Exploring Vector Boson Fusion Di-Higgs Production in the $b\bar{b}\tau^{+}\tau^{-}$ Final State

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The Standard Model (SM)

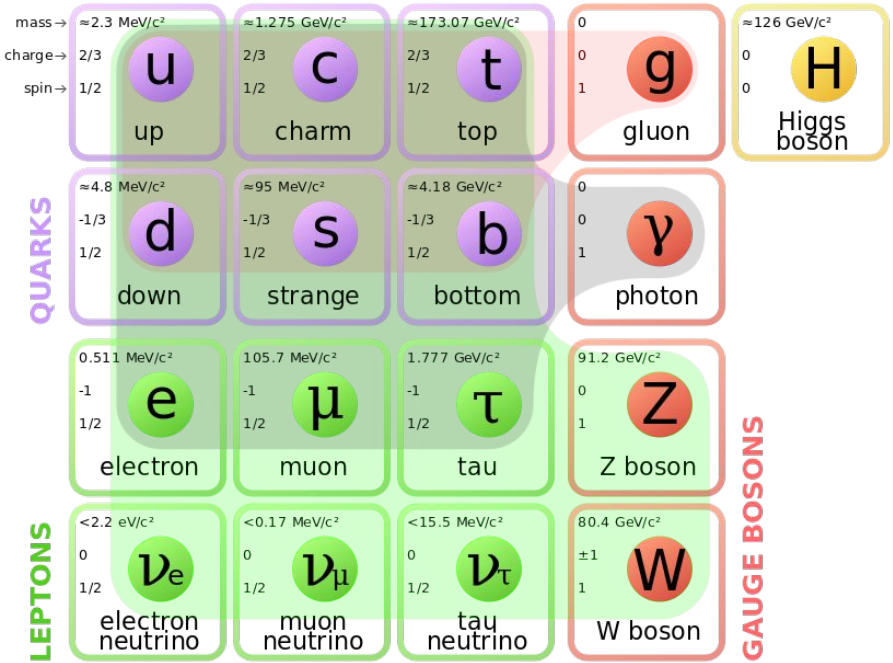


Figure 1. The Standard Model of particle physics [1]

Introduction

A wide range of Higgs boson properties have already been precisely measured

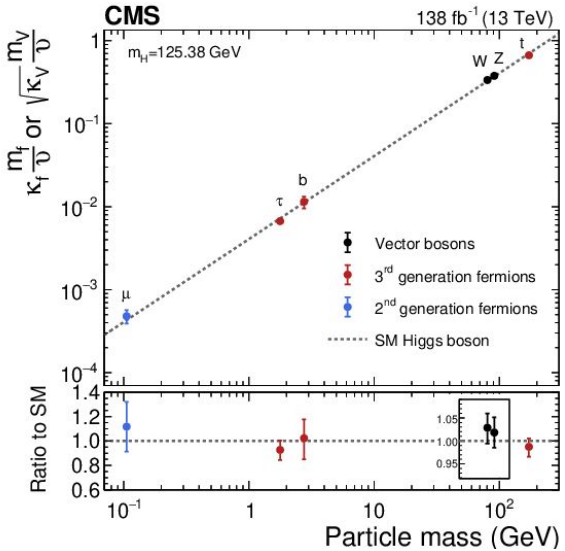


Figure 2. The measured coupling modifiers of the Higgs boson to fermions and heavy gauge bosons, as functions of particle mass [2]

However, not much is known about the Higgs potential and the Higgs self-interaction λ

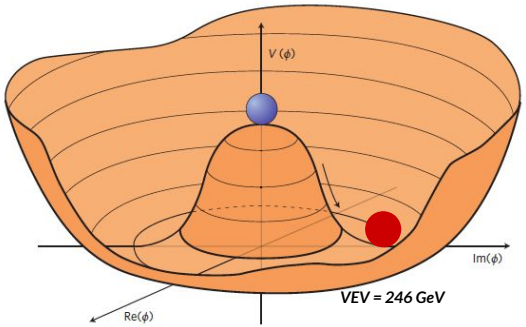
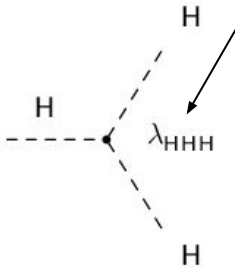


Figure 3. The Higgs potential [3]

Approximation around the VEV

$$V(\phi) \approx \lambda v^2 h^2 + \lambda v h^3 + \frac{1}{4}\lambda h^2$$



Trilinear Higgs self-coupling

Higgs boson pair (HH) production

HH production allows to directly measure λ

κ-framework: Used to measure any coupling, such as: $\kappa_\lambda = \lambda^{Obs} / \lambda^{SM}$

