Z-prime mediated SUSY breaking scenario

Tatsuru Kikuchi (KEK) in collaboration with Takayuki Kubo (KEK, Sokendai)

PLB 666, 262 (2008); PLB 669, 81 (2008)
Introduction

• **Supersymmetry** is one of the most elegant and natural extension of the Standard Model. However even if supersymmetry holds, MSSM may not be the full story.
• Most of the problems of Standard Model remain unsolved, new ones introduced (FCNC, EDM) → **Issues of SUSY breaking**.
• Neutrino oscillation data brings us a motivation to go beyond the Standard Model. What’s the mechanism behind the tiny neutrino mass? maybe related to the B-L breaking scale → **U(1)**\(_\text{B-L} \) extended MSSM.
• From a top point of view, remnants of GUTs/string, typically, some **U(1)**’ may survive to low energy. This motivates us to consider **U(1)**’ extension of MSSM.
• Important to explore some **alternatives/extensions to MSSM**.
Table of contents

1. Introduction
2. Brief overview of U(1)’
3. Introduction to Z’ mediated SUSY breaking phenomenological implications - novel spectrum
   Heavy squarks/sleptons, light gauginos
4. An application: combination of Z’ mediation with anomaly mediation \(\rightarrow\) anomaly mediation becomes a consistent theory with no tachyonic slepton
5. Summary
A TeV scale Z’

• Several new physics models (GUTs, DSB, little Higgs, LED) often involve extra Z’ gauge boson.

• Experimental bound is, typically,

\[ M_{Z'} \geq 600 - 900 \text{ GeV} \text{ (Tevatron, LEP II)} \]
\[ \theta_{Z-Z'} \leq \text{a few } \times 10^{-3} \text{ (Z - pole)} \]

(CDF di-electron : 923 GeV (Z_{\text{seq}}), 822 GeV (Z_{\chi}), 822 GeV (Z_{\psi}), 891 GeV (Z_{\eta}))

• Discovery to \( M_{Z'} \sim 5 - 6 \text{ TeV} \) at LHC, ILC

\( (pp \rightarrow Z' \rightarrow e^+e^-, \mu^+\mu^-, q\bar{q}) \) (depends on couplings, exotics, sparticles)

• SUSY Z’ generally at SUSY-breaking scale (unless along at flat direction)
Implications of a TeV-scale U(1)’

• Extended Higgs sector which is needed to break U(1)’
  – Rich Higgs phenomenology can be expected
• Possibility to raise Higgs mass
• Extended neutralino sector (Z’ gaugino and singlinos)
• Exotics (needed for anomaly-cancellation)
• Connection to a neutrino mass generation mechanism
• For the Majorana neutrinos, the mass scale is dictated by the B-L symmetry, and it is well-motivated to consider U(1)’=U(1)_B-L.
• Z’ decays into sparticles/exotics
• Possible flavor changing neutral currents
Coupling of a U(1)' to a Hidden Sector

[P. Langacker, G. Paz, L. Wang, I. Yavin, PRL 100:041802 (2008)]

- U(1)' may couple to both ordinary and hidden sectors

- \( Z' \) \( \tilde{Z}' \) (gauge boson and gaugino) mass difference may communicate supersymmetry breaking (\( Z' \) mediation)

- Unusual spectrum (similar to gaugino mediation):
  - scalar masses and A terms at 1 loop
  - MSSM gaugino masses at 2 loop

- Predictive, but details depend on U(1)' charges and Yukawas

- Motivated mini split SUSY (FCNC, EDM suppression)
Soft masses in $Z'$ mediation

- All the squarks/sleptons receive a quantum correction to the soft masses from $Z'$ gaugino.

\[
\tilde{m}^2 \sim \frac{\alpha'}{4\pi} \frac{M^2_{Z'}}{\tilde{Z}'}
\]

- On the other hand, the MSSM gaugino masses pick up their soft masses at the two loop level.

\[
M_a \sim \frac{\alpha'}{4\pi} \frac{\alpha_a}{4\pi} M_{\tilde{Z}'}
\]
Description for calculating spectrum in Z’ mediation

• Since Z’ mediation belongs to a class of gaugino mediation, we put no-scale boundary condition at SUSY breaking scale:

\[ \tilde{m} = M_a = 0, \quad M_{\tilde{Z}}, \neq 0 \text{ at } \mu = \Lambda_S \]

• Vanishing MSSM gaugino masses (M=0) is the difference between Z’ mediation and gaugino mediation.

