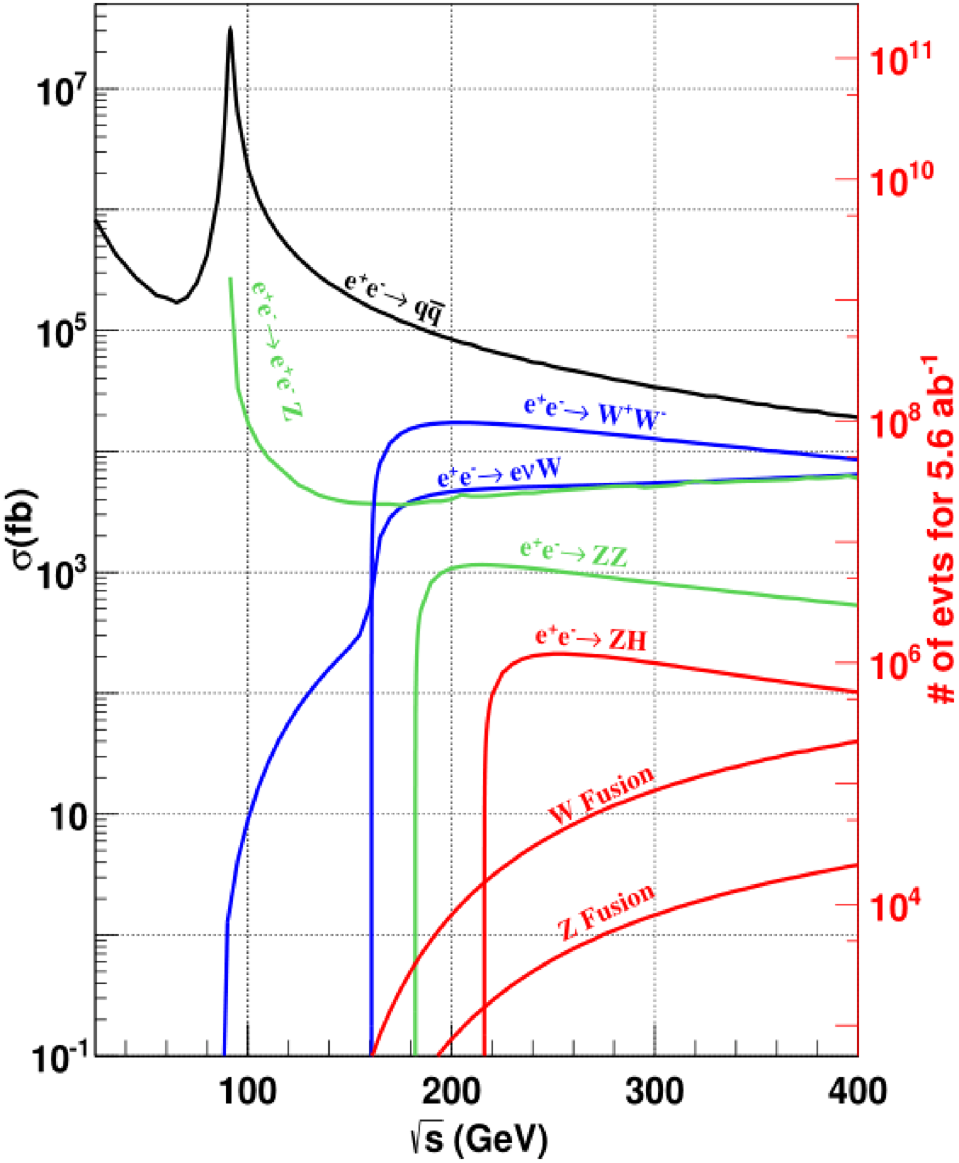
CEPC Higgs @ 240 and 360GeV

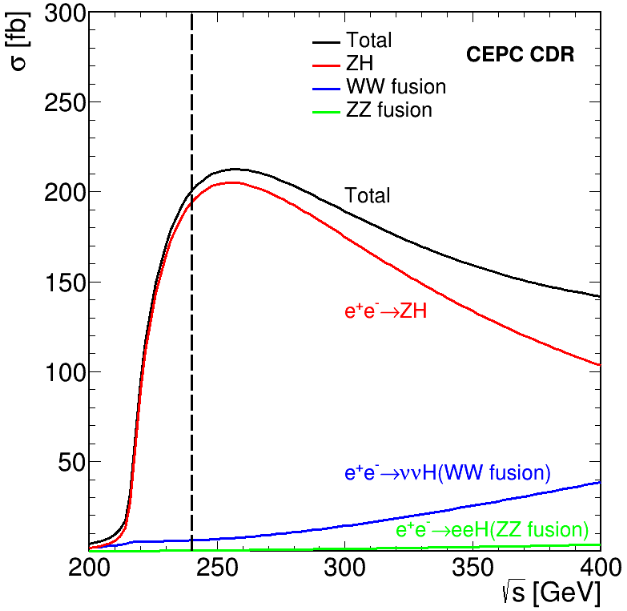
K. Zhang, Z. Liu, Y. Fang, G. Li

CEPC Day

2019.09.27

Higgs Physics @ CEPC





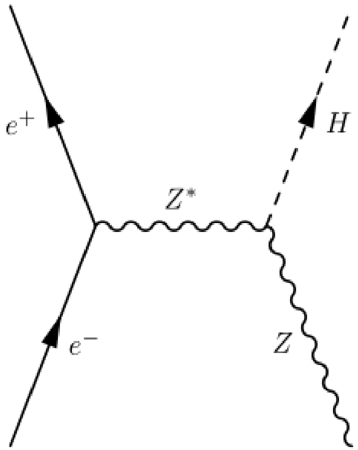
CEPC CDR: arxiv:1811.10545

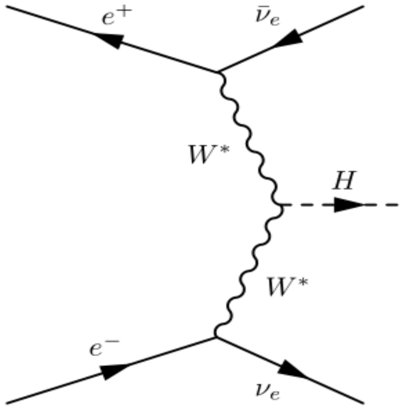
White Paper: arxiv:1810.09037

Combination Report in Oxford;

