Measurement accuracy of Higgs branching ratio in ILC

ECFA 2013 @DESY Higgs/EWSB session

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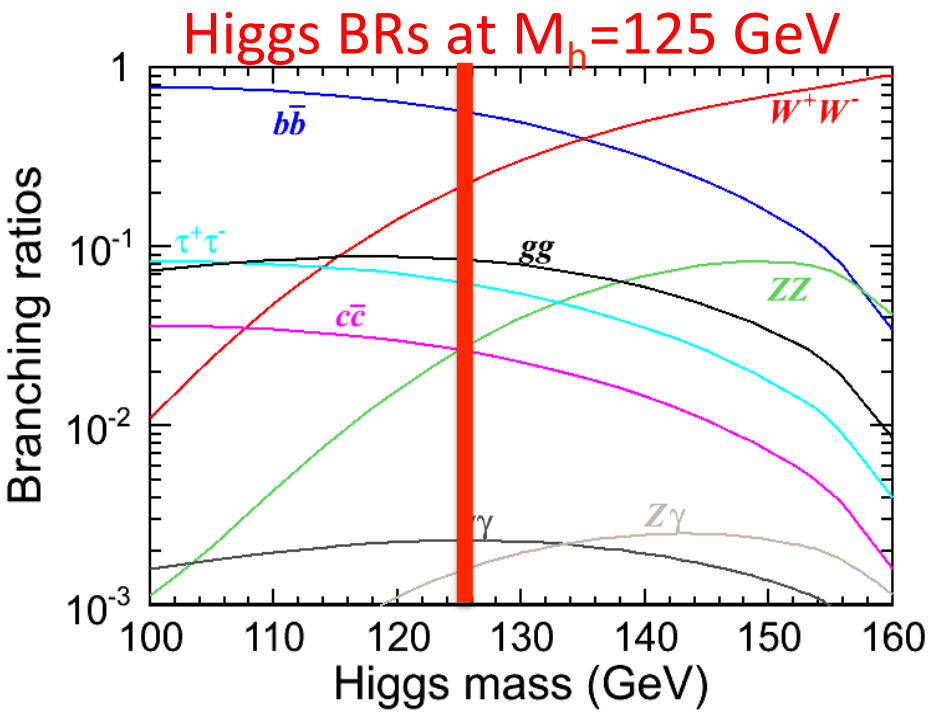
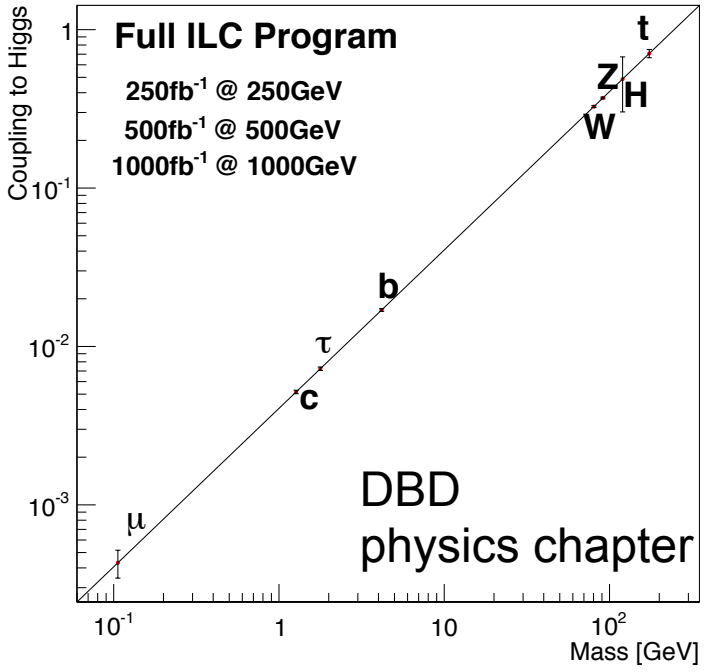
Higgs branching ratio (BR) study

Precise measurement of Higgs BRs is one of key issue in ILC
to figure out the mass-coupling relation between Higgs and particles
and deviation imply the existence of new physics

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



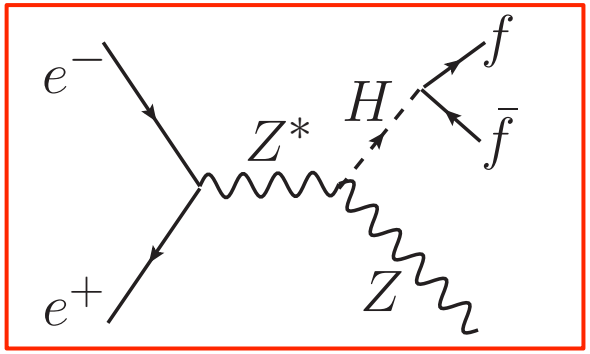


Higgs physics at each energy

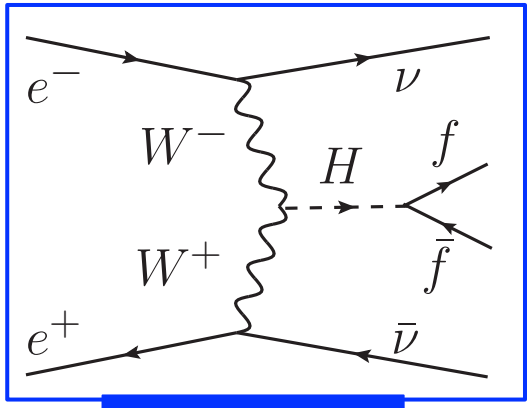
Higgs BR study should be perform at several physics thresholds

E_{cm} (GeV)	L (fb)	Production	Targets
250	250	Zh	Recoil, BR
350, 500	250, 500	Zh+WW-fusion	tt, ZHH, tth
1000	1000	WW-fusion	Rare channel

