SEARCHING FOR
THE MINIMAL SUPERSYMMETRIC MODEL HIGGS BOSONS

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ABSTRACT
A brief overview of the prospects for detecting the Higgs bosons of the Minimal
Supersymmetric Model at future colliders is presented.

Probing the Higgs sector is the fundamental mission of future high energy colliders. The
Minimal Supersymmetric Model (MSSM) is the simplest supersymmetric extension of the
Standard Model (SM), and contains five physical Higgs bosons: the light $h^0$, and heavier
$H^0$, $A^0$, and $H^\pm$. We review our ability to detect these Higgs bosons at LEP-II, SSC/LHC and
a next linear $e^+ e^-$ collider (NLC) with $\sqrt{s} = 500$ GeV. In the latter case, we examine both
direct $e^+ e^-$ collisions and Higgs production via collisions of back-scattered laser beams. See
Ref. [1] for details, plots and references.

As is well-known, the MSSM Higgs sector at tree-level is completely determined by the
choice of just two parameters, conventionally taken as $m_A$ and $\tan \beta = v_2/v_1$. To good
approximation, the only additional parameters needed to determine the one-loop radiative
corrections to the Higgs bosons’ masses and couplings are $m_t$ and the stop mass, $m_{\tilde t}$; in
particular, $(m_h^{\text{max}})^2 \sim m_Z^2 + \text{const.} \times m_t^4 \ln(m_{\tilde t}^2/m_t^2)$ for large $m_A$ and $\tan \beta$. (However, to
determine the decay patterns of the Higgs bosons the masses of neutralinos and charginos
are also required.) The dependence of Higgs masses, couplings and decays on the MSSM
parameters are sufficiently constrained that we can outline the regions of parameter space
for which detection of a given Higgs boson is possible at any given collider. A summary of
the most important results obtained after investigating signals and backgrounds is given in
the following sections.

1. LEP-II

Certainly the most important goal of LEP-II will be to detect the $h^0$ if it exists. In the
most likely scenario where $m_A \gtrsim 2m_Z$, $h^0$ would be searched for in the $e^+ e^- \to Z^* \to Zh^0$
mode. Since the LEP-II energy is likely to be in the vicinity of $2m_Z$, and since $m_h$ can
be larger than $m_Z$, our ability to find the $h^0$ at LEP-II will be extremely sensitive to $\sqrt{s}$, $\tan \beta$, $m_t$ and $m_{\tilde t}$. At large $m_A$, consider fixed ($\sqrt{s}, \tan \beta$) and plot $Zh^0$ discovery contours
in $m_t - m_{\tilde t}$ parameter space. (100 events for $L = 500$ pb$^{-1}$ are adequate.) As expected, $h^0$
detection becomes impossible if either $m_t$ or $m_{\tilde t}$ is too large. The larger $\tan \beta$ and/or the
smaller $\sqrt{s}$, the lower the values of $m_t, m_{\tilde t}$ beyond which discovery is impossible. The most
rapid variation in contour location occurs when $\tan \beta \gtrsim 15$ and $\sqrt{s}$ is increased from 190
GeV to 200 GeV. If $m_t = 135$ GeV and $\tan \beta = 20$, detection of the $h^0$ is possible for all

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m_t \lesssim 1 \text{ TeV} \text{ at } \sqrt{s} = 200 \text{ GeV}, \text{ but becomes impossible for } m_{\tilde{t}} \gtrsim 200 \text{ GeV if } \sqrt{s} = 190 \text{ GeV. A LEP-II energy as low as 175 GeV would make } h^0 \text { detection essentially impossible for any values of } m_t \text{ and } m_{\tilde{t}} \text{ at tan } \beta = 20. \text{ In the opposite extreme, } \sqrt{s} = 240 \text{ GeV would guarantee } h^0 \text{ discovery for any } m_t \lesssim 200 \text{ GeV and } m_{\tilde{t}} \lesssim 1 \text{ TeV even if } \tan \beta \sim 20. \text{ Once } m_t \text{ is known, the precise extent to which the LEP } \sqrt{s} \text{ should be pushed to guarantee } h^0 \text{ discovery for reasonable values of tan } \beta \lesssim 20 \text{ and } m_{\tilde{t}} \lesssim 1 \text{ TeV will be known.}

