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

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Status

- Study full sim bkg
- Comparison with former CDR and FCC-ee results
- Preliminary application of JOI

Introduction

- This study focuses on the precise determination of the branching fractions of $H \rightarrow b\bar{b}/c\bar{c}/gg/WW^{*}/ZZ^{*}/s\bar{s}$ in associated $Z(\mu^{+}\mu^{-})H$ production at the CEPC with a center-of-mass energy of 240 GeV and integrated luminosity of 20 ab $^{-1}$.

- According to theoretical predictions, the branching fractions for the decay of a 125 GeV Higgs boson into $b\bar{b}$, $c\bar{c}$, gg, WW^{*}, ZZ^{*}, are 57.7%, 2.91%, 8.57%, 21.5%, 2.64%, respectively, and $s\bar{s}$ will also be considered. arXiv:1307.1347

- For WW^{*} and ZZ^{*}, the dominant decay modes are hadronic, making it challenging to distinguish them. And this can be overcome by end-to-end ML method.

- The Particle Transformer is applied to separate all decay channels simultaneously with high accuracy.

Sig	$H \rightarrow b\bar{b}$	$H \rightarrow c\bar{c}$	$H \rightarrow gg$	$H \rightarrow ZZ^{*}$	$H \rightarrow WW^{*}$	$H \rightarrow s\bar{s}$
predictions	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}

Event selection

- 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.
- Isolation cut: $E_{\text{cone}}^2 < 4E_\mu + 12.2\text{GeV}$
  - E_{cone} is the sum of energy within a cone ($\cos\theta_{\text{cone}} > 0.98$) around the muon.
- $M_{\mu\mu}$ in Z-mass window [75 GeV, 105 GeV].
- $M_{\mu\mu}^{\text{recoil}}$ in H-mass window [110 GeV, 150 GeV]. $M_{\mu\mu}^{\text{recoil}} = \sqrt{(\sqrt{s} - E_{\mu+} - E_{\mu-})^2 - (\overrightarrow{P_{\mu+}} + \overrightarrow{P_{\mu-}})^2}$
- $|\cos\theta_{\mu^+\mu^-}| < 0.996$: to further reduce the two-fermion backgrounds.
- $N_{\text{charged}} > 7$: to reduce the backgrounds.

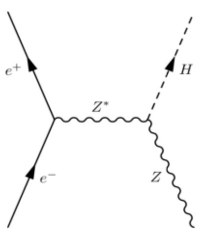
The cutflow selection efficiency

Process	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$
Theo. N	78126	3940	11604	3575	29111	60	11129800
Simu. N	495000	494500	371500	497250	497000	494250	11801264
Muon pair	96.9%	96.7%	96.7%	96.7%	96.7%	96.6%	21.1%
Isolation	90.3%	90.3%	90.5%	90.7%	90.4%	90.5%	19.7%
Z-mass	86.7%	86.7%	86.9%	87.1%	86.8%	86.8%	9.2%
H-mass	86.4%	86.3%	86.5%	86.7%	86.4%	86.5%	1.4%
$\cos\theta_{\mu^+\mu^-}$	86.1%	86.0%	86.2%	86.4%	86.1%	86.2%	1.4%
N_{charged}	86.1%	86.0%	86.2%	86.4%	86.1%	86.1%	1.4%

