Study of Higgs boson decays to tau pairs at the ILC with ILD

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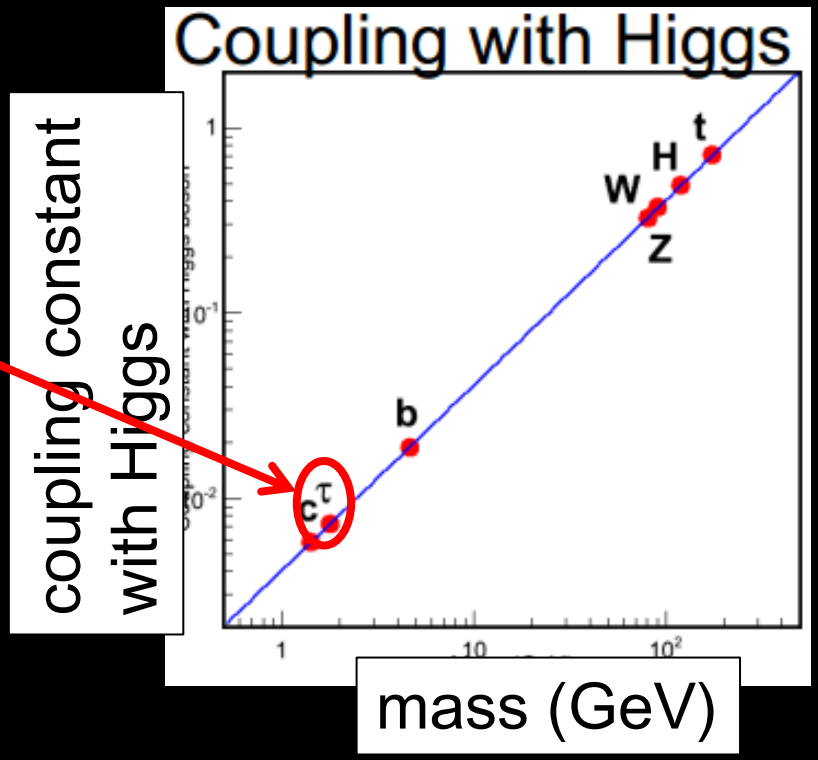
Brief Timeline

- 2007: ILC Reference Design Report (RDR)
- 2009: Detector Letter of Intent (LoI)
- 2013: ILC Technical Design Report (TDR)
  - 250 GeV $H \rightarrow \tau\tau$ result is included (supporting document LC-Note: LC-REP-2013-001)
  - new study 500 GeV $H \rightarrow \tau\tau$ is ongoing

Introduction

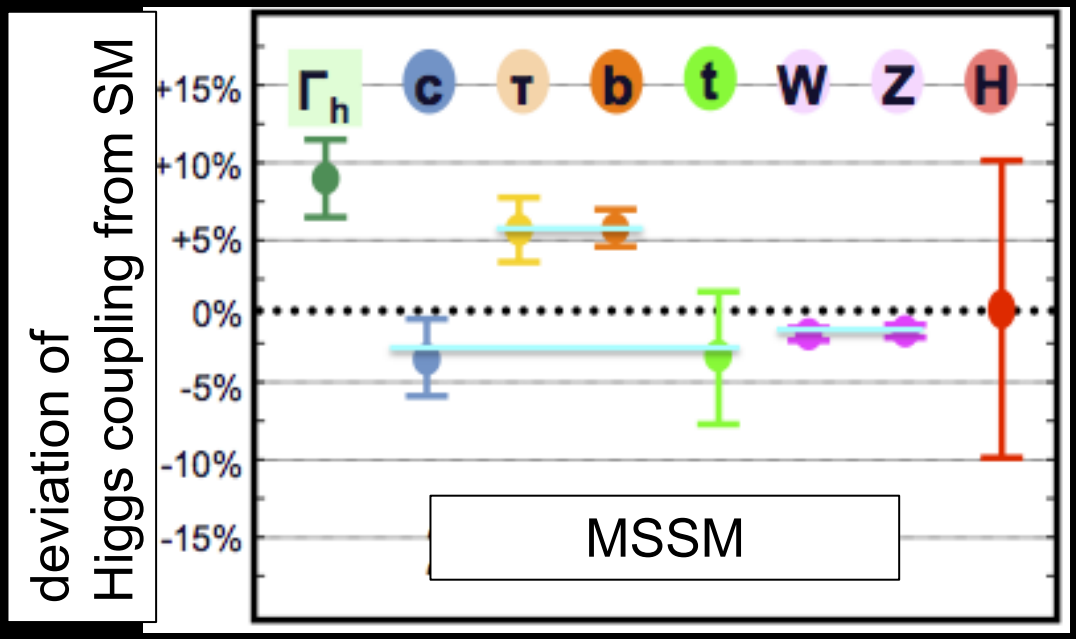
Since the discovery of Higgs boson, the investigation of its properties has become one of the most important themes in particle physics, especially the verification of the mass generation mechanism.

