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

[1]Yanping Huang, [1]Xiaotian Ma, [1,2]Zuofei Wu, [1]Shuo Han

[1]*Institute of High Energy Physics*

[2]*Nanjing University*

Status

- To evaluate sensitivity of Higgs hadronic decay BR in jet-level (JOI) and compare with our previous result in event-level
  - Measurements of decay branching fractions of the Higgs boson to hadronic final states at the CEPC with luminosity of 21.6 ab^{-1}
  - Using Z($\mu\mu$)H signal samples and two-fermion and four-fermion background samples
  - Compare sensitivity of BR of $H \to b\bar{b}/c\bar{c}/gg/s\bar{s}$

Event selection (I)

- 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 [120 GeV, 140 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%
N_{tracks} >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	82.4%	82.3%	82.5%	82.4%	82.8%	82.4%	0.7%

- For event-level classification using ParticleTransformer

Event selection (II)

- Require 2 jets to have the same flavor. (JOI @ BEST WP)
  - After removing two muons from Z, use eek_t algorithm to reconstruct 2 jets
- $H \to b\bar{b}$ selection:

Process	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$
Rel. Eff.	87.2%	0.1%	0.8%	17.9%	0.0%	0.0%	17.0%

- $H \to c\bar{c}$ selection:

Process	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$
Rel. Eff.	0.1%	67.1%	0.8%	8.8%	4.1%	0.1%	11.9%

- $H \to gg$ selection:

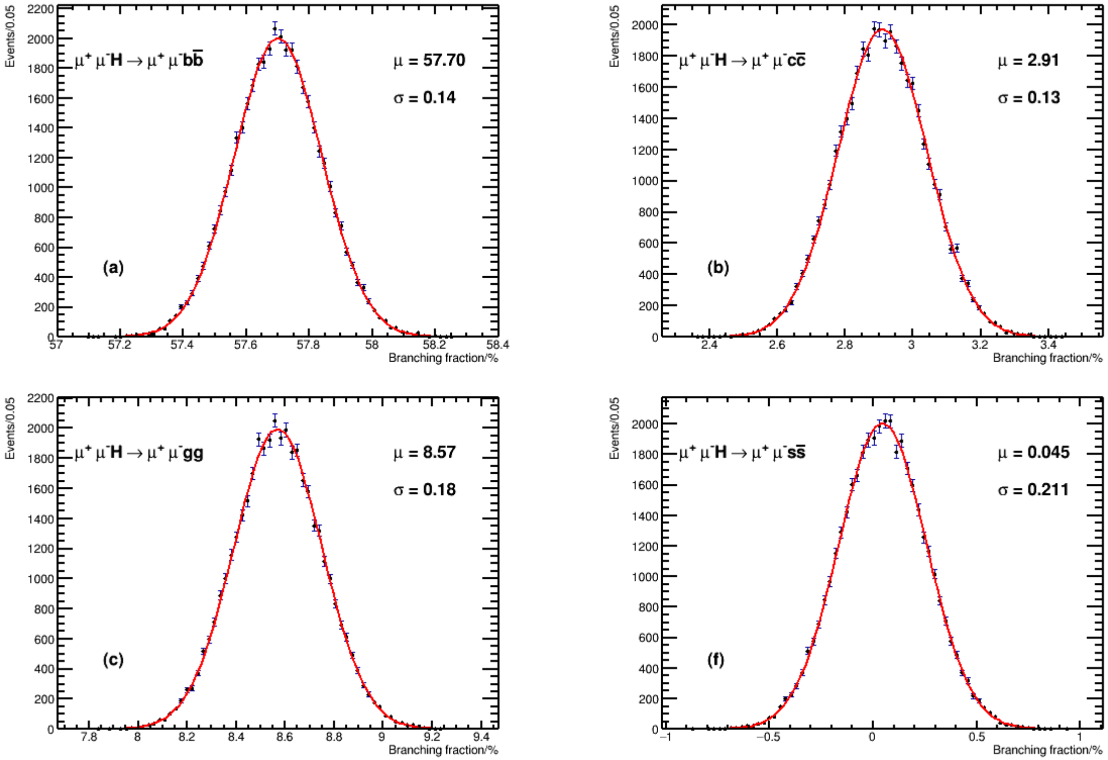
Process	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$
Rel. Eff.	1.3%	1.2%	40.5%	10.6%	14.1%	2.9%	1.7%

