$H \to$ invisible at FCC ee

Higgs FCC Meeting

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Introduction

- Repeat of analysis with Winter 2023 Samples
- Have much better hadronic resolution
- Rerun flavour tagging
- Slow so don't have all the MC stats
- Can use c tagging also

Analysis Overview

- Estimate sensitivity of $H \rightarrow$ invisible using ZH events in e^+e^- simulated data
- Only studied $\sqrt{s} = 240$ GeV events
- Assume $\int L = 5$ ab^{-1}
- Using $Z \rightarrow ee$, $\mu\mu$, bb and qq channels
- Delphes simulation
- Backgrounds dilepton (Z), ZZ, WW and ZH
- Some diagrams not included in ZZ and WW samples labelled 'WZ'
- Will need dedicated four fermion samples with interference, but not expected to make a large difference to results
- SM $ZH \rightarrow \nu\nu\nu\nu$ treated either as a background when determining limits or a signal when determining precision on measurement
- Taus not studies yet but could be useful in reducing backgrounds
- Signal taken at SM value (BR(Hto inv. =0.1%) but shown in plots with a scale of 1000 for clarity

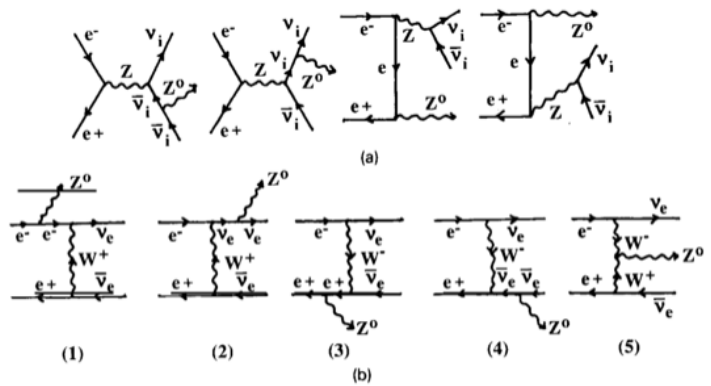
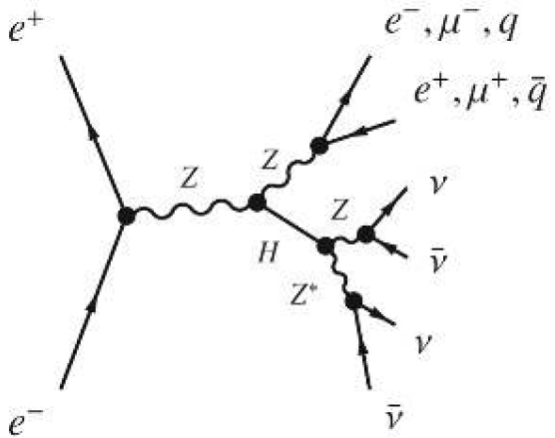


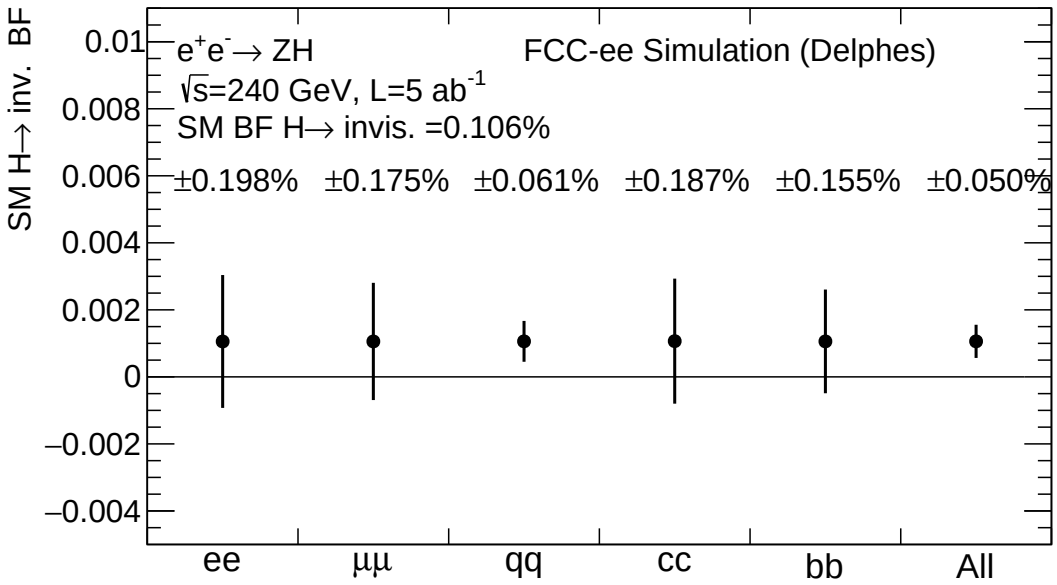
Fig. 1. Feynman diagrams contributing to the process $e^+e^- \rightarrow Z^0\nu\bar{\nu}$: (a) Z-exchange diagrams (with Z^0 in the s-channel); (b) W-exchange diagrams (with $W^\pm$('s) in the t-channel).



