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Higgs boson signatures of MSSM electroweak baryogenesis

Arjun Menon[1] and David E. Morrissey[2]

[1]Michigan Center for Theoretical Physics (MCTP) Physics Department, University of Michigan, Ann Arbor, Michigan 48109, USA
[2]Jefferson Physical Laboratory, Harvard University, Cambridge, Massachusetts 02138, USA
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Electroweak baryogenesis in the minimal supersymmetric standard model can account for the cosmological baryon asymmetry, but only within a restricted region of the parameter space. In particular, minimal supersymmetric standard model electroweak baryogenesis requires a mostly right-handed stop that is lighter than the top quark and a standard model-like light Higgs boson. In the present work we investigate the effects of the light stop on Higgs boson production and decay. Relative to the standard model Higgs boson, we find a large enhancement of the Higgs production rate through gluon fusion and a suppression of the Higgs branching fraction into photon pairs. These modifications in the properties of the Higgs boson are directly related to the effect of the light stop on the electroweak phase transition, and are large enough that they can potentially be tested at the Tevatron and the LHC.

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I. INTRODUCTION

Supersymmetry is a well-motivated solution to the gauge hierarchy problem [1]. Within the minimal supersymmetric extension of the standard model (SM), the MSSM, it is remarkable that one also finds an excellent unification of gauge couplings, a candidate for the dark matter, and the potential to generate the baryon asymmetry of the Universe. In particular, the baryon asymmetry can arise in the MSSM through the mechanism of electroweak baryogenesis (EWBG) [2,3].

While MSSM EWBG can account for the baryon excess, it can only do so within a specific and tightly constrained region of the MSSM parameter space. Successful EWBG requires a significant new source of a*CP* violation beyond the Cabibbo-Kobayashi-Maskawa phase of the SM [4,5], and a strongly first-order electroweak phase transition [2]. Together, these requirements, along with corresponding phenomenological bounds, largely fix the superpartner spectrum of the MSSM.

New sources of *CP* violation are strongly constrained by searches for permanent electric dipole moments (EDMs) of atoms, neutrons, and electrons [6]. MSSM EWBG requires a significant phase in a light electroweak gaugino-Higgsino (chargino and neutralino) sector [7–10].[1] Such phases induce EDMs at one-loop order through quantum corrections involving first- and second-generation squarks and sleptons [12]. To avoid the experimental bounds on permanent EDMs, these sfermions must be heavier than about 10 TeV [13–16]. At two-loop order there arise quantum corrections involving charginos and Higgs bosons that cannot be decoupled in this way [17–20], further constraining the allowed MSSM parameter space [14–17,21–23].

[1]Contributions from *CP*-violating phases in the squark sector are suppressed by the heavy masses of these states [7], even when these phases are flavor-dependent [11].

Successful EWBG also requires a strongly first-order electroweak phase transition. This can be achieved within the MSSM if the lightest Higgs boson is SM-like, and one of the scalar top quarks (stops) is very light [24,25]. Precision electroweak constraints force the light stop to be mostly right handed. On the other hand, the LEP-II bound on the light SM-like Higgs boson mass of 114.7 GeV [26] implies that the second mostly left-handed stop must be much heavier. A recent re-analysis of the electroweak phase transition within the MSSM indicates that the acceptable stop and Higgs sector parameters lie within the ranges [27]

$$\begin{aligned} (-150\ \mathrm{GeV})^2 \lesssim m_{\tilde{t}_R}^2 &\lesssim -(50\ \mathrm{GeV})^2, \\ 0 \lesssim |A_t - \mu\cot\beta|/m_{Q_3} &\lesssim 0.7, \\ m_{Q_3}^2 &\gtrsim (6\ \mathrm{TeV})^2, \\ 5 \lesssim \tan\beta &\lesssim 15. \end{aligned} \tag{1}$$

The tachyonic right-handed stop mass implies that the lightest stop mass eigenstate is lighter than the top quark. It also implies that the standard electroweak vacuum is only metastable against decay to a deeper color-breaking vacuum, but this is acceptable provided the electroweak vacuum forms first and is sufficiently long lived [7,27]. In the region consistent with viable EWBG, the light-stop mass as well as the light Higgs boson mass are both found to lie below 125 GeV [27].

Together, the dual requirements of new *CP* violation and a strongly first-order electroweak phase transition largely fix the MSSM super particle spectrum: all sfermions other than the mostly right-handed stop (and possibly a right-handed sbottom) must be very heavy, while the electroweak gauginos and Higgsinos must remain relatively light. This spectrum is challenging to study at the LHC. The first- and second-generation squarks and sleptons are typically too heavy to be produced directly or to play a significant role in decay cascades. Some information can be obtained about the electroweak gauginos and Higgsinos from electroweak production [16], although the reach is severely diminished if these states decay significantly into the light stop [28]. This leaves the light stop, and possibly a lighter gluino, as the primary sources of LHC signals.

Despite being produced very abundantly, a light mostly right-handed stop is difficult to probe at the LHC. Direct searches for a light stop at the Tevatron require this state to be relatively degenerate with the lightest supersymmetric particle (LSP) or to decay primarily into three- or four-body modes [29–32]. Indeed, a light stop that is nearly degenerate with a mostly Bino neutralino LSP can lead to an acceptable thermal relic density through coannihilation between these states [14,30]. This near degeneracy implies that the decay products of the light stop will be soft and difficult to tag.

A number of studies have investigated ways to probe this light-stop scenario at the LHC [33–38]. Ref. [33] proposed an indirect search for light stops through di-gluino production with decays into same-sign top quarks. With sufficient luminosity, this provides an LHC discovery mode for gluino masses up to about 1000 GeV, although parameter determination is challenging [33,35]. Making use of the very large stop production rate at the LHC, Ref. [36] proposed a search for stops in association with a hard photon or a gluon jet. The additional tag provides a trigger that can be combined with a cut on missing E_T in the event to provide a viable monojet or monophoton signature of the light stop when it is nearly degenerate with the LSP [36]. With a very small mass difference between the stop and a neutralino LSP, the flavor-violating decay mode $\tilde{t}_1 \to c\tilde{\chi}_1^0$ can lead to a displaced vertex in the context of minimal flavor violation [37]. Light stops can also form stoponium, which may potentially be detected through its decays to diphotons [38].

