Higgs boson searches in bottom and top quark production modes

Pascal Bärtschi, Sascha Liechti, Prof. F. Canelli's CMS Group
Physik-Institut, Universität Zürich
contact: pascal.baertschi@uzh.ch, sascha.liechti@cern.ch

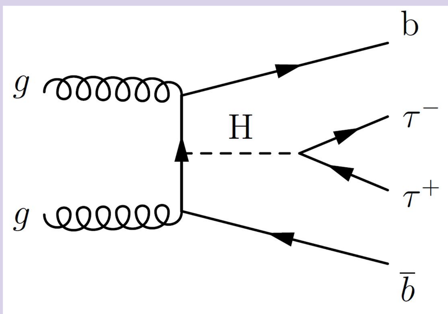
Universität Zürich[UZH]

Group Website

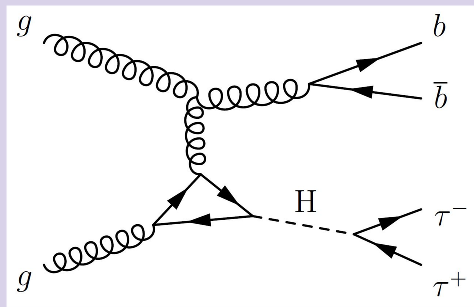
Theoretical motivation and background

The Higgs boson is an excitation of the Higgs field, which couples to the elementary particles and gives them mass. The goal is to analyze the structure of the interactions between the Higgs boson and the bottom/top quarks. In the Standard Model the Higgs boson couples to the bottom and top quark according to the bottom and top quark Yukawa coupling. The top quark Yukawa coupling is close to 1, while the bottom quark Yukawa coupling is only about 0.025.
The data used in the described analyses was measured from 2016 to 2018 in the CMS detector, one of the four main experiments at the CERN LHC.

Constraining the bottom quark Yukawa coupling is a long term goal of the CMS experiment, but with current data measured in the CMS detector this is not yet possible. Two Higgs boson production modes with bbH final states have to be considered:

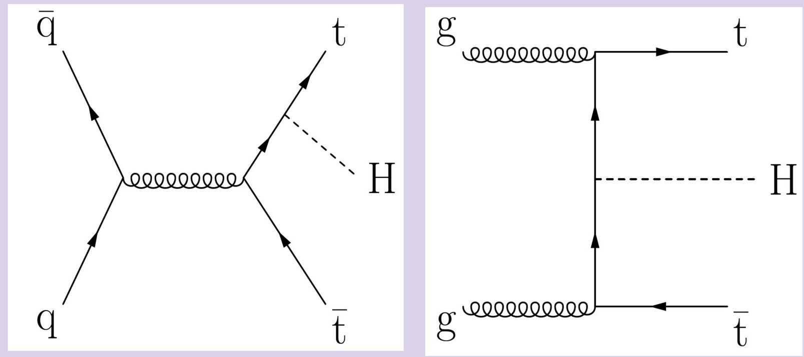


Bottom quark fusion

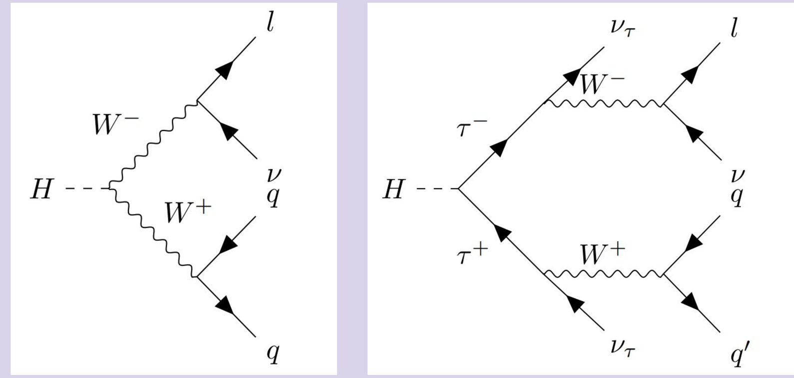


Gluon fusion with gluon splitting

The top quark is by far the heaviest fermion up to date. It's Yukawa coupling is expected to be close to be of order one. The large mass of the top quark may indicate that it plays a special role in the mechanism of electroweak symmetry breaking.



The most common processes for ttH production are gluon and quark fusion



We target processes where the Higgs boson decays either via two W bosons or via two hadronically decaying tau leptons

To maximize sensitivity, we specify three signatures depending on lepton multiplicity, which offer the best signal to background ratio.

