

Higgs BR study status

ILC Physics WG general meeting

2014. Apr. 19

H. Ono (NDU)

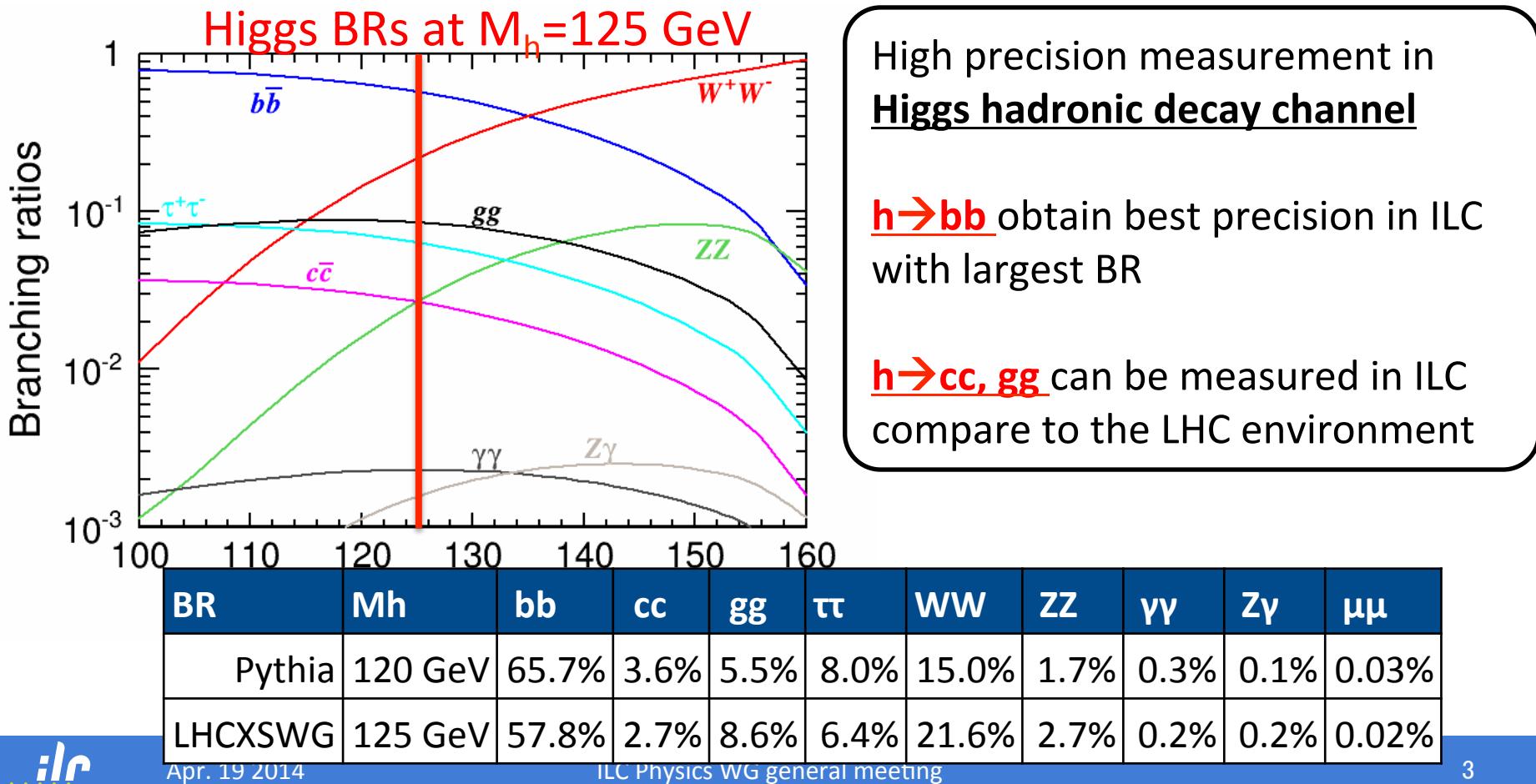
ILC physics requirements

- ILC parameter group require the update of analysis results with $M_h=125$ GeV
- Need to estimate required luminosity to establish the ILC running scenario, staging and start energy especially 250, 350 and 500 GeV.
- 350 GeV evaluation is also requested to evaluate running scenario.
(Recoil and BRs are important arguments)

Higgs BR study in ILC

Important task to measure $\sigma \times \text{BR}$ in ILC

- Determine absolute Higgs BR ($\sigma_{Z\text{H}}$ model independent measurement)
- Complementary study with LHC in Higgs hadronic decay channel



