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THE REACH OF CERN LEP2 AND FERMILAB TEVATRON UPGRADES FOR HIGGS BOSONS IN SUPERSYMMETRIC MODELS

Howard Baer[1], B. W. Harris[1], and Xerxes Tata[2]
[1]*Department of Physics, Florida State University, Tallahassee, FL 32306-4350 USA*
[2]*Department of Physics and Astronomy, University of Hawaii, Honolulu, HI 96822 USA*
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Abstract

Luminosity upgrades of the Fermilab Tevatron $p\bar{p}$ collider have been shown to allow experimental detection of a Standard Model (SM) Higgs boson up to $m_{H_{SM}} \sim 120$ GeV via $WH_{SM} \to \ell\nu b\bar{b}$ events. This limit nearly saturates the parameter space for many models of weak scale supersymmetry (SUSY) with a minimal particle content. It is therefore interesting to examine the SUSY Higgs reach of future Tevatron experiments. Contours are presented of Higgs boson reach for CERN LEP2 and Tevatron luminosity upgrades for three models of weak scale SUSY: the Minimal Supersymmetric Standard Model (MSSM), the minimal Supergravity model (mSUGRA) and a simple Gauge Mediated SUSY Breaking Model (GMSB). In each case we find a substantial gain in reach at the Tevatron with integrated luminosity increasing from 10 fb^{-1} to 25-30 fb^{-1}. With the larger integrated luminosity, a Higgs search at the Tevatron should be able to probe essentially the entire parameter space of these models. While a discovery would be very exciting, a negative result would severely constrain our ideas about how weak scale supersymmetry is realized.

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I. INTRODUCTION

One of the mysteries of elementary particle physics is the origin of electroweak symmetry breaking (EWSB). In the Standard Model (SM), EWSB occurs via the Higgs mechanism, a consequence of which is the existence of a fundamental scalar particle, the Higgs boson H_{SM} [1]. Comparison of precision measurements of electroweak parameters with SM predictions indicates a preference for a light Higgs boson $m_{H_{SM}} = 115^{+116}_{-66}$ GeV [2].

The Higgs boson has been searched for at collider experiments. The current best limit on its mass is $m_{H_{SM}} > 88$ GeV from searches for $e^+e^- \to ZH_{SM}$ at LEP2 [3]. The CERN LEP2 collider is expected to ultimately reach a center-of-mass energy $\sqrt{s} \simeq 200$ GeV and integrated luminosity of 100 pb^{-1} per experiment, allowing an exploration of $m_{H_{SM}}$ up to approximately 107 GeV. Experiments at the CERN LHC ought to be able to observe H_{SM} for $m_{H_{SM}} < 800$ GeV, although if $m_{H_{SM}}$ is in the intermediate mass regime ($m_{H_{SM}} \simeq 90-180$ GeV), several years of running may be required to extract the $H_{SM} \to \gamma\gamma$ signal from QCD two photon backgrounds.

It has been pointed out that a high luminosity Fermilab Tevatron $p\bar{p}$ collider has significant reach for a Higgs boson [4]. The most promising channel at the Tevatron is $q\bar{q}' \to WH_{SM}$, where $W \to \ell\nu$ and $H_{SM} \to b\bar{b}$. Simulations of signal and SM backgrounds [5,6] (mainly $Wb\bar{b}$, $t\bar{t}$, $W^* \to t\bar{b}$, tbq and WZ production) have shown that a 5σ signal ought to be detectable above background if $m_{H_{SM}} = 80 - 120$ GeV, provided that an integrated luminosity of 25 fb^{-1} can be accumulated at $\sqrt{s} = 2$ TeV.

In many particle physics models with weak scale supersymmetry (SUSY) and the low energy particle content of the Minimal Supersymmetric Standard Model (MSSM), the lightest Higgs scalar h has a mass that is typically $m_h \lesssim 120 - 125$ GeV [7]. Furthermore, frequently the lightest SUSY Higgs boson h behaves much like the SM Higgs boson. Thus, the Higgs boson mass reach of the Tevatron collider is particularly fascinating in that it may nearly saturate the parameter space of many interesting supersymmetric models. The implication is that, if SUSY exists, then high luminosity upgrades of the Fermilab Tevatron $p\bar{p}$ collider will either discover the lightest SUSY Higgs boson h, or will exclude much of the parameter space of many SUSY models!

Our goal in this paper is to translate the already calculated Tevatron SM Higgs boson mass reach into a reach in parameter space of three specific models involving weak scale supersymmetry. These models are used for most phenomenological analyses of supersymmetry.

The first model assumes the generic structure of the Minimal Supersymmetric Standard Model (MSSM) [8] with no assumptions about physics at scales beyond ~ 1 TeV. In this case, we set all dimensional SUSY parameters (such as soft SUSY breaking sfermion and gaugino masses, μ, and A-parameters) to $m_{SUSY} = 1$ TeV, so that the relevant parameter space consists of

$$\text{MSSM}: \ \{m_A, \ \tan\beta\} \tag{1.1}$$

where m_A is the mass of the pseudoscalar Higgs boson and $\tan\beta$ is the ratio of Higgs field vacuum expectation values. Several papers have presented SUSY Higgs search projections for LEP2 and LHC in this parameter space [9–14].

The second model we examine is the minimal supergravity (mSUGRA) model [15] with radiative electroweak symmetry breaking. In this model, it is assumed that SUSY breaking takes place in a hidden sector, and SUSY breaking effects are communicated to the observable sector via gravitational interactions. In the minimal rendition of this model, all scalars have a common mass m_0 at the GUT scale, while all gauginos have a common GUT scale mass $m_{1/2}$, and all trilinear scalar couplings unify to A_0, where the universality of the various parameters occurs at some ultra-high scale $\sim M_{GUT}$. Weak scale sparticle and Higgs masses are obtained via renormalization group running of soft SUSY breaking masses and couplings from M_{GUT} down to M_{weak}, where radiative electroweak symmetry breaking occurs. Ultimately, all sparticle masses and mixings are calculated in terms of the parameter set

$$\text{mSUGRA}: \ \{m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)\} \tag{1.2}$$

where μ is the superpotential Higgs mass parameter, whose magnitude is fixed by the condition of radiative electroweak symmetry breaking.

