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Measurements of decay branching fractions of the Higgs boson to hadronic final states at the CEPC

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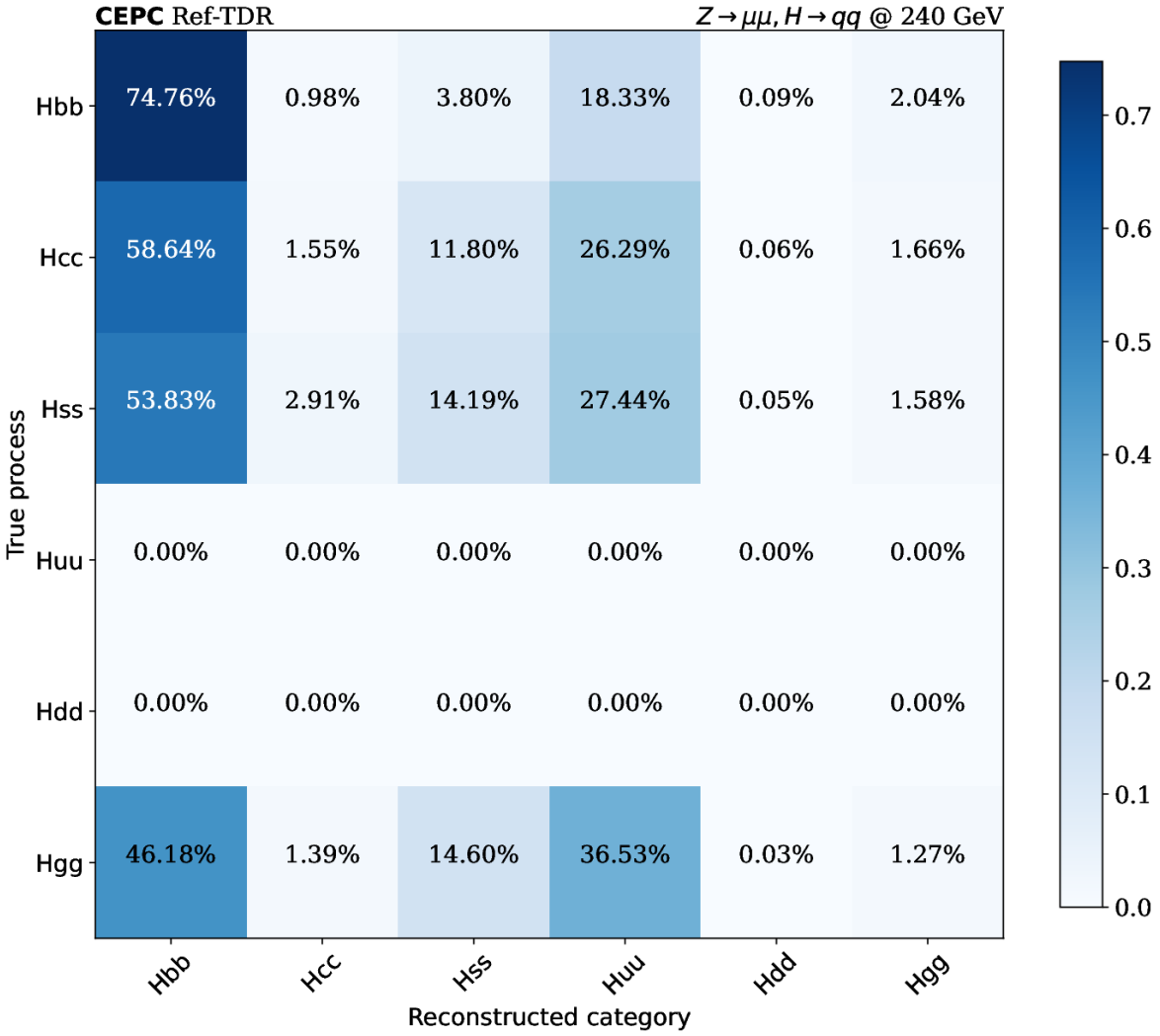
Status

- Application of JOI
  - $ZH \rightarrow \mu\mu qq$
- Measurements of decay branching fractions of the Higgs boson to hadronic final states at the CEPC
  - The results of tight H-mass window
  - Use lepton cut and missing energy cut to separate hadronic Hzz and Hww events

Application of JOI in $ZH \rightarrow \mu\mu qq$



https://code.ihep.ac.cn/zhangkl/PrimeTagSvc

Use bb/cc/ss/gg samples
after muon pair cut > 33w events

- The sum of each row equals 1
- Reconstructed category refers to one with maximum q+qbar score
- As shown in the matrix

