SEARCH FOR A STANDARD MODEL HIGGS AT LHC USING VECTOR BOSON FUSION

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Abstract. The search for a Standard Model Higgs boson produced via Vector Boson Fusion is presented. The study is focused on the intermediated mass range 110 GeV $\leq m_H \leq$ 200 GeV. The LHC potential for Higgs discovery, in this mass range, combining Vector Boson Fusion channels with traditional processes is presented.

1 Introduction

The hunt for the Higgs boson, to clarify the origin of mass, is the most important challenge of the beginning of this century. Recent LEP2 results and the fit to electroweak data[3] favor a relatively low Higgs mass, below O(200 GeV). The CMS[2] and ATLAS[1] collaborations studied, in the past, the Higgs discovery potential, at the LHC, in this mass range using Higgs production via gluon gluon fusion ($\sigma \simeq 20pb$),which has the highest cross section, or in association with a $t\bar{t}$ pair ($\sigma \simeq 300fb$), where the top quark can be tagged.

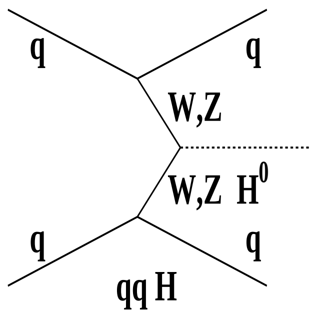

Figure 1: Feynman diagram for Higgs production via Vector Boson Fusion.

It was recently pointed out[4] that Higgs production via Vector Boson Fusion (VBF), fig. 1, could increase the LHC sensitivity for $120GeV < m_H < 200GeV$. Despite the low cross section O(4pb), VBF events have the very distinctive signature of two forward energetic jets generated by the initial partons. In addition, as the Higgs decays into W or τ pairs are considered, the final state topology contains one or two energetic leptons, which are indispensable to trigger the detector and extract the signal over the overwhelming QCD background.

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Process	γ^*/Z+jets $\gamma^*/Z \rightarrow$ ll	$t\bar{t}$	WW+jets (QCD)	qg$\rightarrow$Wt	$\tau\tau$+jets (EW)	WW+jets (EW)
σBR (pb)	5227	55.0	16.7	4.8	0.1708	0.0816

Table 1: Dominant backgrounds for VBF events and the corresponding cross section.

The signal cross section decreases with increasing Higgs masses and ranges, at Leading Order, from 4.36pb for $m_H = 120GeV$ to 2.82pb for $m_H = 180GeV$. The dominant SM backgrounds with one or two leptons in the final state are summarized in table 1. Their production rate is several orders of magnitude higher than the signal one.

The most dangerous backgrounds for $qqH \rightarrow qqWW$ are: tt events, where energetic b-jets fake the signal forward jets and leptons are produced from W decays, and WW+jets. In particular the Electro Weak (EW) component of WW+jets is generated via a t-channel diagram which is very similar to the signal, with no color exchange between the initial partons. The most dangerous background in the $qqH \rightarrow \tau\tau$ channel is Z+jets production, in particular of EW origin.

Both ATLAS and CMS studied, with fast or full simulations 5, the discovery potential of VBF channels at the LHC, for an instantaneous luminosity of $10^{33}cm^{-2}s^{-1}$ as foreseen in the startup phase. The topologies studied and the mass range considered are detailed in table 2.

channel	ATLAS m_H (GeV)	CMS m_H (GeV)
$qqH \rightarrow WW^* \rightarrow l\nu l\nu$	110-190	120
$qqH \rightarrow \tau\tau \rightarrow l\nu\nu l\nu\nu$	110-150	
$qqH \rightarrow \tau\tau \rightarrow l\nu\nu had\nu$	110-150	115-145

Table 2: Topologies and Higgs mass range considered by ATLAS and CMS to study the LHC potential on Higgs production via Vector Boson Fusion

2 Experimental tools

This section summarizes the selection algorithms developed in common for the WW and $\tau\tau$ channels.

Forward Jet Tagging. CMS chose to tag, in each hemisphere, a jet with p_T above 20GeV so as to achieve the maximum rapidity [b] separation between the selected jets. ATLAS chose to tag in each hemisphere the jet with highest p_T among those jet pairs with rapidity separation greater than 3.8. The forward jet tagging efficiency was evaluated with full simulation and the results of the fast simulation corrected accordingly. Typically, tagging algorithms select more than 75% of the signal and reject more than 90% of the $t\bar{t} + jets$ background.

