PROCEEDINGS OF SCIENCE

Boosted Higgs boson measurement at CMS

Chayanit Asawatangtrakuldee[a,*] **for the CMS collaboration**

[a] *Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*

E-mail: chayanit@cern.ch

Searches for the high transverse momentum (p_T) or boosted regime of the Higgs boson via gluon-gluon fusion and vector boson fusion productions are presented, where the Higgs boson decays to either a pair of bottom quarks or τ leptons. The results are based on proton-proton collision data collected by the CMS experiment at the LHC at a center-of-mass energy of 13 TeV. The data corresponds to an integrated luminosity of 138 fb^{-1}. The decay of a high-p_T Higgs boson to a boosted bottom quark-antiquark pair is isolated by selecting large-radius jets and exploiting jet substructure, as well as heavy flavor taggers based on advanced machine learning techniques. The signal production cross sections, relative to the expectations, targeting vector boson fusion and gluon-gluon fusion processes are extracted simultaneously by performing a fit to data in the large-radius jet mass. On the other hand, the decay of a high-p_T Higgs boson to a pair of τ leptons is reconstructed using a dedicated algorithm. The product of the production cross section and branching fraction is measured. The fiducial differential cross section of the Higgs boson is also provided as a function of the Higgs boson and leading jet transverse momenta.

The 2023 European Physical Society conference for High Energy Physics
20-25 August 2023
Universität Hamburg, Hamburg, Germany

[*] Speaker

https://pos.sissa.it/

PoS(EPS-HEP2023)396

1. Introduction

The observation of a new boson consistent with the standard model (SM) Higgs boson and the subsequent measurements of its properties [1, 2] have advanced the understanding of electroweak (EW) symmetry breaking and the origin of the mass of elementary particles. The Higgs boson has been observed at the CERN LHC in all its main expected production modes and several decay modes [3, 4]. Many properties of the Higgs boson have been scrutinized, without evidence of deviations from the SM expectations [5, 6].

Recently, there has been considerable interest in studying Higgs boson production at high momentum transfer because it can be a sensitive probe of beyond the standard model (BSM) physics, particularly momentum-dependent anomalous couplings [7]. Thus, studying Higgs bosons with high transverse momentum (p_T) has become an important part of the Higgs physics program at the LHC.

Existing searches for the boosted Higgs boson at the CMS experiment [8] have focused on inclusive Higgs production and, due to the dominance of gluon-gluon fusion (ggF), are primarily sensitive to new Higgs boson couplings to top quarks and gluons. For the $\mathrm{H} \to \mathrm{b\bar{b}}$ channel [9], an excess of events above the background-only hypothesis is observed with a local significance of 2.5 standard deviations (σ), while the expectation is 0.7. The corresponding signal production cross sections with respect to the standard model expectation is $\mu_{\mathrm{H}} = 3.7 \pm 1.2\,(\mathrm{stat})\,^{+0.8}_{-0.7}\,(\mathrm{syst})\,^{+0.8}_{-0.5}\,(\mathrm{theo})$. For the $\mathrm{H} \to \mathrm{c\bar{c}}$ channel [10], using similar analysis technique, the observed (expected) upper limit on $\sigma(H) \times BR(\mathrm{H} \to \mathrm{c\bar{c}})$ is set at 47 (39) times the SM prediction at 95% confidence level (CL).

Furthermore, searches for the SM Higgs boson decaying to a bottom (charm) quark-antiquark pair, $\mathrm{H} \to \mathrm{b\bar{b}}$ ($\mathrm{H} \to \mathrm{c\bar{c}}$), produced in association with a V (W or Z) boson is also performed by the CMS experiment. The high-p_T Higgs boson is included in the measurement of simplified template cross sections (STXS), targeting the two STXS p_T(V) bins above 250 GeV where the two AK4 jets start to overlap [11]. Combining resolved and boosted topology in the search for VH $\mathrm{H} \to \mathrm{c\bar{c}}$, the observed (expected) upper limit on $\sigma(H) \times BR(\mathrm{H} \to \mathrm{c\bar{c}})$ is 0.94 ($0.50\,^{+0.22}_{-0.15}$) pb at 95% CL, corresponding to 14 ($7.6\,^{+3.4}_{-2.3}$) times the standard model prediction [12].