In the present work we show that the light stop required for EWBG in the MSSM leads to significant modifications of the production and decay rates of the Higgs boson relative to the SM. It is well known that new light colored particles, and the scalar tops of the MSSM, in particular, can have a significant effect on the Higgs production rate through gluon fusion [39–43]. The light stop required for electroweak baryogenesis is unique in that it pushes these effects to their limits. On account of the large hierarchy between the masses of the heavy sfermions and the light stop implied by MSSM EWBG, we make use of an effective theory in which the heavy states are integrated out explicitly to compute the low-energy Higgs-stop couplings [44]. The changes in the properties of the Higgs boson induced by the light stop are directly related to the effects of the light stop on the electroweak phase transition. A measurement of these shifts at the LHC (and other colliders) would therefore provide direct information about the nature of the electroweak phase transition.

The outline of this papers is as follows: In Sec. II, we compute the effects of a light stop on Higgs boson production and decay in the context of MSSM EWBG. We discuss the implications of these results for Higgs boson searches at the Tevatron and LHC in Sec. III. Section IV is reserved for our conclusions. Some additional discussion of parameter dependences is collected in Appendix A.

II. GLUON FUSION AND DI-PHOTON DECAYS

The dominant Higgs boson production mode at the Tevatron and the LHC is gluon fusion $gg \to h^0$ [45,46]. In the SM, this process is dominated by a top quark loop. If the SM is extended to include new colored particles coupling to the Higgs boson, such as stops in supersymmetry, they too will run in loops and contribute to the amplitude for this process. The interference with the top can be constructive or destructive, depending on the spin of the new particle and its couplings to the Higgs boson.

For a lighter SM-like Higgs boson, with mass below about 130 GeV, the most effective discovery mode at the LHC is through its decays to photon pairs [45,46]. This process arises from loops containing charged particles. In the SM, the leading contribution to the amplitude comes from the $W^\pm$ gauge bosons, while the top quark provides a smaller contribution that interferes destructively. When the SM is extended to include new charged states, these exotics will also contribute to the diphoton Higgs width.

The Higgs sector of the MSSM is extended beyond the SM to include a pair of $SU(2)_L$ doublets, and many new charged and colored states couple to these doublets. Even so, in much of the MSSM parameter space consistent with current collider bounds, the phenomenology of the lightest Higgs boson is very similar to that of the SM Higgs. The direct Higgs search bounds from LEP II generally prefer larger values of the Higgs pseudoscalar mass parameter $M_{A^0} \gg M_Z$ to push up the mass of the lightest CP-even Higgs boson h^0 [45,46]. In this limit, the couplings of the h^0 state to SM particles are nearly identical to those of the SM Higgs, up to corrections on the order of $M_Z^2/M_{A^0}^2$ from mixing with the other Higgs states, and loop effects due to the superpartners. For superpartner masses above a few hundred GeV, these loop corrections tend to be fairly mild, and the properties of the h^0 state are very similar to those of the SM Higgs boson [41].

In the small corner of the MSSM parameter space that is consistent with generating the baryon asymmetry through EWBG, there exists a very-light, mostly right-handed stop [27]. This state is unusual, compared to the other superpartners in this scenario, as well as the stops that are usually considered in other supersymmetric scenarios, in that it derives most of its mass from the vacuum expectation values of the Higgs fields. As such, its effect on Higgs production and decay is potentially comparable to that of the top quark. It is precisely this effect that we investigate in the present work.

At tree level in the MSSM, when the right-handed stop soft mass $m_{U_3}^2$ is much smaller than the left-handed soft mass $m_{Q_3}^2$ and there is not much left-right stop mixing, the coupling of the lighter mostly right-handed stop to the SM-like Higgs boson is given by [44]

$$g_{h^0\tilde{t}_1\tilde{t}_1^*} \simeq \sqrt{2}v\left[|y_t|^2\sin^2\beta\left(1-\frac{|X_t|^2}{m_{Q_3}^2}\right)+\frac{1}{3}g'^2\cos 2\beta\right], \quad (2)$$

where $X_t = (A_t - \mu\cot\beta)$, and we normalize $v = 174$ GeV. When this coupling is positive, the light-stop loops contributing to gluon fusion and diphoton decay interfere constructively with the loops of the top quark. This coupling, when it is positive, is also proportional to the Higgs-stop interaction responsible for generating a strongly first-order electroweak phase transition in MSSM EWBG [3,24,25]. Thus, this scenario prefers weaker left-right stop mixing, and the increase in the strength of the phase transition is directly related to the effect of the light stop on the properties of the h^0 Higgs boson. In contrast, when this coupling is negative or when there is strong left-right stop mixing [for which the expression of Eq. (2) is no longer valid] the interference of the stop loops with the top loops is destructive [42].[2]

The $h^0\tilde{t}_1\tilde{t}_1^*$ coupling of Eq. (2) receives corrections enhanced by large logarithms of the ratio $m_{Q_3}^2/|m_{U_3}^2| \gg 1$ in the light-stop scenario motivated by MSSM EWBG. To resum these logs, the heavy supersymmetry and Higgs states should be integrated out at their mass thresholds [44]. The resulting effective theory consists of the SM with a single Higgs boson h^0 augmented by a light stop $\tilde{t}_1$ and lighter gauginos and Higgsinos. Equivalently, the effective theory coincides with the spectrum of focus point [47], PeV scale [48], or split supersymmetry [49] with an additional light stop. The matching and running conditions for this effective theory are computed in Ref. [44], where all the heavy sfermions and heavy Higgs states are integrated out at a universal large mass scale M; $m_{Q_3}^2 = M^2 = M_A^2$, etc.

In this *light-stop effective theory* (LST), the coupling of the stop to the Higgs boson comes from the operator

$$\mathfrak{L} \supset -Q|\tilde{t}_1^2||H|^2, \quad (3)$$

where $\tilde{t}_1$ is the light stop and $H = v + h^0/\sqrt{2}$ is the Higgs field. The coupling Q is obtained by matching at the scale M, where all the heavy Higgs bosons and sfermions are integrated out. The matching condition is

$$Q(M) = g_{h^0\tilde{t}_1\tilde{t}_1^*}(M)/\sqrt{2}v + (\text{threshold corrections}), \quad (4)$$

where $g_{h^0\tilde{t}_1\tilde{t}_1^*}$ is as in Eq. (2) with running parameters evaluated at scale M, and the threshold corrections are given in Ref. [44].

The coupling relevant at lower scales, on the order of the Higgs mass, is obtained by renormalization group evolution in the effective theory down from the scale M. Expanding the Higgs field about its vacuum expectation value, the interaction of Eq. (3), evaluated near the Higgs boson mass scale, then generates the effective $h^0\tilde{t}_1\tilde{t}_1^*$ coupling and contributes to the light-stop mass according to

$$g_{h^0\tilde{t}_1\tilde{t}_1^*} = \sqrt{2}vQ, \qquad m_{\tilde{t}_1}^2 = m_{U_3}^2 + Qv^2. \quad (5)$$

The coupling Q is also responsible for driving the electroweak phase transition to be first order when it is positive. Therefore, the effects of the light stop on the properties of the Higgs boson are in direct proportion to the role of the light stop in the electroweak phase transition.

