CEPC Higgs Coupling

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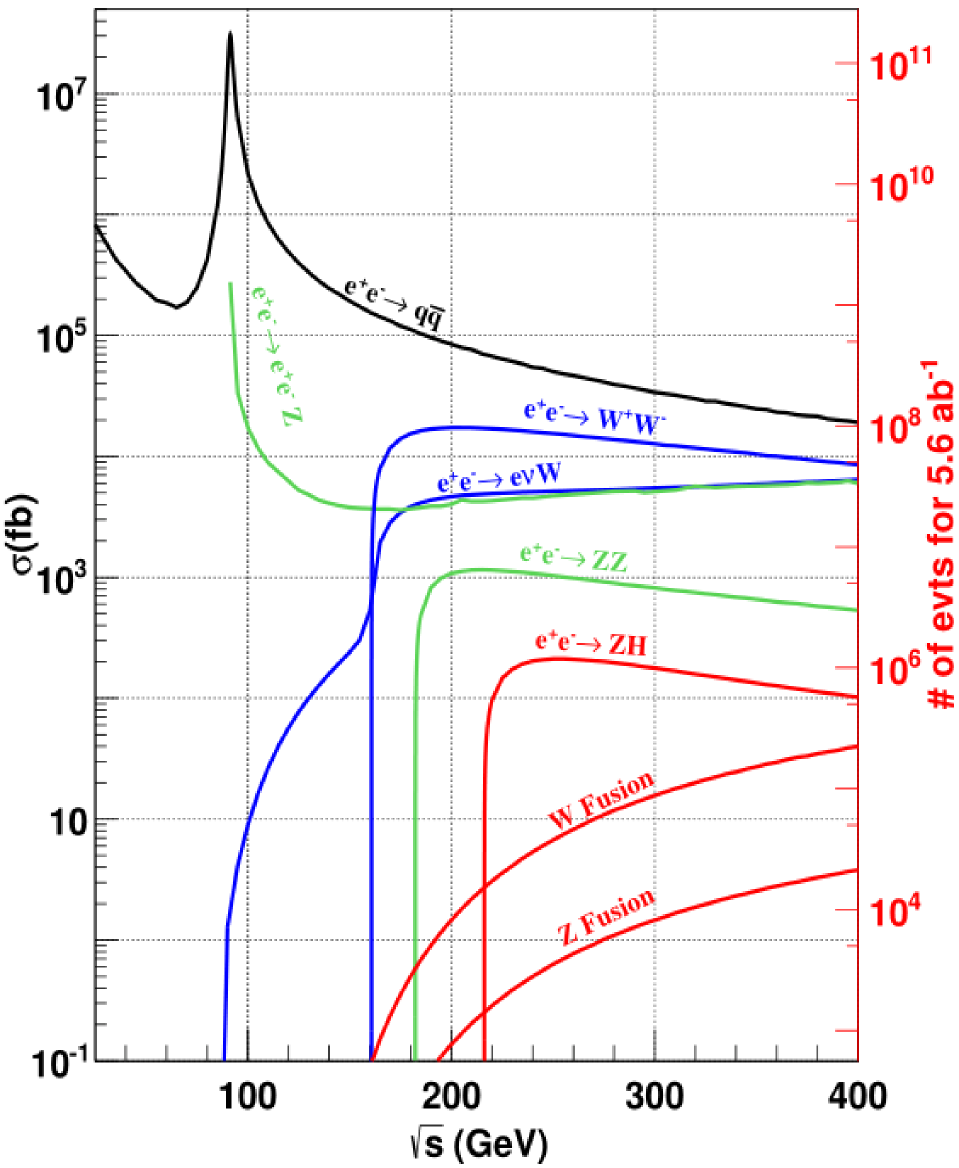
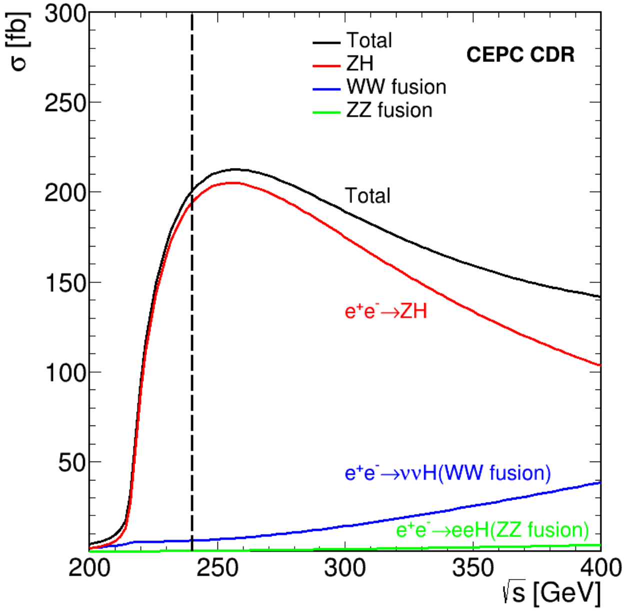
IHEP

