Literature of $H \to \tau\tau$ at Higgs factories and road map of our study

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Literature summary

ILC studies

- Higgs CP properties using the tau decay modes at the ILC (2013)
- ILC Higgs White Paper (2013)
- A study of the measurement precision of the Higgs boson decaying into tau pairs at the ILC (2015)
- ➡ Measuring the CP state of tau lepton pairs from Higgs decay at the ILC (2018)

Channels analyzed:

- $Z \to ee, \mu\mu, qq$ (not $\tau\tau$ or $\nu\nu$), $H \to \tau\tau$, only 1-prong modes
- Best for reconstructing polarimeter vectors, not necessary for cross section measurements

Backgrounds:

- full set of 2- and 4-fermion bkg
- 4-fermion (ZZ) backgrounds dominates
- 2-fermion ($Z/\gamma*$) not negligible
- With ISR and beam remnant bkgs

Process	e	μ	q
Signal	32	36	575
Other $f\bar{f}H, H \to \tau^+\tau^-$	39	43	627
Other $f\bar{f}H$	1	0	58
Other $f\bar{f}\tau^+\tau^-$	32	24	766
Other $4f$	51	35	2834
$2f$	18	0	403

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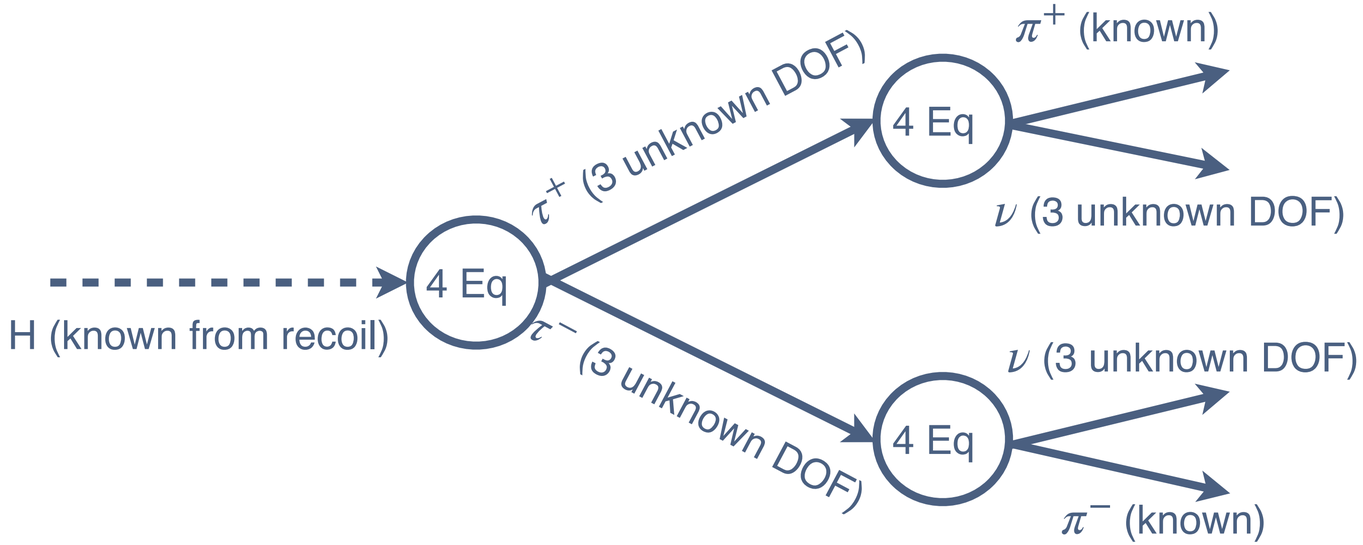
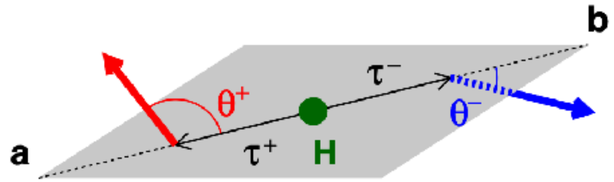
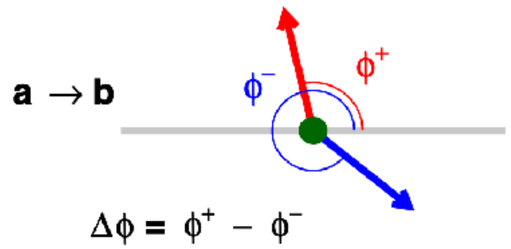
- Fully resolve τ momenta



