Higgs BR study at 250 and 350 GeV

ILC Physics WG general meeting

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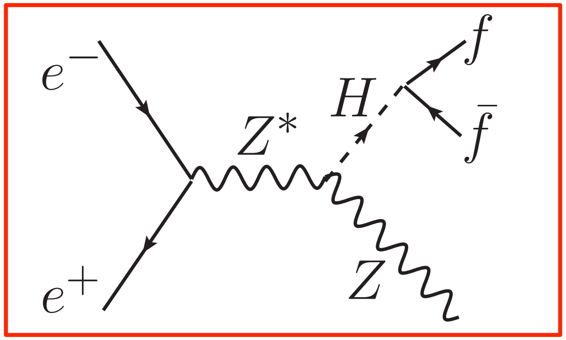
Higgs Branching ratios study

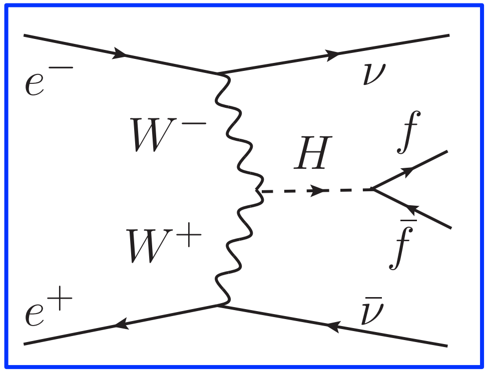
Higgs BRs measurement is an important task on ILC

250 GeV: Zh (Higgs-strahlung) dominant (σ_{Zh}xBR)

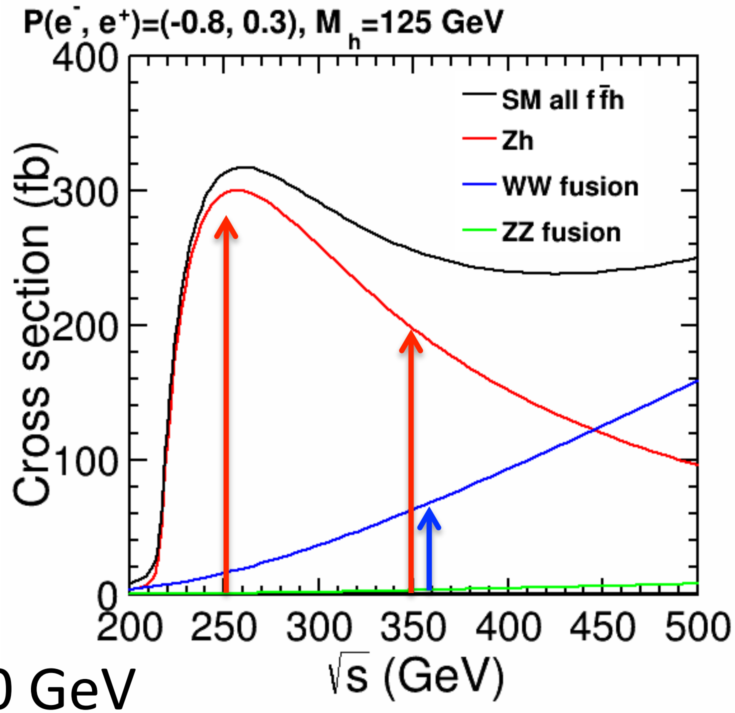
350 GeV: Zh + WW-fusion (σ_{Zh}+σ_{WW} xBR)



Zh (Higgs-strahlung)



