Higgs Branching Fraction Measurement

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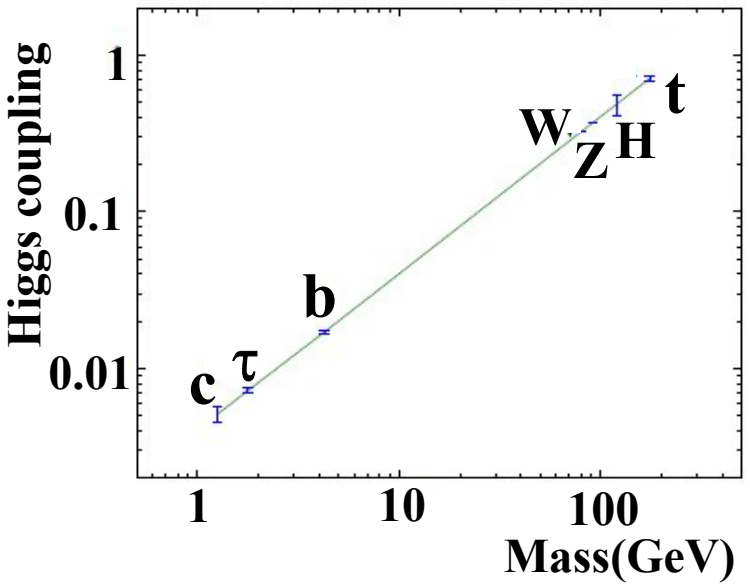
Introduction

Higgs branching ratio

- Proportional to particle masses.
- Measurement of Higgs branching ratio is essential to confirm Higgs mechanism.

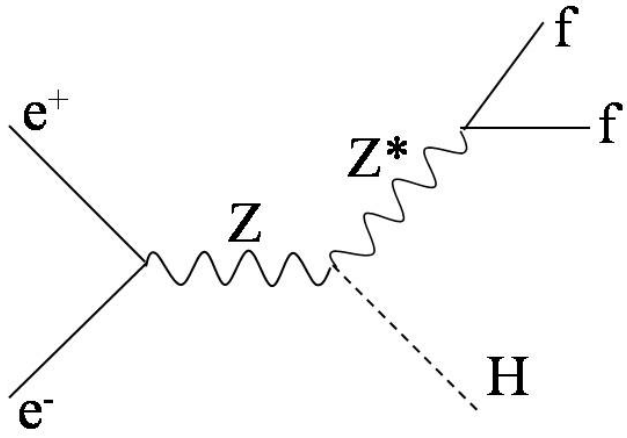
→One of the most important measurements at ILC.

Mass v.s. Higgs coupling



LOI requirement

- Estimation of measurement accuracy of $H \rightarrow c\bar{c}$ with $e^+e^- \rightarrow ZH$.
- Optionally, $H \rightarrow \mu\mu$



In this talk, analysis results of ILD and SiD are compared based on LOI and talk at ALCPG09.

Simulation setup

Simulation setup

- Higgs mass: 120 GeV
- E_{CM} : 250 GeV (with Beamstrahlung, ISR, and FSR)
- Integrated luminosity: 250 fb^{-1}
- Beam energy spread: 0.28% (e^-) and 0.18% (e^+)
- Beam polarization: 80% left-handed for e^- and 30% right-handed for e^+

Signal v.s. BG

- Signal: ZH→ffcc, ffμμ
  - σ(ZH): 387fb
  - BR(H→cc): 3.6%, BR(H→μμ): 0.01%
- BG: qqqq, qq, qqll, ….

