Combination of CEPC Higgs precision measurement

Zhang Kaili, IHEP

Wang Jin, Liu Zhen

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OUTLINE

- Why and How we do combination
- Advantages
- Results of $\sigma(ZH) * \mathrm{Br}$
- κ Framework
- Summary

Why Combination?

- Uniformed, simultaneous statistical framework
  - Get likelihood scan result Robust & Reliable;
  - Correctly consider the correlations between individual channels
    - bb/cc/gg; ZH bkg treatment； WW fusion; width……
  - Extensibility for systematic uncertainties and theoretic assumptions

- Currently, with MC sample
  - We build Asimov* data from signal and bkg spectrum
  - To fit the estimated precisions of $\sigma * Br$, and κ.
  - Can do more with observed data in the future.

*:see more in arXiv:1007.1727

Fit techniques

- Input: (1d) Higgs invariant/recoil mass spectrum; Unbinned

  (2d) bb/cc/gg: likeness templates; ww fusion: mass & cosθ

- POI: $\sigma * Br$, Higgs coupling κ

- NP: represents systematic uncertainties
  - currently set global $\Delta\text{Lumi} = 0.1\%$, not conclude in current fit;
  - more NPs can be introduced in the future.
  - so here results are all determined by statistical uncertainty.

- PDF:
  - signal: Crystal ball + Gaussian; bkg: 2rd-order poly exponential.
  - Use RooHistPdf to fit $Z\gamma$ and 2d templates.

- Algorithm: Likelihood Scan
  - Asymmetric result $\pm 1\sigma$ deviation from profile likelihood

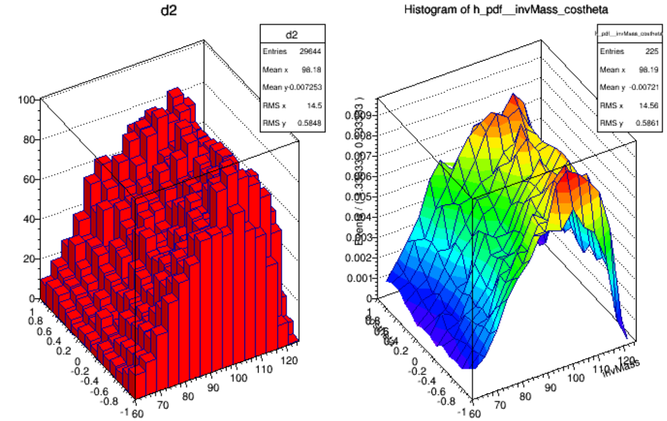
Fit techniques

- For each channel
  - Input observables from MC sample.
  - Build combine S+B Pdf   Tot=N_{bb}*Pdf+N_{cc}*Pdf_{cc}+……+N_{bkg}*Pdf_{bkg}
  - Add μs on events number N_{bb}:
    - When measure $\sigma * Br$, $N_{bb} = N_{bb\_SM} * \mu_{bb}$ N_{bb_SM} directly from event yield ($5ab^{-1}$)
    - When measure Br, $N_{bb} = N_{bb\_SM} * \frac{Br}{Br_{SM}} * \frac{\sigma(ZH)}{\sigma(ZH)_{SM}}$ $\Delta(\sigma(ZH)) = 0.50\%$
    - When measure κ, $N_{bb} = N_{bb\_SM} * \kappa_z^2(\kappa_w^2) * \kappa_b^2/\Gamma_H$
    - Different channel share the same μs. $Z \rightarrow ee, \mu\mu, qq, \nu\nu$, share the same μ_{bb}
    - Events number N_{bb} is float   and the Pdf shape fixed all the time.
- Use Combined pdf to make Asimov data
- Scan the likelihood and get the deviation result

Treatment for ZH bkg

- In individual analysis, other ZH process is tagged as bkg;
  - It's signal of another channel
  - Should taken into account
    - $Z \rightarrow \mu\mu, H \rightarrow \tau\tau$, the main bkg is $H \rightarrow WW$.   Make it contribute to μ_{WW}
  - Measurements not independent in this way
  - Separate ZH events specifically
    - Inclusive ZH events cannot be used
  - Progress undergoing
    - currently not finished yet

Correlation: $\nu\nu H \rightarrow bb$



2d fit
Mass &cos of 2 jets

- WW fusion channel contains many ZH bkg;
  - Initial error is 2.89%, (Pre_CDR 2.8%)
  - But must consider the uncertainty of ZH process(~0.4%)
- In individual analysis
  - assume the error is Gaussian distribution
  - $-\mathrm{Log}L = 0.5\left(\frac{\mu_{ZH}-1}{0.375\%}\right)^2 - P\left(data\middle|\mu_{\mathrm{ZH}}N_{ZH}Pdf_{ZH} + \mu_{\mathrm{wwf}}N_{wwf}Pdf_{wwf} + N_{SM}Pdf_{SM}\right)$
- Here we can directly use the likelihood in Z->ee/mm/qq, H->bb channel
  - Already have the form of μ_{ZH} no assumption made;
- Combine Fit $\{^{+3.11\%}_{-3.10\%}$; consistent with individual result 3.1%.

Correlation: Higgs width

- Model independent determination

$$\Gamma_H = \frac{\Gamma_{H\to ZZ}}{Br(H\to ZZ)} \propto \frac{\sigma(ZH)}{Br(H\to ZZ)} \qquad 5.2\%$$

- and

$$\Gamma_H = \frac{\Gamma_{H\to bb}}{Br(H\to bb)} \propto \frac{\sigma(\nu\nu H\to \nu\nu bb)}{Br(H\to bb)Br(H\to WW)} \qquad 3.3\%$$

- If two independent: 2.83% (pre_CDR 2.8%)
- Consider correlation, then combine in 10κ framework:

