Little Higgs

and other extensions of the EWSB sector

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Not in this talk

- Little Higgs at linear colliders
- Little Higgs and astrophysics/cosmology
- Supersymmetric Little Higgs
- UV completions

Outline

- Models
- Precision electroweak constraints
- Flavor
- LHC discovery potential
- Distinguishing scenarios and models
- Tests of the Little Higgs idea

The models

All LH models are constructed such that the Higgs doublet(s) is a pseudo-Goldstone boson

The shift symmetry

$$h \longrightarrow h + \eta$$

is explicitly broken

The obvious thing does not work:

$$V(h) = \rho\, G(h/f) \propto \rho \left(\frac{h}{f}\right)^2 + \rho \left(\frac{h}{f}\right)^4 + \ldots$$

As both the quartic amd quadratic terms are governed by the same symmetry-breaking parameter ρ

"Collective" symmetry breaking

Shift symmetry preserved despite explicit breaking

$$h \longrightarrow h + \eta_1 \qquad (\rho_1 \neq 0)$$

$$h \longrightarrow h + \eta_2 \qquad (\rho_2 \neq 0)$$

$$V = \rho_1 V_1(\phi^a - h^\dagger \sigma^a h) + \rho_2 V_2(\phi^a + h^\dagger \sigma^a h)$$

$\rho_1, \ \rho_2$ could be two gauge couplings, two Yukawa couplings, two contributions to the Higgs quartic term, etc

Quadratic divergences for the Higgs mass are absent at one loop because there are no one-loop diagrams that involve two different gauge couplings, two Yukawas, etc

The most important, numerically, quadratic divergences are from the top, SU(2) gauge bosons, Higgs, U(1) gauge

If these are absent electroweak theory is natural to 10 TeV.

(It is easy to extend this approach and remove 2, 3, ... loop quadratic divergences. However, it is not useful to do so as logarithmically divergent and finite corrections do bite.)

New TeV-scale particles: top partners, new gauge bosons, SU(2) singlet or triplet scalars.

LH Models are classified according to the global symmetry breaking patterns and the (extended) electroweak gauge group

$SU(3) \times SU(3) \to SU(3)$	$SU(3) \times SU(2) \times U(1)$
$SU(5) \to SO(5)$	$(SU(2) \times U(1))^2$
$SU(6) \to Sp(6)$	$(SU(2) \times U(1))^2$
$(SU(4) \to SU(3))^4$	$SU(4) \times U(1)$
$SU(9) \to SU(8)$	$SU(3) \times U(1)$
$\dots$	$\dots$

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$\ldots$	$\ldots$

An alternative classification is according to the forms of the adjectives “small”, “simple”, “minimal”, “little” used by the authors to describe their models

An important subset of LH models - are "T parity" models

T parity is a discrete, Z_2, symmetry designed such that most, or all, new particles are odd while SM particles are even

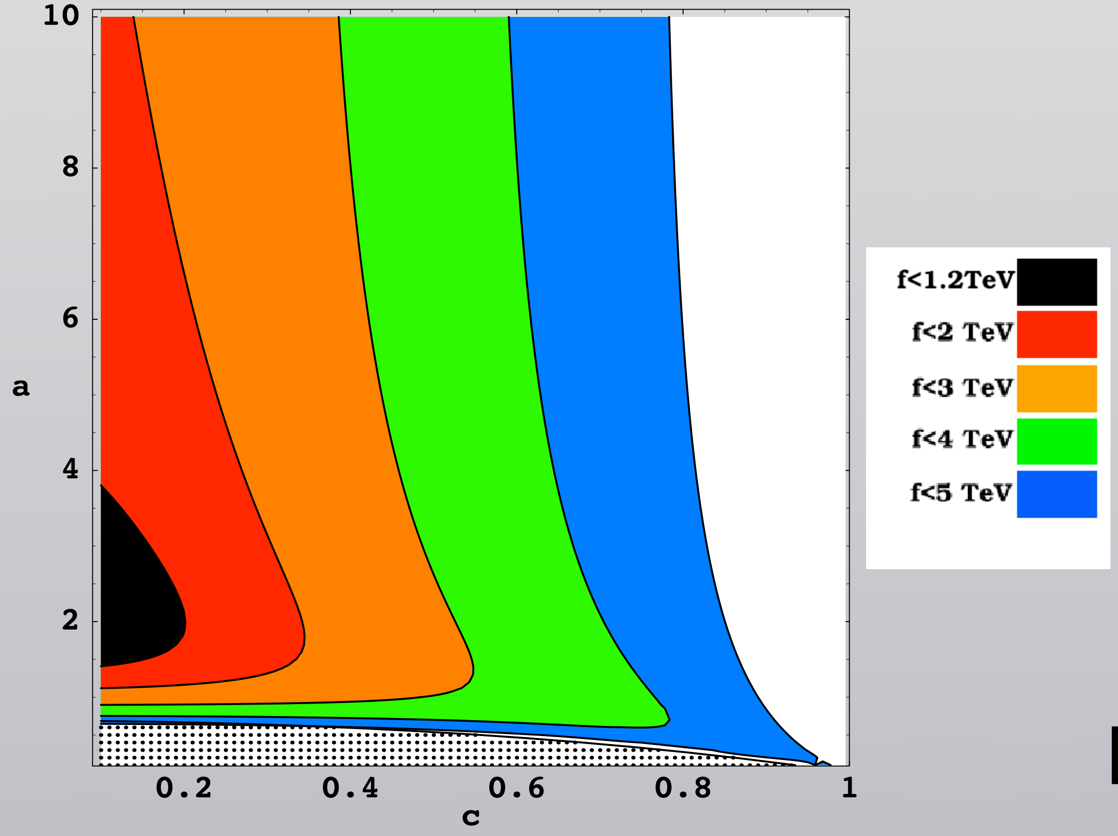
Important consequences:

- no tree level contributions to precision electroweak
- new scalars, especially triplets, don't get vevs
- dark matter candidate

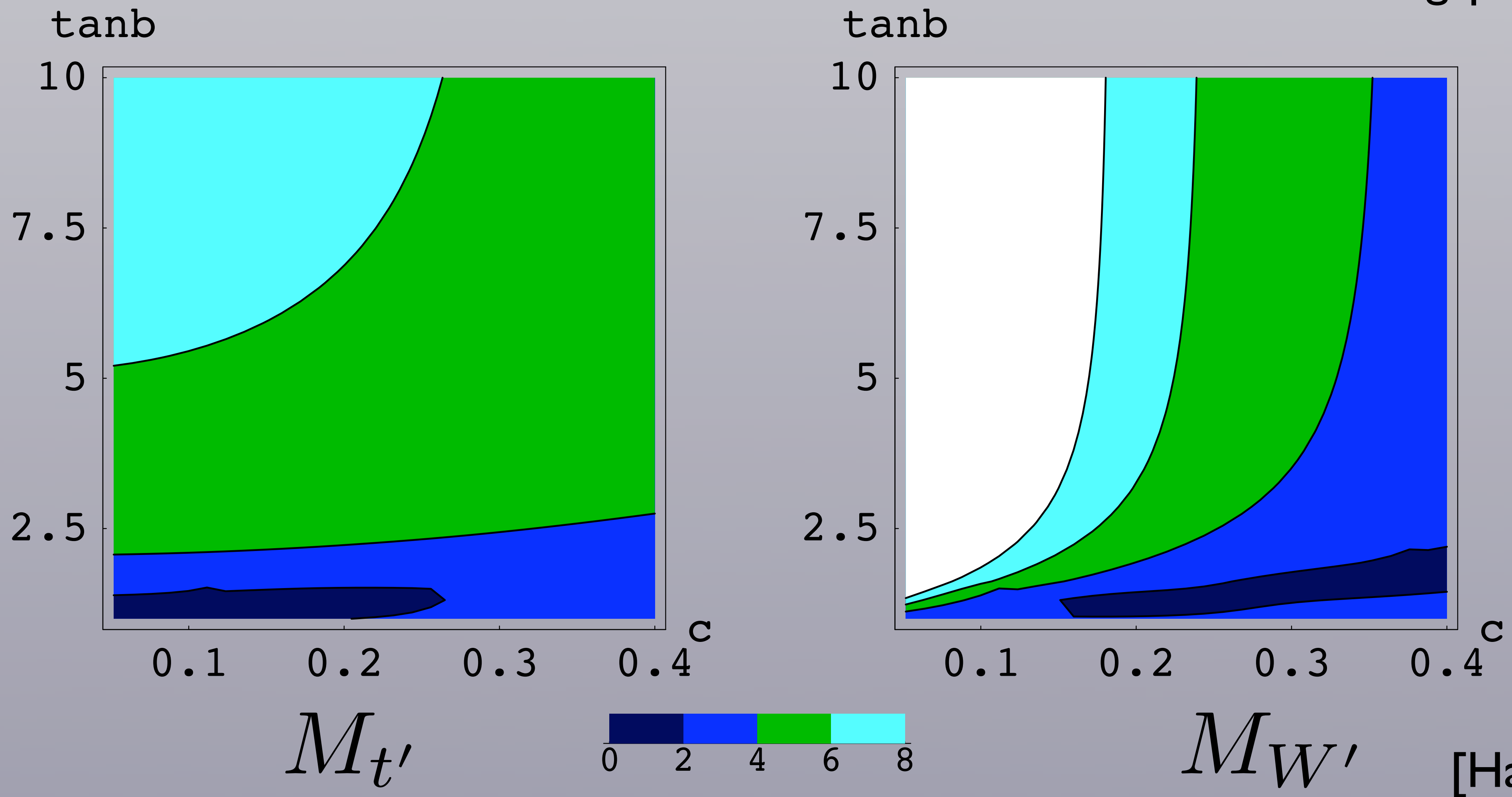
Electroweak constraints

Three main sources of constraints (no T parity):