Method

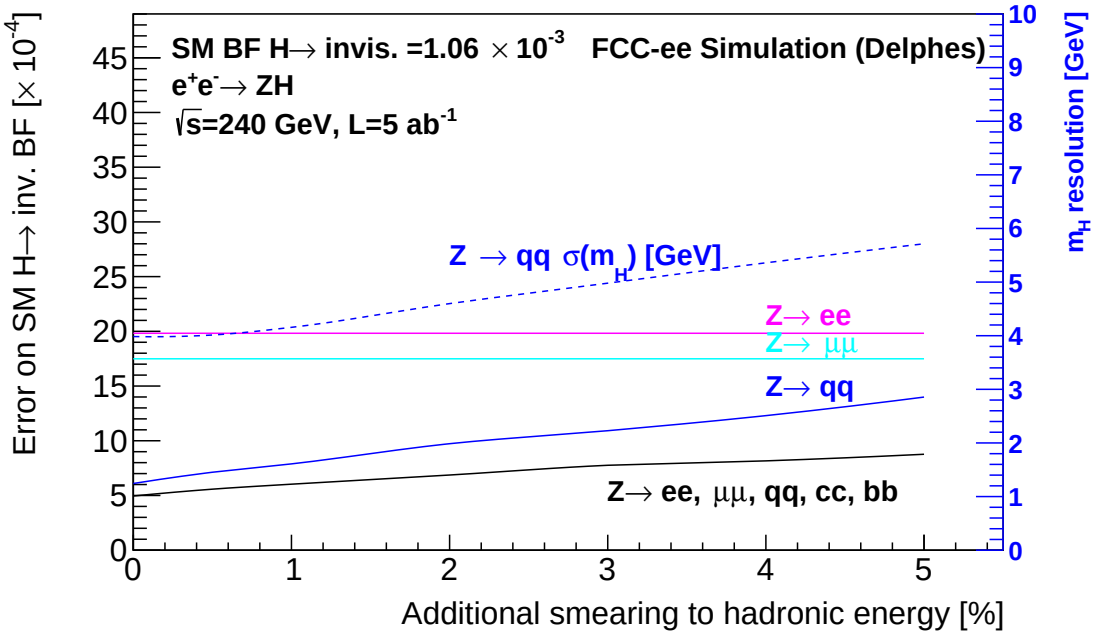
- Split events into exactly $2e$, 2μ and 0 $e{+}\mu$
- Reject events with 1 or $\geq$ 3 leptons
- bb channel defined if at least one of the two leading jets is b-tagged
- cc channel either 1 c-tag or 2 c-tags (split in fit)
- Require $p_T^{\mathrm{miss}} > 10/15$ GeV for ee, $\mu\mu$, qq/cc, bb to suppress dilepton background
- Reconstruct Z from 2 leptons or M_{vis} (Invariant Mass of all particles)
- Cut on 3/6 GeV around $M_Z = 91$ GeV for ee,$\mu\mu$/ qq, cc, bb channels
- Resolution so good in new samples we can have the same cut on bb channel and do not have to scale to Z mass
- Use distribution of M_{miss} in likelihood fit using HistFitter
- Float signal, ZZ and WW backgrounds. Fix ZH and dilepton background
- Easy to add systematics but only lumi (1%) added for now
- Split qq channel into jet multiplicity

Results SM fit



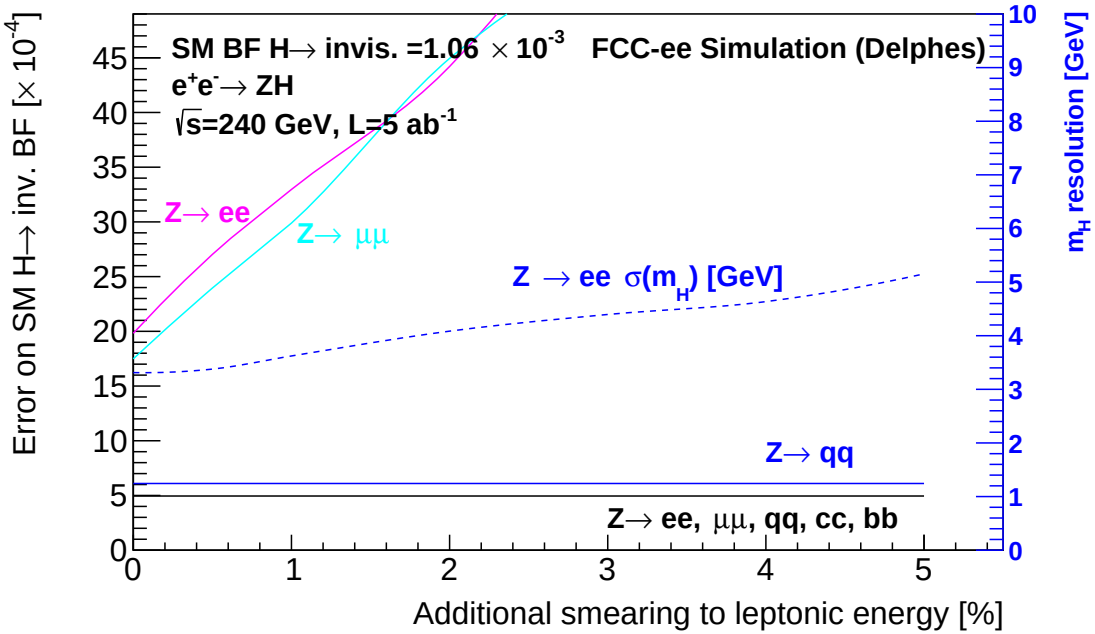
Floating SM signal
50% measurement possible (twice as good as Spring 2021)
bb and *cc* channels better than Spring 2021 *qq*
Better hadronic resolution is the main cause
Smaller improvements from better flavour tagging

Effects of hadronic smearing



Add an extra Gaussian smearing to hadronic channels.
Results in 130% increase in error for qq channel and 80% in the combined for a 5% additional smearing

Effects of leptonic smearing



Add an extra Gaussian smearing to leptonic channels.
Results in 8% increase in the error for the combined for a 5% additional smearing

