Little Higgs

@

Snowmass

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Outline

1. motivation

- "naturalness problem"

2. little Higgs construction

- "collective breaking"

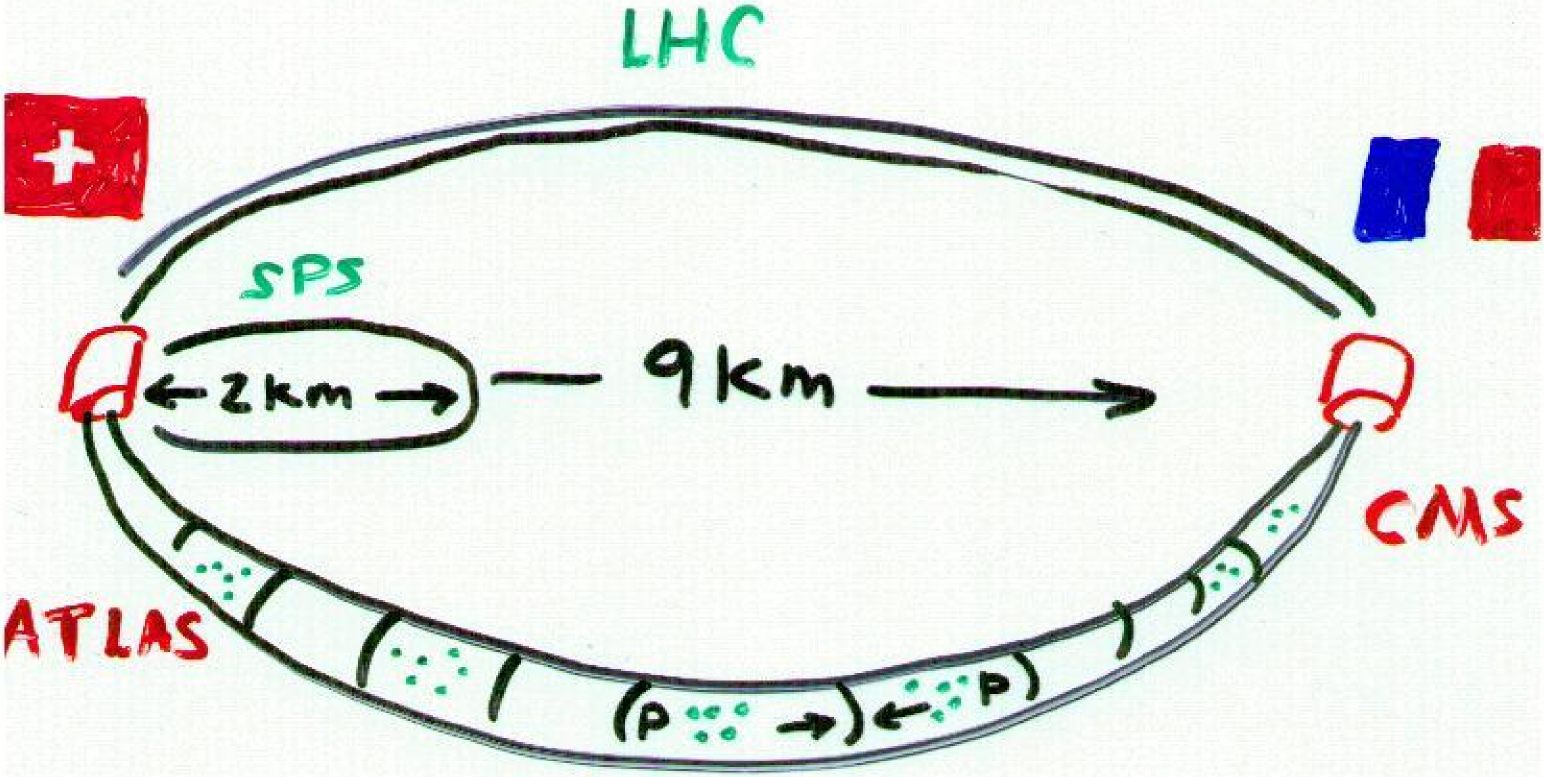
3. little Higgs and experiments

T-parity

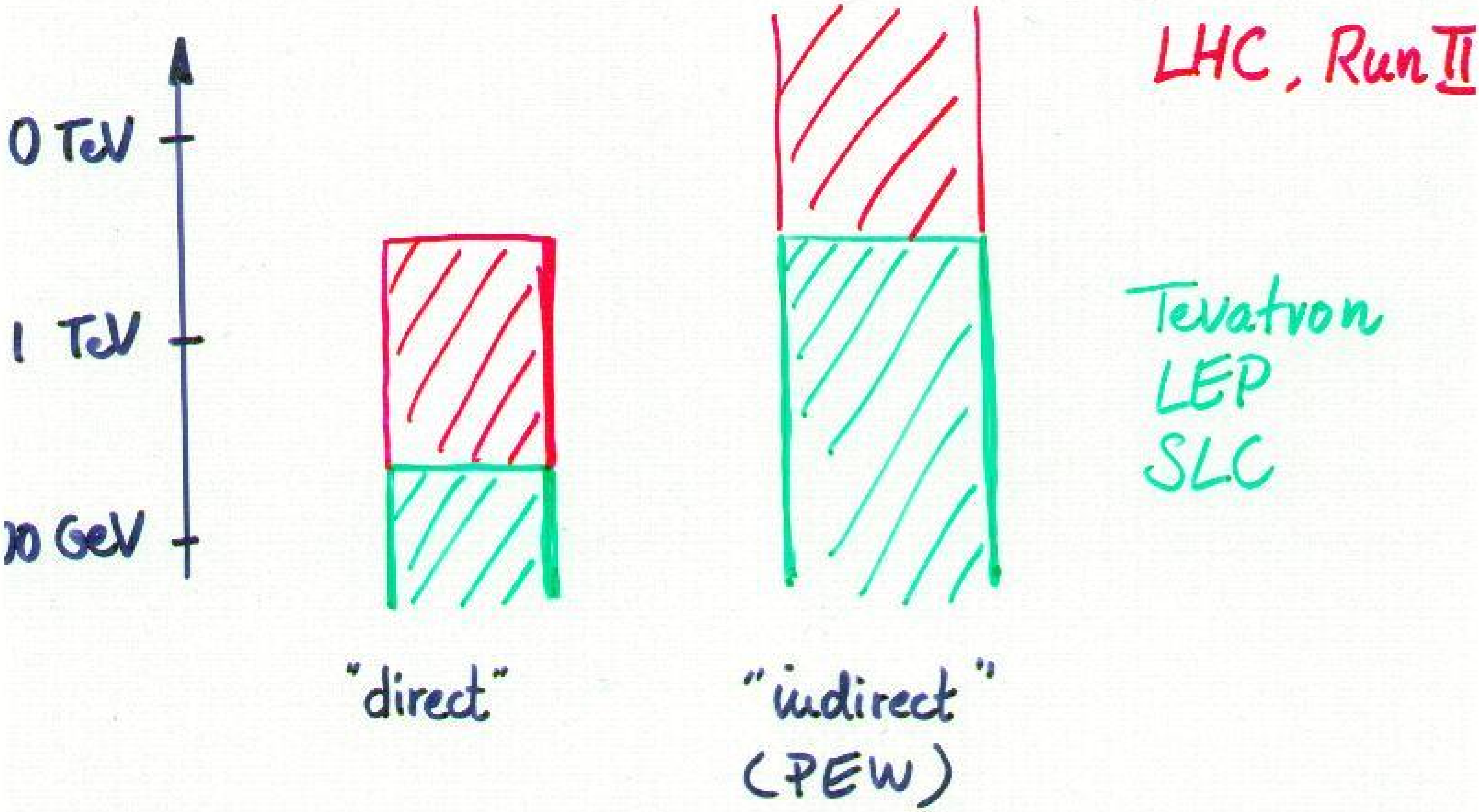
- precision electro-weak ↔ fine tuning
- phenomenology @ LHC

