Higgs BR study at 250 and 350 GeV

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Physics session
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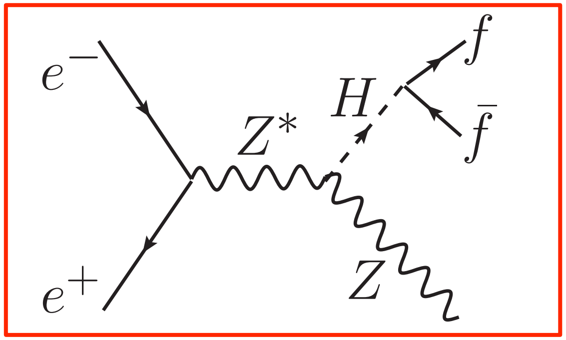
Higgs Branching ratios study

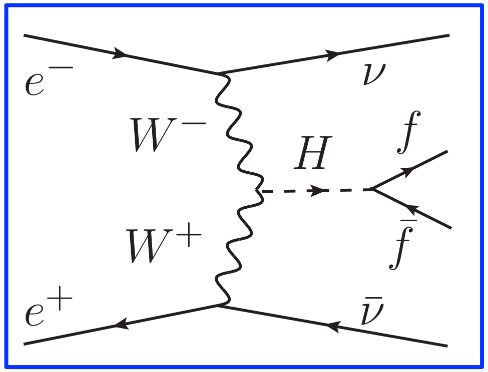
Zh BRs measurement is an important task on ILC

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

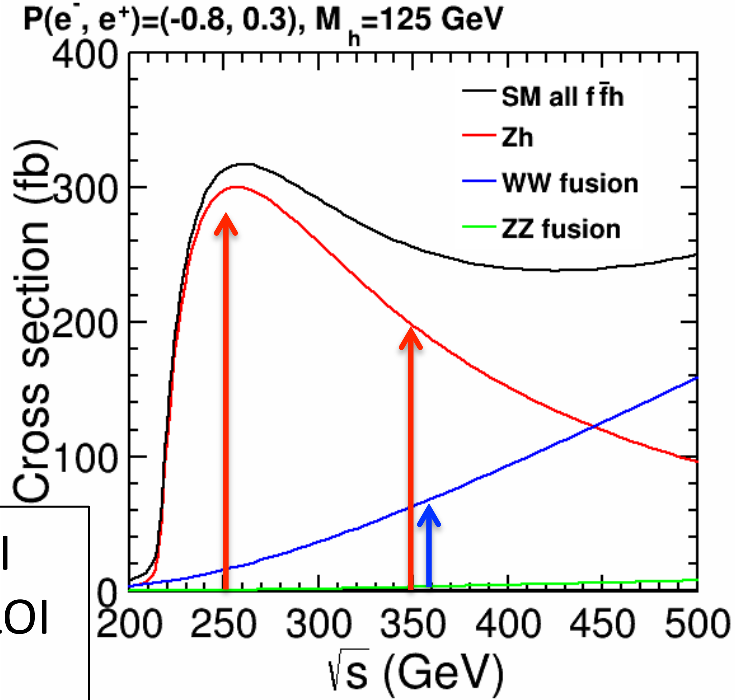
350 GeV: Zh + WW-fusion ($\sigma_{Zh}+\sigma_{WW}$ xBR)



Zh (Higgs-strahlung)



