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Search for doubly-charged Higgs boson in multi-lepton final states at $\sqrt{s}$= 13 TeV with the ATLAS detector

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A search for new high mass resonances decaying to two high-p_{T} leptons with same-charge is presented. The results reported here use the pp collision data sample corresponding to 36.1 fb^{-1} of integrated luminosity collected in 2015 and 2016 by the ATLAS detector at the LHC with a centre-of-mass energy of 13 TeV. The benchmark model is doubly charged Higgs boson (DCH) production via Drell–Yan with subsequent exclusive decay into leptons. Leptonic final states are very interesting since they provide a good sensitivity and small systematic uncertainties. In addition, requiring same-sign leptonic final states reduces the background contamination from Standard Model processes while providing a large sensitivity to Beyond Standard Model phenomena. No significant evidence of a signal was observed and corresponding limits on the production cross-section and a lower limit on $m(H^{\pm\pm})$ were derived at 95% confidence level. The results at $\sqrt{s}$ = 13 TeV complement and improve former ones obtained by the ATLAS Collaboration with data at $\sqrt{s}$ = 8 TeV.

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1. Introduction

Search for new physics (NP), both directly and indirectly, is crucial for the ATLAS [1] research program. Many direct searches for NP can take advantage of very clean signatures, as final states with leptons. Moreover, requiring the leptons to have the same electric charge allows to reject most of the SM background, which predominantly leads to opposite-charge leptons final states. Main backgrounds to this search are therefore events with misreconstructed objects as well as VV[1] and $t\bar{t}V$ production with same-charge prompt lepton final states.

2. Doubly charged Higgs in left-right symmetric models

Doubly charged Higgs bosons (DCH) appear in many NP models. Among them, left-right symmetric models [2] rely on an extended symmetry group, namely $SU(2)_L \times SU(2)_R \times U(1)_{BL}$, restoring parity in weak interactions beyond the TeV scale and introducing right-handed gauge bosons W, Z. Breaking the left-right symmetric group into the SM gauge group, requires the introduction of a triplet of scalar bosons, $H_{L,R} = (H^0_{L,R}, H^{\pm}_{L,R}, H^{\pm\pm}_{L,R})$, acquiring a non-null vacuum expectation value v_Δ. The DCH boson $H^{\pm\pm}$ gives mass to neutrinos via a type II see-saw mechanism. At LHC, DCH is mainly produced in pairs via Drell–Yan while its decay depends on the v_Δ of the triplet. As in this analysis the coupling to W is assumed to be negligible, only DCH decays to leptons are considered, also allowing lepton flavour violation. General final states X other than leptons do not impact on the event yield in signal regions. The total assumed branching ratio of $H^{\pm\pm}$ is therefore $B(H^{\pm\pm} \to \ell^\pm\ell^\pm) + B(H^{\pm\pm} \to X) = 100\%$[2].

3. Data and simulated event samples

The data used in this analysis [3], corresponding to 36.1 fb^{-1}, were collected during 2015 and 2016 with an uncertainty on the combined integrated luminosity of 3.2%. Signal MC samples were generated with $m(H^{\pm\pm})$ masses varying in the range [300,1300] GeV with `PYTHIA 8`. To simulate $Z/\gamma^* \to ee$, $t\bar{t}$ and single top processes `Powheg + PYTHIA8` was used. Diboson samples were generated with `SHERPA 2.2.1` while `MC@NLO + PYTHIA8` was used for $t\bar{t}V$.

4. Analysis regions

In this search events are classified in independent categories called *analysis regions*. *Control Regions* (CR) are used to constrain free background parameters of the model in the final fit (Section 6), such as Drell–Yan and diboson normalization. Background model is validated in *Validation Regions* (VR) and *Signal Regions* (SR) are used to extract signal rate. In regions with more than two leptons, events are discarded if any opposite-charge same-flavour lepton pair is within 10 GeV of the Z boson mass to reject the diboson background. Signal regions require the invariant mass of each same-charge pair to be above 200 GeV. The final fit is performed on the same-charge pair invariant mass spectrum for events containing two or three leptons and on the mean mass of the two same-charge pairs[3] in the four lepton signal region.

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[1] Here V indicates the W and the Z bosons.

[2] This search only considers light leptons final states so that $\ell = \{e, \mu\}$.

[3] The mean mass of the two same-charge pairs is defined as $\bar{M} = (m^{++} + m^{--})/2$.

5. Backgrounds estimation

Prompt backgrounds (see Section 1) are estimated using simulated samples listed in Section 3. The most challenging backgrounds are however the ones with misreconstred objects in the final state such as electrons with wrongly reconstructed charge and *fake* leptons.