$$\Delta(\Gamma_H) = 3.1\%$$

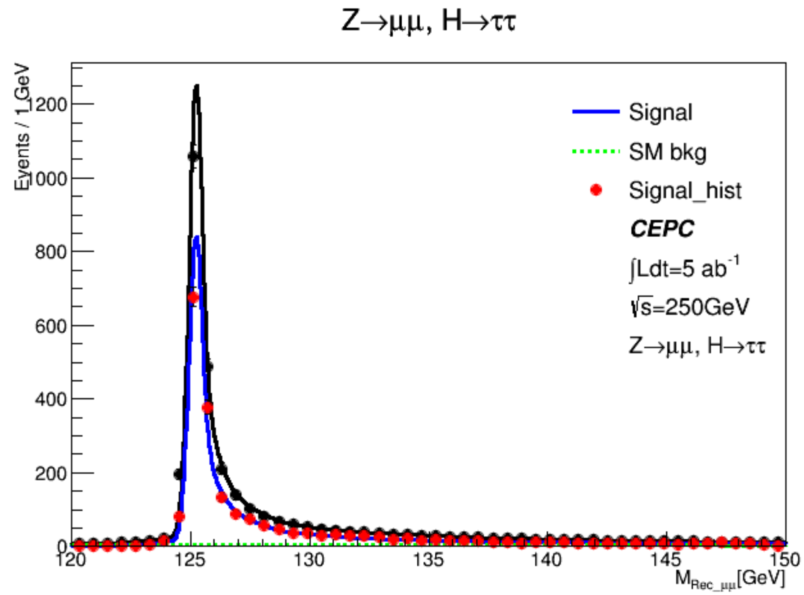
Channels Table

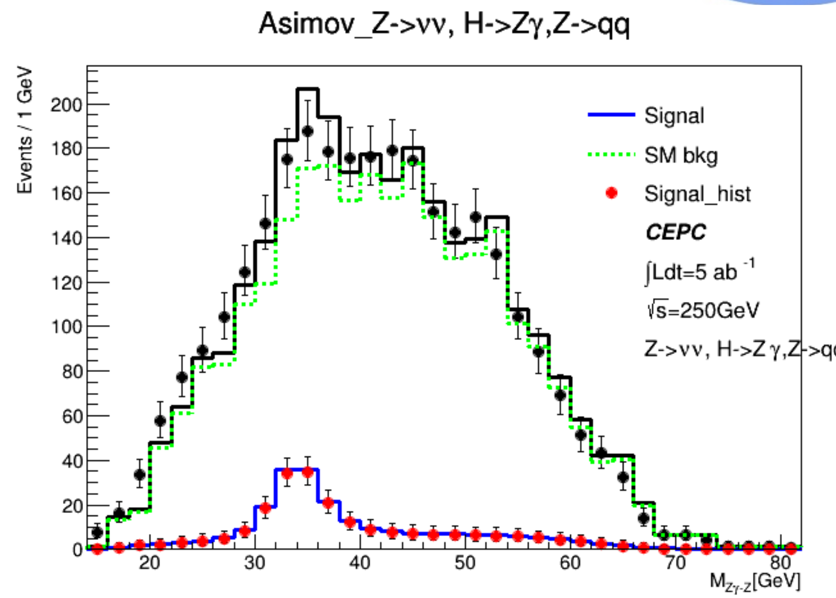
Observed=tagged signal after cutflow and in fit range.
All events are weighted and normalized to $5ab^{-1}$.

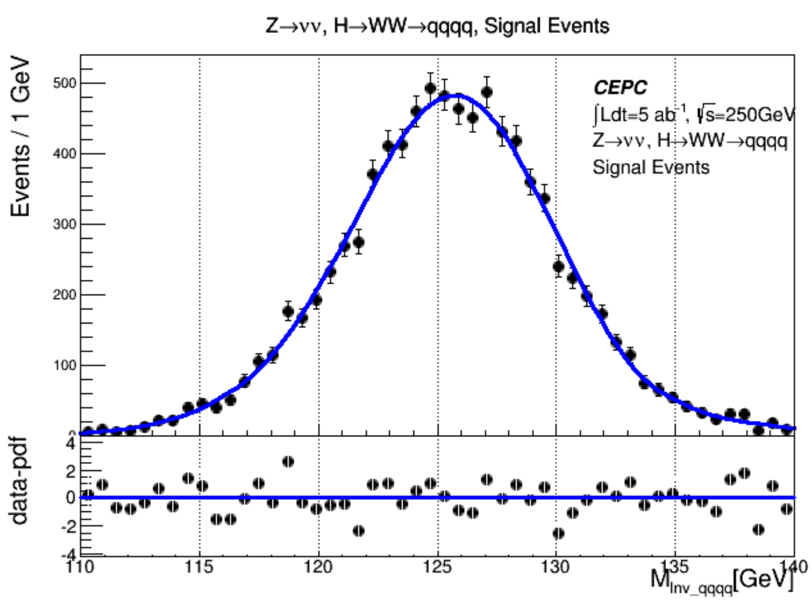
Signal Z	Signal H	Observed Events	Who takes charge	Precision
H->Inclusive				
νν	Inclusive	164170	Liao Libo	\
μμ	Inclusive	29552		
ee	Inclusive	22200		
H->qq				
ee	bb	7655	Bai Yu	1.3%
	cc	351		15%
	gg	1058		8.2%
μμ	bb	11108		1.0%
	cc	567		11%
	gg	1762		5.5%
qq	bb	176542		0.5%
	cc	8272		17%
	gg	25293		7.2%
νν	bb	70608		0.4%
	cc	3061		3.9%
	gg	9633		1.6%
H→γγ,Zγ				
ll	γγ	93	Wang Feng	27%
νν		309		12%
qq		822	Sun Yitian	13%
qq	Zγ	219	Yao Weimin	21%
H->Invisible				Br, Upper
qq	νννν	202	Mo Xin	0.3%
ee		8		1.1%
μμ		18		0.7%
ννH(WW fusion)				
νν	bb	10256	Liang Hao	3.1%

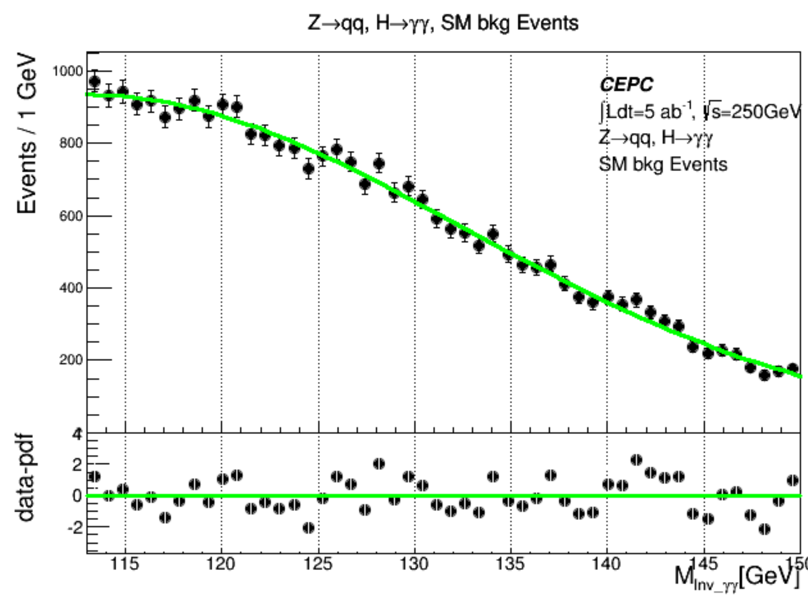
Signal Z	Signal H	Observed Events	Who takes charge	Precision
H->WW				
μμ	μνμν	52	Liao Libo	2.6%
	eνeν	36		
	eνμν	105		
	eνqq	663		
	μνqq	717		
ee	μνμν	44		2.9%
	eνeν	22		
	eνμν	81		
	eνqq	612		
	μνqq	684		
νν	qqqq	9022		1.3%
H->ZZ				
νν	μμjj	179	Wei Yuqian	8.3%
νν	eejj	64		34%
μμ	ννjj	200		7.4%
ee	eejj	55		40%
ee	mmjj	81		23%
H→ττ				
ee	ττ	\	Yu Dan	4.3%
μμ		2068		2.7%
qq		36023		1.7%
νν		12456		4.3%
H→μμ				
qq	μμ	71	Cui Zhenwei	15%
ee		1		
μμ		4		
νν		14		

Mass shape plots









Functions describe the shape of unbinned datasets well.

Fit result of $\sigma(ZH) * \mathrm{Br}$

($5ab^{-1}$)	Pre_CDR	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%	$\{^{+3.49\%}_{-3.47\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	1.6%	$\{^{+1.44\%}_{-1.44\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	1.5%	$\{^{+1.22\%}_{-1.21\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	4.3%	$\{^{+5.29\%}_{-5.15\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	$\{^{+1.31\%}_{-1.30\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	$\{^{+8.28\%}_{-8.19\%}$
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	$\{^{+15.9\%}_{-15.0\%}$
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	2.8%	$\{^{+3.11\%}_{-3.10\%}$
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	0.28%	0.22%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	\	$4\sigma(\{^{+21.0\%}_{-21.4\%})$