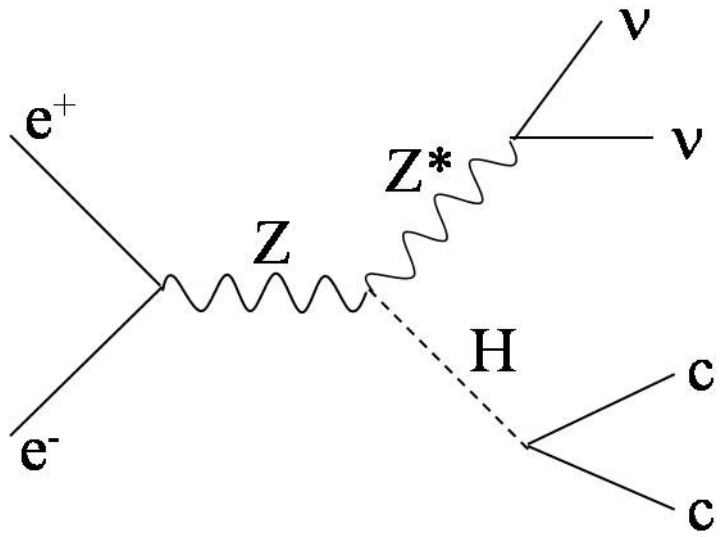
Key point to study BR(H→cc)

Key point to study BR(H→cc)

- Selection of ZH events from SM-BG.
  - There are large SM-BG from ZZ, WW, and etc..
  - The kinematical selection cut is necessary.
- Identification of H→cc and H→bb in ZH events.
  - H→bb is large BG for H→cc.
  - LCFIVertex is used for the flavor tagging.
- Estimation of BR(H→cc)
  - Statistical evaluation assuming knowledge of ZH xsec and Higgs branching ratio other than H→cc.
  - Template fitting

The results for each analysis mode are shown.

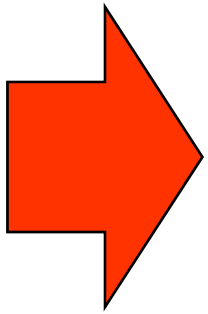
ZH→ννcc



Event selection (ILD)

ZH selection in ILD

- $80\text{GeV} < M_{miss} < 140\text{GeV}$
- $20\text{GeV} < P_T < 70\text{GeV}$
- $P_L < 60\text{GeV}$
- $P_{max} < 30\text{GeV}$
- # of charged tracks >10
- $Y_+ < 0.02$
- $0.2 < Y_- < 0.8$
- $100\text{GeV} < M_{jj} < 130\text{GeV}$



No cut

- Signal: 707
- ZH BG: 18,653
- SM BG: 10,586,927

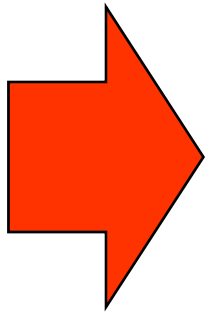
After selection cut

- Signal: 318 (0.45)
- ZH BG: 7,066 (0.38)
- SM BG: 50,106 (0.005)

Event selection (SiD)

ZH selection in SiD

- $20 < P_t < 90$GeV
- # of charged tracks > 4
- $-\log(Y_{min}) < 0.8$
- Thrust < 0.95
- cos(thrust) < 0.98
- $100 < \theta_{jj} < 170$
- $100\text{GeV} < M_{jj} < 140\text{GeV}$
- Highest $E_\gamma < 10$GeV



NN analysis to select H→cc

- Input variables
  - Variables used for selection cut
  - Information of flavor tagging
- # of event after selection
  - Signal : 476 (0.28)
  - ZH BG : 246
  - SM BG : 570

Measurement accuracy of ZH→ννcc

ILD

- Template fitting was used to derive Higgs branching ratio.
- Template: 3D histogram of b/c/bc-likeness obtained by LCFIVertex.
- $\Delta BR(H \to cc) = \mathbf{13.8\%} \oplus \Delta\sigma_{ZH}$

SiD

- The measurement accuracy of BR(H→cc) was estimated with the statistical error after the selection cut.
  - The procedure to estimate ZH-BG should be considered.
- $\Delta BR(H \to cc) = \frac{\sqrt{N_{sig} + N_{ZH\text{-}BG} + N_{SM\text{-}BG}}}{N_{sig}} \oplus \Delta\sigma_{ZH}$

$= \mathbf{10.3\%} \oplus \Delta\sigma_{ZH}$

How is the latest result?

