CEPC Coupling Fits

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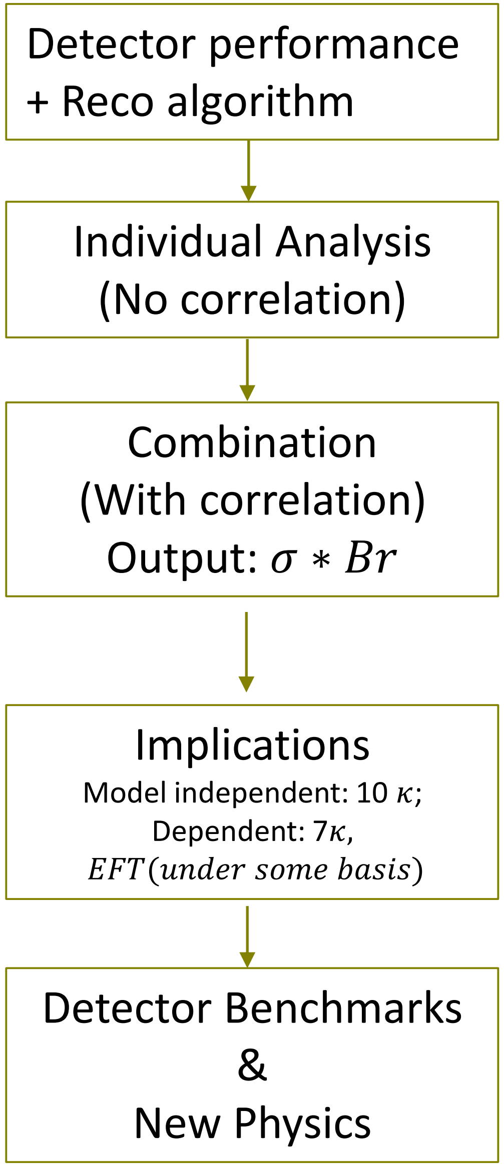
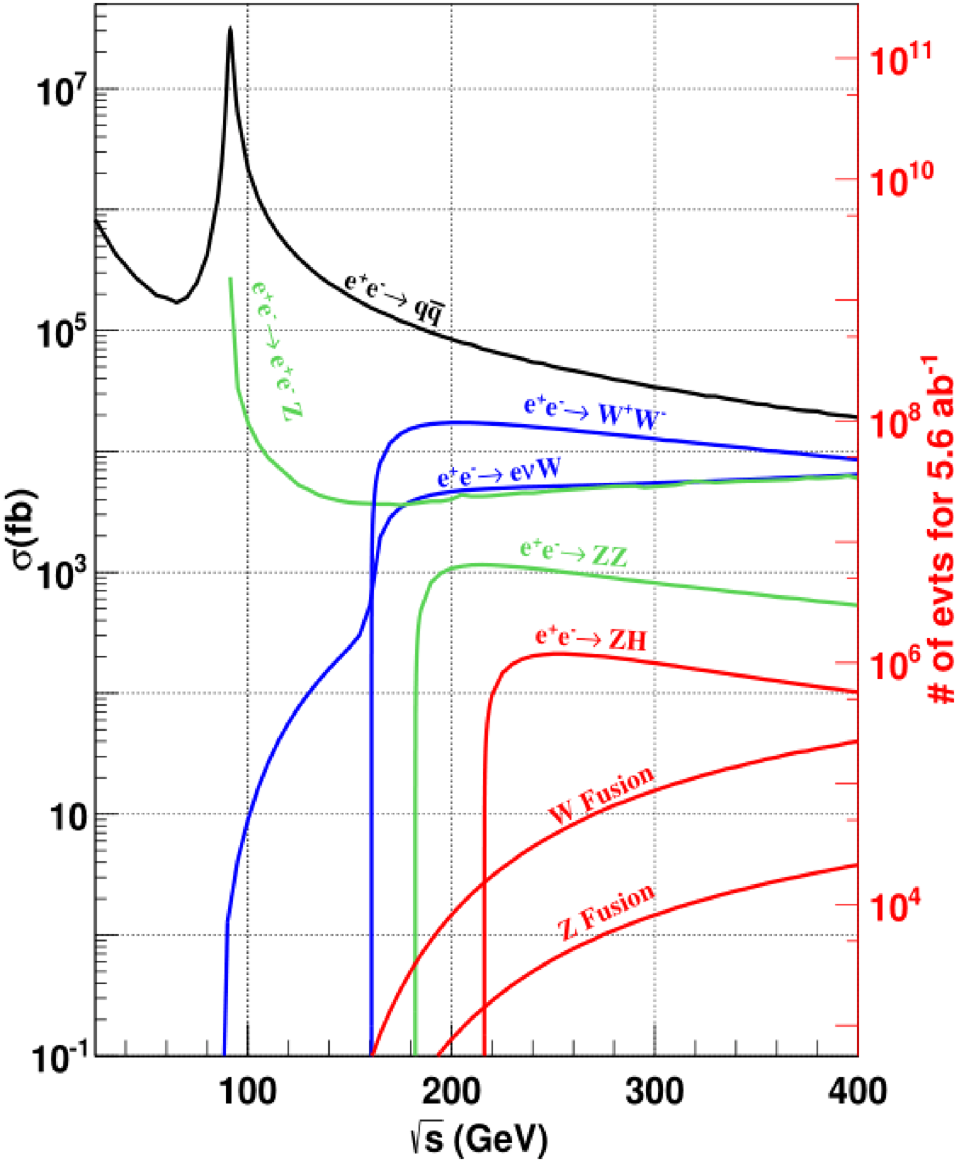
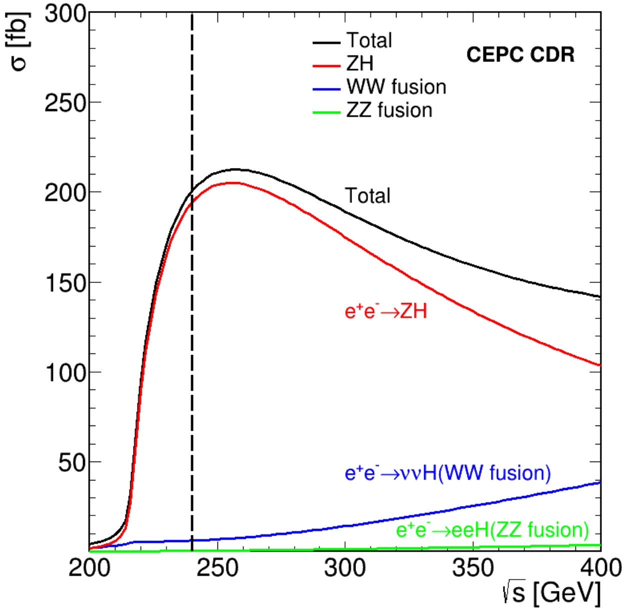
Outline

- CEPC Physics
- κ framework
- EFT Model results
- Synergy with other experiments
- To dos & Summary



Higgs Physics @ CEPC



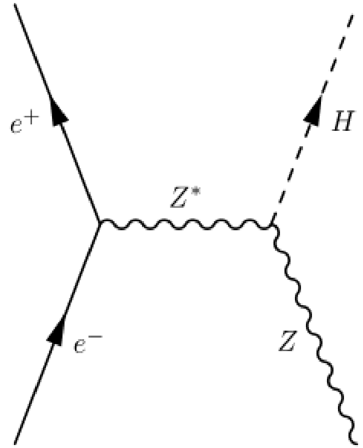


CEPC CDR: arxiv:1811.10545

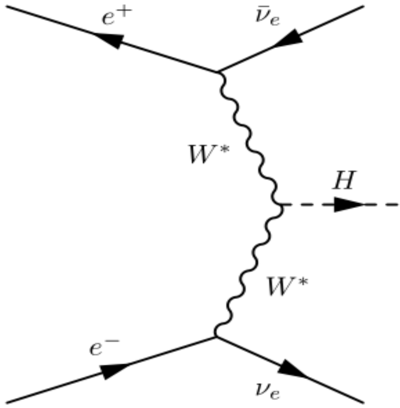
White Paper: arxiv:1810.09037

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

ZH:



vvH:



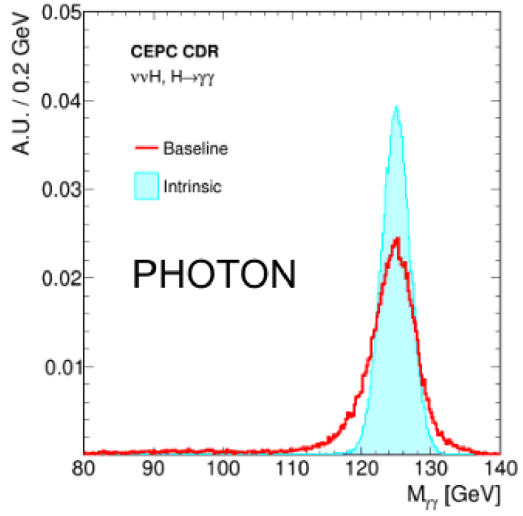
Process	Cross section	Events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	196.2	1.10×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^- \to e^+e^- H$	0.28	1.57×10^3
Total	203.7	1.14×10^6

