Preparation for Studies of Higgs Boson Invisible Decay at CEPC

&

Issues in Electron Reconstruction

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Geliang Liu

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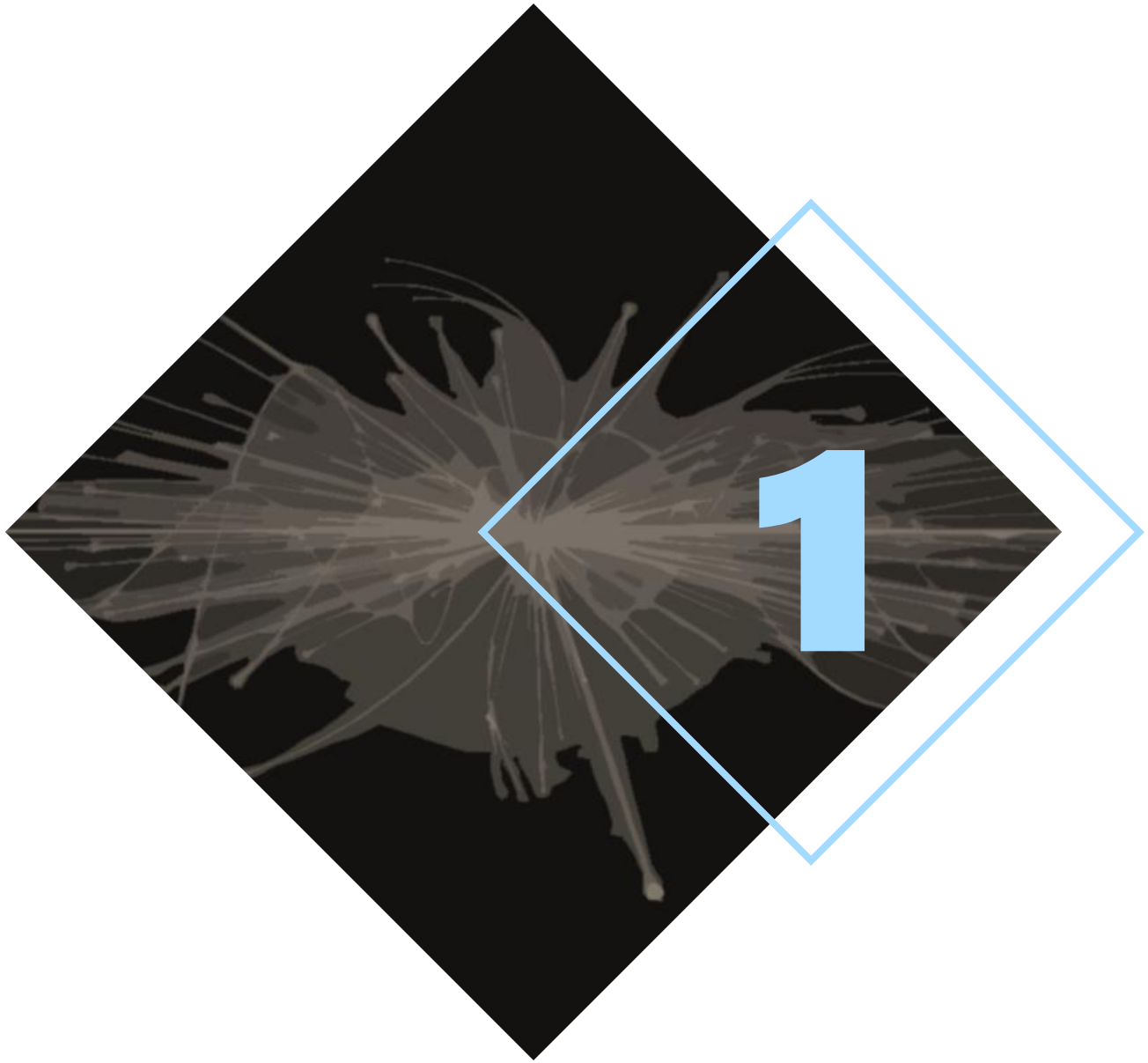
Outlines

- **Higgs boson invisible decay at CEPC**
  - Introduction
  - Preliminary studies on visible / missing energy
  - Towards the complete analysis
- **Electron reconstruction issue**



1 Higgs invisible decay at CEPC

Introduction

➢ Higgs boson invisible decay

- In the SM: H→ZZ→4ν
- BSM: H → dark matter, sparticles, long lived particles

➢ At CEPC

- ee→Z(→ee/μμ/qq)H(→invisible)
- Possible to search for it at both 240 GeV and 350 GeV

➢ Previous studies

Experiments	Data	Results	Publication
ATLAS	LHC Run 2	Expected UL on BR(H→inv): 10%	JHEP08(2022)104
CMS	LHC Run 2	Expected UL on BR(H→inv): 10%	PRD 105 (2022) 092007
ILC	250, 350, 500 GeV 250, 350, 500 fb-1	Expected UL on BR(H→inv): 0.26%	arXiv:1909.07537
FCC-ee	240+365 GeV; 10.8+3 ab-1	3.9 σ on BR(H→ZZ→4ν)	Presentation
CEPC	240 GeV, 5.6 ab-1	Expected UL on BR(H→inv): 0.26%	Chinese Phys. C 44 123001

Preliminary studies

Signal samples

- ee→Z(→qq)H(→ZZ→4ν)
- ee→Z(→μμ)H(→ZZ→4ν)
- ee→Z(→ee)H(→ZZ→4ν)
- All at 240 GeV
- 10000 events each
- /cefs/higgs/liugeliang/CEPC/202501/Production/

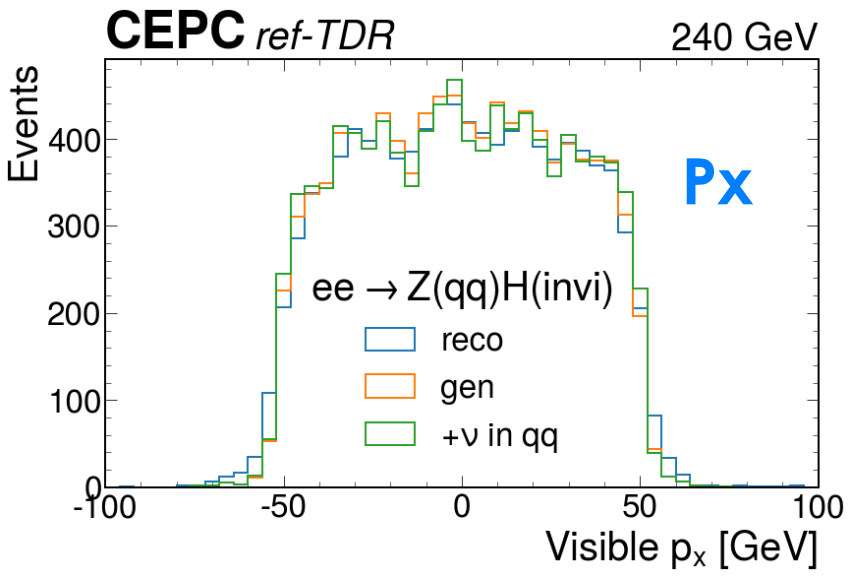
Studies

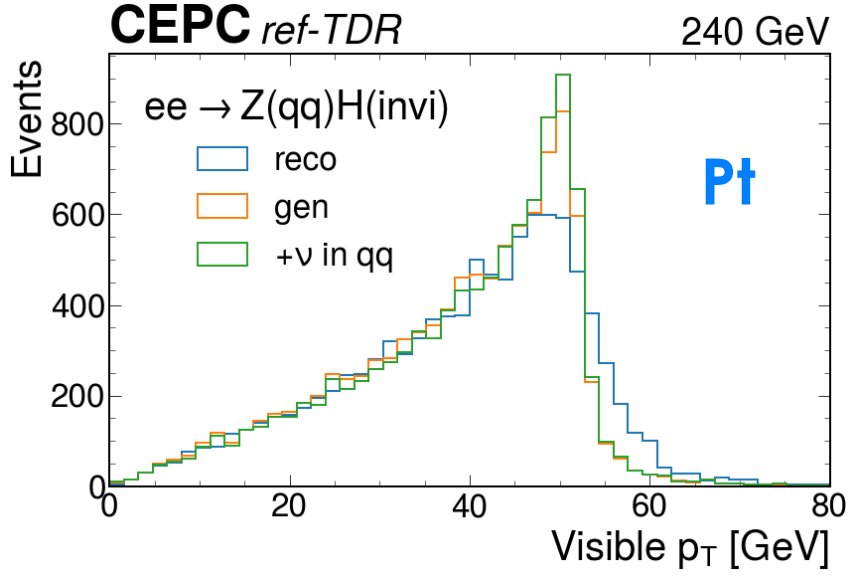
- Check the distributions of total visible 4-momentum and missing 4-momentum
- $\mathrm{p}^{\mathrm{vis}} = \sum_{\mathrm{i}}^{\mathrm{PFO}} \mathrm{p}_{\mathrm{i}}$
- $\mathrm{p}^{\mathrm{mis}} = \mathrm{p}^{\mathrm{tot}} - \mathrm{p}^{\mathrm{vis}}$, $\mathrm{p}^{\mathrm{tot}} = (0, 0, 0, 240\ \mathrm{GeV})$
- For gen-level distributions, replace PFO by final-state MC particles

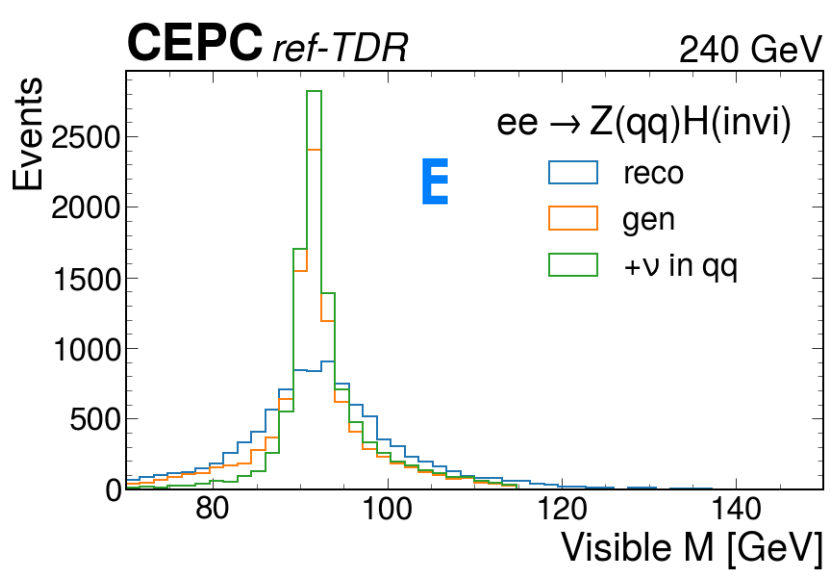
Note

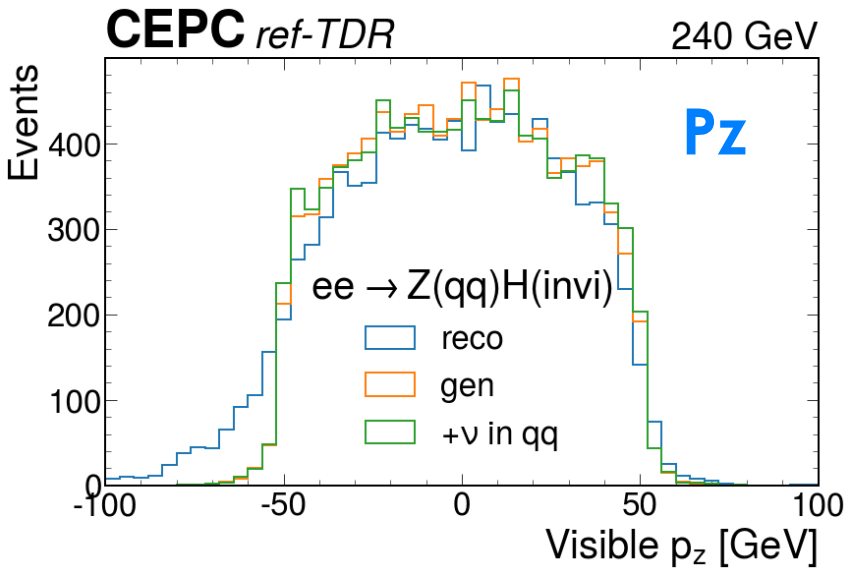
- No PID or event selection is performed
- No jet-related correction is performed