Comparison of H-mass windows

- At least two muons with opposite charge. (muon ID @ BEST WP and $E > 10$ GeV)
  - Choose the muon pair closest to the Z boson mass.
- $|\cos\theta_{\mu^+\mu^-}| < 0.996$: to further reduce the two-fermion backgrounds.
- $N_{\text{charged}} > 7$: to reduce the backgrounds.
- $M_{\mu\mu}$ in Z-mass window [75 GeV, 105 GeV].
- $M_{\mu\mu}^{\text{recoil}}$ in H-mass window [110 GeV, 150 GeV]. $M_{\mu\mu}^{\text{recoil}} = \sqrt{(\sqrt{s} - E_{\mu^+} - E_{\mu^-})^2 - (\overrightarrow{P_{\mu^+}} + \overrightarrow{P_{\mu^-}})^2}$

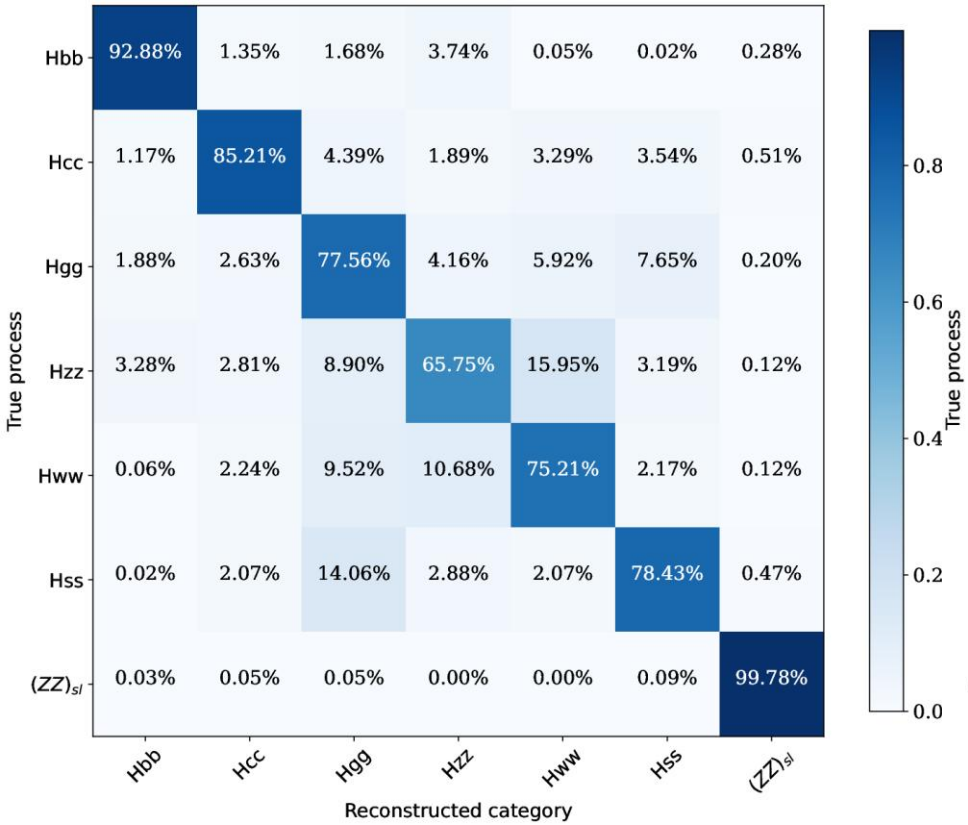
The cutflow selection efficiency

Process	$b\bar{b}$	$c\bar{c}$	gg	WW^*	ZZ^*	$s\bar{s}$	$(ZZ)_{sl}$
Muon pair	96.9%	96.7%	96.7%	96.7%	96.7%	96.6%	21.1%
Isolation	90.3%	90.3%	90.5%	90.4%	90.7%	90.5%	19.7%
$\lvert\cos\theta_{\mu\mu}\rvert$ <0.996	90.0%	90.0%	90.2%	90.1%	90.4%	90.1%	3.0%
Ntracks>7	90.0%	90.0%	90.2%	90.1%	90.4%	90.1%	3.0%
Z mass window	86.4%	86.4%	86.5%	86.4%	86.7%	86.5%	1.4%
H mass window	86.1%	86.0%	86.2%	86.1%	86.4%	86.1%	1.4%
	82.4%	82.3%	82.5%	82.4%	82.8%	82.4%	0.7%

