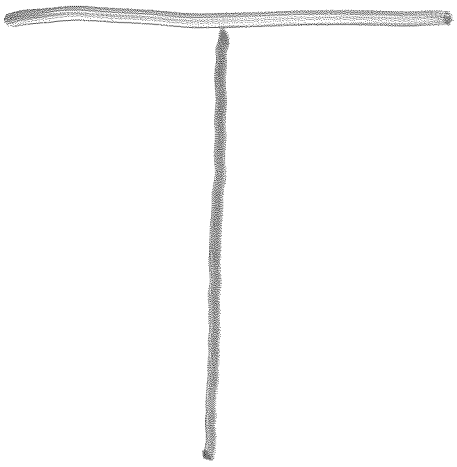
# The Little Higgs

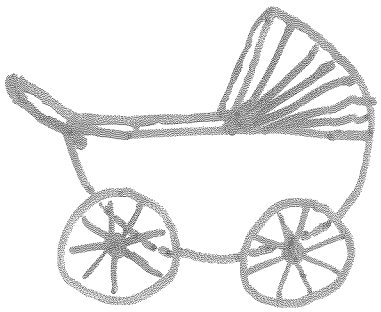
an update

'84 COMPOSITE HIGGS

'19 EXTRA DIMENSIONS



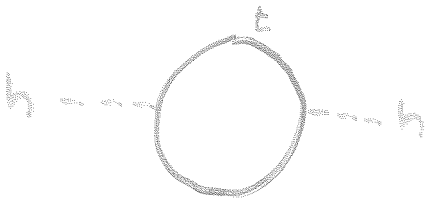
'01



– D KAPLAN

# Naturalness as an argument for New Physics

- Higgs mass sensitive to scale of new physics:




$$\rightarrow \quad m_h^2 = \lambda v^2 \sim \# \frac{y_t^2}{16\pi^2} \Lambda^2$$

$\Lambda$: New physics mass scale

$\Lambda \sim 1$ TeV ?

- Perhaps short distance physics fine-tunes this parameter

(many vacua, statistical distribution of parameters, anthropic arguments, ..)

# Naturalness and Little Hierarchy Problems

- Technicolor

Strong coupling

$$\langle \psi\psi \rangle \neq 0$$

$$m_{W'} \simeq g f_{TC}$$

~ Electroweak Observables S, T

~ Flavor – Nightmarish models + FCNC

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- Supersymmetry

Weak coupling

$$m_h^2 \sim m_{susy}^2 \gtrsim m_e^2 \text{ typically}$$

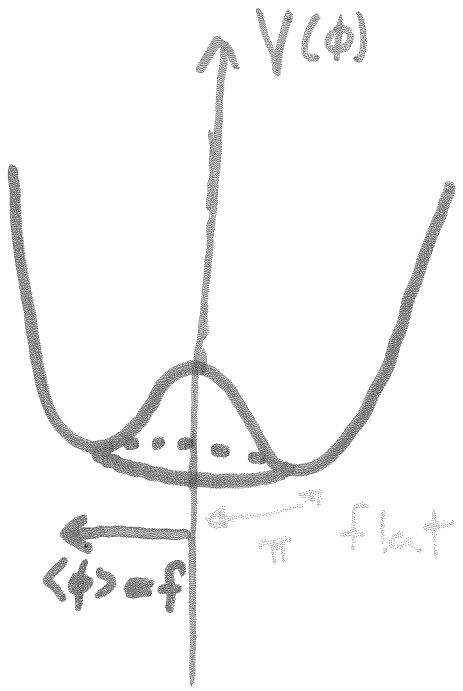
$$\Leftarrow$$

$$\underline{114\,\text{GeV} < m_h < 128\,\text{GeV}} \text{ (MSSM)}$$

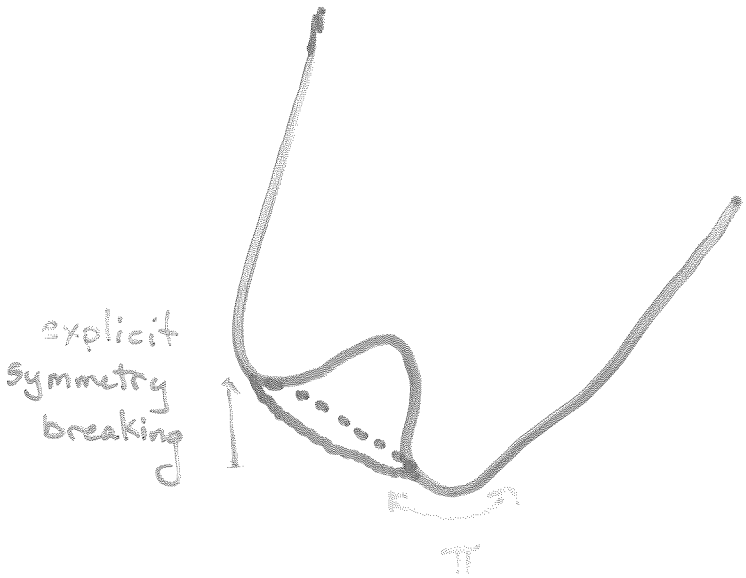
$\pm 3$ GeV $\pm$ 2 GeV ...

