

# Higgs Invisible

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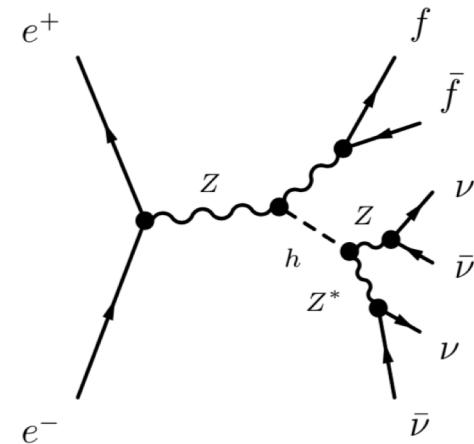
CEPC Workshop at Rome

# Outline

- Introduction
- Past activities
- Current status
- Summary and outlook

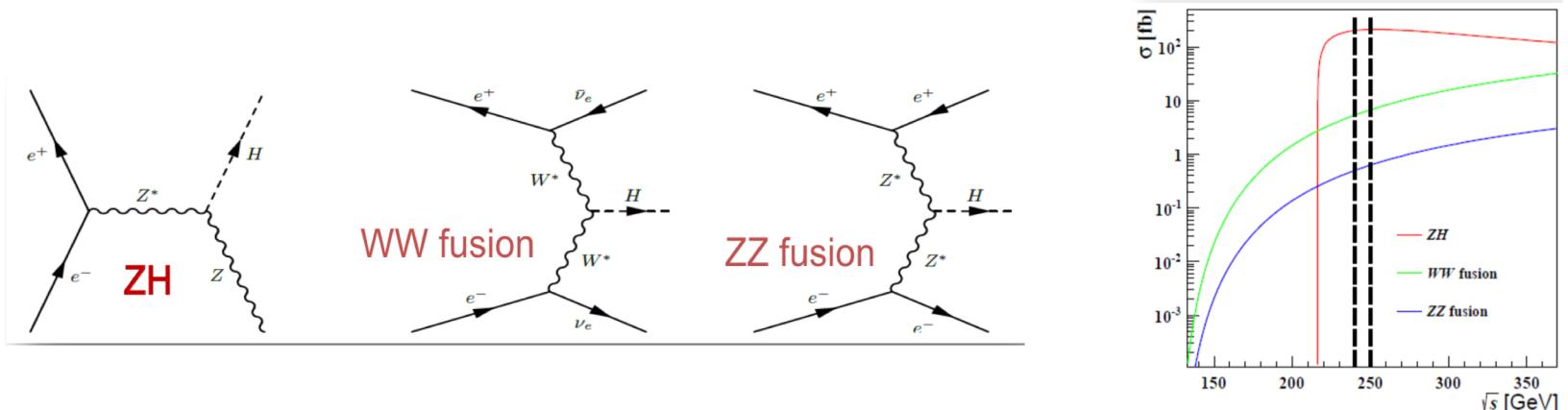
# Introduction

- The Higgs decays invisibly in SM is via four neutrinos, with  $\text{BR} \sim 1 \times 10^{-3}$ .
- May new physics beyond SM suggests enhancement of invisible decay e.g.: Higgs-portal models of dark matter (DM) interactions
- LHC searched invisible Higgs decay through VH and VBF (V for W or Z)  
ATLAS  $\sim \text{UL } 23\%$ , CMS  $\sim \text{UL } 24\%$  for  $\text{BR}(H \rightarrow \text{inv})$



