Higgs recoil analysis and Higgs width measurement

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Outline

- **Introduction**
  Recoil mass method and Higgs width determination

- **Apparatus: CEPC Conceptual Detector**

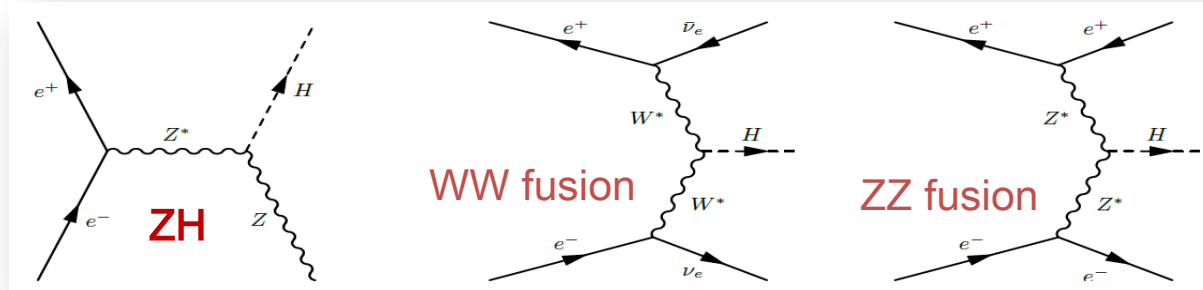- **Monte Carlo Simulation**

- **Recoil mass analysis at CEPC**
  ZH cross section and Higgs mass measurement

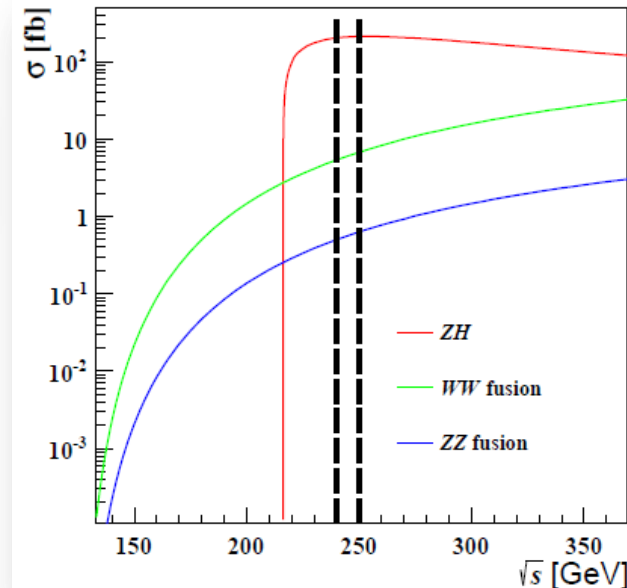- **Higgs width measurement at CEPC**

- **Summary**

Recoil mass

- CEPC will work at 240-250 GeV

- Higgs boson production: **ZH**(dominant), WW fusion, ZZ fusion

- Well known initial states at an e⁺e⁻ collider

- In ZH, the leptonic decay of Z boson can be well reconstructed

- Recoil mass:

$$m_{\text{recoil}}^2 = (\sqrt{s} - E_{f\bar{f}})^2 - p_{f\bar{f}}^2 = s - 2E_{f\bar{f}}\sqrt{s} + m_{f\bar{f}}^2$$

- Higgs mass and ZH cross section can be determined in a model-independent way

Higgs width determination

- The Higgs width is a sensitive probe for BSM. $\Gamma_H \sim$ 4 MeV in SM, it is impossible to make a direct measurement due to limited detector resolution

- An indirect measurement at e^+e^- collider:

➢ Strategy I: with $\sigma(ZH)$ and $BR(H\to ZZ)$
  limited statistics($BR(H\to ZZ)\sim 2.3\%$ in SM)

