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Measuring the Higgs branching fraction into two photons at future linear e^+e^- colliders

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Abstract. We examine the prospects for a measurement of the branching fraction of the $\gamma\gamma$ decay mode of a Standard Model-like Higgs boson with a mass of 120 GeV/c^2 at the future TESLA linear e^+e^- collider, assuming an integrated luminosity of 1 ab^{-1} and centre-of-mass energies of 350 GeV and 500 GeV. A relative uncertainty on BF($H \to \gamma\gamma$) of 16% can be achieved in unpolarised e^+e^- collisions at $\sqrt{s} =$ 500 GeV, while for $\sqrt{s} = 350$ GeV the expected precision is slightly poorer. With appropriate initial state polarisations the uncertainty can be improved to 10%. If this measurement is combined with a measurement of the total Higgs width, a precision of 10% on the Higgs boson partial width for the $\gamma\gamma$ decay mode appears feasible.

1 Introduction

Following the discovery of the Higgs boson, one of the main tasks of a future linear e^+e^- collider will be precise model-independent measurements of its fundamental couplings to fermions and bosons and its total width [1]. The branching fraction of the Higgs boson into two photons, BF($H \to \gamma\gamma$), is of special interest since deviations of BF($H \to \gamma\gamma$) (or the diphoton Higgs partial width $\Gamma(H \to \gamma\gamma)$) from the Standard Model value provide sensitivity to new physics. In particular, by virtue of the fact that the $H \to \gamma\gamma$ coupling can have contributions from loops containing new charged particles, significant differences from the Standard Model value are possible. For example, supersymmetric partners in the loop may increase or decrease the diphoton Higgs boson partial width [2]. Thus, a measurement of BF($H \to \gamma\gamma$) at the next linear collider will be an important contribution to understanding the nature of the Higgs boson and may possibly provide hints for new physics, if the size of the deviation from the Standard Model prediction is larger then the measurement accuracy. The precision of the $H \to \gamma\gamma$ branching fraction measurement attainable in e^+e^- collisions is the subject of this paper.

The ultimate goal of this measurement is to derive the diphoton Higgs boson partial width. This requires knowledge of the total Higgs width. The total width of a light Standard Model Higgs boson is too small to be observed directly, but can be obtained indirectly via measurements of the Higgs branching fraction $BF(H \to b\bar{b})$ and the product $\Gamma(H \to \gamma\gamma) \cdot BF(H \to b\bar{b})$. The first of these quantities can be measured [3] in e^+e^- collisions at a future linear collider while the second will be accessible in the $\gamma\gamma$ collider option of a linear collider. As both these measurements can be achieved with a precision of a few percent, the uncertainty on the total Higgs width will be dominated by the uncertainty in $BF(H \to \gamma\gamma)$.

However, it has been demonstrated recently [4] that a measurement of the branching fraction BF($H \to WW^*$) at a high-luminosity linear e^+e^- collider, combined with a precise value for the rate of the WW fusion process $e^+e^- \to \nu_e\bar{\nu}_e H$ (or for the Higgsstrahlung production rate $\sigma(e^+e^- \to HZ)$ and assuming W-Z universality), would permit an accurate measurement of the total width of the Higgs boson.

The Standard Model Higgs contribution to electroweak observables provides information on its mass. The most recent analysis [5] of the data from LEP, SLC and the Tevatron yields a 95% CL upper limit of 206 GeV/c^2, when recent measurements of the fine-structure constant [6] are included. Direct searches for the Higgs boson at LEP yield a lower bound of $M_H \geq 113.5$ GeV at the 95% confidence level [7], and the LEP collaborations recently reported a 2.9 standard deviation excess of events beyond the expected Standard Model background, consistent with a mass $M_H = 115^{+1.3}_{-0.9}$ GeV/c^2 [7].

High-luminosity linear e^+e^- colliders in the energy range 300 to 500 GeV [8] are ideal machines to perform

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precise measurements of the properties of such a particle. In this paper we investigate the prospects of measuring the branching fraction BF($H \to \gamma\gamma$) with events of the reactions

$$\mathrm{e}^+\mathrm{e}^- \to \mathrm{q\bar{q}}\gamma\gamma \quad (1)$$

and

$$\mathrm{e}^+\mathrm{e}^- \to \nu\bar{\nu}\gamma\gamma \quad (2)$$

assuming a Higgs boson mass $M_H = 120$ GeV/c^2, at centre-of-mass energies $\sqrt{s} = 350$ and 500 GeV and an integrated luminosity of 1 ab^{-1} at each energy.

