DEUTSCHES ELEKTRONEN – SYNCHROTRON

DESY 92-128
September 1992

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ISSN 0418-9833

NOTKESTRASSE 85 · D-2000 HAMBURG 52

DESY 92-128
September 1992

ISSN 0418-9833

HIGGS BOSONS AT FUTURE COLLIDERS*

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ABSTRACT

The prospects for discovering Higgs particles at future pp and e$^+$e$^-$ colliders are reviewed. Both the Standard Model Higgs boson and the Higgs particles of its minimal supersymmetric extension are discussed.

1. Introduction

In order to accomodate the well–established electromagnetic and weak interaction phenomena, the existence of at least one isodoublet scalar field to generate fermion and weak gauge bosons masses is required. The Standard Model makes use of one isodoublet: three Goldstone bosons among the four degrees of freedom are absorbed to build up the longitudinal components of the $W^\pm, Z$ gauge bosons; one degree of freedom is left over, corresponding to a physical scalar particle, the Higgs boson [1]. The discovery of this particle is the ultimate test of the Standard Model.

In the Standard Model (SM), the mass of the Higgs particle is a free parameter. The only available information is the upper limit $M_H > 60$ GeV established at LEP1 [2]; this limit can be raised to 80–90 GeV at LEP2. However, interesting constraints can be derived from assumptions on the energy range within which the model is valid before perturbation theory breaks down and new phenomena would emerge:

(i) If the Higgs mass were larger than ~ 1 TeV, the W and Z gauge bosons would interact strongly with each other to ensure unitarity in their scattering at high energies.

(ii) The quartic Higgs self–coupling, which at the scale M_H is fixed by M_H itself, grows logarithmically with the energy scale. If M_H is small, the energy cut–off Λ at which the coupling grows beyond any bound and new phenomena should occur, is large; conversely, if M_H is large, Λ is small. The condition $M_H < \Lambda$ sets an upper limit on the Higgs mass in the SM; lattice analyses lead to an estimate of about 630 GeV for this limit. Requiring that the SM be extended to the GUT scale, $\Lambda > 10^{15}$ GeV, the Higgs mass should be less than 180 to 200 GeV. Including the effect of top quark loops on the running coupling, a detailed analysis predicts the area of the allowed (m_t, M_H) values shown in Fig. 1 [3].

However, there are two problems that one has to face when trying to extend the SM to $\Lambda_{\rm GUT}$. The first one is the the so–called hierarchy or naturalness problem: the Higgs boson tends to acquire a mass of the order of these large scales [the radiative corrections to M_H are quadratically divergent]; the second one is that the simplest GUTs predict a value for $\sin^2\theta_W$ that is incompatible with the measured value $\simeq 0.23$. Low energy supersymmetry solves these two problems at once: supersymmetric particle loops cancel the quadratic divergences and contribute to the running of the gauge coupling constants, correcting the small discrepancy to the observed value of $\sin^2\theta_W$; see [4] for a review.

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*Talk given at the XV Meeting on Elementary Particle Physics. Kazimierz Poland, May 1992

The minimal supersymmetric extension of the Standard Model (MSSM) [4, 5] requires the existence of two isodoublets of Higgs fields, to cancel anomalies and to give mass separately to up and down–type fermions. Three neutral, h/H(CP=+), A(CP=–) and a pair of charged scalar particles, $H^\pm$, are introduced by this extension of the Higgs sector. Besides the four masses, two additional parameters define the properties of these particles: a mixing angle α in the neutral CP–even sector and the ratio of the two vacuum expectation values tgβ, which from GUT restrictions is assumed in the range $1 < {\rm tg}\beta < m_t/m_b$. Supersymmetry leads to several relations among these parameters and only two of them are in fact independent. These relations impose a strong hierarchical structure of the mass spectrum, $M_h < M_Z, M_A < M_H$ and $M_W < M_{H^\pm}$, which however is broken by radiative corrections if the top quark mass is large [4, 6]. For instance, the upper bound on the mass of the lightest Higgs boson h is shifted from the tree level value M_Z to ~ 140 GeV; Fig. 2. The masses of the heavy neutral and charged Higgs particles can be expected, with a high probability, in the range of the electroweak symmetry breaking scale; Fig. 2. Some of these features are not specific to the minimal extension and are expected to be realized also in more general SUSY models. For instance, a light Higgs boson with a mass below $\mathcal{O}(200$ GeV) is quite generally predicted by SUSY theories [1, 7].