2. NLC-500

Should the $h^0$ not be discovered at LEP-II, an NLC with $\sqrt{s} = 500 \text{ GeV}$ will certainly be able to find it, provided an integrated luminosity of $L = 10 \text{ fb}^{-1}$ is accumulated. In the most likely scenario where $m_A \gtrsim 100 \text{ GeV}$, the $e^+e^- \rightarrow Z^* \rightarrow Zh^0$ and $WW$-fusion $e^+e^- \rightarrow \nu \bar{\nu}W^+W^* \rightarrow \nu \bar{\nu}h^0$ processes will both yield at least 100 events for all $\tan \beta$ values, regardless of the values of $m_t$ and $m_{\tilde{t}}$. However, detection of the $H^0$, $A^0$, and $H^\pm$ is not guaranteed. In fact, for $m_A \gtrsim 120 \text{ GeV}$ the coupling constant relations of the MSSM imply that the only production processes for these Higgs bosons with potentially large rates are the $e^+e^- \rightarrow Z^* \rightarrow H^0A^0$ and $e^+e^- \rightarrow Z^* \rightarrow H^+H^-$ pair-production reactions. When not phase-space suppressed, these reactions yield at least 100 events for all $\tan \beta$ once $m_A \gtrsim 100 \text{ GeV}$. However, if we recall that $m_H \sim m_A \sim m_{H^\pm}$ for $m_A \gtrsim 2m_Z$, it is clear that both reactions become kinematically disallowed for $m_A + m_H \sim 2m_{H^\pm} \sim \sqrt{s}$. At $\sqrt{s} = 500 \text{ GeV}$, the kinematical suppression is such that the largest $m_A \sim m_H \sim m_{H^\pm}$ value that can be probed at the NLC will be between 200 and 210 GeV, i.e. roughly $0.4\sqrt{s}$.

3. SSC/LHC

Of course, even before an NLC will be available the SSC and LHC will both be running. What will be their ability to detect the MSSM Higgs bosons? The answer depends critically on many parameters. In order to restrict the discussion, I adopt a fixed top quark mass of $m_t = 150 \text{ GeV}$, an integrated SSC luminosity of $L = 30 \text{ fb}^{-1}$ (results for the LHC with $L = 100 \text{ fb}^{-1}$ are very similar), and consider three scenarios for other relevant parameters: a) $m_{\tilde{t}} = 1 \text{ TeV}$ and all ino masses $\gtrsim 200 \text{ GeV}$; b) $m_{\tilde{t}} = 1 \text{ TeV}$ and ino masses specified by $M = 200 \text{ GeV and } \mu = 100 \text{ GeV}$; c) $m_{\tilde{t}} = 300 \text{ GeV}$ and ino masses as in b). (The large-tan $\beta$ ino masses for $M = 200 \text{ GeV and } \mu = 100 \text{ GeV}$ are: $\tilde{\chi}^0_i \sim 59, 114, 117, 237 \text{ GeV}$; $\tilde{\chi}^+_i \sim 82, 237 \text{ GeV}$. Even at low tan $\beta$, $m_{\tilde{\chi}^0}$ is above the cosmologically motivated bound quoted by the PDG.) In scenarios a) and b) the radiative corrections to the MSSM Higgs masses (especially $m_h$ and the lower values of $m_H$) are large. In scenario c), these radiative corrections are much smaller. In scenario a) Higgs decays to superpartner particles do not occur for the parameter region to be discussed, whereas in scenarios b) and c) Higgs decays to ino pairs are of considerable importance (sometimes dominant) for the $H^0$, $A^0$ and $H^\pm$ in the higher mass region.

