Tau Identification per Decay Mode

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Hadronic tau reconstruction

- We are continuing our work to develop a **decay-mode based tau algorithm** as a tool that can be used for a variety of physics studies
  - Similar idea as the 3Prong example already in the framework, targeting 1Prong/3Prongs simultaneously
- Very simple approach that follows what has been done in LEP (and LHC) and also rather similar to some of the ILC studies
- Complementary approach to the ParticleNet. Eventually, combined approach?
- ZH as a study case to demonstrate performance. The work started with mumutautau, → **master thesis of Izan Fernández Tostado (UCM)**
  - For the master thesis Izan focused on physics (selection of mumutautau and measurement of Br/Coupling) once we had a first approximation to the tau algo that allowed us to study the process. The performance studies lagged behind.
- Once the algorithm is robust and the performance is understood, we will ask for integration into FCCAnalysis

Decay mode	Resonance	$\mathcal{B}$ (%)	
Leptonic decays		35.2	
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$			17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$			17.4
Hadronic decays		64.8	
$\tau^- \to h^- \nu_\tau$			11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$		25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$		9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$		9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8
Other			3.3

All of this is work in progress, preliminary!

Aiming at ZH Hττ studies

Eur. Phys. J. C (2019) 79:474

Table 4.2 Precision determined in the κ framework of the Higgs boson couplings and total decay width, as expected from the FCC-ee data, and compared to those from HL-LHC [18] and other e^+e^- colliders exploring the 240-to-380 GeV centre-of-mass energy range. All numbers indicate 68% CL sensitivities, except for the last line which gives the 95% CL sensitivity on the "exotic" branching fraction, accounting for final states that cannot be tagged as SM decays. The FCC-ee accuracies are subdivided in three categories: the first sub-column give the results of the model-independent fit expected with 5 ab^{-1} at 240 GeV, the second sub-column in bold – directly comparable to the other collider fits – includes the additional 1.5 ab^{-1} at $\sqrt{s} = 365$ GeV, and the last sub-column shows the result of the combined fit with HL-LHC. The fit to the HL-LHC projections alone (first column) requires two additional assumptions to be made: here, the branching ratios into $c\bar{c}$ and into exotic particles are set to their SM values

Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$LEP3_{240}$	$CEPC_{250}$	$FCC\text{-}ee_{240+365}$		
Lumi (ab^{-1})	3	2	1	3	5	5_{240}	$+1.5_{365}$	+ HL-LHC
Years	25	15	8	6	7	3	+4	
$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6	4.7	3.6	2.8	2.7	**1.3**	1.1
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.5	0.3	0.60	0.32	0.25	0.2	**0.17**	0.16
$\delta g_{HWW}/g_{HWW}$ (%)	1.7	1.7	1.0	1.7	1.4	1.3	**0.43**	0.40
$\delta g_{Hbb}/g_{Hbb}$ (%)	3.7	1.7	2.1	1.8	1.3	1.3	**0.61**	0.56
$\delta g_{Hcc}/g_{Hcc}$ (%)	SM	2.3	4.4	2.3	2.2	1.7	**1.21**	1.18
$\delta g_{Hgg}/g_{Hgg}$ (%)	2.5	2.2	2.6	2.1	1.5	1.6	**1.01**	0.90
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.9	1.9	3.1	1.9	1.5	1.4	**0.74**	0.67
$\delta g_{Hmm}/g_{H\mu\mu}$ (%)	4.3	14.1	n.a.	12	8.7	10.1	**9.0**	3.8
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.8	6.4	n.a.	6.1	3.7	4.8	**3.9**	1.3
$\delta g_{Htt}/g_{Htt}$ (%)	3.4	–	–	–	–	–	–	3.1
BR_{EXO} (%)	SM	< 1.7	< 2.1	< 1.6	< 1.2	< 1.2	**< 1.0**	**< 1.0**