Electron charge misidentification is mainly caused by bremsstrahlung with consequent photon conversion. To properly estimate the contribution of these events, simulation needs to be corrected to account for possible mismodeling due to the complexity of the processes involved and of the detector material. The correction factor is obtained by comparing the charge misidentification probability measured in data to the one from simulation, both extracted by performing a likelihood fit on a dedicated $Z \to ee$ sample. The charge misidentification probability is parametrized as a function of electron p_{T} and η, $P(p_{\mathrm{T}}, \eta) = f(\eta) \times \sigma(p_{\mathrm{T}})$, growing with the amount of detector material traversed by the electron. Prompt electrons in MC are then corrected with a scale factor.[4]

Fake-leptons originate from decay in flight of mesons inside jets, from misreconstructed jets and conversions of initial- and final-state radiation photons. This type of background is estimated with a data-driven approach called the "fake-factor" method, extrapolating the number of events with fake leptons from "side-band regions". Side-band regions require the presence of at least one lepton, called *loose*, failing one of the selection criteria of analysis regions *tight* leptons. The ratio of tight to loose leptons is measured in dedicated regions enriched in fake leptons, determined as a function of lepton flavour, p_{T} and η and referred to as the "fake-factor".

Validation regions (as from Section 4) have been properly designed to test the goodness of charge misidentification and fake background predictions before being applied to signal regions.

6. Fit results and exclusion limits

The statistical analysis of the results implements a maximum-likelihood fit of the dilepton invariant mass distribution in control and signal regions. The likelihood is the product of a Poisson probability density function describing the observed number of events and Gaussian distributions to constrain nuisance parameters associated with systematic uncertainties. Additional free parameters

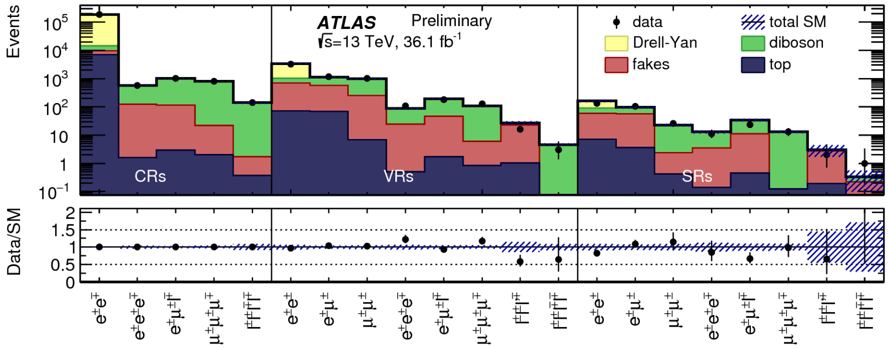

Figure 1: Post-fit normalization in all analysis regions. The hashed bands include all systematic uncertainties. The notations $\ell^{\pm}\ell'^{\pm}\ell^{\mp}$ and $\ell^{\pm}\ell^{\pm}\ell'^{\mp}$indicate that the same-charge leptons have respectively different or same flavour.

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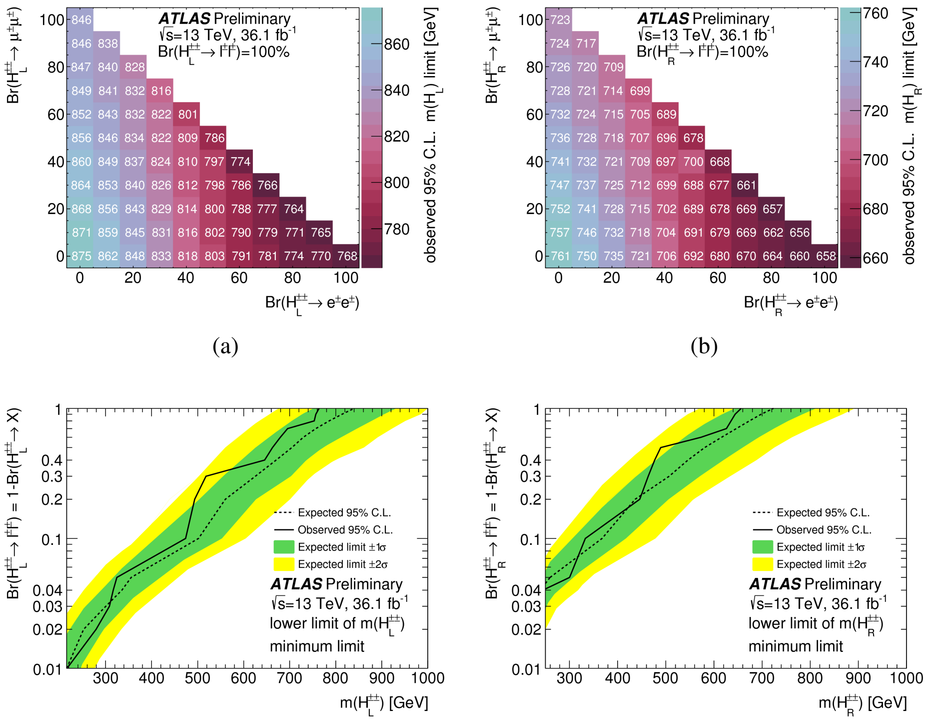
[4] The scale factor is defined as $P(p_{\mathrm{T}}, \eta; \mathrm{data})/P(p_{\mathrm{T}}, \eta; \mathrm{MC})$ if the charge is wrongly reconstructed and $(1 - P(p_{\mathrm{T}}, \eta; \mathrm{data}))/(1 - P(p_{\mathrm{T}}, \eta; \mathrm{MC}))$ if the charge is properly reconstructed.

