Z-primes in Little Higgs Models

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T. Han, H.L., B. McElrath, L.-T. Wang, PRD 67, 095004 (2003)
T. Han, H.L., L.-T. Wang, in preparation

Outline:

Introduction: Z-primes and the Little Higgs

Two types of models: product group vs. simple group

Phenomenology

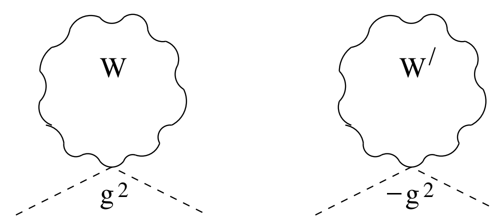
Summary

Z-primes and the Little Higgs

The little Higgs models are a new approach to stabilize the weak scale against radiative corrections, thereby solving the naturalness problem of a light Higgs boson.

Top-down:
Higgs is a pseudo-Nambu-Goldstone boson of a spontaneously broken global symmetry. Explicit breaking of the global symmetry by gauge and Yukawa interactions generates Higgs mass and couplings.

Bottom-up:
New particles at the TeV scale cancel off the SM quadratic divergence of the Higgs mass from top, gauge and Higgs loops.



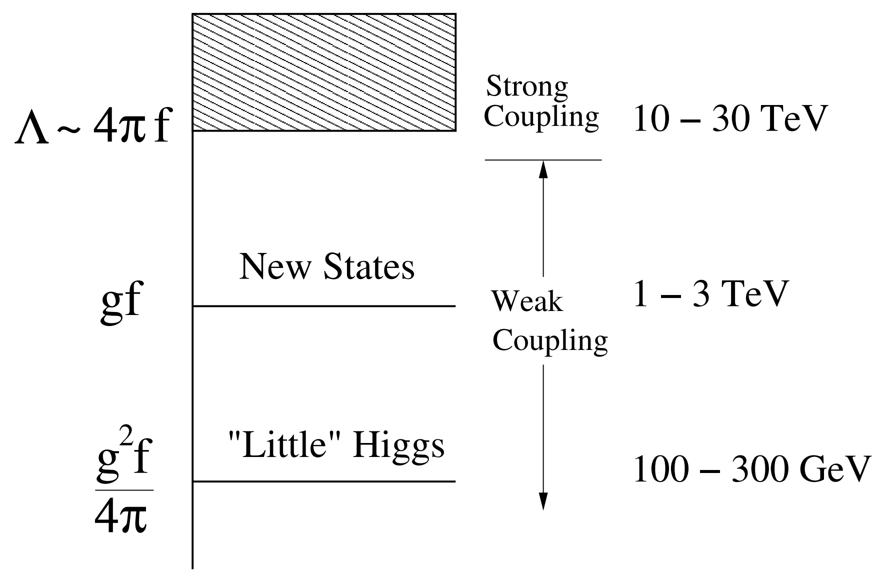
Collective breaking trick: At least two interactions are needed to completely break global symmetry protecting the Higgs mass.
$\longrightarrow$ Eliminates one-loop divergence in Higgs mass.

Mass scales:

- Higgs is a pseudo-Goldstone boson from global symmetry breaking at scale $\Lambda \sim 4\pi f \sim 10 - 30$ TeV;

- Quadratic divergences cancelled at one-loop level by new states $M \sim gf \sim 1 - 3$ TeV;

- Higgs acquires a mass radiatively at the EW scale $v \sim g^2 f/4\pi \sim 100 - 300$ GeV.

