# Higgs Combination at the CEPC

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IHEP

The 2022 International Workshop on the High Energy Circular Electron Positron Collider

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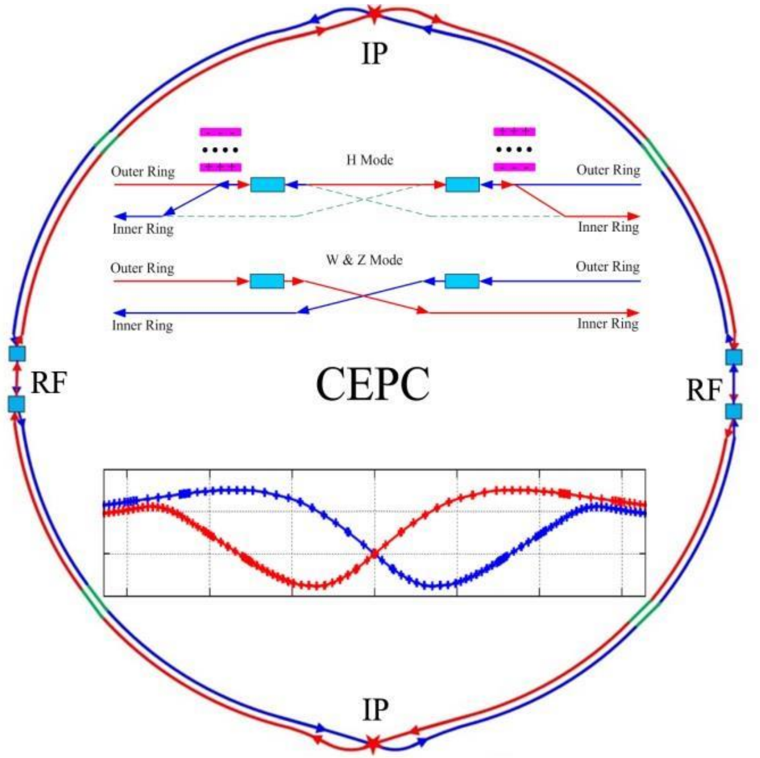
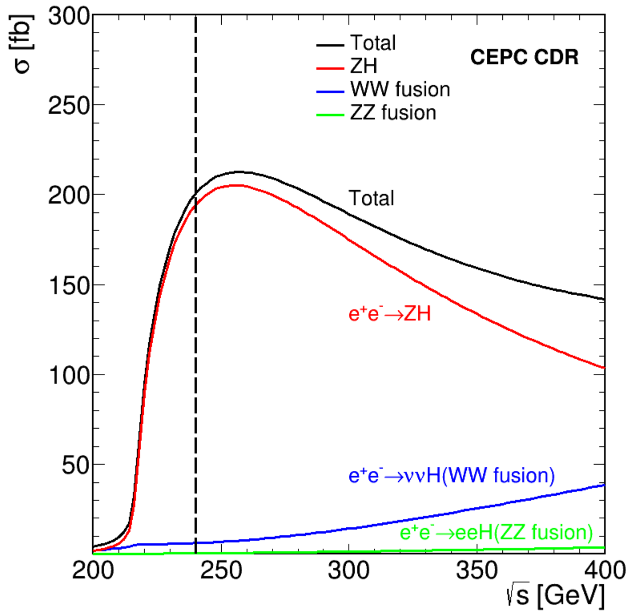
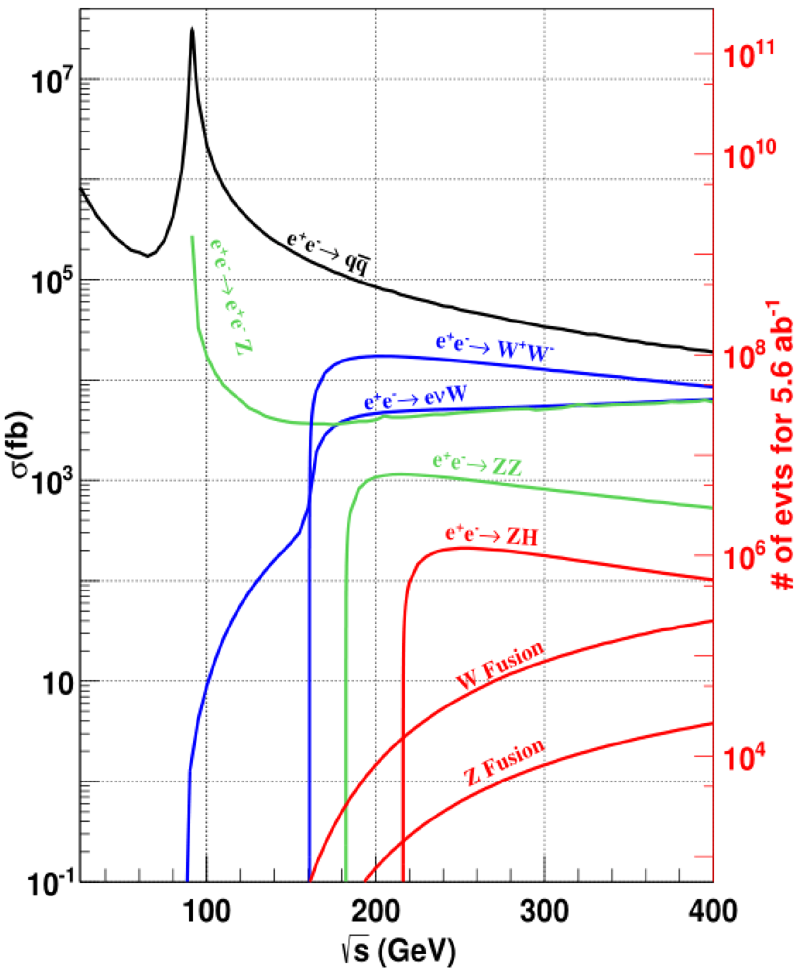
# Higgs@CEPC

100km tunnel;
20iab data in 240GeV, 1iab in 360GeV.



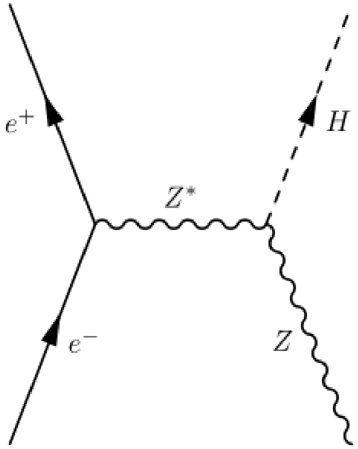



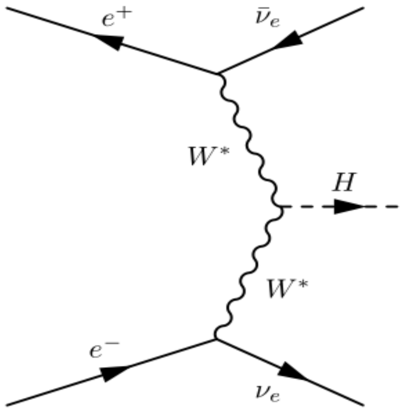

CEPC CDR: arXiv:1811.10545

White Paper: arXiv:1810.09037

CEPC Snowmass 2021(Latest):