WW-fusion

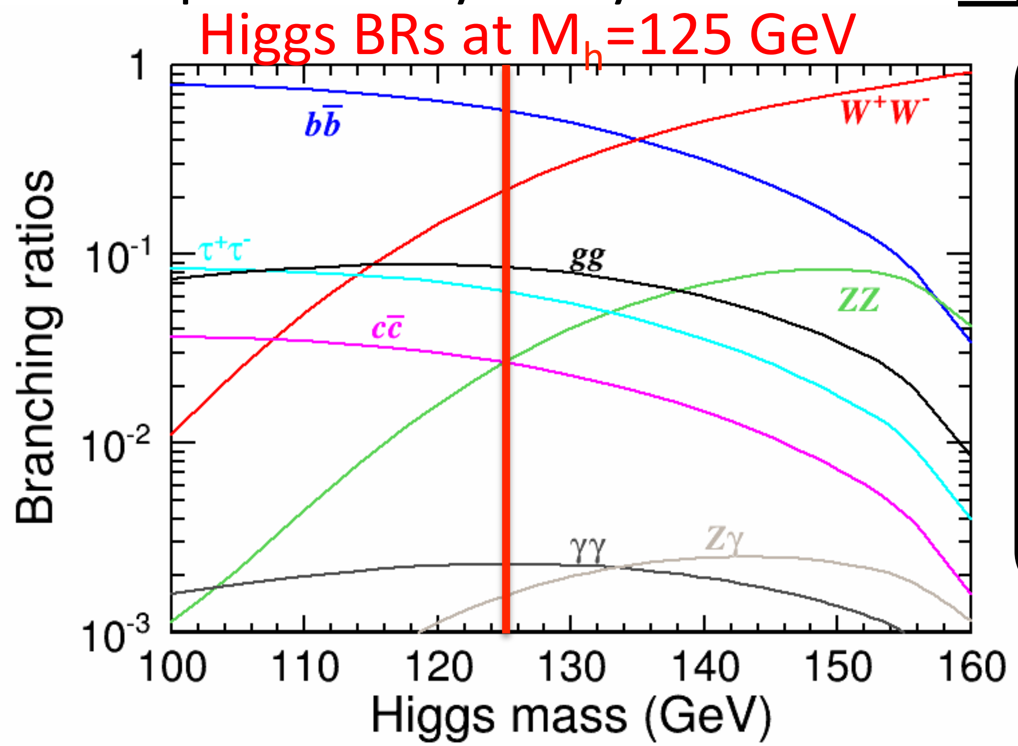


Zh: Hiroaki Ono
250, 350 GeV

vvh (WW-fusion):
Felix Müller (DESY) 350 GeV

Higgs BR study in ILC

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



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

h→bb obtain best precision in ILC with largest BR, B-tagging

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

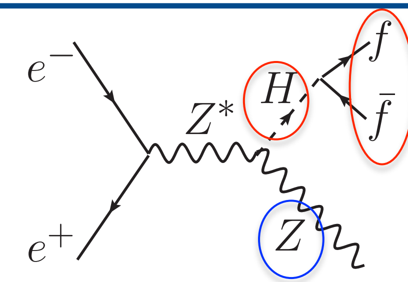
Ecm	250 GeV	350 GeV
SM BGs	σ (-0.8,+0.3)	σ (-0.8, +0.3)
2f	1.2×10^5	7.2×10^4
4f	4.1×10^5	3.1×10^4
6f	Not considered	1.4×10^2
1f_3f	1.3×10^6	1.6×10^6
aa_2f/4f	5.8×10^5	9.6×10^5
tt	None	827.3

	250 GeV ($250\ fb^{-1}$)	350 GeV ($330\ fb^{-1}$)
ννh	19,383	32,555
qqh	52,547	45,837
llh	7,931	7,910

	250 GeV ($250\ fb^{-1}$)	350 GeV ($330\ fb^{-1}$)
BG all	5.1×10^8	8.8×10^8

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)
Events are categorized by Z decay: $e^+e^-\rightarrow$vvh, qqh, llh
Major SM BGs: ee→WW/ZZ (2f, 3f, 4f, aa, and 6f, tt for 350 GeV)



