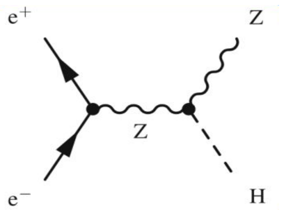
Total ZH cross-section at FCC-ee

Jan Eysermans – March 11 2025

Motivation



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

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

$$\sigma_{\mathrm{ZH}} \times \mathcal{B}(\mathrm{H} \rightarrow \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HZZ}} \times g^2_{\mathrm{HXX}}}{\mathit{\Gamma}_{\mathrm{H}}} \qquad \sigma_{\mathrm{H}\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}} \times \mathcal{B}(\mathrm{H} \rightarrow \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HWW}} \times g^2_{\mathrm{HXX}}}{\mathit{\Gamma}_{\mathrm{H}}}$$

Allows to constrain Higgs total width ~ 0.75%

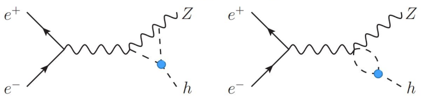
- by measuring H→ZZ* at 240 GeV
- Also accessible via H→bb at 240+365 GeV

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

Allows to probe Higgs self coupling κ_λ ~ 28%

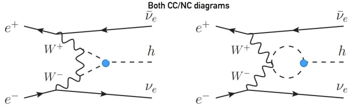
- Through NLO deviations in ZH cross section: $\Sigma_{\mathrm{NLO}} = Z_H \Sigma_{\mathrm{LO}}(1 + \kappa_\lambda C_1)$
- C_1 sensitive to √s: exploit different sensitivities both 240 (dominant) and 365 GeV

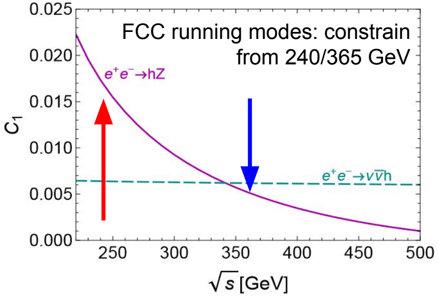
ZH Higgsstrahlung



VBF processes

Both CC/NC diagrams





General note on signal extraction

ZH analysis is a cross-section measurement

- Counting ZH events over background events at √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→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→any)
- POI contains all ZH signals, including vvH, 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 ~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 δZH = 5%, or δBR = 5%/BR and construct pseudo-data
    - This also means δBR >> 5% (true for non-bb Higgs decays); e.g. δZH = 5% means δBR(gg) = 61%
    - Rare decays contribute little to the total ZH cross-section → 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*(μ^{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

Leptonic channel

More details about the analysis can be found in the note:
https://repository.cern/records/a68b8-3mt57 (A. Li, J. Eysermans, G. Bernardi, K. Dewyspelaere)

Changes w.r.t. what was presented before

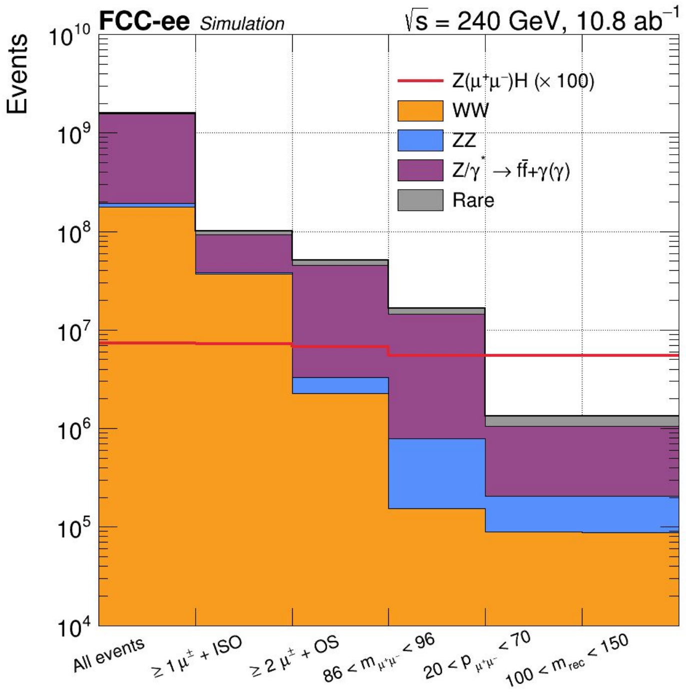
- Revision of fit strategy
- Discussion on model dependence

Z(ℓℓ)H mass analysis

Analysis selection

- Select at least 2 leptons:
  - Momentum p > 20 GeV
  - One lepton required to be isolated
- Pair leptons (in case more than 2 leptons found)
  - Opposite sign lepton pairs
  - Exclude pairs compatible with m_H: $|125-3| < m(\ell\ell)$ (*)
  - Select pair that minimizes

    $$\chi^2 = 0.6 * ((m(\ell\ell) - 91.2)^2 + 0.4*(\text{recoil} - 125)^2)$$
- Kinematic cuts
  - Z mass: $86 < m(\ell\ell) < 96$ GeV
  - Z momentum: $20 < p(\ell\ell) < 70$ GeV
  - Recoil mass: $100 < m_{rec} < 150$ GeV (**)

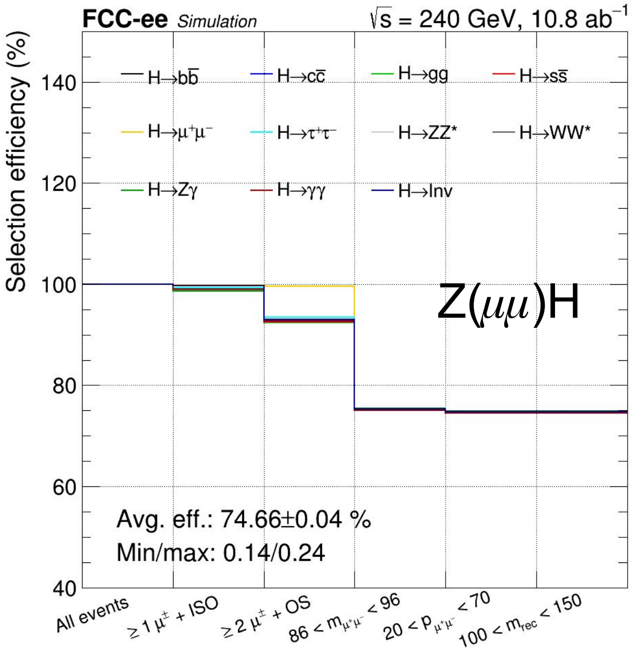


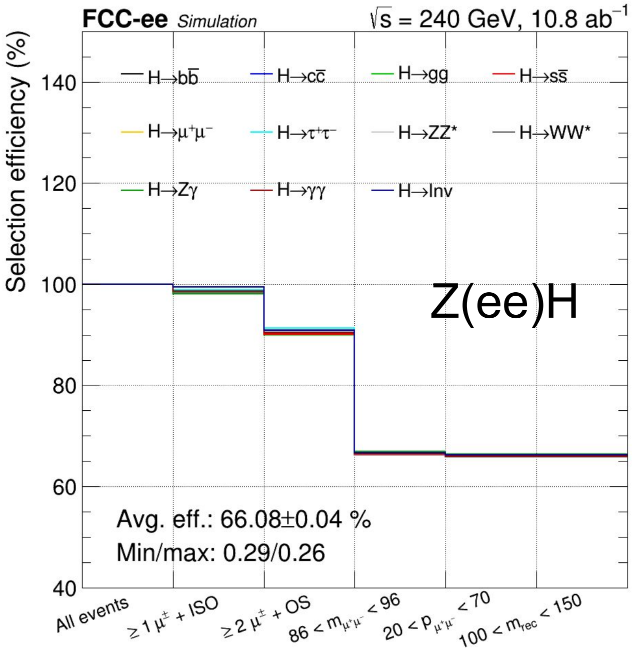
Backgrounds dominated by vector boson (pair) production (WW, ZZ) and single Z/γ*