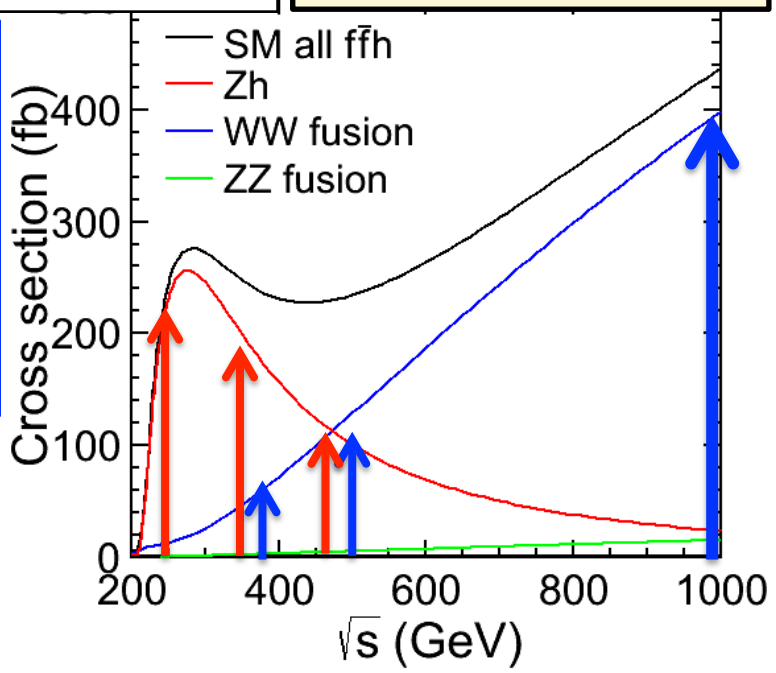
P(-0.8, +0.3)
P(-0.8, +0.2) (1 TeV)
M_h=125 GeV



Zh (Higgs-strahlung)



WW-fusion



250 GeV: Zh (Z information)
Higher energy: WW-fusion (Lumi, xsec)

Higgs BR study update from LOI

DBD study (E_{cm}=1 TeV)
Higgs white paper (E_{cm}=250, 350 (500 GeV))
→Inputs for Snowmass process

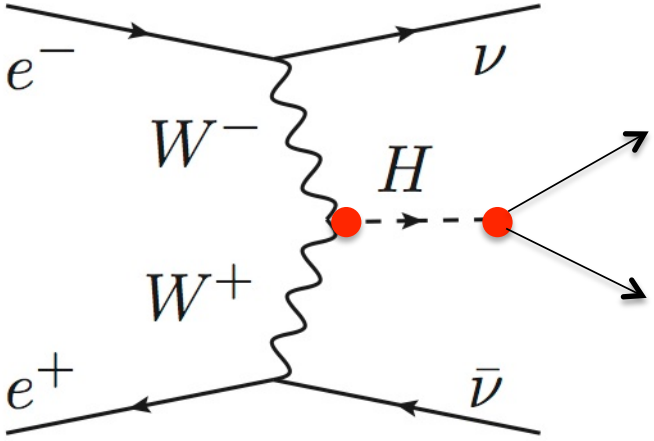
Differences	LOI (and post)	DBD (and post)
Higgs mass	120 GeV	**125 GeV**
BR	Pythia	LHC Higgs XSWG
E_{cm}	250, 350, 500	250, 350, (500) 1000
Beam parameter	RDR	TDR_ws, B1b_ws
Detector model	ILD_00	ILD_o1_v05
Sim/Rec software	ilcsoft v01-06	ilcsoft v01-16-02
Flavor tagging	LCFIVTX	LCFIPlus

250/350 GeV new full simulation samples are also ready

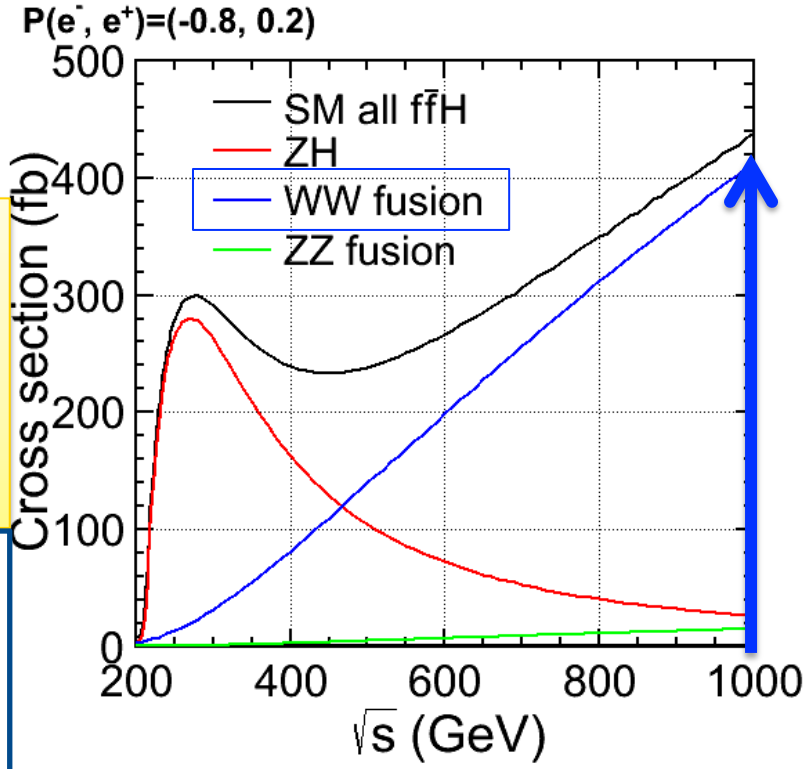
ILD DBD vvh @ 1 TeV

Higgs BR study at 1 TeV

Higgs mainly produced via $e^+e^- \rightarrow \nu_e\nu_e h$ (WW-fusion)



h→bb, cc, gg (two jets)
h→WW* (four jets via hadronic decay)