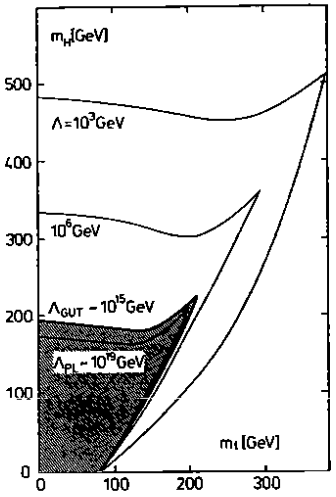

Fig. 1 Allowed values of M_H if the SM can be extended up to the scale Λ; from M. Lindner [3]. The dashed area follows from the extension of the SM to the GUT scale.

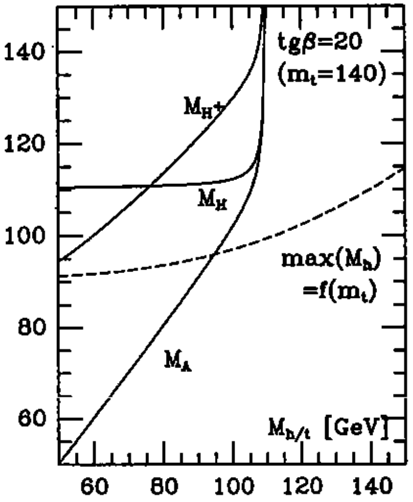

Fig. 2 Upper limit of the h mass as function of m_t and $A, H, H^\pm$ masses a function of M_h for $m_t = 140$ GeV and tg$\beta = 20$; the squark mass is fixed to 1 TeV.

The search for these Higgs particles will be a major goal of the next generation of colliders. In the following, I will discuss the discovery potential of the pp colliders LHC/SSC as well as a future e$^+$e$^-$ linear collider with a c.m. energy of 500 GeV. For the Standard Model Higgs boson, I will put some emphasis on the mass range favored by grand unification i.e. M_H below ~ 250 GeV.

2. Couplings and Decay Modes

In the SM, the profile of the Higgs particle is uniquely determined once M_H is fixed. The decay width, the branching ratios and the production cross sections are given by the strength of the Yukawa couplings to fermions and gauge bosons, the scale of which is set by the masses of these particles. To discuss the Higgs decay modes, it is convenient to divide the Higgs mass into two ranges: the "low mass" range $M_H < 140$ GeV and the "high mass" range $M_H > 140$ GeV. [A detailed discussion as well as the analytic expressions of the various decay widths can be found in Refs. [1, 8]].

In the "low mass" range, the Higgs boson decays into a large variety of channels. The main decay mode is by far the decay into $b\bar{b}$ pairs with a branching ratio of $\sim 90\%$ followed by the decays into $c\bar{c}$ and $\tau^+\tau^-$ pairs with a branching ratio of $\sim 5\%$. Also of significance, the top–loop mediated Higgs decay into gluons, which for M_H around 120 GeV occurs at the level of $\sim 5\%$. The top and W–loop mediated $\gamma\gamma$ and $Z\gamma$ decay modes are very rare the branching ratios being of $\mathcal{O}(10^{-3})$; however these decays lead to very clear signals and are very interesting being sensitive to new heavy particles.

In the "high mass" range, the Higgs particle also decays into WW and ZZ pairs, with one of the gauge bosons being virtual below the respective threshold. Above the ZZ threshold, the Higgs boson decays almost exclusively into these channels with a branchings ratio of 2/3 for WW and 1/3 for ZZ. The opening of the $t\bar{t}$ threshold does not alter significantly this pattern, since for large Higgs masses, the $t\bar{t}$ decay width rises only linearly with M_H while the decay widths to W and Z bosons grow with M_H^3.

The previous discussion is summarized in Fig. 3, where the Higgs decay branching fractions are shown [an update of Ref. [9] by including the electroweak radiative corrections as well as the QCD corrections to the loop mediated decays which have been recently calculated]. In the low mass range, the Higgs boson is very narrow $\Gamma_H < 10$ MeV, but the width becomes rapidly wider for masses larger than 140 GeV, reaching 1 GeV at the ZZ threshold; the Higgs decay width cannot be measured directly in the mass range below 250 GeV.

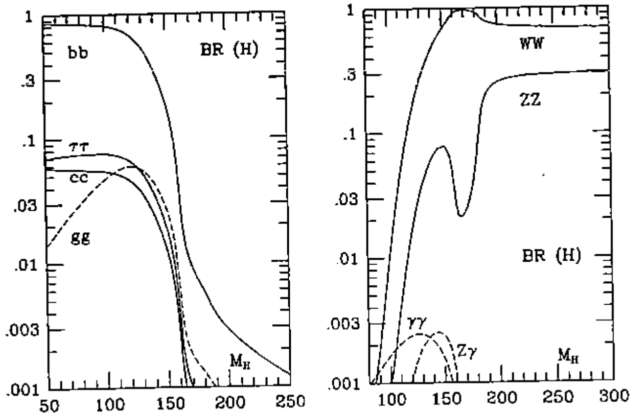

Fig. 3 Branching ratios [in %] of the Standard Model Higgs boson.

