Update on the SM Higgs precision measurements at CEPC

Kaili Zhang

IHEP

The 2024 international workshop on the high energy Circular Electron Positron Collider

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Higgs@CEPC

CEPC, the SOTA project for HEP.

CEPC CDR: arXiv:1811.10545

White Paper: arXiv:1810.09037

CEPC Snowmass 2021:

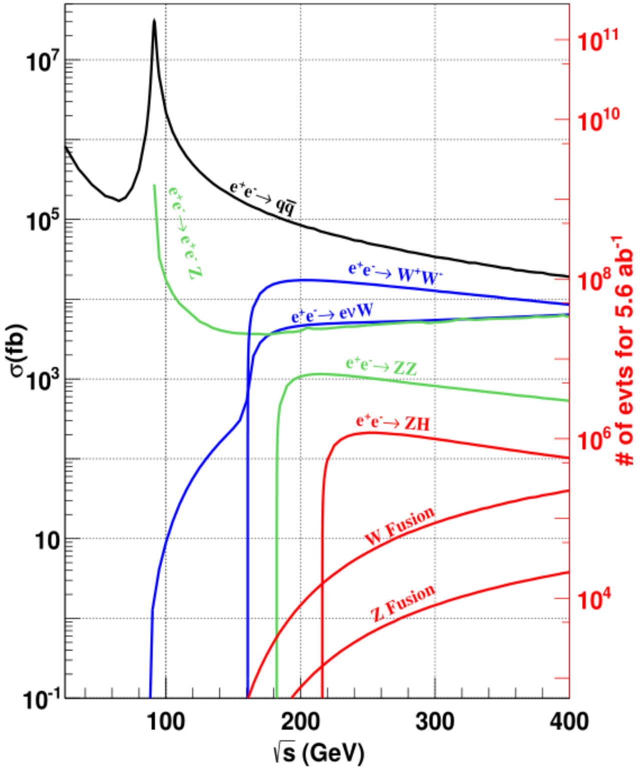
arXiv:2205.08553

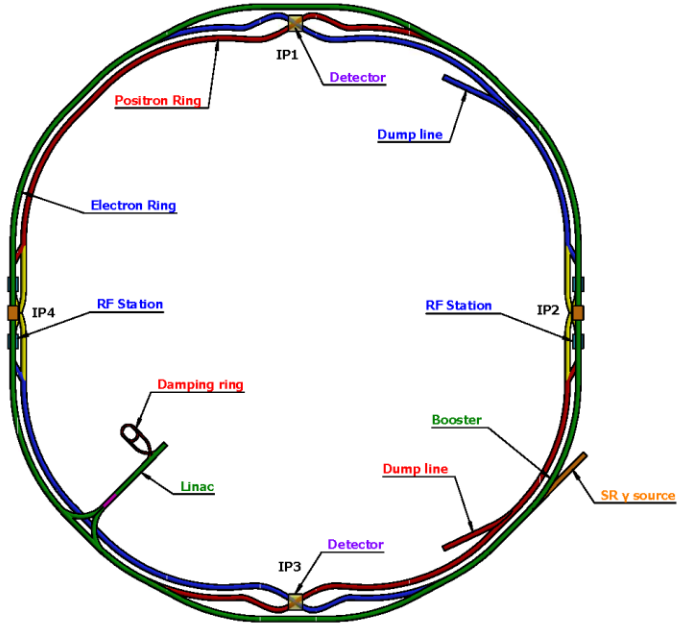
CEPC Accelerator TDR:

arXiv:2312.14363

20iab 240 GeV + 1iab 360 GeV run.

CEPC will collect 4M Higgs.

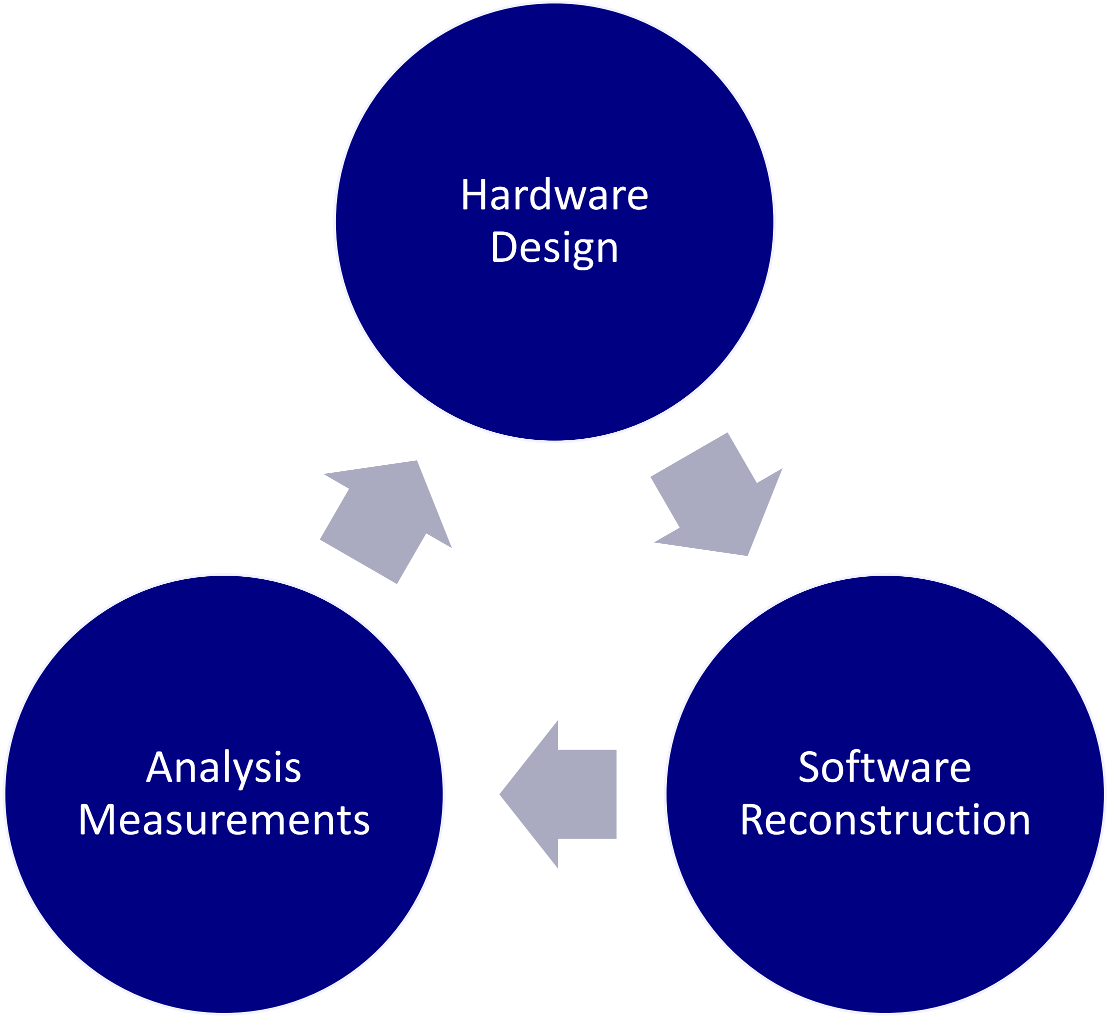




Operation mode		ZH	Z	W⁺W⁻	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	5
30 MW	L / IP [×10^{34} cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.65
	Event yields [2 IPs]	2.6×10^{6}	2.5×10^{12}	1.3×10^{8}	4×10^{5}
50 MW	L / IP [×10^{34} cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	21.6	100	6.9	1
	Event yields [2 IPs]	4.3×10^{6}	4.1×10^{12}	1.1×10^{8}	6×10^{5}

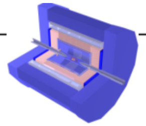
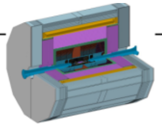
*WW：including 240GeV, WW 4.3*10^8.

Evolving Performance



- CEPC Detector TDR under preparing.
  - Detector design upgraded
    - CEPC-v4 to CEPC Ref-TDR
    - Better VTX, Calo, TOF.
  - Software framework migration
    - CEPCSW, Key4HEP based
    - ArborPFA to CyberPFA
  - Analysis, therefore improved
    - Benchmarks feedback to design

Hardware highlights

	CDR 	Ref-TDR 
VTX	Inner radius of **16 mm**	Inner radius of **11 mm**
	Material Budget: 0.15%*6+0.14%(beampipe)= **1.05% X0**	Material Budget: 0.06%*4(inner)+0.165%*2(outer)+0.2%(beampipe)= **0.77% X0**
Gaseous Tracker	TPC with **1 mm* 6 mm** readout	TPC with **0.5 mm* 0.5 mm** readout To have **dE/dx or dN/dx resolution 3%** (Drift Chamber with the capability of dN/dx as alternative)
ToF	**-**	AC-LGAD, with **50 ps** per MIP
ECAL	Si-W-ECAL: **17%**/√E ⊕ 1%	Crystal Bar-ECAL: **1.3%**/√E ⊕ 0.7%
HCAL	RPC-Iron: **60%**/√E ⊕ 2%	Glass-Iron: **30%**/√E ⊕ 6.5%

Delphes Card with Ref-TDR geometry information can be found in https://code.ihep.ac.cn/zhangkl/delphes_cepc (working in progress).

- VTX
  - Inner radius: 40% (16 mm → 11 mm)
  - Material 30% (1.05% → 0.77% X0)
- Better TPC, with dE/dx, dN/dx 3%;
- TOF readout;
- ECAL: to Cyber: to 1.3%.
- HCAL: to Glass-Iron, to 30%.

Detector/Object Performance

- Reconstruction overview: arXiv:1806.04879
- Jet: arXiv:2104.05029
- Track: arXiv:2209.00397
- dE/dx: arXiv:2209.14486
- Cluster time: arXiv:2209.02932
- TPC: doi:10.1142/S0217751X22460095
- Drift Chamber: doi:10.1007/s41365-024-01497-z
- GSHCAL: doi:10.1016/j.nima.2023.168944

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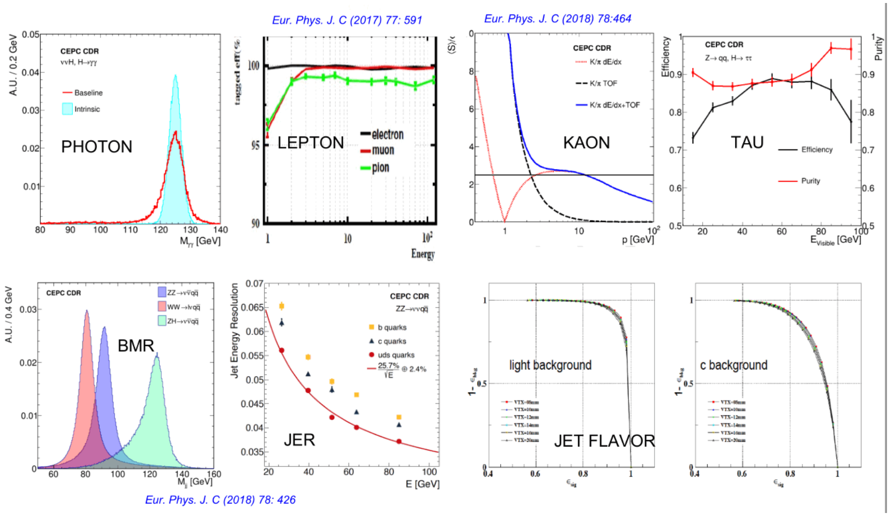
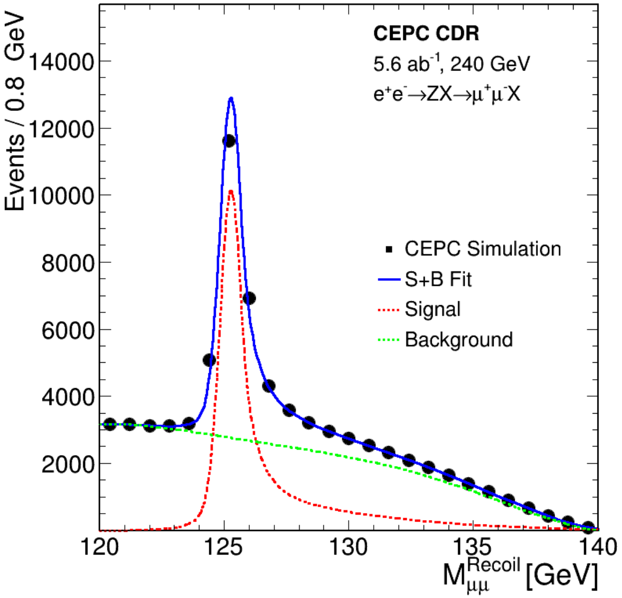
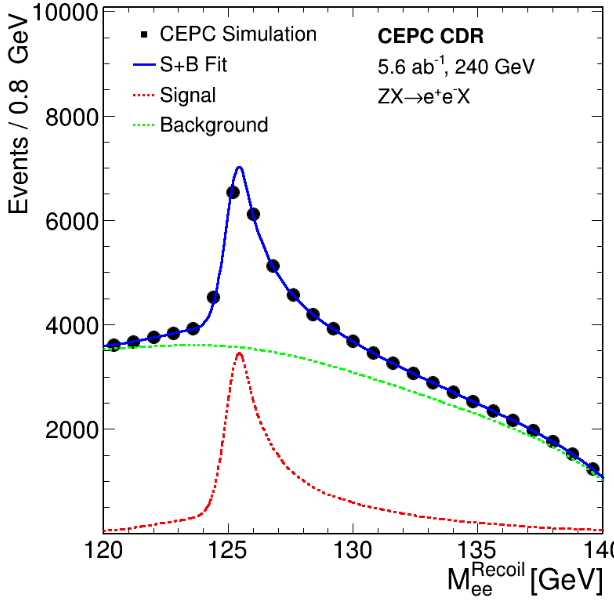