The relative statistical precision on BF($H \to \gamma\gamma$) is given approximately by $\sqrt{S+B}/S$, where S and B are respectively the number of signal and background events within a small interval of the two-photon invariant mass $\Delta M_{\gamma\gamma}$, centred around M_H. Hence, evaluation of all relevant signal and background processes and optimisation of selection procedures are mandatory, taking into account acceptances and resolutions of a linear collider detector.

Our analysis is superior in some respects to the study of [9]. It includes the complete irreducible background in reactions (1) and (2) and demonstrates for the first time the gain in the precision of BF($H \to \gamma\gamma$) when beam polarisation is accounted for in signal and background events.

The paper is organised as follows. In Sect. 2 we discuss simulation of the Higgs signal and background events and their detector response. In Sects. 3 and 4 we present our results for BF($H \to \gamma\gamma$) measurements with unpolarised beams at $\sqrt{s} = 350$ and 500 GeV respectively. In Sect. 5 we discuss improvements to the $H \to \gamma\gamma$ branching fraction measurement with beam polarisation. Section 6 summarises the conclusions.

2 Signal and background reactions

In e$^+$e$^-$ collisions the Standard Model Higgs boson is predominantly produced by two different processes, the Higgsstrahlung process

$$\mathrm{e}^+\mathrm{e}^- \to ZH \quad (3)$$

and the weak boson WW and ZZ fusion reactions

$$\mathrm{e}^+\mathrm{e}^- \to \nu_\mathrm{e}\bar{\nu}_\mathrm{e}H \quad (4)$$

$$\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-H \quad (5)$$

The ZZ fusion process (5) is suppressed with respect to the WW fusion process (4) by a factor of about ten, rather independently of $\sqrt{s}$. Therefore only the Higgsstrahlung and WW fusion reactions (3) and (4) are considered in this study. These processes are part of the 2-to-4 body reactions (1) and (2) if only the most important $Z \to \mathrm{q\bar{q}}$ (about 70% branching fraction) and $\nu\bar{\nu}$ (about 20% branching fraction) decays and the $H \to \gamma\gamma$ decay are accounted for. Events of reactions (1) and (2) were generated by means of the program CompHEP [10], including initial state bremsstrahlung and beamstrahlung for the TESLA linear collider option [11]. In this way, Higgs boson production and the complete irreducible background as well as possible interference effects have been taken into account. The branching fraction for $H \to \gamma\gamma$ was estimated with the program HDECAY [12]. It depends on the Higgs mass and is largest near $M_H = 120$ GeV/c^2. In this study we used BF($H \to \gamma\gamma$)$= 2.2 \times 10^{-3}$.

The Higgsstrahlung reaction (3) is characterised by two hadronic jets originating from the Z, together with two energetic photons with an invariant mass equal to M_H. The background expected in reaction (1) comes from the 100 lowest-order diagrams with q $= d, u, s, c, b$, which are shown, for the d-quark as an example, in Fig. 1. The most serious background arises from the double bremsstrahlung process e$^+$e$^-$ $\to Z\gamma\gamma \to \mathrm{q\bar{q}}\gamma\gamma$. Because of its importance, $Z\gamma\gamma$ events estimated with CompHEP have been cross-checked at the generator level with KORALZ 4.2 [13] and found to be in good agreement, at the level of a few percent, in the $\gamma\gamma$ invariant mass range relevant for this study.

For the signal events in reaction (2), with contributions from WW fusion and Higgsstrahlung processes (and taking into account small interference effects), we expect a signature of two photons, producing two large neutral electromagnetic showers in the detector with no other activity, and large missing energy due to the two undetected neutrinos. The background diagrams contributing to reaction (2) are shown in Fig. 2. They were accounted for at the same level as the signal events. Again, the most serious, irreducible background was found to arise from the double bremsstrahlung process e$^+$e$^-$ $\to Z\gamma\gamma \to \nu\bar{\nu}\gamma\gamma$.

Possible reducible backgrounds to e$^+$e$^-$ $\to HZ$ events which might mimic the signal, such as the reactions e$^+$e$^-$ $\to ZZ$ and e$^+$e$^-$ $\to WW$ with large cross-sections, were found to be very small after application of selection criteria.

Processes such as e$^+$e$^-$ $\to \gamma\gamma(\gamma)$ or e$^+$e$^-$ $\to$ (e$^+$e$^-$) $\gamma\gamma$, when both electrons are undetected, might constitute a significant background to e$^+$e$^-$ $\to ZH$, $\nu\bar{\nu}H \to \nu\bar{\nu}\gamma\gamma$ events. However, after kinematical cuts their rates were also found to be small or negligible.