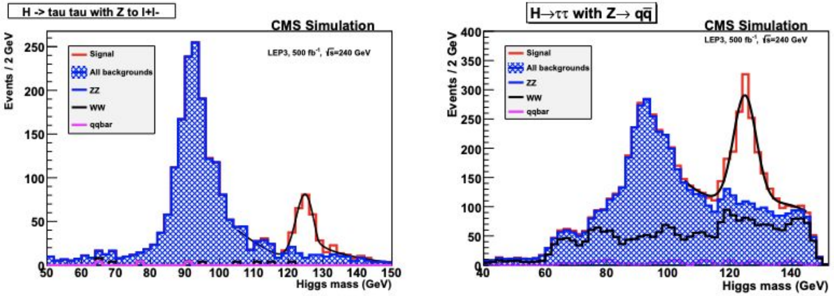


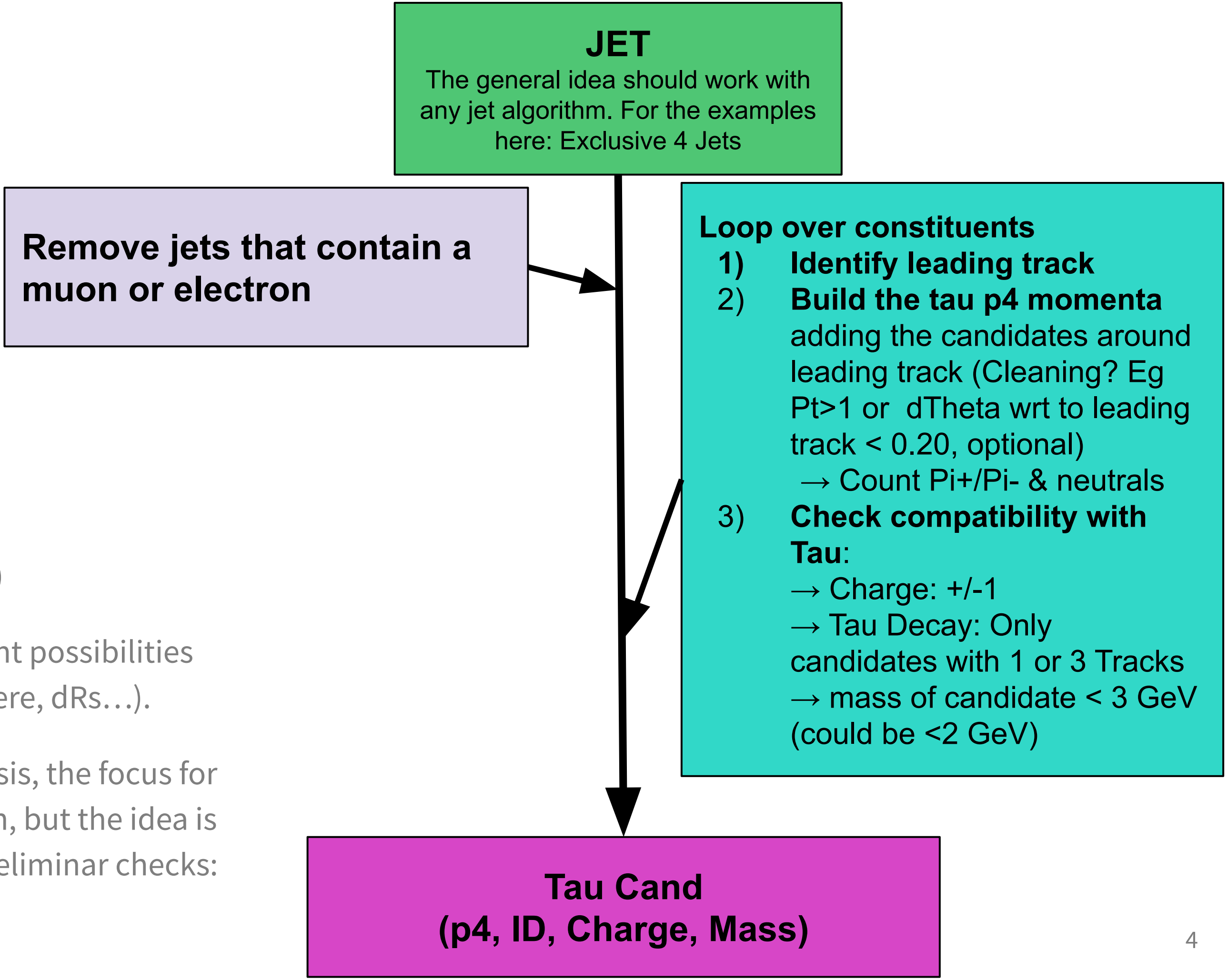
Figure 9: Distribution of the reconstructed Higgs boson mass (labelled "Higgs mass") in the $ZH \to \ell^+\ell^-\tau^+\tau^-$ channel (left) and in the $ZH \to q\bar{q}\tau^+\tau^-$ channel (right), for the HZ signal (hollow histogram) and all backgrounds (shaded histogram).

