Detector requirements from physics: Higgs

Taikan Suehara
Tohoku University

TOHOKU
UNIVERSITY

Higgs is a key to TeV world

GeV world
where SM is
dominant

TeV world
where SM is just
a perturbation

Fermion
mass generation
by Yukawa coupling

Electroweak
symmetry breaking

"The last fundamental
piece unproved in
Standard Model"

Vacuum
condensation
& hhh coupling

Higgs issues
- Naturalness
- Composite Higgs?
- Multiple Higgs?

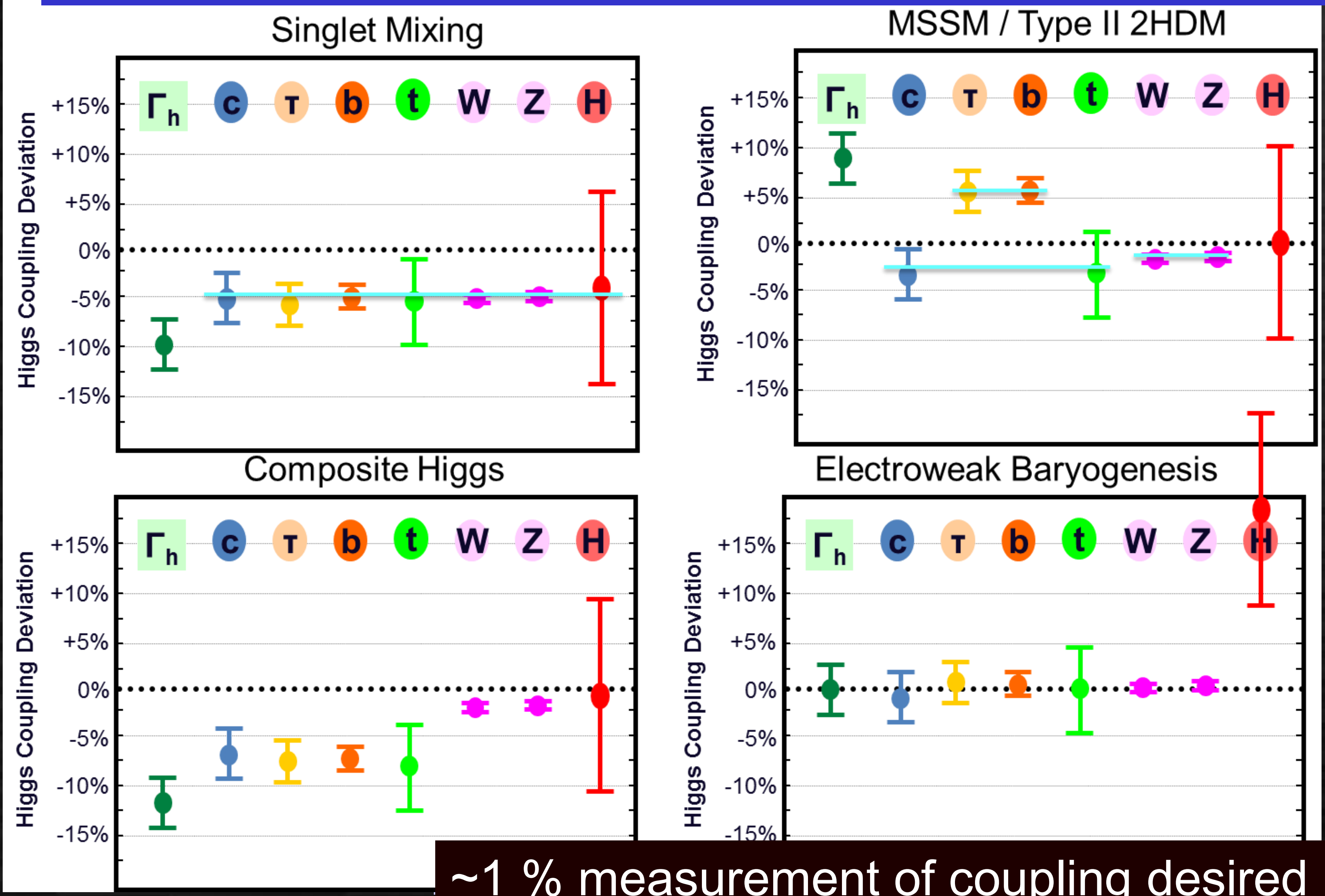
BSM
(SUSY?)

