Institute of Experimental Particle Physics

Karlsruher Institut für Technologie

$H \to \tau\tau$ MEASUREMENTS AT FCC-ee IN THE ZH CHANNEL AT 240 GeV

Sofia Giappichini, Markus Klute, Matteo Presilla, Aaron Wiedl, Xunwu Zuo

Higgs/top performance meeting
Nov. 12th , 2024

Sofia Giappichini - sofia.giappichini@cern.ch

Targets and news

- $H \to \tau\tau$ **cross-section** relative uncertainty at $\sqrt{s} = 240$ GeV at FCC-ee
  ➜ already presented, updates in this presentation
  - **Explicit tau reconstruction** (from Maria Cepeda):
    - Found an issue with the cosine of the angle between the two taus
    - Updated the analysis consequently
  - **ML-based tau reconstruction** (FCC PNet jet tagger):
    - Parallel analysis to see which reconstruction would work better
    - Redefined some cuts and retrained BDTs consequently

- CP violation in the same channel ➜ not yet begun

General workflow

- We use the **inclusive generalized kt algorithm** for all jets with R=0.5 and $p_{T,j} > 2$ GeV, excluding isolated electrons and muons ($p_T > 20$ GeV and iso<0.25)

- We define **nine categories** based on the Z and tau decays
  - $Z \to \ell\ell$
  - $Z \to qq$
  - $Z \to \nu\nu$
  - $H \to \tau_\ell\tau_\ell$
  - $H \to \tau_\ell\tau_h$
  - $H \to \tau_h\tau_h$

- Basic selection requires exactly the objects in each category to be reconstructed
- Quark jets are differentiated from hadronic tau jets depending on the reconstruction method
- Leptonic taus are always handled “manually” by picking the isolated leptons

EXPLICIT TAU RECONSTRUCTION

Tau reconstruction

- Explicit reconstruction from jets:
  - Looks at jets with no electrons or muons
  - Gets the leading constituent (π+ or π−)
  - Adds constituents to the reconstructed tau 4-momentum vector (selection on pt>1 GeV or $\Delta\theta<0.2$ from the leading)
  - Keeps track of the number of photons to define a tau ID (negative for non-tau-like jets)
- Efficiency is for one **reco tau matched to a gen tau** within $\Delta R < 0.2$

