Prospects for Higgs to invisible at the FCC-ee

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Analysis overview

- Estimate sensitivity for H→invisible at $\sqrt{(s)} = 240$ GeV using a combination of full and fast simulation.
- Compare lepton reconstruction between CLD full simulation and Delphes simulations of both CLD and IDEA.

Signal (H→ inv)	Energy	Luminosity	Selection on channels	Bkg
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- Used fast simulation from the winter2023 production.
- WHIZARD and Pythia 8 were used for generation, and simulation used Delphes with the IDEA parameters.
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- Those WHIZARD ZH signal samples were also processed with Delphes with both IDEA and CLD parameters for comparisons.

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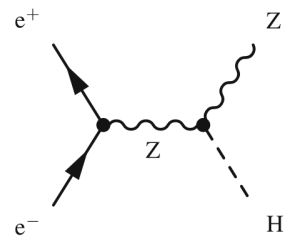
- Higgs-strahlung or $e^+e^- \to ZH$ Feyman diagram.



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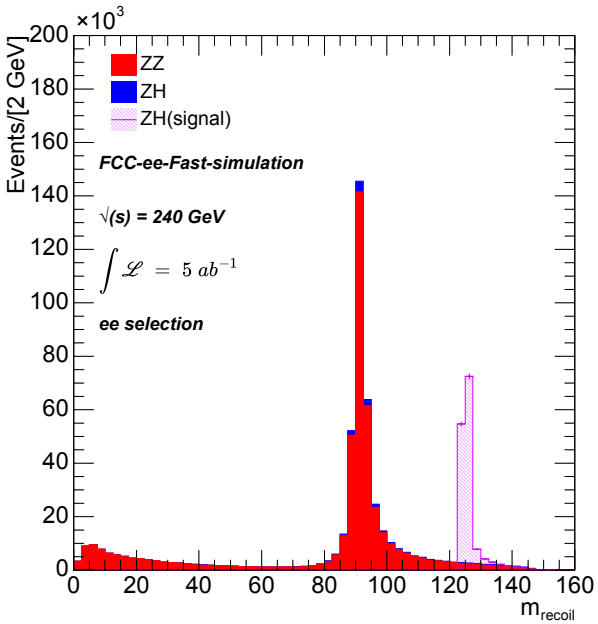
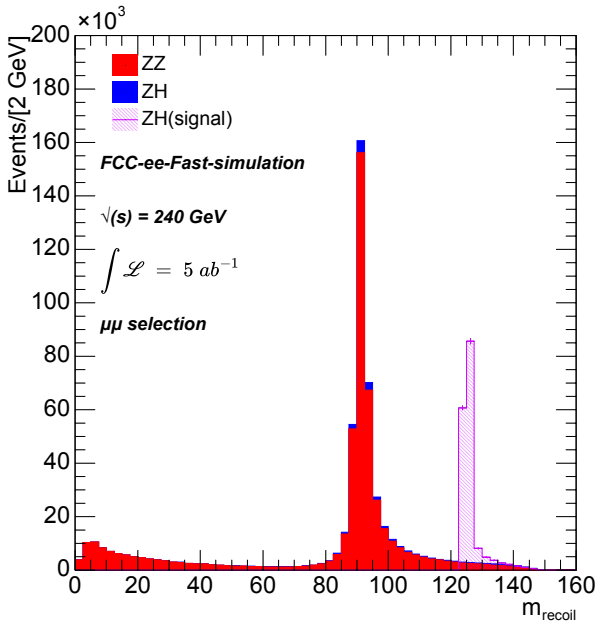
- require MET > 10 GeV.

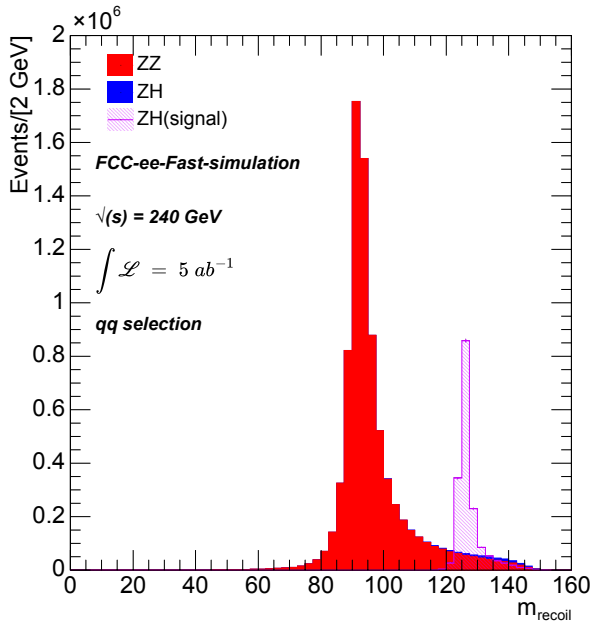
Hadronic channel

- No good leptons.
- Define m_{vis} as the mass of all visible particles, and require:
  - $|m_{\text{vis}} - 91.0| < 5$ GeV
- require MET > 15 GeV.

Assessing sensitivity on fast sim only







- Recoil mass distributions for the different selection channels.
- Only fast simulation is considered.
- The signal and bkgs are normalized with their generator cross-section (p8 for ZZ and wzp6 for ZH).
- For better visualization the signals are scaled by 15 for ee and $\mu\mu$ selections, and 20 for the qq selection.

Limit results

Limit set on $\mathcal{B}(H \to \text{inv})$ in %					
channel	-2σ	-1σ	Limit	+1σ	+2σ
ee	0.02	0.03	0.04	0.06	0.08
$\mu\mu$	0.02	0.03	0.04	0.06	0.07
qq	0.04	0.05	0.07	0.09	0.12

