Measuring the Higgs Hadronic Decay Branching Ratios at the ILC

ILC Tokusui Workshop 2013 Annual Meeting

Dec. 19 2013

H. Ono (NDU)

Status of this year

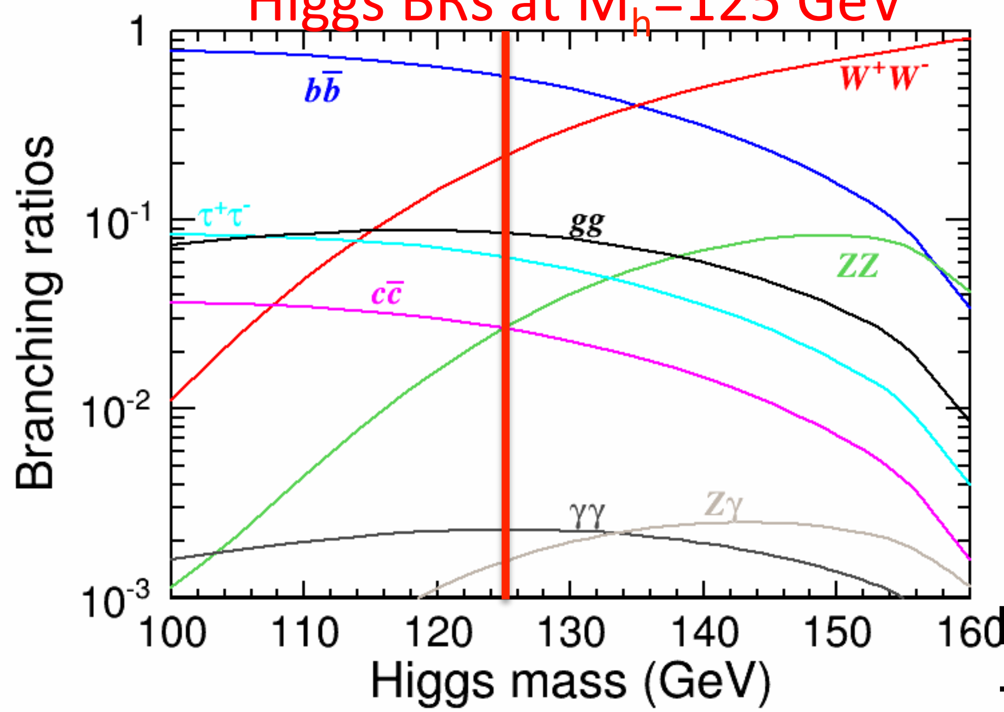
- DBD analysis completion
- Higgs BR paper submission
  "A study of measurement precision of the Higgs boson branching ratios at the International Linear Collider”
  The European Physical Journal C, Volume 73, Issue 3
- New Higgs mass samples analysis
  Higgs mass at 125 GeV
- Higgs BR study white paper submission
  →Sorry for delayed but still on going

Higgs BR study in ILC

Important task to measure σxBR in ILC

- Determine **absolute Higgs BR** (σ_{ZH} model independent measurement)
- Complementary study with LHC in **Higgs hadronic decay channel**

Higgs BRs at M_h=125 GeV



High precision measurement in **Higgs hadronic decay channel**

h→bb obtain best precision in ILC with largest BR

h→cc, gg can be measured in ILC compare to the LHC environment

Precision measurement

→Distinguish new physics existence

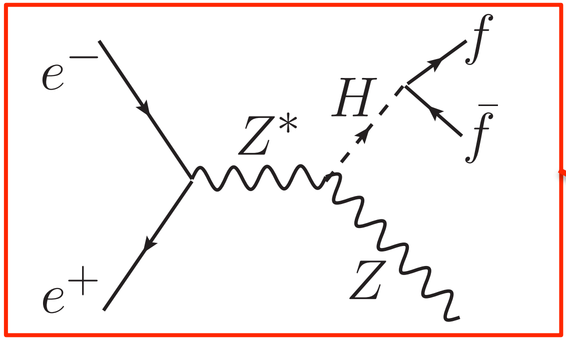
Higgs decay channels	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
Higgs BRs	57.8%	2.7%	8.6%	21.6%	0.02%	6.4%	2.7%	0.23%	0.16%

