Zh branching ratios study

ILC Physics WG general meeting

2014. Aug. 30

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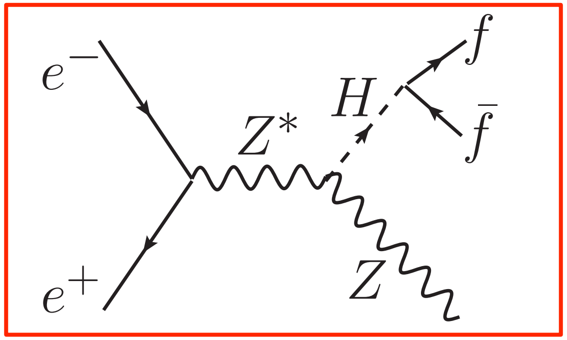
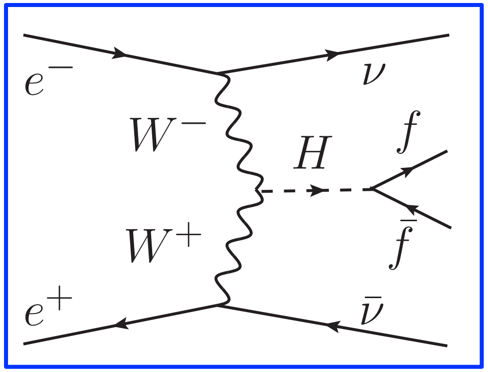
Zh Branching ratio study

Zh BR measurement is an important task on ILC
Especially h→hadronic decay channel (h→bb, cc, gg)
in order to compensate the LHC experiments

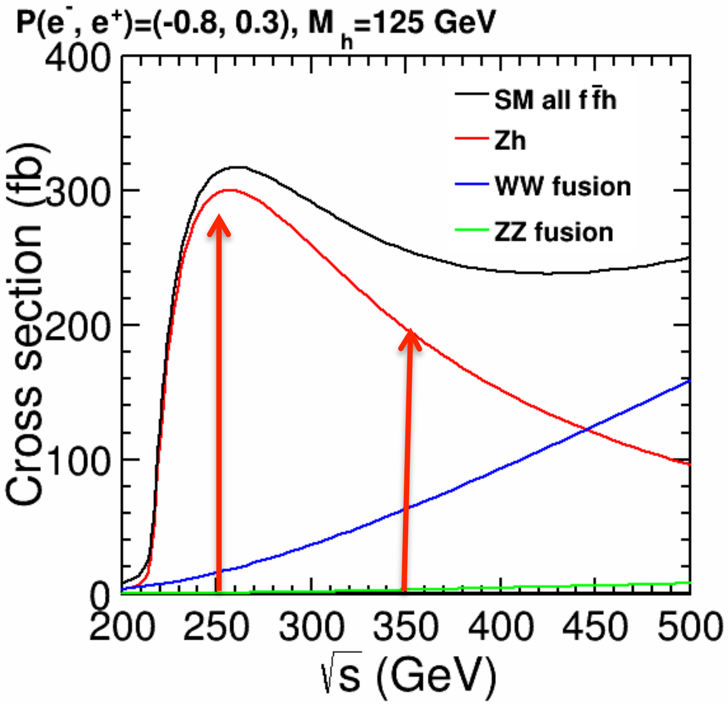
Higgs production process
e^+e^- → Zh (Higgs-strahlung)
e^+e^- → ννh (WW fusion)



Zh (Higgs-strahlung)