Joint Workshop of the CEPC Physics, Software and New Detector Concept

Apr. 14th, 2021 Yang Zhou

Higgs Physics @ CEPC



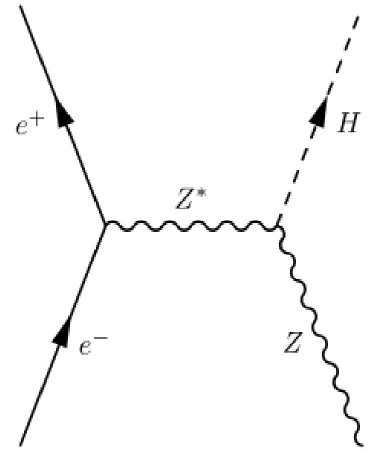


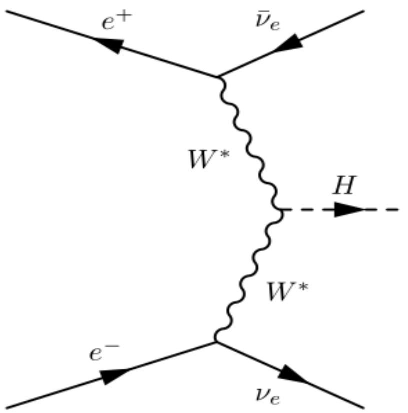
CEPC CDR: arxiv:1811.10545

White Paper: arxiv:1810.09037

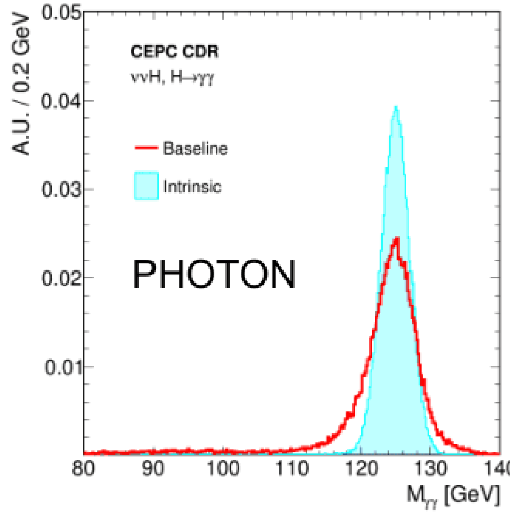
1M Higgs in 240GeV, 5.6ab^{-1}

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

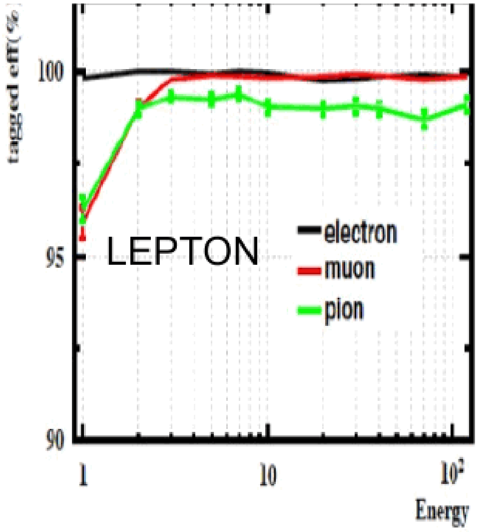




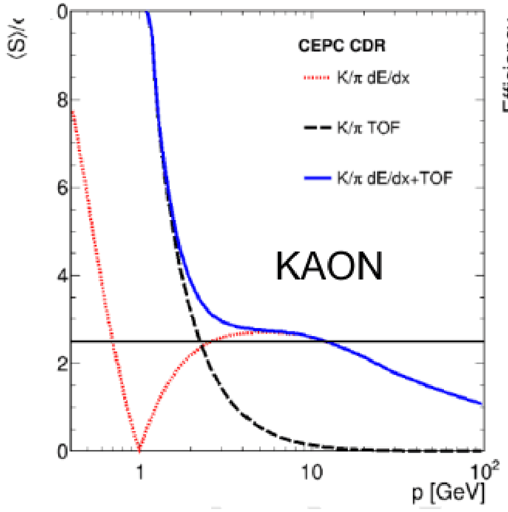
CEPC (evolving) object performance

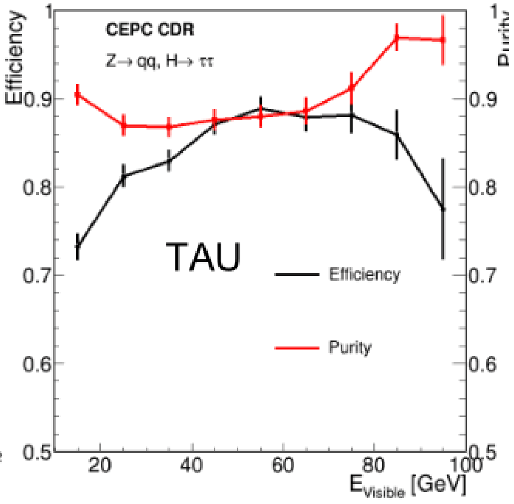


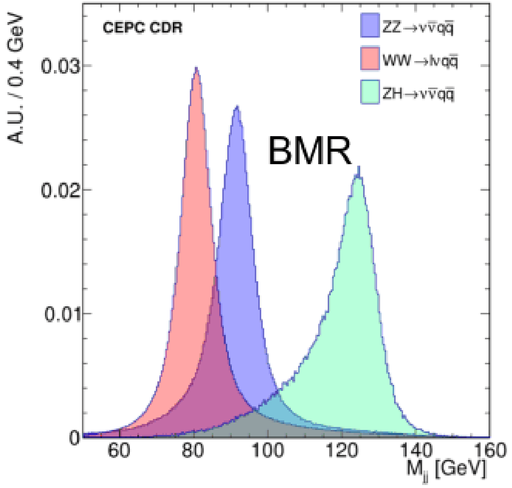
Eur. Phys. J. C (2017) 77: 591

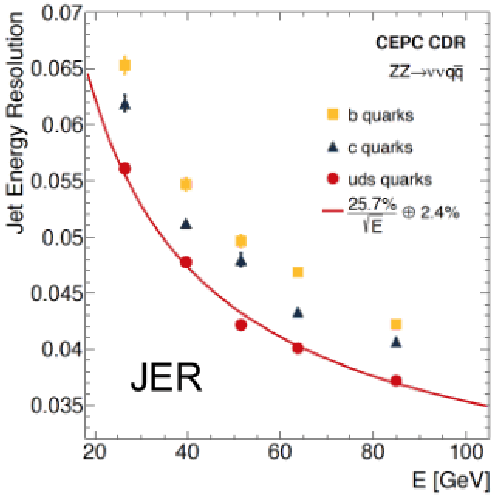


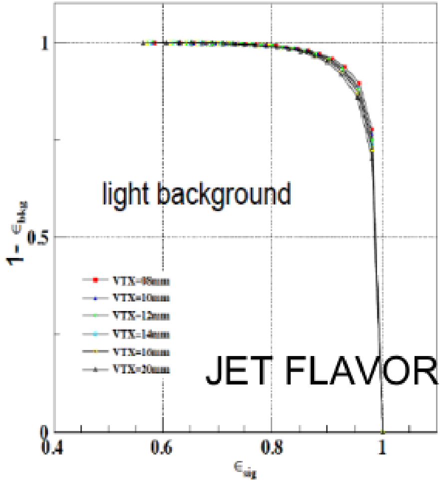
Eur. Phys. J. C (2018) 78:464

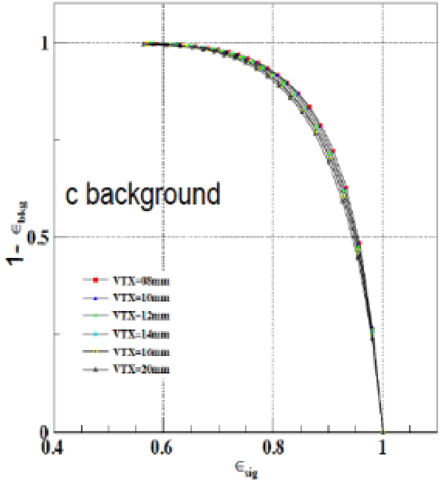












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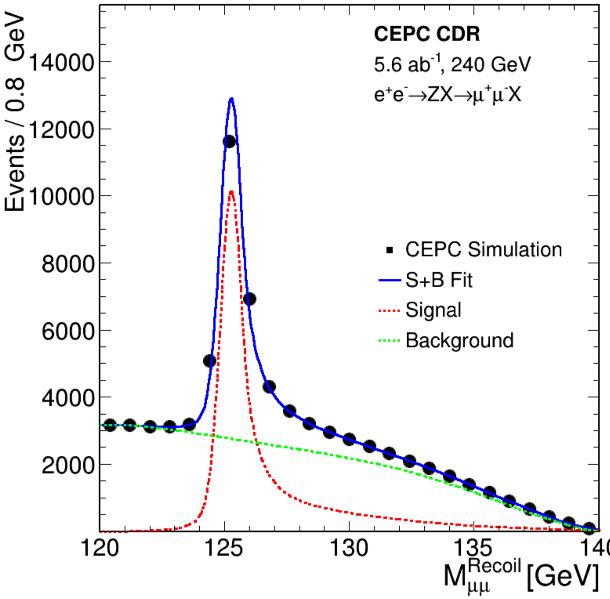
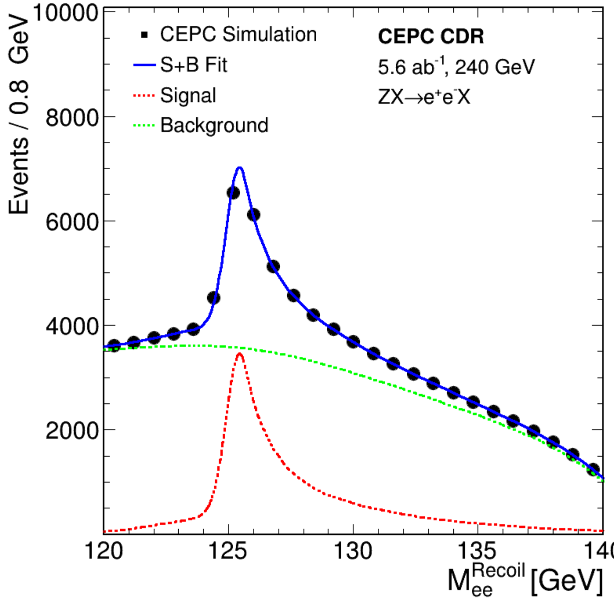
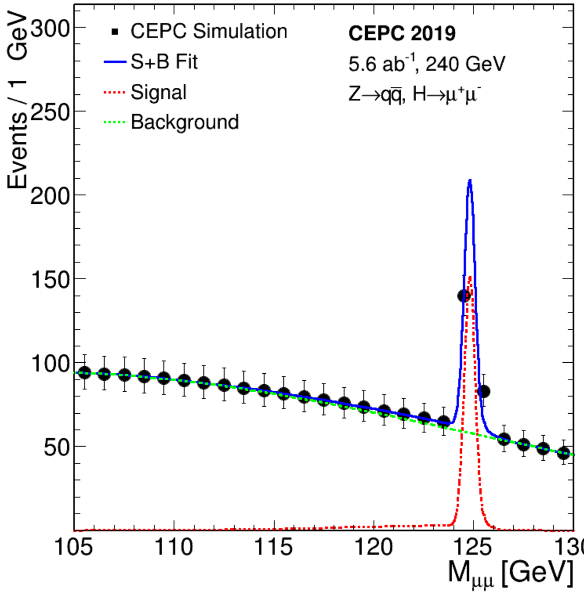
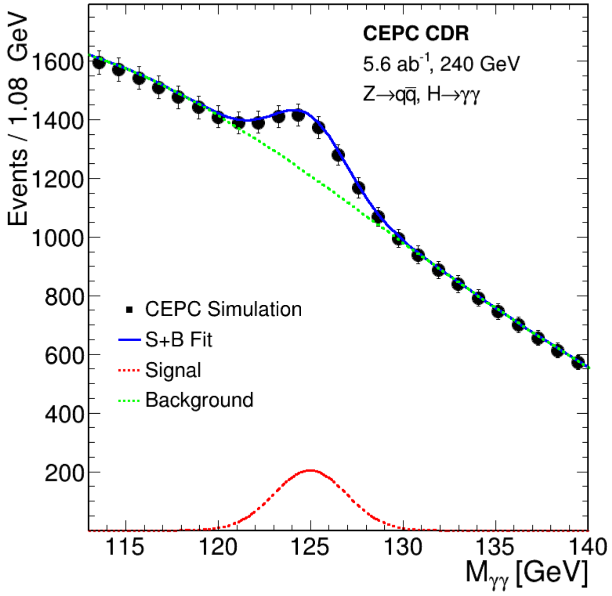
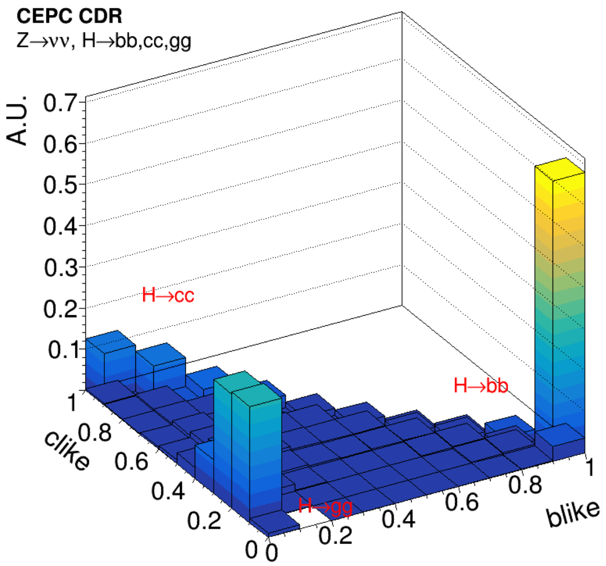
Individual sub channels

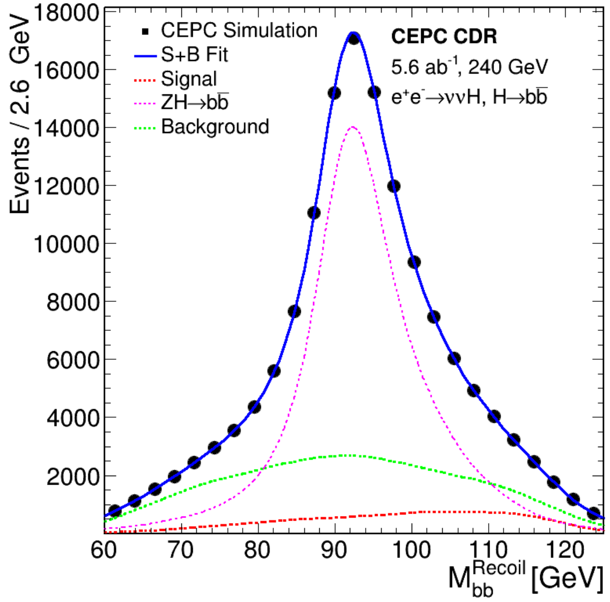


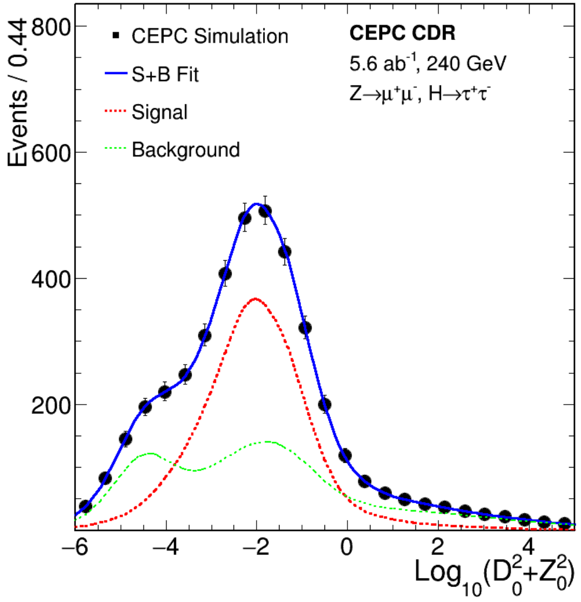












These results are based in 2018 CEPC-v4 layout.

(Ecal: $1.4\% \oplus \frac{16.7\%}{\sqrt{E}}$)

New design, like crystal Ecal not included yet. (3%)

Existing results:240GeV, 5.6iab

(240GeV,5.6ab^{-1})	CDR	2021.04	Reports in this meeting
$\sigma(ZH)$	**0.50%**		
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**0.27%**		**Baiyu**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	**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%**	**7.9%***	**Ryuta**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	**0.8%**		
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	**6.8%**	**5.7%**	
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	**17%**	**18%***	**Kunlin**
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**3.0%**		
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.41%**	**0.24%**	
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**		
Width	**2.8%**		

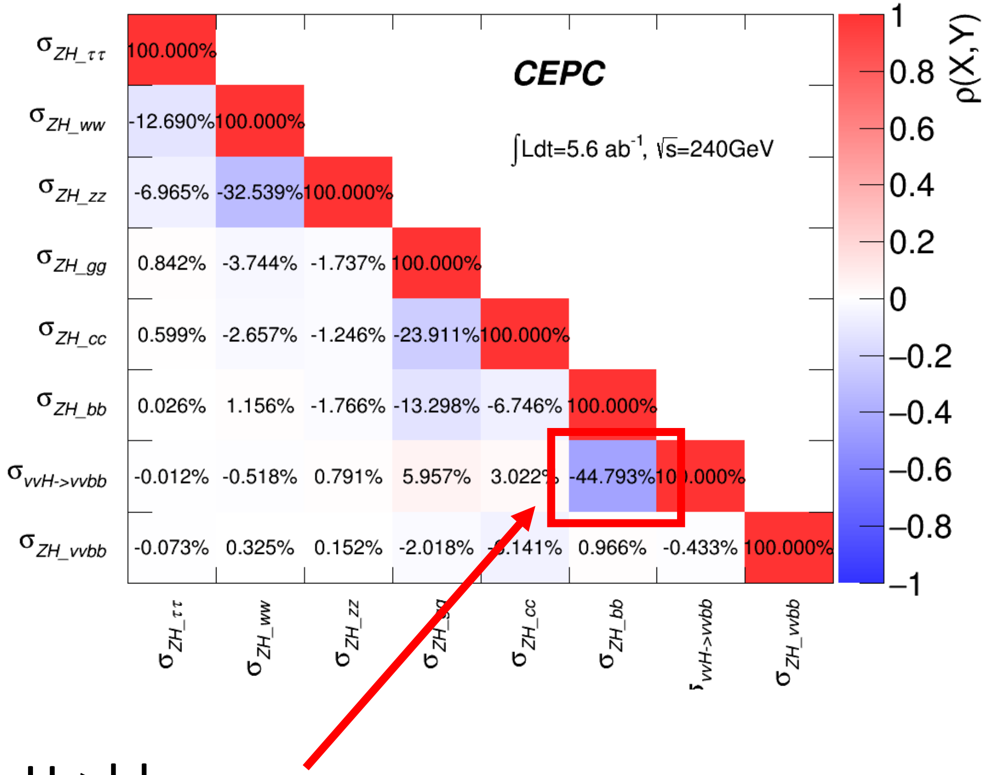
Related publication:
$\sigma(ZH)$: 1601.05352;
bb/cc/gg: 1905.12903;
$\tau\tau$: 1903.12327;
Invisible: 2001.05912;
ZZ: 2103.09633;

Several channels improved since CDR published. Mostly from better analysis strategy.

*:See more in the report from Ryuta and Kunlin.

Combination Framework

- Multiple observables for workspace
  - Mass spectrum, BDT output, Flavor tagging likeness
  - Apply multi dimensional fit if possible
- Input correlation considered
  - σ∗Br + Correlation Matrix = Complete Input.
  - Anti-correlation from measurement;
  - Major form: Higgs yields overlap
  - Cannot be ignored for some crucial channel, like vvH & ZH, H->bb



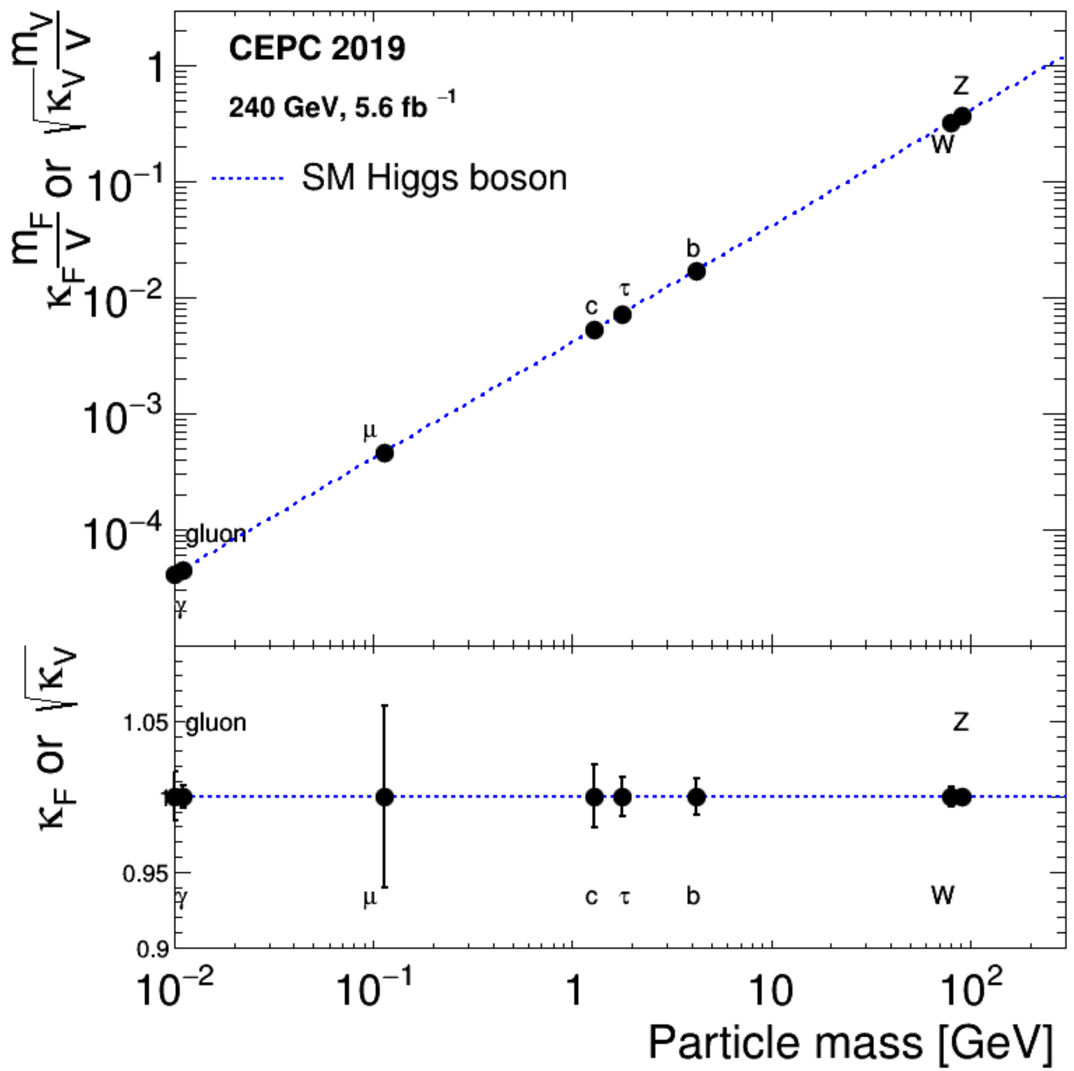
- Higgs width 2.8%
  - Major contributed from $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \rightarrow \mathrm{bb})$ and $\mathrm{Br}(\mathrm{H} \rightarrow \mathrm{ZZ})$