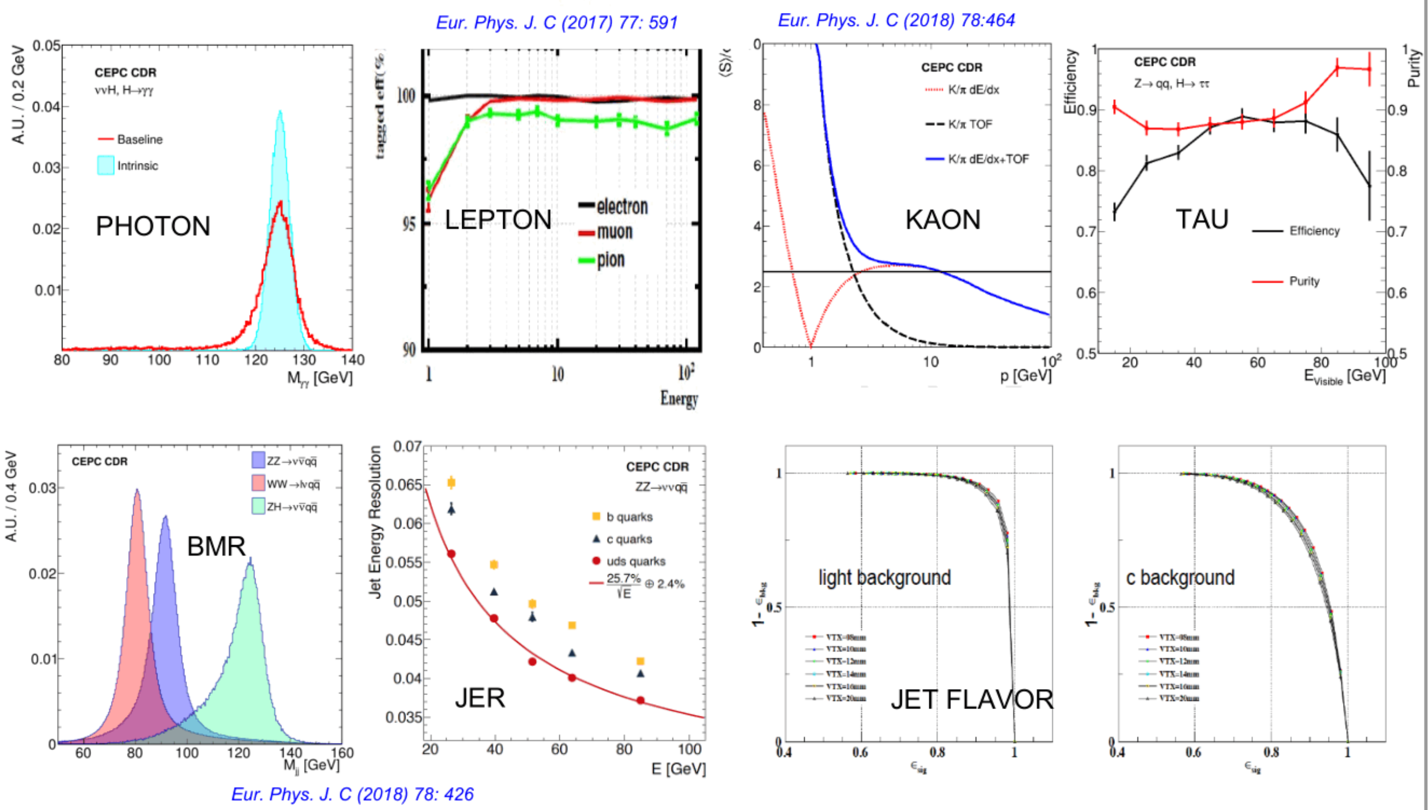
arXiv:2205.08553



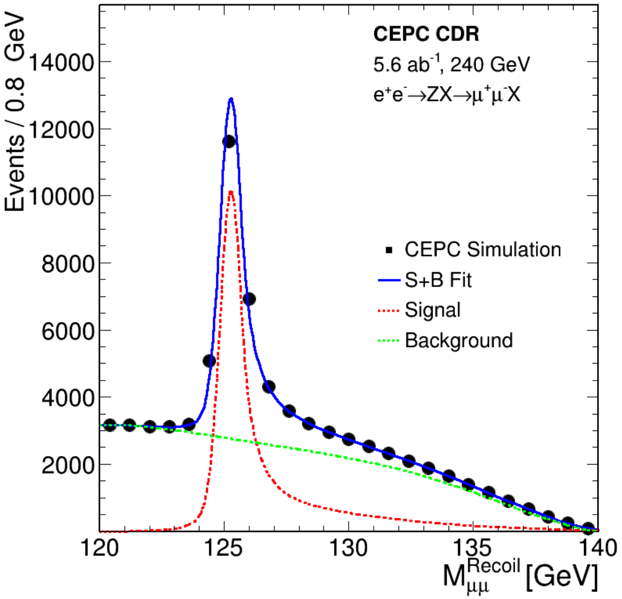
# CEPC (evolving) object performance

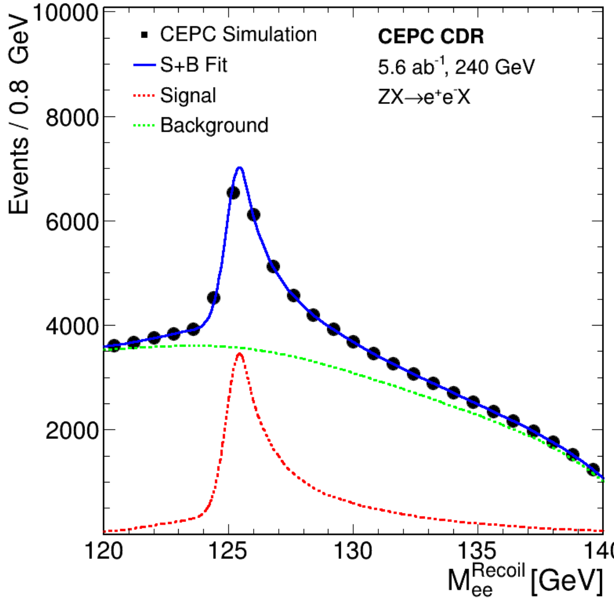
With certain detector parameter and certain reconstruction algorithm, CEPC Higgs measurements are predictable.
Reconstruction overview: arXiv:1806.04879

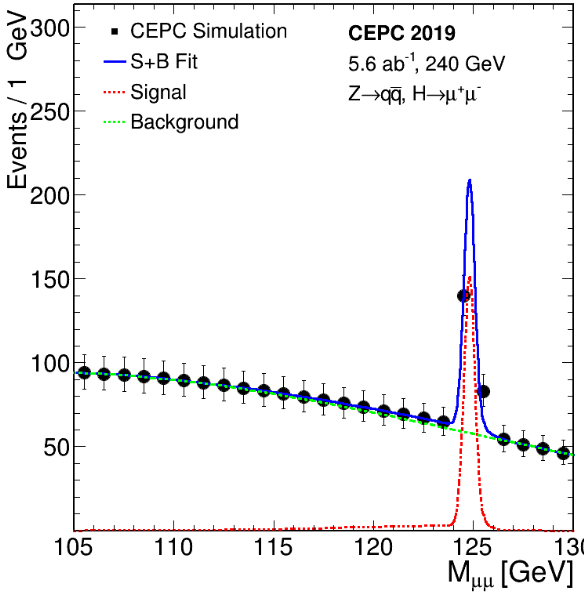


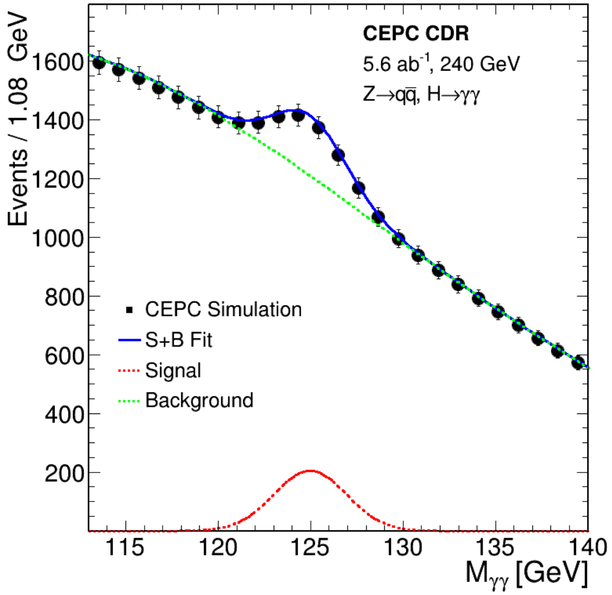

New results:
Jet: arXiv:2104.05029
Track: arXiv:2209.00397
dE/dx: arXiv:2209.14486
Cluster time: arXiv:2209.02932