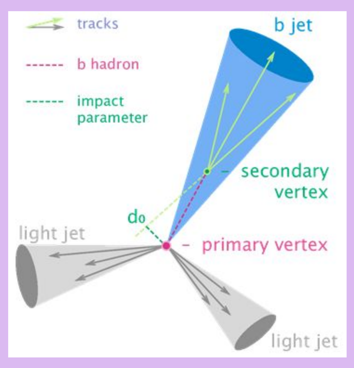
signature	2lss + 0tau	2lss + 1tau	3l + 0tau
signal	222 ± 51	28.9 ± 6.4	61 ± 15
expected bkg	3517 ± 85	179 ± 13	627 ± 20

Around 69000 ± 6900 ttH events have been produced in run 2 of the LHC.

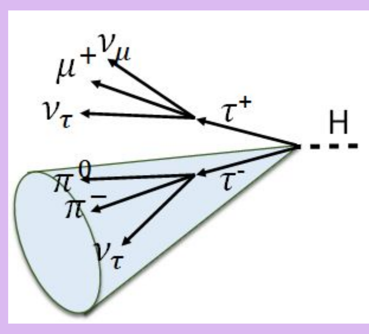
bbH

Search for bbH with Higgs boson decaying to tau leptons

We search for Higgs bosons accompanied by at least one bottom quark jet and decaying to a pair of tau leptons because of the relatively large branching ratio and the tau lepton decay products (electron, muon or jet of pions) leave a clear signal in the detector.

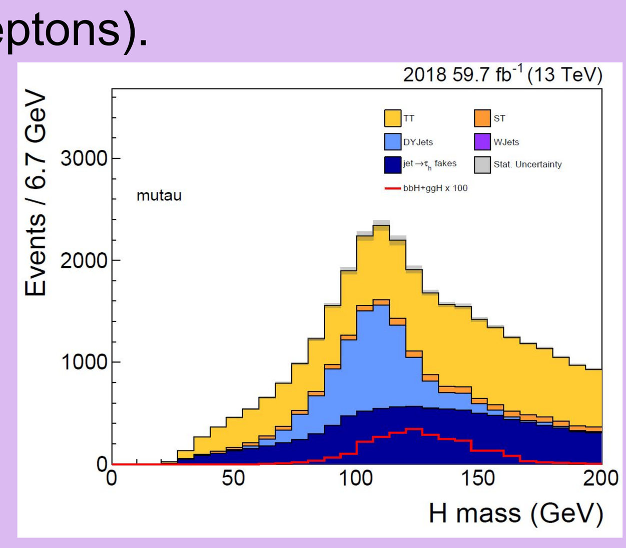


Jets originating from bottom quark hadronization can be identified by a secondary vertex due to the longer lifetime of the bottom quarks.

