CEPC Higgs Combination

Zhang Kaili[1], Wang Jin[2], Liu Zhen[3]

1.Institute of High Energy Physics
2.University of Sydney
3.University of Pittsburgh

The 4th CEPC Physics and Software Workshop

2018.06.27 Beijing

OUTLINE

- Why and How we do combination
- Results of $\sigma(ZH) * \mathrm{Br}$
- κ Framework
- A brief look on individual study
- 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；   WW fusion; width……
  - Extensibility
    - systematic uncertainties, theoretic assumptions……
- Currently, with MC sample (always $\mu = 1$)
  - Build Asimov(1007.1727) data from signal and bkg spectrum
  - To fit the estimated precisions of $\sigma * Br$, and κ.
    - Calculation like Significance / Upper limit also obtained;
  - Can do more with observed data in the future.
  - Results shown in Layout=CEPC_v1, ECM=250GeV, B=3.5T.

Individual Study
(No correlation)

↓

Combination
(With correlation)

↓

Implications like
κ, EFT … …
For physics models.

Fit techniques

- Input: Various. binned/unbinned, 1d/2d spectrum used.
- Parameter of interest: $\sigma * Br$, Higgs coupling κ
  - $\mathrm{N}_{total} = \mu * S + B,$ $\mu = \sigma * Br = \frac{\kappa\kappa}{\Gamma}$ and share the same relative uncertainty;
- Nuisance parameter: Represents systematic uncertainties
  - $\sigma(ZH)$: 0.5%; $\sigma(Lumi)$: 0.1%; more NPs can be introduced in the future.
  - currently results are all determined by statistical uncertainty.
- PDF: To describe the shape of the spectrum.
  - signal: Double sided Crystal ball; bkg: 2rd-order poly exponential.
  - RooHistPdf/RooKeysPdf used for some channels;
- Algorithm: Likelihood Scan
  - Asymmetric result, from Minuit2; $\pm 1\sigma$ deviation from profile likelihood

Fit techniques

- For each channel
  - Input observables from MC sample.
  - Build combined S+B Pdf   Tot=N_{bb}*Pdf+N_{cc}*Pdf_{cc}+……+N_{bkg}*Pdf_{bkg}
  - For event 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, $N_{bb}= N_{bb\_SM} * \kappa_z^2(\kappa_w^2) * \kappa_b^2/\Gamma_H$
    - Channel share the same μs. $Z \to ee, \mu\mu, qq, \nu\nu$, 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 obtain the 1σ deviation

Channels Table(2018.6)

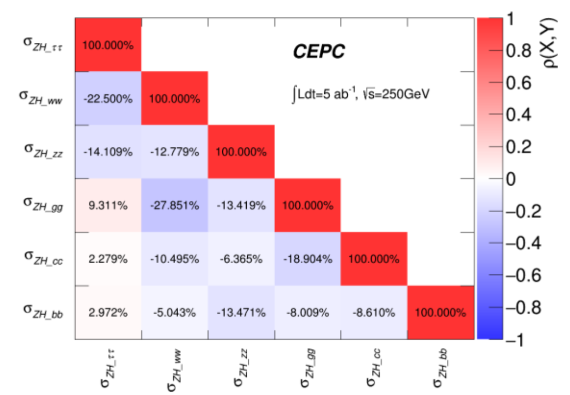
All channels scaled to 5ab-1

Signal Z	Signal H	Precision	Signal Z	Signal H	Precision	Signal Z	Signal H	Precision
H->qq			H->WW			H→γγ, Zγ		
ee	bb	1.30%	ee	lνlν	9.20%	μμ+ττ	γγ	41.00%
	cc	11.77%		eνqq	4.60%	νν		13.70%
	gg	6.17%		μνqq	3.90%	qq		10.30%
μμ	bb	1.00%	μμ	lνlν	7.30%	νν	Zγ(qqγ)	21.20%
	cc	9.41%		eνqq	4.00%	ννH(WW fusion)		
	gg	4.89%		μνqq	4.00%	νν	bb	3.10%
qq	bb	0.48%	νν	qqqq	2.00%	H→μμ		
	cc	11.92%		eνqq	4.70%	qq	μμ	15.90%
	gg	3.94%		μνqq	4.20%	ee		
νν	bb	0.40%		lνlν	11.30%	μμ		
	cc	3.90%	qq	qqqq	1.80%	νν		
	gg	1.55%	H->ZZ			H→ττ		
H->Invisible		Br, Upper	νν	μμqq	7.90%	ee	ττ	2.80%
qq	ZZ(νννν)	0.80%	νν	eeqq	35.20%	μμ		2.80%
ee		0.60%	μμ	ννqq	7.30%	qq		1.00%
μμ		0.60%	ZH bkg contribution		19.40%	νν		3.10%

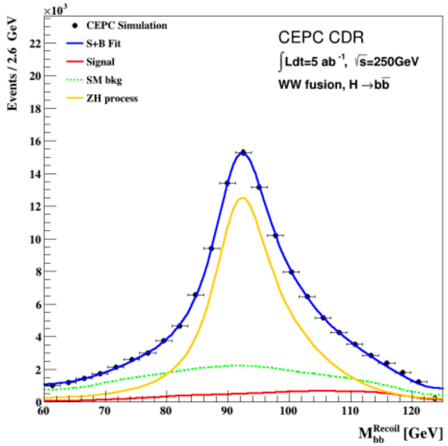
Treatment for ZH bkg

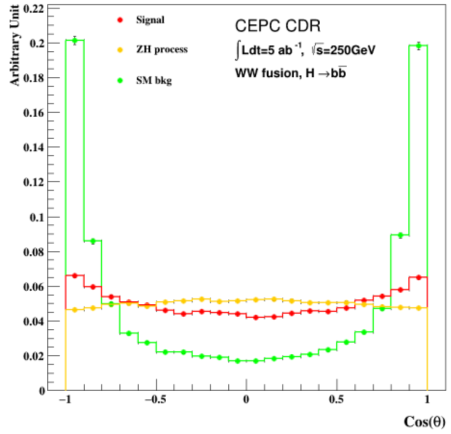
- In individual analysis, other ZH processes are tagged as bkg;
  - Signal in one channel can be bkg for another channel.
  - Should taken into account in combination.
    - $\mathrm{Z} \to \mu\mu, \mathrm{H} \to \tau\tau$, the main bkg is $\mathrm{H} \to \mathrm{WW}$.
      - These WW events should be considered in μ_{WW}.
    - Combined fit for H->bb/cc/gg/ww/zz hadronic decay,   Fully correlated.

