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HIGGS PHYSICS AT THE COLLIDERS* **

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A joint effort of the network in investigation of a Higgs sector in Standard Model and beyond at high energy colliders is summarized.

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1. Introduction

Symmetry plays a basic role in modern particle physics. A spontaneous symmetry breaking of the local SU(2)× U(1) group is considered as an origin of masses of elementary particles in the Standard Model (SM) and beyond. This mechanism known as the Higgs mechanism [1] accounts for masses of vector bosons W and Z, and with additional assumptions also for masses of fermions. It predicts an existence of additional spinless particles, called the Higgs bosons. In a simplest case of the SM one neutral CP-even Higgs boson, with mass according to the latest experimental data above 114 GeV and all couplings to fundamental particles known, is expected. In the models with extended Higgs sector there are more neutral Higgs bosons as well as the charged ones and obviously phenomenology is much reacher, see *e.g.* [7].

Here, I present results which arise mainly from a joint effort of participants of different nodes of the network. To see their relevance and importance I put them in context of the general achievement obtained recently in the field.

1.1. Theory of Matter and Higgs Models

The Standard Model can be treated today as the Theory of Matter if one refers to the core concepts as: quantum field theory, gauge symmetry,

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spontaneous symmetry breaking, asymptotic freedom, the assignments of the lightest quarks and leptons [2]. Wilczek suggested to "keep (a name) SM to describe the (time-dependent!) minimalist position on more negotiable bits, such as number of Higgs doublets". So, as for today the SM contains a Higgs sector with one SU(2) doublet of scalar fields or in short 1HDM, two standard extensions contain two such doublets: these are well known the 2 Higgs Doublet Model (2HDM) and the Minimal Supersymmetric Standard Model (MSSM), the latter one contains in addition to Higgs particles supersymmetric particles. In such models in the Higgs boson sector there are five additional spinless particles, three of them, denoted collectively by ϕ, are neutral and the remaining two are charged, $H^\pm$. In the version with CP invariance we have $\phi = h, H$ (CP even) and A (CP odd).

The nonstandard Higgs scenarios are based on more radical assumptions.

1.2. CP violation in Higgs sector

In the Standard Model CP symmetry is explicitely broken, it appears only in the charged current interaction of quarks and it would vanish in absence of flavor changing interaction. One single phase in the CKM matrix is the only source of CP violation in SM [3].

Although the CP violation exists in the Standard Model, the corresponding parameters (ϵ parameters, electric dipole moment of n and e) can be accounted in various models, with very different CP violation pattern. Besides, additional sources of CP violation are possible in the beyond the SM. Finally it is well known that CP violation is related to baryon asymmetry of the universe and that SM cannot describe the observed matter–antimatter difference. This was one of the most important motivation for introducing various extensions of the Higgs sectors [4], where the CP violation and mixing among particles appears naturally. In such models there appear various phases to be determined from experiment, *e.g.* for MSSM with CP violation there are in principle 44 independent phases.

1.3. Models with two Higgs doublets: 2HDM and MSSM

A general Higgs potential for the extension with two scalar doublets, 2HDM and MSSM, reads [6, 34]

$$\begin{aligned} V \;=\; & \tfrac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \tfrac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) \\ & + \tfrac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \mathrm{h.c.}\right] + \left\{\left[\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2)\right](\phi_1^\dagger\phi_2) + \mathrm{h.c.}\right\} \\ & - \tfrac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \mathrm{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}\,. \end{aligned}$$

No (ϕ_1, ϕ_2) mixing is possible if there is a Z_2 symmetry under the transformation $\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ (or *vice versa*), so when $\lambda_6 = \lambda_7 = m_{12}^2 = 0$. The imposing of a Z_2 symmetry is motivated by avoiding tree-level Flavor-Changing-Neutral-Current effects, which in models with more scalar doublets can be large [5]. The CP violation and the Z_2 violation in the Higgs sector are closely related; if Z_2 holds CP is conserved. In general parameters $\lambda_5, \lambda_6, \lambda_7$, m_{12}^2 can be complex. The mixing among three neutral Higgs bosons is possible, described by a corresponding mixing angles. For a phenomenology very important parameter is $\tan\beta = v_2/v_1$ — a ratio of vacuum expectation values for scalar fields ($v_1^2 + v_2^2 = v^2$, with v=246 GeV). In the case of a soft Z_2 violation in the Higgs potential, which corresponds to $\lambda_6 = \lambda_7 = 0$, only one parameter given by $\mathrm{Im} m_{12}^2 = v_1 v_2 \mathrm{Im}\lambda_5$ governs the CP violation.

The crucial parameter for a Higgs mass spectrum is $\nu = \mathrm{Re}\ m_{12}^2/2v_1v_2$. This parameter appears in the Higgs selfcouplings if they are expressed in terms of masses. If ν is small, some decoupling effects may appear due to heavy Higgs bosons in the interaction of the lightest Higgs boson, even if all direct couplings of the latter one at the tree level are exactly equal to that of the SM Higgs boson. In such case the heavy Higgs boson masses are bounded to be below 600 GeV to satisfy the unitarity constraints. If ν is large, the lightest h particle has all properties of the SM Higgs boson, heavy Higgs bosons masses can be higher, they are highly degenerated, and decouple. This is a case of the CP conserving MSSM. As in the considered models (2HDM, MSSM) the lightest neutral Higgs boson can be SM-like (with or without decoupling of the heavier Higgs particles) precise methods should be developed in order to distinguish such models.

If CP is violated then three neutral Higgs particles h_1, h_2, h_3 have no defined CP parity and they can mix. Since in the considered models couplings to the gauge bosons have the same Lorentz structure, CP violation is realized here only via mixing among neutrals. This leads to change of the events rates only. In a generic case the structure of couplings of the CP-even and CP-odd Higgs particles are different and one expects that asymmetries in distributions should allow to establish the CP properties of a discovered Higgs particle, both for the CP invariant and non-invariant version of models.

There are various versions of 2HDM, depending on a form of the Yukawa interaction, responsible for masses of fundamental fermions. The most popular is Model II, where one of the Higgs scalar doublet couples to the up-type components of isodoublets while the second one to the down-type components. In such model the large FCNC effects can be avoided at the tree level. The Higgs sector in MSSM has a structure of Model II, where typically Yukawa coupling to down-type fermions (quark b, lepton τ) are enhanced for large $\tan\beta$, while for small $\tan\beta$ the corresponding couplings to top-quarks are enhanced. At the tree level one can show that if some neutral Higgs boson has the coupling to the EW gauge bosons equal to that of the SM Higgs boson, both Yukawa couplings (to the up- and down-type fermions) of the same Higgs boson are as in the SM. Note however, that then the other neutral Higgs bosons, which decouple from W/Z, can have enhanced Yukawa couplings for small or large $\tan\beta$.

In the SM, masses decided which Higgs decay channel dominates for a given Higgs boson, in the 2HDM or MSSM large Yukawa couplings may change the decay pattern.

2. Testing Higgs sector at high energy colliders

Higgs physics is one of the major research subject at high energy, high luminosity colliders. There are two hadronic colliders at the highest energy crucial for Higgs searches: the $p\bar{p}$ TEVATRON collider operating at the CM energy 2 TeV and the pp Large Hadron Collider (LHC) which will start running in a few years with the CM energy 14 TeV [8,9]. After the LEP-era, two types of 1 TeV lepton colliders are under discussion. They are considered to be a precision machines, to determine properties of hopefully discovered already at hadron collider the lightest Higgs particle and to search for possible heavier Higgs particles. The e^+e^- linear collider (LC) is planned to run with energy 500–800 GeV (to be upgraded to 1 TeV [10]). Here also the $\gamma\gamma$ and $e^-\gamma$ options (called Photon Linear Collider — PLC) are considered, which operate with the polarized γ beams(s) from the laser backscattering at the energy up to 80% of that of the parent e^+e^- collider LC [11]. Note, that the $\gamma\gamma$ collider can ran at the Higgs resonance. There were also some activities towards a $\mu^+\mu^-$ collider, which also can work as a Higgs factory [12].