- $H \to s\bar{s}$ selection:

Process	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$
Rel. Eff.	0.0%	0.2%	1.8%	3.5%	1.6%	31.7%	8.3%

- For jet-level classification using JOI at BEST WP

Statistical uncertainty



- Use toyMC method, matrix method, least square fit and gaussian fit to estimate statistical uncertainties

$$\begin{bmatrix} N_{s1} \\ N_{s2} \\ \cdots \\ N_{b1} \\ N_{b2} \\ \cdots \end{bmatrix} = \left(M_{\mathrm{mig}}^{T} M_{s}\right)^{-1} \times \begin{bmatrix} n_{s1} \\ n_{s2} \\ \cdots \\ n_{b1} \\ n_{b2} \\ \cdots \end{bmatrix}$$

- (ToyMC method) Sampling for 40k times according to Poisson distribution (SM BRs), efficiency matrix (M_s) and Multinomial distribution (M_7) to get n_s and n_b
- Minimize $\chi^2 = \Sigma_{i=0}^{3} \frac{(Y_i - \eta_i)^2}{\sigma_i^2}$ to get BRs of signals (in which $\sigma(H \to WW^*/ZZ^*)$ and $\sigma((ZZ)_{sl})$ are fixed to SM values)
- Fit with gaussian function

Comparison of results

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

➢ With ParticleTransformer in event level

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%	7.6%	1.1%	93.5%

➢ With JOI BEST WP and double jet-tagging method ($\bar{q}\bar{q}/qq/q\bar{q}/gg$)

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%	/	/	4.4×10^{-4}
Rel. Stat. Un.	0.3%	4.5%	2.1%	/	/	471.7%

➢ With JOI BEST WP and single jet-tagging method ($q/\bar{q}/g$ for jet with max p_T)

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%	/	/	4.4×10^{-4}
Rel. Stat. Un.	0.3%	5.1%	2.3%	/	/	452.8%

Back up

$$Eff. = \frac{S}{N_{truth}}$$

$$purity = \frac{S}{S+B}$$

$$Rel.Stat.Un. = \frac{\sqrt{S+B}}{S} = \frac{1}{\sqrt{Eff.\times purity \times N_{truth}}}$$

```
with purity un. = 0.39%
with purity un. = 2.25%
with purity un. = 1.29%
with purity un. = 7.15%
with purity un. = 1.12%
with purity un. = 88.83%
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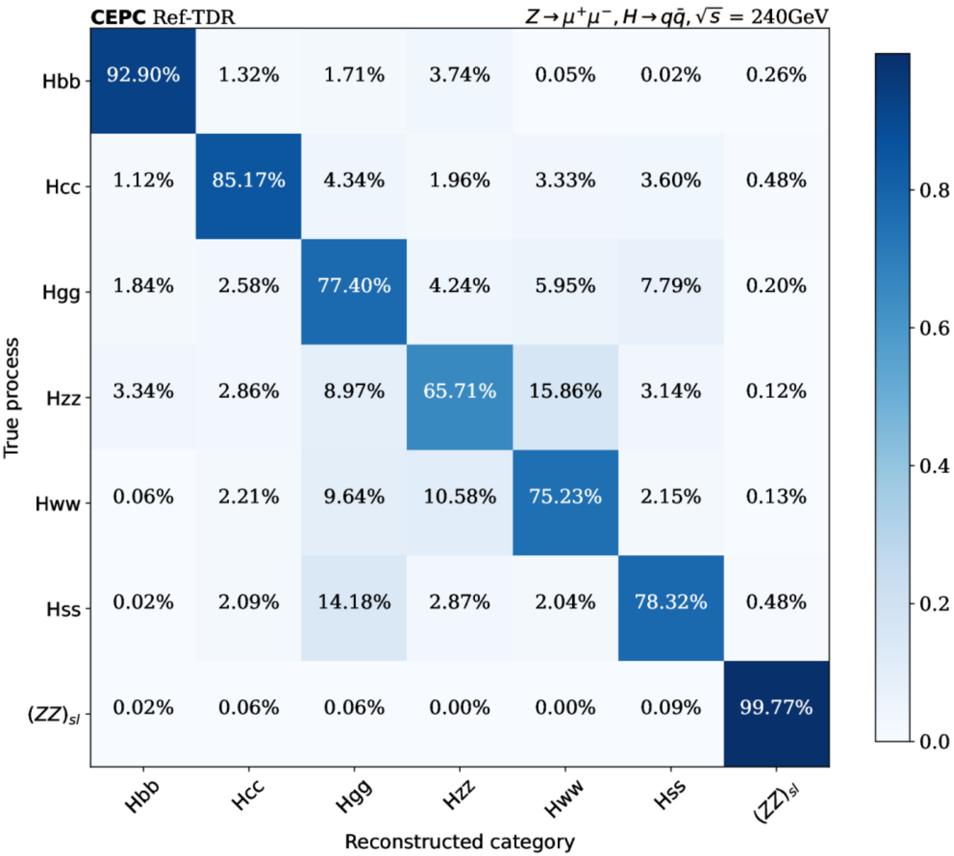
```
with purity un. = 0.45%
with purity un. = 4.77%
with purity un. = 2.18%
with purity un. = 497.49%
```