WW-fusion

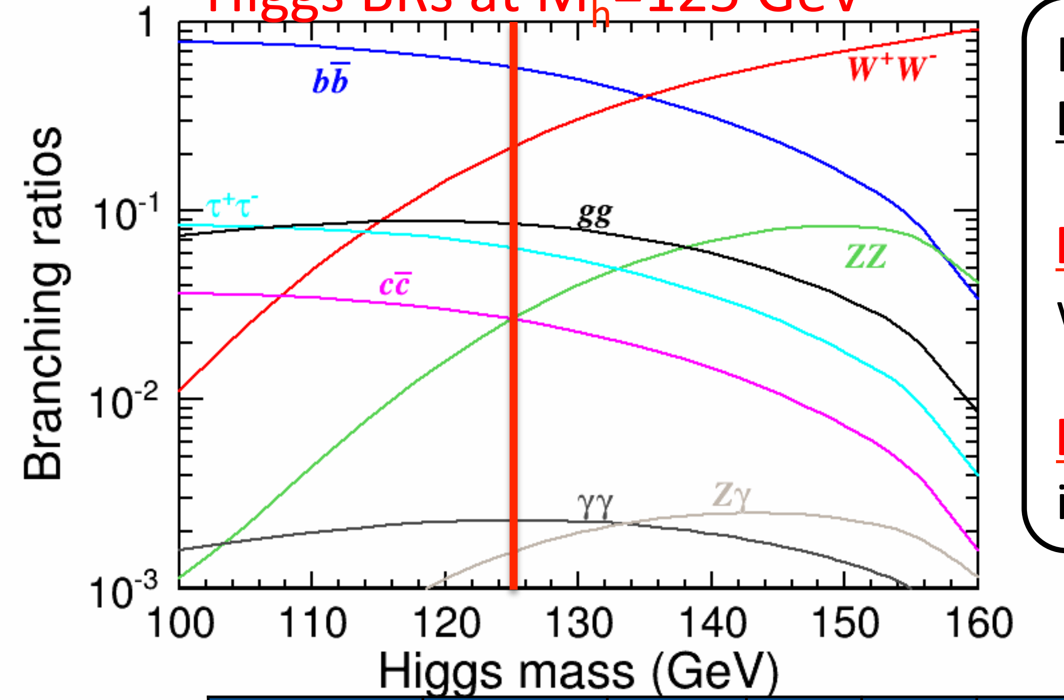


Higgs BR study in ILC

Important task to measure σ_{Zh}xBR 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 are expected to measure in ILC

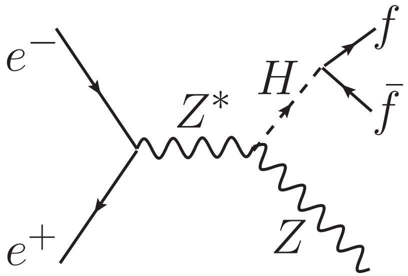
BR	Mh	bb	cc	gg	ττ	WW	ZZ	γγ	Zγ	μμ
Pythia	120 GeV	65.7%	3.6%	5.5%	8.0%	15.0%	1.7%	0.3%	0.1%	0.03%
LHCXSWG	125 GeV	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.2%	0.2%	0.02%

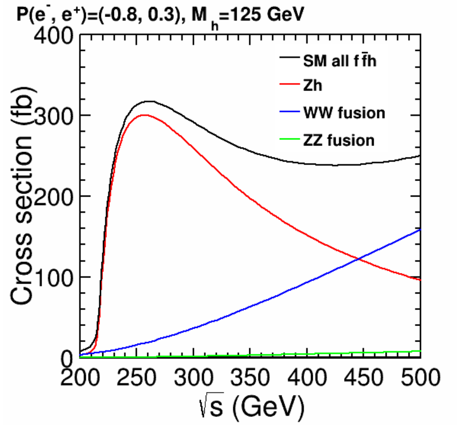
Signal (M_h=125 GeV) and BGs

E_{cm}	250 GeV	350 GeV
Signal	σ (-0.8,+0.3)	σ (-0.8, +0.3)
ννh	77.5	98.7
qqh	210.2	138.9
eeh	10.9	10.2
μμh	10.4	6.9
ττh	10.4	6.9
Total	319.4	261.5

