

Total ZH hadronic cross-section at FCC-ee and combination with leptonic final states

Eysermans Jan ^{1*} and Selvaggi Michele ²

¹ Particle Physics Collaboration, Massachusetts Institute of Technology,
77 Massachusetts Ave, Boston, Cambridge, 02139, MA, USA .

² CERN, 1211 Route de Meyrin, Geneva, 1211, Switzerland .

*Corresponding author(s). E-mail(s): jan.eysermans@cern.ch;
Contributing authors: michele.selvaggi@cern.ch;

Abstract

Measuring the total ZH cross-section at FCC-ee using the hadronic final state of the associated Z boson is attractive due to its high branching ratio. However, maintaining model independence is challenging due to significant hadronic activity and potential overlap with hadronic Higgs decays. This note presents an analysis of the $Z(qq)H$ cross-section at both center-of-mass energies of 240 and 365 GeV, which is then combined with results from leptonic final states to extract the total ZH cross-section at these center-of-mass energies. The model independence of the measurement is assessed through bias tests, considering both Standard Model Higgs decays and potential beyond-Standard-Model Higgs decays into invisible final states.



Total ZH cross-section at FCC-ee

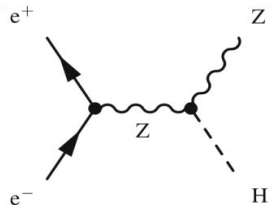
Jan Eysermans



Motivation

Measure HZZ coupling strength g_{ZZ^*} in a model-independent way $\sim 0.15\%$

- Unique to e^+e^- colliders because of known initial state, not possible at hadron colliders
- Once known, determines the couplings to $H \rightarrow XX$ in a model independent way
- Analysis is challenging to ensure model-independence



$$\sigma_{ZH} \times \mathcal{B}(H \rightarrow X\bar{X}) \propto \frac{g_{HZZ}^2 \times g_{HXX}^2}{\Gamma_H} \quad \sigma_{H\nu_e\bar{\nu}_e} \times \mathcal{B}(H \rightarrow X\bar{X}) \propto \frac{g_{HWW}^2 \times g_{HXX}^2}{\Gamma_H}$$

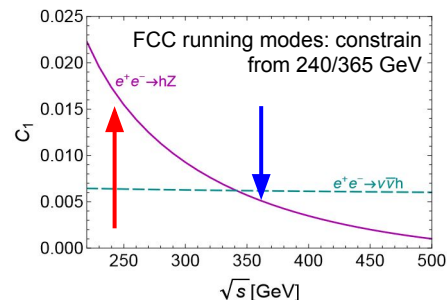
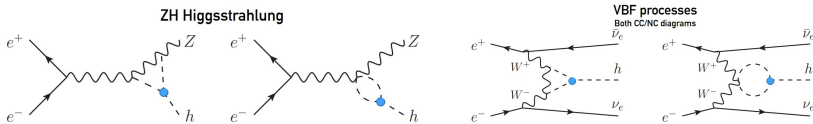
Allows to constrain Higgs total width $\sim 0.75\%$

- by measuring $H \rightarrow ZZ^*$ at 240 GeV
- Also accessible via $H \rightarrow b\bar{b}$ at 240+365 GeV

$$\Gamma_H \propto \frac{\sigma(e^+e^- \rightarrow ZH, H \rightarrow ZZ)^2}{\sigma(e^+e^- \rightarrow ZH)}$$

Allows to probe Higgs self coupling $\kappa_\lambda \sim 28\%$

- Through NLO deviations in ZH cross section: $\Sigma_{\text{NLO}} = Z_H \Sigma_{\text{LO}} (1 + \kappa_\lambda C_1)$
- C_1 sensitive to $\sqrt{s}$: exploit different sensitivities both 240 (dominant) and 365 GeV





General note on signal extraction

ZH analysis is a cross-section measurement

- Counting ZH events over background events at $\sqrt{s} = 240$ and 365 GeV
- ZH events contain contributions from all Z decays: $Z(\mu\mu)H$, $Z(ee)H$, $Z(qq)H$ and $Z(\nu\nu)H$

Three analyses are considered to measure the total ZH cross-section

- Leptonic: $Z(\mu\mu)H$, $Z(ee)H$ and hadronic $Z(qq)H$
- $Z(\nu\nu)H$ is not considered (e.g. cannot measure $H \rightarrow \text{inv}$)
- Analysis optimization is done for the target signal process only

Final extraction is a binned maximum likelihood fit, with a single POI that is the total ZH strength

- The ZH strength should contain all the known Higgs decay modes (SM-like)
- So to say: the total signal is the sum of all $Z(\mu\mu)H$, $Z(ee)H$, $Z(qq)H$ and $Z(\nu\nu)H$ processes ($H \rightarrow \text{any}$)
- POI contains all ZH signals, including $\nu\nu H$, as we should consider all events



Higgs decay-mode independence

How to assess the model-independence of the result?

- Cannot be 100% independent, even for SM Higgs decays, due to detector effects and analysis strategy (selection)
 - This is especially true for the $Z(qq)H$ analysis (see later)
- We can only test it against the known (SM) Higgs decays and unknown invisible decays
- It is always possible to find a BSM Higgs decay that could break the model-independence
 - But we can assume such cases are ruled out by prior experiments (LHC)
 - In case large deviations are observed in the ZH counting, it must be interpreted as BSM Higgs decays and the nature of this decay will have to be studied prior to the ZH analysis

The analyses should be designed to be as much as possible independent of the Higgs decay mode

- Minimize the dependency of the (known) Higgs decay modes in the selection
- Fit strategy and variables should be as much as possible independent of the Higgs decay mode
- In case larger differences occur in the selection efficiency and/or fit procedure, assess the degree of model-dependence by performing bias tests
 - The degree of model-independence should be within the quoted uncertainty on the ZH cross-section



Higgs decay-mode bias tests

Follow ILC bias test approach (see <https://arxiv.org/abs/1509.02853>)

- Assume total ZH cross-section not known within $\sim 5\%$
 - SM or non-SM Higgs decays can induce 5% differences
- Make bias test by assuming each individual Higgs decay can account for 5% change in total ZH cross-section
 - This is, scale independently each BR so that $\delta ZH = 5\%$, or $\delta BR = 5\%/BR$ and construct pseudo-data
 - This also means $\delta BR \gg 5\%$ (true for non-bb Higgs decays); e.g. $\delta ZH = 5\%$ means $\delta BR(gg) = 61\%$
 - Rare decays contribute little to the total ZH cross-section $\rightarrow$ conservative bias test
- Pseudo-data created from perturbed decay mode, keeping the other decay modes unperturbed
 - All production modes are perturbed: $\mu\mu H$, eeH , qqH , $\nu\nu H$
- Perform nominal fit to pseudo data and extract bias = $100 * (\mu^{\text{fit}} - 1.05)$
 - Bias must be smaller than quoted uncertainty
- More stringent when freezing backgrounds in the fit
 - Removes signal-background correlation and assumption on background
 - Pure signal shape comparison



$Z(qq)H$

Leptonic final state $Z(l\bar{l})H$ (reference: <https://doi.org/10.17181/jfb44-s0d81>)

- Selected lepton pair originates from associated Z with high efficiency
- Tight selection to suppress backgrounds