κ framework

- Higgs coupling defined as:

$$\kappa_Z^2 = \frac{g(HZZ)}{g_{SM}(HZZ)} = \frac{\sigma(ZH)}{\sigma_{SM}(ZH)} \qquad \text{->0.5\%;}$$

$$\sigma(\text{vv}H) * \text{Br}(\text{H} \to \text{bb}) \propto \frac{\kappa_{\text{W}}^2 * \kappa_{\text{b}}^2}{\Gamma_H}.$$



We expect excellent κ_Z measurement from $\sigma(ZH)$,

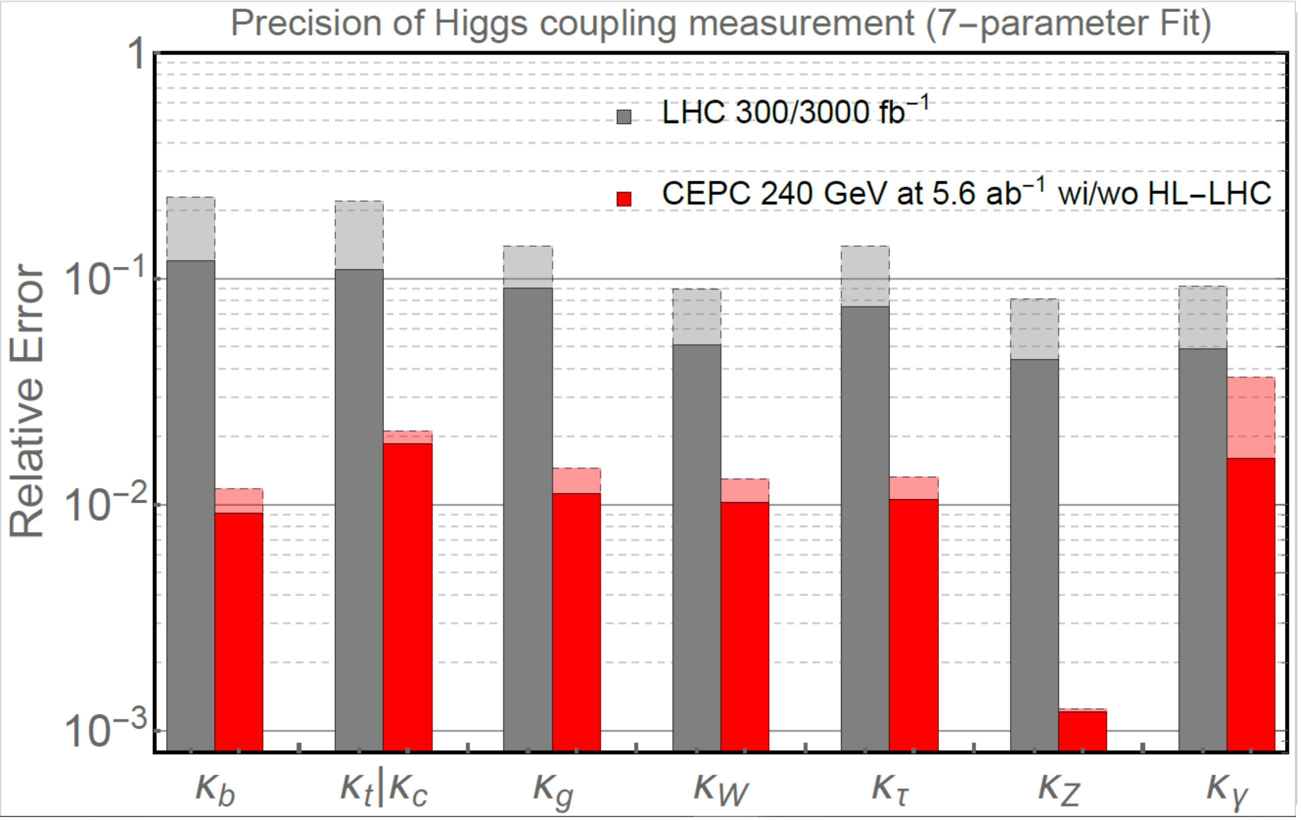
and all other channel suffered from Higgs width.

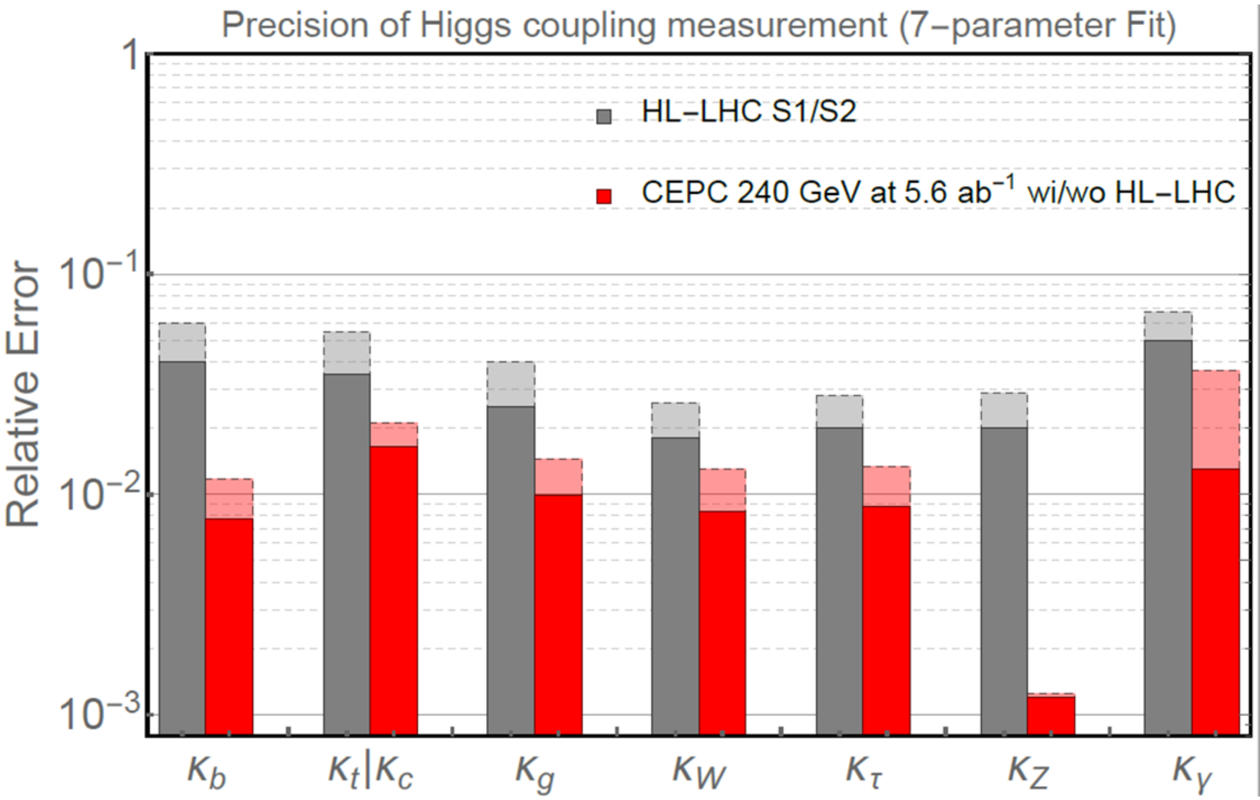
Extract width with branch ratio: Constrained 7-κ

Keep width independent: 10 κ

Constrained 7-κ framework

CEPC would have ~1 order of magnitude improvement compared to pp collider.
While HL-HLC has good $\gamma/lepton$ search. Add constrain like κ_γ/κ_Z would significantly improve the coupling.

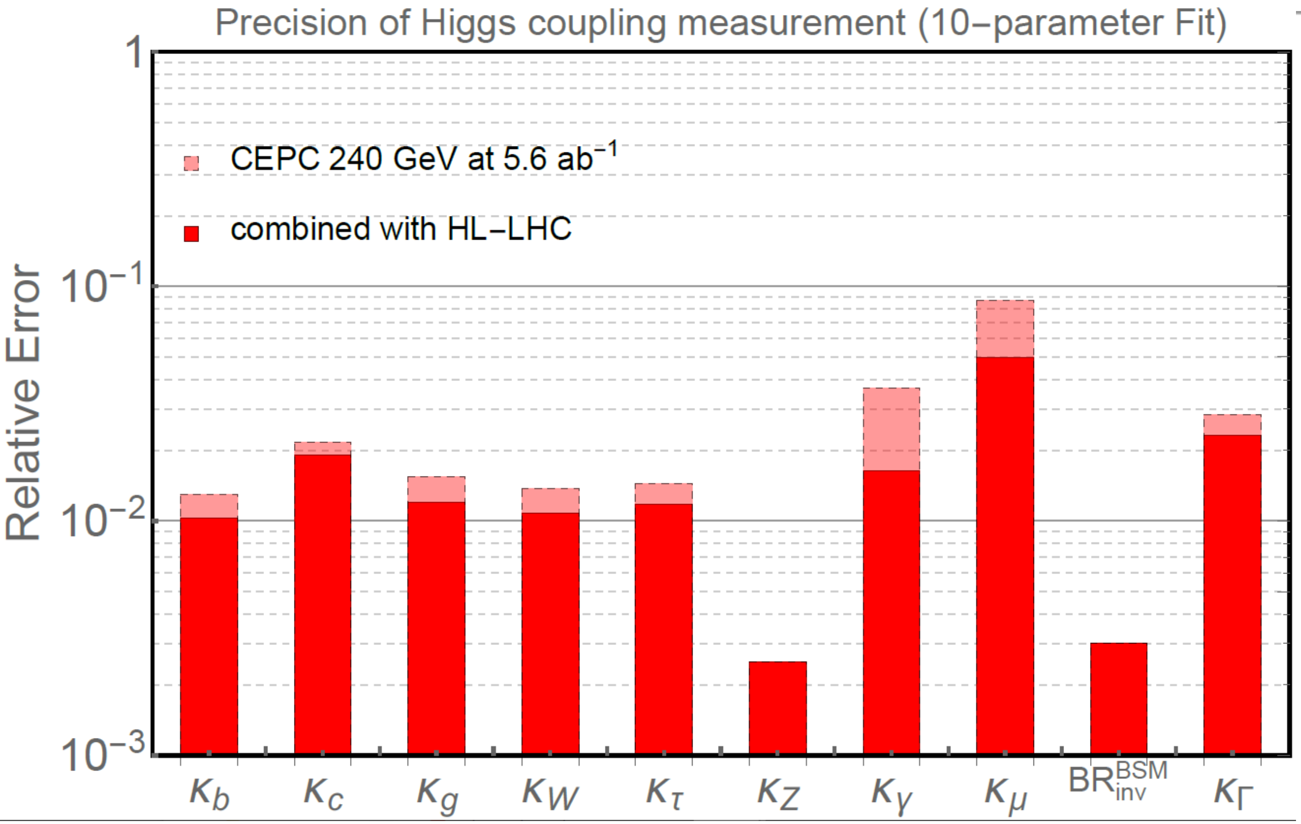


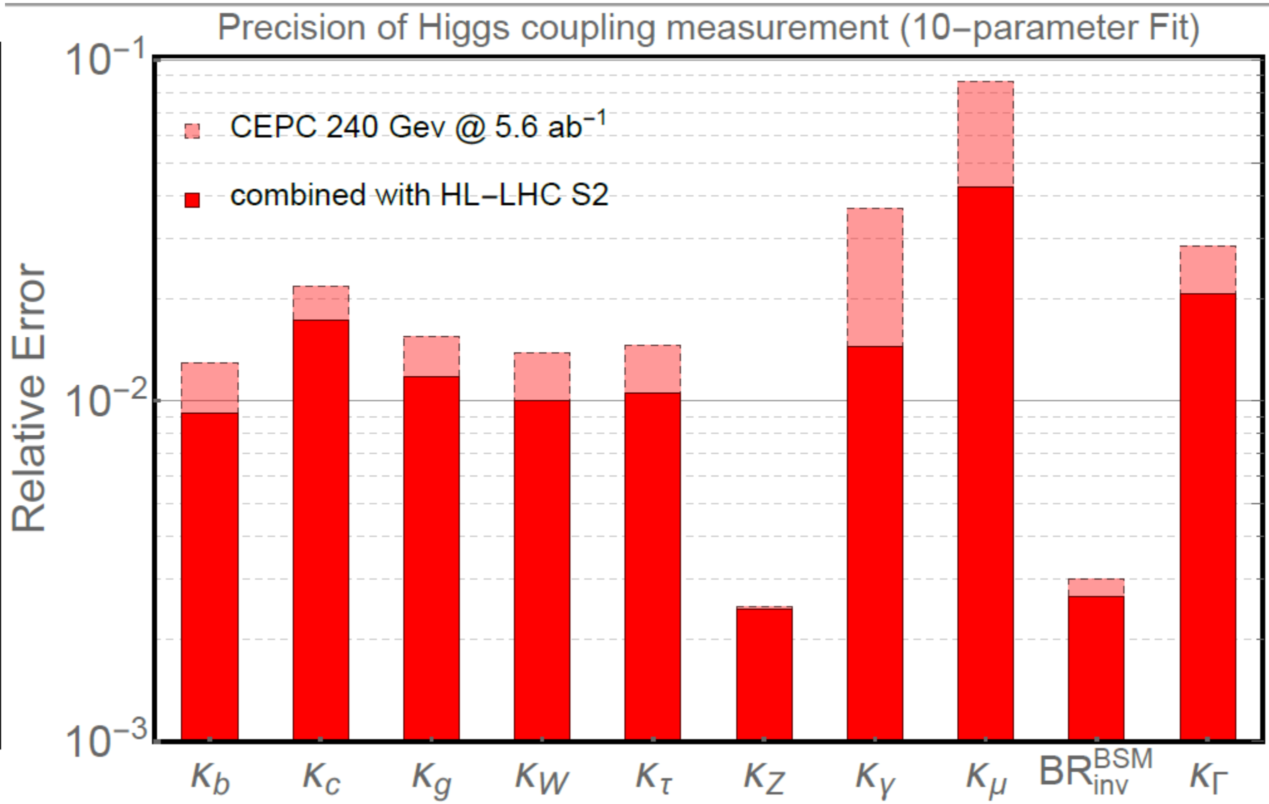


Independent κ fit

See more in Zhen's Slides!

