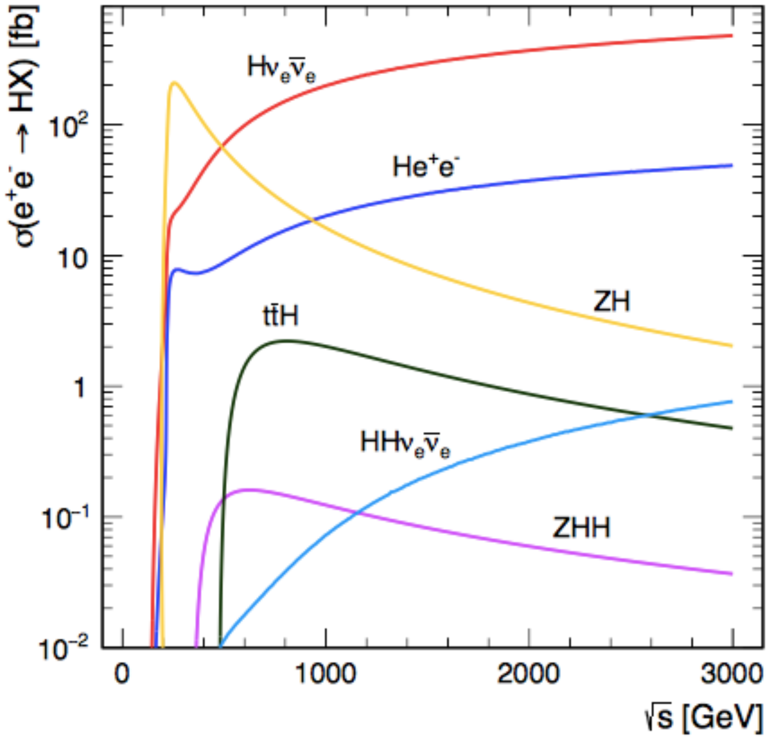
Status of Higgs physics at CEPC

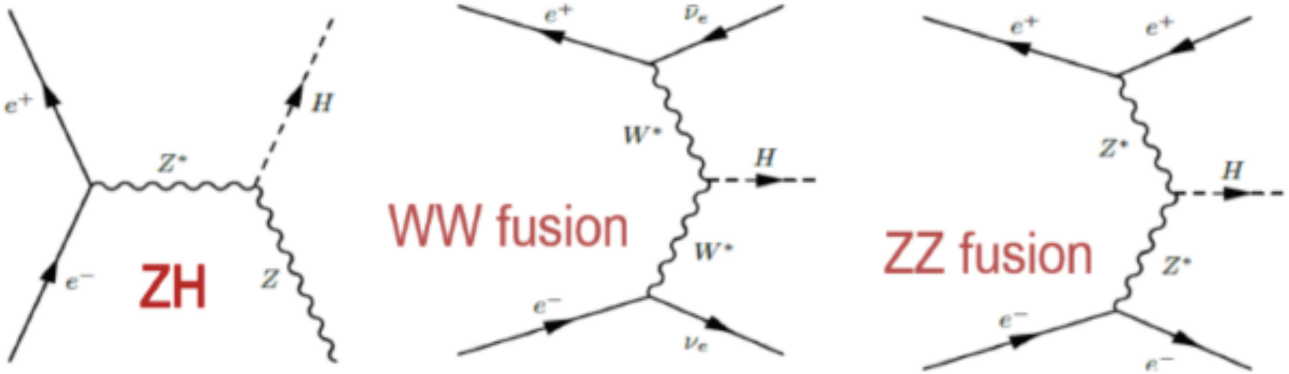
Yaquan Fang (IHEP) on behalf of CEPC Higgs working group

5th China LHC Physics Workshop at Dalian

Oct 23-27, 2019

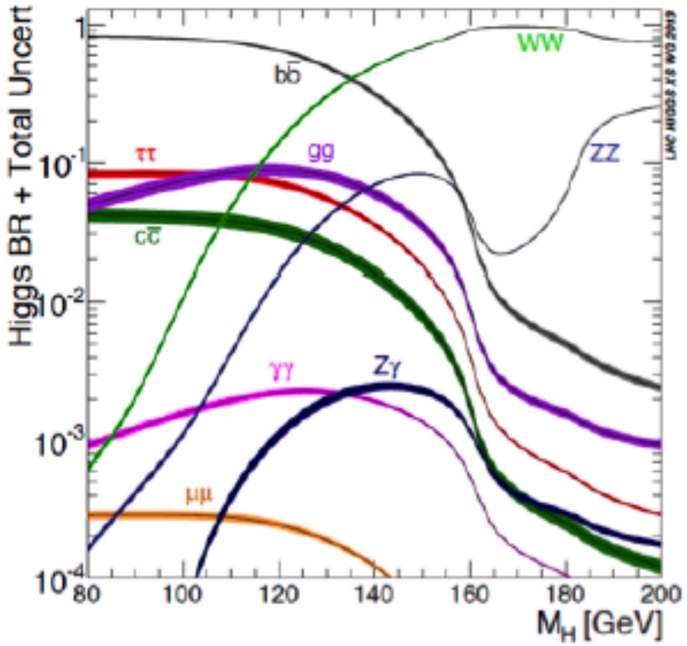
Higgs related physics at e^+e^- collider

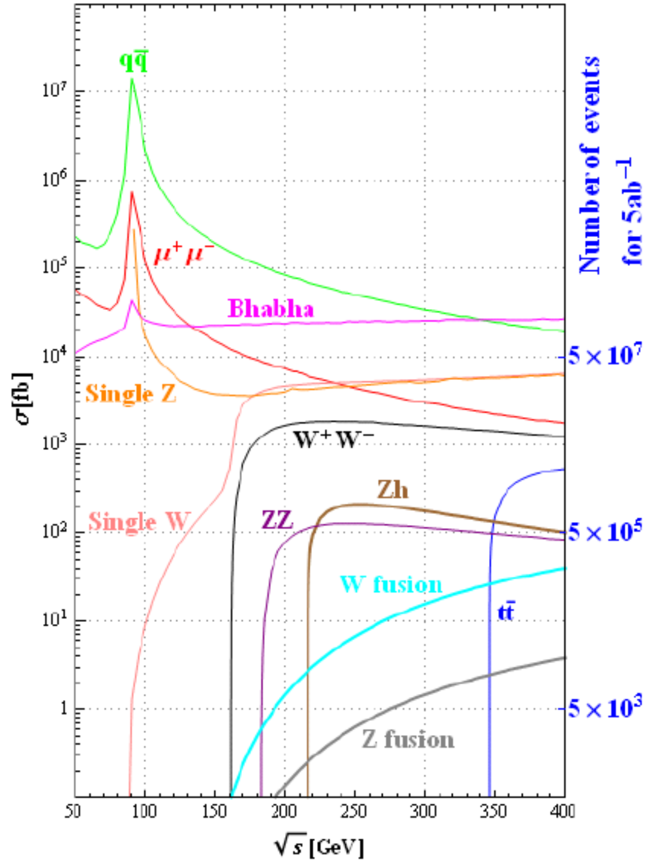




- With the increase of the energy, different Higgs related physics can be explored at e^+e^- collider.
- With the energy around 240 GeV, ZH as well as ww/zz fusion can be intensively studied.
  - the dominant production is from HZ, the WW/ZZ fusions contribute a few percent of the total cross-section.

SM Higgs decay branching ratio, Bkg process

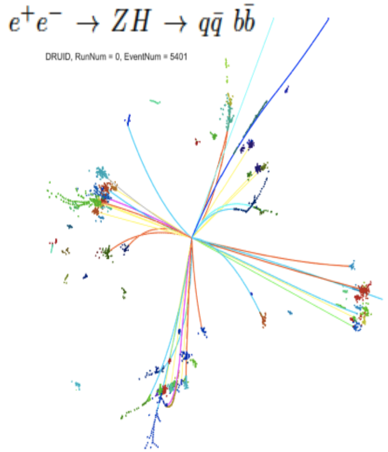


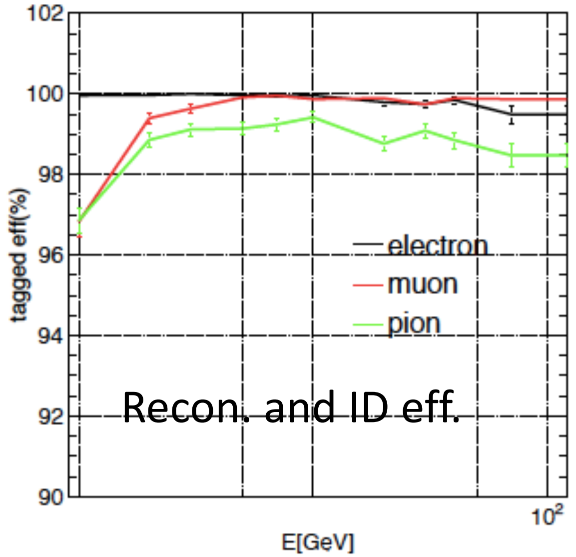


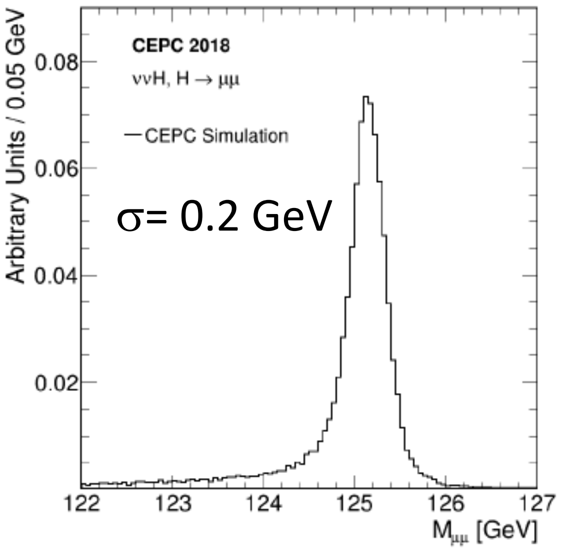
✓ e^+e^- collider provides a good opportunity to measure the jj, invisible decay of Higgs.

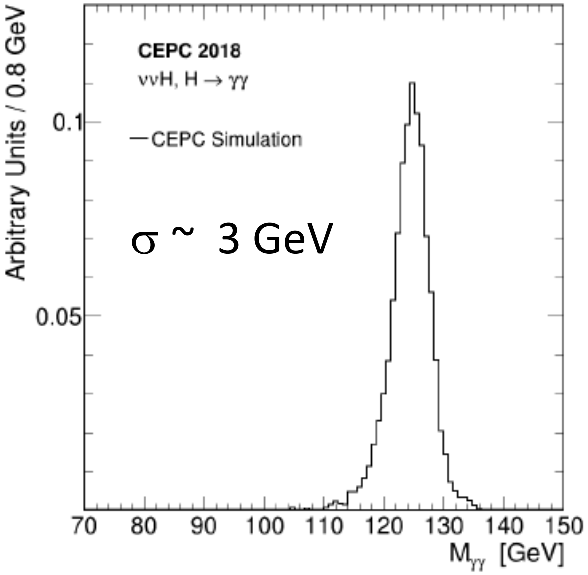
✓ For 5.6 ab^{-1} data with CEPC, 1M Higgs, 10M Z, 100M W are produced.