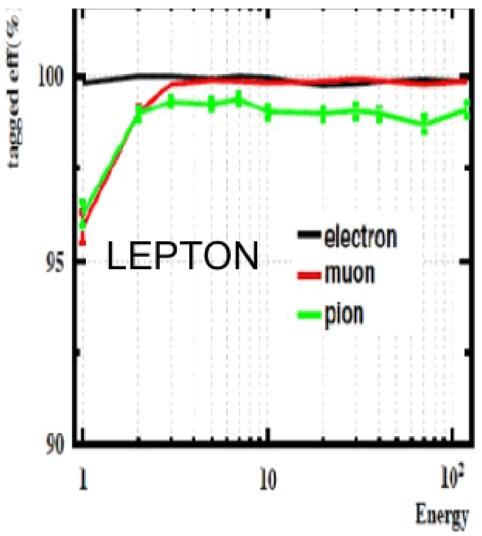
CEPC object performance

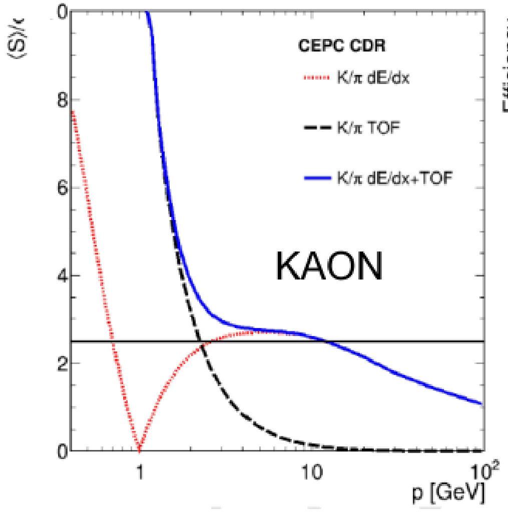
See more in Manqi's slides

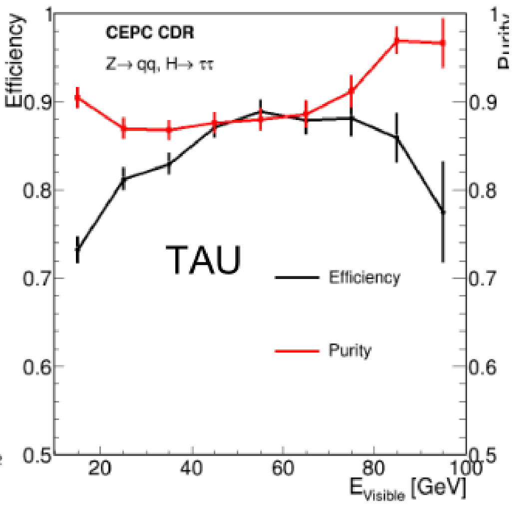
Eur. Phys. J. C (2017) 77: 591

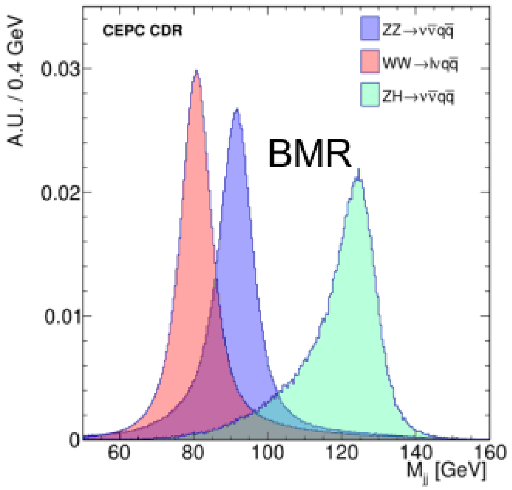
Eur. Phys. J. C (2018) 78:464

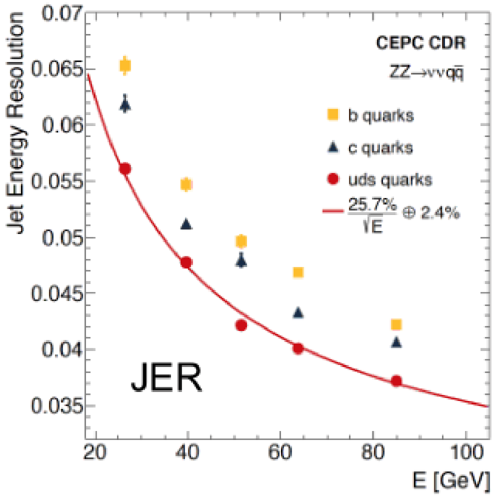


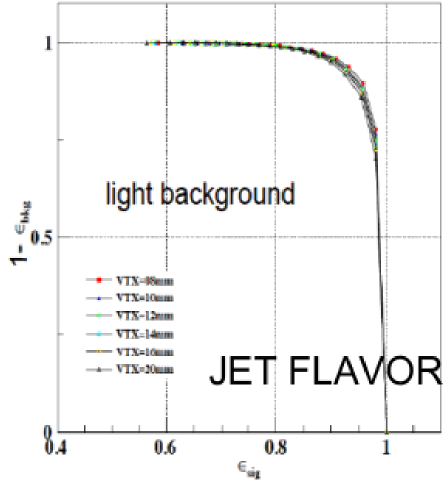


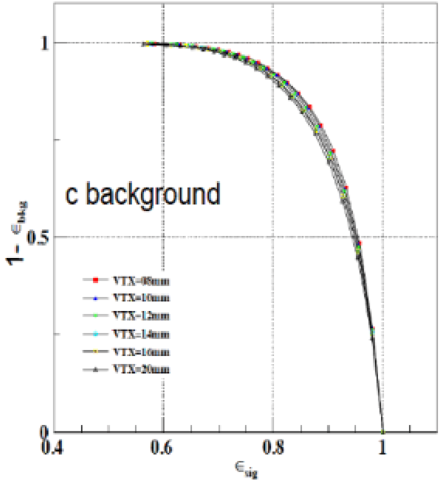






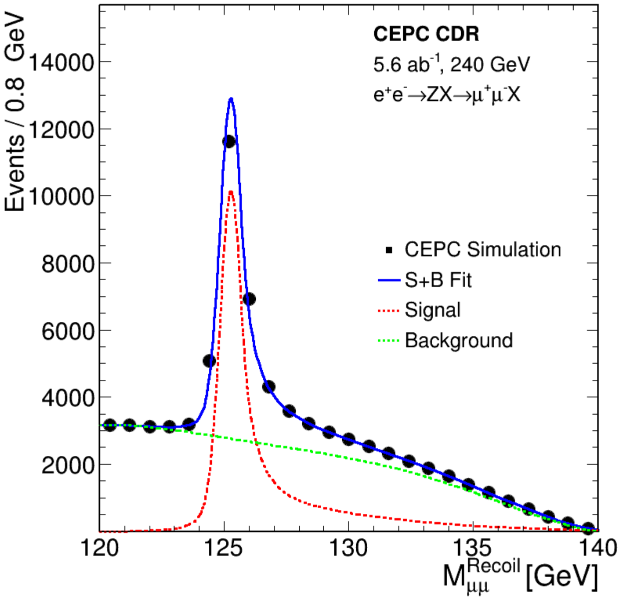


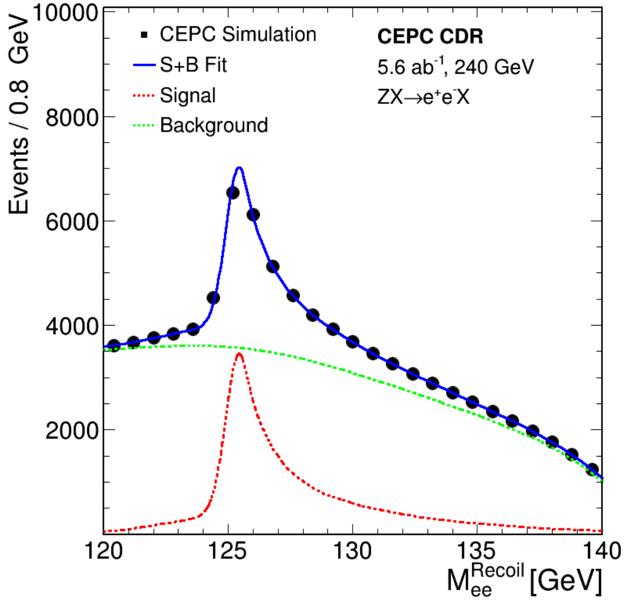


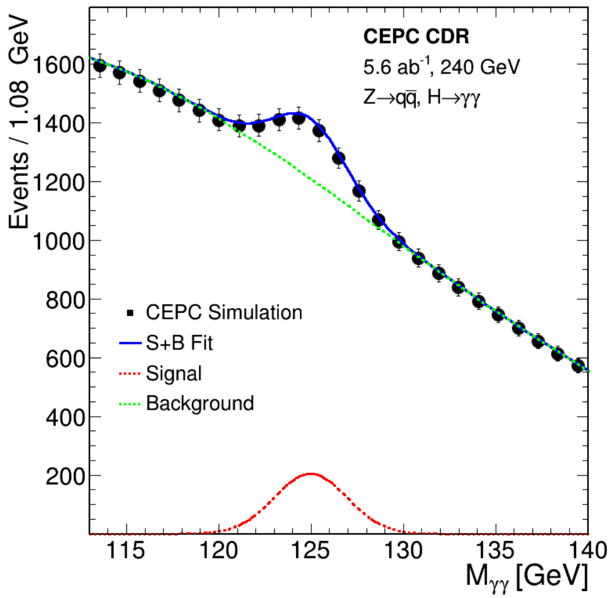


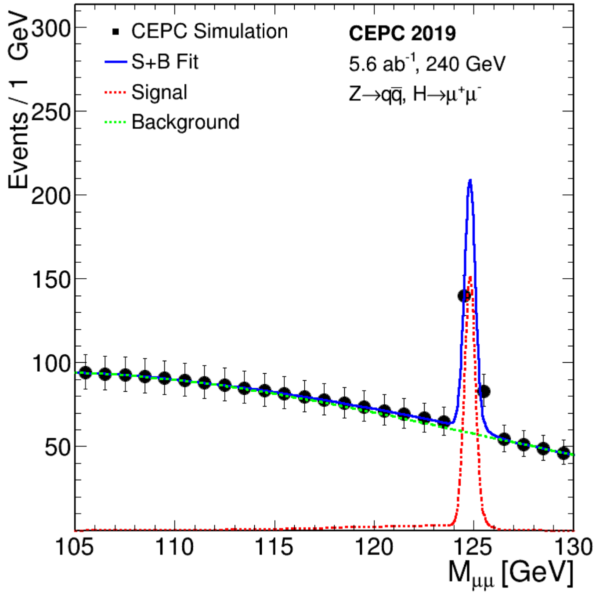
Eur. Phys. J. C (2018) 78: 426

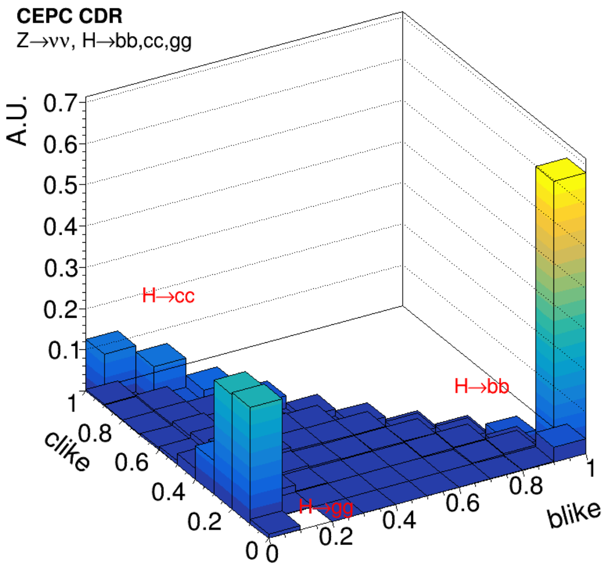
Individual sub channels

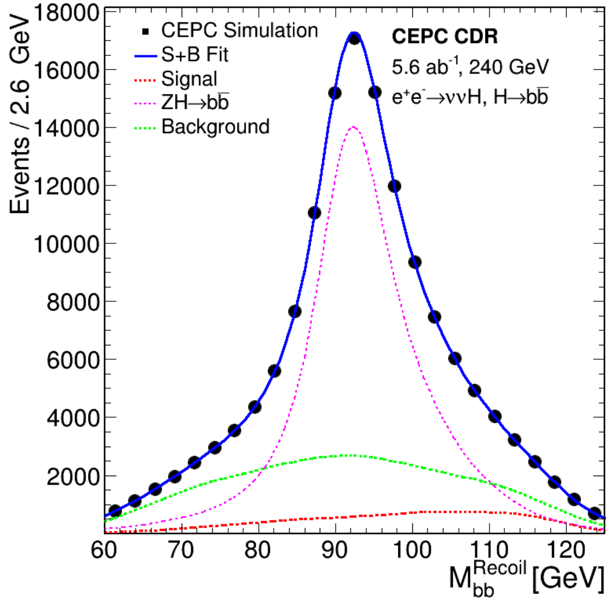


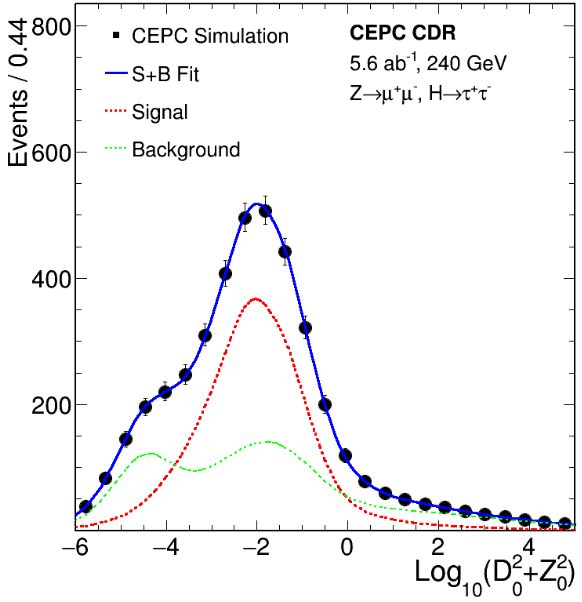












Related publications

for each channel:

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

Individual sub channels

(240GeV,5.6ab^{-1})	CDR, (2018)	Current: 2019.11	Reports in this workshop
$\sigma(ZH)$	**0.50%**		
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**0.27%**		Yu Bai
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	**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%**		Ryuta Kiuchi
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	**0.8%**		Dan Yu
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	**6.8%**	**5.4%**	Fangyi Guo
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	**17%**	**12%**	
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**3.0%**		Hao Liang
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.41%**	**0.2%**	Ryuta Kiuchi
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**		
Width	**2.8%**		

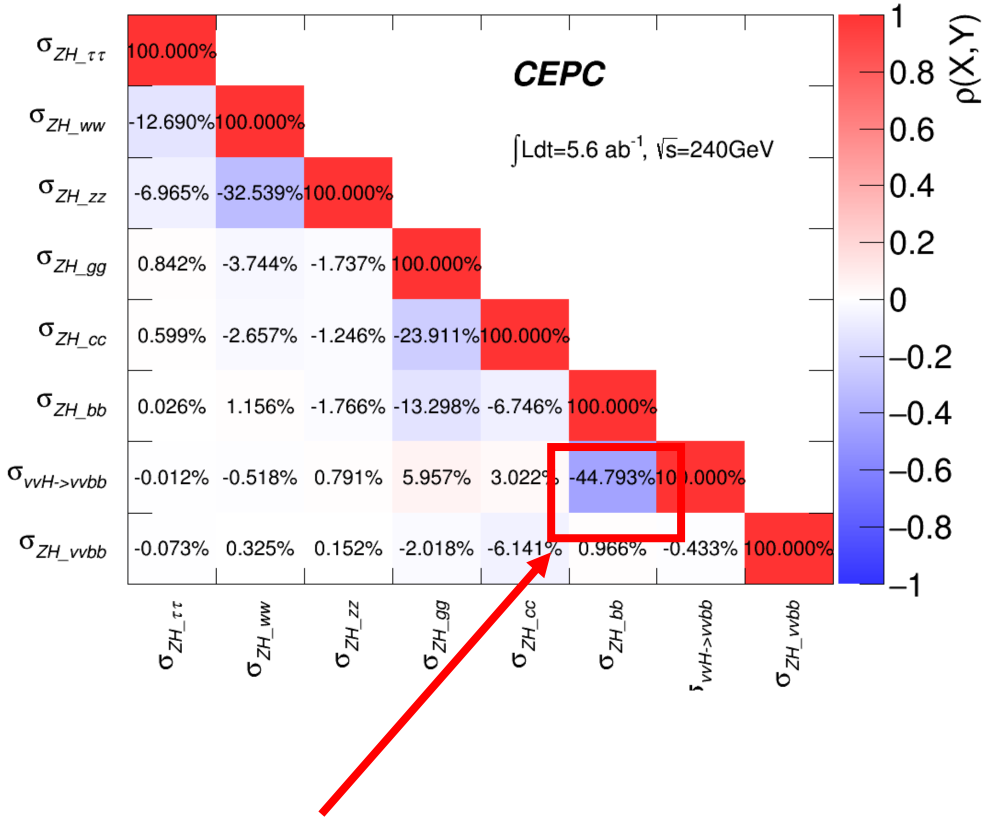
Keep analysis evolving since CDR published. Several results improved from the better analysis strategy.
For each channel, see more details in backups.

To test the expected precision CEPC could ever reach, 1-sigma Gaussian uncertainty of the signal strength(Fix μ, $\sigma * Br = 1$) is used to quantify performance except the invisible channel.

Only statistical uncertainty considered in the table. It is said that theoretic systematics could be small(<1%) on lepton collider.

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



κ framework

- Higgs coupling defined as:

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

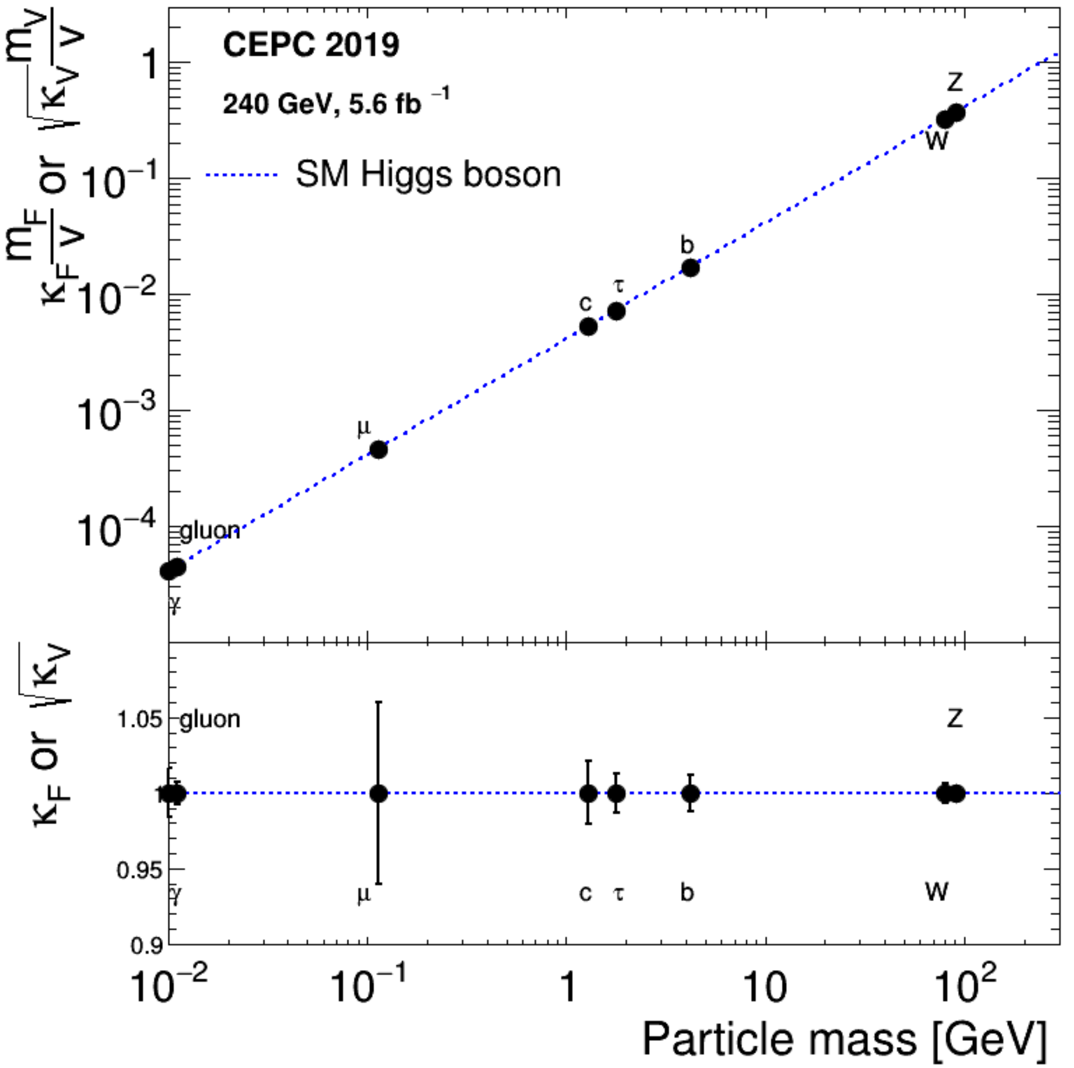
$$\sigma(\text{vv}H) * \text{Br}(\text{H} \to \text{bb}) \propto \kappa_{\text{w}}^2 * \kappa_{\text{b}}^2 / \Gamma_H.$$

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

and all other channel suffered from Higgs width.

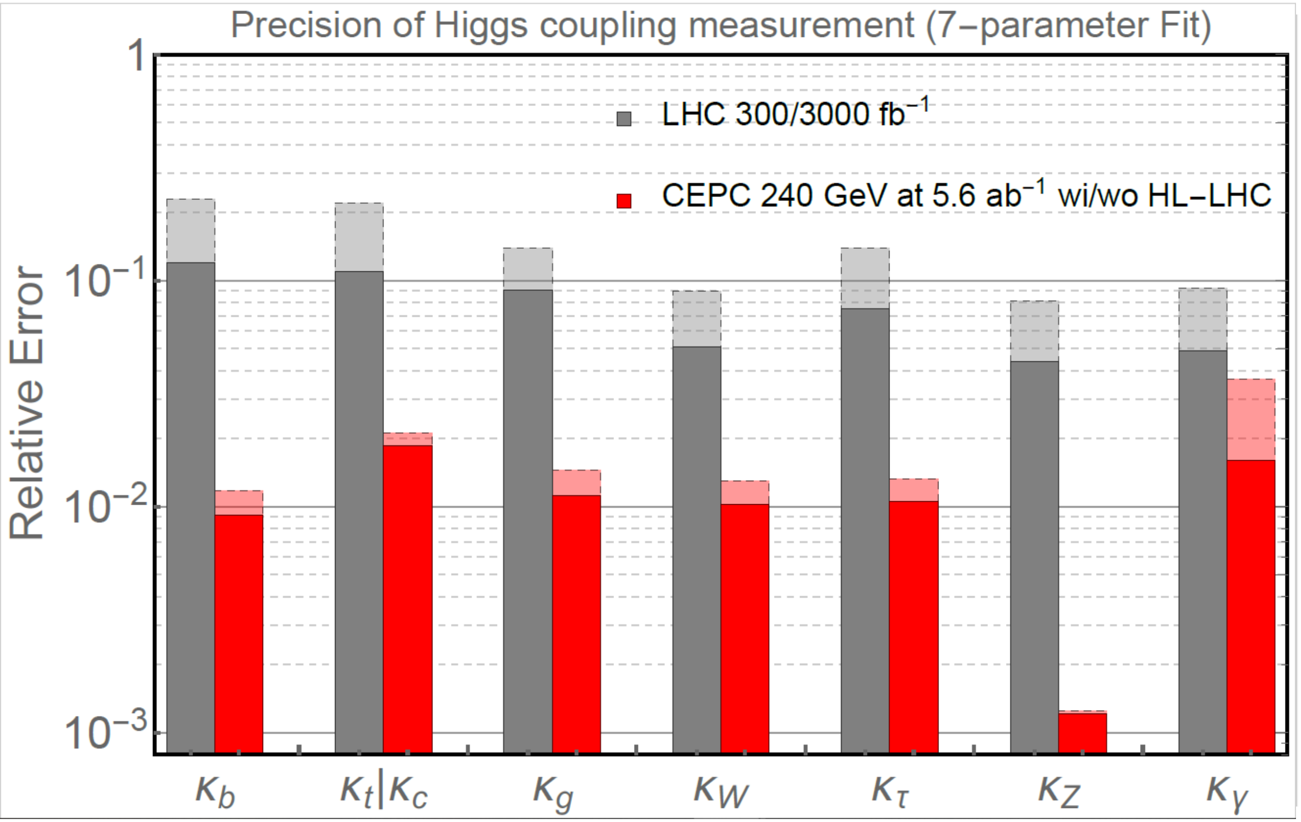
Extract width with branch ratio: Constrained 7-κ