Dark
Matter?

Baryo-
genesis?

Higgs and BSM theories

Typical samples: real deviation of course varied by model parameters



~1 % measurement of coupling desired

Higgs physics program: revisited

target	process	CME	δ(stat)	detector challenge
σ_{ZH}	llh	250	2.6%	track momentum, beam spectrum
		500	4.8%	
	qqh	250	yet	W/Z separation, b-tag, jet charge
		500	3.9%	
BR	h->bb	250	1.0%	b-tag
	h->cc	250	6.9%	c-tag
Width	h->ZZ*	250	19%	W/Z separation, b-tag, jet charge
rare	tth	500	35%	b-tag, jet energy, jet charge
		1000	8%	
	Zhh / $\nu\nu$hh	500	88%	
		1000	21%	

global fit

Snowmass energy frontier report

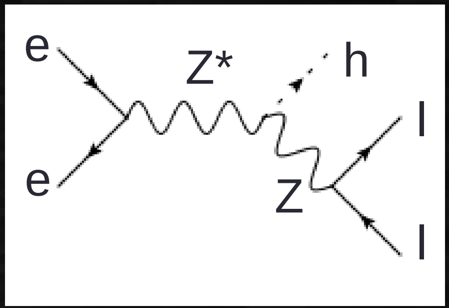
Model independent

Facility		ILC		ILC(LumiUp)
$\sqrt{s}$ (GeV)	250	500	1000	250/500/1000
$\int \mathcal{L} dt$ (fb^{-1})	250	+500	+1000	1150+1600+2500
$P(e^-, e^+)$	$(-0.8, +0.3)$	$(-0.8, +0.3)$	$(-0.8, +0.2)$	(same)
Γ_H	11%	5.9%	5.6%	2.7%
BR_{inv}	$< 0.69\%$	$< 0.69\%$	$< 0.69\%$	$< 0.32\%$
κ_γ	18%	8.4%	4.1%	2.4%
κ_g	6.4%	2.4%	1.8%	0.93%
κ_W	4.8%	1.4%	1.4%	0.65%
κ_Z	1.3%	1.3%	1.3%	0.61%
κ_μ	–	–	16%	10%
κ_τ	5.7%	2.4%	1.9%	0.99%
κ_c	6.8%	2.9%	2.0%	1.1%
κ_b	5.3%	1.8%	1.5%	0.74%
κ_t	–	14%	3.2%	2.0%

limited by σ_{ZH} @ 250 GeV

ll recoil (preliminary)

