

What can we
expect at
the LHC?

Ami Katz
Boston U.

Expect the

Unexpected !

Possible Theories

1) Higgsless Theories

Ex: Technicolor, Extra-Dimensional Models

$E \sim 1 \text{ TeV}$: Strong interactions
(Perhaps similar to QCD)

a) Unfavored by Precision Electro-Weak data (M_W^2/M_Z^2 , etc. at LEP)

b) Challenged by 3rd generation physics (heavy top, $Z b_L b_L$ interaction).

2) Theories with a Higgs

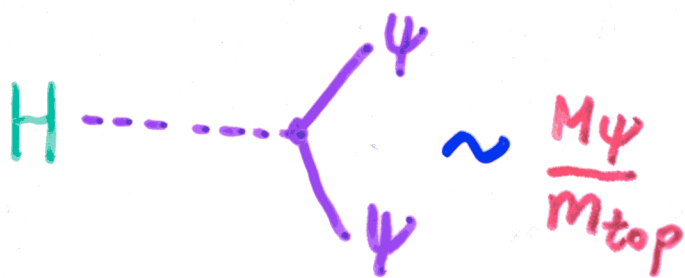
Ex: Supersymmetry

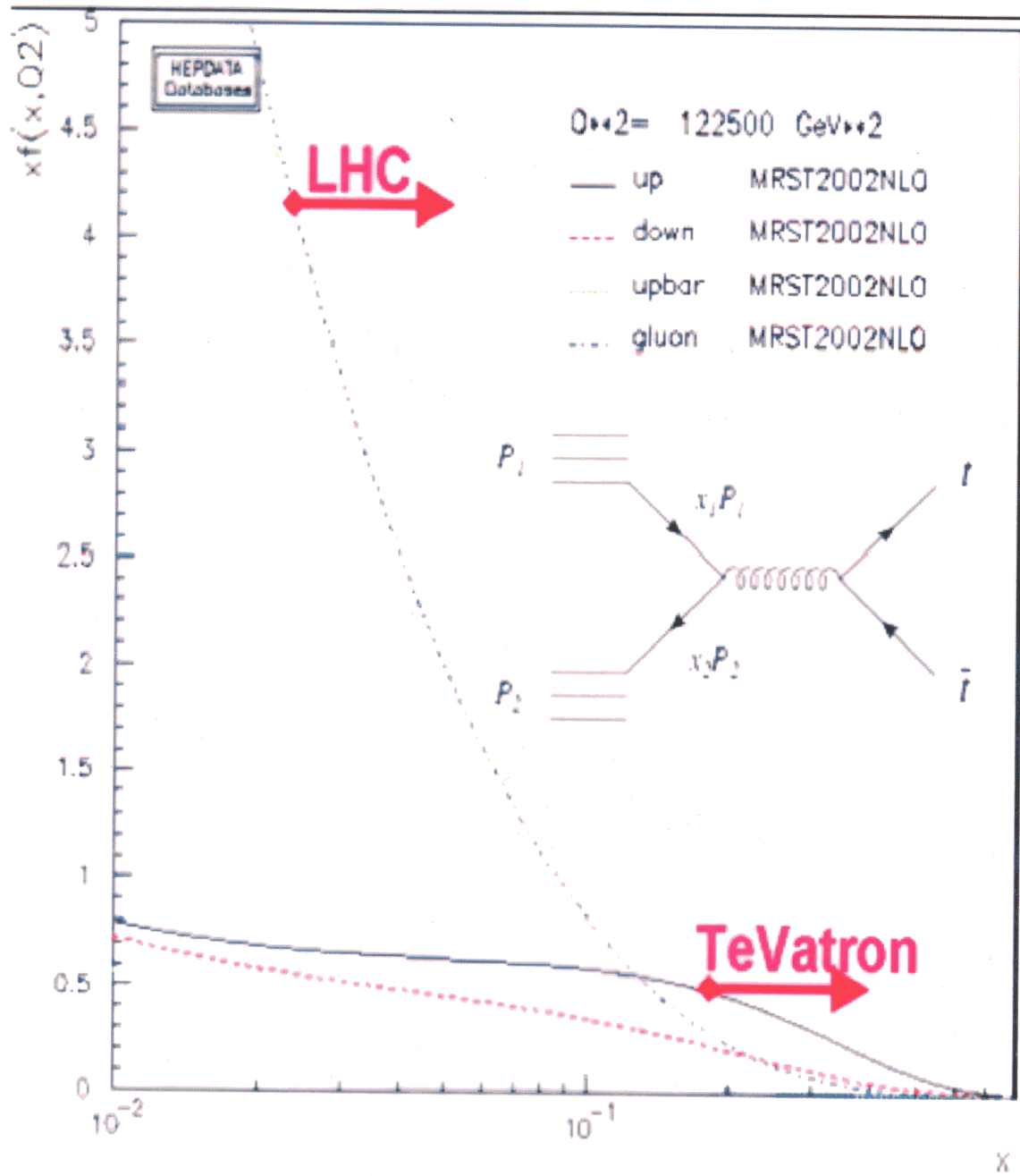
→ Composite Higgs (Little Higgs)
→ Extra-Dim.