Hadronic final state $Z(qq)H$

- Challenging to cluster the PF candidates to match with associated Z only
 - Multi-jet final states depending on Higgs decay ($n=2$, $n=4$)
 - Non-negligible overlap of PF candidates when doing jet clustering, depending on Higgs final state
- Poor hadronic resolution compared to lepton $\rightarrow$ loose cuts to retain signal efficiency

Nevertheless hadronic channel profits of large BR: 70% vs $2 \times 3.5 \sim 7\%$ for leptonic

But explicit decay mode dependence hard to achieve

- Cannot perform selection fully independent of Higgs decay mode $\rightarrow$ but minimize the dependency
- Assess degree of decay-mode dependency based on bias tests
- Use knowledge from leptonic channel where the total cross-section will be measured without bias with precision of 0.52%



Analysis strategy

1. Find the best 2 jets that matches the associated Z in ZH

- Try different clusterings per event: inclusive, exclusive N=2/4/6
- Form all jet pair combinations (per clustering algorithm)
 - Require at least 5 GeV momentum for the jets
- Select pair that is closest to match kinematics of the ZH system:
 - Minimize $\chi^2 = (m_{jj} - m_Z)^2 + (m_{\text{recoil}} - m_H)^2$
 - Pair can come from different clustering algorithms

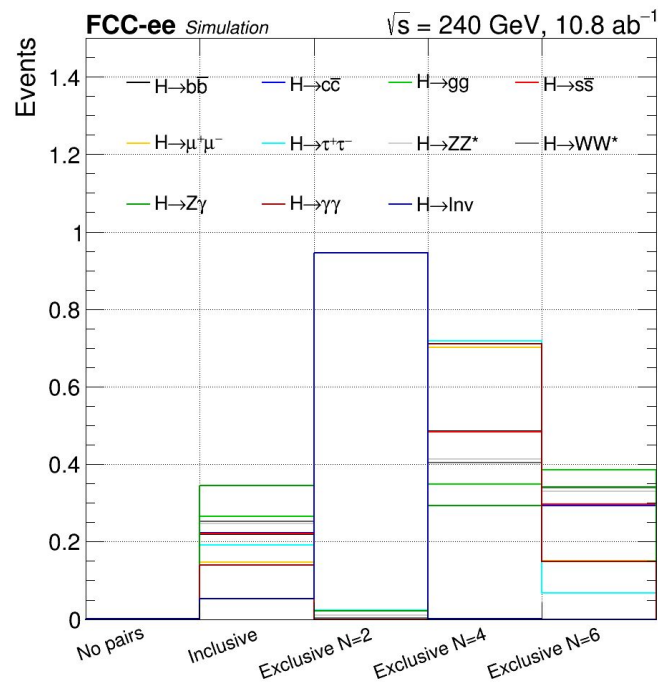
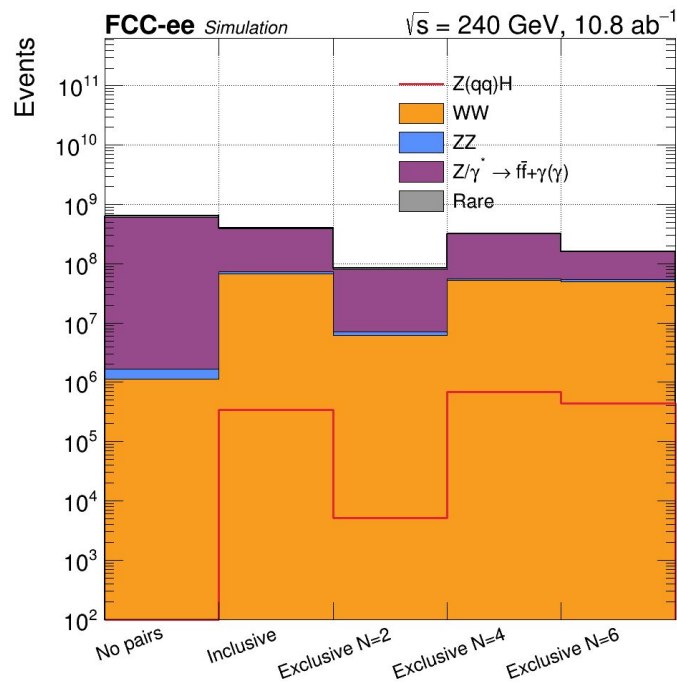
2. Apply loose event selection based only on selected pair of jets

- Veto events from leptonic channel (orthogonal)
- Basic loose kinematic cuts: invariant mass, momentum, angles
- Suppress WW background by clustering events with exclusive N=4 and remove candidates compatible with WW pairs
- Boosted decision tree to further separate main backgrounds WW and Z/ γ

3. Fit on 2D recoil-mjj plane in 2 bins of MVA discriminator

- Take into account correlation between mjj and mrec [imposed by chi2]
- Many events due to loose event selection allows for multi-dimensional fit

Results of jet clustering



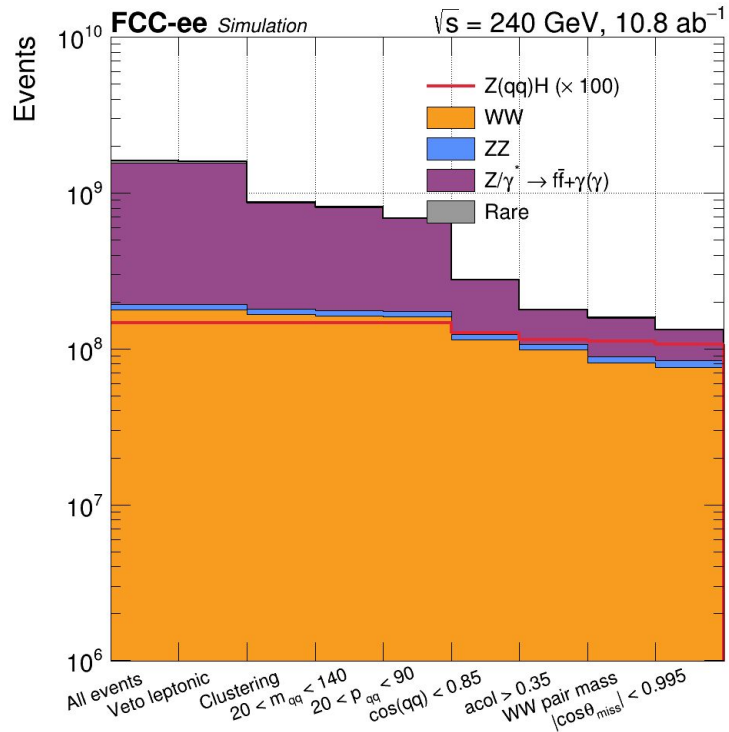
- Chosen jet algorithm after jet pairing optimization
- Follows roughly expected patterns for Higgs decays and backgrounds