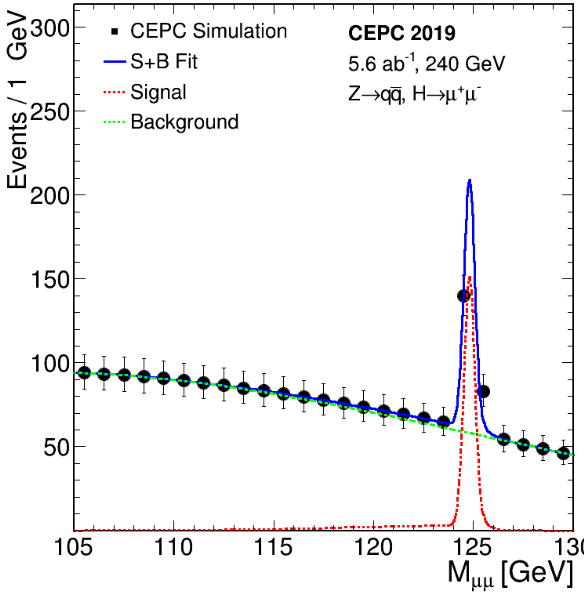
Many contributions since CDR.

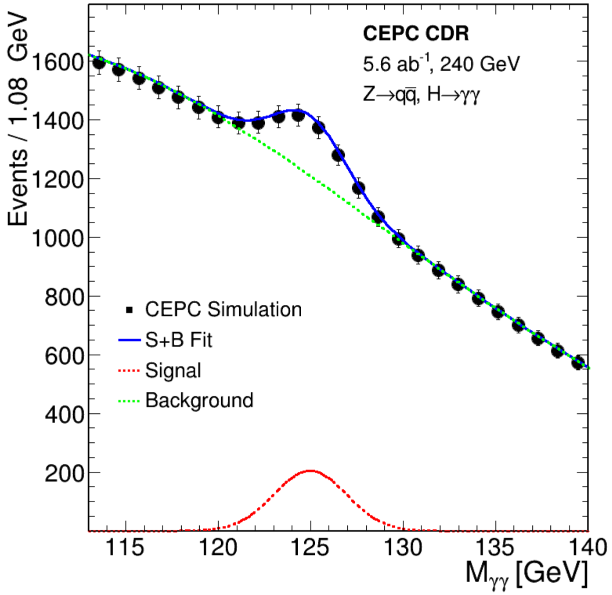
Physics benchmarks also need migration to Ref-TDR layout.

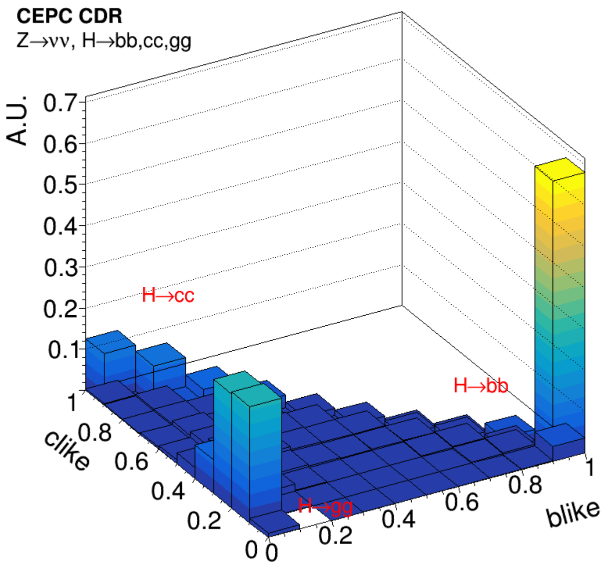
Individual sub channels

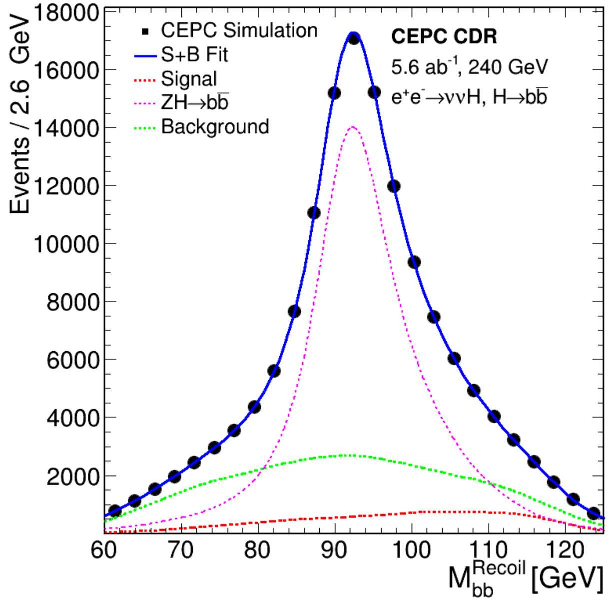


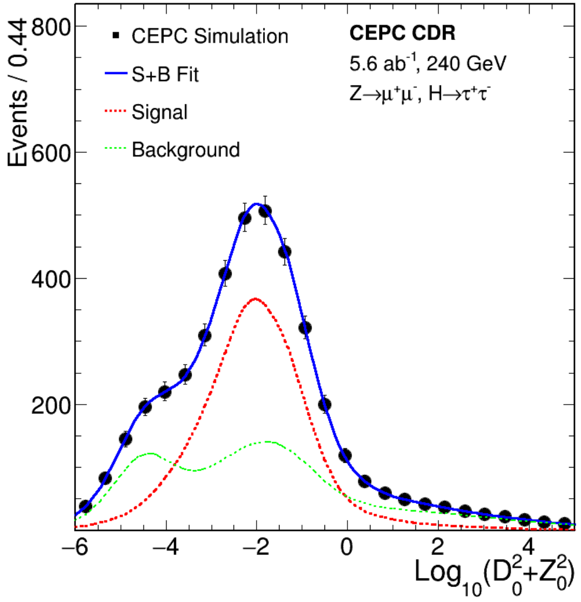








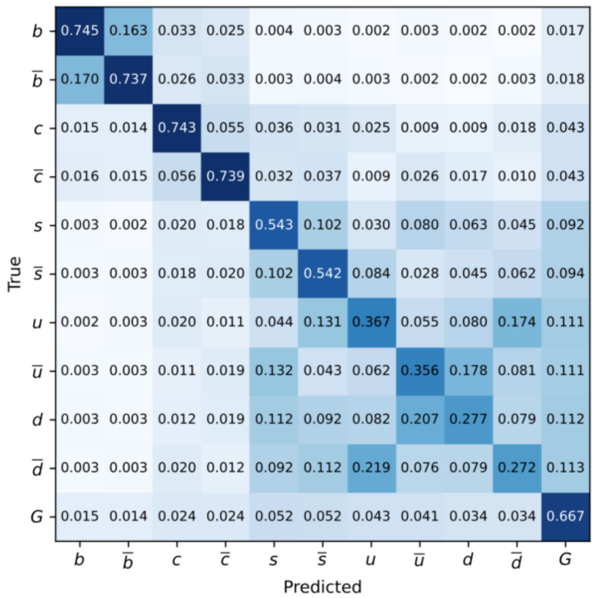


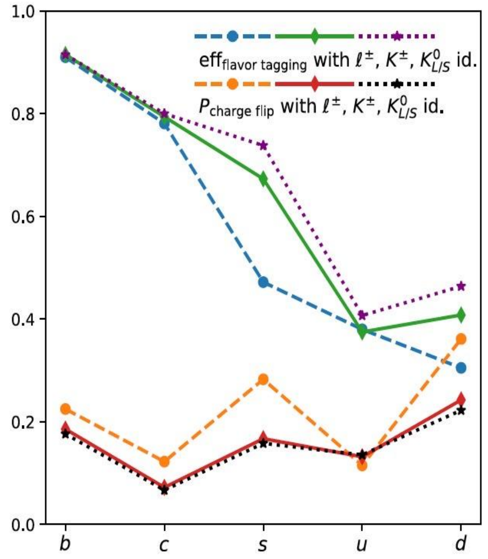


All these plots are based in 2018 CEPC-v4 layout, ECM=240GeV and total statistics 5.6iab.

All these studies will be repeated in Ref-TDR. Here for simple extrapolations first.

Jet: hadronic channels





ParticleTransformer

- Traditional method
  - eeH, mmH by Yu Bai arXiv:1905.12903
  - vvH, qqH by Yongfeng Zhu arXiv:2203.01469
  - b-c likeness from LCFIplus flavor tagging;

- With Advanced ML tools:

ParticleNet/Transformer 2309.13231

Rare decay, ss, dd, uu PRL 132, 221802 (2024)

Particle Flow Network 2410.04465

……

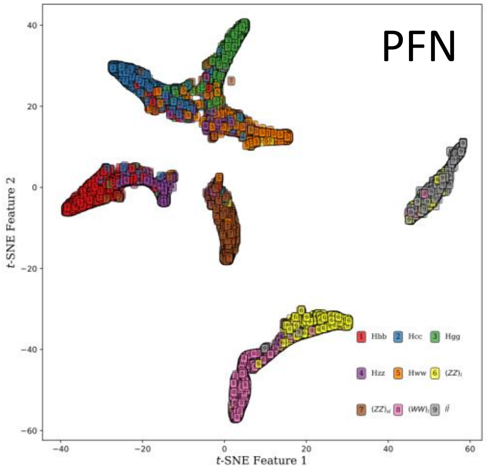
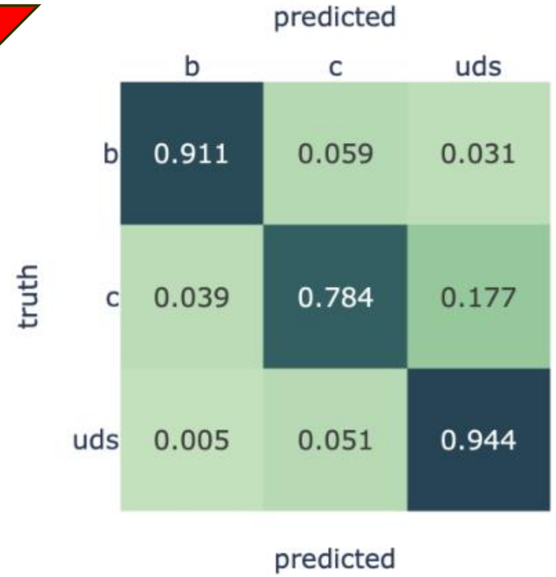


Figure 6: Classification performance visualized using t-SNE algorithm. Different colored squares represent distinct processes, with two t-SNE features corresponding to similarity dimensions. The distance between squares reflects the difference between processes.