# Naturally Light Scalars

- Approximate (pseudo-) Goldstone Boson




- no potential (flat)
- compact




- small potential & interactions
- small mass
- $V \sim \# \cos(\pi/f)$

# Composite Higgs

'84 Georgi, Kaplan

- Higgs like a pion (or $\begin{pmatrix} K^+ \\ K^0 \end{pmatrix}$)

  ↓

  Global Symmetry broken spontaneously by strong dynamics (e.g., chiral symmetry)

- Explicit Symmetry breaking

Pions: $m_q$, $\alpha_{em}$

Composite Higgs: $\alpha_{EW}$, $\alpha_t$, $\Lambda_{quantic}$

# Goal of the Composite Higgs

$$v_{EW} \ll f_{strong}$$

However, typically

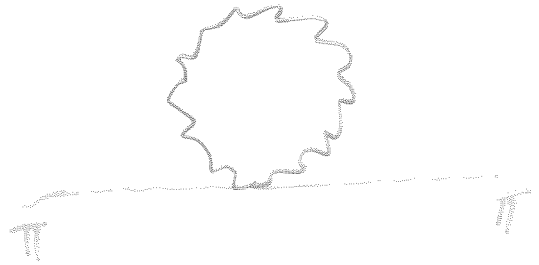
$$m_H \sim f_{strong}$$

As in $\pi$'s interactions

- if $e = 1$,

$m_{\pi^\pm} \simeq f_\pi$ from $\alpha_{em}$

one-loop quadratic divergence




NDA

$$\sim \frac{\alpha}{4\pi}\Lambda^2$$

$$\text{w/ } \Lambda = 4\pi f$$

flavor ???

# Goal of the Little Higgs or

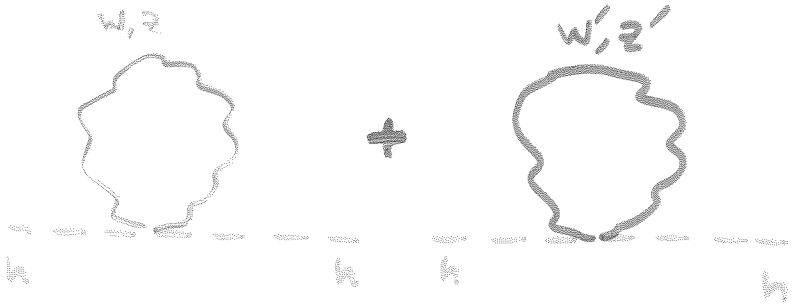
$$v_{EW} \ll f_{strong}$$

How?

- e.g., if gauge group were

$$SU(2)_1 \times SU(2)_2 \to SU(2)_L$$

then




$$+ \quad \sim \frac{\alpha}{4\pi} \frac{m_{W'}^2}{g'^2} \log \Lambda$$

$$\sim \frac{\alpha}{4\pi} f^2 \log \Lambda$$

No quadratic Divergence @ 1 loop

$$v_{EW} \sim f/4\pi$$

Flavor ???

Theory valid up to

$$\Lambda \sim 4\pi f \sim 16\pi^2 v_{EW}$$

$$\sim 10 \text{ TeV}$$

# Generic Spectra

- Partners for all SM ptcl.s with O(1) couplings to h:

Always Same statistics except in Susy

top → $t'(b')$. $\quad m \sim y_t \cdot f$

$W, Z \rightarrow W', Z', B' \quad m \sim g \cdot f$

higgs (self) → $\phi, \eta \quad m \sim m_H \cdot \frac{f}{v}$

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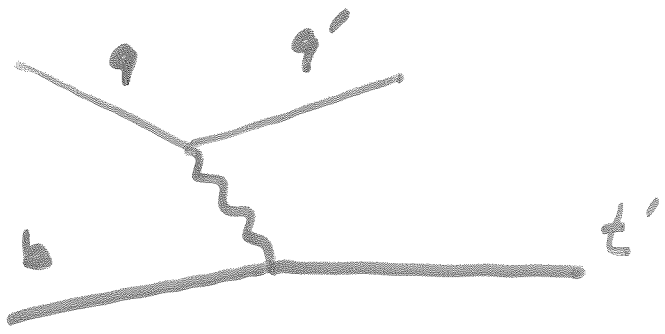
# LHC searches

