Anomalies, parities, (missing energy?) in little higgs models

"T parity in little higgs models"

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Incomplete list of references

Composite models:

Kaplan, Georgi (84), Kaplan, Georgi, Dimopoulos (84), Georgi, Kaplan, Galison (84), Dugan, Georgi Kaplan (85)

Arkani-Hamed, Cohen, Georgi (01) Arkani-Hamed, Cohen, Katz, Kaplan, Schmaltz (03)

Nelson, Gregoire, Wacker (02)

Contino, Nomura, Pomaral (03) Agashe, Contino, Sundrum (2005)

Arkani-Hamed, Cohen, Katz, Nelson (02)

Low, Skiba, Smith (02)

Pierce, Perelstein, Peskin (04)

Han, Logan, Wang (06)

T parity:

Cheng, Low (03,04)

Birkedal-Hansen, Wacker (04) Birkedal-Hansen, Noble, Perelstein, Spray (06) Carena, Hubisz, Perelstein, Verdier (06)

KK parity:

Cheng, Feng, Matchev (02)

Servant, Tait (02) Bertone, Hooper, Silk (05)

talk based on C.T. Hill and R.J Hill, hep-ph/0701044, and to appear

Outline

- little higgs versus non-little higgs
- parities
- anomalies
- missing energy ?
- into the UV

obvious stuff

- standard model description of EWSB simple, minimal
- of the options on the table, many represent physics *never seen before*
    - fundamental scalar
    - supersymmetry
    - extra space dimension
    - ... ?
- there is something that we *have* seen before - composite scalars, bound states of strongly-interacting fermions (QCD)

three components of a weakly coupled “little” higgs sector

1 mechanism for a scalar “higgs” field to leak down from a technicolor/condensate scale

$$\delta m_H^2 = 0 \times g^2 \Lambda_{strong}^2 + \ldots$$

2 mechanism for electroweak-symmetric vacuum to be destabilized

$$m_H^2 < 0$$

3 mechanism for higgs VEV to be stabilized at electroweak scale

$$v_{weak}/\Lambda_{strong} << 1$$

step 1 mechanism for a scalar "higgs" field to leak down from a technicolor/condensate scale

- **easy** - in fact some effort required for it not to happen

in general, have NGB's that are left massless by the strong interactions

simple example: $U = \exp(i\tilde{\pi})\,, \quad \tilde{\pi} = \begin{pmatrix} \pi + \eta/\sqrt{3} & K \\ K^\dagger & -2\eta/\sqrt{3} \end{pmatrix}$

$SU(3)_L$ x $SU(3)_R$ / $SU(3)_V$, gauge two SU(2)xU(1) groups

$$A_{L_\mu} = \begin{pmatrix} W_{L\mu} + B_{L\mu}/\sqrt{3} & 0 \\ 0 & -2B_{L\mu}/\sqrt{3} \end{pmatrix} \qquad A_{R_\mu} = \begin{pmatrix} W_{R\mu} + B_{R\mu}/\sqrt{3} & 0 \\ 0 & -2B_{R\mu}/\sqrt{3} \end{pmatrix}$$

Radiative mass corrections

consider a collection of gauged generators:

$$\Lambda = \underbrace{\Lambda_V}_{\text{unbroken}} + \underbrace{\Lambda_A}_{\text{broken}}$$

one-loop contribution to scalar masses:

$$m^2_{ab} = \underbrace{M^2}_{\text{positive}} \sum_{\Lambda} \underbrace{\mathrm{Tr}\left\{[\Lambda_V, [\Lambda_V, t^a_A]] t^b_A \right\}}_{\text{positive and nonzero if NBG charged}} - \mathrm{Tr}\left\{[\Lambda_A, [\Lambda_A, t^a_A]] t^b_A \right\}$$

example: as long as things are gauged only on left, or only on right, m^2=0 through one loop:

$$\Lambda = \begin{pmatrix} t^a & \cdot \\ \cdot & 0 \end{pmatrix} = \underbrace{\frac{1}{2}\begin{pmatrix} t^a & \cdot \\ \cdot & -t^*_a \end{pmatrix}}_{\Lambda_V} + \underbrace{\frac{1}{2}\begin{pmatrix} t^a & \cdot \\ \cdot & t^*_a \end{pmatrix}}_{\Lambda_A}$$

example: SM hypercharge leaves pions massless

<u>step 2</u> mechanism for electroweak-symmetric vacuum to be destabilized

- **not difficult** - odds are about 50/50

step 1 leaves mass-squared "on the edge"

other ingredients, e.g. SM and mirror fermions tip it in one direction or the other

example: top-quark sector

$$\chi_L = \begin{pmatrix} u_L \\ d_L \\ U_L \end{pmatrix}, U_R\,, u_R \qquad \Delta\mathcal{L} = -\lambda_1 F(0,0,\bar{u}_R)e^{i\tilde{\pi}}\chi_L - \lambda_2 F\bar{U}_R U_L + h.c.$$

