11th FCC (Future Circular Collider) Conference
FCC WEEK 2025
19-23 May, Vienna Hofburg

Single Higgs Boson Production via Vector-Boson Fusion at FCC-ee

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Abstract

The FCC-ee at √s = 365 GeV provides an ideal environment to study Higgs boson production with high precision. This study focuses on single Higgs production via vector-boson fusion (VBF) and associated production (ZH), followed by its $H \rightarrow WW \rightarrow 2\ l$ + MET* decay. Using MadGraph5, event generation was performed for $e^+e^- \rightarrow \nu_l \bar{\nu}_l H$ and $e^+e^- \rightarrow Z H$. Hadron-level events were hadronized with Pythia8 and final-state observables were analyzed via MadAnalysis5. Histograms for missing transverse energy (MET), invariant mass (m_{ll}), and transverse momentum (pT_l) were constructed. Background contributions from ZZ, WW, l^+l^-, and $\tau\tau$ were systematically studied, and optimized kinematic cuts were applied to enhance signal extraction.

To ensure robust signal extraction, background contributions from ZZ, WW, l^+l^- and $\tau\tau$ processes were carefully studied, and systematic uncertainties were minimized through optimized MET and kinematic cuts. The results indicate that FCC-ee provides a highly controlled environment to probe Higgs boson couplings with electroweak gauge bosons. This study contributes to the precise determination of the Higgs coupling constants g_{HWW} and g_{HZZ}, which play a critical role in testing the Standard Model (SM) predictions and exploring possible deviations that could hint at new physics.

Introduction

The precise measurement of the Higgs boson properties is central to testing the electroweak symmetry breaking mechanism of the Standard Model (SM). Lepton colliders, with their clean experimental environment and well-defined initial states, are ideal platforms for such precision studies [1].
The Future Circular Collider (FCC-ee) aims to provide e^+e^- collisions at several center-of-mass energies, including √s = 365 GeV, optimizing sensitivity to Higgs couplings [2]. At this energy, vector-boson fusion (VBF) and associated ZH production dominate single Higgs production. VBF, in particular, offers a unique window into the Higgs–gauge boson coupling, g_{HWW} through the process $e^+e^- \rightarrow \nu_l \bar{\nu}_l H$ [3].
Precise determinations of the Higgs couplings such as g_{HZZ} and g_{HWW} are essential not only for validating the SM but also for revealing deviations indicative of beyond the Standard Model (BSM) scenarios [4].

Methods

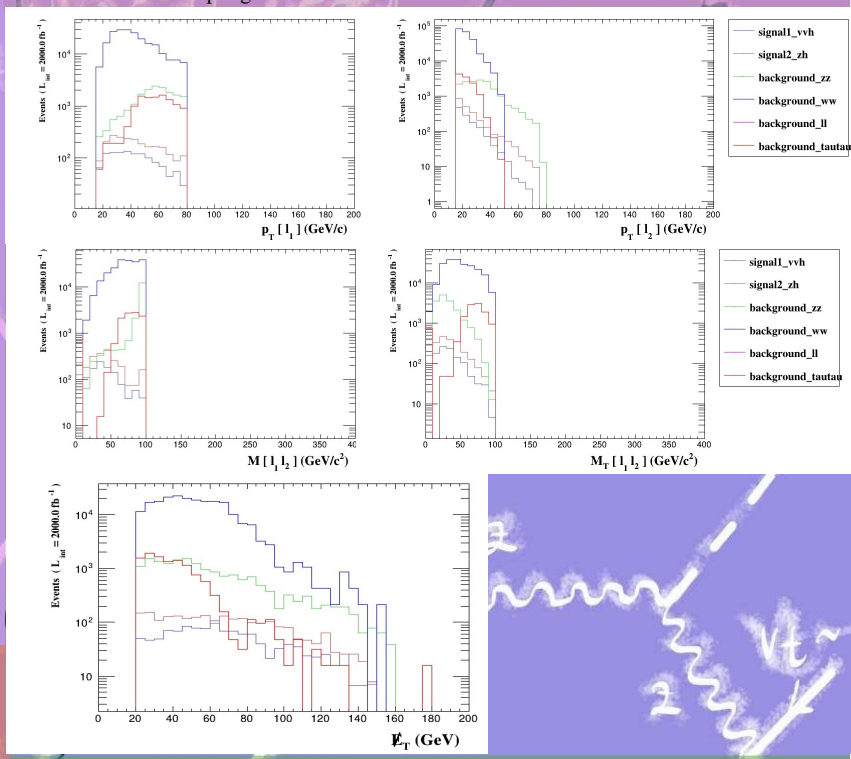
- **Event Generation**:
  Signal processes $e^+e^- \rightarrow \nu_l \bar{\nu}_l H$ and $e^+e^- \rightarrow ZH$ were simulated using **MadGraph5**, with **Pythia8** used for parton showering and hadronization.
- **Analysis Framework**:
  Final-state observables such as MET, m(ll), and pT(l) were analyzed using **MadAnalysis5** at the hadron level.
- **Backgrounds**:
  Main backgrounds included ZZ, WW, and dilepton (l^+l^-) final states. $\tau^+\tau^-$ contributions were also considered.
- **Cuts**:
  Optimized kinematic cuts on MET, invariant mass, and lepton transverse momentum were applied to enhance signal significance.