Jet clustering and flavor tagging

Felix apply kt jet clustering for γγ→hadron BG

↓

Event selection and background reduction

↓

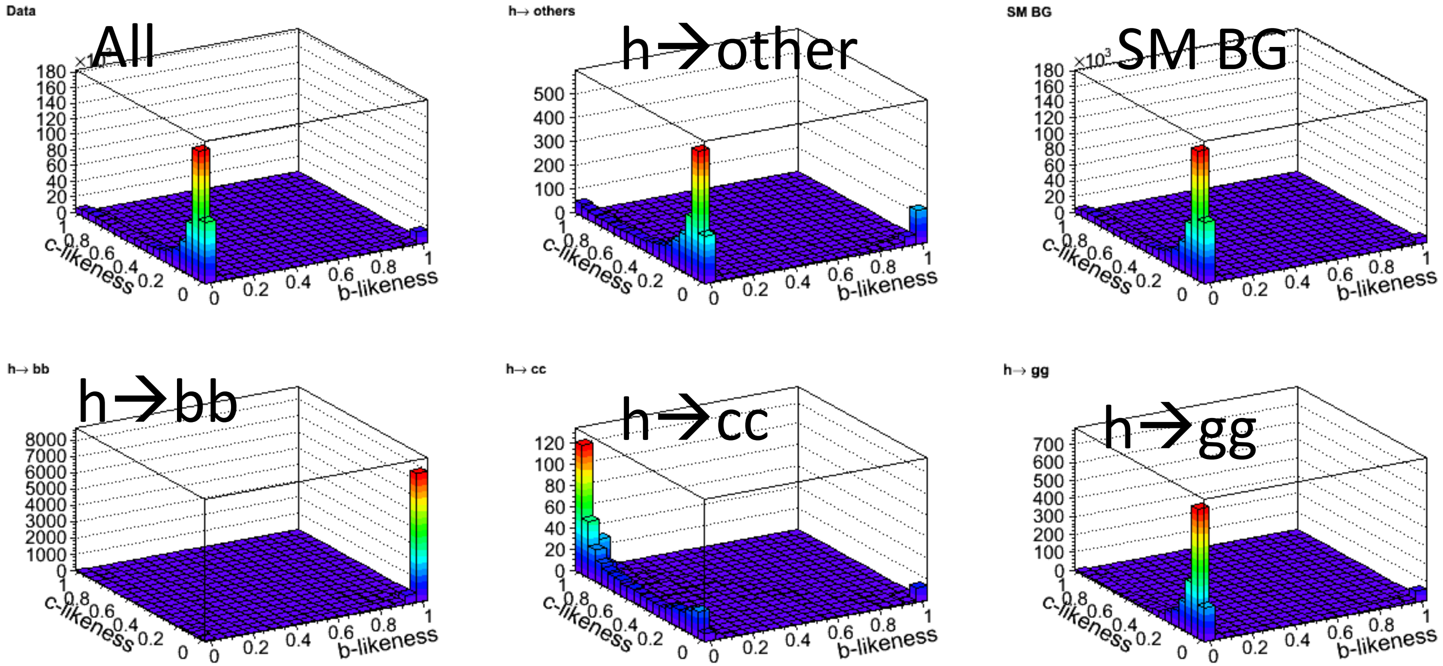
Felix implements MVA cuts

Estimate σBR accuracy with flavor templates

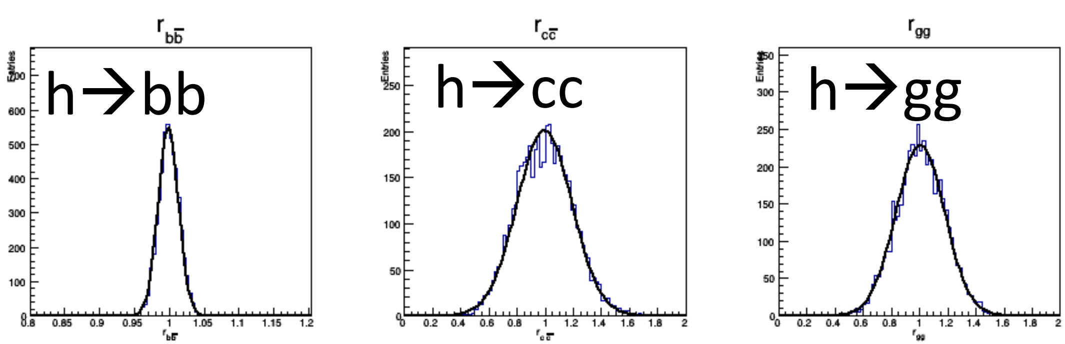
Different flavor definition is evaluated

