Strong Electroweak Symmetry Breaking

M. Gintner

UTEF CVUT Prague

Sep 29, 2009

Outline

Outline

The Minimal EW Theory

the minimal description of measurements:

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{mass}$$

The Minimal EW Theory

the minimal description OF MEASUREMENTS:

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{mass}$$

$\boxed{\mathcal{L}_0}$ = GB kinetic terms (self-ints.) + fermion-to-GB interactions

... local $SU(2)_L \times U(1)_Y$ symmetry

... weak fermion-to-GB: violate P

The Minimal EW Theory

the minimal description OF MEASUREMENTS:

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{mass}$$

$\boxed{\mathcal{L}_0}$ = GB kinetic terms (self-ints.) + fermion-to-GB interactions

... local $SU(2)_L \times U(1)_Y$ symmetry

... weak fermion-to-GB: violate P

$\boxed{\mathcal{L}_{mass}}$ = explicit mass terms: GB + fermions

... local $U(1)_{em}$ symmetry

$\Uparrow$

- no photon mass term
- fermion-to-photon: P-invariant

EW Gauge Symmetry

Belief:

EW symmetry is fundamental

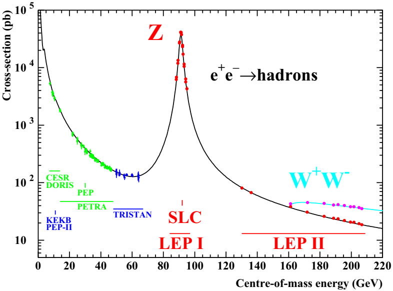
Why?

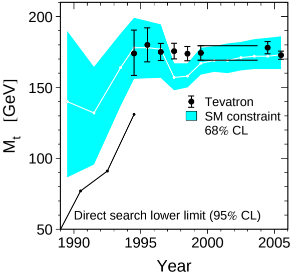
- predicts GB
- observed symmetry of interactions:

$$\left.\begin{array}{l}\text{- } \textit{GB-to-fermions} \\ \text{- } \textit{GB-to-GB}\end{array}\right\} g, g'$$

- renormalizability

Testing EW Symmetry of $\mathcal{L}_0$





Spontaneous Breaking of EW Symmetry

Observation:

mass spectrum breaks EW symmetry (even global)

$$SU(2)_L \times U(1)_Y \to U(1)_{em}$$

QFT: vacuum symmetry $\Rightarrow$ multiplet mass degeneracy

$$\text{symm}(vac) \leq U(1)_{em}$$

Spontaneous Breaking of EW Symmetry

OBSERVATION:

mass spectrum breaks EW symmetry (even global)

$$SU(2)_L \times U(1)_Y \to U(1)_{em}$$

QFT: vacuum symmetry $\Rightarrow$ multiplet mass degeneracy

$$\text{symm}(vac) \leq U(1)_{em}$$

if EW symm. is fundamental $\Rightarrow$ **ESB = SSB**

$$SU(2)_L \times U(1)_Y \to U(1)_{em}$$

SSB def: vacuum symmetry $<$ Lagrangian symmetry

Goldstone Bosons

Goldstone Theorem:

SSB: $G \to H \quad \Rightarrow \quad$ *# of Goldstone bosons* $= \dim G - \dim H$

$$\left.\begin{array}{l} \dim[SU(2)\times U(1)] = 4 \\ \dim U(1) = 1 \end{array}\right\} \quad \Rightarrow \quad 3 \text{ Goldstone bosons}$$

Goldstone Bosons

Goldstone Theorem:

SSB: $G \to H \quad \Rightarrow \quad$ *# of Goldstone bosons* $= \dim G - \dim H$

$$\left.\begin{array}{l} \dim[SU(2)\times U(1)] = 4 \\ \dim U(1) = 1 \end{array}\right\} \quad \Rightarrow \quad 3 \text{ Goldstone bosons}$$

Observation:

no *Goldstone bosons*

The Benchmark Solution

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{SSB}$ ... local symm. $SU(2)_L \times U(1)_Y$

The Benchmark Solution

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_{SSB}$ ... local symm. $SU(2)_L \times U(1)_Y$