- With [120, 140] GeV H-mass window

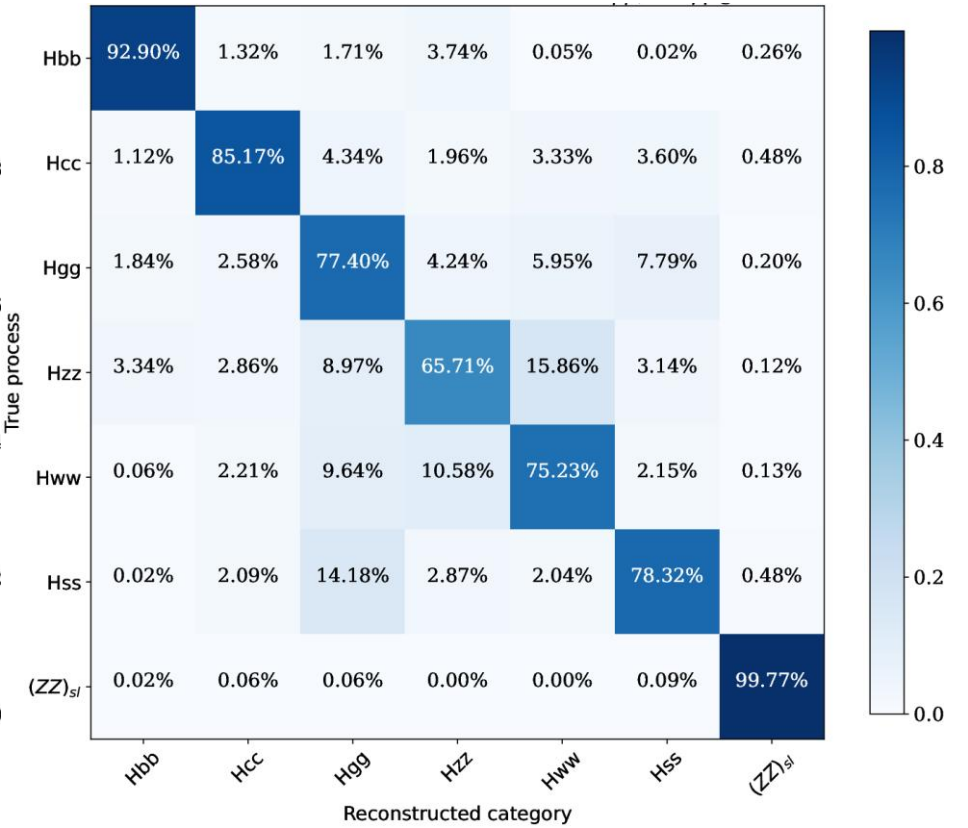
Comparison of model performance

The migration matrix with full sim bkg



- The sum of each row equals 1
- Reconstructed category refers to one with maximum score
- Average accuracy: 82.1%

The migtation matrix with full sim bkg



- With [120, 140] GeV H-mass window
- Average accuracy: 82.1%

Comparison of results

- Results of the measured Higgs branching fractions with relative statistical and systematic uncertainties:

Sig	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$
Branching fraction	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}
Rel. Stat. Un.	0.3%	2.2%	1.3%	7.8%	1.1%	97.2%
Rel. Syst. Un.	0.1%	3.7%	1.8%	4.2%	0.4%	211.7%

➢ With [120, 140] GeV H-mass window

Sig	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$
Branching fraction	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}
Rel. Stat. Un.	0.3%	2.2%	1.3%	7.9%	1.1%	96.9%
Rel. Syst. Un.	0.1%	0.1%	0.3%	2.5%	0.1%	8.7%

Separate hadronic decays from inclusive Hzz and Hww

Z DECAY MODES

Γ_1	e^+e^-		(3.3632 ±0.0042) %
Γ_2	$\mu^+\mu^-$		(3.3662 ±0.0066) %
Γ_3	$\tau^+\tau^-$		(3.3696 ±0.0083) %
Γ_7	invisible		(20.000 ±0.055) %
Γ_8	hadrons		(69.911 ±0.056) %

W^+ DECAY MODES

Γ_2	$e^+\nu$		(10.71 ±0.16) %
Γ_3	$\mu^+\nu$		(10.63 ±0.15) %
Γ_4	$\tau^+\nu$		(11.38 ±0.21) %
Γ_5	hadrons		(67.41 ±0.27) %

τ^- DECAY MODES

Γ_3	$\mu^-\overline{\nu}_\mu\nu_\tau$	[1]	(17.39 ±0.04) %
Γ_4	$\mu^-\overline{\nu}_\mu\nu_\tau\gamma$	[2]	(3.67 ±0.08) $\times10^{-3}$
Γ_5	$e^-\overline{\nu}_e\nu_\tau$	[1]	(17.82 ±0.04) %
Γ_6	$e^-\overline{\nu}_e\nu_\tau\gamma$	[2]	(1.83 ±0.05) %
Γ_7	$h^- \geq 0K^0_L\,\nu_\tau$		(12.03 ±0.05) %
Γ_8	$h^-\nu_\tau$		(11.51 ±0.05) %
Γ_{12}	$h^- \geq 1\,\pi^0\nu_\tau$ (ex.K^0)		(36.50 ±0.09) %