In Fig. 1 we show the value of the coupling Q at the light Higgs mass scale in the LST as well as the uncorrected tree-level value $g_{h^0\tilde{t}_1\tilde{t}_1^*}/\sqrt{2}v$ given in Eq. (2), evaluated using running parameters. We also set $m_{U_3}^2 = -(80\text{ GeV})^2$, $\tan\beta = 10$, $M = 10$, 1000 TeV, and we assume the gluino is light and do not integrate it out explicitly. The tree-level and LST couplings are very similar for $|X_t|/M \sim 0$ but deviate significantly as this ratio grows, illustrating the improvement from the effective theory treatment.

To compute the effect of the light stop on Higgs boson production and decay, we input the Higgs-stop coupling as well as the Higgs boson and light-stop masses computed in the LST into CPSuperH [50]. We use a top quark mass of $m_t = 172.4$ GeV, and the gaugino/Higgsino parameters $\mu = 190$ GeV, $M_2 = 200$ GeV, $M_1 = 100$ GeV, $M_3 = 700$ GeV. As in Ref. [44], we assume all sfermions other

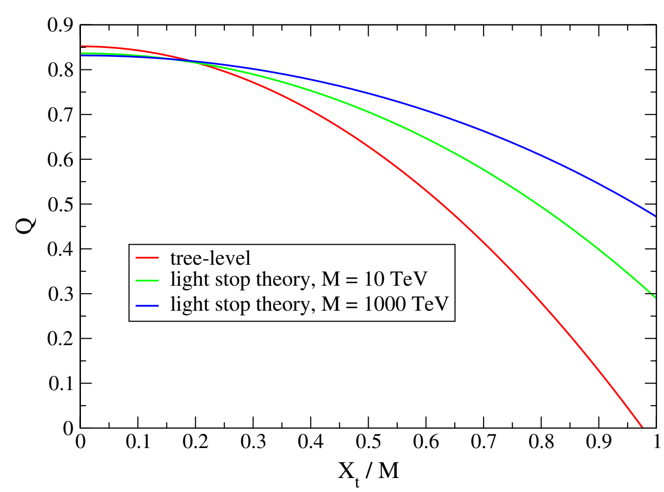

FIG. 1 (color online). Value of the low-energy Higgs-stop coupling Q computed at tree level, and using the light-stop effective theory. The relevant model parameter values are taken to be $m_{U_3}^2 = -(80\text{ GeV})^2$, $\tan\beta = 10$, and $M = m_{Q_3} = 10$, 1000 TeV.

[2]The relevant expansion parameter for small left-right stop mixing is $m_tX_t/m_{Q_3}^2$. This quantity is always small in the light-stop MSSM EWBG scenario, even for $|X_t|/m_{Q_3} \sim 1$, on account of the hierarchy $m_t/m_{Q_3} \lll 1$.

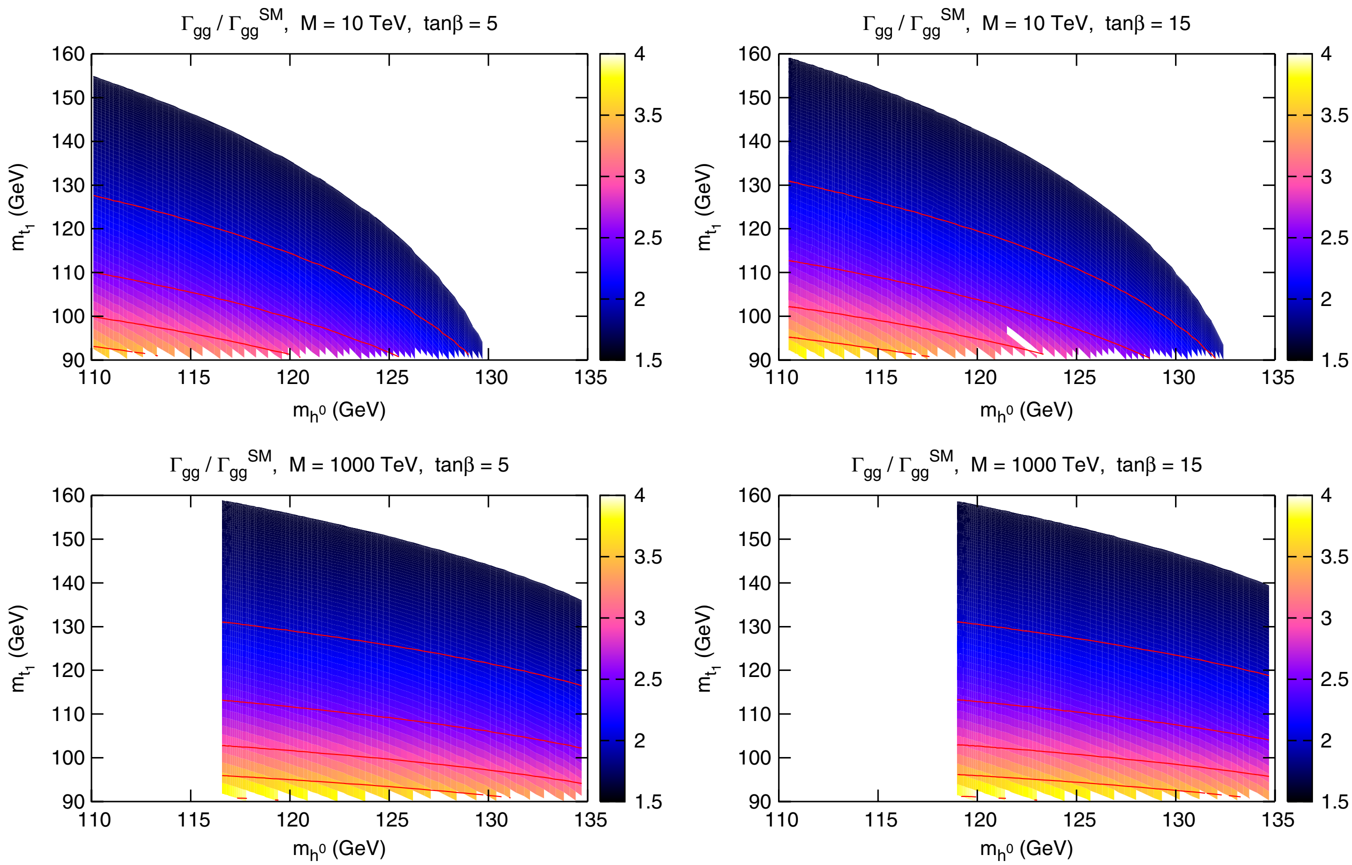

FIG. 2 (color online). Higgs boson decay width to gluons $\Gamma(h^0 \to gg)$ relative to the SM as a function of m_{h^0} and $m_{\tilde{t}_1}$ for $M = 10$, 1000 TeV and $\tan\beta = 5$, 15.

than the light stop and all Higgs bosons other than the h^0 are very heavy with a common mass M. Unlike the sfermions, MSSM EWBG does not require that the heavy Higgs states be much heavier than the electroweak scale with $M_A \simeq M$. However, $M_A \gg M_Z$ helps to induce a strongly first-order phase transition [51], and relaxing the assumption of $M_A \sim M$ will only modify our results by corrections on the order of M_Z^2/M_A^2 [45,46]. In our treatment we also remove by hand the finite corrections to the Yukawa couplings from heavy superpartners since these decouple as $M \to \infty$ provided the gluino and Higgsinos remain relatively light [52].

