The Search for Higgs Bosons of Minimal Supersymmetry at the LHC

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Abstract.
The prospects for discovering neutral Higgs bosons in the minimal supersymmetric model (MSSM) and in the minimal supergravity model (MSUGRA) at the LHC are investigated. Two special discovery channels are discussed: (i) the photon pair decay of the MSSM CP-odd Higgs boson, and (ii) the muon pair decays of neutral Higgs bosons and in the MSUGRA.

INTRODUCTION

In the minimal supersymmetric model (MSSM) [1], there are two Higgs doublets \( \phi_1 \) and \( \phi_2 \) coupling to fermions with \( t_3 = -1/2 \) and \( t_3 = +1/2 \) respectively [2]. After spontaneous symmetry breaking, there remain five physical Higgs bosons: a pair of singly charged \( H^\pm \), two neutral CP-even \( H^0 \) (heavier) and \( h^0 \) (lighter), and a neutral CP-odd \( A^0 \). The Higgs potential is constrained by supersymmetry such that all tree-level Higgs boson masses and couplings are determined by two independent parameters, commonly chosen to be mass of the CP-odd pseudoscalar (\( m_A \)) and ratio of the vacuum expectation values (VEVs) of Higgs fields (\( \tan \beta \equiv v_2/v_1 \)).

Extensive studies have been made for the detection of MSSM Higgs bosons at the CERN LHC [3–10]. Most studies have focused on the SM decay modes \( \phi \to \gamma \gamma \) (\( \phi = H^0, h^0 \) or \( A^0 \)) and \( \phi \to ZZ \) or \( ZZ^* \to 4l \) (\( \phi = H^0 \) or \( h^0 \)). For \( \tan \beta \) close to one, the detection modes \( A^0 \to Zh^0 \to l^+l^-b\bar{b} \) or \( l^+l^-\tau\bar{\tau} \) [11] and \( H^0 \to h^0h^0 \to \gamma\gamma b\bar{b} \) [9] may provide channels to simultaneously discover two Higgs bosons of the MSSM. For large \( \tan \beta \), the \( \tau\bar{\tau} \) decay mode [5,7–9] is a promising discovery channel for the \( A^0 \) and the \( H^0 \); neutral Higgs bosons might be observable via their \( b\bar{b} \) decays [12,13]. In some regions of parameter space, the rates for Higgs boson decays to SUSY particles are dominant. While these decays reduce rates for the standard modes,
they might also open up new promising modes for Higgs detection [6]. Recently, the muon pair decay mode was proposed [14,7,9] to be a promising discovery channel for neutral Higgs bosons. For large tan $\beta$, the muon pair discovery mode might be the only channel that allows precise reconstruction of Higgs masses at the LHC.

In this article, the prospects for discovering neutral Higgs bosons in the MSSM and in the minimal supergravity model (MSUGRA) at the LHC are investigated. Two special discovery channels are discussed: (i) the search for the MSSM CP-odd Higgs boson via its photon pair decay [15], and (ii) the detection of neutral Higgs bosons via their muon pair decays in the MSSM [14] and in the MSUGRA [16].

**THE PHOTON PAIR DISCOVERY CHANNEL**

In this section, we present a realistic study for the observability of the MSSM CP-odd Higgs boson ($A^0$) via its photon pair decay mode $^2$ ($A^0 \to \gamma\gamma$) with the CMS detector performance [15]. The cross section for the process of $pp \to A^0 \to \gamma\gamma + X$ is evaluated from the cross section $\sigma(pp \to A^0 + X)$ multiplied with the branching fractions of $A^0 \to \gamma\gamma$. We take $m_\tilde{q} = m_\tilde{g} = \mu = 1000$ GeV.

![Figure 1](image)

**FIGURE 1.** Number of events versus $M_{\gamma\gamma}$, generated from a simulation with CMS performance, for the signal and the background at $\sqrt{s} = 14$ TeV with $L = 100$ fb$^{-1}$ and $\tan \beta = 1$.