Highlights of our Higgs study are: the detailed analyses related to the Higgs physics at hadron colliders (LHC, Tevatron), feasibility studies of future e^+e^- linear collider and its $\gamma\gamma$ and $e\gamma$ options (Photon Linear Collider), and the investigation of a possible interplay of colliders.

Higgs potential of colliders are studied, both for the direct Higgs boson production and various indirect Higgs boson effects, with aim to establish discovery reach of different colliders, and to determine precisely all basic properties of Higgs particle(s), like mass, electric charge, spin/parity (CP parity), mixing, as well as couplings to gauge bosons, fermions and selfcouplings.

The couplings of neutral Higgs particles, ϕ, to heavy particles: gauge bosons Z and W, heavy quarks — top, bottom and tau leptons are of primary importance. The access to information on such couplings are via the decay widths or branching ratios, or the interference with SM amplitude.

In some cases, especially for the SM-like scenarios the loop-couplings $gg\phi$ and $\gamma\gamma\phi$, $\gamma Z\phi$, sensitive to the heavy particle in the loop (non-decoupling in principle), are crucial. They are also involved in the main production processes at LHC and PLC.

Higgs pair $\phi\phi$ production is sensitive to the selfcouplings, and therefore they play a crucial role in a reconstruction of a form of the Higgs potential. Some sensitivity to the selfcoupling is possible also in the loop-couplings. A discovery of the charged Higgs bosons is also of special interest — it will signal a new physics, even without detailed information on their interaction.

Below we present results on the theoretical progress in the estimation of Higgs boson production in the SM and beyond and, of background processes. They include existing higher order QCD and EW corrections, and some model corrections and often they represent the state-of-art analyses.

The extended study of potential of various colliders are presented in the "Report of the Tevatron Higgs Working Group" [13]. "The Les Houches Higgs working group Summary Report 2001 and Summary Report 2003" are given in [14] and [15], respectively. The opportunities for Higgs physics at future $\mu^+\mu^-$ colliders have been investigated in [16].

3. Higgs models — masses and decays

There is no prediction for mass of the SM Higgs boson, nor there exist corresponding predictions for Higgs bosons in 2HDM. At the same time the precise predictions for masses of neutral Higgs bosons exist in MSSM, especially the upper limits on mass of the lightest Higgs boson is of great phenomenological importance. If other Higgs bosons are heavy enough, they are highly degenerate and decouple, while the lightest Higgs boson has properties as the SM Higgs. Distinguishing SM-like MSSM, from the SM (or the SM-like 2HDM) had to be performed with a high precision.

Precise determination of the neutral Higgs boson masses in the selected number of MSSM scenarios is presented in [17]. The radiative corrections of the Higgs sector are implemented in three public computer codes for the evaluation of the particle spectrum in the MSSM, Softsusy, Spheno and SuSpect. The full one-loop corrections to the Higgs boson masses and the electroweak symmetry breaking conditions, as well as the two-loop QCD corrections with Yukawa couplings of the third generation fermions are incorporated. The theoretical uncertainty on the M_h was estimated to be 3 to 5 GeV. The experimental error in the SM input parameters gives similar effect. With the latest value of the top quark mass, the most conservative upper bound on the lighter Higgs boson mass in the general MSSM is below 152 GeV and that there is no lower bound on $\tan\beta$ from non-observation of the MSSM Higgs bosons at LEP2.

Feynman-diagrammatic results for the CP-even Higgs-boson masses in the MSSM have been obtained in [19, 22, 23] with an impact of different renormalization prescriptions analyzed in [19]. The complete one-loop result for the MSSM with *complex parameters* has been obtained in [23]. Based on the most up-to-date theoretical predictions in the MSSM Higgs sector, an estimate of the remaining theoretical uncertainties has been obtained [22]. The results have been implemented into the `Fortran` program `FeynHiggs` [14, 15, 19, 22, 23], which has been used by the four LEP collaborations for their analyses and which is also widely used for studies at the Tevatron, the LHC, and a future Linear Collider, see also [20,21].

The effective potential calculation of the two-loop, top/bottom Yukawa corrections (up to the second power) to the Higgs boson masses in the Minimal Supersymmetric Standard Model is given in [24]. The corrections to the minimization conditions of the effective potential at the same perturbative order are also commuted. These results extend the existing $\mathcal{O}(a_t^2)$ calculation, and are relevant in regions of the parameter space corresponding to tan(beta) $\gg 1$. The extension to the Yukawa corrections of a convenient renormalization scheme, allows to absorb the bulk of the corrections into the one-loop expression. For large values of tan(beta), the new contributions can account for a variation of several GeV in the lightest Higgs boson mass [24].

The implications of the three most prominent soft SUSY-breaking scenarios, mSUGRA, GMSB and AMSB, on the phenomenology of the Higgs sector have been analyzed in [25]. The upper bound on the mass of the lightest Higgs boson is reduced by 5–10 GeV in these scenarios compared to the unconstrained MSSM. A detailed comparison of these scenarios has been performed, taking into account the bounds obtained from LEP and the prospects for searches at future colliders.

In [26] it has been demonstrated that the mSUGRA scenario is consistent not only with the LEP exclusion bounds but also with the most up-to-date results on $b \to s\gamma$, $g_\mu - 2$ and the cosmological relic density. The sensitivity of precision measurements at the LC for distinguishing the properties of the lightest SUSY Higgs from those of the SM Higgs have been analyzed in this scenario.

Within the unconstrained MSSM, new benchmark scenarios for Higgs searches at the Tevatron and the LHC were suggested in [18] taking into account a possible suppression of the main decay modes of the Higgs boson or of the main Higgs production process at the LHC.

For large values of $\tan\beta$ the SUSY–QCD corrections to the Higgs decays $\phi \to b\bar{b}$ can be large due to non-decoupling contributions from virtual gluino and sbottom exchange [27]. The large size of these corrections requires a resummation of the leading terms partly done in the past [28]. There are additional potentially large but in practice moderate corrections mediated by the trilinear soft-SUSY-breaking coupling A_b, included in the resummation by an appropriate extension, the validity of which can be proven by power counting arguments [29]. The residual theoretical uncertainties originating from scale dependence found to be too large for the anticipated accuracy at future linear e^+e^- colliders, thus calling for a significant improvement beyond NLO [29].

Large quantum effects in the decoupling regime were studied in the Higgs decays in the 2HDM in [30]. If the light CP-even Higgs boson of the 2HDM mimics the Standard Model Higgs boson, not only the one-loop couplings $h \to \gamma\gamma, \gamma Z$ but also the one-loop contribution to $h \to b\bar{b}$ can be used to distinguish between 2HDM and SM. The size of the quantum effects, subject to the unitary constraints, in $h \to b\bar{b}$ are of the same order as in $h \to \gamma\gamma, \gamma Z$ and can reach 25% in both cases.

Some results on the distinction of Higgs boson models are given in [31], where the ratio of branching ratios $R = \mathrm{BR}(H \to b\bar{b})/\mathrm{BR}(H \to \tau^+\tau^-)$ of Higgs boson decays is used as a discriminant quantity between supersymmetric and non-supersymmetric models. A detailed analysis in the effective Lagrangian approach shows how one could discriminate between models at the LHC and the e^+e^- LC at 500 GeV center of mass energy.