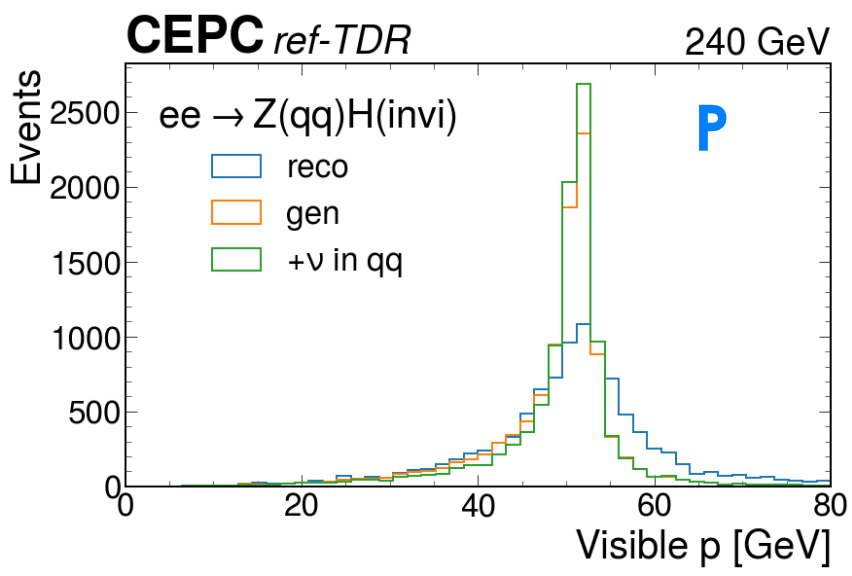
ee→Z(→qq)H(→ZZ→4ν): visible

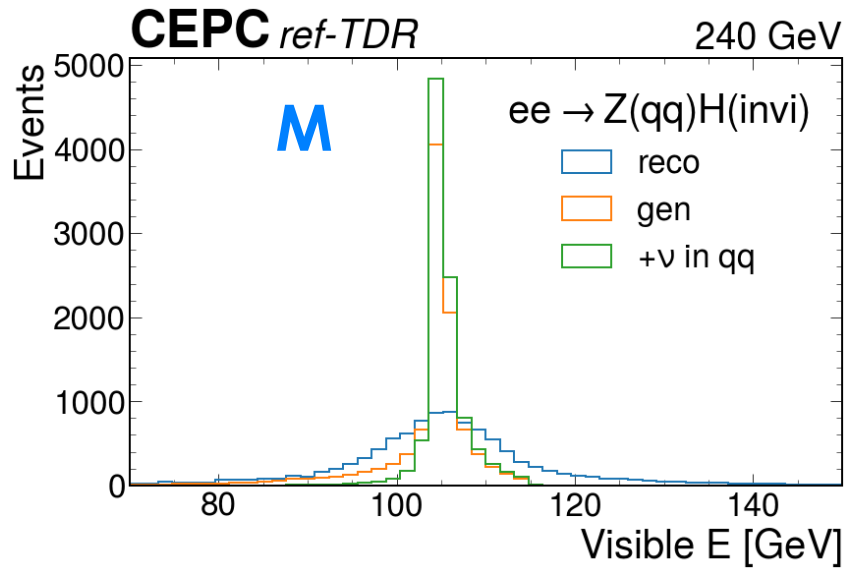












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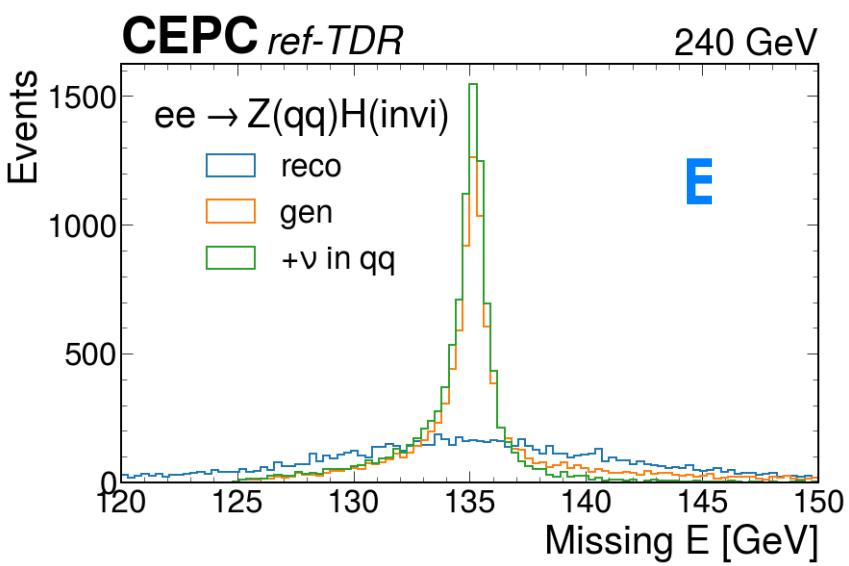
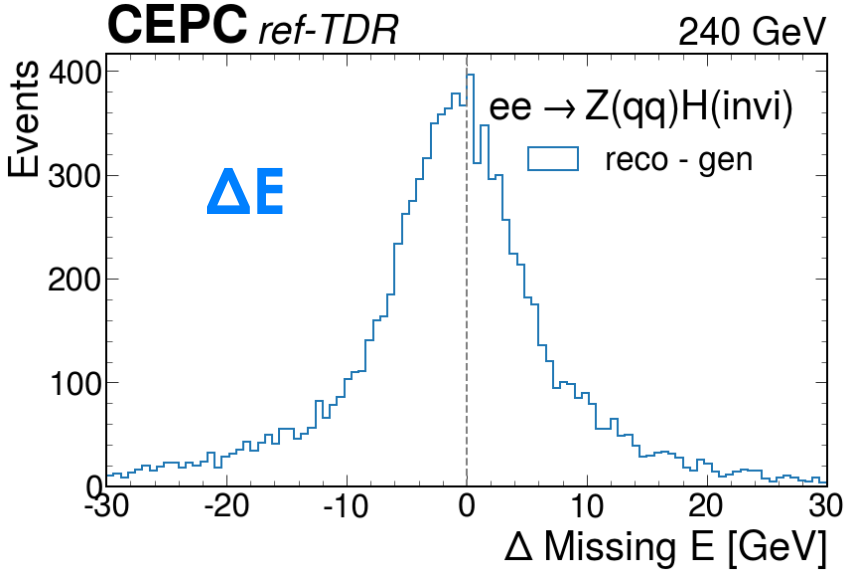
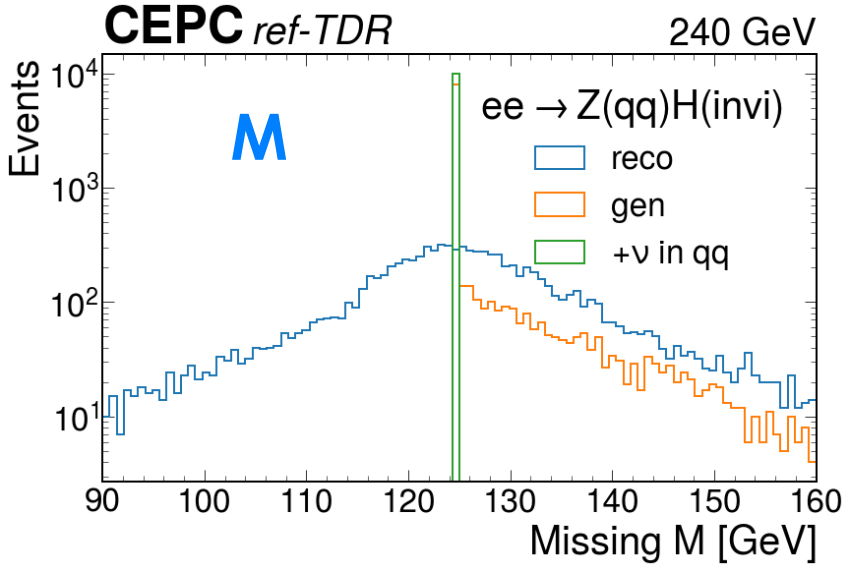
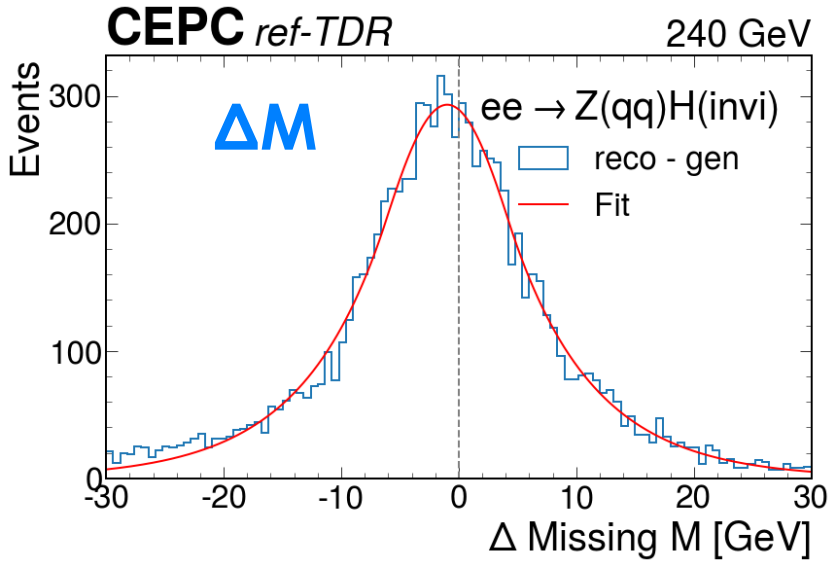