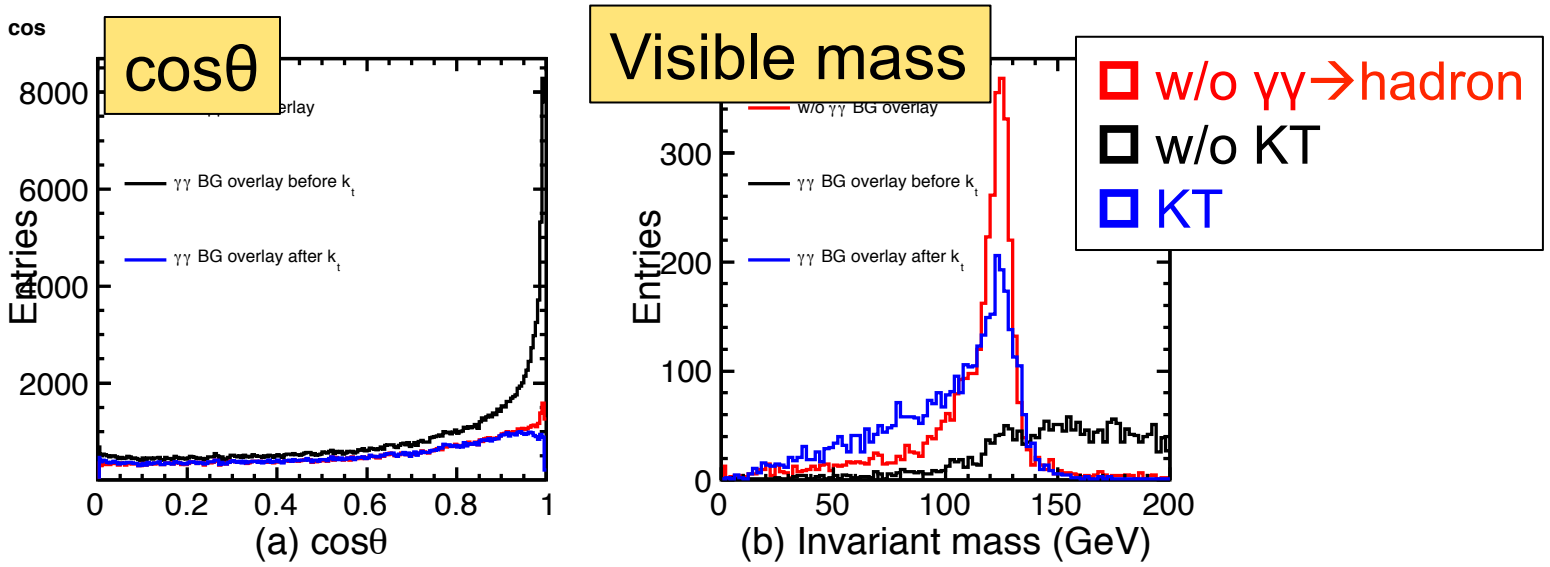


1 TeV beam condition: 1000-B1b_ws
Luminosity: L=1 ab^{-1} (500 fb^{-1} both pol.)
Beam polarization P(e^-, e^+)=(0.8, 0.2)
γγ→hadron BG is overlaid

Larger cross section than Zh@250 GeV
→Statistical gain (xsec and luminosity)
→Measure smaller BR channels

νν̄h @ 1 TeV reconstruction

1. Apply kt jet clustering to remove forward γγ→hadron BGs with R=1.3
2. Clustered particles are used as input of LCFIPlus and re-apply forced two jet clustering for h→bb, cc, gg
3. Cuts are applied and evaluate uncertainties of σBR

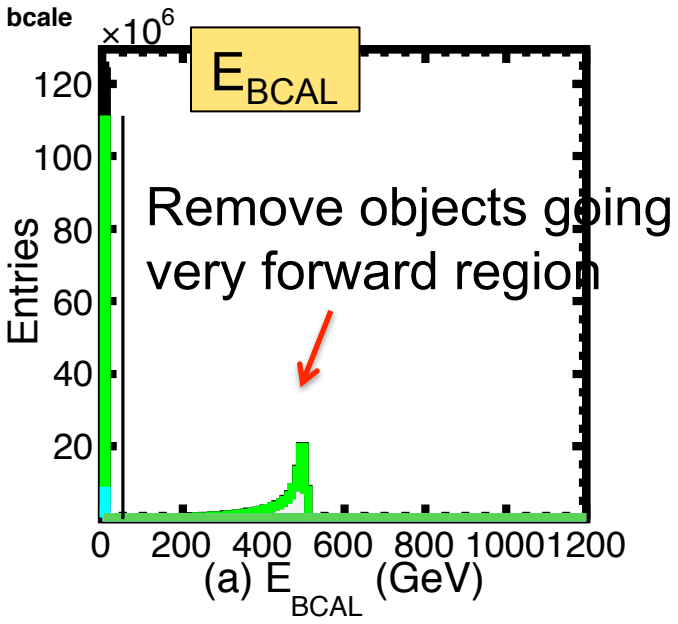


Note: eγ→3f, 5f, γγ→4f backgrounds are produced with SGV fast simulation to produce enough statistics in time

h→bb, cc, gg channel @ 1 TeV

Cut flow

1. E_{BCAL}<50 GeV (Remove forward e, γ)
2. Thrust<0.95
3. Visible energy: 100 < E_{vis} < 400 GeV
4. Transverse momentum: P_T>50 GeV
5. # of PFOs: N_{PFOs}>20
6. $|\cos\theta_h|$<0.95
7. Dijet mass: 110<M_h<150 GeV



	h->bb	h->cc	h->gg	h→other	BGs
No cut	128,700	6,058	19,045	69,604	2.4E+08
After cut	44,988	2,258	6,845	5,214	103,846
Efficiency	35.0%	37.3%	35.9%	7.5%	4.3E-4

h→bb, cc, gg template fitting analysis

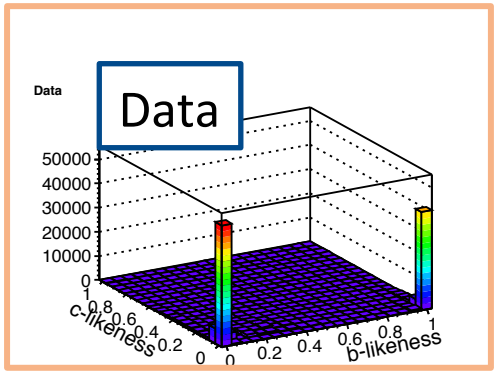
After the cuts, prepare flavor templates of signals and BGs

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

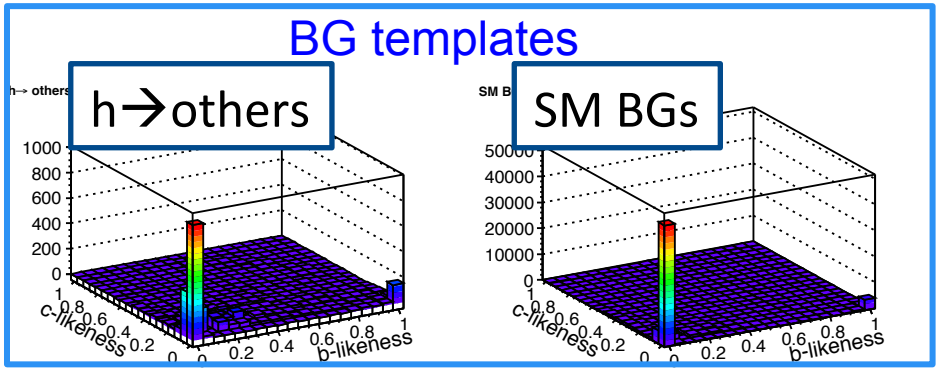
$N^{data}=\Sigma r_{xx} * N^{template}(h\rightarrow xx)+N^{BG}$

