Measuring the Higgs Branching Ratio into Tau Pairs at the ILC

Shin-ichi Kawada (Hiroshima University)

Collaborators:

Tomohiko Tanabe (ICEPP, The University of Tokyo)

Taikan Suehara (Kyushu University)

Tohru Takahashi (Hiroshima University)

Keisuke Fujii (KEK)

$h \to \tau^+\tau^-$ Activities in 2013

- Branching ratio study: SK mainly worked on $\sqrt{s} = 500$ GeV case.
  - lots of talks and documents (next page)
- Higgs CP study: $\sqrt{s} = 250$ GeV case studied by H. Yokoyama (The University of Tokyo)

Talks	Documents
JPS Meeting @ Hiroshima U.	LC-REP-2013-001 input to TDR
ECFA LC 2013 @ DESY	proceedings of APPC12 accepted, will be published soon (on early 2014?)
Snowmass EF Workshop @ Washington U.	arXiv:1308.5489 input to Snowmass process and ILC Higgs White paper
APPC12 (poster) @ Makuhari Messe	proceedings of LCWS2013 will be submitted to arXiv soon
JPS Meeting @ Kochi U.	
LCWS2013 @ Tokyo U.	

Activities in 2013

$Br(h \to \tau^+\tau^-)$

Numbers in Higgs Working Group Report

	ILC 250/500/1000 GeV		ILC LumiUp‡ 250/500/1000 GeV		CLIC 1.4/3.0 TeV		TLEP 240 & 350 GeV
	ZH	$\nu\bar{\nu}H$	ZH	$\nu\bar{\nu}H$	$ZH^\dagger$	$\nu\bar{\nu}H$	$ZH(\nu\bar{\nu}H)$
Inclusive	2.6/3.0/–%	–	1.2/1.7/–%	–	4.2%	–	0.4%
$H \to \gamma\gamma$	29-38%	–/20-26/7-10%	16/19/–%	–/13/5.4%	–	11%/< 11%	3.0%
$H \to gg$	7/11/–%	–/4.1/2.3%	3.3/6.0/–%	–/2.3/1.4%	6%	1.4/1.4%	1.4%
$H \to ZZ^*$	19/25/–%	–/8.2/4.1%	8.8/14/–%	–/4.6/2.6%		2.3/1.5%	3.1%
$H \to WW^*$	6.4/9.2/–%	–/2.4/1.6%	3.0/5.1/–%	–/1.3/1.0%	2%	0.75/0.5%	0.9%
$H \to \tau\tau$	4.2/5.4/–%	–/9.0/3.1%	2.0/3.0/–%	–/5.0/2.0%	5.7%	2.8%/< 2.8%	0.7%
$H \to b\bar{b}$	1.2/1.8/–%	11/0.66/0.30%	0.56/1.0/–%	4.9/0.37/0.30%	1%	0.23/0.15%	0.2% (0.6%)
$H \to c\bar{c}$	8.3/13/–%	–/6.2/3.1%	3.9/7.2/–%	–/3.5/2.0%	5%	2.2/2.0%	1.2%
$H \to \mu\mu$	–	–/–/31%	–	–/–/20%	–	21/12%	13%
	$t\bar{t}H$		$t\bar{t}H$		$t\bar{t}H$		$t\bar{t}H$
$H \to b\bar{b}$	–/28/6.0%		–/16/3.8%		8%/< 8%		–

arXiv:1310.8361 [hep-ex]

Higgs Working Group Report of
the Snowmass 2013 Community Planning Study

$q\bar{q}h$ @ 500 GeV

Simulation Settings

Higgs properties:

$M_h = 125$ GeV

$\mathrm{Br}(h \to \tau^+\tau^-) = 6.32\%$ (LHC Higgs XS WG)

Machine parameters:

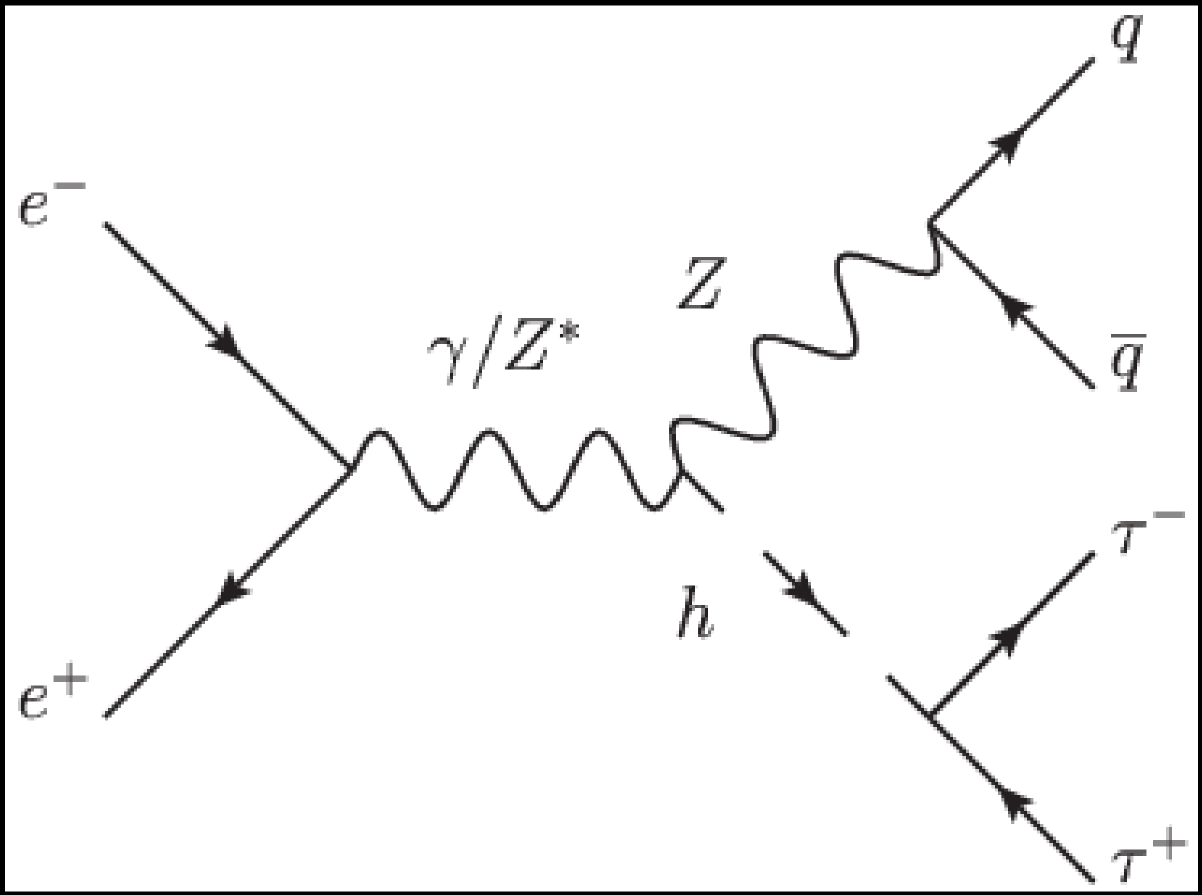
$\sqrt{s} = 500$ GeV, $\int L\,dt = 500$ fb^{-1},

beam pol. $P(e^-, e^+) = (-0.8, +0.3)$

Samples:

TDR samples (2f, 4f, 5f, 6f, $\gamma\gamma \to$ 4f, Higgs)

