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Search for invisibly decaying vector boson fusion produced Higgs bosons with 139 fb^{-1} of pp collisions with the ATLAS detector

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While the Standard Model (SM) predicts a branching ratio of the Higgs boson decaying to invisible particles of O(0.001), the current measurement of the Higgs boson coupling to other SM particles allows for up to 30% of the Higgs boson width to originate from decays beyond the SM (BSM). The small SM-allowed rate of Higgs boson decays to invisible particles can be enhanced if the Higgs boson decays into a pair of weakly interacting massive particles (WIMPs), which may explain the nature of dark matter. The Vector Boson Fusion (VBF) production mechanism of the Higgs boson provides a distinctive signature with two forward jets that are largely separated in pseudorapidity leading to a large invariant mass that can be used to target events with invisible Higgs decays, where particles invisible to the detector are a source of missing transverse energy. The most recent results using the ATLAS detectors at the LHC of VBF-produced Higgs bosons decaying invisibly are presented, utilizing the full Run-2 dataset of 139 fb^{-1} of 13 TeV center-of-mass proton–proton collisions. Further interpretations set limits on the VBF production of other heavy scalars, and the WIMP-nucleon elastic scattering cross-section.

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The Standard Model (SM) allows for Higgs bosons to decay to particles that are invisible to the ATLAS detector at the LHC - neutrinos - by the decay chain $H \to ZZ^* \to \nu\nu\nu\nu$ with a branching ratio of $B_{inv} = 1.13 \times 10^{-3}$ [1]. Neutrinos are "invisible" because they rarely interact directly with the detector. The branching ratio may be enhanced by the presence of Beyond the Standard Model (BSM) physics, such as the direct coupling of the Higgs boson to a pair of weakly interacting massive dark matter (DM) particles as considered in Higgs portal DM theories.

Direct searches for the H→inv. process aim to directly probe the process by searching for events produced with missing transverse energy associated with the invisible Higgs decay. Prior to this result, the strictest upper limit set by the ATLAS collaboration resulted from a statistical combination of three Higgs production modes utilizing 36.1 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collisions and the combined result from Run 1 searches [2]. This limit of $B_{inv} <$ 0.26 (0.17) is driven by the vector boson fusion (VBF) production mode contribution of $B_{inv} <$ 0.37 (0.28) [3]. The sensitivity of the VBF production mode is due to the distinctive topology that the VBF jets provide.

This work addresses the search for H→inv. produced via vector boson fusion with 139 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collision data collected with the ATLAS detector [4]. In the absence of a detection, an observed (expected) upper limit is set on B_{inv} at the 95% CL of $B_{inv} <$ 0.13 (0.13).

Signal candidate events are required to have missing transverse energy (associated with the invisible Higgs decay) of $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV and large $m_{jj} > 800$ GeV. Missing transverse energy is used to trigger data events. Two forward VBF jets are expected, so a large $\Delta\eta_{jj} > 3.8$ between the two jets leading in p_T is required with $\Delta\phi_{jj} < 2$ from the recoil of the system. Up to two additional initial- or final-state radiation jets are allowed in the event, provided they are not central. Events with leptons (electrons and muons) or photons are vetoed.

The increased data statistics play a role in the improved limit observed, but additional improvements are also made to the analysis strategy itself. Higher pileup discrimination is achieved with the consideration of jet timing and forward pileup mitigation in signal selection. The dominant V+jets background is further reduced by improving the required lepton veto. and increasing the Monte Carlo (MC) statistics. Looser kinematic requirements are made on powerful discriminatory variables such as m_{jj} and $\Delta\eta_{jj}$. The binning scheme used in the signal and control regions is also updated to include one multijet bin. Two-jet events are binned orthogonally in the m_{jj} /$\Delta\phi_{jj}$ plane with five m_{jj} bins (endpoints at [0.8, 1.0, 1.5, 2.0, 3.5, +] TeV) and two $\Delta\phi_{jj}$ bins (endpoints at [0, 1, 2]). The bins of highest sensitivity are those at large-m_{jj} and small-$\Delta\phi_{jj}$.