# Higgs invisible on CEPC

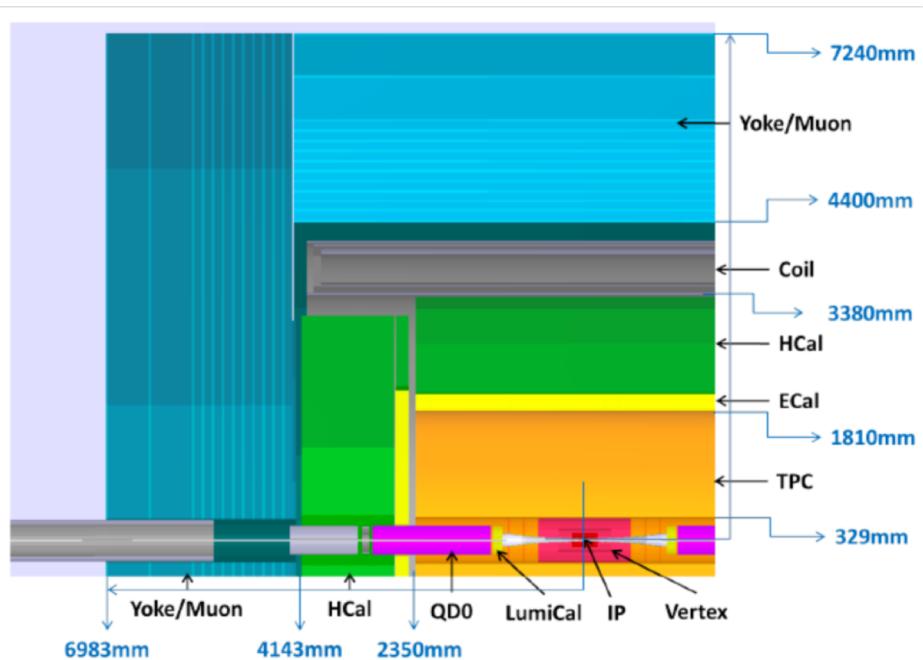
- CEPC work at 240-250 GeV
- Higgs boson production: ZH (dominant), WW fusion, ZZ fusion



- Well known initial states (beam energy and polarization ) at  $e^+e^-$  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 production cross section can be measured model-independently

# CEPC conceptual detector

- Followed design of ILD
- Modifications:
  - Return Yoke: reduced by 1m (not push-pull operation)
  - $L^*$  reduced to 1.5m (3.5m for ILD)

