The measurement of Higgs branching ratio with ILD

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Introduction

- It is very important to estimate the measurement accuracy of Higgs branching ratio to verify the Higgs mechanism.
  - Higgs coupling is proportional to the mass of particle
  - $Br(H \rightarrow cc)/Br(H \rightarrow bb) = m_c^2/m_b^2$

- The study of Higgs branching ratio is ongoing using ZH process for ILD detector.
  - $ZH \rightarrow \nu\nu H$ (K.Yoshida)
  - $ZH \rightarrow qqH$ (H.Ono)
  - $ZH \rightarrow llH$ (K.Yoshida)

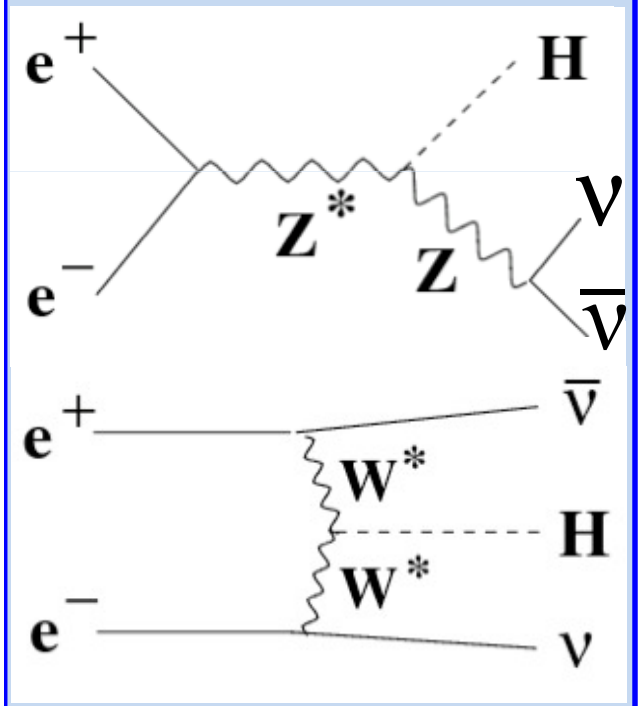
→The current status of these 3 modes will be reported in this talk.

Higgs production

Higgs production process is Higgs-strahlung process.

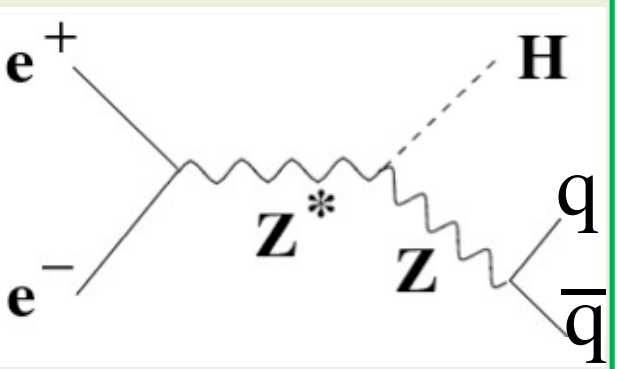
- The boson-fusion process is also included for ZH→ννH, llH process.

ZH→ννH



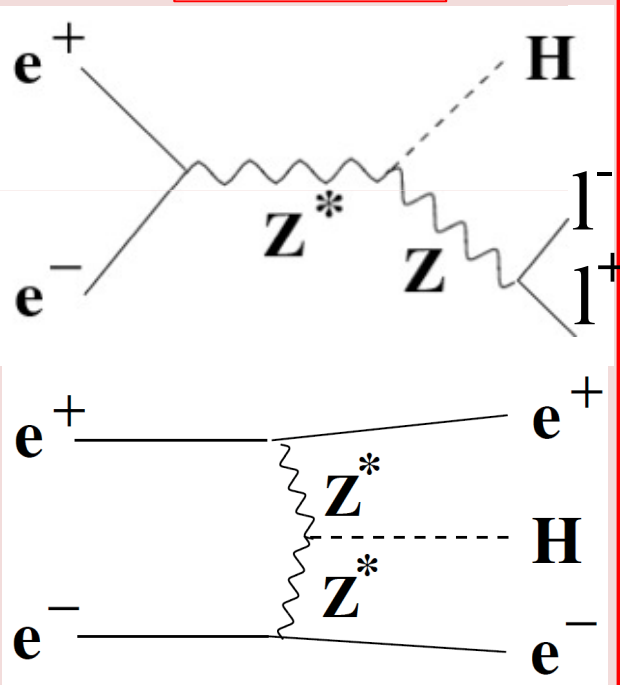
Xsec : 77.4 fb

ZH→qqH



Xsec : 210 fb

ZH→llH



Xsec : 11.1 fb(e)
: 10.4 fb(μ)

