$H \rightarrow$ invisible at FCC ee

FCC Higgs Meeting

Andy Mehta, Nikos Rompotis

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UNIVERSITY OF LIVERPOOL

Analaysis Overview

- Aim look at sensitivity using all decays in simulated data
- Only studied $\sqrt{s} = 240$ GeV events
- Assume $\int L = 5\ \text{ab}^{-1}$
- Using $Z \to ee$, $\mu\mu$, bb and qq channels
- Delphes simulation
- Backgrounds dilepton (Z), ZZ, WW and ZH
- Some diagrams not included in ZZ and WW samples labelled 'WZ'
  - WIP b-tagging needs fixing with this sample
- Will need dedicated four fermion samples with interference, but not expected to make a large difference to results
- SM $ZH \to \nu\nu\nu\nu$ treated as a background when determining limits
- Taus not studies yet but could be useful in reducing backgrounds

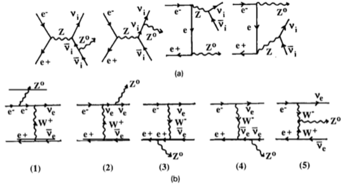
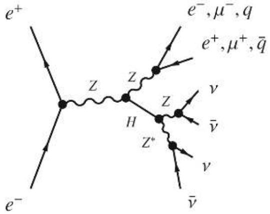


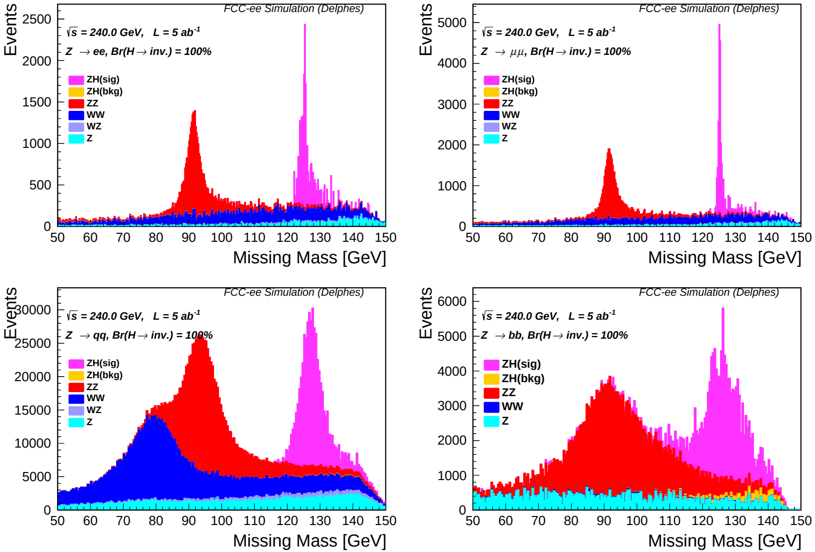
Fig. 1. Feynman diagrams contributing to the process $e^+e^- \to Z^0\nu\bar{\nu}$: (a) Z-exchange diagrams (with Z^0 in the s-channel); (b) W-exchange diagrams (with $W^\pm$('s) in the t-channel).



Method

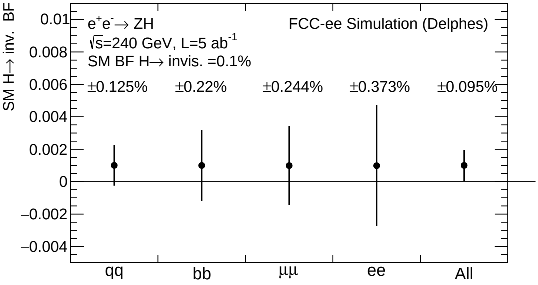
- Split events into exactly 2e, 2μ and 0 e+μ
- Reject events with 1 or $\geq$ 3 leptons
- *bb* channel defined if at least one of the two leading jets is *b*-tagged
- Require $p_T^{\mathrm{miss}} > 10/15/20$ GeV for $ee, \mu\mu/qq/bb$ to suppress dilepton background
- Reconstruct Z from 2 leptons or M_{vis} (Invariant Mass of all particles)
- Cut on 4/5 GeV around $M_Z = 91$ GeV for $ee, \mu\mu/qq$ channels
- Cut on $60 < M_Z < 100$ GeV for *bb* channel
- In *bb* channel to improve M_{miss} resolution scale visible 4 vector by 91/ M_{vis} and recalculate M_{miss}
- 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