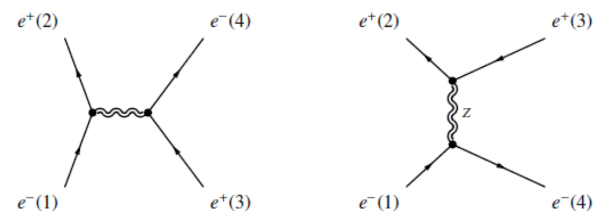
Simulation samples

- 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



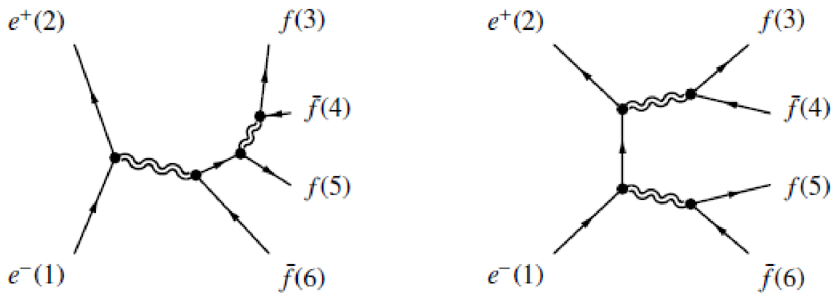
Process	Higgs decays	Cross section/fb
ZH process $Z \to \mu^+\mu^-$	$H \to b\bar{b}$	3.91
	$H \to c\bar{c}$	0.20
	$H \to gg$	0.58
	$H \to WW^*$	1.46
	$H \to ZZ^*$	0.18



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)

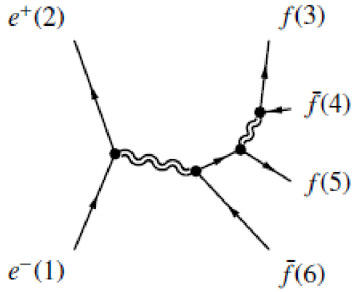


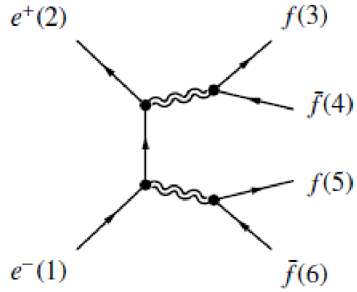
- names refer to final states with leptons (l), hadrons (h), and semileptons (sl).

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 semileptons (sl).

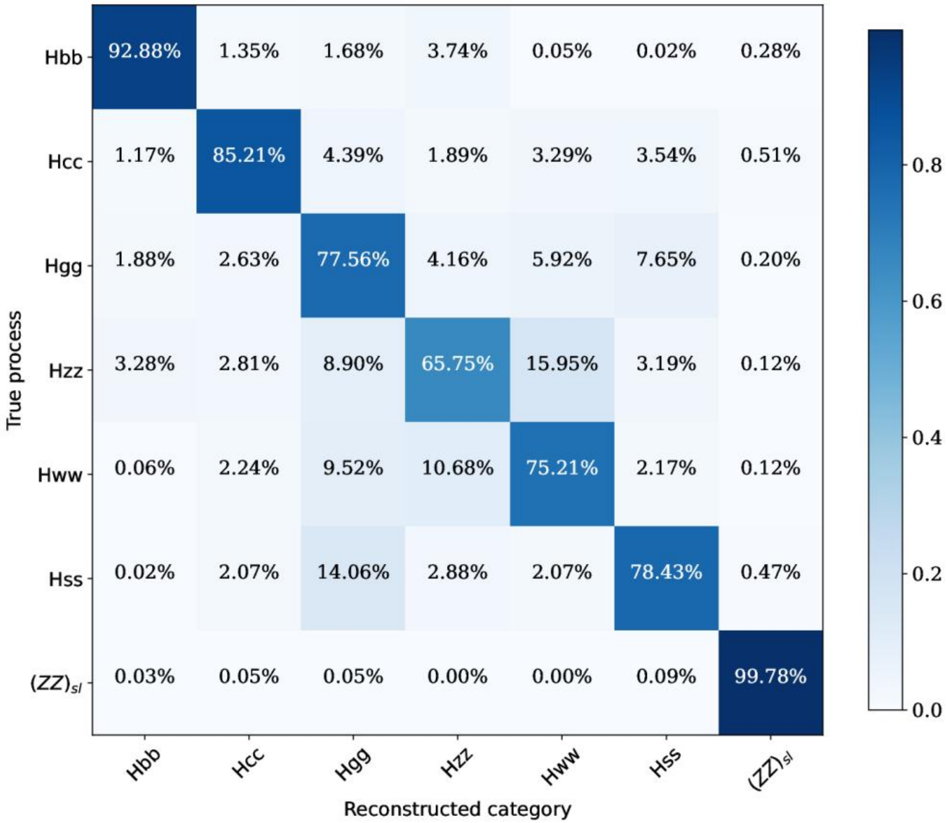
Four-fermion background process

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_h0udud	239800	0	
zzorww_l0mumu	243647	0	
zzorww_l0tautau	399180	0	
szeorsw_l	398788	0	

