Electroweak Symmetry Breaking and Collider phenomenology of Gauge-Higgs Unification Scenarios in Warped Extra Dimensions

Anibal D. Medina

Department of Astronomy and Astrophysics

The University of Chicago and Argonne National Lab

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Collaborators: Marcela Carena, Boris Panes, Nausheen Shah

and Carlos Wagner.

Geometry of Warped Extra Dimensions (RS1)

- Non-factorizable geometry with one extra dimension y compactified on an orbifold S^1/Z_2 of radius R, $0 \leq y \leq \pi$.

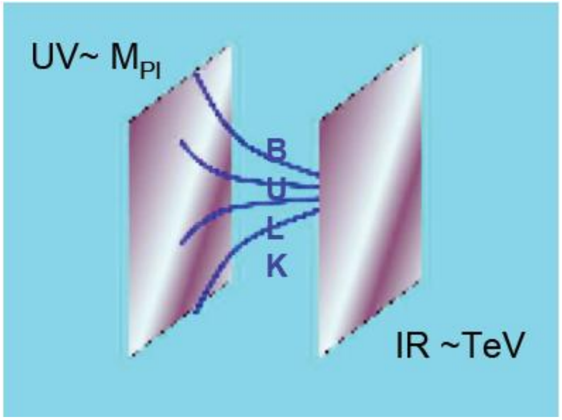
$$ds^2 = e^{-2R\sigma}\eta_{\mu\nu}dx^\mu dx^\nu + R^2 dy^2$$

where $\sigma = k|y|$. Solution to the 5D Einstein equations. Slice of AdS_5 geometry. Mass scale at $y=0$, M_P and at $y=\pi$, $M_p e^{-k\pi R}$.

- 5D Planck mass relates to M_{Pl}: $M_P^2 = M_5^3(1 - e^{-2k\pi R})/k$

- Solution to the hierarchy problem: Assuming that fundamental scales are of the same order $k \sim M_5 \sim M_{Pl}$, Higgs field localized near the IR brane → $v \sim \tilde{k} \equiv k\, e^{-kL} \approx M_{Pl}\, e^{-kL} \sim \mathrm{TeV}$ with $kL \sim 30$, $L = \pi R$

- Geometry diagram



The Randall-Sundrum Model of Warped Space:

==> elegant solution to the hierarchy problem

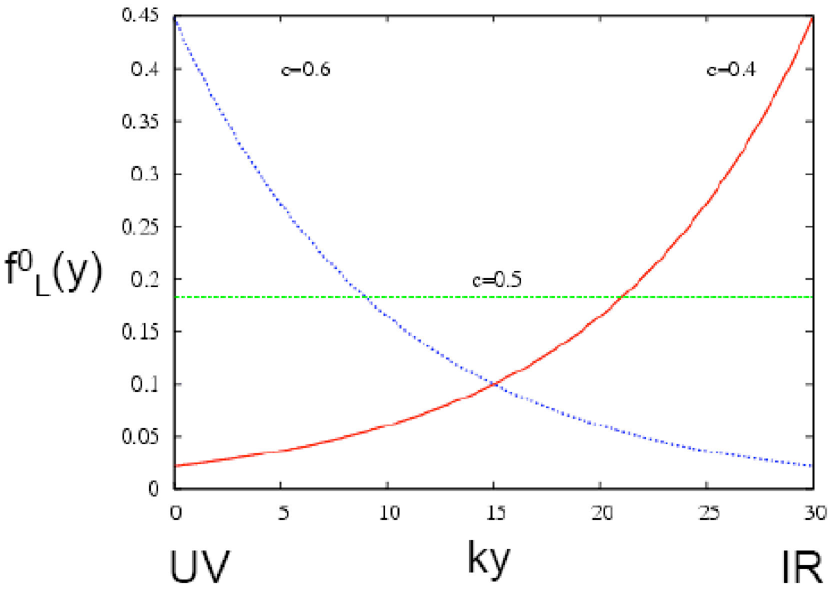
RS With Bulk Fermions and Gauge bosons:

- Higgs field must be located in the IR brane, but SM fields may live in the bulk.
- Fermions in the bulk: ==> suggestive theory of flavor

-- SM fermion masses related to the size of their zero mode wave function at the IR

Localization determined from bulk mass term: $L_m = c_f k \overline{\Psi}\Psi$

$\Downarrow$



KK mode expansion:

$$\Psi_{L,R}(x,y) = e^{3ky}\sum_n \psi^n_{L,R}(x) f^n_{L.R}(y)$$

Boundary conditions for f(y) at the branes (UV, IR) = (+,+) ==> zero mode

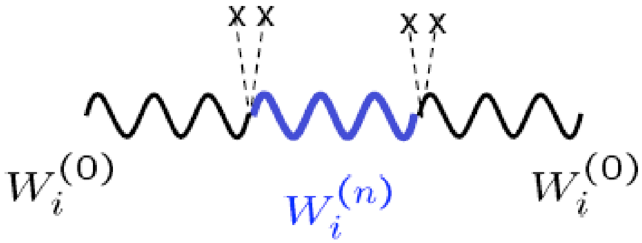
If b.c. (-,+), (+,-) or (-,-) ==> no zero mode

-- The KK spectrum is defined in units of $\tilde{k} = ke^{-kL}$ of factors that depend on c_f and is localized towards the IR brane

Effects of KK modes of the gauge bosons on Z pole observables

SM in the bulk

- Large mixing with Z and W zero modes through Higgs



Large corrections to the M_z/M_w ratio (T parameter)

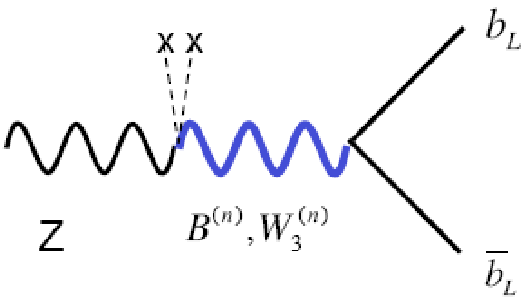
$\Downarrow$

$$M_{KK} \geq 5-10 \ \text{TeV}$$

- Top and bottom zero modes localized closer to the IR brane

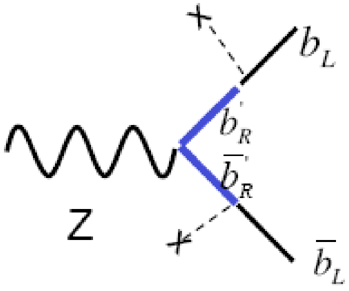
Large gauge and Yukawa couplings to Gauge Bosons and fermion KK modes

Large corrections to the Zbb coupling



$\Downarrow$

$$M_{KK} \gtrsim 7-8 \, \text{TeV}$$

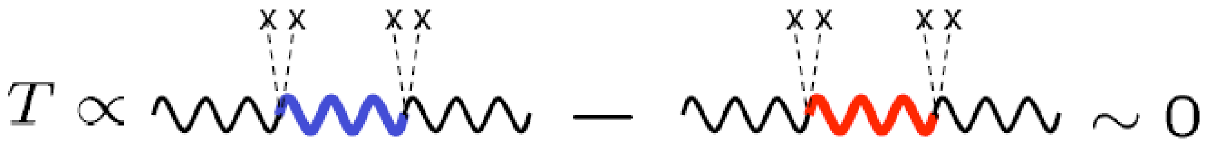


How to obtain a phenomenologically interesting theory?

1) Extend SM bulk gauge symmetry to a custodial symmetry

$SU(2)_L$ x $SU(2)_R$

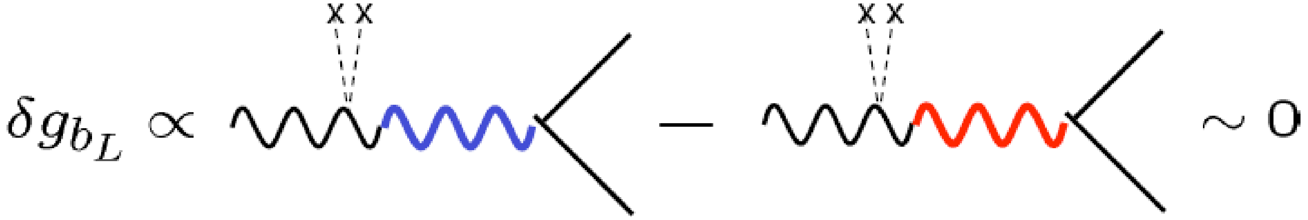
Agashe, Delgado, May,
Sundrum '03



2) The custodial symmetry together with a discrete L ↔ R symmetry and a specific bidoublet structure of the fermions under $SU(2)_L$ x $SU(2)_R$

$$T^3_R(b_L) = T^3_L(b_L)$$

Agashe, Contino, DaRold,
Pomarol '06



==> reduce tree level contributions to the T parameter and the Zbb coupling that allow for lightest KK gauge bosons with $M_{KK} \sim 3$ TeV

Alternative to the above: Large brane kinetic terms

M. Carena, A. Delgado, E. Ponton, T. Tait, C.W. '05,

Holographic Higgs

- Bulk gauge symm.: $SU(3)_c \times SO(5) \times U(1)_X \longrightarrow SO(5) \supset SU(2)_R \times SU(2)_L$.

UV: $SU(2)_L \times U(1)_Y$ IR: $SO(4) \times U(1)_X$.

Extra gauge bosons have the quantum numbers of the Higgs

$SO(5)/SO(4) \longrightarrow A^{1\ldots4}_{\mu}(-,-)$ $A^{1\ldots4}_{5}(+,+) \longleftarrow$ Identify with H.

No tree level Higgs potential ⟶ Induced at one-loop (calculable).

- Coleman-Weinberg Potential has been computed for the model under consideration [A.M, N. Shah and C. Wagner].

1. EWSB minima in large regions of parameter space consistent with EWPT.
2. Consistent with Z, W, bottom quark, top quark masses and Higgs LEP bound.

- EW fit easier in regions Higgs couplings are linear (similar to those of the SM).

