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CMS DP -2023/050

The Compact Muon Solenoid Experiment

CMS Performance Note

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14 August 2023 (v2, 15 August 2023)

Novel strategy targeting HH and HHH production at High Level Trigger in Run 3

CMS Collaboration

Abstract

For 2023, by exploiting the recent improvements in heavy flavour tagging, a new trigger strategy targeting HH and HHH production is deployed at the High Level Trigger (HLT) of the CMS experiment. The new trigger applies a selection criterion based on the total transverse momentum of jets HT > 280 GeV, the presence of at least 4 central jets with $p_T > 30$ GeV and the average ParticleNet b-tagging score of the two small-radius jets with the highest b-tag scores above 0.55. In addition, in 2023, the Level 1 trigger requirement on HT is lowered from 360 GeV to 280 GeV compared to 2022 and 2018. By exploiting the Data Parking strategy, which allows a higher rate and acceptance at the cost of delayed reconstruction, this new HLT trigger records events at 180 Hz at an instantaneous luminosity of 2×10^{34} cm^{-2} s^{-1}. The following studies show the performance of this new trigger for $HH \to 4b$, $HH \to 2b2\tau$, $HHH \to 6b$ and $HHH \to 4b2\tau$ production and corresponding decay modes.

Novel strategy targeting HH and HHH production at High Level Trigger in Run 3

CMS collaboration

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Introduction

One of the key properties of the Higgs boson that has not been measured yet is its self-coupling, which determines the shape of the Higgs potential and the stability of the vacuum. The self-coupling can be probed by studying the production of multiple Higgs bosons through the measurements of HH and HHH production. One of the main challenges of these measurements is the presence of multiple b-jets in the final state, which are subject to a lower identification efficiency at the trigger level.

For 2023, by exploiting the recent improvements in heavy flavour tagging, a new trigger strategy targeting HH and HHH production is deployed at the High Level Trigger (HLT) of the CMS experiment. The new trigger applies a selection criterion based on the total transverse momentum of jets HT > 280 GeV, the presence of at least 4 central jets with pT > 30 GeV and the average ParticleNet [1] b-tagging score of the two small-radius jets with the highest b-tag scores above 0.55. In addition, in 2023, the Level 1 trigger requirement on HT is lowered from 360 GeV to 280 GeV compared to 2022 and 2018.

By exploiting the Data Parking strategy, which allows a higher rate and acceptance at the cost of delayed reconstruction, this new HLT trigger records events at 180 Hz at an instantaneous luminosity of 2x10^34 cm-2 s-1. The following studies show the performance of this new trigger for HH→4b, HH→2b2$\boldsymbol{\tau}$, HHH→6b and HHH→4b2$\boldsymbol{\tau}$ production and corresponding decay modes.

[1] CMS-DP-2023/21

Glossary

HT: Scalar sum of jet transverse momenta in the event. In case of HLT, jets considered in the sum are required to have pT >30 GeV and $|\eta| < 2.4$, meaning they are reconstructed within the central region of the detector.

Missing transverse energy: Magnitude of the vectorial sum of all reconstructed visible momenta.

Level 1 trigger: first stage of the two-stage trigger system that selects events from proton-proton collisions at the LHC

High-level trigger: second stage of the two-stage trigger system

DeepJet: deep neural network tagging algorithm designed to identify flavour of the hadron that initiated a jet

ParticleNet: dynamic graph convolutional neural network to identify flavour of the hadron that initiated a jet

DeepTau: deep neural network to identify hadronic tau-lepton decays

Details of the study

Trigger efficiencies are defined as:

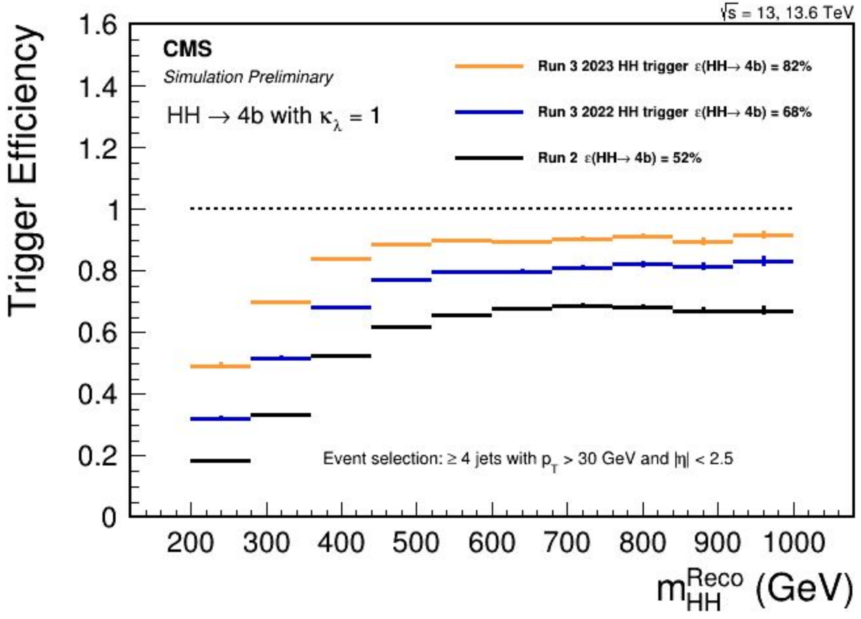
$$\varepsilon = \frac{N_{\text{events}}(\text{pass trigger and event selection})}{N_{\text{events}}(\text{pass event selection})}$$

For each measured trigger efficiency, the event selection applied on the reconstructed objects (after the CMS detector response simulation) is stated in the label of the figures. For results reporting the measurement of HH production, the shape of the invariant mass distribution for the Run 3 data sets is shown using the same event selection as for the trigger efficiency study, highlighting the region of phase-space recorded by the triggers.