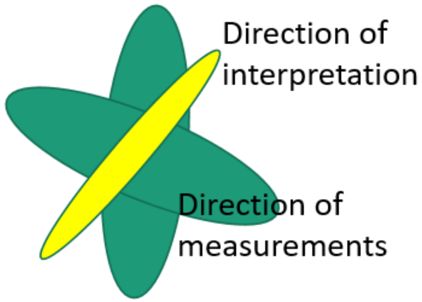
Let Higgs width free. Highlights of lepton collider.



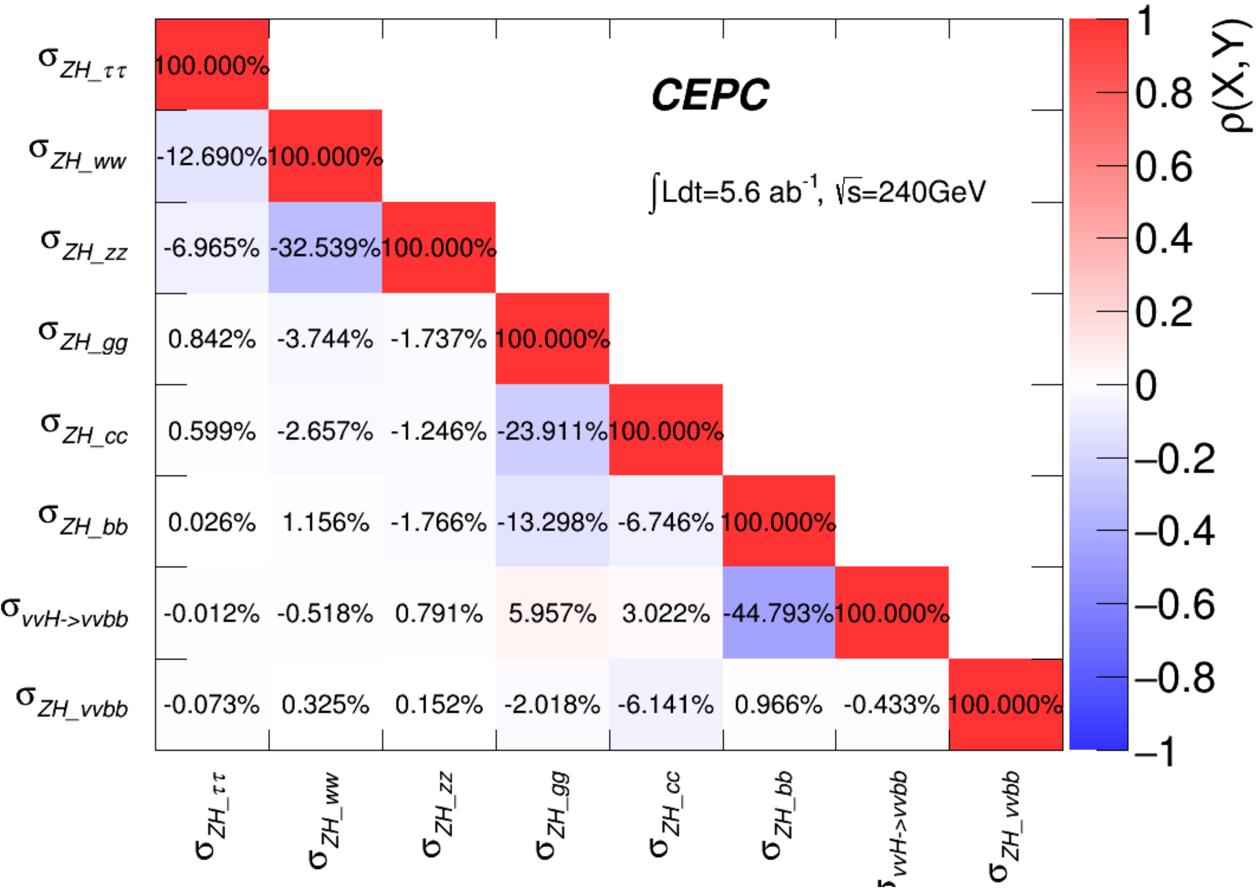


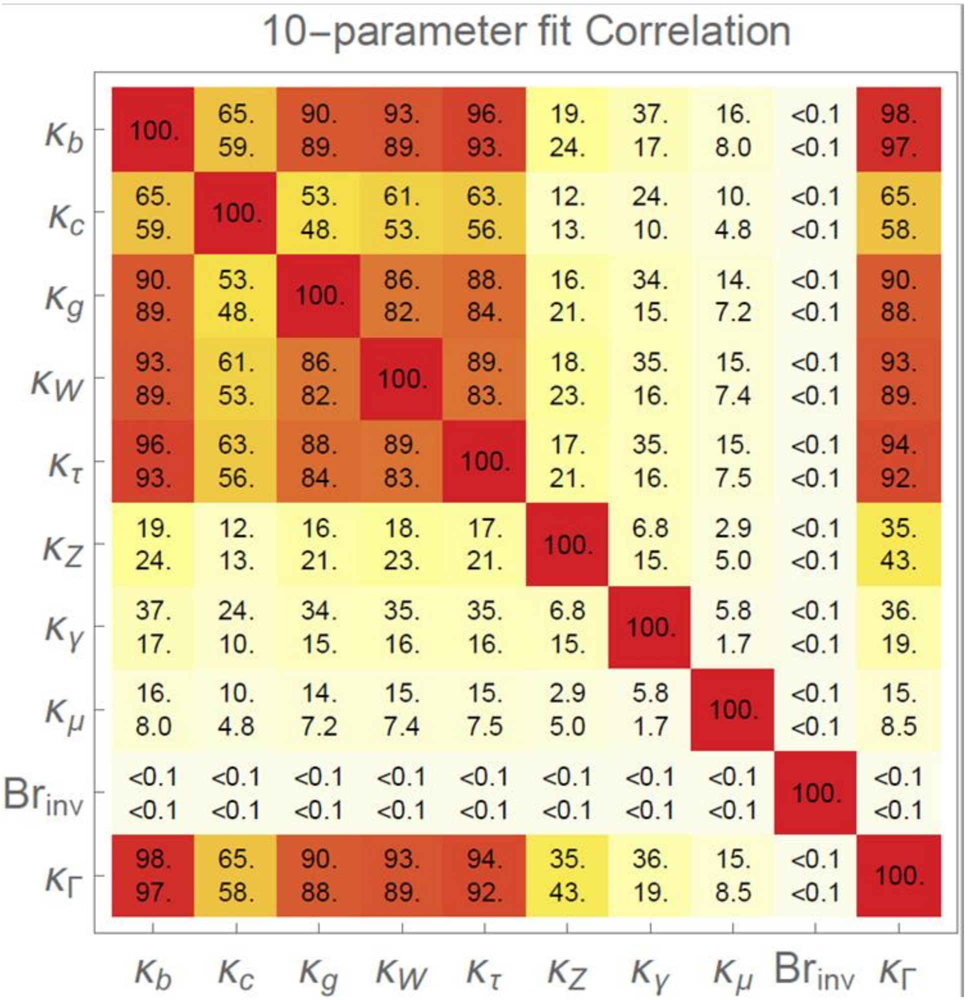
As 240GeV Higgs width ~2.8%, brings a floor effect for all couplings around 1.3%.
All the coupling are positive-correlated this way.

Correlation Matrix



Input | + Interpretation | Output
Measurement → Coupling





Since the correlation is in the different direction, results get improved slightly.

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

360GeV: Higher Energy Run

- 350~365GeV $t\bar{t}$ Run:
  - For Higgs: Larger vvH cross section; Benefit width measurement
  - More advantages for EW/Theoretical part;
  - Fcc-ee/ILC/CLIC all have similar plan
- Temporary benchmark: 2 iab @ 360GeV
  - With current lumi, ~10 years to collect 2iab data, could be faster.
  - 360GeV saves 10% energy with respect to 365 GeV
  - Not determined yet

Fcc-ee has the plan for
0.2iab 350GeV Scan + 1.5iab 365GeV

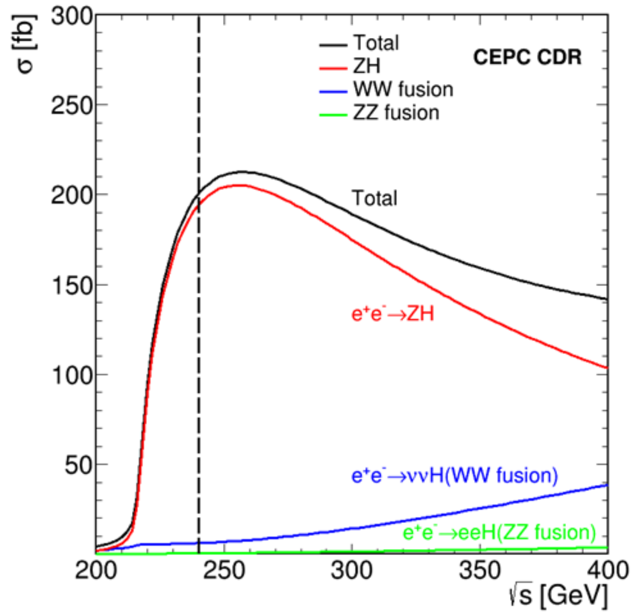
Currently CEPC DO NOT HAVE ANY official plan for higher energy. Here is just some extrapolations……

Signal Cross Sections

ZH/vvH interference already considered.

- 240GeV:
  - ZH: 196.9; vvH: 6.2; interference: ~10% of vvH; about 318:10:1; (Z->vv : vvH = 6.4:1)
- 360GeV: (vvH ~ 117% Z->vv), (eeH ~ 67% Z->ee)

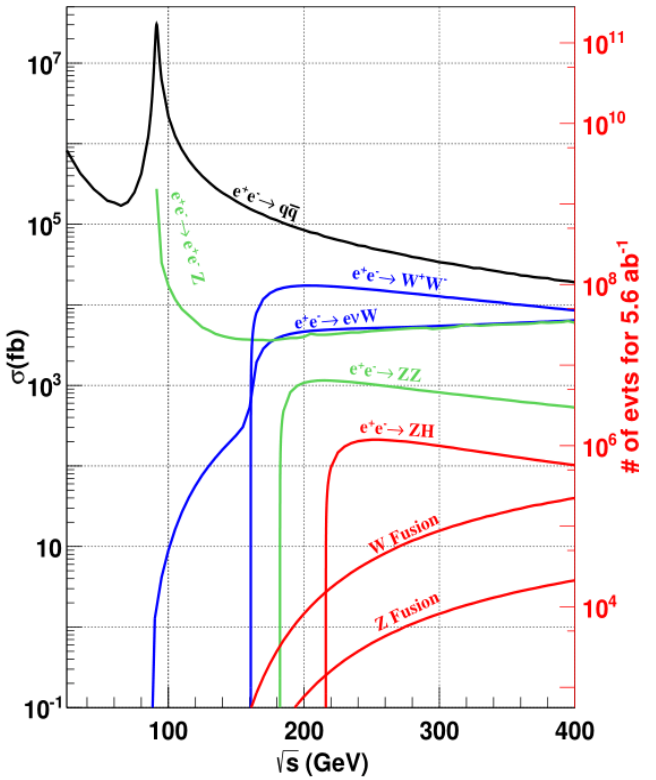
fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Total	203.6		159.0		
Total Events	1.14M		0.32M		



In total ~1.5M Higgs would be collected in CEPC 240+360.
More fusion events, also eeH can not be ignored in 360GeV.

Major background cross sections

pb	240	350	360	365	360/240
ee(γ)	930	336	325	319	-65%
$\mu\mu$(γ)	5.3	2.2	2.1	2.1	-60%
qq(γ)	54.1	24.7	23.2	22.8	-57%
WW	16.7	10.4	10.0	9.81	-40%
ZZ	1.1	0.66	0.63	0.62	-43%
tt	\	0.155	0.317	0.369	
sZ	4.54	5.72	5.78	5.83	+27%
sW	5.09	5.89	6.00	6.04	+18%



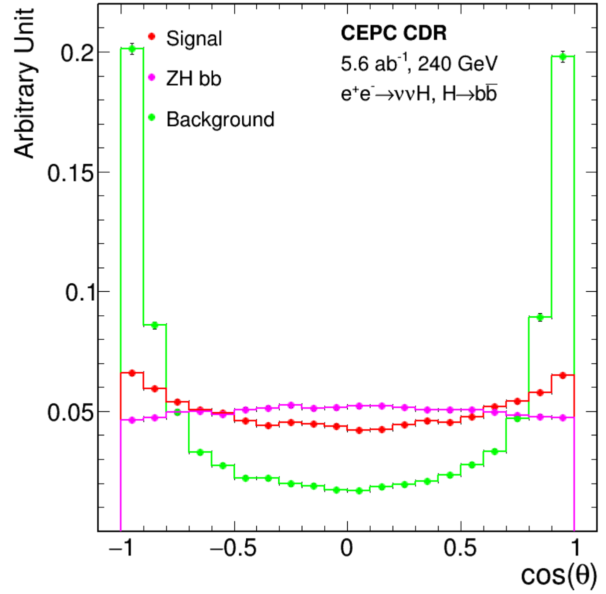
While 2fermion bkg and WW, ZZ bkg reduced, W/Z fusion and $t\bar{t}$ raise.