Event selection

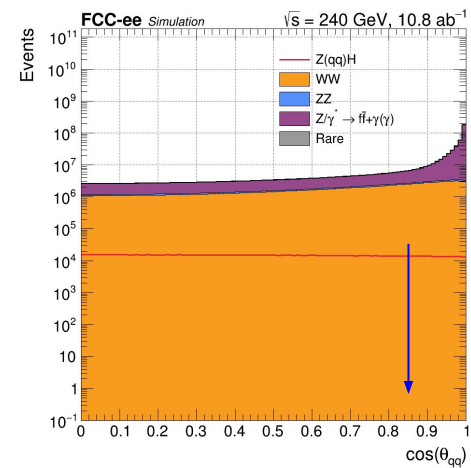
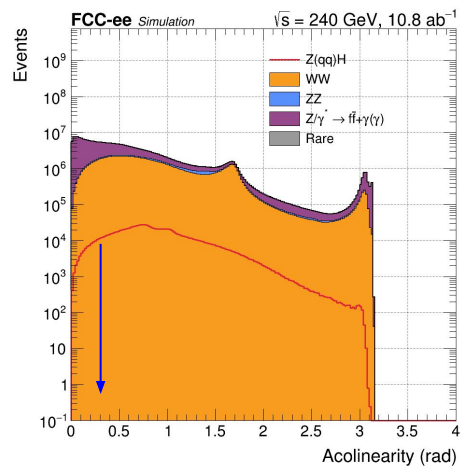
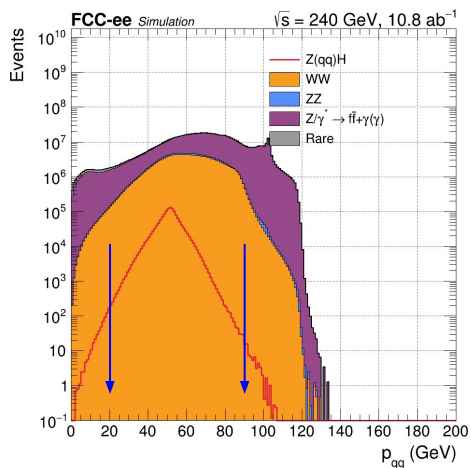
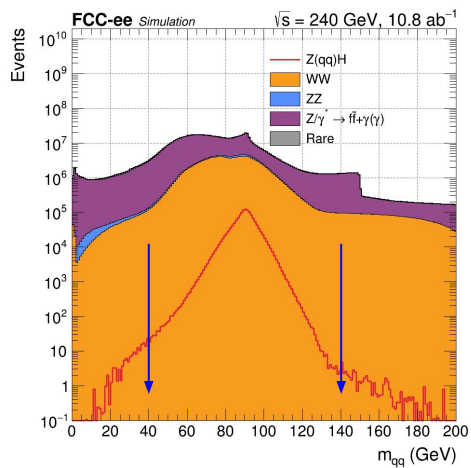
Event selection based on kinematics of selected jet pair

1. Veto the leptonic event selection
2. Apply event clustering
 - Reject events if clustering fails
 - Pick the best jet pair that matches the associated Z
3. Invariant mass: $20 < m_{qq} < 140$
4. Momentum: $20 < p_{qq} < 90$
5. $\cos(\theta_{qq}) < 0.85$
6. Acolinearity > 0.35
7. Acoplanarity – no cut
8. W pair mass cut (see next slide)
9. $\cos(\theta_{\text{miss}}) < 0.995$





Kinematic plots





Rejection of WW background

For each event, use the 4-jet exclusive clustering and form 2 pairs of W bosons

$$\chi^2 = (m_{qq} - 80.4)^2 + (m_{qq} - 80.4)^2$$

- Apply tight 2-D cut in the 2-mass plane: $\Delta(m_W) < 6$ GeV
- W boson masses and momenta used as variables in the BDT

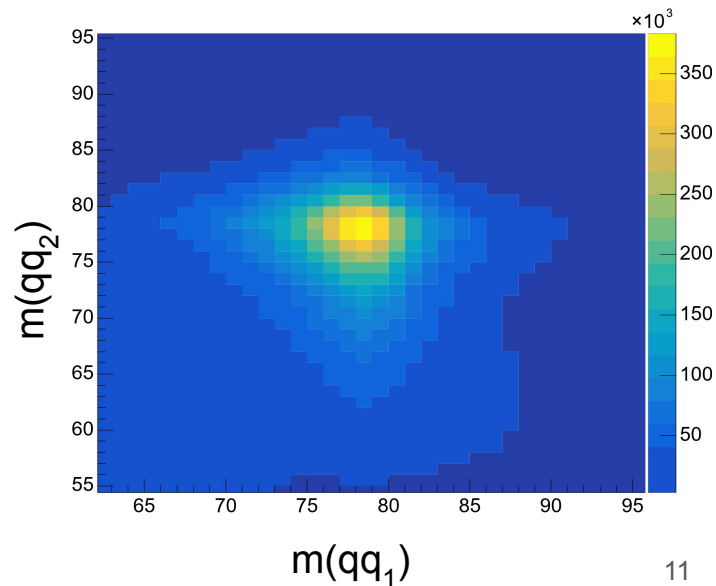
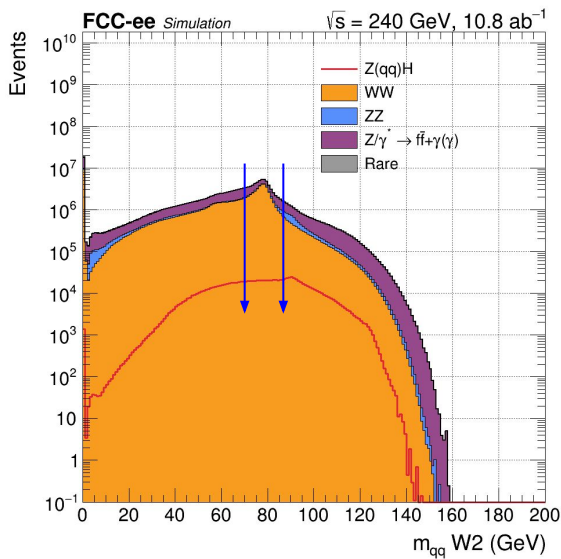
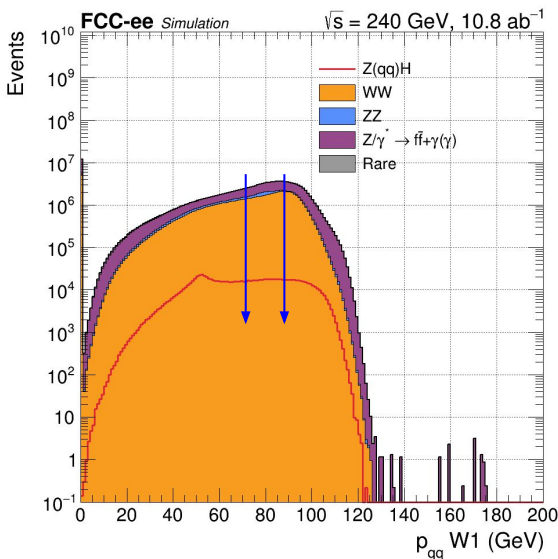