are introduced for Drell–Yan and diboson backgrounds yields. Fitted normalizations are compatible with their SM predictions within the uncertainties as shown in Figure 1. No significant excess is observed in any of the signal regions.

In the assumption $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 100\%$, the final result of the fit is a two-dimensional grid (Fig. 2a and 2b) of the lower limit of the $H^{\pm\pm}$ boson mass. The production cross-section is excluded down to 0.1 fb, corresponding to 3-4 signal events, which is the theoretical limit of a 95% CL exclusion. In the assumption $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) \leq 100\%$, the observed lower mass limits are still above 450 GeV for $H_L^{\pm\pm}$ (Fig. 2c) and 320 GeV for $H_R^{\pm\pm}$ (Fig. 2d) for $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm})$ = 10%.



Br(H±±L→ μ±μ±) \ Br(H±±L→ e±e±)	0	10	20	30	40	50	60	70	80	90	100
100	846										
90	846	838									
80	847	840	828								
70	849	841	832	816							
60	852	843	832	822	801						
50	856	846	834	822	809	786					
40	860	849	837	824	810	797	774				
30	864	853	840	826	812	798	786	766			
20	868	856	843	829	814	800	788	777	764		
10	871	859	845	831	816	802	790	779	771	765	
0	875	862	848	833	818	803	791	781	774	770	768

(a)

Br(H±±R→ μ±μ±) \ Br(H±±R→ e±e±)	0	10	20	30	40	50	60	70	80	90	100
100	723										
90	724	717									
80	726	720	709								
70	728	721	714	699							
60	732	724	715	705	689						
50	736	728	718	707	696	678					
40	741	732	721	709	697	700	668				
30	747	737	725	712	699	688	677	661			
20	752	741	728	715	702	689	678	669	657		
10	757	746	732	718	704	691	679	669	662	656	
0	761	750	735	721	706	692	680	670	664	660	658

(b)

(c)

(d)

Figure 2: Observed lower limits on the $H_L^{\pm\pm}$ (a) and $H_R^{\pm\pm}$ (b) bosons mass for branching ratio combinations summing up to 100%. Observed minimum lower limit as a function of $B(H_L^{\pm\pm} \to \ell^{\pm}\ell^{\pm})$ (c) and $B(H_R^{\pm\pm} \to \ell^{\pm}\ell^{\pm})$ (d) in the assumption $B(H_{L,R}^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) \leq 100\%$.

7. Conclusions

The presented $H^{\pm\pm}$ search yields observed lower limits on the $H_L^{\pm\pm}$ mass varying from 770 GeV to 870 GeV for $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 100\%$ and above 450 GeV for $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) \geq 10\%$ for any combination of partial branching ratios. The observed lower limits on the $H_R^{\pm\pm}$ mass vary from 660 GeV to 760 GeV for $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 100\%$ and are above 320 GeV for $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) \geq 10\%$. The observed limits are consistent with the expected limits. This lower limits on the $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ masses obtained in this search, under the assumption $B(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 100\%$, are at least 300 GeV higher than those from previous ATLAS and CMS analyses [4, 5].

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003

[2] K. Huitu, J. Maalampi, A. Pietila and M. Raidal, Doubly charged Higgs at LHC, Nucl. Phys. **B487** (1997) 27, arXiv: `hep-ph/9606311 [hep-ph]`

[3] ATLAS Collaboration, *Search for doubly charged Higgs boson production in multi-lepton final states with the ATLAS detector using proton-proton collisions at $\sqrt{s}$=13 TeV*, ATLAS-CONF-2017-053, `https://cds.cern.ch/record/2273869`

[4] ATLAS Collaboration, *Search for anomalous production of prompt same-sign lepton pairs and pair-produced doubly charged Higgs bosons with $\sqrt{s}$ = 8 TeV pp collisions using the ATLAS detector*, JHEP **03** (2015) 041, arXiv: `1412.0237[hep-ex]`.

[5] CMS Collaboration, *A search for a doubly-charged Higgs boson in pp collisions at $\sqrt{s}$ = 7 TeV*, Eur. Phys. J. C **72** (2012) 2189, arXiv: `1207.2666[hep-ex]`.