Taus

Why?

arXiv:1905.03764

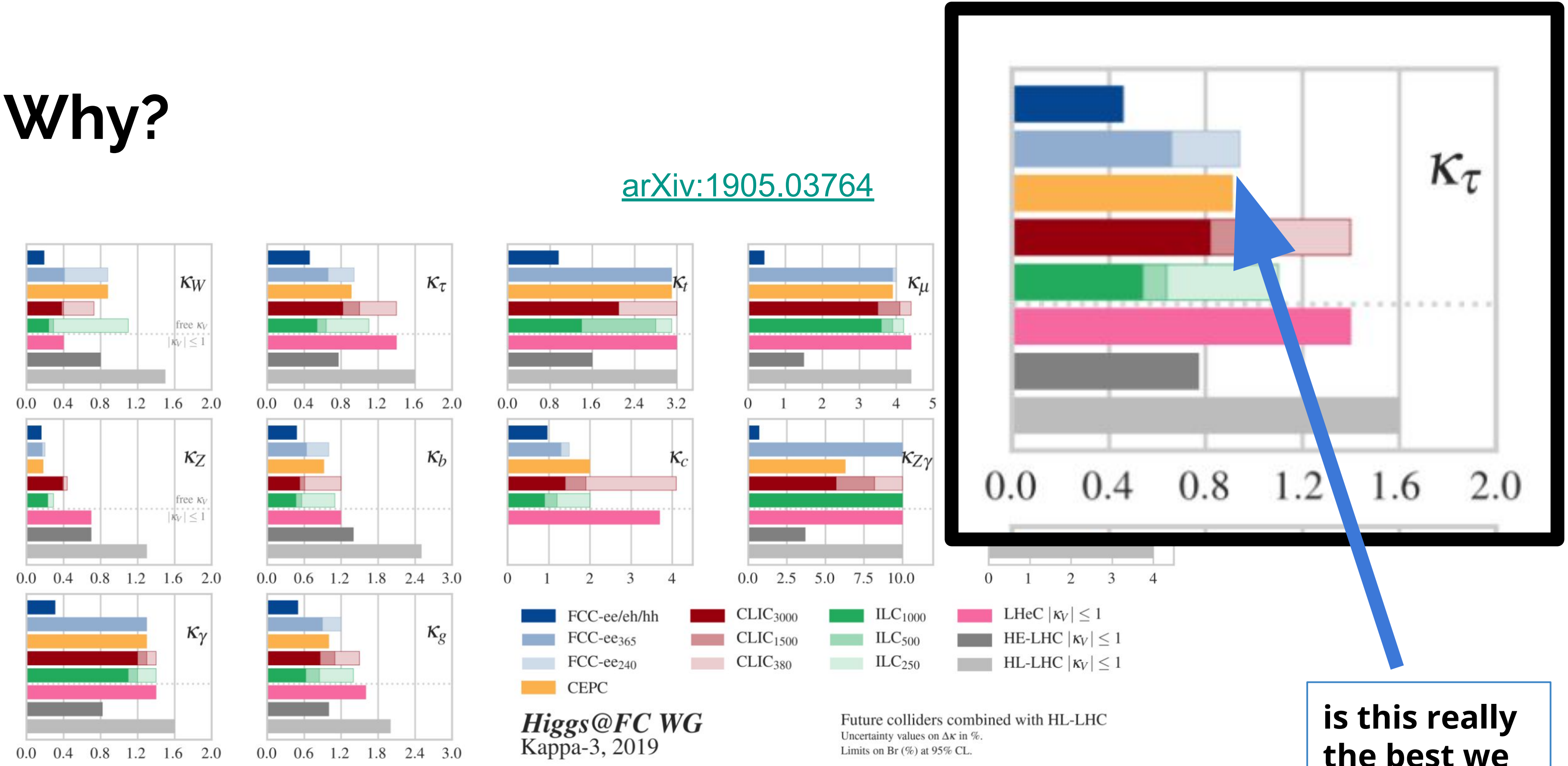
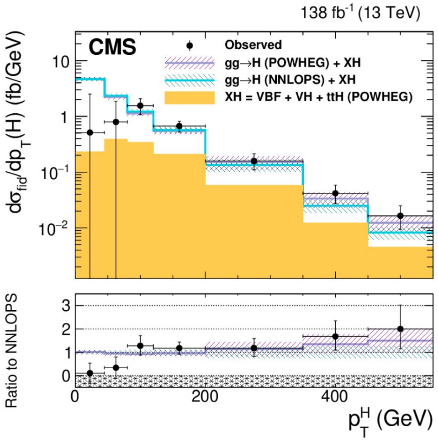


Figure 2. Expected relative precision (%) of the κ parameters in the kappa-3 scenario described in Section 2. For details, see Tables 4 and 5. For HE-LHC, the S2' scenario is displayed. For LHeC, HL-LHC and HE-LHC a constrained $\kappa_V \leq 1$ is applied.

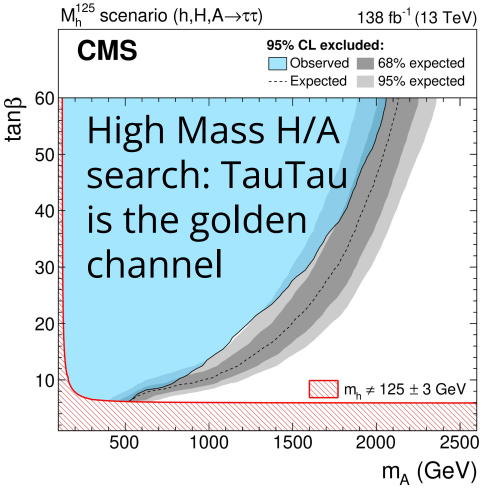
is this really the best we can do?

More reasons for studying Higgs&Taus…

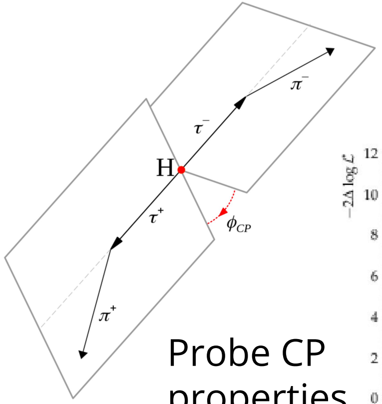
Explore Higgs production (for example: very good at high pt, VBF)

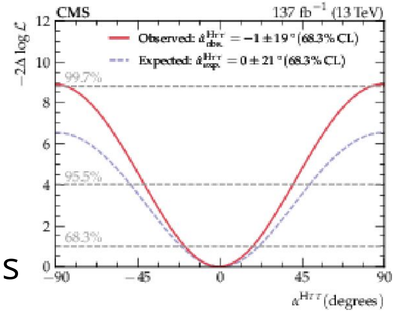


Fundamental to explore BSM Higgs (very important in 2HDM models!)

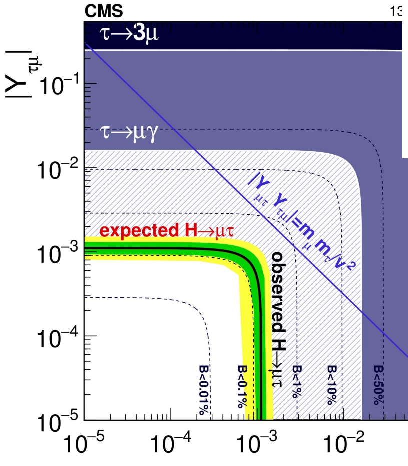


High Mass H/A search: TauTau is the golden channel





Probe CP properties



LFV searches (does the Higgs really follow the SM rules?)

HTauTau at FCCee

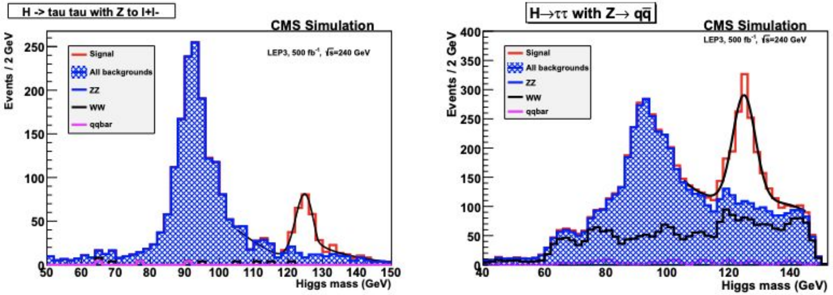
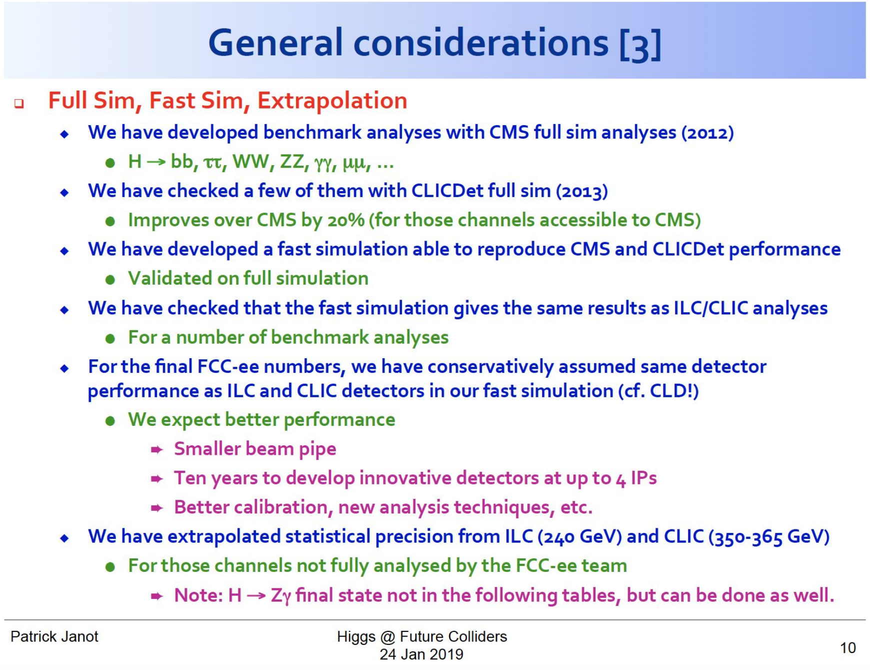


Figure 9: Distribution of the reconstructed Higgs boson mass (labelled "Higgs mass") in the ZH → $\ell^+\ell^-\tau^+\tau^-$ channel (left) and in the ZH → $q\bar{q}\tau^+\tau^-$ channel (right), for the HZ signal (hollow histogram) and all backgrounds (shaded histogram).



General considerations [3]

- Full Sim, Fast Sim, Extrapolation
  - We have developed benchmark analyses with CMS full sim analyses (2012)
    - H → bb, ττ, WW, ZZ, γγ, μμ, …
  - We have checked a few of them with CLICDet full sim (2013)
    - Improves over CMS by 20% (for those channels accessible to CMS)
  - We have developed a fast simulation able to reproduce CMS and CLICDet performance
    - Validated on full simulation
  - We have checked that the fast simulation gives the same results as ILC/CLIC analyses
    - For a number of benchmark analyses
  - For the final FCC-ee numbers, we have conservatively assumed same detector performance as ILC and CLIC detectors in our fast simulation (cf. CLD!)
    - We expect better performance
      - Smaller beam pipe
      - Ten years to develop innovative detectors at up to 4 IPs
      - Better calibration, new analysis techniques, etc.
  - We have extrapolated statistical precision from ILC (240 GeV) and CLIC (350-365 GeV)
    - For those channels not fully analysed by the FCC-ee team
      - Note: H → Zγ final state not in the following tables, but can be done as well.

Patrick Janot
Higgs @ Future Colliders
24 Jan 2019
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benchmark based on CMS (2012): https://arxiv.org/abs/1208.1662 → Referenced by the FCC CDR (https://link.springer.com/article/10.1140/epjc/s10052-019-6904-3)

Does not attempt to do full tau reconstruction. Based on LEP3. Very very old.

HTauTau at FCCee

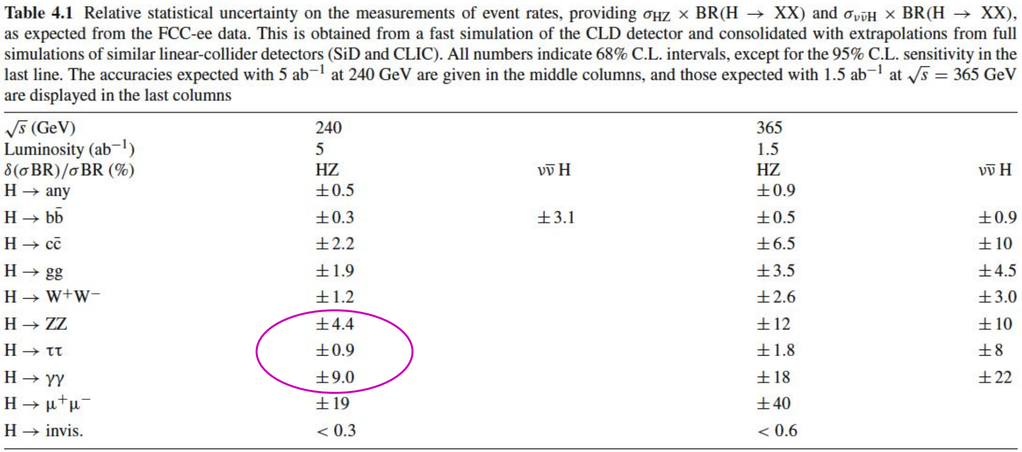

Table 4.1 Relative statistical uncertainty on the measurements of event rates, providing $\sigma_{HZ} \times BR(H \to XX)$ and $\sigma_{\nu\bar{\nu}H} \times BR(H \to XX)$, as expected from the FCC-ee data. This is obtained from a fast simulation of the CLD detector and consolidated with extrapolations from full simulations of similar linear-collider detectors (SiD and CLIC). All numbers indicate 68% C.L. intervals, except for the 95% C.L. sensitivity in the last line. The accuracies expected with 5 ab^{-1} at 240 GeV are given in the middle columns, and those expected with 1.5 ab^{-1} at $\sqrt{s} = 365$ GeV are displayed in the last columns

$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \to$ any	±0.5		±0.9	
$H \to b\bar{b}$	±0.3	±3.1	±0.5	±0.9
$H \to c\bar{c}$	±2.2		±6.5	±10
$H \to gg$	±1.9		±3.5	±4.5
$H \to W^+W^-$	±1.2		±2.6	±3.0
$H \to ZZ$	±4.4		±12	±10
$H \to \tau\tau$	±0.9		±1.8	±8
$H \to \gamma\gamma$	±9.0		±18	±22
$H \to \mu^+\mu^-$	±19		±40	
$H \to$ invis.	< 0.3		< 0.6	