$E \sim 1 \text{ TeV}$: Weak interactions

Meet the Higgs

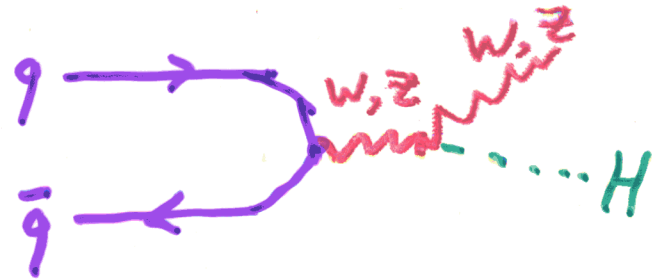
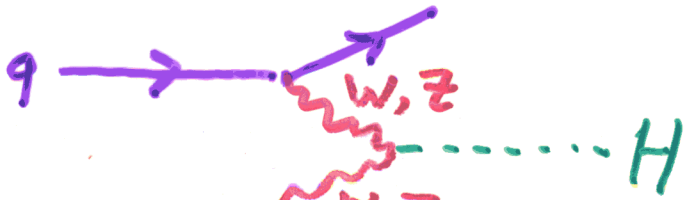
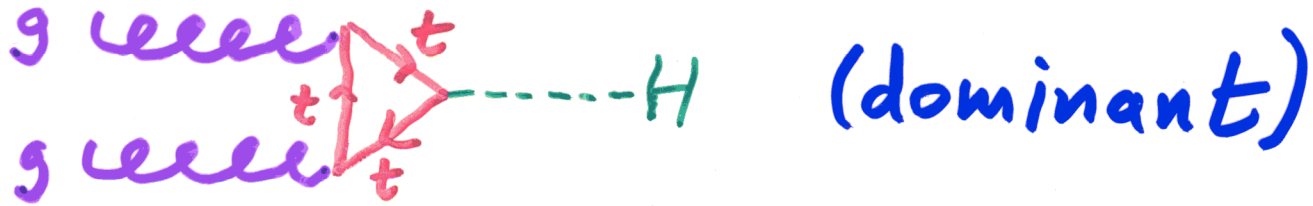
- Only scalar in the SM
(all others are fermions & vector-bosons)
- Higgs mass is the only dimensional parameter:
Sets the scale for masses of fundamental particles
- Without interactions with the Higgs field, all SM particles are massless.



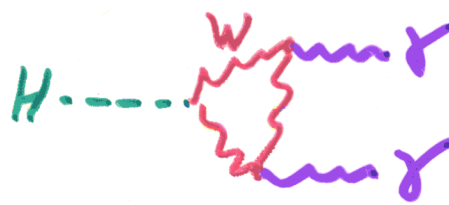
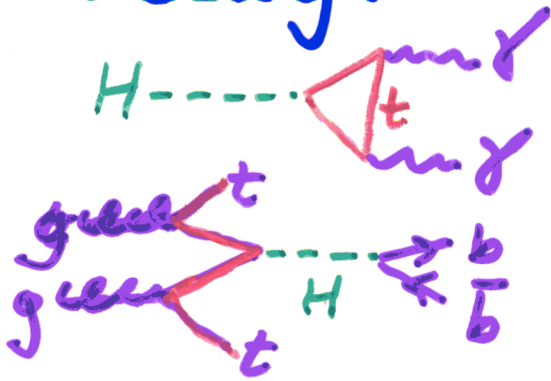


Looking for Higgs at LHC

• Production:



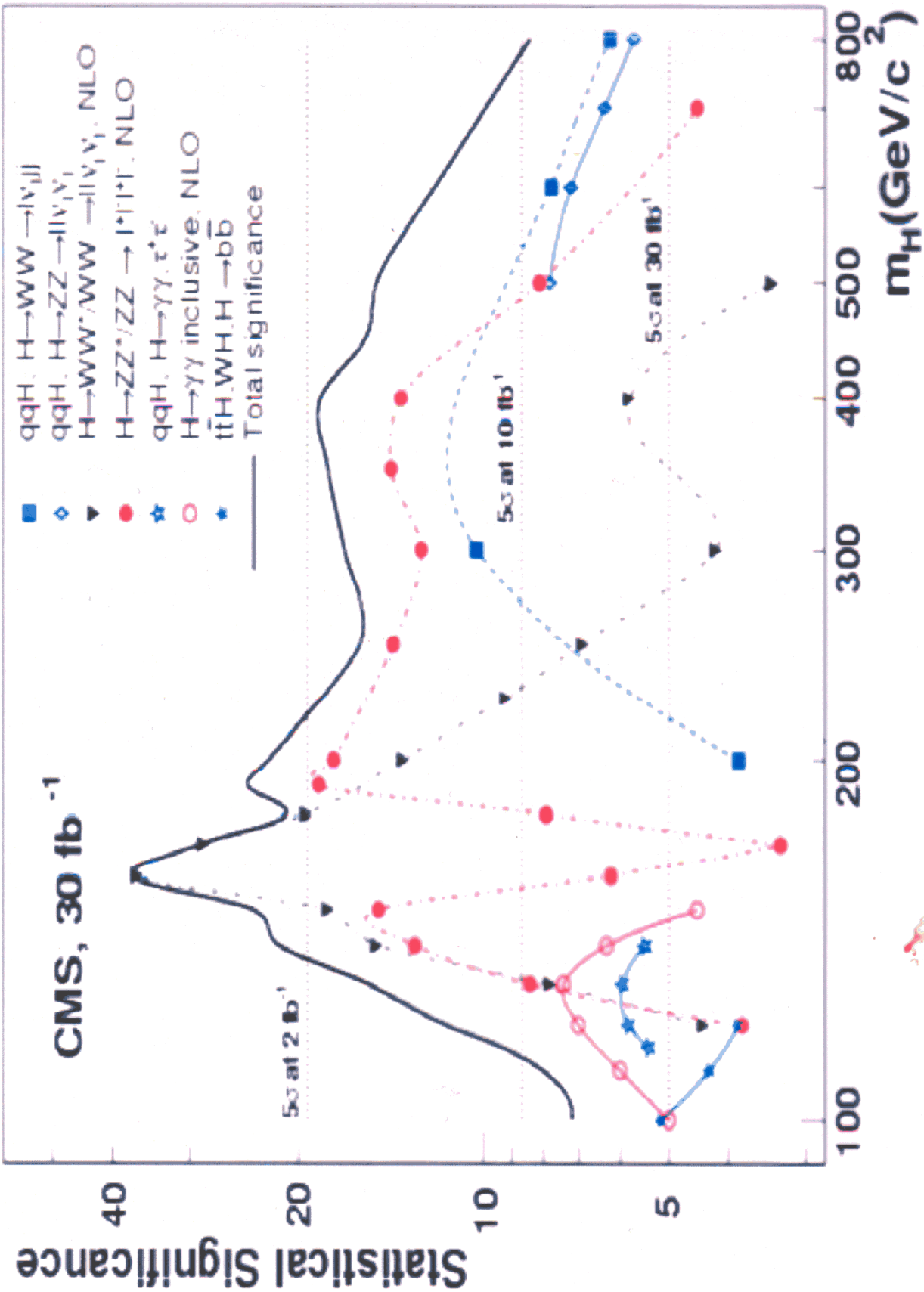
• Decay:



$(m_H \lesssim 125 \text{ GeV})$



High m_H



Beyond the Higgs

- A fundamental scalar & nothing else at high E , is unnatural.