Hττ results in the FCC CDR based on the LEP3 (adapted to FCC). How much better can we do with dedicated Tau reconstruction?

Plans forward beyond tau reconstruction: studies with the ZH channel

Not only Higgs: Connection to other FCC studies with taus.

Rough Tau Algo



Two general approaches tested:

- Start from RP
- Start from Jets (slightly better)

Within the jets: jet version? → Different possibilities tested (exclusive, inclusive, hemisphere, dRs…).

Since the study is geared to ZH analysis, the focus for now on Exclusive 4 Jet reconstruction, but the idea is easily generalizable. Note that the preliminar checks: large jets do not work well.

Rough Tau Algo

JET
The general idea should work with any jet algorithm. For the examples here: Exclusive 4 Jets

Remove jets that contain a muon or electron

Loop over constituents

1) **Identify leading track**
2) **Build the tau p4 momenta** adding the candidates around leading track (Cleaning? Eg Pt>1 or dTheta wrt to leading track < 0.20, optional)
   → Count Pi+/Pi- & neutrals
3) **Check compatibility with Tau**:
   → Charge: +/-1
   → Tau Decay: Only candidates with 1 or 3 Tracks
   → mass of candidate < 3 GeV (could be <2 GeV)

Tau Cand
(p4, ID, Charge, Mass)

Still quite a lot of room for improvement

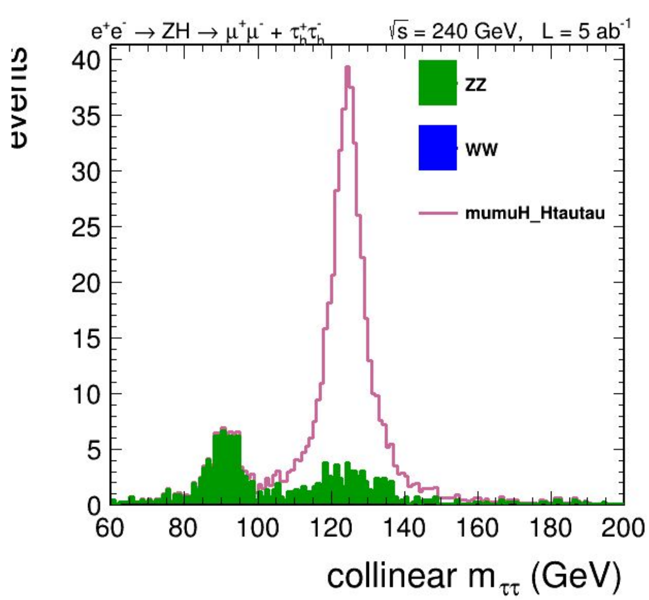
- **Clean up configuration** (make it more in the style of the rest of FCCAnalysis, its too c++ based right now)
- Tune criteria for incorporating candidates (more important for topologies with additional jets). Identify Pi0s?
- Incorporate detector more carefully. FullSim? Go deeper to understand the detector (PID, energy, etc)
- Weaver → Compare to PNet

