Composite GUTs: model building and expectations at the LHC

M. Frigerio J. Serra A. Varagnolo

based on 1103.2997 [hep-ph], JHEP 1106:029,2011

Supersymmetry 2011, Fermilab

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Outline

1. Motivations and Intro
   - SUSY & the ALTERNATIVES
   - Some tools
2. Model Building
   - The idea, and real life
   - Our pNGBs, our Exotics and the EWPTs
3. Some phenomenology
   - Some doubts
   - Some hope

Outline

Motivations for CompoGUTs

- Unification and its many appealing virtues
  - charge quantization
  - gauge quantum numbers of fermions
  - chiral anomalies cancellation
  - relative low energy values of SM gauge couplings
  - and more (DM stability, masses of νs,...)
- solution to the Hierarchy Problem (orthogonal to SUSY)
- predict properties of lightest states coming from the new Strong Sector: partners of Higgs and top
- accept the LHC challenge

SUSY

Why we love SUSY:

- Solution to the Hierarchy Problem
- Improves Unification (with full perturbativity up to M_{GUT})
- Rich Pheno: new states predicted (Dark Matter?)

Of course, we do have some complaints/doubts:

- need for extra symmetry to avoid, e.g., p-decay (R-parity)
- parameter space for simplest models of SUSY shrinking
- nature has shown us other ways (QCD, SC)

All in all, not unwise to consider alternatives

ALTERNATIVES

The big thing: Solve the HP.

Many candidates: Technicolour, Higgsless, Extra Dimensions, . . . Composite Higgs.

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- Solution to HP $\rightarrow$ move to the little HP (Fine Tuning!)
- ?? Unification ?? not perturbative!
- ?? New states ?? Huge model dependence $+$ some of them we cannot control (heavy resonances) $\leftarrow$ the price of having a Low E effective description

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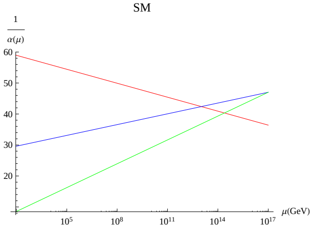
One step at a time. Why can't we tell if our model unifies?

Do you know your beta functions?
Or: how to check if Unification occurs

SM: Unif fails



Higher Orders: NO help

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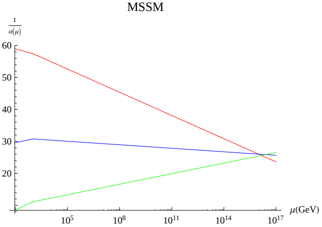

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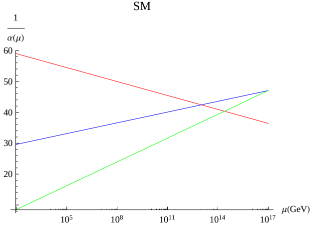

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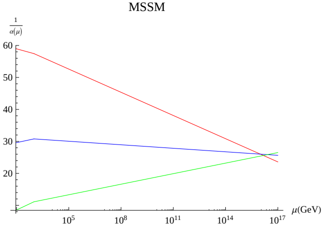

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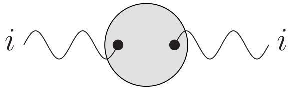

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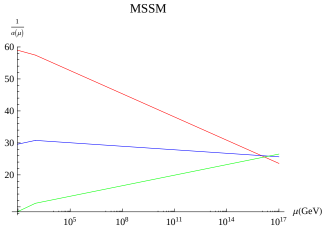

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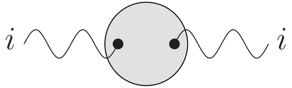

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Our ignorance is partial

$$\frac{d}{d\ln\mu}\left(\frac{1}{\alpha_i}\right) = \frac{b_i^{elem}}{2\pi} + \frac{b_i^{comp}}{2\pi},$$

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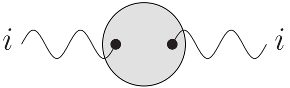

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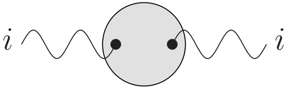

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Notice: the differential running determines unification[1]. A good measure: $R \equiv (b_1 - b_2)/(b_2 - b_3)$. Numerically, we have: $R_{exp} = 1.395 \pm 0.015$ vs $R^{th}_{SM} \simeq 1.9$ vs $R^{th}_{MSSM} = 1.4$ vs ??