SM BGs	250 GeV	350 GeV
Signal	σ (-0.8,+0.3)	σ (-0.8, +0.3)
2f	1.2×10^5	7.2×10^4
4f	4.1×10^5	3.1×10^4
6f	Not considered	1.4×10^2
1f_3f	1.3×10^6	1.6×10^6
aa_2f/4f	5.8×10^5	9.6×10^5

Now I concentrate to Zh channel
ννh (WW-fusion) is doing with
Felix (DESY)





Zh at 250 and 350 GeV analysis

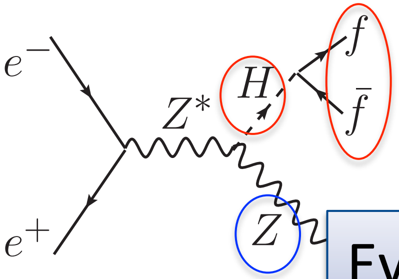
Higgs mass: **125 GeV**

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

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

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

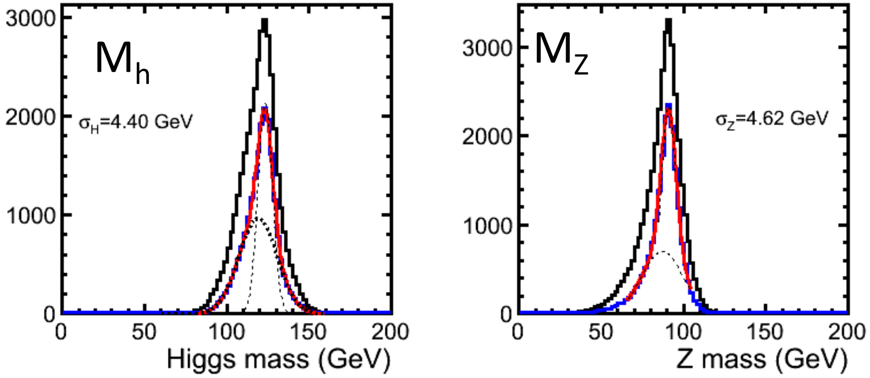
Estimate σBR accuracy with flavor template or counting

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

Zh→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

1. $\chi^2<10$
2. # of chd trk>4
3. $-\mathrm{Log}_{10}(y_{34})<2.7$
4. Thrust<0.9
5. $|\cos\theta_{thrust}|<0.90$
6. $85<M_Z<100$ GeV
7. $120<M_h<135$ GeV
8. # of Isolep<2
9. Likelihood>0.30

LR inputs

1. Thrust
2. # of PFOs
3. $-\mathrm{Log}_{10}(Y_{23})$
4. Minimum jets angle in four jets
5. M_h

Signal significance=25.8
Efficiency(h→2j)=34.0%

Zh→ee/μμh 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

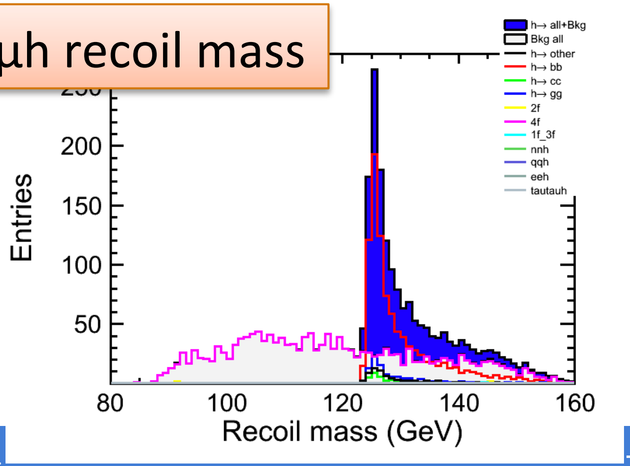
- $E_{ecal}/E_{total}<0.5$, $E_{total}/P<0.4$ (μ)
- $E_{ecal}/E_{total}>0.9$, $0.7<E_{total}/P<1.2$ (e)