Missing mass template is not implemented so far

Current template fitting



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



$$\sigma \mathrm{BR(s)} = \mathrm{r_s} \times \sigma \mathrm{BR^{SM}(s)}$$

$$\frac{\Delta \sigma \mathrm{BR(h \to s)}}{\sigma \mathrm{BR}} = \frac{\Delta \mathrm{r_s}}{\mathrm{r_s}}.$$

ΔσBR/σBR results (M_h=125 GeV)

350 GeV ννh is still Zh and WW-fusion inclusive

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%

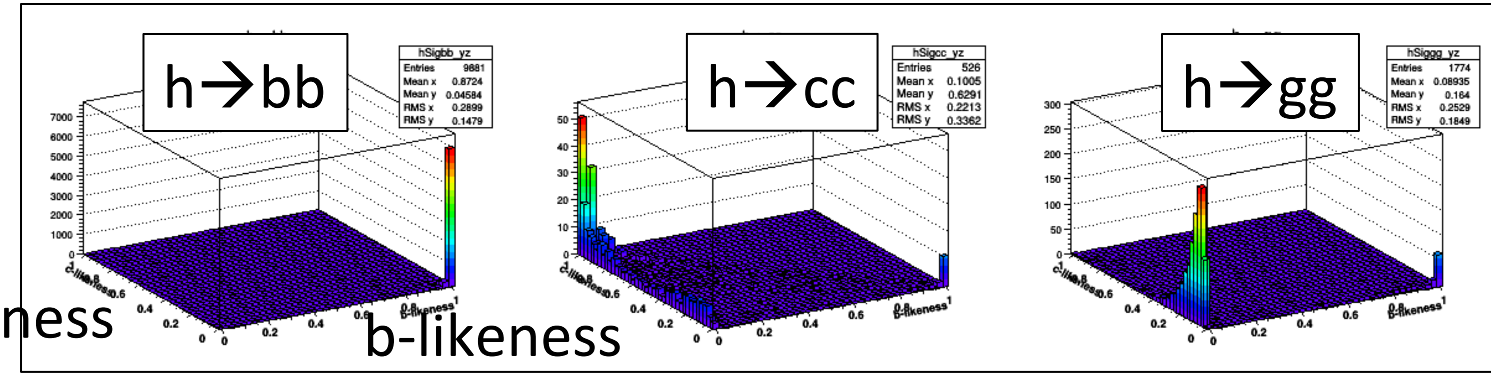
Extrapolation only consider the signal difference between LOI and DBD sample