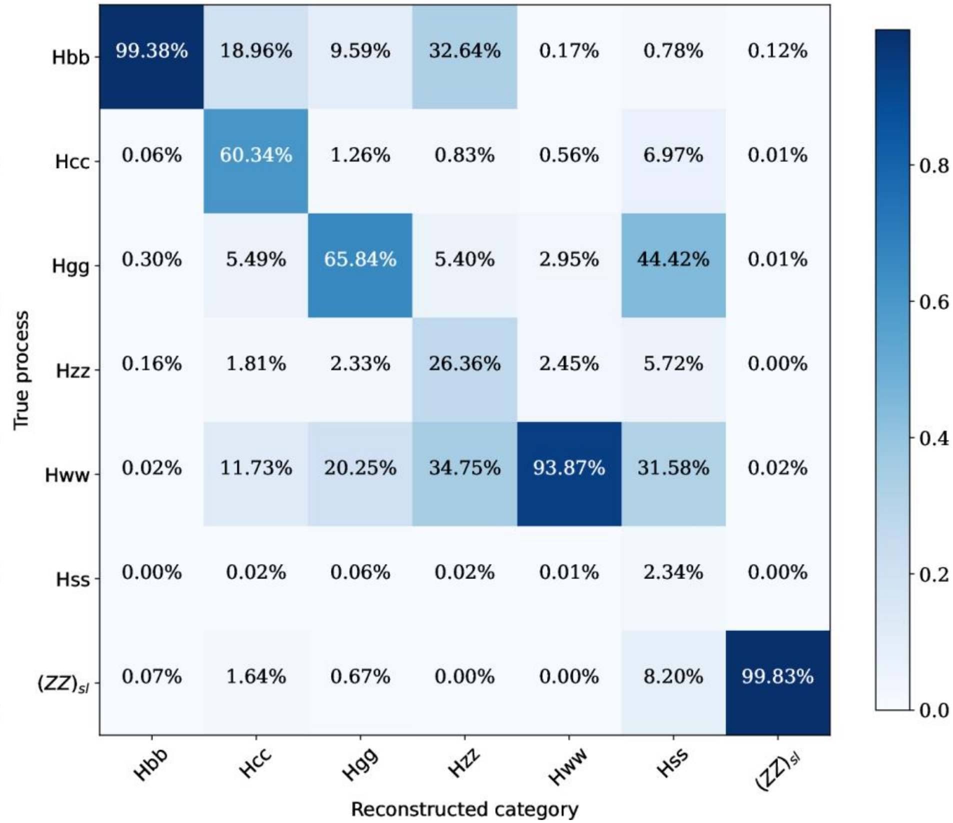
Model Performance

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 purity matrix with full sim bkg



- The sum of each column equals 1
- Reconstructed category refers to one with maximum score
- $(ZZ)_{sl}$ bkg contributes to signal