M_{miss}, M_Z cut, Zoom



Range shown is is used in the fit

Results SM fit



Floating SM signal
100% measurement possible

Summary

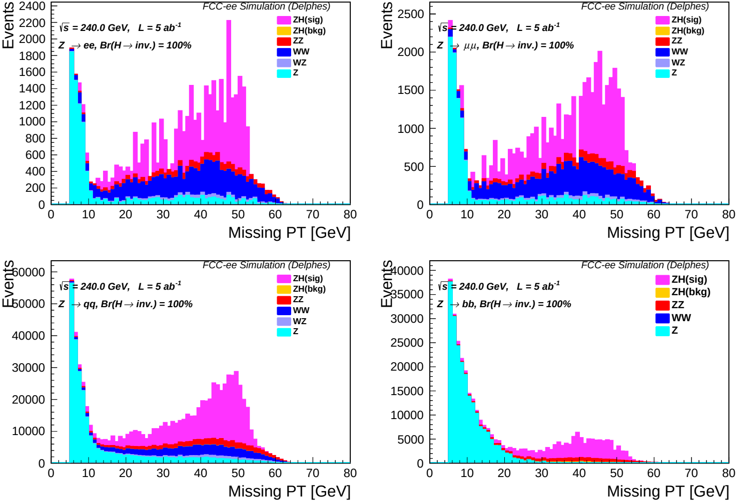
- Estimated FCC ee $H \to$ invisble potential using Delphes simulated data
- $Z \to qq$ channel much better than $Z \to ee$ or $Z \to bb$
- b-tagging and jet multiplicity splitting improves the result a little
- Reach SM precision of $\simeq 0.1\%$
- Best to redo analysis with new samples with correct treatment of ZZ and WW interference
- Could hadronic tau reconstruction help to reduce backgrounds?

Backup

Dilepton Background

Shown after m_Z and M_{miss} cuts

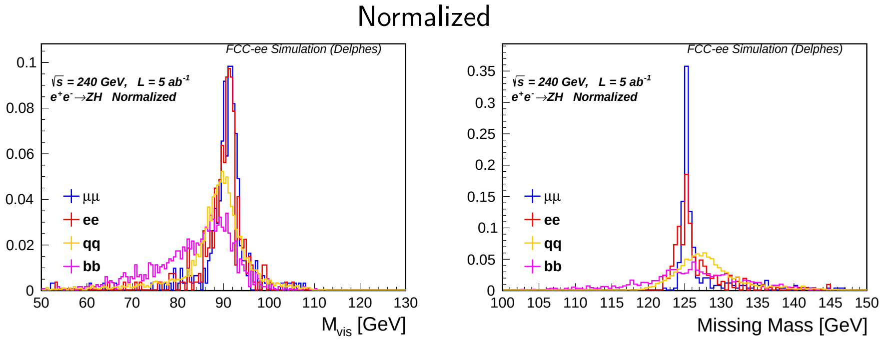
$p_T^{\text{miss}} < 5$ GeV not shown for plot clarity



Very effective cut against dilepton background

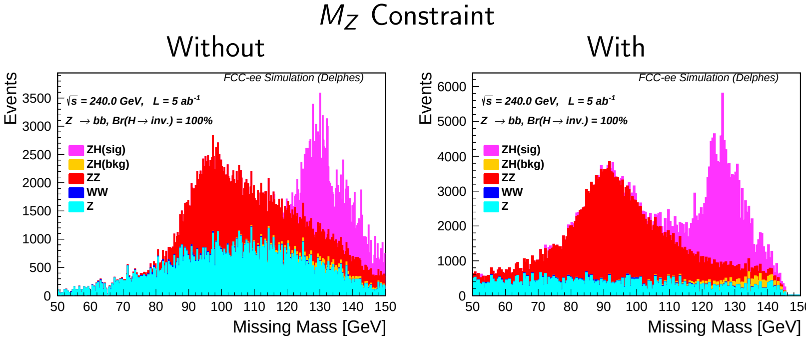
Best to have different cuts for the different channels