Full simulation of $H \to \tau\tau$ mode



Motivation for Precise Measurement

Any deviation in Higgs coupling and mass relation is an indication of new physics.



The small theoretical uncertainty in tau mass makes $H \to \tau\tau$ branching ratio an ideal probe for new physics.

Target of This Study

Estimation of the precision of the branching ratio of $H \to \tau\tau$ mode

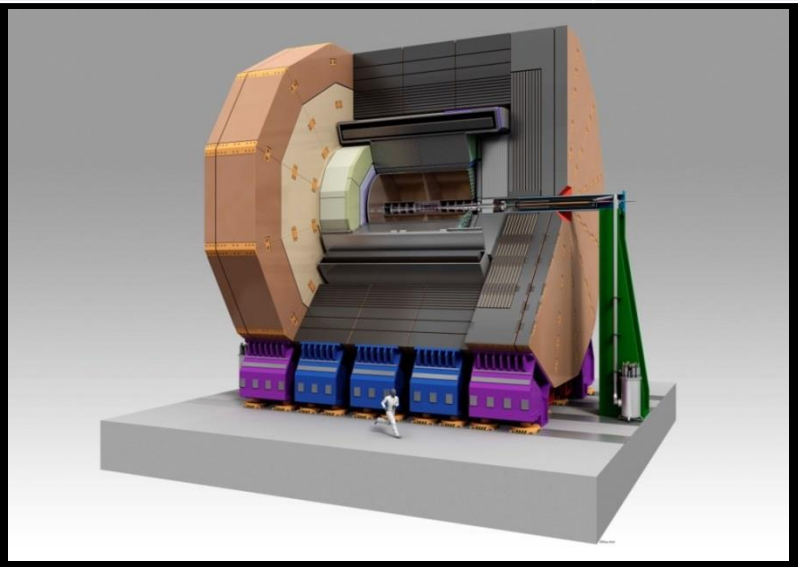
Previous **fast simulation** study (written in RDR)

$\frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})} = 4.6 \sim 7.1\ \%\ (M_H = 120\ \mathrm{GeV}, \int L\, dt = 500\ \mathrm{fb}^{-1})$

We estimated the precision with **full detector simulation (ILD)** at $\sqrt{s} = 250$ GeV and 500 GeV.

Simulation Settings

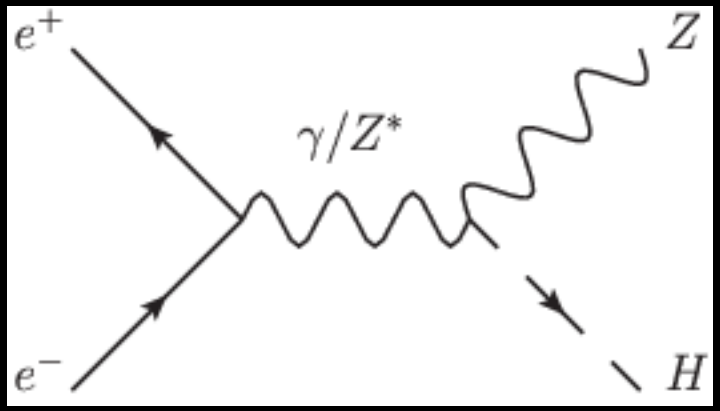
	$\sqrt{s} = 250$ GeV	$\sqrt{s} = 500$ GeV
M_H	120 GeV	125 GeV
$\mathrm{Br}(H \to \tau\tau)$	8.0 %	6.32 %
$\int L\, dt$	250 fb^{-1}	500 fb^{-1}
beam pol. (e^-, e^+)	(-0.8, +0.3)	(-0.8, +0.3)
using sample	LoI	TDR



