Search for chargino and neutralino production with a Higgs boson in the decay chain in one or three leptons final state events with ATLAS

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Abstract

Searches for direct production of chargino (\(\tilde{\chi}_1^\pm\)) and neutralino (\(\tilde{\chi}_2^0\)) leading to final states characterized by the presence of a Higgs boson are reported. Events containing missing transverse momentum and one or three leptons are selected, and various channels sensitive to different Higgs decays are considered. The analyses use 20.3 fb\(^{-1}\) of proton-proton collision data at \(\sqrt{s} = 8\) TeV recorded in 2012 with the ATLAS detector at the Large Hadron Collider. Observations are consistent with the Standard Model expectations and limits are set in \(R\)-parity conserving phenomenological Minimal Supersymmetric Standard Models and in simplified supersymmetric models.

Supersymmetry (SUSY)\(^1\) is an extension to the Standard Model (SM). It postulates the existence of supersymmetric particles, with spin differing by one-half unit with respect to that of their SM partners. Electroweakinos (charginos \(\tilde{\chi}_{1,2}\) and neutralinos \(\tilde{\chi}_{1,2,3,4}\)) are the ordered mass eigenstates formed from the linear superposition of the SUSY partners of the Higgs and electroweak gauge bosons (higgsinos, winos and binos). In \(R\)-parity-conserving models, SUSY particles are pair-produced and the Lightest SUSY Particle (LSP), here assumed to be the \(\tilde{\chi}_1^0\), is stable. Naturalness arguments suggest that the lightest electroweakinos are expected to have mass of order 100 GeV and can be detected at the Large Hadron Collider (LHC). This review presents two searches for pair-produced charginos and neutralinos in the \(Wh\)-mediated channel. The analyses use 20.3 fb\(^{-1}\) of proton-proton collision data at \(\sqrt{s} = 8\) TeV recorded in 2012 with the ATLAS [1] detector at the LHC. Selected events must contain one or three leptons and missing transverse momentum (\(E_T^{\text{miss}}\)) originating from the two undetected LSPs and the neutrinos. The simplified supersymmetric model considered in both searches targets the direct production of \(\tilde{\chi}_1^\pm\) and \(\tilde{\chi}_2^0\), assumed to be mass degenerate and consisting purely of the wino component. The LSP \(\tilde{\chi}_1^0\) is considered bino-like. Sleptons and sneutrinos are assumed to be heavy. The \(\tilde{\chi}_1^\pm\) and \(\tilde{\chi}_2^0\) decay via \(W\) and lightest Higgs bosons, respectively, with a branching fraction of 100%. The Higgs boson considered is SM-like, with a mass of 125 GeV, and is assumed to decay with SM branching ratios. Diagrams of the presented searches are shown in Figure 1.

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\(^1\)Theoretical references can be found in the respective experimental work cited.

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1. One lepton and 2 $b$-jets scenario

This search [2] is performed on events containing exactly one isolated lepton, two jets originating from the hadronisation of the $b$-quarks ($b$-tagged) and $E_T^{\text{miss}}$. The used $b$-tagging algorithm, which exploits the long lifetime of $b$- and $c$-hadron inside a candidate jet, is MV1 at a 70% efficiency. Events should contain exactly two leading $b$-jets and no fourth jet of $p_T > 25$ GeV. Two discriminating variables, the contransverse mass $m_{CT}$, defined as

$$m_{CT} = \sqrt{(E_T(v_1) + E_T(v_2))^2 - (\mathbf{p}_T(v_1) - \mathbf{p}_T(v_2))^2}$$

and the transverse mass $m_T$, given by

$$m_T = \sqrt{2p_T^{\text{miss}} - 2p_T^\ell p_T^{\text{miss}}}$$

are significantly reducing the $t\bar{t}$ and $W+$jets background contributions respectively. Two orthogonal signal regions SRA and SRB are designed to provide the best sensitivity for low and high $\Delta m = m_\chi^0 - m_\chi^\pm$, respectively. In both regions, events must satisfy the conditions $E_T^{\text{miss}} > 100$ GeV, $m_{CT} > 160$ GeV, $m_T > 100$ GeV and $m_{bb}$, where $m_{bb}$ is the invariant mass of the two $b$-jets. Events satisfying (failing) $m_T < 130$ GeV are classified in SRA (SRB).

