PoS PROCEEDINGS OF SCIENCE

Vector Boson Fusion Production of the Standard Model Higgs at the LHC

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The cross section measurements of the Higgs boson production in the vector boson fusion (VBF) process at the LHC followed by a Higgs boson decay into $\tau\tau$, WW and $\gamma\gamma$ will significantly extend the possibility of Higgs boson coupling measurements. Prospective analyses with the CMS experiment are discussed for the $H \to \gamma\gamma$, WW and $\tau\tau$ decay channels for an integrated LHC luminosity of 30 fb^{-1}. For a Higgs boson mass in the range 115 to 140 GeV, an observation with a significance above 2 standard deviations is expected in the H to $\gamma\gamma$ channel, and above 3 standard deviations in the H to $\tau\tau$ channel. The H to WW channel offers a discovery reach above 5 sigma in the mass range 140 to 200 GeV. A new complete strategy is presented for the control of systematics and early searches at very low luminosities of the order of 1 fb^{-1}.

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1. Introduction

Vector Boson Fusion (VBF) Higgs boson production is the second largest production mechanism at the LHC. The cross section measurements of the VBF process, $VV \to H$ ($qq \to qqH$), followed by Higgs boson decays into $\tau\tau$, WW and $\gamma\gamma$ will significantly extend the possibility of Higgs boson coupling measurements [1, 2].

2. Vector Boson Fusion Signature

Events produced by VBF are characterized by a distict topology of the final state: two forward jets with little extra hadronic activity and the decay products of the Higgs boson. The rapidity distribution of the 3rd jet with respect to the two forward jets, η^*_{j3}, is shown in Fig. 1 (left) which shows a double-peak structure for the electroweak processes, including the VBF signal, and is more central for the QCD background samples. Applying a central jet veto (CJV) is a poweful rejection method against the QCD background. To avoid considering jets from pile-up events in the CJV, jets are associated to the signal vertex using tracks. For every extra jet one can define the quantity $\alpha_{\mathrm{j3}} = \Sigma \mathrm{p_{Ttrk}}/\mathrm{E_{Tj3}}$, where $\mathrm{p_{Ttrk}}$ is the $\mathrm{p_T}$ of tracks from the signal vertex within the jet cone and $\mathrm{E_{Tj3}}$ is the jet measured raw $\mathrm{E_T}$. Figure 1 (right) shows α_{3j} tends to peak at low values for non-signal jets. The efficiency of the veto for the background samples versus the signal efficiency is shown in Figure 2 (left) for events containg a 3rd jet with E_T larger than different threshold values. An optimal threshold where the signal process has ~80% efficiency while the backgrounds are suppressed below 50% is used [3]. An alternative approach is to consider a track counting veto (TCV) [4], where the number of tracks between the two leading jets is counted with different p_T thresholds. Figure 2 (right) shows the performance of the TCV algorithm, i.e the efficiency of selecting the signal versus the background for events with an increasing cut on the track multiplicity and p_T. The black star indicates the performance of the CJV based on calorimeter jets. The TCV algorithm can reach similar discrimination power than the central jet veto.

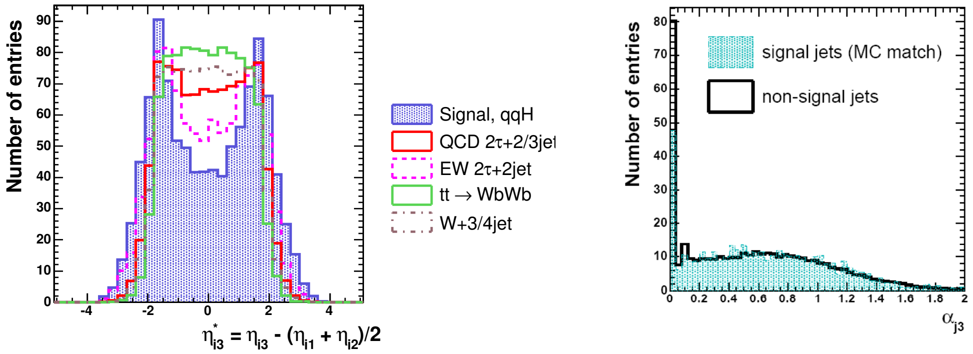


Figure 1: The η distribution of the 3rd jet with respect to the two forward jets (left). The distribution of α_{3j} which is used to match jets to the signal vertex (right).