full simulation with
ILD detector model

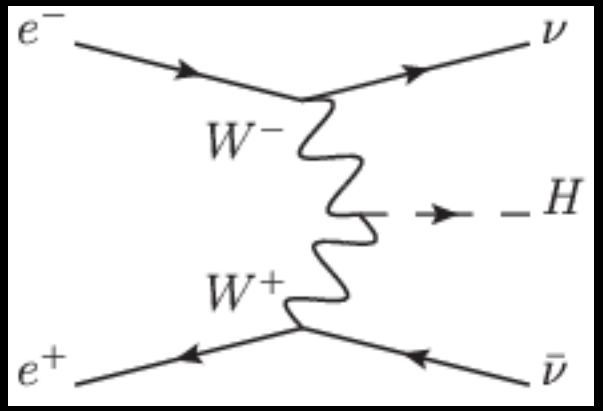
Signals

Higgs-strahlung



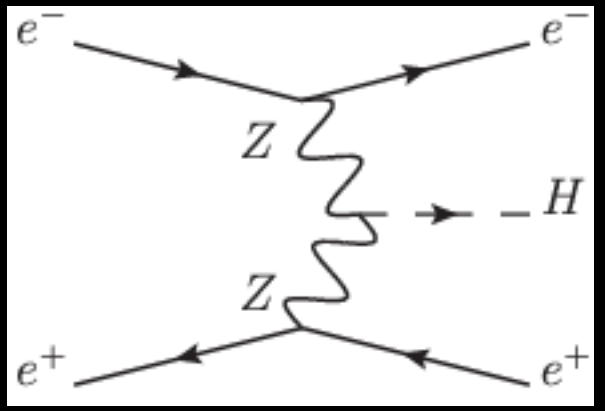
eeH
$\mu\mu H$
qqH
$\nu\nu H$

WW-fusion



$\nu\nu H$

ZZ-fusion

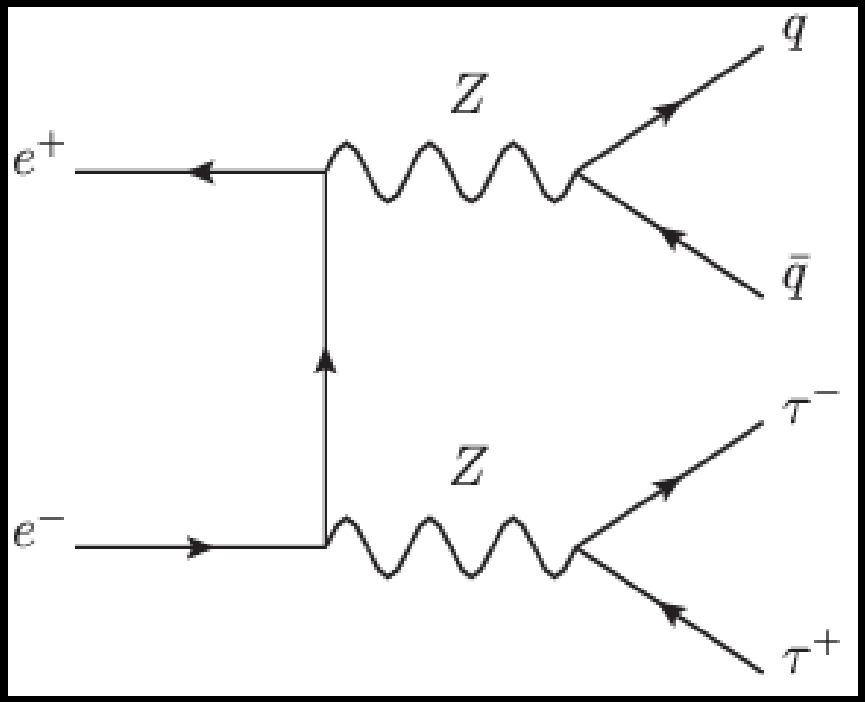


eeH

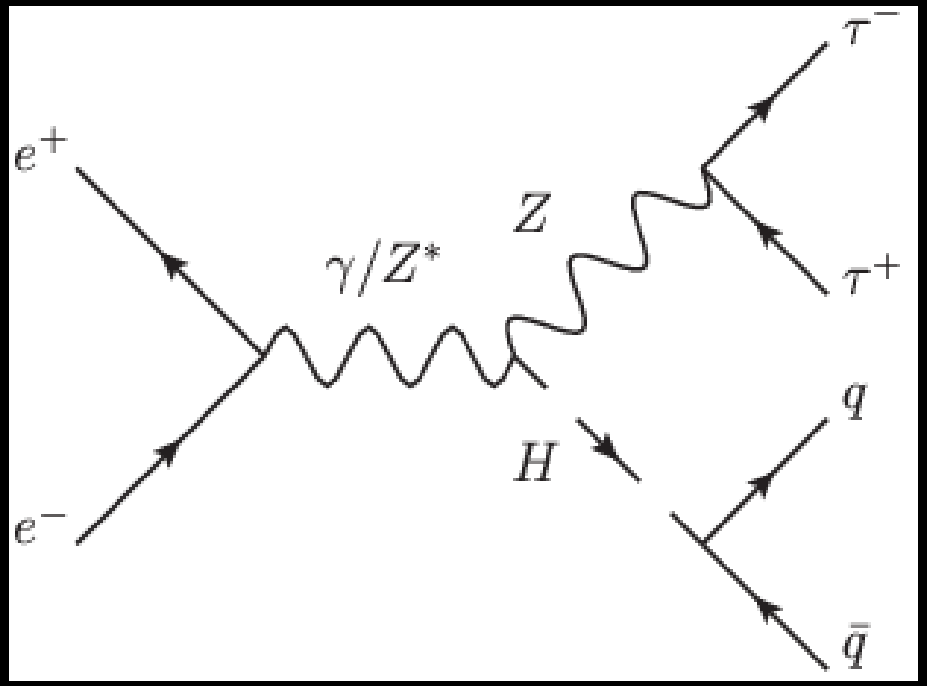