We discuss detection modes involving SM final state particles for which backgrounds have been thoroughly studied and specific detection criteria are known at a high level of confidence. First, there is $W^* \rightarrow WH$ plus $gg \rightarrow t\bar{t}H \rightarrow WHX$ ($H = h^0, H^0, A^0$) followed by $H \rightarrow \gamma\gamma$ and $W \rightarrow l\nu$ — the ‘$\gamma'\gamma'’ mode. Second, there is $gg \rightarrow H \rightarrow ZZ$ or $ZZ^* \rightarrow l^+l^- l^+l^-$ — the ‘$4l$’ mode. Finally, there is detection of $t \rightarrow H^\pm b$ decays. Let us examine the
feasibility of the various modes in terms of the \( m_A - \tan \beta \) parameter space, other masses and parameters being determined by the MSSM relations. We consider only \( m_A \leq 400 \text{ GeV} \) and \( 0.5 \leq \tan \beta \leq 20 \). Recent limits on \( BR(b \to s\gamma) \) imply a lower limit on \( m_{H^\pm} \) such that \( m_A \) values below about 100 GeV are probably ruled out. This implies \( t \to H^\pm b \) will not be possible at \( m_t = 150 \text{ GeV} \). For \( m_A \gtrsim 100 \text{ GeV} \), \( WH^0 \) detection in the \( l\gamma\gamma \) mode is also not possible. Further, \( m_h \) is too light at \( m_t = 150 \text{ GeV} \) for \( h \to 4l \) detection, and \( H^0 \to 4l \) detection is possible only in a very limited region — \( 50 \leq m_A \leq 2m_t \) when \( \tan \beta \lesssim 3.5 - 7 \) in scenario a), decreasing substantially in b), and essentially gone in c). \( A^0 \) detection in any mode is impossible unless \( \tan \beta \lesssim 1 \). However, more or less independent of scenario, the \( WH^0 \to l\gamma\gamma X \) mode at the SSC will be viable for (roughly) \( m_A \gtrsim 160 \text{ GeV} \) at all \( \tan \beta \).

In all three scenarios the SSC will not be able to detect any MSSM Higgs boson (in the modes discussed) between \( m_A \sim 100 \) and \( m_A \sim 160 \text{ GeV} \) (narrower at small \( \tan \beta \)). Over some portion of this region, LEP-II (at \( \sqrt{s} = 200 \text{ GeV} \)) will be able to detect \( h^0Z \) events. For scenarios a) and b) this region is limited to \( \tan \beta \lesssim 12 - 9 \) for \( m_A \sim 100 - 150 \text{ GeV} \) — the large \( m_t \) implies \( m_h \) is too large at higher \( \tan \beta \) values. However, in scenario c), \( m_h \) is always sufficiently light that \( h^0Z \) detection will be possible at LEP-II for \( m_A \gtrsim 100 \text{ GeV} \) for all \( \tan \beta \).

4. Back-Scattered Laser Beams at the NLC

Since only the \( h^0 \) will be easily discovered at LEP-II and/or SSC/LHC, it becomes crucial to see if the reach of NLC-500 in \( A^0, H^0 \) or \( H^\pm \) mass can be extended beyond \( \sim 0.4\sqrt{s} \). We find that \( \gamma\gamma \) collisions of back-scattered laser beams can push the discovery region for the \( A^0 \) and \( H^0 \) to \( \sim 0.8\sqrt{s} \), assuming an ‘effective luminosity’ of 20 fb\(^{-1}\). For instance, the viable channels in the case of the \( A^0 \) are: \( \gamma\gamma \to A^0 \to Zh^0 \) or \( bb \), for \( m_A \lesssim 2m_t \); and \( \gamma\gamma \to A^0 \to t\bar{t} \), for \( m_A \gtrsim 2m_t \). The \( \gamma\gamma \to bb \) and \( t\bar{t} \) backgrounds can be suppressed by appropriate cuts and adequate polarization for the colliding \( \gamma \)’s. Extension to \( A^0 \) masses of order \( 0.8\sqrt{s} \) is only possible for small to moderate values of \( \tan \beta \). By \( \tan \beta = 20 \), the only useful channel is \( \gamma\gamma \to A^0 \to bb \); event rates are adequate for \( m_A \lesssim 200 - 250 \text{ GeV} \) (at \( L_{\text{eff}} = 20 \text{ fb}^{-1} \)).

5. Conclusions

Combining LEP-II and SSC/LHC, detection of the \( h^0 \) is almost guaranteed, but detection of the \( A^0, H^0 \), and \( H^\pm \) is likely to require the use of other (less background free) final state channels. The utility of these other modes remains uncertain at this point in time. The ability to detect the \( A^0 \) and \( H^0 \) is much greater at the NLC.

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6. References

1. J.F. Gunion, preprint UCD-92-20 (1992), to appear in Perspectives in Higgs Physics, ed. G. Kane, World Scientific.