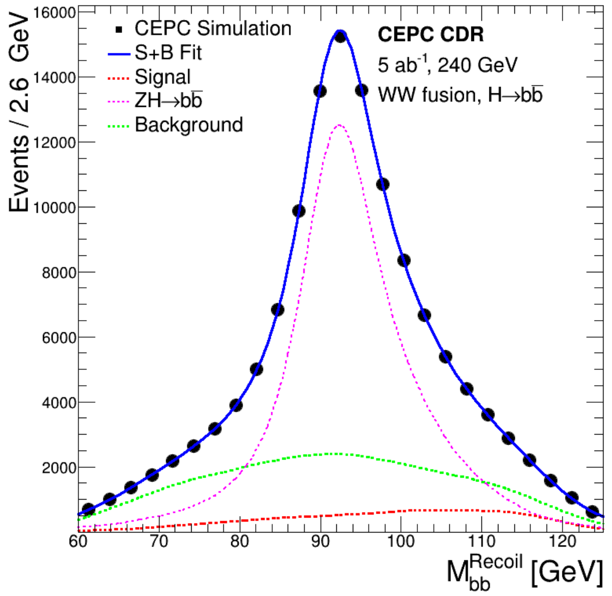
Generally, with larger phase space and smaller bkg cross sections, continuum background would reduce.

Fast simulation samples are generated to check the shape. Then existing yields are scaled to 360GeV.

$\nu\nu H \rightarrow bb$: 240GeV

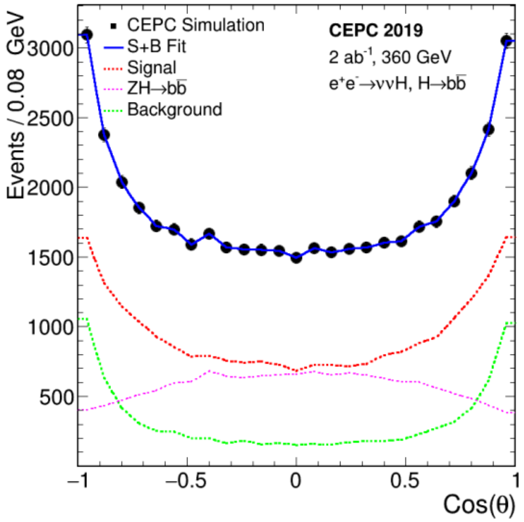
- 2d fit M_{jj}^{reco} & $\mathrm{Cos}\ \theta_{jj}$
- $\nu\nu H \rightarrow bb$ and $ZH \rightarrow bb$
  - Interference ~10% of vvH. (generally, 60: 1 : 10)
    - Add the interference term to vvH side currently;
  - If fix ZH process, Initial uncertainty is 2.8%.
  - ZH->bb constrained by other bb channels. If not, would be 3.4%.
  - $\nu\nu H \rightarrow bb$ and $ZH \rightarrow bb$ share the anti-correlation -45%. (-34% in ILC(1708.08912))
- $\sigma(\nu\nu H) * Br$: 3.0% ;
  - $\sigma(\nu\nu H)$: 3.2%.

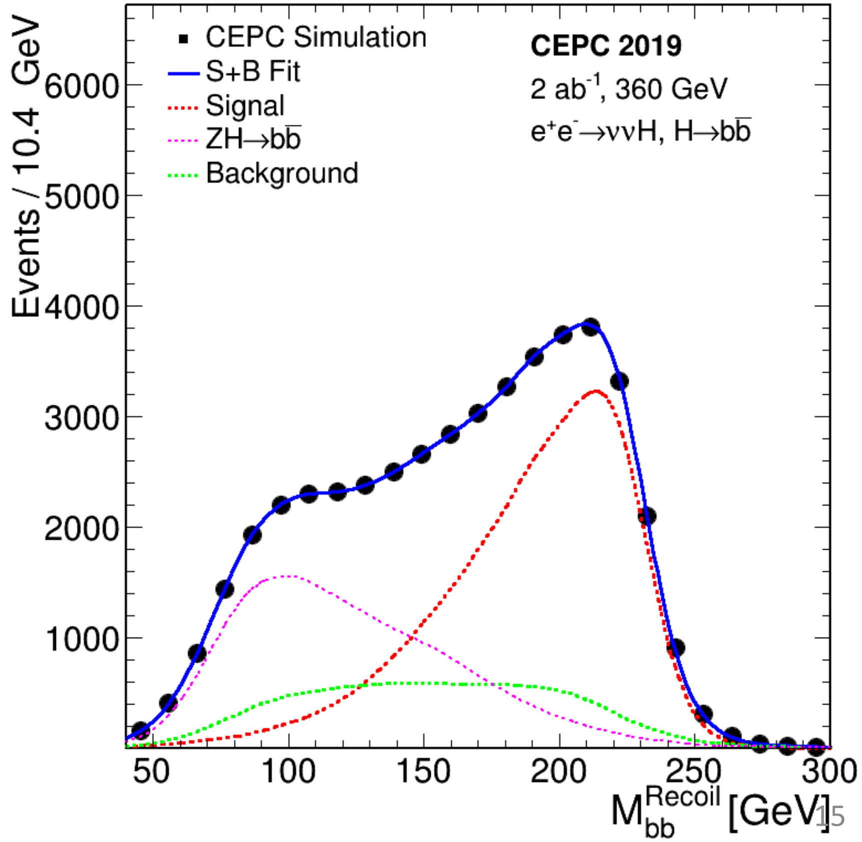




vvH->bb : 360 GeV, full sim

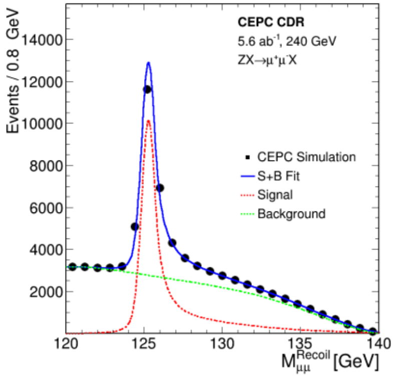
- Clear separation between ZH and vvH.
- Constrain from other ZH->bb($ee, \mu\mu, qq$) considered
  - $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$:0.76%
  - $\sigma(\mathrm{Z}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 0.63%
  - share the anti-correlation -15.8%.

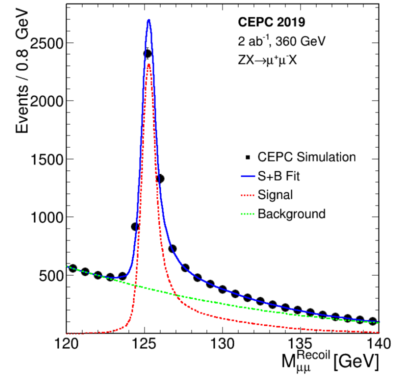




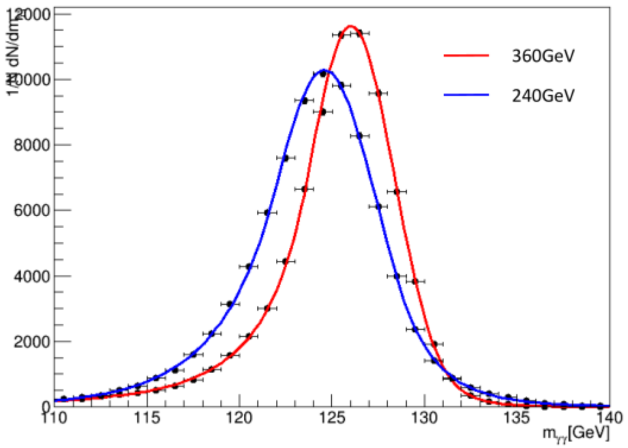
Extrapolations

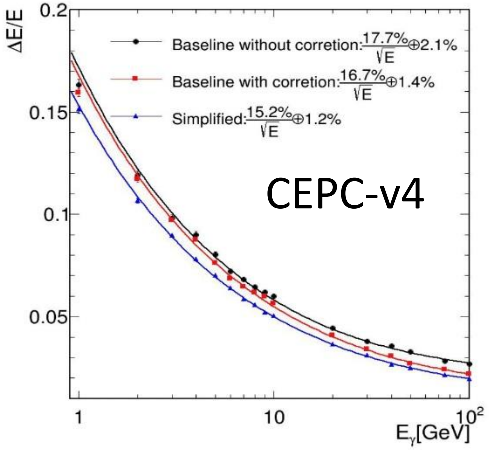
- Mainly scale yields from 240GeV case.
- $\sigma(ZH)$: preliminarily, around 1%
  - Need patient work on qqH channel
- Resolution change
  - Better photon resolution than 240.
  - Could expect smaller higgs width.
    - Full Sim 2.84/2.34GeV, 18% better





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





Other channels, like eeH, invisibles, would rely on future work.

360GeV(Red) peak not calibrated yet.

Higgs width

- Now CEPC Higgs width is fitted in the 10- κ framework.

- Adding one mass point would significantly improve the constrain.
  - Standalone 240GeV gives 2.8%, while 360GeV alone gives 2.8%. These 2 points are independent.
    - Impact from channels like vvH->WW can not be ignored(3.1%).
  - Combined fit

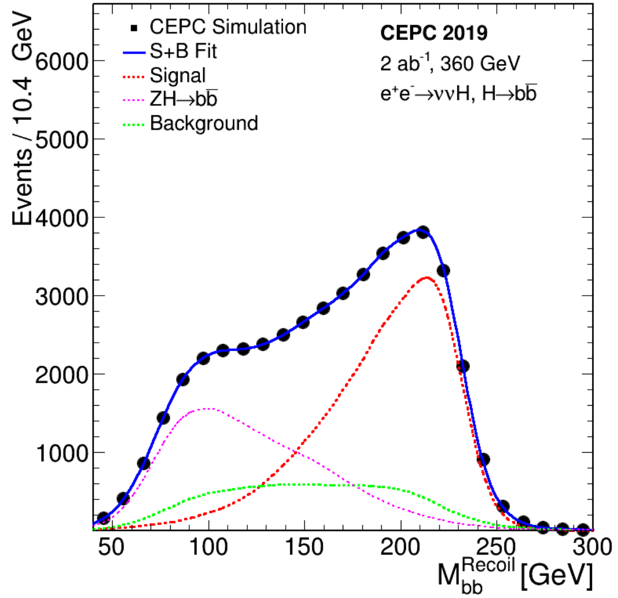
$$\Delta(\Gamma_H) \approx 1.4\%$$

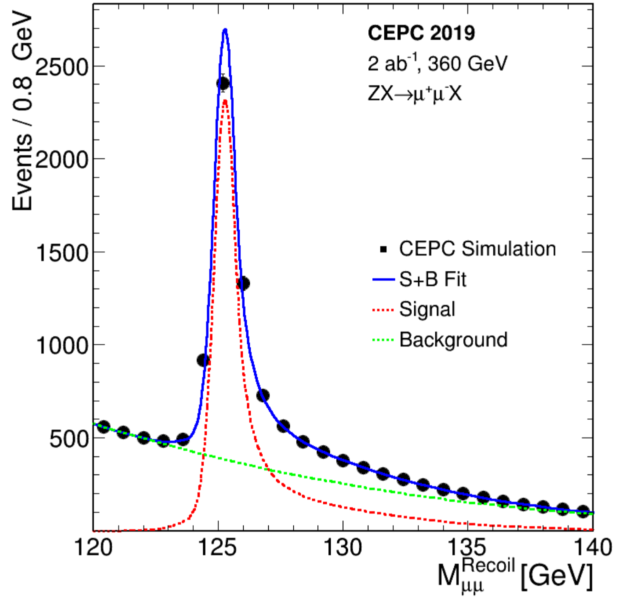
*: Here we do not have the assumption about the exotic decay. This treatment is different with Fcc-ee, which believes exotic Br could not <0.

If we take this assumption, the model-dependent width precision is 1.2%.

Results

	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	ννH
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%**
$H \to ZZ$	**7.9%**	**14%**	**15%**
$H \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$H \to \gamma\gamma$	**5.7%**	**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%**	**1.4%**	





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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
$H \rightarrow$ any	±0.5		±0.9	
$H \rightarrow b\bar{b}$	±0.3	±3.1	±0.5	±0.9
$H \rightarrow c\bar{c}$	±2.2		±6.5	±10
$H \rightarrow gg$	±1.9		±3.5	±4.5
$H \rightarrow W^+W^-$	±1.2		±2.6	±3.0
$H \rightarrow ZZ$	±4.4		±12	±10
$H \rightarrow \tau\tau$	±0.9		±1.8	±8
$H \rightarrow \gamma\gamma$	±9.0		±18	±22
$H \rightarrow \mu^+\mu^-$	±19		±40	
$H \rightarrow$ invisible	< 0.3		< 0.6	

Generally, CEPC and Fcc-ee results are comparable in Higgs precision measurement.
For Higgs coupling, also similar performance could be expected.

