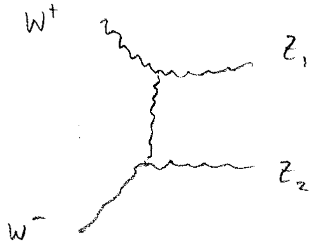
$SU(2) \times U(1)$ breaking
(or: why the LHC)

- Approx sym; Explicit breaking? ie $\mathcal{L}_{break}$

Might suspect issue w/ W_L, Z_L. (again, recalling their propagator)

eg $W_L^+ W_L^- \to Z_L Z_L$

$\mathcal{M} =$ 

$+ \; 1 \leftrightarrow 2 \; + \text{contact} \;\; \underset{E\to\infty}{\simeq} \;\; \dfrac{g_2^2 \, s}{4 \rho M_W^2}$ (ex)

$$w/ \quad \rho = \left(\frac{M_W}{M_Z \cos \theta_W} \right)^2$$

unitarity violating

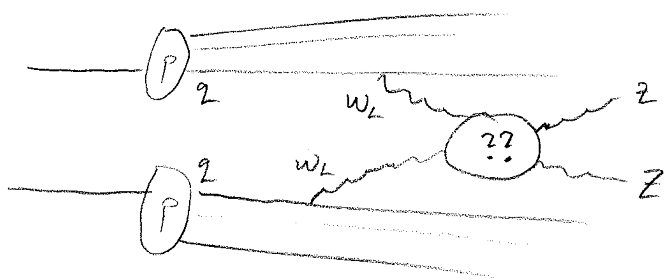
$\mathcal{M} \simeq 1$ at $\sqrt{s} = E_{cm} \sim \dfrac{2 M_W}{g_2} \sim 1 \text{ TeV}$

More careful: violate @ $\simeq 1.8$ TeV

Compare the argument for the Z ...

$\Rightarrow$ New physics. the central LHC question

e.g.



Another clue : $\rho = 1$ to $< 10^{-3}$

Parametrize ignorance : if 4D EFT

$$\mathcal{L}_{unk} = \mathcal{L}(\phi^A) + A^I_\mu j^{I\mu} - A^I A^J \mathcal{O}^{IJ} + \cdots$$

some fields

A^a, B

break $SU(2) \times U(1)$

also

$$+ \quad q_i \mathcal{O}_i \bar{u}_i + q_i \tilde{\mathcal{O}}_i \bar{d}_i + l_i \hat{\mathcal{O}}_i \bar{e}_i + \mathcal{L}_\nu$$

($\mathcal{O}_i, \tilde{\mathcal{O}}_i, \hat{\mathcal{O}}_i$ also break $SU(2) \times U(1)$).

$\rightarrow$ LHC

Vector boson masses $\longleftrightarrow$ SSB

(in a sense, always true)

Consider $\quad \Sigma(x) \in SU(2)$

such that $\quad \Sigma \longrightarrow U_L \Sigma e^{-i\alpha \tau^3/2}$ under $SU(2) \times U(1)$

(compare QCD chiral lagrangian) $\quad \tau^3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

Gauge invt. lagrangian :

$$\mathcal{L}_\Sigma = \mathcal{L}_{GB} - \frac{f^2}{4} \mathrm{Tr}\left[(D_\mu \Sigma)^\dagger (D^\mu \Sigma) \right] \qquad (1)$$

w/ $D_\mu \Sigma = \partial_\mu \Sigma - i g_2 A_\mu \Sigma + i g_1 B_\mu \Sigma \frac{\tau_3}{2}$.

Can gauge: $\Sigma = 1$ "unitary gauge"

Then

$$\mathcal{L}_\Sigma = \mathcal{L}_{GB} - \frac{f^2}{4}\left[g_2^2 W^+ W^- + (g_1^2 + g_2^2) \frac{Z^2}{2} \right]$$

(ex)

$\equiv \mathcal{L}_{EW}$, w/ $M_W = \frac{g_2 f}{2}$

$\frac{M_W}{M_Z} = \cos\theta_W$ ie $\rho = 1$.

$\rho \neq 1 \longleftrightarrow + \gamma_1 f^2 [\mathrm{Tr}(T V_\mu)]^2$ (2)

w/ $T = \Sigma \tau_3 \Sigma^+$ $V_\mu = (D_\mu \Sigma) \Sigma^+$

so can <u>always</u> rewrite as gauge thy w/ field Σ.

Note: (1) invt under $\Sigma \to \Sigma U_R$, (2) not.

custodial SU(2) $\longleftrightarrow$ $\rho = 1$.

(more precisely: true at kinetic level, couplings could spoil)

As in QCD 1) $\Sigma = e^{\frac{2i}{f}\pi^a T^a}$

Goldstone boson mode

broken generators

2) $\mathcal{L}_\Sigma$ = EFT, nonrenormalizable
(indeed, same phys as massive W, Z !)

what completes? at what scale? Λ_{SB}

3) $f \simeq 250\,\text{GeV}$; New phys by $\sim 4\pi f \sim 3$ TeV ✓

— 1/25/07

Equivalence thm (see Peskin & Schroeder ; Chanowitz 2004)

$$\mathcal{M}(W_L W_L \to Z_L Z_L) = \mathcal{M}(w\,w \to z\,z) + \mathcal{O}\left(\frac{M_W}{E}\right) \quad \text{for } E \gg M_W$$

Goldstone bosos

$$= \frac{s}{\rho f^2}$$

(cf earlier)

cut off at $\Lambda_{SB} \ll 1.5$ TeV $\Longleftrightarrow$ weak
$\Lambda_{SB} \sim 1.5$ TeV $\Longleftrightarrow$ strong (near unitary limit)