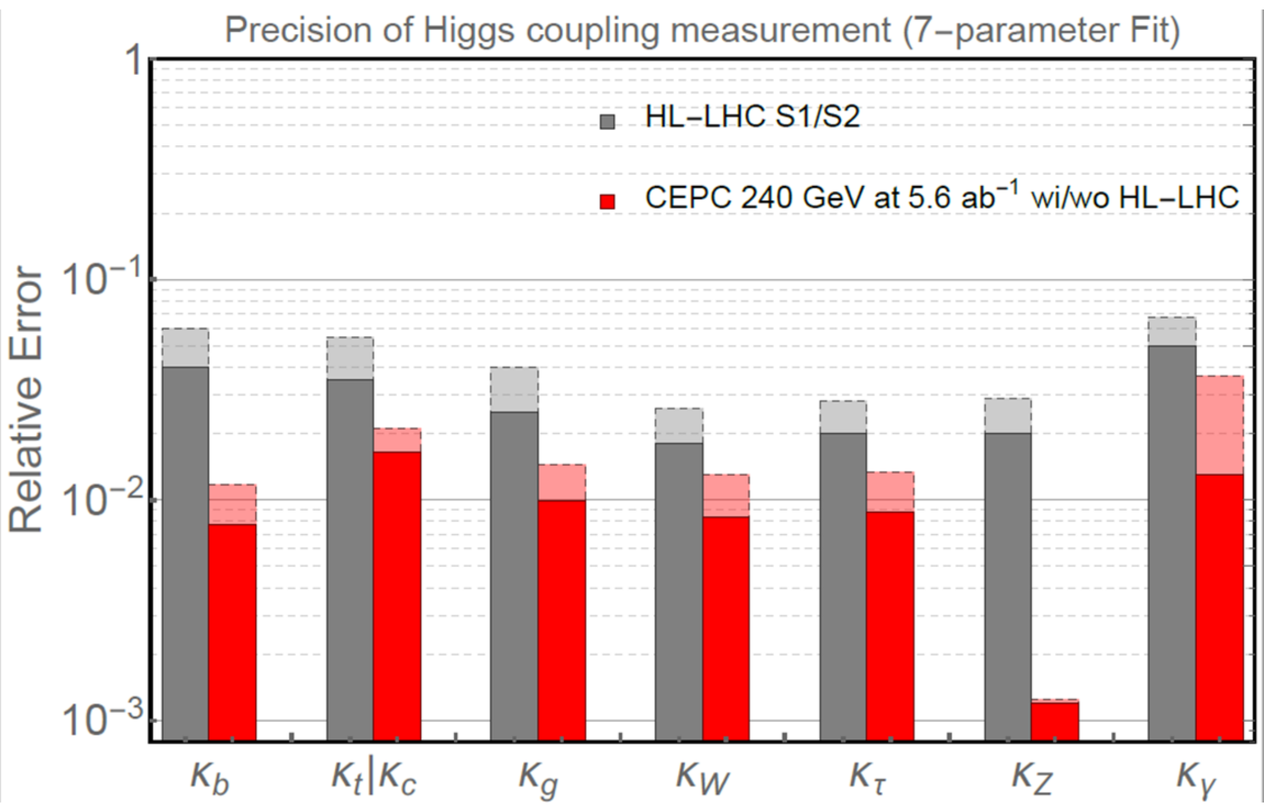
Keep width independent: 10 κ



Constrained 7-κ framework

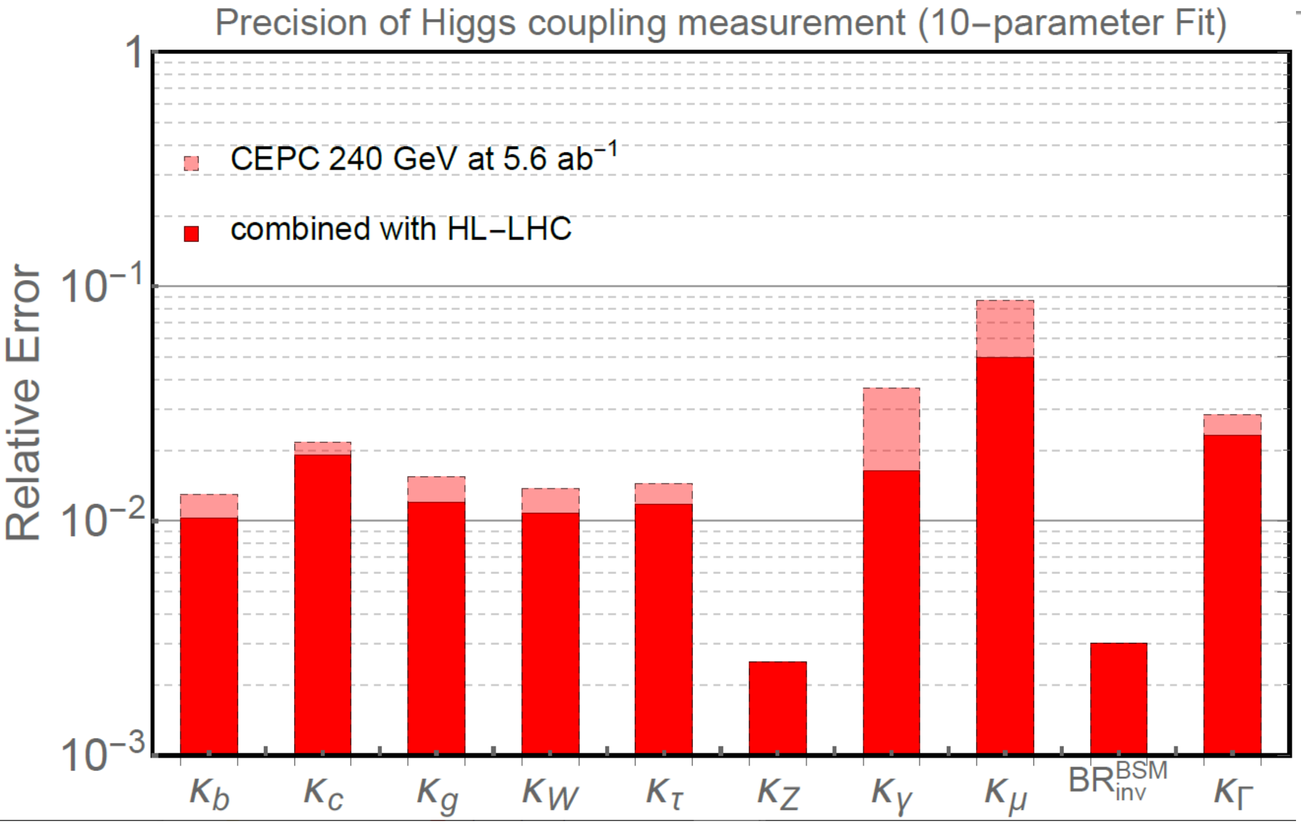
Results are updated with latest HL-LHC projections.
CEPC would have ~1 order of magnitude improvement compared to pp collider.
While HL-HLC has good $\gamma/lepton$ search. Add constrain like κ_γ/κ_Z would significantly improve the coupling.

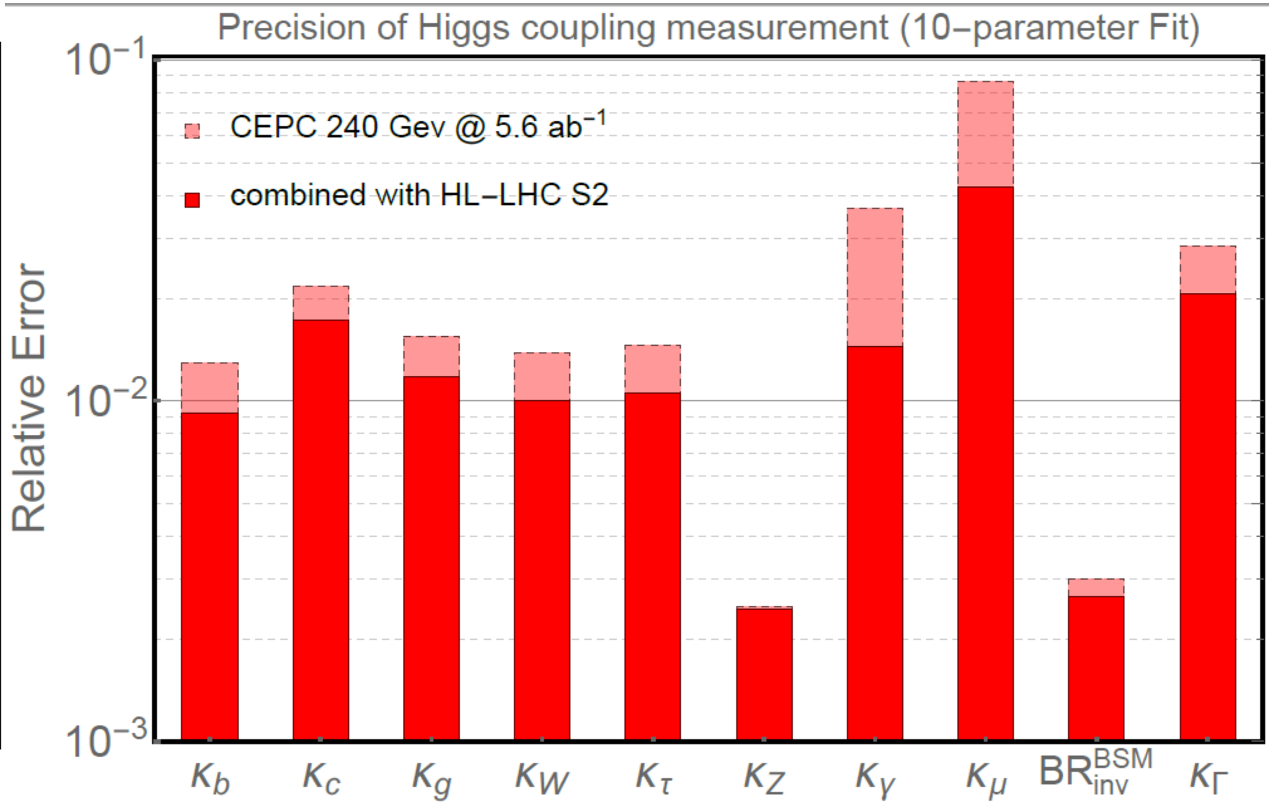




Independent κ fit

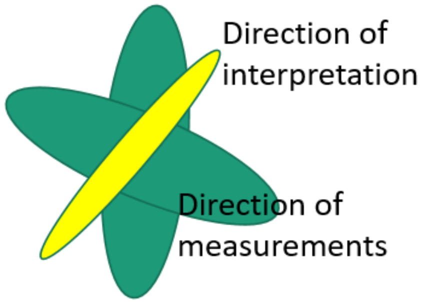
Let Higgs width free. Highlights of lepton collider.