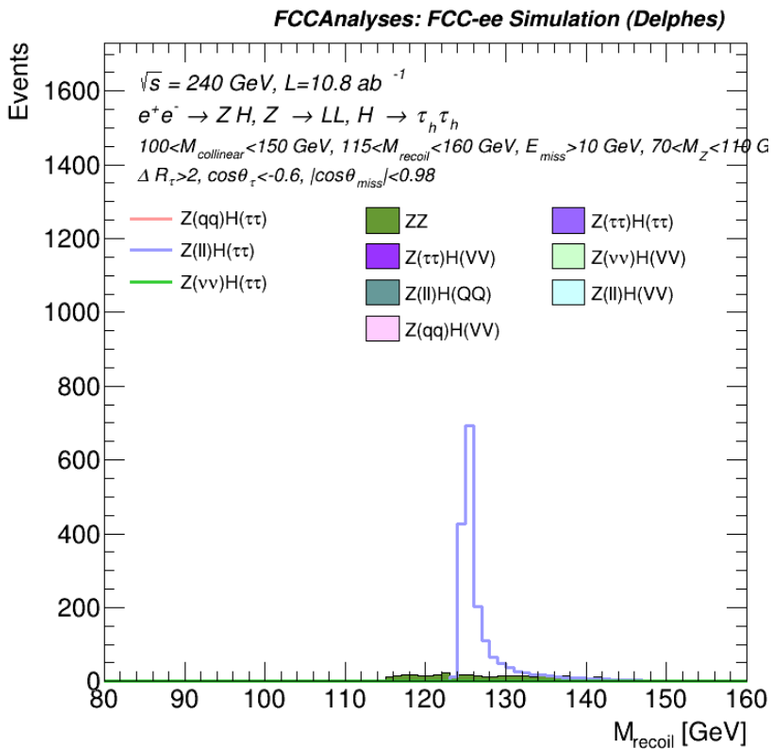
Efficiency

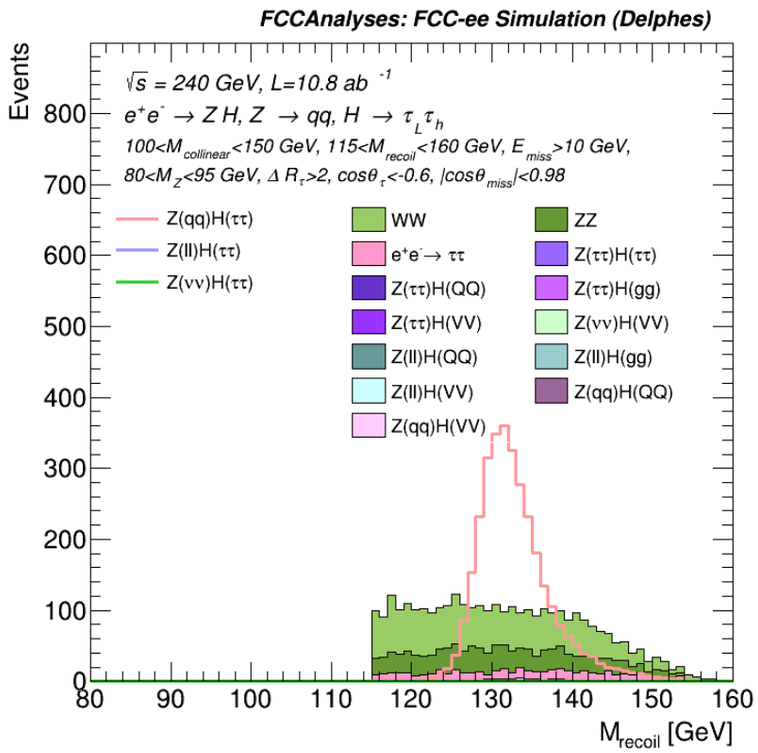
	Explicit reconstruction
wzp6_ee_nunuH_Htautau_ecm240	90.79%
wzp6_ee_eeH_Htautau_ecm240	85.64%
wzp6_ee_mumuH_Htautau_ecm240	85.64%
wzp6_ee_bbH_Htautau_ecm240	78.45%
wzp6_ee_ccH_Htautau_ecm240	79.01%
wzp6_ee_ssH_Htautau_ecm240	79.56%
wzp6_ee_qqH_Htautau_ecm240	79.31%

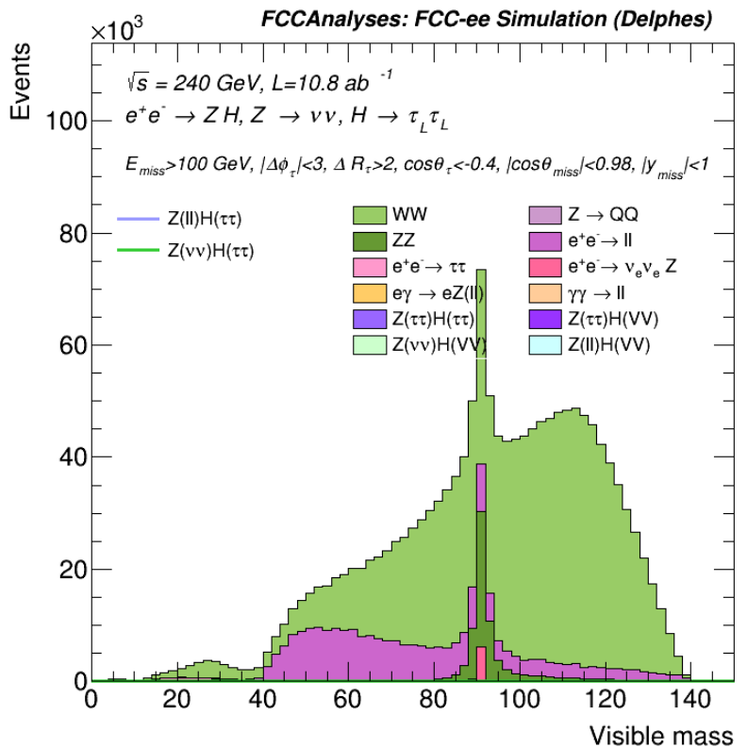
Selection

- Updated cut on $\cos\theta_{\tau\tau}$
- M_{recoil} in $Z \to qq$ has incorrect behavior due to jet clustering

