Yukawa Unification in SUSY SO(10) GUT

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based on the work with Marek Olechowski and Stefan Pokorski

preliminary results

Minimal SO(10) and Yukawa Unification

- For a given generation all matter fermions, including ν_R, sit in one **16** dim. representation of SO(10)
- Both MSSM Higgs doublets are in the **10** dim. representation of SO(10)
- Yukawa interactions are given by

$$W = h\,\mathbf{16}\,\mathbf{10}\,\mathbf{16}$$

which imply unification of $t - b - \tau$ Yukawa coupling at $M_{\rm GUT}$.

Explaining $(g-2)_\mu$ anomaly and Yukawa unification

Yukawa unification prefers $\mu < 0$ but usually $\mu > 0$ is considered.

Why?

$(g-2)_\mu^{SM}$ more than 3σ below experimental value.

$(g-2)_\mu^{SUSY} \sim \mathrm{sgn}(\mu M_2) \Rightarrow (g-2)_\mu$ prefers $\mu > 0$ for universal gaugino masses

but

Universal gaugino masses are not obligatory in SUSY GUTs

Our Strategy

Consider $\mu < 0$ and non-universal gaugino masses with $M_2 < 0$

The model

$\mu < 0$

- Non-universal scalar masses:

$$m_{H_d}^2 = m_{10}^2 + 2D$$
$$m_{H_u}^2 = m_{10}^2 - 2D$$
$$m_{Q,U,E}^2 = m_{16}^2 + D$$
$$m_{D,L}^2 = m_{16}^2 - 3D$$

- Non-universal gaugino masses generated by F-term transforming as **54** dim. representation of SO(10):

$$M_1 = -\frac{1}{2} m_{1/2}$$
$$M_2 = -\frac{3}{2} m_{1/2}$$
$$M_3 = m_{1/2}$$

- Universal trilinear couplings: $A_U = A_D = A_E = A_0$

5 parameters + $\tan\beta$

Methodology

The soft SUSY breaking masses are imposed at the GUT scale and run down to the electroweak scale with RGE code SOFTSUSY. We impose the condition of REWSB, neutral LSP, particle mass bounds and the experimental constraints for the following observables:

- the relic abundance of dark matter $\Omega_{\rm DM}h^2$
- $a_\mu \equiv (g-2)_\mu/2$
- $\mathrm{BR}(b \to s\gamma)$
- $\mathrm{BR}(B_s \to \mu^+\mu^-)$

which we calculate using MicrOMEGAs.

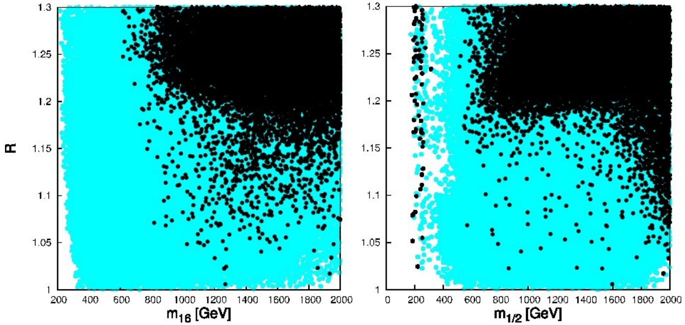
We have performed random scan for the following ranges of parameters:

$$0 \leqslant m_{16} \leqslant 2000\,\mathrm{GeV} \qquad 0.1 \leqslant m_{10}/m_{16} \leqslant 2 \qquad -3 \leqslant A_0/m_{16} \leqslant 3$$

$$0 \leqslant m_{1/2} \leqslant 2000\,\mathrm{GeV} \qquad 0 \leqslant D/m_{16}^2 \leqslant 0.3 \qquad 40 \leqslant \tan\beta \leqslant 55$$

Wide random scan for Yukawa-unified solutions

$$R \equiv \frac{\max(h_t, h_b, h_\tau)}{\min(h_t, h_b, h_\tau)}$$



$b \to s\gamma$ excluded

$b \to s\gamma$ ok

Yukawa unification ($R \approx 1$) can be obtained for a very wide ranges of parameters but majority of points with good yukawa unification excluded by $b \to s\gamma$.