- new gauge bosons: produce four-fermion operators and by mixing with the SM gauge bosons alter the couplings of SM bosons to fermions
- triplet scalar: alters the rho (or T) parameter
- fermion mixing: alters the couplings of SM bosons to fermions

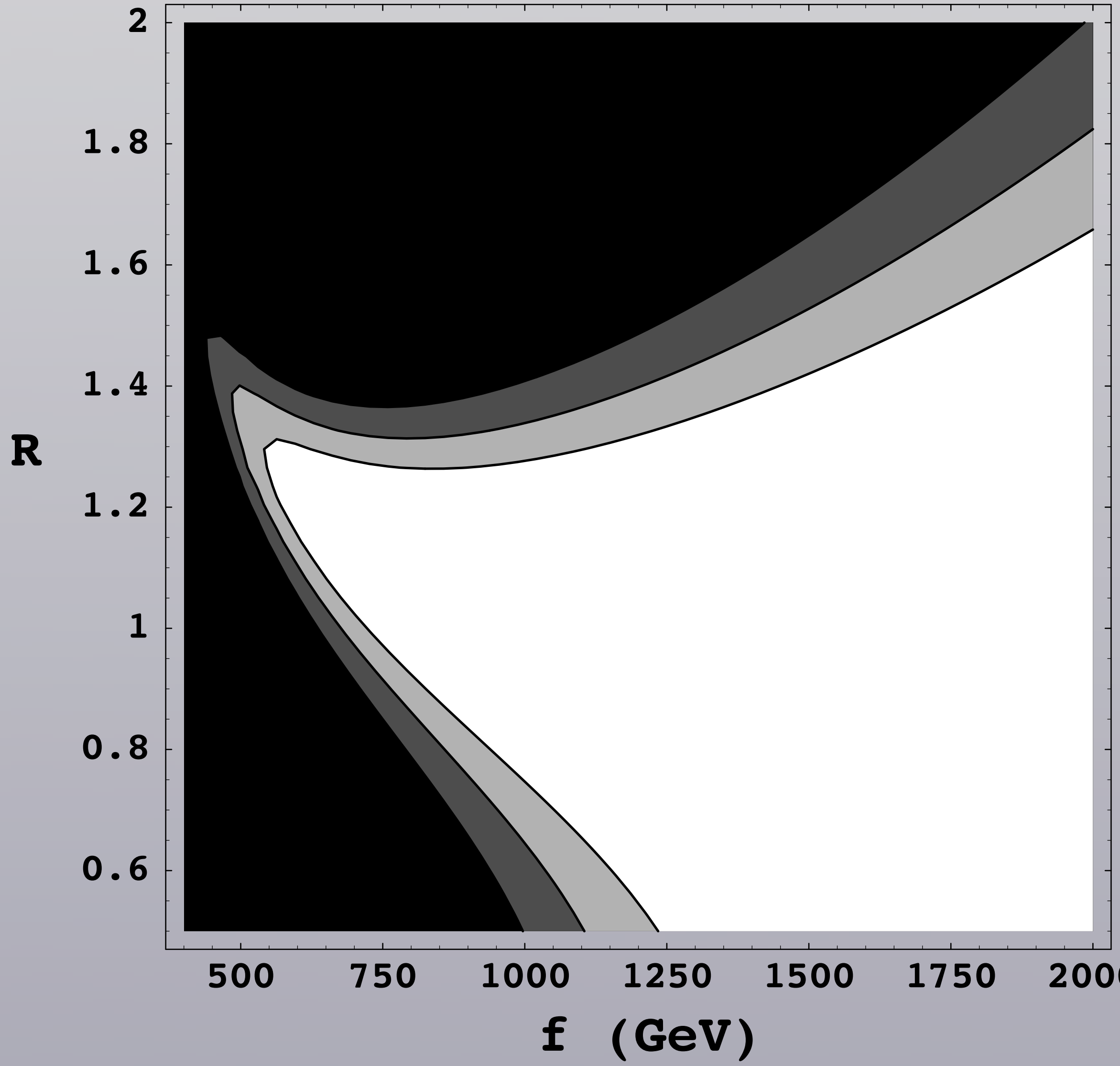


[Csaki, Hubisz, Kribs, Meade, Terning, ph/0303236]



[Han, WS, ph/0506206]

A T-parity LH model: constraints from the S and T parameters



$$R = \frac{\lambda_1}{\lambda_2}$$

(Ratio of Yukawa couplings)

[Hubisz, Meade, Noble, Perelstein, ph/0506042]

Flavor

- New fermions mix with SM fermions, making 3 by 3 CKM matrix non-unitary
- New gauge bosons contribute to box diagrams potentially altering predictions

Constraints (model-dependent) from numerous processes

$K-\overline{K},\ D-\overline{D},\ B-\overline{B},\ BR(D\to ...),\ BR(B\to ...),\ t\to cZ$