Synergy with other experiments

- The comparison is mainly referring [de Blas, J. *et al.* arXiv:1905.03764]
  - Also kappa and EFT results are shown between CEPC240, HL-LHC, Fcc, ILC……
  - In the paper, only CEPC 240GeV results included.

kappa-0	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC-ee/eh/hh
			S2	S2′	250	500	1000	380	15000	3000		240	365	
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12
κ_g [%]	2.3	3.6	1.9	1.2	2.3	0.97	0.66	2.5	1.3	0.9	1.5	1.7	1.0	0.49
κ_γ [%]	1.9	7.6	1.6	1.2	6.7	3.4	1.9	98⋆	5.0	2.2	3.7	4.7	3.9	0.29
$\kappa_{Z\gamma}$ [%]	10.	–	5.7	3.8	99⋆	86⋆	85⋆	120⋆	15	6.9	8.2	81⋆	75⋆	0.69
κ_c [%]	–	4.1	–	–	2.5	1.3	0.9	4.3	1.8	1.4	2.2	1.8	1.3	0.95
κ_t [%]	3.3	–	2.8	1.7	–	6.9	1.6	–	–	2.7	–	–	–	1.0
κ_b [%]	3.6	2.1	3.2	2.3	1.8	0.58	0.48	1.9	0.46	0.37	1.2	1.3	0.67	0.43
κ_μ [%]	4.6	–	2.5	1.7	15	9.4	6.2	320⋆	13	5.8	8.9	10	8.9	0.41
κ_τ [%]	1.9	3.3	1.5	1.1	1.9	0.70	0.57	3.0	1.3	0.88	1.3	1.4	0.73	0.44

kappa-3 scenario	HL-LHC+									
	ILC_{250}	ILC_{500}	ILC_{1000}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	FCC-ee_{240}	FCC-ee_{365}	FCC-ee/eh/hh
κ_W [%]	1.0	0.29	0.24	0.73	0.40	0.38	0.88	0.88	0.41	0.19
κ_Z[%]	0.29	0.22	0.23	0.44	0.40	0.39	0.18	0.20	0.17	0.16
κ_g[%]	1.4	0.85	0.63	1.5	1.1	0.86	1.	1.2	0.9	0.5
κ_γ [%]	1.4	1.2	1.1	1.4∗	1.3	1.2	1.3	1.3	1.3	0.31
$\kappa_{Z\gamma}$ [%]	10.∗	10.∗	10.∗	10.∗	8.2	5.7	6.3	10.∗	10.∗	0.7
κ_c [%]	2.	1.2	0.9	4.1	1.9	1.4	2.	1.5	1.3	0.96
κ_t [%]	3.1	2.8	1.4	3.2	2.1	2.1	3.1	3.1	3.1	0.96
κ_b [%]	1.1	0.56	0.47	1.2	0.61	0.53	0.92	1.	0.64	0.48
κ_μ [%]	4.2	3.9	3.6	4.4∗	4.1	3.5	3.9	4.	3.9	0.43
κ_τ [%]	1.1	0.64	0.54	1.4	1.0	0.82	0.91	0.94	0.66	0.46
BR_{inv} (<%, 95% CL)	0.26	0.23	0.22	0.63	0.62	0.62	0.27	0.22	0.19	0.024
BR_{unt} (<%, 95% CL)	1.8	1.4	1.4	2.7	2.4	2.4	1.1	1.2	1.	1.

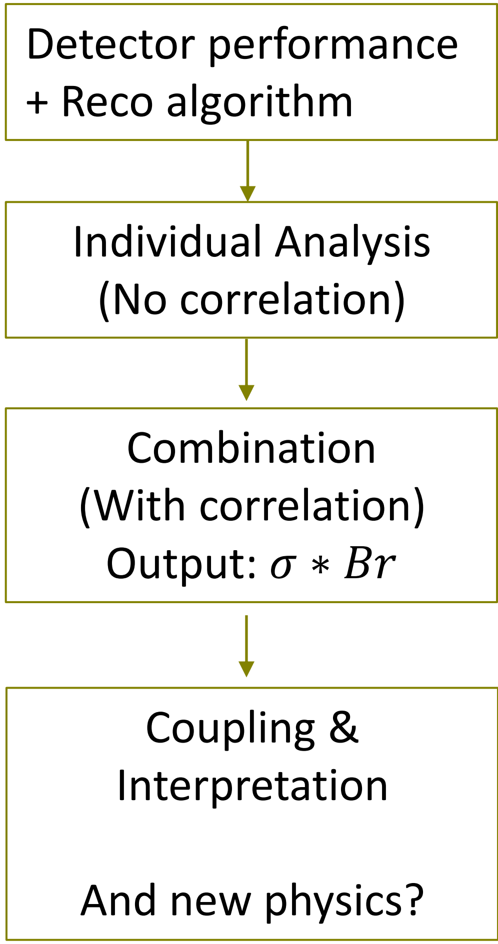
$$\Gamma_H = \frac{\Gamma_H^{SM} \cdot \kappa_H^2}{1 - (BR_{inv} + BR_{unt})}$$

Scenario	BR_{inv}	BR_{unt}	include HL-LHC
kappa-0	fixed at 0	fixed at 0	no
kappa-1	measured	fixed at 0	no
kappa-2	measured	measured	no
kappa-3	measured	measured	yes

Though CEPC@360GeV not included in the synergy, we expect similar performance compared to Fcc-ee.

Evolving Combination

- Good enough results, still a lot of to do
  - Due to limited manpower, analysis update slowly.
  - Many progress from Accelerator, Detector, and object performance since CDR didn't enter the combination yet.
  - Still need to understand the correlation
    - More powerful tools: HEPFit? Matrix method?
  - Far from the CEPC fully/ultimate potential. 1M Higgs!
    - Gang would give a fancy report about the global fit in CEPC later.



- Your effort would be appreciate!

Summary

- Latest CEPC Higgs combination, $\sigma * \mathrm{Br}$ and coupling results are shown.
  - Correlation considered.
- Extrapolation to 360GeV applied
  - Temporary benchmark showed ~1.4% precision for width.
  - Comparable with Fcc-ee.
- Many are done, more to be carried out

	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	ννH
any	**0.50%**	**1%**	\
$\mathrm{H} \to \mathrm{bb}$	**0.27%**	**0.63%**	**0.76%**
$\mathrm{H} \to \mathrm{cc}$	**3.3%**	**6.2%**	**11%**
$\mathrm{H} \to \mathrm{gg}$	**1.3%**	**2.4%**	**3.2%**
$\mathrm{H} \to \mathrm{WW}$	**1.0%**	**2.0%**	**3.1%**
$\mathrm{H} \to \mathrm{ZZ}$	**7.9%**	**14%**	**15%**
$\mathrm{H} \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$\mathrm{H} \to \gamma\gamma$	**5.7%**	**8%**	**11%**
$\mathrm{H} \to \mu\mu$	**12%**	**29%**	**40%**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.2%**	\	\
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**	**25%**	\
Width	**2.9%**	**1.4%**	

backups

$\sigma(ZH)$: H→inclusive

- Possible by tagging higgs with recoil mass
- Zhenxing, arxiv:1601.05352
  - Z → ee, 1.4%; Z→$\mu\mu$, 0.9%;
    - model independently
  - Z→qq: 0.65%, by Janice
    - extrapolated from 1404.3164
  - Combined: 0.5%
- $\sigma(ZH)$ correlations

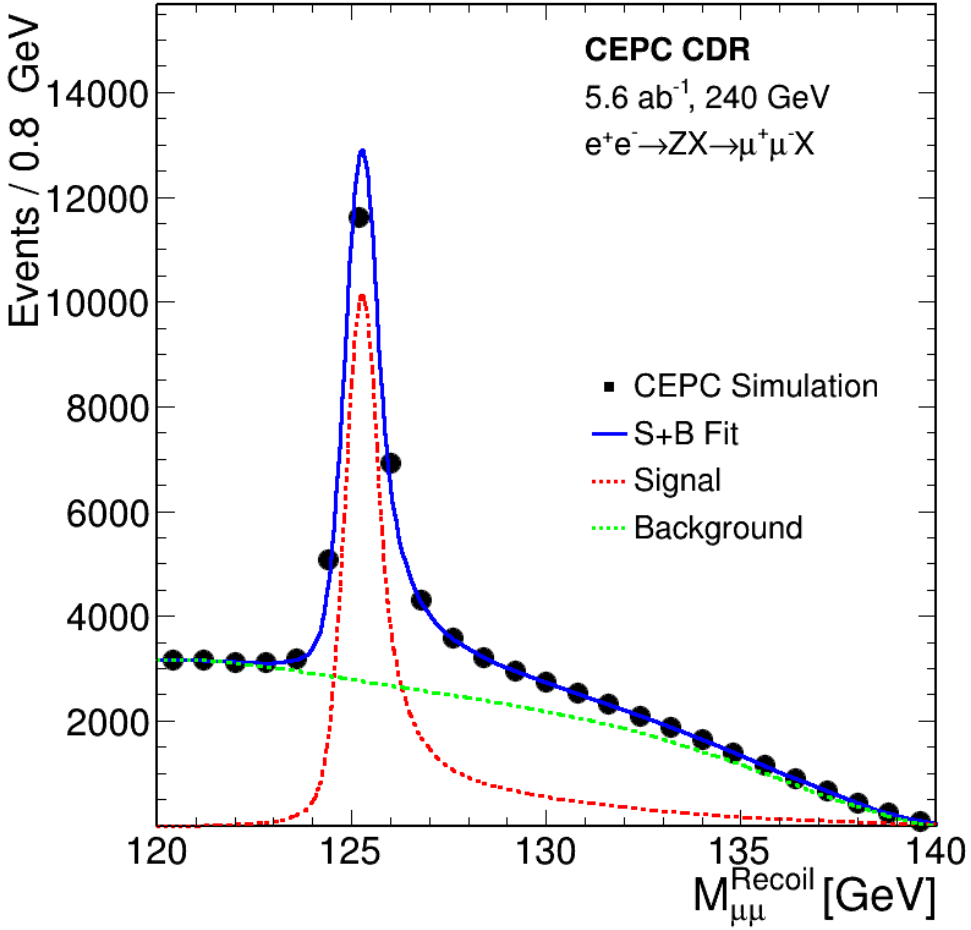


Table 3. Estimation of biases of σ_{ZH} caused by potential variances of the Higgs decay branching ratios.

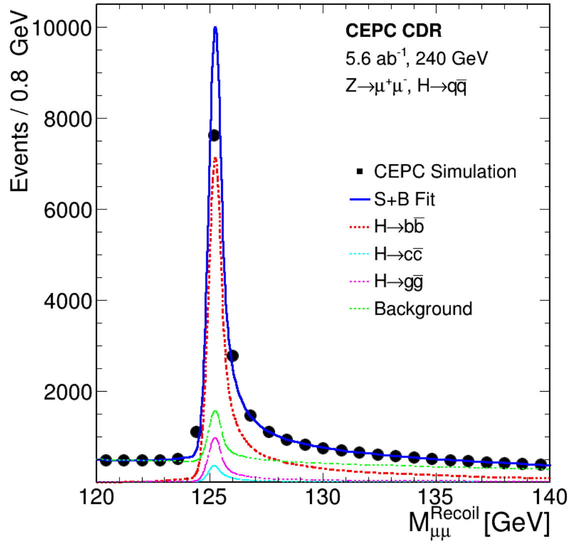
Decay mode	Bias($\times 10^{-4}$)
$H\to b\bar{b}$	-0.10
$H\to WW$	+0.20
$H\to gg$	-0.18
$H\to \tau\tau$	+1.11
$H\to c\bar{c}$	+0.05
$H\to ZZ$	-1.85
$H\to \gamma\gamma$	+2.56
$H\to \gamma Z$	-2.08
$H\to$ inv.	+5.75

Full hadronic jets: bb/cc/gg/WW/ZZ

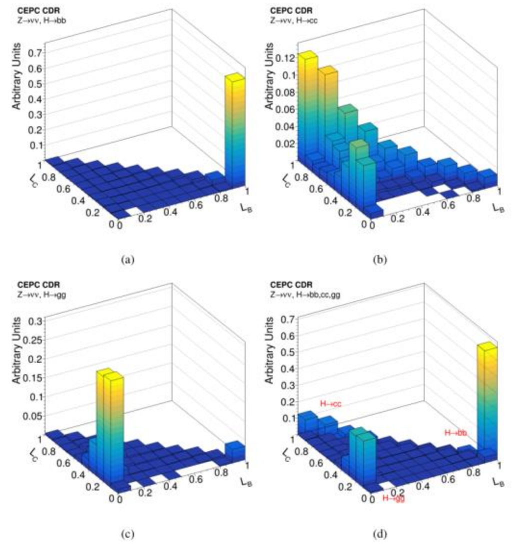
See: 1905.12903;

- Heavily relies on jet clustering algorithm; Hard to separate.
- 3d template fit
  - Mass
  - Dijet’s B likeness and C likeness
- (Z → vv H → bb excluded the vvH part)
- Still, WW/ZZ suffered from the huge ZH events

Scan	μ_bb	μ_cc	μ_gg
eeH	1.3%	13.5%	7.2%
mmH	1.0%	9.5%	5.0%
qqH	0.5%	11.1%	3.6%
vvH	0.4%	3.8%	1.5%
Combined	0.28%	3.3%	1.3%



- Plan to apply categories like “STXS” to avoid the overlap.

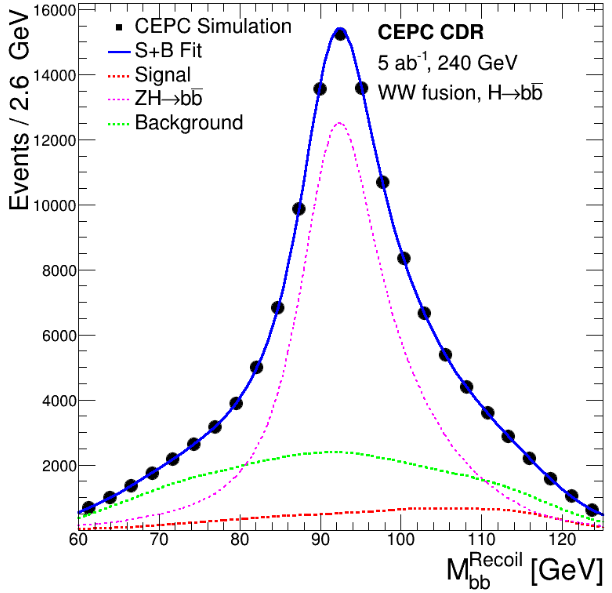


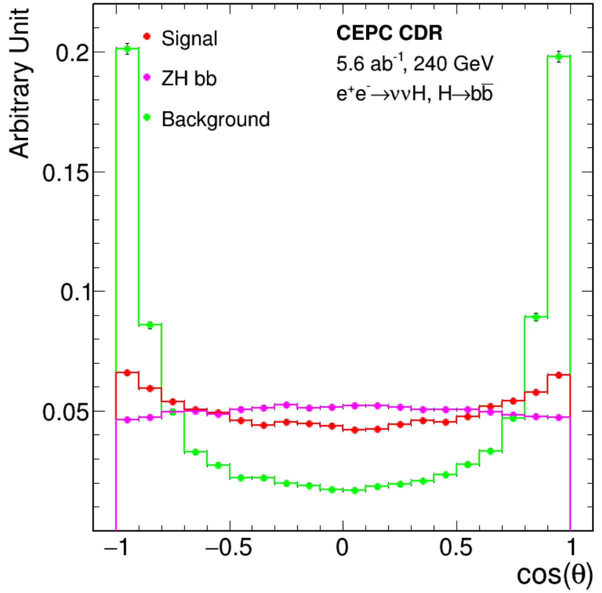
- See more in Baiyu’s slides!

