top-BESS Model

and

its Phenomenology

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MFF UK Bratislava, Nov 15, 2011

putting things straight beforhand ...

top-BESS model

↙ ↘

NO

- fundamental theory
- ESB mechanism

YES

- effective Lagrangian
- strong ESB physics

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Gauge Principle

$\Rightarrow$ Gauge Bosons

$\Rightarrow$ Interactions

$\Rightarrow$ Renormalizability

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⇒ Gauge Bosons

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SM $\rightarrow$ GP Success

SM: $SU(3)_C \times SU(2)_L \times U(1)_Y$

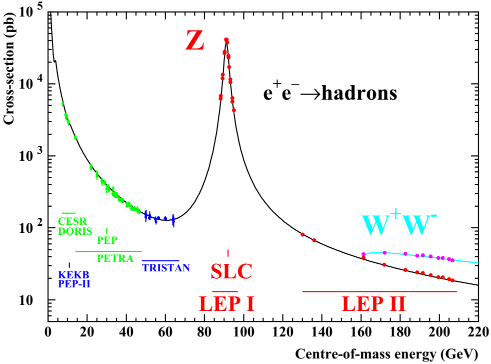
gluons

$W^{\pm}$, Z

photon

SM $\rightarrow$ GP SUCCESS

SM: $SU(3)_C \times SU(2)_L \times U(1)_Y$



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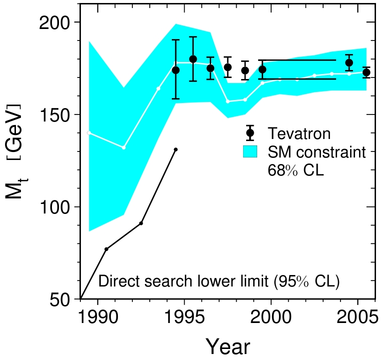

EW SYMMETRY BROKEN!

- fermions:

$$m_t \gg m_b > \quad \dots \quad > m_e \gg m_{\nu_e}$$

- weak gauge bosons:

$$M_Z, M_W \approx 100 \text{ GeV}$$

$$\mathcal{L} = \mathcal{L}_{kin} + \mathcal{L}_{int}$$

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SAVING THE GAUGE PRINCIPLE

ESB = **spontaneous** symmetry breaking:

$$\text{symm}(vacuum) < \text{symm}(Lagr)$$

$$\mathcal{L} = \mathcal{L}_{kin} + \mathcal{L}_{int} + \mathcal{L}_{SSB}$$

$$SU(2)_L \times U(1)_Y \overset{SSB}{\longrightarrow} U(1)_{em}$$

3 Goldstone bosons

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BENCHMARK HYPOTHESIS → SM HIGGS

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- $v = \langle 0|\Phi|0\rangle$

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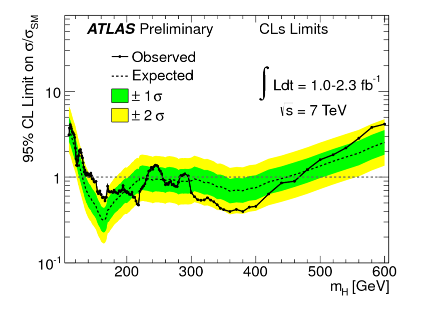

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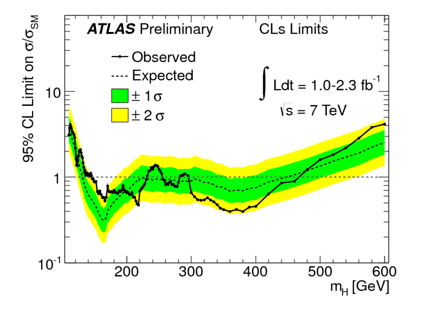

theoretical pathologies

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just a parameterization of ESB?

Higgs boson alternatives

heavy/no Higgs violates unitarity $\approx$ 1 TeV

weakly interacting:

- new forces and particles
- *perturbative*
- more Higgses, SUSY

strongly interacting:

- new forces and particles
- *non-perturbative* $\longrightarrow$ *bound states*
- TC and its extensions

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extra-dimensions:

4D *strongly* interacting $\longleftrightarrow$ 5D *weakly* interacting

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Effective description of Strong ESB

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

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

$$\mathcal{L} = \frac{v^2}{2}\mathrm{Tr}\left[(\partial_\mu U^\dagger)(\partial^\mu U)\right]$$

nonlinear sigma model $\quad U = \exp(2i\pi^a\tau^a/v)$

- ... + resonances

scalar, vector, ...

