Light staus and enhanced Higgs to diphoton rate in SO(10) Yukawa Unification

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Preliminary results

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Brief remarks on the status of a Higgs

The discovery of a Higgs is firmly established with the mass around 125 GeV which is within the range predicted by MSSM

The Higgs branching ratios converge towards the SM but quite slowly and still some room for deviations of order few × 10%

Updated CMS Higgs results in the $\gamma\gamma$ channel no longer show excess over the SM but in ATLAS it is still there.

Combination of ATLAS and CMS in $\gamma\gamma$ channel:

$$\mu_{\gamma\gamma} = 1.2 \pm 0.2 \quad \text{(CMS MVA analysis)}$$

$$\mu_{\gamma\gamma} = 1.4 \pm 0.2 \quad \text{(CMS cut-based analysis)}$$

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No strong hints for new physics but enhanced $\gamma\gamma$ rate remains an interesting and valid possibility

Outline

1. Effects of staus on the Higgs $\gamma\gamma$ rate in MSSM
2. Necessary conditions for top-bottom-tau Yukawa unification
    - non-universalities in the soft masses
    - the sign of μ
3. Yukawa unification and the Higgs $\gamma\gamma$ rate enhancement

Enhancing $h \to \gamma\gamma$ rate in the MSSM

In the SM, the Higgs decays to $\gamma\gamma$ only at loop level so contributions from new particles with e-m charge may significantly affect $\Gamma(h \to \gamma\gamma)$.

In MSSM, only few e-m charged particles may have large enough couplings to the Higgs to substantially enhance $\Gamma(h \to \gamma\gamma)$:

- Strongly mixed stops and sbottoms enhance $\Gamma(h \to \gamma\gamma)$ but suppress $\sigma(gg \to h)$ even more
- Strongly mixed staus enhance $\Gamma(h \to \gamma\gamma)$ without affecting $\sigma(gg \to h)$

Light staus with strong left-right mixing are the most promising to enhance the $\gamma\gamma$ rate.

Stau effects on $\Gamma(h \to \gamma\gamma)$ and m_h

$$\frac{\Gamma\left(h \to \gamma\gamma\right)}{\Gamma\left(h \to \gamma\gamma\right)_{\rm SM}} \approx \left(1 + 0.05\,\frac{m_\tau^2 X_\tau^2}{m_{\tilde{\tau}_1}^2 m_{\tilde{\tau}_2}^2}\right)^2$$

but strongly-mixed light staus give also negative contribution to the Higgs mass:

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{\rm SUSY}^2}\right)\right] + \\ - \frac{g^2}{8\pi^2 m_W^2}\,\frac{m_\tau^4 X_\tau^4}{12 m_{\tilde{\tau}_1}^2 m_{\tilde{\tau}_2}^2}$$

Still, enhancement of $\Gamma(h \to \gamma\gamma)$ up to 50% can be obtained consistently with the 125 GeV Higgs but only if:

Carena et al. '12

1. The lightest stau mass is around 100 GeV
2. Strong left-right mixing i.e. $X_\tau = A_\tau - \mu \tan\beta \gtrsim \mathcal{O}(20\ \mathrm{TeV})$

Enhanced $\gamma\gamma$ rate from light staus

It has not been demonstrated so far that the low-energy MSSM spectrum with strongly-mixed light staus can be obtained from a well-motivated high-energy model

In this talk: $\gamma\gamma$ rate enhancement can be realized in a SO(10) model with top-bottom-tau Yukawa unification

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 Yukawa couplings at M_{GUT}:

$$h = h_t = h_b = h_\tau$$

- Yukawa unification predicts large values of $\tan\beta \sim 50$

Yukawa Unification and REWSB

At large $\tan\beta$ proper REWSB requires $m^2_{H_d} - m^2_{H_u} \gtrsim M^2_Z$

For unified top-bottom-tau Yukawa couplings at the GUT scale, $m^2_{H_d} - m^2_{H_u}$ does not change much during RG evolution

$$\Downarrow$$

REWSB cannot be realized for universal soft terms at the GUT scale

Carena, Olechowski, Pokorski, Wagner '1994

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Carena, Olechowski, Pokorski, Wagner '1994

proper REWSB requires e.g. Higgs splitting at M_{GUT}: $m_{H_u} < m_{H_d}$

Olechowski, Pokorski '1994

Non-universal scalar masses in SO(10)