What do we expect to see @ the LHC ?

Theorists view of the LHC



Experimental tests of the Standard Model



a.) Standard Model only @ multi-TeV

b.) cleverly hidden (weakly coupled) extension beyond the Standard Model

a. ~~Hierarchy~~ Naturalness Problem

Assume that the SM (with a Higgs of mass $\approx$ 200 Ge[V])
is valid up to $\Lambda \gtrsim 10$ TeV

⇒ Problem: quadratic divergences at 1-loop.

top: 

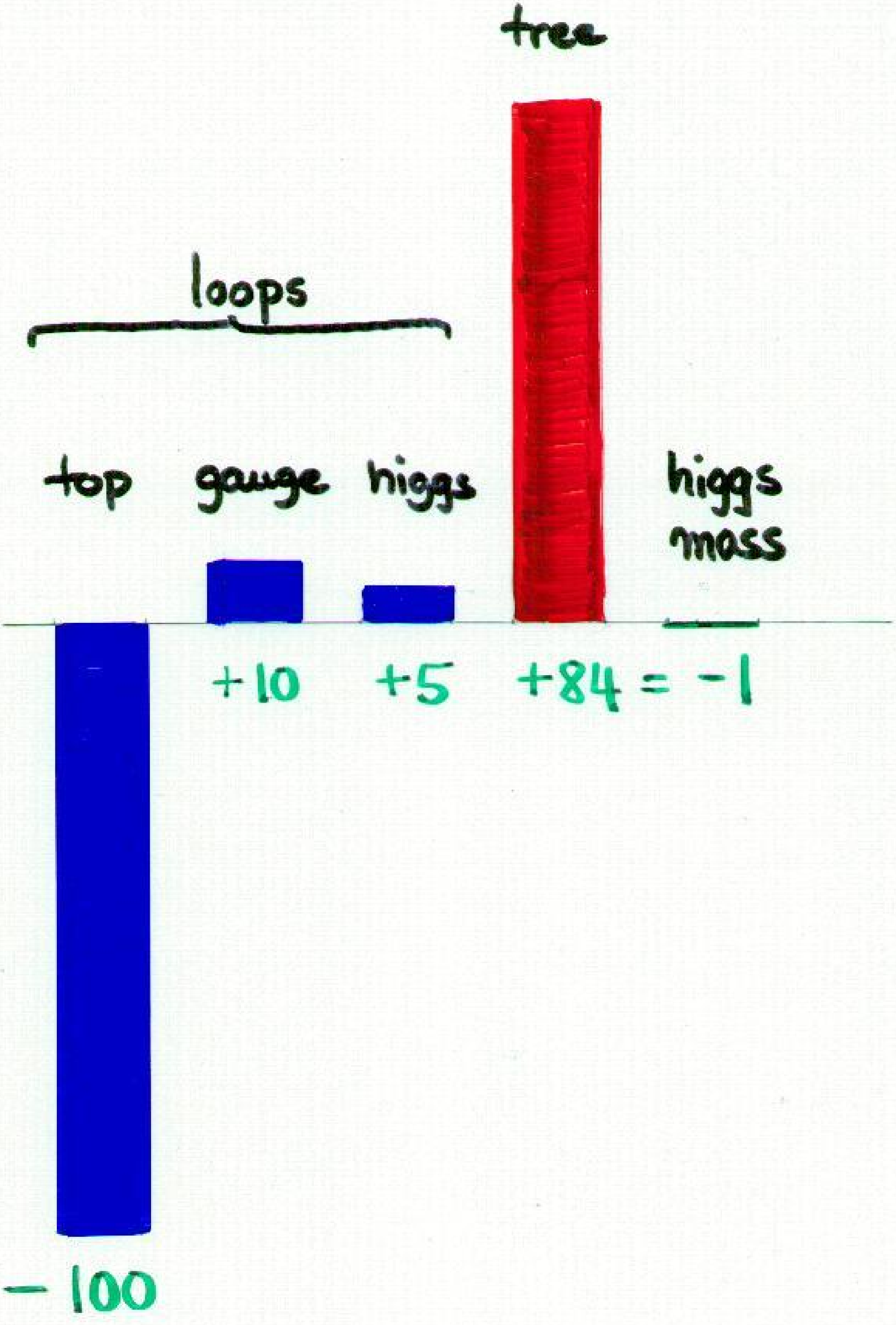
$\sim \frac{-\lambda_t^2}{16\pi^2}\Lambda^2 \approx -(2\,\text{TeV})^2$

SU(2)×U(1) gauge: 
$\approx (700\,\text{GeV})^2$

Higgs: 
$\approx (500\,\text{GeV})^2$

Corrections are 100 times bigger than the expected mass!