Higgs production in ILC

Higgs major production process

$$e^+ e^- \rightarrow Z h \text{ (Higgs-strahlung)}$$

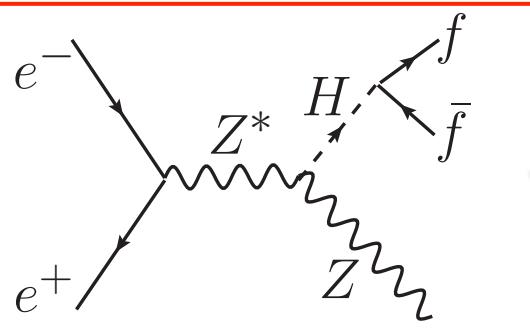
$$e^+ e^- \rightarrow vvh/eeh \text{ (WW/ZZ fusion)}$$

250 GeV: σ_{ZH} , mass

350 GeV: tt, Higgs width

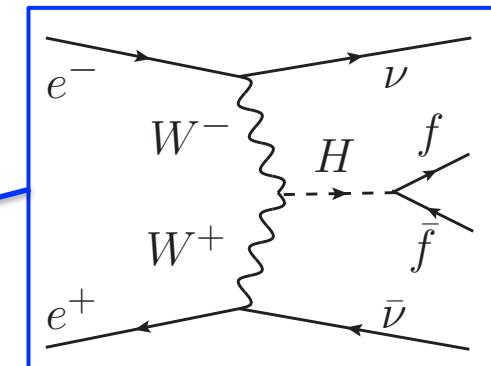
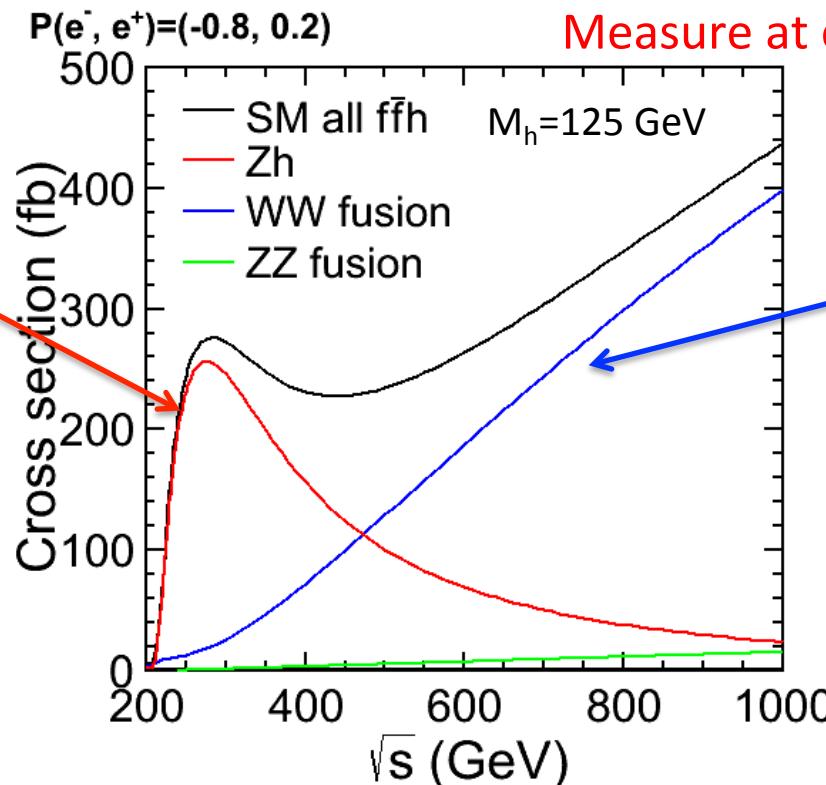
500 GeV: Higgs self-coupling, tth

1 TeV: $h \rightarrow \mu\mu$, rare channel



Zh (Higgs-strahlung)

Cross section measurement
with model independent
 \rightarrow Basic properties



WW-fusion

Increase cross section
and luminosity
 \rightarrow Higher statistics

Ecm	250 GeV			350 GeV			500 GeV			1 TeV
L (fb^{-1})	250	250	250	250	330	330	500	500	500	1000
Prod.	Zh	Zh	vvh	Zh	Zh	vvh	vvh	Zh	vvh	vvh
M_h	120	125	125	120	125	125	120	125	125	125
$h \rightarrow bb$	Ono	Ono	DESY	Ono	Ono	DESY	Ono T. J.		T. J.?	Ono
$h \rightarrow bb$	Ono	Ono		Ono	Ono	DESY	Ono			Ono
$h \rightarrow gg$	Ono	Ono		Ono	Ono	DESY	Ono			Ono
$h \rightarrow WW^*$	Ono	Ono			Ono	DESY	T. J.		T. J.?	Ono
$h \rightarrow \tau\tau$	S. K.	S.K.					S. K.	S. K.	S.K.	S. K.
$h \rightarrow \gamma\gamma$									C. C.	C. C.
$h \rightarrow ZZ^*$	T. J. ?									
$h \rightarrow \mu\mu$										C. C.

