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R. Hempfling
Deutsches Elektronen-Synchrotron DESY, Hamburg

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IMPLICATIONS OF RADIATIVE CORRECTIONS FOR THE SUPERSYMMETRIC HIGGS SEARCH AT THE NLC

Ralf Hempfling*

Deutsches Elektronen-Synchrotron, Notkestraße 85, 22603 Hamburg, Federal Republic of Germany

Abstract. We discuss the importance of radiative corrections for the Higgs boson phenomenology of the minimal supersymmetric model. The Higgs discovery potential of the next e^+e^- linear collider (NLC) with $300\,\mathrm{GeV} \lesssim \sqrt{s} \lesssim 500\,\mathrm{GeV}$ is presented. We pay particular attention to the possibility of disentangling the MSSM from the standard model (SM).

1. Introduction

Supersymmetry (SUSY) is one of the most attractive extensions of the SM both theoretically as well as experimentally. On the one hand it may provide the solution to the hierarchy problem, one of the most puzzling theoretical shortcomings of the SM. One the other hand, SUSY predicts the existence of a whole host of new particles at or slightly above the electroweak scale and, therefore, we expect at least some of them to lie within the discovery limits of NLC. In addition to a supersymmetric partner for every particle of the SM, SUSY predicts the existence of two Higgs doublets.[1] Without adding any other particles we then obtain the minimal version of a supersymmetric extension of the SM (MSSM). After electroweak symmetry breaking the Higgs sector of the MSSM contains five physical particles: two CP-even scalars (h^0, H^0) and CP-odd scalar (A^0) and a pair of charged scalars ($H^\pm$) whose masses are constrained by SUSY, *e.g.*

$$m_{h^0} \leq m_Z + \text{radiative corrections}\,. \tag{1}$$

The couplings of h^0 to gauge bosons and to fermions is determined by the ratio of vacuum expectation values, $\tan\beta$, and the CP-even mixing angle, α, *e.g.*[2]

$$g_{h^0 A} = C_A g_{HA}\,, \quad \text{where } C_A = \sin(\beta-\alpha)\,, \frac{\cos\alpha}{\sin\beta}\,, \frac{\sin\alpha}{\cos\beta}\,, \tag{2}$$

where $A = ZZ, u\bar{u}, d\bar{d}$, and H denotes the SM Higgs boson. Thus, the MSSM Higgs phenomenology differs from the SM already at tree-level and is therefore a very promising place to try and distinguish these two popular models.

2. Radiative Corrections to the Higgs Sector

Radiative corrections to the Higgs masses in the MSSM have been studied very intensively in recent years using a diagrammatic approach,[3] renormalization group analysis,[4;5] and the effective potential formalism.[6] In summary we can say that the most prominent feature of the radiative effects is to increase m_{h^0} by a large, m_t-dependent amount. As a result, the current LEP experiments can only rule out a small region in the m_{A^0}–$\tan\beta$ plane. In addition, LEP 200, while having a good chance of detecting h^0, will not be able to rule out the MSSM, if the Higgs search is negative and $m_t \gtrsim 130\,\mathrm{GeV}$.

On the other hand, h^0 will clearly be kinematically accessible at the NLC with a CM energy of $300\,\mathrm{GeV} \leq \sqrt{s} \leq 500\,\mathrm{GeV}$. However, in order to assure the detection of h^0 or even H^0 it remains to be checked whether the cross section

$$\sigma_\phi \equiv \max\{\sigma(e^+e^- \to Z\phi), \sigma(e^+e^- \to A^0\phi)\} \tag{3}$$

($\phi = h^0, H^0$) is large enough to yield the number of events necessary for the data analysis.[7]

Of the three methods mentioned above the full one-loop calculation is the best suited to answer this question.[8] On the one hand, the assumption of the effective potential formalism that all physical momenta are negligible is clearly inadequate for $\sqrt{s} = 500\,\mathrm{GeV}$. On the other hand, the concept of running coupling constants is technically difficult if one tries to evaluate the ZZh^0 Green function at $\sqrt{s}$ and the mass matrices at m_{h^0}. Nonetheless, a numerical comparison of the latter approach with the full one-loop calculation [9] shows excellent agreement. Moreover, the simplicity of the expression obtained in ref. 5 allows for a detailed scan of the SUSY parameter space. The results of such a scan are presented in fig. 1. The upper left hand corners of fig. 1 are theoretically forbidden. We categorize the area in

