Top-BESS Model

and

its Phenomenology

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Outline

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Challenge

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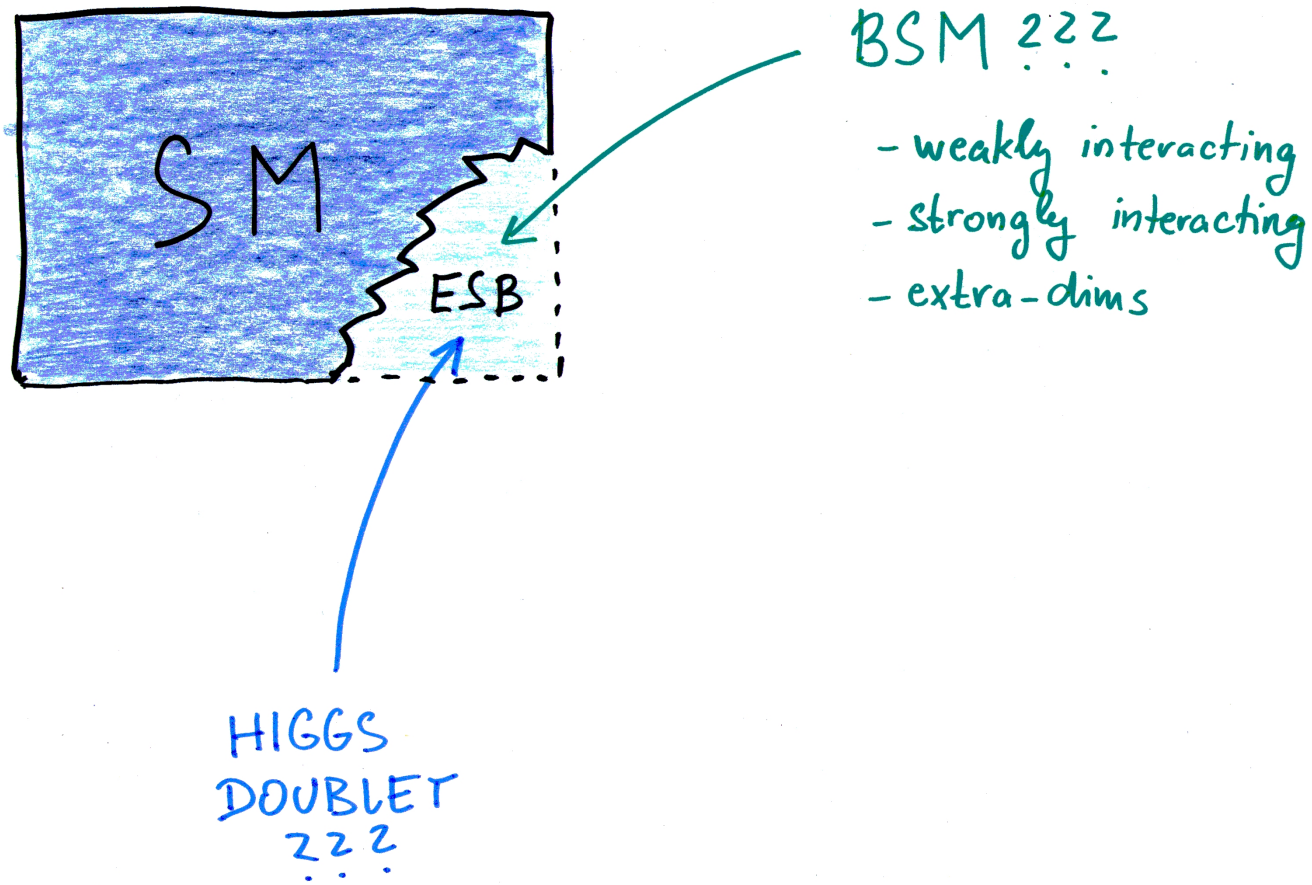
SM
ESB
BSM ???
- weakly interacting
- strongly interacting
- extra-dims
HIGGS
DOUBLET
???