1M Higgs in 240 GeV, 5.6ab^{-1}

Process	Cross section	Events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	196.2	1.10×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^- \to e^+e^- H$	0.28	1.57×10^3
Total	203.7	1.14×10^6



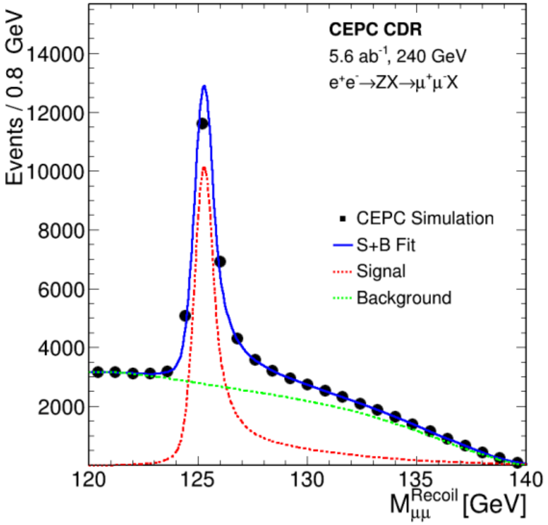


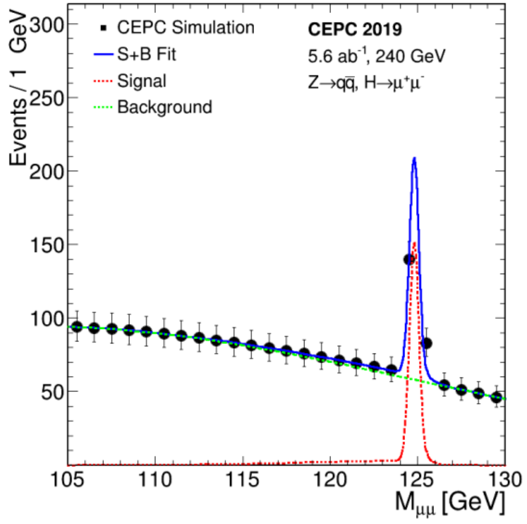
Existing results:240GeV, 5.6iab

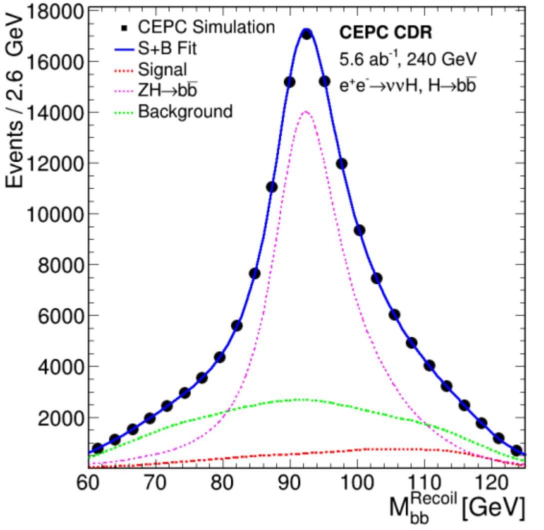
Publications:

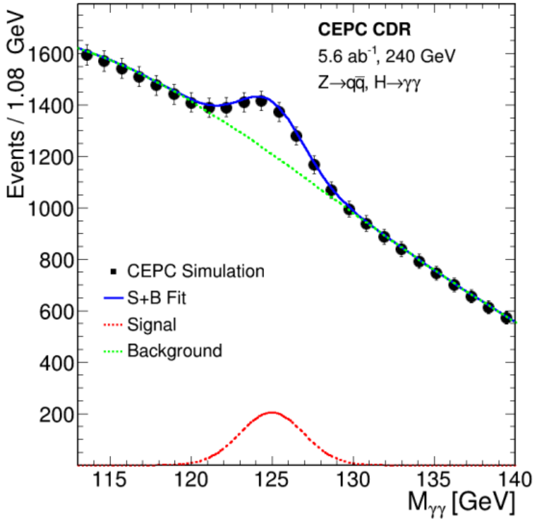
- $\sigma(ZH)$:1601.05352;
- bb/cc/gg: 1905.12903;
- $\tau\tau$:1903.12327……

(240GeV,5.6ab^{-1})	CDR	2019.09
$\sigma(ZH)$	**0.50%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mathrm{bb})$	**0.27%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mathrm{cc})$	**3.3%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mathrm{gg})$	**1.3%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mathrm{WW})$	**1.0%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mathrm{ZZ})$	**5.1%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\tau\tau)$	**0.8%**	
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\gamma\gamma)$	**6.8%**	**5.4%**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to\mu\mu)$	**17%**	**12%**
$\sigma(\mathrm{vv}H)*\mathrm{Br}(\mathrm{H}\to\mathrm{bb})$	**3.0%**	
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H}\to\mathrm{inv.})$	**0.41%**	**0.2%**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to Z\gamma)$	**16%**	
Width	**2.8%**	