Higgs production in ILC

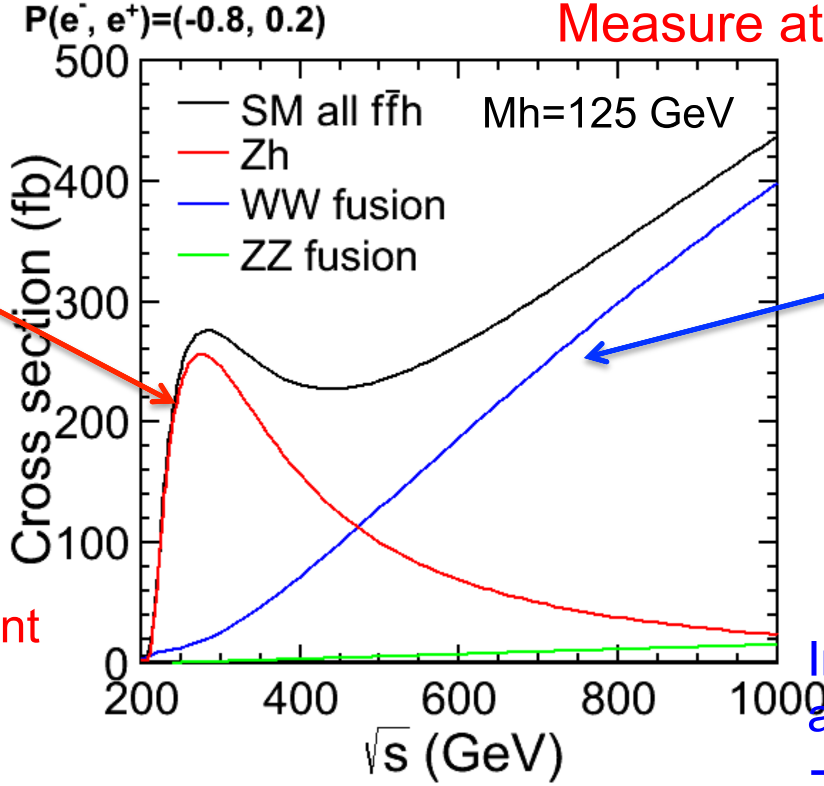
Higgs major production process
$e^+e^- \rightarrow Zh$ (Higgs-strahlung)
$e^+e^- \rightarrow \nu\nu h/eeh$ (WW/ZZ fusion)

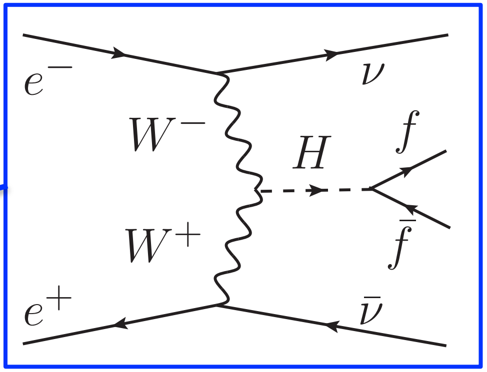
250 GeV: σ_{ZH}, mass
350 GeV: tt, Higgs width
500 GeV: Higgs self-coupling, tth
1 TeV: $h \rightarrow \mu\mu$, rare channel

Measure at each energy



Zh (Higgs-strahlung)





WW-fusion

Cross section measurement with model independent
→Basic properties

Increase **cross section** and **luminosity**
→Higher statistics

Higgs BR study update from LOI

DBD and post studies have done with **Mh=125 GeV**

	LOI	DBD (post)
Higgs mass	120 GeV	125 GeV
Branching ratios	Pythia	LHC Higgs XSWG
E_{cm}	250, 350, 500	250, 350, 500, 1000
Detector model	ILD_00	ILD_o1_v05
Software	ilcsoft v01-06	ilcsoft v01-16
Flavor tagging	LCFIVTX	LCFIPlus

Re-do with new samples and software

BR	Mh	bb	cc	gg	ττ	WW	ZZ	γγ	Zγ	μμ
Pythia	120 GeV	65.7%	3.6%	5.5%	8.0%	15.0%	1.7%	0.3%	0.1%	0.03%
LHCXSWG	125 GeV	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.2%	0.2%	0.02%