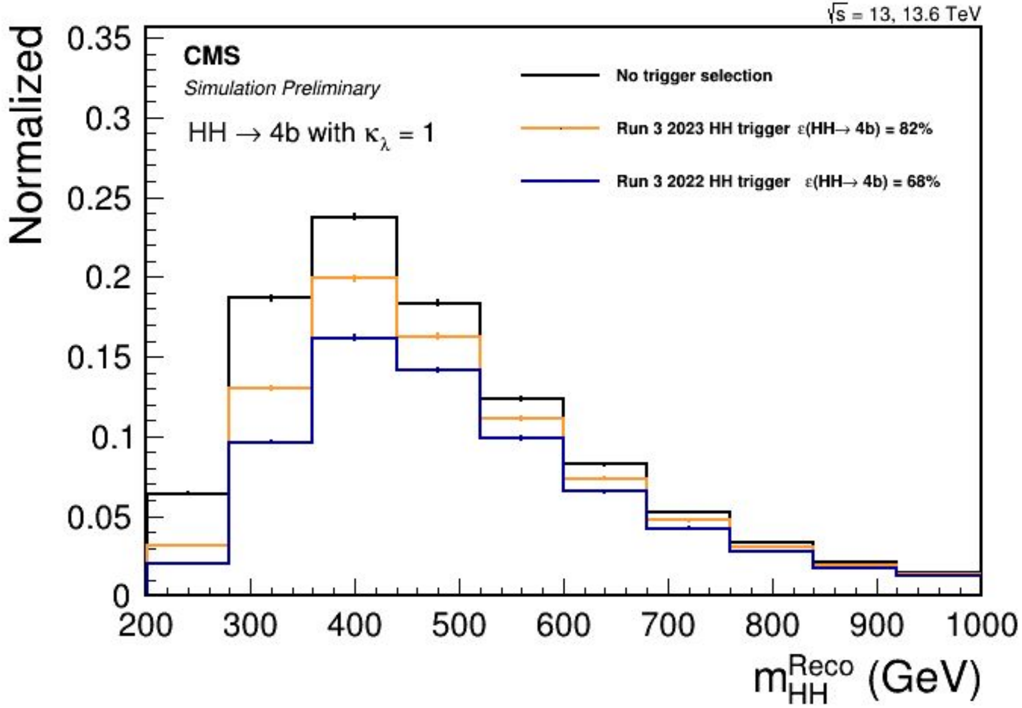
List of triggers

Trigger	Requirement	Rates at HLT at 2x10^34 cm-2s-1
2023 HH trigger	HT > 280 GeV, 4 jets with pT > 30 GeV, PNet@AK4(mean 2 highest b-tag score) > 0.55	180 Hz
2022 HH trigger	4 jets pT > 70, 50, 40, 35 GeV, PNet@AK4(mean 2 highest b-tag score) > 0.65	60 Hz
2018 triple b-tag [2,3]	HT > 340 GeV, 4 jets pT > 75, 60, 45, 40 GeV, 3 b-tags with DeepCSV > 0.24	8 Hz
Run 3 tau-triggers [4]	Double medium DeepTau taus with pT > 35 GeV |η| < 2.1 Double medium DeepTau taus with pT > 30 GeV |η| < 2.1 , PFJet 60 GeV Single loose DeepTau on hadronic tau with pT > 180 GeV |η| < 2.1	50 Hz 20 Hz 17 Hz
Run 3 MET-trigger [5]	Missing transverse energy (MET) (no muon) > 120 GeV, HT (no muon) > 120 GeV	42 Hz

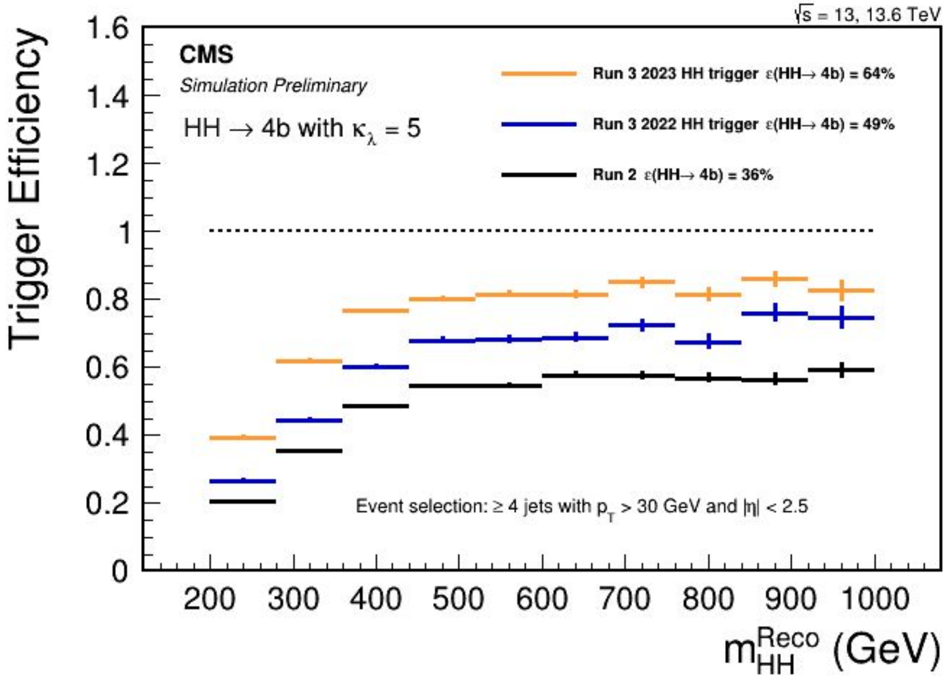
[2] CMS-DP-2019/042 [3] CMS-DP-2019/026 [4] CMS-DP-2023/024 [5] CMS-DP-2023-016