In the MSSM, since the lightest CP–even Higgs boson h is likely to be the particle which will be discovered first, an attractive choice of the two input parameters is the set $(M_h, \mathrm{tg}\beta)$ [with $\mathrm{tg}\beta$ parametrizing the production cross sections]. Once these two parameters [as well as the top quark mass and the associated squark masses which enter through radiative corrections] are specified, all other masses and the angle α can be derived [1, 4].

The couplings of the various neutral Higgs bosons [collectively denoted by Φ] to fermions and gauge bosons will in general strongly depend on the angles α and β; normalized to the SM Higgs couplings, they are given by

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$
A	$1/\mathrm{tg}\beta$	$\mathrm{tg}\beta$	0

The pseudoscalar has no tree level couplings to gauge bosons, and its couplings to down (up) type fermions are (inversely) proportional to $\mathrm{tg}\beta$. For the CP–even Higgs bosons, the couplings to down (up) type fermions are enhanced (suppressed) compared to the SM Higgs couplings [$\mathrm{tg}\beta > 1$]. If M_h is very close to its upper limit for a given value of $\mathrm{tg}\beta$, the couplings to fermions and gauge bosons are SM like. If all other Higgs bosons are very heavy, it is very difficult to distinguish the Higgs sector of the MSSM from the SM.

The lightest Higgs boson will decay mainly into fermion pairs since its mass is smaller than ~ 140 GeV. This is also the dominant decay mode of the pseudoscalar A which has no tree–level couplings to gauge bosons. For values of $\mathrm{tg}\beta$ larger than unity and for masses less than ~ 140 GeV, the main decay modes of the neutral Higgs bosons will be decays into $b\bar{b}$ and $\tau^+\tau^-$ pairs; the branching ratios always being larger than $\sim 90\%$ and 5%, respectively. The decays into $c\bar{c}$ and gg are in general strongly suppressed especially for large values of $\mathrm{tg}\beta$. For high masses, the top decay channels $H, A \to t\bar{t}$ open up; yet this mode remains suppressed for large $\mathrm{tg}\beta$.

If the mass is high enough, the heavy H can in principle decay into WW and ZZ bosons but since the partial widths are proportional to $\cos^2(\beta-\alpha)$, they are strongly suppressed. For the same reason, the cascade decay of the pseudoscalar $A \to Zh$ is suppressed in general. The heavy H boson can also decay into two lighter Higgs bosons; but these modes are restricted to very small domains in the parameter space. The branching ratios of the $\gamma\gamma$ and $Z\gamma$ decays are smaller than in the SM; this is due to the fact that the decays into $b\bar{b}$ are enhanced for $\mathrm{tg}\beta > 1$ and the dominant W–loop contribution is suppressed (absent) in the case of the CP–even (odd) Higgs bosons. Other possible channels are the decays into SUSY particles. While sfermions are likely too heavy to affect Higgs decays, the Higgs decays into charginos and neutralinos could eventually be important since some of these particles are expected to have masses of $\mathcal{O}(M_Z)$. For more details, see Ref. [11].

The couplings of the charged Higgs particle to fermions is a mixture of scalar and pseudoscalar currents. The charged Higgs decays into fermions but also, if allowed kinematically, into hW. Below the tb and Wh thresholds, the charged Higgs particles will decay mostly into $\tau\nu_\tau$ and $c\bar{s}$ pairs, the former being dominant for $\mathrm{tg}\beta > 1$. For large $M_{H^\pm}$ and $\mathrm{tg}\beta$ values, the top–bottom decay $H^+ \to t\bar{b}$ becomes dominant.

Adding up the various decay modes, the width of all five Higgs bosons remains very narrow, being of the order of 1 GeV even for large masses.

3. Production at pp Colliders

The main production mechanisms of neutral Higgs bosons at hadron colliders are,

(*a*)	gluon – gluon fusion	gg	$\rightarrow H$
(*b*)	WW/ZZ fusion	VV	$\rightarrow H$
(*c*)	association with W/Z	$q\bar{q}$	$\rightarrow V + H$
(*d*)	association with $t\bar{t}$	$gg, q\bar{q}$	$\rightarrow t\bar{t} + H$

The cross sections [the analytic expressions can be found in Ref. [9]] are shown in Fig. 4 for a c.m. energy of 16 TeV, typical of LHC. In the mass range we are interested in, $80 < M_H < 250$ GeV, the dominant production process is the gluon–gluon fusion mechanism, for which the cross section is of order a few tens of pb. It is followed by the WW/ZZ fusion processes with a cross section of a few pb; those of the associated production with W/Z or $t\bar{t}$ are an order of magnitude smaller. For the SSC with a c.m. energy of 40 TeV, the cross sections are approximately 3 times larger. Note that for a luminosity of $\mathcal{L} = 10^{33}(10^{34})\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, $\sigma = 1$ pb would correspond to $10^4(10^5)$ events per year.