LOI : $M_h=120 \text{ GeV}$, ilcsoft_v01-06, ILD_00, LCFIVTX flavor tag
 DBD: $M_h=125 \text{ GeV}$, ilcsoft_v01-16-02, ILD_o1_v05, LCFIPlus flavor tag, $\gamma\gamma$ overlay



Current results of $\Delta\sigma\text{BR}/\sigma\text{BR}$

Re-doing with Higgs mass of 125 GeV for 250 and 350 GeV

E_{cm} (GeV)	250	350	500	1000
Pol (e-,e+)	(-0.8,+0.3)	(-0.8,+0.3)	(-0.8,+0.3)	(-0.8,+0.2)
Lumi (fb^{-1})	250	250	500	1000
Simulated samples	LOI			DBD
M_h (GeV)	120	120	120	125
$\Delta\sigma\text{BR}/\sigma\text{BR}(h \rightarrow bb)$	1.0%	1.0%	0.57%	0.39%
$\Delta\sigma\text{BR}/\sigma\text{BR}(h \rightarrow cc)$	6.9%	6.2%	5.2%	3.9%
$\Delta\sigma\text{BR}/\sigma\text{BR}(h \rightarrow gg)$	8.5%	7.3%	5.0%	2.8%
$\Delta\sigma\text{BR}/\sigma\text{BR}(h \rightarrow WW^*)$	8.1%		3.0%	2.5%

Analyses are performed on Post LOI and DBD studies

Zh at 250 and 350 GeV analysis

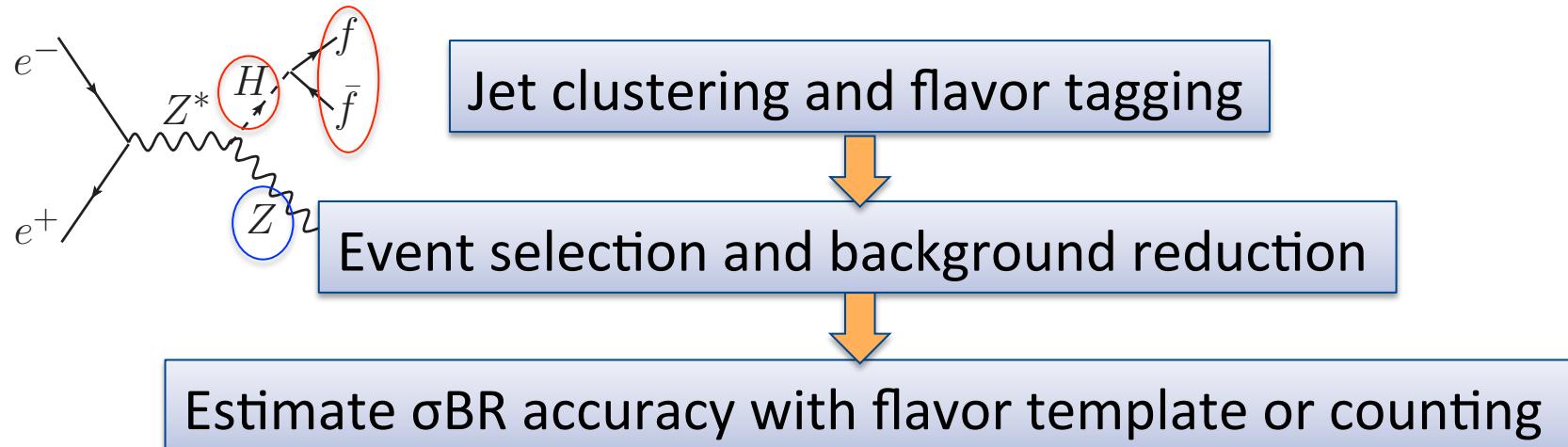
Higgs mass: **125 GeV**

$E_{cm}=250 \text{ GeV}$: $L=250 \text{ fb}^{-1}$, $P(e^-, e^+) = (-0.8, +0.3)$

$E_{cm}=350 \text{ GeV}$: $L=300 \text{ fb}^{-1}$, $P(e^-, e^+) = (-0.8, +0.3)$ ← to be $L=330 \text{ fb}^{-1}$

Zh process categorized by Z decay: e⁺e⁻→Zh→vvh, qqh, llh

Major SM BGs: ee→WW/ZZ (2f, 3f, 4f, aa, and 6f, tt for 350 GeV)



