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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

- Generated full sim $(ZZ)_{sl}$ bkg using genfilter
- Re-trained and updated corresponding results
- Corrected systematic uncertainty estimation

Introduction

- This study focuses on the precise determination of the branching fractions of $H \to b\bar{b}/c\bar{c}/gg/WW^*/ZZ^*/s\bar{s}$ 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	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$
predictions	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}

Event selection

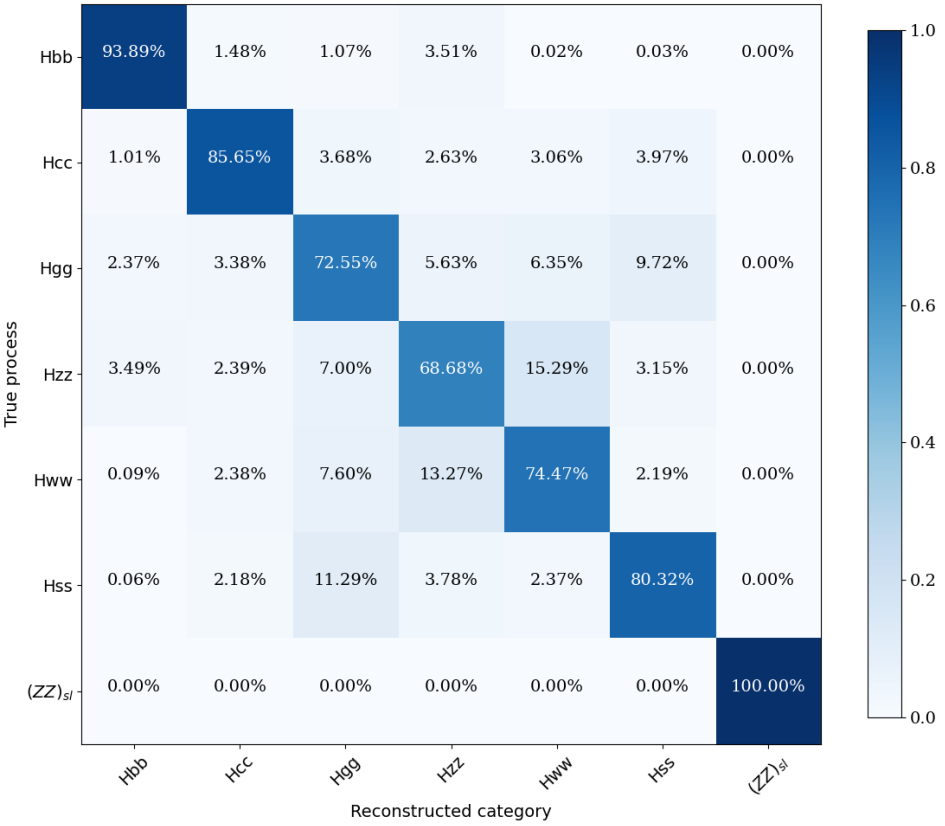
- At least two muons with opposite charge. (muon ID @ BEST WP and $E > 10$ GeV)
  - Choose the muon pair closest to the Z boson mass.
- Isolation cut: $E_{\text{cone}}^2 < 4E_\mu + 12.2\text{GeV}$
  - E_{cone} is the sum of energy within a cone ($\cos\theta_{\text{cone}} > 0.98$) around the muon.
- $M_{\mu\mu}$ 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	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$	$(ZZ)_{sl}$	Fast sim $(ZZ)_{sl}$
Theo. N	78126	3940	11604	3575	29111	60	11129800	11129800
Simu. N	495000	494500	371500	497250	497000	494250	11801264	26499801
Muon pair	96.9%	96.7%	96.7%	96.7%	96.7%	96.6%	21.1%	18.8%
Isolation	90.3%	90.3%	90.5%	90.7%	90.4%	90.5%	19.7%	12.9%
Z-mass	86.7%	86.7%	86.9%	87.1%	86.8%	86.8%	9.2%	9.1%
H-mass	86.4%	86.3%	86.5%	86.7%	86.4%	86.5%	1.4%	1.5%
$\cos\theta_{\mu^+\mu^-}$	86.1%	86.0%	86.2%	86.4%	86.1%	86.2%	1.4%	1.5%
N_{charged}	86.1%	86.0%	86.2%	86.4%	86.1%	86.1%	1.4%	1.5%