Backup 2

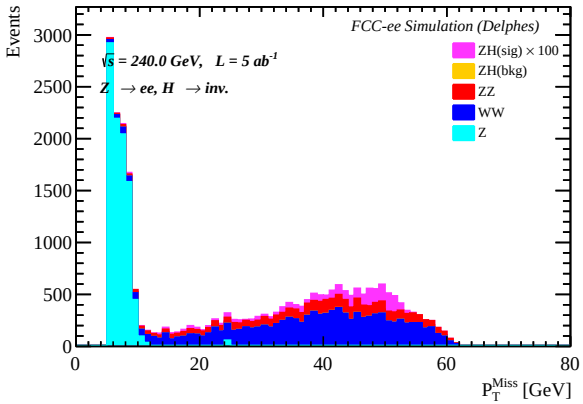
Samples

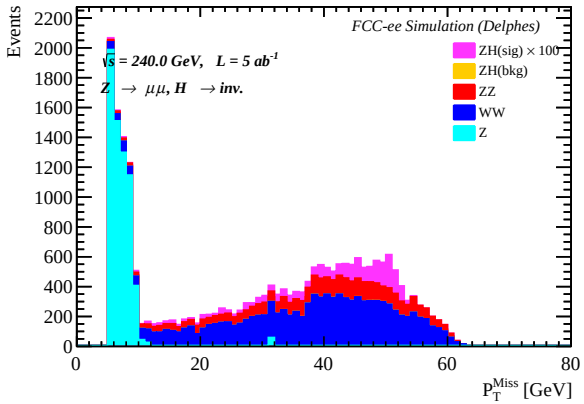
```
/eos/experiment/fcc/ee/generation/DelphesEvents/winter2023/IDEA/
wzp6_ee_qqH_ecm240
wzp6_ee_eeH_ecm240
wzp6_ee_mumuH_ecm240
wzp6_ee_tautauH_ecm240
wzp6_ee_nunuH_ecm240
p8_ee_WW_ecm240
p8_ee_ZZ_ecm240
wzp6_ee_nuenueZ_ecm240
wzp6_ee_ee_Mee_30_150_ecm240
wzp6_ee_mumu_ecm240
p8_ee_Zqq_ecm240
p8_ee_ZZ_ecm240/
```

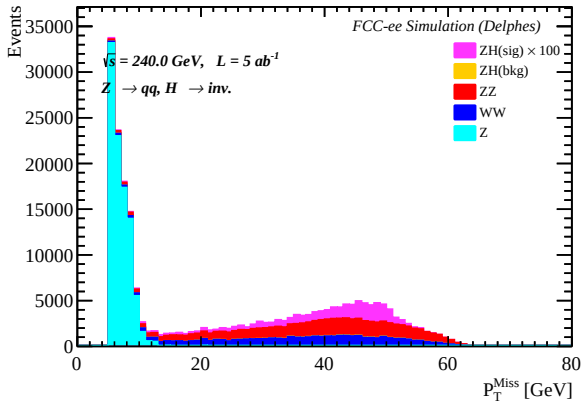
- 10 M events in each sample
- Must split the ZH MC into signal ($H \to \nu\nu\nu\nu$) and background

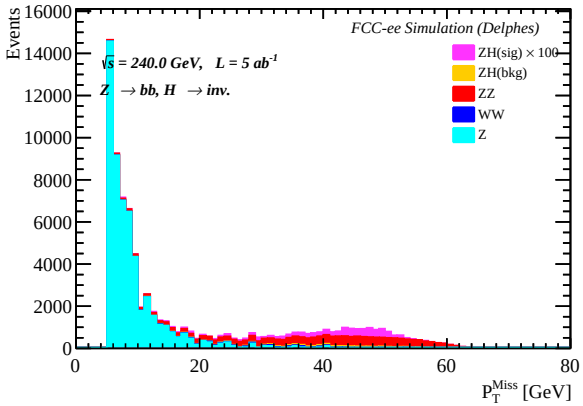
Dilepton Background

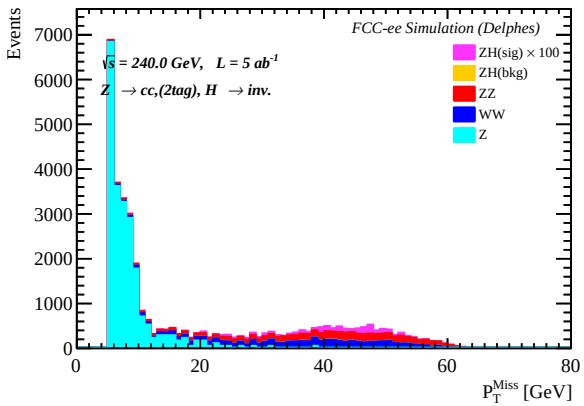
Shown after m_Z and M_{miss} cuts
$p_T^{\mathrm{miss}} < 5$ GeV not shown for plot clarity

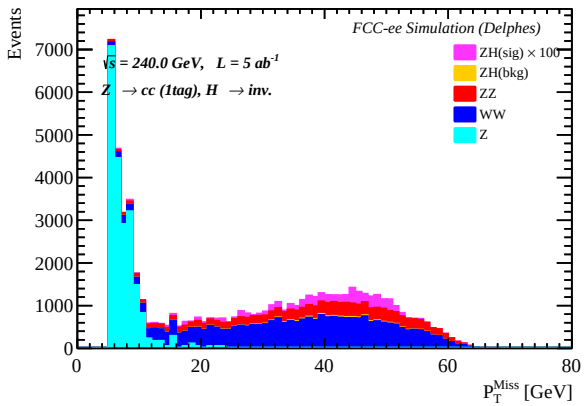








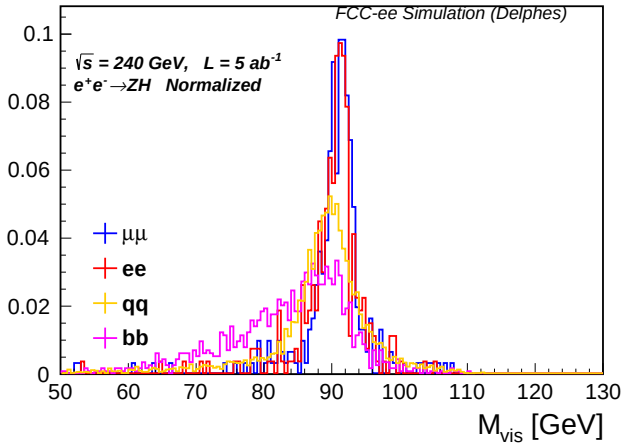


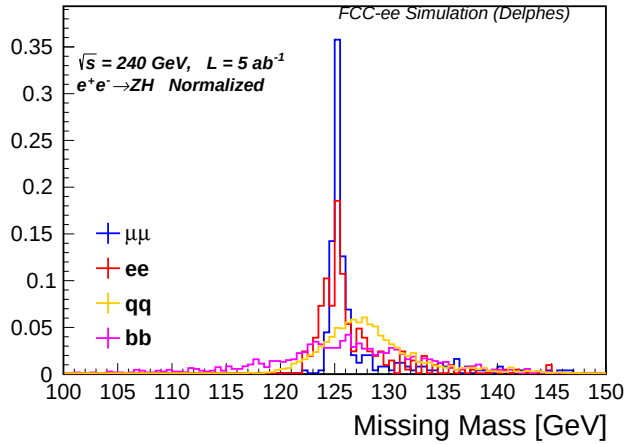


Very effective cut against dilepton background
Best to have different cuts for the different channels

