Dirac Gauginos and the 125 GeV Higgs

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in collaboration with

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Introduction

- Two possible mass terms for gauginos λ:

$$\text{Majorana: } M_M \lambda\lambda\,, \qquad \text{Dirac: } M_D \lambda\Psi$$

(Ψ superfield in adjoint representation)

- Dirac mass terms are theoretical well motivated:

[Fayet; Hall&Randall; Polchinski&Susskind; Fox,Nelson&Weiner; Antoniadis,Benakli,Delgado&Quiros;...]

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- Dirac masses have interesting phenomenological aspects
  - Suppressed cross section for colored SUSY particles

    [Heikinheimo,Kellerstein,Sanz,1111.4322], [Kribs,Martin,1203.4821]
  - Relaxed constraints from flavor physics [Kribs,Poppitz,Weiner,0712.2039]
  - Running sfermion masses independent of M_D [Goodsell,1206.6697]
  - Extended Higgs sector

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  - Extended Higgs sector $\rightarrow$ topic of this talk

Minimal extension of the MSSM with Dirac Gauginos

[Benakli,Goodsell, 0811.4409]

- MSSM extended by:
  • gauge singlet (S), • $SU(2)_L$ triplet (T), • color octet (O)

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- R-parity conserving superpotential

$$
\begin{aligned}
W &= Y_u \hat{u}\hat{q}H_u - Y_d \hat{d}\hat{q}H_d - Y_e \hat{e}\hat{l}H_d + \mu \mathbf{H_u}\cdot\mathbf{H_d} \\
&\quad + \lambda_S \mathbf{S}\mathbf{H_u}\cdot\mathbf{H_d} + 2\lambda_T \mathbf{H_d}\cdot\mathbf{T}\mathbf{H_u} \\
&\quad + L\mathbf{S} + \frac{M_S}{2}\mathbf{S}^2 + \frac{\kappa}{3}\mathbf{S}^3 + M_T \mathrm{tr}(\mathbf{TT}) + M_O \mathrm{tr}(\mathbf{OO}) + W_2 \\
W_2 &= \lambda_{ST}\mathbf{S}\mathrm{tr}(\mathbf{TT}) + \lambda_{SO}\mathbf{S}\mathrm{tr}(\mathbf{OO}) + \frac{\kappa_O}{3}\mathrm{tr}(\mathbf{OOO})
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- R-symmetry demands $W_2 = L = M_S = M_T = M_O = A_i = 0$
- We haven't extended the Higgs sector:

$\rightarrow$ R-symmetry must be broken in Higgs sector

Theoretical limits of the model

1. *MSSM without μ term* ($\not{\mu}$SSM): $\mu = \kappa = 0$, $B_\mu \neq 0$, $v_{S,T}$ small

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1. *MSSM without μ term* ($\not\mu$SSM): $\mu = \kappa = 0$, $B_\mu \neq 0$, $v_{S,T}$ small

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2. *MSSM in disguise*: μ and B_μ present, $\kappa = 0$, $v_{S,T}$ small
3. *Dynamical μ models*: $\mu = 0$, $B_\mu \neq 0$ sizable v_S
4. *Dynamical μ and $B\mu$ models*: $\mu = B_\mu = 0$, sizable v_S and κ

The Higgs sector

The CP even mass matrix in the basis (h, H, S_R, T_R^0) reads

$$\begin{pmatrix} M_Z^2 + \Delta_h s_{2\beta}^2 & \Delta_h s_{2\beta} c_{2\beta} & \Delta_{hs} & \Delta_{ht} \\ \Delta_h s_{2\beta} c_{2\beta} & M_A^2 - \Delta_h s_{2\beta}^2 & \Delta_{Hs} & \Delta_{Ht} \\ \Delta_{hs} & \Delta_{Hs} & \tilde{m}_S^2 & \lambda_S \lambda_T \frac{v^2}{2} \\ \Delta_{ht} & \Delta_{Ht} & \lambda_S \lambda_T \frac{v^2}{2} & \tilde{m}_T^2 \end{pmatrix}$$

$$\Delta_h = \frac{v^2}{2}(\lambda_S^2 + \lambda_T^2) - M_Z^2$$

$$\Delta_{hs} = -2\frac{v_S}{v}\tilde{m}_{SR}^2 - \sqrt{2}\kappa\frac{v_S^2}{v}(A_\kappa + 3M_S) - 2\kappa^2\frac{v_S^3}{v}, \qquad \Delta_{ht} = -2\frac{v_T}{v}\tilde{m}_{2TR}^2$$

$$\Delta_{Hs} = g' m_{1D} v s_{2\beta} - \lambda_S \frac{v(A_s + M_s)}{\sqrt{2}} c_{2\beta}, \qquad \Delta_{Ht} = -g m_{2D} v s_{2\beta} - \lambda_T \frac{v(A_T + M_T)}{\sqrt{2}} c_{2\beta}$$