(*) remove enhancements from H→μμ

(**) enlarge region to have more constraining power for background normalization

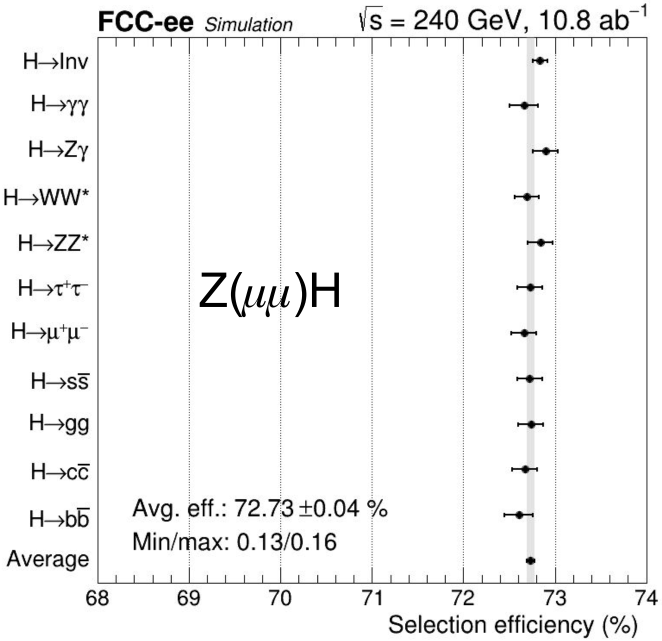
Cut flow for muon/electron channels

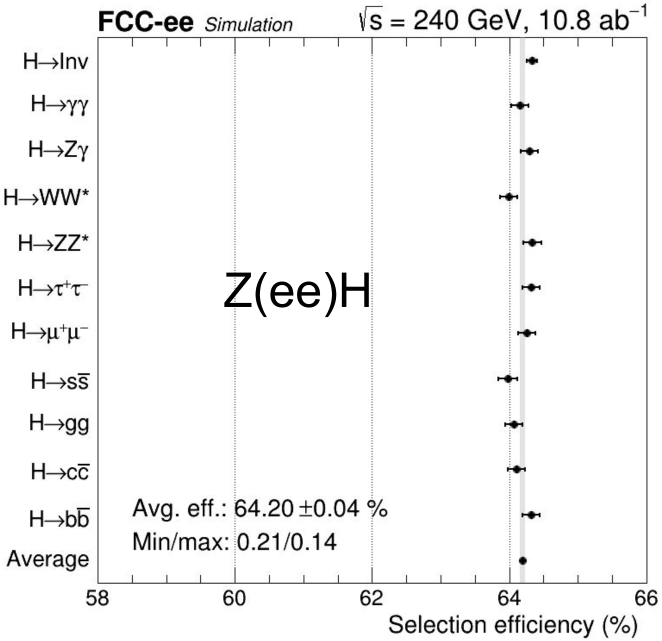




- No bias in selection for SM decays, including H→invisible

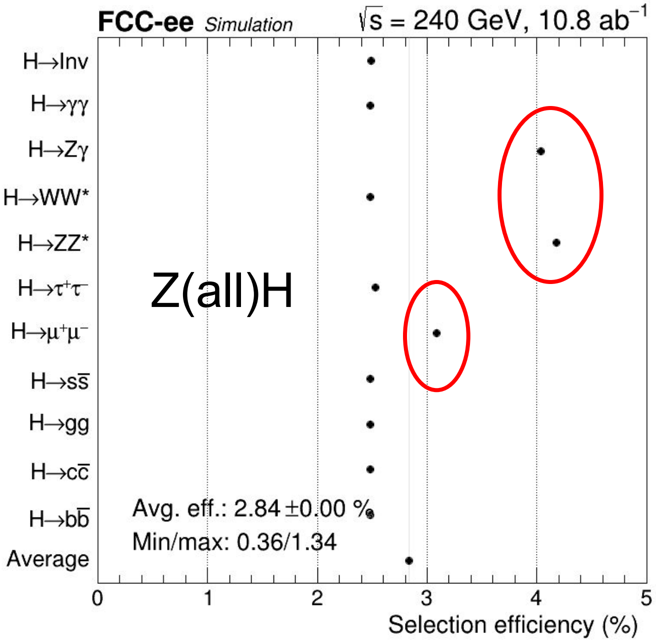
Final selection efficiency – leptonic ZH processes

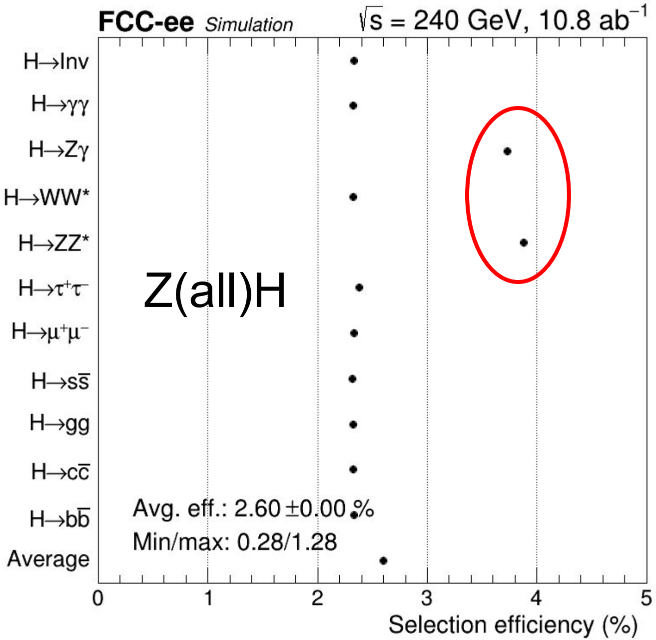




- Shown final selection efficiencies for signal processes Z($\mu\mu$)H and Z(ee)H
- Bias < 0.2% in leptonic channels, including H→invisible
- Distributions are independent of Higgs decay