Warped Extra Dimensions: Gauge-Higgs Unification

- The 5D action is given by,

$$S_{5D} = \int d^4x \int_0^L dx_5 \sqrt{g} \left(-\frac{1}{4g_5^2} \mathrm{Tr}\{\mathrm{F_{MN}F^{MN}}\} - \frac{1}{4\mathrm{g_X^2}} \mathrm{G_{MN}G^{MN}} + \bar{\psi}(\mathrm{i\Gamma^N D_N - M})\psi \right),$$

where $D_N = \partial_N - iA_N^\alpha t^\alpha - iB_N$ and $g_5 \text{ and } g_X$ are the 5D dimensionful gauge couplings. The generators of SU(2)$_{\mathrm{L,R}}$ are denoted by $T^{a_{\mathrm{L,R}}}$, while the generator from the coset SO(5)/SO(4) are denoted by $T^{\hat{a}}$

- Right Hypercharge →

$$\begin{pmatrix} A_M^{\prime 3_\mathrm{R}} \\ A_M^Y \end{pmatrix} = \begin{pmatrix} c_\phi & -s_\phi \\ s_\phi & c_\phi \end{pmatrix} \cdot \begin{pmatrix} A_M^{3_\mathrm{R}} \\ B_M \end{pmatrix}$$

$$c_\phi \equiv \frac{g_5}{\sqrt{g_5^2 + g_X^2}} \quad , \quad s_\phi \equiv \frac{g_X}{\sqrt{g_5^2 + g_X^2}} \quad .$$

- SO(5) breaking b.c.

$$\begin{aligned} \partial_5 A_\mu^{a_\mathrm{L},Y} = A_\mu^{a_\mathrm{R},\hat{a}} = A_5^{a_\mathrm{L},Y} &= 0, \qquad x_5 = 0 \\ \partial_5 A_\mu^{a_\mathrm{L},a_\mathrm{R},Y} = A_\mu^{\hat{a}} = A_5^{a_\mathrm{L},a_\mathrm{R},Y} &= 0, \qquad x_5 = L\,. \end{aligned}$$

→ $H \propto (h^{\hat{1}} + ih^{\hat{2}}, h^{\hat{4}} - ih^{\hat{3}})^t,$

- KK expansion of gauge fields

$$A_\mu^a(x, x_5) = \sum_n f_n^a(x_5, h) A_{\mu,n}(x) \qquad A_5^a(x, x_5) = \sum_n \frac{\partial_5 f_n^a(x_5, h)}{m_n(h)} h_n(x)$$

$$A_\mu^{\hat{a}}(x, x_5) = \sum_n f_n^{\hat{a}}(x_5, h) A_{\mu,n}(x) \qquad A_5^{\hat{a}}(x, x_5) = \frac{C_h}{a^2(x_5)} h^{\hat{a}}(x) + \sum_n \frac{\partial_5 f_n^{\hat{a}}(x_5, h)}{m_n(h)} h_n(x)$$

Warped Extra Dimensions: Gauge-Higgs Unification

- 5D action in terms of KK tower,

$$S_{5D} = \int d^4x \left\{ \frac{1}{2}(\partial_\mu h^{\hat{a}})^2 + \sum_n \left(-\frac{1}{4}[\partial_\mu A_{\nu,n} - \partial_\nu A_{\mu,n}]^2 + \frac{1}{2} m_n^2(h) A_{\mu,n}^2 \right) + \dots \right\}$$

- Solving e.o.m in presence of h difficult → gauge transformation

$$f^\alpha(x_5, h) T^\alpha = \Omega^{-1}(x_5, h) f^\alpha(x_5, 0) T^\alpha \Omega(x_5, h),$$

With

$$\Omega(x_5, h) = \exp\left[-i C_h h T^4 \int_0^{x_5} dy\, a^{-2}(y) \right].$$

- Solutions to the e.o.m in h=0 gauge

$$\begin{aligned} C(x_5, z) &= \frac{\pi z}{2k} a^{-1}(x_5) \left[Y_0\left(\frac{z}{k}\right) J_1\left(\frac{z}{k a(x_5)}\right) - J_0\left(\frac{z}{k}\right) Y_1\left(\frac{z}{k a(x_5)}\right) \right] \\ S(x_5, z) &= \frac{\pi z}{2k} a^{-1}(x_5) \left[J_1\left(\frac{z}{k}\right) Y_1\left(\frac{z}{k a(x_5)}\right) - Y_1\left(\frac{z}{k}\right) J_1\left(\frac{z}{k a(x_5)}\right) \right] \end{aligned}$$

- UV b.c's automatically satisfied. IR b.c's → system of Eqs. With non-trivial solution ↔

$$S(L, m_n) S'^3(L, m_n) C'(L, m_n) \left[2a_L^2 C'(L, m_n) S(L, m_n) + m_n \sin^2\left(\tfrac{\lambda_G h}{f_h}\right) \right]^2 \times$$

$$\left[2a_L^2 C'(L, m_n) S(L, m_n) + (1 + s_\phi^2) m_n \sin^2\left(\tfrac{\lambda_G h}{f_h}\right) \right] = 0$$

where

$$f_h^2 = \frac{1}{g_5^2 \int_0^L dy a^{-2}(y)}$$

Warped Extra Dimensions: Gauge-Higgs Unification

- 3 SO(5) multiplets in the quark sector,

$$\xi_{1L} \sim Q_{1L} = \begin{pmatrix} \chi^u_{1L}(-,+)_{5/3} & q^u_L(+,+)_{2/3} \\ \chi^d_{1L}(-,+)_{2/3} & q^d_L(+,+)_{-1/3} \end{pmatrix} \oplus u'_L(-,+)_{2/3} \,,$$

$$\xi_{2R} \sim Q_{2R} = \begin{pmatrix} \chi^u_{2R}(-,+)_{5/3} & q'^u_R(-,+)_{2/3} \\ \chi^d_{2R}(-,+)_{2/3} & q'^d_R(-,+)_{-1/3} \end{pmatrix} \oplus u_R(+,+)_{2/3} \,,$$

$$Q_{3R} = \begin{pmatrix} \chi^u_{3R}(-,+)_{5/3} & q''^u_R(-,+)_{2/3} \\ \chi^d_{3R}(-,+)_{2/3} & q''^d_R(-,+)_{-1/3} \end{pmatrix}$$

$$\xi_{3R} \sim$$

$$\oplus T_{1R} = \begin{pmatrix} \psi'_R(-,+)_{5/3} \\ U'_R(-,+)_{2/3} \\ D'_R(-,+)_{-1/3} \end{pmatrix} \oplus T_{2R} = \begin{pmatrix} \psi''_R(-,+)_{5/3} \\ U''_R(-,+)_{2/3} \\ D_R(+,+)_{-1/3} \end{pmatrix} ,$$

- Boundary mass mixing terms at the IR brane $\mathcal{L}_m = 2\delta(x_5 - L)\Big[\bar{u}'_L M_{B_1} u_R + \bar{Q}_{1L} M_{B_2} Q_{3R} + \text{h.c.}\Big] \,,$
- Solutions to the e.o.m in the bulk and in the h=0 gauge

$$\begin{aligned} S_{\pm M}(x_5, z) &= \frac{e^{\pm M x_5}}{a^2(x_5)} \tilde{S}_{\pm M}(x_5, z), \\ \dot{S}_{\pm M}(x_5, z) &= \mp \frac{e^{\pm M x_5}}{z a(x_5)} \partial_5 \tilde{S}_{\pm M}(x_5, z). \end{aligned}$$

with normalization $\int_0^L dx_5 \; a(x_5)^3 \; f(x_5, m_n) f(x_5, m_m) = \delta_{m,n}.$

where

$$\tilde{S}_M(x_5, z) = \frac{\pi z}{2k} a^{-c-\frac{1}{2}}(x_5) \left[J_{\frac{1}{2}+c}\left(\frac{z}{k}\right) Y_{\frac{1}{2}+c}\left(\frac{z}{k a(x_5)}\right) - Y_{\frac{1}{2}+c}\left(\frac{z}{k}\right) J_{\frac{1}{2}+c}\left(\frac{z}{k a(x_5)}\right) \right] ,$$

Warped Extra Dimensions: Gauge-Higgs Unification

- Vector functions for fermions in h=0 gauge,

$$f_{1,L}(x_5,0) = \begin{bmatrix} C_1 S_{M_1} \\ C_2 S_{M_1} \\ C_3 \dot{S}_{-M_1} \\ C_4 \dot{S}_{-M_1} \\ C_5 S_{M_1} \end{bmatrix}$$

$$f_{2,R}(x_5,0) = \begin{bmatrix} C_6 S_{-M_2} \\ C_7 S_{-M_2} \\ C_8 S_{-M_2} \\ C_9 S_{-M_2} \\ C_{10} \dot{S}_{M_2} \end{bmatrix}$$

$$f_{3,R}(x_5,0) = \begin{bmatrix} C_{11} S_{-M_3} \\ C_{12} S_{-M_3} \\ C_{13} S_{-M_3} \\ C_{14} S_{-M_3} \\ C_{15} S_{-M_3} \\ C_{16} S_{-M_3} \\ C_{17} S_{-M_3} \\ C_{18} S_{-M_3} \\ C_{19} S_{-M_3} \\ C_{20} \dot{S}_{M_3} \end{bmatrix}$$

- Gauge transformation applied to fermions

$$\begin{aligned} f_{1,L}(x_5,h) &= A\Omega A^{-1} f_{1,L}(x_5,0) \\ f_{2,R}(x_5,h) &= A\Omega A^{-1} f_{2,R}(x_5,0) \\ f_{3,R}(x_5,h) &= B\Omega B^{-1} f_{3,R}(x_5,0) \end{aligned}$$

Where A and B are basis transformations from isospin to canonical base.

