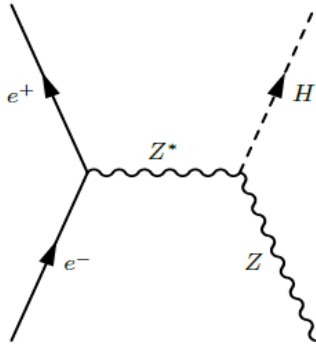


Higgs invisible decay

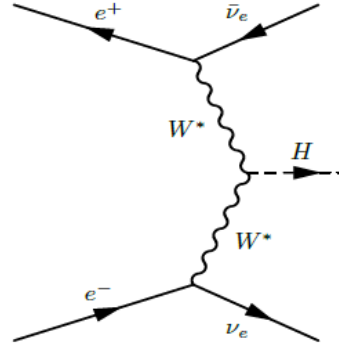
Chen Zhenxing (PKU & IHEP)
Mo Xin(IHEP)

Introduction

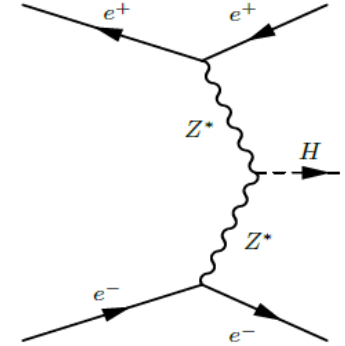
- The Higgs bosons are produced via Higgsstrahlung(ZH), WW fusion and ZZ fusion at CEPC



ZH



WW fusion



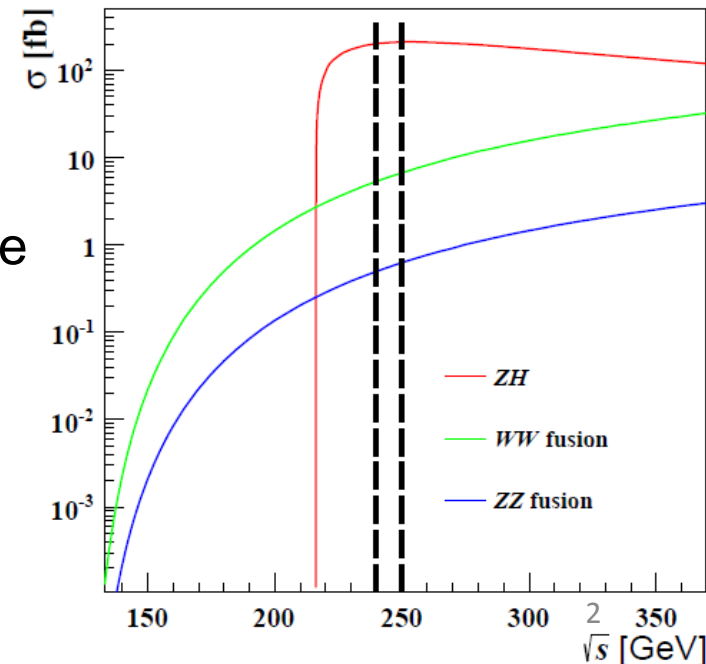
ZZ fusion

- ZH is the dominant Higgs production process
- By tagging the products of Z boson decay, the Higgs candidate can be reconstructed via

$$m_{\text{rec}}^2 = (\sqrt{s} - E_{\ell\ell})^2 - \mathbf{p}_{\ell\ell}^2 = s - 2\sqrt{s}E_{\ell\ell} + E_{\ell\ell}^2 - \mathbf{p}_{\ell\ell}^2$$

$$= s - 2\sqrt{s}(E_{\ell 1} + E_{\ell 2}) + m_{\ell\ell}^2,$$

Inclusive measurement !



Introduction

- In SM, the Higgs has a chance of 1.06×10^{-3} decaying to invisible products
- Many new physics models predict a significant branching ratio of Higgs to invisible
- LHC set an upper limit of 40%
- Higgs invisible decay is a sensitive probe for new physics
- A precise measurement is expected at an e^+e^- collider, the measurement potential of CEPC on Higgs invisible decay is studied

Samples

Central of mass energy: 250 GeV

Beam energy spread: 0.16%

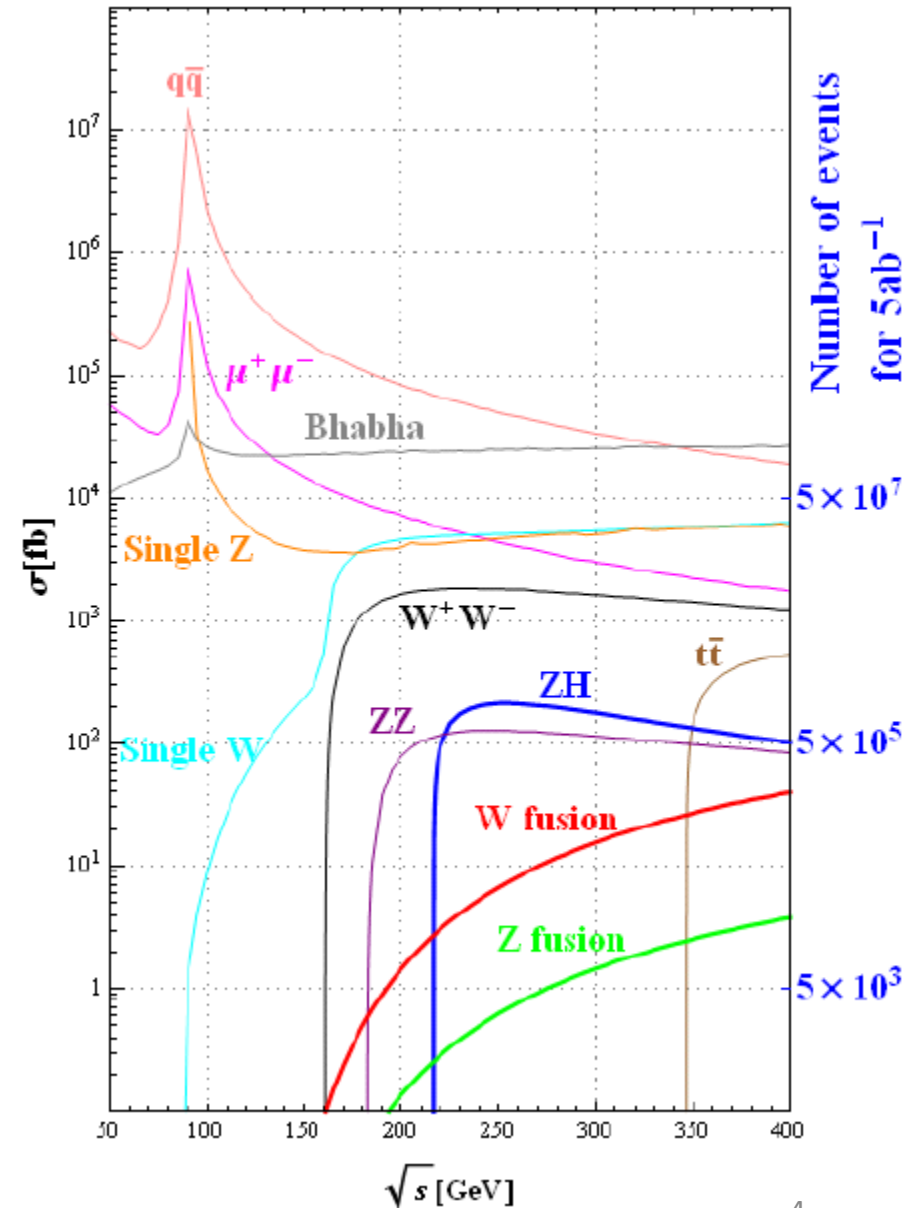
No polarized

Signal: full simulated with Arbor v3_1

Higgs mass: 125 GeV

SM background: fast simulated, with momentum resolution and detection efficiency parameterized for different particle types