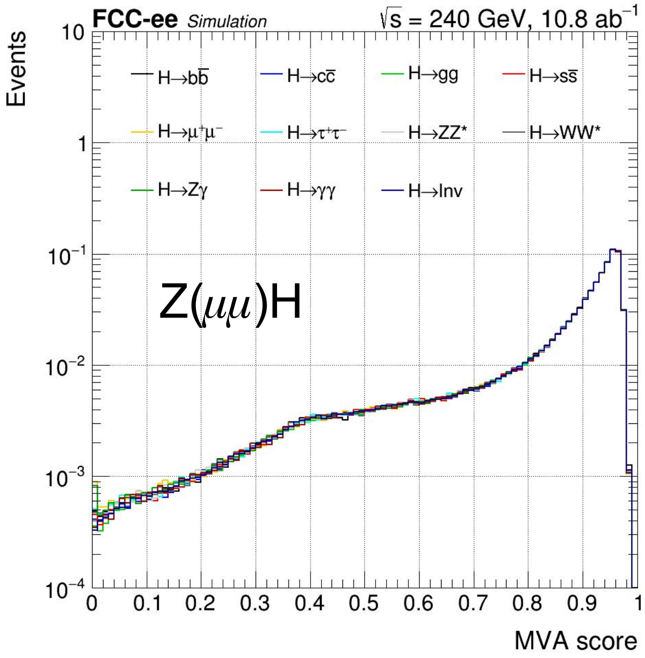
Final selection efficiency – all ZH processes

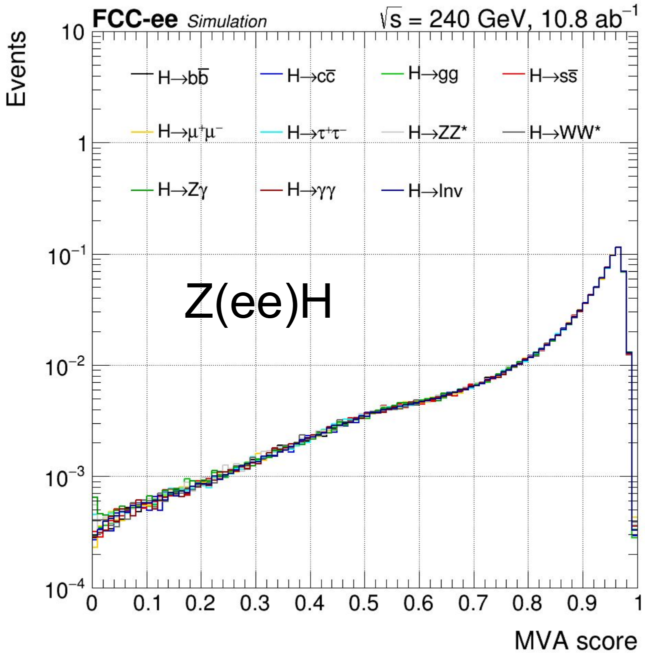




- Shown final selection efficiencies for all Z(XX)H processes
- Higher selection efficiency for final states with real Z boson(s): H(ZZ) and H(Zγ), originating from Z(qq)H and Z($\nu\nu$)H production modes leaking into the leptonic phase space

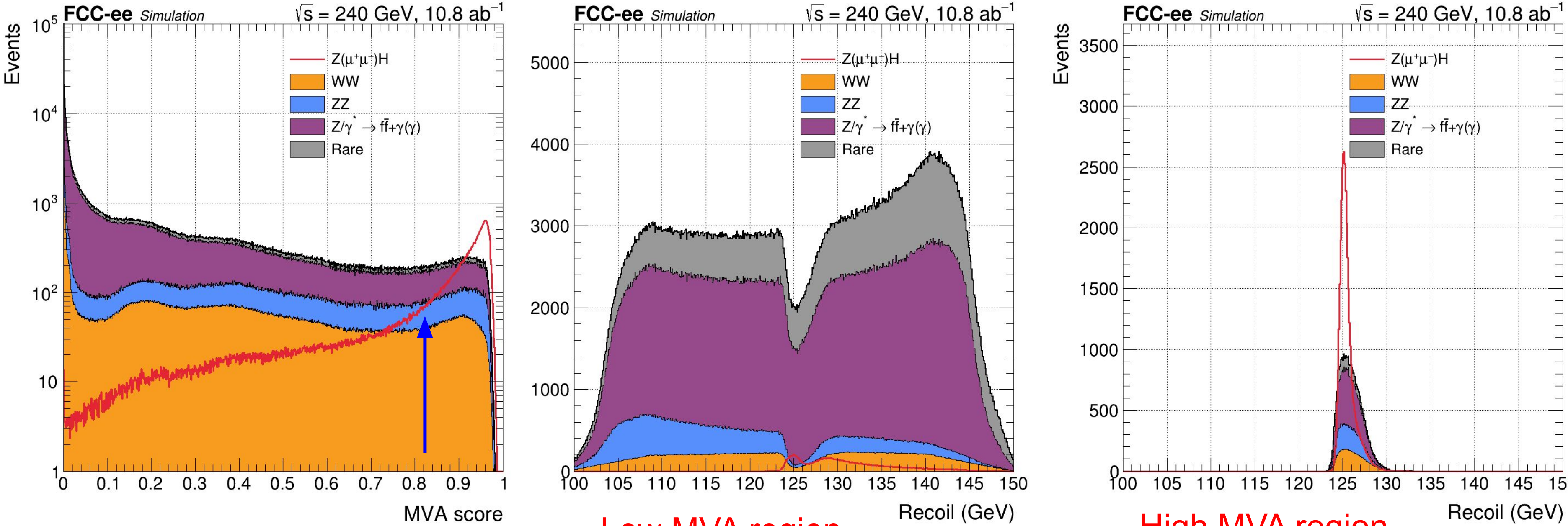
MVA discriminant





- MVA trained to further discriminate signal and backgrounds
- Input variables: lepton kinematics and angular variables, independent of Higgs decay
- Distributions are, as expected, independent of Higgs decay

Final distributions and fit (muon channel)



Low MVA region

High MVA region

Revised fit strategy

- Split MVA at maximal significance ~ 0.8: control and signal region
- Fit recoil mass for both distributions from 100–150 GeV

Results

Binned likelihood performed on recoil distributions in 2 bins of MVA discriminant

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

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

Total uncertainty 0.52% for combined leptonic channels

Uncertainty on Z(ll)H (%)			
Channel	Z($\mu\mu$)H	Z(ee)H	Combination
Nominal fit (bkgs 1.01)	0.68	0.81	0.52
Backgrounds fixed	0.66	0.78	0.51
Nominal fit (bkgs 1.05)	0.74	0.88	0.57
Backgrounds free floating	0.79	1.02	0.60

Higgs decay-mode bias tests

Bias tests performed with 5% prior uncertainty on σ(ZH)

- Biases within quoted uncertainty of 0.52 % for nominal fit config
- Larger biases observed from Zγ and ZZ when backgrounds are frozen
    - Contribution of events from $\nu\nu$H and qqH with a real Z boson in the Higgs decay in the leptonic event selection
    - When fitting only $\mu\mu$H and eeH, bias reduces to < 0.01 % (see backup)
- Can be sensitive to BSM Higgs decays enhanced with Z bosons

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	-0.004	-0.011
cc	-0.006	-0.013
gg	-0.004	-0.013
ss	-0.007	-0.016
$\mu\mu$	0.005	0.095
$\tau\tau$	-0.005	-0.008
ZZ	0.226	0.487
WW	-0.014	-0.023
Zγ	0.195	0.545
γ	0.000	-0.007
inv	0.012	0.002

Hadronic channel

Introduction

Leptonic final state Z(ll)H

- 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 → loose cuts to retain signal efficiency

Nevertheless hadronic channel profits of large BR: 70% vs 2x3.5 ~ 7% for leptonic