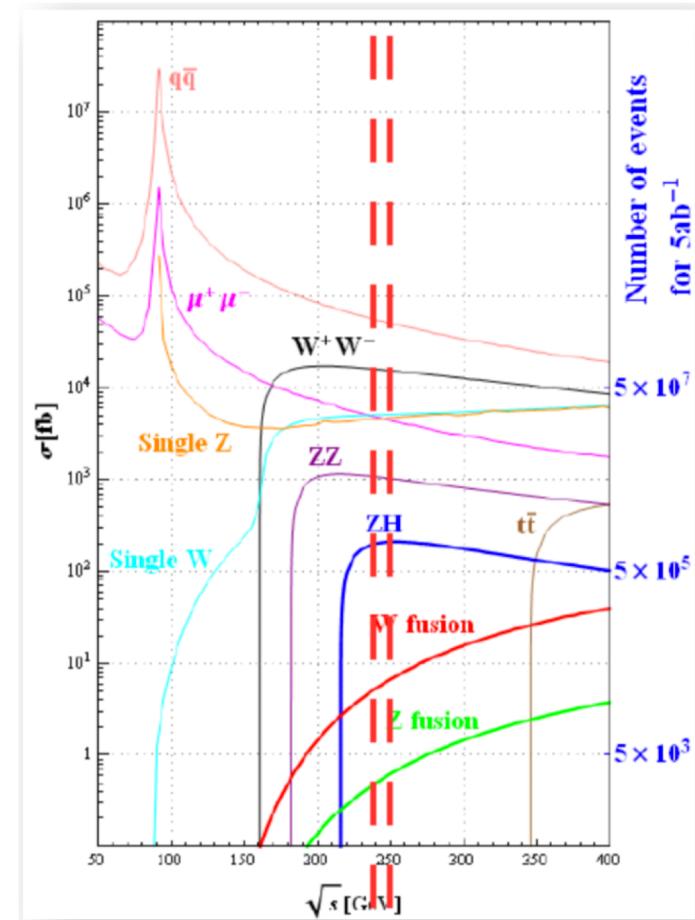


Expected performance

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

# Monte Carlo Simulation

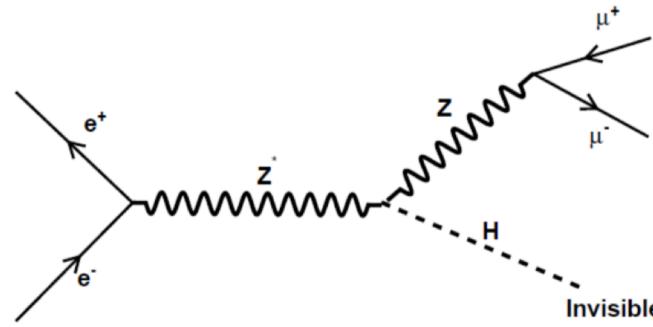
- CEPC\_v1 (250GeV, 3.5T)
- Generator: Whizard 1.95  
(with ISR, Lumi  $5\text{ab}^{-1}$ ,  
 $M_H=125\text{GeV}$ )
- Simulation:  
Geant4 and Mokka  
with ISR and  
bremsstrahlung effects
- Reconstruction:  
Marlin and ArborPFA



# Decay channels

- Leptonic:

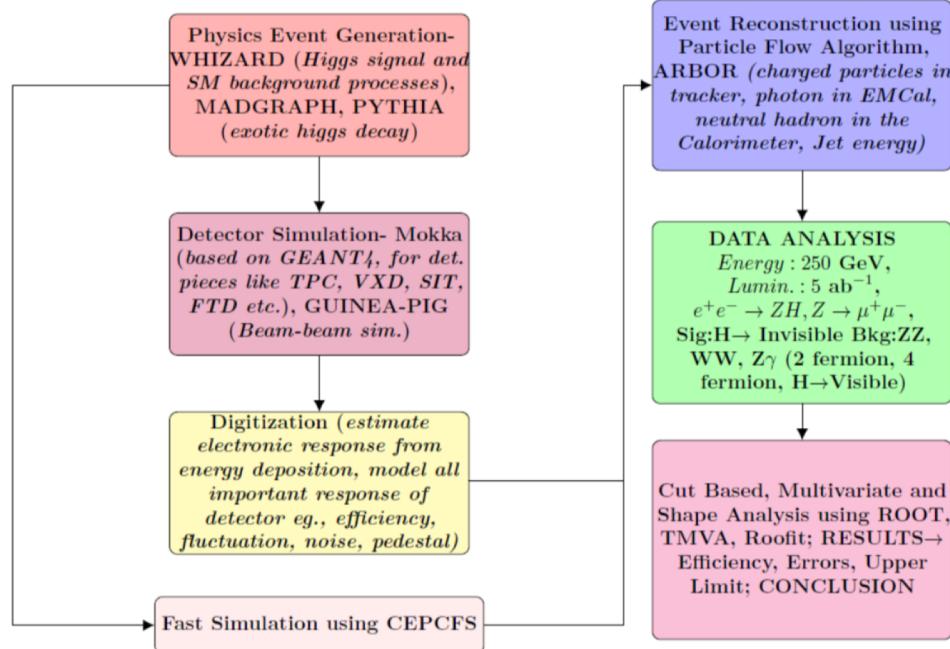
- $Z(\mu\mu)H(\text{inv})$
- $Z(ee)H(\text{inv})$



- Hadronic:

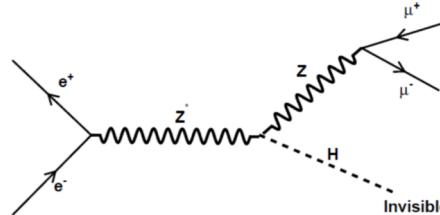
- $Z(q\bar{q})H(\text{inv})$

Scheme for simulation and analysis

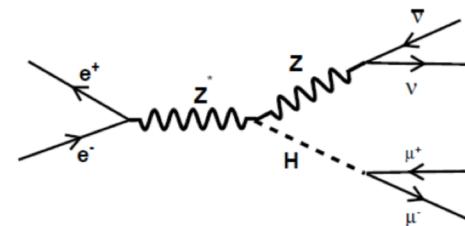
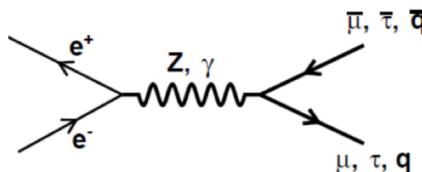


