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An alternative form of supersymmetry with reduced cross-sections and modified experimental signatures

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We have calculated cross-sections for production of superpartners in an alternative form of supersymmetry with modified experimental signatures. The superpartners include an illustrative sample of squarks, gluinos, sleptons, charginos, and neutralinos. The calculations are for proton colliders with center-of-mass energies up to 100 TeV. This version of supersymmetry implies a very different phenomenology from that emphasized in current experimental searches. However, our calculations indicate that, if the present formulation is correct, some superparticles should be observable with the more powerful colliders currently planned – or possibly at the high luminosity LHC, or even current LHC, with a shift in experimental strategies. In the present theory, fermions, gauge bosons, Higgs bosons, and auxiliary fields have the same basic status as in the standard model and standard supersymmetry (with modified couplings), but there is additionally an unconventional scalar-boson sector with only second-order gauge and Higgs couplings. In the version of the theory treated here and in our previous papers, both sfermions and the dominant dark matter WIMPs belong to this new sector.

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There are compelling *physical* arguments for supersymmetry [1–9], which include the following: the Higgs mass is protected from absurdly large radiative corrections, grand unification of nongravitational forces can be achieved, and (with R-parity conservation) there is a dark matter candidate. An additional motivation is the *mathematical beauty* of the superalgebra, with $\left\{Q_S, \overline{Q}_{\dot{\beta}}\right\} = 2\left(\sigma^{\mu}\right)_{\alpha\dot{\beta}} P_{\mu}$ in a standard notation. However, as evidenced by many historical precedents, mathematical beauty must be distinguished from physical correctness, and so far conventional supersymmetry (SUSY) has not been successful as a physical theory.

We have introduced a different version of supersymmetry (called susy to avoid confusion), which is broken by the requirement of a stable vacuum with Lorentz invariance [10, 11]. As a result there are three kinds of scalar boson fields: standard fields ϕ (including the electroweak Higgs field), auxiliary fields F, and unconventional fields φ of a new kind. This last sector includes both the dark matter candidate of our previous papers [12–14] and sfermions in the interpretation discussed below.

In [10], physical scalar fields are obtained by joining a primitive bosonic field Φ_r with spin 1/2 to another such field with the opposite spin, which can be either a $\Phi_{r'}$ with the same quantum numbers or a charge-conjugate field Φ_r^c. In the first case, as detailed in [10], we define amplitude modes ϕ_R which turn out to have the standard action for standard 1-component complex scalar boson fields. In the electroweak sector (and more generally with grand unification) these account for standard Higgs fields.

They could also account for the sfermions in one interpretation of supersymmetry, but here we explore the second interpretation, as emphasized in [10] and [11]. The initial Lagrangians

$$\overline{\mathcal{L}}_s = \Phi_s^{\dagger} D^{\mu} D_{\mu} \Phi_s - y_s^2\, \Phi_s^{\dagger}\, \phi_H^{s\,*} \phi_H^{s}\, \Phi_s \quad , \quad \overline{\mathcal{L}}_s^{c} = \Phi_s^{c\,\dagger} D^{\mu} D_{\mu} \Phi_s^{c} - y_s^{c\,2}\, \Phi_s^{c\,\dagger}\, \phi_H^{s\,*} \phi_H^{s}\, \Phi_s^{c} \tag{1}$$

(with Higgs interactions included and in the notation of [10]) reduce to

$$\overline{\mathcal{L}}_S = \varphi_S^{\dagger}\, \partial^{\mu} \partial_{\mu} \varphi_S - \varphi_S^{\dagger}\, A^{\mu} A_{\mu}\, \varphi_S - y_S^2\, \varphi_S^{\dagger}\, \phi_H^{S\,*} \phi_H^{S}\, \varphi_S \quad , \quad y_S^2 = \frac{1}{2}\left(y_s^2 + y_s^{c\,2}\right) . \tag{2}$$

(The scalar fields φ_S inherit their gauge invariance from the Φ_s, which still exist as primitive fields in the vacuum. If the A_{μ} are subjected to a gauge transformation, the Φ_s, and consequently φ_S, are also appropriately transformed.) In the present context $A_{\mu} = A_{\mu}^{n\,i} t^{n\,i}$ represents the sum of all the relevant terms in the covariant derivative $D_{\mu} = \partial_{\mu} - iA_{\mu}$ (with the generators $t^{n\,i}$ treated as operators). The terms linear in the $t^{n\,i}$ have cancelled to yield (2) for the scalar boson field φ_S. The redefined squarks and other superpartners still protect the Higgs mass-squared from a quadratic divergence and permit unification of coupling constants [10].