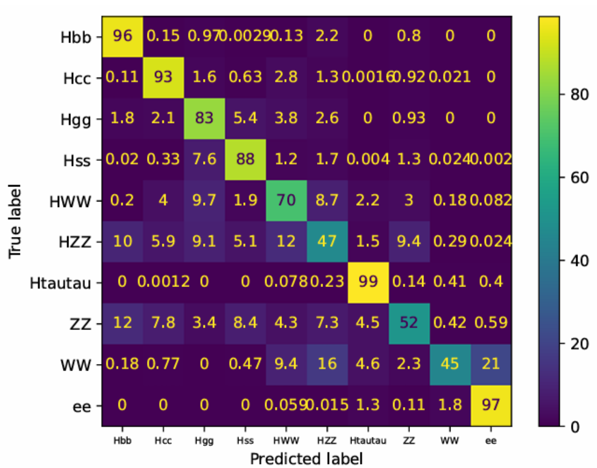
Results

- 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%

CDR results scaling lumi from 5.6 iab to 20 iab

Rel. Stat. Un.	0.3%	4.5%	1.6%	8.4%	0.8%	/

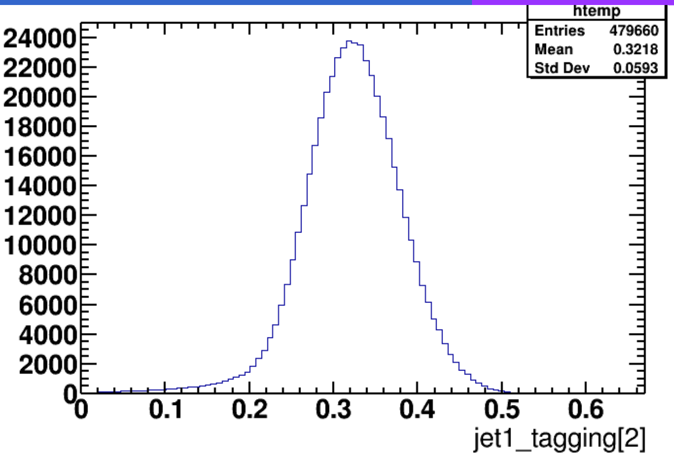


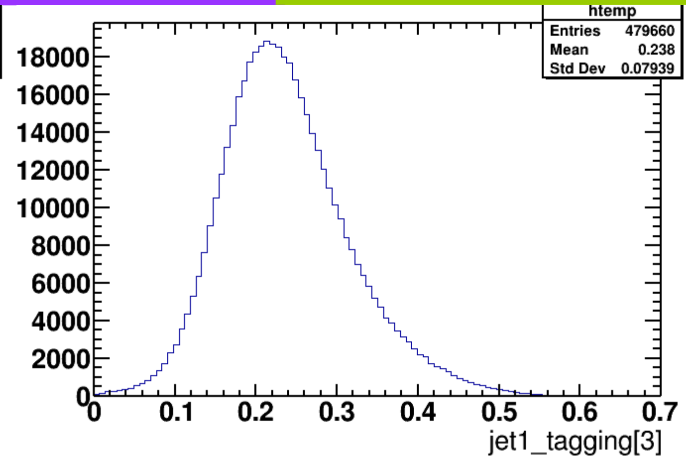
FCC-ee

Table 5: Expected statistical uncertainties on the signal strength in the $\ell\ell H$ production mode assuming an integrated luminosity $L = 10.8$ ab^{-1} of ee collisions at $\sqrt{s} = 240$ GeV, for three different configurations of the POIs.

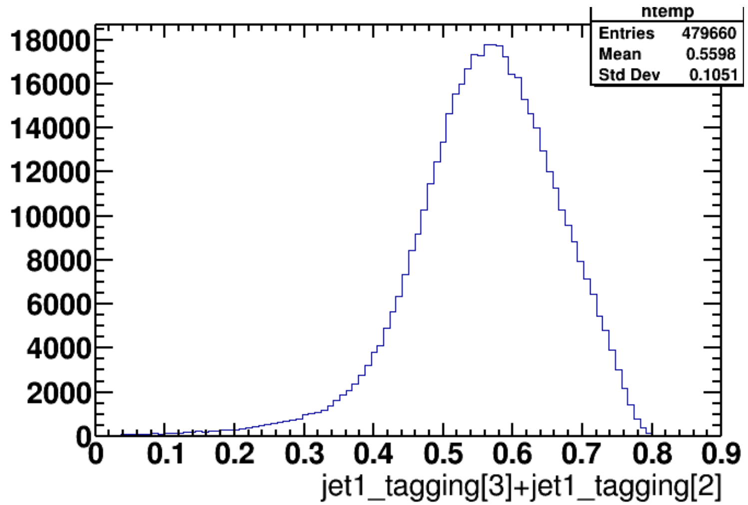
Signal strength	Categories						
	$b\bar{b}$	$c\bar{c}$	gg	$s\bar{s}$	ZZ	WW	$\tau\tau$
Uncertainty (%)	0.60	3.47	1.93	223	7.65	1.49	2.54
Scaled uncertainty	0.44	2.55	1.42	164	5.62	1.09	1.87