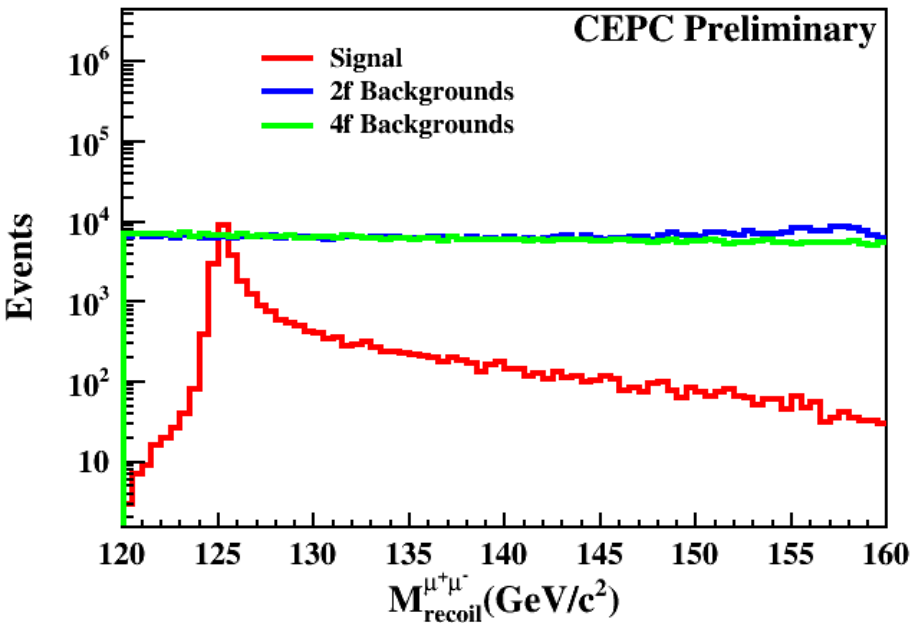
Luminosity: 5 ab^{-1}



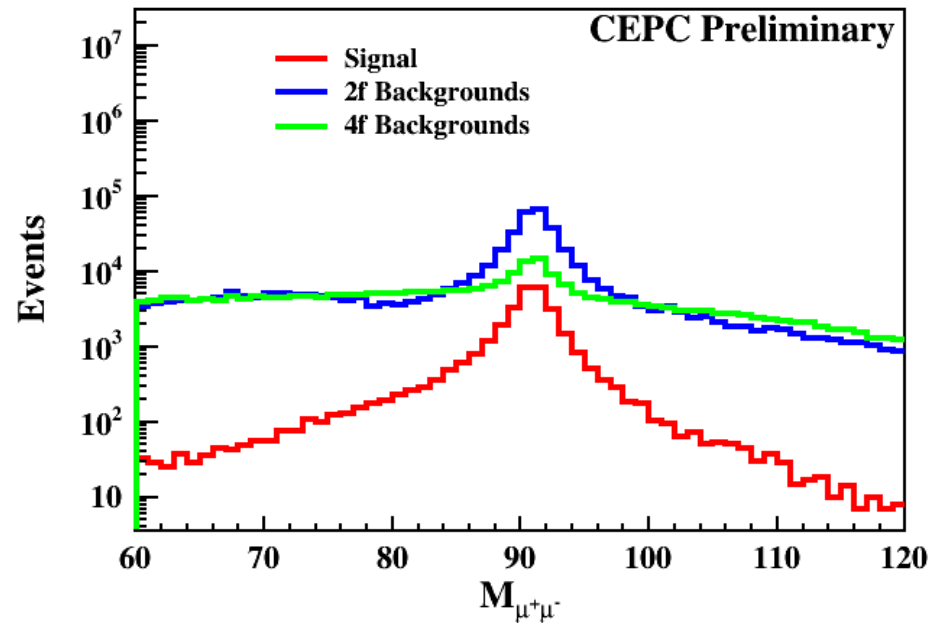
Analysis of $Z \rightarrow \mu^+ \mu^-$

Measurement via $Z \rightarrow \mu^+ \mu^-$

- (1) At least one pair of $\mu^+ \mu^-$ is reconstructed.
- (2) Recoiling mass of $\mu^+ \mu^-$: $120 \text{ GeV} < M_{\mu^+ \mu^-}^{\text{reco}} < 150 \text{ GeV}$
- (3) Invariant mass of $\mu^+ \mu^-$: $80 \text{ GeV} < M_{\mu^+ \mu^-} < 100 \text{ GeV}$



Based on (1)

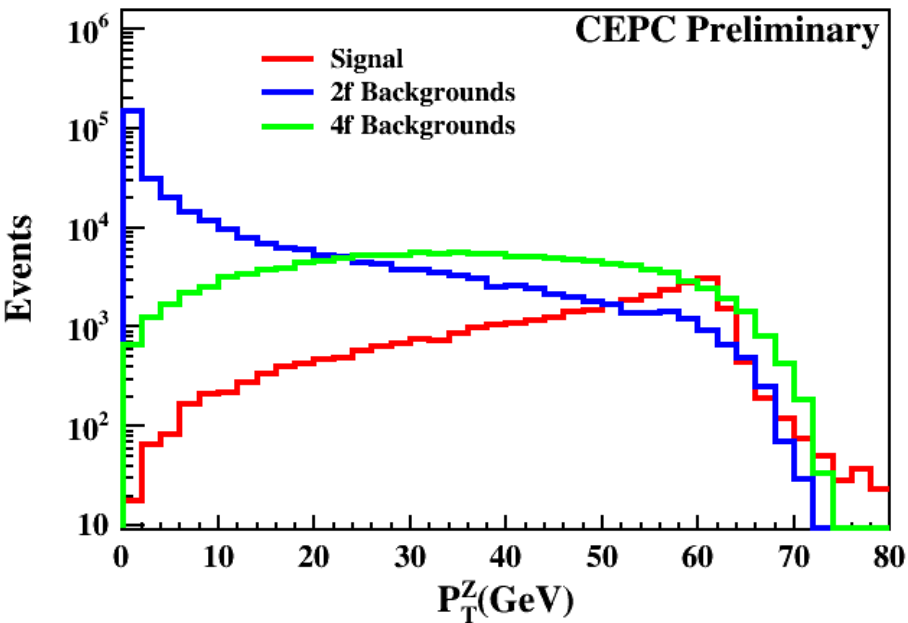


Based on (1)(2)

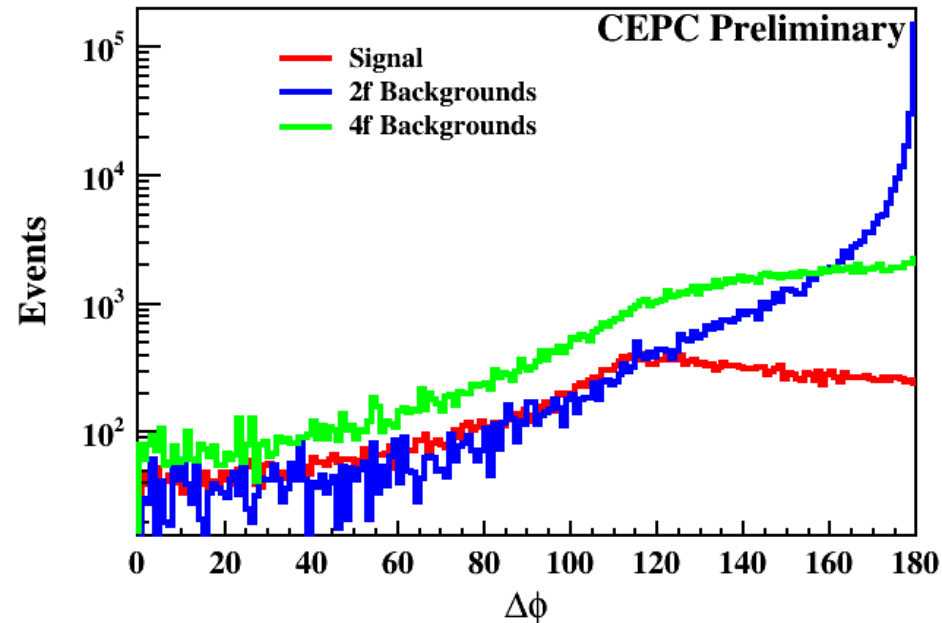
Measurement via $Z \rightarrow \mu^+ \mu^-$

(4) Transverse momentum of Z boson candidate: $P_T^Z > 20$ GeV

(5) The azimuthal angle difference between μ^+ and μ^- : $\Delta\phi < 175^\circ$



Based on (1)(2)(3)



Based on (1)(2)(3)(4)

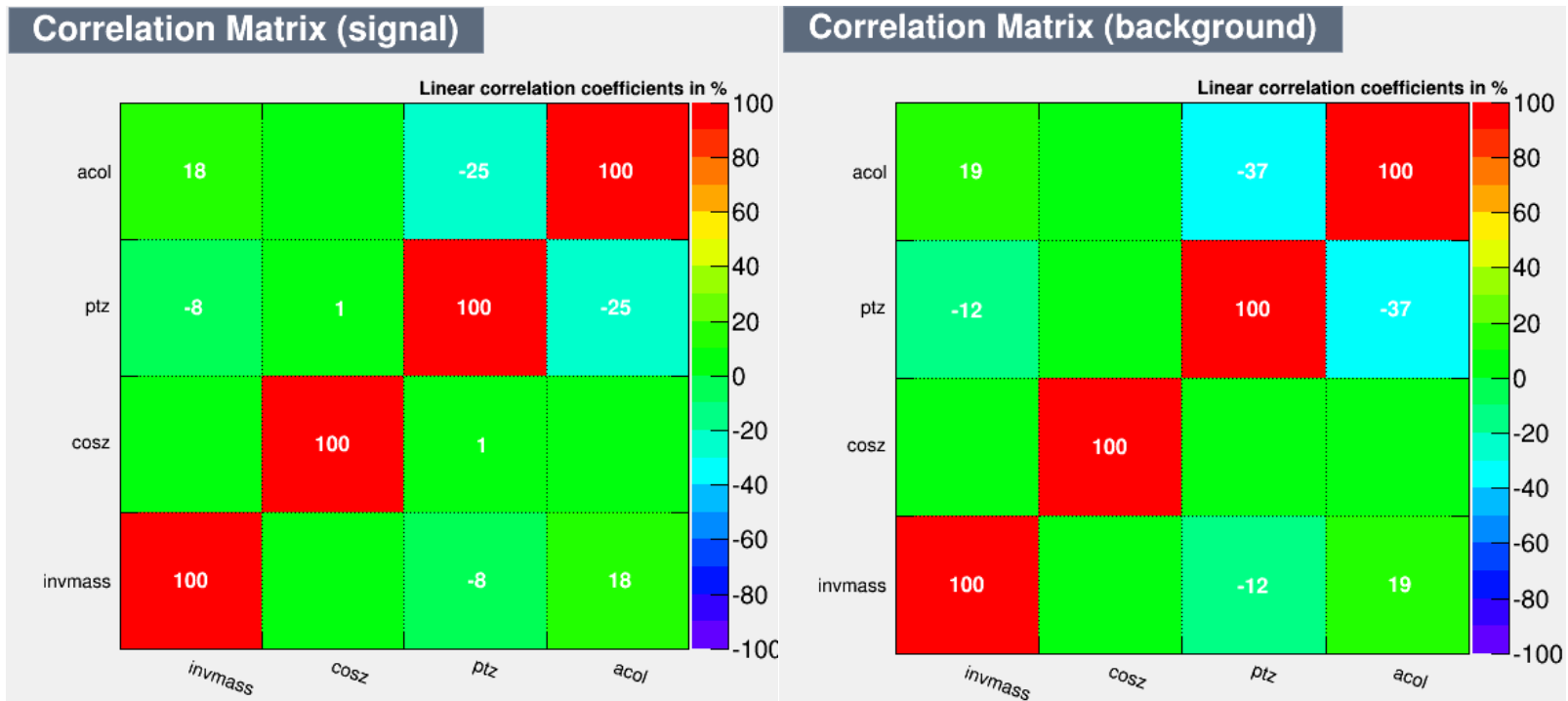
Measurement via $Z \rightarrow \mu^+ \mu^-$