As the cross-sections for the backgrounds discussed above are orders of magnitude larger than the signal cross-sections, the following cuts were applied at the generation level, to both the signal and background events:

- for each photon, the component of the momentum transverse to the axis defined by the beams should exceed 20 GeV/c;
- the two-photon invariant mass, $M_{\gamma\gamma}$, should be greater than 100 GeV/c^2;
- for reaction (1), the q$\bar{\mathrm{q}}$ invariant mass, $M_{\mathrm{q\bar{q}}}$, should lie in the range M_Z - 20 GeV/c^2 to M_Z + 20 GeV/c^2.

After application of these criteria, practically all Higgs events survive, while the background contributions are substantially reduced.

The detector response for all signal and the remaining background events was simulated with the parametrised detector simulation package SIMDET [14], using parameters as presented in the Conceptual Design Report [8].

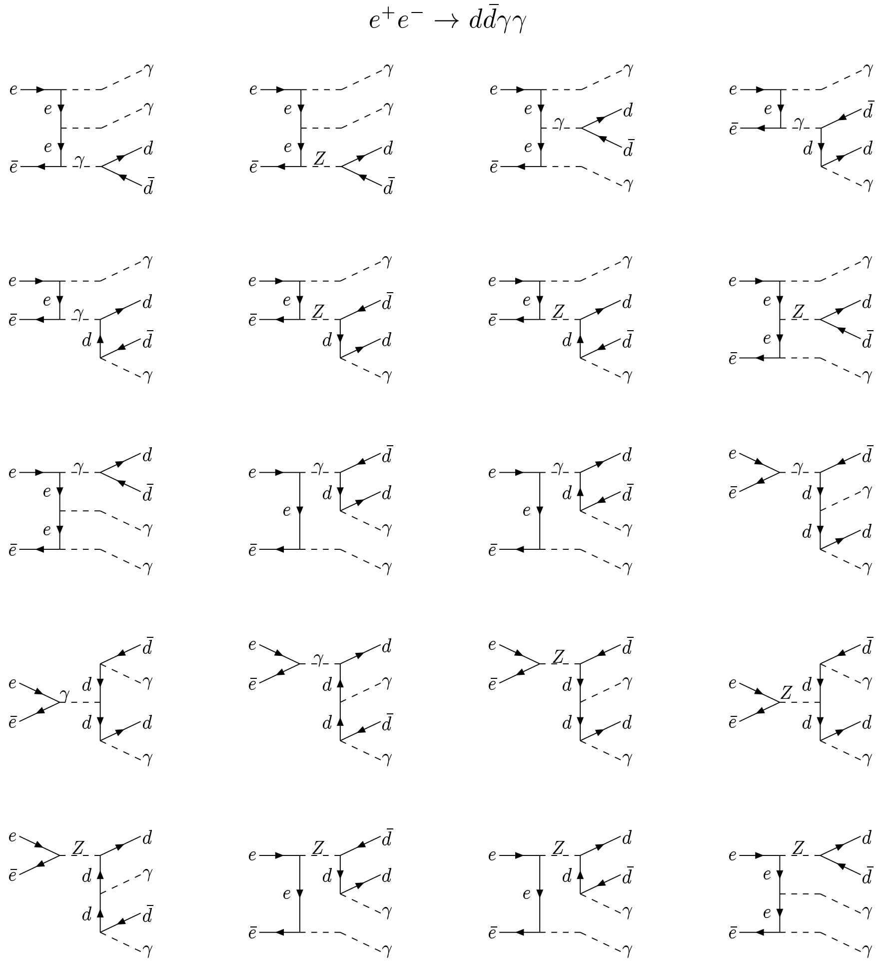

Fig. 1. Background diagrams for the reaction $e^+e^- \to d\bar{d}\gamma\gamma$

3 BF($H \to \gamma\gamma$) measurement at $\sqrt{s} = 350$ GeV

Different Higgs event rates are expected from processes (3) and (4) at the two different centre-of-mass energies, $\sqrt{s} = 350$ and 500 GeV. The Higgsstrahlung cross-section scales with $1/s$ after a maximum close to the threshold, while the WW fusion cross-section rises logarithmically with $\sqrt{s}$. At $\sqrt{s} = 350$ GeV, the Higgsstrahlung cross-section is approximately 140 fb for $M_H = 120$ GeV/c^2, which is about four times larger than the WW fusion cross-section. Since the Z boson hadronic decay mode dominates, $q\bar{q}\gamma\gamma$ events constitute the main source of the Higgs signal. The invisible $Z \to \nu\bar{\nu}$ decay in the Higgsstrahlung channel and the WW fusion channel both lead to an event topology of two isolated high energy photons plus large missing energy due to the two undetected neutrinos and are treated together in our study.