This matrix is diagonalized by real matrix S

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Light Higgs Mass

- New F-term contributions enhance the mass
- Mixing with heavier states reduce the mass

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$$\Delta_h = \frac{v^2}{2}(\lambda_S^2 + \lambda_T^2) - M_Z^2$$

Light Higgs Mass

- New F-term contributions enhance the mass (dominant)
- Mixing with heavier states reduce the mass (subdominant)

$\rightarrow$ Higgs mass of 125 GeV more natural than in the MSSM

Diphoton Rate

$h \to \gamma\gamma$ might be enhanced in comparison to the SM expectation.

$$R_i \equiv \frac{\Gamma(h \to ii)}{\Gamma_{SM}(h \to ii)} = \left| \frac{A_{ii}}{A_{ii}^{SM}} \right|^2 \qquad \mu_{ii} \equiv \frac{\sigma(pp \to h)}{\sigma_{SM}(pp \to h)} \frac{BR(h \to ii)}{BR_{SM}(h \to ii)}$$

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$\mu_{\gamma\gamma} \sim 1.5$ could be an effect of new, charged particles:

- charged Higgs: often in tension with $b \to s\gamma$

  [Schmidt-Hoberg,FS,1208.1683]
- Squarks influence also $\sigma(pp \to h)$ [King,Mühlleitner,Nevzorov,Walz,1211.5074;...]
- Staus promising candidates, but might have problems with vacuum stability [Carena et.al,1205.5842] [Kitahara,1208.4792; Carena et.al, 1211.6136]
- Charginos: contribution small in MSSM but can be important in singlet and triplet extensions

  [Schmidt-Hoberg,FS,1208.1683] [Delgdo et.al,1207.6596]

Chargino contributions

From the charginos mass matrix

$$M_{Ch} = \begin{pmatrix} M_T + \frac{v_S \lambda_{ST}}{\sqrt{2}} & m_{2D} + g_2 v_T & \lambda_T v c_\beta \\ m_{2D} - g_2 v_T & M_2 & g_2 v s_\beta/\sqrt{2} \\ -\lambda_T v s_\beta & g_2 v c_\beta/\sqrt{2} & \tilde{\mu} - \sqrt{2}\lambda_T v_T \end{pmatrix}$$

one gets

$$A_{\gamma\gamma}^{\text{Charginos}} \simeq \frac{4}{3} \frac{1}{\sqrt{2} m_{D2} \tilde{\mu} - g_2 v^2 \lambda_T c_{2\beta}} \times \left[2 g_2 \lambda_T v^2 (-c_{2\beta} S_{11} + s_{2\beta} S_{21}) + \lambda_S v m_{D2} S_{31} \right].$$

$$\longrightarrow R_\gamma = |S_{11} - 0.28 \cot\beta S_{21} - 0.15 \frac{v \lambda_S}{\mu} S_{31}|^2 \quad \text{(large } m_{D_2} \text{ limit)}$$

Chargino contributions

Important for λ_T with large $\tan\beta$ or large λ_S and sizable mixing

Numerical setup

Using in SARAH and SPheno

[FS,0806.0538,0909.2863]; [Porod,hep-ph/0301101], [Porod,FS,1104.1573]

- Support of Dirac Gauginos has been added to SARAH (public with version 3.2.0) [FS,1207.0906]
- SARAH generates Fortran code for a numerical evaluation with SPheno:
  - Complete mass spectrum calculated at 1-loop
  - Calculation of Higgs decays:
    1. (S)lepton and VV^* final states at leading order
    2. (S)quark final states with dominant QCD corrections
    3. decay in $\gamma\gamma$ and gg at full one-loop and dominant NLO corrections
  - Calculation of $\delta\rho$, $b \to s\gamma$, g-2.