Test measurement accuracy and deviation from the SM

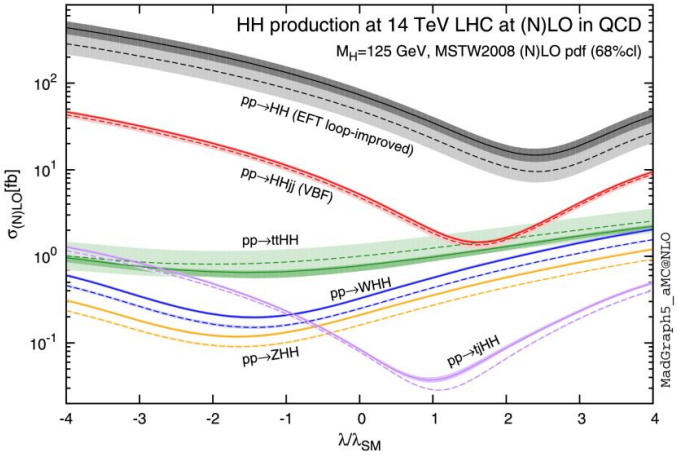
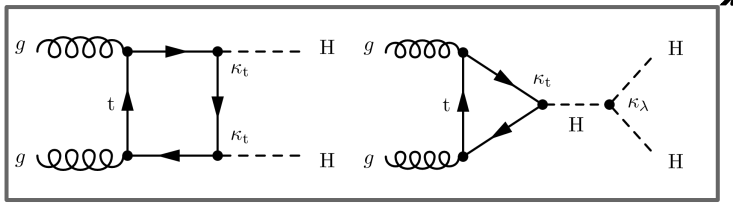


Figure 4. HH production cross section at the LHC [4]

Gluon-Gluon Fusion (ggF) - 31.05 fb at 13 TeV

- Dominant production mechanism, sensitive to κ_λ



Vector Boson Fusion (VBF) - 1.73 fb at 13 TeV

- Subdominant mechanism, sensitive to κ_{2V}

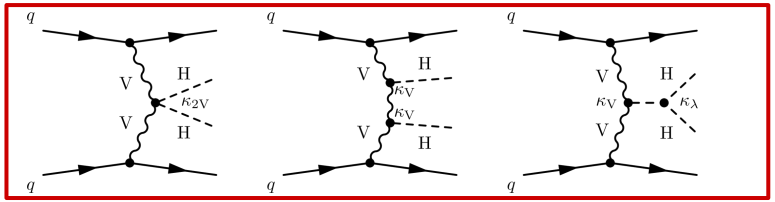


Figure 5. Feynman diagrams for ggHH (gray) and qqHH (red) [5]

CMS HH→bb̄τ⁺τ⁻ analysis

Search for HH production in decay modes with two b-quarks and two tau leptons:

- $H \rightarrow b\bar{b}$
- $H \rightarrow \tau^{+}\tau^{-}$

Investigating both ggHH and qqHH production

Set upper limits on **SM HH** production **cross section**, constraints on $\kappa_{\lambda} = \lambda_{HHH} / \lambda_{HHH}^{SM}$ and κ_{2V}

Run 2 results for HH→bbττ published by CMS in Physics Letters B Volume 842 , 10 July 2023, 137531