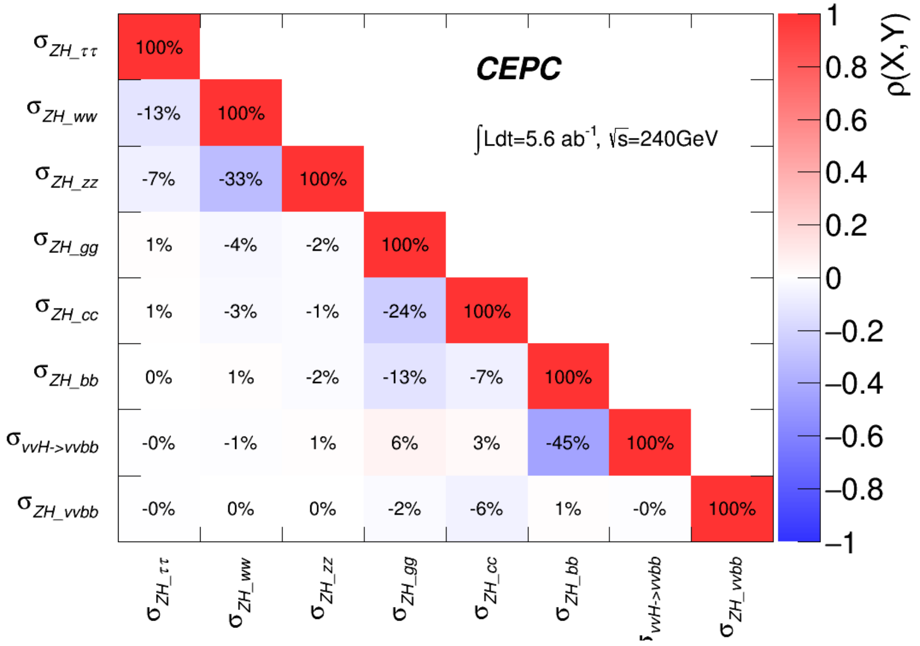


Several channels improved after CDR.

Mostly from better analysis strategy.

Combination

- All Higgs observables as input
  - Shape information
    - Mass spectrum, BDT response, Flavor tagging likeliness
  - Multi-dimensional fit performed if no significant correlation
  - Fixed PDF, Asimov Data, μ float
- Simultaneous fit to all sub-channels
  - Correlation taken into account
    - Such as Higgs yields cross talks, anti-correlation, …
- Precision of Higgs width ~ 2.8%
  - Dominated by $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \rightarrow \mathrm{bb})$ and $\mathrm{Br}(\mathrm{H} \rightarrow \mathrm{ZZ})$