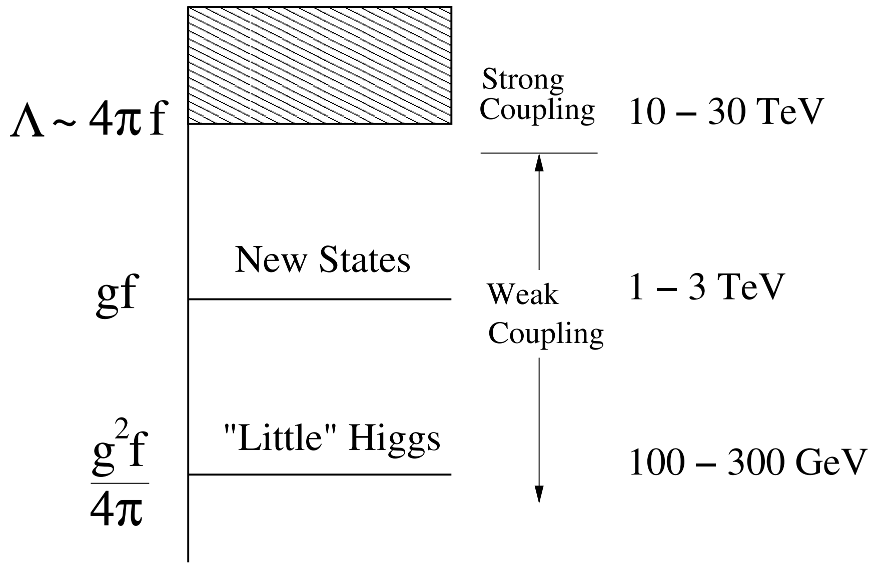


Little Higgs models contain new gauge bosons at the TeV scale to cancel the Higgs mass quadratic divergences from the SM gauge bosons.

- Electroweak gauge group is extended to accomodate global symmetry and collective breaking mechanism

- Extended gauge group is broken by global symmetry breaking vev(s), leaving broken generators as heavy gauge bosons: $M \sim gf \sim 1-3$ TeV

- SM gauge group is left over at low energies



The details of the Z-prime sector depend on the structure of the extended gauge group.

Two classes of Little Higgs models

All the Little Higgs models can be classified based on their extended gauge group structure.

Product group models

SM SU(2)$_L$ gauge group comes from diagonal breaking of a product gauge group:

SU(2)$\times$SU(2)$\rightarrow$SU(2)$_L$

Prototype: Littlest Higgs

Also includes:
Moose models,
SU(6)/Sp(6) model,
Littlest Higgs with custodial SU(2)

Simple group models

SM SU(2)$_L$ gauge group comes from breaking of a simple gauge group:

SU(N)$\rightarrow$SU(2)$_L$

Prototype: SU(3) Simple Group

Also includes:
SU(4) Simple Group,
SU(9)/SU(8) model

Product group models:

Littlest Higgs

$\mathrm{SU}(2)_1 \times \mathrm{SU}(2)_2 \times \mathrm{U}(1)_Y$
$\rightarrow \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$

Broken generators:
SU(2) triplet $W_H^{\pm}$, Z_H

Couplings to fermions:
Left-handed doublets transform under $\mathrm{SU}(2)_1$
Free mixing angle
$\cot\theta = g_1/g_2$

Simple group models:

SU(3) Simple Group

$\mathrm{SU}(3) \times \mathrm{U}(1)_X \rightarrow \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$

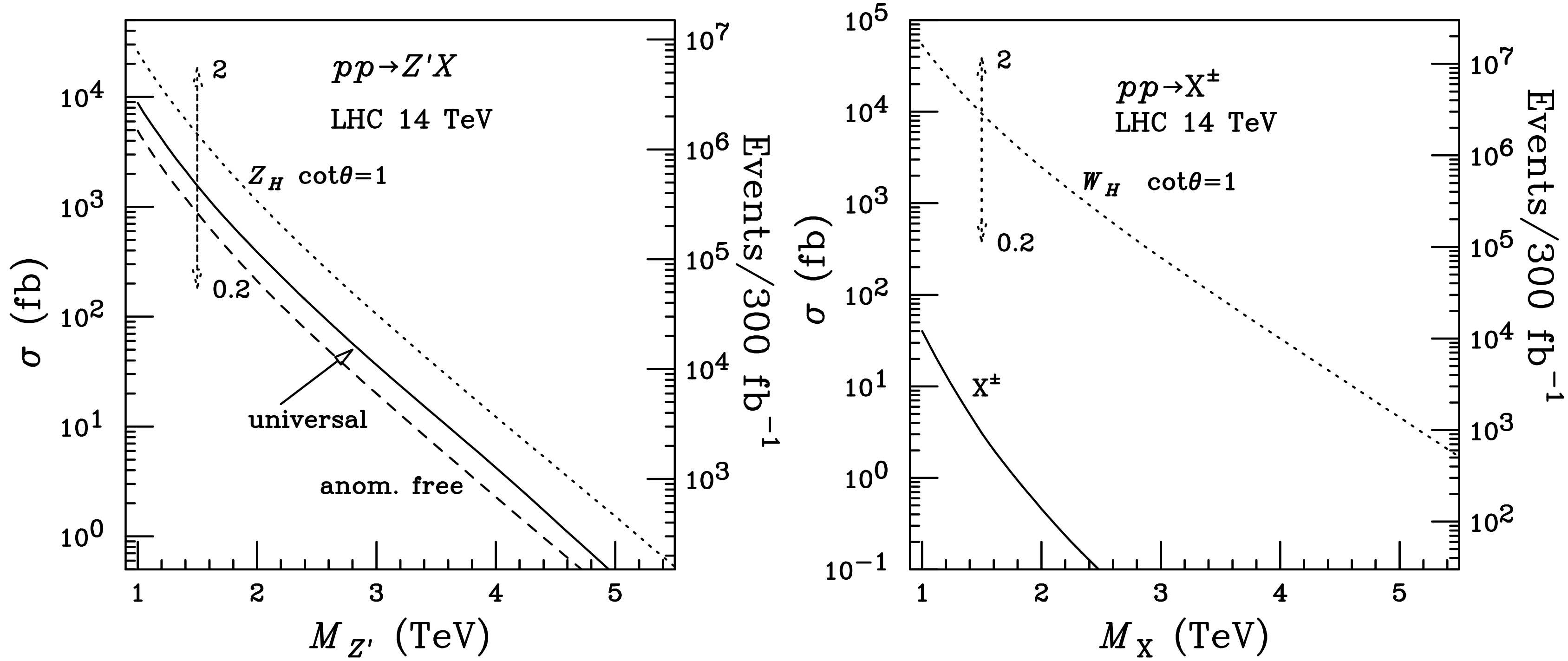
Broken diagonal generator Z';
broken off-diagonal generators $X^{\pm}$, Y^0