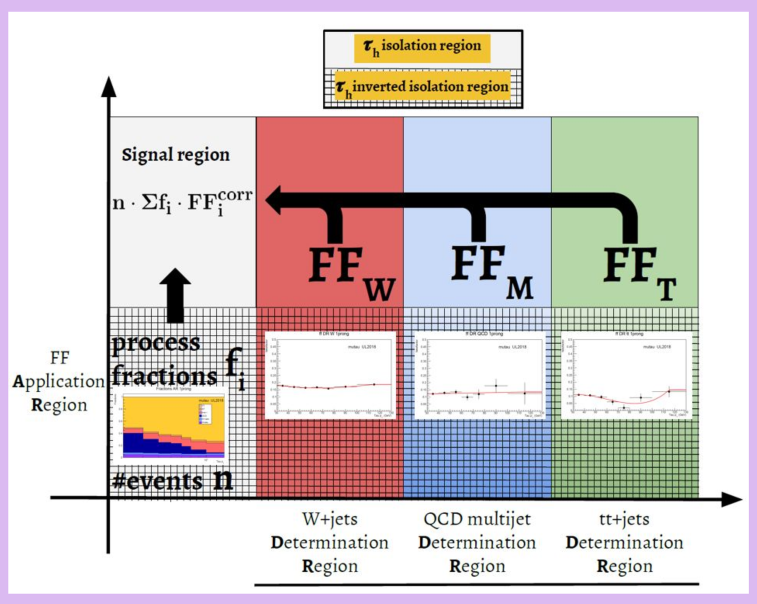


Higgs boson decaying to tau leptons, which decay to a muon and a jet of pions

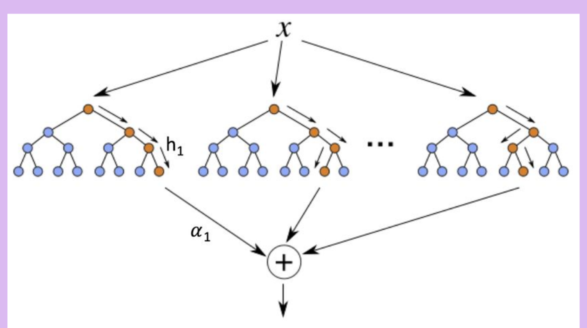
Main backgrounds are top quark pairs, Z/W boson + jets and jets initiated by a quark or gluon but wrongly identified as a tau lepton decaying hadronically (fake tau leptons).

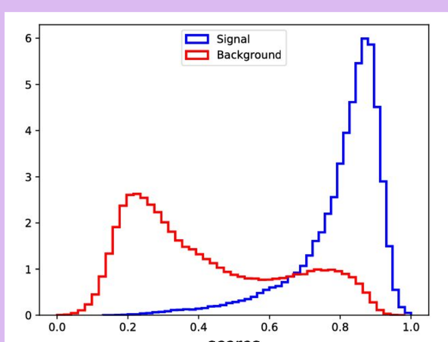


The background from fake tau leptons is estimated using a control region enriched with fake tau leptons.



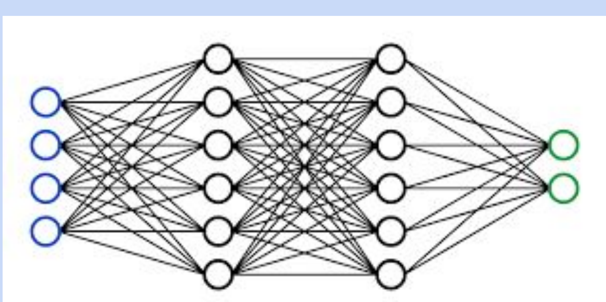
Using Boosted Decision Tree to be able to improve the amount of signal with respect to background events.





Differential ttH production in the multilepton final states

This analysis aims to measure the top Higgs Yukawa coupling via a differential measurement of the Higgs bosons transverse momentum, which allows to disentangle the effects of modified Higgs boson self-coupling values from other effects such as the presence of anomalous top-Higgs couplings. Additionally, we plan to set limits on new physics beyond the standard model.

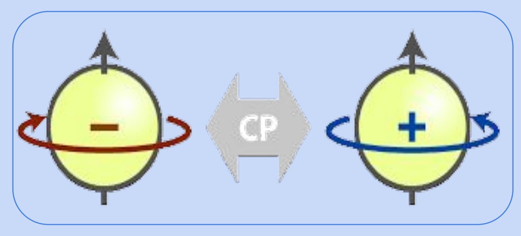


To predict the transverse momentum of the Higgs boson, we use dedicated neural networks for each of the signature regions.

ttH + tH

Search for CP violation in ttH and tH production in multilepton channels

In this specific analysis we want to measure the CP nature of this coupling.



CP violation will show up at tree level

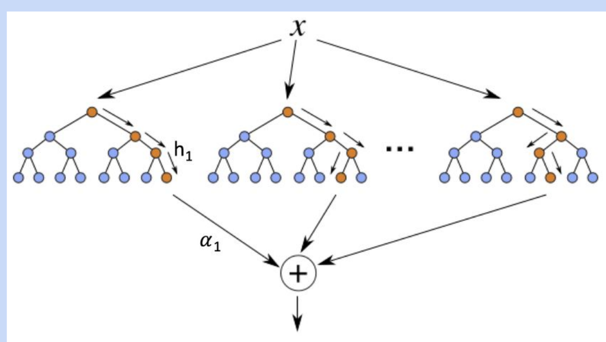
The Higgs boson is expected to be CP-even. Any deviation from a purely CP-even Higgs would indicate new physics.