```
with purity un. = 0.44%
with purity un. = 5.36%
with purity un. = 2.25%
with purity un. = 468.50%
```

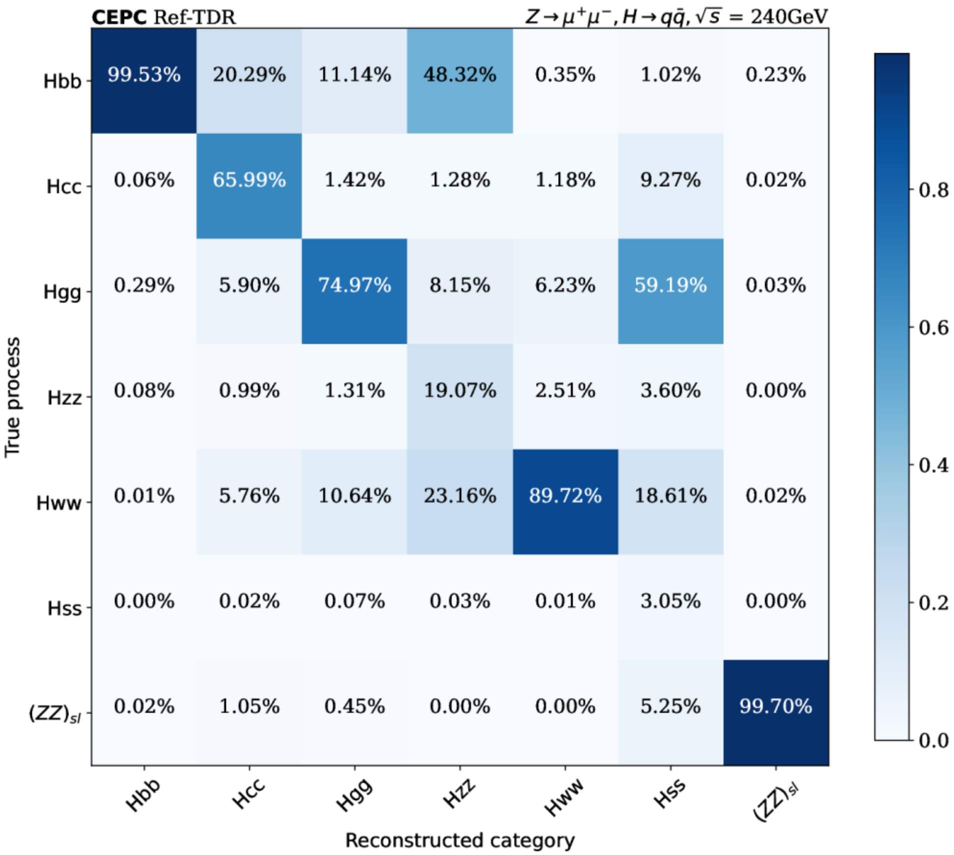
- eff*purity estimations compatible with our ToyMC method
  - Not consider correlations
  - ParT vs JOI double/single tagged

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	84376	4255	12532	1887	14287	64	12020184
Simu. N	495000	494500	371500	497250	497000	494250	11801264

ParT event level