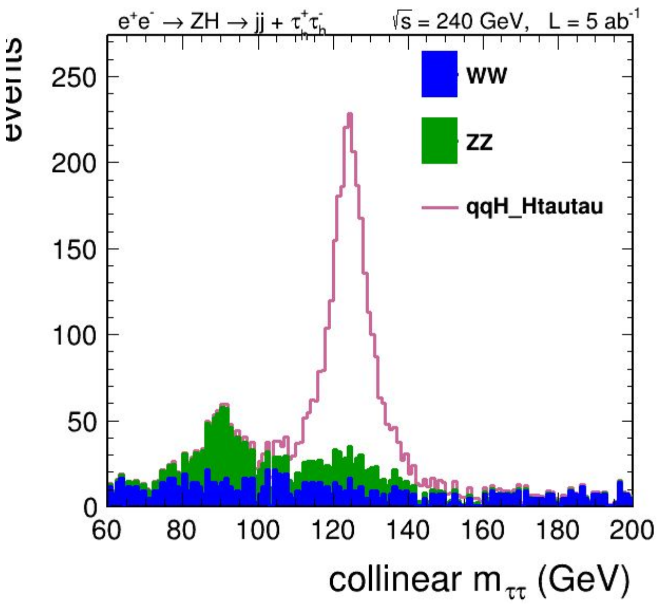
Studying the performance in ZH, H→TauTau

Algorithm developed using Z→MuMu, H→TauTau samples: very clean.

Also tested with Z→QQ samples: checking with different topology shows the need for more studies and improvements in the algorithm).

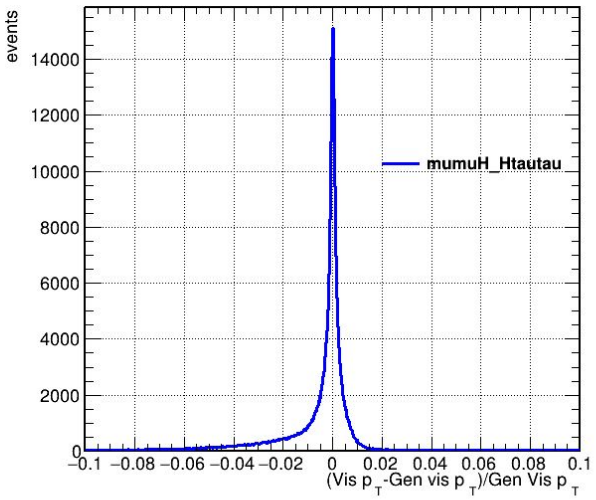
While not perfect, good enough reconstruction to have preliminar ZH results. More details on the analysis side next week.



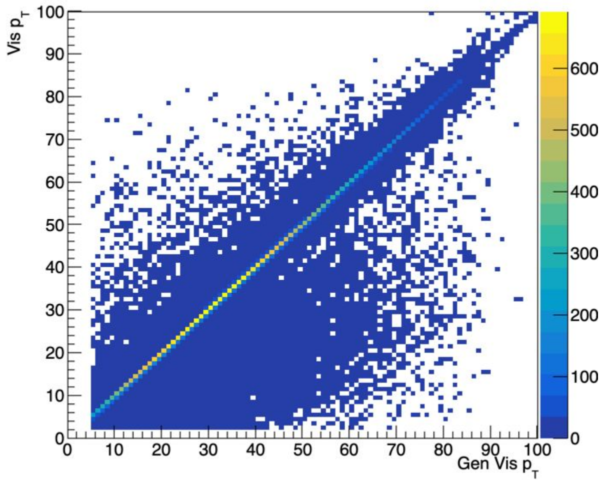


(Plot done for a single experiment, for 4IP scale up the luminosity)

Performance in MuMuTauTau: Resolution



Resolution (computed vs visible Pt)