Signal

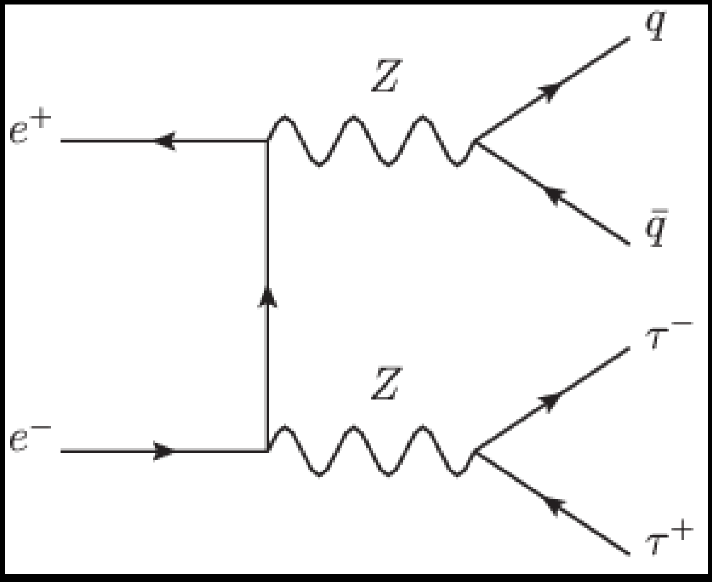


Higgs-strahlung

$e^+e^- \to Zh$

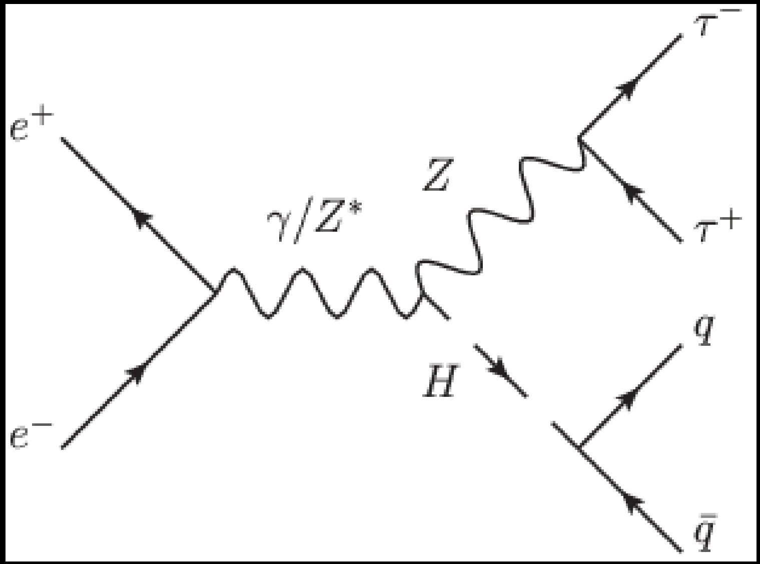
with $Z \to q\bar{q}$

Main Backgrounds



$$e^+e^- \to ZZ \to q\bar{q}\tau^+\tau^-$$

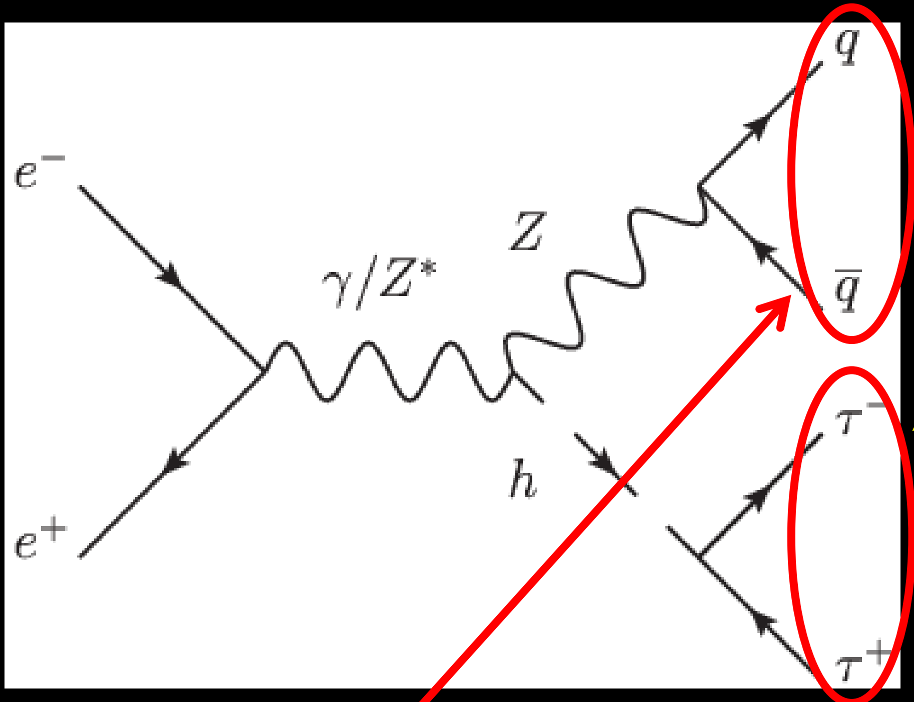
irreducible process



$$e^+e^- \to Zh$$
$$\to (\tau^+\tau^-)(q\bar{q})$$

mimic signal

Reconstruction



(0) k_t clustering

remove beam-induced background ($\gamma\gamma \rightarrow$ hadron(s))

(1) tau & Higgs reco.

tau jet finder

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

collinear approx.

