Jamboree FCC-France

Improvements on ZH cross-section measurement in ZH events at 240 GeV

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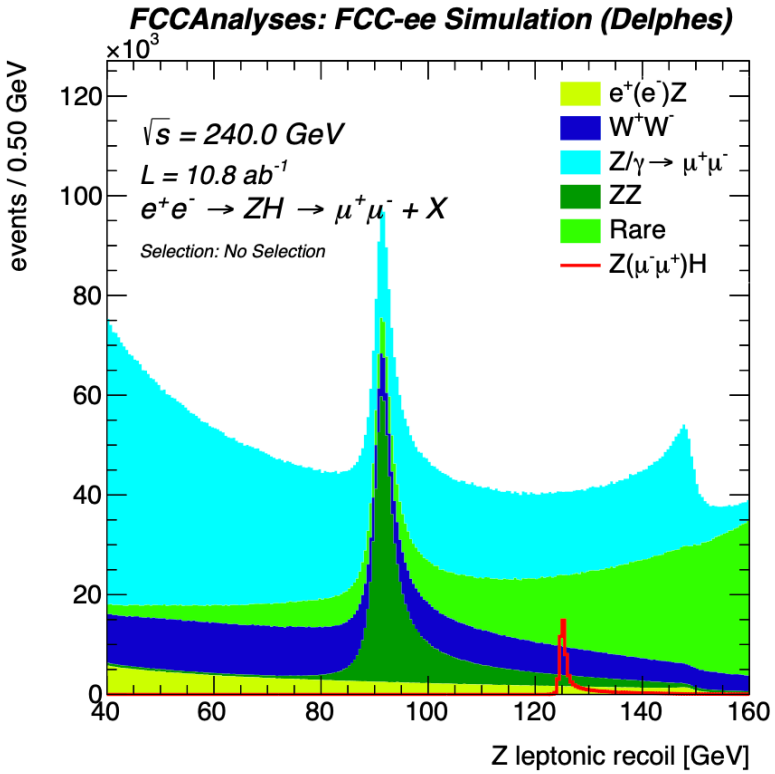
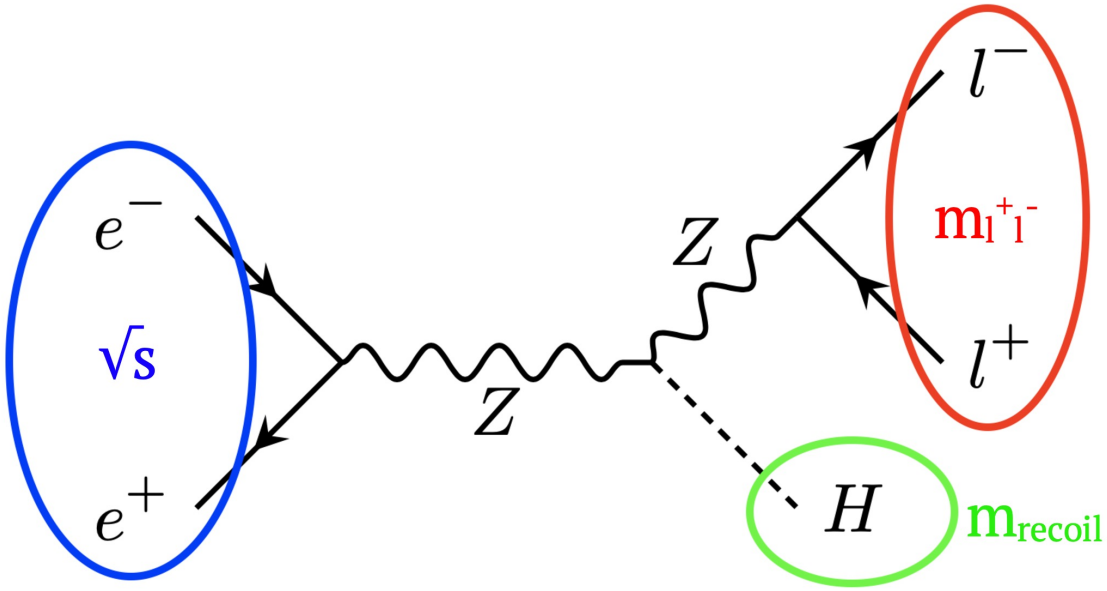
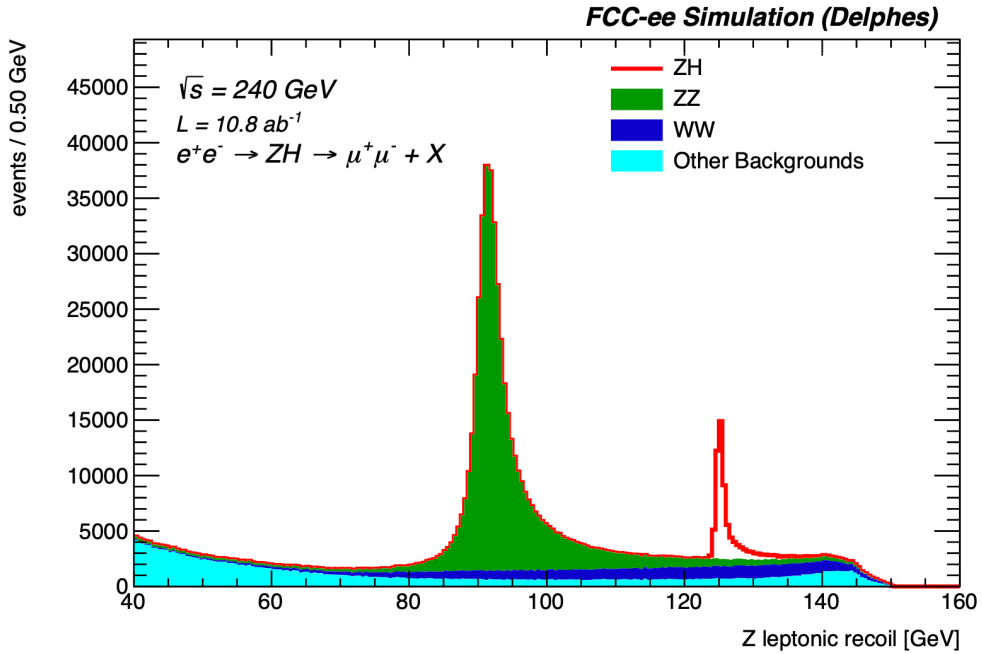
Presentation of the ZH production analysis

To measure ZH production cross-section in a model-independent way, we use the recoil mass method

$$m^2_{\text{recoil}} = (\sqrt{s} - E_{f\bar{f}})^2 - p^2_{f\bar{f}} = s - 2E_{f\bar{f}}\sqrt{s} + m^2_{f\bar{f}}$$







