technipions; masses for quarks and leptons; and possible FCNC in the quark sector.

$$\frac{g_{ETC}^2}{M_{ETC}^2} \left[ C_1(T_L^\dagger \sigma^\mu T_L)(T_R^\dagger \sigma^\mu T_R) + C_2(T_L^\dagger \sigma^\mu q_L)(q_R^\dagger \sigma^\mu T_R) + C_3(q_L^\dagger \sigma^\mu q_L)(q_R^\dagger \sigma^\mu q_R) \right]$$

technipion masses  quark and lepton masses and mixings  FCNC

$$F_{EW}^2 M_{\pi T}^2 \approx \frac{g_{ETC}^2 \langle T \bar{T} T \bar{T} \rangle_{ETC}}{M_{ETC}^2} \approx \frac{16\pi^2 F_{EW}^2}{\Lambda_{ETC}^2}$$

- Basic conflict between mass generation and suppression of FCNC's

$$m_{q,\ell}(M_{ETC}) \approx \frac{g_{ETC}^2 \langle T \bar{T} T \bar{T} \rangle_{ETC}}{M_{ETC}^2} \approx \frac{4\pi F_{EW}^3}{\Lambda_{ETC}^2}$$

but limits on FCNC's in K system require $\Lambda_{ETC} > 10^3$ TeV

- What about the top quark? Separation of ETC and TC scales questionable

[2]  [3]
Walking Technicolor and More

- One possible solution for the first two problems is the idea of walking TC:
  - If there is a large anomalous dimension $\gamma_m$ the issue [2] is reduced.

$$\langle \bar{T}T \rangle_{ETC} = \exp \left( \int_{\Lambda_{TC}}^{M_{ETC}} \frac{d\mu}{\mu} \gamma_m(\mu) \right) \langle \bar{T}T \rangle_{TC} \quad \text{if} \quad \gamma_m \approx 1$$

$$\langle \bar{T}T \rangle_{ETC} \approx \frac{M_{ETC}}{\Lambda_{TC}} \langle \bar{T}T \rangle_{TC} \quad m_q, m_l \sim \frac{g_{ETC}^2}{M_{ETC}^2} (\frac{\lambda_{ETC}}{\Lambda_{TC}})$$

- This can happen if theory near fixed point (coupling runs slowly --> walks) or nearly conformal theory.

This lends itself naturally to multiscale models

- In these cases the issue [1] may also be resolved

- Much lattice effort now focused on evaluating this option.

- In top color models [Hill(1991;1995)] only a part of the top mass is generated by ETC interactions. This may resolve issue [3].

- At present there is no complete model that resolves all these issues. We will have to look to experiment to give us clues to how to build a complete dynamical EWBS model.