- Currently, to avoid the overlap,
  - Remove the bb/cc/gg part in Z->qq/vv, H->WW->qqqq;
  - Remove the WW/ZZ part in Z->qq/vv, H->bb/cc/gg.
  - Still need further discussion



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





- 2d fit $\mathrm{M}_{\mathrm{jj}}^{\mathrm{reco}}$ & $\mathrm{Cos}\ \theta_{\mathrm{jj}}$
- Correlated with ZH process;
  - Fix ZH process, Initial error is 2.7%.
  - But must consider the uncertainty from ZH process.
- Use the likelihood from $Z \rightarrow ee/\mu\mu\ /qq, H \rightarrow bb$ to constrain
  - Already have the form of μ_{ZH}, no assumption made;
  - $\nu\nu H \rightarrow bb$ and $ZH \rightarrow bb$ share the anti-correlation -46%. (-34% in ILC(1708.08912))
- Simultaneous Fit 3.1% ; consistent with individual study 3.1%.
  - Corresponding to this, $ZH \rightarrow bb$ precision 0.33%.
  - $\sigma(\nu\nu H)$ precision 3.16%.

Correlation: Higgs width

- In Pre_CDR, width determined by

$$\Gamma_H = \frac{\Gamma_{H\to ZZ}}{Br(H\to ZZ)} \propto \frac{\sigma(ZH)}{Br(H\to ZZ)} \text{ and } \Gamma_H = \frac{\Gamma_{H\to bb}}{Br(H\to bb)} \propto \frac{\sigma(\nu\nu H\to \nu\nu bb)}{Br(H\to bb)Br(H\to WW)}$$

- If two independent: 2.83% (consistent with pre_CDR, which gives 2.8%)

- But width correlated with all channels

  - Like correlation like $\nu\nu H \to \nu\nu bb$ and $\mathrm{Z}H \to bb$ -46% not included -> would worse the result

- Combined fit in 10κ framework:

$$\Delta(\Gamma_H) = 3.2\%$$

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

($5ab^{-1}$)	Pre_CDR	Current 2018.6	ILC 250	Fcc-ee
$\sigma(ZH)$	0.51%	**0.50%**	1.2%	0.40%
$\sigma(ZH) * \mathrm{Br(H \to bb)}$	0.28%	**0.28%**	0.6%	0.2%
$\sigma(ZH) * \mathrm{Br(H \to cc)}$	2.2%	**3.3%**	3.9%	1.2%
$\sigma(ZH) * \mathrm{Br(H \to gg)}$	1.6%	**1.3%**	3.3%	1.4%
$\sigma(ZH) * \mathrm{Br(H \to WW)}$	1.5%	**1.1%**	3.0%	0.9%
$\sigma(ZH) * \mathrm{Br(H \to ZZ)}$	4.3%	**5.1%**	8.4%	3.1%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	**0.8%**	2.0%	0.7%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	**8.2%**	16%	3.0%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	**16%**	46.6%	13%
$\sigma(\mathrm{vv}H) * \mathrm{Br(H \to bb)}$	2.8%	**3.1%**	11%	2.4%
$\mathrm{Br_{upper}(H \to inv.)}$	0.28%	**0.42%**	0.4%	0.50%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	\	**4σ(21%)**		

ILC: 1310.0763
FCC-ee: 1308.6176

Difference from Pre_CDR

($5ab^{-1}$)	Pre_CDR	Combined
$\sigma(ZH)$	0.51%	**0.50%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	0.28%	**0.28%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	2.2%	**3.3%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	1.6%	**1.3%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	1.5%	**1.1%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	4.3%	**5.1%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	**0.8%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	**8.2%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	**16%**
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	2.8%	**3.1%**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	0.28%	**0.42%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	\	**4σ(21%)**

- CrossSection: minor update.
- bb,cc,gg: due to flavor tagging algorithm, The template gives b/c likeness, updated algorithm has less cc candidate events left.
- WW: more subchannels studied and ZH bkg contribution.
- ZZ: the extrapolation in Pre_CDR from FCC-ee too optimistic.
- $\tau\tau$: τ finding algorithm updated.
- $\gamma\gamma$: different estimation from full/fast simulation.
- $\nu\nu H$: consider the correlation
- $H \to invisible$: Pre_CDR studied an exotic decay $H \to \chi_1\chi_1$ and assuming 200fb^{-1}, gives 0.28%.
- Now we study the upper limit of $H \to ZZ \to \nu\nu\nu\nu$.

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 $\sigma(ZH) = 0.5\%$ 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

In different interpretation,
Higgs width can be independent or resolved by branch ratio.

