ZH CROSS SECTION MEASUREMENT IN ZH EVENTS AT 240 AND 365 GEV AT APC

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PHYSICAL MOTIVATION

Measuring σ_{ZH} → get access to g_{HZZ} in a model-independent way

- $\sigma_{ZH} \times \mathcal{B}(H \to X\bar{X}) \propto {g^2_{HZZ} \times g^2_{HXX}}/{\Gamma_H} \to \sigma_{ZH} \times \mathcal{B}(H \to ZZ^*) \propto {g^4_{HZZ}}/{\Gamma_H}$
- g_{HZZ} can be used as a standard candle to determine g_{HXX} in a model-independent way

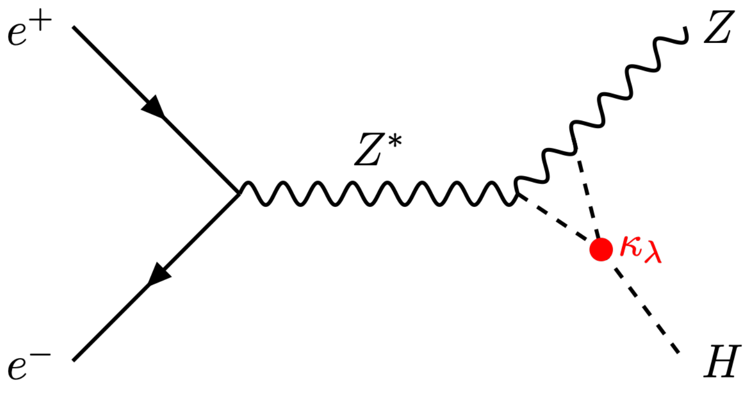
The Higgs width Γ_H can also be measured

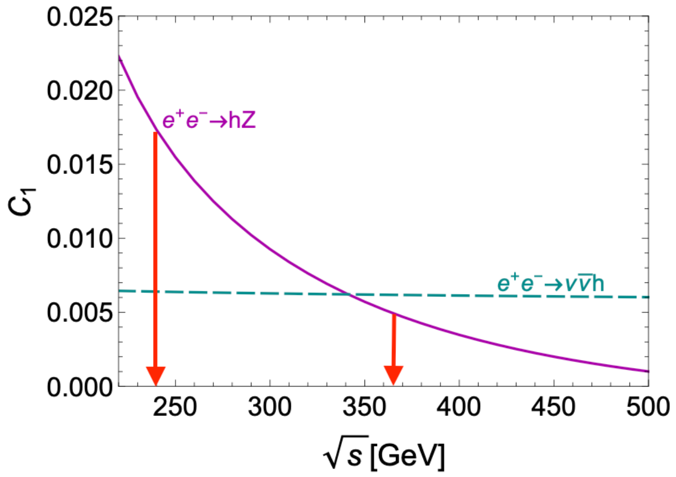
- $\Gamma_H \propto \sigma(e^+e^- \to ZH,\ H \to ZZ^*)^2/\sigma_{ZH}$

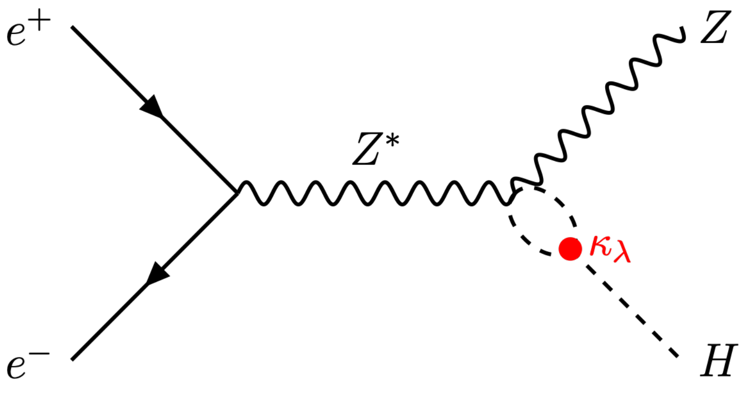
Doing a shape analysis on the m_{recoil} (next slide) give access to m_H with great precision ($\Delta m_H \sim 4\ MeV$)

Allows to indirectly measure the Higgs self-coupling through NLO correction

- $\sigma_{NLO} = Z_H \sigma_{LO}(1 + \kappa_\lambda C_1)$
- $C_1 = C_1(\sqrt{s}) \to$ measuring σ_{ZH} at $\sqrt{s} = 240\ GeV$ and $\sqrt{s} = 365\ GeV$ give better precision on κ_λ
- Will be a complementary measurement to the one made at HL-LHC



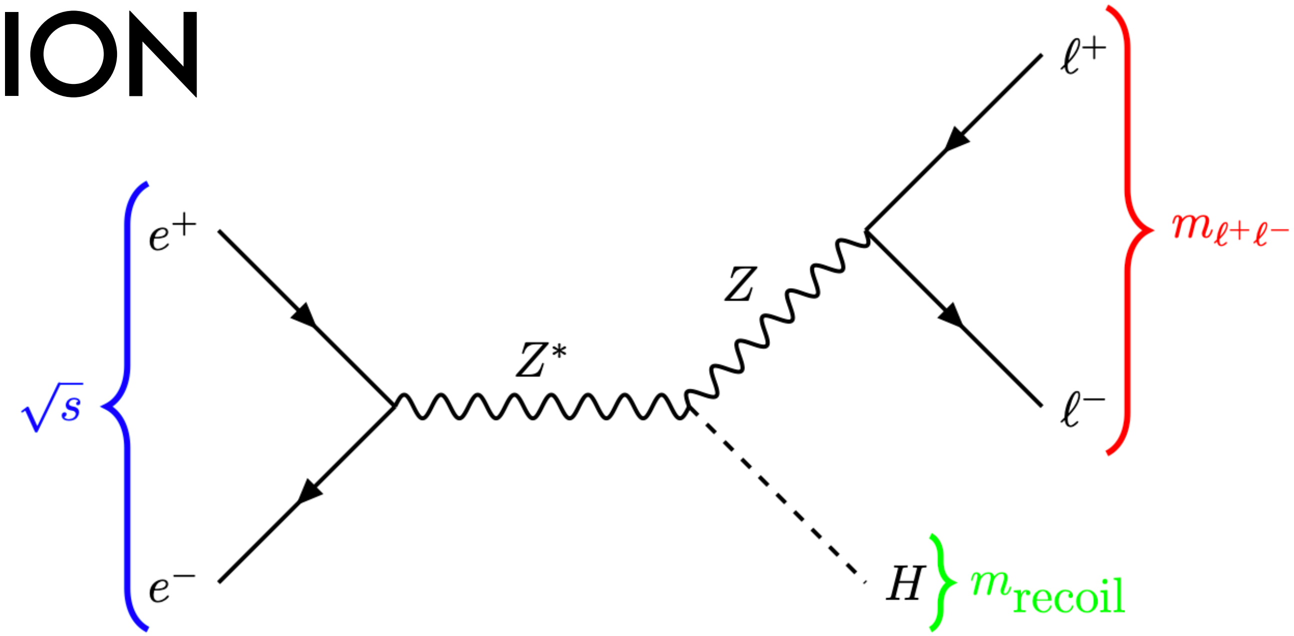


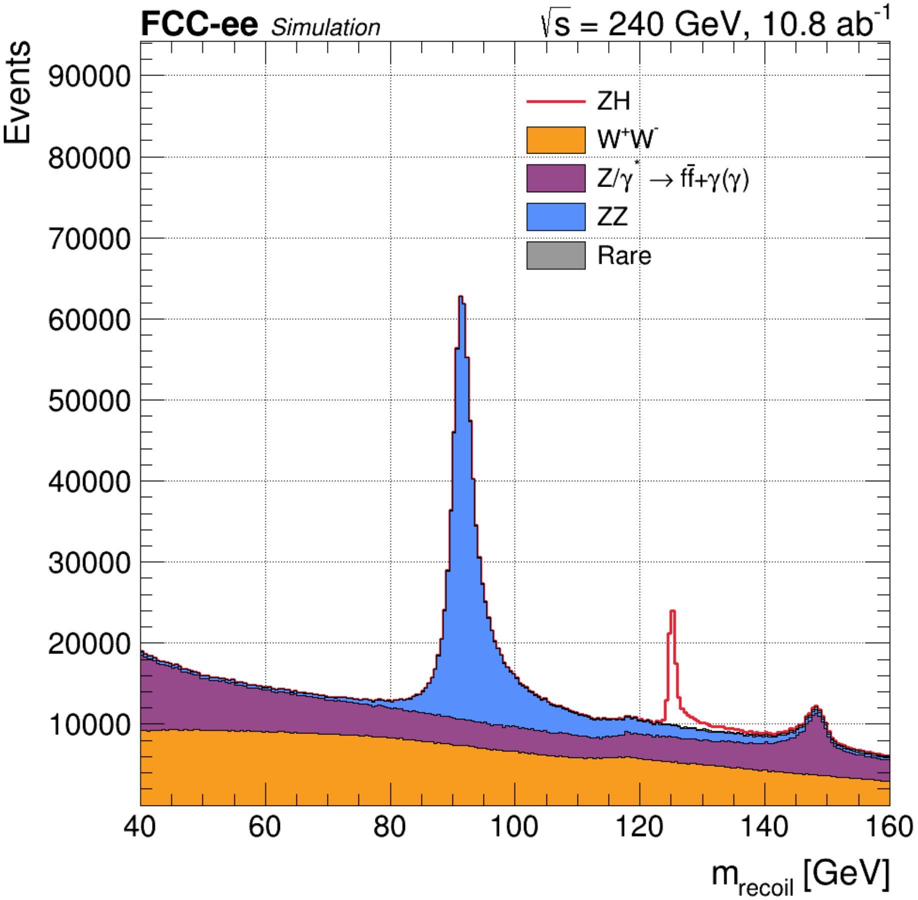


ANALYSIS INTRODUCTION

At FCC-ee we do e^+e^- collisions → initial state known
→ can use the **recoil mass method** to measure σ_{ZH}

$$m_{recoil}^2 = \left(\sqrt{s} - E_{f\bar{f}}\right)^2 - p_{f\bar{f}}^2 = s - 2E_{f\bar{f}}\sqrt{s} + m_{f\bar{f}}^2$$





Only use kinematic variables from the **lepton system** to select events in a **model-independent way** (independent of the Higgs decay)

Analysis separated into 3 channels:

- $Z(\to e^+e^-)H, Z(\to \mu^+\mu^-)H$ → leptonic channel $Z(\ell^+\ell^-)H$
- $Z(\to q\bar{q})H$ → hadronic channel

LEPTONIC CHANNEL

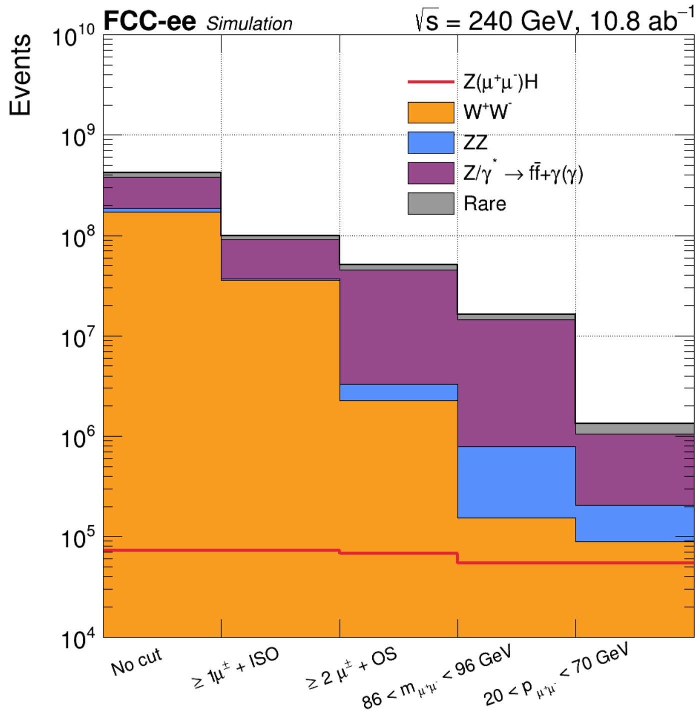
Will only show plot from $Z(\to \mu^+\mu^-)H$ channel at 240 GeV for readability

Will show plots for both channel when possible

365 GeV plots are in the back-up slides for the curious ones

The results will be presented for all channels and both energies

EVENT SELECTION (240 GEV)



Object selection:

- Only consider leptons with $p > 20\ GeV$
- Require at least one isolated lepton ($I_{rel} < 0.25$)
- Require at least 2 leptons with opposite charge

If more than 2 leptons OS in the events:

- Exclude pairs with $|m_{\ell^+\ell^-} - m_H| < 3\ GeV$

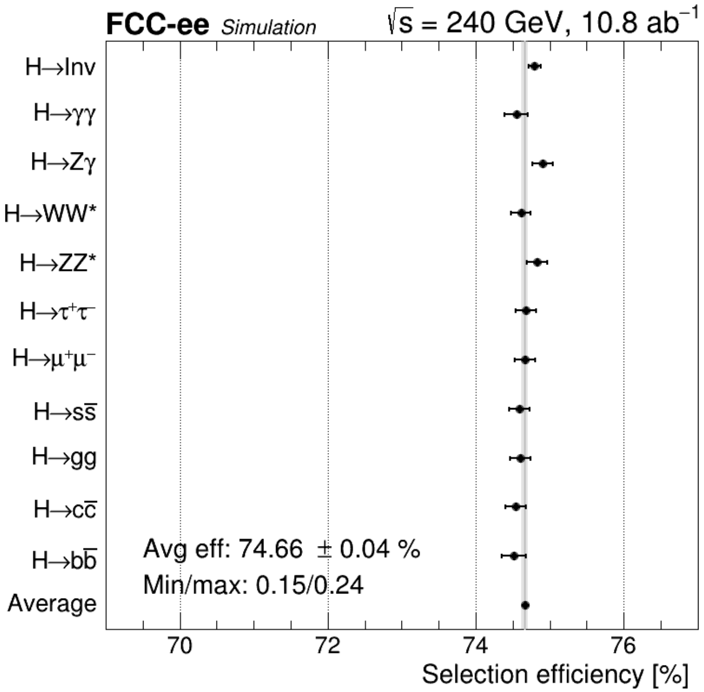
Select the pair that minimizes the χ^2:

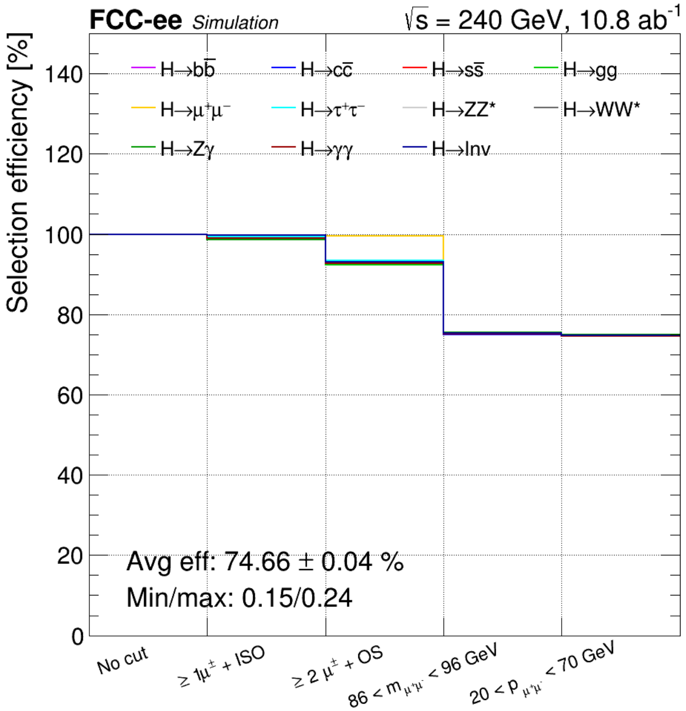
- $\chi^2 = 0.6\times(m_{\ell^+\ell^-} - 91.2\ GeV)^2 + 0.4\times(m_{recoil} - 125\ GeV)^2$

Kinematic selection:

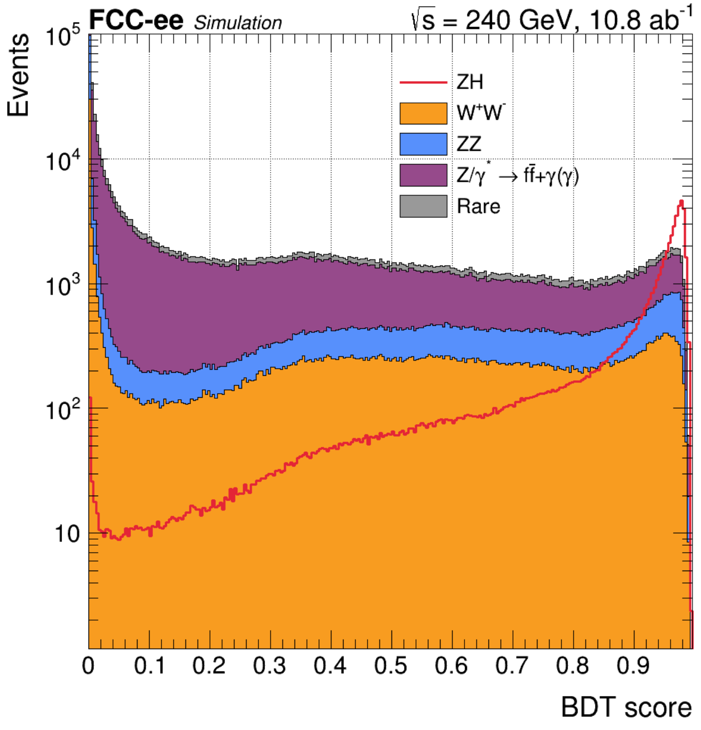
- $86\ GeV < m_{\ell^+\ell^-} < 96\ GeV$
- $20\ GeV < p_{\ell^+\ell^-} < 70\ GeV$

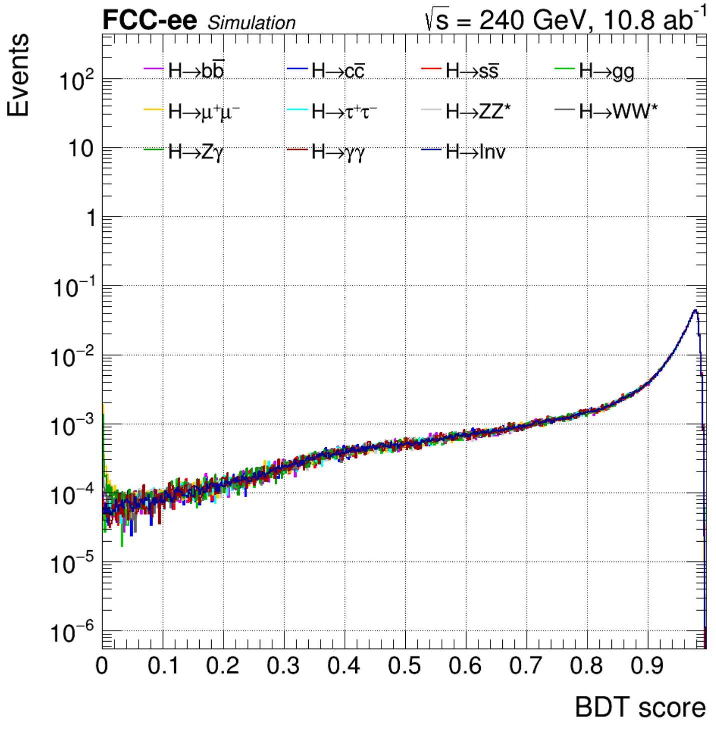
The selection efficiency doesn't depend on the Higgs decay





MVA DISCRIMINATION (240 GEV)





Train a BDT to further discriminate signal from background

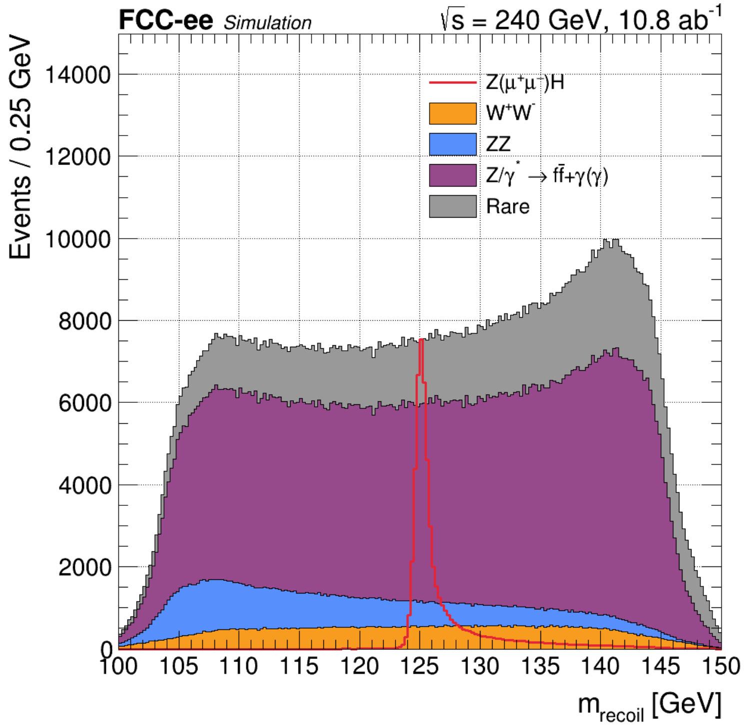
- Give individual lepton and lepton pair kinematics as input
- Also give angular correlation variables as input

BDT score distribution is independent of the Higgs decay

- BDT preserve the model-independence of the selection

Input variables	Description
$p_{leading}$	Leading lepton momentum
$\theta_{leading}$	Leading lepton polar angle
$p_{subleading}$	Subleading lepton momentum
$\theta_{subleading}$	Subleading lepton polar angle
$m_{\ell^+\ell^-}$	Lepton pair invariant mass
$p_{\ell^+\ell^-}$	Lepton pair momentum
$\theta_{\ell^+\ell^-}$	Lepton pair polar angle
$\pi - \Delta\alpha_{\ell^+\ell^-}$	Acolinearity
$\pi - \Delta\phi_{\ell^+\ell^-}$	Acoplanarity

UNCERTAINTY EXTRACTION (240 GEV)



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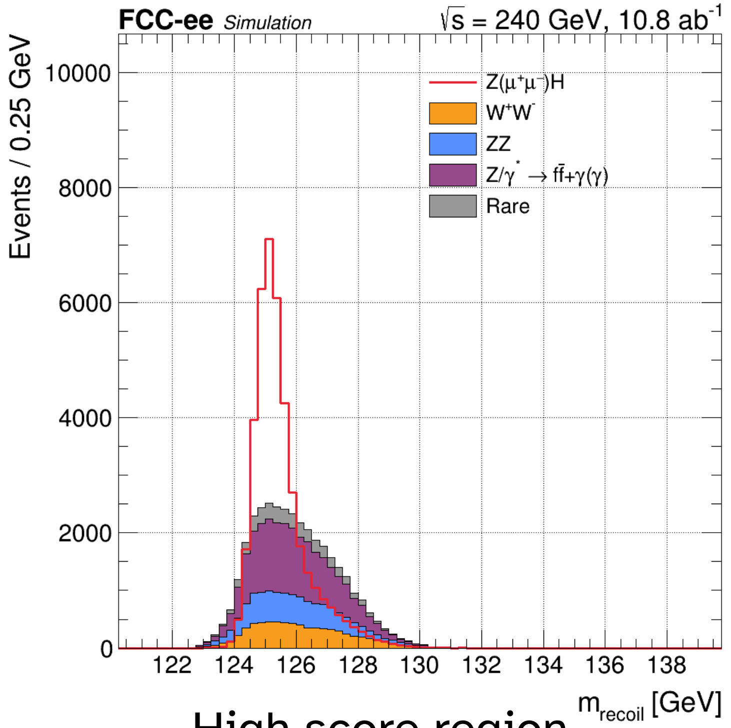
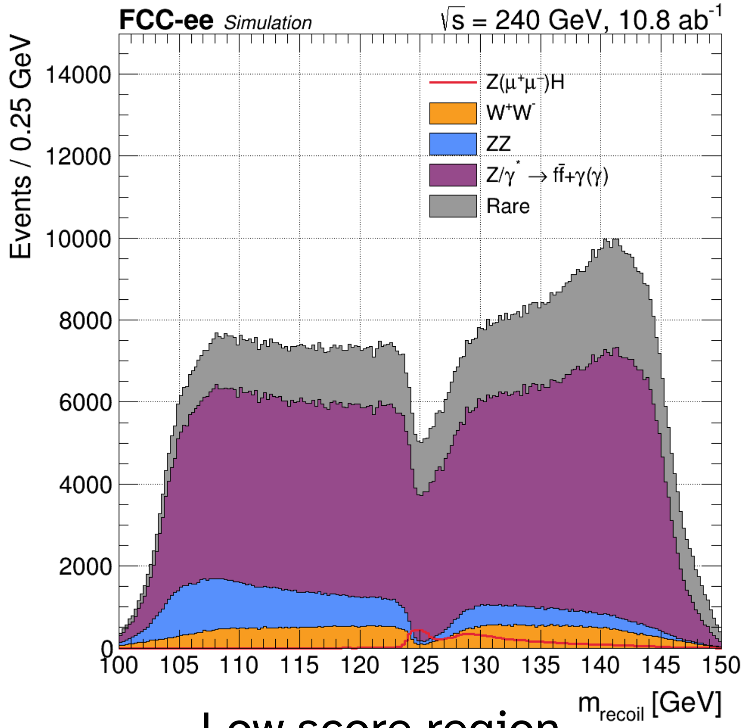


High score region



Low score region

Fit the m_{recoil} distribution in 100-150 GeV range in 2 BDT score regions

- High score region: BDT score > 0.90(0.92) for $\mu^+\mu^-(e^+e^-)$
- Low score region: BDT score < 0.90(0.92) for $\mu^+\mu^-(e^+e^-)$

Also consider contributions from $Z(\to\tau^+\tau^-)H$, $Z(\to\nu\bar{\nu})H$ and $Z(\to q\bar{q})H$

Take a 1% normalization for all background processes (uncorrelated)

Use the same strategy for 365 GeV (see back-up slides)

Channel	$\Delta\sigma_{ZH}$ (240 GeV)	$\Delta\sigma_{ZH}$ (365 GeV)
$Z(\to e^+e^-)H$	0.79%	1.89%
$Z(\to \mu^+\mu^-)H$	0.68%	1.57%
$Z(\to \ell^+\ell^-)H$	0.52%	1.31%

BIAS TEST

Absolute model-independence is not possible

- But can determine the degree of model-dependence

Use the bias test to determine it:

- Modify σ_{ZH} so that $\delta\sigma_{ZH}/\sigma_{ZH} = X\%$
- Attribute this change to one Higgs decay
- Construct pseudo-data from these perturbed branching ratios
- Extract the bias by fitting the pseudo-data
    - $b = 100\times(\mu_{fit} - 1 - X/100)$ with X in %

Model-independence criteria

- If $|b| < \Delta\sigma_{ZH}$, the selection is considered model-independent

Baseline selection biases

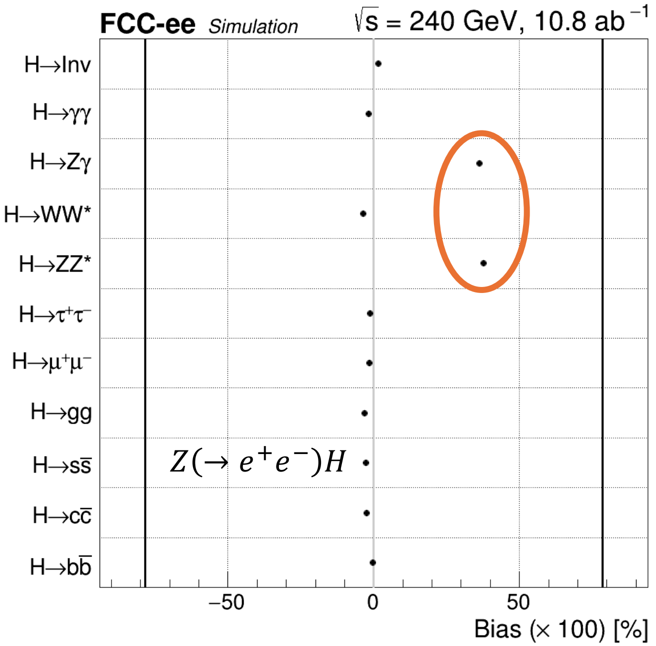
- Biases for $H \to \mu^+\mu^-, ZZ^*, Z\gamma$ are high due to ambiguity in the selection at the χ^2 step (combinatorics)
- Can select events from $Z(\to \tau^+\tau^-, \nu\bar{\nu}, q\bar{q})H$
- $|b| < \Delta\sigma_{ZH}$ for all decays → Baseline is model-independent

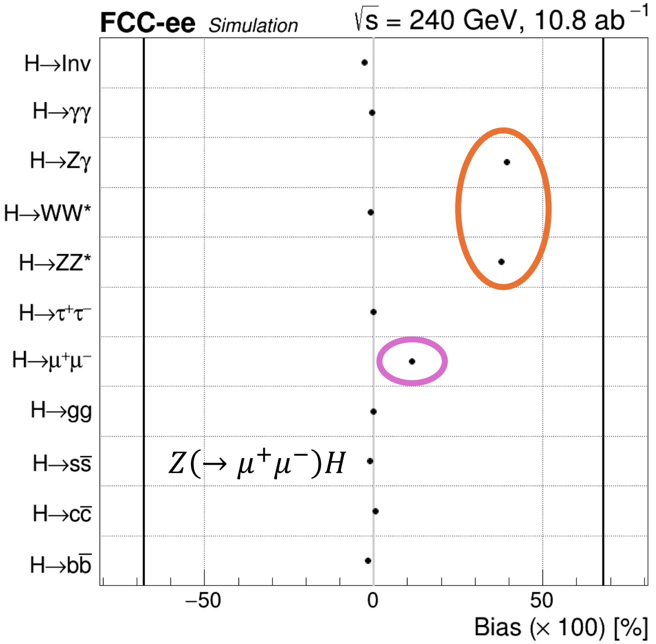
$X = 5\%$ prior taken for all the bias tests

- Conservative value taken
- Deviation of this size would be interpretable as BSM physics

Biases for 365 GeV are in the back-up

- **Black**: Low bias
- **Violet**: Medium bias
- **Orange**: High bias
- **Red**: Unacceptable bias
- **Green**: Improvement





Decays	Biases [%]
$H \to b\bar{b}$	-0.02
$H \to c\bar{c}$	+0.00
$H \to s\bar{s}$	-0.01
$H \to gg$	+0.00
$H \to \mu^+\mu^-$	+0.11
$H \to \tau^+\tau^-$	-0.00
$H \to ZZ^*$	+0.38
$H \to WW^*$	-0.01
$H \to Z\gamma$	+0.39
$H \to \gamma\gamma$	-0.00
$H \to Inv$	-0.03

LEPTONIC CHANNEL IMPROVEMENTS

FSR RECOVERY

Leptons lose energy through FSR thus degrading the Z reconstruction

- Recovering this energy could improve the lepton pairing at the χ^2
- Could also improve the selection efficiency due to better energy reconstruction

We do not want to recover the energy of leptons coming from jets

- Only recover the energy of leptons that are enough isolated
- Only consider leptons with $I_{rel} < 1.80(0.95)$ for 240(365) GeV
- Improve the lepton-photon pairing efficiency