h→cc channel is worse especially at qqh @250 GeV

Different template variables

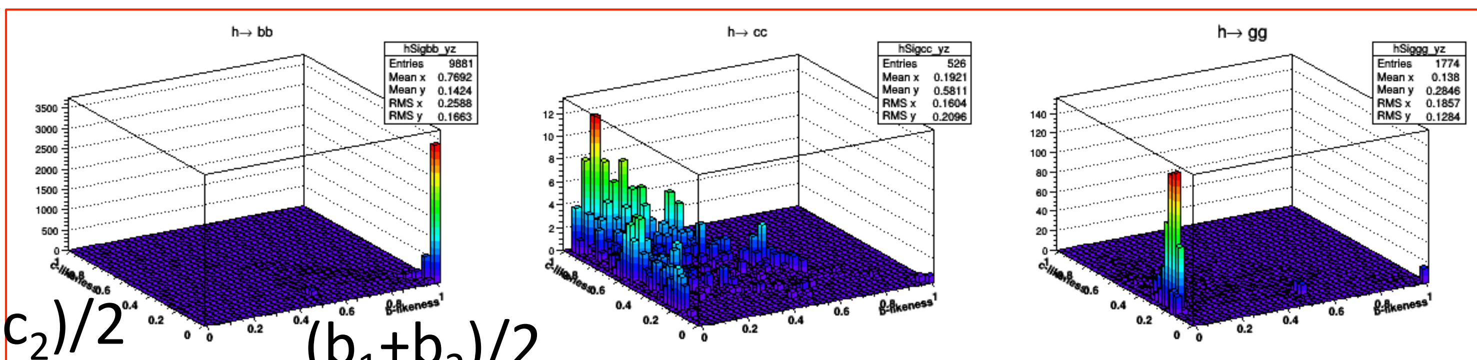
qqh @ 250 GeV template samples

Current



c-likeness b-likeness

Sum $(x_1+x2)/2$



$(c_1+c_2)/2$ $(b_1+b_2)/2$

Difference on h→cc distribution

Missing mass input is under implemented by Felix

Update results with different definition

vvh + qqh combined results with new template definition

vvh, qqh combined	250 GeV (250 fb^{-1})		350 GeV (330 fb^{-1})	
Flavor variable type	Current	$(x_1+x_2)/2$	Current	$(x_1+x_2)/2$
h→bb	1.1%	1.1%	0.9%	0.9%
h→cc	12.6%	11.3%	8.8%	7.9%
h→gg	8.6%	7.7%	6.0%	5.4%

Slightly better accuracies are obtained in both 250 and 350 GeV, vvh, qqh using flavor sum definition

→ Use this definition for updating results

kt clustering with qqh @ 250 GeV

Investigating the degradation of qqh at 250 GeV (h→cc)

kt jet clustering is used to treat γγ→hadron BG
Test with R=1.5 → Re-clustered as 4 jets

qqh @ 250 GeV	No Kt	Apply Kt
h→bb	1.6%	1.6%
h→cc	24.0%	24.1%
h→gg	18.4%	18.6%

No significant difference is observed for final result
→ γγ→hadron contribution looks small especially at 250 GeV

vvh WW-fusion @ 350 GeV

vvh WW-fusion analysis is progressed by Fexlix Muller

Ecm=350 GeV, L=250 fb^{-1}?, P(-0.8, +0.3)

- Kt jet clustering with R=1.5, 4jets → dijet re-clustering
- Cuts are optimized to maximize the signal significance
- Apply BDT TMVA cuts to improve significance
- Apply flavor template fitting with b/c flavor tag
  (Missing mass fit is not yet implemented)
  → Zh/WW-fusion inclusive result w/o missing mass information

From the LCWS14 updates,
first result is obtained with flavor template fitting

- h→cc looks worse from the extrapolation
- Number of generated signals and BGs are now compared
  → Luminosity looks different (250 fb^{-1}?), checking this point

Summary and next steps

- Higgs σBRs are evaluated with M_h=125 GeV
- Other flavor definition is evaluated
  - Better with sum definition for each channel
- kt clustering is tested
  - No difference is observed at 250 GeV qqh
- Test with TMVA to improve significance

- Evaluate different polarization case
- Update 500 GeV analysis

BACKUP

vvh WW-fusion at 350 GeV

- BDT variables:
  - All cut parameters, Longitudinal momentum, global cos(Θ), thrust, thrust axis, jet masses, jet momenta, jet angles

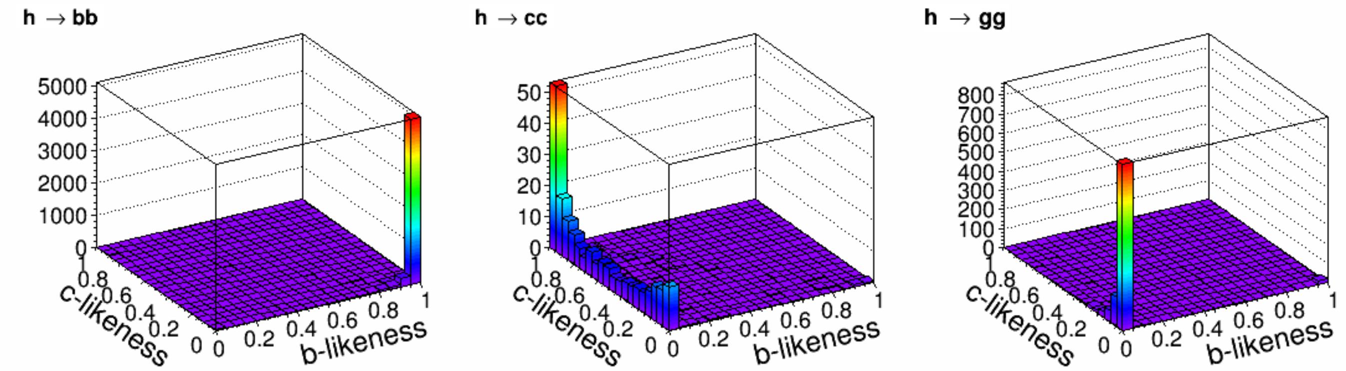
	condition	BG	Signal	Signf
Expected		15042827,7	24663,1	6,4
isolated leptons	#iso lep = 0	12579833,8	21924,6	6,2
Transverse P	$240 > P_{t,vis} > 30$	887408,9	18526,5	19,5
Visible Mass	$135 > m_{vis}$	277267,9	17636,8	32,5
Angle between jets	0.27 > cos a	147209,6	16411,2	40,6
# tracks > 1GeV	$N_{chd} > 26$	44616,3	11306,0	47,8
max. jet mass	$135 > M_{j,max} > 40$	26375,8	10166,5	53,2
Durham minus	$Y_{12} > 0.05$	24821,5	10117,7	54,1
BDT	BDT > -0.02	6777,3	9538,1	74,7