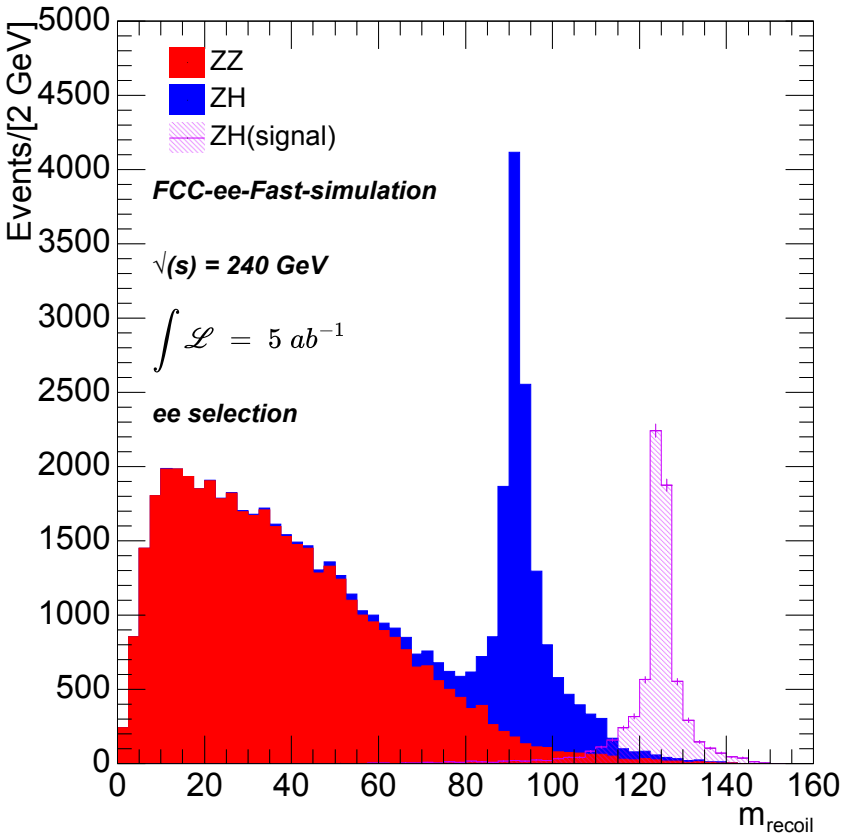
Expected limit set on cross-section

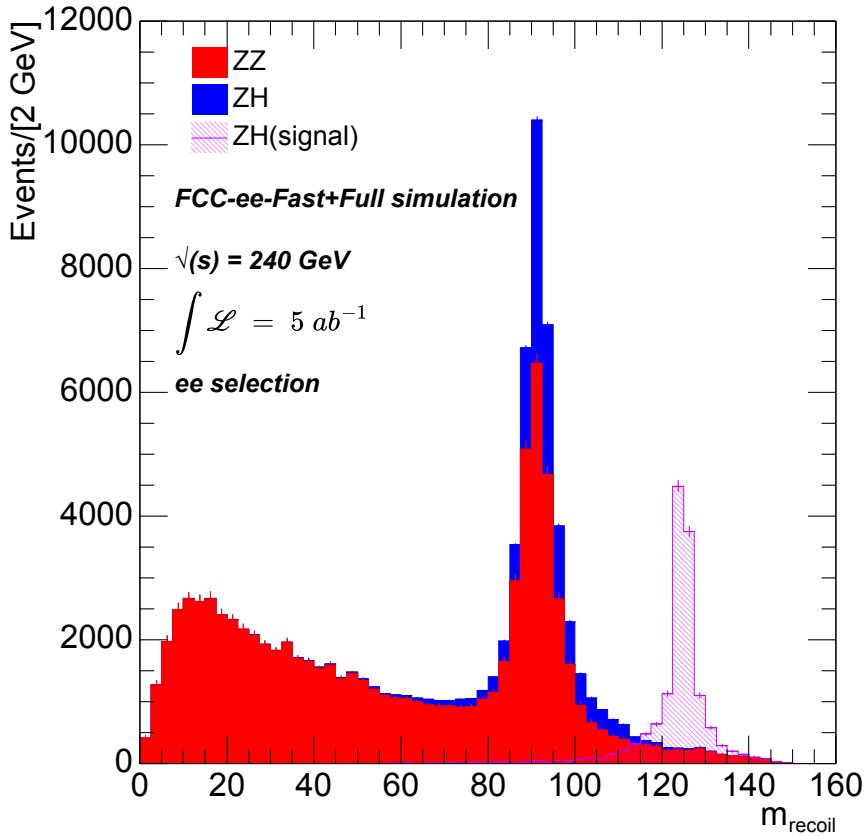
- The limit is obtained by fitting the recoil mass distributions shown in the previous slides.
- The two bkg components (ZZ+ZH) are combined in the limit setting procedure.
- The qq channel gives the worst limit.

Fast and full sim combination for limit study

- The full sim bkg samples used in these studies were generated with the following channels:
  - For ZH: $Z \to \nu\nu$ and $H \to ee\nu\nu$, $\mu\mu\nu\nu$, $qq\nu\nu$, $b\bar{b}$.
  - For ZZ: $ee\nu\nu, \mu\mu\nu\nu, qq\nu\nu, eeqq, \mu\mu qq, qqqq$.
- In order to combine fast and full sim these channels are vetoed in the fast sim samples.
- For the signal, only full sim is used.

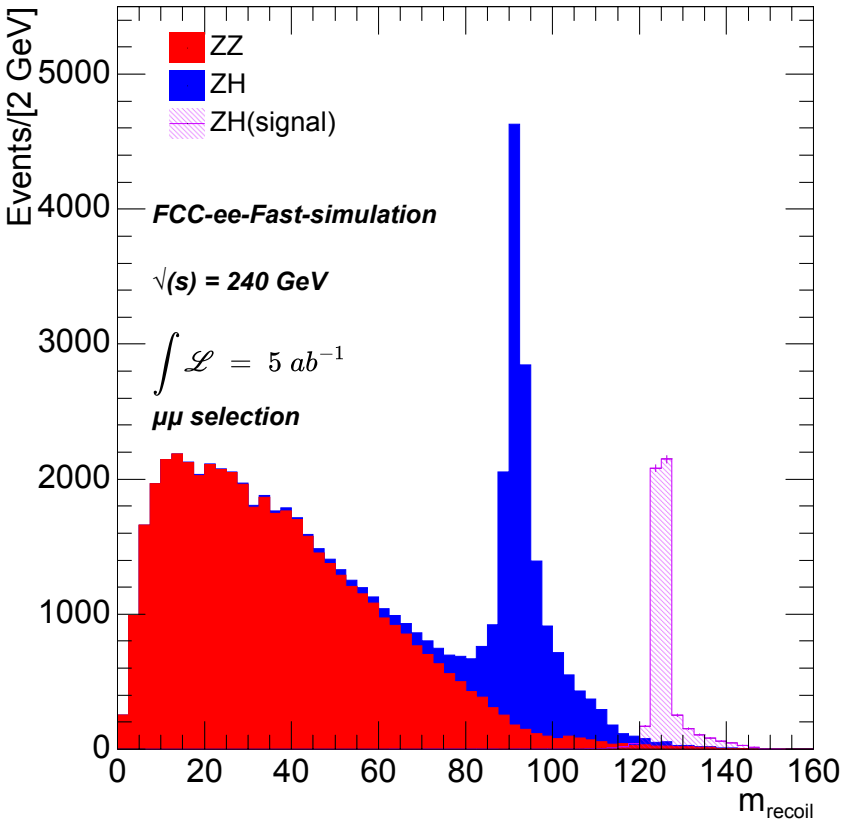
recoil mass distribution for ee selection

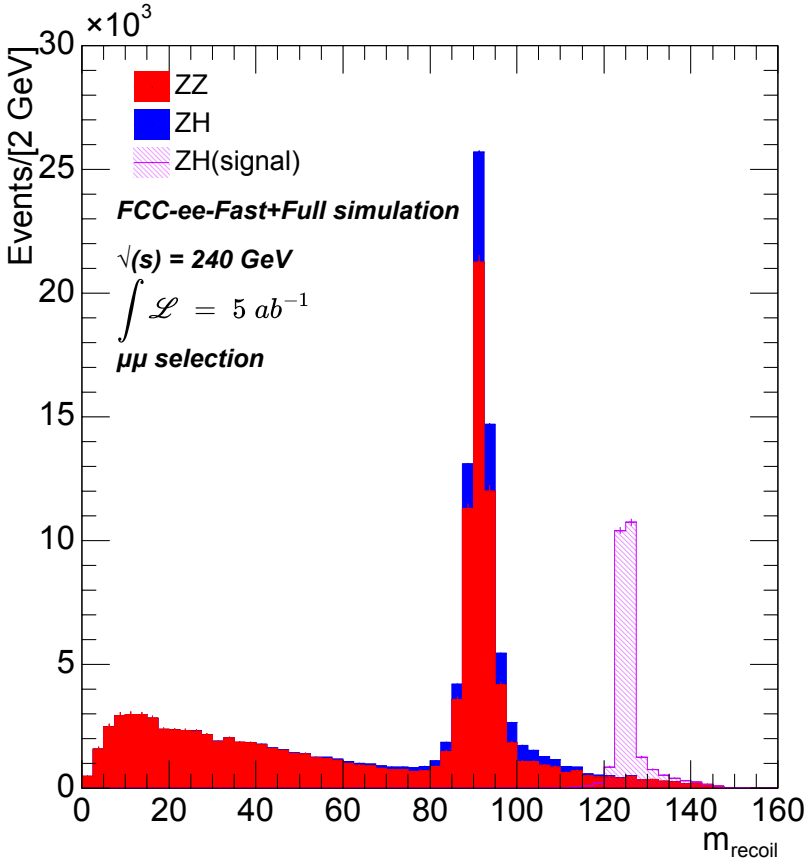




- Left → fast sim with full sim final states vetoed.
- Right → fast and full sim combined.
- ee selection is considered.
- The signal is scaled by 1000 for better visualization.