We merge lepton-photon pair that are collinear enough

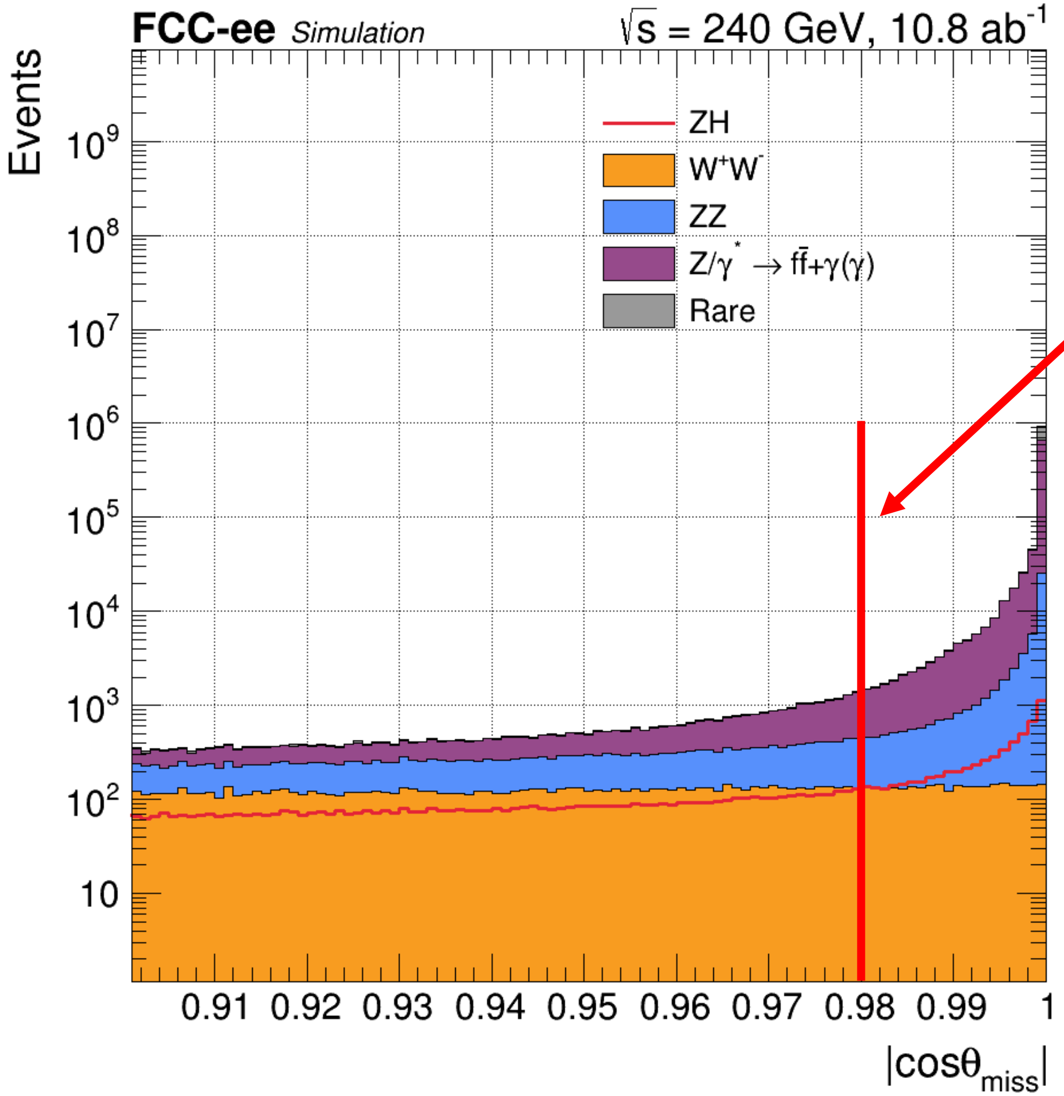
- At 240 GeV, only merge lepton-photon pairs that have $\pi - \Delta\alpha_{\ell^+\ell^-} > 3.08$
- At 365 GeV, only merge lepton-photon pairs that have $\Delta R < 0.25$

Impact on the selection

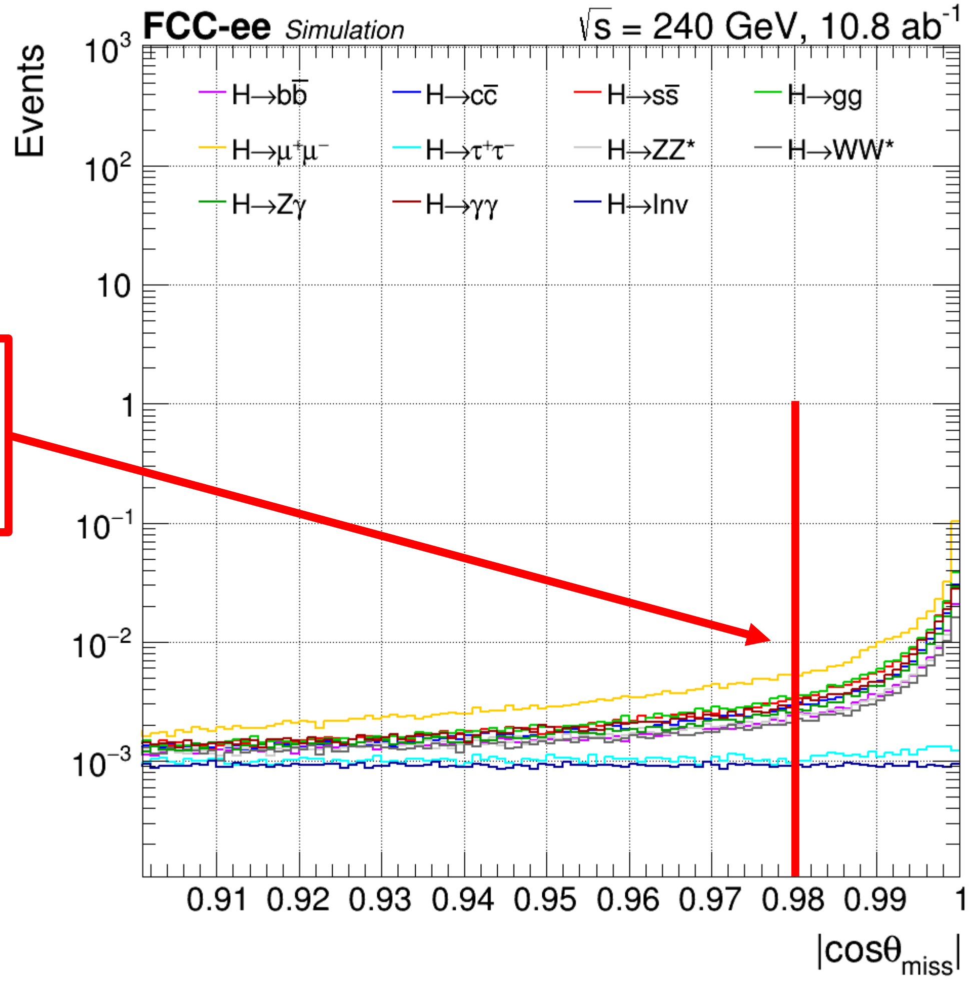
- Improve the pairing efficiency at the χ^2 step of ~3% for $H \to \mu^+\mu^-, ZZ^*, Z\gamma$
- Improve selection efficiency by 3(7)% for $\mu^+\mu^-(e^+e^-)$ channel
  - More signal events pass the $m_{\ell^+\ell^-}$ cut
  - Due to better Z mass reconstruction

Channel	$\Delta\sigma_{ZH}$ (240 GeV)			$\Delta\sigma_{ZH}$ (365 GeV)		
	Baseline	With FSR	Improvement	Baseline	With FSR	Improvement
$Z(\to e^+e^-)H$	0.79%	0.70%	**11.4%**	1.89%	1.65%	**12.7%**
$Z(\to \mu^+\mu^-)H$	0.68%	0.65%	**4.4%**	1.77%	1.65%	**6.8%**
$Z(\to \ell^+\ell^-)H$	0.52%	0.48%	**7.7%**	1.31%	1.18%	**9.9%**

NEW SELECTION CUT



Cut used in Higgs mass analysis



$\cos\theta_{miss}$ is a very discriminant variable

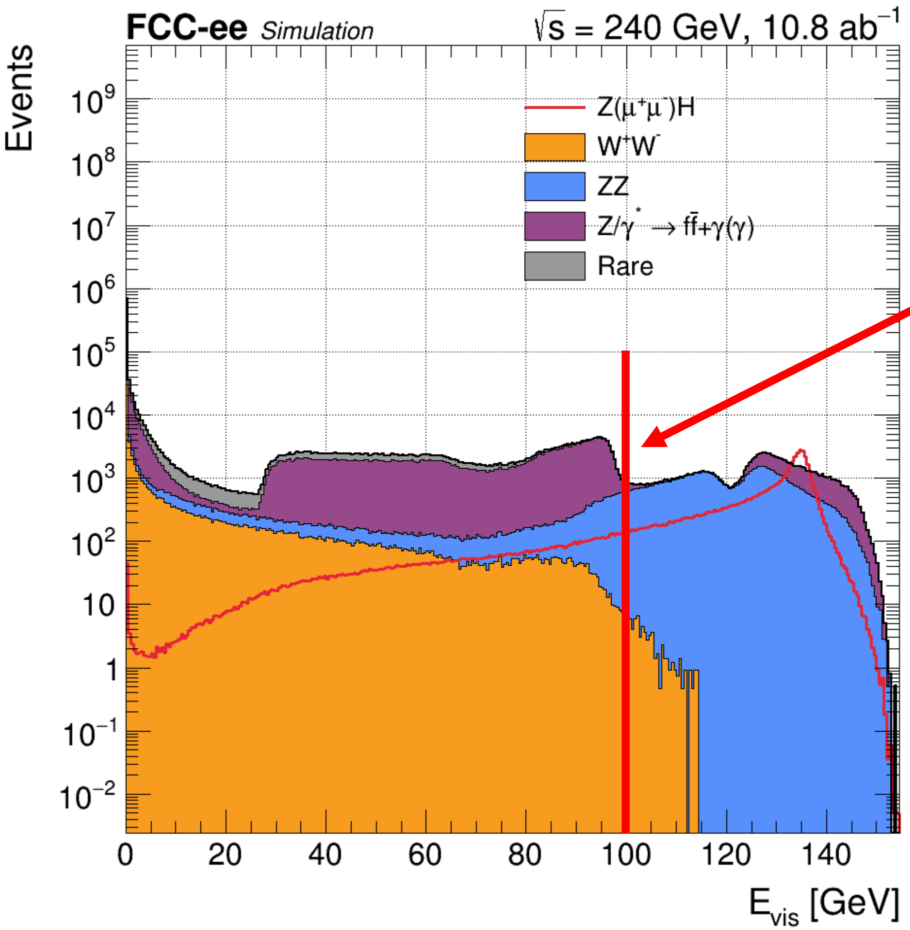
- Good to remove ZZ, Z/γ and Rare backgrounds
- But would break model-independence if used naively

Already used in the Higgs mass analysis

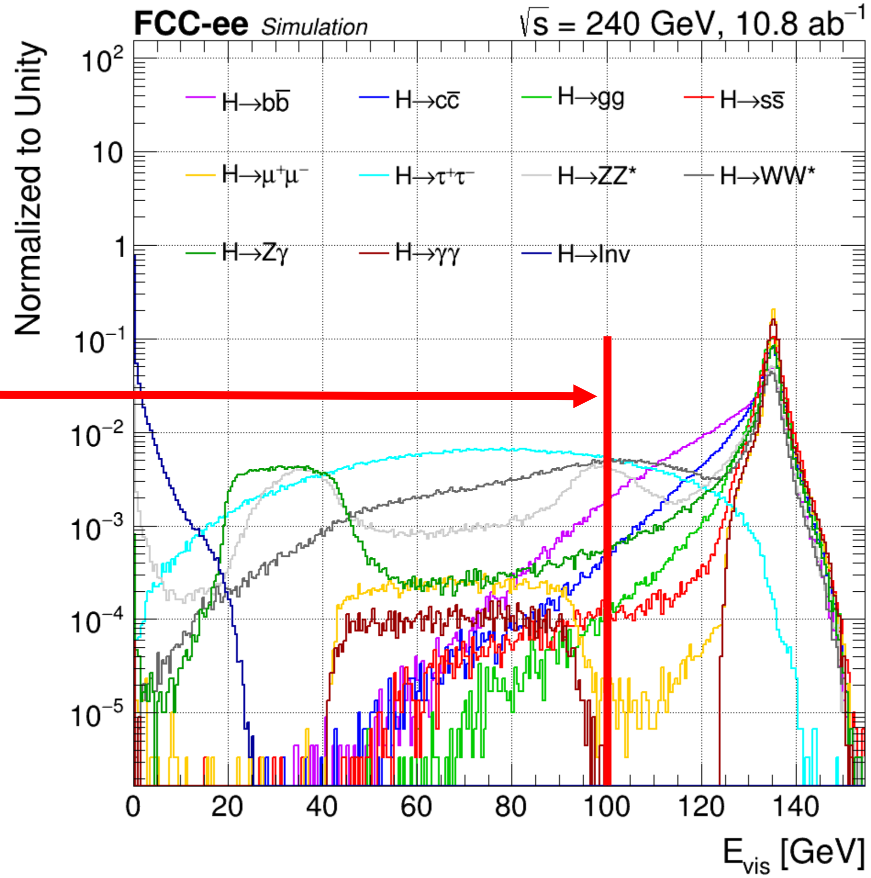
- Don't require model-independence

Will need to use a roundabout approach to use this variable

A ROUNDABOUT APPROACH



Cut used to categorize events into "visible" and "invisible" sample



Visible energy E_{vis} is also a very discriminant variable

- Good to remove WW, Z/γ and Rare backgrounds
- But would also break model-independence if use to remove events

Will instead use it to categorize events*

- Define the "visible" sample: $E_{vis} > 100(171)\ GeV$ for 240(365) GeV
- Define the "invisible" sample: $E_{vis} < 100(171) GeV$ for 240(365) GeV

Will only apply $\cos\theta_{miss} < 0.99$ on the invisible sample

- Where the Z/γ and Rare backgrounds mainly are

(*): Inspired from ILC selection, they separate the analysis into 2 samples based on E_{vis} (arxiv:1604.07524v3)

IMPACT ON THE PRECISION

Channel	$\Delta\sigma_{ZH}$ (240 GeV)			$\Delta\sigma_{ZH}$ (365 GeV)		
	Baseline with FSR recovery	New cut	Improvement	Baseline with FSR recovery	New cut	Improvement
$Z(\to e^+e^-)H$	0.70%	0.58%	**17.14%**	1.65%	1.47%	**10.9%**
$Z(\to \mu^+\mu^-)H$	0.65%	0.57%	**12.3%**	1.65%	1.46%	**11.5%**
$Z(\to \ell^+\ell^-)H$	0.48%	0.41%	**14.6%**	1.18%	1.05%	**11.0%**

Get an improvement of ~15(11)% for 240(365) GeV and an accumulated improvement of ~20%

- Greater improvement for $Z(\to e^+e^-)H$ because electrons radiate more than muons
- Now $Z(\to e^+e^-)H$ and $Z(\to \mu^+\mu^-)H$ have equal precision
- Reach the 1% combined precision for 365 GeV

Channel	$\Delta\sigma_{ZH}$ (240 GeV)			$\Delta\sigma_{ZH}$ (365 GeV)		
	Without FSR recovery	New cut	Improvement	Without FSR recovery	New cut	Improvement
$Z(\to e^+e^-)H$	0.79%	0.58%	**26.6%**	1.89%	1.47%	**22.2%**
$Z(\to \mu^+\mu^-)H$	0.68%	0.57%	**16.2%**	1.77%	1.46%	**17.5%**
$Z(\to \ell^+\ell^-)H$	0.52%	0.41%	**21.2%**	1.31%	1.05%	**19.8%**