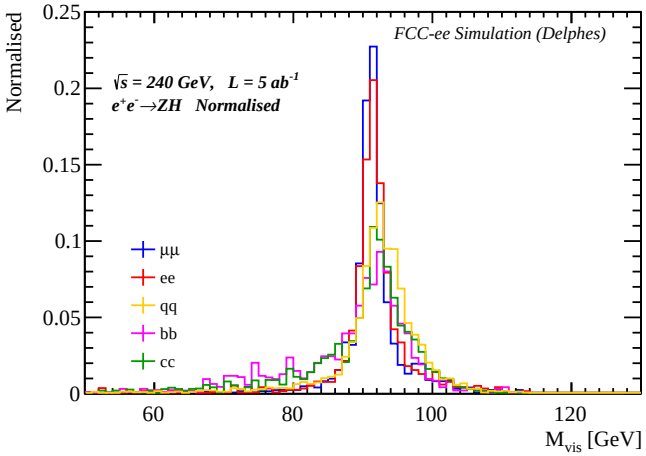
Normalized Signal Resolution

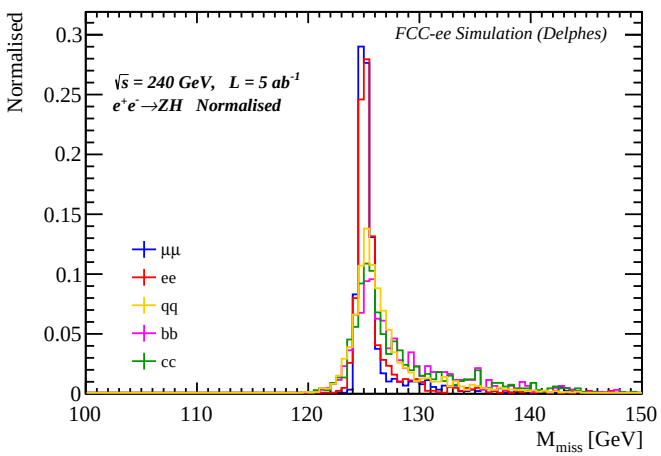
Spring 2021





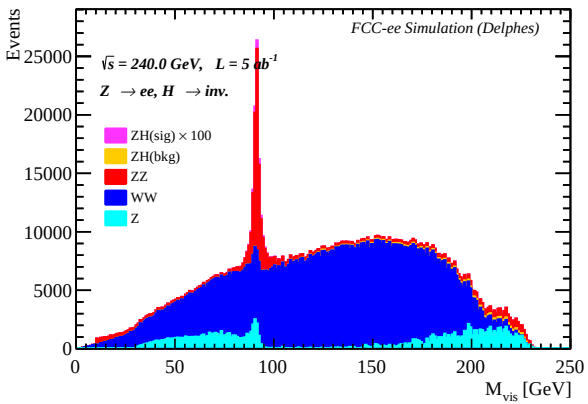
Winter 2023

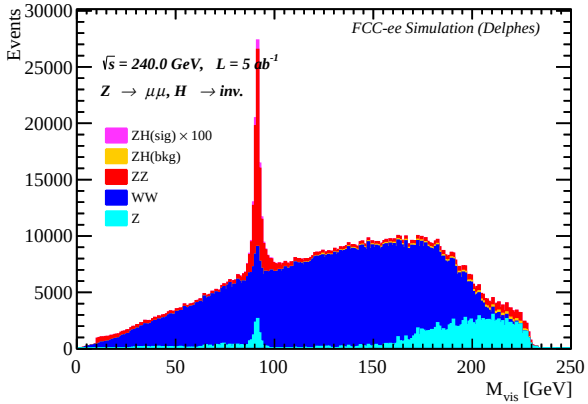


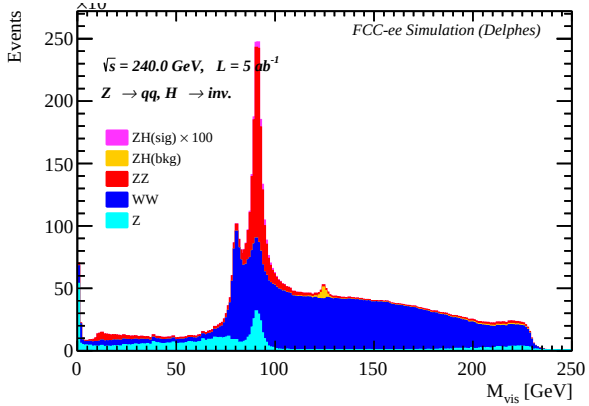


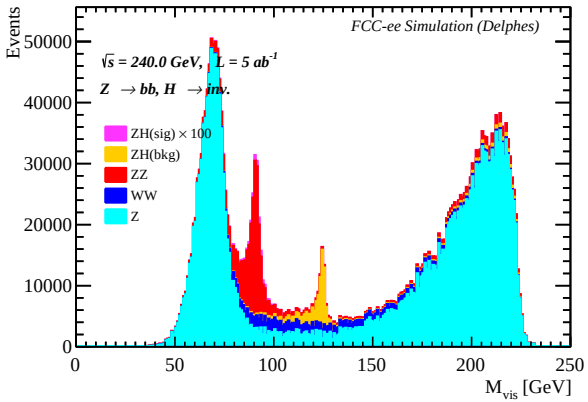
Much better resolutions that old samples
ee channel similar to $\mu\mu$
bb almost as good as *qq* - no rescaling necessary