— Fundamental:

(size of particle) \ll (typical length $\sim 1/E$)



(i.e. it behaves like a point)

— High E : $E \gg M$ or (length) $\ll 1/M$

— Never Seen:

(size of scalar particle) $\ll \frac{1}{M}$

atom: 1 \AA

$1/M_{\text{proton}} \sim \frac{1}{10} \text{ fm}$

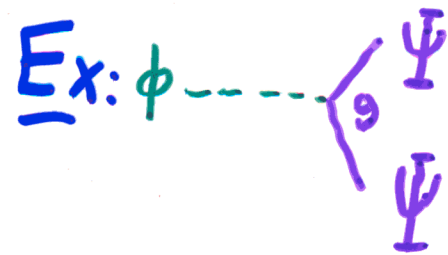
positronium: $\sim \frac{1}{e^2 m_e}$

$\sim \frac{1}{m_e}$

pion: $\frac{1}{10} \text{ fm}$

1 fm

- The mass of an interacting scalar is very sensitive to short distance (or high E) physics.



$$\Delta m_{\phi}^2 \sim g^2 M_{\Psi}^2$$

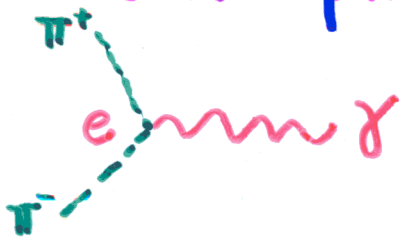
but,



$$\Delta m_{\psi} \sim g^2 m_{\psi} \log(M_{\Phi}).$$

(chiral symmetry)

- Pions & photons:



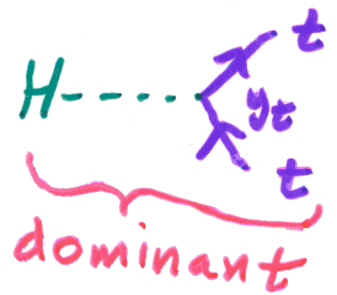
$$\Delta m_{\pi}^2 \sim e^2 \Lambda_{\text{Bind}}^2,$$

$$\Lambda_{\text{Bind}} \sim (\text{pion size})^{-1}$$

(sensitive to details of QCD)

- Back to the Higgs:
- Let Λ_{new} be a scale where the SM+Higgs interactions must be modified (Ex: $\Lambda_{\text{new}} \sim (\text{size of Higgs particle})^{-1}$)
- At which energy scale, Λ_{new} , will $\mathcal{O}(1)$ changes in Λ_{new} have $\mathcal{O}(1)$ effect on the Higgs mass?

$$\Delta m_H^2 \sim \frac{y_t^2}{(4\pi)^2} \Lambda_{\text{new}}^2$$



Since $y_t \sim \mathcal{O}(1)$, $m_H \sim 100 \text{ GeV} \Rightarrow$
 $\Lambda_{\text{new}} \gtrsim 1 \text{ TeV}$

or if

$\Lambda_{\text{new}} \gg 1 \text{ TeV} \Rightarrow$ "fine tuned new" physics

(tiny changes in $\Lambda_{\text{new}} \Rightarrow \mathcal{O}(1) m_H$)

- Generic new physics at $E \sim \text{TeV}$

Beyond the SM theories

- Decrease the sensitivity of m_H to short distance physics.

SUSY:

SM particle \longleftrightarrow particle of opposite stat.
partner

spin $\frac{1}{2}$ e^-

spin 0 \tilde{e}^-

spin $\frac{1}{2}$ q

spin 0 \tilde{q}

spin 1 g, γ, W

spin $\frac{1}{2}$ $\tilde{g}, \tilde{\gamma}, \tilde{W}$

Spin 0 H (boson)

spin $\frac{1}{2}$ \tilde{H} (fermion)

m_H

\equiv
(perfect SUSY)