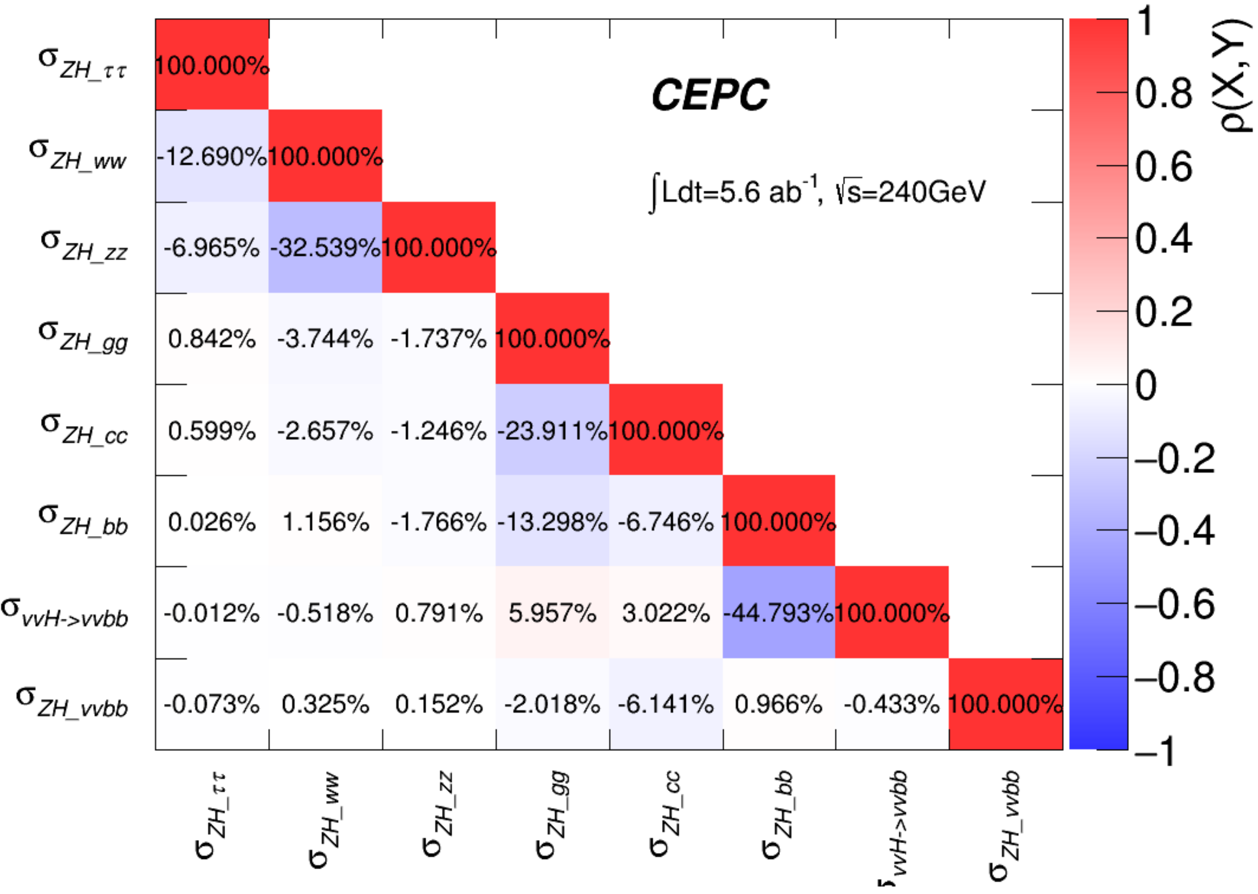
Higgs width brings a floor effect around 1.3%.

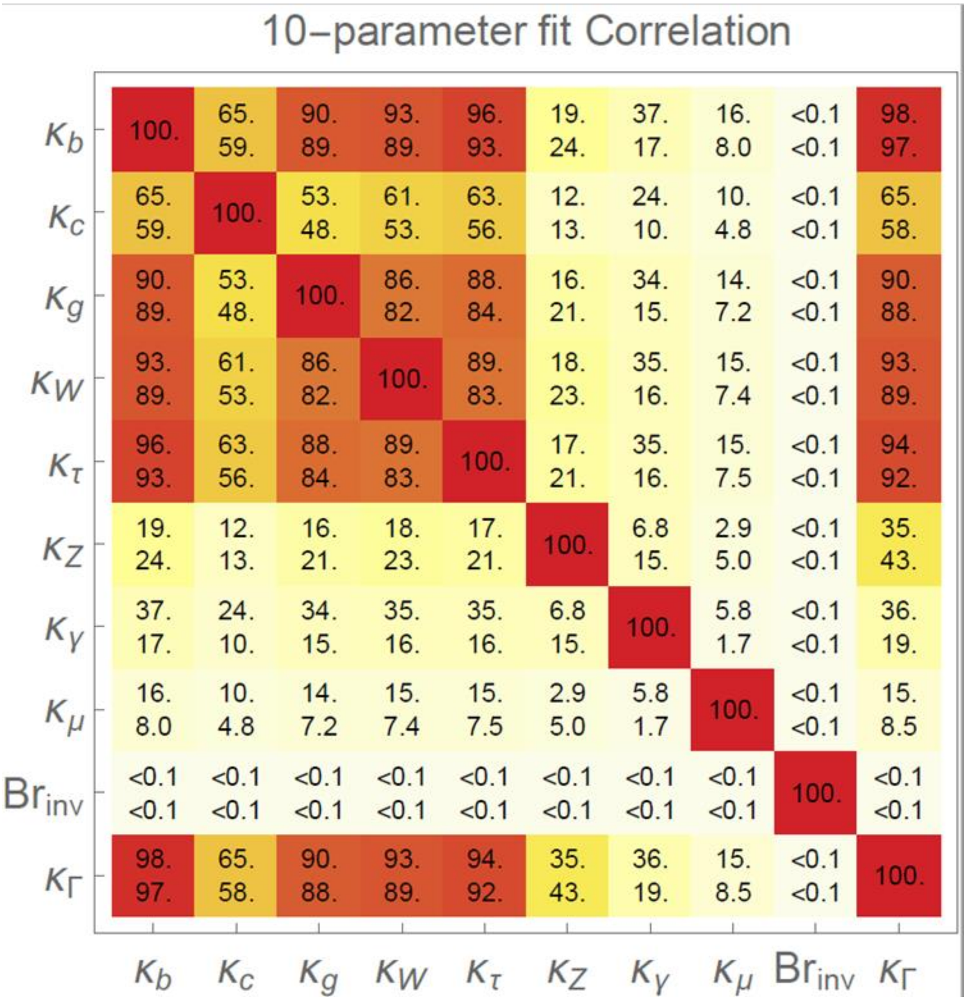
Correlation Matrix



Input | + Interpretation | Output

Measurement → Coupling





See Zhen's report

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

EFT fit

See Jiayin's Report

- One parameterization of BSM contributions to Higgs couplings.

$$\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4} \mathcal{O}_j^{(8)} + \cdots$$

  - Powerful and …… not so friendly
    - Leading order D6 operators has 2499 parameter for 3 generation.

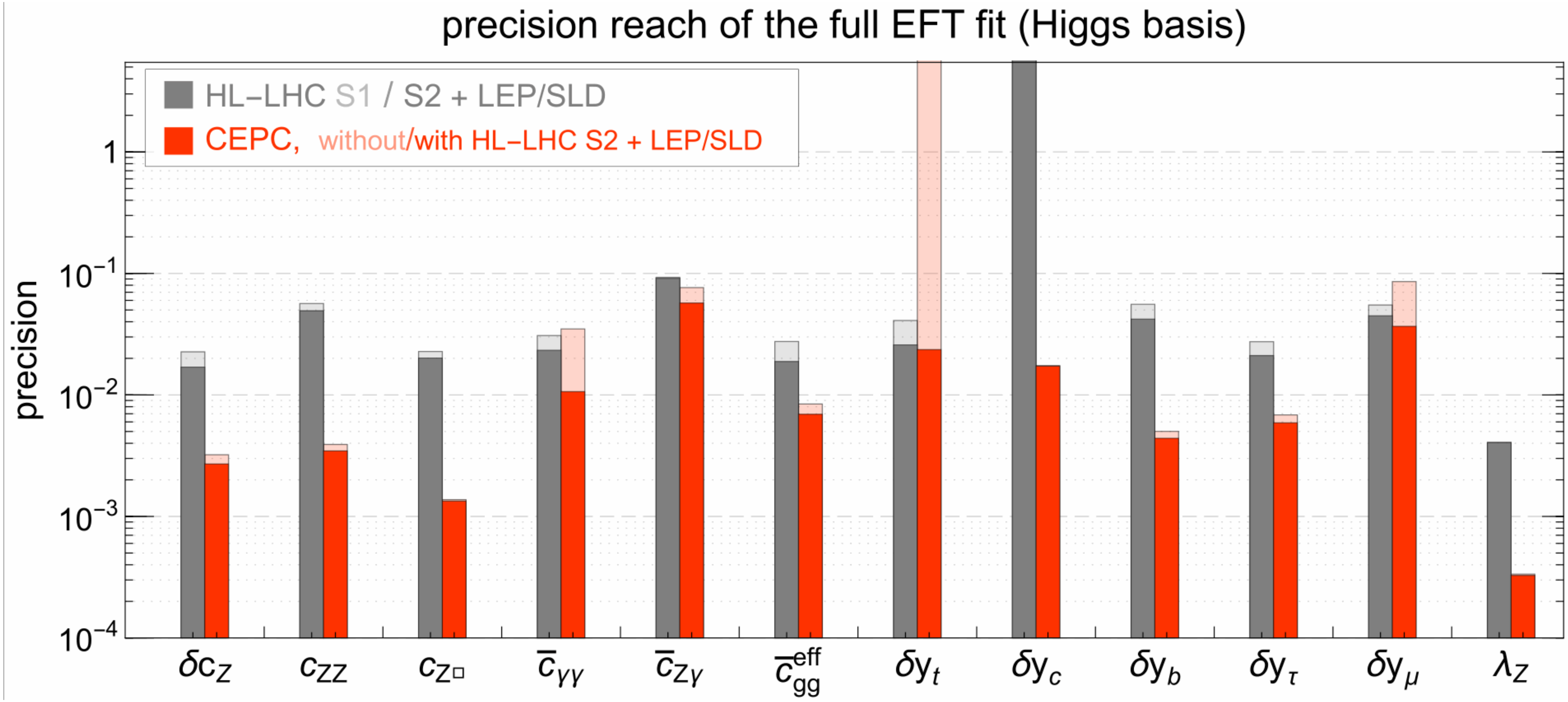
While theorists enjoy this badly……

- Higgs + aTGC + EW = **28** parameters in our framework
  - CP-even only, no fermion dipole interactions,
  - only consider the diagonal Yukawa couplings of t, c, b, τ, μ,
  - impose $U(2)$ on 1st and 2nd generation quarks, exclude $Zt\bar{t}$ and Wtb couplings.
  - We don't consider flavor violating Higgs or Z decays, which can be studied separately.