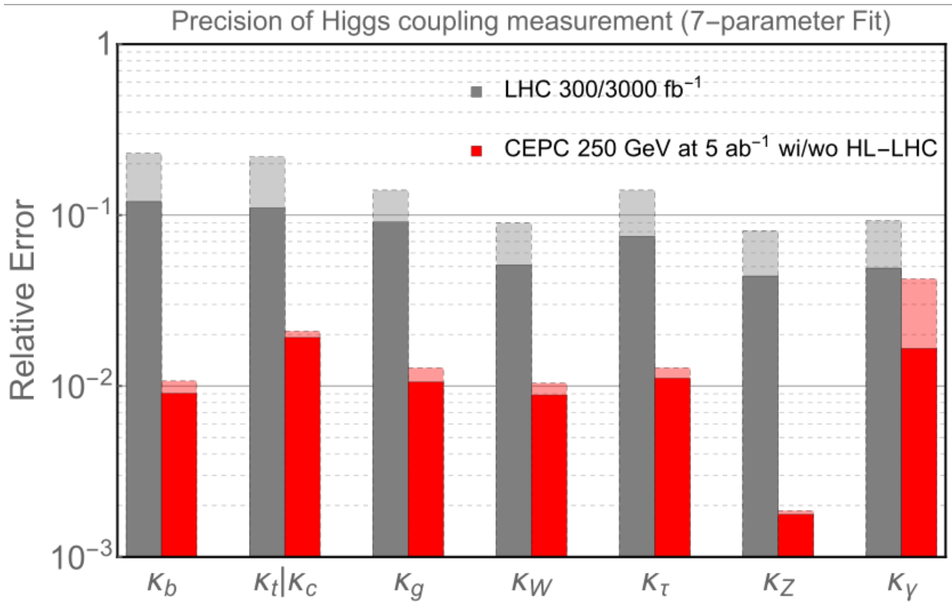
	10κ	Pre_CDR	**7κ**	Pre_CDR
κ_b	**1.6%**	1.3%	**1.0%**	1.2%
κ_c	**2.3%**	1.7%	**2.1%**	1.6%
κ_g	**1.6%**	1.5%	**1.2%**	1.5%
κ_γ	**4.4%**	4.7%	**4.3%**	4.7%
κ_τ	**1.6%**	1.4%	**1.1%**	1.3%
κ_Z	**0.21%**	0.26%	**0.17%**	0.16%
κ_W	**1.4%**	1.2%	**1.0%**	1.2%
κ_μ	**8.1%**	8.6%		
Br_{inv}	**0.42%**	0.28%		
Γ_H	**3.3%**	2.8%		

From 10κ to 7κ, we assume
- No exotic decay Γ_{BSM}
- Drop Br_{inv}
- κ_μ=κ_τ

Integration to HL-LHC

The improvement of κ_γ from ${}^{Br_{ZZ}}/_{Br_{\gamma\gamma}} = 4\%$

	10-parameter fit		7-parameter fit	
	CEPC	+HL-LHC	CEPC	+HL-LHC
Γ_h	3.2	2.5	–	–
κ_b	1.6	1.2	1.0	0.9
κ_c	2.3	2.0	2.1	1.9
κ_g	1.6	1.2	1.2	1.0
κ_W	1.4	1.1	1.0	0.9
κ_τ	1.6	1.2	1.1	1.0
κ_Z	0.21	0.21	0.17	0.16
κ_γ	4.4	1.7	4.3	1.7
κ_μ	8.1	4.9	–	–
$\mathrm{BR_{inv}}$	0.31	0.31	–	–