The last model we consider is the simplest gauge mediated SUSY breaking model [16]. In this model, SUSY breaking again takes place in a hidden sector, but SUSY breaking is communicated to the visible sector via messenger fields which also interact via usual gauge interactions. Sparticle masses are proportional to their gauge couplings, and their overall scale is set by the parameter $\Lambda = \frac{F}{M}$, where $\sqrt{F}$ is the SUSY breaking scale and M the mass scale for the messenger particles. The model is parameterized in terms of [17,18]

$$\text{GMSB}: \ \{\Lambda,\ M_{mes},\ n_5,\ \tan\beta,\ sign(\mu),\ C_{grav}\} \tag{1.3}$$

where n_5 is the number of complete $SU(5)$ messenger multiplets ($n_5 \leq 4$ if M_{mes} is $\leq$ 1000 TeV), and C_{grav} is the ratio of hidden sector to messenger sector vacuum expectation values of auxiliary fields.

II. CALCULATIONS

These SUSY models are incorporated in the event generator ISAJET 7.37 [18]. Therein the SUSY Higgs boson masses are calculated by minimizing the renormalization-group-improved one-loop effective potential. The minimization is performed at an optimized scale choice $Q \simeq \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$, which effectively includes the dominant two-loop contributions [19] to m_h. We input SUSY parameter space values into ISAJET to calculate the various Higgs boson and SUSY particle masses and mixing angles, as well as Higgs boson branching fractions to SM and SUSY particles [20].

A. Calculations for CERN LEP2

The associated and pair production cross sections of SUSY Higgs bosons at e^+e^- colliders can be expressed as [20–22]

$$\begin{aligned}
\sigma(e^+e^- \to Zh) &= \sin^2(\alpha+\beta)\ \sigma_{SM} \\
\sigma(e^+e^- \to ZH) &= \cos^2(\alpha+\beta)\ \sigma_{SM} \\
\sigma(e^+e^- \to Ah) &= \cos^2(\alpha+\beta)\ \sigma_{SM}\ \overline{\lambda}_{Ah} \\
\sigma(e^+e^- \to AH) &= \sin^2(\alpha+\beta)\ \sigma_{SM}\ \overline{\lambda}_{AH}
\end{aligned} \tag{2.1}$$

where

$$\overline{\lambda}_{Aj} = \frac{\lambda^{3/2}(m_j^2, m_A^2, s)}{\lambda^{1/2}(m_j^2, m_Z^2, s)[\lambda(m_j^2, m_Z^2, s) + 12m_Z^2/s]}. \tag{2.2}$$

They are written in terms of the SM result for associated Higgs production given by

$$\begin{aligned}\sigma_{SM} &\equiv \sigma(e^+e^- \to ZH_{SM}) \\ &= \frac{G_F^2 m_Z^4}{96\pi s}(v_e^2 + a_e^2)\lambda^{1/2}(m_j^2, m_Z^2, s)\frac{\lambda(m_j^2, m_Z^2, s) + 12m_Z^2/s}{(1 - m_Z^2/s)^2}\end{aligned} \tag{2.3}$$

with $\lambda(x, y, z) = (1 - x/z - y/z)^2 - 4xy/z^2$, $v_e = -1 + 4\sin^2\theta_W$, and $a_e = -1$.

The initial state QED corrections to the above processes are sizeable [23] and are therefore included in our analysis. This is accomplished by a resummation (exponentiation) of large logarithms due to soft photon emission [24]. The final form is a convolution of the leading order cross section with a resummed piece:

$$\sigma(s) = \int_{M_H^2/s}^1 dx\; G(x)\; \sigma_{BORN}(xs) \tag{2.4}$$

where the resummed piece

$$G(x) = \beta(1 - x)^{\beta - 1}\delta^{S+V} + \delta^H(x). \tag{2.5}$$

The soft/virtual and hard photon contributions represented by δ^{S+V} and δ^H may be be found in Ref. [24] to $\mathcal{O}(\alpha_{em}^2)$. They are polynomials in $L = \ln s/m_e^2$. The term in the exponent $\beta = 2\alpha_{em}(L - 1)/\pi$ where $\alpha_{em} = 1/137.0359\ldots$.

We obtain contours of LEP2 excluded regions for $e^+e^- \to Zh$ or ZH searches by calculating the SM cross section for ZH_{SM} production for $m_{H_{SM}} = 88$ GeV and $\sqrt{s} = 183$ GeV [3], and then requiring that the corresponding Zh and ZH cross sections be less than this value.

The LEP2 ultimate reach contours are calculated by assuming LEP2 to run at $\sqrt{s} = 200$ GeV, with each experiment accumulating 100 pb^{-1} of integrated luminosity. This has been projected [25] to yield a discovery limit of about 107 GeV for H_{SM} via the Bjorken process; we normalize our ultimate SUSY Higgs Zh and ZH cross sections to the corresponding SM cross section.

To obtain contours of the LEP2 excluded region from $e^+e^- \to Ah$ searches, we normalize the Ah production cross section to the exclusion contours presented in Ref. [26], which, for instance, exclude $m_h = m_A = 76$ GeV for $\tan\beta = 20$ at $\sqrt{s} = 184$ GeV. We also project the ultimate LEP2 reach via hA production assuming that discovery will be possible if the corresponding cross section at $\sqrt{s} = 200$ GeV is larger than 0.1 pb, while the charged Higgs boson will be detectable if it is lighter than 95 GeV.

B. Calculations for the Fermilab Tevatron

Detailed simulations of the $p\bar{p} \to WH_{SM} + X \to \ell\nu b\bar{b} + X$ signal and background have been performed in Ref. [5] and [6], using the VECBOS, PYTHIA and HERWIG event generators. The event selection cuts were as follows [5]:

- $p_T(\ell) > 20$ GeV,
- $\not\!\!E_T > 25$ GeV,
- number of jets ($E_T > 15$ GeV, $|\eta| < 2.5$) $\geq$ 2,
- number of jets ($E_T > 30$ GeV, $|\eta| < 2.5$) $\leq$ 2,
- $m_{min} \leq m_{jj} \leq m_{max}$,

where m_{min} and m_{max} are variable end-points for the dijet mass bin (for $m_{H_{SM}} = 100$ GeV, $m_{min} = 84$ GeV and $m_{max} = 117$ GeV, for example). In addition,

- the two jets are tagged via the CDF secondary vertex (SVX) b-tagging algorithm.

In Ref. [6], the signal was increased by adopting the CDF standard soft lepton tag (SLT) and the CDF loose SVX b-tag to the second b-jet. Finally, some additional optimization of signal to background was obtained by imposing the cut

- $|\cos\theta_H| < 0.8$,

in the WH_{SM} center-of-mass system. Tables for signal and background were presented for $m_{H_{SM}} = 60$, 80, 100 and 120 GeV.

