23 APRIL 2012

JAVI: HIGGS A NGB [COMPOSITE]

↑ not necessarily, but req. by naturalness

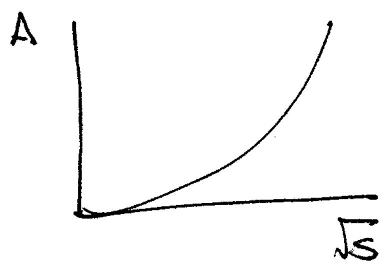
$M^2_{W/Z} \neq 0$ $\quad (M^2 \sim g^2 v^2)$

↑

2 TRANSV + LONGITUDINAL

⇓

$W_L W_L \to W_L W_L$ POORLY BEHAVED @ Hi E.



$A \sim \frac{s}{v^2} \leftarrow$ 

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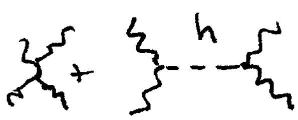
for $\sqrt{s} \simeq 2$ TeV, $A \gtrsim 1$ } VIOLATES UNITARITY

THE HIGGS: 

$\sim \frac{m_h^2}{s}$

↑ IF THE COUPLINGS ARE CORRECT

⇒ Standard Model

SM: $V(H) = m_H^2 |H|^2 + \lambda |H|^4 \rightarrow \langle H \rangle = v$

from EFT PERSPECTIVE: $m_H^2 \sim \epsilon \Lambda_{UV}^2$ w/ $\varepsilon \sim \mathcal{O}(1)$

$\varepsilon \sim +1$: NO EWSB ✗

$\varepsilon \sim -1$: MEXICAN HAT, BUT $\langle H \rangle \sim \Lambda_{UV}$ ✗

<u>HIERARCHY PROBLEM</u>

<u>NEED</u>: $\varepsilon \sim -10^{-3} \Rightarrow \langle H \rangle = v = 246$ GeV

why is ε so small?

<u>SOLUTIONS</u>: SUSY, <u>STRONG DYNAMICS</u>

UNKNOWN DYNAMICS GENERATES W_L, Z_L + (?)

~~<u>OLD DAYS</u>: thing which unitarizes $W_L W_L$ scattering~~

can be anything: eg ρ-like VECTOR MESON

NOW: WE NEED A <u>HIGGS</u> (for 125 GeV state)

[TeV] [strong dynamics] → ρ

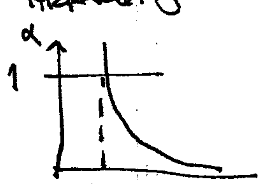
↓

W_L, Z_L, (h)

↑

today's talk

SOLVES HIERARCHY



Λ_{strong}

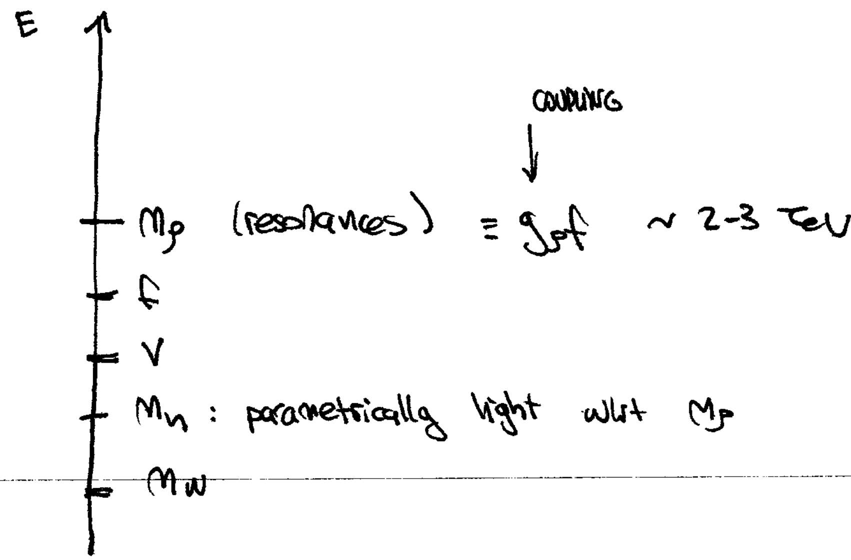
ANALOG TO RS.