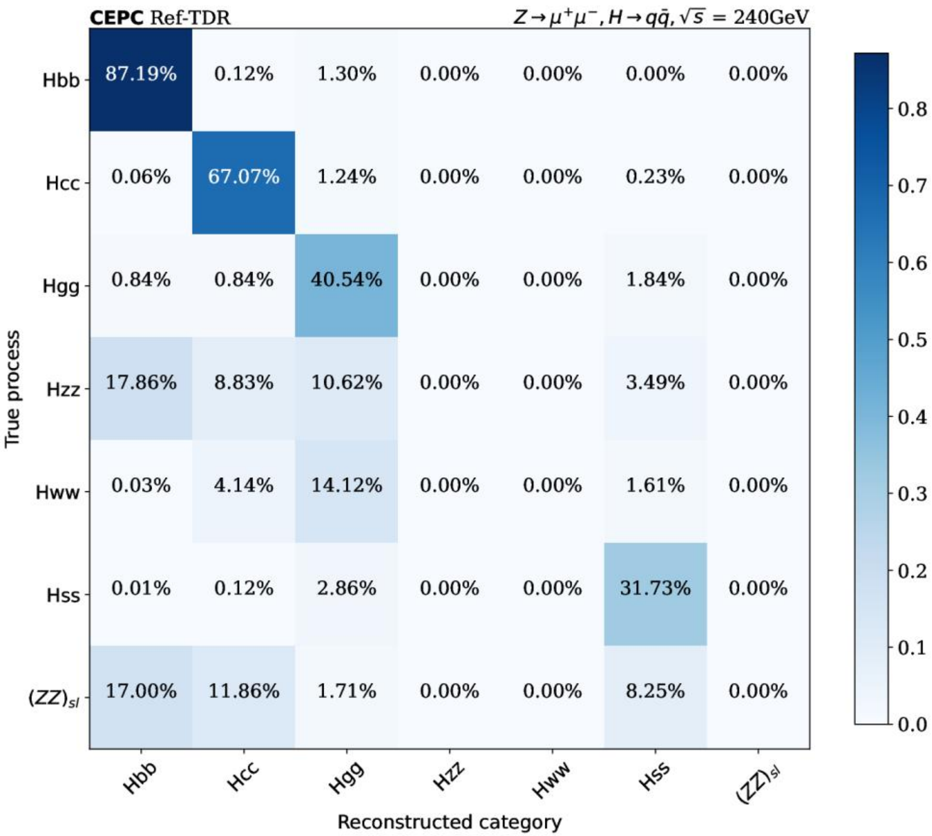


The migration matrix



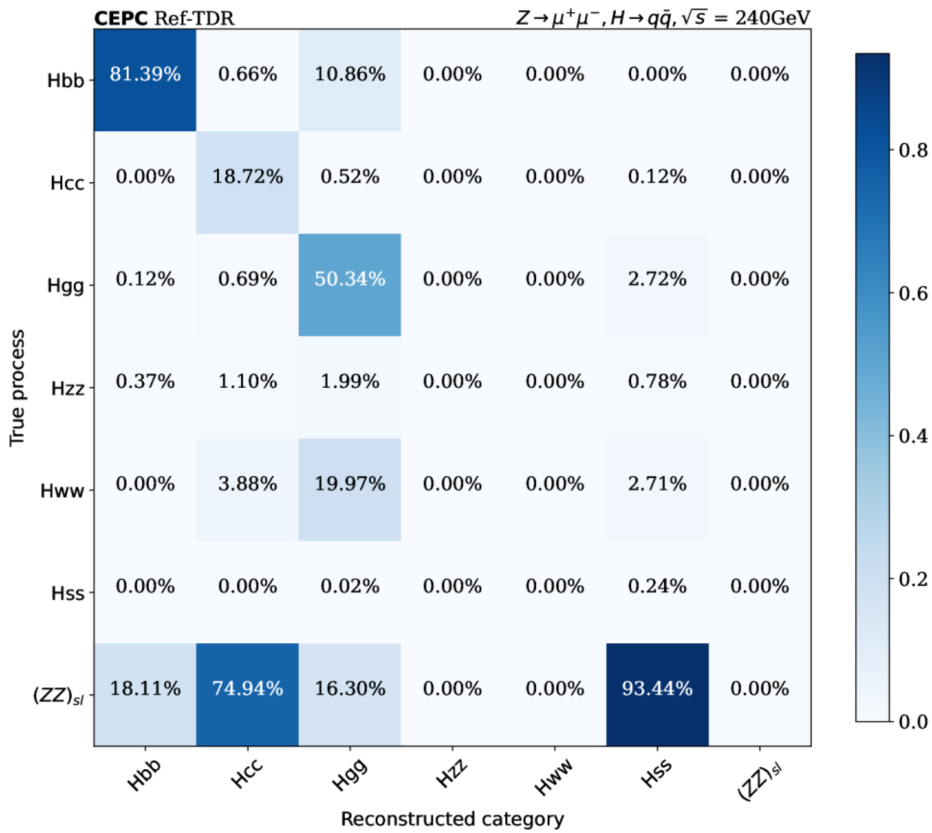
The purity matrix

JOI jet level – double tagged



True process \ Reconstructed	Hbb	Hcc	Hgg	Hzz	Hww	Hss	$(ZZ)_{sl}$
Hbb	87.19%	0.12%	1.30%	0.00%	0.00%	0.00%	0.00%
Hcc	0.06%	67.07%	1.24%	0.00%	0.00%	0.23%	0.00%
Hgg	0.84%	0.84%	40.54%	0.00%	0.00%	1.84%	0.00%
Hzz	17.86%	8.83%	10.62%	0.00%	0.00%	3.49%	0.00%
Hww	0.03%	4.14%	14.12%	0.00%	0.00%	1.61%	0.00%