qqH is most sensitive channel at 250 GeV

Analysis of qqH mode

Main Backgrounds

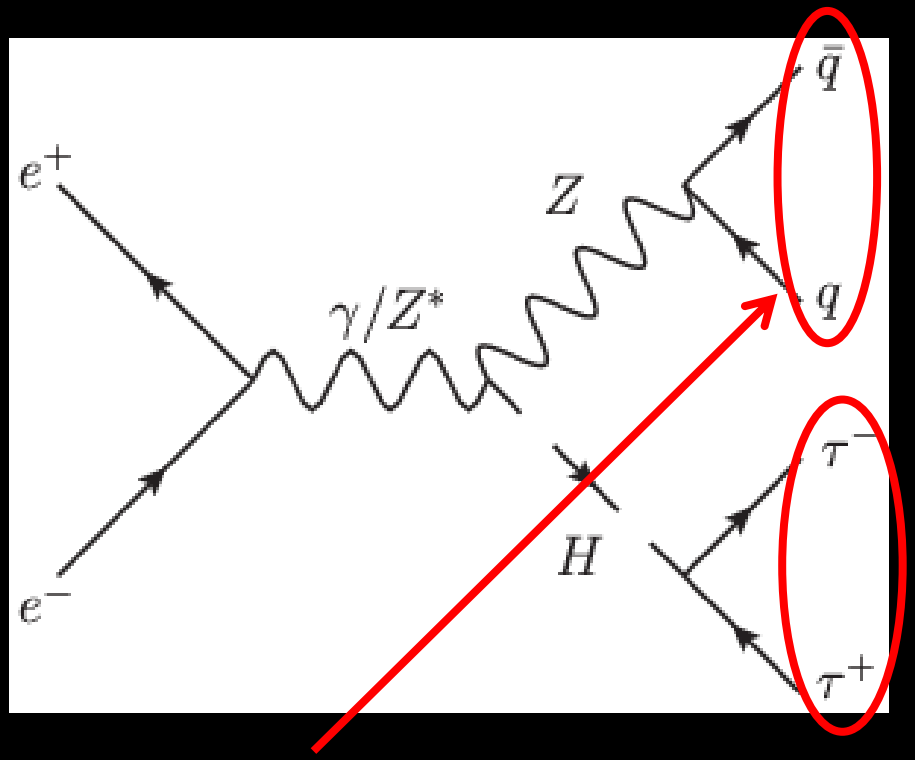


$e^+e^- \rightarrow qqqq, qqll, qqlv$
$qq\tau\tau$: irreducible



$e^+e^- \rightarrow ZH \rightarrow (ll)(qq)$
$ZH \rightarrow \tau\tau qq$: mimic signal