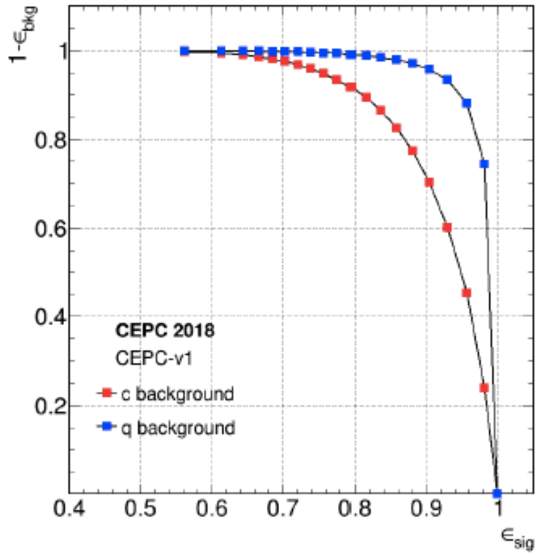
Performance



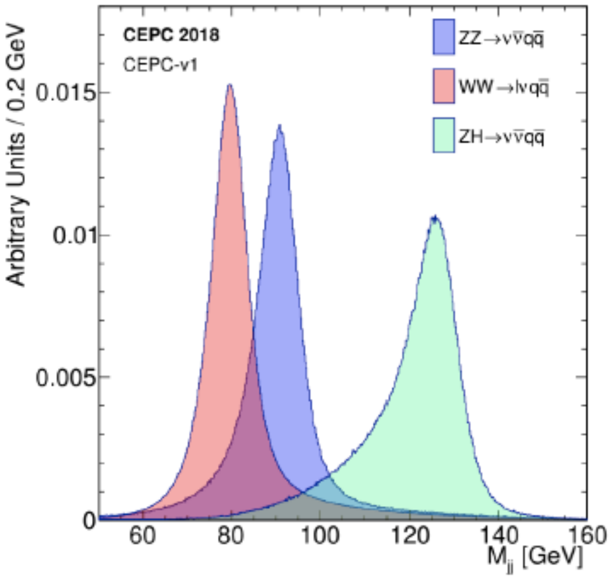






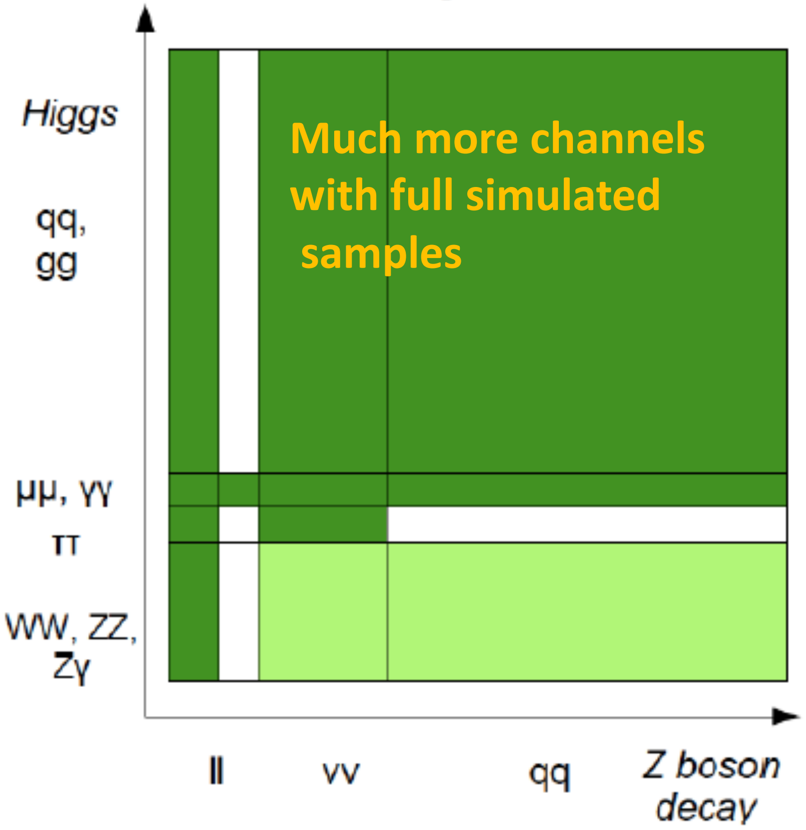


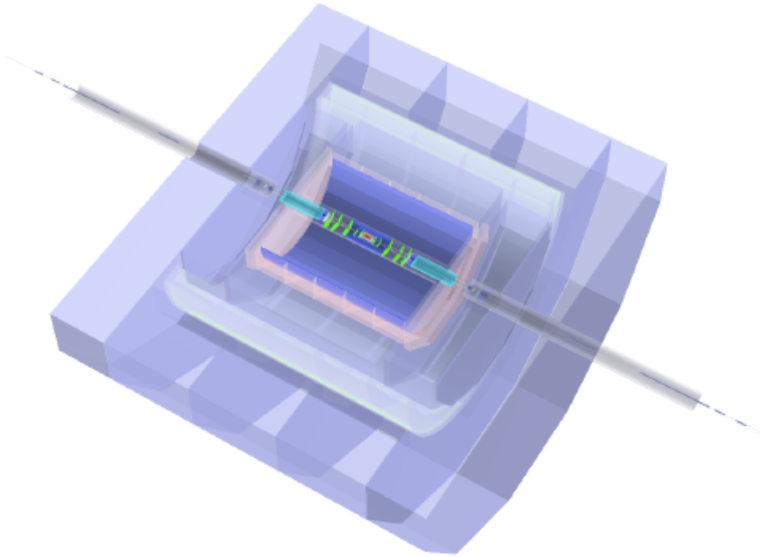
B-tagging eff. vs rejection of other jets



- Reliable Particle recon., ID and fake rejection
- Good mass resolution of Higgs masses.

Higgs analyses @CEPC CDR



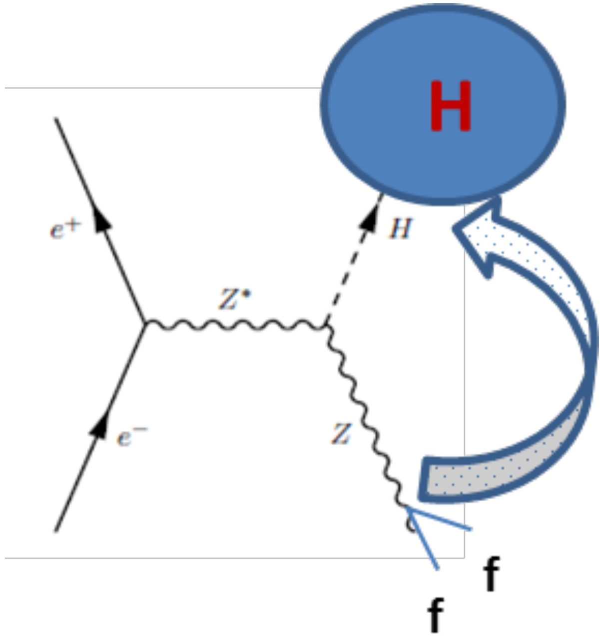


CEPC-v4: 240 GeV/3T,….

A lot of decay channels can be investigated.

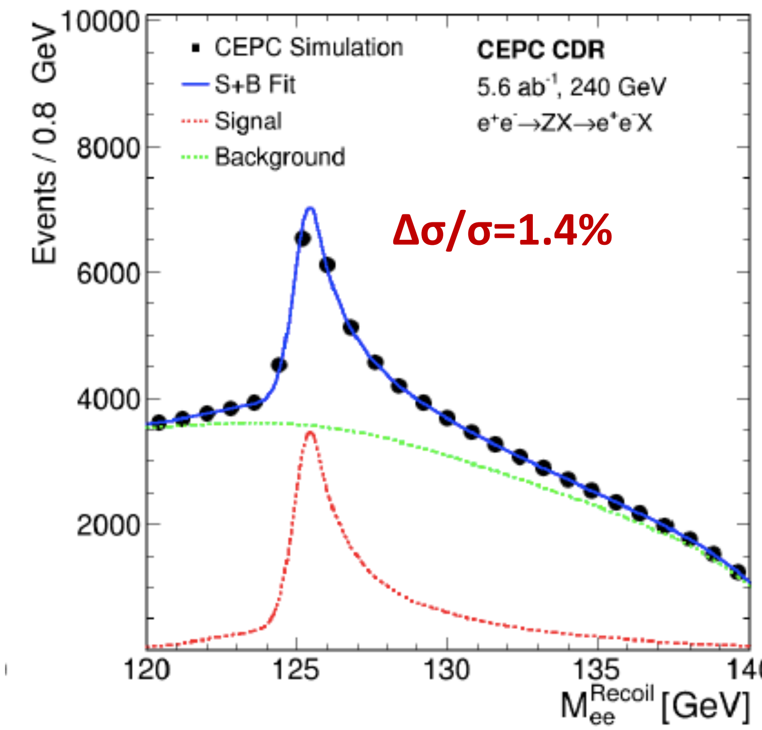
Direct measurement of Higgs cross-section

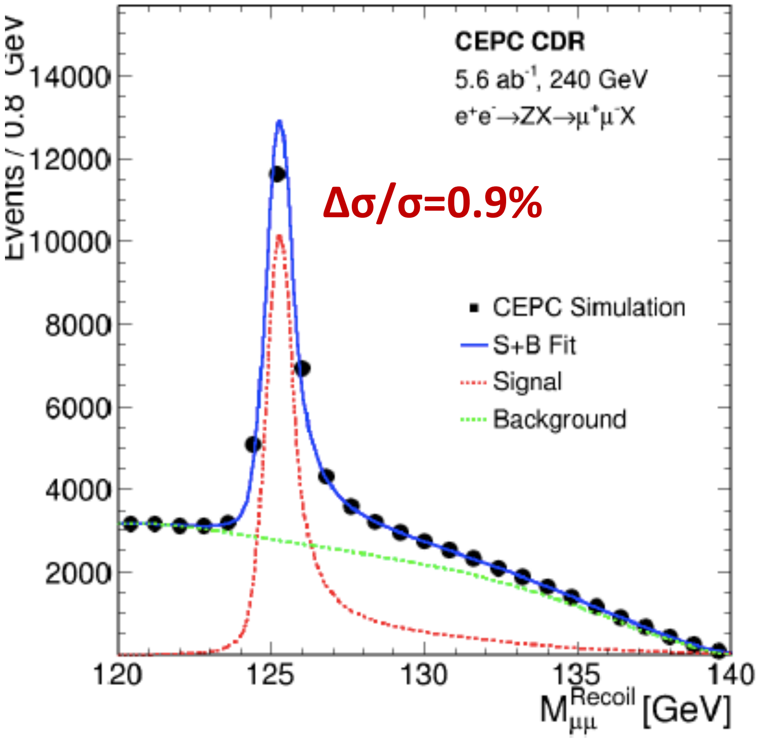
$$M_{\mathrm{recoil}}^2 = (\sqrt{s} - E_{ff})^2 - p_{ff}^2 = s - 2E_{ff}\sqrt{s} + m_{ff}^2$$

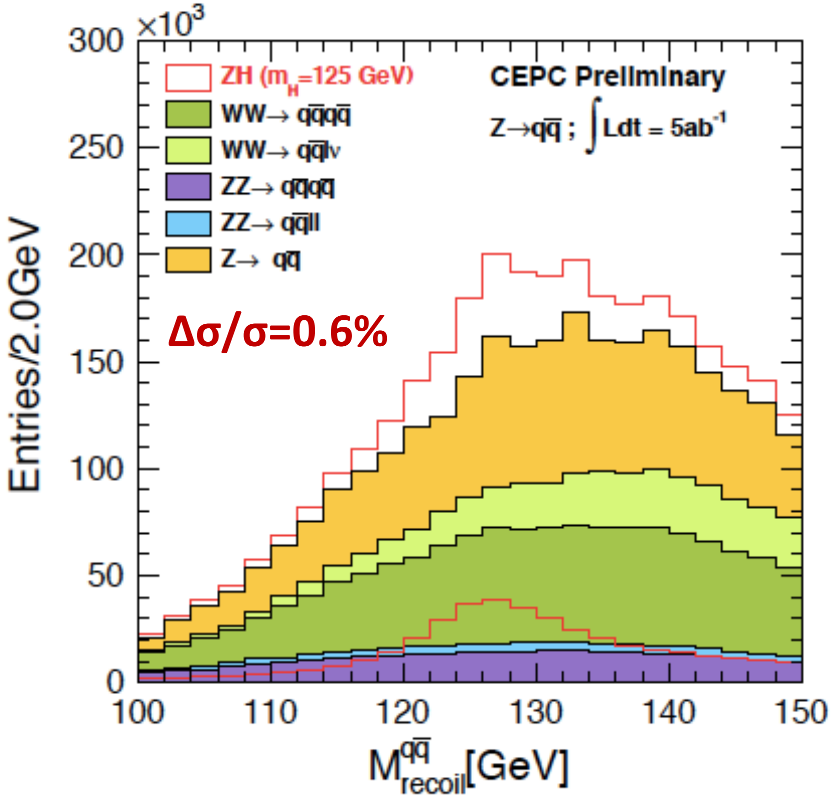


- ✓ **For this model independent analysis, we reconstruct the recoil mass of Z without touching the other particles in a event.**
- ✓ **The M_{recoil} should exhibit a resonance peak at m_H for signal; Bkg is expected to smooth.**
- ✓ **The best resolution can be achieved from $Z(\rightarrow e^+e^-, \mu^+\mu^-)$.**

