The Constrained Minimal Dirac Gaugino Supersymmetric Standard Model

Florian Staub

BCTP Bonn

in collaboration with

K. Benakli, M. Goodsell, W. Porod

1403.5122

Helmholtz-Alliance Linear Collider Forum

Bonn, 29. April 2014

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;. . .]

  - Consequence of $N = 2$ SUSY
  - Consistent with R-symmetry (in contrast to Majorana terms)

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;. . .]
  - Consequence of $N = 2$ SUSY
  - Consistent with R-symmetry (in contrast to Majorana terms)
- 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]
  - Rich Higgs sector [Benakli,Goodsell,FS,1211.0552]

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)

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)
- Superpotential

$$
\begin{aligned}
W_R &= Y_u \hat{u}\hat{q}H_u - Y_d \hat{d}\hat{q}H_d - Y_e \hat{e}\hat{l}H_d \\
&\quad + \lambda_S \mathbf{S}\mathbf{H_u}\cdot\mathbf{H_d} + 2\lambda_T \mathbf{H_d}\cdot\mathbf{T}\mathbf{H_u} \\
W_{\not{R}} &= \mu \mathbf{H_u}\cdot\mathbf{H_d}
\end{aligned}
$$

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)
- Superpotential

$$
\begin{aligned}
W_R &= Y_u \hat{u}\hat{q}H_u - Y_d \hat{d}\hat{q}H_d - Y_e \hat{e}\hat{l}H_d \\
&\quad + \lambda_S \mathbf{S}\mathbf{H_u}\cdot\mathbf{H_d} + 2\lambda_T \mathbf{H_d}\cdot\mathbf{T}\mathbf{H_u} \\
W_{\not R} &= \mu \mathbf{H_u}\cdot\mathbf{H_d}
\end{aligned}
$$

- R-symmetry broken in Higgs sector by μ

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)
- Superpotential

$$
\begin{aligned}
W_R &= Y_u \hat{u}\hat{q}H_u - Y_d \hat{d}\hat{q}H_d - Y_e \hat{e}\hat{l}H_d \\
&\quad + \lambda_S \mathbf{S}\mathbf{H_u}\cdot\mathbf{H_d} + 2\lambda_T \mathbf{H_d}\cdot\mathbf{T}\mathbf{H_u} \\
W_{\not R} &= \mu \mathbf{H_u}\cdot\mathbf{H_d}
\end{aligned}
$$

- R-symmetry broken in Higgs sector by μ
- Majorana gaugino masses and trilinear soft-terms remain zero

Minimal extension of the MSSM with Dirac Gauginos

[Benakli,Goodsell, 0811.4409]

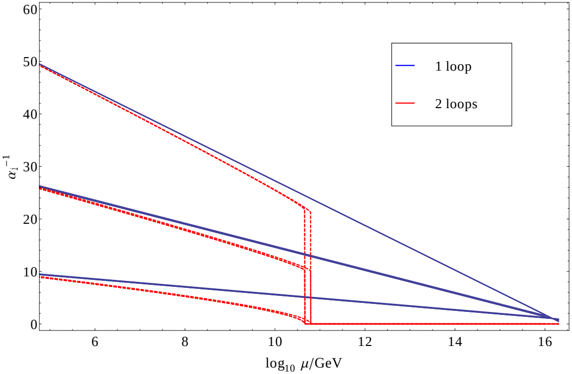
- MSSM extended by:
  • gauge singlet (S), • $SU(2)_L$ triplet (T), • color octet (O)
- Superpotential

$$\begin{aligned} W_R &= Y_u \hat{u}\hat{q}H_u - Y_d \hat{d}\hat{q}H_d - Y_e \hat{e}\hat{l}H_d \\ &\quad + \lambda_S \mathbf{S}\mathbf{H_u}\cdot\mathbf{H_d} + 2\lambda_T \mathbf{H_d}\cdot\mathbf{T}\mathbf{H_u} \\ W_{\not R} &= \mu \mathbf{H_u}\cdot\mathbf{H_d} \end{aligned}$$

- R-symmetry broken in Higgs sector by μ
- Majorana gaugino masses and trilinear soft-terms remain zero
- Minimal model not consistent with gauge coupling unification