tau pair mass reconstruction

(2) Z reco.

jet finder with Durham algorithm into 2 jets by T. Suehara

TaJet finder (1)

High-purity tau tagging
in presence of jet background

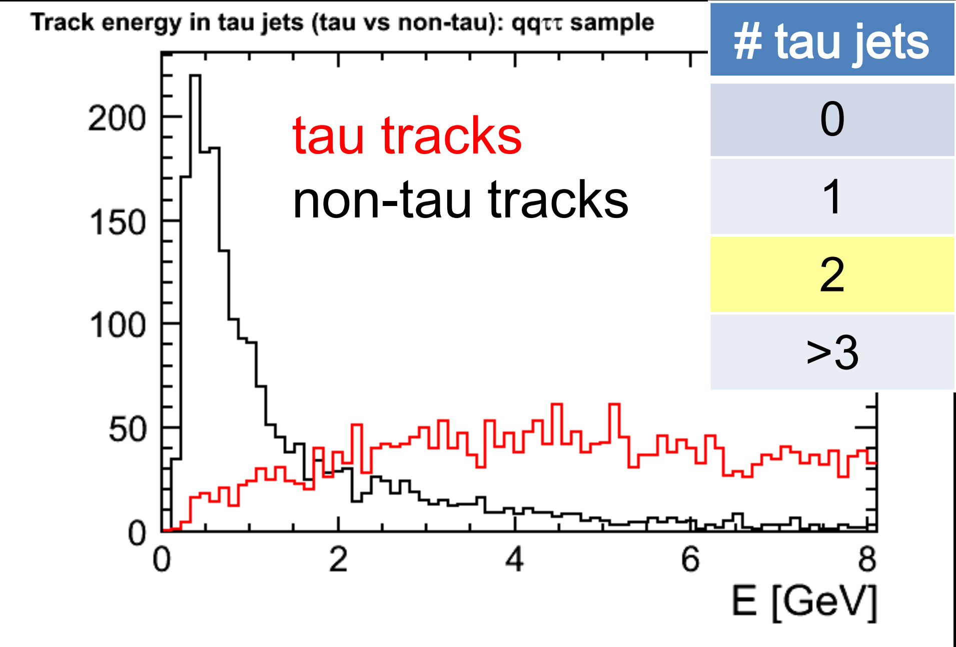
1. Order charged tracks by largest energy
2. Select the first track
3. Combine neighboring particles -> "Tau Jet"
   - Combined mass < 2 GeV && cosθ w.r.t. jet axis > 0.98
4. Tau selection (tuned for rejecting qq background)
   1. Tau Jet energy > 3 GeV
   2. Veto >=3 prong + neutrals (> 1 GeV)
   3.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