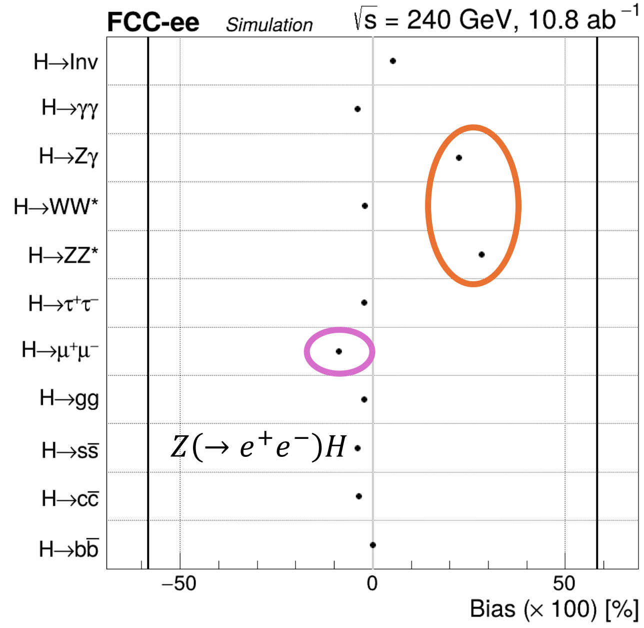
BIAS TEST FOR NEW SELECTION

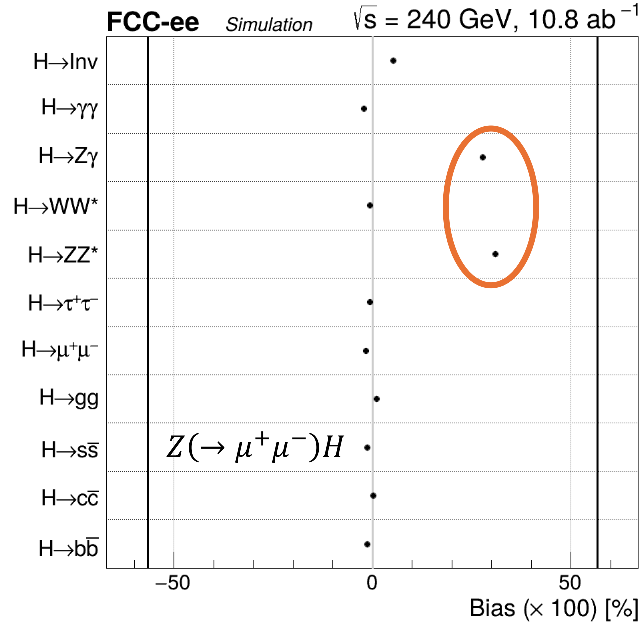
Compared to the original selection

- No higher bias observed for all decays
- Still get high bias for $H \rightarrow \mu^+\mu^-, ZZ^*, Z\gamma$
  - No high bias for $H \rightarrow \mu^+\mu^-$ in $Z(\rightarrow \mu^+\mu^-)H$
  - Still observe it for $Z(\rightarrow e^+e^-)H$
- High biases still due to ambiguity in the χ^2 step

No $|b| > \Delta\sigma_{ZH}$ observed

- No new bias introduced in the new selection
- New selection is thus model-independent





Decays	$Z(e^+e^-)H$	$Z(\mu^+\mu^-)H$
$H \rightarrow b\bar{b}$	+0.00	-0.01
$H \rightarrow c\bar{c}$	-0.04	+0.00
$H \rightarrow s\bar{s}$	-0.04	-0.01
$H \rightarrow gg$	-0.02	+0.01
$H \rightarrow \mu^+\mu^-$	-0.09	-0.02
$H \rightarrow \tau^+\tau^-$	-0.02	+0.01
$H \rightarrow ZZ^*$	+0.28	+0.31
$H \rightarrow WW^*$	-0.02	-0.01
$H \rightarrow Z\gamma$	+0.22	+0.28
$H \rightarrow \gamma\gamma$	-0.04	-0.02
$H \rightarrow Inv$	+0.05	+0.05

HADRONIC CHANNEL

Will only show plots for 240 GeV

Plots for 365 GeV are in the back-up slides for the curious ones

The results will be presented for both energies

EVENT SELECTION (240 GEV)

<u>Veto the leptonic analysis:</u>

- Remove events that pass the leptonic selection
- Ensure orthogonality between the channel

<u>Object selection:</u>

- Use exclusive N=2,4,6 and inclusive clustering algorithm
- Remove jets with $p_j < 5$ GeV

For each algorithm, select the jet pair that minimize the χ^2:

- $\chi^2 = \left(m_{jj} - 91.2\ GeV\right)^2 + \left(p_{jj} - p_Z\right)^2 + (m_{recoil} - 125\ GeV)^2$
- $p_Z = 52$ GeV, reduce ambiguity

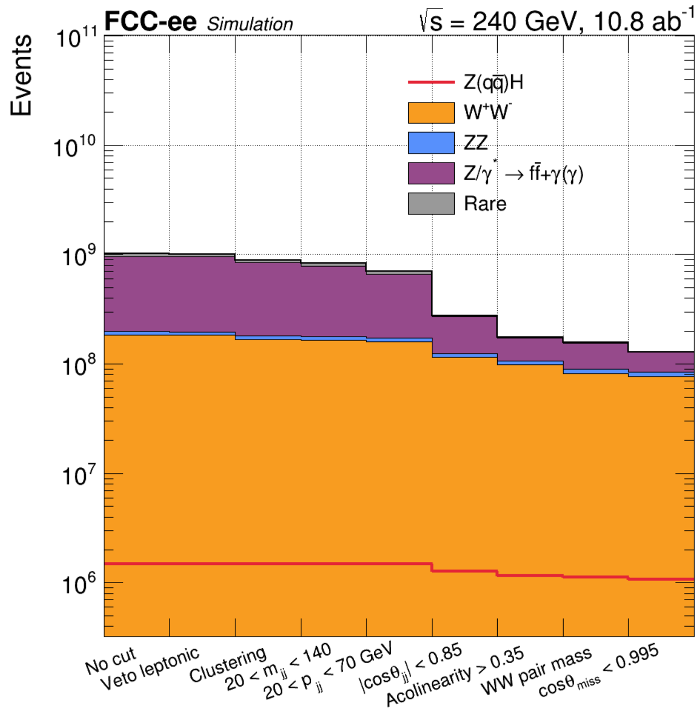
Select the clustering algorithm with the lowest χ^2

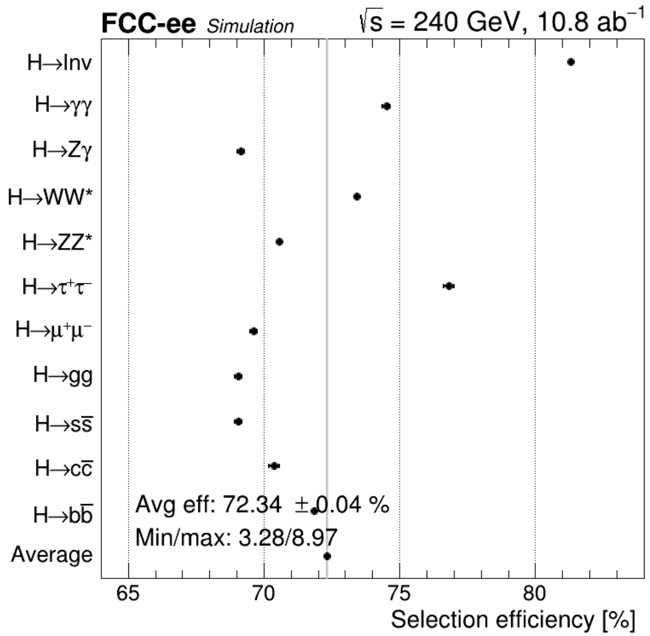
- Reject events if the clustering fails

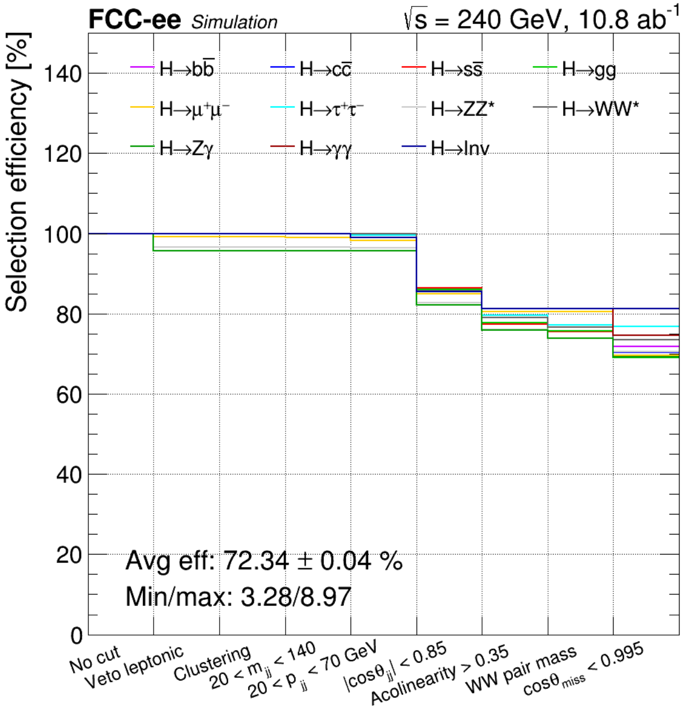
<u>Kinematic selection:</u>

- $20\ GeV < m_{jj} < 140\ GeV$
- $20 < p_{jj} < 90\ GeV$
- $|\cos\theta_{jj}| < 0.85$
- $\pi - \Delta\alpha_{jj} > 0.35$
- WW pair mass cut
- $|\cos\theta_{miss}| < 0.995$

More spread in the selection efficiency due to ambiguity in the selection



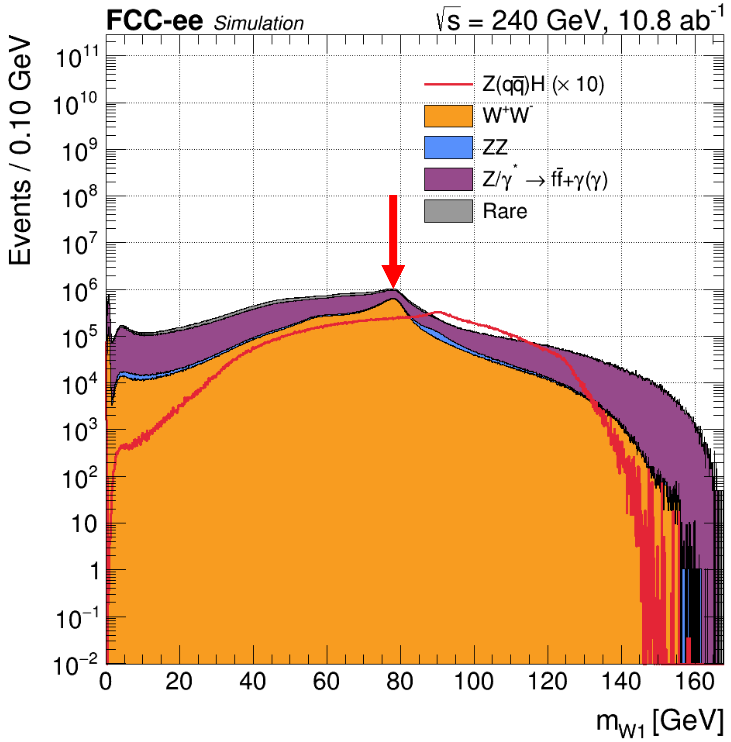


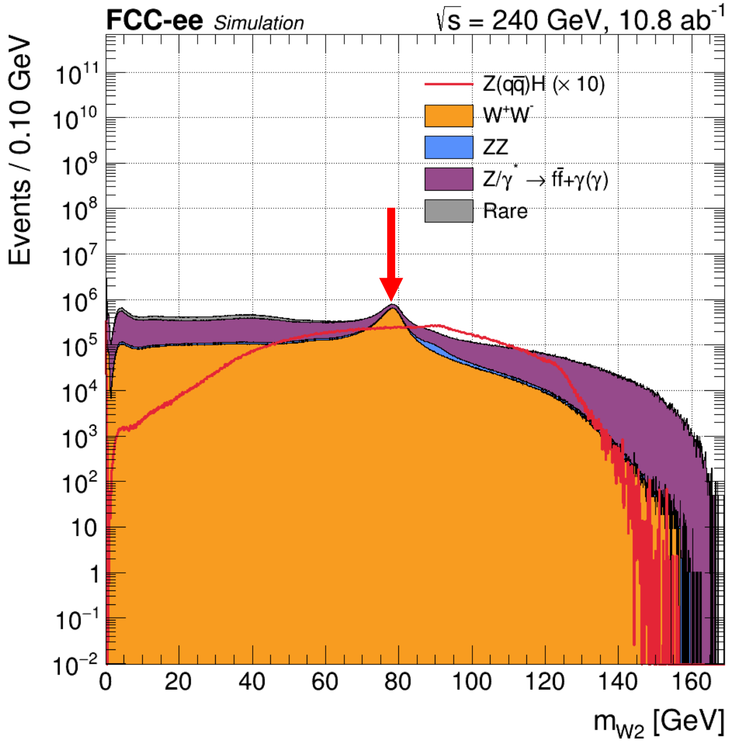


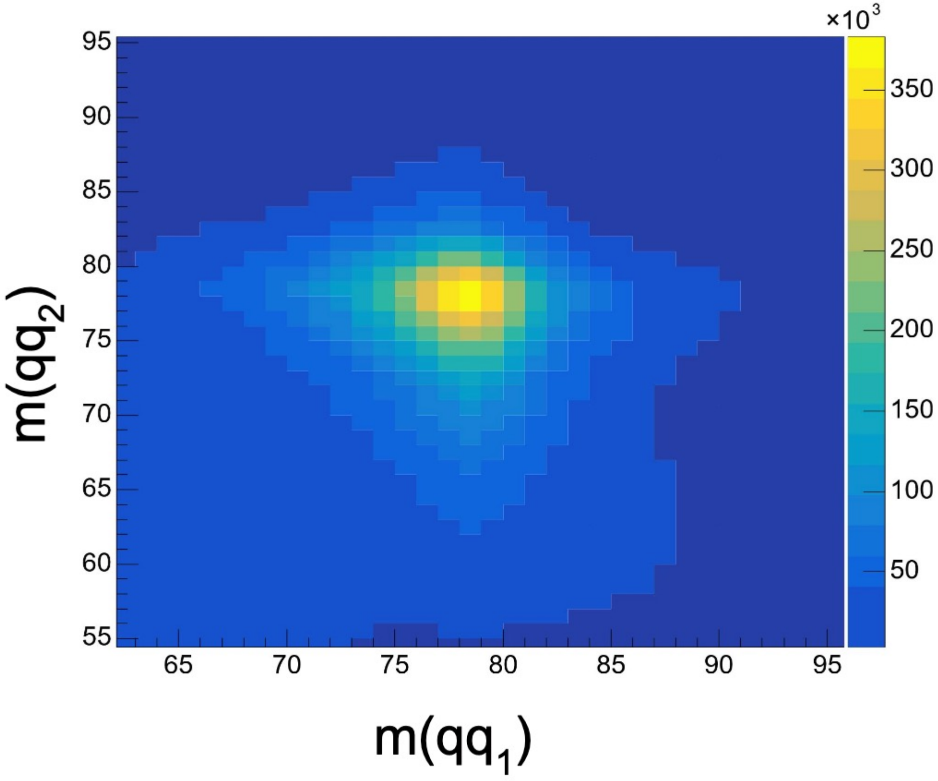
WW PAIR MASS CUT

For each events, use the N=4 clustering algorithm to reconstruct a pair of W boson

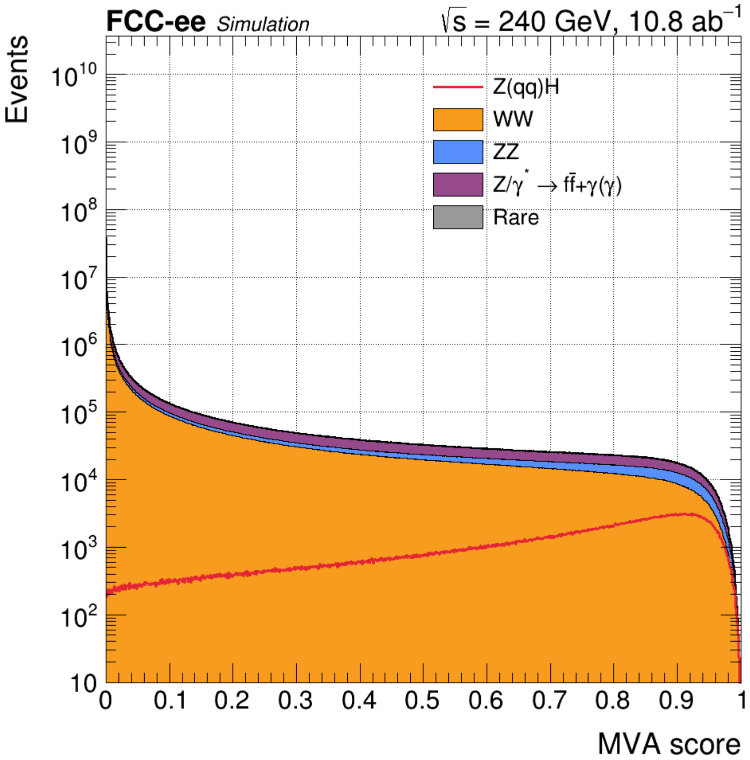
- Form pairs that minimize $\chi^2 = \left(m_{jj} - 80.4\ \mathrm{GeV}\right)^2 + \left(m_{jj} - 80.4\ \mathrm{GeV}\right)^2$
- Apply a 2D cut in the $m_{W1} - m_{W2}$ mass plane
- Remove events with $\Delta m_W < 6\ \mathrm{GeV}$