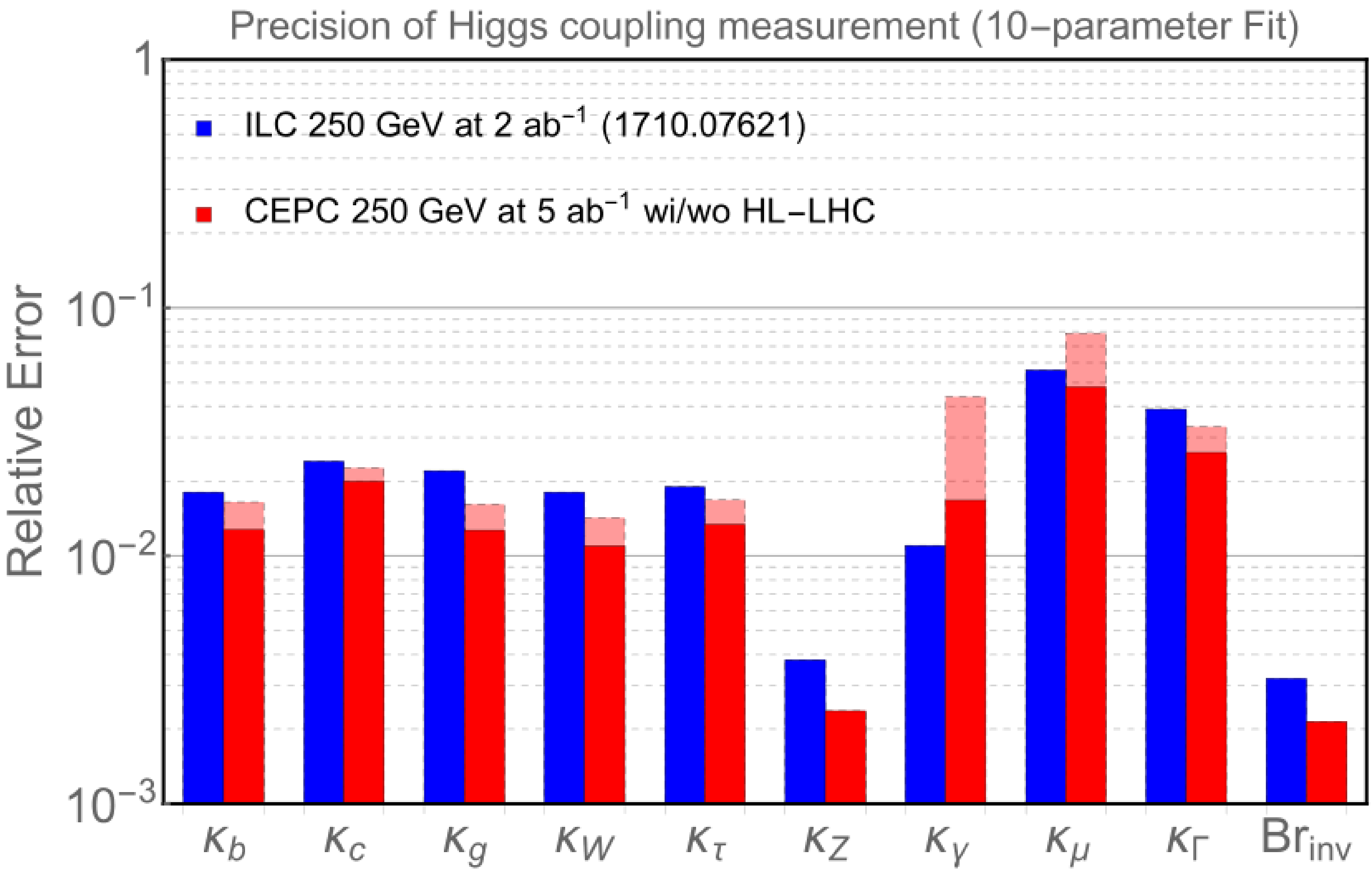


ATL-PHYS-PUB-2014-016

*: here Br_{inv} for BSM.

Compared to ILC(1710.07621)

ILC used more aggressive κ_γ , by ratio ${}^{Br_{ZZ}}/_{Br_{\gamma\gamma}} = 2\%$



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.	−35. / −32.	−52. / −51.	−59. / −56.	−44. / −43.	66. / 63.	−9.6 / −3.7
κ_c	−35. / −32.	100.	2.5 / −3.4	17. / 16.	2.9 / 2.8	−38. / −36.	2.4 / 0.92
κ_g	−52. / −51.	2.5 / −3.4	100.	6.7 / 1.6	6.8 / 4.3	−39. / −28.	2.2 / 0.55
κ_W	−59. / −56.	17. / 16.	6.7 / 1.6	100.	−22. / −21.	−55. / −56.	2.8 / 1.1
κ_τ	−44. / −43.	2.9 / 2.8	6.8 / 4.3	−22. / −21.	100.	1.8 / 1.3	−0.85 / −0.32
κ_Z	66. / 63.	−38. / −36.	−39. / −28.	−55. / −56.	1.8 / 1.3	100.	−4.7 / −7.5
κ_γ	−9.6 / −3.7	2.4 / 0.92	2.2 / 0.55	2.8 / 1.1	−0.85 / −0.32	−4.7 / −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.	−4.4 / −4.2	−7.6 / −6.1	−19. / −19.	4.2 / 4.2	78. / 77.	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−92. / −91.
κ_c	−4.4 / −4.2	100.	−19. / −18.	−9.3 / −8.6	2.3 / 2.2	−6.1 / −5.7	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	2.7 / 2.5
κ_g	−7.6 / −6.1	−19. / −18.	100.	−25. / −19.	9.2 / 7.4	3.2 / 8.7	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−5.8 / −13.
κ_W	−19. / −19.	−9.3 / −8.6	−25. / −19.	100.	−22. / −21.	−6.9 / −7.8	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	5.7 / 5.5
κ_τ	4.2 / 4.2	2.3 / 2.2	9.2 / 7.4	−22. / −21.	100.	25. / 24.	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	−31. / −31.
κ_Z	78. / 77.	−6.1 / −5.7	3.2 / 8.7	−6.9 / −7.8	25. / 24.	100.	2.8 / −4.7	1.5 / −0.61	<0.1 / <0.1	−83. / −83.
κ_γ	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	2.8 / −4.7	100.	<0.1 / <0.1	<0.1 / <0.1	−3.4 / −1.3
κ_μ	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	<0.1 / <0.1	1.5 / −0.61	<0.1 / <0.1	100.	<0.1 / <0.1	−1.8 / −1.1
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	−92. / −91.	2.7 / 2.5	−5.8 / −13.	5.7 / 5.5	−31. / −31.	−83. / −83.	−3.4 / −1.3	−1.8 / −1.1	<0.1 / <0.1	100.

Summary

	Current
$\sigma(ZH)$	0.50%
$\sigma(ZH) * Br(H \to bb)$	0.28%
$\sigma(ZH) * Br(H \to cc)$	3.3%
$\sigma(ZH) * Br(H \to gg)$	1.3%
$\sigma(ZH) * Br(\mathrm{H} \to WW)$	1.1%
$\sigma(ZH) * Br(H \to ZZ)$	5.1%
$\sigma(ZH) * Br(H \to \tau\tau)$	0.8%
$\sigma(ZH) * Br(H \to \gamma\gamma)$	8.2%
$\sigma(ZH) * Br(H \to \mu\mu)$	16%
$\sigma(\mathrm{vvH}) * Br(H \to \mathrm{bb})$	3.1%
$Br_{\mathrm{upper}}(H \to inv.)$	0.42%
$\sigma(ZH) * Br(H \to Z\gamma)$	4σ(21%)

	10κ	**7κ**
κ_b	1.6%	1.0%
κ_c	2.3%	2.1%
κ_g	1.6%	1.2%
κ_γ	4.4%	4.3%
κ_τ	1.6%	1.1%
κ_Z	0.21%	0.17%
κ_W	1.4%	1.0%
κ_μ	8.1%	
Br_{inv}	0.42%	
Γ_H	3.2%	

	10-parameter fit		7-parameter fit	
	CEPC	+HL-LHC	CEPC	+HL-LHC
Γ_h	3.2	2.5	–	–
κ_b	1.6	1.2	1.0	0.9
κ_c	2.3	2.0	2.1	1.9
κ_g	1.6	1.2	1.2	1.0
κ_W	1.4	1.1	1.0	0.9
κ_τ	1.6	1.2	1.1	1.0
κ_Z	0.21	0.21	0.17	0.16
κ_γ	4.4	1.7	4.3	1.7
κ_μ	8.1	4.9	–	–
$\mathrm{BR}_{\mathrm{inv}}$	0.31	0.31	–	–

- Updated fit results of CEPC Higgs are shown.
- Correlations are taken in consideration in the simultaneous framework.
- To be used in the CDR and white paper.

