Trigger Studies for the search of a heavy Charged Higgs

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Abstract: *The efficiency of different triggers for the search of a charged Higgs is studied using generator-level simulations. A charged Higgs boson with a mass heavier than the top quark mass is produced in association with a top quark and can decay to $t\bar{b}$ ($gg \rightarrow \bar{t}bH^+/H^+ \rightarrow t\bar{b}$) resulting to an all hadronic final state. In order to improve the efficiency of the triggers, several kinematic variables are examined.*

1 Introduction

Several extentions of the Standard Model include an additional Higgs doublet which leads to five physical Higgs states: the CP-even h^0 and H^0 (where $m_{h^0} < m_{H^0}$), the CP-odd A^0 and the electrically charged H^+ and H^- states. The simplest of those models is the two-Higgs-doublet model (2HDM) where the Minimal Supersymmetric Standard Model belongs to one of the four differnet types of the 2HDM. The newly discovered higgs boson [1] [2] could be either the light CP-event or the heavy CP-event boson. Since the Standard Model (SM) does not predict any elementary charged scalar particle, the observation of a charged Higgs boson would indicate new physics [3].

Light charged Higgs scenarios refers to Higgs boson masses smaller that the mass of the top quark ($m_{H^\pm} < 160GeV/c^2$) where the primary production mechanism is through the decay of a top quark (t$\rightarrow$ bH^+). On the other hand, the heavy charged Higgs scenarios refers to Higgs boson masses larger than the mass of the top quark ($m_{H^\pm} > 180GeV/c^2$) where the dominant $H^\pm$ boson production mode at the LHC is in association with a top quark [3] (figure 1).

(a) five-flavour scheme (5FS)

(b) four-flavour scheme (4FS)

Figure 1: Feynman diagrams of the charged Higgs boson production in the MSSM scenario for a charged Higgs boson mass larger than the top quark mass (left - the four-flavor scheme, right - the five flavor scheme)

In this study we consider a charged Higgs heavier than the top quark in the mass range from 180 to 500 GeV/c^2. We consider the decay chain $gg \to H^+\bar{t}b \to (t\bar{b})(W^-\bar{b})b$ (figure 2) as well as the decay chain $qq \to g \to \bar{t}t \to H^+b$ with a fully hadronic final state in both cases.