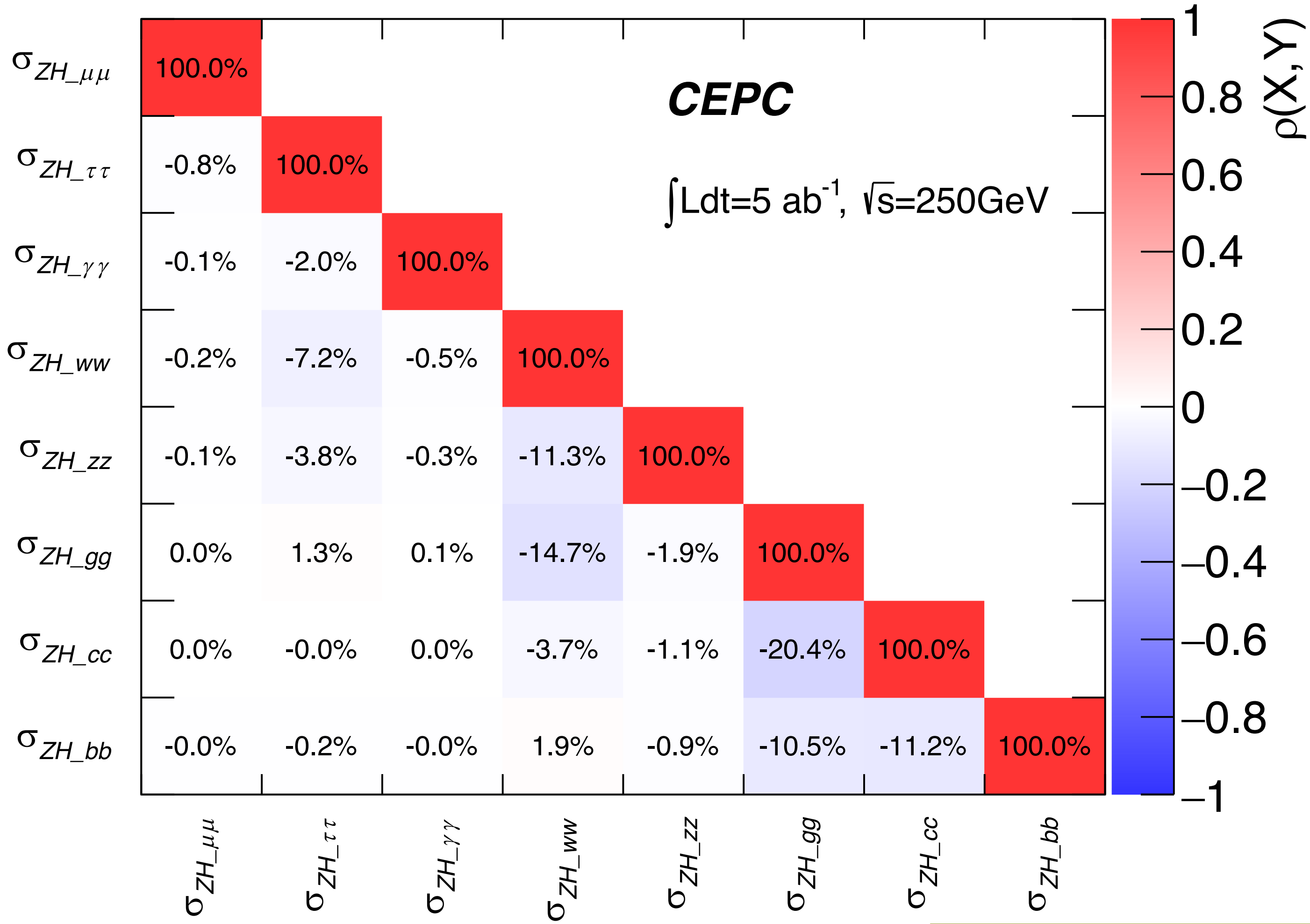
Δm_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\bar{\nu}H) \times \mathrm{BR}(H \to b\bar{b})$
5.9 MeV	3.1%	0.50%	3.1%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	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%
$H \to \tau^+\tau^-$	1.3%	1.4%
$H \to WW^*$	1.2%	1.3%
$H \to ZZ^*$	5.2%	5.2%
$H \to \gamma\gamma$	8.2%	8.2%
$H \to \mu^+\mu^-$	15%	15%
$H \to \mathrm{inv}$	–	0.22%

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

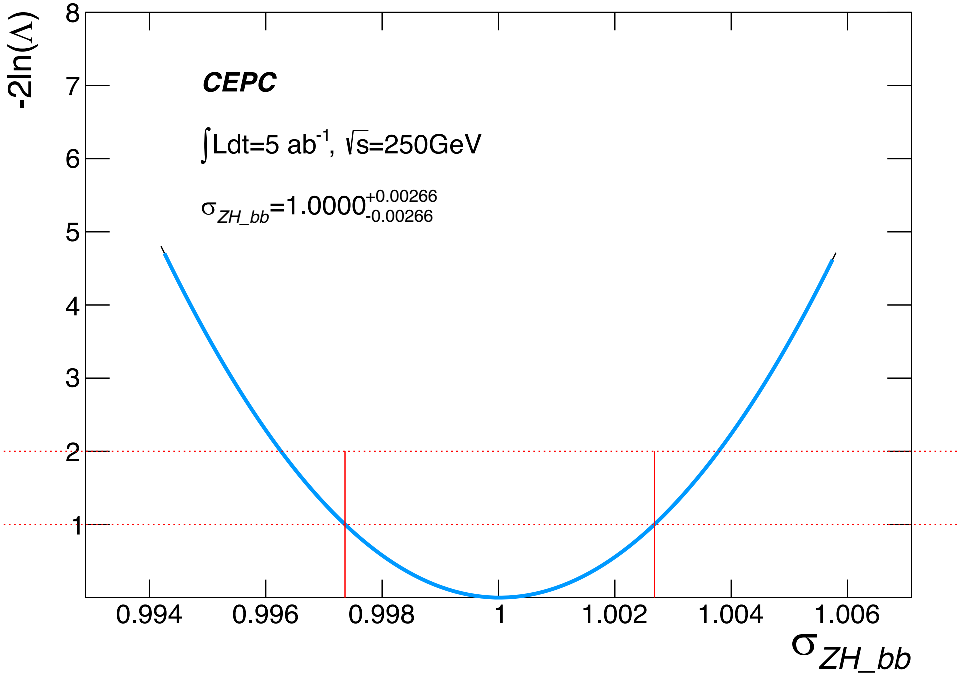
See more in backup slides.

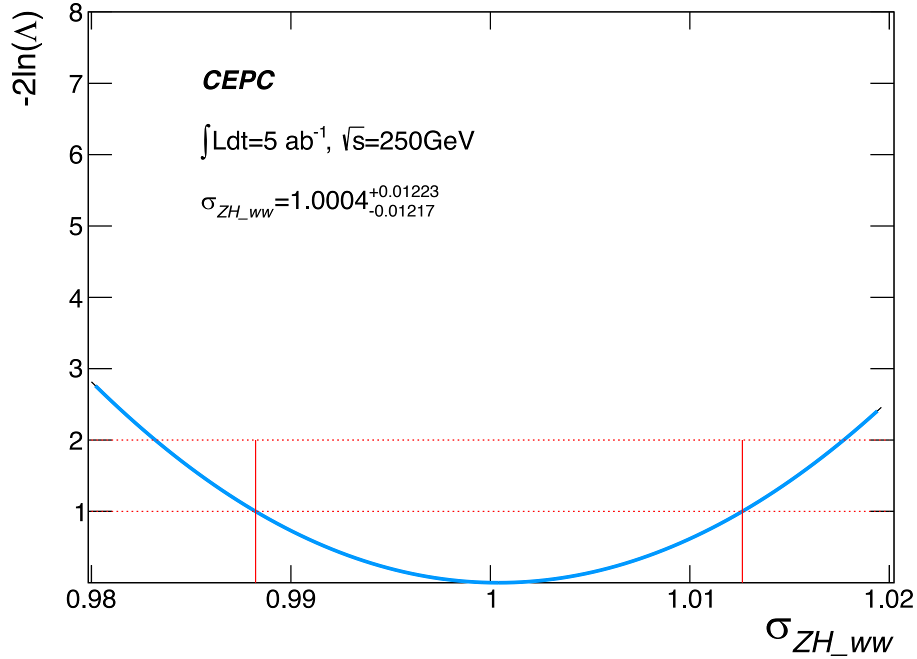
Correlations in channel



bb/cc/gg highly correlated because template fit;
Other are linked by ZH bkg events.

