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Summary of Ph.D thesis

Search for direct production of charginos and neutralinos in final states with three leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 8\,\text{TeV}$ with the ATLAS detector

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Abstract

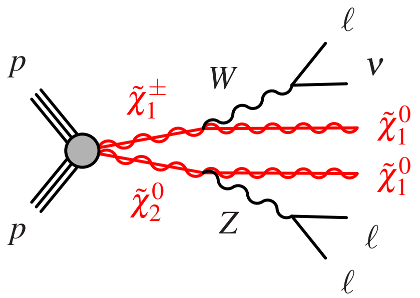
This thesis reports the results of a search for direct production of charginos and neutralinos with the ATLAS detector. The analysis is based on $20.3\,\text{fb}^{-1}$ of proton-proton collision data with the centre-of-mass energy of $\sqrt{s} = 8\,\text{TeV}$ delivered by the Large Hadron Collider. The target mode is the direct production of the lightest chargino and the second lightest neutralino, $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, where the final states would include three leptons and missing transverse momentum. The optimal selections and the estimation of the fake background are described in detail. No significant deviation from the Standard Model expectation is observed. Exclusion limits are set at 95% confidence level in simplified models for each decay mode from electroweak production of supersymmetry.

Supersymmetry (SUSY) [1–9] is a promising candidate for beyond the Standard Model (SM). It introduces a symmetry between bosons and fermions and provides super-partners for all of the SM particles. The theory has some powerful characteristics to solve the remaining problems in the SM. This thesis discusses following three problems; the hierarchy problem in the gauge theory, the dark matter, and the deviation of the muon anomalous magnetic moment (muon $g-2$). The hierarchy problem is the difference between electroweak scale $M_{\text{EW}} \sim 10^2\,\text{GeV}$ and the Planck scale $M_{\text{Pl}} \sim 10^{19}\,\text{GeV}$. It affects the Higgs mass calculation. Since there is no mechanism to cancel the quadratic terms in the Higgs quantum correction for scalar particles, the Higgs mass is tuned by the order of 10^{17} in order to make the mass of $125\,\text{GeV}$. SUSY undertakes the role to provide the symmetry to cancel the quadratic terms. The dark matter, which is required to exist due to the explanation of the rotation velocity of galaxies, is not described by the SM. If the quantum number of the SUSY (R-parity) is conserved, the lightest SUSY particle is stable. This would be a good candidate for the dark matter. For the muon $g-2$, 3σ deviation between the predicted value based on the SM calculation and the experimental result from the E821 experiment [10] is reported. The difference corresponds to the amount of the electroweak contribution of the muon $g-2$. Thus the SUSY particles which interact via electroweak force are the possible candidate of the new particles. If the electroweak SUSY explains the deviation, the order of mass of the electroweak SUSY of $O(100)\,\text{GeV}$ is required.

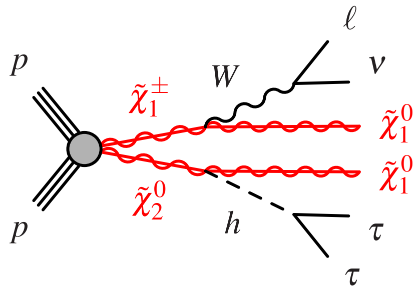
Although SUSY searches have been performed in many experiments, there has been no evidence of supersymmetry reported at LEP, Tevatron, and LHC searches up to now. The exclusion limits are set for the various SUSY particles as greater than $1\,\text{TeV}$ for the mass of squarks and gluinos, $300\,\text{GeV}$ for the mass of sleptons, and $\sim 160\,\text{GeV}$ for the mass of electroweak gauginos. Therefore, if the SUSY particles with the light masses exist, the possible candidates are light charginos and neutralinos. The light electroweak SUSY particles are favoured in terms of the muon $g-2$, as described above.

In this thesis, a search for direct production of charginos and neutralinos is presented. The analysis is based on $20.3\,\text{fb}^{-1}$ of proton-proton collision data with the centre-of-mass energy of $\sqrt{s} = 8\,\text{TeV}$ delivered by the Large Hadron Collider and recorded with the ATLAS detector in 2012. The ATLAS detector [11] consists of the inner detector, the calorimeters and the muon spectrometer. The inner detector has the silicon pixel detectors at the innermost part of the detector, the silicon strip detectors at the middle part, and the transition radiation chambers at the outer part. This contributes to reconstruct vertices and tracks of charged particles. The electromagnetic and hadronic calorimeters surround the inner detector. The electromagnetic calorimeter is made of the liquid argon detectors with lead absorber plates, and the hadronic calorimeter is made of the tile calorimeters in the barrel region and the liquid argon detector in the end-cap and forward regions. They contribute to reconstruct the particle energy, where most of photons, electrons and jets are absorbed. The outermost part of the ATLAS detector is the muon spectrometer. Since muons have much heavier mass than the electron mass, the bremsstrahlung is strongly suppressed. Muons do not make electromagnetic showers in the calorimeters, while they make a track in the inner detector and the muon spectrometer.

The target mode is the direct production of the lightest chargino and the second lightest neutralino, $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, which has the maximum cross section of the electroweak productions of the supersymmetric particles with multiple leptons in final states. The lightest neutralino is assumed to be bino-like. The lightest charginos and the second lightest neutralinos are assumed to be wino-like and have degenerate mass spectra $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$, and directly decay into the lightest neutralinos and the SM bosons (W, Z or Higgs) with 100% branching ratio (simplified model). The possible Feynman diagrams are shown in Fig. 1. The decay scenarios of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to$



(a) WZ channel



(b) Wh channel

Figure 1: Feynman diagrams of WZ and Wh channels.

