Compact Supersymmetry

飛岡 幸作
Kavli IPMU, 東京大学

Collaboration with
Hitoshi Murayama, Yasunori Nomura and Satoshi Shirai
Table of my talk

1. Introduction
   I. Current Situation
   II. Weaker constraint by LHC on Compressed Scenario

2. Compact Supersymmetry model
   I. Scherk-Schwarz mechanism ~ Radion Mediation
   II. Model setup
   III. Phenomenology

3. Summary
Current Situation

1. Higgs like particle is discovered around 125 GeV

**Implication to Supersymmetry**

Tightly constraints MSSM, need to boost the Higgs mass by radiative corrections:

- High scale of $M_{\text{SUSY}}$ (Split) and/or
- Large A term
1. Higgs like particle is discovered around 125 GeV

*Implication to Supersymmetry*

Tightly constraints MSSM, need to boost the Higgs mass by radiative corrections:

- High scale of $M_{\text{SUSY}}$ (Split) and/or
- Large A term

Measure $M_{\text{SUSY}}$

arXiv:1207.3608

Sato, Shirai, Tobioka
Current Situation

2. No signal of Beyond Standard Model with Missing Energy

\[ M_{\text{gluino}} = M_{\text{squark}} > 1.4\text{TeV for 5 fb}^{-1} \]
\[ (>1\text{TeV for 1 fb}^{-1}) \]
Current Situation

2. No signal of Beyond Standard Model with Missing Energy

Implication to Supersymmetry
- Split -> Small cross section
- R-parity violation
- Compressed Spectrum -> Small q-value (this talk)
2. No signal of Beyond Standard Model with Missing Energy

- Compressed Spectrum -> Small q-value (this talk)

**Current Situation**

**MSUGRA like**

<table>
<thead>
<tr>
<th>Gluino, Squark</th>
</tr>
</thead>
</table>

**Compressed**

| Small $E_T^{miss}$ |

Difficult to extract the signal from the background (ttbar, W+jets)
Weaker constraint by LHC in Compressed scenario

Experimentalist’s Analysis
ATLAS-CONF-2011-155

- Gluino+LSP model
  \( M_{\text{gluino}} \sim 350 \text{GeV} \)

- Squark+LSP model
  \( M_{\text{squark}} \sim 250 \text{GeV} \)
  \( (\Delta m > 100 \text{GeV}) \)

- Gluino+Squark+LSP model
  \( M_{\text{gluino}} = M_{\text{squark}} \sim 400 \text{GeV} \)
  \( (\Delta m = 5 \text{GeV})! \)

Actually much weaker constraint, 400 GeV << 1 TeV
Weaker constraint by LHC in Compressed scenario

Theorist’s Analysis

Phenomenological model + ATLAS Multijet search

\[ M_{\text{gluino}} \approx M_{\text{squark}} \sim 650\text{GeV} \text{ when } \Delta m \geq 100\text{GeV} \]

Recent analysis
H. K. Dreiner et al. [arXiv: 1207.1613]

Phenomenological model + Monojet/Various CMS analyses

\[ M_{\text{gluino}} \approx M_{\text{squark}} \sim 650\text{GeV} \text{ when } \Delta m \geq 1\text{GeV} ! \]

Still much weaker constraint, 650 GeV \(<<\) 1 TeV
Weaker constraint by LHC in Compressed scenario

Phenomenological model + ATLAS Multijet search
\[ M_{\text{gluino}} \simeq M_{\text{squark}} \sim 650\text{GeV} \text{ when } \Delta m \geq 100\text{GeV} \]

\[ M_1 = \left( \frac{1 + 5c}{6} \right) M_{\tilde{g}} \]
\[ M_2 = \left( \frac{1 + 2c}{3} \right) M_{\tilde{g}} \]

Phenomenological model + Monojet/Various CMS analyses
\[ M_{\text{gluino}} \simeq M_{\text{squark}} \sim 650\text{GeV} \text{ when } \Delta m \geq 1\text{GeV} ! \]