Couplings to fermions:
Left-handed doublets embedded in SU(3); $\mathrm{U}(1)_X$ charges fixed by hypercharges.
Two possible embeddings:
universal and anomaly-free,
each with fixed couplings.

Phenomenology:
Measure couplings to identify Z-prime

Z-prime production at LHC

T. Han, H.L., L.-T. Wang, prelim.



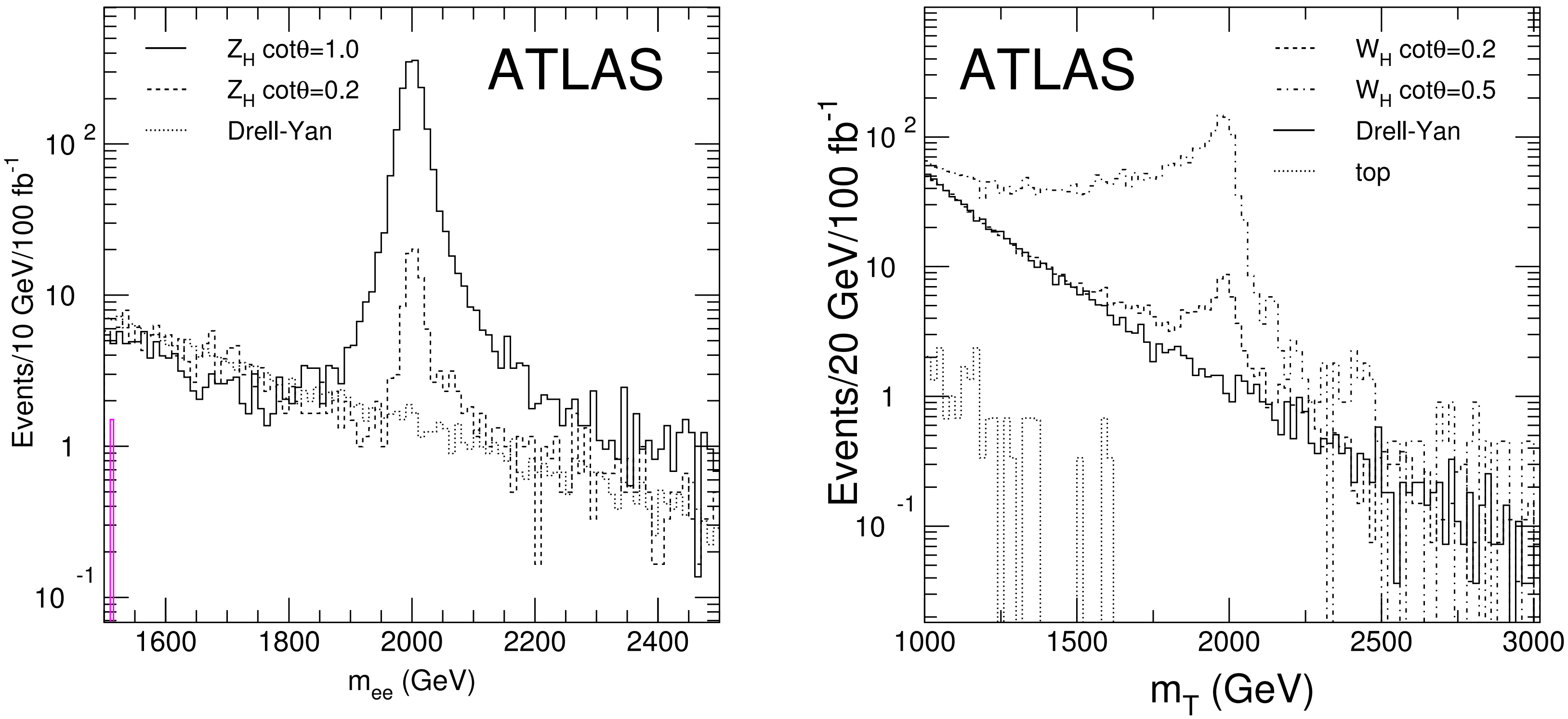
Littlest Higgs: $M_{Z_H} = M_{W_H}$. Cross section $\propto \cot^2\theta$.