We performed a simple fit to the signal presented in Table IV of Ref. [6], and found that the number of signal events $S(m_{H_{SM}})$ in 10 fb^{-1} could be represented by

$$S(x) = 640.6 - 8.765x + 0.03125x^2, \tag{2.6}$$

while the number of background events could be represented by $B(m_{H_{SM}})$ with

$$B(x) = 2948 - 62.6x + 0.5075x^2 - 0.0015x^3. \tag{2.7}$$

The numerical results of Table IV of Ref. [6] and the above fitted curves are shown in Fig. 1.

The supersymmetric Wh and WH production cross sections are given by

$$\begin{aligned} \sigma(p\bar{p} \to Wh) &= \sin^2(\alpha+\beta)\ \sigma_{SM} \\ \sigma(p\bar{p} \to WH) &= \cos^2(\alpha+\beta)\ \sigma_{SM} \end{aligned} \tag{2.8}$$

where $\sigma_{SM} = \sigma(p\bar{p} \to WH_{SM})$. Thus,

$$\sigma(p\bar{p} \to Wh \to \ell\nu b\bar{b}) = \sin^2(\alpha+\beta)\frac{BF(h \to b\bar{b})}{BF(H_{SM} \to b\bar{b})}\left[\frac{S(m_h)}{10\ fb^{-1}}\right], \tag{2.9}$$

with a similar equation for WH production. The SUSY and SM branching fractions are extracted from ISAJET and are given in [20].

As a criterion for observability at the Tevatron, we use $S/B > 0.2$ and $S/\sqrt{B} > 5$. We note that $S/B \sim 0.3$ throughout most of parameter space.

III. RESULTS

A. Minimal Supersymmetric Standard Model (MSSM)

Our first results are presented in Fig. 2 for the MSSM m_A *vs.* $\tan\beta$ plane, where all SUSY mass parameters have been set to 1 TeV, and $m_{top} = 175$ GeV. The region labelled LEP1 is excluded because the rate for $Z \to Z^* h$, hA and H^+H^- would violate limits placed on Higgs masses from LEP1 runs at the Z-pole. The region below the contour labelled "$LEP2$ current" yields a Zh or ZH signal in excess of the ZH_{SM} rate for $m_{H_{SM}} = 88$ GeV. In the region below the "$LEP2$ ultimate" contour, the signal ought to be detectable by LEP2 experiments sensitive to $m_{H_{SM}} = 107$ GeV at $\sqrt{s} = 200$ GeV. The region to the left of the contour labelled "$LEP2$ Ah" is excluded by current LEP2 experiments searching for $Z^* \to Ah$. The ultimate LEP2 Ah reach is only a slight extension of the current $LEP2$ Ah contour and is not shown. The reach via H^+H^- production lies well within the region probed by Ah searches. Finally, there may exist a region of this parameter plane at high $\tan\beta$ that is excluded by $b\bar{b}h$, $b\bar{b}H$ and $b\bar{b}A$ searches at the Tevatron, where the Higgs bosons decay to $\tau\bar{\tau}$; refined calculations of this are in progress [27].

The reach of the Fermilab Tevatron experiments for $\ell\nu b\bar{b}$ events with 10 fb^{-1} of integrated luminosity corresponds to the region below the contour marked "Wh at 10 fb^{-1}". If the integrated luminosity is increased to 25 fb^{-1}, then the region to the right of the contour labelled "Wh at 25 fb^{-1}" can be seen. In addition, at low values of m_A, the region interior to the contour labelled "WH at 25 fb^{-1}" can be seen.

We find a window of non-observability (labelled NO) at $m_A \simeq 115$ GeV where *none* of the SUSY Higgs bosons can be seen at LEP2 or the Fermilab Tevatron collider. In this region, both h and H may contain a significant portion of the SM Higgs scalar, so that $\sin(\alpha+\beta)$ is significantly smaller than unity and $\sigma(Wh)$ is suppressed, while H is somewhat heavier than 120 GeV [28]. This window is similar to but smaller than the one noted in Refs. [9–14] that also occurs at the CERN LHC. Most or all of the window may be filled in at the CERN LHC by high luminosity running, and by searches for $\tau\bar{\tau}$, $\mu\bar{\mu}$ or $4b$ modes from Higgs production. If the Tevatron integrated luminosity is increased to 30 fb^{-1}, the WH region increases towards lower $\tan\beta$, but most of the unobservable domain persists even at this higher integrated luminosity, and is not filled in even by our projection of the ultimate reach of LEP2. The NO window persists even for an integrated luminosity of 50 fb^{-1}. A similar plot for $\mu = -1000$ GeV was constructed, but was indistinguishable from Fig. 2. Finally, to test the robustness of our conclusions, we re-mapped our contours assuming an increase of 3 GeV in all the Higgs masses throughout parameter space. The resulting plot was qualitatively similar to the one presented in Fig. 2, with a modest increase in the size of the window of non-obervability.

B. Minimal Supergravity Model (mSUGRA)

A similar analysis of SUSY Higgs observability can be made within the context of the mSUGRA model, except that in this case there exists the possibility of light superpartners which can affect both the Higgs boson masses and branching fractions. The results are presented in Fig. 3 for $\tan\beta = 2$ and for *a*) $\mu < 0$ and *b*) $\mu > 0$. The TH region is excluded

either due to a lack of appropriate electroweak symmetry breaking, or because the lightest neutralino is not the lightest SUSY particle (LSP). The EX region is excluded by the negative results from LEP2 searches for chargino pair production, which require $m_{\widetilde{W}_1} > 85$ GeV [29].

The Higgs boson search at LEP2 presently excludes the region below the contours labelled "$LEP2$ current". We see that for $\tan\beta = 2$ and $\mu < 0$, the current LEP2 Higgs bound rules out a significant portion of mSUGRA parameter space up to $m_{1/2} \simeq 400$ GeV, corresponding to $m_{\tilde{g}} \simeq 1000$ GeV! However, for $\mu > 0$ it gives only a slight additional excluded area beyond the chargino bound. For both parameter planes for $\tan\beta = 2$, experiments at LEP2 will ultimately probe the entire parameter space shown, so that these will either discover a Higgs boson or rule out mSUGRA if $\tan\beta$ happens to be small [30].

The Fermilab Tevatron collider has no reach for Higgs bosons with 2 fb^{-1} of integrated luminosity, but ought to be able to explore the entire plane of Fig. 3a for $\mu < 0$ with 10 fb^{-1}. For $\mu > 0$, the Tevatron reach is to $m_{1/2} \simeq 300 - 400$ GeV for 10 fb^{-1}, while the entire plane can be explored with 25 fb^{-1} of integrated luminosity that might be accumulated at the TeV33 upgrade of the Tevatron. The entire $\tan\beta = 2$ parameter space can be explored by LEP2 and a 25 fb^{-1} Tevatron even if we allow $m_h \to m_h + 3$ GeV everywhere.