Still much weaker constraint, 650 GeV << 1TeV

Mostly based on Phenomenological models, Scherk-Schwarz SUSY breaking generates universal soft masses
1. Introduction
   I. Current Situation
   II. Weaker constraint by the LHC on Compressed Scenario

2. Compact Supersymmetry model
   I. Scherk-Schwarz mechanism ~ Radion Mediation
   II. Model setup
   III. Phenomenology

3. Summary
Scherk-Schwarz mechanism

- 5D Minimal SUSY (corresponding to $\mathcal{N}=2$ in 4D)
- Geometry: $S^1/Z_2$ (chiral for zero mode, $\mathcal{N}=1$ in 4D)

[Scherk and Schwarz (1979)]
Scherk-Schwarz mechanism

- 5D Minimal SUSY (corresponding to $\mathcal{N}=2$ in 4D)
- Geometry: $S^1/Z_2$ (chiral for zero mode, $\mathcal{N}=1$ in 4D)
- Non-trivial boundary condition on SU(2)$_R$ space breaks supersymmetry

Non-trivial B.C.

$$
\begin{pmatrix}
\lambda_1 \\
\lambda_2
\end{pmatrix}
(x_\mu, y + 2\pi R) = e^{-2\pi i \alpha \sigma_2} \begin{pmatrix}
\lambda_1 \\
\lambda_2
\end{pmatrix}
(x_\mu, y)
$$

- $y$: 5th dimensional coordinate
- $R$: radius of extra dimension

Continuous twist parameter

We take $\alpha << 1$
Scherk-Schwarz mechanism

- 5D Minimal SUSY (corresponding to $\mathcal{N}=2$ in 4D)
- Geometry: $S^1/Z_2$ (chiral for zero mode, $\mathcal{N}=1$ in 4D)
- Non-trivial boundary condition on $\text{SU(2)}_R$ space breaks supersymmetry = Scherk-Schwarz mechanism

Non-trivial B.C.

$$
\begin{pmatrix}
\lambda_1 \\
\lambda_2
\end{pmatrix}
(x_\mu, y + 2\pi R) = e^{-2\pi i \alpha \sigma_2}
\begin{pmatrix}
\lambda_1 \\
\lambda_2
\end{pmatrix}
(x_\mu, y)
$$

- $y$: 5th dimensional coordinate
- $R$: radius of extra dimension

Continuous twist parameter

We take $\alpha \ll 1$

Resulting KK decomposition

$$
\begin{pmatrix}
\lambda_1 \\
\lambda_2
\end{pmatrix}
(x_\mu, y) = \sum_{n=0}^{\infty} e^{-i\alpha \sigma_2 y / R}
\begin{pmatrix}
\lambda_1^{(n)}(x_\mu) \cos[ny / R] \\
\lambda_2^{(n)}(x_\mu) \sin[ny / R]
\end{pmatrix}
$$

5D derivative generates (soft) masses in 4D

$$
\boxed{
\begin{align*}
m_n &= \begin{cases}
\alpha / R & \text{zero mode} \\
(\alpha \pm n) / R & \text{non-zero modes}
\end{cases}
\end{align*}
}$$
Field Properties in 5th dimension

Fields: $V, \chi, \Phi, \Phi^c$

$V$: Vector superfield
$\chi$: Adjoint chiral superfield
$\Phi^{(c)}$: Hypermultiplet of matter fields

Higgs localized at $y=0$: $H_u(x), H_d(x)$

$A_\mu, \lambda_1$

$\lambda_2, A_5, \Sigma$

$\phi^{(c)}, \psi^{(c)}$
Field Properties in 5th dimension

Fields: \( V, \chi, \Phi, \Phi^c \)

- \( V \): Vector superfield
- \( \chi \): Adjoint chiral superfield
- \( \Phi^{(c)} \): Hypermultiplet of matter fields

Higgs localized at \( y=0 \): \( H_u(x), H_d(x) \)