recoil mass distribution for $\mu\mu$ selection





- Left → fast sim with full sim final states vetoed.
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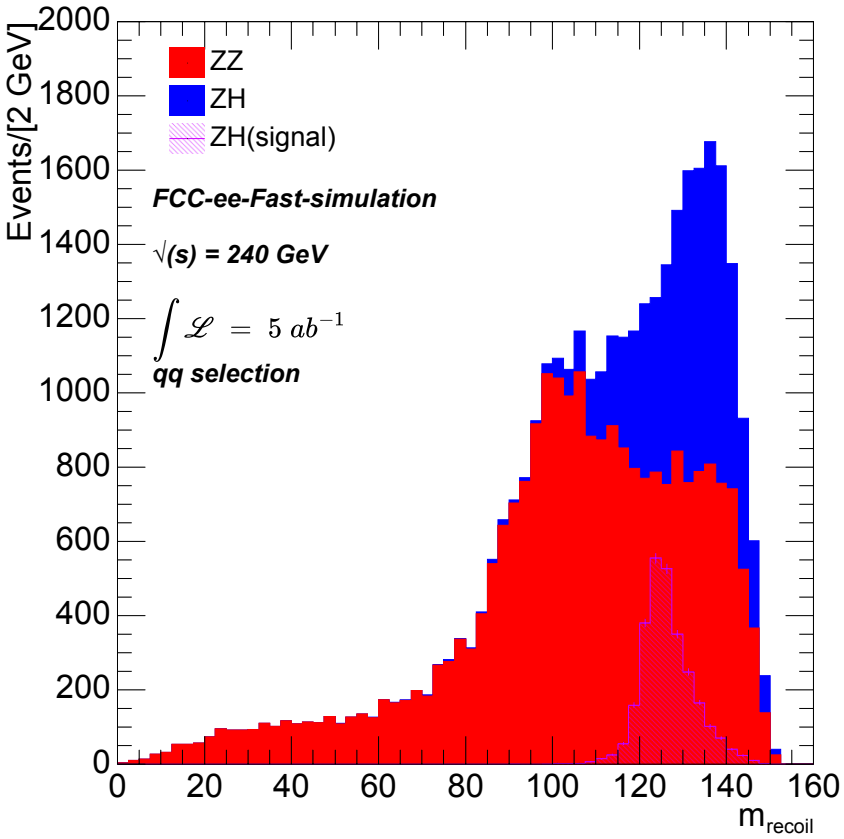
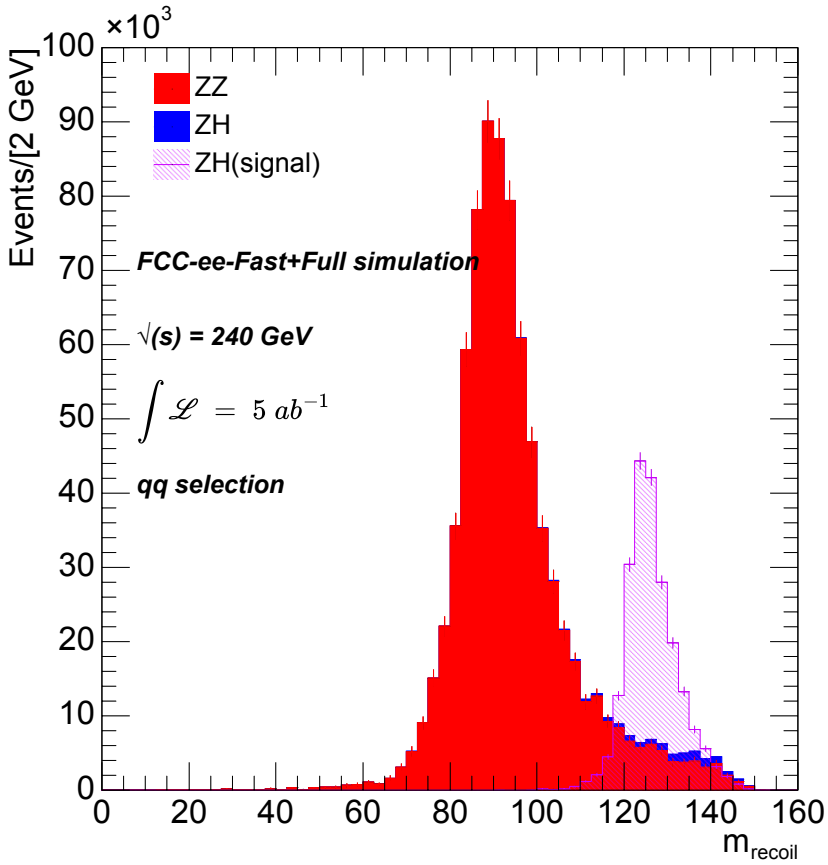
- $\mu\mu$ selection is considered.
- The signal is scaled by 1000 for better visualization.

recoil mass distribution for qq selection





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- Right → fast and full sim combined.
- qq selection is considered.
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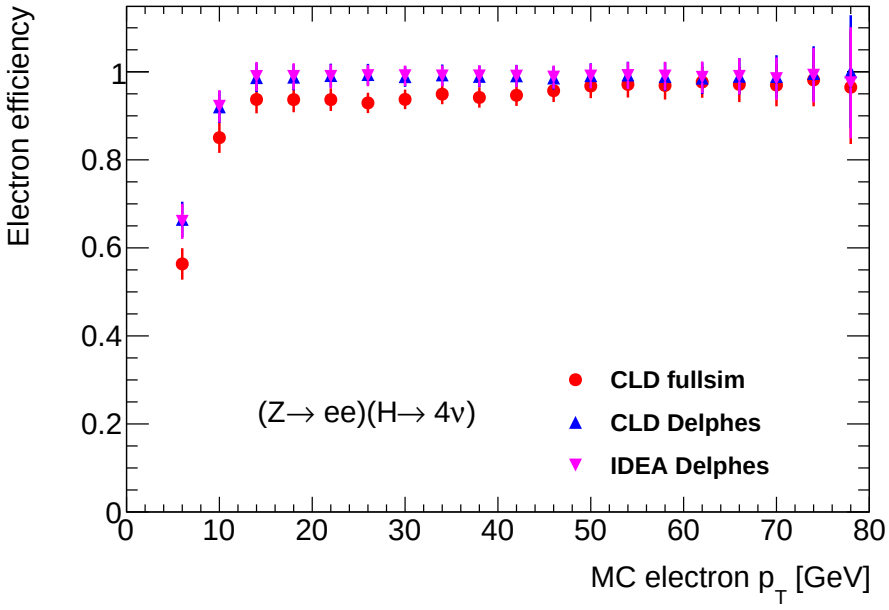
Limit results