For $H \to ZZ$:
Hadronic 48.9%
Semi-leptonic 42.0%
Leptonic 9.1%

For $H \to WW$:
Hadronic 45.4%
Semi-leptonic 44.0%
Leptonic 10.6%

For τ
~35% Leptonic

pdgLive

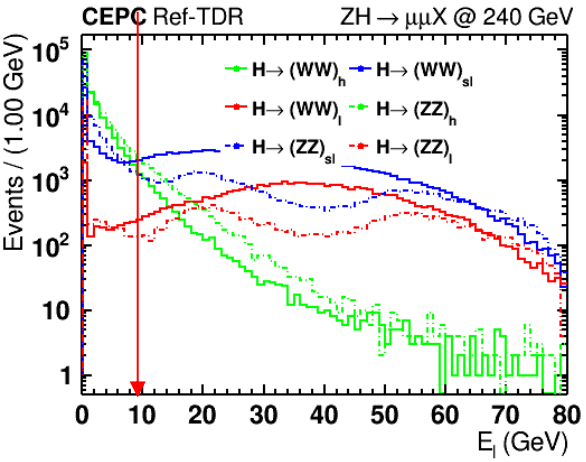
Separate hadronic decays from inclusive Hzz and Hww

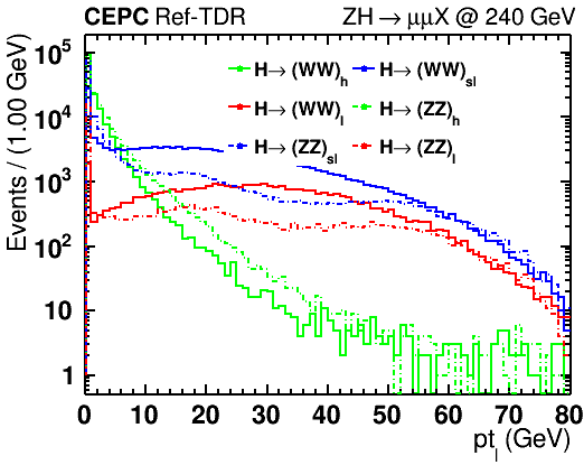
Process	$H \to WW^*$			$H \to ZZ^*$		
Final states	Hadronic	Semi-leptonic	Leptonic	Hadronic	Semi-leptonic	Leptonic
Theoretical N	176766	170918	41316	186411	160459	34530
Simulated N	178264	169905	40831	185120	161172	35108
Muon pair & Z-mass	161636	154675	37437	167775	147049	32247
$E_l < 9.5\text{GeV}^*$	155453	46695	3491	155273	104557	17782
$E_{mis} < 15\text{GeV}^{**}$	143410	1789	3	138790	3850	11
Total efficiency	80.4%	1.1%	0.01%	75.0%	2.4%	0.03%