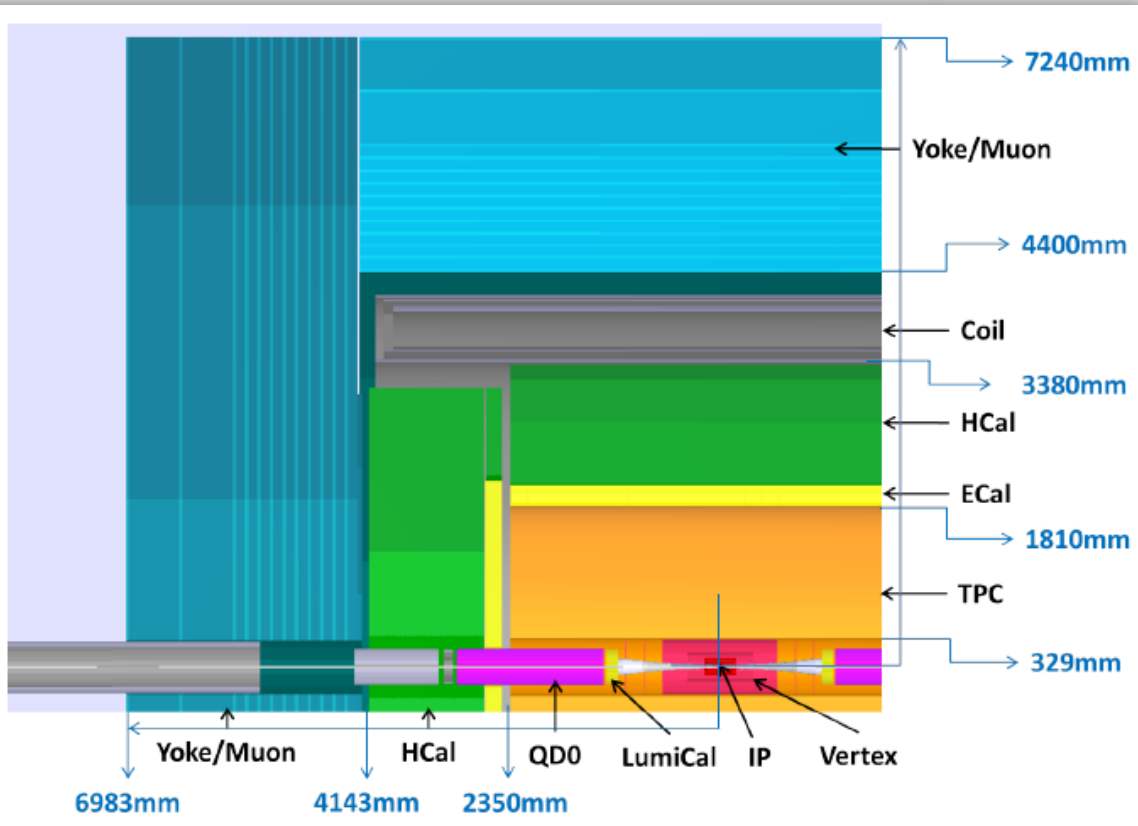$$\Gamma_H = \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

➢ Strategy II: with a series of measurements including $\sigma(ZH)$, $\sigma(\nu\nu H, H\to bb)$, $\sigma(ZH, H\to bb)$, $\sigma(ZH, H\to WW)$

$$\Gamma_H = \frac{\Gamma(H \to bb)}{BR(H \to bb)}$$

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

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

CEPC conceptual detector

Expected performance

Parameter	ε(%)
Charged reconstruction (E >10 GeV)	99.5
Muon identification(E > 10 GeV)	98.5
Electron identification(E > 10 GeV)	99.5
Photon tagging(E > 1 GeV)	98
Jet energy resolution	3~4
b-tagging	90
c-tagging	60

● Basically follow the design of ILD

● Modification:
  ✓ Return Yoke: reduced by 1 m (not push-pull operation)
  ✓ L* reduced to 1.5 m (3.5m for ILD)

Monte Carlo Simulation

Generator: Whizard 1.95 (with ISR, Luminosity: 5ab^{-1}, M$_H$=125 GeV)