- IR boundary conditions,

$$f_{1,R}^{1,\ldots,4} + M_{B_2} f_{3,R}^{1,\ldots,4} = 0 \qquad f_{1,R}^{5} + M_{B1} f_{2,R}^{5} = 0 \qquad f_{2,L}^{1,\ldots,4} = 0$$

$$f_{3,L}^{1,\ldots,4} - M_{B_2} f_{1,L}^{1,\ldots,4} = 0 \qquad f_{2,L}^{5} - M_{B_1} f_{1,L}^{5} = 0 \qquad f_{3,L}^{5,\ldots,10} = 0$$

Warped Extra Dimensions: Gauge-Higgs Unification

- Vanishing determinant →

$$\tilde{S}'^{3}_{-M_2} = 0$$

$$\tilde{S}'^{5}_{-M_3} = 0$$

$$\left[M_{B_2}^2 \tilde{S}_{M_1} \tilde{S}_{-M_3} - \tfrac{a_L^2}{z^2} \tilde{S}'_{M_1} \tilde{S}'_{-M_3}\right]^2 = 0$$

$$2\tilde{S}_{M_3} \left[M_{B_2}^2 \tilde{S}_{-M_3} \tilde{S}'_{-M_1} + \tilde{S}_{-M_1} \tilde{S}'_{-M_3}\right] - M_{B_2}^2 \tilde{S}'_{-M_1} \sin^2\left(\tfrac{\lambda_F h}{f_h}\right) = 0$$

$$\begin{aligned}
&2\left[M_{B_1}^2 \tilde{S}_{M_1}\left(-1 + \tilde{S}_{M_2}\tilde{S}_{-M_2}\right)\left(M_{B_2}^2 \tilde{S}_{-M_3}\tilde{S}'_{-M_1} + \tilde{S}_{-M_1}\tilde{S}'_{-M_3}\right) + \right.\\
&\left.\tilde{S}_{M_2}\tilde{S}'_{-M_2}\left(M_{B_2}^2\left(-1 + \tilde{S}_{M_1}\tilde{S}_{-M_1}\right)\tilde{S}_{-M_3} - \tfrac{a_L^2}{z^2}\tilde{S}_{-M_1}\tilde{S}'_{M_1}\tilde{S}'_{-M_3}\right)\right] + \\
&\left[M_{B_2}^2 \tilde{S}_{M_2}\tilde{S}_{-M_3}\tilde{S}'_{-M_2} + M_{B_1}^2\left(2M_{B_2}^2 \tilde{S}_{M_1}\tilde{S}_{-M_3}\tilde{S}'_{-M_1} + \tilde{S}'_{-M_3} + 2\tilde{S}_{M_1}\tilde{S}_{-M_1}\tilde{S}'_{-M_3} - \right.\right.\\
&\left.\left.\tilde{S}_{M_2}\tilde{S}_{-M_2}\tilde{S}'_{-M_3}\right)\right]\sin^2\left(\tfrac{\lambda_F h}{f_h}\right) - M_{B_1}^2 \tilde{S}'_{-M_3}\sin^4\left(\tfrac{\lambda_F h}{f_h}\right) = 0
\end{aligned}$$

- Coleman-Weinberg Potential for the Higgs boson at one loop,

$$\begin{aligned}
V(h) \;=\; &\int_0^\infty dp p^3 \left(-\frac{12}{(4\pi)^2}\left\{\log\left[1 + F_{t_1}(-p^2)\sin^2\left(\frac{\lambda h}{f_h}\right) + F_{t_2}(-p^2)\sin^4\left(\frac{\lambda h}{f_h}\right)\right] + \right.\right.\\
&\left.\log\left[1 + F_b(-p^2)\sin^2\left(\frac{\lambda h}{f_h}\right)\right]\right\} + \frac{6}{(4\pi)^2}\log\left[1 + F_W(-p^2)\sin^2\left(\frac{\lambda h}{f_h}\right)\right] + \\
&\left.\frac{3}{(4\pi)^2}\log\left[1 + F_Z(-p^2)\sin^2\left(\frac{\lambda h}{f_h}\right)\right]\right)
\end{aligned}$$

Warped Extra Dimensions: Gauge-Higgs Unification

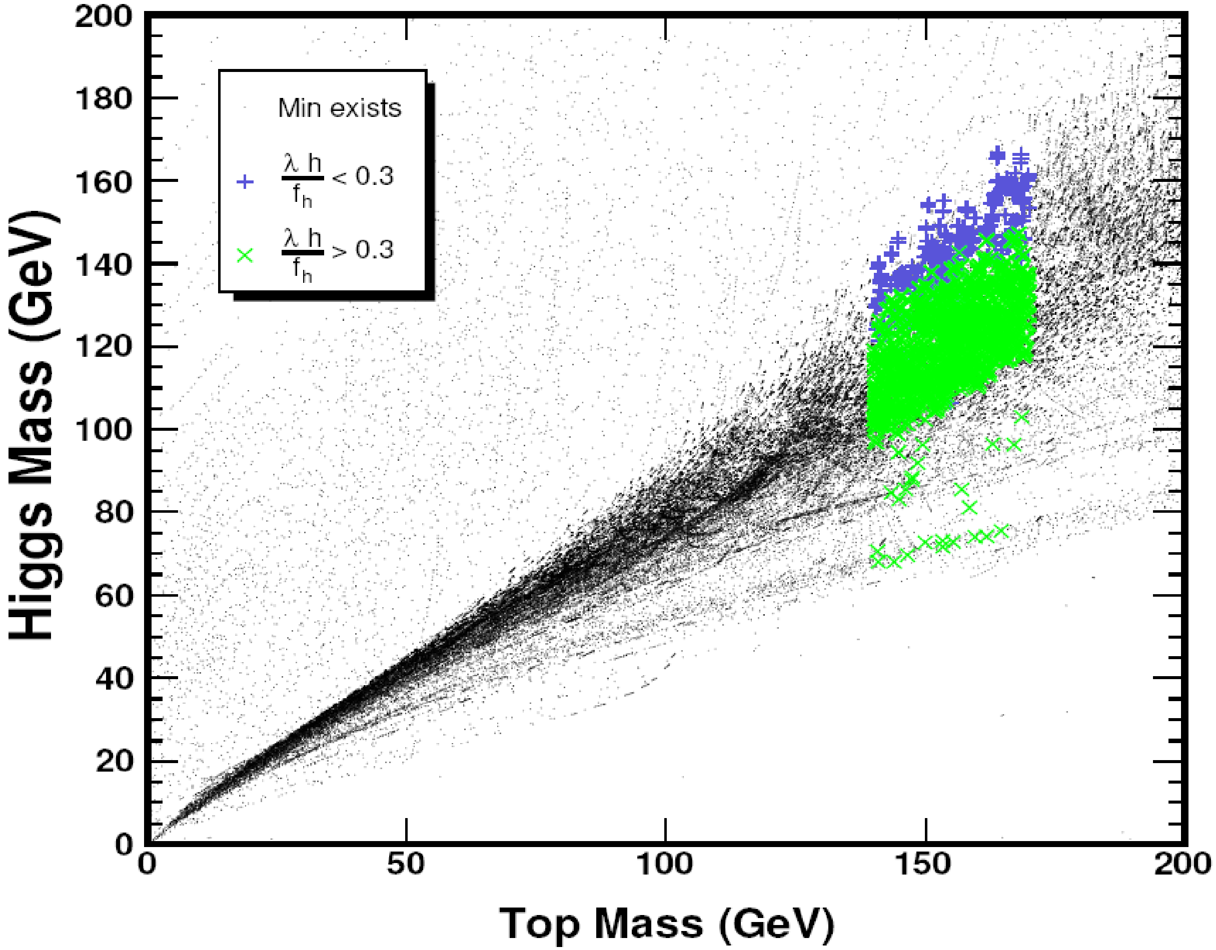


Figure 1: Higgs Mass vs top mass in GeV. Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime and black dots where a minimum for the effective potential exists.

Warped Extra Dimensions: Gauge-Higgs Unification

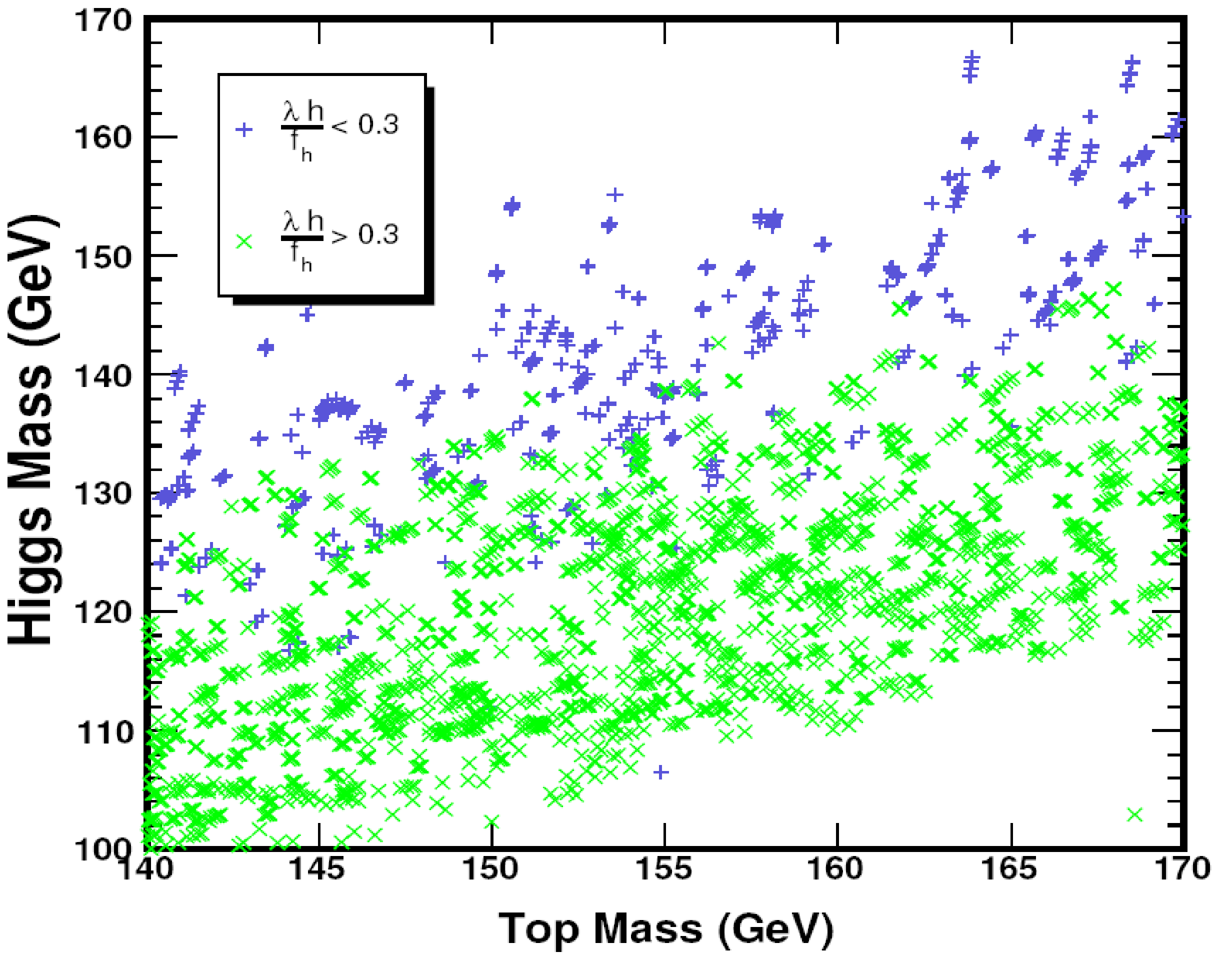


Figure 2: Higgs Mass vs top mass in GeV, zoomed in region. Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime.

