Phenomenology of a little Higgs model with T-parity

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hep-ph/0411246

Introduction – The little Hierarchy Problem

- We want the Higgs to be light
- We want to avoid EWP constraints

} Tension

New physics that couples to SM shifts observables (e.g. EWPT's)

scale of new physics must be high!

Need to keep the Higgs mass light

scale of new physics must be low!

- Goal: Introduce new physics in a way such that *both* issues are resolved

Little Higgs and Supersymmetry

- For some time, SUSY was the only weakly coupled theory that solved the little hierarchy problem

  strong coupling (technicolor) has EWP issues of its own (but concept very attractive)

- Are there other models of *weakly* coupled physics at ~1 TeV that solve the (big) hierarchy problem?

- Can we introduce this new physics in such a way that we alleviate the little hierarchy?

  little Higgs models are an attempt to do just this

Little Higgs models

- The new concept is "*collective symmetry breaking*"

Higgs is a pseudo-Goldstone boson (PGB) kept light by approximate global symmetries (old idea, new features)

Georgi, Kaplan – early 80's

Global symmetries are broken explicitly, but in a special way

Arkani-Hamed, Cohen, Georgi hep-ph/0105239

$$\mathcal{L} = \mathcal{L}_1 + \mathcal{L}_2$$

- $\mathcal{L}_1$ breaks some of global symmetries
- $\mathcal{L}_2$ breaks some others

Together, couplings break all symmetries protecting the Higgs mass, and we generate an m_H^2 at *two-loop order*

Example – The littlest Higgs

Arkani-Hamed, Cohen, Katz, Nelson hep-ph/0206021

- Parametrize SU(5)/SO(5) breaking by nlσm
- VEV Σ_0 breaks $[SU(2)xU(1)]^2$ to $SU(2)_L xU(1)_Y$

New gauge bosons get mass ~ f

$$\Sigma = e^{2i\Pi/f}\Sigma_0 \qquad \Sigma_0 = \langle\Sigma\rangle = \Sigma_0 = \begin{pmatrix} & & & 1 & \\ & & & & 1 \\ & & 1 & & \\ 1 & & & & \\ & 1 & & & \end{pmatrix}$$

$$\Pi = \begin{pmatrix} 0 & \frac{H}{\sqrt{2}} & \Phi \\ \frac{H^\dagger}{\sqrt{2}} & 0 & \frac{H^T}{\sqrt{2}} \\ \Phi^\dagger & \frac{H^*}{\sqrt{2}} & 0 \end{pmatrix}$$

Higgs is exact Goldstone under either SU(3)

Φ is a complex triplet under $SU(2)_L$

Collective breaking (littlest Higgs)

SU(5)/SO(5) symmetry breaking pattern – gauge symmetries embedded in SU(5) global symmetry

$$Q_1^a = \begin{pmatrix} \sigma^a/2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \qquad Y_1 = \mathrm{diag}(3,3,-2,-2,-2)/10$$

$$Q_2^a = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\sigma^{a*}/2 \end{pmatrix}, \qquad Y_2 = \mathrm{diag}(2,2,2,-3,-3)/10\,,$$

$$[SU(2) \times U(1)]^2$$

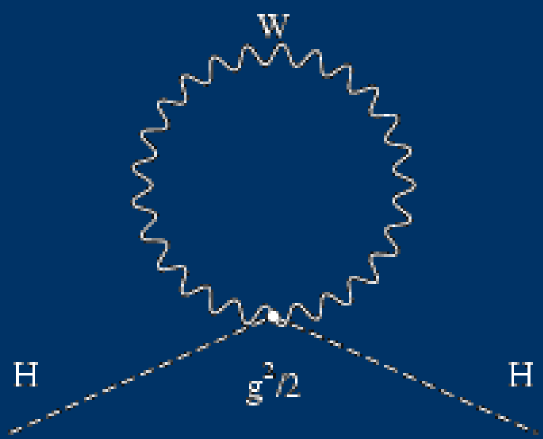
$\mathcal{L}_1$ preserves SU(3) in bottom right

$\mathcal{L}_2$ preserves SU(3) in upper left

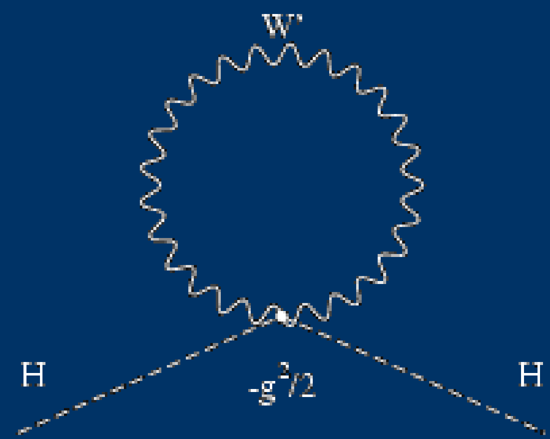
Either SU(3) is enough to keep Higgs massless