SU(3) Simple Group: Z' cross section depends only on fermion embedding (discrete choice). $M_X = 0.82 M_{Z'}$; $X^{\pm}$ production very suppressed.

Littlest Higgs:

Z_H and W_H signals at LHC

G. Azuelos et al, hep-ph/0402037



Relative couplings of Z-primes to different fermion species:
(neglecting final-state masses)

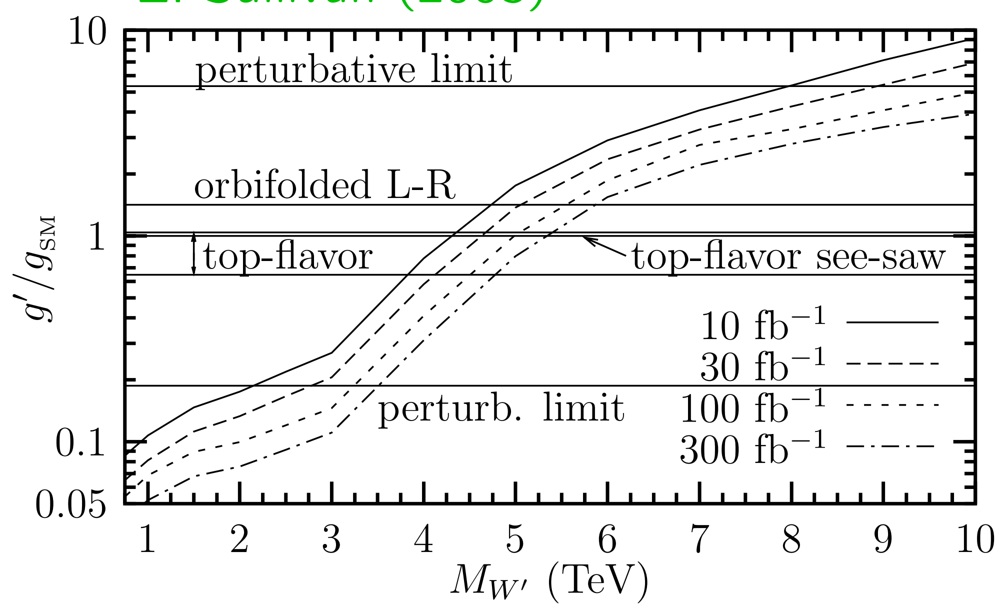
T. Han, H.L., L.-T. Wang, prelim.