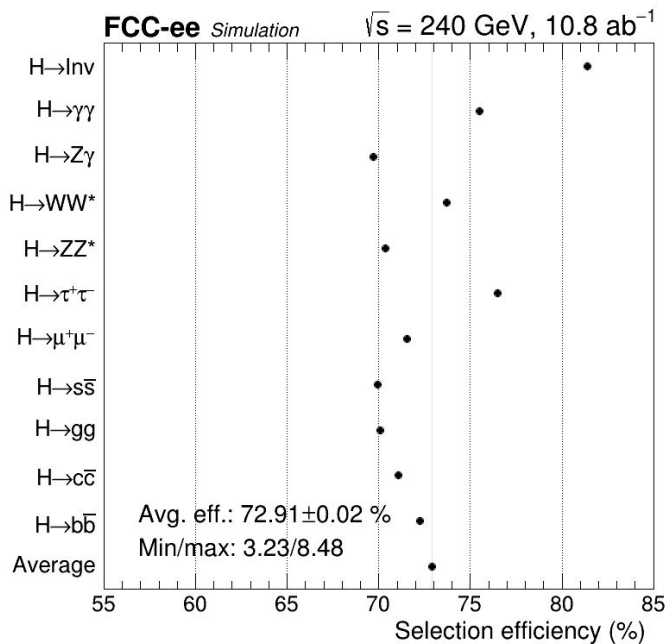
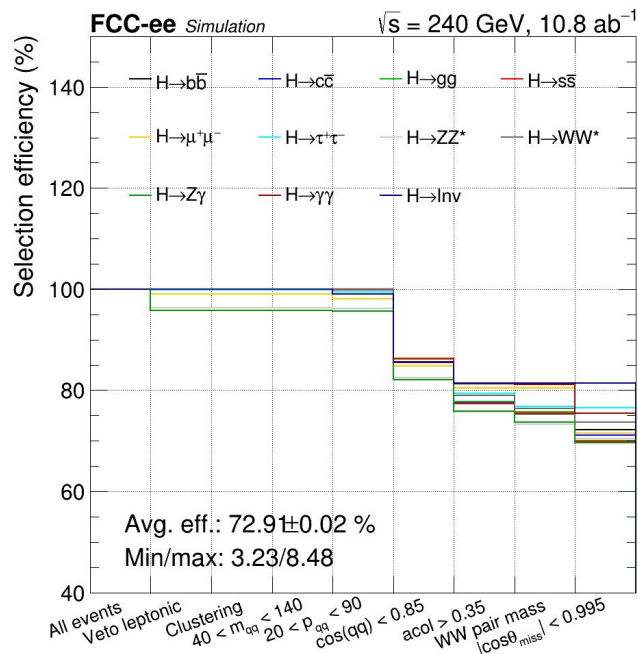


Table of yields

Cut	Significance	ZqqH	WW	ZZ	Zgamma	Rare
Cut 0	36.752	1.4727e+06	1.7734e+08	1.4677e+07	1.3717e+09	3.8944e+07
Cut 1	36.754	1.4711e+06	1.7715e+08	1.4448e+07	1.3691e+09	3.8529e+07
Cut 2	49.766	1.4711e+06	1.6606e+08	1.3485e+07	6.8342e+08	7.9237e+06
Cut 3	51.565	1.4711e+06	1.6315e+08	1.3211e+07	6.2745e+08	7.1277e+06
Cut 4	56.004	1.4700e+06	1.6013e+08	1.2972e+07	5.1002e+08	2.9071e+06
Cut 5	75.540	1.2653e+06	1.1406e+08	9.6222e+06	1.5373e+08	6.0678e+05
Cut 6	85.550	1.1476e+06	9.8418e+07	8.5578e+06	7.0173e+07	5.0876e+05
Cut 7	87.940	1.1141e+06	8.1132e+07	8.3697e+06	6.8264e+07	5.0876e+05
Cut 8	91.903	1.0689e+06	7.5988e+07	7.7336e+06	4.9074e+07	3.3470e+05



Selection efficiency



- Final selection efficiency spread $\sim 10\%$ among Higgs decays
- Largest bias for $H \rightarrow \text{invisible}$



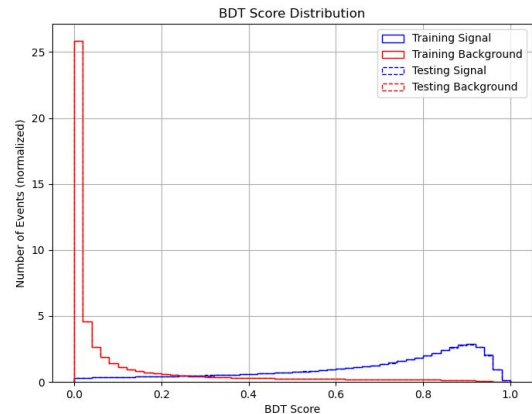
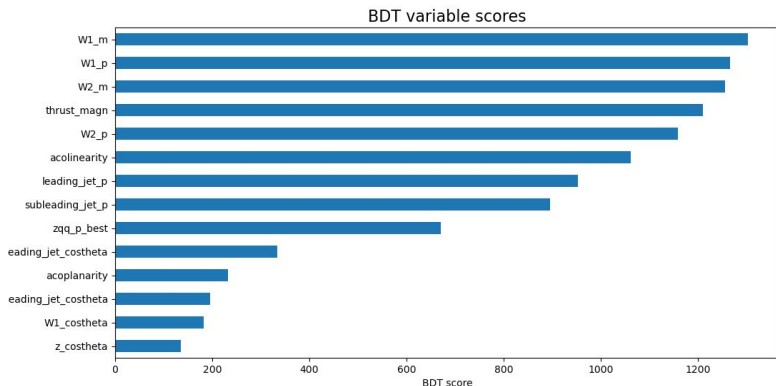
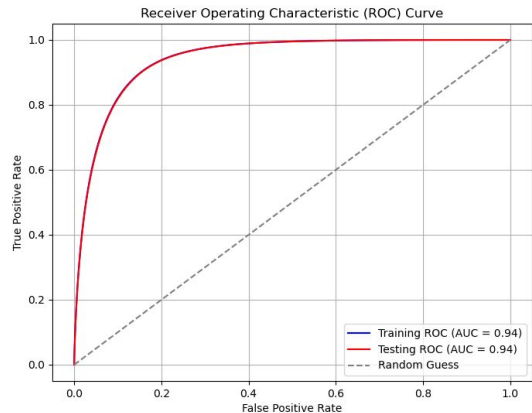
Boosted Decision Tree

Train BDT to further discriminate signal and $WW\text{--}Z/\gamma$ background

Input variables:

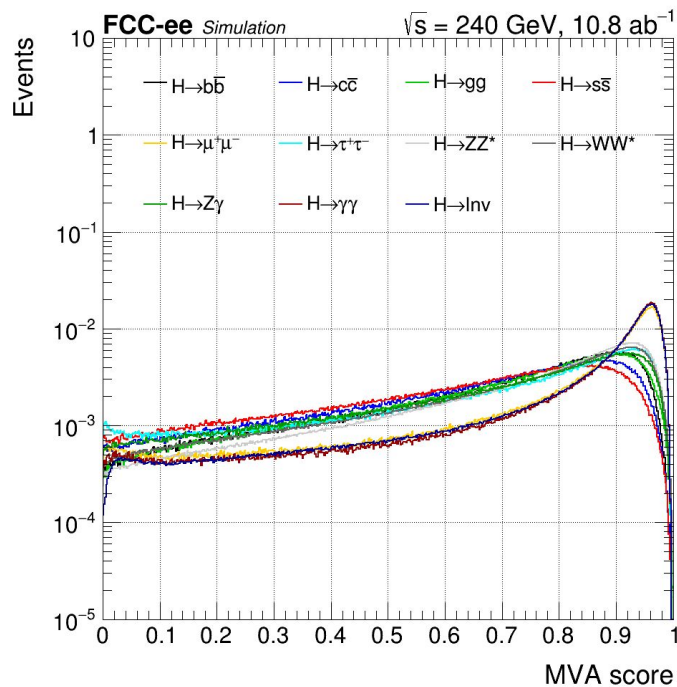
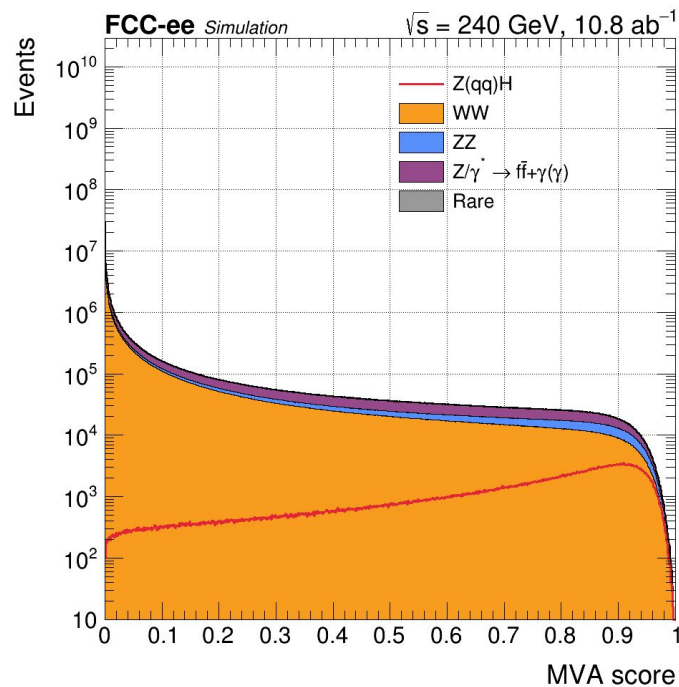
- Momenta and masses of 4-jet clustering forced to a pair of W bosons
- Thrust of the event
- Kinematics of the 2 selected jets:
 - Acolinearity, acoplanarity
 - Momenta, cosine of polar angle
 - Cosine polar angle of the dijet system (representing the Z)

Processes: all $Z(qq)H$ signals (equal cross-sections), WW , Z/γ



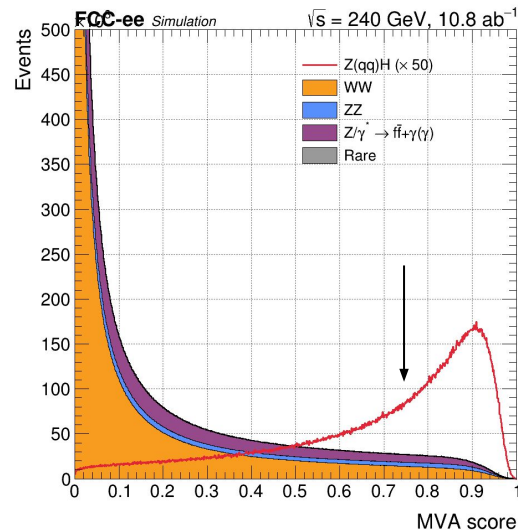
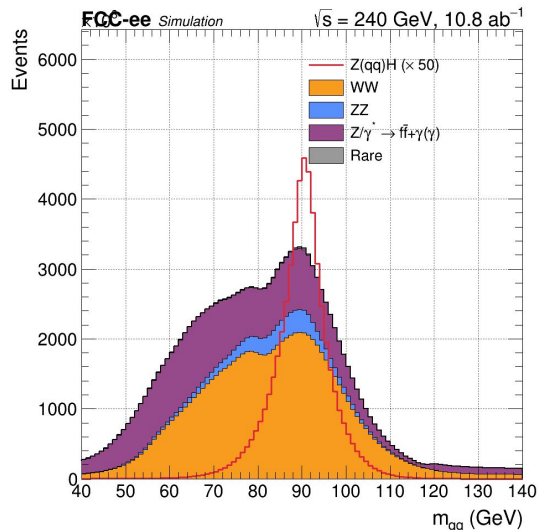
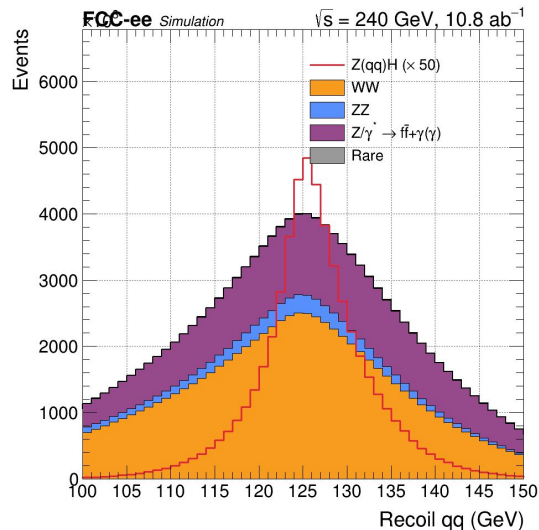


Boosted Decision Tree



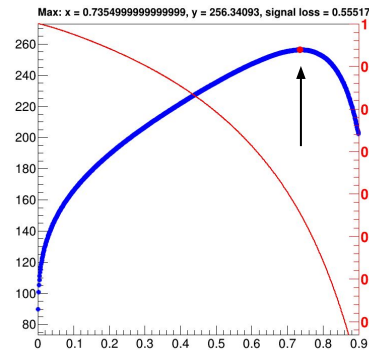
- BDT output discriminant
- Largest shape difference for Higgs $\rightarrow$ Invisible, $Z\gamma$, $\mu\mu$

Final distributions and fit



Perform 2D fit on recoil- m_{qq} plane in 2 bins of BDT discriminator

- $MVA > 0.75$: signal dominated, signal region
- $MVA < 0.75$: backgrounds dominated, control region
- 0.75 value chosen that maximizes the significance





Results

Binned likelihood performed on recoil- m_{qq} plane in 2 bins of MVA discriminant

Background processes WW, ZZ, Z/ γ , rare processes

- Normalization 1% for all background processes (uncorrelated)
- Constrained in situ by control region

Total uncertainty 0.38% for hadronic channel

Uncertainty on Z(H)H (%)	
Channel	Z(qq)H
Nominal fit (bkgs 1.01)	0.38
Backgrounds fixed	0.30
Nominal fit (bkgs 1.05)	0.40
Backgrounds free floating	0.40



Higgs decay-mode bias tests

Bias tests performed with 1% prior uncertainty on $\sigma(\text{ZH})$

- Use knowledge of leptonic channel that is unbiased well within $< 1\%$
- Largest bias on $\text{H} \rightarrow \text{inv}, Z\gamma, \mu\mu$ as expected, around 1σ of the quoted uncertainty (lower bias when backgrounds are frozen)

Overall biases within quoted uncertainty of 0.38 %

Bias on $\sigma(\text{ZH})$ (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.037	0.027
cc	-0.082	-0.085
gg	-0.041	-0.024
ss	-0.171	-0.168
$\mu\mu$	0.264	0.149
$\tau\tau$	-0.041	-0.072
ZZ	0.015	0.023
WW	-0.071	-0.039
$Z\gamma$	-0.168	-0.132
γ	0.428	0.285
inv	0.508	0.362