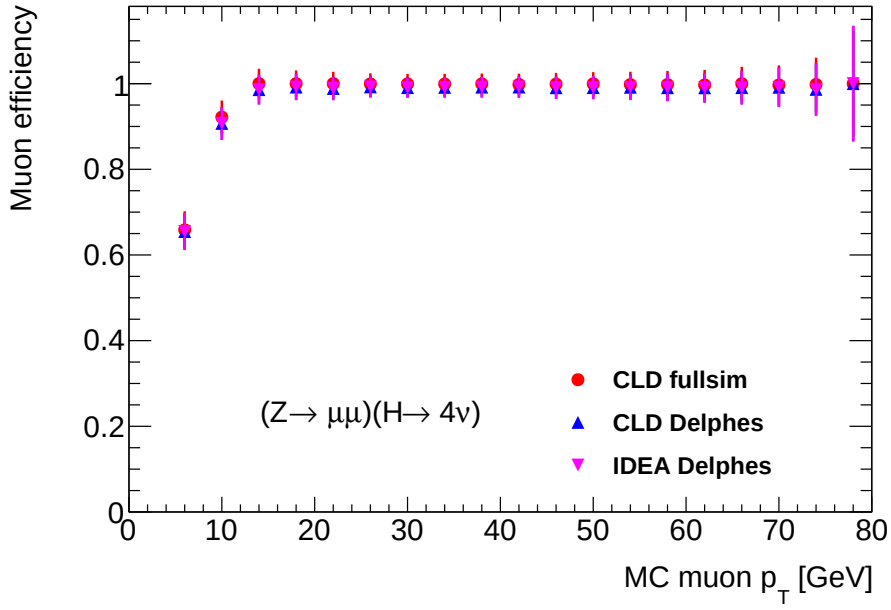
Limit set on $\mathcal{B}(H \to \text{inv})$ in%					
channel	-2σ	-1σ	Limit	+1σ	+2σ
ee	0.15	0.20	0.28	0.40	0.54
$\mu\mu$	0.08	0.11	0.15	0.21	0.29
qq	0.09	0.12	0.16	0.23	0.31

Expected limit

- The limit is obtained by fitting the recoil mass distributions shown in the previous slides.
- The two bkg components (ZZ+ZH) are combined in the limit setting procedure.
- The best limit is obtained with 2μ selection and qq selection is the worse limit.
- The limit result is 1 order of magnitude worse compared to the fast simulation one (slide 5) which could be explained by the bad resolution/efficiency of the full simulation as detailed in the next slides.

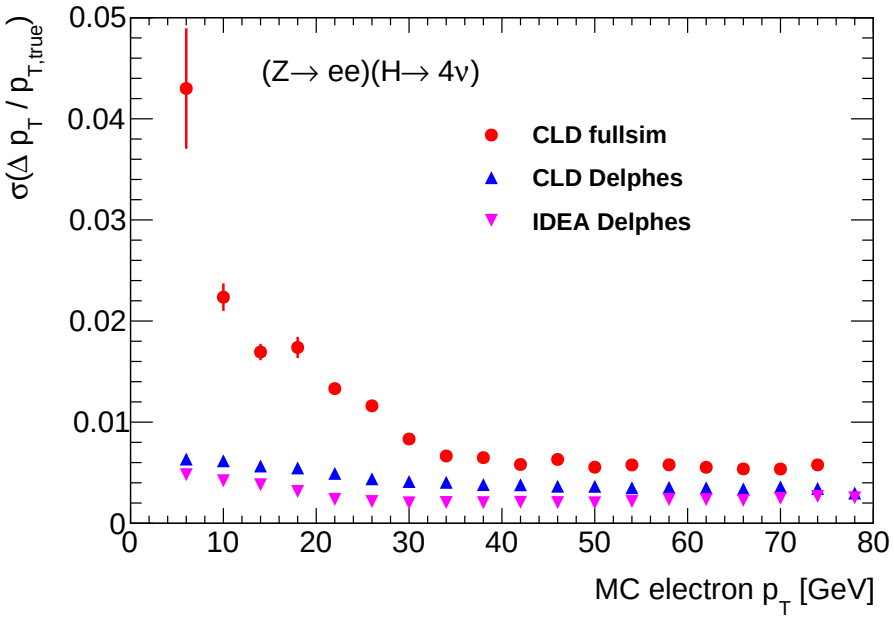
Efficiency study between fast sim and full sim

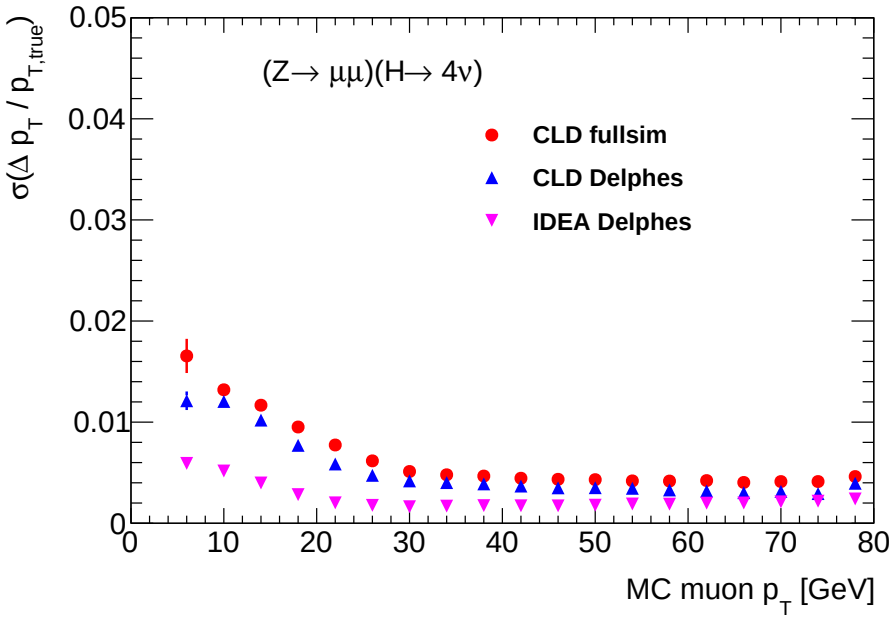




- Using WHIZARD $(Z \to ee/\mu\mu)(H \to 4\nu)$ samples.
- Same samples processed with CLD full simulation and CLD and IDEA Delphes fast simulation.
- Efficiency is nearly identical for IDEA and CLD fast simulation.
- Electron efficiency is worse for full sim than for fast sim, especially at low p_T.
- But muon efficiency is very similar for full and fast simulation.

Resolution study between fast sim and full sim





- Using WHIZARD $(Z \to ee/\mu\mu)(H \to 4\nu)$ samples.
- Same samples processed with CLD full simulation and CLD and IDEA Delphes fast simulation.
- Resolution is worse for CLD than IDEA fast simulation. This is more pronounced for muon than electron.
- Resolution is worse for full sim than for fast sim, especially at low p_T and also for electron.