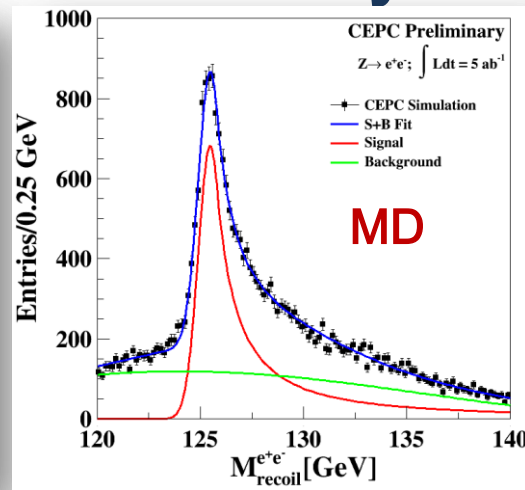Background: 2-fermion (lepton or quark pairs)
4-fermion (WW, ZZ, Single W and Single Z)
Chin. Phys. C 40 (2016) 033001
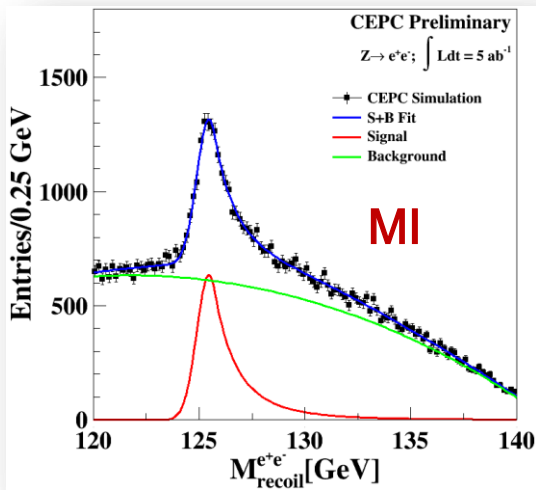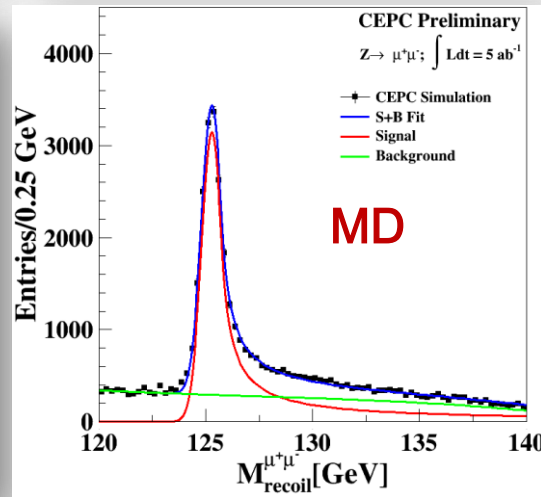
Simulation: Mokka

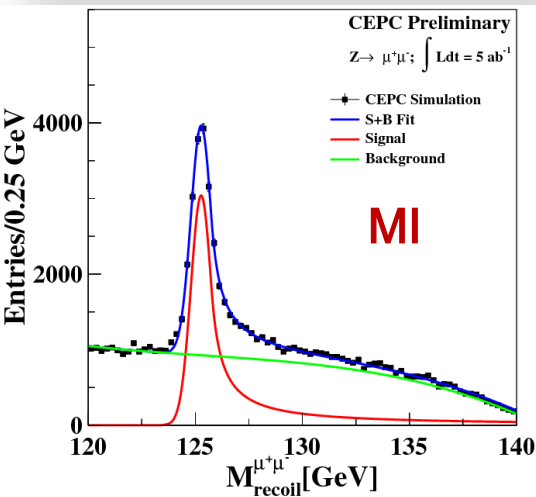Reconstruction: Arbor
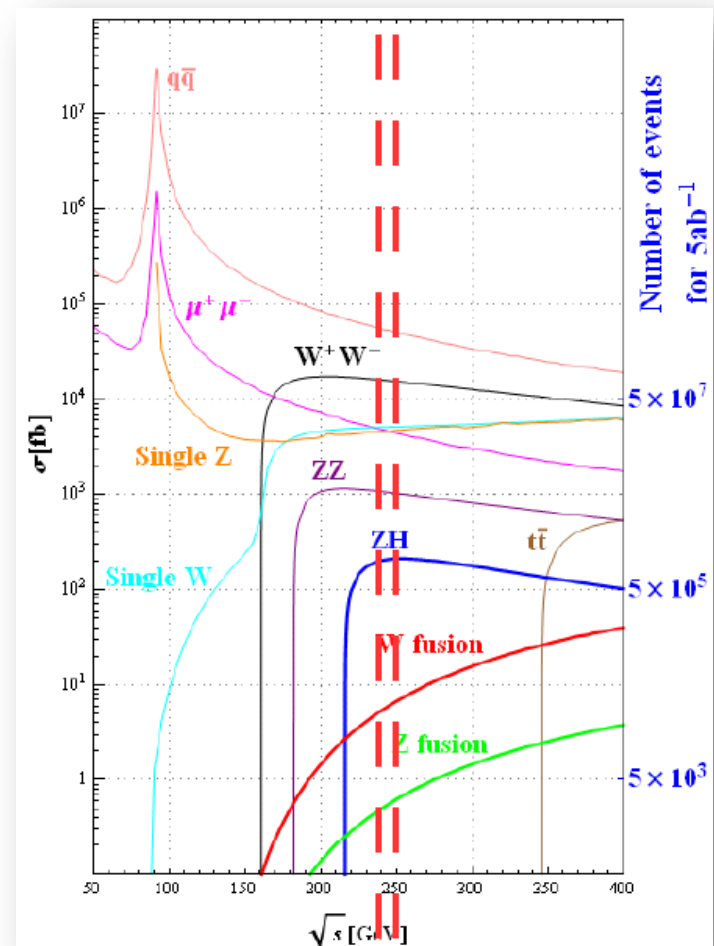
Recoil mass analysis: Z→e⁺e⁻ or μ⁺μ⁻