Considering only the $Z \to q\bar{q}$ and $Z \to \nu\bar{\nu}$ decay modes and the Higgs decay into two photons, we expect respectively about 220 and 130 Higgs events in reactions (1) and (2) at $\sqrt{s} = 350$ GeV for an integrated luminosity of 1 ab^{-1}. Different event selection procedures were applied to the $q\bar{q}\gamma\gamma$ and $\nu\bar{\nu}\gamma\gamma$ event samples in order to account for the distinct properties of the final states.

An initial preselection was applied for the two-jet two-photon candidate events. It was required that:

– there be at least two isolated neutral electromagnetic showers, each compatible with originating from a photon with a component of the momentum transverse to the beams greater than 20 GeV/c;
– there be no particle in a cone of half-angle 10° around the isolated photon directions;
– there be more than five charged particle tracks;
– the total visible energy in the event be greater than $0.8 \times \sqrt{s}$;
– the component of the total event momentum along the beam direction have a magnitude less than 100 GeV/c.

All particles excluding the two selected photons were then forced into two hadronic jets. The invariant mass of the two-jet system was required to lie in the range 70 GeV/c^2 to 110 GeV/c^2, compatible with a Z boson hadronic decay. After all cuts the background to the Higgsstrahlung events close to M_H was significantly reduced, but was still one order of magnitude greater than the signal, so further selection criteria were applied to improve the signal-to-background ratio.

In a first attempt, a conventional method using consecutive cuts on kinematical variables was applied. In particular, it was demanded that:

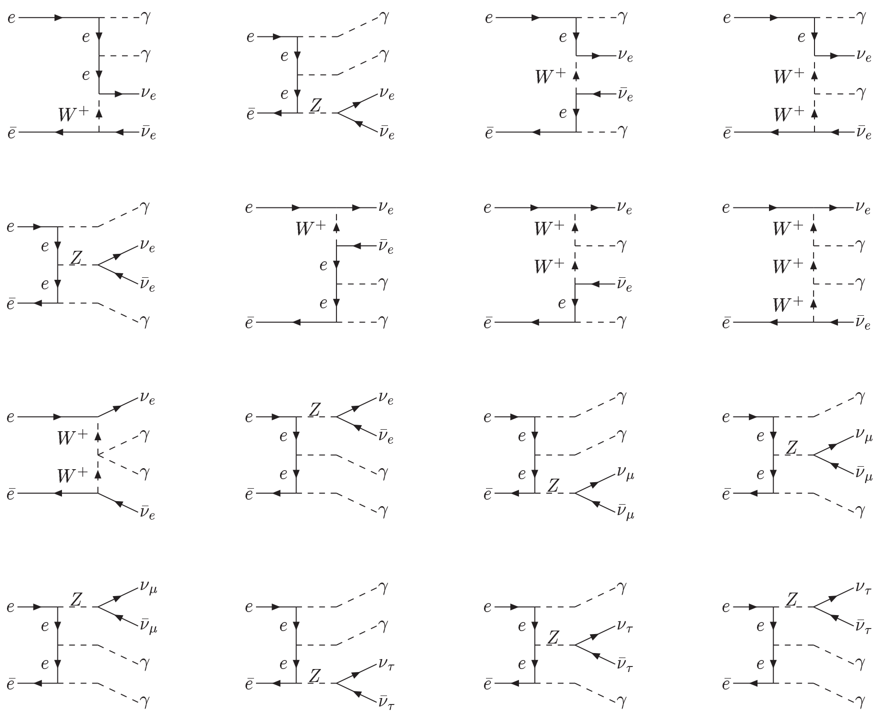

Fig. 2. Background diagrams for the reaction $e^+e^- \to \nu\bar{\nu}\gamma\gamma$

- the energy of the two-photon system lie in the range 140 to 200 GeV;
- the transverse energy, defined as the product of the energy and the sine of the polar angle $\theta_{\gamma\gamma}$ of the momentum vector of the two-photon system, be greater than 50 GeV;
- each photon polar angle θ_γ should lie in the range defined by $|\cos\theta_\gamma| < 0.9$;
- the polar angle of the two-photon system should lie in the range defined by $|\cos\theta_{\gamma\gamma}| < 0.8$.