2. Boosted ggF/VBF Higgs boson decayintg to a pair of bottom quarks

The Higgs boson production modes with highest cross sections at the LHC are gluon-gluon fusion (ggF) and vector boson fusion (VBF), respectively. The ggF contributes 87% of the total Higgs production. However, this number decreases to 50% above a p_T of 450 GeV [13]. Above p_T = 1200 GeV, the ggF and VBF rates are comparable. The VBF production mode provides a direct probe of Higgs couplings to vector bosons, and new physics contributions can manifest strongly at high p_T.

In order to disentangle the ggF and VBF production modes, the analysis is performed in two dedicated categories, VBF and ggF. In both categories, the $\mathrm{H} \to \mathrm{b\bar{b}}$ decay mode is isolated by a selection on the DEEPDOUBLEBVL − V2 (DDB) multivariate jet tagger [14].

Events with DDB tag discriminant > 0.64 (< 0.64) are selected into the DDB passing (failing) region – signal region. The failing region is used to constrain the normalization and shape of the QCD background by two multiplicative transfer factors. Both transfer factors are aimed to accommodate difference in the shape of soft drop mass between passing and failing regions due to the tagger selection and between data and simulation. For each transfer factor, the optimal number of free parameters is determined by a Fisher F-test.

Finally, a binned maximum likelihood fit to the observed soft drop mass distributions has performed using the sum of the signal and background contributions. The fit is performed simultaneously in all differential bins of the ggF and VBF categories, in the single muon control region (top background), and in both the DDB passing and failing regions.

The combined signal production cross sections relative to the expectations (signal strength) for the VBF (ggF) process is measured to be $5.0^{+2.1}_{-1.8}$ $(2.1^{+1.9}_{-1.7})$. The corresponding significance is calculated with the another signal freely floating: the observed (expected) VBF significance is 3.0 σ (0.9 σ), the observed (expected) ggF significance is 1.2 σ (0.9 σ) [15].

The observed data and fitted soft drop mass distributions in the VBF category are shown in Figure 1 (top), and the ggF category (bottom). The DDB fail region is shown on the left, and the signal enriched DDB pass region on the right. A large enhancement in the relative contribution from $Z \rightarrow b\bar{b}$ decay is clearly visible after the DDB cut is applied.

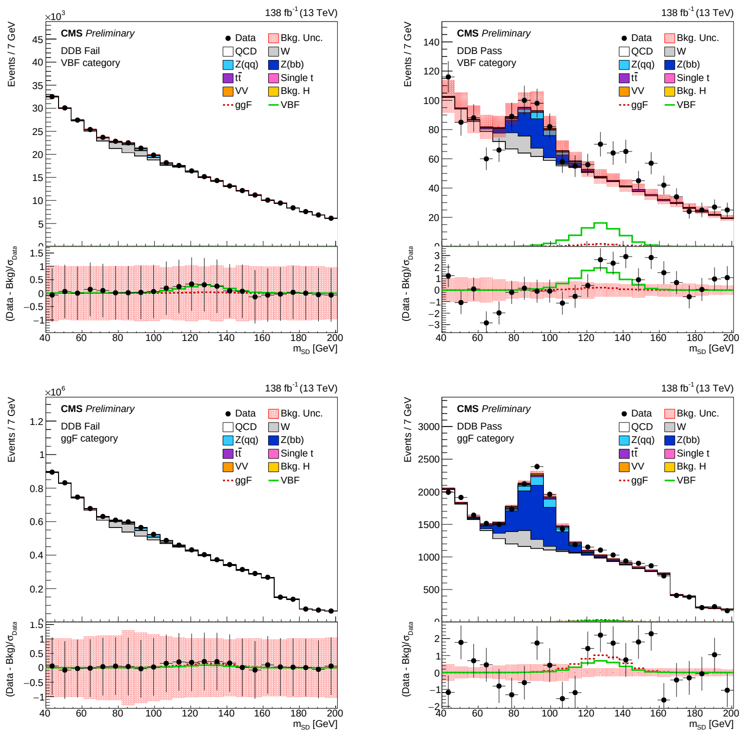

Figure 1: Data and fitted soft drop mass distribution in the VBF category (top) and ggF category (bottom), summed over all data-taking periods. The DDB failing (left) and passing (right) regions are shown. The ggF and VBF signals are scaled to the fitted event yields.