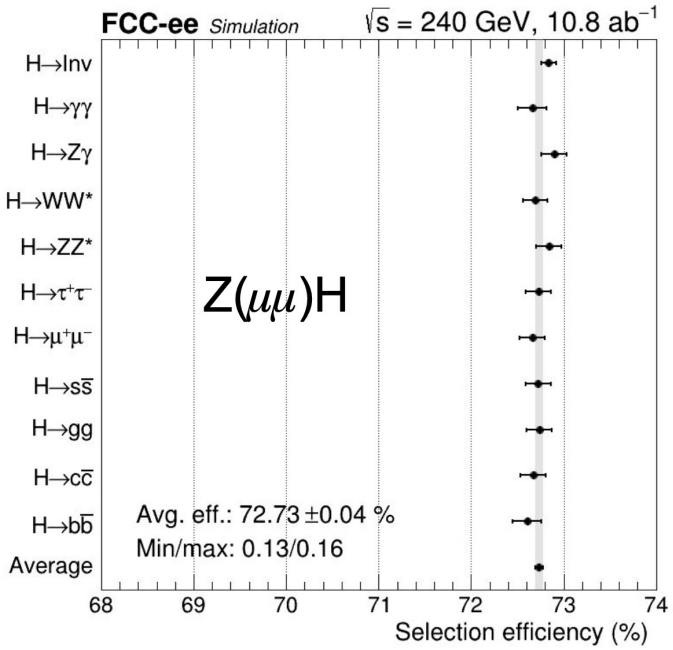
Analysis done in 3 channels:
leptonic $[\mathrm{Z}(e^+e^-), Z(\mu^+\mu^-)]$ and hadronic $\mathrm{Z}(q\bar{q})$

Leptonic channel selection

Selection cuts:

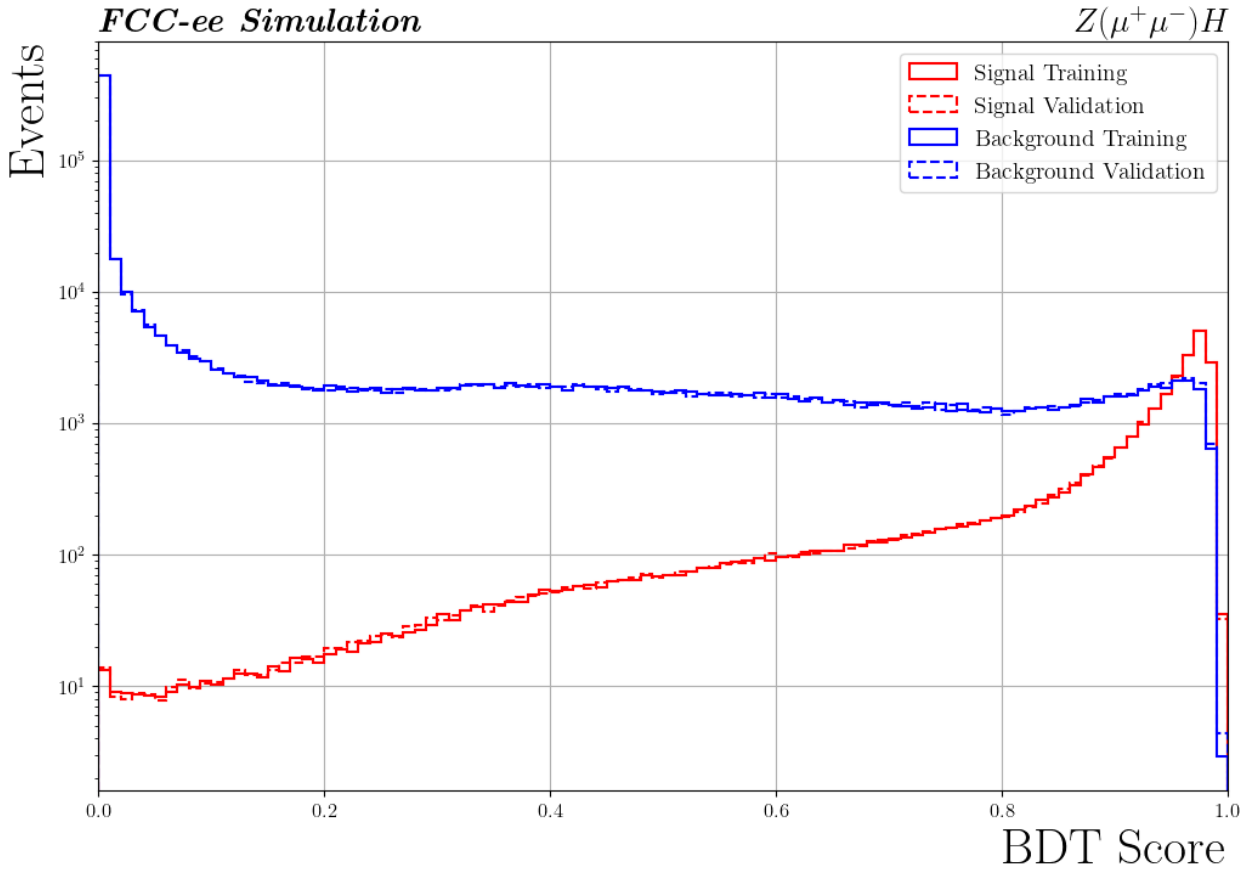
- At least 2 leptons
  - Momentum $p > 20\ GeV$
  - At least one lepton isolated ($I_{rel} < 0.25$)
  - Opposite signed
- If more than 2 leptons
  - Select pair that minimize:
    - $\chi^2 = 0.6\times(m_{l^+l^-} - 91.2\ GeV)^2 + 0.4\times(m_{recoil} - 125\ GeV)^2$
- Kinematic cuts:
  - $86\ GeV < m_{l^+l^-} < 96\ GeV$
  - $20\ GeV < p_{l^+l^-} < 70\ GeV$
  - $100\ GeV < m_{recoil} < 150\ GeV$

Selection preserves invariance of the selection efficiency



BDT used in the analysis

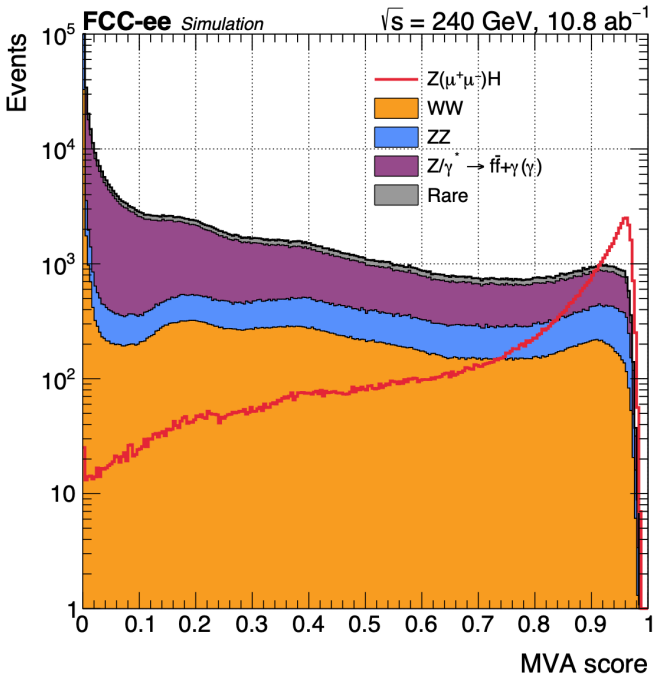
- To further separate signal from background, we use a BDT
- Only give it variable from lepton pair