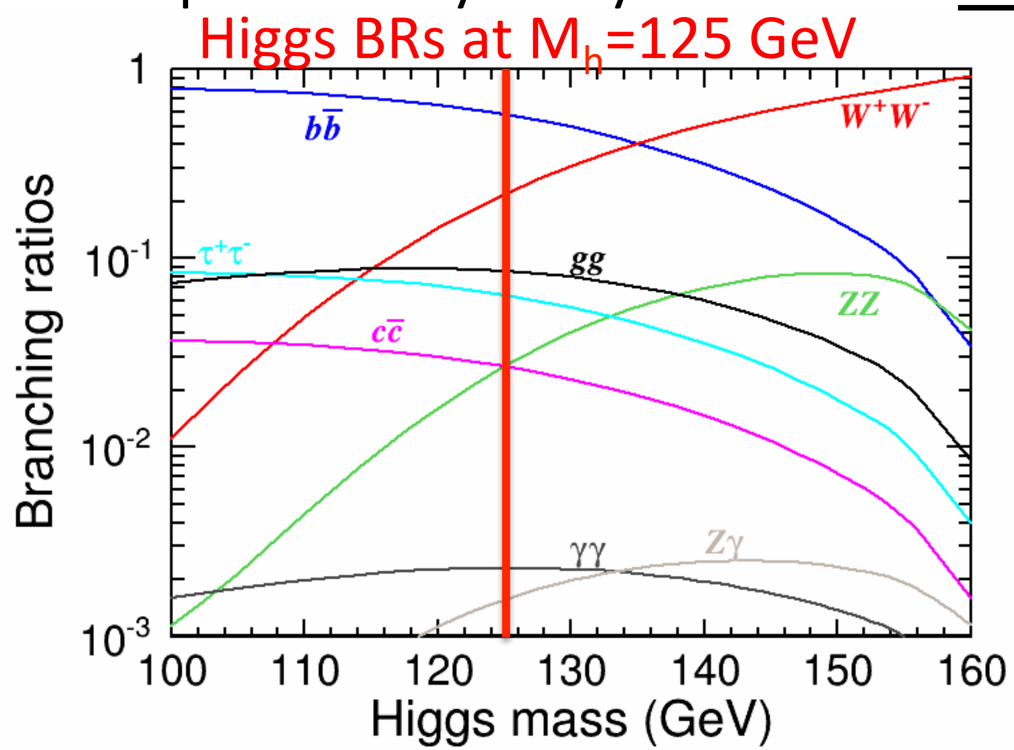
WW-fusion



- Zh with M_h=120 GeV (250, 350 GeV): done at LOI
- vvh with M_h=120 GeV @500 GeV: done at post LOI
- M_h=125 GeV at 1 TeV: done at DBD
- 250 and 350 GeV are on-going (re-do post DBD)

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

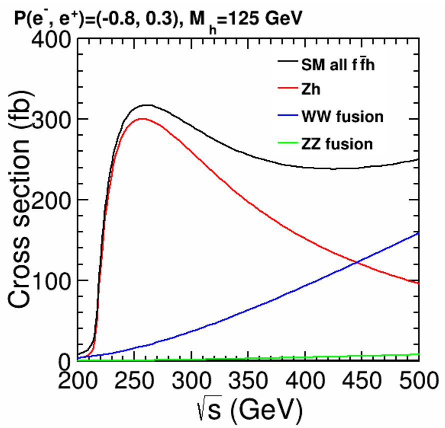
h→cc, gg are expected to measure in ILC

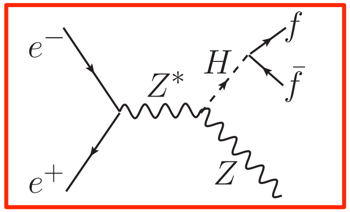
BR	Mh	bb	cc	gg	ττ	WW	ZZ	γγ	Zγ	μμ
Pythia	120 GeV	65.7%	3.6%	5.5%	8.0%	15.0%	1.7%	0.3%	0.1%	0.03%
LHCXSWG	125 GeV	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.2%	0.2%	0.02%

Signal (M_h=125 GeV) and BGs

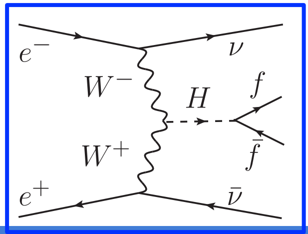
E_{cm}	250 GeV	350 GeV
Signal	σ (-0.8,+0.3)	σ (-0.8, +0.3)
ννh	77.5	98.7
qqh	210.2	138.9
eeh	10.9	10.2
μμh	10.4	6.9
ττh	10.4	6.9
Total	319.4	261.5

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
tt	None	827.3



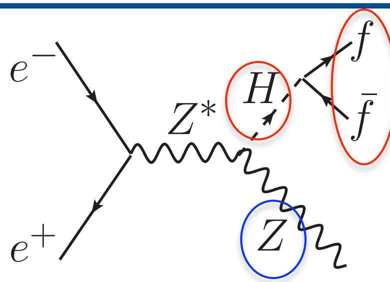


Zh: Hiroaki Ono
250, 350 GeV



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

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^-→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, Missing mass

Evaluate σBR with flavor template fitting

Felix will add Missing mass for WW-fusion evaluation

vvh analysis procedure (H.Ono)