[1] provided no Landau pole is hit

Composite Higgs

New Strong Dynamics triggers G/K global symm breaking, NGBs π s.t. $\pi \supset H$, with σ-model scale f
@ Low E: $\mathcal{L} = \mathcal{L}^{G_{SM}}_{elementary} + \mathcal{L}^{G\to K}_{composite} + \mathcal{L}^{G_{SM}}_{mixing}$
The mixing term will generate (CW) a $V_{eff}(\pi) \neq 0$. Fine Tuning measure: $\xi = v^2/f^2$. Resonances @ scale $m_\rho \sim$ few TeV, inter-compo coupling: $g_\rho = m_\rho/f$, $g_{elem} \leq g_\rho \leq 4\pi$

Composite Top

A closer look: $\mathcal{L}^{G_{SM}}_{mixing} = \lambda_{\psi_L}\overline{\psi_L}\mathcal{O}_{\psi_L} + \lambda_{\psi_R}\overline{\psi_R}\mathcal{O}_{\psi_R} + g_i A_{i\mu}\mathcal{J}^\mu$
Yukawa: $y_\psi \simeq \lambda_{\psi_L}\lambda_{\psi_R}/g_\rho \to$ top mostly/totally composite. Must choose t_R, otherwise big troubles[a] with $Zb\bar{b}$
Also: $\hat{T} \simeq v^2/f^2 \to$ Better impose Custodial Symmetry $(SU(2)_L \times SU(2)_R)$ on the whole Strong Sector

[a]Can cure this by extending CS with LR parity. Check r-h coupling!

Outline

A way out

$G/K \to$ Composite stuff (i.e. Higgs, top, heavy resonances)

Agashe, Contino, Sundrum (2005) realized that if

$G_{SM} \subset G$ simple $\Rightarrow$ contribution of strong sector to b_is above compositeness scale becomes universal! ($b_i^{compo} \to b^{compo}$)

Then $b_i - b_j = b_i^{elem} - b_j^{elem}$ and we can compute! (modulo small corrections from Low E region, if K is not simple)

Equivalently: we subtract the contributions of composite modes to the differential running, i.e.

$$R(SM) \to R(SM \setminus \{\text{Composite stuff}\})$$

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But careful: $b^{compo} < 10$, or you hit a Landau pole before M_{GUT}!

Requirements on G/K

(A) $G/K \to$ NGBs contain the Higgs, or a $(2,2)_0$ repr of $SU(2)_L \times SU(2)_R \times U(1)'$
(B) $K_{min} = SU(3) \times SU(2)_L \times SU(2)_R \times U(1)'$
(C) G a simple group s.t. $G_{SM} \subset G$

$A + B + C \Rightarrow$ rank$(G) \geq 5$: $G = SO(10)$? Life's not that easy...

Minimal rank sol'ns:

$G \to K$	R_{NGB}
$SO(11) \to SO(7) \times SU(2) \times SU(2)$	$(\mathbf{7}, \mathbf{2}, \mathbf{2})$
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To fit fermion Y & to prevent p-decay and too large ν masses

What about fermions?

Which repr of $SO(10)$ contains t_R? Obvious[2] answer is: $\overline{16} \supset t_R$, as typical in canonical GUTs. Then, however, t_R comes with a plethora of new composite massless (before EWSB) states: exotics $\overline{16} = (x_R, t_R)$. In order to

- avoid experimental constraints on masses of extra fermions
- cancel anomalies

we need to pair them to a $16 \setminus t'_L = x_L$ of **elementary** fields!
Consequence for unification: $R \to R(SM \setminus \{H, t_R, t_R^c\})$
Bottom line: for K simple unification is guaranteed.
Numerically: $R \simeq 1.45$ vs. $R_{exp} = 1.395$ vs. $R_{SUSY} = 1.4$
Higher orders: **hard** to evaluate, very model dependent.