$Z \to \ell\ell$ Selection	$Z \to qq$ Selection	$Z \to \nu\nu$ Selection
$100 < M_{collinear} < 150$ GeV		$E^{miss} > 100$ GeV
$115 < M_{recoil} < 160$ GeV		
$E^{miss} > 10$ GeV		$\lvert y^{miss}\rvert < 1$
$70 < M_Z < 100$ GeV	$80 < M_Z < 95$ GeV	$\lvert\Delta\phi_{\tau\tau}\rvert < 3$
$\cos\theta_{\tau\tau} < -0.6$		$\cos\theta_{\tau\tau} < -0.4$
$\Delta R_{\tau\tau} > 2$		
$\lvert\cos\theta^{miss}\rvert < 0.98$		

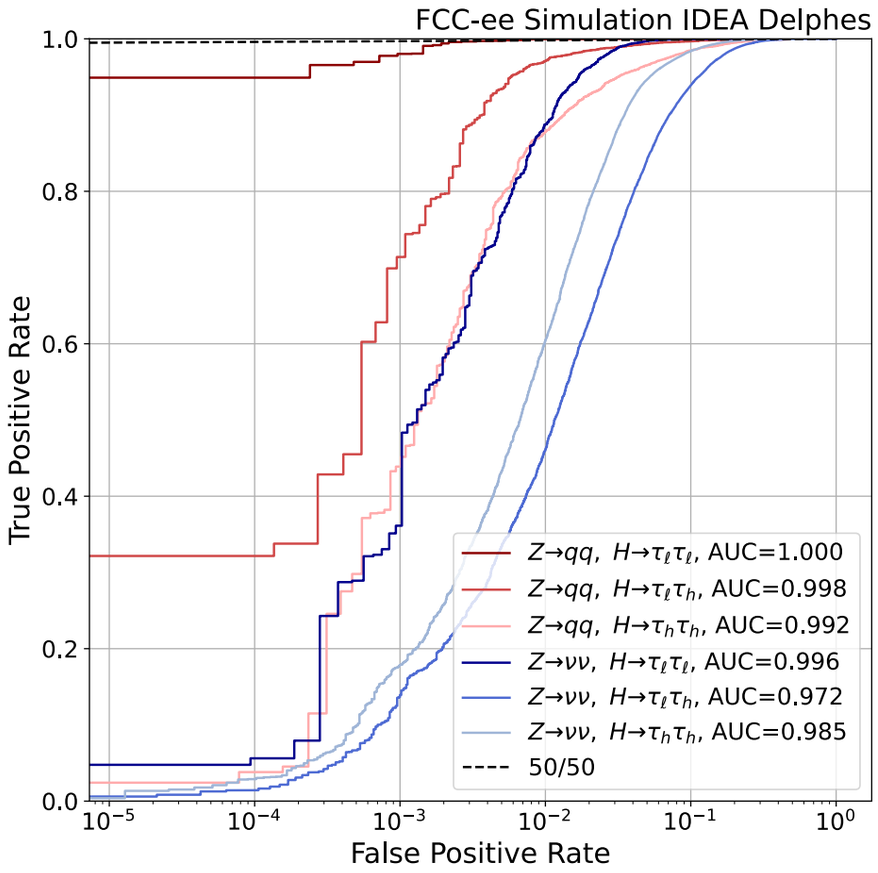


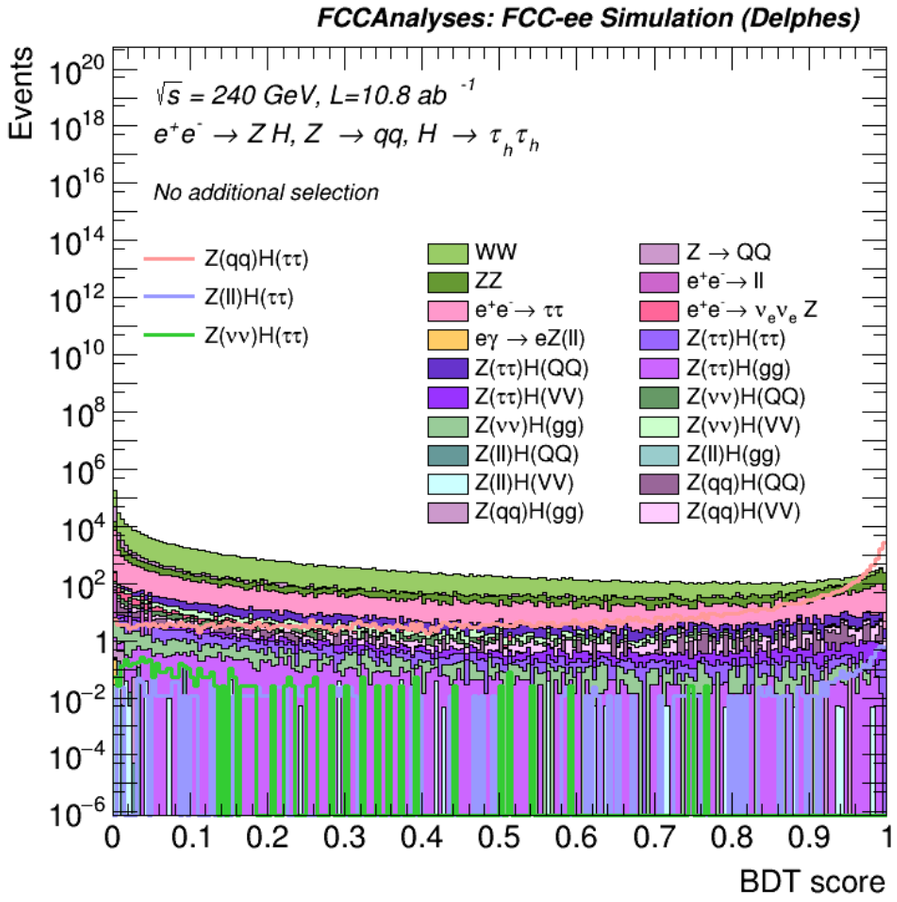




BDT training

- We trained a different BDT in each category for $Z \to qq$ and $Z \to \nu\nu$
- Events used in the training are also used when applying the BDT later on in the analysis
- No significant overtraining was observed for BDT of 200 trees and depth of 2 (shown in plots) and for 1000 trees and depth of 4





PNet RECONSTRUCTION

Tau reconstruction

- Found a second peak in the tau score at 0.9 coming from single photon jets
  - Taus are identified with PNet score above 0.5, unitary charge of the jet's constituents, mass smaller than 3 GeV
  - Quark jets are the rest with score below 0.5

- Efficiency is for one **reco tau matched to a gen tau** within $\Delta R < 0.2$