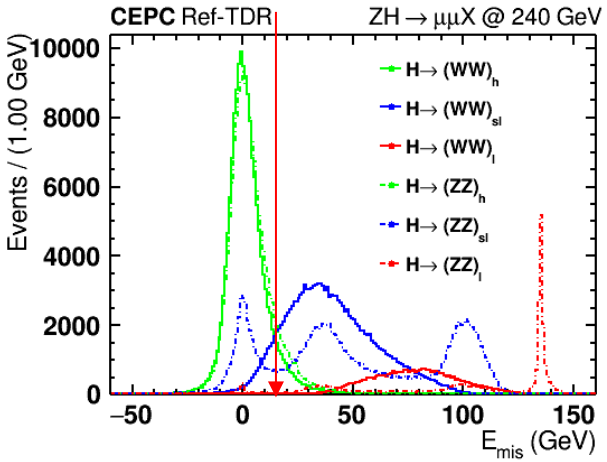
The cutflow

$*$: $lepton\ with\ the\ maximum\ energy\ (veto\ muons\ from\ Z)$

$**$: $E_{mis} = 240\text{GeV} - \Sigma E_{vis}$



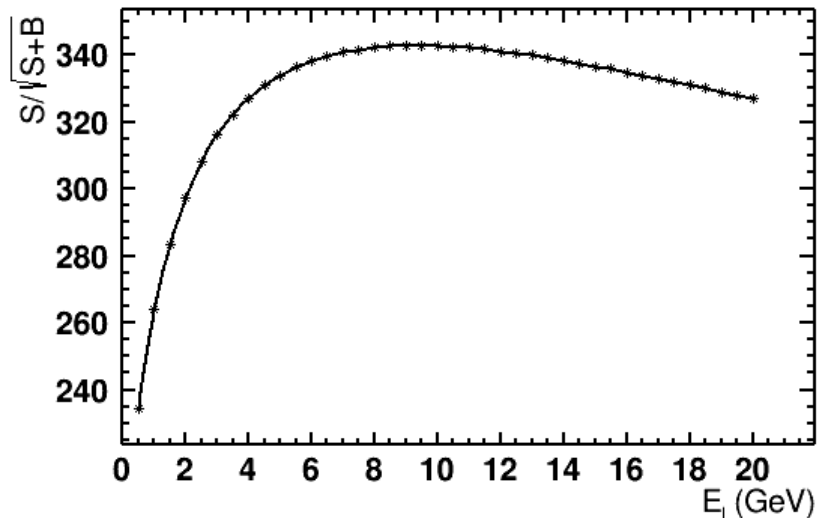


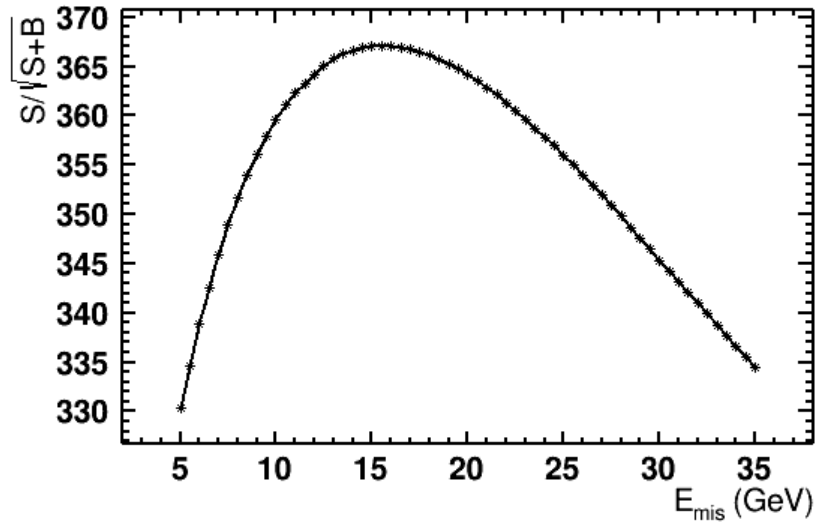


Back up

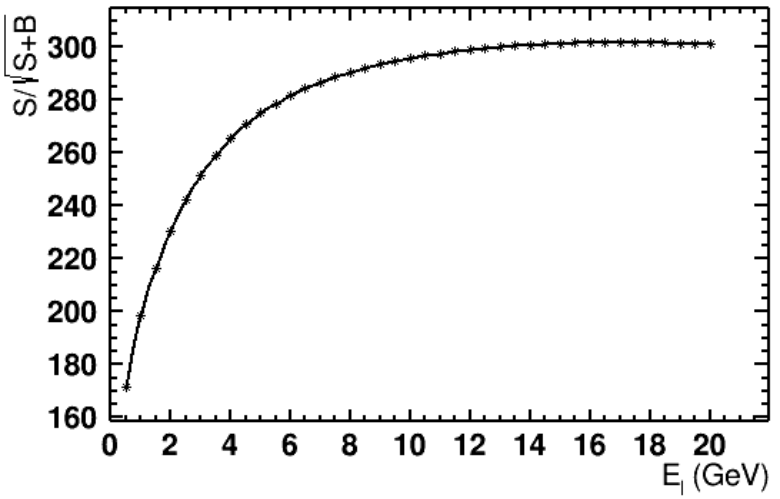
Cut optimization

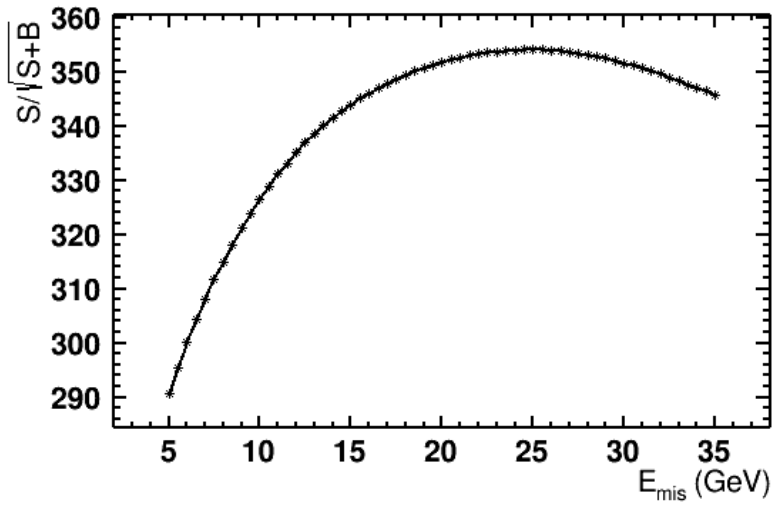
$H \to WW^*$



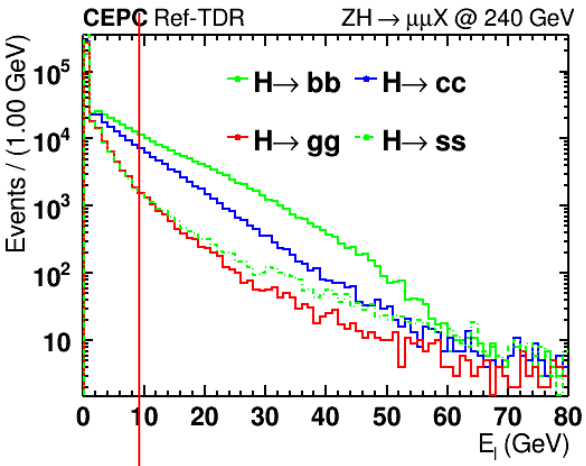


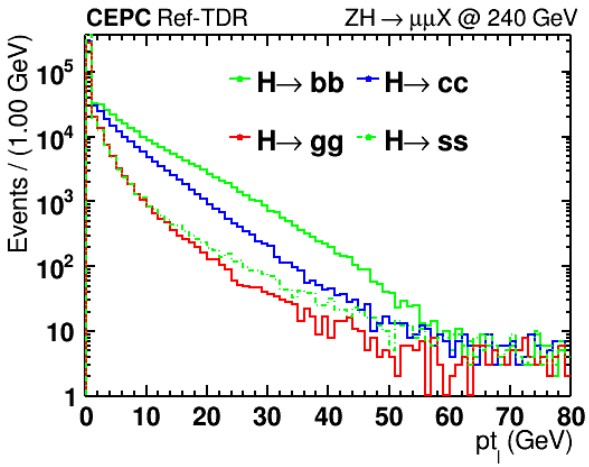
$H \to ZZ^*$

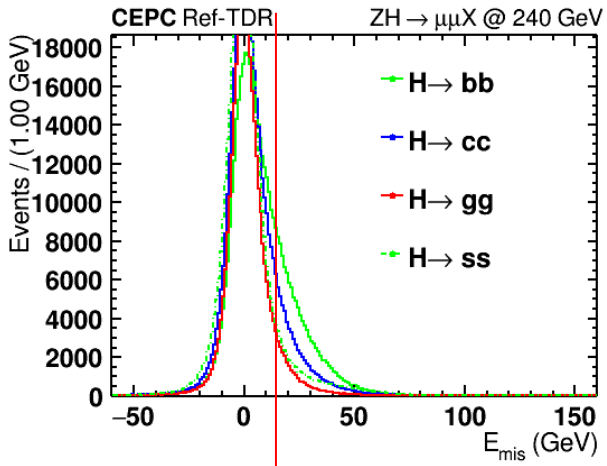


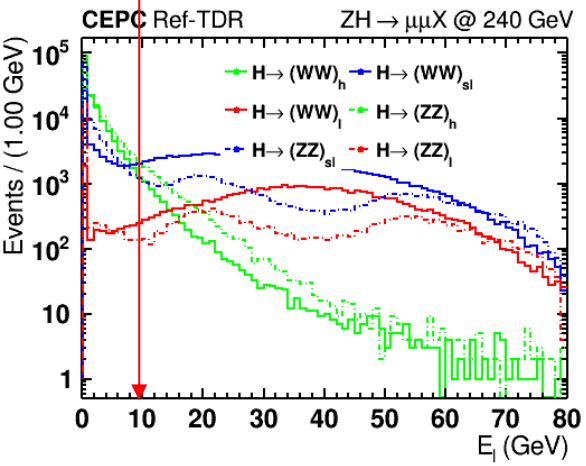


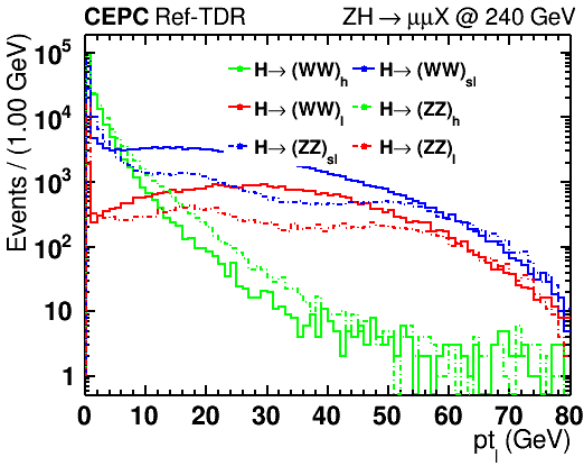
Distributions of El and Emis

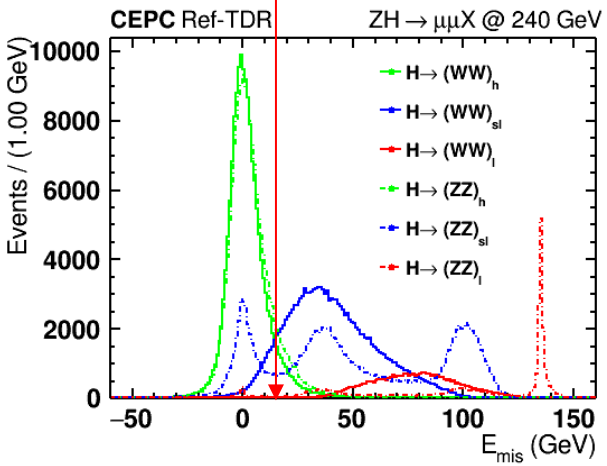