fine tuning with $\Lambda = 10$ TeV

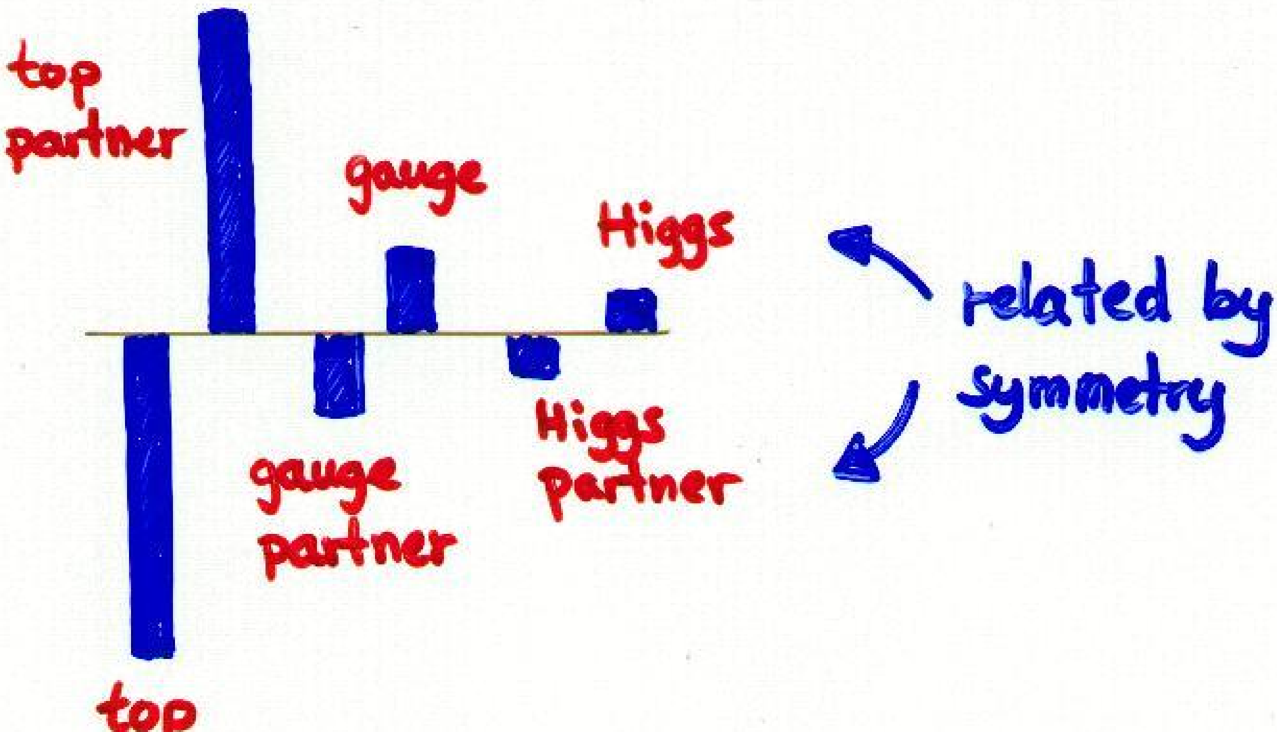


b. (weakly coupled extension)

What to do ?

Cancel the divergences with new particles running in the loop

+ a symmetry



Example: SUSY

couplings related by SUSY

$$\delta m_H^2 \simeq -\frac{\lambda_t^2}{16\pi^2}\Lambda^2 + \frac{\lambda_t^2}{16\pi^2}\Lambda^2$$

fermion cancelled by boson

Summarize ...

Precision EW data

+

Higgs naturalness problem

predict

New (weakly coupled) particles
related to ...

top		2 TeV
W, Z	at or below	5 TeV
higgs		10 TeV

(assumed ≤ 10% tuning)

the MSSM is fine-tuned,

are there alternatives?