Signal (M_h=125 GeV) and BGs

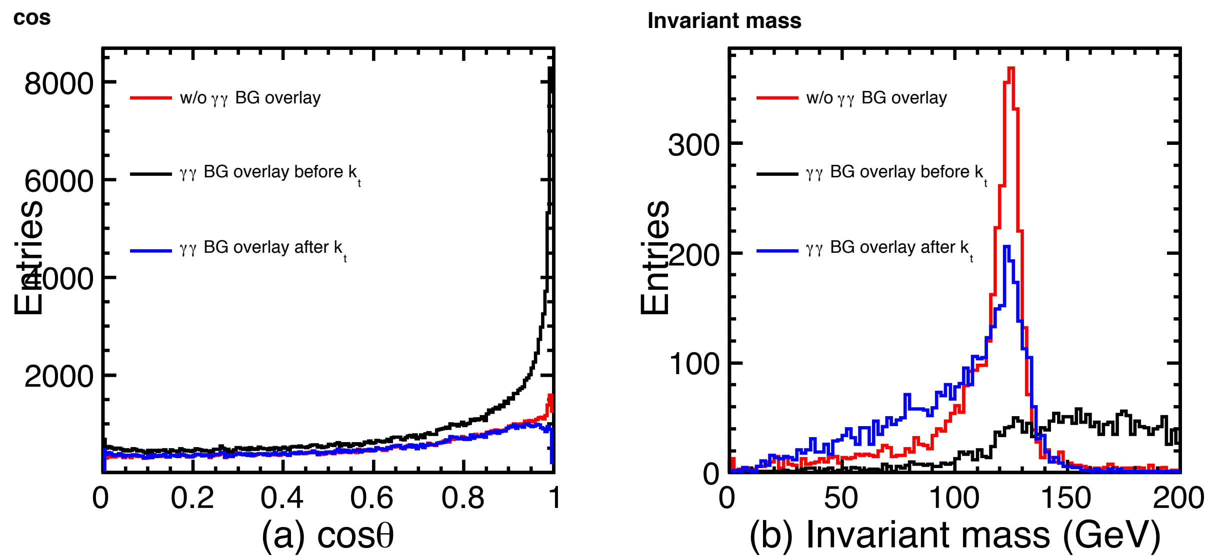
E_{cm}	250 GeV		350 GeV		1 TeV	
Signal	σ (-0.8,+0.3)	N (250 fb^{-1})	σ (-0.8, +0.3)	N (300 fb^{-1})	σ(-0.8, 0.2)	N(500 fb^{-1})
νvh	77.5	19,383	98.7	29,596	404.0	202,022
qqh	210.2	52,546	138.9	41,670	17.8	8,885
eeh	10.9	2,729	10.2	3,073	23.2	11,600
μμh	10.4	2,603	6.9	2,061	0.9	450
ττh	10.4	2,598	6.9	2,057	0.9	450
Total	319.4	79,860	261.5	78,457	446.8	223,408
SM BGs						
2f	$1.2x10^5$	$2.9x10^7$	$7.2x10^4$	$2.2x10^7$	$7.8x10^3$	3.9×10^6
4f	$4.1x10^5$	$1.0x10^7$	$3.1x10^4$	$9.4x10^6$	$2.7x10^4$	1.4×10^7
6f	Not considered		$1.4x10^2$	$4.3x10^4$	$6.9x10^2$	3.5×10^5
1f_3f	$1.3x10^6$	$3.3x10^8$	$1.6x10^6$	$4.8x10^8$	$4.6x10^5$	$2.3x10^8$
aa_2f/4f	$5.8x10^5$	$1.4x10^8$	$9.6x10^5$	$2.9x10^8$	$3.1x10^3$	$1.6x10^6$

vvh @ 1 TeV study (DBD)

Detector capability at E_{cm}=1 TeV (e^+e^-→vvh, WW-fusion)

Treat γγ→hadron background (4.1 event/BX)

→ Beam related backgrounds are removed with k_t jet clustering algorithm



After removing beam related background,
selected particles are re-clustered as
two jets (h→bb, cc, gg) or four jets (h→WW*→4j)

1 TeV cut flow and template fitting

1. Visible energy on beam calorimeter	$E_{BCAL} < 50$ GeV	3f, aa contribution remove
2. Thrust value	Thrust < 0.95	
3. Visible energy	$100 < E_{vis} < 400$ GeV	
4. Transverse visible momentum	$P_T > 50$ GeV	2f, 3f suppression
5. Number of charged particle flow object	$N_{ChdPFO} > 15$	
6. Azimuthal angle of Higgs flight direction	$\lvert \cos\theta_h \rvert < 0.95$	
7. Reconstructed dijet mass	$110 < M_{jj} < 150$ GeV	

$r_{xx} = \sigma BR / \sigma BR^{SM}(h \rightarrow xx)$

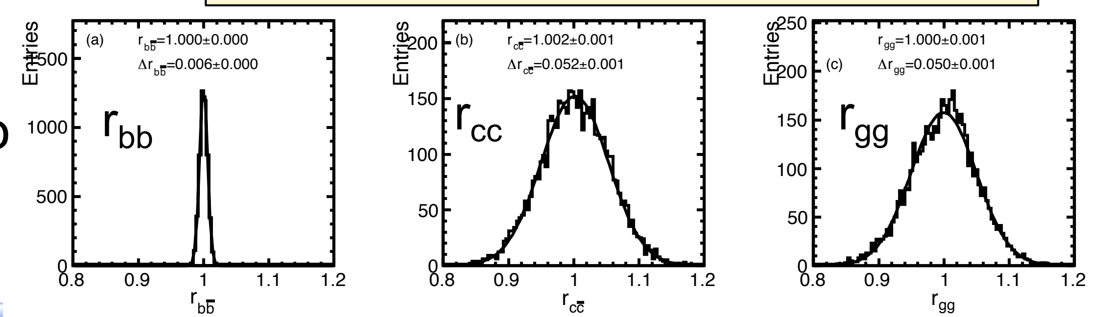
$N^{data} = \Sigma r_{xx} * N^{template}(h \rightarrow xx) + N^{BG}$