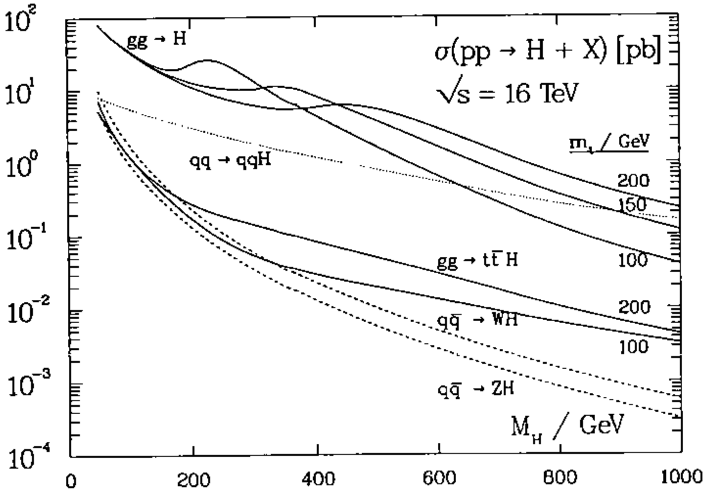

Fig. 4 Cross sections [in pb] for the main production mechanisms of Higgs bosons at the LHC as a function of the Higgs mass.

Besides the errors due to the poor knowledge of the gluon distribution at small x, the lowest order cross sections are affected by large uncertainties due to higher order corrections. Including the next to leading QCD corrections, the total cross sections can be defined properly: the scale at which one defines the strong coupling constant is fixed and the [generally non-negligible] corrections are taken into account. The "K-factors" for WH/ZH production [which can be inferred from the Drell–Yan production of weak bosons] and the VV fusion mechanisms are small [10], increasing the total cross sections by ~ 20 and 10% respectively; the corrections to the associated $t\bar{t}H$ production are still not known. The QCD corrections to the main production mechanism, $gg \rightarrow H$, have been computed recently [12, 13] and I will briefly summarize the results.

Since already at the Born level the process $gg \rightarrow H$ proceeds through a one–loop diagram, the virtual QCD corrections [which include self-energy, vertex and box corrections] are at the two–loop level. The [one–loop] real corrections consist not only of the emission of a gluon [from the internal quark or from the initial gluon legs], but also from $q\bar{q}$ and qg scattering which occur at the same order; Fig. 5a. The contributions of these diagrams have ultraviolet, infrared as well as collinear singularities. Adding the virtual and the real corrections, only the collinear singularities are left over and they are absorbed in the parton densities. The result [12] of the calculation is shown in Fig. 5b for LHC and SSC energies with m_t fixed to 140 GeV. The dotted lines are for the Born cross sections and the other lines are for the QCD corrected cross sections for two choices of the parton densities; the lower (upper) boundaries of the shaded area are for the choice of the renormalization and factorization scales $\mu^2 = Q^2 = \hat{s}(M_H^2)$. The arbitrariness of this choice and also the one of the parton densities, lead to un uncertainty of about $\sim 30\%$. The QCD corrections are rather large and increase the cross sections by a factor $\simeq 1.8$ both at LHC and SSC: clearly, they have to be taken into account.

