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Dirac gauginos in low scale supersymmetry breaking

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Abstract

It has been claimed that Dirac gaugino masses are necessary for realistic models of low-scale supersymmetry breaking, and yet very little attention has been paid to the phenomenology of a light gravitino when gauginos have Dirac masses. We begin to address this deficit by investigating the couplings and phenomenology of the gravitino in the effective Lagrangian approach. We pay particular attention to the phenomenology of the scalar octets, where new decay channels open up. This leads us to propose a new simplified effective scenario including only light gluinos, sgluons and gravitinos, allowing the squarks to be heavy – with the possible exception of the third generation. Finally, we comment on the application of our results to Fake Split Supersymmetry.

1. Introduction

The non-observation of supersymmetric particles so far, has cast doubts on our expectations for a solution of the hierarchy problem within the standard realisations of supersymmetry (SUSY). One direction beyond minimality that has received much interest in the recent years is

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to consider models where the SUSY breaking scale is in the multi-TeV range [1–10]. Indeed, although there are increasingly stringent bounds on superpartners from LHC, a *low* scale of SUSY breaking can actually help reduce fine-tuning, as it is associated with a low cutoff for the effective supersymmetric theory so that there are no large effects from renormalisation-group running of SUSY breaking parameters over different energy scales.

Lowering the SUSY breaking scale to the multi-TeV range has several important consequences. First, the gravitino in these models is within the milli-eV range, introducing a new ultralight fermionic degree of freedom in the low energy theory. According to the high-energy equivalence theorem [11], at LHC energies gravitino dynamics are dominated by the goldstino longitudinal component. Therefore we can use this spin-1/2 fermionic field to describe gravitino interactions with the rest of the fields. Second, the Higgs sector is modified in a way that alleviates the little hierarchy problem [7,9]. Third, since the cutoff scale is low, higher-dimensional effective operators can introduce interesting phenomenological effects such as contributions to $h \to \gamma\gamma/\gamma Z$, $gg \to h$, wrong Higgs–Yukawa couplings, monophoton + MET signals and four-fermion contact interactions [7,10]. Fourth, while in principle it is possible to write down an effective theory with Majorana gauginos and SUSY broken at a low scale, in practice it is very difficult to construct an explicit model where the Majorana masses are not unacceptably small. Model building aspects of low-scale SUSY breaking suggest that the gauginos should be of Dirac type [12,13].

This last consequence has many far reaching implications for the phenomenology of low-scale breaking models which have received very little attention so far in the literature, with the exception of [13,14] (in the context of brane-worlds). On the other hand, conventional signatures of Dirac gauginos are attracting much attention, see for example [14–56]. The supersymmetric multiplets that need to be added in order to make the gauginos Dirac include scalar fields in the adjoint representation of the gauge groups, and the potential of detecting some of these particles, in particular the colour octets, has been extensively investigated in the literature [24,26,57–60] as well as their effect on the scalar potential and the Higgs sector of the theory [27,36,38,48,54,55]. However, in the presence of gravitino interactions we expect that the experimental signatures of the adjoints will be modified. Furthermore, Dirac gauginos have modified interactions with gravitinos compared to the standard interactions of Majorana gauginos. This implies that the limits and studies of such models should be revisited.

The goal of this paper is to study these effects and highlight the interesting features for future LHC phenomenological studies. In Section 2 we use effective field theory to construct the general expression of the couplings of the goldstino to the adjoint multiplets and we discuss the new physics that these couplings introduce with respect to the Majorana case. In Section 3 we compute the widths of the various decay modes of the colour octet scalars, quantifying the significance of the decay modes that appear in presence of the light gravitinos. Outside the restriction of low-scale SUSY breaking, in Section 4 we describe how the decays of gluinos to gravitinos are modified in the limit of heavy squarks and when gauginos have both Majorana and Dirac masses, as in the context of Fake Split SUSY [61,62].

2. Goldstino couplings with Dirac gauginos

In a supersymmetric gauge theory with Dirac gauginos, spontaneous breaking of supersymmetry induces couplings of the massive gravitino to all fields, including the new degrees of freedom that are required in order to attribute Dirac masses to the gauginos. According to the supersymmetric equivalence theorem [11], in the high energy limit ($E \gg m_G$) the dynamics of