\( A_\mu, \lambda_1 \)
\( \lambda_2, A_5, \Sigma \)
\( \phi^{(c)}, \psi^{(c)} \)

Inversion

\[
\begin{pmatrix}
V(x, -y) \\
\chi(x, -y)
\end{pmatrix}
= \begin{pmatrix}
V(x, y) \\
-\chi(x, y)
\end{pmatrix}
\]

\[
\begin{pmatrix}
\Phi(x, -y) \\
\Phi^c(x, -y)
\end{pmatrix}
= \begin{pmatrix}
\Phi(x, y) \\
-\Phi^c(x, y)
\end{pmatrix}
\]

Translation (SS mechanism)

For \( SU(2)_R \) doublets, common twist

\[
\begin{pmatrix}
\lambda_1(x, y + 2\pi R) \\
\lambda_2(x, y + 2\pi R)
\end{pmatrix}
= e^{-2\pi \alpha \sigma_2}
\begin{pmatrix}
\lambda_1(x, y) \\
\lambda_2(x, y)
\end{pmatrix}
\]

\[
\begin{pmatrix}
\phi(x, y + 2\pi R) \\
\phi^{\dagger}(x, y + 2\pi R)
\end{pmatrix}
= e^{-2\pi \alpha \sigma_2}
\begin{pmatrix}
\phi(x, y) \\
\phi^{\dagger}(x, y)
\end{pmatrix}
\]

same for gravitinos

For others,

\( X(x, y + 2\pi R) = X(x, y) \)
Field Properties in 5th dimension

Fields: $V, \chi, \Phi, \Phi^c$

$V$: Vector superfield
$\chi$: Adjoint chiral superfield
$\Phi^c$: Hypermultiplet of matter fields

Higgs localized at $y=0$: $H_u(x), H_d(x)$

$A_\mu, \lambda_1$
$\lambda_2, A_5, \Sigma$
$\phi(c), \psi(c)$

Inversion

$$
\begin{align*}
(V(x, -y)) &= (V(x, y)) \\
(\chi(x, -y)) &= (-\chi(x, y)) \\
(\Phi(x, -y)) &= (\Phi(x, y)) \\
(\Phi^c(x, -y)) &= (-\Phi^c(x, y))
\end{align*}
$$

Translation (SS mechanism)

For $SU(2)_R$ doublets, common twist

$$
\begin{align*}
(\lambda_1(x, y + 2\pi R)) &= e^{-2\pi\alpha\sigma_2} (\lambda_1(x, y)) \\
(\lambda_2(x, y + 2\pi R)) &= e^{-2\pi\alpha\sigma_2} (\lambda_2(x, y)) \\
(\phi(x, y + 2\pi R)) &= e^{-2\pi\alpha\sigma_2} (\phi(x, y)) \\
(\phi^c\dagger(x, y + 2\pi R)) &= e^{-2\pi\alpha\sigma_2} (\phi^c\dagger(x, y))
\end{align*}
$$

same for gravitinos

For others,

$$
X(x, y + 2\pi R) = X(x, y)
$$

$m_{1/2, squark, slepton} = \frac{\alpha}{R}$

Common soft mass
Radion mediation: SUSY breaking by the Radion superfield vev

\[ T = R + iB_5 + \theta \Psi_R^5 + \theta^2 F_T \]

~Dynamical realization of Scherk-Schwarz mechanism

Radion Mediation ~ SS mechanism

Radion mediation: SUSY breaking by the Radion superfield vev

\[ T = R + iB_5 + \theta \Psi_R^5 + \theta^2 F_T \]