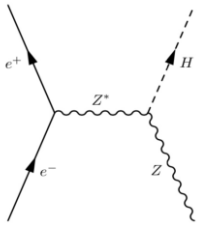




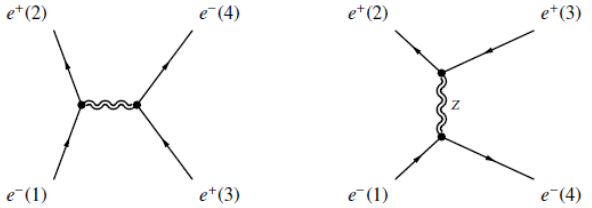
Simulation samples

- Using Whizard 1.95 and Pythia6 for the fragmentation and hadronization
- Signal process: Z decays to a pair of muons and H decays in pairs of $b\bar{b}/c\bar{c}/gg/WW^*/ZZ^*/s\bar{s}$, full simulation generated under Ref-TDR CEPCSW
- Backgrounds: processes with two-fermion and four-fermion final states, full simulation generated under Ref-TDR CEPCSW

Signal process



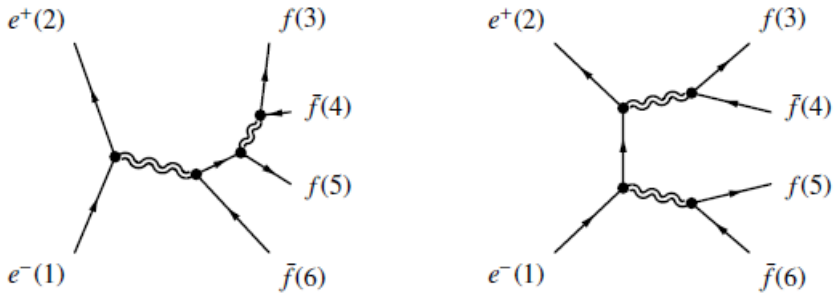
Process	Higgs decays	Cross section/fb
ZH process $Z \to \mu^+\mu^-$	$H \to b\bar{b}$	3.91
	$H \to c\bar{c}$	0.20
	$H \to gg$	0.58
	$H \to WW^*$	1.46
	$H \to ZZ^*$	0.18