The irreducible backgrounds considered are, (i) $q\bar{q} \to \gamma\gamma$ and (ii) $gg \to \gamma\gamma$ (Box). In addition, we consider reducible backgrounds with at least one $\gamma$ in the final state,

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$^2$) This important channel was not included in the CMS and the ATLAS technical proposals [7,8].
(i) $q\bar{q} \to g\gamma$, (ii) $qg \to q\gamma$, and (iii) $gg \to g\gamma$ (Box). In Figure 1, we present number of events for the signal and the background at the LHC versus $M_{\gamma\gamma}$.

We use PYTHIA 5.7 and JETSET 7.4 generators [17] to simulate events at the particle level. The PYTHIA/JETSET outputs are processed with the CMSJET program [18]. The resolution effects are taken into account by using the parameterizations obtained from the detailed GEANT [19] simulations. The ECAL resolution is assumed to be $\sigma(E)/E = 5%/\sqrt{E} + 0.5\%$ (CMS high luminosity regime). We require that every photon should have a transverse momentum ($p_T$) larger than 40 GeV and $|\eta| < 2.5$, and both photons must be isolated, i.e., (i) there is no charged particle with $p_T > 2$ GeV in the cone $R = 0.3$; and (ii) the total transverse energy $\sum E_{T}^{\text{cell}}$ is taken to be less than 5 GeV in the cone ring $0.1 < R < 0.3$. To be conservative, we assume no rejection power against $\pi^0$'s with high $p_T$, i.e., all $\pi^0$'s surviving the cuts ($p_T$, isolation, etc.) are considered as $\gamma$'s.  

For each $m_A$ and $\tan\beta$, the values of mass window around the peak (within the range 2-6 GeV) and $p_T$ cut (50-100 GeV) were chosen to provide the best value of $N_S = S/\sqrt{B}$. For example, the best values of the mass window and $p_T$ cut for $m_A = 200$ GeV are 2 GeV and 60 GeV respectively, whereas these values equal to 4 GeV and 100 GeV for $m_A = 350$ GeV. Figures 2 shows the discovery contour for $pp \to A^0 \to \gamma\gamma$ at $\sqrt{s} = 14$ TeV, in the ($m_A,\tan\beta$) plane, with an integrated luminosity ($L$) of 100 fb$^{-1}$ and 300 fb$^{-1}$.

![Figure 2](image_url)

**FIGURE 2.** The 5$\sigma$ contour in the ($m_A,\tan\beta$) plane, generated from a simulation with CMS performance, for $pp \to A^0 \to \gamma\gamma + X$ at the LHC with $L = 100$ fb$^{-1}$ and 300 fb$^{-1}$.

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3) The background from the $\pi^0$ is overestimated, especially in the low mass $M_{\gamma\gamma}$ region.
THE MUON PAIR DISCOVERY CHANNEL

The cross section of $pp \rightarrow \phi \rightarrow \mu \bar{\mu} + X$ ($\phi = A^0, H^0, \text{or } h^0$) is evaluated from the Higgs boson cross section $\sigma(pp \rightarrow \phi + X)$ multiplied with the branching fraction of the Higgs decay into muon pairs $B(\phi \rightarrow \mu \bar{\mu})$. The Higgs masses and couplings are evaluated with one loop corrections from the top and the bottom Yukawa interactions in the one-loop effective potential [20].

In the MSSM, gluon fusion ($gg \rightarrow \phi$) is the major source of neutral Higgs bosons for $\tan \beta \lesssim 4$. If $\tan \beta$ is larger than about 10, neutral Higgs bosons are dominantly produced from $b$-quark fusion ($b\bar{b} \rightarrow \phi$) [21] because the $\phi b\bar{b}$ couplings are enhanced by $1/\cos \beta$. We have evaluated the cross section of Higgs bosons in $pp$ collisions $\sigma(pp \rightarrow \phi + X)$, with two dominant subprocesses: $gg \rightarrow \phi$ and $gg \rightarrow \phi b\bar{b}$. For $m_A > 150$ GeV, the couplings of the lighter scalar $h^0$ to gauge bosons and fermions become close to those of the SM Higgs boson, therefore, gluon fusion is the major source of the $h^0$ even if $\tan \beta$ is large.