These cuts gave a selection efficiency of 56% for Higgs signal events.

The second approach involved a more sophisticated selection procedure. Kinematical variables of the final state photons and of the $\gamma\gamma$ subsystem were combined into a global discriminant variable P_H, designed to give a measure of the "Higgs-likeness" of any particular event. This quantity was constructed from a variety of normalised variables based on large statistics samples of simulated signal and background events. In particular, the variables used were the energies, transverse momenta and polar angles of both photons, the angle between the photons, and the energy, transverse energy and polar angle of the two-photon system. For each event, signal and background probabilities were then calculated, and by multiplication of all signal probabilities the sensitivity for an event to be a Higgs candidate was maximised. The quantity so obtained was constrained to lie in the region [0;1]. Background events were preferentially distributed at low P_H values while for Higgs signal events P_H is close to unity. The distribution of P_H is shown in Fig. 3. A cut of $P_H > 0.85$ was applied to select candidate Higgs events. This method resulted in a signal selection efficiency of 42% with 2.3 times less background, giving a significantly better signal-to-background ratio than the selection method using successive cuts. Therefore only results using the discriminant variable procedure are discussed in the following.

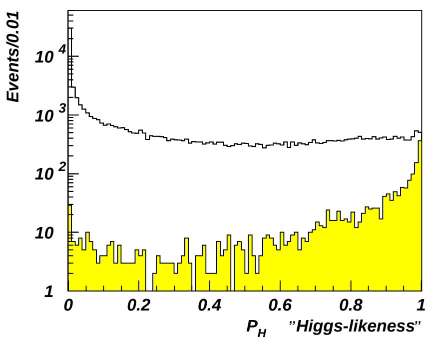

Fig. 3. Distribution of the discriminant variable P_H for $e^+e^- \to HZ \to q\bar{q}\gamma\gamma$ signal events (shaded histogram) and the background (solid line)

Figure 4a shows the spectrum of the two-photon invariant mass $M_{\gamma\gamma}$ for the $q\bar{q}\gamma\gamma$ signal and background events surviving the cut $P_H > 0.85$. The superimposed curve is the result of a fit to the sum of a Gaussian function, used to describe the signal, and a second order polynomial function, which was found to describe the background well between 110 and 130 GeV/c^2.

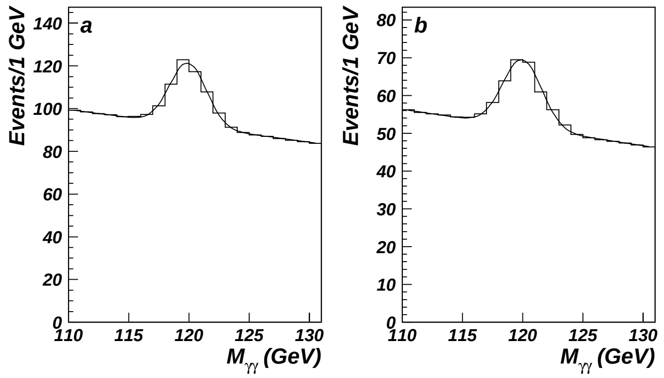

Fig. 4a,b. Distributions of the two-photon invariant mass $M_{\gamma\gamma}$ at $\sqrt{s}$ =350 GeV for: **a** q$\bar{\text{q}}\gamma\gamma$ and **b** $\nu\bar{\nu}\gamma\gamma$ events. The background contributions in the histograms have been smoothed to avoid accidental fluctuations

From the normalisations of the signal and background, which were allowed to vary, the number of signal and background events in an optimal $M_{\gamma\gamma}$ window width of 2.5 GeV/c^2 around M_H was obtained[1]. These numbers are collected in Table 1 and gave a relative statistical uncertainty of 23% for $\sigma(\text{e}^+\text{e}^- \to HZ) \cdot BF(H \to \gamma\gamma)$ in the reaction $\text{e}^+\text{e}^- \to ZH \to \text{q}\bar{\text{q}}\gamma\gamma$.

Candidate Higgs events in the $\gamma\gamma\nu\bar{\nu}$ final state were required to have no charged particle tracks reconstructed in the detector. Events with two photons were selected by requiring that an event contains at least two electromagnetic clusters, each with a transverse momentum larger than 20 GeV/c and with a polar angle θ_γ lying in the range defined by $|\cos\theta_\gamma| < 0.9$. It was further required that the polar angle $\theta_{\gamma\gamma}$ of the two-photon system (the candidate Higgs decay) should lie in the region defined by $|\cos\theta_{\gamma\gamma}| < 0.8$.