Model-Independent: only information from Z boson decays ➡ an inclusive measurement
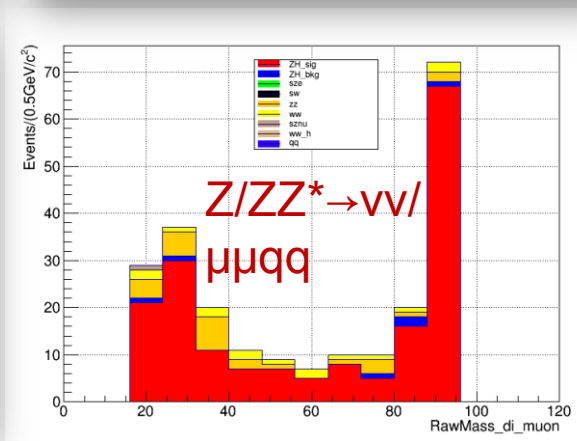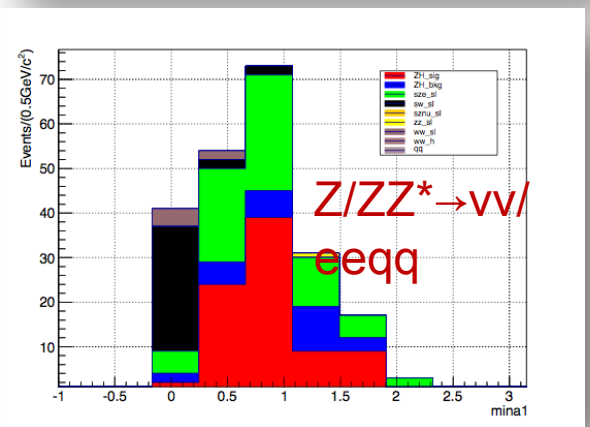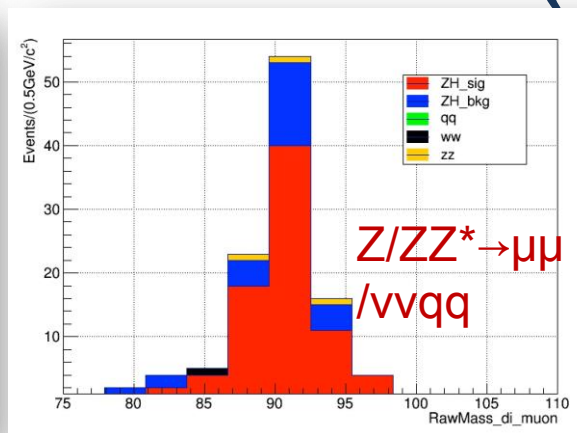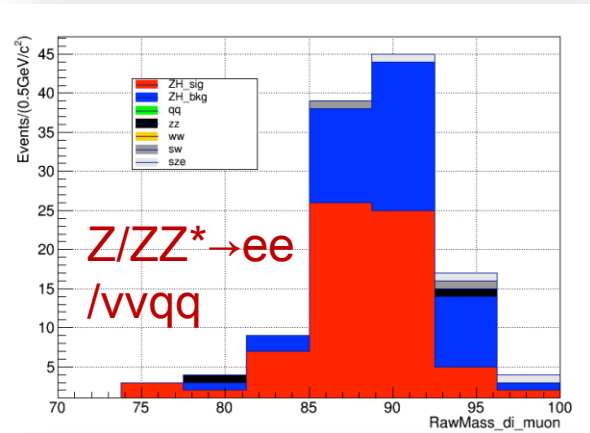
Model-Dependent: SM assumption ➡ reduced background and improved m_H precision

with a 0.16% beam energy spread

Channel	$\Delta\sigma(ZH)/\sigma(ZH)$	Δm_H (MI)	Δm_H (MD)
e⁺e⁻	1.49%	19.2 MeV	13.1 MeV
μ⁺μ⁻	0.92%	6.5 MeV	5.4 MeV