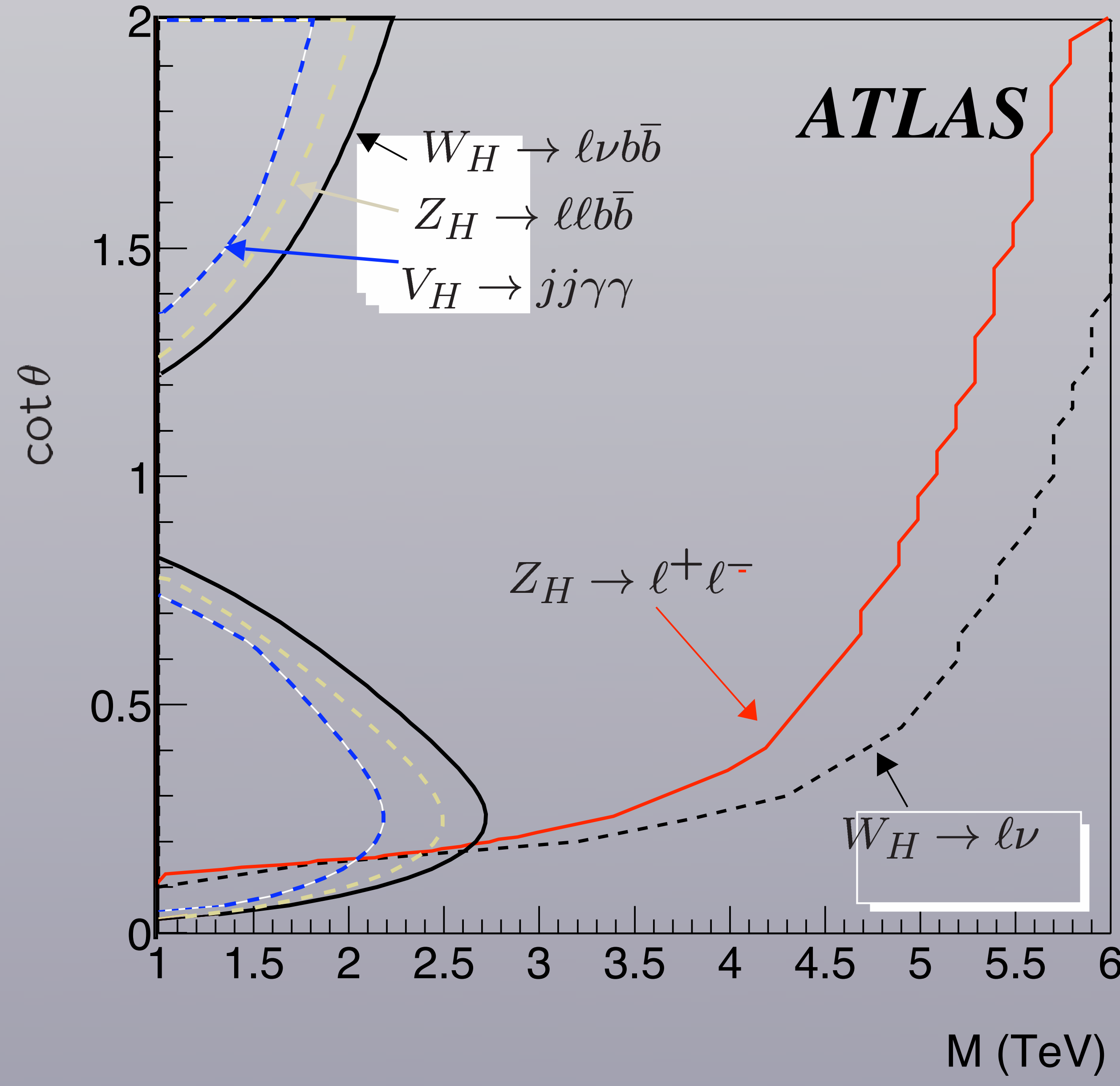
$\mu\to e\gamma,\ \mu\to 3e,\ \tau\to l\pi$

[A. Buras and collaborators, others]

