Two-Photon Width of the Higgs Boson

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This study investigates the potential of a photon collider for measuring the two photon partial width times the branching ratio of a light Higgs boson. The analysis is based on the reconstruction of the Higgs events produced in the $\gamma\gamma \to$h process, followed by Higgs decay into a b$\bar{\text{b}}$ pair. A statistical error of the measurement of the two-photon width times the b$\bar{\text{b}}$ branching ratio of the Higgs boson is found to be 1.7 % with an integrated luminosity of 80 fb^{-1} in the high energy part of the spectrum.

1. INTRODUCTION

The central challenge for particle physics nowadays is the origin of mass. In the Standard Model both fermions and gauge boson masses are generated through interactions with the same scalar particle, the Higgs boson, h. If it exists, the Higgs boson will certainly be discovered by the time a photon collider is constructed. The aim of this machine will be then a precise measurement of the Higgs properties. The photon scattering can be used to produce the Higgs particles singly in the s-channel of the colliding photons. This facility permits a high precision measurement of the h $\to \gamma\gamma$ partial width, which is sensitive to new charged particles. The measurement is significantly important. If we find a deviation of the two photon width from the standard model prediction it means that an additional contribution from unknown particles is present, and so it is a signature of physics beyond the SM. For example, the minimal extension of the SM predicts the ratio of the two photon width $\Gamma(\text{h} \to \gamma\gamma, \text{MSSM})/\ \Gamma(\text{h} \to \gamma\gamma, \text{SM}) < 1.2$ [1] for a Higgs boson with a mass of 120 GeV, assuming a supersymmetry scale of 1 TeV and the chargino mass parameters M and μ of 300 and 100 GeV, respectively.

A photon collider can measure the product $\Gamma(\text{h} \to \gamma\gamma)\times\text{BR}(\text{h} \to \text{X})$. To obtain the two-photon partial width independent of the branching ratio one has to combine with an accurate measurement of the BR(h $\to$ X) from another machine.

This study investigates the accuracy of the measurement of the two photon decay width times the branching ratio for a Higgs boson with the mass of 120 GeV, the preferred mass region by recent electroweak data [2]. The signal and background processes studied are specified in section 2. Event selection is described in section 3. Results are summarized in section 4.

The feasibility of the measurement of the two photon decay width of the Higgs boson in this mass region has also been reported by [3].

2. SIMULATION OF THE SIGNAL AND BACKGROUND PROCESSES

High energy photon beams can be produced at a high rate in Compton backscattering of laser photons off high energy electrons [4]. Setting opposite helicities for the laser photons and the beam electrons the energy spectrum of the backscattered photons is peaked at 80% of the e$^-$ beam energy. The backscattered photons are highly polarized in this high energy region. With an integrated luminosity of 80 fb^{-1} per year for $\sqrt{s}_{ee} > 0.8\sqrt{s_{ee}^{max}}$ [4], about 20000 Higgs bosons with standard model coupling and a mass of 120 GeV can be produced in the $\gamma\gamma \to$h process. In this mass region the Higgs particle will decay dominantly into a b$\bar{\text{b}}$ pair.

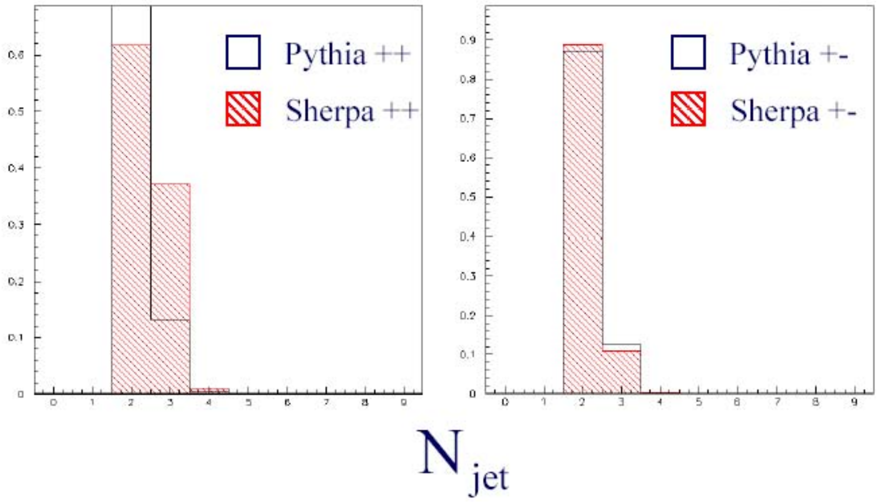

Figure 1: Distributions for the number of jets simulated with PYTHIA and SHERPA for the $\gamma\gamma \to \mathrm{b\bar{b}(g)}$ and $\gamma\gamma \to \mathrm{c\bar{c}(g)}$ processes for $J_z = 0$ and $J_z = 2$.