Measurement of ZH(H→ZZ*)

Z/ZZ*→ee/vvqq

Z/ZZ*→μμ/vvqq

Z/ZZ*→vv/eeqq

Z/ZZ*→vv/μμqq

	Z→ll	taus	vv	qq
ZZ*→4q	888	444	3.10k	9.24k
vv+qq	508	254	1.77k	5.29k
ll+qq	170	85	596	1.78k
4v	73	36	254	756
ll+vv	49	24	170	508
4l	8	4	28	86
X+tau	120	60	418	1.25k

Limited accuracy ~ > 50%

H→invisible ~ 40%

Full simulated

Await for tau finder

Extrapolated from TLEP

Await for Jet Clustering

Not Covered yet

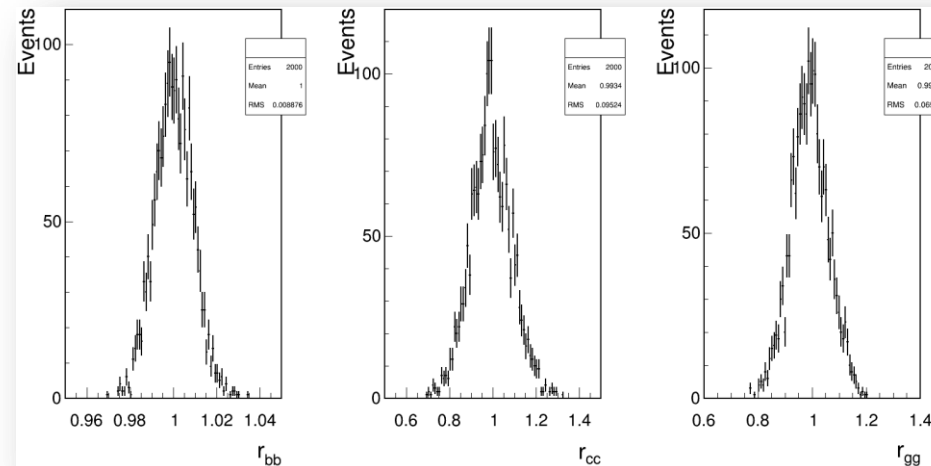| Final state	Δσ(ZH, H→ZZ*)/σ(ZH, H→ZZ*)
ee + qq + vv	12.7%
μμ + qq + vv	7.0%
μμ + μμ + qq	19.9%
ee + μμ + qq	15.5%
Combined	5.4% (*TLEP: 4.3%*)

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Measurement of ZH(H→bb)
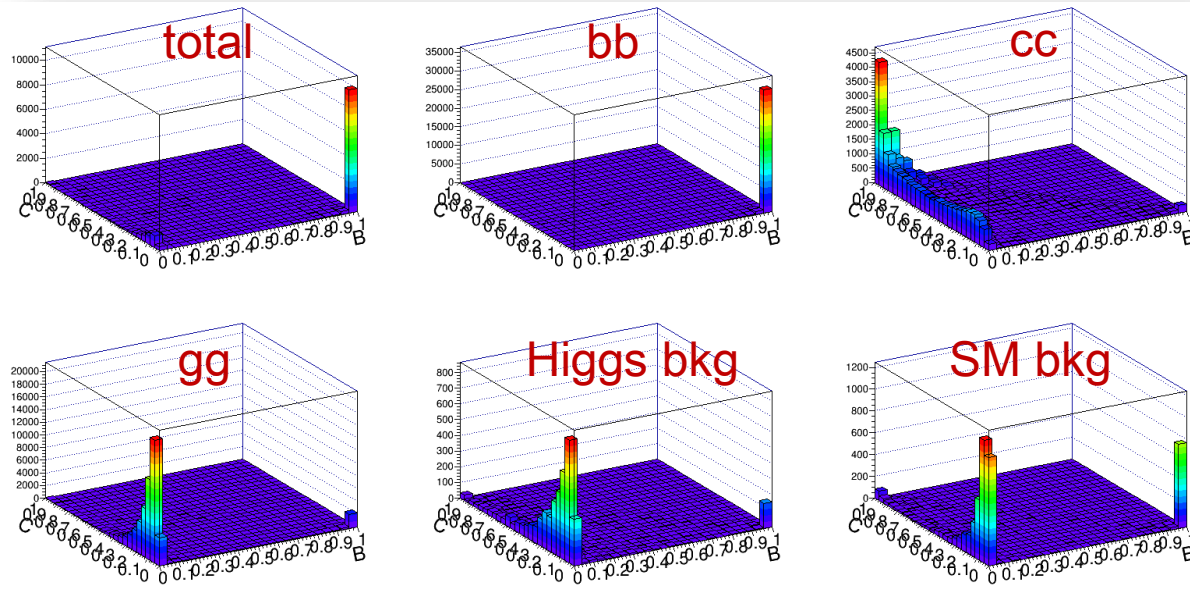
- Based on an analysis of Higgs decaying to 2 jets