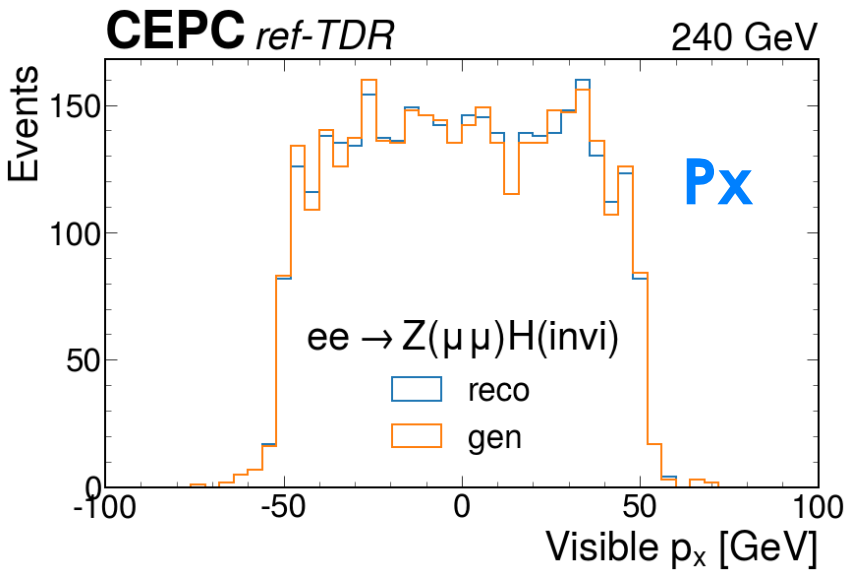


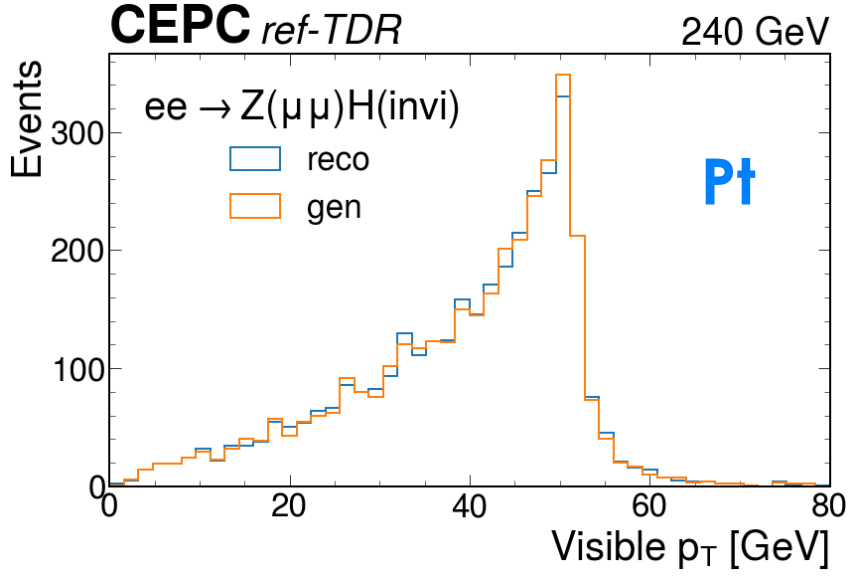


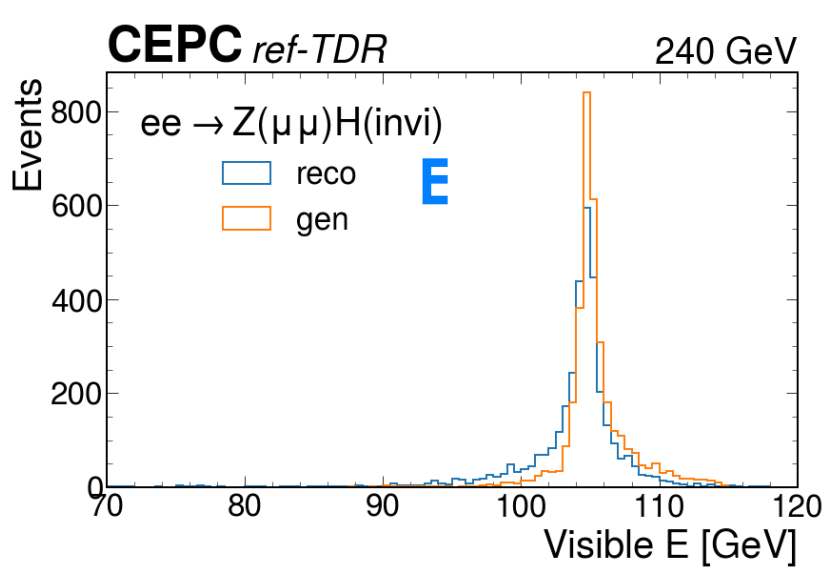


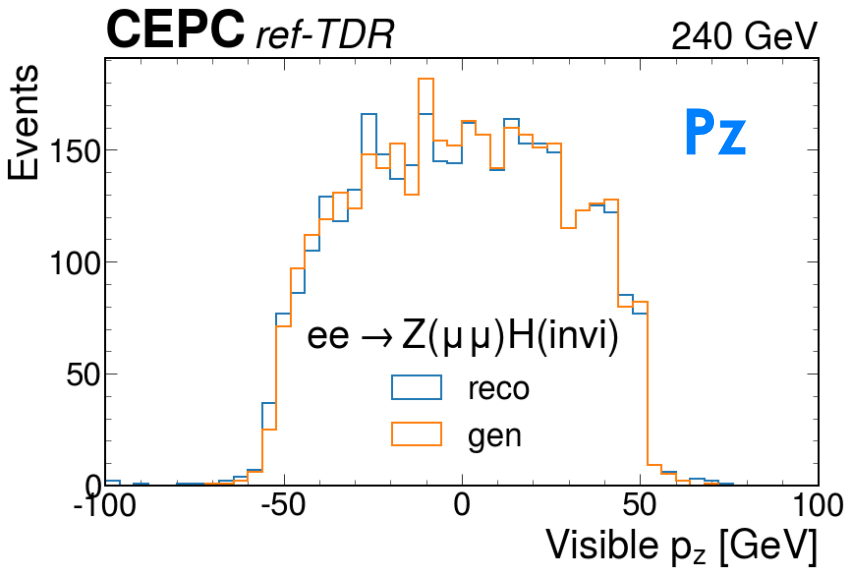
- σ=6.0 ± 0.2 GeV
- Resolution = 4.8 %

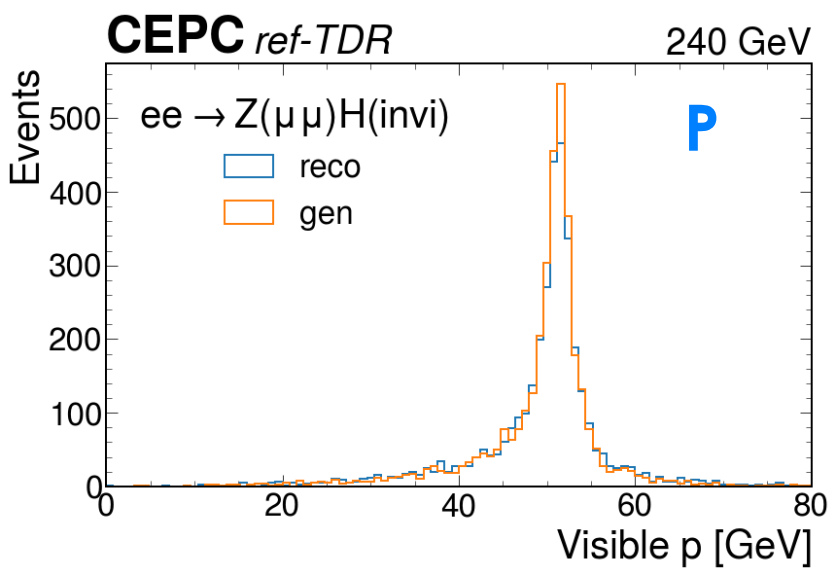
ee→Z(→μμ)H(→ZZ→4ν): visible

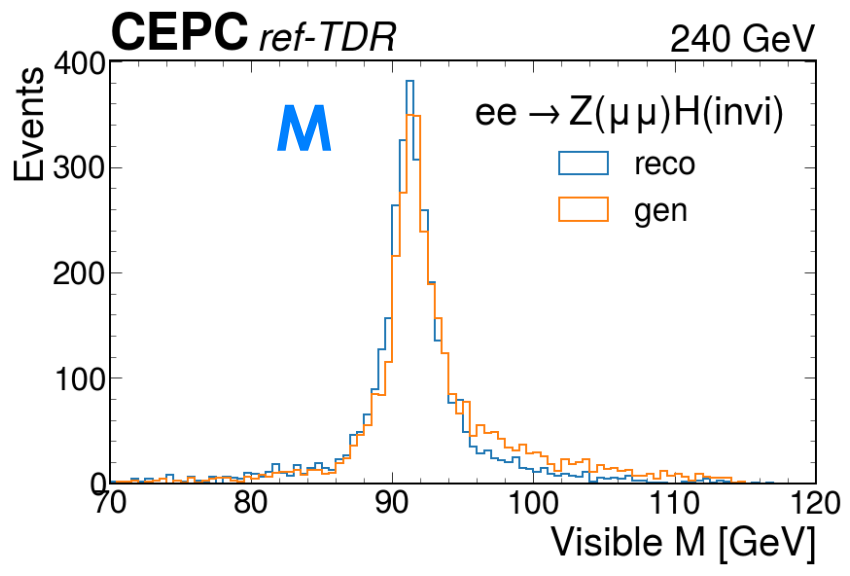




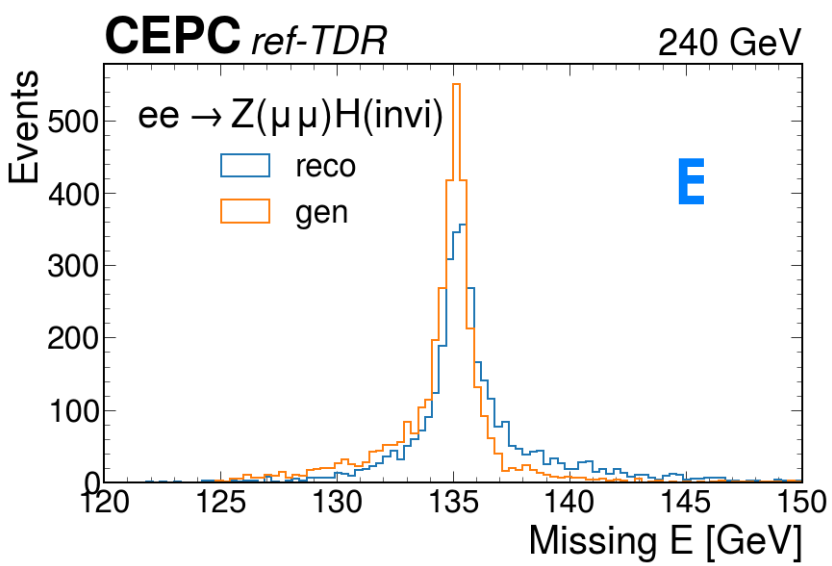