Two-fermion background process

Category	Name	Decay modes	Cross section/fb
Two-fermion background	$l\bar{l}$	$e^+e^- \to e^+e^-$	24992.21
		$e^+e^- \to \mu^+\mu^-$	4991.91
		$e^+e^- \to \tau^+\tau^-$	4432.18
	$\nu\bar{\nu}$	$e^+e^- \to \nu_e\bar{\nu}_e$	45390.79
		$e^+e^- \to \nu_\mu\bar{\nu}_\mu$	4416.30
		$e^+e^- \to \nu_\tau\bar{\nu}_\tau$	4410.26
	$q\bar{q}$	$e^+e^- \to u\bar{u}$	10110.43
		$e^+e^- \to d\bar{d}$	10010.07
		$e^+e^- \to c\bar{c}$	10102.75
		$e^+e^- \to s\bar{s}$	9924.40
		$e^+e^- \to b\bar{b}$	9957.70

- leptons (l), neutrinos (ν), and quarks (q)



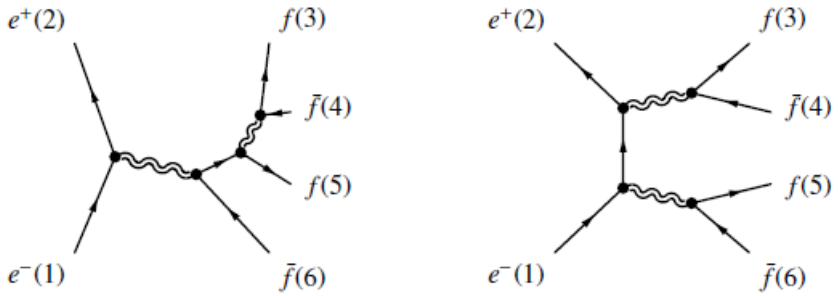
- names refer to final states with leptons (l), hadrons (h), and semil eptons (sl).