MVA:

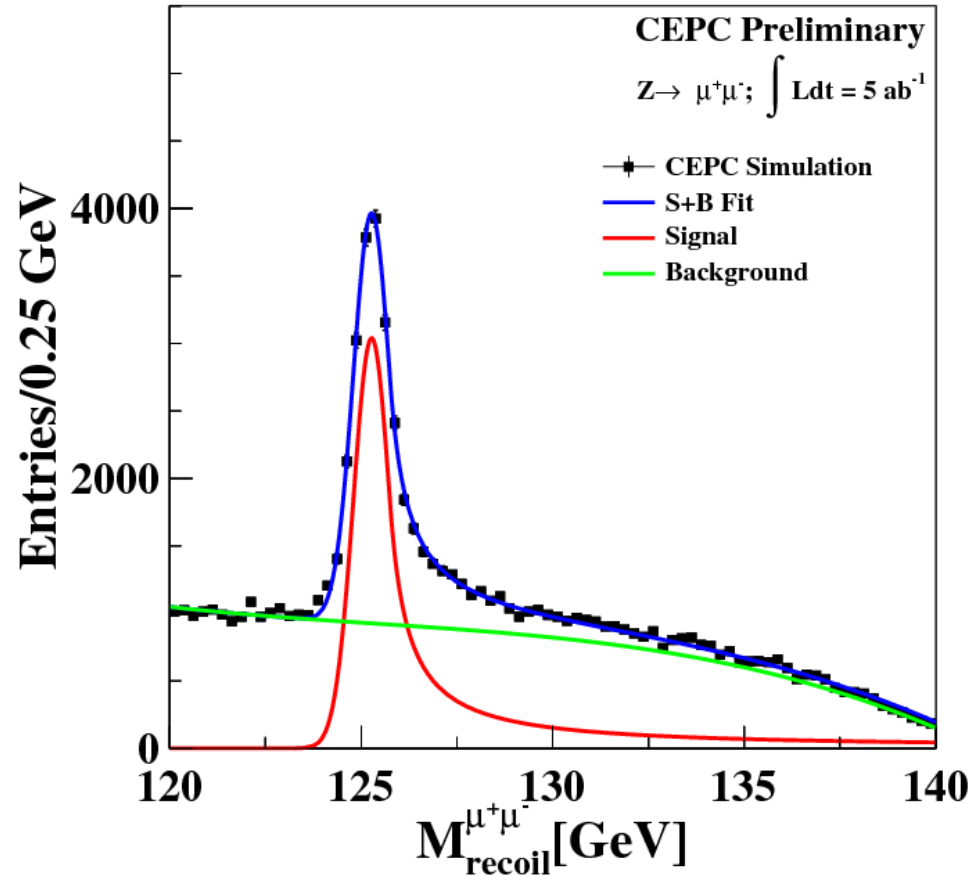
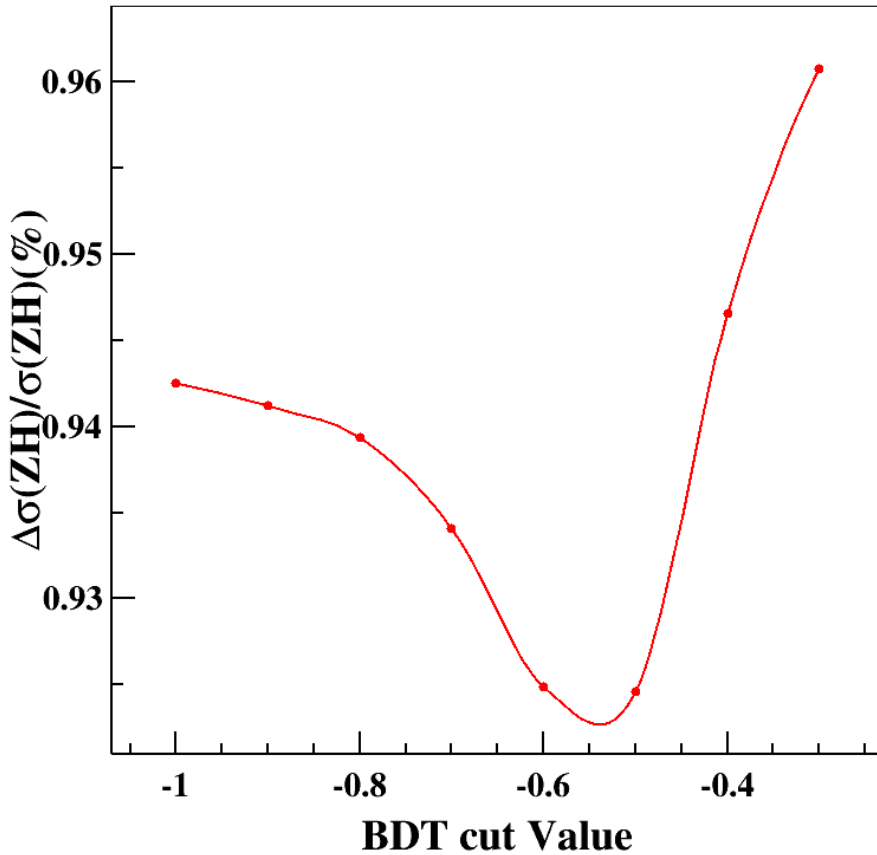
Inputs: $M_{\mu^+ \mu^-}$
 P_T^Z

$\cos \theta_Z$ (θ_Z is the polar angle of Z boson candidate)

acollinearity (the angle between μ^+ and μ^-)



Measurement via $Z \rightarrow \mu^+ \mu^-$



Signal: Crystal Ball Background: shape extracted from MC sample
BDT optimized according to the ZH cross section precision
Cross section precision: 0.92%
Higgs mass precision: 6.52 MeV

Cut flow

	ZH	ZZ	WW	ZZorWW	Single Z	Z(2f)
Total	35247	5347053	44180832	17801222	7809747	418595861
$N_{\mu^+} \geq 1, N_{\mu^-} \geq 1$	95.73%	11.95%	0.65%	3.92%	9.75%	1.64%
$120\text{GeV}/c^2 < M_{\text{rec}} < 150\text{GeV}/c^2$	93.19%	1.71%	0.23%	0.70%	1.93%	0.17%
$80\text{GeV}/c^2 < M_{\mu^+\mu^-} < 100\text{GeV}/c^2$	85.47%	0.68%	0.06%	0.22%	0.22%	0.10%
$P_{\text{TZ}} > 20\text{GeV}/c$	80.22%	0.57%	0.06%	0.17%	0.16%	0.02%
$ \phi_{\mu^+} - \phi_{\mu^-} < 175$	77.76%	0.51%	0.05%	0.17%	0.15%	0.01%
BDT cut	65.48%	0.26%	0.01%	0.05%	0.06%	0.01%
$120\text{GeV}/c^2 < M_{\text{rec}} < 140\text{GeV}/c^2$	65.33%	0.26%	0.01%	0.05%	0.06%	0.01%

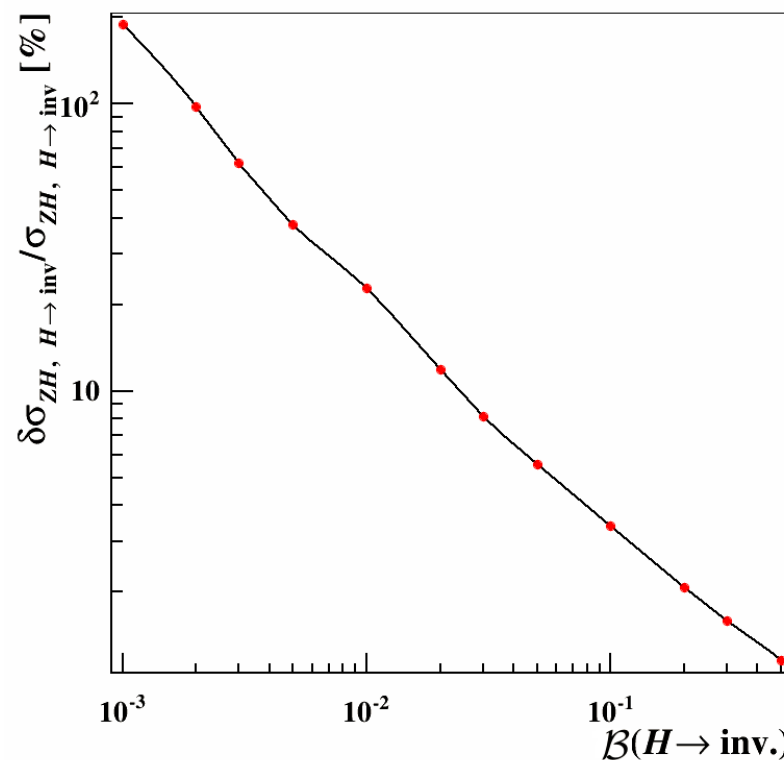
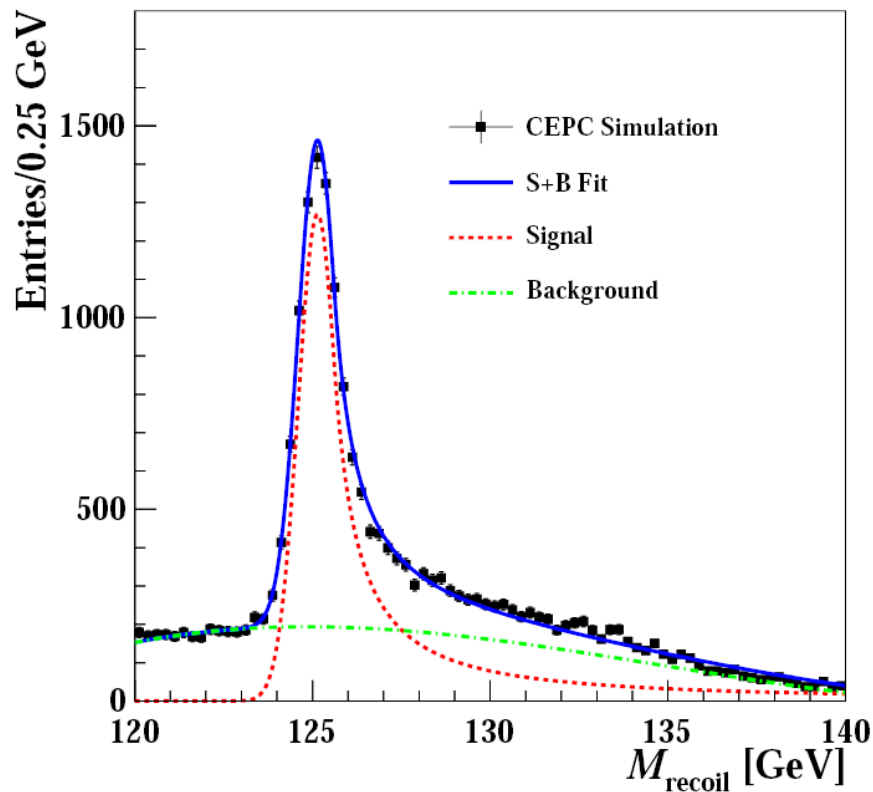
The main remaining backgrounds are Z(2f)