# Backgrounds for $Z(\mu\mu)$

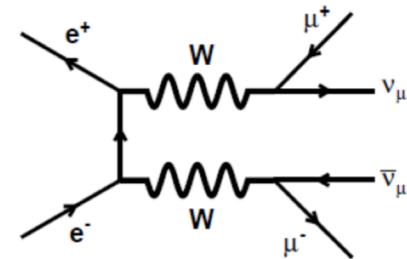
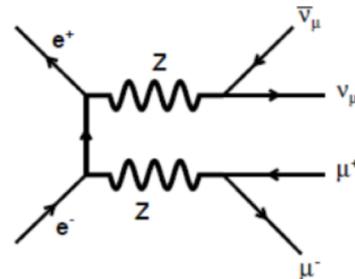
- Higgs backgrounds due to  $ZH$  processes  $Z(vv)$ ,  $H(\mu\mu)$



- Two fermions



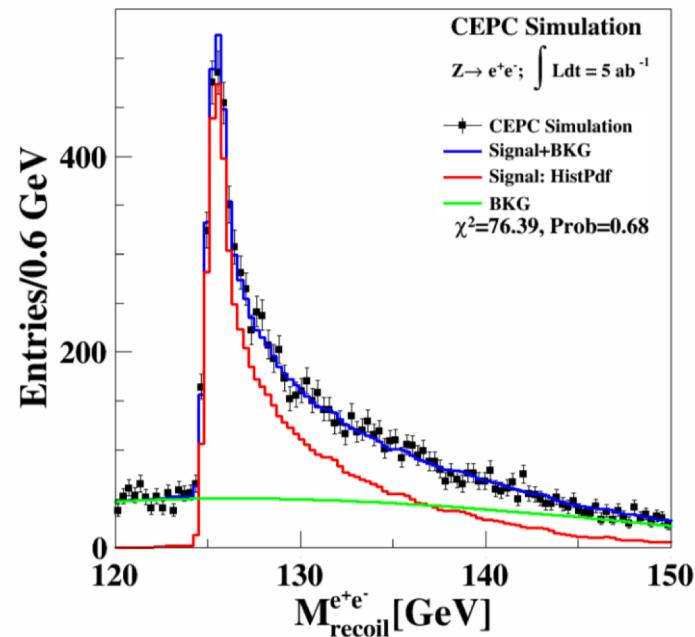
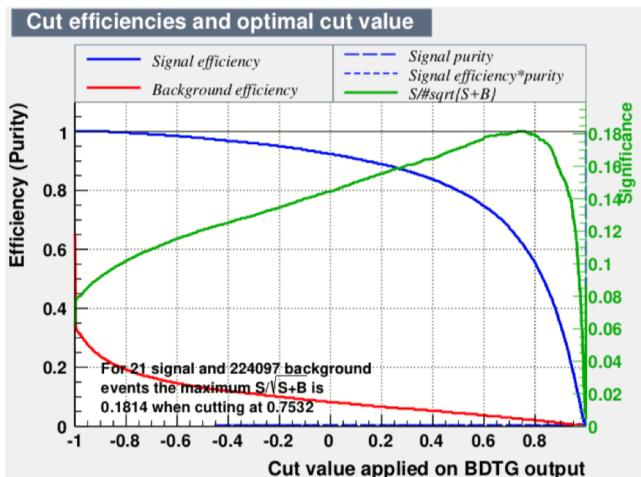
- Four fermions