$$\delta m_H^2 \sim -\lambda_t^2 \log\frac{\Lambda^2}{m_T^2}$$

step 3 mechanism for higgs VEV to be stabilized at electroweak scale

- **not as easy** - but at least a few in-principle examples

step 2 destabilizes EW-symmetric vacuum

need to stabilize it at $v \neq 0$ but $v \ll \Lambda_{strong}/4\pi$

example: integrate out scalars that receive large radiative corrections ⇒ higgs potential

$$m_\phi \sim g\Lambda_{strong} \gg v_{weak}$$

parities

can define an internal "T" parity

[V,V]~V, [V,A]~A, [A,A]~V

V→+V

unbroken "vector" generators

A→-A

broken "axial" generators

- scalars are odd
- massless vectors are even

$$g_L \frac{1-\gamma_5}{2} \lambda^a W_L^a + g_R \frac{1+\gamma_5}{2} \lambda^a W_R^a$$

$$= \quad \frac{\sqrt{2} g_L g_R}{\sqrt{g_L^2 + g_R^2}} \lambda^a W^a + \left(\frac{\sqrt{g_L^2 + g_R^2}}{\sqrt{2}} \gamma_5 \lambda^a + \frac{g_L^2 - g_R^2}{\sqrt{2}\sqrt{g_L^2 + g_R^2}} \lambda^a \right) W'^a$$

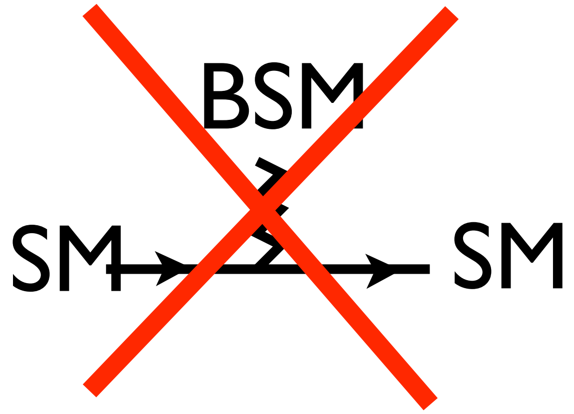
massless

massive

- if couplings are equal, massive vectors are odd

why an exact parity might be nice

- forbids large nonstandard EW effects
- organizing principle for models



what it might imply

- missing energy signature ?
- dark matter candidate ?

effective actions

write down the most general effective action for NGB's

$$\Gamma \sim \int d^4x \,\mathrm{Tr}\Big[|D_\mu U|^2 + c_1 |D_\mu U|^4 + c_2 D_\mu U D_\nu U^\dagger D_\mu U D_\nu U^\dagger + \dots \Big]$$

need to include all operators - in particular, the "topological term"

Nothing subtle, just another way of building a local, four-dimensional, SU(3)-invariant action.

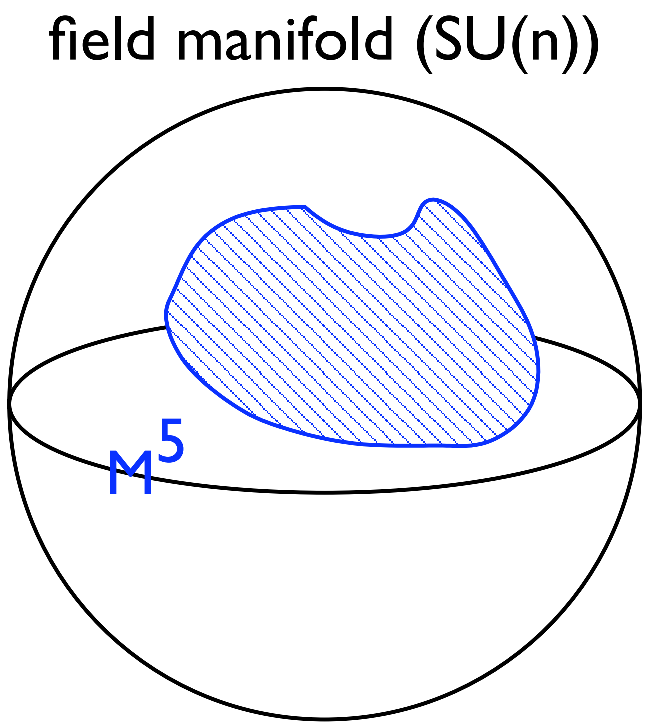
Topological, or Wess-Zumino-Witten terms

Consider SU(n)xSU(n)/SU(n):

$$\Gamma'(U) = \text{number} \times \text{“area bounded by the image of spacetime on } SU(N)\text{”}$$

$$\Gamma'(U) = -\frac{iN_c}{240\pi^2}\int_{M^5} \mathrm{Tr}(\alpha^5)$$

$$\alpha = (dU)\,U^\dagger$$



- construction allowed by $\pi_4(SU(n))=0$, $\pi_5(SU(n))=Z$
- quantization condition necessary for consistency

T parity violation by anomalies

given a parity: we can define it, but is it respected by the dynamics ?