Higgs invisible decay

Extra criteria: Only two charged tracks and no isolated photon

The cross section of SM ZH is fixed
Varied fractions of Higgs invisible decay are combined with the SM sample

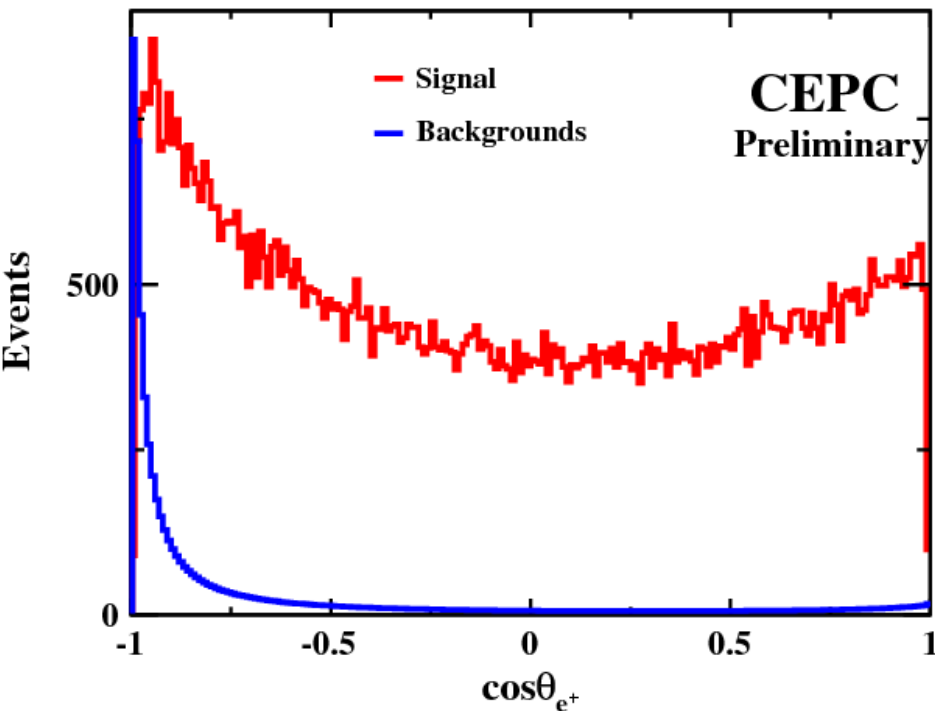
$\text{Br}(H \rightarrow \text{inv}) = 50\%$: 1.16%



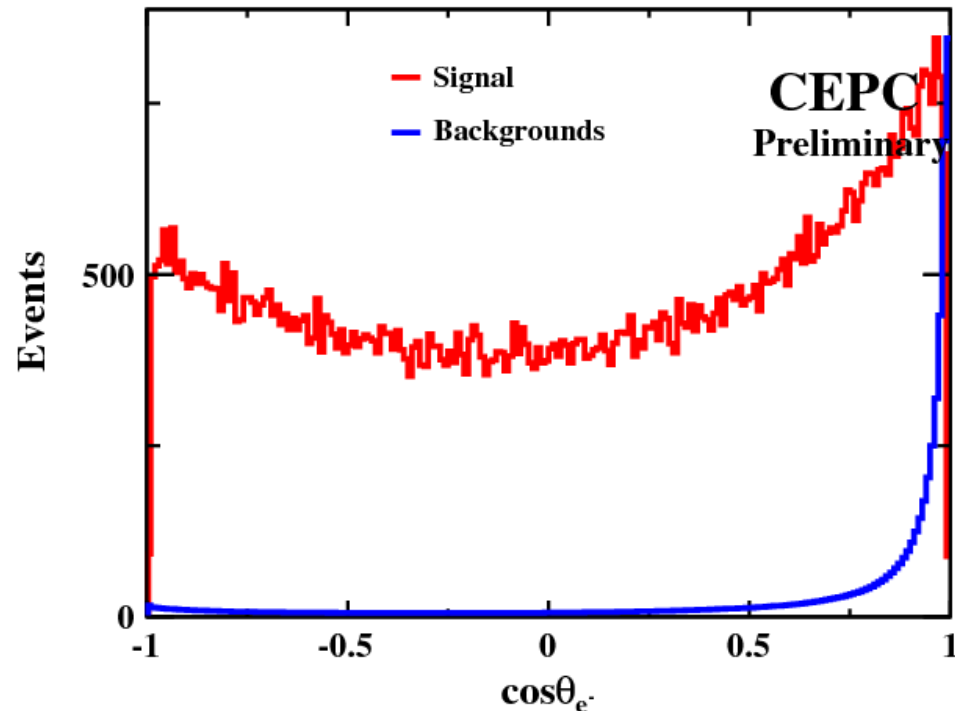
Analysis of $Z \rightarrow e^+e^-$

Measurement via $Z \rightarrow e^+e^-$

- (1) At least one pair of e^+e^- is reconstructed.
- (2) Large background from Bhabha. Polar angle of electron and positron:
 $\cos\theta_{e^+} > -0.9$ $\cos\theta_{e^-} < 0.9$



Based on (1)



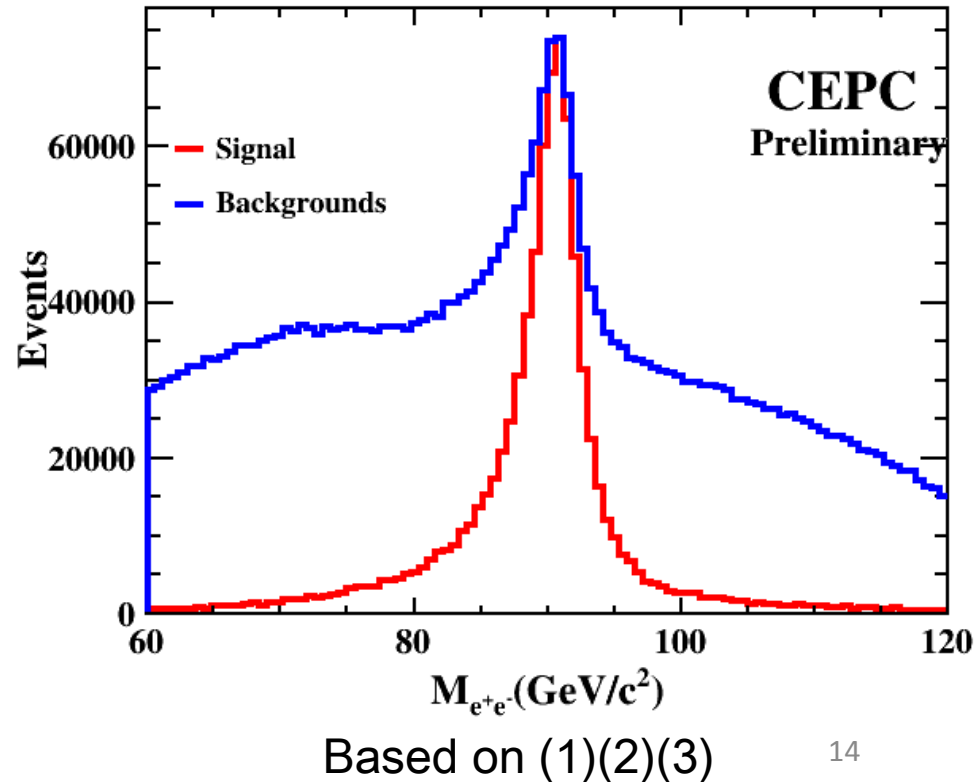
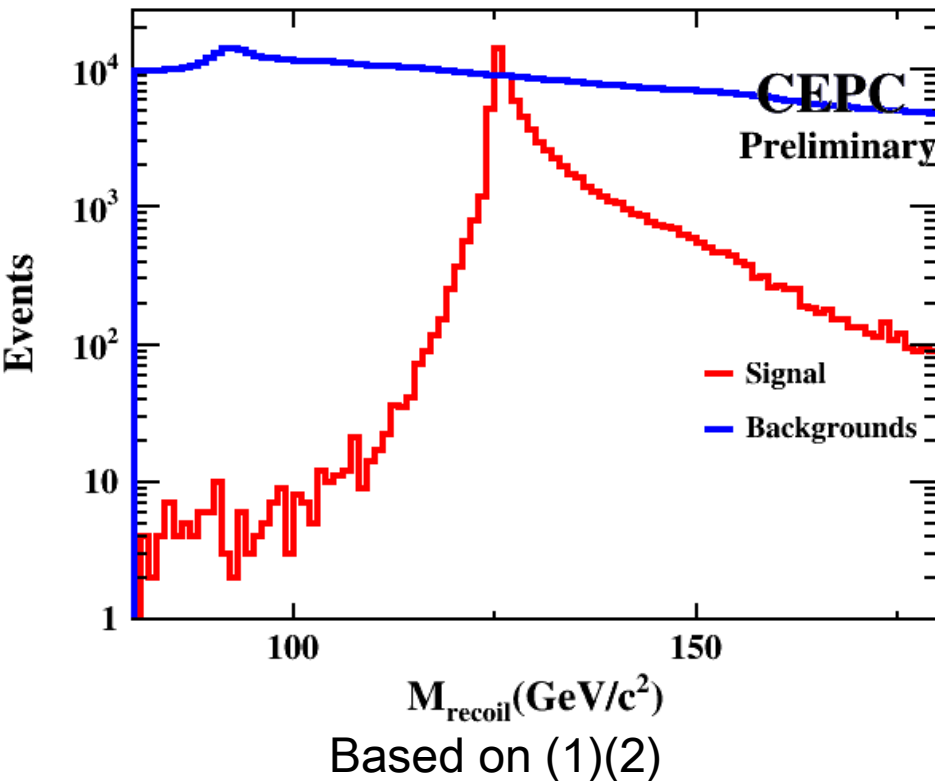
Based on (1)