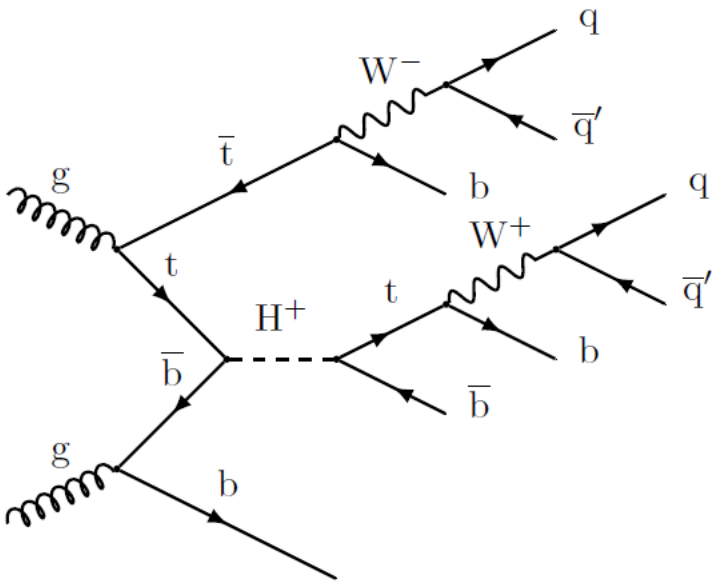
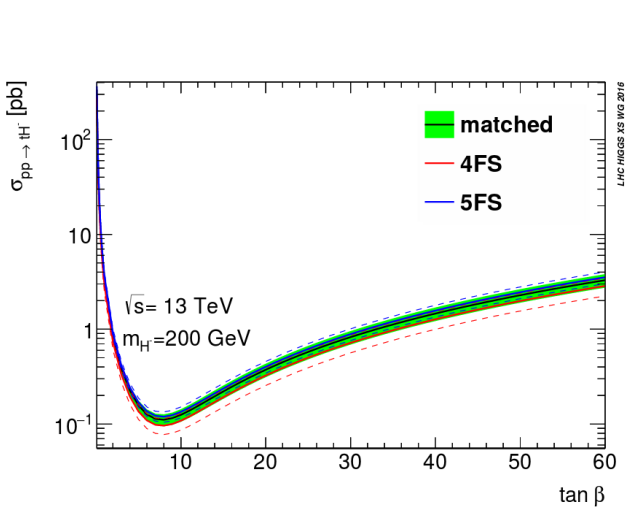
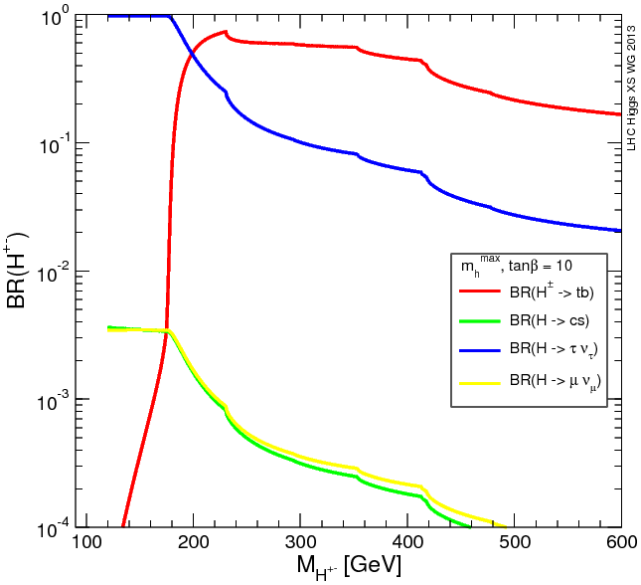


Figure 2: The fully hadronic final state

The cross section $\sigma_{pp} \to tH^+$ depends on the value of $\tan\beta$ as it shows in figure 3a. For $\tan\beta \approx 2$ the $\sigma_{pp} \to tH^+ \approx 1$ pb and for $\tan\beta \approx 10$ the $\sigma_{pp} \to tH^+$ is greater than 0.1 pb. For masses greater than 180 GeV/c^2 the $BR(H \to tb)$ becomes larger than the $BR(H \to \tau\nu)$ and at larger masses of H^+ the $BR(H \to tb)$ dominates as it shows in figure 3b. For $m_{H^+} \approx 200 GeV/c^2$ the $BR(H \to tb) \approx 0.4$.



(a)



(b)

Figure 3: (a) H^+ cross section plot (2HDM), for the two flavor schemes and after matchine, including uncertainties. (b) H^+ BR plot for an MSSM scenario. [4]

2 Triggers

We are looking for a suitable trigger for our signal ($H^+ \to t\bar{b}$) and as a first step we examined the efficiencies of the CMS triggers as illustrate in figure 4. We are looking for triggers based on calorimeter activity like the presence of relativly large HT and jets.

As we can see, the most efficient triggers are the HLT HT200 and the HLT PFHT300. Unfortunately, both triggers have huge prescale factors (6720 for the HT200 and 1280 for the PFHT300, as found using the CMS condDB). The signal we are looking for is expected to be rare and therefore we cannot choose a prescaled trigger. The unprescaled triggers are:

1) HT650

2) PFHT400 SixJet30 DoubleBTagCSV p056

3) PFHT450 SixJet40 BTagCSV p056

4) QuadPFJet BTagCSV p016 VBF Mqq500

5) QuadPFJet BTagCSV p016 p11 VBF Mqq240

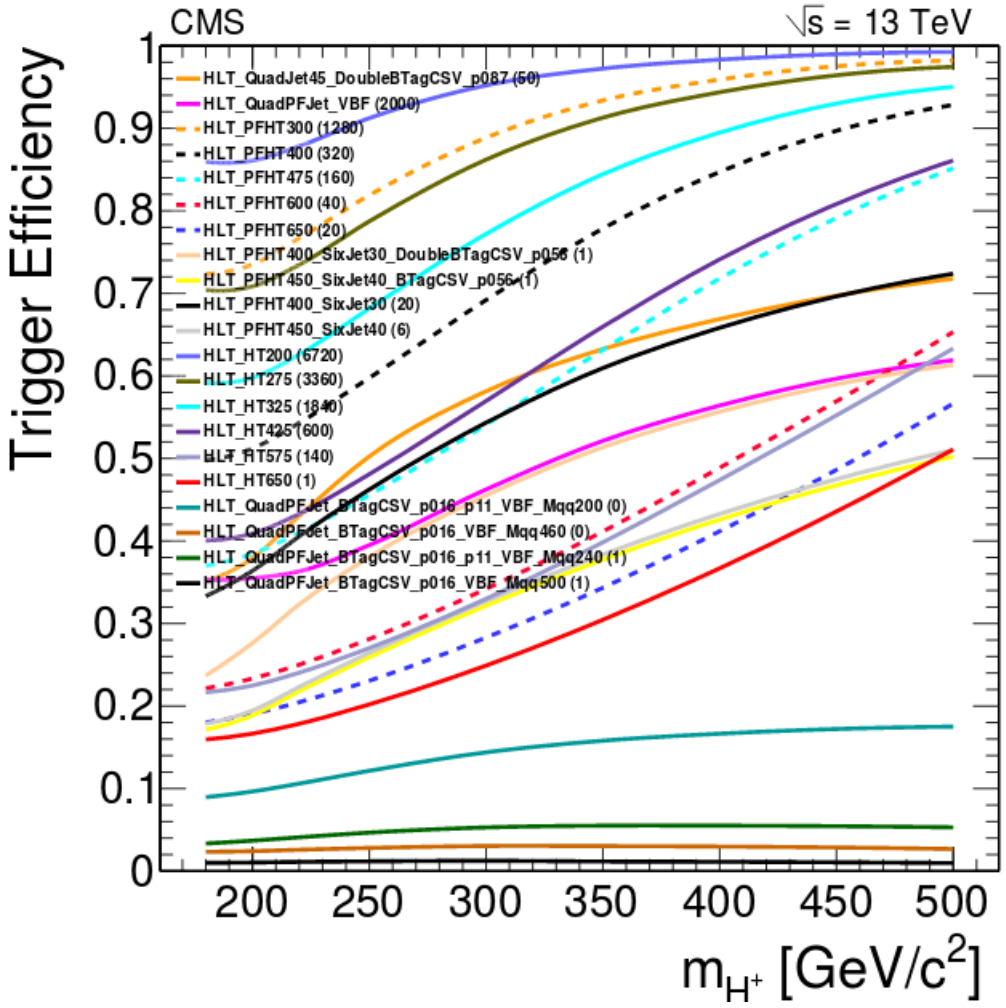


Figure 4: Trigger Efficiencies as a function of charged Higgs mass. The number inside the brackets denotes the prescale factor for an instantaneous luminosity equal to $10^{34} cm^{-2} s^{-1}$.