Esp. for vvH & ZH, H->bb

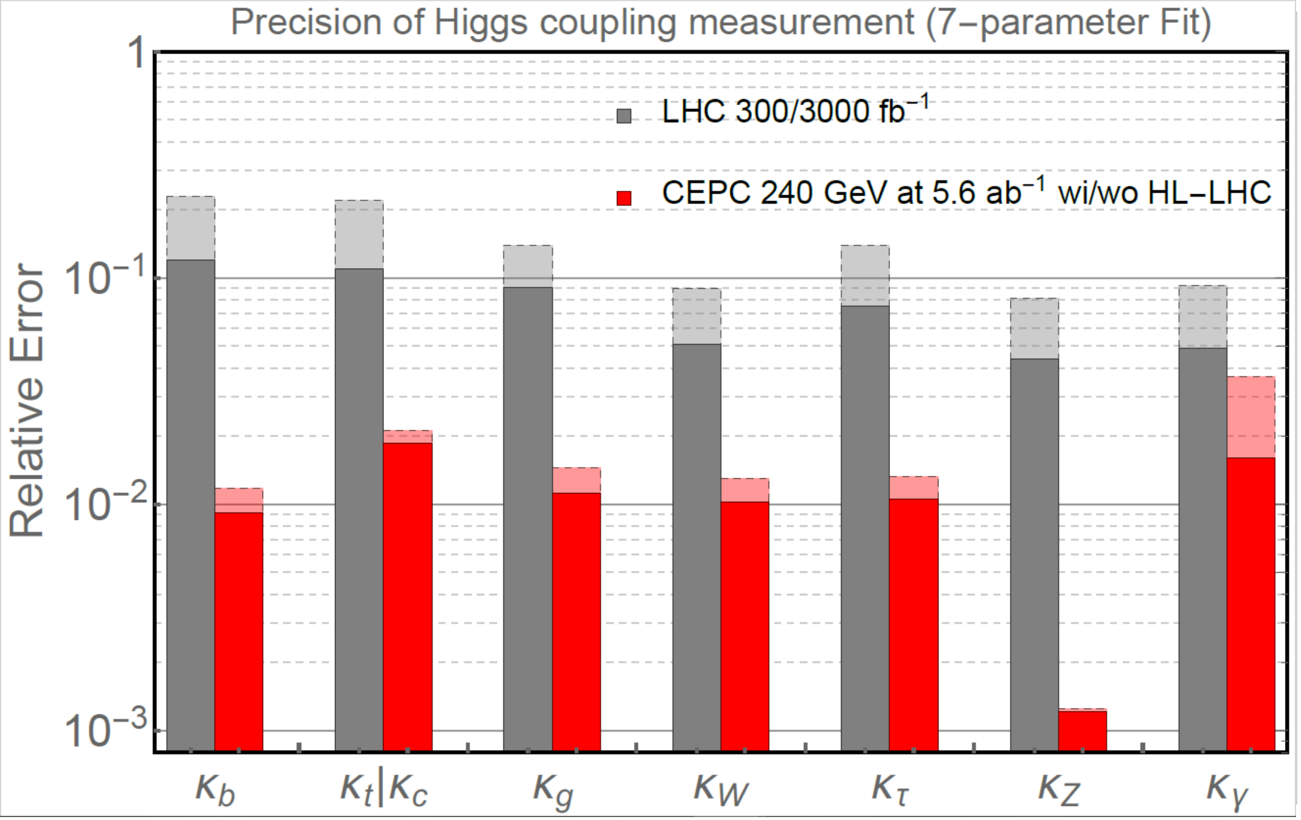
Constrained 7-κ fremework

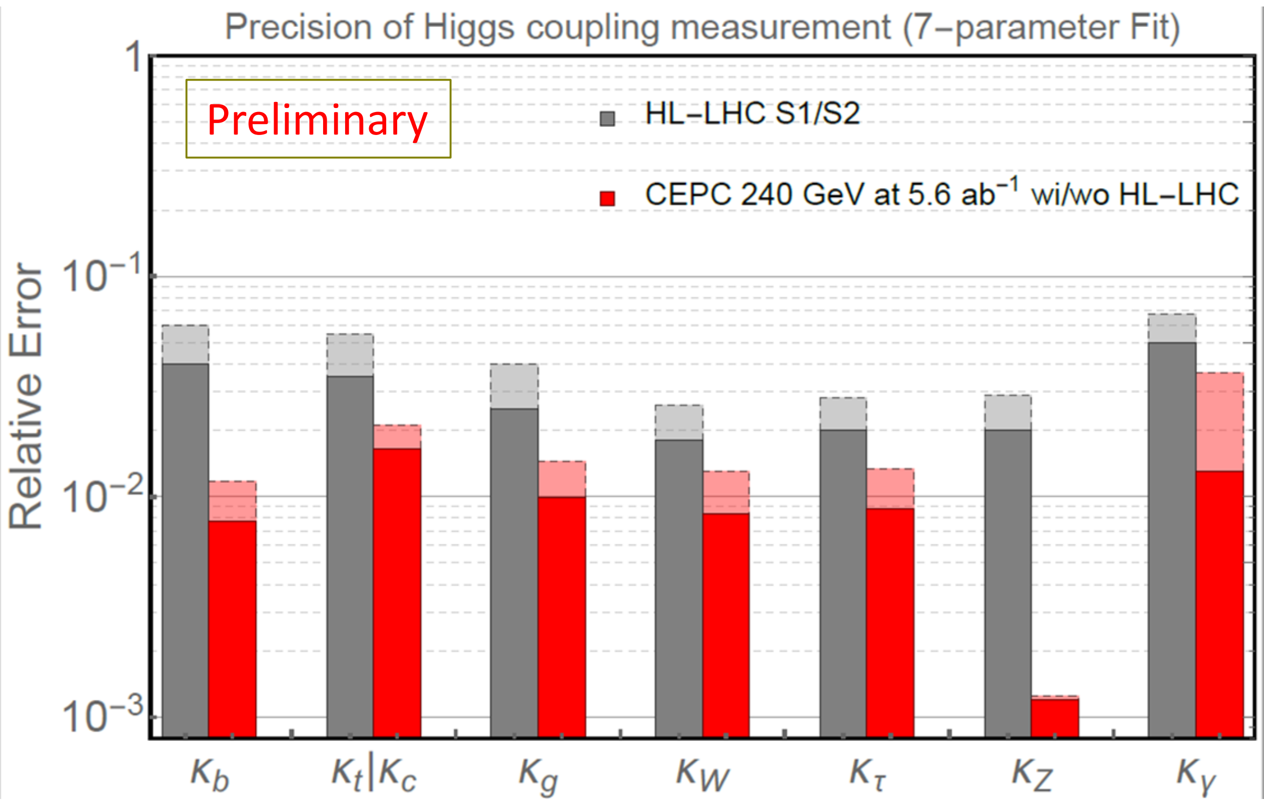
Updated based on latest HL-LHC projections.

CEPC ~1 order of magnitude improvement w.r.t pp collider.

While HL-HLC has advantages on $\gamma/lepton$ statistics.

κ_γ/κ_Z constraints could improve the other couplings in a model-dependent way.