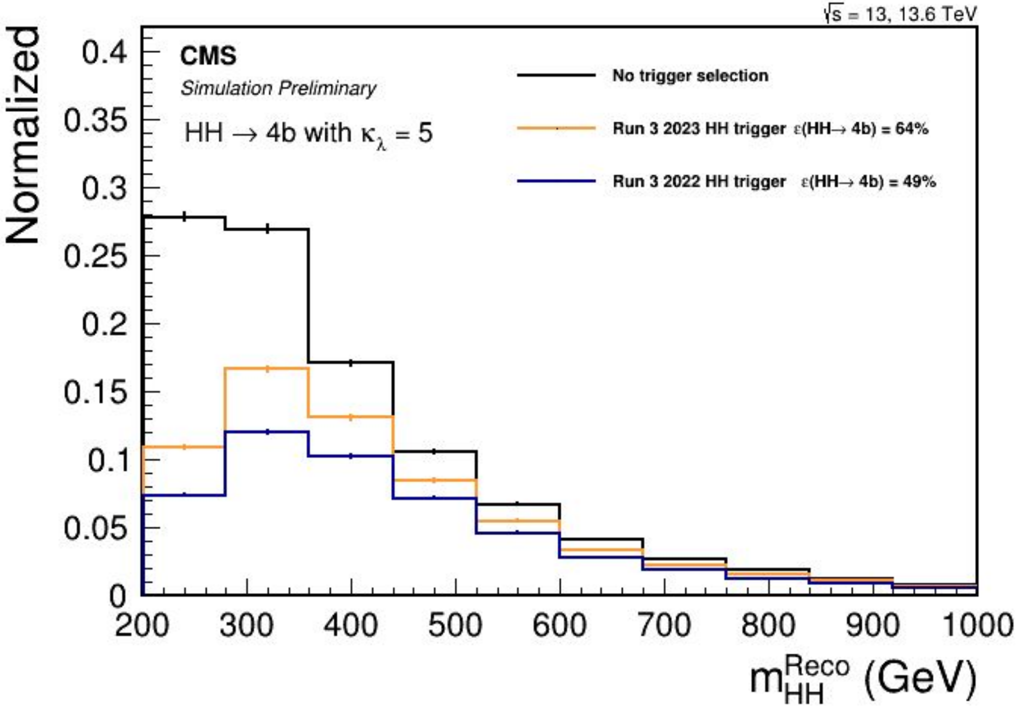
Trigger efficiency as a function of the invariant mass m_{HH} for the simulated Standard Model HH→4b process with κ_λ = 1 shown for Run 2 (black), Run 3 2022 (blue) and Run 3 2023 trigger (orange). The two Higgs boson candidates are reconstructed from four central jets with the highest b-tagging scores. The trigger efficiency achieved by the new strategy is 82%, improved by 57% with respect to Run 2 and 20% with respect to 2022. The better performance of ParticleNet tagging on small-radius jets with respect to Run 2 taggers and the lowered HT requirement from 360 GeV to 280 GeV at the L1 trigger result in a higher trigger efficiency on the full spectrum of the m_{HH} distribution.



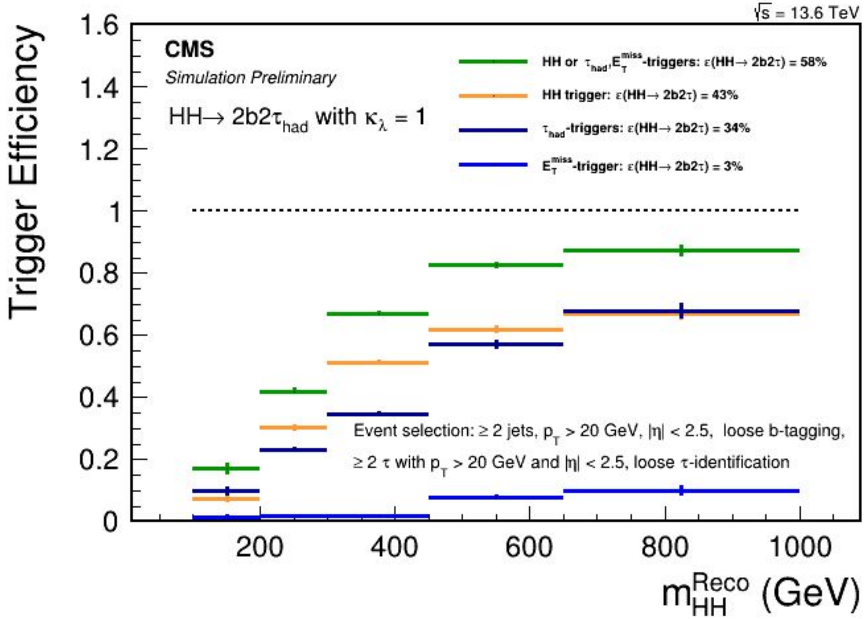
Invariant mass m_{HH} distribution of the HH candidates for the simulated Standard Model HH→4b process with $\boldsymbol{\kappa}_{\lambda}$ = 1 shown for no trigger requirement (black), Run 3 2022 (blue) and Run 3 2023 trigger (orange). The two Higgs boson candidates are reconstructed from four central jets with the highest b-tagging score.