# Efficiencies in $Z(e^+e^-)$ channel

	Signal	$VV$	$SV$	$Z(2f)$	$Z(e^+e^-)H$
total generated	100000	68484064	26534108	423674068	100000
$2 \leq N_e \leq 3, N_{ch} \leq 3$	74.5%	0.05%	11.0%	17.3%	0.57%
$N_\gamma \leq 1$	68.2%	0.05%	10.2%	11.7%	0.13%
$10\text{GeV} < P_t^{e^+e^-} < 70\text{GeV}$	66.4%	0.04%	6.91%	6.61%	0.12%
$ P_z^{e^+e^-}  < 60\text{GeV}$	65.4%	0.04%	5.03%	2.97%	0.12%
$ \cos\theta_{e^+e^-}  < 0.8$	64.9%	0.03%	4.24%	2.89%	0.11%
90GeV; Visible Energy; 120GeV	63.9%	0.00%	0.62%	0.04%	0.02%
$70\text{GeV} < M_{e^+e^-} < 100\text{GeV}$	56.4%	0.00%	0.42%	0.03%	0.01%
BDT cut	34.5%	0.00%	0.02%	0.00%	0.01%
fit window	34.2%	0.00%	0.01%	0.00%	0.01%

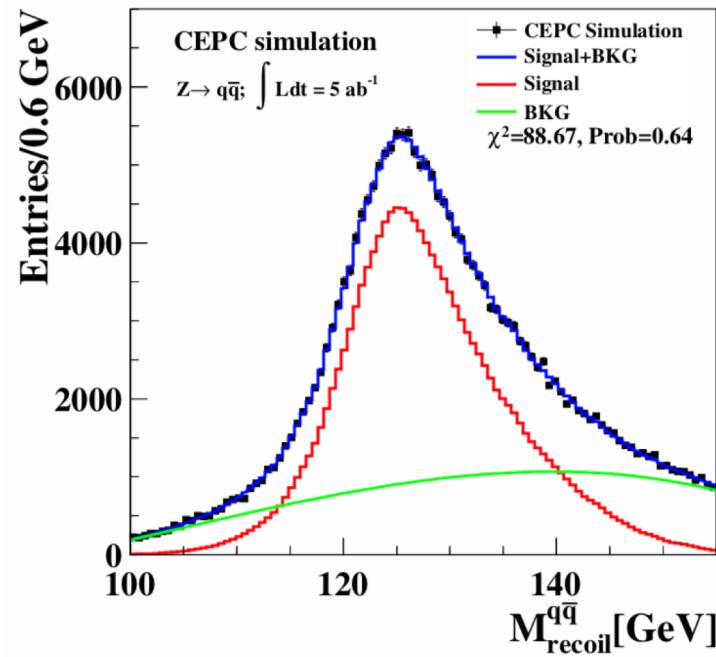
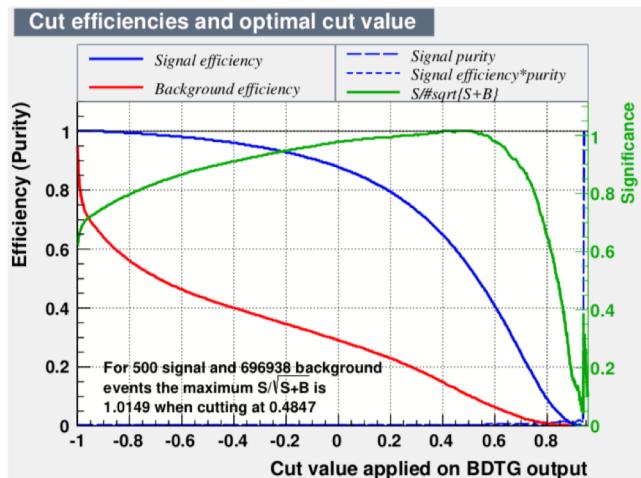
- Eff ~ 34%