In Fig. 2 we show the ratio of the decay width of the Higgs boson to a pair of gluons $\Gamma(h^0 \to gg)$ computed in the LST relative to the value in the SM with the same value of the Higgs boson mass as a function of m_{h^0} and $m_{\tilde{t}_1}$ for $\tan\beta = 5$, 15 and $M = 10$, 1000 TeV. In generating these figures we scan over the ranges $-(150\ \text{GeV})^2 \leq m_{U_3}^2 \leq (0\ \text{GeV})^2$ and $0 \leq |X_t/M| \leq 0.9$. These parameter ranges are a superset of the values that are consistent with a strongly first-order phase transition required for EWBG. (We also exhibit the dependence of the physical masses $m_{\tilde{t}_1}$ and m_{h^0} on the underlying Lagrangian parameters in Appendix A.)

From Fig. 2 we see a significant enhancement in the decay width to gluons relative to the SM by as much as a factor of 4. Since this decay width is nearly proportional to the Higgs production rate through gluon fusion at hadron colliders at leading order (LO), including the Tevatron at $\sqrt{s} = 1.96$ TeV and the LHC at $\sqrt{s} = 10$–14 TeV, our results imply a strong enhancement in this production mode.[3] The enhancement is greatest for smaller values of the Higgs boson m_{h^0} and stop $m_{\tilde{t}_1}$ masses, corresponding to smaller values of $m_{U_3}^2$ and $|X_t|/m_{Q_3}$. Indeed, it is for these smaller mass values that the electroweak phase transition can be strong enough to allow viable EWBG. The recent analysis of Ref. [27] finds that this region falls within the lower-left corner of the $m_h^0 - m_{\tilde{t}_1}$ plane with $m_{\tilde{t}_1}, m_{h^0} <$ 125 GeV, where the enhancement is greater than a factor of 2.

[3]Our computation of the $\Gamma(h^0 \to gg)$ width is at LO. While next-to-leading order corrections are significant, their effect is to rescale both the SM and squark LO contributions to the production rate in nearly the same way [41,53,54]. Thus, we expect the bulk of these higher-order corrections to cancel in the ratios of decay widths, interpreted as ratios of gluon fusion production rates, which we display.

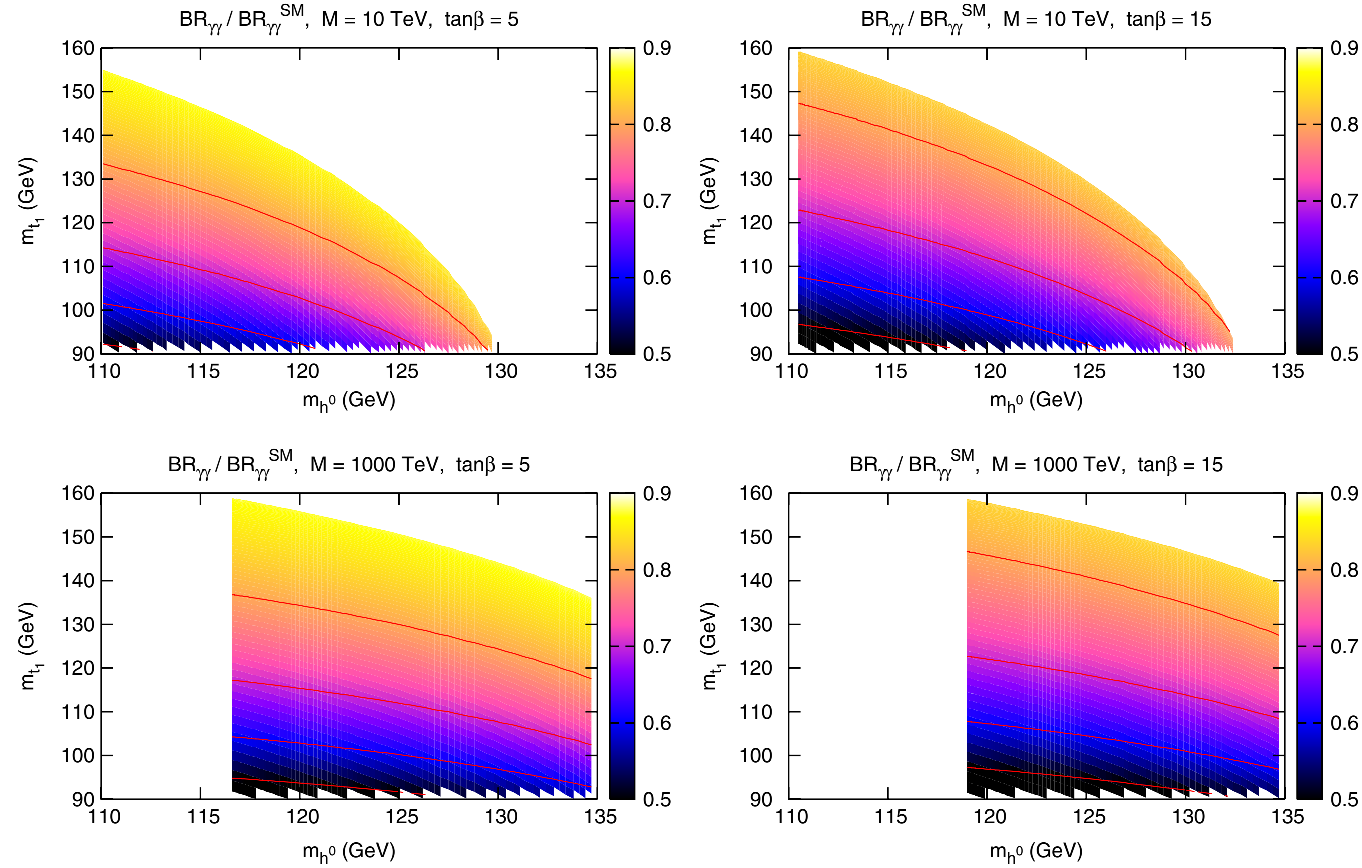

FIG. 3 (color online). Higgs boson branching fraction to diphotons $BR(h^0 \to \gamma\gamma)$ relative to the SM as a function of m_{h^0} and $m_{\tilde{t}_1}$ for $M = 10$, 1000 TeV and $\tan\beta = 5$, 15.