ZZ -> qq$\tau\tau$ 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

by T. Suehara

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	$qq\tau\tau$	$qql\nu$
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)

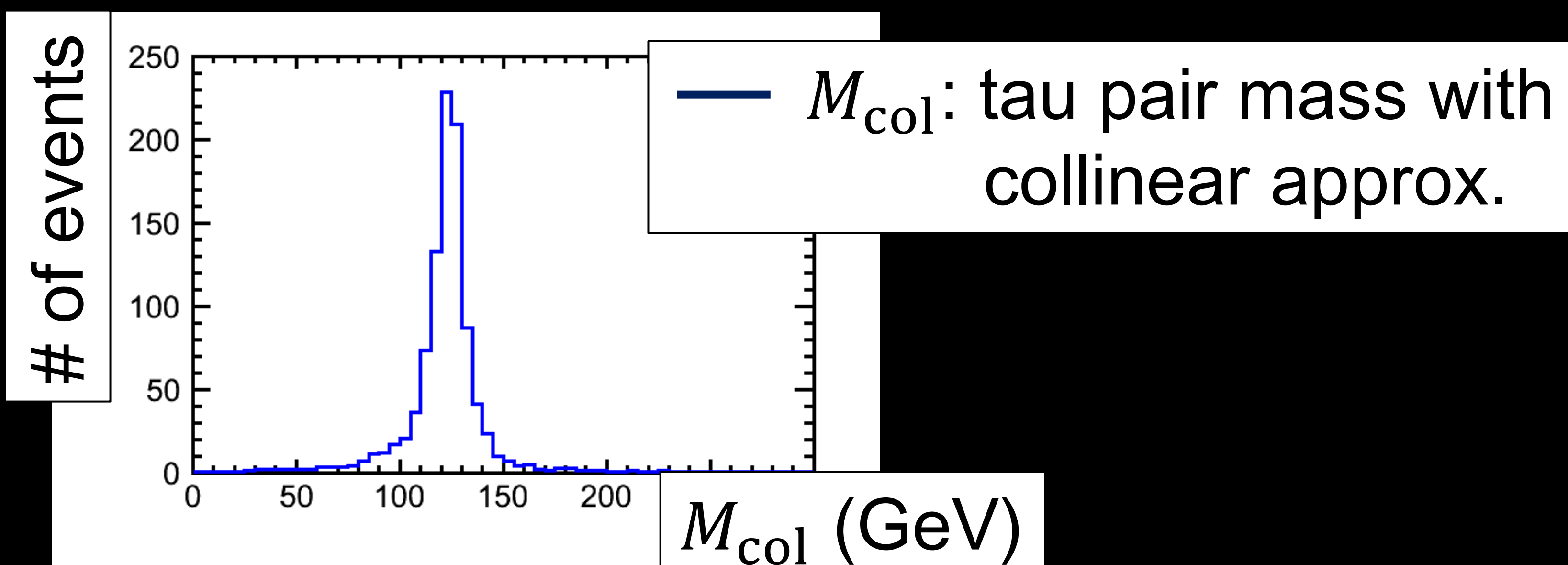
Collinear Approximation

Method of reconstructing tau pair mass ($M_{\tau^+\tau^-} = M_h$)

Assumptions:

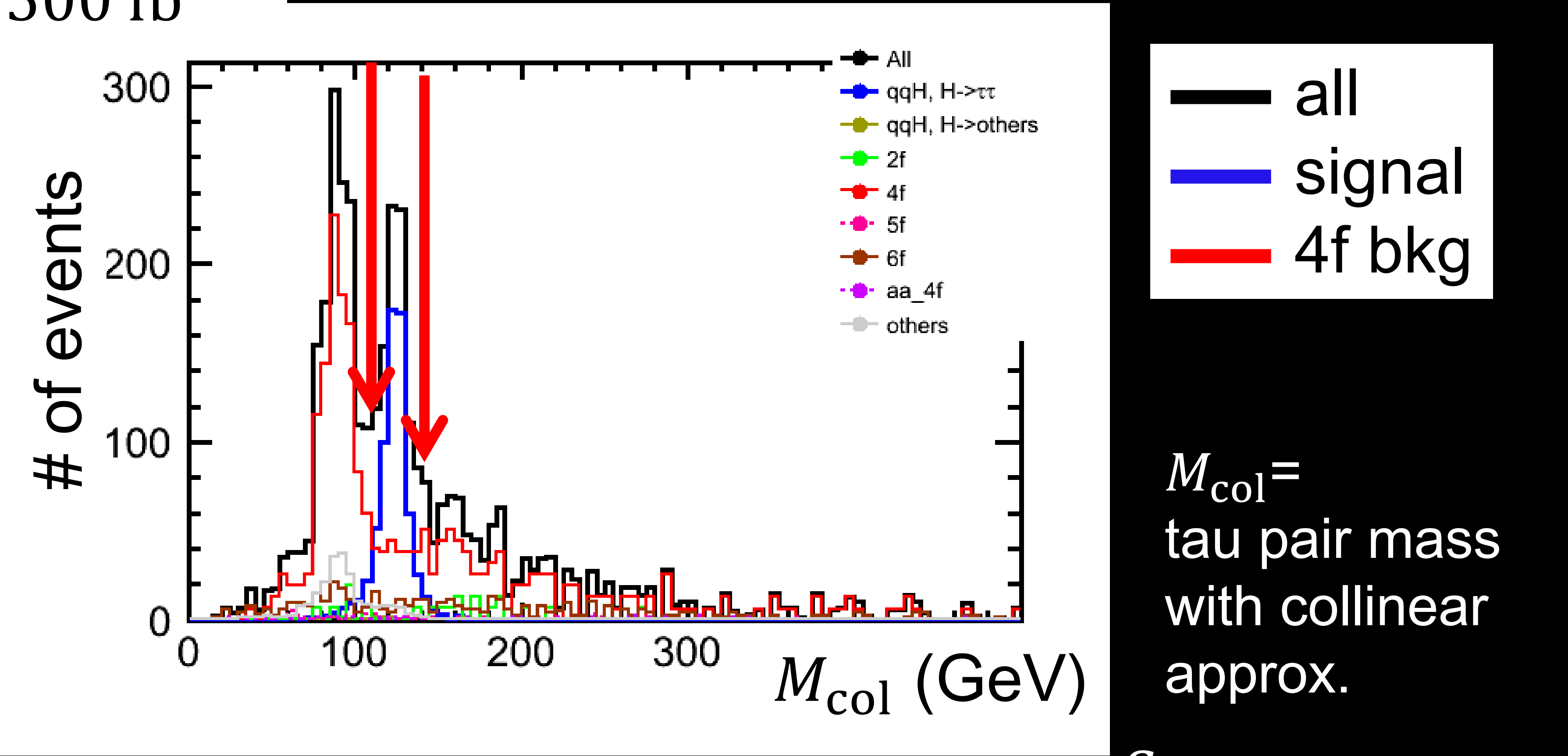
- visible tau decay products and neutrinos are collinear
- contribution of missing transverse momentum comes only from neutrinos of tau decay