Distinguishing the SM-like 2HDM from the SM were analyzed for the loop-couplings at PLC [33], where the 10 % effect of non-decouplings were found in decay width to $\gamma\gamma$, $\Gamma_{\gamma\gamma}$ due to $H^\pm$ exchange. In $gg\phi$ the deviation from SM is due to different than in SM sign of one of Yukawa coupling. A case with a 2HDM with CP violation was studied in [34], both for LHC and PLC.

Two heavy neutral Higgs bosons can be nearly degenerate in many 2-Higgs doublet models, and particularly in supersymmetric models. In such a scenario the mixing between the states can be very large if the theory is CP-non-invariant. The formalism with the effect due to a finite width of Higgs particles was presented in [35]. Deacays of Higgs bosons into top quark in 2HDM, and into bottom in MSSM due to FCNC are studied in [87,88].

The scenario within MSSM framework where all Higgs bosons are rather light, with masses of $\mathcal{O}(100)$ GeV, and couple maximally to electroweak gauge bosons and strongly to standard third generation fermions, *i.e.* for large $\tan\beta$ ("intense-coupling" scenario) was analyzed in [36]. The available constraints from direct searches of Higgs bosons at LEP2 and the Tevatron as well as the indirect constraints from precision measurements such as the ρ parameter, the $Zb\bar{b}$ vertex, the muon $(g-2)$ and the decay $b \to s\gamma$ were discussed. Here also predictions for the Tevatron Run II, the LHC, a 500 GeV e^+e^- linear collider (in the e^+e^- and $\gamma\gamma$ options) as well as at a $\mu^+\mu^-$ collider were presented.

The Higgs boson spectrum of the Next-to-Minimal Supersymmetric Standard Model was examined in [37]. The model includes a singlet Higgs field S in addition to the two Higgs doublets of the minimal extension. 'Natural' values of the parameters of the model are motivated by their renormalization group running and the vacuum stability. The Higgs boson masses depend on strength of the Peccei–Quinn U(1) symmetry breaking, measured by the selfcoupling of the singlet field in the superpotential. This extension allows one to link the Higgs-higgsino mass parameter to a vacuum expectation value of the new scalar field, thus providing a solution to the μ-problem of the MSSM. A particularly interesting is NMSSM scenario with extra Higgs scalar rather light [38], see also discussion below.

Genuine dimension-six Higgs operators can modify the couplings of the Higgs boson to the EW gauge bosons and, in particular, the Higgs selfinteractions. For $\sqrt{s} = 500$ GeV LC with a luminosity of 1 ab^{-1} the anomalous WWH and ZZH couplings may be probed to about the 0.01 level, and the anomalous HHH coupling to about the 0.1 level [39].

4. Identifying quantum numbers

Series of analyses were performed both for LC and LHC with aim to identify quantum numbers of neutral Higgs particles in the processes involving couplings to gauge bosons. To this aim also the Higgs boson decays into tau can be used.

Measuring the spin and parity of the Higgs boson was discussed as a task for LC in [40], assuming CP invariance. In PLC the production of Higgs particle via $\gamma\gamma h$ coupling rules out the spin-1 state due to Landau–Yang theorem, to rule out other possibilities more effort is needed. By studying the Higgs-strahlung process $e^+e^- \to HZ$, with a characteristic threshold dependence of the excitation curve and the angular distribution of H/Z together with the final state fermions distributions $Z \to f\bar{f}$ the spin of the Higgs boson in the Standard Model and related extensions can be determined unambiguously in a model-independent way.

The spin and parity P (equivalent here to CP) can be determine at LHC and PLC by using Higgs boson decays into Z pair, with further decays into fermion pairs. This is presented in [41] as a complementary method to spin-parity measurements in the Higgs-strahlung. For a Higgs mass above the on-shell ZZ decay threshold, a model-independent analysis can be performed, but only by making use of additional angular correlation effects in gluon–gluon fusion at the LHC and γ–γ fusion at linear colliders. In the intermediate mass range, in which the Higgs boson decays into pairs of real and virtual Z bosons, threshold effects and angular correlations, parallel to Higgs-strahlung, may be adopted to determine spin and parity. This idea was implemented in simulation performed in [42], where the determination of the Higgs-boson couplings and CP properties in the SM-like 2HDM were studied at PLC using the decays into WW and ZZ (see also [43]). A generic case with CP violation is studied in [44], with the model-independent determination of the Higgs-boson CP properties at the PLC, for masses between 200 and 350 GeV. A similar analysis for LHC, performed in [45] shows that the quantum numbers of the Higgs can be determined using the angular correlations of the decay products in the process $H \to ZZ \to l^+l^-l^+l^-$. Full luminosity of the LHC allows to distinguish between various coupling structures of the Higgs boson to vector bosons if the mass of the Higgs is above the ZZ threshold. Below the threshold the analysis is limited by statistics.

Spin effects in tau-lepton pair production at LHC, in $Z/\gamma \to \tau^+\tau^-$ process is studied in detail in [46], in context of the MSSM Higgs searches. For these processes, the SM $Z/\gamma \to \tau\tau$ production is a dominant background. The spin effects in high energy physics reactions can be implemented up to certain approximation, independently of the algorithm and matrix elements used by the production program. Further study was done in [47], where the transverse spin effects in H/A decays $\to \tau^+\tau^-$, with $\tau^\pm \to \nu X^\pm$ were studied. Correlations *e.g.* in distribution of acollinearity angle of $X^\pm$ in decay chain $H/A \to \tau^+\tau^-$; $\tau^\pm \to \nu X^\pm$ allow to establish CP property of Higgs boson provided reconstruction of its rest-frame is possible. The TAUOLA (tau-lepton decay library) includes the complete spin effects needed for such study. Probing the CP nature of the Higgs boson at linear colliders using tau spin correlations was studied in [48] for the case of mixed scalar-pseudoscalar couplings.

5. Various production mechanisms and determination of couplings

Higgs production in association with the Standard Model particles has been studied for a variety of processes relevant for the Tevatron and the LHC, and the LC/PLC. The QCD corrections to the radiation of Higgs bosons of top and bottom quarks have been studied in [66,67,72]. Photonic and QCD radiative corrections to $\mu^+\mu^- \to H \to f\bar{g}$ is studied in [86].

The SM Higgs boson production in association with $t\bar{t}$ pairs plays a significant role at the LHC for Higgs masses below about 130 GeV, since this production mechanism makes the observation of $H \to b\bar{b}$ possible [8,9]. The decay $H \to \gamma\gamma$ is potentially visible in this channel at high integrated luminosity. For Higgs masses above about 130 GeV, the decay $H \to W^*W$ can be observed [68].

In contrast to $t\bar{t}H$ production, however, $b\bar{b}H$ production at hadron colliders develops potentially large logarithms, $\log m_\phi^2/m_b^2$, in the high-energy limit due to the smallness of the bottom quark mass, which are related to the development of b densities in the initial state. They can be resummed by evolving the b densities according to the DGLAP equations and introducing them in the production process [71]. The introduction of conventional b densities, however, requires an approximation of the hard process kinematics, *i.e.* the initial and final b quarks are assumed to be massless, on-shell and traveling predominantly in forward and backward direction.