Current combination didn’t use the full hadronic W/Z
and b/c/g correlation value. More study are needed to understand.

$vvH \to bb$

- 2d fit M_{jj}^{reco} & $\text{Cos}\ \theta_{jj}$
- $vvH \to bb$ and $ZH \to bb$
    - Interference ~10% of vvH. (generally, 60: 1 : 10)
        - Add the interference term to vvH side currently;
    - If fix ZH process, Initial uncertainty is 2.8%.
    - ZH->bb constrained by other bb channels. If not, would be 3.4%.
    - $vvH \to bb$ and $ZH \to bb$ share the anti-correlation -45%. (-34% in ILC(1708.08912))
- $\sigma(vvH) * Br$： 3.0% ;
    - $\sigma(vvH)$: 3.2%.

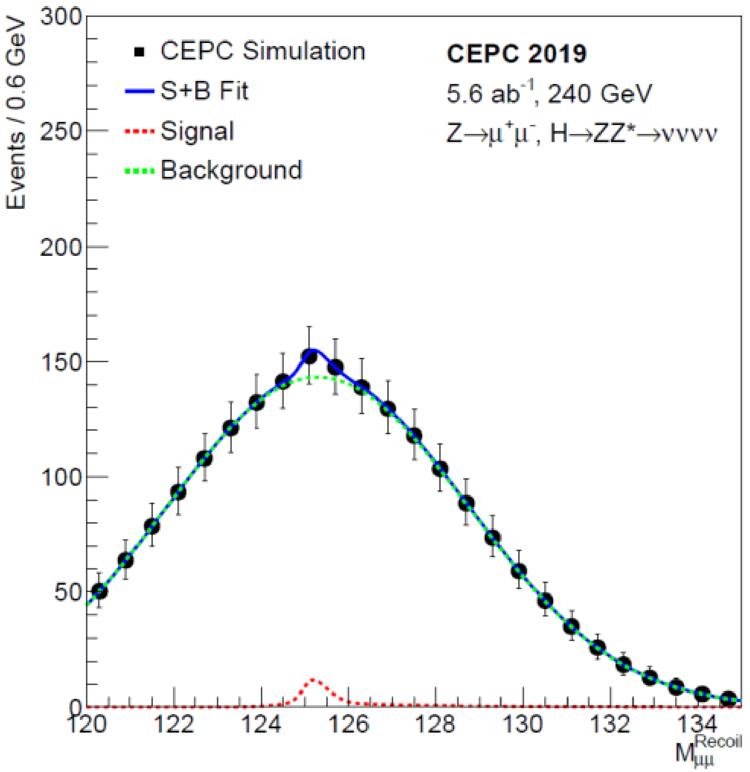




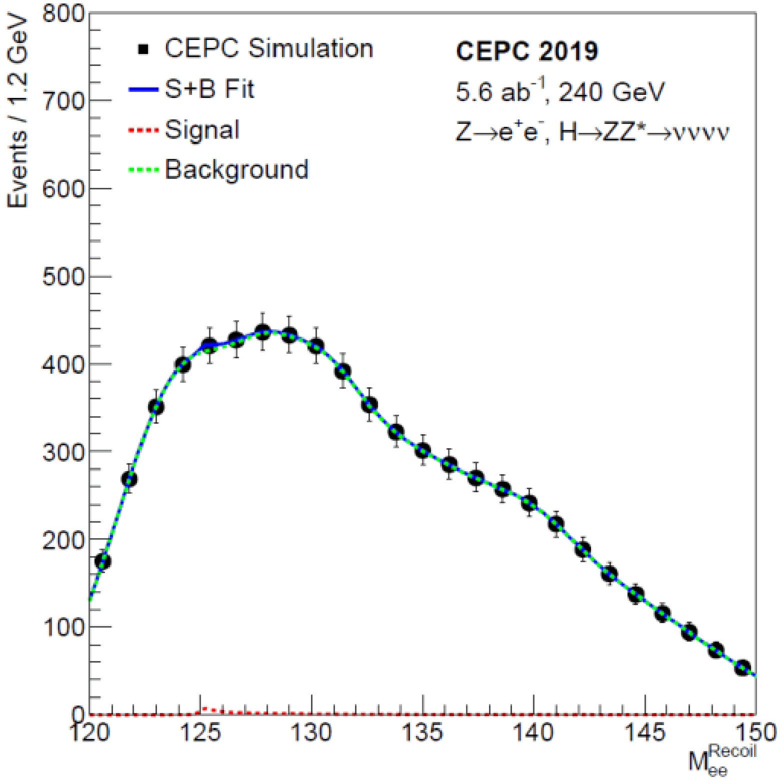
Invisible

See 2001.05912;

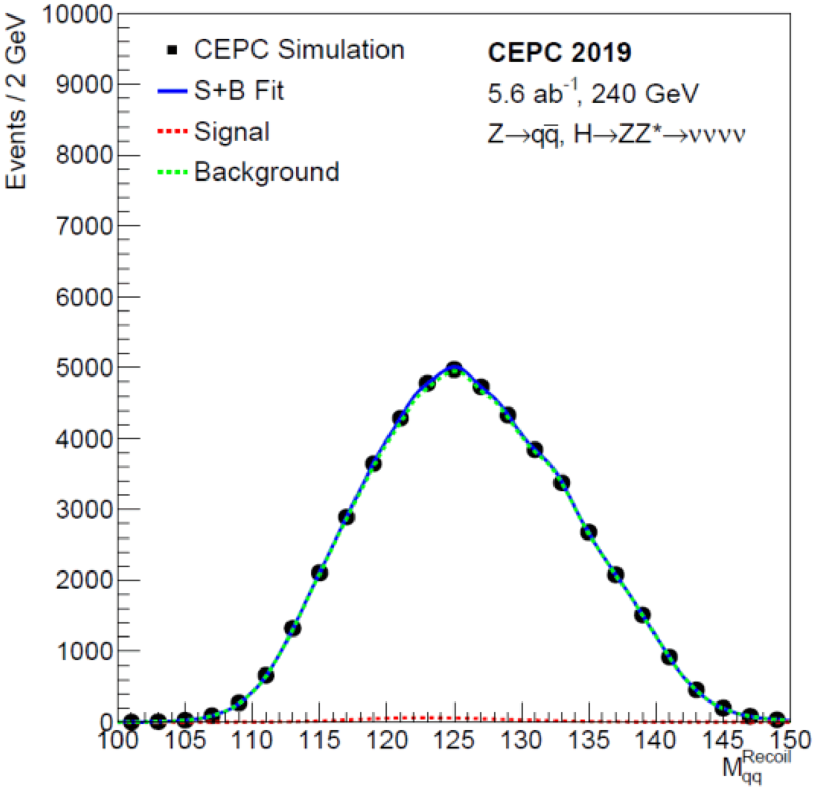
ZH final state studied	Relative precision on $\sigma(ZH)\times$BR	Upper limit on BR (H→inv.)
Z→ e^+e^-, H→inv.	403%	0.96%
Z→ $\mu^+\mu^-$, H→inv.	98%	0.31%
Z→ $q\bar{q}$, H→inv.	85%	0.29%
Combination	63%	0.24%



ZH(Z->$\mu^+\mu^-$,H->invisible)



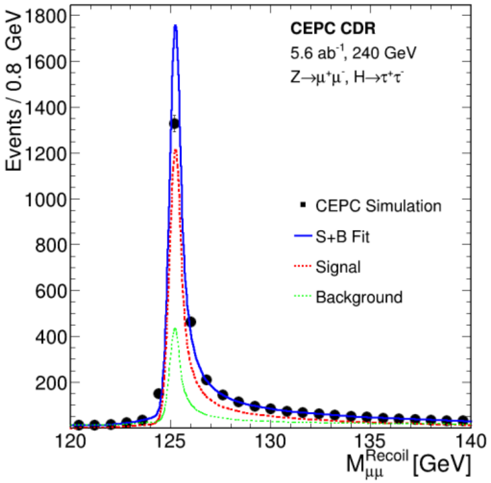
ZH(Z->e^+e^-,H->invisible)



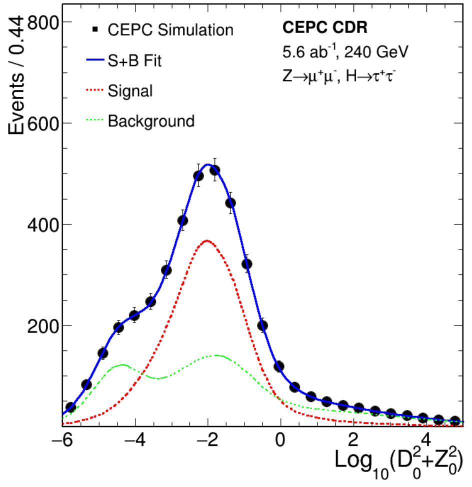
ZH(Z->qq,H->invisible)

$\tau\tau$, $\mu\mu$

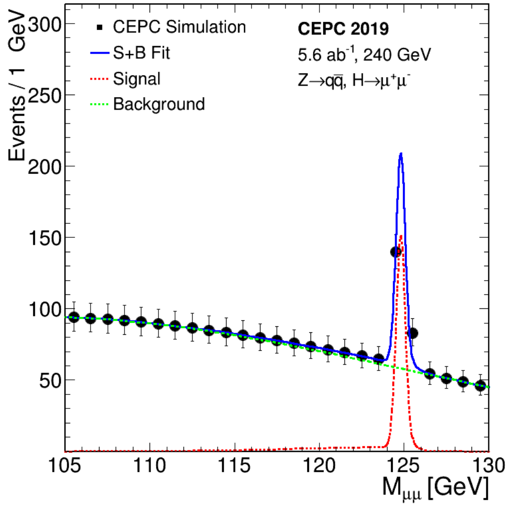
- $\tau\tau$: 1903.12327;
  - Develop LICH to identify lepton. Eff>99%
  - Signal and ZH events(Main WW) share the same shape
  - use $\log_{10}(D_0^2 + Z_0^2)$ + mass 2d fit to separate signal
    - Impact parameter, Distance from beam spot
- $\mu\mu$
  - See more in Kunlin's slides



ZH final state		Precision
$Z\to\mu^+\mu^-$	$H\to\tau^+\tau^-$	2.6%
$Z\to e^+e^-$	$H\to\tau^+\tau^-$	2.7%
$Z\to\nu\bar{\nu}$	$H\to\tau^+\tau^-$	2.5%
$Z\to q\bar{q}$	$H\to\tau^+\tau^-$	0.9%
Combination		0.8%



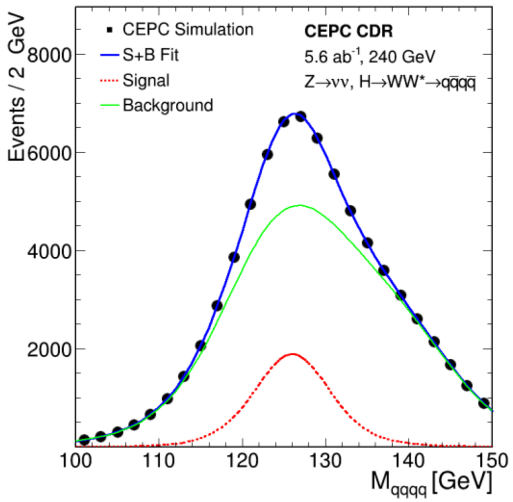
	qqh_e2e2		
[%]	Stat	Eff	Rel
Initial	148.85	100	100
N_mum > 0, N_mup > 0	148	99.43	99.43
105 < M_mumu < 130 GeV	123.75	83.14	83.62
25 < N_particle < 115	123.02	82.64	99.41
55 < M_qq < 125 GeV	122.02	81.97	99.19
P_ppmumu < 32 GeV, 195 < E_ppmumu < 265 GeV	121.32	81.51	99.43
35 < E_mum < 100 GeV, 35 < E_mup < 100 GeV	120.89	81.22	99.65
16 < p_mumu < 72 GeV	120.31	80.82	99.51
N_em < 6, N_ep < 6, N_e < 10	119.33	80.17	99.19
E_em < 10 GeV, E_ep < 10 GeV, E_ee < 19 GeV	116	77.93	97.21
124 < m_mumu < 125 GeV	73.27	49.22	63.17

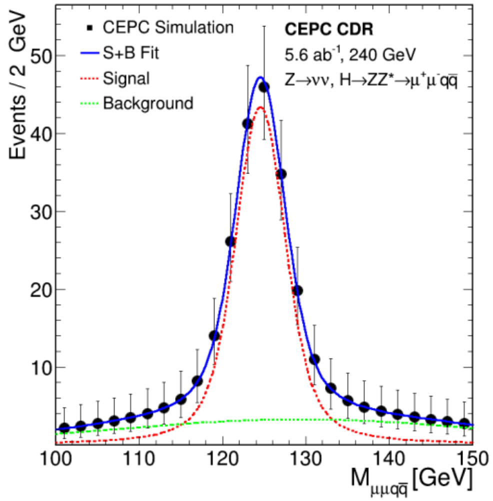


WW, ZZ

- ZZ: 2103.09633;
  - CDR ZZ results a bit overestimated;
  - Current ZZ 7.9% didn’t include all the possible ZZ channels yet,
  - Still have room to improve.