An intermediate value of $\tan\beta = 10$ is shown for the mSUGRA model in Fig. 4a and 4b for $\mu < 0$ and $\mu > 0$, respectively. As $\tan\beta$ increases, m_h generally increases [31], and in fact the current LEP2 SM Higgs search imposes no additional constraints beyond those from other SUSY particle searches. In fact, the LEP2 ultimate reach lies only slightly beyond the current chargino mass exclusion contour, making Higgs searches at LEP2 difficult for larger values of $\tan\beta$.

At $\tan\beta = 10$, the Fermilab Tevatron experiments have *no reach* for Higgs bosons with 10 fb^{-1} of integrated luminosity. However, if an integrated luminosity of 25 fb^{-1} can be accumulated, then the Tevatron Higgs search may probe $m_{1/2}$ values as high as $m_{1/2} \simeq 800$ GeV (650 GeV) for $\mu < 0$ ($\mu > 0$) via the Wh channel. (These values change to $m_{1/2} \sim 300 - 500$ GeV if $m_h \to m_h + 3$ GeV). An increase in integrated luminosity to 30 fb^{-1} allows complete coverage of the parameter space shown.

Finally, we show in Fig. 5a and b the corresponding mSUGRA reach plots for $\tan\beta = 35$. In this case, there are some additional TH excluded regions at large m_0 and $m_{1/2} \sim 100 - 300$ due to lack of radiative EWSB, though the exact computation of this region is numerically somewhat sensitive. In this large $\tan\beta$ case, there will be *no reach* by LEP2 Higgs searches beyond the regions already excluded by current chargino searches. However, Fermilab Tevatron experiments can explore via Wh searches up to $m_{1/2} \simeq 600 - 700$ GeV with 25 fb^{-1} of integrated luminosity ($m_{1/2} \simeq 300 - 400$ GeV if $m_h \to m_h + 3$ GeV), and they can probe once again the entire parameter space shown with 30 fb^{-1} of integrated luminosity. From these results, we conclude that the Fermilab Tevatron collider with 30 fb^{-1} of integrated luminosity ought to either discover a light Higgs boson, or can exclude the mSUGRA model. We do not expect our results to change significantly with changes in the A_0 parameter.

C. Gauge Mediated SUSY Breaking Model (GMSB)

Results for the GMSB model are shown in Fig. 6, in the Λ *vs.* $\tan\beta$ plane for *a)* $\mu < 0$ and *b)* $\mu > 0$. We take the messenger scale $M_{mes} = 1000$ TeV and first assume the messenger

sector is comprised of just a single set $n_5 = 1$ of "quark" and "lepton" superfields in a $5 + \bar{5}$ representation of $SU(5)$. The TH regions are excluded because they do not lead to proper radiative EWSB: in these regions, either $m_A^2 < 0$ or $m_{\tilde{\tau}_R}^2 < 0$. The EX regions are excluded by the ALEPH bound $m_{\widetilde{Z}_1} > 71$ GeV on the unstable neutralino which decays via $\widetilde{Z}_1 \to \gamma\tilde{G}$ from searches for $e^+e^- \to \gamma\gamma\not{E}_T$ [32], or by $m_{\tilde{\tau}_1} > 60$ GeV, from searches for staus in GMSB models [33]. The D0 and CDF experiments at the Tevatron [34], from a non-observation of di-photon events with large $\not{E}_T$ have inferred a lower bound of about 150 GeV on the chargino mass: this excludes essentially the same region as the ALEPH neutralino bound.

The current bound from LEP2 due to Higgs boson searches is shown as the region below the contour labelled "LEP2 current" in the very low $\tan\beta$ region of each plot. The LEP2 ultimate reach is for the area below the contour labelled "$LEP2$ ultimate", and can only probe parameter space with $\tan\beta < 4 - 7$.

Experiments at the Fermilab Tevatron will explore the region below the "Wh at 10 fb^{-1}" contour with 10 fb^{-1} of integrated luminosity. By increasing the integrated luminosity to 25 fb^{-1}, almost the entire parameter space should be explorable via Higgs boson searches. The exception is the region at $\Lambda \gtrsim 250$ TeV and $\tan\beta \sim 10 - 50$. This additional region, however, can be covered with an integrated luminosity of 30 fb^{-1}. Finally, there is a narrow sliver of region at $\tan\beta \simeq 52 - 54$ which is not seeable at the Tevatron via Wh searches; however, most of this sliver is accessible via WH production at 25 fb^{-1}.

We have also again examined the effect of setting $m_h \to m_h + 3$ GeV for the GMSB model. The most obvious impact is on the size of the region that cannot be explored with 25 fb^{-1} of data: the boundary of this region shifts from $\Lambda \sim 250$ TeV to $\Lambda \sim 150$ TeV for both signs of μ, and furthermore, this region then extends down to $\tan\beta \sim 6$.

Finally, we have also explored the Higgs boson reach for the case $n_5 = 4$, the largest value of n_5 for which couplings remain perturbative up to a large scale when M_{mes} is 1000 TeV. The EX region may be somewhat underestimated [17] since we obtain it using the same bound $m_{\widetilde{Z}_1} > 71$ GeV used in the $n_5 = 1$ case, in conjunction with the bound on $m_{\tilde{\tau}_1}$. In this case, m_h is typically larger for a given Λ and $\tan\beta$ value than for the $n_5 = 1$ case. These results are shown in Fig. 7. The overall structure of the plot is similar to the results from Fig. 6, except that the Wh reach for 25 fb^{-1} is considerably smaller. However, the whole parameter plane shown can once again be covered by 30 fb^{-1} of integrated luminosity.

IV. CONCLUSIONS

The lightest neutral scalar Higgs boson is lighter than $120 - 125$ GeV in a wide variety of interesting models commonly used for phenomenological studies of weak scale supersymmetry. This observation, together with the fact that the most careful study to date yields a SM Higgs boson reach of about 120 GeV at proposed luminosity upgrades of the Tevatron, motivated us to translate this reach to the corresponding reach in three classes of SUSY models: the MSSM with $m_{SUSY} = 1$ TeV, the mSUGRA model, and finally, the GMSB model. While there are viable models where the ~ 125 GeV limit on the lightest of the neutral Higgs scalars can be significantly surpassed, these models generally contain additional fields (most commonly Higgs singlets) which serve no specific purpose, and hence are less attractive theoretically.