Jet: hadronic channels

LCFIPlus

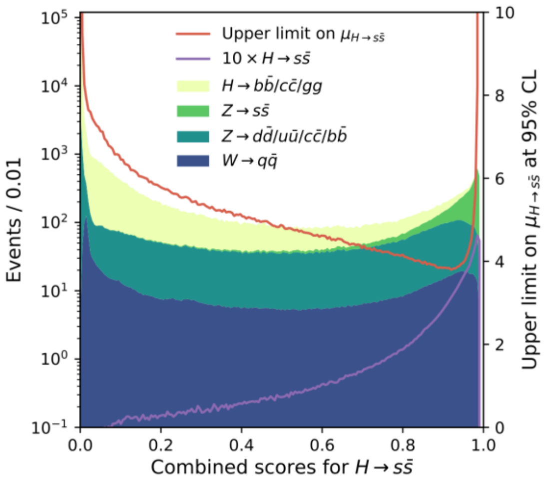
Migration Matrix Upgraded

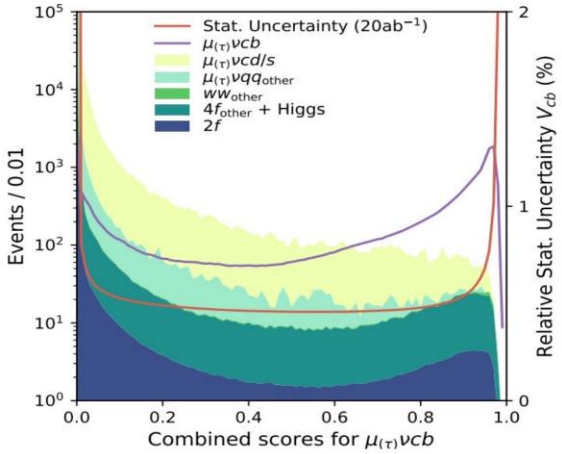


ParticleNet

With better detector performance and reconstruction algorithms, novel concepts emerge like Jet Origin ID and Color Singlet ID.

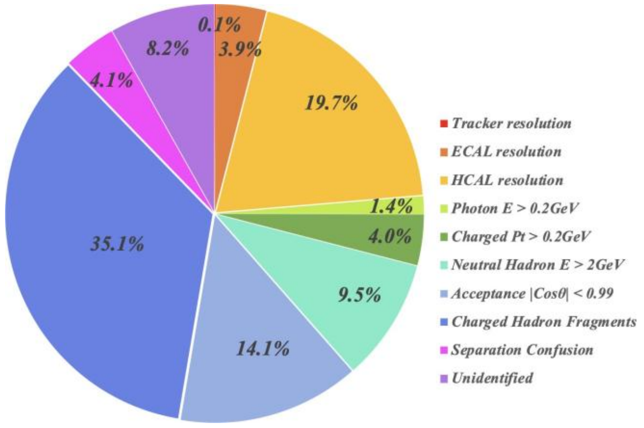
Much better classifications can be done.
Even H->ss final states possible:

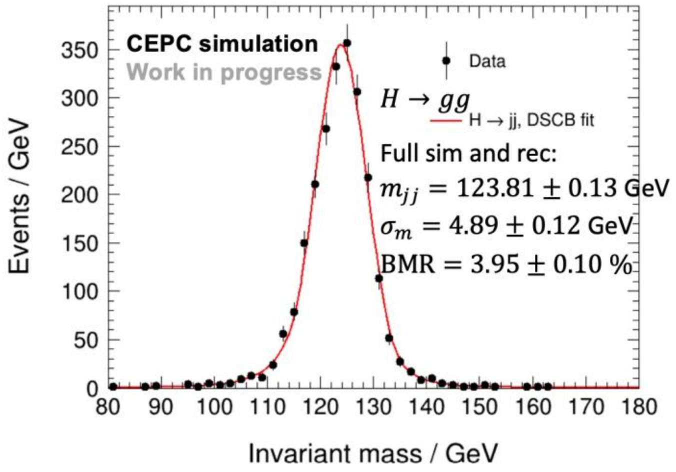




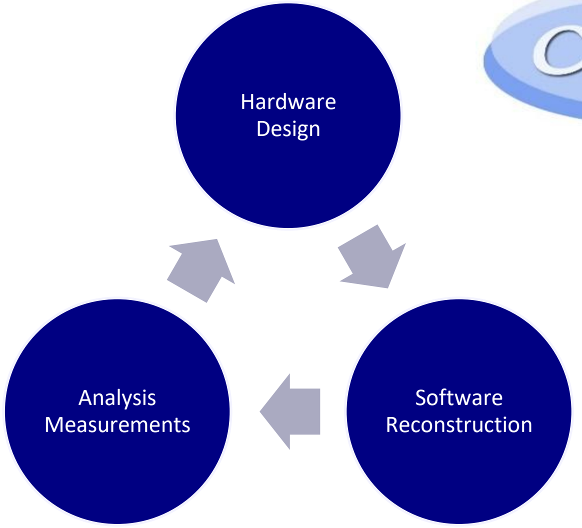
Jet: BMR

- Boson Mass Resolution, to quantify Jet energy scale.
- CDR BMR expect to 3.7%, to separate Z/W/H.
- Preliminary BMR at ref-TDR: 4.0%.
- Effective control of confusion(like fake particles) are crucial(50%). Others are detector resolution(25%) and acceptance(25%).
- Need further development on PFA pattern recognition.
- Further, if BMR of 3% achieved, precisions of most benchmarks could be further improved by 5-10%.





Higgs Hadronic channels



- For all Higgs hadronic channels,(b/c/g/w/z……)
  - Current Hadronic ZZ are not included in coupling yet
  - Refer to Xiaotian's report, big improvement. (double?)

- Expect
  - ~5% from better detector response like VTX; (Trace 2.64->2.68)
  - ~10% from better reconstruction classifications.
  - Further ~10% if BMR can improve 4% -> 3%.

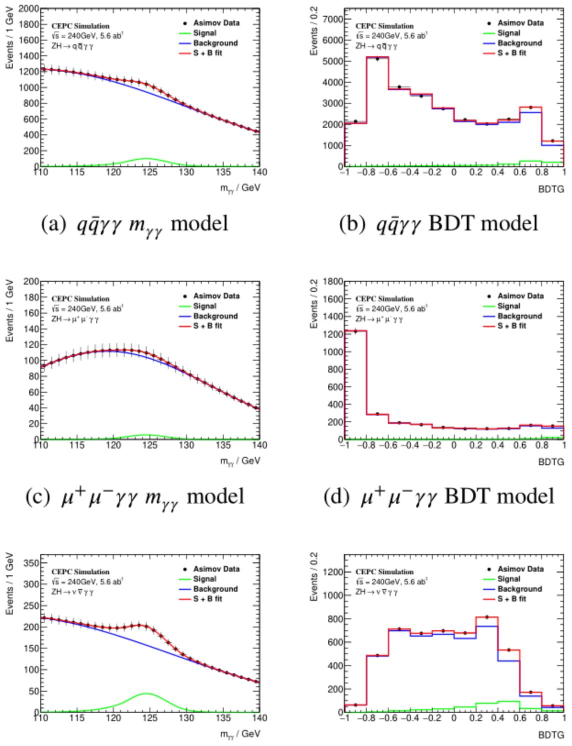
  - H->bb 0.14% -> 0.12%. Need careful systematic uncertainties study.

$H \to \gamma\gamma$

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

- Ecal performance dominated.
- CDR 17% -> Ref-TDR Cyber-PFA: 1.3%.

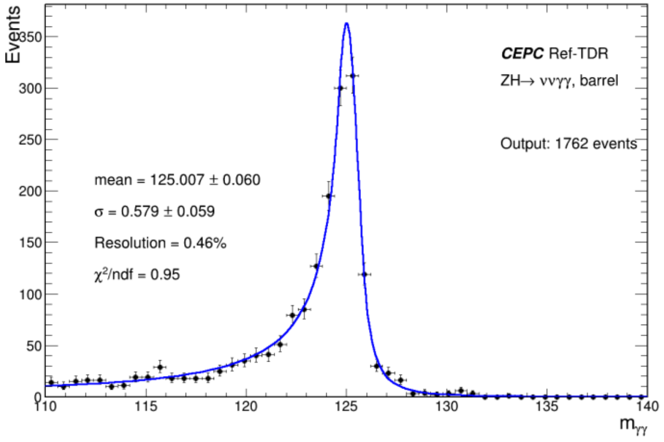
Channel	μ @ 5.6 ab^{-1}	μ @ 20 ab^{-1}
$q\bar{q}\gamma\gamma$	1.00 ± 0.0879	1.00 ± 0.0465
$\mu^+\mu^-\gamma\gamma$	1.00 ± 0.3571	1.00 ± 0.1920
$\nu\bar{\nu}\gamma\gamma$	1.00 ± 0.1142	1.00 ± 0.0605
Combined	1.00 ± 0.0688	1.00 ± 0.0364



(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



Expect precision to 1.8%.

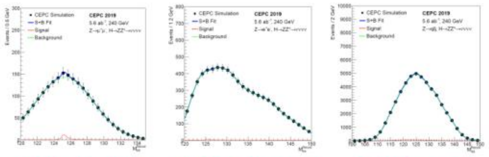
DSCB fit give resolution 0.46%.
low mass tail can be further controlled with Ecal PFA algorithm.

Channels with small change

- We expect similar results for those channels from CDR to Ref-TDR.
- See Previous report on CEPC 2023;

H →invisible and $Z\gamma$

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

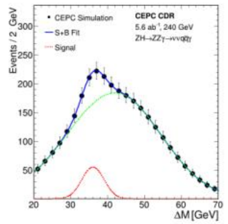


ZH(Z->$\mu^+\mu^-$,H->invisible) ZH(Z->e^+e^-,H->invisible) ZH(Z->qq,H->invisible)

ZH final state studied	Relative precision on $\sigma(ZH)\times$BR	Upper limit on BR (H→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%

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

- H → $Z\gamma$, 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%.

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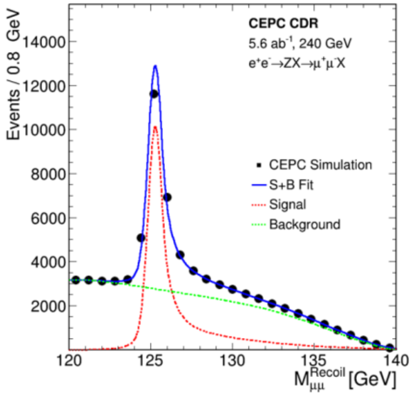
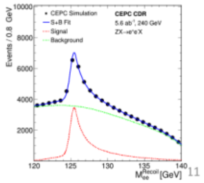
$\sigma(ZH)$: $H \to$ inclusive

- 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%





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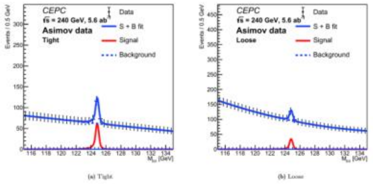
H → $\mu\mu$ and $\tau\tau$

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



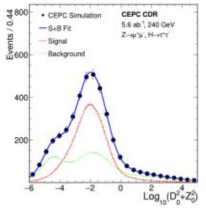
(a) Tight (b) Loose

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

Smearing	25%	50%	100%
μ	$1.00^{+0.21}_{-0.20}$	$1.00^{+0.22}_{-0.21}$	$1.00^{+0.25}_{-0.24}$
Significance	5.5σ	5.1σ	4.4σ
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%



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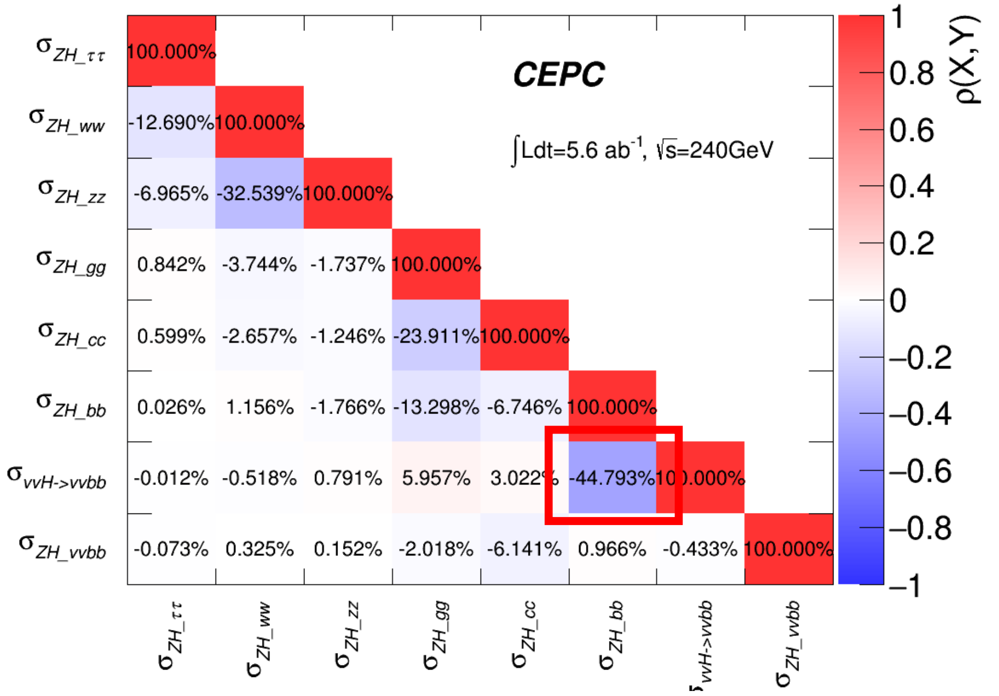
Combination Framework

- Easy for extrapolation
- Multiple observables for workspace
    - Mass spectrum, BDT output, Flavor tagging likeness
    - Apply multi dimensional fit if possible
- Input correlation in hadronic channels 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



Personally suggest to provide the migration matrix with correlation matrix at the same time.