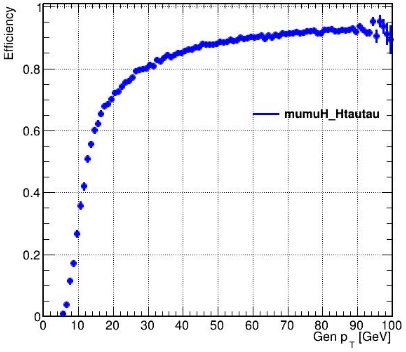


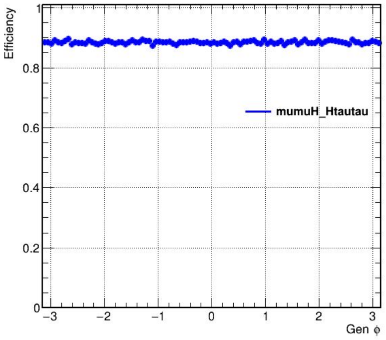
Gen vs Reco

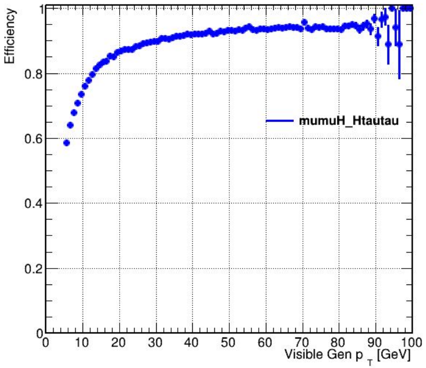
Algorithm developed using Z→MuMu, H→TauTau samples: very clean events

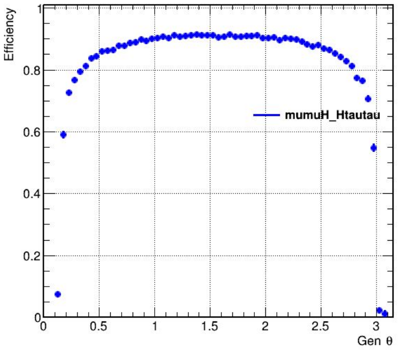
Reasonable reconstruction of the tau Pt

Performance in MuMuTauTau: Efficiencies







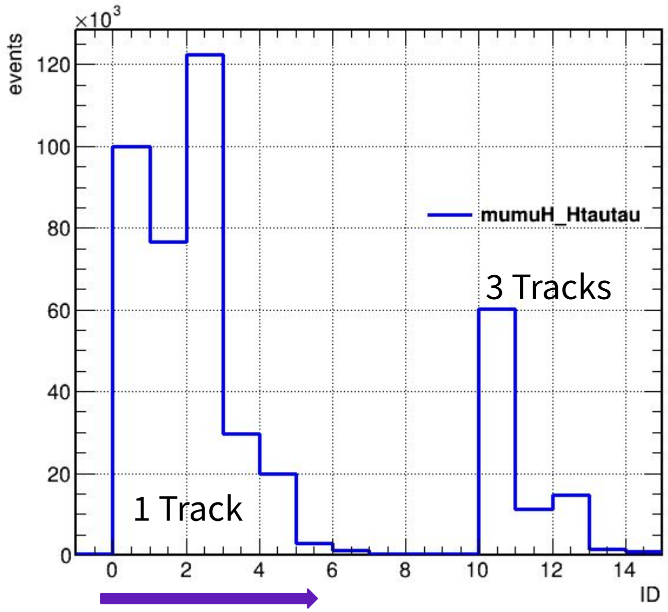


Efficiency computed per ‘true’ hadronic tau at gen level

Reasonable performance. Further studies per exclusive Tau Decay Mode (at Gen level!) ongoing

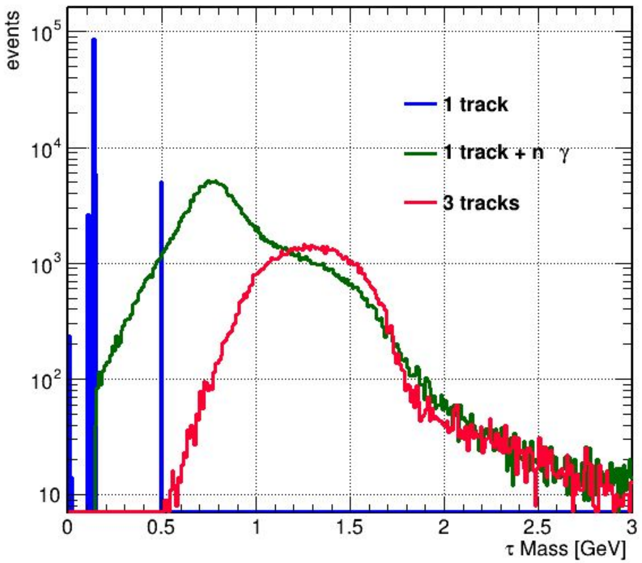
Performance checked (superficially) for different kinds of Jets. Settled on this configuration mostly for analysis reasons.