S. Watanuki, TS

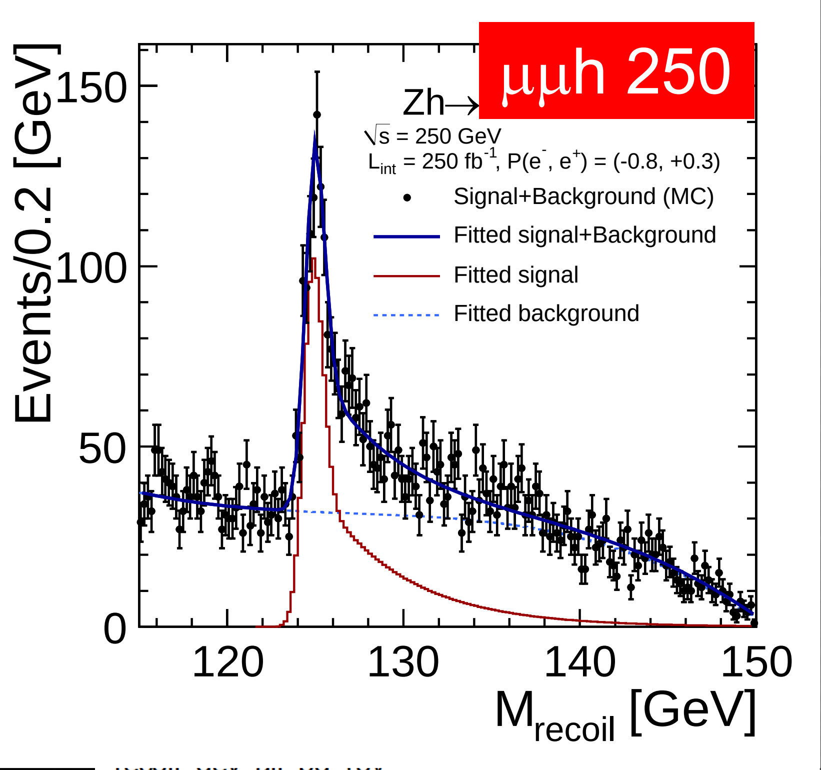


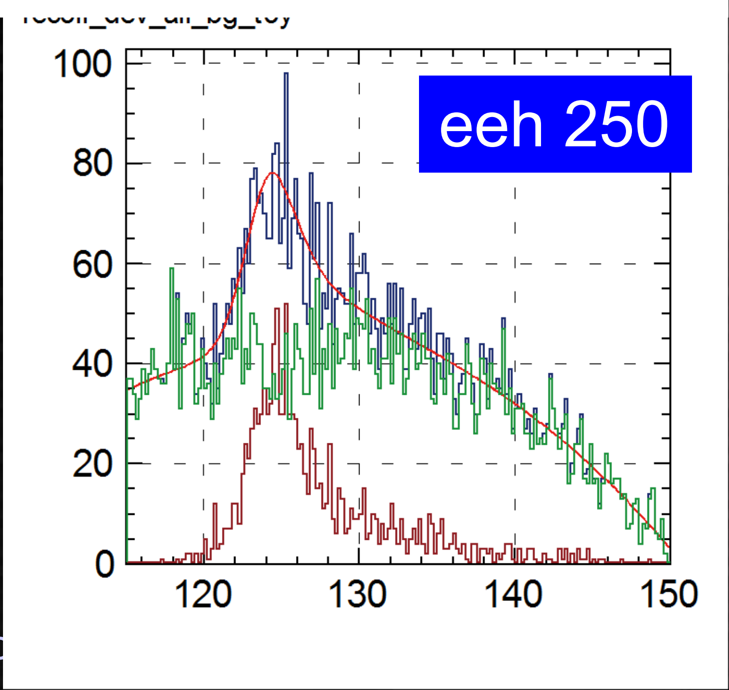
Recoil mass
- do not see
'h' to measure 'h'

proc	N (no cut)	N (cut)
μμh	2,574	1,565
μμνν	150,000	2,401
μμff	160,000	1,734
τlnn	600,000	333
others	(mainly μμ)	350

μμh 250

CME/meas	μμh	eeh	combined
250 / mass	37 MeV	-	-
250 / σ_{ZH}	3.6%	5.2%	3.0%
500 / σ_{ZH}	6.5%	7.1%	4.8%





Taikan Suehara, ILD worksho

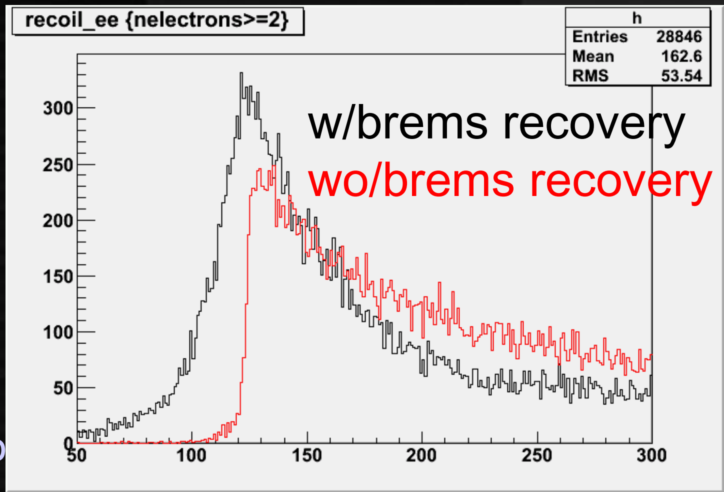
ll recoil

- Major performance driver
  - Background: mainly irreducible (2l + X)
  - Peak width: beam energy spread