Central Jet Veto. Signal events have very little jet activity in the central region of the detector, but the superposition of pile-up events can fake the presence of central hadrons.

[b] rapidity is defined as $\eta = -ln(\theta/2), where \theta is the polar angle with respect to the beamline.$

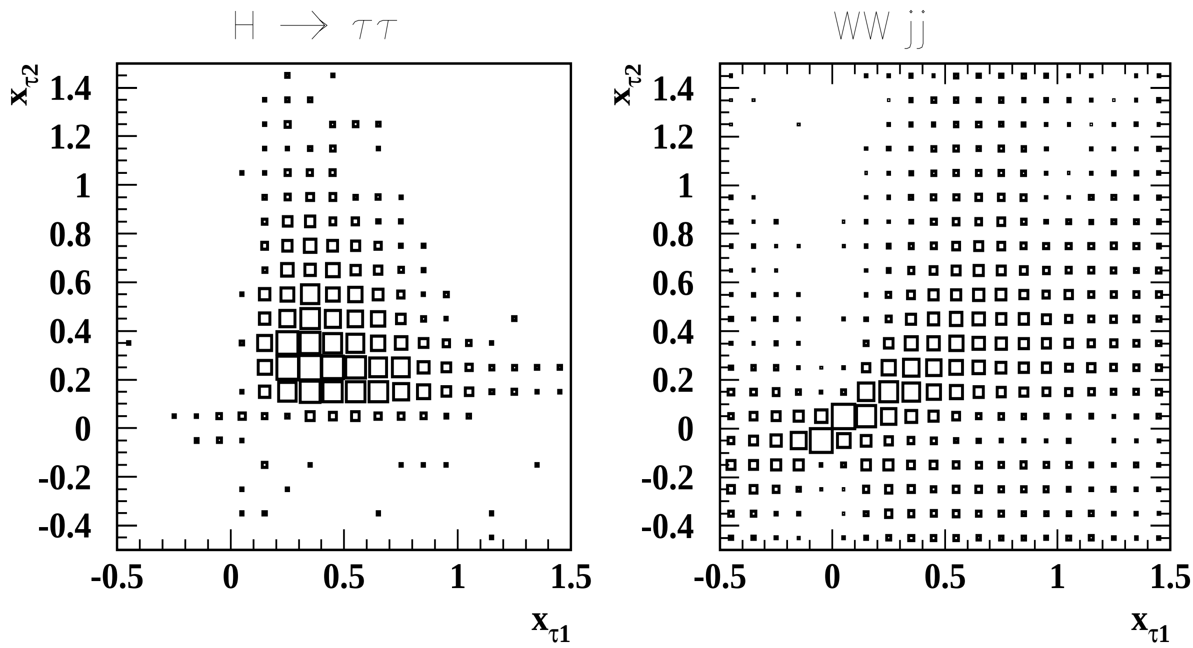

Figure 2: Distribution of the momentum fractions for signal (left) and WW+jets (right).

A central jet veto was studied and optimized with full simulation: events with central jets above a certain p_T threshold were discarded. The study showed that, using a p_T threshold of 20GeV, it should be possible to keep the fake veto rate at the level of 1% and maintain an high signal efficiency.

Tau reconstruction and identification. It is important not only in the $\tau\tau$ channel to tag signal events, but also in the WW channel to veto background processes as $Z \to \tau\tau$. The taus produced in a boson decay are boosted and their decay products tend to be close, in space, to the original τ direction. In case of leptonic decays, it is therefore justified to use the collinear approximation and estimate the τ direction with the lepton direction. In this framework, the fraction x of the τ momentum carried by the lepton can be computed analytically from the conservation of transverse energy and momentum. Fig. 2 shows the distribution of x_1 versus x_2 for signal (left) and WW+jets (right) events having two leptons (electron or muons) in the final state. The signal contains two real τ and, as expected, both momentum fractions are concentrated between 0 and 1, while for WW+jets their distribution is spread. Within the collinear approximation, it's possible to estimate the Higgs mass as: $m_H = m_{\tau\tau} = m_{ll}/\sqrt{x_1 x_2}$.

Other characteristic of the signal that were exploited in both channels were:

- leptons lie within the forward jets;
- a sizable missing transverse momentum is expected, due to ν produced in the W or τ leptonic decays. This is important to suppress the Drell-Yann background in final states with leptons of the same flavor;
- the forward jets tend to have an higher invariant mass than typical QCD jets as the signal is produced via an EW diagram;

- the total p_T of the forward jets is expected to balance the Higgs p_T that can be reconstructed from the measured momenta of the W or tau decay products plus the missing momentum vector. The equality would be exact for events with no initial or final state radiation.