We show in Fig. 3 the value of the branching fraction $BR(h^0 \to \gamma\gamma)$ in the light-stop scenario relative to the SM for the same value of the Higgs boson mass as a function of m_{h^0} and $m_{\tilde{t}_1}$. As above, we consider $\tan\beta = 5, 15$ and $M = 10$, 1000 TeV, and scan over the ranges $-(150\text{ GeV})^2 \leq m^2_{U_3} \leq (0\text{ GeV})^2$ and $0 \leq |X_t/M| \leq 0.9$. The diphoton branching fraction is significantly suppressed, particularly for the lower values of $m_{\tilde{t}}$ and m_{h^0} favored by EWBG. The suppression originates from two sources. First, there is destructive interference between the stop and the $W^{\pm}$ gauge bosons in the loop-level amplitude for $h^0 \to \gamma\gamma$. Second, the enhancement of the Higgs boson decay width into gluons increases the total decay width, thereby diluting the fraction of decays to photon pairs. Between these two effects, the suppression factor for $BR(h^0 \to \gamma\gamma)$ relative to the SM is always less about 0.7 and as small as 0.5 within the region of parameters consistent with EWBG. The light charginos that are also required for successful EWBG can further modify the Higgs boson decay width to diphotons. We find that this effect is less than about 5% once the LEP-II bound of 104 GeV is imposed on the lightest chargino [55].

In Fig. 4 we show contours of the total inclusive $pp \to h^0 \to \gamma\gamma$ production rate in the light-stop scenario relative to the SM with the same value of the Higgs boson mass as a function of m_{h^0} and $m_{\tilde{t}_1}$. As above, we consider $\tan\beta = 5$, 15 and $M = 10$, 1000 TeV, and scan over the ranges $-(150\text{ GeV})^2 \leq m^2_{U_3} \leq (0\text{ GeV})^2$ and $0 \leq |X_t/M| \leq 0.9$. We also assume that gluon fusion makes up 83% of the inclusive production rate before including the enhancement from a light stop, which is approximately the expected fraction contributing to the inclusive signal for a light SM Higgs boson at the LHC with $\sqrt{s} = 14$ TeV [56,57]. From Figs. 2 and 3 we know that the Higgs boson production rate through gluon fusion is enhanced, while the branching ratio into diphotons is suppressed. The total rate is approximately proportional to the product of these quantities. This product is ultimately enhanced in the light-stop scenario because the stop loop interferes constructively with the top quark loop in the production rate and destructively with a more dominant $W^{\pm}$ loop in the decay width to diphotons. In the region of parameter space consistent with a strongly first-order phase transition, the inclusive production rate is enhanced by a factor between 1.4 and 1.6.

The light stop in the MSSM EWBG scenario will also lead to modifications of other Higgs boson search channels. There will be an enhancement in all channels for

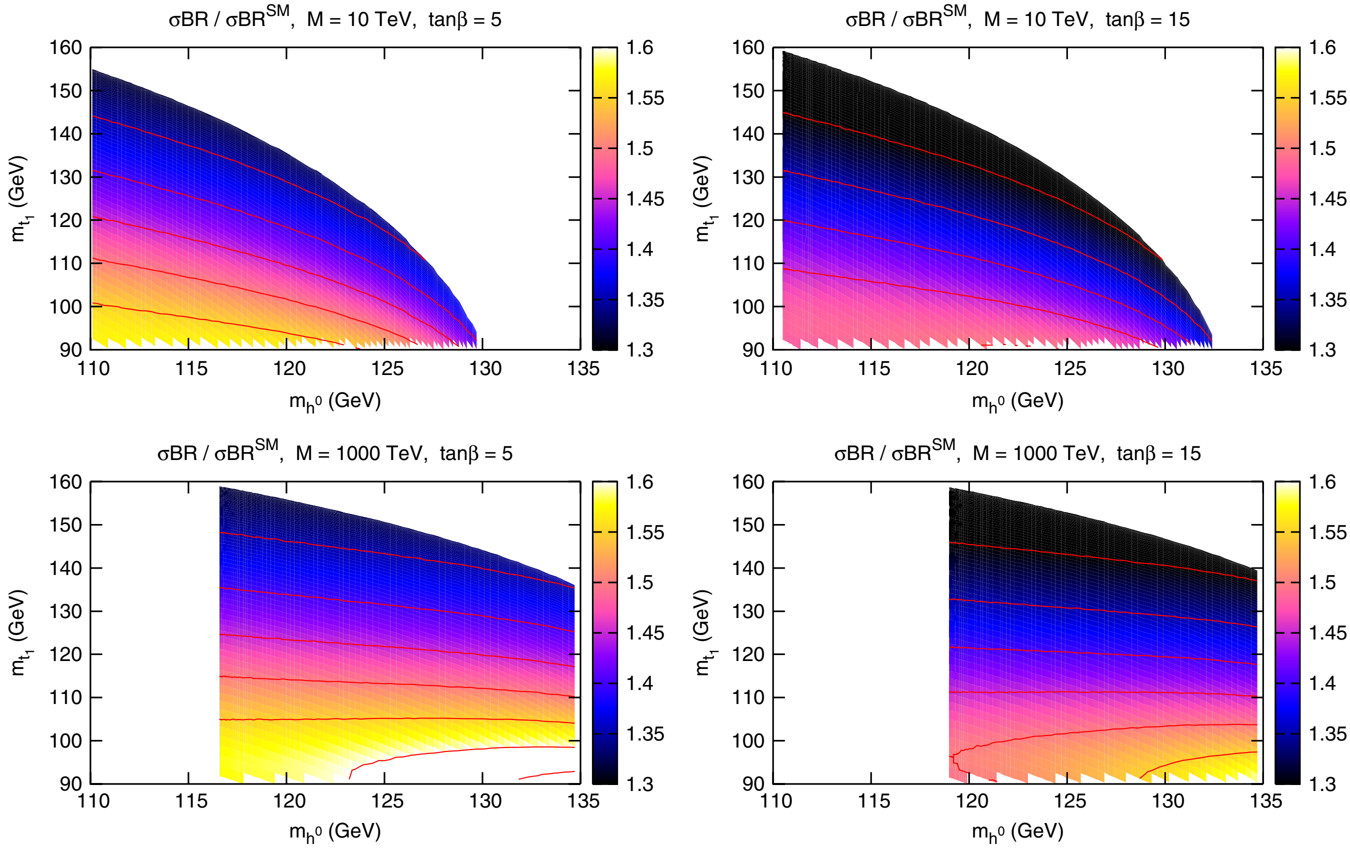

FIG. 4 (color online). Inclusive $pp \to h^0 \to \gamma\gamma$ production rate at the LHC relative to the SM as a function of m_{h^0} and $m_{\tilde{t}_1}$ for $M = 10$, 1000 TeV and $\tan\beta = 5$, 15.