LHC → the *lightest* BSM resonances

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Hidden Local Symmetry

M. Bando, T. Kugo, K. Yamawaki (1984)

Any NLσM(G/H) is *gauge equivalent* to "linear" $G_{glob} \times H_{loc}$ model.

$G_{glob} \times H_{loc}$ Lagrangian … $g \in G$, $h(x) \in H_{loc}$

$\xi = \mathrm{e}^{i\pi^a X^a/v}\, \mathrm{e}^{i\sigma^b S^b/v}$ $\longrightarrow g\, \xi\, h(x)$

$\boldsymbol{V}_\mu = V_\mu^a\, S^a$ $\longrightarrow h^\dagger\, \boldsymbol{V}_\mu\, h + h^\dagger \partial_\mu h$

$$\omega_\mu = \xi^\dagger \partial_\mu \xi \;\in \mathcal{G}, \qquad \omega_\mu^{\parallel,\perp} = [\omega_\mu \pm \tau(\omega_\mu)]/2 \;\in \mathcal{H}, \mathcal{G}\backslash\mathcal{H}$$

$$\mathcal{L} = -v^2 \left[\mathrm{Tr}(\omega_\mu^\perp)^2 + \alpha \mathrm{Tr}(\omega_\mu^\parallel - \boldsymbol{V}_\mu)^2 \right] = \frac{v^2}{4} \mathrm{Tr}[(\partial_\mu U^\dagger)(\partial^\mu U)]$$

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Transition to "U-gauge"

$$\nearrow \boxed{h(x) = e^{-i\sigma(x)/v} \in H_{loc}} \searrow$$

linear

$$\xi(x) = e^{i\pi(x)/v} e^{i\sigma(x)/v}$$
$$U = \xi\,\tau(\xi^\dagger) = e^{2i\pi(x)/v}$$

$G \times H_{loc}$: ... $h(x) \in H_{loc}$

$$\xi \longrightarrow g\ \xi\ h(x)$$
$$U \longrightarrow g\ U\ \tau(g^\dagger)$$
$$V_\mu \longrightarrow h^\dagger(x)\ V_\mu\ h(x) + h^\dagger \partial_\mu h$$

$$\mathcal{L} = \frac{v^2}{4} \mathrm{Tr}[(\partial_\mu U^\dagger)(\partial^\mu U)]$$

U-gauge: *non-linear*

$$\xi(x) = e^{i\pi(x)/v}$$
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G : ... $g_h \in H \subset G$

$$\xi \longrightarrow g\ \xi\ g_h^\dagger(g,\xi)$$
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BESS model

Breaking Electroweak Symmetry Strongly

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PL**B155**, 95 (1985), NP**B282**, 235 (1987)

- effective Lagrangian
- H̸SM + new vector resonances

$$\mathcal{L}_{BESS} = \mathcal{L}_{GB}(W, B, V) + \mathcal{L}_{ESB}(\vec{\pi}, \vec{\sigma}) + \mathcal{L}_{ferm}$$

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BESS symmetries and couplings

- *global symmetry:*

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

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- *gauge sector:*

$$W^\pm, Z \quad A \quad V^\pm, V^0$$ …mixing

- *fermion sector:*
  - direct cplg: … $bg''\ \bar\psi_L \not{V} \psi_L,\ b'g''\ \bar\psi_R \not{V} \psi_R$ … **universal**
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Outstanding Top Quark

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

new physics behind m_t

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ESB related	ESB *un*related
Extended TC, ...	Topcolor Assisted TC, ...

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Phys. Rev. **D84**, 035013 (2011)

- *gauge sector ≡ BESS*
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  - *bottom*$_R$ vs. *top*$_R$ ... p
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NEW RESONANCE MASSES

- mass of the vector resonance:

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

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

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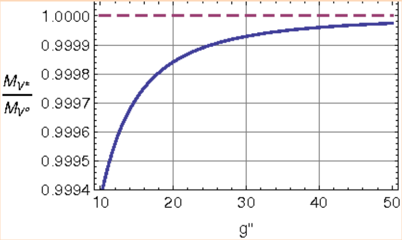
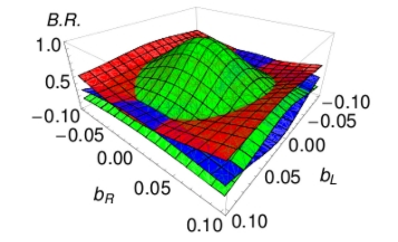