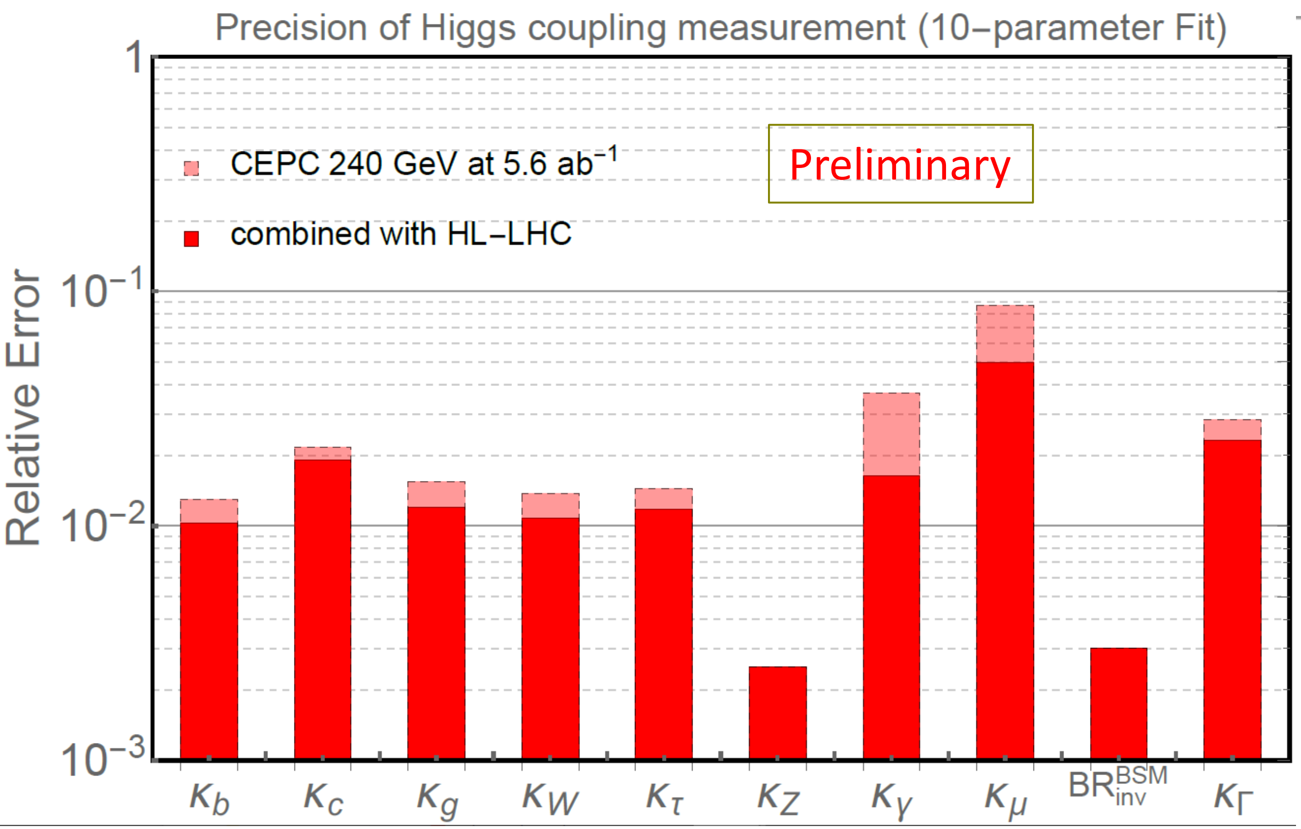


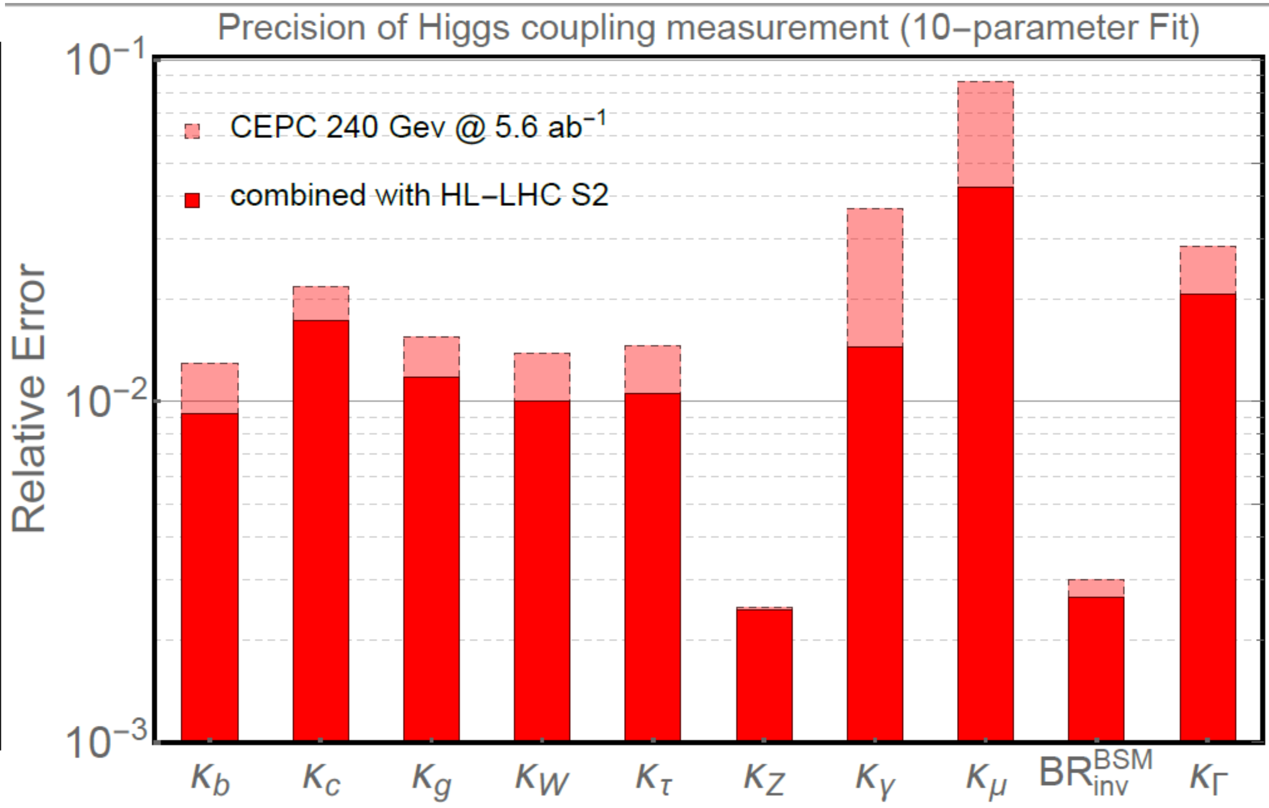


κ_Z: Best, ~0.16%

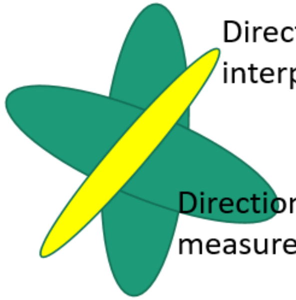
Independent κ fit

The Higgs width is free. Only lepton colliders could apply.
The best constraint of the CEPC is κ_Z, $0.5\%\,\sigma(ZH) \to 0.25\%\kappa_Z$
Higgs width brings a floor effect around 1.4%.





