Search for R-parity Violation in Multilepton Final States in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

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Abstract

The result of a search for gaugino pair production with a trilepton signature is reinterpreted in the framework of minimal supergravity (mSUGRA) with R-parity violation via leptonic λ Yukawa couplings. The search used 95 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV recorded by the DØ detector at the Fermilab Tevatron. A large domain of the mSUGRA parameter space is excluded for $\lambda_{121},\ \lambda_{122} \geq 10^{-4}$.

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Supersymmetry (SUSY) is one of the possible extensions of the standard model (SM). For each SM particle there is a hypothesized supersymmetric partner with spin differing by 1/2-integer. Most searches for supersymmetric particles assume conservation of R-parity, R_p, a multiplicative quantum number defined as $(-1)^{3N_B+N_L+2S}$, where N_B is the baryon number, N_L is the lepton number, and S is the spin quantum number [1]. However, SUSY does not require R-parity conservation. In particular, the lightest supersymmetric particle (LSP) can decay into a purely leptonic state due to the presence of an R_p- and N_L-violating term in the supersymmetric potential, $\lambda_{ijk}L_iL_jE_k^C$, where L_i and E_k are isodoublet and isosinglet supersymmetric lepton fields, respectively (the superscript C indicates charge conjugation). The indices i, j, k run over the three lepton generations and the potential is antisymmetric for the indices i and j. Current upper limits on R-parity violating SUSY Yukawa couplings, λ_{ijk}, are of the order of $\approx 10^{-2}$ [2]. If these couplings are not vanishingly small, an enhancement is expected in the number of produced multilepton events.

In this paper, we reinterpret the result of a previous search by the DØ collaboration for gaugino pair production in multilepton channels [3]. We use the minimal low-energy supergravity model [4,5] (mSUGRA) as a starting point, and add non-vanishing λ_{ijk} couplings. The mSUGRA model has four continuous parameters and one discrete parameter: m_0 — the universal scalar mass, $m_{1/2}$ — the universal gaugino mass, A_0 — the common trilinear interaction term, $\tan\beta$ — the ratio of the vacuum expectation values of the two Higgs fields, and the sign of μ — the Higgsino mass parameter. The mass spectrum of the SUSY partners at the electroweak scale and their decay branching ratios are obtained from the above parameters by solving a set of renormalization group equations using the program ISAJET [6]. Present limits on the λ_{ijk} Yukawa couplings [2] imply that this mass spectrum is the same as for the case of conserved R-parity. In this analysis we consider only parameter regions with a neutralino ($\tilde{\chi}_1^0$) as LSP.

The CDF and DØ collaborations have previously reported on searches for R-parity violation in the di-electron+jets channels [7,8]. They assumed an R_p- and N_L-violating supersymmetric potential term $\lambda'_{ijk} Q_i L_j D^C_k$, where Q_i and D_k are isodoublet and isosinglet supersymmetric quark fields, respectively. Some regions of the mSUGRA parameter space are excluded by non-observation of SUSY or Higgs particles at the CERN e^+e^- collider (LEP2): the present limit on the mass of the lightest neutral SUSY Higgs boson (88.3 GeV [9]) implies that $\tan\beta \leq 2$ is excluded, independent of the other parameters. At higher $\tan\beta$, part of the parameter space is excluded by the lower limit on the $\tilde{\chi}^0_1$ mass [10] obtained assuming R-parity violation through λ couplings.

The event selection and background estimations used in this work are discussed in the above-mentioned DØ search [3]. Four different final states were considered: eee, $ee\mu$, $e\mu\mu$, and $\mu\mu\mu$, requiring at least three electrons, two electrons and a muon, two muons and an electron, or three muons, in the respective channels. No acceptable events were found. The result is summarized in Table I. The corresponding selection criteria (including the triggers) are detailed in Ref. [3]. We consider these selection criteria adequate for the present analysis.

Our search is most sensitive to decays with highest electron and muon multiplicity, i.e., those with no τ lepton among the decay products of the LSP. The detection efficiency is highest, especially for the case of λ_{121}, when electrons dominate. On the other hand, couplings λ_{133} and λ_{233} correspond to decays with least sensitivity, because the number of τ leptons is highest. We limit ourselves to the three extreme cases: λ_{121}, λ_{122} and λ_{233}.