	Z_H	Z'_{uni}	Z'_{af}	Z'_{seq}	Z'_{ψ}	Z'_{χ}	Z_R
$\mathrm{BR}(tt)/\mathrm{BR}(ee)$	3	4.8	4.8	3.4	3	0.6	4.4
$\mathrm{BR}(bb)/\mathrm{BR}(ee)$	3	1.3	1.3	1.3	0.082	0.016	4.4

Similarly for W_H in Littlest Higgs model:

$\mathrm{BR}(tb)/\mathrm{BR}(e\nu) = 3$

Z. Sullivan (2003)

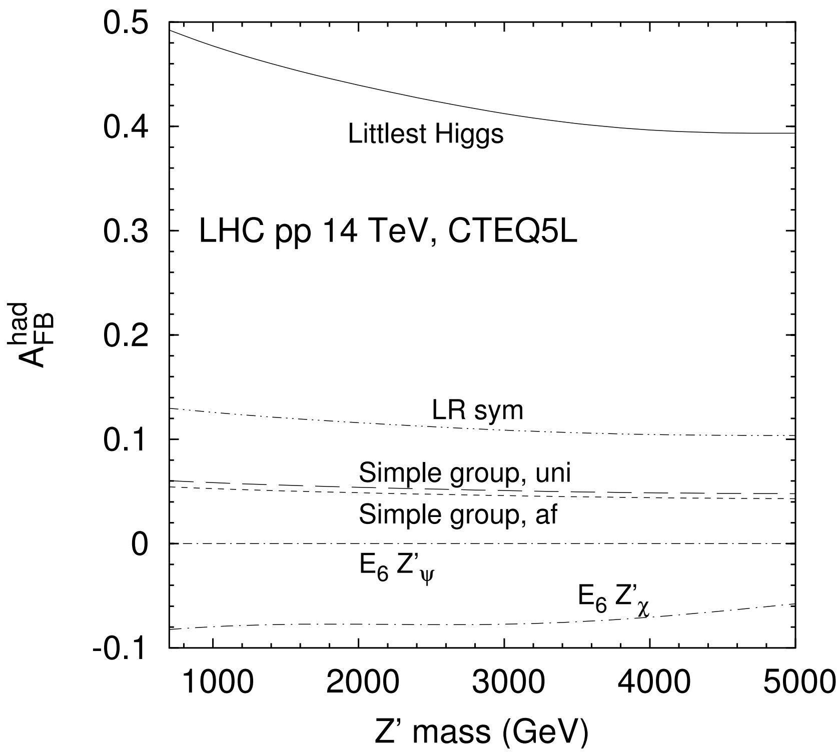


$W' \to tb$ reach at LHC

Forward-backward asymmetry:
sensitive to chirality of fermion couplings.
Distinguish different Z' models.

Littlest Higgs: Purely left-handed couplings.
SU(3) Simple Group: Left- and right-handed couplings.

T. Han, H.L., L.-T. Wang, prelim.



$pp \to Z' \to e^+e^-$

Forward-backward asymmetry at a pp machine:

$$A_{FB}^{\text{had}} = \frac{N_F - N_B}{N_F + N_B}$$

Define forward direction as direction of boost: quarks in proton carry larger momentum fraction.

Sensitive to $\mathcal{A}_f$:

$$\mathcal{A}_f = \frac{(g_L^f)^2 - (g_R^f)^2}{(g_L^f)^2 + (g_R^f)^2}$$

Product group models:

Littlest Higgs

SU(2)$_1\times$SU(2)$_2\times$U(1)$_Y$
$\to$SU(2)$_L\times$U(1)$_Y$

Broken generators:
SU(2) triplet $W_H^\pm$, Z_H

Couplings to Higgs:
Collective breaking structure:
Higgs transforms under both SU(2)s

$\mathcal{L} \supset g_1 g_2 W_1 W_2 h h^\dagger/4$
$= g^2[WW - W_H W_H$
$-2\cot 2\theta W W_H] h h^\dagger/4$

Simple group models:

SU(3) Simple Group

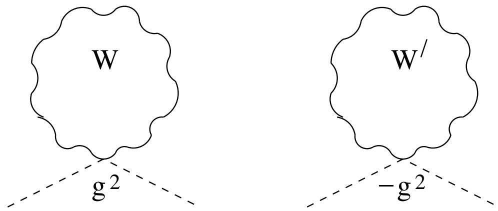
SU(3)$\times$U(1)$_X$ $\to$SU(2)$_L\times$U(1)$_Y$

Broken diagonal generator Z';
broken off-diagonal generators $X^\pm$, Y^0

Couplings to Higgs:
Higgs embedded in SU(3) triplet as nlσm pion

$\mathcal{L} \supset g^2[W^+W^- - X^+X^-]H^2/4$
$+(g^2/8c_W^2)[ZZ - Z'Z'$
$+2c_W(1-t_W^2)/\sqrt{3-t_W^2}ZZ']H^2$