Correlation Matrix



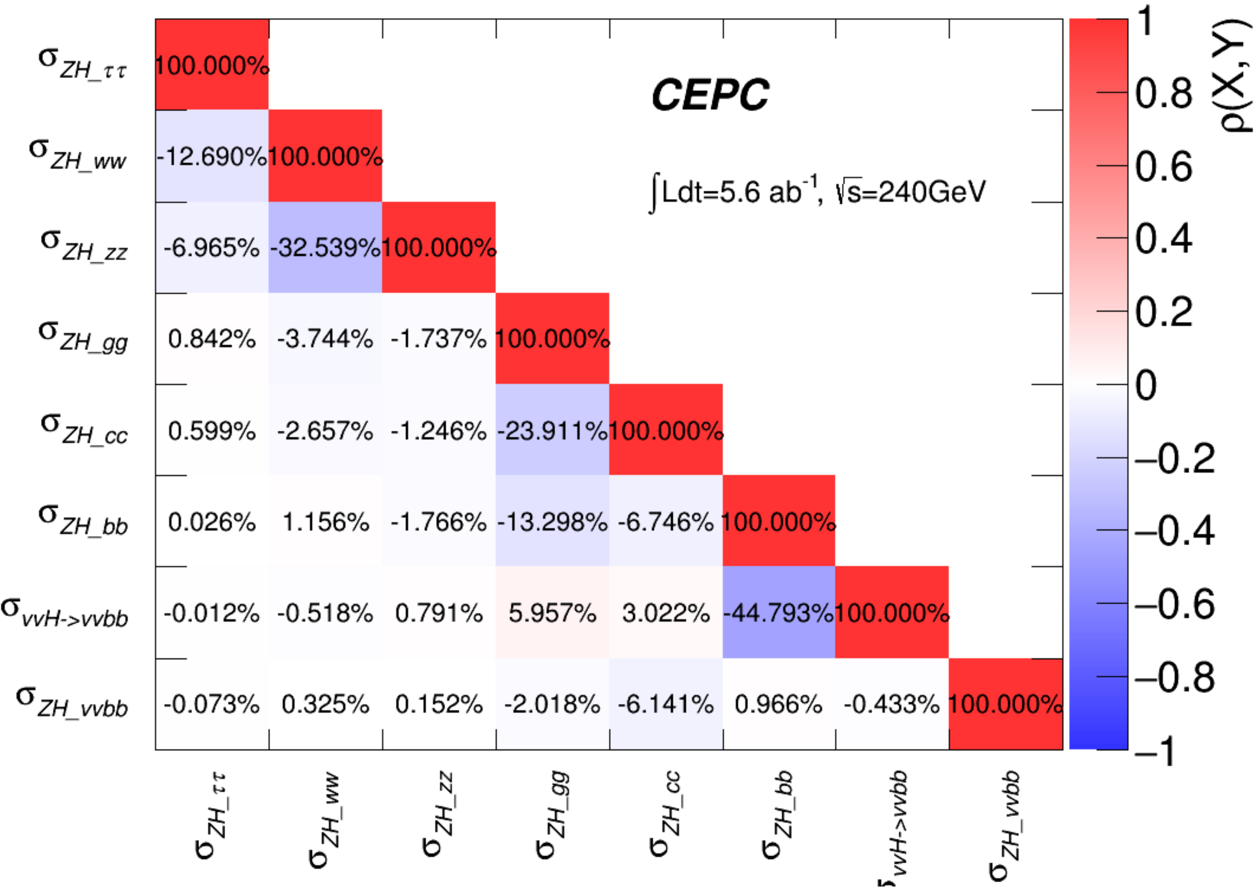
Input

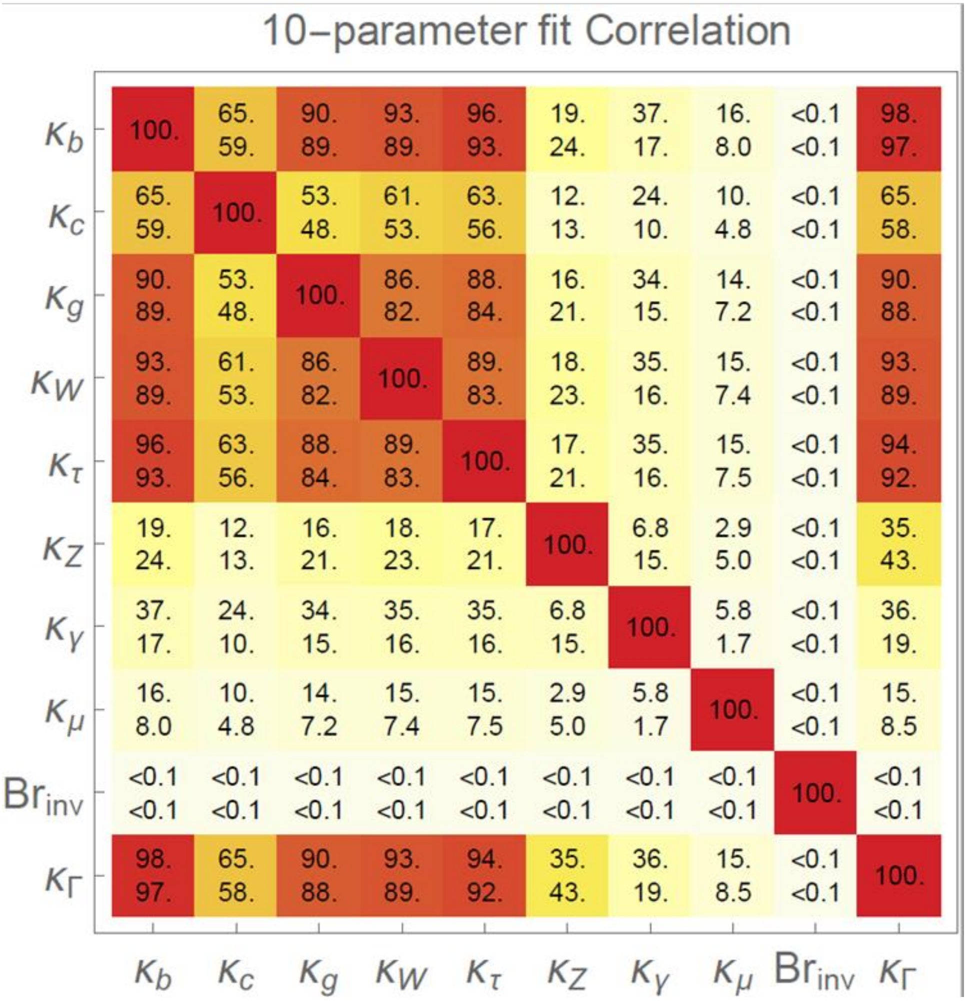
Observables

+ Interpretation

Output

Couplings





Upper entries: CEPC alone;
Lower entries: combining with HL-LHC (get reduced);

Higgs precisions @ 360 GeV

Higher Energy Run

- 350~365GeV Run: worthwhile
  - Over top threshold, EW/EFT/Theoretical part benefits;
  - Larger vvH cross section could benefits to Higgs width
  - FCC-ee/ILC/CLIC already have similar plan
  - Why 360? It saves 10% energy w.r.t 365 GeV
- Temporary benchmark: 2 ab^{-1} @ 360GeV
  - Not determined yet→ depends on study of top scan