Cuts	Signal (S)	Background (B)	S / √B
Initial (no cut)	347800	6.0657524	1.41×10^{1}
Select: N(l) = 2.0	75831	5.86557058	3.13×10^{0}
Select: PT(l[1]) > 15 and PT(l[1]) < 80	22670	5.27564256	9.87×10^{-1}
Select: PT(l[2]) > 15 and PT(l[2]) < 80	5372.0	5.26687351	2.34×10^{-1}
MET > 20.0	3519.9	7.14403×10^{5}	4.16×10^{-1}
DELTAR(l[1], l[2]) < 3.5	3506.0	4.94522×10^{5}	4.99
M(l[1] l[2]) < 100.0	3461.8	2.45420×10^{5}	6.99

Results

The histograms of the leptons (leading lepton and trailing lepton), transverse momentum (P_T), transverse mass (M_T), invariant mass $M_{(ll)}$, missing transverse energy (MET) are shown in Figures.

- **Signal and Background Separation**:
  Histogram analysis showed effective separation between signal and background using MET and pT(l) distributions.
- **Optimized Cuts**:
  - ✓ Reject events with pT(l[1]) and pT(l[2]) < 15 GeV
  - ✓ Apply invariant mass window around m_Z for ZH process
  - ✓ MET > 20 GeV for VBF-enhanced topologies
- **Cross Section Estimations**:
  The total cross section after cuts was enhanced for signal relative to background, improving the statistical reach for coupling extraction.



Discussion

The clean experimental conditions of the FCC-ee enable precision measurements of rare Higgs processes, which are often limited by background systematics in hadron colliders.

Our results demonstrate that optimized event selection enhances the signal of VBF and ZH topologies. These observations are instrumental for determining the coupling strengths g_{HWW} and g_{HZZ} , which are sensitive to loop-induced or higher-dimensional operators in BSM scenarios such as SMEFT (Standard Model Effective Field Theory) [5]. Furthermore, this analysis strategy sets a template for future differential measurements of Higgs couplings at lepton colliders.

$$\frac{d\sigma}{d\cos\theta} \propto g_{HWW}^2 \left(1 + \cos^2\theta\right) \qquad \Gamma(H \rightarrow WW^*) \propto g_{HWW}^2 \frac{m_H^3}{m_W^2}$$

Finally, with the selection shown in Table, it is shown that in the 2 lepton+ MET final state, the signals measurable greater than 5σ significance at FCC-ee with 365 GeV.

References
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