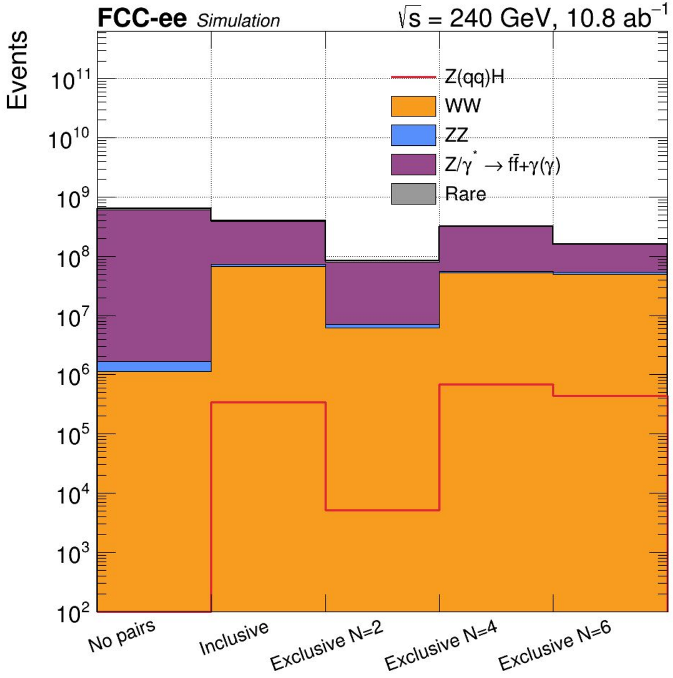
But explicit decay mode dependence hard to achieve

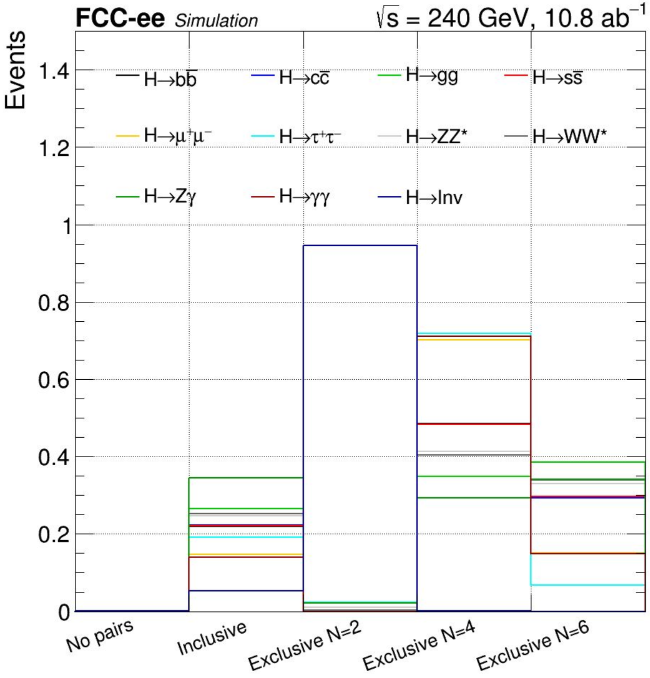
- Cannot perform selection fully independent of Higgs decay mode → but minimize the dependency
- Assess degree of decay-mode dependency based on bias tests
- Use knowledge from leptonic channel where the total cross-section will be measured without bias with precision of 0.52%

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 $\chi^2 = (m_{jj} - m_Z)^2 + (m_{recoil} - m_H)^2$
        - 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



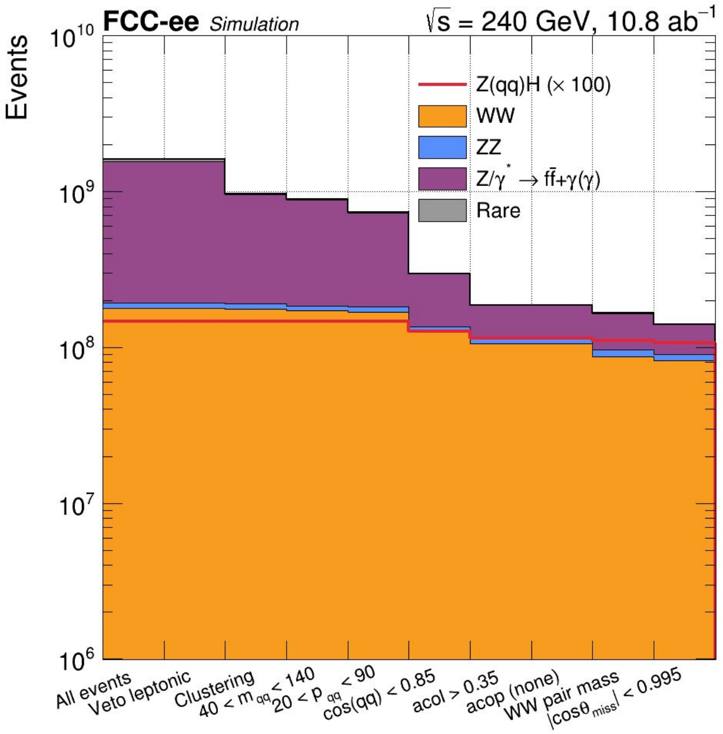


- Chosen jet algorithm after jet pairing optimization
- Follows roughly expected patterns for Higgs decays and backgrounds

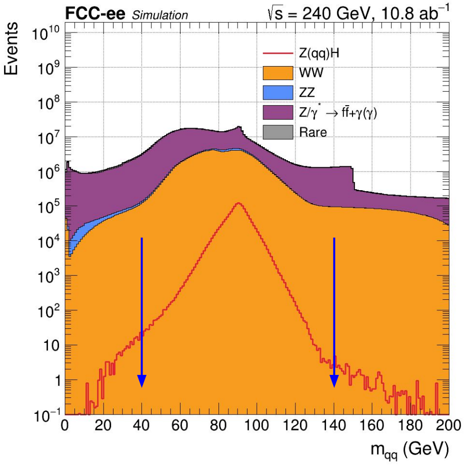
Event selection

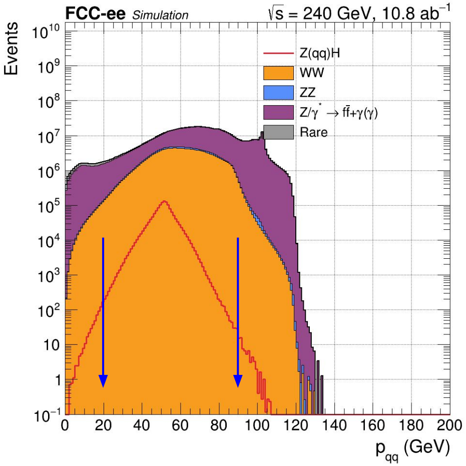
Event selection based on kinematics of selected jet pair

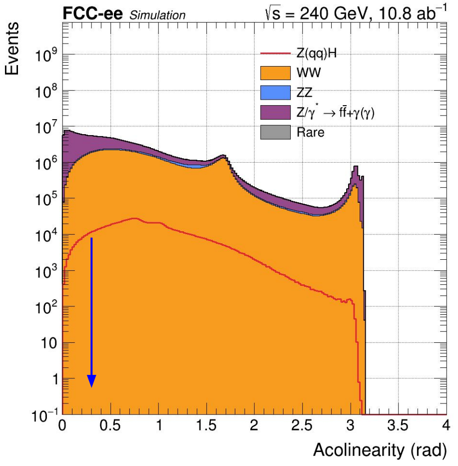
1. Veto the leptonic event selection
2. Apply event clustering
    - Reject events if clustering fails
    - Pick the best jet pair that matches the associated Z
3. Invariant mass: $40 < m_{qq} < 140$
4. Momentum: $20 < m_{qq} < 90$
5. $\cos(\Theta_{qq}) < 0.85$
6. Acolinearity > 0.35
7. Acoplanarity – no cut
8. W pair mass cut (see next slide)
9. $\cos(\theta_{miss}) < 0.995$