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

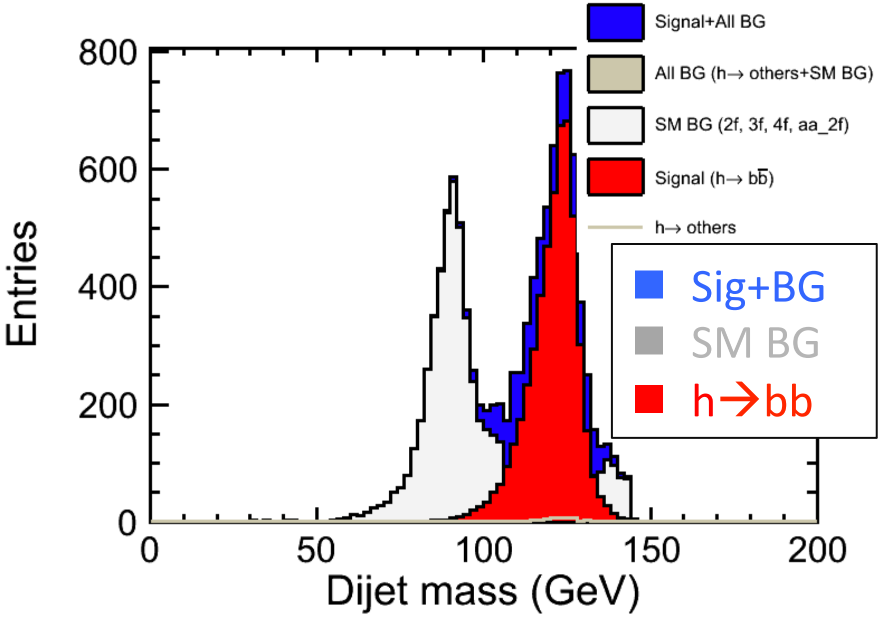
vvh cut flow 250 GeV (for 350 GeV)

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



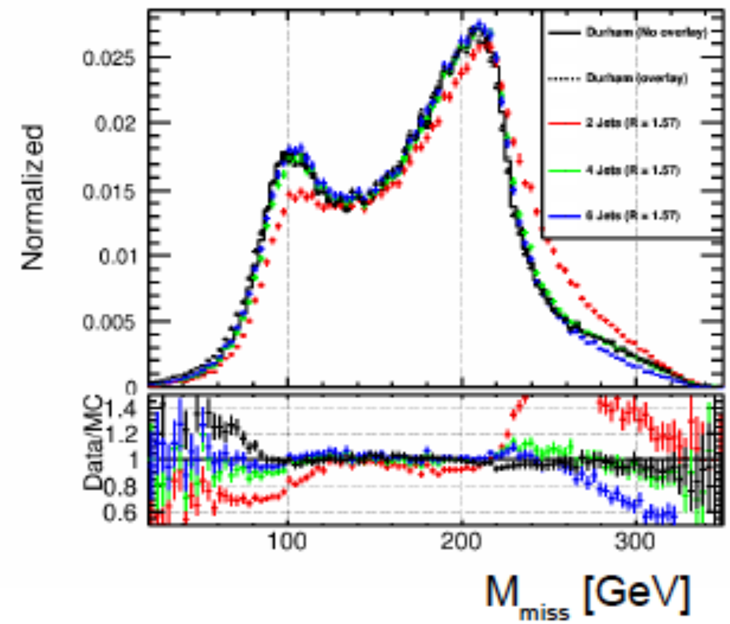
Significance: S/√(S+B)=51.2 (67.3)
Efficiency (h→2j) = 39.7% (46.3%)

Reconstruction Strategy   νvh @350 GeV Felix Müller

- νvh → 2 Jets + Missing Mass
- FastJetProcessor to remove γγ-overlay
  - kt algorithm, R value 1.5, 4 exclusive jets
- Uncluster the 4 jets and use Durham to cluster the particles in 2 jets
- Use LCFIPlus for flavor tagging
- Evaluate flavor likeness X_i of the event (i=b,c,bc)

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

  with x_i the flavor tag of the single jets
- Event selection with cut analysis and BDT
- Template fit to the flavor likeness of the Higgs di-jets



Missing mass distribution
kt jet clustering is optimized

Cut Optimization

vvh @350 GeV Felix Müller

- Cuts optimized for significance and for equal sensitivity to Higgs strahlung and WW fusion (~39% signal left for both processes)
- BDT variables:
  - All cut parameters, Longitudinal P, global cos(Θ), thrust, thrust axis, jet masses, jet momenta, jet angles