Warped Extra Dimensions: Gauge-Higgs Unification

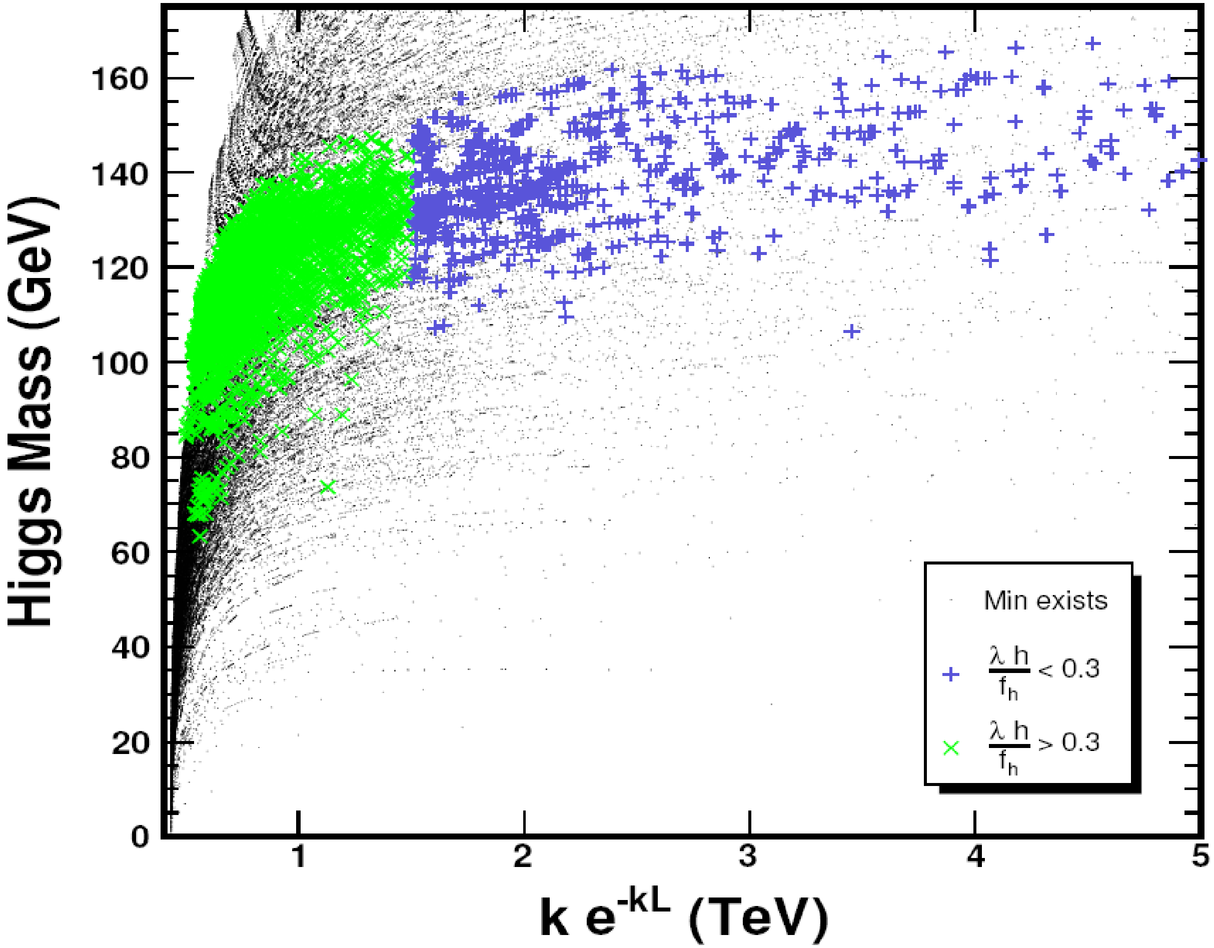


Figure 3: Higgs Mass (GeV) vs $\tilde{k}$ (TeV). Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime and black dots where a minimum for the effective potential exists.

Warped Extra Dimensions: Gauge-Higgs Unification

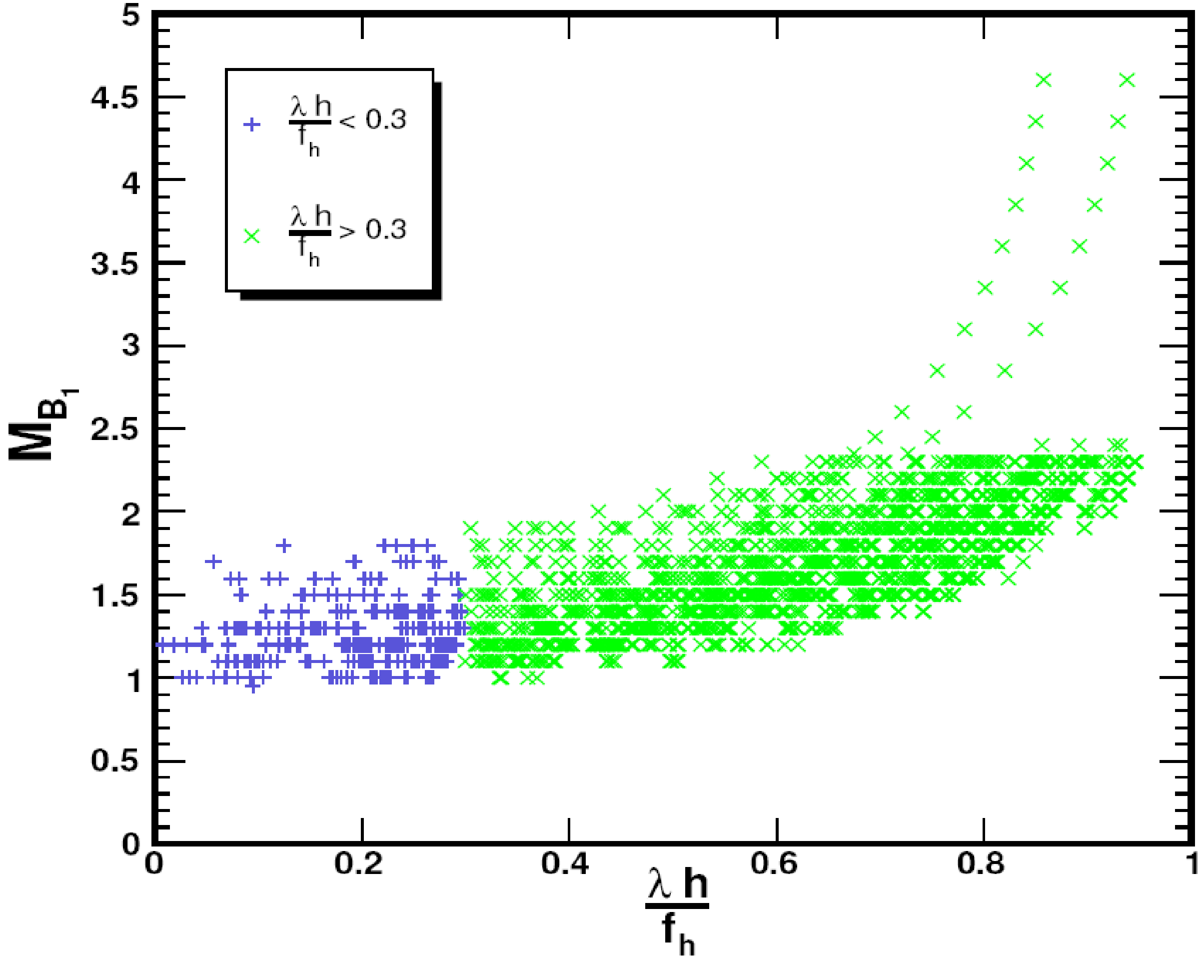


Figure 4: Minimum vs M_{B_1}. Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime. The sparse region for higher values of M_{B_1} is due to a coarser grid scanned in that region.

Warped Extra Dimensions: Gauge-Higgs Unification

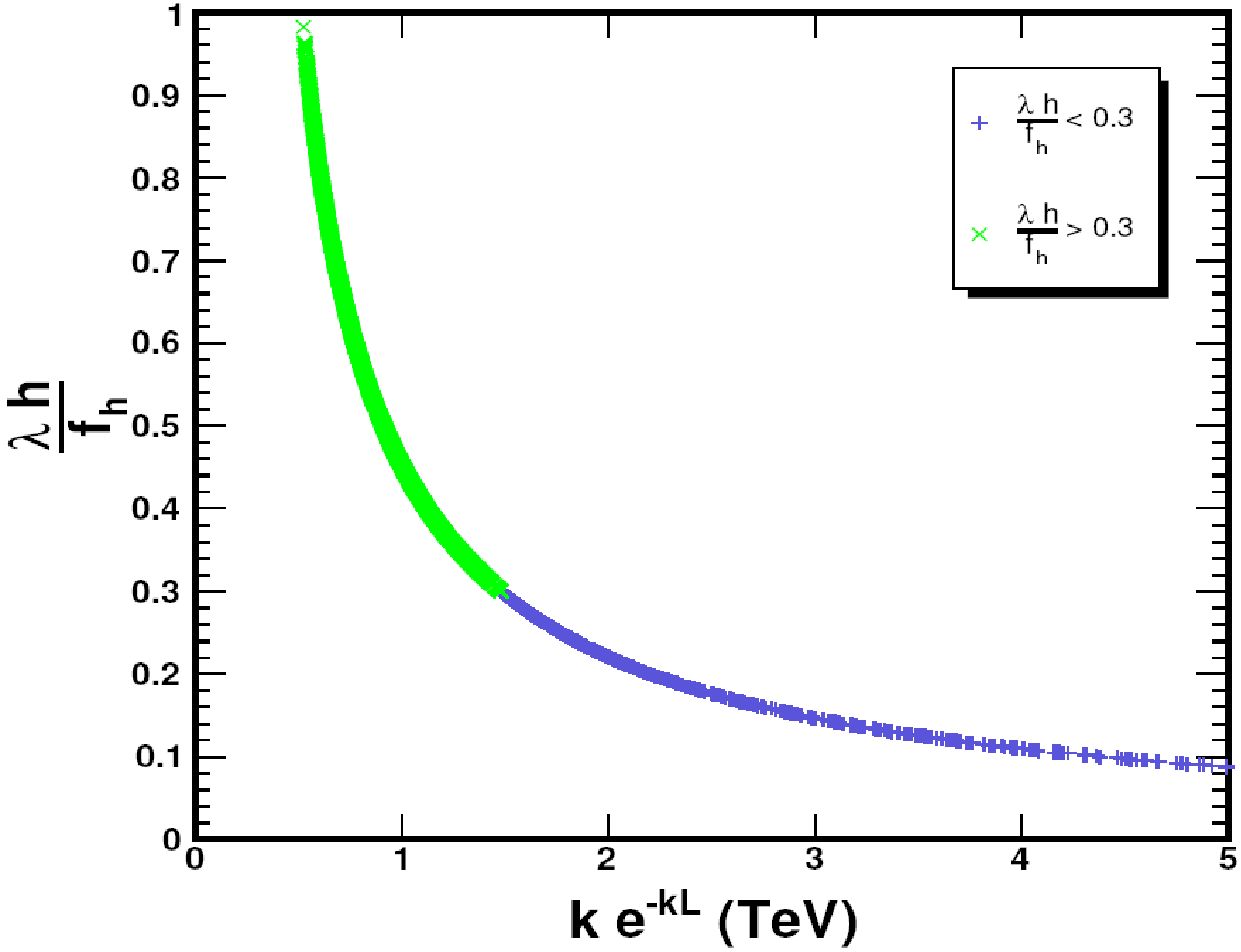


Figure 5: Minimum vs $\tilde{k}$ (TeV). Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime

Warped Extra Dimensions: Gauge-Higgs Unification

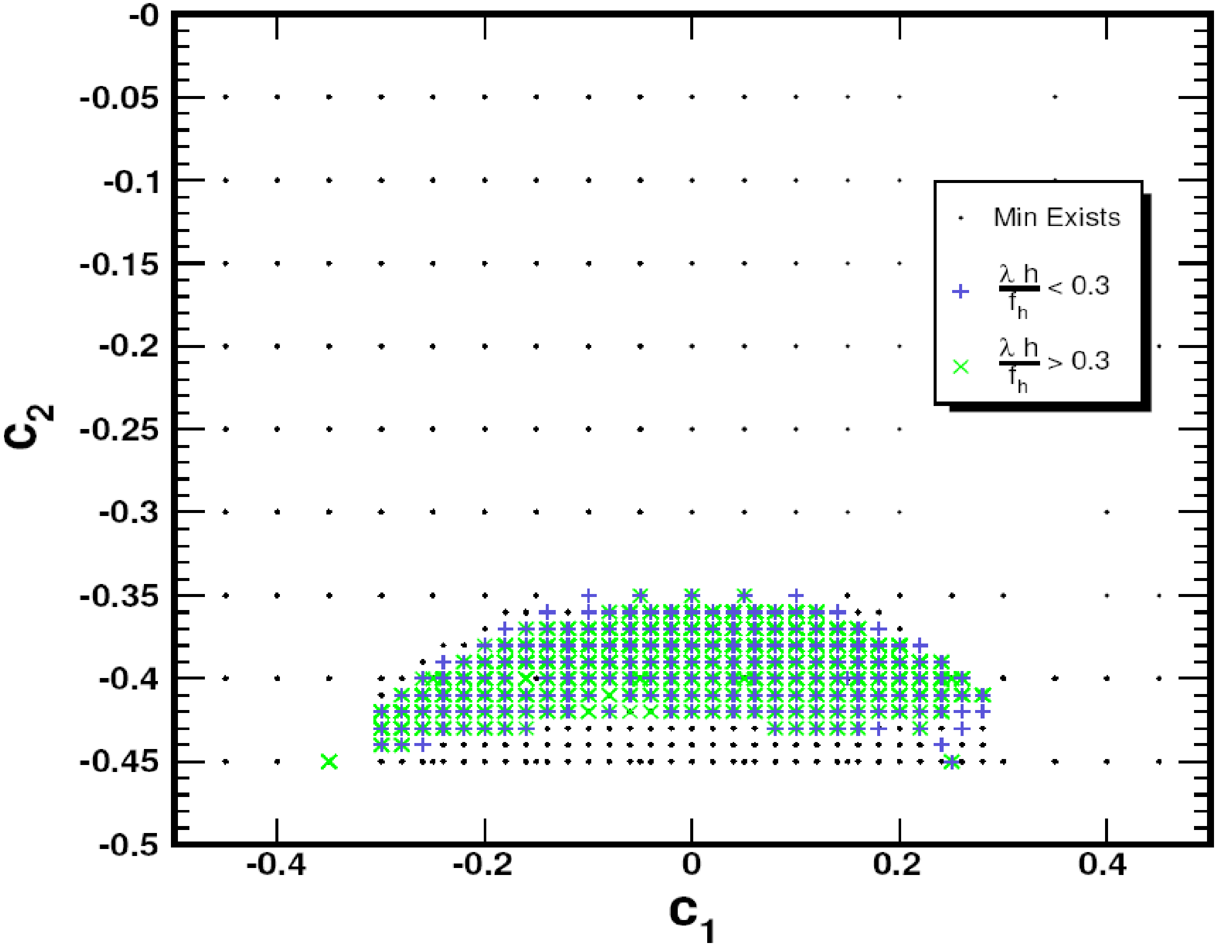


Figure 6: c_1 vs $c2$. Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime and black dots where a minimum for the effective potential exists.

Warped Extra Dimensions: Gauge-Higgs Unification

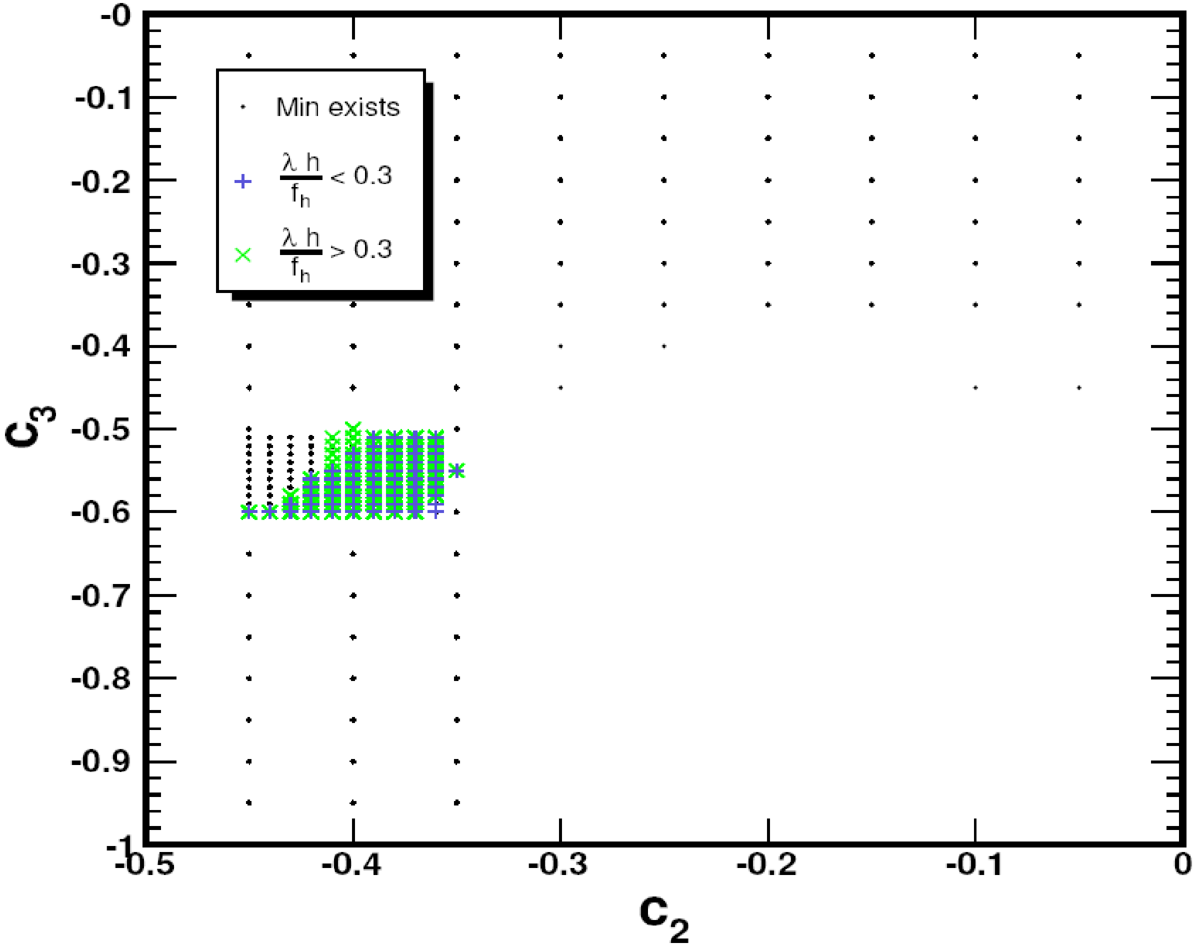


Figure 7: c_2 vs. c_3. Blue (dark gray) crosses represent the linear regime, green (light gray) x's the non-linear regime and black dots where a minimum for the effective potential exists.