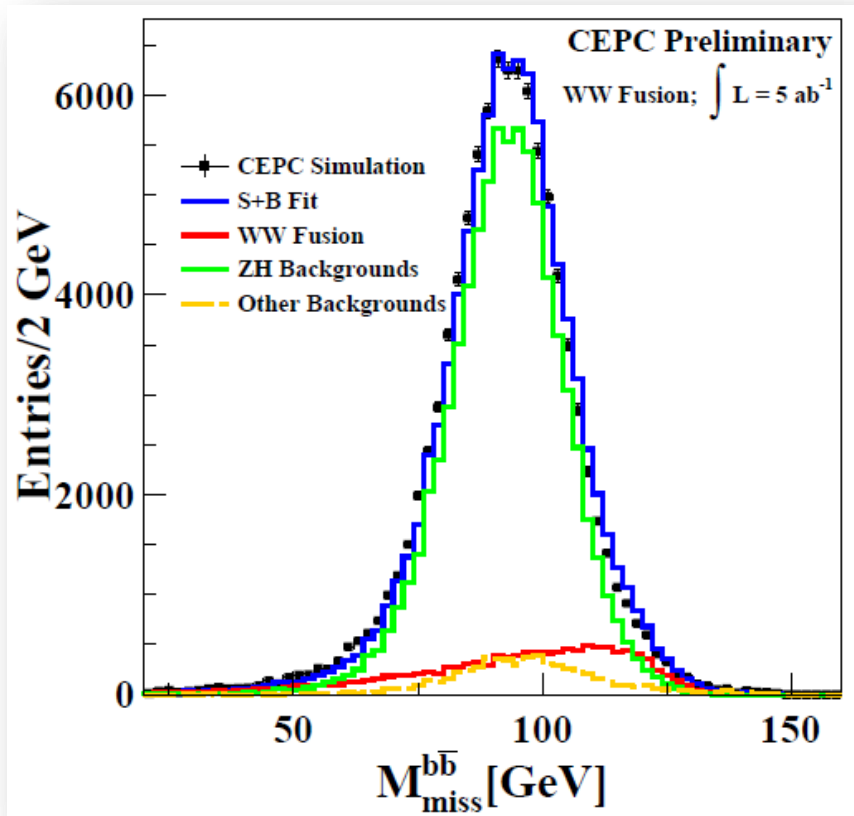- Precision extracted from a template fit on flavor tagging information

Z→μ⁺μ⁻

Z→	Δσ(ZH, H→bb)/σ(ZH, H→bb)
e⁺e⁻	1.3%
μ⁺μ⁻	0.9%
νν	0.3%
qq	0.4%
Combined	0.2%

Measurement of vvH(H→bb)

- $\sigma(vvH)/\sigma(ZH) \sim 10^{-2}$
- Recoil mass of 2 jets: limited discriminating power
- main background: ZH(Z→vv,H→bb) (interference ignored)

