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Search for charged Higgs bosons decaying to $W^{\pm}W^{\pm}$ or $W^{\pm}Z$ in 139 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector

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This document presents a search for charged Higgs bosons decaying into *WW* or *WZ* bosons, involving experimental signatures with two, three and four leptons with a variety of charge combinations, missing transverse momentum and jets. We are using a data sample of proton-proton collisions at centre-of-mass energy of 13 TeV measured with the ATLAS detector between 2015 and 2018. The total integrated luminosity fot this data is 139 fb^{-1}. The search is guided by a type-II seesaw model that extends the scalar sector of the Standard Model with a scalar triplet, leading to a phenomenology that includes doubly and singly charged Higgs bosons. Two scenarios are explored, corresponding to the pair production of doubly charged H bosons, or the associated production of a doubly charged H boson and a singly charged H boson. No significant deviations from the Standard Model predictions are observed. $H^{\pm\pm}$ bosons are excluded at 95% confidence level up to 350 GeV and 230 GeV for the pair and associated production modes, respectively [1]. The results of this search have been published here.

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1. Introduction

Type-II seesaw mechanism is an addition to the Standard Model (SM) sector which allows the neutrino masses by extending the Higgs sector with a hypercharge $Y = 2$ scalar triplet. Guided by this model, after the electroweak symmetry breaking (EWSB), a rich phenomenology with seven scalar bosons results: $H^{\pm\pm}$, $H^{\pm}$, A^0 (CP odd), H^0 (CP even) and h^0 (CP even). The vacuum expectation value is assumed to be 100 MeV [2]. For this analysis only the pair production of doubly charged $H^{\pm\pm}$ bosons and the associated production of a doubly charged $H^{\pm\pm}$ boson and a singly charged $H^{\pm}$ boson are considered. In this analysis three final states are taken into account, according to the number of leptons in the final state: two same-charge (SC) leptons ($2l^{SC}$), three leptons ($3l$), and four leptons ($4l$) [3]. The production modes of the $H^{\pm\pm}$ and $H^{\pm}$ are shown in Figure 1. In the context of this model, the branching ratios of the $H^{\pm\pm}$ boson decay into a pair of W bosons with the same charge is 100%, and depending on the $H^{\pm}$ boson mass, the branching ratio varies between 40% and 60%.

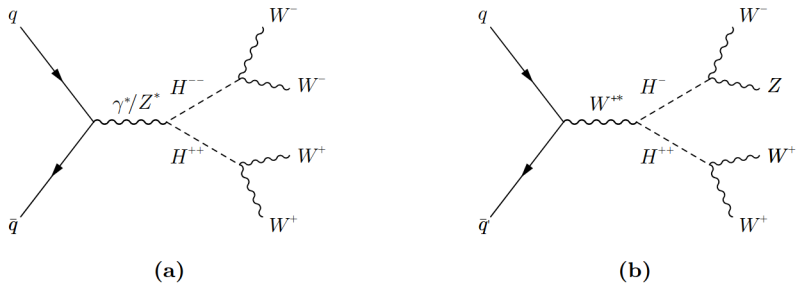

Figure 1: Feynman diagrams of the production and subsequent decay of the $H^{\pm\pm}$ and $H^{\pm}$ bosons: (a) $H^{\pm\pm}$ pair production and (b) $H^{\pm}$ associated production.

2. Analysis strategy

2.1 Signal regions

Two steps are required to proceed the event selection: the preselection and the signal regions (SRs) selection. In Table 1 the preselection is defined; three channels are defined ($2l^{SC}$, $3l$ and $4l$) and are required to be mutually exclusive. The events are selected only if the absolute value of the sum of charges of leptons is two, one, and two or zero for the $2l^{SC}$, $3l$ and $4l$ channels, respectively. For the $2l^{SC}$ channel the second-highest-p_T lepton is required to have $p_T > 20$ GeV and both leptons to be tight. Similarly for each lepton in the pair of leptons of the same charge for the $3l$ channel.

Further requirements are based on E_T^{miss}, the jet multiplicity, N_{jets}, and the number of b-jets, N_{b-jet}. In order to reduce the contributions coming from electron charge misidentification, in the $2l^{SC}$ channel the Z-boson invariant mass veto is applied to $e^{\pm}e^{\pm}$ events. Lastly, the invariant mass of the same-flavour opposite-charge lepton pair is required to be different from the nominal Z-boson mass by 10 GeV.