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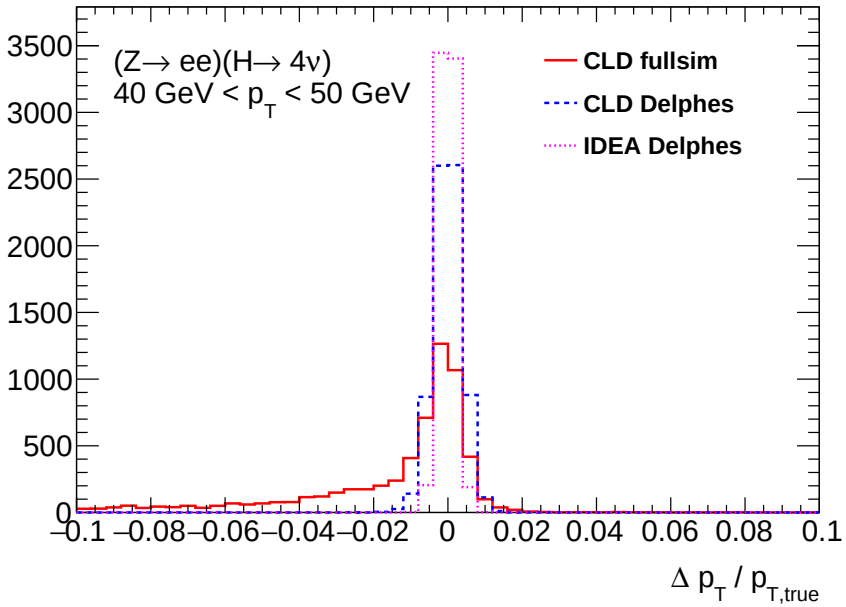
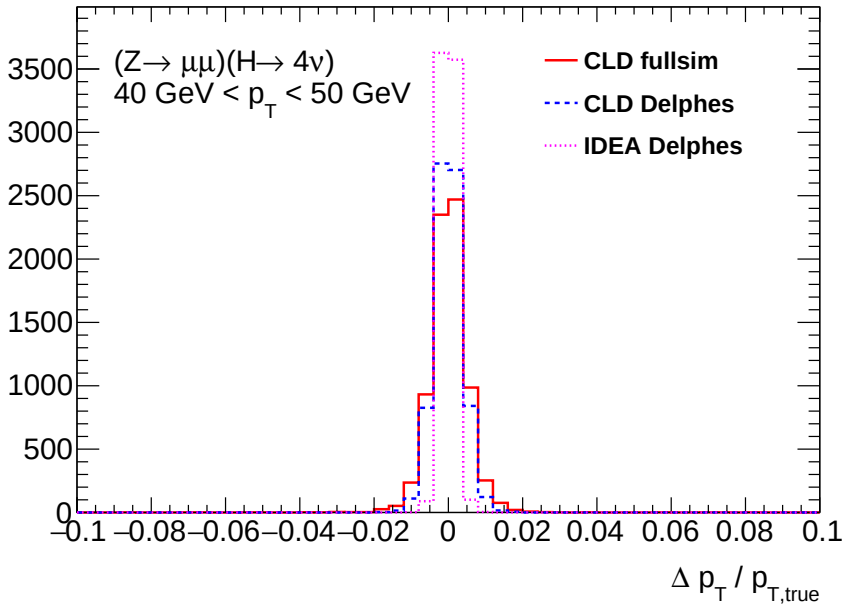
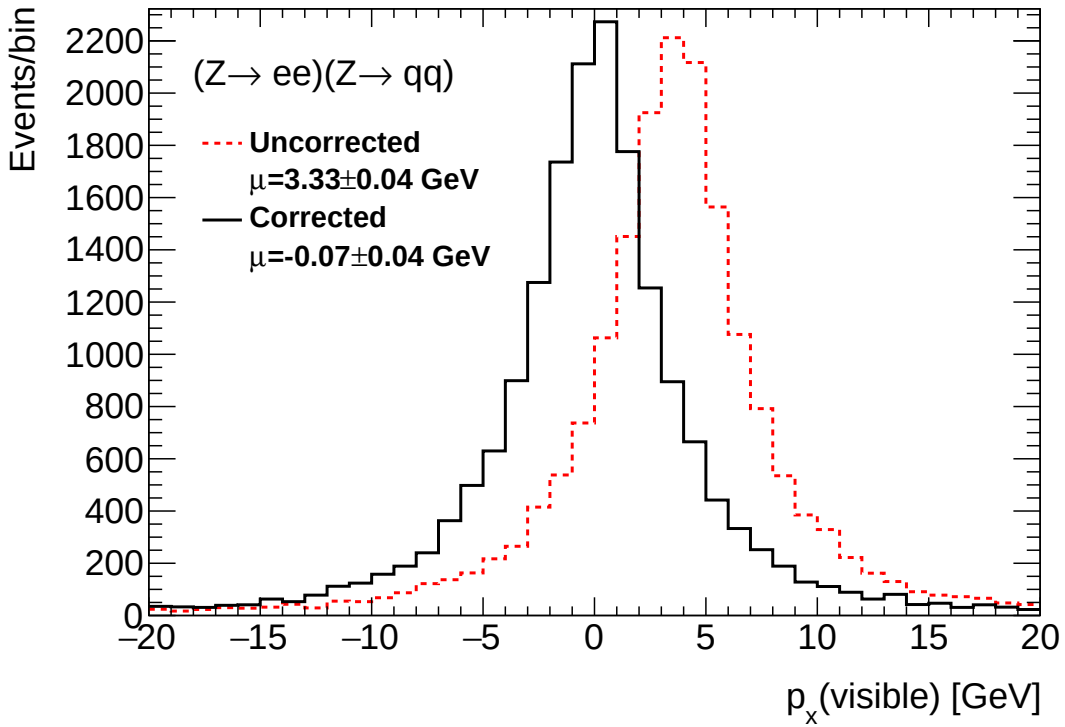




- These plots correspond to one p_T slice: $40\,\text{GeV} < p_T < 50$ GeV.
- We note the low-end tail on the electron resolution that is not reproduced by the fast simulation.

Effect on the crossing angle p_x(visible)



- p_x(visible) → x component of the total momentum for the ZZ samples with final states $qqqq$, $eeqq$, and $\mu\mu qq$.
- Correction→ boost in the negative x direction by $\beta = \sin(\theta/2)$, where $\theta \rightarrow$ total crossing angle of 0.03 rd.
- This effect is not seen/included in fast simulation.

Conclusion

- A study on the Higgs $\rightarrow$ inv at $\sqrt{(s)} = 250$ GeV is presented.
  - A combination of fast and full simulations is used.
  - The recoil mass is fitted to set limit on $\mathcal{B}(H \rightarrow \text{inv})$and the best limit is obtained with $\mu\mu$ selection channel while qq is shows the worse limit results.

