

# Detector optimisation for future linear collider

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# Abstract

This is my abstract. To be or not to be.



## Declaration

This dissertation is the result of my own work, except where explicit reference is made to the work of others, and has not been submitted for another qualification to this or any other university. This dissertation does not exceed the word limit for the respective Degree Committee.

Boruo Xu



## Acknowledgements

Of the many people who deserve thanks, some are particularly prominent, such as my supervisor. . .





# Preface

This will be my preface. Where is Wolly?



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*“Two bags of pork scratchings are worth  
a bag of gold.”*

— Joris the Dutch



# Chapter 1

## Double Higgs Bosons Analysis

### 1.1 Motivation

Ha there is a higgs.

We found higgs. Higgs is cool. It explains mass.

Why double higgs. Double higgs coupling is unique to linear collider. It can reveal much about the BSM models.

Generator level study has performed. ILC has done this this and that.  $g_{HHH}$  in CLIC before

Here we do things differently. First subchannels, then extract both couplings simultaneously.

### 1.2 Theory

general higgs field

Lagrangian

current constraint

single higgs coupling measurement done in higgs

Double higgs measurement

The main mechanism for double Higgs production

### 1.3 Analysis Straggly Overview

Proof-of-principle study was performed at CLIC for  $\sqrt{s} = 1.4 \text{ TeV}$  and  $3 \text{ TeV}$ . Simulated samples, including those containing double higgs production were used. Signal events, events with double higgs production, were selected via a set of carefully designed and complicated methods.  $g_{HHH}$  and  $g_{WWHH}$  are extracted simultaneously with template fitting with modified couplings samples.

### 1.4 Monte Carlo Sample Generation

Single channel is defined as  $e^-e^+ \rightarrow HH\nu\bar{\nu}$ . It is divided into sub-channel  $HH \rightarrow b\bar{b}W^+W^-$  and  $HH \rightarrow b\bar{b}b\bar{b}$  to allow closer examination and an improvement of signal selection when combined. In particular, I studied  $HH \rightarrow b\bar{b}W^+W^-$  sub-channel.

Selected background samples, including processes initiated by photons, are considered in the analysis and listed in Table ???. These background were expected share similar topologies with the signal process. When describing a multi-quark final state, it is referring to all final states of the same number of quarks, including final states with possible additional neutrinos and or leptons. A multi-quark final state does not include higgs production, unless explicitly stated.

The usual two-quark and four-quark final states were considered. Since the significant presence of beamstrahlung, where photon produced due to the high electric field generated by the colliding beams, processes initiated by photons are also included.

Processes involving real photons from beamstrahlung (BS) and “quasi-real” photons are generated separately. For the “quasi-real” photon initiated processes, the Equivalent Photon Approximation (EPA) has been used.

Photon-electron/photon-photon interactions with four-quark final states were considered. Photon-electron interaction with two-quark final state, one Higgs, and one neutrino is considered. Photon-electron interaction with two-quark final state, one Higgs, and one lepton is not considered due to its negligible cross section.

Single higgs productions are not considered because topologies are very different to the single process. Six-quark final states were not considered due to computational limitation.



For processes involving Higgs production explicitly, simulated Higgs mass is 126 GeV. As multi-quark final state background samples could, in principle, contain double higgs production, they are generated with a Higgs mass of 14 TeV. This will produce negligible double higgs production cross section.

All samples are generated with WHIZARD 1.95 [1], taking into account the expected CLIC luminosity spectrum. PYTHIA 6.4 [2] tuned on LEP data [3] is used to describe fragmentation, hadronisation processes, and Higgs decays. TAUOLA [4] is used for  $\tau$  lepton decays.

### Simulation

For most background processes, events are simulated when invariant mass of quarks are above 50 GeV. For electron-photon interaction with four quarks and a neutrino final state, events are simulated when invariant mass of quarks are above 120 GeV. These limits are necessary to generate a large amount of background samples in a feasible time, without losing much signal samples.

Finally, the main beam induced background  $\gamma\gamma \rightarrow \text{hadrons}$  is simulated and overlayed [5] to all samples according to the integration time of each subdetector.

## 1.5 Physics object and event reconstruction

Simulation is performed by MOKKA, interfacing GEANT 4. The reconstruction is done via Marlin in iLCSoft. Separate software package (processor) exists for identification of electrons, muons, taus, and jet reconstruction. New processors have been developed and existing processors have been optimised for a compromise of signal selection and background rejection.

### 1.5.1 Electron and Muon identification

For my signal channel,  $HH \rightarrow b\bar{b}W^+W^-$ , there is no electron nor muon in the final state. Hence a effective light lepton identifier would improve the signal identification.

In Marlin package, IsolatedLeptonFinderProcessor has been used and optimised. The particle is identified as an isolated light lepton if it passes a chain of cuts.