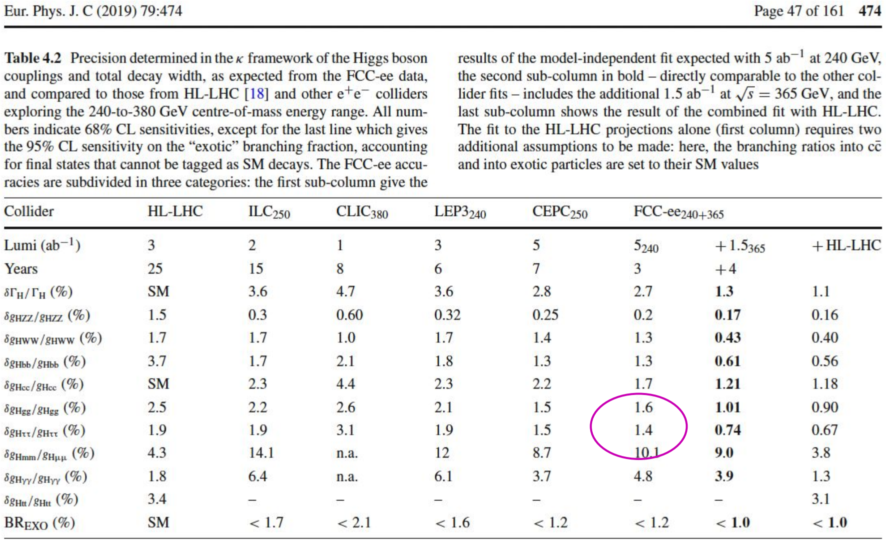

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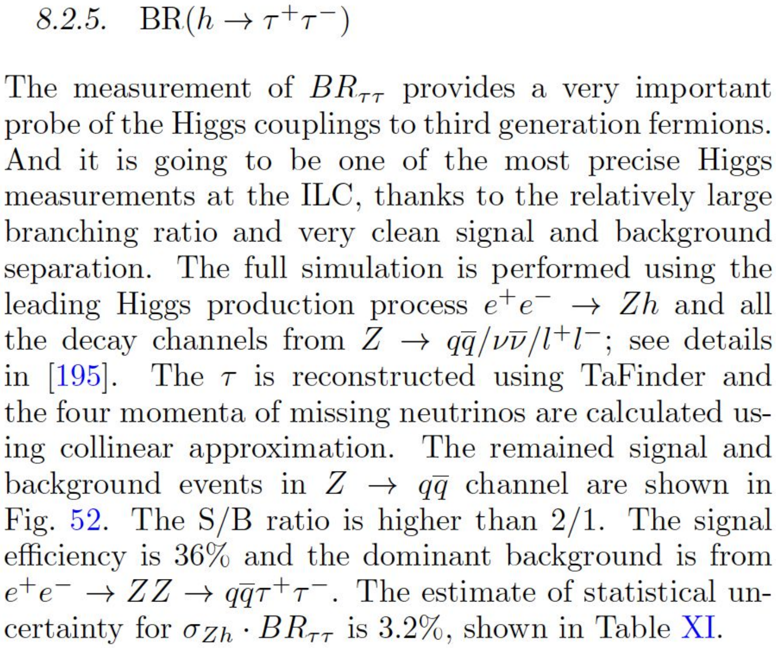
Table 4.2 Precision determined in the κ framework of the Higgs boson couplings and total decay width, as expected from the FCC-ee data, and compared to those from HL-LHC [18] and other e^+e^- colliders exploring the 240-to-380 GeV centre-of-mass energy range. All numbers indicate 68% CL sensitivities, 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-$ee_{240+365}$		
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**

HTauTau at ILC



8.2.5. 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

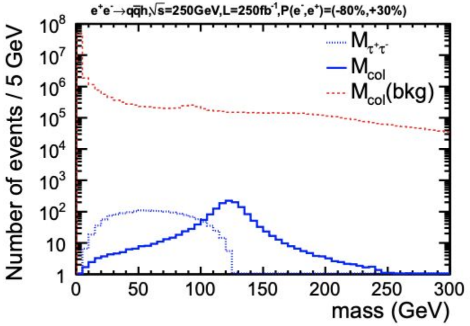


Fig. 3 Distributions of the invariant mass of the reconstructed tau lepton pairs at $\sqrt{s} = 250$ GeV for the $e^+e^- \to q\bar{q}h$ mode. $M_{\tau^+\tau^-}$ and M_{col} stand for the tau pair masses before and after the collinear approximation, respectively, for the signal. M_{col}(bkg) is the tau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

Ref 195: arxiv:1509.01885v3

proper tau identification

Very much dominated by stat uncertainty

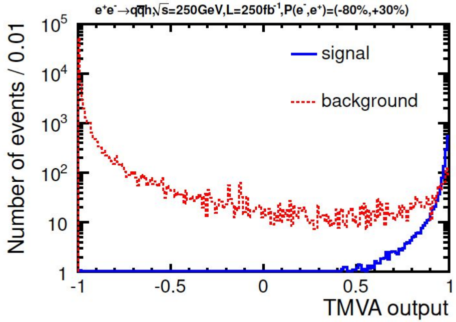
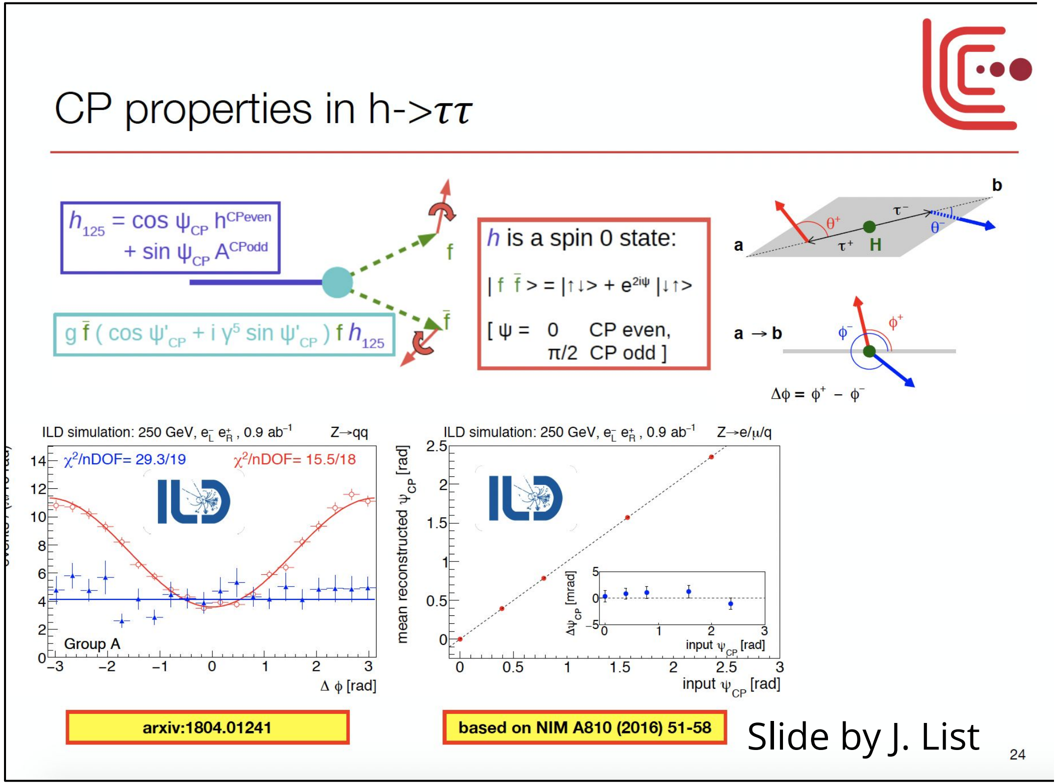


FIG. 52: MVA output for the signal $e^+e^- \to q\bar{q}h, h \to \tau^+\tau^-$ and the SM background at 250 GeV [195].

CP in HTauTau at ILC



CP properties in h->$\tau\tau$

$h_{125} = \cos\psi_{CP}\, h^{CPeven} + \sin\psi_{CP}\, A^{CPodd}$

$g\bar{f}\,(\cos\psi'_{CP} + i\gamma^5 \sin\psi'_{CP})\, f\, h_{125}$

h is a spin 0 state:

$|f\bar{f}\rangle = |\uparrow\downarrow\rangle + e^{2i\psi}|\downarrow\uparrow\rangle$

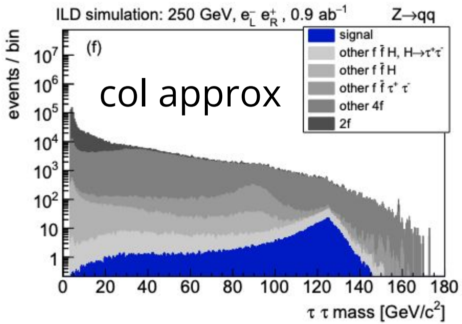
[ψ = 0 CP even,
$\pi/2$ CP odd]

$\Delta\phi = \phi^{+} - \phi^{-}$

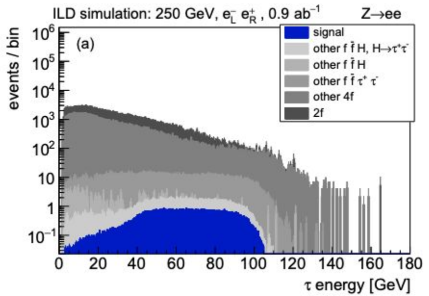
arxiv:1804.01241

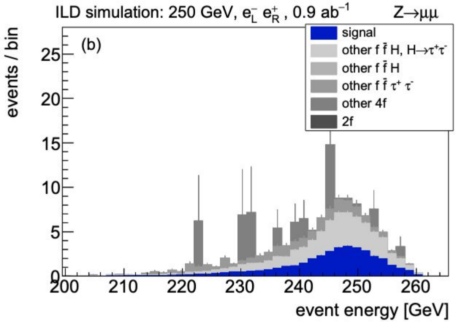
based on NIM A810 (2016) 51-58

Slide by J. List



col approx

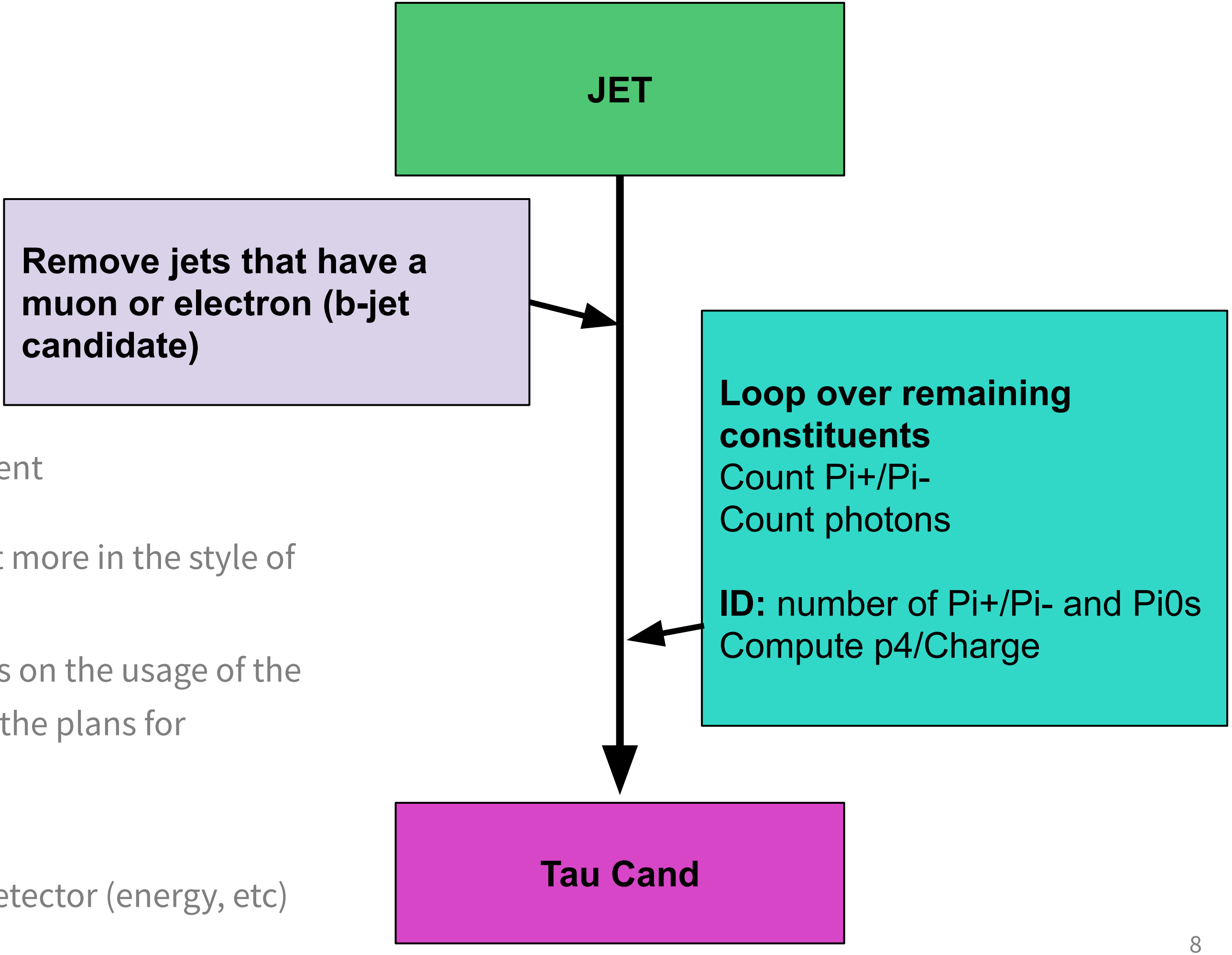




Good paper focusing on CP: arxiv:1804.01241

→ only the decay modes that allow to probe CP

Rough Tau Algo



JET

Remove jets that have a muon or electron (b-jet candidate)