The NLO QCD corrections to the exclusive $b\bar{b}H$ production process in the Standard Model have been obtained [72, 73]. They increase the total cross section by about 60–130% at the Tevatron and 10–80% at the LHC and thus play a significant role [72]. After requiring a minimal transverse momentum of 20 GeV for the final-state bottom jets the radiative corrections reduce to a moderate size [72, 73]. The scale dependence is significantly reduced at NLO which implies that the process is under control. However, for the total cross section a sizeable scale dependence of about 30% remains at NLO and thus calls for a further improvement of the prediction. After choosing a suitable factorization scale $\mu = M_H/4$ reasonable agreement has been obtained between the approaches with and without bottom densities [74].

The connection between the production channels, $bg \to bh$ and $gg \to b\bar{b}h$, at next-to-leading order (NLO) in perturbative QCD and present results for the cases with two high $p_{\mathrm{T}}b$ jets and with one high $p_{\mathrm{T}}b$ jet at both the Tevatron the LHC is discussed in [76]. The total cross sections without cuts are compared between $gg \to b\bar{b}h$ at NLO and $b\bar{b} \to h$ at NNLO.

Higgs-boson production in association with bottom quarks is one of the most important discovery channels for supersymmetric Higgs particles at the Tevatron and the LHC. In supersymmetric theories $b\bar{b}\phi$ ($\phi = h, H, A$) production becomes the dominant Higgs boson production mechanism for large values of $\tan\beta$ [70], where the bottom Yukawa coupling is strongly enhanced. The NLO QCD corrections reduce the renormalization and factorization scale dependence and thus stabilize the theoretical predictions, especially when the Higgs boson is produced in association with high-p_{T} bottom quarks. The next-to-leading order predictions for the total cross section are in reasonable numerical agreement with calculations based on bottom–quark fusion $b\bar{b} \to H$.

In [49,50] it has been shown how LHC Higgs boson production and decay data can be used to extract gauge and fermion couplings of Higgs bosons. Very mild theoretical assumptions, which are valid in general multi-Higgs doublet models, are sufficient to allow the extraction of absolute values for the couplings rather than just ratios of the couplings. The sensitivity to deviations from the SM predictions has been studied in several supersymmetric benchmark scenarios.

5.1. Higgs-strahlung and VV fusion

Precision calculations for associated WH and ZH (Higgsstrahlung) production at hadron colliders, as well as for LC were performed both for SM and MSSM. As the Higgsstrahlung is a perfect channel to study a light Higgs boson, the WW (ZZ) fusion is more important for heavier Higgs bosons. Here PHASE [51], the dedicated program for fusion process at LHC can be used.

The processes $p\bar{p} \to WH/ZH + X$, is the most promising discovery channel for a light SM Higgs particle at hadron colliders. The calculation of the electroweak $\mathcal{O}(\alpha)$ corrections to these processes decrease the theoretical prediction by up to 5–10%. An update of the prediction for associated WH and ZH production at the Tevatron and at the LHC, including the next-to-leading order electroweak and QCD corrections, is presented in [52]. The study of the theoretical uncertainties from factorization and renormalization scale dependences and the parton distribution functions was also performed. The next-to-next-to-leading order QCD corrections to the process $q\bar{q} \to HV$ with $V = W, Z$ in the SM are presented for Tevatron and LHC in [53]. For the Higgs boson masses $M_H \lesssim$ 200–300 GeV, the two-loop corrections are small, increasing the production cross sections by less than 5% and 10%, respectively; the scale dependence is reduced to a level of less than a few per cent. These various corrections are briefly discussed and combined into state-of-the-art predictions for the cross sections in [54].

A calculation of the complete $\mathcal{O}(\alpha)$ EW corrections to the processes $e^+e^- \to f\bar{f}H$ in the Standard Model for final-state neutrinos was performed in [57,58,63,64]. The initial-state radiation beyond $\mathcal{O}(\alpha)$ at the leading-logarithmic level as well as QCD corrections are also included in the analysis. The electroweak corrections turn out to be sizable and reach the order of $\pm$ 10% [58].The study for the particular Higgsstrahlung process $e^+e^- \to \mu^+\mu^- b\bar{b}$ with QED ISR corrections was performed in [60].

In [55, 56] the radiative corrections to Higgs-boson production in the MSSM via the WW-fusion channel at the LC, $e^+e^- \to \nu_e\bar{\nu}_e\{h, H\}$, have been obtained, taking into account all $\mathcal{O}(\alpha)$ corrections arising from loops of fermions and sfermions. For the lightest MSSM Higgs boson, h, genuine loop corrections (beyond the universal Higgs propagator corrections) are up to -5%. For the heavy CP-even neutral Higgs boson, H, which decouple at tree level, there are non-negligible corrections which enhance the cross section. At a center-of-mass energy of $\sqrt{s} = 1$ TeV, $M_H \lesssim 750$ GeV are accessible at the LC in favorable regions of the MSSM parameter space [55].

Neutral MSSM Higgs boson production at e^+e^- LC colliders, in $e^+e^- \to hZ$ and $e^+e^- \to hA$ processes, were calculated in the Feynman diagrammatic approach in [59].

5.2. Determination of the Yukawa couplings

The $t\bar{t}H$ production at LHC could conceivably be used to determine the top Yukawa coupling in SM directly from the cross section, for which the NLO QCD corrections have become available. They decrease the cross section at the Tevatron by about 20% [66, 69], while they increase the signal rate at the LHC by about 20–40% [66]. The scale dependence of the production cross section is significantly reduced, to a level of about 10–15%, which can be considered as an estimate of the theoretical uncertainty. The transverse momentum and rapidity distributions at NLO can be approximated by a rescaling of the LO distributions with a constant K factor within 10–15% [67].

A study of the $H \to b\bar{b}$ decay in the electroweak boson fusion (WBF) production channel and of its backgrounds, from point of view of the potential of this process for the determination of the Hbb Yukawa coupling in SM at LHC is presented in [77]. The main features of the signal, to be exploited in the event selection, are: presence of two, high-p_{T}, b jets, showing an invariant-mass peak; presence of a pair of jets in the forward and backward rapidity regions were used to optimize the signal significance $(S/\sqrt{B})$. The result of such a study shows that $BR(H \to b\bar{b})$ can be measured at the LHC with a 20% precision for an Higgs mass around 120 GeV assuming that the coupling HWW is the one predicted by the SM or determined in other reactions. In the analysis program ALPGEN [78] was used.

Higgs radiation off quarks in the Standard Model and supersymmetric theories at e^+e^- colliders were studied including the complete NLO QCD corrections in [65].

A calculation of the complete $\mathcal{O}(\alpha)$ corrections to such processes in the Standard Model for final-state top quarks is described in [57,58,61,62], as discussed above. Here, we would like to point out after authors, that this process permits a direct access to the top-Yukawa coupling.

MSSM Higgs bosons can be copiously produced in association with $\tau^+\tau^-$ pairs at $\gamma\gamma$ colliders [79]. This process has been shown to be dominated by the photon splittings into tau pairs, $\gamma \to \tau^+\tau^-$, followed by the fusion process of two taus to the Higgs bosons, $\tau^+\tau^- \to \phi$. After imposing appropriate cuts on the tau energies and angles, as well as the invariant $b\bar{b}$ mass in order to reconstruct the Higgs mass the background processes can be suppressed significantly. The $\tau\tau$ fusion process with $\phi = h/H/A$ decaying into b-quarks allows an accurate determination of the SUSY parameter $\tan\beta$ in the range $\tan\beta \gtrsim 10$ [79].