Signal Resolution



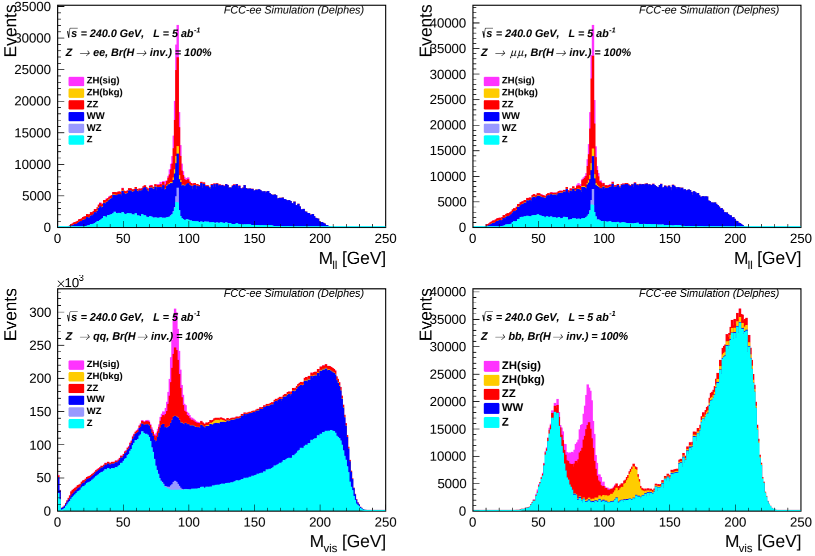
As expected worse *qq* resolution than *ee* or $\mu\mu$.
ee worse than $\mu\mu$ for M_{miss}
bb very bad due to neutrinos in *b* hadron decays

M_Z Constraint in bb Channel



Scale visible 4 vector by 91/ M_{vis} and recalculate M_{miss}
bb channel much worse without the M_Z constraint

M_Z Full Range After p_T^{miss} cut

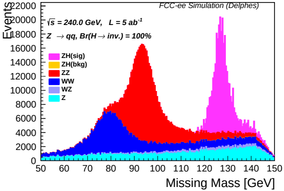


As there is no jet selection qq channel also includes $ZZ/WW \rightarrow qqqqq$

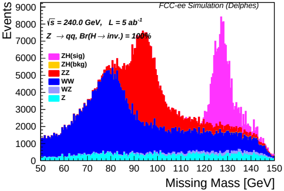
Jet Splitting in qq channel

Split qq into N jet categories
Using Valencia
Cone size 0.5
Inclusive jets
5 GeV energy cut
E ordering
E scheme

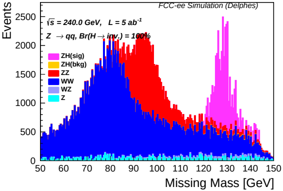
$\leq$ 2 jets



3 jets

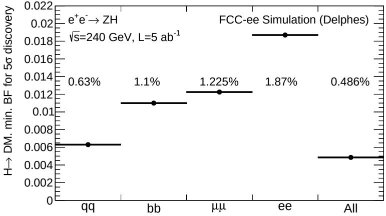


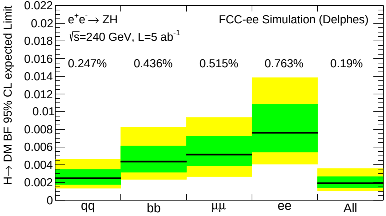
$\geq$ 4 jets



WW background increases with jet multiplicity
dilepton background decreases with jet multiplicity
Use 3 categories in the fit

Discovery Fit





SM signal treated as a background
Could discover $H \rightarrow$new invisible above SM background with BF=0.5%

Summary

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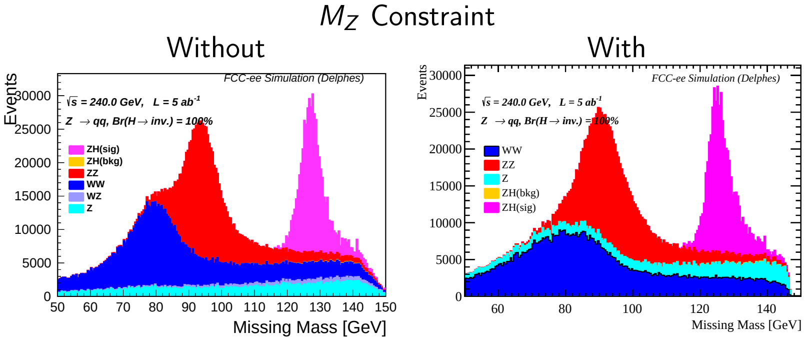
- b-tagging and jet multiplicity splitting improves the result a little
- Reach SM precision of $\simeq 0.1\%$