$h \rightarrow bb, cc, gg$ accuracies are evaluated with flavor template fitting

$\Delta\sigma\text{BR}/\sigma\text{BR}$ $E_{\text{cm}}=250$ GeV

$E_{\text{cm}}=250$ GeV comparing extrapolated and simulated results

$E_{\text{cm}}=250$ GeV	Extrapolation			New sample results		
M_h	$120 \rightarrow 125$ GeV			125 GeV		
Lumi.	250 fb^{-1}			250 fb^{-1}		
$\Delta\sigma\text{BR}/\sigma\text{BR}$	bb	cc	gg	bb	cc	gg
vvh	1.8%	12.9%	11.2%	1.6%	13.4%	9.3%
qqh	1.6%	11.8%	10.5%	1.6%	21.3%	15.1%
eeh	4.0%	31.4%	25.3%	4.3%	59.4%	36.9%
$\mu\mu h$	3.5%	26.3%	19.1%	3.4%	32.7%	21.0%
Combined	1.1%	8.0%	6.8%	1.0%	10.6%	7.3%

Statistical uncertainty only

Preliminary results

Investigating discrepancy of $h \rightarrow cc/gg$ on $Zh \rightarrow qqh$ channel

Need to compare LOI samples with new samples

$\Delta\sigma\text{BR}/\sigma\text{BR}$ at $E_{\text{cm}}=350 \text{ GeV}$

Not changed from previous LCWS13 results.

Comparable with extrapolation and investigating difference between 250 and 350 GeV

$E_{\text{cm}}=350 \text{ GeV}$	Extrapolation			New samples result		
Mh	120 → 125 GeV			125 GeV		
Lumi.	300 fb^{-1}			300 fb^{-1}		
$\Delta\sigma\text{BR}/\sigma\text{BR}$	bb	cc	gg	bb	cc	gg
vvh	1.4%	9.3%	6.9%	1.3%	9.7%	7.9%
qqh	1.5%	10.8%	10.2%	1.4%	11.8%	12.4%
eeh	5.4%	33.3%	27.1%			
$\mu\mu h$	5.1%	33.3%	24.6%			
Combined	1.0%	6.8%	5.5%	1.0%	7.5%	6.5%

Statistical uncertainty only Need to update from 300 fb^{-1} to nominal 330 fb^{-1}

