Prospects for Higgs to invisible at the FCC-ee

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Goal of the talk

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- **The goal of the talk is to give an update regarding the Higgs to invisible study that uses (partially) full simulation**.
- **Reminder that Higgs to invisible effort is also carried out by Liverpool folks, using fast simulation**.
- **Recently, we reported a limit on the branching ratio of Higgs to invisible which is inconsistent with the results obtained from Liverpool team with the following concern**:
  - **Why muon-channel limits are 10x worse than the Delphes case (Liverpool results). ?**
- **After some checks it's found out that the WW sample obtained from full simulation was wrong. Hence, for the WW sample, fast simulation simulation was used, and now the results are consistent. They presented in the following slides**.

Analysis overview

- Estimate sensitivity for H→invisible at $\sqrt{(s)} = 240$ GeV using a combination of full and fast simulation.
- Will discuss about the Effect of the FCC crossing angle, and also the Bremsstrahlung recovery for full simulation.

Signal (H→ inv)	Energy	Luminosity	Selection on channels	Bkg
ZH	240 GeV	5 ab^{-1}	$ee, \mu\mu, qq$	ZZ, Zγ, WW, ZH

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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.
- Small samples with full CLD simulation were generated privately, using WHIZARD for both ZH and ZZ samples.
- Those WHIZARD ZH signal samples were also processed with Delphes with both IDEA and CLD parameters for comparisons.

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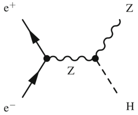
- Higgs-strahlung or $e^+e^- \rightarrow ZH$ Feyman diagram.



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- Exactly two same-flavor, opposite sign e (μ).
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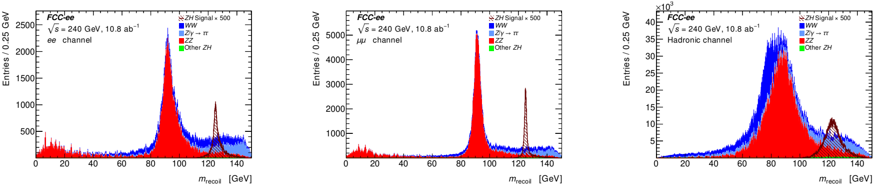
Hadronic channel

- No good leptons.
- Define m_{vis} as the mass of all visible particles, and require:
  - 86 GeV $< m_{\mathrm{vis}} <$ 105 GeV
- require MET > 15 GeV.



- Distribution of reconstructed invisible recoil mass after all selections normalized to an integrated luminosity of 10.8 ab−1 for the signal and backgrounds available with full simulation for the ee, , $\mu\mu$, and hadronic channels, on the left, middle and right hand side respectively.
- The signal cross section is multiplied by a factor of 500 for a better visualization.

Limit set on $\mathcal{B}(H \to \text{inv})$					
Channels	-2σ	-1σ	Limit	+1σ	+2σ
ee	5.2×10^{-3}	6.9×10^{-3}	9.7×10^{-3}	1.4×10^{-2}	1.8×10^{-2}
$\mu\mu$	2.2×10^{-3}	3.0×10^{-3}	4.0×10^{-3}	5.8×10^{-3}	7.8×10^{-3}
qq	2.5×10^{-3}	3.4×10^{-3}	4.8×10^{-3}	6.6×10^{-3}	9.0×10^{-3}

Table 1: Limit of on the Higgs to invisible branching ratio for different channels

- The limit is obtained by fitting the recoil mass distributions shown in the previous slides.
- All bkg components are combined in the limit setting procedure.
- Our results are now consistent with Liverpool results with sqrt(2) worse limit for our case which is expect given the difference between CLD vs. IDEA.

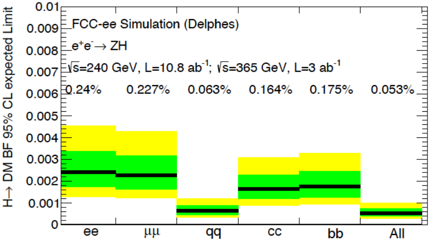


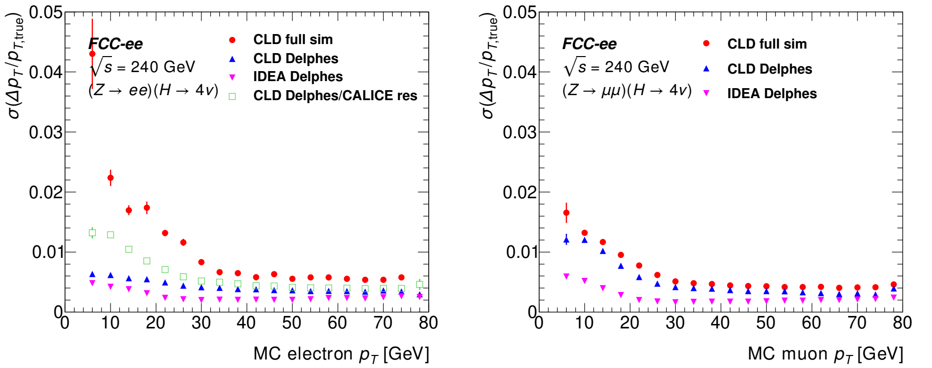
Figure 1: Liverpool results

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.
  - Our previous results show 10x worse limit compared to Delphes.
  - After investigation we realized that the WW samples obtained with full simulation was wrong, and by switching to WW fast simulation the results now are consistent with fast simulation with sqrt(2) worse than Delphes which expected given the resolution difference between CLD and IDEA.
- During the making of the slides, we realized that Ztautau bkg are not included in the limit calcualtion for both Delphes (Liverpool study) and also our study presented.
- However from slide 5, these bkgs are not that negliegeable and there is no clear reason why they shouldn't be included.

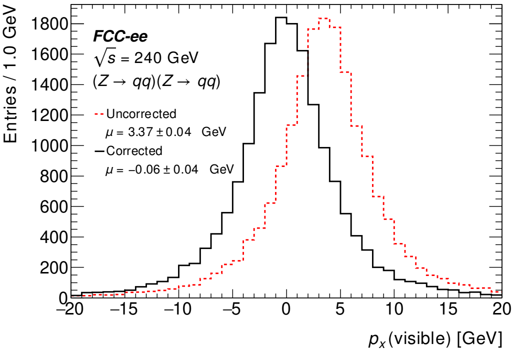
BACKUP

Resolution study between fast sim and full sim



- Relative transverse momentum resolution as a function of transverse momentum for electrons (left) and muons (right).
- Within each transverse momentum bin, the resolution distribution is fit to a Gaussian distribution.
- Full sim fast sim for both CLD and IDEA configurations, and fast simulation for CLD with the calorimeter resolution function replaced with the expected resolution for a silicon-tungsten CALICE-like calorimeter are shown.

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 θ → total crossing angle of 0.03 rd.
- This effect is not seen/included in fast simulation.