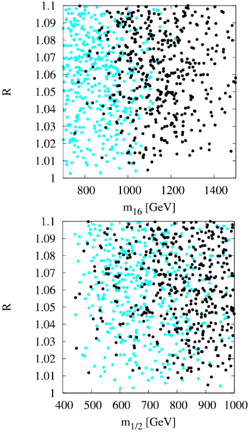
Strong correlation between $(g-2)_\mu$ and $b \to s\gamma$

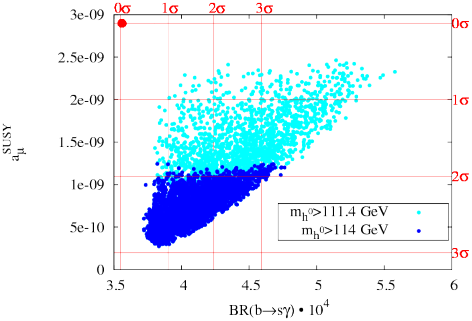
For the points not excluded by $b \to s\gamma$, $(g-2)_\mu$ typically very small

How to disentangle $(g-2)_\mu$ from $b \to s\gamma$?

We have identified 2 classes of solutions with good yukawa unification, consistent with all the experimental constraints (including $b \to s\gamma$) with large SUSY contribution to $(g-2)_\mu$

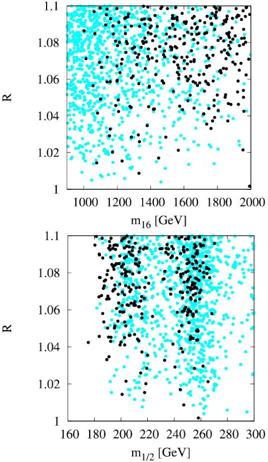
- Large D-terms to push up $m_{H^\pm}$ and suppress Higgs contribution to $\mathrm{BR}(b \to s\gamma)$
- $A_t \approx 0$ at M_{EW} (this require large positive A-terms at M_{GUT}) to suppress chargino-stop mixing contribution to $\mathrm{BR}(b \to s\gamma)$ without suppressing chargino contribution to $(g-2)_\mu$
- bino-like LSP with the relic abundance satisfying WMAP bound due to stau coannihilations

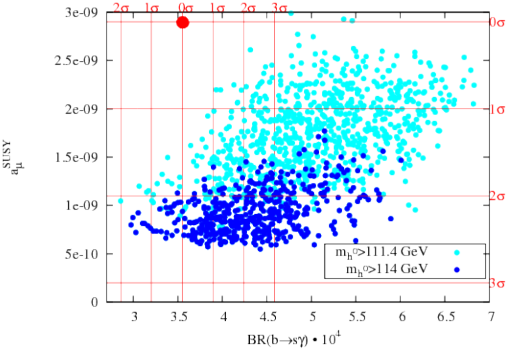




$(g-2)_\mu$ within 2σ from exp. value
(1σ relaxing Higgs mass bound)

- $m_{1/2} \ll m_{16} \Rightarrow$ light gluinos (500-700 GeV)
- Large chargino mixing ($M_2 \approx \mu$ at $M_{\rm EW}$) which results in negative chargino contribution to BR($b \to s\gamma$)
- bino-like LSP with non-negligible higgsino component which allows for resonant annihilations through h^0 or Z bosons





$(g-2)_\mu$ within 2σ from exp. value (1σ relaxing Higgs mass bound)

Conclusions

Yukawa coupling unification in SUSY SO(10) consistent with all the phenomenological constraints is much more natural for $\mu < 0$.

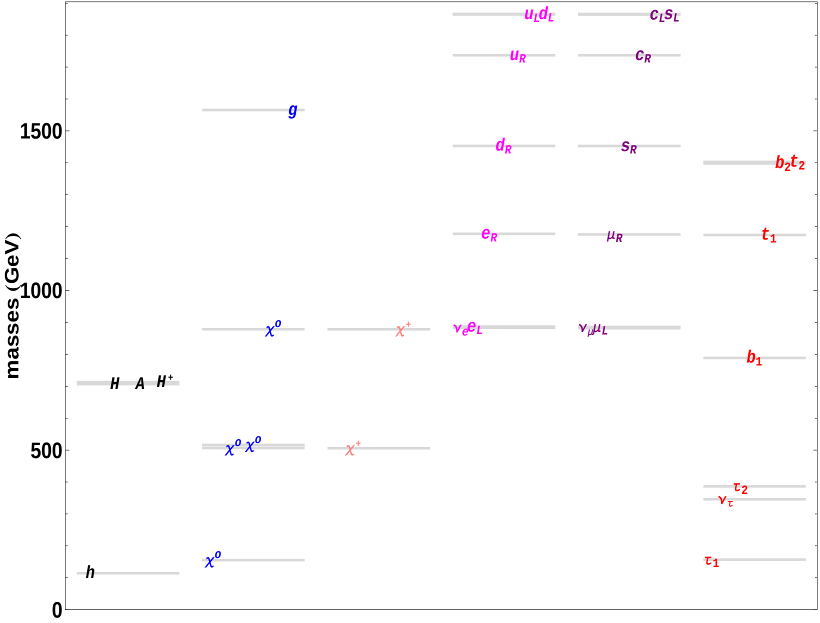
- Proper REWSB requires non-universal scalar masses at $M_{\rm GUT}$ which is generic in the SO(10) GUT $\rightarrow$ D-term splitting, RG running between $M_{\rm Pl}$ and $M_{\rm GUT}$
- Non-universal gaugino masses with $M_2 < 0$, as required by $(g-2)_\mu$ constraint, can be generated by the F-term in **54** rep. of SO(10)
- $(g-2)_\mu$ can be disentangled from $b \rightarrow s\gamma$ and compatible with the experimental value at 1σ level. Upper limit for $(g-2)_\mu$ is set by the LEP bound on m_{h^0}.