Loop over remaining constituents
Count Pi+/Pi-
Count photons

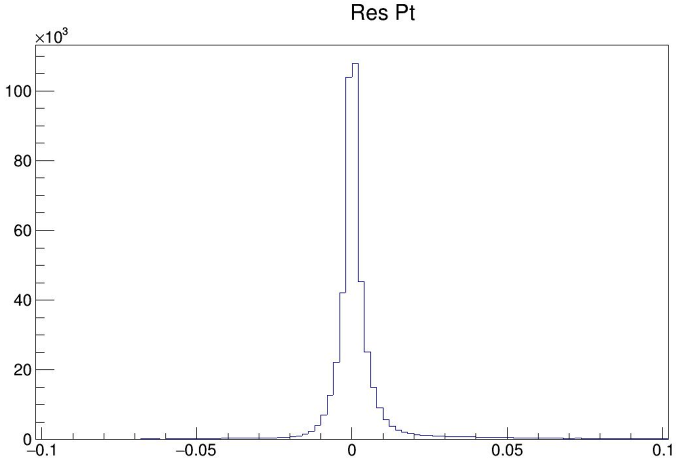
ID: number of Pi+/Pi- and Pi0s
Compute p4/Charge

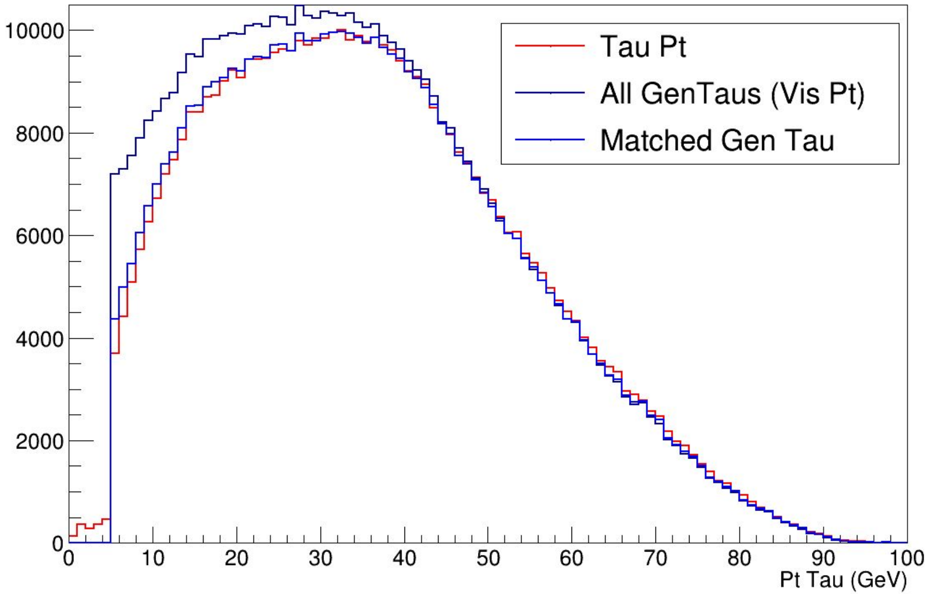
Tau Cand

Still quite a lot of room for improvement

- Clean up configuration (make it more in the style of the rest of FCCAnalysis)
- I have some technical questions on the usage of the mass to discriminate, what are the plans for particleID?
- Vertexing
- Go deeper to understand the detector (energy, etc)

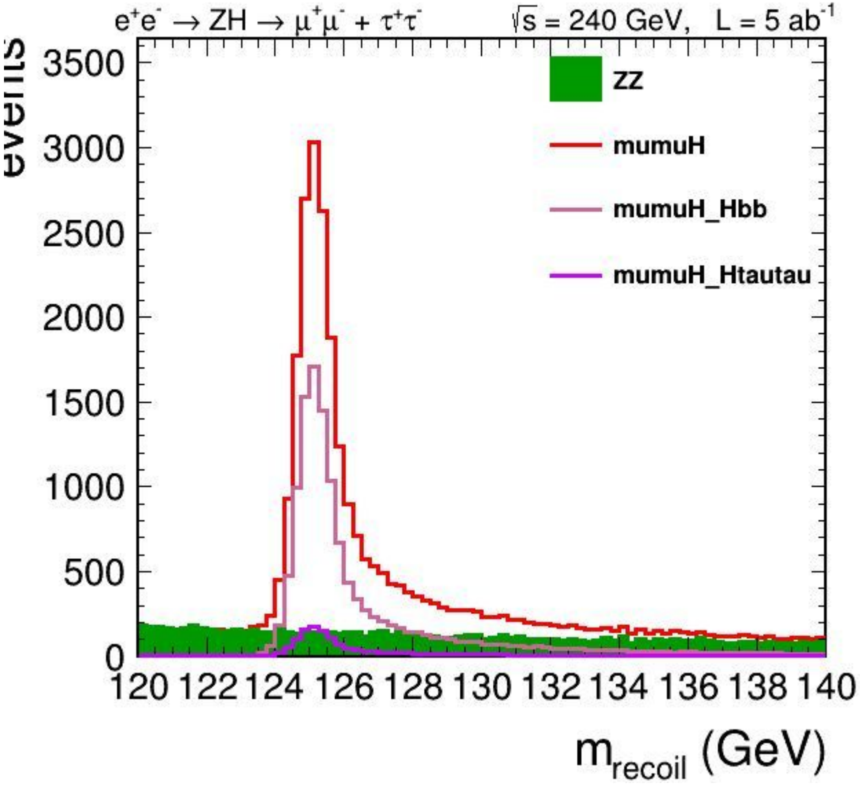
Performance





To be checked better: proper efficiencies, etc

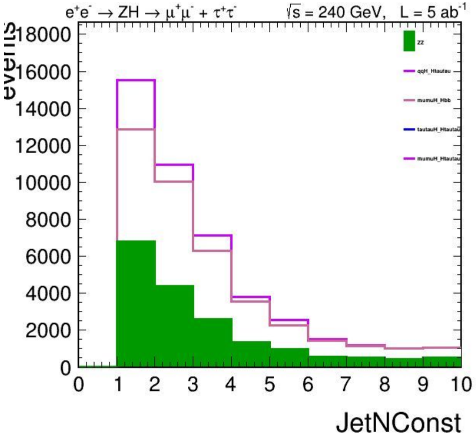
MuMuH + X (Winter23)

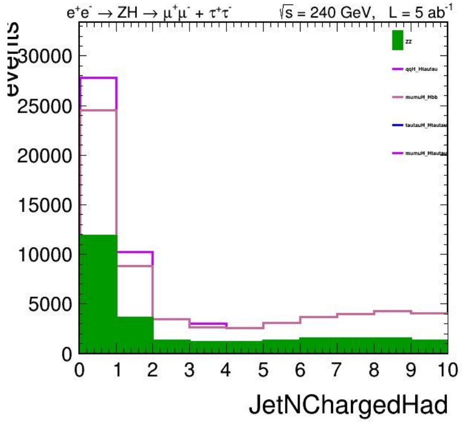


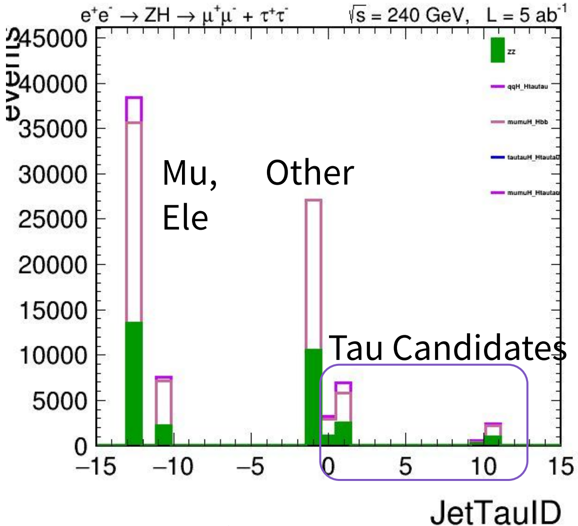
YIELDS (from Recoil_mass)
... p8_ee_ZZ_ecm240_newtau2 9514
... wzp6_ee_mumuH_ecm240_newtau2 20734
... wzp6_ee_mumuH_Hbb_ecm240_newtau2 12299
... wzp6_ee_mumuH_Htautau_ecm240_newtau2 1336

After careful checking, the Br are wrong for the 'inclusive' sample: we can only look at the exclusive modes

MuMuH + Jets (Winter23)





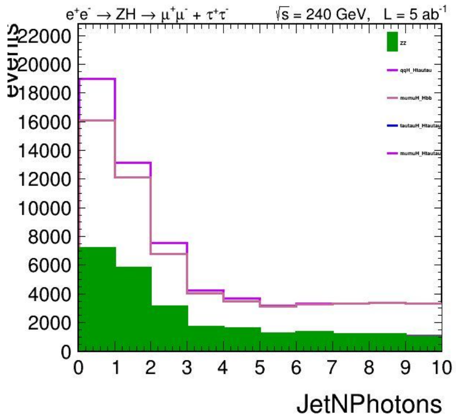


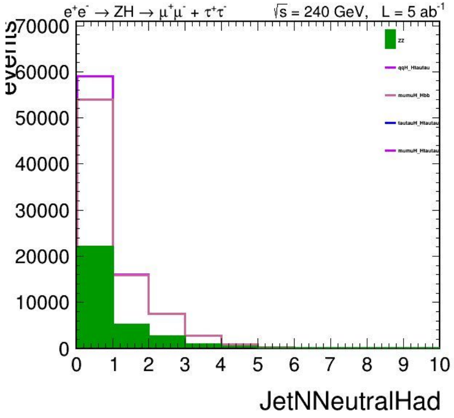
Mu, Ele

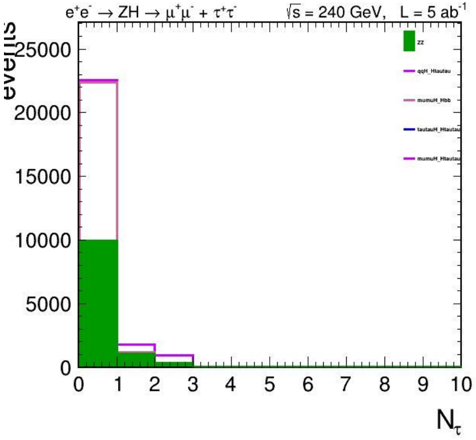
Other

Tau Candidates

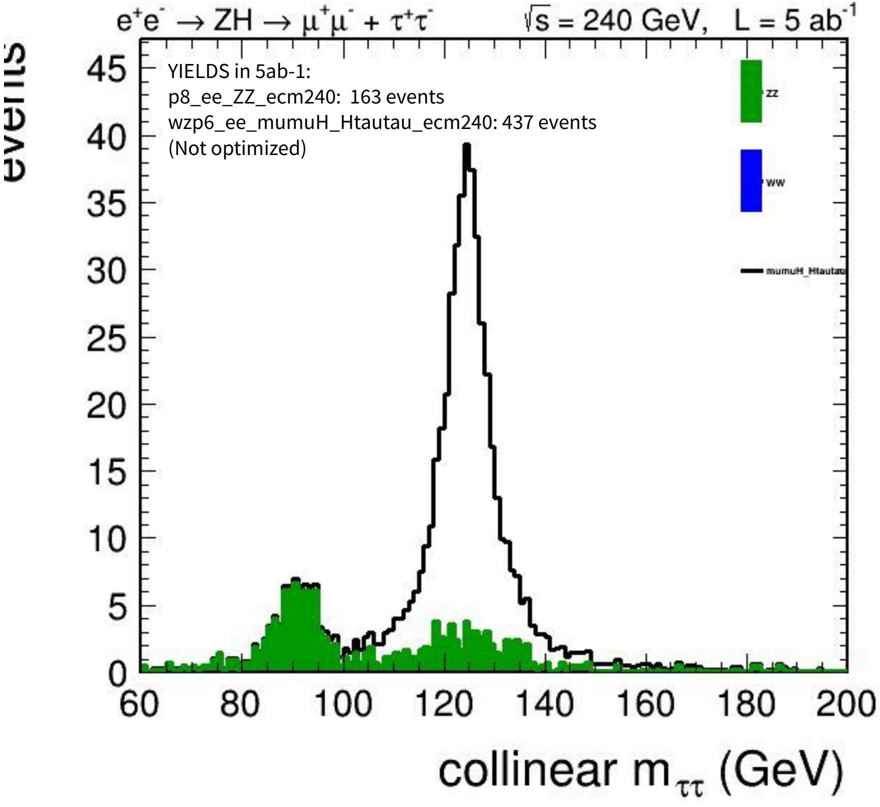
(ee_kt, 4 exclusive jets)



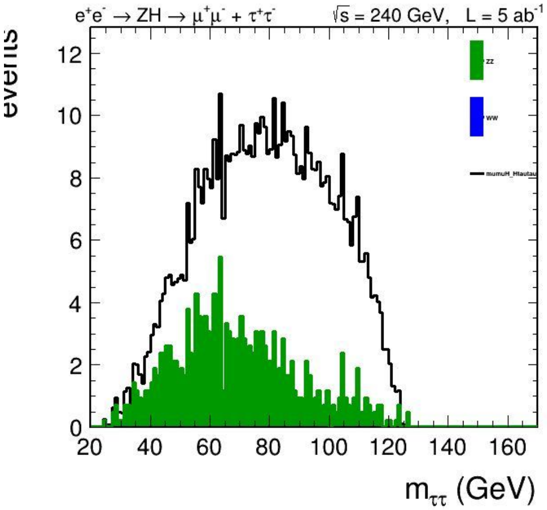


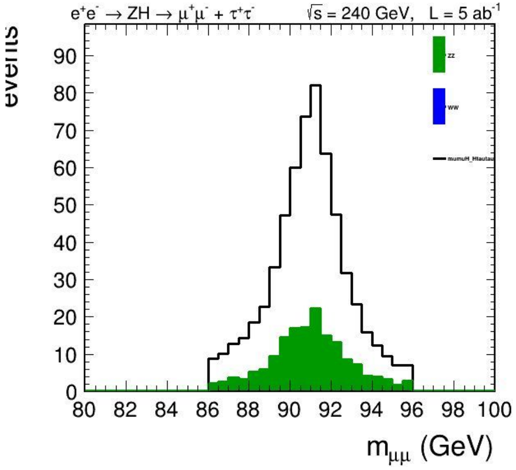


MuMu+Tau$_h$Tau$_h$ (Winter23)