Single $t'$ → DECAYS → $ht$, $W^+b$, $Zt$



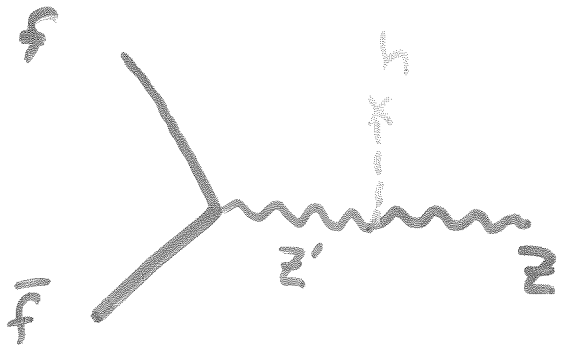

(Han, et.al. '03)

(Perelstein, Peskin, Pierce '03)

# Precision Tests?

- Generically, there's still a problem:

(most recent - Marandella, Schappacher, Strumia '05)




$$\delta m_Z^2 \sim \frac{v^2}{f^2} \sim .01$$

vs.

$$m_Z = \frac{m_W}{\cos\theta_W}$$

Force

$f > 3\text{-}4$ TeV

→ fine tuning is back

(& hard to see!)

→ at weak coupling, we can do something about it

# T-Parity & Viable Models

(H.C. Cheng, Low '04)

Why does susy do okay? Rparity

- at the time (Dimopoulos, Georgi '81)
  for p-decay

~ Possible to implement a similar symmetry in most Little Higgs models

SM: gauge, higgs, fermions } EVEN

Partners: gauge, scalar } ODD

fermions – EVEN / ODD (some of each)

→ No Z-Z' mixing;

→ No $\bar{f}\gamma^\mu f Z'_\mu$ coupling

} Effects at loop level

# Spectra with T-parity

Typical Bounds:

$f > 450$ GeV

$M_{W',Z'} \gtrsim 280$ GeV

$M_{B'} \gtrsim 60$ GeV

$M_{t'} \gtrsim 640$ GeV

(e.g. "Littlest Higgs" SU(5)/SO(5))

- Lightest T-odd Particle stable (LTP)
- Similar missing energy signatures to Susy
- $t'$ still can be singly produced
- e.g. $W' \longrightarrow W\hat{B}'$
  $Z' \longrightarrow WW\hat{B}'$
  $\emptyset \longrightarrow WW', (Z,h)(Z',\hat{B}')$

# Above 10 TeV

Who cares?

— "10 TeV" often leaks down to "multi-TeV"

e.g. $m_\rho$ vs. $m_\rho$ or $4\pi f_\pi$

— Are these theories compelling without a UV completion?

It was flavor (Yukawas, CKM, FCNC) that caused technicolor to fall from favor more than precision electroweak