\sim \text{Dynamical realization of Scherk-Schwarz mechanism}


\[ \begin{align*}
\bullet \text{Gauge sector} \\
S_5 & = \int d^4x \, d\theta \left[ \frac{1}{4g_5^2} \int d^2\theta \left( \frac{T}{R} \right) W^\alpha W_\alpha + \text{h.c.} + \frac{1}{g_5^2} \int d^4\theta \frac{2R}{T + T^\dagger} \left( \partial_5 V - \frac{\chi + \chi^\dagger}{\sqrt{2}} \right)^2 \right]
\end{align*} \]

\[ \begin{align*}
\bullet \text{Matter sector} \\
S_5 & = \int d^4x \, d\theta \left[ \frac{1}{4g_5^2} \int d^4\theta \, \frac{T + T^\dagger}{2R} \left( \Phi^\dagger e^{-V} \Phi + \Phi^c e^V \Phi^c\dagger \right) + \int d^2\theta \, \Phi^c \left( \partial_5 - \frac{\chi}{\sqrt{2}} \right) \Phi + \text{h.c.} \right]
\end{align*} \]

Radion vev: \( < T > = R + F_T \theta^2 \)

\[ \frac{F_T}{2} = -\alpha \]

Canonically normalize:

\[ \Phi^{(c)} \rightarrow \left( 1 - \frac{F_T}{2R} \theta^2 \right) \Phi^{(c)} , \quad \chi \rightarrow \left( 1 + \frac{F_T}{2R} \theta^2 \right) \chi \]

Actually this theory is identified as SSSB
Higgs fields and Yukawa interactions are localized on the brane at $y=0$

$$\mathcal{L}_{\text{brane}} = \delta(y) \int d^2 \theta \left( y_U^{ij} Q_i U_j H_u + y_D^{ij} Q_i D_j H_d 
+ y_E^{ij} L_i E_j H_d + \mu H_u H_d \right).$$
Compact Supersymmetry model

Higgs fields and Yukawa interactions are localized on the brane at $y=0$

$$\mathcal{L}_{\text{brane}} = \delta(y) \int d^2 \theta \left( y_U^{ij} Q_i U_j H_u + y_D^{ij} Q_i D_j H_d + y_E^{ij} L_i E_j H_d + \mu H_u H_d \right).$$

Large A term is generated by the field redefinition

$$\Phi(c) \rightarrow \left( 1 - \frac{F_T}{2R} \theta^2 \right) \Phi(c), \quad y_U^{ij} Q_i U_j H_u \rightarrow (1 - \frac{F_T}{R} \theta^2) y_U^{ij} Q_i U_j H_u$$

$$= (1 + \frac{2\alpha}{R} \theta^2) y_U^{ij} Q_i U_j H_u$$

$$\frac{F_T}{2} = -\alpha$$

$$A_0 = -\frac{2\alpha}{R}$$
Compact Supersymmetry model

- Take $\alpha << 1$
- KK states ($\sim n/R$) are decoupled $\rightarrow$ MSSM at low energy
- Compact parameter set rather than CMSSM:

At tree level and at scale $\sim 1/R$,

$$
M_{1/2} = \frac{\alpha}{R}, \quad m_{Q, \bar{Q}, D, \bar{D}, L, \bar{L}}^2 = \left(\frac{\alpha}{R}\right)^2, \quad m_{H_u, H_d}^2 = 0,$$

$$A_0 = -\frac{2\alpha}{R}, \quad \mu \neq 0, \quad B = 0,$$
Compact Supersymmetry model

- Take $\alpha << 1$
- KK states ($\sim n/R$) are decoupled $\Rightarrow$ MSSM at low energy
- Compact parameter set rather than CMSSM:

\[
M_{1/2} = \frac{\alpha}{R}, \quad m_{\tilde{Q},\tilde{U},\tilde{D},\tilde{L},\tilde{E}} = \left(\frac{\alpha}{R}\right)^2, \quad m_{H_u,H_d}^2 = 0,
\]
\[
A_0 = -\frac{2\alpha}{R}, \quad \mu \neq 0, \quad B = 0,
\]