FCC-ee:
0.2 ab^{-1} 350 GeV + 1.5 ab^{-1} 365 GeV

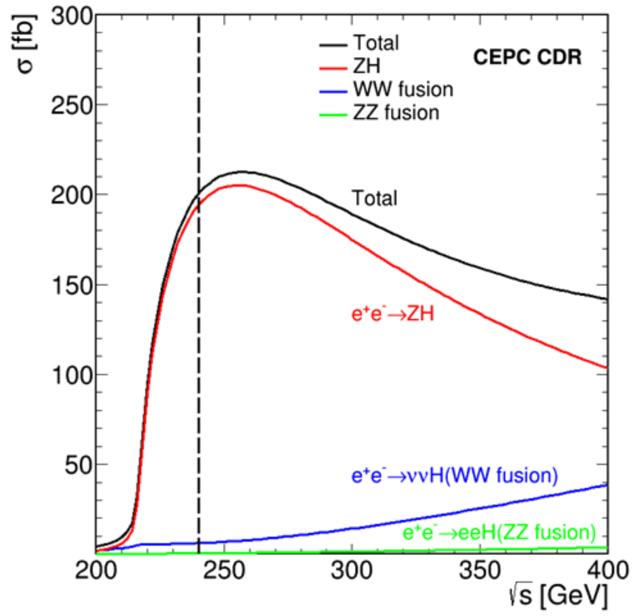
Currently CEPC DO NOT HAVE official plan for higher energy. Here is just some extrapolations……

Signal Cross Sections

ZH/vvH interference included

- 240GeV:
  - vvH: 6.2fb, interference: ~10% of vvH;
- 360GeV: (vvH ~ 117% Z->vv), (eeH ~ 67% Z->ee)

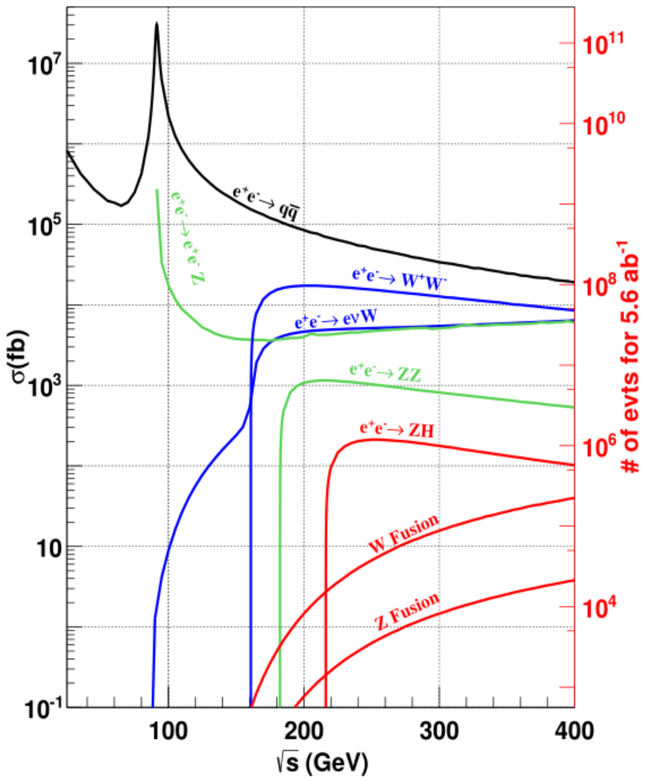
fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Total	203.6		159.0		
Total Events	1.14M		0.32M		



In total ~1.5M Higgs would be collected in CEPC 240+360.
More fusion events, sizable eeH at 360GeV.

Major background cross sections

pb	240	350	360	365	365/240
$ee(\gamma)$	930	336	325	319	-66%
$\mu\mu(\gamma)$	5.3	2.2	2.1	2.1	-60%
$qq(\gamma)$	54.1	24.7	23.2	22.8	-58%
WW	16.7	10.4	10.0	9.81	-41%
ZZ	1.1	0.66	0.63	0.62	-44%
tt	\	0.155	0.317	0.369	
sZ	4.54	5.72	5.78	5.83	+28%
sW	5.09	5.89	6.00	6.04	+19%



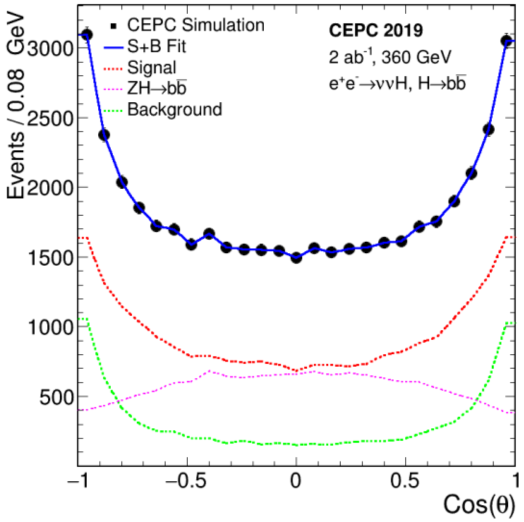
While 2fermion and WW, ZZ bkgs reduced, W/Z fusion and $t\bar{t}$ raise.

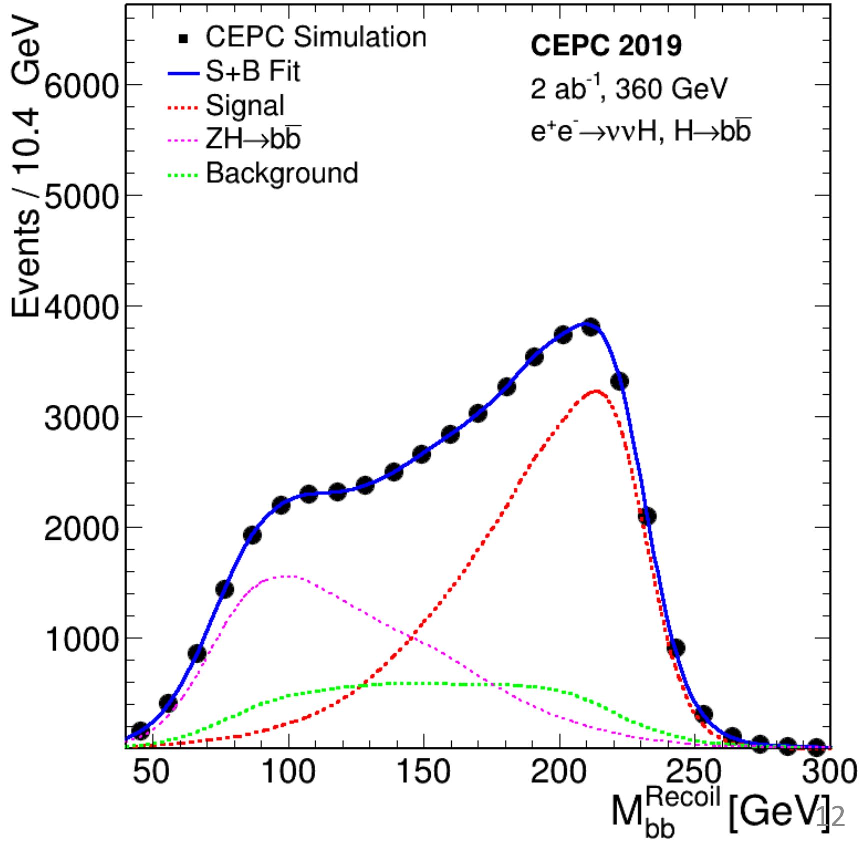
Generally, SM bkgs in 360 GeV are smaller than 240GeV.