Direct measurement of Higgs cross-section and m_H







- ✓ **The combined precision with three channels is** **Δσ/σ=0.5%**
- ✓ **Similar sub-percent level for ILC/FCC-ee**
- ✓ **The mass of Higgs can be measured with a precision 5.9 MeV combining Z→ee (14 MeV) and Z→μμ (6.5 MeV)**

Measurement of Higgs width

- **Method 1: Higgs width can be determined directly from the measurement of σ(ZH) and Br. of (H->ZZ*)**

$$\Gamma_H \propto \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

Precision : 5.1%

  - **But the uncertainty of Br(H->ZZ*) is relatively high due to low statistics.**

- **Method 2: It can also be measured through:**

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{BR(H \to bb)} \qquad \sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b}) \propto \Gamma(H \to WW^*) \cdot \mathrm{BR}(H \to bb) = \Gamma(H \to bb) \cdot \mathrm{BR}(H \to WW^*)$$

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

3.0%

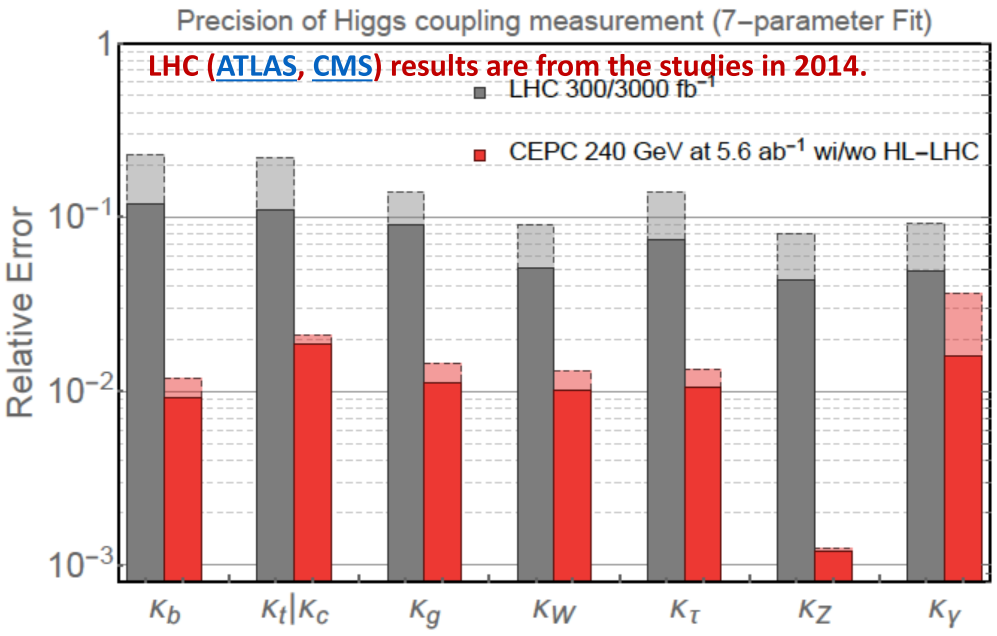
Precision : 3.5%

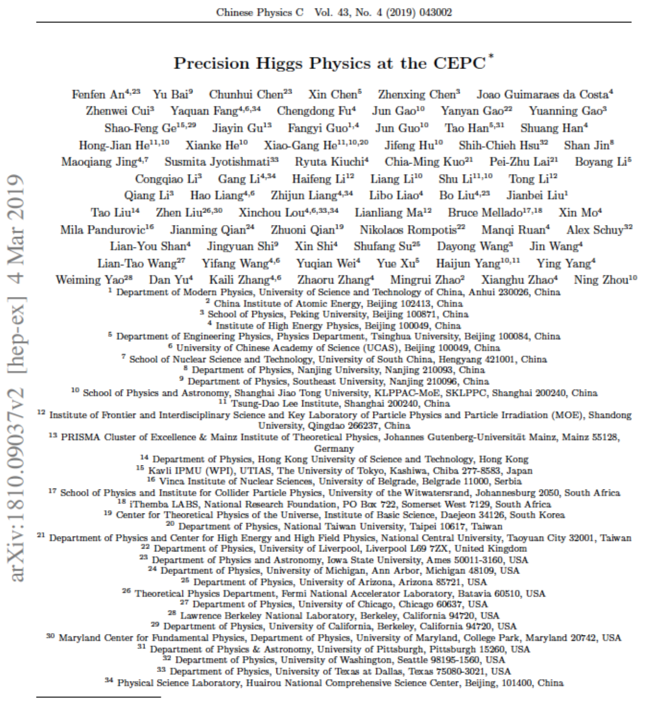
- **These two orthogonal methods can be combined to reach the best precision.**

Precision : 2.8%

Summary of the precision for the measurement of Higgs

Property	Estimated Precision			
	CEPC-v1		CEPC-v4	
m_H	5.9 MeV		5.9 MeV	
Γ_H	2.7%		2.8%	
$\sigma(ZH)$	0.5%		0.5%	
$\sigma(\nu\bar{\nu}H)$	3.0%		3.2%	
Decay mode	$\sigma\times$BR	BR	$\sigma\times$BR	BR
$H\to b\bar{b}$	0.26%	0.56%	0.27%	0.56%
$H\to c\bar{c}$	3.1%	3.1%	3.3%	3.3%
$H\to gg$	1.2%	1.3%	1.3%	1.4%
$H\to WW^*$	0.9%	1.1%	1.0%	1.1%
$H\to ZZ^*$	4.9%	5.0%	5.1%	5.1%
$H\to\gamma\gamma$	6.2%	6.2%	6.8%	6.9%
$H\to Z\gamma$	13%	13%	16%	16%
$H\to\tau^+\tau^-$	0.8%	0.9%	0.8%	1.0%
$H\to\mu^+\mu^-$	16%	16%	17%	17%
$\mathrm{BR}^{\mathrm{BSM}}_{\mathrm{inv}}$	–	$<0.28\%$	–	$<0.30\%$





Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs Physics at the CEPC*

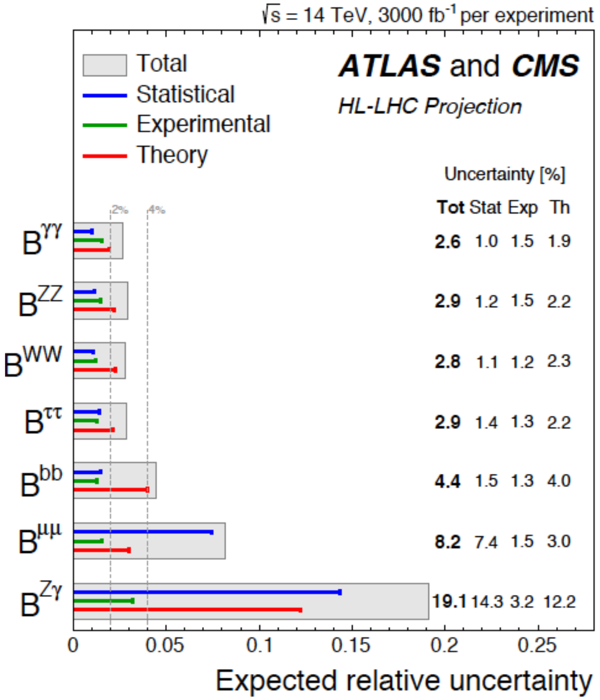
Fenfen An[4,23] Yu Bai[9] Chunhui Chen[23] Xin Chen[5] Zhenxing Chen[3] Joao Guimaraes da Costa[4]
Zhenwei Cui[3] Yaquan Fang[4,6,34] Chengdong Fu[4] Jun Gao[10] Yanyan Gao[22] Yuanning Gao[3]
Shao-Feng Ge[15,29] Jiayin Gu[13] Fangyi Guo[1,4] Jun Guo[10] Tao Han[5,31] Shuang Han[4]
Hong-Jian He[11,10] Xianke He[10] Xiao-Gang He[11,10,20] Jifeng Hu[10] Shih-Chieh Hsu[32] Shan Jin[8]
Maoqiang Jing[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4] Chia-Ming Kuo[21] Pei-Zhu Lai[21] Boyang Li[5]
Congqiao Li[3] Gang Li[4,34] Haifeng Li[12] Liang Li[10] Shu Li[11,10] Tong Li[12]
Qiang Li[3] Hao Liang[4,6] Zhijun Liang[4,34] Libo Liao[4] Bo Liu[4,23] Jianbei Liu[1]
Tao Liu[14] Zhen Liu[26,30] Xinchou Lou[4,6,33,34] Lianliang Ma[12] Bruce Mellado[17,18] Xin Mo[4]
Mila Pandurovic[16] Jianming Qian[24] Zhuoni Qian[19] Nikolaos Rompotis[22] Manqi Ruan[4] Alex Schuy[32]
Lian-You Shan[4] Jingyuan Shi[9] Xin Shi[4] Shufang Su[25] Dayong Wang[3] Jin Wang[4]
Lian-Tao Wang[27] Yifang Wang[4,6] Yuqian Wei[4] Yue Xu[5] Haijun Yang[10,11] Ying Yang[4]
Weiming Yao[28] Dan Yu[4] Kaili Zhang[4,6] Zhaoru Zhang[4] Mingrui Zhao[2] Xianghu Zhao[4] Ning Zhou[10]

[1] Department of Modern Physics, University of Science and Technology of China, Anhui 230026, China
[2] China Institute of Atomic Energy, Beijing 102413, China
[3] School of Physics, Peking University, Beijing 100871, China
[4] Institute of High Energy Physics, Beijing 100049, China
[5] Department of Engineering Physics, Physics Department, Tsinghua University, Beijing 100084, China
[6] University of Chinese Academy of Science (UCAS), Beijing 100049, China
[7] School of Nuclear Science and Technology, University of South China, Hengyang 421001, China
[8] Department of Physics, Nanjing University, Nanjing 210093, China
[9] Department of Physics, Southeast University, Nanjing 210096, China
[10] School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai 200240, China
[11] Tsung-Dao Lee Institute, Shanghai 200240, China
[12] Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao 266237, China
[13] PRISMA Cluster of Excellence & Mainz Institute of Theoretical Physics, Johannes Gutenberg-Universität Mainz, Mainz 55128, Germany
[14] Department of Physics, Hong Kong University of Science and Technology, Hong Kong
[15] Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan
[16] Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade 11000, Serbia
[17] School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg 2050, South Africa
[18] iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, South Africa
[19] Center for Theoretical Physics of the Universe, Institute of Basic Science, Daejeon 34126, South Korea
[20] Department of Physics, National Taiwan University, Taipei 10617, Taiwan
[21] Department of Physics and Center for High Energy and High Field Physics, National Central University, Taoyuan City 32001, Taiwan
[22] Department of Physics, University of Liverpool, Liverpool L69 7ZX, United Kingdom
[23] Department of Physics and Astronomy, Iowa State University, Ames 50011-3160, USA
[24] Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA
[25] Department of Physics, University of Arizona, Arizona 85721, USA
[26] Theoretical Physics Department, Fermi National Accelerator Laboratory, Batavia 60510, USA
[27] Department of Physics, University of Chicago, Chicago 60637, USA
[28] Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[29] Department of Physics, University of California, Berkeley, California 94720, USA
[30] Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, Maryland 20742, USA
[31] Department of Physics & Astronomy, University of Pittsburgh, Pittsburgh 15260, USA
[32] Department of Physics, University of Washington, Seattle 98195-1560, USA
[33] Department of Physics, University of Texas at Dallas, Texas 75080-3021, USA
[34] Physical Science Laboratory, Huairou National Comprehensive Science Center, Beijing, 101400, China

- ✓ **With combination of σ▪Br of ννH(→bb) /Br(H→bb)/Br(H→ww) and the direct measurement, one can obtain the decay width of Higgs with the precision at ~3%.**
- ✓ **The measurement of Br is done by introducing the uncertainty of xsection of ZH from the direct measurement around sub-precent level.**
- ✓ **Most precisions are a few percent or lower (bb, invisible), allowing us to be sensitive to BSM deviation**
- ✓ **In comparison with HL-LHC, e$^+$e$^-$ machine is expected to have much better performance in the measurements of the coupling constants .**
- ✓ **Higgs white paper are published at CPC (arxiv: 1810.09037) and results are included in CDR.**
    - ✓ **Other publications:** $\sigma(ZH)$:1601.05352; bb/cc/gg: 1905.12903; $\tau\tau$:1903.1232

Recent status for Higgs measurement

arxiv: 1902.00134



Width: $4.1^{+0.7}_{-0.8}$ MeV.