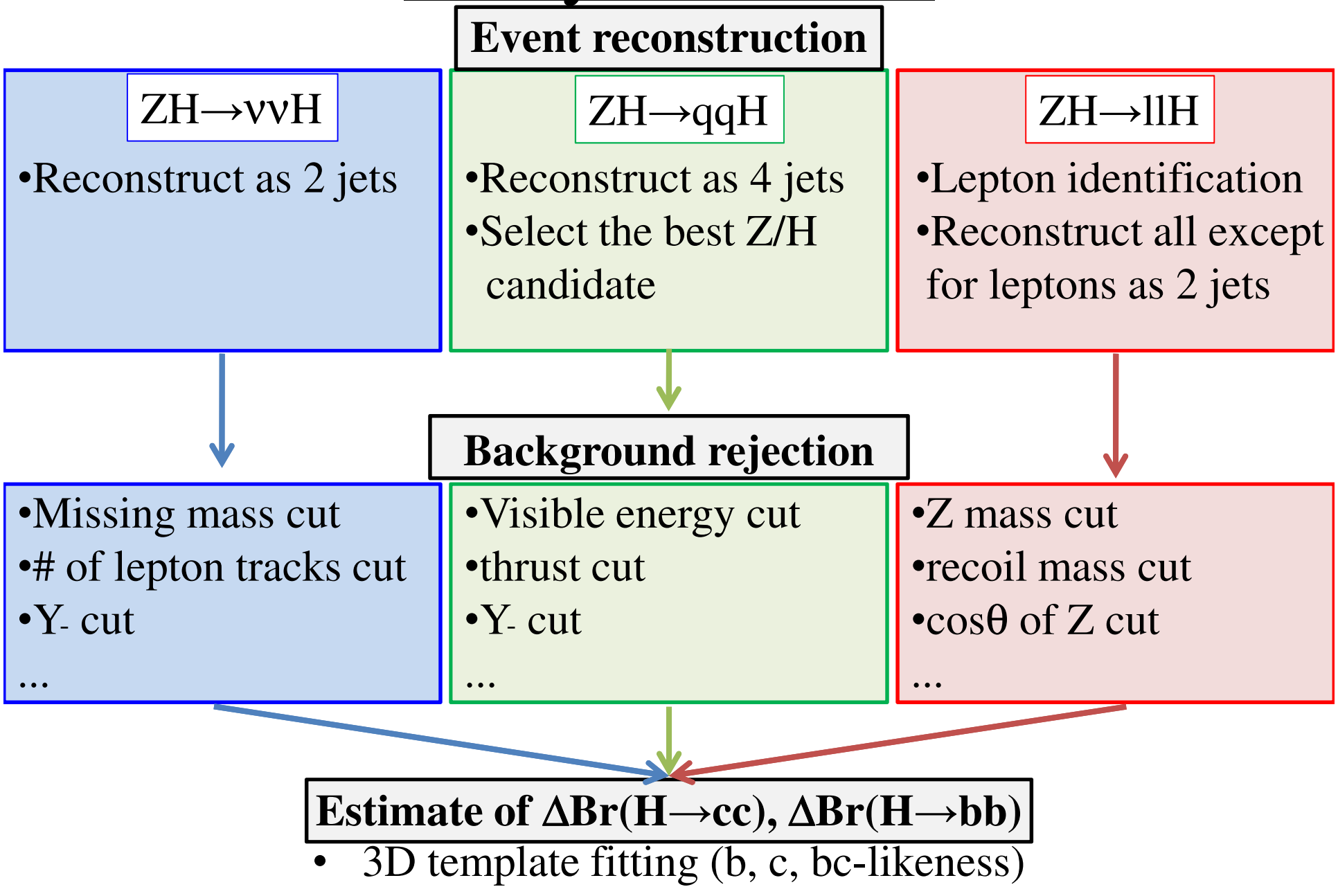
* $E_{C.M.}$: 250 GeV, $(e^-, e^+) = (-80\%, +30\%)$

Simulation setup

- $E_{C.M.}$: 250 GeV
- Luminosity : 250 fb^{-1}
- Beam polarization : $(e^-, e^+) = (-80\%, +30\%)$
- M_H : 120 GeV
- Software
  - Detector simulation : Mokka
  - Reconstruction : Marlin
- Data

Signal	Background
$ZH \rightarrow \nu\nu H$	$\nu\nu ll$, νlqq, $qqqq$, $\nu\nu qq$, $llqq$, $llll$
$ZH \rightarrow qqH$	$qqqq$, νlqq, $llqq$, $\nu\nu qq$, qq
$ZH \rightarrow eeH$	$eeqq$, $\nu_e eqq$
$ZH \rightarrow \mu\mu H$	$\mu\mu qq$, $\nu_\mu \mu qq$