Consider the "ordinary" action:

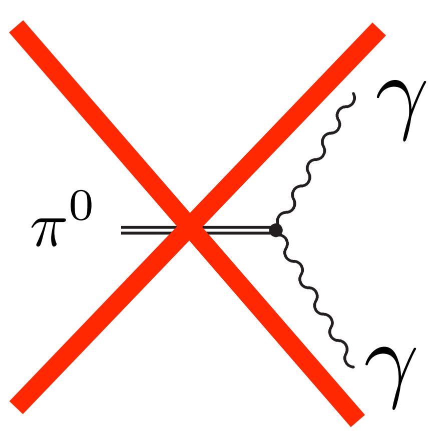
$$\Gamma \sim \int d^4x \,\mathrm{Tr}\left[|D_\mu U|^2 + c_1 |D_\mu U|^4 + c_2 D_\mu U D_\nu U^\dagger D_\mu U D_\nu U^\dagger + \ldots \right]$$

even under space-parity

$(t,x) \to (t,-x)$, $\pi \to \pi$, $(V^0, V) \to (V^0, -V)$, $(A^0, A) \to (A^0, -A)$

even under NGB parity ("T parity")

$(t,x) \to (t,x)$, $\pi \to -\pi$, $(V^0, V) \to +(V^0, V)$, $(A^0, A) \to -(A^0, A)$



- in QCD coupled to electromagnetism, π^0 is stable (lightest T-odd particle)

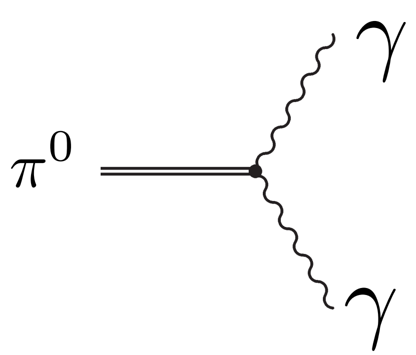
The topological action:

$$\Gamma'(U) = \int d^4x\, \epsilon^{\mu\nu\rho\sigma} \mathrm{Tr}(\tilde{\pi}\partial_\mu\tilde{\pi}\partial_\nu\tilde{\pi}\partial_\rho\tilde{\pi}\partial_\sigma\tilde{\pi} + \dots)$$

odd under space-parity

odd under NGB parity

- this is the well-known resolution for how a chiral Lagrangian can correctly describe low-energy QCD



theory: $\Gamma(\pi^0 \to \gamma\gamma) = \frac{N_c\alpha^2}{96\pi^2}\frac{m_\pi^3}{f_\pi^2} = N_c \times 2.4\,\mathrm{eV}$

experiment: $7.7 \pm 0.6\,\mathrm{eV}$

T parity from an internal symmetry

[V,V]~V, [V,A]~A, [A,A]~V

V→+V unbroken "vector" generators

A→-A broken "axial" generators

- as in QCD, topological interaction breaks this internal parity

T parity from "identical" sectors

$$\delta\left[\Gamma'(\Phi_1) \pm \Gamma'(\Phi_2)\right] \sim \int \epsilon(dA)^2 \pm \epsilon(dA)^2$$

- if sectors are really identical, then they give identical (not cancelling) anomalies

In both cases, the decays of "lightest T odd particle" must proceed through the topological interaction ⇒ distinct signatures !

spectator sector

to accomplish step (1) above, need to gauge broken U(1) current

- unless integer coefficient of WZW is zero, theory is incomplete

- need mechanism of anomaly cancellation

note: no assumption that the UV theory is a theory of fermions - just some theory that exhibits a certain symmetry breaking pattern

decays of T-odd gauge bosons

Return to simple example. To take care of anomalies, two copies of $SU(3)_L \times SU(3)_R / SU(3)_V$

- a 2HDM:

$$\Gamma_{WZW} \propto \frac{-N_c s_W g^3}{\pi^2} \int d^4x \, \epsilon^{\mu\nu\rho\sigma} (v_1^2 - v_2^2) B'_\mu Z_\nu \partial_\rho Z_\sigma + \dots$$

$$\Gamma(B' \to ZZ) \propto \left(\frac{N_c (1 - \tan^2\beta)}{\pi^2} \right)^2 \frac{\alpha^3 m_Z^2}{m_{B'}} + \dots$$

$$\approx 10^{-8}\,\mathrm{GeV} \left(\frac{\mathrm{N_c}}{3} \right)^2 \left(\frac{500\,\mathrm{GeV}}{\mathrm{m'_B}} \right)$$

Similar results in general models, e.g. SU(5)/SO(5), SU(6)/Sp(6)

Summary

- is electroweak symmetry broken by fermion condensation ? weakly coupled composite higgs an important case to investigate
    - can look a lot like a SM higgs
- even without mention of fermions, need to worry about anomalies in a little higgs model
- T parity generally violated
    - hard to find dark matter candidate or missing energy signal in gauge/higgs sector of composite models
- topological interactions offer exciting probe of UV completion