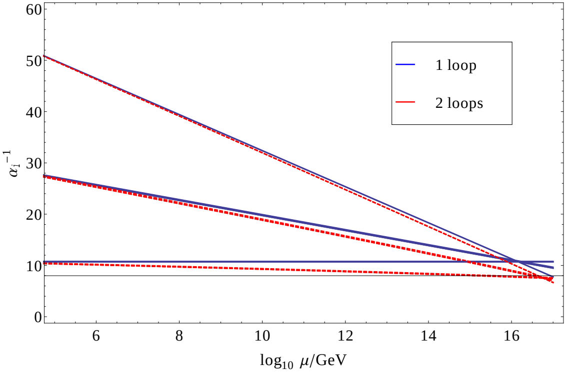
Building a GUT model

$$SU(5):\ (\mathbf{3},\mathbf{2})_{5/6} + (\bar{\mathbf{3}},\mathbf{2})_{-5/6}$$



Building a GUT model

$$(SU(3))^3\text{: } (\mathbf{1},\mathbf{2})_{1/2} + (\mathbf{1},\mathbf{2})_{-1/2} + 2\times(\mathbf{1},\mathbf{1})_{\pm 1}$$



Building a GUT model

Field	$(SU(3), SU(2))_Y$
R_u	$(\mathbf{1},\mathbf{2})_{-1/2}$
R_d	$(\mathbf{1},\mathbf{2})_{1/2}$
$\hat{E}_{1,2}$	$(\mathbf{1},\mathbf{1})_{1}$
$\hat{\hat{E}}_{1,2}$	$(\mathbf{1},\mathbf{1})_{-1}$

$$
\begin{aligned}
W = &\cdots + \\
&+(\mu_R + \lambda_{SR} S) R_u R_d + 2\lambda_{TR} R_u T R_d \\
&+(\mu_{\hat{E}\,ij} + \lambda_{S\hat{E}\,ij} S)\hat{E}_i \hat{\hat{E}}_j \\
&-Y_{\hat{E}i} R_u H_d \hat{E}_i - Y_{\hat{\hat{E}}i} R_d H_u \hat{\hat{E}}_i \\
&-Y^{ij}_{LFV} L_i \cdot H_d \hat{E}_j - Y^{j}_{EFV} R_u H_d E_j
\end{aligned}
$$

Building a GUT model

Field	$(SU(3), SU(2))_Y$
R_u	$(\mathbf{1},\mathbf{2})_{-1/2}$
R_d	$(\mathbf{1},\mathbf{2})_{1/2}$
$\hat{E}_{1,2}$	$(\mathbf{1},\mathbf{1})_{1}$
$\hat{\hat{E}}_{1,2}$	$(\mathbf{1},\mathbf{1})_{-1}$

$$
\begin{aligned}
W = &\cdots + \\
&+(\mu_R + \lambda_{SR} S) R_u R_d + 2\lambda_{TR} R_u T R_d \\
&+(\mu_{\hat{E}\,ij} + \lambda_{S\hat{E}\,ij} S)\hat{E}_i \hat{\hat{E}}_j \\
&-Y_{\hat{E}i} R_u H_d \hat{E}_i - Y_{\hat{\hat{E}}i} R_d H_u \hat{\hat{E}}_i \\
&-Y^{ij}_{LFV} L_i \cdot H_d \hat{E}_j - Y^{j}_{EFV} R_u H_d E_j
\end{aligned}
$$

New Yukawas are constrained by flavor observables

Additional couplings have a negligible impact on masses of MSSM fields

We use in the following

$$Y_{\hat{E}i} = Y_{\hat{\hat{E}}i} = Y^{ij}_{LFV} = Y^{j}_{EFV} = \lambda_{TR} = \lambda_{SR} = 0$$

The CMDGSSM

CMDGSSM

- m_{D_0}: common Dirac mass term for all gauginos
- m_0: common scalar mass for all sfermions and $\hat{E}$, $\hat{R}$
- We allow for different softs for adjoints m_Σ and singlet m_s
- Higgs soft-terms and v_S, v_T fixed by vacuum conditions
- Additional parameters: μ, B_μ, λ, $\tan\beta$

λ_T constrained by ρ-paramter: taken to be zero.