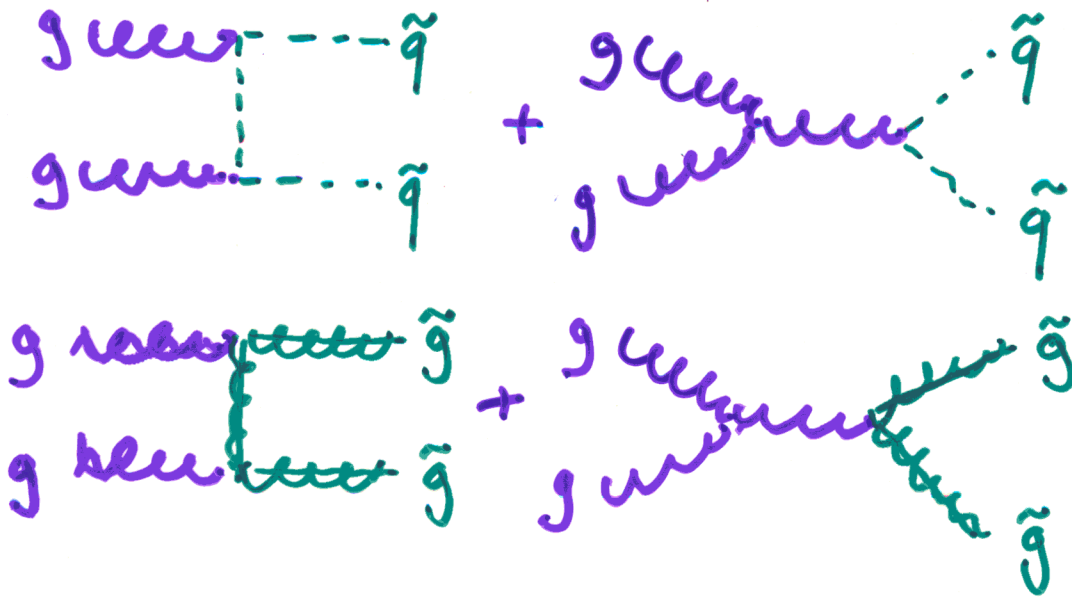
$m_{\tilde{H}}$

$\Delta m_{\tilde{H}} \sim m_{\tilde{H}} \text{Log}(\Lambda_{\text{new}})$

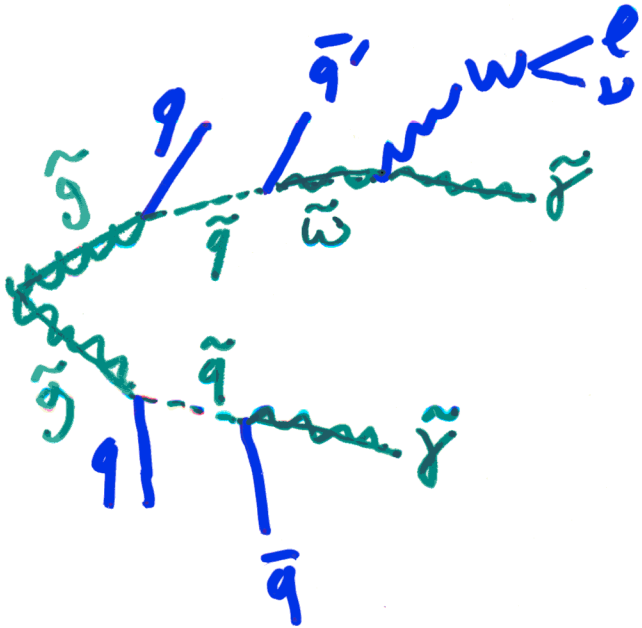
- $\Lambda_{\text{new}} \gg 1 \text{ TeV}$, $\mathcal{O}(1)$ changes in Λ_{new} amount to % changes in m_H

SUSY - Rich LHC Pheno

- New colored particles: \tilde{q}, \tilde{g}

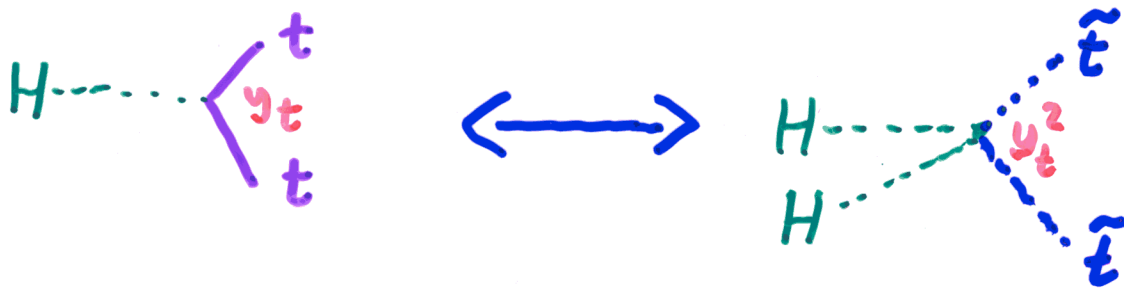


- Cascade Decays:



- General aspects of SUSY:
 - No proton decay \Rightarrow Lightest SUSY particle is stable \Rightarrow every event has \cancel{E}_T .
 - Typical event: jets, leptons, hard photons, \cancel{E}_T .
 - Might even get displaced vertices (Ex: $\tilde{\gamma} \rightarrow \gamma \tilde{G}$)
 - Cascades provide mass difference info.
 - Gluino may decay to same sign leptons (Majorana).
 - The stop should be light.