- One method (polarimetric vector) to reconstruct ϕ_{CP}





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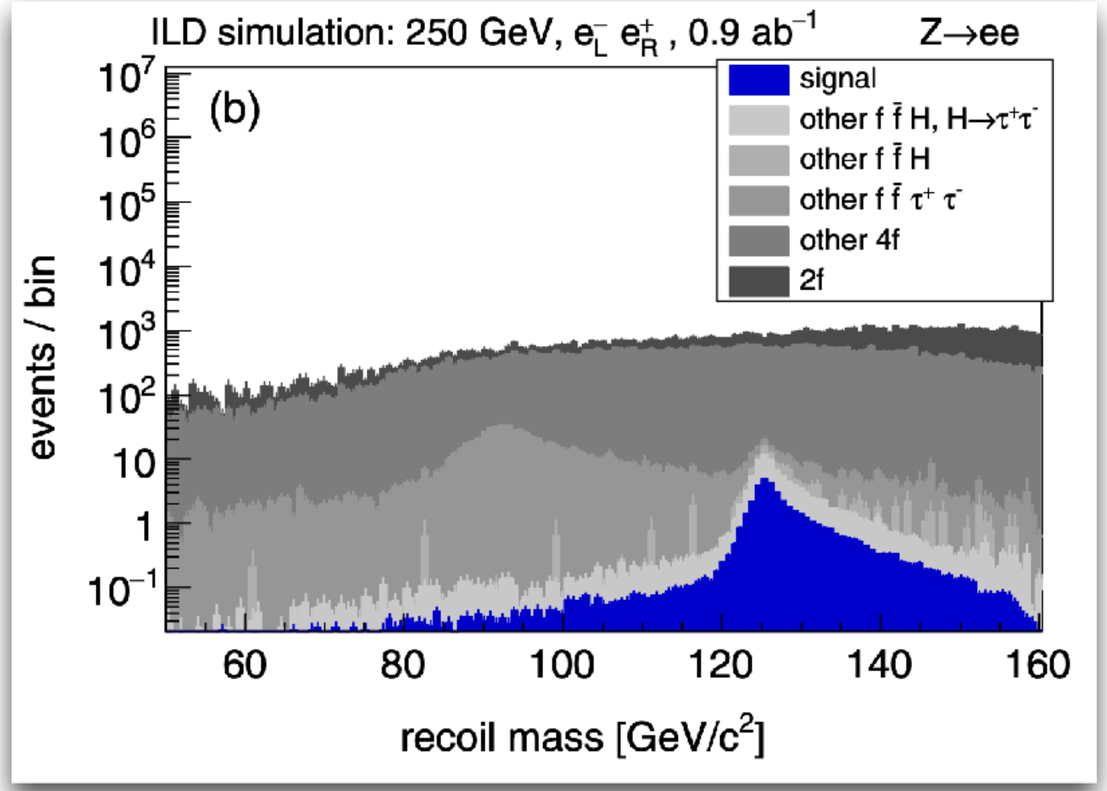
What matters for the cross section
Z decays are always visible in this analysis, the recoil mass is the best variable.