- Radiative corrections from at and above $1/R$ are under control because of symmetries of higher dimensions
- Calculated threshold corrections to the Higgs mass parameters:

\[
\begin{align*}
\delta m_{H_u}^2 &= \left( -\frac{33y_t^2}{8\pi^2} + \frac{9(g_2^2+g_1^2/5)}{16\pi^2} \right) \left(\frac{\alpha}{R}\right)^2, \\
\delta m_{H_d}^2 &= \frac{9(g_2^2+g_1^2/5)}{16\pi^2} \left(\frac{\alpha}{R}\right)^2, \\
\delta B &= \left( \frac{9y_t^2}{8\pi^2} - \frac{3(g_2^2+g_1^2/5)}{8\pi^2} \right) \frac{\alpha}{R},
\end{align*}
\]
Compact Supersymmetry model

- Take $\alpha << 1$
- KK states ($\sim n/R$) are decoupled $\Rightarrow$ MSSM at low energy
- Compact parameter set rather than CMSSM:

\[
\begin{align*}
M_{1/2} &= \frac{\alpha}{R}, \\
m^2_{Q,U,D,L,E} &= \left(\frac{\alpha}{R}\right)^2, \\
m^2_{H_u,H_d} &= 0, \\
A_0 &= -\frac{2\alpha}{R}, \\
\mu &\neq 0, \\
B &= 0,
\end{align*}
\]

At tree level and at scale $\sim 1/R$,

- Radiative corrections from at and above $1/R$ are under control because of symmetries of higher dimensions
- Calculated threshold corrections to the Higgs mass parameters

\[
\begin{align*}
\delta m^2_{H_u} &= \left(-\frac{33y_t^2}{8\pi^2} + \frac{9(g_2^2 + g_1^2/5)}{16\pi^2}\right) \left(\frac{\alpha}{R}\right)^2, \\
\delta m^2_{H_d} &= \frac{9(g_2^2 + g_1^2/5)}{16\pi^2} \left(\frac{\alpha}{R}\right)^2, \\
\delta B &= \left(\frac{9y_t^2}{8\pi^2} - \frac{3(g_2^2 + g_1^2/5)}{8\pi^2}\right) \frac{\alpha}{R},
\end{align*}
\]

Only three parameters!

\[
\begin{pmatrix}
\frac{1}{R'} & \frac{\alpha}{R'} & \mu
\end{pmatrix}
\]
Take alpha<<1

KK states (~n/R) are decoupled -> MSSM at low energy

Compact parameter set rather than CMSSM:

\[ M_{1/2} = \frac{\alpha}{R}, \quad m_{\tilde{Q}, \tilde{U}, \tilde{D}, \tilde{E}}^2 = \left( \frac{\alpha}{R} \right)^2, \quad m_{H_u, H_d}^2 = 0, \]

\[ A_0 = -\frac{2\alpha}{R}, \quad \mu \neq 0, \quad B = 0, \]

At tree level and at scale ~1/R,

Radiative corrections from at and above 1/R are under control because of symmetries of higher dimensions

Calculated threshold corrections to the Higgs mass parameters

\[ \delta m_{H_u}^2 = \left( -\frac{33y_t^2}{8\pi^2} + \frac{9(g_2^2 + g_1^2/5)}{16\pi^2} \right) \left( \frac{\alpha}{R} \right)^2, \]

\[ \delta m_{H_d}^2 = \frac{9(g_2^2 + g_1^2/5)}{16\pi^2} \left( \frac{\alpha}{R} \right)^2, \]

\[ \delta B = \left( \frac{9y_t^2}{8\pi^2} - \frac{3(g_2^2 + g_1^2/5)}{8\pi^2} \right) \frac{\alpha}{R}, \]

Only three parameters!

\[ \frac{1}{R'}, \quad \frac{\alpha}{R'}, \quad \mu. \]

• No physical phase  ✔ CP
• Geometry is universal  ✔ Flavor
Brane-localized kinetic terms and cutoff

- Radiative corrections from above $1/R$ generates boundary kinetic terms from dimensional analysis

$$\frac{\delta M_{1/2}}{M_{1/2}}, \frac{\delta m_f^2}{m_f^2}, \frac{\delta A_0}{A_0} \approx O\left(\frac{1}{16\pi^2} \ln(\Lambda R)\right).$$