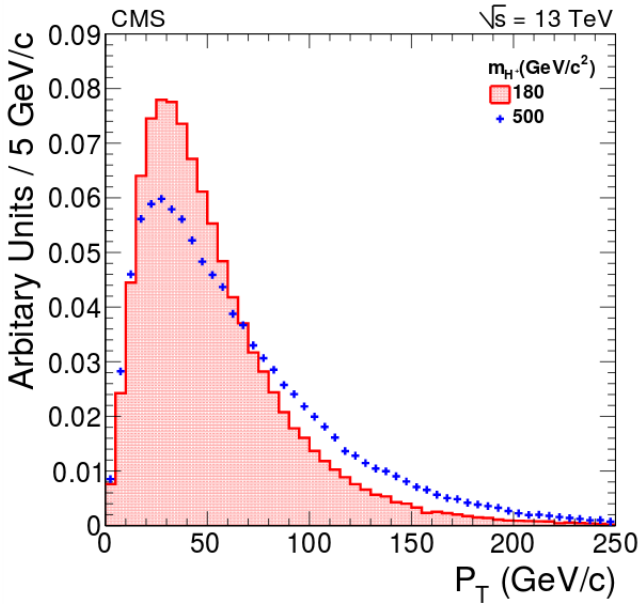


Figure 5: P_T of all leptons in the events

The triggers 4) and 5) have very low efficiencies and we will not consider them further. They also include VBF processes and the event topology of the VBF case can not accommodate our signal. On the other hand, the triggers 2) and 3) could work well for our signal if we find ways to increase their efficiency. A kinematic study of the events is needed to be done to help us decide the suitable cuts and preselections for the events.

3 Kinematics

3.1 Leptons

The final state of our process is fully hadronic and therefore we need to veto events with leptons in order to make our analysis also orthogonal to the ones looking for leptonic top decays. The distributions in figure 5 shows that a nice cut can be at $Pt > 20GeV/c$. If we ask for events with no leptons with $Pt > 20GeV/c$ most of the events with leptons will not pass. Futhermore, it is found that those leptons originate from a W daecay. The Pt distribution of leptons for the sample in which the Higgs has mass $180GeV/c^2$ differs from the corresponding distribution for the sample in which the Higgs has mass $500GeV/c^2$. That means the Pt distribution of leptons is mass dependent. This is expected since the top that comes from the H^+ is more boosted as the H^+ mass increases and so its decay products. However, the cut for leptons with $Pt > 20GeV/c$ is a good cut for both masses.

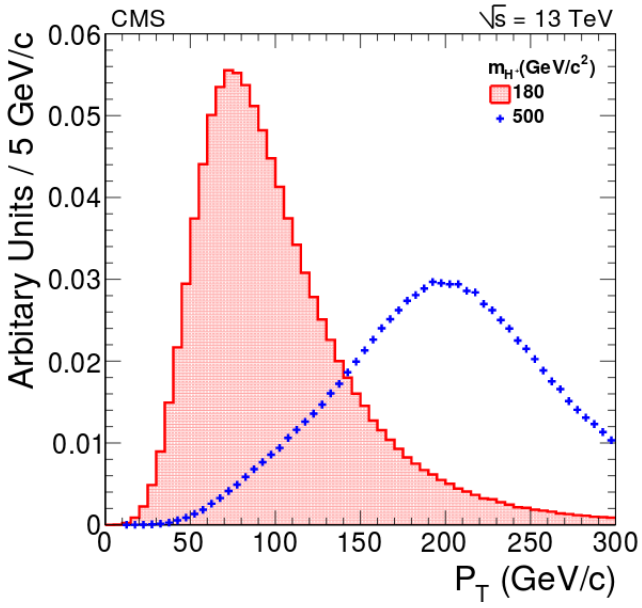


Figure 6: P_T of the most energetic b-quark in the event

3.2 b-quarks

The final state of our decay contains 4 b-quarks: the associate b (or flavor excited), the b from the H^+ decay and the two b-quarks from the decays of the two top quarks in the event. The histogram in figure 6 shows the Pt of the most energetic b-quark of the event. Almost all events have at least one b-quark with $Pt > 30GeV/c$ and therefore this could be a good preselection criterion for the b-quarks. It also helps to reduce the amount of generic QCD events where the presence of b-quarks is suppresed.