Application of JOI

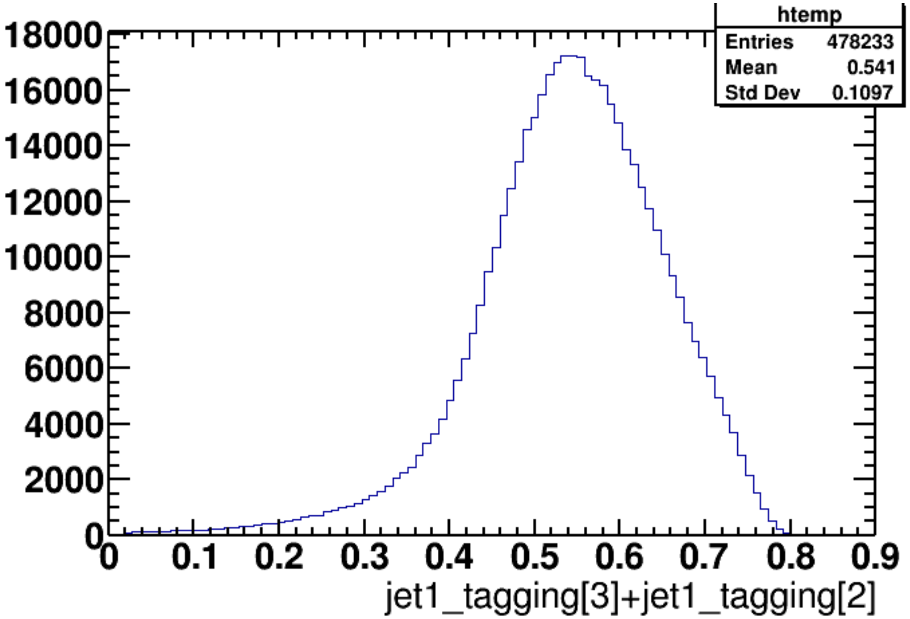


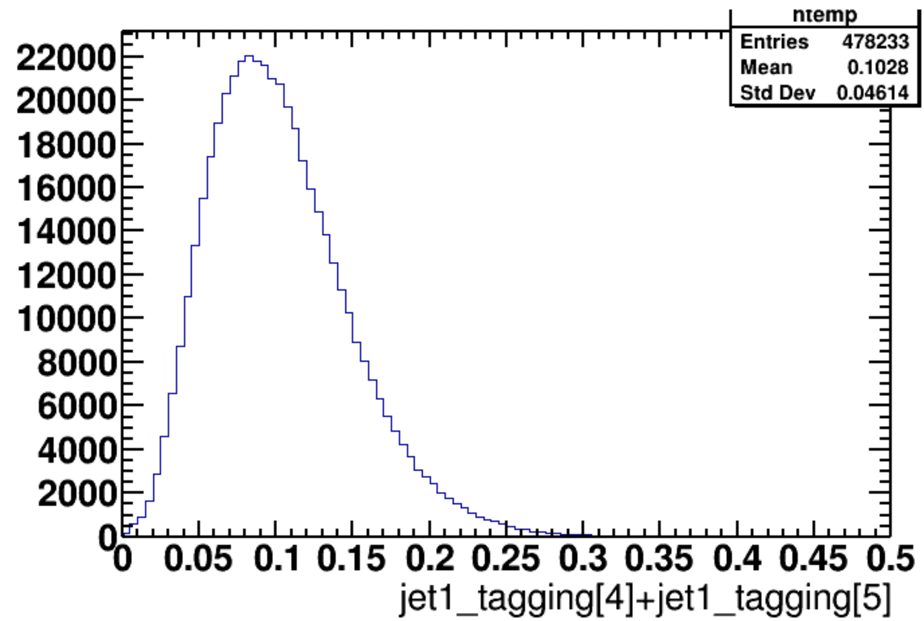


E240_mmHbb.root
btag score



Application of JOI