We have used MadGraph to calculate cross-sections for production of squarks, gluinos, sleptons, charginos, and neutralinos in proton colliders up to $\sqrt{s} = 100$ TeV in this version of supersymmetry [11]. Representative processes and cross-sections are shown in Figures 1-5, with the physical significance discussed in the captions. Many further results will be reported elsewhere [11], and we are using other software to calculate other experimentally relevant quantities. In all our calculations we begin with the standard MSSM and then subtract out the processes (represented by Feynman diagrams) which are not allowed in the present formulation (with fewer interactions than conventional SUSY).

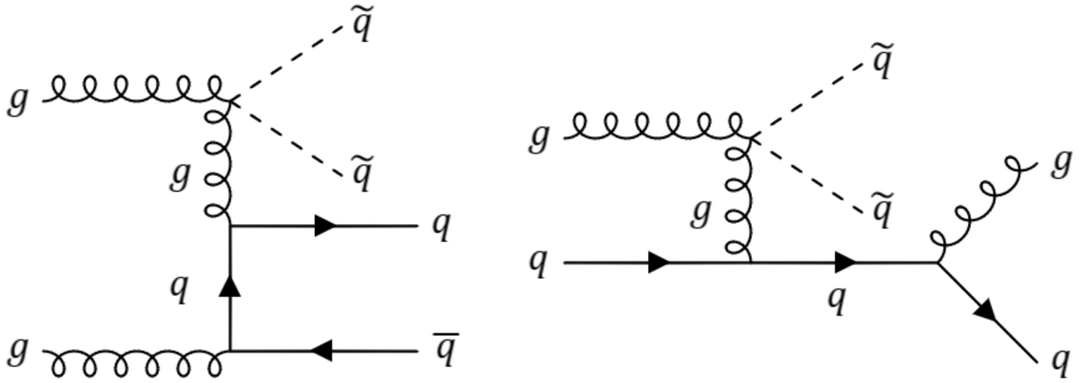

Figure 1: Two of the Feynman diagrams associated with production of a squark pair accompanied by jets – in these cases two quark jets or a quark jet and a gluon jet. In conventional supersymmetry (SUSY) the squarks will decay, and this is a leading signature for conventional searches. In the present formulation (susy) an initial squark can undergo a transformation of species and hadronize, but will not decay in the usual sense, so there is a very different experimental signature [10, 11].

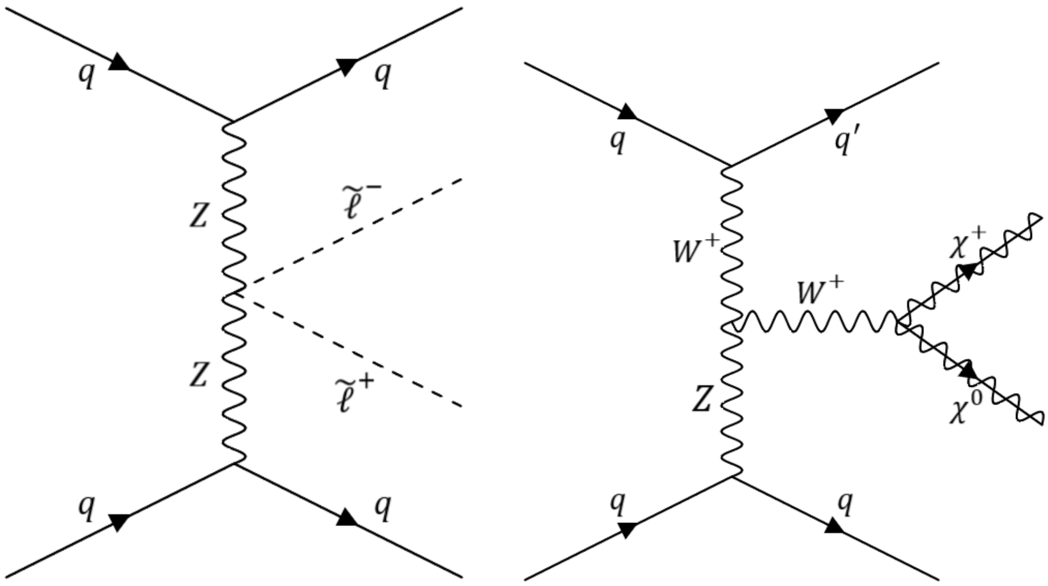

Figure 2: Two of the Feynman diagrams associated with production of a pair of sleptons (left panel) or a chargino-neutralino pair (right panel), accompanied by quark jets. An initial slepton can undergo a transformation of species, but will not decay in the usual sense. Charginos and higher-mass neutralinos will decay as usual because they are fermions (rather than unconventional scalar bosons). The fact that charginos and neutralinos have not been detected must then be primarily attributed to weaker interactions and higher masses.

