Composite unification at the LHC

Michele Frigerio (IFAE, Barcelona & L2C, Montpellier)

with Javi Serra & Alvise Varagnolo,
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Motivations & outline

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- EWSB with no hierarchy problem: supersymmetry or a new strongly coupled sector ?
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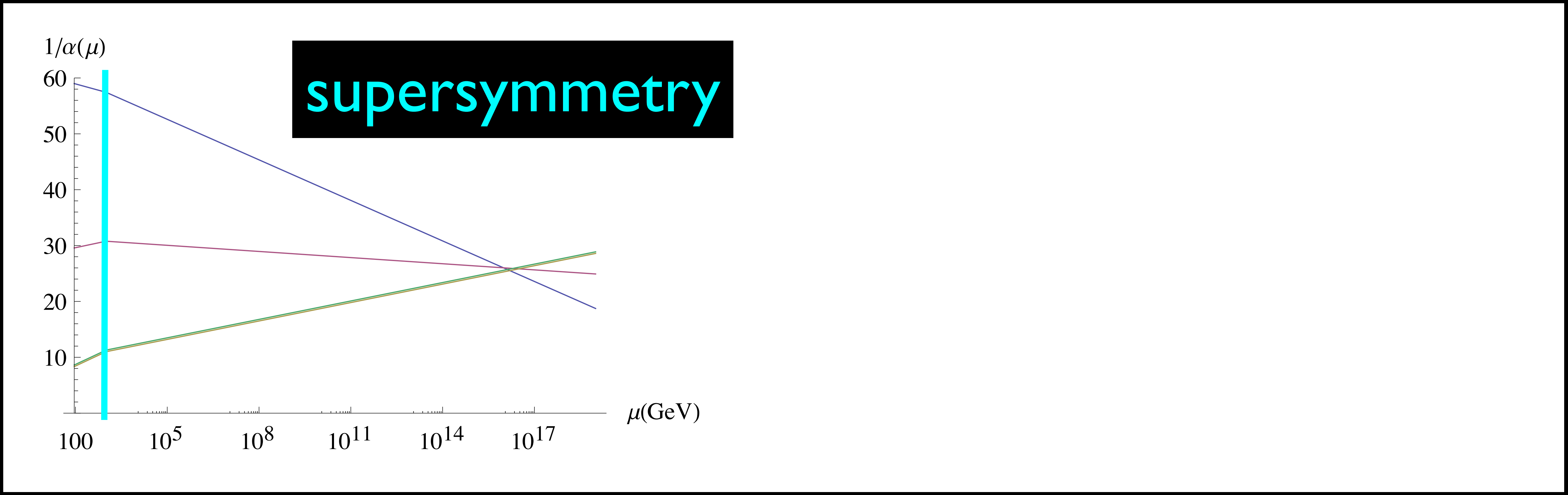
- EWSB with no hierarchy problem: supersymmetry or a new strongly coupled sector ?
- the appeal of GUTs (*charge quantization, anomaly cancellation, Yukawa relations, neutrino masses ...*) favours an EWSB sector that accounts for precision gauge coupling unification
- to build a strongly coupled model (with the Higgs as a composite pseudo-Nambu-Goldstone boson) where gauge running can be controlled & unification is achieved
- to predict the lightest new particles of the strong sector: the composite partners of the Higgs and the top quark
- to sketch their phenomenology at the early LHC

EWSB & gauge unification

$$\frac{1}{\alpha_i(\mu)} = \frac{1}{\alpha(m_Z)} - \frac{b_i^{SM}}{2\pi}\log\frac{\mu}{m_Z} - \frac{b_i^{EWSB}}{2\pi}\log\frac{\mu}{m_{EWSB}}$$

What is the contribution of the EWSB to the gauge coupling evolution ?



