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Low-scale gravity mediation in warped extra dimension and collider phenomenology on hidden sector*

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Abstract. We propose a new scenario of gravity-mediated supersymmetry breaking (gravity mediation) in a supersymmetric Randall–Sundrum model, where the gravity mediation takes place at a low scale due to the warped metric. We investigate collider phenomenology involving the hidden sector field, and find a possibility that the hidden sector field can be produced at the LHC and the ILC. The hidden sector may no longer be hidden.

Keywords. Supersymmetry; supersymmetry breaking; collider.

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1. Introduction

Supersymmetric (SUSY) extension of the standard model is one of the most promising ways to solve the gauge hierarchy problem of the standard model. However, since no superpartner has been observed in the current experiments, SUSY should be broken at low energies. The origin of SUSY breaking and its mediation mechanism to the visible (MSSM) sector is one of the most important issues in any supersymmetric phenomenological models.

The simplest model of SUSY breaking is the Polonyi model, where a chiral superfield singlet under the standard model gauge group is introduced and SUSY is broken by its non-zero F-term. After SUSY is broken, the SUSY breaking is transmitted to the visible sector through some mechanism. One simple mechanism is the

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gravity mediation in the minimal supergravity scenario [1], where SUSY breaking is transmitted through higher dimensional contact operators between the hidden sector and the visible sector superfields. In the scenario, the scale of the SUSY breaking mediation is the Planck scale which is nothing but the cutoff scale of (four-dimensional) supergravity.

In this work, we propose a new scenario of the gravity mediation in a supersymmetric Randall–Sundrum model. Due to the warped metric, the gravity mediation takes place at the low-scale, and we call this scenario 'low-scale gravity mediation'. We investigate collider phenomenology involving the hidden sector field, when the gravity mediation scale is low enough.

2. Low-scale gravity mediation

We consider a supersymmetric Randall–Sundrum model, where the fifth dimension is compactified on the orbifold S^1/Z_2 with two branes, ultraviolet (UV) and infrared (IR) branes, sitting on each orbifold fixed point. The system is a slice of a AdS_5 with the warped metric [2], $\mathrm{d}s^2 = \mathrm{e}^{-2kr|y|}\eta_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu - r^2\mathrm{d}y^2$, where k is the AdS curvature, and r and y are the radius and the angle of S^1, respectively.

The set-up of our model is that both the hidden and visible sectors reside on the IR brane. We introduce the Polonyi model with a singlet chiral superfield (X) as the hidden sector. Then, we consider the gravity mediation on the IR brane, namely SUSY breaking is transmitted through contact operators between the visible sector and the hidden sector superfields. In four-dimensional models, the contact operators are suppressed by the four-dimensional Planck mass (M_P), which is nothing but the cutoff of four-dimensional supergravity. In our case, because of the warped metric, the effective cutoff scale on the IR brane is warped down to a low scale, $\Lambda_\mathrm{IR} = \omega M_\mathrm{P}$, where $\omega = \mathrm{e}^{-\pi kr}$ is the warp factor. Therefore, the gravity mediation occurs at the low scale, $\Lambda_\mathrm{IR} \ll M_\mathrm{P}$.

In effective four-dimensional theory, the contact operators relevant to the gravity mediation are described as

$$\mathcal{L}^{\mathrm{eff}}_{\mathrm{contact}} = -\int \mathrm{d}^4\theta \, \left(c_A \frac{X + X^\dagger}{\Lambda_\mathrm{IR}} + c_0 \frac{X^\dagger X}{\Lambda_\mathrm{IR}^2} \right) Q_i^\dagger Q_i - \frac{1}{4}\int \mathrm{d}^2\theta \; c_a \frac{X}{\Lambda_\mathrm{IR}} \mathcal{W}^{a\alpha}\mathcal{W}^a_\alpha, \tag{1}$$

where Q_i denotes matter and Higgs chiral superfields in the MSSM, c_A, c_0 and c_a are dimensionless parameters naturally of order one (flavor universality has been assumed, for simplicity), and $a = 3, 2, 1$ corresponds to the standard model gauge groups $SU(3) \times SU(2) \times U(1)$. Plugging non-zero F-term of the hidden sector field ($X = \theta^2 F_X$) into the above contact operators, we obtain soft SUSY breaking terms in the MSSM (scalar squared masses, A-parameter and gaugino masses) such as

$$\tilde{m}^2 = (c_A^2 + c_0)\frac{|F_X|^2}{\Lambda_\mathrm{IR}^2}, \quad A = 3c_A \frac{F_X}{\Lambda_\mathrm{IR}}, \quad M_a = \frac{1}{2} c_a \frac{F_X}{\Lambda_\mathrm{IR}}. \tag{2}$$