Selection criteria	$2l^{SC}$	$3l$	$4l$
At least one offline tight lepton with skfsvbjsfnsv			
N_l (type L)	= 2	= 3	= 4
N_l (type L*)	-	-	= 4
N_l (type T)	= 2	≥ 2 ($l_{1,2}$)	≥ 1
$\lvert \sum Q_l \rvert$	= 2	= 1	
Lepton p_T	$p_T^{l_1,l_2}$ > 30, 20 GeV	$p_T^{l_0,l_1,l_2}$ > 10, 20, 20 GeV	$p_T^{l_1,l_2,l_3,l_4}$ > 10 GeV
E_T^{miss}	> 70 GeV	> 30 GeV	> 30 GeV
N_{jets}	≥ 3	≥ 2	-
N_{b-jets}	= 0		
Low SFOC m_{ll} veto	-	m_{ll}^{OC} > 15 GeV	
Z boson decay veto	$\lvert m_{ll}^{SC} - m_Z \rvert$ > 10 GeV	$\lvert m_{ll}^{OC} - m_Z \rvert$ > 10 GeV	

Table 1: The preselection criteria for the $2l^{SC}$, $3l$ and $4l$ analysis channels. The leptons are required to pass the loose (L), loose and minimally isolated (L*) or tight (T) requirements. The leptons are ordered by decreasing p_T (l_1, l_2, ...) in the $2l^{SC}$ and $4l$ channels, while for the $3l$ channel l_1 and l_2 denote the two same-charge leptons and l_0 denotes the lepton with a charge opposite to the total lepton charge. Ql denotes the charge of each lepton. SFOC refers to the same–flavour opposite-charge lepton pairs. The symbol "-" means no requirement is made.

The SRs are summarized in Table 2 and defined for each channel. They were defined and then optimized for the $H^{\pm\pm}$ pair production mode, using the $m_{H^{\pm\pm}}$ = 200, 300, 400 and 500 GeV mass hypotheses. The same SRs are used for the study of the $H^{\pm}$ associated production mode.

Charged Higgs boson mass	$m_{H^{\pm\pm}}$ = 200 GeV	$m_{H^{\pm\pm}}$ = 300 GeV	$m_{H^{\pm\pm}}$ = 400 GeV	$m_{H^{\pm\pm}}$ = 500 GeV
Selection criteria	$2l^{SC}$ channel			
m_{jets} [GeV]	[100, 450]	[100, 500]	[300, 700]	[400, 1000]
S	< 0.3	< 0.6	< 0.6	< 0.9
$\Delta R_{l^{\pm}l^{\pm}}$	< 1.9	< 2.1	< 2.2	< 2.4
$\Delta\Phi_{ll,E_T^{miss}}$	< 0.7	< 0.9	< 1.0	< 1.0
m_{xl} [GeV]	[40, 150]	[90, 240]	[130, 340]	[130, 400]
E_T^{miss} [GeV]	> 100	> 130	> 170	> 200
Selection criteria	$3l$ channel			
$\Delta R_{l^{\pm}l^{\pm}}$	[0.2, 1.7]	[0.0, 2.1]	[0.2, 2.5]	[0.3, 2.8]
m_{xl} [GeV]	> 160	> 190	> 240	> 310
E_T^{miss} [GeV]	> 30	> 55	> 80	> 90
ΔR_{ljet}	[0.1, 1.5]	[0.1, 2.0]	[0.1, 2.3]	[0.5, 2.3]
$p_T^{leadingjet}$ [GeV]	> 40	> 70	> 100	> 95
Selection criteria	$4l$ channel			
m_{xl} [GeV]	> 230	> 270	> 360	> 440
E_T^{miss} [GeV]	> 60	> 60	> 60	> 60
$p_T^{l_1}$ [GeV]	> 65	> 80	> 110	> 130
$\Delta R_{l^{\pm}l^{\pm}}^{min}$	[0.2, 1.2]	[0.2, 2.0]	[0.5, 2.4]	[0.6, 2.4]
$\Delta R_{l^{\pm}l^{\pm}}^{max}$	[0.3, 2.0]	[0.5, 2.6]	[0.4, 3.1]	[0.6, 3.1]

Table 2: Definiton of the signal regions optimised for the study of different $H^{\pm\pm}$ and $H^{\pm}$ mass hypotheses. For the $H^{\pm\pm}$ pair production mode, the $m_{H^{\pm\pm}}$ = 300 GeV signal regions are also used for $m_{H^{\pm\pm}}$ = 350 GeV. For the $H^{\pm\pm}$ and $H^{\pm}$ associated production mode, the $m_{H^{\pm\pm}}$ = 200 GeV, 400 GeV and 500 GeV signal regions are also used for $m_{H^{\pm\pm}}$ = 220 GeV, 450 GeV and 550 GeV, respectively.