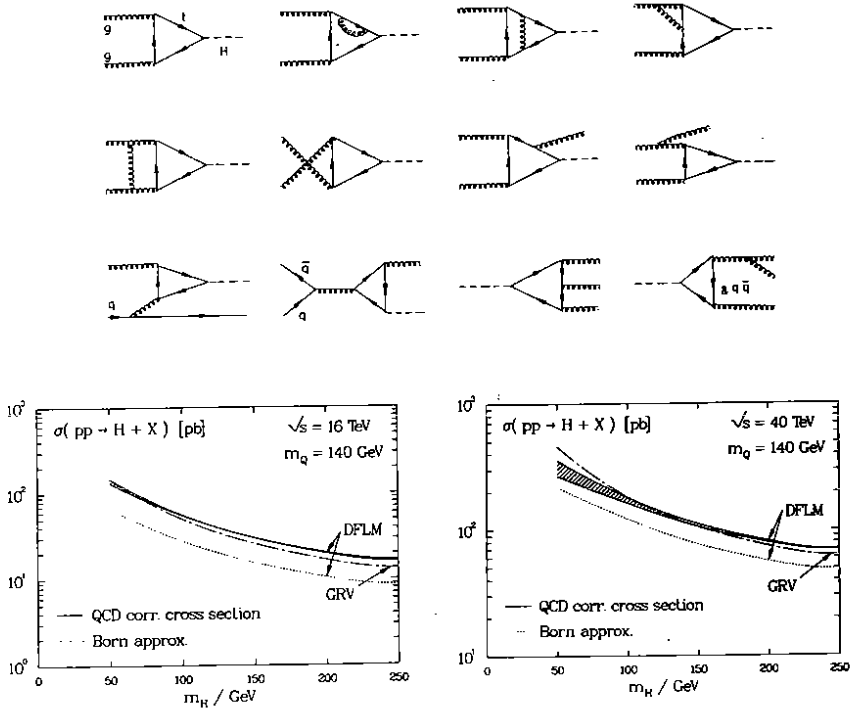

Fig. 5 Generic Feynman diagrams and the cross sections for the Born term and for the QCD correction to Higgs production in gg fusion at LHC and SSC; m_t is fixed to 140 GeV.

The signals which are best suited to identify the produced Higgs particles at pp colliders have been studied in great detail in Ref. [14] for the LHC and in Ref. [15] for the SSC. I briefly summarize here the main conclusions of these studies.

For Higgs bosons in the "high mass" region, $M_H > 140$ GeV, the signal consists of the so-called "gold-plated" events $H \to ZZ^{(*)} \to 4l^{\pm}$ with $l = e, \mu$. The backgrounds are relatively small, and one can probe Higgs masses up to $\mathcal{O}(1$ TeV$)$ with a luminosity $\int \mathcal{L} = 100(10)$ fb^{-1} at LHC(SSC). The $H \to WW^{(*)}$ decay channel is more difficult to use because of the large background from $t\bar{t}$ pair production.

For the "low mass" range, the situation is more complicated. The branching ratio for $H \to ZZ^*$ becomes too small and due to the huge QCD jet background, the dominant mode $H \to b\bar{b}$ is useless; one has then to rely on the rare $\gamma\gamma$ decay mode with a branching ratio of $\mathcal{O}(10^{-3})$. At LHC with a luminosity of $\int \mathcal{L} = 100$ fb^{-1}, the cross section times the branching ratio leads to $\mathcal{O}(10^3)$ events but one has to fight against formidable backgrounds. Jets faking photons need a rejection factor larger than 10^8 to be reduced to the level of the physical background $q\bar{q}, gg \to \gamma\gamma$ which is still very large. However, if very good geometric resolution and stringent isolation criteria, combined with excellent electromagnetic energy resolution to detect the narrow $\gamma\gamma$ peak of the Higgs boson are available [at LHC one also needs a high luminosity $\mathcal{L} \simeq 10^{34}$ cm^{-2}s^{-1}], this channel, although very difficult, is feasible. A complementary channel would be the $q\bar{q} \to WH, t\bar{t}H \to \gamma\gamma l\nu$ for which the backgrounds are much smaller; however the signal cross sections are also very small: only few tens of events are expected making this process also difficult.

In the MSSM, the situation is even more difficult. The production mechanisms of the SUSY Higgs bosons are practically the same as those of the SM Higgs; one only has to take the b quark [whose couplings are strongly enhanced for large tgβ values] contributions into account in process (a) [extra contributions from squarks decouple for high masses] and (d) [for tg$\beta \gg 1$, $q\bar{q} \to b\bar{b}H$ becomes the dominant production process]. The various signals for the SUSY Higgs bosons can be summarized as follows:

i) Since the lightest Higgs boson mass is always smaller than ~ 140 GeV, the ZZ signal cannot be used. Furthermore, the $hWW(hb\bar{b})$ coupling is suppressed (enhanced) leading to a smaller $\gamma\gamma$ branching ratio than in the SM [additional contributions from chargino and sfermion loops can also alter the decay width] making the search more difficult. If M_h is close to its maximum value, h has SM like couplings and the situation is similar to the SM case with $M_H = 100$–140 GeV.

ii) Since the pseudoscalar A has no tree-level couplings to gauge bosons and since the couplings of the heavy CP-even H are strongly suppressed, the gold-plated ZZ signal is lost [for H it survives only for small tgβ and M_H values, provided that $M_H < 2m_t$]. One has therefore to rely on the $A, H \to \tau^+\tau^-$ channels for large tgβ values. This mode, which is hopeless for the SM Higgs, seems to be feasible in this case.

iii) Charged Higgs particles, if lighter than the top quark, can be accessible in top decays $t \to H^+b$. This results in a surplus of τ lepton final states [the main decay mode is $H^- \to \tau\nu_\tau$] over μ, e final states, an apparent breaking of τ *vs.* e, μ universality. At LHC, $H^{\pm}$ masses up to ~ 100 GeV can be probed for $m_t \simeq 140$ GeV.