Trigger efficiency as a function of the invariant mass m_{HH} for the simulated HH→4b process with $\boldsymbol{\kappa}_{\lambda}$ = 5 shown for Run 2 (black), Run 3 2022 (blue) and Run 3 2023 trigger (orange). The two Higgs boson candidates are reconstructed from four central jets with the highest b-tagging score. The trigger efficiency achieved by the new strategy is 64%, improved by 78% with respect to Run 2 and 30% with respect to 2022.

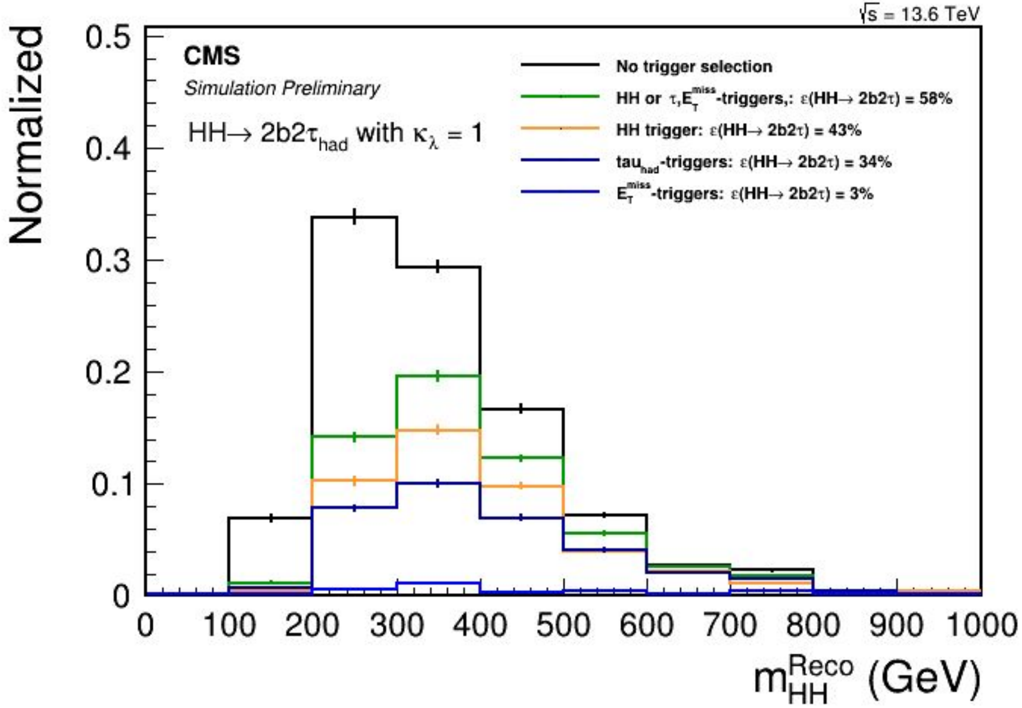


Invariant mass m_{HH} distribution of the HH candidates for the simulated HH→4b process with $\boldsymbol{\kappa}_\lambda$ = 5 shown for no trigger requirement (black), Run 3 2022 (blue) and Run 3 2023 trigger (orange). The two Higgs boson candidates are reconstructed from four central jets with the highest b-tagging score.