New results of ZH→νvcc

Results at LOI

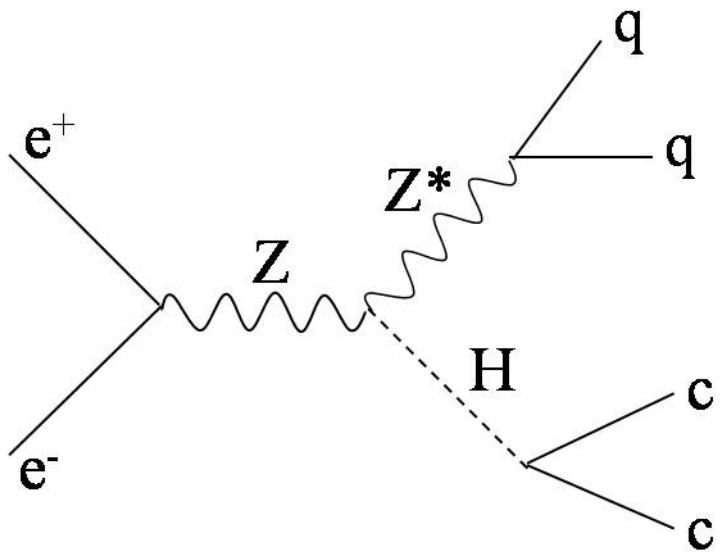
- ILD: 13.8% ⊕ $\Delta\sigma_{ZH}$
- SiD: 10.3% ⊕ $\Delta\sigma_{ZH}$

New results at ALCPG09

- ILD: **13.8%** ⊕ $\Delta\sigma_{ZH}$
- SiD: **11.6%** ⊕ $\Delta\sigma_{ZH}$
  - The numerical treatments and program bugs were corrected.

The results of ILD and SiD are in the consistent level.

ZH→qqcc



Event selection (ILD)

ZH selection in ILD

- Pre-selection
- Thrust ≤ 0.85
- $|\cos\theta_T| \leq 0.8$
- acoplanarity ≥ 0.01
- $\theta_{jj}^{min} \geq 40$
- $\chi_{kin}^2(M_{j1j2}=M_Z)$ prob. > 0.01
- $\chi_{kin}^2(M_{j1j2}=M_{j3j4})$ prob. < 0.0001
- $115\text{GeV} < M_H < 125\text{GeV}$

Selecttion of H→cc

- c-likeness for two jets to reconstruct Higgs candidate >0.5 & combined c-likeness > 0.8

No cut

- Signal: 1,864
- ZH BG: 43,601
- SM BG: 7,463,574

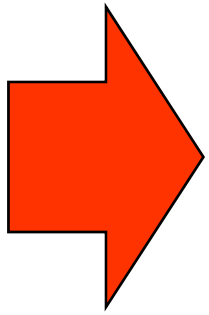
After selection cut

- Signal: 37 (0.02)
- ZH BG: 24 (0.0006)
- SM BG: 97 (0.00001)

Event selection (SiD)

ZH selection in SiD

- # of charged tracks > 4
- $-\log(Y_{min}) < 2.7$
- Thrust < 0.95
- cos(thrust) < 0.96
- $75 < \theta_{13} < 165$
- $50 < \theta_{13} < 150$
- $95\text{GeV} < M_H < 145\text{GeV}$
- $45\text{GeV} < M_Z < 105\text{GeV}$
- Highest $E_\gamma < 10\text{GeV}$



NN analysis to select H→cc

- Input variables
  - Variables used for selection cut
  - Information of flavor tagging
- # of event after selection
  - Signal : 814 (0.47)
  - ZH BG : 547
  - SM BG : 569

Measurement accuracy of ZH→qqcc

The measurement accuracy of BR(H→cc) was estimated with the statistical error after the selection cut in both ILD and SiD.