- $\mathcal{L}_{SSB}$: $\pi_1, \pi_2, \pi_3, \sigma \rightarrow SU(2)_L$ complex scalar doublet
- symm$(\mathcal{L}_{SSB})$ = local $SU(2)_L \times U(1)_Y$ = symm$(\mathcal{L})$
- SSB: $SU(2)_L \times U(1)_Y \rightarrow U(1)_{em}$ $\Rightarrow$ 3 Goldstone bosons
- gauge trafo can eliminate 3 scalar fields (Higgs mechanism)
  $\Rightarrow$ π fields are not physical
- Higgs boson, m_H ... free parameter
- particle masses:

$$m_{W,Z} \sim v, \quad m_f \sim \lambda_f v$$

Outline

Unitarity Violation

Equivalence Theorem:

$$A(V_L V_L \to V_L V_L) \quad \overset{E \gg M_V}{=} \quad A(\pi\pi \to \pi\pi)$$

$$A(\pi^a \pi^b \to \pi^c \pi^d) = A(s)\delta^{ab}\delta^{cd} + A(t)\delta^{ac}\delta^{bd} + A(u)\delta^{ad}\delta^{bc}$$

$$A(s) = \frac{s}{v^2}\left[1 + \mathcal{O}\left(\frac{M_W^2}{s}\right)\right]$$

- perturbative unitarity violation: $E \approx \mathcal{O}(1)$ TeV
- non-renormalizability
- the problem confined to $\mathcal{L}_{SSB}$
- ESB dynamics should restore unitarity

SM Higgs — The Savior

- a scalar particle in the spectrum: $m_H = \sqrt{2\lambda}v$
- unitarity restored if $m_H < 1$ TeV
- renormalizability

Experimental Limits on m_H

- **exclusion direct limit** $(95\%$ C.L.):

  $$m_H \nleq 114.4 \text{ GeV}$$

  and

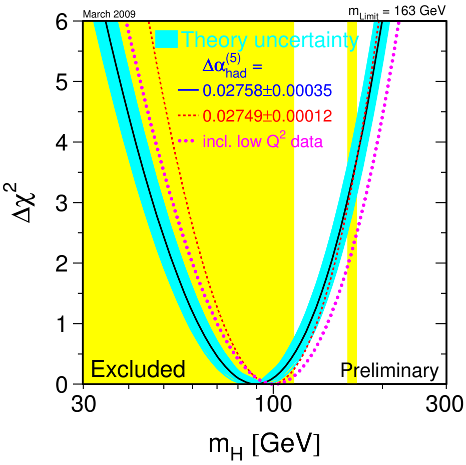
  $$m_H \notin (160, 170) \text{ GeV}$$

- **indirect limit** $(68\%$ C.L.):

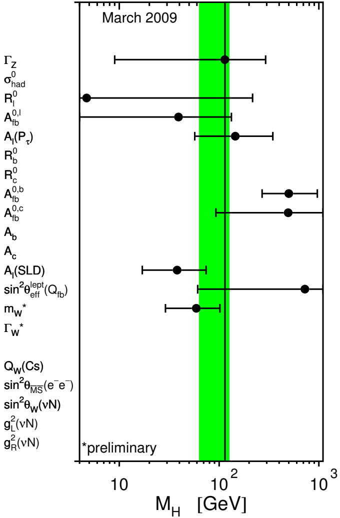
  $$m_H = 90^{+36}_{-27} \text{ GeV}$$

- **combined** $(95\%$ C.L.):

  $$m_H < 191 \text{ GeV}$$



The Close-Up of Indirect Limits on m_H



- all SM observables fit:

  15%

- m_H most sensitive SM observables fit:

  $< 2\%$

SM Higgs — The Troublemaker

- **Naturalness** problem $\rightarrow$ fine tuning

  BSM physics $\rightarrow$ Λ_{BSM}

  loop corrections to m_H^2:

$$\delta m_H^2 \propto \Lambda_{BSM}^2$$

$$\Downarrow$$

what would keep m_H small?

$\swarrow$ $\searrow$

fine tuning? | $\Lambda_{BSM} \leq 1$ TeV?

SM Higgs — The Troublemaker

- **Naturalness** problem $\rightarrow$ fine tuning

  BSM physics $\rightarrow$ Λ_{BSM}

  loop corrections to m_H^2:

$$\delta m_H^2 \propto \Lambda_{BSM}^2$$

$$\Downarrow$$

what would keep m_H small?

$\swarrow$ $\searrow$

fine tuning?	$\Lambda_{BSM} \leq 1$ TeV?