$\Delta\sigma(vvH, H\to bb)/\sigma(vvH, H\to bb)$: 2.8%

Fast simulated, consistent with preliminary full simulation

Measurement of ZH(H→WW*)
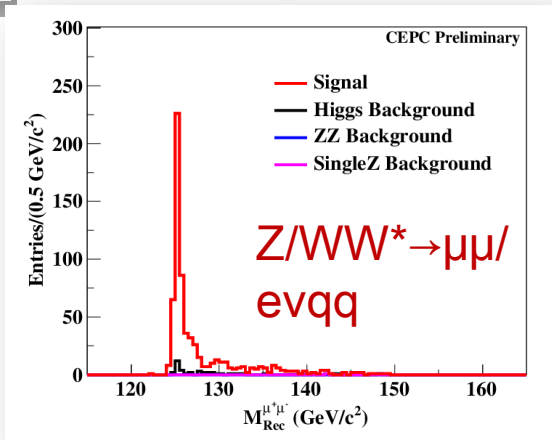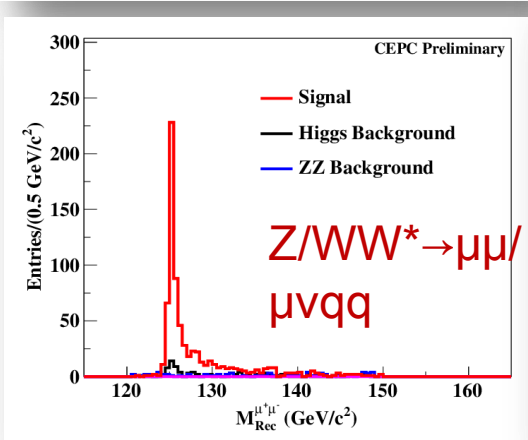
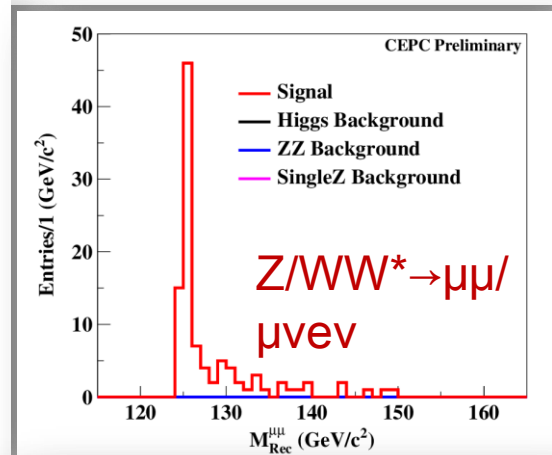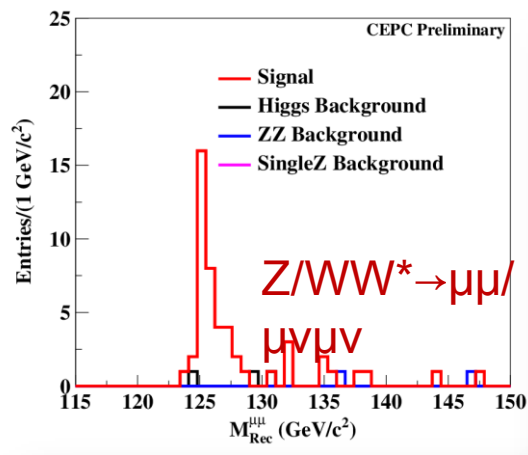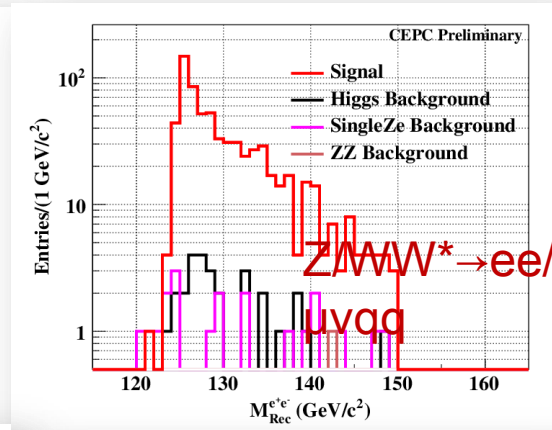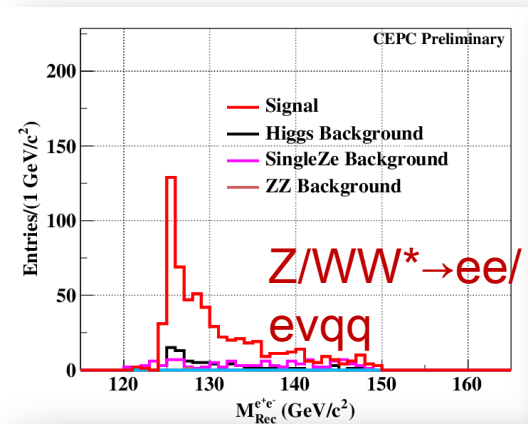|	Z→ll	taus	νν	qq
WW*→4q	6.91k	3.45k	19.74k	69.1k
lv+qq	4.53k	2.27k	12.94k	45.3k
lv+lv	745	377	2.13k	7.45k
X+tau	3.2k	1.60k	9.14k	32.0k