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

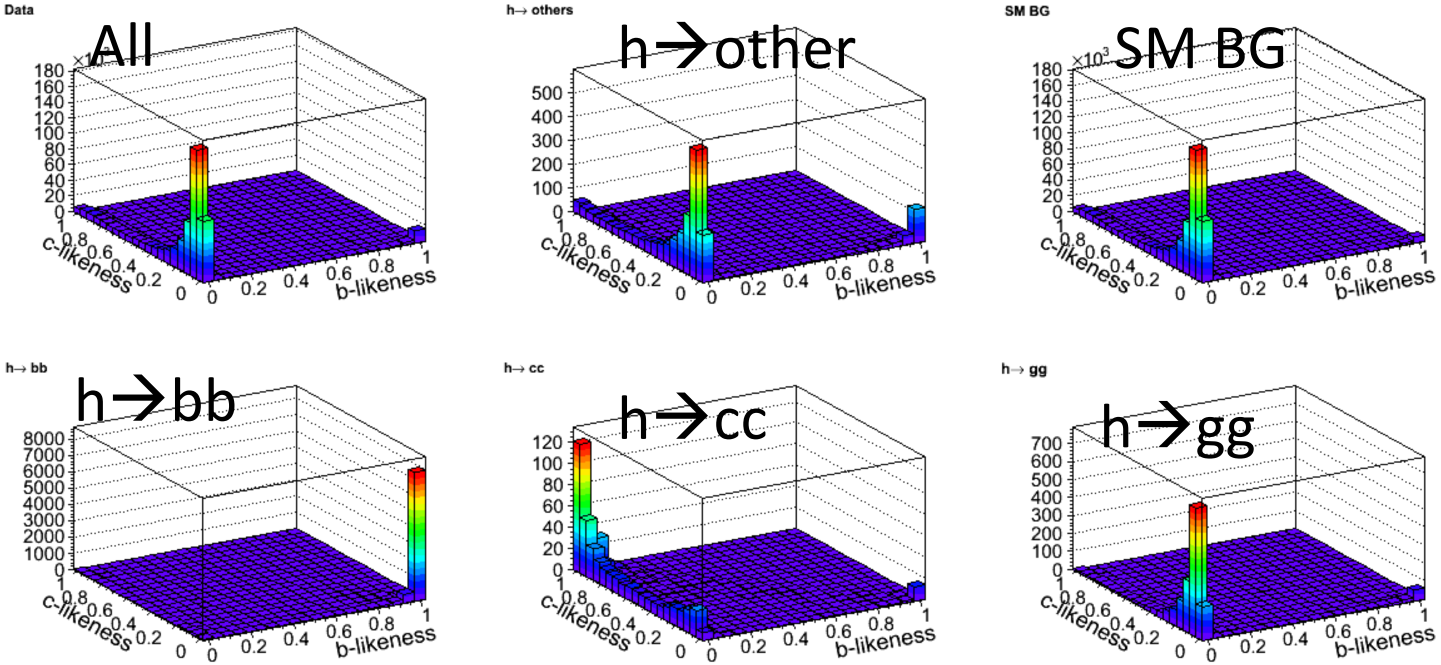
1. # of e/μ candidate >= 2
2. Selected isolated leptons = 2
3. $E_{vis}>200$ GeV
4. NPFOs > 30
5. Thrust>0.8 (Thrust<0.8 at 350 GeV)
6. $|\cos\theta_Z|<0.9$
7. $70<M_{ll}<110$ GeV
8. $100<M_{jj}<150$ GeV
9. $120<M_{recoil} < 160$ GeV