Assuming that the conclusion about the reach for the SM Higgs boson holds up to closer scrutiny [35], we find that it should be possible to discover at least one of the Higgs bosons over the entire parameter space of the mSUGRA and GMSB models, and over most of the parameter space of the MSSM, provided Tevatron experiments can accumulate an integrated luminosity of 25-30 fb^{-1}. The large integrated luminosity is crucial for an exploration of the parameter space: if the integrated luminosity is "just" 10 fb^{-1} the signal is detectable over a much smaller range of parameters. Specifically, for the case of the MSSM, experiments at TeV33 should be able to probe the entire model parameter space given 25 fb^{-1} of integrated luminosity, except for a window of unobservability around $m_A \sim 115$ GeV. For the case of the mSUGRA model, both LEP2 and TeV33 should be able to probe the entire parameter space for low $\tan\beta$; for higher $\tan\beta$, the reach of LEP2 will be limited, and Tevatron experiments will need 30 fb^{-1} of integrated luminosity to probe the entire model parameter space. For GMSB models, the ultimate reach of LEP2 is limited to low values of $\tan\beta$, while the Fermilab Tevatron will need ~ 30 fb^{-1} of integrated luminosity to probe the entire parameter space. This conclusion is insensitive to the specific value of n_5 as long as the messenger scale M_{mes} is not too large.

In summary, if future luminosity upgrades of the Tevatron are able to accumulate an integrated luminosity of 25-30 fb^{-1}, experiments at these facilities should be able to probe most of the parameter space of these models via a search for $p\bar{p} \to Wh(H) \to \ell\nu b\bar{b}$ events. While a discovery of a signal would be very exciting, it would not, by itself, allow us to conclude that we had discovered SUSY. If instead Tevatron experiments do accumulate the required data sample and conclusively find no signal for the Higgs boson, it would exclude most of the parameter space of currently popular SUSY models, and cause us to rethink our ideas of how weak scale supersymmetry might be realized in nature.

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Figure Captions

Fig. 1 Number of events expected after cuts at the Fermilab Tevatron for 10 fb^{-1} of integrated luminosity for the WH_{SM} signal (solid) and SM background (dashes), as a function of $m_{H_{SM}}$. The crosses denote points from the calculations of Kim *et al.*, Ref. [6]. The curves denote our fit to these points.

Fig. 2 Regions of the MSSM m_A *vs.* $\tan\beta$ plane accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV and set $m_{SUSY} = 1$ TeV.

Fig. 3 Regions of mSUGRA model parameter space accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV, $A_0 = 0$ and $\tan\beta = 2$.

Fig. 4 Regions of mSUGRA model parameter space accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV, $A_0 = 0$ and $\tan\beta = 10$.

Fig. 5 Regions of mSUGRA model parameter space accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV, $A_0 = 0$ and $\tan\beta = 35$.

Fig. 6 Regions of GMSB model parameter space accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV, $M_{mes} = 1000$ TeV and $n_5 = 1$.

Fig. 7 Regions of GMSB model parameter space accessible to current and future Higgs boson searches at LEP2 and the Fermilab Tevatron. We take $m_{top} = 175$ GeV, $M_{mes} = 1000$ TeV and $n_5 = 4$.

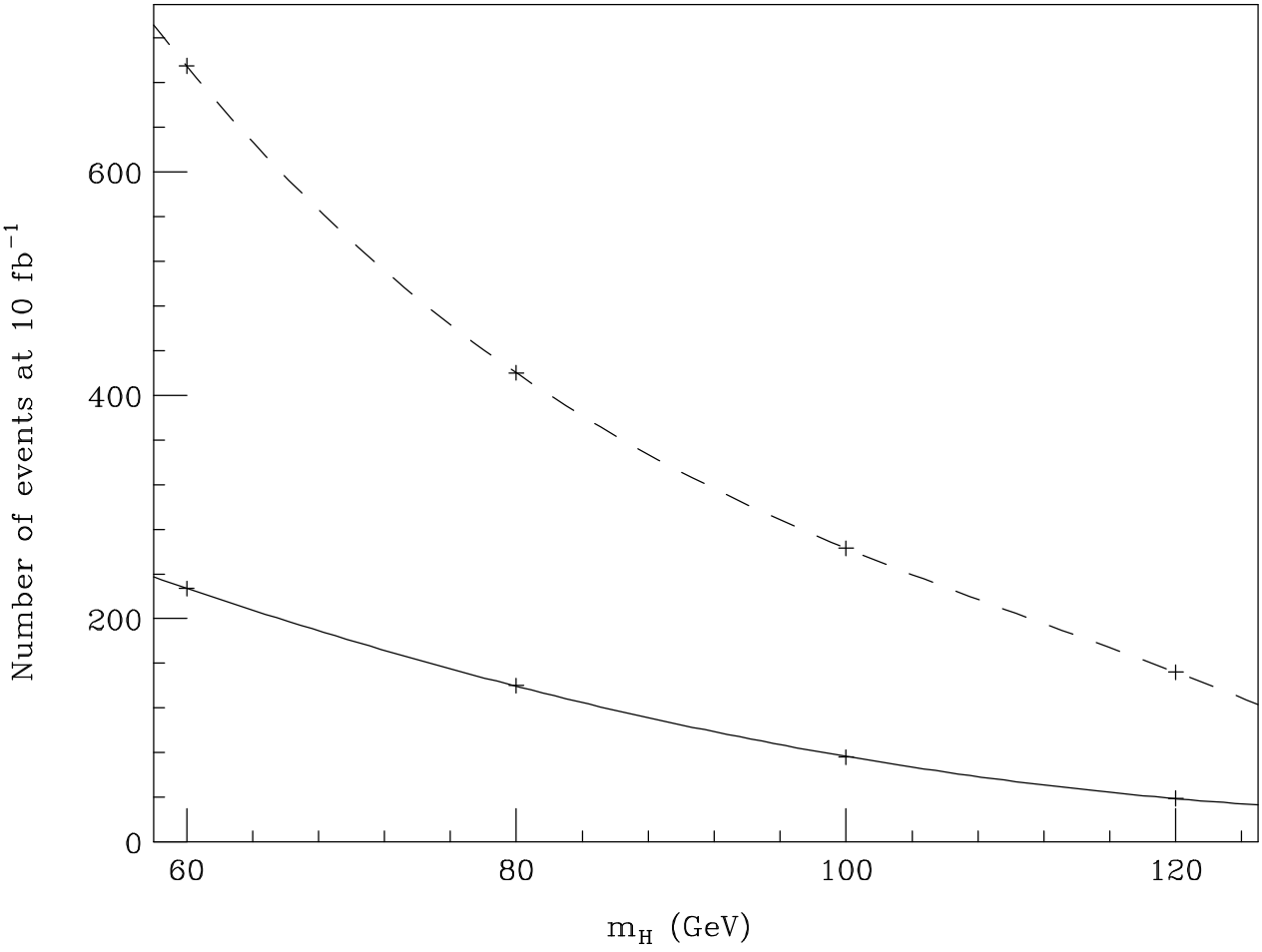

FIG. 1.