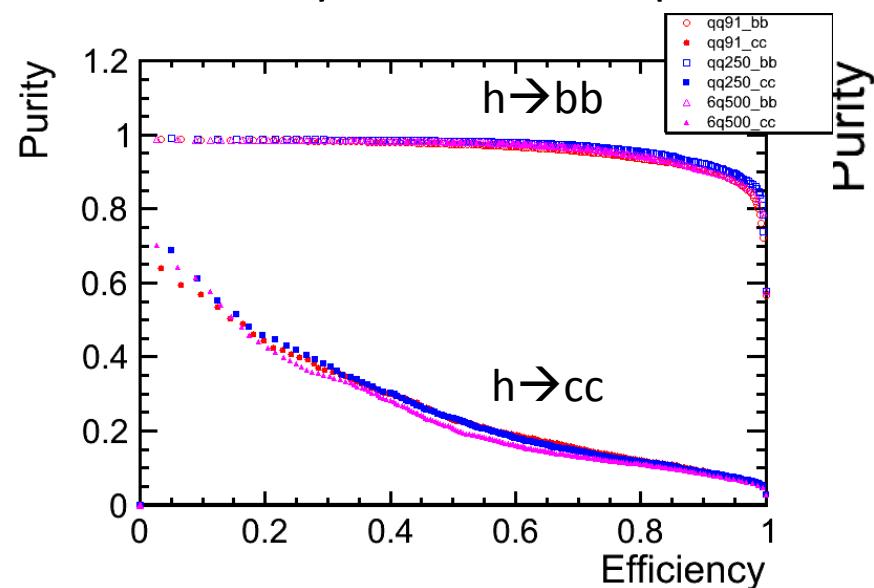
Preliminary results

llh channel have some template fitting problem, under investigation

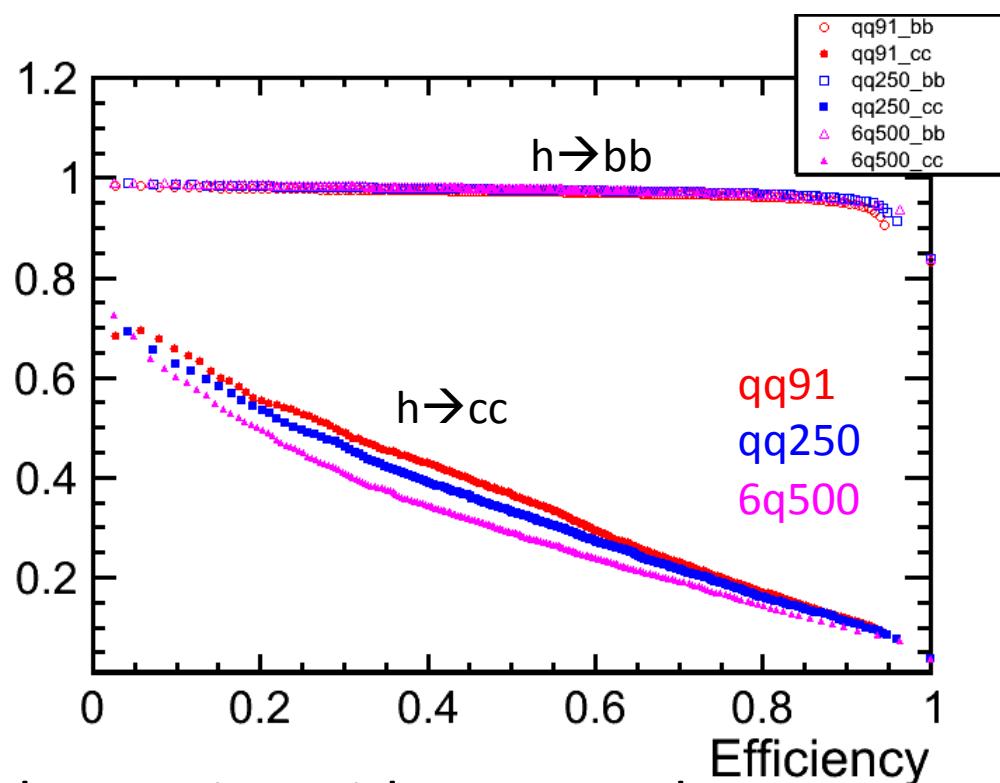
qqh flavor tagging outputs

qqH sample at Ecm=250 GeV. L=250 fb⁻¹

Eff. vs.Purity on h→All sample



Eff. vs.Purity only with h→bb, cc, gg samples



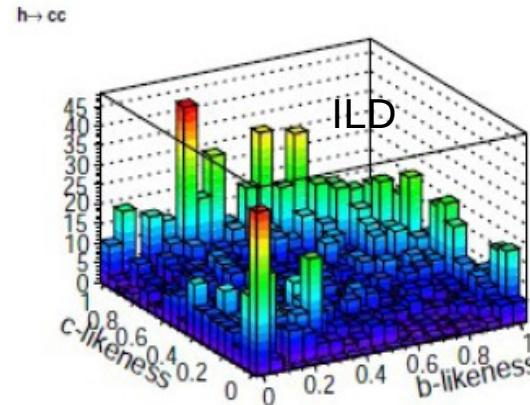
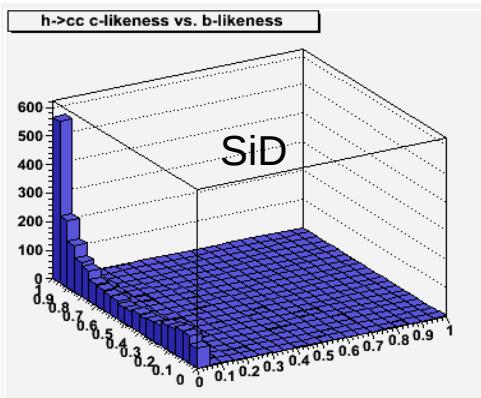
$\Delta\sigma BR/\sigma BR(h \rightarrow cc)$

22.3% (6q500) → 21.3% (qq91)

Need to compare c-tagging and bc-tagging with LOI samples

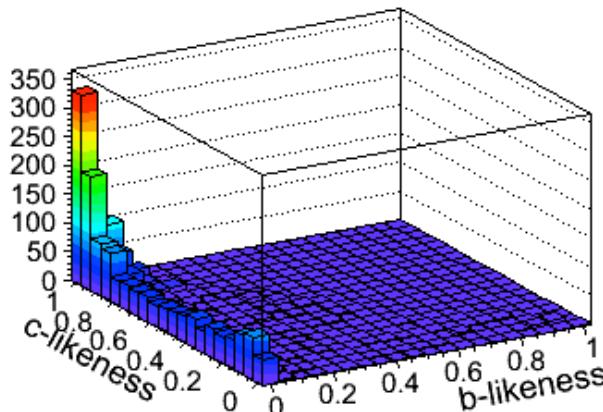
Flavor template correction

$h \rightarrow cc$ channel templates



Conversion was applied by mistake to put into template from x-likeness

Discrepancy on $h \rightarrow cc$ template is mentioned



pure c-likeness vs b-likeness
Re-check with corrected templates

Compare with new corrected template

$E_{cm}=250 \text{ GeV}$	Previous templates			Corrected templates		
M_h	125 GeV			125 GeV		
$L (\text{fb}^{-1})$	250 fb^{-1}			250 fb^{-1}		
$\Delta\sigma/\sigma$	bb	cc	gg	bb	cc	gg
vvh	1.6%	13.4%	9.3%	1.6%	14.8%	9.7%
qqh	1.4%	21.3%	15.1%	1.6%	24.0%	18.4%
eeh	4.3%	59.4%	36.9%	4.3%	68.7%	39.1%
$\mu\mu h$	3.4%	32.7%	21.0%	3.4%	34.0%	22.3%
Combined	1.0%	10.5%	7.3%	1.0%	11.6%	7.8%