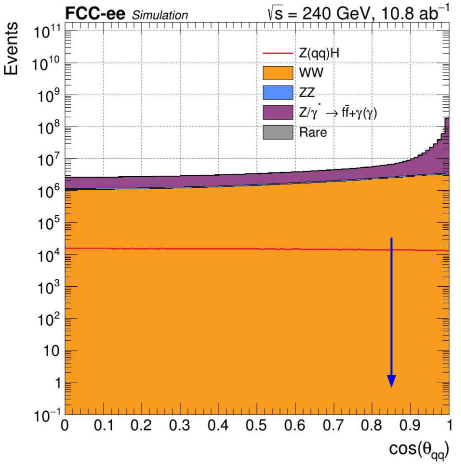


Kinematic plots







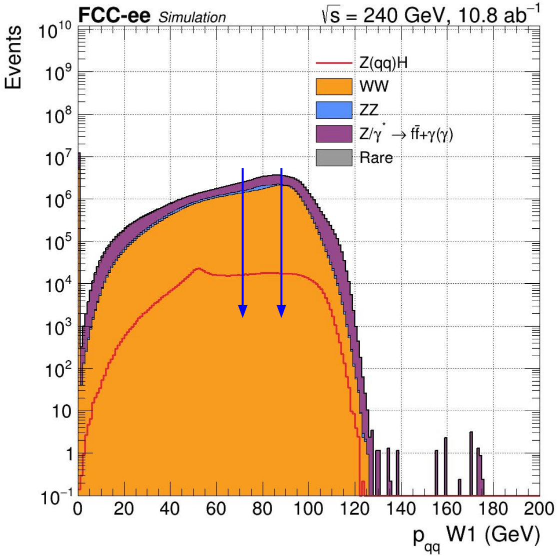


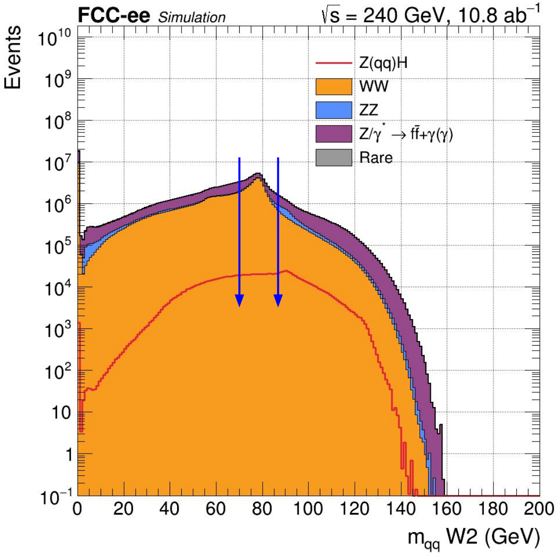
Rejection of WW background

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





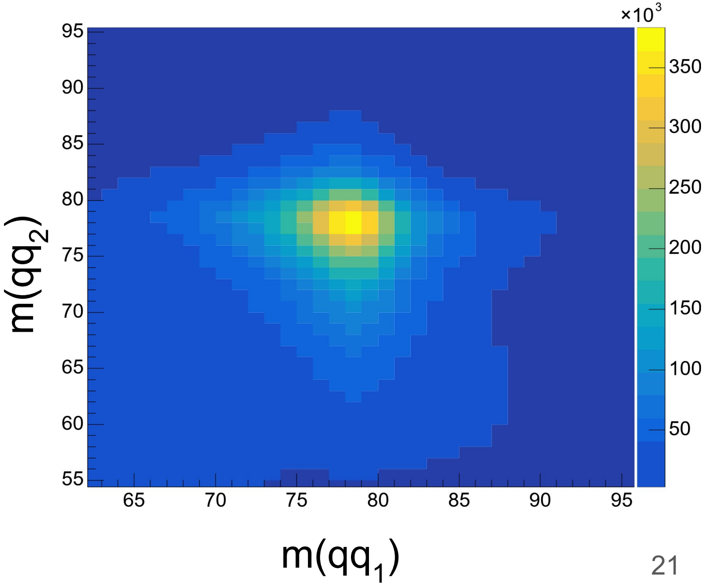


Table of yields

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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      36.746                    1.4717e+06    1.7724e+08    1.4596e+07    1.3705e+09    3.8739e+07
Cut 2      47.284                    1.4717e+06    1.7611e+08    1.4034e+07    7.6161e+08    1.4011e+07
Cut 3      49.219                    1.4716e+06    1.7125e+08    1.3788e+07    6.9276e+08    1.3217e+07
Cut 4      54.289                    1.4709e+06    1.6873e+08    1.3544e+07    5.4225e+08    6.6232e+06
Cut 5      73.303                    1.2659e+06    1.2555e+08    1.0099e+07    1.5934e+08    7.0155e+05
Cut 6      83.569                    1.1460e+06    1.0507e+08    8.8249e+06    7.1283e+07    5.8234e+05
Cut 7      83.569                    1.1460e+06    1.0507e+08    8.8249e+06    7.1283e+07    5.8234e+05
Cut 8      85.744                    1.1109e+06    8.7301e+07    8.6133e+06    6.9142e+07    5.8193e+05
Cut 9      89.242                    1.0657e+06    8.2215e+07    7.9459e+06    4.9968e+07    3.4690e+05
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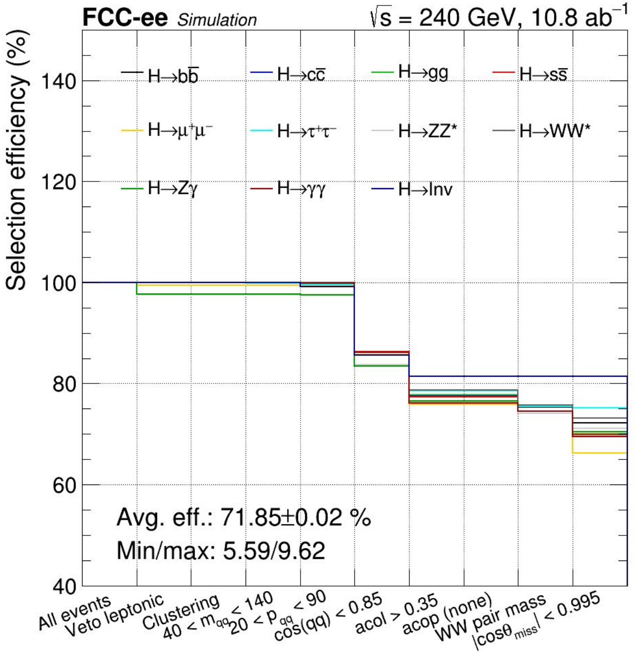
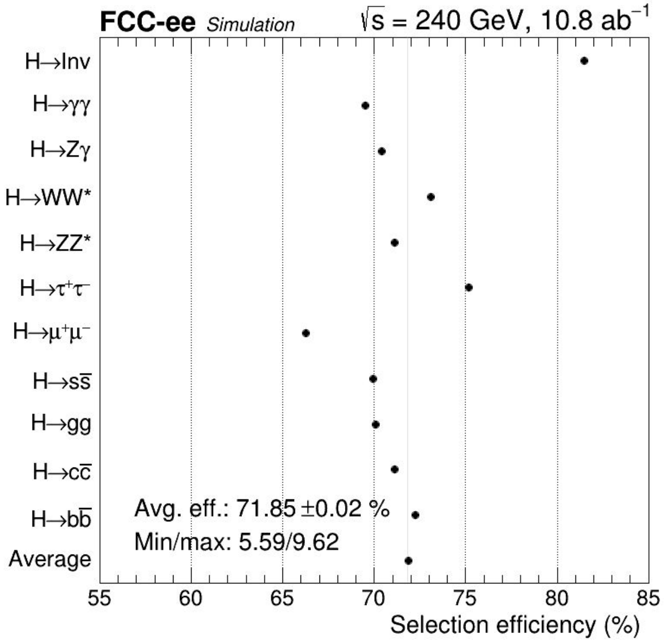
Selection efficiency





