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H>ZZ* decay

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Updates

A. FCC-ee analysis and ILC analysis on h>ZZ*?

B. Analysis detail for H>ZZ*

C. For correlative signal fit:

1. (VBF) ee>vvh contributes ~14% vvh signal?

2. Z[vv]H[mumujj]: 10%~20% background is Z[jj]H[WW*>evev]

3. Z[mumu]H[vvjj] : >~90% background are ZH[bb/WW*]

FCC-ee study

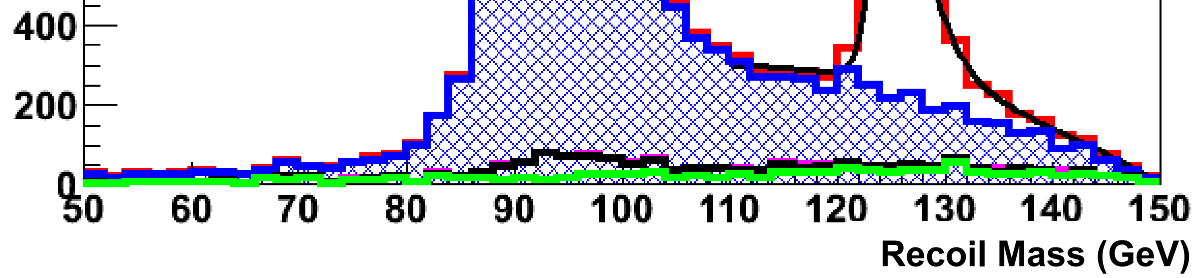

Figure 9. Distribution of the mass recoiling against the lepton pair in the $e^+e^- \to HZ$ channel, in the $Z \to \ell^+\ell^-$ final state ($\ell = e, \mu$), taken from ref. [36], for an integrated luminosity equivalent to one year of data taking with one TLEP detector (assumed to be the CMS detector). The number of Higgs boson events (the red histogram) obtained from a fit of this distribution is proportional to the inclusive HZ cross section, σ_{HZ}.

to this distribution of the signal and background contributions allows the total $e^+e^- \to HZ$ cross section to be measured with a precision of 0.4% at TLEP. As pointed out in ref. [41], the measurement of the total $e^+e^- \to HZ$ cross section is a sensitive probe of possible new physics that can reduce the fine-tuning of the Higgs boson mass. Such new physics would also renormalize the Higgs couplings by a universal factor, and the TLEP measurement of the $e^+e^- \to HZ$ cross section with a precision of 0.4% would be sensitive to new particles that could not be meaningfully probed in any other way.

A summary of the statistical precision of the measurements presented in ref. [36] for $\sqrt{s} = 240\,\text{GeV}$ — extrapolated to the TLEP luminosity and to four detectors — is given in table 4. In this table, a few numbers are added with respect to ref. [36]. First, the precision for $\sigma_{HZ} \times BR(H \to c\bar{c})$ and $\sigma_{HZ} \times BR(H \to gg)$ is extrapolated from the ILC prediction, as would be obtained if the CMS detector were upgraded with a vertex detection device with adequate c-tagging performance. Secondly, the precision for $\sigma_{HZ} \times BR(H \to ZZ)$ is obtained from an almost background-free dedicated search for ZZZ final states including four leptons, recently developed for that purpose.

The latter measurement has an important consequence for the determination of the total Higgs decay width. In e^+e^- collisions, it is not possible to directly observe the width of the Higgs boson if it is as small as the Standard Model prediction of 4 MeV. However, the total width of the Higgs boson is given by $\Gamma_{tot} = \Gamma(H \to ZZ)/BR(H \to ZZ)$. As the partial decay width $\Gamma(H \to ZZ)$ is directly proportional to the inclusive cross section σ_{HZ}, Γ_{tot} can be measured with the same precision as the ratio $\sigma^2_{HZ}/\sigma_{HZ} \times BR(H \to ZZ)$. Therefore,

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Figure 2.11. Distribution of the angle ϕ between two decay planes of W and W^* from the decay $H \to WW^* \to 4j$ with the inclusion of anomalous couplings [97]. (a) The SM curve along with that for $a = 1$, $b = \tilde{b} = 0$, $\Lambda = 1$ TeV; the position of the minimum is the same for both distributions. (b) The SM result with the cases $\tilde{b} = \pm 5$, $a = b = 0$, $\Lambda = 1$ TeV; the position of the minimum is now shifted as discussed in the text. From [97].