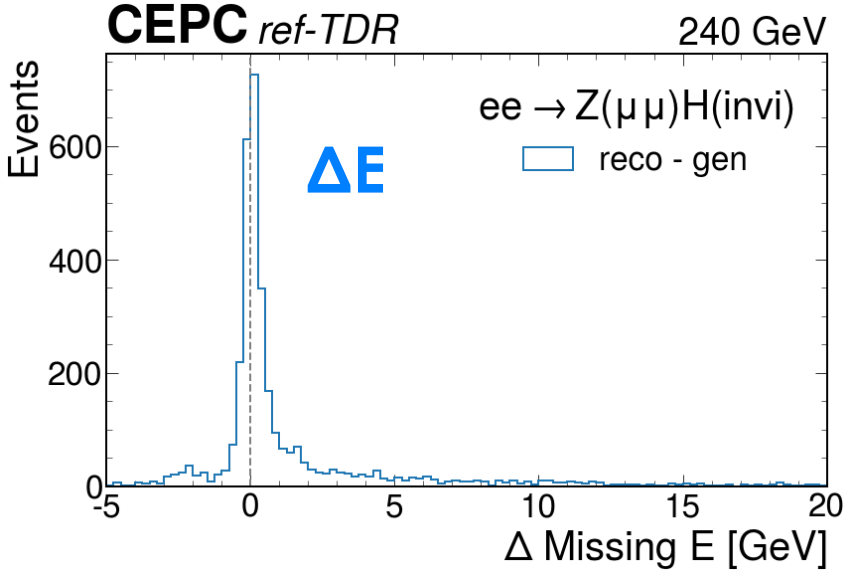


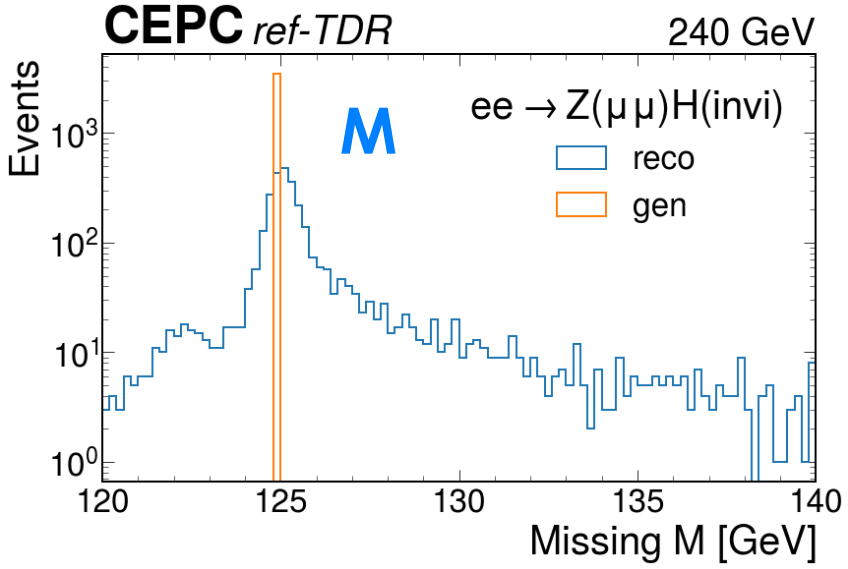


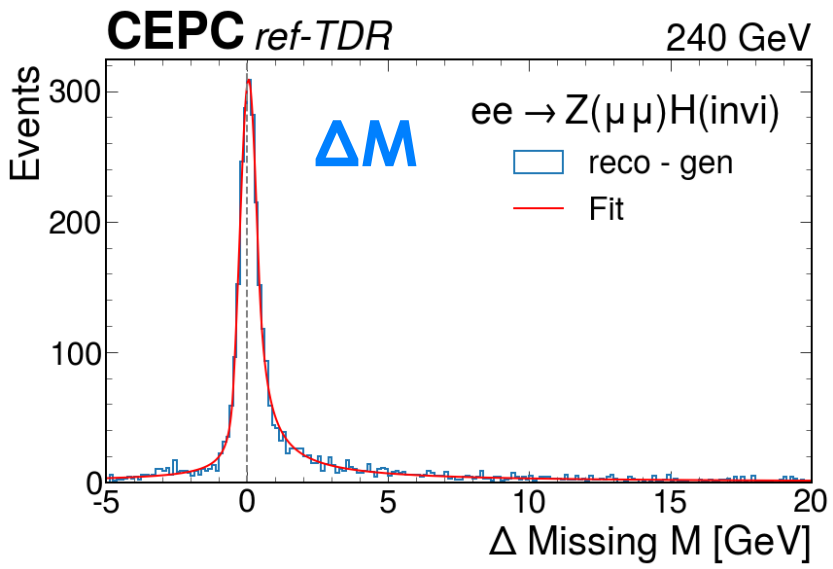


ee→Z(→μμ)H(→ZZ→4ν): missing



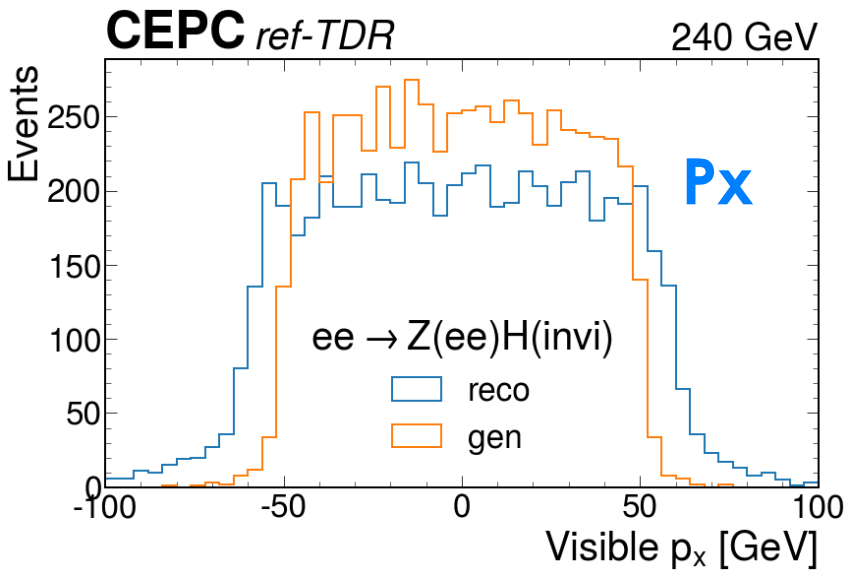


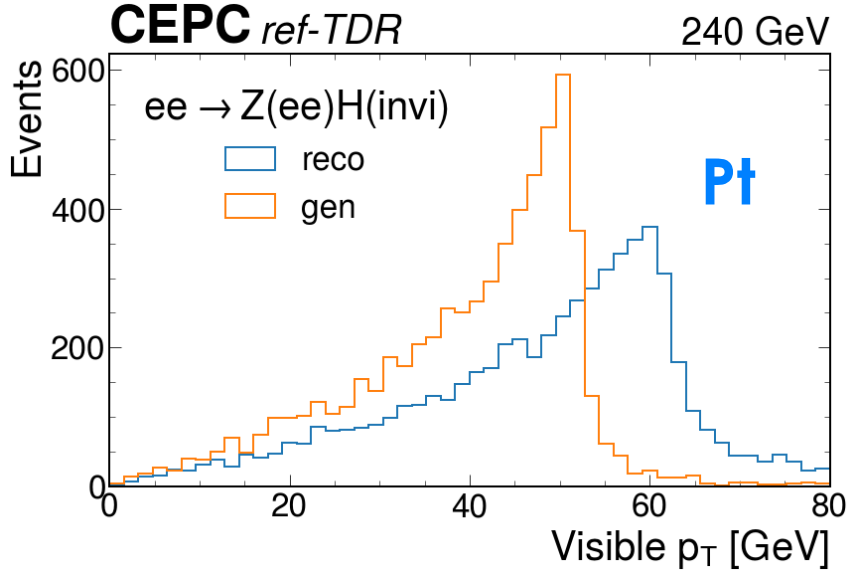


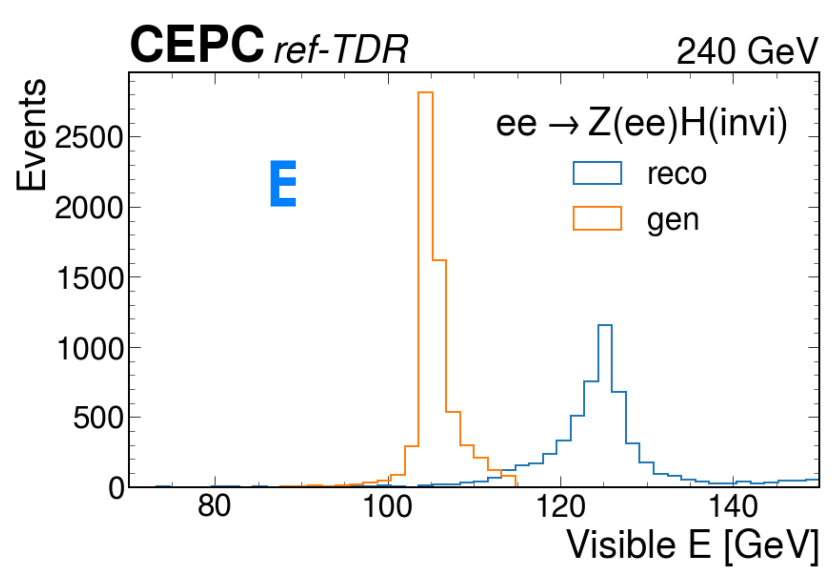


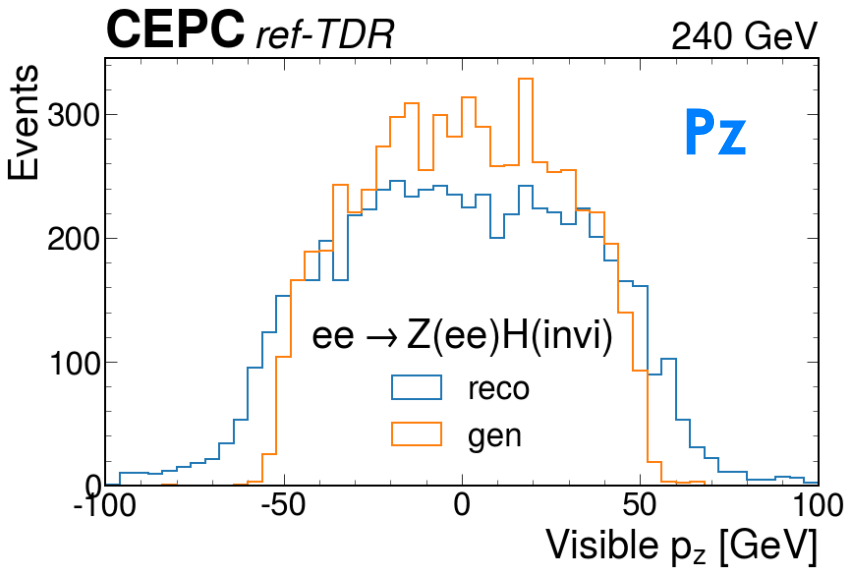
- σ=0.320 ± 0.004 GeV
- Resolution = 0.256 %

