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Determination of the Higgs Profile: HFITTER

Klaus Desch* and Marco Battaglia**

*Universität Hamburg, D-22607 Hamburg Germany
**CERN, CH-1211 Geneva 23 Switzerland

Abstract. We study the prospects to extract the Higgs boson couplings to fermions and bosons from the various measurements which are possible at a future linear e^+e^- collider using a global fit. The method provides optimal sensitivity to the couplings and accounts for experimental correlations among the measurements. For a Higgs boson mass of 120 GeV and an integrated luminosity of $500 fb^{-1}$ at 350 GeV or 500 GeV and $1 ab^{-1}$ at 800 GeV, the coupling to massive gauge bosons can be determined with approximately 1% accuracy while the couplings to heavy fermions (tau leptons, charm, bottom, and top quarks) can be determined with 2–3% experimental accuracy. Except for the precise top quark coupling the whole parameter set can already be obtained at 500 GeV centre-of-mass energy.

I METHOD

If a Higgs boson is found, the precise determination of its couplings to massive gauge bosons and fermions is of primary interest and can be carried out at a future linear e^+e^- collider (LC). The different couplings are probed in the various production processes (Higgs–strahlung, $e^+e^- \to H^0Z^0$, WW–fusion, $e^+e^- \to \nu_e\bar{\nu}_e H^0$, and Higgs radiation off top-quarks, $e^+e^- \to t\bar{t}H^0$) and the Higgs boson decay branching ratios which are accessible ($H^0 \to b\bar{b}, H^0 \to c\bar{c}, H^0 \to \tau^+\tau^-, H^0 \to W^+W^-, H^0 \to gg, H^0 \to \gamma\gamma$). These branching ratios depend in general on all Higgs boson couplings. Especially loop-induced decays, such as photon and gluon pairs probe more than one coupling.

The experimental accuracies on the Higgs boson couplings are estimated using a global fit. The measured observables are predicted as a function of the values of the couplings. The couplings considered here are to τ leptons, ($g_{H\tau\tau}$), to c–quarks (g_{Hcc}), to b–quarks (g_{Hbb}), to t–quarks (g_{Htt}), to Z^0–bosons (g_{HZZ}) and to $W^\pm$–bosons (g_{HWW}). In the fit these couplings are varied independently and a χ^2 is calculated from the prediction and the measured values (which are taken to be the SM predictions). For the prediction of the branching ratios the program HDECAY [1] is used. The cross section for Higgs–strahlung and WW-fusion are calculated according to [2]. For the cross section of $e^+e^- \to t\bar{t}H^0$ no explicit calculation is used. It is assumed that this cross section is proportional to g_{Htt}^2 and independent of the other Higgs boson couplings.

II INPUT MEASUREMENTS

In Table 1 the measurements which are used as input to the fit are listed together with their assumed errors which were obtained in experimental studies including effects from backgrounds and detector acceptance and resolution. These studies were carried out for the TESLA linear collider project.

TABLE 1. *Linear Collider measurements which are used as input to the global fit together with their relative errors*

measurement	relative uncertainty	reference
$\mathrm{BR}(H^0 \to bb)$	0.024	[3]
$\mathrm{BR}(H^0 \to c\bar{c})$	0.083	[3]
$\mathrm{BR}(H^0 \to \tau^+\tau^-)$	0.050	[3]
$\mathrm{BR}(H^0 \to gg)$	0.055	[3]
$\mathrm{BR}(H^0 \to W^+W^-)$	0.051	[4]
$\mathrm{BR}(H^0 \to \gamma\gamma)$	0.190	[5]
$\sigma(e^+e^- \to H^0 Z^0)$	0.025	[6]
$\sigma(e^+e^- \to \nu_e \bar{\nu}_e H^0)$	0.028	[7]
$\sigma(e^+e^- \to t\bar{t}H^0)$	0.055	[8]

Correlations between the branching ratio measurements are taken into account in the fit. While branching ratio measurements to quarks and electroweak gauge bosons are mainly sensitive to the respective couplings, the branching ratio to gluons provides sensitivity to g_{Htt} and the branching ratio to photons is sensitive to both g_{HWW} and g_{Htt} through the corresponding loop diagrams.