E_{cm}=350 GeV, L=250 fb^{-1}

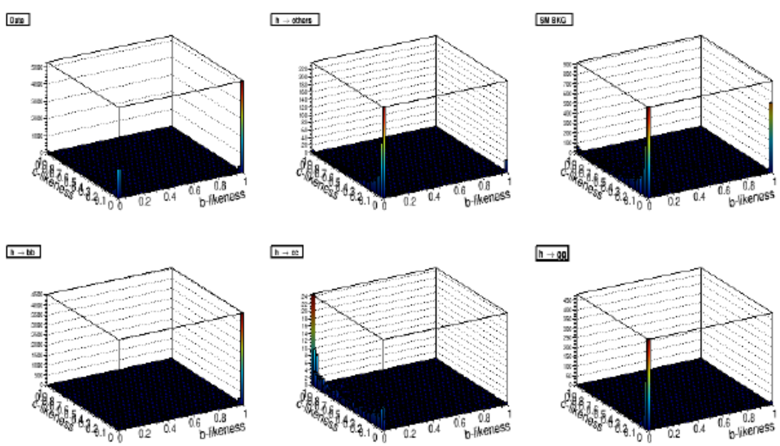
	condition	BG	Signal	Signf
Expected		15042827,7	24663,1	6,4
isolated leptons	#iso lep = 0	12579833,8	21924,6	6,2
Transverse P	$240 > P_{t,vis} > 30$	887408,9	18526,5	19,5
Visible Mass	$135 > m_{vis}$	277267,9	17636,8	32,5
Angle between jets	0.27 > cos a	147209,6	16411,2	40,6
# charged tracks > 1GeV	$N_{chd} > 26$	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

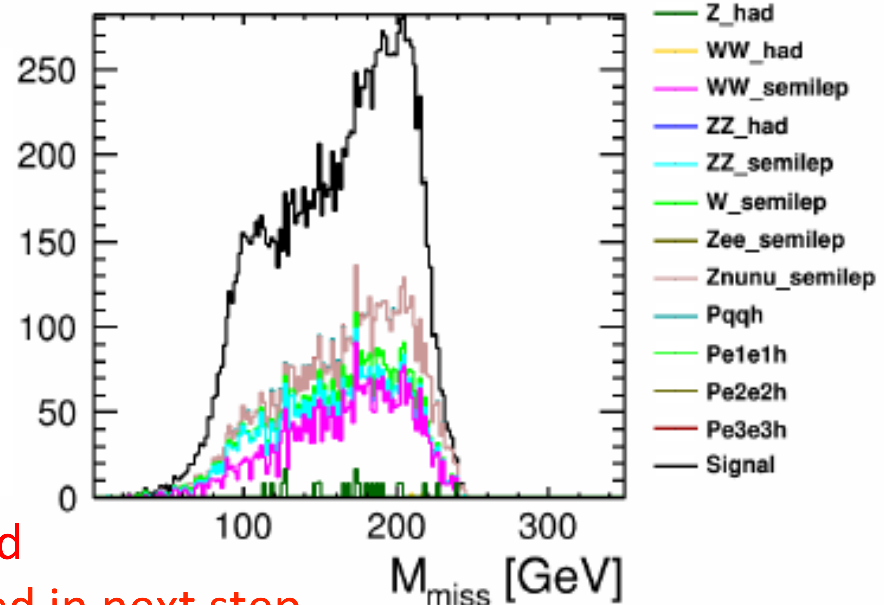
Improve the signal significant with MVA (BDT)

Missing Mass

vvh @350 GeV Felix Müller

- The expected behavior is visible in the missing mass distribution
  - A peak at the Z mass from the Higgs strahlung events
  - A sharp cutoff at 350 GeV- M_{higgs} from the WW fusion events
- A large tail to higher missing masses was removed by rejecting isolated leptons (the tail originated from Higgs decaying into W or tau) (see plot on page 3)
- Using missing mass in the fitting procedure has yet to be implemented





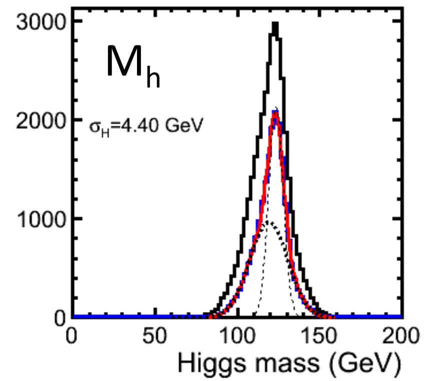
Flavor template fitting is now tested

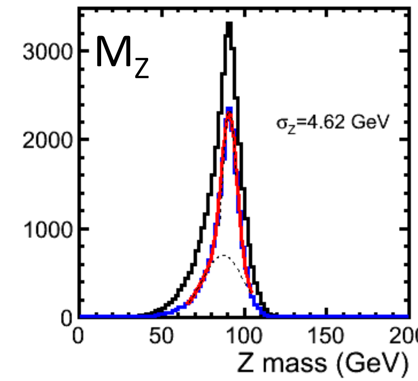
→Missing mass will be implemented in next step