Event Reconstruction



1: $\tau \& H$ reconstruction

- **tau jet finder**

clustering based on tau mass optimized in the presence of jet background

- **collinear approximation**

tau pair mass reconstruction

2: Z reconstruction

jet finder w/ Durham (kT) algorithm into 2 jets

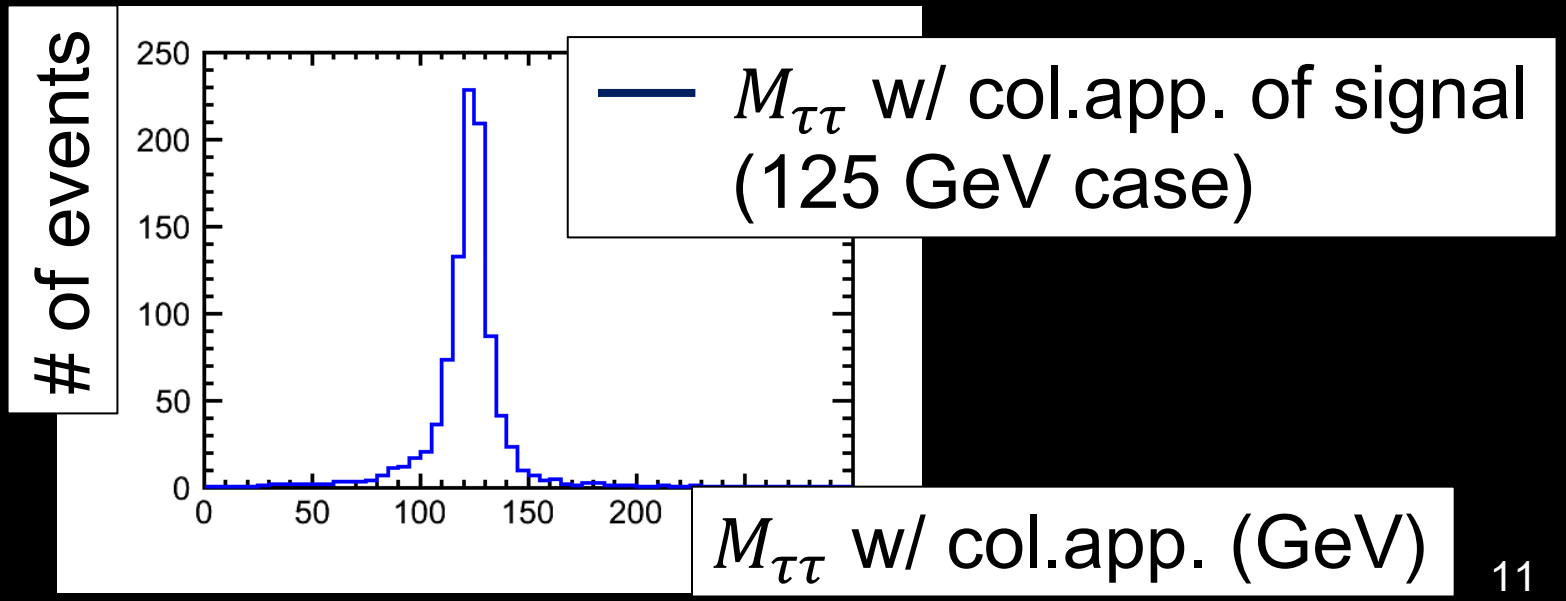
Collinear Approximation

Method of reconstructing tau pair mass ($M_{\tau\tau} = M_H$)

Assumptions:

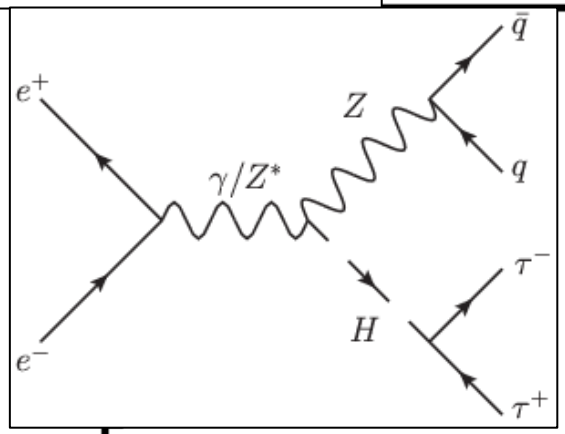
- visible tau decay products and neutrinos are collinear
- contribution of missing momentum comes only from neutrinos of tau decay

We use the knowledge of the initial 4-momentum at the ILC.