Likelihood scan





As we use MC sample, the signal strength is always very close to 1.

κ Framework

κ defined as the ratio of the Higgs coupling to SM expects.

$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})},\ \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

- Model independent implication
  - Detector's benchmark; Constrain to new physics models;
- In CEPC
  - We have $\sigma(ZH)$ =0.50% constrain $\sigma(\kappa_z) < 0.25\%$.
  - For Production, ZH & WW fusion process, all contribute to $\kappa_Z^2; \kappa_W^2;$
  - For Partial decay, no top quark κ_t like: $\kappa_Z^2, \kappa_W^2, \kappa_b^2, \kappa_c^2, \kappa_g^2, \kappa_\tau^2, \kappa_\gamma^2, \kappa_\mu^2,$ ... ...
  - For Total width Γ_H. $\Gamma_H = \Gamma_{SM} + \Gamma_{BSM}$.
  - If we assume no exotic decay, Γ_{SM} can be resolved as: all κ correlated this way;

$$\Gamma_{SM} = 0.2137\kappa_W^2 + 0.02619\kappa_Z^2 + 0.5824\kappa_b^2 + 0.08187\kappa_g^2 + 0.002270\kappa_\gamma^2 + 0.06294\kappa_\tau^2 + 0.02891\kappa_c^2$$

  - $Z \to \mu\mu, H \to \tau\tau$ channel, the signal will be $\kappa_Z^2\kappa_\tau^2/\Gamma_H$; For $\nu\nu H \to bb$, it's $\kappa_W^2\kappa_b^2/\Gamma_H$

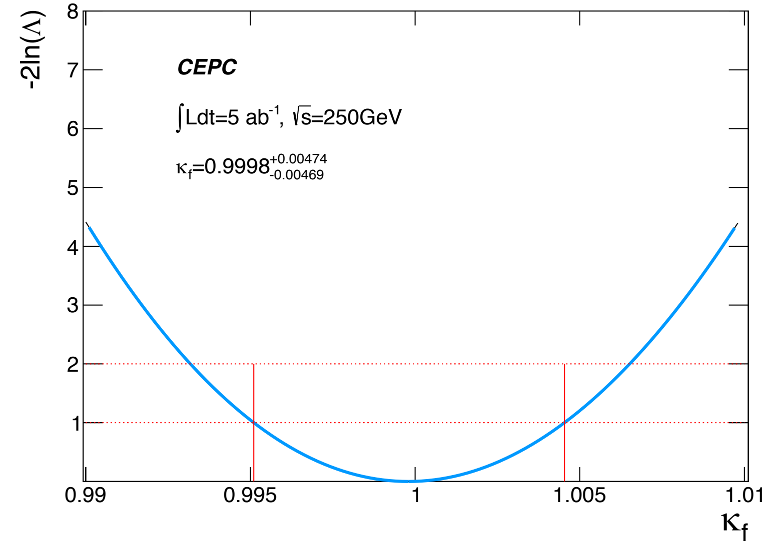
Fit result of κ

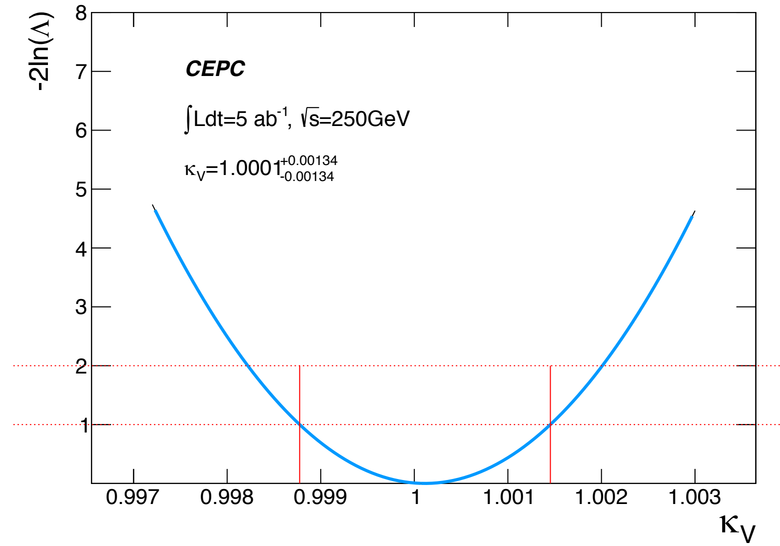
	10κ	Pre_CDR	7κ	Pre_CDR
κ_b	1.5%	1.3%	1.5%	1.2%
κ_c	2.4%	1.7%	2.4%	1.6%
κ_g	1.6%	1.5%	1.6%	1.5%
κ_γ	4.4%	4.7%	4.4%	4.7%
κ_τ	1.6%	1.4%	1.6%	1.3%
κ_Z	0.25%	0.26%	0.15%	0.16%
κ_W	1.4%	1.2%	1.4%	1.2%
κ_μ	7.9%	8.6%		
Br_{inv}	0.22%	0.28%		
Γ_H	3.1%	2.8%		

From 10κ to 7κ, we assume

- No exotic decay Γ_{BSM}
- Drop Br_{inv}
- $\kappa_\mu = \kappa_\tau$

2κ: Boson & Fermi (0.13%,0.47%)

