$H \rightarrow$ invisible at FCC ee

FCC Meeting QMUL

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Analysis Overview

- Estimate sensitivity of $H \rightarrow$ invisible using ZH events in e^+e^- simulated data
- Only studied $\sqrt{s} = 240$ GeV events
- Assume $\int L = 10$ ab^{-1} (four detectors)
- 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($H \rightarrow$ inv. =0.1%) but shown in plots with a scale of 1000 for clarity

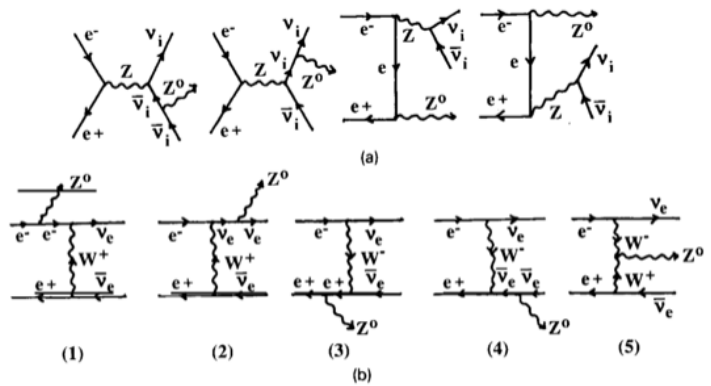
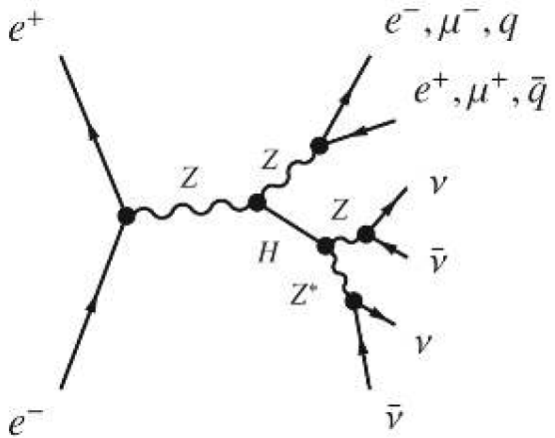


Fig. 1. Feynman diagrams contributing to the process $e^+e^- \rightarrow Z^0\nu\bar{\nu}$: (a) Z-exchange diagrams (with Z^0 in the s-channel); (b) W-exchange diagrams (with $W^\pm$('s) in the t-channel).



Method

- Split events into exactly $2e$, 2μ and 0 e+μ
- Reject events with 1 or $\geq$ 3 leptons
- bb channel defined if at least one of the two leading jets is b-tagged (ParticleNet b output>0.9)
- cc channel either 1 c-tag or 2 c-tags (split in fit) (ParticleNet c output>0.9)
- 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
- No jet selection or splitting in the qq channel