6. Higgs selfcouplings and neutral Higgs-boson pair production

The complete reconstruction of the Higgs potential necessarily requires the measurement of the trilinear Higgs self-coupling. All processes where Higgs particles are produced in pairs The leading production channels of Higgs boson pairs at hadron colliders are

$$gg \to HH \quad gg, q\bar{q} \to Q\bar{Q}HH \; qq^{(\prime)} \to qq^{(\prime)}HH \quad q\bar{q}^{(\prime)} \to VHH \;, \qquad (1)$$

with $V = W^{\pm}$ or Z, $Q = b, t$ and $q^{(\prime)}$ — any possible light (anti)quark flavor combination.

The detection of boson pairs via $gg \to HH \to b\bar{b}b\bar{b}$ which dominate for masses between 120 GeV and 140 GeV within the SM is most probably not feasible at the LHC. A detailed signal-to-background analysis [80] (using [78]) shows that a signal for g_{hhh} in the decoupling limit of 2HDM should be seen, since here g_{hhh} can considerably differ form the SM value [81]. In Ref. [80] this possibility is analyzed by implementing the exact couplings of a generic 2HDM and scanning the parameter space. The general scan was subject to the constraints of tree-level unitarity and to the requirement that the couplings g^2_{hVV}, g^2_{htt} and g^2_{hbb} differ from the SM values by no more than 30%, 30% and 70%, respectively, and with masses of the heavy Higgs states $\gtrsim$ 1000 GeV. Furthermore, the absolute value of the ratio between the light Higgs trilinear coupling and the coupling of h with the heavier Higgs states is constrained to be greater that 1/4. Results of the analysis show *e.g.* that for mass 120 GeV $-15 < g_{hhh}/g^{\rm SM}_{hhh} < 14$ is allowed at LHC, and this should hold for more general models as well.

The most promising channels at future hadron and e^+e^- colliders, together with background studies to evaluate the feasibility of the selfcoupling measurement are presented in [82]. The light Higgs SM scalars, with mass below the W^+W^- threshold produced in the double Higgs-strahlung channel $e^+e^- \to HHZ$ and decaying via the dominant mode $H \to b\bar{b}$ were considered. The number of events are low, however the observation is possible. The production of pairs of neutral Higgs bosons in all relevant channels of double Higgs-strahlung, associated multiple Higgs production and WW/ZZ fusion to Higgs pairs at LC is studied in [83].

Recent study for PLC and LHC can be found in [84] and [85], respectively.

7. Charged Higgs boson productions

The observable ratio $R = \mathrm{BR}(H^+ \to \tau\nu)/\mathrm{BR}(H^+ \to t\bar{b})$ of charged Higgs boson decay rates can be used as a discriminant quantity between supersymmetric and non-supersymmetric models for $\tan\beta \gtrsim 20$ [89]. Simulation of measurements of this quantity through the process $gb \to tbH^+$ and relative backgrounds in the two above decay channels has been performed in the context of ATLAS. A $12 - 14\%$ accuracy on R can be achieved for $\tan\beta = 50, M_{H^+} = 300$–$500$ GeV and after an integrated luminosity of 300 fb^{-1} [32].

Charged Higgs bosons in the transition region, with mass $M_{H^\pm}$ close to m_t at the LHC, was studied in [90]. Refs. [16,91,92] reassessed the potential of Tevatron and LHC in detecting and measuring properties of charged Higgs bosons of the MSSM, in presence of new and more sophisticated simulation tools (as implemented in HERWIG and PYTHIA). It has been shown that the scope of both colliders is actually better than previously thought, thereby increasing their chance of finally determining whether the structure of the Higgs sector is consistent with the SM dynamics or indeed requires SUSY.

The feasibility of detecting at LHC a heavy charged Higgs boson, $M_H^\pm > m(t) + m(b)$, decaying in the $H^\pm \to tb$ channel was studied in [93] with the fast simulation of the ATLAS detector using $gg \to H^\pm tb$ production process which together with the aforementioned decay channel leads to four b-quarks in the final state. Employing multivariate techniques in the event reconstruction and requiring four b-tagged jets in the event helps to effectively suppress the Standard Model backgrounds. As a results charged Higgs bosons can be discovered at the LHC up to high masses 400 GeV in the case of large $\tan\beta$ [93].

In [97] corrections to single charged Higgs-boson production at the LC have been calculated in the CP conserving MSSM for fusion γW or ZW, and for $e^+e^- \to e\nu H^\pm$ process. In the typical benchmark scenarios a cross section is smaller than ~ 0.01 fb for $\sqrt{(s)}/2 \lesssim M_H^\pm$.

A strong consistency test involving the soft supersymmetric breaking parameters M_1, M_2, the Higgsino parameter μ, and $\tan\beta$ is possible in the production of neutralino, chargino, and charged Higgs boson pairs in the MSSM framework at future e^+e^- colliders [94]. This was shown for CM energies in the 1 TeV range and in a "moderately" light SUSY scenario. The leading (double) and next-to leading (linear) supersymmetric logarithmic terms of the so-called "Sudakov expansion" at one loop were computed in [95]. A combined analysis of the slopes of the chargino and of the charged Higgs production cross sections would offer a simple possibility for determining $\tan\beta$ for large ($\gtrsim 10$) values and an allowed strip in the (M_2, μ) plane.

For CM energies in the 1 TeV range, a one-loop logarithmic Sudakov expansion that includes an "effective" next-to subleading order term is adequate to the expected level of experimental accuracy [96]. The coefficient of the linear (subleading) SUSY Sudakov logarithm and the SUSY next to subleading term of the expansion depend on the supersymmetric parameters of the model in drastically different way. In particular the coefficient of the

SUSY logarithm is only dependent on $\tan\beta$ while the next to subleading term depends on a larger set of SUSY parameters. This would allow to extract from the data separate informations and tests of the model.

Exotic extensions of the Higgs sector involving higher isospin multiplets naturally predict the existence of doubly-charged Higgs bosons $\Delta^{\pm\pm}$. Particular examples are left-right symmetric models [75]. However, higher Higgs multiplets are generally severely constrained by the ρ parameter which is unity at tree-level. In order to fulfill these constraints, very particular Higgs representations have to be chosen or fine-tuning is required between different Higgs multiplets. The simplest options allowed by the ρ parameter are Higgs multiplets without neutral states or representations containing neutral states with a very small vacuum expectation value. These exotic Higgs states have been searched for at LEP [98] and the Tevatron [99]. The NLO QCD corrections to the Drell–Yan-type production process $q\bar{q} \to \gamma^*, Z^* \to \Delta^{++}\Delta^{--}$ have been obtained [100]. They increase the production cross section by 20–30% and reduce the scale dependence to a level of 5–10%. These results are currently included in the search for doubly-charged Higgs bosons at the Tevatron [99].

8. Loop couplings

The loop couplings play an important role in various productions mechanisms, and also in testing indirectly the content and properties of models, as we discussed in previous sessions. Some other dedicated studies based on loop coupling were performed.

The heavy neutral Higgs signature in the $\gamma\gamma \to ZZ$ process was studied in [101] and the process $\gamma\gamma \to ZH$ in the SM and MSSM in [102].

Dedicated analyses of measurements the partial decay width $\Gamma_{\gamma\gamma}$ for a light SM Higgs decaying into bb at PLC were performed in [103], while in [104] the width $\Gamma_{\gamma\gamma}$ and the phase of $\gamma\gamma h$ amplitude were determined for a heavier Higgs bosons in SM and 2HDM.

9. Interplay of colliders

There are many analyses addressing the point of interplay or synergy of different colliders, which is especially important for distinguishing models with small non-decoupling effects, as mentioned already in Sec. 3.