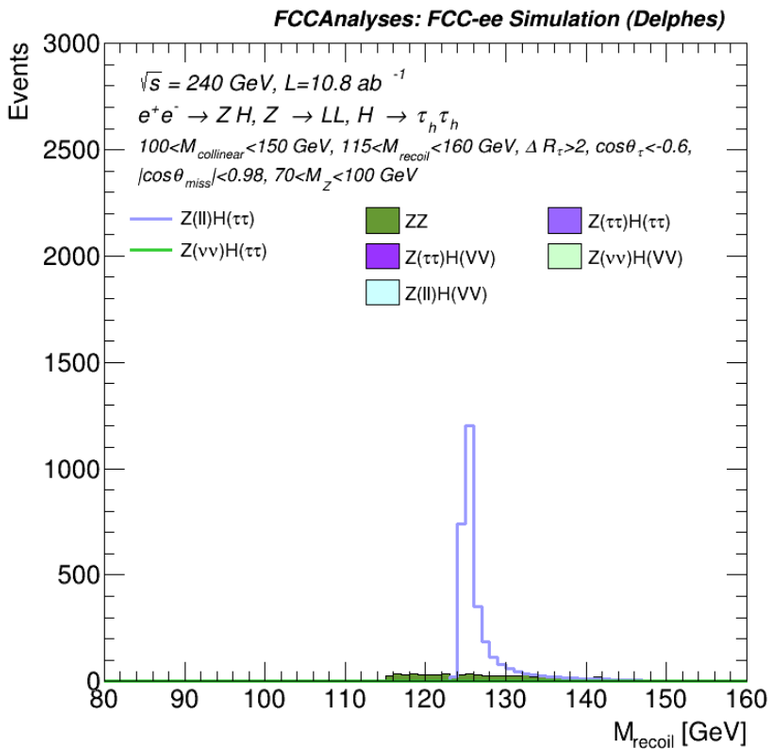
Efficiency

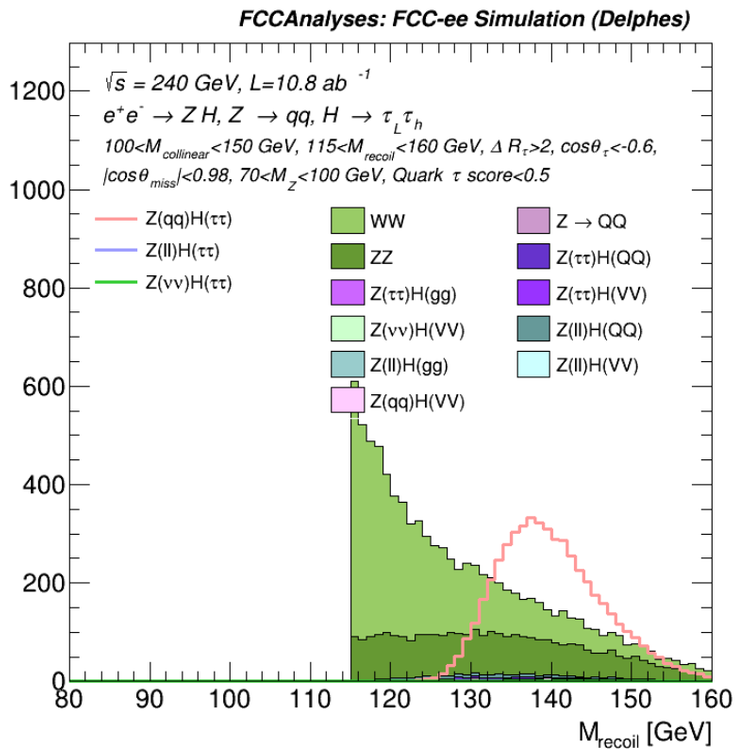
	PNet tagger (score>0.5)	Explicit reconstruction
wzp6_ee_nunuH_Htautau_ecm240	97.42%	90.79%
wzp6_ee_eeH_Htautau_ecm240	91.71%	85.64%
wzp6_ee_mumuH_Htautau_ecm240	91.71%	85.64%
wzp6_ee_bbH_Htautau_ecm240	64.09%	78.45%
wzp6_ee_ccH_Htautau_ecm240	65.19%	79.01%
wzp6_ee_ssH_Htautau_ecm240	65.75%	79.56%
wzp6_ee_qqH_Htautau_ecm240	65.71%	79.31%