Decay Widths

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

$M_V = 1$ TeV, $g'' = 20$, $p = 0$



WW, *tt*, *bb*

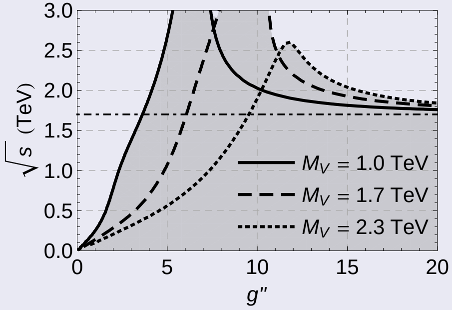
Unitarity constraints

- 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



Low-energy limits

experiment: LEP + SLC + Tevatron

EWPD ϵ-analysis: ϵ_1, ϵ_2, ϵ_3, ϵ_b, $\Gamma(Z \to b\bar{b})$, $B \to X_s\gamma$, $p\bar{p} \to WZX$

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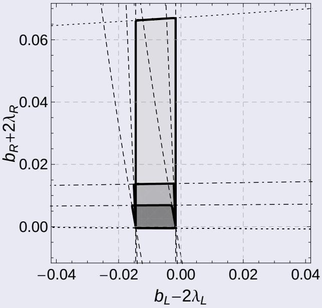


Intersections of 90% C.L. allowed regions.

$M_V = 1$ TeV
$g'' = 10$

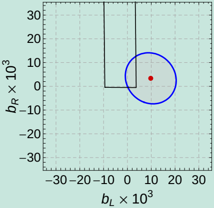
The Death Valley

direct + indirect *cplgs* $\Rightarrow$ DV

THE DEATH VALLEY

direct + indirect *cplgs* $\Rightarrow$ DV

$V^0 \to t\bar{t}$

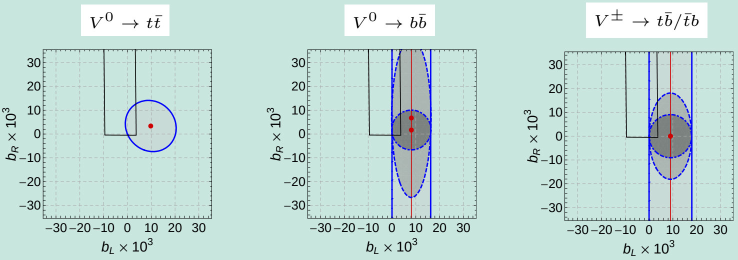


$g'' = 10,\ \lambda_L = \lambda_R = 0$

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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Hiding the peak

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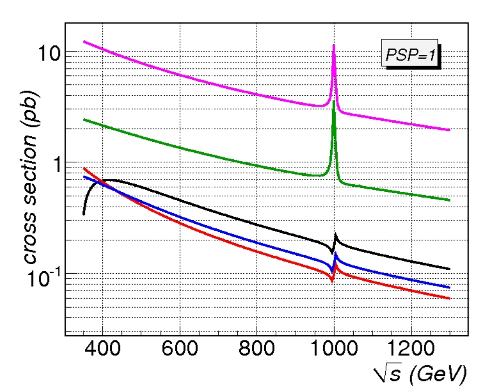

- **no direct cplng**
  $b_L = 0$
  $b_R = 0$
  $\lambda_L = 0$
- **outside the DV**
  $b_L = -0.010$
  $b_R = +0.030$
  $\lambda_L = 0$
- **$t\bar{b}$ & $b\bar{b}$ in the DV**
  $b_L = +0.009$
  $b_R = +0.030$
  $\lambda_L = +0.006$
- **all in the DV**
  $b_L = +0.0098$
  $b_R = +0.0034$
  $\lambda_L = +0.006$

$e^+e^- \to W^+W^-$ $u\bar{d} \to W^+Z$ $e^+e^- \to t\bar{t}$ $u\bar{d} \to t\bar{b}$ $e^+e^- \to b\bar{b}$