($r_{bb,cc,gg}$ are fitted parameters)

Efficiency
bb:35.0%, cc:37.3%, gg:35.9%
bb:45,000, cc: 2,258, gg:6,845
Significance = 133.9 ($h \rightarrow 2j$)

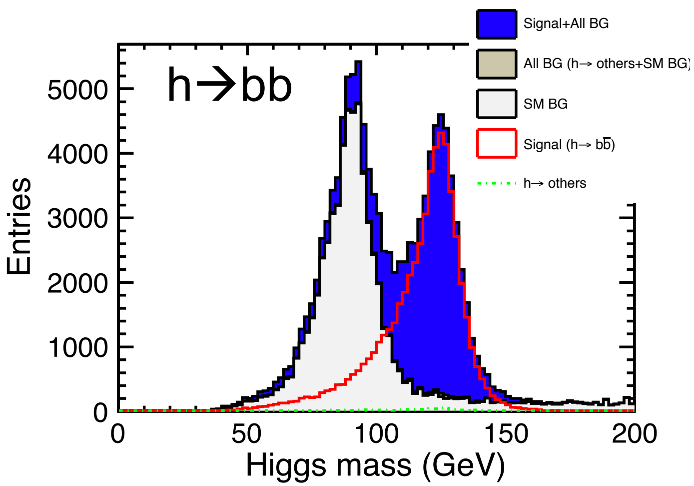
Prepare 3D flavor templates

5,000 times Toy MC is applied to extract the uncertainty of σBR

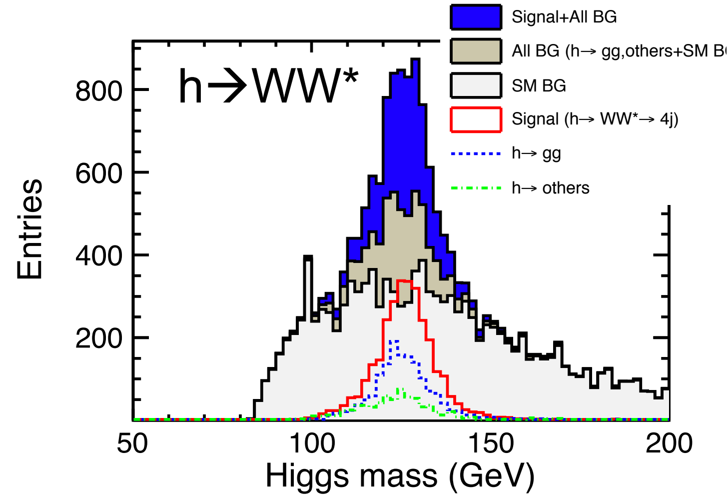


Reconstructed Higgs and ΔσBR/σBR

Requiring b-tagging



Requiring WW*→4j

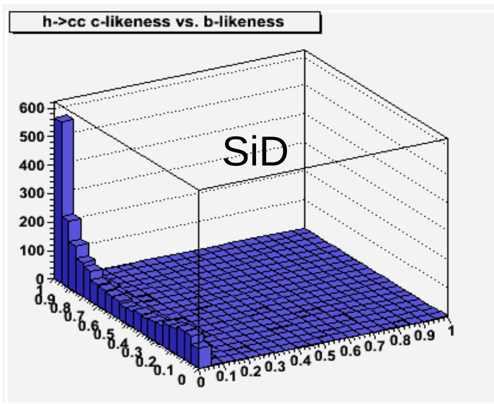


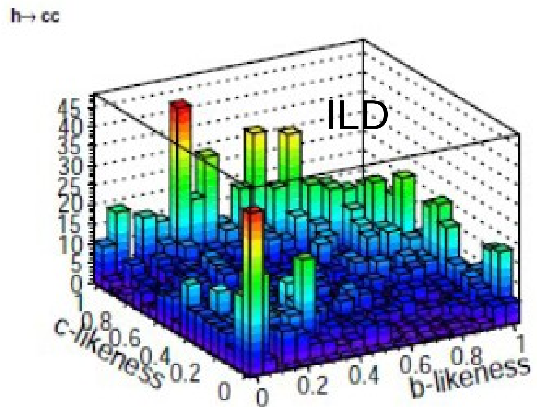
Integrated luminosity	$500\ \mathrm{fb}^{-1}$		$1\ \mathrm{ab}^{-1}$
Beam polarization $\mathrm{P}(e^-,\ e^+)$	$\mathrm{P}(-0.8,\ +0.2)$	$\mathrm{P}(+0.8,-0.2)$	$\mathrm{P}(-0.8,\ +0.2)$
$\Delta\sigma\mathrm{BR}/\sigma\mathrm{BR}(h \to b\bar{b})$	0.54%	2.1%	0.39%
$\Delta\sigma\mathrm{BR}/\sigma\mathrm{BR}(h \to c\bar{c})$	5.7%	36.8%	3.9%
$\Delta\sigma\mathrm{BR}/\sigma\mathrm{BR}(h \to gg)$	3.9%	25.7%	2.8%
$\Delta\sigma\mathrm{BR}/\sigma\mathrm{BR}(h \to WW^* \to 4j)$	3.6%	23.7%	2.5%