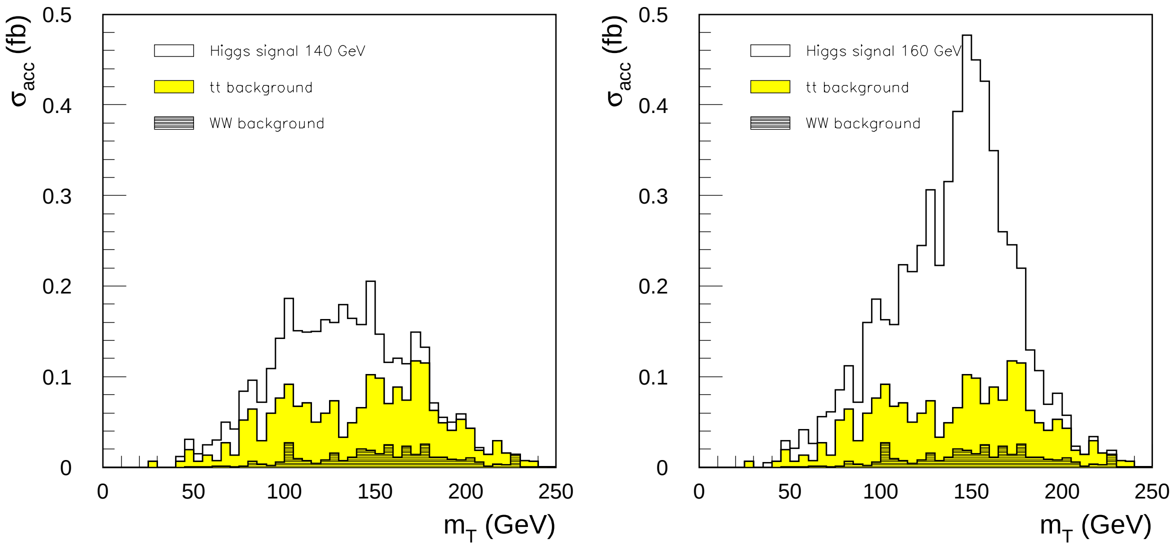

Figure 3: ATLAS study. Transverse mass distribution at the final stage of the selections in the WW channel for m_h=140 GeV (left) andm_h=160 GeV (right).

3 $qqH \to qqWW \to qql\nu l\nu$

This channel can be triggered by the single lepton or two leptons triggers. The typical p_T threshold in the single (two) lepton trigger are 25 (15) GeV for electrons and 20 (10) GeV for muons.

In this topology some kinematic variables could be used to improve the background rejection. In the signal, the spin correlation between the two W is reflected in the angular distribution of the leptons which are more back to back than in background events. In addition, in the Higgs frame, the invariant lepton mass is limited to half the Higgs mass. In this channel only the Higgs transverse mass (m_T) can be reconstructed due to the presence of ν in the final state. Events are selected in a window around the expected m_T of the signal while side bands events give an important handle to check the overall background normalization.

At the final stage of the selections the EW component of WW+ jets is the dominant background. Fig. 3 shows the final m_T distribution for signal and backgrounds, for a Higgs mass of 140 GeV (left) and 160 GeV (right).

A summary of the expected rates for signal and background events can be found in sec. 5 where the signal significance for this channel is also presented.

4 $qqH \rightarrow qq\tau\tau \rightarrow qql\nu\nu l\nu\nu$ and $qqH \rightarrow qq\tau\tau \rightarrow qql\nu + hadrons$

These channels can be triggered by the single lepton or two leptons triggers.

For the hadronic channel the standard tau identification was applied and the typical performance expected is an identification efficiency of the order of 40% for a jet rejection of the order of 10^3 when tau candidates are selected with p_T above 30-40GeV.