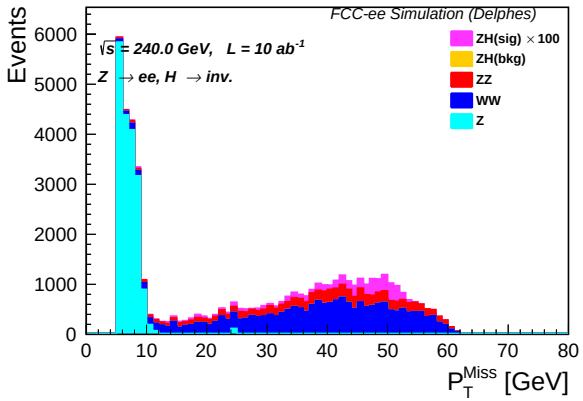
Samples

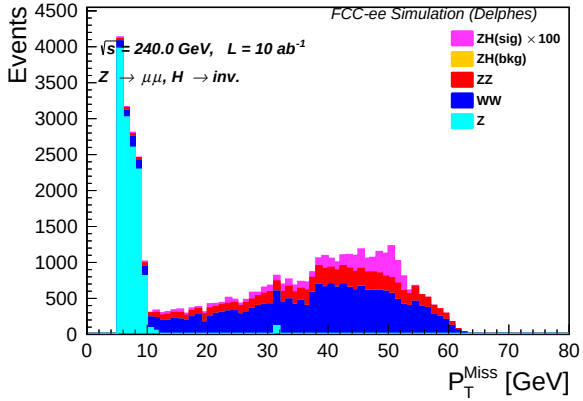
```
/eos/experiment/fcc/ee/generation/DelphesEvents/winter2023/IDEA/
wzp6_ee_qqH_ecm240
wzp6_ee_eeH_ecm240
wzp6_ee_mumuH_ecm240
wzp6_ee_tautauH_ecm240
wzp6_ee_nunuH_ecm240
p8_ee_WW_ecm240
p8_ee_ZZ_ecm240
wzp6_ee_nuenueZ_ecm240
wzp6_ee_ee_Mee_30_150_ecm240
wzp6_ee_mumu_ecm240
p8_ee_Zqq_ecm240
p8_ee_ZZ_ecm240/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

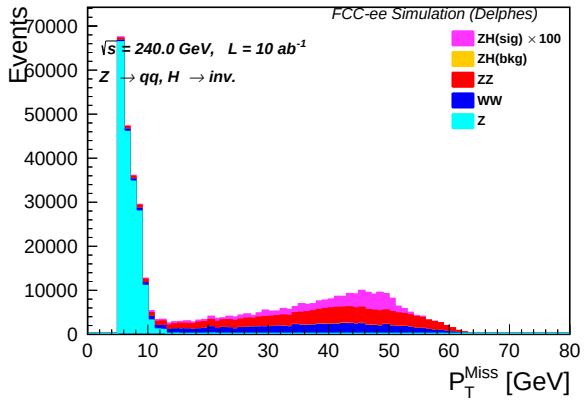
- 10 M events in each sample
- Must split the ZH MC into signal ($H \to \nu\nu\nu\nu$) and background