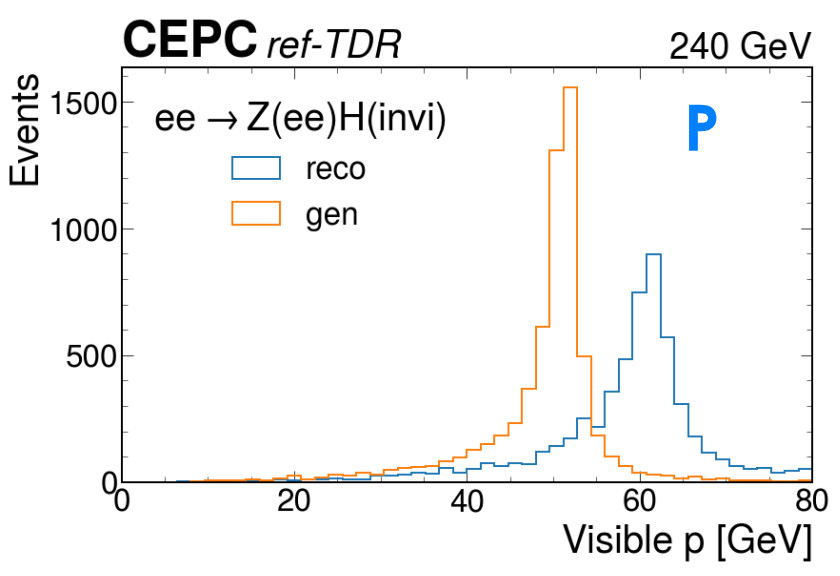
ee→Z(→ee)H(→ZZ→4ν): visible

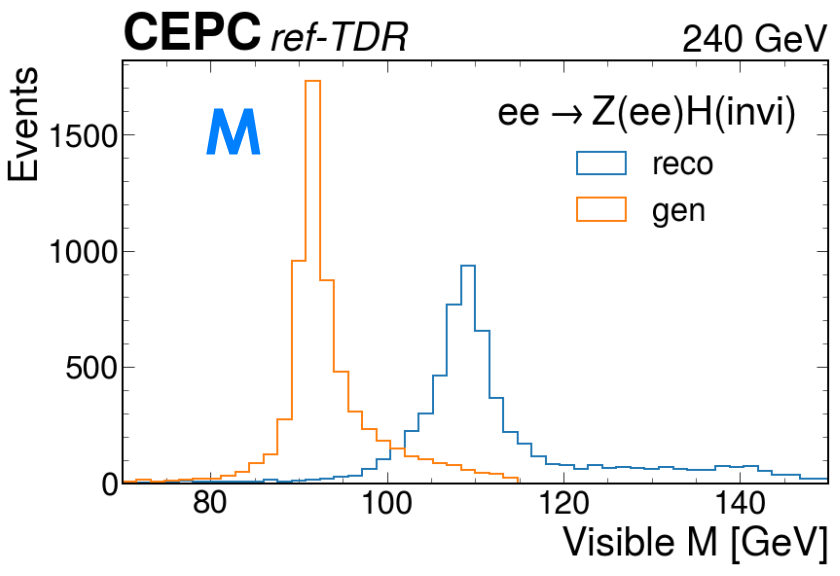




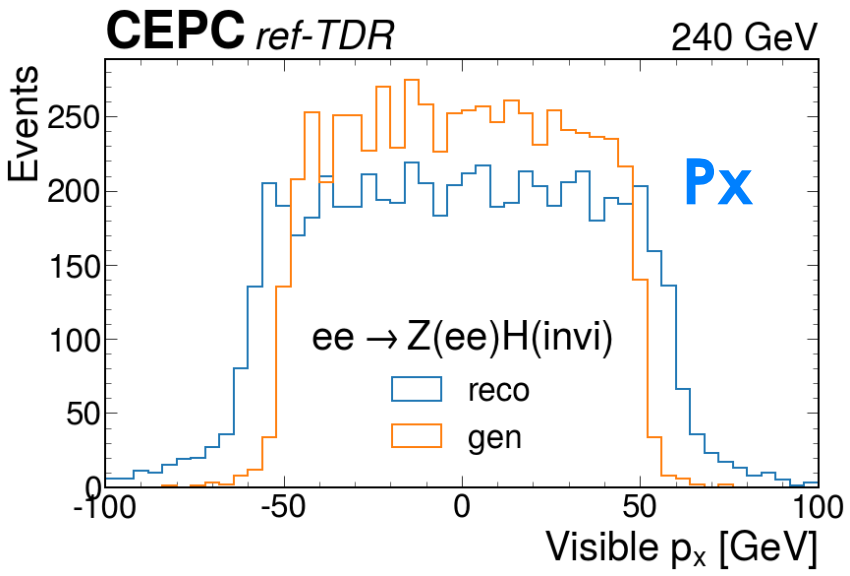


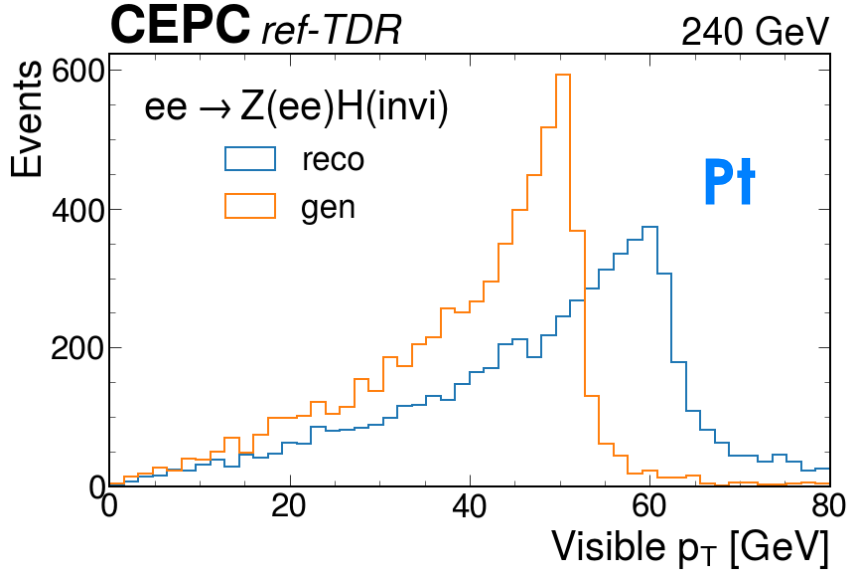


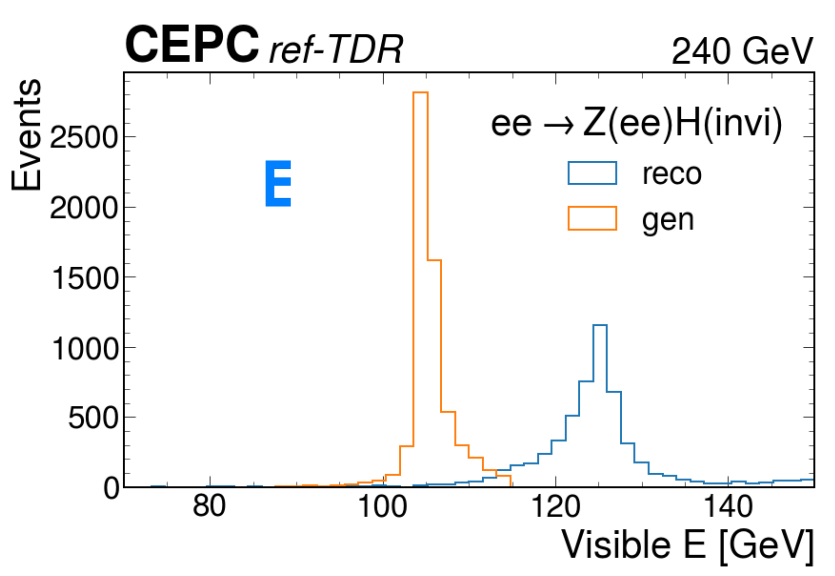


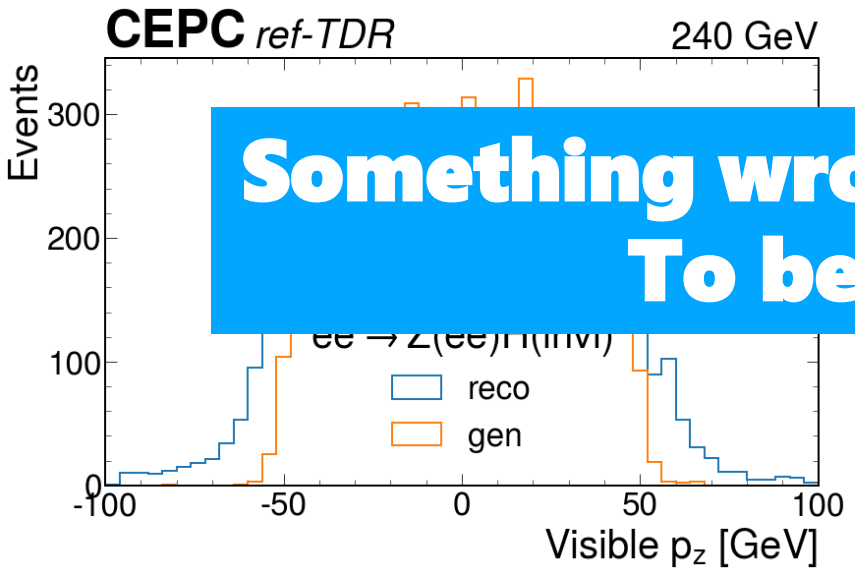


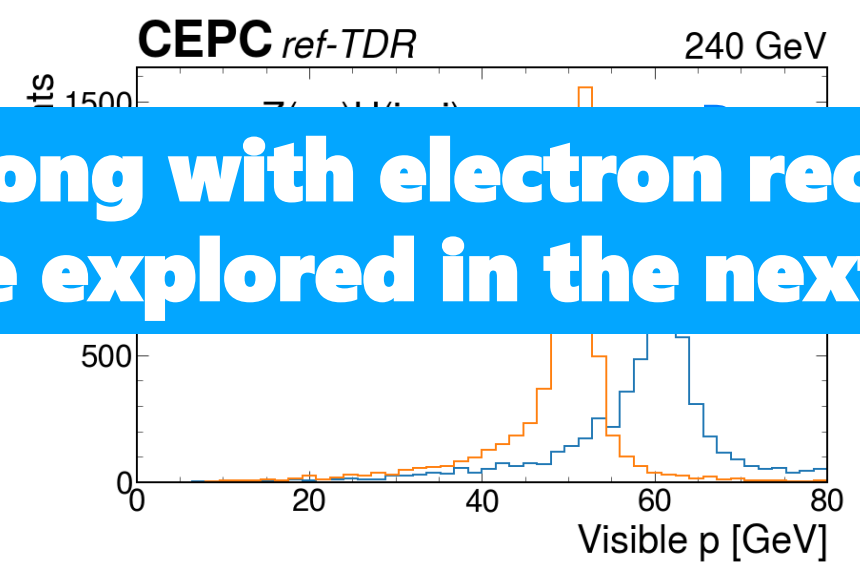
ee→Z(→ee)H(→ZZ→4ν): visible

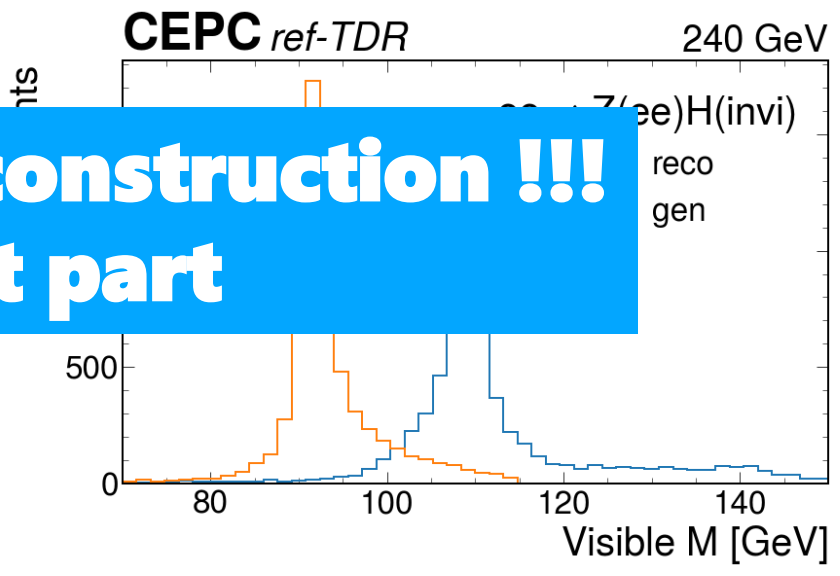












Something wrong with electron reconstruction !!!
To be explored in the next part

Summary & Further steps

➢ Missing momentum & energy reconstructed

- Okay performance; can be used in analysis

➢ Simulation samples missing

- Production en masse after updates on ECAL granularity
- **Large quantities of background** samples needed

Process	qqH_inv	$2f$	single_w	single_z	szorsw	zz	ww	zzorww	ZH_visible	total_bkg	Significance
Total generated	76614	801152072	19517400	9072952	1397088	6389432	50826216	20440840	1140496	909936496	2.54