which gluon fusion is the dominant production mechanism. For example, the rate for inclusive $pp \to h^0 \to ZZ^*$ at the LHC (assuming the gluon fusion makes up 83% of the total rate) is increased by a factor of 1.75–3 within the parameter region consistent with viable EWBG. On the other hand, the suppression in the $h^0 \to \gamma\gamma$ branching fraction reduces proportionally the signal rates from Higgs production through vector-boson-fusion (VBF) or in association with $t\bar{t}$ or W/Z. Interesting further possibilities that we do not explore are Higgs boson production in association with light stops [58,59], or a modification of the Higgs self-couplings [60].

III. PROSPECTS AT THE TEVATRON AND LHC

The results of the previous section indicate that within the parameter region consistent with MSSM EWBG the production and decay of modes of the h^0 Higgs boson are significantly modified relative to the SM by the presence of a light stop. Measuring Higgs boson couplings at the Tevatron and LHC will be extremely challenging, and will require both a large amount of integrated luminosity and a detailed understanding of systematics. Even so, the effects of a light stop consistent with MSSM EWBG on h^0 Higgs boson observables are large enough that they can likely be distinguished from a SM Higgs boson by LHC data, and may also have a discernible impact on Tevatron Higgs searches.

Before discussing the future prospects of detecting this scenario, let us also point out that the modifications of the Higgs properties induced by a light stop do not run afoul of existing collider bounds or modify the limits imposed by previous Higgs boson searches. The most stringent bound comes from LEP II, which places a lower limit on the SM Higgs boson mass of 114.7 GeV [26]. This limit also applies to the h^0 state in the light-stop scenario.

Present limits from the Tevatron strongly constrain a SM Higgs boson with mass near 160 GeV through searches for inclusive Higgs production with decays to W^+W^- [61]. For lighter SM-like Higgs bosons with $m_{H^0} \lesssim 125$ GeV, the Tevatron bounds are much weaker and are dominated by the W/Z associated production channels with decays to $b\bar{b}$. These will not be significantly modified by the presence of a light stop. Among the inclusive search channels (dominated by gluon fusion) that will be enhanced by a light stop, the most promising is $h^0 \to WW^*$. Current Tevatron data with 3.0 fb^{-1} of integrated luminosity constrain the total rate for this mode, for $m_{h^0} \lesssim 125$ GeV, to be less than about 8 times that predicted by the SM [62,63]. We find the enhancement in the light-stop scenario consistent with EWBG to be in the range of 2–4 times the SM. However, with the projected integrated luminosity on the order of 10 fb^{-1} and expected improvements in Higgs search analyses [61], the Tevatron may potentially be able to probe the enhancement in inclusive Higgs production due to a light stop through this channel, particularly for h^0 masses toward the upper range (~ 125 GeV) of what is consistent with EWBG.

At the LHC, the most effective search mode for a light SM-like Higgs boson with $m_{h^0} \lesssim 135$ GeV is inclusive $h^0 \to \gamma\gamma$ [56,57]. This channel also allows for a precise measurement of the Higgs boson mass with an uncertainty below 0.2 GeV with 30 fb^{-1} of data [56]. Inclusive $h^0 \to ZZ^* \to 4\ell$, as well as $h^0 \to \gamma\gamma$ and $h^0 \to \tau\tau$ through VBF, and $h^0 \to \gamma\gamma$ via production in association with W/Z or $t\bar{t}$ are also relevant with a large integrated luminosity [56,57]. Including the effects of a light stop, the inclusive $h^0 \to \gamma\gamma$ and $h^0 \to ZZ^*$ channels are significantly enhanced, while the net rates for $h^0 \to \gamma\gamma$ through VBF or associated production are somewhat suppressed. By comparing the rates for these various channels, it may be possible to detect the enhancement in the gluon fusion rate from a light stop.

A program to extract Higgs boson couplings from LHC data was outlined in Refs. [64–66]. The estimated rates and systematic uncertainties (mostly from higher-order corrections, PDFs, and luminosity) used in Refs. [64–66] stand up quite well to the more recent analyses of Refs. [56,57] with the exception of the $t\bar{t}h \to t\bar{t}b\bar{b}$ channel, which does not play an important role in extracting the Higgs decay width to gluons or photons. Refs. [64–66] find that the partial width $\Gamma(h^0 \to gg)$ can be determined for a SM Higgs boson with a 1σ error of 30% (90%) with 200 fb^{-1} (30 fb^{-1}) of integrated luminosity. This estimate is obtained primarily from a comparison of the inclusive $h^0 \to \gamma\gamma$ rate to that from VBF, and assumes SM-strength Higgs boson couplings to the electroweak gauge bosons.

The analysis of Refs. [64–66] can be applied directly to the light-stop scenario, for which the assumption of SM-strength electroweak gauge boson couplings holds to an excellent approximation. The reduction in the VBF diphoton signal will increase the statistical error on the determination of $\Gamma(h^0 \to gg)$, but the effect will be small (for 200 fb^{-1} of data) relative to the assumed 20% systematic uncertainty on the (SM) gluon fusion rate. Thus, we expect an uncertainty on the gluon width of about 30% with 200 fb^{-1} of data. Given the light-stop enhancement of this width by a factor of at least two in the region consistent with EWBG, the enhancement in the gluon decay width relative to the SM can be detected at the LHC with a significance greater than 3σ.

A similar estimate can be obtained using the updated ATLAS detector-level analysis of Ref. [57]. Here, the comparison would be between the rates for the inclusive $h^0 \to \gamma\gamma$ channel and the diphoton channels in association with one or two hard jets. The inclusive channel is dominated by gluon fusion, while the channels involving additional jets receive a larger contribution from VBF. For a light stop in the MSSM EWBG region, the enhancements in these channels relative to the SM are by factors of about 1.6, 1.2, 0.7, respectively. Based on statistics alone, we find that it will be possible to easily distinguish this pattern from the SM with 200 fb^{-1} of data. To be effective when systematics are included, however, a better understanding of the gluon fusion contribution to the two-jet channel is needed [57].