$$\mathcal{L} = \mathcal{L}_{CP-even} + \mathcal{L}_{CP-odd}$$

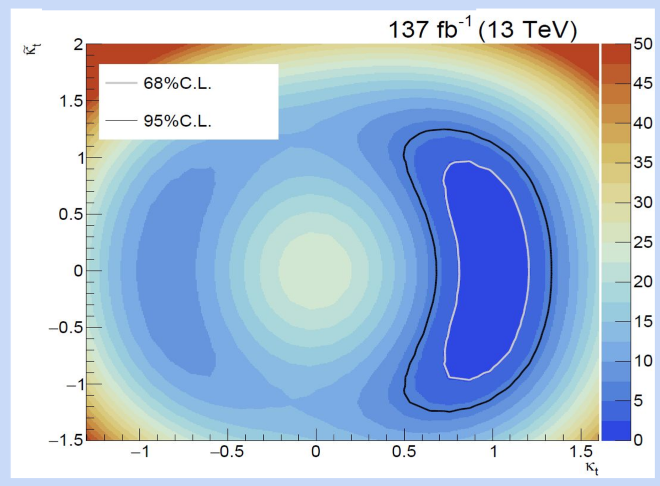
$$\mathcal{L}_{t\bar{t}H} = \frac{-y_t}{2}\bar{\Psi}_t(\kappa_t + i\gamma_5\tilde{\kappa}_t)\Psi_t H$$

To fully describe any potential CP behaviour we expand the Lagrangian by a CP-odd term. The interaction is then parametrized by κ_t and $\tilde{\kappa}_t$.

We use boosted decision trees to separate CP-even and CP-odd like behaviour.



Expected results for κ_t and $\tilde{\kappa}_t$



Effective Field Theory searches

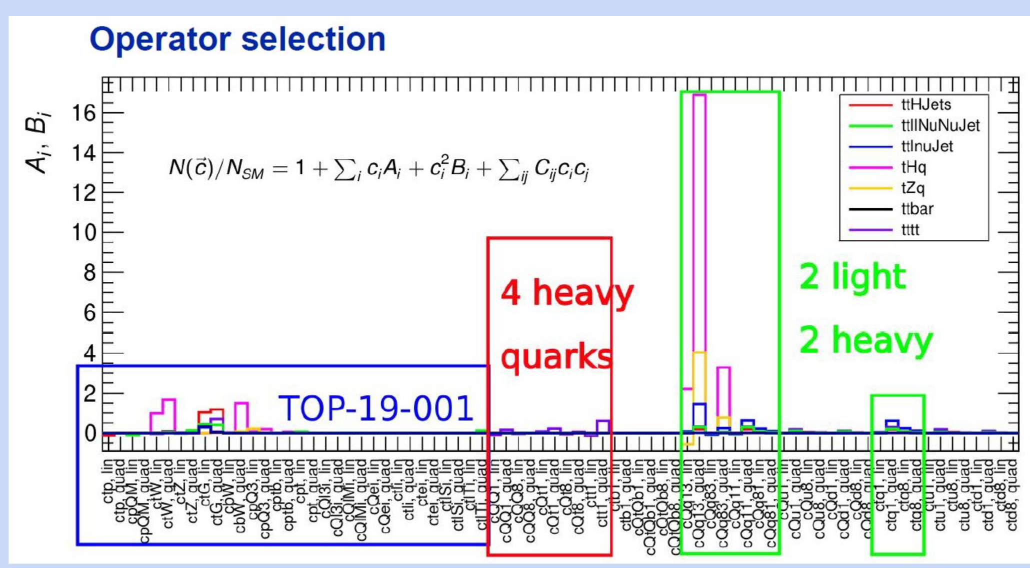
The goal of effective field theory searches is to constrain possible new physics beyond the standard model. There are numerous motivations, like the strong evidence for dark matter or the asymmetry between matter and antimatter in the universe, to search for new particles or interactions at the CERN LHC.

A way to include new interactions, also often referred to as "new physics", is to expand the standard model lagrangian by adding new interactions via six-dimensional operators.

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{d,i} \frac{c_i^d}{\Lambda^{d-4}} O_i^d$$

Currently we plan to constrain 26 operators in this analysis that are sensitive to various top quark processes. The plot below visualizes the ratio by which various EFT operators can modify the cross sections of the included processes.

This analysis considers a rich phenomenology of processes: ttH, ttlnu, ttll, tllq, tHq, tttt



References
N. Deutschmann, F. Maltoni, M. Wiesemann, M. Zaro, "Top-Yukawa contributions to bbH production at the LHC", JHEP 07(2019)054
Sirunyan, Albert M and others, "Measurement of the Higgs boson production rate in association with top quarks in final states with electrons, muons, and hadronically decaying tau leptons at √ s = 13 TeV", Eur. Phys. J. C 81 (2021) no.4, 378
A.M. Sirunyan et al. [CMS] "Search for new physics in top quark production with additional leptons in proton-proton collisions at √ s = 13 TeV using effective field theory", JHEP 03(2021)095