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- A comparison on the lepton reconstruction between CLD full simulation and Delphes simulations of CLD and IDEA is shown.
- A study of the efficiency and resolution are performed for this comparison.
  - A nearly identical efficiency is observed for IDEA and CLD fast sim.
  - Electron efficiency is worse for full sim than for fast sim, especially at low p_T.
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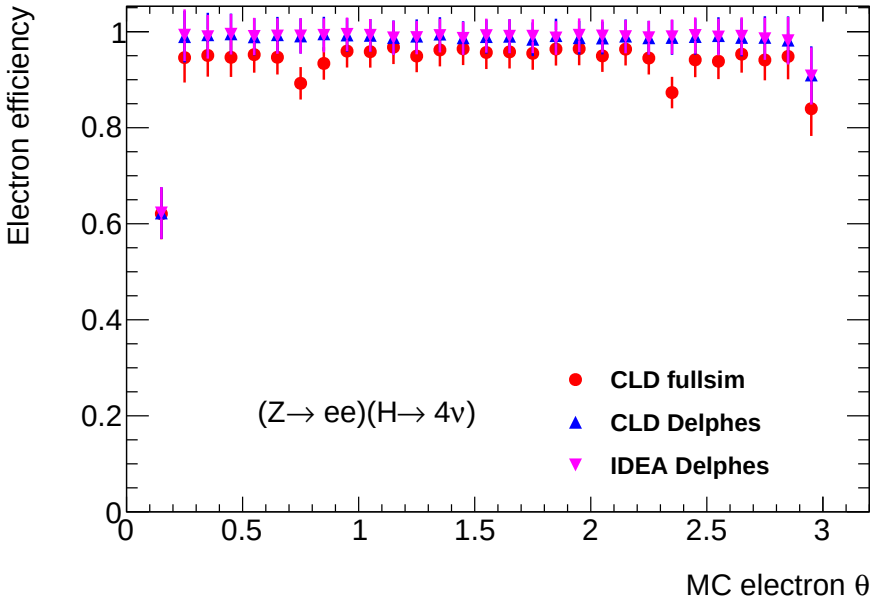
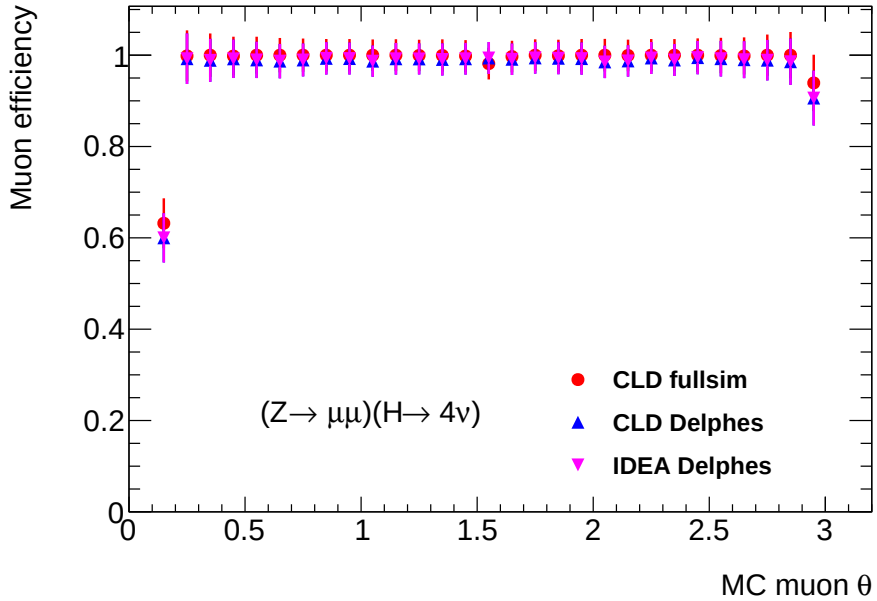
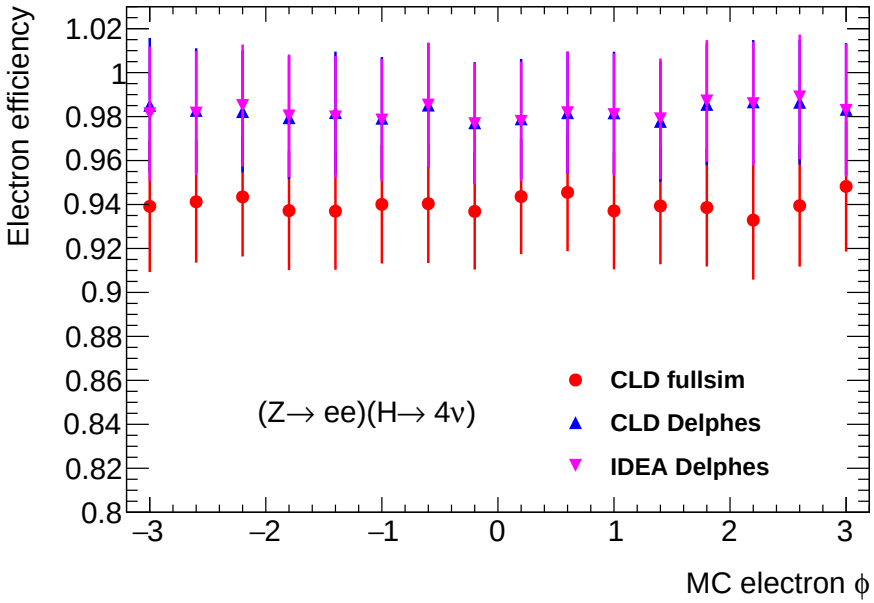
- The crossing angle effect is also studied.
  - A small asymmetry is observed when considering $qqqq$, $eeqq$, $\mu\mu qq$ final state.
  - The asymmetry disappears when all final states are considered.

