The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2326-12

School on Strongly Coupled Physics Beyond the Standard Model

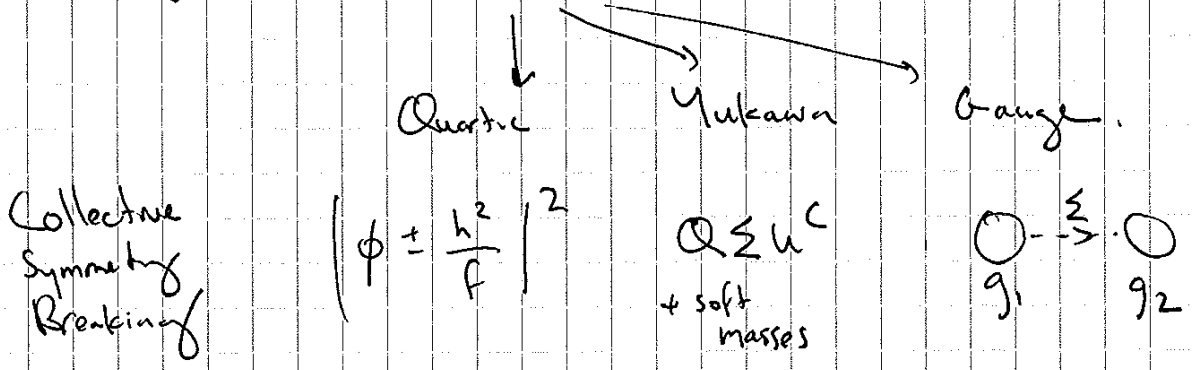
16 - 24 January 2012

Little Higgs Models - Lecture 3

J. Thaler
MIT
U.S.A.

Lecture 3 : Little Technicolor & Gauge Boson Partners

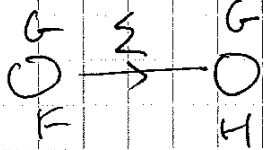
Last time: LH



These are basic features of LH. Yukawa & Gauge structure shared by composite models.

Today: Interesting possibilities for gauge partner structures. Generic & Quasi-Model independent.

$F \subset G/H \quad \approx \Rightarrow$

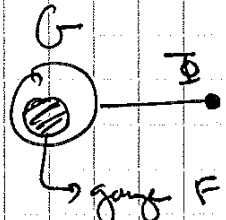


Same low energy physics, with very different UV structures.

Simplest way to generate gauge partners.

G/H contains Higgs

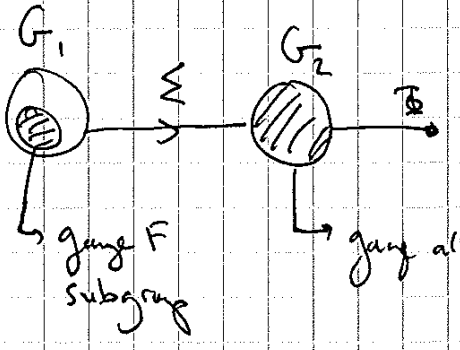
gauge $F \subset G$, usually generates quadratic divergence in Higgs potential



$\langle \Phi \rangle \Rightarrow G/H$

A fool-proof way to get gauge partners?

Need to make G a "better" symmetry.



Why does this work? Take $\langle \Phi \rangle = 0$, $\langle \Sigma \rangle = F$

Massless mode:

$$\frac{1}{g_F^2} = \frac{1}{g_1^2} + \frac{1}{g_2^2}$$

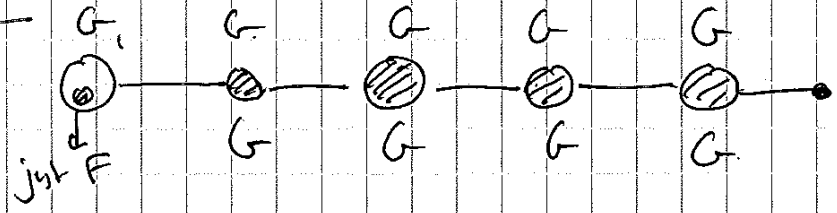
Massive modes:

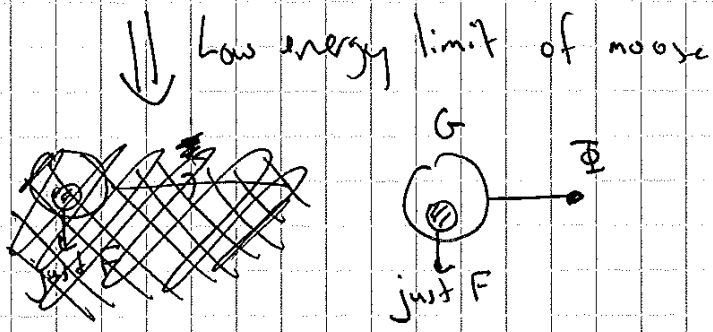
In F: $m_F^2 = (g_1^2 + g_2^2) F^2$

In G/F: $m_{F'}^2 = g_2^2 F^2$

So in $F \to \infty$ limit, recover original theory!