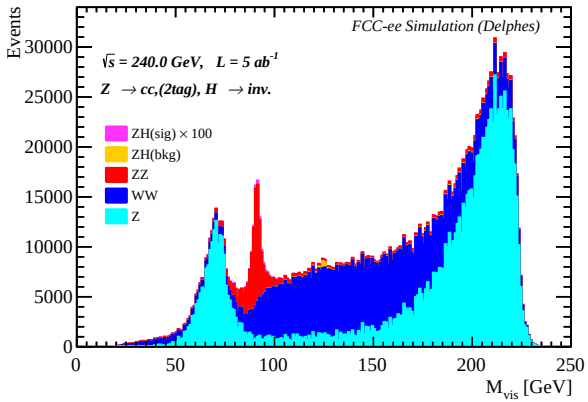
M_Z Full Range After p_T^{miss} cut

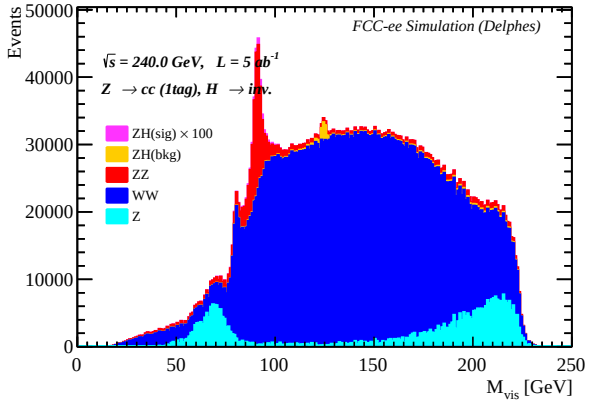






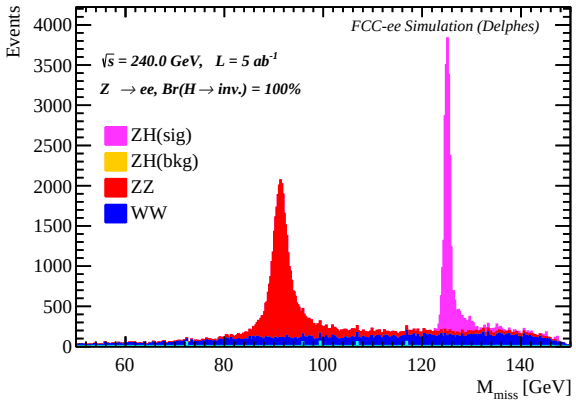


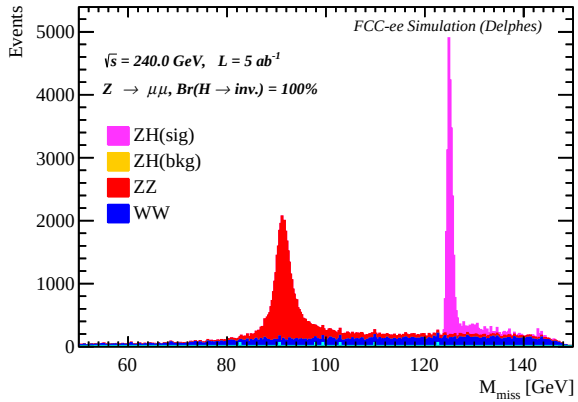


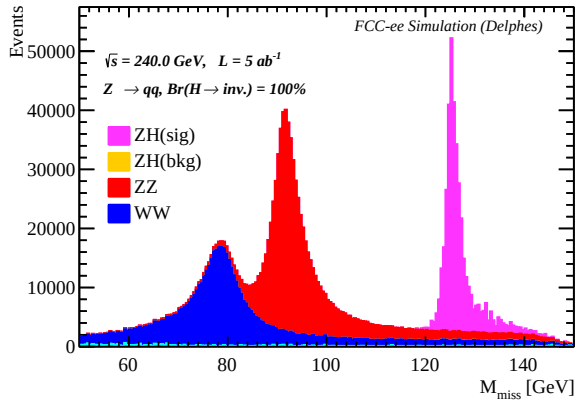


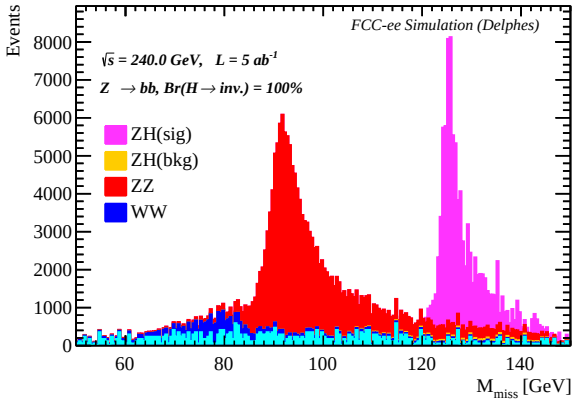
As there is no jet selection qq channel also includes $ZZ/WW \rightarrow qqqq$