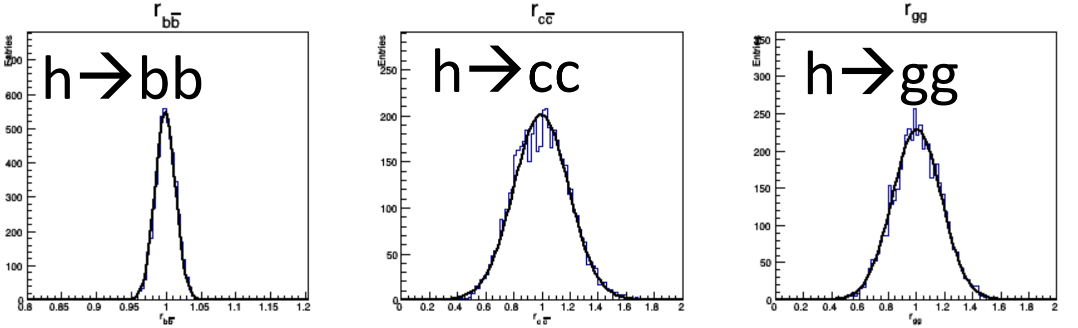
μμh recoil mass

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

3D template fitting



Apply 5,000 times template fitting Toy MC → Extract accuracy of sigma X BR



sigma x BR results

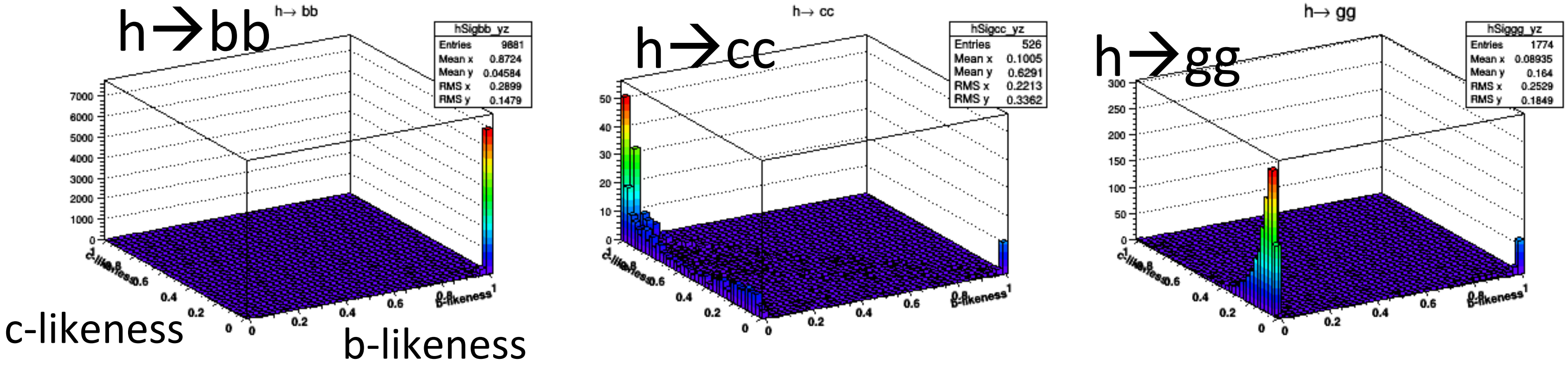
Extract measurement accuracy from template fitting

Update results	**250 GeV**			**350 GeV**		
L (fb-1)	250 fb^{-1} P(-0.8, +0.3)			330 fb^{-1} P(-0.8, +0.3)		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	1.6%	14.8%	9.7%	1.2%	10.9%	6.7%
qqh	1.6%	24.0%	18.4%	1.5%	15.0%	13.2%
eeh	4.4%	57.4%	36.3%	6.5%	>100%	>100%
μμh	3.4%	34.0%	22.3%	4.6%	65.7%	30.9%
Combined	1.0%	11.6%	7.6%	0.9%	8.8%	5.0%
Extrapolation	1.1%	8.0%	6.8%	0.9%	6.5%	5.2%