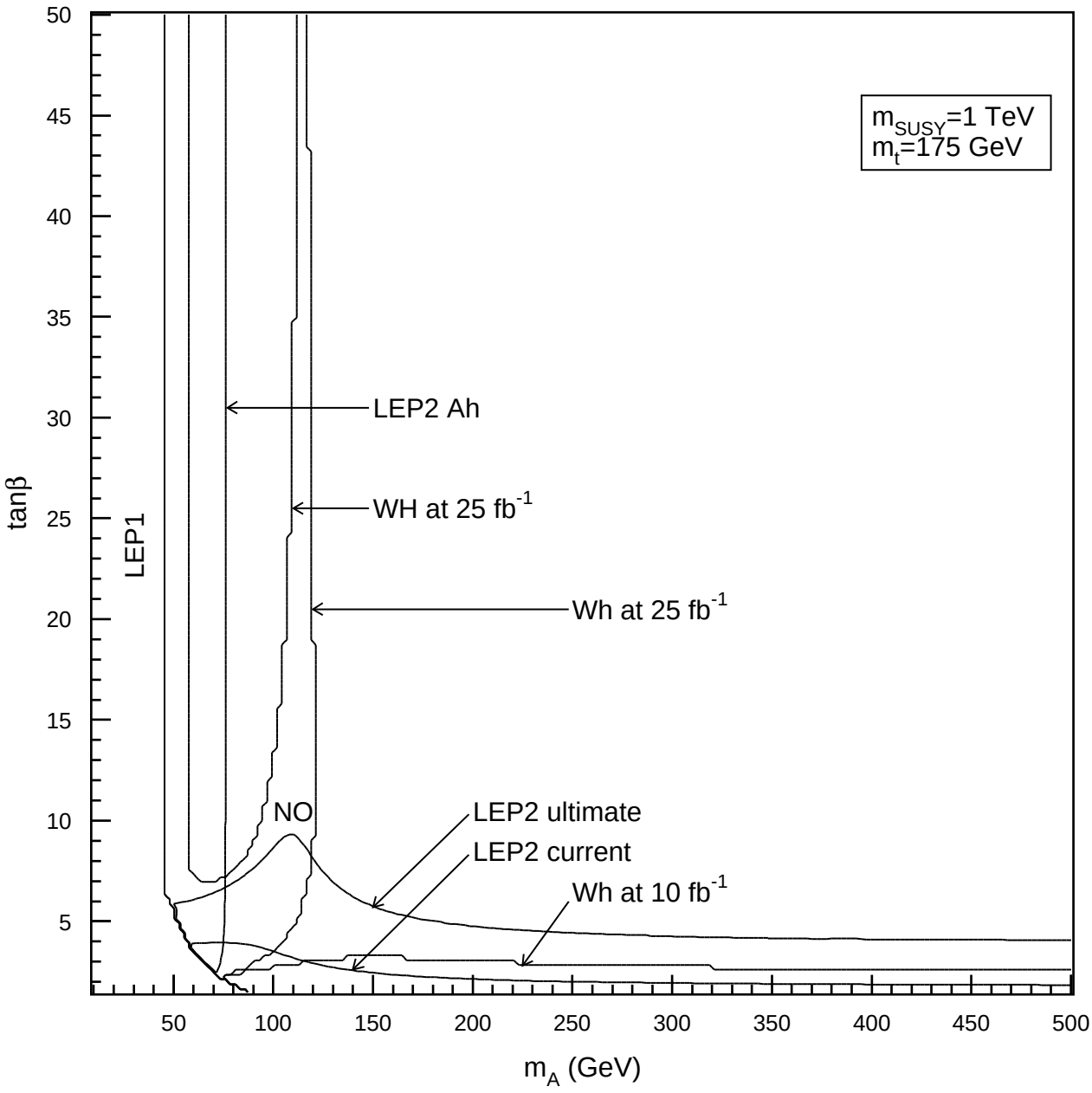
m_SUSY=1 TeV
m_t=175 GeV
LEP2 Ah
WH at 25 fb-1
Wh at 25 fb-1
LEP1
NO
LEP2 ultimate
LEP2 current
Wh at 10 fb-1
tanβ
m_A (GeV)
50
45
40
35
30
25
20
15
10
5
50
100
150
200
250
300
350
400
450
500

FIG. 2.

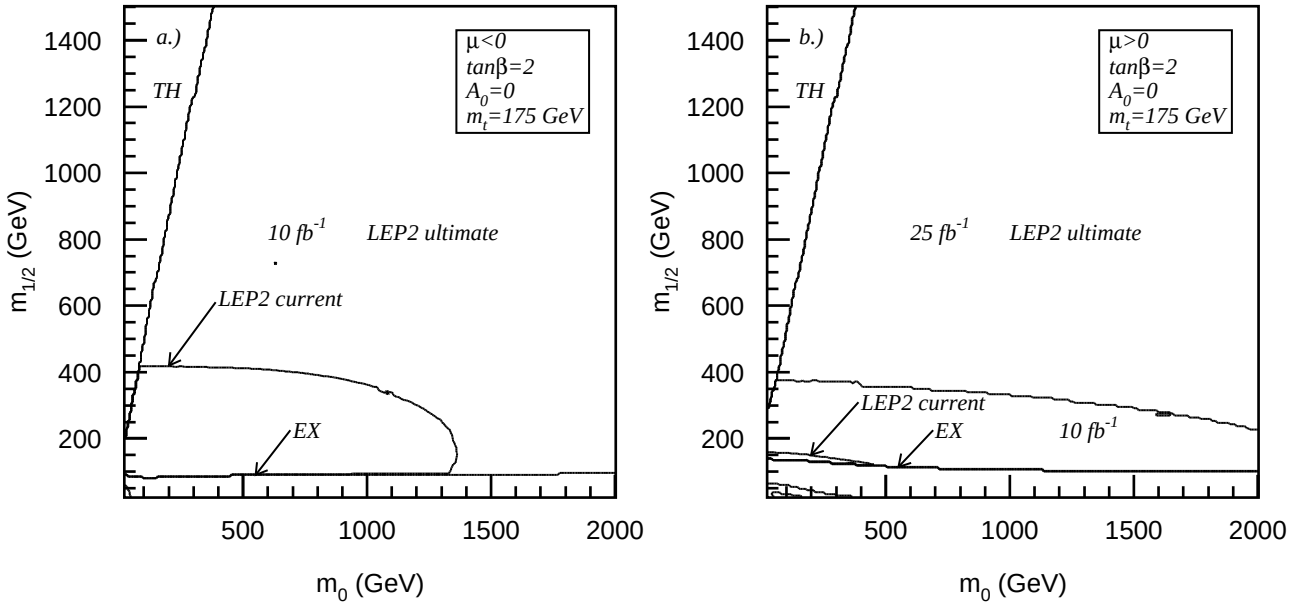
a.)
μ<0
tanβ=2
A_0=0
m_t=175 GeV
TH
10 fb-1
LEP2 ultimate
LEP2 current
EX
m1/2 (GeV)
m0 (GeV)
b.)
μ>0
tanβ=2
A_0=0
m_t=175 GeV
TH
25 fb-1
LEP2 ultimate
LEP2 current
EX
10 fb-1
m1/2 (GeV)
m0 (GeV)