Remark: strong dynamics & XD are *not* necessarily complimentary pics.

THE HIGGS IN STRONG DYNAMICS

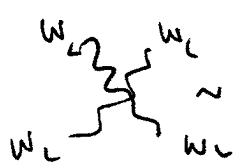
↑ LIGHT: NEED PROTECTION MECHANISM → GOLDSTONE'S THM

SHIFT SYMMETRY: $h \to h + \alpha$; eg MASS TERM FORBIDDEN



GOLDSTONES: $U = e^{i\pi/f}$ ← characteristic scale

recall:



$\sim \frac{\partial^2}{v^2}$ ← v HERE IS CHARAC. SCALE

NOW FOR US: STRONG SECTOR GENERATES $\frac{H}{f} \leftarrow W_L, Z_L, h$

$$V(H) \Rightarrow \langle H \rangle = v < f$$

MUCH BETTER THAN TECHNICOLOR
SM OBSERVABLES CORRECTED
@ ORDER v^2/f^2

[TECHNICOLOR: $v = f$
SM: $v \ll f$]

TECHNICOLOR WAS ALREADY IN BAD SHAPE BEFORE LHC:
<u>S-PARAMETER</u>

↳ $W^3_{\mu\nu} \sim\sim\sim \bullet \sim\sim\sim B_{\mu\nu}$ KIN. MIXING

OR $\gamma - Z$ KIN MIXING

$$\hat{S} \sim \frac{g^2}{g_\rho^2} \frac{v^2}{f^2}$$ ← 1 IN TECHNICOLOR

$$\hat{S}_{exp} < 2 \times 10^{-3}$$

→ TECHNI RES. $g_\rho \sim 4\pi$ → strongly coupled
incalculable.

for us: ⇒ $\boxed{v^2/f^2 \sim 0.1 - 0.3}$
this is our tuning.

ALL OBSERVABLES ARE MODIFIED BY $\mathcal{O}(v^2/f^2)$

→ IN PARTICULAR: HIGGS COUPLINGS

SO: PREDICTIONS for HIGGS AS NGB [recent work)

$$\mathcal{L}_{eff} = \frac{1}{2}(\partial h)^2 + \frac{M_W^2}{2} WW\left[1 + 2a\frac{h}{v} + b\frac{h^2}{v^2}\right]$$

$$- m_i \bar{\psi}_{L_i}\left(1 + c\frac{h}{v}\right)\psi_{R_i}$$

$$+ \frac{1}{2}m_h^2 h^2 + d_3\frac{1}{6}\left(\frac{3m_h^2}{v}\right)h^3 + d_4\frac{1}{24}\left(\frac{3m_h^2}{v^2}\right)h^4$$

$$+ c_g\frac{\alpha_s}{4\pi}\frac{h}{v}G_{\mu\nu}^2 + c_\gamma\frac{\alpha}{4\pi}\frac{h}{v}F_{\mu\nu}^2$$

<u>SM</u>: $a = b = c = d_3 = d_4 = 1 \qquad c_g = c_\gamma = 0$

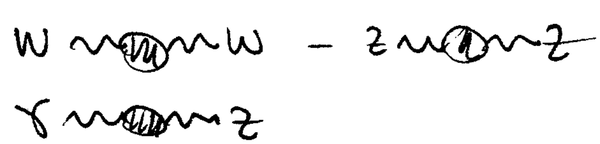
<u>NGB</u>: $a, b, c, d_3, d_4 \sim \mathcal{O}(1) \qquad c_g = c_\gamma \sim \frac{\alpha_i}{4\pi}$