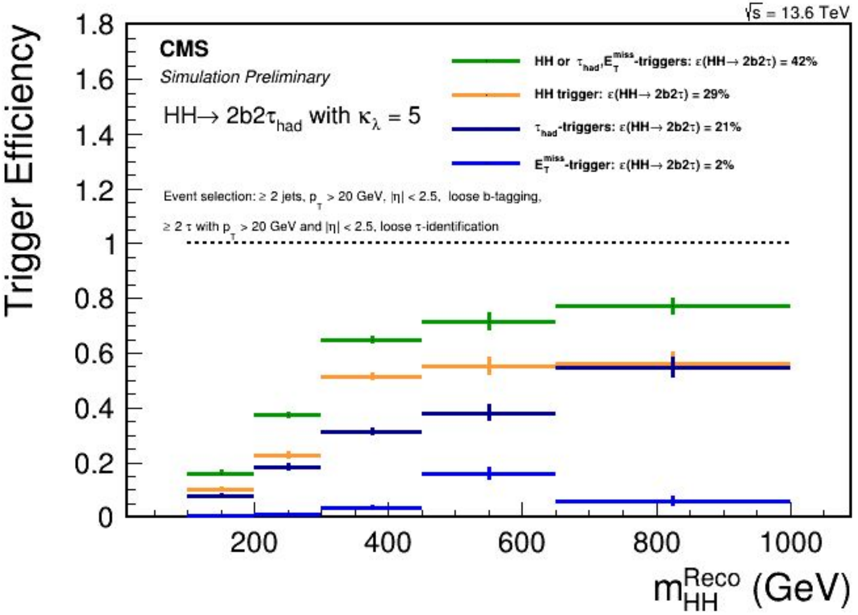


Trigger efficiency as a function of the invariant mass m_{HH} for the simulated Standard Model $HH \rightarrow 2b2\tau_{had}$ process with κ_{λ} = 1 shown for Run 3 hadronic τ triggers (blue), Run 3 2023 HH trigger (orange) and a combination of both triggers (green). The two Higgs boson candidates are reconstructed from two loose b-tagged (DeepJet [6], 10% mis-identification on usdg-jets) central jets and two τ candidates satisfying a loose hadronic τ identification (DeepTau [7], 80% identification of hadronic τ). The trigger efficiency achieved by the new strategy is 43% and the hadronic τ triggers efficiency is 34%. Combining both triggers together with the missing transverse energy trigger results in a 58% trigger efficiency.