Gauge divergence cancellation: sum rule for couplings



$$\sum_i G_{HHV_iV_i^*} = 0$$

SM couplings:

$$G_{HHW^+W^-} = g^2/4 \qquad G_{HHZZ} = g^2/8c_W^2$$

Littlest Higgs model (product group)

$$G_{HHW_H^+W_H^-} = -g^2/4 \qquad G_{HHZ_HZ_H} = -g^2/8$$

SU(3) Simple Group model

$$G_{HHX^+X^-} = -g^2/4 \qquad G_{HHZ'Z'} = -g^2/8c_W^2$$

Decay branching fractions of Z-primes:
(neglecting final-state masses)

Decay mode	Branching fraction			
	SU(3) simple group Z'		Littlest Higgs Z_H	
	universal	anomaly-free	$\cot\theta = 1$	$\cot\theta = 0.2$
$ee = \mu\mu = \tau\tau$	3.0%	3.7%	4.2%	0.60%
$\sum \nu\bar{\nu}$	5.2%	6.3%	12.5%	1.8%
$t\bar{t}$	15%	18%	12.5%	1.8%
$b\bar{b}$	13%	16%	12.5%	1.8%
$u\bar{u} = c\bar{c}$	15%	13%	12.5%	1.8%
$d\bar{d} = s\bar{s}$	13%	11%	12.5%	1.8%
$ZH = WW$	0.87%	1.1%	0	43%
Total width	15 GeV	12 GeV	34 GeV	9.5 GeV

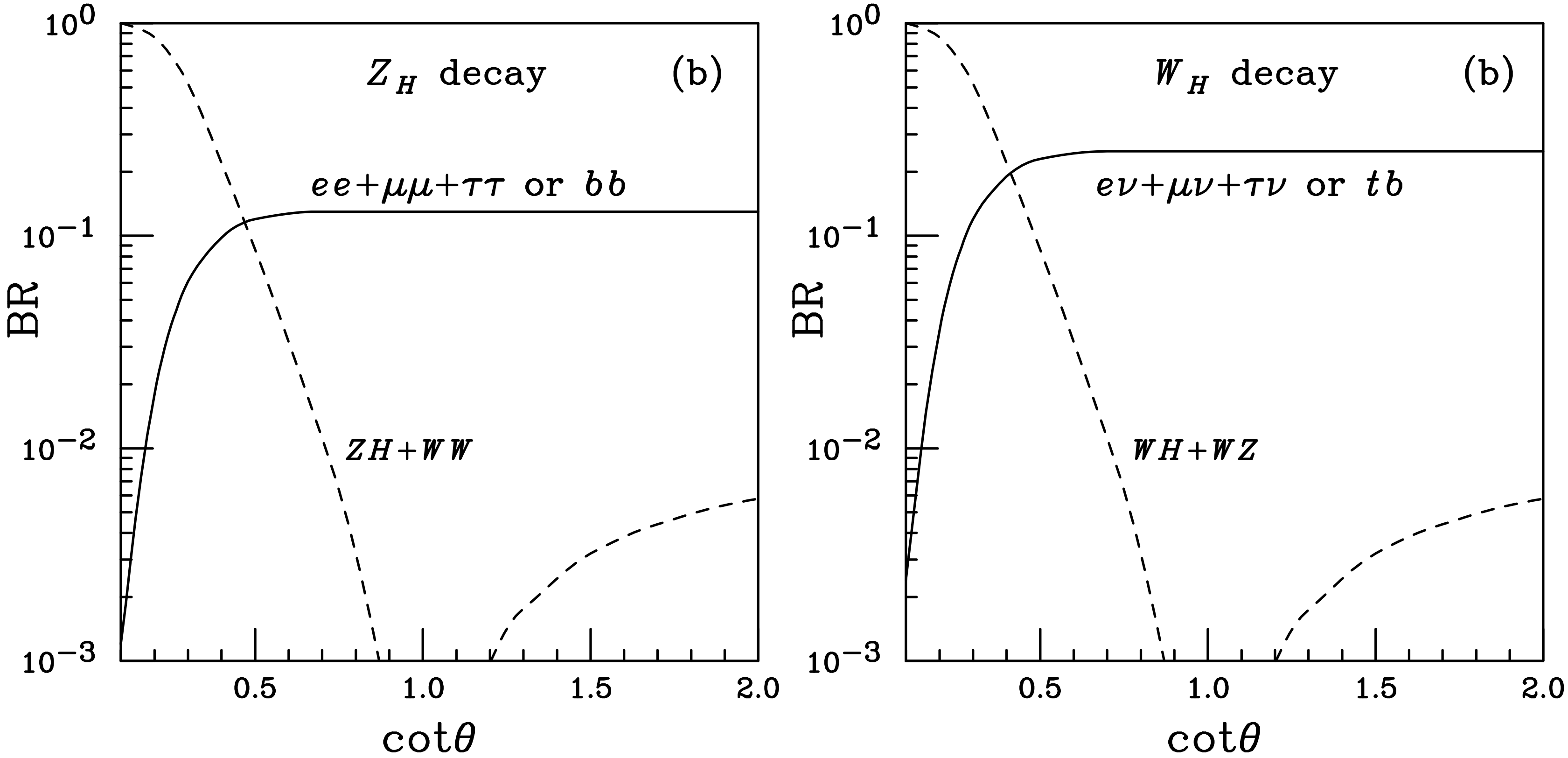
T. Han, H.L., L.-T. Wang, prelim.