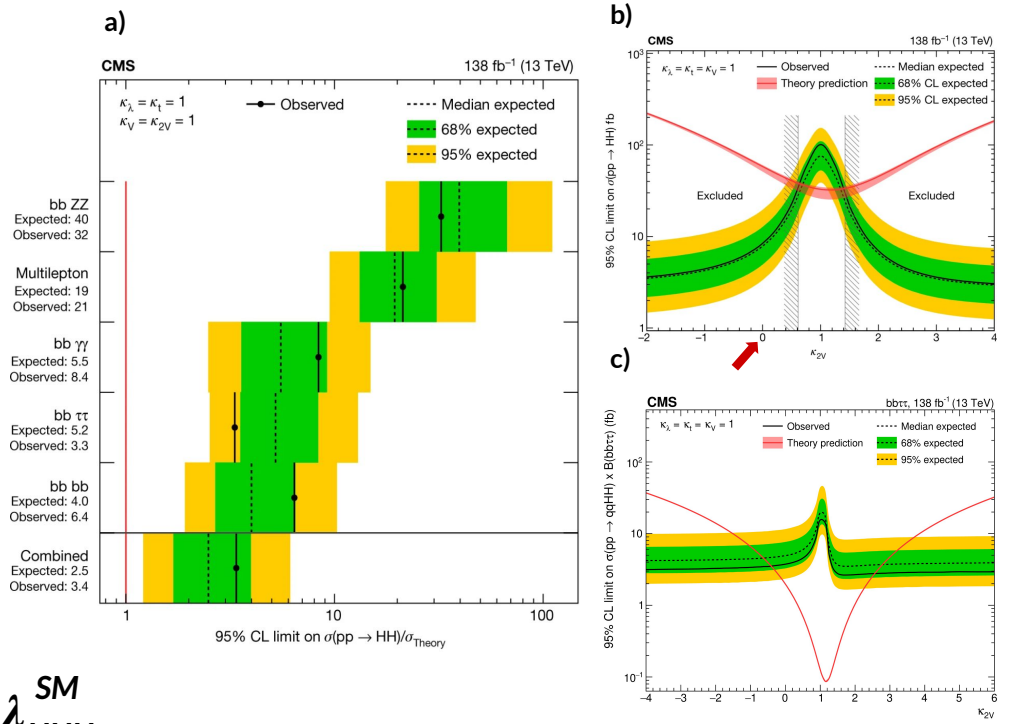
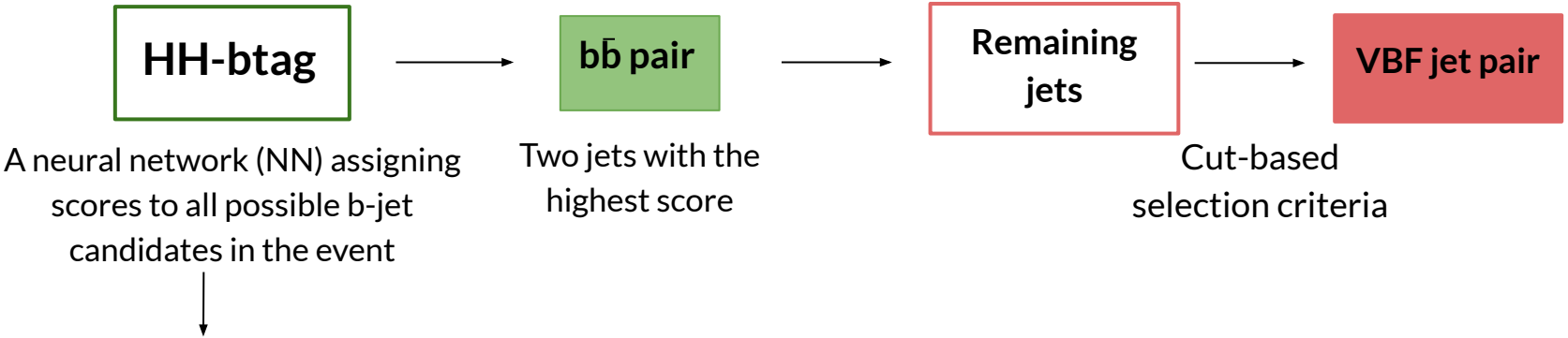


Figure 6. (a) Upper limits on HH production cross section for different final states [2]. Constrains on κ_{2V} for all final states combined **(b)** [2] and only for bbττ **(c)** [5]

CMS HH→bb̄τ⁺τ⁻ analysis

The identification and selection of bb̄ and VBF jets in the run 2 analysis:



Strategy for tagging VBF jets for the run 3 analysis

The framework used for this analysis is developed by physicists at Universität Hamburg (UHH) in collaboration with our group, and is based on Columnflow [6]

Steps for approaching the tagging of VBF jets:

- Validate the object and event selection criteria
- Study the qqHH signal distributions, develop discriminants
- Train a neural network