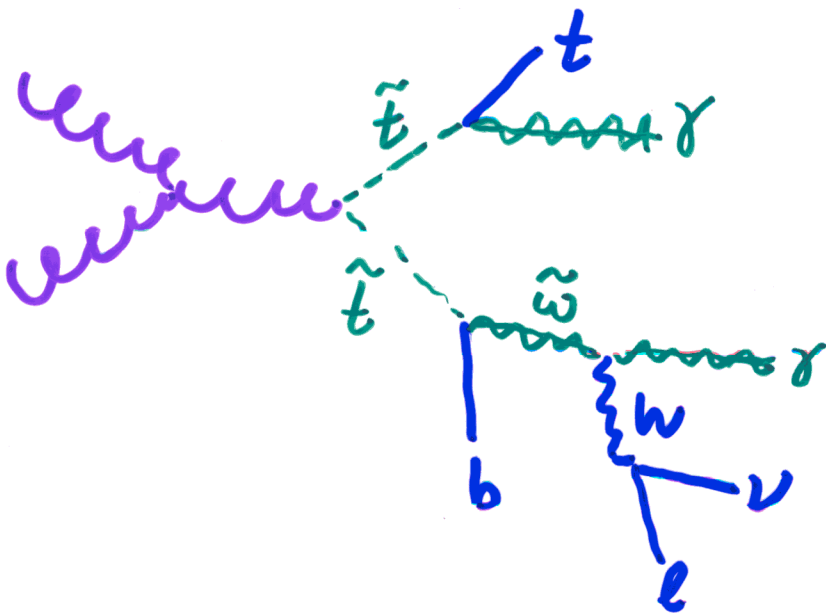
SUSY:



$$\Delta m_H^2 \sim \frac{y_t^2}{(4\pi)^2} M_{\tilde{t}}^2$$

Lack of fine tuning:

$$M_{\tilde{t}} \lesssim 1 \text{ TeV}$$



Composite Higgs

- Higgs is a boundstate of fermions (similar to the pion).

$$\Lambda_{\text{new}} \sim (\text{Higgs size})^{-1}$$

- Early attempts:

$\Lambda_{\text{new}} \sim 1 \text{ TeV}$, $m_H \sim 100 \text{ GeV}$,
but difficult $M_W \ll 1 \text{ TeV}$
(required fine-tuning).

- "Little" Higgs:

— Careful use of symmetry:

$$\Lambda_{\text{new}} \sim 10 \text{ TeV}, m_H \sim 100 \text{ GeV}$$

Nature of symmetry is
similar to isospin nuclear symm.
(relate pions to each other, $N \leftrightarrow p$)

