The effective description of strong electroweak symmetry breaking

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Outline

- Introduction
- BESS model
- top-BESS model
- Phenomenology of the models
- Conclusion

Introduction

- SM of electroweak interactions based on the gauge principle
- gauge symmetry of Lagrangian $SU(2)_L \times U(1)_Y$

  → massless A, $W^{\pm}$, Z

- massive gauge bosons
- Higgs mechanism based on **S**pontaneous **S**ymmetry **B**reaking (SSB)

- unknown mechanism of **E**lectroweak **S**ymmetry **B**reaking (ESB)
- benchmark hypothesis:

$$\Phi(x) = \begin{pmatrix} \pi_2(x) + i\pi_1(x) \\ v + h(x) - i\pi_3(x) \end{pmatrix}, \qquad \langle \Phi \rangle_0 = v$$

$\Rightarrow$ Higgs boson

- Higgs not observed yet

Introduction

Existing scenarios of ESB

- **weakly-interacting:**
  ESB is broken by perturbative interactions
  elementary scalar fields
  - SM Higgs sector $\Rightarrow$ Higgs boson
  - SUSY: more Higgs bosons
  - ...

- **strongly-interacting:**
  ESB is broken by new strong interactions
  no Higgs, composite particles
  - Technicolor-like theories
  - ...

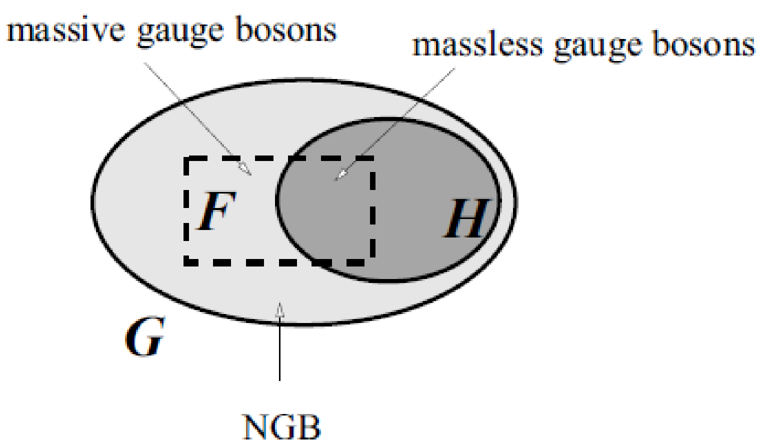
- **extra-dimensions, ...**
  AdS/CFT correspondence
  - Kaluza-Klein towers
  - gauge-Higgs unification
  - ...

- a lot of models
- low-energy phenomenology based on Effective Lagrangian

ESB: general requirements

Goldstone theorem:

SSB: $G \to H$ $\Rightarrow$ the # of Goldstone Bosons $= \dim G - \dim H$



- at least 3 NGB's $\Rightarrow$ $\dim G - \dim H \geq 3$
- the massive gauge bosons must be coupled to the corresponding three NGB's

- $SU(2)_L \times U(1)_Y \subset G, \quad U(1)_{em} \subset H$ $\Rightarrow \quad \dim G \geq 4,\ \dim H \geq 1$
- if SSB $\Rightarrow M_{W,Z}$ then $M_{W,Z} = \mathcal{O}(v)$
- EXP: $\rho \equiv \dfrac{\text{charged current}}{\text{neutral current}} \approx 1$

if $SU(2)_V \subset H$ then $\rho = 1$

  tree: $\rho = M_W^2/(M_Z^2 \cos^2\theta_W) = 1$
  loop: g' breaks $SU(2)_V$, $\mathcal{O}(g'^2) \sim 0.01$
  $\Rightarrow \quad \dim H \geq 3$
- no NGB's observed $\Rightarrow \quad \dim G - \dim H = 3$

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

BESS model

- effective description of the **B**reaking **E**l-weak **S**ymmetry **S**trongly
- effective non-renormalizable Lagrangian
- **H**idden **L**ocal **S**ymmetry approach $[SU(2)_L \times SU(2)_R]^{glob} \times SU(2)_V^{loc}$

$SU(2)_V$ vector boson triplet V_μ^a a=1,2,3 (gauge fields in HLS)

- other fields:

  SM gauge bosons, SM fermions, no Higgs, 6 unphys. scalar fields
- interaction of SM gauge bosons modified by the mixing with V_μ^a
- interaction with fermions with V_μ^a:

  direct (inter-generational universality), indirect

[1] R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, *Phys. Lett.* **B155** (1985) 95.

[2] R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, *Nucl. Phys.* **B282** (1987) 235.

[3] R. Casalbuoni, P. Chiappetta, S. De Curtis, F. Feruglio, R. Gatto, B. Mele, J. Terron, *Phys. Lett.* **B249** (1990) 130.

[4] G. Altarelli, R. Casalbuoni, D. Dominici, F. Feruglio, R. Gatto, *Nucl. Phys.* **B342** (1990) 15.

top-BESS model

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- modification of the BESS model
- motivation: mass of top quark – too big and close to scale of ESB

(might be a sign of top`s special role in new physics behind mechanism of ESB)

top-BESS model

- **interactions of V_μ^a to fermions:**
  - inter-generational universality broken:
    - *no* direct interactions to leptons
    - *no* direct interactions to u, d, c, s
    - direct interaction to the left (t, b) doublet: b_1
    - direct interaction to the right t quark: b_2
    - direct interaction to the right b quark: pb_2 , $0 \leq p \leq 1$
  - global $SU(2)_R$ broken down to $U(1)_{R3}$ if $p < 1$

- **interactions of the SM gauge bosons to fermions:**
  - symmetries of the model admit modification of the SM gauge-boson-to-fermion couplings not considered previously in the original BESS model:

    ... to the left (t, b) doublet: λ_1

    ... to the right (t, b) doublet: λ_2
  - parity violation terms

top-BESS model

Symmetries

global

$[SU(2)_L \times SU(2)_R \times U(1)_{B-L}]^{glob} \times SU(2)_V^{loc} \rightarrow [SU(2)_V \times U(1)_{B-L}]^{glob} \times SU(2)_V^{loc}$

local

$[SU(2)_L \times U(1)_Y \times SU(2)_V]^{loc} \rightarrow U(1)_{em} \times SU(2)_V^{loc}$