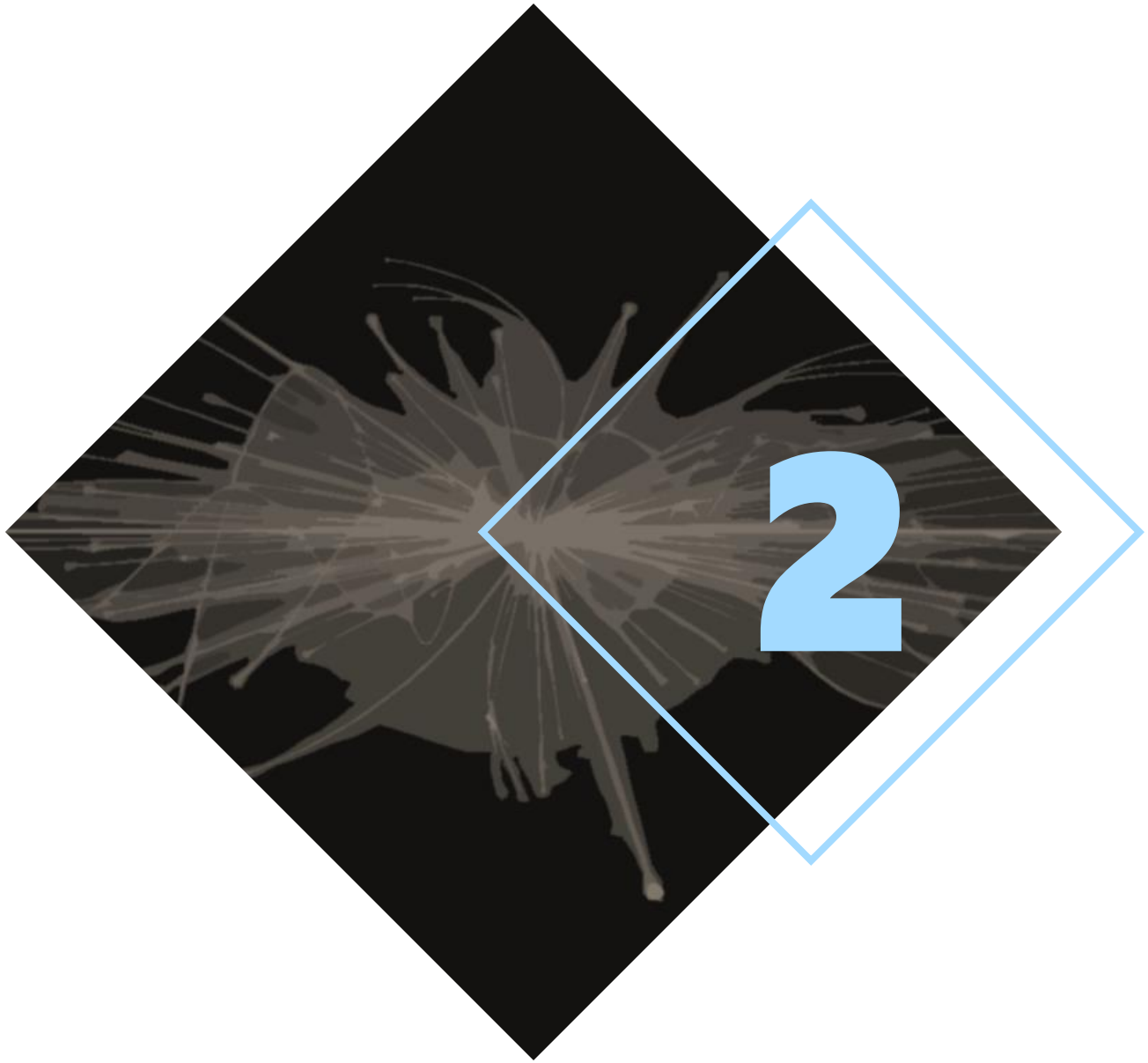
Total yields with 5.6 ab-1 from Chinese Phys. C 44 123001

➢ Event selection missing

- **Require PID:**
  - ID of electron, muon, photon against hadrons
  - ID of prompt leptons against jets
- **Kinematic requirements:** studies of significance

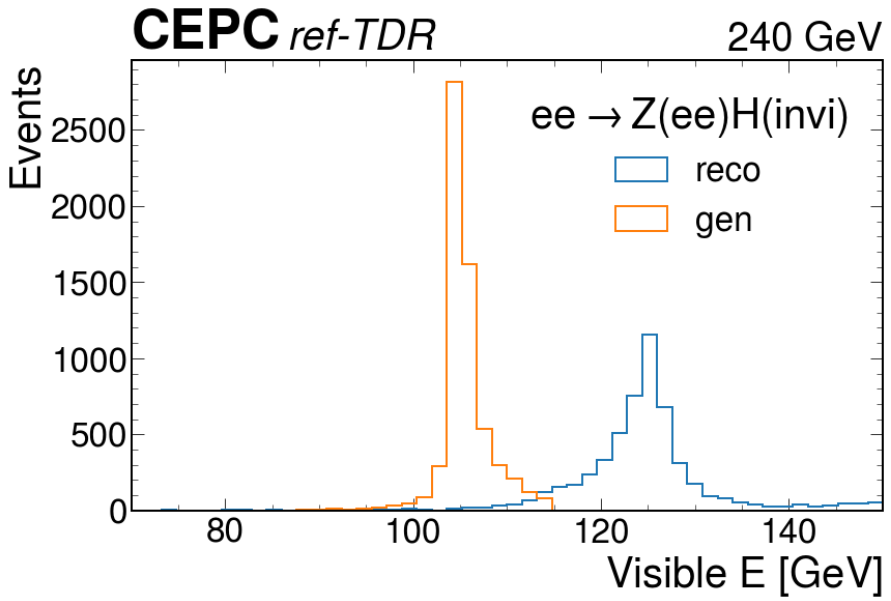
➢ Event categorization missing

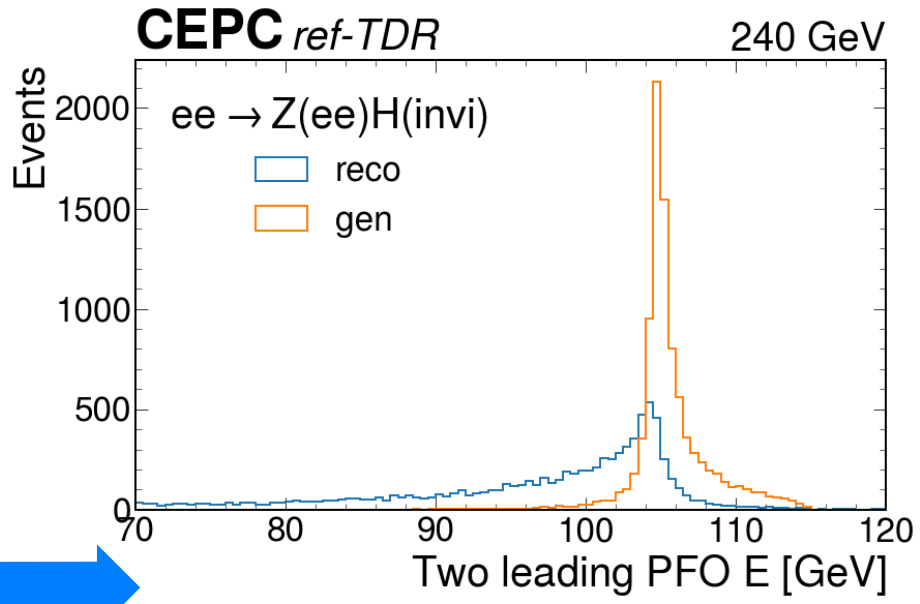
- **Based on Z→qq flavors:**
  - Require jet-flavor-tagging algorithms

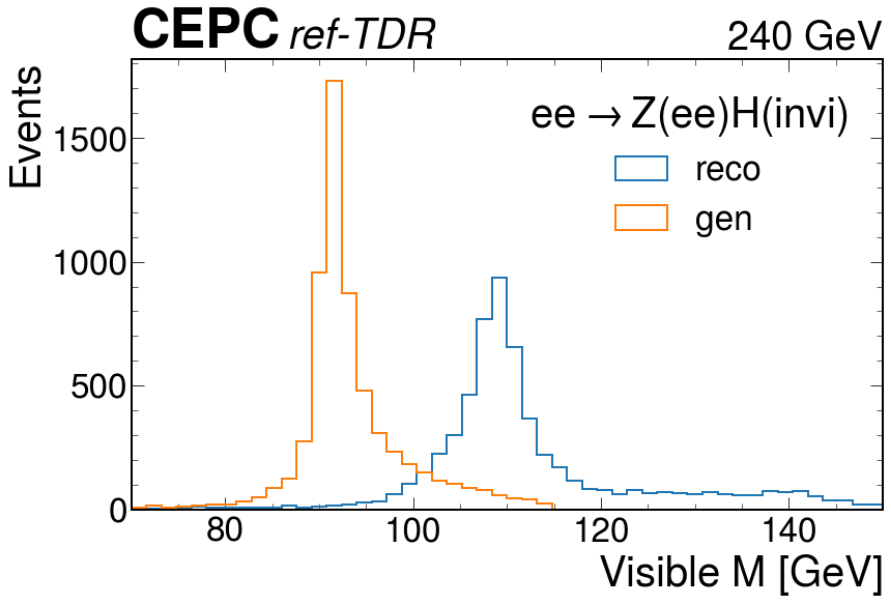


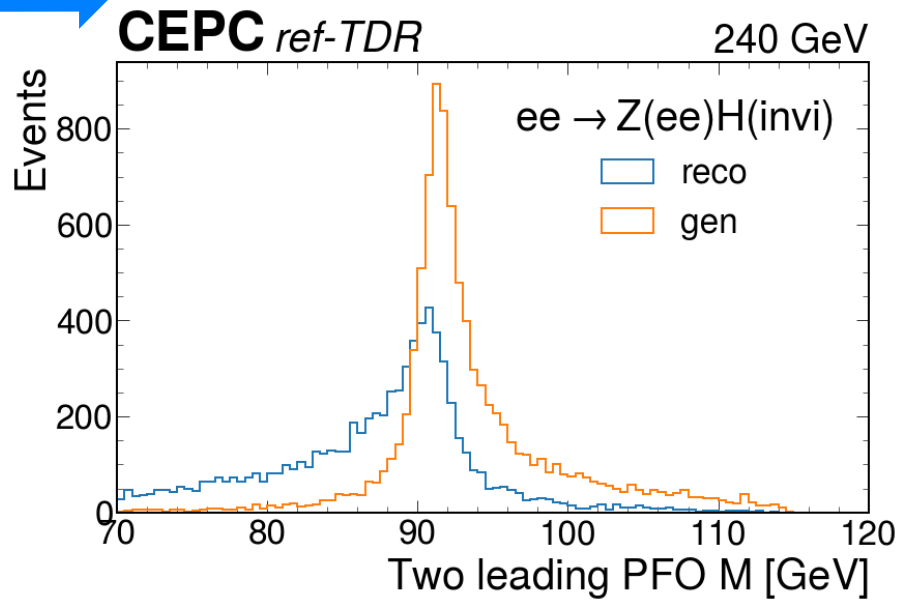
2 Issues in Electron reconstruction

Visible v.s. Two Leading Electrons









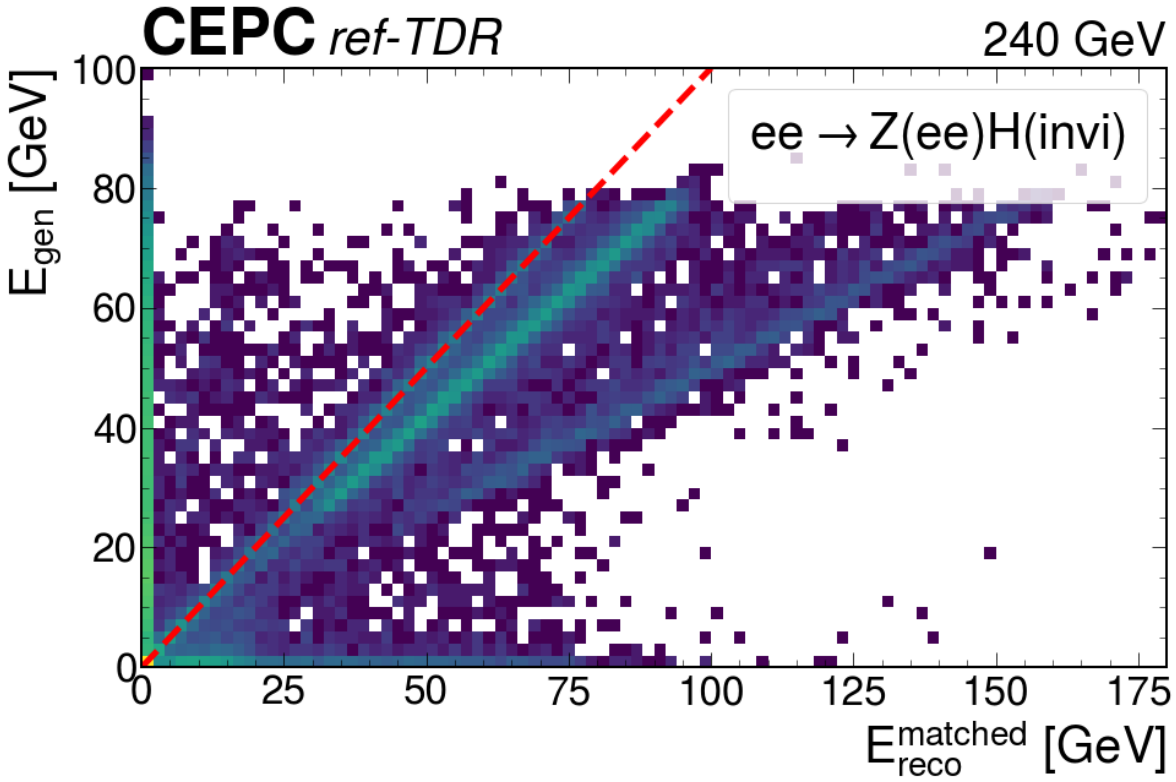
- More reasonable with 2 leading PFO
- Reco < gen due to FSR
- **Additional energetic PFOs reconstructed**