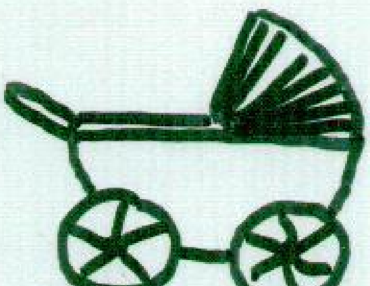
2. Little Higgs

'84 Composite Higgs

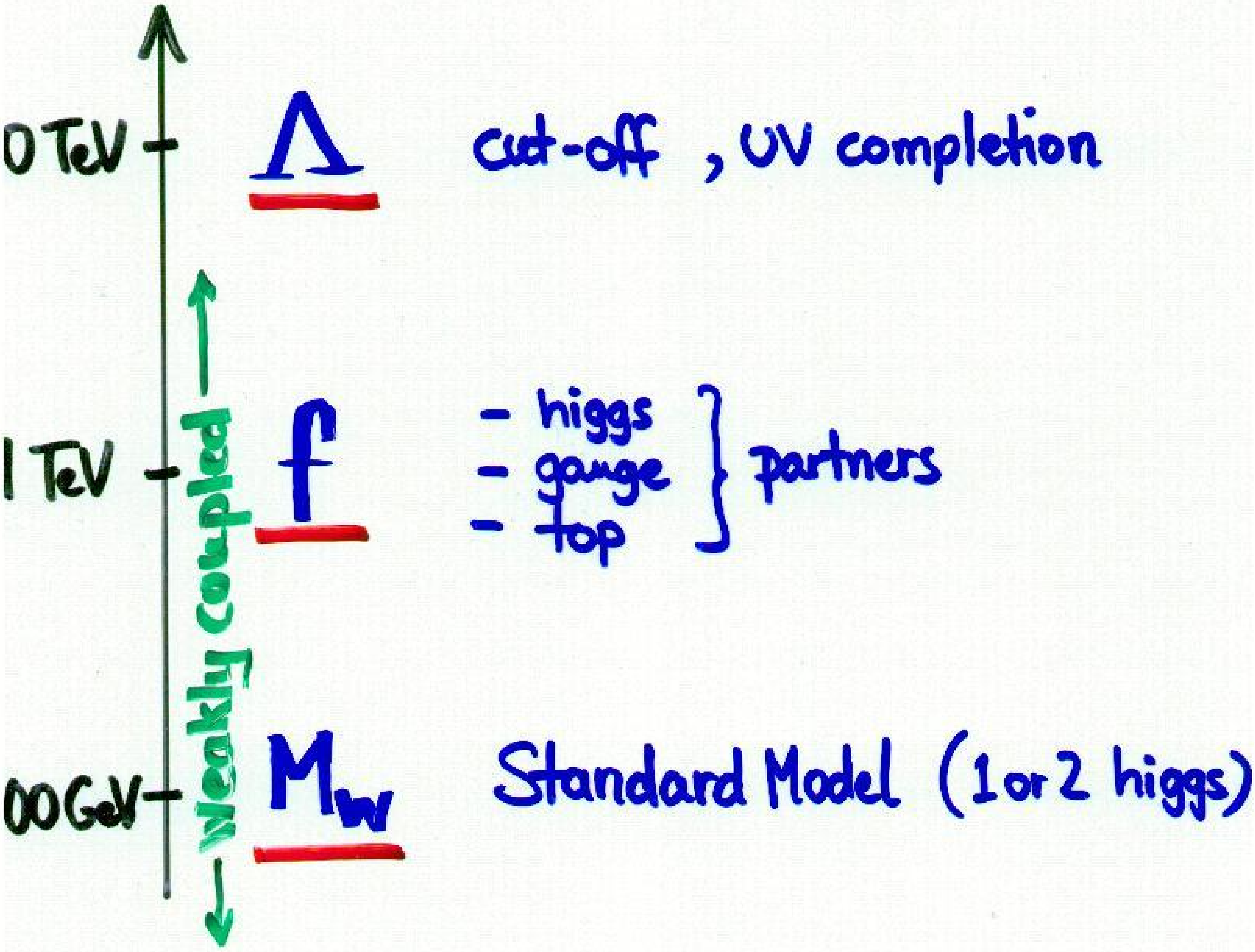
'19 Extra Dimensions

$\Downarrow$

'01

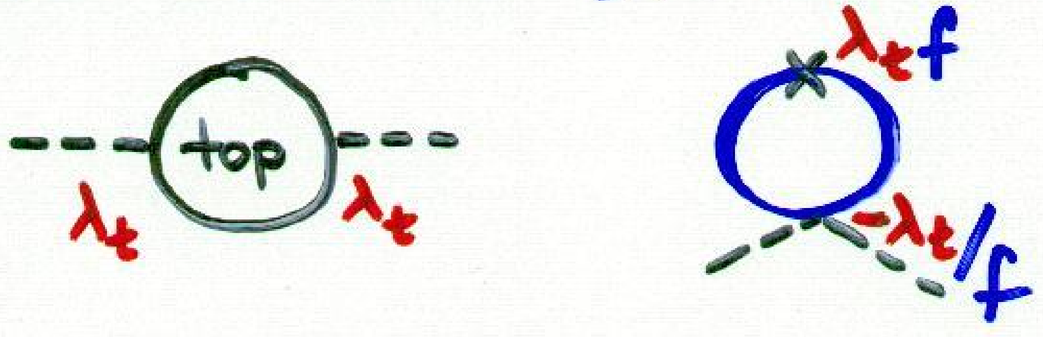


little higgs spectrum



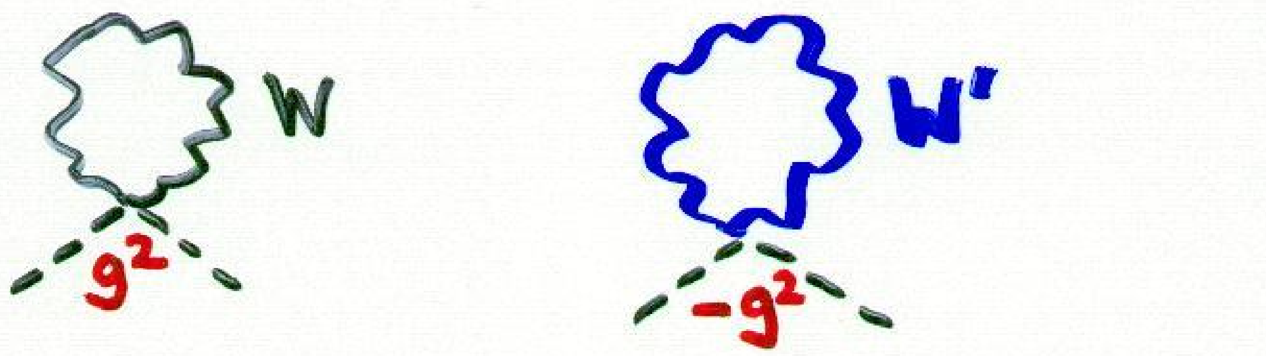
Little Higgs loop cancellations

- new colored fermion χ, mass ~ TeV



fermion cancels fermion

- new gauge bosons W', Z', mass ~ TeV



boson cancels boson

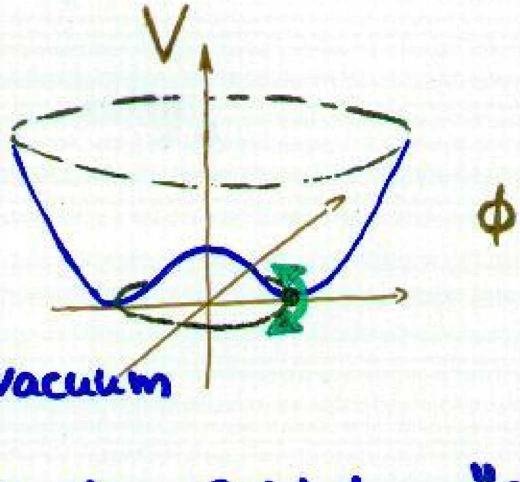
What symmetry relates
the coupling constants ?

the little higgs is a
"pseudo-Nambu-Goldstone-
boson"

Higgs as a Nambu-Goldstone boson

Complex ϕ

symmetry $\phi \to e^{i\alpha}\phi$



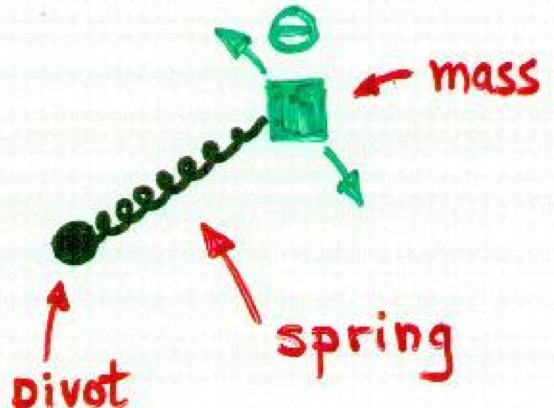
$\Rightarrow$ degenerate ground state-vacuum

$\Rightarrow$ massless excitations: "Nambu-Goldstone" fields

$$\phi(x) = r(x)\, e^{i\theta(x)}$$

$\theta(x)$ massless, but also • no potential

• no couplings to top gauge field



Higgs as a NGB

* spontaneously broken global symmetry *

e.g. "simplest" : $SU(3)/SU(2)$

Kaplan, Schmaltz

5 NGBs

$= H$ complex doublet

$+ \eta$ real scalar

top Yukawa (1)

larger symmetry ($SU(2) \to SU(3)$)

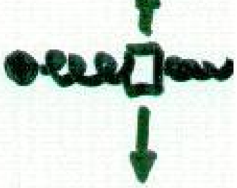
$\Rightarrow$ larger representations

e.g. $\begin{pmatrix} t_L \\ b_L \\ T_L \end{pmatrix}$ $\begin{pmatrix} H \\ \eta \end{pmatrix}$

"L.H. partners"

TeV scale masses

top Yukawa (2)

* collective symmetry breaking 

$$\lambda_t \begin{pmatrix} t_L \\ b_L \end{pmatrix} t_R \, H$$

$$\downarrow$$

$$\lambda_1 \begin{pmatrix} t_L \\ b_L \\ T_L \end{pmatrix} t_R^1 \begin{pmatrix} H \\ \eta \end{pmatrix} + \lambda_2 \begin{pmatrix} t_L \\ b_L \\ T_L \end{pmatrix} t_R^2 \begin{pmatrix} -H \\ -\eta \end{pmatrix}$$

note: SU(3) symmetry relates t, T couplings

SU(2) gauge sector

$$\left(\begin{array}{c|c} W^{\pm}, Z^{0} & W' \\ \hline W' & Z' \end{array}\right)$$