3.3 GenJets

Figure 7 shows a histogram with the number of genJet with $Pt > 30GeV/c$ and $|\eta| < 2.5$. Events with $m_H = 180GeV/c^2$ have on average 5 genJets and events with $m_H = 500GeV/c^2$ have approximately 6 genJets. The two triggers we are interested in, the PFHT400 SixJet30 DoubleBTagCSV p056 and the PFHT450 SixJet40 BTagCSV p056 are asking for 6 Jets with $Pt > 30GeV/c$ and $Pt > 40GeV/c$ respectively. Considering all these, a preselection criterion for genJets could be to ask for 6 genJet with $Pt > 30GeV/c$ and $|\eta| < 2.5$.

The histogram in figure 8 shows the H_T for events with at least 6 genJets with $Pt > 30GeV/c$ and $|\eta| < 2.5$. The H_T is calculated as the sum of the Pt off all genJets with $Pt > 30GeV/c$ and $|\eta| < 2.5$. As we can see, if we ask for $HT > 250GeV/c$ then almost all events are included.

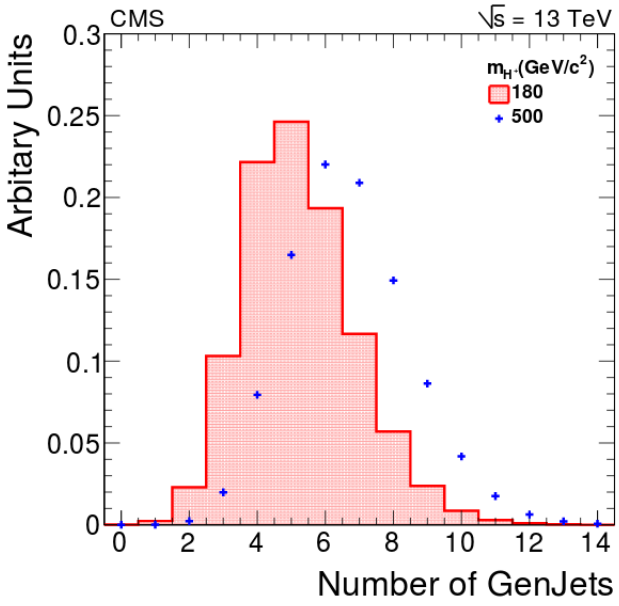


Figure 7: Number of GenJets with $P_T > 30GeV/c$ and $|\eta| < 2.5$ in each event

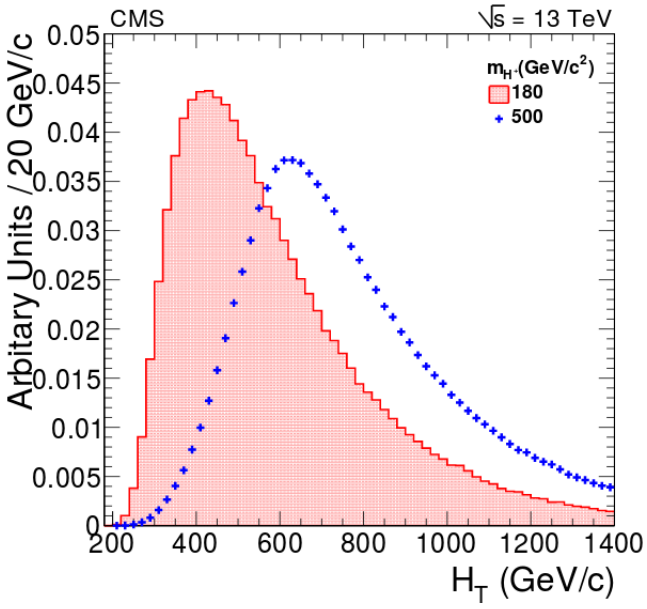


Figure 8: Sum of the Pt of the genJets with $Pt > 30GeV/c$ and $|\eta| < 2.5$

4 Trigger Efficiencies with preselections

From the study of the kinematics of the events we ended up with the follow preselections criteria:

- No lepton with $Pt > 20 GeV/c$ and $|\eta| < 2.5$
- At least 1 b-quark with $Pt > 30 GeV/c$ and $|\eta| < 2.5$
- At least 6 GenJets with $Pt > 30 GeV/c$ and $|\eta| < 2.5$
- $H_T > 250 GeV/c$