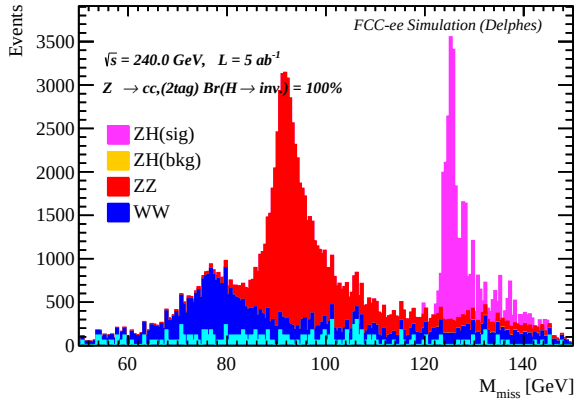
M_{miss}, M_Z cut, Zoom

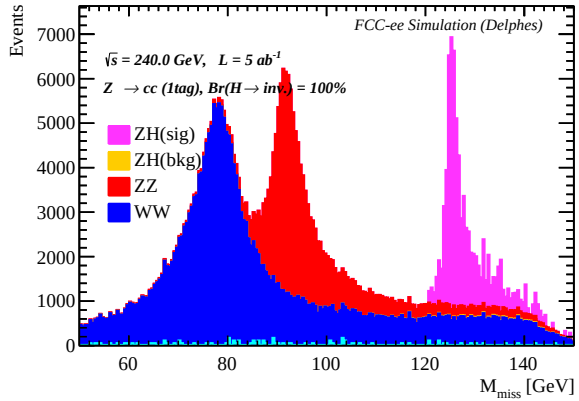






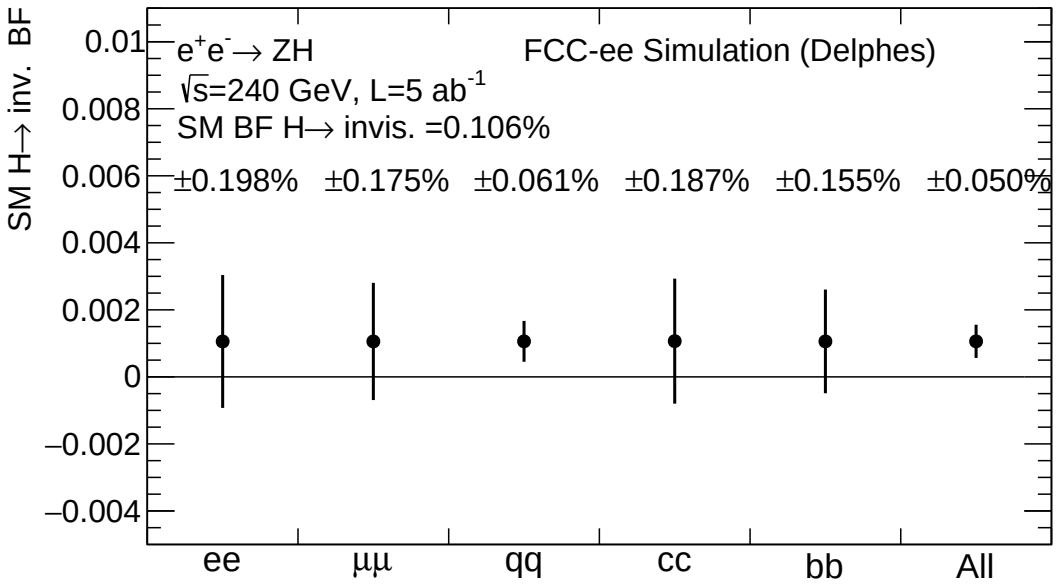






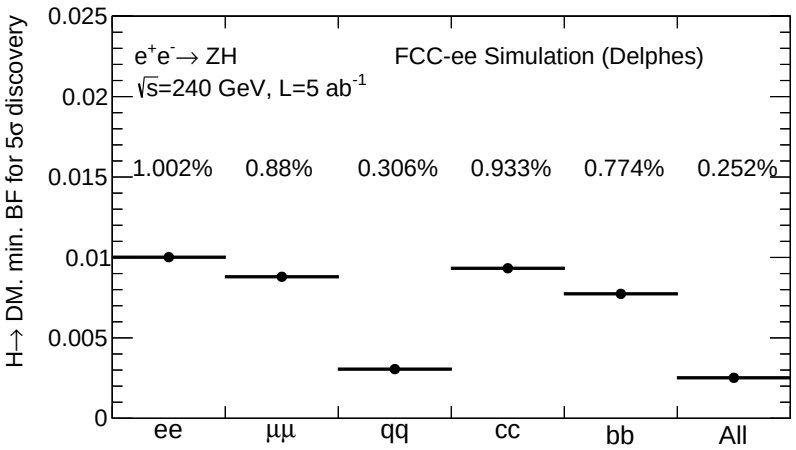
Range shown is is used in the fit

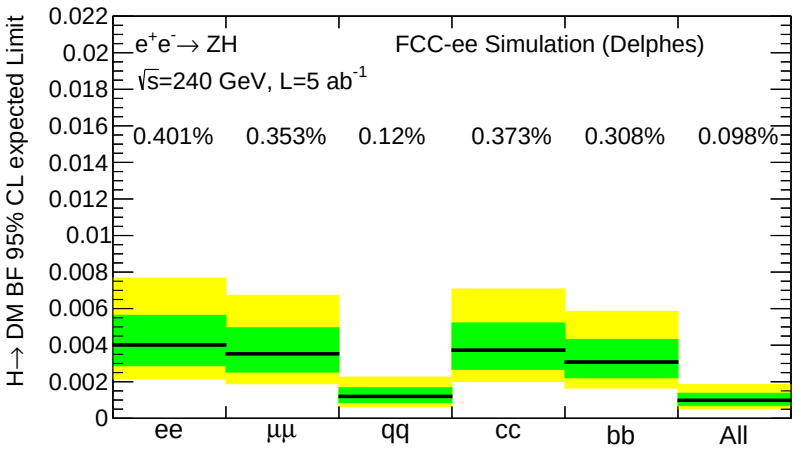
Results SM fit



Floating SM signal
50% measurement possible (twice as good as Spring 2021)
bb and *cc* channels better than Spring 2021 *qq*
Better hadronic resolution is the main cause
Smaller improvements from better flavour tagging

Discovery Fit





SM signal treated as a background
Could discover $H \rightarrow$new invisible above SM background with BF=0.2%

Summary

- Estimated FCC ee $H \rightarrow$ invisble potential using Delphes simulated data
- Looked at new Winter 2023 samples
- Much better resolutions than previous
- $Z \rightarrow qq$ channel much better than other channels
- c-tagging, b-tagging and jet multiplicity splitting improves the result a little
- 2 σ measurement assuming SM (BR$\simeq$ 0.1%)