Used experimental constraints

- Higgs sector:

$$\begin{aligned} m_H &= 125.8 \pm 0.4 \pm 0.4 \text{ GeV (CMS)} \\ & 126.0 \pm 0.4 \pm 0.4 \text{ GeV (ATLAS)} \end{aligned}$$

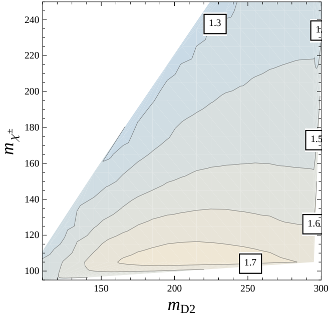
	CMS	ATLAS	Tevatron
$\mu_{\gamma\gamma}$	1.6 ± 0.4	1.8 ± 0.5	$3.62^{+2.96}_{-2.54}$
μ_{ZZ}	$0.8^{+0.35}_{-0.28}$	1.4 ± 0.6	
μ_{WW}	0.74 ± 0.25	1.5 ± 0.6	$0.32^{+1.13}_{-0.32}$
μ_{bb}	$1.3^{+0.7}_{-0.6}$	$-0.4 \pm 0.4 \pm 0.4$	$1.56^{+0.72}_{-0.73}$
$\mu_{\tau\tau}$	0.72 ± 0.52	0.7 ± 0.7	

- Precision observables

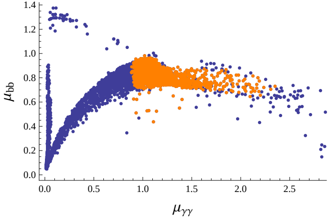
$$\Delta\rho = (4.2 \pm 2.7) \times 10^{-4}.$$

$$R \equiv \frac{\text{BR}(b \to s\gamma)_{\text{SUSY}}}{\text{BR}(b \to s\gamma)_{\text{SM}}} \qquad R = [0.87, 1.31]$$

Results for $\mu_{\gamma\gamma}$



$\tan\beta = 50,\ \lambda_T = 0.7$



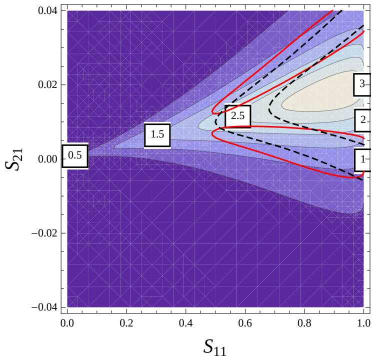
$\tan\beta = 1.5,\ \lambda_T = 0.021$

Enhanced diphoton rate

- Light charginos needed, but bound relaxed for larger m_{D2}
- $\mu_{bb} \simeq 1$ possible for $\mu_{\gamma\gamma} > 1.5$

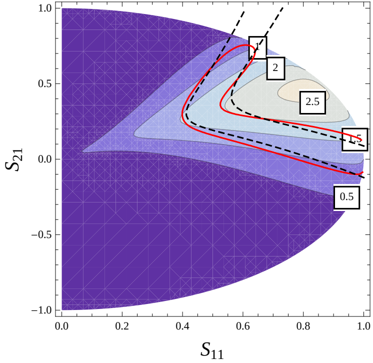
Results including all constraints

MSSM in disguise



$\frac{\lambda_S v}{m_{\tilde{\chi}^+}} = -3$, $\tan\beta = 50$, $\lambda_T = 1$

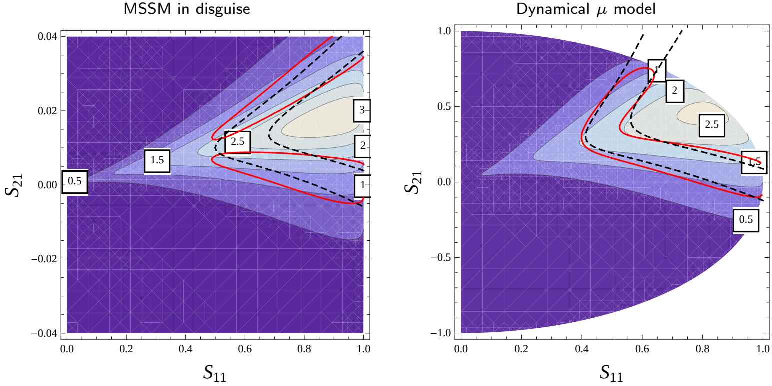
Dynamical μ model



$\tan\beta = 1.5$, $\frac{\lambda_S v}{m_{\tilde{\chi}^+}} = -2$, $\lambda_T = 0.021$

Contour lines for constant $\mu_{\gamma\gamma}$, dashed line: $\mu_{WW} = 1.0 \pm 0.3$, red line: in agreement with all data

Results including all constraints



Main chargino contributions

- large $\tan\beta$ and λ_T (left)
- significant mixing in Higgs sector (right)

Summary

- Models with Dirac instead of Majorana mass terms are theoretical well motivated and have interesting, phenomenological aspects
- A Higgs mass of 125 GeV is more natural than in the MSSM and also the diphoton rate can be enhanced due to light charginos or stops
- `SARAH` and `SPheno` support now Dirac gauginos and give the possibility for an easy and precise study of these models