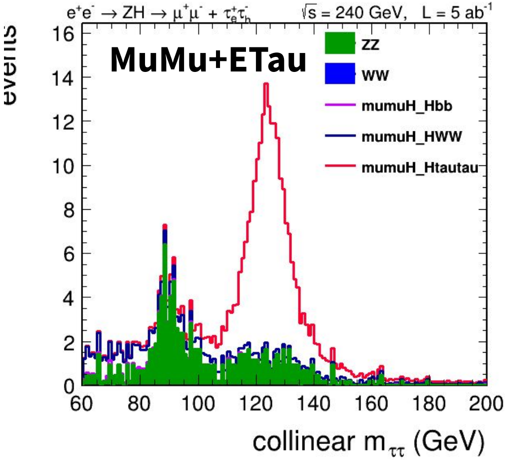


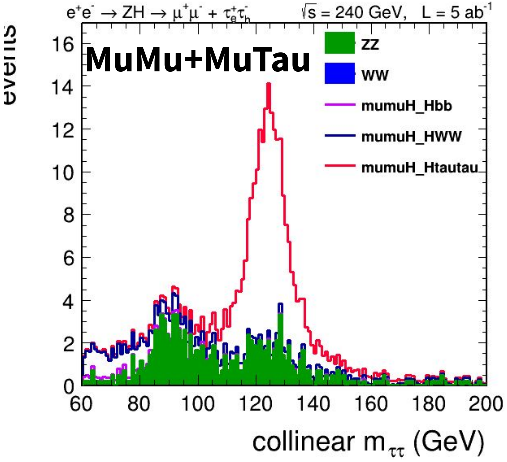
YIELDS in 5ab-1:
p8_ee_ZZ_ecm240: 163 events
wzp6_ee_mumuH_Htautau_ecm240: 437 events
(Not optimized)

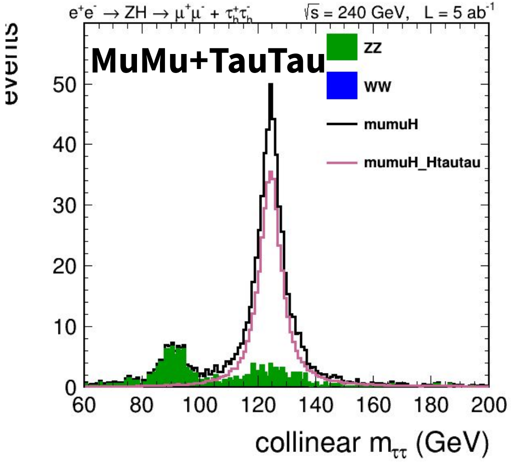




mumuH, HTauTau: Comparison of channels





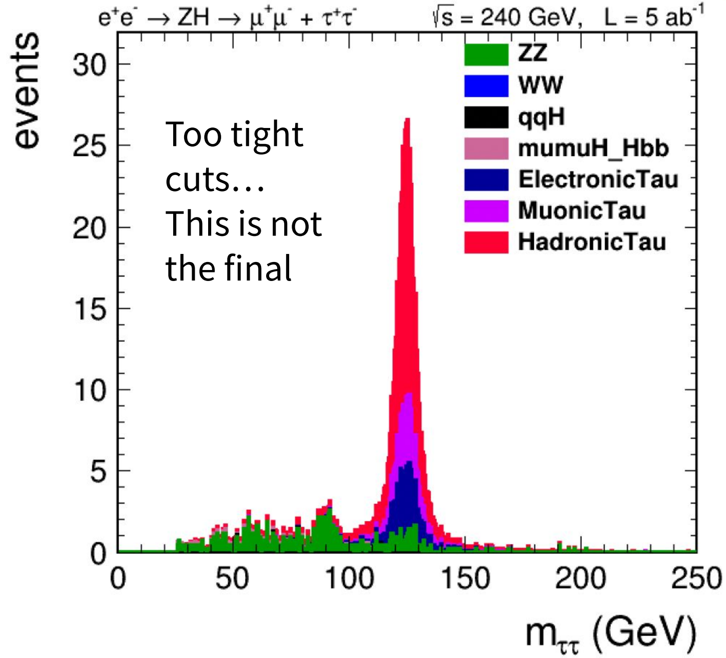


	TauTau	MuTau	ETau	All
Signal	437	208	207	852

Playing with the selection to check whether looser or tighter is better
Assuming we can extract the signal cleanly, ignoring bg uncertainty.

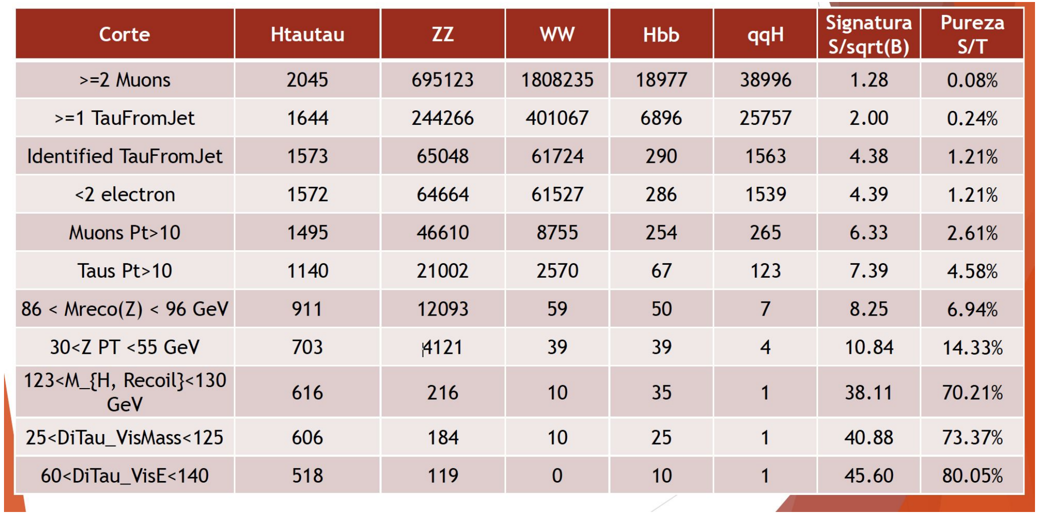
Izan - Master Thesis

$H \rightarrow \tau_h \tau_h,\ H \rightarrow \tau_h \tau_e,\ H \rightarrow \tau_h \tau_\mu$



Too tight cuts…
This is not the final

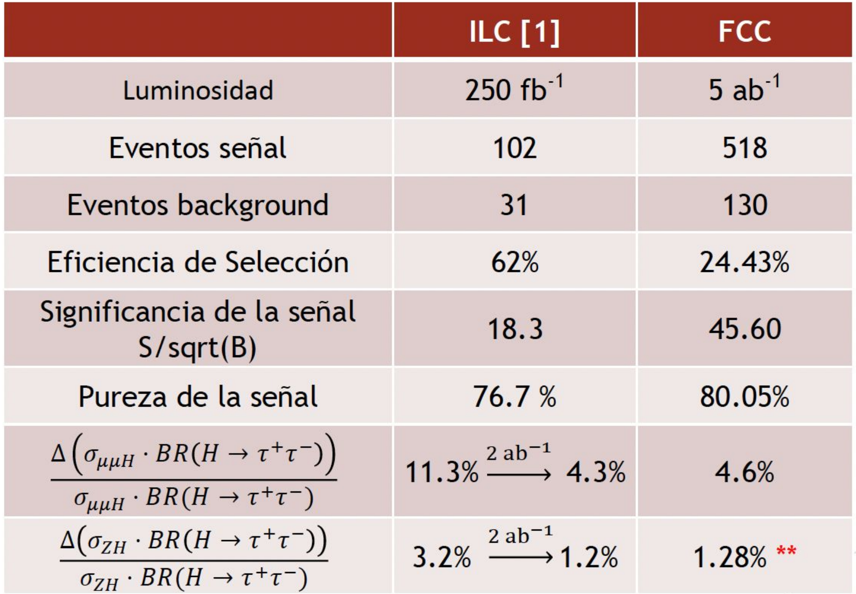
Too tight cuts… I have significatively more signal than he does, will give him feedback on this



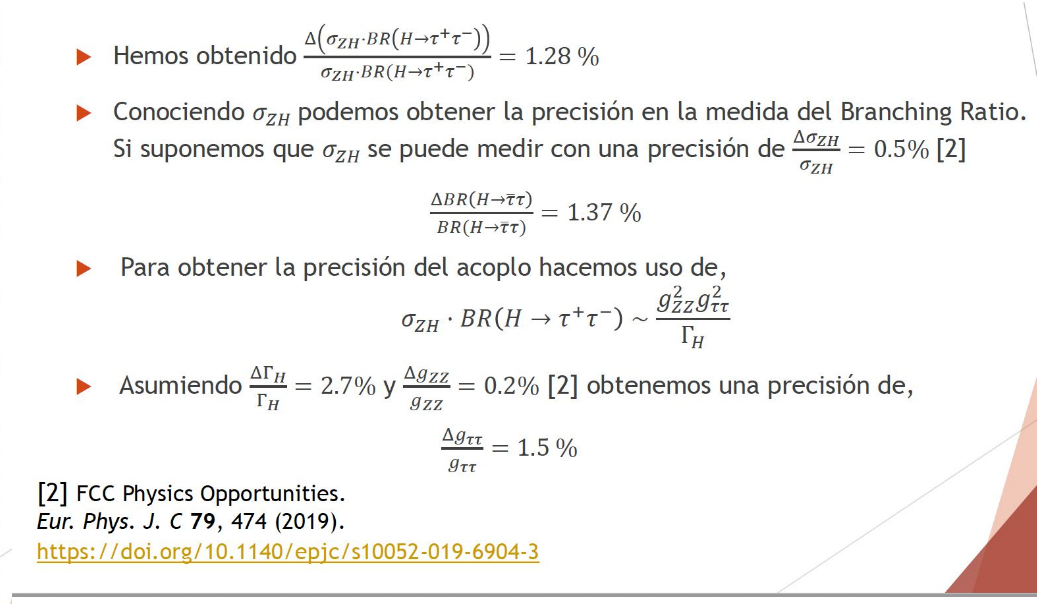
Corte	Htautau	ZZ	WW	Hbb	qqH	Signatura S/sqrt(B)	Pureza S/T
>=2 Muons	2045	695123	1808235	18977	38996	1.28	0.08%
>=1 TauFromJet	1644	244266	401067	6896	25757	2.00	0.24%
Identified TauFromJet	1573	65048	61724	290	1563	4.38	1.21%
<2 electron	1572	64664	61527	286	1539	4.39	1.21%
Muons Pt>10	1495	46610	8755	254	265	6.33	2.61%
Taus Pt>10	1140	21002	2570	67	123	7.39	4.58%
86 < Mreco(Z) < 96 GeV	911	12093	59	50	7	8.25	6.94%
30<Z PT <55 GeV	703	4121	39	39	4	10.84	14.33%
123<M_{H, Recoil}<130 GeV	616	216	10	35	1	38.11	70.21%
25<DiTau_VisMass<125	606	184	10	25	1	40.88	73.37%
60<DiTau_VisE<140	518	119	0	10	1	45.60	80.05%

Izan - Master Thesis

Too tight cuts… This is not the final



	ILC [1]	FCC
Luminosidad	250 fb^{-1}	5 ab^{-1}
Eventos señal	102	518
Eventos background	31	130
Eficiencia de Selección	62%	24.43%
Significancia de la señal S/sqrt(B)	18.3	45.60
Pureza de la señal	76.7 %	80.05%
$\frac{\Delta\left(\sigma_{\mu\mu H}\cdot BR(H\to\tau^+\tau^-)\right)}{\sigma_{\mu\mu H}\cdot BR(H\to\tau^+\tau^-)}$	$11.3\% \xrightarrow{2\ \mathrm{ab}^{-1}} 4.3\%$	4.6%
$\frac{\Delta\left(\sigma_{ZH}\cdot BR(H\to\tau^+\tau^-)\right)}{\sigma_{ZH}\cdot BR(H\to\tau^+\tau^-)}$	$3.2\% \xrightarrow{2\ \mathrm{ab}^{-1}} 1.2\%$	1.28% **



- Hemos obtenido $\frac{\Delta\left(\sigma_{ZH}\cdot BR(H\to\tau^+\tau^-)\right)}{\sigma_{ZH}\cdot BR(H\to\tau^+\tau^-)} = 1.28\ \%$
- Conociendo σ_{ZH} podemos obtener la precisión en la medida del Branching Ratio. Si suponemos que σ_{ZH} se puede medir con una precisión de $\frac{\Delta\sigma_{ZH}}{\sigma_{ZH}} = 0.5\%$ [2]

$$\frac{\Delta BR(H\to\bar{\tau}\tau)}{BR(H\to\bar{\tau}\tau)} = 1.37\ \%$$

- Para obtener la precisión del acoplo hacemos uso de,

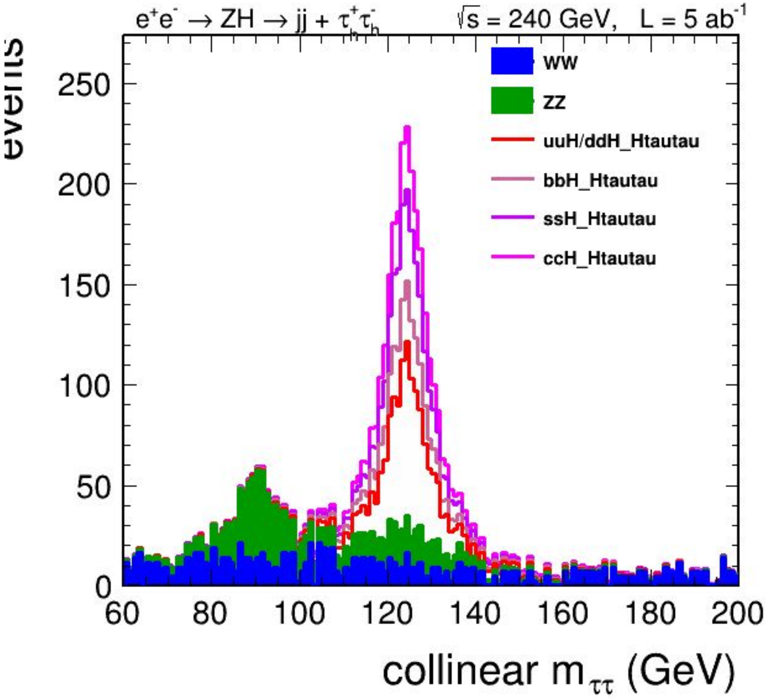
$$\sigma_{ZH}\cdot BR(H\to\tau^+\tau^-)\sim\frac{g_{ZZ}^2 g_{\tau\tau}^2}{\Gamma_H}$$

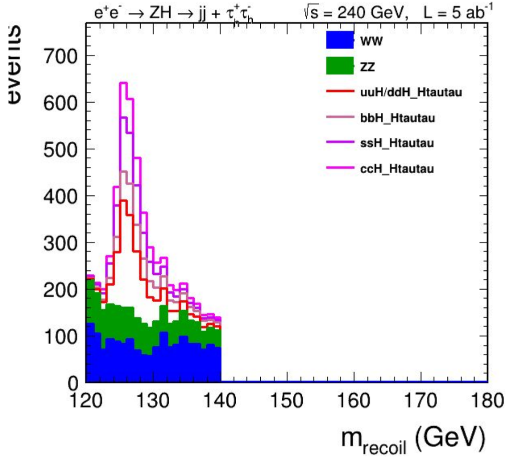
- Asumiendo $\frac{\Delta\Gamma_H}{\Gamma_H} = 2.7\%$ y $\frac{\Delta g_{ZZ}}{g_{ZZ}} = 0.2\%$ [2] obtenemos una precisión de,

