Z'-mediated Supersymmetry Breaking

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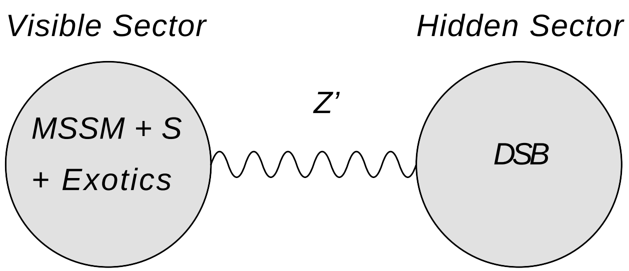
Motivation

- High(er) energy models (e.g. superstring constructions) often involves extra $U(1)'$
- Mediation mechanism of SUSY breaking determines the low energy phenomenology
- $U(1)'$ mediator of SUSY breaking sets μ to the scale of $m_{\rm soft}$
- Can we use it to construct viable models?

Sectors

- No direct renormalizable interaction between visible and hidden sector fields

- **Both** are charged under $U(1)'$



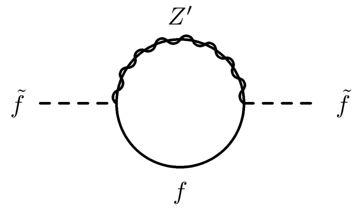
- At Λ_S the Z'-ino becomes massive. For $X = M + \theta^2 F$

$$M_{\tilde{Z}'} \sim \frac{g_{z'}^2}{16\pi^2}\frac{F}{M}$$

- How are MSSM fields affected?

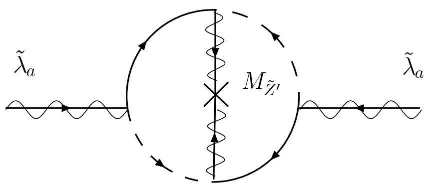
Masses

- Scalars get a mass at one loop



$$m^2_{\tilde{f}_i} \sim \frac{g^2_{z'} Q^2_{f_i}}{16\pi^2} M^2_{\tilde{Z}'} \log\left(\frac{\Lambda_S}{M_{\tilde{Z}'}}\right)$$

- $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauginos get a mass at two loops



$$M_a \sim \frac{g^2_{z'} g^2_a}{(16\pi^2)^2} M_{\tilde{Z}'} \log\left(\frac{\Lambda_S}{M_{\tilde{Z}'}}\right)$$

- Ratio of masses

$$\frac{m_{\tilde{f}_i}}{M_a} \sim \frac{M_{\tilde{Z}'}}{4\pi} \Big/ \frac{M_{\tilde{Z}'}}{(4\pi)^4} = (4\pi)^3 \sim 1000$$

Masses

- Ratio of masses

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- LEP direct searches imply EW-ino mass > 100 GeV

  $\Rightarrow$ heavy scalars ~ 100 TeV $\Rightarrow M_{\tilde{Z}'} \sim 1000$ TeV

- Mini version of split-susy (Arkani-Hamed & Dimopoulos 2004)

  split susy scalar mass 10^9 GeV

- Like split-susy no flavor or CPV problems due to heavy scalars

- Like split-susy need one fine-tuning to set EW breaking scale

- Unlike split-susy μ parameter scale set by $U(1)'$ breaking

Elements of Z' mediation

- To break the $U(1)'$ symmetry introduce SM singlet field (charged under $U(1)'$)
- $\mu\, H_u\, H_d \;\rightarrow\; \lambda\, S\, H_u\, H_d \Rightarrow$ Large μ term
- Include exotic matter $\sum_i Y_i\, S\, X_i\, X_i^c$
  - Cancel anomalies associated with $U(1)'$
  - Drive S negative

Higgs mass matrix

- Higgs mass matrix

$$\mathcal{M}_H^2 = \begin{pmatrix} m_2^2 & -A_H\langle S\rangle \\ -A_H\langle S\rangle & m_1^2 \end{pmatrix}$$

$$m_2^2 = m_{H_u}^2 + g_{z'}^2 Q_S Q_2 \langle S\rangle^2 + \lambda^2 \langle S\rangle^2$$
$$m_1^2 = m_{H_d}^2 + g_{z'}^2 Q_S Q_1 \langle S\rangle^2 + \lambda^2 \langle S\rangle^2$$

- To generate $\Lambda_{\rm EW}$ must fine-tune linear combination of H_i to be much lighter than natural scale
- Typically find solutions by tuning $|m_2^2| \ll m_1^2 \sim g_{z'}^2 M_{\tilde{Z}'}^2/16\pi^2$
- $\tan\beta \approx m_1^2/A_H\langle S\rangle \sim 10 - 100$
- Get single SM-like Higgs scalar, with mass ∼140 GeV.
- Remaining Higgs particles are at $\sim$ 100 TeV

Mass Spectrum

- $g_{z'} \sim \lambda \sim (0.1 - 1)$
  - High energy spectrum :

    Z'-ino mass $M_{\tilde{Z}'} \sim 1000$ TeV

    Typical scalar mass $m_{\tilde{f}_i} \sim 100$ TeV

    Exotic superfield mass $Y_i \langle S \rangle \sim 10 - 100$ TeV

    $M_{Z'} = \sqrt{2} g_{z'} Q_S \langle S \rangle \sim 10 - 100$ TeV

    $M_{\tilde{S}} = \frac{M_{Z'}}{M_{\tilde{Z}'}} M_{Z'} \sim 1 - 10$ TeV
  - Low energy spectrum

    SM + Higgs + $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauginos
- Interesting case for $g_{z'} \ll \lambda$ "accidental tuning"