Individual analysis

A reminder for following discussion

A (not) quick introduction for statistics: https://indico.ihep.ac.cn/event/7826/session/0/contribution/4/material/slides/0.pdf and Cowan's Talk

bb/cc/gg

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

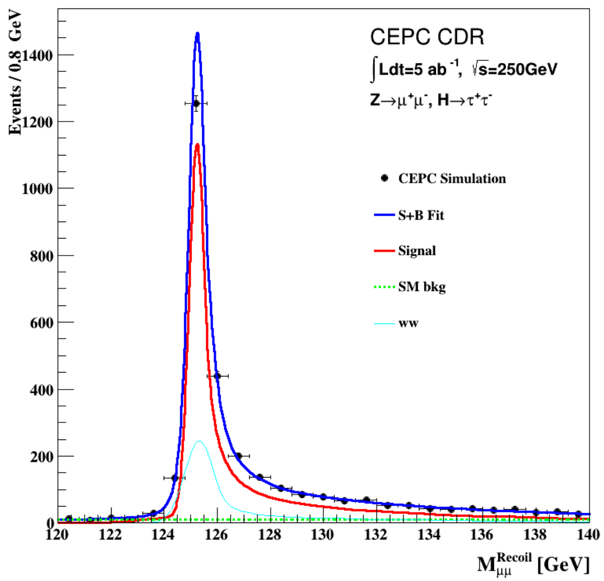
- Template fit: Flavor tagging algorithm
  - $Z \to ee\ \mu\mu\ qq\ vv, \mathrm{H} \to bb/cc/gg$ are studied.
  - 2D fit, with dijets' b/c likeness; mass info not used;
  - 7 parts, Tot=bb+cc+gg+ww+zz+tt+bkg_{sm}.
  - Build individual pdf by MC, then fit to determine fraction.
  - the shape of bkg is fixed.
    - Which means we have a wonderful understanding with bkg,
    - may be more suitable for CEPC.
  - ToyMC test to get precision
  - Now use 3d fit in llH;
  - Systematic uncertainties ongoing;

Scan	μ_bb	μ_cc	μ_gg
eeH	1.3%	11.8%	6.2%
mmH	1.0%	9.4%	4.9%
qqH	0.5%	11.9%	3.94%
vvH	0.4%	3.9%	1.6%
Combined	0.28%	3.3%	1.3%

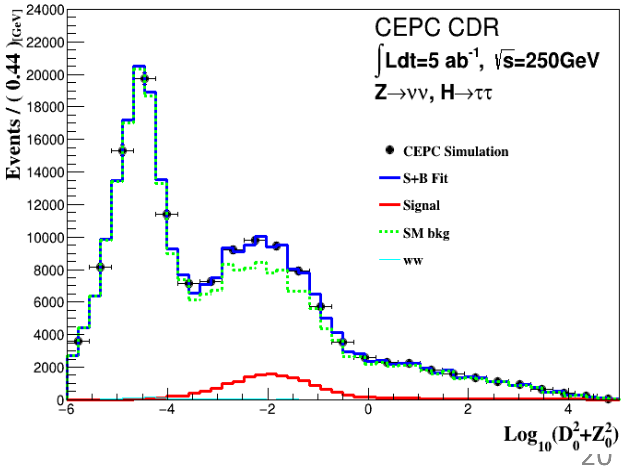
$\tau\tau$

	preCDR	Now
$\tau\tau$	1.2%	**0.81%**

- 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
  - use $\log_{10}(D_0^2 + Z_0^2)$ fit to separate signal
    - Impact parameter, Distance from beam spot



	BR (H→ $\tau\tau$)	$\delta(\sigma\times$ BR $)/(\sigma\times$ BR)
$\mu\mu$H	6.40	2.68%
eeH(extrapolated)	6.37	2.72%
$\nu\nu$H	6.26	4.38%
qqH	6.23	0.93%
combined	6.28	0.81%