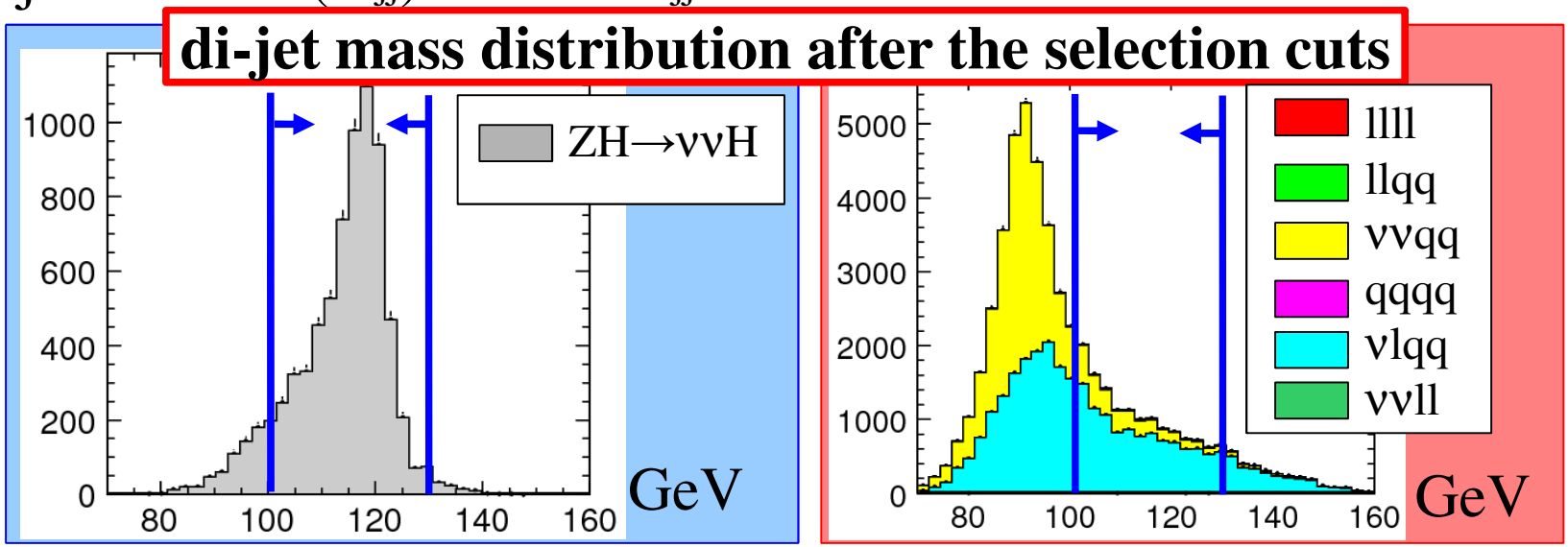
Analysis outline



Background rejection

Background rejection for ZH→ννH

- missing mass cut(m_{miss}) : $80 < m_{miss} < 140$ GeV
- momentum cuts
  - $20 < P_T < 70$ GeV, $-60 < P_L < 60$ GeV, $P_{max} < 30$ GeV
- the number of charged tracks cut (N_{tracks}) : $N_{tracks} > 10$
- Y value cuts
  - $Y_- < 0.02$, $0.2 < Y_+ < 0.8$
- di-jet mass cut(m_{jj}) : $100 < m_{jj} < 130$ GeV



Reduction Table for ZH→ννH

	No cut	m_{miss}	P_T	P_L	N_{tracks}	P_{max}	Y_-	Y_+	m_{jj}	efficiency
ZH→ννH	19360	15637	13900	13501	12768	11674	7711	7384	6672	34.46%
ZH→ννbb	13062	11662	10408	10136	9852	9063	6717	6434	5810	44.48%
ZH→ννcc	707	643	574	561	533	466	333	318	306	43.22%
$\nu_e$eqq	1460797	80931	67135	61437	25966	5088	961	851	448	0.03%
ν_μμqq	1327332	92360	75143	61715	52355	10540	2747	2288	888	0.07%
ν_ττqq	1326061	386690	268190	200443	176370	123045	29135	24979	10131	0.76%
ννqq	149979	124843	85774	49745	43229	35942	26713	21653	3345	2.23%
other	6318190	491631	337800	266307	2676	2001	370	335	226	0.00%

Background was rejected efficiently.