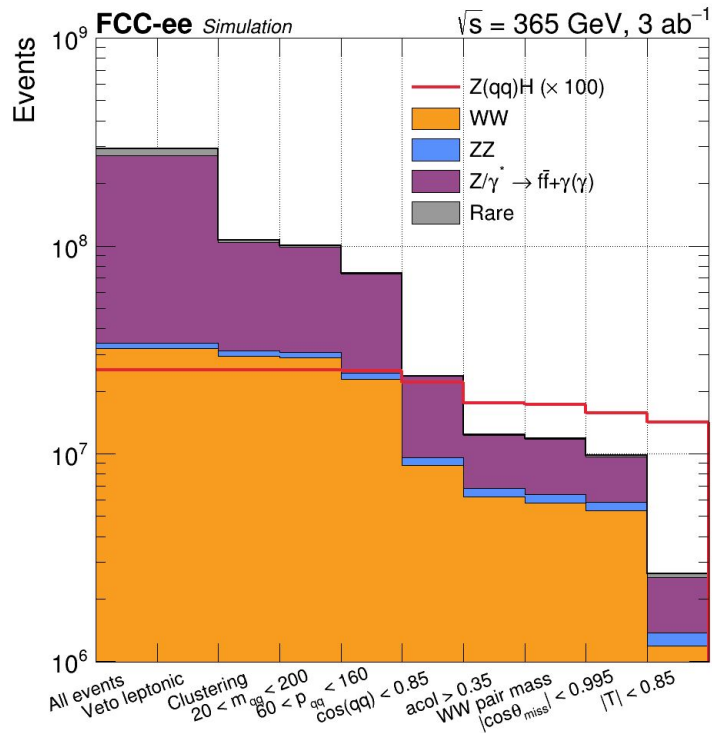


Event selection at $\sqrt{s} = 365$ GeV

Similar event selection as 240 GeV, cuts slightly change, added thrust variable to further remove boosted backgrounds

Event selection based on kinematics of selected jet pair

1. Veto the leptonic event selection
2. Apply event clustering
 - Reject events if clustering fails
 - Pick the best jet pair that matches the associated Z
3. Invariant mass: $20 < m_{qq} < 200$
4. Momentum: $60 < p_{qq} < 160$
5. $\cos(\theta_{qq}) < 0.85$
6. Acolinearity > 0.35
7. Acoplanarity – no cut
8. W pair mass cut
9. $\cos(\theta_{miss}) < 0.995$
10. Thrust magnitude < 0.85



In general, objects are more boosted and smeared w.r.t. 240 GeV
→ looser kinematic cuts

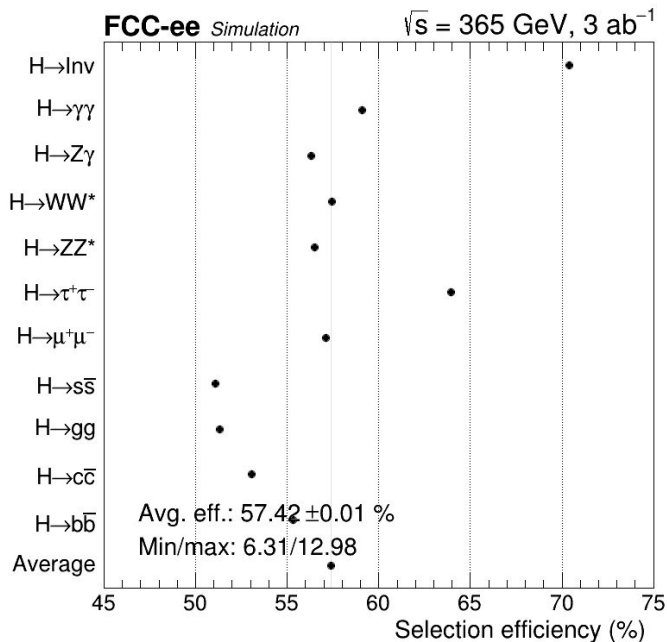
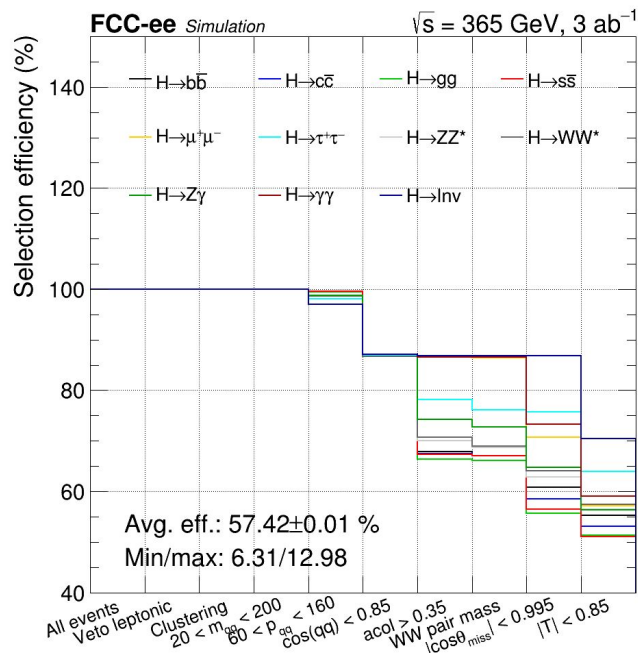


Table of yields at $\sqrt{s} = 365$ GeV

Cut	Significance	ZqqH	WW	ZZ	Zgamma	Rare
Cut 0	14.768	2.5305e+05	3.2158e+07	1.9284e+06	2.3823e+08	2.0777e+07
Cut 1	14.768	2.5305e+05	3.2158e+07	1.9284e+06	2.3823e+08	2.0777e+07
Cut 2	24.489	2.5305e+05	2.9536e+07	1.7706e+06	7.2688e+07	2.2724e+06
Cut 3	25.208	2.5305e+05	2.9015e+07	1.7333e+06	6.7742e+07	1.7726e+06
Cut 4	29.117	2.5121e+05	2.2878e+07	1.5653e+06	4.9094e+07	3.9529e+05
Cut 5	44.815	2.2008e+05	8.7713e+06	7.7258e+05	1.3999e+07	1.3398e+05
Cut 6	49.019	1.7481e+05	6.2209e+06	5.9125e+05	5.4240e+06	1.3131e+05
Cut 7	49.264	1.7226e+05	5.7768e+06	5.7788e+05	5.3964e+06	1.3131e+05
Cut 8	49.394	1.5709e+05	5.3093e+06	5.2028e+05	3.8400e+06	1.3052e+05
Cut 9	82.840	1.4163e+05	1.1940e+06	1.8056e+05	1.1735e+06	9.1846e+04