$\downarrow$

$U(1)_{em}$

$U(1)_Y$ as a "diagonal" subgroup of $U(1)_{R3} \times U(1)_{B-L}$

$[SU(2)_V \times U(1)_{B-L}] \cap [SU(2)_L \times U(1)_Y] \equiv U(1)_{em}$

diagonal group $U(1)_{em} \equiv U(1)_{L3} \times U(1)_{R3} \times U(1)_{B-L}$

$$Q \equiv T_L^3 + Y$$

$$Y \equiv T_R^3 + \tfrac{1}{2}(B-L)$$

$SU(2)_V$ triplet: $\boldsymbol{V}_\mu = i\frac{g''}{2} V_\mu^a \tau^a$

$SU(2)_L$ triplet: $\boldsymbol{W}_\mu = igW_\mu^a \tau^a$

$U(1)_Y$ singlet: $\boldsymbol{B}_\mu = ig' B_\mu Y$

top-BESS Lagrangian

$$\mathcal{L} = -v^2[\mathrm{Tr}(\bar{\omega}_\perp^\mu)^2 + \alpha\,\mathrm{Tr}(\bar{\omega}_\parallel^\mu)^2] + \mathcal{L}_{Wkin} + \mathcal{L}_{Bkin} + \mathcal{L}_{Vkin} + \mathcal{L}_f$$

v, α free real parameters

$$\mathcal{L}_f = \mathcal{I}_a^{L,R} + \frac{1}{1+b_{L,R}}\mathcal{I}_c^{L,R} + \frac{b_{L,R}}{1+b_{L,R}}\mathcal{I}_b^{L,R} + \frac{\lambda_{L,R}}{1+b_{L,R}}\mathcal{I}_\lambda^{L,R} - m_f\mathcal{I}_m$$

$b_{L,R}$, $\lambda_{L,R}$ and m_f are free real parameters (L, R --> 1, 2)

I_a, I_c and I_m kinetic and mass terms

I_c, I_b and I_λ only $(t, b)_{L,R}$ dublets

$b_{L,R}$ direct interaction of $(t, b)_{L,R}$ dublets with V_μ

$\lambda_{L,R}$ modification of interaction of $(t, b)_{L,R}$ with W_μ, B_μ

Gauge boson mixing

$$\mathcal{L} = -v^2[\mathrm{Tr}(\bar{\omega}_\perp^\mu)^2 + \alpha\,\mathrm{Tr}(\bar{\omega}_\|^\mu)^2] + \mathcal{L}_{W\,kin} + \mathcal{L}_{B\,kin} + \mathcal{L}_{V\,kin} + \mathcal{L}_f$$

Gauge boson mixing

charged sector

$$W_\mu^+, V_\mu^+ \to \tilde{W}_\mu^+, \tilde{V}_\mu^+$$

$$W_\mu^-, V_\mu^- \to \tilde{W}_\mu^-, \tilde{V}_\mu^-$$

neutral sector

$$W_\mu^3, B_\mu, V_\mu^3 \to A_\mu, Z_\mu, \tilde{V}_\mu^0$$

Due to mixing also 1st and 2nd generation of leptons can interacts with $\tilde{V}_\mu$ (except ν_R).

Low-energy limits

From limits on anomalous *tbW*, *bbZ* and *ttZ* couplings:
(from measurements at LEP/SLC and CLEO)

$$g'' \gtrsim 20$$

$$-0.003 < b_1 - \lambda_1 < 0.01$$

$p > 0$: $$|p(b_2 - \lambda_2)| < 0.008$$

$p = 0$: $$-0.03 < b_2 - \lambda_2 < 0.04$$

BESS limits: $b \lesssim 0.01, \quad b' = 0$

Our modifications of the BESS model relaxes the low-energy limits on the original BESS model`s parameters.

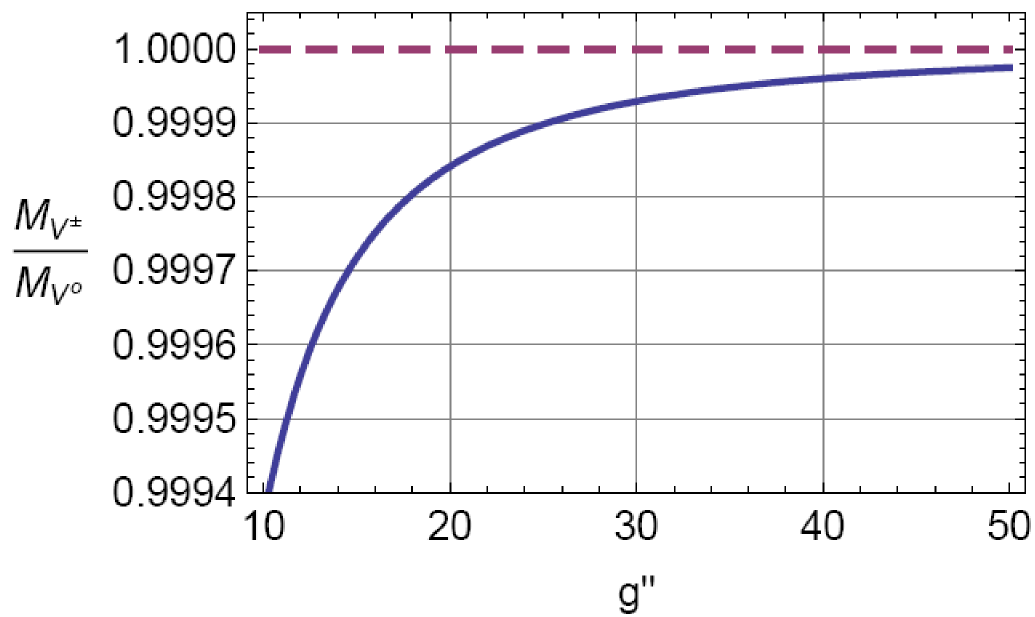
Phenomenology of the models

Comparison of the models:

- $m_f = 0$
- b_1, b_2 vs. $b, b' = 0$
- $p = 0, \lambda = 0$

We assume $M_{V^0} = 1$ TeV.

$$M_{V^0} \approx M_{V^\pm} \approx \frac{\sqrt{\alpha} v g''}{2}$$



The splitting of the mass degeneracy.