LOI Study		11092,0	9543,0	66,4

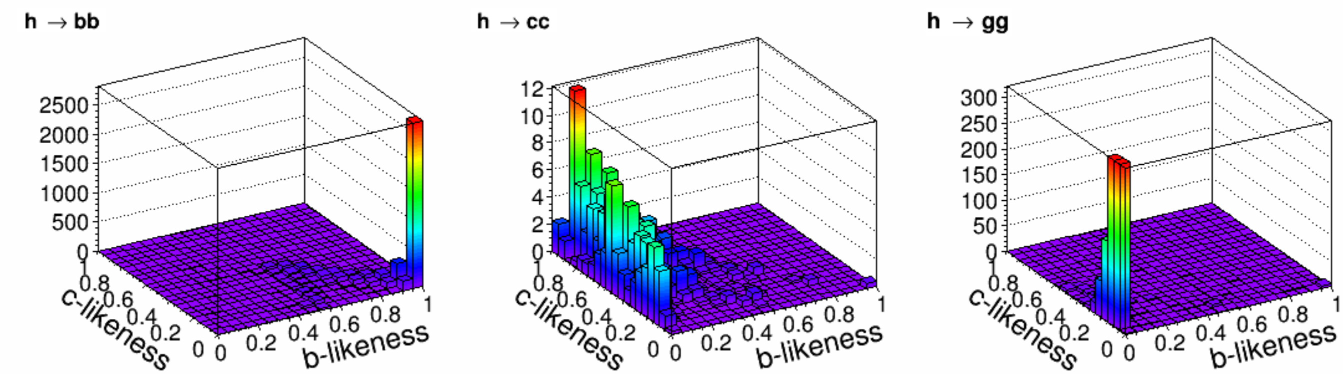
Felix Muller at LCWS14

Different Flavor Likeness Definitions

$$\frac{x_{i1}x_{i2}}{x_{i1}x_{i2}+(1-x_{i1})(1-x_{i2})}$$



$$\frac{x_{i1}+x_{i2}}{2}$$



Simple mean tag value gives better results than the standard likeness definition

h->	Standard likeness	$(x_1+x_2)/2$
bb	1.148+-0.013	1.135+-0.013
cc	15.35+-0.16	14.56+-0.16
gg	4.758+-0.052	4.694+-0.049

Felix Muller at LCWS14

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=330 fb^{-1})		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh	1.4%	8.6%	9.2%	1.3%	8.9%	6.6%
qqh	1.5%	10.1%	13.7%	1.4%	10.3%	9.7%
eeh	5.3%	30.5%	35.8%	5.1%	31.8%	25.8%
μμh	5.1%	30.9%	33.0%	4.9%	31.8%	23.5%
Combined	1.0%	6.2%	7.3%	0.9%	6.5%	5.2%

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

vvh analysis procedure (H.Ono)