the absolute partial width $\Gamma(ZZ)$. However, to use this value to normalize the other Higgs partial widths in a completely model-independent analysis, we would need to use the formula similar to (2.34)

$$\Gamma(A) = \Gamma(ZZ) \cdot \frac{BR(A)}{BR(ZZ)}, \tag{2.35}$$

and so we again need to measure the branching ratio for $h \to ZZ^*$. This is not easy to do at the ILC because it is a rare mode giving low statistics for a Higgs boson with $m_h \simeq 120$ GeV. No full simulation study of the $h \to ZZ^*$ branching ratio in $e^+e^- \to Zh$ is currently available. We will therefore use the result of the $h \to WW^*$ study [85] and scale accordingly. The error for the $h \to WW^*$ decay implies a 26% relative error for the $h \to ZZ^*$ branching ratio. The use of the formula (2.35) then implies that the uncertainties in absolute partial widths or Higgs couplings are those listed convolved with $2.5 \oplus 26\%$. This significantly degrades the precision information obtained at the ILC.

An alternative is to use the theoretical assumption

$$g(hWW)/g(hZZ) = \cos^2\theta_W \tag{2.36}$$

to tie together the hZZ and hWW couplings. Now $BR(WW^*)$ can be used in the denominator of Eq.(2.35). The error added in converting from branching ratios to partial widths is $2.5 \oplus 8.6\% = 9.0\%$.

A better way is to use the WW fusion process, $e^+e^- \to \nu\bar{\nu}h$. The cross section for this process is proportional to $g^2(hWW)$ and thus to the $h \to WW^*$ partial width [95]. Although the WW fusion cross section is small at $\sqrt{s} = 250$ GeV, 18 fb for $m_h = 120$ GeV and the standard left-hand beam combination, $(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$, the expected yield exceeds 4k events and allows the measurement of the WW fusion cross section to $\Delta\sigma(WW)/\sigma(WW) = 7.2\%$ for the $250\,\text{fb}^{-1}$. Combining the $BR(WW^*)$ measurement, this implies that the total width can be determined to 11% in a completely model-independent way from 250 GeV data alone [96]. As we will see below

Channels Table (now 43)

Kaili-0925

Observed=tagged signal after cutflow and in fit range.
All events are weighted and normalized to $5ab^{-1}$.

Signal Z	Signal H	Observed Events	Who takes charge	Last update
H->Inclusive				
νν	Inclusive	164170	Libo	2017.8
μμ	Inclusive	29552		
ee	Inclusive	22200		
H->qq				
ee	bb	7655	Baiyu	2017.7
	cc	351		
	gg	1058		
μμ	bb	11108		2017.9
	cc	567		
	gg	1762		
qq	bb	176542		2017.7
	cc	8272		
	gg	25293		
νν	bb	70608		
	cc	3061		
	gg	9633		
H→γγ,Zγ				
ll	γγ	93	Feng	2015
νν		309		
qq		822	Yitian	2017.4
qq	Zγ	219	Weimin	2017.9
H->Invisible				
qq	νννν	202	MoXin	2017.7
ee		8		
μμ		18		

Signal Z	Signal H	Observed Events	Who takes charge	Last update
ννH(WW fusion)				
νν	bb	10256	LiangHao	2017.9
H->WW				
μμ	μνμν	52	Libo	2017.4
	eνeν	36		
	eνμν	105		
	eνqq	663		
	μνqq	717		
ee	μνμν	44		
	eνeν	22		
	eνμν	81		
	eνqq	612		
	μνqq	684		
νν	qqqq	9022		
H->ZZ				
νν	μμjj	190	Yuqian	2016.9
μμ	ννjj	200		
ee	ννjj	69		
H→ll				
μμ	ττ	2068	Dan	2017.9
qq		36023		
νν		12456		
qq	μμ	71	Zhenwei	2017.8
ee		1		
μμ		4		
νν		14		

Questions on H>ZZ*:

- (Pre)selection cuts, BDT, TMVA? (Need description)
- Signal: Full simulation;
  Background: Fast simulation (ZH bkg)
- Kaili's fit (based on YQ's 2016.09 update):

  z->vv, h->mmjj is +7.53%,-7.19%
  z->mm, h->vvjj is +10.5%, -10.1%.
  z->ee, h->vvjj is +34.9%, -33.8%.