- But the sum of *all* the gauge interactions breaks all symmetries protecting the Higgs mass

New Symmetries = New Particles



$$\sim \frac{3g^2\Lambda^2}{(4\pi)^2}$$



$$\sim -\frac{3g^2\Lambda^2}{(4\pi)^2}$$

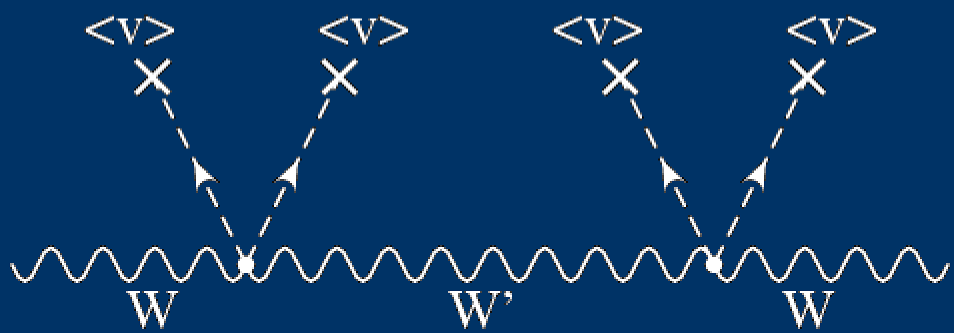
New 'partners' of standard model fields cancel one loop quadratic divergences

Global symmetry structure ensures relation between couplings

Partners (unlike in SUSY) have *same statistics*

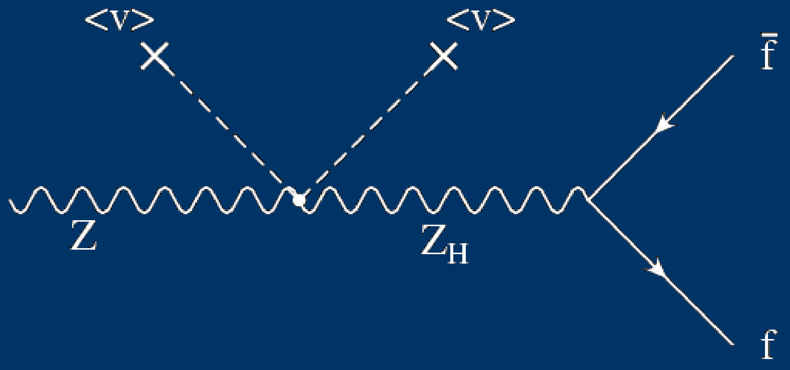
Electroweak Precision

Simplest models still require fine tuning



Such diagrams give large contributions to custodial SU(2) violation – large ρ (or T) parameter contributions

Also contributions to $Zb\bar{b}$ vertex



Summary of Littlest Higgs

- Global SU(5) is explicitly broken to SU(3) by any one given interaction
- New gauge bosons and scalars near SU(5) breaking scale f
- Interactions of standard model particles with new degrees of freedom create tension with EWP (no solution to little hierarchy)
- An effective theory which is good only to ~10 TeV

T-Parity and the littlest Higgs

Cheng, Low

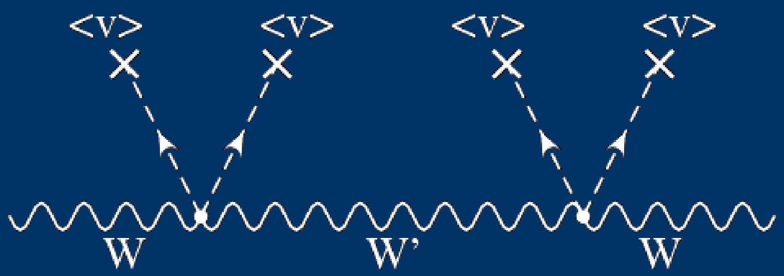
- Original models have stringent EWP bounds

