Higgs branching ratios study in ILC

LCWS13 at Tokyo Higgs/EWSB session

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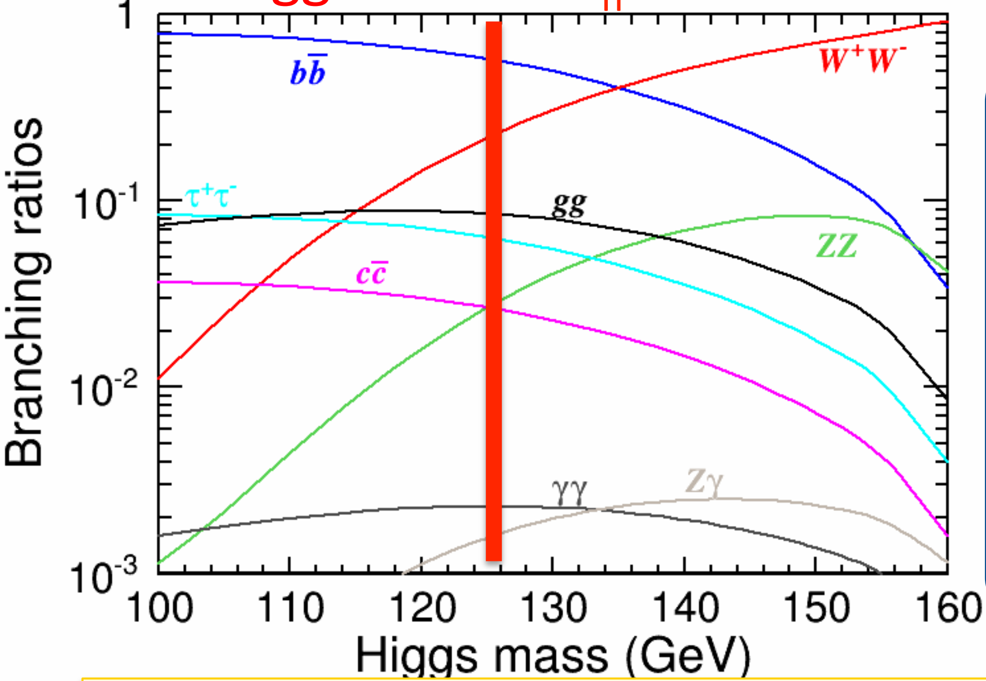
Higgs branching ratio (BR) study

Precise measurement of Higgs BRs is one of key issue in ILC project after the discovery of 125 GeV Higgs boson in LHC.

Higgs BRs at M_h=125 GeV



Higgs BR study in ILC

Higgs mainly decay to **h→bb** at **M_h=125 GeV**
→Precision measurement of Higgs **hadronic decay** channel

Cross section (σ) will be measured model independently
→Determine **absolute Higgs BR**

M_h=125 GeV has chance to access to each particle BR

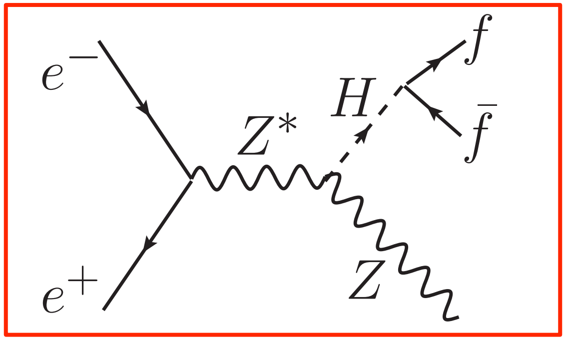
Higgs decay channels	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
Higgs BRs	57.8%	2.7%	8.6%	21.6%	0.02%	6.4%	2.7%	0.23%	0.16%

Higgs measurements in ILC

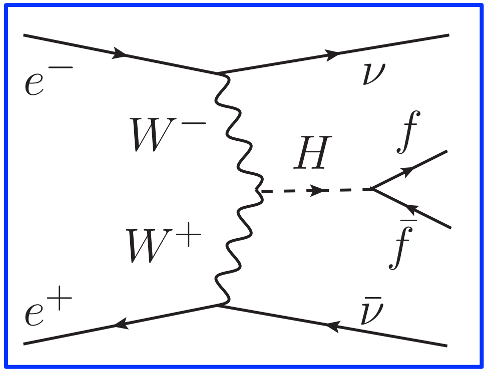
Expected Higgs production process and luminosity are different at each energy