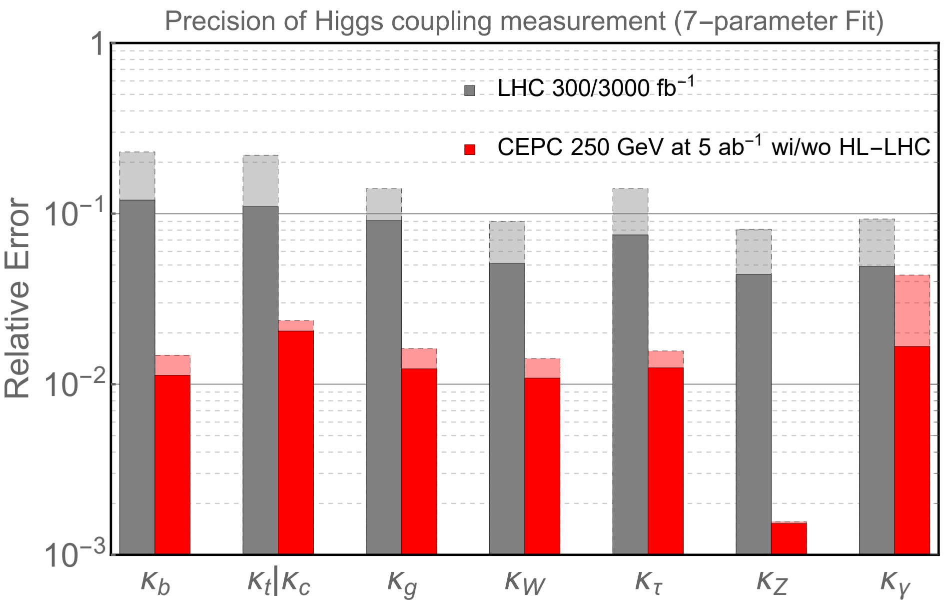




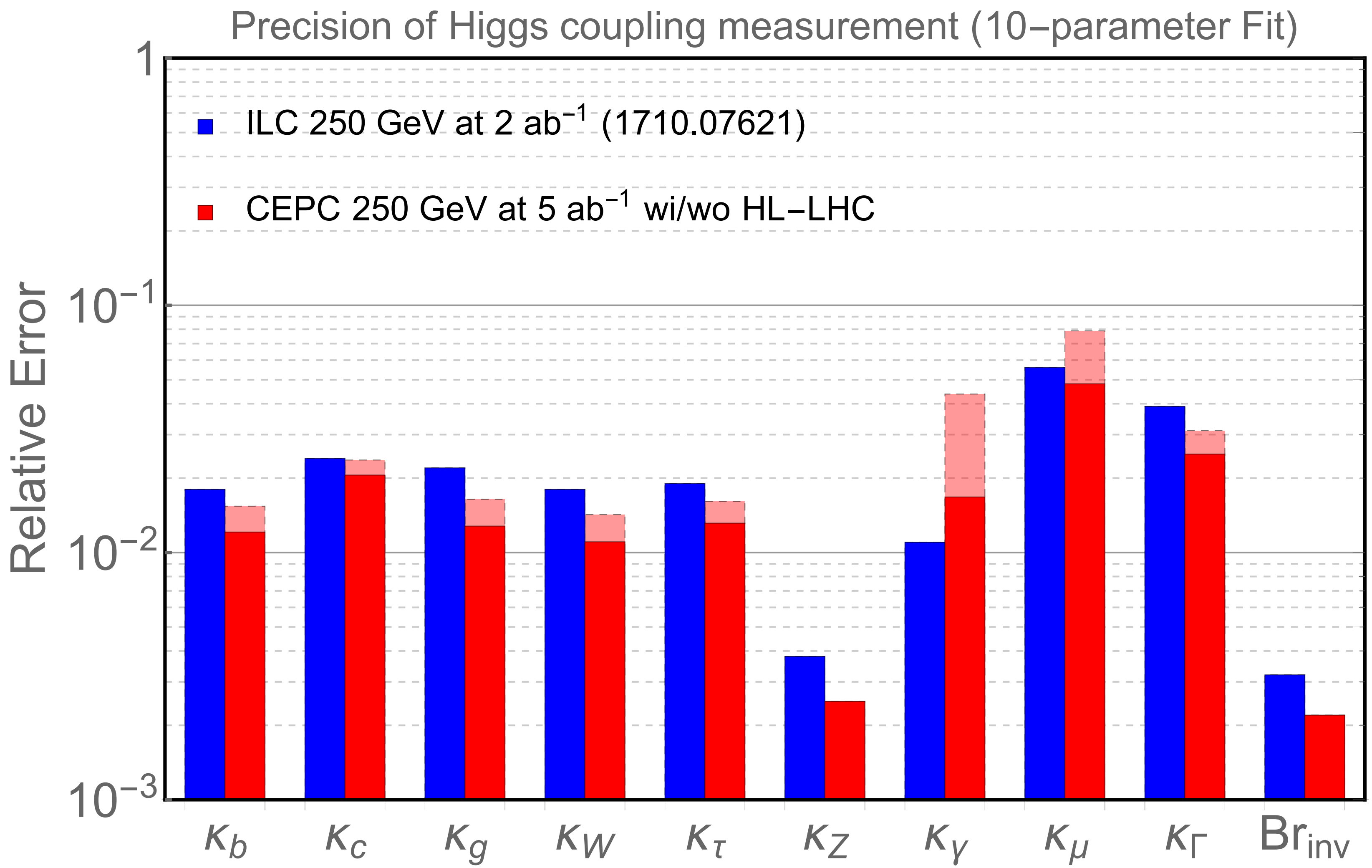
Integration to HL-LHC

ATL-PHYS-PUB-2014-016	HL-LHC
$\sigma(ZH) * Br(H \to bb)$	13%
$\sigma * Br(H \to WW)$	5%
$\sigma * Br(H \to ZZ)$	4%
$\sigma * Br(H \to \tau\tau)$	7%
$\sigma * Br(H \to \gamma\gamma)$	4%
$\sigma * Br(H \to \mu\mu)$	12%
$\sigma(WH) * Br(H \to bb)$	36%
$\sigma * Br(H \to Z\gamma)$	27%

	10-parameter fit		7-parameter fit	
	CEPC	+HL-LHC	CEPC	+HL-LHC
Γ_h	3.1	2.5	–	–
κ_b	1.5	1.2	1.5	1.1
κ_c	2.4	2.1	2.4	2.0
κ_g	1.6	1.3	1.6	1.2
κ_W	1.4	1.1	1.4	1.1
κ_τ	1.5	1.2	1.5	1.1
κ_Z	0.25	0.25	0.15	0.15
κ_γ	4.4	1.7	4.4	1.7
κ_μ	7.9	4.8	–	–
BR_{inv}	0.22	0.22	–	–



Compared to ILC(1710.07621)



Correlation of κ

For each entry,
upper one is CEPC result
lower one is CEPC+HL-LHC result.

7−parameter fit Correlation

	κ_b	κ_c	κ_g	κ_W	κ_τ	κ_Z	κ_γ
κ_b	100.	−25. / −23.	−51. / −51.	−74. / −70.	−47. / −46.	62. / 59.	−8.7 / −3.4
κ_c	−25. / −23.	100.	−7.1 / −12.	11. / 11.	2.4 / 2.4	−24. / −23.	1.1 / 0.42
κ_g	−51. / −51.	−7.1 / −12.	100.	14. / 7.0	1.6 / −0.91	−28. / −17.	1.1 / 0.15
κ_W	−74. / −70.	11. / 11.	14. / 7.0	100.	3.5 / 3.8	−60. / −61.	2.2 / 0.89
κ_τ	−47. / −46.	2.4 / 2.4	1.6 / −0.91	3.5 / 3.8	100.	−12. / −12.	−1.1 / −0.42
κ_Z	62. / 59.	−24. / −23.	−28. / −17.	−60. / −61.	−12. / −12.	100.	−4.0 / −7.5
κ_γ	−8.7 / −3.4	1.1 / 0.42	1.1 / 0.15	2.2 / 0.89	−1.1 / −0.42	−4.0 / −7.5	100.