- Assume the tree level contributions are same size of radiative ones

$$\sim \frac{y_t^2}{16\pi^2} O(1)$$

Effective theory with tree level estimation of soft parameters is valid for

$$\Lambda R \ll 16\pi^2$$
Power of $\mathcal{N}=2$

- $S^1/Z_2$ orbifolding makes zero modes chiral, but higher KK modes consist of $\mathcal{N}=2$ multiplets.
- No wavefunction renormalization of hypermultiplet in $\mathcal{N}=2$ SUSY.

$$S_5 = \int d^4 x d^4 y \left[ \frac{1}{4g_5^2} \int d^4 \theta \left[ \frac{T + T^\dagger}{2R} \right] (\Phi^\dagger e^{-V} \Phi + \Phi^c e^V \Phi^{c\dagger}) + \int d^2 \theta \Phi^c \left( \partial_5 - \frac{\chi}{\sqrt{2}} \right) \Phi + \text{h.c.} \right]$$

- **Even log divergences** are cancelled out for each KK mode ($n>0$).
- Only MSSM($n=0$) particles give log divergences.
Gravitino mass

- Obviously the SU(2)R doublets should have same soft mass from their 5d derivatives

- SUSY breaking is from Radion

- GR action

\[ M_{pl}^2 R \rightarrow M_{pl}^2 \left( \frac{T + T^\dagger}{R} \right)^2 \]

\[ \left( g_{55} \rightarrow \frac{T + T^\dagger}{R} \right) \]

- Gravitino mass

Radion should be canonically normalized

\[ M_{3/2} \sim \frac{\langle \mathcal{F} \rangle}{M_{pl}} \sim \frac{(F_T/R)M_{pl}}{M_{pl}} \]

\[ M_{1/2}, \text{squark, slepton} = M_{3/2} = \frac{\alpha}{R} \]
Spectrum

Point 1: $\alpha/R = 1400$ GeV, $1/R = 10^4$ GeV
Point 2: $\alpha/R = 800$ GeV, $1/R = 10^5$ GeV

<table>
<thead>
<tr>
<th>Particle</th>
<th>Point 1</th>
<th>Point 2</th>
<th>Particle</th>
<th>Point 1</th>
<th>Point 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{g}$</td>
<td>1494</td>
<td>949</td>
<td>$\tilde{u}_R$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\tilde{u}_L$</td>
<td>1467</td>
<td>939</td>
<td>$\tilde{d}_R$</td>
<td>1459</td>
<td>925</td>
</tr>
<tr>
<td>$\tilde{d}_L$</td>
<td>1469</td>
<td>942</td>
<td>$\tilde{d}_R$</td>
<td>1458</td>
<td>924</td>
</tr>
<tr>
<td>$\tilde{b}_2$</td>
<td>1460</td>
<td>924</td>
<td>$\tilde{b}_1$</td>
<td>1430</td>
<td>875</td>
</tr>
<tr>
<td>$\tilde{t}_2$</td>
<td>1557</td>
<td>988</td>
<td>$\tilde{t}_1$</td>
<td>1267</td>
<td>681</td>
</tr>
<tr>
<td>$\tilde{t}_1$</td>
<td>1411</td>
<td>822</td>
<td>$\tilde{\nu}_\tau$</td>
<td>1410</td>
<td>822</td>
</tr>
<tr>
<td>$\tilde{\nu}$</td>
<td>1411</td>
<td>822</td>
<td>$\tilde{\nu}_R$</td>
<td>1406</td>
<td>812</td>
</tr>
<tr>
<td>$\tilde{e}_L$</td>
<td>1413</td>
<td>826</td>
<td>$\tilde{e}_R$</td>
<td>1402</td>
<td>809</td>
</tr>
<tr>
<td>$\tilde{\tau}_2$</td>
<td>1417</td>
<td>823</td>
<td>$\tilde{\tau}_1$</td>
<td>1402</td>
<td>809</td>
</tr>
<tr>
<td>$\tilde{\chi}^0_1$</td>
<td>767</td>
<td>630</td>
<td>$\tilde{\chi}^0_2$</td>
<td>777</td>
<td>671</td>
</tr>
<tr>
<td>$\tilde{\chi}^0_3$</td>
<td>1384</td>
<td>755</td>
<td>$\tilde{\chi}^0_4$</td>
<td>1410</td>
<td>821</td>
</tr>
<tr>
<td>$\tilde{\chi}^0_{1\pm}$</td>
<td>771</td>
<td>642</td>
<td>$\tilde{\chi}^{\pm}_2$</td>
<td>1409</td>
<td>817</td>
</tr>
<tr>
<td>$h^0$</td>
<td>125</td>
<td>120</td>
<td>$H^0$</td>
<td>819</td>
<td>718</td>
</tr>
<tr>
<td>$A^0$</td>
<td>819</td>
<td>717</td>
<td>$H^{\pm}$</td>
<td>822</td>
<td>722</td>
</tr>
</tbody>
</table>