Measurement via $Z \rightarrow e^+e^-$

(3) Recoiling mass of e^+e^- : $120 \text{ GeV} < M_{e^+e^-}^{\text{reco}} < 160 \text{ GeV}$

(4) Invariant mass of e^+e^- : $80 \text{ GeV} < M_{e^+e^-} < 100 \text{ GeV}$

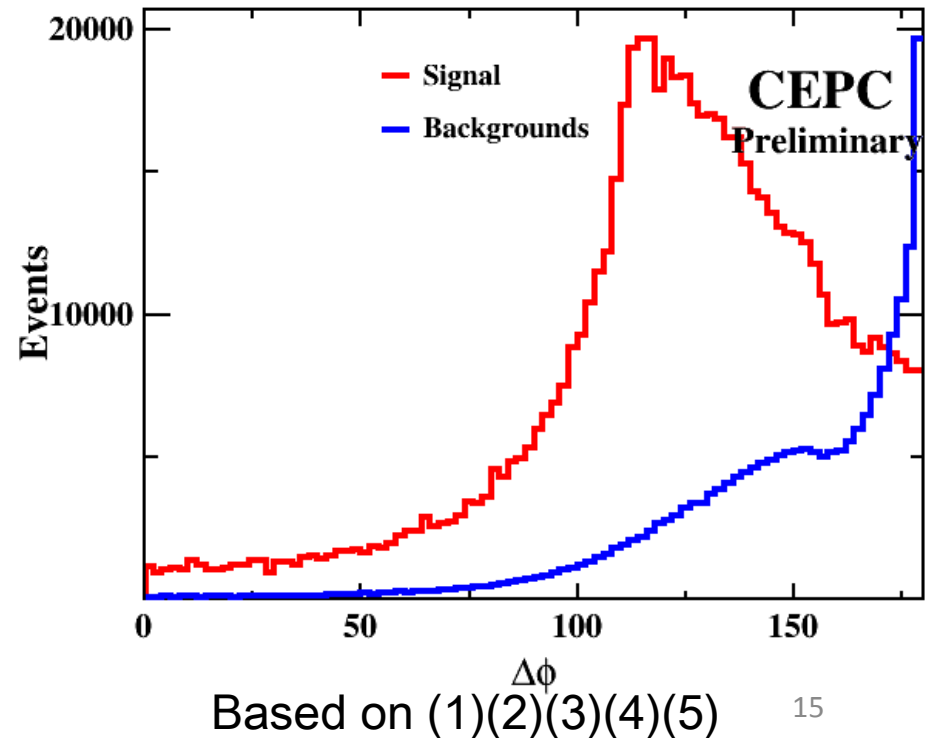
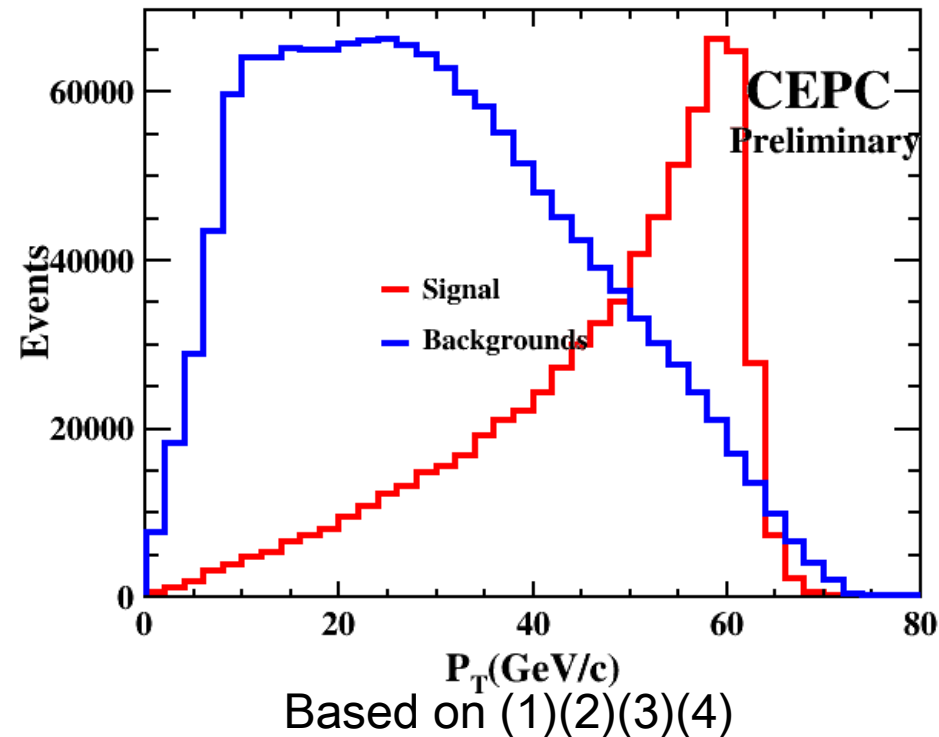
Bremstrahlung recovery: the momentum of photon close to the electron or positron in Z candidate is added



Measurement via $Z \rightarrow e^+e^-$

(5) Transverse momentum of Z boson candidate: $P_T^Z > 20$ GeV

(6) The azimuthal angle difference between e^+ and e^- : $\Delta\phi < 175^\circ$



Measurement via $Z \rightarrow e^+e^-$

MVA:

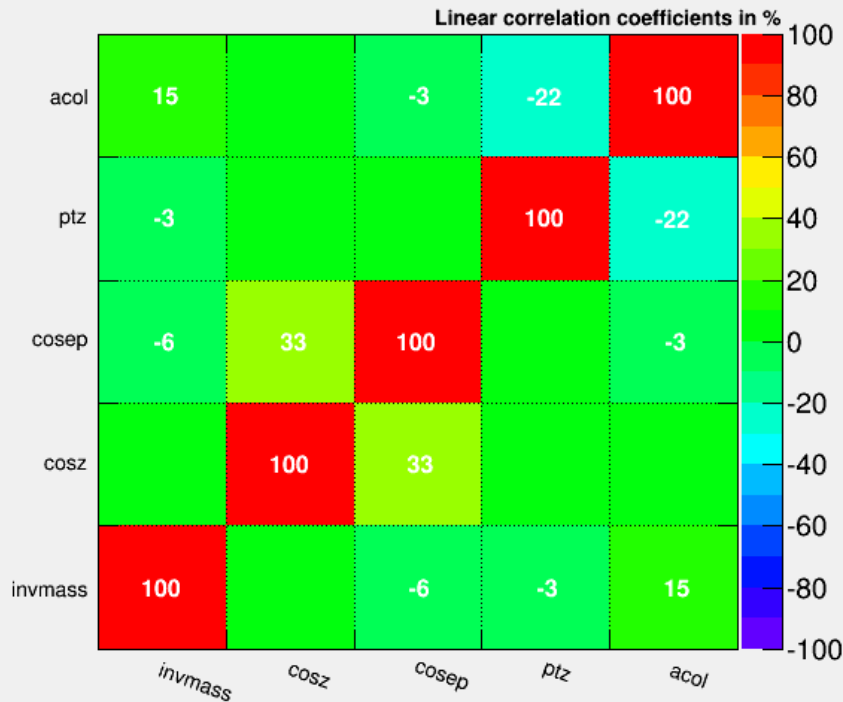
Inputs: $M_{e^+e^-}$
 P_T^Z

$\cos \theta_Z$ (θ_Z is the polar angle of Z boson candidate)