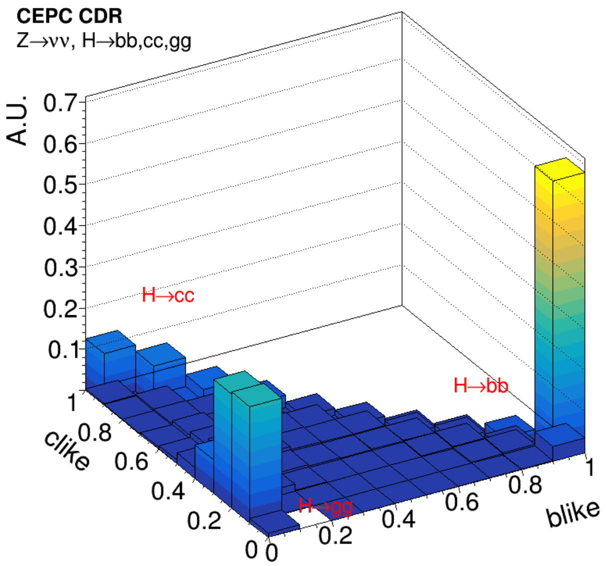
# Individual sub channels

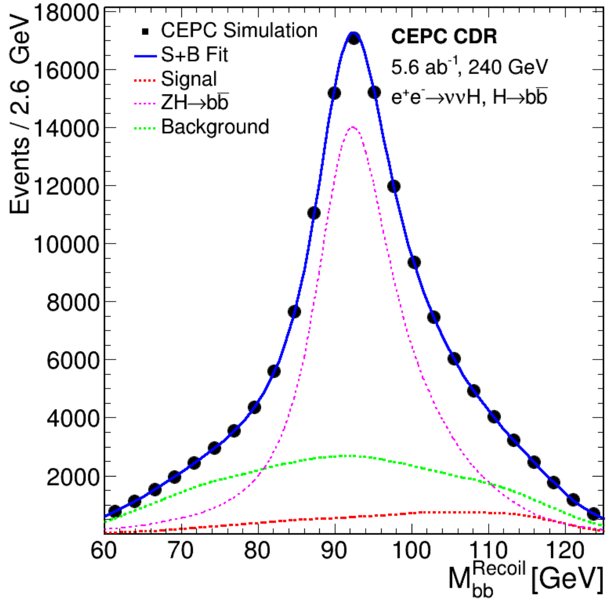


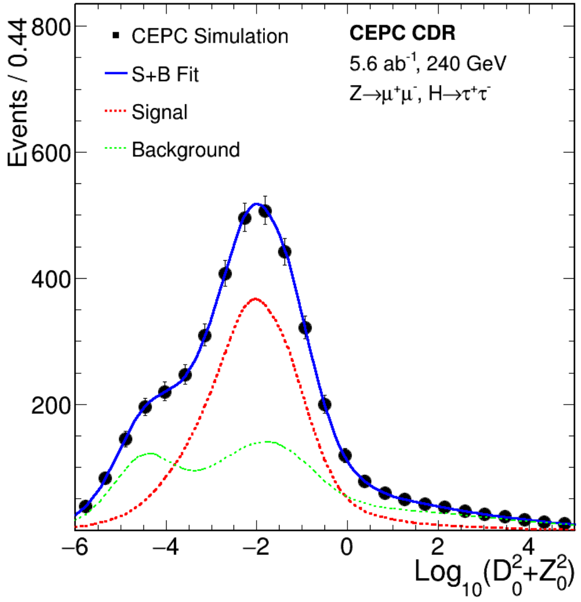



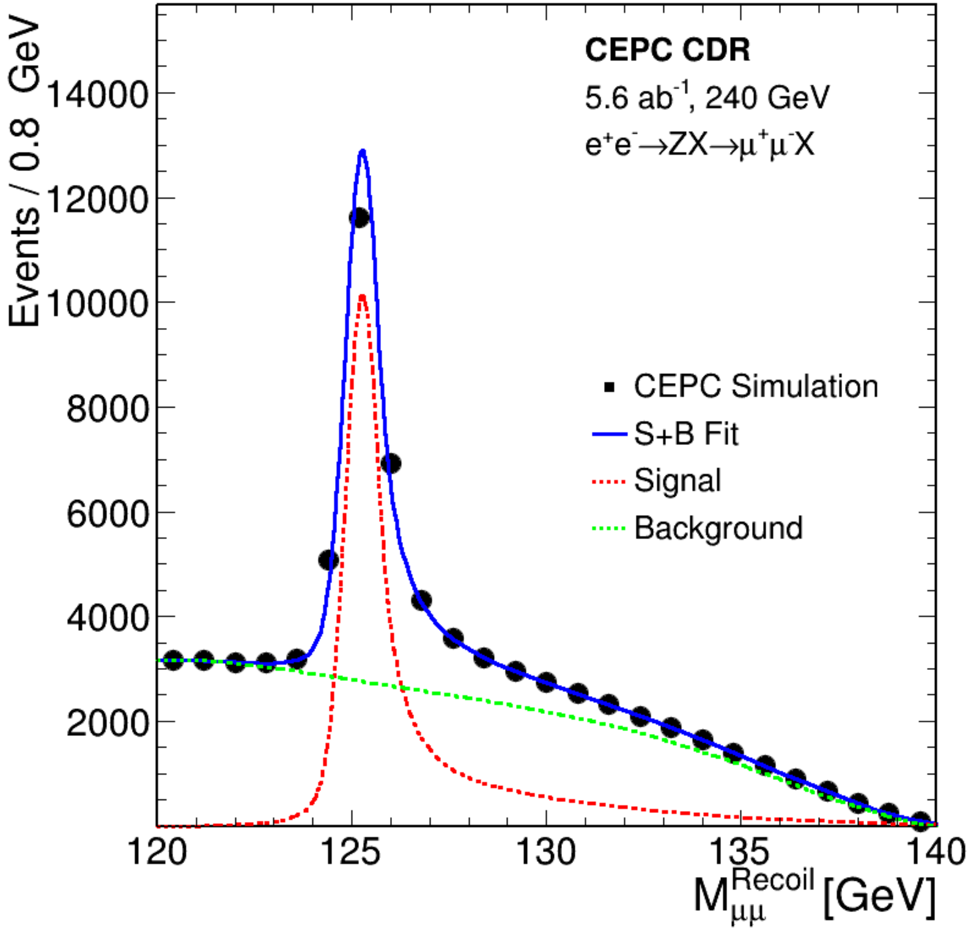



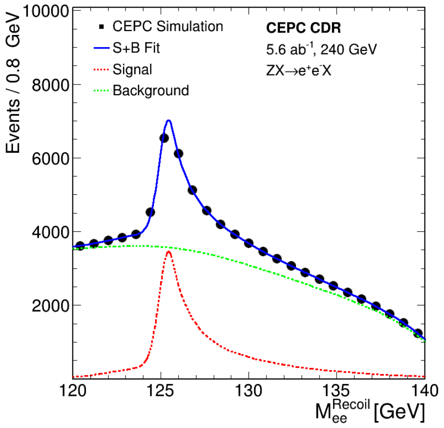




All these results are based in 2018 CEPC-v4 layout, ECM=240GeV and total statistics 5.6iab.

# $\sigma(ZH)$: $H \rightarrow$ 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%

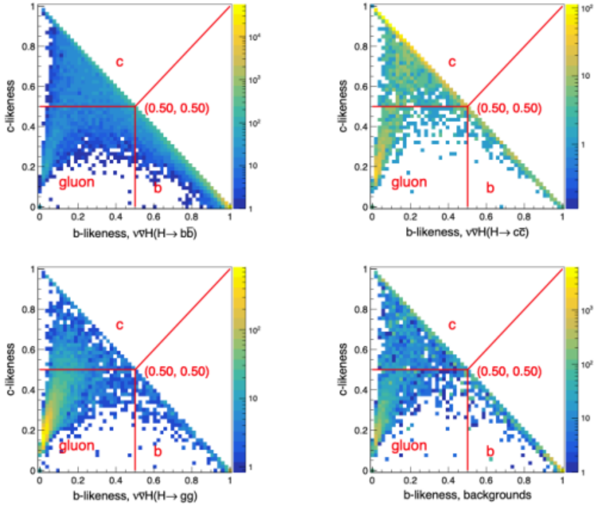


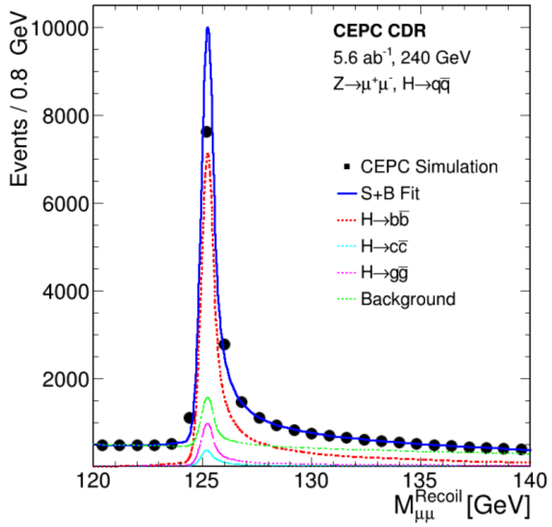



# bb, cc, gg

Slides in this workshop
vvH, qqH by Yongfeng Zhu, arXiv:2203.01469
eeH, mmH by Yu Bai, arXiv:1905.12903

- vvH, qqH used jet b-c likeness 2-d template fit
  - No direct truth information used in the analysis.
- eeH, mmH + recoil mass, 3-d fit
- Brief systematics, dependence on detector performance studied;



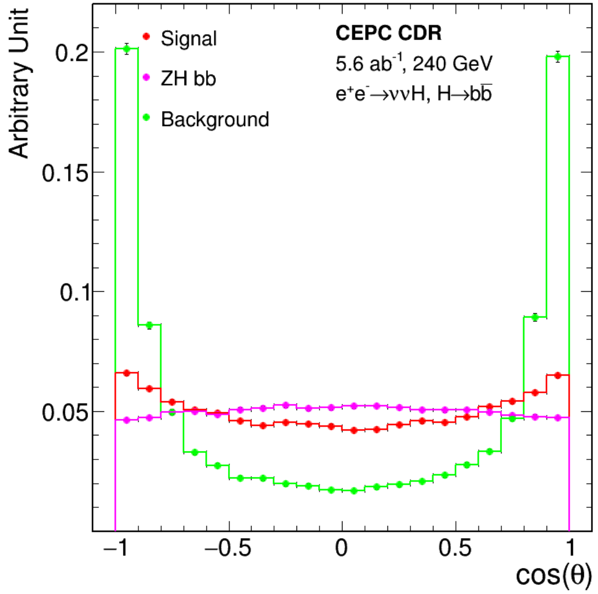



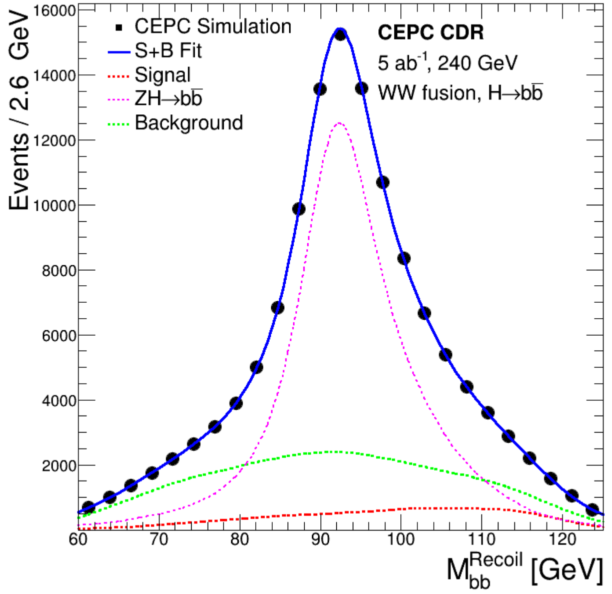

| Z decay mode | $H \to b\bar{b}$ | $H \to c\bar{c}$ | $H \to gg$ |
|---|---|---|---|
| $Z \to e^+e^-$ | 1.57% | 14.43% | 10.31% |
| $Z \to \mu^+\mu^-$ | 1.06% | 10.16% | 5.23% |
| $Z \to q\bar{q}$ | 0.35% | 7.74% | 3.96% |
| $Z \to \nu\bar{\nu}$ | 0.49% | 5.35% | 1.77% |
| combination | 0.27% | 4.03% | 1.56% |

# $\nu\nu H \to bb$

by Hao Liang.

- Crucial channel for Higgs width
- 2d fit $M_{jj}^{reco}$ & $\cos\theta_{jj}$
- $\nu\nu H \to bb$ and $ZH \to bb$
  - Interference ~10% of vvH. ( generally, 60: 1 : 10)
    - CEPC add the interference term to vvH side currently;
  - $\nu\nu H \to bb$ and $ZH \to bb$ share the anti-correlation -45%. (-34% in ILC(1708.08912))
- $\sigma(\nu\nu H) * Br(H \to bb)$: 3.0% ;



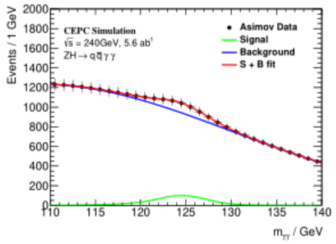

- if fix ZH process, Initial $\nu\nu H \to bb$ uncertainty is 2.8%.
- if float ZH process, $\nu\nu H \to bb$ would be 3.4%.
- Need use other ZH processes to constrain ZH.

# $\mathrm{H} \rightarrow \gamma\gamma$

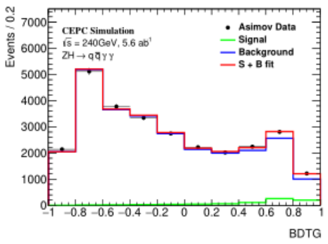
arXiv:2205.13269 by Fangyi Guo;
Previous studied by Feng Wang, Yitian Sun;

Diphoton heavily rely on Ecal performance;

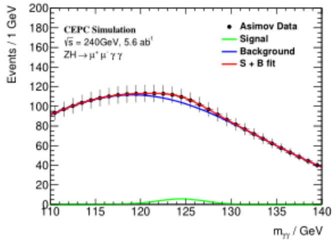
- BDT+mass 2d fit;