CEPC studies

- Higgs → ττ Branching Ratio Measurement at CEPC (2017)

➡ Higgs to ττ analysis in the future e+e– Higgs factories (2019)

- Precision Higgs physics at the CEPC (2019)

Channels analyzed:

- $Z \to ee, \mu\mu, \nu\nu, qq$ (not $\tau\tau$), $H \to \tau\tau$, only 1-prong modes

Main bkgs

- WW and ZZ, single Z (4f), single W (4f)
- 2 fermion (DY, Bhabha)

τ reco via “TAURUS” package, not with specific modes,

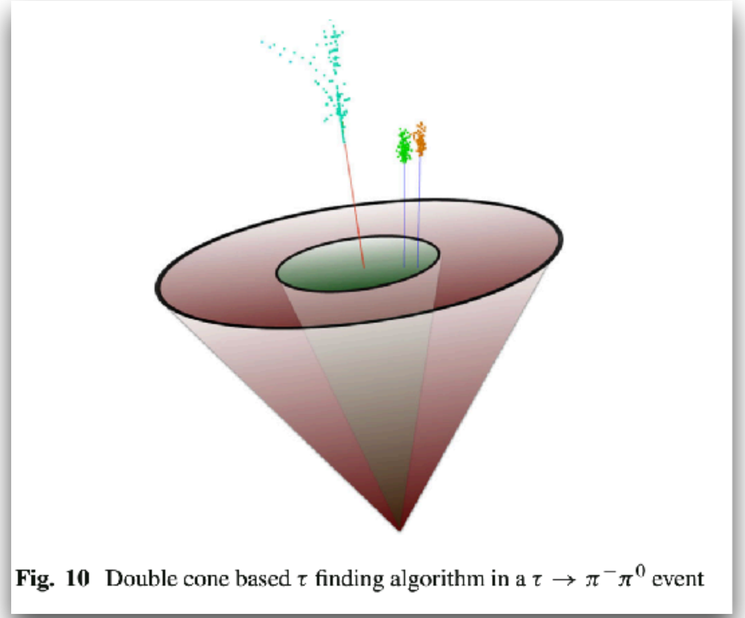


Fig. 10 Double cone based τ finding algorithm in a $\tau \to \pi^- \pi^0$ event

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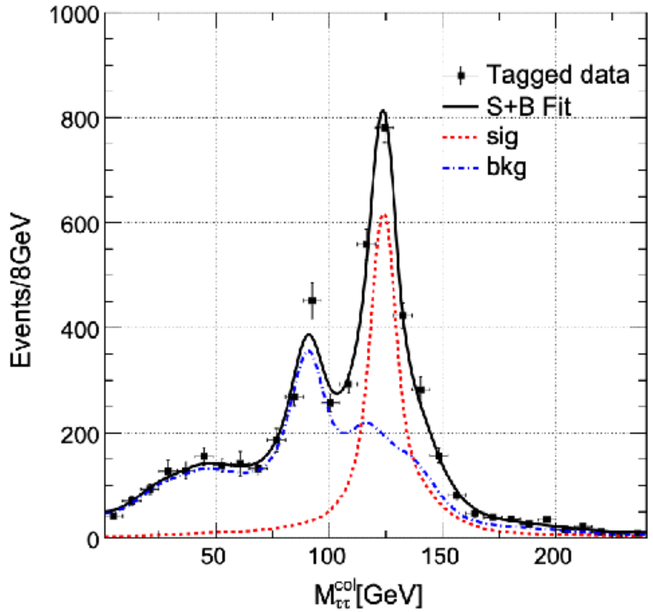
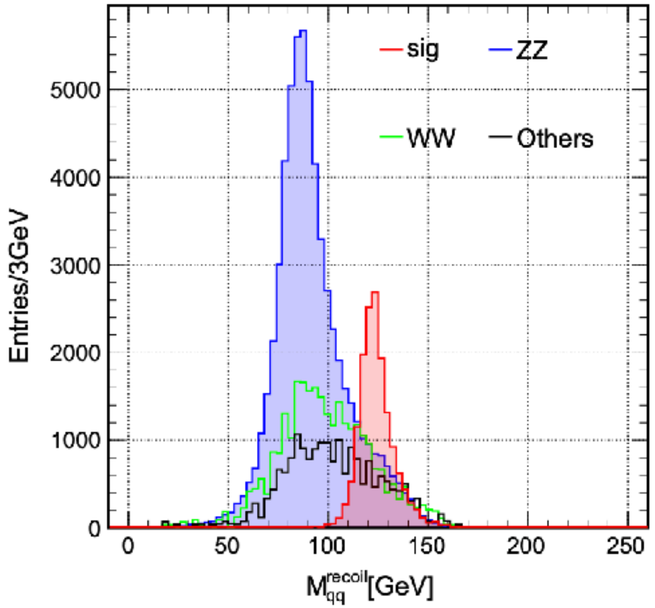
For $\ell\ell\tau\tau$ channel