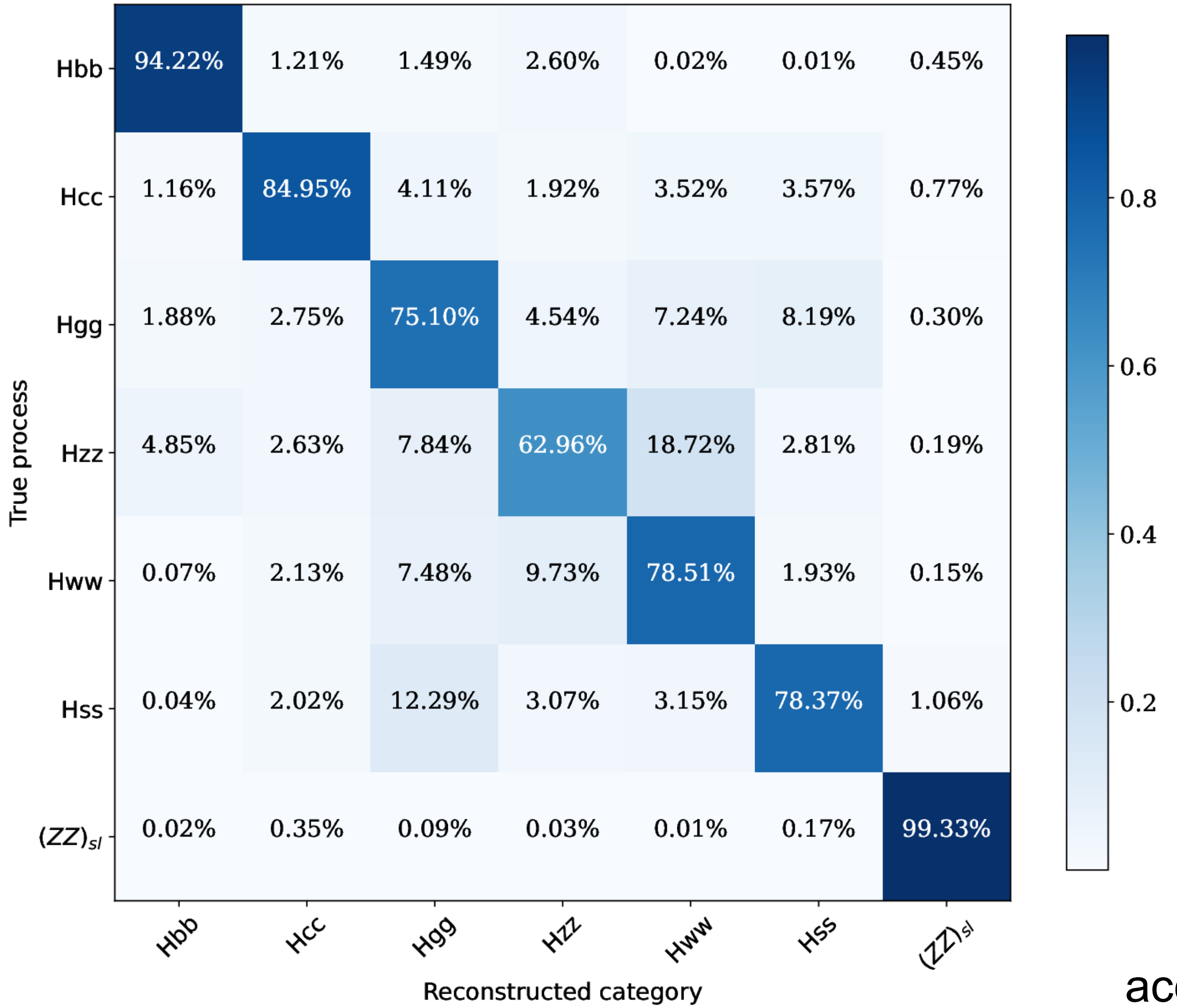


E240_mmHcc.root
btag & ctag score

Back up

Former report: link

w/o isolation cut model performance



acc: 0.8192