Basic features of decay widths

7 decay channels of $V^\pm$: $V^- \to \bar{t}b, \bar{c}s, \bar{u}d, \tau\bar{\nu}_\tau, \mu\bar{\nu}_\mu, e\bar{\nu}_e, W^-Z$

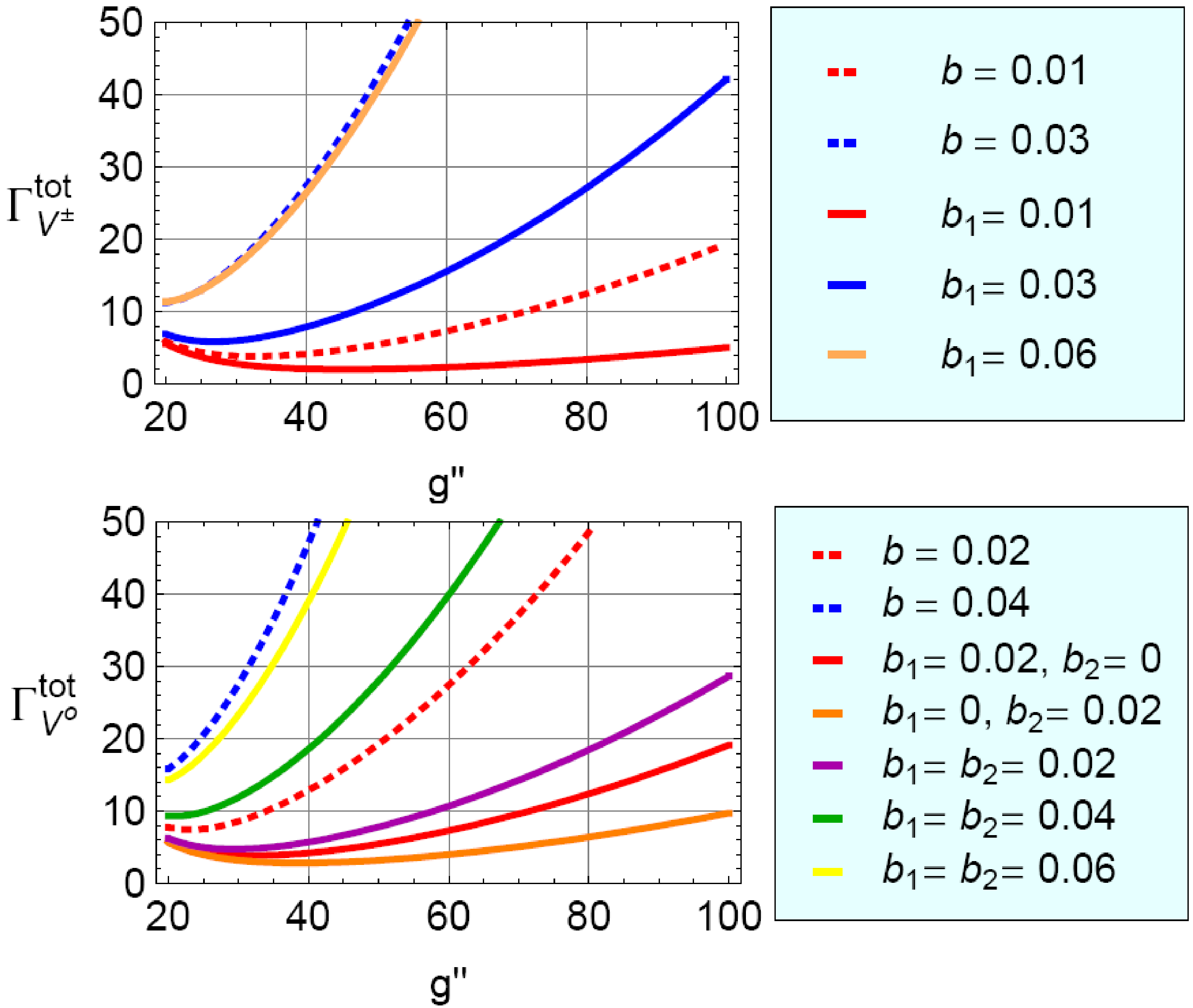
13 decay channels of V^0: $V^0 \to b\bar{b}, t\bar{t}, s\bar{s}, c\bar{c}, d\bar{d}, u\bar{u}, \nu_\tau\bar{\nu}_\tau, \tau\bar{\tau}, \nu_\mu\bar{\nu}_\mu, \mu\bar{\mu}, \nu_e\bar{\nu}_e, e\bar{e}, W^+W^-$

Both BESS models have the same partial decay widths: $V^\pm \to W^\pm Z$, $V^0 \to W^+W^-$

If all b`s = 0 then BESS = top-BESS.

If $b_2 = 0$ and $b_1 = b$ then Γ(tt, bb, tb) are the same.