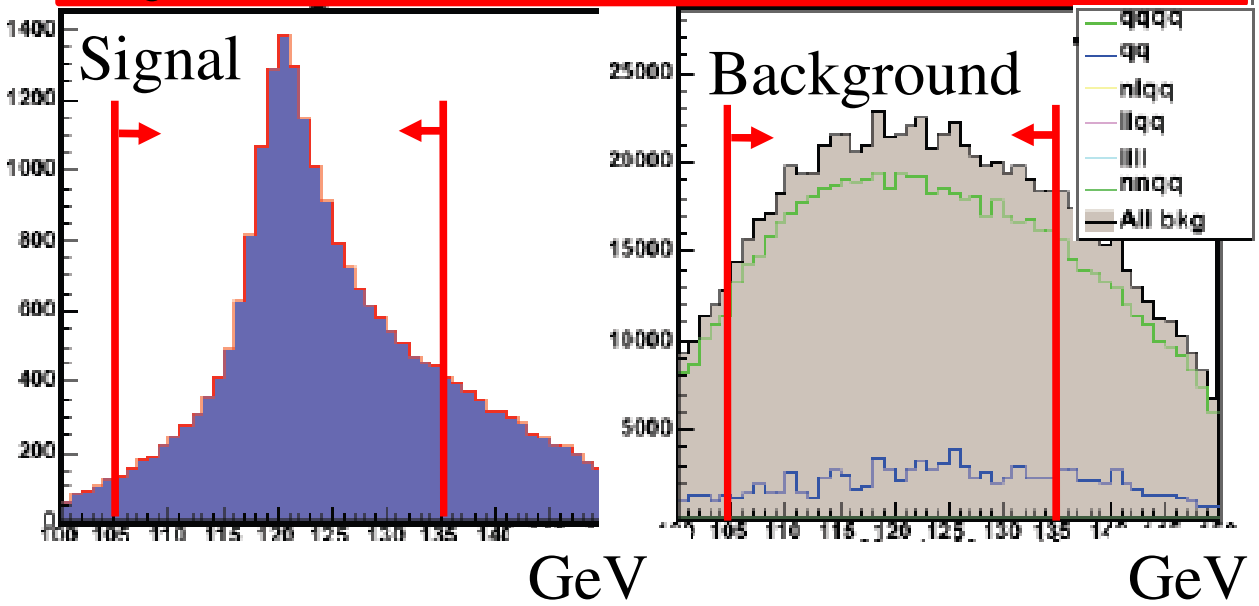
Background rejection for ZH→qqH

- χ^2<10 from jet combination
- $|P_l^Z|$<70 GeV
- 200<E_{vis}<270 GeV
- $|\cos\theta_H|$<0.85
- thrust<0.9
- #(PFOs)>10 in each jet
- E_{jmin}/E_{jmax}>0.25
- 50<P_{jmax}<100 GeV
- Y_{+}>2.0e-4
- Y_{-}>1.0e-3
- 20<θ_{min}<120 deg
- 110<θ_{max}<170 deg
- 105<M_H<135 GeV

χ^2 to select best Z/H candidates

$$\chi^2 = \left(\frac{M_{12} - M_Z}{\sigma_Z}\right)^2 + \left(\frac{M_{34} - M_H}{\sigma_H}\right)^2$$

di-jet mass distribution after selection cuts



Reduction Table for ZH→qqH

	qqh	qqbb	qqcc	qqqq	nlqq	llqq	nnqq	llll	qq
Reconstructed	52506.9	34962.8	1915.43	4.05E+06	4.11E+06	398324	149979	762975	3.54E+07
$\chi^2<10$	38691.2	29011.4	1661.43	1.82E+06	48728.8	63300.7	1.14147	30435.1	2.01E+06
-70<Pl_Z<70	38408.4	28830.8	1647.6	1.74E+06	48474.7	55837.3	1.14147	22944.1	1.62E+06
200<Evis<270	37916.1	28541.1	1641.3	1.72E+06	43655.3	54742.8	0.581929	22377.1	1.59E+06
$-0.85<\cos\theta_\mu<0.85$	32615.7	24564.3	1411.91	1.41E+06	35553.1	38466.2	0.426926	8723.81	1.14E+06
thrust<0.9	32026	24063	1382.13	1.40E+06	31342.4	35665	0	5572.8	502334
NPFOs in jets >10	26709.5	20677.5	1151.55	985671	127.197	191.979	0	0	174110
Ejmin/ Ejmax>0.25	25951.6	20096.9	1117.04	946401	123.815	176.712	0	0	151730
50<Pjmax<100	25761.4	19935.7	1104.31	924106	120.202	171.281	0	0	139277
Yplus>2.0e-4	25604.6	19800.3	1085.17	899125	116.804	169.394	0	0	136762
Yminus>1.0e-3	25576.8	19774.5	1083.83	898310	106.163	166.368	0	0	129520
20<θmin<120	25339.3	19562.2	1072.43	890169	106.163	154.779	0	0	114719
110<θmax<170	24043.3	18624.5	1017.44	804065	85.1689	145.004	0	0	109094
$105<M_\mu<135$	18334.7	14296	809.984	526827	41.3248	87.5279	0	0	70296.7

Leptonic mode is suppressed and bkg is dominated with qqqq and qq.