Category	$\frac{\Delta(\sigma \cdot BR)}{(\sigma \cdot BR)}$ [%] cut-based	BDT
$\mu\mu H\nu\nu qq^{\mathrm{cut/mva}}$	15	14
$\mu\mu H qq\nu\nu^{\mathrm{cut/mva}}$	48	42
$\nu\nu H\mu\mu qq^{\mathrm{cut/mva}}$	12	12
$\nu\nu H qq\mu\mu^{\mathrm{cut/mva}}$	23	20
$qqH\nu\nu\mu\mu^{\mathrm{cut/mva}}$	45	37
$qqH\mu\mu\nu\nu^{\mathrm{cut/mva}}$	52	44
Combined	8.3	7.9

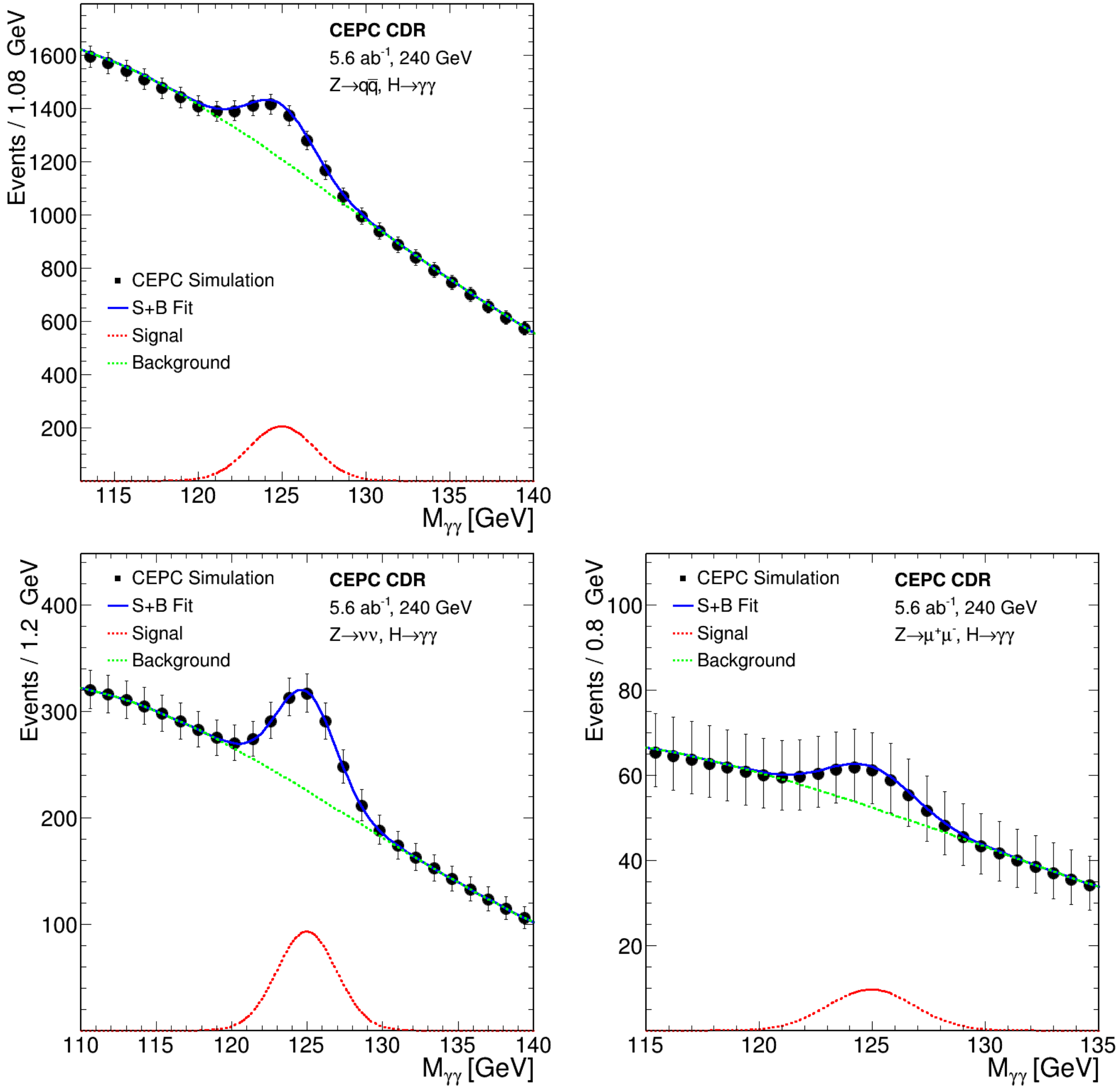




- WW
  - Much more channels studied since Pre_CDR.

	Z	ee	μμ	νν	qq
WW	eν+eν				
	μν+μν				
	eν+μν				
	eν+qq				
	μν+qq				
	qq+qq				

H→ $\gamma\gamma$



- Use $m_{\gamma\gamma}$ and MVA.
- Photon convention not counted in current study.

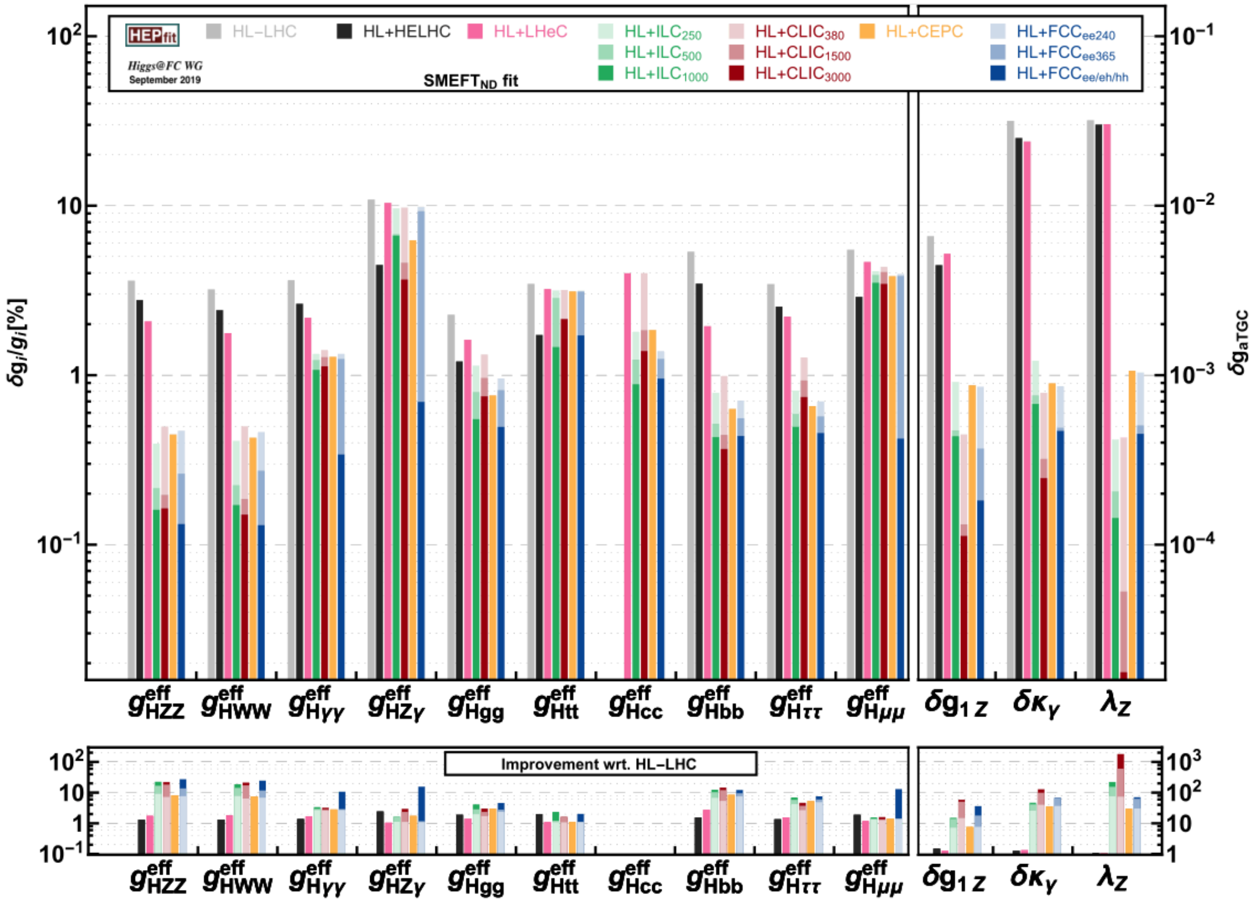
Results based in CEPC-v4 layout,

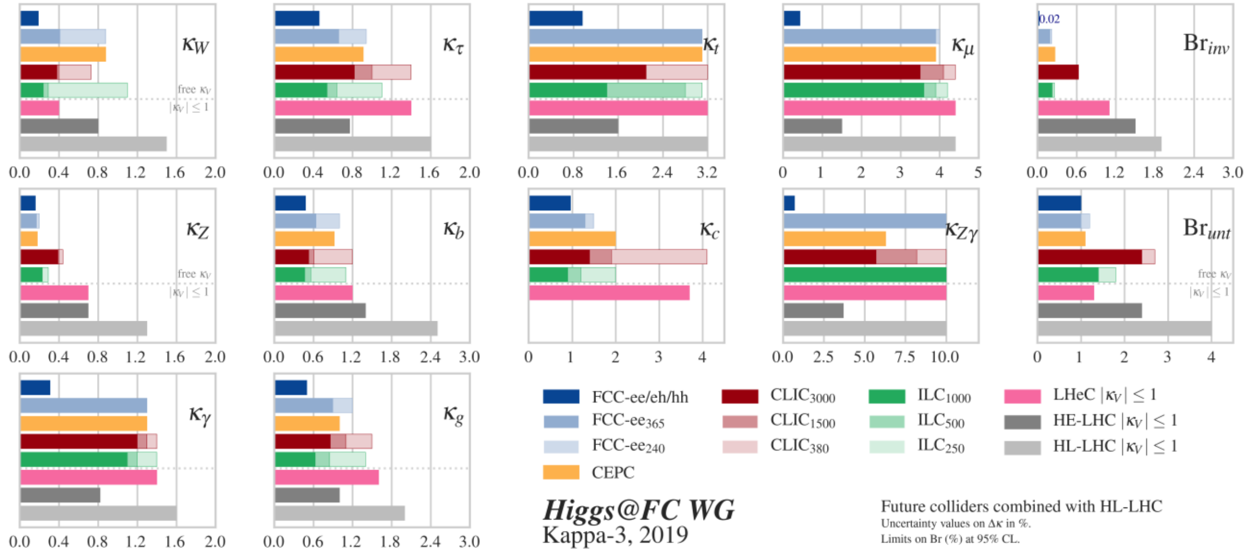
16% Ecal resolution.

Recent study done by Fangyi showed,

Crystal Ecal, 5% resolution would make the results 23% better.

Kappa / EFT Synergies





Though I am not the expert on this……
It looks fine.

Synergy with other experiments

From: 1905.03764v2

kappa-0	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC-ee/eh/hh
			S2	S2′	250	500	1000	380	15000	3000		240	365	
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12
κ_g [%]	2.3	3.6	1.9	1.2	2.3	0.97	0.66	2.5	1.3	0.9	1.5	1.7	1.0	0.49
κ_γ [%]	1.9	7.6	1.6	1.2	6.7	3.4	1.9	98⋆	5.0	2.2	3.7	4.7	3.9	0.29
$\kappa_{Z\gamma}$ [%]	10.	–	5.7	3.8	99⋆	86⋆	85⋆	120⋆	15	6.9	8.2	81⋆	75⋆	0.69
κ_c [%]	–	4.1	–	–	2.5	1.3	0.9	4.3	1.8	1.4	2.2	1.8	1.3	0.95
κ_t [%]	3.3	–	2.8	1.7	–	6.9	1.6	–	–	2.7	–	–	–	1.0
κ_b [%]	3.6	2.1	3.2	2.3	1.8	0.58	0.48	1.9	0.46	0.37	1.2	1.3	0.67	0.43
κ_μ [%]	4.6	–	2.5	1.7	15	9.4	6.2	320⋆	13	5.8	8.9	10	8.9	0.41
κ_τ [%]	1.9	3.3	1.5	1.1	1.9	0.70	0.57	3.0	1.3	0.88	1.3	1.4	0.73	0.44

kappa-3 scenario	HL-LHC+									
	ILC_{250}	ILC_{500}	ILC_{1000}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	FCC-ee_{240}	FCC-ee_{365}	FCC-ee/eh/hh
κ_W [%]	1.0	0.29	0.24	0.73	0.40	0.38	0.88	0.88	0.41	0.19
κ_Z[%]	0.29	0.22	0.23	0.44	0.40	0.39	0.18	0.20	0.17	0.16
κ_g[%]	1.4	0.85	0.63	1.5	1.1	0.86	1.	1.2	0.9	0.5
κ_γ [%]	1.4	1.2	1.1	1.4∗	1.3	1.2	1.3	1.3	1.3	0.31
$\kappa_{Z\gamma}$ [%]	10.∗	10.∗	10.∗	10.∗	8.2	5.7	6.3	10.∗	10.∗	0.7
κ_c [%]	2.	1.2	0.9	4.1	1.9	1.4	2.	1.5	1.3	0.96
κ_t [%]	3.1	2.8	1.4	3.2	2.1	2.1	3.1	3.1	3.1	0.96
κ_b [%]	1.1	0.56	0.47	1.2	0.61	0.53	0.92	1.	0.64	0.48
κ_μ [%]	4.2	3.9	3.6	4.4∗	4.1	3.5	3.9	4.	3.9	0.43
κ_τ [%]	1.1	0.64	0.54	1.4	1.0	0.82	0.91	0.94	0.66	0.46
BR_{inv} (<%, 95% CL)	0.26	0.23	0.22	0.63	0.62	0.62	0.27	0.22	0.19	0.024
BR_{unt} (<%, 95% CL)	1.8	1.4	1.4	2.7	2.4	2.4	1.1	1.2	1.	1.