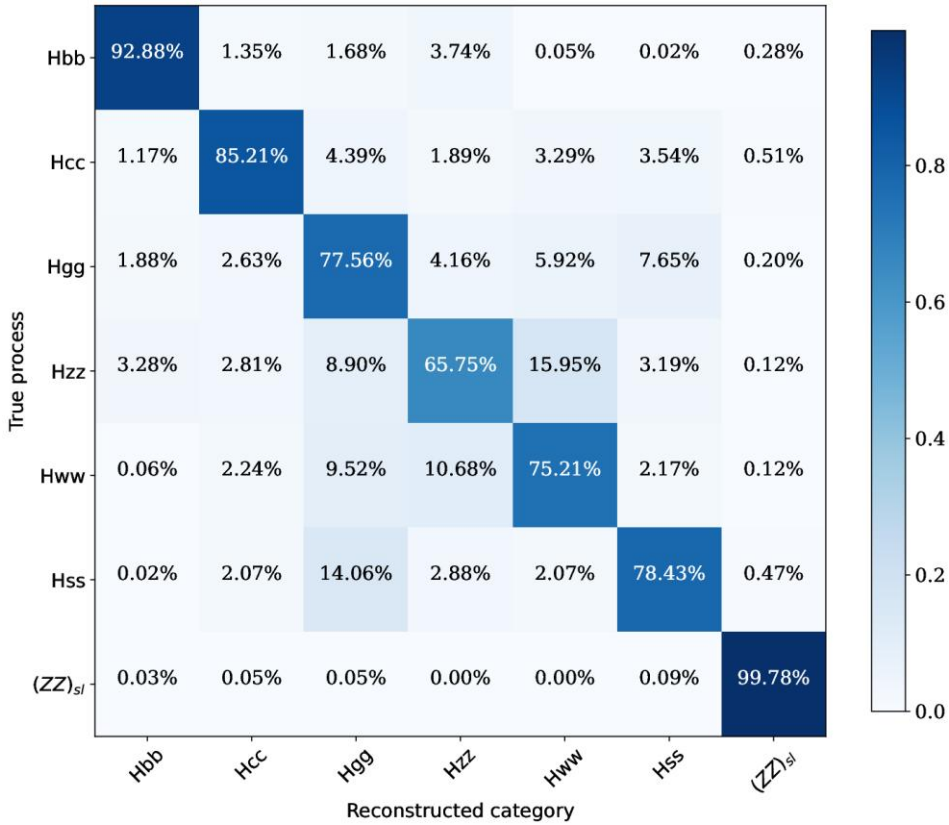
Model Performance

The migration matrix with fast sim bkg



- The sum of each row equals 1
- Reconstructed category refers to one with maximum score
- Average accuracy: 82.2%