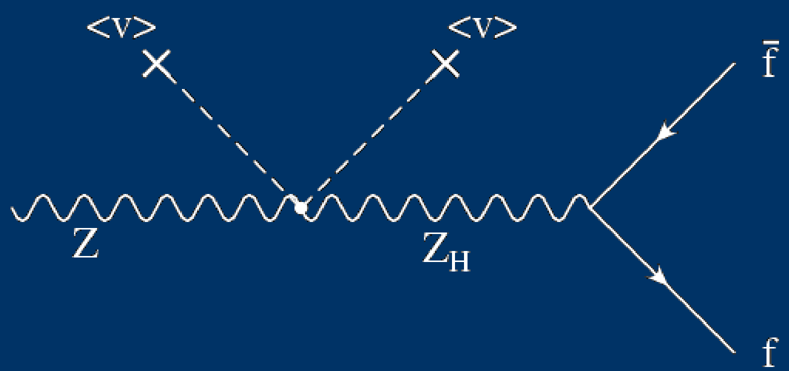
Csaki, Hubisz, Kribs, Meade, Terning

- New models which evade constraints exist, but involve more complicated gauge/global symmetry structures
- Just as R-parity cures ills of SUSY (proton decay, lepton flavor violation), T-parity is a discrete symmetry that is added to solve the tree level EWP issues in LH
- Can also provide a weak scale dark matter candidate

T-Parity

- (almost) all new particles introduced are odd under a discrete symmetry (W', Z', A', Φ)
- Dangerous diagrams are forbidden (e.g. tree level mass shifts, and 4-Fermi operators)
- Discrete symmetry exchanges the two gauge groups $[SU(2)xU(1)]_1$ and $[SU(2)xU(1)]_2$
- T-parity enforces relations between couplings (i.e. $g_1 = g_2$)





Missing Energy Signal

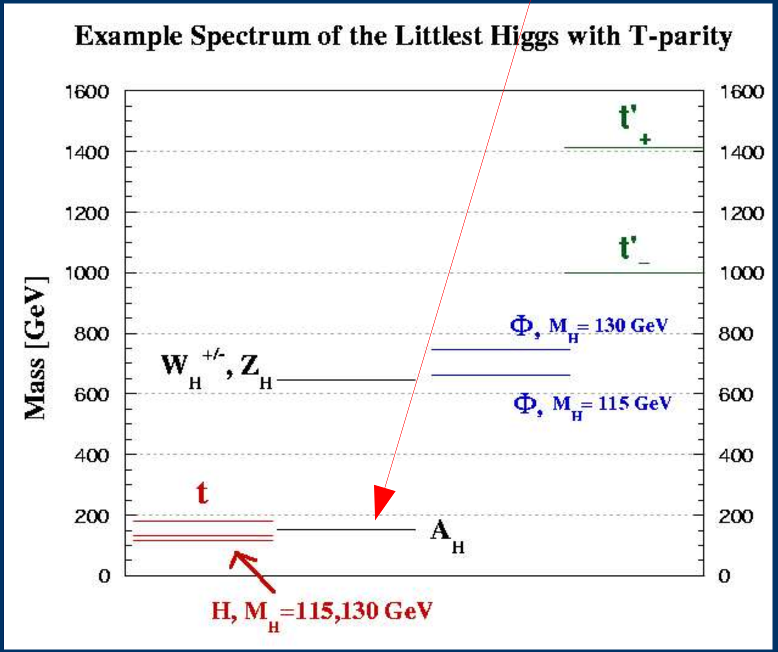
- If T-Parity is exact, lightest T-odd particle is stable (like lightest SUSY partner is stable due to R-parity) and neutral
- Leaves the detector without depositing any energy
- Reconstruction difficult