We generate Monte Carlo (MC) events with all possible production and decay modes of SUSY particles assuming the mSUGRA model using ISAJET [6] with R-parity violation [11,12]. We apply the same selection criteria as used in [3] to these generated events, and calculate all signal efficiencies.

Detector response is modeled using a parameterized, fast, particle-level simulation of isolated electrons, photons, and both isolated and non-isolated muons. The model contains jet reconstruction and a simulation of the missing transverse energy in an event. Lepton acceptance criteria include the loss of electrons in the region between the central and end cryostats of the calorimeter ($1.2 \leq |\eta| \leq 1.4$), and a lookup table of the muon efficiency as a function of η and ϕ [13,14], where η and ϕ are the pseudorapidity and the azimuthal angle of the lepton, respectively. The parameters of the program are tuned so that the total acceptance, $\epsilon^{\rm total}$, and the shapes of the missing transverse energy distributions and charged lepton η, ϕ and transverse energy distributions agree with detailed simulation based on GEANT [15,16]. The total acceptance includes the geometrical acceptance, efficiency factors for the trigger, track reconstruction, and lepton identification. It depends mainly on the type of coupling and on the value of $m_{1/2}$. In the vicinity of the exclusion contour, the typical values are 20%, 10%, and 0.3% for λ_{121}, λ_{122}, and λ_{233}, respectively. $\epsilon^{\rm total}$ decreases with decreasing $m_{1/2}$, mainly because the masses of the gauginos decrease and the energies of their decay products fall below the detection threshold.

Our 95% C.L. exclusion contours are based on a Bayesian approach [17,18]. For each point in the $(m_0, m_{1/2})$ plane, we calculate a 95% C.L. upper limit on the cross section. The excluded region is determined from the intersection of this surface with the corresponding cross section predicted by ISAJET. In this calculation, we use as input the total integrated luminosities, and the uncertainties in the numbers of background events (cf. Table I) and in $\epsilon^{\rm total}$. The latter includes the statistical error, an overall 10% systematic error in the MC simulation, and the error on efficiency factors for the trigger, track reconstruction, and lepton identification, determined through independent measurements described in Ref. [3]. Their values are between 10% and 20%, and depend on the event category (and therefore on the λ_{ijk} coupling) and to a lesser extent on event kinematics (e.g., on supersymmetric particle masses). Finally, we include a 10% uncertainty on the theoretical cross section, due to e.g., the choice of parton distribution function.

Figures 1 through 4 show, respectively, the exclusion regions in the $(m_0, m_{1/2})$ plane for the three chosen couplings, for $\tan\beta = 5$ and 10, and for both signs of μ. Since the characteristics of SUSY signatures at hadron colliders are rather insensitive to values of A_0 [19], we have fixed the value of A_0 to zero. The dashed line indicates the limit of our sensitivity in $m_{1/2}$ for the least favorable case, i.e., for the coupling of λ_{233}, where $\epsilon^{\rm total} < 10^{-4}$. The exclusion regions correspond to the spaces below the solid lines labelled with the coupling types, and above the higher of the dashed line and the dash-dotted curves specifying the numerical values of λ. In the regions beyond the dash-dotted curves, the average decay length of the LSP calculated for the value of the coupling indicated on the curve, is less than 1 cm. Since efficiency studies for high impact parameter tracks have not been done, we conservatively restrict the present study to decay lengths less than 1 cm. Thus, for example, the region between curves labelled with λ_{121} and 10^{-3} is excluded if $\lambda_{121} > 10^{-3}$. The shaded areas indicate the regions where there is no electroweak symmetry breaking or where the LSP is not the lightest neutralino. Finally, we also show limits corresponding to the present lower limit on the $\tilde{\chi}_1^0$ mass (dotted line), which exclude the regions below. The wiggles on the λ_{233} curves are due to statistical fluctuations and to the 10 GeV spacing between neighboring m_0 points used to calculate the curves.

In conclusion, we have reinterpreted the result of a search for trilepton events in terms of possible R-parity violation in decays of the LSP. We have found that a large domain of mSUGRA parameter space can be excluded, provided that R-parity breaking is achieved by lepton-number non-conservation with λ_{121} or λ_{122} couplings greater than $\approx 10^{-4}$. The region of sensitivity extends beyond that presently excluded by LEP experiments [9,10]. For λ_{233}, where our experiment is least sensitive, only a very limited domain of parameter space can be excluded, and this region is already excluded by LEP. The excluded values of $m_{1/2}$ depend mainly on the type of coupling, and much less on the values of other parameters. In particular, the excluded region is slightly larger for μ >0 than for μ <0, and is almost independent of tanβ.