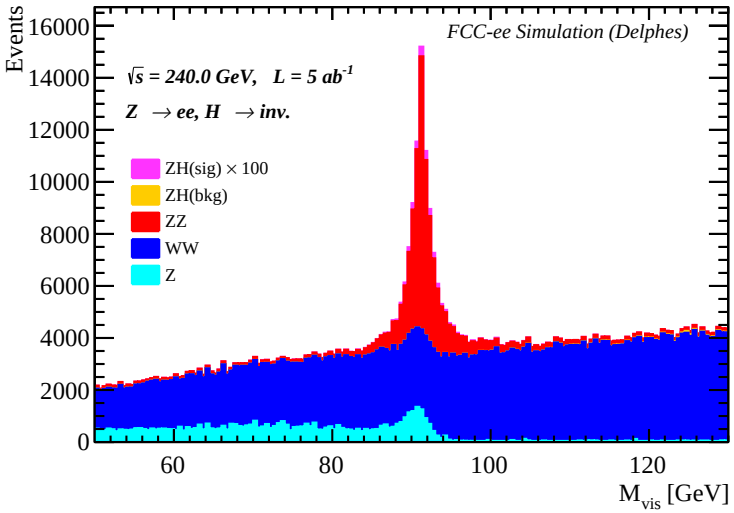
Backup 2

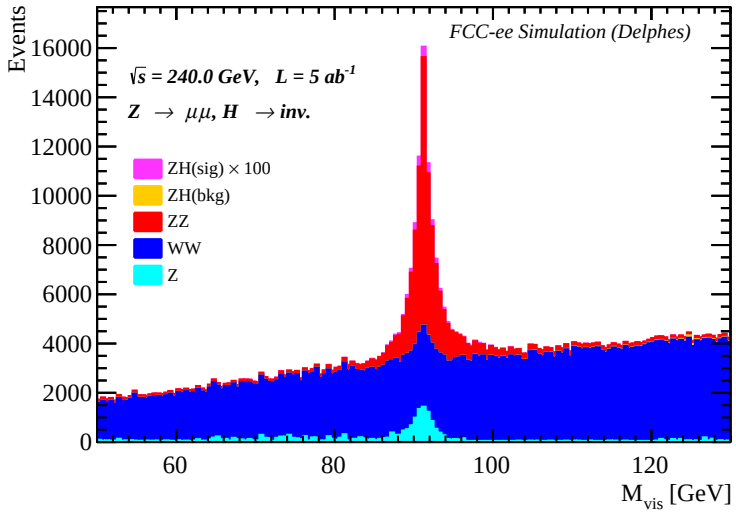
Old Samples

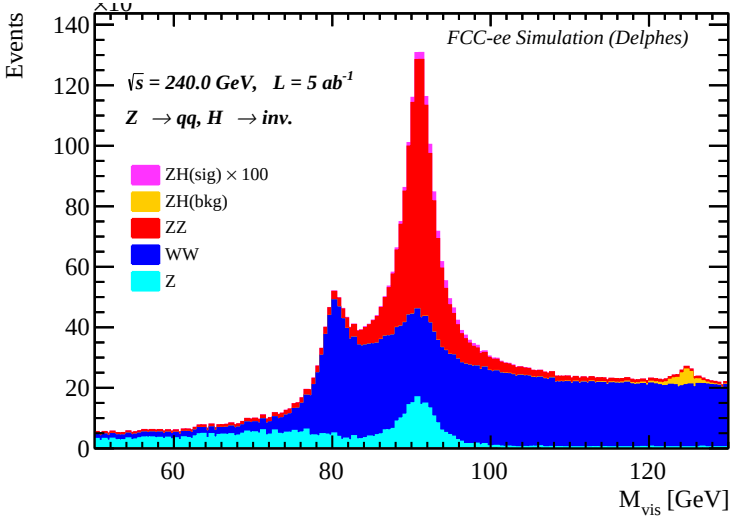
```
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_ZZ_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_WW_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_ZH_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_Zll_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_Zqq_ecm240/
```

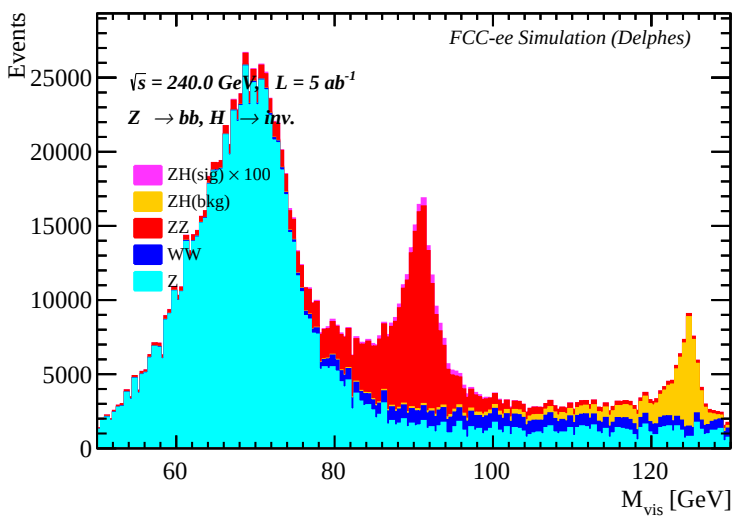
- 10 M events in each sample
- Must split the ZH MC into signal ($H \to \nu\nu\nu\nu$) and background