Higgs width

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.

- CEPC Higgs width is fitted in the 10κ framework.
- Adding one mass point would significantly improve the constrain.
    - Standalone 240GeV 20ab^{-1} gives 1.5%, while 360GeV 1ab^{-1} alone gives 3.3%.
    - These 2 points are independent.
    - Combined χ^2 fit gives:

For the constrained-Γ_H fit, the outcome of this analysis is similar to that presented in Ref. [25], with the exception of the CEPC results where one observes the expected improvement in the sensitivity to Higgs couplings derived from the increase in the luminosity at 240 GeV, together with the addition of the new set of measurements that would be possible at 360 GeV. The sensitivity to the aTGC via the optimal

$$\Delta(\Gamma_H) < 1.0\%$$

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.

Results in Snowmass: 2205.08553

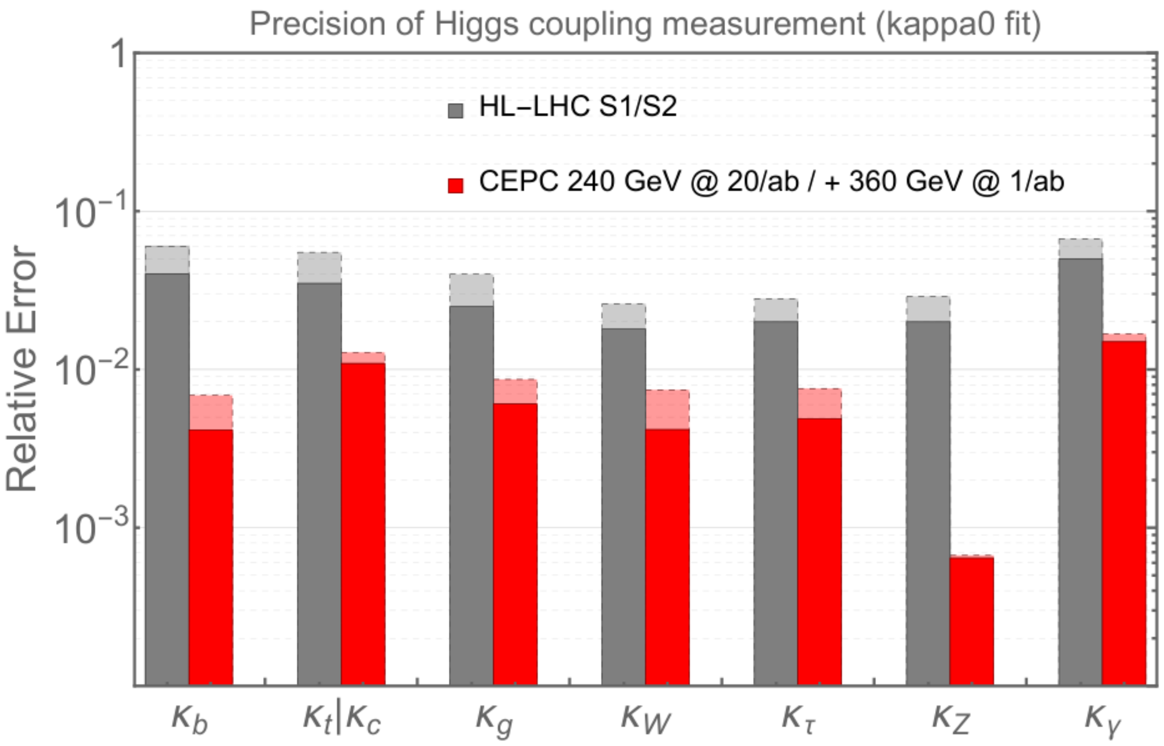
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
any	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	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

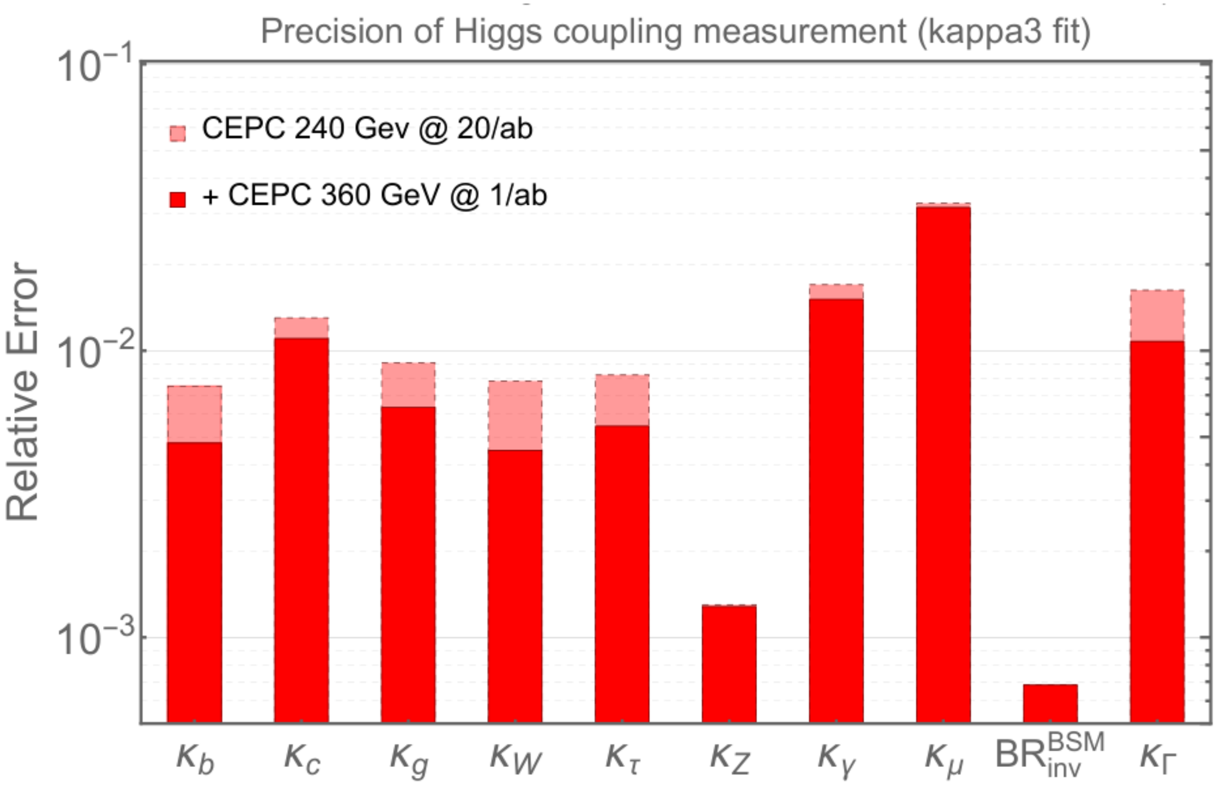
Estimated improvement from Snowmass to Ref-TDR:

- Inclusive, dimuon, invisible: Kept;
- bb, cc, gg: 15% improvement.
- Diphoton: Double.
- (hadronic) zz: Double.
- (hadronic) ww, tautau, Zgamma: 15%
- Width: 15%. 1.1% to <1% can be achieved.

Kappas in Snowmass: 2205.08553

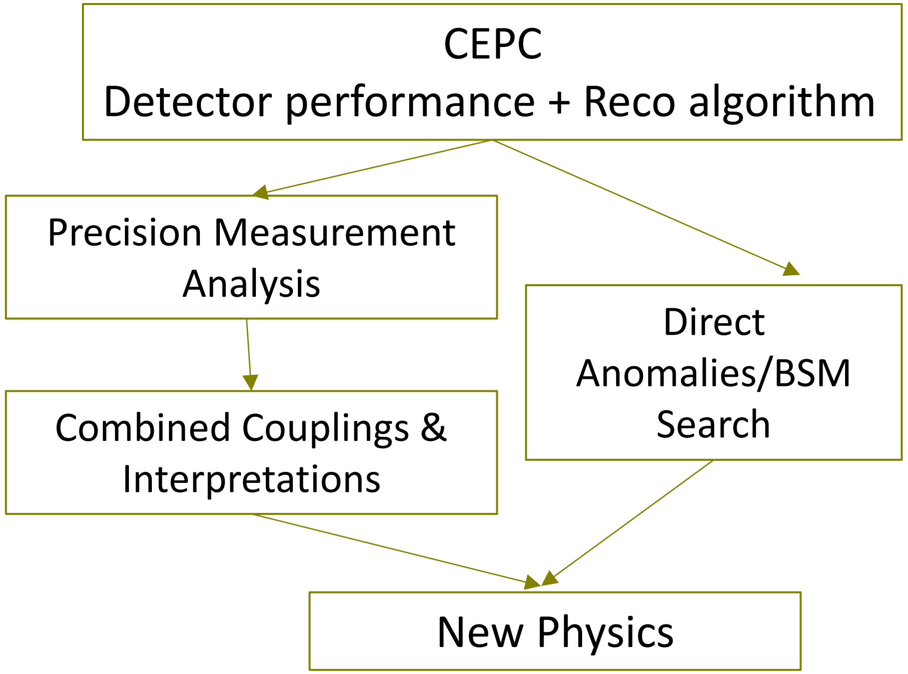
In CEPC Ref-TDR, κ_Γ expected to <1%; κ_γ to ~1.2%.
Other kappas 10%-20% improved from both individual analysis and also width constrain.