It will be more challenging to directly probe the effect of the light stop on $\Gamma(h^0 \to \gamma\gamma)$. Refs. [64–66] find that this width can be determined for a SM Higgs boson with an error of 20% (40%) with 200 fb^{-1} (30 fb^{-1}) of data. With a light stop, the reduction in $BR(h^0 \to \gamma\gamma)$ will further degrade the statistics in the nongluon fusion production modes. Thus, it does not appear to be possible to see the stop effects on $\Gamma(h^0 \to \gamma\gamma)$ above the 2σ level. However, relative to Refs. [64–66], a very light stop enhances the prospects for $h^0 \to ZZ^* \to 4\ell$. The ratio of this rate to that for inclusive $h^0 \to \gamma\gamma$ may allow for an improved test of the effect of the light stop on $\Gamma(h^0 \to \gamma\gamma)$ for Higgs boson masses toward the upper end of the range consistent with MSSM EWBG, although it will be limited by statistics.

Let us emphasize that the estimates made above based on Refs. [64–66] are conservative, in that improvements in the systematic uncertainties associated with Higgs boson production and decay at the LHC are likely to further improve the determination of Higgs couplings. For example, Refs. [64–66] assumed a 20% error in the prediction for the SM gluon fusion rate. Significant progress has been made recently in computing this rate at higher orders with the inclusion of electroweak corrections [67–69], along with a resummation of the apparent leading loop-level enhancements [70]. Together, these indicate perturbative uncertainty less than 3%, down from about 10% [70]. There is an additional estimated 10% uncertainty from the parton distribution functions [71], which could potentially be reduced with LHC data [72,73]. Along with a large amount of luminosity, these and future advances may make it possible to observe the effect of a light stop on $\Gamma(h^0 \to \gamma\gamma)$, and to even estimate the Higgs-stop coupling Q within the context of this scenario. A reduction in the various systematic uncertainties would also greatly improve the ability of the SLHC to probe Higgs boson couplings [74].

VI. CONCLUSIONS

MSSM EWBG can account for the baryon asymmetry of the Universe provided the lightest CP-even Higgs boson h^0 is SM-like and there exists a mostly right-handed stop that is significantly lighter than the top quark. In the present work we have investigated the effect of this light stop on h^0 Higgs boson production and decay. We find a significant enhancement in the Higgs production rate through gluon fusion and a less pronounced suppression of the Higgs boson branching fraction to pairs of photons. The enhancement in $\Gamma(h^0 \to gg)$ is large enough that it can potentially be detected at the LHC after several years of running.

Similar enhancements of the gluon fusion rate can arise in a variety of contexts, such as with fourth-generation [75–77] or exotic quarks [78,79]. On the other hand, the rate for gluon fusion is suppressed within the *golden region* of the MSSM where fine-tuning is minimized [42,43], as well as in many little Higgs models [80], and in other contexts [81–84]. Within the MSSM, the observation of an enhancement in the gluon fusion Higgs production rate would provide evidence for a light stop that is complementary to direct collider searches for this state. While these direct search channels can provide a more efficient stop discovery mode, they often do not yield much information about the nature of the electroweak phase transition or the composition of the light-stop state. The observation of direct stop signals in combination with modified Higgs boson production and decay signatures would together provide evidence in favor of MSSM EWBG and a direct test of the strength of the electroweak phase transition.

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APPENDIX: HIGGS AND STOP MASS DEPENDENCE

We collect here several plots of h^0 Higgs boson and $\tilde{t}_1$ stop masses as functions of the underlying MSSM parameters. In Fig. 5 we show contours of the Higgs boson mass as a function of the underlying parameters m_{U_3} and $|X_t|/M$ for $\tan\beta = 5$, 15 and $M = 10$, 1000 TeV computed at one-loop order in the LST. In generating these figures we scan over the ranges $-(150\text{ GeV})^2 \leq m_{U_3}^2 \leq (0\text{ GeV})^2$ and $0 \leq |X_t/M| \leq 0.9$, and use a top quark mass of $m_t = 172.4$ GeV. The unfilled regions of these plots correspond to areas where $m_{h^0} < 110$ GeV or $m_{\tilde{t}_1} < 90$ GeV. These limits are slightly weaker than the current LEP-II mass bounds: $m_{h^0} > 114.7$ GeV, and $m_{\tilde{t}_1} > 95.7$ GeV [26]. We