LoI

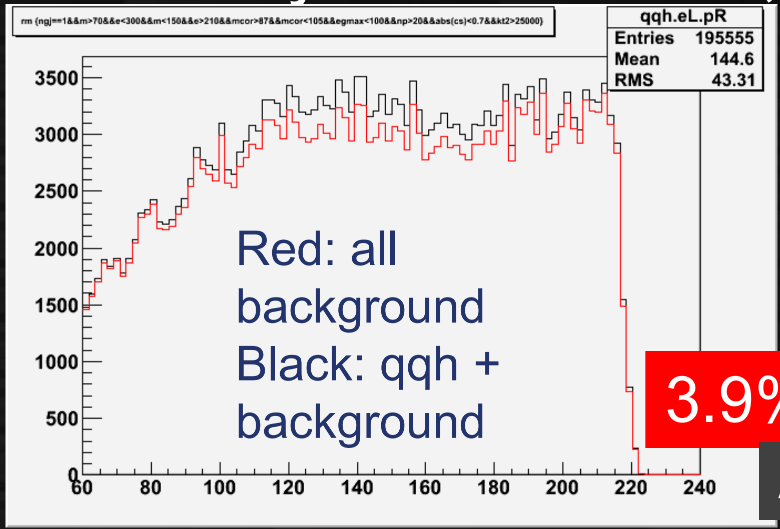
	$\Delta M_{tot.}$ (MeV)	ΔM machine	ΔM detector
$\mu\mu X$	650	560	330
eeX	750	560	500

- Detector-related performance drivers
  - Momentum resolution – keep current?
  - ISR tagging – not studied yet
  - Lower material – brems in eeh
    - but effect is minor?



qq recoil

- Dedicated to absolute cross section meas.
  - hope to improve σ_{ZH} greatly
- > 10 x statistics compared to llh
- Less model independent –
  efficiency affected more on Higgs final state
  - Smaller effects also exist in llh – to be checked
- 250 GeV yet to be done, 350/500 done (preliminary)



currently not so powerful as llh, but another 3.9% is anyhow important for combination

3.9% (500 GeV)