The beam spectra at $\sqrt{s}_{ee} = 210$ GeV are simulated using the CompAZ [5], a fast parameterization which includes multiple interactions and non-linearity effects.

The response of the detector has been simulated with SIMDET 4 [6], a parametric Monte Carlo for the TESLA $\mathrm{e^+e^-}$ detector. It includes a tracking and calorimeter simulation and a reconstruction of energy-flow-objects (EFO). Only EFOs with a polar angle above 7^0 can be taken for the Higgs reconstruction simulating the acceptance of the photon collider detector as the only deference to the $\mathrm{e^+e^-}$ detector [7].

The considered backgrounds are the direct continuum $\gamma\gamma \to \mathrm{b\bar{b}}$ and $\gamma\gamma \to \mathrm{c\bar{c}}$ production. Due to helicity conservation, the continuum background production proceeds mainly through states of opposite photon helicities, making the states $J_z = 2$. Choosing equal helicity photon polarizations the cross section of the continuum background is suppressed by a factor $M_{\mathrm{q}}^2/s_{\gamma\gamma}$, with M_{q} being the quark mass. Unfortunately, this suppression does not apply to the process $\gamma\gamma \to \mathrm{q\bar{q}g}$, because after the gluon radiation the $\mathrm{q\bar{q}}$ system is not necessarily in a $J_{\mathrm{z}} = 0$ state. The surviving background is large and overwhelms the signal.

Signal $\gamma\gamma \to \mathrm{h} \to \mathrm{b\bar{b}}$ events are generated using PYTHIA 6.2 [8]. Background processes $\gamma\gamma \to \mathrm{q\bar{q}(g)}$ are generated with the SHERPA (The simulation for High Energy Reactions of Particles) [9] generator. Higher order QCD effects are simulated in PYTHIA by evolving the hard process event using the parton shower, which allows partons to split into pairs of other partons. This technique is most effective when the emitted gluons are soft or collinear, while the region of high transverse momentum is poorly described. For a reliable background estimation correct NLO corrections are needed. Combining the hard process with its higher order correction in PYTHIA is not trivial. A fraction of $\gamma\gamma \to \mathrm{b\bar{b}g}$ events are included in the $\gamma\gamma \to \mathrm{b\bar{b}}$ process via gluon radiation in the parton shower. Combining the two processes without special procedures amounts in double counting of some phase space regions. SHERPA [9] is a generator which matches correctly the exact matrix elements with showering. A comparison between the distributions of jet multiplicity in the $\gamma\gamma \to \mathrm{b\bar{b}(g)}$ process obtained with PYTHIA and SHERPA is shown in Figure 1. However, since virtual diagrams are not included, to obtain the correct rates the SHERPA results for the spin $J_z = 0$ states have to be scaled by the correct NLO cross section. The cross sections at the NLO for the $\gamma\gamma \to \mathrm{q\bar{q}g}$ process have been calculated [10], [11]. A cross section comparison is shown in Figure 2.

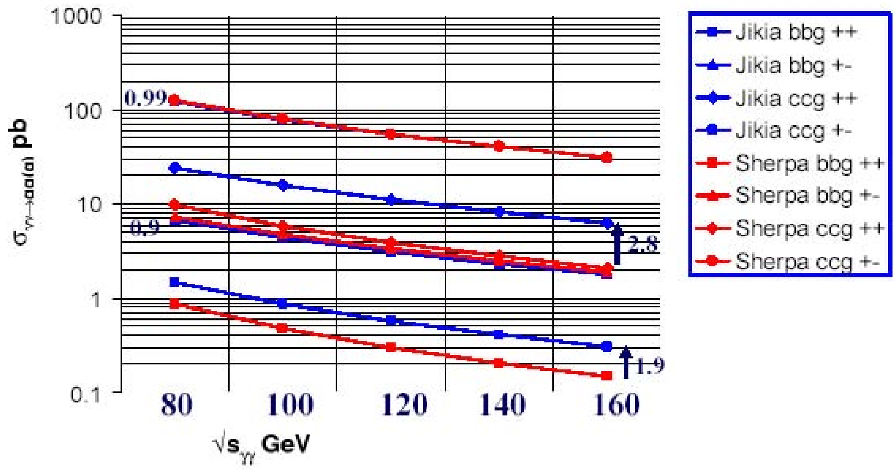

Figure 2: Cross section comparison for the $\gamma\gamma \to \mathrm{b\bar{b}(g)}$ and $\gamma\gamma \to \mathrm{c\bar{c}(g)}$ processes as gives by SHERPA and the correct NLO values.