Performance in MuMuTauTau: Tau Decays



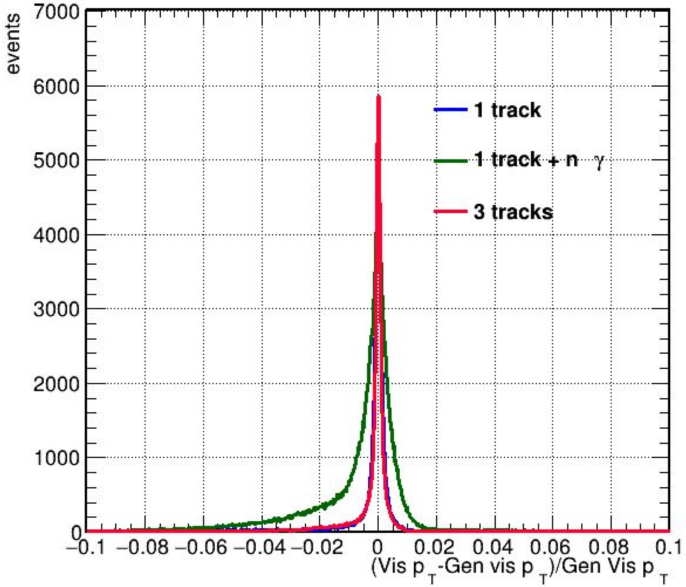
number of
Photons
(Pt>1 GeV)

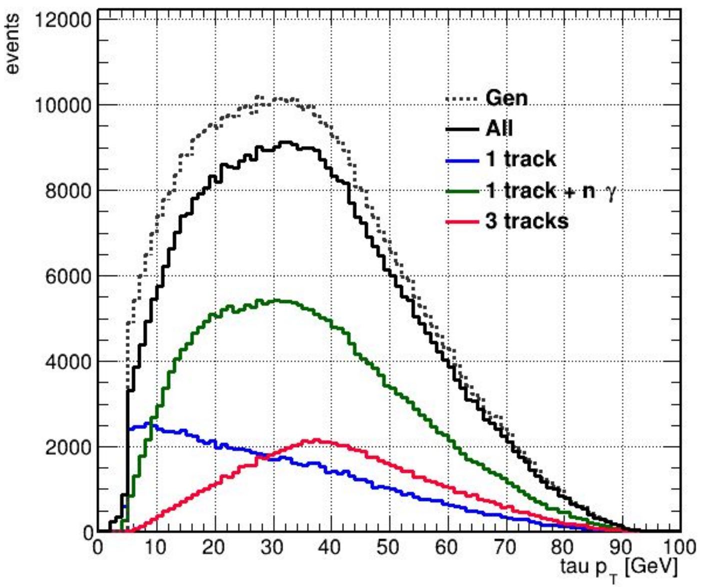
(ongoing:
preselect pi0)



Performance for different tau decay modes

Room for improvement. In terms of resolution particularly in cases with photons.