Warped Extra Dimensions: Gauge-Higgs Unification

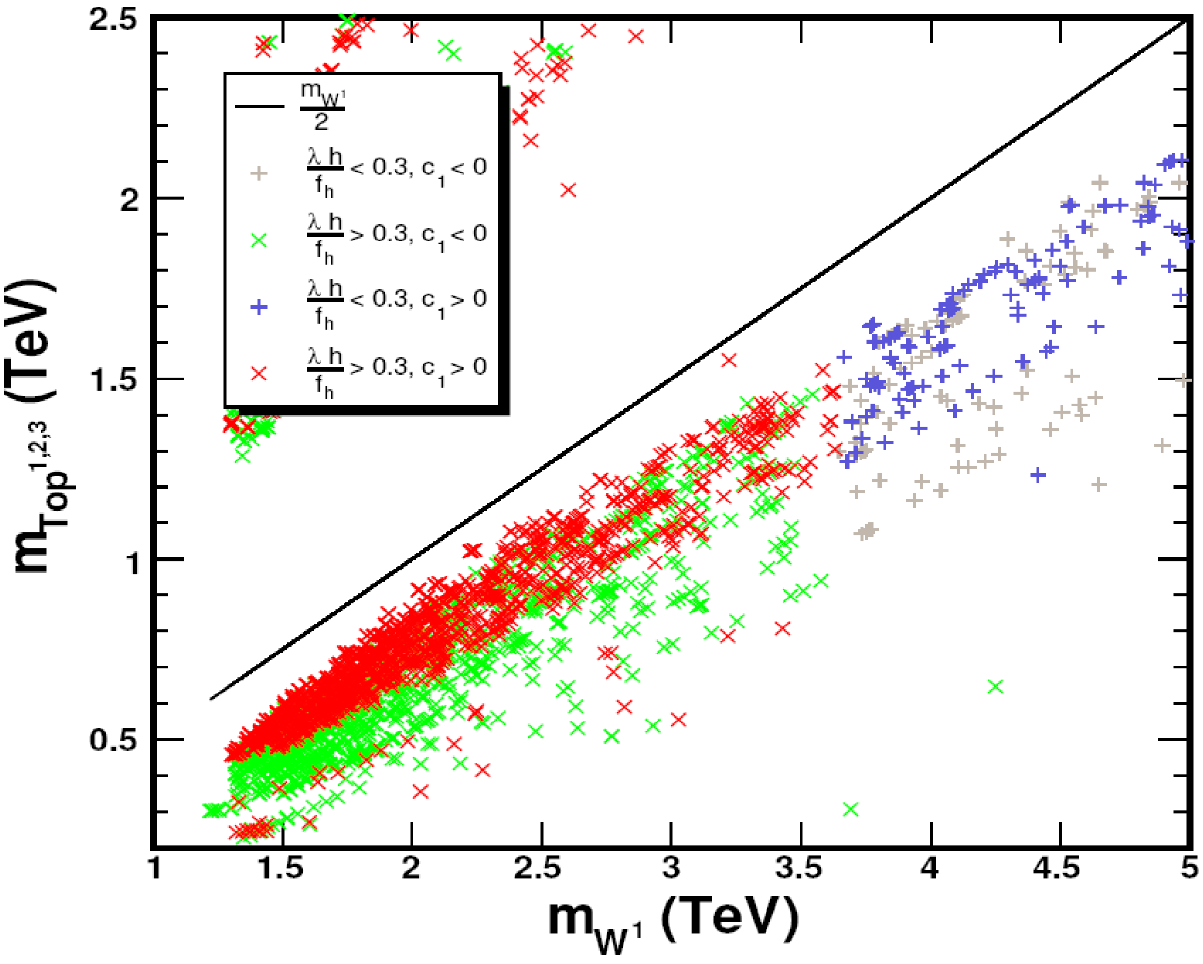


Figure 8: m_{W^1} vs $m_{Top^{1,2,3}}$ in TeV. Also marked is $m_{W^1}/2$ showing that only the first excited top mode can decay into gauge bosons. Blue (dark gray) crosses represent the linear regime with $c_1 > 0$, gray (light gray) crosses the linear regime with $c_1 < 0$, red x's (dark gray) the non-linear regime with $c_1 > 0$, green x's (light gray) the non-linear with $c_1 < 0$.

Warped Extra Dimensions: Gauge-Higgs Unification

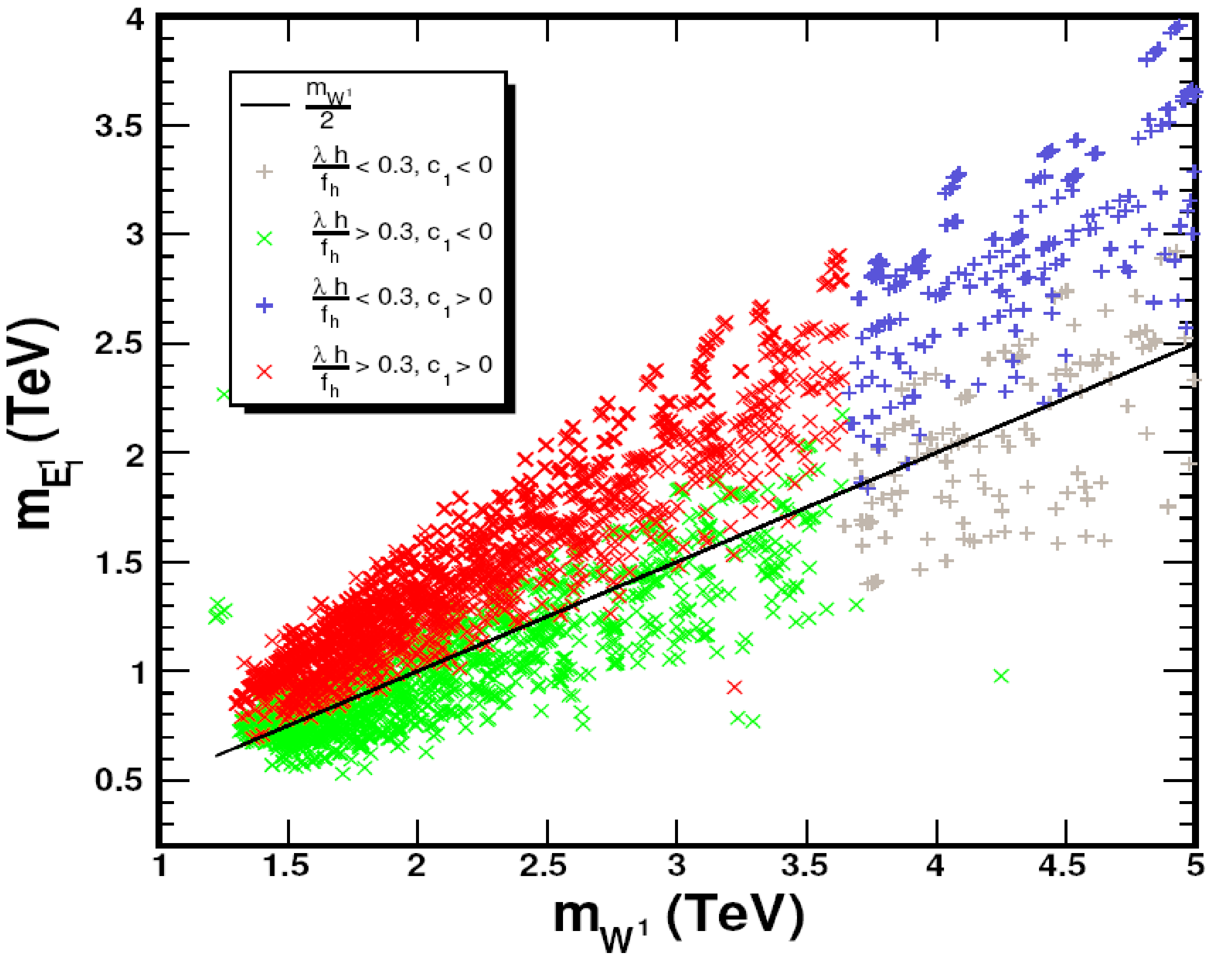


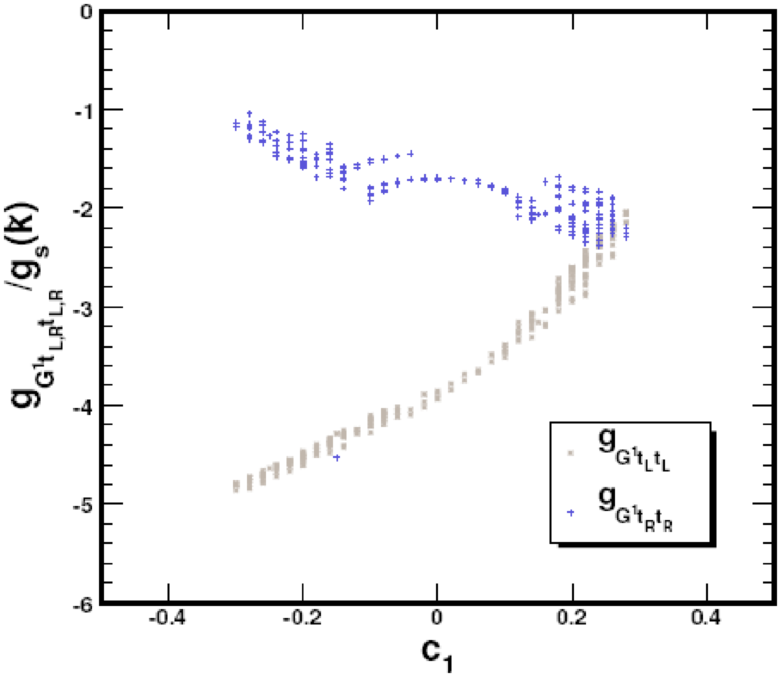
Figure 9: m_{W^1} vs $m_{E_1^{1,2}}$ in TeV. Also marked is $m_{W^1}/2$ showing that depending on the value of the parameters (c_i and B_i) the first mode of the lightest exotic fermion may decay into the gauge bosons. Blue (dark gray) crosses represent the linear regime with $c_1 > 0$, gray (light gray) crosses the linear regime with $c_1 < 0$, red x's (dark gray) the non-linear regime with $c_1 > 0$, green x's (light gray) the non-linear with $c_1 < 0$.

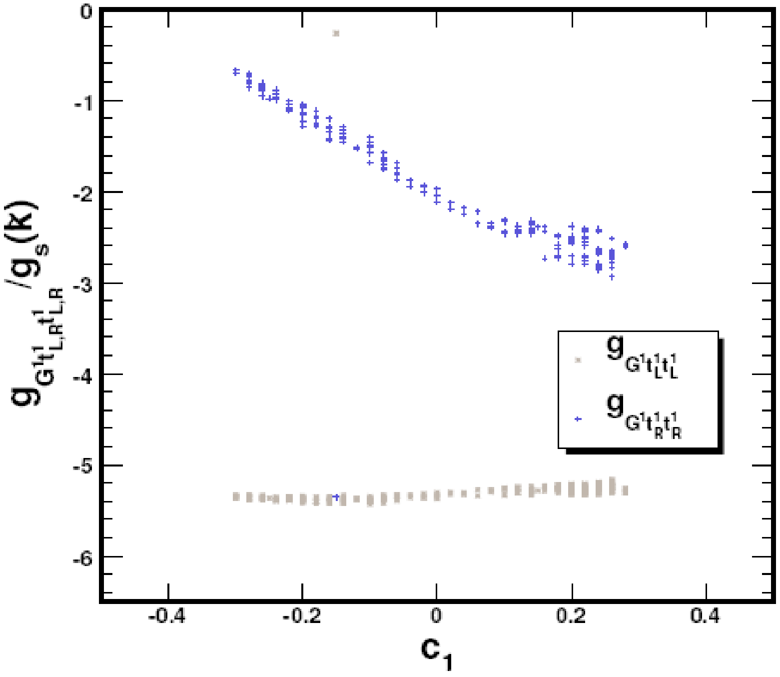
Gauge-Higgs Unification: Collider Phenomenology

- Decays of excited state of gluons G^1 into pairs of excited tops t^1, mostly singlets under SM gauge group. Improve reach to probe t^1-masses further than direct QCD production. The pairs of t^1 decay into either W^+b, Ht or Zt.