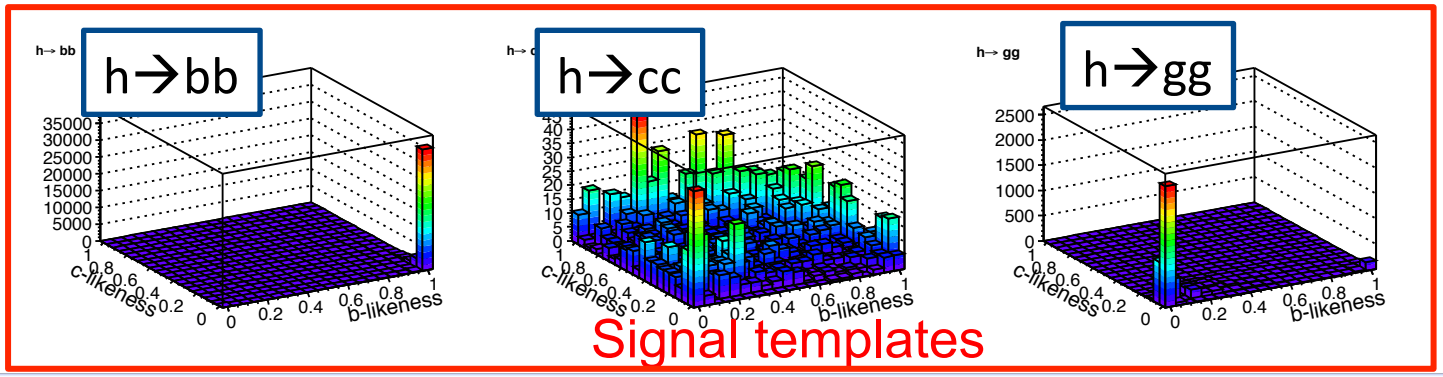
(r_{xx} is a fitted parameter)

N_{data} is fluctuated wit Poisson 5,000 times of Toy MC is applied to evaluate the accuracy of σBR



BG templates

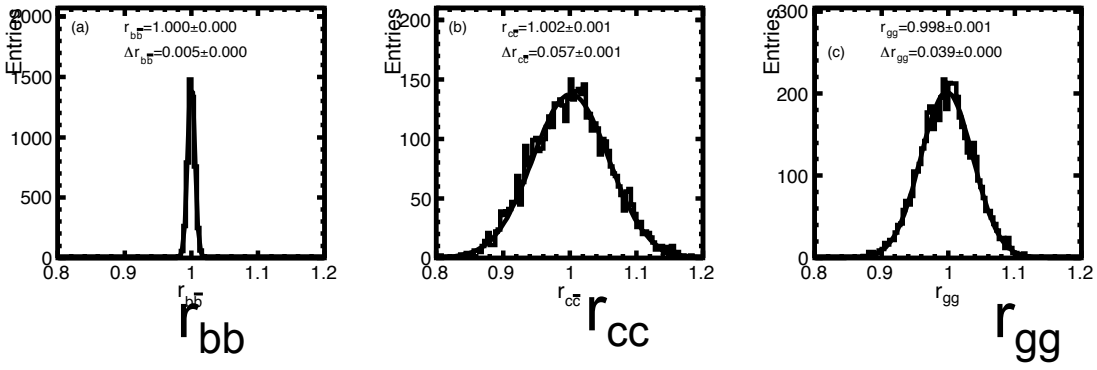




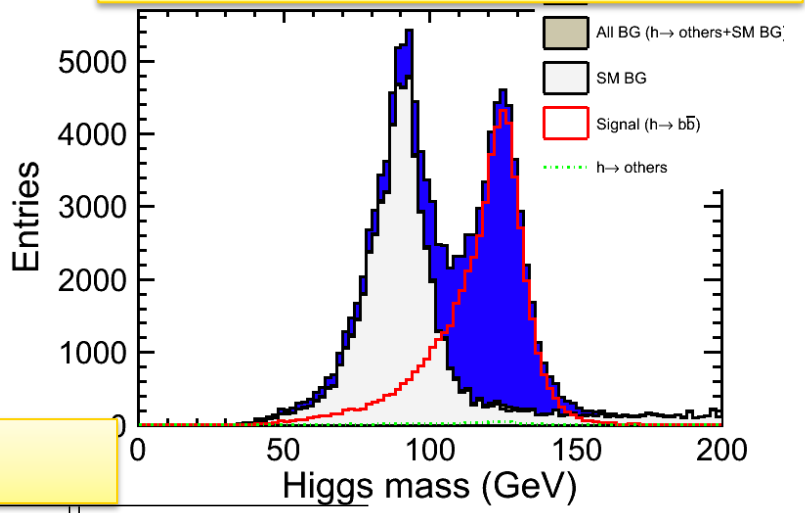
h→bb, cc, gg hadronic channel @ 1 TeV

Flavor template for h→bb, cc, gg and others are prepared
Template fitting is performed to evaluate accuracy of σBR

Fitted r_{bb}, r_{cc}, r_{gg}



h→bb with b-likeness >0.6 cut



L=500 fb^{-1} P(-+0.8, +-0.2) and 1 ab^{-1} P(-0.8, +0.2)