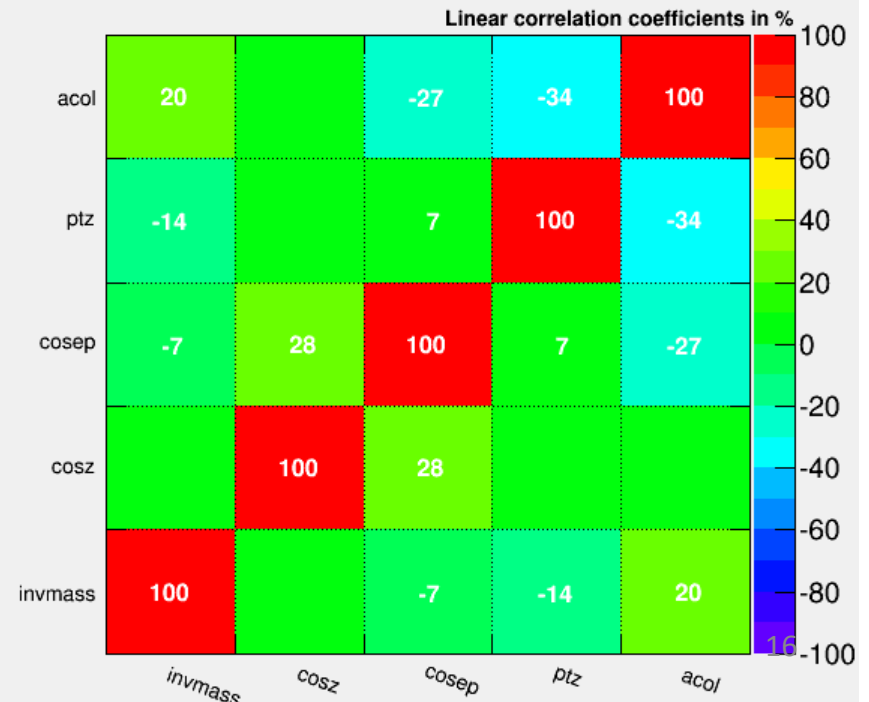
$\cos \theta_{e^+}$ (θ_{e^+} is the polar angle of positron)

acollinearity (the angle between e^+ and e^-)

Correlation Matrix (signal)



Correlation Matrix (background)



Cut flow

	ZH	ZZ	WW	ZZorWW	Z	W	ZorW	Z(2f)
total	35247	5436373	44181064	17799208	7808854	17020374	1246802	418598154
$N_{e^+} \geq 1, N_{e^-} \geq 1$ $\cos\theta_{e^+} > -0.9, \cos\theta_{e^-} < 0.9$	28010	13615	16266	20105	574212	222811	626516	6594087
$120\text{GeV}/c^2 < M_{\text{rec}} < 160\text{GeV}/c^2$	26437	903	1428	3667	122997	82943	156757	1204575
$80\text{GeV}/c^2 < M_{e^+e^-} < 100\text{GeV}/c^2$	22958	118	220	1497	45438	25050	53851	414026
$P_{TZ} > 20\text{GeV}/c$	21574	85	166	1056	36414	22252	43108	263375
$ \varphi_{e^+} - \varphi_{e^-} < 175$	20908	64	157	986	33909	20613	41468	206862
BDT cut	14614	4	9	68	10961	3512	10085	37160

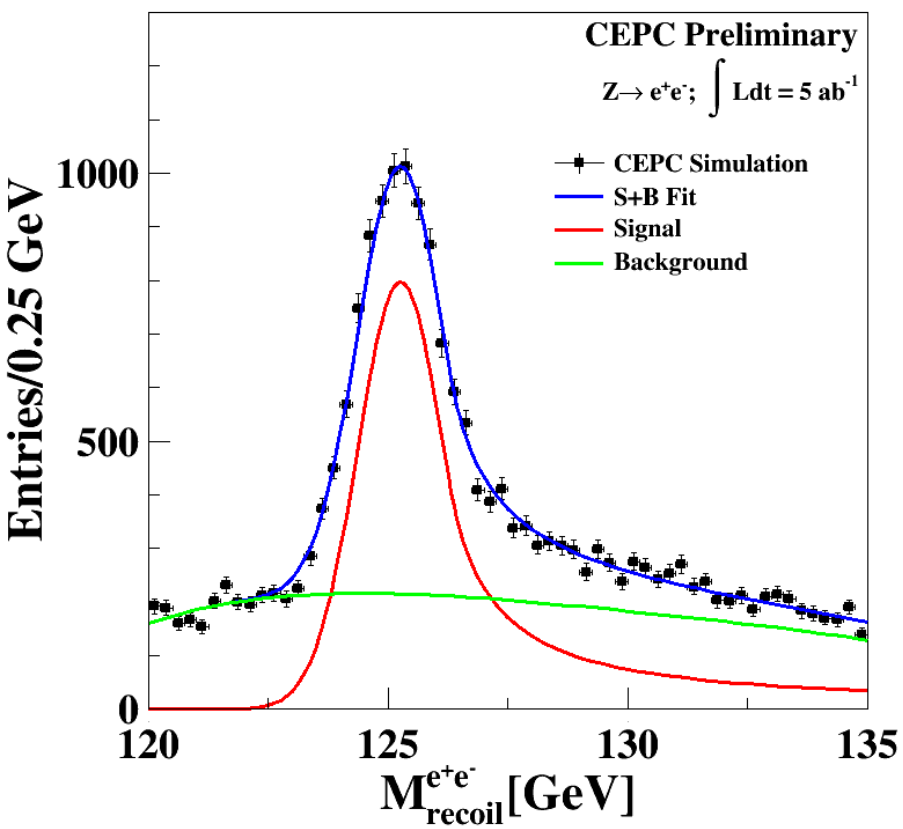
Signal efficiency: 41.46%

The main remaining backgrounds are Z(2f)

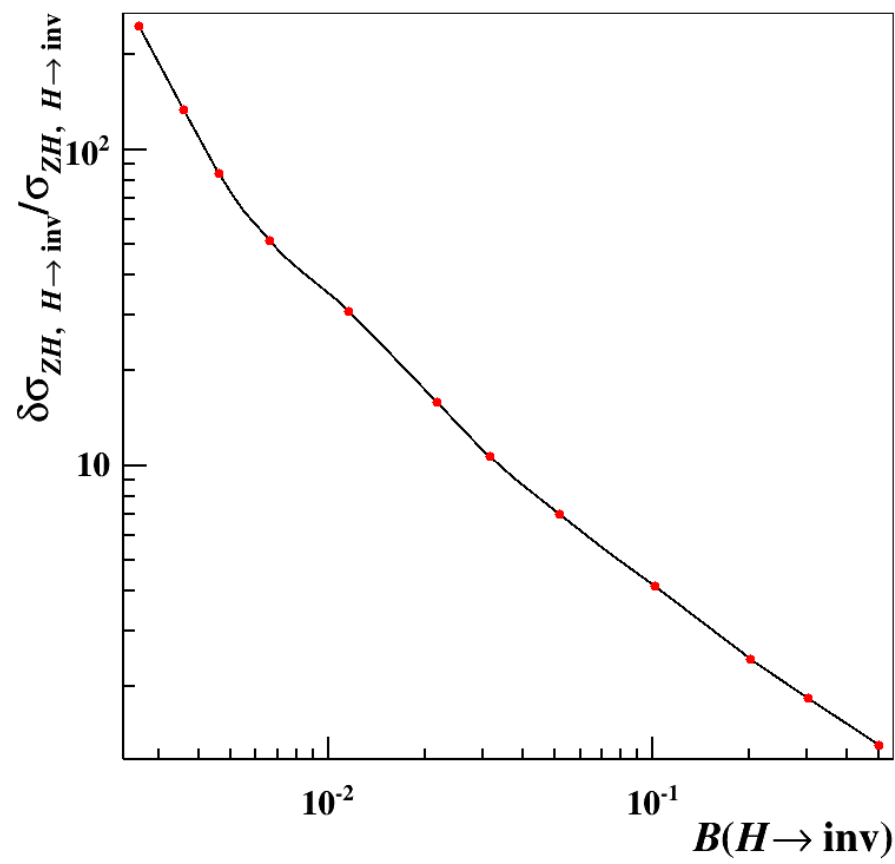
Higgs invisible decay

Extra criteria: Only two charged tracks and no isolated photon

$\text{Br}(H \rightarrow \text{inv}) = 50\%$: 1.31%



The cross section of SM ZH is fixed
Varied fractions of Higgs invisible decay are combined with the SM sample