- Example of important couplings to consider:

$$g_{G^1\bar{t}t} \;=\; g_{5s} N_{G^1} \int_0^L \left(\sum_i f^{2/3*}_{F,i,m_t}(x_5,h).f^{2/3}_{F,i,m_t}(x_5,h) \right) C[x_5, m_{G^1}] dx_5$$





Gauge-Higgs Unification: Collider Phenomenology

- t^1 decay branching ratios,

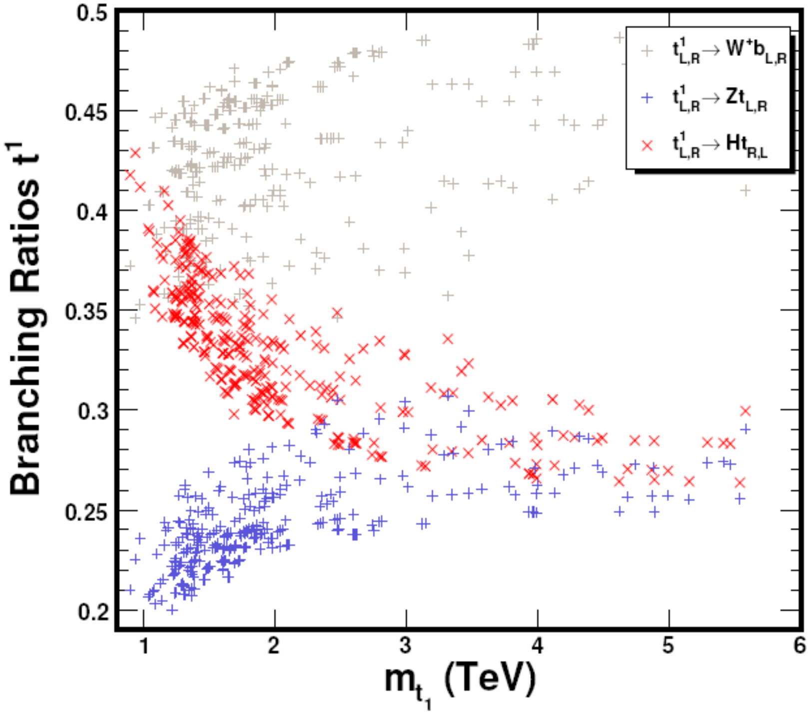


Figure 4: Branching ratios for the decay of t^1 vs m_{t^1} (GeV). Notice that the 2:1:1 relations holds for large m_{t^1}.

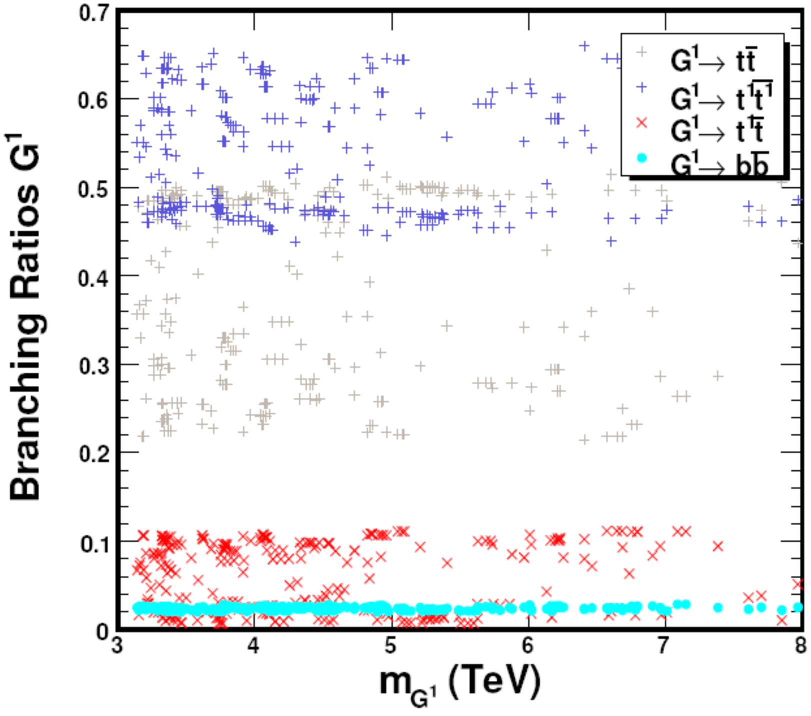


Figure 5: Branching ratios for the decay of G^1 vs m_{G^1} (GeV). Notice that G^1 decays mostly to t^1 pairs.

Gauge-Higgs Unification: Collider Phenomenology

- t^1 production cross section through QCD alone and through QCD+G^1 for M_{G1}=4 TeV.

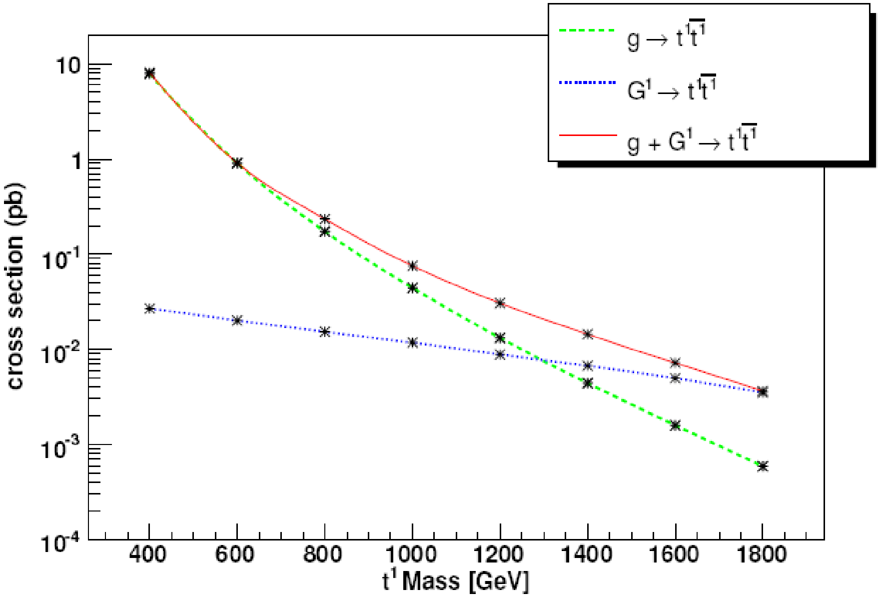


Figure 5: Cross section for $M_{G^1} = 4.0$ TeV with couplings $g_{G^1\bar{t}^1{}_L t^1_L}/g_s(\tilde{k}) = -5.18$ and $g_{G^1\bar{t}^1{}_R t^1_R}/g_s(\tilde{k}) = -2.77$.

Notice that for $M_{t1} \approx$ 1.5 TeV, G^1-induced production contributes in a significant amount to the t^1 production cross section.

Gauge-Higgs Unification: Collider Phenomenology

- From the Goldstone Equivalence Theorem → 50 % of times, t^1 decays in W^+b. We shall therefore concentrate on the channel:

$$pp \to (g+G^1) \to t^1\bar{t^1} \to W^+bW^-\bar{b} \to l^-\bar{\nu}b\bar{b}jj, \quad (l=e,\mu)$$

- Backgrounds for this signal: top quark pair production induced by G^1 in addition to QCD (main background), W+jets and Z+jets (last two backgrounds are reducible to negligible levels by requiring 2 b-tags and lepton+MET).

- Points chosen to analyze:

c_1	c_2	c_3	M_{B_1}	M_{B_2}	$h/(\sqrt{2}f_h)$	m_{G^1}	m_{t^1}	$g_{G^1\bar{t}t_R}$	$g_{G^1\bar{t}t_L}$	$g_{G^1\bar{t^1}t^1_R}$	$g_{G^1\bar{t^1}t^1_L}$
0.26	-0.41	-0.57	2.2	0.4	0.278	3915.8	1470.2	-2.09	-2.28	-2.73	-5.22
0.24	-0.41	-0.58	2.3	0.5	0.318	3439.6	1250.5	-2.12	-2.50	-2.67	-5.20

Table 1: Points of parameter space chosen for t^1 detection. All masses are given in GeV and the couplings are in units of $g_s(\tilde{k})$.

- We set cone reconstruction algorithm to $\Delta R=(\Delta\eta^2+\Delta\phi^2)^{1/2}=0.6$ for W invariant mass reconstruction.

Gauge-Higgs Unification: Collider Phenomenology

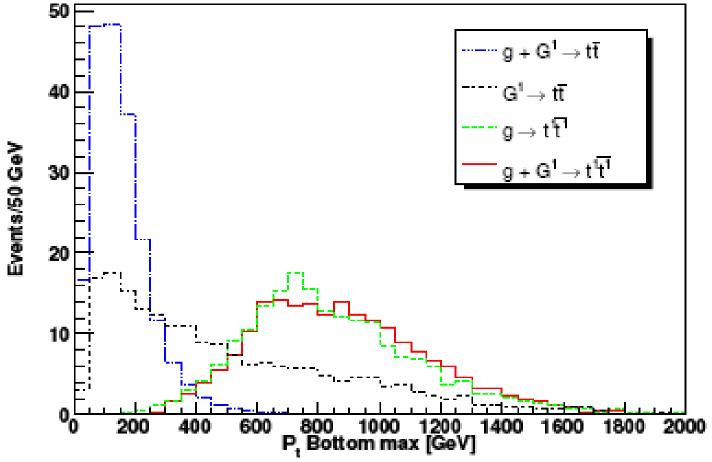
Event Selection: First selection cut on hadronized events:

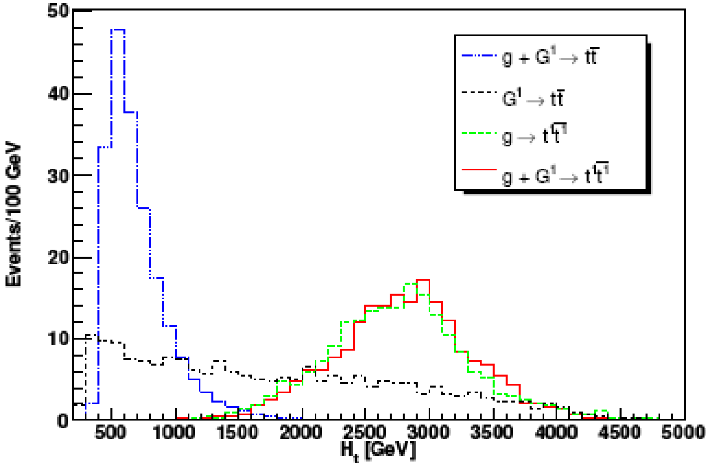
1. Isolated lepton with p_t>20 GeV and $|\eta|$<2.5 plus missing energy with p_t>20 GeV.
2. At least three jets with p_t>20 GeV and $|\eta|$<2.5, with exactly 2 bottom-tags.