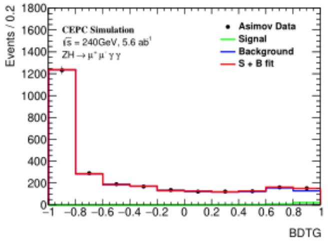

(a) $q\bar{q}\gamma\gamma$ $m_{\gamma\gamma}$ model



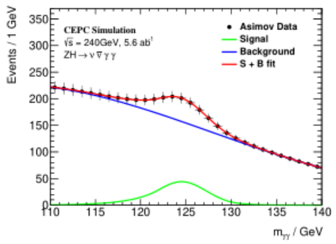

(b) $q\bar{q}\gamma\gamma$ BDT model



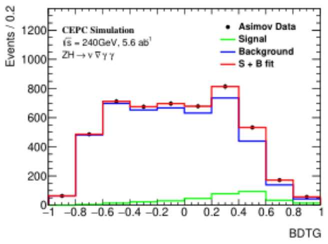

(c) $\mu^+\mu^-\gamma\gamma$ $m_{\gamma\gamma}$ model



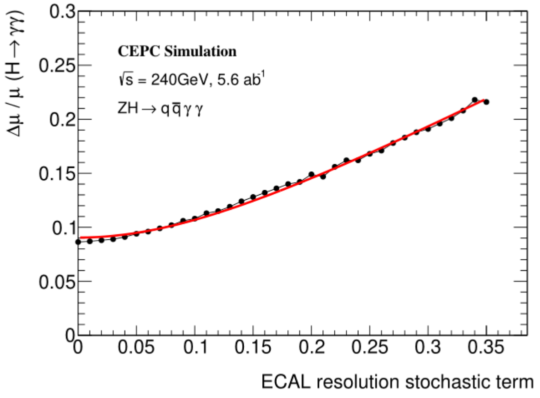

(d) $\mu^+\mu^-\gamma\gamma$ BDT model




(e) $\nu\bar{\nu}\gamma\gamma$ $m_{\gamma\gamma}$ model




(f) $\nu\bar{\nu}\gamma\gamma$ BDT model



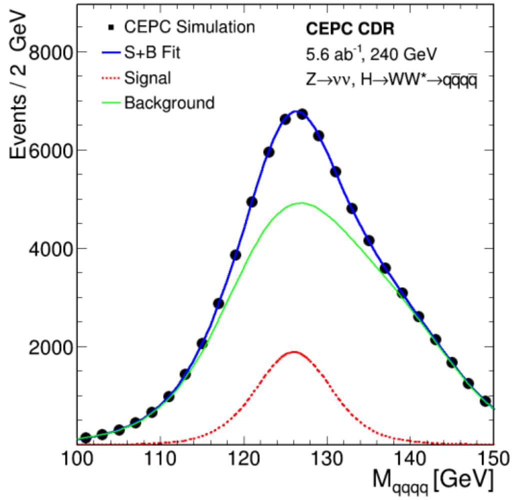

| Channel | $\mu$ @ 5.6 $ab^{-1}$ | $\mu$ @ 20 $ab^{-1}$ |
|---|---|---|
| $q\bar{q}\gamma\gamma$ | $1.00 \pm 0.0879$ | $1.00 \pm 0.0465$ |
| $\mu^+\mu^-\gamma\gamma$ | $1.00 \pm 0.3571$ | $1.00 \pm 0.1920$ |
| $\nu\bar{\nu}\gamma\gamma$ | $1.00 \pm 0.1142$ | $1.00 \pm 0.0605$ |
| Combined | $1.00 \pm 0.0688$ | $1.00 \pm 0.0364$ |

# H → WW, ZZ

Current CEPC use LCFIplus for Jet clustering;
See jet separation in 10.1140/epjc/s10052-019-6719-2 and arXiv:1812.09478

- Leptonic, semi-leptonic WW by Libo Liao;
- Hadronic WW by Mila Pandurovic;

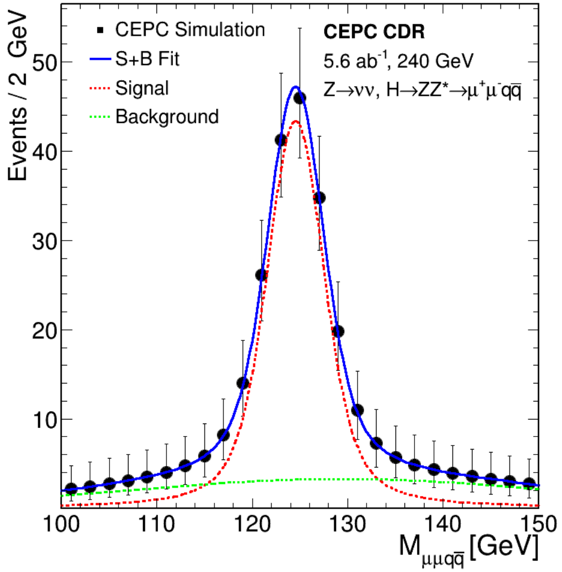
- ZZ by Ryuta Kiuchi, Yanxi Gu and Min Zhong. arXiv:2103.09633,
- previous studied by Zhuoni Qian, Yuqian Wei;




| | Z | ee | μμ | νν | qq |
|---|---|---|---|---|---|
| WW | ev+ev | | | | |
| | μv+μv | | | | |
| | ev+μv | | | | |
| | ev+qq | | | | |
| | μv+qq | | | | |
| | qq+qq | | | | |

| Signal: Z | Signal: H | Precision |
|---|---|---|
| H->WW | | |
| ee | lvlv | 9.2% |
| | evqq | 4.6% |
| | μvqq | 3.9% |
| μμ | lvlv | 7.3% |
| | evqq | 4.0% |
| | μvqq | 4.0% |
| νν | qqqq | 2.0% |
| | evqq | 4.7% |
| | μvqq | 4.2% |
| | lvlv | 11.3% |
| qq | lvqq | 2.2%(ILC) |
| ZH bkg contribution | | 3.0% |

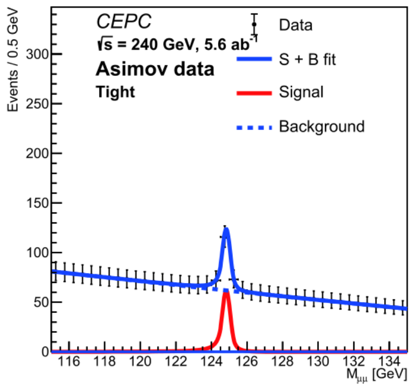
| Category | $\frac{\Delta(\sigma\cdot BR)}{(\sigma\cdot BR)}$ [%] cut-based | BDT |
|---|---|---|
| $\mu\mu H\nu\nu qq^{cut/mva}$ | 15 | 14 |
| $\mu\mu Hqq\nu\nu^{cut/mva}$ | 48 | 42 |
| $\nu\nu H\mu\mu qq^{cut/mva}$ | 12 | 12 |
| $\nu\nu Hqq\mu\mu^{cut/mva}$ | 23 | 20 |
| $qqH\nu\nu\mu\mu^{cut/mva}$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



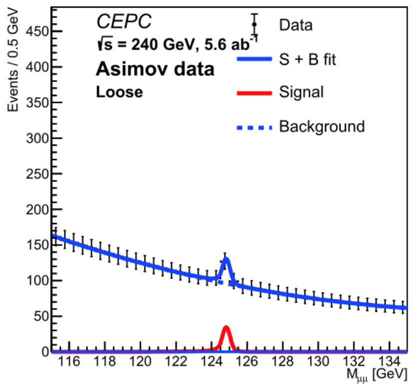

Both WW ZZ can obtain improvements from full hadronic bb/cc/gg ZH backgrounds.

# H → $\mu\mu$ and $\tau\tau$

- $\mu\mu$ by Qi Liu, Kunlin Ran *CPC* **46** 093001
- Previous studied by Zhenwei Cui;
- BDT+mass fit, based in 3T magnet;




(a) Tight



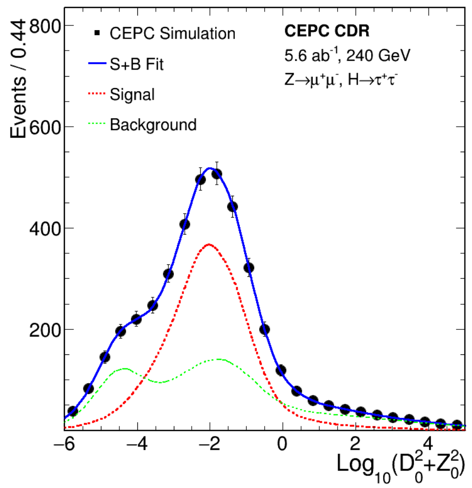

(b) Loose

**Table 3.** Expected signal strength $\mu$, significance, and reduction in significance with the resolution of the muon momentum smeared by 25%, 50%, and 100%.

| Smearing | 25% | 50% | 100% |
|---|---|---|---|
| $\mu$ | $1.00^{+0.21}_{-0.20}$ | $1.00^{+0.22}_{-0.21}$ | $1.00^{+0.25}_{-0.24}$ |
| Significance | $5.5\sigma$ | $5.1\sigma$ | $4.4\sigma$ |
| Reduction in significance | 10% | 16% | 28% |

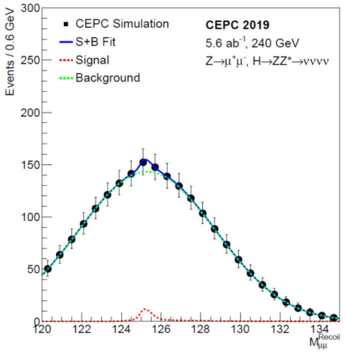
- $\tau\tau$, by Dan Yu arXiv:1903.12327
- Develop LICH to identify lepton, Eff>99%
- Use $\log_{10}(D_0^2 + Z_0^2)$ + mass 2d fit to separate signal from WW
  - Impact parameter, Distance from beam spot

| $ZH$ 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% |

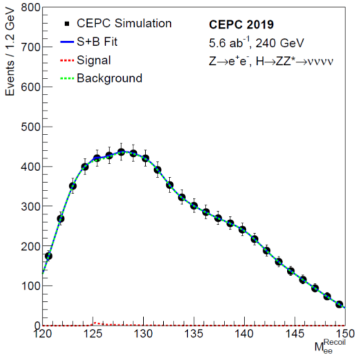


# H $\rightarrow$invisible and $Z\gamma$

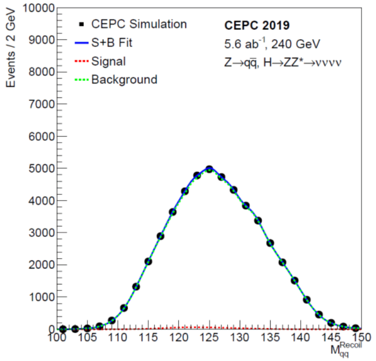
Invisible, arXiv:2001.05912 by Yuhang Tan;
Previous studied by Xin Mo;




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




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

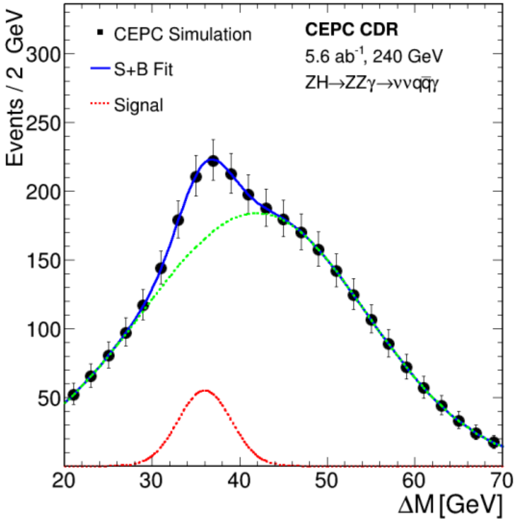



ZH(Z->qq,H->invisible)

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

In SM, H $\rightarrow$invisible refers
$H \rightarrow ZZ \rightarrow \nu\nu\nu\nu$, 0.106%.
For BSM contribution, limit set to 0.13%.