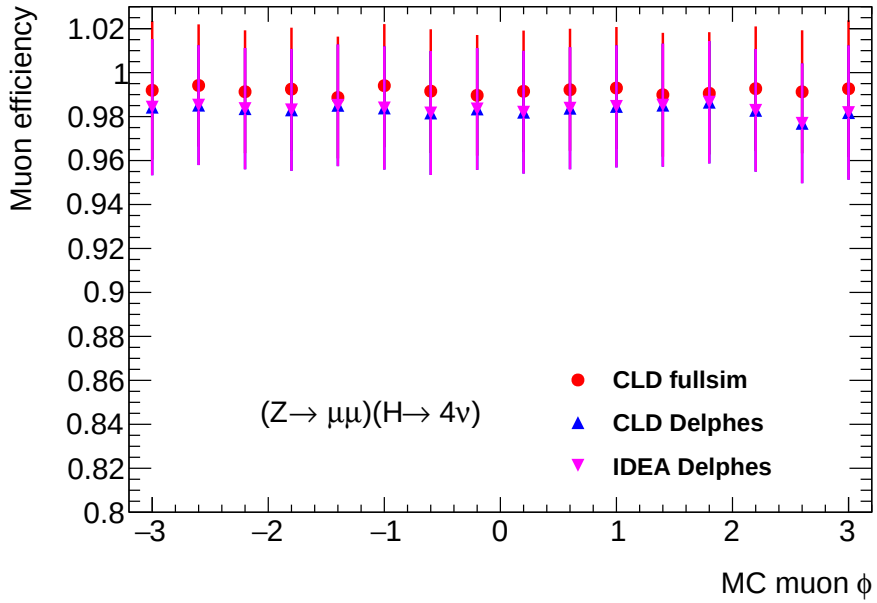
BACKUP

Efficiency study between fast sim and full sim

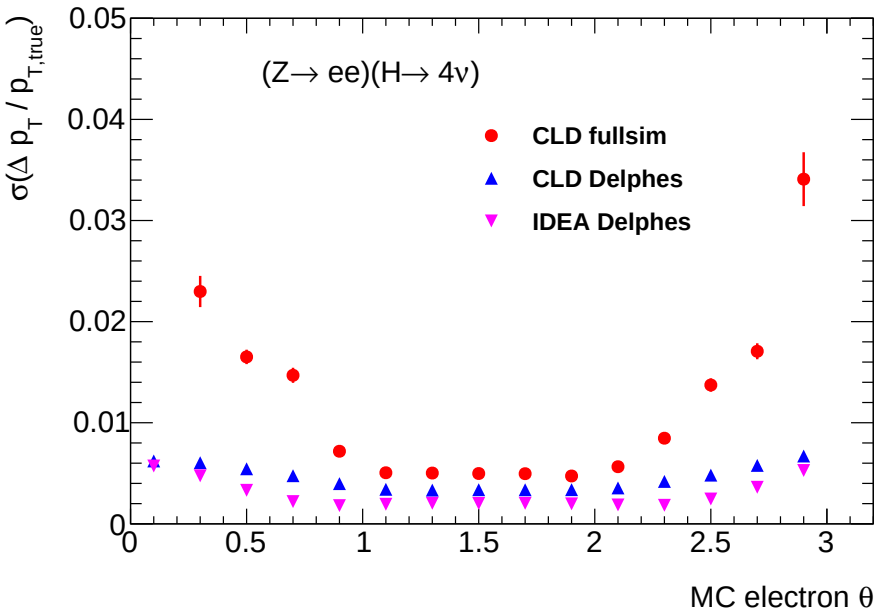


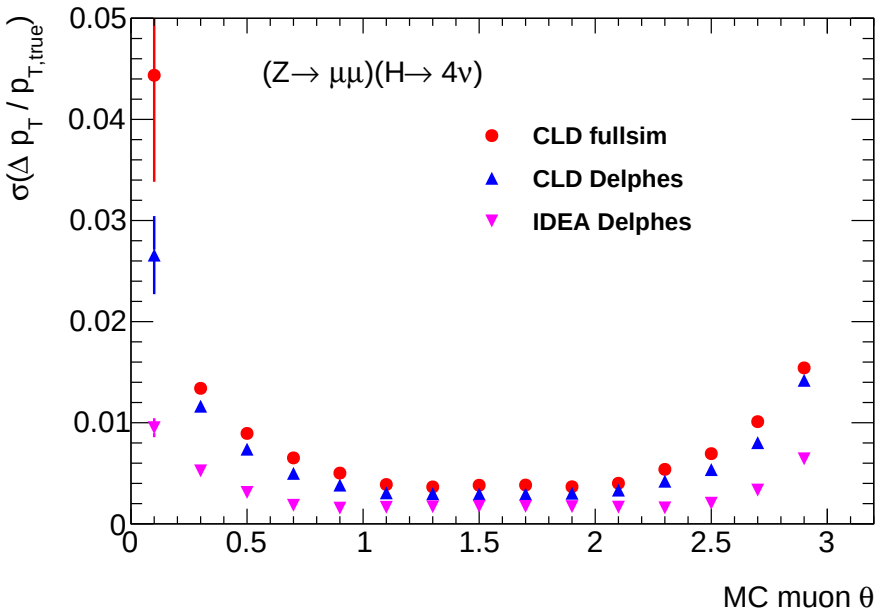


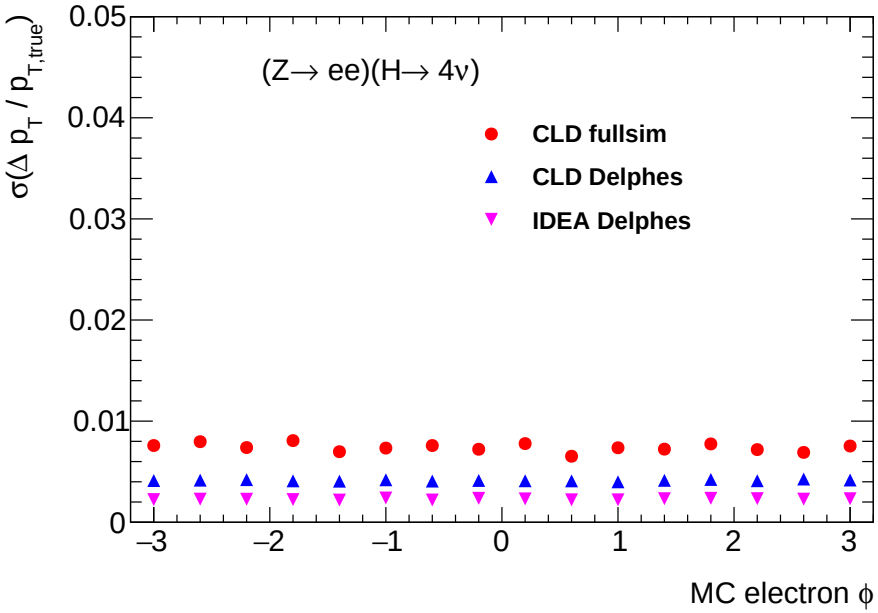


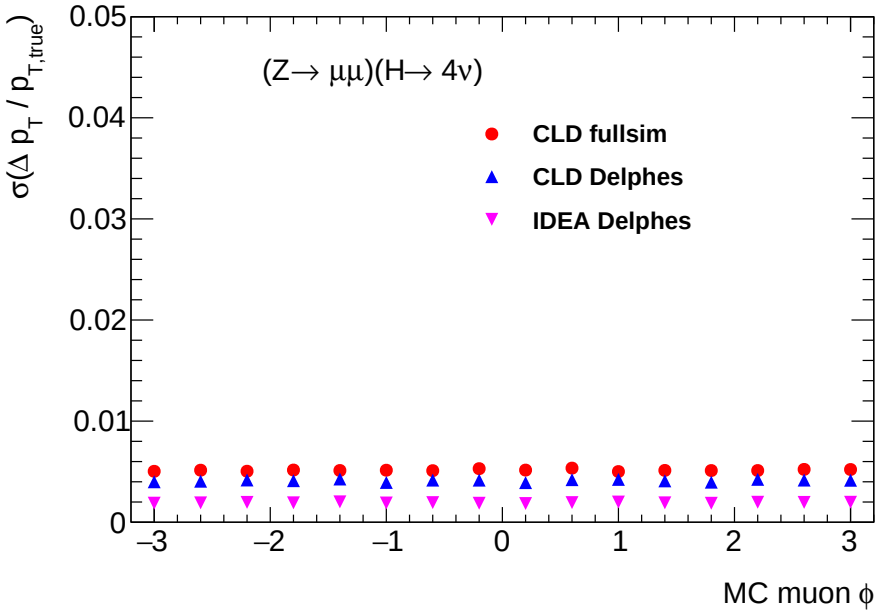


Resolution study between fast sim and full sim

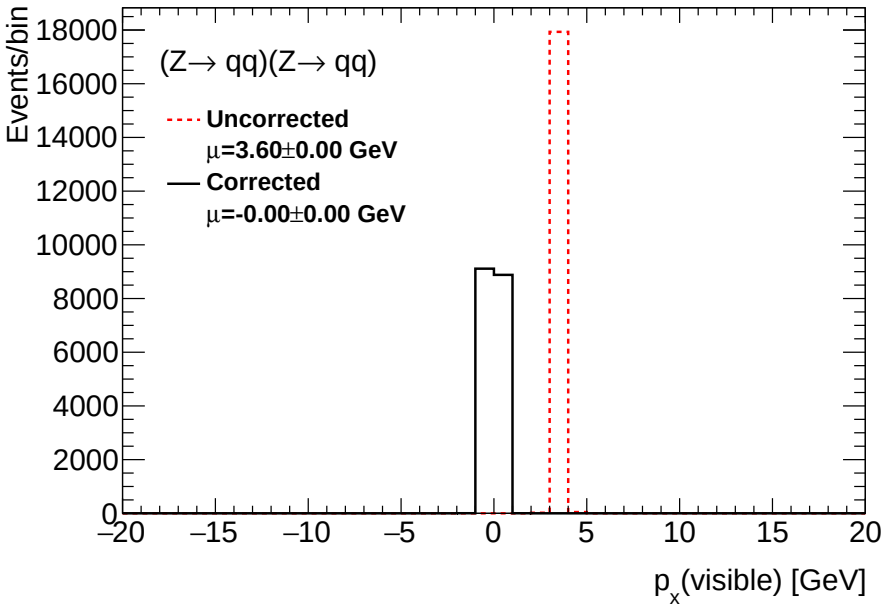


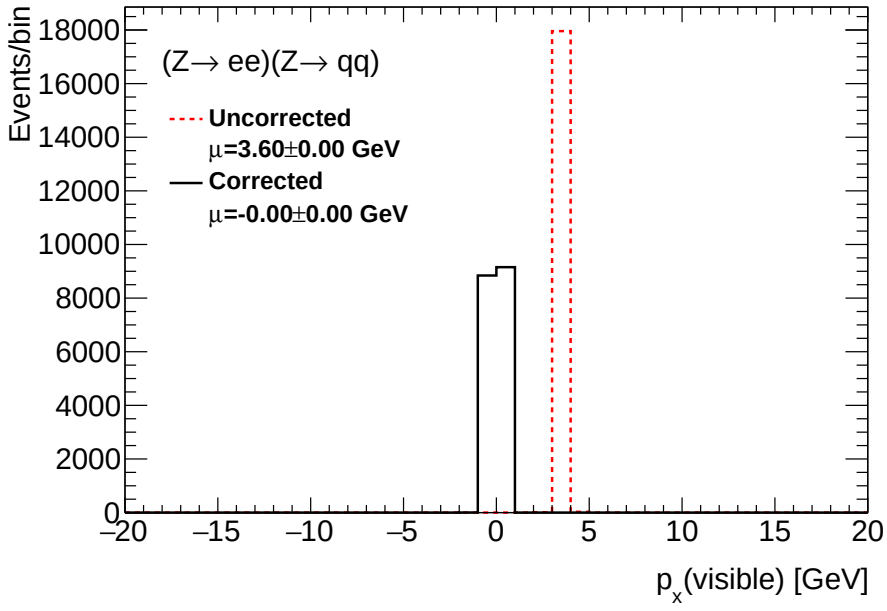