Table I: Cross sections and the number of expected and generated events for the signal and background processes

	Number of selected events
Signal process	
$\gamma\gamma \to \mathrm{h} \to \mathrm{b\bar{b}}$	6044
Background	
$\gamma\gamma \to \mathrm{b\bar{b}(g)}$	1755.0
$J = 0$	
$\gamma\gamma \to \mathrm{b\bar{b}(g)}$	1865.0
$J = 2$	
$\gamma\gamma \to \mathrm{c\bar{c}(g)}$	298.6
$J = 0$	
$\gamma\gamma \to \mathrm{c\bar{c}(g)}$	641.0
$J = 2$	

3. EVENT SELECTION

The analysis aims to select events with two or three jets from the Higgs boson decay. Two of these jets contain bottom quarks. The invariant mass of the jets has to be consistent with the Higgs mass.

High multiplicity (FEO) events are selected and their visible energy is required to be greater than 95 GeV. Events with longitudinal imbalance greater than 10% of the visible energy are rejected. Finally the cosine of the thrust angle has to be less than 0.7.

In the remaining event sample jets are reconstructed using the DURHAM clustering scheme [12] with the resolution parameter $\mathrm{y_{cut}}$=0.02.

The cross section for the continuum production of the charm quark is 16 times larger than for bottom quarks, therefore b-quark tagging is crucial for this analysis. The b-tagging algorithm combines several discriminating variables, as for example, the impact parameter joint probability tag introduced by ALEPH [13], the p_t corrected vertex invariant mass obtained with the ZVTOP algorithm written for the SLD experiment [14] and a one-prong charm tag, into a feed forward neural network with 12 inputs and 3 output nodes, described in Ref. [15].

The distribution of the neural network output NN_{out} to discriminate b-quark jets from u-, d-, s- and c-quark jets

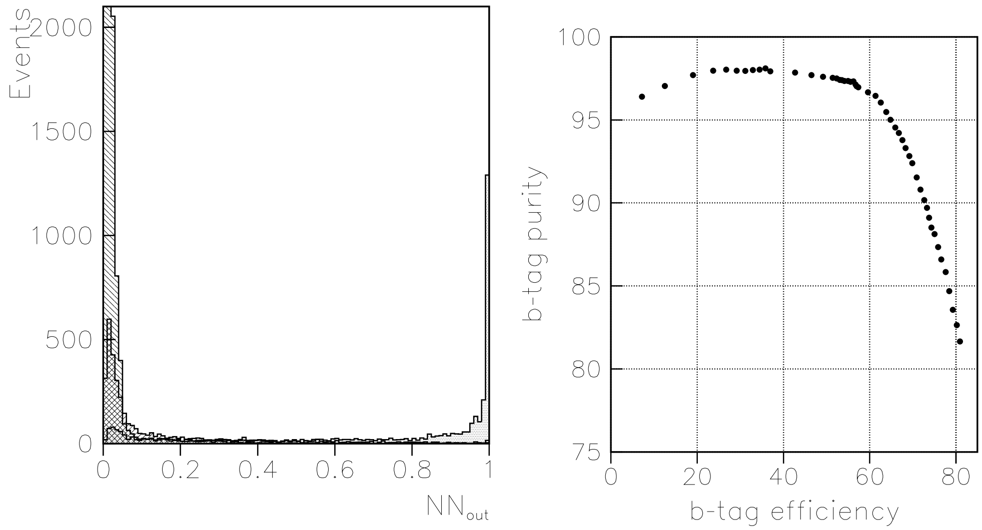

Figure 3: a) Distribution of the neural network output and b) efficiency versus purity curve for the neural network based b-tag in Z^0 decays.

is presented in Figure 3a. The performance of the neural network b-tag in Z^0 decays is shown in Figure 3b. The b-tagging efficiency is 70% and corresponds to a purity of 98%.

The b-quarks coming from the decay of the Higgs boson are highly energetic, whereas in the case of the background processes the gluon and one b-quark jet are the most energetic. In order to reduce the background further we look at the two fastest jets in the event and require the $NN_{\rm out}$ to be greater than 0.95 for one jet and greater than 0.2 for the second one.

The expected number of signal and background events are summarized in Table I. A total signal efficiency is estimated to be 36%.

The hadronic cross section for $\gamma\gamma \rightarrow$hadrons events, within the energy range above 2 GeV, is about 400 nb, so that about 1 such event is produced per bunch crossing (pileup). These events obscure the interesting physics processes described in the previous sections. For this reason this class of events needs to be included in the PYTHIA simulation for overlap in the next step of this analysis. The HADES [16] program will be used for this purpose. A large fraction of this background is distributed at small angles and we believe that it can be reduced cutting on the polar angle of the tracks [17]. A careful study of this hadronic background is currently being performed.