Studies done with `SARAH`, `SPheno` and `HiggsBounds`

The RGEs change significantly

- Sfermions
  - Dirac masses for gauginos don't enter at one- and two-loop
    $\rightarrow$ Mass difference between sleptons/squarks much smaller
  - New contributions due to scalar adjoints

Running squarks of 1./2. generation

CMDGSSM: $m^2_{Q,U,D} \simeq m_0^2 - 0.08 m_O^2 - 0.1 m_0^2$

CMSSM: $m_Q^2 \simeq m_0^2 + 4.3 M_{1/2}^2 \,, m_D^2 \simeq m_U^2 \simeq m_0^2 + 4 M_{1/2}^2$

The RGEs change significantly

- Sfermions
  - Dirac masses for gauginos don't enter at one- and two-loop
    $\rightarrow$ Mass difference between sleptons/squarks much smaller
  - New contributions due to scalar adjoints

Running squarks of 1./2. generation

CMDGSSM: $m^2_{Q,U,D} \simeq m_0^2 - 0.08 m_O^2 - 0.1 m_0^2$

CMSSM: $m_Q^2 \simeq m_0^2 + 4.3 M_{1/2}^2$, $m_D^2 \simeq m_U^2 \simeq m_0^2 + 4 M_{1/2}^2$

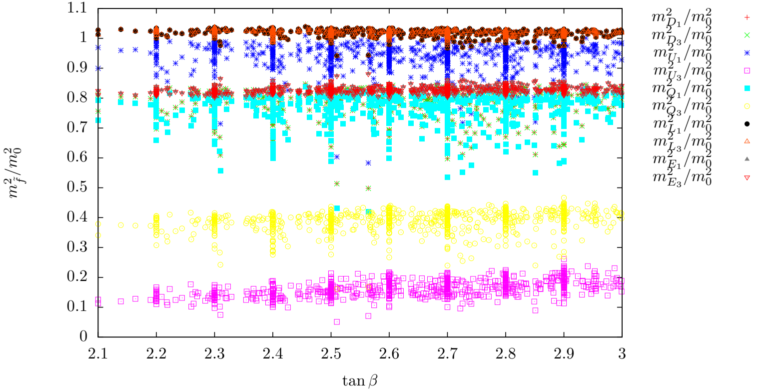
- Gauginos:
  - Different gauge factors; $g_{GUT}^{CMDGSSM} > g_{GUT}^{CMSSM}$
  - λ enters the evaluation already at one-loop

Running gaugino masses

CMDGSSM: $b_1 = \frac{2}{5} m_{DY} (24 g_1^2 + 5\lambda^2)$, $b_2 = 0$, $b_3 = -6 g_3^2 m_{D3}$

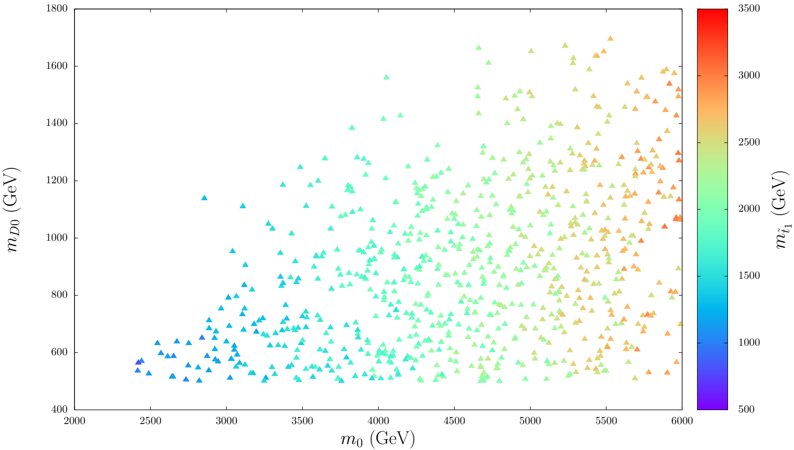
CMSSM: $b_1 = \frac{66}{5} M_1 g_1^2$, $b_2 = 2 g_2^2 M_2$, $b_3 = -6 g_3^2 M_3$