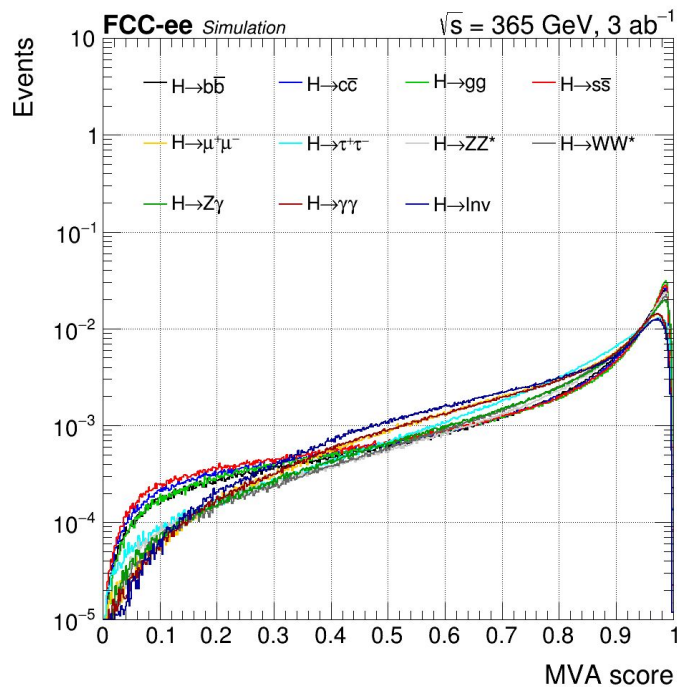
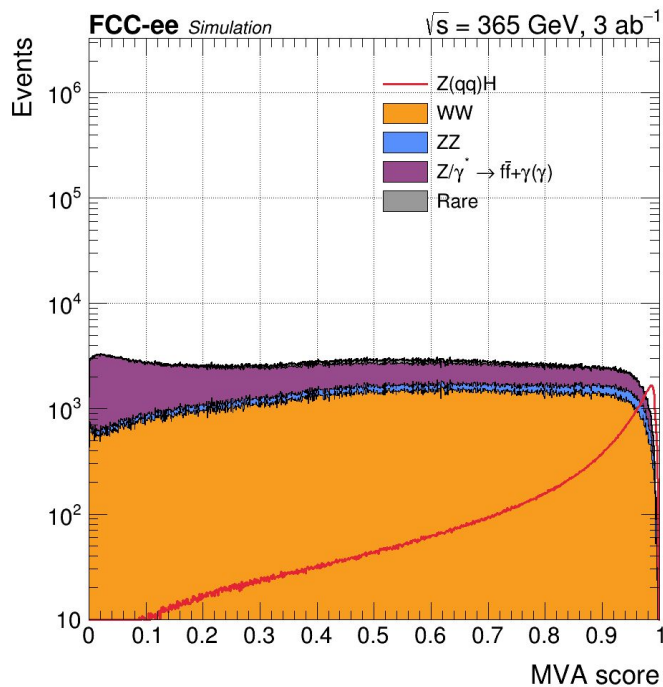
Selection efficiency at $\sqrt{s} = 365$ GeV



- Final selection efficiency spread $\sim 13\%$ among Higgs decays
- Largest bias for $H \rightarrow \text{invisible}$



Boosted Decision Tree at $\sqrt{s} = 365$ GeV



- BDT output discriminant



Results at $\sqrt{s} = 365 \text{ GeV}$

Binned likelihood performed on recoil- $m_{q\bar{q}}$ plane in 2 bins of MVA discriminant

Background processes WW, ZZ, Z/ γ , rare processes

- Normalization 1% for all background processes (uncorrelated)
- Constrained in situ by control region

Total uncertainty 0.57% for hadronic channel

Uncertainty on Z(l)H (%)	
Channel	Z(qq)H
Nominal fit (bkgs 1.01)	0.57
Backgrounds fixed	0.47
Nominal fit (bkgs 1.05)	0.59
Backgrounds free floating	0.60



Higgs decay-mode bias tests at $\sqrt{s} = 365$ GeV

Bias tests performed with 1.5% prior uncertainty on $\sigma(\text{ZH})$

- Use knowledge of leptonic channel that is unbiased well within $< 1.5\%$

Overall biases within quoted uncertainty of 0.57 %

Bias on $\sigma(\text{ZH})$ (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.100	0.098
cc	0.100	0.111
gg	0.142	0.151
ss	0.093	0.099
$\mu\mu$	-0.506	-0.518
$\tau\tau$	-0.561	-0.518
ZZ	-0.078	-0.097
WW	-0.159	-0.168
$Z\gamma$	-0.236	-0.280
γ	-0.423	-0.452
inv	-0.372	-0.365

Hadronic + leptonic combination



Results at $\sqrt{s} = 240 \text{ GeV}$

Combine fit of leptonic and hadronic channels

Background processes WW, ZZ, Z/ γ , rare processes

- Normalization 1% for all background processes (uncorrelated)
- Constrained in situ by control region in hadronic channel

Total combined uncertainty of 0.31%

Uncertainty on Z(l)H (%)				
Channel	Z($\mu\mu$)H	Z(ee)H	Z(qq)H	Combination
Nominal fit (bkgs 1.01)	0.68	0.81	0.38	0.31
Backgrounds fixed	0.66	0.78	0.30	0.26
Nominal fit (bkgs 1.05)	0.74	0.88	0.40	0.31
Backgrounds free floating	0.79	1.02	0.40	0.31



Higgs decay-mode bias tests at $\sqrt{s} = 240$ GeV

Bias tests performed with 1% prior uncertainty on $\sigma(\text{ZH})$

- Use knowledge of leptonic channel that is unbiased well within $< 1\%$
- Largest bias on $\text{H} \rightarrow \text{inv}$ as expected

Biases within quoted uncertainty of 0.31 %

Bias on $\sigma(\text{ZH})$ (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.024	0.02
cc	-0.056	-0.063
gg	-0.028	-0.018
ss	-0.115	-0.124
$\mu\mu$	0.178	0.115
$\tau\tau$	-0.025	-0.054
ZZ	0.034	0.042
WW	-0.047	-0.03
$\text{Z}\gamma$	-0.089	-0.069
γ	0.284	0.209
inv	0.339	0.267



Results at $\sqrt{s} = 365 \text{ GeV}$

Combine fit of leptonic and hadronic channels

Background processes WW, ZZ, Z/ γ , rare processes

- Normalization 1% for all background processes (uncorrelated)
- Constrained in situ by control region in hadronic channel

Total combined uncertainty of 0.53%

Uncertainty on Z(H)H (%)				
Channel	Z($\mu\mu$)H	Z(ee)H	Z(qq)H	Combination
Nominal fit (bkgs 1.01)	1.83	1.95	0.57	0.53
Backgrounds fixed	1.80	1.90	0.47	0.44
Nominal fit (bkgs 1.05)	2.10	2.20	0.59	0.56
Backgrounds free floating	2.88	3.00	0.60	0.56



Higgs decay-mode bias tests at $\sqrt{s} = 365$ GeV

Bias tests performed with 1.5% prior uncertainty on $\sigma(\text{ZH})$

- Use knowledge of leptonic channel that is unbiased well within $< 1.5\%$
- Largest bias on $\text{H} \rightarrow \text{inv}$ as expected

Biases within quoted uncertainty of 0.53 %

Bias on $\sigma(\text{ZH})$ (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.089	0.087
cc	0.089	0.098
gg	0.122	0.133
ss	0.083	0.087
$\mu\mu$	-0.437	-0.456
$\tau\tau$	-0.484	-0.458
ZZ	-0.069	-0.083
WW	-0.143	-0.149
$\text{Z}\gamma$	-0.199	-0.236
γ	-0.368	-0.399
inv	-0.322	-0.322