CEPC Ref-TDR Physics benchmarks

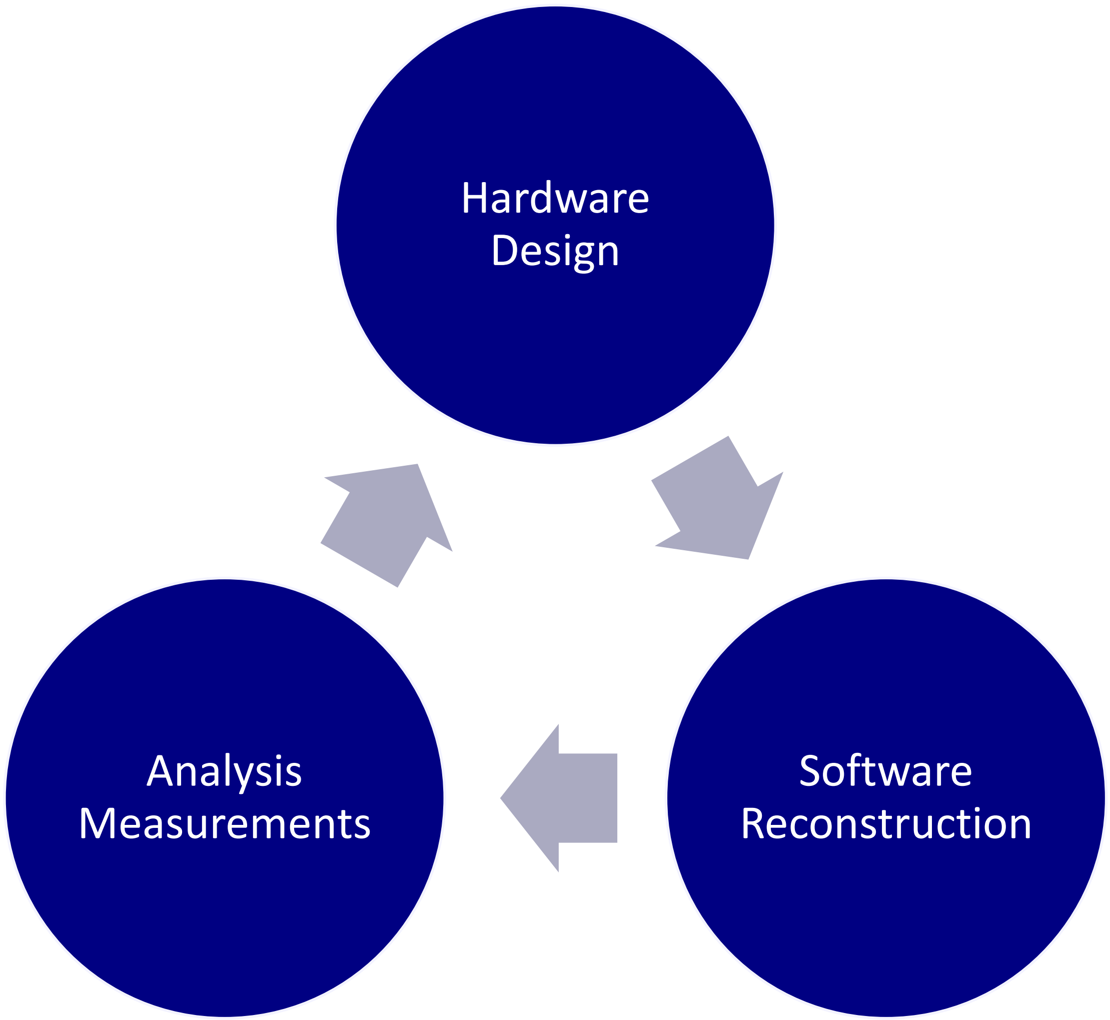
	Process @ c.m.e	Domain	Sensitivities using **CDR** det. + TDR lumi., with JOI	**@Ref-TDR**
H→cc	ννH @ 240 GeV	Higgs	1.7%	1.6%
H→ss [1]			95% UL of 0.75E-3	95% UL of 0.70E-3
H→sb [1]			95% UL of 0.22E-3	95% UL of 0.20E-3
H→inv [2]	qqH	Higgs/BSM	95% UL of 0.13%	Same
Vcb [3]	WW→$\ell\nu qq$ @ 240/160 GeV	Flavor	0.4%	0.36%
W fusion Xsec [2]	ννH @ 360 GeV	Higgs	1.1%	Same
α_S	Z→ττ @ 91.2 GeV	QCD	NAN	Theory Unc. Dominant
CKM angle $\gamma-2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	NAN	~0.1-1 degree
Weak mixing angle [4]	Z @ 91.2 GeV	EW	2.4E-6 using 1 month of Z data	tiny improvement due to VTX
Higgs recoil [5]	$\ell\ell H$	Higgs	δm = 2.5 MeV; δσ/σ = 0.25%/0.4% (wi/wo qqH)	Same
H→bb, gg [2]	ννH + qqH	Higgs	bb: 013%; gg: 0.65%	bb: 012%; gg: 0.62%
H→μμ [2]	qqH	Higgs	6.4%	Same
H→γγ [2]	qqH	Higgs	3%	1.8%
W mass & width [6]	Threshold scan @ 160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab	Same
Top mass & width [7]	Threshold scan @ 360 GeV	EW	9 MeV & 26 MeV @ 100 ifb	Same
$B_s\to\nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)	Same, if object recon. ~ CDR
$B_c\to\tau\nu$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)	Same, if object recon. ~ CDR
$B_0\to 2\pi^0$ [10]	91.2 GeV	Flavor	NAN	0.3% (need to validate photons finding)
H→LLP	qqH	BSM	NAN	Work in progress
H→aa→4γ	qqH	BSM	NAN	Work in progress



Captured from Mingshui's report. A list of key physics benchmarks raised by the community. Extensive CEPC Physics studies conducted among all fields.

Your contributions are welcome!

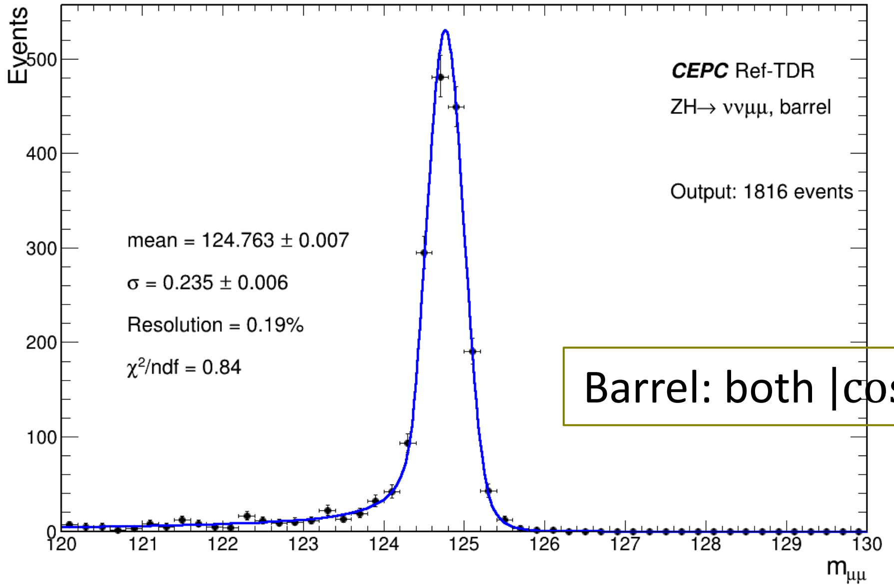
Summary



- Significant progress from Accelerator, Detector, Object performance and analysis strategy
  - Closely iterates with all parts R&D for improvements
- Trying to maximizing the CEPC potential.
  - Many results improved in Ref-TDR compared to CDR and Snowmass report.
  - Still challenging on uncertainty control and many fields.

Backups

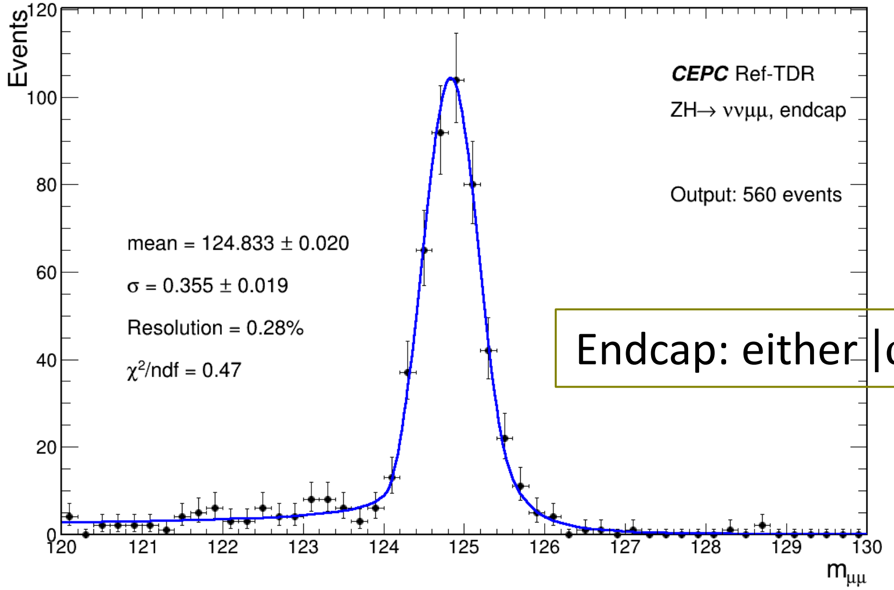
Dimuon Barrel/Endcap:



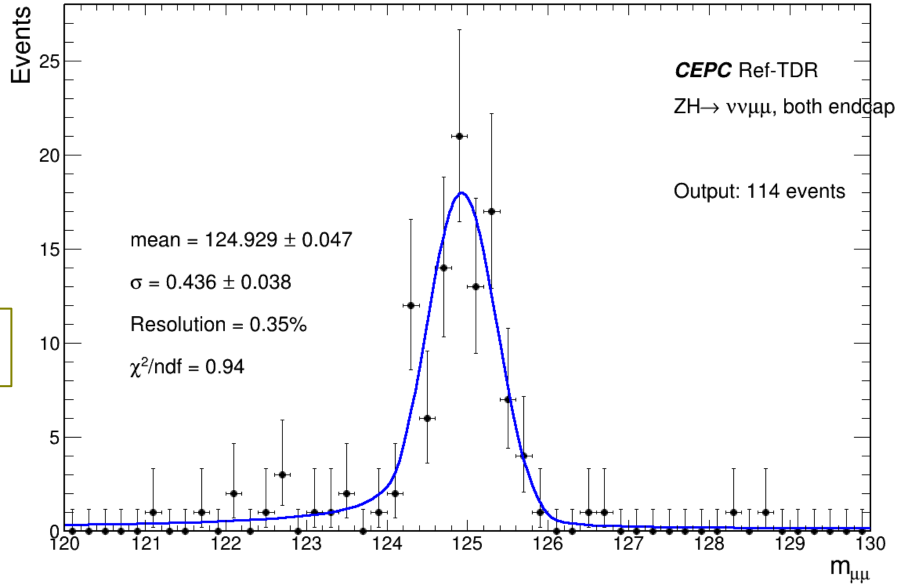
For Ref-TDR, ~0.1% achievable for the majority of tracking resolution.

Barrel: both $|\cos\theta_{truth}| < 0.85$

Endcap: both $|\cos\theta_{truth}| > 0.85$



Endcap: either $|\cos\theta_{truth}| > 0.85$



Challenges & Plans

- **Challenges:**
  - Impact of beam-induced background
  - Managing high data rates at the Z pole: necessitates reconstruction in spacetime (PFA in spacetime)
  - Development of New CyberPFA: relies on full simulation, significantly impacts the final resolution on hadronic objects
- **Plans:**
  - Assessing the impact of beam-induced background, the readout, particularly at the Z pole (~ Nov. 2024)
  - Advancing reconstruction algorithms and validating them with full simulation (~ Dec. 2024): PFA, utilizing smarter algorithms with AI tools
  - Conducting benchmark analyses with full simulation (H measurements) + fast simulation (~ Jan. 2025)
  - Engaging the theory community more extensively to ensure control over theoretical uncertainties

Team

- Physics and performance team (IHEP, PKU, SCNU, SJTU, NJU, Nankai U.):
  - ~ 10 staff members + 4 postdocs + ~10 students, more joining
- Synergizing efforts with sub-detector teams
- Collaboration with PKU, LLR & CERN on Machine Learning algorithms
- Physics white paper efforts:

  IHEP team + ~ > 20 staffs from ~ 10 Universities
  - Flavor Physics: Tao Liu (HKUST), Lorenzo (NKU), Shanzhen Chen(IHEP) etc
  - New Physics: Xuai Zhuang (IHEP), Mengchao Zhang (JNU)
  - EW: Zhijun Liang (IHEP), Jiayin Gu (FuDan U), Siqi Yang (USTC)
  - QCD: Zhao Li (IHEP), Meng Xiao (ZJU), Huaxing Zhu (PKU)
- Physics studies in pace with ECFA physics focus studies

Benchmark Reference

Physics Benchmarks using CDR detector and TDR lumi

	Process @ c.m.e	Domain	Sensitivities using CDR baseline detector + TDR lumi., with JOI
H→cc	ννH @ 240 GeV	Higgs	1.7%
H→ss [1]			95% UL of 0.75E-3
H→sb [1]			95% UL of 0.22E-3
H→inv [2]	qqH	Higgs/BSM	95% UL of 0.13%
Vcb [3]	WW→ℓνqq @ 240/160 GeV	Flavor	0.4%
W fusion Xsec [2]	ννH @ 360 GeV	Higgs	1.1%
α_S	Z→ττ @ 91.2 GeV	QCD	NAN
CKM angle $\gamma-2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	NAN
Weak mixing angle [4]	Z @ 91.2 GeV	EW	2.4E-6 using 1 month of Z pole data (~2E11 Z)
Higgs recoil [5]	ℓℓH	Higgs	δm = 2.5 MeV; δσ/σ = 0.25%/0.4% (wi/wo qqH)
H→bb, gg [2]	ννH + qqH	Higgs	bb: 013%; gg: 0.65%
H→μμ [2]	qqH	Higgs	6.4%
H→γγ [2]	qqH	Higgs	3%
W mass & width [6]	Threshold scan @ 160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab
Top mass & width [7]	Threshold scan @ 360 GeV	EW	9 MeV & 26 MeV @ 100 ifb
Bs→ $\nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)
Bc→ $\tau\nu$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)
$B_0 \to 2\pi^0$ [10]	91.2 GeV	Flavor	NAN
H→LLP	qqH	BSM	NAN
H→aa→4γ	qqH	BSM	NAN