Results



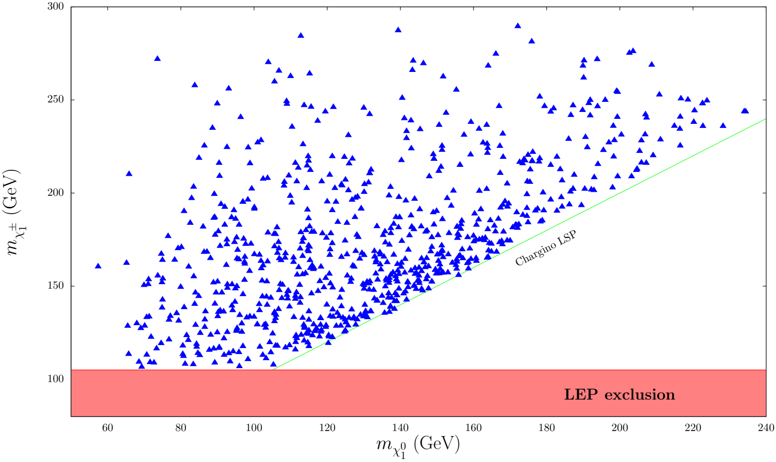
$$m^2_{U33} : m^2_{Q33} : m^2_{Q11} : m^2_{Dii} : m^2_{Eii} : m^2_{U11} : m^2_{Lii}$$
$$= \quad 0.16 : 0.39 : 0.77 : 0.79 : 0.83 : 0.93 : 1.02$$

Results



Large m_0 necessary for EWSB and non-tachyonic spectrum as M_{SUSY}.
$\rightarrow$ Sfermions (but stops) are often much heavier than electroweakinos

Results



LSP either a Bino or Higgsino

CMDGSSM vs. CMSSM

	CMSSM	CMDGSSM
GUT scale	$2 \cdot 10^{16}$ GeV	$1.8 \cdot 10^{17}$ GeV
g_{GUT}	0.7	1.1
Sfermions (1./2. gen.)	$m_Q^2 : m_D^2 : m_U^2 : m_E^2 : m_L^2$ [1] $= 5.3 : 5.0 : 5.0 : 1.13 : 1.44$	$m_Q^2 : m_D^2 : m_E^2 : m_U^2 : m_L^2$ $= 0.77 : 0.79 : 0.83 : 0.93 : 1.02.$
Gauginos	$M_1 : M_2 : M_3$ $0.44 : 0.84 : 2.34.$	$m_{DY} : m_{D2} : m_{D3}$ $0.22 : 0.9 : 3.5.$
m_h^{Tree}	$M_Z \cos^2 2\beta$	$M_Z(\cos^2 2\beta + \frac{\lambda^2}{g^2} \sin^2 2\beta)$

[1] $m_0 = M_{1/2}$

Conclusion

- We have constructed a model for Dirac Gauginos consistent with GUT unification
- The mass pattern can differ significantly from CMSSM expectations
- 1. & 2. generation of sleptons and squarks are close in mass and often very heavy
- 3. generation sfermions can be significantly lighter despite the vanishing trilinear terms
- Light electroweak fermions often present
- More studies are to come to explore this model in more detail: stay tuned

$$\frac{m_Q^2}{m_0^2} \underset{\text{CMSSM}}{\simeq} 1 + 4.3\frac{M_{1/2}^2}{m_0^2} \quad , \quad \frac{m_D^2}{m_0^2} \underset{\text{CMSSM}}{\simeq} \frac{m_U^2}{m_0^2} \underset{\text{CMSSM}}{\simeq} 1 + 4\frac{M_{1/2}^2}{m_0^2}$$

$$\frac{m_L^2}{m_0^2} \underset{\text{CMSSM}}{\simeq} 1 + 0.44\frac{M_{1/2}^2}{m_0^2} \quad , \quad \frac{m_E^2}{m_0^2} \underset{\text{CMSSM}}{\simeq} 1 + 0.13\frac{M_{1/2}^2}{m_0^2},$$