- H $\rightarrow Z\gamma$, by Wei-Ming Yao;
- Br 0.154%;




- $\Delta M(M_{qq\gamma} - M_{qq}, or\ M_{\nu\nu\gamma} - M_{\nu\nu})$ shown.
- Sensitivity 16%.

# Existing results:240GeV, 5.6iab

| (240GeV,5.6ab$^{-1}$) | CDR | 2022.10 |
|---|---|---|
| $\sigma(ZH)$ | **0.50%** | |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$ | **0.27%** | **0.27%** |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$ | **3.3%** | **4.0%** |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$ | **1.3%** | **1.5%** |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$ | **1.0%** | |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$ | **5.1%** | **7.9%** |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$ | **0.8%** | |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$ | **6.8%** | |
| $\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$ | **17%** | **18%** |
| $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$ | **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%** | |

See previous slides for related publications.
Changes mostly from better analysis strategy.

All existing results are based in (240 GeV,5.6ab$^{-1}$).

Now with the scenario upgrade published in Snowmass 2021, the new run will based in (240 GeV 20ab$^{-1}$ + 360 GeV 1ab$^{-1}$).

7 years 240 GeV
->
10 years 240 GeV + 5 years 360 GeV.

# 360GeV: Higher Energy Run

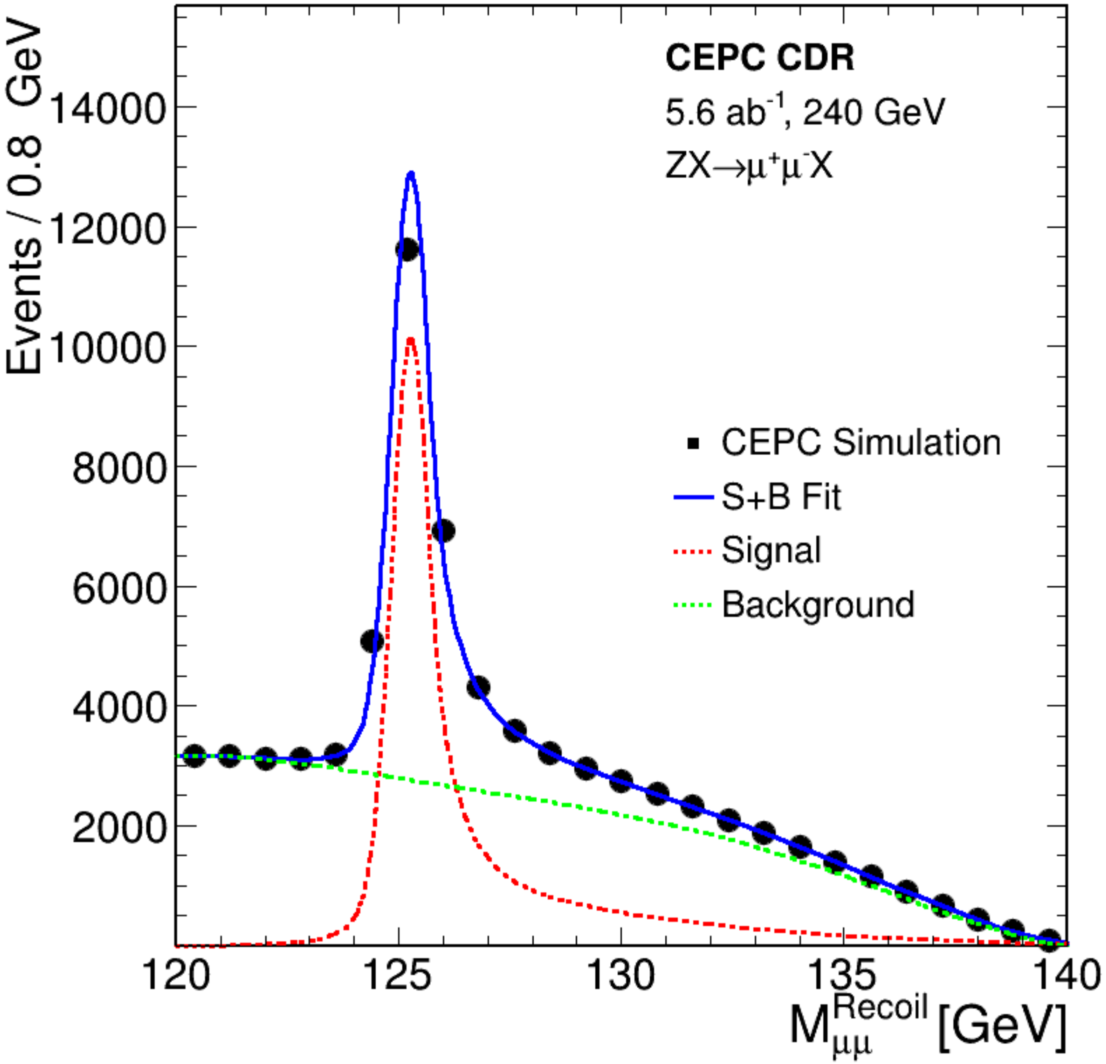
- 350~365GeV $t\bar{t}$ Run:
  - For Higgs: Larger vvH cross section; Benefit width measurement
  - More advantages for EW/Theoretical part;
- Current benchmark: 1ab$^{-1}$ @ 360GeV
  - 360GeV saves 10% energy with respect to 365 GeV
  - With current lumi, 5 years to collect 1iab data.
  - Also $t\bar{t}$ threshold scan plan
    - See Zhan's report for top mass scan measurement.

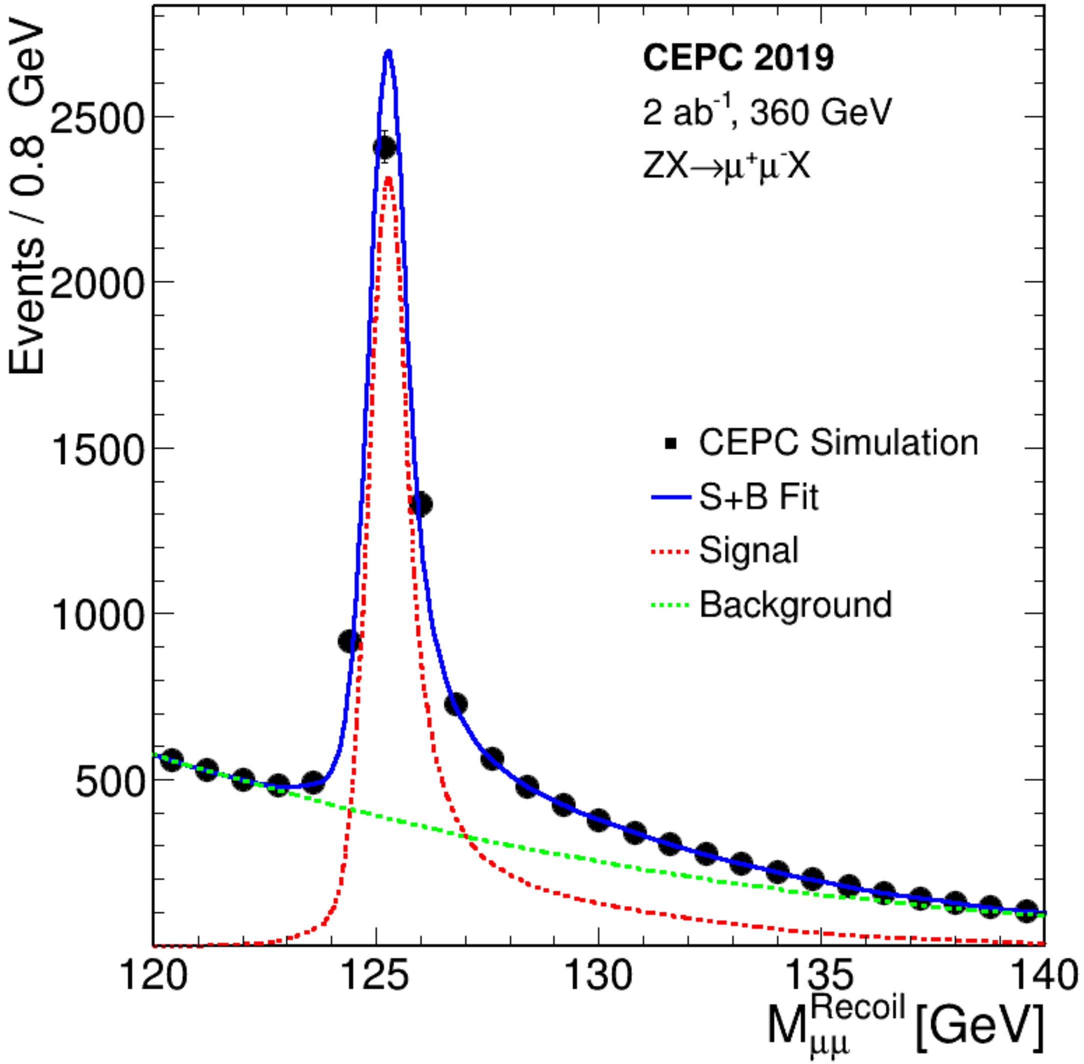
Plan from Fcc-ee:
0.2ab$^{-1}$ 350GeV Scan + 1.5ab$^{-1}$ 365GeV

# Extrapolations

Using existing 240GeV to estimate 360GeV……

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



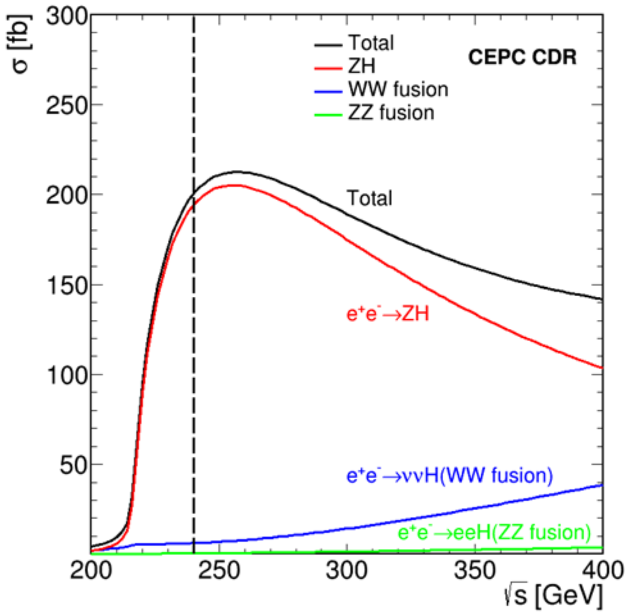



# Extrapolations: signals

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)

