Snowmass2021 - Letter of Interest

Measurement of branching fractions of Higgs hadronic decays

Thematic Areas: (check all that apply □/■)

■ (EF01) EW Physics: Higgs Boson properties and couplings
□ (EF02) EW Physics: Higgs Boson as a portal to new physics
□ (EF03) EW Physics: Heavy flavor and top quark physics
□ (EF04) EW Precision Physics and constraining new physics
□ (EF05) QCD and strong interactions: Precision QCD
□ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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Collaboration: CEPC

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Abstract: The high-precision measurement of Higgs boson properties is one of the primary goals of the Circular Electron Positron Collider (CEPC). The measurements of $H \to b\bar{b}/c\bar{c}/gg$ decay branching fraction in the CEPC experiment was presented. In order to improve the sensitivity and separation power of the 3 di-jet decay modes, simultaneous fit will be performed on the 5 decays modes including the Higgs di-jet decay modes of $H \to b\bar{b}/c\bar{c}/gg$ and the 2 background components with the 4-quark final states from the $H \to WW$ and $H \to ZZ^*$ decays. With the technique of machine learning and the matrix method, the brahch ratio of the 5 decays modes will be estimated.

Since the Higgs boson was discovered in 2012, the Higgs properities have been widely investigated. Different decay modes of the Higgs boson can be identified through their unique signatures, enabling the measurements of the production rates of these decays and Higgs mass, width, CP etc. Neverthless, there are many important areas beyond our current measurement precision due to low decay rates or large background contamination etc. For a SM Higgs boson with a mass of 125 GeV, nearly 70% of all Higgs bosons decay into a pair of jets: b-quarks (57.7%), c-quarks (2.9%) and gluon (8.6%). Table.1 shows the cross section of ZH to $H \to bb$, $H \to cc$, $H \to gg$ with the center-of-mass energy of 13TeV at the LHC experiment. Although the $H \to b\bar{b}$ has been observed at the LHC, the $H \to c\bar{c}$ and $H \to gg$ decays are difficult, if not impossible, to be conclusively identified even at the HL-LHC due to the large background, where the $H \to c\bar{c}$ decay is important to investigate the Higgs boson coupling to second-generation quarks.

Table 1: Cross sections of ZH to $H \to bb$, $H \to cc$, $H \to gg$ and $H \to 4q$ in the CEPC and LHC experiments.

ZH	$H \to bb$	$H \to cc$	$H \to gg$	$H \to 4q$	Total
CEPC (240 GeV)	118.31 fb	5.87 fb	16.66 fb	22.34 fb	163.18 fb
LHC (13 TeV)	512.59 fb	25.45 fb	72.18 fb	96.80 fb	707.01 fb

In CEPC, the three Higgs quark decays can be isolated and studied at the CEPC. The $H \to b\bar{b}/c\bar{c}/gg$ condidates can be identified through the dijet invariant mass, or the recoil mass and the visible Z boson decays, or both. Jet flavor tagging can be employed to separate $H \to b\bar{b}/c\bar{c}/gg$ contributions. The mis-identification in the jet flavor tagging will cause the peak contamination on the di-jet mass spectrum between each other. In order to improve the separation power of different Jet flavor typies, the likeness of different jet flavor tag can be used. Here, the b-weight likeness of the two individual jets of any selected event, Lb1 and Lb2, can be used to construct the combined B likenessu X_B. The c-weight likeness is defined in the same way to construct the combined C likenessu X_c. With the 3D fitting, the final statisitcal uncertainties on the cross section measurement for the $H \to b\bar{b}$, $H \to c\bar{c}$ and $H \to gg$ are 1.1%, 10.5% and 5.4% respectively for the $\mu^+\mu^- H$ channel. Meanwhile, there is the sizeable background contamination from the $H \to WW$ and $H \to ZZ^*$ decays with the final states of 4 quarks, which will behavor as the peaking background in the measurement of $H \to b\bar{b}/c\bar{c}/gg$ decays. Table.1 shows the cross sections of ZH to $H \to bb$, $H \to cc$, $H \to gg$ and $H \to 4q$ with the center-of-mass energy of 240GeV at the CEPC experiment. The signal and background ratio s/b can reach to about 2. The systematic uncertainties on those branch fration measurements are estimated, and the main sources are from the background uncertainty and jet favor tagging. More details are in [1].

In this study, a novelty way will be used to measure the production rates of those di-jet decay modes. Instead of separated measurement of each individual decay mode, we can perform the simultaneous measurement on the 5 decays modes including the Higgs di-jet decay modes of $H \to b\bar{b}/c\bar{c}/gg$ and the 2 background components with the 4-quark final states from the $H \to WW$ and $H \to ZZ^*$ decays. This work presented will focus on the Higgs boson production in asssociated with a pair of leptons of $\mu\mu$. Making use of the topology and kinematic information of the 5 kinds of decay modes, the technique of meachine learning will be employed to tag the 5 types of decay modes. The yields of the 5 tagged types can be measured at the reconstruction level. After that, we can unfold the reconstructed yields to the expected yields of the 5 genuine decays with the matrix inversion method. Eventually, we can measure the production rates of the 5 decays modes simultaneously.

Table 2: Uncertainties on $\sigma^{b\bar{b}}_{l^+l^-H}$, $\sigma^{c\bar{c}}_{l^+l^-H}$ and $\sigma^{gg}_{l^+l^-H}$ [1].

Higgs boson production	$\mu^+\mu^- H$		
Higgs boson decay	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
statistic uncertainty	1.1%	10.5%	5.4%
fixed background	-0.2% +0.1%	+4.1% -4.2%	7.6%
event selection	+0.7% -0.2%	+0.4% -1.1%	+0.7% -1.7%
flavor tagging	-0.4% +0.2%	+3.7% -5.0%	+0.2% -0.7%
combined systematic uncertainty	+0.7% -0.5%	+5.5% -6.6%	+7.6% -7.8%

References

[1] Yu Bai, Chunhui Chen, Yaquan Fang, Gang Li, Manqi Ruan, Jing-Yuan Shi, Bo Wang, Pan-Yu Kong, Bo-Yang Lan, and Zhan-Feng Liu. Measurements of decay branching fractions of $H \to b\bar{b}/c\bar{c}/gg$ in associated $(e^+e^-/\mu^+\mu^-)H$ production at the CEPC. *Chin. Phys. C*, 44(1):013001, 2020.