1. H. Liang, et al, PHYSICAL REVIEW LETTERS 132, 221802 (2024)
2. CEPC Phy-Det Snowmass White Paper, arXiv:2205.08553v1
3. H. Liang, Ph.D thesis
4. Z. Zhao, et al., Chinese Physics C Vol. 47, No. 12 (2023) 123002
5. Z. Yang, et al., Chinese Physics C Vol. 41, No. 2 (2017) 023003
6. P. Shen, et al., Eur. Phys. J. C (2020) 80:66
7. Z. Li, et al., arXiv:2207.12177
8. Y. Wang, et al., PHYSICAL REVIEW D 105, 114036 (2022)
9. T. Zheng, et al., Chinese Physics C Vol. 45, No. 2 (2021) 023001
10. Y. Wang, et al., JHEP12(2022)135

Will evaluate if RefTDR design can meet or exceed these sensitivities

1

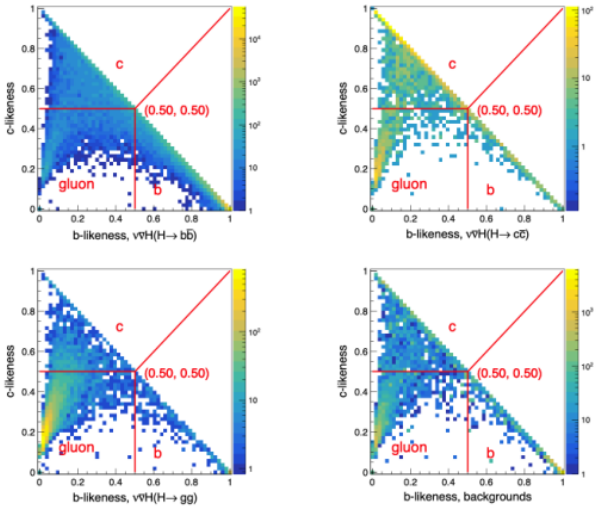
bb, cc, gg

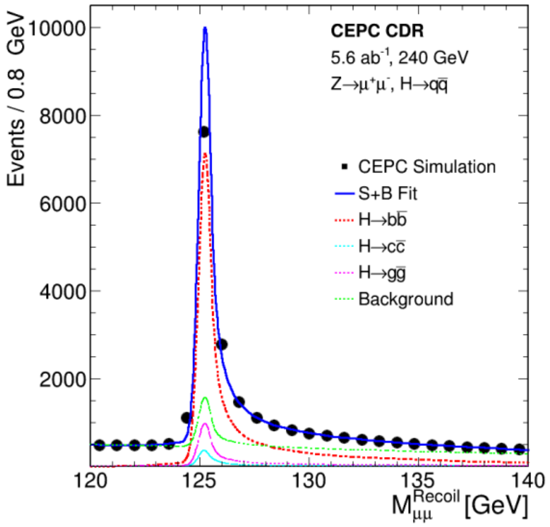
vvH, qqH by Yongfeng Zhu, arXiv:2203.01469
eeH, mmH by Yu Bai, arXiv:1905.12903

- 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;
- New studies:

ParticleNet on Flavor tagging 2309.13231

Rare decay like ss, dd, uu 2310.03440

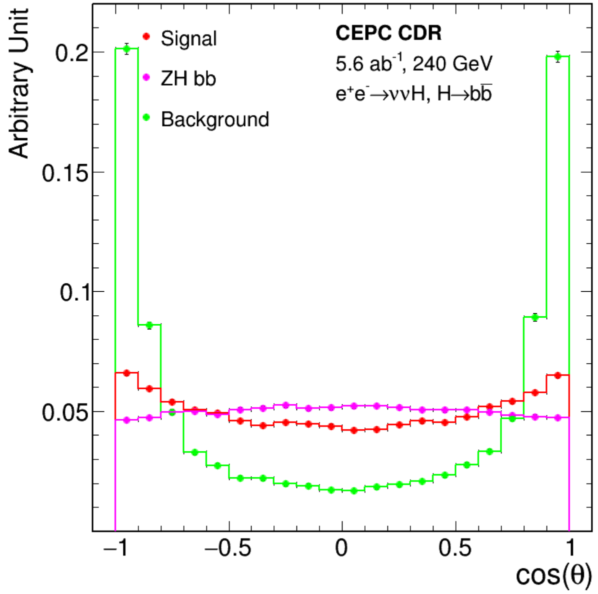


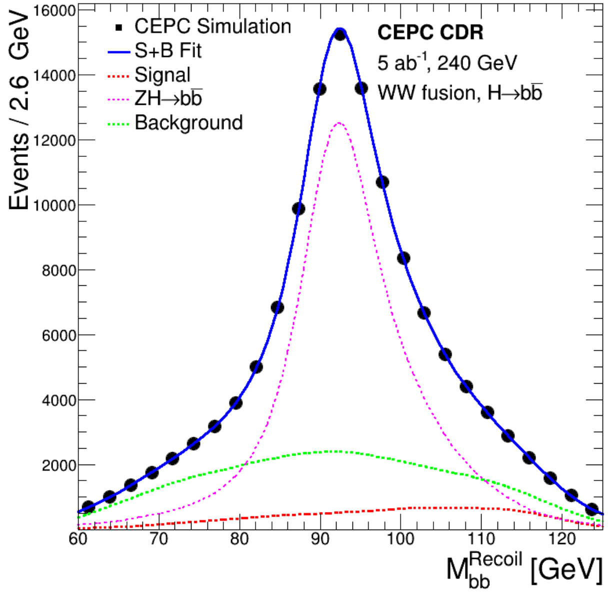


Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.35%	1.77%
combination	0.27%	4.03%	1.56%

$\nu\nu H \rightarrow bb$

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



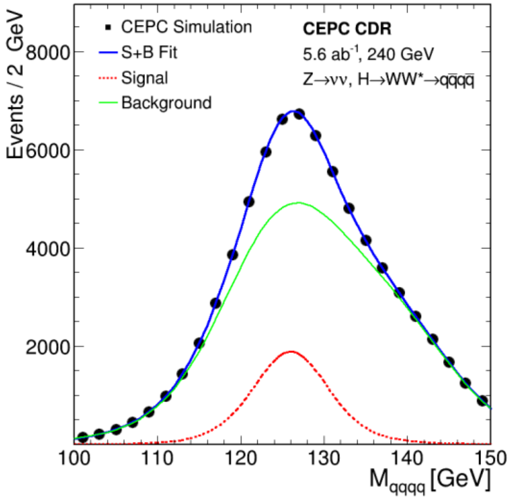


- if fix ZH process, Initial $\nu\nu H \rightarrow bb$ uncertainty is 2.8%.
- if float ZH process, $\nu\nu H \rightarrow bb$ would be 3.4%.
- Need use other ZH processes to constrain ZH.

$H \rightarrow WW, ZZ$

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

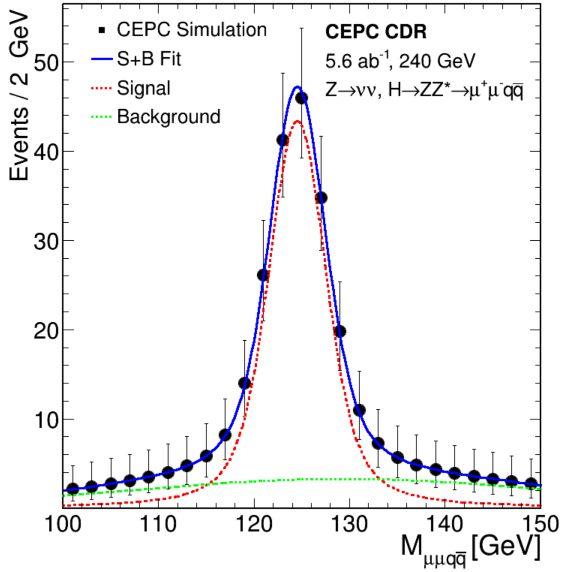
- Leptonic, semi-leptonic WW by Libo Liao;
- Hadronic WW by Mila Pandurovic;
- ZZ by Ryuta Kiuchi, Yanxi Gu and Min Zhong. arXiv:2103.09633



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

Signal		Precision
Z	H	
H->WW		
ee	lvlv	9.2%
	evqq	4.6%
	μvqq	3.9%
μμ	lvlv	7.3%
	evqq	4.0%
	μvqq	4.0%
vv	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

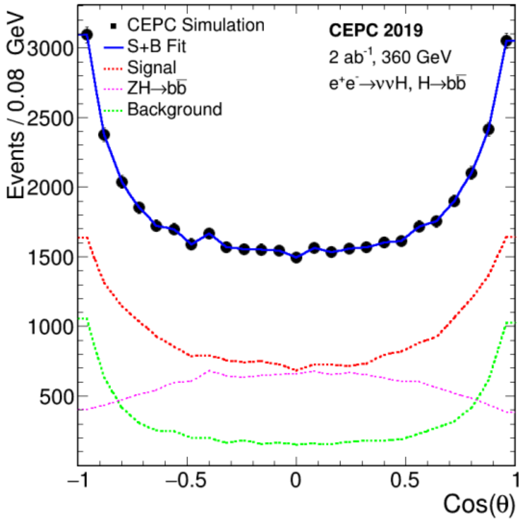


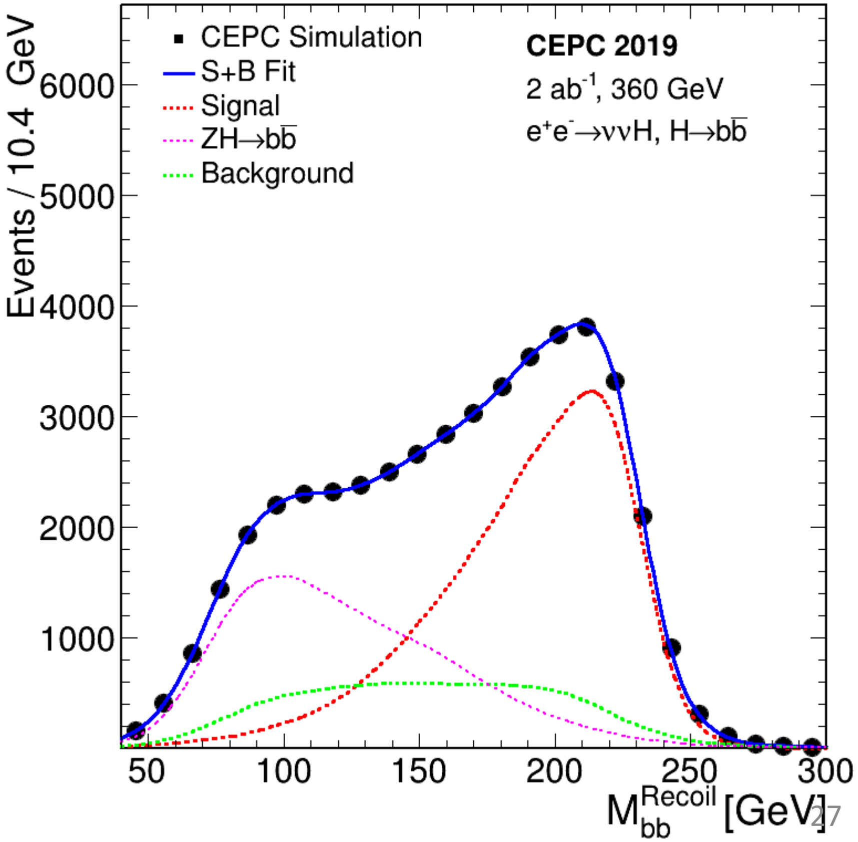
Both WW ZZ can obtain improvements from full hadronic bb/cc/gg ZH backgrounds.

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%.