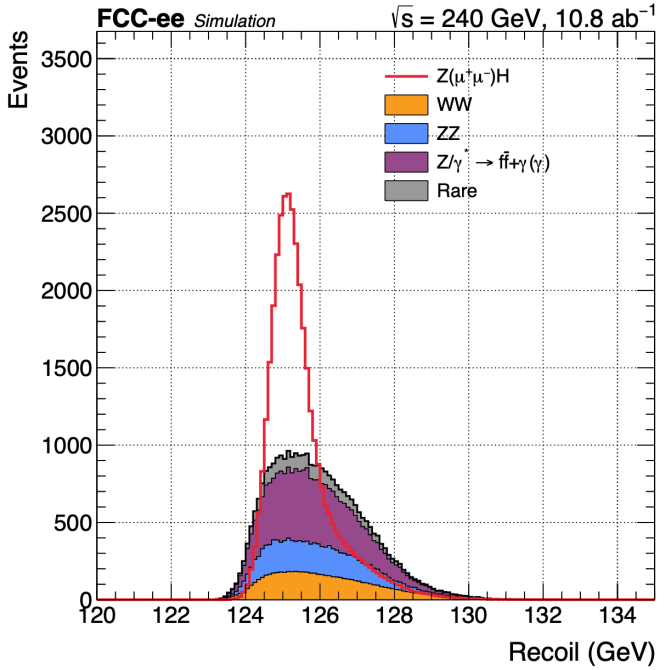
Variables	Description
$m_{l^+l^-}$	Lepton pair invariant mass
$p_{l^+l^-}$	Lepton pair momentum
$\theta_{l^+l^-}$	Lepton pair polar angle
$p_{leading}$	Momentum of the leading lepton
$\theta_{leading}$	Polar angle of the leading lepton
$p_{subleading}$	Momentum of the subleading lepton
$\theta_{subleading}$	Polar angle of the subleading lepton
$\Delta\theta_{l^+l^-}$	Acolinearity of the lepton pair
$\pi - \Delta\phi_{l^+l^-}$	Acoplanarity of the lepton pair

Extraction of the total cross-section

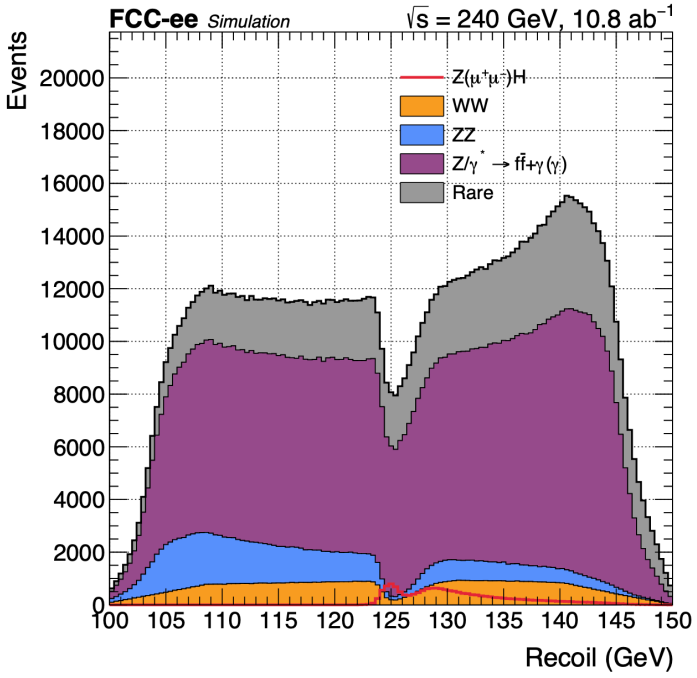
The total ZH cross-section is obtained by fitting the m_{recoil} distribution in 2 bins of the BDT score



BDT score



High score region



Low score region

Channel	$Z(e^+e^-)H$	$Z(\mu^+\mu^-)H$	$Z(q\bar{q})H$	Combined
Uncertainty	$\pm 0.81\%$	$\pm 0.68\%$	$\pm 0.41\%$	$\pm 0.32\%$

My activities:

- Reproduce/Improve the ZH analysis in the leptonic canal

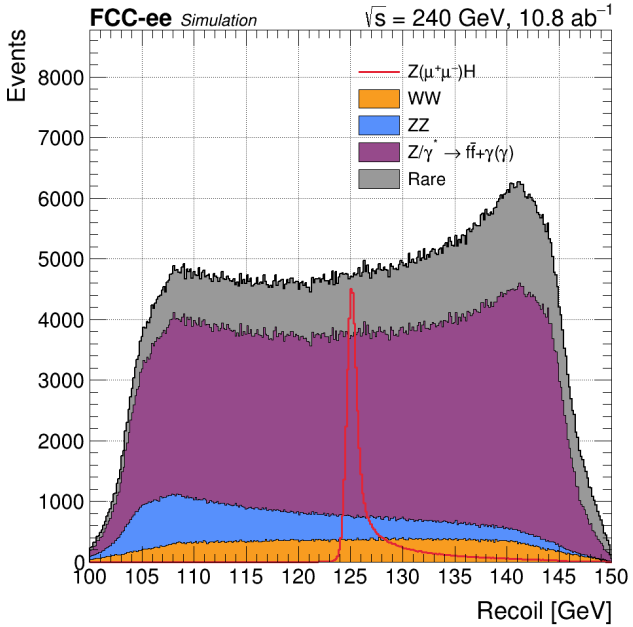
Test different selections

- Baseline
  - Same as the one presented before
- Baseline + $\cos\theta_{miss}$ cut
  - Baseline
  - $\cos\theta_{miss} < 0.98$

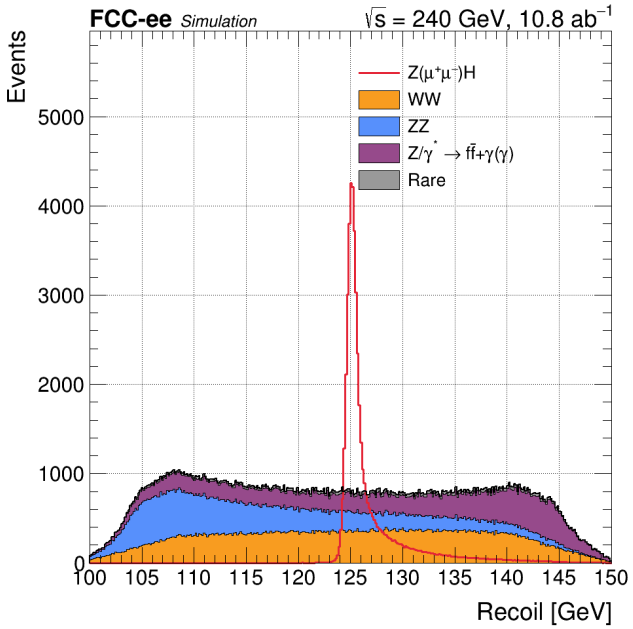
Still under study

- Baseline + $\cos\theta_{miss}$ input
  - Baseline
  - $\cos\theta_{miss}$ is given as input to the BDT
- E_{vis} + separated events
  - Use visible energy to separate events