- $m_{recoil} > 110$ GeV used for selection
- $m_{\tau\tau}^{col}$ used for fit (WHY?)



For $qq\tau\tau$ channel

- $90 < m_{\tau\tau}^{col} < 160$ GeV used for selection
- m_{recoil} used for fit



Our status and planning

Our work - status

Samples we have (copied to KIT)

- All combinations of ZH and $\nu\nu H$ decays
- Inclusive ZZ, WW
- $Z/\gamma* \rightarrow \tau\tau, qq$
- No single W, probably negligible

$e\gamma \rightarrow e\tau\tau$ not exist yet
could make it, probably negligible

We can take $\gamma\gamma \rightarrow \tau\tau$

We can take $\nu\nu Z$, too

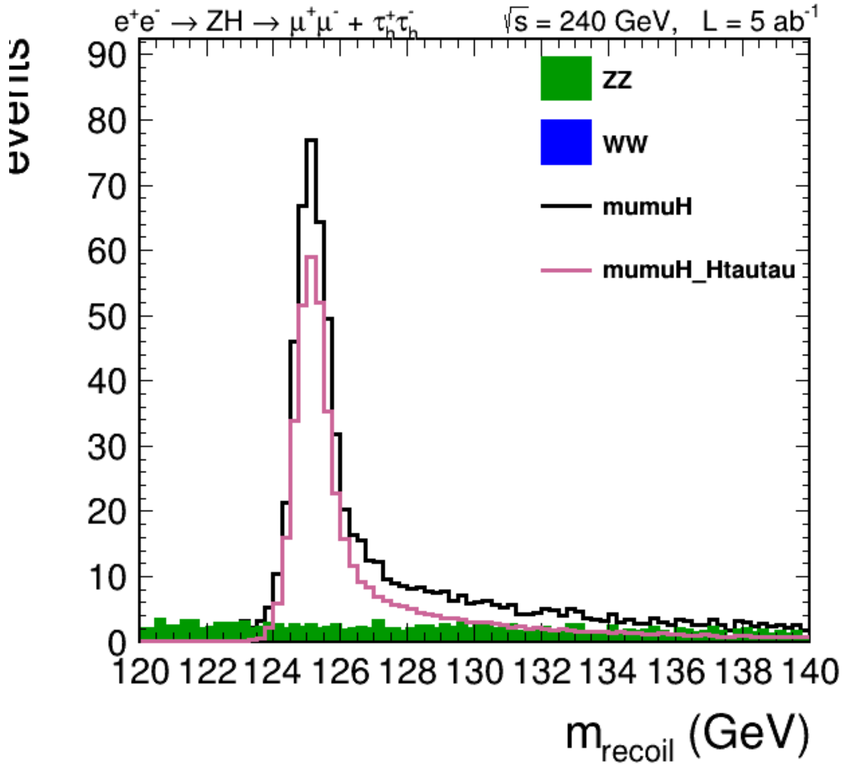
Sample Name	Processes	Generator	# of events	x-section(pb)
Higgs Processes				
wzp6_ee_mumuH	$e^+e^- \rightarrow \mu^+\mu^- H$	WHIZARD + PYTHIA6	1,200,000	0.0067643
wzp6_ee_eeH	$e^+e^- \rightarrow e^+e^- H$	WHIZARD + PYTHIA6	1,200,000	0.0071611
Diboson Processes				
p8_ee_ZZ_ecm240	$e^+e^- \rightarrow ZZ$	PYTHIA8	56,162,093	1.35899
p8_ee_WW_ecm240	$e^+e^- \rightarrow WW$	PYTHIA8	373,375,386	16.4385
Dilepton Processes				