The QCD radiative corrections to $gg \rightarrow \phi$ was found to be large [22], the same corrections to $gg \rightarrow \phi b\bar{b}$ are still to be evaluated. To be conservative, we take a K-factor of 1.5 and 1.0 for the contributions from $gg \rightarrow \phi$ and $gg \rightarrow \phi b\bar{b}$ respectively, to evaluate the cross section of $pp \rightarrow \phi + X$. For the dominant Drell-Yan background [14,7,9], we have adopted the well known K-factor from reference [23].

If the $b\bar{b}$ mode dominates Higgs decays, the branching fraction of $\phi \rightarrow \mu \bar{\mu}$ is about $m^2_{\mu}/3m^2_{\phi}$, where 3 is the color factor of the quarks. The QCD radiative corrections greatly reduce the decay width of $\phi \rightarrow b\bar{b}$ [24]. For $\tan \beta > 10$, the $b\bar{b}$ decay mode dominates, and the branching fraction of $B(\phi \rightarrow \mu \bar{\mu})$ ($\phi = A^0, H^0, \text{or } h^0$) is about $2 \times 10^{-4}$. For $m_A$ less than about 80 GeV, the $H^0$ decays dominantly into $h^0h^0$, $A^0A^0$ and $ZA^0$.

Higgs Bosons of Minimal Supersymmetry

In Figs. 3(a) and 3(b), we present the cross section of the MSSM Higgs bosons at the LHC, $pp \rightarrow \phi \rightarrow \mu \bar{\mu} + X$, as a function of $m_A$ for $\tan \beta = 15$ and $\tan \beta = 40$. As $\tan \beta$ increases, the cross section is enhanced because for $\tan \beta \gtrsim 10$, it is dominated by $gg \rightarrow \phi b\bar{b}$ and enhanced by the $\phi b\bar{b}$ Yukawa coupling. Also shown is the same cross section for the SM Higgs boson $h^0_{SM}$ with $m_{h_{SM}} = m_A$. For $m_{h_{SM}} > 140$ GeV, the SM $h^0_{SM}$ mainly decays into gauge bosons; therefore, the branching fraction $B(h^0_{SM} \rightarrow \mu \bar{\mu})$ drops sharply.

To study the observability for the muon pair decay mode, the dominant background from the Drell-Yan (DY) process, $q\bar{q} \rightarrow Z, \gamma \rightarrow \mu \bar{\mu}$ is considered. We take $\Delta M_{\mu \bar{\mu}}$ to be the larger of the ATLAS muon mass resolution (about 2% of the Higgs bosons mass) [8,9] or the Higgs boson width.\(^4\) The minimal cuts applied are (1) $p_T(\mu) > 20$ GeV and (2) $|\eta(\mu)| < 2.5$ for both the signal and background.

\(^4\) The CMS mass resolution will be better than 2% of $m_\phi$ for $m_\phi \lesssim 500$ GeV [14,7].
FIGURE 3. The cross sections of $pp \to A^0, H^0, h^0 \to \mu\bar{\mu} + X$ in fb at $\sqrt{s} = 14$ TeV, versus $m_A$ for $m_{\tilde{g}} = m_{\tilde{q}} = -\mu = 1$ TeV, (a) $\tan\beta = 15$ and (b) $\tan\beta = 40$. Also shown is the cross section for the SM Higgs boson with $m_{h_{SM}} = m_{A^0}$. The $5\sigma$ contours at the LHC with $L = 300$ fb$^{-1}$ are shown for (c) $m_{\tilde{g}} = m_{\tilde{q}} = -\mu = 1$ TeV, and (d) $m_{\tilde{g}} = m_{\tilde{q}} = -\mu = 300$ GeV.

For $m_A \gtrsim 130$ GeV, $m_A$ and $m_H$ are almost degenerate while for $m_A \lesssim 100$ GeV, $m_A$ and $m_h$ are very close to each other [14,7]. Therefore, we sum up the cross sections of the $A^0$ and the $h^0$ for $m_A \leq 100$ GeV and those of the $A^0$ and the $H^0$ for $m_A > 100$ GeV.