The efficiency of all the triggers are increasing when asking for the preselection criteria (figure 9). The efficiency of the trigger PFHT400 SixJet30 DoubleBTagCSV p056 increases from 23% without the preselections to 53% for $m_H = 180\ GeV/c^2$ and from 62% to 79% for $m_H = 500\ GeV/c^2$. The efficiency of the trigger PFHT450 SixJet40 BTagCSV p056 increases from 17% without the preselections to 42% for $m_H = 180\ GeV/c^2$ and from 50% to 69% for $m_H = 500\ GeV/c^2$.

5 Turn-On Curves

We examined the efficiency of the triggers by examining the ratio of the events that pass a specific part of the trigger over the number of events that pass a more inclusive trigger. We examine this ratio as a function of the H_T (figure 10b) in the event or the P_T of the 6th Jet (figure 10a). The graph in figure 10a shows that the requirement of two b-tagged jets (DoubleBtag) in the trigger is higher for low P_T and lower for high P_T than the requirement of one b-tagged jet (SingleBTag) in the trigger. Similar results obtained for the ratio as a function of H_T. That means the combination of the two triggers can give a higher efficiency than each one of them separately as it shows in figure 11. The turn-on-curves of the combined trigger has a faster turn-on and therefore the combined trigger could be a possible trigger for our study.