Precision mass of **10-20 MeV plausible**

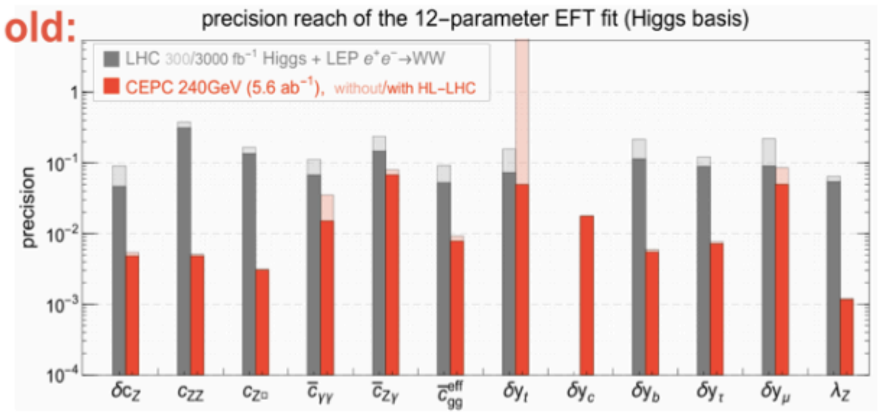
Fcc-ee 240 GeV/365 GeV:
CERN-ACC-2018-0057

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

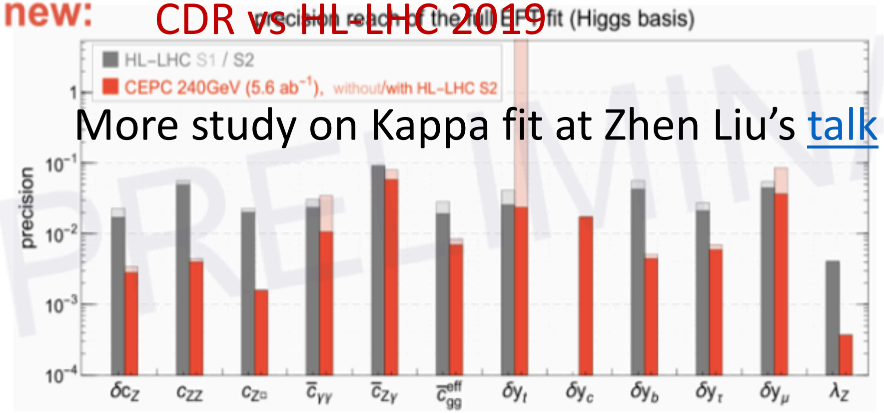
Width : ~1.3%

CDR vs HL-LHC 2014

old:



new: CDR vs HL-LHC 2019



More study on Kappa fit at Zhen Liu's talk

EFT 2.0 updated with new HL-LHC resutls (Jiayin's talks)

- LHC updated their projected results based on current Run 2 studies and possible improvements on uncertainties :
  - theory ½ and experimental systematics 1/sqrt(L) of current ones (check talk at CEPC workshop in Oxford)
- Fcc-ee has similar results as CEPC but including a 365 GeV run improving the measurement of Higgs width.

Higgs talks at the workshop in Peking University (July 1-4, 2019)

14:00 - 15:30 Higgs
Conveners: Liantao Wang (University of Chicago), WANG Jianchun

- 14:00 **Introduction and plan for Higgs physics** *25'*
  Speaker: Prof. Yaquan FANG Yaquan (高能所)
  Material: Slides
- 14:25 **Kappa measurement on CEPC Higgs** *25'*
  Speakers: Zhen Liu (FNAL), Zhen Liu (University of Pittsburgh)
  Material: Slides
- 14:50 **EFT on CEPC Higgs physics** *20'*
  Speaker: Dr. Jiayin Gu (JGU Mainz)
  Material: Slides
- 15:10 **Alternative method for Higgs measurement** *20'*
  Speaker: Dr. Gang LI (EPD, IHEP, CAS)
  Material: Slides

15:30 - 15:50 Coffee Break

15:50 - 17:15 Higgs
Conveners: Jianming Qian (University of Michigan), Dr. Gang LI (EPD, IHEP, CAS)

- 15:55 **WW fusion with 360 GeV** *25'*
  Speaker: Hao Liang
  Material: Slides
- 16:20 **Combination for Higgs measurement with 360 GeV** *25'*
  Speaker: Kaili Zhang (IHEP)
  Material: Slides
- 16:45 **Update on the mesurement of bb, cc, gg** *25'*
  Speaker: Yu Bai (Southeast University)
  Material: Slides

Wednesday, July 3, 2019

09:00 - 10:30 Higgs
Convener: Xin Shi (IHEP)

- 09:00 **Update on H->tautau** *25'*
  Speakers: Mrs. Dan YU (LLR), YU Dan
  Material: Slides
- 09:25 **Status of H->mumu** *20'*
  Speaker: Kunlin RAN (Beijing)
  Material: Slides
- 09:45 **the study of Higgs invisible decay** *20'*
  Speaker: TAN Yuhang (高能所)
  Material: Slides
- 10:05 **Higgs decaying into ZZ*** *20'*
  Speaker: Ryuta Kiuchi
  Material: Slides

10:30 - 10:50 Coffee Break

10:50 - 12:20 Higgs
Convener: Prof. Yaquan FANG Yaquan (高能所)

- 10:50 **MVA anlsysi on H->gamma gamma** *20'*
  Speaker: Fangyi Guo (IHEP)
  Material: Slides
- 11:10 **Differential measurement on Higgs** *20'*
  Speaker: ABDUALAZEM FADOL MOHAMMED EBRHIM (高能所)
  Material: Slides
- 11:30 **Review and Discussion on Higgs physics** *40'*
  Speaker: Jianming Qian (University of Michigan)
  Material: Slides

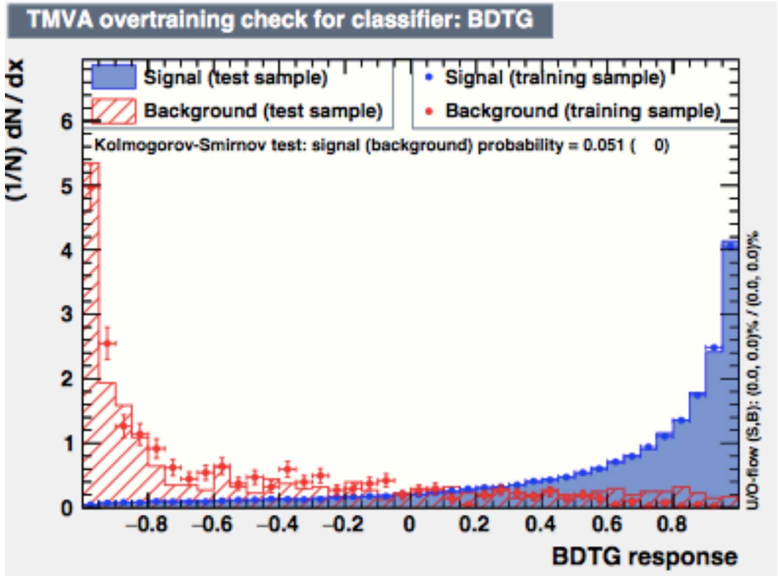
- 14 Higgs talks are presented in the workshop
- They triggered a lot of discussions for the study of the CEPC Higgs physics in the future.

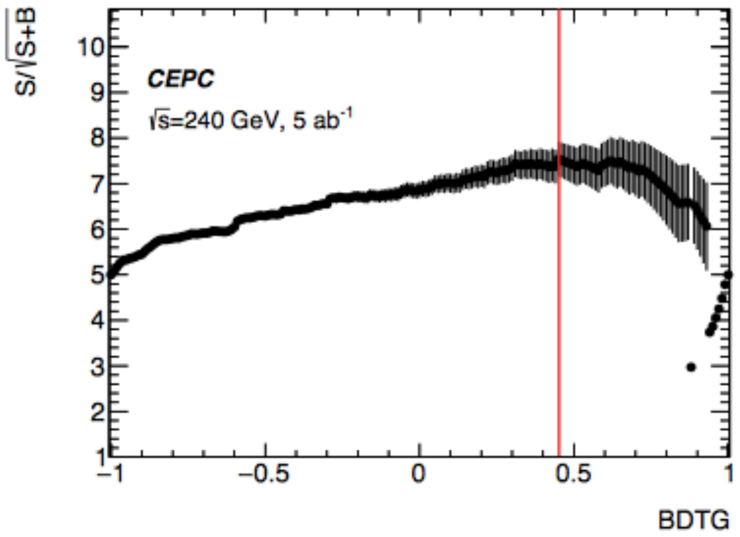
CEPC Higgs physics after CDR

- Improve the analyses with different technologies:
  - MVA, multi-dim fit.
  - Improve the performance b-tagging, photon ID/conversion etc.
  - Test different setup-of the detectors
- Test the analyses with different colliding energy
  - Benchmark : 360 GeV/1.5(2.0) ab^{-1}
  - Improvement of ww fusion on the Higgs width as well as the precision measurement.
  - *ttbar run*
- Differential xsection measurements
  - Start to do that.
- Interpretation on the results
  - Further cooperation with theorists (in particular the domestic theorists)
- Wrap up with a post CDR Higgs paper.

MVA H->μμ

- After training with 6 variables: $cos\theta_{ee}$, $cos\theta_{\mu\mu}$, $\Delta_{\mu,\mu}$, M_{qq}, E_{ee}, $E_{qq\mu\mu}$, get the BDTG response





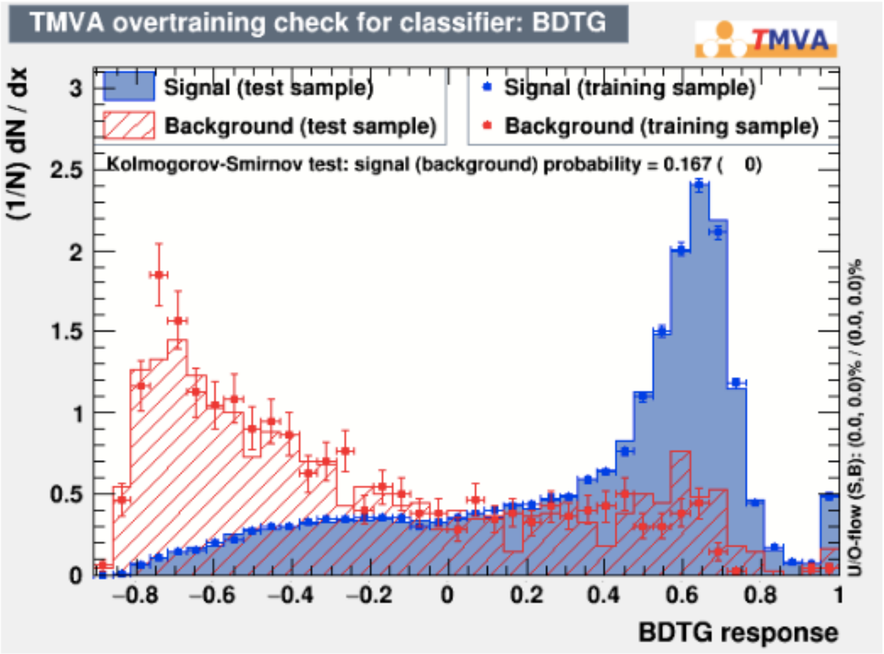
- There is a overtraining in the background due to poor statistics: ~1600
- Scan the total sensitivity ($S/\sqrt{S+B}$) vs BDTG to find the optimal BDTG point
- The sensitivity is estimated in the 90% signal coverage region

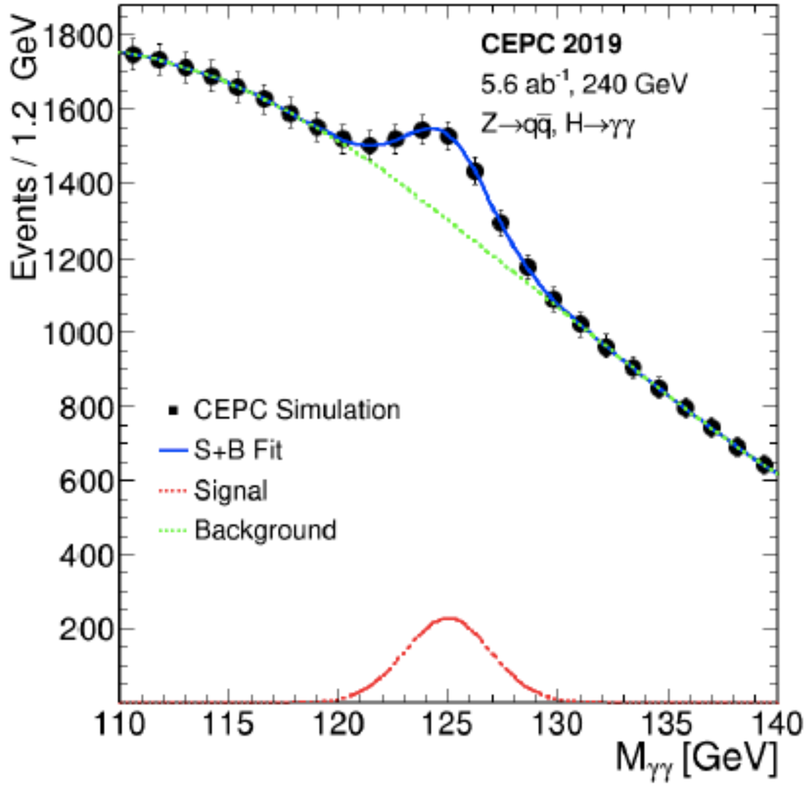
	Sig yield	Bkg yield	Sensitivity	Mass range (GeV)
BDTG > 0.45	86.20 +/- 0.51	198.20 +/- 19.82	7.46 +/- 0.27	[120.78 - 125.33]
BDTG < 0.45	29.77 +/- 0.30	1402.95 +/- 52.73	1.08 +/- 0.03	[114.08 - 125.28]
Total	115.97 +/- 0.59	1601.15 +/- 56.33	7.54 +/- 0.38	

- ➢ The improvement is ~35% w.r.t cut based one for the signal significance.
- ➢ See more in Kunlin Ran's talk.