New production channels for single heavy quarks

LHC discovery

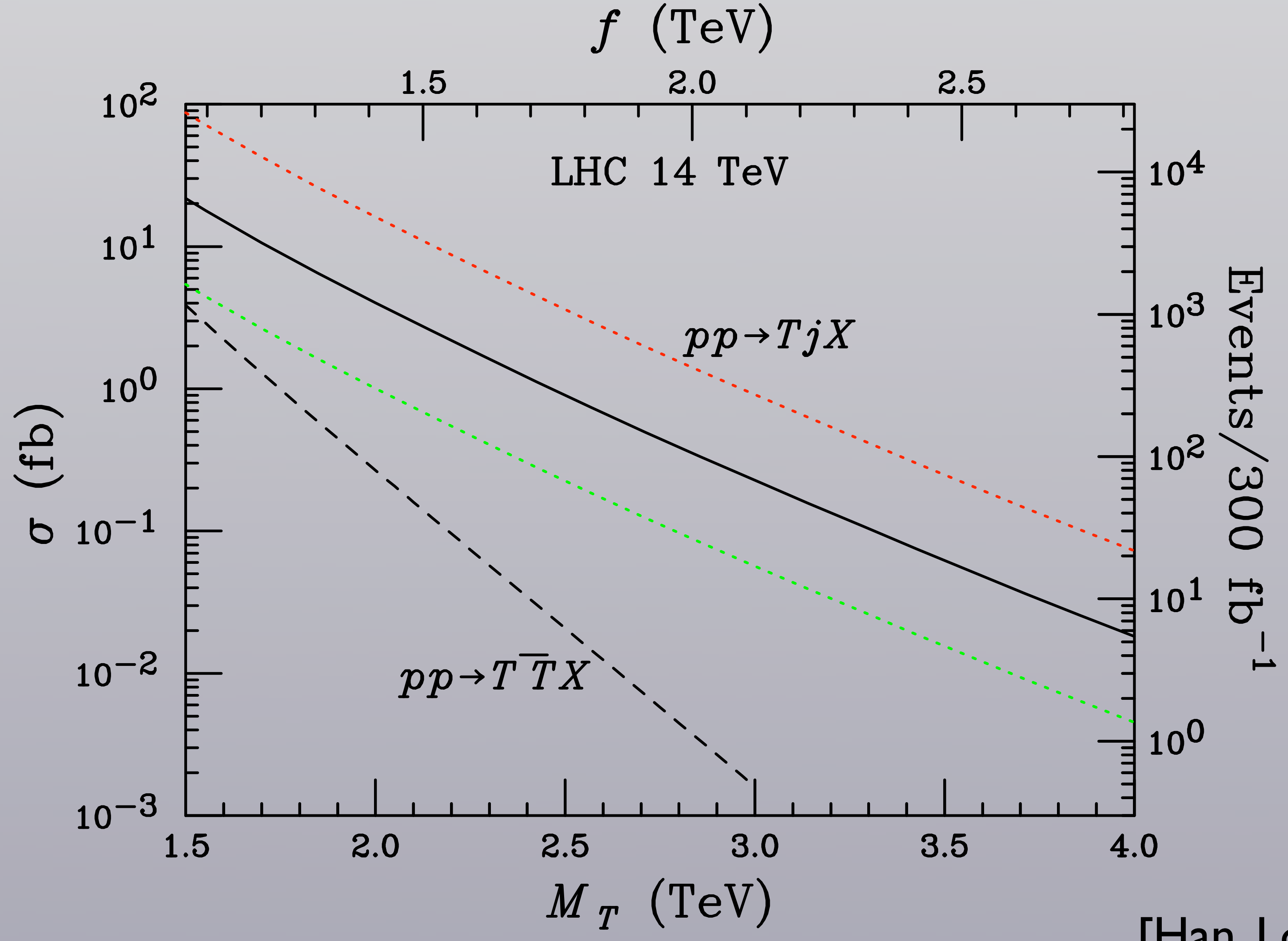
Models without T parity - standard heavy gauge boson and heavy quark searches



[300 inverse fb,
an (SU(2)xU(1))^2 model]

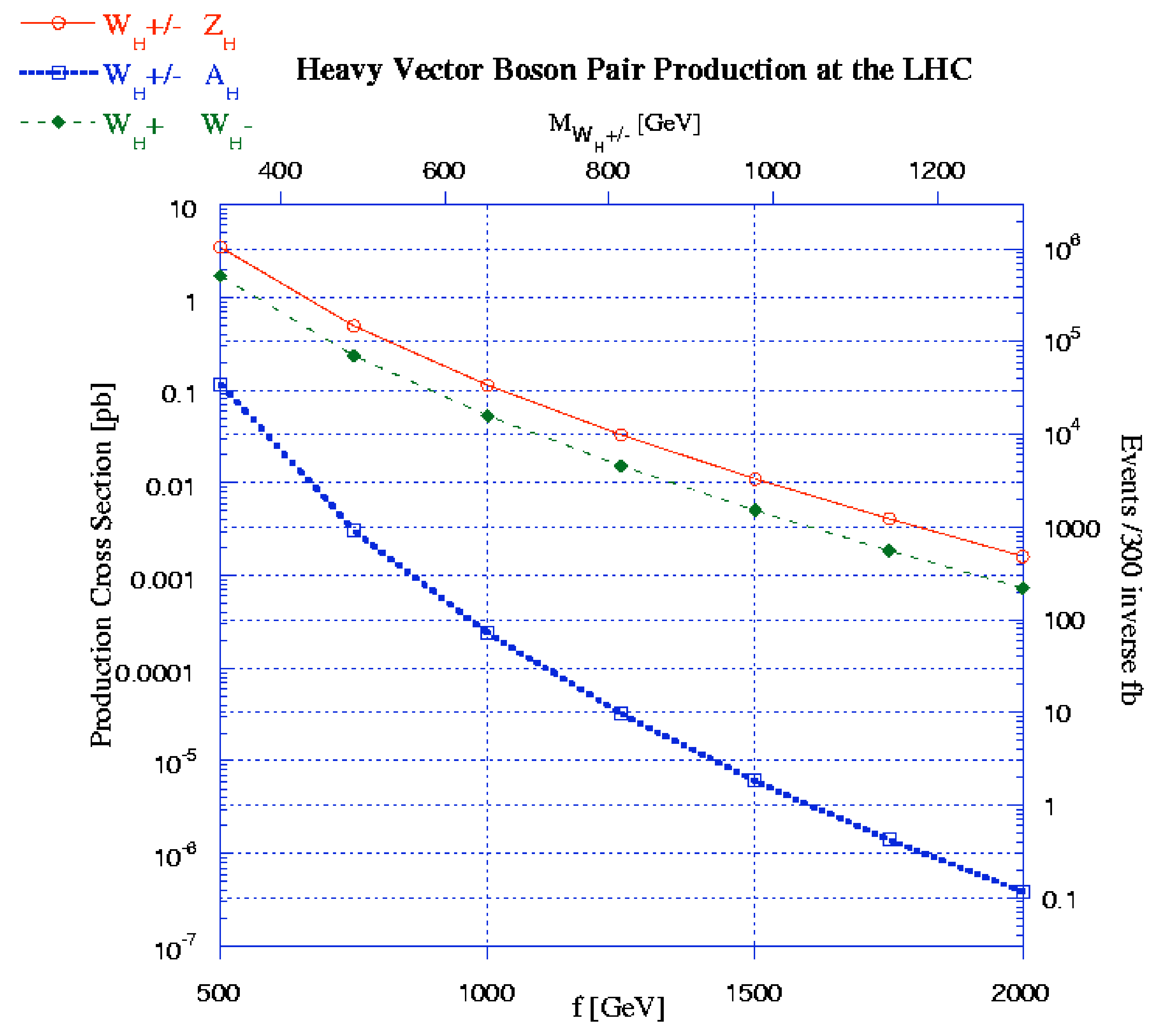
[Azuelos et al, ph/0402037]