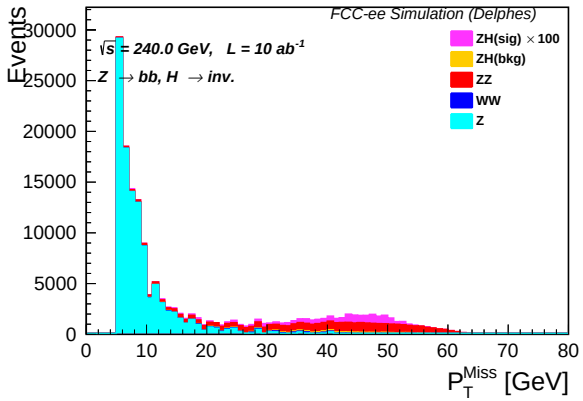
Dilepton Background

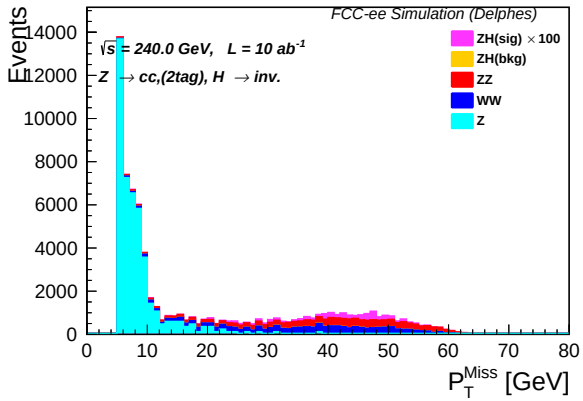
Shown after m_Z and M_{miss} cuts
$p_T^{\mathrm{miss}} < 5$ GeV not shown for plot clarity

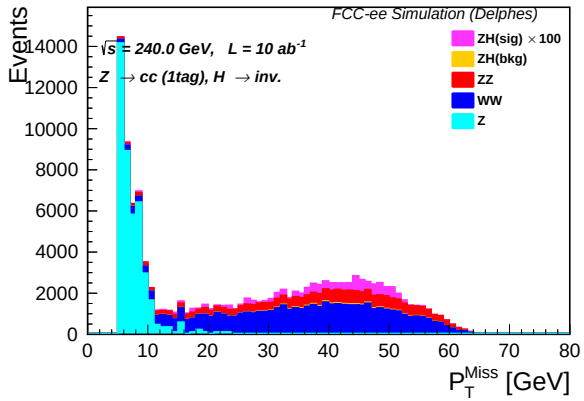








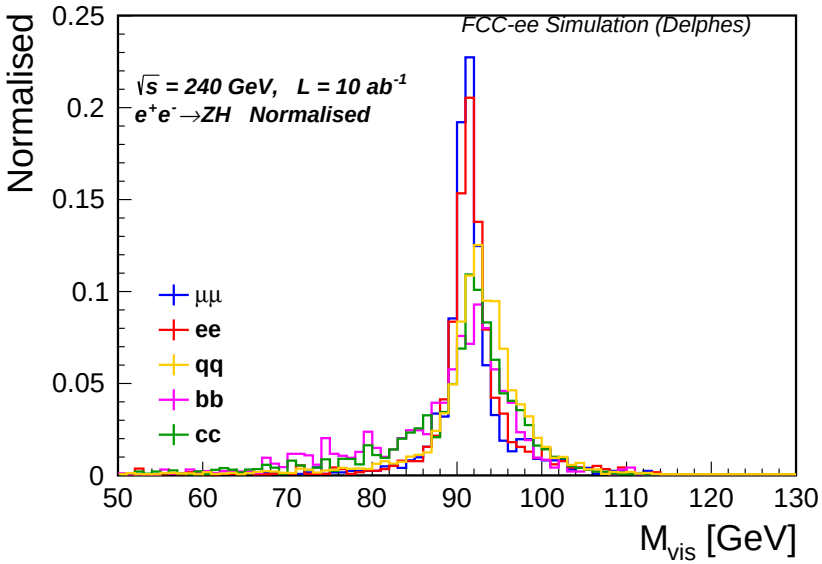




Very effective cut against dilepton background
Best to have different cuts for the different channels

Normalized Signal Resolution

Winter 2023



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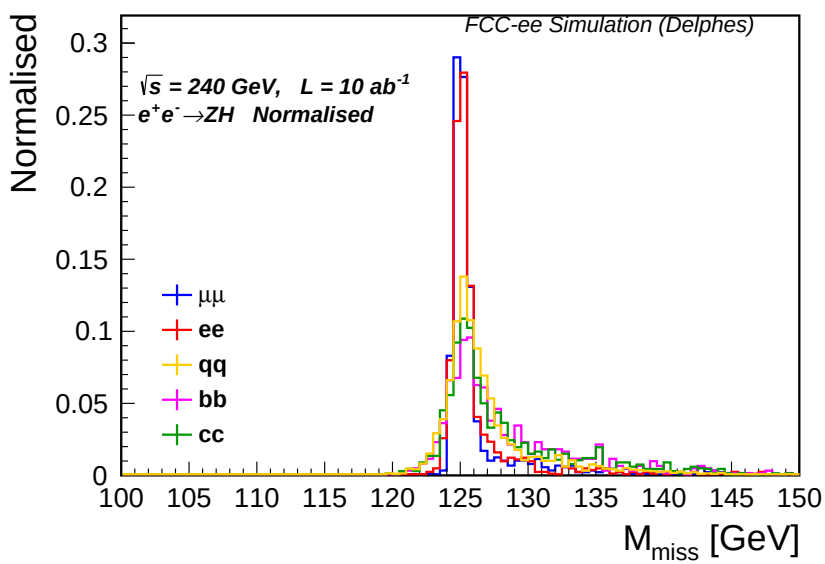
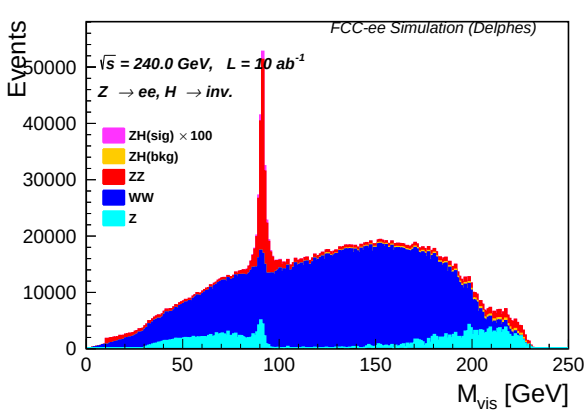