Ecm (GeV)	Lumi (fb^{-1})	Production	Targets
250	250	Zh	Recoil, BR
350	300	Zh+WW-fusion	tt
500	500	Zh+WW-fusion	ZHH, tth
1000	1000	WW-fusion	Rare channel

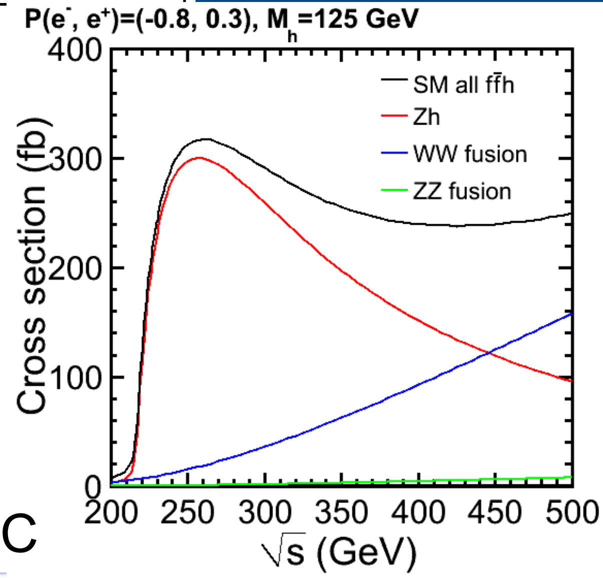
Pol(-0.8, +0.3)
M_h=125 GeV



Zh (Higgs-strahlung)



WW-fusion



Evaluate Zh channel at E_{cm}= 250 and 350 GeV in ILC

Current results of ΔσBR/σBR

Previous LOI study used Higgs mass of **120 GeV**
→ Need to update the Higgs mass 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
Mh (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%

Evaluate ΔσBR/σBR with new M_h=125 GeV full simulation samples at E_{cm}=250 and 350 GeV

Higgs BR study update from LOI

Updates LOI analysis with latest software and new samples

	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%

New 250, 350 GeV samples (M_h=125 GeV)

E_{cm}	250 GeV		350 GeV	
Signal	σ (fb)	N (250 fb^{-1})	σ (fb)	N (300 fb^{-1})
ννh	77.5	19,383	98.7	29,596
qqh	210.2	52,546	138.9	41,670
eeh	10.9	2,729	10.2	3,073
μμh	10.4	2,603	6.9	2,061
ττh	10.4	2,598	6.9	2,057
Total	319.4	79,860	261.5	78,457

M_h=125 GeV
Pol_L(-0.8, +0.3)

250 GeV, 250 fb^{-1}
350 GeV, 300 fb^{-1}

	250 GeV		350 GeV	
SM BGs	σ (fb)	N (250fb^{-1})	σ (fb)	N (300fb^{-1})
2f	1.2×10^5	2.9×10^7	7.2×10^4	2.2×10^7
4f	4.1×10^8	1.0×10^7	3.1×10^4	9.4×10^6
6f	Not considered		1.4×10^2	4.3×10^5
1f_3f	1.3×10^6	3.3×10^8	1.6×10^6	4.8×10^8
aa_2f	5.8×10^5	1.4×10^8	9.6×10^5	2.9×10^8

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

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

Analysis procedure of Higgs channels

Analysis condition

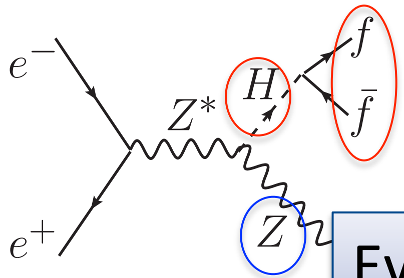
Higgs mass: **125 GeV**

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 would be analyzed with the flavor template fitting to extract accuracies