- Final selection efficiency spread ~ 10% among Higgs decays
- Largest bias for H→invisible

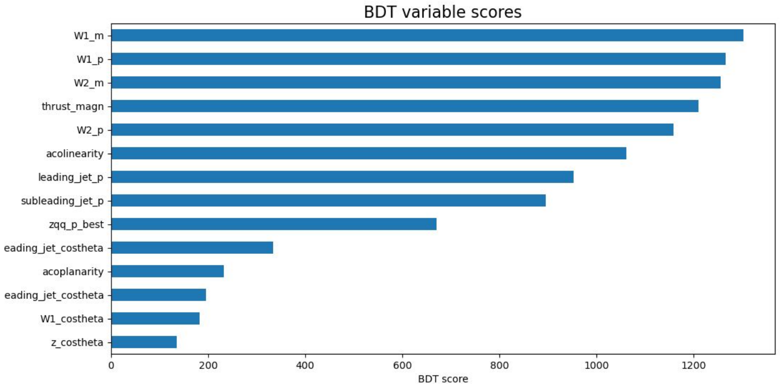
Boosted Decision Tree

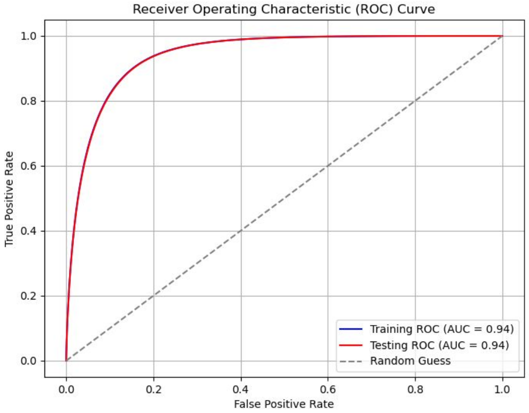
Train BDT to further discriminate signal and WW–Z/γ background

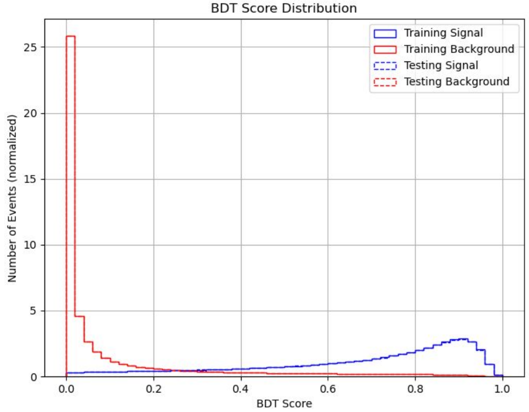
Input variables:

- 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)

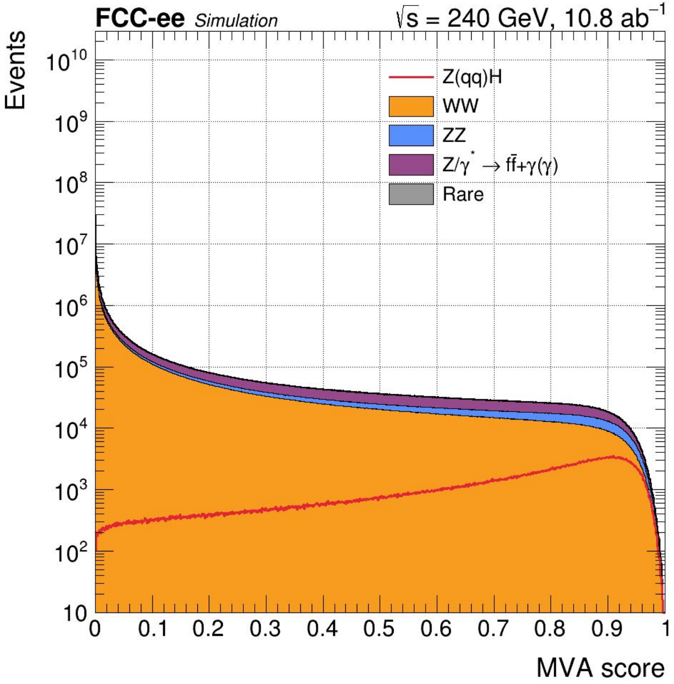
Processes: all Z(qq)H signals (equal cross-sections), WW, Z/γ