Heavy top production



[Han, Logan, McElrath, Wang, ph/0301040]

Heavy gauge bosons with T parity



[Hubisz, Meade, ph/0411264]

Telling scenarios/models apart

Paradoxically, distinguishing scenarios may be more difficult than distinguishing among LH models

If few new states are observed, many such states are generic to almost any extension of the Standard Model

LH with T parity - a particular challenge (SUSY, UED)

Spin determination very important, see for example
“A review of spin determination at the LHC”
Wang, Yavin, ph/0802.2726

Many concrete ideas, but no silver bullet

- heavy fermion decays (Han, Logan, Wang)

- angular distributions of t tbar pairs (Barger, Han, Walker)

- helicity of W’ couplings to fermions (Rizzo)

- trileptons (Datta et al)

- angular distributions in t’ events with missing ET (Hallenbeck et al)

Tests of the LH mechanism

Are the signs of various Higgs couplings to the new vector bosons, quarks, scalars such that the quadratic divergences do indeed cancel?

This is a really, really difficult experimental task. Measuring signs would requires measuring the sign of interference terms and it requires a Higgs, or two.

Heavy vector boson decays: $Z' \to Zh, W' \to Wh$

The off-diagonal coupling of the Higgs is not directly related to the divergence cancellation

However, the magnitude of such couplings does differ in models where quadratic divergences cancel and when they do not

For example, the number of Zh invents is about a factor of 10 fewer in little Higgs models vs generic model with heavy vectors