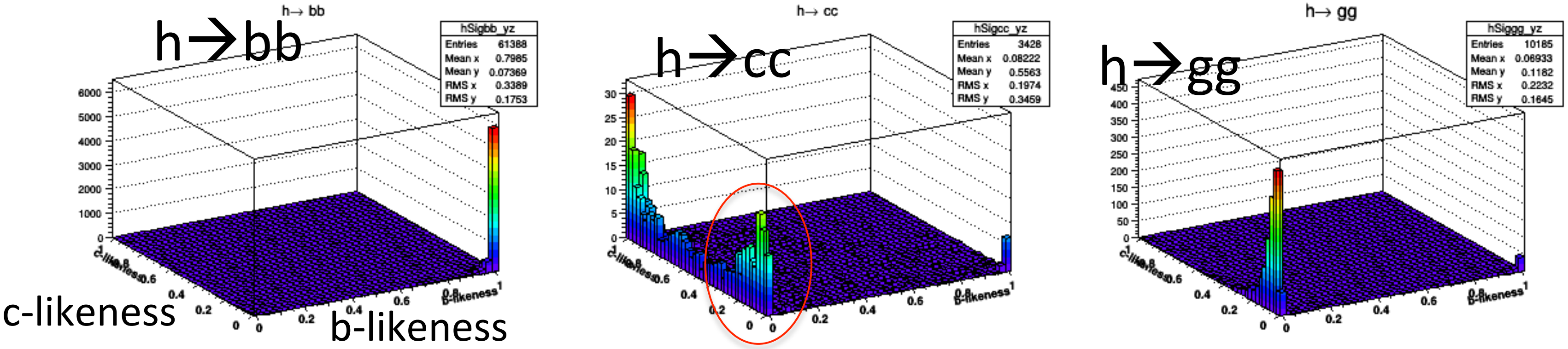
- eeh @ 350 GeV only ~10 events remains with h→cc samples even with L=330 fb^{-1}
- Extrapolation only consider the signal difference

Difference between LCFIPlus and LCFIVTX

LCFIPlus (with qq91_v02_p01)



LCFIVTX



Shape difference on h→cc and h→gg

LCFIVTX: Broader distribution on h→cc

Test with LCFIVTX

Prepare 3D templates processed both LCFIPlus and LCFIVTX for same Mh=125 GeV samples with same cut conditions.
Apply template fitting with two types of flavor tagging.

Sample: Zh→qqh 250 GeV, L=250 fb^{-1}, P(-0.8, +0.3)

qqh 250 GeV	LCFIPlus	LCFIVTX
h→bb	1.6%	1.6%
h→cc	24.0%	26.9%
h→gg	18.4%	22.9%

BCtag variable definition is different:
LCFIVTX: C-tag trained with b background
LCFIPlus: BCtag=Ctag/(Btag+Ctag)

Preliminary results

- B-tagging performance looks comparable with both processor
- h→cc and gg results looks better by LCFIPlus