qq recoil

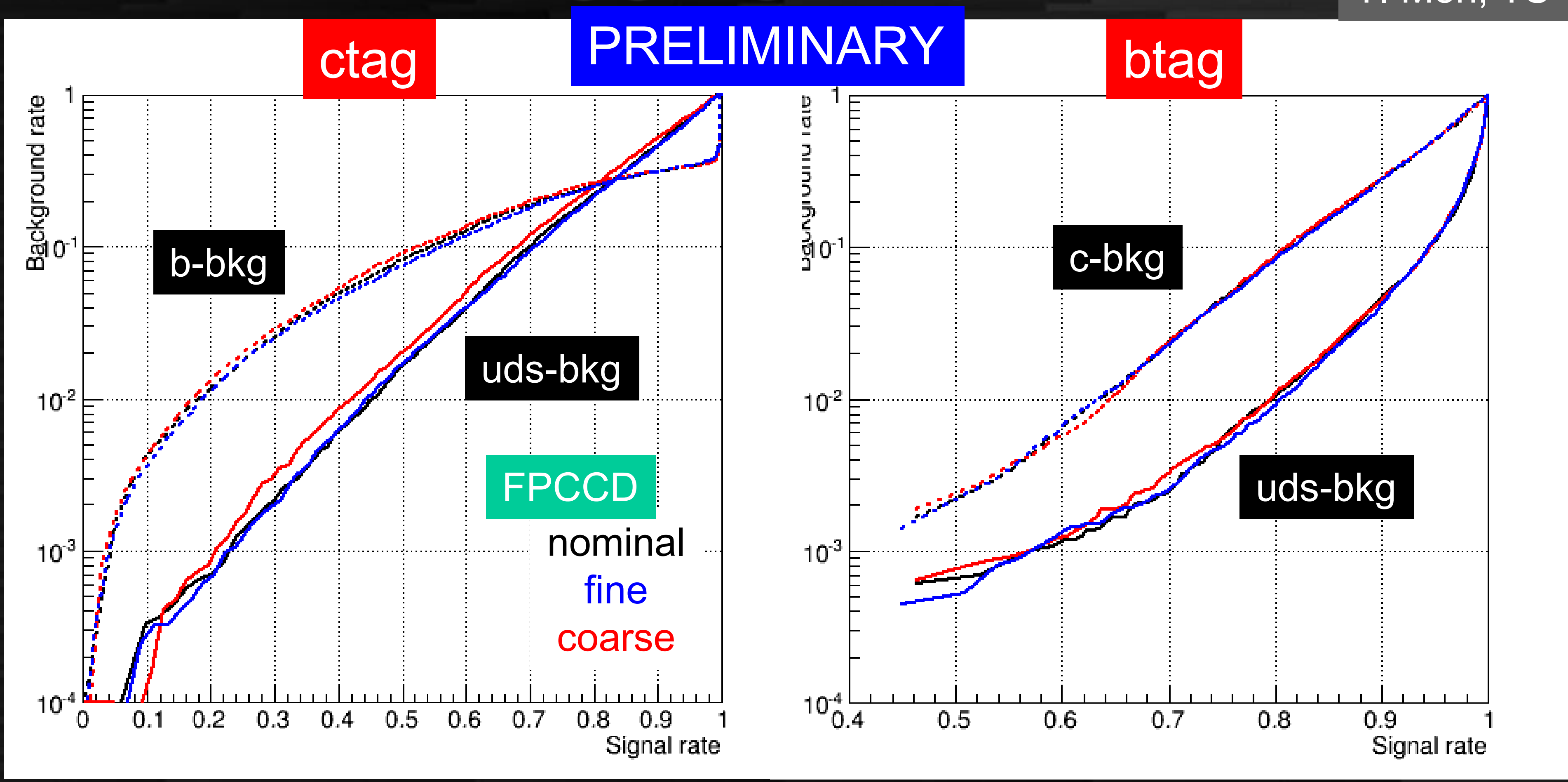
- Strategy
  - Fixed y (Durham) or R (k_T) clustering
  - Select combination using Z mass
    b-tag / c-tag / jet charge may be usable
  - Apply several cuts to Z/recoil
    to separate WW/ZZ
  - Calculate recoil
- Detector requirement
  - Jet energy resolution (W/Z separation, recoil)
  - flavor tagging / jet charge (minor)

h→bb, cc, gg

- main processes to determine Yukawa coupling of Higgs
  - h→bb: great accuracy expected (<< 1%)
    - maybe limited by b-mass accuracy
    - systematic errors should be carefully investigated
  - h→cc: not possible at all in LHC
  - h→gg: not possible directly in LHC
    - But cannot separate from u/d/s quarks in ILC
- Performance depends almost exclusively on flavor tagging – good benchmark

flavor tagging vs pixel size

T. Mori, TS



Actually complicated – depends on vertex finding efficiency, b-c separation efficiency with optimization of algorithm

Some difference in c-tag, less apparent in b-tag

Zhh, tth

- huge background of tt
- many jets in final states
- → very high purity b-tag is essential
- → jet clustering

Zhh 500 GeV, m_h=120 GeV

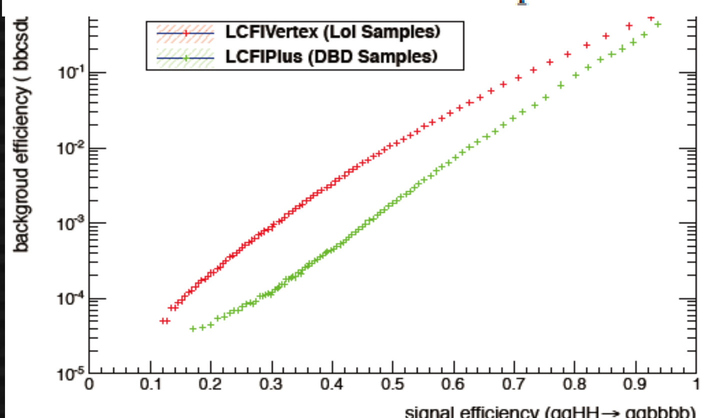
Decay mode	BR.	# events in 2 ab^{-1}
qqbbbb	32%	146
ννbbbb	9%	42
qqbbWW*->qqbbqqqq	6%	28
tt -> bbqqqq		~800,000
ZZZ, ZZH -> qqbbbb		~600