Total width given for $M_{Z'} = 1$ TeV; scales proportional to $M_{Z'}$.

Littlest Higgs:

$\cot\theta$ dependence of Z_H and W_H decays

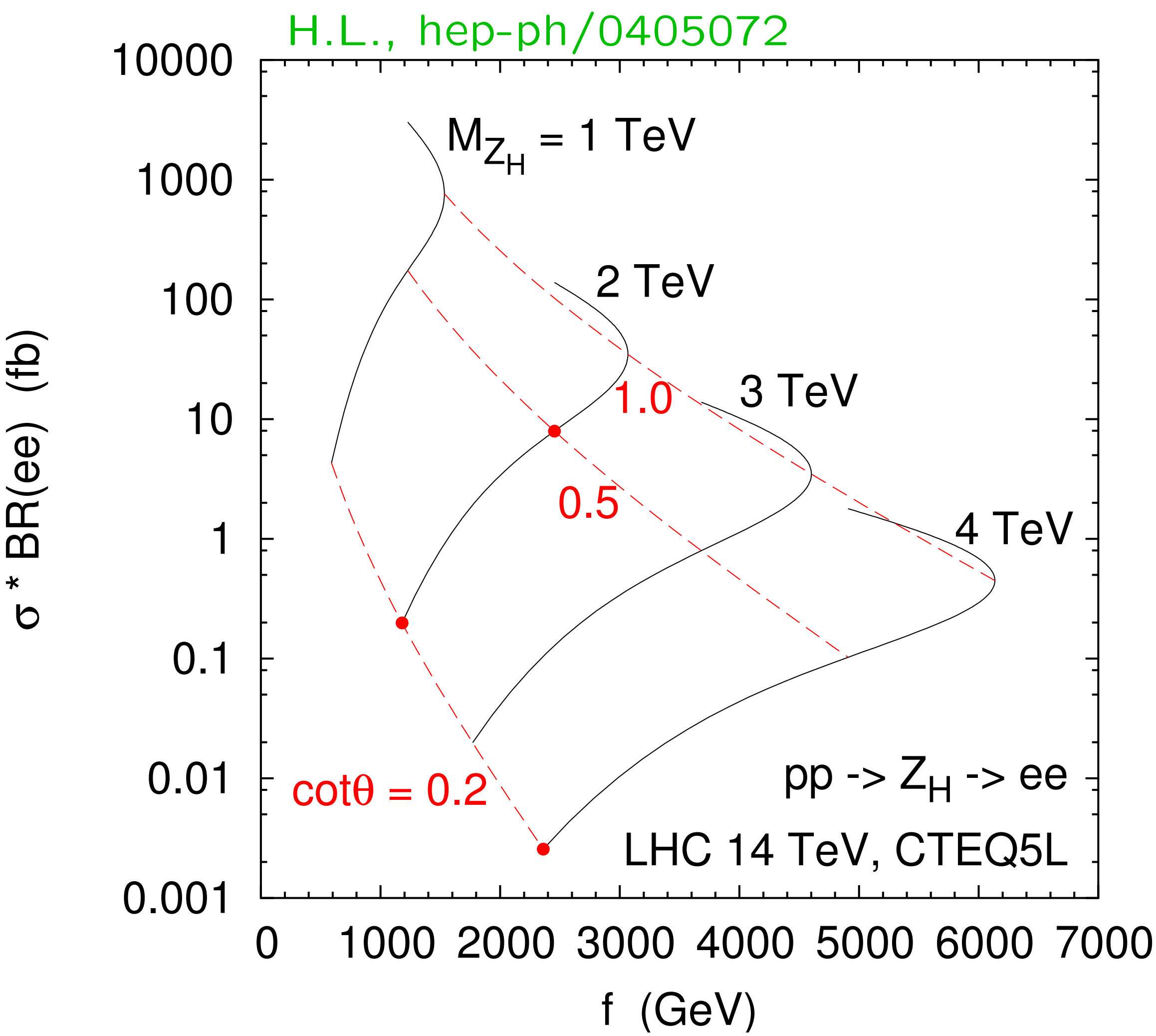
T. Han, H.L., B. McElrath, L.-T. Wang (2003)