The dominant V+jets background is irreducible and constitutes nearly 95% of background events in the signal region. It is estimated through a transfer-factor method in which control regions (CRs) orthogonal to the signal region (based upon lepton multiplicity) and enriched in these backgrounds are defined. Data and MC from these control regions with detected leptons are used to define normalization factors β that scale the backgrounds in the signal region like Equation 1,

$$B^{\mathrm{SR}} = B^{\mathrm{SR,MC}} \cdot \frac{N^{\mathrm{CR}} - B^{\mathrm{CR}}_{\mathrm{non-V}}}{B^{\mathrm{CR,MC}}} = B^{\mathrm{SR,MC}} \cdot \beta\,, \tag{1}$$

where B are background yields (those from MC noted with "MC") and N is the observed yield in data. Factors are computed separately for each bin, and separately for the W and Z backgrounds. Data driven methods are used to estimate the QCD multijet background and jets faking electrons that are selected into the W CR. Direct MC estimation is used for the small multiboson and $t\bar{t}$ backgrounds.

A maximum likelihood fit is performed simultaneously across all signal and control regions. Sources of uncertainties that most impact the search are data and MC statistics of the V+jets background and the data-driven multijet background estimate. The lack of an excess leads to an upper limit on the branching ratio being set at the 95% confidence level of $B_{inv} < 0.13$ $\left(0.13^{+0.05}_{-0.04}\right)$ observed (expected).

Further interpretations are also considered. The limit on B_{inv} can be related to a limit on the spin-independent weakly interacting massive particle (WIMP) – nucleon cross section, across a range of WIMP masses. The Higgs portal model used assumes that the Higgs boson is the only mediator between the SM and this DM. This search extends sensitivity to low-WIMP mass regions and therefore is complimentary to direct DM detection experiments in this phase space (see Figure 1 (a)). New heavy scalar mediators other than the SM Higgs boson could also lead to this signature, and Figure 1 (b) shows the bounds that this search set on $\sigma^{\mathrm{VBF}} \times B_{inv}$ across a range of mediator masses.

The ATLAS detector collaboration at the LHC utilized the full Run 2 dataset of 139 fb^{-1} in the search of vector boson fusion produced Higgs boson and their decay to invisible particles. An upper limit on the branching ratio B_{inv} of $B_{inv} < 0.13$ (0.13) was set in this channel, and further interpretations produced limits on a WIMP-nucleon scattering cross section and $\sigma \times B_{inv}$ for new scalar mediators up to a mass of 1 TeV.

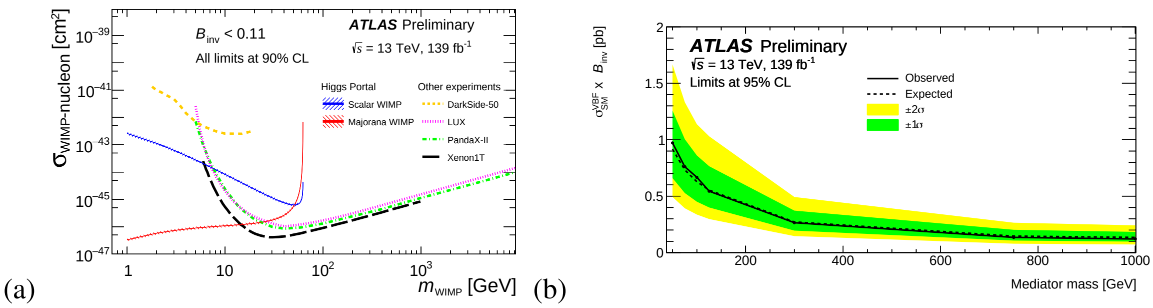

Figure 1: Further interpretations of the search include setting limits on (a) WIMP–nucleon cross sections and (b) $\sigma \times \mathcal{B}_{\mathrm{inv.}}$ of new heavy scalars [4]

References

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