T-Parity fixes most parts of the low energy spectrum shown here

Breaking scale f fixes the new gauge boson masses

Higgs mass fixes the triplet mass

One free parameter in the new top sector

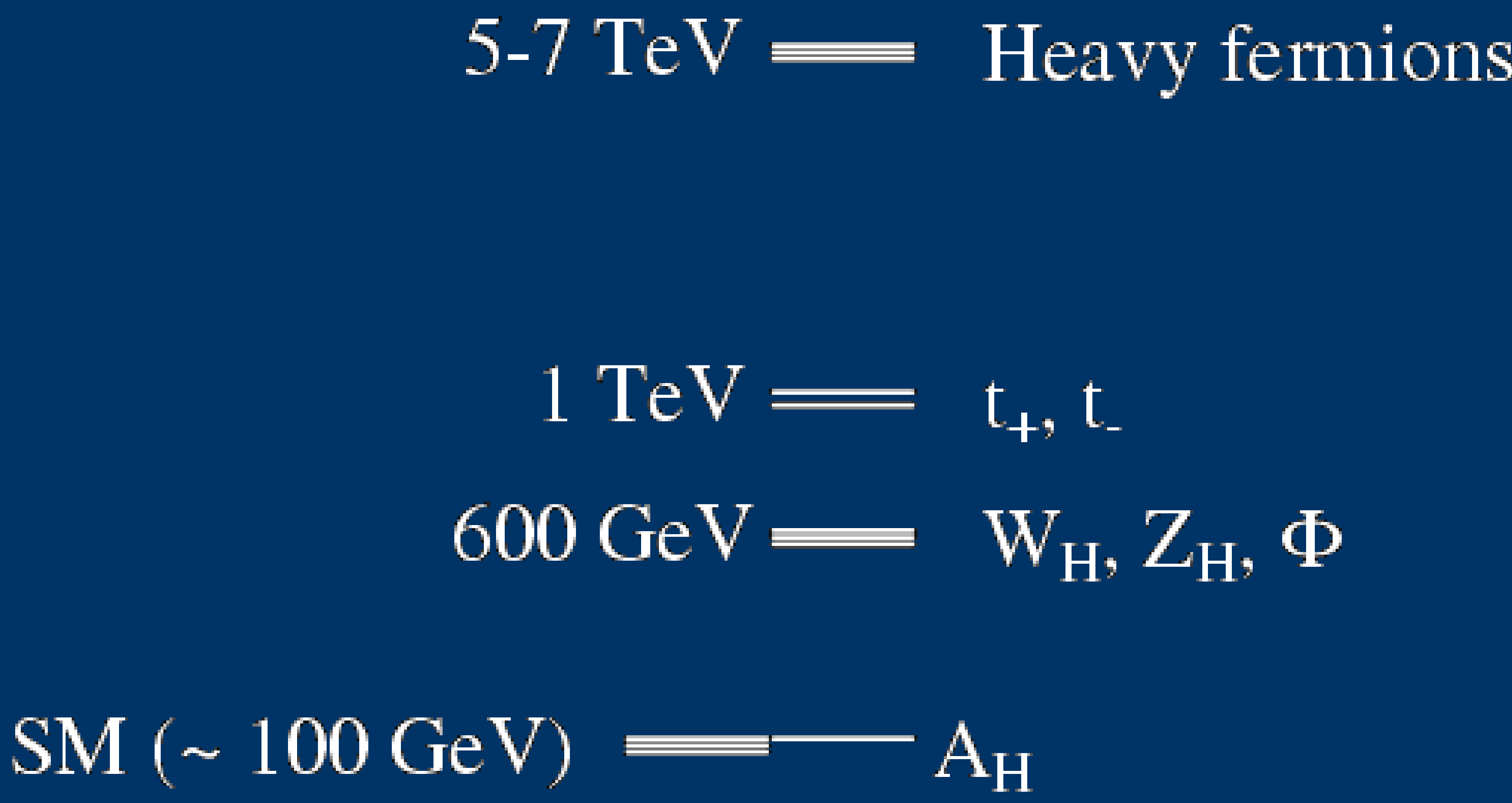


New degrees of freedom

- Littlest Higgs spectrum is same, with the exception of a new t_ SU(2) singlet
- Many new T-odd fermions (T-parity partners of standard model quarks and leptons)
- In our analysis we decouple most particles not involved in the little Higgs mechanism

Look at phenomenology of simpler model before including many new degrees of freedom, and many new parameters

Spectrum (f ~ 1 TeV)



Collider Phenomenology

- Expand nlσm fields in powers of π/f and read off interactions
- Program interactions into COMPHEP
- Generate cross sections (LHC), decay widths, and branching fractions of new particles

Event generation
Detector simulation

future work

What's new with T-Parity?

- T-odd particles must be pair produced

  Radically different collider signal compared to original little Higgs models

- t_+ is the exception (new T-even particle needed for LH mechanism)