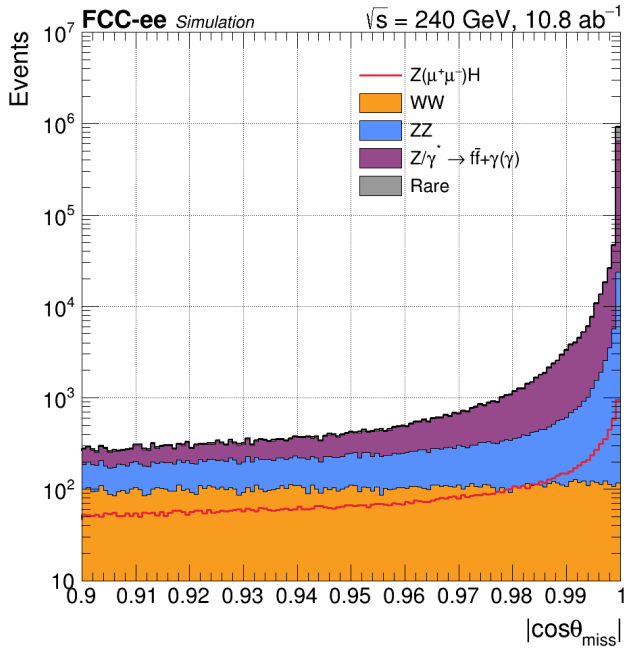
Motivation of $\cos\theta_{miss}$ cut



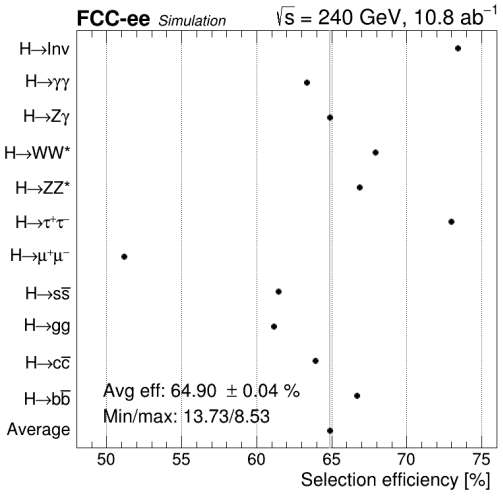
Without $\cos\theta_{miss}$ cut

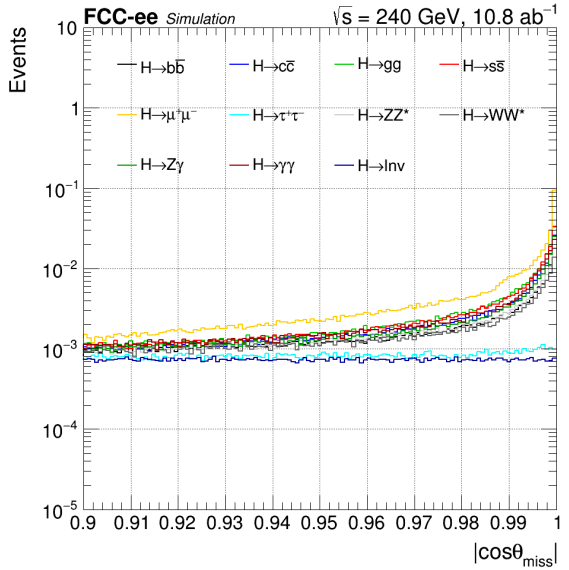


With $\cos\theta_{miss}$ cut

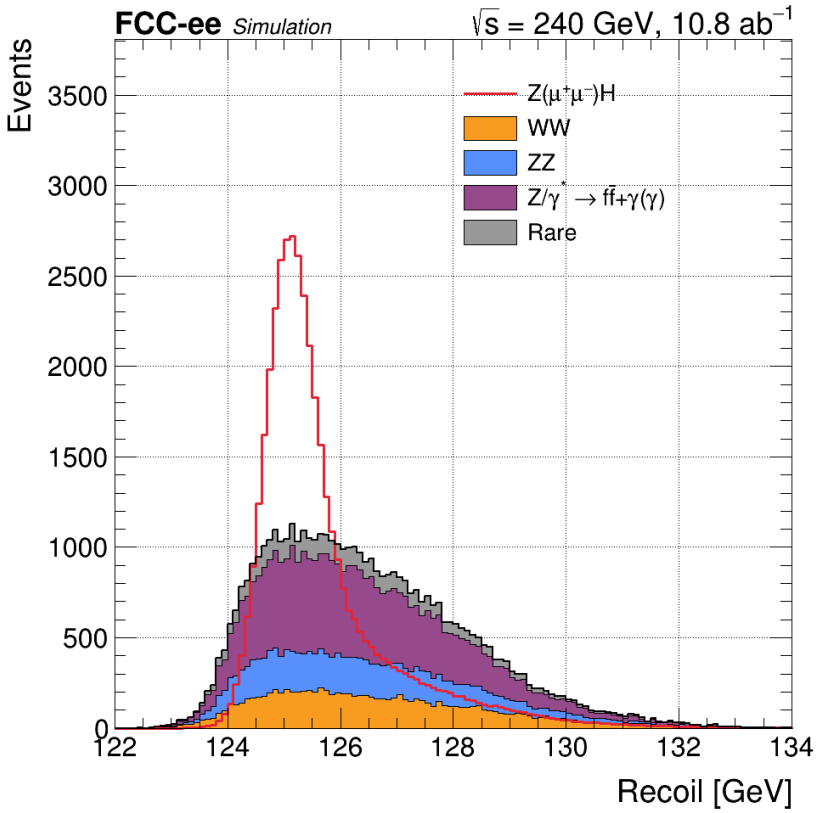


- $\cos\theta_{miss}$ is good to discriminate signal from background
- But don't preserve invariance of the selection efficiency
- Used for the Higgs mass measurement
- We try to include it in this analysis