All sfermions in **16**-dim rep. of SO(10) while Higgses in **10**-dim rep.
⇒ Pattern of soft scalar masses restricted by SO(10) gauge symmetry:

$$m_{H_d,H_u} = m_{10}$$
$$m_{Q,U,D,L,E} = m_{16}$$

This is not enough for $t - b - \tau$ Yukawa unification with proper REWSB

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D-term contribution

Rank of SO(10) is larger than the rank of SM gauge group
⇒ in the effective theory below the GUT scale soft scalar masses acquire new contribution proportional to D-term and charges of the broken U(1):

Kawamura, Murayama, Yamaguchi '1994

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

$D > 0$ may allow for proper REWSB

Murayama, Olechowski, Pokorski '1995

Yukawa Unification and the Sign of μ

$b-\tau$ Yukawa unification leads to tree level bottom mass bigger than the observed mass

SUSY loop correction to the bottom mass must be negative with the magnitude between 10 to 20%:

$$\left(\frac{\delta m_b}{m_b}\right) \approx \frac{g_3^2}{6\pi^2}\mu m_{\tilde{g}} \tan\beta\, I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, m^2_{\tilde{g}}) + \frac{h_t^2}{16\pi^2}\mu A_t \tan\beta\, I(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2)$$

The gluino-sbottom contribution dominates over majority of parameter space so Yukawa unification favours $\mu < 0$

Necessary conditions for enhanced $\Gamma\left(h \to \gamma\gamma\right)$

Since the lightest stau mass has to be around 100 GeV, the neutralino LSP must be even lighter:

$$\left|M_1^{\rm EW}\right| \text{(or } \left|M_2^{\rm EW}\right|\text{)} \lesssim 100~{\rm GeV}$$

while LHC limits on the gluino mass give $\left|M_3^{\rm EW}\right| \gtrsim 1.2~{\rm TeV}$ so:

$$\left|\frac{M_1}{M_3}\right| \lesssim \frac{1}{2} \text{ or } \left|\frac{M_2}{M_3}\right| \lesssim \frac{1}{4} \text{ at the GUT scale}$$

Assumption of universal gaugino masses has to be relaxed

Gaugino Masses from Non-singlet F-terms

Gaugino masses in SUGRA can arise from dimension 5 operator:

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

- $\langle F^{ab}\rangle$ must transform as a singlet under the SM gauge group
- $\langle F^{ab}\rangle$ must belong to the symmetric part of $\mathbf{45}\times\mathbf{45}$
- $\langle F^{ab}\rangle$ can be in a non-singlet representation of SO(10)

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

If $\langle F^{ab}\rangle$ transforms as **24** $\subset$ **54** of SU(5) $\subset$ SO(10), gaugino masses are given by:

Martin, 2009

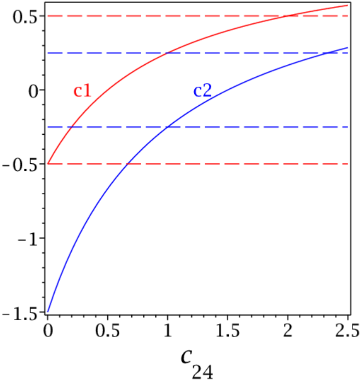
$$M_1 : M_2 : M_3 = -\frac{1}{2} : -\frac{3}{2} : 1$$

$\left|\frac{M_1}{M_3}\right| \lesssim \frac{1}{2}$ and/or $\left|\frac{M_2}{M_3}\right| \lesssim \frac{1}{4}$ possible if both the singlet and **24** F-terms break SUSY

Gaugino Masses from the singlet and **24** F-term

$$M_1 \equiv c_1 M_3 \qquad c_1 = \frac{-\frac{1}{2} + c_{24}}{1 + c_{24}}$$

$$M_2 \equiv c_2 M_3 \qquad c_2 = \frac{-\frac{3}{2} + c_{24}}{1 + c_{24}} \qquad c_{24} \equiv M_3^{(1)}/M_3^{(24)}$$



Enhanced $\Gamma(h \to \gamma\gamma)$ viable only for:

$$0 \lesssim c_{24} \lesssim 2.3$$

$c_{24} \lesssim 1.2 \to$ bino dominates LSP

$c_{24} \gtrsim 1.2 \to$ wino dominates LSP

The SO(10) model

$$\boxed{\mu < 0}$$

- Non-universal scalar masses:

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

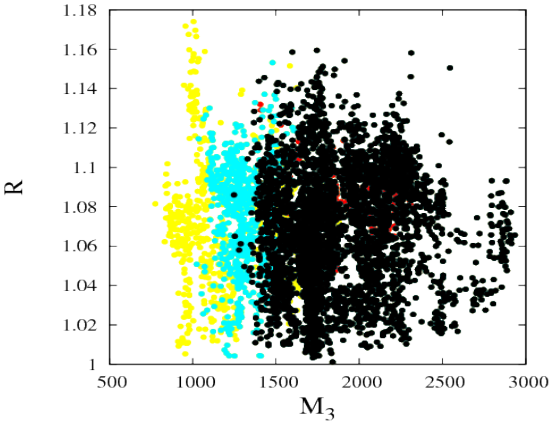
- Non-universal gaugino masses:

$$\begin{aligned} M_1 &= \frac{-\frac{1}{2} + c_{24}}{1 + c_{24}} M_3 \\ M_2 &= \frac{-\frac{3}{2} + c_{24}}{1 + c_{24}} M_3 \end{aligned}$$

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

Numerical results

$$R \equiv \left. \frac{\max(h_t, h_b, h_\tau)}{\min(h_t, h_b, h_\tau)} \right|_{\mathrm{GUT}} \qquad R_{\gamma\gamma} \equiv \frac{\sigma(gg \to h) \times \mathrm{BR}(h \to \gamma\gamma)}{\sigma(gg \to h)^{\mathrm{SM}} \times \mathrm{BR}(h \to \gamma\gamma)^{\mathrm{SM}}}$$



$m_h > 123$ GeV

$m_{\mathrm{stau}} > 90$ GeV

$m_{\mathrm{chargino}} > 103.5$ GeV

$m_A > 750$ GeV

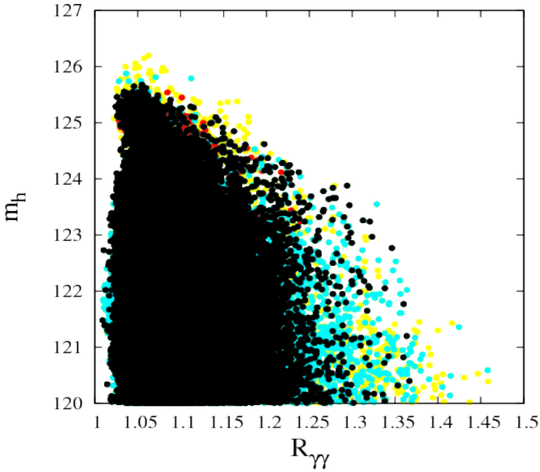
$R_{\gamma\gamma} > 1.1$

Black points satisfy $b \to s\gamma$, $B_s \to \mu^+\mu^-$, the upper WMAP bound on Ω_{LSP} and direct limits on sparticles masses.

Blue (red) points violate $b \to s\gamma$ ($B_s \to \mu^+\mu^-$)