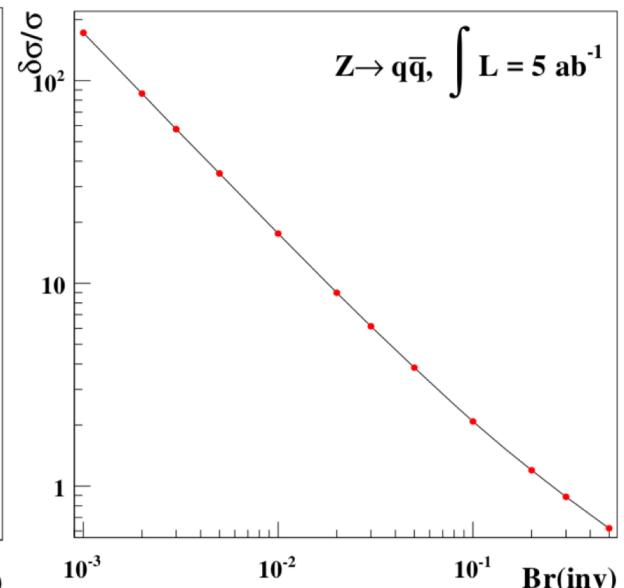
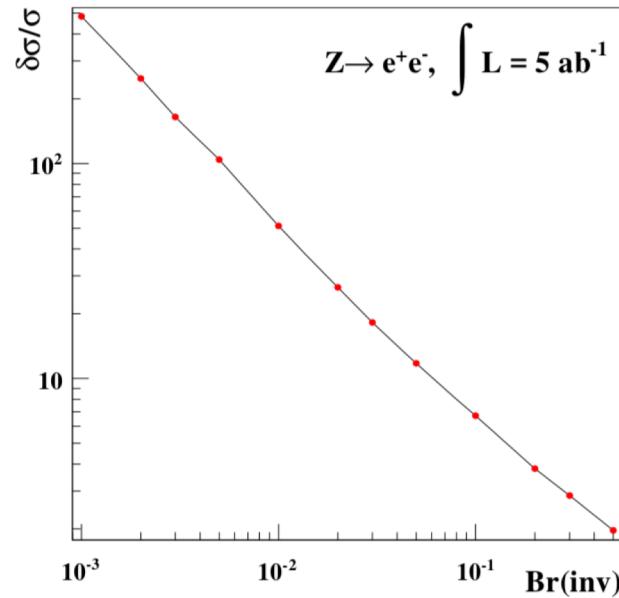
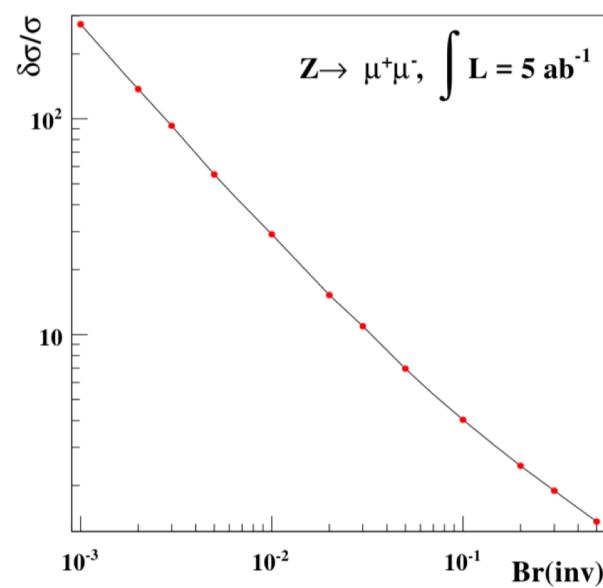
# Efficiencies in Z(qq) channel

	Signal	VV	SV	Z(2f)	Z( $q\bar{q}$ )H
total generated	723755	68484064	26534108	423674068	723755
$N_{Lep} \leq 1, N_{trks} \leq 40, 10 < N_{clus} < 90$	95.9%	59.5%	42.7%	45.7%	26.0%
$20\text{GeV} < P_t^{q\bar{q}} < 70\text{GeV}$	88.2%	20.6%	29.6%	0.55%	10.6%
$ P_z^{q\bar{q}}  < 70\text{GeV}$	88.0%	18.2%	26.7%	0.48%	10.6%
$-0.9 < \cos\theta_{q\bar{q}} < -0.2$	78.4%	9.67%	14.7%	0.06%	5.55%
$90\text{GeV} < VisibleEnergy < 130\text{GeV}$	75.4%	0.98%	1.21%	0.01%	0.49%
$80\text{GeV} < M_{q\bar{q}} < 105\text{GeV}$	69.2%	0.66%	0.87%	0.00%	0.15%
BDT cut	38.4%	0.06%	0.14%	0.00%	0.05%
fit window	38.1%	0.06%	0.13%	0.00%	0.05%