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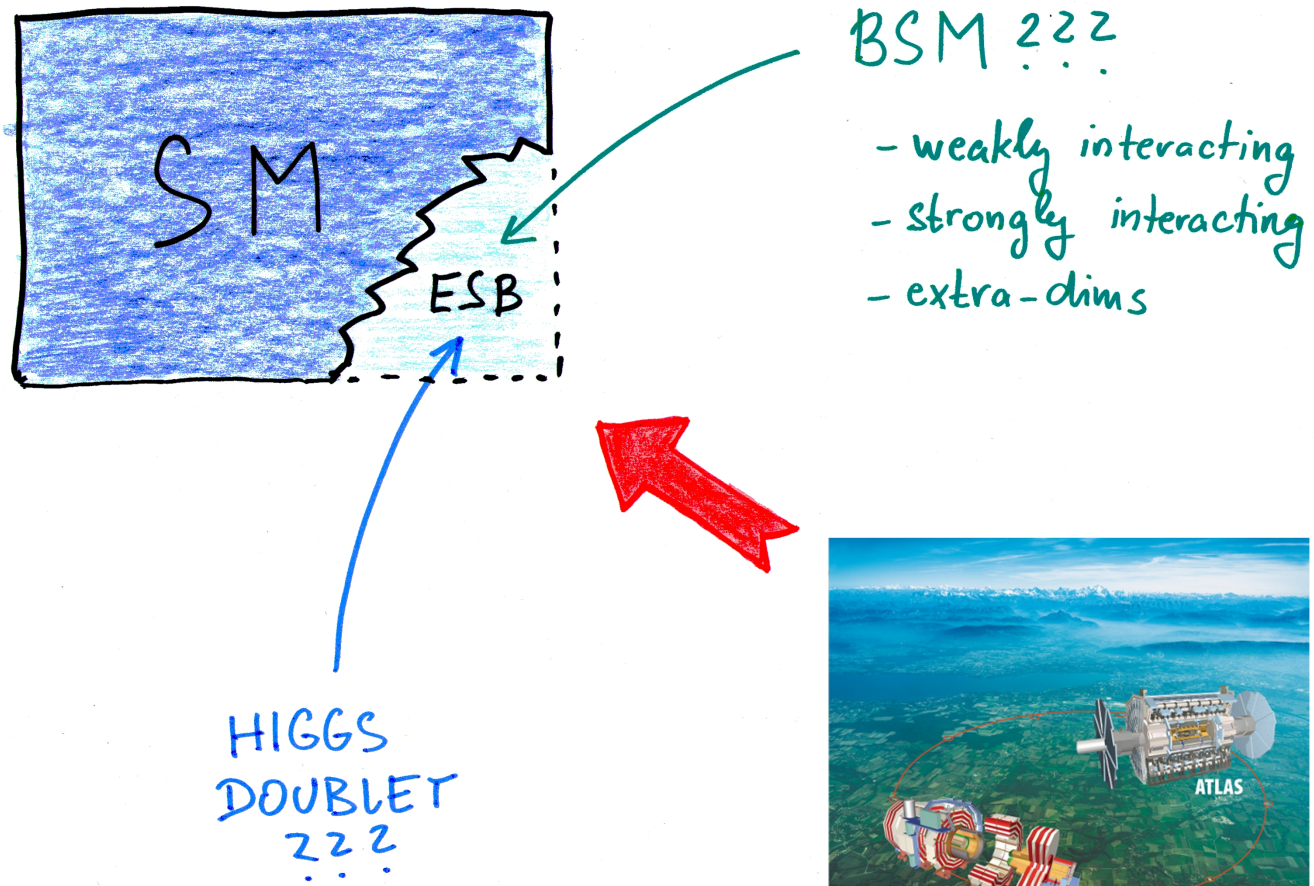
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ATLAS
CMS

Effective description of Strong ESB

$SU(2)_L \times U(1)_Y$ broken *dynamically*:

- *not* solvable perturbatively
- *chiral effective* Lagrangian for Goldstone bosons

  nonlinear sigma model
- ... + resonances

  scalar, vector, ...

LHC $\rightarrow$ the *lightest* BSM resonances

Outline

BESS MODEL

BREAKING ELECTROWEAK SYMMETRY STRONGLY

- R. Casalbuoni *et al*, PL**B155**,95(1985); NP**B282**,235(1987)
- ~~H~~SM + new vector resonances
- Hidden Local Symmetry [M. Bando *et al* (1984)]

- *global symmetry:*

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(2)_{HLS} \xrightarrow{SSB} SU(2)_{L+R} \times U(1)_{B-L}$$

- *local symmetry:*

$$\underset{g}{SU(2)_L} \times \underset{g'}{U(1)_Y} \times \underset{g''}{SU(2)_{HLS}} \xrightarrow{SSB} \underset{e}{U(1)_{em}}$$

BESS Lagrangian: ESB

ESB sector (NGB's + gauge bosons):

$$\mathcal{L}_{ESB} = \underbrace{-v^2 \mathrm{Tr}[(\bar{\omega}_\mu^\perp)^2] - \alpha\, v^2 \mathrm{Tr}[(\bar{\omega}_\mu^\parallel)^2]}_{\sim \text{ gauged NLSM}} + \underbrace{\mathcal{L}_{GB}(W, B, V)}_{\text{kin. terms + self-interactions}}$$

GB masses + mixing

$$\Downarrow$$

$$W^\pm, Z \qquad A \qquad V^\pm, V^0$$

$$M_V = \tfrac{1}{2}\sqrt{\alpha}\, g'' \, v$$

BESS Lagrangian: FERMIONS

fermion sector (SM fermions):

$$\mathcal{L}_f^{BESS} = \underbrace{\mathcal{L}_f^{SM}(W,B)}_{\text{mixing induced Vff cplngs}} + \underbrace{\mathcal{L}_f^{BSM}(W,B,V)}_{\text{direct universal chiral Vff cplngs}}$$

$\sim 1/g''$

$\sim b_L\, g''$, $\sim b_R\, g''$

universality:

- ν_R absence, K_L-K_S mass difference $\Rightarrow$ $b_R \to 0$
- $Z \to \bar{f} f$ at LEP $\Rightarrow$ tight limits on b_L

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Outstanding Top Quark

$m_t \approx v/\sqrt{2}$ $\rightarrow$ special role in ESB?

new physics behind m_t

ESB related

Extended TC, ...

ESB *un*related

Topcolor Assisted TC, ...