Bosonic decays important at low $\cot\theta$: fermion couplings suppressed.

Littlest Higgs:

Extract f and $\cot\theta$ from M_{Z_H} and rate in dileptons



$M_{Z_H} = gf/\sin 2\theta$

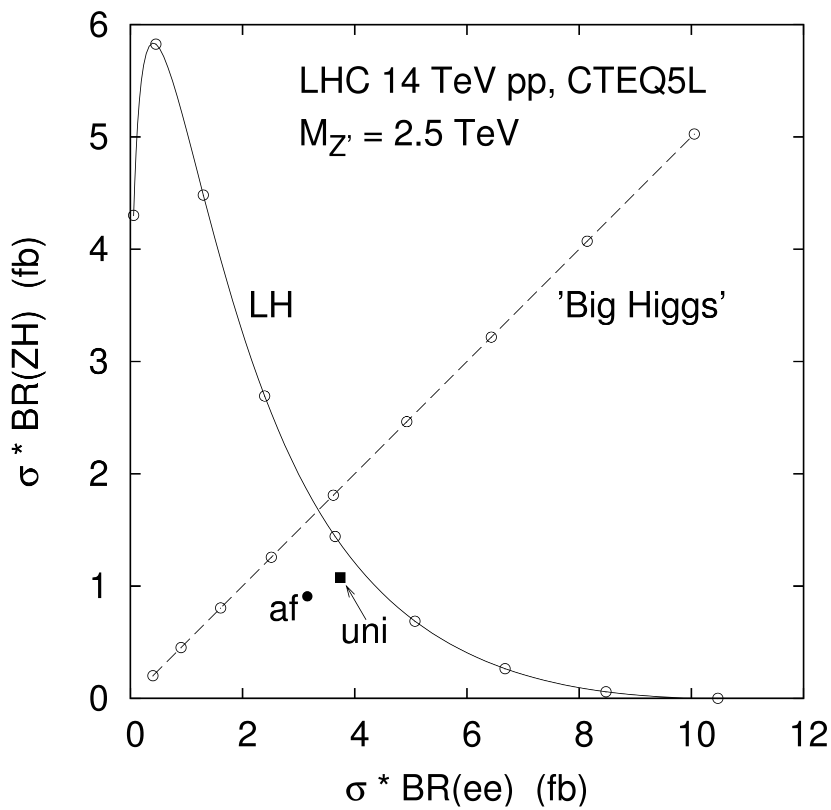
Production cross section $\sim \cot^2\theta$

Partial width to electrons $\sim \cot^2\theta$

Partial width to bosons $\sim \cot^2 2\theta$

Bosonic vs. leptonic rates for Z-primes:

T. Han, H.L., L.-T. Wang, prelim.



2.5 TeV Z'

Littlest Higgs:

Production $\propto \cot^2\theta$

Decay to fermions $\propto \cot^2\theta$

Decay to bosons $\propto \cot^2 2\theta$

SU(3) Simple Group:

Production and decay couplings fixed once fermion embedding is chosen.

"Big Higgs":

$SU(2)_1 \times SU(2)_2 \to SU(2)_L$ model with Higgs transforming linearly under $SU(2)_1$.

No quadratic divergence cancellation.

Production and decay couplings all $\propto \cot^2\theta$.

Summary

Little Higgs models contain new gauge bosons (Z-primes, W-primes) that cancel the Higgs mass quadratic divergences from the SM gauge bosons.

Properties of Z-prime sector depend on gauge structure of LH model above 1 TeV: product group vs. simple group.

The Z-prime(s) can be discovered at LHC and their couplings measured to shed light on the extended gauge structure at the TeV scale.