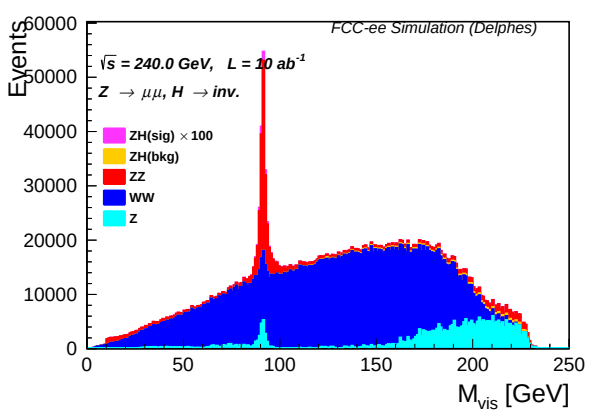
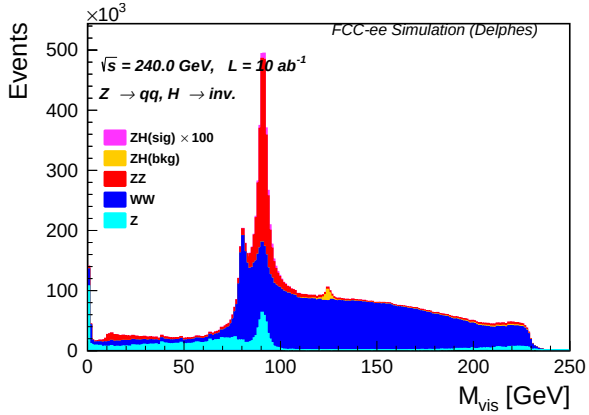


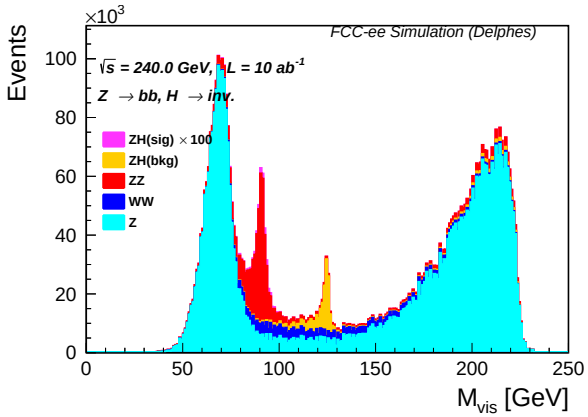
ee channel similar to $\mu\mu$
bb almost as good as *qq* - no rescaling necessary

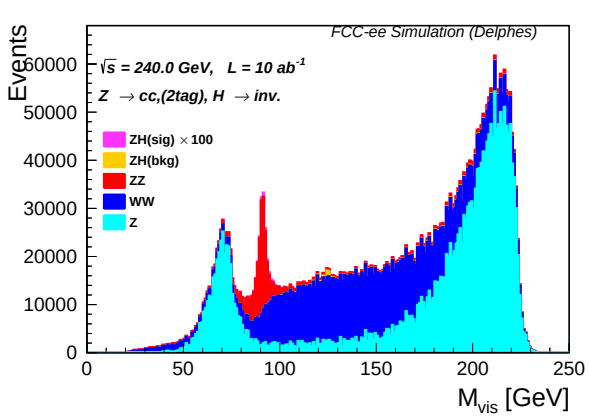
M_Z Full Range After p_T^{miss} cut

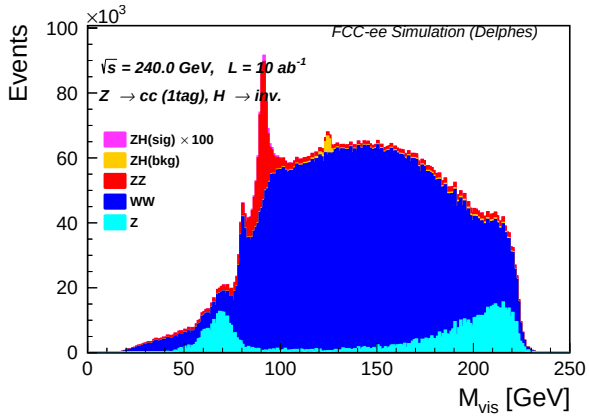






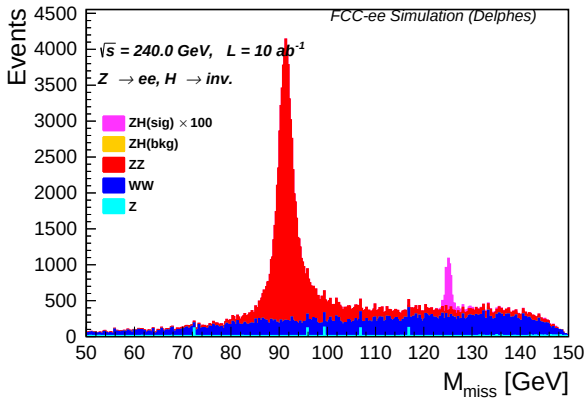


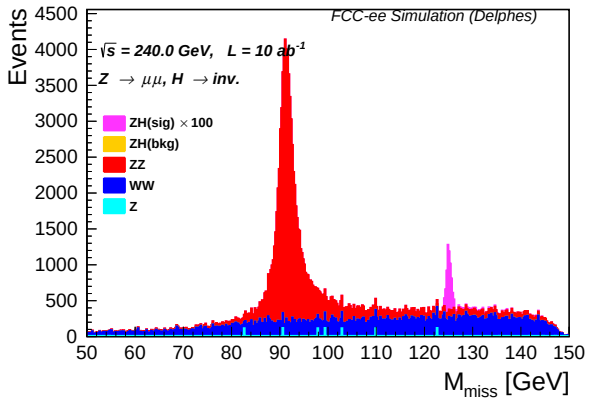


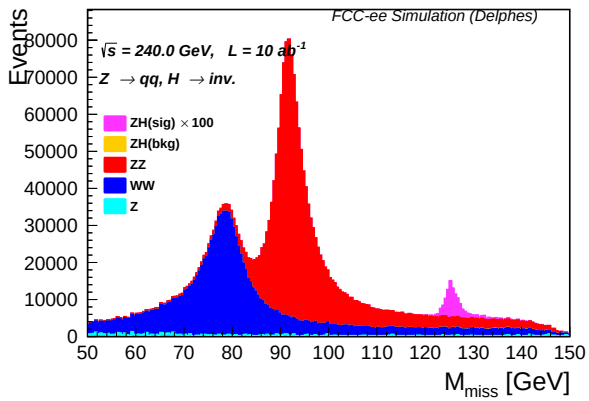


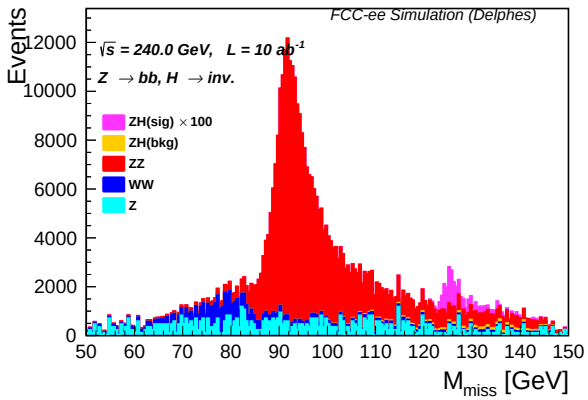
As there is no jet selection qq channel also includes $ZZ/WW \rightarrow qqqq$

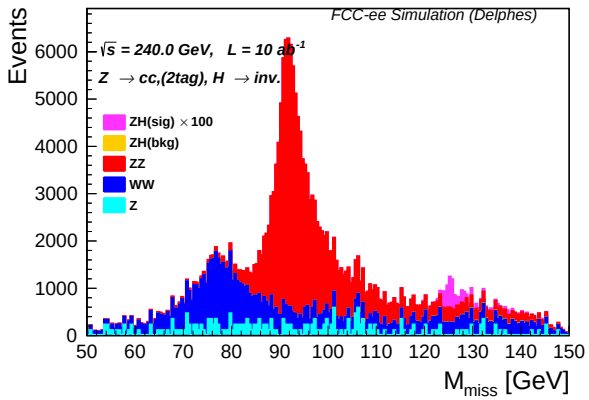