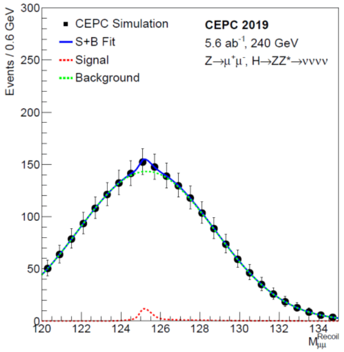
This measurement gives very excellent constrain for Higgs width.



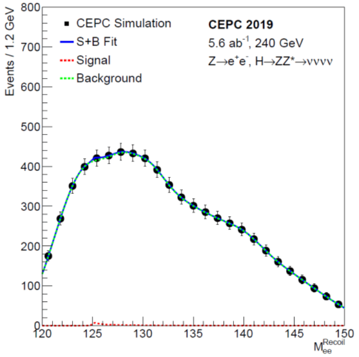


H →invisible and $Z\gamma$

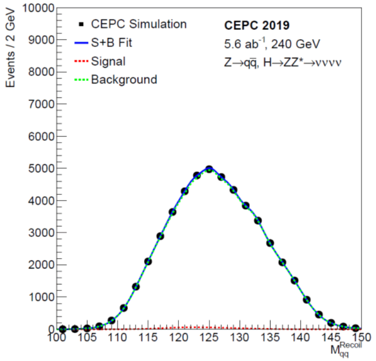
Invisible, arXiv:2001.05912 by Yuhang Tan;
Previous studied by Xin Mo;



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



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

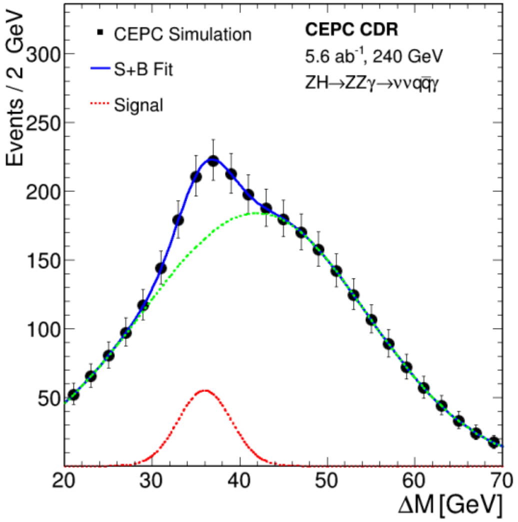


ZH(Z->qq,H->invisible)

ZH final state studied	Relative precision on $\sigma(ZH)\times$BR	Upper limit on BR (H→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%

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

- H → $Z\gamma$, 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%.

Couplings: κ framework

- Higgs coupling defined as:

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

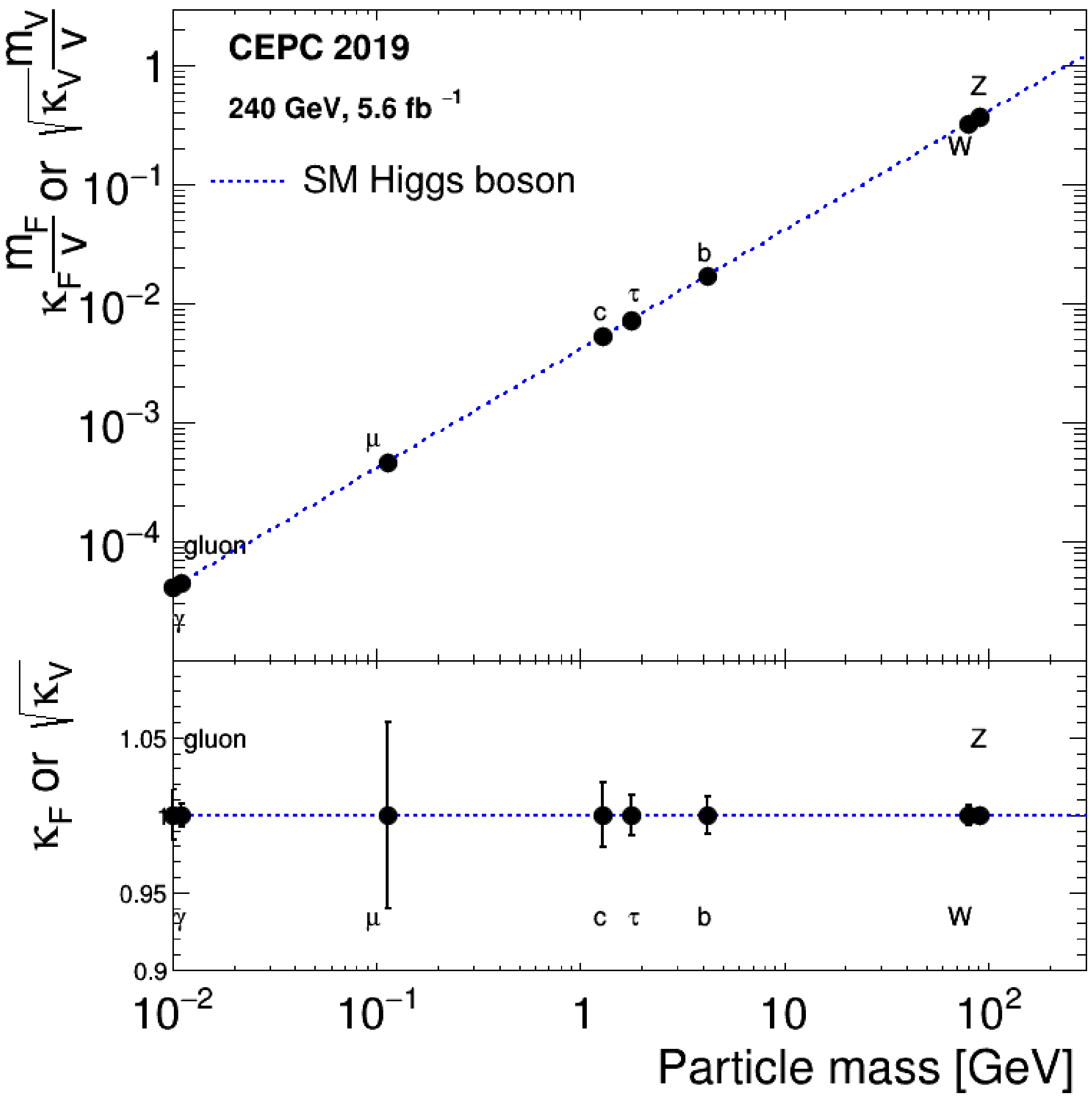
$$\sigma(\nu\nu H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb}) \propto \frac{\kappa_\mathrm{w}^2 * \kappa_\mathrm{b}^2}{\Gamma_H}.$$

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

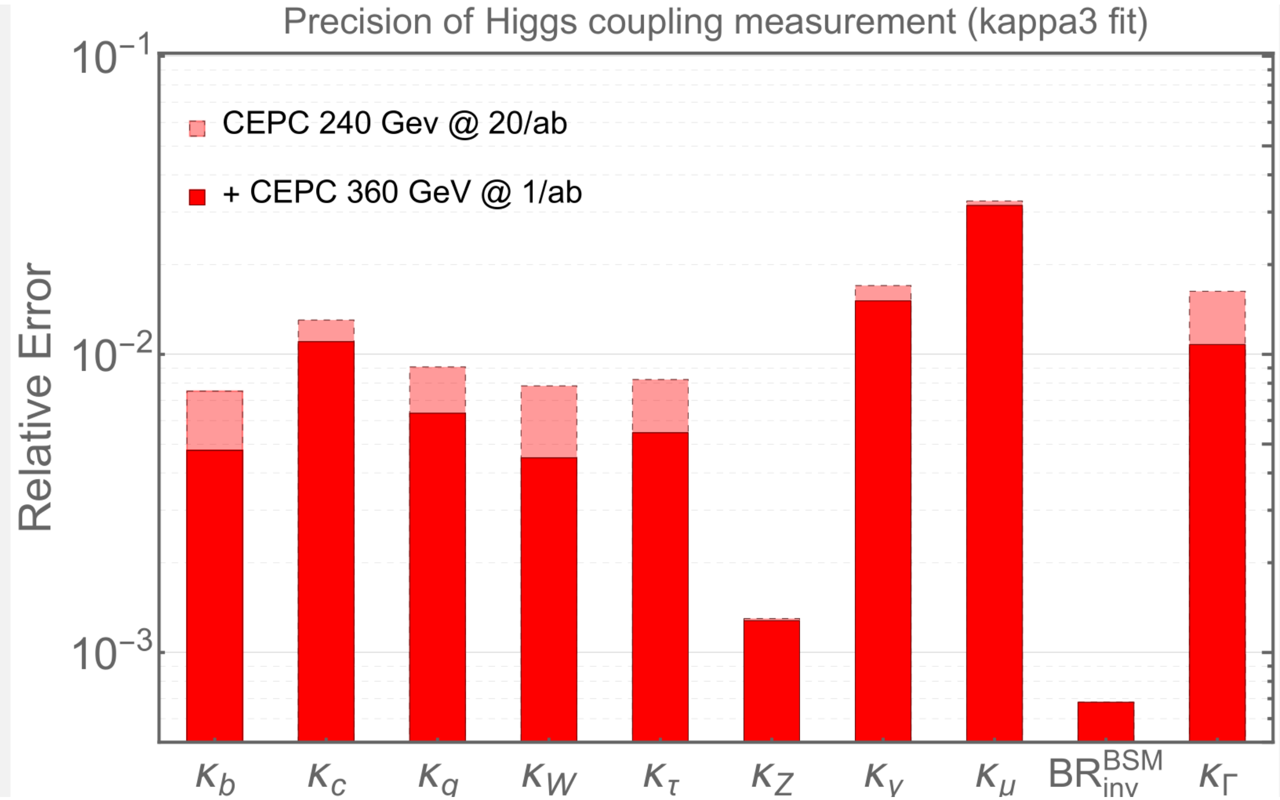
and all other channel suffered from Higgs width.

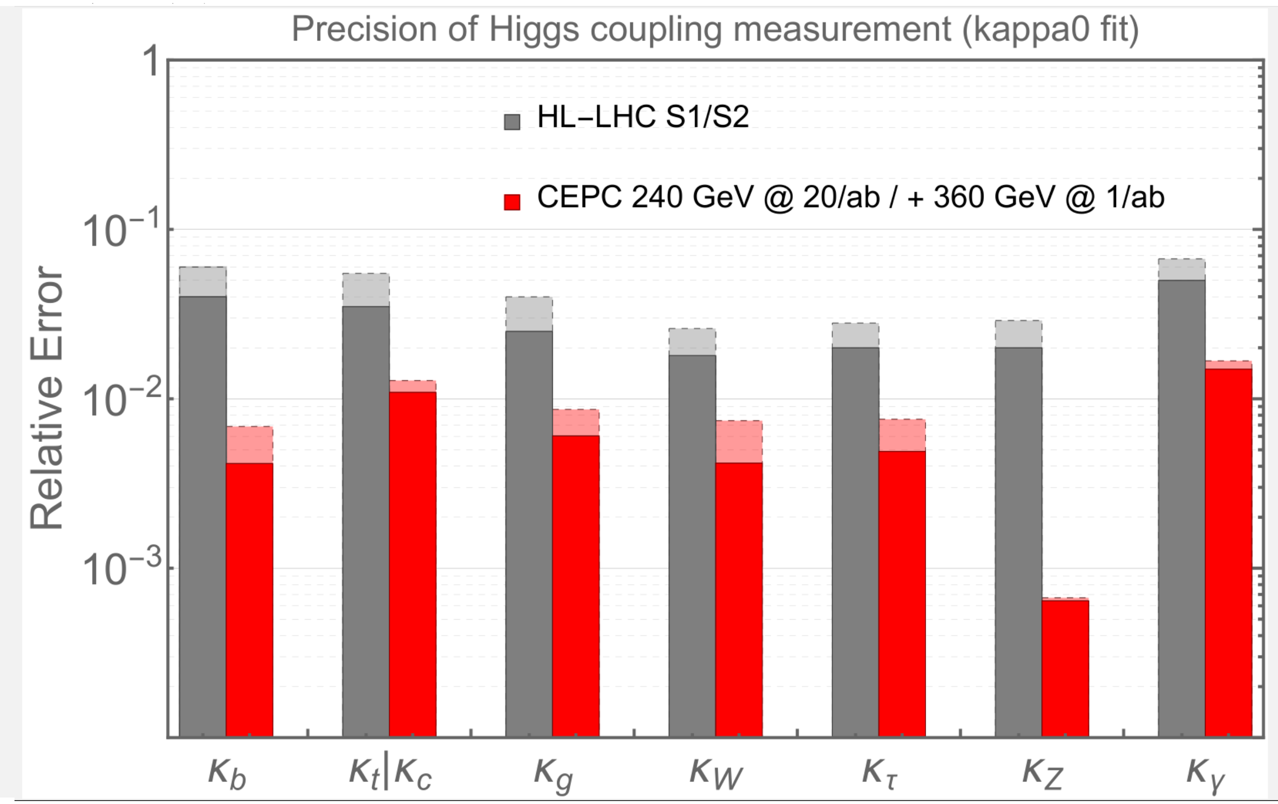
Extract width with branch ratio: Constrained 7-κ