M_Z Zoomed



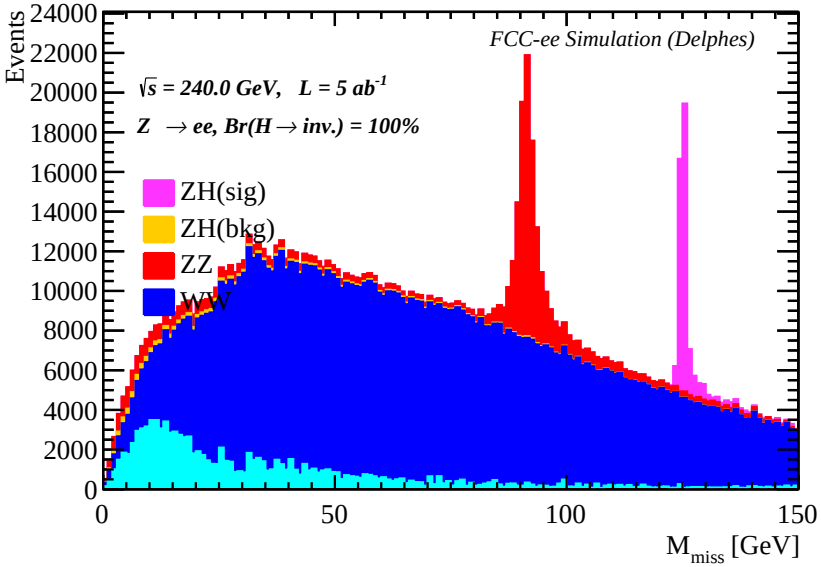


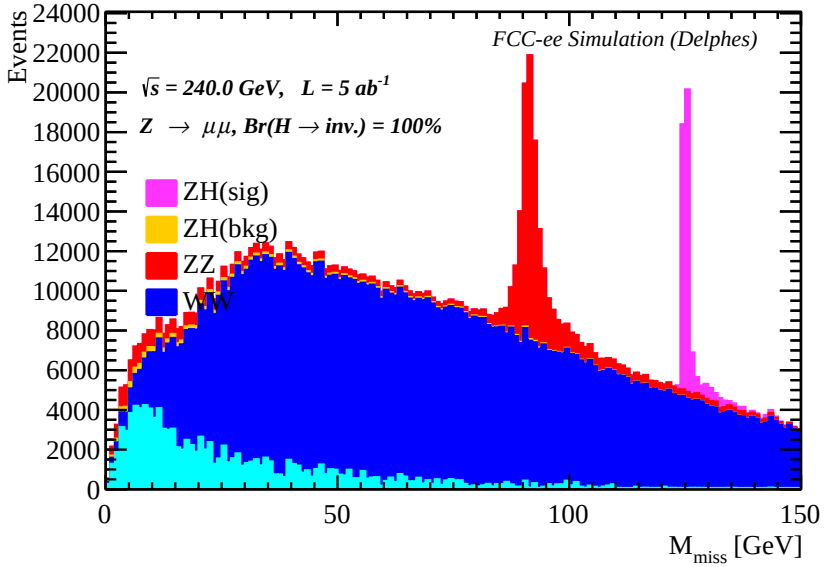


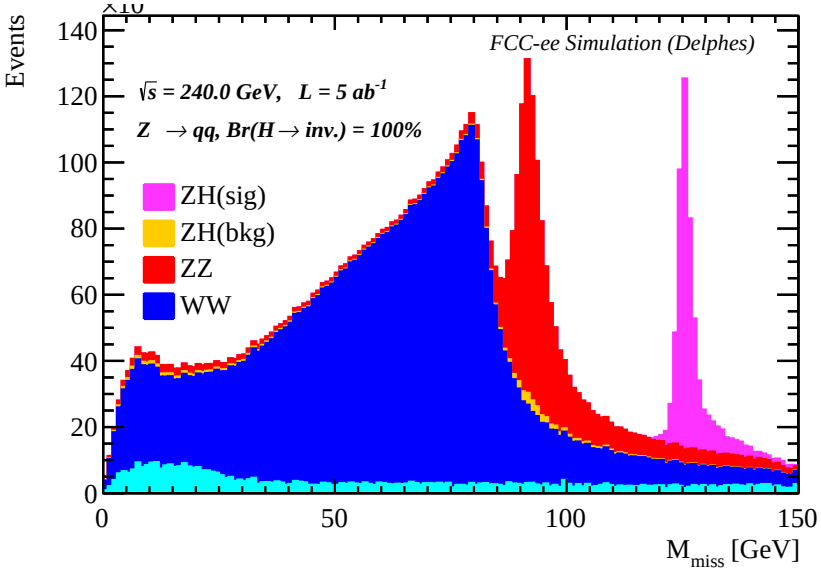


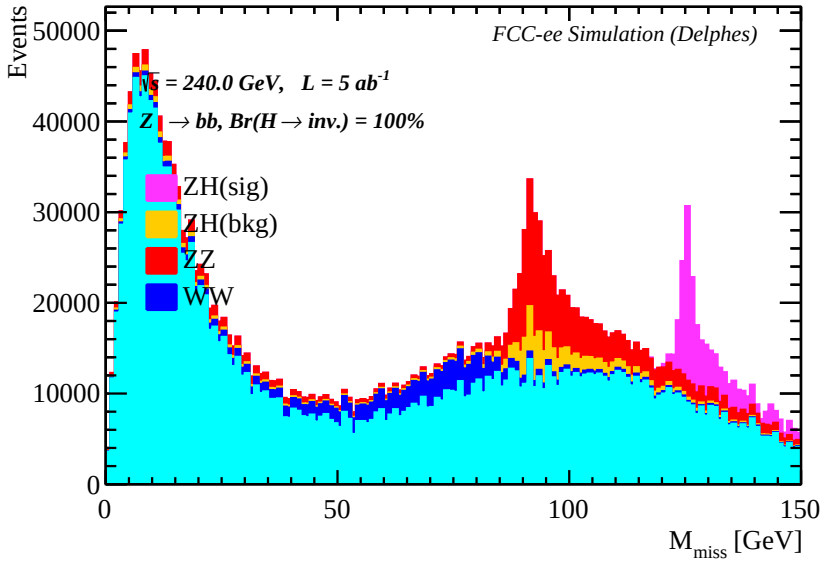
ZH background already very small. Handronic Higgs decay ($ZH \to \nu\nu bb$ or $ZH \to \nu\nu qqqq$) well separated from Z peak.
dilepton background small but not negligible

M_{miss} w/o M_Z cut









M_{miss} very effective against ZZ background