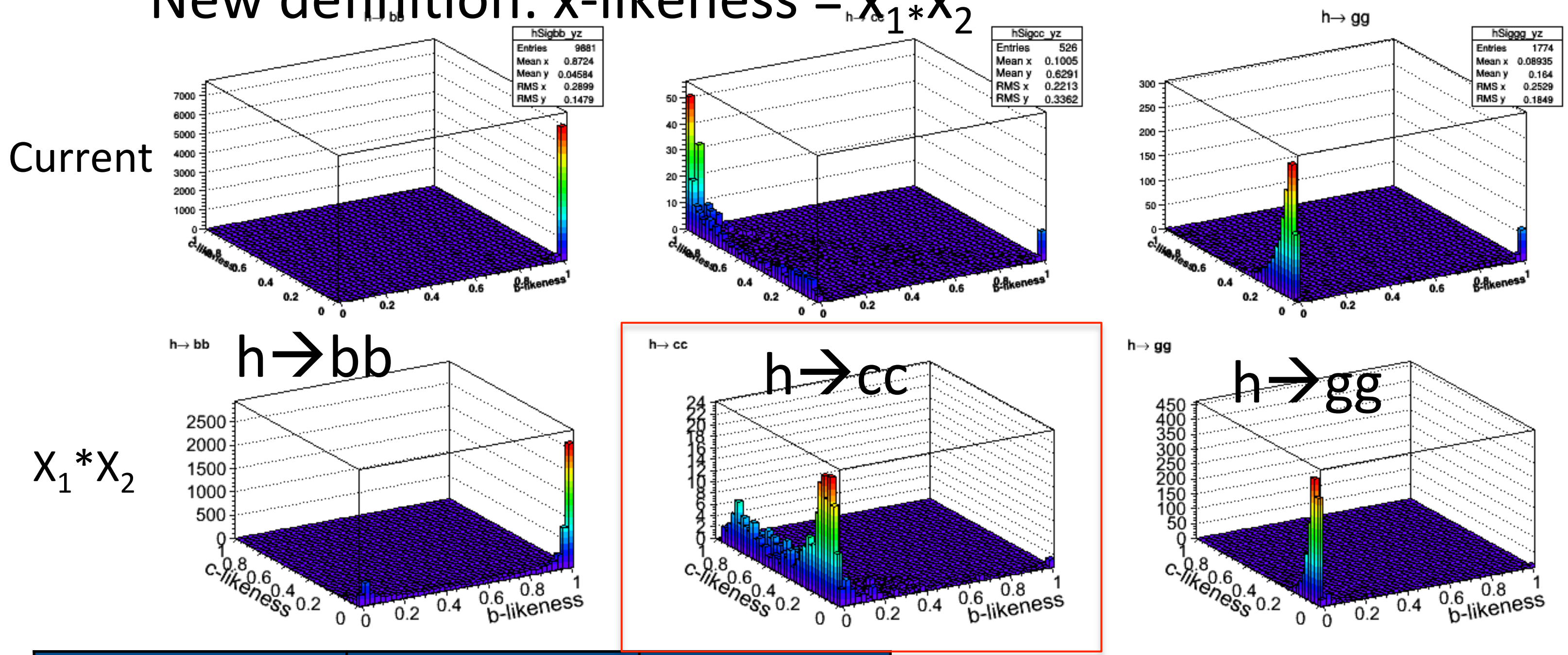
It can caused by the template separation between h→cc and h→gg

LCFIVTX does not apply any optimization for new samples

Different flavor tag definition

Current definition : x-likeness = $x_1x_2/(x_1x_2+(1-x_1)(1-x_2))$

New definition: x-likeness = $x_1 * x_2$



qqh 250 GeV	Current	X1*X2
h→bb	1.6%	1.5%
h→cc	24.0%	22.3%
h→gg	18.4%	19.9%

h→bb, cc accuracies are slightly improved

Now apply for other channel

Next step and plans

- Zh channel is analyzed at Ecm=250 and 350 GeV
- Compare LCFIVTX and LCFIPlus
  - Comparable on h→bb
  - LCFIPlus looks better for h→cc, gg
- Try different flavor likeness definition $(X_1+X_2)/2$
- Check eeh channel selection code and cut optimization
- Different polarization case

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
νν̄h	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
νν̄h	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

Current results of ΔσBR/σBR

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
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%

Analyses are performed on Post LOI and DBD studies

ΔσBR/σBR E_{cm}=250 GeV

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

E_{cm}=250 GeV	**Extrapolation**			**Extrapolation**		
M_h	120→125 GeV			120→125 GeV		
Lumi.	250 fb^{-1}			300 fb^{-1}		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	1.8%	12.9%	11.2%	1.4%	9.3%	6.9%
qqh	1.6%	11.8%	10.5%	1.5%	10.8%	10.2%
eeh	4.0%	31.4%	25.3%	5.4%	33.3%	27.1%
μμh	3.5%	26.3%	19.1%	5.1%	33.3%	24.6%
Combined	1.1%	8.0%	6.8%	1.0%	6.8%	5.5%

Statistical uncertainty only

Preliminary results

Investigating discrepancy of h→cc/gg on Zh→qqh channel

Need to compare LOI samples with new samples

ΔσBR/σBR at E_{cm}=350 GeV

Not changed from previous LCWS13 results.