Event Selection Example : M_{recoil}

$\int L\,dt = 250\ \mathrm{fb}^{-1}$



All processes

$ZH \to qq\tau\tau$

$qq\tau\tau$

$q_{\mathrm{recoil}} = q_{\mathrm{CM}} - q_Z$

# of events

0 20 40

60 80 100 120 140 160 180

M_{recoil} (GeV)

Results of qqH mode

$\sqrt{s} = \mathbf{250\ GeV}$ ($M_H = 120$ GeV)

	signal	all bkg.
No cut	4233	1.495e+10
After cut	1032	564.8

efficiency = 24.4%, purity = 64.7%

significance = 25.8σ

$$\leftrightarrow \frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})} = 3.9\%$$

(scaled to $M_H = 125$ GeV: 4.6%)

$\sqrt{s} = \mathbf{500\ GeV}$ ($M_H = 125$ GeV)
(preliminary)

	signal	all bkg.
No cut	2158	3.007e+07
After cut	453.7	219.5

efficiency = 21.0%, purity = 67.4%

significance = 17.5σ

$$\leftrightarrow \frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})} = 5.7\%$$

Summary and Prospects

Expected accuracies in TDR ($M_H = 125$ GeV)

	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$			
$\sqrt{s}$ and $\mathcal{L}$ (P_{e-}, P_{e+})	250 fb^{-1} at 250 GeV (-0.8,+0.3)		500 fb^{-1} at 500 GeV (-0.8,+0.3)	
mode	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
$h \to \tau^+\tau^-$	4.2%	-	5.4%	14%

5.7% qqH only preliminary

7.5% preliminary

Study @ 250 GeV is completed, 500 GeV is ongoing.
We expect improvement by better treatment of $\gamma\gamma \to$ hadron(s) background and optimizing tau reconstruction.

BACKUP SLIDES

by T. Suehara

TaJet finder (1)

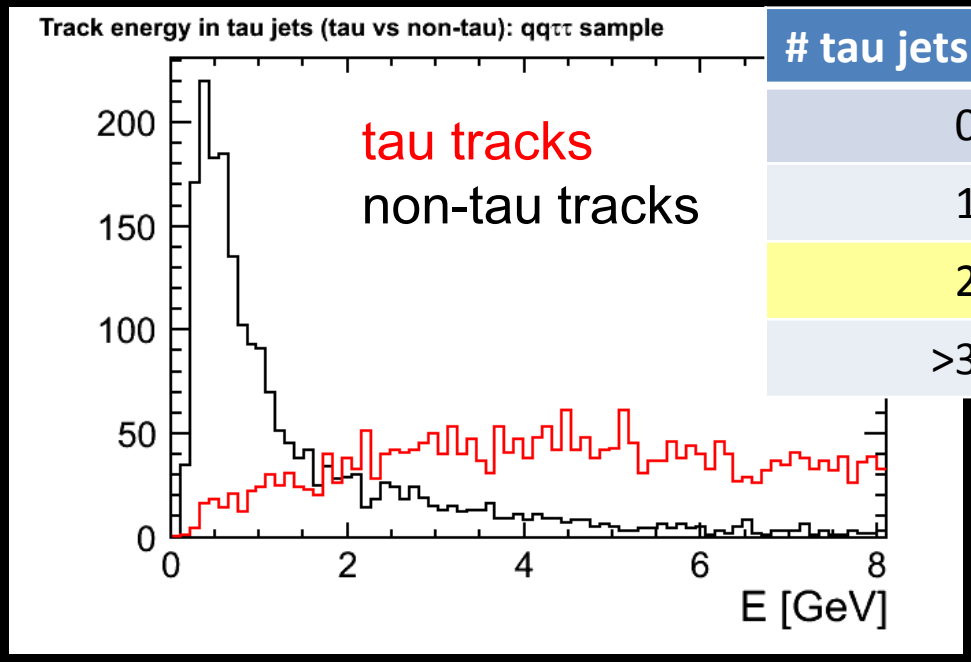
High-purity tau tagging
in presence of jet background

1. Order charged tracks by largest energy
2. Select the first track
3. Combine neighboring particles -> “Tau Jet”
   - Combined mass < 2 GeV && cosθ w.r.t. jet axis > 0.98
4. Tau selection (tuned for rejecting qq background)
   1. Tau Jet energy > 3 GeV
   2. Veto >=3 prong + neutrals (> 1 GeV)
   3. Cone energy ($E_{cone} < 0.1E_{taujet}$) with $\cos\theta_{cone} = 0.9$

ZZ -> qqττ 250 GeV, 13600 taus	1-prong		3-prong wo/ neutral		3-prong w/ neutral	
	tau	non-tau	tau	non-tau	tau	non-tau
No cut	10326	43286	716	1616	777	4280
$E_{taujet} > 3$	8679	7145	708	1304	742	4244
$E_{cone} < 0.5E_{taujet}$	7170	1009	621	181	681	1813
$E_{cone} < 0.2E_{taujet}$	6455	446	567	64	616	1020
$E_{cone} < 0.1E_{taujet}$	6001	254	527	30	570	620

TaJet finder (2)