These cuts gave a Higgs selection efficiency of 45% and removed most possible backgrounds. The resulting $M_{\gamma\gamma}$ mass distribution is shown in Fig. 4b. The expected numbers of signal and background events, obtained in the same manner as for the q$\bar{\text{q}}\gamma\gamma$ events, are shown in Table 1. An estimated relative statistical uncertainty of 28.5% was obtained. After combining the q$\bar{\text{q}}\gamma\gamma$ and $\nu\bar{\nu}\gamma\gamma$ events and neglecting uncertainties on the Higgs cross-section, which should be precisely measured at a future linear collider, the expected fractional uncertainty on the $H \to \gamma\gamma$ branching ratio was estimated to be 18% at $\sqrt{s}$ = 350 GeV.

4 BF($H \to \gamma\gamma$) measurement at $\sqrt{s}$ = 500 GeV

At $\sqrt{s} = 500$ GeV, the cross-sections for the Higgs signal reactions (3) and (4) are about equal, hence most Higgs events have a $\nu\bar{\nu}\gamma\gamma$ signature, with the dominant contribution being the WW fusion process.

The Higgs candidate selection procedures were similar to those at $\sqrt{s} = 350$ GeV. For the q$\bar{\text{q}}\gamma\gamma$ events, the same criteria were applied, resulting in a two-photon invariant mass distribution as shown in Fig. 5a. Signal and background event numbers obtained from the fit are also presented in Table 1. The signal has little statistical significance, and hence these events were not considered in the analysis.

For the $\nu\bar{\nu}\gamma\gamma$ events it was required that at least one of the photons has a transverse momentum greater than 50 GeV/c, and that the recoil mass against the two-photon system, defined as $M_{rec} = \sqrt{s + M_{\gamma\gamma}^2 - 2\sqrt{s}M_{\gamma\gamma}}$, should lie in the range 150 to 370 GeV/c^2.

The recoil mass cut reduced substantially the main background from double bremsstrahlung $\text{e}^+\text{e}^- \to \gamma\gamma Z \to \gamma\gamma\nu\bar{\nu}$ events. It also elimated events from the low rate Higgsstrahlung $\text{e}^+\text{e}^- \to ZH \to \nu\bar{\nu}\gamma\gamma$ process. The surviving background arose mainly from W-exchange diagrams shown in Fig. 2, with two photons radiated from the beam particle(s). The transverse momentum cut removed part of this background.

The two-photon invariant mass distribution for candidate $\gamma\gamma\nu\bar{\nu}$ events is shown in Fig. 5b. The signal and background event rates are given in Table 1. The relative precision obtained on $\sigma(\text{e}^+\text{e}^- \to H + \nu\bar{\nu}) \cdot BF(H \to \gamma\gamma)$ was 16.4%.

Table 1. Numbers of signal and background events estimated from fits to $M_{\gamma\gamma}$ spectra and the precisions expected for the product of the cross-section times the $H \to \gamma\gamma$ branching fraction

Energy	350 GeV			500 GeV	
Process	q$\bar{\text{q}}\gamma\gamma$	$\nu\bar{\nu}\gamma\gamma$	Total	q$\bar{\text{q}}\gamma\gamma$	$\nu\bar{\nu}\gamma\gamma$
Signal (S)	93	57	150	35	99
Background (B)	366	206	572	410	163
$S/\sqrt{B}$	4.9	4.0	6.3	1.7	10.2
Precision(%)	23.0	28.5	17.9	60.3	16.4

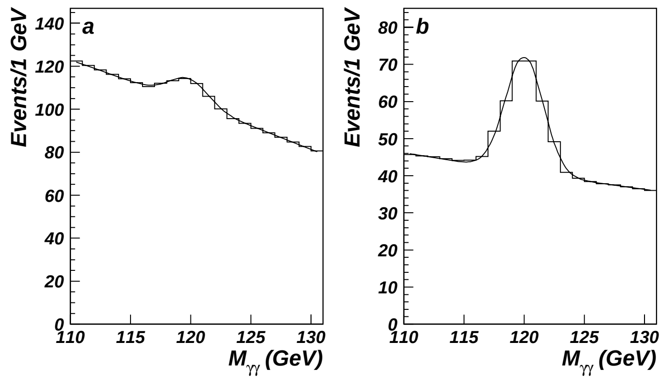

Fig. 5a,b. $M_{\gamma\gamma}$ invariant mass distributions at $\sqrt{s}$ =500 GeV: **a** q$\bar{\text{q}}\gamma\gamma$ and **b** $\nu\bar{\nu}\gamma\gamma$ events. The background in the histograms has been smoothed to avoid accidental fluctuations