W, Z "partners" with TeV scale masses

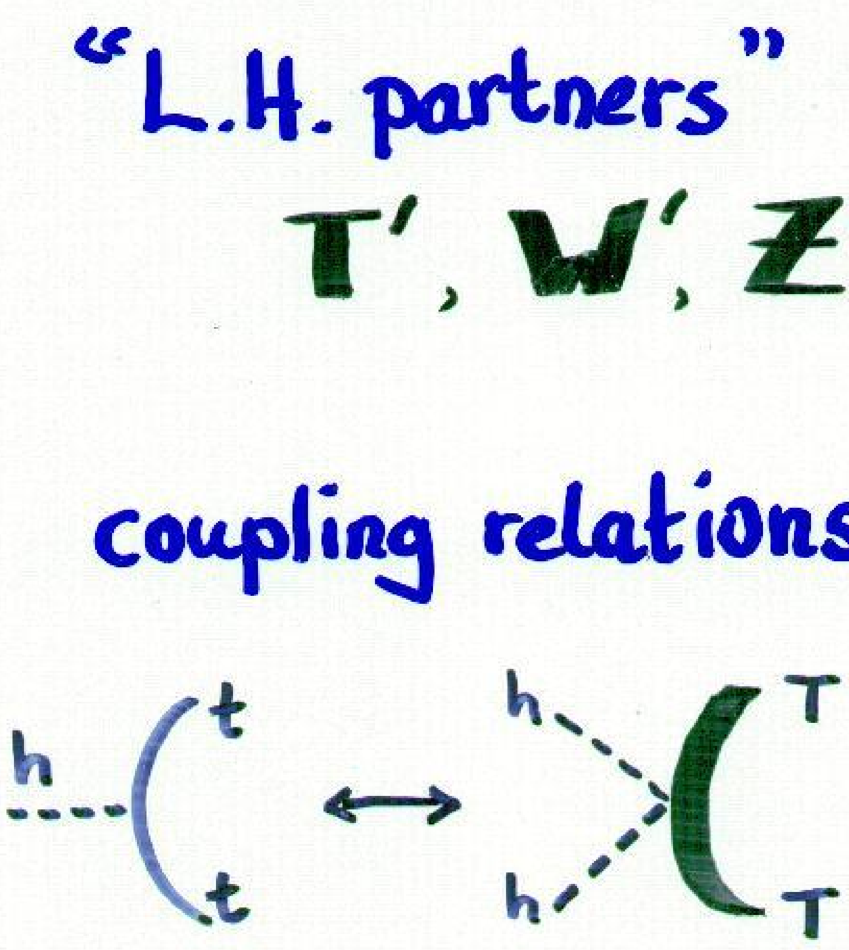
General L.H. features

* new bosonic symmetry

1. "L.H. partners"

   $T', W', Z', \eta \ldots$

2. coupling relations



New predicted particles

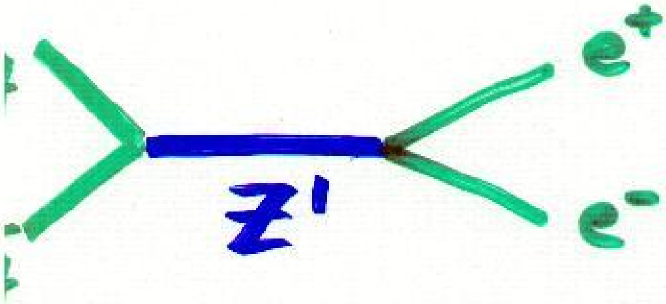
* top partner : $\underline{\underline{T}}$ $\qquad m_T \sim 1\text{-}2$ TeV

* gauge boson partners : $\underline{\underline{W', Z'}}$ $\qquad m_{Z'} \sim 3\text{-}5$ TeV

* scalars : ϕ ? $\qquad m_\phi \sim$??

(lower bounds on masses from precision EW, upper bounds from Higgs naturalness)

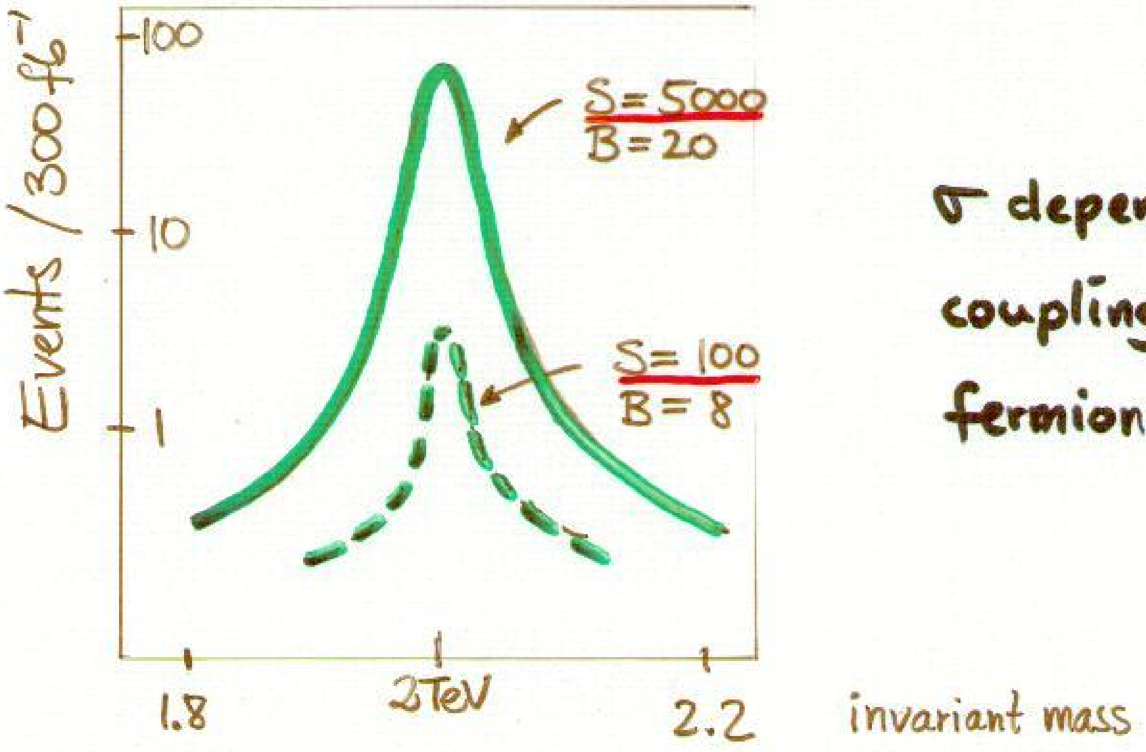
Z' at the LHC (ATLAS)