Yellow points violate both

$t - b - \tau$ Yukawa unification allows for enhanced $R_{\gamma\gamma}$



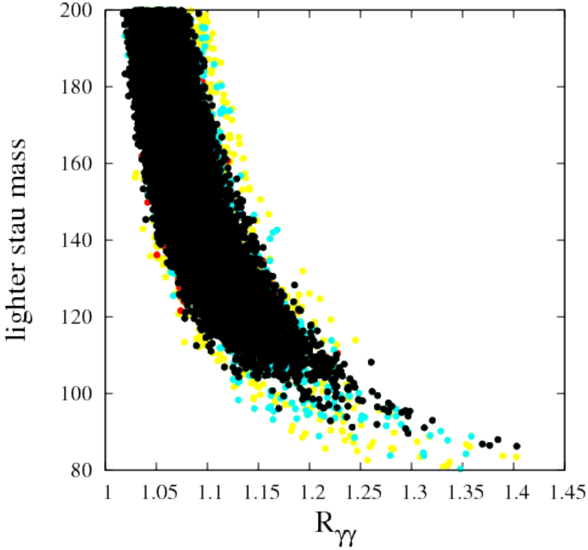
$m_{\text{stau}} > 90$ GeV

$m_{\text{chargino}} > 103.5$ GeV

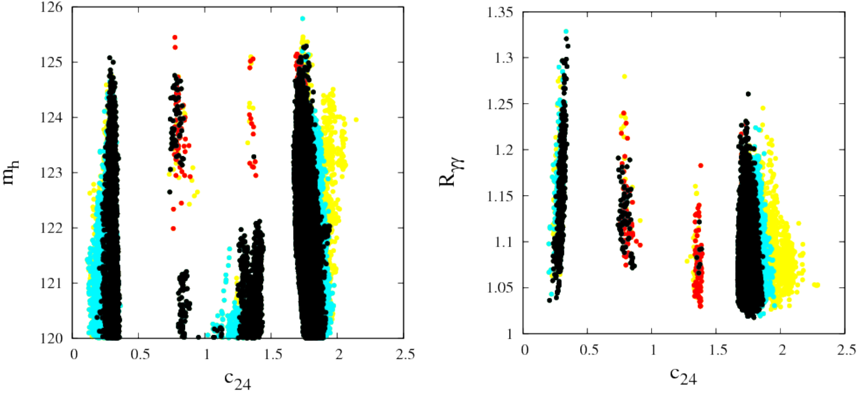
$m_A > 750$ GeV

$R < 1.1$

$h \to \gamma\gamma$ **rate can be enhanced by more than 30 %**



$R_{\gamma\gamma} > 1.1$ for $m_{\tilde{\tau}_1} \lesssim 170$ GeV



24 F-term domination $(c_{24} < 1)$

bino-like LSP - WMAP bound saturated due to stau coannihilations

Positive contribution to $(g-2)_\mu$

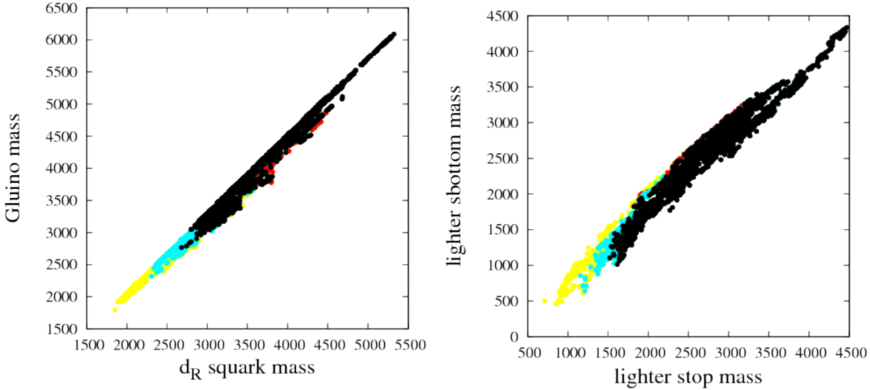
Heavy squarks and gluinos

Singlet F-term domination $(c_{24} > 1)$

wino-like LSP - Ω_{LSP} too small

Negative contribution to $(g-2)_\mu$

Even heavier squarks and gluinos



$b \to s\gamma$ and $B_s \to \mu^+\mu^-$ set stronger lower mass limits on sparticle masses than the 125 GeV Higgs

- gluino and 1st gen. squark masses $\gtrsim 2.5$ TeV - might be reached at the 13 TeV LHC (if we are lucky)
- sbottom may be as light as 1 TeV - not far above current limit of about 600 GeV

Conclusions

SO(10) models with $t - b - \tau$ Yukawa coupling unification can accommodate enhanced $h \to \gamma\gamma$ rate

Non-universal soft scalar masses at $M_{\rm GUT}$ are necessary for proper REWSB

Non-universal gaugino masses at $M_{\rm GUT}$ are necessary for light strongly-mixed staus enhancing $\Gamma(h \to \gamma\gamma)$

Appropriate pattern of non-universalities easily accommodated in SUSY SO(10) GUT:

- $m_{10} - m_{16}$ splitting and D-term contribution to scalar masses
- gaugino masses from a mixture of singlet and non-singlet F-term in **24** of SU(5) $\subset$ SO(10)

For enhanced $h \to \gamma\gamma$ rate:

Flavour observables push up the gluino and 1st gen. squark masses above 2.5 TeV but sbottom may be light enough to be detected at the LHC

Bino-like LSP can be a good dark matter candidate