We define the signal to be observable if the 99% confidence level upper limit on the background is smaller than the corresponding lower limit on the signal plus background [3,25], namely,

$$L(\sigma_s + \sigma_b) - N\sqrt{L(\sigma_s + \sigma_b)} > L\sigma_b + N\sqrt{L\sigma_b}$$

$$\sigma_s > \frac{N^2}{L}[1 + 2\sqrt{L\sigma_b/N}]$$  \hspace{1cm} (1)$$

where $L$ is the integrated luminosity, and $\sigma_b$ is the background cross section within a bin of width $\pm \Delta M_{\mu\bar{\mu}}$ centered at $M_\phi$; $N = 2.32$ corresponds to a 99% confidence level and $N = 2.5$ corresponds to a $5\sigma$ signal.

The $5\sigma$ discovery contours at $\sqrt{s} = 14$ TeV and $L = 300$ fb$^{-1}$ are shown in Figs. 3(c) and 3(d) for $m_{\tilde{g}} = m_{\tilde{q}} = -\mu = 1$ TeV and $m_{\tilde{g}} = m_{\tilde{q}} = -\mu = 300$ GeV. The discovery region of $H^0 \to \mu\bar{\mu}$ is slightly enlarged for a smaller $\mu$, but the observable region of $h^0 \to \mu\bar{\mu}$ is slightly reduced because the lighter top squarks make the $H^0$ and the $h^0$ lighter and enhance the $H^0 b\bar{b}$ coupling while reduce the $h^0 b\bar{b}$ coupling.
Higgs Bosons of Minimal Supergravity

In the minimal supergravity model (MSUGRA) [26], it is assumed that SUSY
is broken in a hidden sector with SUSY breaking communicated to the observable
sector through gravitational interactions, leading naturally to a common scalar
mass \(m_0\), a common gaugino mass \(m_{1/2}\), a common trilinear coupling \(A_0\)
and a common bilinear coupling \(B_0\) at the GUT scale. Through minimization of the
Higgs potential, the \(B\) parameter and magnitude of the superpotential Higgs mixing
parameter \(\mu\) are related to \(\tan \beta\) and \(M_Z\).

The SUSY particle masses and couplings at the weak scale can be predicted
by the evolution of RGEs [27] from the unification scale [28,29]. Since \(A_0\) mainly
affects the masses of third generation sfermions, it is taken to be zero in most of
our analysis. We calculate masses and couplings in the Higgs sector with one loop
corrections from the top and the bottom Yukawa interactions in the RGE-improved
one-loop effective potential [20] at the scale \(Q = \sqrt{m_{t L} m_{t R}}\) [30,31]. At this scale,
the RGE improved one-loop corrections approximately reproduce the dominant two
loop corrections [35] to the mass of the lighter CP-even scalar \((m_h)\).

The mass matrix of the charginos in the weak eigenstates \((\tilde{W}^\pm, \tilde{H}^\pm)\) has the
following form [28]

\[
M_C = \begin{pmatrix}
M_2 & \sqrt{2} M_W \sin \beta \\
\sqrt{2} M_W \cos \beta & -\mu
\end{pmatrix}
\]  

(2)

The form of Eq. (2) establishes our sign convention for \(\mu\). Recent measurements of
the \(b \rightarrow s \gamma\) decay rate by the CLEO [32] and the LEP collaborations [33] excludes
most of the MSUGRA parameter space for \(\mu > 0\) with a large \(\tan \beta\) [34]. Although
we choose \(\mu < 0\) in our analysis, our results and conclusions are almost independent
of the sign of \(\mu\).

Figure 4 shows masses, in the case of \(\mu < 0\), for neutral Higgs bosons: the lighter
CP-even \((h^0)\), the heavier CP-even \((H^0)\) and the CP-odd \((A^0)\). Also shown are
the regions that do not satisfy the following theoretical requirements: electroweak
symmetry breaking (EWSB), tachyon free, and the lightest neutralino \((\chi^0)\) as the
lightest supersymmetric particle (LSP). The region excluded by the \(m_{\chi^0_1} > 85\) GeV
limit from the chargino search [36] at LEP 2 is indicated. There are a couple of
interesting aspects to note: (i) an increase in \(\tan \beta\) leads to a larger \(m_h\) but a
reduction in \(m_A\) and \(m_H\); (ii) increasing \(m_0\) raises \(m_A, m_H\) and masses of the other
scalars significantly.