The LHC / LC Study Group investigates how analyses at the LHC could profit from results obtained at a future Linear Collider and *vice versa*, leading to mutual benefits for the physics program at both machines. Some examples of results obtained within this working group so far concerning searches for new physics are briefly summarised in [108]. Combining LHC information on the heavy Higgs states of the MSSM with precise measurements of the mass and branching ratios of the lightest CP-even Higgs boson at the LC provides a sensitive consistency test of the MSSM [107]. This allows to set bounds on the trilinear coupling A_t. In a scenario where LHC and LC only detect one light Higgs boson, the prospects for an indirect determination of M_A have been analyzed. In particular, the impact of the experimental errors of the other SUSY parameters is analyzed in detail.

There is the large wedge in which the LHC can only discover the light scalar MSSM Higgs particle, it can be covered at PLC collider, where the MSSM Higgs bosons can be produced as s-channel resonances. It can easily be extracted in the $b\bar{b}$ final states which constitute the dominant decay channel of the heavy MSSM Higgs bosons for moderate and large values of $\tan\beta$ [105]. The full NLO QCD corrections to the signal and background processes as well as the interference and in addition the resummation of large logarithms due to soft gluon radiation were included in the analysis. Moreover, the maximal Higgs boson mass reachable at a $\gamma\gamma$ collider is significantly larger than in the e^+e^- mode. A strong cut on configurations containing only two bottom jets in the final state is crucial, however chargino pairs look promising, too, if this decay mode of the heavy Higgs bosons is kinematically possible. Experimental confirmation of possible measurement of the MSSM Higgs-bosons production in $\gamma\gamma \to A, H \to b\bar{b}$ at the PLC at TESLA was done in [106].

CP property of the Higgs sector is discussed for high energy colliders in [43], where various methods of determining the CP properties of Higgs bosons at different colliders and identification of areas where more study is required, are presented. An example of a synergy between the LHC, an e^+e^- LC and a PLC, for the examination of CP-violation in a 2HDM is provided.

NMSSM scenario with light Higgs boson were studied for the LHC and LC. It will be difficult to observe the lightest scalar at the LHC, however it can instead be observed at LC for all but a small window of parameter space [38].

10. Summary

No doubt — the Higgs sector is a clue to a deeper understanding of matter. This review shows how many important basic results, new ideas and precise calculations, and in some cases detailed simulations were obtained by the network with the hope that at least one Higgs particle exists in Nature. If it is so, the Higgs boson will be found at high energy colliders.

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REFERENCES

[1] P.W. Higgs, *Phys. Lett.* **12**, 132 (1964), *Phys. Rev.* **145**, 1156 (1966); F. Englert, R. Brout, *Phys. Rev. Lett.* **13**, 321 (1964); G.S. Guralnik, C.R. Hagen, T.W. Kibble, *Phys. Rev. Lett.* **13**, 585 (1964).

[2] F. Wilczek, LEPFest, Nov.2000, `hep-ph/0101187`.

[3] G. C. Branco, L. Lavoura, J.P. Silva, *CP violation*, Oxford Univ. Press, 1999.

[4] T.D. Lee, *Phys. Rev.* **D8**, 1226 (1973).

[5] S.L. Glashow, S. Weinberg, *Phys. Rev.* **D15**, 1958 (1977).

[6] J.F. Gunion, H.E. Haber, G. Kane, S. Dawson, *The Higgs Hunter's Guide*, Addison-Wesley, Reading 1990; J.F. Gunion, H.E. Haber, `hep-ph/0207010`.

[7] G. Abbiendi *et al.* [OPAL Collaboration], "Search for neutral Higgs boson in CP-conserving and CP-violating MSSM scenarios", *Eur. Phys. J.* **C37**, 49 (2004).

[8] ATLAS Collaboration, Technical Design Report, CERN–LHCC 99–14 (May 1999).

[9] V. Drollinger, T. Müller, D. Denegri, `hep-ph/0111312`; M. Sapinski, D. Cavalli, *Acta Phys. Pol. B* **32**, 1317 (2001); E. Richter-Was, M. Sapinski, *Acta Phys. Pol.* **B30**, 1001 (1999); D. Green, K. Maeshima, R. Vidal, W. Wu, S. Kunori, FERMILAB-FN-0705.

[10] J.A. Aguilar-Saavedra *et al.* [ECFA/DESY LC Physics Working Group Collaboration], "TESLA Technical Design Report Part III: Physics at an e+e- Linear Collider", `hep-ph/0106315`.

[11] I.F. Ginzburg, G.L. Kotkin, S.L. Panfil, V.G. Serbo, V.I. Telnov, *Nucl. Instrum. Methods* **219**, 5 (1984); B. Badelek *et al.*, Photon Collider at TESLA, TESLA Technical Design Report, Part 6, Chapter 1, DESY-2001-011, ECFA-2001-209, DESY-TESLA-2001-23, DESY-TESLA-FEL-2001-05, March 2001, `hep-ex/0108012`.

[12] G.G. Hanson, *Nucl. Instrum. Methods* **A503**, 96 (2003).

[13] M. Carena *et al.* [Higgs Working Group Collaboration], "Report of the Tevatron Higgs working group", `hep-ph/0010338`.

[14] D. Cavalli *et al.*, "The Higgs working group: Summary report 2001", `hep-ph/0203056`.

[15] K.A. Assamagan *et al.* [Higgs Working Group Collaboration], "The Higgs working group: Summary report 2003", `hep-ph/0406152`.

[16] C. Blochinger *et al.*, "Physics opportunities at mu+ mu- Higgs factories", `hep-ph/0202199`.

[17] B.C. Allanach, A. Djouadi, J.L. Kneur, W. Porod, P. Slavich, *J. High Energy Phys.* **0409**, 044 (2004).

[18] M. Carena, S. Heinemeyer, C.E.M. Wagner, G. Weiglein, *Eur. Phys. J.* **C26**, 601 (2003).

[19] M. Frank, S. Heinemeyer, W. Hollik, G. Weiglein, "FeynHiggs1.2: Hybrid MS-bar / on-shell renormalization for the CP-even Higgs boson sector in the MSSM", `hep-ph/0202166`.

[20] S. Heinemeyer, G. Weiglein, "Precision observables in the MSSM: Status and perspectives", `hep-ph/0301062`.

[21] S. Heinemeyer, G. Weiglein, *J.High Energy Phys.* **0210**, 072 (2002).

[22] G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich, G. Weiglein, *Eur. Phys. J.* **C28**, 133 (2003).

[23] M. Frank, S. Heinemeyer, W. Hollik, G. Weiglein, "The Higgs boson masses of the complex MSSM: A complete one-loop calculation", `hep-ph/0212037`.

[24] A. Dedes, G. Degrassi, P. Slavich, *Nucl. Phys.* **B672**, 144 (2003).

[25] A. Dedes, S. Heinemeyer, S. Su, G. Weiglein, *Nucl. Phys.* **B674**, 271 (2003).

[26] J. R. Ellis, S. Heinemeyer, K.A. Olive, G. Weiglein, *J. High Energy Phys.* **0301**, 006 (2003).

[27] L. Hall, R. Rattazzi, U. Sarid, *Phys. Rev.* **D50**, 7048 (1994); R. Hempfling, *Phys. Rev.* **D49**, 6168 (1994); M. Carena, M. Olechowski, S. Pokorski, C.E.M. Wagner, *Nucl. Phys.* **B426**, 269 (1994); D. Pierce, J. Bagger, K. Matchev, R. Zhang, *Nucl. Phys.* **B491**, 3 (1997).