WW

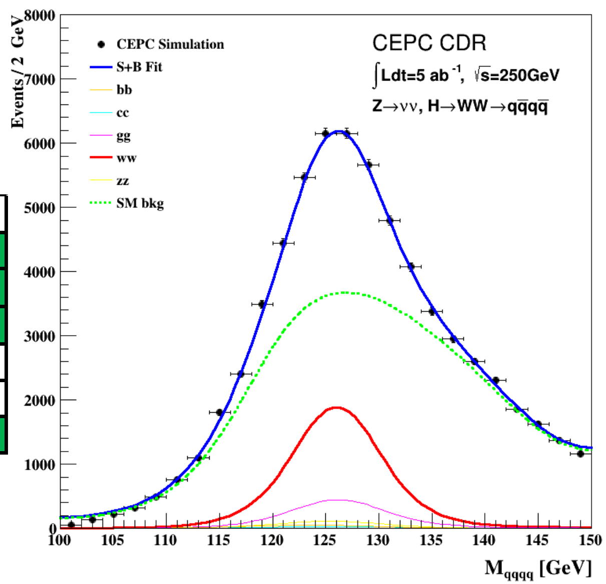
	preCDR	Now
WW	1.5%	1.1%

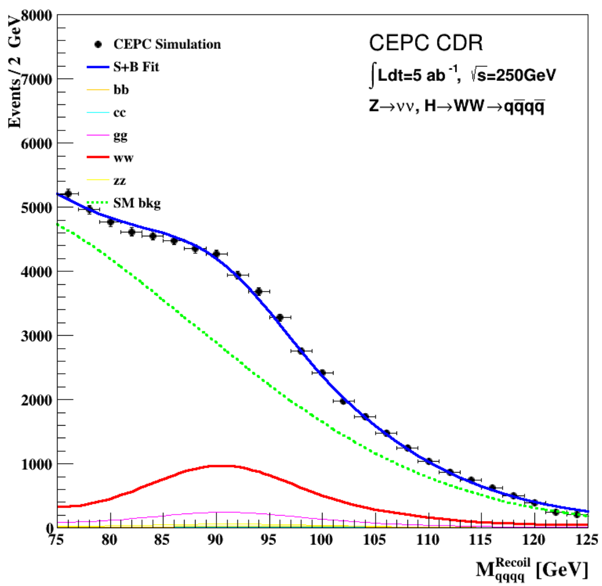
Signal: Z	Signal: H	Precision
H->WW		
ee	lvlv	9.20%
	evqq	4.60%
	μvqq	3.90%
μμ	lvlv	7.30%
	evqq	4.00%
	μvqq	4.00%
vv	qqqq	2.00%
	evqq	4.70%
	μvqq	4.20%
	lvlv	11.30%
qq	qqqq	1.80%

- Currently have 17 channels of WW

Green: studied

	Z	ee	μμ	vv	qq
WW	ev+ev				
	μv+μv				
	ev+μv				
	ev+qq				
	μv+qq				
	qq+qq				





ZZ

	preCDR	Now
ZZ	4.3%	5.1%

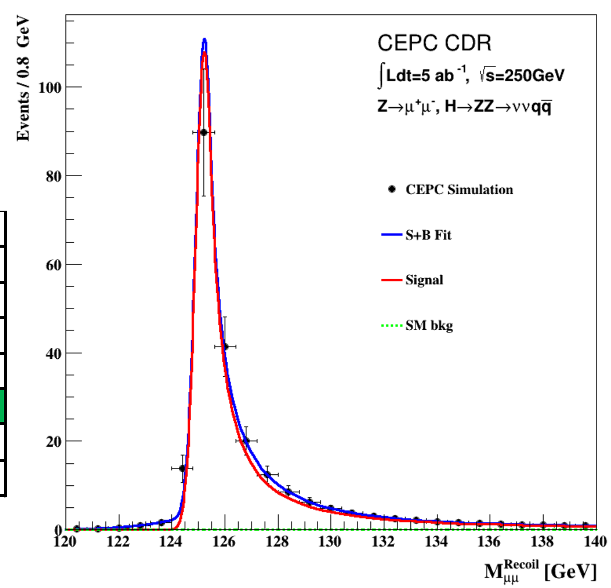
Channel	Precision	Comment
$\sigma(Z(\nu\bar{\nu})H + \nu\bar{\nu}H) \times \mathrm{BR}(H \to ZZ)$	6.9%	CEPC Fast Simulation
$\mathrm{BR}(H \to ZZ^*)$	4.3%	Extrapolation from FCC-ee [36]

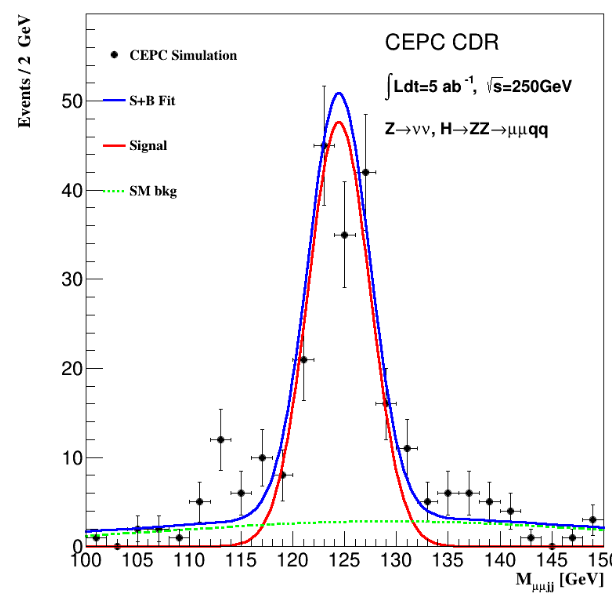
- Pre_CDR's result from extrapolating the FCC-ee.

Signal		Precision
Z	H	
H->ZZ		
νν	μμqq	7.90%
νν	eeqq	35.20%
μμ	ννqq	7.30%
ZH bkg contribution		19.40%

Green: studied
Yellow: with problem

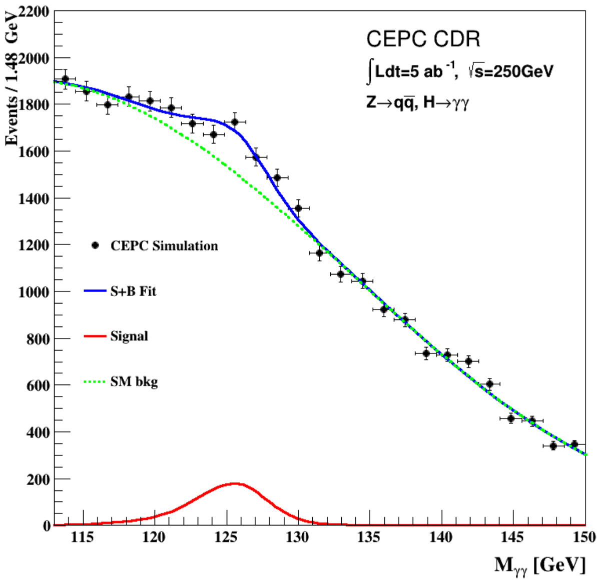
	Z	ee	μμ	νν	qq
ZZ	ee+qq				
	μμ+qq				
	νν+qq				
	ll+ll				
(Invi)	νν+νν				
	qq+qq				
	ll+νν				