FIG. 3.

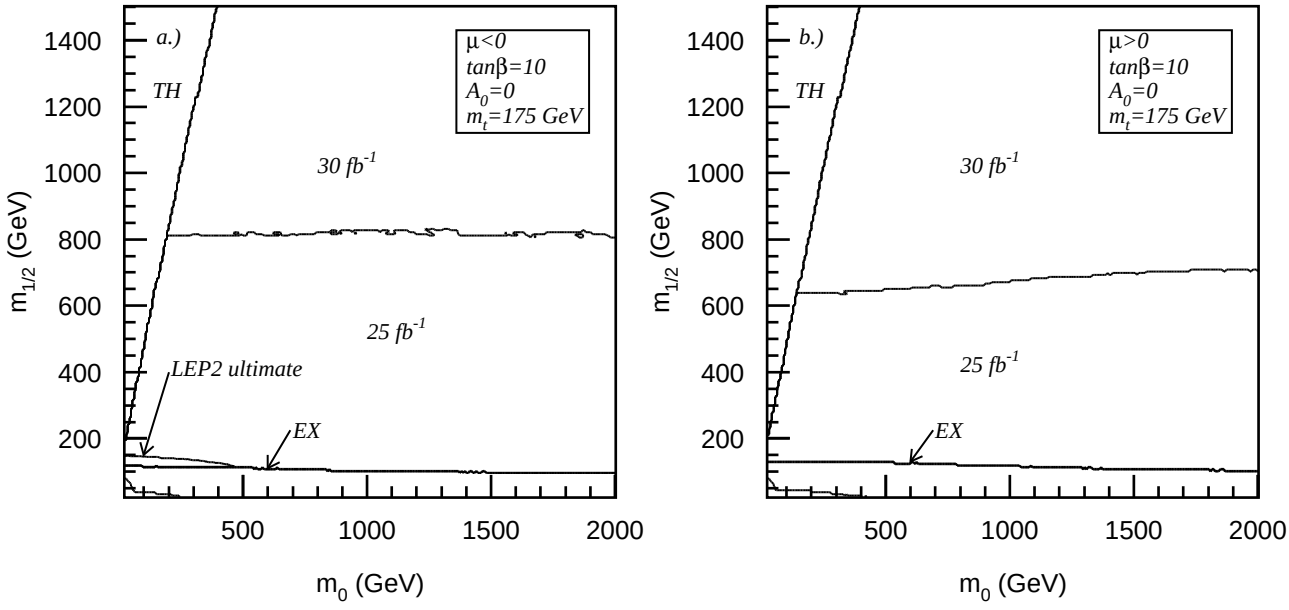
a.)
μ<0
tanβ=10
A0=0
mt=175 GeV
TH
30 fb-1
25 fb-1
LEP2 ultimate
EX
m1/2 (GeV)
m0 (GeV)
b.)
μ>0
tanβ=10
A0=0
mt=175 GeV
TH
30 fb-1
25 fb-1
EX
m1/2 (GeV)
m0 (GeV)

FIG. 4.

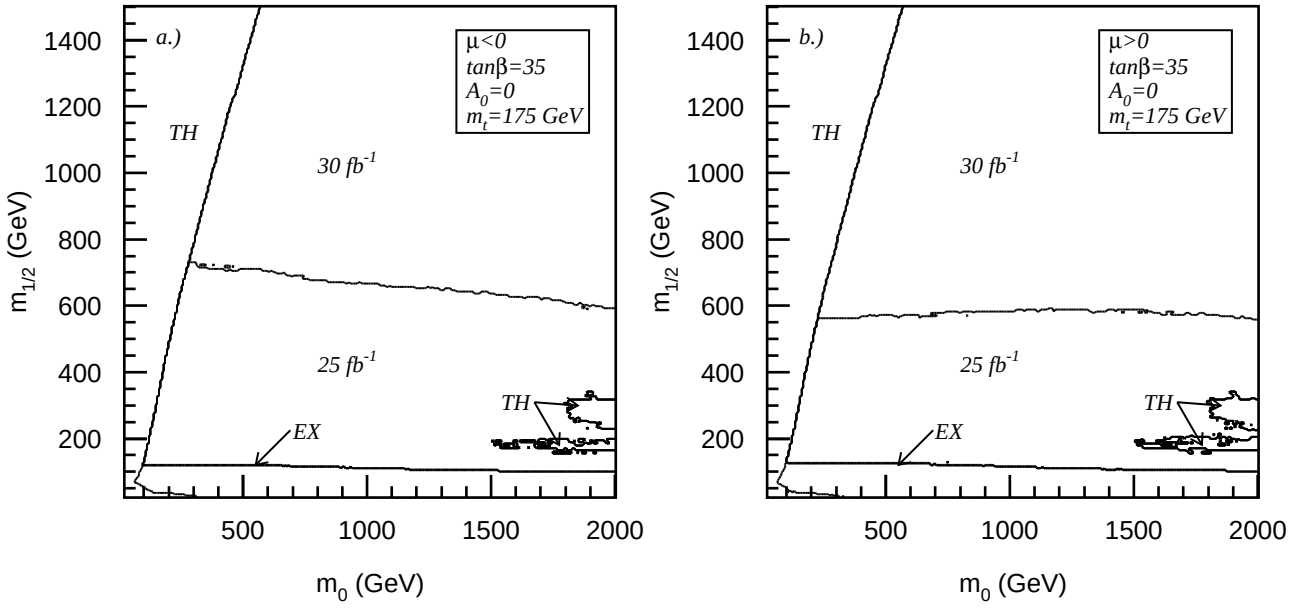
a.)
μ<0
tanβ=35
A0=0
mt=175 GeV
TH
30 fb-1
25 fb-1
TH
EX
m1/2 (GeV)
m0 (GeV)
b.)
μ>0
tanβ=35
A0=0
mt=175 GeV
TH
30 fb-1
25 fb-1
TH
EX
m1/2 (GeV)
m0 (GeV)

FIG. 5.