wzp6_ee_mumu	$e^+e^- \rightarrow \mu^+\mu^-$	WHIZARD + PYTHIA6	53,400,000	5.288
wzp6_ee_ee_Mee_30_150	$e^+e^- \rightarrow e^+e^-$	WHIZARD + PYTHIA6	85,400,000	8.305
wzp6_ee_tautau	$e^+e^- \rightarrow \tau^+\tau^-$	WHIZARD + PYTHIA6	52,400,000	4.668
Electron Photon Processes				
wzp6_egamma_eZ_Zmumu	$e^-\gamma \rightarrow e^- Z(\mu^+\mu^-)$	WHIZARD + PYTHIA6	6,000,000	0.10368
wzp6_gammae_eZ_Zmumu	$e^+\gamma \rightarrow e^+ Z(\mu^+\mu^+)$	WHIZARD + PYTHIA6	5,600,000	0.10368
wzp6_egamma_eZ_Zee	$e^-\gamma \rightarrow e^- Z(e^+e^-)$	WHIZARD + PYTHIA6	6,000,000	0.05198
wzp6_gammae_eZ_Zee	$e^+\gamma \rightarrow e^+ Z(e^+e^-)$	WHIZARD + PYTHIA6	6,000,000	0.05198
Photon Photon Processes				
wzp6_gaga_mumu_60	$\gamma\gamma \rightarrow \mu^+\mu^-$	WHIZARD + PYTHIA6	33,900,000	1.5523
wzp6_gaga_ee_60	$\gamma\gamma \rightarrow e^+e^-$	WHIZARD + PYTHIA6	22,500,000	0.873
wzp6_gaga_tautau_60	$\gamma\gamma \rightarrow \tau^+\tau^-$	WHIZARD + PYTHIA6	33,700,000	0.836
Other Processes				
wzp6_ee_nuenueZ	$e^+e^- \rightarrow \nu_e\bar{\nu}_e Z$	WHIZARD + PYTHIA6	2,000,000	0.033274