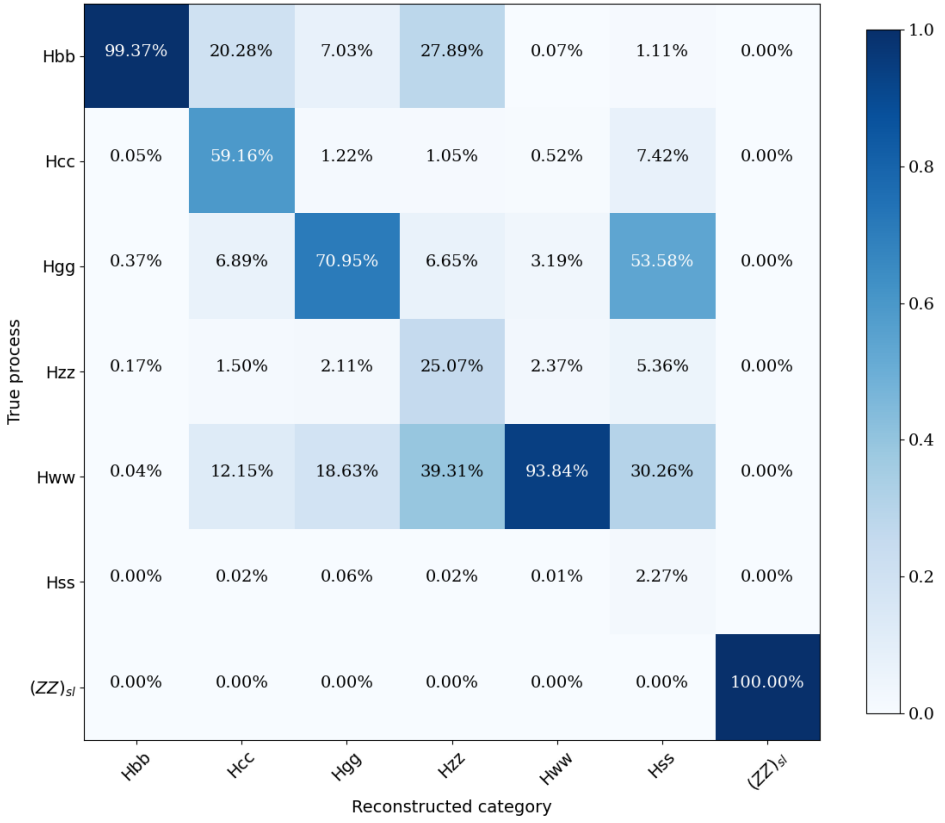
The migration matrix with full sim bkg



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

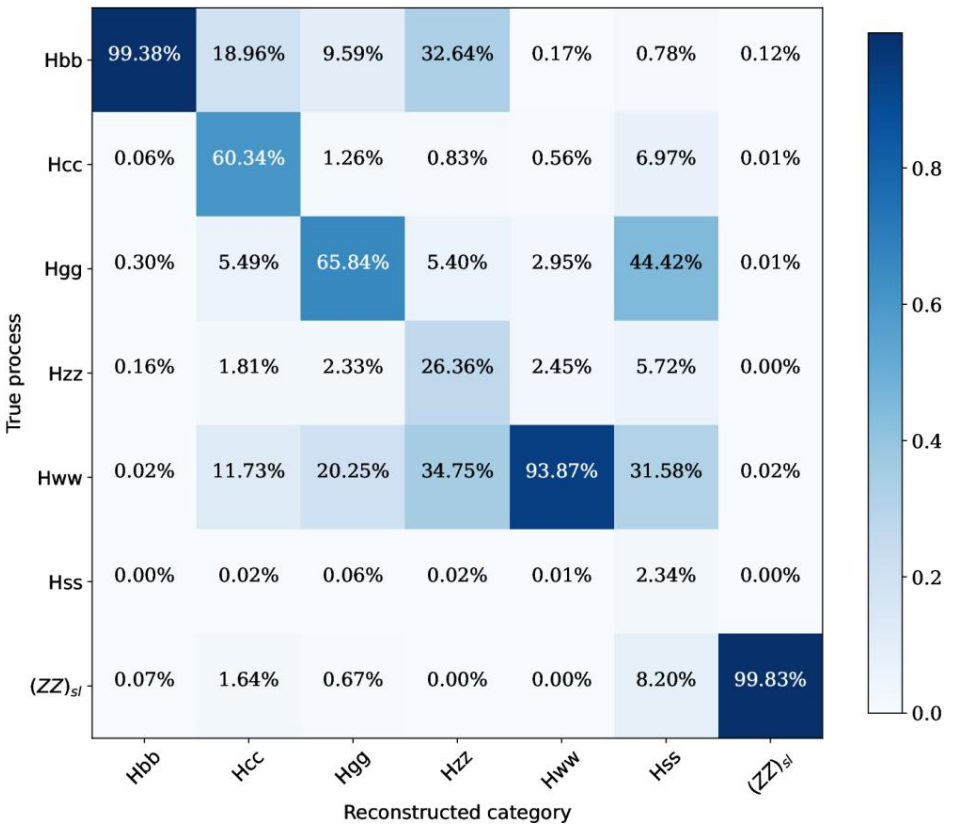
Purity matrix

The purity matrix with fast sim bkg



- The sum of each column equals 1
- Reconstructed category refers to one with maximum score

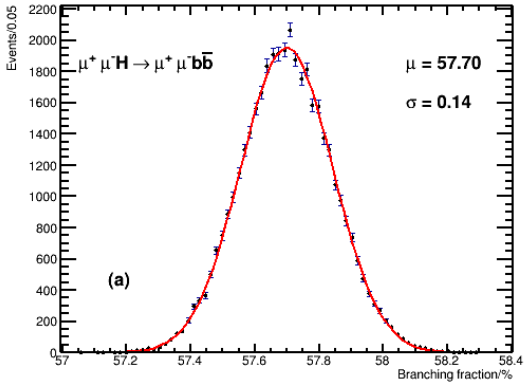
The purity matrix with full sim bkg

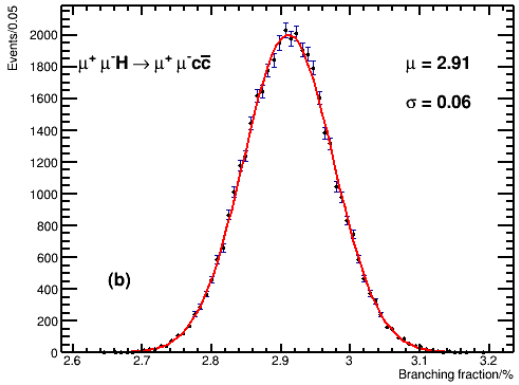


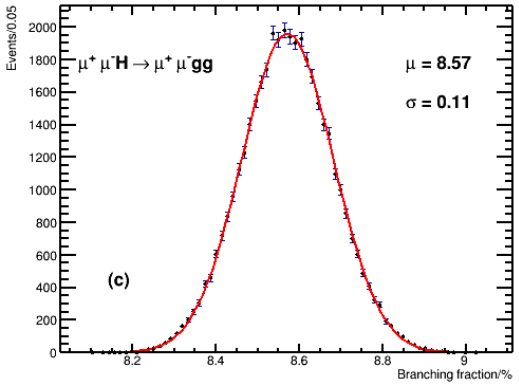
- The sum of each column equals 1
- Reconstructed category refers to one with maximum score
- $(ZZ)_{sl}$ bkg contributes to signal

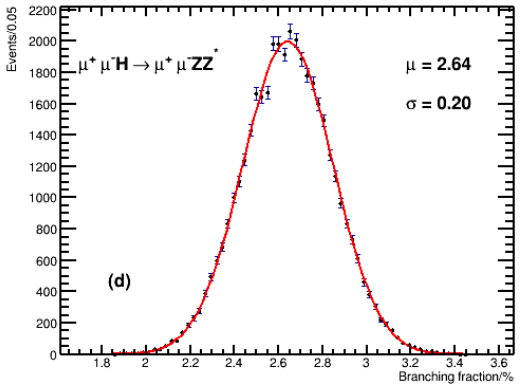
Statistical uncertainty

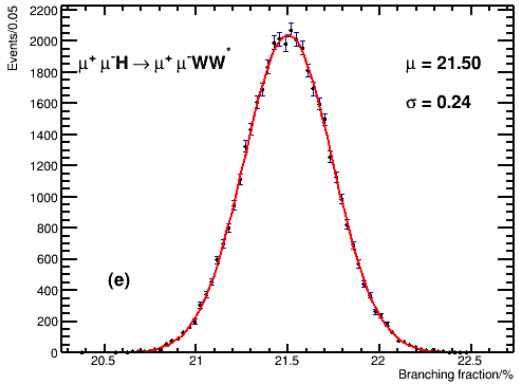
ToyMC test result

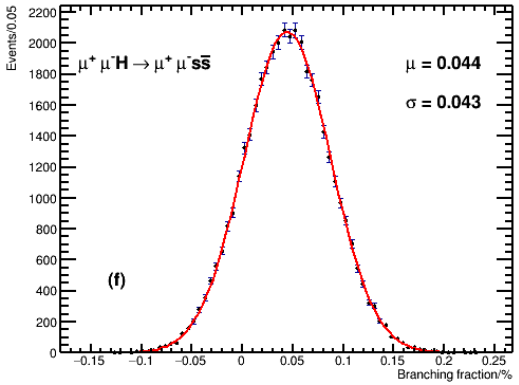












Sig	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to ZZ^*$	$H \to WW^*$	$H \to s\bar{s}$
Branching fraction	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}
Rel. Stat. Un.	0.3%	2.2%	1.3%	7.8%	1.1%	97.2%
Rel. Stat. Un. with fast sim bkg	0.3%	2.2%	1.3%	7.8%	1.2%	98.8%

Systematic uncertainty

- To account for detector-related effects, particularly those arising from vertex reconstruction and tracking, the D_0/Z_0 of each track was conservatively smeared by 20% of its error.
- By applying the previous ML model to MC samples generated with updated resolutions, the differences in branching fractions before and after the resolution change are considered as the systematic uncertainty.