Zh→ννh analysis procedure

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

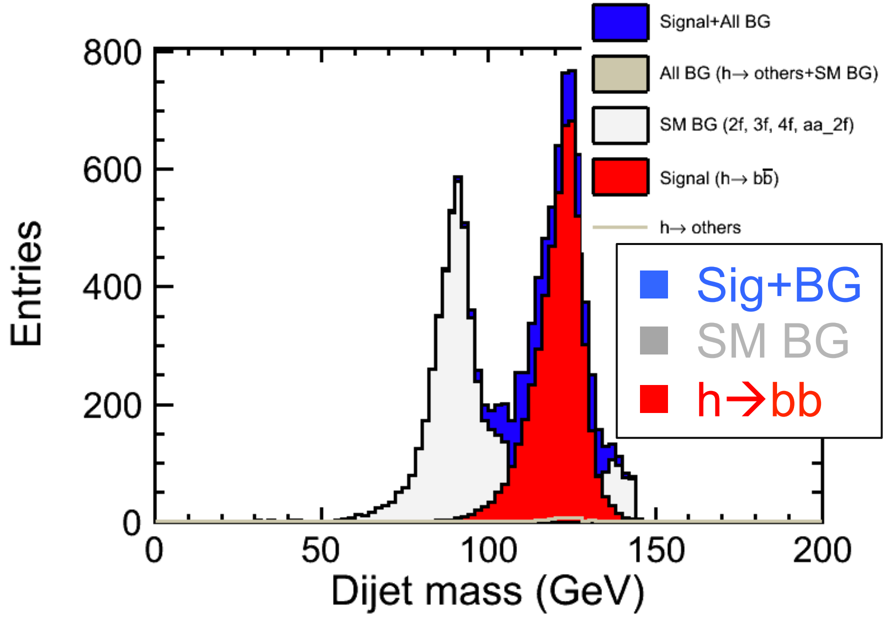
ννh cut flow 250 GeV (for 350 GeV)

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%)

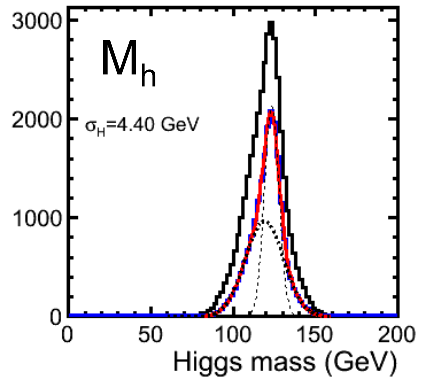
Zh→nnh @250 GeV cut summary

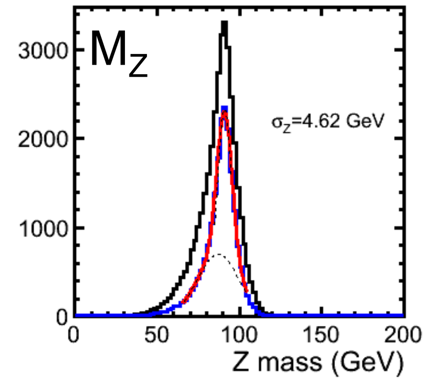
E_{cm}=250 GeV	nnh signal				SM backgrounds				
L=250 fb^{-1}	h->bb	h->cc	h->gg	h->others	2f	4f	1f_3f	aa_2f	Other ZH
No cut	11,223	520	1,649	5,990	2.9×10^7	1.1×10^7	3.1×10^8	1.7×10^8	60,477
30<Pt<100 GeV	8,882	422	1,333	4,043	504,080	3.7×10^6	257,605	1,499	6,203
|Pz|<60 GeV	8,678	413	1,299	3,919	433,467	3.2×10^6	183,052	1,179	6,096
# of PFOs >30	8,546	394	1,299	2,557	104,294	2.2×10^6	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

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%)

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%

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)