  Previous studies do not apply

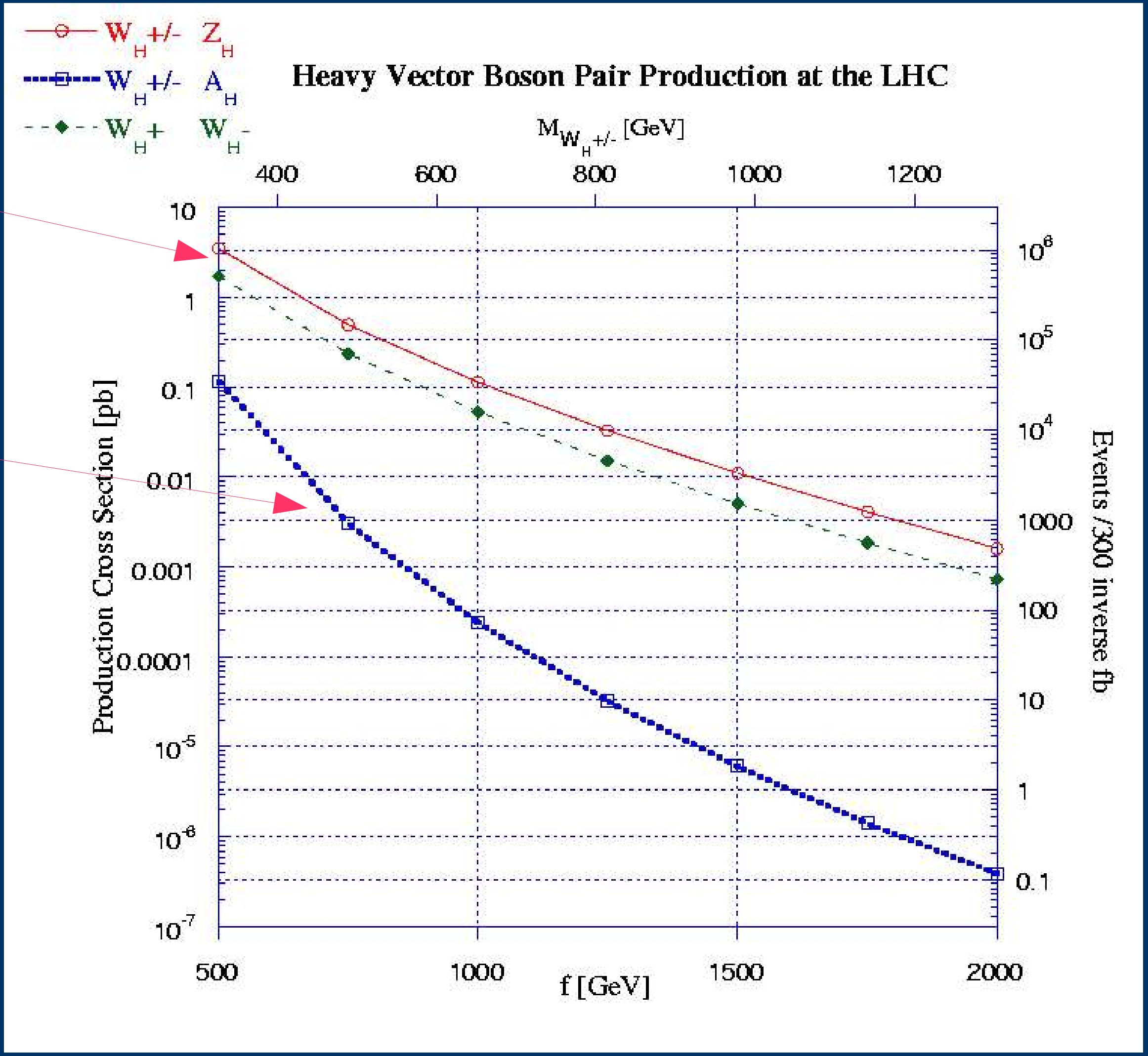
- FAKING SUSY – difficult to determine spins at LHC, and final states similar

Heavy vector boson pair production

Primary production channels are $W_H + Z_H$ and $W_H + W_H$

$W_H + A_H$ suppressed by small mixing angle

EWSB effect is $(v/f)^2$ suppressed



Heavy gauge boson decays

If T-parity is exact, then A_H escapes detector

$Z_H \to H A_H$ 100%

$W_H^{\pm} \to W^{\pm} A_H$ 100%

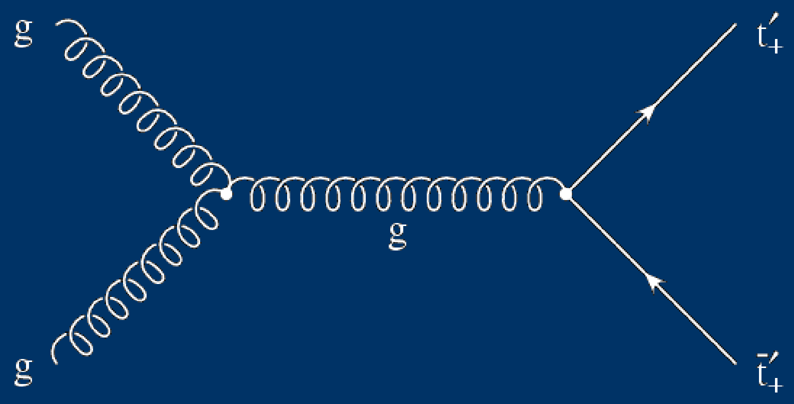
Either Higgs + W in the final state or two Higgses, while rest goes into missing energy