TOP-BESS MODEL

PHYS. REV. **D84**, 035013 (2011)

ESB sector $\equiv$ *BESS*

fermion sector (SM fermions):

$$\mathcal{L}_f^{tBESS} = \underbrace{\mathcal{L}_f^{SM}(W,B)}_{\text{mixing induced Vff cplngs}} + \underbrace{\mathcal{L}_{(t,b)}^{BSM}(W,B,V)}_{\text{direct chiral cplngs}} + \underbrace{\mathcal{L}_{(t,b)}^{BSM'}(W,B)}_{\text{new W/B cplngs}}$$

$\sim 1/g''$

Vtt ...	$\sim b_{L,R} \cdot g''$	Xtt ... $\sim \lambda_{L,R} \cdot g_X$
$Vt_L b_L$ ...	$\sim b_L \cdot g''$	$Xt_L b_L$ ... $\sim \lambda_L \cdot g_X$
$Vb_L b_L$ ...	$\sim b_L \cdot g''$	$Xb_L b_L$ ... $\sim \lambda_L \cdot g_X$
$Vt_R b_R$ ...	$\sim p\, b_R \cdot g''$	$Xt_R b_R$ ... $\sim p\, \lambda_R \cdot g_X$
$Vb_R b_R$ ...	$\sim p^2 b_R \cdot g''$	$Xb_R b_R$ ... $\sim p^2 \lambda_R \cdot g_X$

$0 \leq p \leq 1$

$X{=}W,B, \quad g_X = g, g'$

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direct chiral cplngs		new W/B cplngs	
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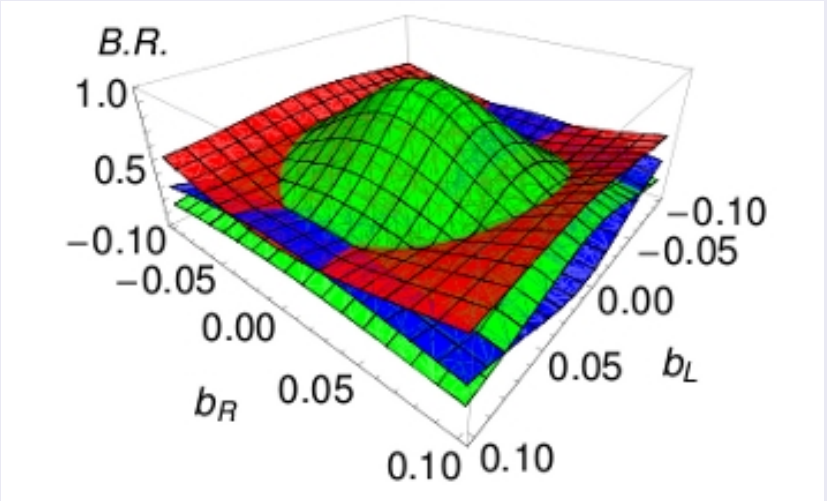
Outline

V Decay Widths

- $V^0 \to W^+W^- + t\bar{t} + b\bar{b} + \ldots$
- $V^+ \to W^+Z + t\bar{b} + \ldots$
- $\Gamma \sim 10 - 100$ GeV



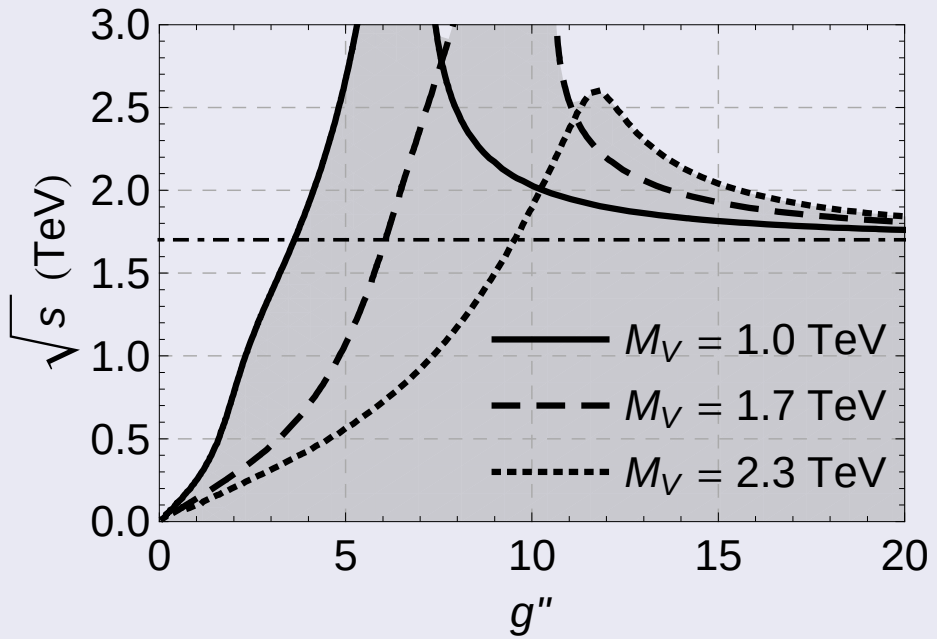
WW, *tt*,*bb*

effect of λ's is negligible

Unitarity & perturbativity

Unitarity:

- GB scatterings:
  $W_L^+ W_L^-$, $Z_L Z_L$,
  $W_L^\pm Z_L$, $W_L^\pm W_L^\pm$
- tree level
- Equivalence Theorem



Perturbativity:

$$\frac{g''}{2} \lesssim 4\pi \quad \Rightarrow \quad g'' \lesssim 30$$

Low-energy limits

Low-energy Lagrangian ... $\alpha \to \infty \quad \Rightarrow \quad M_V \to \infty$

free parameters:

$$\begin{aligned} x &= g/g'' \\ \Delta L &= b_L - 2\lambda_L \\ \Delta R &= b_R + 2\lambda_R \\ & p \end{aligned}$$