Discrepancy between SiD and ILD results are still investigating with SiD person

Flavor template correction

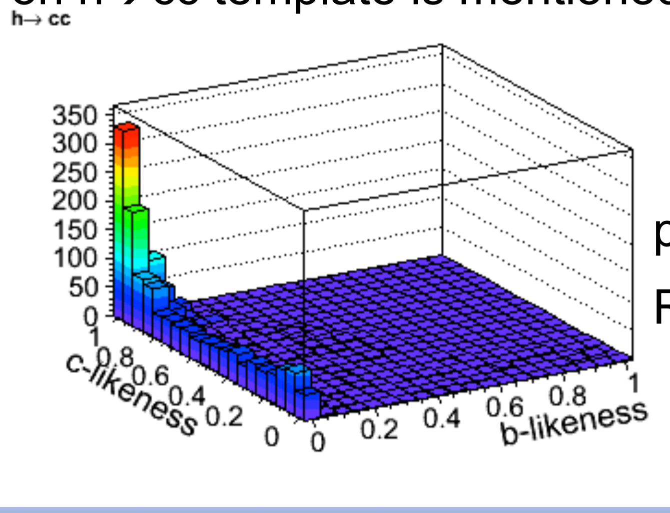
h→cc channel templates





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

Discrepancy on h→cc template is mentioned → Miss conversion is found



pure c-likeness vs b-likeness

Re-check with corrected templates

1 TeV ΔσBR/σBR check

vvh 1 TeV with L=500 fb^{-1}

Preliminary result with pure x-likeness

Hiiggs decay channel	ΔσBR/σBR (correct)	DBD result	SiD new
h→bb	0.53%	0.54%	0.66%
h→cc	6.0%	5.6%	8.8%
h→gg	4.2%	3.9%	4.6%

Small difference is observed but it can not explain the difference between SiD and ILD result

Keep investigate this reason between SiD and ILD
→Compare with SiD cut reduction, backgrounds again
(Contacting SiD analysis person)

Current results of ΔσBR/σBR

Need to update the Higgs mass from **120 to 125 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
ΔσBR/σBR(h→bb)	1.0%	1.0%	0.57%	0.39%
ΔσBR/σBR(h→cc)	6.9%	6.2%	5.2%	3.9%
ΔσBR/σBR(h→gg)	8.5%	7.3%	5.0%	2.8%
ΔσBR/σBR(h→WW*)	8.1%		3.0%	2.5%

Re-evaluate ΔσBR/σBR with new M_h=125 GeV full simulation samples at E_{cm}=250 and 350 GeV too.

Zh at 250 and 350 GeV analysis

Analysis condition: Optimize for new samples, LCFIPlus

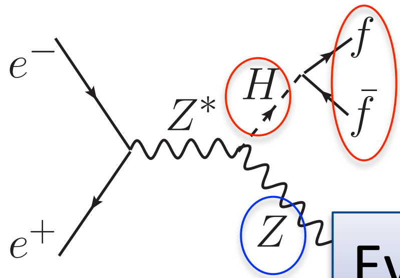
Higgs mass: **125 GeV**

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

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



Jet clustering and flavor tagging

↓

Event selection and background reduction

↓

Estimate σBR accuracy with flavor template or counting

h→bb, cc, gg accuracies are evaluated with flavor template fitting

Zh→vvh analysis procedure

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

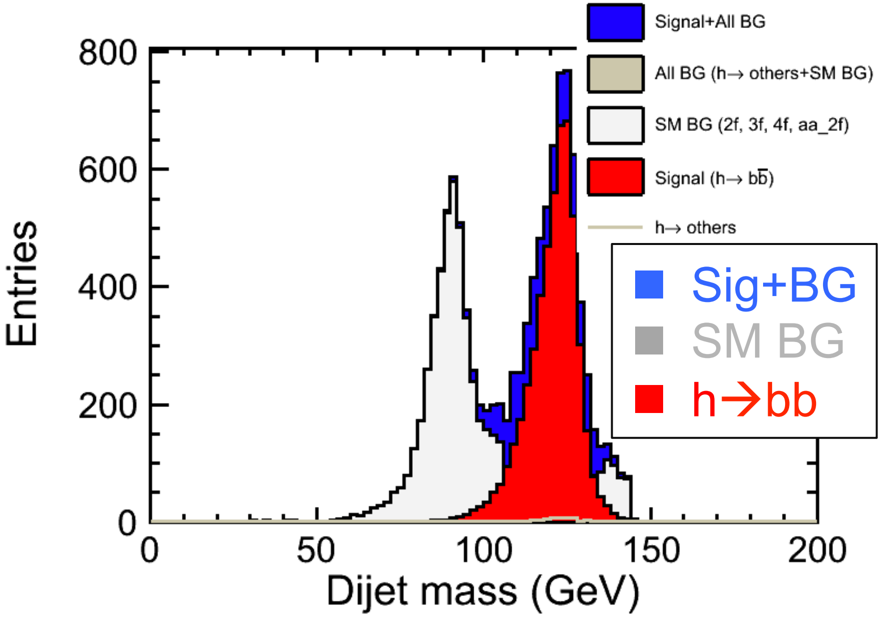
vvh cut flow 250 GeV (for 350 GeV)

