# Supersymmetry

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## 1. Introduction

Deciphering hidden symmetries in nature has been one of the most exciting and challenging tasks in physics. For example, the discovery of the massive W and Z gauge bosons has established a spontaneously broken gauge symmetry as the basis of the electroweak theory, or the Standard Model of particle physics. Here, we discuss how one may discover the massive gravitino, which would establish spontaneously broken local supersymmetry as a fundamental, hidden symmetry of nature.

## 2. Physics beyond the Standard Model

The Standard Model of particle physics, supplemented with neutrino masses, has been remarkably successful in explaining presently known phenomena of particle physics. However, it is widely believed that the Standard Model is not the fundamental, ultimate theory. For instance, the huge hierarchy between the electroweak energy scale (about 100 GeV) and the Planck scale (about 10^18 GeV) is very puzzling, especially once quantum corrections to the Higgs mass are taken into account.

## 3. Supersymmetry and Supergravity

Supersymmetry (SUSY) is the leading candidate for physics beyond the Standard Model [1]. It is a symmetry between bosons and fermions, and introduces supersymmetric partners for each particle in the Standard Model (see Table.1). Once the Standard Model is augmented with SUSY, (i) the aforementioned hierarchy problem is solved, (ii) the three gauge coupling constants of the Standard

Model beautifully unifies at high energy 2 x 10^16 GeV, which reproduces the prediction of the Grand Unified Theory, (iii) it now has a candidate for the Dark Matter.

If the theory underlying the standard model is supersymmetric, one may find superpartners of quarks, leptons and gauge bosons at the Large Hadron Collider (LHC) or the International Linear Collider (ILC). Even though an exciting discovery, this would still not answer the question how SUSY is realized in nature. If SUSY is a fundamental symmetry underlying in nature, it is likely based on a local symmetry, like the gauge symmetry in the Standard Model. A locally supersymmetric theory is called Supergravity, and necessarily includes the gravity in it. The superstring theory, which is the leading candidate for the ultimate theory including gravity, also predicts Supergravity as an effective theory.

**Supergravity**

**supersymmetric Standard Model**

| Standard Model | spin | | | |
|---|---|---|---|---|
| quark | 1/2 | $\longleftrightarrow$ | 0 | squark |
| $u, c, t$ | | | | $\widetilde{u}, \widetilde{c}, \widetilde{t}$ |
| $d, s, b$ | | | | $\widetilde{d}, \widetilde{s}, \widetilde{b}$ |
| lepton | 1/2 | $\longleftrightarrow$ | 0 | slepton |
| $e, \mu, \tau$ | | | | $\widetilde{e}, \widetilde{\mu}, \widetilde{\tau}$ |
| $\nu_e, \nu_\mu, \nu_\tau$ | | | | $\widetilde{\nu_e}, \widetilde{\nu_\mu}, \widetilde{\nu_\tau}$ |
| gauge boson | 1 | $\longleftrightarrow$ | 1/2 | gaugino |
| $g$ | | | | $\widetilde{g}$ |
| $\gamma, W, Z$ | | | | $\widetilde{B}, \widetilde{W^0}, \widetilde{W^\pm}$ |
| Higgs boson | 0 | $\longleftrightarrow$ | 1/2 | higgsino |
| $H$ | | | | $\widetilde{h}$ |
| graviton | 2 | $\longleftrightarrow$ | 3/2 | gravitino |
| $h_{\mu\nu}$ | | | | $\psi_\mu$ |

Table 1: Supersymmetric Standard Model and Supergravity. The particles on left hand side are the known ones, and those in the right hand side are the hypothetical particles introduced in the supersymmetric theory.

## 4. Gravitino at the colliders

The gravitino, which is the superpartner of the graviton (see Table.1), is an inevitable and unique prediction of the Supergravity. If the gravitino will be discovered, it would establish the local SUSY, or Supergravity, which would become a milestone discovery of particle physics. However, since the interactions between the gravitino and other particles are extremely weak, it is very difficult to produce gravitinos or to confirm the existence of the gravitino. In Ref.[2], we have shown that, if the gravitino is the Lightest SUSY Particle (LSP) and the next-to-lightest SUSY particle (NLSP) is electrically charged, it may be possible to identify the graivitino in the future colliders. (The gravitino LSP can also be a candidate for the Dark Matter of the Universe.) One of the proposed methods is quite simple: by studying the 2-body decay of the NLSP into a gravitino, it is possible to measure the coupling constant of the gravitino, which is nothing but the Planck scale in Supergravity. It would be extremely exciting and interesting to compare the microscopically measured Planck scale with the macroscopically determined Planck scale of the Einstein gravity, corresponding the Newton constant. If they agree, it will be a crucial test of the Supergravity.

Since the decay of the NLSP into the gravitino occurs via the extremely weak interaction, the lifetime of the NLSP becomes very long, and hence the NLSPs produced at colliders escape from the main detectors. In order to study the decay of the NLSP, therefore, it is crucial to collect or trap the NLSPs. In Refs.[3,4], we have shown that it is indeed possible to trap sufficiently many NLSPs at LHC and ILC, if a 1 kton to O(10) kton detector could be placed next to the main detector of those colliders.

***References***

[1] For review, see S.P.Martin, "A supersymmetry primer," arXiv:hep-ph/9709356.

[2] W.Buchmuller, K.Hamaguchi, M.Ratz, T.Yanagida, Phys.Lett.B588 (2004) 90.

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[4] K.Hamaguchi, M.M.Nojiri, A. de Roeck, JHEP 0703 (2007) 046.