<u>the game</u>: fit these parameters to LHC

<u>EXPERIMENT</u>: a HAS BEEN MEASURED INDIRECTLY

$\hat{T}$

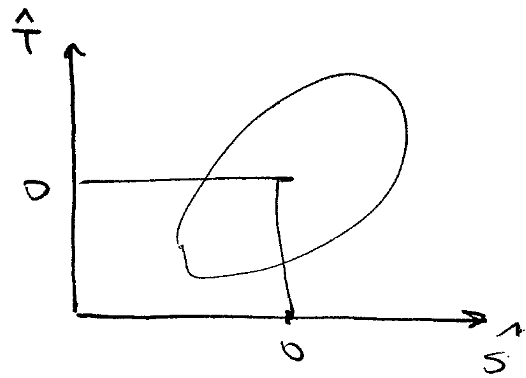
$\hat{S}$



MASS DIFFERENCE

KIN. MIXING

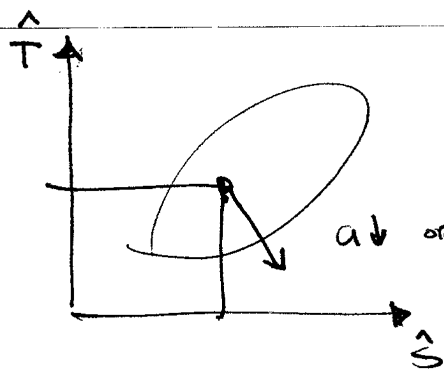
LEP:



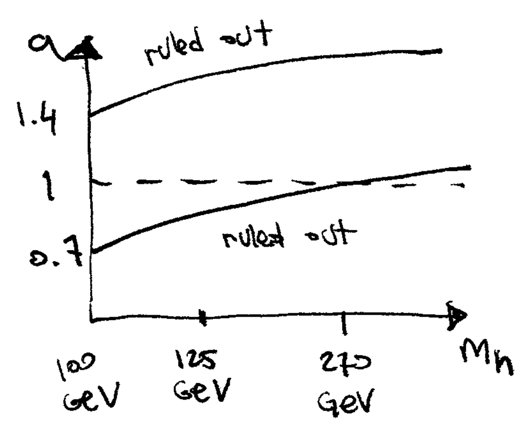
$\hat{S}$ & $\hat{T}$ ARE CORRECTED BY HIGGS LOOPS:

$$\Delta\hat{T}, \Delta\hat{S}\big|_h \sim \frac{\#}{16\pi^2}(1-a^2)\log\left(\frac{\Lambda^2}{m_h^2}\right)$$

TRICK: SM ⇒ $a = 1$



$a\downarrow$ or $m_h\uparrow$ TAKES YOU OUT OF ELLIPSE



PREDICTIONS FROM $SO(5)/SO(4)$ COMPOSITE HIGGS MODEL

$$a = \sqrt{1 - \frac{v^2}{f^2}} \qquad b = 1 - 2\frac{v^2}{f^2}$$ } kind of model independent

(IV) $c = d_3 = \sqrt{1 - v^2/f^2}$

(V) $c = d_3 = \dfrac{1 - 2v^2/f^2}{\sqrt{1 - v^2/f^2}}$

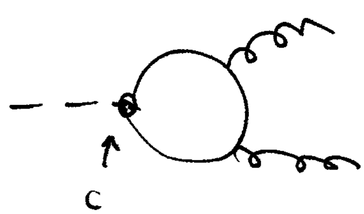
(but also top loop)

MEASURE :

$$\frac{\Gamma(h\to VV)}{\Gamma_{SM}(h\to VV)} = a^2 \sim \frac{\Gamma(h\to \gamma\gamma)}{\Gamma_{SM}(h\to\gamma\gamma)}$$

$$\frac{\Gamma(h\to gg)}{\Gamma_{SM}(h\to gg)} = \frac{\Gamma(h\to t\bar{t})}{\Gamma_{SM}(h\to t\bar{t})} = c_t^2$$

$\neq$ when $c_g \neq 0$



$$\frac{\Gamma(h\to f\bar{f})}{\Gamma_{SM}(h\to f\bar{f})} = c_f^2$$

OBSERVE: $a < 1$

$h \to \gamma\gamma$ REDUCED (but can push up by reducing $h \to b\bar{b}$)

$c < 1$

$h \to t\bar{t}$ REDUCED "now it's a game"

[Dean's Q: COMPOSITE 2HDM w/ NGB HIGGSES?
yes - Jaui has done the theory
but not the pheno]

REMARK ON BREAKING PATTERNS :