Four-fermion background process

Four-fermion background

$(ZZ)_h$	$Z \to c\bar{c}, Z \to d\bar{d}/b\bar{b}$	98.97
	$ZZ \to d\bar{d}d\bar{d}$	233.46
	$ZZ \to u\bar{u}u\bar{u}$	85.68
	$Z \to u\bar{u}, Z \to s\bar{s}/b\bar{b}$	98.56
$(ZZ)_l$	$Z \to \mu^+\mu^-, Z \to \mu^+\mu^-$	15.56
	$Z \to \tau^+\tau^-, Z \to \tau^+\tau^-$	4.61
	$Z \to \mu^+\mu^-, Z \to \nu_\mu\bar{\nu}_\mu$	19.38
	$Z \to \tau^+\tau^-, Z \to \mu^+\mu^-$	18.65
	$Z \to \tau^+\tau^-, Z \to \nu_\tau\bar{\nu}_\tau$	9.61
$(ZZ)_{sl}$	$Z \to \mu^+\mu^-, Z \to d\bar{d}$	136.14
	$Z \to \mu^+\mu^-, Z \to u\bar{u}$	87.39
	$Z \to \nu\bar{\nu}, Z \to d\bar{d}$	139.71
	$Z \to \nu\bar{\nu}, Z \to u\bar{u}$	84.38
	$Z \to \tau^+\tau^-, Z \to d\bar{d}$	67.31
	$Z \to \tau^+\tau^-, Z \to u\bar{u}$	41.56
$(WW)_h$	$WW \to uubd$	0.05
	$WW \to ccbs$	5.89
	$WW \to ccds$	170.18
	$WW \to cusd$	3478.89
	$WW \to uusd$	170.45

Process	Simu. N	Seleced N	Eff/%
zz_h0cc_nots	393200	1	0.0003
zz_h0dtdt	394200	1	0.0003
zz_h0utut	395600	0	
zz_h0uu_notd	150400	0	
4mu	378911	7	0.0018
zz_l04tau	398394	38	0.0095
zz_l0mumu	802297	0	
zz_l0taumu	398550	857	0.2150
zz_l0tautau	397879	0	
mumudown	395000	15979	4.0453
mumuup	396600	14553	3.6694
zz_sl0nu_down	245800	0	
zz_sl0nu_up	240000	0	
zz_sl0tau_down	243000	59	0.0243
zz_sl0tau_up	253200	32	0.0126
ww_h0ccbs	395600	0	
ww_h0ccds	395800	0	
ww_h0cuxx	395400	0	
ww_h0uubd	395000	1	0.0003
ww_h0uusd	396000	1	0.0003



- names refer to final states with leptons (l), hadrons (h), and semil eptons (sl).

Four-fermion background process

Four-fermion background

$(WW)_l$	$WW \to 4leptons$	403.66
$(WW)_{sl}$	$W \to \mu\bar{\nu}_\mu, W \to q\bar{q}$	2423.43
	$W \to \tau\bar{\nu}_\tau, W \to q\bar{q}$	2423.56
$(SZ)_l$	$e^+e^-, Z \to e^+e^-$	78.49
	$e^+e^-, Z \to \mu^+\mu^-$	845.81
	$e^+e^-, Z \to \nu\nu$	28.94
	$e^+e^-, Z \to \tau^+\tau^-$	147.28
	$\nu^+\nu^-, Z \to \mu^+\mu^-$	43.42
	$\nu^+\nu^-, Z \to \tau^+\tau^-$	14.57
$(SZ)_{sl}$	$e^+e^-, Z \to d\bar{d}$	125.83
	$e^+e^-, Z \to u\bar{u}$	190.21
	$\nu^+\nu^-, Z \to d\bar{d}$	90.03
	$\nu^+\nu^-, Z \to u\bar{u}$	55.59
$(SW)_l$	$e\nu_e, W \to \mu\nu_\mu$	436.70
	$e\nu_e, W \to \tau\nu_\tau$	435.93
$(SW)_{sl}$	$e\nu_e, W \to qq$	2612.62
$(mix)_h$	$ZZ/WW \to ccss$	1607.55
	$ZZ/WW \to uudd$	1610.32
$(mix)_l$	$ZZ/WW \to \mu\mu\nu_\mu\nu_\mu$	221.10
	$ZZ/WW \to \tau\tau\nu_\tau\nu_\tau$	211.18
	$SZ/SW \to ee\nu_e\nu_e$	249.48

Process	Simu. N	Seleced N	Eff/%
ww_l0ll	399590	1	0.0003
ww_sl0muq	397600	227	0.0571
ww_sl0tauq	397200	22	0.0055
sw_l0mu	399193	0	
sw_l0tau	397596	0	
sw_sl0qq	396400	0	
sze_l0e	397799	0	
sze_l0mu	388340	1	0.0003
sze_l0nunu	399756	0	
sze_l0tau	397588	0	
sze_sl0dd	391000	0	
sze_sl0uu	398800	2	0.0005
sznu_l0mumu	328834	0	
sznu_l0tautau	398383	0	
sznu_sl0nu_down	396400	0	
zzorww_h0cscs	227600	0	
zzorww_h0ududd	239800	0	
zzorww_l0mumu	243647	0	
zzorww_l0tautau	399180	0	
szeorsw_l	398788	0	