- The procedure to estimate ZH-BG should be considered.

ILD

- $\Delta BR(H\to cc) = \frac{\sqrt{N_{sig} + N_{ZH\text{-}BG} + N_{SM\text{-}BG}}}{N_{sig}} \oplus \Delta\sigma_{ZH}$

$= \mathbf{30.0\%} \oplus \Delta\sigma_{ZH}$

SiD

- $\Delta BR(H\to cc) = \frac{\sqrt{N_{sig} + N_{ZH\text{-}BG} + N_{SM\text{-}BG}}}{N_{sig}} \oplus \Delta\sigma_{ZH}$

$= \mathbf{5.8\%} \oplus \Delta\sigma_{ZH}$

There is a big difference between ILD and SiD.

→ Let's compare the latest results!

New results of ZH→qqcc

Results at LOI

- ILD: 30.0% ⊕ $\Delta\sigma_{ZH}$
- SiD: 5.8% ⊕ $\Delta\sigma_{ZH}$

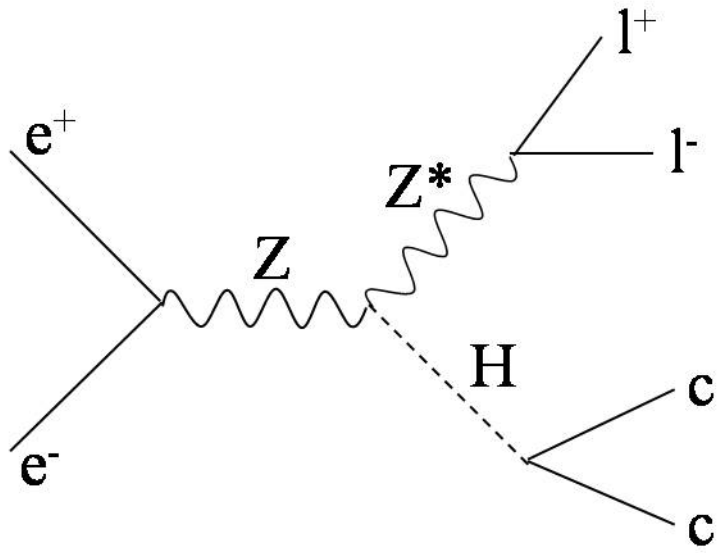
New results at ALCPG09

- ILD: **16.6%** ⊕ $\Delta\sigma_{ZH}$
  - The selection criteria was modified and the template fitting was used to derive Higgs BR.
- SiD: **8.8%** ⊕ $\Delta\sigma_{ZH}$
  - The numerical treatments and program bugs were corrected.

There is still large difference.

→ To be checked with both groups.

ZH→llcc

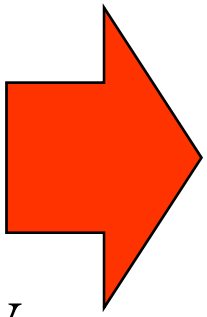


Event selection (ILD)

Measurement accuracy of ZH→llcc was studied only in ILD.

ZH selection

- $N_{particle} > 25$
- $70GeV < M_Z < 110GeV$
- $117GeV < M_H < 150GeV$
- $|\cos \theta_Z| < 0.9$
- $100GeV < M_{recoil} < 140GeV$
- Likelihood cut (e-channel)



After selection cut (No cut)

- e-channel
  - Signal: 1,240(2,493)
  - eeqq: 941(87,580)
  - evqq: 62(218,378)
- μ-channel
  - Signal: 1,371(2,202)
  - μμqq: 1,665(24,003)

Measurement accuracy (ILD)