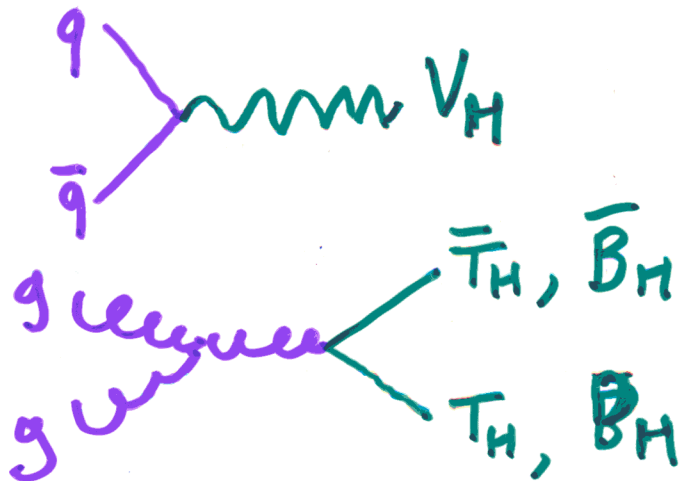
- Larger Symm: New multiplets -

Generically: $H \longleftrightarrow$ New scalars

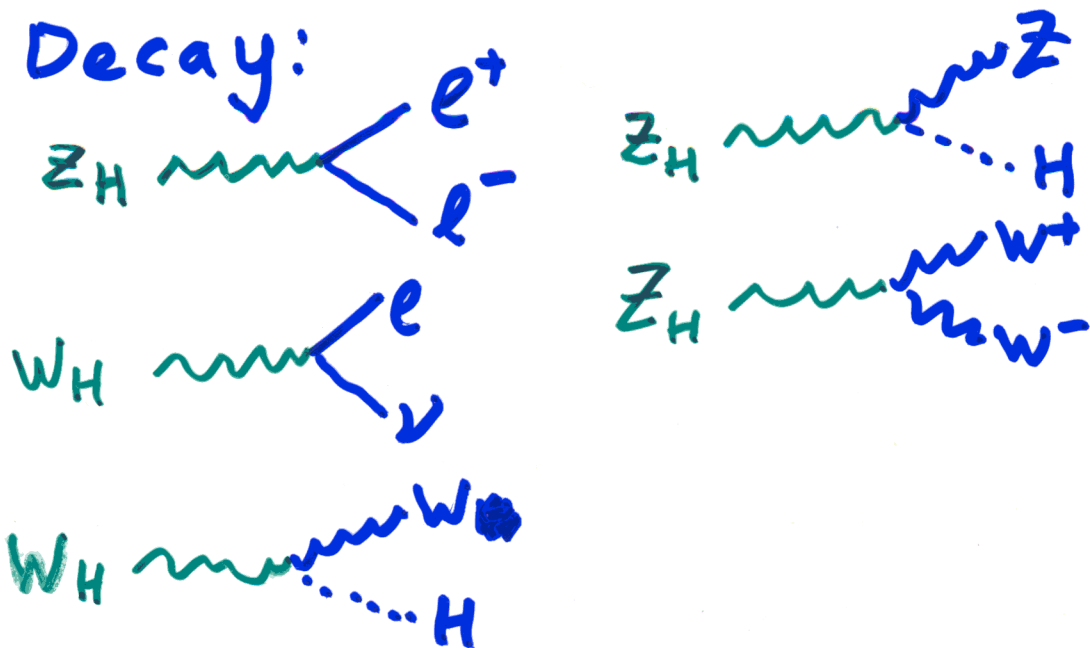
$t \longleftrightarrow$ New colored fermions

$W, Z \longleftrightarrow$ New weakly interacting vector - bosons

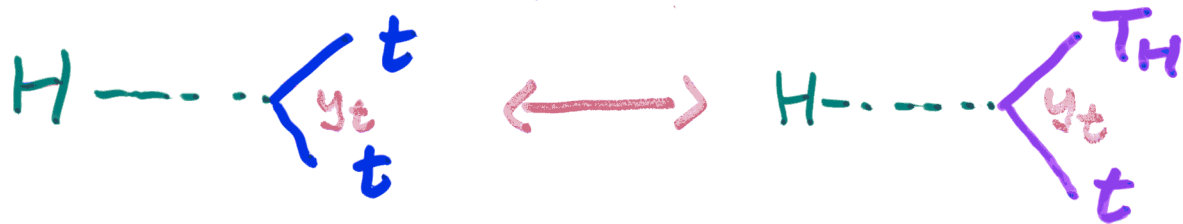
- Production:



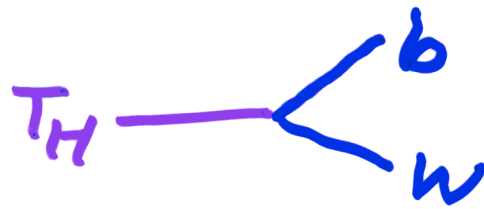
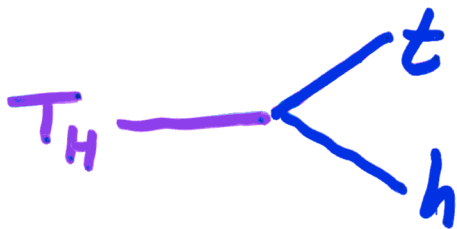
- Decay:



- As with SUSY, top-partner must be light



$$\Delta M_H^2 \sim \frac{y_t^2}{(4\pi)^2} M_{T_H}^2$$



Conclusion

- There must be new physics beyond the Higgs
- Because of large Higgs-top interaction, we expect new colored particles
(Having a gluon collider)
is good
- LHC physics will be rich.