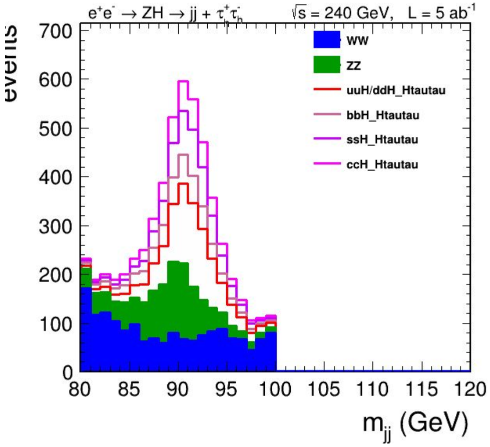
$$\frac{\Delta g_{\tau\tau}}{g_{\tau\tau}} = 1.5\ \%$$

[2] FCC Physics Opportunities.
Eur. Phys. J. C **79**, 474 (2019).
https://doi.org/10.1140/epjc/s10052-019-6904-3

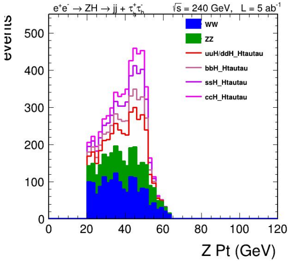
QQ + TauTau: Harder to select

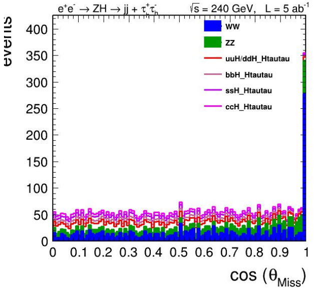


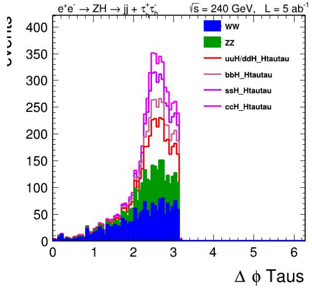




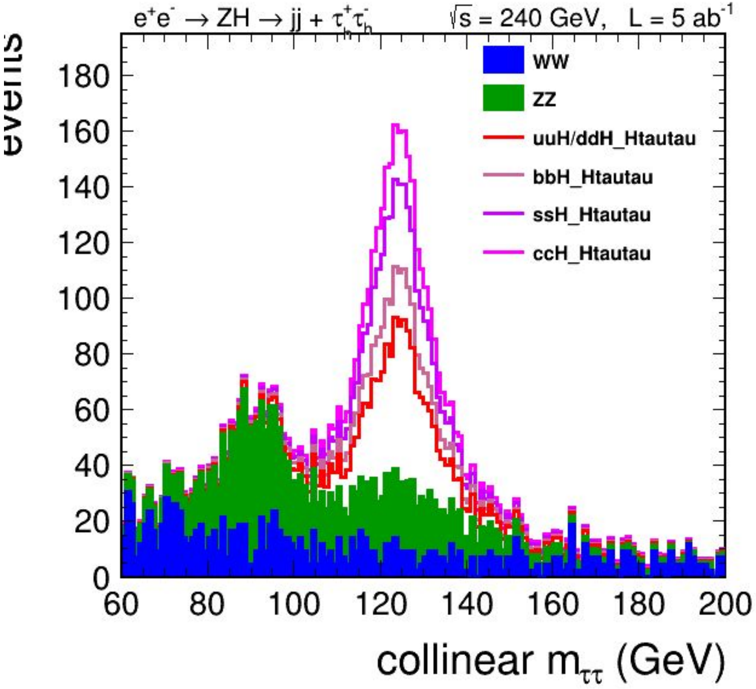
bad acceptance. 2673 signal events out of ~17990 possible .

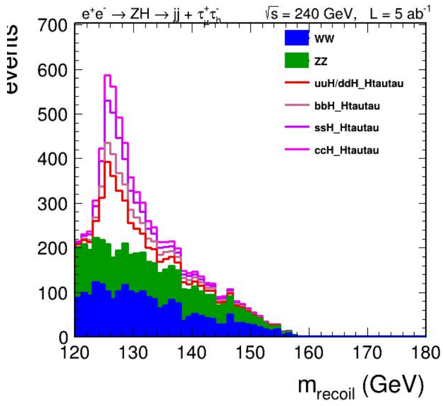


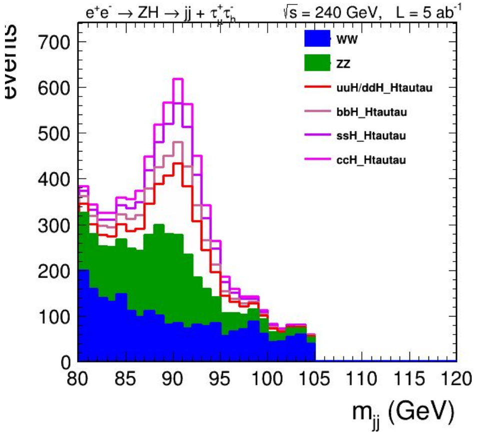


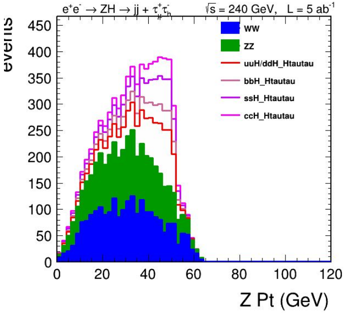


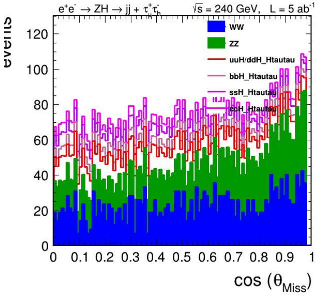
QQ + MuTau: Trying a looser selection?

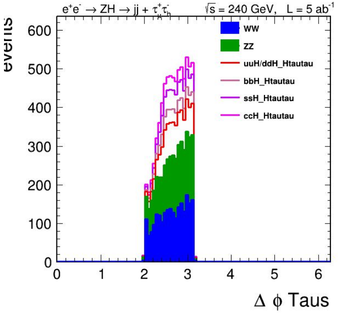












Slightly different (looser) selection. much more bg. ~2800 events out of ~10000 possible

Acc Numbers

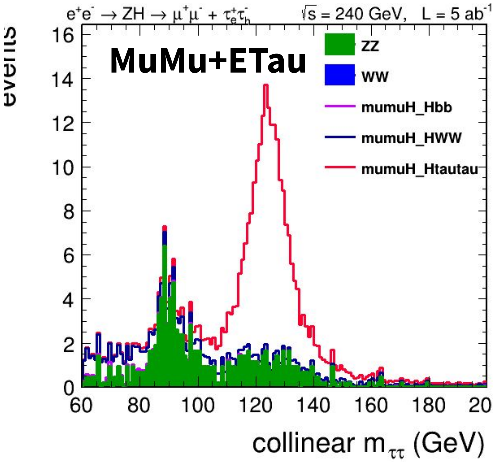
QQTauTau

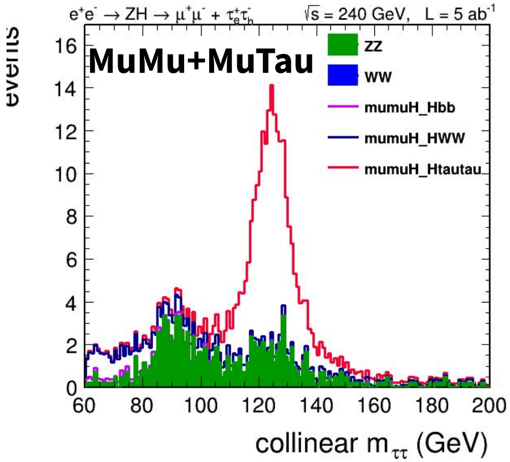
```
CutFlow for process wzp6_ee_uuHorddH_Htautau_ecm240
No Muons  : pass=158281     all=200000     -- eff=79.14 % cumulative eff=79.14 %
No Electrons: pass=120576     all=158281     -- eff=76.18 % cumulative eff=60.29 %
Events with exactly two taus: pass=57841      all=120576     -- eff=47.97 % cumulative eff=28.92 %
Tau Pt>10 GeV: pass=46836      all=57841      -- eff=80.97 % cumulative eff=23.42 %
Identified Taus: pass=42892      all=46836      -- eff=91.58 % cumulative eff=21.45 %
Tau mass < 2 GeV: pass=36546      all=42892      -- eff=85.20 % cumulative eff=18.27 %
Taus with opposite charge: pass=34102      all=36546      -- eff=93.31 % cumulative eff=17.05 %
DiTauMass > 40 GeV: pass=32751      all=34102      -- eff=96.04 % cumulative eff=16.38 %
Two jets  : pass=22589      all=32751      -- eff=68.97 % cumulative eff=11.29 %
Jet Pt>20 : pass=19887      all=22589      -- eff=88.04 % cumulative eff=9.94 %
80 < Mreco(diJet) < 100 GeV: pass=16152      all=19887      -- eff=81.22 % cumulative eff=8.08 %
20 < Pt(DiJet) < 70 GeV: pass=14304      all=16152      -- eff=88.56 % cumulative eff=7.15 %
120<Recoil<140 GeV: pass=13539      all=14304      -- eff=94.65 % cumulative eff=6.77 %
```

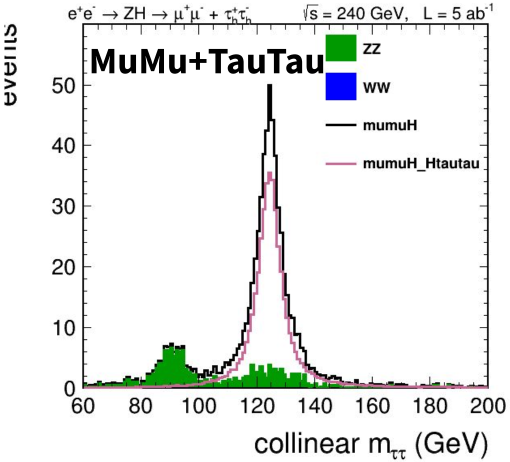
QQMuTau

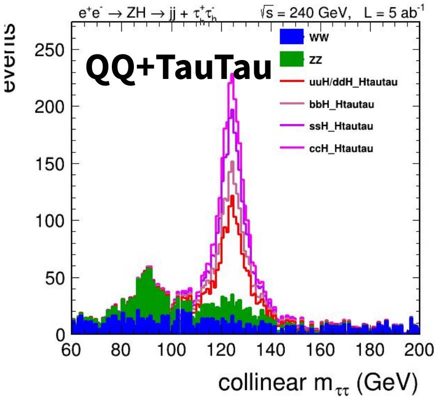
```
CutFlow for process wzp6_ee_uuHorddH_Htautau_ecm240
Events with at least one tau: pass=174560     all=200000     -- eff=87.28 % cumulative eff=87.28 %
No Electrons with more than 5 GeV: pass=134028     all=174560     -- eff=76.78 % cumulative eff=67.01 %
At least one muon with 5 GeV: pass=35215      all=134028     -- eff=26.27 % cumulative eff=17.61 %
Tau Pt>10 GeV: pass=30900      all=35215      -- eff=87.75 % cumulative eff=15.45 %
Identified Taus: pass=28414      all=30900      -- eff=91.95 % cumulative eff=14.21 %
Tau mass < 2 GeV: pass=25022      all=28414      -- eff=88.06 % cumulative eff=12.51 %
Muon Pt>5 GeV: pass=25022      all=25022      -- eff=100.00 % cumulative eff=12.51 %
DPhiTaus>2: pass=22067      all=25022      -- eff=88.19 % cumulative eff=11.03 %
Taus with opposite charge: pass=21445      all=22067      -- eff=97.18 % cumulative eff=10.72 %
Missing_costheta<0.98: pass=21135      all=21445      -- eff=98.55 % cumulative eff=10.57 %
Two jets  : pass=17072      all=21135      -- eff=80.78 % cumulative eff=8.54 %
Jet Pt>15 : pass=17072      all=17072      -- eff=100.00 % cumulative eff=8.54 %
80 < Mreco(diJet) < 105 GeV: pass=14519      all=17072      -- eff=85.05 % cumulative eff=7.26 %
120<Recoil<160 GeV: pass=14276      all=14519      -- eff=98.33 % cumulative eff=7.14 %
```

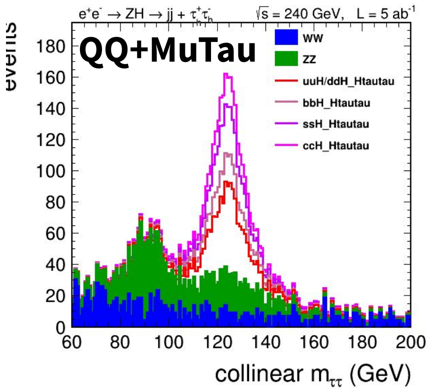
Status: ZH, HTauTau: Comparison of channels











Playing with the selection to check whether looser or tighter is better

Summary of channels: looser selection

Rough yields for signal (depends on how tight the selection is)

	TauTau	MuTau	ETau	HTauTau
QQ	2673	2797 (very loose)	~2700?	~8000 ?
MuMu	437	208	207	852 ?
EE ?				~850 ?

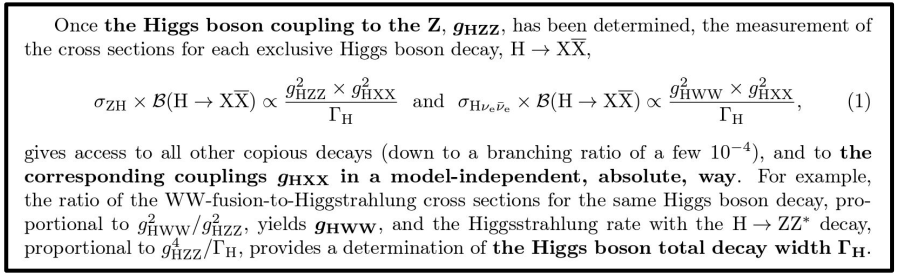
Assuming only stat uncertainty on the signal (no bg uncertainty, no syst): ~>9000 events in 5ab-1 → 1.% uncertainty on sigma*Br

Assuming two experiments, 0.74% on sigma*Br . In FCCee CDR : 0.9%

Can we do better? Polish selection! The acceptance I have for MuMuH is ~OK. The one I have for QQH is rather bad (the cuts are tighter! including the Jet ones). The tau reco efficiency is reasonable (could be improved, but, that is not the problem). Note that ILC uses a BDT and has much better acceptance in the end.