$h \rightarrow cc$ and gg degradation looks large by this correction

Try to re-optimize these templates and investe bad channels (qqh, eeh)

Next step and plans

- Still updating results using new samples at $E_{cm}=250$ and 350 GeV
 - qqh @250 GeV is one of problem
- vvh @350 GeV (WW-fusion) is shared with DESY group people
- JSPS grant-in-aid for science research budget for non-ILC related contents is adopted and need to work with Niigata University people too, this is new problem for me...

BACKUP

analysis status

ECM	@ 250 GeV		@ 350 GeV		@ 500 GeV		@ 1 TeV
luminosity · fb	250		330		500		1000
polarization (e-,e+)	(-0.8, +0.3)		(-0.8, +0.3)		(-0.8, +0.3)		(-0.8, +0.2)
process	ZH	vvH	ZH	vvH	ZH	vvH	vvH
cross section	EH	-	G		-	-	-
	$\sigma \cdot \text{Br}$						
H-->bb	EH	F	EH	EEF	EEH	F	F
H-->cc	EH		EH	EEH	EEH	EH	F
H-->gg	EH		EH	EEH	EEH	EH	F
H-->WW*	EH		EEH	EEF	EEH	F	F
H--> $\tau\tau$	EH		EEH	EEH	EH	EH	EEH
H-->ZZ*	F		EEG	EEG	G	G	G
H--> $\gamma\gamma$	G		G	EEF	G	F	F
H--> $\mu\mu$			-				F
H-->Inv. (95% C.L.)	F		-		-		
ttH, H-->bb	-			EH/EF		F	

F: done by full simulation w/ mH=125GeV

EH: extrapolated from full simulation w/ mH=120GeV

EEH: extrapolated from full simulation at other ecm w/ mH = 120 GeV

EEF: extrapolated from full simulation at other ecm w/ mH = 125 GeV

G: guesstimate from old fast simulation

black: ongoing or completed

red: still missing

Signal ($M_h=125$ GeV) and BGs

E_{cm}	250 GeV		350 GeV		1 TeV	
Signal	$\sigma (-0.8, +0.3)$	$N (250 \text{ fb}^{-1})$	$\sigma (-0.8, +0.3)$	$N (300 \text{ fb}^{-1})$	$\sigma (-0.8, 0.2)$	$N (500 \text{ fb}^{-1})$
vvh	77.5	19,383	98.7	29,596	404.0	202,022
qqh	210.2	52,546	138.9	41,670	17.8	8,885
eeh	10.9	2,729	10.2	3,073	23.2	11,600
$\mu\mu h$	10.4	2,603	6.9	2,061	0.9	450
$\tau\tau h$	10.4	2,598	6.9	2,057	0.9	450
Total	319.4	79,860	261.5	78,457	446.8	223,408
SM BGs						
2f	1.2×10^5	2.9×10^7	7.2×10^4	2.2×10^7	7.8×10^3	3.9×10^6
4f	4.1×10^5	1.0×10^7	3.1×10^4	9.4×10^6	2.7×10^4	1.4×10^7
6f	Not considered		1.4×10^2	4.3×10^4	6.9×10^2	3.5×10^5
1f_3f	1.3×10^6	3.3×10^8	1.6×10^6	4.8×10^8	4.6×10^5	2.3×10^8
aa_2f/4f	5.8×10^5	1.4×10^8	9.6×10^5	2.9×10^8	3.1×10^3	1.6×10^6