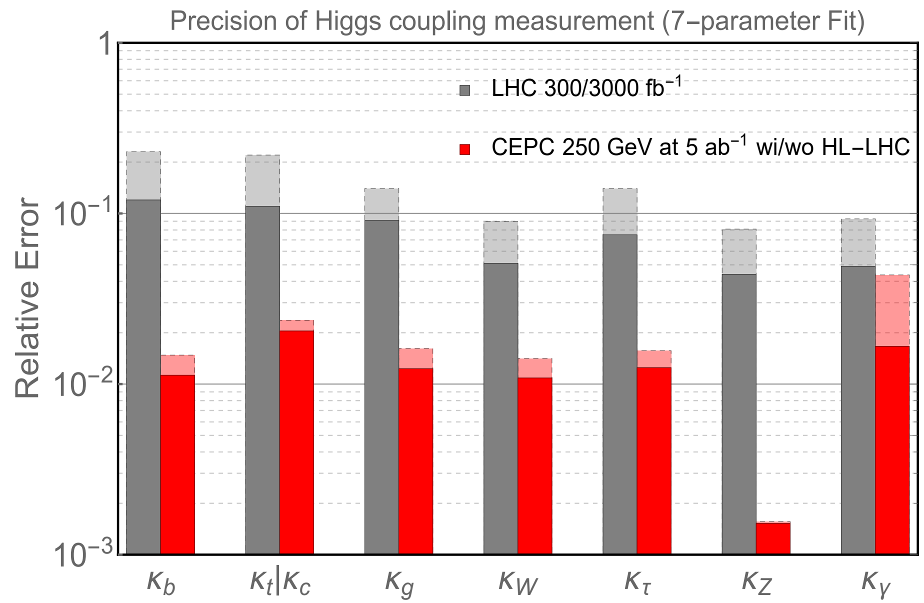
10−parameter fit Correlation

	κ_b	κ_c	κ_g	κ_W	κ_τ	κ_Z	κ_γ	κ_μ	Br_{inv}	κ_Γ
κ_b	100.	3.7 / 3.5	−0.24 / −0.19	−13. / −12.	<0.1 / <0.1	84. / 83.	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−94. / −93.
κ_c	3.7 / 3.5	100.	−16. / −16.	−9.1 / −8.3	0.13 / 0.13	6.6 / 6.2	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−6.8 / −6.4
κ_g	−0.24 / −0.19	−16. / −16.	100.	−7.2 / −5.6	0.45 / 0.36	13. / 16.	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−15. / −19.
κ_W	−13. / −12.	−9.1 / −8.3	−7.2 / −5.6	100.	−5.5 / −5.3	1.3 / −0.16	−0.85 / −0.33	−0.34 / −0.20	<0.1 / <0.1	−4.9 / −4.7
κ_τ	<0.1 / <0.1	0.13 / 0.13	0.45 / 0.36	−5.5 / −5.3	100.	16. / 16.	−1.1 / −0.45	−0.47 / −0.29	<0.1 / <0.1	−19. / −19.
κ_Z	84. / 83.	6.6 / 6.2	13. / 16.	1.3 / −0.16	16. / 16.	100.	2.4 / −4.8	1.3 / −0.65	<0.1 / <0.1	−89. / −89.
κ_γ	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−0.85 / −0.33	−1.1 / −0.45	2.4 / −4.8	100.	<0.1 / <0.1	<0.1 / <0.1	−2.8 / −1.1
κ_μ	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−0.34 / −0.20	−0.47 / −0.29	1.3 / −0.65	<0.1 / <0.1	100.	<0.1 / <0.1	−1.5 / −0.93
Br_{inv}	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	100.	<0.1 / <0.1
κ_Γ	−94. / −93.	−6.8 / −6.4	−15. / −19.	−4.9 / −4.7	−19. / −19.	−89. / −89.	−2.8 / −1.1	−1.5 / −0.93	<0.1 / <0.1	100.

Summary

	Current
$\sigma(ZH)$	0.50%
$\sigma(ZH) * Br(H \to bb)$	$\{^{+0.27\%}_{-0.27\%}$
$\sigma(ZH) * Br(H \to cc)$	$\{^{+3.49\%}_{-3.47\%}$
$\sigma(ZH) * Br(H \to gg)$	$\{^{+1.44\%}_{-1.44\%}$
$\sigma(ZH) * Br(H \to WW)$	$\{^{+1.22\%}_{-1.21\%}$
$\sigma(ZH) * Br(H \to ZZ)$	$\{^{+5.29\%}_{-5.15\%}$
$\sigma(ZH) * Br(H \to \tau\tau)$	$\{^{+1.31\%}_{-1.30\%}$
$\sigma(ZH) * Br(H \to \gamma\gamma)$	$\{^{+8.28\%}_{-8.19\%}$
$\sigma(ZH) * Br(H \to \mu\mu)$	$\{^{+15.9\%}_{-15.0\%}$
$\sigma(\nu\nu H) * Br(H \to bb)$	$\{^{+3.11\%}_{-3.10\%}$
$Br_{upper}(H \to inv.)$	0.22%
$\sigma(ZH) * Br(H \to Z\gamma)$	$4\sigma(\{^{+21.0\%}_{-21.4\%})$

	10κ	7κ
κ_b	1.5%	1.5%
κ_c	2.4%	2.4%
κ_g	1.6%	1.6%
κ_γ	4.4%	4.4%
κ_τ	1.6%	1.6%
κ_Z	0.25%	0.15%
κ_W	1.4%	1.4%
κ_μ	7.9%	
Br_{inv}	0.22%	
Γ_H	3.1%	



Δm_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\bar{\nu}H) \times \mathrm{BR}(H \to b\bar{b})$
5.9 MeV	3.1%	0.50%	3.1%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	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%
$H \to \tau^+\tau^-$	1.3%	1.4%
$H \to WW^*$	1.2%	1.3%
$H \to ZZ^*$	5.2%	5.2%
$H \to \gamma\gamma$	8.2%	8.2%
$H \to \mu^+\mu^-$	15%	15%
$H \to \mathrm{inv}$	–	0.22%

To be presented in CDR & whitepaper

backup

Individual analysis

bb/cc/gg

- Template fit: Flavor tagging algorithm
- Pre_CDR
  - bb/cc/gg separated (not reasonable)
  - $\nu\bar{\nu}H$, $\bar{q}qH$ results are extrapolated from ILC studies.
  - Bkg estimation optimistic
- Baiyu's template fit
  - $Z \to ee\ \mu\mu\ qq\ \nu\nu$, $\mathrm{H} \to bb/cc/gg$ are studied.
  - 2D fit, with dijets' b/c likeness; mass info not used;
  - 5 parts, Tot=bb+cc+gg+bkg_{zh}+bkg_{sm}.
  - Build individual pdf by MC, then fit to determine fraction.
  - the shape of bkg is fixed.
    - Which means we have a wonderful understanding with bkg,
    - may be more suitable for CEPC.
  - ToyMC test to get precision
  - Now plan to use 3d fit in llH;
  - Systematic uncertainties ongoing;

$$B_{likeness} = \frac{b_{j1}b_{j2}}{b_{j1}b_{j2} + (1-b_{j1})(1-b_{j2})}$$

Pre_CDR	μ_bb	μ_cc	μ_gg
eeH	1.1%	14.6%	5.6%
mmH	0.9%	12.6%	3.8%
qqH	0.4%	3.0%	2.6%
vvH	0.45%	3.2%	2.8%
Combined	0.28%	2.2%	1.6%

Baiyu's	μ_bb	μ_cc	μ_gg
eeH	1.2%	14.4%	7.8%
mmH	1.1%	12.8%	6.9%
qqH	0.4%	8.0%	5.2%
vvH	0.4%	3.8%	1.6%
Combined	0.3%	3.2%	1.6%

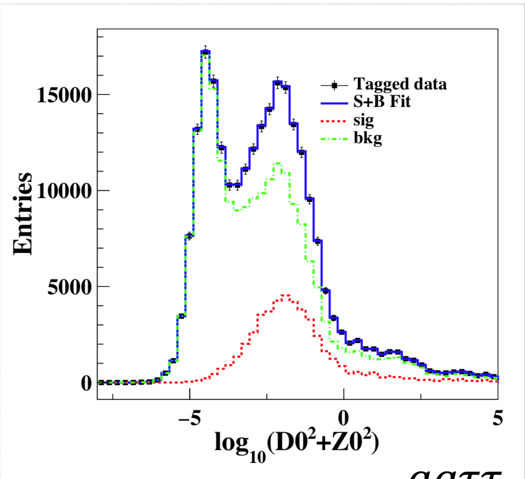
Scan	μ_bb	μ_cc	μ_gg
eeH	1.3%	15.0%	8.2%
mmH	1.0%	11.3%	5.5%
qqH	0.5%	17%	7.2%
vvH	0.4%	3.9%	1.6%
Combined	0.27%	3.48%	1.44%

$\tau\tau$

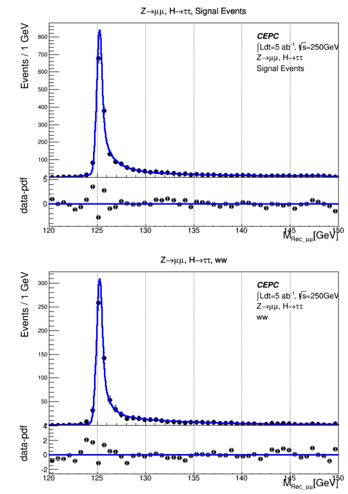
	preCDR	Now
$\tau\tau$	1.2%	**1.30%**

- Pre_CDR concludes the precision 1.2% but no description.
- Develop LICH to identify lepton. Eff>99%
- Signal and ZH events(Main WW) share the same shape
    - Dan use $\log_{10}(D_0^2 + Z_0^2)$ fit to separate signal
        - Impact parameter, Distance from beam spot
    - Determine the ratio, then use ratio to produce signal sample.
    - eeH is extrapolated from mmH, assuming bkg 4 times worse;

	BR ($H\to\tau\tau$)	$\delta(\sigma\times BR)/(\sigma\times BR)$
$\mu\mu$H	6.40 ± 0.18	2.68%
eeH(extrapolated)	6.37 ± 0.18	4.34%
$\nu\nu$H	6.19 ± 0.17	4.29%
qqH	6.25 ± 0.04	1.71%
combined	6.28 ± 0.07	1.30%