M_{miss}, M_Z cut, Zoom

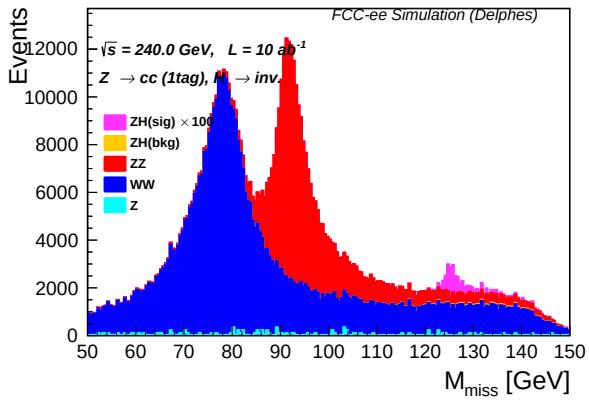






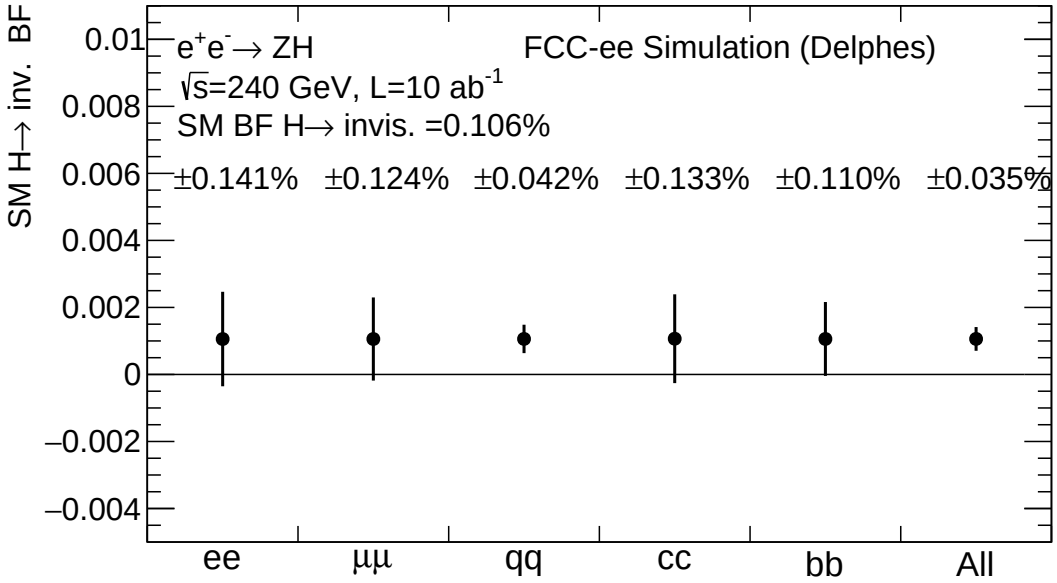






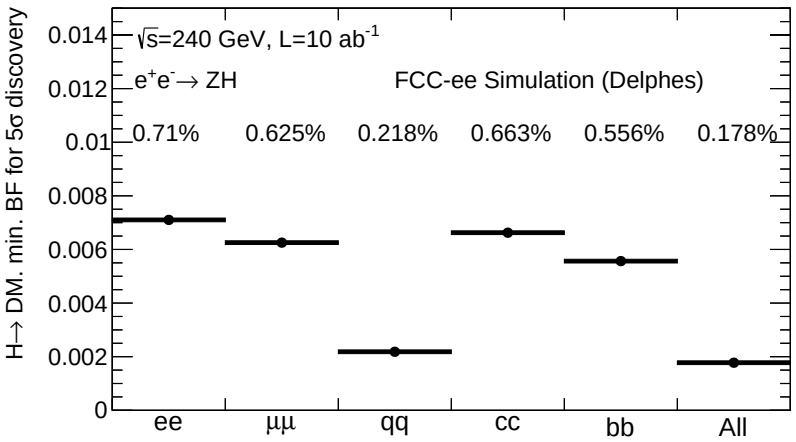
Range shown is is used in the fit

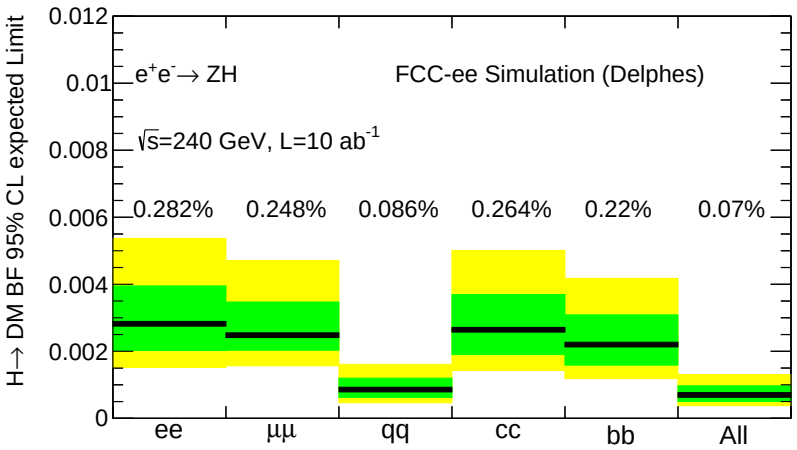
Results SM fit



Floating SM signal
35% measurement possible with 10 ab^{-1} of data
qq channel is by far the best
other channels do make a significant difference though

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
- $Z \rightarrow qq$ channel much better than other channels
- c-tagging, b-tagging improves the result a little