Zh → vvh analysis procedure

Apply **forced two-jet clustering** after the LCFIPlus vertex tag

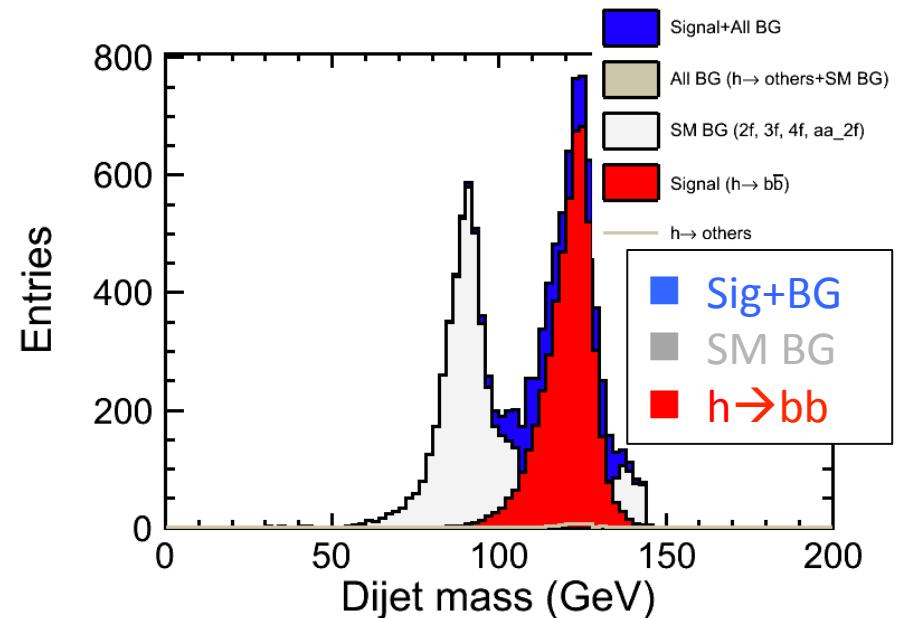
vvh cut flow 250 GeV (for 350 GeV)

1. $30 < P_t < 100$ GeV (150 GeV)
2. $|P_z| < 60$ GeV (130 GeV)
3. NPFOs > 30
4. $100 < E_{vis} < 150$ GeV (120 < E_{vis} < 200)
5. $80 < M_{miss} < 120$ GeV (230 GeV)
6. Thrust > 0.8 (No thrust for 350 GeV)
7. $-\log_{10}(Y_{34}) > 2.0$
8. $-\log_{10}(Y_{23}) > 1.5$
9. $110 < M_{vis} < 140$ GeV
10. LR > 0.35 (0.5)

LR inputs

Missing mass, NPFOs
 $-\log_{10}(Y_{12})$, $\cos\theta_{\text{thrust}}$, Thrust, M_h

Visible mass with b-tagging



Significance: $S/\sqrt{S+B} = 51.2$ (67.3)
Efficiency ($h \rightarrow 2j$) = 39.7% (46.3%)

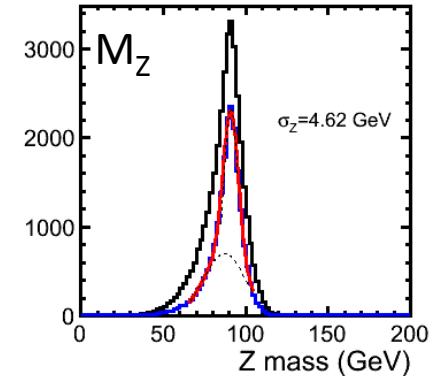
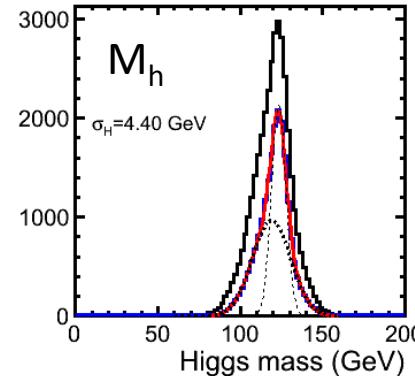
Zh \rightarrow qqh analysis procedure

Apply forced four-jet clustering and select minimum χ^2 jets pair

$$\chi^2 = \left(\frac{M_{12} - M_Z}{\sigma_Z} \right)^2 + \left(\frac{M_{34} - M_H}{\sigma_H} \right)^2$$

qqh selection at 250 GeV (350 GeV)

1. $\chi^2 < 50$
2. $E_{vis} > 200$ GeV (270 GeV)
3. $0.5 < -\text{Log}_{10}(Y_{34}) < 2.7$
4. # of particle in jet > 0
5. # of chd trk > 20
6. $|\cos\theta_{\text{thrust}}| < 0.90$
7. Thrust < 0.9
8. $\theta_{hjj} > 110^\circ$ ($80 < \theta_{hjj} < 120^\circ$)
9. $\theta_{Zjj} > 90^\circ$ ($60 < \theta_{Zjj} < 100^\circ$)
10. $80 < M_Z < 100$ GeV
11. $115 < M_h < 135$ GeV
12. LR > 0.50



LR inputs

1. Thrust
2. # of particles from h decay
3. $-\text{Log}_{10}(Y_{12})$
4. $-\text{Log}_{10}(Y_{23})$
5. Minimum jets angle in four jets
6. M_h

Signal significance=29.8 (43.8)
Efficiency($h \rightarrow 2j$)=46.3% (30.7%)