III RESULTS AND INTERPRETATION

The results of the global fit are listed in Table 2. It can be seen that for the gauge couplings to massive gauge bosons a precision of approximately 1% is achievable and for the Yukawa couplings to fermions the precision ranges from 2% to 3%. It is interesting to note that the inclusion of the measurement of the cross section for WW–fusion with the subsequent decay $H^0 \to b\bar{b}$ has a large impact on the fit since it not only increases the sensitivity to g_{HWW} but also constrains g_{Hbb} which is less constrained from the branching ratios due to their inherent negative correlations (see Fig. 1c). The precision is almost unchanged if the $t\bar{t}H^0$ production cross section at $\sqrt{s} = 800$ GeV is omitted, except for the precision on g_{Htt} itself. Hence, the largest part of the program is feasible already at a $\sqrt{s} = 500$ GeV machine.

TABLE 2. *Results of the global fit of the Higgs boson couplings. The first column uses all measurements listed in Table 1. In the second column the WW-Fusion cross section measurement is omitted, and in the third column the measurement of the $t\bar{t}H^0$ cross section at $\sqrt{s} = 800$ GeV is omitted.*

coupling	$\Delta g/g$ all meas.	$\Delta g/g$ without WW–fusion	$\Delta g/g$ without $t\bar{t}H^0$
g_{HWW}	0.012	0.045	0.012
g_{HZZ}	0.012	0.012	0.012
g_{Htt}	0.022	0.027	0.036
g_{Hbb}	0.021	0.041	0.023
g_{Hcc}	0.031	0.034	0.042
$g_{H\tau\tau}$	0.032	0.110	0.034

In the Minimal Supersymmetric Standard Model (MSSM) the Higgs boson couplings differ from the SM prediction due to the presence of two Higgs doublets. The couplings are determined in terms of the ratio of the two vacuum expectation values $\tan\beta$ and the mixing angle between the two CP-even Higgs fields, α. The parameter α is in turn predicted in the MSSM as a function of the mass of the CP-odd Higgs A^0 and the soft SUSY breaking parameters of the MSSM. In particular, the tree level couplings can be written as:

$$g_{Hbb} = \frac{\sin\alpha}{\cos\beta}\, g^{SM}_{Hbb}; \quad g_{H\tau\tau} = \frac{\sin\alpha}{\cos\beta}\, g^{SM}_{H\tau\tau}; \quad g_{Hcc} = \frac{\cos\alpha}{\sin\beta}\, g^{SM}_{Hcc};$$

$$g_{HZZ} = \sin(\beta - \alpha)\, g^{SM}_{HZZ}; \quad g_{HWW} = \sin(\beta - \alpha)\, g^{SM}_{HWW}$$

We calculate these couplings for a representative scan over $\tan\beta$ and M_A, the so-called MSSM–benchmark scan defined in [9]. In Fig. 1 the 1σ and 95% confidence level contours for some of the couplings are shown as two–dimensional projections. Also shown is the MSSM–prediction for a scan over M_A in (b) – (d). For small values of M_A , large deviations from the SM prediction are predicted. The precise measurement of the couplings can be used to indirectly determine M_A. Sensitivity to the A^0–boson is obtained up approximately 1 TeV at the 1σ–level. Note, that this sensitivity does not account for theoretical uncertainties, yet, and the interpretation is restricted to the above–mentioned benchmark scenario. For a full scan of the MSSM parameter space see [3].

IV SUMMARY

The couplings of the Higgs boson to gauge bosons and massive fermions can be accurately determined using a global fit of the future linear collider measurements.

The framework allows the straight–forward inclusion of both experimental correlations and theoretical uncertainties. With the current level of estimated precision, the gauge couplings can be determined to approximately 1% precision and the fermion couplings to 2–3% precision after 500 fb^{-1} of data at $\sqrt{s}$ = 350–500 GeV and 1 ab^{-1} at $\sqrt{s}$ = 800 GeV. Without the data at 800 GeV, the accuracy is only slightly deteriorated.