Cut	leptonic	semileptonic	hadronic	tth→other	$t\bar{t}Z$	$t\bar{t}b\bar{b}$	$t\bar{t}$	$\frac{S}{\sqrt{S+B}}$
Total Events	151.4	628.7	652.7	1046.1	5332.4	1434.5	308800.9	1.11
$BDTG_{semil} > 0.1325$	18.7	208.0	2.1	10.1	126.1	125.4	261.2	7.59

Table 4: The number of events passed each cut in the TMVA analysis for the semileptonic channel.

Cut	leptonic	semileptonic	hadronic	tth→other	$t\bar{t}Z$	$t\bar{t}b\bar{b}$	$t\bar{t}$	$\frac{S}{\sqrt{S+B}}$
Total Events	151.4	628.7	652.7	1046.1	5332.4	1434.5	308800.9	1.11
$BDTG_{had} > -0.5334$	0.3	65.5	365.6	25.0	260.5	222.6	513.6	9.59

Table 5: The number of events passed each cut in the TMVA analysis for the hadronic channel.



	ILC500	ILC500-up	ILC1000	ILC1000-up
$\sqrt{s}$ (GeV)	500	500	500/1000	500/1000
$\int \mathcal{L}dt$ (fb^{-1})	500	$1600^{\ddagger}$	500+1000	$1600+2500^{\ddagger}$
$P(e^-, e^+)$	$(-0.8, 0.3)$	$(-0.8, 0.3)$	$(-0.8, 0.3/0.2)$	$(-0.8, 0.3/0.2)$
$\sigma(ZHH)$	42.7%	?	42.7%	23.7%
$\sigma(\nu\bar{\nu}HH)$	–	–	26.3%	16.7%
λ	83%	46%	21%	13%

Higgs coupling determination

[Junping Tian]

Absolute determination of couplings require knowledge of the total width:

$$Br(H \to XX) = \frac{\Gamma(H \to XX)}{\Gamma_0} \propto \frac{g^2_{HXX}}{\Gamma_0} \quad \rightarrow \quad \Gamma_0 \propto \frac{g^2_{HXX}}{Br(H \to XX)}$$

An easy example:

$$\Gamma_0 \propto \frac{g^2_{HZZ}}{Br(H \to ZZ^*)} \propto \frac{\sigma(e^+e^- \to ZH)}{Br(H \to ZZ^*)}$$

~20% precision at 250 GeV

Performance driver:
250 GeV: ZH → ZZZ*

A more sophisticated example:

$$Y_1 = \sigma_{ZH} = g^2_{HZZ}$$

$$Y_2 = \sigma_{ZH} \cdot Br(H \to b\bar{b}) = \frac{g^2_{HZZ} \cdot g^2_{Hbb}}{\Gamma_0}$$

$$Y_3 = \sigma_{\nu\bar{\nu}H} \cdot Br(H \to b\bar{b}) = \frac{g^2_{HWW} \cdot g^2_{Hbb}}{\Gamma_0}$$

$$Y_4 = \sigma_{\nu\bar{\nu}H} \cdot Br(H \to WW^*) = \frac{g^4_{HWW}}{\Gamma_0}$$

$$\rightarrow \quad \Gamma_0 = \frac{Y_1^2 \cdot Y_3^2}{Y_2^2 \cdot Y_4}$$

~6% precision combining 250 GeV + 500 GeV

500 GeV: ννH → ννWW*

Total width: h→ZZ*/WW*

H→ZZ* @ 250 GeV

BR@125: 2.6%

not done yet?

various decay modes:

- 6q
- 4q2n
- 4q2l
- 2q2l2n
- 4l(2q,2n)

analysis needs a lot of work

separation from ZWW
→ need W/Z separation
in jet → jet energy resolution

H→WW* @ 500 GeV

BR@125: 21.5%

J. Tian

pre-selection:

- MVA to remove the very forward overlaid particles
- reject the events with isolated electron or muon
- four jets clustering and flavor tagging, No. of PFOs >= 40 (7,6,5,4)

final-selection:

- Y34 > 0.0026, Y23 > 0.0076 (cut1)
- Evis < 230 GeV, Pt > 20 GeV, MissingMass > 200 GeV (cut2)
- Isolate lepton rejection: P(Lmax) < 2*Econe + 9. (cut3)
- b-jet rejection: (btag1+2btag2<0.7, btag3+2btag4<0.14) (cut4)
- 54 < M(W1) < 94, 11 < M(W2) < 64 (cut5)
- Higgs mass: (114, 142) GeV (cut6)

$$\frac{\delta(\sigma \cdot \mathrm{Br})}{\sigma \cdot \mathrm{Br}} = 2.8\%$$

Energy	Γ_H
250	20% (just an extrapolation)
500	6%

Misc analyses

- Angular property of Higgs in search of BSM
  - H→WW* anomalous coupling (Takubo et al.)
    - Will improve using c-jet charge
  - H→$\tau\tau$ with Higgs CP-mixing (Yokoyama et al.)
    - Require τ decay measurements

Physics summary

Measure	Detector challenge	Current @CME (nominal lumi)	Improve needs / possibility	Critical other than detector
mass	tracking	37 MeV @ 250	* / **	beam
σ_{ZH}	calo/vertex	3% @ 250	**** / ***	qqh analysis
h->bb	vertex(b-tag)	1% @ 250	** / **	b mass
h->cc/gg	vertex(c-tag)	7-8% @ 250	*** / ***	c-tag algo
h->$\tau\tau$	vertex(d_0/z_0)	4% @ 250	*** / **	
h->WW*	calorimeter	6% @ 250	** / **	
h->ZZ*	calorimeter	(19% @ 250)	*** / ***	analysis
h->$\gamma\gamma$	calorimeter	30% @ 250	* / **	
h->$\mu\mu$	tracking	30% @ 1000	** / *	
tth	vertex/calo	4.3% @ 1000	*** / **	jet clustering
hhh	vertex/calo	21% @ 1000	**** / **	jet clustering

coupling

Detector requirements summary

- Vertex finder
  - b-tag (tth, hhh)
  - c-tag (h->cc)
- Tracking
  - no critical
- Calorimeter/PFA
  - W/Z separation (qqh, h->ZZ*) esp. ~ 50 GeV
    - Analysis needed!
    - Better energy resolution?
  - resolution in general (tth, hhh) 100 - 200 GeV
    - Jet clustering more important

PFA still
have some room?

	Frac	σ/√E	Identical case (100 GeV)
Photon	~ 30%	15%	15% / √30 x 30 = 0.82
Neut. H	~ 10%	60%	60% / √10 x 10 = 1.90
PFA		30%	0.82 (+) 1.90 = 2.07 GeV

Things to do

- Analysis with benchmark detectors
  - Better performance
    - better vertex resolution
    - better energy resolution
  - Better in cost
    - worse energy resolution (fewer segment / smaller radius)
    - smaller magnetic field

intensive work by all analysis workers is highly needed!

- Software/analysis
  - Systematic errors with control samples
  - Better algorithms
    - flavor tag, jet clustering, MVA analysis etc.

Total width: h→ZZ*/WW*

$$\Gamma_H = \Gamma(H \to XX) \,/\, BR(H \to XX)$$

Analysis with the same vertex of production and decay

250: $e^+e^- \to Z^* \to Zh \to ZZZ^*$

500: $e^+e^- \to \nu\nu W^*W^* \to \nu\nu h \to \nu\nu WW^*$

performance drivers

Partial cross section / total cross section

Use recoil at 250

h→ZZ* analysis:

- 6q
- 4q2n
- 4q2l
- 2q2l2n
- 4l(2q,2n)

separation from ZWW → need W/Z separation in jet → jet energy resolution

not analyzed yet!

Energy	Γ_H
250	20% (not confirmed!)
500	6%