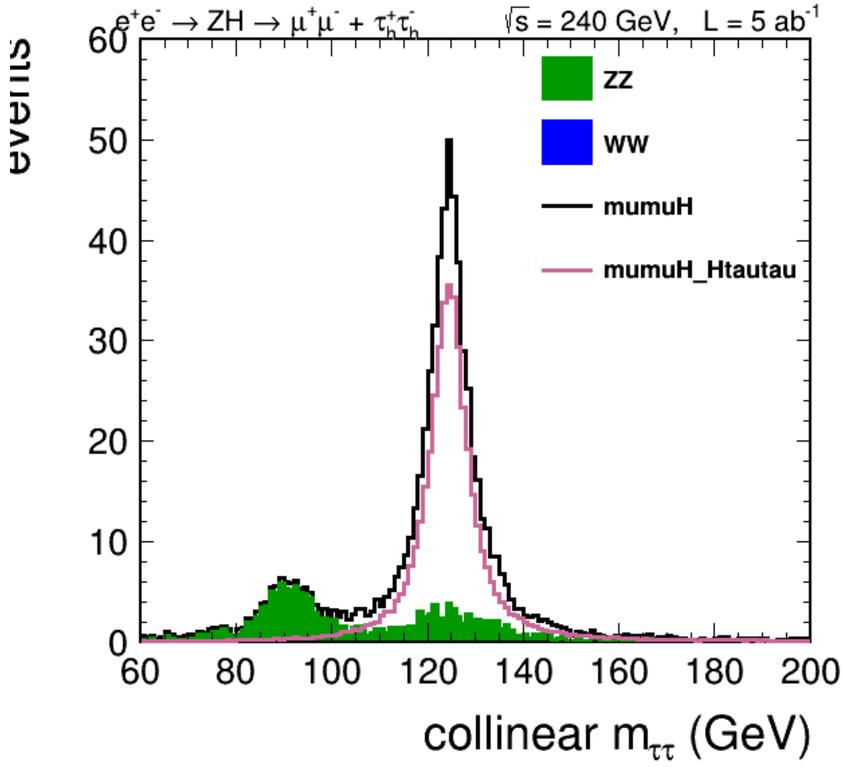
Samples used by JHU

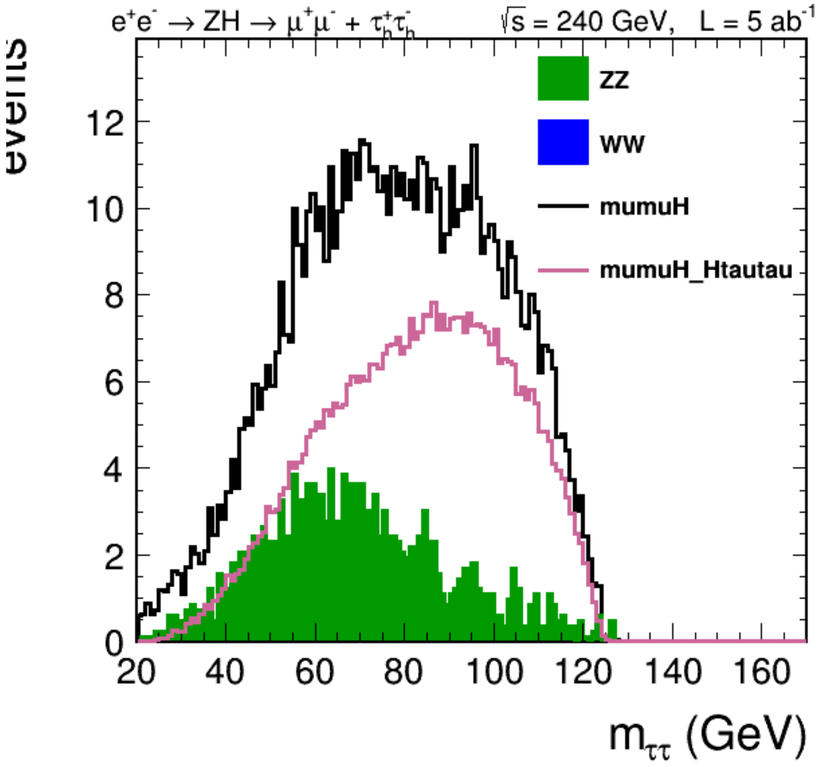
Our work - status

Provided by Maria

- $\mu\mu\tau\tau, ee\tau\tau, qq\tau\tau$ channels
- calculations for $m_{recoil}, m_{\tau\tau}^{col}, m_{\tau\tau}^{vis}$







Our work - planning

Directions	Tasks	Priority	Status
MC samples	SM samples	**Essential**	complete-ish
	EFT samples	needed for CP	workflow ready, to understand generators better, can start production
tau tagger	Explicit reco (from jets)	**Essential**	ready, in use
	ML tagger	Good to have	Either ParticleNet from Michele, or Transformer from Lars. To check
Analysis workflow	variables for xsec analysis	**Essential**	Everything in place Easy to add more
	CP observables	needed for CP	Many for HZZ CP, not yet for Htautau CP, can ask CMS colleagues for examples
	event categories	**Essential**	selection to be refined, nunuH can be added
Interpretation	combined fit	**Essential**	straightforward
	EFT interpretation	needed for CP	to be discussed

Backups

CLIC studies

- Measurement of σ (e+e– → Hνν)×BR(H → ττ) at CLIC @ 1.4 TeV (2013)
- Higgs physics at the CLIC electron–positron linear collider (2017)