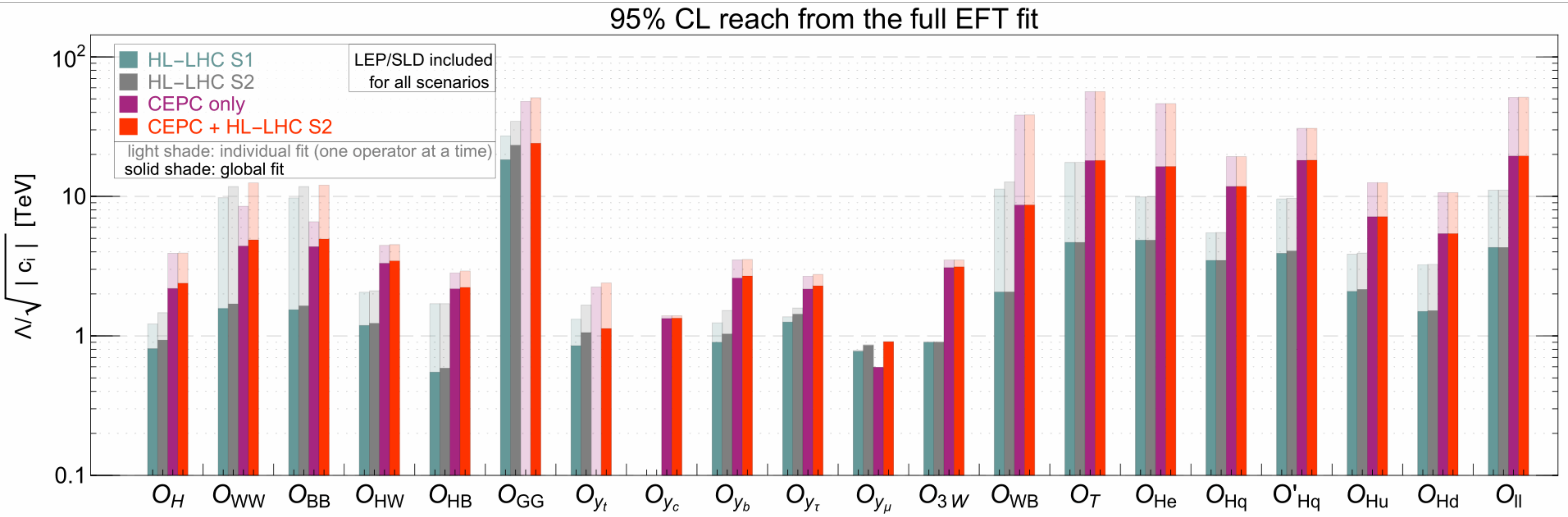
aTGCs:
anomalous Triple Gauge Couplings

- CEPC also provides very precise EW measurement besides Higgs.
- Ideal for EFT study

Higgs basis (12 parameters)



Higgs related parameters in full fit



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……
  - CEPC results updated a little since the paper published but no huge difference.

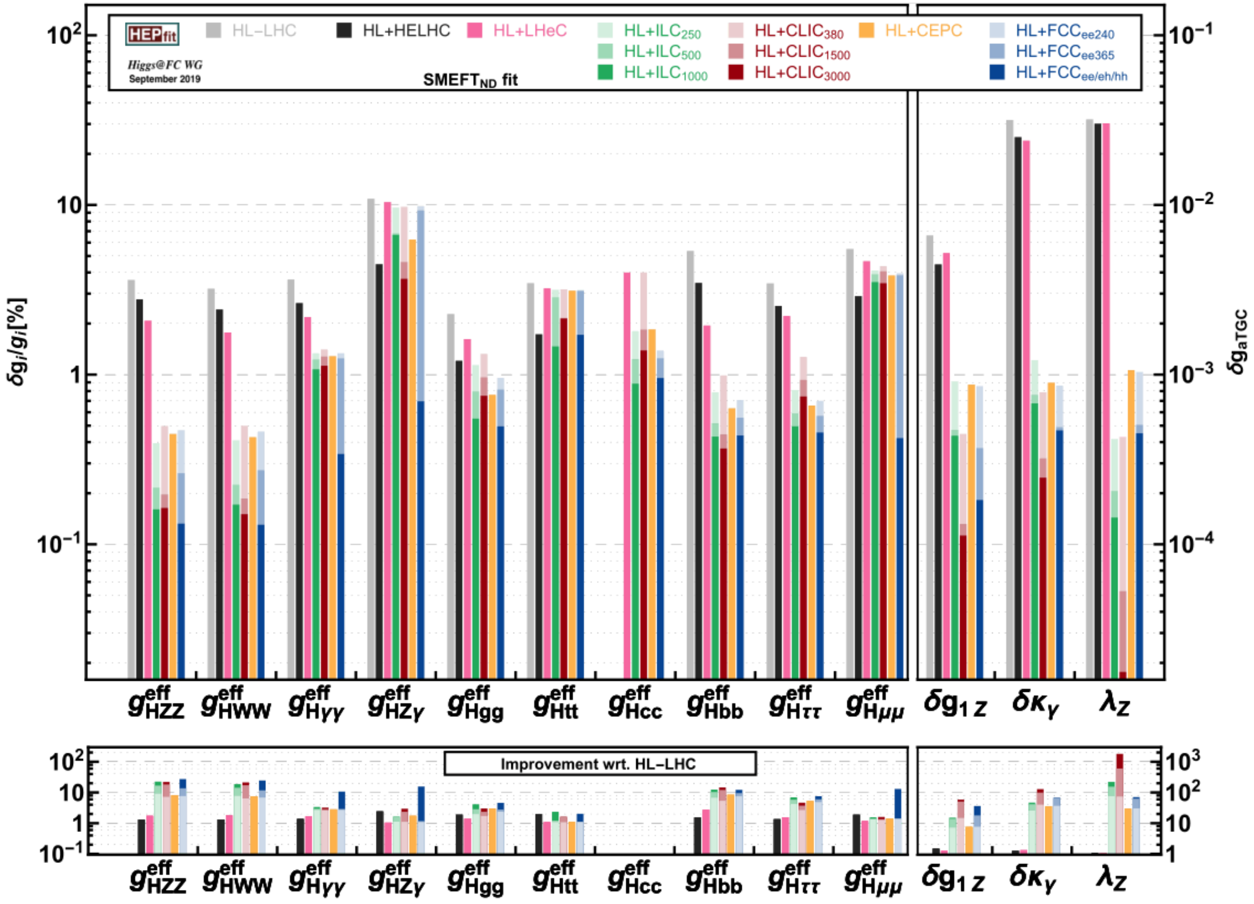
kappa-0	HL-LHC	LHeC	HE-LHC S2	HE-LHC S2′	ILC 250	ILC 500	ILC 1000	CLIC 380	CLIC 15000	CLIC 3000	CEPC	FCC-ee 240	FCC-ee 365	FCC-ee/eh/hh
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12
κ_g [%]	2.3	3.6	1.9	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

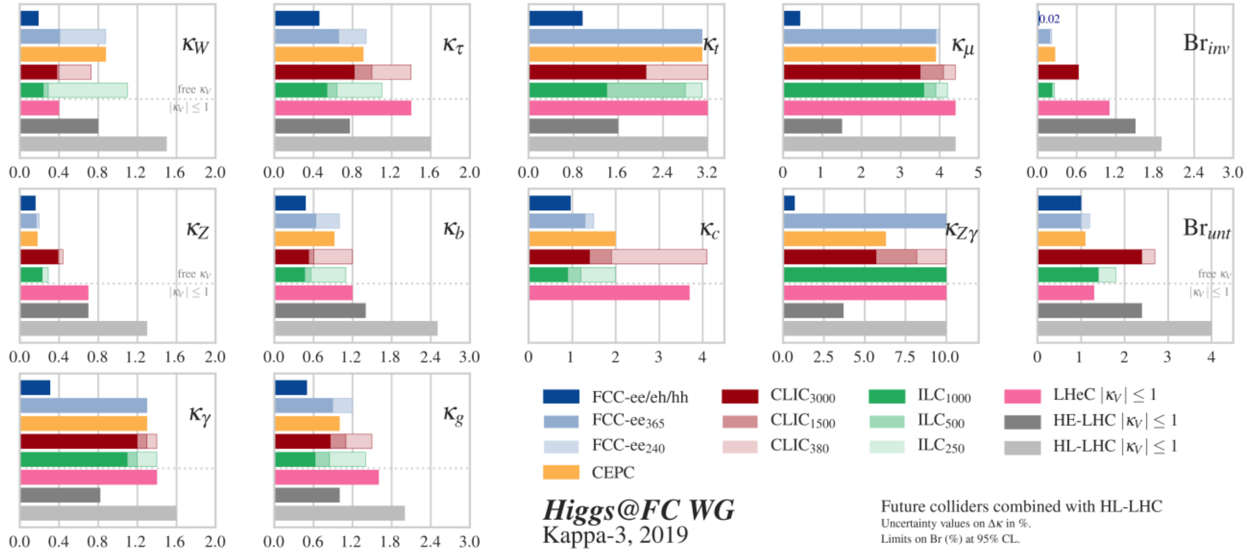
kappa-3 scenario	HL-LHC+ ILC_{250}	ILC_{500}	ILC_{1000}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	FCC-ee_{240}	FCC-ee_{365}	FCC-ee/eh/hh
κ_W [%]	1.0	0.29	0.24	0.73	0.40	0.38	0.88	0.88	0.41	0.19
κ_Z[%]	0.29	0.22	0.23	0.44	0.40	0.39	0.18	0.20	0.17	0.16
κ_g[%]	1.4	0.85	0.63	1.5	1.1	0.86	1.	1.2	0.9	0.5
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

Kappa / EFT Synergies





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

CEPC: Higher energy

- Currently CEPC DO NOT HAVE ANY official plan for higher energy…… But we also did some PRELIMINARY study.
- ttbar run would mostly benefit the physics like EW, while for Higgs it improves width best.
  - Much more vvH event and better separation. Significantly improve the constrain.
- CEPC Higgs fitted in the 10κ framework.
  - (240GeV, 5.6iab) gives 2.9%, while (360GeV, 2iab) alone gives 2.8%, constrained by statistics and $\sigma(ZH)$.
  - 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%. While Fcc-ee have 1.3%.

- Generally CEPC could expect similar Higgs performance in higher energy run as Fcc-ee.

Evolving Combination

- Good enough results, still a lot of to do
  - Analysis update slowly. Esp. for some crucial channels.
  - Many progress Manqi showed in the performance session didn’t enter the combination yet, like jet separation, tau finding……

  -> Limited manpower, Your effort would be appreciated!

  - Still need to understand the correlation
  - More powerful tools: HEPFit? Use workspace in each channel?
  - Far from the CEPC fully/ultimate potential. 1M higgs!

Detector performance
+ Reco algorithm

↓

Individual Analysis
(No correlation)

↓

Combination
(With correlation)
Output: $\sigma * Br$

backups

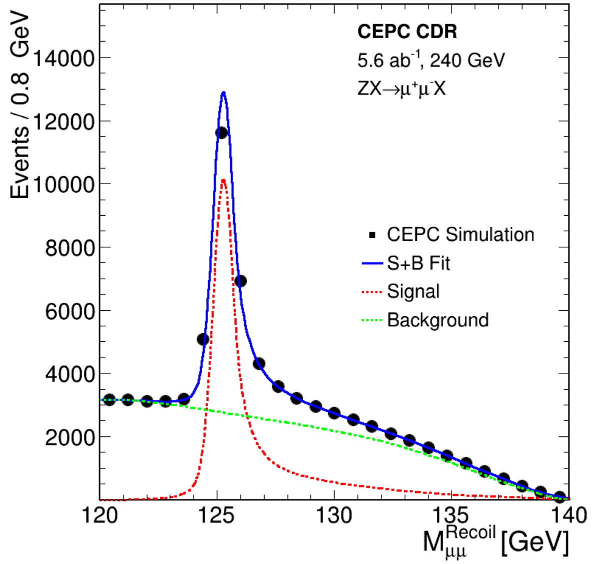
Channels Table (2018.11)

All scaled to 240 GeV，5.6ab^{-1}

Signal		Precision	Signal		Precision	Signal		Precision
Z	H		Z	H		Z	H	
H->qq			H->WW			H→γγ, Zγ		
ee	bb	1.32%	ee	lvlv	9.52%	μμ	γγ	23.7%
	cc	13.5%		evqq	4.56%	vv		10.5%
	gg	7.22%		μvqq	3.93%	qq		9.84%
μμ	bb	0.99%	μμ	lvlv	7.29%	vv	Zγ(qqγ)	15.7%
	cc	9.54%		evqq	3.90%	vvH(WW fusion)		
	gg	5.01%		μvqq	3.90%	vv	bb	3.00%
qq	bb	0.46%	vv	qqqq	1.90%	H→μμ		
	cc	11.1%		evqq	4.65%	qq	μμ	17.1%
	gg	3.64%		μvqq	4.14%	ee		
vv	bb	0.39%		lvlv	11.5%	μμ		
	cc	3.83%	qq	qqqq	1.75%	vv		
	gg	1.47%	H->ZZ			H→ττ		
H->Invisible			vv	μμqq	8.26%	ee	ττ	2.75%
qq	ZZ(vvvv)	232%	vv	eeqq	40%	μμ		2.61%
ee		370%	μμ	vvqq	7.32%	qq		0.95%
μμ		245%	ZH bkg contribution		19.4%	vv		2.66%