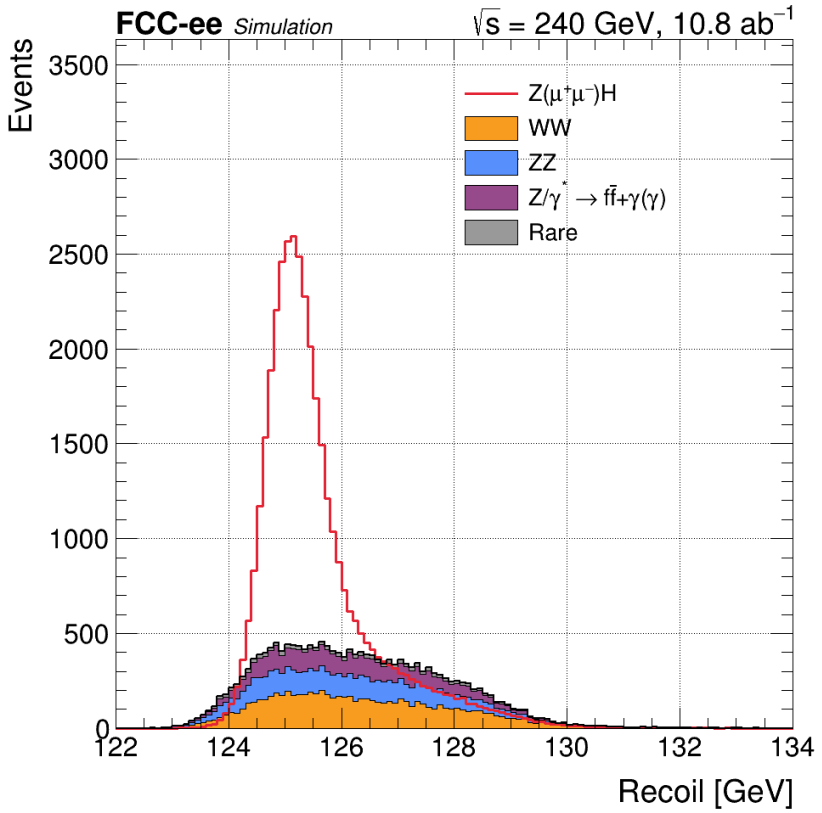




Recoil mass distribution for high BDT score region



Baseline



With $\cos\theta_{miss}$ cut

We have a better backgorund rejection when adding $\cos\theta_{miss}$ cut

ZH uncertainty

Selection	$\mu^+\mu^-$ channel	e^+e^- channel	Combined
Baseline	0.67 %	0.79 %	0.53 %
$\cos\theta_{miss}$ cut	0.60 %	0.67 %	0.45 %

We have a better uncertainty when adding $\cos\theta_{miss}$ cut

Bias test

$100\ \%$ model-independence is not possible

We use a bias test to determine the degree of independence of the selection:

- Suppose ZH cross-section is not known up to $X\ \%$
- Suppose each Higgs mode can individually explain this $X\ \%$ difference
- Rescale each mode independently to obtain $\delta ZH = X\ \%$
- Construct pseudo-data from the rescaling
- Extract the bias by fitting the pseudo-data
  - $b = 100 \times (\mu_{fit} - 1 - X/100)$ with X in $\%$
- If b is within the quoted uncertainty, the test is a success

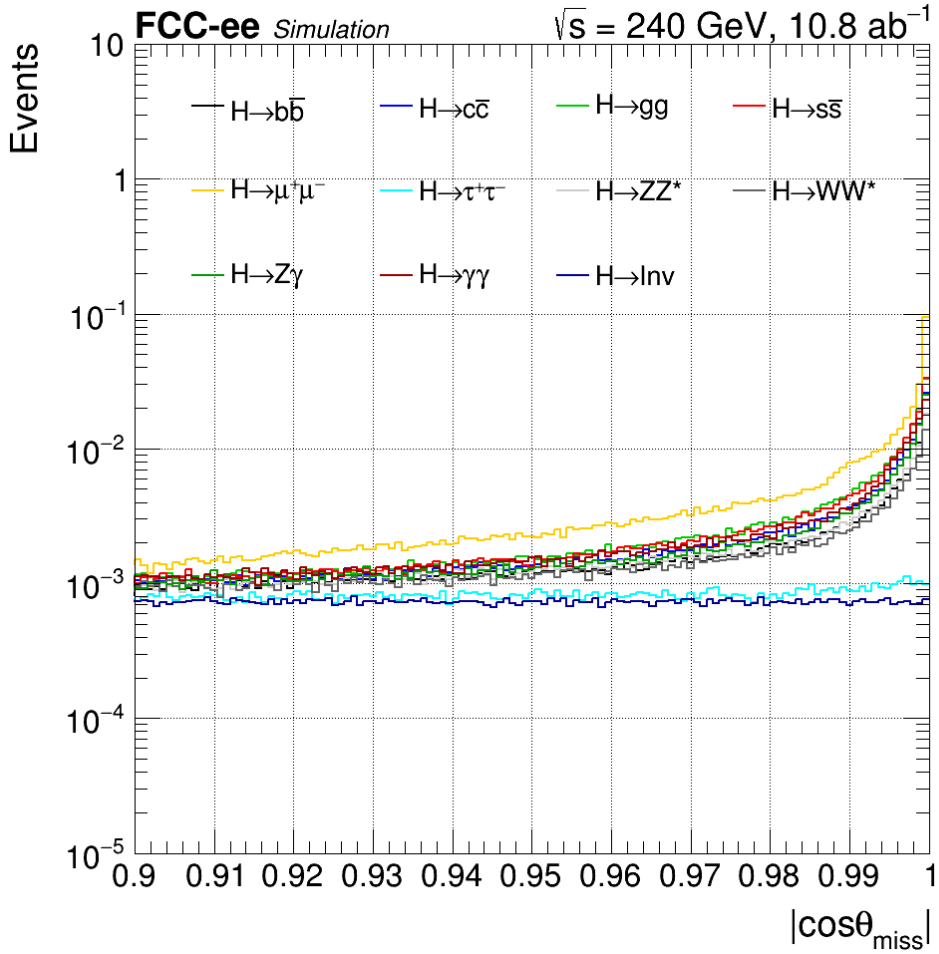
Bias test for the different selection in the $\mu^+\mu^-$ channel

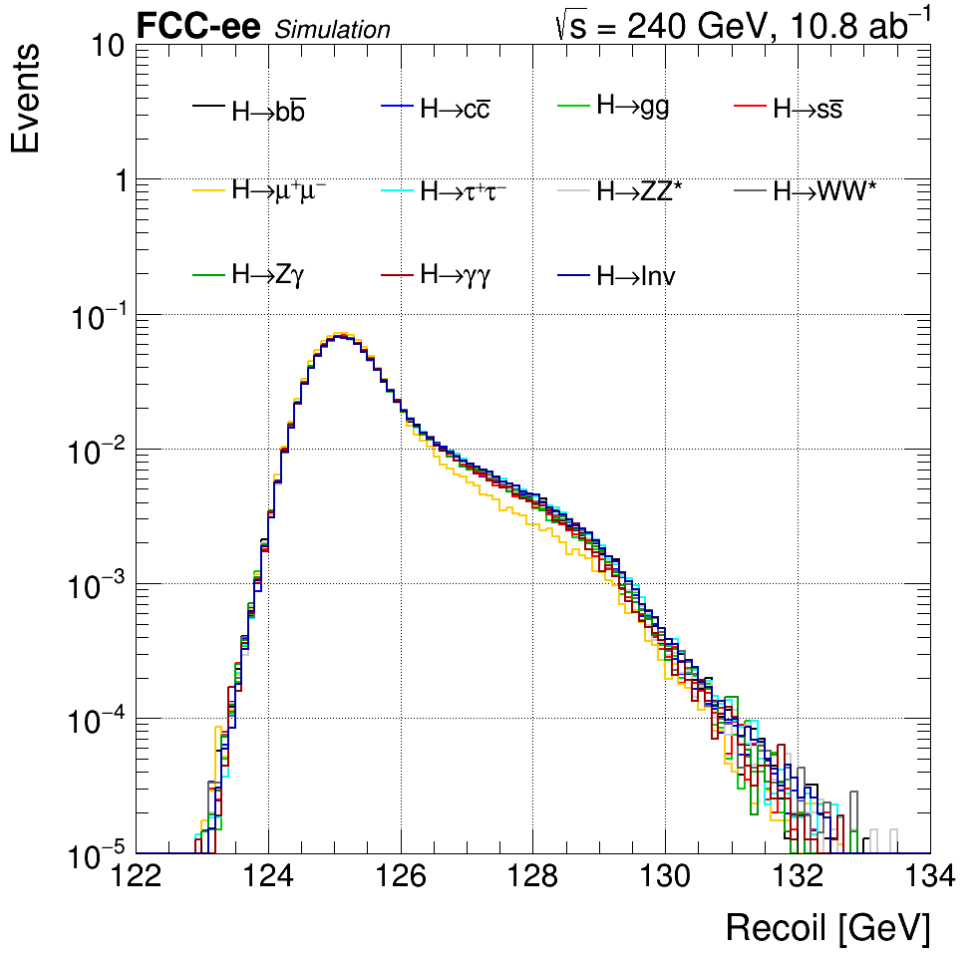
Selection	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to s\bar{s}$	$H \to gg$	$H \to \mu^+\mu^-$
Baseline	-0.02	+0.00	-0.02	-0.01	+0.10
With $\cos\theta_{miss}$ cut	-0.02	-0.09	-0.18	-0.21	-0.70
Selection	$H \to \tau^+\tau^-$	$H \to ZZ^*$	$H \to WW^*$	$H \to Z\gamma$	$H \to \gamma\gamma$
Baseline	-0.01	+0.34	-0.01	+0.38	-0.01
With $\cos\theta_{miss}$ cut	+0.21	+0.27	+0.03	+0.21	+0.02