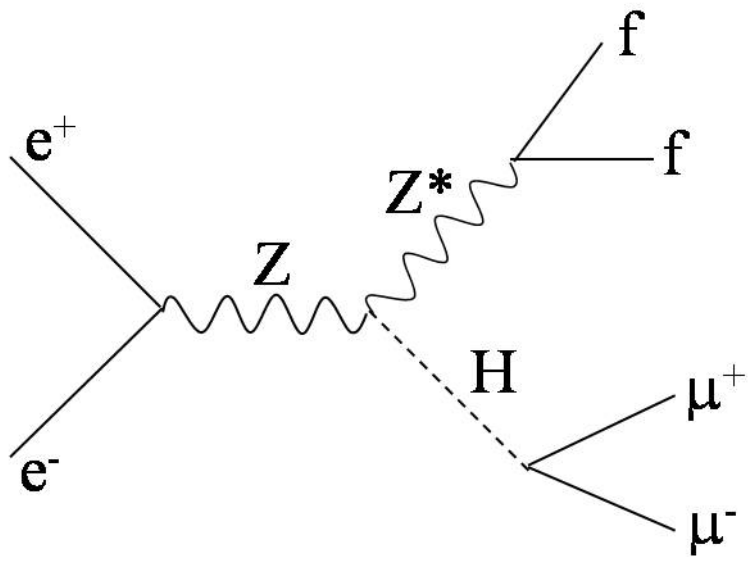
LOI resutls at ILD

- Template fitting was used to derive Higgs branching ratio.
- Template: 2D histogram of b/c-likeness obtained by LCFIVertex.
- $\Delta BR(H \rightarrow cc) =$ **28%** $\oplus$ $\Delta\sigma_{ZH}$
  - e-channel: 36%
  - μ-channel: 46%

New result at ALCPG09

- $BR(H \rightarrow cc)$: **20.8%** $\oplus$ $\Delta\sigma_{ZH}$
  - e-channel: 29.1%
  - μ-channel: 29.8%
- 3D histogram of b/c/bc-likeness was used as the template instead of 2D histogram.

$ZH \rightarrow ff\mu\mu$



Analysis of ZH→qqμμ (SiD)

Measurement accuracy of ZH→qqμμ was studied only in SiD.

ZH selection

- 2 muon track selection
- # of charged tracks > 5
- E_{vis} > 190GeV
- 30GeV < E_{j1} < 105GeV & 10GeV < E_{j2} < 70GeV
- $P_T(j1)$ < 90GeV & $P_T(j2)$ < 60GeV
- 119.1GeV < $M_{\mu\mu}$ < 120.9GeV
- $\cos\theta_{\mu\mu}$ < -0.5 & $\cos\theta_{BB}$ < -0.8
- $\theta_{\mu j}$ > 0.1 rad.
- Acoplanarity in BB system > 2.8 rad.
- 80 < χ_{ZZ}^2 < 120 & χ_{ZH}^2 < 20
- Higgs & Z mass cut

After selection cut

- Signal: 7.66 (0.41)
- SM BG: 39.3

Signal significance: 1.1

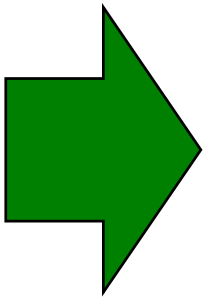
- ZH→νννμμ is also ongoing.
- Multi-variate analysis will improve the result.

Comparison between ILD and SiD

The analysis results obtained by ILD and SiD are summarized.

LOI

	ILD	SiD
• ZH→ννcc	: 13.8%	10.3%
• ZH→qqcc	: 30.0%	5.8%
• ZH→llcc	: 28.0%	
• ZH→qqμμ	:	1.1σ



ALCPG09

	ILD	SiD
• ZH→ννcc	: 13.8%	11.6%
• ZH→qqcc	: 16.6%	8.8%
• ZH→llcc	: 20.8%	
• ZH→qqμμ	:	1.1σ

Conclusions

- ZH→ννcc: The result is almost consistent ← OK!
- ZH→qqcc: There are still large difference ← To be checked.
- ZH→llcc/ffμμ: It is preferable to study in both groups.