- $\simeq 3\ \sigma$ measurement assuming SM (BR$=0.106\%$) and 10 ab^{-1} of data
- Note has been prepared and waiting for public release

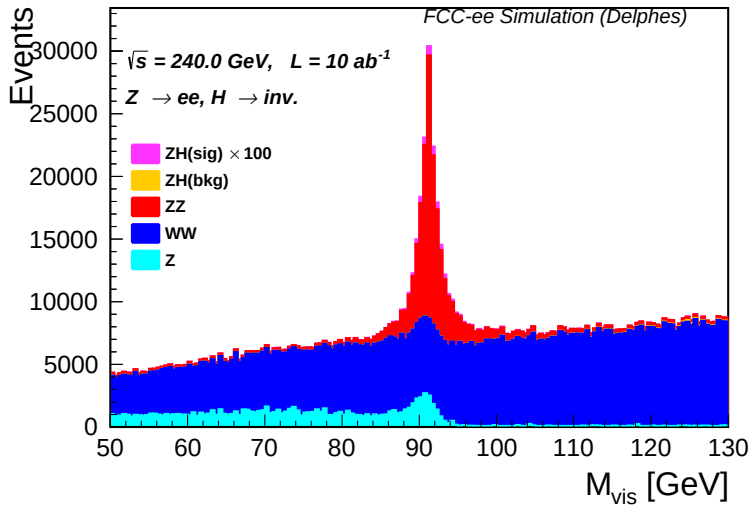
Backup

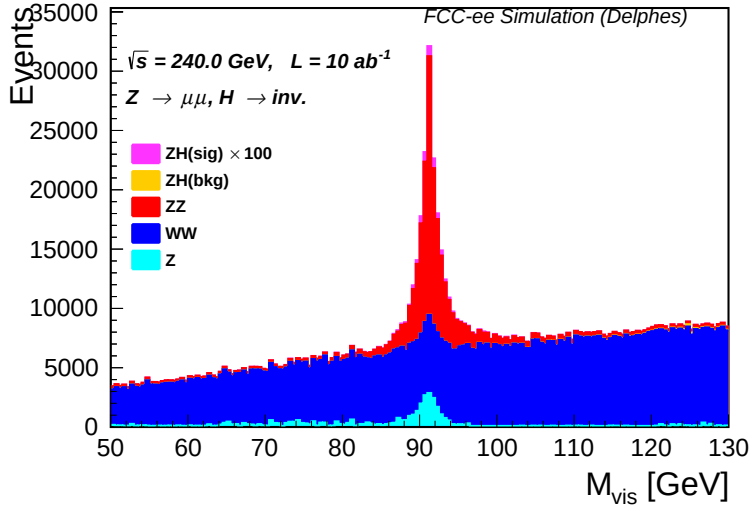
Old Samples

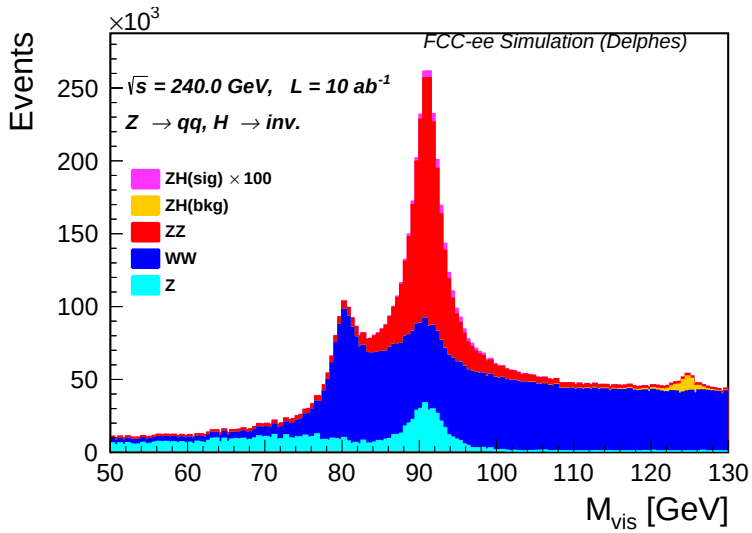
```
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_ZZ_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_WW_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_ZH_ecm240/
/eos/experiment/fcc/ee/generation/DelphesEvents/spring2021/IDEA/p8_ee_Zll_ecm240/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