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. χ^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

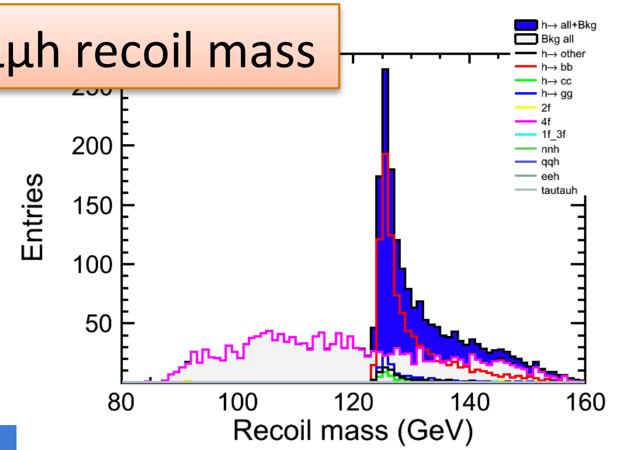
- σ_{d0}, σ_{z0}, σ_{r0}

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

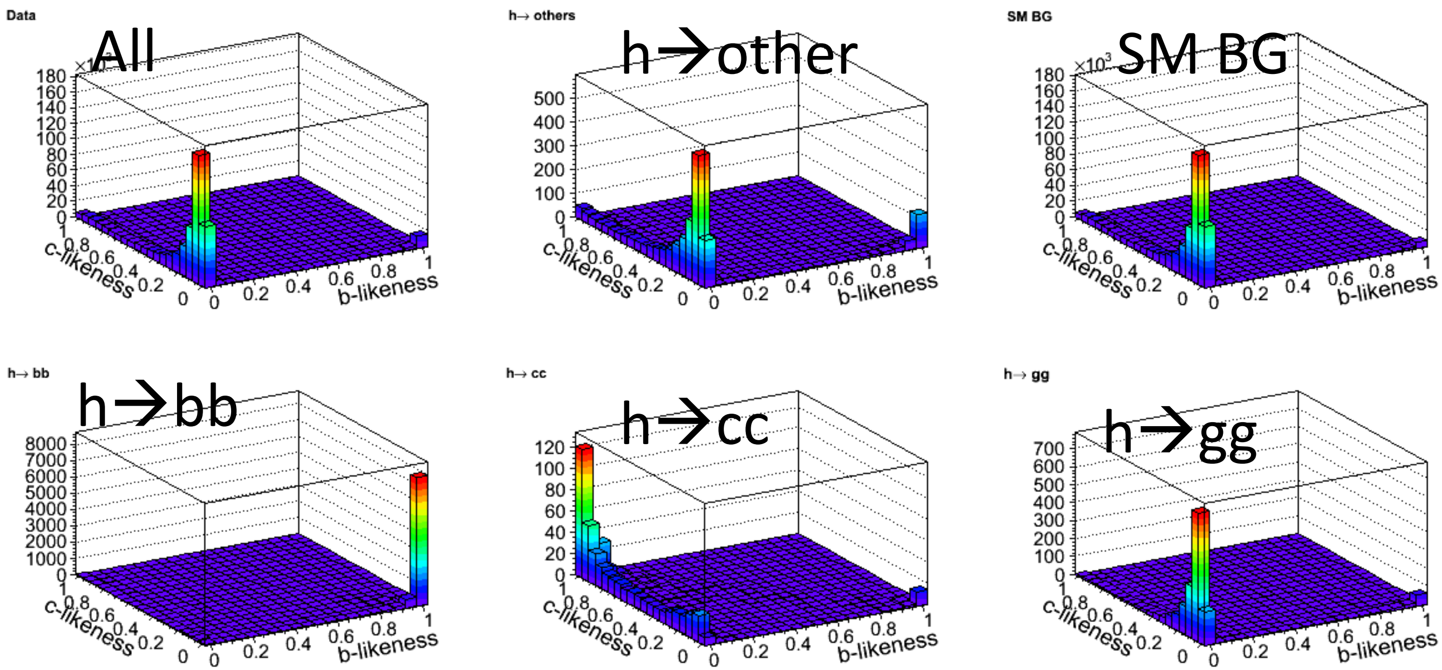
1. # of e/μ candidate >= 2
2. Selected isolated leptons = 2
3. $E_{vis}>200$ GeV
4. NPFOs > 30
5. Thrust>0.8 (Thrust<0.8 at 350 GeV)
6. $|\cos\theta_Z|<0.9$
7. $70<M_{ll}<110$ GeV
8. $100<M_{jj}<150$ GeV
9. $120<M_{recoil} < 160$ GeV