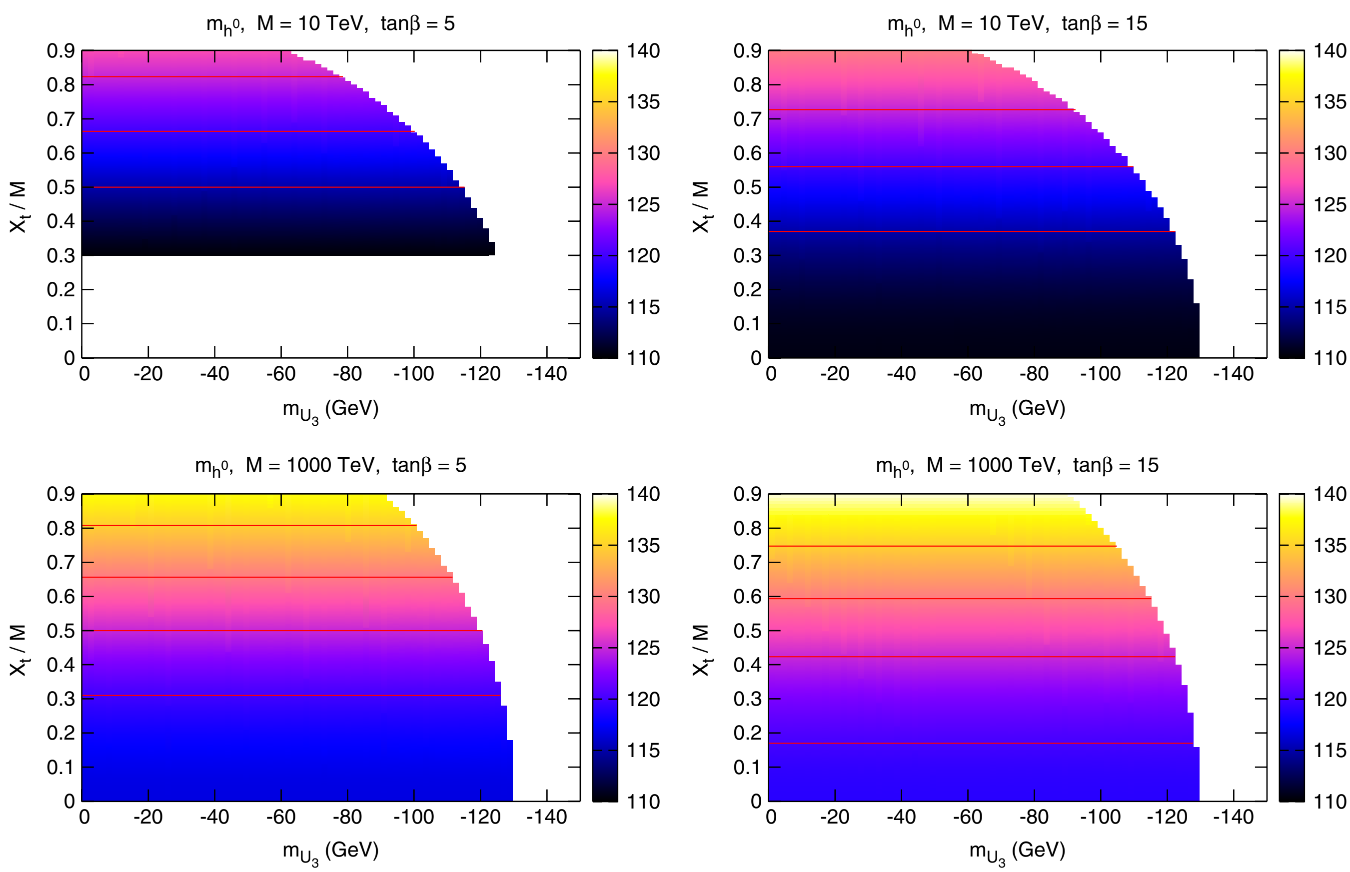

FIG. 5 (color online). Higgs boson masses as a function of m_{U_3} and $|X_t|/M$ for $\tan\beta = 5$, 15 and $M = 10$, 1000 TeV.

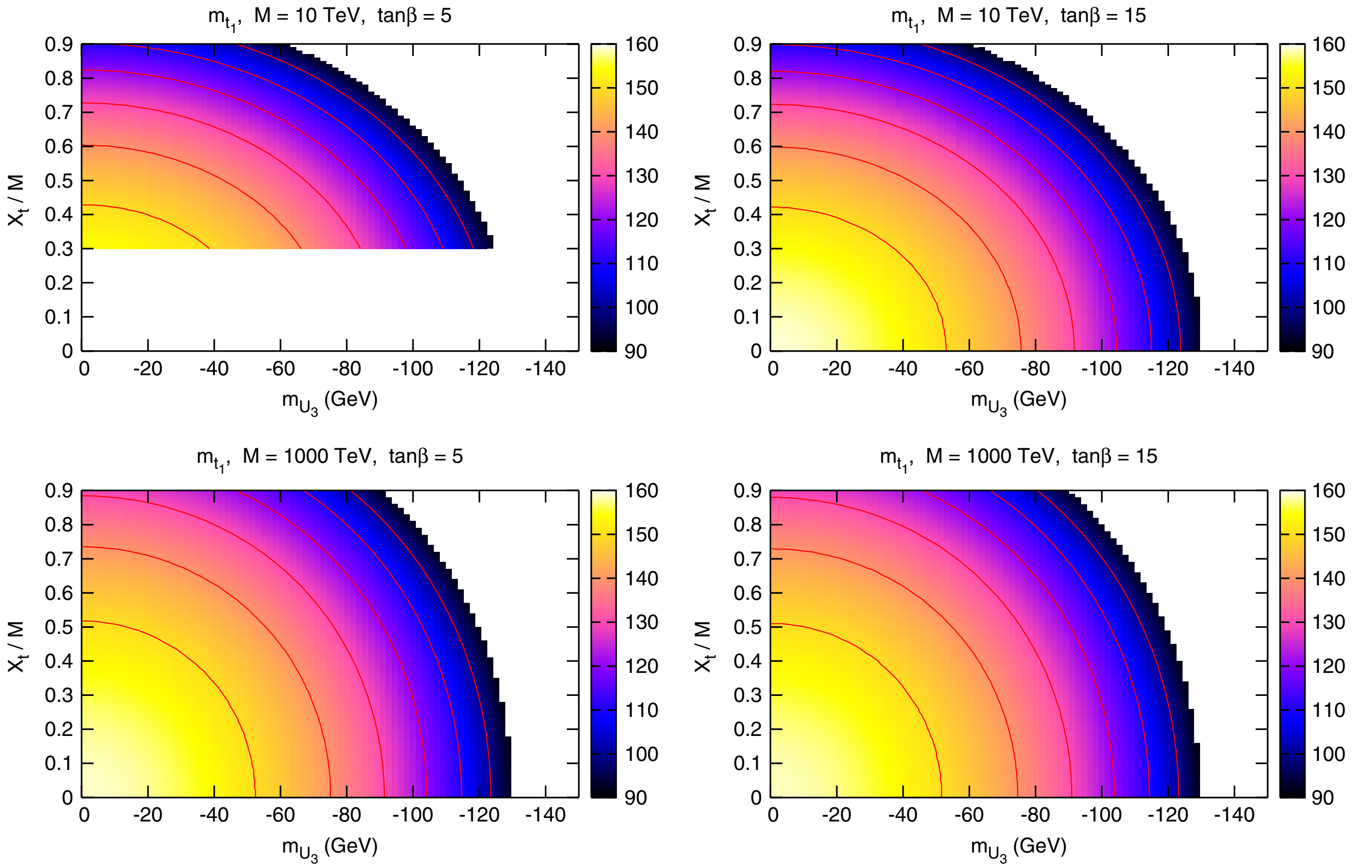

FIG. 6 (color online). Light-stop masses as a function of m_{U_3} and $|X_t|/M$ for $\tan\beta = 5$, 15 and $M = 10$, 1000 TeV.

apply weaker bounds here for illustrative purposes, to account for theoretical uncertainties (particularly in the h^0 Higgs mass), and for the weakening of the stop mass bound for stop-LSP mass differences less than 10 GeV. From Fig. 5 we observe that for $M = 1000$ TeV the Higgs boson mass is $\gtrsim 118$ GeV for these ranges of X_t and $m_{U_3}^2$. We also see that the mass falls for smaller values of $|X_t|$, but is relatively insensitive to value of $m_{U_3}^2$.

We show contours of the light $\tilde{t}_1$ stop mass in Fig. 6 for the same parameter ranges of X_t and $m_{U_3}^2$ as were used in Fig. 5. Again, the unfilled regions of these plots correspond to areas where $m_{h^0} < 110$ GeV or $m_{\tilde{t}_1} < 90$ GeV. At lower values of X_t and $|m_{U_3}^2|$ the stop mass is close to that of the top quark, and its value decreases with increasing values of X_t and $-m_{U_3}^2$.

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