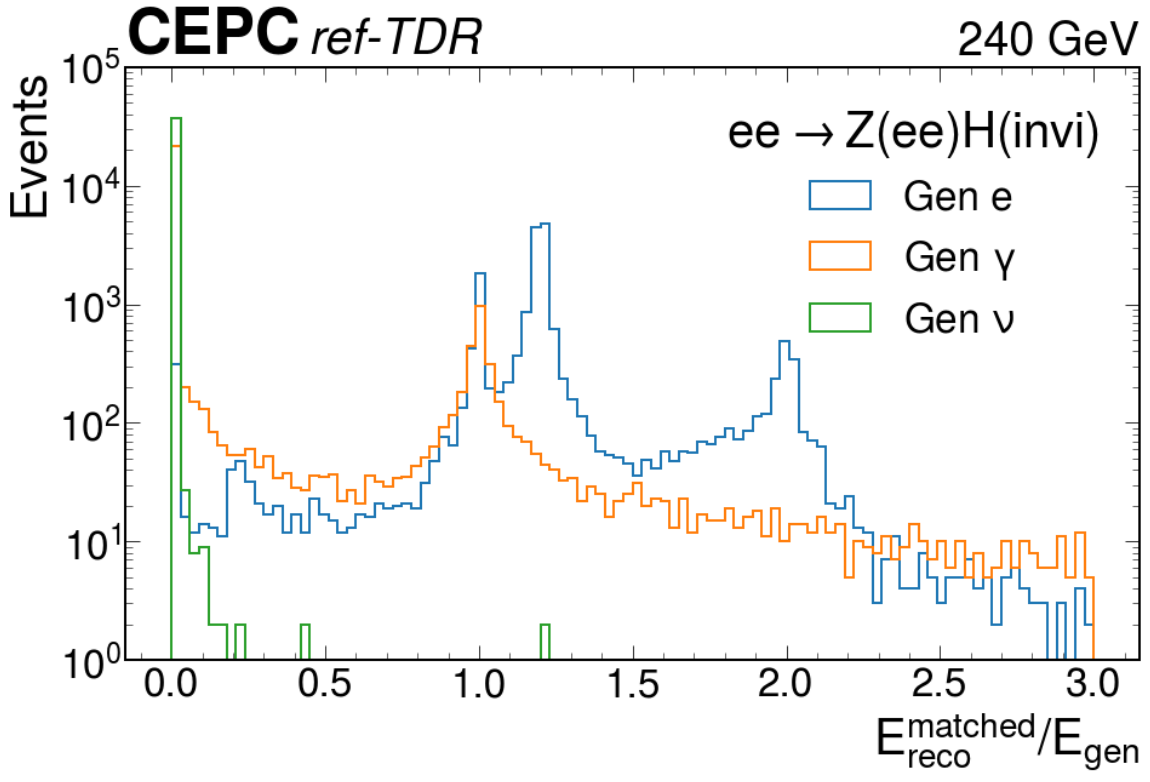
Studies with GenMatch

➢ GenMatch

- For each PFO, match it to a stable MC particle that has the smallest ΔR with it.
- For each stable MC particle, compare its energy to the energy sum of all PFOs that match to it.

In ee→Z(ee)H(inv)





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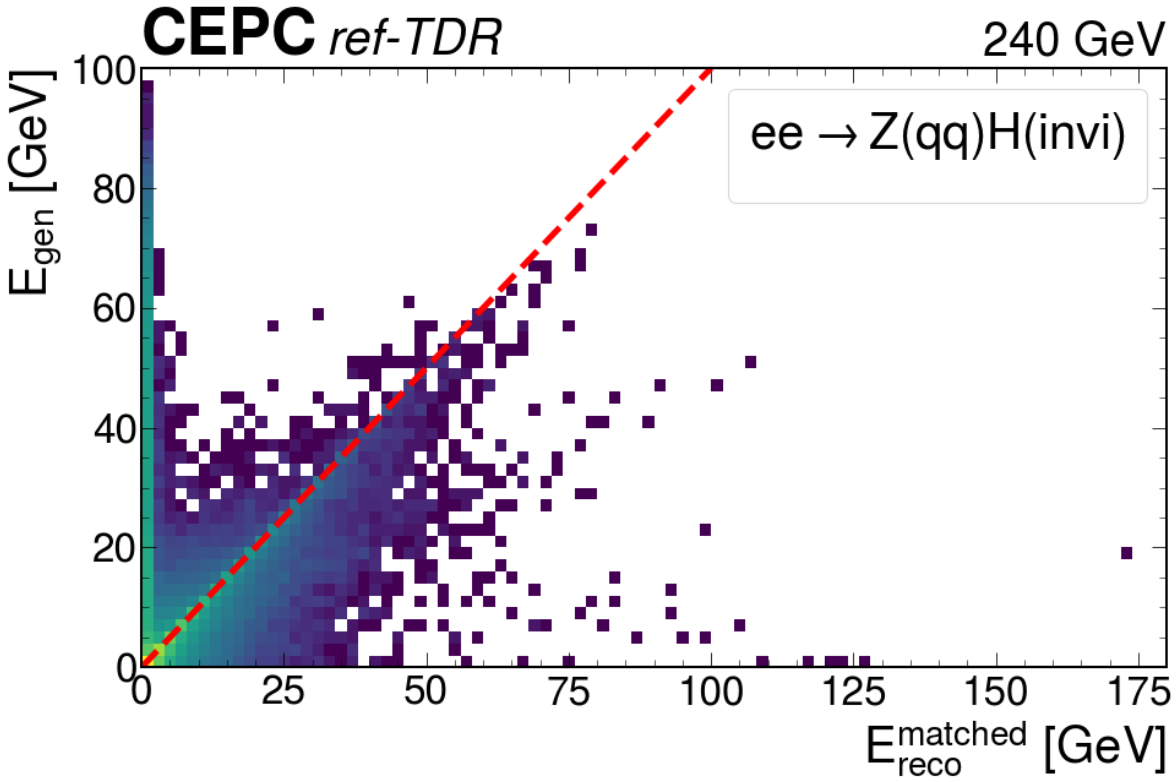
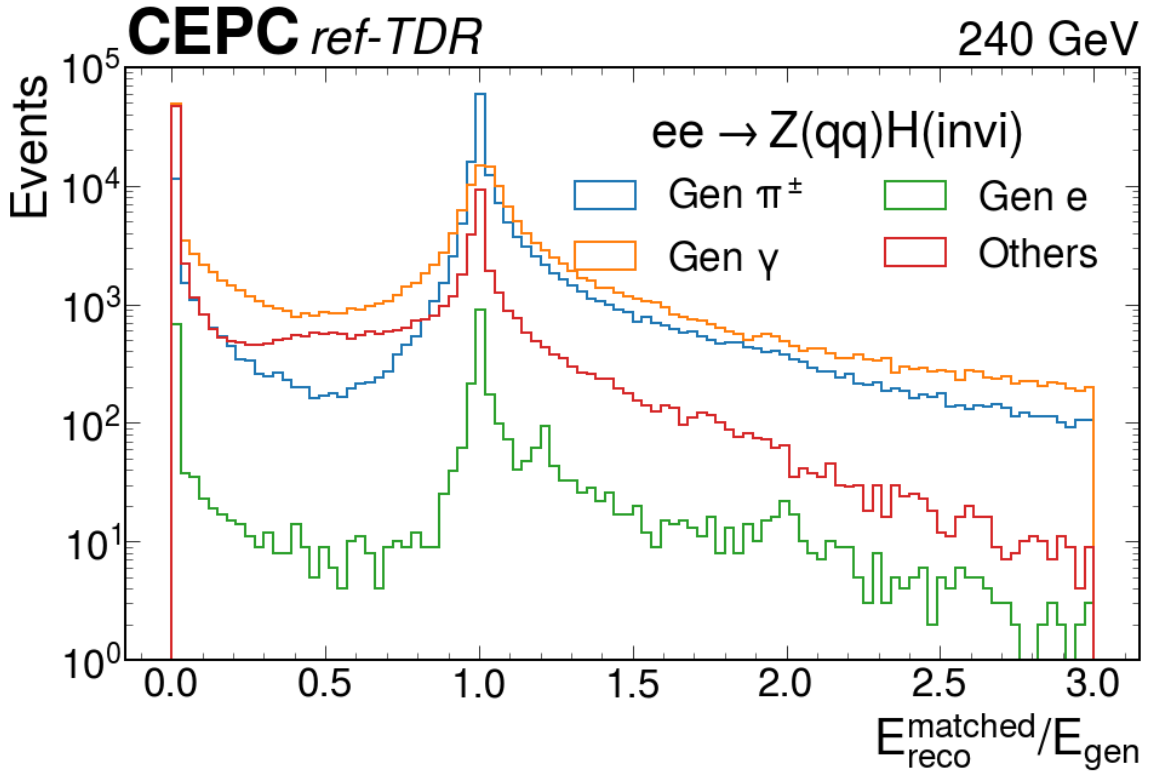
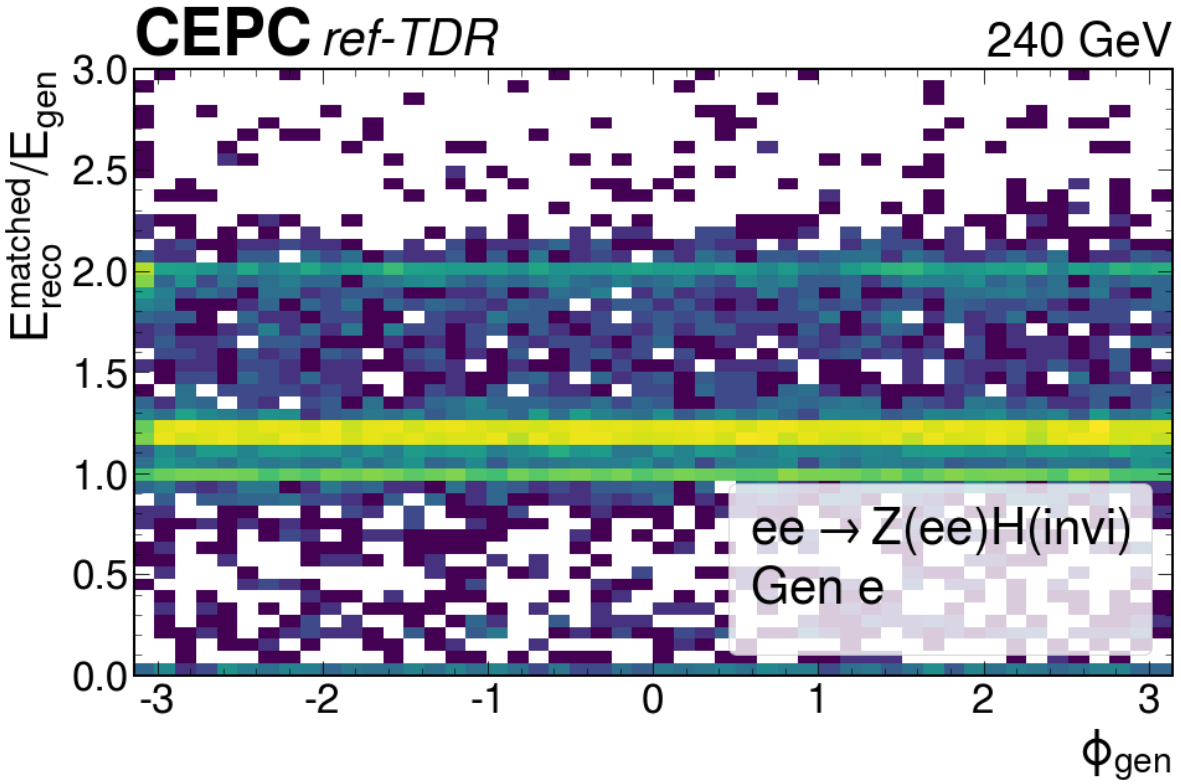
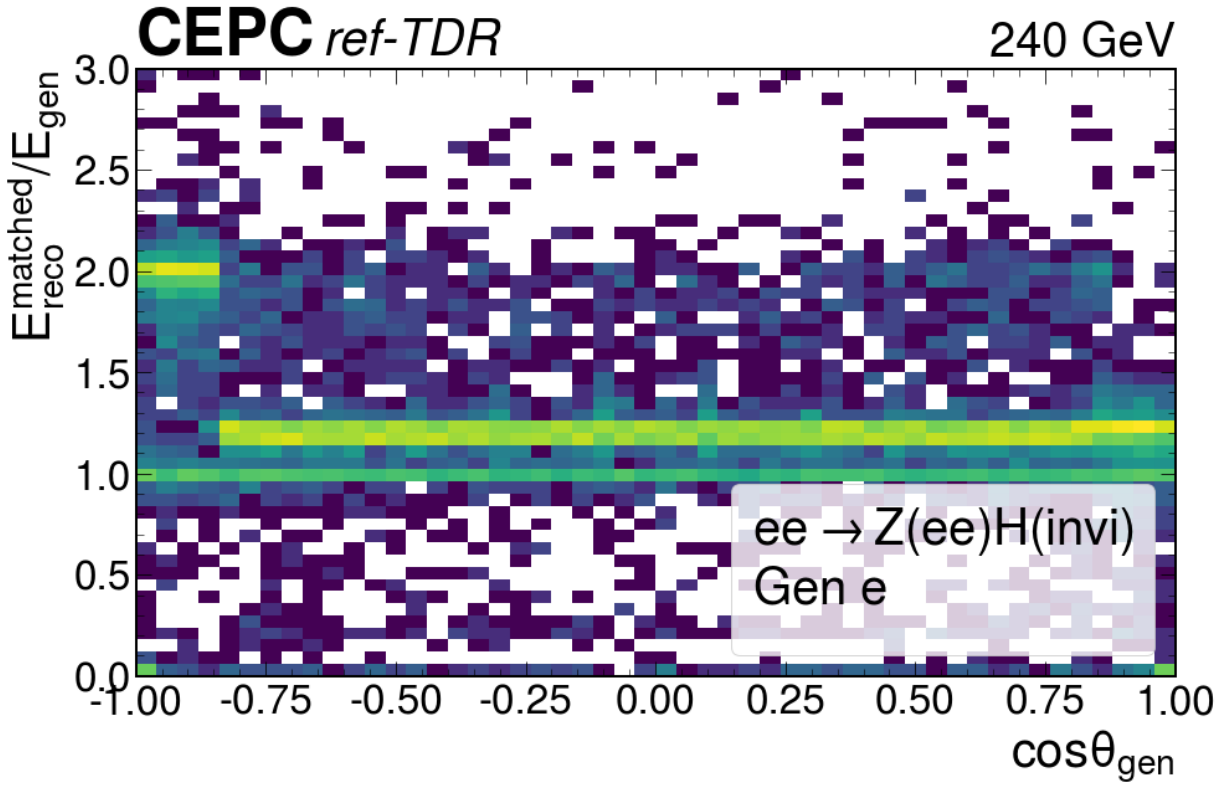