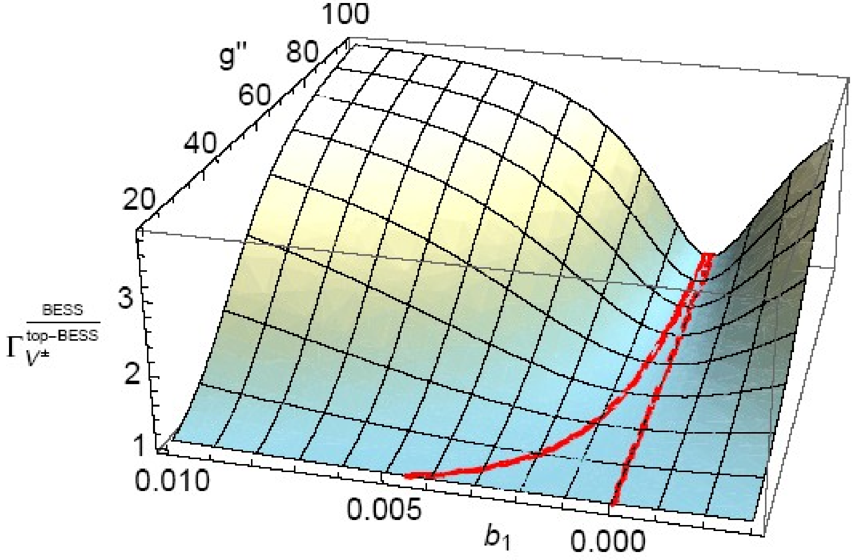
Phenomenology of the models

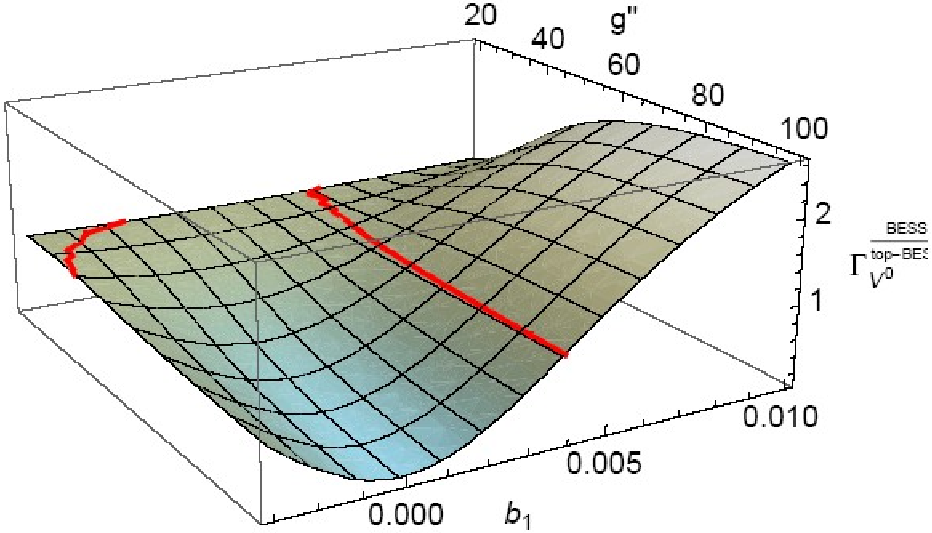


Total decay width of $V^\pm$ and V^0 (in GeV).

BESS model dotted lines, top-BESS model solid lines.

Phenomenology of the models

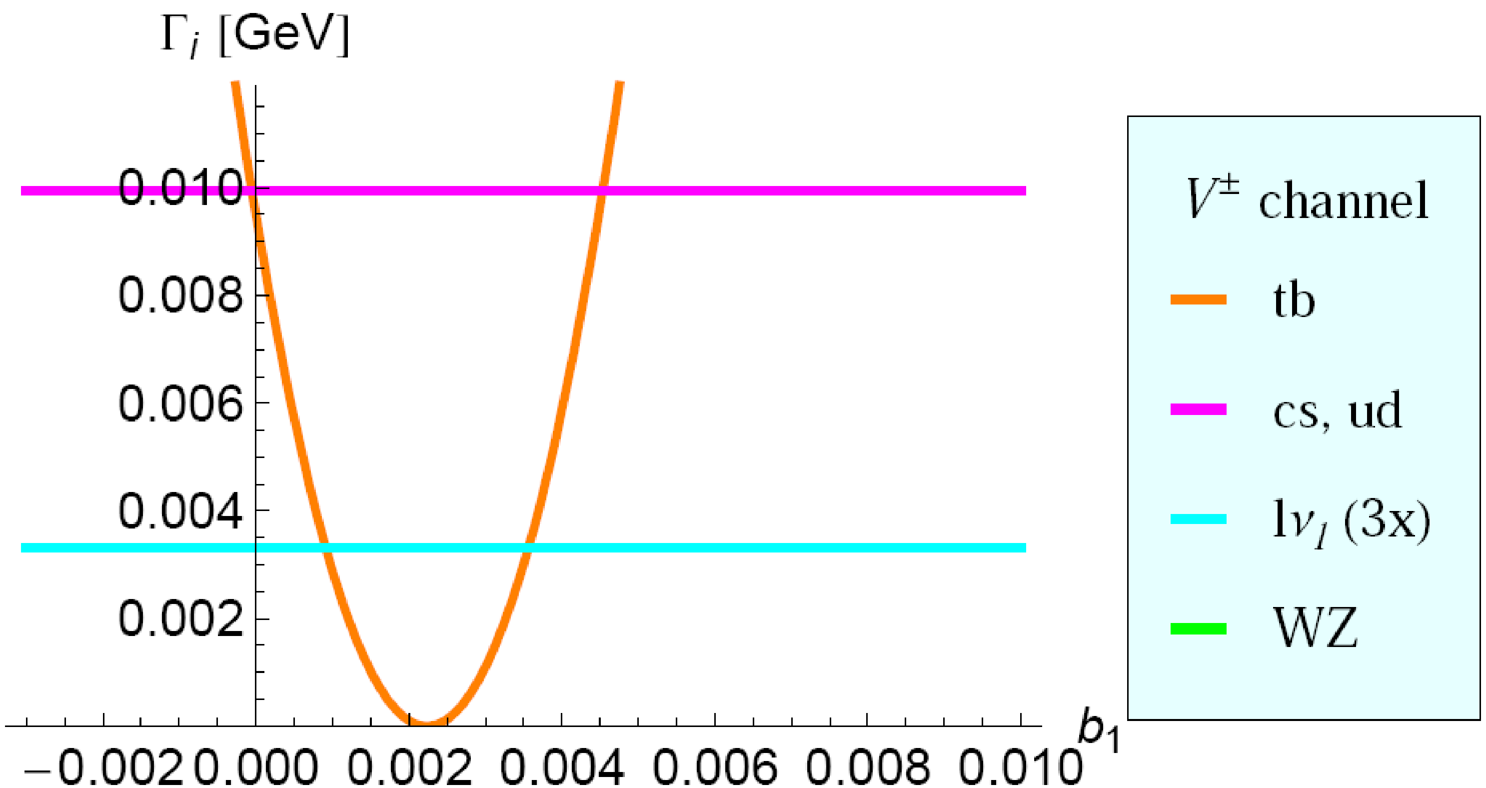




Ratio of total charged (on the left) and neutral (on the right; b_2=0.01, b'=0) decay width of BESS to top-BESS model.

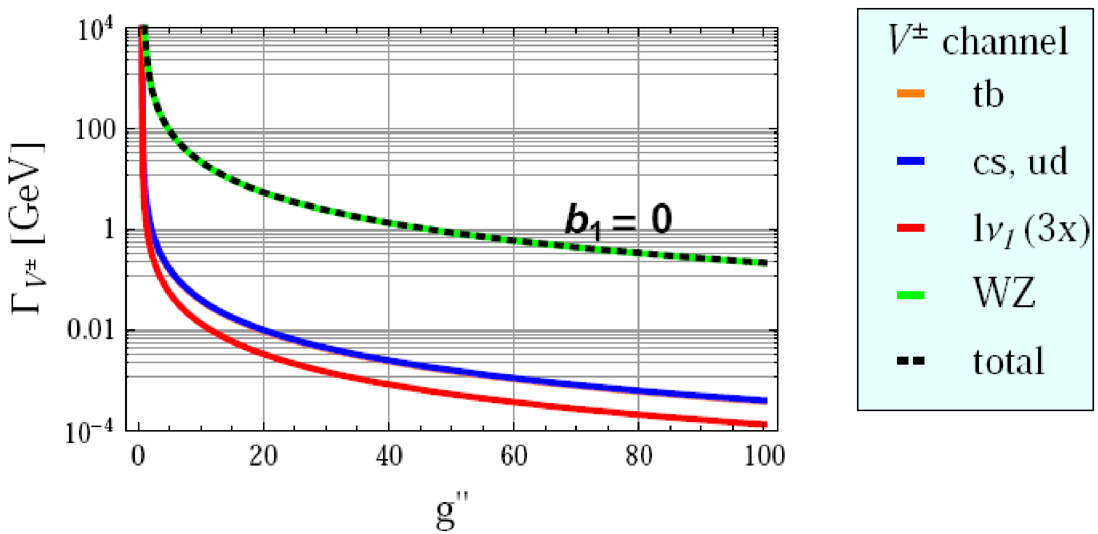
Red curve is ratio one.