Yukawa unification in SO(10) with light SUSY spectrum:

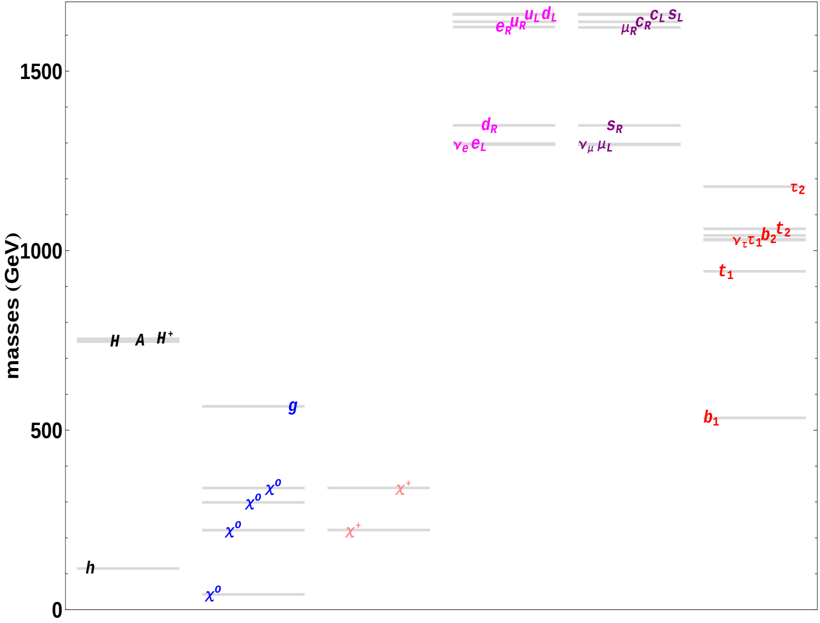
Light gluinos for the early LHC

Backup slides

Solution 1: typical spectrum



Solution 2: typical spectrum



Sources of non-universal scalar masses

RG running from the Planck scale

In gravity mediation soft SUSY breaking terms are supposed to be generated around M_{Pl}.

Running from the Planck scale to the GUT scale splits 10 and 16. We parameterize this effect by setting m_{10} for Higgses and m_{16} for squarks at M_{GUT}.

D-term contribution

When the gauge symmetry is broken and its rank is reduced, soft scalar masses acquire new contribution from D-terms of the broken U(1) which is proportional to charges of the broken U(1)

For SO(10) $\rightarrow G_{\mathrm{SM}}$:

$$m_{H_d}^2 = m_{10}^2 + 2D$$
$$m_{H_u}^2 = m_{10}^2 - 2D$$
$$m_{Q,U,E}^2 = m_{16}^2 + D$$
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Non-universal gaugino masses from non-singlet F-terms

Gaugino masses in SUGRA can arise from dimension 5 operator:

$$\mathcal{L} \supset -\frac{F^{ab}}{2M_{\rm Planck}}\lambda^a\lambda^b + {\rm c.c.}$$

$\langle F^{ab}\rangle$ must transform as a singlet under the SM gauge group
but can be in a non-singlet representation of SO(10)

Non-zero gaugino masses arise from F^{ab} representations in the symmetric part of the direct product of the adjoint representation:

$$(\mathbf{45}\times\mathbf{45})_S = \mathbf{1}+\mathbf{54}+\mathbf{210}+\mathbf{770}$$

If $\langle F^{ab}\rangle$ transforms as **54**, gaugino masses are determined by:

Martin, 2009

$$M_1 : M_2 : M_3 = -\frac{1}{2} : -\frac{3}{2} : 1$$

$M_2 < 0 \Rightarrow \mu < 0$ can be consistent with $(g-2)_\mu$ constraint!