Lepton identification for ZH→llH

- Leptons are identified by PFOID.
- Following selections are applied.

electron-channel

- Ecal energy/(Ecal + Hcal energy) > 0.9
- 0.8 < (Ecal + Hcal energy)/Momentum < 1.2
- Momentum > 4 GeV

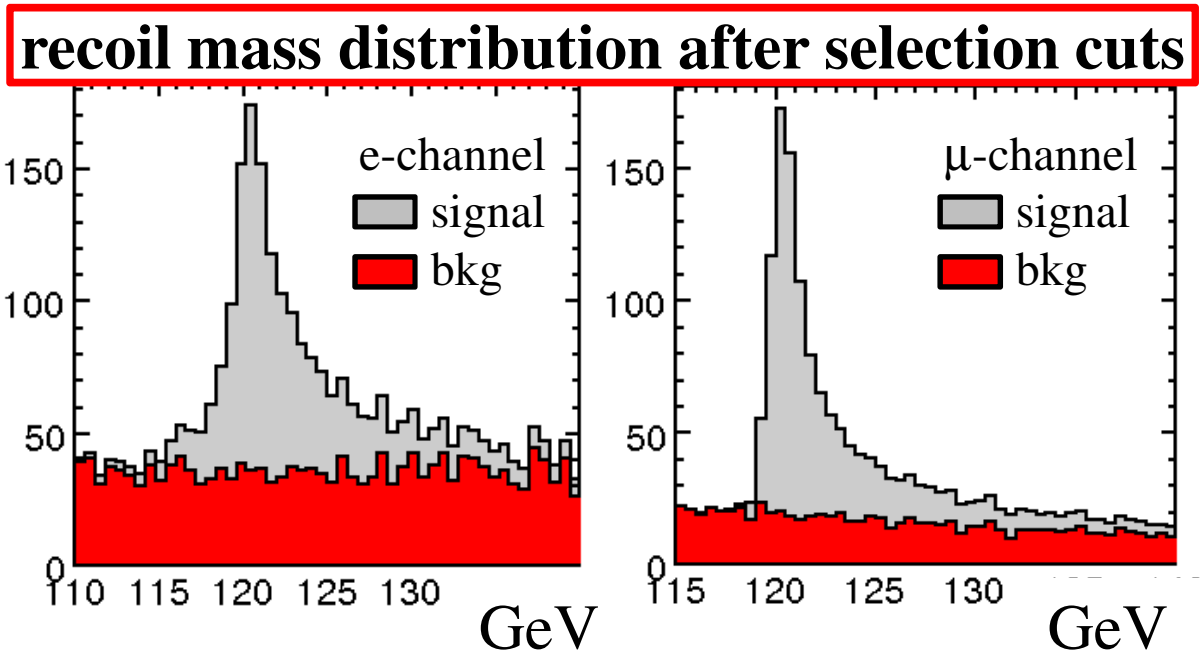
muon-channel

- (Ecal + Hcal energy)/Momentum < 0.3
- Ecal energy/(Ecal + Hcal energy) < 0.5
- Ecal energy < 2.5 GeV
- Hcal energy < 15 GeV

→We required only the events which have $e^+e^-(\mu^+\mu^-)$ pair.

Background rejection for ZH→llH

- M_Z cut
  - $70<M_Z<110$ GeV (e), $80<M_Z<100$ GeV (μ)
- M_H cut
  - $100<M_H<140$ GeV (e,μ)
- Recoil mass cut(M_{recoil})
  - $110<M_{recoil}<140$ GeV (e), $115<M_{recoil}<140$ GeV (μ)
- cosθ of Z cut
  - $-0.8<\cos\theta<0.8$ (e,μ)



Reduction Table for ZH→eeH

	no cut	Electron ID	M_Z	M_H	recoil mass	cosθ of Z	Efficiency
ZH→eeH	2777	2471	2249	1706	1570	1295	46.6%
ZH→eebb	1854	1650	1501	1290	1188	979	52.8%
ZH→eecc	101	90	82	77	71	58	58.0%
eeuu	120653	23746	7289	1231	714	356	0.3%
eedd	25852	12040	5503	972	583	343	1.3%
eecc	120806	23899	7265	1150	676	351	0.3%
eess	25836	11828	5416	960	552	330	1.3%
eebb	21553	11846	5372	782	480	278	1.3%
$\nu_e$eud	730300	77761	13533	296	117	77	0.0%
$\nu_e$ecs	730497	85778	12152	265	101	63	0.0%

Reduction Table for ZH→μμH

	no cut	Muon ID	M_Z	M_H	recoil mass	cosθ of Z	Efficiency
ZH→μμH	2601	1965	1744	1328	1250	1039	39.96%
ZH→μμbb	1727	1304	1160	1006	948	789	45.66%
ZH→μμcc	93	69	62	58	55	46	50.08%
μμuu	8010	4292	2592	503	221	151	1.88%
μμdd	8679	4705	2864	582	255	175	2.01%
μμcc	8028	4320	2585	464	217	153	1.91%
μμss	8689	4674	2872	592	245	163	1.87%
μμbb	8523	4707	2858	449	223	156	1.83%
ν_μμud	663845	2856	69	0	0	0	0.00%
ν_μμcs	663488	6718	302	7	7	0	0.00%

Estimate of Higgs branching ratio

Estimation of Higgs branching ratio

- The ratio of BR(H→cc) to BR(H→bb) is estimated.

$$\frac{BR(H \to cc)}{BR(H \to bb)} = \frac{r_{cc} / \varepsilon_{cc}}{r_{bb} / \varepsilon_{bb}}$$

  - ε_{cc},ε_{bb} are the selection efficiency and estimated from reduction table.