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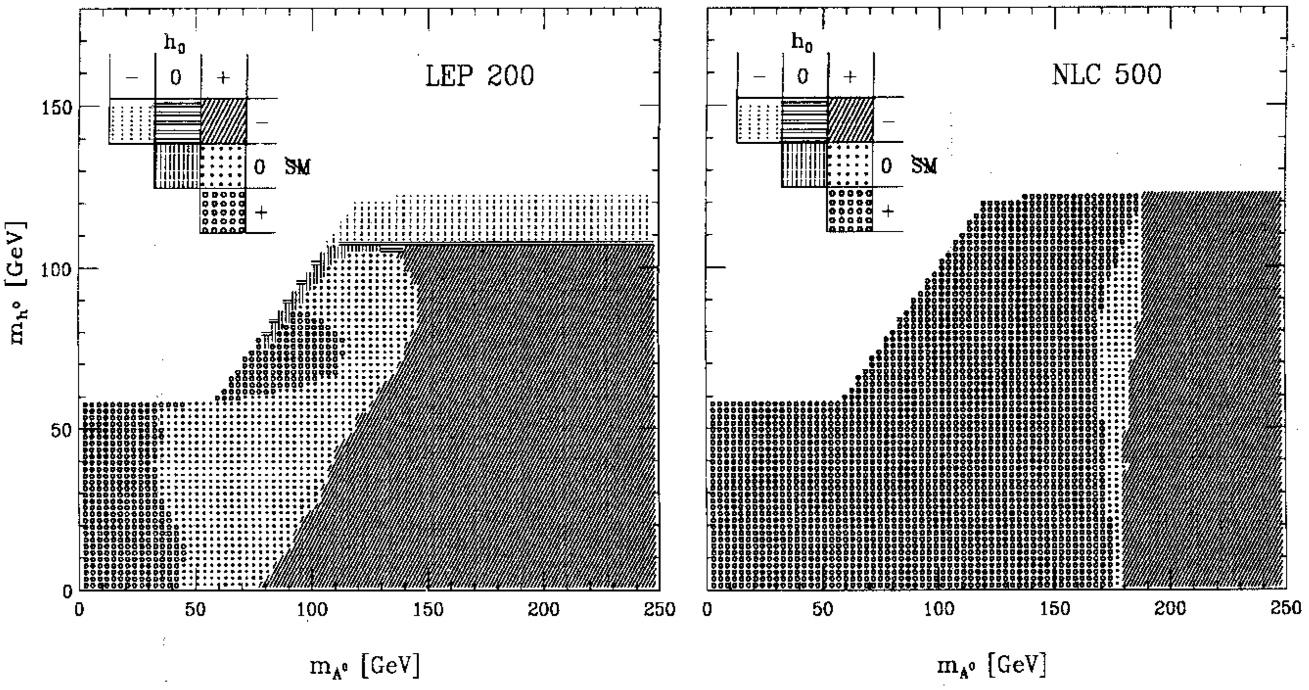

Fig. 1. Regions in the m_{A^0}–m_{h^0} plane where h^0 and deviations of the SM (S̸M) can be detected at LEP ($\sqrt{s} = 200\,\mathrm{GeV}$) and NLC ($\sqrt{s} = 500\,\mathrm{GeV}$). All parameters are varied as described in the text.

the m_{A^0}–m_{h^0} plane by whether a Higgs boson (h^0 or H^0) can be discover and by whether a deviation of the SM (S̸M) can be observed. A (+) indicates that the detection of h^0 or a deviation from the SM is certain (independent of the choice of SUSY parameters). A (−) indicates that the detection of h^0 or a deviation from the SM is impossible within the MSSM for any choice of parameters and a (0) indicates that it depends on the choice of parameters whether or not h^0 or a deviation of the SM can be detected. As deviation of the SM counts the observation of more than one Higgs boson, as well as a deviation of the Higgs production rate from its SM prediction by more than two standard deviations. We assume, that the analysis requires 50 (150) events at LEP (NLC) with a luminosity of $0.5\,\mathrm{fb}^{-1}$ ($10\,\mathrm{fb}^{-1}$) and $\sqrt{s} = 200\,\mathrm{GeV}$ (500 GeV). Here we vary the common SUSY mass scale within $200\,\mathrm{GeV} \le M_{\tilde{Q}} \le 1000\,\mathrm{GeV}$, the mass parameter of the superpotential within $-1 \le \mu/M_{\tilde{Q}} \le 1$ and the A-parameters within $0 \le A_{\tilde{Q}} \le M_{\tilde{Q}}$. We allow all values $0.5 \le \tan\beta \le 50$ and $100\,\mathrm{GeV} \le m_t \le 200\,\mathrm{GeV}$ but require that $m_t/\sin\beta \le 220\,\mathrm{GeV}$. Ths requirement assures that the top Yukawa coupling remains preturbative all the way to the Planck scale ($10^{19}\,\mathrm{GeV}$). Without this constraint, the area where a discovery of h^0 is parameter dependent and where an observation of a deviation of the SM is parameter dependent will grow significantly (somewhat) for LEP (NLC).