Comparison with other lepton colliders



ZH cross-section at lepton colliders

Channel	Accelerator	Lumi (fb ⁻¹)	ZH uncertainty (%)	Scaled to FCC (10.8 ab ⁻¹)
Hadronic	CLIC [1]	500	3.65	0.79
	ILC [2]	250	2.6/2.4 (+/-)	0.40/0.37
	FCC (this work)	10800	0.41	0.41
Leptonic	ILC [3]	250	2.5/2.9 (+/-)	0.38/0.44
	FCC (this work)	10800	0.52	0.52
Total ZH	ILC/CLIC [4]	250	2.0/2.0 (+/-)	0.30
	FCC CDR	5000	0.50	0.34
	FCC (this work)	10800	0.32	0.32

General remarks on ILC/CLIC studies

- ILC/CLIC often quote uncertainties with beam polarization, but in coupling fits [4] seems no difference between +/-
- Analyses done separately for visible and invisible decays, the result is combined statistically
- No info given on background treatment (stat only assumed)
- Bias tests performed with signals only $\mu\mu H$, eeH , qqH – other signals discarded

[1] M. Thompson: <https://arxiv.org/abs/1509.02853>
[2] Tomita et al. https://agenda.linearcollider.org/event/6557/contributions/31831/attachments/26241/40201/Asian_Linear_Collider_Workshop_tomita.pdf – NOT PUBLISHED
[3] <https://arxiv.org/pdf/1604.07524>
[4] <https://arxiv.org/pdf/1708.08912> Table 6



Comparison FCC and ILC

Compare FCC and ILC for the leptonic $\mu\mu H$ channel (stat. only results)

- | | |
|---|--------------|
| - FCC 10.8 ab ⁻¹ | 0.66 % |
| - FCC 250 fb ⁻¹ | 4.34 % |
| - ILC 250 fb ⁻¹ (2 polarization) | 3.2–3.6% [3] |

**FCC 35–20% worse than ILC
for same luminosity**

4 main potential differences between FCC and ILC analyses

1. ILC applies cut on $\cos(\theta_{\text{miss}})$ which drastically reduces dominant Z/γ background + categorization in visible and invisible Higgs decays
2. ECM: 240 GeV vs 250 GeV
3. Beam polarization
4. Different selection (apart from $\cos(\theta_{\text{miss}})$)
 - ILC has loose event selection
 - FCC tighter event selection, but well scrutinized and optimized
 - Tried similar loose event selection as ILC → no impact
 - We can assume both event selections are optimized

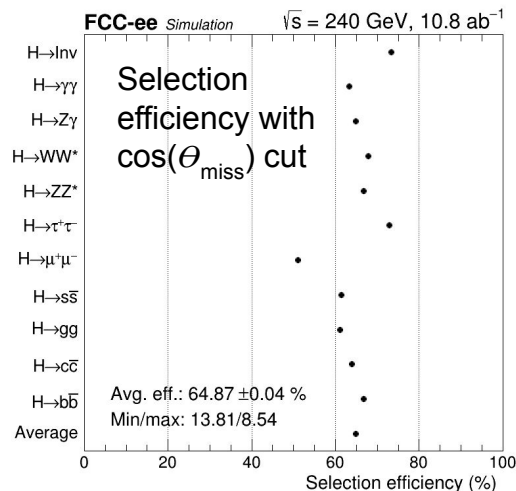


Comparison FCC and ILC

Cut on $\cos(\theta_{\text{miss}})$

- ILC applies this cut, which drastically reduces the Z/γ background
- FCC does not apply it, as we have **proven that this breaks the model independence** →
- FCC instead uses a BDT, but it is not as strong as $\cos(\theta_{\text{miss}})$:
 - Without $\cos(\theta_{\text{miss}})$ cut 0.82 %
 - With $\cos(\theta_{\text{miss}})$ cut 0.58 % → $\cos(\theta_{\text{miss}})$ cut improves with 30 %
 - BDT 0.66 % → BDT improves improves with 20 %

→ BDT ~ 10 % worse than $\cos(\theta_{\text{miss}})$ cut



To further compare FCC with ILC, we will include the $\cos(\theta_{\text{miss}})$ cut (and not the BDT)

- FCC 10.8 ab^{-1} 0.58 %
- FCC 250 fb^{-1} 3.81%
- ILC 250 fb^{-1} (2 polarization) 3.2–3.6%

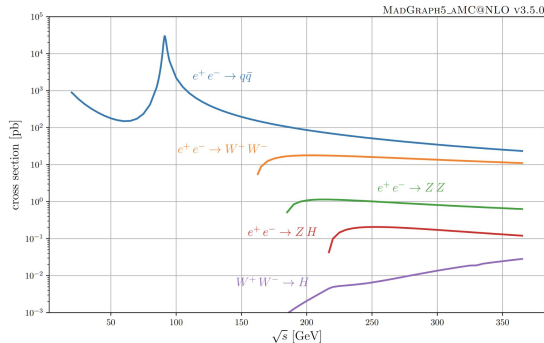
**Still, FCC 19–6% worse than ILC
for same luminosity**



Comparison FCC and ILC

ECM and polarization

- ECM 240 → 250 GeV: $\sigma(\text{ZH})$ higher, $\sigma(\text{WW}, \text{ZZ}, \text{Z}/\gamma)$ lower
- Beam polarization in ILC $-80/+30\%$ (left) and $+80/-30\%$ (right)
- Different polarizations schemes enhances/suppresses SM processes



Impact on ECM and beam polarization estimated as follows:

- Recompute the cross-sections for ZH(signal), WW, ZZ and Z/ γ backgrounds
- Propagate to the analysis by rescaling with the cross-sections

Cross-sections calculated with Whizard 3 (pb)				
	ZH ($\mu\mu\text{H}$)	WW	ZZ	Z/ γ
FCC 240	0.00676	0.221	0.015	5.299
ILC 250	0.00709	0.214	0.014	4.870
ILC 250 polL	0.01050	0.478	0.020	6.691
ILC 250 polR	0.00708	0.048	0.015	5.394
Ratio (ILC 250)/(FCC 240)	1.048	0.971	0.939	0.919
Ratio (ILC 250 polL)/(FCC 240)	1.554	2.166	1.330	1.263
Ratio (ILC 250 polR)/(FCC 240)	1.047	0.219	1.011	1.018

Remarkable changes:

Z/ γ reduced 10% from 240→250

Signal +50% with left pol.

WW reduced 5x with right pol.



Comparison with ILC ($\mu\mu H$)

Results after rescaling, the numbers are in agreement with ILC for both polarizations

Uncertainty (%)	
240	3.81
250	3.69
250 polL (= 3.2% at ILC)	3.10
250 polR (= 3.6% at ILC)	3.52

Summary of contributions (all rescaled to ILC luminosity)

	Uncertainty (%)	Relative impact (%)
FCC baseline	4.34	—
Replace BDT with $\cos(\theta_{\text{miss}})$	3.81	12%
ECM 240 $\rightarrow$ 250 GeV	3.69	3%
Beam polarization	3.10–3.52	16–5%



Conclusions and outlook

Presented path to model-independent ZH cross-section at center-of-mass energy of 240(365) GeV

- Hadronic channel 0.38(0.57)%
- Hadronic+leptonic combined uncertainty of 0.31(0.53)%
- Proven to be model-independent within quoted uncertainties