Improvement on precision: 17% -> 12%

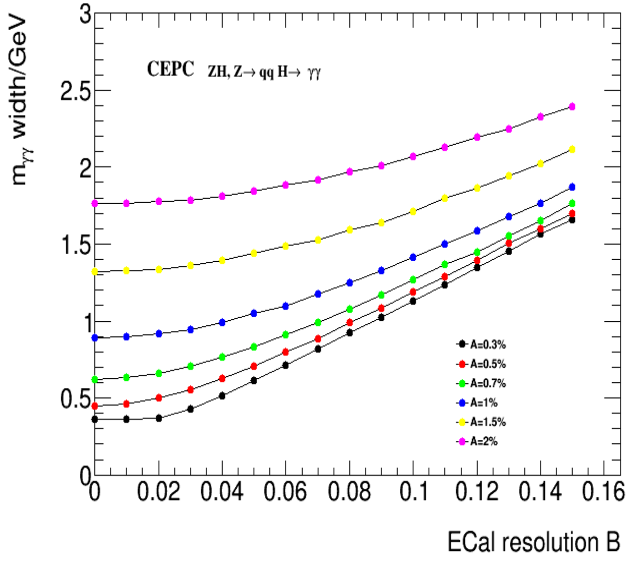
MVA H->γγ



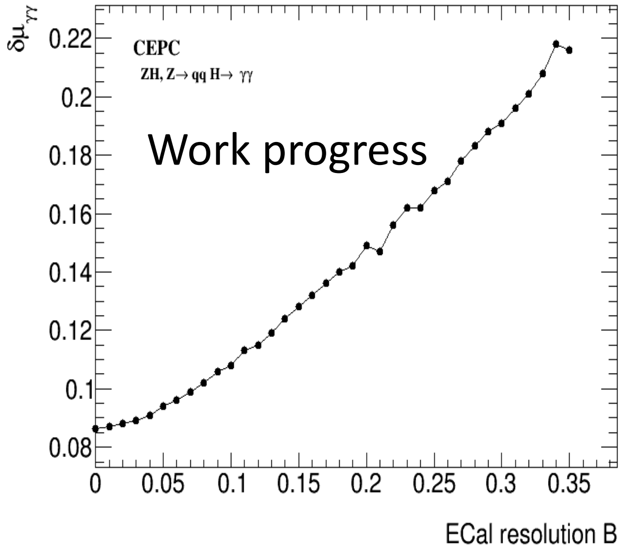


Impact of variation of B on the $M_{\gamma\gamma}$ resolution

$$\frac{\delta E}{E} = A \oplus \frac{B}{\sqrt{E}},$$



Impact on the measured precision



- ➢ Variables having low correlations with $m_{\gamma\gamma}$ are chosen as inputs to MVA
- ➢ Two dimensional fit is implemented to extract the precision of the measurement.
- ➢ The improvement is ~30% in the channel of Z(->qq)H->γγ for the precision measurement.
- ➢ See more in Fangyi Guo's talk.

H->invisible, H->ZZ and differential measurement.

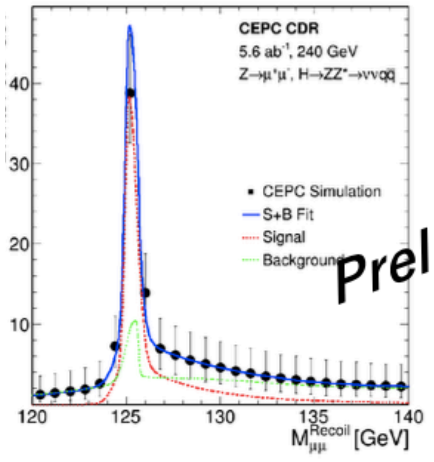
- For H->invisible, assuming the Br at 0.1%,

the expected measured precision is 42%.

- A note is being prepared.
- Details can be found at Yuhang Tan's talk.

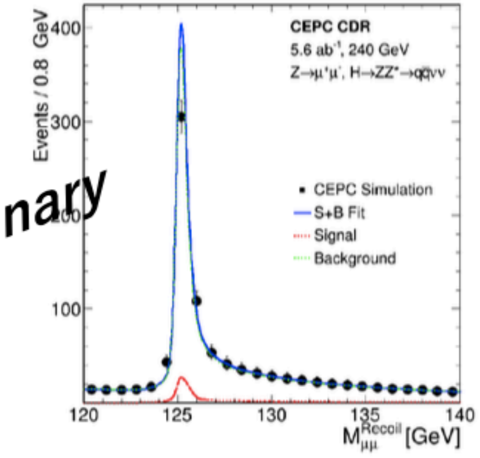
ZH final state studied	Relative precision on $\sigma(ZH)/BR$	Upper limit on $BR(H \to inv)$
$Z \to e^+e^-$, H→ inv	301%	0.698%
$Z \to \mu^+\mu^-$, H→inv	105%	0.329%
$Z \to q\bar{q}$, H→inv	46%	0.204%
Combination	42%	0.194%

Process	qqh_invi	2f	single_w	single_z	szorsw	zz	ww	zzorww	ZH_visible	total_bkg	$\frac{\sqrt{S+B}}{S}$
Total generated	383068	801152072	19517400	9072951	1397088	6389430	50826214	20440840	1140495	909936490	7.88 %
$100GeV < M_{recoil}^{visible} < 150GeV$	368367	34602867	1342725	818614	225883	503588	1666338	518251	96885	39775151	1.72 %
$30GeV < P_T^{visible} < 60GeV$	280799	2532942	718721	186863	104495	203426	853612	247154	55983	4903196	0.81 %
90GeV<Visible Energy<117GeV	268711	1545260	432951	158180	64932	169826	528936	145922	22807	3068814	0.68 %
$85GeV < M_{visible} < 102GeV$	227114	301096	168343	107155	26193	101355	265697	58251	12417	1040507	0.50 %
$\Delta\phi_{dijet} < 175^o$	220612	194003	163303	103004	25731	97518	258678	56622	11908	910767	0.48 %
$P_{visible} < 58GeV$	209722	139241	109114	51235	16966	34630	158955	44160	10161	564462	0.42 %
$N_{neutral} > 15, N_{electron} < 7$	207426	6617	10326	12539	116	9172	35114	5813	3343	83040	0.26 %
$N_{IsoMuon} = 0, N_{IsoElectron} = 0$	206299	1656	3214	11818	22	8513	16819	4362	2433	48837	0.24 %
Efficiency	53.85 %	0.00 %	0.02 %	0.13 %	0.00 %	0.13 %	0.03 %	0.02 %	0.21 %	0.01 %	



$$\frac{\sqrt{S+B}}{S} = 11.2\%$$

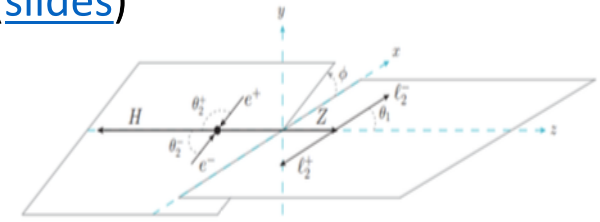
① $Z(\mu^+\mu^-)H(Z\to\nu\nu, Z^*\to jj)$

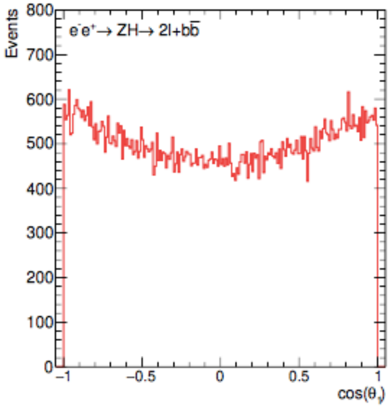


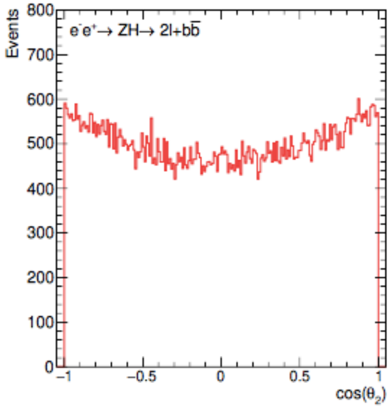
$$\frac{\sqrt{S+B}}{S} = 40.3\%$$

② $Z(\mu^+\mu^-)H(Z^*\to\nu\nu, Z\to jj)$

Abdualazem Fadol starts to study
The differential measurement
(slides)







- ➢ For H->ZZ, more channels will be explored (e.g. Z(->ee) H->ZZ
- ➢ MVA analyses will be implemented.
- ➢ Further bkg suppressions will be studied.
- ➢ See more at Ryuta Kiuchi's presentation

Alternative: Global analysis approach on Higgs measurement

More at Gang's slides

Solve N_i by minimizing the χ^2 with constraint

$$\chi^2 = \sum_i \frac{(\sum \epsilon_{ij} N_j - n_i)^2}{\sigma^2_{n_i}} + \frac{(\sum_l N_l - N)^2}{\sigma^2_N}$$

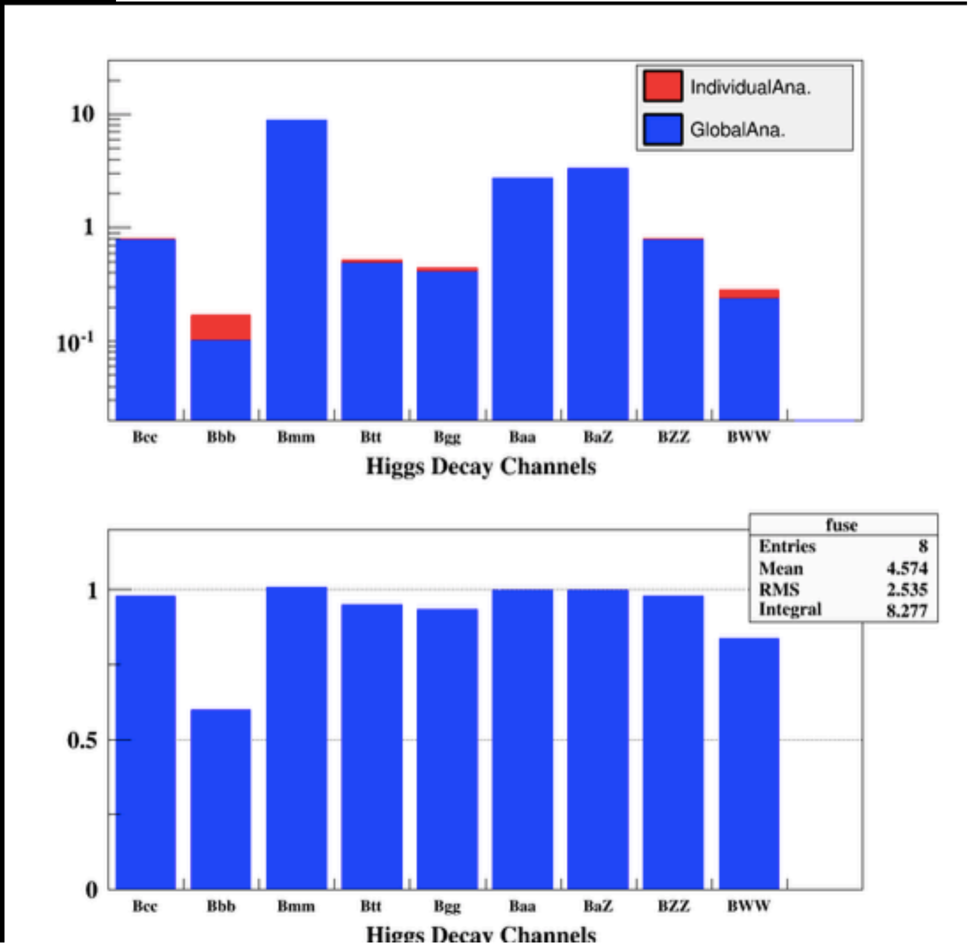
Higgs -> cc, bb, mm, tt, gg, aa, aZ, ZZ, WW