The main SM irreducible background contributions in the signal regions, estimated with Monte Carlo (MC), arise from $t\bar{t}$, single-top and $W+$jet production. The reducible background, mostly from QCD multi-jet events, where a lepton originating from the $b$-decay fakes a signal lepton, is estimated through the “matrix method” and found to be negligible. The main systematics uncertainties on the background are the Jet Energy Scale, $b$-tagging and the single-top theoretical production.

A simultaneous fit of the control and signal regions is performed. Overall normalizations of the main backgrounds ($t\bar{t}$ and $W+$jets) are allowed to float, along with the signal strength to account for potential signal contamination in the control regions. Figure 2 shows the $m_{bb}$ distributions in SRA and SRB. The number of observed events in the signal bin ($m_{bb}$ [GeV] ∈ [105, 135]) is found in agreement with the SM expectations.

Given the absence of signal, exclusion limits are set at 95% confidence level (CL). Model-independent limits on the visible cross-section $\sigma^{95}_{\text{vis}}$ (product of production cross-section, acceptance and efficiency) are derived in each signal bin from the number of observed and predicted events, the latter being extrapolated to the signal regions from the background-only fit results. Table 1 shows the results based both on pseudo-experiments and asymptotic formulae for a profile-log-likelihood test statistic. Figure 3 displays 95% CL exclusion region obtained in the $m_{\ell_1\ell_2\ell_3} - m_{\ell_1}$ plane. For a massless LSP, the mass ranges of 125 < $m_{\ell_1\ell_2\ell_3}$ < 141 GeV and 166 < $m_{\ell_1\ell_2\ell_3}$ < 287 GeV are excluded at 95% CL, determined at 1$\sigma$ signal theoretical uncertainty, with an expected exclusion range of 225 < $m_{\ell_1\ell_2\ell_3}$ < 235 GeV.

2. Three leptons scenario

This search [3] targets events containing exactly three signal tagged leptons separated from each other by a distance parameter $\Delta R > 0.3$. At least one electron or muon is required and must have fired one of the single- or double-lepton triggers. Events with $b$-jets are vetoed. To identify the hadronically decaying $\tau$, a jet anti-$k_t$ algorithm has been optimised with a boosted decision tree (BDT). Signal regions are defined according to the flavour and charge of the leptons and are labelled by the number of $\tau$ leptons selected.

Processes leading to three real (isolated) leptons are classified into the irreducible background and are gen-
The dominant reducible background component is estimated using the “matrix method”. The limits on the number of non-SM events by dividing the limits on the number of non-SM events by the integrated luminosity.

Table 1: Model-independent limits in the $m_{bb}$ signal bin on the expected number of signal events $S_{exp}$ and observed 95% upper limit on the visible cross-section $\sigma_{vis}$ for non-SM events (obtained by dividing the limits on the number of non-SM events by the integrated luminosity).

<table>
<thead>
<tr>
<th></th>
<th>SRA</th>
<th>SRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asymptotic</td>
<td>Observed $S_{exp}$ ($\sigma_{vis}$)</td>
<td>6.5 (0.32 fb)</td>
</tr>
<tr>
<td></td>
<td>Expected $S_{exp}$</td>
<td>$7.0^{+1.1}_{-1.9}$</td>
</tr>
<tr>
<td>Pseudo-experiments</td>
<td>Observed $S_{exp}$ ($\sigma_{vis}$)</td>
<td>6.9 (0.34 fb)</td>
</tr>
<tr>
<td></td>
<td>Expected $S_{exp}$</td>
<td>$7.0^{+2.8}_{-1.6}$</td>
</tr>
</tbody>
</table>

Table 2: Expected numbers of SM background events and observed numbers of data events in the signal regions sensitive to the Wh-imediator scenario. For $p_0$-values below 0.5, the observed number of standard deviations, $\sigma$, is shown in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>SR0rb</th>
<th>SR1r</th>
<th>SR2rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total SM</td>
<td>$3.8 \pm 1.2$</td>
<td>$10.3 \pm 1.2$</td>
<td>$7.2^{+0.7}_{-0.8}$</td>
</tr>
<tr>
<td>Data</td>
<td>3</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>$p_0$</td>
<td>0.50</td>
<td>0.19 (0.86 $\sigma$)</td>
<td>0.50</td>
</tr>
</tbody>
</table>

200 GeV and $M_2 > 200$ GeV, the sensitivity is reduced as the decay mode $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$ is kinematically allowed.


References