Phenomenology of the models

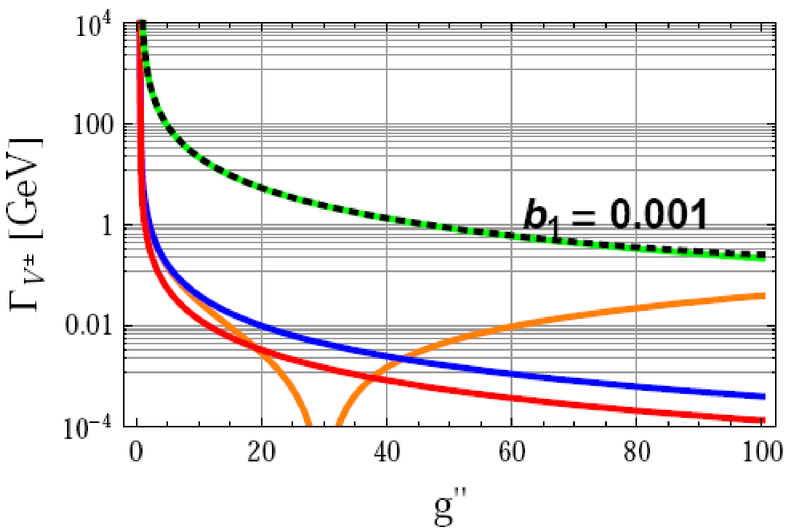


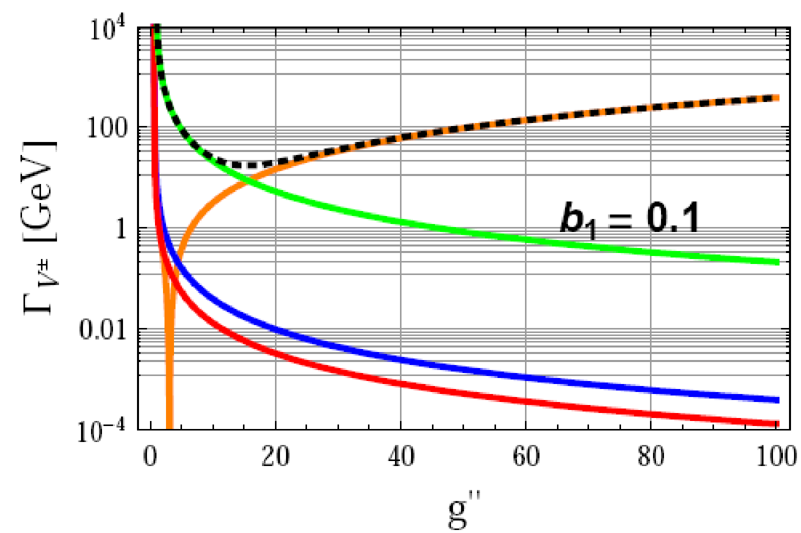
Partial decay width of $V^{\pm}$ for $g'' = 20$. $\Gamma_{WZ} \doteq 5.4$ GeV.

Phenomenology: top-BESS model

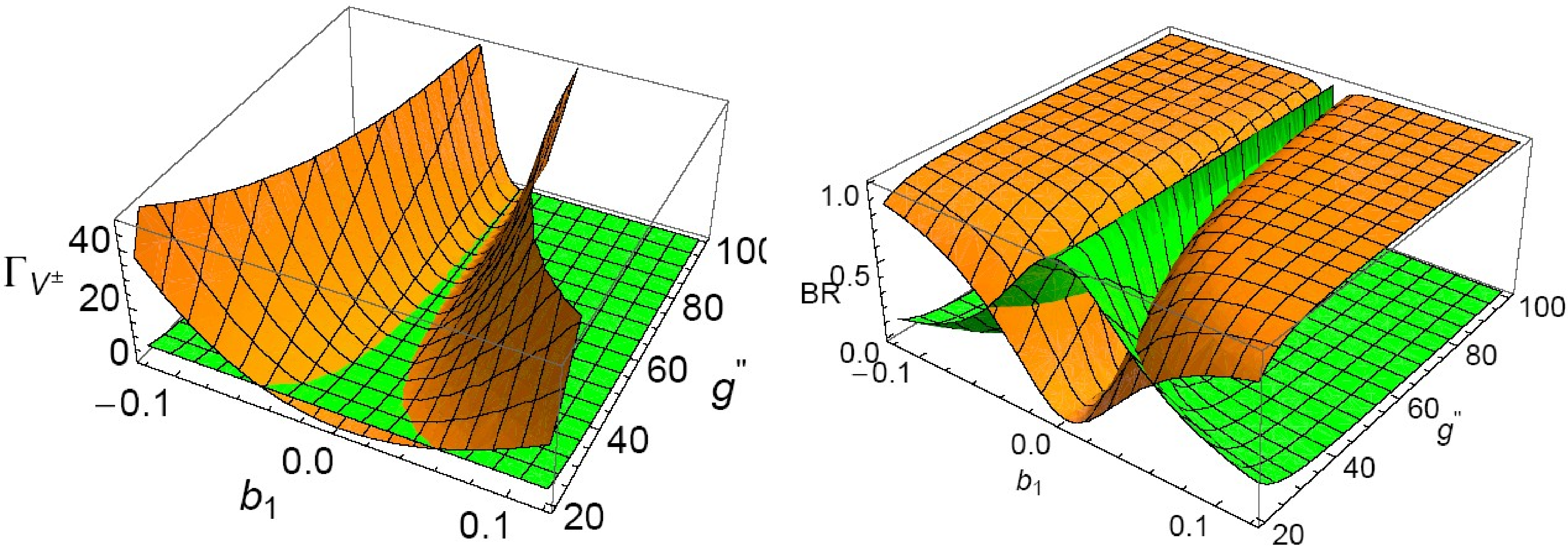


Decay width of charged resonance.