• The resultant mass spectra have a large mass hierarchy between squarks/sleptons and gauginos:

\[ M_{\tilde{Z}}, \gg \tilde{m} \gg M_a \]

• A typical mass spectra for a fixed gaugino mass M=1TeV (mini spit SUSY like):

\[ M_{\tilde{Z}}, \sim 10^3 \text{TeV}, \quad \tilde{m} \sim 10^2 \text{TeV}, \quad M_a \sim 1\text{TeV} \]
**Z’ mediation combined with anomaly mediation**

[T.K. and T. Kubo, PLB 669, 81 (2008)]

- Overall scale of Z’ mediation can in principle be lowered so that the scalar masses are set at TeV scale.
- It is interesting to combine Z’ mediation with the other SUSY breaking scenario. We consider the anomaly mediation as the other source of SUSY breaking.
- Its automatic for Z’ mediation to give positive contribution to cure the tachyonic slepton problem in anomaly mediation.

\[
\tilde{m}^2 \bigg|_{Z'\text{-med}} \sim Q^2 \frac{\alpha'}{4\pi} M_{Z'}^2 > 0
\]

- A sample spectrum

\[
\tilde{m} = \tilde{m}^{\text{AMSB}} + \tilde{m}^{Z'} \sim \text{TeV}
\]

\[
M_a = M_a^{\text{AMSB}} \sim \text{TeV}
\]

\[
M_{Z'} \sim 10^2 \text{TeV}, \quad \tilde{m}^{Z'} \sim 1 \text{TeV}, \quad M_a^{Z'} \sim 1 \text{GeV}
\]
RG flow of slepton soft mass in $Z'$ mediation combined with anomaly mediation

[T.K. and T. Kubo, PLB 669, 81 (2008)]

- Pure anomaly mediation predicts the tachyonic sleptons.
- We consider $Z'$ mediation combined with anomaly mediation. $Z'$ mediated contribution gives positive contribution so as to cure the tachyonic slepton problem in anomaly mediation.
Mass spectra in $Z'$ assisted anomaly mediation

[T.K. and T. Kubo, PLB 669, 81 (2008)]

- Sleptons become heavier for larger U(1)' gauge coupling constant

<table>
<thead>
<tr>
<th>$(g_{B-L} \quad M_{Z'_{B-L}})$</th>
<th>(0.1, 3 TeV)</th>
<th>(0.3, 3 TeV)</th>
<th>(0.5, 3 TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\tilde{\chi}_{1,2,3,4}^0}$</td>
<td>132, 455, 719, 726</td>
<td>131, 455, 742, 749</td>
<td>131, 454, 745, 754</td>
</tr>
<tr>
<td>$m_{\tilde{\chi}_{1,2}^\pm}$</td>
<td>133, 717</td>
<td>132, 741</td>
<td>132, 746</td>
</tr>
<tr>
<td>$m_{\tilde{g}}$</td>
<td>1297</td>
<td>1298</td>
<td>1299</td>
</tr>
<tr>
<td>$m_{\tilde{e},\tilde{\mu}_{1,2}}$</td>
<td>318, 360, 299, 355</td>
<td>864, 881, 855, 877</td>
<td>941, 957, 931, 953</td>
</tr>
<tr>
<td>$m_{\tilde{\tau}_{1,2}}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{\tilde{\nu}_{1,2}}$</td>
<td>1216, 1228, 979, 1121</td>
<td>1246, 1257, 1004, 1146</td>
<td>1252, 1263, 1007, 1149</td>
</tr>
<tr>
<td>$m_{\tilde{d},\tilde{s}_{1,2}}$</td>
<td>1219, 1226, 1088, 1211</td>
<td>1248, 1256, 1115, 1240</td>
<td>1255, 1262, 1119, 1247</td>
</tr>
<tr>
<td>$m_{\tilde{b}_{1,2}}$</td>
<td>1088, 1211</td>
<td>1115, 1240</td>
<td>1119, 1247</td>
</tr>
<tr>
<td>$m_h$</td>
<td>124</td>
<td>124</td>
<td>124</td>
</tr>
<tr>
<td>$m_H$</td>
<td>663</td>
<td>685</td>
<td>690</td>
</tr>
<tr>
<td>$m_A$</td>
<td>662</td>
<td>685</td>
<td>690</td>
</tr>
<tr>
<td>$m_{H^\pm}$</td>
<td>667</td>
<td>690</td>
<td>694</td>
</tr>
</tbody>
</table>
Conclusion

- U(1)’ coupling to hidden sector quite possible but little explored. Such a scenario is dictated as \( Z' \) mediated SUSY breaking.

- \( Z' \rightarrow \tilde{Z}' \) mediation \( \rightarrow \) interesting (hierarchical) mass spectra; motivated form of mini split SUSY.

- \( Z' \) mediation predicts novel spectrum. The details depend on U(1)’ charges, but usually, squarks, sleptons, at 10 -100 TeV while gauginos are at 100 GeV-1 TeV.

- \( Z' \) mediated contributions to the soft SUSY breaking masses are always there! This is true if U(1)’ gaugino feels the SUSY breaking. From neutrino viewpoint, it is natural to consider a gauged U(1)\(_{B-L}\).
Combining the other SUSY breaking scenario (anomaly mediation) with $Z'$ mediation is interesting possibility.

- We have considered the case of $Z'$ mediation combined with anomaly mediation, which gives a consistent framework for anomaly mediation by putting the scalar mass at a TeV scale. So the gaugino mass from $Z'$ gives negligible contribution.

Interesting mass spectra.

- Gaugino masses ← determined by anomaly mediation
- Squark/Slepton masses ← determined by both anomaly mediation and $Z'$ mediation

Conclusion