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. Syst. Un.	0.1%	3.7%	1.8%	4.2%	0.4%	211.7%
Rel. Syst. Un. with fast sim bkg	0.1%	1.9%	1.7%	1.0%	0.9%	179.0%

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 fast sim bkg			
Rel. Stat. Un. with fast sim bkg	0.3%	2.2%	1.3%	7.8%	1.2%	98.8%
Rel. Syst. Un. with fast sim bkg	0.1%	1.9%	1.7%	1.0%	0.9%	179.0%

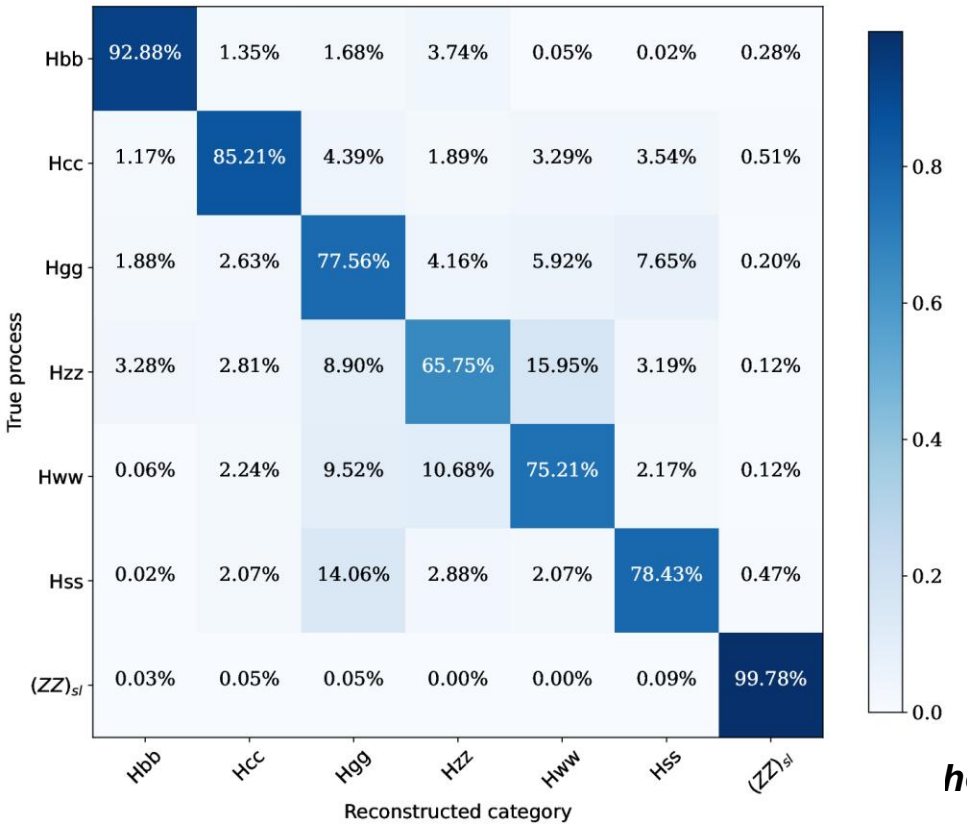
Back up

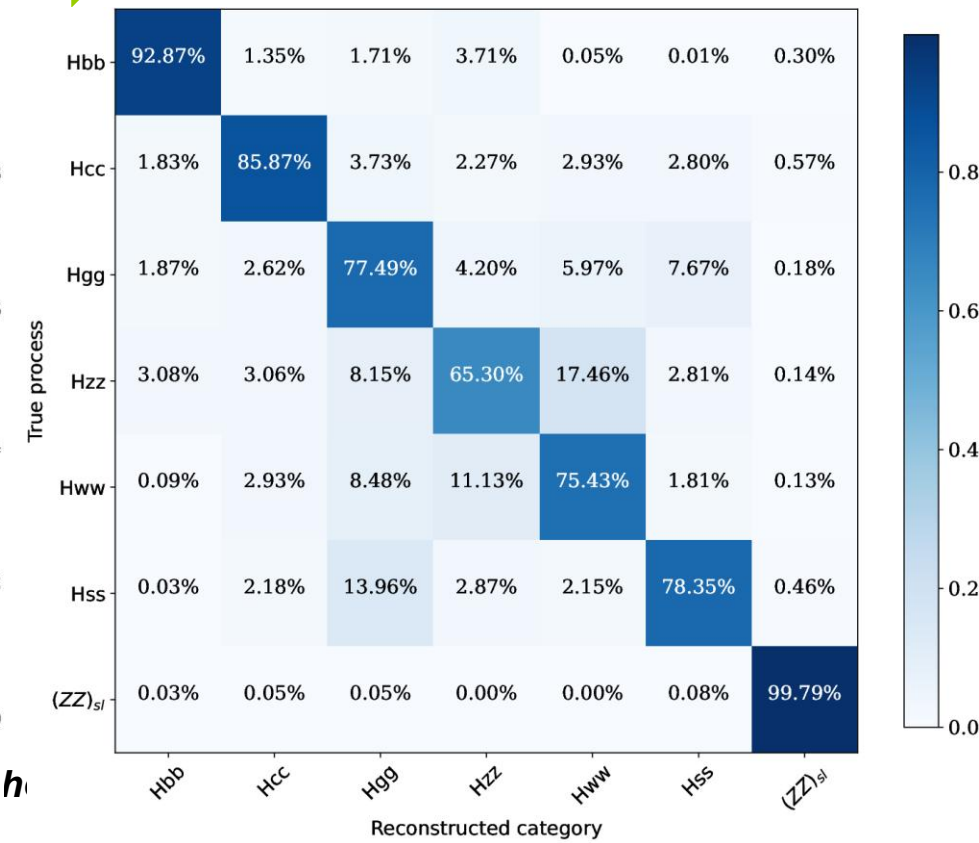
Former report: link

Systematic uncertainty

The sum of each row equals 1

After smear

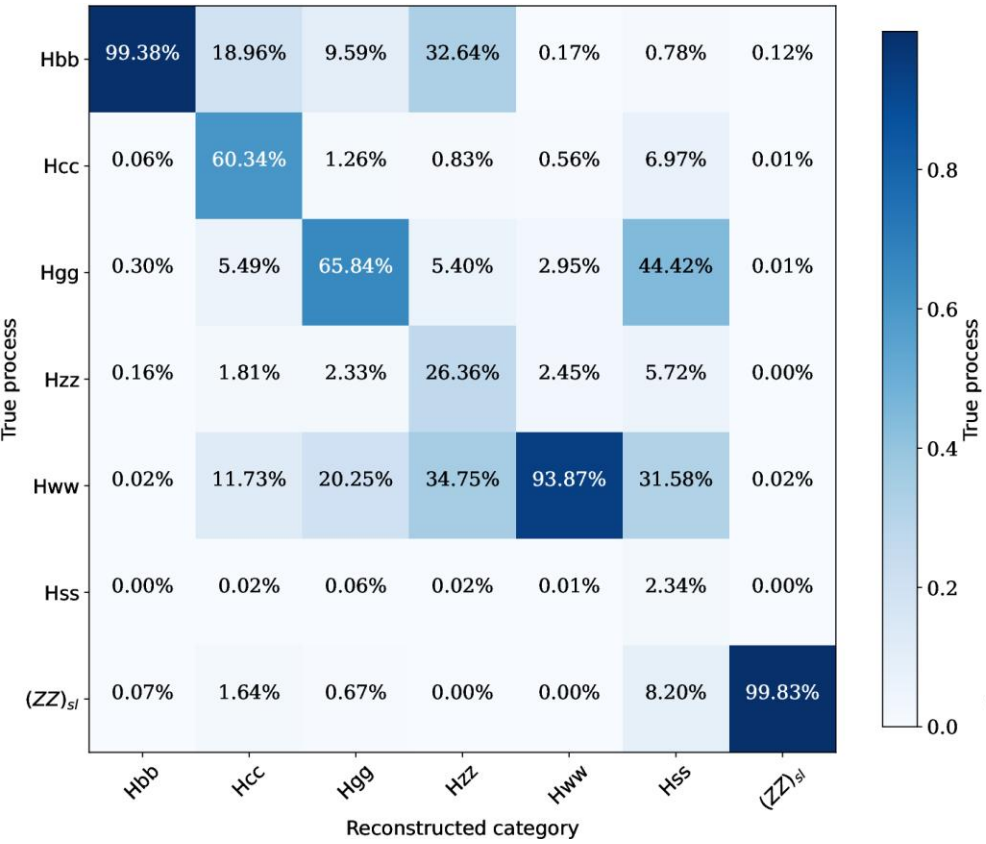


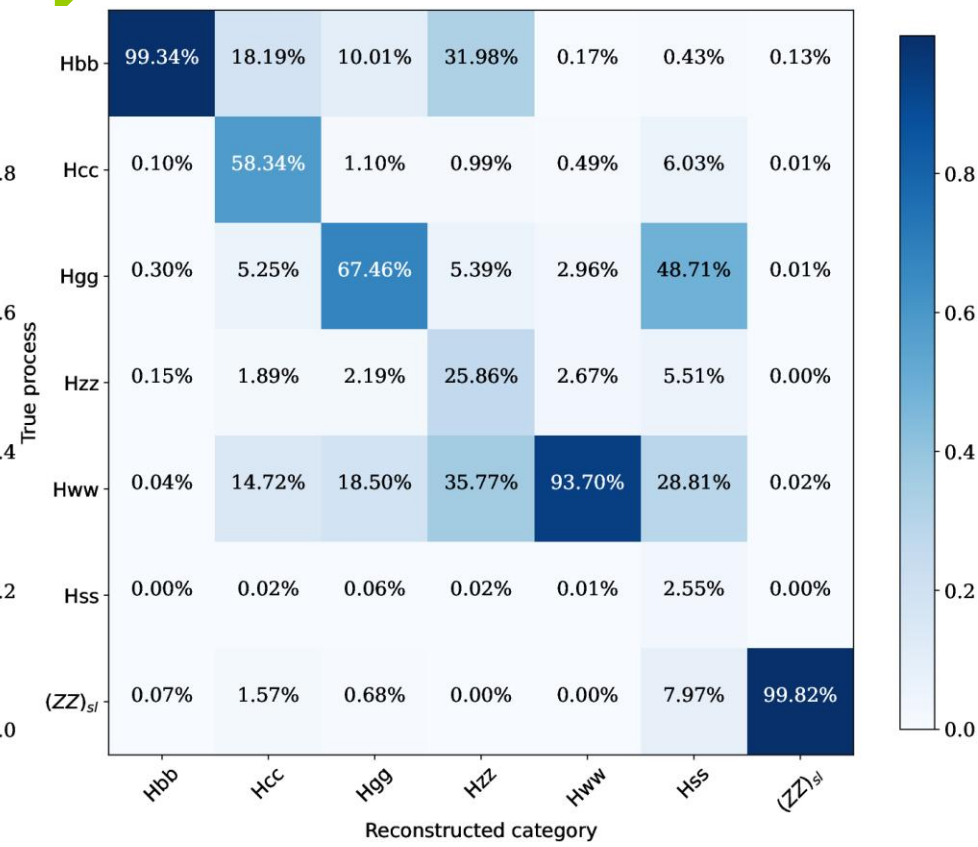


Systematic uncertainty

The sum of each column equals 1