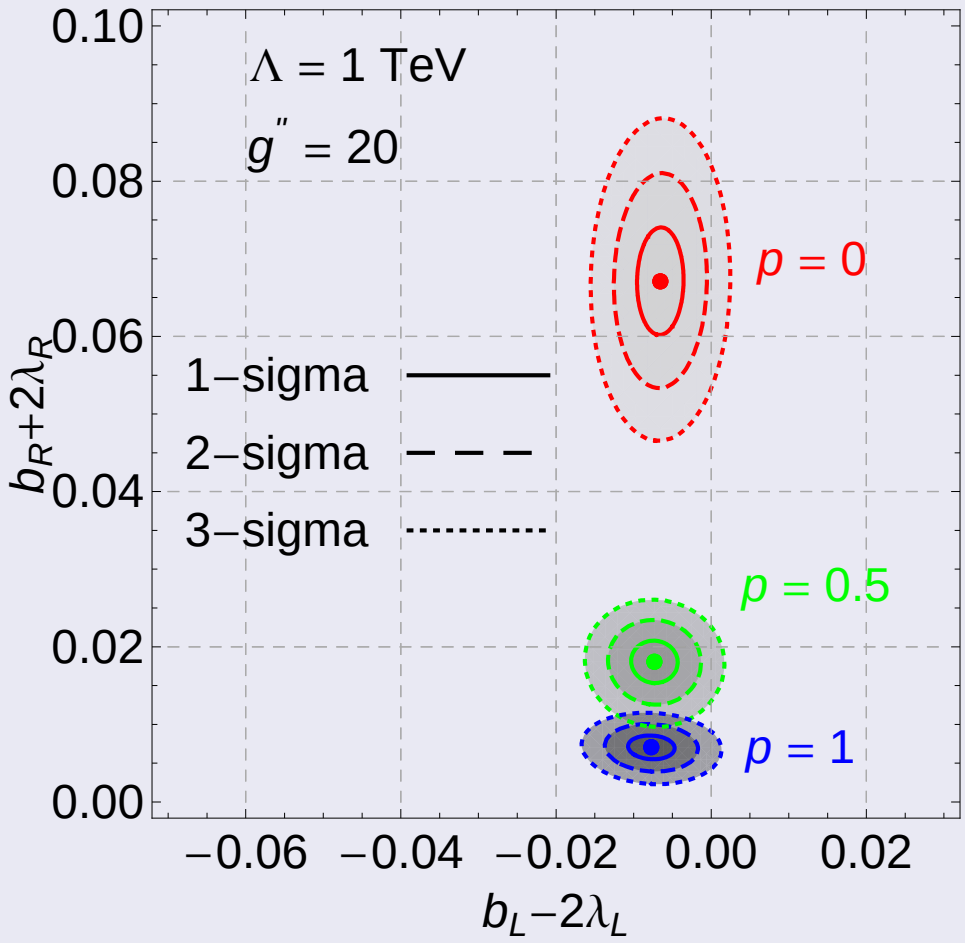
experiment: LEP + SLC + Tevatron

$$\begin{aligned} \epsilon_1 &\overset{exp}{=} (+5.4 \pm 1.0) \times 10^{-3} \\ \epsilon_2 &\overset{exp}{=} (-8.9 \pm 1.2) \times 10^{-3} \\ \epsilon_3 &\overset{exp}{=} (+5.34 \pm 0.94) \times 10^{-3} \\ \Gamma(Z \to \bar{b}b) &\overset{exp}{=} (0.3773 \pm 0.0013)\,\text{GeV} \\ B.R.(B \to X_s\gamma) &\overset{exp}{=} (3.55 \pm 0.26) \times 10^{-4} \end{aligned}$$

Low-energy limits for FERMION PARAMS

χ^2-fit:

- 5 observables:
  ϵ_1, ϵ_2, ϵ_3, $\Gamma(Z \to b\bar{b})$,
  BR$(B \to X_s\gamma)$
- 2 fitted params:
  $\Delta L = b_L - 2\lambda_L$
  $\Delta R = b_R + 2\lambda_R$
- fixed params:
  $g'' = 20$
  $p = 0,\ 0.5,\ 1$
  $\Lambda = 1$ TeV
- confidence levels:
  1 sigma ... 39%
  2 sigma ... 86%
  3 sigma ... 99%