2 isolated electrons

invariant mass > 800 GeV

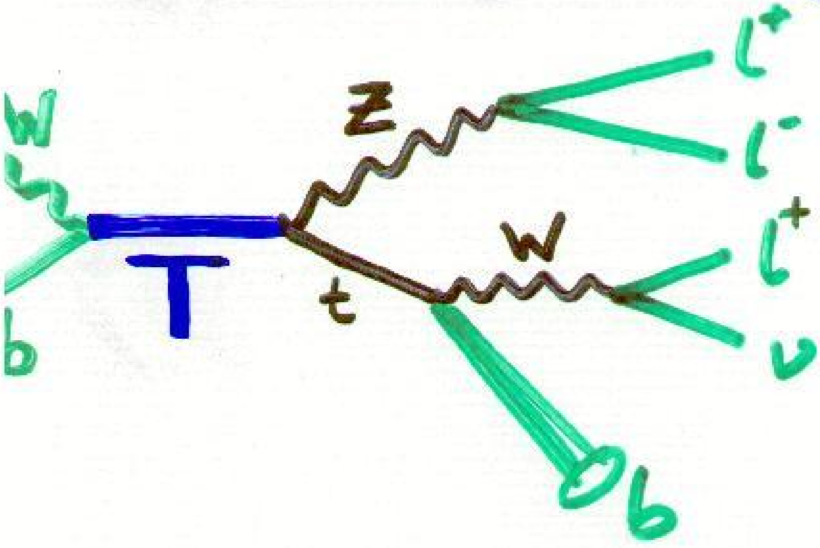
$M_{Z'} = 2$ TeV



σ depends on Z' coupling to light fermions

background: Drell-Yan $Z/\gamma \rightarrow e^+e^-$

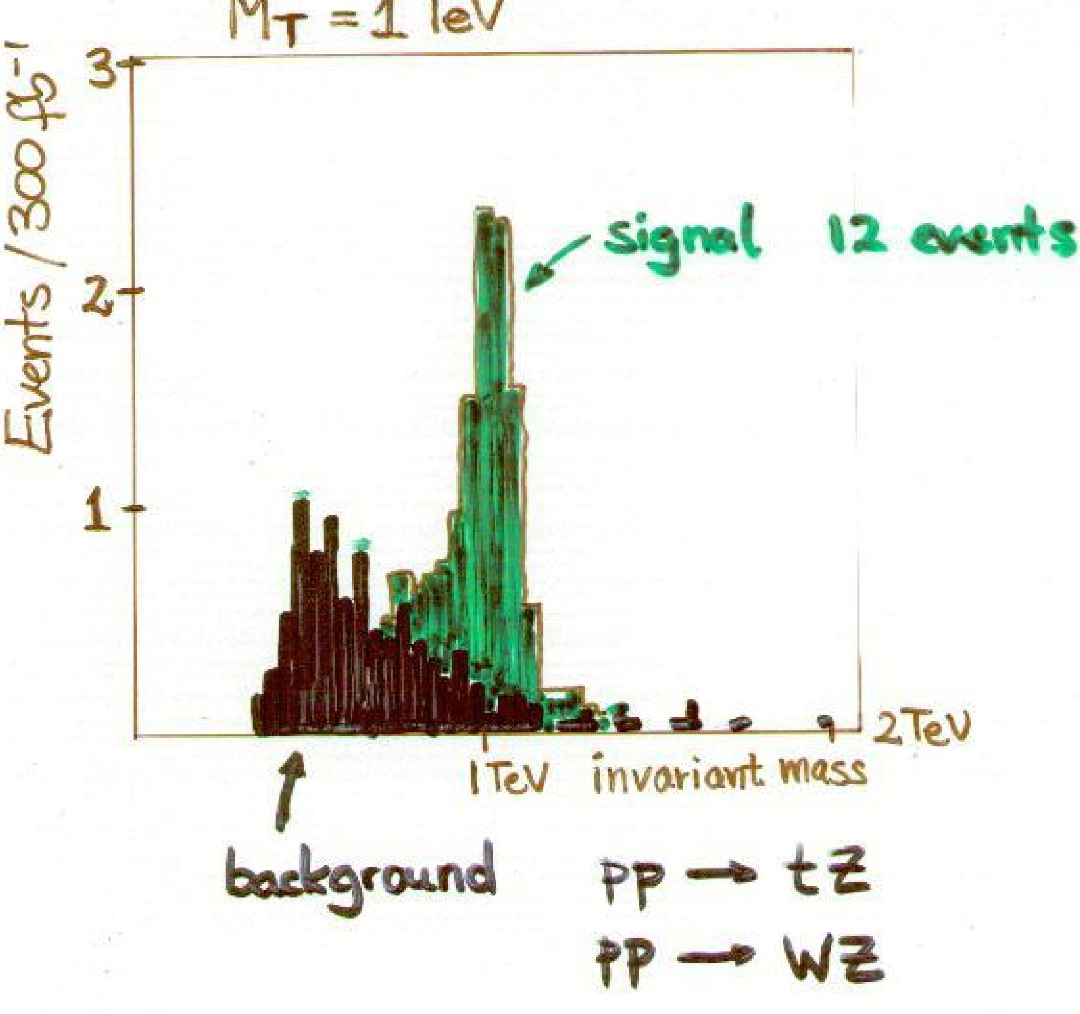
T at the LHC (ATLAS study)



3 isolated leptons

$\not{E}_T$ (> 100 GeV)

1 b jet



Precision EW constraints

Kribs et.al. - Gregoire et.al. - Marandella et.al.
Han-Skiba

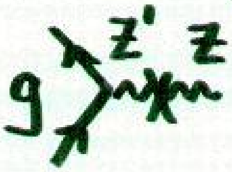
- **$Z-Z'$ mixing**

$m^2_{Z'}$

$$g^2 \begin{pmatrix} f^2 & v^2 \\ v^2 & v^2 \end{pmatrix} \Rightarrow \delta m_Z^2 \approx \frac{v^4}{f^2}$$

m^2_Z

- **Z coupling modification**



$$\Longrightarrow \delta g \approx \frac{v^2}{f^2}$$

- **four fermion operators**

$$\approx \frac{E^2}{f^2}$$

$f \gtrsim$ few TeV

a conundrum ...

in Little Higgs

$$m_{LH} \gtrsim \text{few TeV}$$

in SUSY

$$m_{SUSY} \gtrsim \text{few 100 GeV}$$

... from Precision EW

R-parity

all superpartners odd

LSP dark matter!