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

Statistical uncertainty only

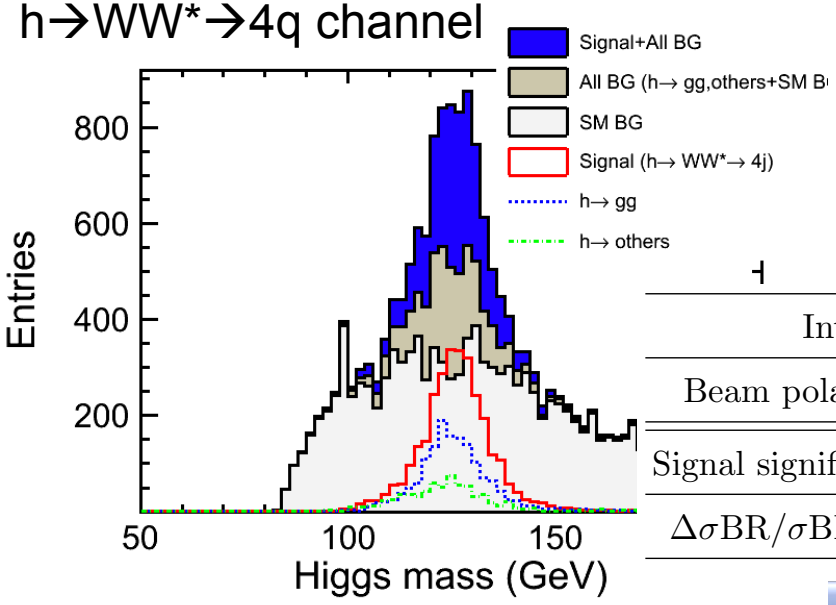
h→WW* channel @ 1 TeV

e+e-→ννh→2ν+4q (4 jet final state)

1. Kt jet reconstruction (R=1.1)
2. Forced four jet clustering
3. Require minimum $|M_{jj}-M_W|$ pair
4. Background reduction
   3f, 4f, h→gg, bb are major BGs

1. $E_{BCAL} < 50$ GeV (Reduce forward e/γ)
2. Thrust < 0.95
3. $100 < E_{vis} < 400$ GeV
4. $P_T < 50$ GeV
5. $N_{chd} > 25$
6. $|\cos\theta_j| < 0.90$
7. $-\log_{10}Y_{34} < 3.0$ (Reduce h→gg)
8. $-\log_{10}Y_{23} < 2.2$ (Reduce h→gg)
9. $BTag_{sum} < 0.8$ (Reduce h→bb)
10. $60 < M_{W1} < 95$ GeV (On-shell W)
11. $15 < M_{W2} < 60$ GeV (Off-shell W)
12. $110 < M_h < 140$ GeV

h→WW*→4q channel



Integrated luminosity	500 fb^{-1}	500 fb^{-1}	1 ab^{-1}
Beam polarization $P(e^-, e^+)$	$P(-0.8, +0.2)$	$P(+0.8, -0.2)$	$P(-0.8, +0.2)$
Signal significance $(S/\sqrt{S+B})$	27.9	4.2	39.7
$\Delta\sigma BR/\sigma BR(h \to WW^* \to 4j)$	3.6%	23.7%	2.5%

Current Higgs BR summary (ΔσBR/σBR)

E_{cm} (GeV)	250	350	500	1000	Comment
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	
h→bb	1.0%	1.0%	0.57%	0.39%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→cc	6.9%	6.2%	5.2%	3.9%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→gg	8.5%	7.3%	5.0%	2.8%	Eur. Phys. J. C 73, 2343 (2013) LC-REP-2013-005
h→WW*	8.1%		3.0%	2.5%	LC-REP-2013-006 250, 500 GeV to be prepared
h→ττ	3.5%				LC-REP-2013-001
h→μμ				31%	LC-REP-2013-006

Re-do with new 125 GeV full simulation samples

250 GeV new samples

M_h=120 GeV to 125 GeV

Cross sections at each energy

Calculate by whizard 1.95

E_{cm}	M_h	beam pol	σ(ffh)	σ(vvh)	σ(eeh)	σ(Zh)	beam param
250	120	P(-0.8,+0.3)	319.6	15.7	0.7	303.1	4 (RDR_ISR_on)
250	125	P(-0.8,+0.3)	319.4	15.9	0.5	303.0	22 (TDR_ws)
500	120	P(-0.8,+0.3)	269.3	159.7	8.6	101.1	2 (RDR)
500	125	P(-0.8,+0.3)	257.7	149.5	7.8	100.4	21 (TDR_ws)
1000	120	P(-0.8,+0.2)	458.5	409.6	22.9	26.0	18 (1000_B1b_ws)
1000	125	P(-0.8,+0.2)	447.5	399.5	22.4	25.6	18 (1000_B1b_ws)

Almost same cross section including beam parameter difference

Branching ratios (120 GeV w/ Pythia, 125 GeV w/ LHC Handbook BRs)

Mh (GeV)	bb	cc	gg	WW*	ZZ*	ττ	γγ	μμ	Zγ	ss
120 (LOI)	65.7%	3.6%	5.5%	15.0%	1.72%	8.0%	0.29%	0.03%	0.13%	0.03%
125 (DBD)	57.8%	2.7%	8.6%	21.6%	2.67%	6.4%	0.23%	0.02%	0.16%	0.04%

250 GeV samples (M_h=125 GeV)

E_{cm}=250 GeV, L=250 fb^{-1}, M_h=125 GeV, $P_{L/R}$=(-+0.8, +-0.3)
Beam parameter: 250_TDR_ws (22)

Process	σ(-0.8,+0.3) (fb)	σ(+0.8,-0.3) (fb)	N_L 250fb^{-1}	N_R 250 fb^{-1}
nnh	77.5	42.6	19,383	10,646
qqh	210.2	142.0	52,546	35,488
eeh	10.9	7.4	2,729	1,844
μμh	10.4	7.0	2,603	1,756
ττh	10.4	7.0	2,598	1,752
Total	319.4	205.9	79,860	51,487

1000 fb^{-1} Higgs samples are generated/reconstructed recently

Total events is almost same as LOI M_h=120 GeV, Beam: 250_RDR_w_ISR (4)

Process	σ(-0.8,+0.3) (fb)	σ(+0.8,-0.3) (fb)	N_L 250fb^{-1}	N_R 250 fb^{-1}
2f	116,224	81,199	29,055,940	20,299,596
4f	40,853	5,099	10,213,367	1,274,770
1f_3f	33,198	18,313	8,299,546	4,578,233

Analysis at the E_{cm}=250 GeV

Main production: **Zh @ 250 GeV**
→Analysis is categorized by Z decay channel
→**h→2 jet (bb, cc, gg) channel** is considered as first step

Zh→ννh

Dijet + missing (Z→νν)

Forced 2 jet rec.
$M_{vis}=M_H$

Main BG: 4f_zz_sl, 4f_ww_sl, 2f_z_h

Zh→μμh, eeh

Dilepton + dijet (Z→ll)

Isolated lep+e/μ ID
2 jet rec. w/o dilep.