The Death Valley

direct + indirect *cplgs* $\Rightarrow$ DV

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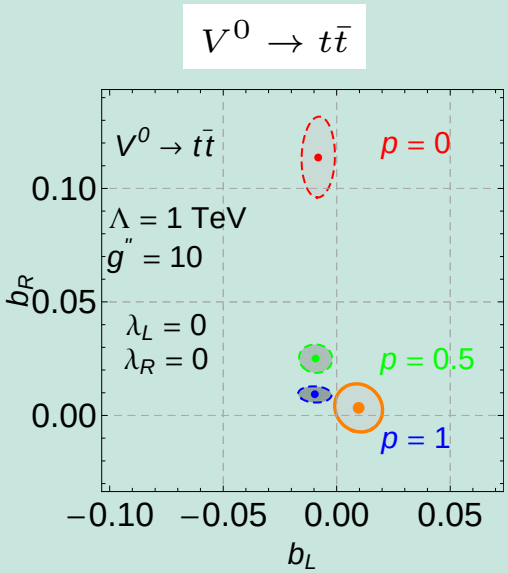
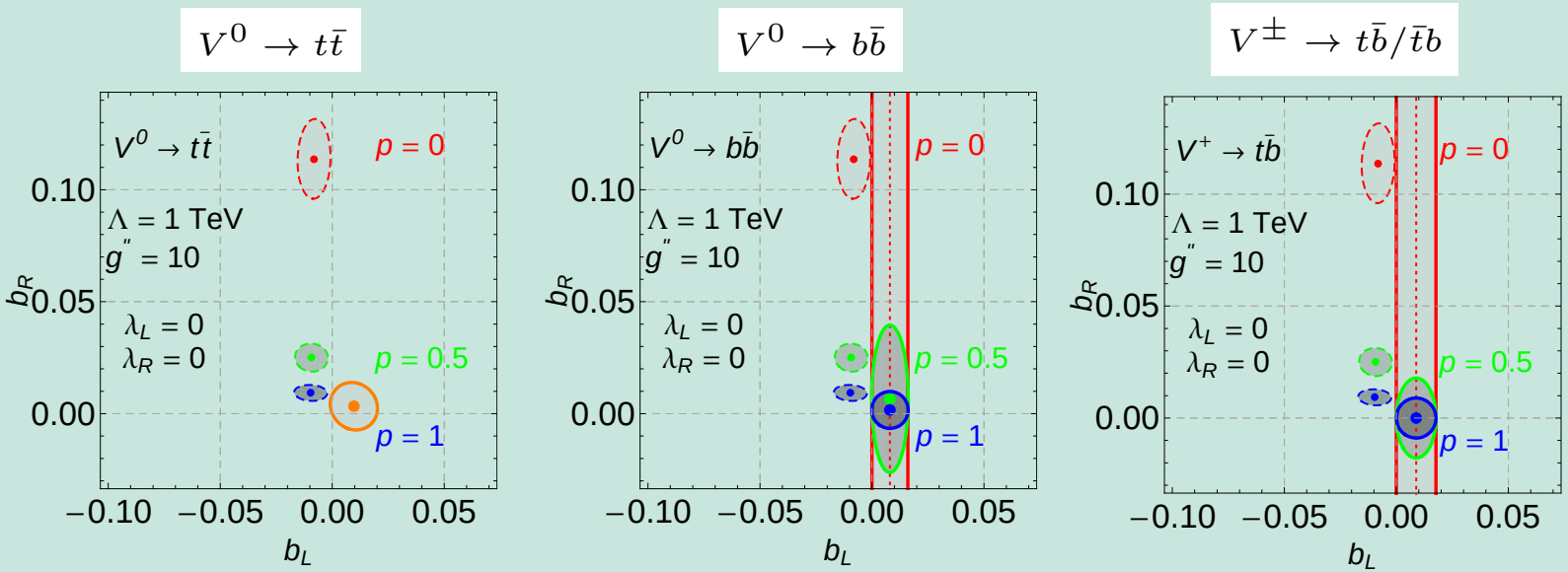


$g'' = 10,\ \lambda_L = \lambda_R = 0$

The Death Valley regions of the $V \to t\bar{t}/b\bar{b}/tb$ decays.

The Death Valley

direct + indirect *cplgs* $\Rightarrow$ *DV*



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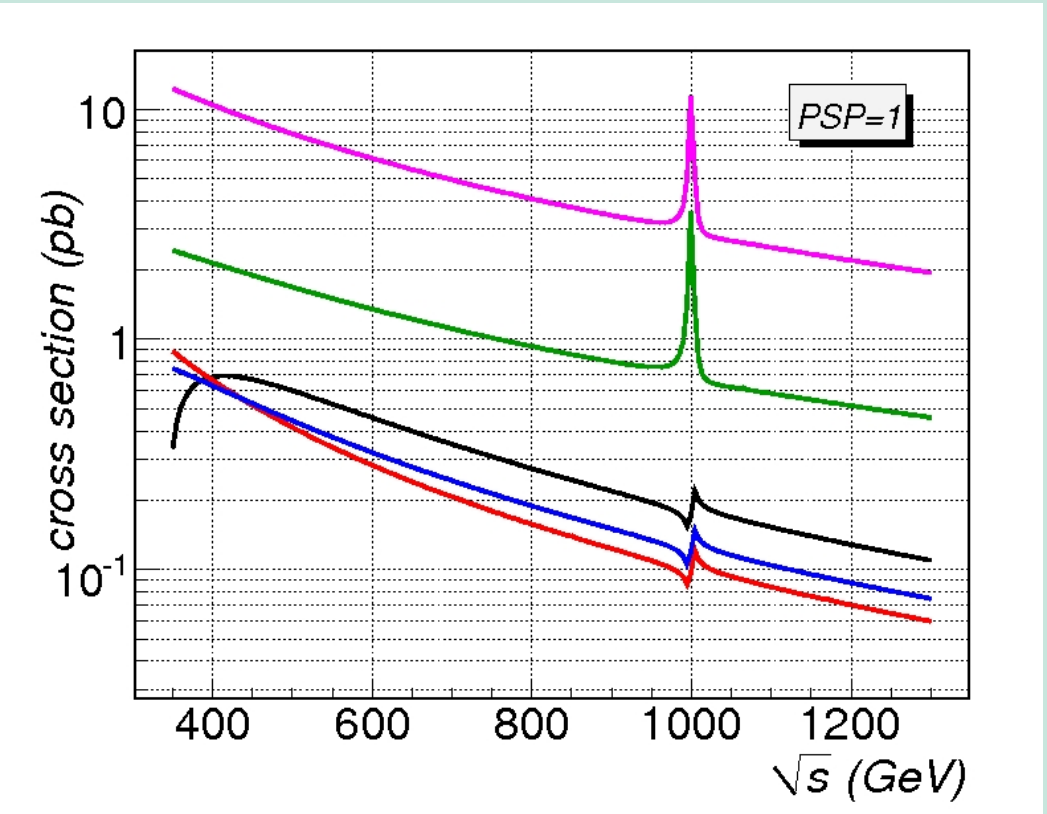
The Death Valley regions of the $V \to t\bar{t}/b\bar{b}/tb$ *decays.*