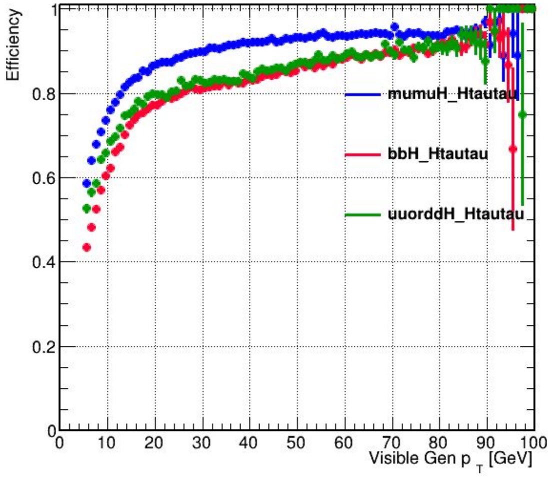


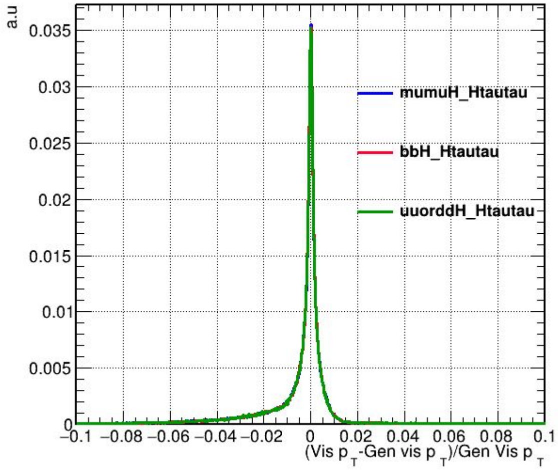


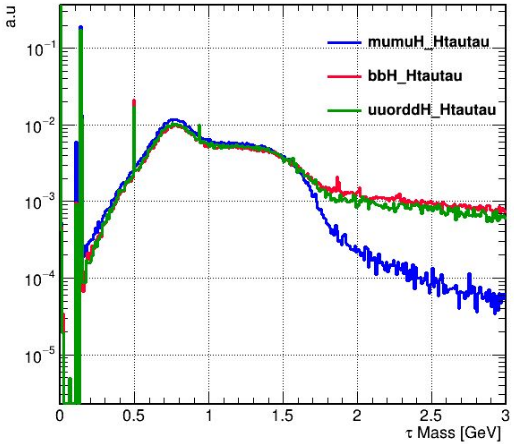
Other topologies: QQTauTau as example.

Performance degraded when complicating the topology: still reasonable efficiency, but effects coming from the more complicated events arise.

Work ongoing to understand this case & make the algorithm more robust.







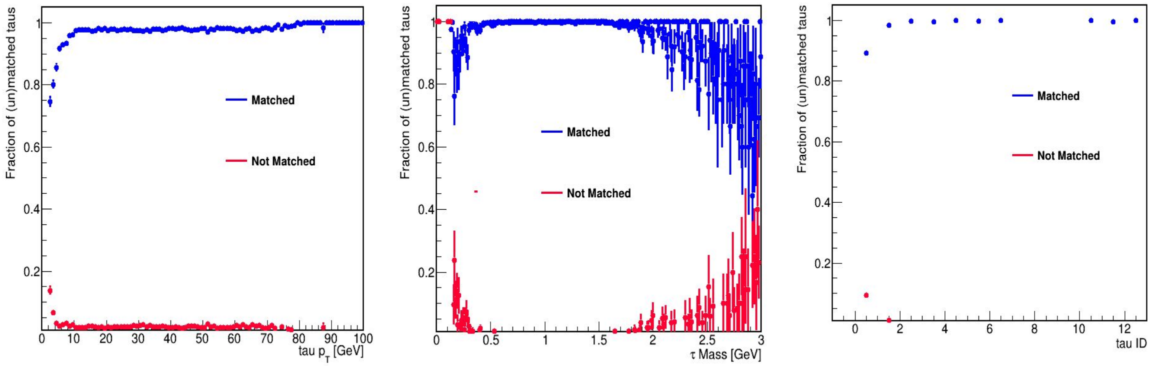
Jet→Taus?

In the qq case: misidentification of jets as taus (affecting both signal selection and ZZ/WW backgrounds).