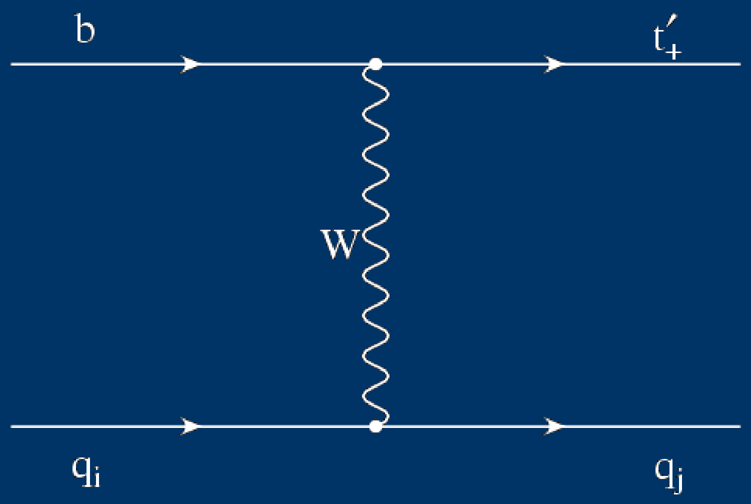
- But T-Parity need not be exact! (If we give up on LH dark matter)

Violations of 10% or so still solve little hierarchy problem

Small deviations in gauge coupling relations lead to leptonic decay of A_H - Nice signal!

t'_+ Production at the LHC



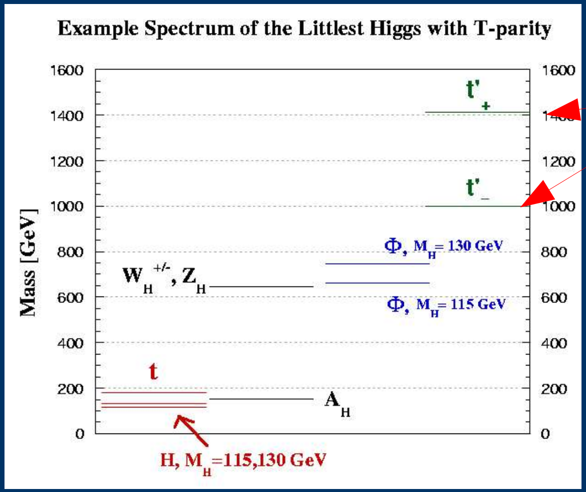


- Gluon fusion and W-b fusion produce the T-even partner of the top
- New particle does not need to be pair produced

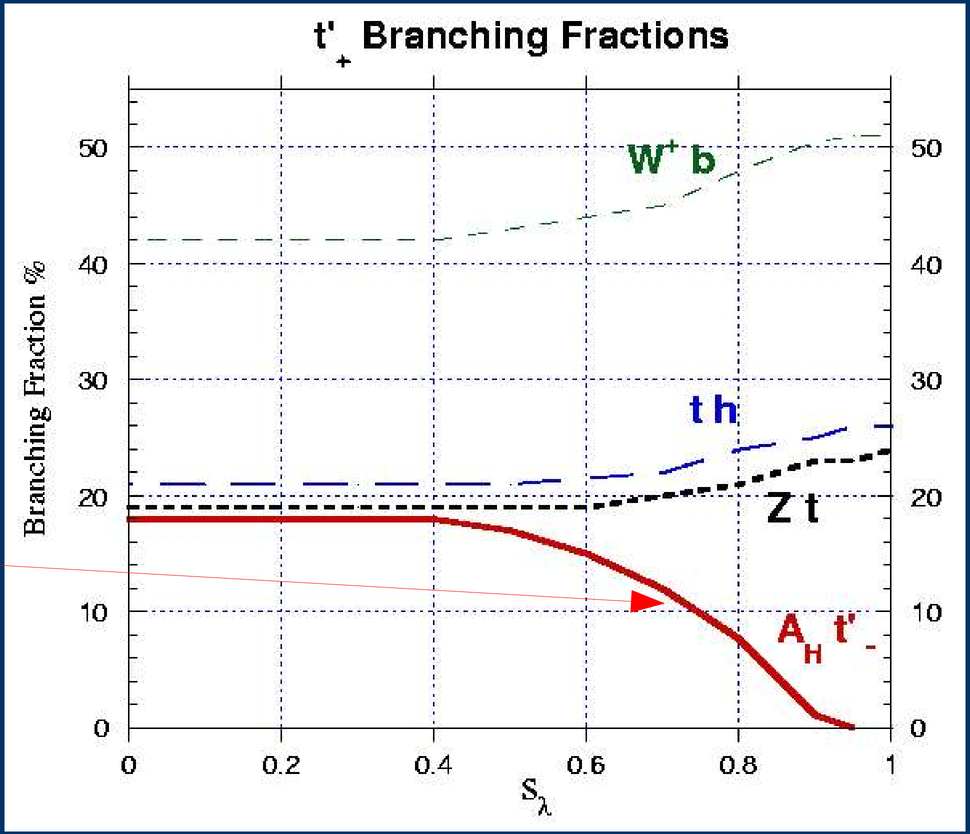
Production cross sections are the same as those calculated for littlest Higgs w/o T-parity