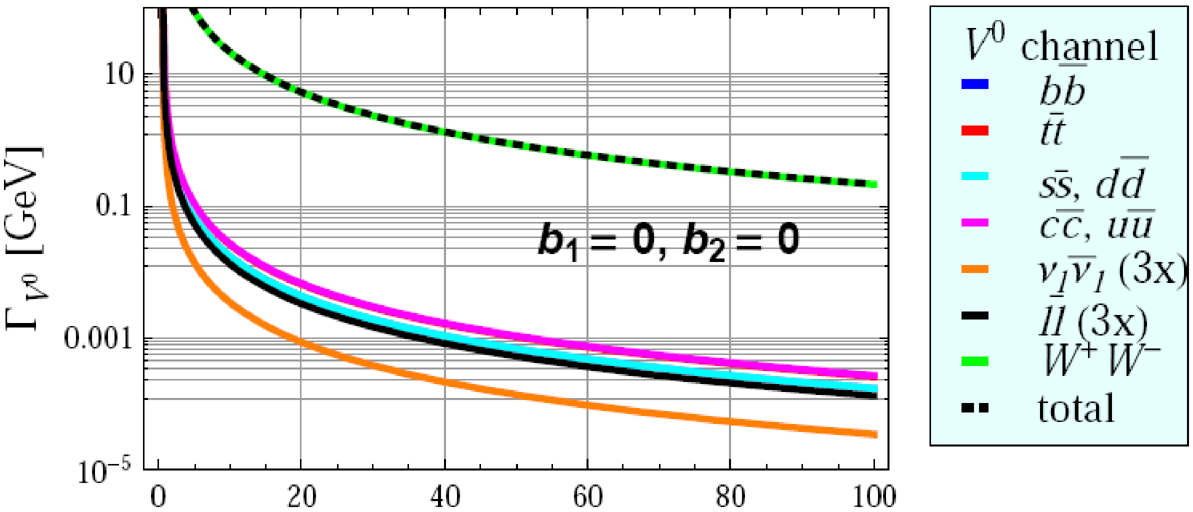


Phenomenology: top-BESS model

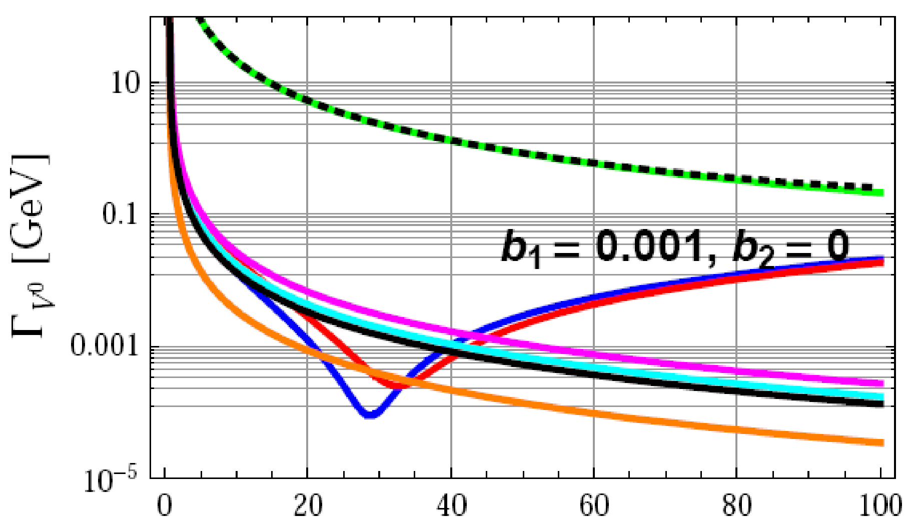


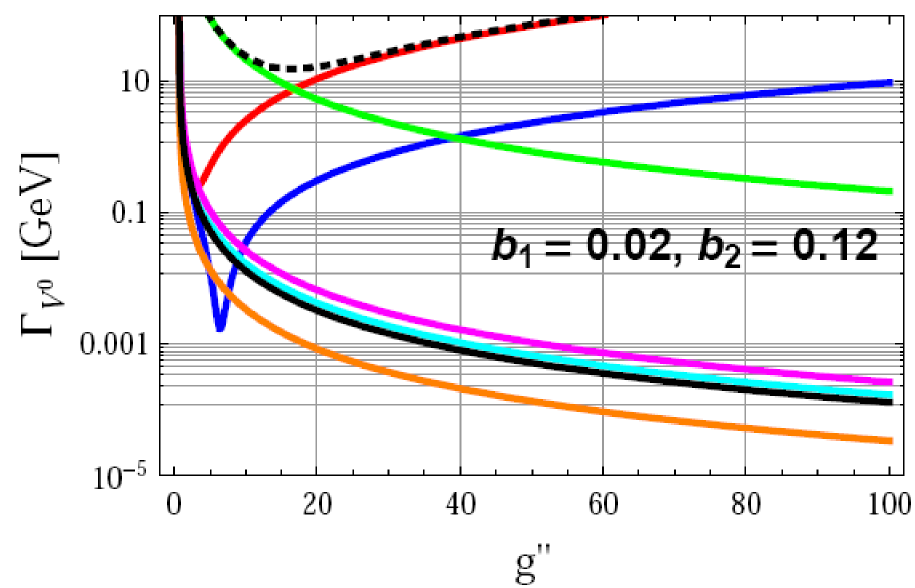
The top-BESS dominant partial decay widths of V^+ (left) and their branching ratio (right) as functions of b_1 and g''. The green, orange surfaces correspond to the W^+Z, $t\bar{b}$ channels, respectively. The partial decay widths are in GeV.