Fast simulation samples to check the eff./shape/resolution. Then scale the existing 240 GeV results to 360GeV according to the eff./shape/xsections changes.

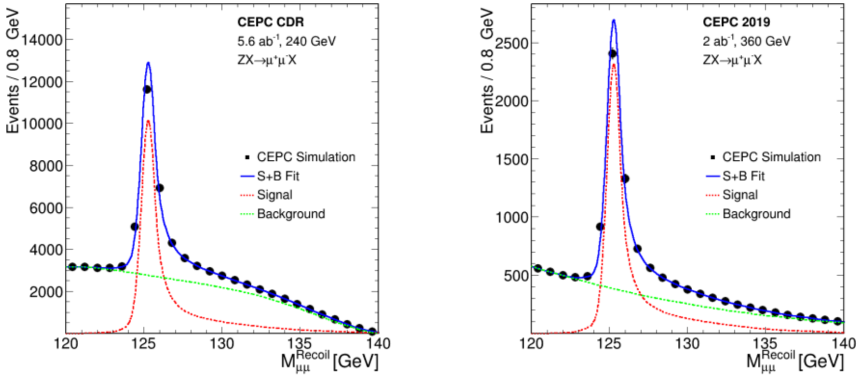
vvH->bb, full simulation

- 2D: Recoil qq + Cos θ_{qq} Fit
- Clear separation between ZH and vvH.
- Constraints from other ZH->bb($ee, \mu\mu, qq$) considered
  - $\sigma(\text{vv}H) * \text{Br}(\text{H} \to \text{bb})$:0.76%
  - $\sigma(\text{Z}H) * \text{Br}(\text{H} \to \text{bb})$: 0.63%
  - Correlation -16%. (-45%@240 GeV)
- One conservative bkg estimation gives 0.79%
  - (more irreducible $t\bar{t}$)
  - Significant improvement corresponding to 240GeV(2.8%)





Extrapolations



Ideal inclusive $Z \to \mu\mu$: $0.92\% \to 1.72\%$

- Mainly scale yields from 240GeV case.
- $\sigma(ZH)$: preliminarily around 1%
  - Need efforts to update qqH channel
- Resolution change: 2 benchmarks
  - dimuon: worse: ~0.3GeV → 1GeV; (23% -> 29%)
  - diphoton: better: ~2.5GeV → 2GeV; (9% -> 8%)
- $H \to invisible(ZZ \to \nu\nu\nu\nu)$ Upper limit
  - Sensitive to background shape, needs study in details

Higgs width

- Absolute width measurement by 2 dominant channels:

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

- ZZ provide ~10% precision.

- At 360 GeV, $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 0.76% $\sigma(\mathrm{Z}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 0.63% correlation -16%.

  - $Br(H \to WW)$ ~2% @ 360GeV + 1%@240 GeV .

  - Combined fit in 10κ framework:

$$\Delta(\Gamma_H) \approx 1.6\%$$

Summary

	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	vvH
any	**0.50%**	**1%**	****
$H \to bb$	**0.27%**	**0.63%**	**0.76%**
$H \to cc$	**3.3%**	**6.2%**	**11%**
$H \to gg$	**1.3%**	**2.4%**	**3.2%**
$H \to WW$	**1.0%**	**2.0%**	**3.1%**
$H \to ZZ$	**5.1%**	**12%**	**13%**
$H \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$H \to \gamma\gamma$	**5.4%**	**8%**	**11%**
$H \to \mu\mu$	**12%**	**29%**	**40%**
$Br_{upper}(H \to inv.)$	**0.2%**	****	****
$\sigma(ZH) * Br(H \to Z\gamma)$	**16%**	**25%**	****
Width	**2.8%**	**1.6%**	

Generally, even though the extrapolation not so accurate, results comparable with FCC-ee

For Higgs coupling, also similar performance could be expected.

Fcc:

$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \to$ any	±0.5		±0.9	
$H \to b\bar{b}$	±0.3	±3.1	±0.5	±0.9
$H \to c\bar{c}$	±2.2		±6.5	±10
$H \to gg$	±1.9		±3.5	±4.5
$H \to W^+W^-$	±1.2		±2.6	±3.0
$H \to ZZ$	±4.4		±12	±10
$H \to \tau\tau$	±0.9		±1.8	±8
$H \to \gamma\gamma$	±9.0		±18	±22
$H \to \mu^+\mu^-$	±19		±40	
$H \to$ invisible	< 0.3		< 0.6	

For $H \to \gamma\gamma$ and $H \to \mu\mu$, resolution changes considered.
Keep di-photon resolution ~(2.5GeV) : 9%
2.5GeV to 2GeV: 8%

Keep di-muon resolution ~(0.3GeV): 23%
0.3 GeV to 1 GeV: 29%

Summary

- Latest CEPC Higgs combination, $\sigma * \mathrm{Br}$ and coupling results are shown.
  - Correlation considered.
- Extrapolation to 360 GeV
  - Temporary benchmark showed ~1.6% precision for width.
  - Comparable with FCC-ee.
- Many done, but more need to be carried out