Hiding the peak

$$M_V = 1 \text{ TeV}, \quad g'' = 20, \quad p = 0, \quad \lambda_R = 0$$



- **no direct cplng**
  $b_L = 0$
  $b_R = 0$
  $\lambda_L = 0$
- **outside the DV**
  $b_L = -0.010$
  $b_R = +0.030$
  $\lambda_L = 0$
- **$t\bar{b}$ & $b\bar{b}$ in the DV**
  $b_L = +0.009$
  $b_R = +0.030$
  $\lambda_L = +0.006$
- **all in the DV**
  $b_L = +0.0098$
  $b_R = +0.0034$
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$e^+e^- \to W^+W^-$ $\quad u\bar{d} \to W^+Z$ $\quad e^+e^- \to t\bar{t}$ $\quad u\bar{d} \to t\bar{b}$ $\quad e^+e^- \to b\bar{b}$

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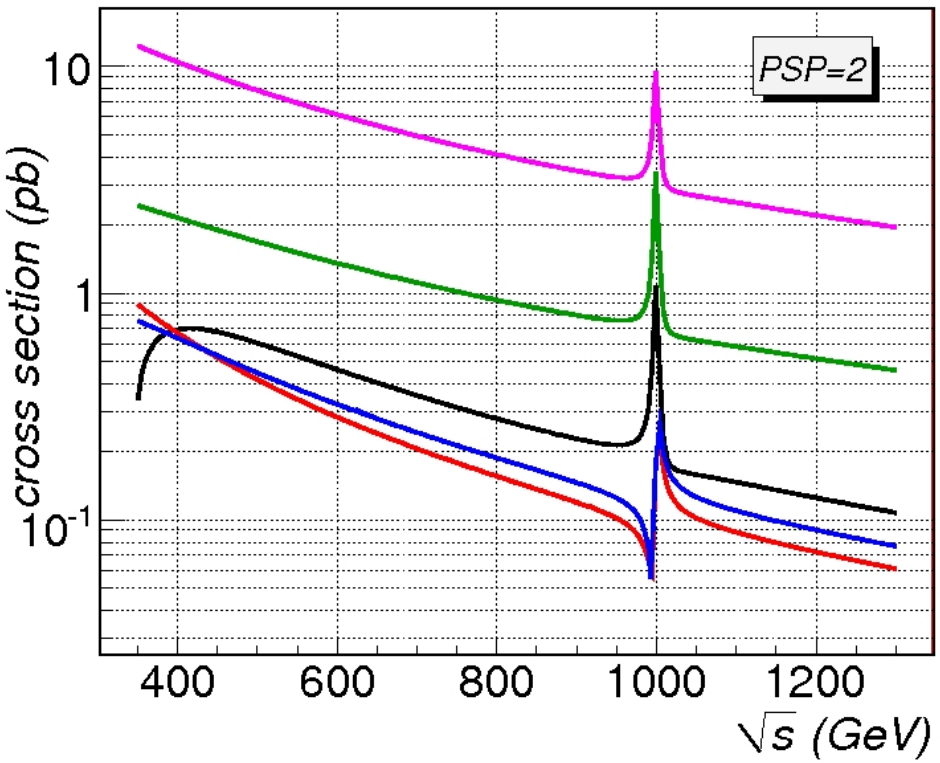

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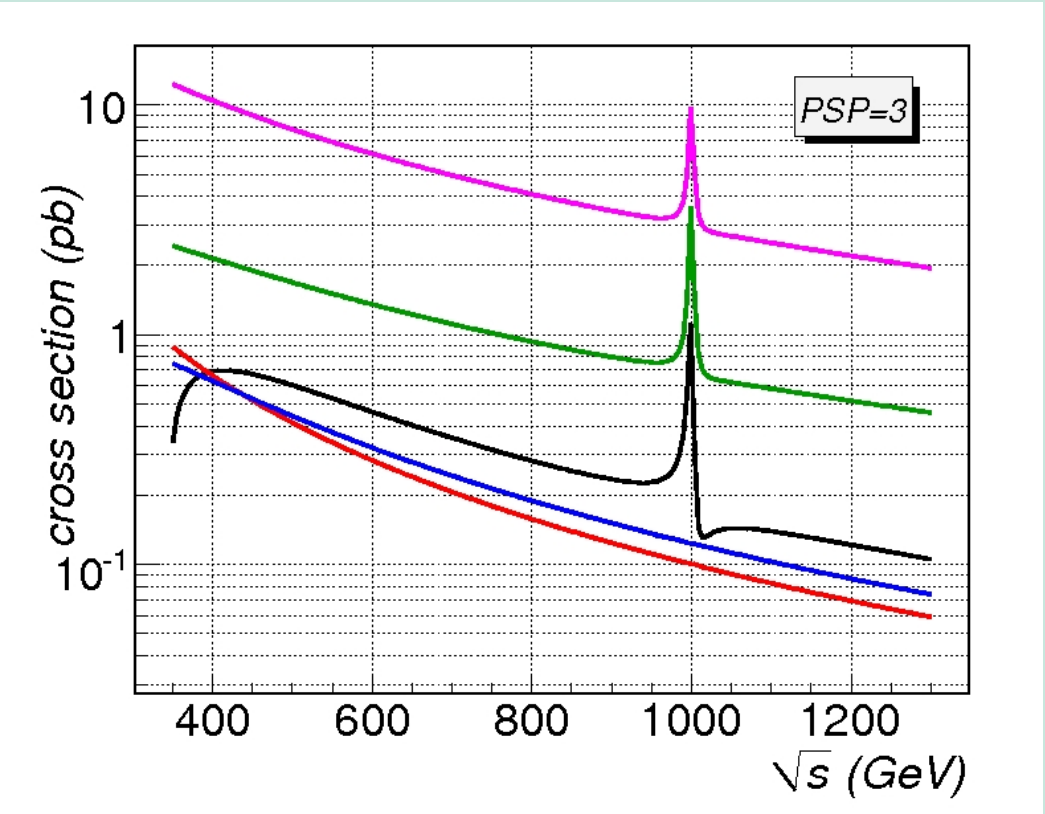