$W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$ are called WZ and Wh channels, respectively. This thesis discusses the results of the search for the SUSY events with three leptons ($\ell = e, \mu, \tau$) and missing transverse momentum in final states, in particular the detail of the setting of the optimal selections (signal regions) and a method of estimating fake leptons contributions in order to achieve the best sensitivity with the acquired data. For WZ channel, 20 "binned" signal regions are defined to obtain high sensitivity. The binned signal regions have an advantage of having the information of the shapes of the distributions. For Wh channel, the bias of the difference of the azimuthal angles of two leptons for the $h \to WW$ channel and the Higgs mass requirement for the $h \to \tau\tau$ channel contribute to obtain maximal sensitivity.

The background suppression is improved in this thesis. Estimation of the mis-identified leptons (fake leptons) of the analysis has been performed using a data-driven method. This is called the simplified matrix method, which is based on the standard "matrix method." The matrix method uses the fake probabilities for various fake origins. The fake probabilities are calculated in each signal region. In the simplified matrix method, the reconstructed lepton with the highest transverse momentum in the event is assumed to be real lepton, which is defined as the lepton that is produced in the primary process and is from the interacting point. This assumption contributes to reduce the variables in the equation of the method to half. The fake probabilities significantly vary with the transverse momentum p_{T} and the pseudorapidity η. Improving binning of the fake probabilities with p_{T} and η has contributed to reproduce the fake backgrounds precisely.

Validation of the estimation of the background modelling works satisfactorily within the uncertainties. No significant deviation from the Standard Model expectation has been observed. Exclusion limits for masses of charginos and neutralinos are set at 95% confidence level at simplified models $m_{\tilde{\chi}_1^{\pm}} < 360\,\mathrm{GeV}$ (WZ channel) and $m_{\tilde{\chi}_1^{\pm}} < 150\,\mathrm{GeV}$ (Wh channel) for the zero-mass lightest neutralino. The exclusion limit for the Wh channel has been set for the first time.

The specific analysis for the scenario where the difference of masses between the second lightest neutralino and the lightest neutralino is less than 50 GeV has also been carried out. The region has leptons with low transverse momenta p_{T}, hence it is difficult to suppress the fake contribution. In this thesis, the specific variables related to the initial state radiation jets and a method for fake estimation based on the simplified matrix method are investigated and applied to the signal regions. Three specific variables are employed: the ratio of the transverse momenta of the lepton and the jet with the highest transverse momenta $p_{\mathrm{T}}(\ell)/p_{\mathrm{T}}(j)$, the difference of the azimuthal angles of the missing transverse momentum and the jet with the highest transverse momentum $\Delta\phi_{E_{\mathrm{T}}^{\mathrm{miss}},j}$, and the difference of the azimuthal angles of the missing transverse momentum and the three-lepton system $\Delta\phi_{E_{\mathrm{T}}^{\mathrm{miss}},\sum\ell}$. Four signal regions are defined and no significant excess has been observed. The exclusion limit is set to the simplified model of the compressed mass scenario as $m_{\tilde{\chi}_2^0} < 110\,\mathrm{GeV}$ for the difference of masses of $\Delta m_{\tilde{\chi}_2^0,\tilde{\chi}_1^0} = 25\,\mathrm{GeV}$.

These results are consistent with the corresponding results obtained by the CMS Collaboration [12]. The results are interpreted for the scenarios with the sleptons channel and the pMSSM. The sleptons channel is the scenario where the produced $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decay into sleptons with 100% branching ratio, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \nu\tilde{\ell}\ell\tilde{\ell} \to \nu\ell\tilde{\chi}_1^0\ell\ell\tilde{\chi}_1^0$. This scenario is realised if the sleptons are lighter than $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, and have the mass satisfied that the difference of masses $\Delta m_{\tilde{\chi}_2^0,\tilde{\chi}_1^0} < 50\,\mathrm{GeV}$ or the slepton mass $m_{\tilde{\ell}} > 300\,\mathrm{GeV}$. The 700 GeV charginos are excluded with the assumption that the slepton mass is in the middle of $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$, $m_{\tilde{\ell}} = (m_{\tilde{\chi}_2^0} + m_{\tilde{\chi}_1^0})/2$ for the sleptons channel. For the pMSSM scenario, the 200 GeV charginos are excluded. This analysis has largely improved the existing limits from the LEP analyses [13] and the ATLAS 7 TeV analyses [14].

Discussions are given in terms of the dark matter limits and the deviation of the muon anomalous magnetic moment. As the thesis assumes that the lightest neutralino is the bino-like, the Higgs annihilation or the bino-wino coannihilation processes are necessary in order to reduce the relic density of the dark matter, according to the Planck Experiment [15]. The exclusion limit is set for Higgs annihilation scenario, while the bino-wino coannihilation scenario cannot be excluded in this analysis. A part of the favourable region where the new quantum corrections of the supersymmetric particles are the source of the deviation of the muon anomalous magnetic moment has been excluded by this analysis.

The prospects for the improvement of this analysis for next LHC Run-2 are also discussed. The suppressing and estimating precisely for fake backgrounds are important for upcoming experiments.

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