Estimation of uncertainties on gtautau?

Assuming only stat uncertainty on the signal (no bg uncertainty, no syst): ~>9000 events in 5ab-1 → 1.% uncertainty on sigma*Br . **Assuming two experiments, 0.74% on sigma*Br**



Once **the Higgs boson coupling to the Z, $g_{\mathbf{HZZ}}$**, has been determined, the measurement of the cross sections for each exclusive Higgs boson decay, $\mathrm{H} \to \mathrm{X\overline{X}}$,

$$\sigma_{\mathrm{ZH}} \times \mathcal{B}(\mathrm{H} \to \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HZZ}} \times g^2_{\mathrm{HXX}}}{\Gamma_{\mathrm{H}}} \quad \text{and} \quad \sigma_{\mathrm{H}\nu_e\bar{\nu}_e} \times \mathcal{B}(\mathrm{H} \to \mathrm{X\overline{X}}) \propto \frac{g^2_{\mathrm{HWW}} \times g^2_{\mathrm{HXX}}}{\Gamma_{\mathrm{H}}}, \qquad (1)$$

gives access to all other copious decays (down to a branching ratio of a few 10^{-4}), and to **the corresponding couplings $g_{\mathbf{HXX}}$ in a model-independent, absolute, way**. For example, the ratio of the WW-fusion-to-Higgsstrahlung cross sections for the same Higgs boson decay, proportional to $g^2_{\mathrm{HWW}}/g^2_{\mathrm{HZZ}}$, yields $g_{\mathbf{HWW}}$, and the Higgsstrahlung rate with the $\mathrm{H} \to \mathrm{ZZ}^*$ decay, proportional to $g^4_{\mathrm{HZZ}}/\Gamma_{\mathrm{H}}$, provides a determination of **the Higgs boson total decay width $\mathbf{\Gamma_H}$**.

(snapshot from the Snowmass FCC submission)

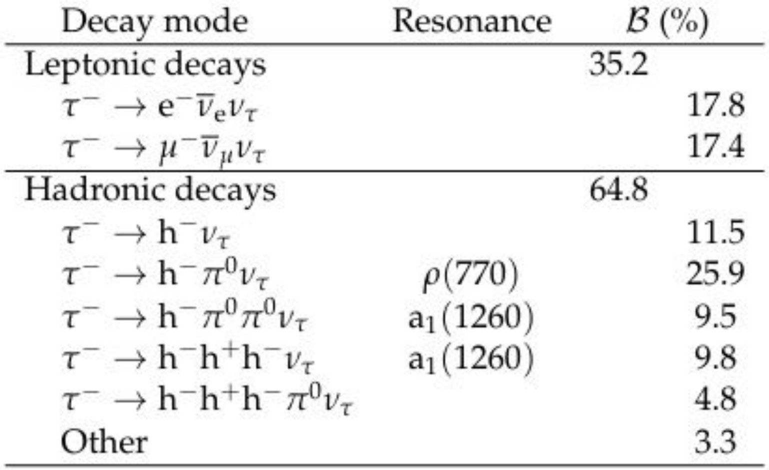
1.4% on the gtautau coupling (assuming 2.7% uncertainty on width and 0.2% on gzz). This is the same as the official FCC numbers.

Note that in the end the 2.7% from the width dominates for the coupling: with the 'ultimate' 1% width → ~0.7% for gtautau

Older

Proposal for tau reconstruction developments

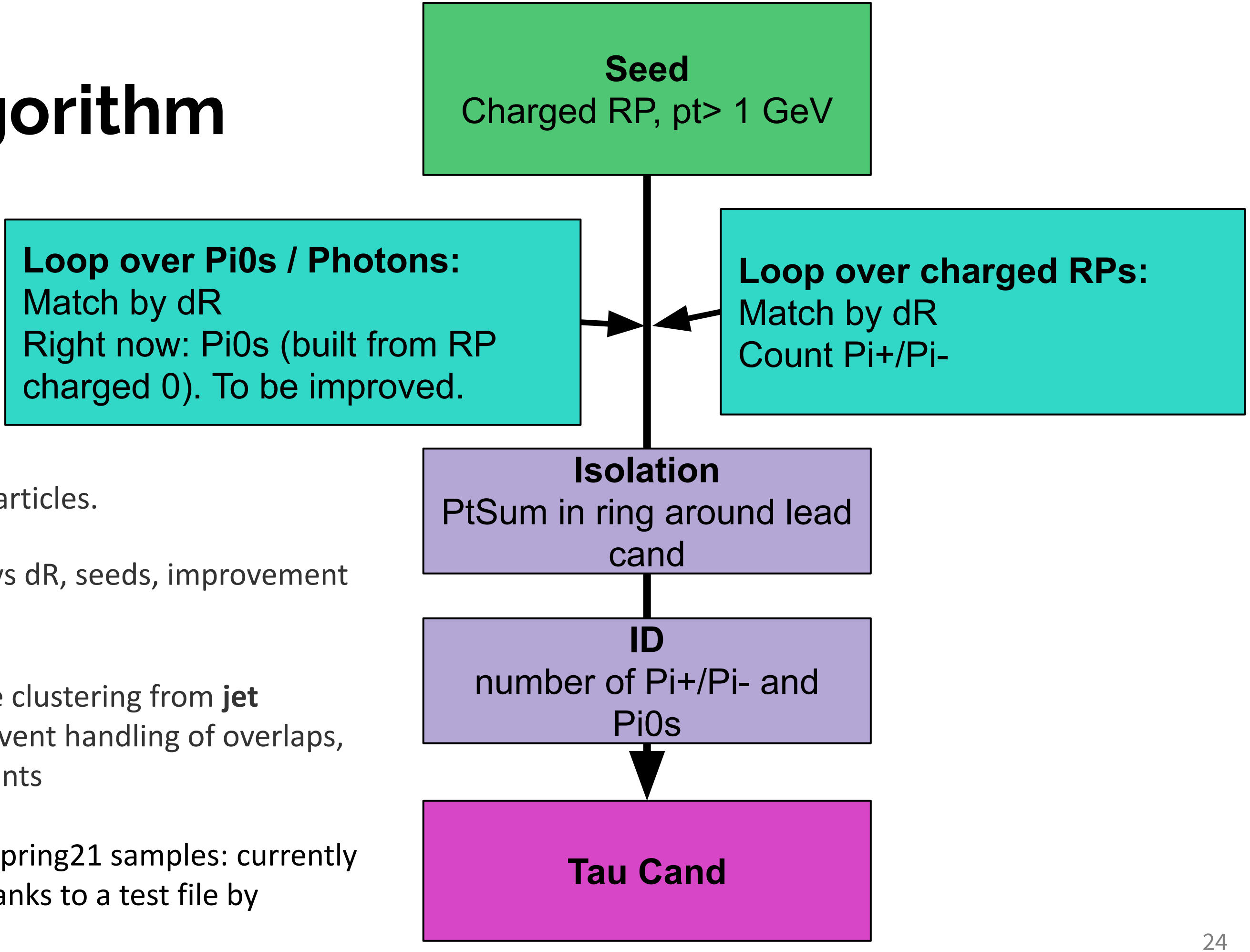
- Developing a decay-mode based tau algorithm as a tool that can be used for a variety of physics studies
  - Similar idea as the 3Prong example already in the framework, targeting 1Prong/3Prongs simultaneously
- Very simple approach that follows what has been done in LEP/LHC and also rather similar 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, moving to qqtautau) → [master thesis in progress (Izan Fernández Tostado)]
- 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	
$\tau^- \rightarrow e^- \overline{\nu}_e \nu_\tau$			17.8
$\tau^- \rightarrow \mu^- \overline{\nu}_\mu \nu_\tau$			17.4
Hadronic decays		64.8	
$\tau^- \rightarrow h^- \nu_\tau$			11.5
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho(770)$		25.9
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$		9.5
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1(1260)$		9.8
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.8
Other			3.3

Important note: all of this is work in progress, extremely preliminary!

OLD (naive) algorithm



Seed
Charged RP, pt> 1 GeV

Loop over Pi0s / Photons:
Match by dR
Right now: Pi0s (built from RP charged 0). To be improved.

Loop over charged RPs:
Match by dR
Count Pi+/Pi-

Isolation
PtSum in ring around lead cand

ID
number of Pi+/Pi- and Pi0s

Tau Cand

Simple DM finding starting from RecoParticles.

Configuration to be tuned (eg: dTheta vs dR, seeds, improvement of the pi0s/photons, etc)

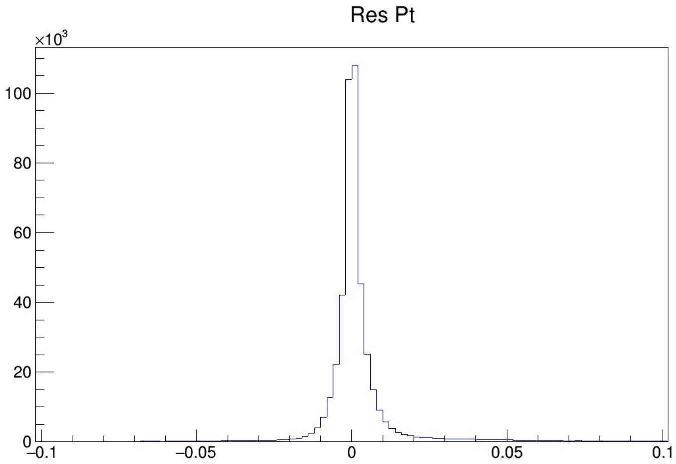
In a next step, we will move to start the clustering from **jet constituents** for simplicity and better event handling of overlaps, and to benefit from parallel developments

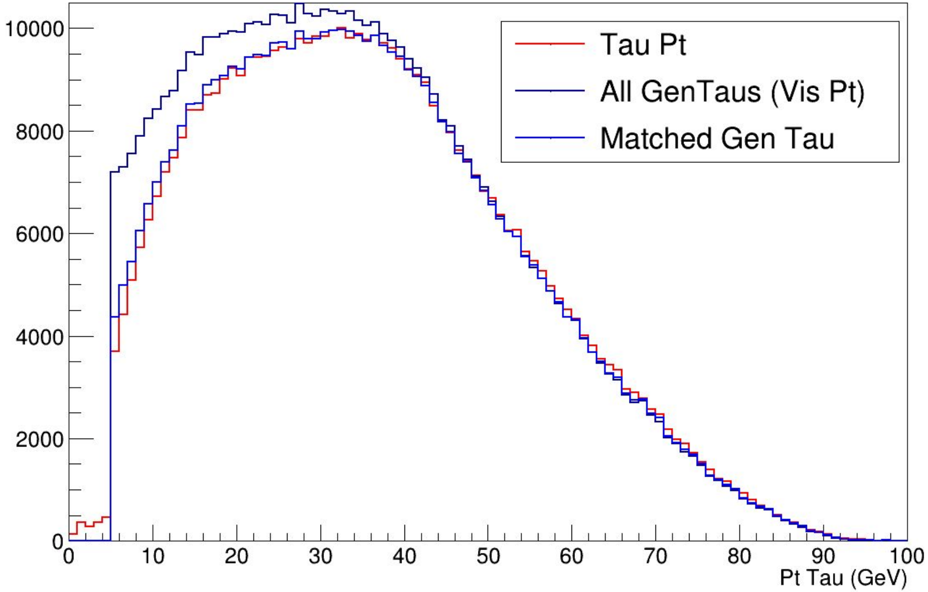
So far, all the development done with Spring21 samples: currently moving to the winter23 production (thanks to a test file by Michele)

Updates to last presentation

- As promised, reconstruction now starts from Jets (based on the weaver configuration, using the particle ID developed for the tagger)
  - Note: rebuilding the jets (ee_kt, 4 exclusive jets), since what I use as benchmark is ZH. The ‘standard’ ee_genkt 1.5 jets do not work for this (too wide)
- Reconstruction flow changed to start by rejectings jets that contain muons and electrons (as opposed to removing the muons/electrons from the calculation)
  - This makes the former “isolation” cut that I had redundant, since what I had was contamination from b-jets
- Now using consistently Winter23 samples

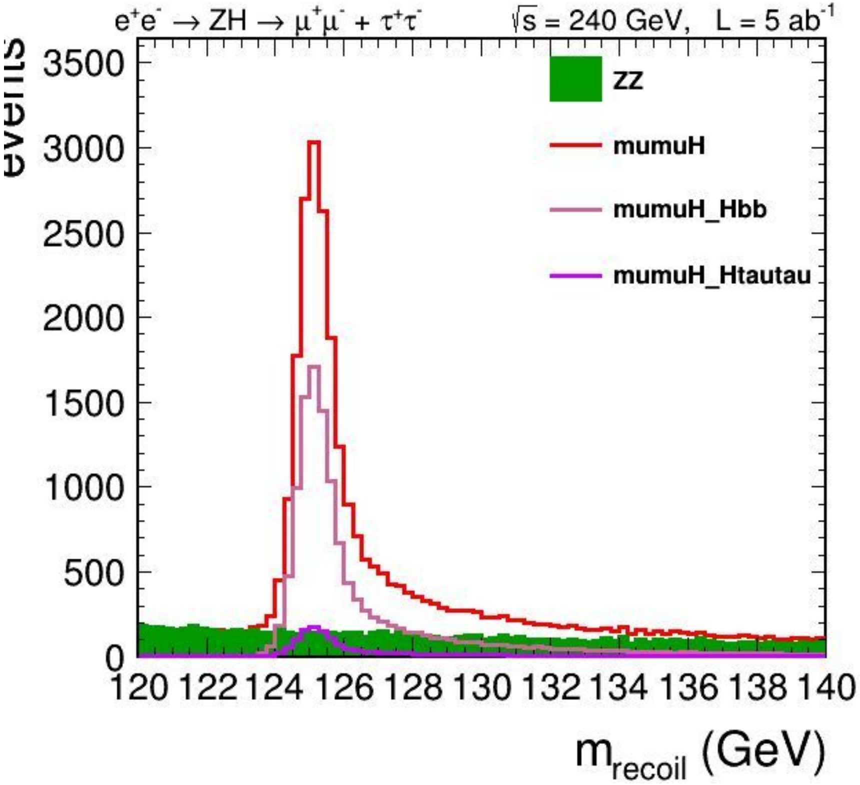
Performance





To be checked: which ones do I lose?