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

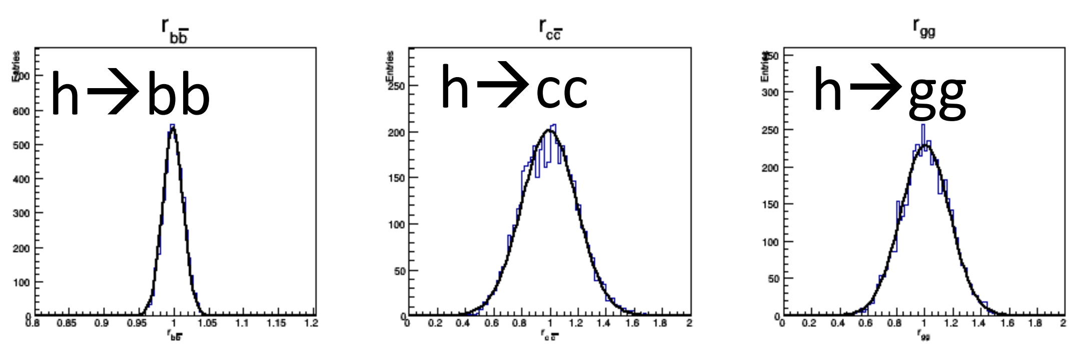
μμh recoil mass



3D 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 νvh is still Zh and WW-fusion inclusive

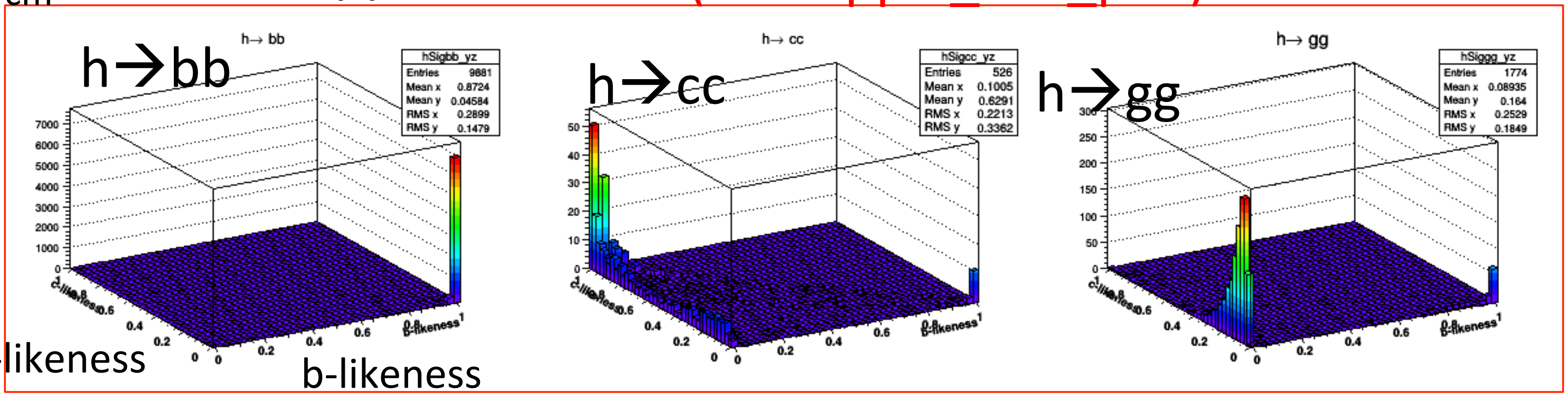
Update results	250 GeV			350 GeV		
L (fb^{-1})	250 fb^{-1} P(-0.8, +0.3)			330 fb^{-1} P(-0.8, +0.3)		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
νvh	1.6%	14.8%	9.7%	1.2%	10.9%	6.7%
qqh	1.6%	24.0%	18.4%	1.5%	15.0%	13.2%
eeh	4.4%	57.4%	36.3%	6.5%	>100%	>100%
μμh	3.4%	34.0%	22.3%	4.6%	65.7%	30.9%
Combined	1.0%	11.6%	7.6%	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
- Extrapolation only consider the signal difference between LOI and DBD sample