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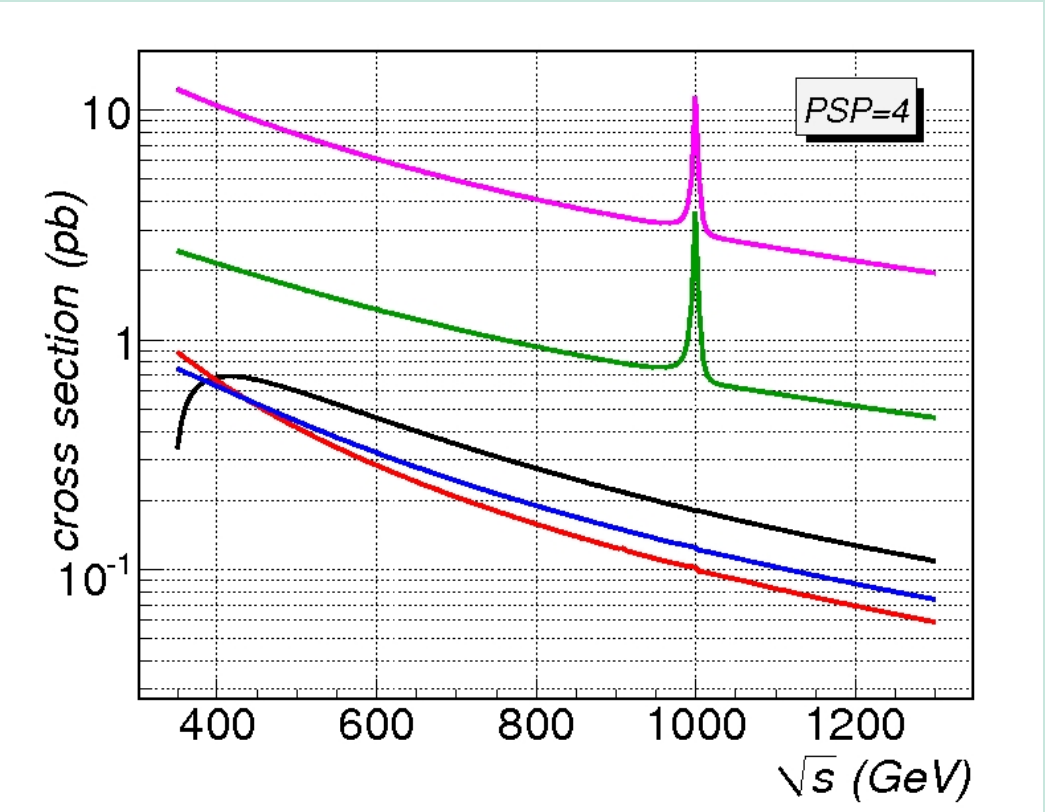

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$pp \to t\bar{b} + X$ @ LHC

$$\sqrt{s} = 14 \text{ TeV}, \ \Gamma_{V^\pm} = 50 \text{ GeV}$$

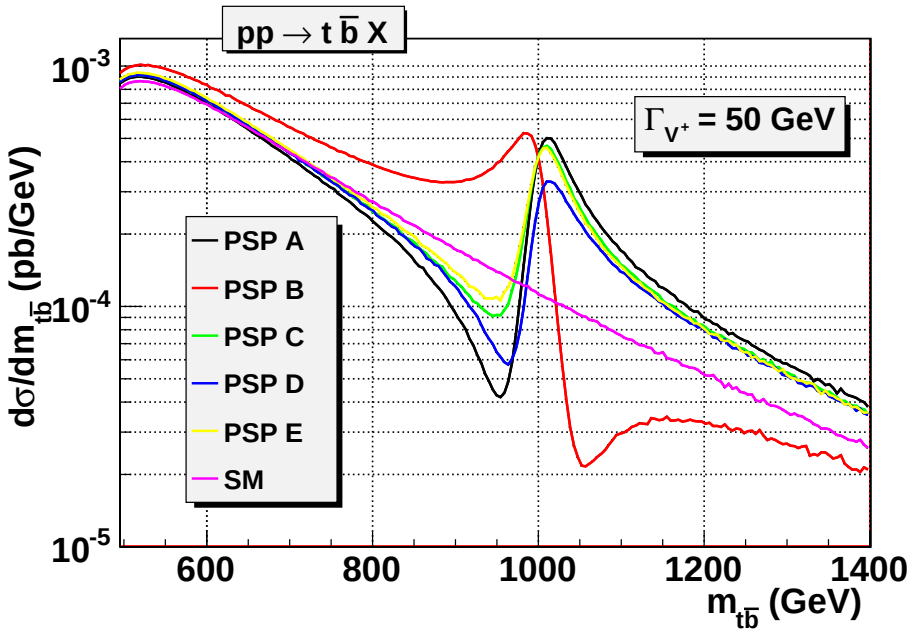
$$|y(t)|, \ |y(\bar{b})| < 2.5, \qquad p_T(t), \ p_T(\bar{b}) > 200 \text{ GeV}$$

