Top physics and strong electroweak symmetry breaking

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CERN TH

May 2009

Outline

Why strong EWSB?

What has strong EWSB got to do with the top?

Hints from flavour physics

Hints from EW precision tests

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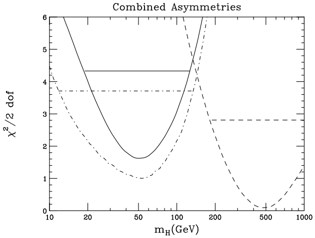
Why strong EWSB?

Why *not* weak EWSB?

Tension in the data



- solid: leptonic asymmetries, $m_h \sim 50\text{GeV}$
- dash: hadronic asymmetries, $m_h \sim 500\text{GeV}$
- dot-dash: non-asymmetry measurements, $m_h \sim 50\text{GeV}$
- combined, $m_h \sim 85\text{GeV}$, $CL(14.1, 7) = 0.05$
- *cf.* $m_h \gtrsim 114\text{GeV}$

Chanowitz, 0806.0890

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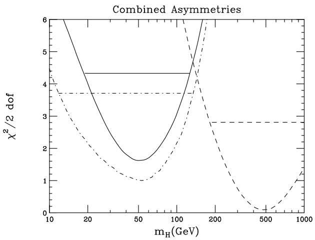

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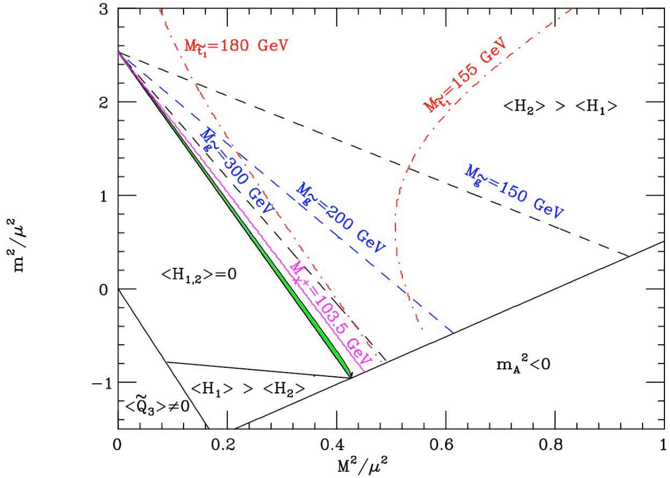
What about the hierarchy?

If it's SUSY, why haven't we seen any superpartners yet?



Giudice and Rattazzi, 0606105

Why strong EWSB?

Why strong EWSB?

- A natural hierarchy, *cf* QCD
- Calculability via AdS/CFT

Why *not* strong EWSB?

Why *not* strong EWSB?

- Electroweak precision tests
- Flavour changing neutral currents

WW scattering I

The obvious place to look for strong EWSB is *WW* scattering . . .

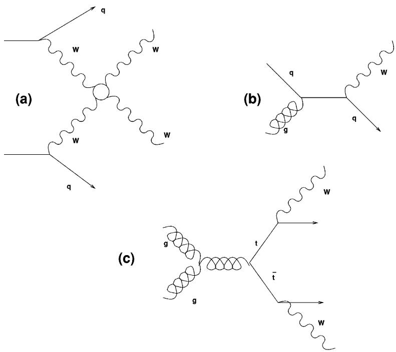
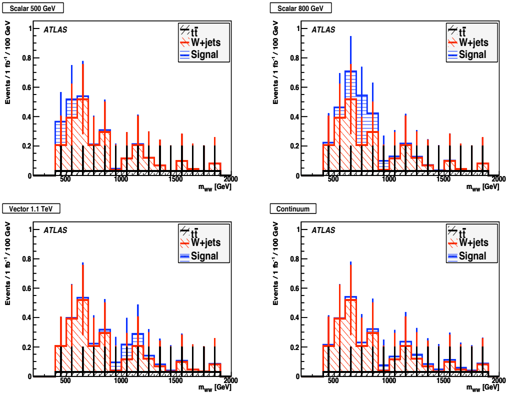


FIG. 10. Typical diagrams for signal and background processes: (a) signal; (b) W+jets; (c) $t\bar{t}$.

Butterworth, Cox & Forshaw, 0201098

Bagger et al., 9504426

WW scattering II



ATLAS, 0901.0512

- Can LHC see it, if it's there?
- Is it there? $4\pi v \sim 3$ TeV

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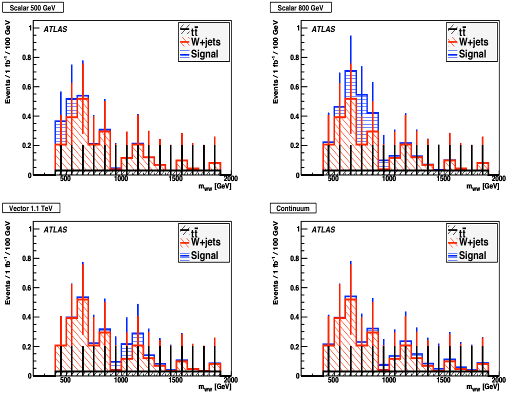

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What has strong EWSB got to do with the top?

