SUSY Breaking by Coexisting Walls

Nobuhito Maru

Department of Physics, University of Tokyo, Tokyo 113-0033, JAPAN

Abstract

Supersymmetry (SUSY) breaking without messenger fields is proposed. We assume that our world is on a wall and SUSY is broken only by the coexistence of another wall with some distance from our wall. The Nambu-Goldstone (NG) fermion is localized on the distant wall. Its overlap with the wave functions of physical fields on our wall gives the mass splitting of physical fields thanks to a low-energy theorem. We propose that this overlap provides a practical method to evaluate mass splitting in models with SUSY breaking due to the coexisting walls.

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1 Introduction

Recently, Brane World scenario \cite{1, 2} has opened new directions to the hierarchy problem, flavor physics, cosmology, astrophysics and so on. In this scenario, our world is considered as four dimensional topological objects embedded in higher dimensional spacetime.

On the other hand, it is well known that topological objects break SUSY partially in general. Therefore, it is interesting to consider SUSY breaking in the context of the brane world scenario and also interesting to compare with other SUSY breaking mechanisms proposed so far, that is, gravity mediation, gauge mediation, anomaly mediation, gaugino mediation and radion mediation and so on.

In this talk, we propose a SUSY breaking mechanism due to the coexistence walls\footnote{This talk is based on the work with N. Sakai, Y. Sakamura and R. Sugisaka \cite{3}.}. An idea similar to ours has also been proposed and discussed in Ref. \cite{4}.

2 SUSY breaking due to the other wall

In this section, our idea is briefly summarized. In order to avoid inessential complications, a toy model is discussed. Schematic picture is depicted in Fig 1. The Bulk space-time is four dimensional. Two BPS domain walls are embedded. We assumed the bulk SUSY to be $\mathcal{N} = 1$. We call one of the walls as “our wall” where the matter field are localized and another wall as “the other wall”, which is the source of SUSY breaking. We have $\mathcal{N} = 2$ SUSY in three dimension,

\[ Q^{(1)}, Q^{(2)}, Q^{(1)}, Q^{(2)} \]

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Schematic picture of our setup.}
\end{figure}

\[ \text{our wall} \quad \text{the other wall} \]
which is denoted as $Q^{(1)}, Q^{(2)}$. $Q^{(1)}$ is conserved and $Q^{(2)}$ is spontaneously broken on our wall, and vice versa on the other wall. Remarkable features of this SUSY breaking mechanism are as follows. First, we need no SUSY breaking sector. Second, we also need no bulk messenger fields. Third, the half of SUSY is preserved on each wall but completely broken in the whole system.

3 A Model with wall and antiwall

To illustrate the idea, we discuss a soluble example. The model is a minimal Wess-Zumino model in four dimensions. The Lagrangian is

$$\mathcal{L} = \Phi^\dagger \Phi|_{g^2 \bar{g}^2} + W(\Phi)|_{g^2} + h.c.$$  \hspace{1cm} (3.1)

where

$$W(\Phi) = \Lambda^2 \Phi - \frac{g}{3} \Phi^3,$$  \hspace{1cm} (3.2)

and $\Phi$ is a chiral superfield. One of the spatial direction $y$ is compactified on $S^1$ of the radius $R$.

This model has a nontrivial classical background solution [5]:

$$A_{cl}(y) = \frac{k\omega}{g} \text{sn}(\omega(y - y_0), k), \quad \omega = \frac{\sqrt{2g\Lambda}}{\sqrt{1 + k^2}}, \quad 0 \leq k \leq 1.$$  \hspace{1cm} (3.3)

By taking the radius $R$ appropriately, we obtain a wall-antiwall configuration. The properties of this configuration are the following. First, this configuration is static but not stable. Second, this instability is not essential to our SUSY breaking mechanism. Third, if walls are infinitely separated, this configuration reduces to the familiar single wall solution, $A_{cl}(y) \rightarrow \frac{\Lambda}{\sqrt{g}} \text{tanh}(\sqrt{g}\Lambda y)$.