Isolated lepton+MET reduces backgrounds from QCD jets.

	Point 1			Point 2		
Process	σ $[fb]$	N^0 Events	N^0 after cuts	σ $[fb]$	N^0 Events	N^0 after cuts
$G^1 \to t\bar{t}$	4.12	1236	1	4.43	443	0
$g \to t^1\bar{t}^1$	0.23	70	6	0.687	69	5
$g + G^1 \to t\bar{t}$	3025	907527	7	3085	308509	6
$g + G^1 \to t^1\bar{t}^1$	0.88	266	24	2.015	201	14

Big top background which must be reduced to manageable levels → Cuts $p_{t,\mathrm{bottom}}$ and H_t.





Gauge-Higgs Unification: Collider Phenomenology

W-mass reconstruction through two methods:

1. W→ 2 jets. Works well for t^1 masses less than 1 TeV. Uses $\Delta R=0.4$.
2. W→1 jet. Works well for t^1 masses bigger than 1 TeV. Increases signal and decreases background. Uses $\Delta R=0.6$. Figures in the case of point 1.

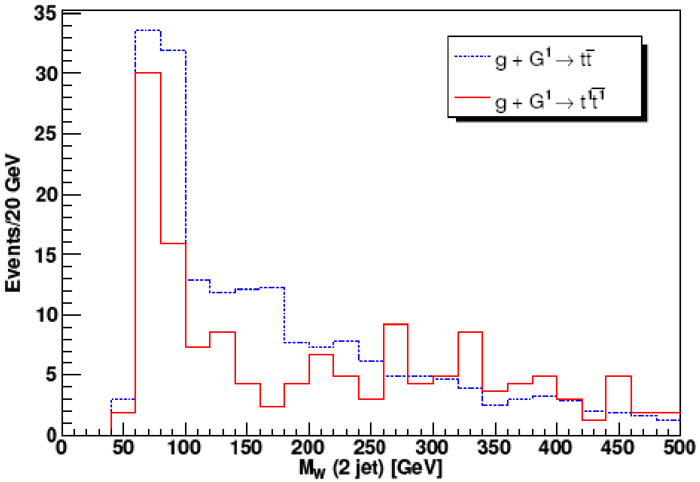


Figure 9: Invariant reconstructed W mass using the method of two jets. Distribution normalized to 200 events.

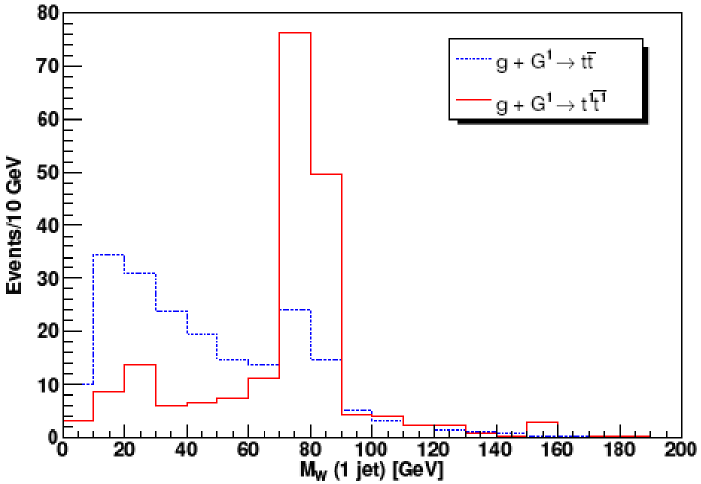


Figure 10: Invariant reconstructed W mass using the method of only one jet. Distribution normalized to 200 events.

Gauge-Higgs Unification: Collider Phenomenology

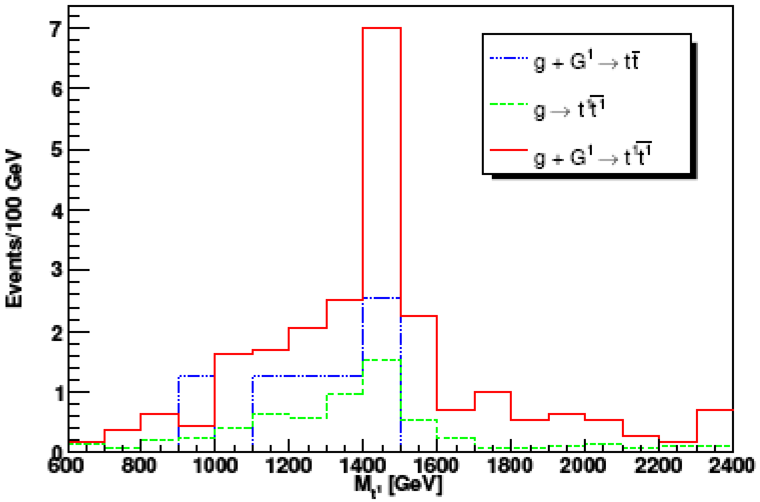
- Final set of cuts for reconstruction of t¹ mass distribution:

$$\begin{aligned} p_t^{b,max} &\geqslant 350\ \mathrm{GeV}, & p_t^{b,max} &\geqslant 300\ \mathrm{GeV}, \\ H_t &\geqslant 1900\ \mathrm{GeV}, & H_t &\geqslant 1800\ \mathrm{GeV}, \\ p_t^{lepton} &\geqslant 200\ \mathrm{GeV}, & p_t^{lepton} &\geqslant 150\ \mathrm{GeV}. \end{aligned}$$

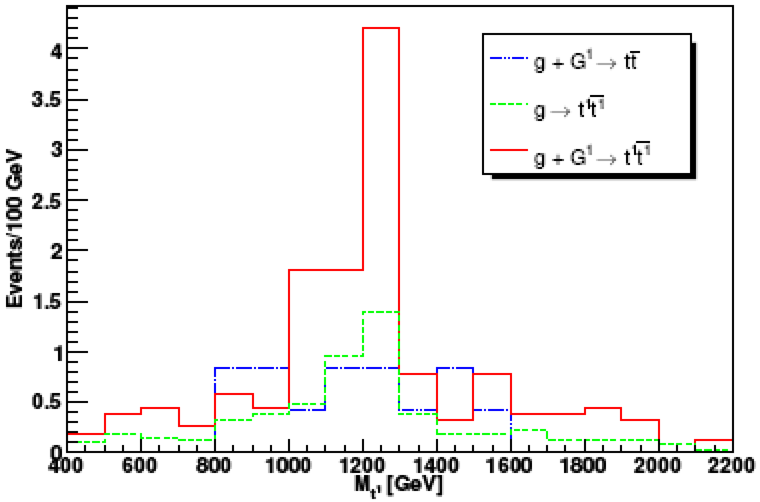
$$\begin{aligned} p_t^{j,max} &\geqslant 250\ \mathrm{GeV}, \\ |M_W - M_W^j| &\leqslant 20\ \mathrm{GeV}, \\ |m_{Wb_i} - m_t| &\geqslant 50\ \mathrm{GeV}, \end{aligned}$$

- Reconstructed t¹ invariant mass distribution choosing bottom with biggest ΔR w.r.t W,

Point 1



Point 2



Gauge-Higgs Unification: Collider Phenomenology

Results

We estimate statistical significance as $S/(S+B)^{1/2}$.

With the inclusion of K factors, K~1.5, presence of these particles may be found already at 100 fb^{-1} for Point 1 (60 fb^{-1} point 2) and discovery at 300 fb^{-1} for point 1 (200 $\mathrm{fb}^{-1}$for point 2).

Gauge-Higgs Unification: Collider Phenomenology

- Constant cross-section curves in (m_{G1}, m_{t1}) plane to estimate LHC reach at 300 fb^{-1}.

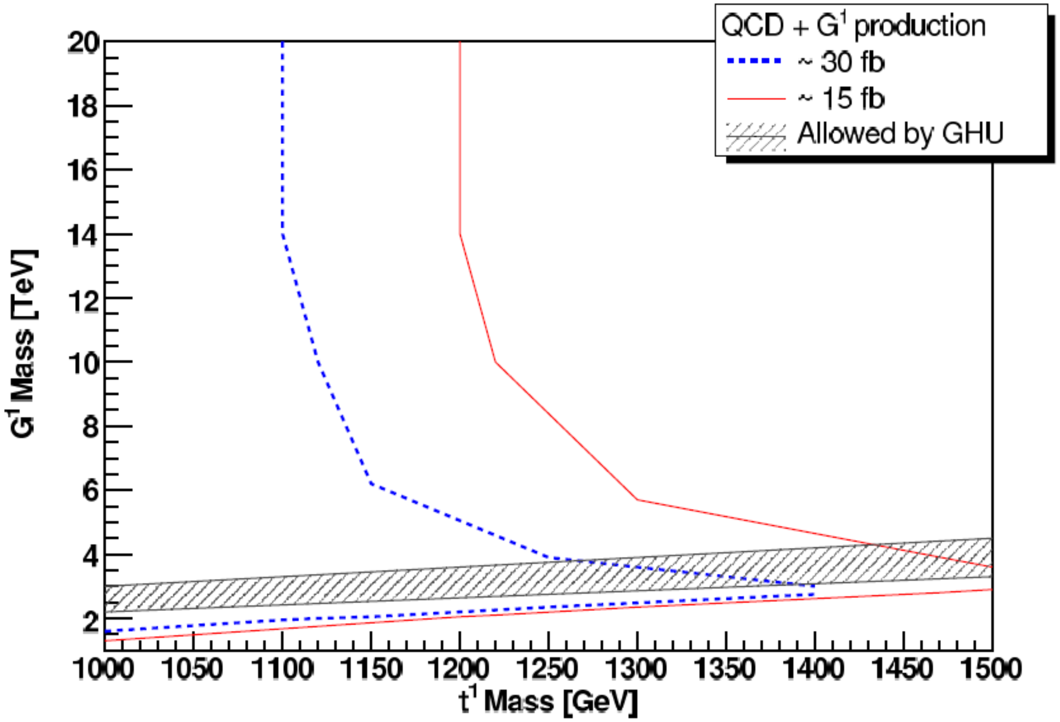


Figure 20: Curves of constant cross section for QCD in addition of G^1 decay, in (m_{G^1}, m_{t^1}) plane.

Conclusions

- Electroweak symmetry breaking in consistent regions given by electroweak precision tests.

- Higgs mass between 116 GeV and 160 GeV.

- First KK excitation of the top quark t^1 light enough to be produced from decays of first excited KK state of the gluon.

- Rich collider phenomenology: G^1 decays into t^1 expand the reach of t^1 detection to masses around 1.5 TeV.

- Consistent phenomenological model which will be tested at the LHC.