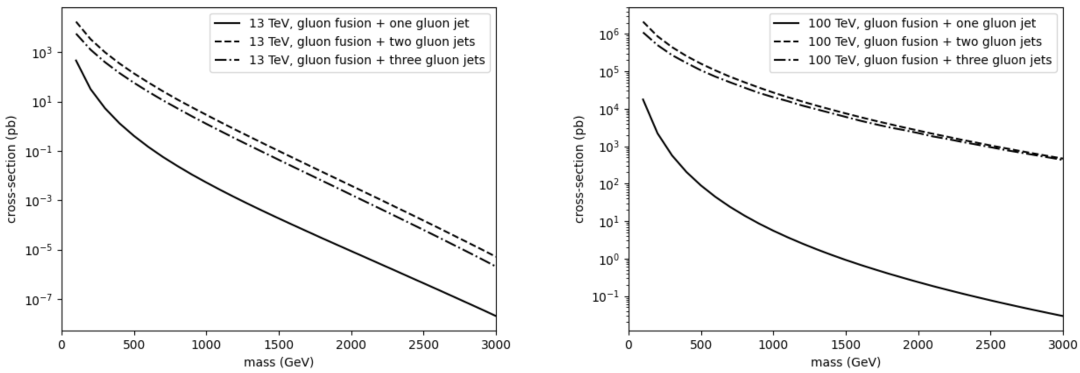

Figure 3: Calculated cross-sections for production of a pair of left top squarks accompanied by one, two, or three gluon jets. There is a potentially observable cross-section for production up to $\sim 1-2$ TeV at current LHC energies of 13-14 TeV. If one or more of the 12 squark species have a mass in this range of masses, the nonobservation is attributed to the different experimental signatures required for observation in the present formulation. The cross-sections for production at the planned 100 TeV future circular collider are orders of magnitude higher, allowing definitive tests for even much higher masses.

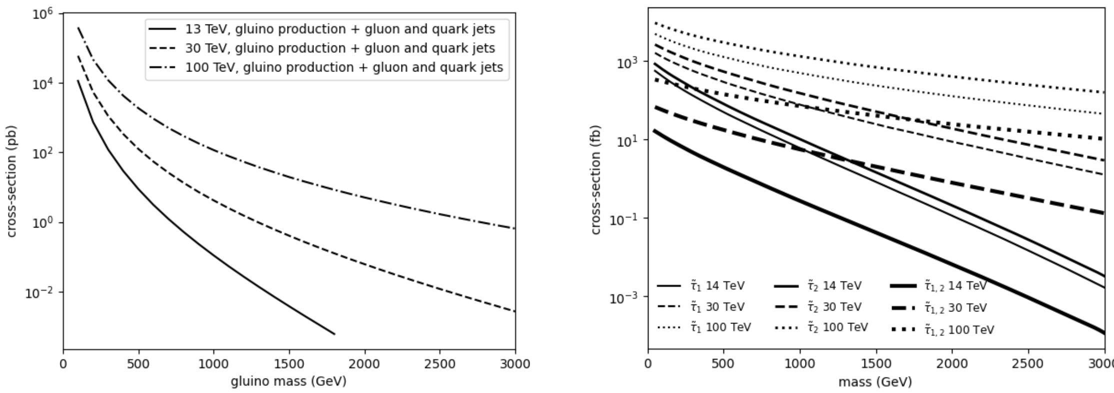

Figure 4: Left panel: Calculated cross-sections for production of a pair of gluinos accompanied by a quark jet and a gluon jet, at energies corresponding to the current LHC and the up to 100 TeV proton colliders planned for the future. The comment in the caption to Fig. 3 also holds for gluinos: If one or more of the 8 gluino species have a mass in this range of masses, the current nonobservation is attributed to the different experimental signatures required in the present formulation, since gluinos can transform and hadronize, but not decay in the usual sense. Right panel: Calculated cross-sections for production of a pair of staus – a $\widetilde{\tau}_1$ pair, a $\widetilde{\tau}_2$ pair, or a mixed $\widetilde{\tau}_1$, $\widetilde{\tau}_2$ pair (taken to have the same masses for simplicity in these initial studies). The first two possibilities have potentially observable cross-sections at even LHC energies for masses below 1 TeV, but these particles again do not decay as usual in the present formulation.