1974 to 1981: from GUTs to SUSY GUTs

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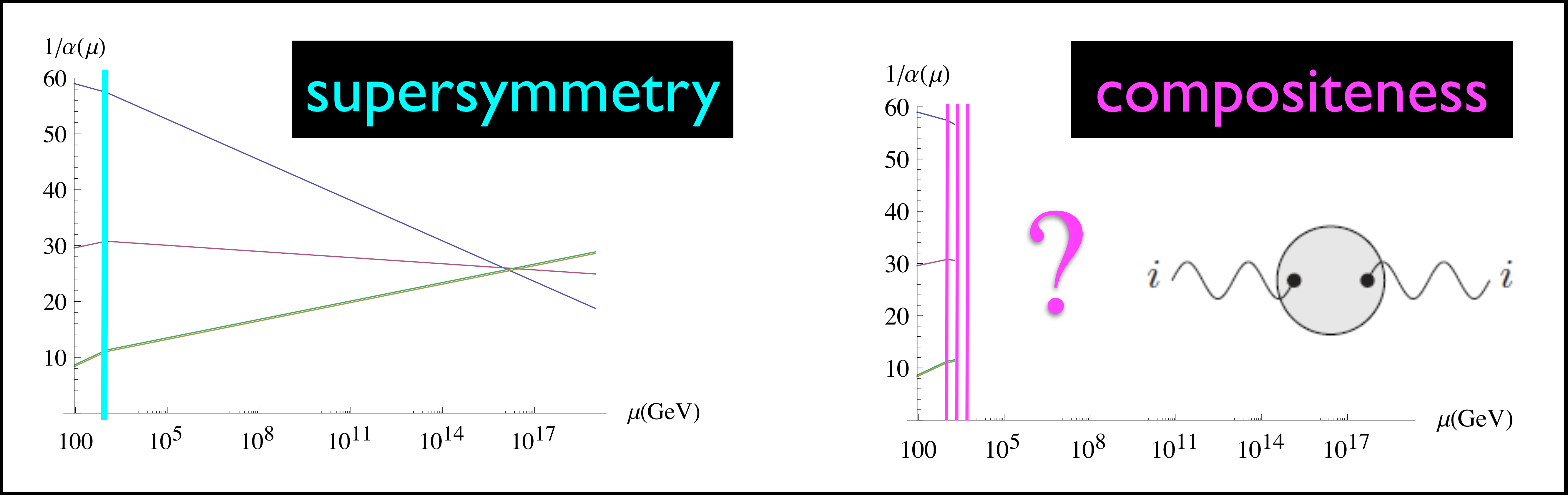
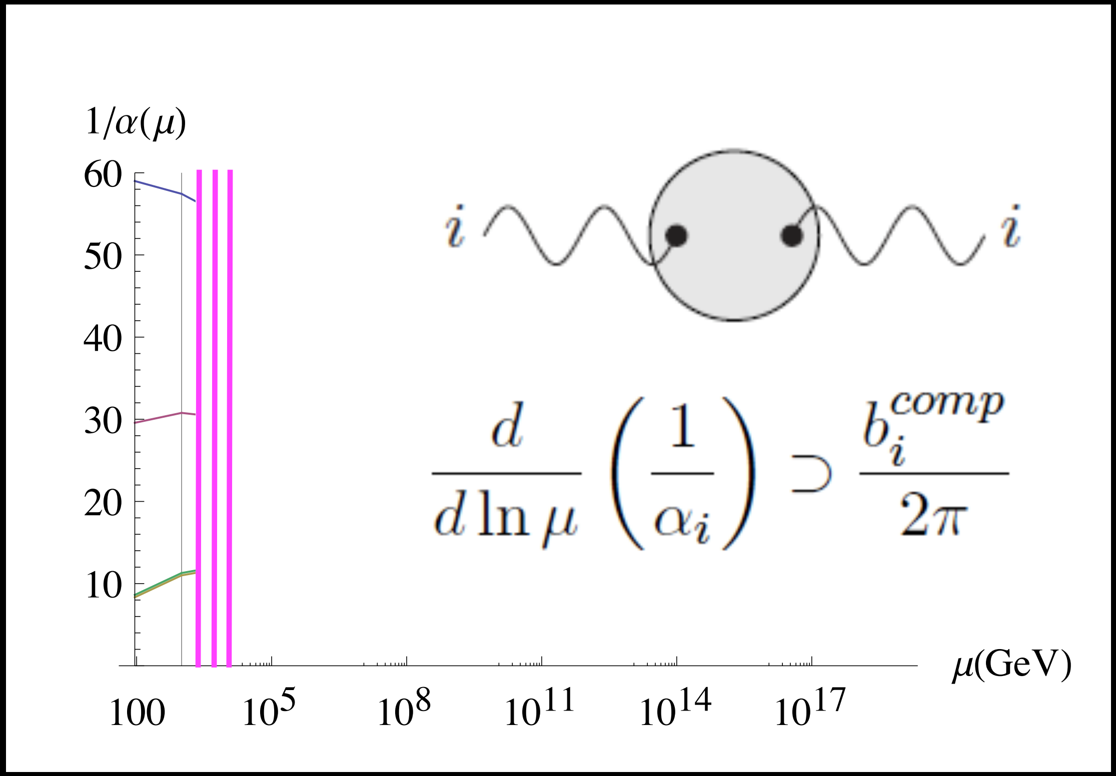