$\sigma(ZH)$: 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



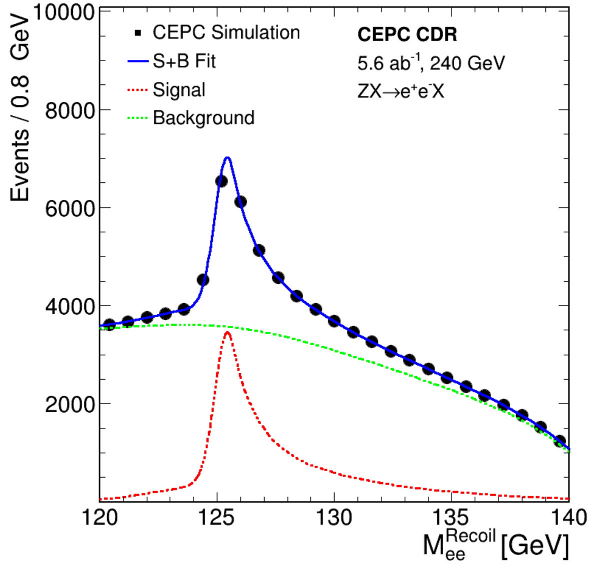


Table 3. Estimation of biases of σ_{ZH} caused by potential variances of the Higgs decay branching ratios.

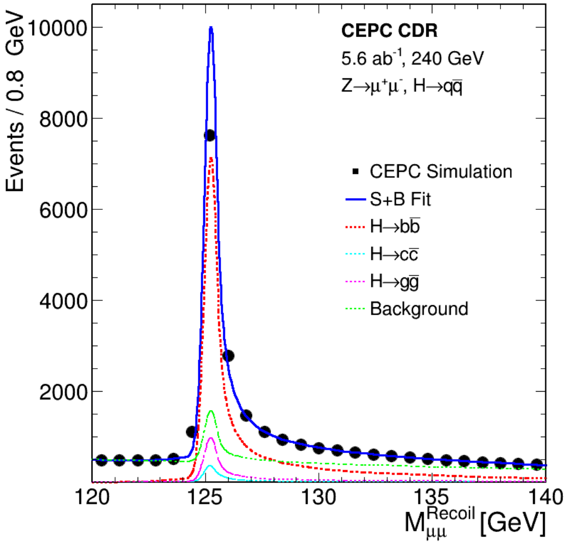
Decay mode	Bias($\times 10^{-4}$)
$H \to b\bar{b}$	-0.10
$H \to WW$	+0.20
$H \to gg$	-0.18
$H \to \tau\tau$	+1.11
$H \to c\bar{c}$	+0.05
$H \to ZZ$	-1.85
$H \to \gamma\gamma$	+2.56
$H \to \gamma Z$	-2.08
$H \to$ inv.	+5.75

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

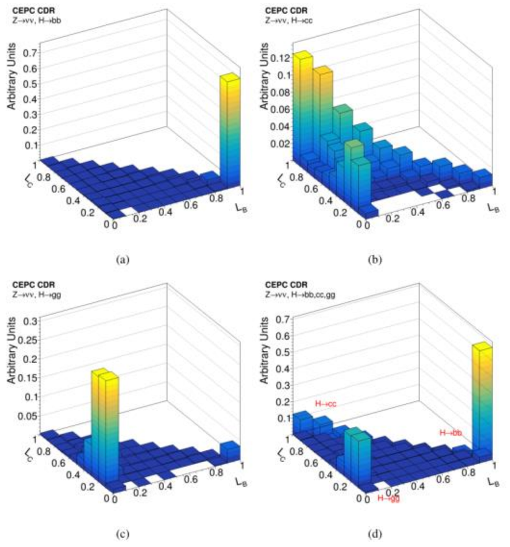
- Heavily relies on jet clustering algorithm; Hard to separate.

- 3d template fit
  - Mass
  - Dijet’s B likeness and C likeness

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%



- (Z → vv H → bb excluded the vvH part)



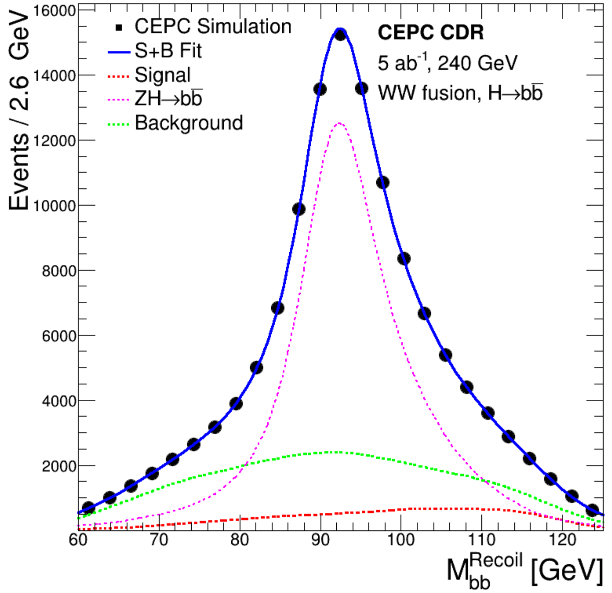
- Still, WW/ZZ suffered from the huge ZH events

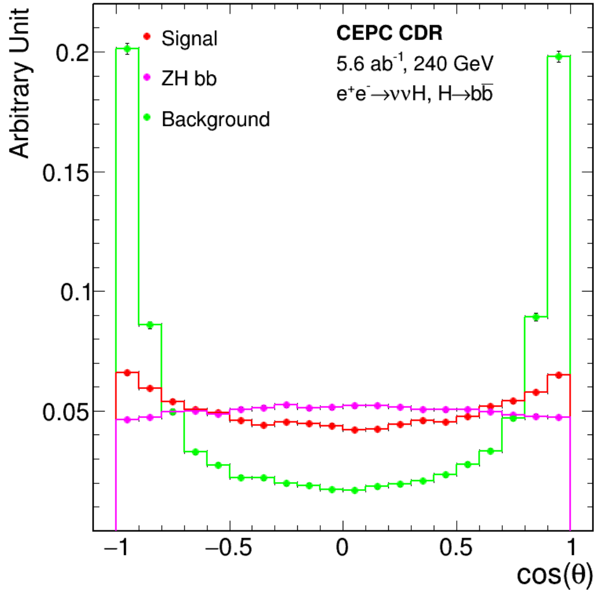
  Current combination didn’t use the full hadronic W/Z
  and b/c/g correlation value. More study are needed to understand.

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

$vvH \rightarrow bb$

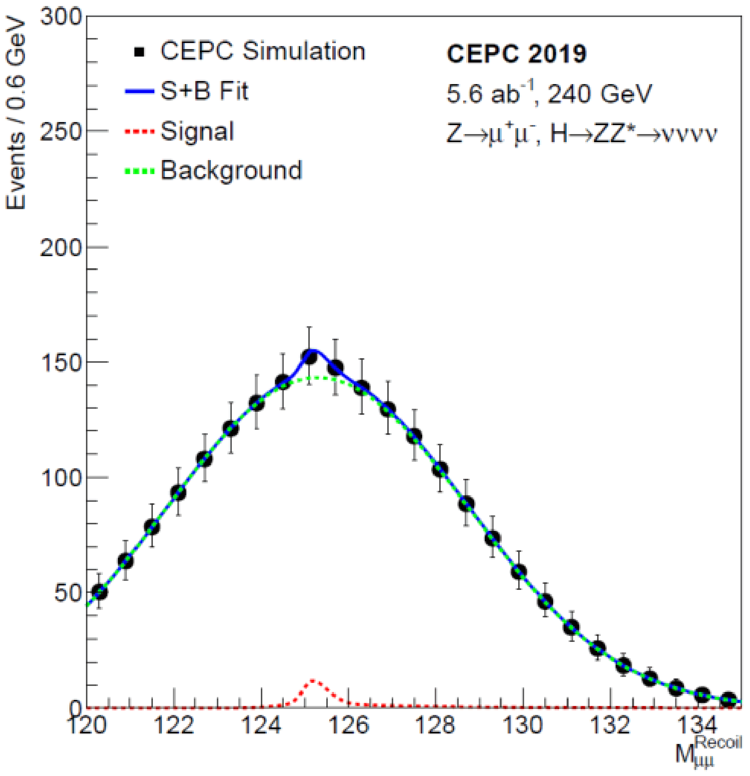
- 2d fit M_{jj}^{reco} & $\mathrm{Cos}\ \theta_{jj}$
- $vvH \rightarrow bb$ and $ZH \rightarrow bb$
  - Interference ~10% of vvH. (generally, 60: 1 : 10)
    - Add the interference term to vvH side currently;
  - If fix ZH process, Initial uncertainty is 2.8%.
  - ZH->bb constrained by other bb channels.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