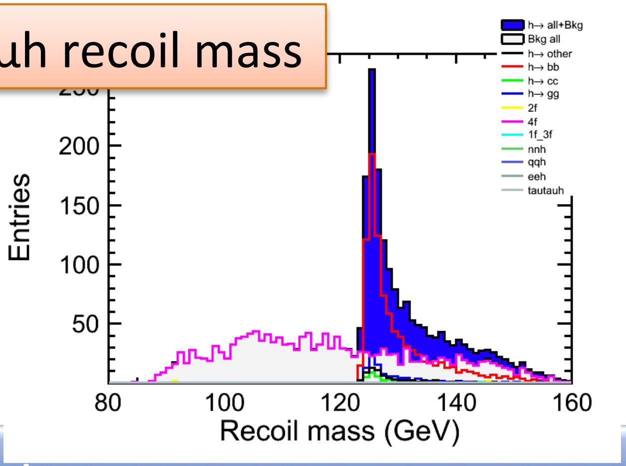
Require track from IP

- 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



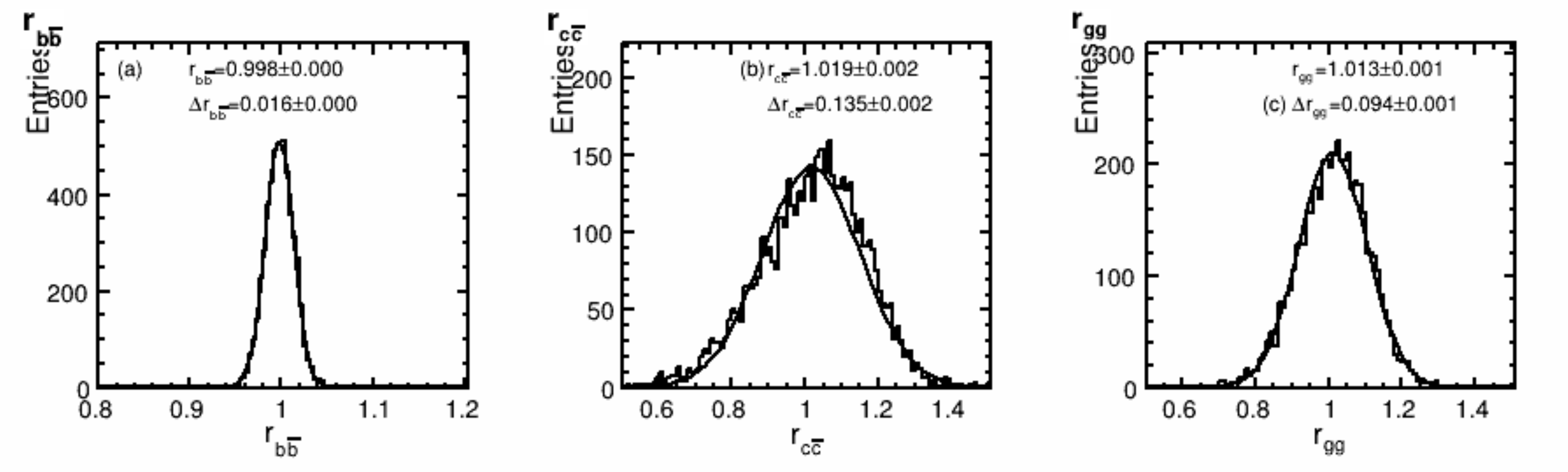
eeh: Signif = 16.9, Eff = 44.1%
μμh: Signif = 25.1, Eff =60.8%

Flavor template fitting

b/c/bc-tagging 3D flavor templates are prepared for each samples

$r_{xx}=\sigma BR/\sigma BR^{SM}(h\rightarrow xx)$
$N^{data}=\Sigma r_{xx} * N^{template}(h\rightarrow xx)+N^{BG}$
($r_{bb,cc,gg}$ are fitted parameters)

Uncertainty of fitted parameters $r_{bb,cc,gg}$ are obtained by 5000 times of toy-MC
Evaluate ΔσBR/σBR with template fitting



ΔσBR/σBR are extracted from the uncertainty of fitted parameters

Current results E_{cm}=250 GeV

Ecm=250 GeV with comparison between 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

Investigating discrepancies in qqh and eeh on h→cc/gg channels.
Something wrong in my code

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 steps

- Re-analyze Higgs hadronic decay channels at 250 and 350 GeV.
- More or less obtained the expected uncertainty but Zh→qqh, eeh are still under investigation

- Systematic uncertainty should be considered especially h→bb channel

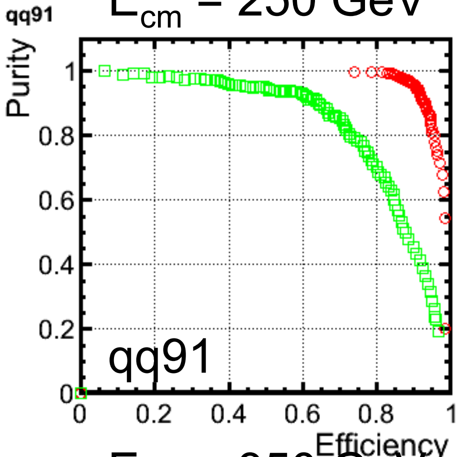
- H→WW* study for both 250 and 350 GeV
- Higgs hadronic decay at 500 GeV is also next target