Phenomenology: top-BESS model

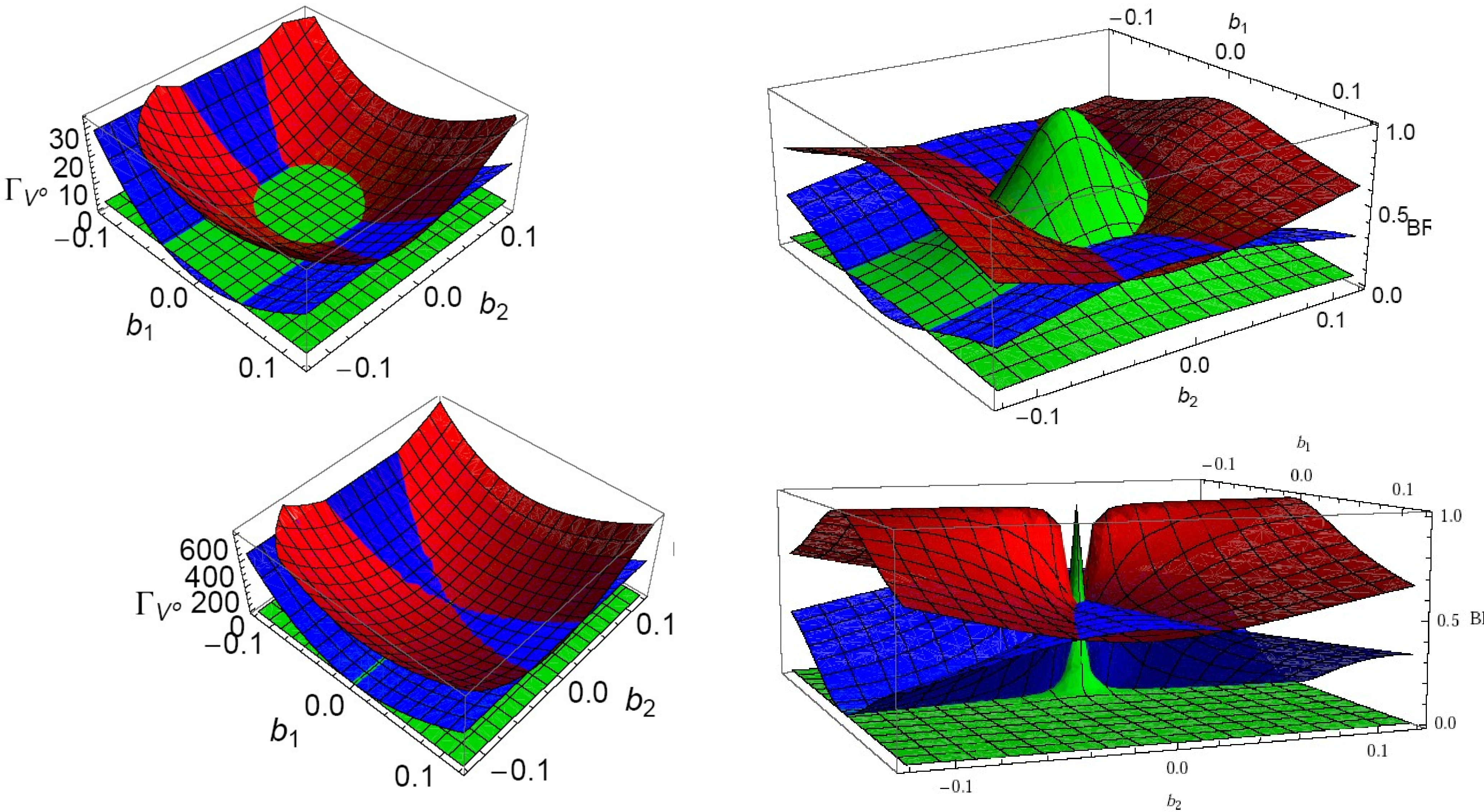


Decay width of neutral resonance.





Phenomenology: top-BESS model



The top-BESS dominant partial decay widths of V^0 (left) and their branching ratio (right) as functions of b_1 and b_2 at $g'' = 25, 100$, from the top to the down, respectively. The green, blue, red surfaces correspond to the W^+W^-, $b\bar{b}$, $t\bar{t}$ channels, respectively. The partial decay widths are in GeV.