$qq\tau\tau$



$\mu\mu\tau\tau$, signal/WW

see more details in https://agenda.linearcollider.org/event/7645/contributions/40070/attachments/32408/49220/lcws2017_Dan.pdf

WW

	preCDR	Now
WW	1.5%	1.2%

- Pre_CDR's result contains:

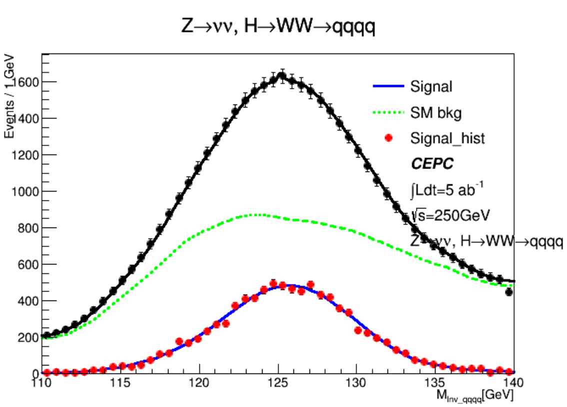
Channel	Precision	Comment
$Z \to \mu\mu, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	7.0%	Scaled from $\mu^+\mu^-$ channel
$Z \to \nu\bar{\nu}, H \to WW^* \to qqqq$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to \ell\nu qq$	2.2%	Extrapolated from ILC result
Combined	1.5%	

Excepted signal events of each type

W boson decay \ Z boson decay	ee	$\mu\mu$	$\tau\tau$	$\nu\nu$	qq
$WW^* \to e\nu e\nu$	88	88	88	525	1836
$WW^* \to \mu\nu\mu\nu$	87	87	87	517	1808
$WW^* \to e\nu\mu\nu$	175	175	175	1052	3644
$WW^* \to e\nu\tau\nu$	187	187	188	1116	3901
$WW^* \to \mu\nu\tau\nu$	186	186	186	1107	3872
$WW^* \to \tau\nu\tau\nu$	99	99	99	593	2072
$WW^* \to e\nu qq$	1111	1112	1114	6612	23112
$WW^* \to \mu\nu qq$	1103	1104	1105	6562	22939
$WW^* \to \tau\nu qq$	1181	1182	1183	7025	24558
$WW^* \to qqqq$	3498	3502	3506	20808	72735

Done
To do

- Currently have 11 channels of WW (with box)
  - Data entry is different with Pre_CDRs'.
  - Others are undergoing



Libo's summary

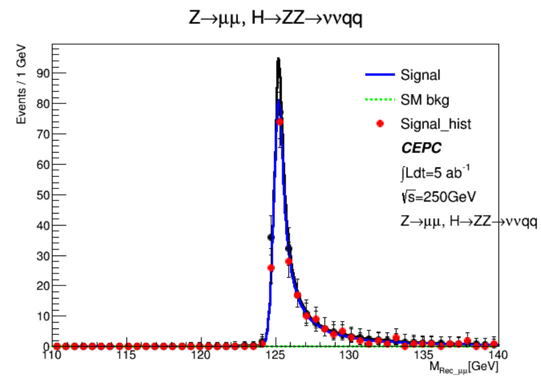
Category	Signal	Relative uncertainty	Efficiency of se
$Z \to e^+e^-; H \to WW^* \to e\nu e\nu$	20±7	35%	25.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu\mu\nu$	44±8	18.2%	43.1%
$Z \to e^+e^-; H \to WW^* \to e\nu\mu\nu$	53±8	15.1%	27.6%
$Z \to e^+e^-; H \to WW^* \to e\nu qq$	435±23	5.3%	37.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu qq$	551±24	4.5%	48.0%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu e\nu$	23±5	21.7%	25.8%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu\mu\nu$	39±7	18%	44.8%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu\mu\nu$	93±10	11%	54.1%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu qq$	573±25	4.0%	51.7%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu qq$	756±30	4.4%	68.4%
$Z \to \nu\bar{\nu}; H \to WW^* \to qqqq$	8403±202	2.4%	34.7%
$Z \to \mu^+\mu^-; H \to WW^* \to qqqq$	±	2.93%	

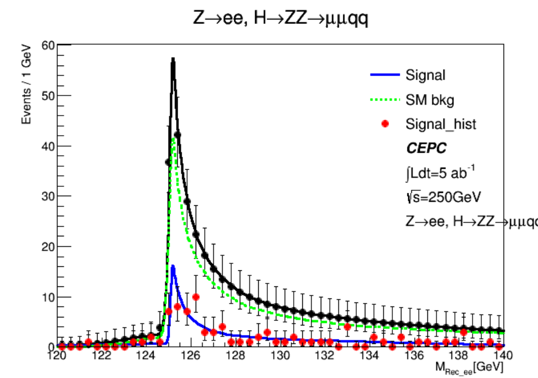
ZZ

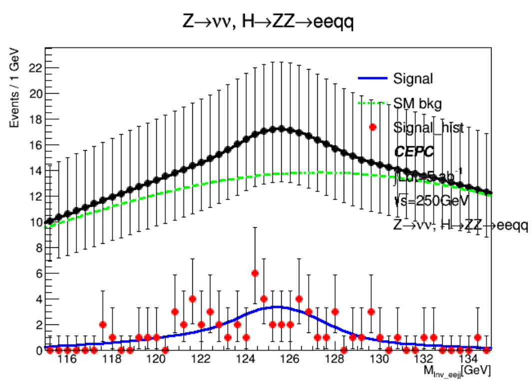
	preCDR	Now
ZZ	4.3%	5.2%

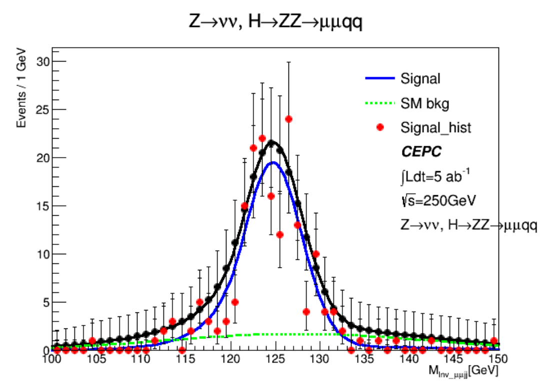
Channel	Precision	Comment
$\sigma(Z(\nu\bar{\nu})H + \nu\bar{\nu}H) \times \mathrm{BR}(H \to ZZ)$	6.9%	CEPC Fast Simulation
$\mathrm{BR}(H \to ZZ^{*})$	4.3%	Extrapolation from FCC-ee [36]

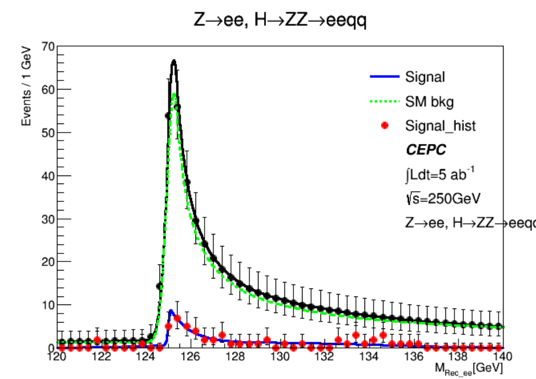
- 3 final Z, one off-shell.
- Pre_CDR's result from extrapolating the FCC-ee.
- Now has 5 channels clear and easy to study
    - Others are rather difficult;