The LHC discovery contours in the minimal supergravity model are presented in
Figure 5 for (a) the \(m_{1/2}\) versus \(\tan \beta\) plane with \(m_0 = 150\) GeV, (b) the \(m_{1/2}\) versus
\(\tan \beta\) plane with \(m_0 = 500\) GeV, (c) the \(m_{1/2}\) versus \(m_0\) plane with \(\tan \beta = 15\), and
(d) the \(m_{1/2}\) versus \(m_0\) plane with \(\tan \beta = 40\). The discovery region is the part of
the parameter space between the curve of square symbol and the dash line. The
QCD radiative corrections to background from the Drell-Yan process are included.
FIGURE 4. Masses of $H^0$, $h^0$, and $A^0$ at the mass scale $Q = \sqrt{m_t m_{\tilde{t}_R}}$, versus $m_{1/2}$.

CONCLUSIONS

The discovery channel of $A^0 \rightarrow \gamma\gamma$ might provide a good opportunity to precisely reconstruct the CP-odd Higgs boson mass ($m_A$) for $170 \text{ GeV} < m_A < 2m_t$ if the decays of the $A^0$ into SUSY particles are forbidden and $\tan \beta$ is close to one. The impact of SUSY decays on this discovery channel might be significant [6] and it is under investigation with realistic simulations.

The muon pair decay mode can be a very promising channel to discover the neutral Higgs bosons of minimal supersymmetry and minimal supergravity, and this mode will provide a good channel to precisely reconstruct Higgs boson masses. The $A^0$ and $H^0$ might be observable in a large region of parameter space with $\tan \beta \gtrsim 10$. The $h^0$ might be observable in a region with $m_A < 120 \text{ GeV}$ and $\tan \beta \gtrsim 5$. For $m_A \gtrsim 200 \text{ GeV}$ and $\tan \beta > 25$, $L = 10 \text{ fb}^{-1}$ would be enough to obtain Higgs boson signals with a statistical significance larger than 7 [14].

In the MSUGRA, the observable regions of the parameter space are found to be

\begin{align*}
  m_0 &= 150 \text{ GeV} : \quad m_{1/2} \lesssim 400 \text{ GeV} \quad \text{and} \quad \tan \beta \gtrsim 12 \\
  m_0 &= 500 \text{ GeV} : \quad m_{1/2} \lesssim 1 \text{ TeV} \quad \text{and} \quad \tan \beta \gtrsim 28
\end{align*}

For two specific choices of large $\tan \beta$, the observable regions are

\begin{align*}
  \tan \beta &= 15 : \quad m_{1/2} \lesssim 200 \text{ GeV} \quad \text{and} \quad m_0 \lesssim 200 \text{ GeV} \\
  \tan \beta &= 40 : \quad m_{1/2} \lesssim 600 \text{ GeV} \quad \text{and} \quad m_0 \lesssim 800 \text{ GeV}.
\end{align*}
FIGURE 5. The 5σ contours for detecting Higgs bosons of MSUGRA at the LHC with $L = 300 \text{ fb}^{-1}$. Also shown are (i) the mass contours for $m_A = 100$ GeV, 500 GeV and 1000 GeV, (ii) the parts of the parameter space excluded by theoretical requirements (dark shading), and (iii) the region excluded by the $m_{\chi^+} > 85$ GeV limit from the chargino search at LEP 2.

ACKNOWLEDGMENTS

I am grateful to Salavat Abdullin, Vernon Barger and Nikita Stepanov for enjoyable and inspiring collaborations. This research was supported in part by the U.S. Department of Energy under Grant No. DE-FG02-95ER40896, and in part by the University of Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research Foundation.