Await for tau finder		Await for SM background	
Extrapolated from ILC		Full simulated	
Preliminary		Not covered yet	

Final state	Δσ(ZH, H→WW*)/σ(ZH, H→WW*)
	1.6%
	1.6%
Combined	1.1%

Higgs width determination

Strategy I:

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

Strategy II:

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

σ(ZH)	0.50%	
Decay mode	Cross section precision	Branching ratio precision
ZH, H→bb	0.21%	0.54%
ZH, H→WW	1.6% (*ILC: 1.1%*)	1.7% (*ILC: 1.2%*)
ZH, H→ZZ	5.4% (*TLEP: 4.3%*)	5.4% (*TLEP: 4.3%*)
vvH, H→bb	2.8%	-

- Higgs total width:
  - ✓ Strategy I: 5.4% (*TLEP: 4.4%*)
  - ✓ Strategy II: 3.3% (*ILC: 3.1%*)

Combined: 2.8% (with extrapolation: 2.6%)

Summary

✓ Based on 5 ab^{-1} full simulated (part of backgrounds are fast simulated) MC samples at the CEPC, the results of benchmark analysis are presented

✓ Using the recoil mass method, the ZH cross section is determined in a model-independent way, with a precision of 0.50%. Meanwhile, the precision of Higgs mass is 5.0 MeV

✓ Based on the measurements of σ(ZH) , σ(ZH, H→bb), σ(vvH, H→bb) , σ(ZH, H→WW), σ(ZH, H→ZZ), the relative precision of Higgs width is determined to be 2.8%

Thanks for your attention!

BACKUP

Fast Simulation

- The detector responses (momentum resolution and detection efficiency) are parameterized with full simulated single particle events

- The generator particles are processed with the full simulated parameters
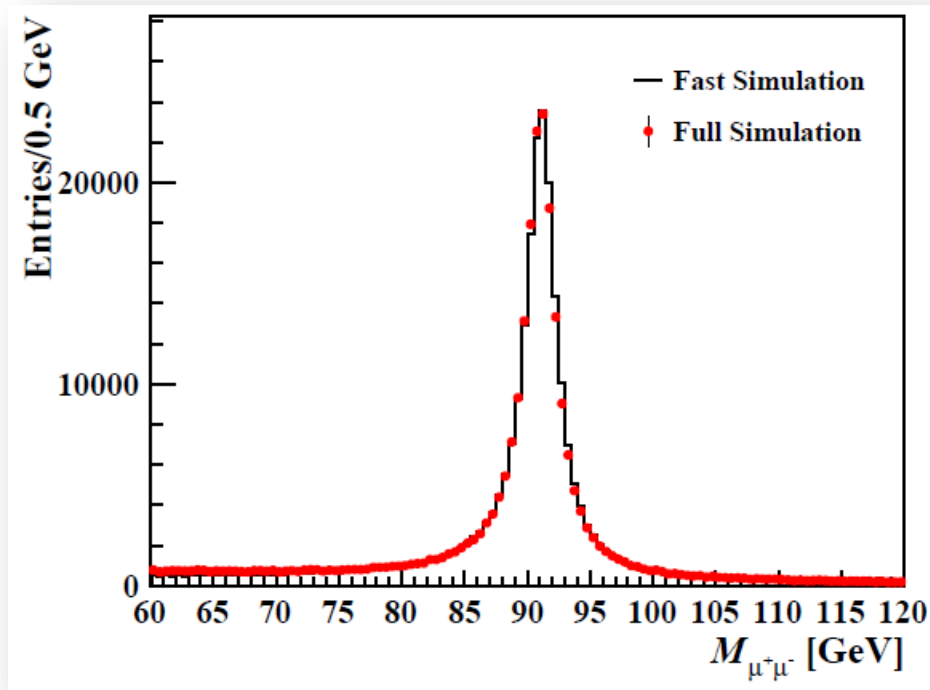
A validation with ZZ background sample