HH $\rightarrow$ bb$\tau\tau$

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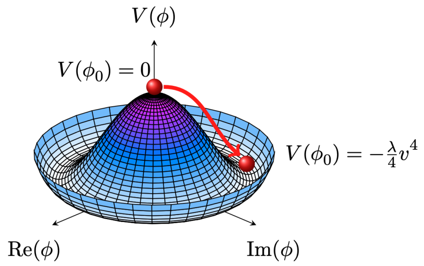
With the discovery of the Higgs boson in 2012, the Standard Model of particle physics has found its last predicted particle. So far, the mass of the Higgs boson, the vacuum expectation value (VEV), and the Yukawa couplings of the third generation leptons have been measured. Among the things that are yet to be measured is the shape of the Higgs potential - in particular, the Higgs self-coupling. It is fully constrained by the Higgs mass and the VEV, and any deviation from the expected value would indicate new physics. This makes the measurement of the Higgs self-coupling very appealing.



The direct way to measure the self-coupling is to search for di-Higgs production in collisions. In the Large Hadron Collider (LHC), which collides proton bunches, there are several ways on how we can produce two Higgs bosons in an event. The two most prominent production modes are gluon-gluon fusion (Fig. 1) with a cross-section of $\sigma_{ggF}^{SM}(\sqrt{s} = 13.6\text{ TeV}) \approx 34.13\,\text{fb}$, and vector-boson fusion (Fig. 2) with a cross-section of $\sigma_{VBF}^{SM}(\sqrt{s} = 13.6\text{ TeV}) \approx 1.874\,\text{fb}$. Although individual contributions for the cross-section are fairly large in both production modes, they interfere destructively, reducing the cross-section to around 1/1500 that of the single Higgs production. While the gluon-gluon fusion has a much larger cross-section, the vector-boson fusion has two additional jets separated by large pseudo-rapidity, making it easier to "tag" it, and therefore, worthy of exploration.

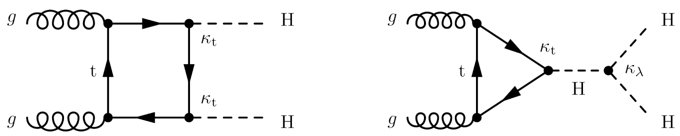


Figure 1: The leading-order Feynman diagrams of di-Higgs gluon-gluon fusion

Since Higgs boson is not a stable particle, it decays, and its decay has numerous possibilities. In order to select the decay channel, at least one of two conditions should preferably be met. Ideally, it should have a sizeable branching ratio or the signal should

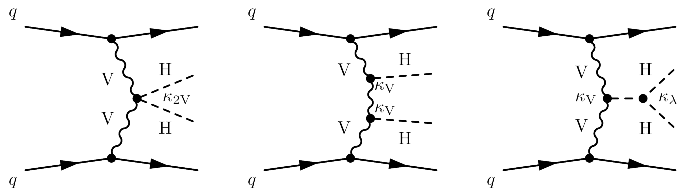


Figure 2: The leading-order Feynman diagrams of di-Higgs vector-boson fusion

have high purity. The $bb\tau\tau$ final state offers a compromise between those two conditions, as we get a sizeable branching ratio from the Higgs decay to two b quarks, and good purity from the decay into two τ leptons (Fig. 3). The b quarks will hadronize, forming jets, while τ leptons can decay either leptonically or hadronically. In this analysis, final states where at least one τ lepton decays hadronically are used as signal channels - the ones that we're actually measuring - while final states where both τ leptons decay leptonically (to an electron or a muon) are used as control channels - to check that our Monte-Carlo simulation is in agreement with the measured data (Fig. 4).

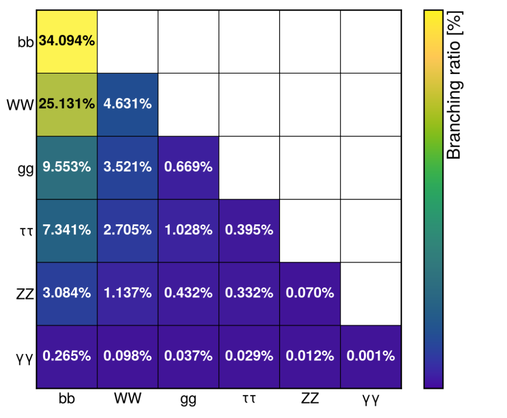


Figure 3: di-Higgs branching ratios

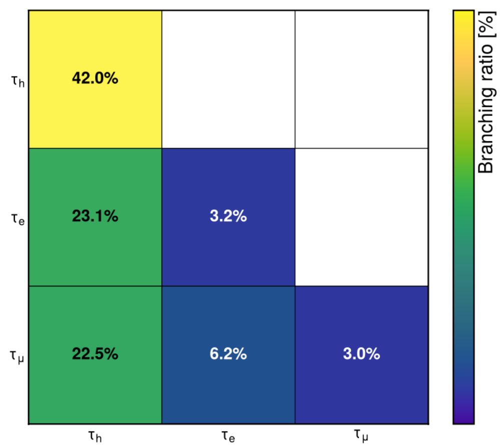


Figure 4: $\tau\tau$ branching ratios

The analysis proceeds as follows. First, a pair of τ leptons with high isolation requirements is selected. Next, a pair of b jets or one large-radius jet is selected. Finally, two VBF jet candidates are selected if present. From all the object pairs, various properties, like invariant mass, are extracted and then the events are categorized into several categories. If VBF jets satisfy conditions of large invariant mass of two jets and large pseudorapidity gap, the event will be treated as the VBF candidate. Otherwise, it is treated as the ggF candidate. After categorization, the properties of the event and its objects are fed into a neural network that classifies how likely is for the how likely the event is to originate from a di-Higgs production or from a certain background. Finally, the score of the neural network is used to obtain the limits on the production modes of the di-Higgs event, as well as constraints on the self-coupling.