[1] In order to estimate the optimised number of signal to background events for a narrow Gaussian resonance whose observed width is dominated by instrumental effects, the mass window chosen should be 1.2 Γ_{exp}, centred on the actual Higgs mass

Since the signal-to-background ratio is expected to be less than unity, it should be emphasized that copious π^0 background events and the large continuum $\gamma\gamma$ production must be rejected by excellent geometrical resolution and stringent isolation criteria combined with excellent electromagnetic energy resolution and hermiticity. Systematic uncertainties due to detector effects such as the photon detection efficiency, energy scale and the electromagnetic calorimeter resolution are believed to be small and can be estimated from comparison of data with well understood Standard Model processes such as $e^+e^- \to \gamma\gamma$, Compton scattering events and both radiative and non-radiative Bhabha events. The sytematic uncertainty on the integrated luminosity is expected to be below 0.5%, and statistical uncertainties due to the finite simulation sample sizes should be kept below a few percent. Simulations of the Standard Model background channels are expected to yield most of the systematic uncertainty. In our study some confidence on this uncertainty was obtained by comparing two event generators for the dominant double bremsstrahlung background process $e^+e^- \to Z\gamma\gamma$, where the agreement was at the level of a few percent in the relevant two-photon invariant mass region. Taking all these effects together, it appears that the uncertainty on the measurement of $\sigma(e^+e^- \to H+X) \cdot BF(H \to \gamma\gamma)$ will be dominated by the statistical uncertainty.

5 Polarisation

Linear e^+e^- colliders offer the possibility for longitudinally polarised electron and positron beams, with varying polarisation degrees in right-handed or left-handed modes. Higgs boson production rates in both processes (3) and (4) depend strongly on the polarisation degree and the helicity of the incoming particles.

For any given process i, the ratio R_i of the cross-section for given electron (P_-) and positron (P_+) beam polarisations divided by the cross-section for unpolarised beams can be expressed by

$$R_i = 1 + \eta_i(P_- - P_+) - P_-P_+ \quad , \tag{6}$$

where η_i is the asymmetry factor for the cross-sections,

$$\eta_i = \frac{\sigma_i^{+-} - \sigma_i^{-+}}{\sigma_i^{+-} + \sigma_i^{-+}} \quad , \tag{7}$$

and $\sigma_i^{+-}(\sigma_i^{-+})$ denotes the cross-section for 100% right-handed (left-handed) polarised electrons in collision with 100% left-handed (right-handed) polarised positrons. We define $i = 1$ for the Higgsstrahlung process and $i = 2$ for the WW fusion process. The asymmetry factors calculated with CompHEP were found to be $\eta_1 = -0.21$ and $\eta_2 = -1$. For the WW fusion process the absolute value of η_2 is maximal because this process occurs via only a selected combination of e^- and e^+ helicities. If only the e^- beam is polarised, $R_i = 1 + \eta_i P_-$. Various values of R_i for different beam polarisations are shown in Table 2, which illustrates the potential of polarised colliding beams for

Table 2. Cross-section scaling factors R for Higgsstrahlung (3rd column) and WW fusion (4th column) for various combinations of beam polarisations

e^- beam (P_-)	e^+ beam (P_+)	$e^+e^- \to HZ$	$e^+e^- \to \nu_e\bar{\nu}_e H$
+1	0	0.79	0
−1	0	1.21	2
+0.8	0	0.83	0.2
−0.8	0	1.17	1.8
+1	−1	1.58	0
−1	+1	2.42	4
+0.8	−0.4	1.07	0.12
−0.8	+0.4	1.57	2.52
+0.8	−0.6	1.19	0.08
−0.8	+0.6	1.77	2.88

Higgs boson physics at a linear collider. The Higgs event rate is enhanced most for left-handed e^- colliding with right-handed e^+ with as large a degree of polarisation as possible.

However, the dominant background in processes (1) and (2), such as $Z\gamma\gamma$ and W-exchange $\nu_e\bar{\nu}_e\gamma\gamma$, scale in approximately the same way with beam polarisations as the signal processes, as verified by CompHEP simulations. Hence, the two-photon invariant mass spectra shown in Figs. 4 and 5 can be rescaled by the appropriate R_i factor, and the statistical precision of the $H \to \gamma\gamma$ branching fraction improves by only a factor $\sqrt{R_i}$.