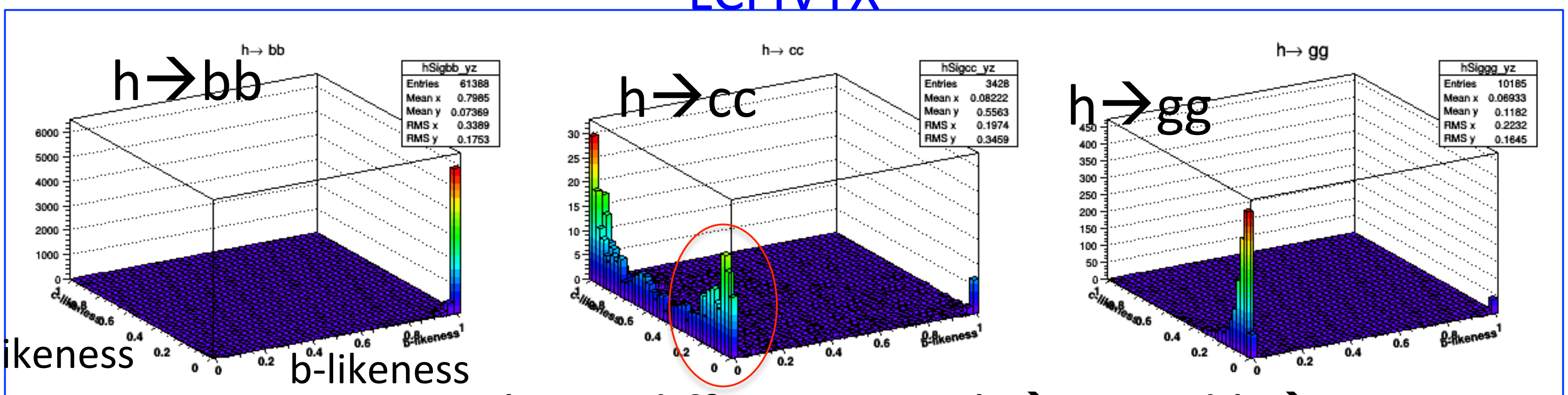
Difference between LCFIPlus and LCFIVTX

E_{cm}=250 GeV, qqh

LCFIPlus (with qq91_v02_p01)