1974 to 1981: from GUTs to SUSY GUTs

The composite sector contributes with unknown coefficients b_i^{comp} to the gauge coupling β-functions

Composite route to unification



Agashe-Contino-Sundrum 2005

If the composite sector above Λ_{EW} has a simple global symmetry group $G \supset SU_{321}$ then b^{comp} is universal: the differential running controlled by $(b_i - b_j)$ is independent from the strong dynamics

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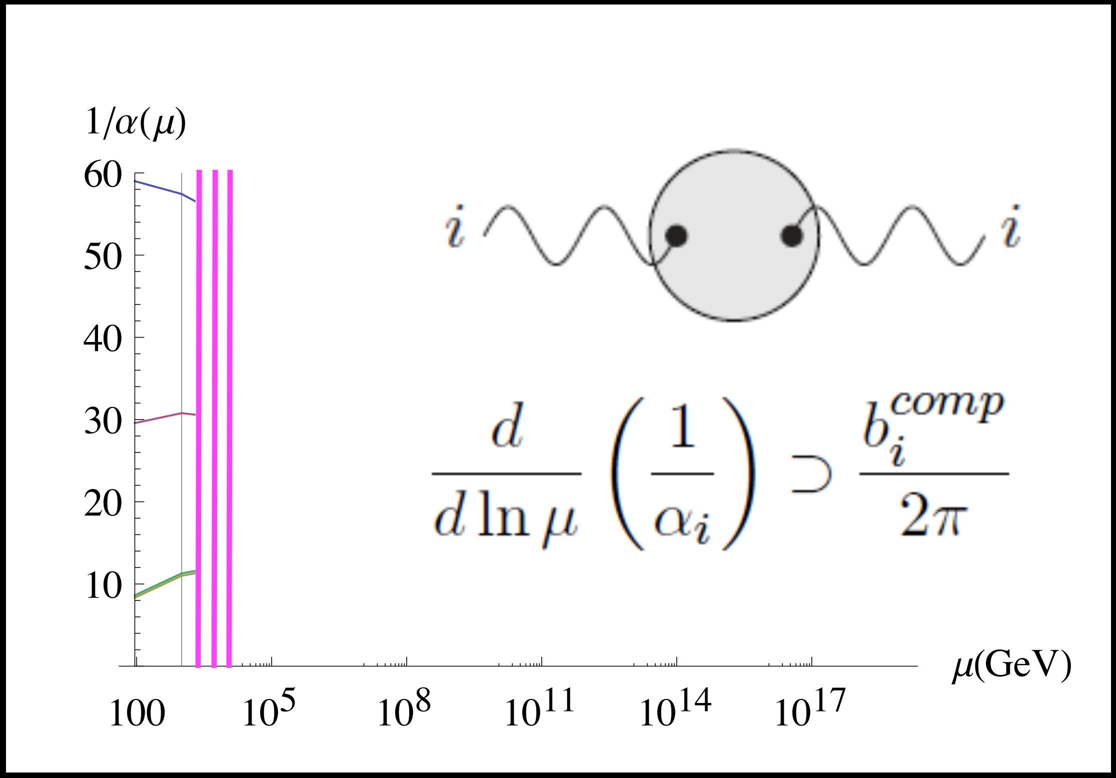

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If H and t_R are composite they must be subtracted from the running:

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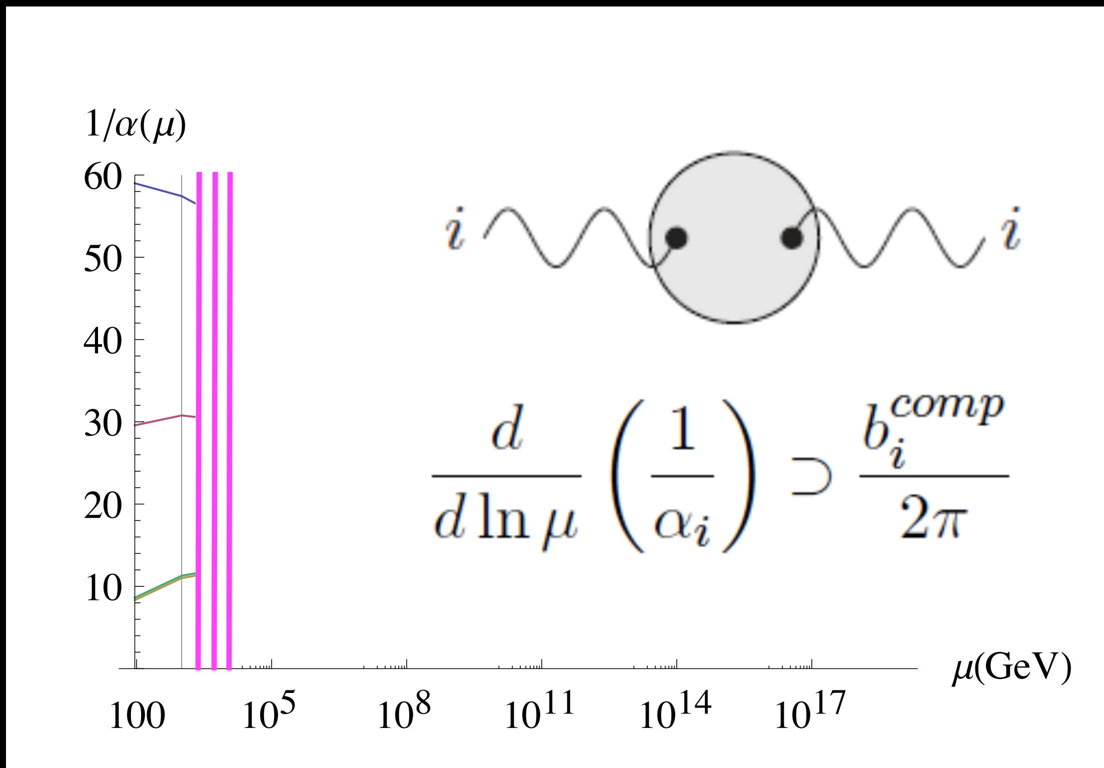

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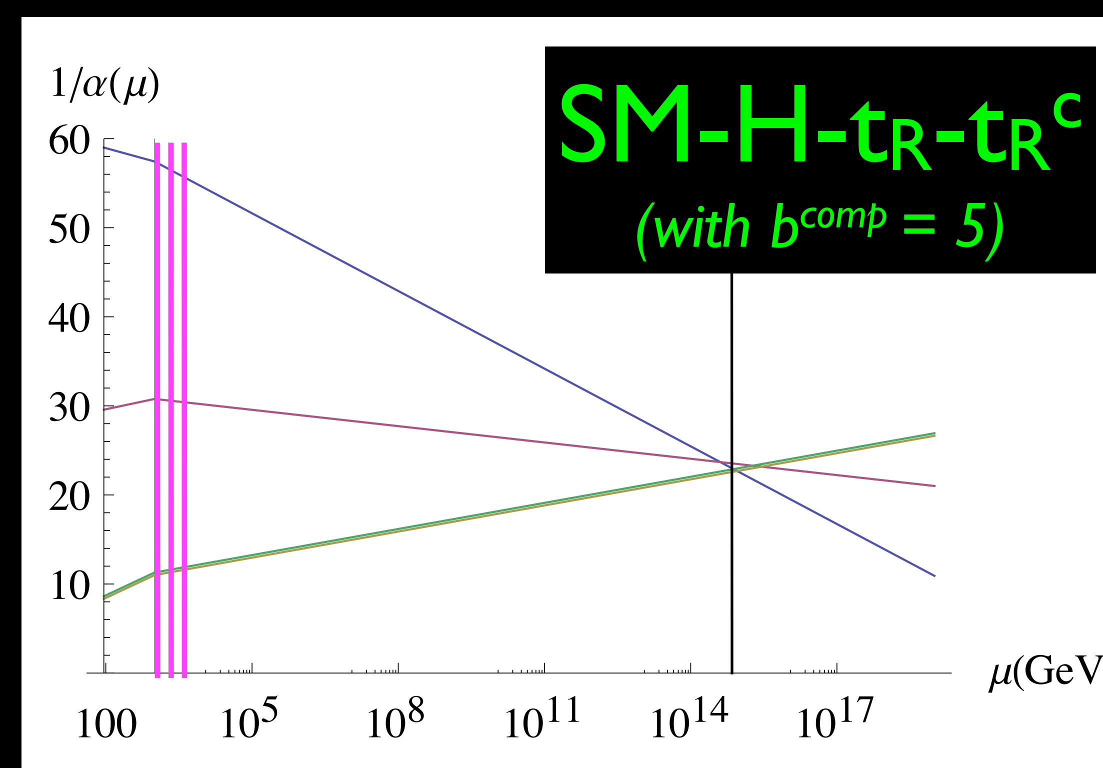