5. Jet charge recovery (for better efficiency)
   - Tracks with energy < 2 GeV are detached one by one until tau jet has 1 or 3 tracks and sum charge is +1 or -1
   - Jet is rejected if above condition cannot be satisfied after detaching all < 2 GeV tracks
6. Return to 2. (previous page) with the remaining tracks
   - Stop after all E > 2 GeV tracks have been processed



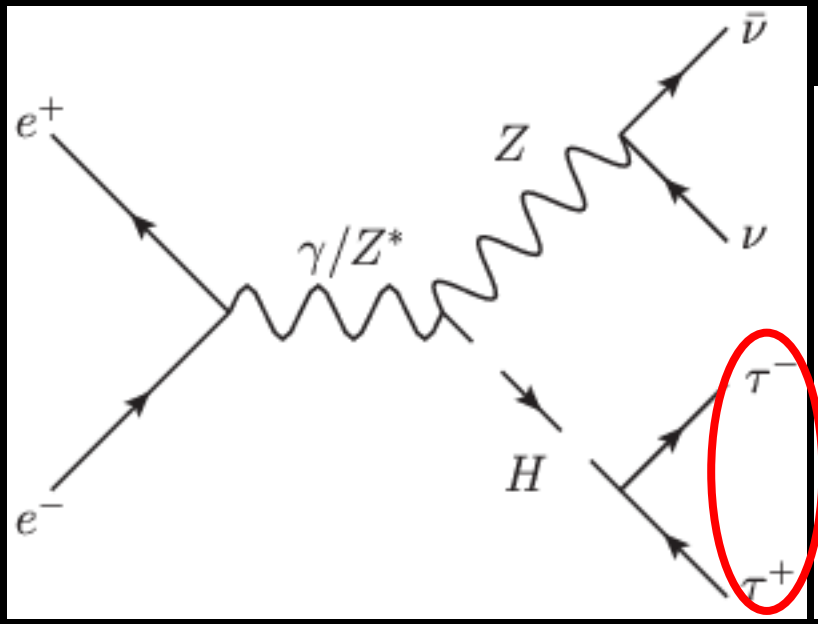
# tau jets	$qq\tau\tau$	$qqlv$
0	27.1%	47.6%
1	36.3%	46.6%
2	34.0%	5.4%
>3	2.4%	0.3%

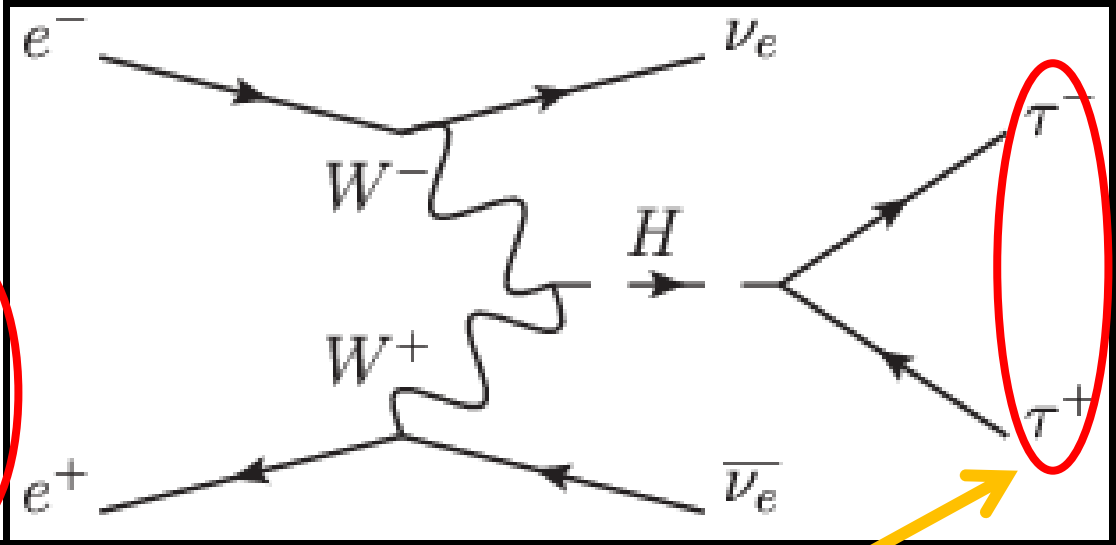
efficiency:
58.1% (1-prong)
73.6% (3-prong)

purity of tau in $qq\tau\tau$:
94.2% (overall)
96.5% (# tau jets == 2)