1 2 3 4 5 6 7 8 9

$$\begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \\ n_8 \\ n_9 \end{pmatrix} = \begin{pmatrix} \epsilon_{11} & \epsilon_{12} & \epsilon_{13} & \epsilon_{14} & \epsilon_{15} & \epsilon_{16} & \epsilon_{17} & \epsilon_{18} & \epsilon_{19} \\ \epsilon_{21} & \epsilon_{22} & \epsilon_{23} & \epsilon_{24} & \epsilon_{25} & \epsilon_{26} & \epsilon_{27} & \epsilon_{28} & \epsilon_{29} \\ \epsilon_{31} & \epsilon_{32} & \epsilon_{23} & \epsilon_{34} & \epsilon_{35} & \epsilon_{36} & \epsilon_{37} & \epsilon_{38} & \epsilon_{39} \\ \epsilon_{41} & \epsilon_{42} & \epsilon_{33} & \epsilon_{44} & \epsilon_{45} & \epsilon_{46} & \epsilon_{47} & \epsilon_{48} & \epsilon_{49} \\ \epsilon_{51} & \epsilon_{52} & \epsilon_{43} & \epsilon_{54} & \epsilon_{55} & \epsilon_{56} & \epsilon_{57} & \epsilon_{58} & \epsilon_{59} \\ \epsilon_{61} & \epsilon_{62} & \epsilon_{53} & \epsilon_{64} & \epsilon_{65} & \epsilon_{66} & \epsilon_{67} & \epsilon_{68} & \epsilon_{69} \\ \epsilon_{71} & \epsilon_{72} & \epsilon_{63} & \epsilon_{74} & \epsilon_{75} & \epsilon_{76} & \epsilon_{77} & \epsilon_{78} & \epsilon_{79} \\ \epsilon_{81} & \epsilon_{82} & \epsilon_{73} & \epsilon_{84} & \epsilon_{85} & \epsilon_{86} & \epsilon_{87} & \epsilon_{88} & \epsilon_{89} \\ \epsilon_{91} & \epsilon_{92} & \epsilon_{83} & \epsilon_{94} & \epsilon_{95} & \epsilon_{96} & \epsilon_{97} & \epsilon_{98} & \epsilon_{99} \end{pmatrix} \begin{pmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \\ N_7 \\ N_8 \\ N_9 \end{pmatrix}$$

Neglect e and uds decays — constraint feasible

$$\sum_i N_i = N^{tag} \text{ or } \sum_i B_i = 1 \qquad B_i = \frac{N_i}{N}$$



Conclusion

- The Higgs CDR is done and the studies post CDR toward TDR start
  - Maximum use of the detector information:
    - Improve electron energy measurement
    - Estimate the sensitivities of missing final states.
  - Improve the existing analyses.
    - Fully exploit kinematic information for signal and background.
    - MVA analyses implemented for different channels.
    - Global analysis approaches.
  - In addition:
    - Different cross section, Spin/CP properties, BSM studies (H->invisible etc…).
  - Impact from physics analyses on the detector design changes.
- Manpower needed (welcome to join)

backup slides

High energy (360 GeV) Run

	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%**
$H \to ZZ$	**5.1%**	**12%**	**13%**
$H \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$H \to \gamma\gamma$	**5.4%**	**8%**	**11%**
$H \to \mu\mu$	**12%**	**29%**	**40%**
$Br_{upper}(H \to inv.)$	**0.2%**	\	\
$\sigma(ZH) * Br(H \to Z\gamma)$	**16%**	**25%**	\
Width	**2.9%**		
Combined Width 240/360	**1.4%**		

Generally, since the extrapolation is not so accurate, results are comparable.
For Higgs coupling, also similar performance could be expected.

Fcc-ee: width : 1.3%

WW fusion with 360 GeV (Hao Liang's talk)

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

- For $H \to \gamma\gamma$ and $H \to \mu\mu$, resolution changes considered.

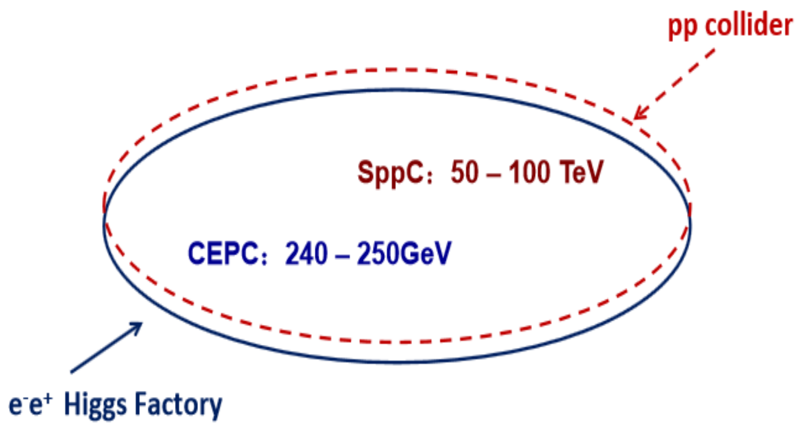
Keep diphoton resolution ~(2.5GeV) : 9%
2.5GeV to 2GeV: 8%

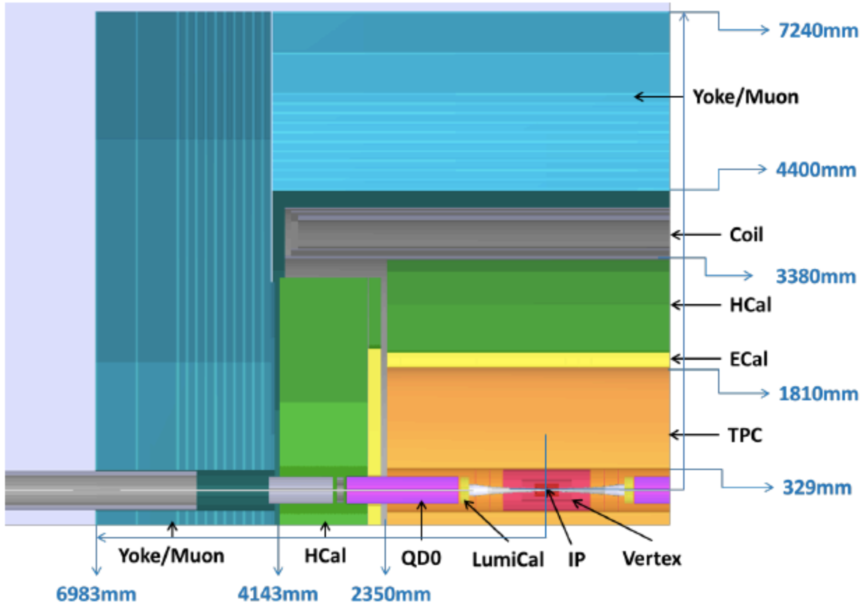
- Keep the resolution of di-muon ~(0.3GeV): 23%

0.3GeV to 1GeV: 29%

- For the measurement of Higgs width, CEPC can reach 1.4% combining 240 GeV and 360 GeV measurement
  - Comparable to FCC-ee: 1.3%
  - If we take the same assumption as Fcc-ee, one can reach 1.2%

CEPC





- ✓ A CEPC (phase I)+ Super proton-proton Collider (SPPC) was proposed
- ✓ Ecm ~240-250 GeV, Lum 5.6 ab^{-1} for 10 years

Table 2. Key characteristic/performance of a conceptual CEPC detector.

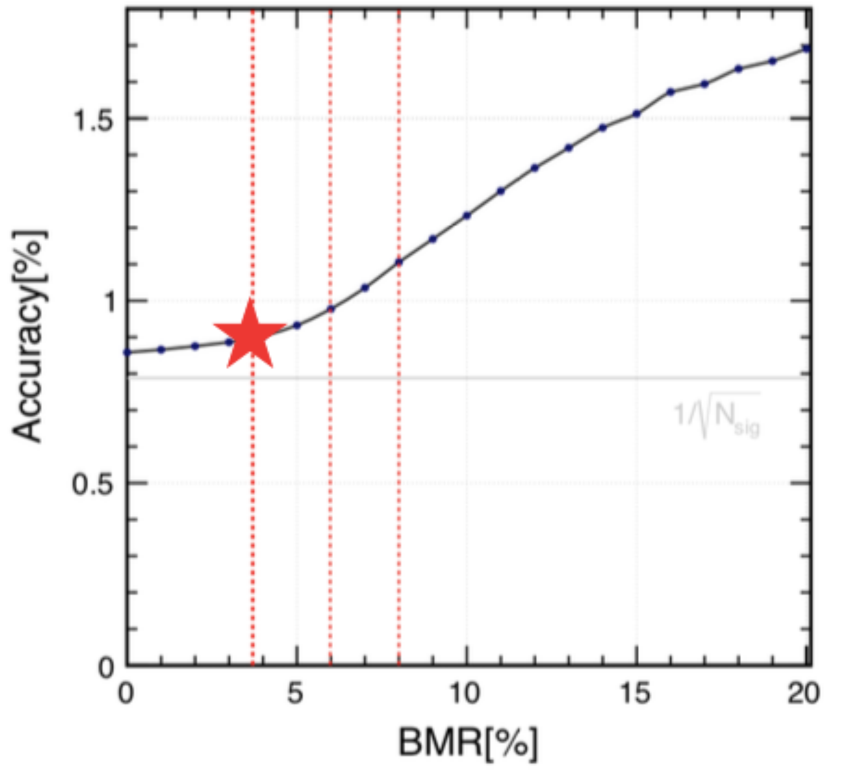
Geometry acceptance	TPC (97%), FTD (99.5%)
Tracking efficiency	~ 100% within geometry acceptance
Tracking performance	$\Delta(1/p_T) \sim 2 \times 10^{-5}$ (1/GeV)
ECAL intrinsic energy resolution	$16\%/\sqrt{E} \oplus 1\%$ (GeV)
HCAL intrinsic energy resolution	$60\%/\sqrt{E} \oplus 1\%$ (GeV)
Jet energy resolution	3-4%
Impact parameter resolution	5 μm

Status of H->ττ

- Develop signal strength analysis with and without jets
  - MVA for the former
  - TAURUS package
- Study BMR dependency
- Decay modes ID….