4. RESULTS

The reconstructed invariant mass for the selected signal and background events is shown in Figure 4. To enhance the signal a cut on the invariant mass is tuned such that the statistical significance of the signal over background is maximized. Events in the mass region of 114 GeV $< M_{jj} <$ 126 GeV are selected. The number of estimated signal and background events in this window are 4505 and 1698, respectively.

The two photon decay width of the Higgs boson is proportional to the event rates of the Higgs signal. The statistical error of the number of signal events, $\sqrt{N}_{\rm obs}/(N_{\rm obs} - N_{\rm bkg})$, corresponds to the statistical error of this measurement. Here $N_{\rm obs}$ is the number of observed events, while $N_{\rm bkg}$ is the number of expected background events.

We obtain

$$\frac{\Delta[\Gamma(\mathrm{h} \rightarrow \gamma\gamma) \times \mathrm{BR}(\mathrm{h} \rightarrow \mathrm{b\bar{b}})]}{[\Gamma(\mathrm{h} \rightarrow \gamma\gamma) \times \mathrm{BR}(\mathrm{h} \rightarrow \mathrm{b\bar{b}})]} = \sqrt{N}_{\rm obs}/(N_{\rm obs} - N_{\rm bkg}) = 1.7\%.$$

We conclude that for a Higgs boson with a mass $M_{\rm H}$=120 GeV we can measure the product $\Gamma(\mathrm{H} \rightarrow \gamma\gamma) \times \mathrm{BR}(\mathrm{H} \rightarrow$

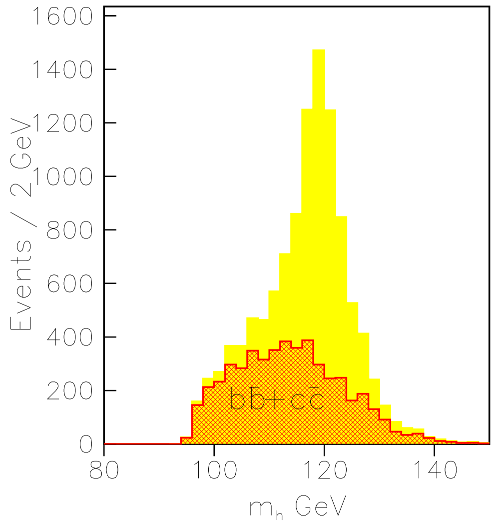

Figure 4: Distribution of the reconstructed invariant mass for the signal and background events.

$b\bar{b}$) with an accuracy of 1.7% using an integrated luminosity corresponding to one year of data taking at the TESLA Photon Collider.

References

[1] D.L. Borden, D.A. Bauer and D.O. Caldwell, Phys. Rev. D48 (1993) 4018.

[2] LEP Electroweak Working Group website: http://www.cern.ch/LEPEWWG.

[3] T. Ohgaki, T. Takahashi and I. Watanabe, hep-ph/9703301; G. Jikia and S. Söldner-Rembold, Nucl. Inst. and Meth A472 (2001) 133; P. Niezurawski, A.F. Zarnecki and M. Krawczyk, Acta Physica Polonica B34 (2003) 177. P. Niezurawski, A.F. Zarnecki and M. Krawczyk, hep-ph/0307183.

[4] B. Badelek *et al., TESLA Technical Design Report Part VI, Chapter I: The Photon Collider at TESLA*, DESY-01-011.

[5] A.F. Zarnecki, Acta Phys. Polon. **B34** (2003) 2741-2758.

[6] M.Pohl and H.J. Schreiber, SIMDET-version4, A parametric Monte Carlo for a TESLA Detector, DESY 02-061, May 2002.

[7] K. Mönig, A Photon Collider at TESLA, LC-DET-2004-014.

[8] T. Sjöstrand, CERN-TH/7112/93 (1993), revised August 1995; T. Sjöstrand, Comp. Phys. Comm. 82 (1994) 74.

[9] T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. Winter, JHEP 0402 (2204) 056 (hep-ph/0311263).

[10] G. Jikia and A. Tkabladze, Phys. Rev. D54 (1996) 2030.

[11] M. Melles and W.J. Stirling, Phys. Rev. D59 (1999) 94009; M. Melles and W.J. Stirling, Eur. Phys. J. C9 (1999) 101.

[12] S. Bethke *et al.*, Nucl. Phys. B370 (1992) 310.

[13] D. Buskulic *et al.* [ALEPH Collaboration], Phys. Lett. B313 (1993) 535.

[14] D.J. Jackson, Nucl. Instr. Meth. A388 (1997) 247.

[15] R. Hawkings, LC-PHSM-2000-021.

[16] D. Schulte, http://clicphysics.web.cern.ch/CLICphysics/.

[17] A. Rosca, talk presented at the 3rd ECFA/DESY Workshop on Physics and Detectors for a 90-800 GeV Linear Collider, Prague, Czech Republic, November 2002.