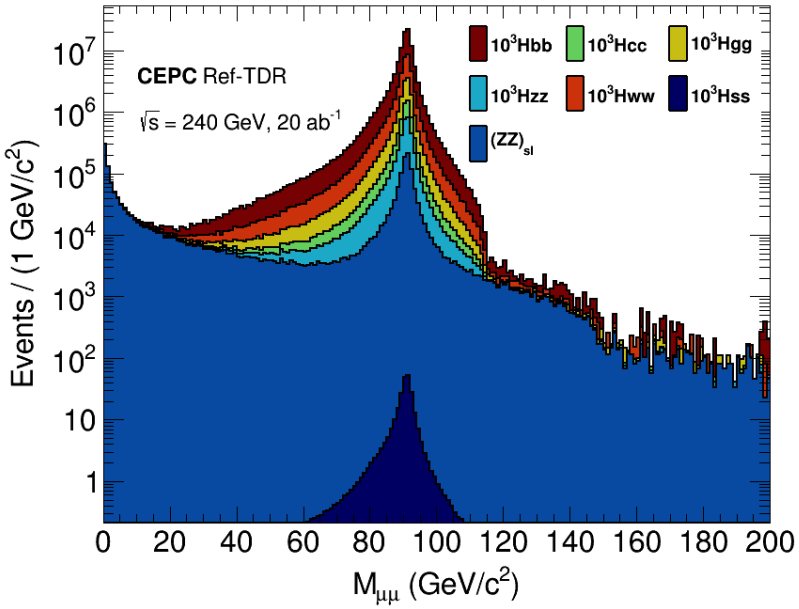
After smear



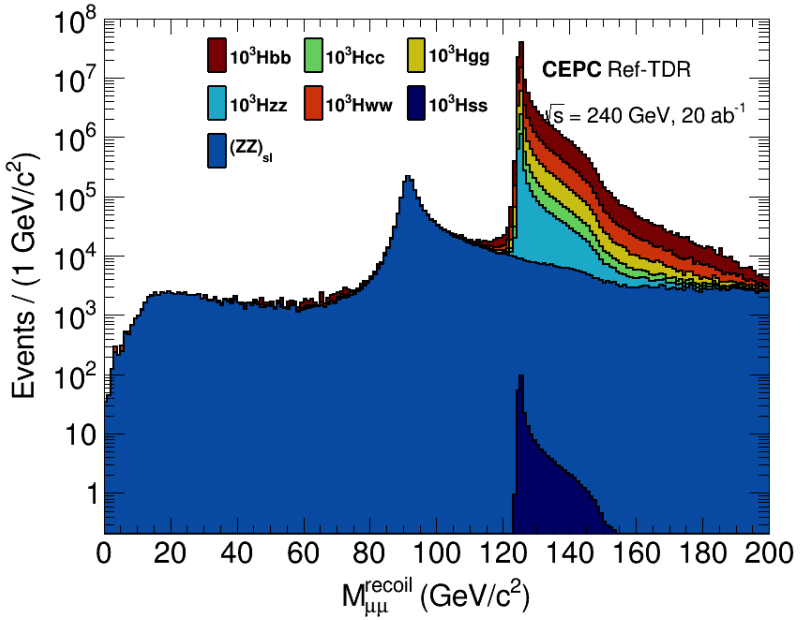


Event selection

- $M_{\mu\mu}$ and $M_{\mu\mu}^{\mathrm{recoil}}$ distributions for signal and background events, following the muon pair and isolation selection criteria.



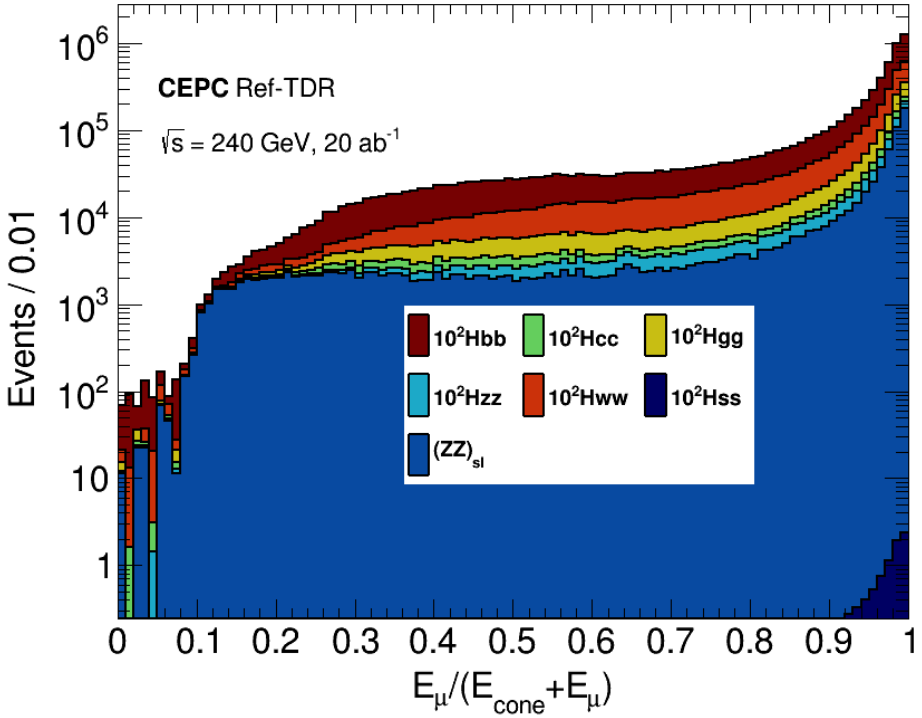
The invariant mass distributions of the muon pair