2.2 Background estimation

The background sources can be divided into two main categories: prompt background (estimated using Monte Carlo (MC) simulations) and fake/non-prompt background (estimated using

data-based methods); the first category originates from SM events which contain reconstucted charged leptons coming from leptonic decays of W and Z bosons. The second category is populated by non-prompt leptons and charge-flip electrons. Leptons coming from b- and c-hadrons decay, or single pions that mimic the electron signatures are labeled as non-prompt-lepton category. The electrons coming from hadronic decays into photons with pairs of electrons in the final state also enter this category.

3. Results and conclusion

The observed data event yields and the corresponding estimates for the background in the SRs are shown in Figure 2. No significant excess over the expected yields is observed in any of the SRs.

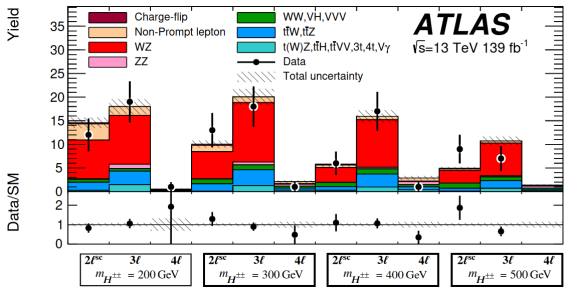

Figure 2: Data event yields compared with the expected contributions from relevant background sources, for the combination of the individual channels of the $2l^{SC}$, $3l$ and $4l$ SRs. The $m_{H^{\pm\pm}}$ = 220 GeV, 350 GeV and 450 GeV signal hypotheses use the signal regions defined for the $m_{H^{\pm\pm}}$ = 200 GeV, 300 GeV and 400 GeV signal. The $m_{H^{\pm\pm}}$ = 550 GeV and $m_{H^{\pm\pm}}$ = 600 GeV signal hypotheses use the signal regions defined for the $m_{H^{\pm\pm}}$ = 500 GeV. The total uncertainties in the expected event yields are shown as the hatched bands.

The expected and observed upper limits on the $H^{\pm\pm}$ pair production and the $H^{\pm\pm}$ and $H^{\pm}$ associated production cross sections times branching fraction at 95% confidence level (CL) for the five mass hypotheses are shown in figures 3. They are obtained from the combination of $2l^{SC}$, $3l$ and $4l$ SRs. Assuming a linear dependence of the cross-section limit between neighbouring mass points, the observed 95% CL lower limit on the mass of the $H^{\pm\pm}$ boson is 350 GeV for the pair production mode and 230 GeV for the associated production mode.

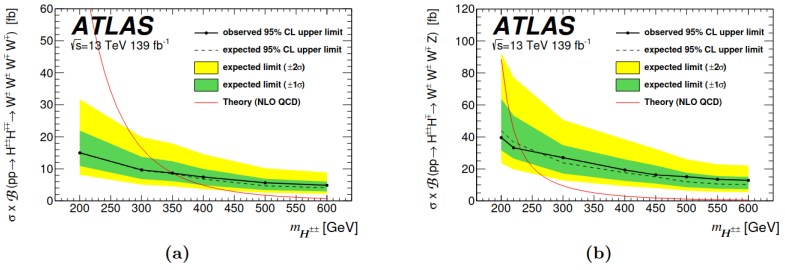

Figure 3: Observed and expected upper limits on the (a) $H^{\pm\pm}$ pair production and (b) $H^{\pm\pm}$ and $H^{\pm}$ associated production cross section times branching fraction at 95% CL obtained from the combination of $2l^{SC}$, $3l$ and $4l$ channels. The region above the observed limit is excluded by the measurement. The bands represent the expected exclusion curves within one and two standard deviations.

References

[1] *Search for doubly and singly charged Higgs bosons decaying into vector bosons in multi-lepton final states with the ATLAS detector using proton-proton collisions at $\sqrt{s} = 13$ TeV,* JHEP06 (2021) 146

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[3] W. Konetschny and W. Kummer, *Nonconservation of total lepton number with scalar bosons,* Phys.Lett.B 70 (1977) 433