Figure 2 shows the combined two-dimensional likelihood scan performed over the ggF and VBF signal production cross sections. The best fit point differs from the SM expectation by 2.6 σ, and from the null hypothesis (no Higgs boson) by 3.9 σ.

PoS(EPS-HEP2023)396

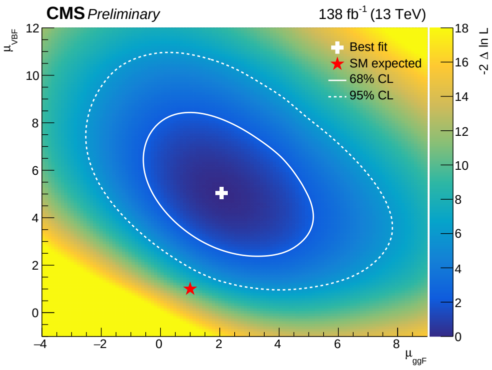

Figure 2: Two-dimensional likelihood contour of the ggF and VBF signal strengths. The color scale represents twice the negative log likelihood difference with respect to the best fit point. The observed 95% (dashed) and 68% (solid) contours are shown in white, and the best fit point as a white cross. The SM expectation is marked by a red star.

3. Boosted Higgs boson decaying to a pair of τ leptons

A measurement of the highly Lorentz-boosted Higgs boson cross section is presented, where the Higgs boson decays to a pair of τ leptons and its transverse momentum is greater than 250 GeV [16]. The τ leptons are required to be spatially close, and a dedicated algorithm is used to reconstruct and identify them. The analysis combines the most four sensitive channels: $\mu\tau_h$, $e\tau_h$, $e\mu$ and $\tau_h\tau_h$.

To reconstruct the boosted τ_h candidate, particles are first clustered in a large-radius jet with the Cambridge–Aachen algorithm with a distance parameter of 0.8 and $p_T > 170$ GeV. The final step of the jet clustering is reversed to find two sub-jets consistent with τ leptons. The sub-jets are then processed with the standard τ algorithm to identify the τ_h decay modes and compute discriminants to reject mis-reconstructed jets, electrons, and muons.

A multi-class NN is then used to construct a discriminant that separates the signal from the Drell–Yan and mis-ID backgrounds. Based on the maximum of the three scores, each normalized to unity for a probabilistic interpretation, events are sorted into one signal-enriched region and two background-dominated regions.

The signal region is divided in four $p_T^{\rm H}$ bins: 250, 350, 450, and 600 GeV. Finally, a binned maximum likelihood fit considering the systematic uncertainties as nuisance parameters is performed to the NN output distributions to compute the probability of the compatibility of observed data with the background-only hypothesis. The best fit signal strength modifier is also extracted from a maximum likelihood fit to the same distributions and is found to be $1.64\,^{+0.68}_{-0.54}$, in agreement with the SM prediction. The combined NN distributions in the signal region are shown in Figure 3.

The inclusive fiducial cross section is measured from the $p_T^{\rm H}$ distributions used in the differential analysis. Its best-fit value is $1.96^{+0.86}_{-0.69}$ fb, which is consistent with the SM prediction of 1.20 ± 0.20 fb.