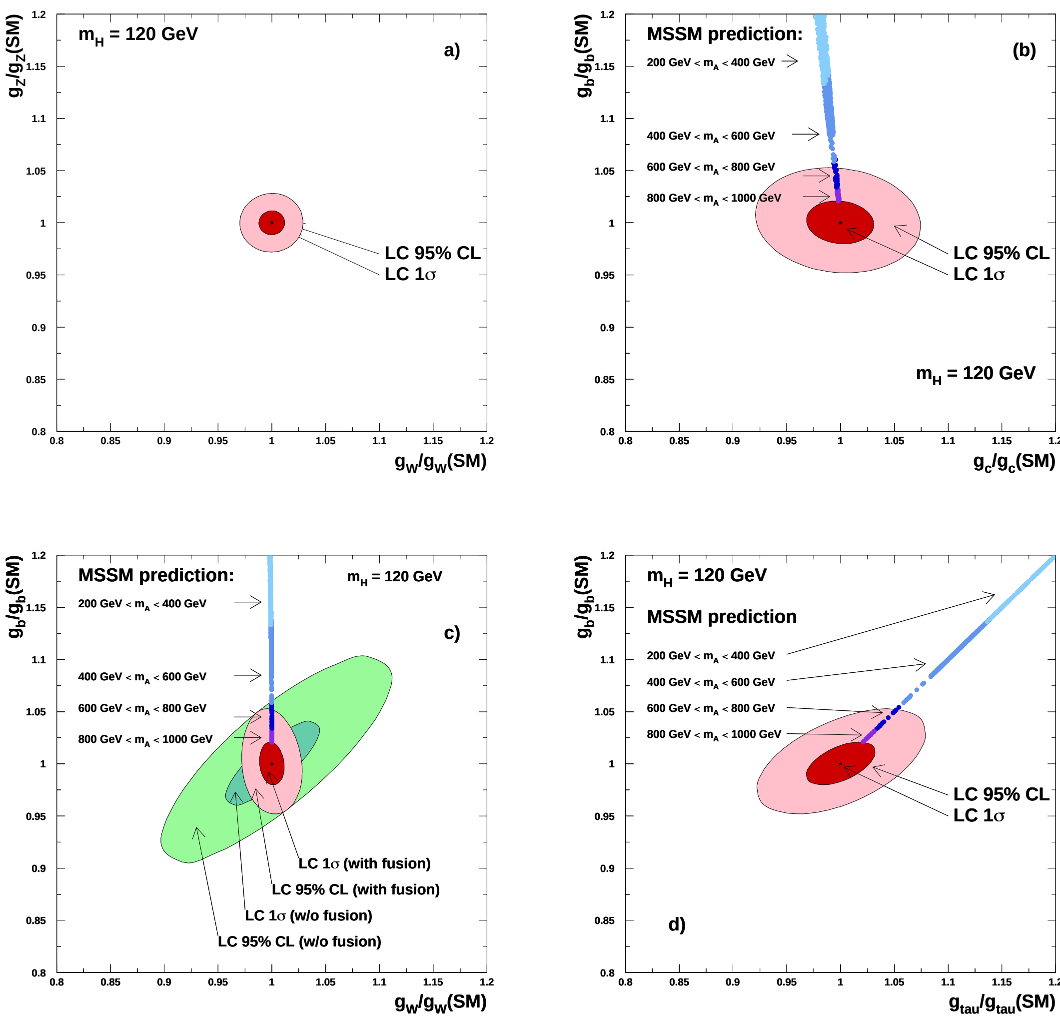

FIGURE 1. *The fitted values for the Higgs boson couplings. The dark ellipse shows the 1σ contour, the light ellipse the 95% confidence level contour. The star indicates the SM prediction, the thick line indicates MSSM predictions for different masses of the CP–odd Higgs boson, M_A.*

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