Analysis of $\nu\nu H$ mode

Event Reconstruction

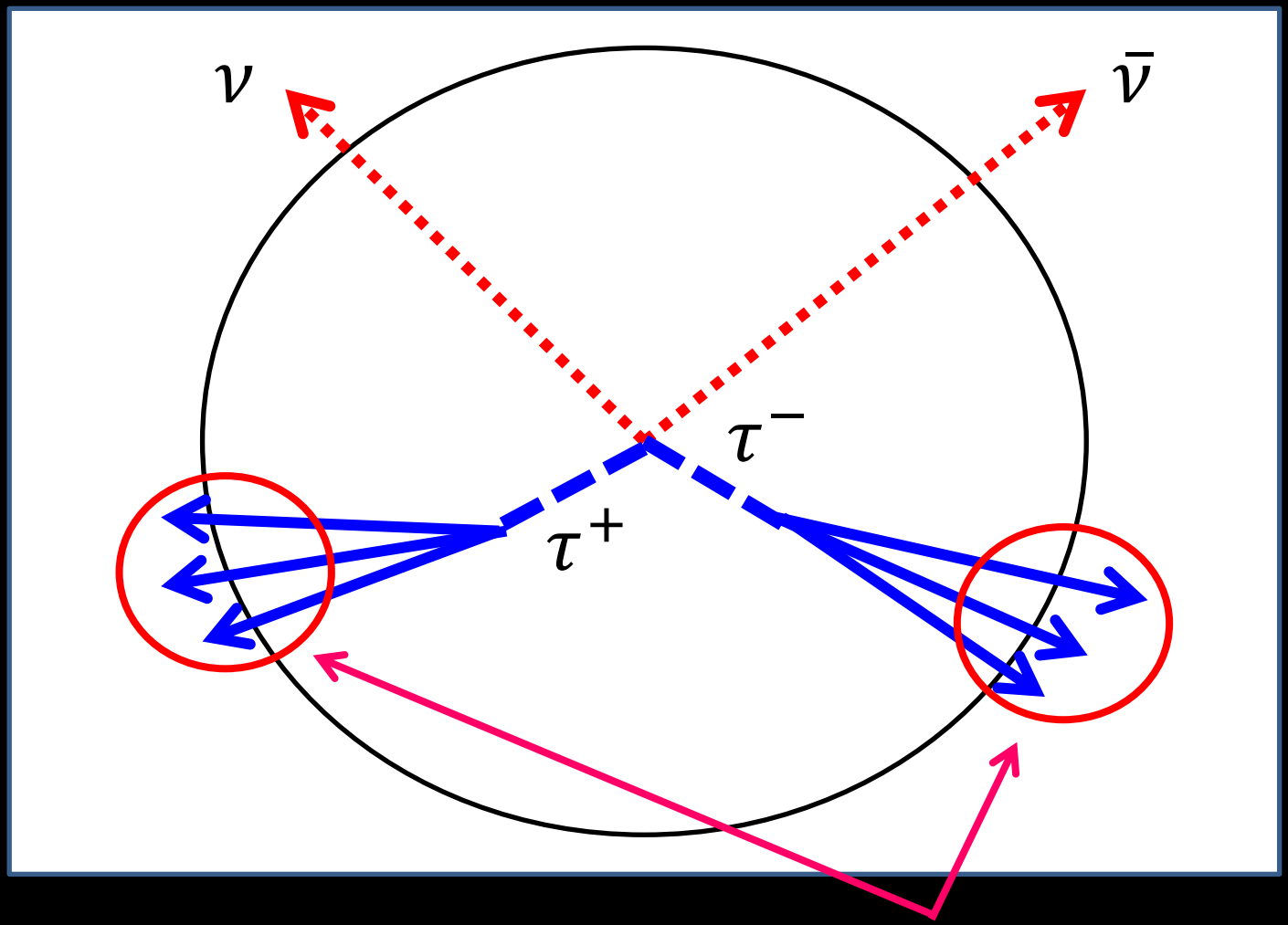




tau reconstruction

clustering based on tau mass

Tau Reconstruction



Event Reconstruction

- Most energetic tau+ and tau- is combined as the Higgs boson. ---> suppress combinatorial background ($\gamma\gamma \rightarrow \mathrm{hadrons}$ overlay)

Results of $\nu\nu H$ mode

$\sqrt{s} = 500$ GeV ($M_H = 125$ GeV)
(preliminary)

	signal	all bkg.
No cut	5401	3.006e+07
After cut	**1382**	9464

significance = 13.3σ

$$\leftrightarrow \frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})} = 7.5\%$$