In fact can repeat this trick to build an extra dimension!

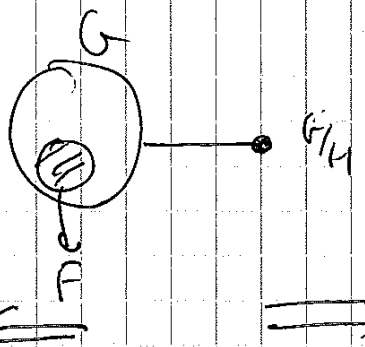




This is a deconstructed version of collective symmetry breaking!

If any $g \to 0$, no low energy gauge coupling, thus, no $\Delta m^2 \sim g^2 \Lambda^2$ possible.

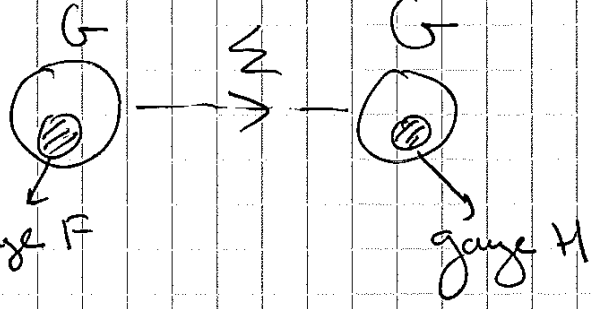
Trivial way to add gauge partners (in full representation of G) leaving low energy physics essentially unchanged.



easy to extend gauge groups this direction

Can you extend this way??

"Little Technicolor"



Remarkable statement!

$$\frac{F \subset G}{H} \Longrightarrow \frac{F \times H \subset G \times G}{G}$$

Same low energy physics, (exact in $g_H \to \infty$)

What was a preserved global Symmetry ... $\Longrightarrow$ ... becomes a spontaneously broken gauge symmetry.

(Known in some circles as "Hidden Local Symmetry")

Some Plausibility Checks.

$G/H \Longrightarrow$ # goldstones = dim G − dim H

$G \times G/G \Longrightarrow$ # uneaten goldstones = dim G − dim H ✓

with H gauged

eaten goldstones = dim H

dim G total goldstone modes

Same low energy d.o.f counting.

Implications for LH models.

Crazy symmetry breaking patterns ...

$SU(5)/SO(5)$ Littlest Higgs

$SU(6)/Sp(6)$ Antisymmetric Condensate LH

... are just versions of QCD-like dynamics!

$SU(5)_L \times SU(5)_R / SU(5)_V$ with SO(5) gauge bosons.

$SU(6)_L \times SU(6)_R / SU(6)_V$ with Sp(6) gauge bosons.

From a practical point of view

G/H requires full CCWZ formalism

$G \times G/G$ is a simple NLSM.

Let's derive "Little Technicolor"

(Can add F as well, but just muddies the derivation)

$$\mathcal{L} = -\frac{1}{2g_H^2} H_{\mu\nu}^2 + f^2 \mathrm{tr} |D_\mu \Sigma|^2$$

$$\Sigma = e^{i\pi^a T^a} \qquad D_\mu \Sigma = \partial_\mu \Sigma - i \Sigma H_\mu .$$

$$\langle \Sigma \rangle = 1$$

We want to integrate out H_μ and derive low energy spectrum.

$$\xi^\dagger \partial_\mu \xi \equiv \underset{\uparrow}{V_\mu} + \underset{\uparrow}{\beta_\mu}$$

in H in G/H

(These are in fact the objects that appear in CCWZ formulation, but here they come from just a NLΣM)

$$\mathcal{L} \supset f^2 \, \mathrm{tr} \left| V_\mu + \beta_\mu - i H_\mu \right|^2$$

$$= f^2 \, \mathrm{tr} \left| V_\mu - i H_\mu \right|^2 + f^2 \, \mathrm{tr} \left| \beta_\mu \right|^2$$