$\Rightarrow$ pair production

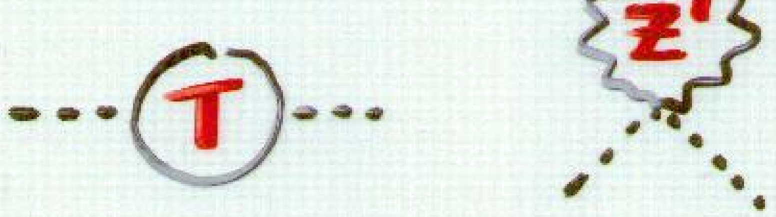
$\Rightarrow$ no tree level precision EW

$$\delta_{PEW} \sim \frac{1}{16\pi^2} \frac{m_Z^2}{m_{SUSY}^2}$$

T - parity

H.-C. Cheng, I. Low

Naturalness requires new states in Loops !



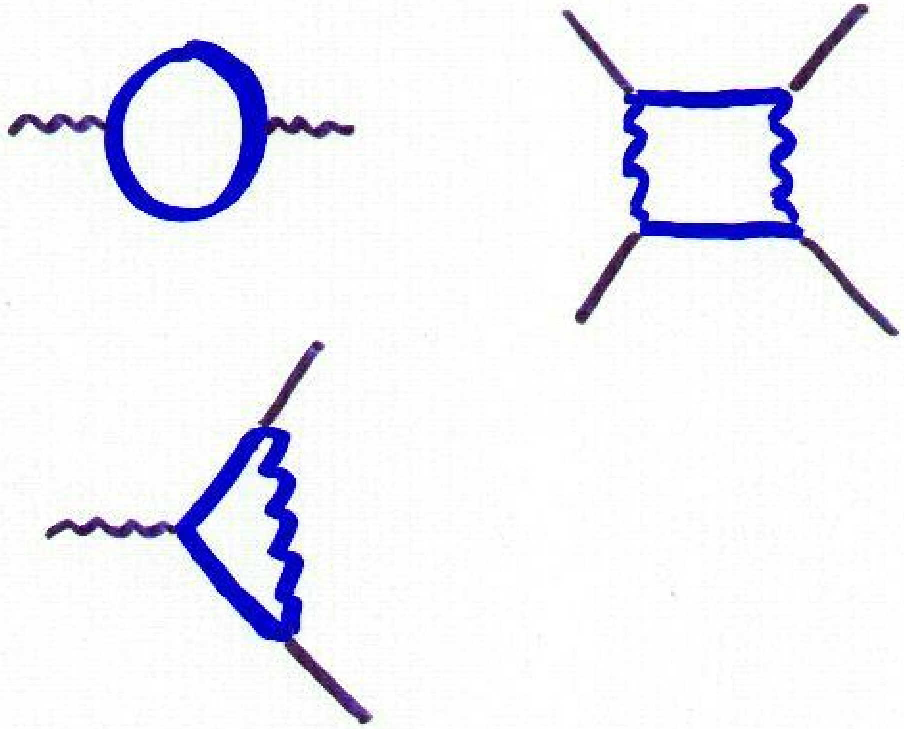
Precision EW problems arise from Trees !

all new heavy states carry new Z_2 charge : T-parity

T parity precision EW

Hubisz, Meade, Noble, Perelstein in "littlest Higgs" Cheng, Low

$$m_{lh} \gtrsim 500\ \text{GeV}$$



T parity pheno

(Hubisz, Meade)
Littlest Higgs

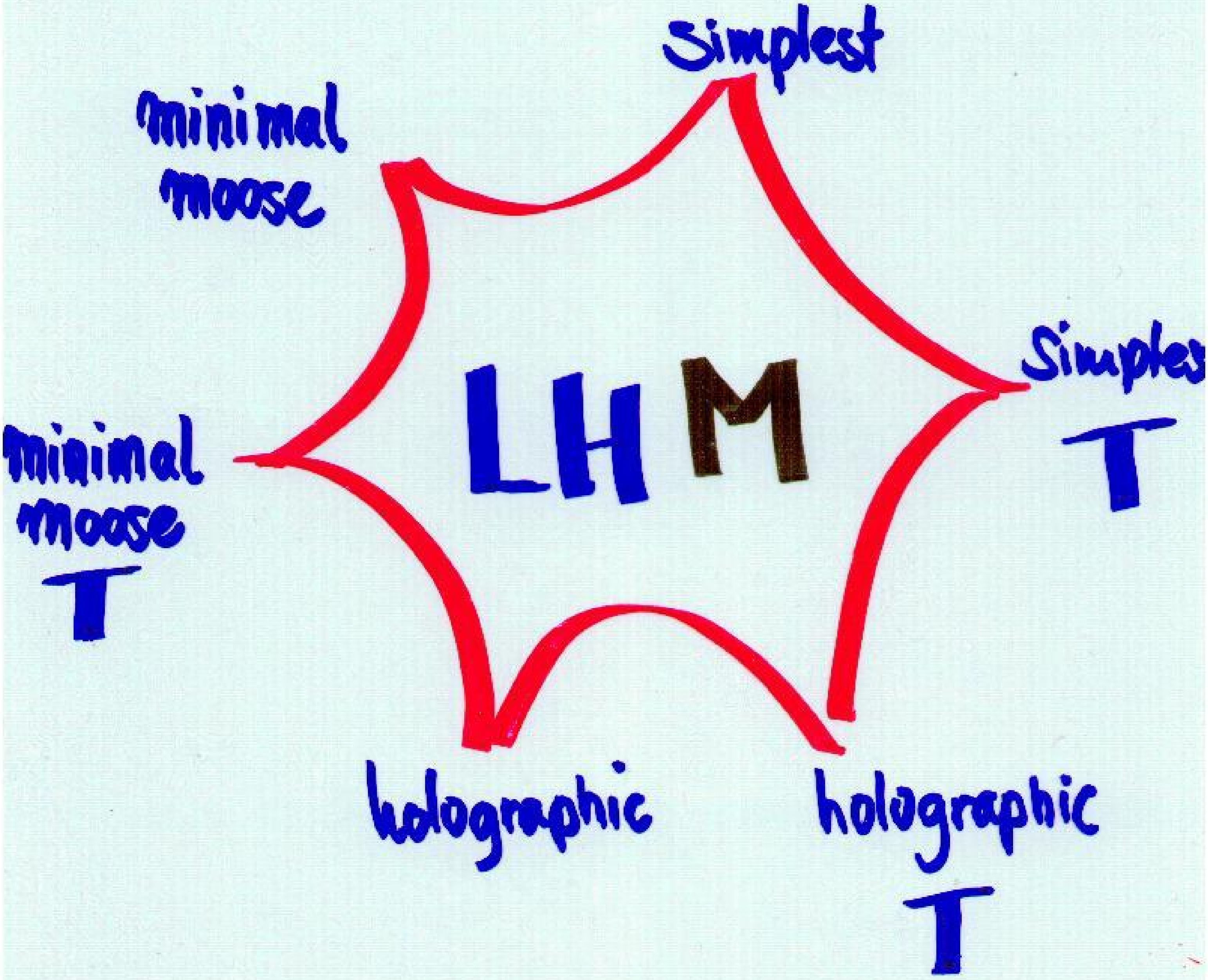
- pair produce new particles
  (exception: T partner)
- cascade decays
- missing energy signals

Similar to SUSY !