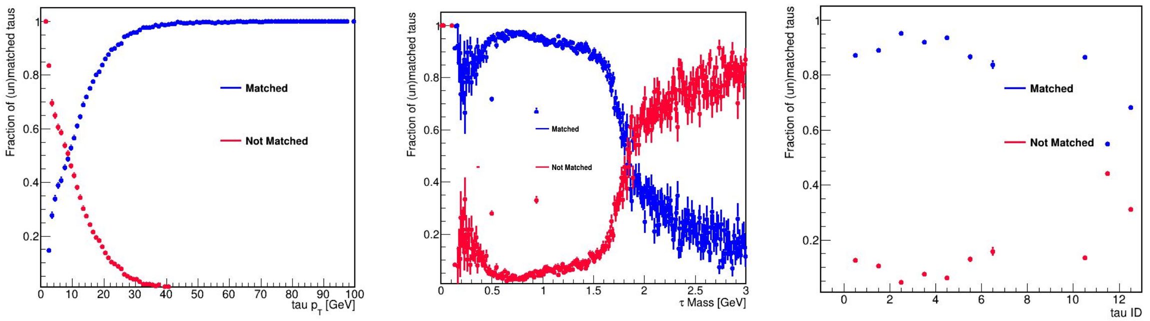
The ID requirements & selection minimize this issue, but this needs to be improved in the next version.

Proper misidentification/ID study to be done still. As a first step, see the difference in the fraction of reco taus that are matched to a true hadronic tau at gen level in qqtautau and mumutautau

mumutautau



qqtautau



Next steps

Check performance for exclusive tau decays at generator level

Continue checks with different jet reconstruction

Improving incorporation of neutrals: pi0 reconstruction

Reducing/understanding the jet→tau ‘fake’ rate (ZZ peak under Higgs signal)

Further tuning / simplification of the algorithm

Comparison with ParticleNet tagging

What about ILC?

8.2.5. $\mathrm{BR}(h \to \tau^+\tau^-)$

The measurement of $BR_{\tau\tau}$ provides a very important probe of the Higgs couplings to third generation fermions. And it is going to be one of the most precise Higgs measurements at the ILC, thanks to the relatively large branching ratio and very clean signal and background separation. The full simulation is performed using the leading Higgs production process $e^+e^- \to Zh$ and all the decay channels from $Z \to q\bar{q}/\nu\bar{\nu}/l^+l^-$; see details in [195]. The τ is reconstructed using TaFinder and the four momenta of missing neutrinos are calculated using collinear approximation. The remained signal and background events in $Z \to q\bar{q}$ channel are shown in Fig. 52. The S/B ratio is higher than 2/1. The signal efficiency is 36% and the dominant background is from $e^+e^- \to ZZ \to q\bar{q}\tau^+\tau^-$. The estimate of statistical uncertainty for $\sigma_{Zh} \cdot BR_{\tau\tau}$ is 3.2%, shown in Table XI.

ILC report: arXiv:1903.01629v2

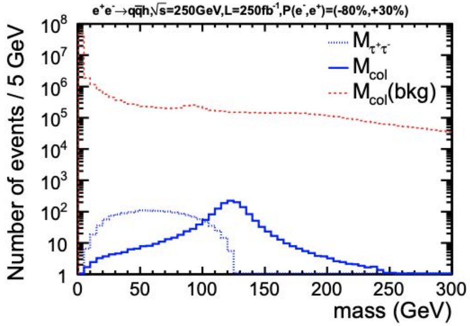


Fig. 3 Distributions of the invariant mass of the reconstructed tau lepton pairs at $\sqrt{s} = 250$ GeV for the $e^+e^- \to q\bar{q}h$ mode. $M_{\tau^+\tau^-}$ and M_{col} stand for the tau pair masses before and after the collinear approximation, respectively, for the signal. M_{col}(bkg) is the tau pair mass with the collinear approximation for the background.

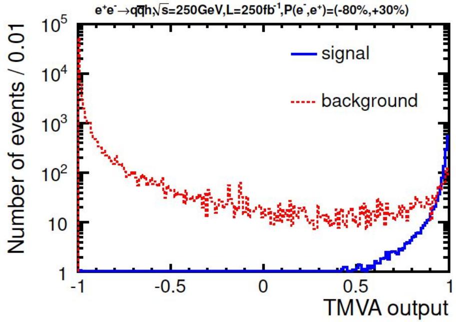


FIG. 52: MVA output for the signal $e^+e^- \to q\bar{q}h, h \to \tau^+\tau^-$ and the SM background at 250 GeV [195].

Ref 195: arxiv:1509.01885v3

Tau identification, very similar approach to this one only starting by particles, not jets

Very much dominated by stat uncertainty. MVA for analysis.