A leading candidate:

<u>The Higgs</u> $\qquad \phi$ scalar, 2 of $SU(2)$

$$\mathcal{L}_\phi = -|D_\mu\phi|^2 - \frac{\lambda}{4}\left(\phi^\dagger\phi - \frac{v^2}{2}\right)^2$$

$$\Rightarrow \quad |\langle\phi\rangle|^2 = \frac{v^2}{2} \qquad SU(2) \text{ rot.} \rightsquigarrow \langle\phi\rangle = \begin{pmatrix} v/\sqrt{2} \\ 0 \end{pmatrix}$$

need $Q = 0 = T_3 + Y \Rightarrow Y = -1/2$

$\therefore$ breaks $SU(2)\times U(1) \longrightarrow U(1)$

<u>relate to chiral lag.:</u>

let $\tilde{\phi} = \epsilon\phi^*$ ... also 2

and $\hat{\Sigma} = (\phi, \tilde{\phi})$.

Transforms as:

$$\hat{\Sigma} \longrightarrow \underbrace{U_L}_{\text{obvious}} \hat{\Sigma} \underbrace{e^{-i\alpha\tau_3/2}}_{\text{ex (easy)}}$$

note $\operatorname{Tr}\hat{\Sigma}^\dagger\hat{\Sigma} = 2|\phi|^2$

in general $\quad \phi(x) = \underbrace{\Sigma(x)}_{SU(2)} \begin{pmatrix} (v+h(x))/\sqrt{2} \\ 0 \end{pmatrix}$

$$\Rightarrow \qquad \hat{\Sigma} = \frac{v + h(x)}{\sqrt{2}}\, \Sigma$$

$$-\,|D\phi|^2 = -\tfrac{1}{2}\,\mathrm{Tr}(D\hat{\Sigma})^2 = -\frac{v^2}{4}\,\mathrm{Tr}(D\Sigma)^2 - \frac{(\partial h)^2}{2} + \cdots$$

(ex)

$$\therefore \qquad f = v$$

$$M_W = \frac{g_2 v}{2}\,, \quad \rho = 1$$

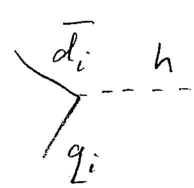
<u>Fermion masses</u> $\qquad \phi = (2, -1/2)$

$q\bar{d}\ :\ Y = 1/2 \quad \Rightarrow$

$\lambda_i^d\, \epsilon_{\alpha\beta}\, \phi^\alpha q_i^\beta \bar{d}_i$ allowed ... <u>Yukawa couplings</u>

$\langle\phi\rangle \rightsquigarrow \quad m_i^d = \lambda_i^d v/\sqrt{2}$

<u>also</u>



likewise e_i's ; $\quad m_i^e = \lambda_i^e v/\sqrt{2}$

ups? $\quad q\bar{u}$: $Y = -1/2$

can get as $\tilde{\phi} = \epsilon \phi^*$

alternately, $\tilde{\phi} \neq \epsilon\phi^*$ (SUSY, ...)

$$\lambda_i^u \tilde{\phi} q_i \bar{u}_i \quad \rightsquigarrow \quad m_i^u = \lambda_i^u v/\sqrt{2}$$

<u>notes on symmetries:</u>

a) w/out Higgs, also have <u>chiral</u> symmetry

$$q_i \to U_{ij} q_j \qquad [U(3)]^5$$

$$\bar{u}_i, \bar{d}_i \to U_{ij} \; \bar{u}_j, \bar{d}_j$$

l_i, $\bar{e}_i$ also.

Higgs explicitly breaks

2 Higgs restores $U(1)$ (classical) : $\quad \phi \to e^{-2i\alpha}\phi$, $\quad \tilde{\phi} \to e^{-2i\alpha}\tilde{\phi}$

($\leftrightarrow$ SUSY ...)

b) custodial $\hat{\Sigma} \to \hat{\Sigma}\, U_R$

$\uparrow$

$(\phi\, \tilde{\phi})$

- not present if Higgs $\neq 2$ (& "accidental")
- calculable violation $\propto \lambda_i^u - \lambda_i^d$, g_1

eg. if equal,

$$\lambda_i \, q_i \, \hat{\Sigma} \begin{pmatrix} \bar{u}_i \\ \bar{d}_i \end{pmatrix} = \text{invt.}$$

rotates by U_R – see p 2.19.

Couplings renormalizable

(Renormalizability w/ SSB : 't Hooft - Veltman ⇝ Nobel)

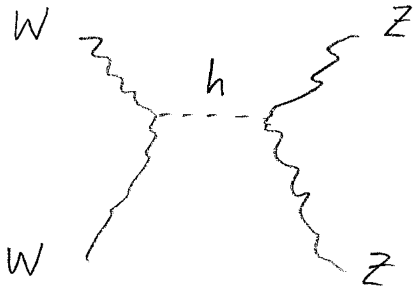
... minimal renormalizable theory
1 new degree of freedom.

mass :
$$V(\phi) = \frac{\lambda}{4}\left(\frac{v^2 + 2hv + h^2}{2} - \frac{v^2}{2} \right)^2$$

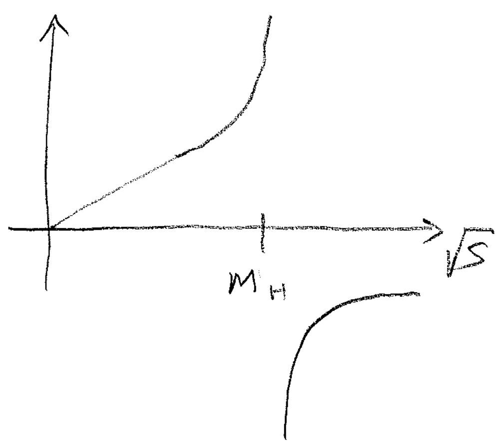
$$= \frac{\lambda}{4}(vh)^2 + \dots \Longrightarrow$$

$$m_h = \frac{\sqrt{\lambda}\, v}{\sqrt{2}}$$

Unitarity $\quad \mathcal{M}(W_L W_L \to Z_L Z_L) \supset$



$$\mathcal{M}_{tot} \underset{HE}{\simeq} \frac{g_2^2 s}{4M_W^2} \frac{m_H^2}{m_H^2 - s} \qquad \text{(HW)}$$



(tree level only ...)

$\therefore$ h cuts of growth of Goldstone boson piece.

$m_H \ll 1$ TeV $\leftrightarrow$ weak

$m_H \gtrsim 1$ TeV $\leftrightarrow$ strong

$m_H \gtrsim 114$ GeV LEP 2 direct (hints ?)

loop corrns (precise EW - later ?):

$m_H \lesssim 199$ GeV

(see Altarelli & other refs.)

<u>The Standard Model</u>

$$\mathcal{L}_{SM} = \mathcal{L}_{sym} + \mathcal{L}_\phi$$

gains: unitarity, renormalizability

problems: rest listed before, and ...

<u>naturalness</u>
- $V(\phi)$ renormalized
- expect $\delta m_h^2 \sim \delta(\lambda v^2) \sim \Lambda^2_{\text{New Phys}}$

unless fine tuning. (why not M^2_{Planck} ??)

not as bad as ~~unitarity~~, nonrenorm

but explanation needed. (environmental selection ??)

this "hierarchy problem" suggests:

<u>new physics nearby</u>

Also $\quad m_h \gtrsim 180$ GeV $\Rightarrow$ Landau pole $(\lambda \to \infty)$

$m_h \lesssim 130$ GeV $\Rightarrow$ instability : $\lambda \to\ < 0$

— 1/30/07