LCFIVTX



Shape difference on h→cc and h→gg

LCFIVTX: Broader distribution on h→cc

LCFIPlus and 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 packages

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

No optimization was applied for LCFIVTX for new DBD samples

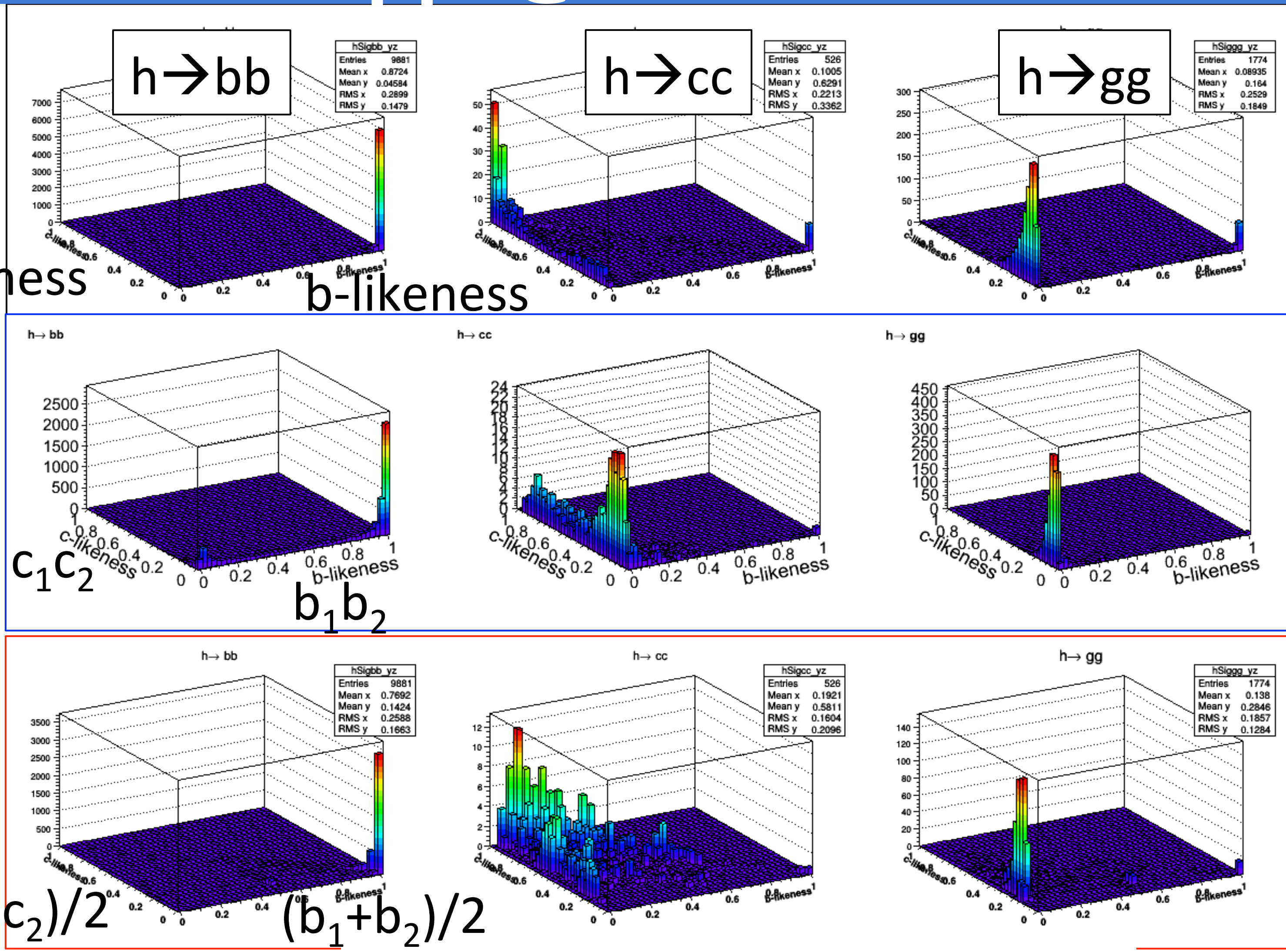
Degradation of h→cc on DBD sample will not caused by LCFIPlus

Different flavor-likeness definition qqh @ 250 GeV

Current

Product $x_{1*}x_2$

Sum $(x_1+x2)/2$



Difference on h→cc distribution

Different flavor-likeness definition

Template fitting is applied with different flavor-likeness definition
Sample: Zh→qqh @250 GeV, L=250 fb^{-1}, P(-0.8, +0.3)

Current	$x_1x_2/(x_1x_2+(1-x_1)(1-x_2))$
Product	x_1x_2
Sum	$(x_1+x_2)/2$

qqh 250 GeV	Current	x_1*x_2	$(x_1+x_2)/2$
h→bb	1.6%	1.5%	1.5%
h→cc	24.0%	22.3%	20.5%
h→gg	18.4%	19.9%	16.1%

Sum definition looks slightly improved the relative accuracy especially on h→cc/gg channel

Summary and next steps

- Higgs σBRs are evaluated with M_h=125 GeV
- Compare LCFIVTX and LCFIPlus
  - Comparable on h→bb
  - LCFIPlus looks slightly better on h→cc, gg
- Investigating qqh, eeh channel degradation
  - kt clustering, MVA selection
- Evaluate different polarization case
- Update 500 GeV analysis

BACKUP

Signal (M_h=125 GeV) and BGs

E_{cm}	250 GeV		350 GeV	
Signal	σ (-0.8,+0.3)	N (250 fb^{-1})	σ (-0.8, +0.3)	N (330 fb^{-1})
ννh	77.5	19,383	98.7	32,555
qqh	210.2	52,546	138.9	45,837
eeh	10.9	2,729	10.2	3,381
μμh	10.4	2,603	6.9	2,267
ττh	10.4	2,598	6.9	2,262
Total	319.4	79,860	261.5	86,303
SM BGs				
2f	$1.2x10^5$	$2.9x10^7$	$7.2x10^4$	$2.4x10^7$
4f	$4.1x10^5$	$1.0x10^7$	$3.1x10^4$	$1.1x10^7$
6f	Not considered		$1.4x10^2$	47,676
1f_3f	$1.3x10^6$	$3.3x10^8$	$1.6x10^6$	$5.1x10^8$
aa_2f/4f	$5.8x10^5$	$1.4x10^8$	$9.6x10^5$	$3.4x10^8$

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
(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