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



$\int L\,dt = 500\ \mathrm{fb}^{-1}$

Cut-based Analysis



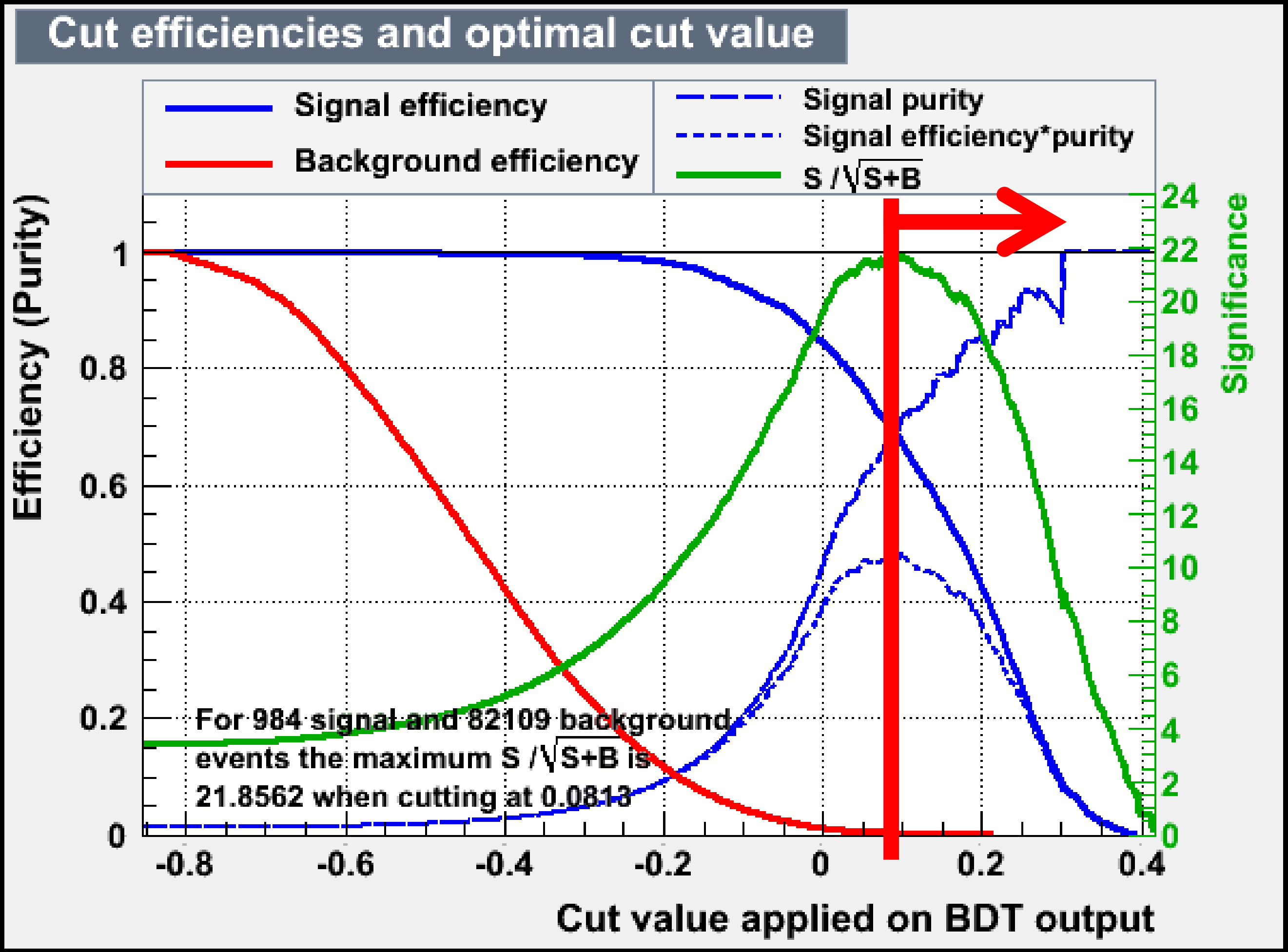
M_{col}= tau pair mass with collinear approx.