- **Triviality** problem

SM Higgs — The Troublemaker

- **Naturalness** problem $\rightarrow$ fine tuning

  BSM physics $\rightarrow$ Λ_{BSM}

  loop corrections to m_H^2:

$$\delta m_H^2 \propto \Lambda_{BSM}^2$$

$$\Downarrow$$

what would keep m_H small?

$\swarrow$ $\searrow$

fine tuning? | $\Lambda_{BSM} \leq 1$ TeV?

- **Triviality** problem
- **Cosmological constant** problem

Can SUSY Save The Day?

- supersymmetry $\Rightarrow$ particles + sparticles
- EW symmetry broken spontaneously: several elementary Higgses
- exact SUSY:
  fermion loops cancel *boson* loops in δm_H^2 $\Rightarrow$ no fine tuning
- unitarity + renorm

Can SUSY Save The Day?

- supersymmetry $\Rightarrow$ particles + sparticles
- EW symmetry broken spontaneously: several elementary Higgses
- exact SUSY:
  fermion loops cancel *boson* loops in δm_H^2 $\Rightarrow$ no fine tuning
- unitarity + renorm

but

Can SUSY Save The Day?

- supersymmetry $\Rightarrow$ particles + sparticles
- EW symmetry broken spontaneously: several elementary Higgses
- exact SUSY:
  fermion loops cancel *boson* loops in δm_H^2 $\Rightarrow$ no fine tuning
- unitarity + renorm

but

- no sparticles observed $\Rightarrow$ SUSY must be broken
- **fine-tuning is back!**

Is An Elementary Higgs Necessary?

- *"Several people believe, and I share this view, that the Higgs scheme is a convenient parameterization of our ignorance concerning the dynamics of spontaneous symmetry breaking, and elementary scalar particles do not exist."*

  Jean Iliopoulos

Is An Elementary Higgs Necessary?

- *“Several people believe, and I share this view, that the Higgs scheme is a convenient parameterization of our ignorance concerning the dynamics of spontaneous symmetry breaking, and elementary scalar particles do not exist.”*

Jean Iliopoulos

… **still we need to tame the unitarity!!!**

Is An Elementary Higgs Necessary?

- *"Several people believe, and I share this view, that the Higgs scheme is a convenient parameterization of our ignorance concerning the dynamics of spontaneous symmetry breaking, and elementary scalar particles do not exist."*

  Jean Iliopoulos

… **still we need to tame the unitarity!!!**

- new physics … new particles
- $\Lambda_{BSM} \leq \mathcal{O}(1)$ TeV

Outline

Custodial Symmetry

- global symm. of $\mathcal{L}_{SSB}^{\text{SM Higgs}}$:

$$\boxed{SU(2)_L \times SU(2)_R \to SU(2)_V}$$ ... if $g' = 0, \lambda_u = \lambda_d$

Custodial Symmetry

- global symm. of $\mathcal{L}_{SSB}^{\text{SM Higgs}}$:

$$\boxed{SU(2)_L \times SU(2)_R \to SU(2)_V} \qquad \ldots \text{ if } g' = 0, \lambda_u = \lambda_d$$

- custodial $SU(2)_V$ symmetry:
  - $\rho \equiv \frac{M_W^2}{M_Z^2 \cos^2 \theta_W} = 1$ @ tree level
  - *loop corrections* $\delta\rho$ are small

Custodial Symmetry

- global symm. of $\mathcal{L}_{SSB}^{\text{SM Higgs}}$:

$$\boxed{SU(2)_L \times SU(2)_R \to SU(2)_V} \qquad \ldots \text{ if } g' = 0, \lambda_u = \lambda_d$$

- custodial $SU(2)_V$ symmetry:
  - $\rho \equiv \frac{M_W^2}{M_Z^2 \cos^2 \theta_W} = 1$ @ tree level
  - *loop corrections* $\delta\rho$ are small
- $SU(2)_L \times U(1)_Y$ symm. admits more terms to $\mathcal{L}_{SSB}$ $\rightarrow$ large $\delta\rho$

Custodial Symmetry

- global symm. of $\mathcal{L}_{SSB}^{\text{SM Higgs}}$:

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$ ... if $g' = 0, \lambda_u = \lambda_d$