  Very light singlino $M_{\tilde{S}} \sim \left(10^{-3} - 10^{-5}\right) M_{\tilde{Z}'}$

  Z' gauge-boson, $M_{Z'} \sim g_{z'} Q_S \langle S \rangle$,

  even light enough to be produced @ LHC
  - Low energy spectrum

    SM + Higgs + $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauginos +

    + Singlino and even Z'

Specific Models

- The free parameters are: $g_{z'}$, λ, Y_i, $U(1)'$ charges, $M_{\tilde{Z}'}$, and SUSY breaking scale Λ_S
- Minimal choice (leads to a light wino, $M_2 < M_{1,3}$):
  - 3 families of colored exotics (D)
  - 2 families of uncolored $SU(2)_L$ singlet families (E)

  both have $U(1)_Y$ charge
- Superpotential

$$W = \lambda\, S\, H_u\, H_d + y_D\, S\, D\, D^c + y_E\, S\, E\, E^c + \text{quark} + \text{lepton}$$

- Taking $Q_1 = 1$, Q_2 and Q_Q are free parameters

  (other charges are determined by anomalies)
- Other constraints
  - $U(1)'$ spontaneously broken by radiative corrections
  - Allow appropriate fine tuning to break EW symmetry
  - Check for color or charge breaking minima

Five Benchmark Models

All mass units are GeV $M_{\tilde{Z}'}$ **fixed** at 1000 TeV

	1	2	3	4	5
Q_2	$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{2}$	$-\frac{1}{2}$
Q_Q	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	-2	-2
$g_{z'}$	0.45	0.23	0.23	0.06	0.04
λ	0.5	0.8	0.8	0.3	0.3
Y_D	0.6	0.7	0.8	0.4	0.6
Y_E	0.6	0.6	0.6	0.1	0.1
$\langle S \rangle$	2×10^5	7×10^4	6×10^4	2×10^5	8×10^4
$\tan\beta$	20	29	33	45	60
M_1	2700	735	650	760	270
M_2	710	195	180	340	123
M_3	4300	1200	1100	540	200
m_H	140	140	140	140	140
$m_{\tilde{Q}_3}$	1×10^5	5×10^4	4×10^4	8×10^4	4×10^4
$m_{\tilde{L}_3}$	3×10^5	10^5	10^5	2×10^4	10^5
$m_{3/2}$	890	3600	810	3	0.1
$m_{\tilde{S}}$	4300	230	160	31	4
$m_{Z'}$	7×10^4	1.5×10^4	1.3×10^4	5600	2100

Future Directions

- Other Z' mediation models

  Models with gauge unification?

  Models with wino/bino LSP?

- Combine with other mediation mechanisms

  e.g. Y. Nakayama (arXiv:0712.0619 [hep-ph])

  combines Z' mediation with (strongly coupled) D-term gauge mediation

- Incorporate in other top-down models

- Models of the hidden sector

Conclusions

- Motivated by top-down constructions:

  New mechanism for mediation of SUSY breaking

  via a U(1)' gauge interaction

- Particle spectrum includes
  - heavy sfermions, Higgsinos, exotics, and $Z' \sim 10$ - 100 TeV
  - Light gauginos $\sim 100 - 1000$ GeV, of which the lightest can be wino-like and a light Higgs ~ 140 GeV
  - Singlino that can also be light

- More work to be done!

Back-up slide: Higgs Mass

- At low energies, one light Higgs $m_H^2 = 2\lambda_H v^2$ ($v = 174$ GeV)
- λ_H determined by matching at $M_{\tilde{Z}'}$ and running down to EW scale:

$$
\begin{aligned}
16\pi^2 \frac{d\lambda_H}{dt} &= 12\left(\lambda_H^2 + \lambda_H y_t^2 - y_t^4\right) \\
\lambda_H(\mu \approx M_{\tilde{Z}'}) &= \frac{1}{4}(g_2^2 + g_Y^2) + g_{z'}^2 Q_2^2 + \frac{1}{2}\lambda^2 \sin^2 2\beta
\end{aligned}
$$

- But
  - F-term $\lambda^2 \sin^2 2\beta$ negligible ($\tan\beta \gg 1$)
  - $U(1)'$ D-term $< SU(2) \times U(1)_Y$ D-term ($g_{z'}$, Q_2 small)

  $\Rightarrow$ m_H insensitive to the precise details of the high-energy parameters
- m_H affected by running from $M_{\tilde{Z}'}$ down to EW scale

$\Rightarrow$ $m_H \sim 140$ GeV with few % uncertainty from precise matching and value of $M_{\tilde{Z}'}$ (fixed at $M_{\tilde{Z}'} = 1000$ TeV for concreteness)

Back-up slide: Ino Spectra

Lightest inos : wino, singlino, and possibly gravitino

- Choice of exotics $\Rightarrow$ of the gauginos, wino is the lightest

  Dark matter density too low

- Gravitino mass $m_{3/2} \sim F/M_P$

$$\text{At } \Lambda_S : \qquad M_{\tilde{Z}'} \sim \frac{g_{z'}^2}{16\pi^2}\frac{F}{M}$$

  Assuming $\sqrt{F} \sim M \sim \Lambda_S$, $\sqrt{F} \sim 10^7 - 10^{11}$ GeV

  Λ_S is constrained logarithmically by the requirement of radiative symmetry breaking

  $\Rightarrow m_{3/2}$ is exponentially sensitive to the choice of model parameters

- Interesting LHC phenomenology:
  - Wino LSP only
  - Wino NLSP and Singlino LSP
  - Singlino NLSP and Wino LSP