	ZH→ννH	**ZH→qqH**	**ZH→eeH**	**ZH→μμH**
ε_{cc}	0.432	0.423	0.58	0.501
ε_{bb}	0.445	0.409	0.528	0.457

  - r_{cc}, r_{bb} are the ratio of ZH→ννcc, ννbb(qqcc/bb, llcc/bb) to ZH→ννH(qqH, llH) after the selection cuts.

r_{cc}, r_{bb} are evaluated by template fitting.

Template fitting

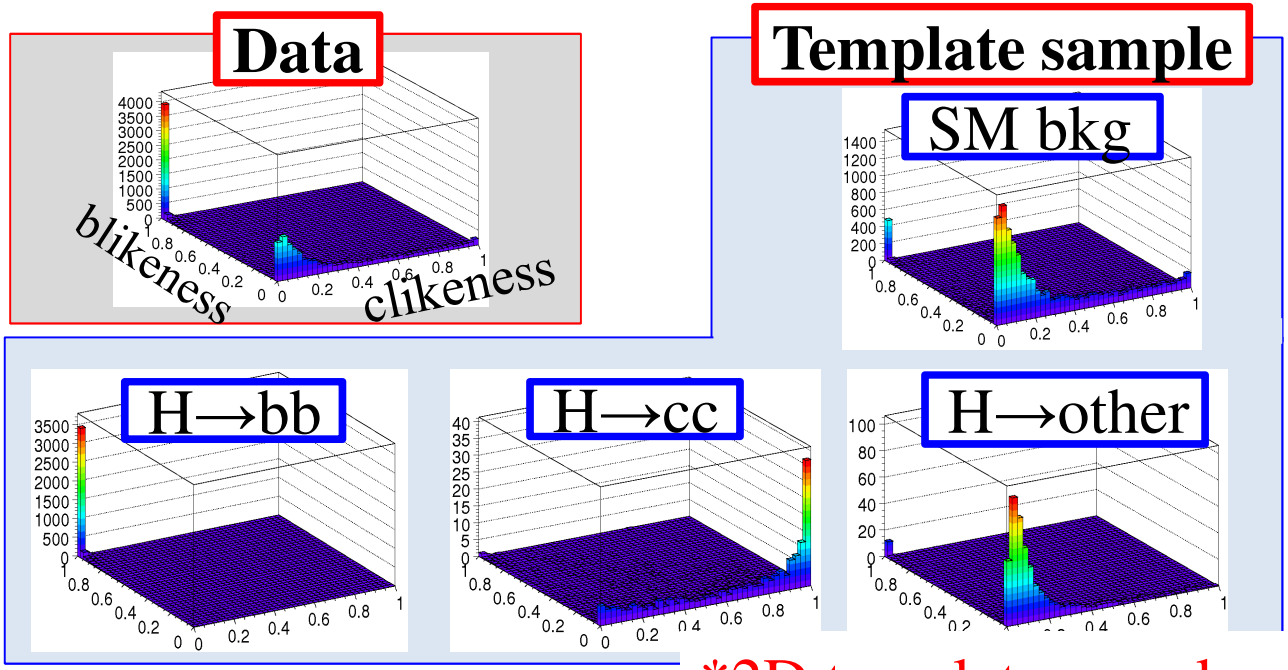
3Dtemplate fitting is done(b,c,bc-likeness).

- Template sample is separated to H→bb, cc, other events and SM bkg.
  - H→gg/WW events are dominant in H→other events.

$$\chi^2 = \sum_i \sum_j \sum_k \left(\frac{\sum_{s=bb,cc,oth,bkg} r_s \times (N^{data}/N^s) \times N^s_{ijk}}{\sigma_{N^{data}_{ijk}}} \right)^2$$

($r_{oth} = 1 - r_{bb} - r_{cc}$)

(r_{bkg} = fixed(=1) or free)