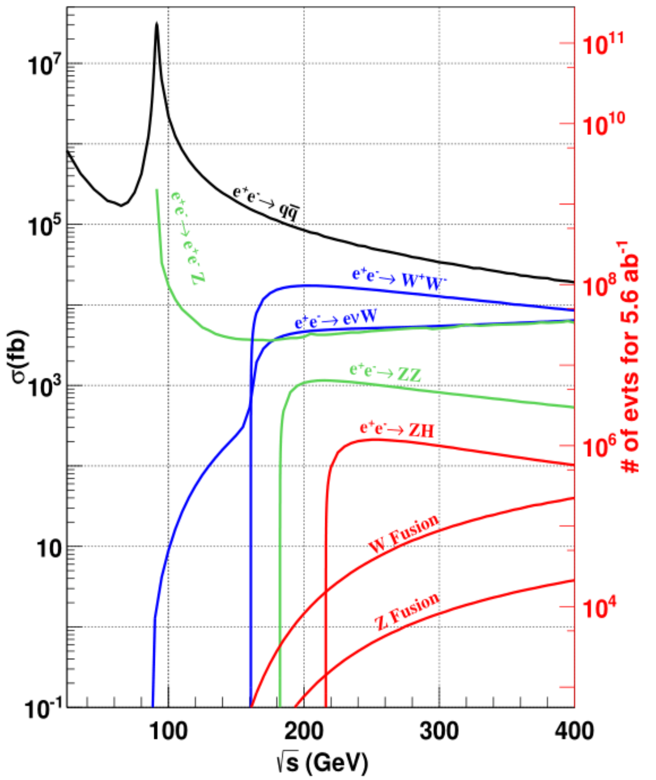
| fb | 240 | 350 | 360 | 365 | 360/240 |
|---|---|---|---|---|---|
| ZH | 196.9 | 133.3 | 126.6 | 123.0 | -36% |
| WW fusion | 6.2 | 26.7 | 29.61 | 31.1 | +377% |
| ZZ fusion | 0.5 | 2.55 | 2.80 | 2.91 | +460% |
| Total | 203.6 | | 159.0 | | |
| Total Events | 4M | | 0.16M | | |




In total ~4M Higgs would be collected in CEPC 240+360.
More fusion events, also eeH can not be ignored in 360GeV.

# Extrapolations: backgrounds

| pb | 240 | 350 | 360 | 365 | 360/240 |
|---|---|---|---|---|---|
| $ee(\gamma)$ | 930 | 336 | 325 | 319 | -65% |
| $\mu\mu(\gamma)$ | 5.3 | 2.2 | 2.1 | 2.1 | -60% |
| $qq(\gamma)$ | 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% |
| $t\bar{t}$ | \ | 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.

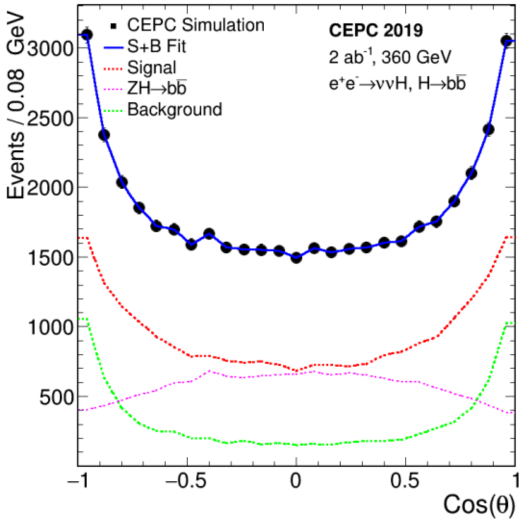
Generally, with larger phase space and smaller bkg cross sections, continuum background would reduce.

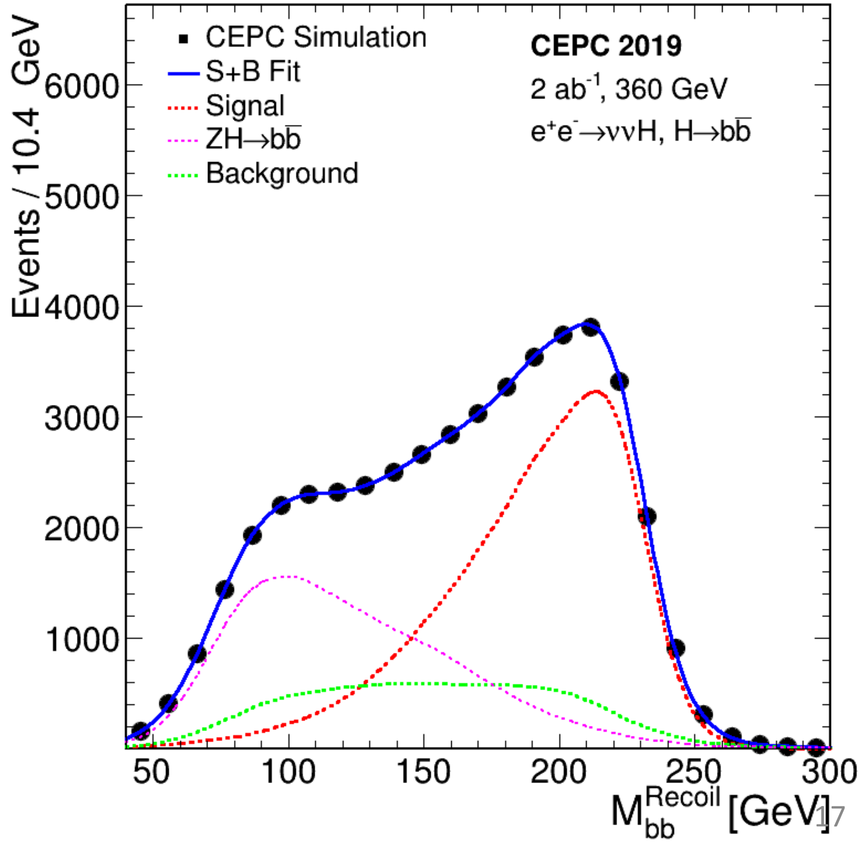
Processes are extrapolated to 360GeV in this ratio.
Kinematic distributions are also scaled with phase space.

# vvH->bb : 360 GeV, full sim

- Clear separation between ZH and vvH.
- Constrain from other ZH->bb($ee, \mu\mu, qq$) considered.
- In current 1iab,
  - $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 1.10%
  - $\sigma(\mathrm{Z}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 0.90%
  - share the anti-correlation -15.8%.

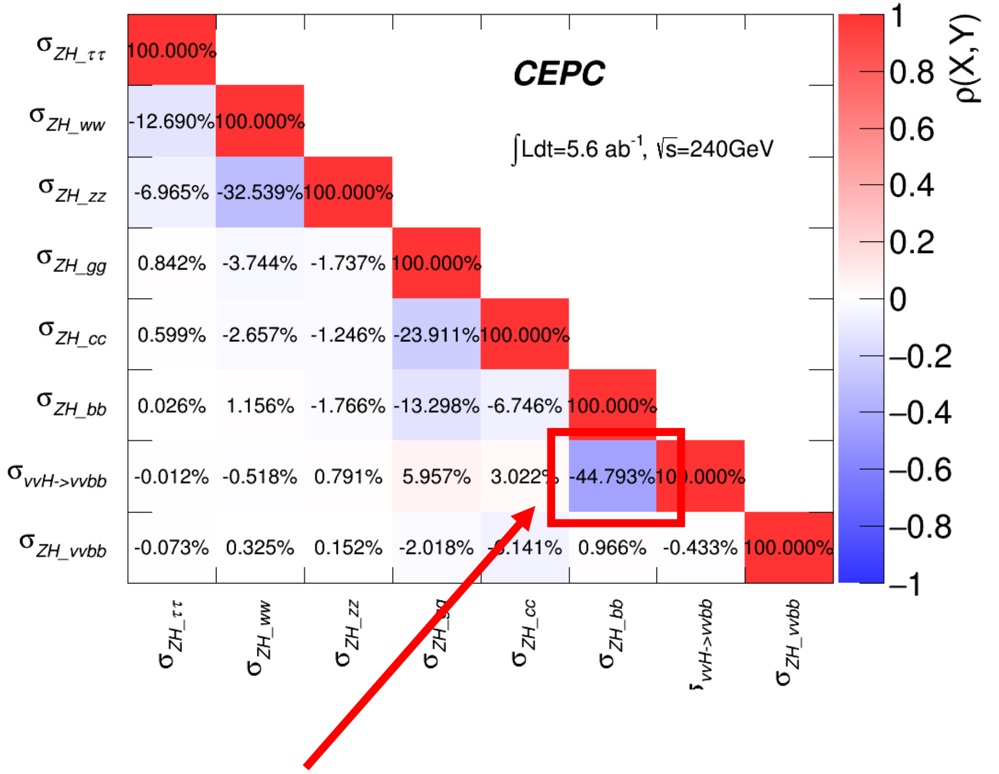
This measurement gives very excellent constrain for Higgs width.