Higgsino like LSP

$\sim 120$ GeV

$\sim \mu$
Spectrum

Higgsino like LSP

~ μ

~120GeV

Higgsino like LSP

Point1: $\alpha/R = 1400$ GeV, $1/R = 10^4$ GeV
Point2: $\alpha/R = 800$ GeV, $1/R = 10^5$ GeV

<table>
<thead>
<tr>
<th>Particle</th>
<th>Point1</th>
<th>Point2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{g}$</td>
<td>1494</td>
<td>949</td>
</tr>
<tr>
<td>$\tilde{u}_L$</td>
<td>1467</td>
<td>939</td>
</tr>
<tr>
<td>$\tilde{d}_L$</td>
<td>1469</td>
<td>942</td>
</tr>
<tr>
<td>$\tilde{b}_L$</td>
<td>1460</td>
<td>924</td>
</tr>
<tr>
<td>$\tilde{t}_2$</td>
<td>1557</td>
<td>988</td>
</tr>
<tr>
<td>$\tilde{t}_1$</td>
<td>1411</td>
<td>822</td>
</tr>
<tr>
<td>$\tilde{\nu}$</td>
<td>1413</td>
<td>826</td>
</tr>
<tr>
<td>$\tilde{e}_L$</td>
<td>1417</td>
<td>823</td>
</tr>
<tr>
<td>$\tilde{\tau}_2$</td>
<td>767</td>
<td>630</td>
</tr>
<tr>
<td>$\tilde{\chi}_1^0$</td>
<td>1384</td>
<td>755</td>
</tr>
<tr>
<td>$\tilde{\chi}_2^0$</td>
<td>771</td>
<td>642</td>
</tr>
<tr>
<td>$h^0$</td>
<td>125</td>
<td>120</td>
</tr>
<tr>
<td>$A^0$</td>
<td>819</td>
<td>717</td>
</tr>
</tbody>
</table>

Spectra are available!
http://www-theory.lbl.gov/~shirai/compactSUSY.php

PPP2012, Yukawa Institute, Kyoto Kohsaku Tobioka (Kavli IPMU)
More compressed as $\mu \rightarrow \alpha/R$

$$m_{H_u}^2 + |\mu|^2 \sim m_Z^2 \cos 2\beta/2 \quad \text{(EWSB)}$$

i.e. larger $1/R$ ($Q_0$)

$$\delta m_{H_u}^2 = \left( -\frac{33y_t^2}{8\pi^2} + \frac{9(g_2^2 + g_1^2/5)}{16\pi^2} \right) (\frac{\alpha}{R})^2$$

$$\Delta m_{H_u}^2 \sim \frac{3y_t^2}{8\pi^2}(m_Q^2 + m_{u_3}^2 + |A_0|^2)\Delta \ln \left( \frac{Q}{Q_0} \right)$$