Main BG: 4f_zz_sl

Zh→qqh

Four jets (Z→qq)

Forced 4 jet rec.
Jet pairing
M_{12}~M_Z, M_{34}~M_H

Main BG: 4f_zz_h

We start to check the new 125 GeV samples.
Start from Zh→ννh, llh channels. Soon move to qqh

Zh→vvh @ 250 GeV

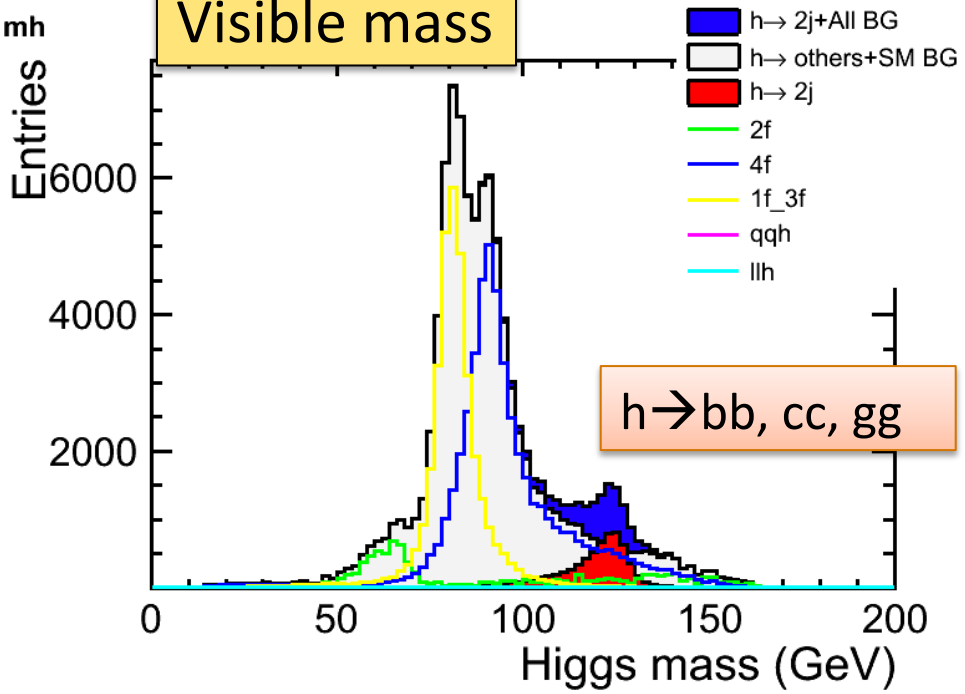
Zh→vvh, E_{cm}=250 GeV, L=250fb^{-1}, P(-0.8, +0.3)

Apply LCFIPlus vertex finder and forced two-jet clustering

vvh cut flow

1. Thrust > 0.8
2. 20 < P_t < 70 GeV
3. # of charged tracks > 10
4. $|\cos\theta_h|$<0.9
5. Maximum P_{trk} < 30 GeV
6. Y_{23}<0.02
7. 80 < M_{miss} < 150 GeV
8. 110<M_{vis}<140 GeV

Visible mass



Visible mass distribution
all cuts w/o b-tagging

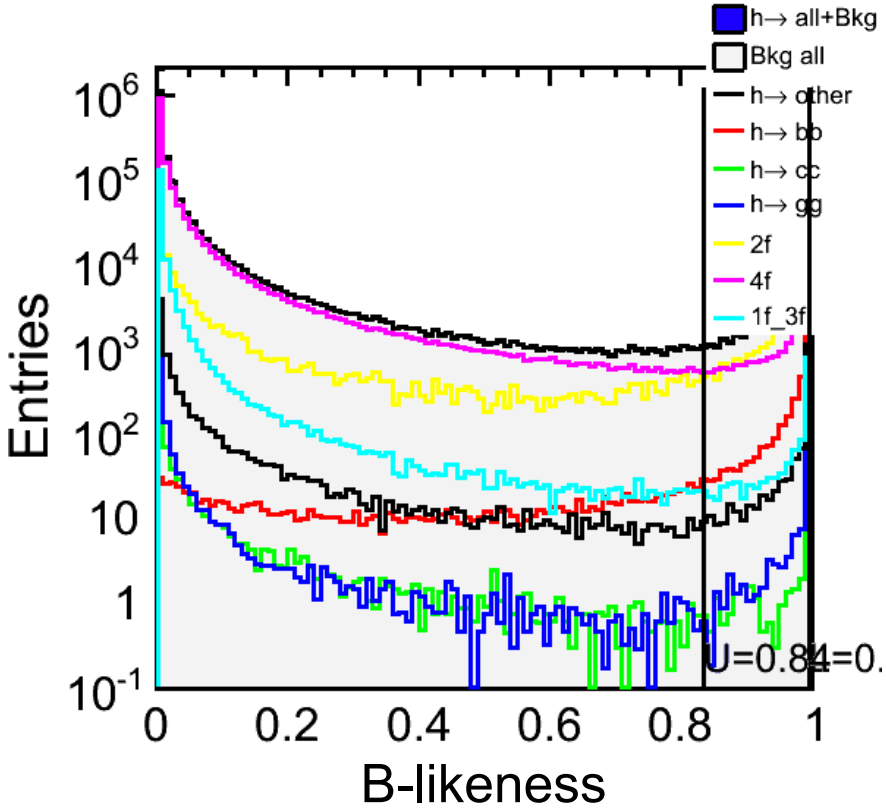
Zh→vvh cut summary

Cuts	h→bb	h→cc	h→gg	h→oth	2f	4f	1f_3f	qqh	llh
No cuts	11,199	523	1,655	6,007	2.9×10^7	1.0×10^7	1.0×10^8	52,547	2,598
Thrust>0.8	9,710	457	1,101	3,309	2.3×10^7	6,136,990	9.6×10^7	13,546	1,063
$20<P_t<70$ GeV	8,525	403	971	2,482	827,364	2,959,710	244,599	2,451	616
N in Jet > 10	8,297	382	962	993	264,666	1,003,050	100,453	2,341	516
$\lvert\cos\theta_h\rvert<0.98$	8,297	382	962	993	263,940	1,002,690	99,852	2,341	516
$P_{max}<30$	7,455	311	893	772	106,937	186,066	79,666	1,262	336
$Y_{34}<0.02$	6,294	261	628	309	84,016	94,646	68,346	352	126
$80<M_{miss}<150$ GeV	5,836	240	573	245	9,062	49,579	34,335	119	41
$110<M_{vis}<150$ GeV	4,671	219	567	124	2,670	8,223	445	70	34
Efficiency	41.7%	41.8%	34.3%	2.1%	9.2.E-05	8.1.E-04	4.3.E-06	1.3.E-03	1.3.E-02