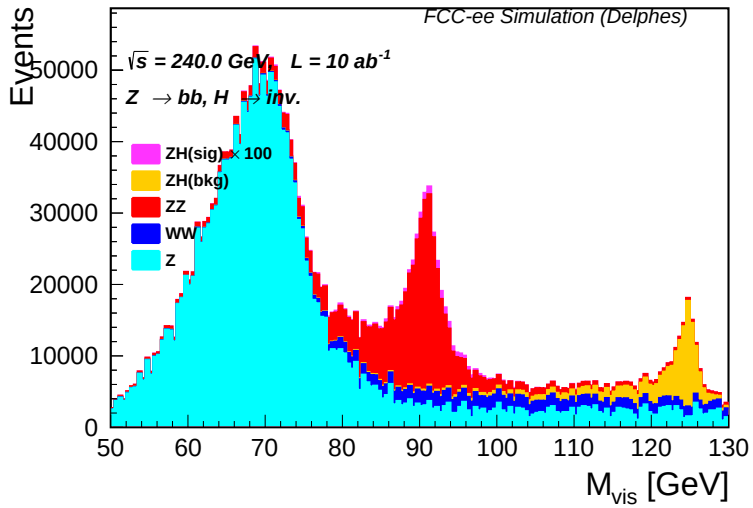
- 10 M events in each sample
- Must split the ZH MC into signal ($H \to \nu\nu\nu\nu$) and background