PSP	g''	p	b_L	b_R	R
A	20	0	-0.15	N/A	11.6
B	20	0	$+0.16$	N/A	12.1
C	20	1	-0.11	-0.11	10.7
D	30	0	-0.11	N/A	6.5
E	20	1	-0.11	$+0.11$	10.6

$$R = \frac{N_{tBESS} - N_{SM}}{\sqrt{N_{SM}}}$$

$$N = \sigma L \, \epsilon_1 \epsilon_b^2$$

$L = 100 \text{ fb}^{-1}$, $\epsilon_1 = 0.216$, $\epsilon_b = 0.4$



Summary

- effective description of strong ESB new physics
- top-BESS — modification of BESS, special role of top quark
  - *new SU(2) resonance triplet*
  - *direct coupling to top and bottom*
  - *λ-terms*
- low-E limits on the fermion parameters relaxed
- the Death Valley effect
- LHC: $pp \to t\bar{b}X$

BACKUP

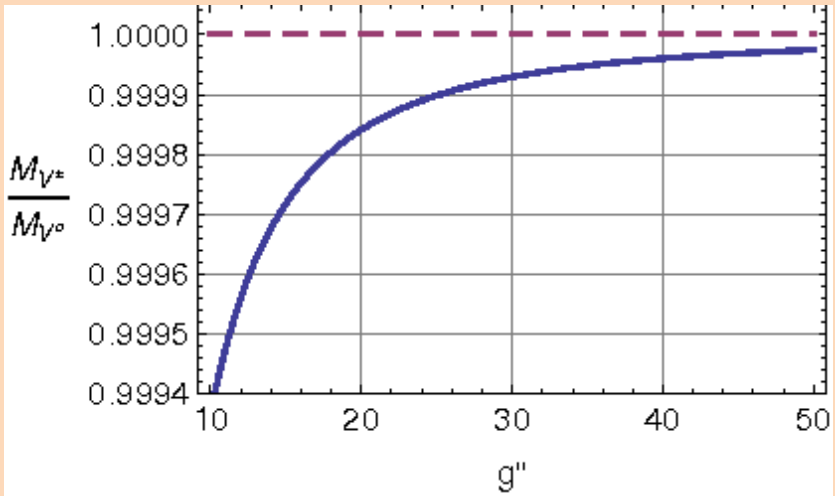
BACKUP SLIDES

NEW RESONANCE MASSES

- mass of the vector resonance:

$$M_V = \frac{\sqrt{\alpha}\, g'' v}{2}$$

- EW gauge bosons $\rightarrow$ mixing $\rightarrow$ mass splitting



Low-energy limit for g''

THEORY:

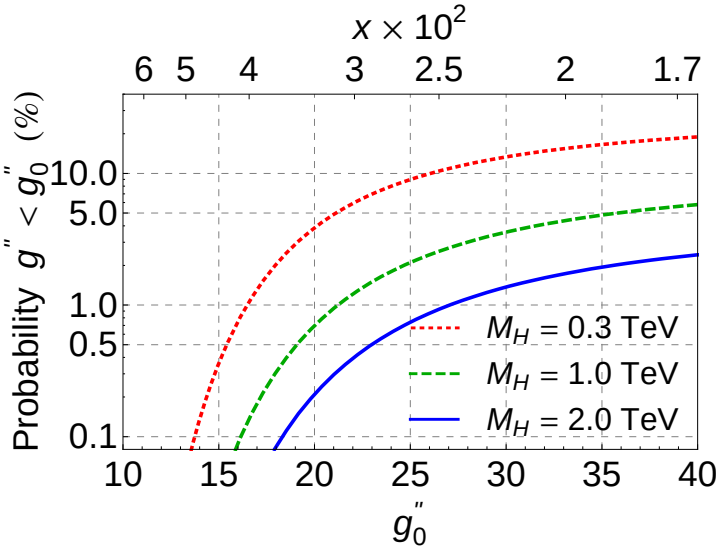
$$\epsilon_3 \approx \epsilon_3^{tree} + \underbrace{\left(5.25 + 0.54 \ln \frac{M_H}{M_Z}\right) \times 10^{-3}}_{\epsilon_3^{SM\ loop}}$$

M_H(TeV)	0.3	1	2	$\epsilon_3^{exp} \times 10^3$
$\epsilon_3^{SM\ loop} \times 10^3$	5.89	6.54	6.92	5.34 ± 0.94

$$\Rightarrow \quad \epsilon_3^{tree} < 0$$

$$\epsilon_3^{tree}(BESS) = -\frac{b_L}{2} + \left(\frac{g}{g''}\right)^2$$

$$\epsilon_3^{tree}(tBESS) = \left(\frac{g}{g''}\right)^2$$



NP fermion Invariants

$$I_c^L = i\bar{\psi}_L(\not{\partial}+\not{W}+\not{B})\psi_L$$

$$I_c^R = i\bar{\psi}_R(\not{\partial}+\not{B})\psi_R$$

$$I_b^h = i\bar{\chi}_h(\not{\partial}+\not{V}+ig'\not{B}\,(B-L)/2)\chi_h$$

$$\begin{aligned} I_\lambda^h &= i\bar{\chi}_h\bar{\not{\varphi}}^\perp\chi_h \\ &= i\bar{\chi}_h[\not{\varphi}^\perp+(\xi_L^\dagger\not{W}\xi_L-\xi_R^\dagger\not{B}^{R3}\xi_R)]\chi_h \end{aligned}$$

$$\chi_h = \xi_h^\dagger\psi_h, \quad h = L, R$$