1. 30 < P_t < 100 GeV (150 GeV)
2. $|P_Z|$<60 GeV (130 GeV)
3. NPFOs > 30
4. 100 < Evis < 150 GeV (120<Evis<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. -log10(Y23)>1.5
9. 110<M_{vis}<140 GeV
10. LR>0.35 (0.5)

LR inputs

Missing mass, NPFOs
-log10(Y12), $\cos\theta_{thrust}$, Thrust, M_h

Visible mass with b-tagging

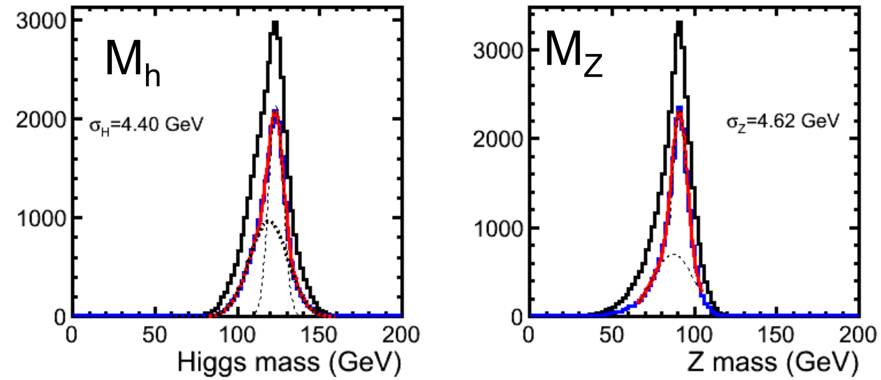


Significance: S/√(S+B)=51.2 (67.3)
Efficiency (h→2j) = 39.7% (46.3%)

Zh→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. $0.5<-\mathrm{Log}_{10}(y_{34})<2.7$
4. # of particle in jet > 0
5. # of chd trk>20
6. $|\cos\theta_{thrust}|<0.90$
7. Thrust<0.9
8. $\theta_{hjj} > 110^o$ $(80<\theta_{hjj}<120^o)$
9. $\theta_{Zjj} > 90^o$ $(60<\theta_{Zjj}<100^o)$
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. $-\mathrm{Log}_{10}(Y_{12})$
4. $-\mathrm{Log}_{10}(Y_{23})$
5. Minimum jets angle in four jets
6. M_h

Signal significance=29.8 (43.8)
Efficiency(h→2j)=46.3% (30.7%)

Zh→llh analysis procedure

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

μ/e selection

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

Calorimeter Edep information

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

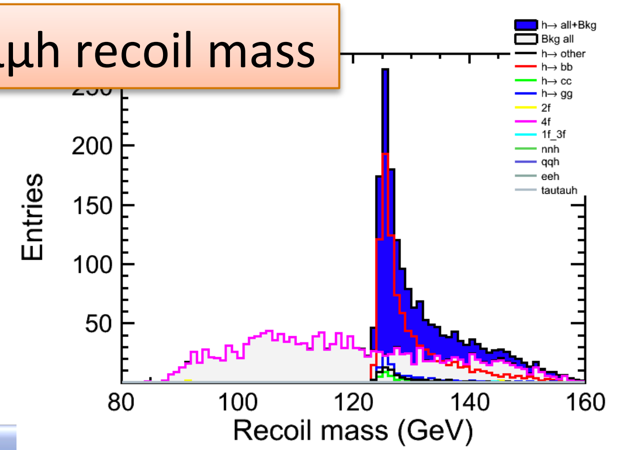
Require track from IP

- σ_{d0}, σ_{z0}, σ_{r0}

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

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

μμh recoil mass



eeh: Signif = 16.9, Eff = 44.1%
μμh: Signif = 25.1, Eff =60.8%

Current results E_{cm}=250 GeV

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

E_{cm}=250 GeV	Extrapolated 125 GeV (250 fb^{-1})			Simulated 125 GeV (250fb^{-1})		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	1.8%	12.9%	11.2%	1.6%	13.4%	9.3%
qqh	1.6%	11.8%	10.5%	1.6%	22.3%	15.5%
eeh	4.0%	31.4%	25.3%	4.3%	59.4%	36.9%
μμh	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

Still investigating discrepancies in qqh and eeh on h→cc/gg channels.