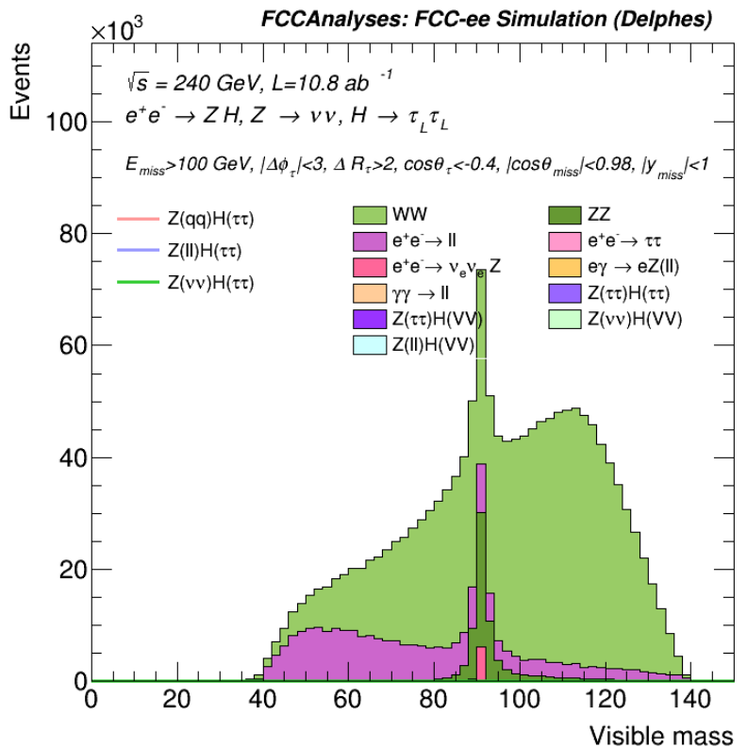
Selection

- More events in $Z \to \ell\ell$ due to higher efficiency
- Some changes in backgrounds composition and shape

	$Z \to \ell\ell$ Selection	$Z \to qq$ Selection	$Z \to \nu\nu$ Selection
$H \to \tau_\ell\tau_\ell$	$100 < M_{collinear} < 150$ GeV		$E^{miss} > 100$ GeV
	$115 < M_{recoil} < 160$ GeV		$\lvert y^{miss}\rvert < 1$
	$70 < M_Z < 100$ GeV		$\lvert\Delta\phi_{\tau\tau}\rvert < 3$
	$\cos\theta_{\tau\tau} < -0.6$		$\cos\theta_{\tau\tau} < -0.4$
	$\Delta R_{\tau\tau} > 2$		
	$\lvert\cos\theta^{miss}\rvert < 0.98$		
	$E^{miss} > 10$ GeV		