	signal	4f	other SM bkg
No cut	2158	1.598*10^7	1.409*10^7
After cut	530.9	124.0	74.3

$$\frac{S}{\sqrt{S+B}} = 19.7\sigma$$

$$\frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})} = 5.1\%$$

TMVA Analysis



BDT analysis optimized for the pre-cut

remained events: $N_{\mathrm{sig}} = 691.2,\ N_{\mathrm{bkg}} = 309.0$

$\frac{S}{\sqrt{S+B}} = 21.9\sigma,\ \frac{\Delta(\sigma\cdot\mathrm{Br})}{(\sigma\cdot\mathrm{Br})} = \mathbf{4.6\%}$

Summary: Current Numbers

$\sqrt{s}$	250 GeV	500 GeV			
$\int L\,dt$	250 fb^{-1}	500 fb^{-1}			
Mode	$q\bar{q}h$ e^+e^-h $\mu^+\mu^-h$	$\nu\bar{\nu}h$	$q\bar{q}h$	e^+e^-h	$\mu^+\mu^-h$
$\frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})}$ Cut-based	4.2% Extrapolation from $M_h = 120$ GeV to $M_h = 125$ GeV	7.4%	5.1%	20.8%	18.2%
$\frac{\Delta(\sigma \cdot \mathrm{Br})}{(\sigma \cdot \mathrm{Br})}$ TMVA	-	6.0%	4.6%	22.7%	17.5%

Plans for Next Year

- Check the results and more optimization for $\sqrt{s} = 500$ GeV
- Re-do the analysis of $\sqrt{s} = 250$ GeV with $M_h = 125$ GeV (Cut-based and TMVA)
- Write a paper & PhD thesis

	$\nu\nu h$ $h \to \tau\tau$	$\nu\nu h$ $h \nrightarrow \tau\tau$	2f	4f	5f	6f	aa_4f	$\nu\nu h$ llh	signi.
No Cut	2158	3.139e04	1.320e07	1.598e07	6.895e05	5.888e05	1.041e05	9.511e04	0.394
pre-sel	969.6	223.5	8.053e04	2.113e05	4237	1.700e04	4062	4696	1.71
# of tracks	936.3	219.1	2.328e04	1.516e05	3762	1.663e04	2496	4522	2.08
M_{vis}	929.3	209.7	1.118e04	1.250e05	3500	1.626e04	1831	3569	2.31
P_t	893.0	201.8	6083	7.985e04	2763	1.508e04	1233	3467	2.7
thrust	844.7	173.5	1819	4.504e04	2703	1.495e04	1203	3251	3.19
$\cos\theta_{\mathrm{miss}}$	781.9	145.7	506.8	2.211e04	1497	1.238e04	567.2	2117	3.9
$M_Z(M_{qq})$	701.1	104.1	89.73	1.282e04	766.8	4660	292.2	1889	4.8
$E_Z(E_{qq})$	660.8	98.57	62.02	9473	254.8	1172	89.27	1398	5.75
$\cos\theta_{qq}$	660.5	98.57	54.59	9388	254.8	1166	89.27	1396	5.77
$M_{\tau\tau}$	658.4	96.53	33.40	7032	117.3	822.9	37.69	1253	6.57
$E_{\tau\tau}$	657.2	96.53	33.40	5878	109.1	822.9	36.69	1179	7
$\cos\theta_{\tau\tau}$	655.8	49.73	20.67	3311	94.10	727.2	27.81	390.4	9.03
$d_0$sig	617.2	22.23	20.29	1860	34.43	333.8	15.90	216.1	11
M_{colapp}	539.4	5.265	0.376	168.4	3.575	40.83	0	33.25	19.2
E_{colapp}	537.6	4.680	0.376	136.6	3.575	40.82	0	33.10	19.5
M_{recoil}	530.9	4.680	0.376	124.0	3.575	33.25	0	32.37	19.7