» Can we measure spin of "partners" at the LHC ?

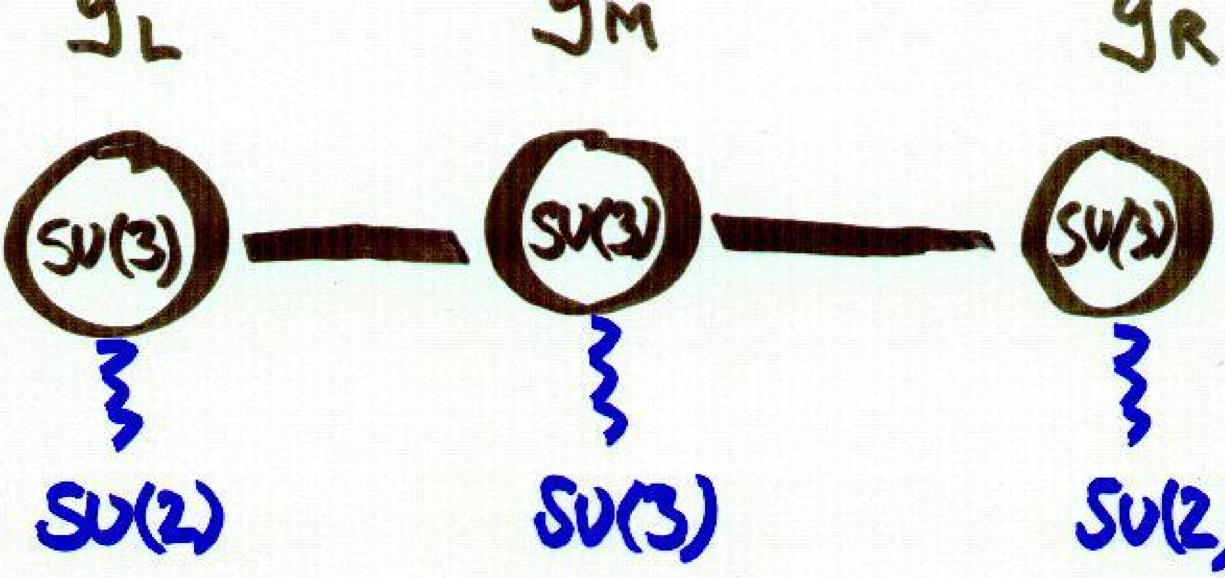
- **LTP** dark matter

Little Higgs- M-theory



LHM

- Thaler
- Cheng, Thaler, Wang



- $g_L = g_R \Rightarrow$ **T** parity
- $g_L, g_R \gg g_M \Rightarrow$ simplest
- $\ll \Rightarrow$ minimal moose

LHM

Cheng, Thaler, Wang
to appear

one Lagrangian

$\Longleftrightarrow$ many little higgs model

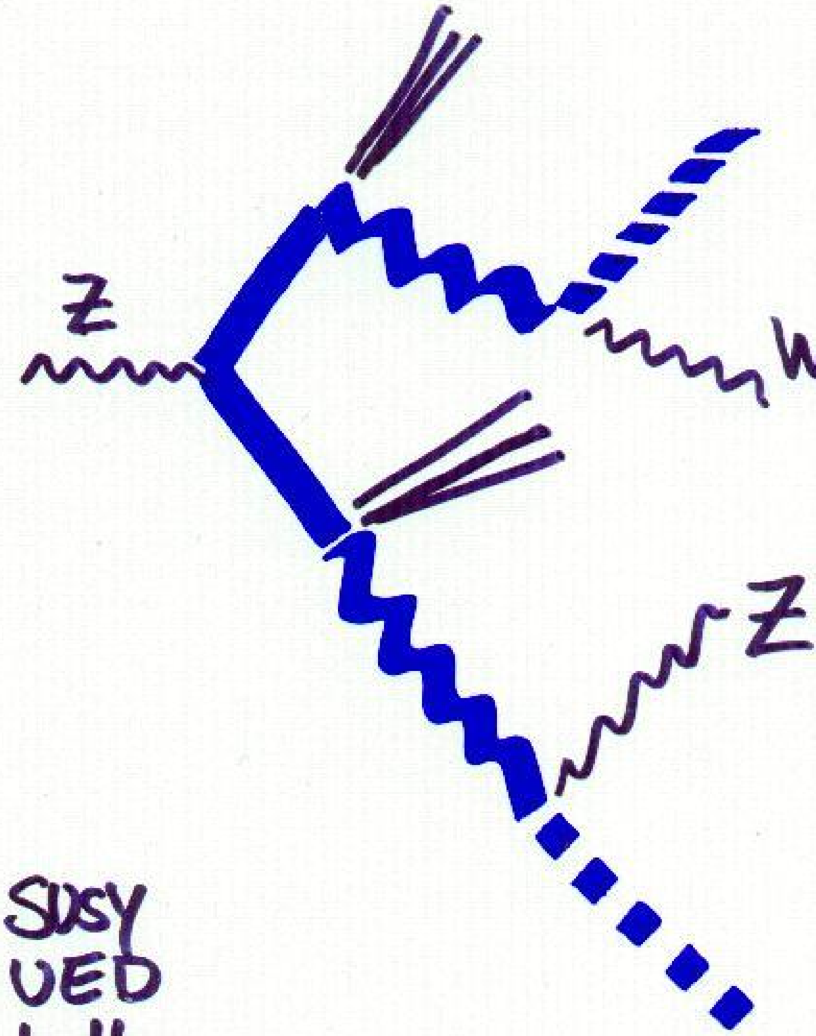
great for unified L.H. study !

(like MSSM)

General lesson ?

- precision EW
- weak scale dark matter

New particle Parity



- pair product
- $\not{E}_t$
- cascades

- SUSY
- UED
- L.H.

???

Summary

★ the SM works with a cut-off @ 1 TeV

but fine tuned for $\Lambda \gtrsim 2$ TeV

$\Rightarrow$ predict colored field $\lesssim 2$ TeV

gauge partners $\lesssim 5$ TeV

★ little Higgs = perturbative theory

with naturally canceling Λ^2

divergences, " collective "

- precision EW implies $f \gtrsim$ few TeV

or

T-parity

- didn't talk about ....

... flavor

... UV completions

... other models