- Mass in unit of $\alpha/R$
- Collider bound

Compressed Spectra are available!
http://www-theory.lbl.gov/~shirai/compactSUSY.php

5 fb$^{-1}$ data
Higgs mass and tuning

- Theoretical error of Higgs mass is not small
  \[ |\Delta M_H| \approx 2 - 3 \text{ GeV} \]
  • Also deviation from top mass
  \[ \Delta m_t = \pm 0.9 \text{ GeV} \]
  \[ \Delta M_H \approx \pm 1 \text{ GeV} \]

- Fine tuning of sub-% level mainly from \( \mu \)
  better than CMSSM

\[ \Delta^{-1} \equiv \min_x |\partial \ln m_Z^2/\partial \ln x|^{-1} \text{ with } x = \alpha, \mu, 1/R, y_t, g_3, \cdots \]

Spectra are available!
http://www-theory.lbl.gov/~shirai/compactSUSY.php
Possible NMSSM extension

Work in progress [Murayama, Nomura, Shirai, KT]

Singlet Hypermultiplet in the bulk

$$W_{NMSSM} = (\lambda S H_u H_d + \frac{1}{3} \kappa S^3) \delta(y)$$

- Again, soft parameters of singlet are automatically determined by SS mechanism

$$V_{soft}^{NMSSM} = (a_\lambda S H_u H_d + \frac{1}{3} a_\kappa S^3 + \text{h.c.}) + m_s |S|^2$$

where

$$a_\lambda = - \frac{\alpha}{R}, \quad a_\kappa = - \frac{3\alpha}{R}, \quad m_s^2 = \left( \frac{\alpha}{R} \right)^2,$$

- No CP violation source
- Cubic term of $S$ is important for vacuum

- Not necessarily consider the landau pole
  - Relatively free $\lambda, \kappa$ realize various Higgs mass
Thermal relic of LSP is not enough for observed DM density unless LSP $\gtrsim$ TeV

- Relic abundance
- Spin-Indep. cross section with a nucleon

Direct detection of DM does not exclude this scenario, and the future update will be interesting

$\Omega_{DM} h^2 \approx 0.1$

Effective DM-nucleon cross section

$$\sigma_{\text{Nucleon}}^{\text{eff}} \equiv \sigma_{\text{Nucleon}} \frac{\min\{\Omega_{\chi}, \Omega_{DM}\}}{\Omega_{DM}}$$
Summary

- Compressed scenario is rather difficult to test at the LHC
- This scenario is realized by Compact SUSY model

- This model has only 3 parameters (No Flavor and CP problem)
- Less fine-tuned than CMSSM, and alive in sub-TeV

- Large radiative corrections boost Higgs mass (up to 125GeV?)

- LSP is sub-dominant component of DM

Future work
- Higgs sector and DM in NMSSM
- Non-thermal production of DM
- Non-trivial radiative corrections from KK modes
- Correspondence of SS mechanism and Radion mediation
Thank you for your attention

ありがとうございます
$M_{\text{squark}} \sim 250 \text{ GeV}$, $M_{\text{gluino}} \sim 350 \text{ GeV}$

100 GeV splitting

Squarks+LSP model

Gluino+LSP model
Squarks+Gluino+LSP model

\[ M_{\text{squark}} = M_{\text{gluino}} \approx 400 \text{GeV} \]

with >5 GeV splitting!
Gluino, Squark -> LSP

\[ m_{\text{wino}} = m_{\text{gluino}} + 100 \text{ GeV} \]

Gluino -> LSP

\[ m_{\text{wino}} = m_{\text{gluino}} + 100 \text{ GeV} \]
\[ m_{\text{squark}} = m_{\text{gluino}} + 1 \text{ TeV} \]

100 GeV splitting

\[ M_1 = \left( \frac{1 + 5e}{6} \right) M_g, \quad M_2 = \left( \frac{1 + 2e}{3} \right) M_{\tilde{g}}. \]