Hss	0.01%	0.12%	2.86%	0.00%	0.00%	31.73%	0.00%
$(ZZ)_{sl}$	17.00%	11.86%	1.71%	0.00%	0.00%	8.25%	0.00%

The migration matrix

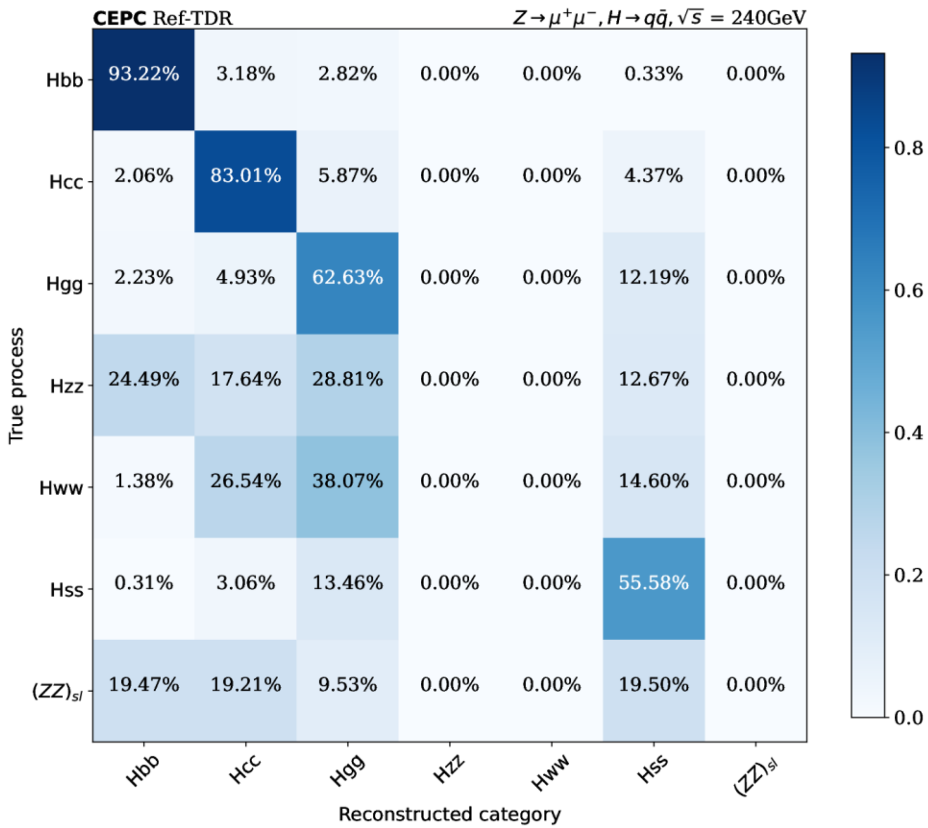


True process \ Reconstructed	Hbb	Hcc	Hgg	Hzz	Hww	Hss	$(ZZ)_{sl}$
Hbb	81.39%	0.66%	10.86%	0.00%	0.00%	0.00%	0.00%
Hcc	0.00%	18.72%	0.52%	0.00%	0.00%	0.12%	0.00%
Hgg	0.12%	0.69%	50.34%	0.00%	0.00%	2.72%	0.00%
Hzz	0.37%	1.10%	1.99%	0.00%	0.00%	0.78%	0.00%
