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Search for the direct production of chargino pairs decaying via W boson in 13 TeV pp collisions with the ATLAS detector

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A search for the direct production of pairs of charginos, each decaying into a lightest neutralino and a W-boson, which in turn decays leptonically, is presented. Previous LHC Run 2 analyses have already excluded the existence of chargino and neutralino in regions where the difference between their masses is larger than the W-boson mass with a 95% CL. The aim of the current search is to explore the so called "compressed regions", with a chargino-neutralino mass difference of the order of the W-boson mass. The analysis strategy uses machine learning techniques to improve the Standard Model background rejection. The analysis targets events with two leptons, missing transverse energy and no hadronic activity in the final state, and uses pp collision data at 13 TeV collected by the ATLAS experiment during Run 2 at LHC, corresponding to an integrated luminosity of 139 fb^{-1}.

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1. Introduction

Supersymmetry (SUSY) is one of the most accredited theories in the search for physics beyond the Standard Model (SM), providing a solution to several open problems of the SM, like the fundamental interaction unification and the dark matter. It assumes, for each SM fermion and boson, the existence of a new particle (called *superpartner*) with the same quantum numbers but with spin (S) which differs by 1/2. In the *Minimal Supersymmetric Standard Model* (MSSM) leptonic (L) and baryonic (B) numbers are not conserved separately. The R-parity quantum number, $R = (-1)^{3(B-L)+2S}$, and the hypothesis of its conservation are introduced. Among these new particles there are *neutralinos* ($\tilde{\chi}^0_i$, $i = 1,2,3,4$) and *charginos* ($\tilde{\chi}^\pm_j$, $j = 1,2$), obtained from the combination of the superpartners of the SM gauge and Higgs bosons. The $\tilde{\chi}^0_1$ is the Lightest Supersymmetric Particle (LSP) and a good candidate of dark matter.

2. Chargino direct production

The search described here targets the direct production of chargino pairs $\tilde{\chi}^+_1\tilde{\chi}^-_1$, where each chargino decays in a neutralino and a W-boson, which in turn decays leptonically, as shown in Figure 1. Data collected in pp collisions at the LHC during Run 2 (2015-2018), by the ATLAS experiment [1], at $\sqrt{s} = 13$ TeV, corresponding to 139 fb^{-1}, are used. A previous analysis [2] has been already performed on this channel and has produced exclusion limits in the mass plane $(m(\tilde{\chi}^\pm_1), m(\tilde{\chi}^0_1))$ at 95% Confidence Level (CL), reported in Figure 2, in kinematic regions with large mass-splitting,

$$\Delta m(\tilde{\chi}^\pm_1, \tilde{\chi}^0_1) = m(\tilde{\chi}^\pm_1) - m(\tilde{\chi}^0_1) > m(W).$$

This analysis targets the *moderately compressed region* (indicated in the figure), that is the region with mass-splitting of the order of the W-boson mass.

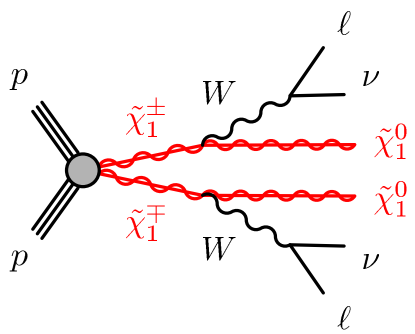

Figure 1: Feynman diagram of the chargino via W-boson electroweak production.

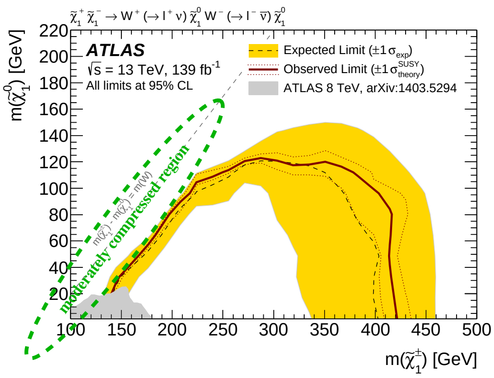

Figure 2: Expected and observed exclusion limits for chargino via W-boson pair production [2].