We conclude that at NLC h^0 will be found over the whole range of parameters. A discovery of A^0 (and of H^0) is possible for $m_{A^0} \le 190\,\mathrm{GeV}$ and certain for $m_{A^0} \le 170\,\mathrm{GeV}$ if we require 150 events. This upper limit is purely kinematical and thus almost parameter independent (this limit is significantly smaller than $\sqrt{s}/2$ due to P–wave suppression near threshold and a significant A^0–H^0 mass splitting). If we assume that the analysis can be done with only 50 events the discovery limit is 210 GeV and can be extended to 230 GeV with a luminosity of $50\,\mathrm{fb}^{-1}$.

Let us now assume that one Higgs boson is found with a mass compatible with the constraints of the MSSM but no other particle is found, that would indicate the existence of SUSY. (This would imply that $m_{A^0} \gtrsim 200\,\mathrm{GeV}$.) The natural question is whether in such a scenario the MSSM and the SM can be distinguished. From eq. (2) we see that the production and decay rates differ in both models at tree-level. However, the difference in the production (decay) rate vanishes in the large m_{A^0} limit as $m_Z^4/m_{A^0}^4$ ($m_Z^2/m_{A^0}^2$) and thus will be very small in the cases considered here. Thus radiative corrections have to be included in any consistent analysis.

The full one-loop calculation to the Higgs decay by A. Dabelstein and W. Hollik[10] shows that the MSSM prediction differs from the SM prediction only by a few % in the scenario where all superpartners are too heavy to be produced directly.

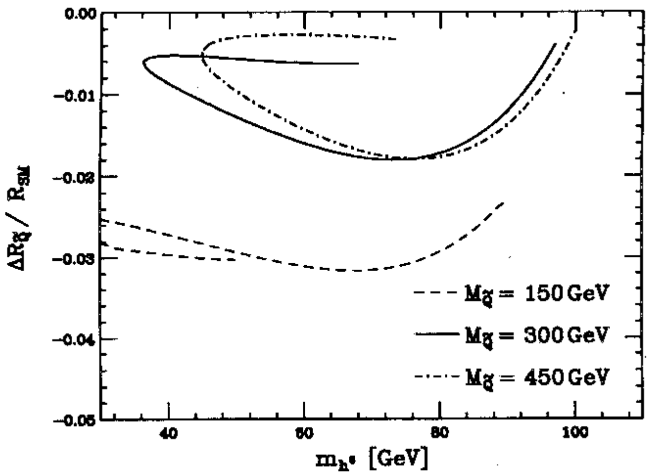

Fig. 2. Relative deviation of the MSSM prediction of $\sigma(e^+e^- \to Zh^0)/\sigma(e^+e^- \to \mu^+\mu^-)$ from its SM value at $\sqrt{s} = 300$ GeV as a function of m_{h^0} for three choices of $A_U = A_D = M_{\tilde{U}} = M_{\tilde{D}} = M_{\tilde{Q}}$ assuming $m_t = 150$ GeV. This includes all leading-log corrections with $m_{A^0} = 200$ GeV as well as the sfermionic one-loop contributions

The situation for the Higgs production is similar [see fig. 2]. Here, the experimental error has been reduced significantly by forming the ratio of partial cross sections $R \equiv \sigma(e^+e^- \to Zh^0)/\sigma(e^+e^- \to \mu^+\mu^-)$ due to the cancellations of the uncertainty in the luminosity. In fig. 2 we plot the difference of the prediction in the MSSM and in the SM, $\Delta R_{\tilde{Q}} \equiv R_{\rm MSSM} - R_{\rm SM}$,[11] (the subscript $\tilde{Q}$ indicates that only the squark and slepton loop contributions are included). Here we choose $m_{A^0} = 200\,\mathrm{GeV}$, $m_t = 150\,\mathrm{GeV}$ and $\sqrt{s} = 300\,\mathrm{GeV}$. All the soft squark parameters are set equal to $M_{\tilde{Q}}$. The leading-log corrections are included as described in ref. 5.

A detailed study [11] shows that the radiative corrections are negative throughout. They grow with m_t^2 and decrease with the inverse power of $M_{\tilde{Q}}^2$.

3. Summary

The lightest Higgs boson of the MSSM, h^0, will be detected at NLC for any choice of parameters and both A^0 and H^0 can be detected if $m_{A^0} \lesssim 210\,\mathrm{GeV}$.

Furthermore, we have investigated the scenario in which h^0 is the only detected particle at NLC. In this case the CP-even mixing effects in the Higgs sector is enhanced by radiative corrections. However, the effects remain in the few % range and will be concealed by statistical fluctuation.

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