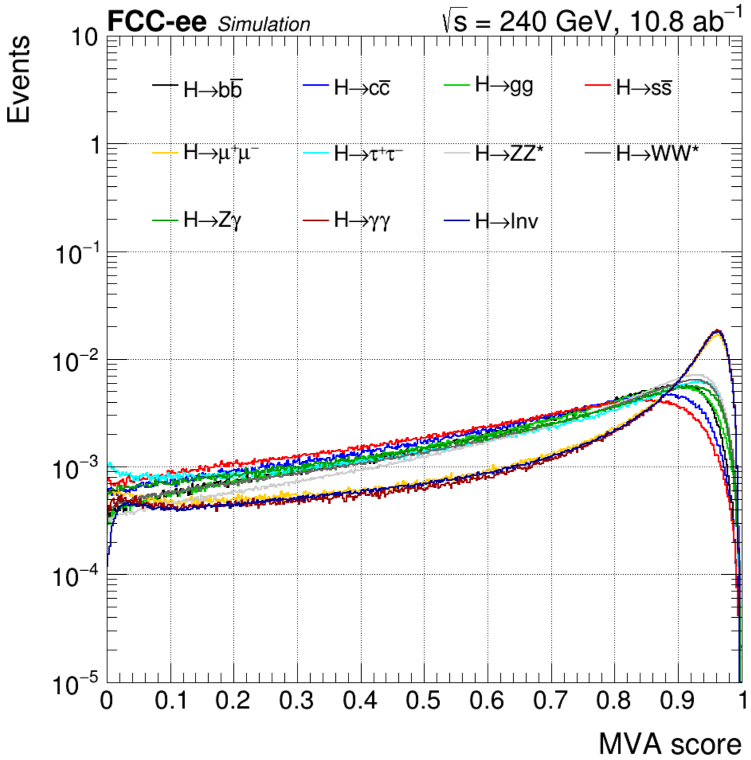






MVA DISCRIMINATION (240 GEV)





Variables	Description
$p_{leading}$, $p_{subleading}$	Leading and subleading jet momentum
$\theta_{leading}$, $\theta_{subleading}$	Leading and subleading jet momentum
p_{jj}	Jet pair momentum
θ_{jj}	Jet pair polar angle
$\pi - \Delta\alpha_{jj}$	Acolinearity
$\pi - \Delta\phi_{jj}$	Acoplanarity
$m_{W1,2}$	First and second W mass
$p_{W1,2}$	First and second W momentum
$\theta_{W1,2}$	First and second W polar angle
T	Thrust of the event

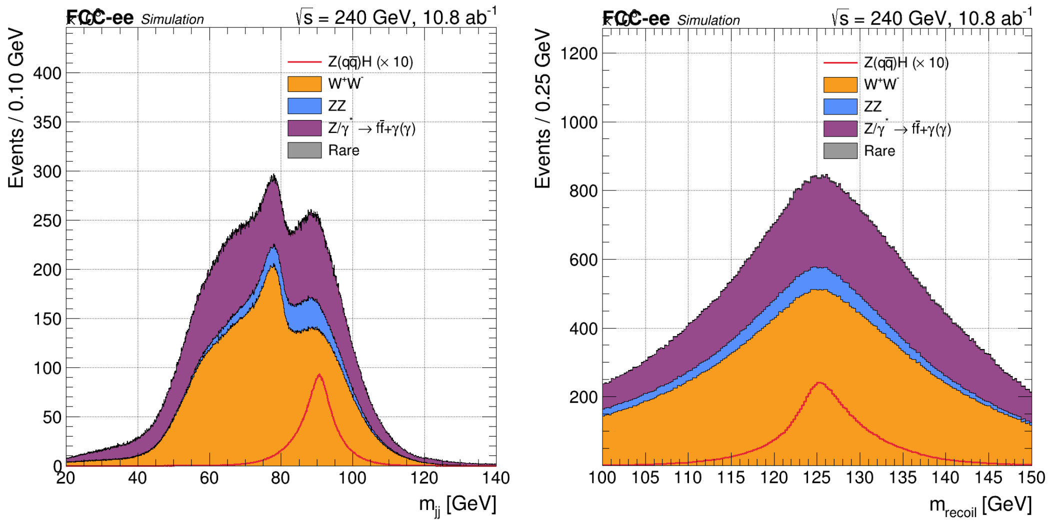
Train a BDT to further discriminate signal from background

- Give individual jet and jet pair kinematics as input
- Give angular correlation variables as input
- Give the reconstructed WW pair variables and the thrust of the event

BDT score distribution has some differences between the Higgs decays

- $H \rightarrow \mu^+\mu^-, \gamma\gamma, Inv$ have the same shape distribution
- The other decays also have roughly the same shape distribution
- Better distribution for H not decaying hadronically

UNCERTAINTY EXTRACTION (240 GEV)



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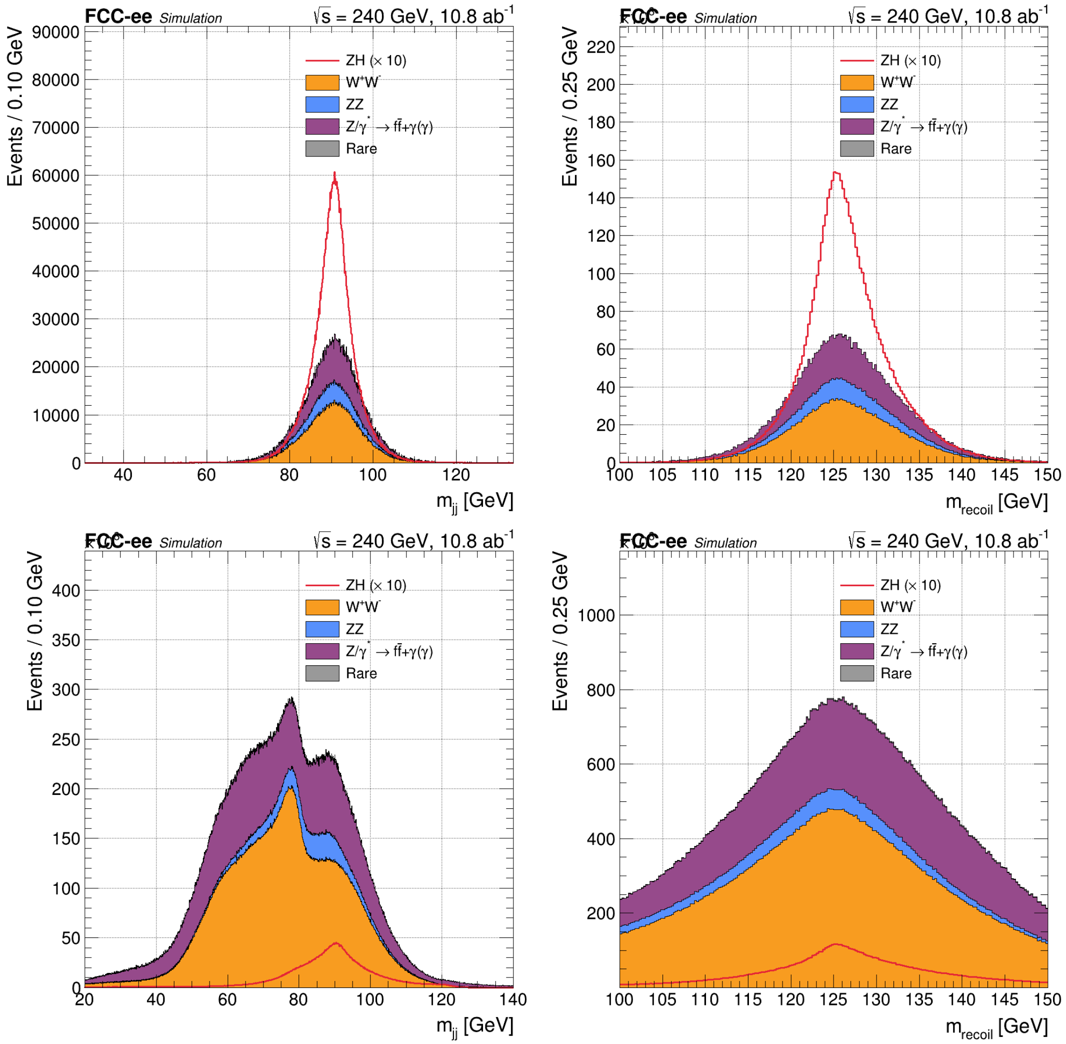


Fit the $m_{jj} - m_{recoil}$ distribution in 2 BDT score regions

- High score region: BDT score > 0.75
- Low score region: BDT score < 0.75

Also consider contributions from $Z(\rightarrow \ell^+\ell^-)H$ and $Z(\rightarrow \nu\bar{\nu})H$

Take a 1% normalization for all background processes

Use the same strategy for 365 GeV (see back-up slides)

Channel	$\Delta\sigma_{ZH}$(240 GeV)	$\Delta\sigma_{ZH}$(365 GeV)
$Z(\rightarrow q\bar{q})H$	0.38%	0.56%

SELECTION BIAS (240 GEV)

Take a $X = 1\%$ prior for the hadronic channel

- Take a lower value because σ_{ZH} already constrained by $Z(\to \ell^+\ell^-)H$
- $\Delta\sigma_{ZH} \ll X$ for $Z(\to q\bar{q})H \to$ still a conservative value

$|\boldsymbol{b}| > \boldsymbol{\Delta\sigma_{ZH}}$ **for** $\boldsymbol{H \to \gamma\gamma, Inv}$

- Bias slightly higher than uncertainty
- Due to BDT score distribution dependence on these decay
- $H \to \gamma\gamma, Inv$ have a small branching ratios
    - Test remains conservative and biases acceptable

Could implement the improvement from $\boldsymbol{Z(\to \ell^+\ell^-)H}$

- Could reduce the biases
- Working on it

Decays	Biases [%]
$H \to b\bar{b}$	+0.04
$H \to c\bar{c}$	-0.08
$H \to s\bar{s}$	-0.17
$H \to gg$	-0.04
$H \to \mu^+\mu^-$	+0.26
$H \to \tau^+\tau^-$	-0.04
$H \to ZZ^*$	+0.02
$H \to WW^*$	-0.07
$H \to Z\gamma$	-0.17
$H \to \gamma\gamma$	+0.43
$H \to Inv$	+0.51

LEPTONIC + HADRONIC COMBINATION

LEPTONIC AND HADRONIC COMBINATION

Channel	$\Delta\sigma_{ZH}$ (240 GeV)			$\Delta\sigma_{ZH}$ (365 GeV)		
	Baseline	New selection	Improvement	Baseline	New selection	Improvement
$Z(\rightarrow e^+e^-)H$	0.79%	0.58%	**26.6%**	1.89%	1.47%	**22.2%**
$Z(\rightarrow \mu^+\mu^-)H$	0.68%	0.57%	**16.2%**	1.77%	1.46%	**17.5%**
$Z(\rightarrow \ell^+\ell^-)H$	0.52%	0.41%	**21.2%**	1.31%	1.05%	**19.8%**
$Z(\rightarrow q\bar{q})H$	0.38%	**X**	**X**	0.56%	**X**	**X**
ZH	0.31%	0.28%	**9.7%**	0.52%	0.49%	**5.8%**

Combine all channels to get the total precision on σ_{ZH}

- Use a 1% normalization on the backgrounds (uncorrelated)
- Hadronic channel gives most of the sensitivity

Get a small improvement on the total $\Delta\sigma_{ZH}$

- The improvement of $Z(\rightarrow \ell^+\ell^-)H$ is screened by $Z(\rightarrow q\bar{q})H$
- Leptonic precision is similar to the hadronic one for 240 GeV
- At 365 GeV, the leptonic precision is twice the hadronic one
  - Get a better improvement at 240 GeV than at 365 GeV

CONCLUSION AND OUTLOOK

Improved the leptonic channel precision by ~20% for 240 GeV and 365 GeV

- Did it while keeping the bias low
- Due to categorizing the events with E_{vis}

Combined the new precision with the hadronic channel

- Get a lower improvement (~5-10%)
- Because the hadronic channel gives most of the total sensitivity

Will now work on improving the hadronic channel

- Will try to use the new method to improve the precision
- Will also work on reducing the biases

After the hadronic channel is implemented

- Will propagate the improvement on the Higgs self-coupling

THANKS FOR LISTENING

Link to the code used: https://github.com/tomfournier/FCCWorkspace

Email: tom.fournier@cern.ch

BACK-UP SLIDES

LEPTONIC CHANNEL

EVENTS SELECTION (365 GEV)

<u>Object selection:</u>

- Only consider leptons with $p > 20\ GeV$
- Require at least one isolated lepton ($I_{rel} < 0.25$)
- Require at least 2 leptons with opposite charge

If more than 2 leptons OS in the events:

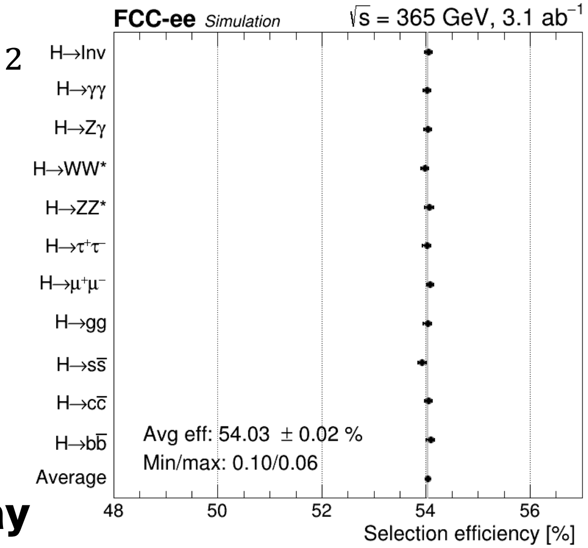
- Exclude pairs with $|m_{\ell^+\ell^-} - m_H| < 3\ GeV$

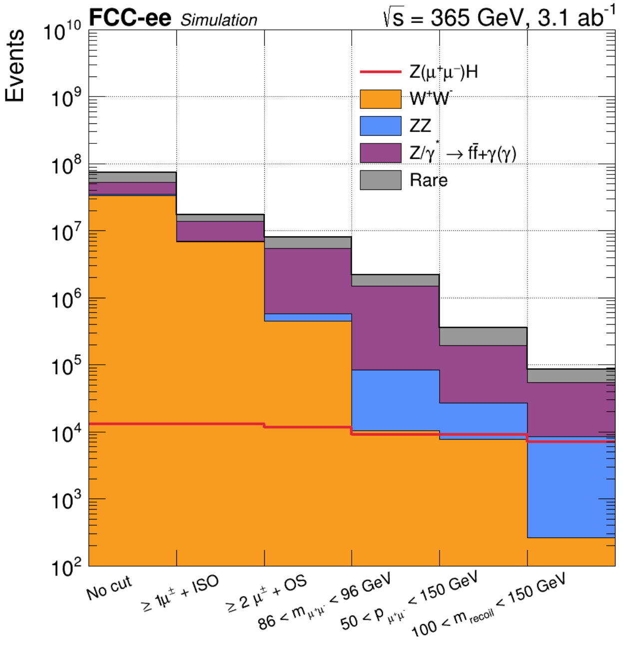
Select the pair that minimizes the χ^2:

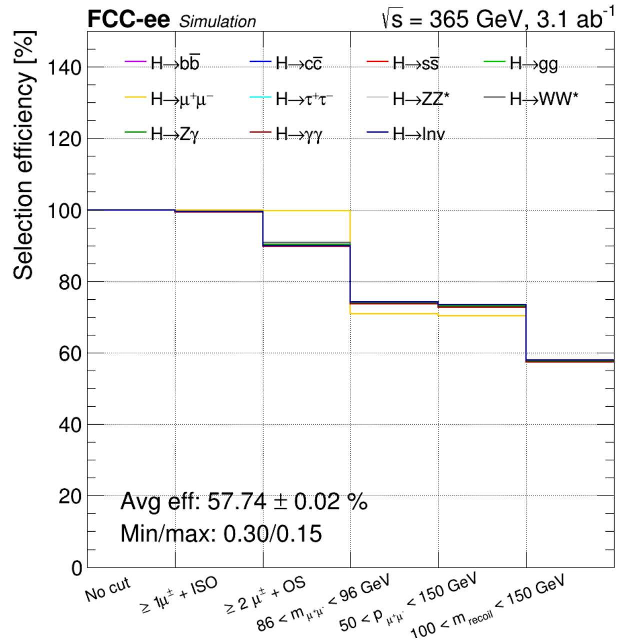
- $\chi^2 = 0.6\times(m_{\ell^+\ell^-} - 91.2\ GeV)^2 + 0.4\times(m_{recoil} - 125\ GeV)^2$

<u>Kinematic selection:</u>

- $86\ GeV < m_{\ell^+\ell^-} < 96\ GeV$
- $50\ GeV < p_{\ell^+\ell^-} < 150\ GeV$ (boosted regime)
- $100\ GeV < m_{recoil} < 150\ GeV$





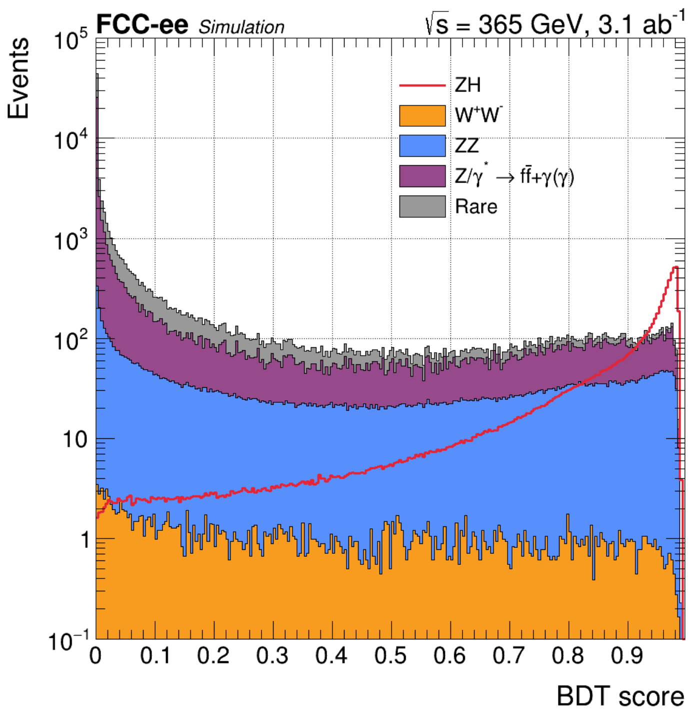


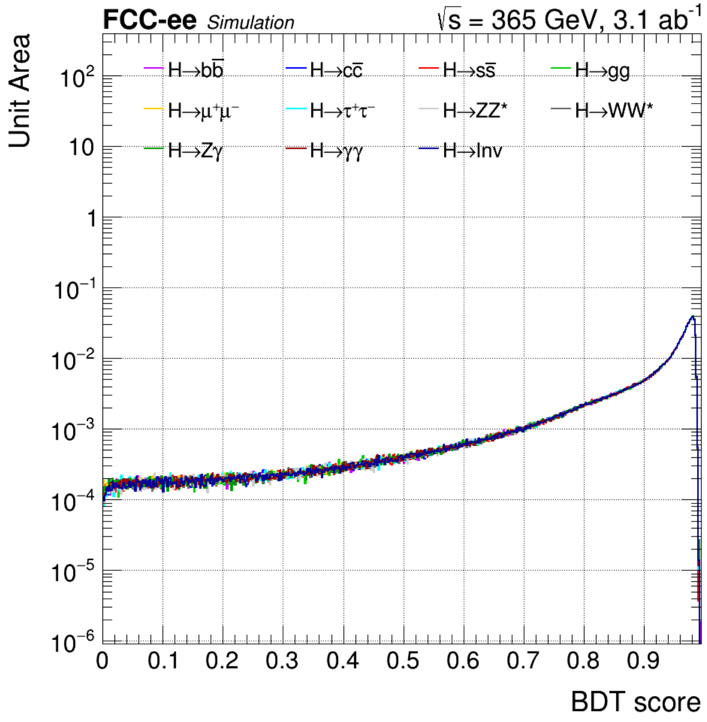
Selection efficiency also independent of the Higgs decay

Added m_{recoil} cut to cutflow at 365 GeV

- Implicitly done when making the m_{recoil} histograms for the fit
- Negligible impact for 240 GeV so was not included
- Included at 365 GeV because of its large effect on the cutflow

MVA DISCRIMINATION (365 GEV)



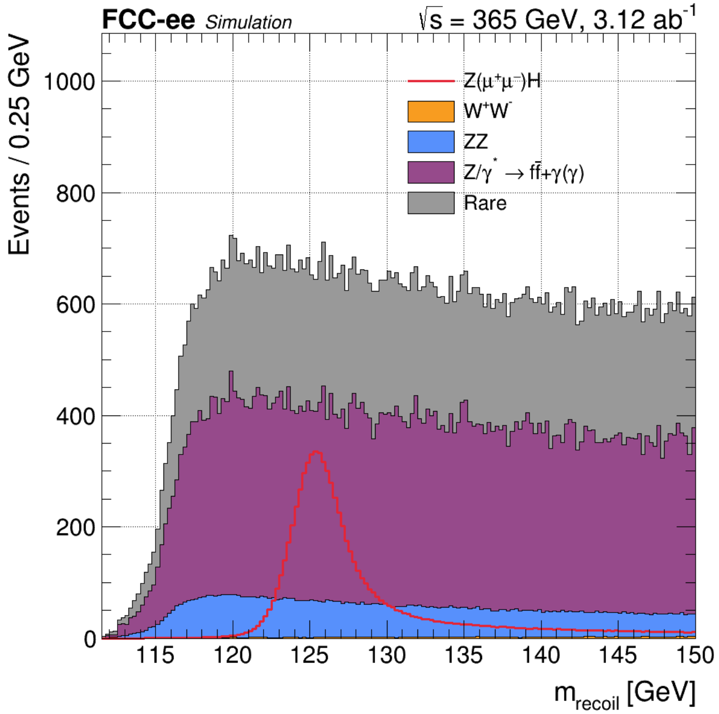


Train a BDT to further discriminate signal from background
- Give individual lepton and lepton pair kinematics as input
- Also give angular correlation variables as input
- $\gamma\gamma \to e^+e^-$ is not included for $Z(\to e^+e^-)H$ training
  - Not enough events due to low selection efficiency

BDT score distribution is independent of the Higgs decay
- BDT preserve the model-independence of the selection

Input variables	Description
$p_{leading}$	Leading lepton momentum
$\theta_{leading}$	Leading lepton polar angle
$p_{subleading}$	Subleading lepton momentum
$\theta_{subleading}$	Subleading lepton polar angle
$m_{\ell^+\ell^-}$	Lepton pair invariant mass
$p_{\ell^+\ell^-}$	Lepton pair momentum
$\theta_{\ell^+\ell^-}$	Lepton pair polar angle
$\pi - \Delta\alpha_{\ell^+\ell^-}$	Acolinearity
$\pi - \Delta\phi_{\ell^+\ell^-}$	Acoplanarity

UNCERTAINTY EXTRACTION (365 GEV)



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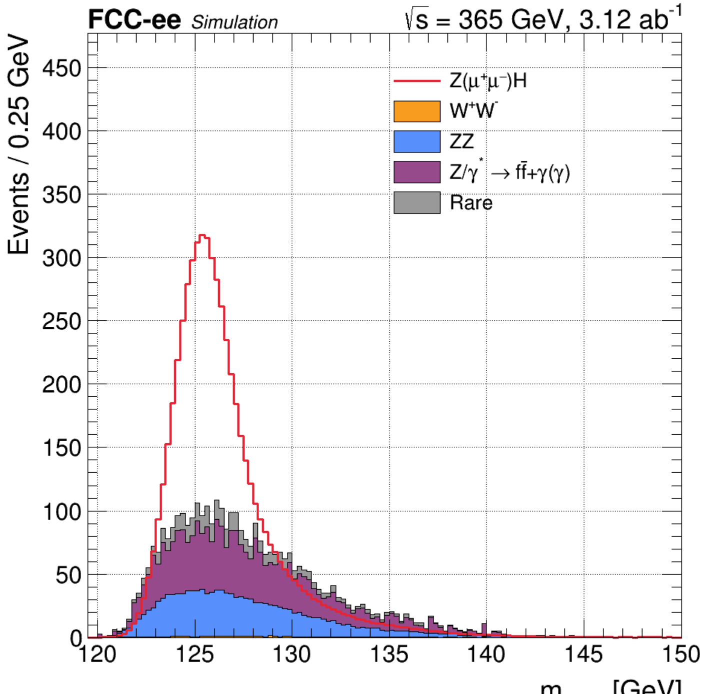
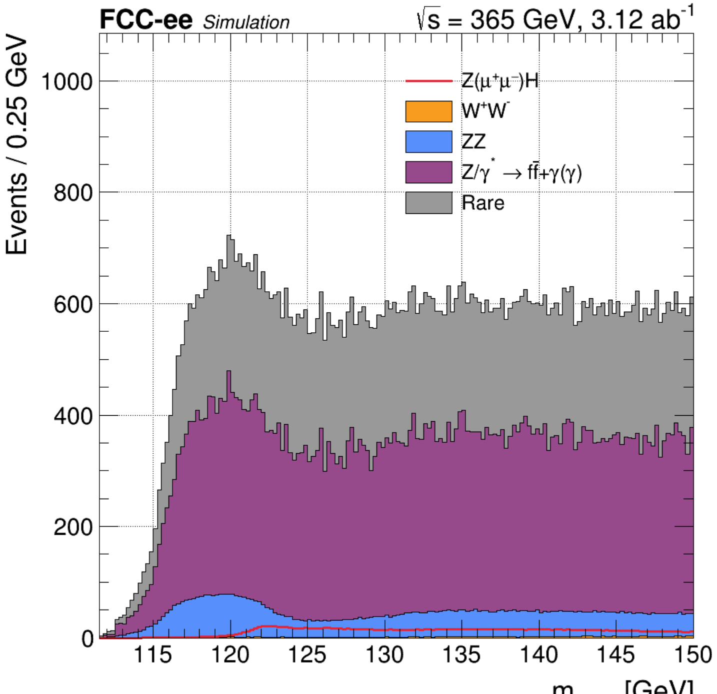


High score region



Low score region

Fit the m_{recoil} distribution in 100-150 GeV range in 2 BDT score regions

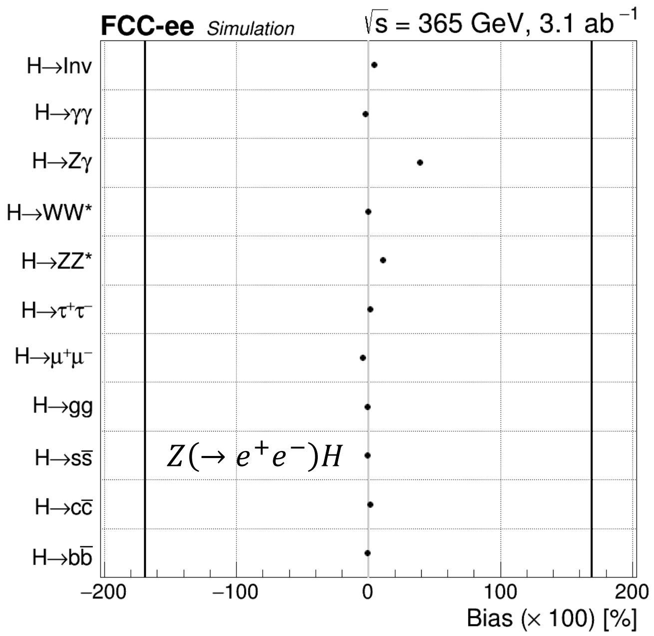
- High score region: BDT score > 0.83(0.79) for $\mu^+\mu^-(e^+e^-)$
- Low score region: BDT score < 0.83(0.79) for $\mu^+\mu^-(e^+e^-)$

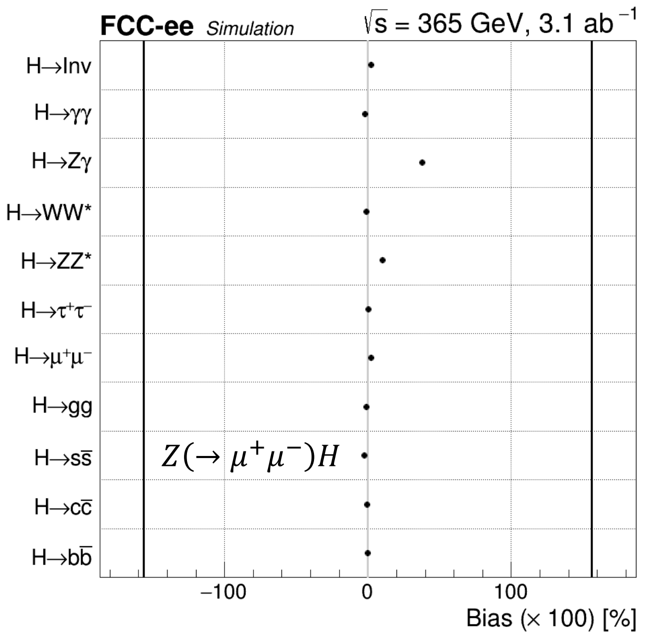
Also consider contributions from $Z(\to \tau^+\tau^-)H$, $Z(\to \nu\bar{\nu})H$ and $Z(\to q\bar{q})H$

Take a 1% normalization for all background processes (uncorrelated)

Channel	$\Delta\sigma_{ZH}$ (240 GeV)	$\Delta\sigma_{ZH}$ (365 GeV)
$Z(\to e^+e^-)H$	0.79%	1.89%
$Z(\to \mu^+\mu^-)H$	0.68%	1.57%
$Z(\to \ell^+\ell^-)H$	0.52%	1.17%

BIAS TEST (365 GEV)



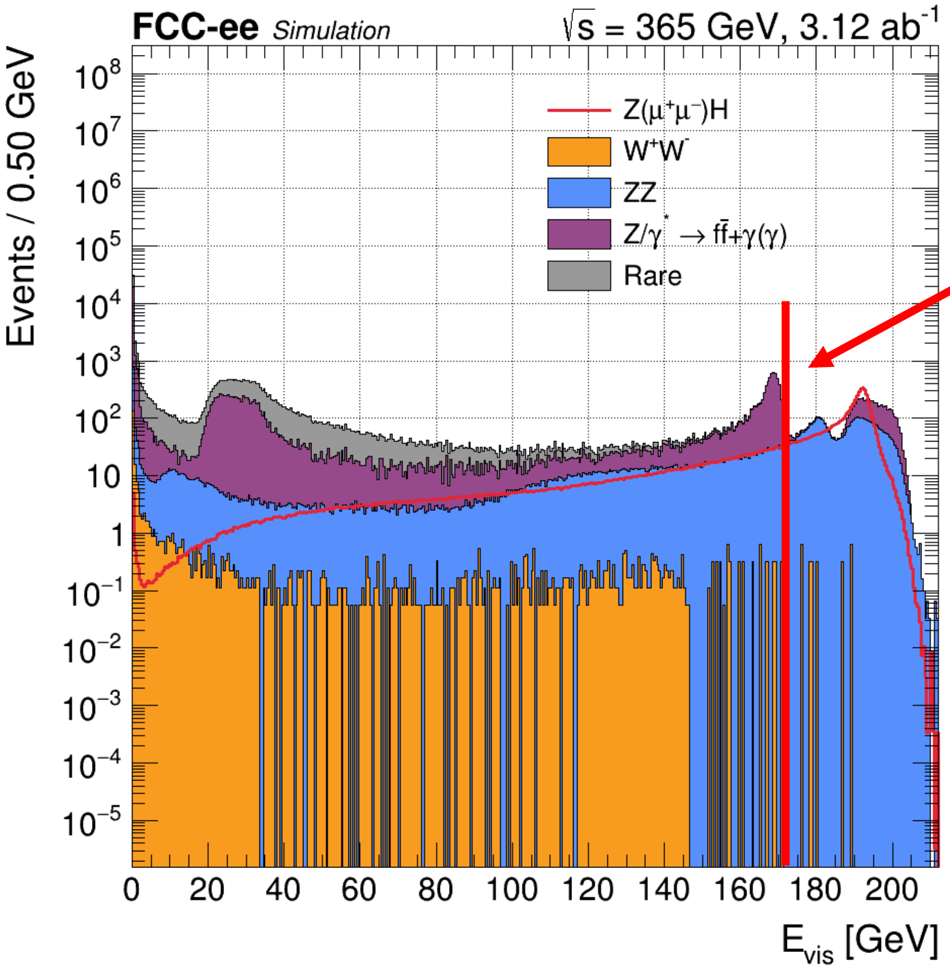


$|b| < \Delta\sigma_{ZH}$ for all decays → selection is model-independent at 365 GeV