REFERENCES

1. H.P. Nilles, Phys. Rep. 110 (1984) 1; H. Haber and G. Kane, Phys. Rep. 117 (1985) 75.
2. J. Gunion, H. Haber, G. Kane and S. Dawson, The Higgs Hunter’s Guide (Addison-Wesley, Redwood City, CA, 1990).
3. H. Baer, M. Bisset, C. Kao and X. Tata, Phys. Rev. D46 (1992) 1067.
4. V. Barger, M. Berger, A. Stange and R. Phillips, Phys. Rev. D45 (1992) 4128; J. Gunion, R. Bork, H. Haber and A. Seiden, Phys. Rev. D46, 2040 (1992); J. Gunion, H. Haber and C. Kao, Phys. Rev. D46, 2907 (1992); J.F. Gunion and L. Orr, Phys. Rev. D46 (1992) 2052.
5. Z. Kunszt and F. Zwirner, Nucl. Phys. B385 (1992) 3.
6. H. Baer, M. Bisset, D. Dicus, C. Kao and X. Tata, Phys. Rev. D47 (1993) 1062; H. Baer, M. Bisset, C. Kao and X. Tata, Phys. Rev. D50 (1994) 316.
7. CMS Technical Proposal, CERN/LHCC 94-38 (1994).
8. Atlas Technical Proposal, CERN/LHCC 94-43 (1994).
9. E. Richter-Was, D. Froidevaux, F. Gianotti, L. Poggioli, D. Cavalli, and S. Resconi, CERN report CERN-TH-96-111, (1996).
10. Recent reviews can be found in: H. Haber, T. Han, F.S. Merritt, J. Womersley et al., in Proceedings of the 1996 DPF/DPB Summer Study on New Directions for High Energy Physics, Snowmass, CO, hep-ph/9703391; J.F. Gunion, L. Poggioli, R. Van Kooten, C. Kao, P. Rowson et al., ibid., hep-ph/9703330; H. Haber, to appear in Proceedings of the Ringberg Workshop on the Higgs Puzzle, Ringberg Castle, Germany (1996), hep-ph/9703836; J.F. Gunion, to appear in Perspectives on Higgs Physics, ed. G. Kane, 2nd edition (World Scientific Publishing), hep-ph/9705282; V. Barger, to appear in Proceedings of 5th International Conference on Supersymmetries in Physics (SUSY 97), Philadelphia, PA, 27-31 May 1997, hep-ph/9708442; and references therein.
11. S. Abdullin, H. Baer, C. Kao, N. Stepanov and X. Tata, Phys. Rev. D54 (1996) 6728; H. Baer, C. Kao and X. Tata, Phys. Lett. B303 (1993) 284.
12. J. Dai, J.F. Gunion and R. Vega, Phys. Lett. B315 (1993) 355; Phys. Lett. B345 (1995) 29; B387 (1996) 801.
13. E. Richter-Was and D. Froidevaux, CERN report CERN-TH-97-210, (1997), hep-ph/9708455.
14. C. Kao and N. Stepanov, Phys. Rev. D 52 (1995) 5025.
15. S. Abdullin, C. Kao, and N. Stepanov, research performed for the 1996 DPF/DPB Summer Study on New Directions for High-energy Physics (Snowmass 96), Snowmass, CO, 25 Jun - 12 Jul 1996, CMS Technical Notes CMS TN/96-102, University of Wisconsin Report MADPH–96–976.
16. V. Barger and C. Kao, University of Wisconsin report MADPH-97-1020, hep-ph/9711328.
17. T. Sjöstrand, Computer Physics Commun. 39 (1986) 347; CERN-TH.7112/93; T. Sjöstrand and M. Bengtsson, Computer Physics Commun. 43 (1987) 367; H. U. Bengtsson and T. Sjöstrand, Computer Physics Commun. 46 (1987) 43.
18. S. Abdullin, A. Khanov, N. Stepanov, CMS TN/94-180 (1994).
19. R. Brun et al., GEANT3, CERN DD/EE/84-1 (1986).
20. H. Haber and R. Hempfling, Phys. Rev. Lett. 66 (1991) 1815; J. Ellis, G. Ridolfi and F. Zwirner, Phys. Lett. B257 (1991) 83; Y. Okada, H. Yamaguchi and T. Tanagida, Prog. Theor. Phys. Lett. 85 (1991) 1; We use the calculations of M. Bisset, Ph.D. thesis, University of Hawaii (1994).