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TABLES

Event categories	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
$\mathcal{L}_{\text{int}}$ (pb^{-1})	98.7 ± 5.2	98.7 ± 5.2	93.1 ± 4.9	78.3 ± 4.1
Observed events	0	0	0	0
Background events	0.34 ± 0.07	0.61 ± 0.36	0.11 ± 0.04	0.20 ± 0.04

TABLE I. The result of the search for a trilepton signature at DØ [3].

FIGURES

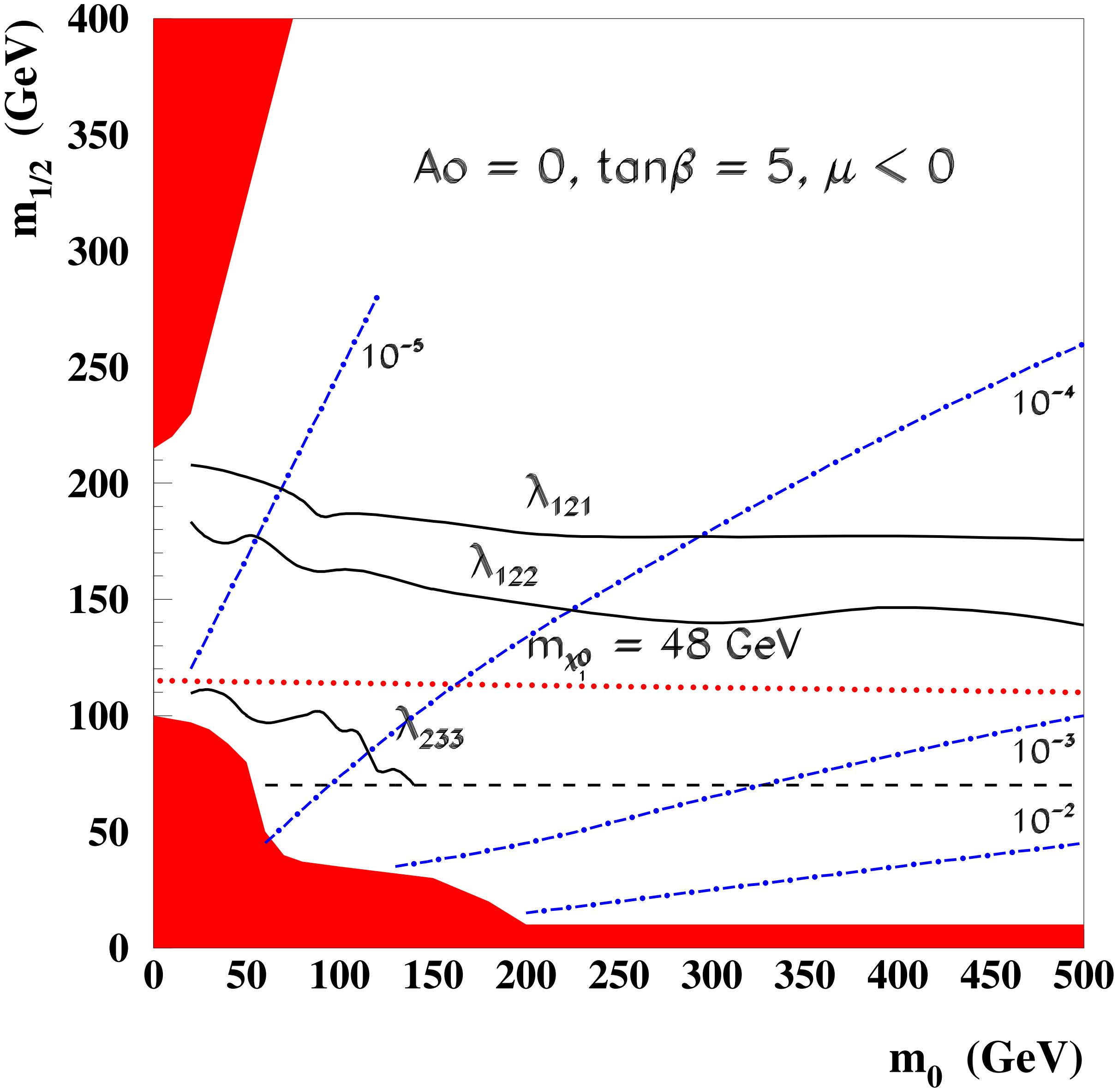

FIG. 1. Exclusion contours at 95% C.L. limits for tanβ = 5, μ <0, for the case of finite λ_{121}, λ_{122} and λ_{233} couplings. For the explanation of the different curves, see the text.