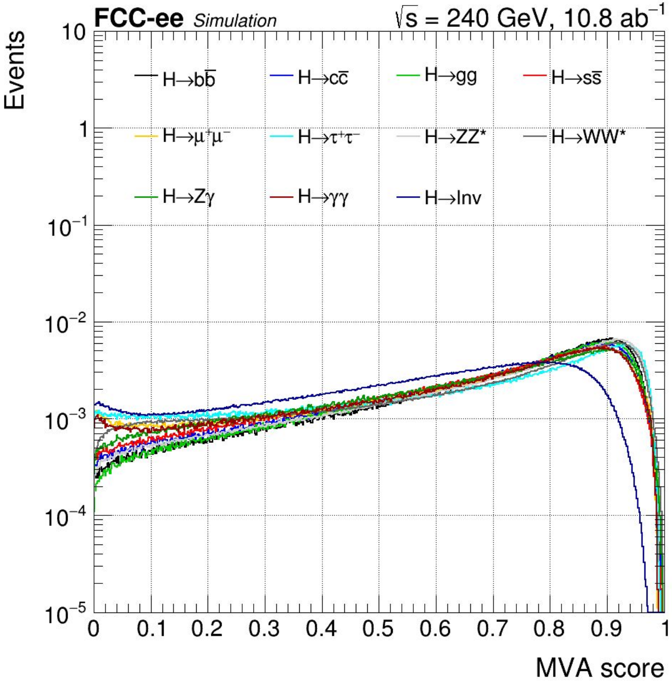






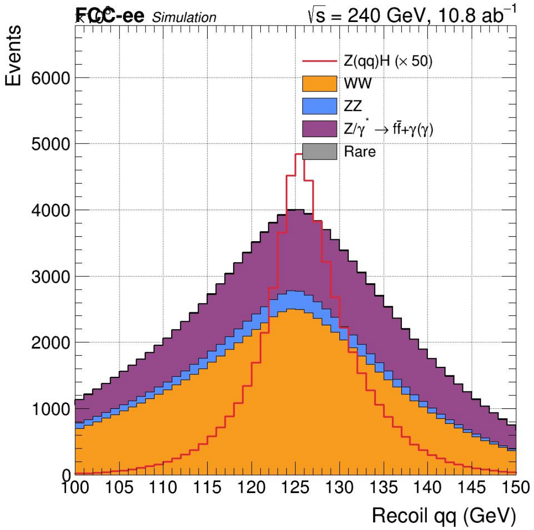
Boosted Decision Tree

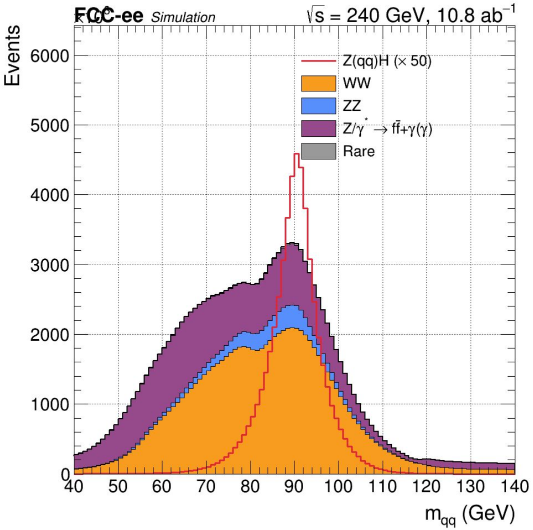


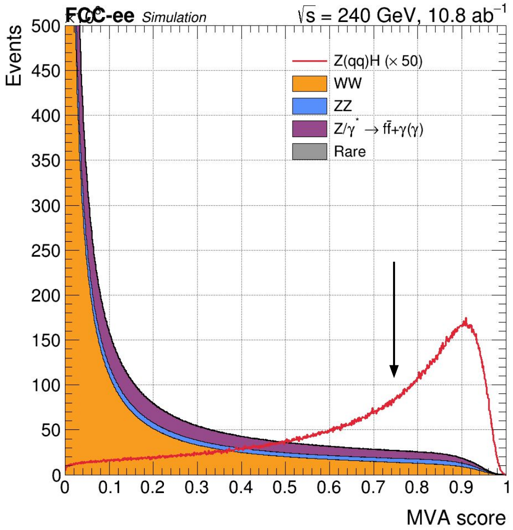


- BDT output discriminant
- Largest shape difference for Higgs→Invisibe (not great, not terrible)

Final distributions and fit

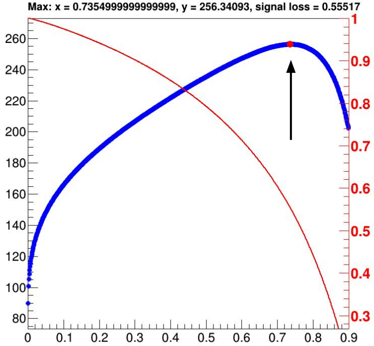






Perform 2D fit on recoil–m_{qq} plane in 2 bins of BDT discriminator

- 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 0.41% for hadronic channel

Uncertainty on Z(ll)H (%)	
Channel	Z(qq)H
Nominal fit (bkgs 1.01)	0.41
Backgrounds fixed	0.32
Nominal fit (bkgs 1.05)	0.42
Backgrounds free floating	0.42

Higgs decay-mode bias tests

Bias tests performed with 1% prior uncertainty on σ(ZH)

- Use knowledge of leptonic channel that is unbiased within < 1%
- Largest bias on H→inv as expected
- 5% bias test in backup

Biases within quoted uncertainty of 0.41 %

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.067	0.047
cc	-0.016	-0.032
gg	-0.044	-0.022
ss	-0.075	-0.090
$\mu\mu$	-0.136	-0.177
$\tau\tau$	-0.031	-0.081
ZZ	-0.026	-0.007
WW	-0.147	-0.087
Zγ	-0.229	-0.174
γ	-0.098	-0.139
inv	-0.096	-0.225

Hadronic + leptonic combination

Results

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 0.32%

Uncertainty on Z(ll)H (%)				
Channel	Z($\mu\mu$)H	Z(ee)H	Z(qq)H	Combination
Nominal fit (bkgs 1.01)	0.68	0.81	0.41	0.32
Backgrounds fixed	0.66	0.78	0.32	0.27
Nominal fit (bkgs 1.05)	0.74	0.88	0.42	0.32
Backgrounds free floating	0.79	1.02	0.42	0.32

Higgs decay-mode bias tests

Bias tests performed with 1% prior uncertainty on σ(ZH)

- Use knowledge of leptonic channel that is unbiased within < 1%
- Largest bias on H→inv as expected
- 5% bias test in backup

Biases within quoted uncertainty of 0.32 %

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.040	0.033
cc	-0.011	-0.024
gg	-0.028	-0.017
ss	-0.047	-0.065
$\mu\mu$	-0.080	-0.122
$\tau\tau$	-0.019	-0.058
ZZ	0.012	0.023
WW	-0.091	-0.063
Zγ	-0.116	-0.094
γ	-0.059	-0.100
inv	-0.059	-0.161

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

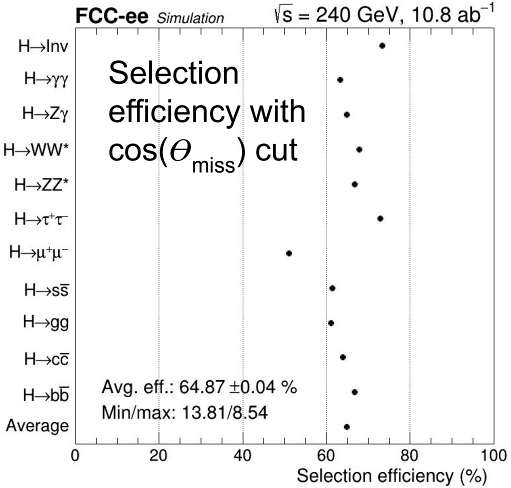
1. ILC applies cut on cos(Θ_{miss}) which drastically reduces dominant Z/γ background + categorization in visible and invisible Higgs decays
2. ECM: 240 GeV vs 250 GeV
3. Beam polarization
4. Different selection (apart from cos(Θ_{miss}))
    - ILC has loose event selection
    - FCC tighter event selection, 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(θ_{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(θ_{miss}):
    - Without cos(θ_{miss}) cut 0.82 %
    - With cos(θ_{miss}) cut 0.58 % → cos(θ_{miss}) cut improves with 30 %
    - BDT 0.66 % → BDT improves improves with 20 %

→ BDT ~ 10 % worse than cos(θ_{miss}) cut



Selection efficiency with cos(θ_{miss}) cut

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

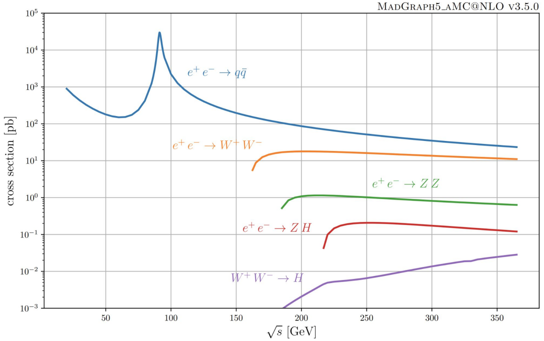
FCC 10.8 ab^{-1}	0.58 %
FCC 250 fb^{-1}	3.81%
ILC 250 fb^{-1} (2 polarization)	3.2–3.6%