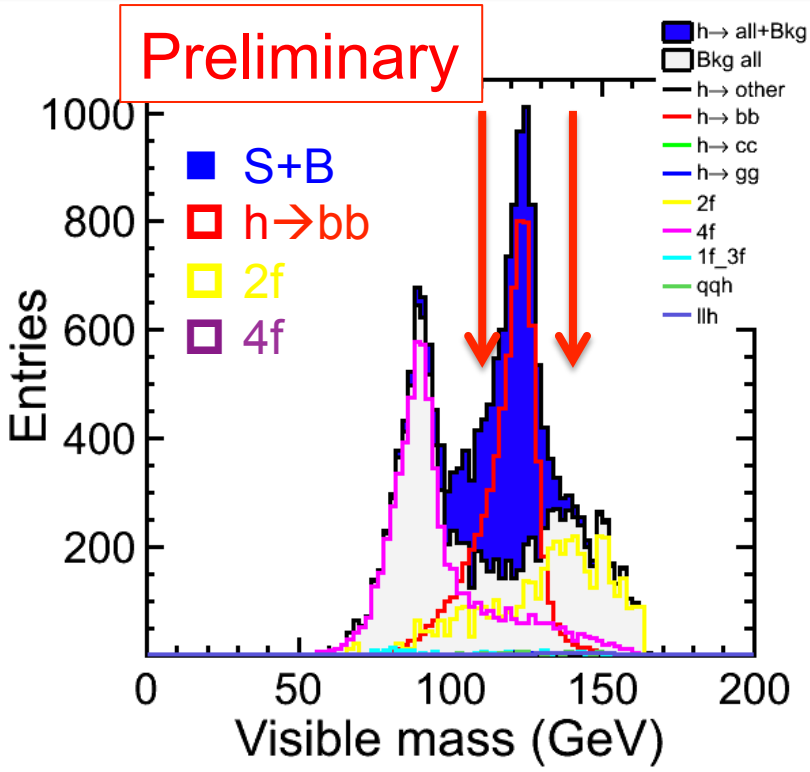
Signal significance h→2j in vvh channel: $S/\sqrt{(S+B)}=41.8$
(Almost same as LOI result (Signif=41.7))

Preliminary

B-tagging in vvh @ 250 GeV



(B-likeness=$b_1b_2/((1-b_1)(1-b_2))$



Dijet mass distribution after apply b-likeness>0.8 cut

h→bb signal significance=52.9

Next step is flavor template fitting to extract result

Preliminary

Zh→llh @250 GeV

μ/e selection

- ConeE< 20 GeV (in 10 degree)
- $10<E_{PFO}<100$ 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)

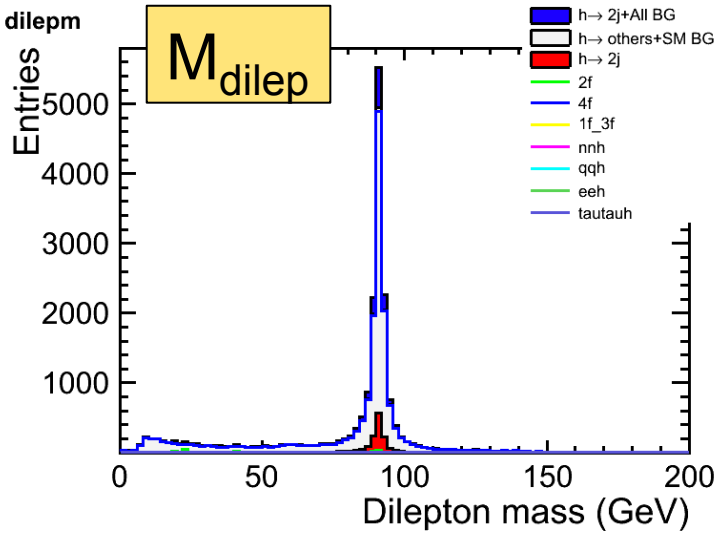
If # of candidates greater than two, select lepton pair whose mass as close as Z mass