Effect on the crossing angle p_x(visible)





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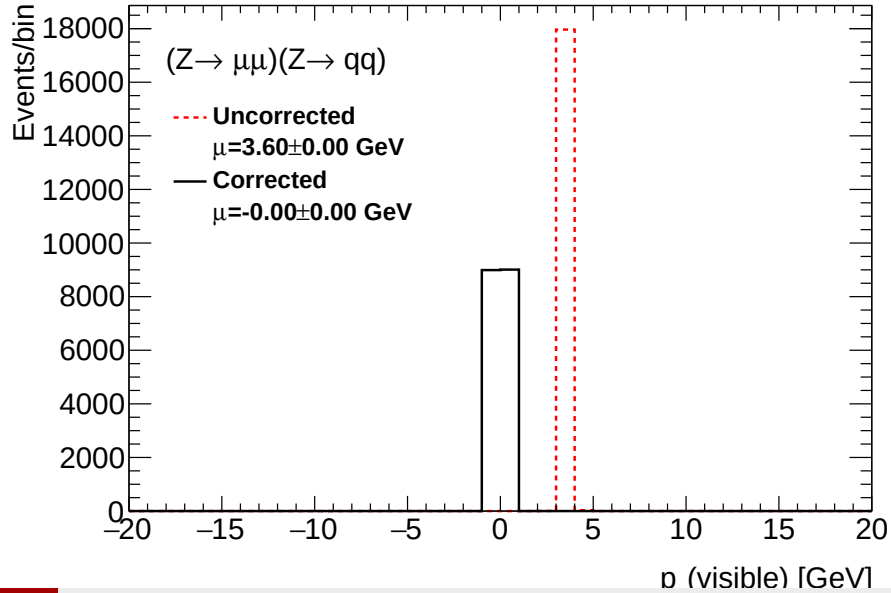
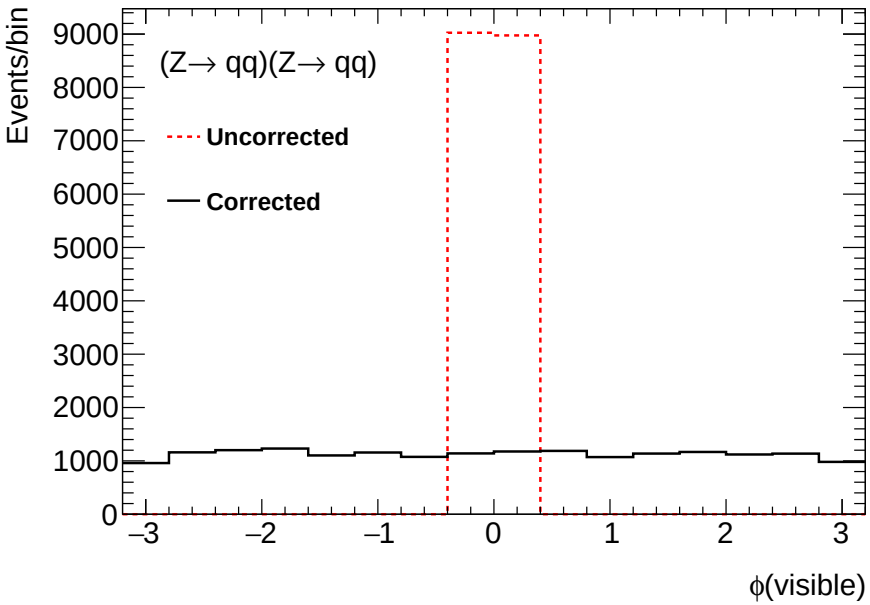
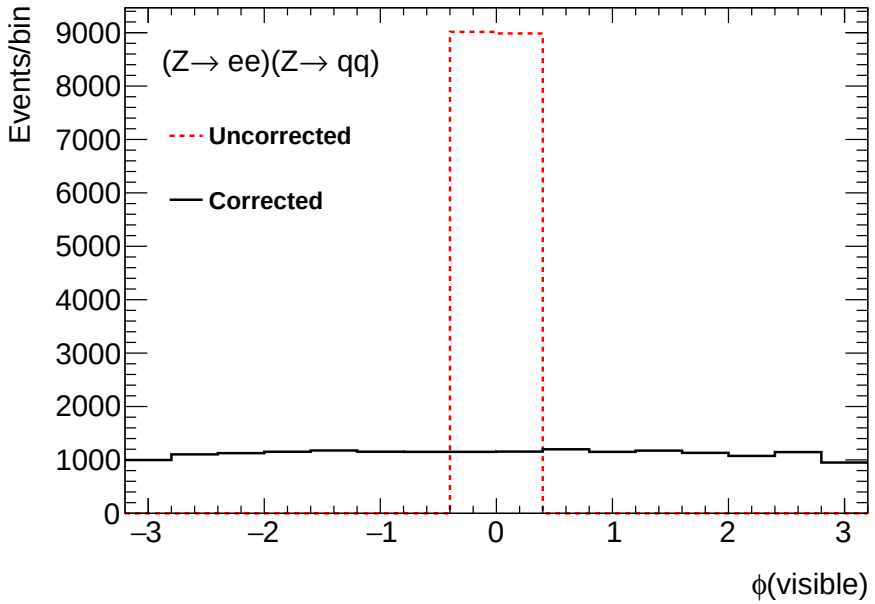


Effect on the crossing angle ϕ(visible)





- ϕ(visible) $\rightarrow$ ϕ vector sum of all reconstructed particles.
- No asymmetry observed when all final states are considered (but the crossing angle effect remains).