Current results E_{cm}=350 GeV

Analysis with the 350 GeV with same procedure with 250 GeV
Cut parameters are optimized for the 350 GeV

E_{cm}=350 GeV	Extrapolated M_h=125 GeV (L=300 fb^{-1})			Simulated M_h=125 GeV (L=300 fb^{-1})		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	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%			
μμh	5.1%	33.3%	24.6%			
Combined	1.0%	6.8%	5.5%			

Preliminary results

Statistical uncertainty only

Other channel analyses are still on-going.
Discrepancy looks small compare to 250 GeV. Now investigating this reason
Need to separate Zh and WW-fusion process in ννh and eeh channels

Summary and next plans

- 1 TeV νvh result is still investigating

- Re-analyze Higgs hadronic decay channels at 250 and 350 GeV.
  - Some discrepancy should be solved

- h→WW* analysis is next target (250, 350, 500 GeV)

Backup

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})		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	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%
μμh	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})		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	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%
μμh	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
ννh	105.2 fb	98.7 fb
qqh	144.4 fb	138.9 fb
eeh	11.0 fb	10.2 fb
μμh	7.2 fb	6.9 fb

BR, Luminosity, and σ are different

Zh→nnh @250 GeV cut summary

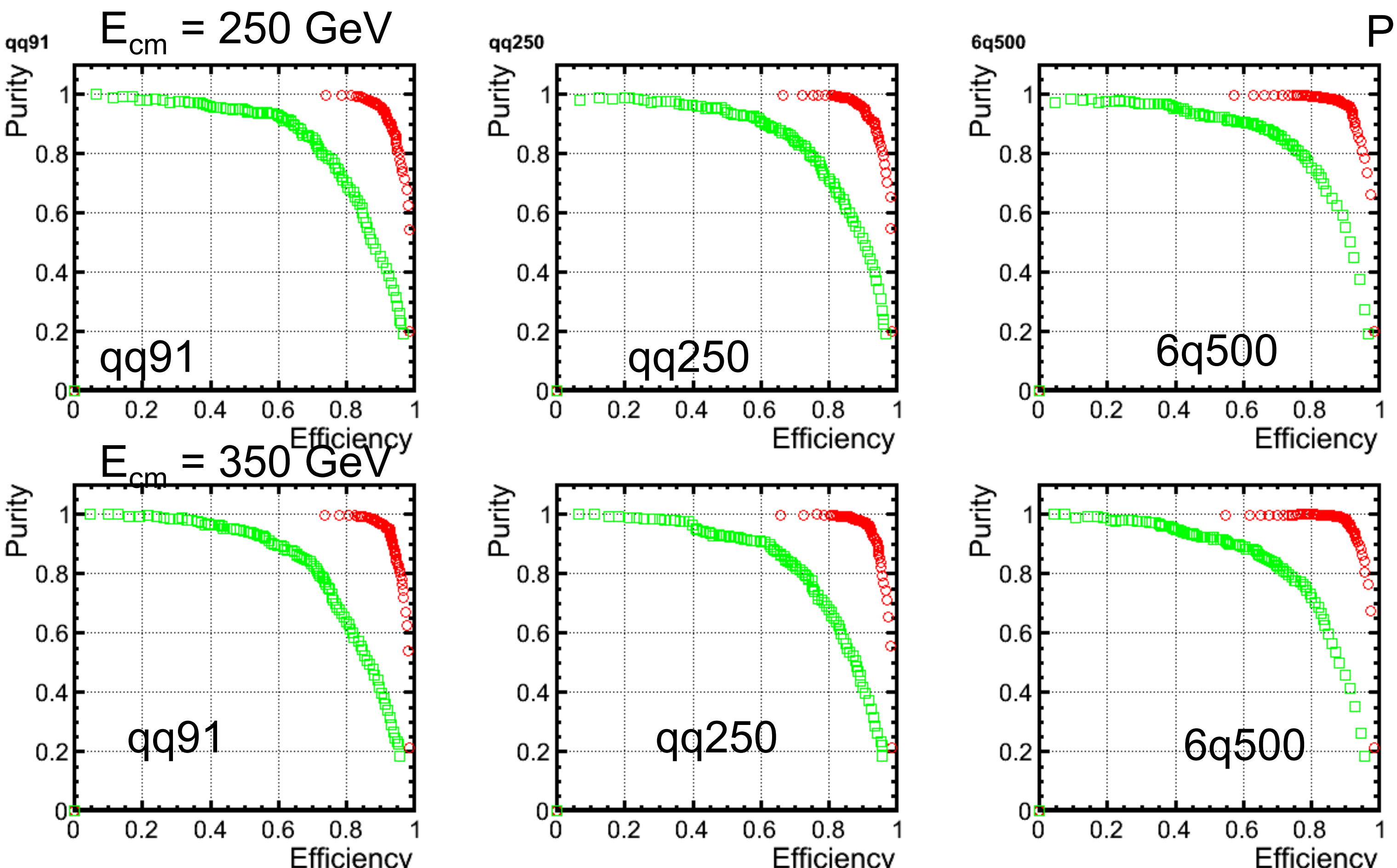
E_{cm}=250 GeV	nnh signal				SM backgrounds				
L=250 fb^{-1}	h->bb	h->cc	h->gg	h->others	2f	4f	1f_3f	aa_2f	Other ZH
No cut	11,223	520	1,649	5,990	$2.9x10^7$	$1.1x10^7$	$3.1x10^8$	$1.7x10^8$	60,477
30<Pt<100 GeV	8,882	422	1,333	4,043	504,080	$3.7x10^6$	257,605	1,499	6,203
|Pz|<60 GeV	8,678	413	1,299	3,919	433,467	$3.2x10^6$	183,052	1,179	6,096
# of PFOs >30	8,546	394	1,299	2,557	104,294	$2.2x10^6$	100,198	0	5,540
100<E_{vis}<150 GeV	8,085	370	1,223	2,234	2,073	380,255	51,872	0	791
80<M_{miss}<120	6,750	326	1,117	1,803	1,644	190,468	20,822	0	645
Thrust>0.8	5,858	284	754	534	1,514	79,182	9,052	0	246
-$Log_{10}(Y_{34})$>2.0	5,770	282	719	400	1,482	74,113	8,884	0	204
-$Log_{10}(Y_{23})$>1.5	5,360	260	624	225	1,360	52,351	8,138	0	143
110<M_h<140 GeV	4,858	250	620	173	986	16,349	499	0	112
LR>0.35	4,511	215	589	134	572	4,437	246	0	53
Efficiency	40.2%	41.4%	35.7%	2.2%	1.9.E-05	4.0.E-04	8.0.E-07	0.0%	8.8.E-04