The EWSB/top connection I

- Of SM couplings, y_t is largest
- Can we say anything stronger?
- Recall the ills of strong EWSB: FCNC and EWPT

Strong EWSB and FCNC

$\Lambda_{IR} \ll E \ll \Lambda_{UV} \implies$ The language of hierarchy is CFT

Natural hierarchy $\implies d[\mathscr{O}] \gtrsim 4$

Two ways to get fermion masses:

- Bi-linear:
$$\mathscr{L} = y f_L \mathscr{O}_H f_R, \quad \mathscr{O}_H \sim (1,2)_{\frac{1}{2}}$$
- Linear:
$$\mathscr{L} = y_L f_L \mathscr{O}_R + y_R f_R \mathscr{O}_L + m \mathscr{O}_L \mathscr{O}_R, \quad \mathscr{O}_R \sim (3,2)_{\frac{1}{6}}$$

D. B. Kaplan, 1991

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Bi-linear fermion masses

$$\mathscr{L} = \frac{f_L \mathscr{O}_H f_R}{\Lambda_F^{d-1}} + \frac{f_L f_R f_L f_R}{\Lambda_F^2}$$

$$\text{FCNC} \implies \Lambda_F \gtrsim 10^{3-4}\, TeV \implies d \lesssim 1.2 - 1.3$$

- RS: $d \to \infty$
- TC: $d \sim 3$
- WTC: $d \sim 2$
- SM: $d \sim 1$ (but then $d[\mathscr{O}_H^\dagger \mathscr{O}_H] \sim 2$)

Strassler, 0309122

Luty & Okui, 0409274

Rattazzi, Rychkov & Vichi, 0807.0004

Rychkov & Vichi, 0905.2211

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Linear fermion masses

$$\mathscr{L} = y_L f_L \mathscr{O}_R + y_R f_R \mathscr{O}_L + m \mathscr{O}_{L,R} \mathscr{O}_{L,R}$$

- $\mathscr{O}_{L,R}$ can be relevant
- Flavour can be decoupled
- RS-GIM

Gherghetta & Pomarol, 0003129

Huber & Shafi, 0010195

Agashe, Perez & Soni, 0406101

Agashe, Perez & Soni, 0408134

Agashe, Contino & Pomarol, 0412089

Compositeness I

$$\mathscr{L} = \mathscr{L}_{el}(g_{el}) + \mathscr{L}_{comp}(g_*) + \mathscr{L}_{mix}$$

- $1 \lesssim g_* \lesssim 4\pi$
- $|SM\rangle = \cos\phi|el\rangle + \sin\phi|comp\rangle$
- $|heavy\rangle = -\sin\phi|el\rangle + \cos\phi|comp\rangle$

Contino, Kramer, Son & Sundrum, 0612180

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- Higgs: $\sin\phi_h = 1$,
- Top Yukawa: $y_t \sim g_* \sin\phi_{q_L} \sin\phi_{t_R}$
- q_L or t_R fully composite

Pomarol & Serra, 0806.3247

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Compositeness III

Effects of higher-d operators

$$\mathscr{L} = (\bar{t}_R t_R)^2 + (\bar{q}_L q_L)^2 + H^\dagger \sigma^i DH \, \bar{q}_L \sigma^i q_L$$

- $t\bar{t} \to t\bar{t}, b\bar{b}$ scattering
- anomalous $Wt_L\bar{b}_L, \ldots$ couplings

Eichten, Lane & Peskin , 1983

Georgi, Kaplan, Morin & Schenk, 9410307

Giudice, Grojean, Rattazzi, Pomarol, 0703164

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Compositeness IV

Are there (narrow) resonances?

- Couple most strongly to t, b (and W_L, Z_L)
- EWPT and fine-tuning $\Longrightarrow$ light fermionic resonances
- What else do EWPT imply?

Compositeness IV

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Strong EWSB and EWPT:

Effective Lagrangian at M_W:

$$\mathscr{L} = \Pi_{+-} W^+ W^- + \Pi_{33} W^3 W^3 + \Pi_{3Y} W^3 B + \Pi_{YY} BB$$

- $\Pi(q^2) = \Pi(0) + q^2 \Pi'(0) + \ldots$
- $\Pi_{ab} \sim \langle J_a J_b \rangle$
- $\Pi_{+-} - \Pi_{33} \sim T$
- $\Pi'_{3B} \sim S$

Peskin & Takeuchi, 1990; 1992

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Strong EWSB and EWPT: T

$$\frac{SU(2)_L \times U(1)_Y}{U(1)_Q} \longrightarrow \frac{SU(2)_L \times SU(2)_R}{SU(2)_V} = \frac{SO(4)}{SO(3)}$$

Sikivie, Susskind, Voloshin & Zakharov, 1980

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Strong EWSB and EWPT: S

Second problem is S

- S contains a $\mathbf{1}$ of $SU(2)_V$
- $SU(2)_V$ doesn't protect S
- Nothing protects S
- $S > 0 \implies$ no cancellation
- Make S small somehow?

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There is a symmetry for S: $SU(2)_L$

- $\implies S \sim v^2/\Lambda^2$
- $v \ll \Lambda$?
- Put back Higgs: $SO(4)/SO(3) \to SO(5)/SO(4)$
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Strong EWSB and EWPT: $Z \to b\bar{b}$

$Z \to b_L \bar{b}_L$ coupling fits SM within 0.25 *per cent*

$$\frac{g}{\cos\theta_W}(Q_L^3 - Q\sin^2\theta_W)$$

- $P_{LR} : SU(2)_L \leftrightarrow SU(2)_R$
- P_{LR} and $U(1)_V \implies \delta Q_L^3 = 0$
- $b_L \in \mathbf{4}$ of $O(4)$

Agashe, Contino, Da Rold & Pomarol, 0605341

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Back to top physics

Fermionic Resonances (Top Partners) come in

- $q_L \in \mathbf{4} \ldots$ of $O(4)$
- $t_R \in \mathbf{1} \ldots$ of $O(4)$

Fixed spectrum of electric charges

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Fixed spectrum of electric charges

- Strong EWSB/Top physics connected via FCNC/EWPT
- Search for compositeness
- Search for resonances . . .