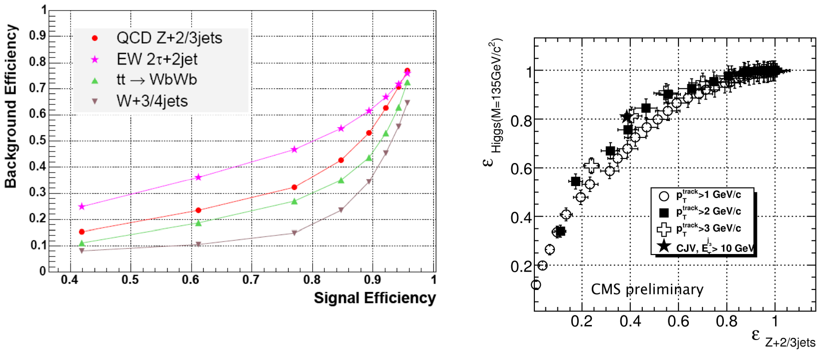
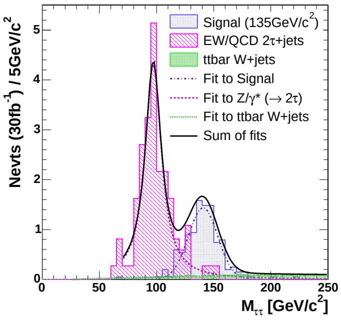


Figure 2: Efficiency of the CJV for background versus signal (M_H=135 GeV), for increasing 3rd jet E_{Tth} threshold (left). TCV performance for different p_t^{track} and track multiplicity thresholds compared to the performance of the CJV.

3. Vector Boson Fusion Higgs Discovery Potential

The observability of the VBF Higgs boson production has been studied with the full CMS detector simulation in the $H \longrightarrow \tau\tau$, $\gamma\gamma$ and WW decay channels [5]. VBF $H \longrightarrow \tau\tau$ production has been studied in the Higgs mass range of 115 to 145 GeV in the lepton plus τ_{jet} final state. Figure 3 (left) shows the expected di-τ mass distribution using the collinear approximation [3] for a luminosity of 30 fb^{-1}. Figure 3 (right) shows the significance of the expected number of signal events for different Higgs masses. A statistical signal significance of 3.9σ is expected for a Higgs mass of 135 GeV.



M_H [GeV]	115	125	135	145
N_S (30 fb^{-1})	10.47	7.79	7.94	3.63
N_B (30 fb^{-1})	3.70	2.21	1.84	1.42
S_{cP} at 30 fb^{-1} (no uncertainty)	4.04	3.71	3.98	2.19
S_{cP} at 30 fb^{-1} ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
S_{cP} at 60 fb^{-1} ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19

Figure 3: Di-τ invariant mass expected for a luminosity of 30 fb^{-1} (left). Significance of the expected number of signal events for different Higgs boson masses (right).

VBF $H \longrightarrow WW$ production in the lepton plus two jet final state has been studied in the Higgs mass range between 120 and 250 GeV. Figure 4 (left) shows the signal significance expected with 30 fb^{-1} for different central jet veto selections [6]. In the mass range between 140-200 GeV a 5σ significance can be achieved. VBF $H \longrightarrow \gamma\gamma$ production has also been studied in the Higgs mass range between 115 and 150 GeV [7]. Figure 4 (right) shows the signal significance expected with 30 and 60 fb^{-1}. With 60 fb^{-1} of collected data a 3σ significance can be achieved for a low mass Higgs in the range 115 to 130 GeV.

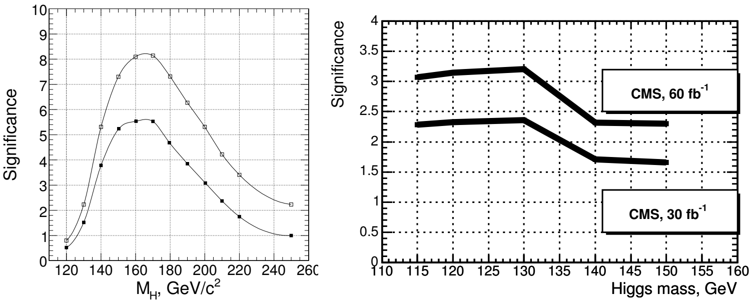


Figure 4: Signal significance of VBF $H \rightarrow WW$ for 30 fb^{-1}. The high (low) curves correspond to full (loose) extra jet veto (left). Signal significance of VBF $H \rightarrow \gamma\gamma$ for 30 and 60 fb^{-1} (right).