- custodial $SU(2)_V$ symmetry:
  - $\rho \equiv \frac{M_W^2}{M_Z^2 \cos^2 \theta_W} = 1$ @ tree level
  - *loop corrections* $\delta\rho$ are small
- $SU(2)_L \times U(1)_Y$ symm. admits more terms to $\mathcal{L}_{SSB}$ $\rightarrow$ large $\delta\rho$
- **measurement:**

$$\rho_{exp} = 1 + \mathcal{O}(10^{-2})$$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$
- no Goldstones observed $\Rightarrow$ $\dim G - \dim H = 3$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$
- no Goldstones observed $\Rightarrow$ $\dim G - \dim H = 3$
- $SU(2)_L \times U(1)_Y \subset G \Rightarrow \dim G \geq 4$
  $U(1)_{em} \subset H \Rightarrow \dim H \geq 1$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$
- no Goldstones observed $\Rightarrow$ $\dim G - \dim H = 3$
- $SU(2)_L \times U(1)_Y \subset G \Rightarrow \dim G \geq 4$
  $U(1)_{em} \subset H \Rightarrow \dim H \geq 1$
- ESB scale $\Lambda_{ESB} = v \simeq 250$ GeV
  $m_W = gv/2, \quad G_F = 1/(\sqrt{2}v^2)$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$
- no Goldstones observed $\Rightarrow$ $\dim G - \dim H = 3$
- $SU(2)_L \times U(1)_Y \subset G \Rightarrow \dim G \geq 4$
  $U(1)_{em} \subset H \Rightarrow \dim H \geq 1$
- ESB scale $\Lambda_{ESB} = v \simeq 250$ GeV
  $m_W = gv/2, \quad G_F = 1/(\sqrt{2}v^2)$
- $\rho = 1 + \mathcal{O}(g'^2) \Rightarrow SU(2)_V \subset H \Rightarrow \dim H \geq 3$

General Requirements for $\mathcal{L}_{SSB}$

- at least 3 Goldstones for massive GB's
  $\Rightarrow$ global $G \to H$: $\dim G - \dim H \geq 3$
- no Goldstones observed $\Rightarrow$ $\dim G - \dim H = 3$
- $SU(2)_L \times U(1)_Y \subset G \quad \Rightarrow \quad \dim G \geq 4$
  $U(1)_{em} \subset H \quad \Rightarrow \quad \dim H \geq 1$
- ESB scale $\Lambda_{ESB} = v \simeq 250$ GeV
  $m_W = gv/2, \quad G_F = 1/(\sqrt{2}v^2)$
- $\rho = 1 + \mathcal{O}(g'^2) \quad \Rightarrow \quad SU(2)_V \subset H \quad \Rightarrow \quad \dim H \geq 3$

the only choice:

$$G = SU(2)_L \times SU(2)_R, \qquad H = SU(2)_V$$

The Precedence

Dynamical symmetry breaking:

The Precedence

Dynamical symmetry breaking:

- **QCD:**
  - strong interactions $\Rightarrow$ bound states, non-perturbative
  - $m_{u,d} = 0 : SU(2)_L \times SU(2)_R$
  - $\langle q_L \bar{q}_R \rangle \neq 0 \quad \rightarrow \quad$ SSB: $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
  - χPT: non-linear σ-model: π_1, π_2, π_3 ... Goldstone bosons

The Precedence

Dynamical symmetry breaking:

- **QCD:**
  - strong interactions $\Rightarrow$ bound states, non-perturbative
  - $m_{u,d} = 0 : SU(2)_L \times SU(2)_R$
  - $\langle q_L \bar{q}_R \rangle \neq 0 \quad \rightarrow \quad$ SSB: $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
  - χPT: non-linear σ-model: π_1, π_2, π_3 ... Goldstone bosons
- **superconductivity:**
  - weak nonrelat. interactions
  - a charge-2 composite of electrons

The Precedence

Dynamical symmetry breaking:

- **QCD:**
  - strong interactions $\Rightarrow$ bound states, non-perturbative
  - $m_{u,d} = 0 : SU(2)_L \times SU(2)_R$
  - $\langle q_L \bar{q}_R \rangle \neq 0 \quad \rightarrow \quad$ SSB: $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
  - χPT: non-linear σ-model: π_1, π_2, π_3 ... Goldstone bosons
- **superconductivity:**
  - weak nonrelat. interactions
  - a charge-2 composite of electrons

no precedence for fundamental scalars

Dynamical ESB

Technicolor, Extended TC, Walking TC, ...