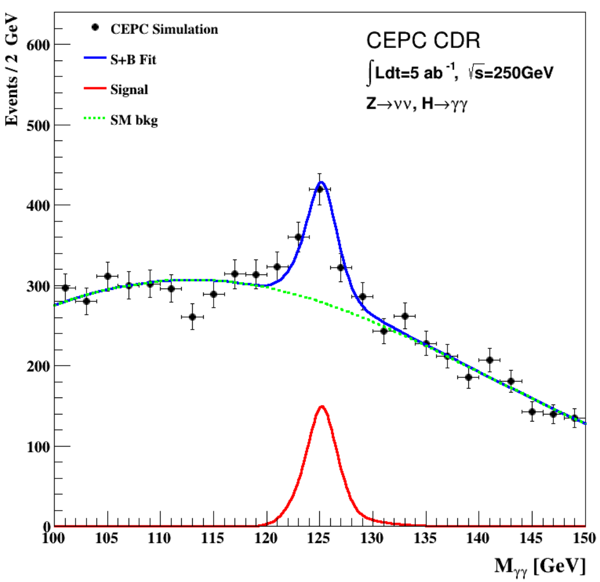


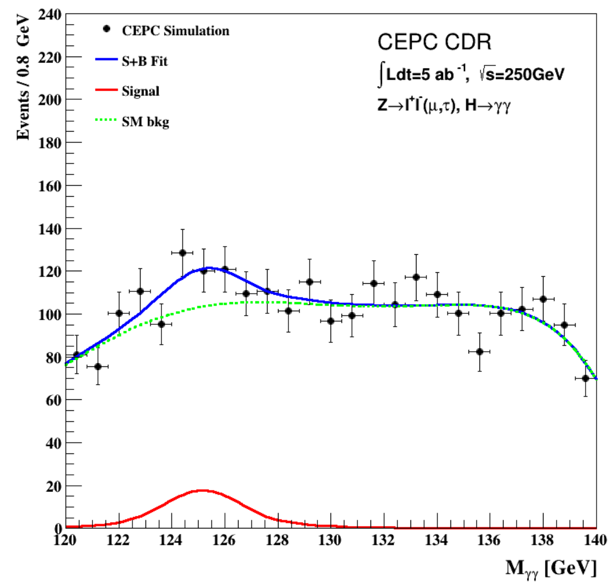
$\gamma\gamma$

	preCDR	Now
$\gamma\gamma$	9.0%	8.1%



Signal		Precision
Z	H	
H→γγ		
μμ+ττ	γγ	24.8%
νν		11.7%
qq		12.8%

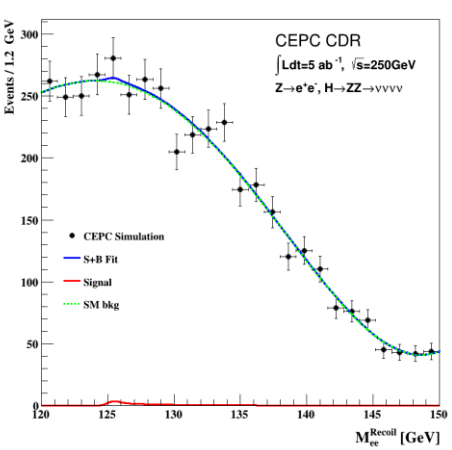


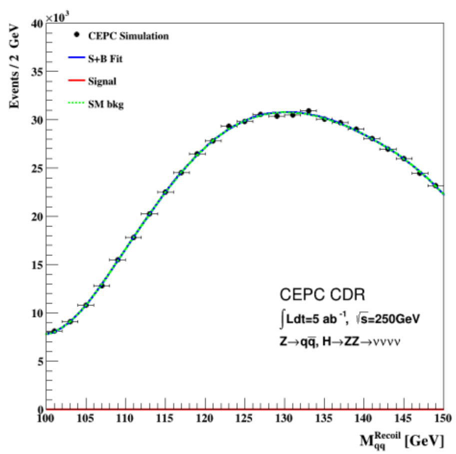


$H \rightarrow invisible$

	preCDR	Now
invisible	0.28%	0.42%

- Moxin studied H->ZZ->vvvv
  - Large irreducible bkg, use BDT and seek upper limit.
  - Huge fluctuation, use Asimov Data to get correct fit result.
  - precision 148%, upper limit for Br: 0.42%
  - Upper limit for BSM H->invisible: 0.31%

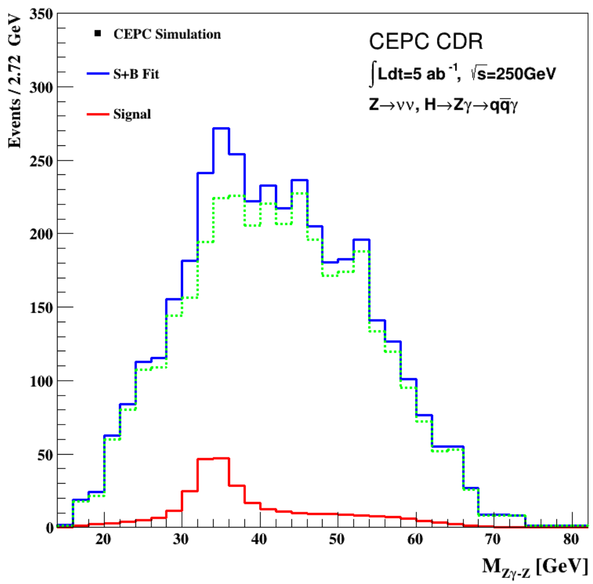




	Precision	significance	Br Upper limit
Z->ee	350%		0.84%
Z->mm	242%		0.62%
Z->qq	226%		0.59%
Combined	148%	0.68σ	0.42%

$Z\gamma$

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

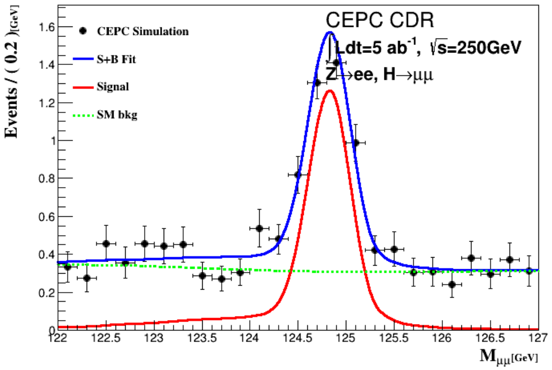


- $e\mu, ee$ process studied.
  - Since low stats and no clear ratio, not taken into fit model.