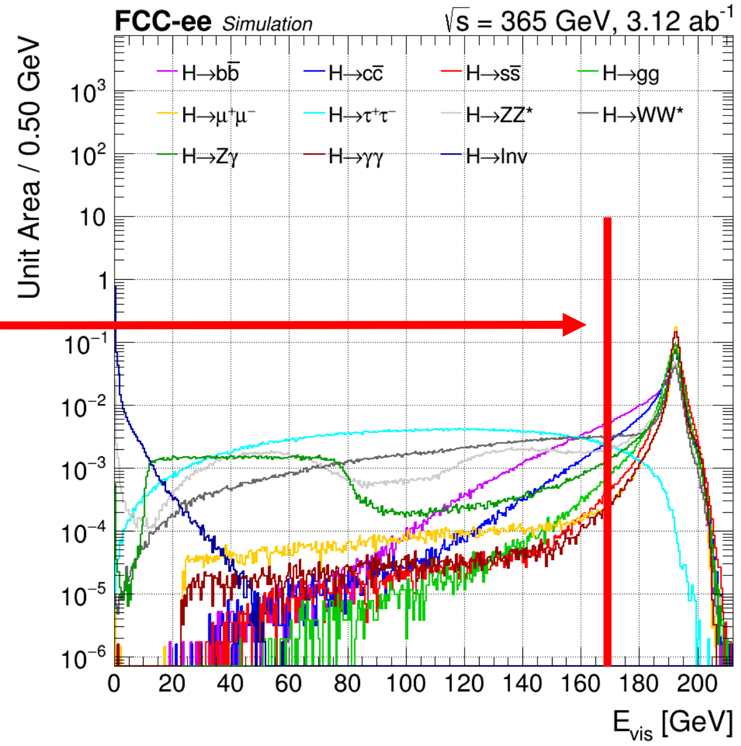
- Bias for $H \rightarrow ZZ^*$ is lower than for 240 GeV
- Still get a high bias for $H \rightarrow Z\gamma$
- No bias observed for $H \rightarrow \mu^+\mu^-$ at 365 GeV

Decays	Biases [%]	Biases [%]
$H \rightarrow b\bar{b}$	+0.00	+0.00
$H \rightarrow c\bar{c}$	-0.00	-0.01
$H \rightarrow s\bar{s}$	-0.03	-0.04
$H \rightarrow gg$	-0.01	-0.01
$H \rightarrow \mu^+\mu^-$	+0.03	+0.02
$H \rightarrow \tau^+\tau^-$	-0.01	+0.00
$H \rightarrow ZZ^*$	+0.06	+0.10
$H \rightarrow WW^*$	-0.01	-0.01
$H \rightarrow Z\gamma$	+0.28	+0.36
$H \rightarrow \gamma\gamma$	-0.00	-0.02
$H \rightarrow Inv$	-0.00	+0.02

A ROUNDABOUT APPROACH (365 GEV)



Cut used to categorize events into "visible" and "invisible" sample



Visible energy E_{vis} is also a very discriminant variable

- Good to remove WW, Z/γ and Rare backgrounds
- But would also break model-independence if use to remove events

Will instead use it to categorize events*

- Define the "visible" sample: $E_{vis} > 171\ GeV$
- Define the "invisible" sample: $E_{vis} < 171\ GeV$

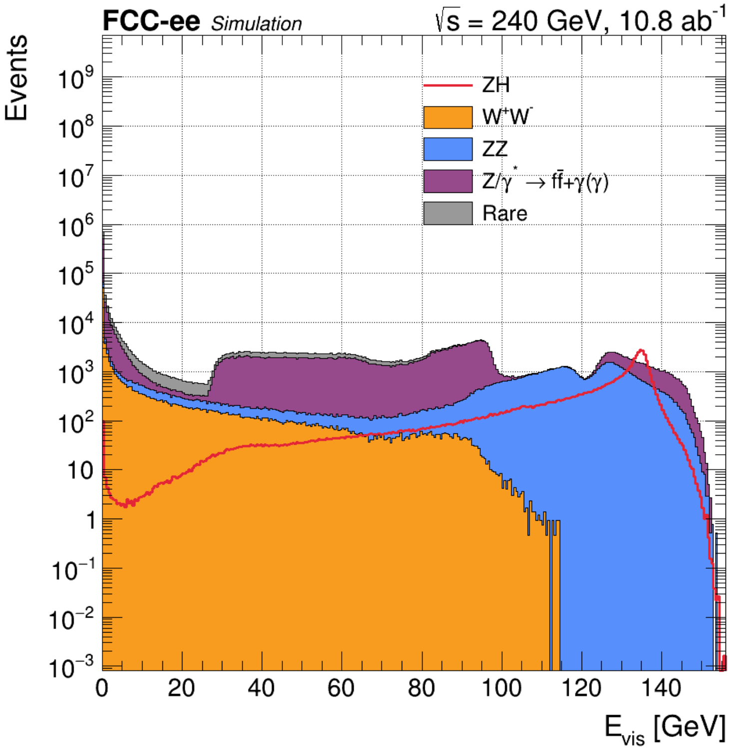
Will only apply $\cos\theta_{miss} < 0.99$ on the invisible sample

- Where the Z/γ and Rare backgrounds mainly are

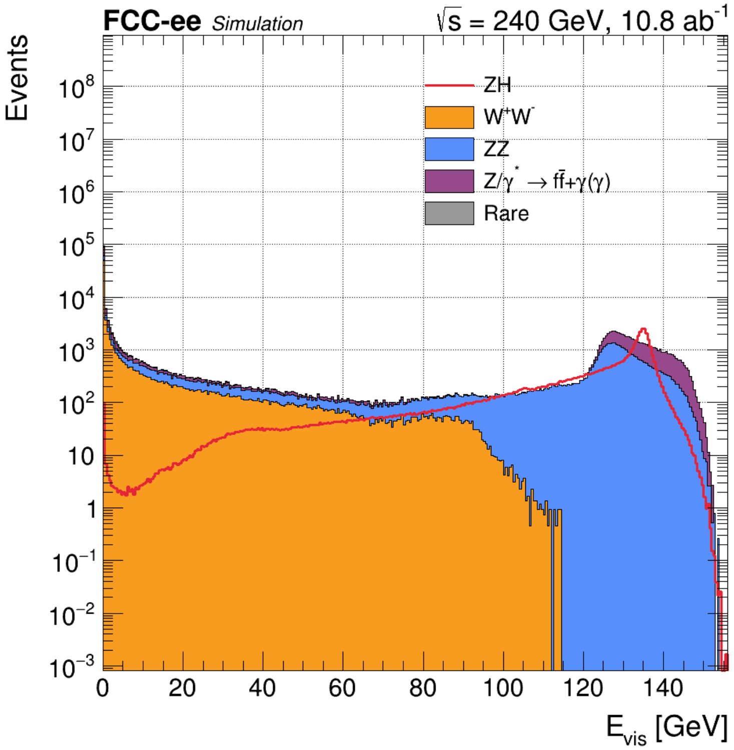
(*): Inspired from ILC selection, they separate the analysis into 2 samples based on E_{vis} (arxiv:1604.07524v3)

IMPACT OF $\cos\theta_{miss}$ ON E_{vis}

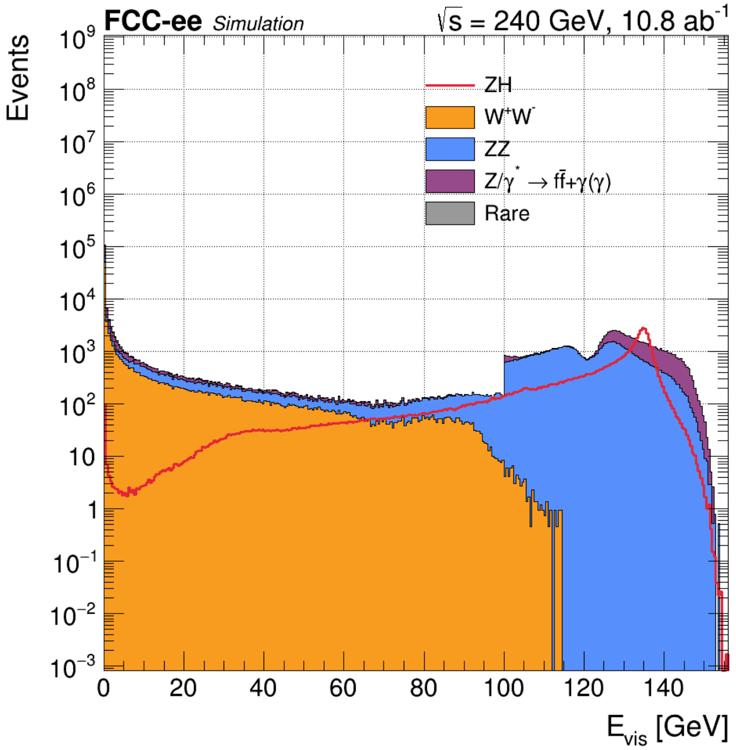
$\cos\theta_{miss}$ IMPACT ON E_{vis} (240 GEV)



Baseline



Baseline+ $\cos\theta_{miss}$ cut



New selection

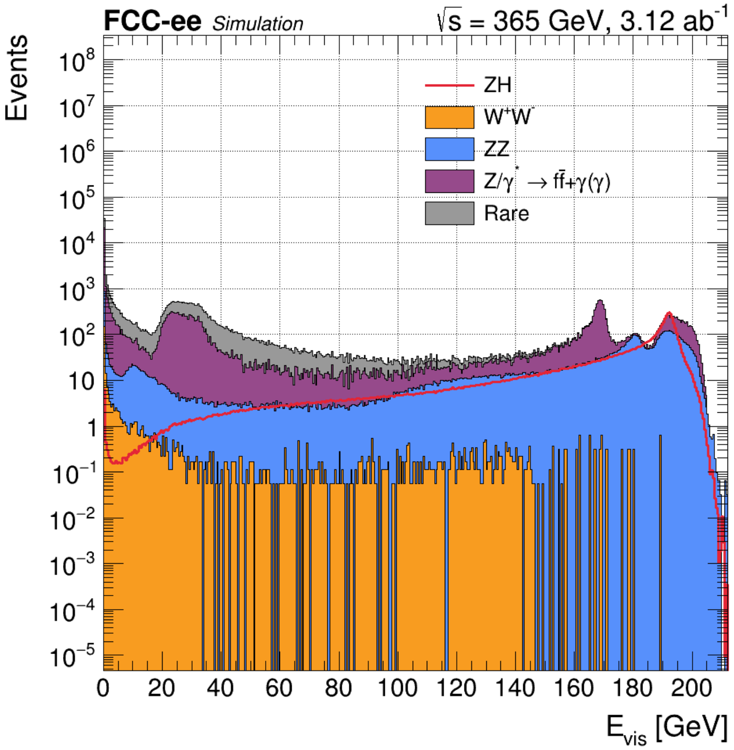
$\cos\theta_{miss}$ cut remote Z/γ and Rare background with low E_{vis}

- Also remove signal with high E_{vis} which induce bias

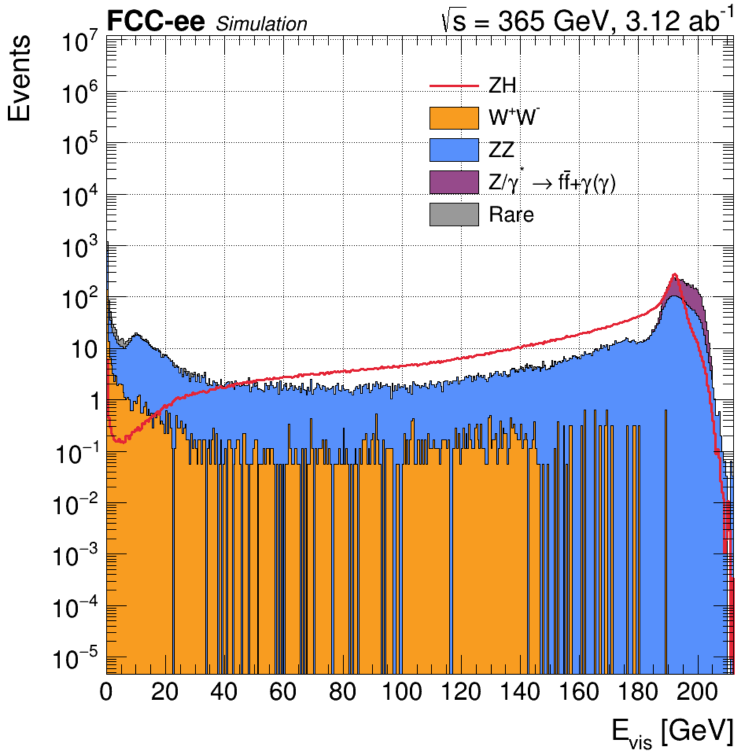
To avoid biases

- Use $\cos\theta_{miss}$ cut only on events with low E_{vis}
- Only cut on a small fraction of the events

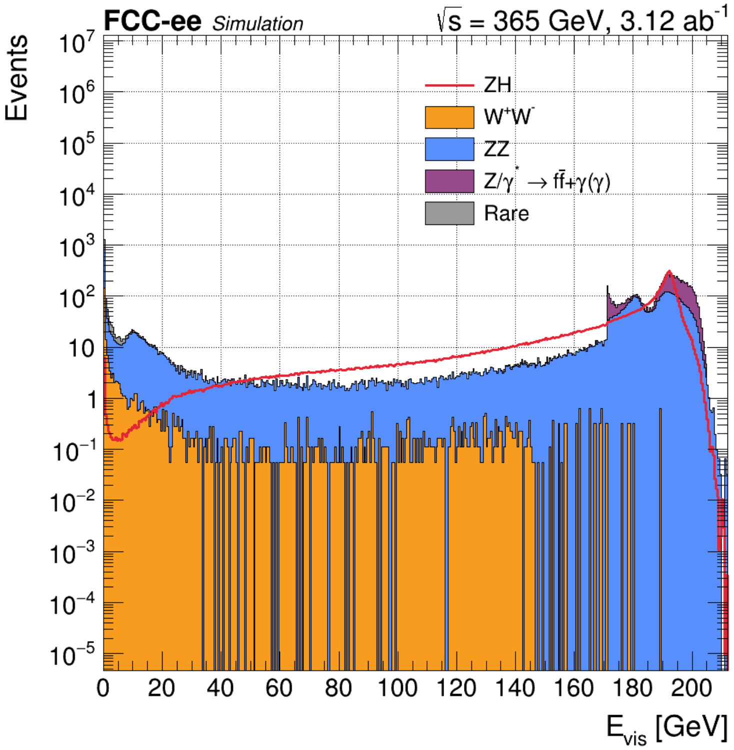
$\cos\theta_{miss}$ IMPACT ON E_{vis} (365 GEV)



Baseline



Baseline+ $\cos\theta_{miss}$ cut



New selection

$\cos\theta_{miss}$ cut remote Z/γ and Rare background with low E_{vis}

- Also remove signal with high E_{vis} which induce bias

To avoid biases

- Use $\cos\theta_{miss}$ cut only on events with low E_{vis}
- Only cut on a small fraction of the events

Must change the cut for 365 GeV to account for the boosted regime

HADRONIC CHANNEL

EVENT SELECTION (365 GEV)

Veto the leptonic analysis:

- Remove events that pass the leptonic selection
- Ensure orthogonality between the channel

Object selection:

- Use exclusive N=2,4,6 and inclusive clustering algorithm
- Remove jets with $p_j < 5$ GeV

For each algorithm, select the jet pair that minimize the χ^2:

- $\chi^2 = \left(m_{jj} - 91.2\ GeV\right)^2 + \left(p_{jj} - p_Z\right)^2 + (m_{recoil} - 125\ GeV)^2$
- $p_Z = 143$ GeV, reduce ambiguity

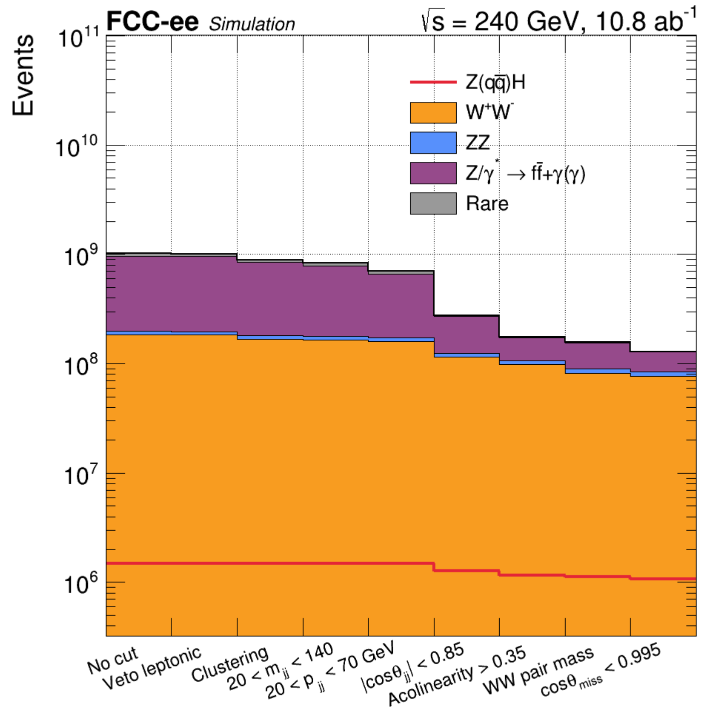
Select the clustering algorithm with the lowest χ^2

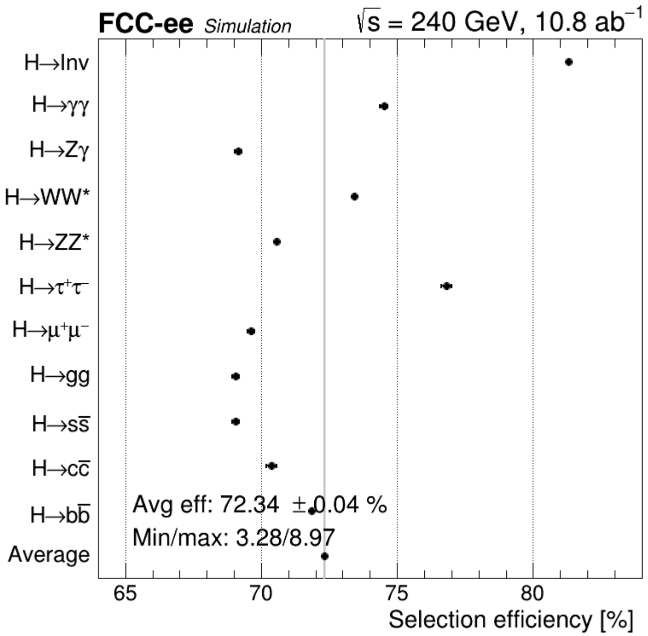
- Reject events if the clustering fails

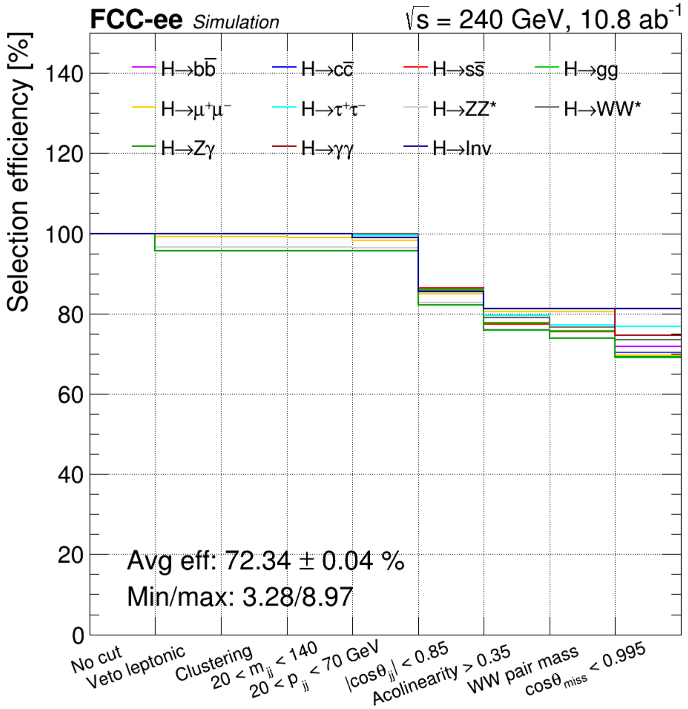
Kinematic selection:

- $60\ GeV < m_{jj} < 200\ GeV$
- $20 < p_{jj} < 160\ GeV$
- $|\cos\theta_{jj}| < 0.85$
- $\pi - \Delta\alpha_{jj} > 0.35$
- WW pair mass cut
- $|\cos\theta_{miss}| < 0.995$
- $T < 0.85$

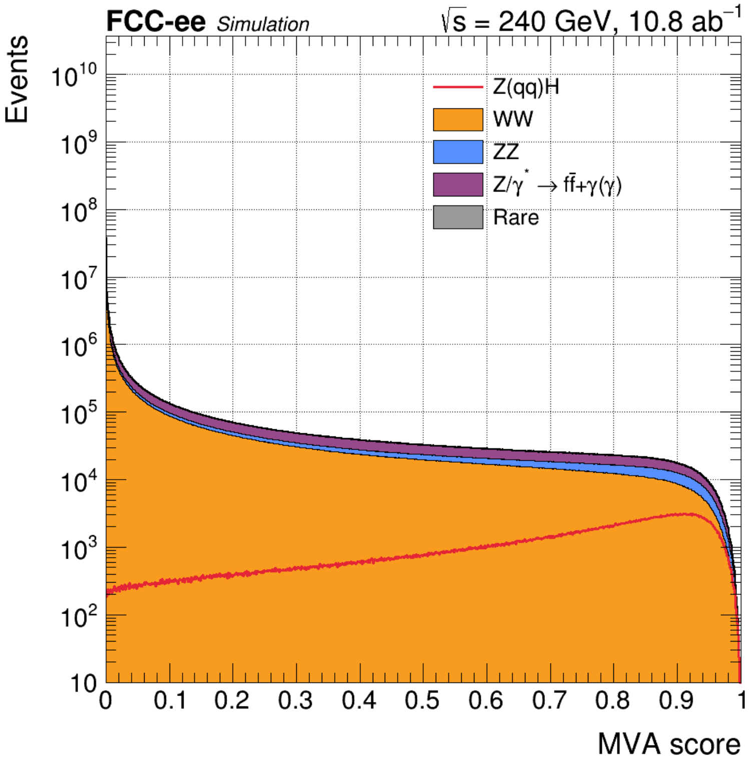
More spread in the selection efficiency due to ambiguity in the selection

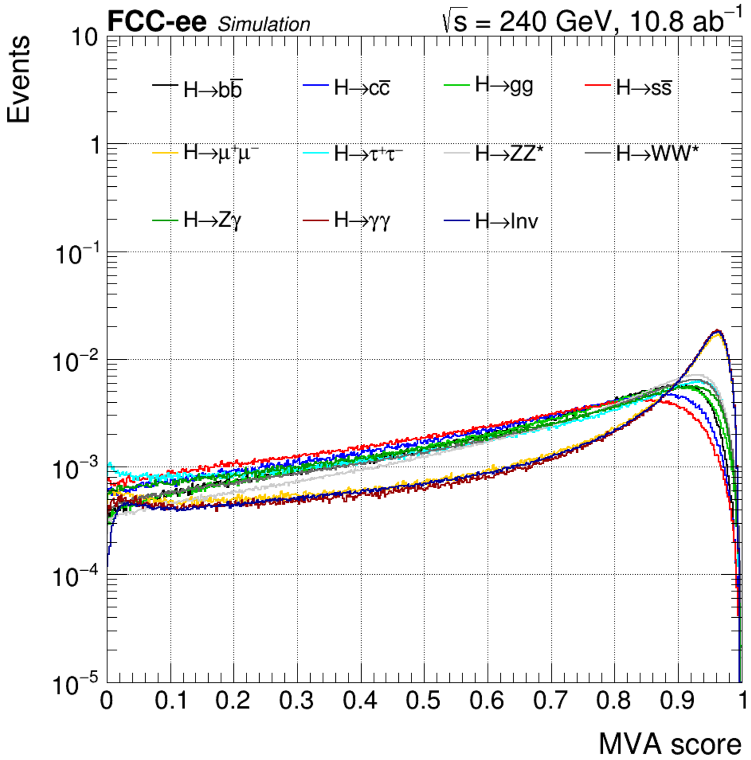






MVA DISCRIMINATION (365 GEV)





Train a BDT to further discriminate signal from background

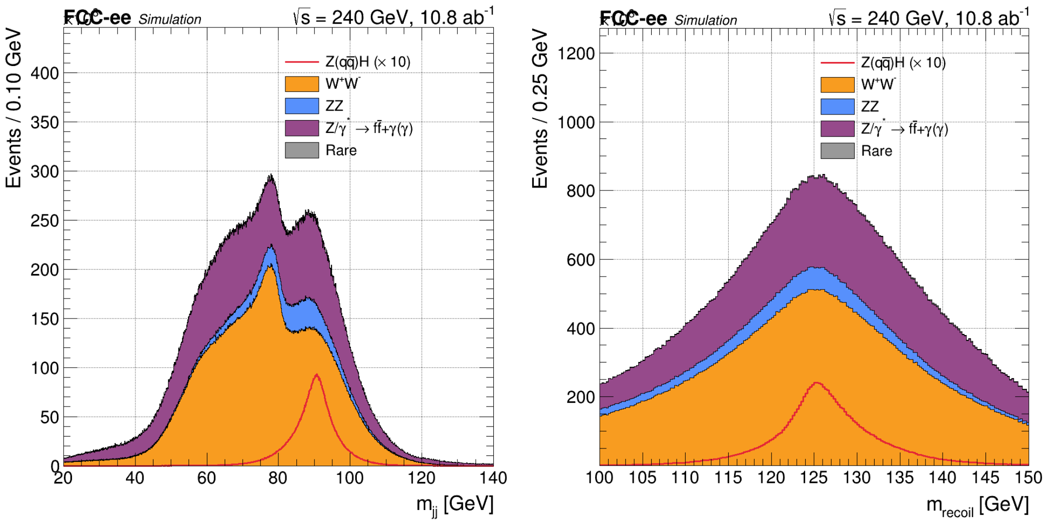
- Give individual jet and jet pair kinematics as input
- Give angular correlation variables as input
- Give the reconstructed WW pair variables and the thrust of the event

BDT score distribution has some differences between the Higgs decays

- $H \rightarrow \mu^+\mu^-, \gamma\gamma, Inv$ have the same shape distribution
- The other decays also have roughly the same shape distribution
- Better distribution for H not decaying hadronically

Variables	Description
$p_{leading}$, $p_{subleading}$	Leading and subleading jet momentum
$\theta_{leading}$, $\theta_{subleading}$	Leading and subleading jet momentum
p_{jj}	Jet pair momentum
θ_{jj}	Jet pair polar angle
$\pi - \Delta\alpha_{jj}$	Acolinearity
$\pi - \Delta\phi_{jj}$	Acoplanarity
$m_{W1,2}$	First and second W mass
$p_{W1,2}$	First and second W momentum
$\theta_{W1,2}$	First and second W polar angle
T	Thrust of the event

UNCERTAINTY EXTRACTION (365 GEV)



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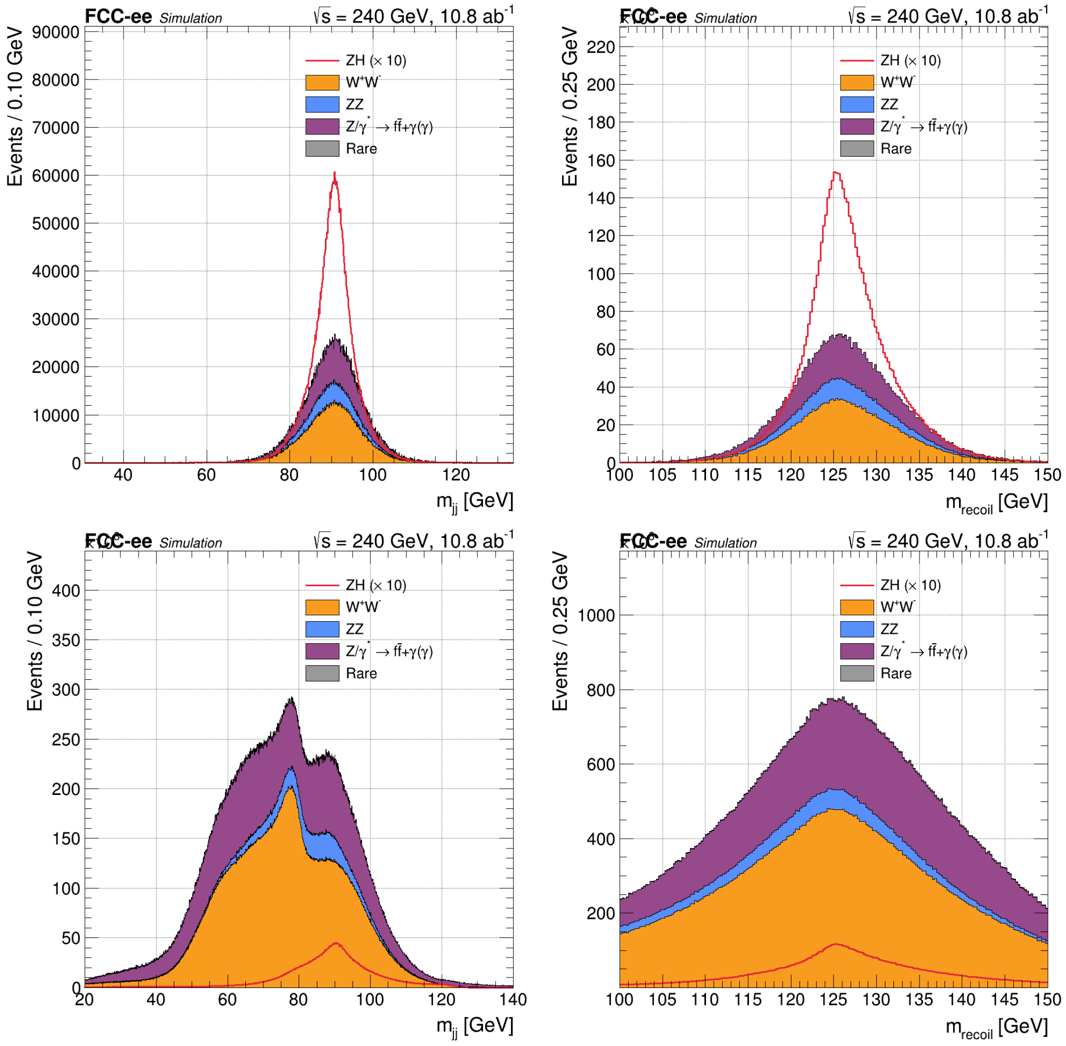

Fit the $m_{jj} - m_{recoil}$ distribution in 2 BDT score regions

- High score region: BDT score > 0.95
- Low score region: BDT score < 0.95

Also consider contributions from $Z(\to \ell^+\ell^-)H$ and $Z(\to \nu\bar{\nu})H$

Take a 1% normalization for all background processes

Channel	$\Delta\sigma_{ZH}$(240 GeV)	$\Delta\sigma_{ZH}$(365 GeV)
$Z(\to q\bar{q})H$	0.38%	0.56%