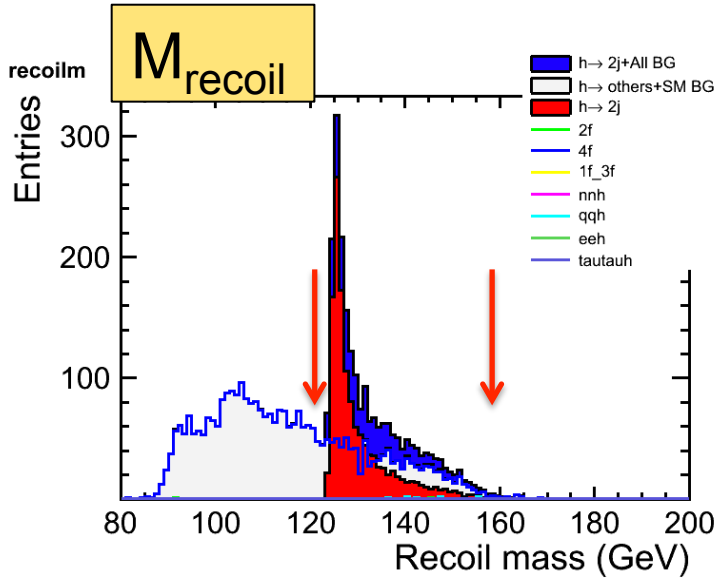
Cut condition

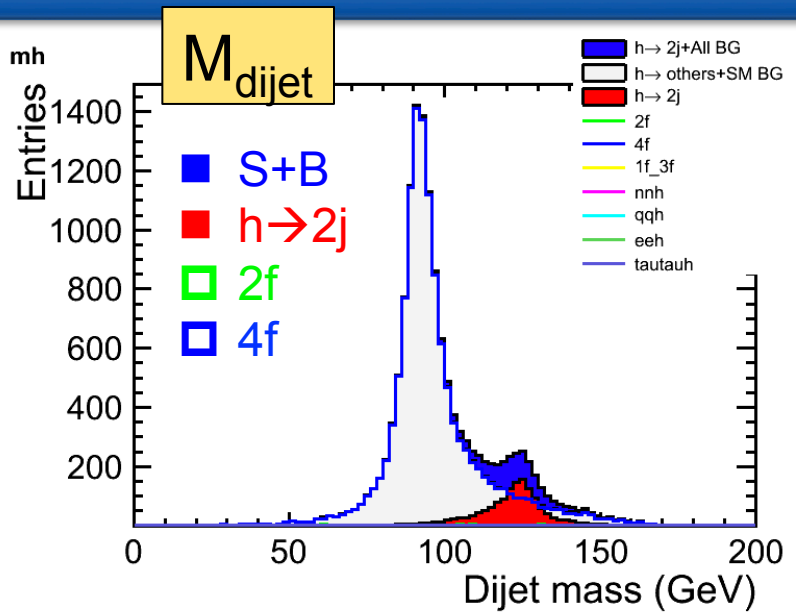
1. # of e/μ candidate >= 2
2. Selected isolated leptons = 2
3. $E_{vis}>200$ GeV
4. NPFOs > 30
5. Thrust>0.8
6. $|\cos\theta_Z|<0.9$
7. $70<M_{ll}<110$ GeV
8. $100<M_{jj}<150$ GeV
9. $120<M_{recoil}<160$ GeV

Same conditions/selecitons are applied with previous LOI study
Consider to use latest isolated Z→ll finder processor

Zh→μμh @ 250 GeV reconstruction







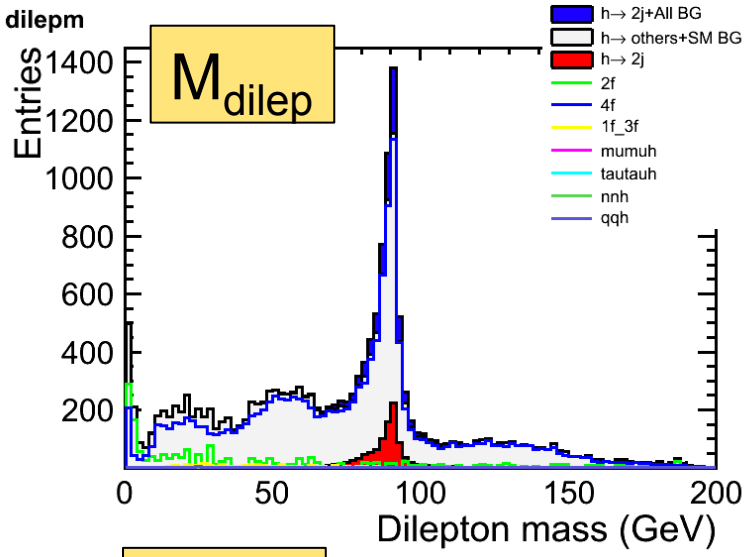
Preliminary

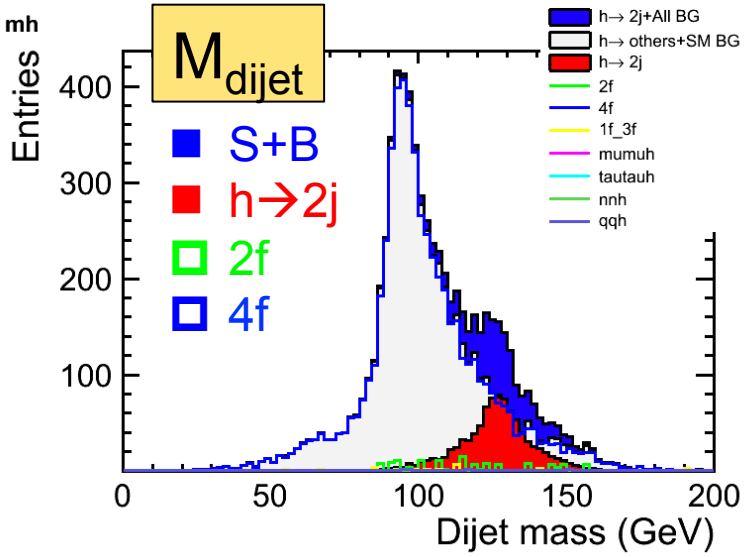
Zh→μμh reconstruction

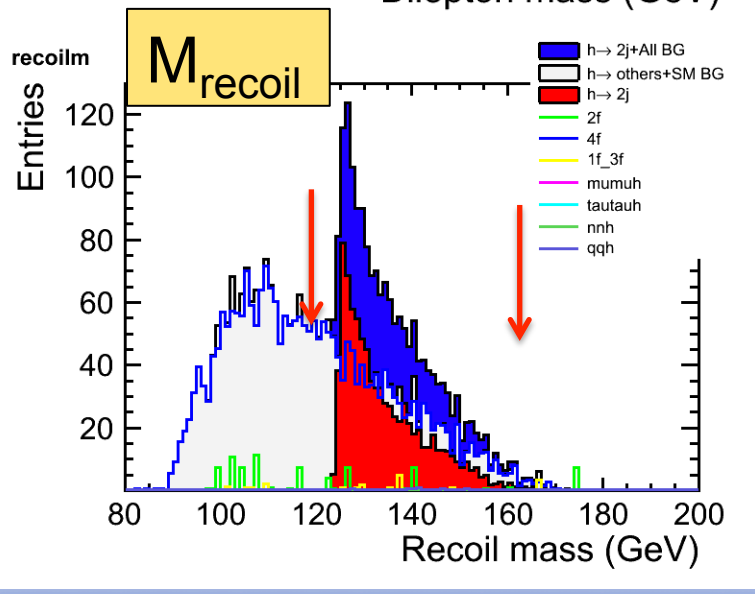
Efficiency=71.1% (bb, cc, gg)

S/√(S+B)=25.0

Zh→eeh @250 GeV reconstruction







Preliminary

Zh→eeh reconstruction

Efficiency=54.3% (bb, cc, gg)

S/√(S+B)=17.6

Summary

- Higgs BR study at 1 TeV has done
  - Thank you very much for people who prepare huge samples
- Higgs BR study re-do with the new simulation samples with Higgs mass of 125 GeV.
  - 250 GeV analysis is just on-going (qqh too)
  - 350 GeV analysis should also done after 250 GeV
  - Hopefully include 500 GeV results