# Combination Framework

- Easy for extrapolation
- 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



# Results in Snowmass: 2205.08553

| | 240 GeV, 20 $ab^{-1}$ | | 360 GeV, 1 $ab^{-1}$ | | |
|---|---|---|---|---|---|
| | ZH | **vvH** | ZH | **vvH** | **eeH** |
| any | **0.26%** | | **1.40%** | \ | \ |
| H→bb | **0.14%** | **1.59%** | **0.90%** | **1.10%** | **4.30%** |
| H→cc | **2.02%** | | **8.80%** | **16%** | **20%** |
| H→gg | **0.81%** | | **3.40%** | **4.50%** | **12%** |
| H→WW | **0.53%** | | **2.80%** | **4.40%** | **6.50%** |
| H→ZZ | **4.17%** | | **20%** | **21%** | |
| $H \rightarrow \tau\tau$ | **0.42%** | | **2.10%** | **4.20%** | **7.50%** |
| $H \rightarrow \gamma\gamma$ | **3.02%** | | **11%** | **16%** | |
| $H \rightarrow \mu\mu$ | **6.36%** | | **41%** | **57%** | |
| $Br_{upper}(H \rightarrow inv.)$ | **0.07%** | | \ | \ | |
| $H \rightarrow Z\gamma$ | **8.50%** | | **35%** | \ | |
| Width | **1.65%** | | **1.10%** | | |

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 | $\pm0.5$ | | $\pm0.9$ | |
| $H \rightarrow b\bar{b}$ | $\pm0.3$ | $\pm3.1$ | $\pm0.5$ | $\pm0.9$ |
| $H \rightarrow c\bar{c}$ | $\pm2.2$ | | $\pm6.5$ | $\pm10$ |
| $H \rightarrow gg$ | $\pm1.9$ | | $\pm3.5$ | $\pm4.5$ |
| $H \rightarrow W^+W^-$ | $\pm1.2$ | | $\pm2.6$ | $\pm3.0$ |
| $H \rightarrow ZZ$ | $\pm4.4$ | | $\pm12$ | $\pm10$ |
| $H \rightarrow \tau\tau$ | $\pm0.9$ | | $\pm1.8$ | $\pm8$ |
| $H \rightarrow \gamma\gamma$ | $\pm9.0$ | | $\pm18$ | $\pm22$ |
| $H \rightarrow \mu^+\mu^-$ | $\pm19$ | | $\pm40$ | |
| $H \rightarrow$ 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.**

# Couplings: $\kappa$ framework

- Higgs coupling defined as:

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

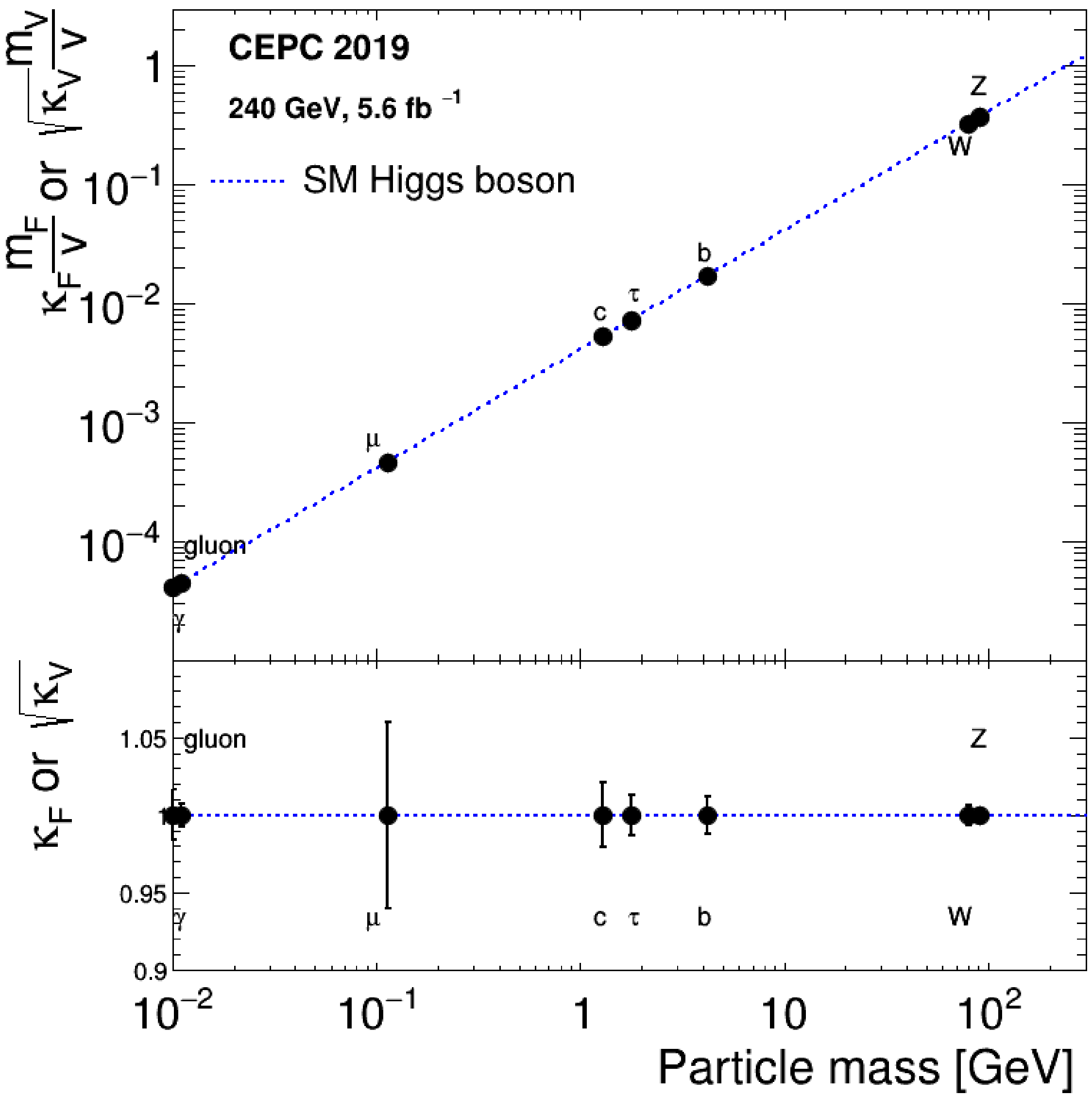
$$\sigma(\nu\nu H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb}) \propto \frac{\kappa_{\mathrm{w}}^2 * \kappa_{\mathrm{b}}^2}{\Gamma_H}.$$

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

and all other channel suffered from Higgs width.

Extract width with branch ratio: Constrained 7-$\kappa$

Keep width independent: 10 $\kappa$



# Higgs width

- CEPC Higgs width is fitted in the 10$\kappa$ framework.

- Adding one mass point would significantly improve the constrain.

  - Standalone 240GeV 20ab$^{-1}$ gives 1.65%, while 360GeV 1ab$^{-1}$ alone gives 3.65%.

  - These 2 points are independent.

  - Combined $\chi^2$ fit gives:

Results not sensitive to the statistics for 360GeV run
For Higgs, we do not need too much 360GeV events;
But we do need it for the independent constrain.