Keep width independent: 10 κ



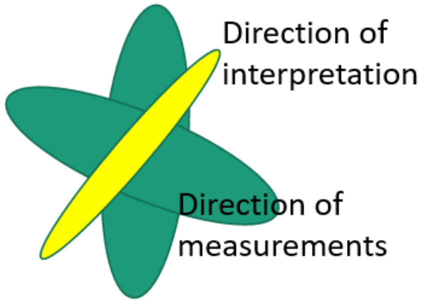
κ : CEPC latest





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

Correlation Matrix



Input

Measurements

Anti-correlated

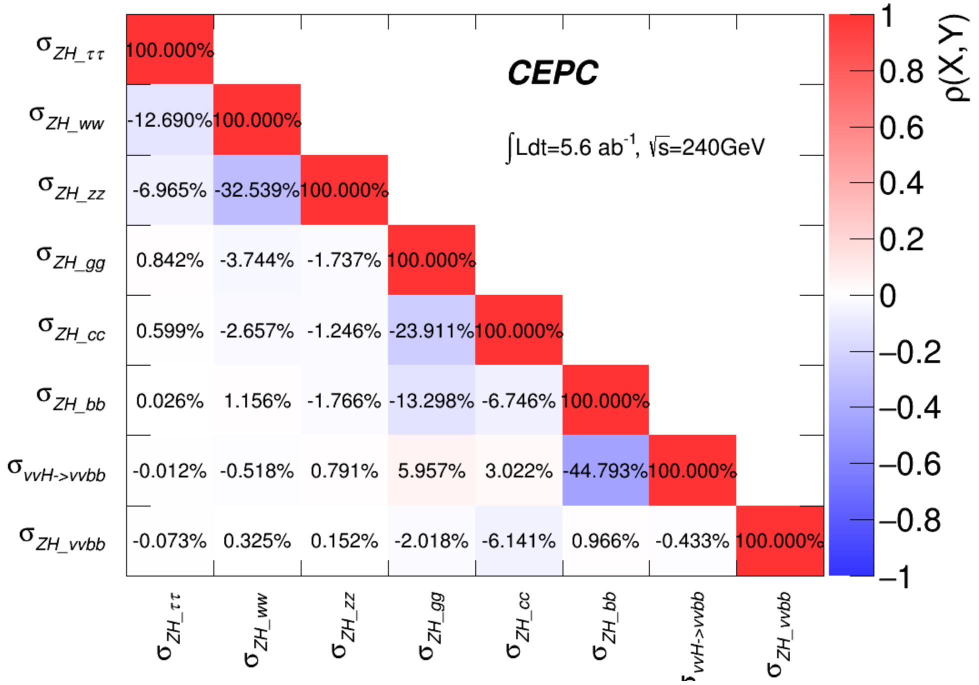
+ Interpretation →

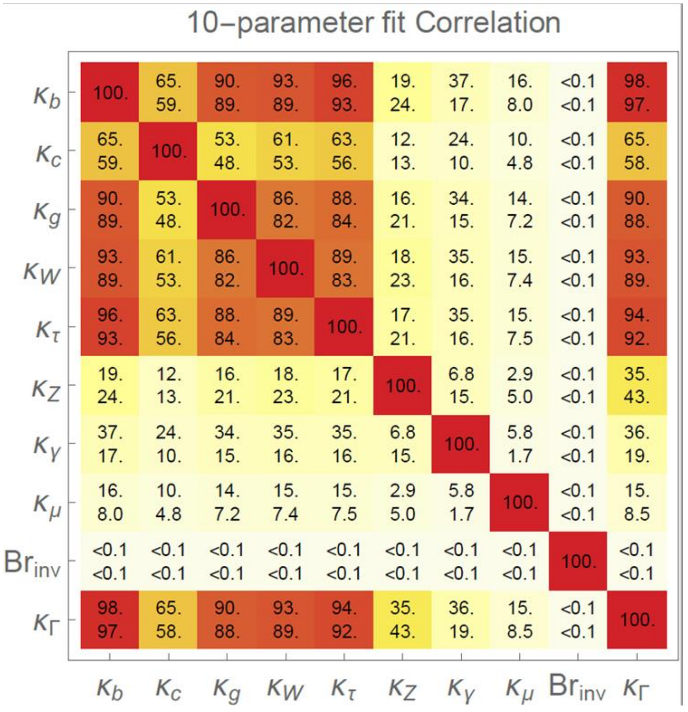
Output

Couplings

Coupled by width

2nd correlation differentials

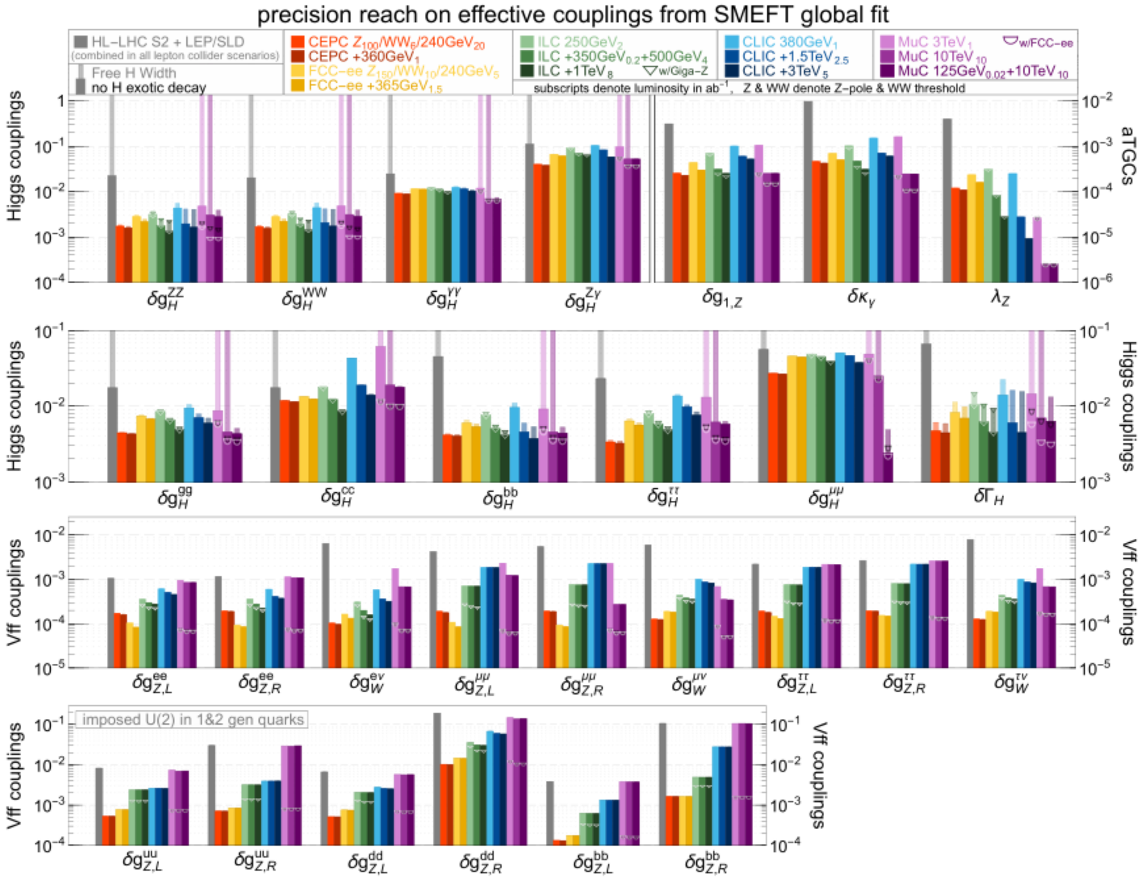


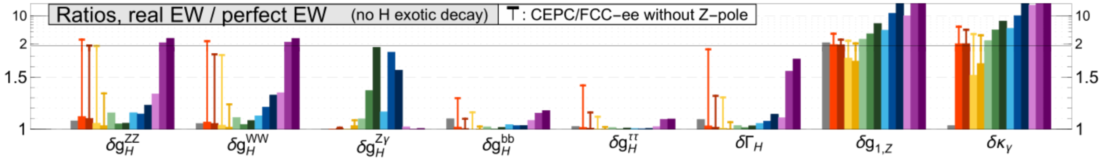


Upper entries: CEPC alone;
Lower entries: combining with HL-LHC (get reduced);

Global fit synergy with other experiments

- [de Blas, J. *et al.* arXiv:2206.08326]
  - Also kappa and EFT results are shown between CEPC240, CEPC360, HL-LHC, Fcc, ILC……





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

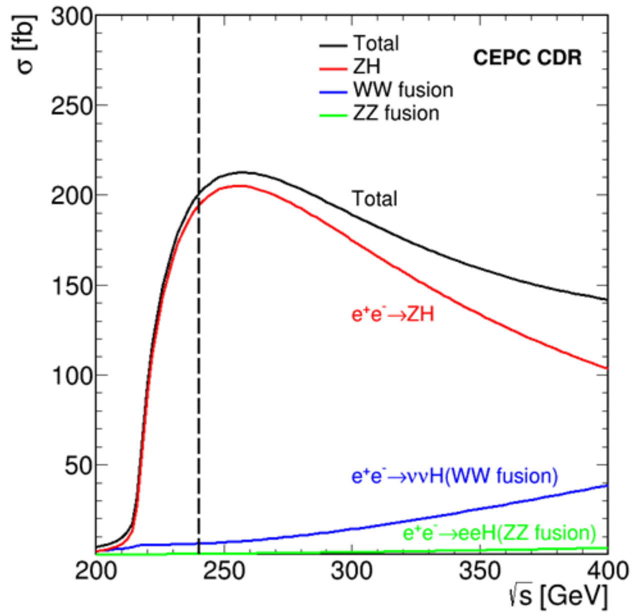
$$\Gamma_H = \frac{\Gamma_H^{SM} \cdot \kappa_H^2}{1 - (BR_{inv} + BR_{unt})}$$

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)

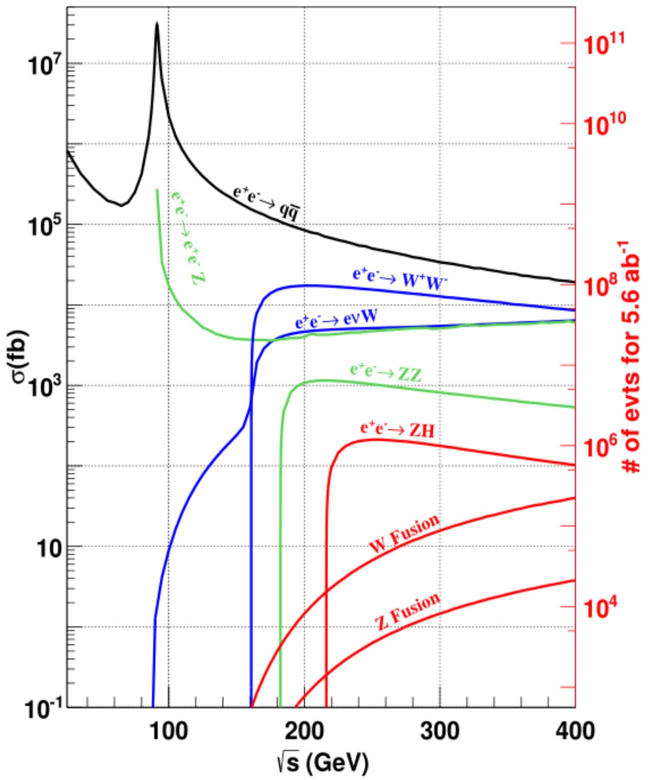
fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Total	203.6		159.0		
Total Events	4M		0.16M		



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.