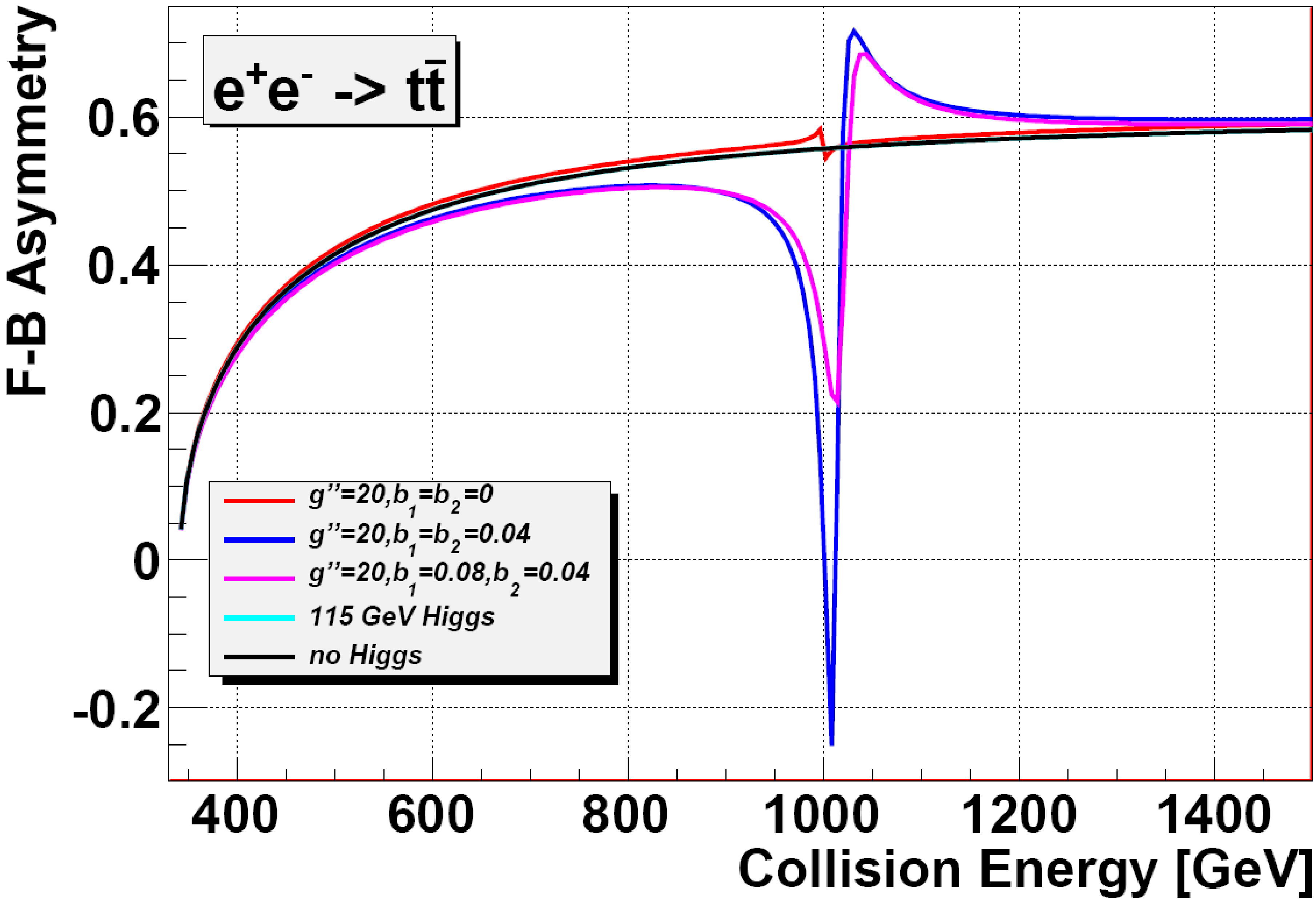
top-BESS model @ LHC

process	P	cut	σ (pb)	R_0	R (100 fb^{-1})
$pp \to t\bar{b}X + c.c$	SM	no	5.84	0	0
	2		6.17	0.136	43.04
	SM	0.7 TeV $\leq m_{tb} \leq$ 1.1 TeV	0.14	0	0
	2		0.20	0.163	51.47
$pp \to W^+ZX + c.c$	SM	no	14.77	0	0
	3		16.96	0.570	180.37
	SM	0.7 TeV $\leq m_{WZ} \leq$ 1.1 TeV	0.20	0	0
	3		0.29	0.188	59.30
$pp \to W^+W^-X$	SM	no	29.86	0	0
	3		31.86	0.366	115.74
	SM	0.7 TeV $\leq m_{WW} \leq$ 1.1 TeV	0.37	0	0
	3		0.42	0.097	30.75

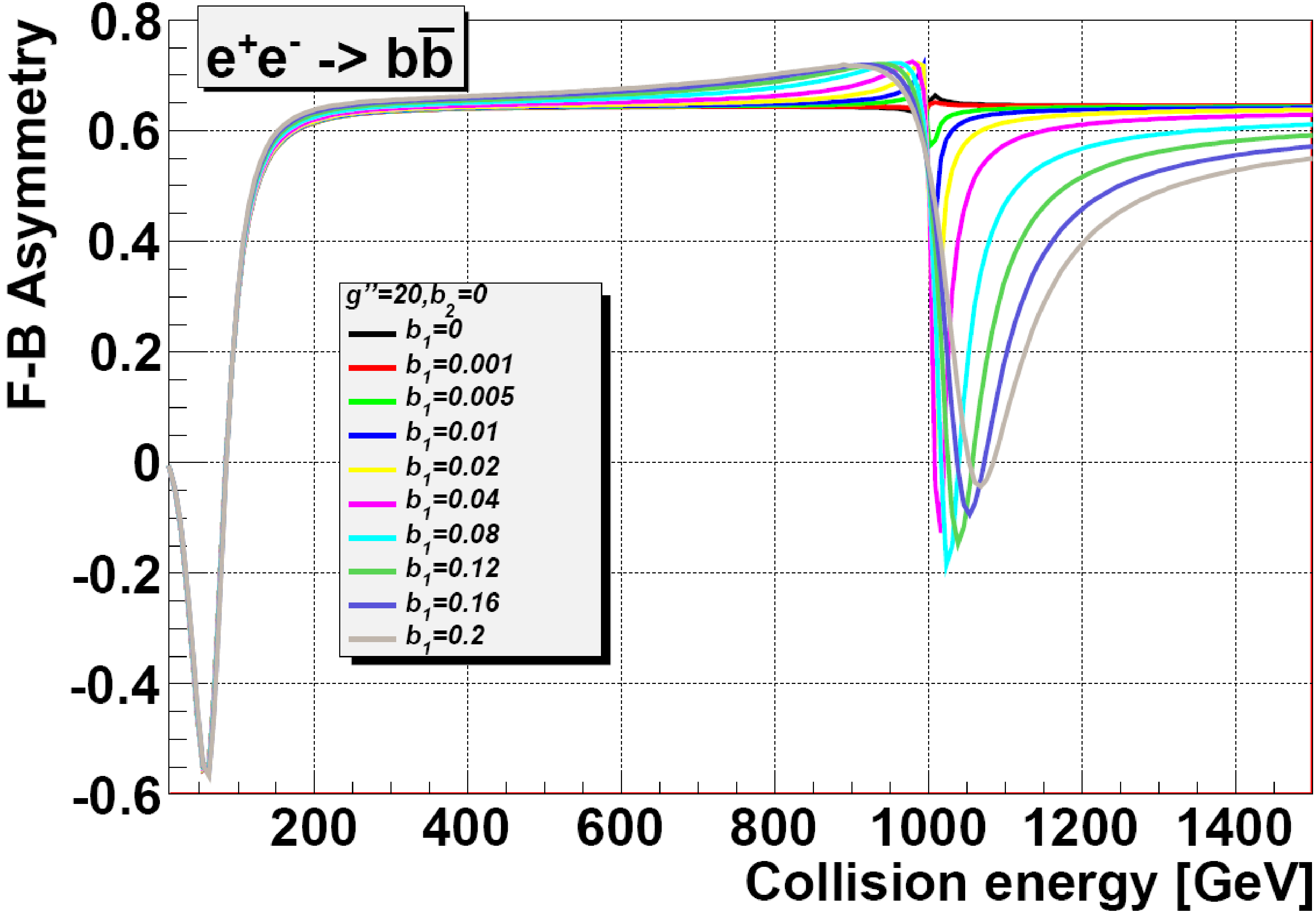
Cross sections and statistical significance R of the model signals with respect to the SM for the studied processes when the integrated luminosity $\mathcal{L} = 100$ fb^{-1}. $R_0 = (\sigma_P - \sigma_{SM})/\sqrt{\sigma_{SM}}$.

$R = \dfrac{N_P - N_{SM}}{\sqrt{N_{SM}}}$ where N_P and N_{SM} are the numbers of the events of our model and the SM

top-BESS model @ ILC



top-BESS model @ ILC



Conclusion

- top-BESS model as modification of BESS model
- effective description of a Higgsless ESB mechanism accompanied by a hypothetical strong triplet of vector resonances
- motivated by special role of top quark in the ESB mechanism

- BESS model versus top-BESS model
- our resonances decay dominantly to the SM gauge bosons and/or to the third generation of quarks
- smaller, i.e. narrower decay widths of our resonances
- relaxing the L-E limits on the original BESS model`s parameters

- cross sections and statistical significance of signals studied
- properties of our model can be studied at the LHC, ILC colliders
- further investigation is needed (study of backgrounds and the detector reconstruction efficiency) work is in progress

Thank you for your attention.