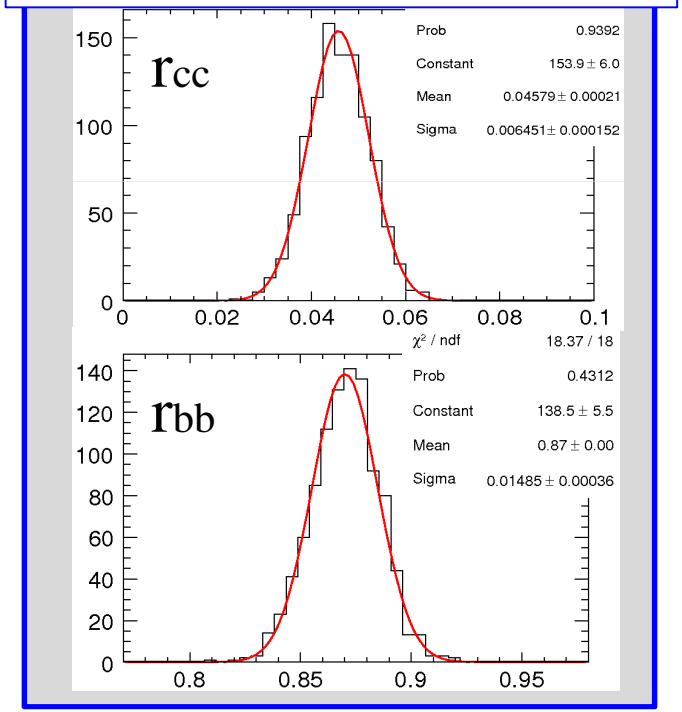


*2D template samples for ZH→ννH

Fitting result (r_{bkg}:fixed)

The data was fluctuated by poisson distribution and applied template fitting 1000 times.

The result for ZH→ννH



	r_{cc} (true r_{cc})	r_{bb} (true r_{bb})
ZH→ννH	0.046 +/- 0.006 (0.046)	0.87 +/- 0.01 (0.87)
ZH→qqH	0.044 +/- 0.007 (0.044)	0.78 +/- 0.01 (0.78)
ZH→eeH (preliminary)	0.045 +/- 0.013 (0.045)	0.76 +/- 0.02 (0.76)
ZH→μμH (preliminary)	0.044 +/- 0.013 (0.044)	0.76 +/- 0.02 (0.76)

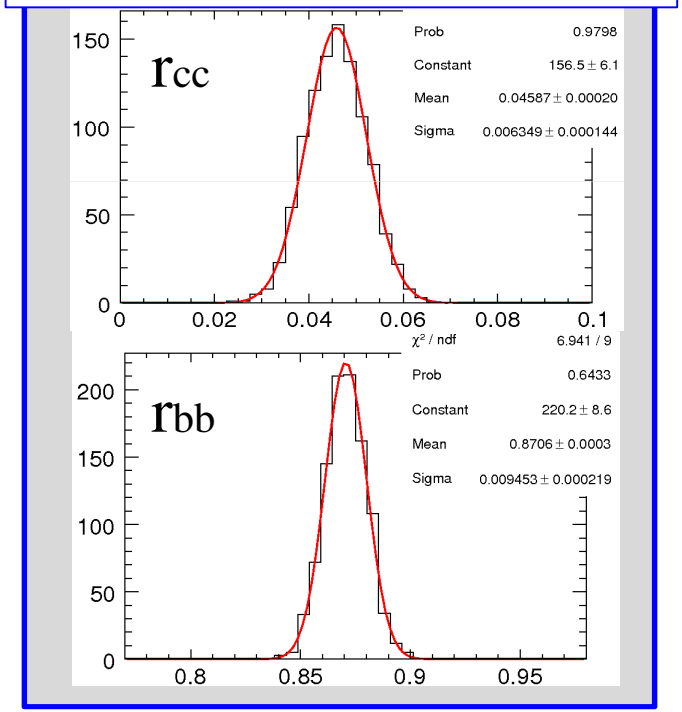
* The results of ZH→llH are preliminary.

The results of template fitting were consistent with true values.

Fitting result(r_{bkg}:free)

The same procedure of the template fitting in the case that r_{bkg} is fixed was applied.

The result for ZH→νν̄H



	r_{cc} (true r_{cc})	r_{bb} (true r_{bb})
ZH→νν̄H	0.046 +/- 0.006 (0.046)	0.87 +/- 0.01 (0.87)
ZH→qq̄H	0.044 +/- 0.007 (0.044)	0.78 +/- 0.02 (0.78)
ZH→eeH (preliminary)	0.045 +/- 0.013 (0.045)	0.76 +/- 0.02 (0.76)
ZH→μμH (preliminary)	0.044 +/- 0.013 (0.044)	0.76 +/- 0.02 (0.76)

These results were almost the same as in the case of fixed r_{bkg} because of good separated template samples.

Relative Higgs branching ratio

By previous formula, the relative Higgs branching ratio was estimated.

$$\frac{BR(H \to cc)}{BR(H \to bb)} = \frac{r_{cc}/\varepsilon_{cc}}{r_{bb}/\varepsilon_{bb}}$$

	r_{bkg}:fixed	r_{bkg}:free
ZH→ννH	0.0542 +/- 0.0075 (13.8%)	0.0542 +/- 0.0077 (14.2%)
ZH→qqH	0.0548±0.0091 (16.6 %)	0.0546 +/- 0.0091 (16.8%)
ZH→eeH (preliminary)	0.0547 +/- 0.0159 (29.1%)	0.0546 +/- 0.0161 (29.5%)
ZH→μμH (preliminary)	0.0531 +/- 0.0158 (29.8%)	0.0532 +/- 0.0159 (29.9%)
Combined accuracy	9.45%	9.64%

Summary

The measurement accuracy of Higgs branching ratio was estimated using ZH process.