3. Collider phenomenology involving the hidden sector field

If the effective cutoff scale $\Lambda_{\rm IR}$ is low enough, higher dimensional interactions suppressed by $\Lambda_{\rm IR}$ have an impact on collider physics. Note that the contact operators relevant to the gravity mediation also provide contact interactions between the hidden sector scalar field and the standard model fields. From the operator giving masses to gauginos in eq. (1), we can extract interactions among the hidden sector scalar and the standard model gauge bosons such that

$$\mathcal{L}_{\rm int} = -\frac{1}{4}\int {\rm d}^2\theta\; c_a \frac{X}{\Lambda_{\rm IR}} \mathcal{W}^{a\alpha}\mathcal{W}^a_\alpha \supset -\frac{c_a}{4\sqrt{2}}\frac{\chi}{\Lambda_{\rm IR}}\mathcal{F}^{a\mu\nu}\mathcal{F}^a_{\mu\nu}, \tag{3}$$

where χ is the real component of the hidden scalar field X, and $\mathcal{F}^a$ is the field strength of the corresponding standard model gauge fields. The operators in eq. (1) also give interactions between the hidden scalar and standard model fermions,

$$\mathcal{L}_{\rm int} = \int {\rm d}^4\theta\; c_A \frac{X + X^\dagger}{\Lambda_{\rm IR}} Q_i^\dagger Q_i \supset \sqrt{2} c_A \frac{\chi}{\Lambda_{\rm IR}} \mathcal{L}^{\rm fermion}_{\rm kin}, \tag{4}$$

where $\mathcal{L}^{\rm fermion}_{\rm kin}$ is the kinetic term for each standard model fermion.

Now we investigate collider phenomenologies involving the hidden scalar based on the above interactions. If χ is light enough and $\Lambda_{\rm IR}$ is low enough, it may be possible to produce the hidden scalar at future colliders through the interactions in eq. (3). At the LHC, the dominant χ production process is the gluon fusion process. Note that the process is the same as the dominant production process for the Higgs boson (h) of the standard model through the effective interaction, $\mathcal{L}_{\rm eff} \sim -\frac{\alpha_s}{16\pi}\frac{h}{v} G^{a\mu\nu}G^a_{\mu\nu}$, of the same form as eq. (3). Therefore, in the production process, the hidden scalar χ behaves like the Higgs boson in the standard model. Comparing coefficients of their interactions, we find that their production cross-sections become comparable for $\Lambda_{\rm IR} \simeq 10$ TeV, assuming the same masses for them.

When we consider the decay process of χ, we find a big difference between χ and the Higgs boson. The branching ratio of the χ decay into the standard model particles is depicted in figure 1. Note that the branching ratio of $\chi \to \gamma\gamma$ is large, ${\rm Br}(\chi \to \gamma\gamma) \simeq 0.1$, while the branching ratio of the Higgs boson into two photons is at most 10^{-3} even when the Higgs boson is light, $m_{\rm h} < 2m_W$.

At the LHC, the most important channel for the search of the lightest Higgs boson in the MSSM is its decay process into two photons. Therefore, the χ production and the large branching ratio of its decay into two photons have a great impact on the Higgs boson search at the LHC. The ratio between two-photon events from the χ decay and the Higgs boson decay is found to be

$$\frac{\sigma(gg \to \chi){\rm Br}(\chi \to \gamma\gamma)}{\sigma(gg \to h){\rm Br}(h \to \gamma\gamma)} \simeq 100 \left(\frac{\Lambda_{\rm IR}}{10\ {\rm TeV}}\right)^{-2}, \tag{5}$$

for $c_1 = c_2 = c_3 = c_A = 1$ and $m_\chi = m_{\rm h} = 120$ GeV. If $\Lambda_{\rm IR}$ is around 10 TeV, the hidden sector scalar χ can be discovered at the LHC with a very clean signature.