- Problem with the $H \to \mu^+\mu^-$ channel for the selection with $\cos\theta_{miss}$ cut
- Bias in $H \to ZZ^*$ and $H \to Z\gamma$ due to ambiguity in the selection
- $H \to Inv$ not shown due to problem with the code not yet resolved

- Red: Very bad
- Orange: A bit bad
- Blue: Improvement

Selection efficiency with $\cos\theta_{miss}$ cut





- Largest bias on $H \to \mu^+\mu^-$ due to loss in selection efficiency
- Different shape for $H \to \mu^+\mu^-$ in the recoil mass in the high BDT score region
- Cut too agressive to preserve model-independence

Conclusion

- $\cos\theta_{miss}$ is a very good variable to discriminate signal from background
- Used in Higgs mass measurement
- But induce a bias in the selection
- Break model-independence of the selection
  - Can't use it like that

Possible solutions

- Separate events with E_{vis} and then use $\cos\theta_{miss}$
- Can use it as a input for the BDT
  - Proved to reduce bias
  - But worse uncertainty obtained
  - Still working on improving it

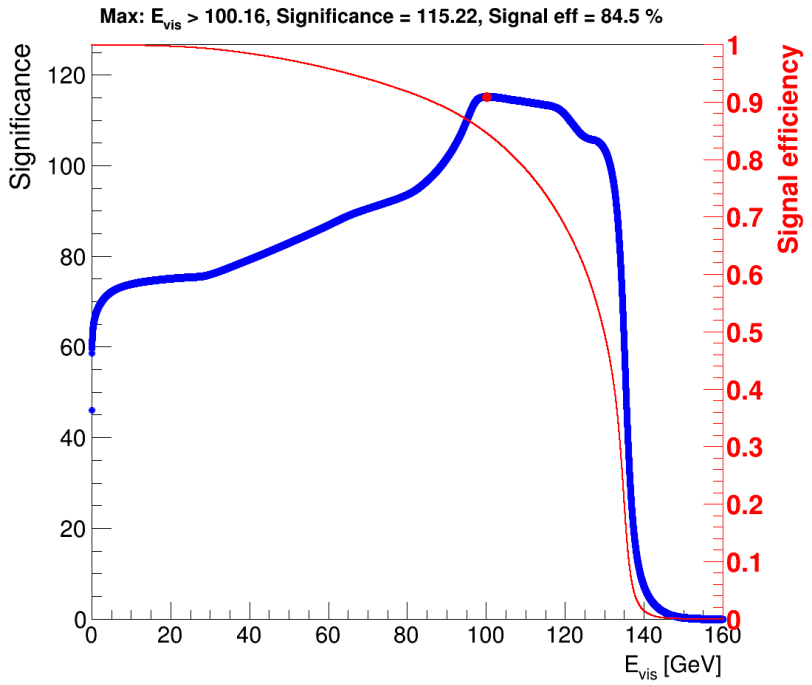
THANKS FOR LISTENING

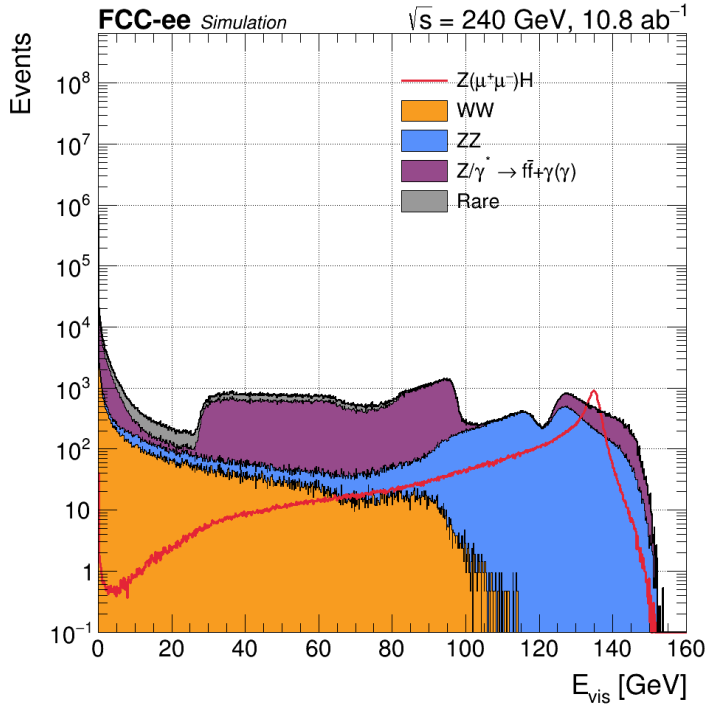
BACK UP

Bias test for the three selections

Selection	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to s\bar{s}$	$H \to gg$	$H \to \mu^+\mu^-$
Baseline	-0.02	+0.00	-0.02	-0.01	+0.10
With $\cos\theta_{miss}$ cut	-0.02	-0.09	-0.18	-0.21	-0.70
With $\cos\theta_{miss}$ as BDT input	-0.01	+0.01	-0.00	+0.01	+0.06
Selection	$H \to \tau^+\tau^-$	$H \to ZZ^*$	$H \to WW^*$	$H \to Z\gamma$	$H \to \gamma\gamma$
Baseline	-0.01	+0.34	-0.01	+0.38	-0.01
With $\cos\theta_{miss}$ cut	+0.21	+0.27	+0.03	+0.21	+0.02
With $\cos\theta_{miss}$ as BDT input	+0.00	+0.15	+0.00	+0.17	+0.00