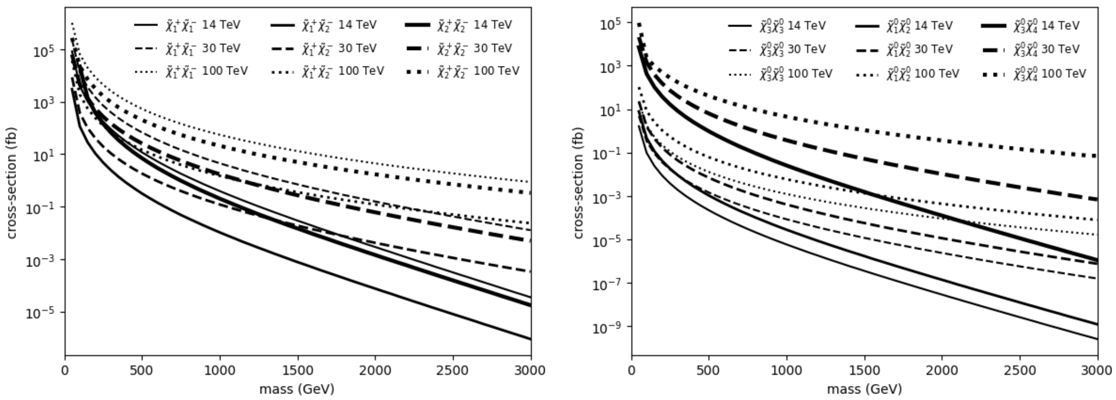

Figure 5: Cross-sections for production of various combinations of charginos (left panel) and neutralinos (right panel), accompanied by a single quark or gluon jet. All these particles can decay except for the lightest neutralino (if assumed to be the lightest superpartner), but the cross-sections for production are relatively small and fall rapidly after a few hundred GeV. For these weakly interacting sparticles the nonobservation must be primarily attributed to weaker interactions and higher masses, whereas the nonobservation of strongly interacting particles is potentially attributed to modified experimental signatures.

All the results of this paper are for the modified susy in which sfermions have the modified Lagrangian of (2). Fermions, gauge bosons, Higgs bosons, and auxiliary fields have the same basic status as in the standard model and standard supersymmetry – with the major additional exception that all fermions, including superpartners, have only gauge and Higgs couplings, so that gauginos and higgsinos are not coupled to sfermions [10].

The most dramatic prediction of the present formulation is that the redefined squarks and sleptons experience only the interactions of (2). This implies that the lightest squark, the lightest gluino, and the lightest slepton (as well as the lightest neutralino) are stable, since an incident squark, gluino, or slepton must be accompanied by an outgoing squark, gluino, or slepton at each vertex. (Gluino decay in the usual sense would require a gluino-squark-antiquark or gluino-antisquark-quark vertex, and this is not allowed if all squark interactions have the form of (2).) These lightest superpartners of each kind can radiate other particles, transform into other species of the same kind, and (if experiencing the strong interaction) hadronize, but not decay in the usual sense.

The results of Figs. 1-5 illustrate the central point of this paper: There are substantial cross-sections for production of squarks, gluinos, and sleptons with masses $\sim$ 1 TeV at current LHC energies, and much bigger cross-sections for the planned proton colliders with larger center-of-mass energies. However, the conventional squark, gluino, and lepton decays, which are of central importance in current searches, do not exist in the present formulation.

The key feature of the present theory is a new sector φ of scalar-boson fields, which supplement the standard fermion, gauge-boson, Higgs, and auxiliary fields of the standard model and standard supersymmetry. Both the redefined sfermions considered here and the dark matter candidate of our previous papers [12–14] belong to this sector. The unconventional couplings of this sector, in (2), lead to reduced cross-sections and modified experimental signatures, and this fact may then potentially provide a unified explanation of why both superpartners and dark matter WIMPs have not yet been observed.

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