For the idealised case of collisions between fully left-polarised e^- and fully right-polarised e^+ beams, the relative precision achievable for $\sigma(e^+e^- \to H+X) \cdot BF(H \to \gamma\gamma)$ is expected to be 10.3% at $\sqrt{s}$=350 GeV and 8.2% at $\sqrt{s}$=500 GeV. This is obtained assuming a 1 ab^{-1} integrated luminosity with the combination of reactions (3) and (4) at $\sqrt{s}$=350 GeV and considering only reaction (4) at $\sqrt{s}$=500 GeV. For the feasible (though ambitious) case of collisions between an e^- beam with polarisation $P_- = -0.8$ and an e^+ beam with polarisation P_+=+0.6, the expected statistical precision for $\sigma(e^+e^- \to H+X) \cdot BF(H \to \gamma\gamma)$ would be 12.1% at $\sqrt{s}$=350 GeV and 9.6% at $\sqrt{s}$=500 GeV. In the less ambitious case with a lower e^+ beam polarisation of P_+=+0.4, the expected resolutions are 12.8% and 10.2% respectively. The uncertainties on the diphoton branching fraction of the Higgs boson are then deduced after convolution with the uncertainties on the inclusive Higgs production rates which are expected to be measured with a relative precision better than or about 2% [15]. However, it should be noted that other physics processes will demand different beam polarisations and the assumption of using the full luminosity with the desired beam polarisation for this particular measurement gives a lower bound to the attainable precision.

6 Conclusions

We have examined the prospects at a future linear e^+e^- collider of measuring the branching fraction of a Standard

Model-like Higgs boson into two photons, BF($H \to \gamma\gamma$). A Higgs boson mass of 120 GeV/c^2 and an integrated luminosity of 1 ab^{-1} at either $\sqrt{s} = 350$ or 500 GeV were assumed. In order to estimate the precision on BF($H \to \gamma\gamma$) which can be attained, all expected background processes were included in the analysis, and acceptances and resolutions of a linear collider detector were taken into account. In particular, by simulating the 2-to-4 particle reactions $e^+e^- \to q\bar{q}\gamma\gamma$ and $e^+e^- \to \nu\bar{\nu}\gamma\gamma$, in which the signal reactions are embedded, the complete irreducible background has been taken into account.

For unpolarised beams at $\sqrt{s} = 350$ GeV, where both the Higgsstrahlung and the WW fusion mechanisms contribute significantly, the expected statistical uncertainty on BF($H \to \gamma\gamma$) was 18%, after combining both Higgs production channels and convolution with the uncertainty on the more precisely measured inclusive Higgs boson cross-sections. The isolation of $e^+e^- \to ZH \to q\bar{q}\gamma\gamma$ signal events required a multidimensional analysis on a likelihood estimator. Otherwise, background from double bremsstrahlung was overwhelming and greatly hindered the measurement.

For unpolarised beams at $\sqrt{s} = 500$ GeV, only the $\nu\bar{\nu}\gamma\gamma$ final state was worth consideration and the application of consecutive cuts on kinematical variables resulted in a reasonable signal-to-noise ratio and a convincing signal. The expected relative precision for the $H \to \gamma\gamma$ branching fraction was found to be 16%.

For e^- beam polarisation of -0.8 and e^+ beam polarisation of $+0.4$ (or $+0.6$), the Higgsstrahlung and WW fusion cross-sections are significantly enhanced, so improving substantially the precision on BF($H \to \gamma\gamma$), even taking into account the fact that the background scales in the same way. Under such circumstances, the relative uncertainty on BF($H \to \gamma\gamma$) is lowered to 12.8% (12.1%) at $\sqrt{s} = 350$ GeV and 10.2% (9.6%) at $\sqrt{s} = 500$ GeV.

With these uncertainties it should be possible to deduce a relative precision for the diphoton Higgs partial width of $\frac{\Delta\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)} \simeq 13.5\%(12.6\%)$ at $\sqrt{s} = 350$ GeV, and 11.1%(10.6%) at $\sqrt{s} = 500$ GeV, if an uncertainty of 4.3% for the total Higgs width [15] is included. These uncertainties are about a factor five worse than those expected from measurements of the reaction $\gamma\gamma \to H \to b\bar{b}$ [16], possible after conversion of an e^+e^- collider to a Compton collider.

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