Channel	$\sigma(\sqrt{s} = 3 \text{ TeV}) / \text{fb}$	$\sigma(\sqrt{s} = 1.4 \text{ TeV}) / \text{fb}$
$e^-e^+ \rightarrow HH\nu\bar{\nu}$	0.588	0.149
$e^-e^+ \rightarrow q_l q_l H\nu\bar{\nu}$	1.78	0.86
$e^-e^+ \rightarrow c\bar{c}H\nu\bar{\nu}$	1.12	0.36
$e^-e^+ \rightarrow b\bar{b}H\nu\bar{\nu}$	1.91	0.31
$e^-e^+ \rightarrow qq\bar{q}q$	546.5	1245.1
$e^-e^+ \rightarrow qq\bar{q}q\ell\bar{\ell}$	169.3	62.1
$e^-e^+ \rightarrow qq\bar{q}q\ell\nu$	106.6	110.4
$e^-e^+ \rightarrow qq\bar{q}q\nu\bar{\nu}$	71.5	23.2
$e^-e^+ \rightarrow qq$	2948.9	4009.5
$e^-e^+ \rightarrow qq\ell\nu$	5561.1	4309.7
$e^-e^+ \rightarrow qq\ell\bar{\ell}$	3319.6	2725.8
$e^-e^+ \rightarrow qq\nu\nu$	1317.5	787.7
$e^-\gamma(\text{BS}) \rightarrow e^-qq\bar{q}q$	1268.7	1160.7
$e^+\gamma(\text{BS}) \rightarrow e^+qq\bar{q}q$	1267.6	1156.3
$e^-\gamma(\text{EPA}) \rightarrow e^-qq\bar{q}q$	287.9	287.1
$e^+\gamma(\text{EPA}) \rightarrow e^+qq\bar{q}q$	287.8	286.9
$e^-\gamma(\text{BS}) \rightarrow \nu qq\bar{q}q$	262.5	136.9
$e^+\gamma(\text{BS}) \rightarrow \bar{\nu} qq\bar{q}q$	262.3	136.4
$e^-\gamma(\text{EPA}) \rightarrow \nu qq\bar{q}q$	54.2	32.6
$e^+\gamma(\text{EPA}) \rightarrow \bar{\nu} qq\bar{q}q$	54.2	32.6
$e^-\gamma(\text{BS}) \rightarrow qqH\nu\bar{\nu}$	58.6	15.8
$e^+\gamma(\text{BS}) \rightarrow qqH\nu\bar{\nu}$	58.5	15.7
$e^-\gamma(\text{EPA}) \rightarrow qqH\nu\bar{\nu}$	11.7	3.39
$e^+\gamma(\text{EPA}) \rightarrow qqH\nu\bar{\nu}$	11.7	3.39
$\gamma(\text{BS})\gamma(\text{BS}) \rightarrow qq\bar{q}q$	13050.3	21406.2
$\gamma(\text{BS})\gamma(\text{EPA}) \rightarrow qq\bar{q}q$	2420.6	4018.7
$\gamma(\text{EPA})\gamma(\text{BS}) \rightarrow qq\bar{q}q$	2423.1	4034.8
$\gamma(\text{EPA})\gamma(\text{EPA}) \rightarrow qq\bar{q}q$	402.7	753.0

**Table 1.1:** List of signal and background samples with the corresponding cross sections at  $\sqrt{s} = 3 \text{ TeV}$  and  $\sqrt{s} = 1.4 \text{ TeV}$ .  $q$  can u, d, s, b or t. Unless specified,  $q$ ,  $\ell$  and  $\nu$  represent particles and its corresponding anti-particles.  $\gamma$  (BS) represents a real photon from beamstrahlung (BS).  $\gamma$  (EPA) represents a “quasi-real” photon, simulated with the Equivalent Photon Approximation. For processes involving Higgs production explicitly, simulated Higgs mass is 126 GeV. Otherwise, Higgs mass is set to 14 TeV.

A charge track is considered if it has more than 15 GeV energy. An electron is identified if the energy in the ECal is over 90% of the total calorimetric energy. A muon is identified if the energy in the ECal is between 5% and 25% of the total calorimetric energy. Furthermore, only primary track is selected, which requires the Euclidean distance in the x-y plane, the distance in z direction, the Euclidean distance in the x-y-z three dimensional space of the track starting point to the impact point to be less than 0.02 mm, 0.03mm, and 0.04 mm, respectively. The isolation criteria states that

$$E_{\text{cone}}^2 \leq 5.7 \times E_l - 50 \quad (1.1)$$

where,  $E_{\text{cone}}$  is the total energy of PFOs within an opening angle of  $\cos^{-1}(0.995)$  of the light lepton, and  $E_l$  is the energy of the light lepton.

For the identification of electrons and muons the IsolatedLeptonFinderProcessor [1] has been used. The processor uses a combination of track energy, calorimeter energy, impact parameter, and isolation information to distinguish between light leptons and other objects. In order to improve the identification efficiency, the method has been integrated with the particle flow information from Pandora [2]. Particle ID from Pandora uses shower shape information which is complementary to the IsolatedLeptonFinderProcessor.

This results in a significant rejection of background events with forward electrons and positrons, at the price of a moderate loss of signal events, O(%).

For the identification of tau lepton decays, the TauFinder [3] has been used. The processor aims to identify high energetic, low multiplicity jets, including criteria on impact parameter and cone isolation. This method has been improved by searching for 1-prong and 3-prong decays specifically, which account for X% of the tau lepton decays.



# Colophon

This thesis was made in  $\text{\LaTeX} 2_{\epsilon}$  using the “hepthesis” class [\[1\]](#).



# Bibliography

- [1] A. Buckley, The hepthesis  $\LaTeX$  class.





## List of figures



# List of tables

1.1	List of signal and background samples with the corresponding cross sections at $\sqrt{s} = 3 \text{ TeV}$ and $\sqrt{s} = 1.4 \text{ TeV}$ . $q$ can u, d, s, b or t. Unless specified, $q$ , $\ell$ and $\nu$ represent particles and its corresponding anti-particles. $\gamma$ (BS) represents a real photon from beamstrahlung (BS). $\gamma$ (EPA) represents a “quasi-real” photon, simulated with the Equivalent Photon Approximation. For processes involving Higgs production explicitly, simulated Higgs mass is 126 GeV. Otherwise, Higgs mass is set to 14 TeV. . . . .	4
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