Cut summary of Zh→qqh 250 GeV

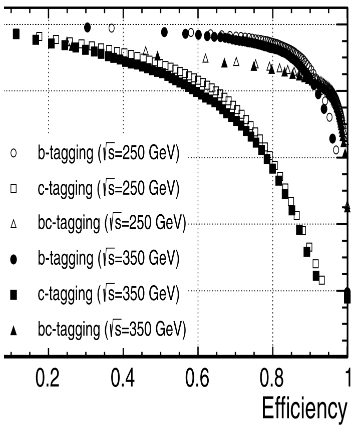
E_{cm}=250 GeV	h->bb	h->cc	h->gg	h→oth	2f	4f	1f_3f	aa_2f	Other ZH
No Cut	30,334	1,399	4,499	16,314	2.9×10^{7}	1.1×10^{7}	3.1×10^{8}	1.7×10^{8}	27,314
χ^2<50	26,303	1,246	4,067	8,773	3.8×10^{6}	2.7×10^{6}	1.8×10^{8}	7.0×10^{7}	5,263
E_{vis}>200 GeV	26,134	1,244	4,065	8,501	2.2×10^{6}	2,359,420	57,636	2,434	4,674
$-\text{Log}_{10}(y_{34})$<2.7	25,850	1,230	4,040	8,475	904,843	2,301,130	15,601	674	4,611
# of particle in Jets >0	25,446	1,204	3,998	7,659	488,383	2,107,160	2,485	228	1,926
Nchdtrk>20	25,423	1,202	3,998	7,531	475,755	2,076,650	1,852	188	1,755
$\lvert\cos\theta_{thrust}\rvert$<0.90	22,394	1,058	3,532	6,605	396,735	1,456,120	565	72	1,539
Thrust<0.9	21,918	1,033	3,502	6,581	259,777	1,445,340	500	62	1,489
θ_{hjj} >110	21,123	994	3,246	5,861	242,540	1,277,220	470	62	1,406
θ_{Zjj} >90	20,839	980	3,163	5,667	224,017	1,212,590	448	62	1,378
80<Mz<100 GeV	18,486	885	2,833	4,632	173,464	885,324	310	40	1,172
110<M_h<150 GeV	18,486	885	2,833	4,632	173,441	885,311	310	40	1,172
LR>0.50	13,821	596	2,373	3,452	66,581	229,205	63	20	650
Efficiency	45.6%	42.6%	52.7%	21.2%	2.2×10^{-3}	2.1×10^{-2}	2.1×10^{-7}	1.2×10^{-7}	2.4%

LCFIPlus performance check

Test sample: 4f_sznu_sl (ZZ→nnqq final state) as Zh→nnqq pseudo sample



Previous LCFIVTX



● b-likeness
● c-likeness

Use common weight file in ILDConfig: 6q500_v02_p01
Looks slightly improving from LCFIVTX