Comparable with extrapolation and investigating difference between 250 and 350 GeV

E_{cm}=350 GeV			
Mh			
Lumi.			
ΔσBR/σBR			
νvh			
qqh			
eeh			
μμh			
Combined			

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

Zh→vvh analysis procedure

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

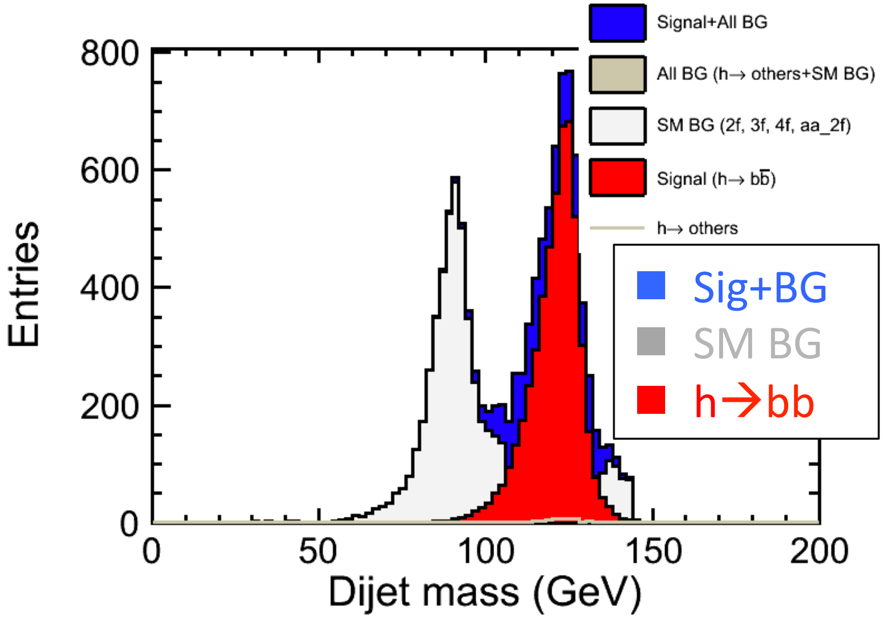
vvh cut flow 250 GeV (for 350 GeV)

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 @ 250 GeV (L=250 fb^{-1})

Cut #	h->bb	h->cc	h->gg	h->others	2f	4f	1f_3f	aa_2f	ZH others
1	30,334	1,399	4,499	16,314	29,694,600	11,011,500	306,702,000	165,506,000	27,314
2	15,248	841	2,497	3,568	2,138,770	1,164,830	182,855,000	69,647,800	3,029
3	15,248	841	2,497	3,568	467,865	805,323	6,478	483	2,524
4	15,126	836	2,485	3,561	247,536	793,883	3,225	148	2,497
5	14,811	818	2,465	3,540	178,115	788,554	2,129	48	2,411
6	13,103	726	2,179	3,107	131,351	547,542	858	24	2,113
7	11,505	656	1,931	2,415	93,514	395,171	518	22	1,851
8	11,327	645	1,875	2,307	85,063	365,816	435	22	1,819
9	11,274	642	1,866	2,233	84,436	357,332	393	22	237
10	9,999	536	1,783	1,981	52,701	160,492	99	10	122
Eff.	33%	38%	40%	12%	1.8.E−03	1.5.E−02	3.2.E−07	6.0.E−08	4.5.E−03