Dan Yu's talk

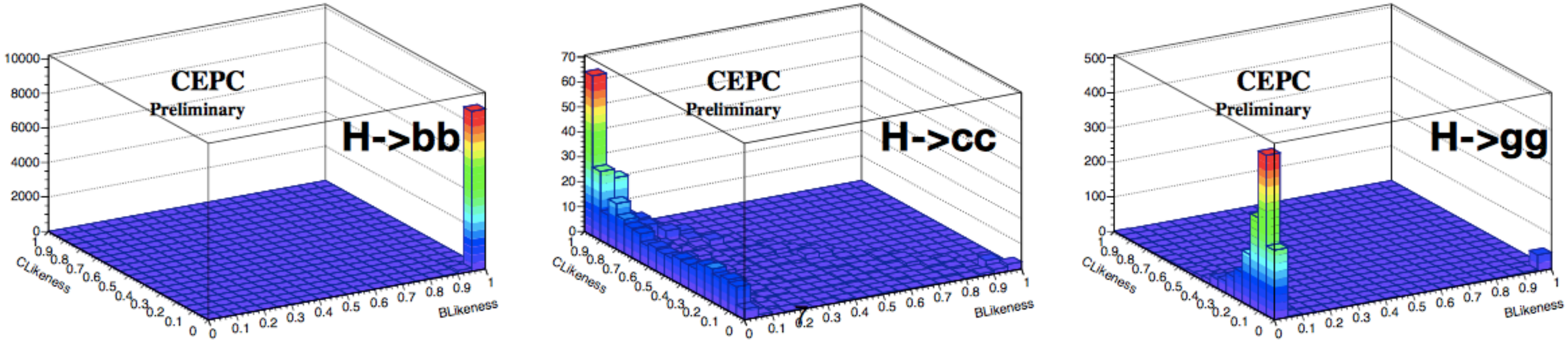
	$\delta(\sigma\times BR)/(\sigma\times BR)$
$\mu\mu H$	2.8%
eeH	5.1%
$\nu\nu H$	7.9%
qqH	0.9%
combined	0.8%



Status of H->bb,cc,gg

More at Yu Bai's talk

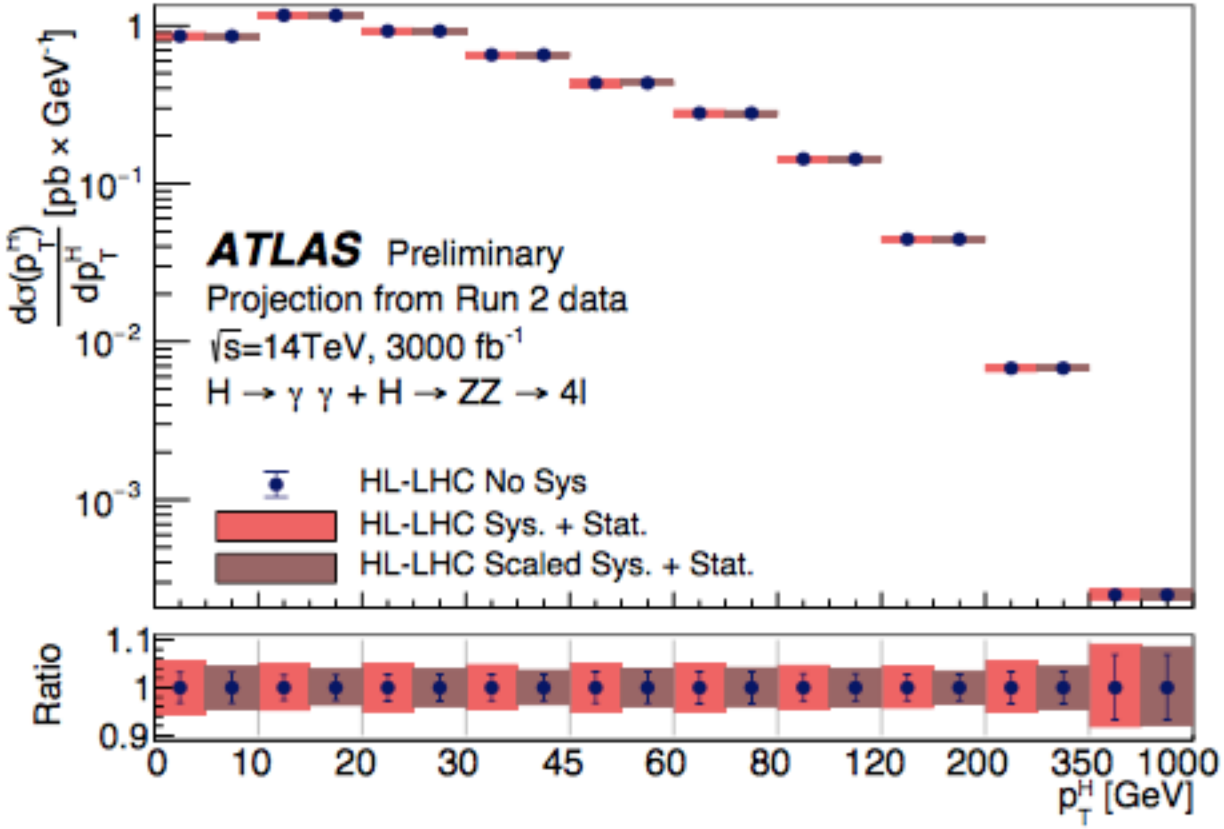
- Wrap the analysis into a note and submit to CPC.
- Flavor tagging used in the fit (3 dim)

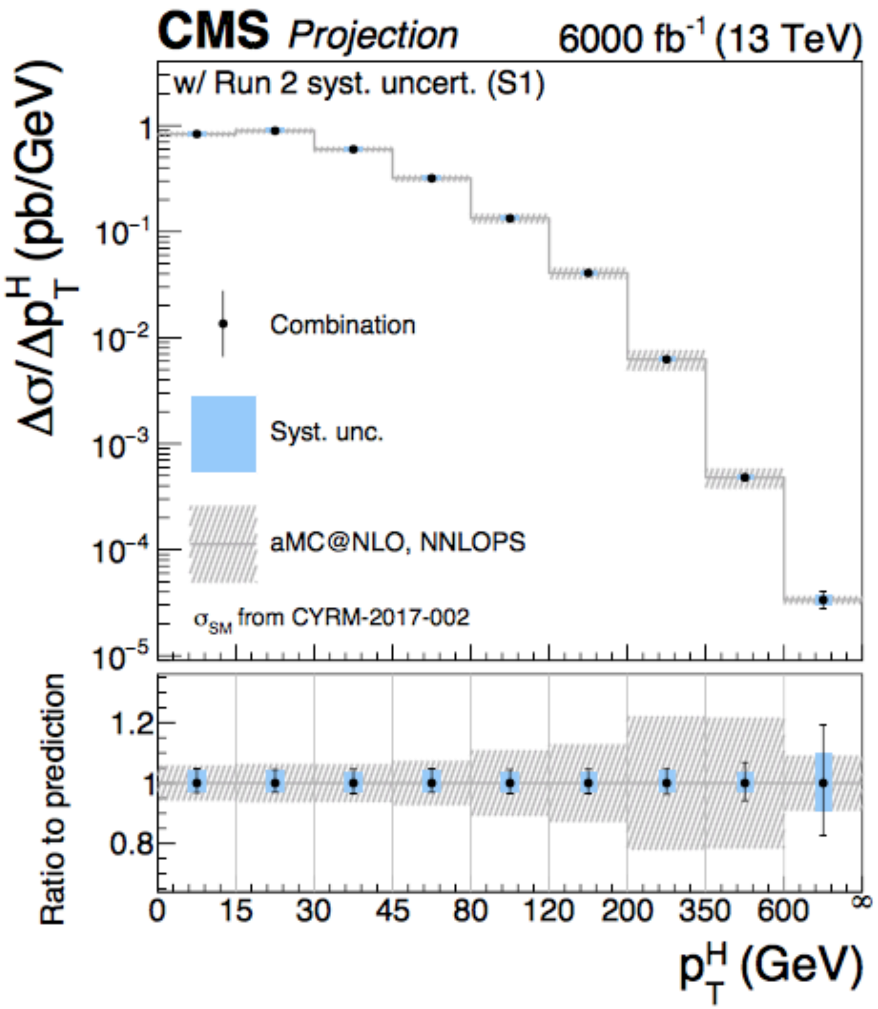


- Start to consider the systematics.

Decay mode	$\sigma(ZH)\times$ BR	BR
$H\to b\bar{b}$	0.28%	0.57%
$H\to c\bar{c}$	2.2%	2.3%
$H\to gg$	1.6%	1.7%

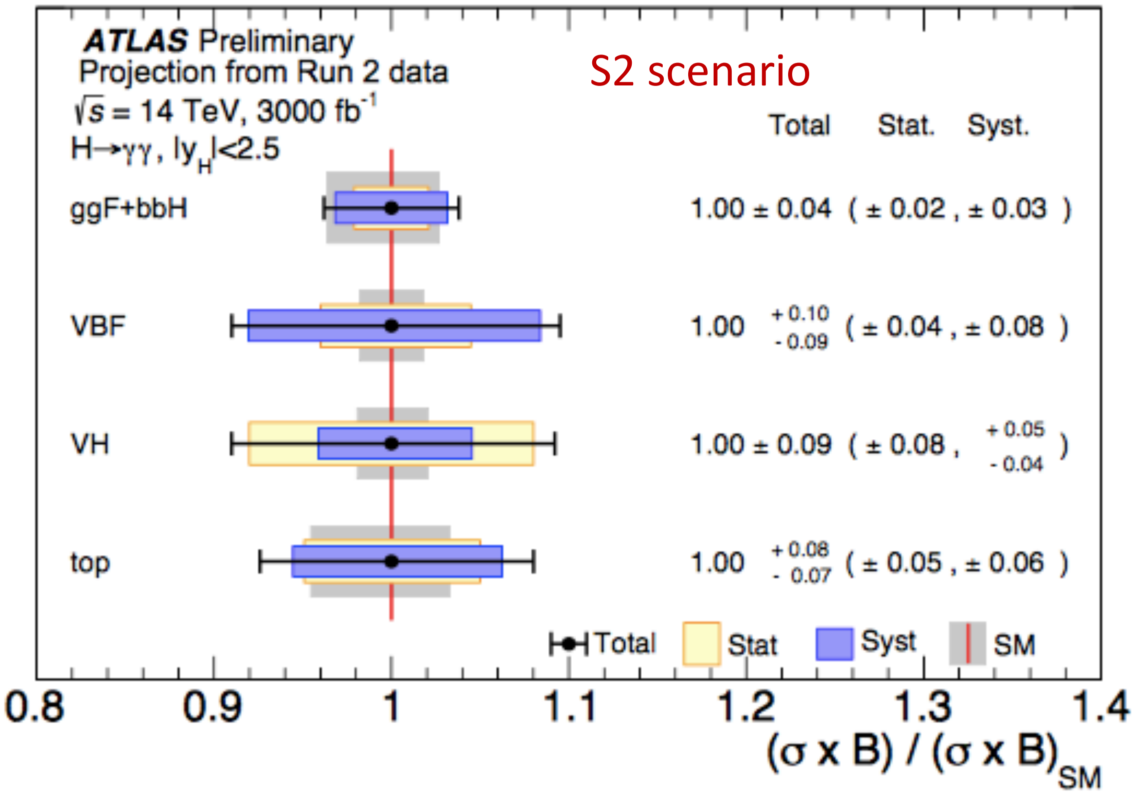
HL-LHC: Differential xsection measurement

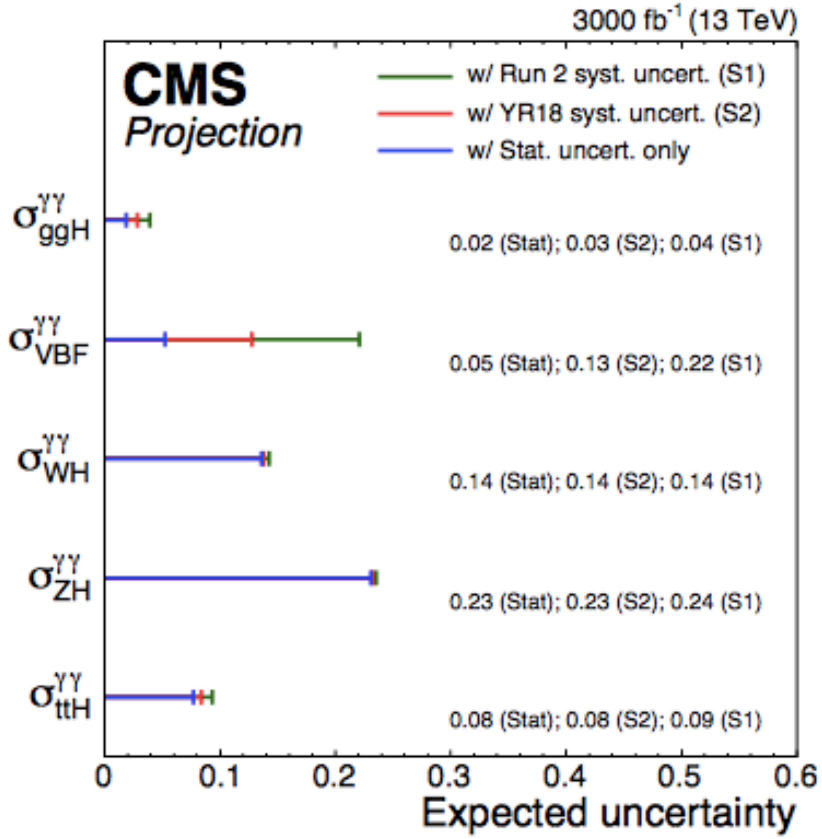




The precision can reach a few percent for different p_T bins.