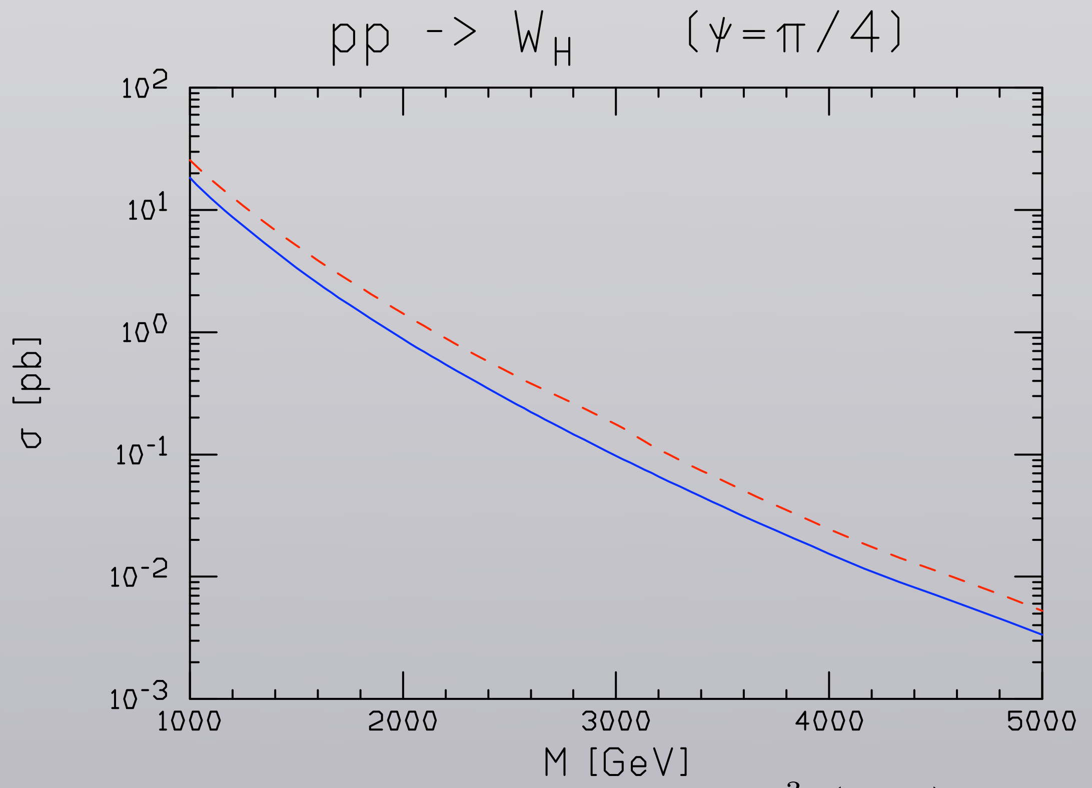


FIG. 3. Production cross sections for W_H^3 (solid) and $W_H^\pm$ (dashed) at the LHC, for $\psi = \pi/4$. We use the CTEQ5L parton distribution function.

[Burdman, Perelstein, Pierce, ph/0212228]

Heavy Top decays and production

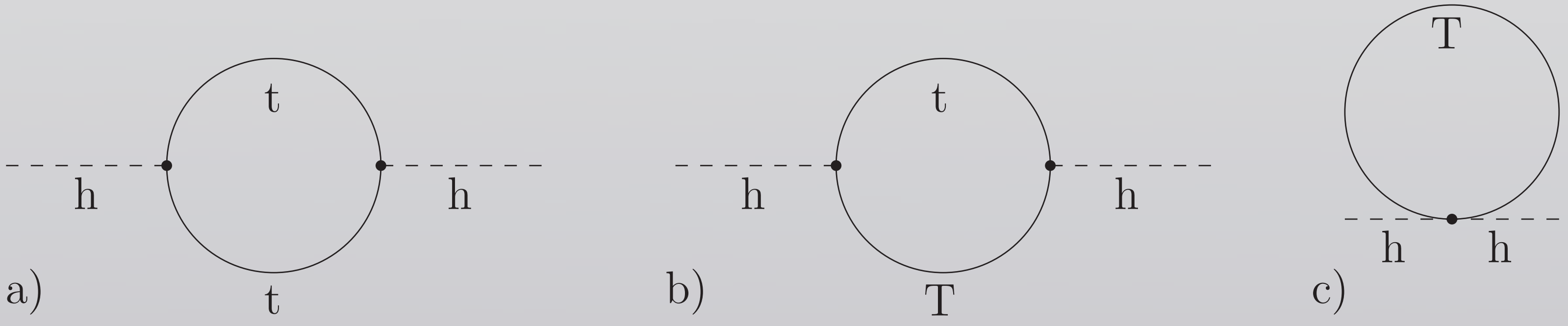


Figure 2: One-loop contributions to the Higgs boson $(\text{mass})^2$ in the Little Higgs model.

Both the production cross section of the heavy top and its width can be used to measure the coupling

$$\Gamma(T \to th) \approx \Gamma(T \to tZ) \approx \frac{m_T \lambda_T^2}{64\pi}$$