Han, Logan, McElrath, Wang
Perelstein, Peskin, Pierce

t'_+ Decays



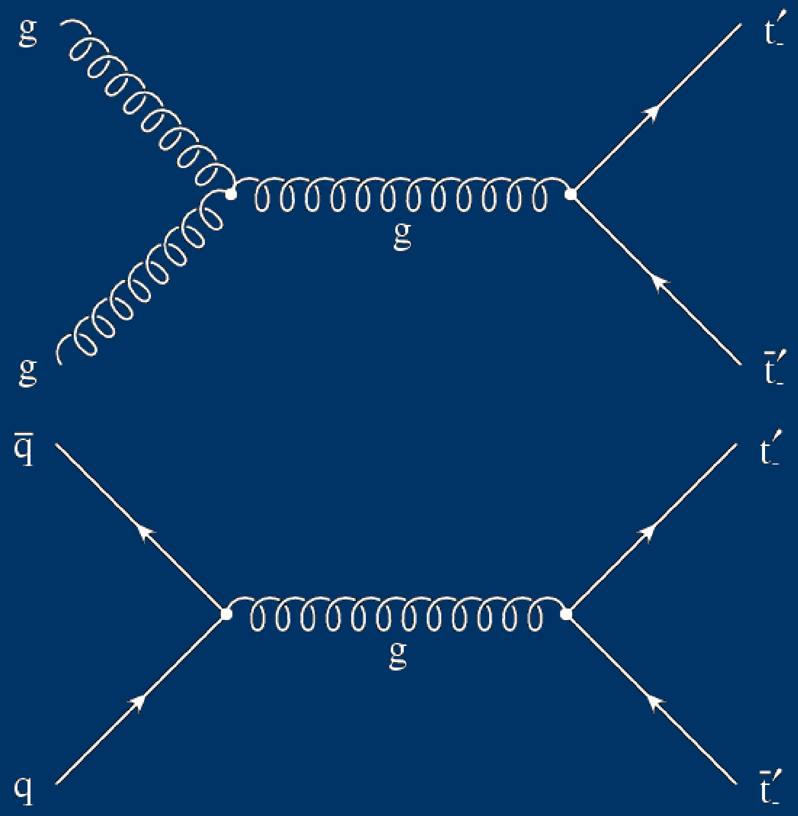
t_- is always lighter than t_+

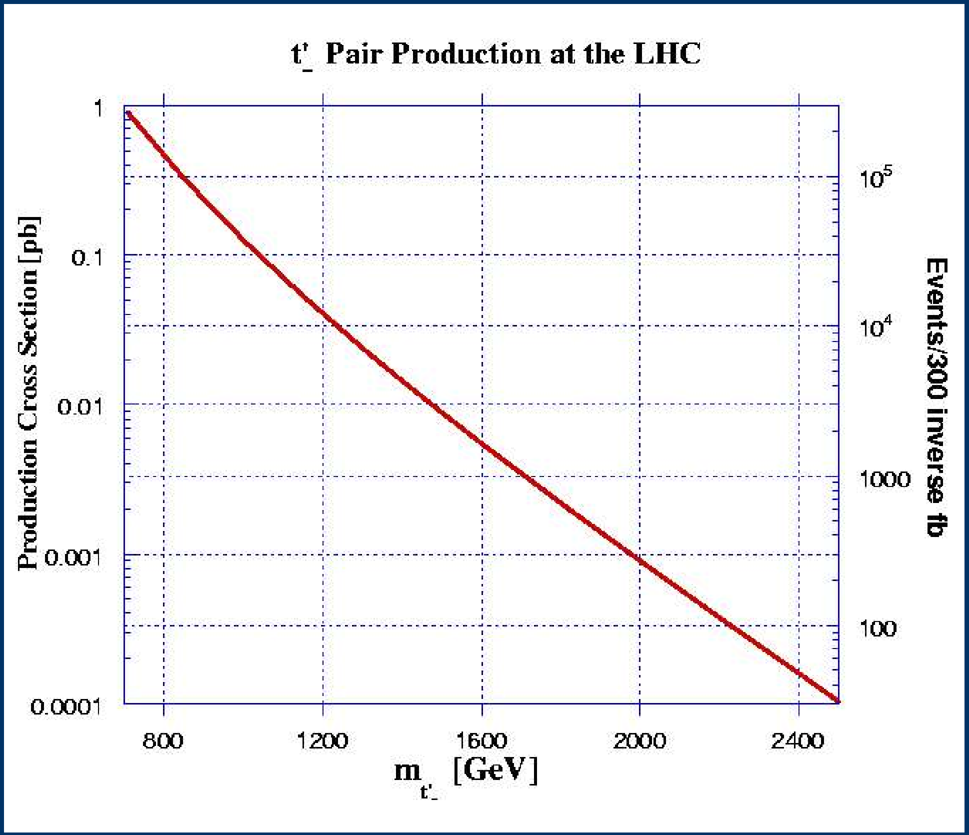


Sizable branching fraction to missing energy

Cannot extract total width as with original littlest Higgs

t'_- Production





T-odd, so can they can only be pair produced

t_- decay:

$t_- \rightarrow tA_H$ 100%

Triplet production

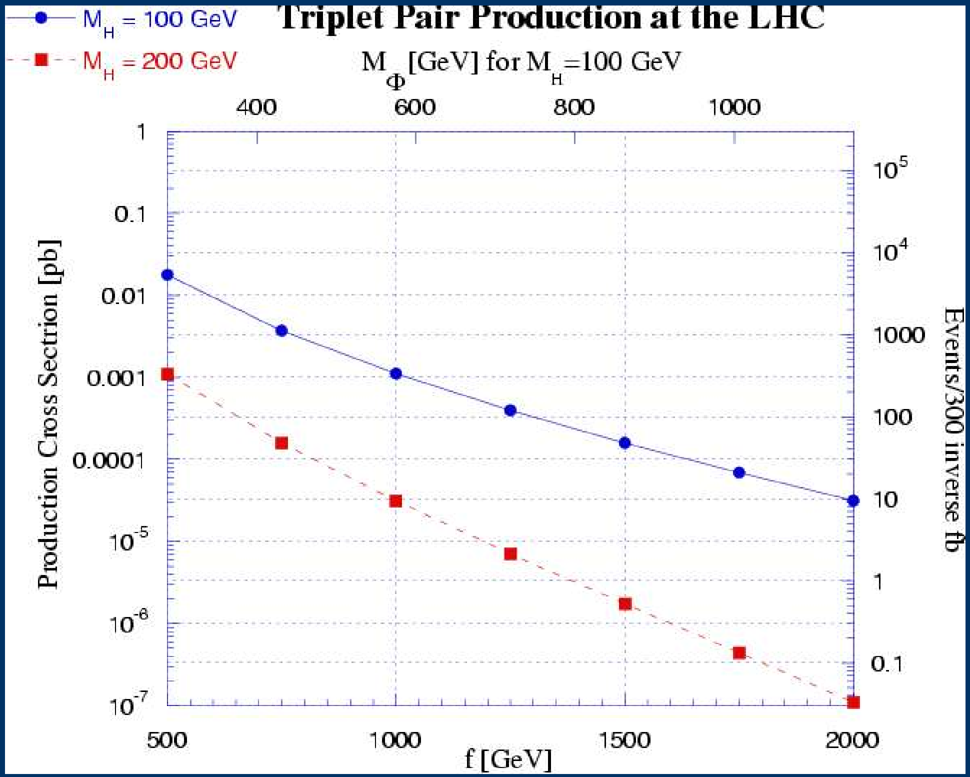
$\phi^{\pm\pm}$, $\phi^{\pm}$, ϕ^{S}, and ϕ^{0}

Symmetries give mass relation between Higgs and triplet:

$$m_\Phi^2 = \frac{2m_H^2 f^2}{v^2}$$

Promising signal:

$$pp \to \phi^{\pm}\phi^{S} \to W^{\pm} A h A_H A_H$$



Standard model background is small, but signal gives only 10-100 events at f ~ 1 TeV

Conclusions

- Possible to construct a LH model with no tree level EWP constraints
- Minimal spectrum similar to many other LH models
- Collider signals can fake SUSY at the LHC

Future: Discovery possibility analysis
EWP at one loop level
Analysis including additional heavy fermions