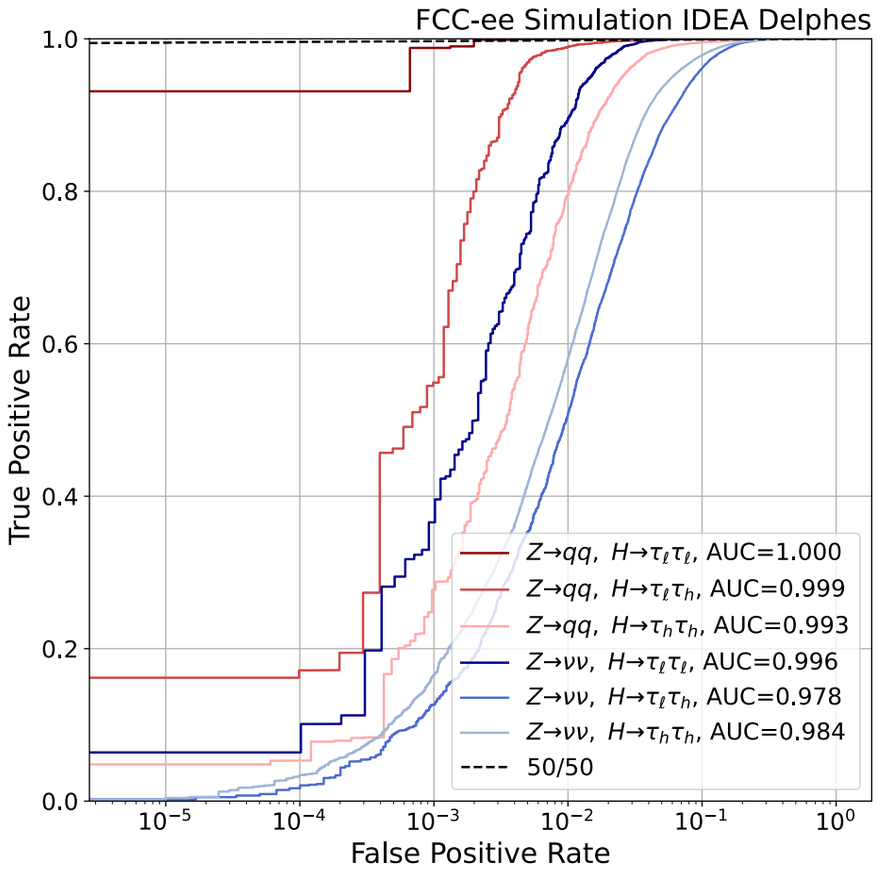


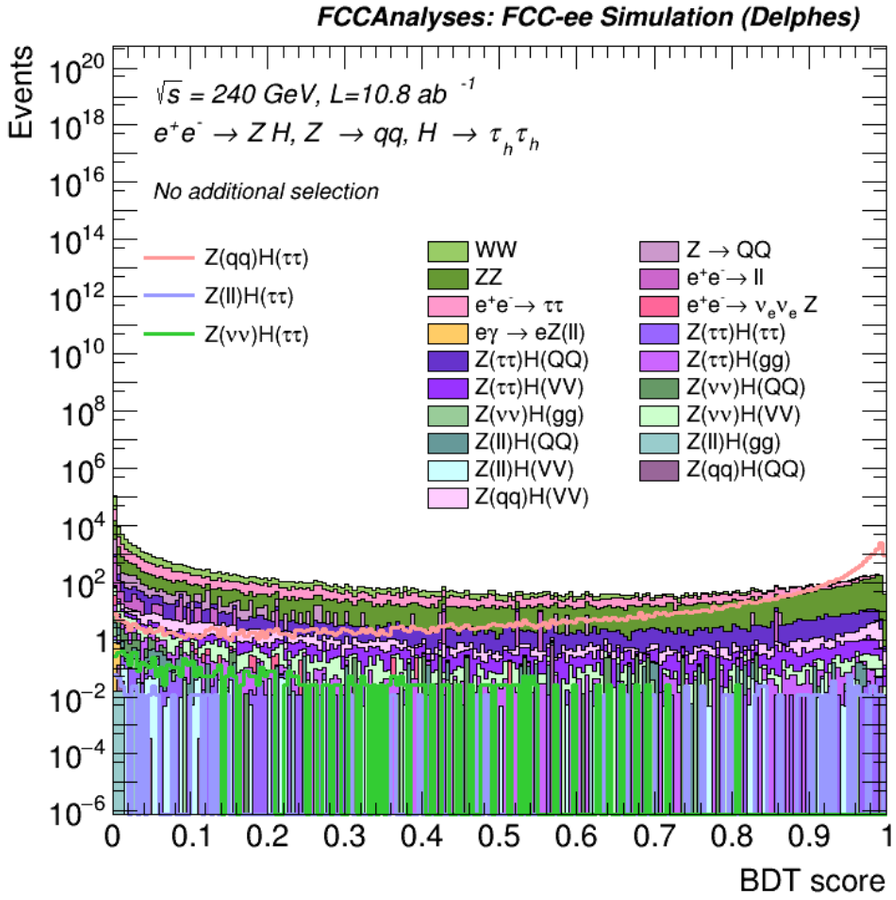




BDT training

- We trained a different BDT in each category for $Z \to qq$ and $Z \to \nu\nu$
- Events used in the training are also used when applying the BDT later on in the analysis
- No significant overtraining was observed for BDT of 200 trees and depth of 2 (shown in plots) and for 1000 trees and depth of 4





Results

- **Combine shape-based fit** arXiv:2404.06614 with freely floating processes
  - Explicit reco: M_{recoil} for $Z \to \ell\ell$ and $Z \to qq$, M_{vis} for $Z \to \nu\nu$
  - PNet reco: M_{recoil} for $Z \to \ell\ell$, BDT score above 0.5 for $Z \to qq$ and $Z \to \nu\nu$
- Relative uncertainty (68% CL) at $\sqrt{s}$=240 GeV, $\mathscr{L}$=10.8 ab^{-1}

	Explicit tau reconstruction	**PNet tau reconstruction**
Cut-based analysis	±1.17 %	±0.94 %
BDT analysis 200 trees	±1.06 %	±0.85 %
BDT analysis 1000 trees	±1.11 %	± %