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/
```

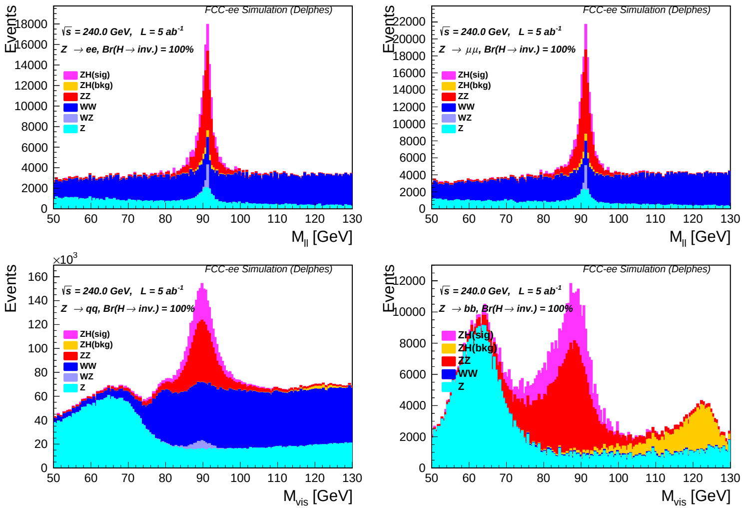
- 10 M events in each sample
- Must split the ZH MC into signal ($H \to \nu\nu\nu\nu$) and background
- Switched to 2T samples
- Include Z backgrounds

M_Z Constraint in qq Channel ?



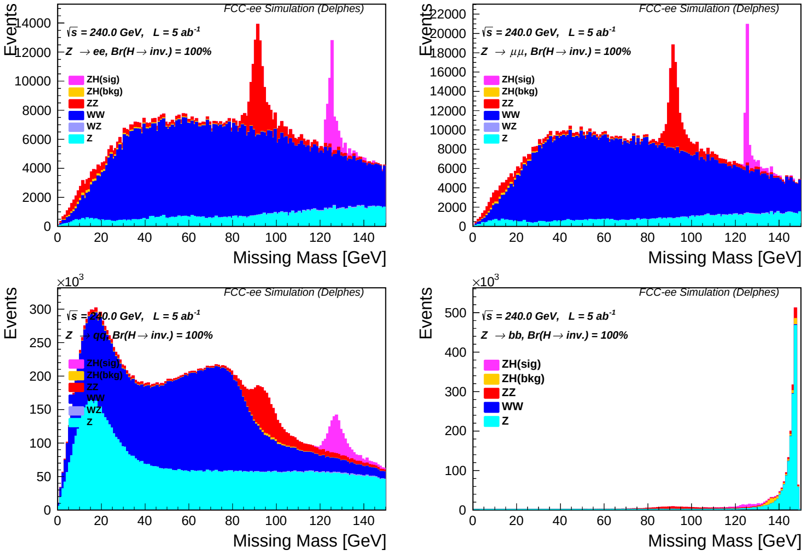
qq channel doesn't show improvement

M_Z Zoomed



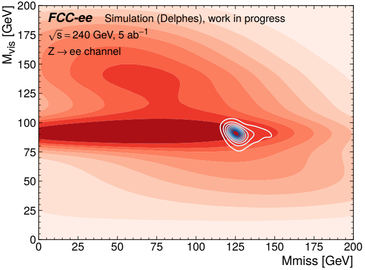
ZH background already very small. Handronic Higgs decay ($ZH \to \nu\nu bb$ or $ZH \to \nu\nu qqqq$) well separated from Z peak.
dilepton background small but not negligible

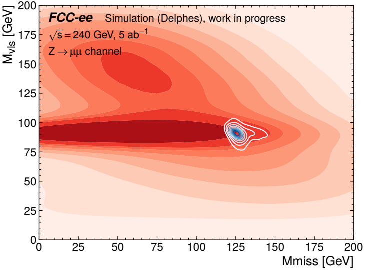
M_{miss} w/o M_Z cut

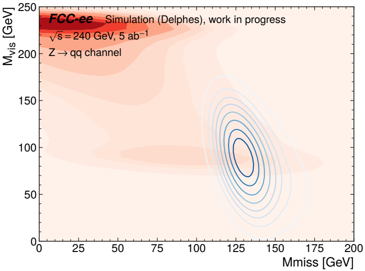


M_{miss} very effective against ZZ background

2D correlations







Possible gains to be made with non-rectangular cuts