Only simplified SUSY models, where few new particles are included with masses as free parameters, are considered. Events with two oppositely charged signal leptons (electrons or muons) having $p_T > 27$ GeV (leading lepton) and $p_T > 9$ GeV (sub-leading lepton) are selected and separated in two classes: “same flavour” (SF) and “different flavour” (DF) events. The final event selection is performed by separating signal from SM background using different kinematic variables, and *Signal Regions* (SRs), where the SUSY signal is maximized, are defined. The estimate of the dominant SM backgrounds uses a partially data-driven technique. Dedicated *Control Regions* (CRs), enriched in particular backgrounds, are used to normalize MC simulation yields to data. The CRs are designed to be both orthogonal and similar to the SRs, whilst also having little signal contamination; this is achieved by taking the SR definitions and inverting some of the selection criteria. Dedicated *Validation Regions* (VRs) are defined to be kinematically close to CRs and SRs, and are used to assess the quality of the background estimation and its extrapolation to the SRs. Data in the SRs are compared with the normalized SM backgrounds and, if no significant excess of data over the expected background is observed, upper limits on the SUSY cross section and on the tested model parameters are set.

3. Machine learning approach

In order to improve the signal from background discrimination a machine learning technique based on the Boost Decision Tree (BDT) discriminator, is used. The BDT training uses a set of kinematic variables for the signal-background discrimination and combines signal samples with $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 90$ or 100 GeV. The classifier is trained to separate events into four classes: signal, diboson (VV) and top ($t\bar{t}$ and Wt), which are the main SM backgrounds in the analysis, and all other backgrounds (Z+jets, Z($\rightarrow \tau\tau$)+jets, VVV and minor backgrounds). For each event, the four scores (BDT-signal, BDT-VV, BDT-top and BDT-others) provide the probability for the event to belong to each class, and sum to one. The training has been performed separately for DF and SF events with no hadronic jets in the final state (DF0J and SF0J).

4. Signal, Control and Validation Regions

After a preselection of the events, only those with $n_{\text{b-tagged jets}} = 0$ and $n_{\text{non-b-tagged jets}} = 0$ are retained. The first cut reduces the $t\bar{t}$ and Wt backgrounds, and the second one has been observed to increase the sensitivity of the analysis. Signal regions have been defined as bins with high values in BDT-signal: as the BDT-signal increases the SM backgrounds decrease while the SUSY signal stays constant. Therefore, 16 SRs for the DF0J channel, starting from 0.81 up to 1 in the BDT-signal score, and 8 SRs for the SF0J channel, starting from 0.77 up to 1, have been defined. Table 1 gives the detailed definition of these signal regions.

Signal region (SRs)	SR-DF	SR-SF
$n_{b\text{-tagged jets}}$	= 0	
$n_{\text{non-}b\text{-tagged jets}}$	= 0	
E_T^{miss} significance	>8	
m_{T2} [GeV]	>50	
BDT-other	< 0.01	
BDT-signal	∈(0.81 ,0.8125]	∈(0.77 ,0.775]
	∈(0.8125 ,0.815]	∈(0.775 ,0.78]
	∈(0.815 ,0.8175]	∈(0.78 ,0.785]
	∈(0.8175 ,0.82]	∈(0.785 ,0.79]
	∈(0.82 ,0.8225]	∈(0.79 ,0.795]
	∈(0.8225 ,0.825]	∈(0.795 ,0.80]
	∈(0.825 ,0.8275]	∈(0.80 ,0.81]
	∈(0.8275 ,0.83]	∈(0.81 ,1]
	∈(0.83 ,0.8325]	
	∈(0.8325 ,0.835]	
	∈(0.835 ,0.8375]	
	∈(0.8375 ,0.84]	
	∈(0.84 ,0.845]	
	∈(0.845 ,0.85]	
	∈(0.85 ,0.86]	
	∈(0.86,1]	

Table 1: Signal Region definition [3].