- Eff ~ 38%



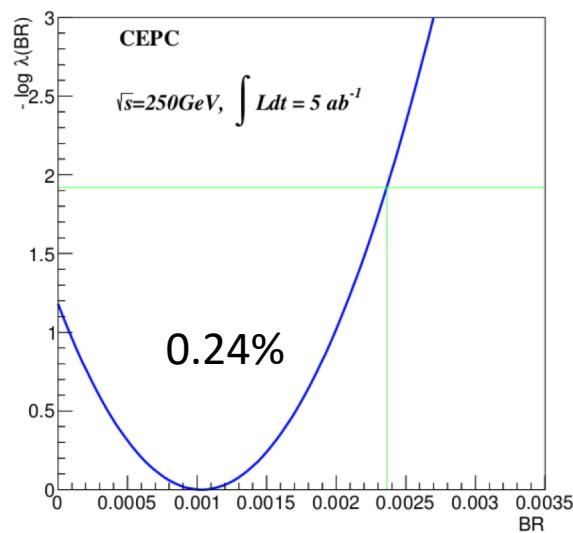
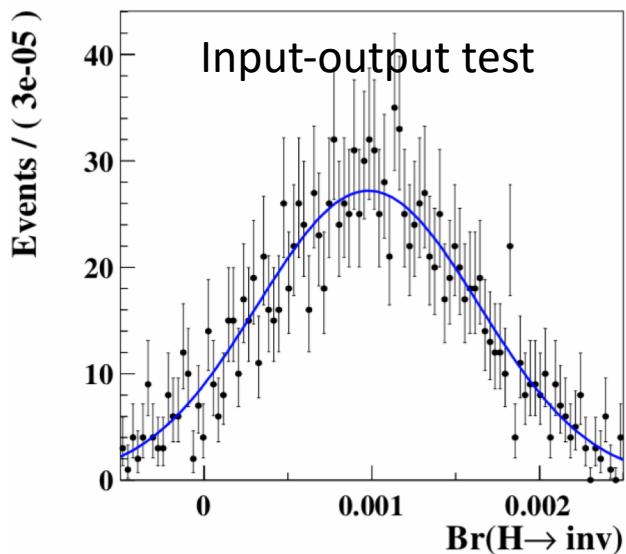
# Cross-sections



The precision of the cross sections of Higgs decaying to invisible final states

# Combination of the results from all channels

- The simultaneous fit is adopted to measure the branching ratio, which is defined as the ratio of the signal yield to the SM production assuming  $\text{BR}(\text{H} \rightarrow \text{inv}) = 100\%$ .



	$Z(e^+e^-)H(\text{inv})$	$Z(\mu^+\mu^-)H(\text{inv})$	$Z(q\bar{q})H(\text{inv})$	Combined
Br	$0.35 \pm 0.510\%$	$0.350\% \pm 0.290\%$	$0.094\% \pm 0.150\%$	$0.103\% \pm 0.075\%$
95% CL upper limit	1.30%	0.90%	0.37%	0.24%

# Current status

- New analysis team formed
- Cross-check the 3.5T results
- Update with CEPC\_v4 (240GeV, 3.0T)
- Input for CDR

# Summary and outlook

- Higgs invisible decay is important for new physics BSM especially on CEPC
- Three channels has been done with CEPC\_v1 (250GeV, 3.5T)  $Z(ee, \mu\mu, qq)H(inv)$   
UL  $\sim 0.24\%$  for combined results
- New team will update with CEPC\_v4(240GeV, 3.0T) configuration for CDR.