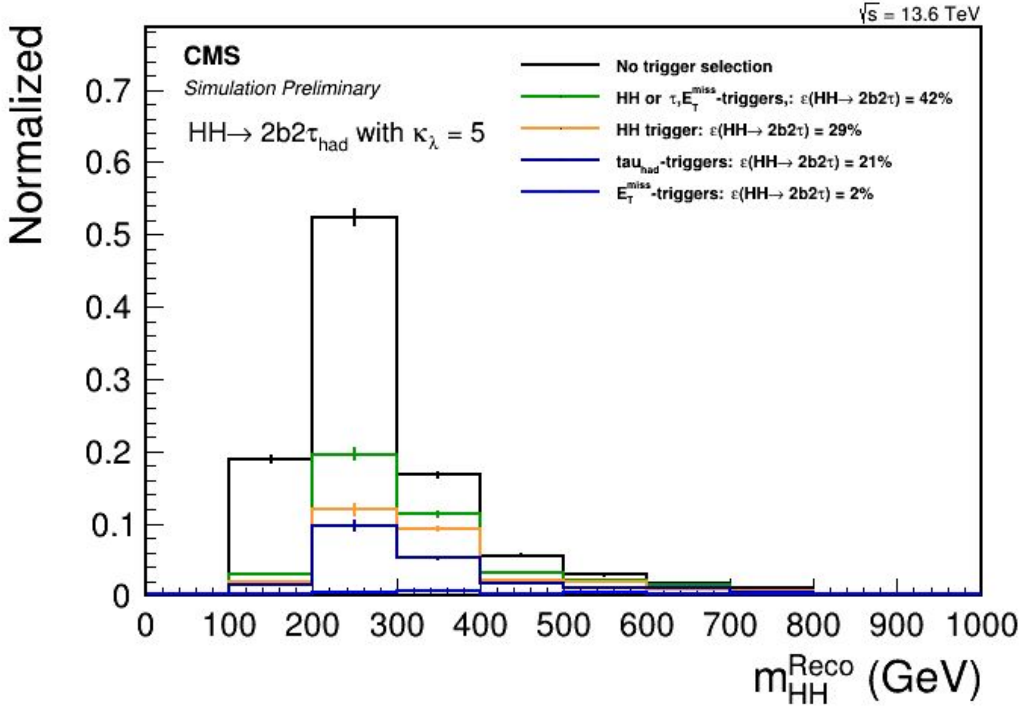
[6] CMS-BTV-20-001 [7] CMS-TAU-20-001



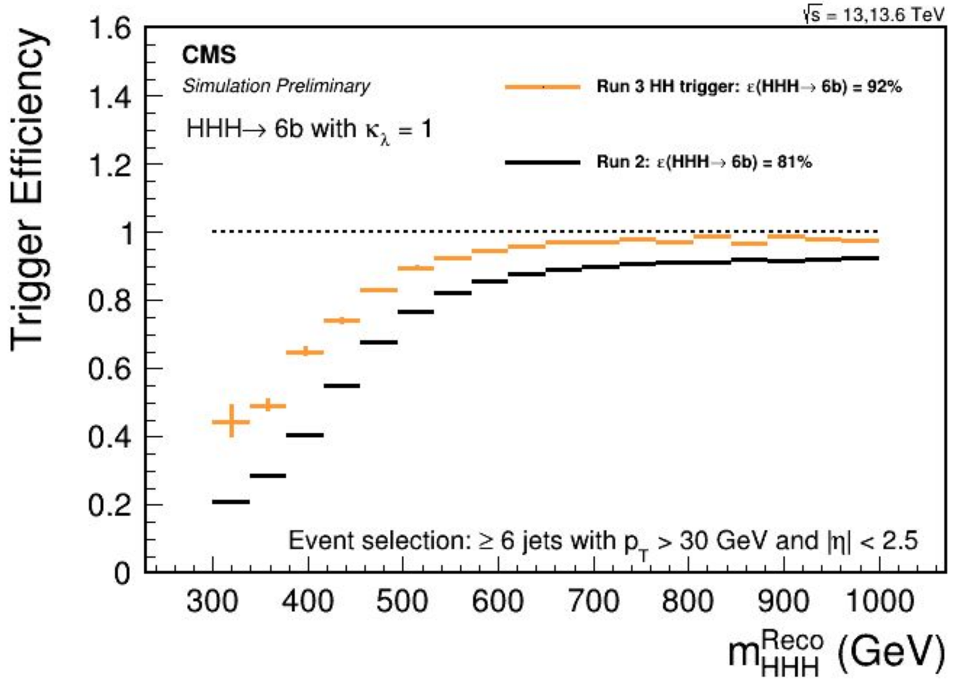
Invariant mass m_{HH} distribution of the HH candidates for the simulated Standard Model HH→2b2$\boldsymbol{\tau}_{had}$ process with $\boldsymbol{\kappa}_{\lambda}$ = 1 shown for no trigger requirement (black), Run 3 hadronic $\boldsymbol{\tau}$ triggers (blue), Run 3 2023 HH trigger (orange) and a combination of both triggers (green). The two Higgs boson candidates are reconstructed from two loose b-tagged central jets and two $\boldsymbol{\tau}$ candidates satisfying a loose hadronic $\boldsymbol{\tau}$ identification.