Analysis of $Z \rightarrow qq$

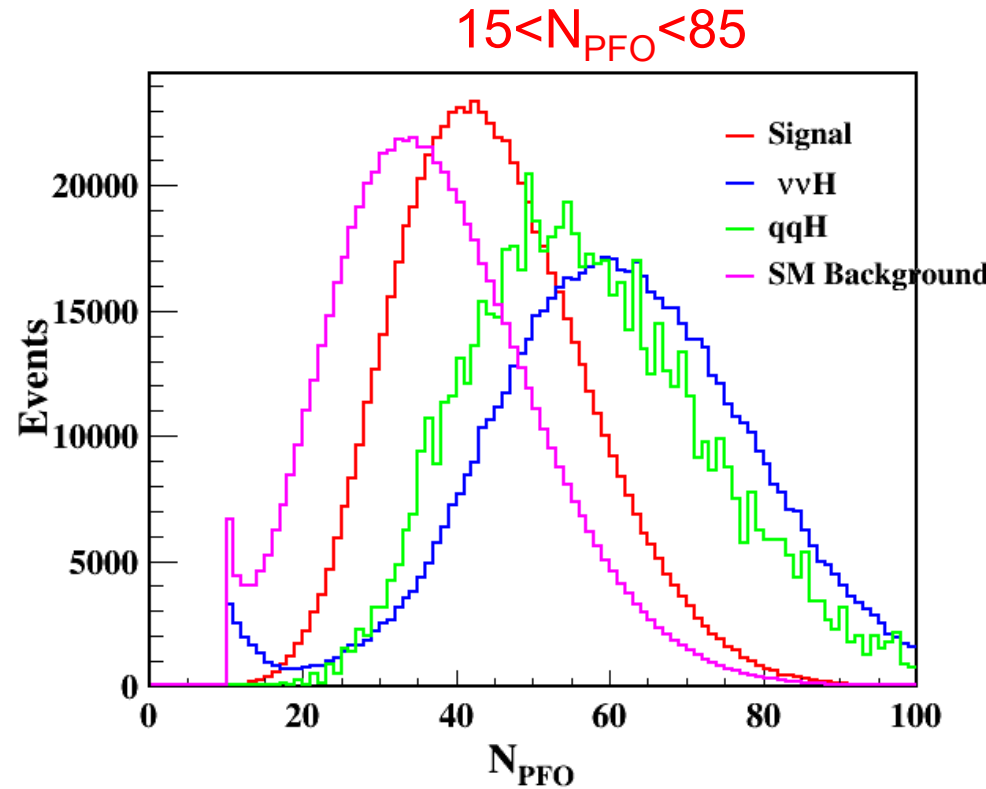
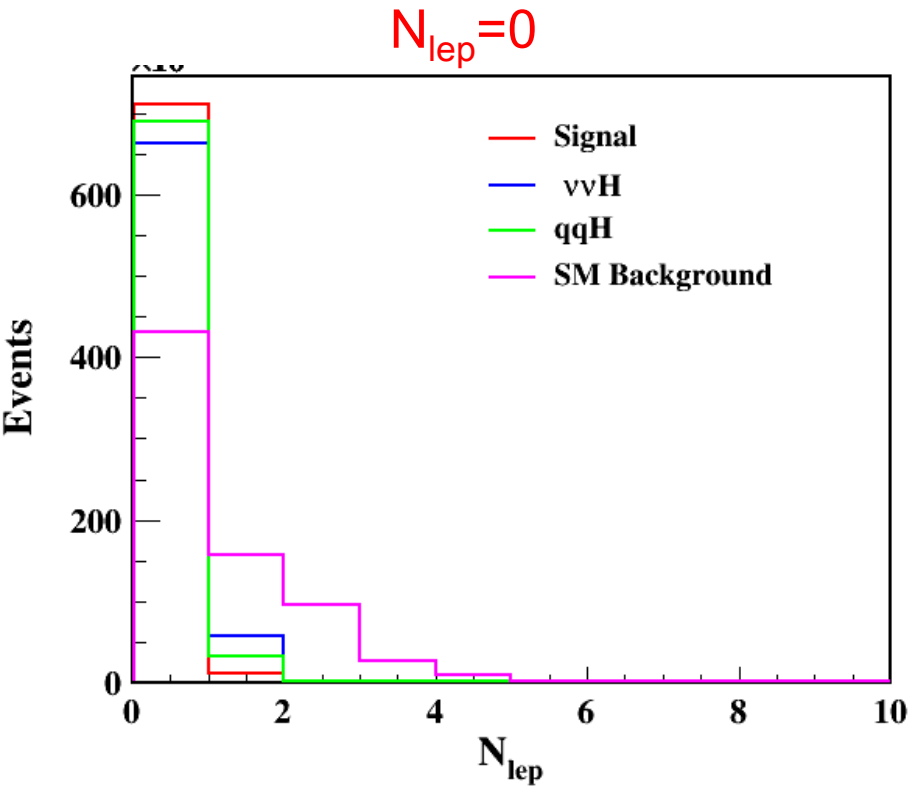
Measurement via $Z \rightarrow qq$

Pre-selection:

Inclusive 2jets

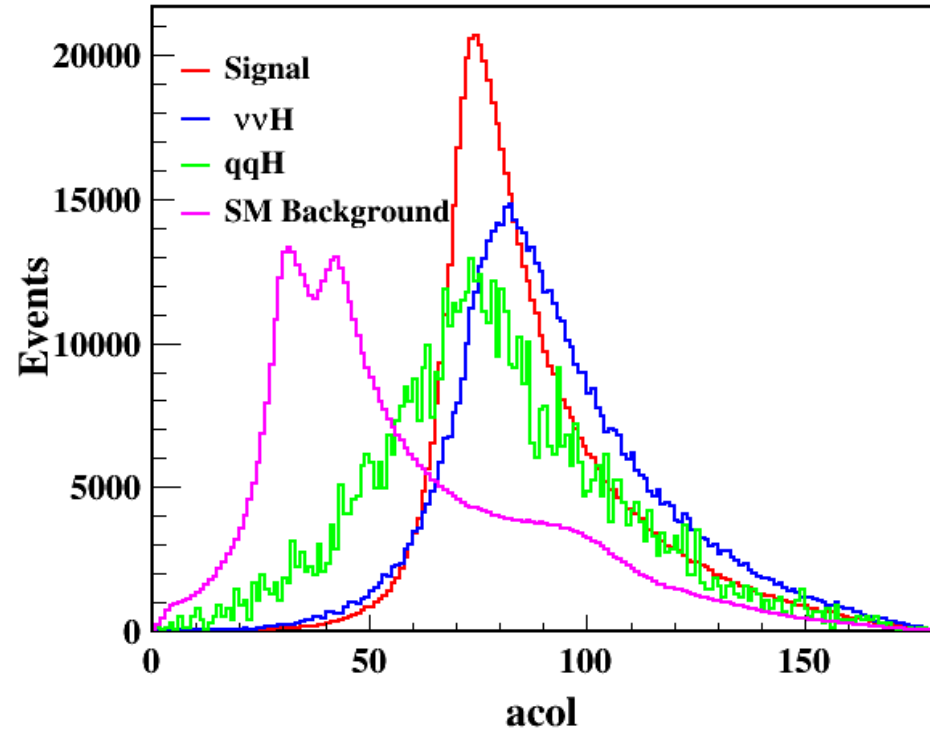
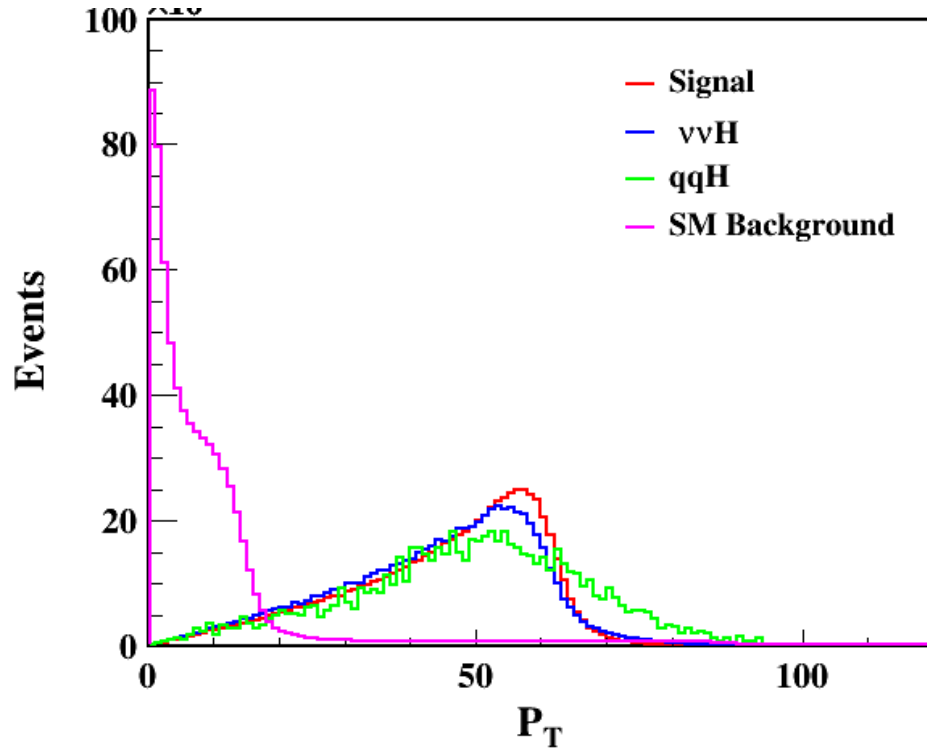
$N_{\text{PFO}} > 10$