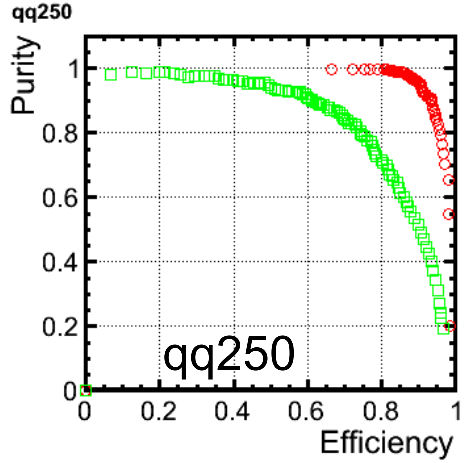
Backup

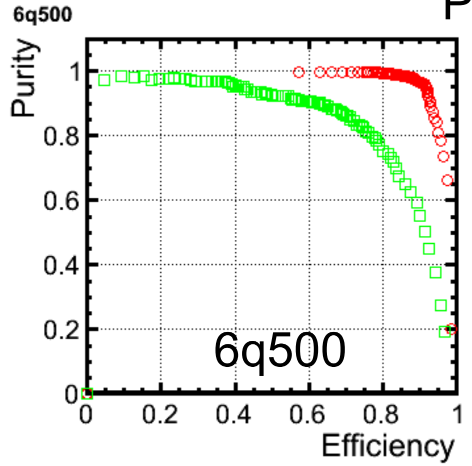
LCFIPlus performance check

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

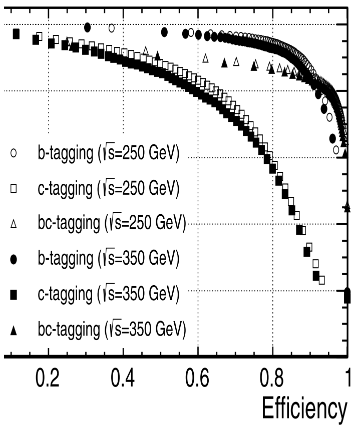
E_{cm} = 250 GeV



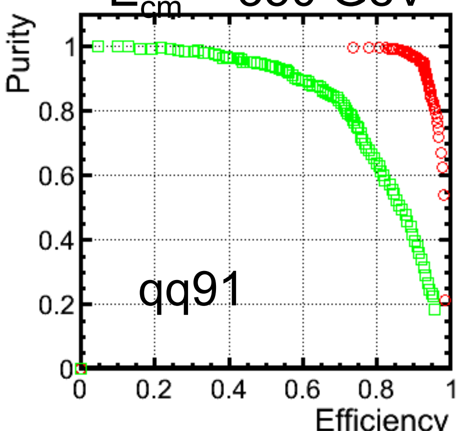


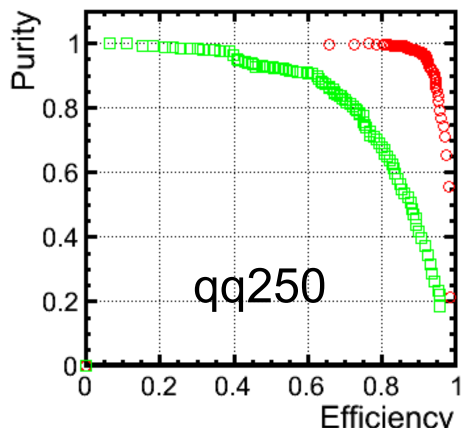


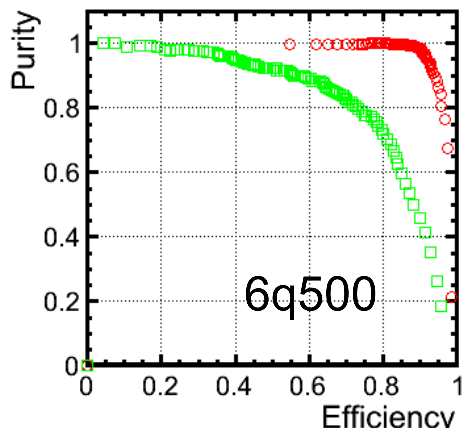
Previous LCFIVTX



E_{cm} = 350 GeV







● b-likeness
● c-likeness

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