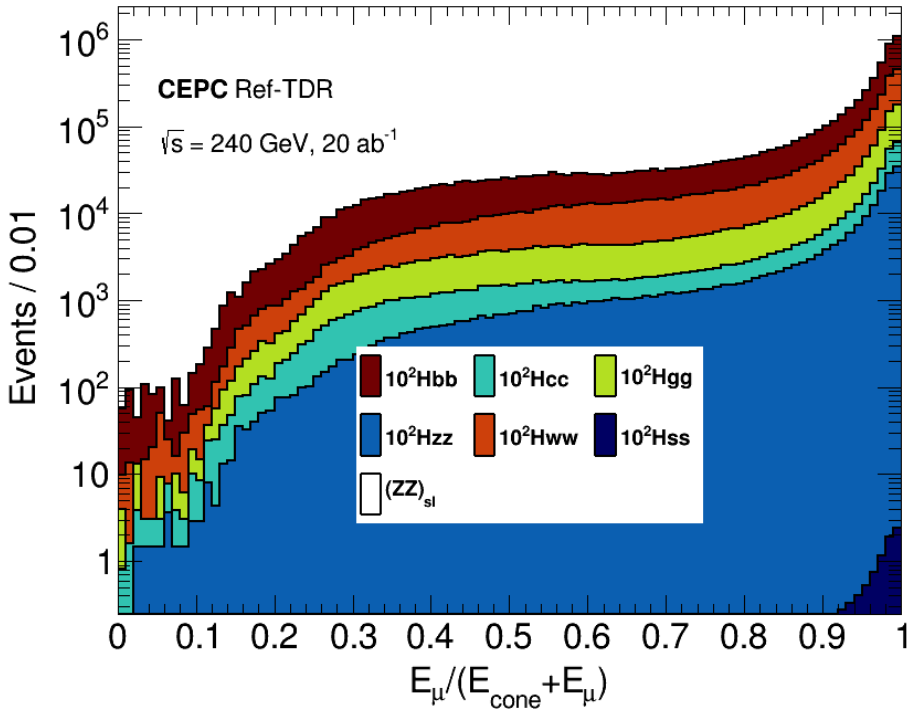


The invariant mass distributions of the muon pair recoil system

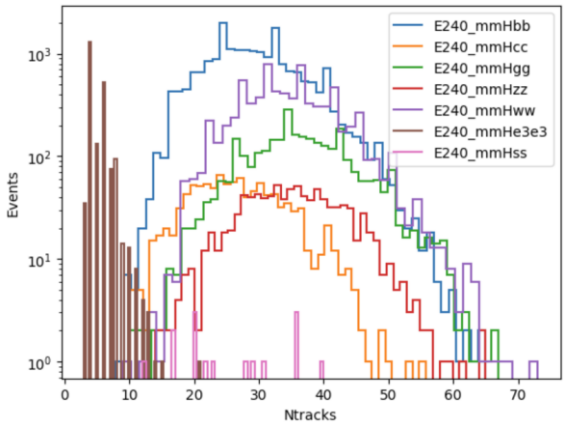
- The signal is well preserved while background contributions are significantly suppressed.