[28] M. Carena, D. Garcia, U. Nierste, C. E. M. Wagner, *Nucl. Phys.* **B577**, 88 (2000).

[29] J. Guasch, P. Hafliger, M. Spira, *Phys. Rev.* **D68**, 115001 (2003).

[30] A. Arhrib, W. Hollik, S. Penaranda, M. Capdequi Peyranere, *Phys. Lett.* **B579**, 361 (2004).

[31] J. Guasch, W. Hollik, S. Penaranda, "Some results on the distinction of Higgs boson models", `hep-ph/0307012`.

[32] K.A. Assamagan, J. Guasch, S. Moretti, S. Penaranda, "Distinguishing Higgs models in H+ $\rightarrow$ tau+ nu / t anti-b at large tan beta", `hep-ph/0409189`.

[33] I.F. Ginzburg, M. Krawczyk, P. Osland, "Standard-model-like scenarios in the 2HDM and photon collider potential", `hep-ph/0101331`; *Nucl. Instrum. Methods* **A472**, 149 (2001).

[34] I. F. Ginzburg, M. Krawczyk, P. Osland, "Two-Higgs-doublet models with CP violation", `hep-ph/0211371`; I.F. Ginzburg, M. Krawczyk, "Symmetries of two Higgs doublet model and CP violation", `hep-ph/0408011`.

[35] S.Y. Choi, J. Kalinowski, Y. Liao, P.M. Zerwas, "H / A Higgs mixing in CP-noninvariant supersymmetric theories", `hep-ph/0407347`.

[36] E. Boos, A. Djouadi, M. Muhlleitner, A. Vologdin, *Phys. Rev.* **D66**, 055004 (2002).

[37] D.J. Miller, R. Nevzorov, P.M. Zerwas, *Nucl. Phys.* **B681**, 3 (2004).

[38] D. J. Miller, S. Moretti, `hep-ph/0403137`.

[39] V. Barger, T. Han, P. Langacker, B. McElrath, P. Zerwas, *Phys. Rev.* **D67**, 115001 (2003).

[40] D.J. Miller, S.Y. Choi, B. Eberle, M.M. Muhlleitner, P.M. Zerwas, *Phys. Lett.* **B505**, 149 (2001).

[41] S.Y. Choi, D.J. Miller, M.M. Muhlleitner, P.M. Zerwas, *Phys. Lett.* **B553**, 61 (2003).

[42] P. Niezurawski, A. F.Zarnecki, M. Krawczyk, "Determination of the Higgs-boson couplings and CP properties in the SM-like two Higgs doublet model", `hep-ph/0403138`; "Measurement of the Higgs-boson CP properties using decays into W W and Z Z at the photon collider", `hep-ph/0307175`.

[43] R.M. Godbole, S. Kraml, M. Krawczyk, D.J. Miller, P. Niezurawski, A.F. Zarnecki, "CP studies of the Higgs sector", `hep-ph/0404024`;

[44] P. Niezurawski, A.F. Zarnecki, M. Krawczyk, "Model-Independent Determination of CP Violation from Angular Distributions in Higgs Boson Decays to WW and ZZ at the Photon Collider", `hep-ph/0410291`.

[45] C.P. Buszello, P. Marquard, J.J. van der Bij, "On the determination of the structure of the scalar Higgs boson's couplings to vectorbosons", `hep-ph/0406181`. C.P. Buszello, I. Fleck, P. Marquard, J.J. van der Bij, *Eur. Phys. J.* **C32**, 209 (2004).

[46] T. Pierzchala, E. Richter-Was, Z. Was, M. Worek, *Acta Phys. Pol. B* **32**, 1277 (2001).

[47] Z. Was, M. Worek, *Acta Phys. Polon. B* **33**, 1875 (2002).

[48] K. Desch, A. Imhof, Z. Was, M. Worek, *Phys. Lett.* **B579**, 157 (2004).

[49] M. Duhrssen, S. Heinemeyer, H. Logan, D. Rainwater, G. Weiglein, D. Zeppenfeld, "Extracting Higgs boson couplings from LHC data", `hep-ph/0406323`.

[50] M. Duhrssen, S. Heinemeyer, H. Logan, D. Rainwater, G. Weiglein, D. Zeppenfeld, "Determination of Higgs-boson couplings at the LHC", `hep-ph/0407190`.

[51] E. Accomando, A. Ballestrero, E. Maina, `arXiv:hep-ph/0404236`.

[52] M.L. Ciccolini, S. Dittmaier, M. Kramer, *Phys. Rev.* **D68**, 073003 (2003).

[53] O. Brein, A. Djouadi, R. Harlander, *Phys. Lett.* **B579**, 149 (2004).

[54] O. Brein, M. Ciccolini, S. Dittmaier, A. Djouadi, R. Harlander, M. Kramer, "Precision calculations for associated W H and Z H production at hadron colliders", `hep-ph/0402003`.

[55] T. Hahn, S. Heinemeyer, G. Weiglein, *Nucl. Phys.* **B652**, 229 (2003).

[56] T. Hahn, S. Heinemeyer, G. Weiglein, *Nucl. Phys. Proc. Suppl.* **116**, 336 (2003).

[57] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, *Eur. Phys. J.* **C33**, S635 (2004).

[58] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, "Electroweak corrections to e+ e- $\rightarrow$ f anti-f H", `hep-ph/0406335`.

[59] S. Heinemeyer, W. Hollik, J. Rosiek, G. Weiglein, *Eur. Phys. J.* **C19**, 535 (2001).

[60] F. Jegerlehner, K. Kolodziej, T. Westwanski, "Towards precise predictions for the Higgsstrahlung at a linear collider", `hep-ph/0407071`.

[61] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, *Nucl. Phys.* **B680**, 85 (2004).

[62] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, *Phys. Lett.* **B575**, 290 (2003).

[63] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, *Nucl. Phys.* **B660**, 289 (2003).

[64] A. Denner, S. Dittmaier, M. Roth, M.M. Weber, *Phys. Lett.* **B560**, 196 (2003).

[65] S. Dittmaier, P. M. Zerwas, M. Kramer, M. Spira, "Higgs radiation off quarks in the standard model and supersymmetric theories at e+ e- colliders", LC-TH-2001-069, also *Phys. Lett.* **B478**, 247 (2000).

[66] W. Beenakker, S. Dittmaier, M. Kramer, B. Plumper, M. Spira, P. M. Zerwas, *Phys. Rev. Lett.* **87**, 201805 (2001).

[67] W. Beenakker, S. Dittmaier, M. Kramer, B. Plumper, M. Spira, P.M. Zerwas, *Nucl. Phys.* **B653**, 151 (2003).

[68] F. Maltoni, D. Rainwater, S. Willenbrock, `hep-ph/0202205`.

[69] L. Reina, S. Dawson, *Phys. Rev. Lett.* **87**, 201804 (2001); L. Reina, S. Dawson, D. Wackeroth, *Phys. Rev.* **D65**, 053017 (2002).

[70] M. Spira, *Fortschr. Phys.* **46**, 203 (1998).

[71] R.M. Barnett, H.E. Haber, D.E. Soper, *Nucl. Phys.* **B306**, 697 (1988); D.A. Dicus, S. Willenbrock, *Phys. Rev.* **D39**, 751 (1989).

[72] S. Dittmaier, M. Kramer, M. Spira, "Higgs radiation off bottom quarks at the Tevatron and the LHC", `hep-ph/0309204`; S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth, `hep-ph/0408077`.

[73] S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth, *Phys. Rev.* **D69**, 074027 (2004).