Object and event selection using Columnflow

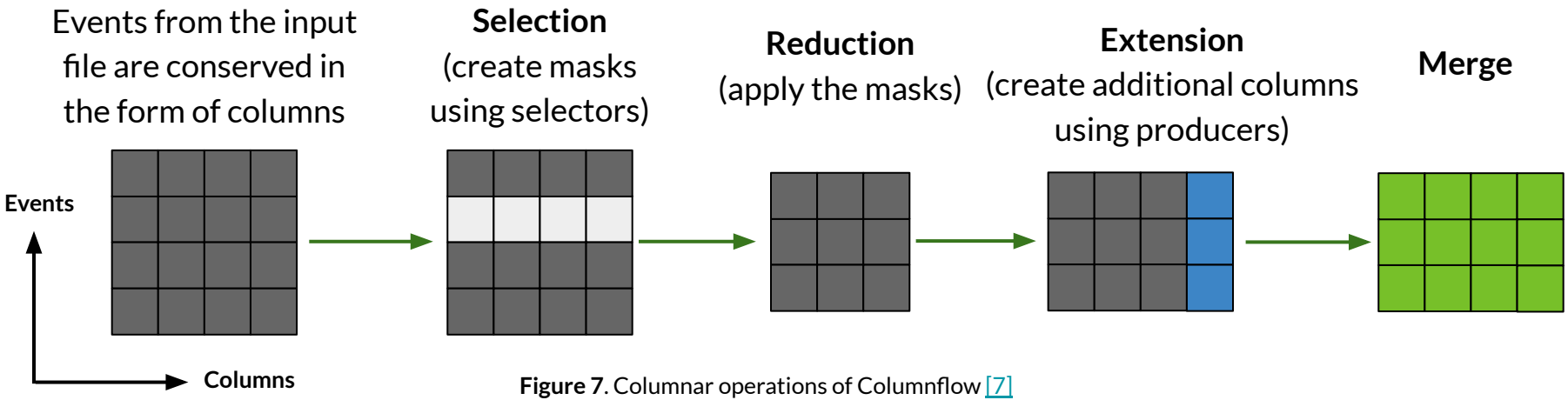


Figure 7. Columnar operations of Columnflow [7]

Current VBF jet selection

Select AK4 jets with:

VBF mask

- p_T = 30 GeV
- $|\eta| < 4.7$
- $m_{jj}^{VBF} > 500$ GeV
- $|\Delta\eta_{jj}^{VBF}| > 3$

Apply mask → The set of all AK4 jets

Subset of AK4 jets → VBF jets

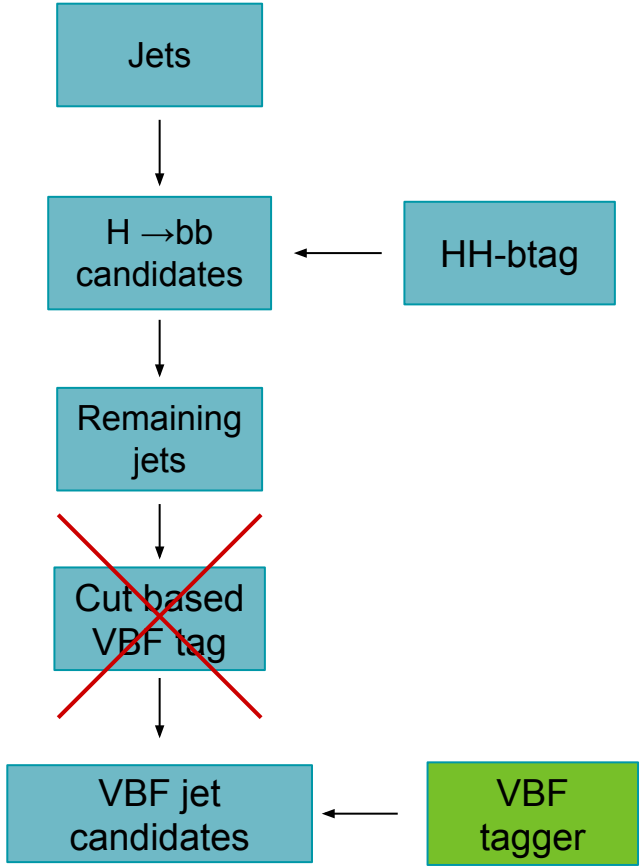
VBF tagger

Train a NN capable of finding the VBF jet pair

Analogous to the HH-btag used in the run 2 analysis:

- Assign VBF scores to jets, choose the jets with the highest scores as the VBF pair