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$$\mathcal{L}_{mixing} = g_i A_i^\mu \mathcal{J}_\mu + \lambda_\psi \overline{\psi} \mathcal{O}_\psi$$

The mixing of elementary fields with composite operators breaks explicitly (weakly) G, while preserving G_{SM}

Higgs & top SO(10) partners

$$10_{PNGB} = (H, \boxed{T})$$

- Composite pNGBs from SO(11) → SO(10)
- Elementary t_R is not there
- Composite t_R is part of a full SO(10) multiplet of composite chiral fermions
- The t_R partners x_R must be made vector-like to avoid anomalies and acquire a mass above experimental bounds
- Need for a set of exotic elementary fermions x_L

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The set of "comparts"

The partners of the composite Higgs and RH top quark are the lightest new states (lighter than $m_\rho \sim$ few TeV)

These composite partners ("comparts") are the counterpart of SUSY partners ("sparticles")

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

The comparts gauge quantum numbers are fixed by SO(10)

To avoid proton-decay we assume a $\mathrm{U}(1)_B$ symmetry external to SO(10)

Comparts at the LHC

$m_\rho \approx 4$ TeV

$f \approx 750$ GeV

$v = 246$ GeV

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

$$m_x \simeq \lambda_x f \simeq 1.9TeV \left(\frac{\lambda_x}{2.5}\right) \left(\frac{f}{750GeV}\right)$$

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- Mostly pair production via gauge interactions:
  at LHC-14 TeV, cross section ~1 pb for colour comparts with mass ~ 500 GeV

- Stability depends on baryon triality: $B_3 = (3B - n_C)_{\text{mod } 3}$

- Comparts with $B_3 = 0$ can decay to SM (t, b, W_L, Z_L, h)

- Among the comparts with $B_3 \neq 0$, the lightest is stable:
  the others decay into SM + lightest stable compart

Comparts decay channels

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CMS, 1102.4746

$b' \to bh,\ tW_L,\ bZ_L$

Direct bound on 4th family bottom: $m_{b'} > 350$GeV
Indirect bound from Zbb coupling: $m_{b'} > 1.4$ TeV

$$\frac{\Delta g_{b_L}}{g_{b_L}} = -\frac{m_t^2}{m_{b'}^2} > -0.015$$

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The other comparts cannot decay to SM. Assume T is the lightest :

$$t^c \to bT\ ,\ b^c \to tT\ ,\quad e^c \to tT^*\ ,\ \nu^c \to bT^*\ ,\quad \nu' \to bT^*$$

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$e' \to bb\bar{t}T^*$

4-body decay via dim-7 operator with width naively of the order $(0.5\ \mu m)^{-1}$
[displaced vertex visible at LHCb above 50 µm]

Stable T as lightest compart

- T (pair-produced or from decay chains) promptly hadronizes to colour singlets Td or Tu

$T \sim (3, 1, -1/3)_{B=0}$

- Neutral T-hadrons look like missing E_T Charged T-hadrons (CHAMPs) look like heavy muons relatively easy to detect

Cheung-Cho '02,
ATLAS, 1103.1984:
stable squarks > 300 GeV

- Cleanest channels for this scenario appear to be pairs of t's or b's + CHAMPs or missing E_T

jets + missing E_T
(+ lepton)
at CMS, 1101.1628
(Atlas, 1102.2357)

- T relic density suppressed by its large gauge & composite interactions

Barbieri, Rychkov,
Torre, '10

Stable N as lightest compart

Assume the lightest compart is a neutral fermion N mixing of the isosinglet ν' and the isodoublet $l^c = (\nu^c\ e^c)$

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- Other comparts with $B_3 \neq 0$ undergo decay chains to SM + N, that manifests as missing E_T

$$t^c\overline{t^c} \to bb\bar{b}\bar{b} + \not{E}_T \qquad b^c\overline{b^c} \to tb\bar{t}\bar{b} + \not{E}_T$$