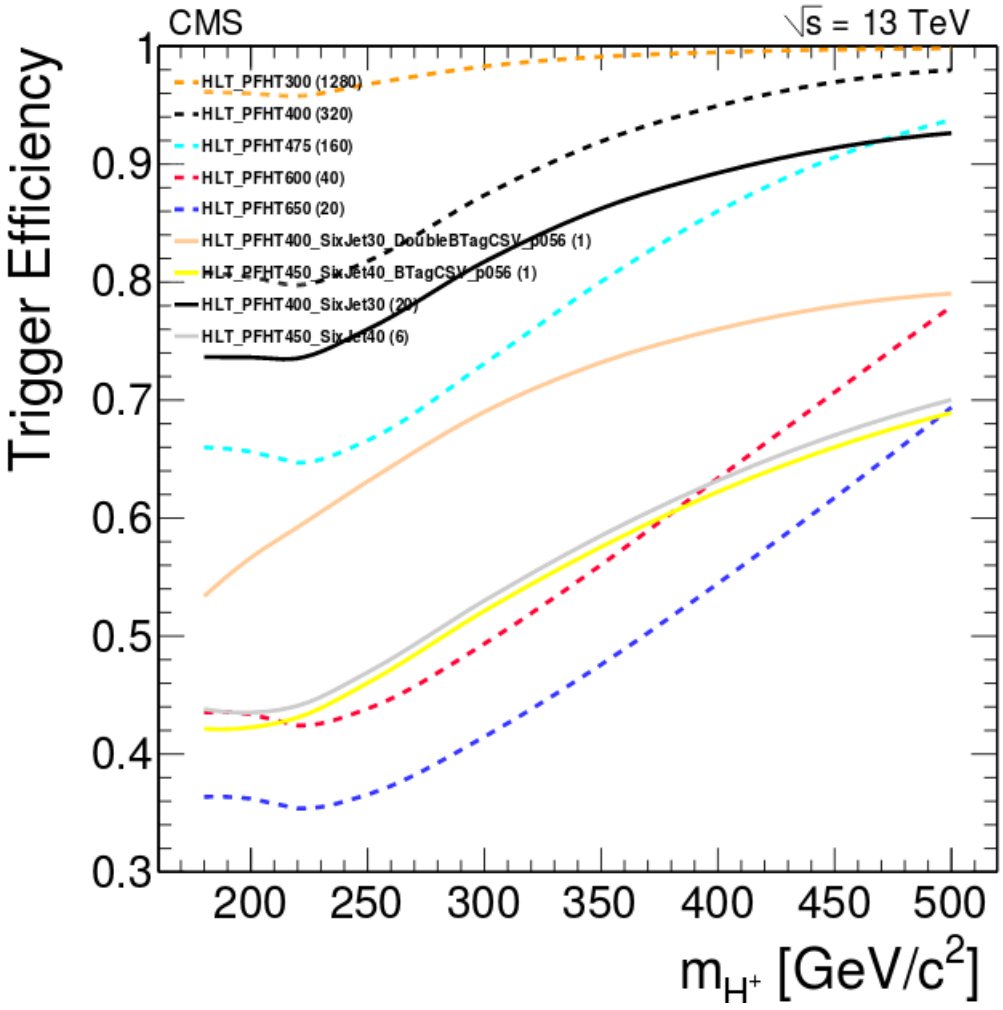
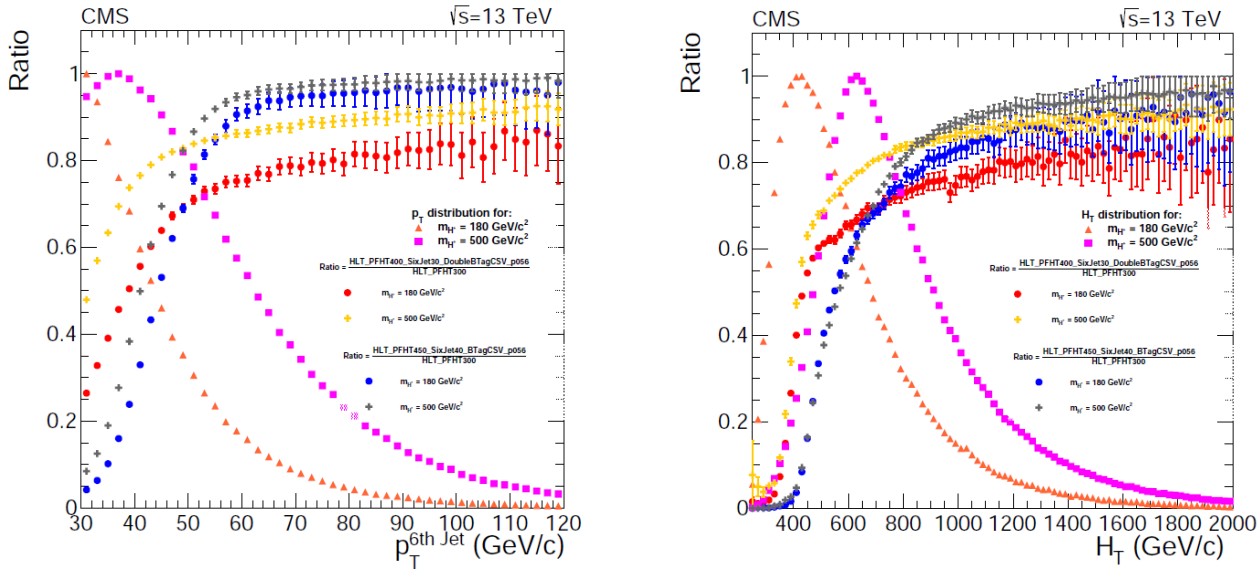
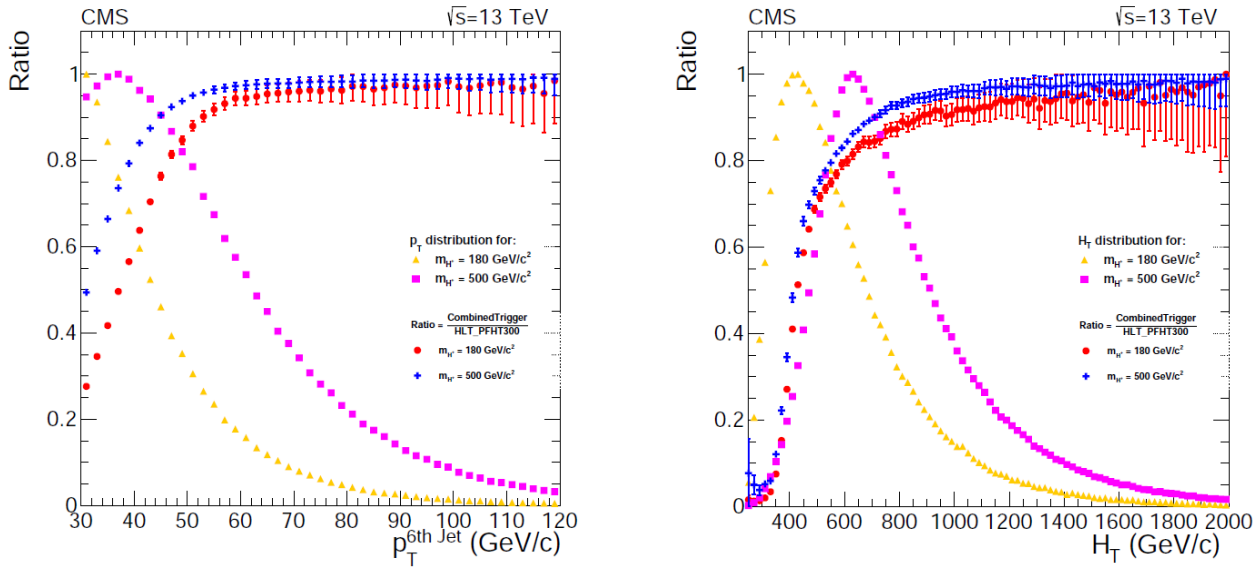