The general strategy to define CRs and VRs relies on reversing the BDT-signal cut applied to the SRs or selecting events with $n_{\text{b-tagged-jets}} = 1$ for the top CR, in order to ensure orthogonality with the SRs and a low signal contamination. Two CRs are used, CR-VV to target the diboson VV and CR-top to target the top-quark backgrounds ($t\bar{t}$ and Wt), and six VRs, the definitions of which are described in Table 2.

	Control regions (CRs)				Validation Regions (VRs)					
	CR-VV		CR-top		VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
E_T^{miss} significance	> 8				> 8					
m_{T2} [GeV]	> 50				> 50					
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$				$= 0$					
Lepton Flavour	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$	$= 1$	$= 0$	$= 0$	$= 1$	$= 1$	$= 0$	$= 0$
BDT-other	-	< 0.01	-	< 0.01	-	< 0.01	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.2, 0.65]$	$\in (0.2, 0.65]$	$\in (0.5, 0.7]$	$\in (0.7, 0.75]$	$\in (0.65, 0.81]$	$\in (0.65, 0.77]$	$\in (0.7, 1]$	$\in (0.75, 1]$	$\in (0.5, 0.81]$	$\in (0.5, 0.77]$
BDT-VV	> 0.2	> 0.2	-	-	> 0.2	> 0.2	-	-	< 0.15	< 0.15
BDT-top	< 0.1	< 0.1	-	-	< 0.1	< 0.1	-	-	-	-

Table 2: Definition of Control and Validation Regions [3].

5. Results and conclusions

No significant deviations in data from the SM predictions have been observed in any of the SRs, as shown in Figure 3. Therefore, exclusion limits at 95% CL are set in the $(m(\tilde{\chi}_1^{\pm}), \Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0))$ plane, as shown in Figure 4, which extends the limits set by previous analyses on the same search: chargino masses up to 135 GeV are excluded at 95% CL in the case of a mass splitting between chargino and neutralino up to 100 GeV.

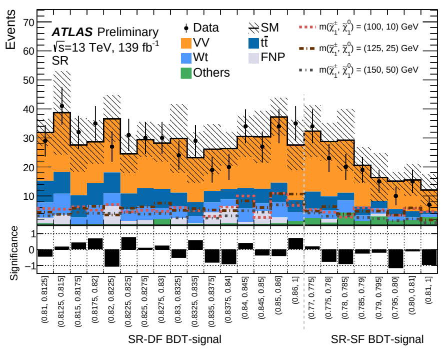

Figure 3: Observed number of events in the SRs and expected SM backgrounds [3].

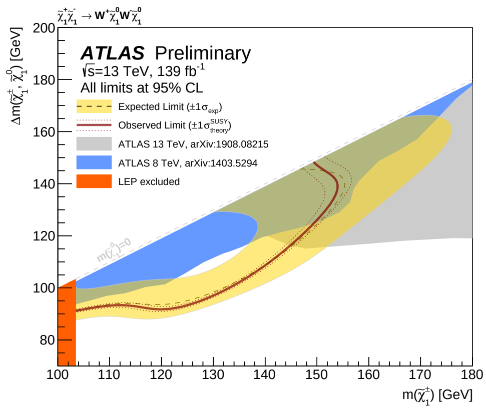

Figure 4: Observed and expected exclusion limits [3].

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

[2] ATLAS Collaboration, *Search for electroweak production of charginos and sleptons decaying into final states with two leptons and missing transverse momentum in $\sqrt{s}$=13 TeV pp collisions using the ATLAS detector*, Eur. Phys. J. C 80 123, 2020, arXiv:1908.08215

[3] ATLAS Collaboration, *Search for direct pair production of sleptons and charginos decaying to two leptons and neutralinos with mass splittings near the W boson mass in $\sqrt{s}$=13TeV pp collisions with the ATLAS detector*, 2022, ATLAS-CONF-2022-006