4. Search of Higgs$\rightarrow \tau\tau \rightarrow$ lepton $+ \tau_{\text{jet}}$ with 1 fb^{-1}

A selection strategy for the search of VBF Higgs $\rightarrow \tau\tau \rightarrow$ lepton $+ \tau_{\text{jet}}$ with 1 fb^{-1} has been developed and is described in detail in [8]. The di-τ invariant mass will be analyzed to search for the presence of a Higgs boson in the region above the $Z \rightarrow \tau\tau$ mass peak. It is important to know well the shape of the $Z \rightarrow \tau\tau$ background. The dominant uncertainty comes from the modeling of the missing transverse momentum related to the effects of pile-up, underlying event and the calorimeter noise and response. A method to model the di-τ mass has been developed [4]. $Z \rightarrow \mu\mu$ data events are selected and the muons are removed from the real event. Di-τ Monte Carlo events are generated with the same kinematics as the real muons and their detector response is fully simulated. Finally the real $Z \rightarrow \mu\mu$ events with the muons removed and the simulated di-τ events are super-imposed to form one event, $Z \rightarrow \tau_\mu \tau_\mu$, and the di-$\tau$ mass is calculated. The reconstructed di-τ mass for real and fake $Z \rightarrow \tau\tau$ events for inclusive Drell-Yan and Z+jets events are shown in Fig. 5. A good agreement between the di-τ mass shapes is obtained.

The expected di-τ mass distribution for the background and the Higgs signal for 1 fb^{-1} is shown in Fig. 6 (left). A profile likelihood method is used to evaluate the upper limit on the number of signal events. Figure 6 (right) shows the expected 95% CL limit on the cross section times branching ratio as a function of the Higgs boson mass.

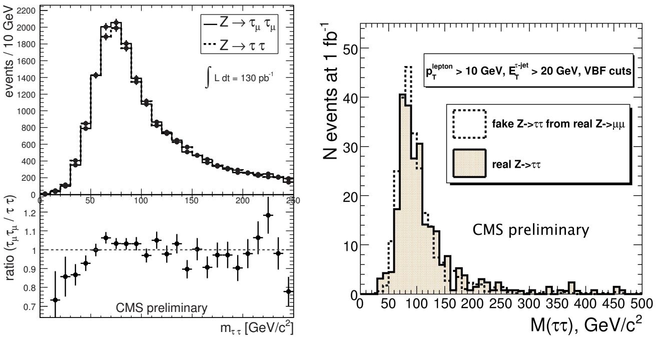


Figure 5: Reconstructed di-τ mass for real and fake $Z \rightarrow \tau\tau$ events for the final states (left) $\tau\tau \rightarrow \mu\nu\nu + \mu\nu\nu$ from inclusive Drell-Yan events and (right) $\tau\tau \rightarrow l\nu\nu + \tau_{jet}\nu$ from Z+jets events.

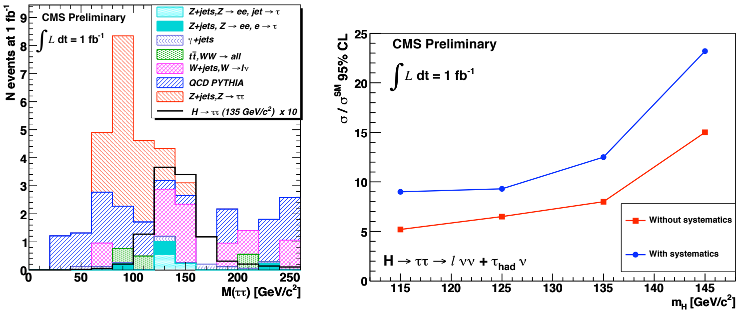


Figure 6: Di-τ mass distribution of expected backgrounds with 1 fb^{-1} after all selection. Backgrounds are shown cumulative. The signal mass distribution scaled by a factor 10 is also shown for M_H= 135 GeV.

5. Conclusion

A selection strategy for the Standard Model Higgs boson produced in vector boson fusion decaying to a pair of τ leptons with 1 fb^{-1} of early CMS data at the LHC has been presented. No signal evidence is expected and upper limit on the cross section times branching ratio is evaluated. Prospective analyses for the $H \rightarrow \gamma\gamma$, WW and $\tau\tau$ decay channels for a luminosity of 30 fb^{-1} have also been discussed. For a Higgs boson mass in the range 115 to 140 GeV, an observation with a significance above 2 standard deviations is expected in the H to $\gamma\gamma$ channel, and above 3 standard deviations in the H to $\tau\tau$ channel. The H to WW channel offers a discovery reach above 5 sigma in the mass range of 140 to 200 GeV.

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