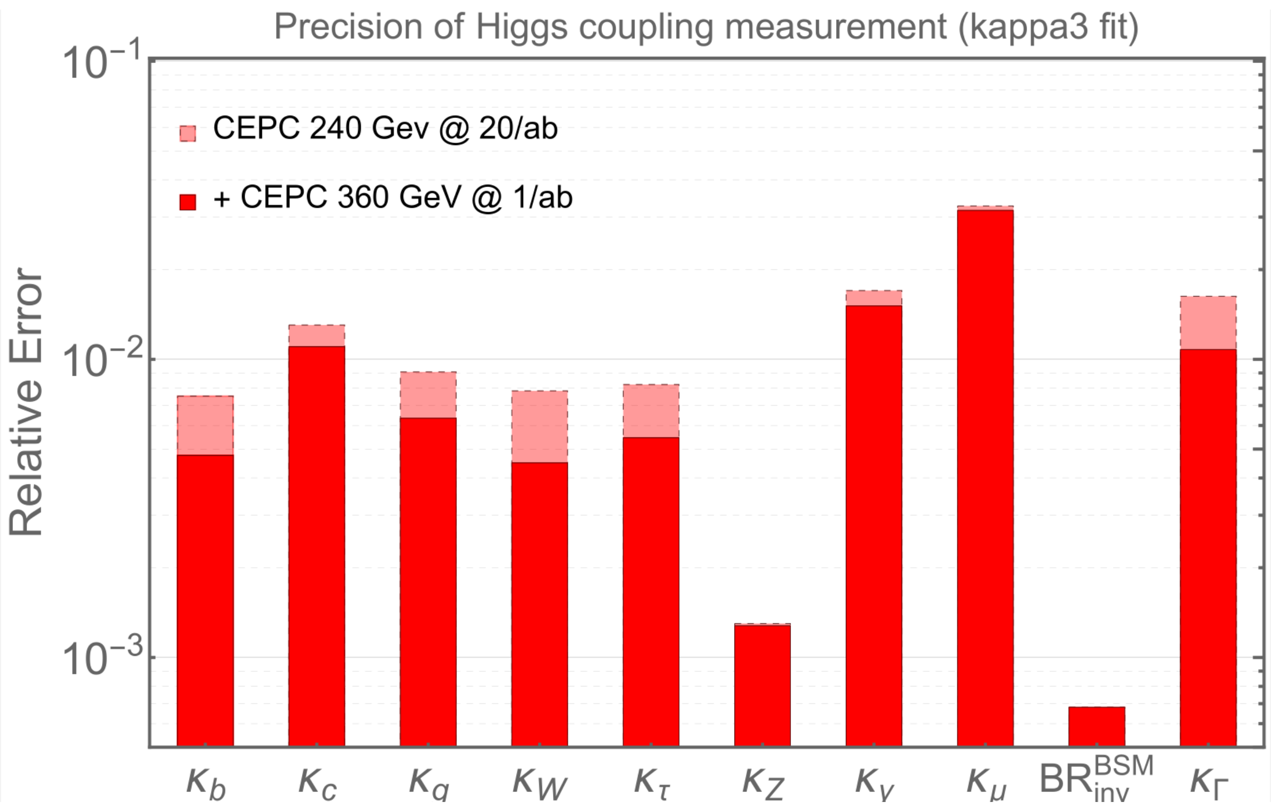
$$\Delta(\Gamma_H) \approx 1.10\%$$

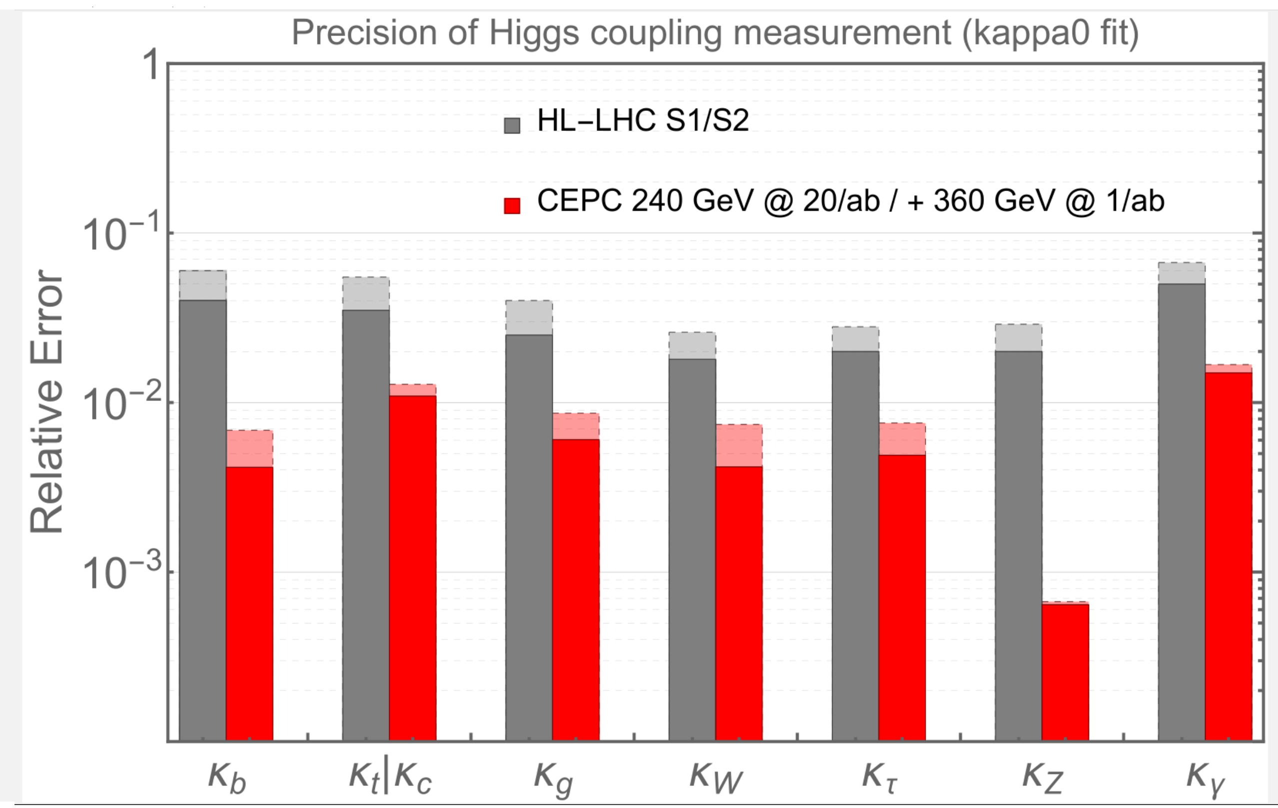
As width in everywhere, width helps all kappas even better.

*: Here we do not have the assumption about the exotic decay. This treatment is different with Fcc-ee, which believes exotic Br can not be less than 0. If we take this assumption, the model-dependent width precision would be even better.

# $\kappa$ : CEPC latest

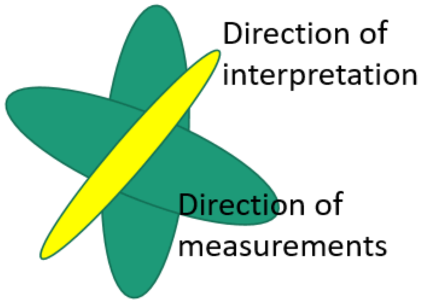
- Compared to HL-LHC, lepton colliders 1-2 order better in Higgs coupling.
- Adding 360GeV will signifantly improve $\kappa$ results.



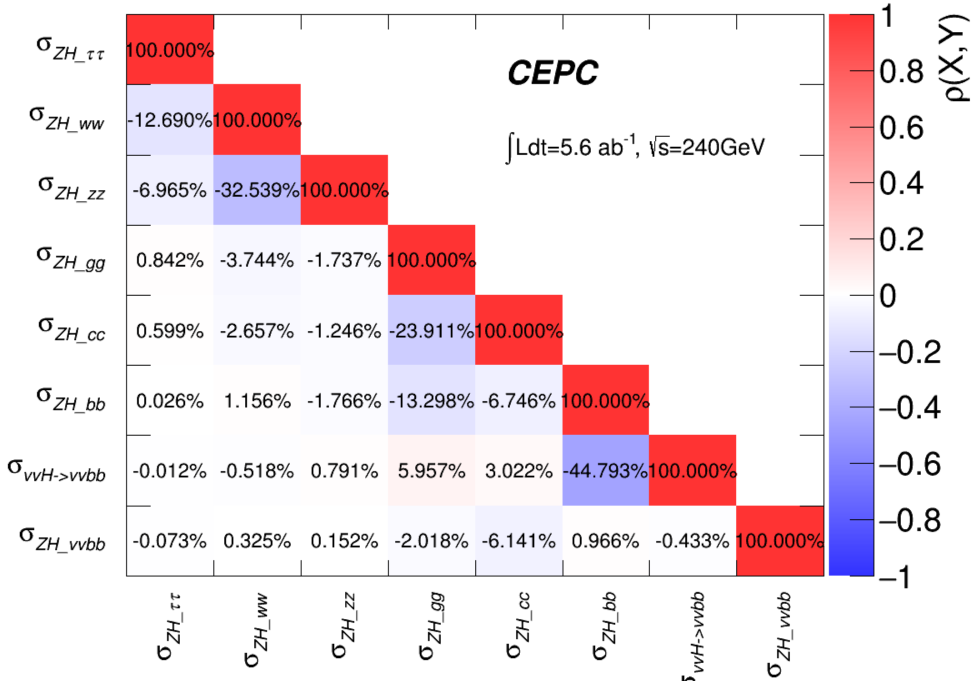

For kappa0 and kappa3 fit and the comparison among future colliders, see [de Blas, J. *et al.* arXiv:1905.03764]

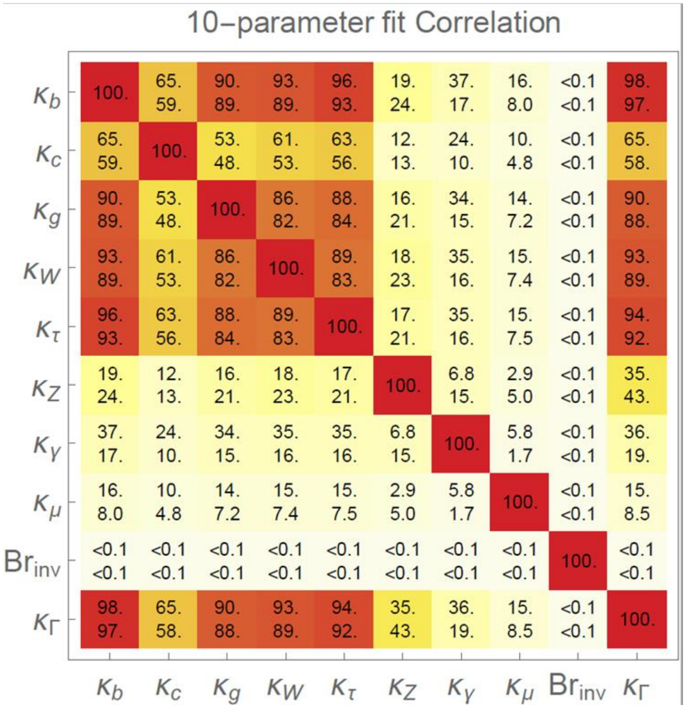
# Correlation Matrix




Input | + Interpretation | Output
---|---|---
Measurements | → | Couplings
Anti-correlated | | Coupled by width

2nd correlation differentials




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

# Synergy with other experiments

- [de Blas, J. *et al.* arXiv:1905.03764]

See Jiayin's slides for more interpretations!

- Also kappa and EFT results are shown between CEPC240, HL-LHC, Fcc, ILC……
- In the paper, only CEPC 240GeV 5.6iab 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 | |
| $\kappa_W$ [%] | 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 |
| $\kappa_Z$ [%] | 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 |
| $\kappa_g$ [%] | 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 |
| $\kappa_\gamma$ [%] | 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 |
| $\kappa_c$ [%] | – | 4.1 | – | – | 2.5 | 1.3 | 0.9 | 4.3 | 1.8 | 1.4 | 2.2 | 1.8 | 1.3 | 0.95 |
| $\kappa_t$ [%] | 3.3 | – | 2.8 | 1.7 | – | 6.9 | 1.6 | – | – | 2.7 | – | – | – | 1.0 |
| $\kappa_b$ [%] | 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 |
| $\kappa_\mu$ [%] | 4.6 | – | 2.5 | 1.7 | 15 | 9.4 | 6.2 | 320⋆ | 13 | 5.8 | 8.9 | 10 | 8.9 | 0.41 |
| $\kappa_\tau$ [%] | 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 | $FCC\text{-}ee_{240}$ | $FCC\text{-}ee_{365}$ | FCC-ee/eh/hh |
| $\kappa_W$ [%] | 1.0 | 0.29 | 0.24 | 0.73 | 0.40 | 0.38 | 0.88 | 0.88 | 0.41 | 0.19 |
| $\kappa_Z$[%] | 0.29 | 0.22 | 0.23 | 0.44 | 0.40 | 0.39 | 0.18 | 0.20 | 0.17 | 0.16 |
| $\kappa_g$[%] | 1.4 | 0.85 | 0.63 | 1.5 | 1.1 | 0.86 | 1. | 1.2 | 0.9 | 0.5 |
| $\kappa_\gamma$ [%] | 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 |
| $\kappa_c$ [%] | 2. | 1.2 | 0.9 | 4.1 | 1.9 | 1.4 | 2. | 1.5 | 1.3 | 0.96 |
| $\kappa_t$ [%] | 3.1 | 2.8 | 1.4 | 3.2 | 2.1 | 2.1 | 3.1 | 3.1 | 3.1 | 0.96 |
| $\kappa_b$ [%] | 1.1 | 0.56 | 0.47 | 1.2 | 0.61 | 0.53 | 0.92 | 1. | 0.64 | 0.48 |
| $\kappa_\mu$ [%] | 4.2 | 3.9 | 3.6 | 4.4∗ | 4.1 | 3.5 | 3.9 | 4. | 3.9 | 0.43 |
| $\kappa_\tau$ [%] | 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

- Significant progress from Accelerator, Detector, and Object performance since CDR didn't enter the combination yet.
- Global optimization to handle the correlations
- Careful systematic estimation required by precise result ($H \rightarrow bb$ $0.14\%$)
- Far from the CEPC fully/ultimate potential. 4M Higgs!
    - More powerful tools can be imported. HEPFit, ML, Quantum computing……
- Your efforts are always appreciated!

Detector performance
+ Reco algorithm

Individual Analysis
(No correlation)

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

Coupling &
Interpretation

And new physics?

# Summary

- Latest CEPC Higgs combination, $\sigma * \mathrm{Br}$ and coupling results are shown.
- Extrapolation to 360GeV applied
  - 1.10% precision for width expected.

| | 240 GeV, 20 $ab^{-1}$ | | 360 GeV, 1 $ab^{-1}$ | | |
|---|---|---|---|---|---|
| | ZH | **vvH** | ZH | **vvH** | **eeH** |
| any | **0.26%** | | **1.40%** | \ | \ |
| H→bb | **0.14%** | **1.59%** | **0.90%** | **1.10%** | **4.30%** |
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