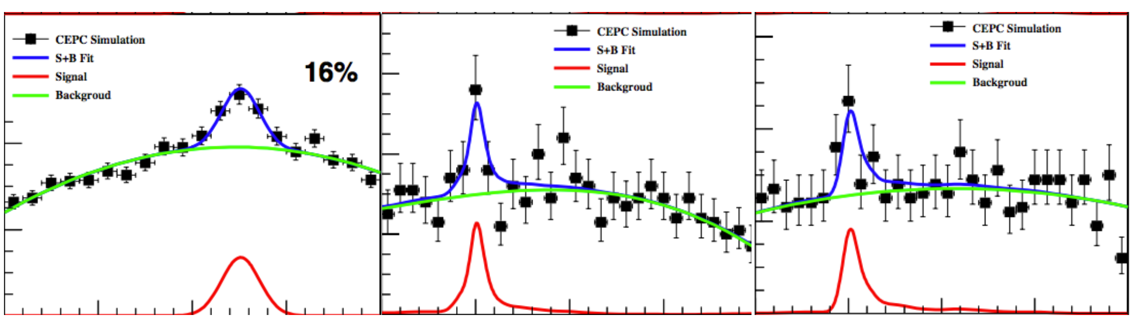
$\gamma\gamma$

	preCDR	Now
$\gamma\gamma$	9.0%	8.2%

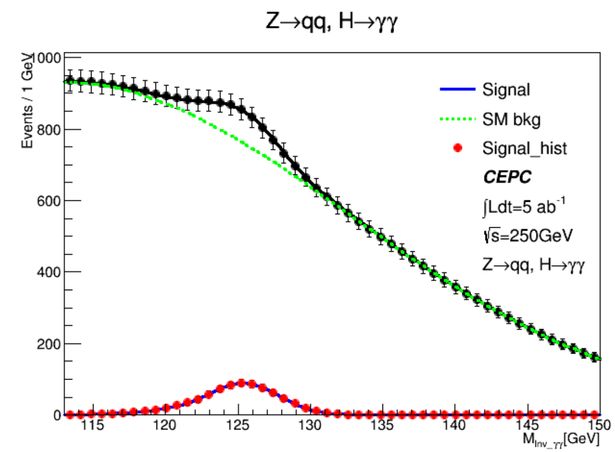
Z	H	Mine	CDR
ll		90	62+56
vv	γγ	328	339
qq		828	582

Signal events comparison

- 3 channels of $\gamma\gamma$ ($ll, vv, qq + \gamma\gamma$, lepton=$\mu, \tau$)
- Pre_CDR assume ECAL's resolution $\sim \frac{16\%}{\sqrt{E}} \oplus 1\,\%$, then to 9%.
- llrr, vvrr are fast simulated by Feng in 2015.
- qqrr updated by Yitian in 2017.4.



z->vv z->mm z-> $\tau\tau$

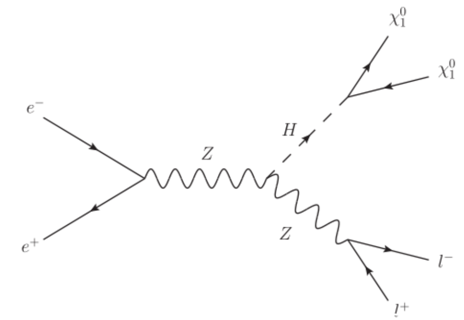


$H \rightarrow invisible$

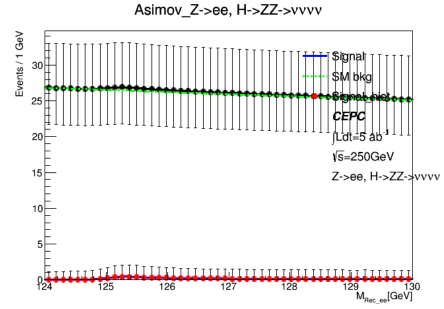
	preCDR	Now
$invisible$	0.28%	0.22%

- In pre_CDR, plan to search exotic decay
  - SUSY $H \rightarrow \chi_1 \chi_1$ assume σ =200 fb.

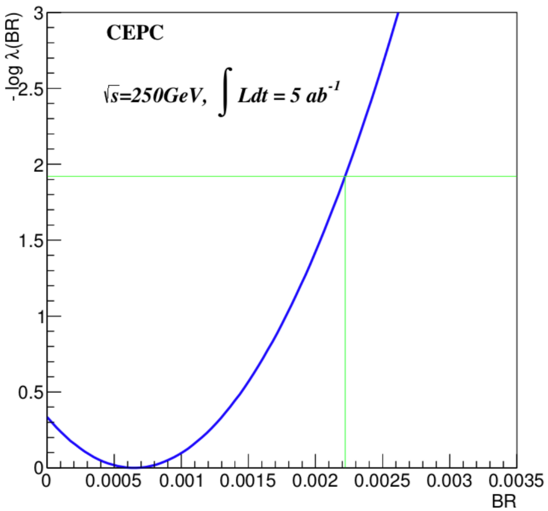
  In this case, extrapolated from ILC studies, precision is 0.14%



- Moxin studied H->ZZ->vvvv
  - 3 channels analyzed by Moxin, Z->ee/mumu/qq
  - Large irreducible bkg, seek upper limit
  - After BDT and combination, 0.22% (in pre_CDR 0.28%)

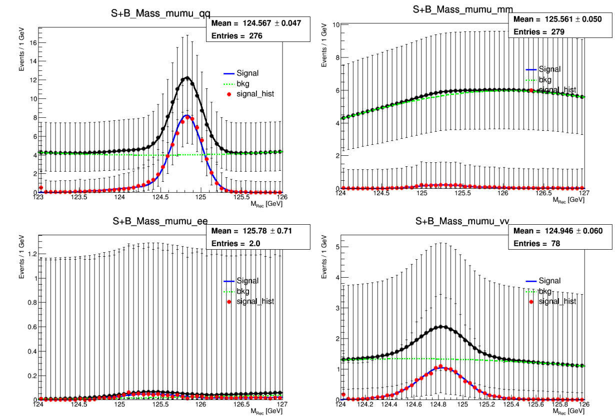


	e^+e^-h	$\mu^+\mu^-h$	$q\bar{q}h$
Br	$0.077 \pm 0.510\%$	$0.150\% \pm 0.290\%$	$0.069\% \pm 0.150\%$
95% CL upper limit	1.07%	0.70%	0.34%
Combination	Br $0.070\% \pm 0.079\%$, CL 95% upper limit 0.22%		

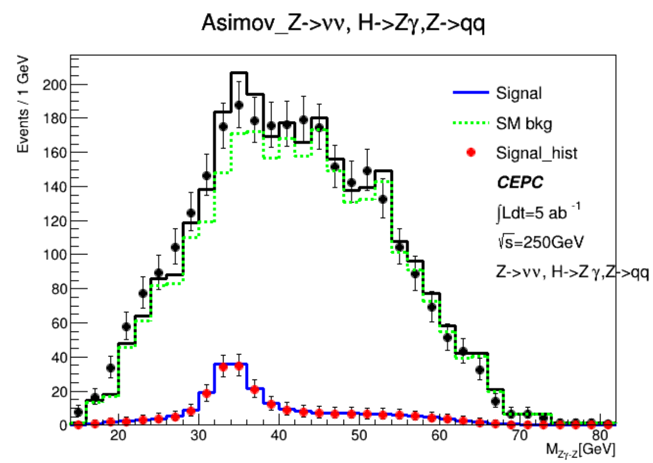


$\mu\mu, Z\gamma$ and others

	preCDR	Now
$\mu\mu$	17%	15%



- $\mu\mu$ process
  - Pre_CDR's 17% not reliable;
  - Zhen Wei separate Z->ee,mm, vv and qq
  - Small signal window; After cut 90 signals left.



- $Z \to qq,\ H \to Z\gamma \to qq\gamma$ studied;
  - Pre_CDR not conclude;
  - Take $\mathrm{m}_{Z\gamma-\mathrm{Z}}$ as observable;
  - 4σ significance; Precision about 21%.

- $e\mu, ee$ process studied.
  - Since low stats and no clear ratio, not taken into fit model.