HL-LHC H->γγ: one example





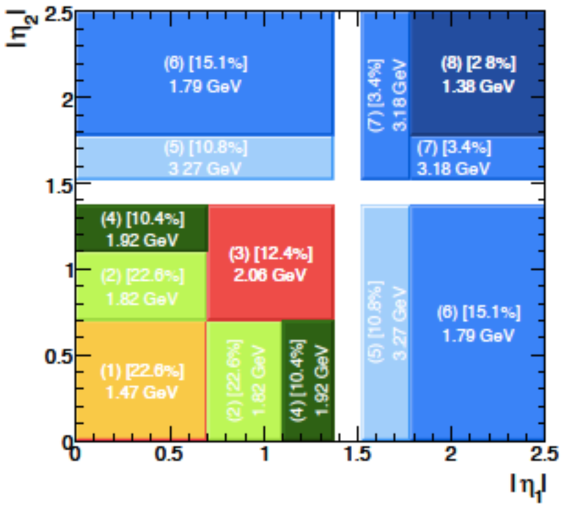
Scenario S1: Total uncertainty is half of the one used for the result of 80 fb^{-1}.

Scenario S2: Total uncertainty is 1/3 of the one for 80 fb^{-1}.

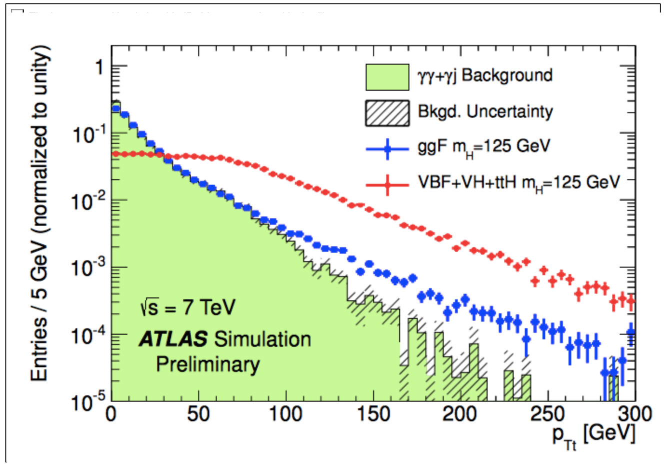
HL-LHC H->γγ: very advanced analyses (example)

- The inclusive analysis is very simple :
  - Photon ID, Isolation, Kinematic cuts on leading/subleading photon.
- Explore other possible improvements ?
  - Divide events into different categories.

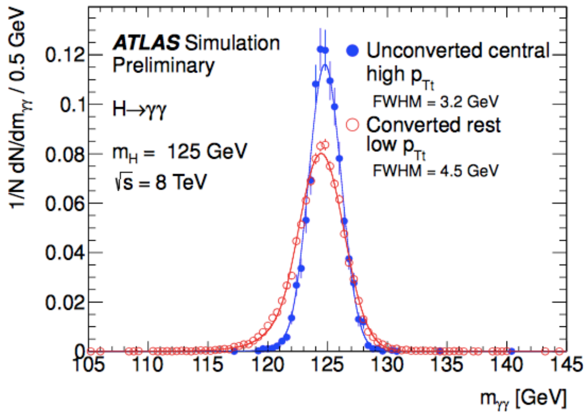
Divide different eta regions for two photons



P_T of Higgs (P_{Tt} is perpendicular to the thrust direction of two photon)



Conversion of the photons



Higgs white paper @ CDR

Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs Physics at the CEPC*

Fenfen An[4,23] Yu Bai[9] Chunhui Chen[23] Xin Chen[5] Zhenxing Chen[3] Joao Guimaraes da Costa[4]
Zhenwei Cui[3] Yaquan Fang[4,6,34] Chengdong Fu[4] Jun Gao[10] Yanyan Gao[22] Yuanning Gao[3]
Shao-Feng Ge[15,29] Jiayin Gu[13] Fangyi Guo[1,4] Jun Guo[10] Tao Han[5,31] Shuang Han[4]
Hong-Jian He[11,10] Xianke He[10] Xiao-Gang He[11,10,20] Jifeng Hu[10] Shih-Chieh Hsu[32] Shan Jin[8]
Maoqiang Jing[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4] Chia-Ming Kuo[21] Pei-Zhu Lai[21] Boyang Li[5]
Congqiao Li[3] Gang Li[4,34] Haifeng Li[12] Liang Li[10] Shu Li[11,10] Tong Li[12]
Qiang Li[3] Hao Liang[4,6] Zhijun Liang[4,34] Libo Liao[4] Bo Liu[4,23] Jianbei Liu[1]
Tao Liu[14] Zhen Liu[26,30] Xinchou Lou[4,6,33,34] Lianliang Ma[12] Bruce Mellado[17,18] Xin Mo[4]
Mila Pandurovic[16] Jianming Qian[24] Zhuoni Qian[19] Nikolaos Rompotis[22] Manq
Lian-You Shan[4] Jingyuan Shi[9] Xin Shi[4] Shufang Su[25] Dayong Wang[3]
Lian-Tao Wang[27] Yifang Wang[4,6] Yuqian Wei[4] Yue Xu[5] Haijun Yang[10,
Weiming Yao[28] Dan Yu[4] Kaili Zhang[4,6] Zhaoru Zhang[4] Mingrui Zhao[2] Xiang

[1] Department of Modern Physics, University of Science and Technology of China, Anhui 230
[2] China Institute of Atomic Energy, Beijing 102413, China
[3] School of Physics, Peking University, Beijing 100871, China
[4] Institute of High Energy Physics, Beijing 100049, China
[5] Department of Engineering Physics, Physics Department, Tsinghua University, Beijing 100
[6] University of Chinese Academy of Science (UCAS), Beijing 100049, China
[7] School of Nuclear Science and Technology, University of South China, Hengyang 42100
[8] Department of Physics, Nanjing University, Nanjing 210093, China
[9] Department of Physics, Southeast University, Nanjing 210096, China
[10] School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shan
[11] Tsung-Dao Lee Institute, Shanghai 200240, China
[12] Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irr
University, Qingdao 266237, China
[13] PRISMA Cluster of Excellence & Mainz Institute of Theoretical Physics, Johannes Gutenberg-Universi
Germany
[14] Department of Physics, Hong Kong University of Science and Technology, Hong K
[15] Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, J
[16] Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade 11000, Serl
[17] School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johanne
[18] iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, Sou
[19] Center for Theoretical Physics of the Universe, Institute of Basic Science, Daejeon 34126,
[20] Department of Physics, National Taiwan University, Taipei 10617, Taiwan
[21] Department of Physics and Center for High Energy and High Field Physics, National Central University, T
[22] Department of Physics, University of Liverpool, Liverpool L69 7ZX, United Kingd
[23] Department of Physics and Astronomy, Iowa State University, Ames 50011-3160, USA
[24] Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA
[25] Department of Physics, University of Arizona, Arizona 85721, USA
[26] Theoretical Physics Department, Fermi National Accelerator Laboratory, Batavia 60510, USA
[27] Department of Physics, University of Chicago, Chicago 60637, USA
[28] Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[29] Department of Physics, University of California, Berkeley, California 94720, USA
[30] Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, Maryland 20742, USA
[31] Department of Physics & Astronomy, University of Pittsburgh, Pittsburgh 15260, USA
[32] Department of Physics, University of Washington, Seattle 98195-1560, USA
[33] Department of Physics, University of Texas at Dallas, Texas 75080-3021, USA
[34] Physical Science Laboratory, Huairou National Comprehensive Science Center, Beijing, 101400, China

arXiv:1810.09037v2 [hep-ex] 4 Mar 2019

	Estimated Precision			
Property	CEPC-v1		CEPC-v4	
m_H	5.9 MeV		5.9 MeV	
Γ_H	2.7%		2.8%	
$\sigma(ZH)$	0.5%		0.5%	
$\sigma(\nu\bar{\nu}H)$	3.0%		3.2%	
Decay mode	$\sigma\times$BR	BR	$\sigma\times$BR	BR
$H\to b\bar{b}$	0.26%	0.56%	0.27%	0.56%
$H\to c\bar{c}$	3.1%	3.1%	3.3%	3.3%
$H\to gg$	1.2%	1.3%	1.3%	1.4%
$H\to WW^*$	0.9%	1.1%	1.0%	1.1%
$H\to ZZ^*$	4.9%	5.0%	5.1%	5.1%
$H\to\gamma\gamma$	6.2%	6.2%	6.8%	6.9%
$H\to Z\gamma$	13%	13%	16%	16%
$H\to\tau^+\tau^-$	0.8%	0.9%	0.8%	1.0%
$H\to\mu^+\mu^-$	16%	16%	17%	17%
$\mathrm{BR}^{\mathrm{BSM}}_{\mathrm{inv}}$	–	< 0.28%	–	< 0.30%

V2 is at arxiv.
CPC : Vol 43, No.4 (2019) 043002

Thanks to those colleagues for great efforts.
Welcome to new colleagues to join in.

CEPC Higgs to TDR

该二维码7天内(7月8日前)有效，重新进入将更新

Mailing list: cepc-physics@maillist.ihep.ac.cn

One example

ATLAS-CONF-2016-017

Category	Events	B_{90}	S_{90}	f_{90}	Z_{90}	S_{90}^{fit}
Central low-$p_{\text{T}t}$	31907	3500	180	0.05	3.04	120
Central high-$p_{\text{T}t}$	1319	140	20	0.13	1.66	15
Forward low-$p_{\text{T}t}$	85129	13000	310	0.02	2.73	200
Forward high-$p_{\text{T}t}$	3977	540	33	0.06	1.38	25

The improvement of significance w.r.t. inclusive one is from 4.0 to 4.6, corresponding 13% improvement on the precision.

Results and systematics for H->bb,cc,gg

Combination of the 4 channels:

Statistic precision of σ(ZH)*Br(H->bb/cc/gg) is 0.3% 3.3% and 1.3%

Consistent with the goal expected in pre-CDR with full simulation samples

Decay mode	$\sigma(ZH) \times$ BR	BR
$H \to b\bar{b}$	0.28%	0.57%
$H \to c\bar{c}$	2.2%	2.3%
$H \to gg$	1.6%	1.7%

llH with 3D fit and systematic uncertainties considered:

Table 2. Uncertainties of $H \to b\bar{b}$, $H \to c\bar{c}$ and $H \to gg$

	$\mu^+\mu^- H$			$e^+e^- H$		
	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
Statistic Uncertainty	1.1%	10.5%	5.4%	1.6%	14.7%	10.5%
Fixed Background	-0.2% +0.1%	+4.1% -4.2%	7.6%	-0.2% +0.1%	+4.1% -4.2%	7.6%
Event Selection	+0.7% -0.2%	+0.4% -1.1%	+0.7% -1.7%	+0.7% -0.2%	+0.4% -1.1%	+0.7% -1.7%
Flavor Tagging	-0.4% +0.2%	+3.7% -5.0%	+0.2% -0.7%	-0.4% +0.2%	+3.7% -5.0%	+0.2% -0.7%
Non uniformity	$<0.1\%$			$<0.1\%$		
Combined Systematic Uncertainty	+0.7% -0.5%	+5.5% -6.6%	+7.6% -7.8%	+0.7% -0.5%	+5.5% -6.6%	+7.6% -7.8%

Analysis with more reliable approaches. Systematic uncertainties considered.

Measurement of Higgs width

- **Method 1: Higgs width can be determined directly from the measurement of σ(ZH) and Br. of (H->ZZ*)**

$$\Gamma_H \propto \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

Precision : 5.1%

  - **But the uncertainty of Br(H->ZZ*) is relatively high due to low statistics.**

- **Method 2: It can also be measured through:**

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{BR(H \to bb)} \qquad \sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b}) \propto \Gamma(H \to WW^*) \cdot \mathrm{BR}(H \to bb) = \Gamma(H \to bb) \cdot \mathrm{BR}(H \to WW^*)$$

3.0%

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

Precision : 3.5%

- **These two orthogonal methods can be combined to reach the best precision.**

Precision : 2.8%