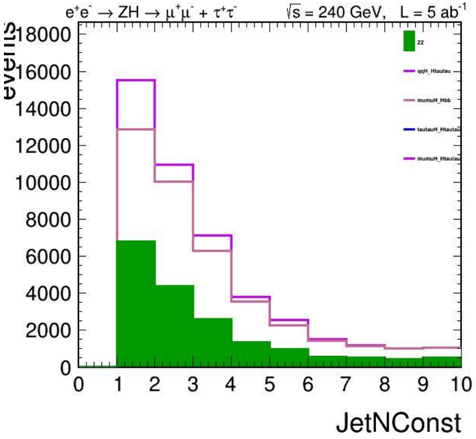
MuMuH + X (Winter23)

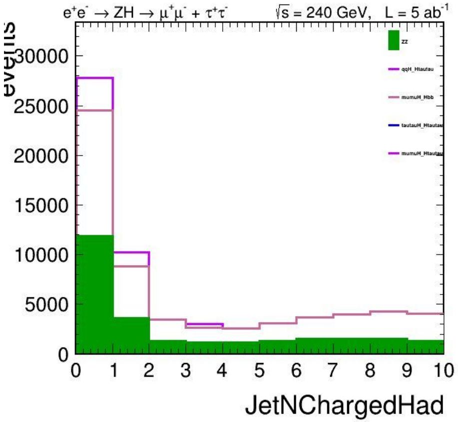


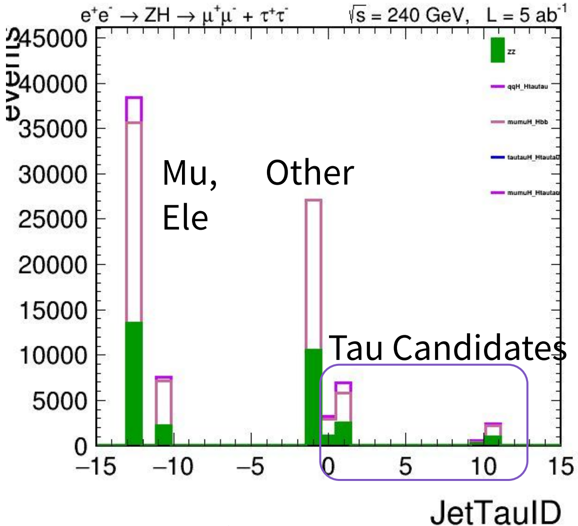
YIELDS (from Recoil_mass)
... p8_ee_ZZ_ecm240_newtau2 9514
... wzp6_ee_mumuH_ecm240_newtau2 20734
... wzp6_ee_mumuH_Hbb_ecm240_newtau2 12299
... wzp6_ee_mumuH_Htautau_ecm240_newtau2 1336

After careful checking, the Br are wrong for the 'inclusive' sample: we can only look at the exclusive modes

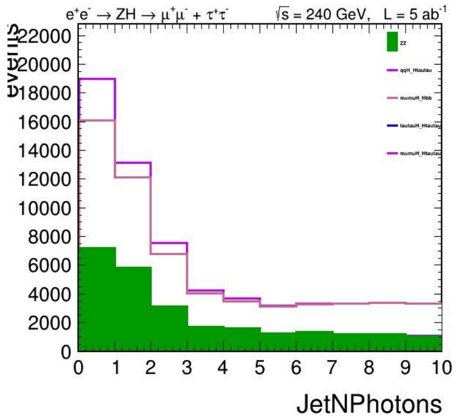
MuMuH + Jets (Winter23)

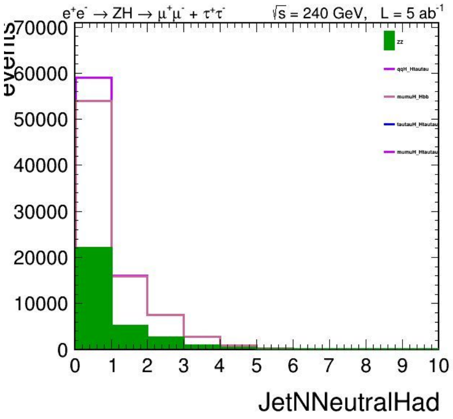


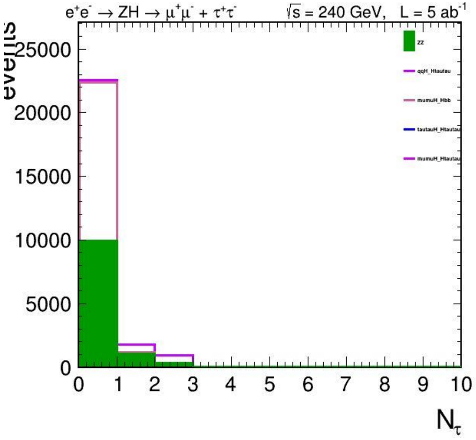




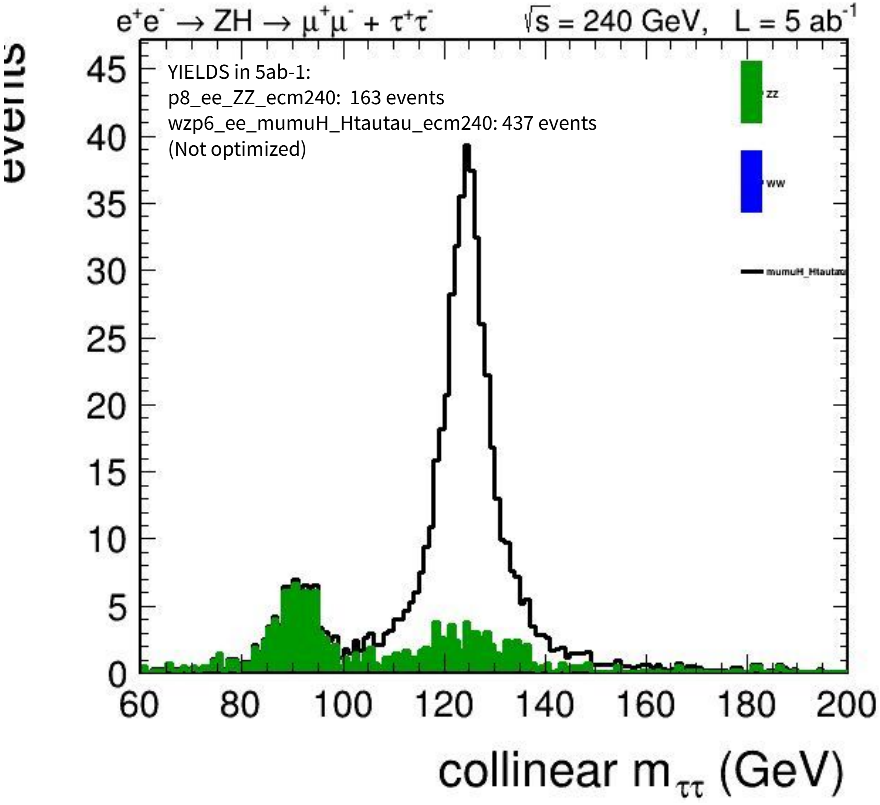
(ee_kt, 4 exclusive jets)



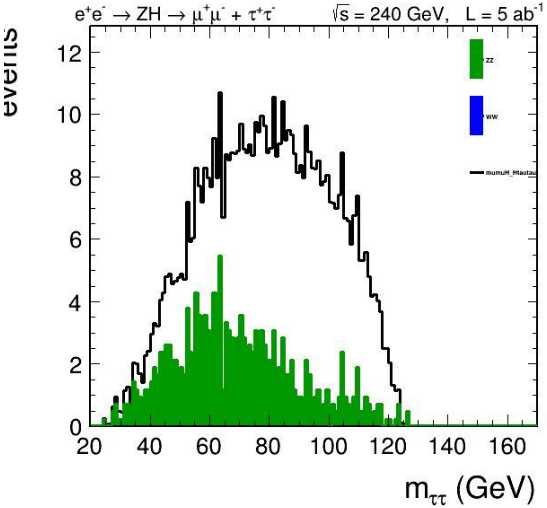


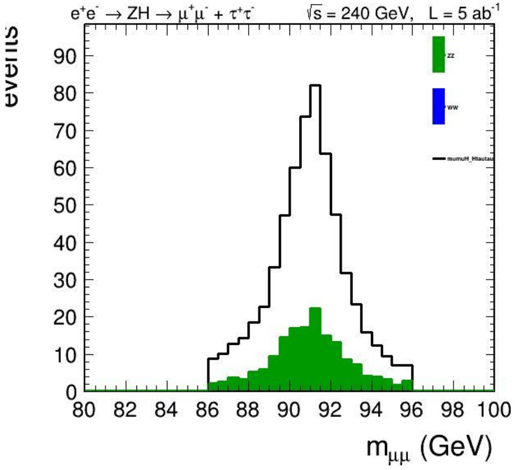


MuMu+Tau$_h$Tau$_h$ (Winter23)



YIELDS in 5ab-1:
p8_ee_ZZ_ecm240: 163 events
wzp6_ee_mumuH_Htautau_ecm240: 437 events
(Not optimized)





Yields

```
CutFlow for process wzp6_ee_mumuH_Htautau_ecm240_newtau2

Events with at least two muons: pass=385572        all=400000        -- eff=96.39 % cumulative eff=96.39 %

Muon Pt>10: pass=369837        all=385572        -- eff=95.92 % cumulative eff=92.46 %

Muons with opposite charge: pass=350199   all=369837        -- eff=94.69 % cumulative eff=87.55 %

86 < Mreco(dimuon) < 96 GeV: pass=268226  all=350199        -- eff=76.59 % cumulative eff=67.06 %

Recoil>120: pass=267190   all=268226        -- eff=99.61 % cumulative eff=66.80 %

cos(theta_miss)<0.98: pass=260649        all=267190        -- eff=97.55 % cumulative eff=65.16 %

Events with exactly two taus: pass=114891   all=260649        -- eff=44.08 % cumulative eff=28.72 %

Tau Pt>10 GeV: pass=96204        all=114891        -- eff=83.74 % cumulative eff=24.05 %

Identified Taus: pass=96204        all=96204        -- eff=100.00 % cumulative eff=24.05 %

Taus with opposite charge: pass=96191        all=96204        -- eff=99.99 % cumulative eff=24.05 %

DiTauMass > 20 GeV: pass=96191     all=96191        -- eff=100.00 % cumulative eff=24.05 %
```

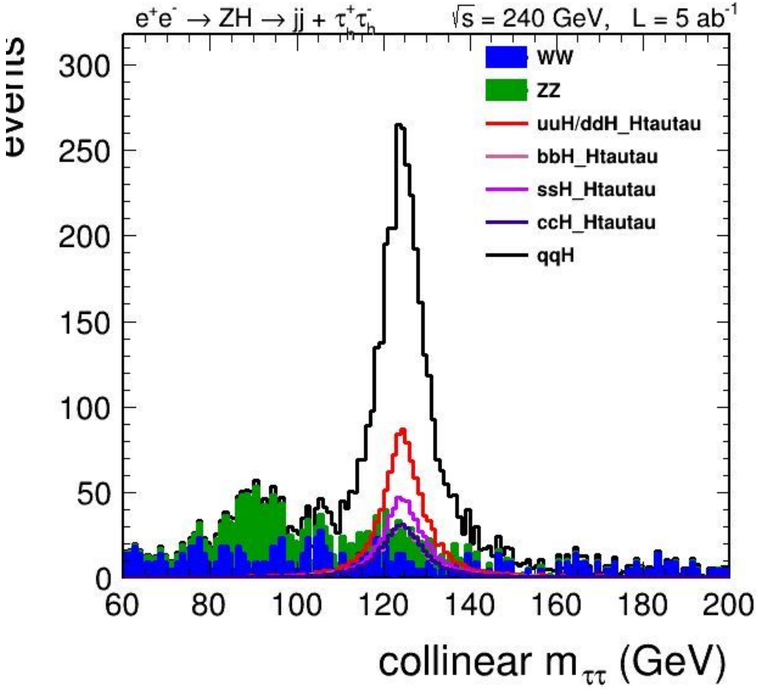
Requiring 2 Hadronically Decaying taus is a 40% acceptance (before selection)

65% of the acceptance in dimuon sel

in the ditau, other 40%.

note that I am not considering lepton-tau signatures → to be checked better

QQ+TauTau (Winter23)



YIELDS (from DiTau_coll_mass)
... p8_ee_WW_ecm240 1068
... p8_ee_ZZ_ecm240 1186
... wzp6_ee_qqH_Htautau_ecm240 1108
... wzp6_ee_bbH_Htautau_ecm240 473
... wzp6_ee_ssH_Htautau_ecm240 636
... wzp6_ee_ccH_Htautau_ecm240 456
... wzp6_ee_qqH_ecm240 3250

The extra events in the main qqH sample (compared to the exclusive qqH_Htautau samples) come from Hbb/HWW mostly - similarly to the ZZ events that fall under the Higgs peak (Zbb events, the collinear mass approximation pushes the mass upwards).

The acceptance here is very low (tau reco , but also the Htautau and Zqq selections to reduce the WW/ZZ contribution)

Careful: the qqH sample is wrong, we need to use the exclusive ones

QQTauTau

Requiring 2 Hadronically Decaying taus is a 40% acceptance (before selection): the reco/id cut of two taus is really 70-75% (29/40)

CutFlow for process wzp6_ee_qqH_Htautau_ecm240

No Muons : pass=158281 all=200000 -- eff=79.14 % cumulative eff=79.14 %

No Electrons: pass=120576 all=158281 -- eff=76.18 % cumulative eff=60.29 %

Events with exactly two taus: pass=57841 all=120576 -- eff=47.97 % cumulative eff=28.92 %

Tau Pt>10 GeV: pass=46836 all=57841 -- eff=80.97 % cumulative eff=23.42 %

Identified Taus: pass=42892 all=46836 -- eff=91.58 % cumulative eff=21.45 %

Tau mass < 2 GeV: pass=36546 all=42892 -- eff=85.20 % cumulative eff=18.27 % → this is to kill WW/quarks

Taus with opposite charge: pass=34102 all=36546 -- eff=93.31 % cumulative eff=17.05 %

DiTauMass > 40 GeV: pass=32751 all=34102 -- eff=96.04 % cumulative eff=16.38 %

Two jets : pass=22589 all=32751 -- eff=68.97 % cumulative eff=11.29 %

Jet Pt>20 : pass=19887 all=22589 -- eff=88.04 % cumulative eff=9.94 %

80 < Mreco(diJet) < 100 GeV: pass=16152 all=19887 -- eff=81.22 % cumulative eff=8.08 %

20 < Pt(DiJet) < 70 GeV: pass=14304 all=16152 -- eff=88.56 % cumulative eff=7.15 %

120<Recoil<140 GeV: pass=13539 all=14304 -- eff=94.65 % cumulative eff=6.77 % :(

ILC

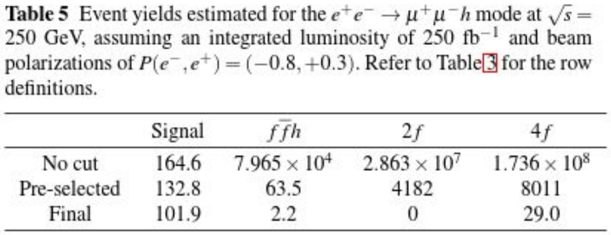


Table 5 Event yields estimated for the $e^+e^- \to \mu^+\mu^- h$ mode at $\sqrt{s} =$ 250 GeV, assuming an integrated luminosity of 250 fb^{-1} and beam polarizations of $P(e^-, e^+) = (-0.8, +0.3)$. Refer to Table 3 for the row definitions.