Thus, the search for SUSY Higgs bosons is more difficult than the search for the SM Higgs. Detailed analyses have shown that there is a substantial area in the SUSY parameter space where no Higgs particle can be found at hadron colliders [16].

4. Production at e$^+$e$^-$ Colliders

At e^+e^- linear colliders operating in the 500 GeV energy range, the main production mechanisms for Higgs particles are,

(a)	bremsstrahlung process	$e^+e^- \to (Z) \to Z + H$
(b)	WW fusion process	$e^+e^- \to \bar{\nu}\,\nu\,(WW) \to \bar{\nu}\,\nu + H$
(c)	ZZ fusion process	$e^+e^- \to e^+e^-(ZZ) \to e^+e^- + H$
(d)	radiation off tops	$e^+e^- \to (\gamma, Z) \to t\bar{t} + H$

The expressions of the cross sections have been compiled in ref. [8]. The bremsstrahlung process is dominant for moderate values of $M_H/\sqrt{s}$, but falls off like $\sim s^{-1}$ at high energies. The WW fusion process, on the other hand, is more important for small values of the ratio $M_H/\sqrt{s}$, i.e. high energies where the cross section grows $\sim M_W^{-2}\log s$. For Higgs masses arround 150 GeV, the cross sections for the bremsstrahlung and WW fusion processes are of comparable size at $\sqrt{s} = 500$ GeV, while the ZZ fusion cross section is smaller by an order of magnitude [Fig. 6]. With $\sigma \sim 100$ fb, a rate of ~ 1000 Higgs particles can be produced at a luminosity $\int \mathcal{L} = 10$ fb^{-1}. For $M_H < 120$ GeV, the cross section for $e^+e^- \to t\bar{t}H$ [17] is of the order of a few fb; this process can be used only to measure the $Ht\bar{t}$ Yukawa coupling once the Higgs boson is found. [Additional production mechanisms are provided by the processes $\gamma\gamma \to H$ and $e\gamma \to \nu WH$, the high energy photons generated by Compton back-scattering of laser light].

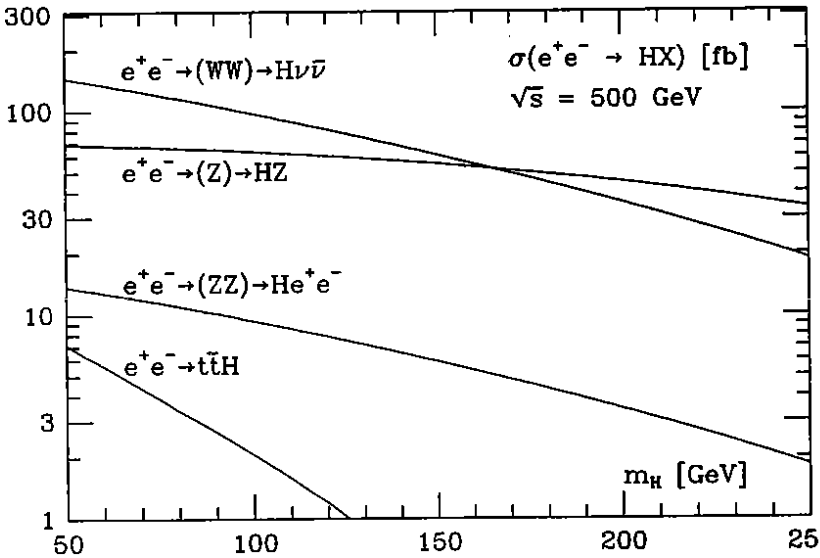

Fig. 6 Cross sections for the main production mechanisms of Higgs bosons at a $\sqrt{s} = 500$ GeV e^+e^- collider; m_t is fixed to 140 GeV in the $e^+e^- \to t\bar{t}H$ process.

A large variety of channels can be exploited to search for Higgs particles in the bremsstrahlung and fusion processes [8]. In the bremsstrahlung process, missing–mass techniques can be applied in events with leptonic Z decays and the Higgs may be reconstructed in $H \to b\bar{b}$ directly. [Missing–mass techniques of course call for collider designs in which beamstrahlung is minimal.] These techniques can be applied for Higgs masses > 100 GeV; below this value, $b\bar{b}$ tagging through micro-vertex detectors must be used to separate the ZH signal from the ZZ background. The WW fusion process requires the reconstruction of the Higgs particle, while missing–mass techniques can also be used in ZZ fusion. Background events from single W and Z production restrict these experimental search techniques in the fusion channels to Higgs masses above 100 GeV.