$M_{\text{vis}} < 130 \text{ GeV}/c^2$



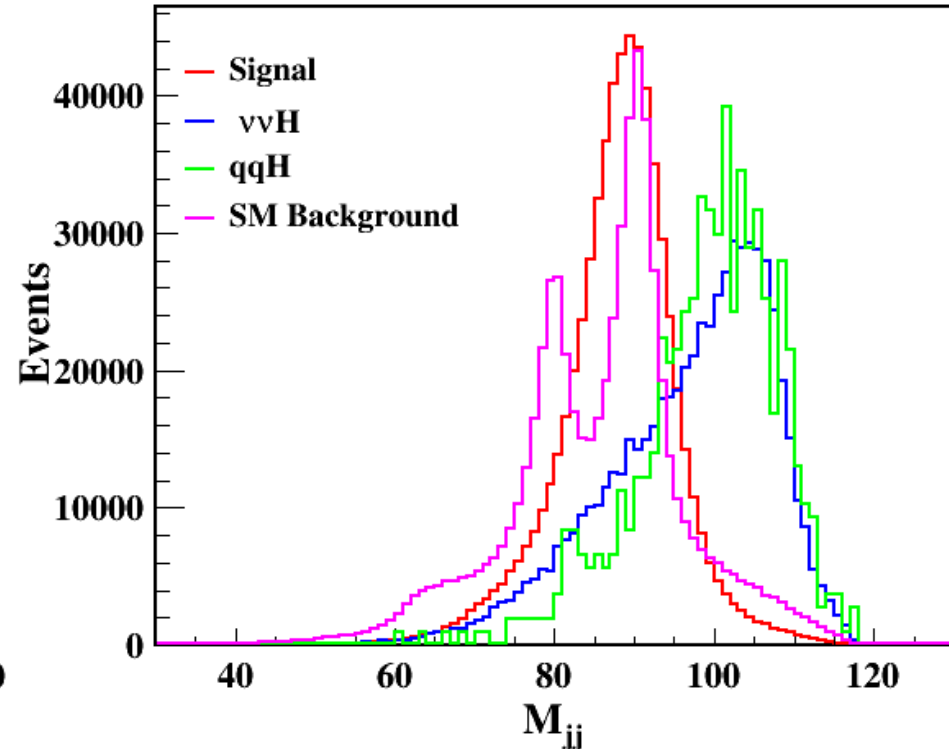
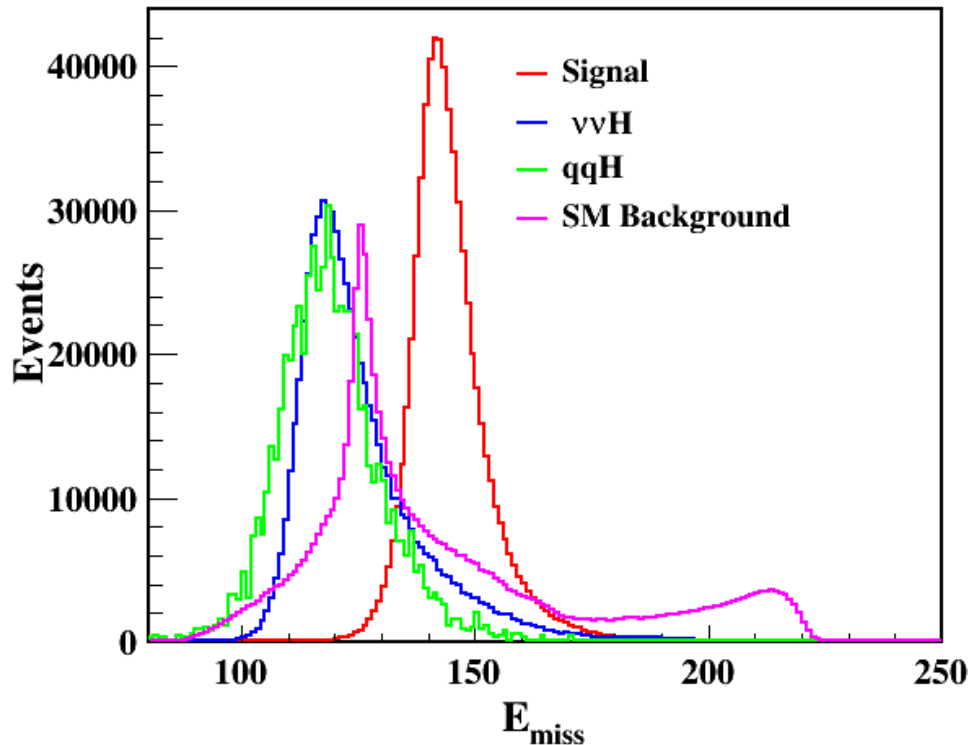
Measurement via $Z \rightarrow qq$

- Transverse momentum of Z boson candidate: $P_T^Z > 20$ GeV
- The angle between two jets: $\text{acol} > 50^\circ$



Measurement via $Z \rightarrow qq$

- Missing energy: $130 \text{ GeV} < E_{\text{miss}} < 170 \text{ GeV}$
- The invariant mass of two jets: $75 \text{ GeV} < M_{jj} < 100 \text{ GeV}$



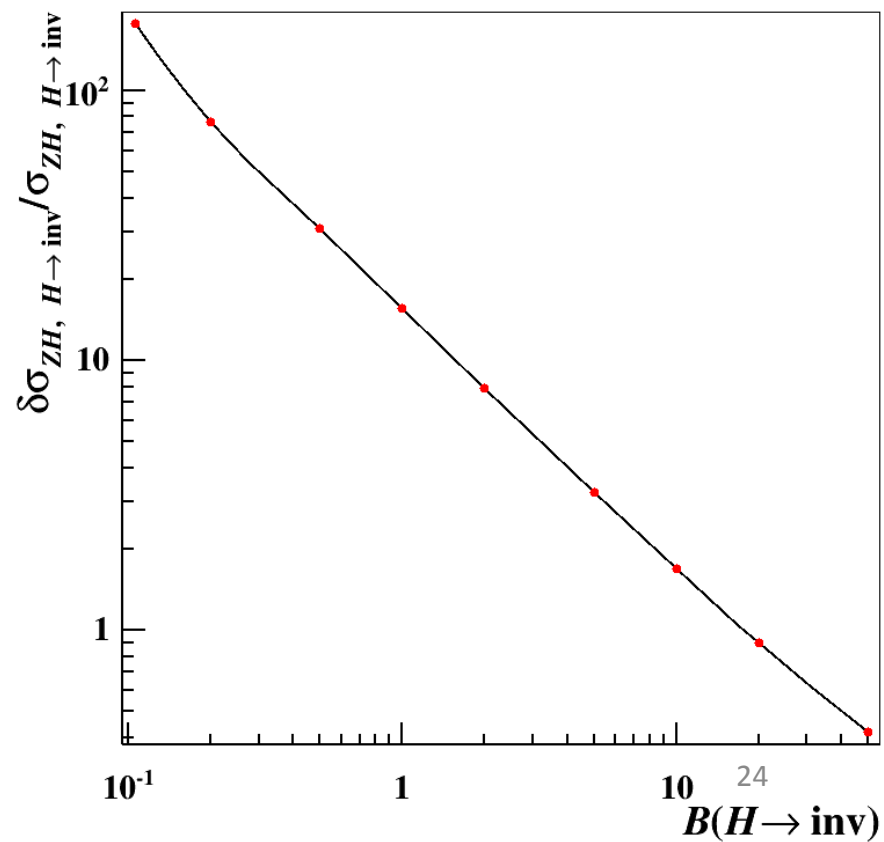
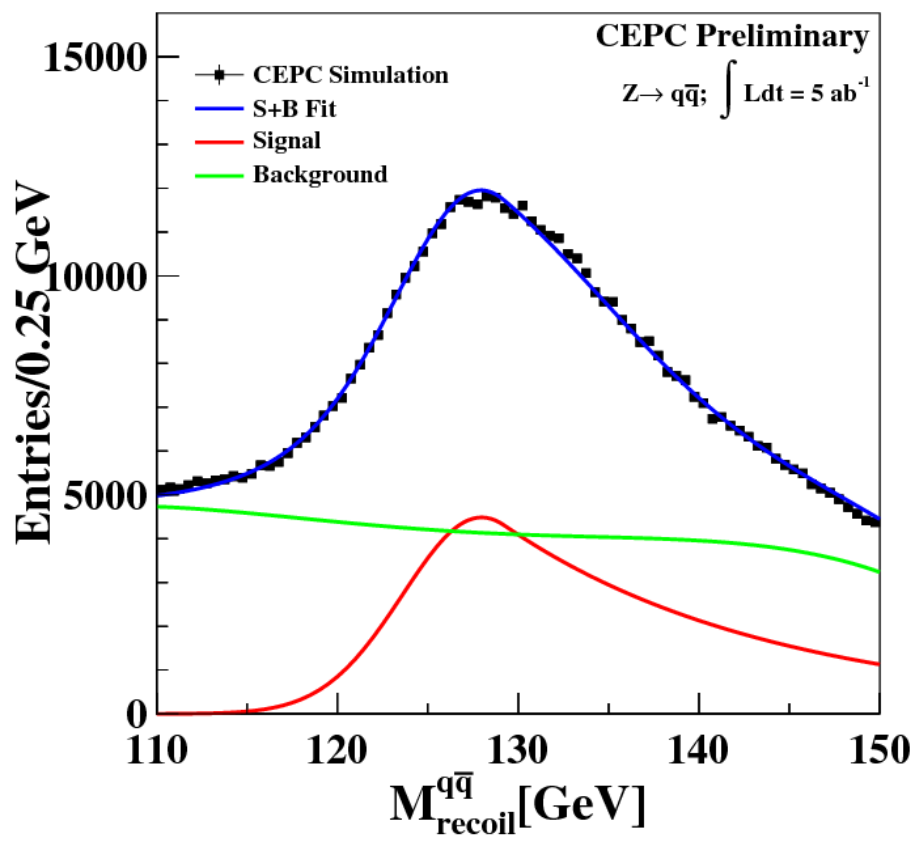
Cut flow

	Signal	qqH	vvH	SM BKG
Pre-cut	721232	8435	205822	69071903
$N_{lep}=0$	710648	5738	188928	41315384
$15 < N_{PFO} < 85$	708747	5464	171283	39890767
$P_T > 20 \text{ GeV}/c$	658280	5086	157211	3547505
$A_{col} > 50$	650532	4423	153950	1735168
$130 \text{ GeV} < E_{miss} < 170 \text{ GeV}$	629616	668	38430	620395
$75 \text{ GeV} < M_{jj} < 100 \text{ GeV}$	571924	317	19503	484991
$110 \text{ GeV} < M_{reco} < 150 \text{ GeV}$	550989	287	16322	336582

Higgs invisible decay

The cross section of SM ZH is fixed
Varied fractions of Higgs invisible decay are combined with the SM sample

$\text{Br}(H \rightarrow \text{inv}) = 50\%: 0.42\%$



Summary

Based on a full simulated ZH sample of $5ab^{-1}$, the measurement potential of CEPC on Higgs invisible decay is investigated

With fixed SM ZH cross section, the invisible cross section precision under different invisible branching ratios are presented.

Assuming $Br(H \rightarrow inv) = 50\%$

e^+e^- : 1.31%

$\mu^+\mu^-$: 1.16%

qq: 0.42%

Thanks!