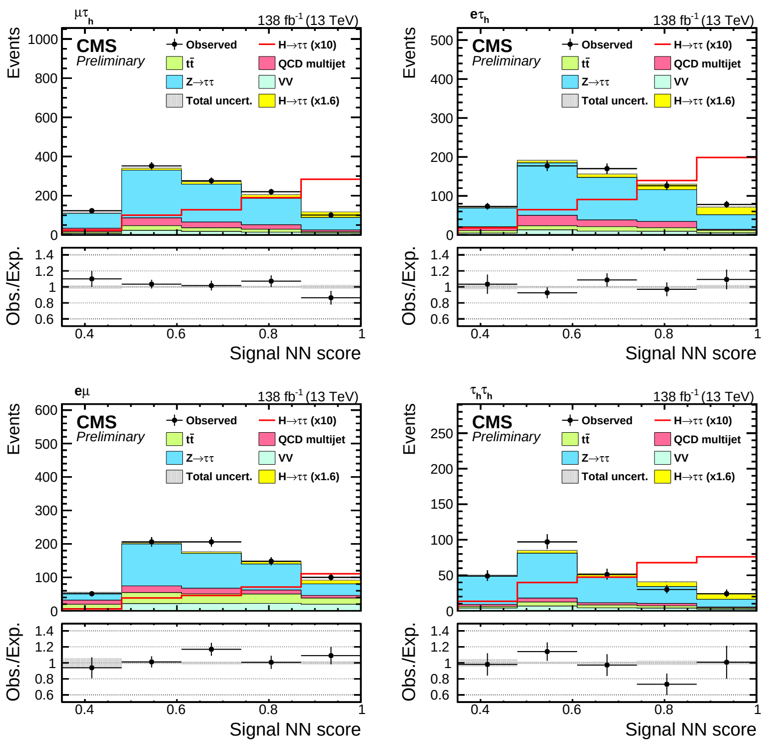

Figure 3: Observed and expected NN distributions in the signal region, after combining all four p_T^{H} bins, in the $\mu\tau_h$ (top left), $e\tau_h$ (top right), $e\mu$ (bottom left) and $\tau_h\tau_h$ (bottom right) channels.

4. Summary

Searches and measurements of highly Lorentz-boosted Higgs boson have been presented using data collected by the CMS experiment at the LHC at a center-of-mass energy of 13 TeV. The data corresponds to an integrated luminosity of 138 fb^{-1}. The boosted topology of the Higgs boson has provided the precious value to the LHC Higgs program.

5. Acknowledgements

This work has received funding support from the NSRF via the Program Management Unit for Human Resources & Institutional Development, Research and Innovation [**B37G660013**] and financially supported by Sci-Super IX fund from Faculty of Science, Chulalongkorn University.

References

[1] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, *Phys. Lett. B* **716** (2012) 1.

[2] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, *Phys. Lett. B* **716** (2012) 30.

[3] ATLAS Collaboration, *Combined measurements of Higgs boson production and decay using up to 80 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV collected with the ATLAS experiment*, *Phys. Rev. D* **101** (2020) no 1, 012002.

[4] CMS Collaboration, *Combined measurements of higgs boson couplings in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, *Eur. Phys. J. C* **79** (2019) 421.

[5] ATLAS Collaboration, *A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery*, *Nature* **607** (2022) 52.

[6] CMS Collaboration, *A portrait of the Higgs boson by the CMS experiment ten years after the discovery*, *Nature* **607** (2022) 60.

[7] X. Chen et al., *NNLO QCD corrections to Higgs boson production at large transverse momentum*, *JHEP* **10** (2016) 066.

[8] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** S08004 (2008).

[9] CMS Collaboration, *Inclusive search for highly boosted Higgs bosons decaying to bottom quark-antiquark pairs in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, *JHEP* **12** (2020) 085.

[10] CMS Collaboration, *Search for Higgs Boson and Observation of Z Boson through Their Decay into a Charm Quark-Antiquark Pair in Boosted Topologies in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV*, *Phys. Rev. Lett.* **131** (2023) 041801.

[11] CMS Collaboration, *Simplified template cross section measurements of Higgs boson produced in association with vector bosons in the* $\mathrm{H} \rightarrow \mathrm{b\bar{b}}$ *decay channel in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, CMS-PAS-HIG-20-001.

[12] CMS Collaboration, *Search for Higgs Boson Decay to a Charm Quark-Antiquark Pair in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV*, *Phys. Rev. Lett.* **131** (2023) 061801.

[13] CMS Collaboration, *Search for boosted Higgs bosons produced via vector boson fusion in the $H \rightarrow b\bar{b}$ decay mode using LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV*, CMS-PAS-HIG-21-020.

[14] CMS Collaboration, *Performance of the mass-decorrelated DeepDoubleX classifier for double-b and double-c large-radius jets with the CMS detector*, CMS-DP-2022-041.

[15] K. Becker, F. Caola, A. Massironi, et al., *Precise predictions for boosted higgs production*, (2021). `arXiv:2005.07762`.

[16] CMS Collaboration, *Measurement of the highly Lorentz-boosted Higgs boson cross section in the decay mode of a pair of τ leptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, CMS-PAS-HIG-21-017.

PoS(EPS-HEP2023)396