Once the Higgs boson has been found, it will be very important to explore its properties. This is possible at great detail in the clean environment of e^+e^- colliders. The zero–spin of the Higgs particle is reflected in the angular distribution in the bremsstrahl process which asymptotically must follow the $\sin^2\theta$ law, corresponding to the predominantly longitudinal polarization of the accompanying Z boson. Of great importance is the measurement of the couplings to gauge bosons and matter particles. The strength of the couplings to Z and W bosons is reflected in the magnitude of the production cross sections. The relative strength of the couplings to fermions is accessible through the decay branching ratios. The absolute magnitude is difficult to measure directly; the measurement is possible only in a small mass window where the Higgs decays to $b\bar{b}$ and WW^* compete with each other. Indirect access to the top–Higgs coupling is provided by top-loop mediated photonic and gluonic Higgs decays [and the reverse processes at $\gamma\gamma$ and pp colliders]. Else, Higgs bremsstrahlung off top quarks or Higgs decays to $t\bar{t}$ pairs offer opportunities to measure the ttH coupling directly in limited ranges of the Higgs mass.

An even stronger case for e^+e^- colliders in the 300–500 GeV energy range is made by the MSSM [11, 18, 19]. In e^+e^- collisons, besides the usual bremsstrahlung and fusion processes for h and H production, the neutral Higgs particles can also be produced pairwise: $e^+e^- \to A + h/H$. The various cross sections are shown as functions of the Higgs masses in Fig. 7a, for $\mathrm{tg}\beta = 20$. The cross sections for the bremsstrahlung and the pair production as well as the cross sections for the production of h and H are mutually complementary, coming either with a coefficient $\sin^2(\beta-\alpha)$ or $\cos^2(\beta-\alpha)$. The cross section for hZ production is large for large values of M_h, being of $\mathcal{O}(50)$ fb; by contrast, the cross section for HZ is large for light h [implying small M_H]. In major parts of the parameter space, the signals consist of a Z boson and a $b\bar{b}$ or a $\tau^+\tau^-$ pair, which is easy to separate from the main background, $e^+e^- \to ZZ$ [for $M_h \simeq M_Z$, efficient b detection is needed]. For the associated production, the situation is opposite: the cross section for Ah is large for light h whereas AH production is preferred in the complementary region. The signals consists mostly of four b quarks in the final state, requiring efficient $b\bar{b}$ quark tagging; mass constraints help to eliminate the QCD jets and ZZ backgrounds. The CP-even Higgs particles can also be searched for in the WW and ZZ fusion mechanisms; Fig. 7a.

In e^+e^- collisions, charged Higgs bosons can be produced pairwise, $e^+e^- \to H^+H^-$ through γ, Z exchange. The cross section depends only on the charged Higgs mass; it is large up to $M_{H^\pm} \sim 230$ GeV. Charged Higgs bosons can also be created in laser–photon collisions, $\gamma\gamma \to H^+H^-$ but due to the reduced energy, only smaller masses than previously can be probed. The cross section however is enhanced in the low mass range.

Finally, charged Higgs bosons can be produced in top decays as discussed above. In the range $1 < \mathrm{tg}\beta < m_t/m_b$, the $t \to H^+b$ branching ratio varies between $\sim 2\%$ and 20%. Since the cross section for $t\bar{t}$ production is $\mathcal{O}(0.5)$ pb at $\sqrt{s} = 500$ GeV, this corresponds to 200 and 2000 charged Higgs bosons at a luminosity $\int\mathcal{L} = 10$ fb^{-1}. See Fig. 7b.

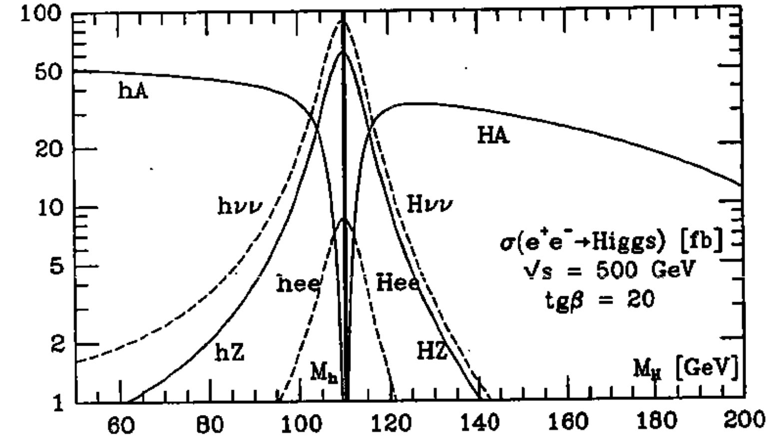

Fig. 7a Cross sections for the production of the SUSY neutral Higgs bosons at a $\sqrt{s} = 500$ GeV e^+e^- collider; $\mathrm{tg}\beta = 20$ and $m_t = 140$ GeV, $M_S = 1$ TeV have chosen.