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

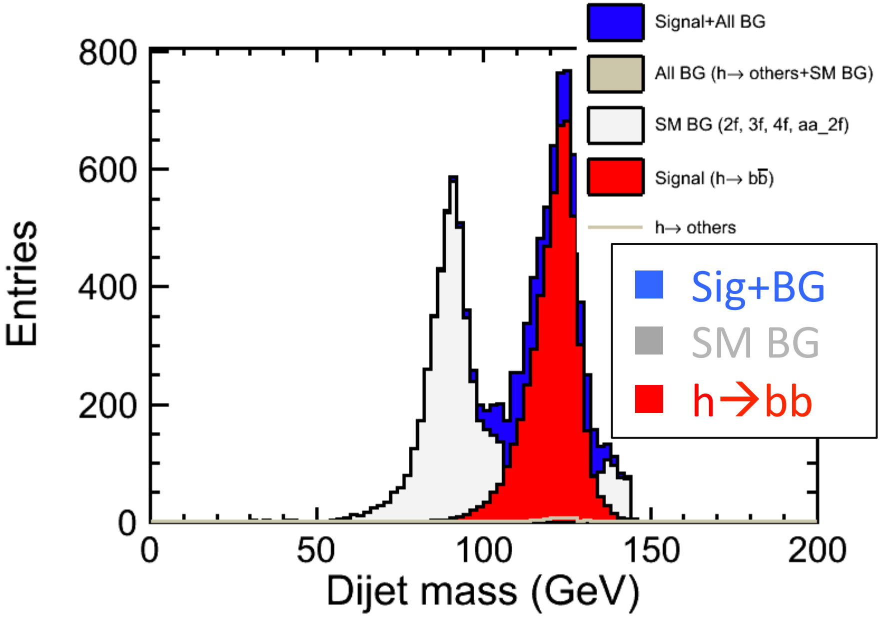
vvh cut flow 250 GeV (for 350 GeV)

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

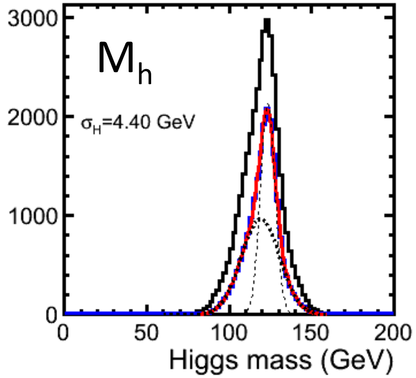


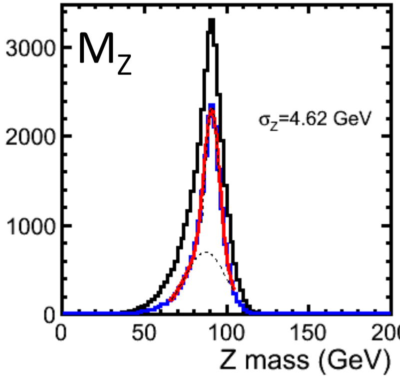
Significance: S/√(S+B)=51.2 (67.3)
Efficiency (h→2j) = 39.7% (46.3%)

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. Likelhood>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%

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)

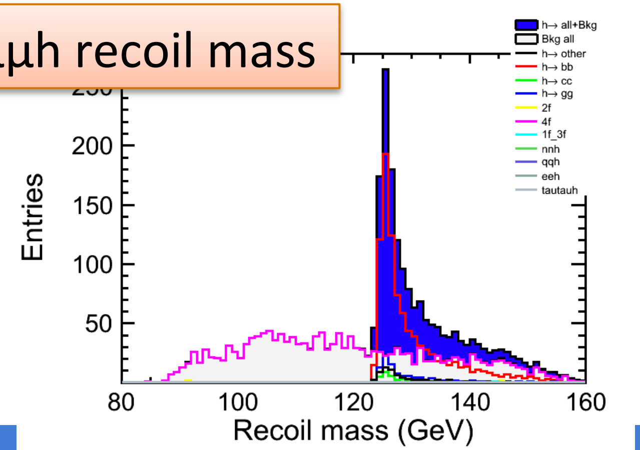
Require track from IP

- 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%

ΔσBR/σBR results (M_h=125 GeV)

350 GeV ννh is still Zh and WW-fusion inclusive

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
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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
- Extrapolation only consider the signal difference between LOI and DBD sample