Hww	0.00%	3.88%	19.97%	0.00%	0.00%	2.71%	0.00%
Hss	0.00%	0.00%	0.02%	0.00%	0.00%	0.24%	0.00%
$(ZZ)_{sl}$	18.11%	74.94%	16.30%	0.00%	0.00%	93.44%	0.00%

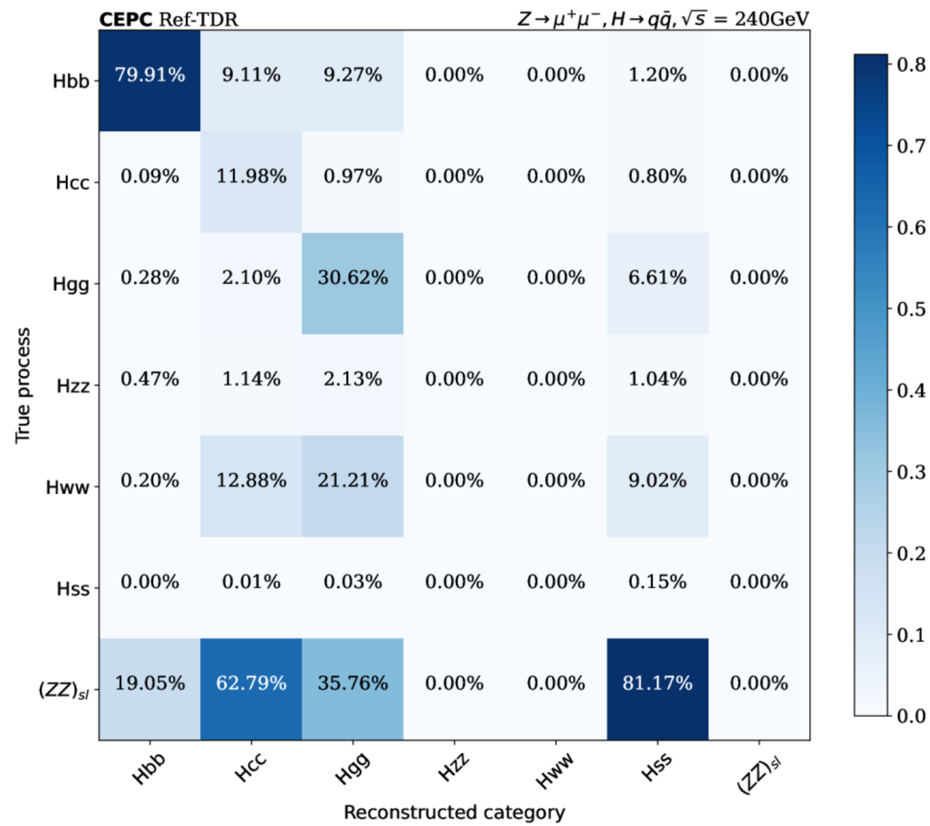
The purity matrix

- Maybe add JOI score as a training variable, and that should improve our results

JOI jet level – single tagged



The migration matrix



The purity matrix

- Maybe add JOI score as a training variable, and that should improve our results