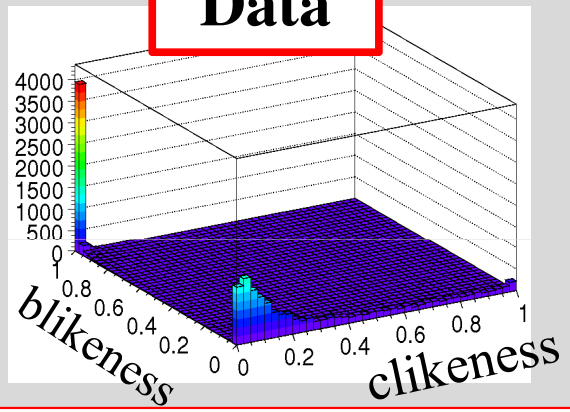
	r_{bkg}:fixed	r_{bkg}:free
ZH→ννH	0.0542 +/- 0.0075 (13.8%)	0.0542 +/- 0.0077 (14.2%)
ZH→qqH	0.0548±0.0091 (16.6 %)	0.0546 +/- 0.0091 (16.8%)
ZH→eeH (preliminary)	0.0547 +/- 0.0159 (29.1%)	0.0546 +/- 0.0161 (29.5%)
ZH→μμH (preliminary)	0.0531 +/- 0.0158 (29.8%)	0.0532 +/- 0.0159 (29.9%)
Combined accuracy	9.45%	9.64%

Template samples

Template samples(H→bb,cc,other, SM background) were created.

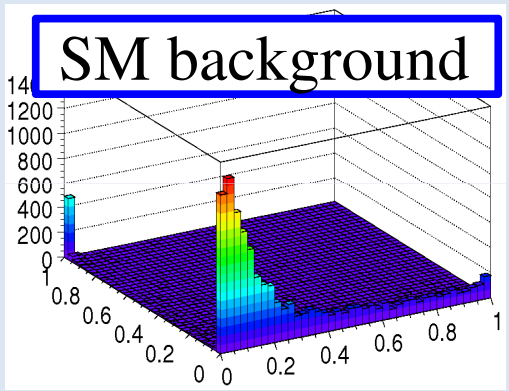
- H→gg/WW event are dominant in H→other sample.

Data

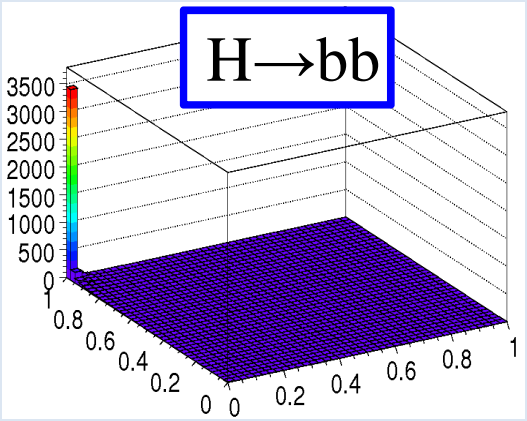


Template sample

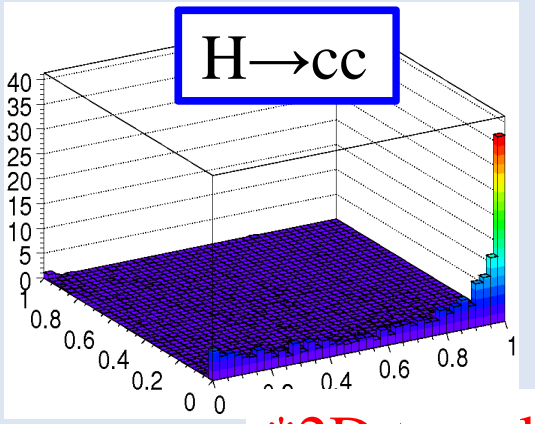
SM background



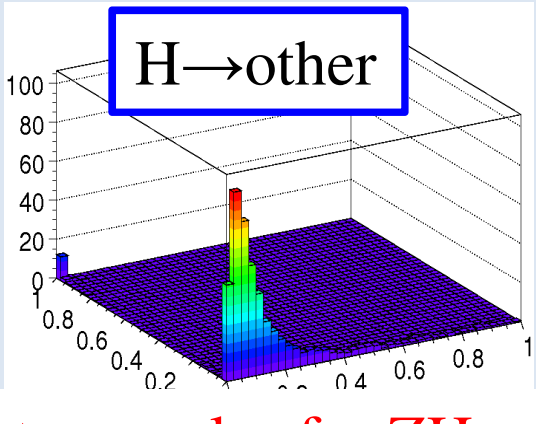
H→bb



H→cc



H→other



*2D template samples for ZH→ννH