Significance scan

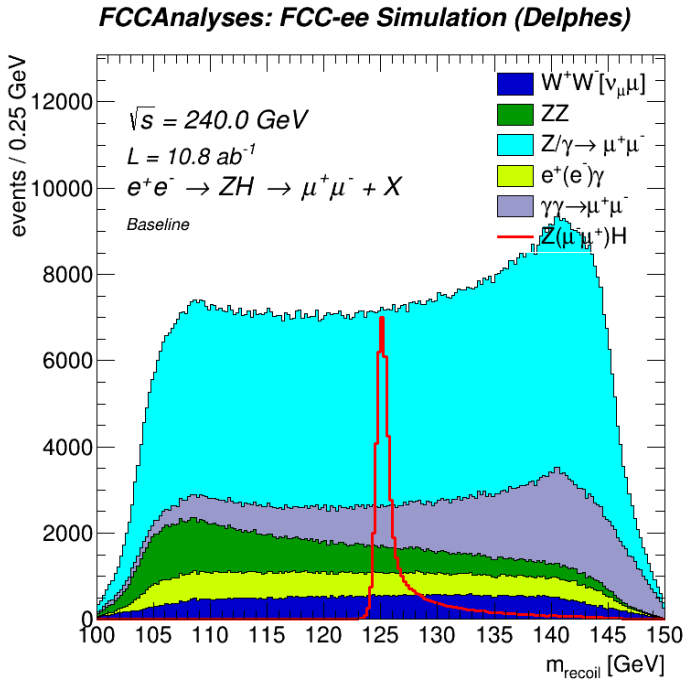




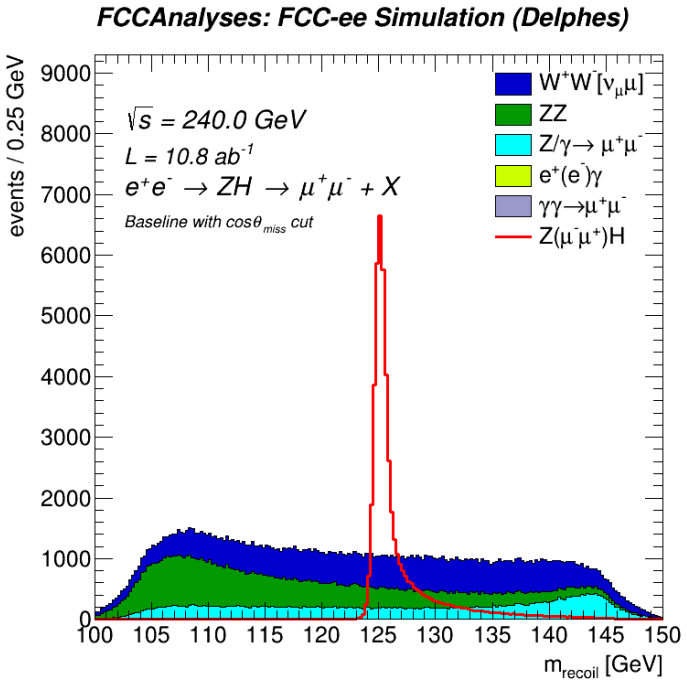
- $E_{vis} > 100\ GeV$
- Remove W^+W^- and rare background

	Signal	W^+W^-	ZZ	Z/γ	$e^{\pm}\gamma$	$\gamma\gamma$
Baseline	54 514	85 945	117 227	814 729	89 655	197 839
E_{vis} cut	45 255	1	78 456	35 840	26	1
Ratio	83.02%	0.001%	66.93%	4.40%	0.029%	0.0005%