H→$\mu\mu$

- Z->ee

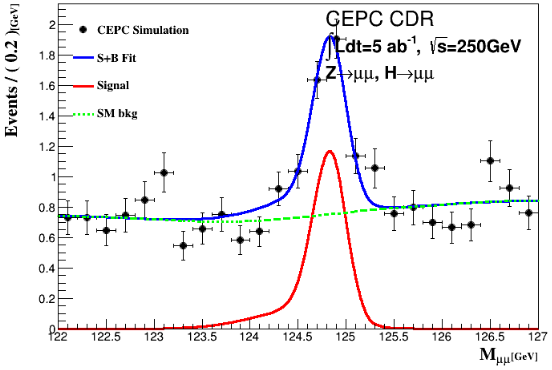
bkg shape all after smoothing. (10~100x bkg events used)



Cutflow	signal	ZZ	WW	ZZorWW	SingleZ	2f
Init	4.7	18	0	9	22672	8
$120 < M_{\mu^+\mu^-} < 130$	4.3	0	0	0	747	0
$89 < M_{reco}^{\mu^+\mu^-} < 94$	3.0	0	0	0	56	0
$138 < E_{\mu^+\mu^-} < 140$	2.2	0	0	0	8	0
efficiency	46.81%					

Bkg: Sz(l)e.l0mu;

- Z->mm combination to minimize $\delta = (\frac{pair1.M}{\Delta Z})^2 + (\frac{pair2.M}{\Delta H})^2$
  - $\Delta Z = 1.5, \Delta H = 0.75$

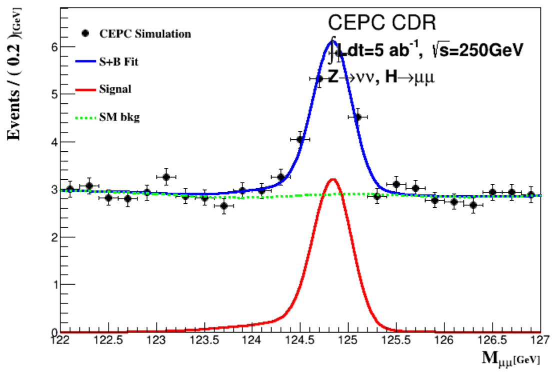


Category	signal	ZZ	WW(SW)	ZZorWW	SingleZ	2f
Preselection	6.6	17631.0	0	0	0	0.0
$120<E_{\mu^+\mu^-}<130$	6.0	1685.2	0	0	0	0.0
$90.6< M_{recoil_\mu} <93.4$	3.9	128.8	0	0	0	0.0
$90.2<M_{\mu^+\mu^-}$(Z)<92.8	3.2	58.1	0	0	0	0.0
$cos_{\mu^+\mu^-}$(H)<-0.603	3.2	50.0	0	0	0	0.0
$cos_{\mu^+\mu^-}$(Z)<-0.364	3.2	47.0	0	0	0	0.0
$138.0<E_{\mu^+\mu^-}$(H)<139.8	3.0	15.5	0	0	0	0.0
$P_{T_{\mu^+\mu^-}}$(H)<62.5	3.0	14.7	0	0	0	0.0
efficiency	45.5%					

Bkg: ZZ(l).4mu;

ZH→$\nu\nu\mu\mu, qq\mu\mu$

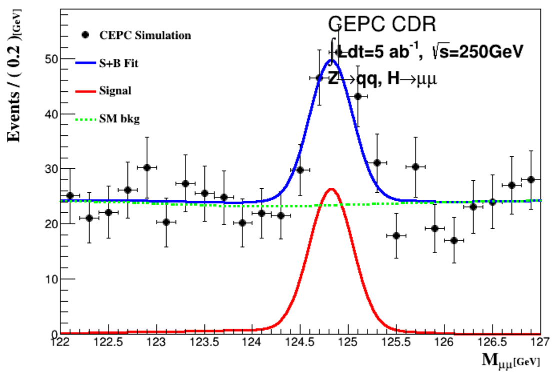
- Z->vv
  - 38%



Cutflow	signal	ZZ	WW	ZZorWW	SingleZ	2f
Init	41.7	34901	121952	489686	25619	1635887
$120 < M_{\mu^+\mu^-} < 130$	38.4	382	16677	56029	315	49490
MET¿8.5	37.9	291	16264	53740	305	8600
$89 < M^{\mu+\mu-}_{reco} < 94$	28.1	96	834	2034	79	184
$\cos\theta_{\mu_+} > 0, \cos\theta_{\mu_-} - 0$	9.1	22	11	86	17	9
efficiency	21.82%					

Cut for Z->qq H->$\mu\mu$ may too tight; should reconsider.

- Z->qq
  - 17%



Cutflow	signal	ZZ	WW	ZZorWW	SingleZ	2f
Init	156.3	390775	183751	463361	101164	63217
$120 < M_{\mu^+\mu^-} < 130$	141.6	3786	181	227	244	100
$M_{j1} > 4.2, M_{j2} > 2.8$	133.0	3216	111	0	9	60
$M_{jj} > 76.0$	127.5	2917	2	0	8	59
$89 < M^{\mu+\mu-}_{reco} < 94$	86.1	1106	0	0	0	0
efficiency	55.08%					

- Combined:15.9%
  - Considering the scheduled time, CEPC could be the first detector to see this process.

Main bkg: ZZ(sl)mu.down, ZZ(sl)mu.up