Angular dependence

- Studies with Gen e in ee→Z(ee)H(inv)

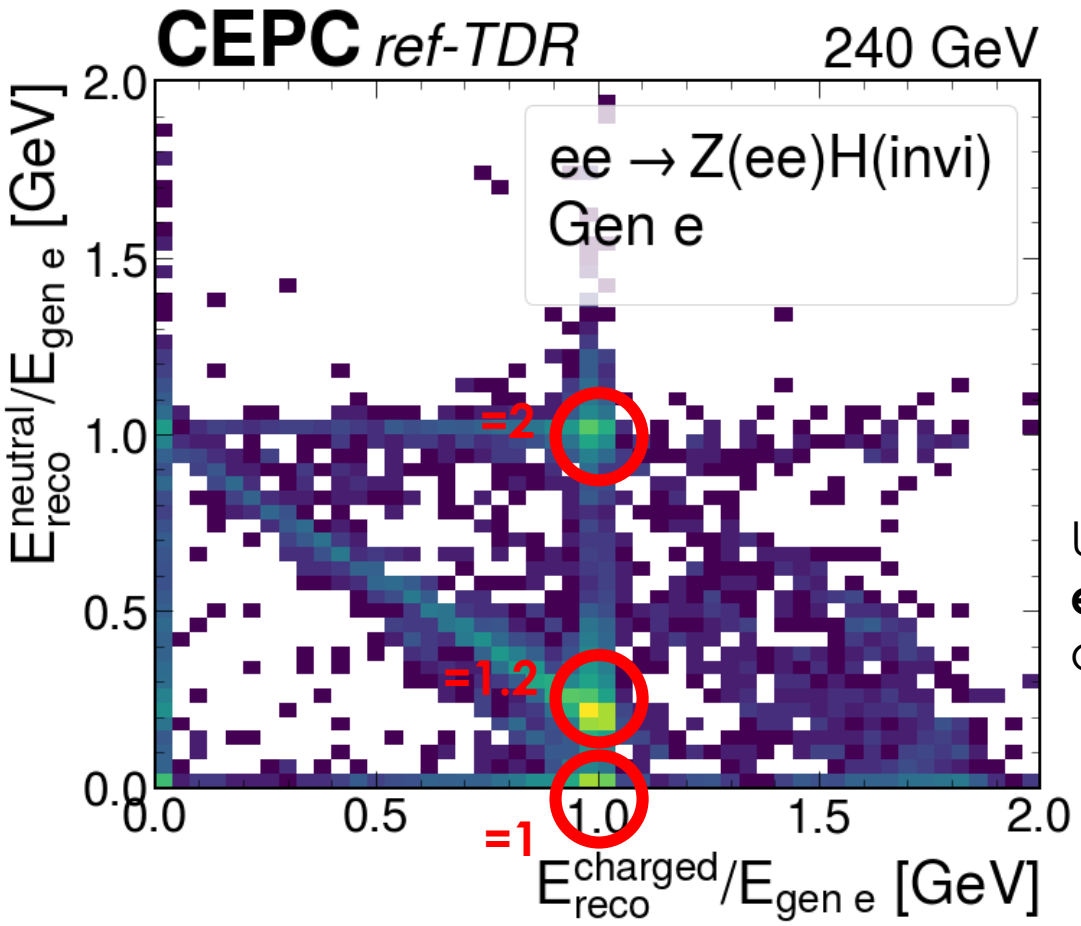




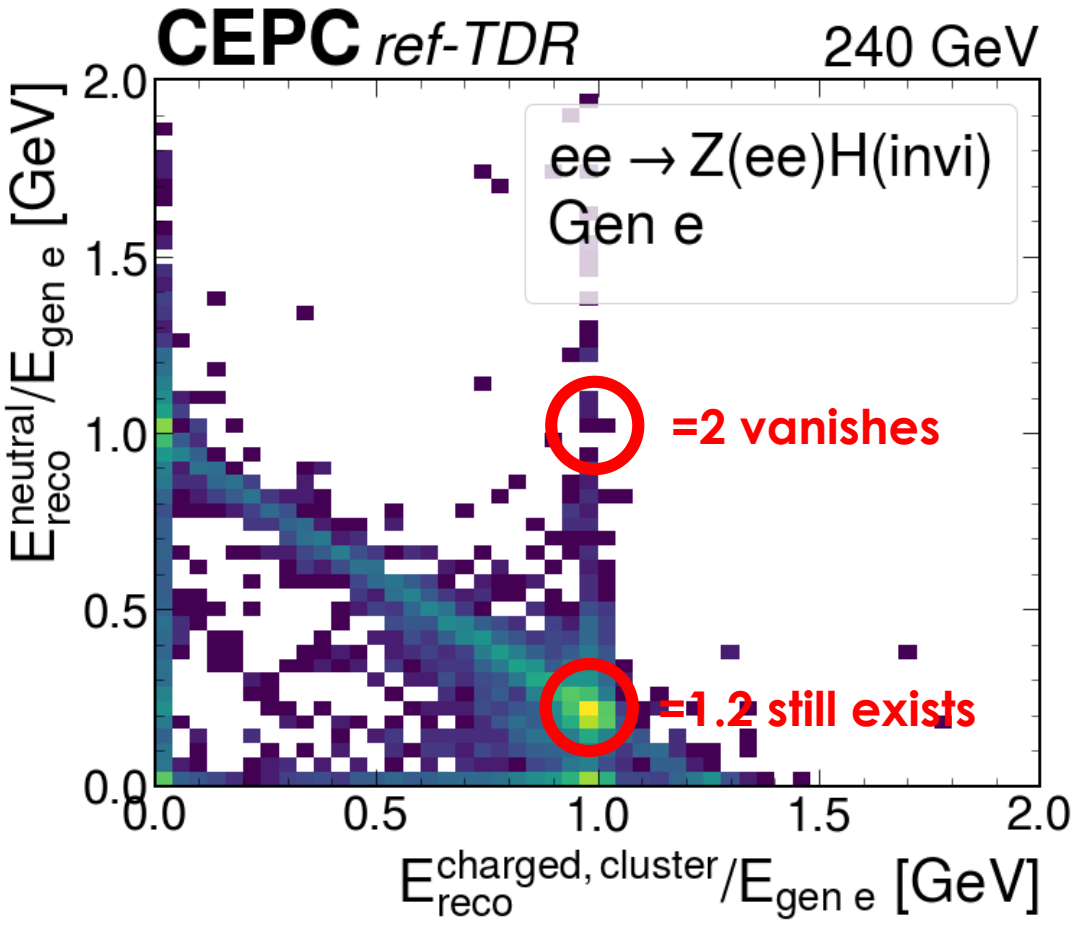
- $E^{matched}_{reco}/E_{gen}$ = 1: no dependence
- $E^{matched}_{reco}/E_{gen}$ = 1.2: no dependence on ϕ; doesn't exist in one endcap.
- $E^{matched}_{reco}/E_{gen}$ = 2: mostly around $\phi = -\pi$; mostly in one endcap.

Charged PFO v.s. Neutral PFO

- Split $E_{reco}^{matched}$ into $E_{reco}^{charged}$ and $E_{reco}^{neutral}$



Use **cluster energy** instead of **PFO energy**



Discussion

- $E_{reco}^{matched}/E_{gen}$ = 2 can be explained by the situation where:
  - the electron track not matched to its cluster;
  - the cluster reconstructed as a photon;
  - the energy counted **twice**.

- $E_{reco}^{matched}/E_{gen}$ = 1.2 cannot be explained by that:
  - even if the electron cluster energy is already similar to the gen energy, there is still a photon with sizable energy matched to it.
  - Potentially a bug in electron / photon reconstruction? It seems such clusters are still counted twice.