M_Z Zoomed



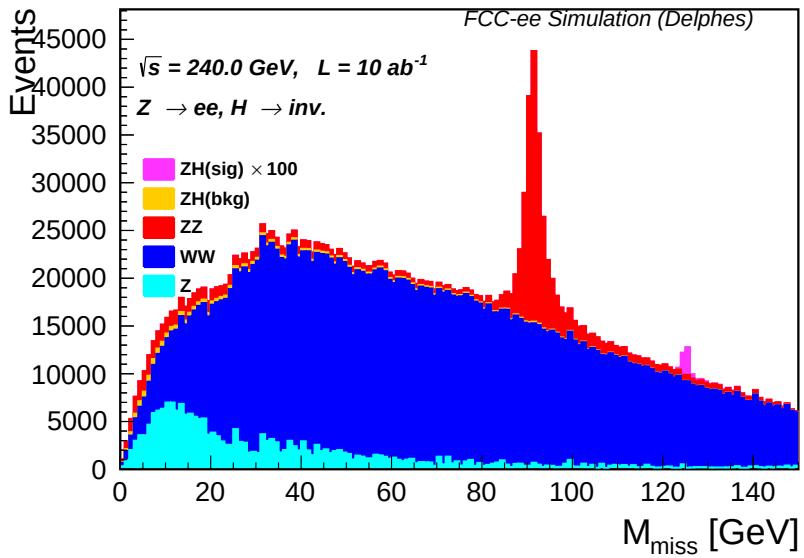


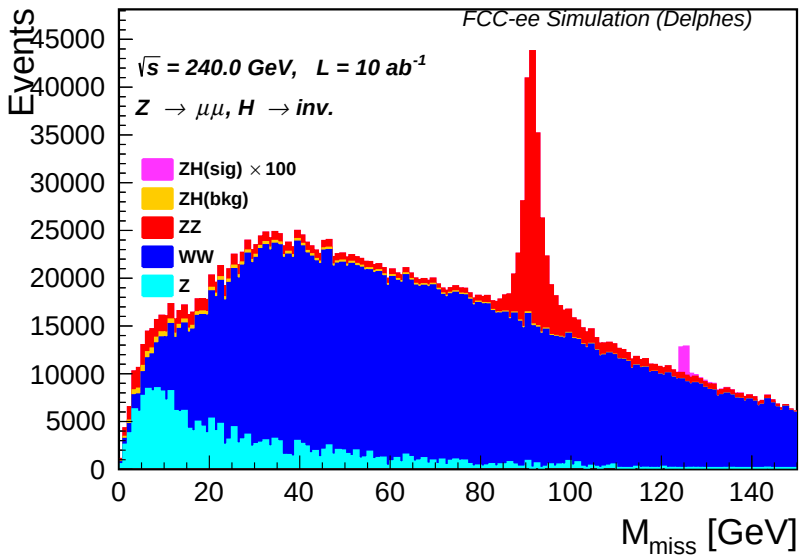


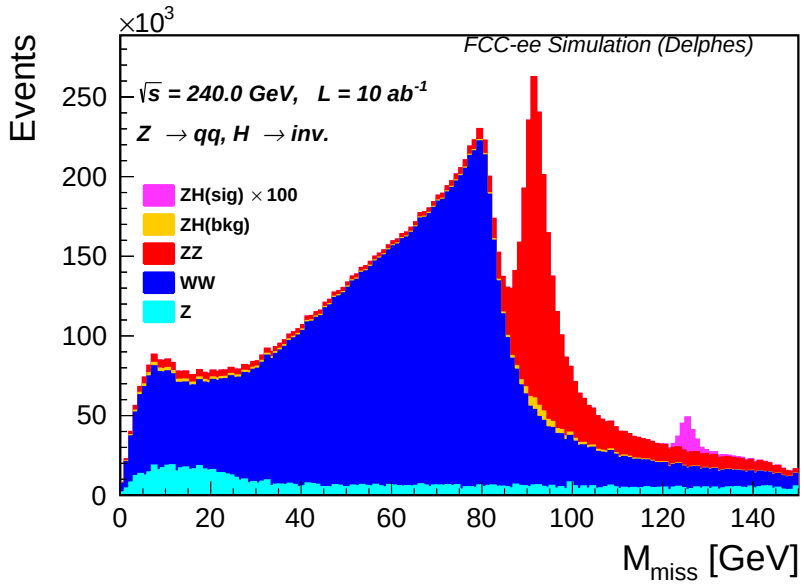


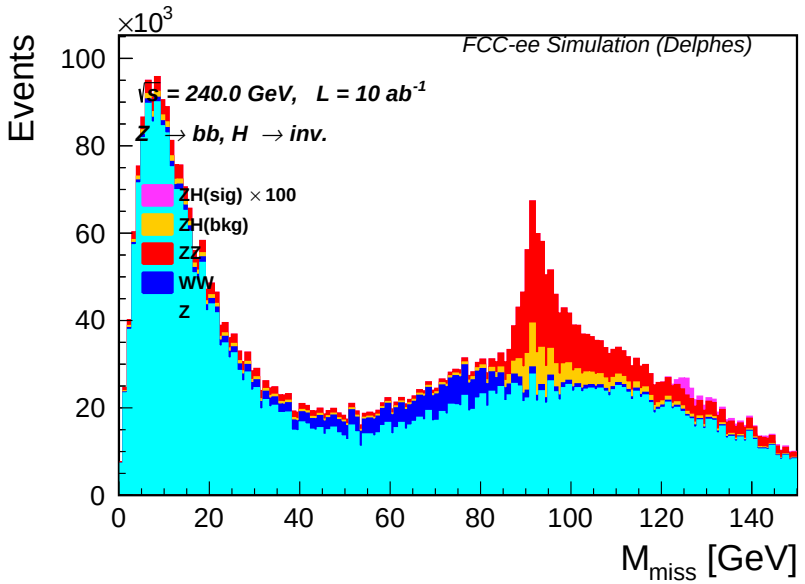
ZH background already very small. Handronic Higgs decay ($ZH \to \nu\nu bb$ or $ZH \to \nu\nu qqqq$) well separated from Z peak.
dilepton background small but not negligible

M_{miss} w/o M_Z cut









M_{miss} very effective against ZZ background