	Signal	$f\bar{f}h$	$2f$	$4f$
No cut	164.6	7.965×10^4	2.863×10^7	1.736×10^8
Pre-selected	132.8	63.5	4182	8011
Final	101.9	2.2	0	29.0

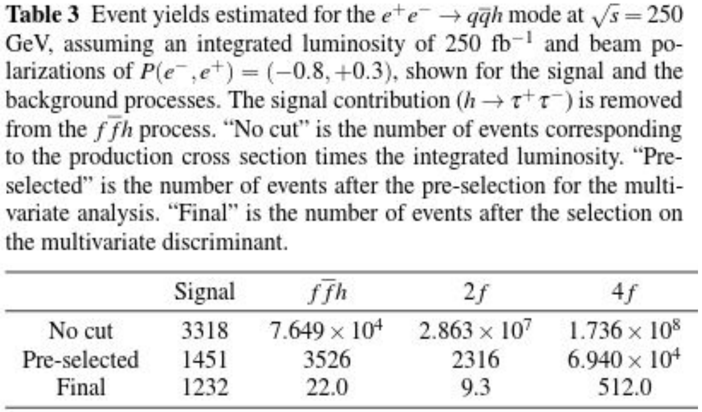


Table 3 Event yields estimated for the $e^+e^- \to q\bar{q}h$ mode at $\sqrt{s} = 250$ GeV, assuming an integrated luminosity of 250 fb^{-1} and beam polarizations of $P(e^-, e^+) = (-0.8, +0.3)$, shown for the signal and the background processes. The signal contribution ($h \to \tau^+\tau^-$) is removed from the $f\bar{f}h$ process. "No cut" is the number of events corresponding to the production cross section times the integrated luminosity. "Pre-selected" is the number of events after the pre-selection for the multivariate analysis. "Final" is the number of events after the selection on the multivariate discriminant.

	Signal	$f\bar{f}h$	$2f$	$4f$
No cut	3318	7.649×10^4	2.863×10^7	1.736×10^8
Pre-selected	1451	3526	2316	6.940×10^4
Final	1232	22.0	9.3	512.0

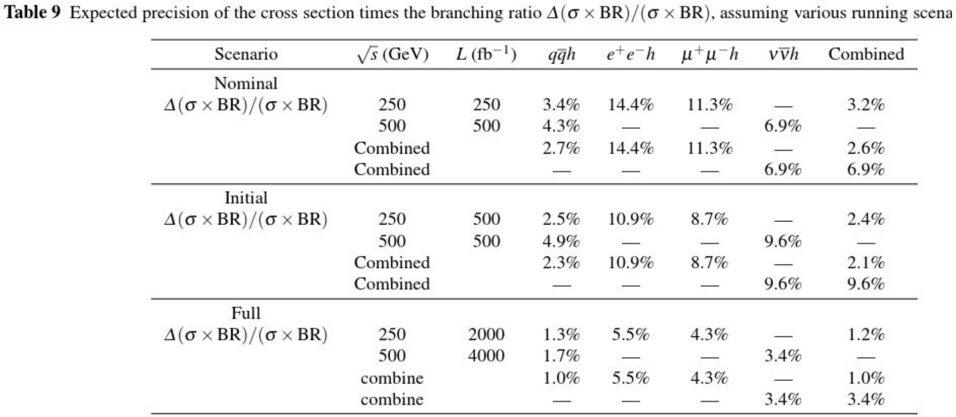


Table 9 Expected precision of the cross section times the branching ratio $\Delta(\sigma \times \text{BR})/(\sigma \times \text{BR})$, assuming various running scena

Scenario	$\sqrt{s}$ (GeV)	L (fb^{-1})	$q\bar{q}h$	e^+e^-h	$\mu^+\mu^-h$	$\nu\bar{\nu}h$	Combined
Nominal $\Delta(\sigma \times \text{BR})/(\sigma \times \text{BR})$	250	250	3.4%	14.4%	11.3%	—	3.2%
	500	500	4.3%	—	—	6.9%	—
	Combined		2.7%	14.4%	11.3%	—	2.6%
	Combined		—	—	—	6.9%	6.9%
Initial $\Delta(\sigma \times \text{BR})/(\sigma \times \text{BR})$	250	500	2.5%	10.9%	8.7%	—	2.4%
	500	500	4.9%	—	—	9.6%	—
	Combined		2.3%	10.9%	8.7%	—	2.1%
	Combined		—	—	—	9.6%	9.6%
Full $\Delta(\sigma \times \text{BR})/(\sigma \times \text{BR})$	250	2000	1.3%	5.5%	4.3%	—	1.2%
	500	4000	1.7%	—	—	3.4%	—
	combine		1.0%	5.5%	4.3%	—	1.0%
	combine		—	—	—	3.4%	3.4%

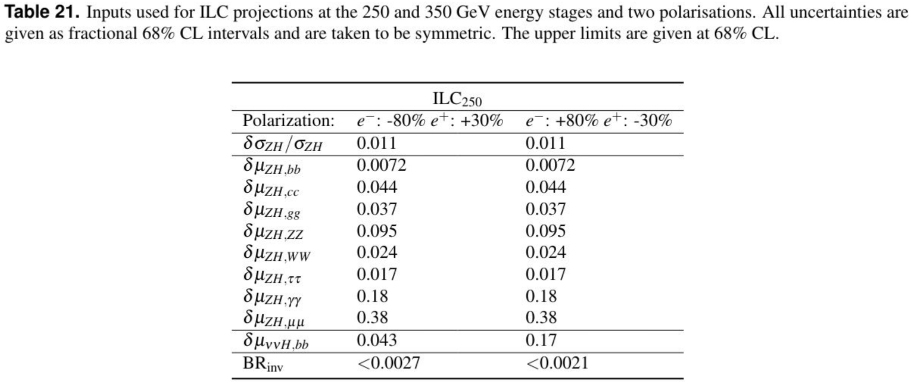
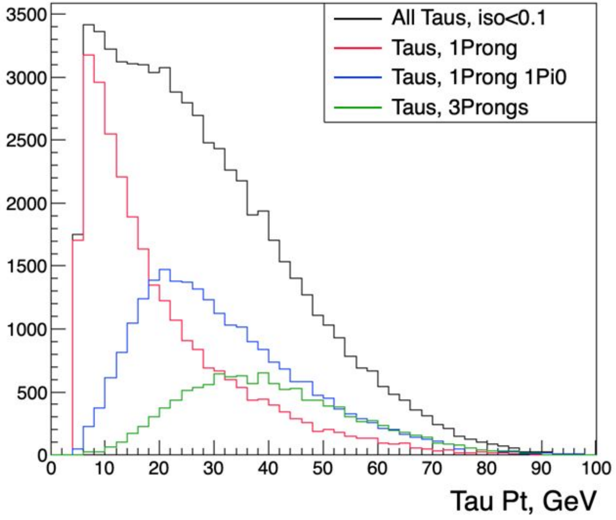
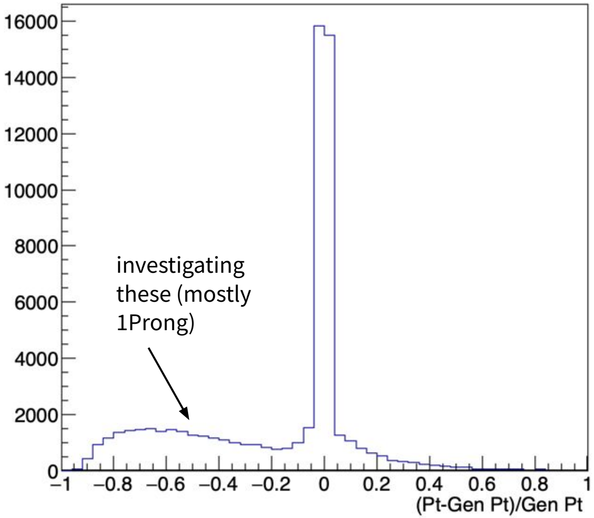


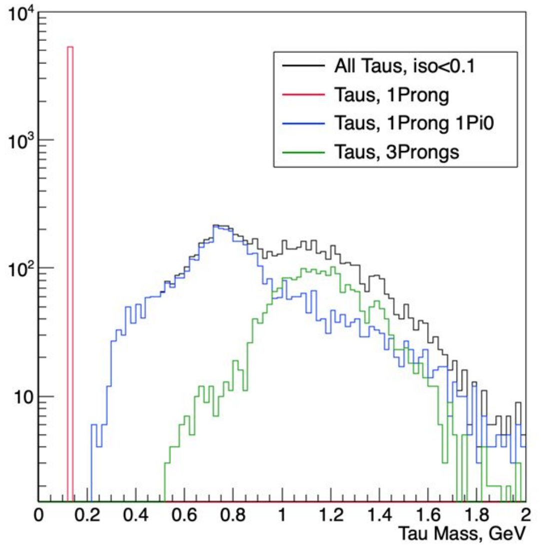
Table 21. Inputs used for ILC projections at the 250 and 350 GeV energy stages and two polarisations. All uncertainties are given as fractional 68% CL intervals and are taken to be symmetric. The upper limits are given at 68% CL.

	ILC_{250}	
Polarization:	e^-: -80% e^+: +30%	e^-: +80% e^+: -30%
$\delta\sigma_{ZH}/\sigma_{ZH}$	0.011	0.011
$\delta\mu_{ZH,bb}$	0.0072	0.0072
$\delta\mu_{ZH,cc}$	0.044	0.044
$\delta\mu_{ZH,gg}$	0.037	0.037
$\delta\mu_{ZH,ZZ}$	0.095	0.095
$\delta\mu_{ZH,WW}$	0.024	0.024
$\delta\mu_{ZH,\tau\tau}$	0.017	0.017
$\delta\mu_{ZH,\gamma\gamma}$	0.18	0.18
$\delta\mu_{ZH,\mu\mu}$	0.38	0.38
$\delta\mu_{\nu\nu H,bb}$	0.043	0.17
BR_{inv}	<0.0027	<0.0021

Example of performance (spring21, pythia8 samples)



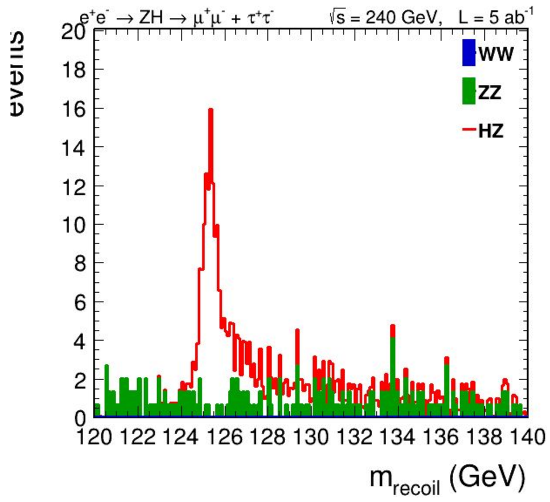

investigating these (mostly 1Prong)

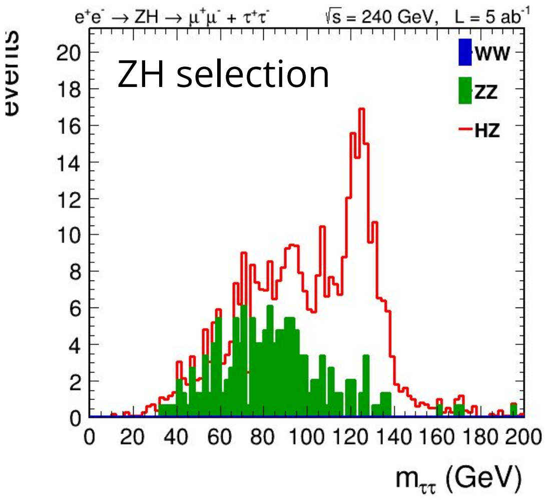


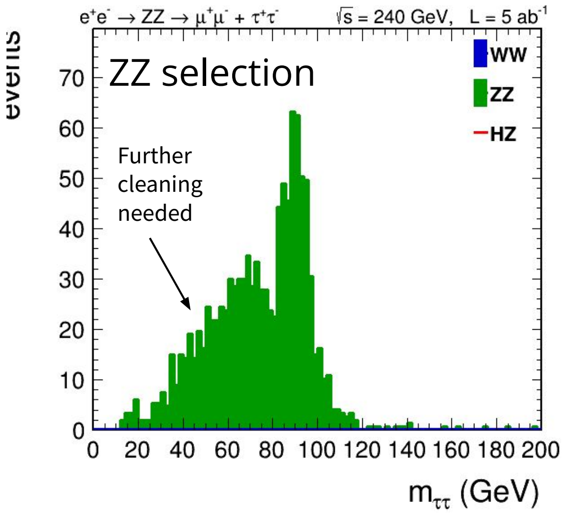
The comparison to ‘true’ tau pt is done using the “visible” Pt (sum of the visible decay products of hadronic taus, excluding muons, electrons, neutrinos)

Very similar results with a test sample of the winter23 production. Further studies (per decay mode performance, improvement of algorithm, change to jet constituents, etc) ongoing with it

MuMu+TauTau proof of principle (spring21, pythia8)







Preliminary MuMu+TauTau selection with Spring21 samples. Currently both tau_h.

Combinatorics (best tautau combination) and proper cleaning to be improved. Leptonic decays to be incorporated (for full mumu + mutau, etau, tautau analysis).

On the analysis side, moving to ZqqHtautau to improve statistics

Next Steps