Zh → llh analysis procedure

Select di-lepton, then apply forced two-jet clustering

μ/e selection

$10 < E_{\text{PFO}} < 100 \text{ GeV}$ @ 250 GeV
 $(10 < E_{\text{PFO}} < 160 \text{ GeV}$ @ 350 GeV)

Calorimeter Edep information

- $E_{\text{ecal}}/E_{\text{total}} < 0.5, E_{\text{total}}/P < 0.4$ (μ)
- $E_{\text{ecal}}/E_{\text{total}} > 0.9, 0.7 < E_{\text{total}}/P < 1.2$ (e)

Require track from IP

- $\sigma_{d0}, \sigma_{z0}, \sigma_{r0}$

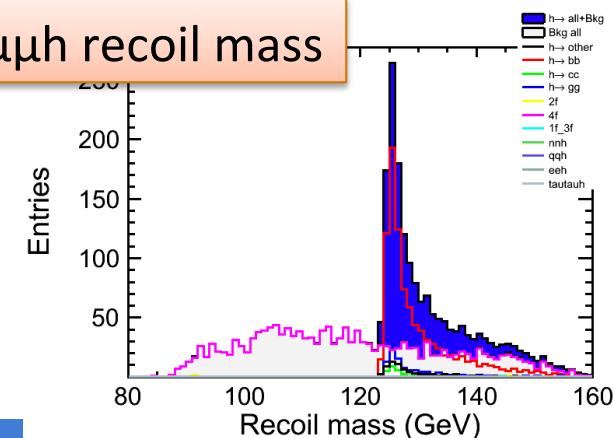
If # of candidates greater than two,
select lepton pair whose mass
as close as Z mass

eeh: Signif = 16.9, Eff = 44.1%

μμh: Signif = 25.1, Eff = 60.8%

1. # of e/ μ candidate ≥ 2
2. Selected isolated leptons = 2
3. $E_{\text{vis}} > 200 \text{ GeV}$
4. NPFOs > 30
5. Thrust > 0.8
6. $|\cos\theta_z| < 0.9$
7. $70 < M_{ll} < 110 \text{ GeV}$
8. $100 < M_{jj} < 150 \text{ GeV}$
9. $120 < M_{\text{recoil}} < 160 \text{ GeV}$

μμh recoil mass



Extrapolated results ($E_{cm}=250$ GeV)

Expected accuracies by extrapolating 120 GeV results to 125 GeV w/o cut eff. diff.

$E_{cm}=250$ GeV	$M_h=120$ GeV ($L=250$ fb $^{-1}$)			$M_h=125$ GeV ($L=250$ fb $^{-1}$)		
$\Delta\sigma/\sigma$	bb	cc	gg	bb	cc	gg
vhv	1.7%	11.2%	13.9%	1.8%	12.9%	11.2%
qqh	1.5%	10.2%	13.1%	1.6%	11.8%	10.5%
eeh	3.8%	26.8%	31.3%	4.0%	31.4%	25.3%
$\mu\mu h$	3.3%	22.6%	23.9%	3.5%	26.3%	19.1%
Combined	1.0%	6.9%	8.5%	1.1%	8.0%	6.8%

BR	120 GeV	125 GeV
BR(bb)	65.7%	57.8%
BR(cc)	3.6%	2.7%
BR(gg)	5.5%	8.6%

Cross sections at $M_h=120$ and 125 GeV
are almost comparable in LOI samples
and new samples
(Lumi linker difference suppress mass diff.)

Main contribution comes from BR difference between $M_h=120$ and 125 GeV

Extrapolated results ($E_{cm}=350$ GeV)

Expected accuracies by extrapolating 120 GeV results to 125 GeV w/o cut eff. diff.

$E_{cm}=350$ GeV	$M_h=120$ GeV ($L=250$ fb $^{-1}$)			$M_h=125$ GeV ($L=300$ fb $^{-1}$)		
$\Delta\sigma/\sigma$	bb	cc	gg	bb	cc	gg
vvh	1.4%	8.6%	9.2%	1.4%	9.3%	6.9%
qqh	1.5%	10.1%	13.7%	1.5%	10.8%	10.2%
eeh	5.3%	30.5%	35.8%	5.4%	33.3%	27.1%
$\mu\mu h$	5.1%	30.9%	33.0%	5.1%	33.3%	24.6%
Combined	1.0%	6.2%	7.3%	1.0%	6.8%	5.5%

BR	120 GeV	125 GeV
BR(bb)	65.7%	57.8%
BR(cc)	3.6%	2.7%
BR(gg)	5.5%	8.6%

Cross section	120 GeV	125 GeV
vvh	105.2 fb	98.7 fb
qqh	144.4 fb	138.9 fb
eeh	11.0 fb	10.2 fb
$\mu\mu h$	7.2 fb	6.9 fb

BR, Luminosity, and σ are different