Kaili-0925

$\Delta(Br * \sigma)$ fit Result

	PreCDR	Current
$\sigma(ZH)$	0.51%	0.50%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	0.28%	$\{^{+0.27\%}_{-0.27\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	2.2%	$\{^{+3.45\%}_{-3.43\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	1.6%	$\{^{+1.43\%}_{-1.42\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	1.5%	$\{^{+1.20\%}_{-1.20\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	4.3%	$\{^{+5.91\%}_{-5.74\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	$\{^{+0.68\%}_{-0.67\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	$\{^{+8.26\%}_{-8.17\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	$\{^{+15.8\%}_{-14.9\%}$
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	2.8%	$\{^{+3.12\%}_{-3.11\%}$
$\mathrm{Br}(\mathrm{H} \to \mathrm{inv.})$	0.28%	0.18%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	\	$4\sigma(\{^{+15.4\%}_{-14.9\%})$

In general, fit result is consistent with results of Pre_CDR and Individual studies.

CEPC-Current

Separate sensitivities on Zh and vvH production channel?

Table 13. Estimated precision of Higgs boson property measurements at the CEPC. All the numbers refer to relative precision except for m_H and BR($H \to$ inv) for which Δm_H and 95% CL upper limit are quoted respectively.

Δm_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\bar{\nu}H) \times \mathrm{BR}(H \to b\bar{b})$
5.9 MeV	2.8%	0.50%	3.12%

Decay mode	$\sigma(ZH) \times$ BR	BR
$H \to b\bar{b}$	0.27%	0.57%
$H \to c\bar{c}$	3.5%	3.5%
$H \to gg$	1.4%	1.5%
$H \to \tau^+\tau^-$	0.68%	0.84%
$H \to WW^*$	1.2%	1.3%
$H \to ZZ^*$	5.9%	5.9%
$H \to \gamma\gamma$	8.2%	8.2%
$H \to \mu^+\mu^-$	15%	15%
$H \to$ inv	–	0.18%

Then fit the 2(prod)*9(decay) channels simultaneously?

CEPC-Current

Section 6.2 Total Width

$$\sigma_{ZH}^{inc} \sim g_Z^2$$

$$\sigma_{ZH,H\to ZZ} \sim \frac{g_Z^2 g_Z^2}{\Gamma_H}$$

$$\Gamma_H \sim \frac{\sigma_{ZH}^{inc}}{\sigma_{ZH,H\to ZZ}}$$

$$\frac{\delta\Gamma_H}{\Gamma_H} \approx \frac{\delta\sigma_{ZH,H\to ZZ}}{\sigma_{ZH,H\to ZZ}}$$

Summary

A. **Lacking** FCC-ee analysis and ILC analysis on h>ZZ*

B. **Need** Analysis description for H>ZZ* channels (cuts, BDT?)

C. For correlative signal fit (**Step C depends on B!**):

1. (VBF) ee>vvh contributes ~14% vvh signal? **=>** (vvH[ZZ*>mmqq,qqmm])
2. Z[vv]H[mmjj]: 10%~20% background **=>** Z[jj]H[WW*]
3. Z[mm]H[vvjj] : ~80% background **=>** Z[jj]H[WW*]

Yuqian-2016/11

Current state

SM background : fastsimulation

ZZZ*	Yield	Object reconstructed	Signal Efficiency(%)	Main Background	Accuracy (%)	Comments
μμvvqq	128	118	63.3	h->ww&zz_sl	12.9	Need a tau finder to increase the accuracy
μμqqvv	128	125	-	h->bb&zz_sl	>25	
eevvqq	132	91	53.8	h->ww&sze_sl	15.8	reconstructed efficiency of electron need to be improved
eeqqvv	132	88	-	h->bb&zz_sl	>25	
vvμμqq	152	121	61.4	h->t,w&zz_sl	11.0	
vvqqμμ	152	123	51.9	h->w,b&zz_sl	12.9	
vveeqq	151	118	43.1	h->w&sze_sl	21.3	
vvqqee	151	134	-	h->bb&sze_sl	>25	
qqμμvv	135	115	-	h->tt&zz_sl	>25	Comparing to leptons&higgs channel,qq recoil mass couldn't offer enough distinguishing power to SM
qqvvμμ	135	122	-	h->t,w&zz_sl	>25	
qqeevv	127	107	-	h->tt&sze_sl	>25	
qqvvee	127	123	-	h->t,w&sze_sl	>25	
μμμμqq/qqμμ	43	39	69.8	h->tt&zz_sl	19.9	Need a tau finder to increase the accuracy
μμeeqq/qqee	43	39	60.5	h->tt&zz_sl	21.2	
eeeeqq/eeqqee	43	33	-	h->tt&sze_sl	>25	reconstructed efficiency of electron need to be
eeμμqq/eeqqμμ	43	41	58.2	h->tt&sze_sl	19.9	