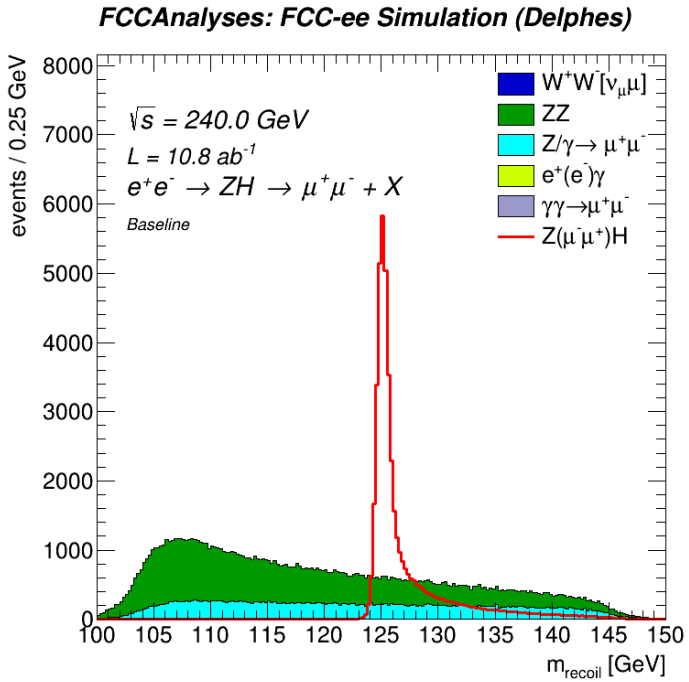
Recoil mass distribution comparison



Without cut on E_{vis}



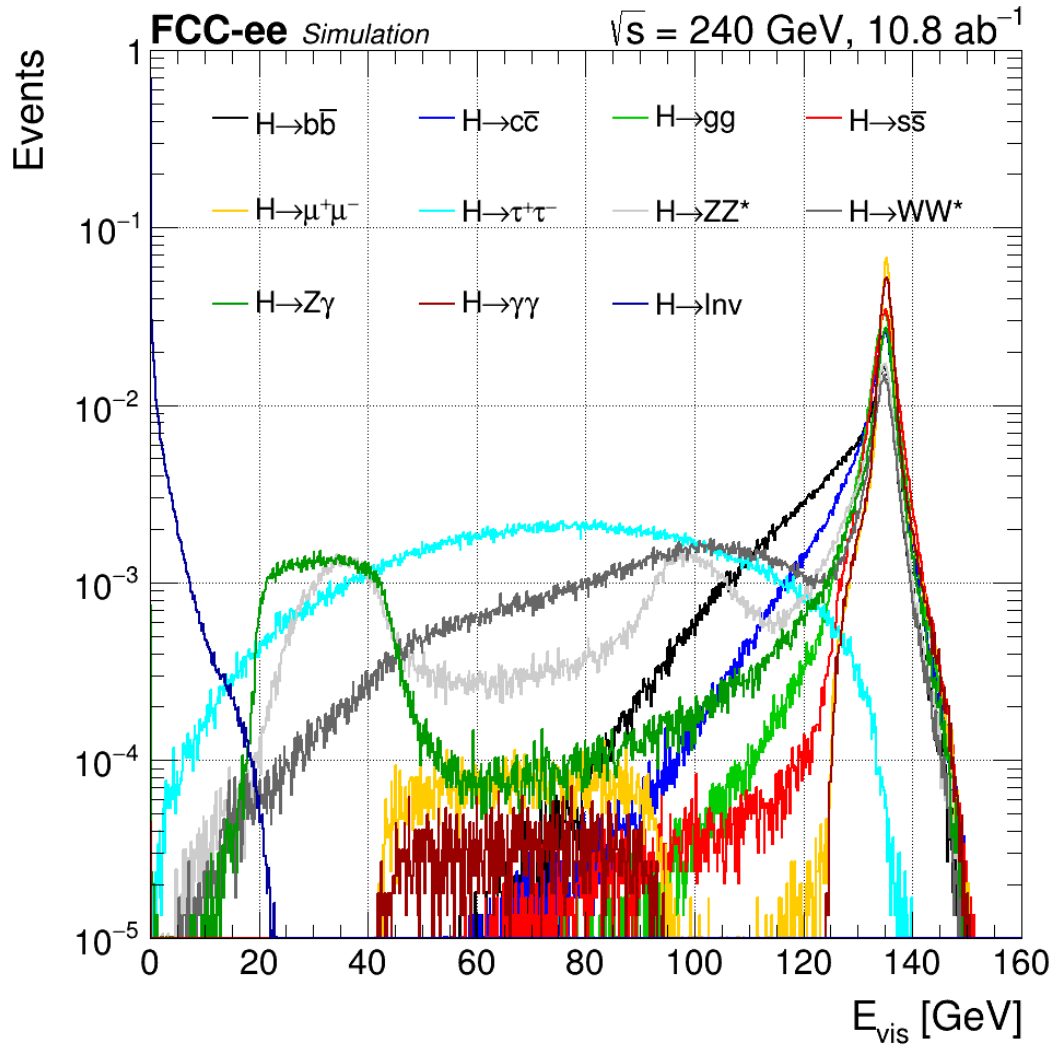
$\cos\theta_{miss} < 0.98$



$E_{vis} > 100\ GeV$

- Remove 17% of signal
- But remove almost all WW and rare background
- Can further remove ZZ and Z/γ background with $\cos\theta_{miss}$ cut

Model independence

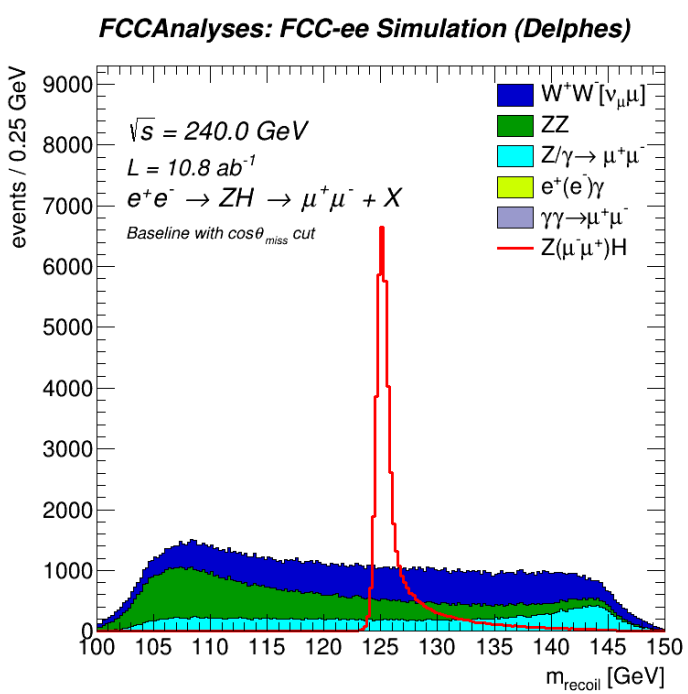


- But E_{vis} is highly dependent on the Higgs decay mode
- Can't use it like this for ZH cross-section measurement
- But can use it for Higgs mass measurement

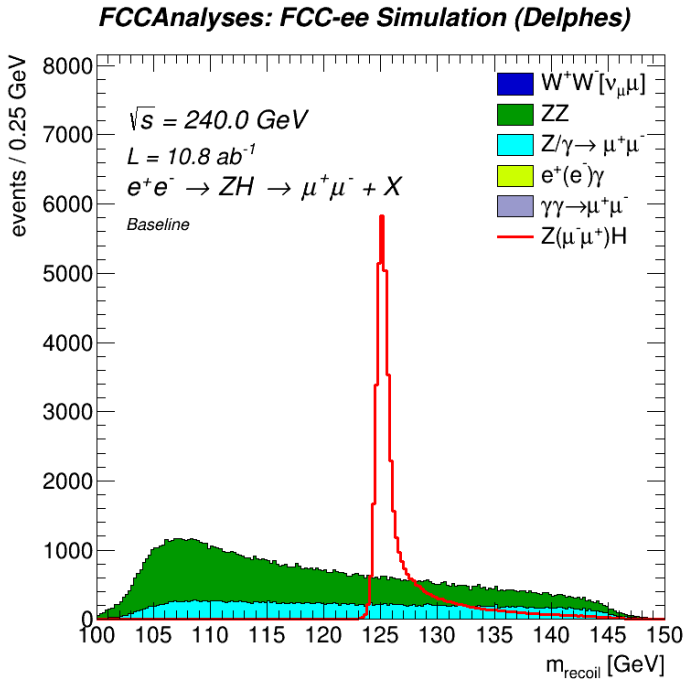
But we can use this variable to separate the events into visible and invisible samples and optimize them separately

Done by ILC and seem to preserve model-independence

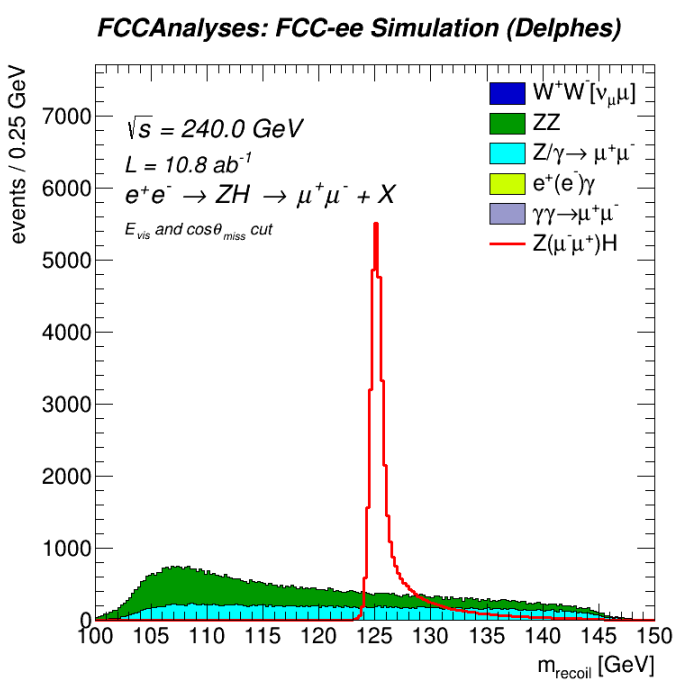
Recoil mass distribution comparison



$\cos\theta_{miss} < 0.98$



$E_{vis} > 100\ GeV$



Both cut

Significance:

- $\cos\theta_{miss}$ cut: 112
- E_{vis} cut: 134
- Both cut: 150

Event selection comparison

	Signal	W^+W^-	ZZ	Z/γ	$e^{\pm}\gamma$	$\gamma\gamma$
$\cos\theta_{miss} < 0.98$	49 036	83 183	69 489	39 873	164	49
$E_{vis} > 100\ GeV$	45 255	1	78 456	35 840	26	1
Ratio	92.29%	0.001%	112%	89.89%	15.85%	2.04%
Both	40 146	1	41 371	30 606	0	0
Ratio	81.87%	0.001%	59.54%	76.76%	0%	0%

We can see a net improvement in background rejection when both cut are combined