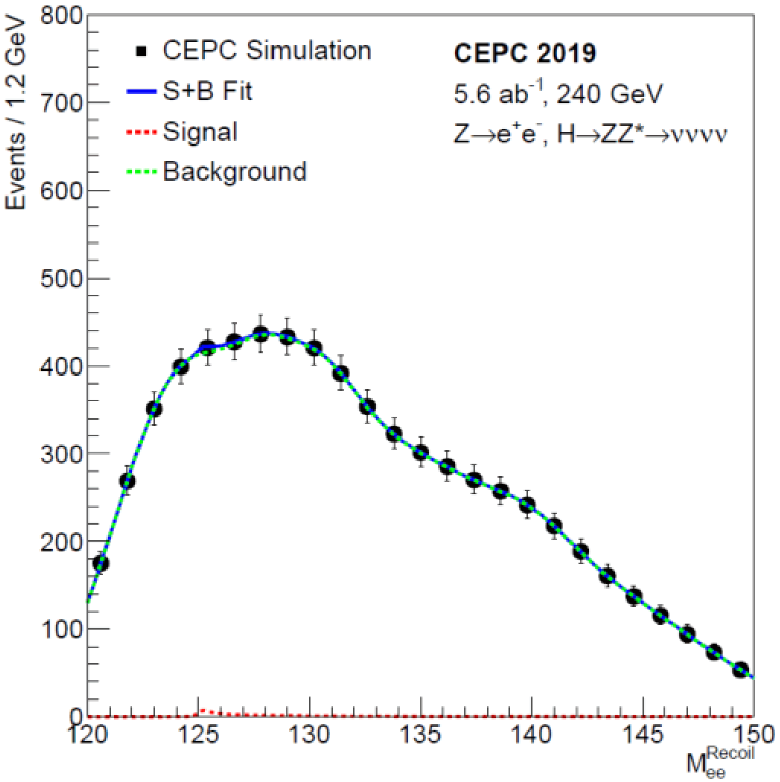


Invisible

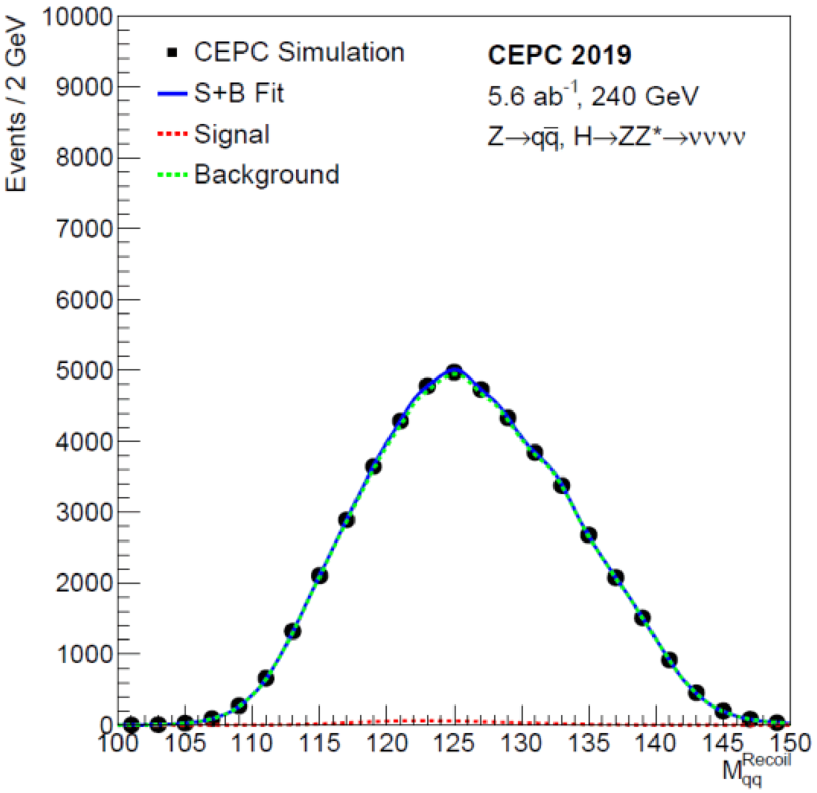
ZH final state studied	Relative precision on $\sigma(H\to inv.)/BR$	Upper limit on $BR(H\to inv.)$
$Z\to e^+e^-$, $H\to inv.$	368%	0.89%
$Z\to \mu^+\mu^-$, $H\to inv.$	103%	0.32%
$Z\to q\bar{q}$, $H\to inv.$	46%	0.20%
Combination	42%	0.19%



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



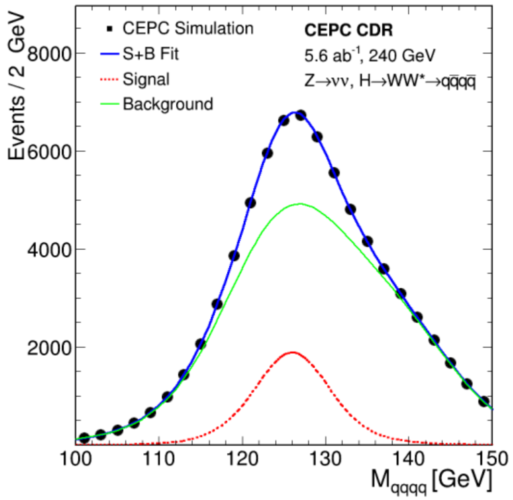
ZH(Z->e^+e^-,H->invisible)



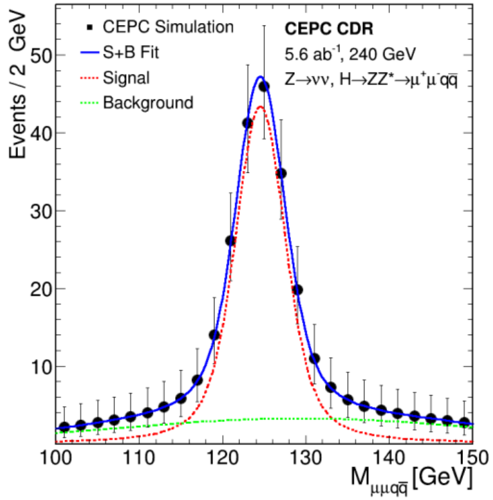
ZH(Z->qq,H->invisible)

WW, ZZ

- ZZ
  - Pre_CDR ZZ result extrapolated from Fcc-ee.　Overestimated;
  - Current ZZ study suffered from huge background
  - Also gained contribution from H → bb/cc/gg/WW decay.



- WW
  - Much more channels studied since Pre_CDR.



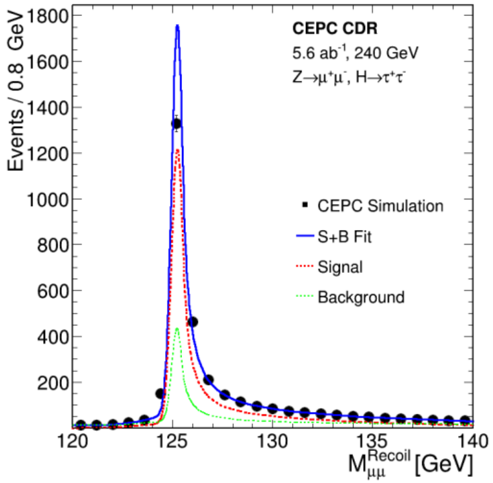
Green: studied
Yellow: Problematic

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

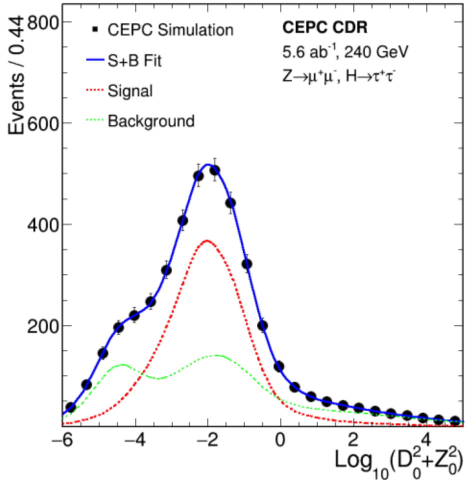
	Z	ee	μμ	νν	qq
ZZ	ee+qq				
	μμ+qq				
	νν+qq				
	ll+ll				
(Invi)	νν+νν				
	qq+qq				
	ll+νν				

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

- $\tau\tau$:
  - 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

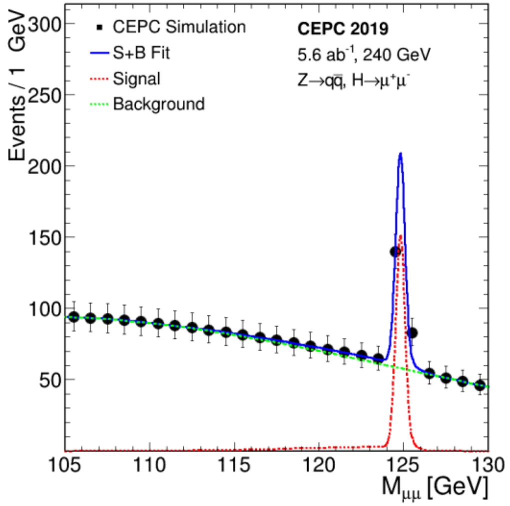


ZH final state		Precision
$Z\to\mu^+\mu^-$	$H\to\tau^+\tau^-$	2.6%
$Z\to e^+e^-$	$H\to\tau^+\tau^-$	2.7%
$Z\to\nu\bar{\nu}$	$H\to\tau^+\tau^-$	2.5%
$Z\to q\bar{q}$	$H\to\tau^+\tau^-$	0.9%
Combination		0.8%

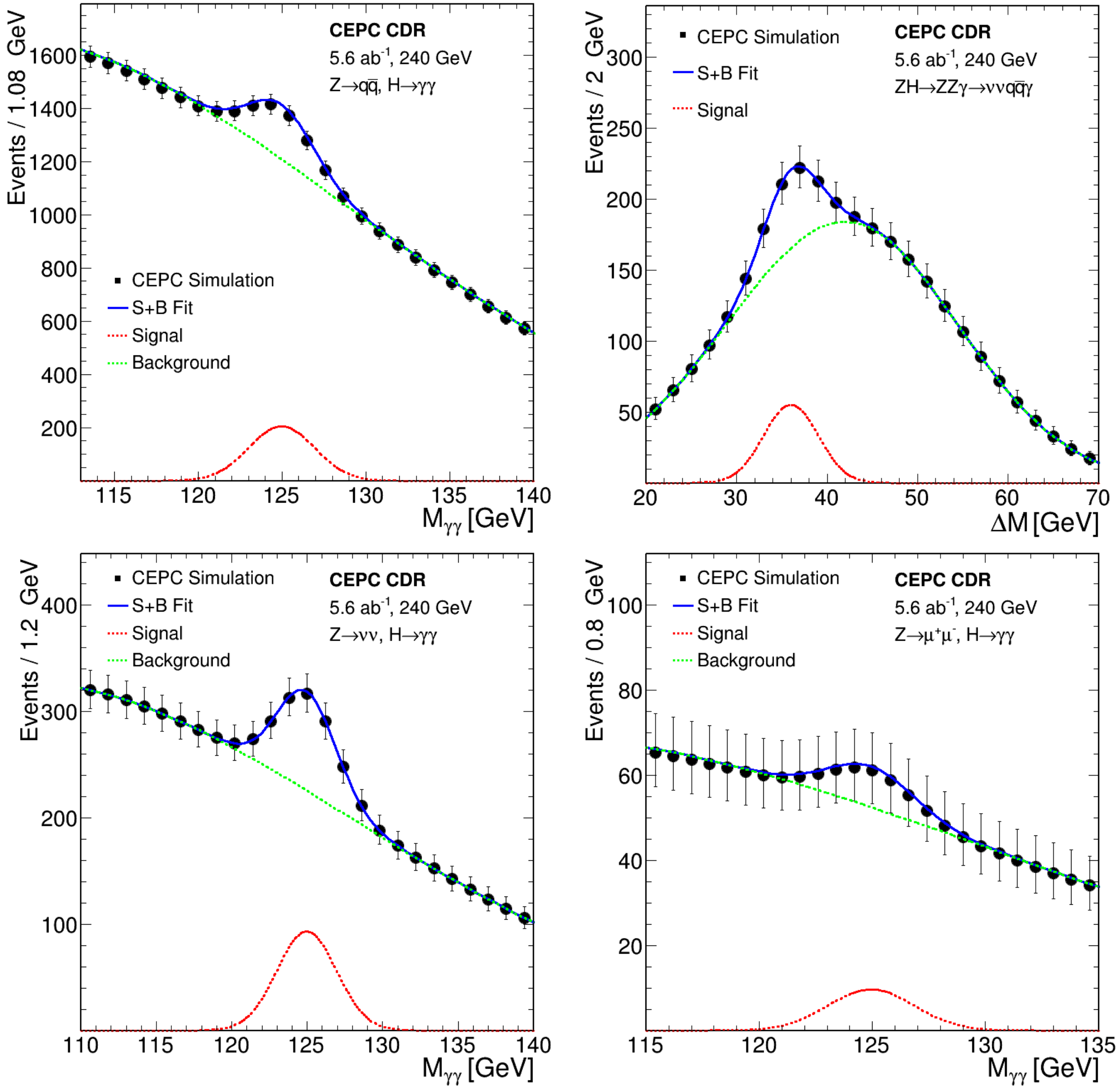


- $\mu\mu$
  - By Kunlin

[%]	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



$\gamma\gamma, Z\gamma$



- Use $m_{\gamma\gamma}, m_{\gamma\gamma}^{recoil}$ 2d fit to improve $\gamma\gamma$ precision.
- MVA improved more
- Photon convention not counted in current study.