[2]But one can engineer, e.g., $t_R \subset \mathbf{10}$

H & T & *x*s

The masses are predicted as follows:

$$m_h^2 \simeq N_x \frac{\lambda_x^4}{16\pi^2} v^2 \simeq (440\, GeV)^2 \, (\lambda_x/2.5)^4 \ ,$$

$$m_T{}^2 \simeq N_g \frac{g_s^2}{16\pi^2} m_\rho^2 \simeq (1.2\, TeV)^2 \, (m_\rho/4.5\, TeV)^2 \ ,$$

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Important #1: couplings of pNGBs ($\supset H$) come with factor $\sqrt{1 - v^2/f^2}$. Numerically, $f \simeq 750\ GeV$ easily realized (in region allowed by EWPTs) $\Rightarrow$ factor 0.95 (lower possible).

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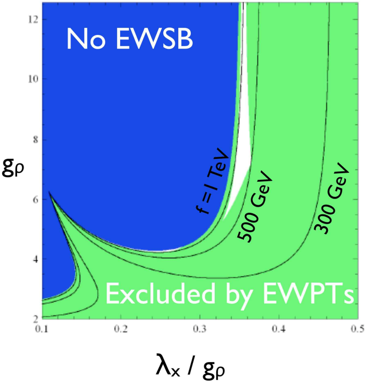
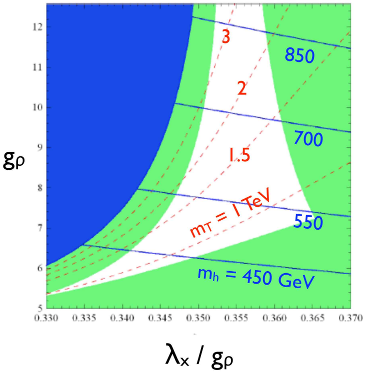
Important #2: bound from $Zb\bar{b}$: $m_{b'} > 1.4\ TeV$. λ_x must be smaller than g_ρ, for V_{eff} computation to make sense.

EWPTs (warning: numbers!)

We use exact formulae for V_{eff}, m_H, m_T ... $\Rightarrow$ numerics! But ...





Lots of $O(1)$ unknown coefficients in V_{eff}: not strict predictions, only behavior shown. However, analytic properties are there.

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T's & Exotics' Pheno @ LHC $\rightarrow$ to be revised!

	q^c	b'	l^c	ν'	e'	T
$SU(3)_C$	$\bar{3}$	3	1	1	1	3
$SU(2)_L$	2	1	2	1	1	1
$U(1)_Y$	$-\frac{1}{6}$	$-\frac{1}{3}$	$\frac{1}{2}$	0	-1	$-\frac{1}{3}$
$U(1)_{B_E}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0
$U(1)_{B_I}$	$-\frac{1}{3}$	$\frac{1}{3}$	1	-1	-1	$-\frac{2}{3}$

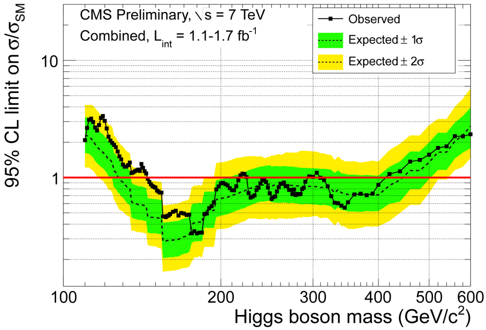
Mostly pair produced via gauge int's: @ 14 *TeV* LHC cross section $\sim$ 0.01 (0.05) *pb* for masses $\sim$ 1 *TeV* for coloured scalars (fermions).
Depending on B, lightest state can be stable (baryon triality).

Assume T stable.
LHC produced: hadronizes $\mathcal{T}^0 = T\bar{d}$ or $\mathcal{T}^- = T\bar{u}$:
$\mathcal{T}^0 \sim$ missing E_T;
$\mathcal{T}^- \sim$ heavy μ
(both should come with pairs of $t's$ or $b's$)

If N (mix of l^c and ν') stable:
missing E_T + (t's & b's pairs)
N can be DM candidate, but need to be mostly ν' to avoid direct detection & relic density ($\neq$ SUSY annihil'n).

Higgs: surviving @ LHC

CMS 22/08: excluded SM Higgs for 140 $GeV \leq m_H \leq 440$ GeV



The good properties of *our* Higgs:

- it's typically heavy (from 400 GeV upwards)
- couplings & cross sections reduced wrt SM Higgs'

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- lightest of comparts might be stable; production @ LHC might be significant (problem?)

to do list

- check attentively LHC signals: do we survive? more FT?
- attempt the construction of UV-completion

Until next time...