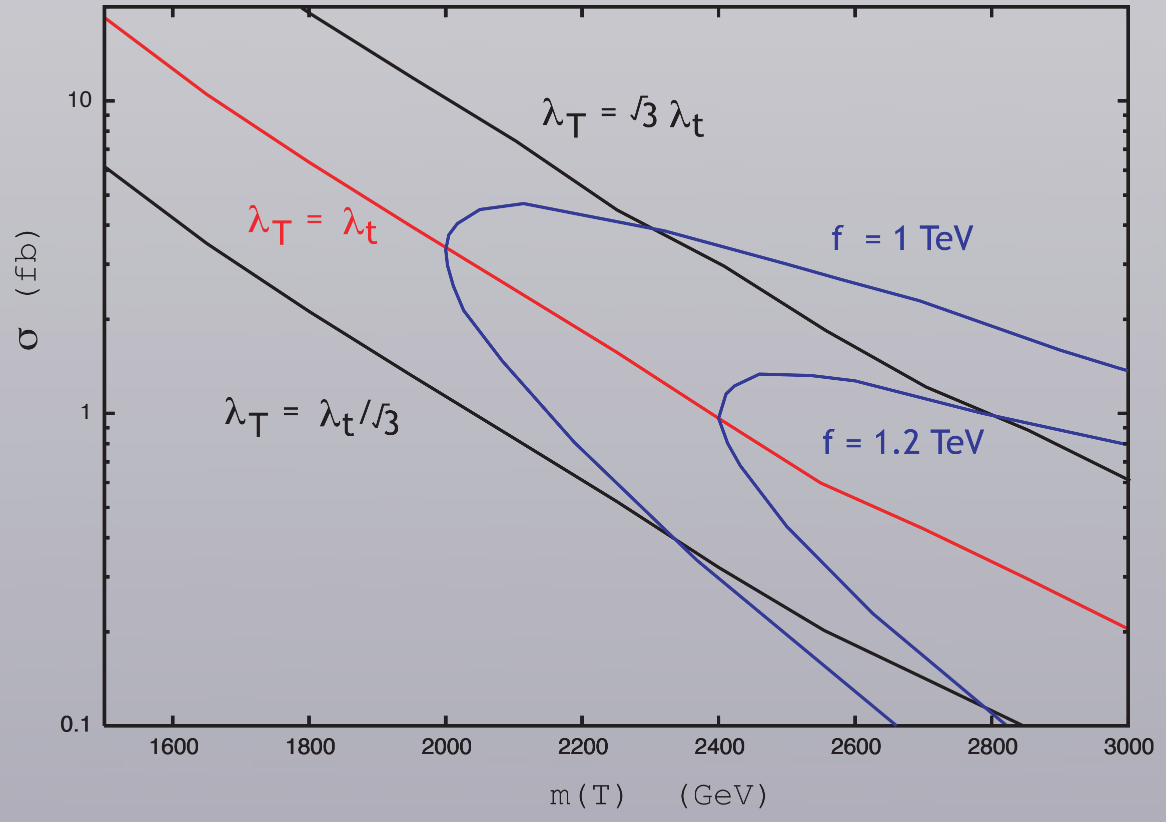


Figure 6: Parton level production cross section for the heavy top in the channel $bq \to Tq'$ at the 14 TeV Large Hadron Collider. The figure is made with the CTEQ4l parton distribution function. The different lines show the difference in the production cross section for various values of λ_T. The parabolas represent the predictions of the Little Higgs model for a constant f as λ_T is varied.

[Perelstein, Peskin,Pierce, ph/0310039]

Double Higgs production

This is plausible for light Higgs mass, due to statistics

(a) (b)

[and other diagrams]

FIG. 2: Triangle contributions to Higgs boson pair production at LHC in a Little Higgs model.

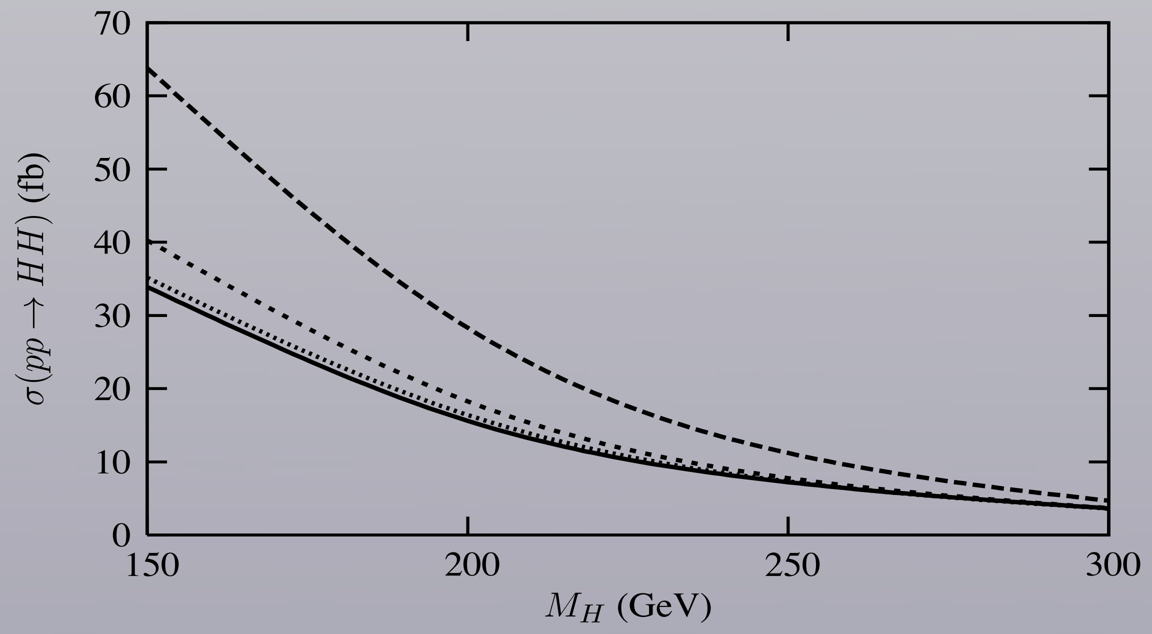


FIG. 4: Cross section for double Higgs production at the LHC for $M_T = 4$ TeV and $f = 500$ GeV (dashed line), 1000 GeV (short dashed line) and 2000 GeV (dotted line). In solid line is shown the SM result.

[no detector effects]

[Dib, Rosenfeld, Zerwekh, ph/0509179]

Summary

- Little Higgs an interesting case study for weakly coupled models that address the hierarchy problem
- T-parity little Higgs in many respects similar to SUSY
- Spin measurements important
- If it looks like little Higgs, that is not supersymmetry, showing a hint of divergence cancellation challenging

the end ■