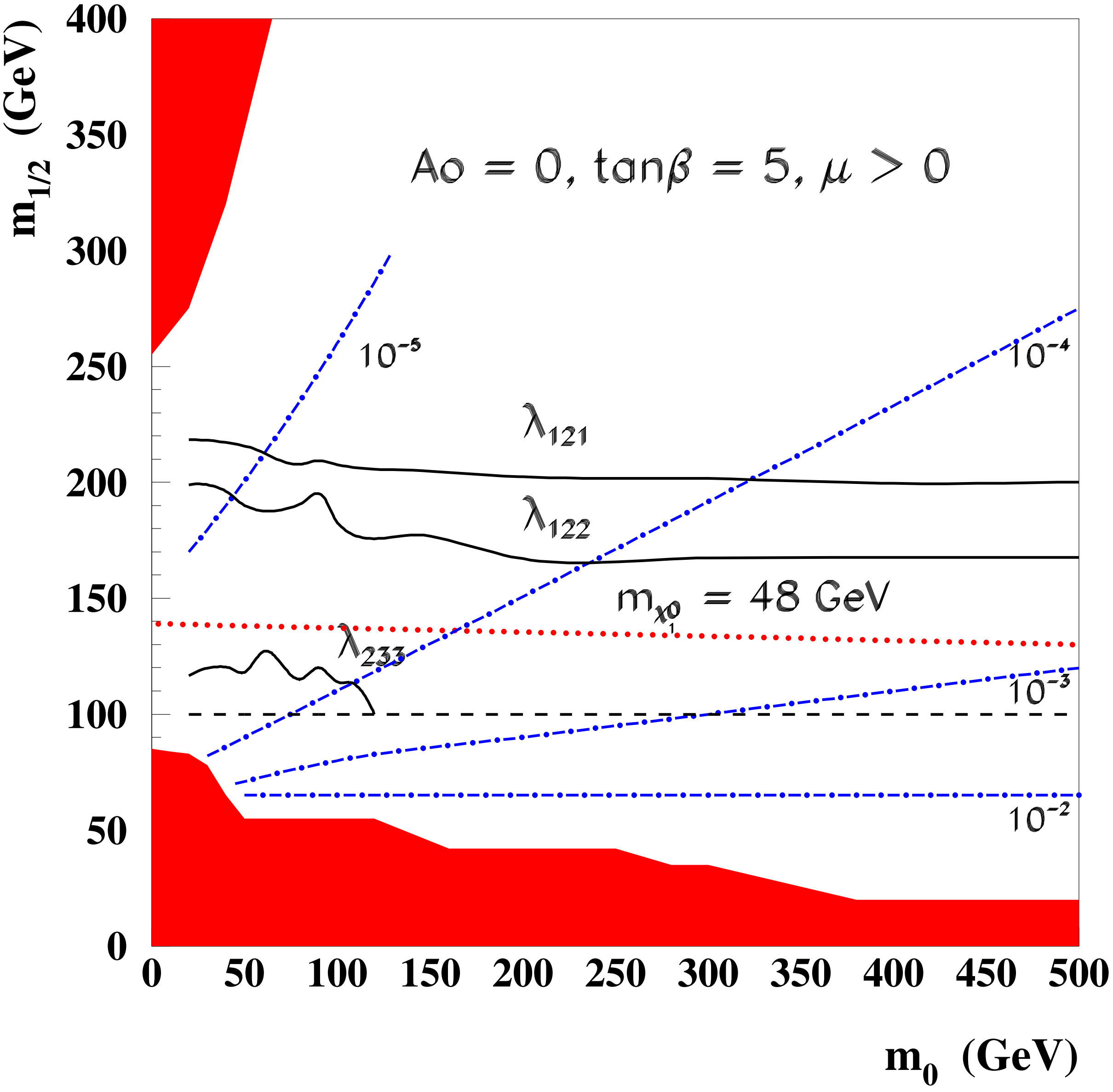

FIG. 2. Exclusion contours at 95% C.L. limits for $\tan\beta = 5$, $\mu > 0$, for the case of finite λ_{121}, λ_{122} and λ_{233} couplings.