Next, let us investigate phenomenology at the ILC, the linear e^+e^- collider. The most clean channel of the Higgs boson production at the ILC is the associated

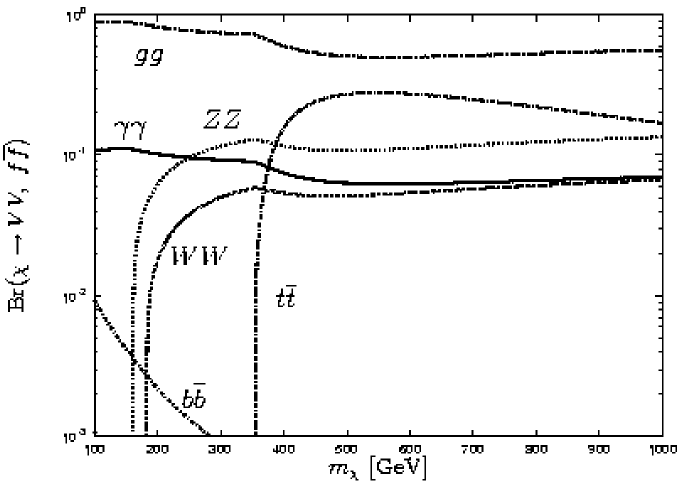

Figure 1. The branching ratio of the hidden scalar (χ) as a function of its mass m_χ for $c_1 = c_2 = c_3 = c_A = 1$.

Higgs production (Higgsstrahlung production), $e^+e^- \to Zh$, through the standard model interaction $\mathcal{L}_{\rm int} = \frac{m_Z^2}{v} h Z^\mu Z_\mu$. Since the hidden sector scalar χ has the vertex among Z-boson in eq. (3), we can consider the same associated process for the χ production. At the ILC with the collider energy $\sqrt{s} = 1$ TeV, the ratio of the total cross-sections between χ and Higgs boson productions is found to be

$$\frac{\sigma(e^+e^- \to Z\chi)}{\sigma(e^+e^- \to Zh)} \simeq \left(\frac{\Lambda_{\rm IR}}{1.3\ {\rm TeV}}\right)^{-2}, \tag{6}$$

for $c_1 = c_2 = c_3 = c_A = 1$ and $m_\chi = m_{\rm h} = 120$ GeV.

The coupling manner among χ and the Z-boson pair is different from that of the Higgs boson, and this fact reflects into the difference of the angular distribution of the final state Z-boson. In the high energy limit, we find $\frac{{\rm d}\sigma}{{\rm d}\cos\theta}(e^+e^- \to Z\chi) \propto 1 + \cos^2\theta$, while $\frac{{\rm d}\sigma}{{\rm d}\cos\theta}(e^+e^- \to Zh) \propto 1 - \cos^2\theta$. Therefore, even if $m_\chi = m_{\rm h}$ and the cross-sections of χ and Higgs boson productions are comparable ($\Lambda_{\rm IR} \sim 1$ TeV), we can distinguish the χ production from the Higgs boson by the difference of the angular dependences. Of course, detecting two photons from the χ decay with the sizable branching ratio $\mathrm{Br}(\chi \to \gamma\gamma) \sim 0.1$ would be an easy way to distinguish χ from Higgs boson, as discussed in the case of the LHC.

4. Summary

We have proposed the low-scale gravity mediation scenario with the warped extra dimension. In this scenario, the effective cutoff on the IR brane is warped down, so that the gravity mediation takes place at low energies. The contact operators relevant to the gravity mediation also provide contact interactions among the hidden sector scalar and the standard model particles. In the case where the effective cutoff scale is low enough, we have investigated collider physics involving the hidden sector scalar field. We have found the possibility that the hidden sector scalar can be discovered at the LHC and the ILC. The hidden sector may be no longer hidden.

References

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