- a scaled-up version of QCD
- technigluons, technifermions, TC strong at Λ_{EW}
- $\langle U\bar{U}\rangle = \langle D\bar{D}\rangle \neq 0$ ... breaks EW symmetry
- non-perturbative, technimesons $\Rightarrow$ effective theory
- fundamental Lagrangian *but* unable to solve:
  parameters of resonances (masses, couplings) are unknown
- QCD-inspired assumptions $\Rightarrow$ problem with S parameter
- TC is the *only* natural solution to the gauge hierarchy problem

Extra-Dimensional Models

- *new effort in modelling strong dynamics using weakly coupled 5D models*

Extra-Dimensional Models

- *new effort in modelling strong dynamics using weakly coupled 5D models*

- **AdS/CFT duality** (*Maldacena's conjecture*):
  D-dim *strongly* cpld gauge th. ⇔ (D+1)-dim *weakly* cpld gravity

Extra-Dimensional Models

- *new effort in modelling strong dynamics using weakly coupled 5D models*

- **AdS/CFT duality** (*Maldacena's conjecture*):
  D-dim *strongly* cpld gauge th. $\Leftrightarrow$ (D+1)-dim *weakly* cpld gravity
- **KK decomposition:**
  - 5D-field $= \sum$ 4D-fields $\times$ profile function in the 5th dim
  - integrate over the 5th dimension $\Rightarrow$ series of 4D fields (KK towers)
  - all fields of a KK tower have the same quantum numbers
  - different profiles $\Rightarrow$ different masses
  - the lightest fields (zero-modes) = SM gauge fields $W^{\pm}, Z, \gamma$

Extra-Dimensional Models

- *new effort in modelling strong dynamics using weakly coupled 5D models*

- **AdS/CFT duality** (*Maldacena's conjecture*):
  D-dim *strongly* cpld gauge th. ⇔ (D+1)-dim *weakly* cpld gravity
- **KK decomposition:**
  - 5D-field $= \sum$ 4D-fields $\times$ profile function in the 5th dim
  - integrate over the 5th dimension ⇒ series of 4D fields (KK towers)
  - all fields of a KK tower have the same quantum numbers
  - different profiles ⇒ different masses
  - the lightest fields (zero-modes) = SM gauge fields $W^{\pm}, Z, \gamma$
- **Higgs-like scalar fields not necessary**

Extra-Dimensional Models

- *new effort in modelling strong dynamics using weakly coupled 5D models*

- **AdS/CFT duality** (*Maldacena's conjecture*):
  D-dim *strongly* cpld gauge th. $\Leftrightarrow$ (D+1)-dim *weakly* cpld gravity

- **KK decomposition:**
  - 5D-field $= \sum$ 4D-fields $\times$ profile function in the 5th dim
  - integrate over the 5th dimension $\Rightarrow$ series of 4D fields (KK towers)
  - all fields of a KK tower have the same quantum numbers
  - different profiles $\Rightarrow$ different masses
  - the lightest fields (zero-modes) $=$ SM gauge fields $W^{\pm}, Z, \gamma$

- **Higgs-like scalar fields not necessary**

- fundamental theory unknown *but* **calculable** parameters (resonances, S)

Hidden Local Symmetry

Low-energy effective description of TC/extra-dim:

Hidden Local Symmetry

Low-energy effective description of TC/extra-dim:

- new massive vector resonances interacting and mixing with SM GB
  - TC: γ, Z with ρ_T, ω_T; gluons with ρ_T^{color}, ...
  - extra-dim models: γ, Z, W with KK resonances
  - hadron physics: $\gamma, \rho, \omega \quad \rightarrow$ VMD hypothesis
  - some ext. of SM

Hidden Local Symmetry

Low-energy effective description of TC/extra-dim:

- new massive vector resonances interacting and mixing with SM GB
  - TC: γ, Z with ρ_T, ω_T; gluons with ρ_T^{color}, ...
  - extra-dim models: γ, Z, W with KK resonances
  - hadron physics: $\gamma, \rho, \omega \quad \rightarrow$ VMD hypothesis
  - some ext. of SM
- Hidden Local Symmetry approach:
  - Any G/H NLσM is *gauge equivalent* to a $G_{glob} \times H_{loc}$ linear model
  - HLS H_{loc} is induced gauge symmetry by compositeness, not on fund. level
  - $H_{loc} \quad \leftrightarrow \quad$ new gauge bosons
  - SSB: $G_{glob} \times H_{loc} \rightarrow H_{glob} \times H_{loc} \quad \Rightarrow \quad$ new GB masses
  - fixing H_{loc} gauge $\quad \rightarrow \quad G/H$ NLσM