Figure 9: Trigger Efficiencies when asking also for preselection criteria as a function of the charged Higgs mass. The number inside the brackets denotes the trigger prescale factor applied for a luminosity equal to $10^{34} cm^{-2} s^{-1}$.



(a) (b)

Figure 10: Efficiency plot for the PFHT400 SixJet30 DoubleBTagCSV p056 as measured using events that pass the PFHT300 trigger and efficiency plot for PFHT450 SixJet40 BTagCSV p056 as measured using events that pass the PFHT300 trigger for two different masses as a function of a) the P_T of the 6th jet and b) the H_T. In both cases we require the events to pass the preselection requirements described in the previous sections. On the same graph there are also the distributions of a) the P_T of the 6th jet and b) the H_T.



(a) (b)

Figure 11: Efficiency plot for the combine trigger PFHT400 SixJet30 DoubleBTagCSV p056 or PFHT450 SixJet40 BTagCSV p056 as measured using events that pass the PFHT300 trigger for two different masses as a function of a) the P_T of the 6th jet and b) the H_T. In both cases we require the events to pass the preselection requirements described in the previous sections. On the same graph there are also the distributions of a) the P_T of the 6th jet and the b) the H_T.

6 Conclusions

We examined the efficiencies of the cms triggers that can be used in a search of heavy charged Higgs ($m_{H^+} > m_t$) that decays to tb and results in a full hadronic final state. We find that the PFHT400 SixJet30 DoubleBTagCSV p056 and the PFHT450 SixJet40 BTagCSV p056 are unprescale and can accommodate our needs. Futhermore, the combination of the two triggers results in a much higher efficiency. Preselections cuts also improve the efficiencies. The previously described studies need to be extended to the reconstruction level to have more realistic estimates of the trigger efficiencies.

References

[1] Atlas Collaboration et al. "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC". In: *arXiv preprint arXiv:1207.7214* (2012).

[2] Serguei Chatrchyan et al. "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC". In: *Physics Letters B* 716.1 (2012), pp. 30–61.

[3] Celine Degrande et al. "Heavy charged Higgs boson production at the LHC". In: *arXiv preprint arXiv:1507.02549* (2015).

[4] *LHC Higgs Cross Section WG Picture Gallery*. URL: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGCrossSectionsFigures#H_BR_plots_MSSM (visited on 09/19/2016).