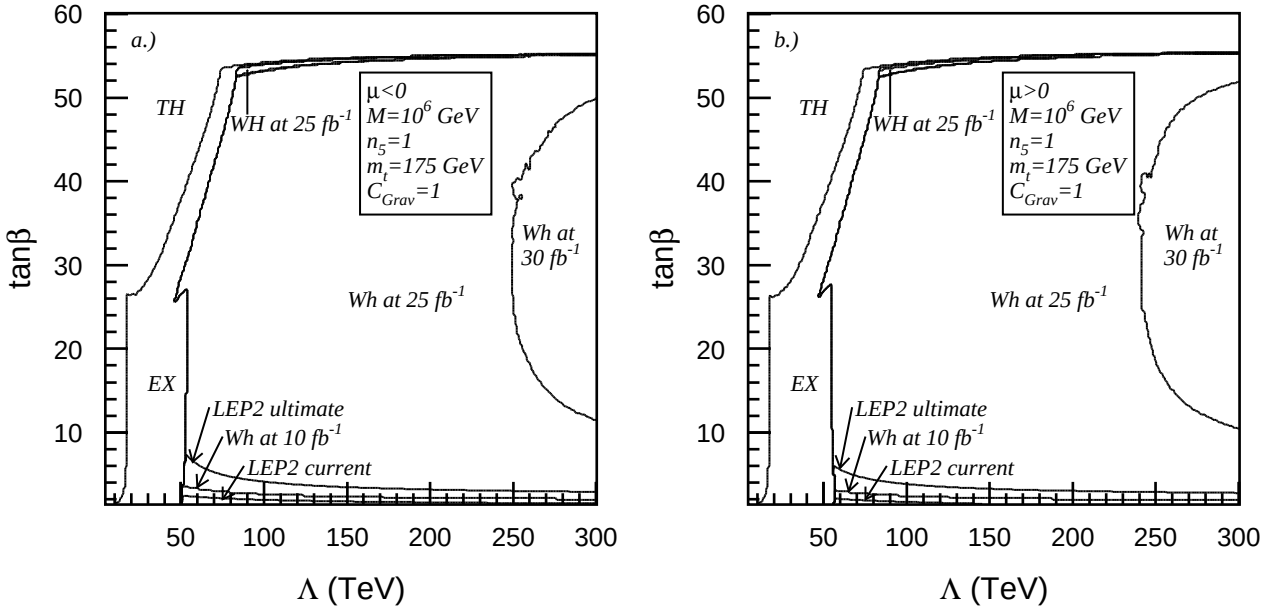
a.)
TH
WH at 25 fb-1
μ<0
M=10^6 GeV
n5=1
mt=175 GeV
CGrav=1
Wh at 30 fb-1
Wh at 25 fb-1
EX
LEP2 ultimate
Wh at 10 fb-1
LEP2 current
tanβ
Λ (TeV)
b.)
μ>0

FIG. 6.

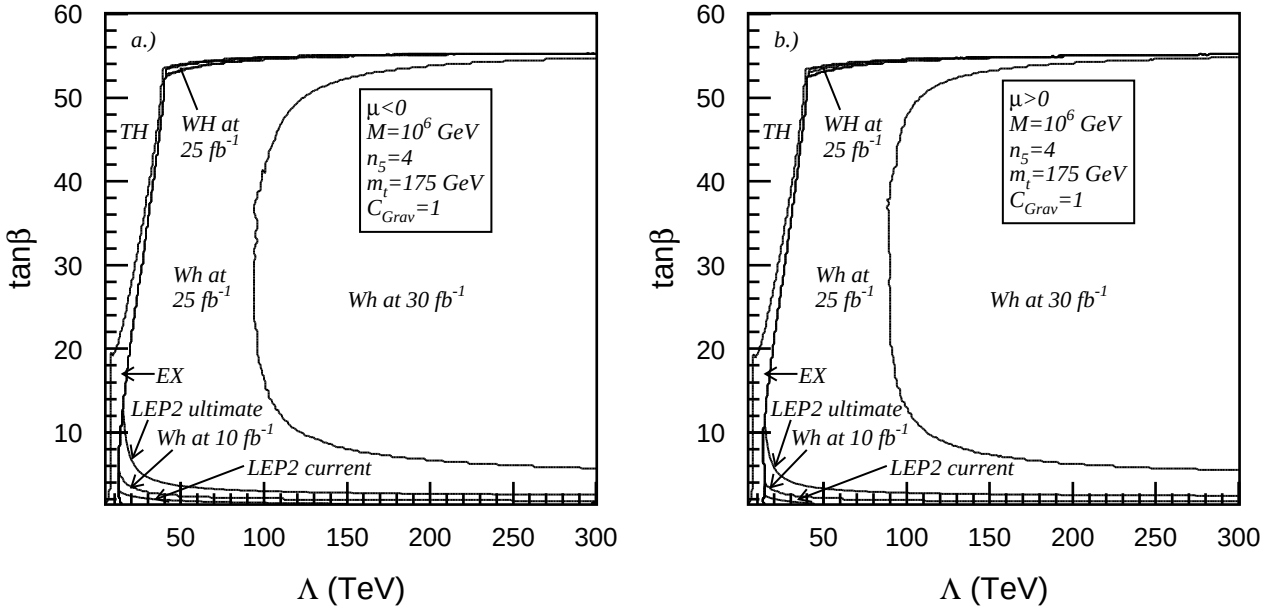
a.)
b.)
tanβ
Λ (TeV)
TH
WH at 25 fb-1
Wh at 25 fb-1
Wh at 30 fb-1
EX
LEP2 ultimate
Wh at 10 fb-1
LEP2 current
μ<0
M=10^6 GeV
n5=4
mt=175 GeV
CGrav=1
μ>0
M=10^6 GeV
n5=4
mt=175 GeV
CGrav=1

FIG. 7.