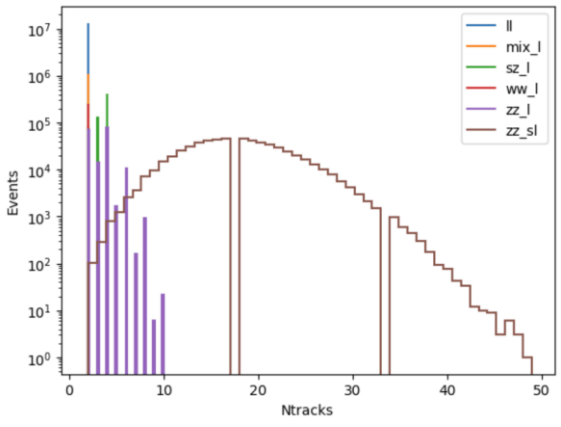
Isolation distributions

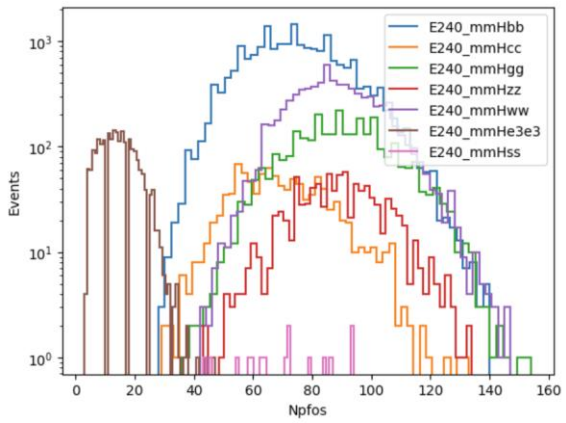


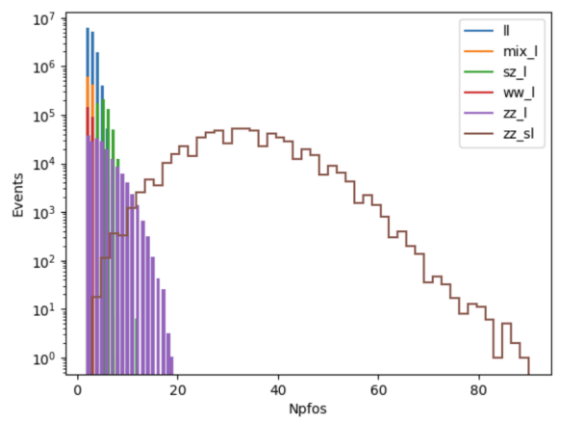


Distributions of signal vs fast sim bkg





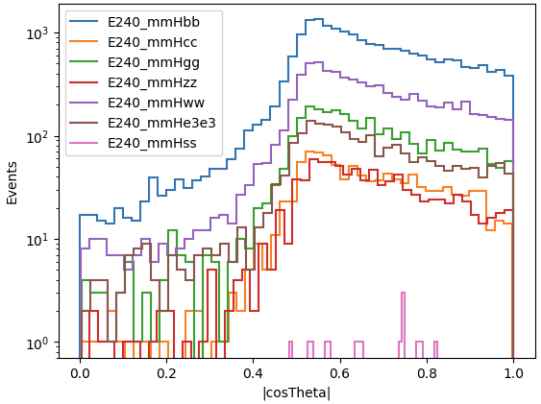




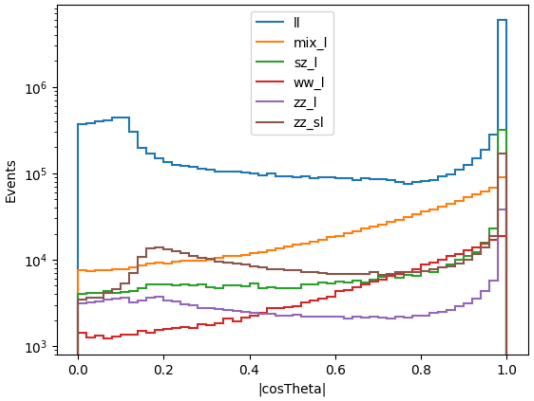
in signal

in bkg

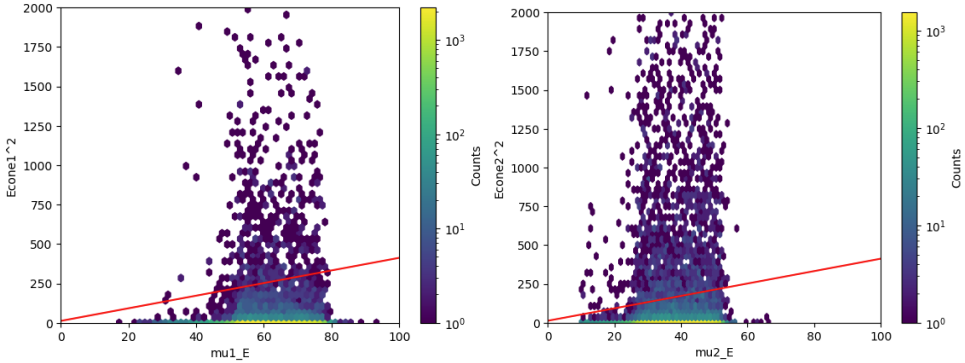
Distributions of signal vs fast sim bkg



$|\cos\theta|$ distributions in signal

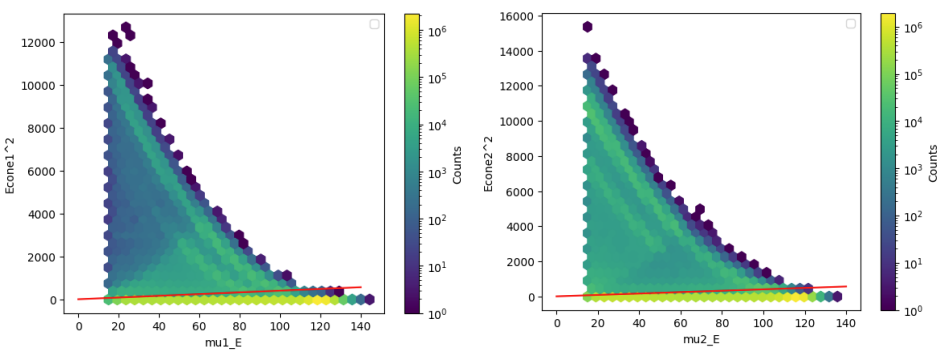


$|\cos\theta|$ distributions in background



signal

E^2_{cone} vs E_μ in muon pairs.



background

13-classification results (fast sim bkg)

Table 15.6: The cutflow selection efficiency for signal processes.

Process	$b\bar{b}$	$c\bar{c}$	gg	$\tau\bar{\tau}$	WW^*	ZZ^*	$s\bar{s}$
Muon pair	93.4%	93.1%	92.9%	94.3%	93.0%	93.1%	93.2%
Isolation	93.0%	93.3%	93.7%	94.6%	93.6%	93.8%	93.5%
Z mass window	96.1%	96.1%	96.1%	93.2%	96.0%	96.0%	96.0%
H mass window	99.6%	99.6%	99.6%	98.5%	99.6%	99.6%	99.6%
$\lvert\cos\theta_{\mu\mu}\rvert$ <0.996	99.6%	99.7%	99.6%	99.7%	99.6%	99.7%	99.7%
Total eff.	82.8%	82.9%	83.0%	81.6%	82.9%	83.2%	83.0%

Table 15.7: The cutflow selection efficiency for background processes.

Process	$(ZZ)_l$	$(ZZ)_{sl}$	$(WW)_l$	ll	$(SZ)_l$	$(mix)_l$
Muon pair	46.1%	18.8%	11.0%	11.9%	9.7%	29.3%
Isolation	77.4%	68.8%	98.0%	94.6%	48.2%	96.1%
Z mass window	66.4%	70.4%	34.7%	41.8%	28.3%	16.8%
H mass window	15.6%	16.3%	58.6%	6.6%	29.3%	41.1%
$\lvert\cos\theta_{\mu\mu}\rvert$ <0.996	98.8%	99.5%	98.7%	90.3%	99.0%	99.4%
Total eff.	3.7%	1.5%	2.2%	0.3%	0.4%	1.9%

Relative efficiency and total efficiency for each survived channel