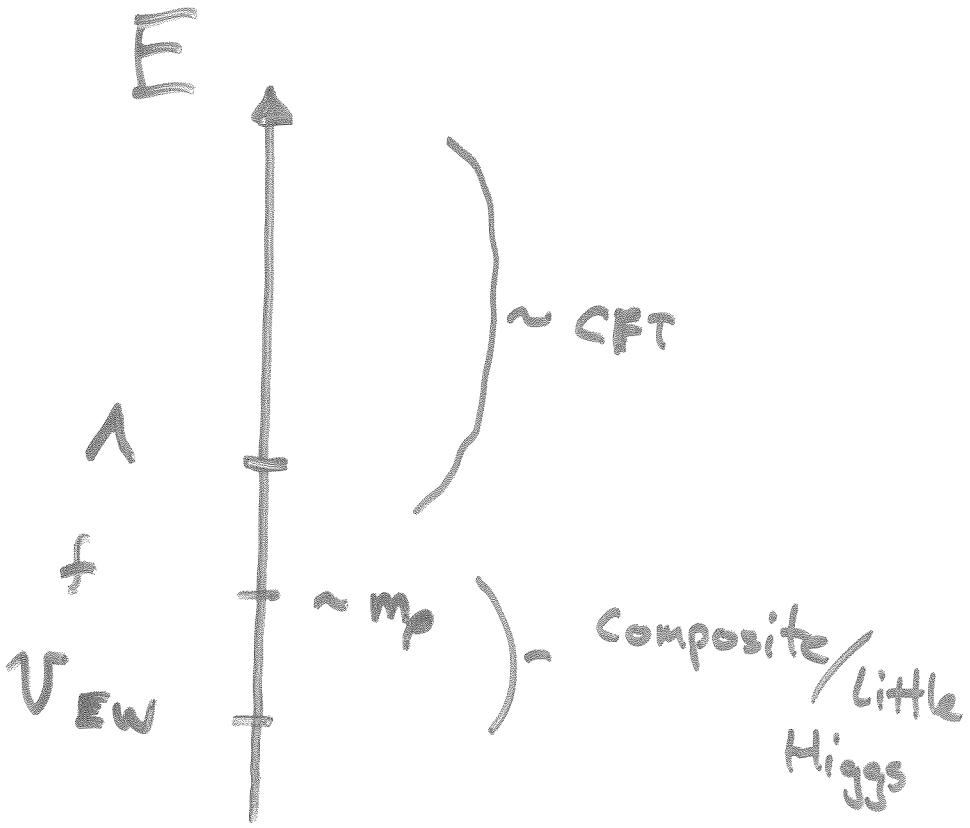
# ~ Conformal Field Theory

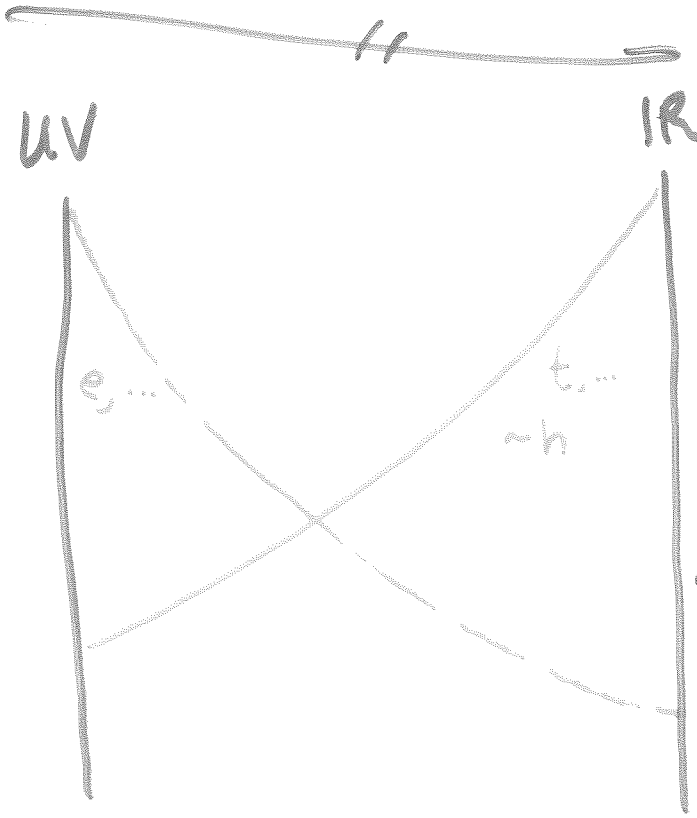
## UV completion

Extending AdS/CFT to cutoff Spaces ("UV" and "IR" boundaries)

- Can describe a heuristic UV completion as a 5-dimensional theory

| AdS | CFT |
| --- | --- |
| K-K modes | Strong Resonances |
| Weak Gauge Symmetries | Global Symmetries |
| $A_5$ component of Broken gauge Symmetry | Goldstone Boson |




Flavor can be done!

Agashe, Perez, Soni '04

Agashe, Contino, Pomarol '04

Agashe, Delgado, May, Sundrum '03

# Weak Coupling Above a TeV ?

- We are doing symmetry breaking (Goldstone Bosons) to generate symmetry breaking (EW).

Can We stack Little Higgs Models ?

| Gauge | Scalars |
|---|---|
| ⋮ | ⋮ |
| SU(14) | 128 |
| SU(12) | 32 |
| SU(4) | 8 |
| SU(2) | 2 |

→ Becomes Large N Theory

$\alpha_{t'Hooft} = g^2 N$

# Conclusion

- Little Higgs in toddler years
  T-parity

- Watch for phenomenology of
  Little Higgs / Composite Higgs
  soon

- Paradigm of SUSY vs. Strong dynamics
  hasn't changed...

higgs mass fine tuning? Weakly coupled
Tumbling gauge theories?