Preliminary task - Study qqHH signal distributions



First look at qqHH signal distributions

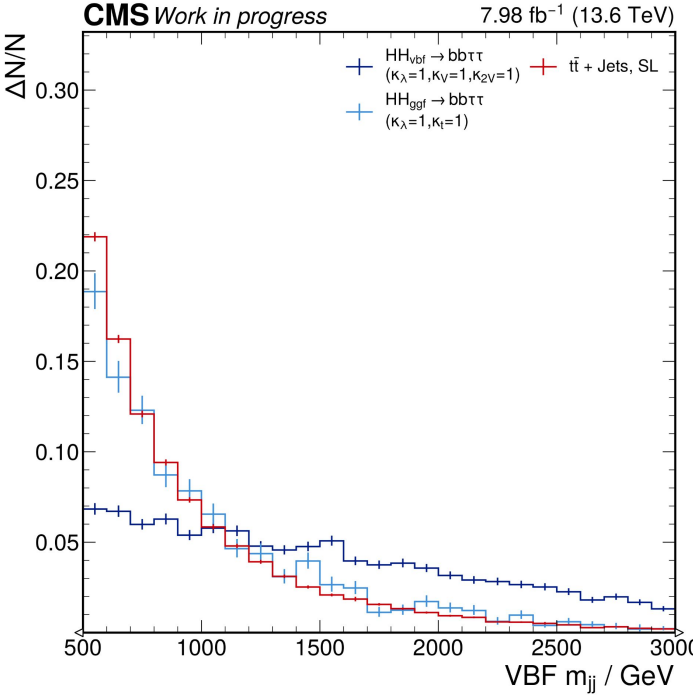


Figure 8. Invariant mass of the VBF jet pair for SM-like ggHH, qqHH and tt

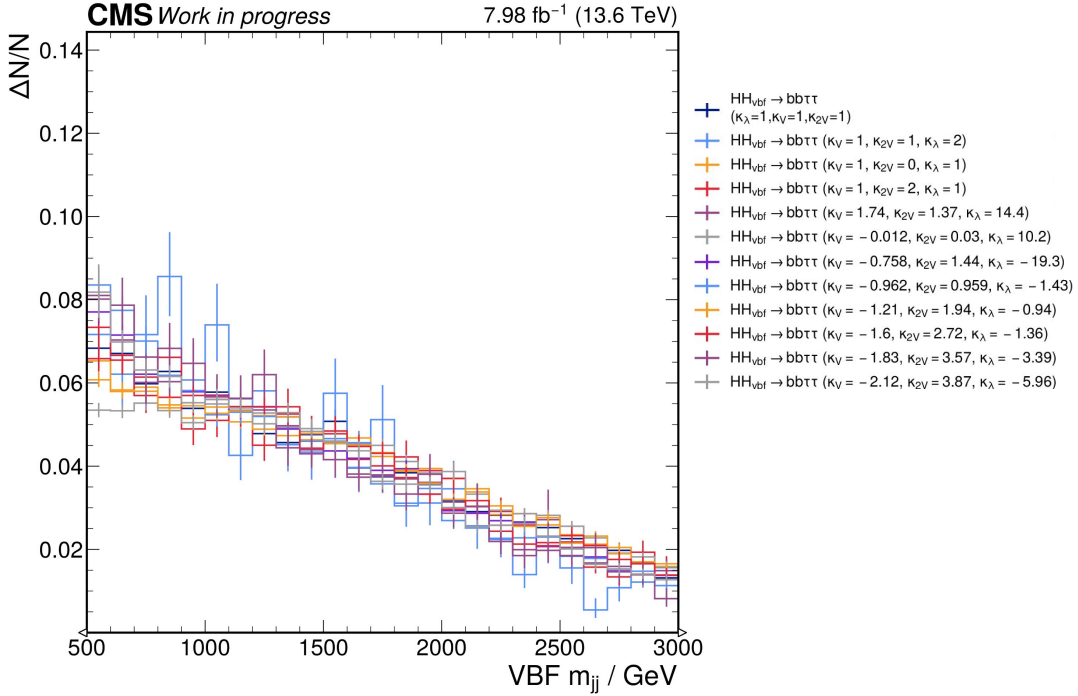


Figure 9. Invariant mass of the VBF jet pair for various VBF signal samples

Current status

Write new producers

- Produce new columns containing the features of the VBF jet pair ✔

Validating the object and event selection

- Generator level jets need to be matched to reco level jets to confirm the correct selection of VBF jets ⏳

Investigating the qqHH signal distribution for different variables

- Add new variables in the producers ⏳

Summary and outlook

- Search for HH production in the $bb\bar{\tau}^{+}\tau^{-}$ final state
- Improve the VBF jet pair identification used in the run 2 analysis
- Neural network based VBF tagger development
- Work in progress

References

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[2] The CMS Collaboration. A portrait of the Higgs boson by the CMS experiment ten years after the discovery. Nature 607, 60–68 (2022). https://doi.org/10.1038/s41586-022-04892-x
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[4] R. Frederix et al. “Higgs pair production at the LHC with NLO and parton-shower effects”. In: Physics Letters B 732 (May 2014), pp. 142–149. https://doi.org/10.48550/arXiv.1401.7340
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Backup

Analysis flow