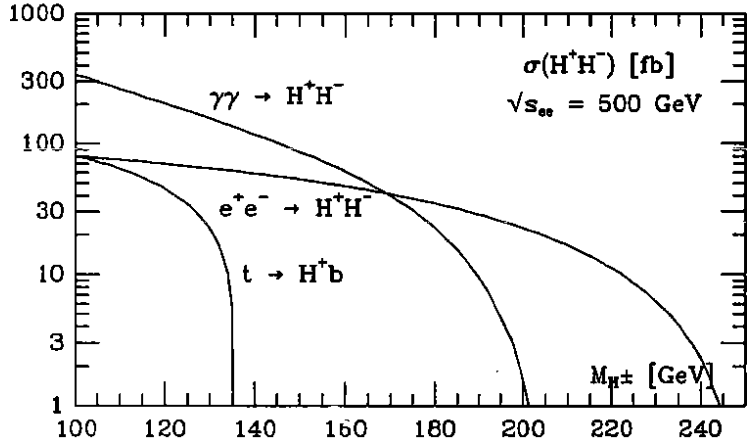

Fig. 7b Cross sections for the production of charged Higgs bosons in e^+e^- and $\gamma\gamma$ collisions as well as from top decays $t \to H^+b$; $\sqrt{s} = 500$ GeV and $m_t = 140$ GeV.

The preceding discussion on the MSSM Higgs sector in e^+e^- linear colliders can be summarized in the following points:

i) The Higgs boson h can be detected in the entire range of the MSSM parameter space, either through the bremsstrahlung process or through pair production; see Fig. 8. In fact, this conclusion holds true even at a c.m. energy of 300 GeV [19].

ii) There is a substantial area of the $(M_h, \mathrm{tg}\beta)$ parameter space where *all* SUSY Higgs bosons can be discovered at a 500 GeV collider; Fig. 8. This is possible if the H, A and $H^\pm$ masses are less than ~ 230 GeV.

iii) In some parts of the MSSM parameter space, the lightest Higgs h can be detected, but it cannot be distinguished from the SM Higgs boson. In this case, Higgs production in $\gamma\gamma$ fusion [which receives extra contributions for SUSY particles] can be helpful.

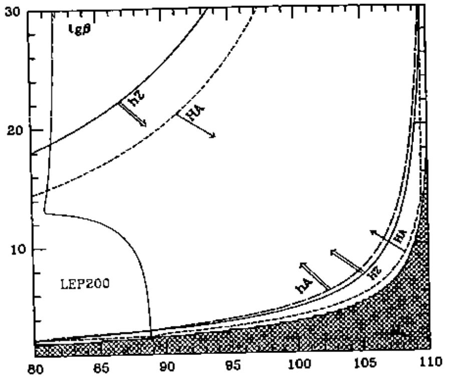

Fig. 8 Regions of the $(M_h, \mathrm{tg}\beta)$ plane where the processes $e^+e^- \to hZ, HZ, hA, HA$ are observable [25 events with $\int \mathcal{L} = 10\ \mathrm{fb}^{-1}$]. The dashed area is the theoretically forbidden region. The thin lines are the regions which can be probed at LEP200 [25 events at $\sqrt{s} = 180$ GeV and $\int \mathcal{L} = 500\ \mathrm{pb}^{-1}$.]

5. Summary

At the hadron colliders LHC/SSC, the Standard Model Higgs boson can, in principle, be discovered up to masses of $\mathcal{O}(1\ \mathrm{TeV})$. While the region $M_H > 140$ GeV can be easily probed through the $H \to 4l^\pm$ channel, the $M_H < 140$ GeV region is difficult to explore and a dedicated detector [as well as a high-luminosity at LHC] is required to isolate the $H \to \gamma\gamma$ decay. SUSY Higgs bosons are more difficult to search for and in some areas of the MSSM parameter space, it is possible that no Higgs particle will be found.

e^+e^- linear colliders with energies in the range of ~ 500 GeV are ideal instruments to search for Higgs particles in the mass range below ~ 250 GeV. The search for the Standard Model Higgs particle can be carried out in several channels and the clean environment of the colliders allows to investigate thoroughly its properties. In the MSSM, at least the lightest neutral Higgs particle must be discovered and the heavy neutral and charged Higgs particles can be observed if their masses are smaller than ~ 230 GeV. High energy e^+e^- colliders are therefore complementary to hadron colliders.

Acknowledgements: I would like to thank Jan Kalinowski, Michael Spira and Peter Zerwas for the enjoyable collaborations which led to parts of the work presented in this report. Thanks also go to Francesca Borzumati and Manuel Drees for discussions.

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