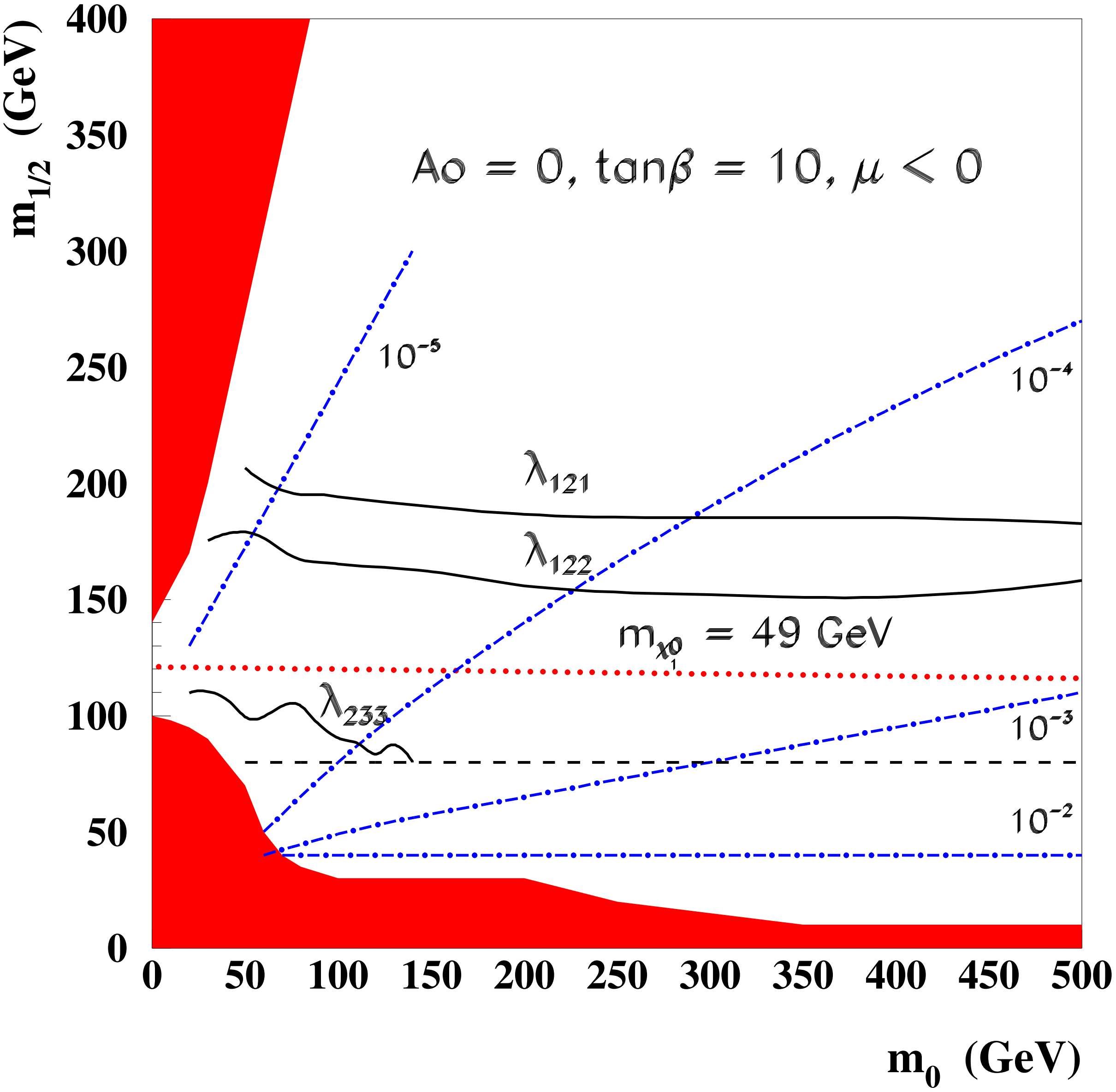

FIG. 3. Exclusion contours at 95% C.L. limits for $\tan\beta = 10$, $\mu < 0$, for the case of finite λ_{121}, λ_{122} and λ_{233} couplings.