[74] J. Campbell, S. Dawson, S. Dittmaier, C. Jackson, M. Krämer, F. Maltoni, L. Reina, M. Spira, D. Wackeroth, S. Willenbrock, Proceedings of the 3rd Les Houches Workshop: Physics at TeV Colliders, Les Houches, France, 26 May - 6 June 2003, `hep-ph/0405302` and `hep-ph/0406152`.

[75] G.B. Gelmini, M. Roncadelli, *Phys. Lett.* **B99**, 411 (1981); R.N. Mohapatra, J.D. Vergados, *Phys. Rev. Lett.* **47**, 1713 (1981); R.N. Mohapatra, G. Senjanovic, *Phys. Rev.* **D23**, 165 (1981); V. Barger, H. Baer, W.Y. Keung, R.J.N. Phillips, *Phys. Rev.* **D26**, 218 (1982); T.G. Rizzo, *Phys. Rev.* **D25**, 1355 (1982); M. Lusignoli, S. Petrarca, *Phys. Lett.* **B226**, 397 (1989); J.F. Gunion, *Int. J. Mod. Phys.* **A11**, 1551 (1996); C.S. Aulakh, A. Melfo, G. Senjanovic, *Phys. Rev.* **D57**, 4174 (1998); Z. Chacko, R.N. Mohapatra, *Phys. Rev.* **D58**, 15003 (1998); B. Dutta, R.N. Mohapatra, *Phys. Rev.* **D59**, 15018 (1999).

[76] J. Campbell *et al.*, "Higgs boson production in association with bottom quarks", `hep-ph/0405302`.

[77] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau, A.D. Polosa, *Phys. Lett.* **B556**, 50 (2003).

[78] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau, A.D. Polosa, *J. High Energy Phys.* **0307**, 001 (2003).

[79] S.Y. Choi, J. Kalinowski, J.S. Lee, M.M. Muhlleitner, M. Spira, P.M. Zerwas, "Determining tan(beta) in tau tau fusion to SUSY Higgs bosons at a photon collider", `hep-ph/0404119`, `hep-ph/0407048`.

[80] M. Moretti, S. Moretti, F. Piccinini, R. Pittau, A.D. Polosa, Higgs boson self-couplings at the LHC as a probe of extended Higgs sectors, `hep-ph/0410334`.

[81] S. Kanemura, Y. Okada, E. Senaha, `hep-ph/0410048`. S. Kanemura, S. Kiyoura, Y. Okada, E. Senaha, C. P. Yuan, *Phys. Lett.* **B558**, 157 (2003).

[82] D. J. Miller, S. Moretti, *Eur. Phys. J.* **C13**, 459 (2000).

[83] A. Djouadi, W. Kilian, M. Muhlleitner, P.M. Zerwas, *Eur. Phys. J.* **C10**, 27 (1999).

[84] R. Belusevic, G. Jikia, `hep-ph/0403303`.

[85] U. Baur, T. Plehn, D.L. Rainwater, *Phys. Rev.* **D69**, 053004 (2004); U. Baur, T. Plehn, D.L. Rainwater, *Phys. Rev.* **D67**, 033003 (2003).

[86] S. Dittmaier, A. Kaiser, *Phys. Rev.* **D65**, 113003 (2002) [`arXiv:hep-ph/0203120`].

[87] S. Bejar, J. Guasch, J. Sola, *Nucl. Phys.* **B675**, 270 (2003).

[88] S. Bejar, F. Dilme, J. Guasch, J. Sola, *J. High Energy Phys.* **0408**, 018 (2004).

[89] K.A. Assamagan, J. Guasch, S. Moretti, S. Penaranda, "Determining the ratio of the H+ → tau nu to H+ → t anti-b decay rates for large tan(beta) at the Large Hadron Collider", `hep-ph/0402212`.

[90] K. A. Assamagan, M. Guchait, S. Moretti, "Charged Higgs bosons in the transition region M(H+-) approx. m(t) at the LHC", `hep-ph/0402057`.

[91] J. Alwall, C. Biscarat, S. Moretti, J. Rathsman, A. Sopczak, "The p anti-p → t b H+- process at the Tevatron in HERWIG and PYTHIA simulations", `hep-ph/0312301`.

[92] A. Belyaev, J. Guasch, J. Sola, *Nucl. Phys. Proc. Suppl.* **116**, 296 (2003). A. Belyaev, D. Garcia, J. Guasch, J. Sola, *J. High Energy Phys.* **0206**, 059 (2002); *Phys. Rev.* **D65**, 031701 (2002).

[93] K.A. Assamagan, N. Gollub, "The ATLAS discovery potential for a heavy charged Higgs boson in g g → t b H+- with H+- → t b", `hep-ph/0406013`.

[94] M. Beccaria, H. Eberl, F. M. Renard, C. Verzegnassi, "Testing soft electroweak SUSY breaking from neutralino, chargino, and charged Higgs boson pairs production at linear colliders", `hep-ph/0406253`.

[95] M. Beccaria, H. Eberl, F. M. Renard, C. Verzegnassi, *Phys. Rev.* **D69**, 091301 (2004).

[96] M. Beccaria, F.M. Renard, S. Trimarchi, C. Verzegnassi, *Phys. Rev.* **D68**, 035014 (2003); *Pramana* **62**, 671 (2004).

[97] O. Brein, T. Hahn, S. Heinemeyer, G. Weiglein, "Single charged MSSM Higgs-boson production at a linear collider", `hep-ph/0402053`.

[98] G. Abbiendi *et al.* [OPAL Collaboration], *Phys. Lett.* **B526**, 221 (2002).

[99] V.M. Abazov *et al.* [D0 Collaboration], "Search for doubly-charged Higgs boson pair production in the decay to mu+ mu+ mu- mu- in p anti-p collisions at s**(1/2) = 1.96-TeV", `hep-ex/0404015`; D. Acosta *et al.* [CDF Collaboration], `hep-ex/0406073`; D. Acosta *et al.* [CDF Collaboration], "Search for doubly-charged Higgs bosons decaying to dileptons in p anti-p collisions at s**(1/2) = 1.96-TeV", `hep-ex/0406073`.

[100] M. Muhlleitner, M. Spira, *Phys. Rev.* **D68**, 117701 (2003).

[101] G.J. Gounaris, P.I. Porfyriadis, F.M. Renard, *Eur. Phys. J.* **C19**, 57 (2001).

[102] G.J. Gounaris, P.I. Porfyriadis, F.M. Renard, *Eur. Phys. J.* **C20**, 659 (2001).

[103] P. Niezurawski, A. F. Zarnecki, M. Krawczyk, "Light Higgs-boson production at the photon collider at TESLA with an improved background analysis", `hep-ph/0307183`; "The SM Higgs boson production gamma gamma → h → b anti-b at the photon collider at TESLA", *Acta Phys. Pol. B* **34**, 177 (2003).

[104] P. Niezurawski, A.F. Zarnecki, M. Krawczyk, *J. High Energy Phys.* **0211**, 034 (2002).

[105] M.M. Muhlleitner, M. Kramer, M. Spira, P.M. Zerwas, *Phys. Lett.* **B508**, 311 (2001).

[106] P. Niezurawski, A.F. Zarnecki, M. Krawczyk, "Measurement of the MSSM Higgs-bosons production in gamma gamma → A, H → b anti-b at the Photon Collider at TESLA", `hep-ph/0307180`.

[107] K. Desch, E. Gross, S. Heinemeyer, G. Weiglein, L. Zivkovic, *J. High Energy Phys.* **0409**, 062 (2004).

[108] G. Weiglein, *Eur. Phys. J.* **C33**, S797 (2004).