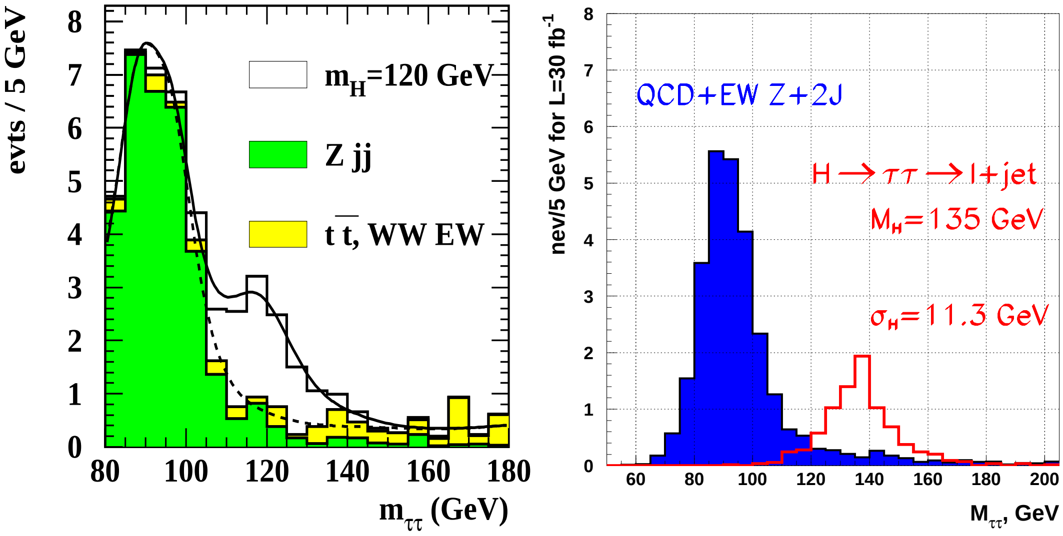

Figure 4: $\tau\tau$ channel.Reconstructed Higgs mass in the leptonic channel on the left (ATLAS study) and hadronic on the right (CMS study).

The key issue is the Higgs mass reconstruction as the invariant mass of the tau pair. The resolution achieved on the Higgs peak is crucial to disentangle the signal from Z+jets events as shown in fig. 4 for the leptonic (hadronic) channel on the left (right). Typical resolutions achieved are of the order of 11 GeV for the hadronic topology and 8 or 12 GeV for the leptonic one respectively in CMS and ATLAS. It is possible to keep under control the background normalization using side-band events far from the Higgs peak. A summary of the expected rates for signal and background events can be found in sec. 5 where the signal significance for this channel is also presented.

5 Signal significance

The numbers of signal and background events expected from the ATLAS study are shown in table 3 for the WW channel with $10fb^{-1}$ and table 4 for the $\tau\tau$ channel with $30fb^{-1}$. The statistical significance for the observation of a Higgs produced via VBF is shown too. CMS found very similar results.

The signal acceptance for leptons of same flavor is slightly lower than for leptons of different flavor because one needs to introduce more stringent cuts, on the missing momentum and lepton invariant mass, to reject Drell-Yann events.

In each of the WW topologies, with only $10fb^{-1}$, the signal sensitivity ranges between 2.5 and 8, for Higgs masses between 130 and 190 GeV. In the $\tau\tau$ channel the signal rate

m_H (GeV)	110	120	130	140	150	160	170	180	190
$qqH \to qqWW^{(*)} \to e\mu + X$									
Signal (10 fb)	1.0	3.8	9.3	16.3	26.2	42.5	42.7	35.6	27.8
Background (10 fb)	4.9	5.9	6.9	8.1	9.8	12.4	13.8	16.3	17.1
Stat. significance (10 fb)	-	1.5	2.9	4.3	6.0	8.1	7.8	6.3	5.0
$qqH \to qqWW^{(*)} \to ee/\mu\mu + X$									
Signal (10 fb)	0.8	3.3	8.6	16.4	27.8	40.2	44.8	36.0	25.9
Background (10 fb)	6.1	7.4	8.9	10.0	12.2	14.3	15.9	18.4	19.2
Stat. significance (10 fb)	-	1.4	2.5	3.9	5.8	7.4	7.6	6.1	4.5

Table 3: Expected signal and background rates and signal significance for the $WW^{(*)}$ channel as a function of m_H assuming an integrated luminosity of 10 fb.

m_H (GeV)	110	120	130	140	150
$H \to \tau\tau \to e\mu p_T^{miss}$					
Signal	7.7	7.0	5.1	3.3	1.5
Background	10.1	3.7	3.3	2.7	2.2
Stat. significance	2.1	2.8	2.2	1.6	-
$H \to \tau\tau \to ee/\mu\mu p_T^{miss}$					
Signal	9.2	7.2	5.7	3.1	1.5
Background	15.4	7.6	5.6	4.6	3.4
Stat. significance	2.1	2.2	2.0	1.2	-
$H \to \tau\tau \to l\ had\ p_T^{miss}$					
Signal	19	15.6	13	10	5
Background	27.0	11.7	10.6	7.4	6.7
Stat. significance	3.3	3.8	3.4	3.0	1.6
combined					
Stat. significance	4.3	5.1	4.4	3.6	2.1

Table 4: Expected signal and background rates and statistical significance for the three $\tau\tau$ decay channels as a function of m_H assuming an integrated luminosity of 30 fb .

is lower and $30fb^{-1}$ are needed to observe the signal in the mass range 110-140 GeV with significance between 3.6 and 5 combining both the topologies studied.