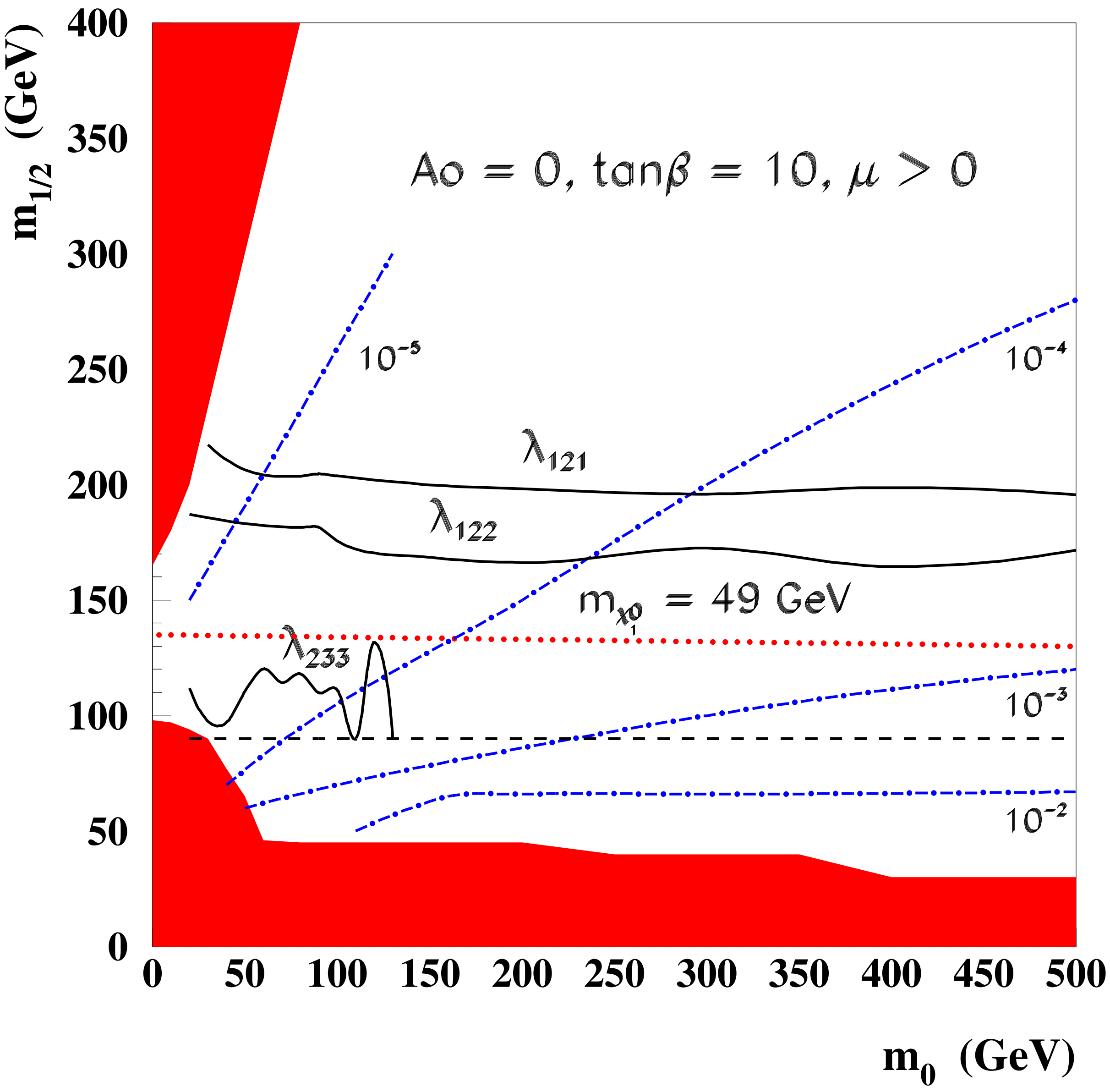

FIG. 4. Exclusion contours at 95% C.L. limits for $\tan\beta = 10$, $\mu > 0$, for the case of finite λ_{121}, λ_{122} and λ_{233} couplings.

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