Hiding the peak

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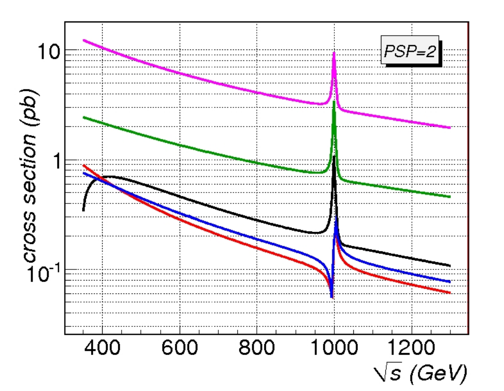

- **no direct cplng**
  $b_L = 0$
  $b_R = 0$
  $\lambda_L = 0$
- **outside the DV**
  $b_L = -0.010$
  $b_R = +0.030$
  $\lambda_L = 0$
- **$t\bar{b}$ & $b\bar{b}$ in the DV**
  $b_L = +0.009$
  $b_R = +0.030$
  $\lambda_L = +0.006$
- **all in the DV**
  $b_L = +0.0098$
  $b_R = +0.0034$
  $\lambda_L = +0.006$

$e^+e^- \to W^+W^-$ $u\bar{d} \to W^+Z$ $e^+e^- \to t\bar{t}$ $u\bar{d} \to t\bar{b}$ $e^+e^- \to b\bar{b}$

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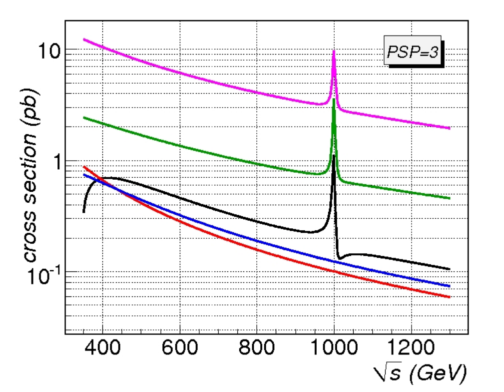

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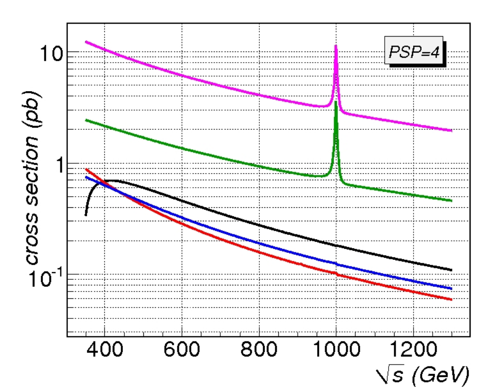

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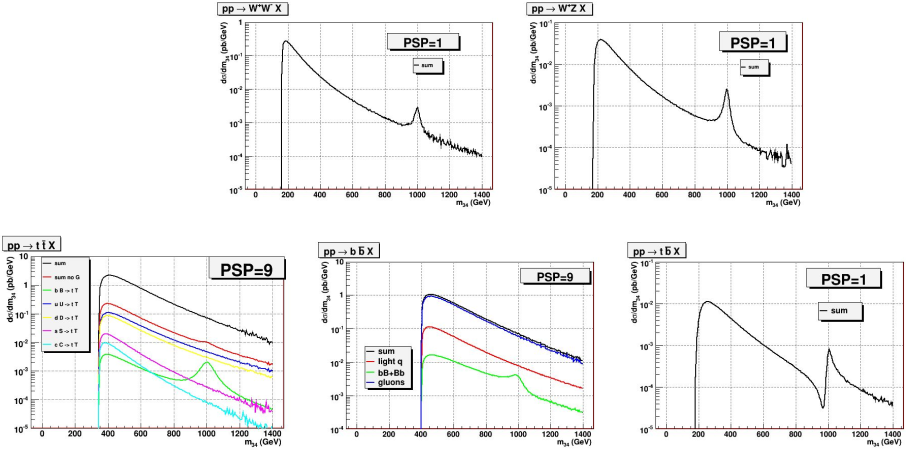
WHAT'S NEXT?

- theoretical development
  - low-energy limits
  - scrutinizing the parameter space
  - relation to existing theories
  - ...
- probing tBESS at LHC and ILC
  - Drell-Yan processes at LHC
  - ...

Drell-Yan at LHC

... peeking



Conclusions

- effective description of strong ESB new physics needed
- 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: Drell-Yan processes

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I WANT **YOU** !!!

Enlist Now!