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

Comparison FCC and ILC

ECM and polarization

- ECM 240 → 250 GeV: σ(ZH) higher, σ(WW,ZZ,Z/γ) 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 ($\mu\mu$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(θ_{miss})	3.81	12%
ECM 240 → 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 GeV

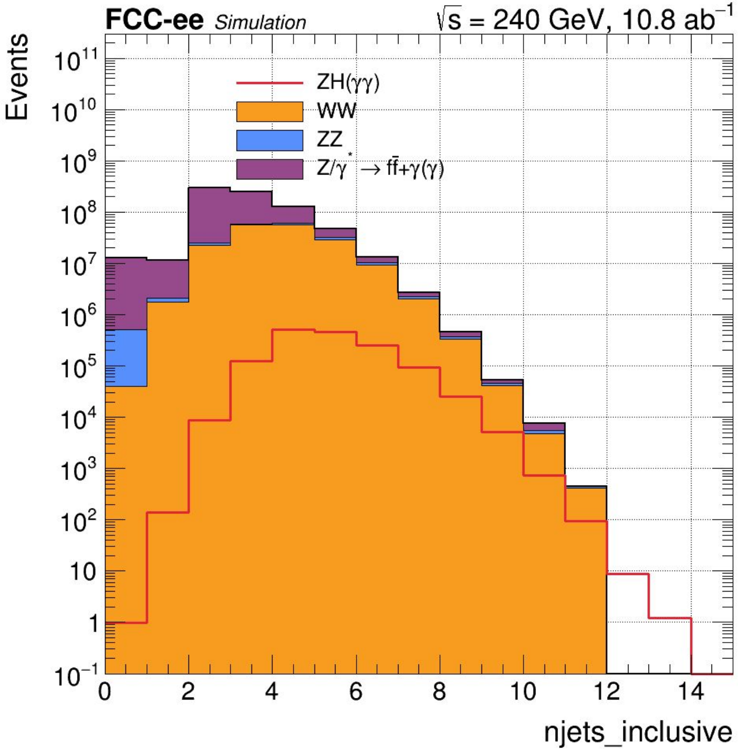
- Revised leptonic channels – 0.52%
- Implemented hadronic channel – 0.41%
- Combined uncertainty of 0.32%
- Proven to be model-independent within quoted uncertainties

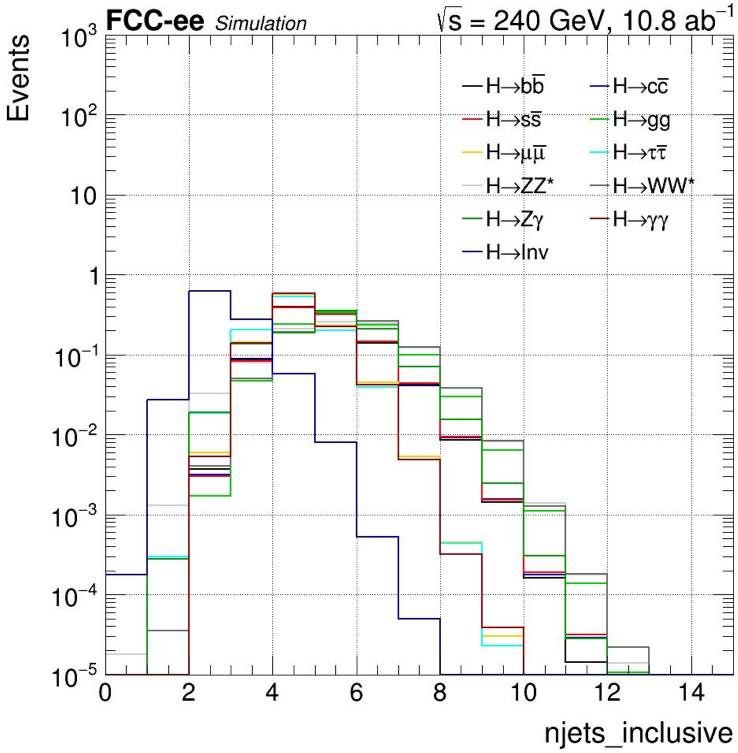
Outlook

- Reload the analysis at 365 GeV

Backup

Inclusive clustering





Higgs decay-mode bias tests – leptonic

Bias tests performed with 5% prior uncertainty on σ(ZH)

- Only $\mu\mu$H and eeH as signal
- Biases reduce to zero

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.003	0.003
cc	0.001	0.001
gg	0.002	0.001
ss	-0.001	-0.002
$\mu\mu$	-0.012	-0.008
$\tau\tau$	-0.003	-0.002
ZZ	-0.006	-0.003
WW	-0.007	-0.008
Zγ	0.004	0.005
γ	0.007	0.007
inv	0.019	0.016

Higgs decay-mode bias tests – leptonic

Added cos(thetaMiss) cut of 0.98 (maximizes the significance)

- Result goes from 0.52% to 0.45% (improvement of 15%)

Clearly absolute decay mode independence is lost

- Selection efficiencies biased, especially for tau and inv
- Bias tests of 5% do not cover the uncertainty

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.002	0.002
cc	-0.085	-0.106
gg	-0.199	-0.236
ss	-0.160	-0.200
$\mu\mu$	-0.716	-0.785
$\tau\tau$	0.206	0.244
ZZ	-0.021	-0.019
WW	0.024	0.031
Zγ	-0.051	-0.067
γ	0.041	-0.007
inv	0.260	0.294

Higgs decay-mode bias tests – hadronic

Bias tests performed with 5% prior uncertainty on σ(ZH)

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.332	0.235
cc	-0.079	-0.160
gg	-0.220	-0.110
ss	-0.376	-0.448
$\mu\mu$	-0.686	-0.889
$\tau\tau$	-0.156	-0.405
ZZ	-0.130	-0.033
WW	-0.733	-0.432
Zγ	-1.146	-0.869
γ	-0.492	-0.695
inv	-0.486	-1.126

Higgs decay-mode bias tests – leptonic + hadronic

Bias tests performed with 5% prior uncertainty on σ(ZH)

Bias on σ(ZH) (%)		
Channel	Nominal fit	Freeze bkg.
bb	0.040	0.166
cc	-0.011	-0.119
gg	-0.028	-0.083
ss	-0.047	-0.327
$\mu\mu$	-0.080	-0.613
$\tau\tau$	-0.019	-0.293
ZZ	0.012	0.113
WW	-0.091	-0.317
Zγ	-0.116	-0.472
γ	-0.059	-0.502
inv	-0.059	-0.809

What is the cos(Θ_{miss}) cut?

cos($\boldsymbol{\theta}_{miss}$) is the angle of the missing energy vector

- For Z/γ at 240 GeV: the ISR photons go into the beampipe
- Missing energy aligned with beamline ~ cos($\boldsymbol{\theta}_{miss}$) = 1
- Very effective to reduce Z/γ (typical cut < 0.98)

Using this variable to cut affects the Higgs decay mode independence

- ILC claims to be decay-mode independent with this cut
- FCC proven it breaks the model independence
    - FCC tighter constraints as the total uncertainty is much smaller than ILC
- We apply it for the mass analysis