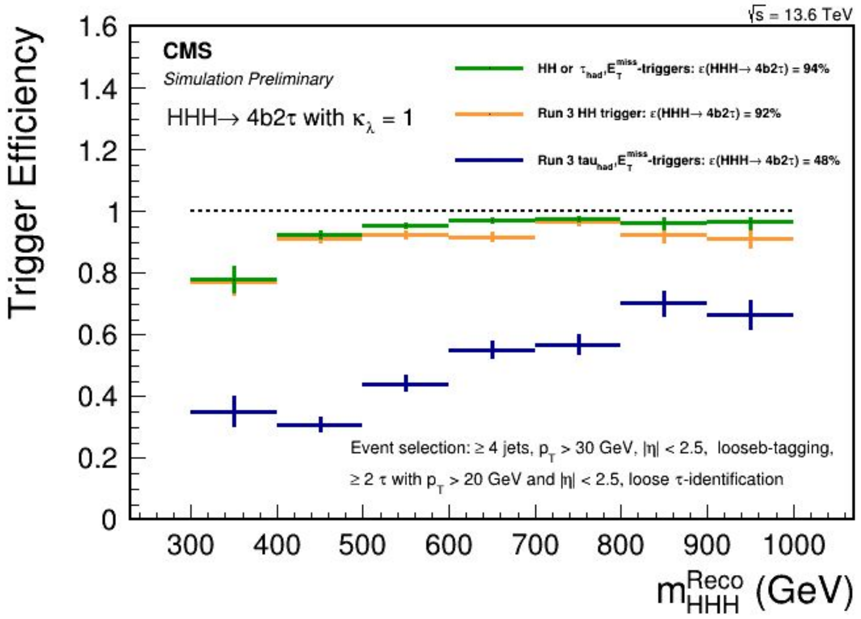
Trigger efficiency as a function of the invariant mass m_{HH} for the simulated HH→2b2$\boldsymbol{\tau}_{had}$ process with $\boldsymbol{\kappa}_{\lambda}$ = 5 shown for Run 3 hadronic $\boldsymbol{\tau}$ triggers (blue), Run 3 2023 HH trigger (orange) and a combination of both triggers (green). The two Higgs boson candidates are reconstructed from two loose b-tagged central jets and two $\boldsymbol{\tau}$ candidates satisfying a loose hadronic $\boldsymbol{\tau}$ identification. The trigger efficiency achieved by the new strategy is 29% and the hadronic $\boldsymbol{\tau}$ triggers efficiency of 21%. Combining both triggers together with the missing transverse energy trigger results in a 42% trigger efficiency in the selected phase-space.



Invariant mass m_{HH} distribution of the HH candidates for the simulated HH→4b process with $\boldsymbol{\kappa}_\lambda$ = 5 shown for no trigger requirement (black), Run 3 hadronic $\boldsymbol{\tau}$ triggers (blue), Run 3 2023 HH trigger (orange) and a combination of both triggers (green). The two Higgs boson candidates are reconstructed from two loose b-tagged central jets and two $\boldsymbol{\tau}$ candidates satisfying a loose hadronic $\boldsymbol{\tau}$ identification.



Trigger efficiency as a function of the invariant mass m_{HHH} for the Standard Model HHH→6b process comparing the Run 3 2023 HH trigger (orange) with the Run 2 trigger (black). The three Higgs boson candidates are reconstructed from the six central jets with the highest b-tagging score. The trigger efficiency achieved by the new strategy is 92%, improved by 14% with respect to Run 2.



Trigger efficiency as a function of the invariant mass m_{HHH} for the simulated Standard Model HHH→4b2τ_{had} process, with the comparison of the 2023 HH measurement strategy (orange) with respect to the hadronic τ triggers (blue) and a combination of both strategies (green). The three Higgs bosons candidates are reconstructed from the four central jets with the highest b-tagging score with at least two loose b-tagged jets and two τ candidates satisfying a loose hadronic τ identification. The trigger efficiency achieved by the new strategy is 94% complementary to the hadronic τ triggers efficiency of 48%.