(no cross terms b/c $\mathrm{tr}(T^a T^b) = \frac{1}{2}\delta^{ab}$)

Trivial to integrate out H_μ.

$$\mathcal{L}_{\text{eff}} = f^2 \, \mathrm{tr} \, \beta_\mu \beta_\mu^\dagger$$

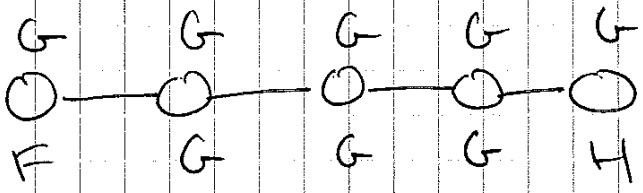
with $\beta_\mu^a = 2 \, \mathrm{tr}\left(\xi^\dagger \partial_\mu \xi \, X^a \right)$

(X^a: broken generator in G/H)

This *is* CCWZ formalism.

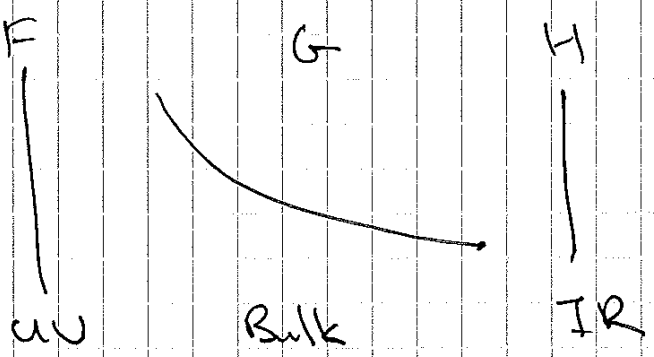
So in low energy limit

$F \subset G/H \Longrightarrow$



This is a lattice version of extra dimension!

(AdS/CFT via RS)

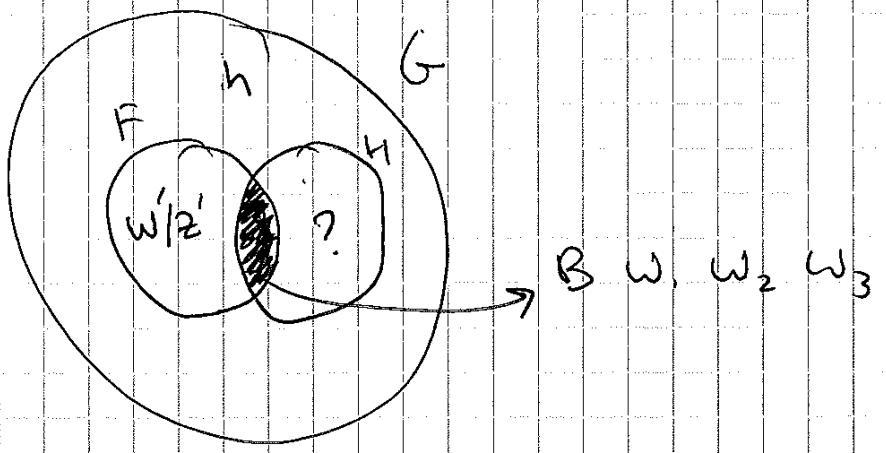


which is dual to $F \subset G/H$!

All perfectly consistent.

Summary

What is composite Higgs?



h = Higgs as PNGB

$\gamma/W/Z$ = Gauge Bosons

W'/Z' = Gauge Partners

$(P_{TC}=)?$ = Additional potential gauge partners.

Different names for massive spin-1 fields. Offers considerable flexibility in UV interpretations

What is Little Higgs?

Composite Higgs with $v_{EW} << f_\pi$

Collective Quartic Coupling $|\phi \pm h^3/f|^2$

- 1HDM $\Longrightarrow$ triplet scalar
- 2HDM $\Longrightarrow$ triplet or singlet scalar
- Beware of dangerous singlets

Collective Yukawa Coupling $Q \Sigma u^c$

- Maintain G symmetry when coupling to fermions.
- Break only via soft masses.

Collective Gauge Coupling

- Many options for gauge partners.
- Extra dimensions / Little Techn.color are nice templates.

LHC?

- Heavy Resonances: W'/Z'
- Top Partners: QCD pair produce t', b'
- Elementary-ish Higgs Sectors: $m_H \leq 125$ GeV ?!