21. D. Dicus and S. Willenbrock, Phys. Rev. D39 (1989) 751.
22. S. Dawson, Nucl. Phys. B359 (1991) 283; A. Djouadi, M. Spira and P.M. Zerwas, Phys. Lett. B264 (1991) 440; D. Graudenz, M. Spira and P.M. Zerwas, Phys. Rev. Lett. 70 (1993) 1372; M. Spira, A. Djouadi, D. Graudenz and P.M. Zerwas, Nucl. Phys. B453 (1995) 17; S. Dawson, A. Djouadi and M. Spira, Phys. Rev. Lett. 77 (1996) 16.
23. V. Barger and R. Phillips, *Collider Physics, updated edition*, (Addison-Wesley Publishing Company, Redwood City, CA, 1997).
24. E. Braaten, J.P. Leveille, Phys. Rev. D22 (1980) 715; M. Drees and K. Hikasa, Phys. Lett. B240 (1990) 455; (E)-*ibid.* B262 (1991) 497.
25. N. Brown, Z. Phys. C49 (1991) 657.
26. A. Chamseddine, R. Arnowitt and P. Nath, Phys. Rev. Lett. 49, 970 (1982); L. Ibañez and G. Ross, Phys. Lett. B110 (1982) 215; R. Barbieri, S. Ferrara and C. Savoy, Phys. Lett. B119, 343 (1982); L.J. Hall, J. Lykken and S. Weinberg, Phys. Rev. D27, 2359 (1983); L. Alvarez-Gaumé, J. Polchinski and M. Wise, Nucl. Phys. B121 (1983) 495.
27. K. Inoue, A. Kakuto, H. Komatsu and H. Takeshita, Prog. Theor. Phys. 68, 927 (1982) and 71, 413 (1984).
28. V. Barger, M.S. Berger, P. Ohmann, Phys. Rev. D47 (1993) 1093; D49 (1994) 4908; V. Barger, M.S. Berger, P. Ohmann and R.J.N. Phillips, Phys. Lett. B314 (1993) 351.
29. J. Ellis and F. Zwirner, Nucl. Phys. B338 (1990) 317; G. Ross and R.G. Roberts, Nucl. Phys. B377 (1992) 571; R. Arnowitt and P. Nath, Phys. Rev. Lett. 69 (1992) 725; M. Drees and M.M. Nojiri, Nucl. Phys. B369 (1993) 54; S. Kelley et. al., Nucl. Phys. B398 (1993) 3; M. Olechowski and S. Pokorski, Nucl. Phys. B404 (1993) 590; G. Kane, C. Kolda, L. Roszkowski and J. Wells, Phys. Rev. D49 (1994) 6173; D.J. Castaño, E. Piard and P. Ramond, Phys. Rev. D49 (1994) 4882; W. de Boer, R. Ehret and D. Kazakov, Z. Phys. 67 (1995) 647; H. Baer, M. Drees, C. Kao, M. Nojiri and X. Tata, Phys. Rev. D 50 (1994) 2148; H. Baer, C.-H. Chen, R. Munroe, F. Paige and X. Tata, Phys. Rev. D 51 (1995) 1046.
30. H. Baer, C.-H. Chen, M. Drees, F. Paige and X. Tata, Phys. Rev. Lett. 79 (1997) 986.
31. V. Barger and C. Kao, University of Wisconsin report, MADPH-97-992, (1997), hep-ph/9704403, to be published in Phys. Rev. D.
32. M.S. Alam et al., (CLEO Collaboration), Phys. Rev. Lett. 74 (1995) 2885.
33. P.G. Colrain and M.I. Williams, talk presented at the International Europhysics Conference on High Energy Physics, Jerusalem, Israel, August 1997.
34. P. Nath and R. Arnowitt, Phys. Lett. B336 (1994) 395; Phys. Rev. Lett. 74 (1995) 4592; Phys. Rev. D54 (1996) 2374; F. Borzumati, M. Drees and M. Nojiri, Phys. Rev. D51 (1995) 341; H. Baer and M. Brhlik, Phys. Rev. D55 (1997) 3201.
35. M. Carena, J.R. Espinosa, M. Quiros, and C.E.M. Wagner, Phys. Lett. B355 (1995) 209; M. Carena, M. Quiros, C.E.M. Wagner, Nucl. Phys. B461 (1996) 407; H. Haber, R. Hempfling and A. Hoang, CERN-TH/95-216 (1996), hep-ph/9609331.
36. ALEPH collaboration, talk presented at CERN by G. Cowan, February, 1997.