Outline

BESS Model*

Effective descr. of Higgsless dynamical ESB:

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

BESS Model*

Effective descr. of Higgsless dynamical ESB:

- non-linear theory with $SU(2)_V$ vector triplet V

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

BESS Model*

Effective descr. of Higgsless dynamical ESB:

- non-linear theory with $SU(2)_V$ vector triplet V
- global: $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to SU(2)_V \times U(1)_{B-L}$
  local: $SU(2)_L \times U(1)_Y \to U(1)_{em}$

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

BESS Model*

Effective descr. of Higgsless dynamical ESB:

- non-linear theory with $SU(2)_V$ vector triplet V
- global: $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to SU(2)_V \times U(1)_{B-L}$
  local: $SU(2)_L \times U(1)_Y \to U(1)_{em}$
- HLS: $[SU(2)_L \times SU(2)_R]^{glob} \times SU(2)_V^{loc}$

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

BESS Model*

Effective descr. of Higgsless dynamical ESB:

- non-linear theory with $SU(2)_V$ vector triplet V
- global: $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to SU(2)_V \times U(1)_{B-L}$
  local: $SU(2)_L \times U(1)_Y \to U(1)_{em}$
- HLS: $[SU(2)_L \times SU(2)_R]^{glob} \times SU(2)_V^{loc}$
- new interactions:
  - modified SM GB interactions (mixing)
  - *indirect* V-to-fermion interactions (mixing)
  - *direct* V-to-fermion interactions to $SU(2)_{L,R}$ fermion doublets with **inter-generational universality**

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

BESS Model*

Effective descr. of Higgsless dynamical ESB:

- non-linear theory with $SU(2)_V$ vector triplet V
- global: $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to SU(2)_V \times U(1)_{B-L}$
  local: $SU(2)_L \times U(1)_Y \to U(1)_{em}$
- HLS: $[SU(2)_L \times SU(2)_R]^{glob} \times SU(2)_V^{loc}$
- new interactions:
  - modified SM GB interactions (mixing)
  - *indirect* V-to-fermion interactions (mixing)
  - *direct* V-to-fermion interactions to $SU(2)_{L,R}$ fermion doublets with **inter-generational universality**
- tight low-energy limits:
  - existing measurements of SM gauge boson vertices
  - no right-handed neutrinos
  - $K_L - K_S$ mass difference

*[R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, PLB155(1985)95; NPB(1987)235]

Top Quark and ESB

$$\boxed{m_t \gg m_f, \forall f}$$

$$+$$

$$\boxed{m_t \simeq \Lambda_{ESB}}$$

$$\Downarrow$$

a hint of a special role in ESB

TOP-BESS MODEL*

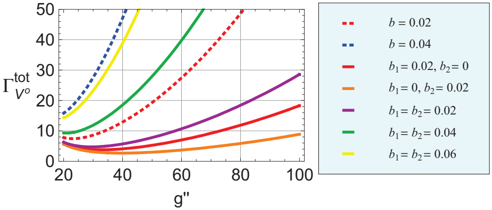
modified BESS model:

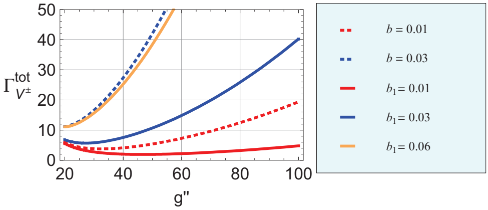
- inter-generational universality broken:
  - *no* direct interactions to leptons
  - *no* direct interactions to u, d, c, s
  - direct interaction to the left (t, b) doublet
  - direct interaction to the right t quark
  - direct interaction to the right b quark
  - additional interactions, not considered in the BESS model
- low-energy limits relaxed

*[M. Gintner, I. Melo]

BESS *vs* Top-BESS Models

$M_V = 1$ TeV





SUMMARY

- ESB mechanism = open question
- SM Higgs not necessary
- dynamical ESB is a viable candidate
- study of TC/extra-dim requires effective approach
- HLS based BESS-like models might do the job