Next steps

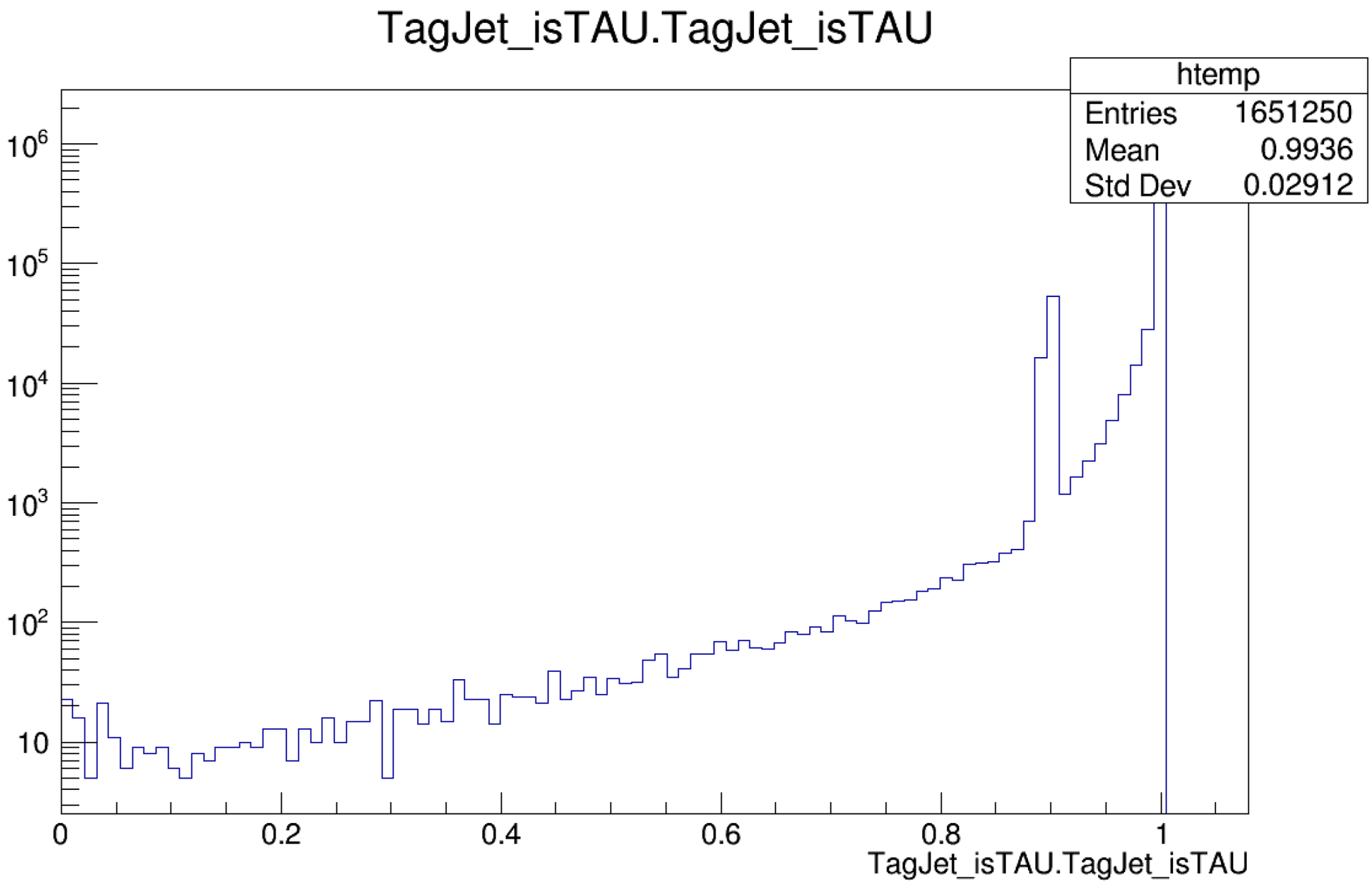
- Clean up the inclusive jets from the single photon jets that mess up the tagger score
- Try exclusive jet clustering, especially in the $Z \to qq$ channel, to possibly recover the correct Z reconstruction and get higher tau efficiency

- Everything (done at that point) will be documented in an update of the analysis note by Nov. 18
- Plans to continue working on the analysis after that
- CP study will come later on

Karlsruher Institut für Technologie

BACKUP

Issue with jet tagging



shown 1M events of $e^+e^- \to ZH, Z \to \nu\nu, H \to \tau\tau$

same behavior in backgrounds