$SO(5)/SO(4)$: GIVES W_L, Z_L, h
(minimal composite higgs)

HIGGS AS A NGB

$G \to H$ NGB $= G/H$

REQUIREMENTS :
1. $G \supset SU(2)_L \times U(1)_Y$
2. $H \supset SO(4) \cong SU(2) \times SU(2)$

AVOIDS TREE-LEVEL CORRECTIONS TO $\hat{T}$

HIGGS VEV: $SU(2)_L \times SU(2)_R \xrightarrow{\langle H \rangle} SU(2) \cong SO(3)$

$H = \begin{pmatrix} \cdot \\ \cdot \\ \cdot \\ \cdot \end{pmatrix} \Big\} SO(4) \nearrow$

$\langle H \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ v \end{pmatrix} \Big\}$ ROTATION OF $\rightarrow$ $W = \begin{pmatrix} W^1 \\ W^2 \\ W^3 \end{pmatrix} \Big\} \nearrow$

3) $G/H \supset (\underline{2}, \underline{2})$ of $SU(2)_L \times SU(2)_R$

quantum #'s of Higgs

(WE HAVE $SU(2)_L \times SU(2)_R$ IN SM:

WRITE HIGGS AS 4-VECTOR ϕ

$$V = m_h^2 \, \vec{\phi} \cdot \vec{\phi} + \lambda (\vec{\phi} \cdot \vec{\phi})^2$$)

THE SMALLEST COSETS THAT CAN HAVE HIGGS AS NGB

	G	H	N_G	rep[$SU(2)_L \times SU(2)_R$]
worked out	SO(5)	SO(4)	4	(2, 2) ← HIGGS
being worked on	SO(6)	SO(5)	5	(1,1) + (2,2) — extra singlet (easy to hide)
only theory, no analysis	SO(6)	SO(4)×SO(2)	8	2× (2,2) 2HDM
	SO(7)	G_2	7	(1,3) + (2,2) — ↑ easier to hide

WHICH of THESE CAN WE GET LIKE QCD?

↑ sym of techniquarks ie breaking by fermions

~~MINIMUM WHICH CONTAINS A HIGGS~~

techniquark w/ 4 flavors: ($(SU(4)_F$)

$$\tilde{\psi}_\alpha = \begin{pmatrix} y \\ x \\ x \\ x \end{pmatrix}_\alpha$$

↑ strongly coupled → HAS TO BE Sp(N)

techniq - techniq BOUND STATE ↘

↓ cf QCD WHICH IS q-antiq BOUND STATE

$$\langle \tilde{\psi}_\alpha \tilde{\psi}_\beta \rangle \neq 0 \Rightarrow SU(4) \to Sp(4)$$

$\langle \tilde{\psi}_\alpha \tilde{\psi}_\beta \rangle$ ~ $\delta_{\alpha\beta}$ [FLAVOR MATRIX]

$SU(4) \cong SO(6) \to Sp(4) \cong SO(5)$

↓ minimal model in terms of techniquarks

RECENT PAPER: COMPOSITE SCALAR DM ↙ η

→ $SO(6)/SO(5)$ MODEL whose singlet is DM

↳ COUPLINGS: $\left(\frac{W_L \partial W_L \, \eta \partial \eta}{f^2} \right)$

PARITY REQ TWO η's.

BUT NEED TO WORRY THAT STRONG SECTOR RESPECTING THE PARITY

↳ $O(6)/O(5)$

RESPECTS PARITY

EXPLICIT BREAKING ↓

COUPLING TO FERMIONS $\bar{\psi}_L H \psi_R \frac{\eta^2}{f^2}$ → controls pheno

ANOMALIES? $\eta \, G_{\mu\nu} \tilde{G}^{\mu\nu}$

↳ like π^0: $\pi \gamma\gamma$, "strong cp problem" can be done, (can make it zero)

← SCALES w/ E SO CAN HOPE for SIGNAL @ 14 TeV

THESE KINDS OF COUPLINGS PROBE COMPOSITENESS of η.

Cuidado:

the point is that once you embed your nice model into strong dynamics (as in susy) there are PREDICTIONS for how the model must behave.

↳ analogous to susy ⇒ 2HDM.