In all channels the signal over background ratio is greater than 1 so the results are not very sensitive to uncertainty in the background estimate.

Fig. 5 shows the significance that could be achieved in ATLAS for the observation of the SM Higgs with $30fb^{-1}$ combining all channels, including Vector Boson Fusion.

6 Conclusions

The ATLAS and CMS collaborations studied the Higgs discovery potential of VBF channels in the mass range $120GeV < m_H < 200GeV$. Both the Higgs decays in WW and $\tau\tau$ were considered. The results, considering one single experiment, can be summarized as follows:

- with $10fb^{-1}$ a Higgs boson in the mass range 140-190GeV could be observed in the channel $qqH \to qqWW \to qql\nu l\nu$ with a significance above 4 sigmas;

- with $30fb^{-1}$ $qqH \to qq\tau\tau$ events would be observable as well. In particular combining the leptonic and hadronic tau decays one could observe a Higgs in the range

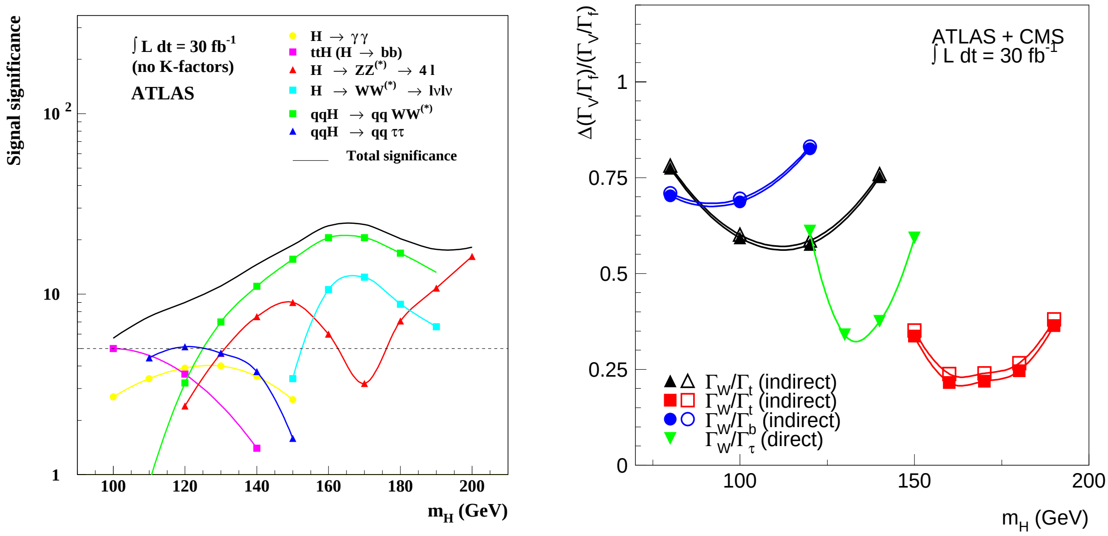

Figure 5: Left: ATLAS discovery potential, with an integrated luminosity of 30 fb^{-1},for a SM Higgs boson with mass below 200 GeV, including VBF channels. Right: precision achievable, at the LHC, with $30fb^{-1}$ per experiment, on the ratio of the Higgs coupling strengths to bosons and fermions, using different channels.

115-140GeV with a significance above 3.5 sigmas;

- with $30fb^{-1}$ and considering the combination of VBF with the others discovery channels a Higgs boson could be observed over the whole mass range 115-200 GeV with a significance above 7 sigma.

Besides its relevance for discovery, VBF is very interesting for the measurement of the Higgs parameters. As an example, the ratio of the Higgs coupling strength to bosons and fermions can be determined directly from the ratio of the measured rates of VBF events in the WW and $\tau\tau$ channels. The precision achieved on this measurement is shown by the green curve in fig. 5 for an integrated luminosity of $30fb^{-1}$ combining ATLAS and CMS data. For Higgs masses between 120-150 GeV the precision is about 30% which is a factor 2 better than what could be obtained with indirect measurements using other production channels.

These studies prove that VBF has a good discovery potential at LHC in the intermediate mass range and it has also a very interesting potential in the measurement of Higgs parameters.

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