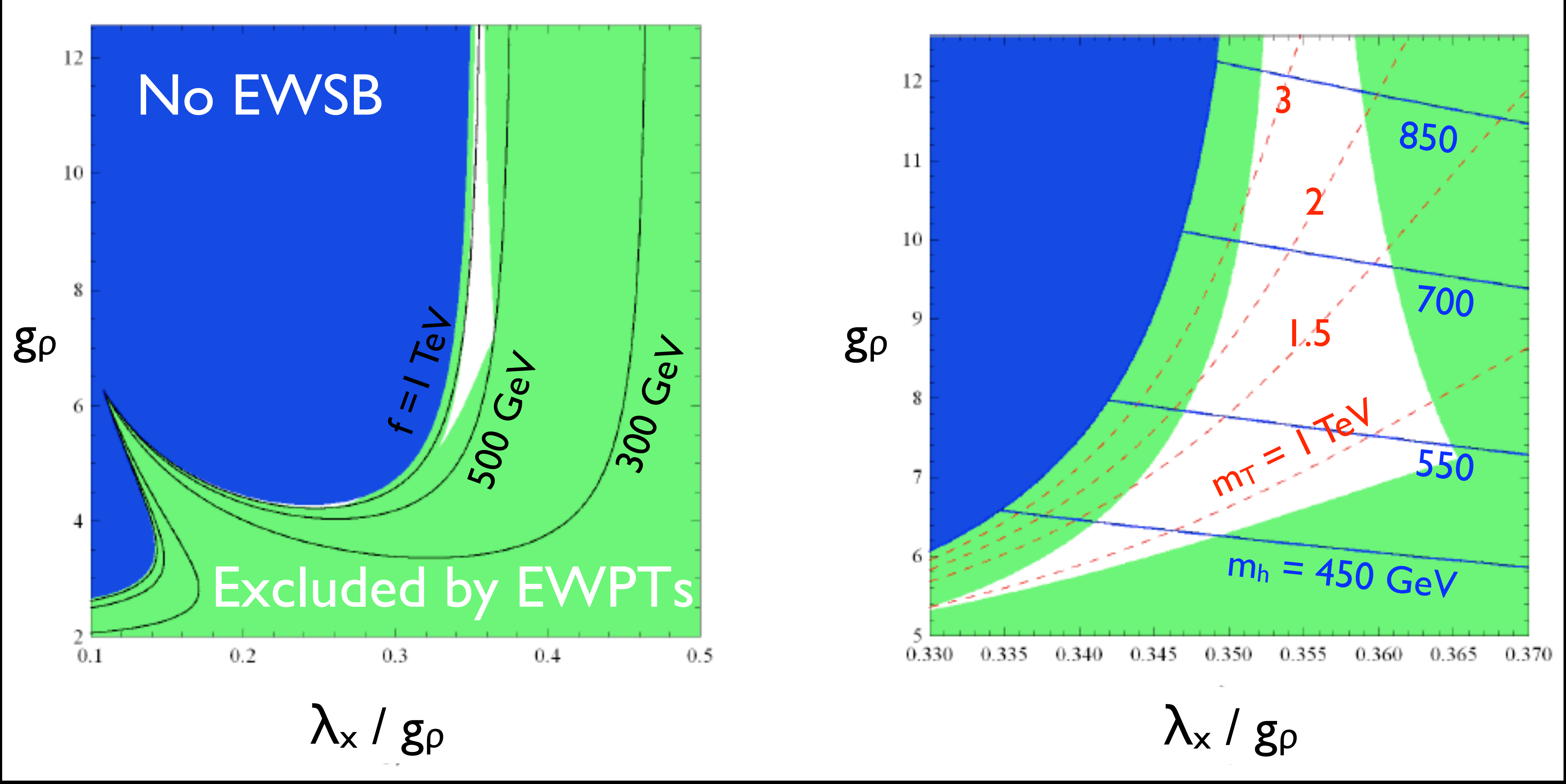
SUSY with 3rd family lighter, Barbieri-Pappadopulo, '09

- N is a good dark matter candidate: similarities with Higgsino-Bino LSP in SUSY, but it must be mostly ν' to avoid dark matter direct detection bounds (annihilation channels different from SUSY control the relic density...)

Warped ED analog, Agashe-Servant '04

EWSB parameter space

- we computed the one-loop effective potential for the pNGBs generated by the elementary-composite mixing
- two free parameters: the exotic fermion coupling λ_x and $g_\rho = m_\rho/f$ (plus a set of order one coefficients from strong dynamics)



Summary

- Composite GUTs account at the same time for the stability of the EW scale and precise gauge unification
- They predict that H and t_R are composite and accompanied by SO(10) partners lighter than the compositeness scale
- EWSB is natural and can be realized with a little tuning, as long as compart masses are $\leq$ 1-2 TeV
- Coloured comparts should be copiously produced in the early LHC, with final states reach in top and bottom quarks
- The lightest compart may be stable depending on its baryon number