Summary

- The measurement accuracy of Higgs branching ratio was studied in detail for LOI.
- Analysis results were compared between ILD and SiD.
  - For ZH→ννcc, both group have the same level of the measurement accuracy (11~14%).
  - For ZH→qqcc, there are large difference in the results.
  - Analysis procedure of ZH→qqcc must be checked in both groups.
- ZH→llcc/ffμμ should be studied in both groups.
- ILD and SiD group will continue to improve their results.

Selection of ννcc at LOI (SiD)

	ZH→ννcc	ZH others	SM BG
No cut	2,869	76,910	9,275,594,683
2 lepton track selection	637	14,294	45,936,973
$20 < P_t < 90$GeV	619	13,783	18,374,789
# of charged tracks > 4	618	13,729	17,123,140
$-\log(Y_{min}) < 0.8$	609	13,416	6,849,256
Thrust < 0.95	560	12,179	685,329
cos(thrust) < 0.98	550	11,945	627,113
$100 < \theta_{jj} < 170$	525	10,226	576,422
$100\text{GeV} < M_{jj} < 140\text{GeV}$	519	10,088	203,292
Highest $E_\gamma < 10$GeV	506	9,902	109,057

Selection of qqcc at LOI (ILD)

	ZH→vvcc	ZH others	SM BG
Pre-selection	1864.1	43600.5	7463574
Thrust < 0.85	1653.7	39644.7	4000974
cos(thrust)<0.8	1282.8	30593.2	2259571
Acoplanarity > 0.01	1195.1	29164.6	1922816.7
$\theta_{jj} > 40$	1057.9	26025.9	1660416.4
$\chi^2_{kin}(M_{j1j2}=M_Z)$ prob. > 0.01	265.4	4760.5	287230.7
$\chi^2_{kin}(M_{j1j2}=M_{j3j4})$ prob. < 0.0001	203.3	3508.6	117657.6
115GeV< M_H <125GeV	118.8	1821.4	10337.8
c-likeness for two jets to reconstruct Higgs candidate >0.5 & combined c-likeness > 0.8	37.2	24.3	96.9

Selection of qqcc at LOI (SiD)

	ZH→qqcc	ZH others	SM BG
No cut	2,869	76,910	9,275,594,683
No lepton track selection	1,837	41,016	39,398,366
# of charged tracks > 4	1,143	19,954	18,601,753
$-\log(Y_{min}) < 2.7$	1,101	19,011	13,921,271
Thrust < 0.95	1,047	17,743	8,737,017
cos(thrust) < 0.96	1,017	17,106	7,943,851
$105 < \theta_{13} < 165$	979	16,262	5,871,237
$70 < \theta_{24} < 160$	978	16,247	4,898,312
$110\text{GeV} < M_H < 140\text{GeV}$	966	16,027	1,917,231
$80\text{GeV} < M_Z < 110\text{GeV}$	963	16,018	1,561,432
Highest $E_\gamma < 10\text{GeV}$	947	15,687	967,312

Selection of qqcc at ALCPG09(ILD)

	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
$-70<P_L Z<70$	38408.4	28830.8	1647.6	1.74E+06	48474.7	55837.3	1.14147	22944.1	1.62E+06
$200<E_{vis}<270$	37916.1	28541.1	1641.3	1.72E+06	43655.3	54742.8	0.581929	22377.1	1.59E+06
$-0.85<\cos\theta_{miss}<0.85$	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
Eimin/Eimax>0.25	25951.6	20096.9	1117.04	946401	123.815	176.712	0	0	151730
50<Pimax<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
$20<\theta_{min}<120$	25339.3	19562.2	1072.43	890169	106.163	154.779	0	0	114719
$110<\theta_{max}<170$	24043.3	18624.5	1017.44	804065	85.1689	145.004	0	0	109094
$105<M_{rec}<135$	18334.7	14296	809.984	526827	41.3248	87.5279	0	0	70296.7