Now, since we are interested in the effective theory on our wall, we would like to know the massless spectrum in the wall-antiwall background. There is a massless scalar field $\phi_{a,0}$, which implies a NG boson associated with the breaking of the translational invariance. The bosonic sector also has a tachyon $\phi_{a,-1}$, which implies the instability of the wall-antiwall system. On the other hand, there are two massless fermions $\psi^{(1)}, \psi^{(2)}$. One is a NG fermion associated with $Q^{(1)}$ SUSY breaking, another is one associated with $Q^{(2)}$ SUSY breaking.

4 Estimation of $\Delta m^2$

In this section, we estimate the mass splitting $\Delta m^2$ of the chiral multiplet localized on our wall. In order to do that, we obtain a three dimensional effective theory by integrating out massive modes. In the effective theory, the effective Yukawa coupling $\sqrt{2}g_{eff} a_{-1}\psi_0^{(1)} \psi_0^{(2)}$ is important
because in our approach, the mass splitting $\Delta m^2$ is calculated through the supersymmetric analog of Goldberger-Treiman relation 

$$g_{\text{eff}} = \frac{-\Delta m^2}{\sqrt{2}f}, \quad \Delta m^2 \equiv m_B^2 - m_F^2,$$

(4.1)

$$g_{\text{eff}} = \int_{-\pi R}^{\pi R} dy \phi_{a,-1}(y)\varphi_0^{(1)}(y)\varphi_0^{(2)}(y),$$

(4.2)

where $f$ is the order parameter of SUSY breaking. Note that the effective Yukawa coupling $g_{\text{eff}}$ becomes an overlap integral of modes localized on different walls. The result is displayed in Fig 2. The mass splitting decays exponentially as the wall distance increases. Note that this exponential

![Figure 2](image_url)  

Figure 2: The wall distance dependence of the mass splitting.

suppression is obtained in spite of SUSY breaking at the classical level.

5 Matter fields

We can also introduce a matter chiral superfield $\Phi_m$ interacting with $\Phi$ through

$$W_{\text{int}} = -h\Phi \Phi_m^2.$$  

(5.1)

Then, the matter fields is localized on our wall. When $h > g$, several light modes of $\Phi_m$ are localized on our wall.

What is interesting here is that the mass splitting of the matter fields becomes larger for heavy fields\footnote{For details, see [3]}. This situation is easy to understand in our framework because the heavy modes
have a large overlap with NG fermion localized on the other wall. We expect this phenomenon to be generic in our framework.

6 The tachyonless model

The wall-antiwall system discussed previously has a tachyonic mode, that is, the system is unstable. Here, we consider a tachyonless model to show such an instability does not necessarily appear.

We consider the following model with two fields \([7]\),

\[
\mathcal{L} = \Phi^\dagger \Phi |_{\theta^2 \bar{\theta}^2} + X^\dagger X |_{\theta^2 \bar{\theta}^2} + W(\Phi, X) |_{\theta^2} + h.c.,
\]

(6.1)

where

\[
W(\Phi, X) = \frac{m^2}{\lambda} \Phi - \frac{\lambda}{3} \Phi^3 - \frac{\lambda}{4} \Phi X^2.
\]

(6.2)

This model has four supersymmetric vacua \(X = 0, \Phi = \pm m/\lambda\) and \(\Phi = 0, X = \pm 2m/\lambda\). Tachyonless Non-BPS configuration is constructed from a superposition of BPS walls:

\[
\phi_{cl}(y) = \frac{m}{2\lambda} \left( \tanh \frac{my}{2} - \tanh \frac{m(y - d)}{2} \right),
\]

(6.3)

\[
\chi_{cl}(y) = \frac{\sqrt{2}m}{\lambda} \left( \sqrt{1 - \tanh \frac{my}{2}} - \sqrt{1 + \tanh \frac{m(y - d)}{2}} \right).
\]

(6.4)

Since the vacua at \(y = -\infty\) and \(y = \infty\) are different, this configuration is stable. We have checked that the mass splitting can also be calculated by the overlap integral and exponentially suppressed in this model.

7 Summary

- We have investigated a mechanism of SUSY breaking due to the coexistence of walls.
- The mechanism does not need any SUSY breaking sector or messenger bulk fields.
- The effective SUSY breaking scale observed on our wall becomes exponentially small as the distance between two walls grows.
- SUSY breaking effects we observe can be calculated from the overlap of mode functions.
- The mass splittings of the matter fields becomes large for heavier modes.
• The instability of the configuration in the model discussed here is not essential to our SUSY breaking mechanism.

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