論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Search for scalar top quarks and higgsino-like neutralinos in pp collisions at a center-of-mass energy of 8 TeV with the ATLAS detector
著者(和文)	野辺拓也
Author(English)	Takuya Nobe
出典(和文)	学位:博士（理学）, 学位授与機関:東京工業大学, 報告番号:甲第9705号, 授与年月日:2015年3月26日, 学位の種別:課程博士, 審査員:久世　正弘,柴田　利明,陣内　修,垣本　史雄,今村　洋介
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第9705号, Conferred date:2015/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Search for scalar top quarks and higgsino-like neutralinos in pp collisions at a center-of-mass energy of 8 TeV with the ATLAS detector

Takuya Nobe

Tokyo Institute of Technology

February 2015

Contents

1 Introduction

Supersymmetry (SUSY) [1–9] is a strong candidate of new physics beyond the Standard Model. It introduces a new symmetry between bosons and fermions, which suppresses the known hierarchy problem of the Standard Model [10–13]. In this thesis, a search for scalar top quark (stop, indicated by the character $\tilde{t}_1$) pair production has been performed in proton-proton collisions at a center-of- mass energy of 8 TeV at the Large Hadron Collider (LHC). Stop is the supersymmetric partner of top quark. The target decay mode in this thesis is stop going into b quark and chargino ($\tilde{\chi}_1^{\pm}$), assuming a 100 % decay branching ratio. For a natural solution of the hierarchy problem, masses of stop and higgsino are required to be small [14], where higgsino is the supersymmetric partner of a Higgs boson. Most of such light stop signals are already excluded by the previous analyses at the LHC [15–23], but there remain some phase spaces not explored yet due to the difficulty of the analysis. If the lightest SUSY particle (LSP), which is assumed to be neutralino ($\tilde{\chi}_1^0$) in this thesis, has a higgsino component, the mass difference between chargino and the LSP:

$$\Delta m = m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} \tag{1}$$

is expected to be small, where $m_{\tilde{\chi}_1^{\pm}}$ and $m_{\tilde{\chi}_1^0}$ are masses of chargino and the LSP, respectively. In such a case, chargino decays in three body into the LSP and the Standard Model fermion pair. Momenta of the final-state fermions are expected to be low, depending on Δm. Following the previous ATLAS analysis requiring the absence of leptons in the event (0-lepton analysis) [15], two benchmark points of $\Delta m = 5$ GeV and 20 GeV are considered. The 0-lepton analysis has a good sensitivity on signals with $\Delta m = 5$ GeV and excludes a wide range of stop masses of $m_{\tilde{t}_1} < 600$ GeV with $m_{\tilde{\chi}_1^0} < 280$ GeV, but the sensitivity is weakened at $\Delta m = 20$ GeV. In this thesis, one requires the existence of a low-momentum (soft) lepton as a probe of the signal and aims to improve the sensitivity at this phase space. Signal characteristics are, thus, two b quarks from the stop decay, large missing transverse energy coming from the non-detected LSP and one soft lepton.

2 The LHC and the ATLAS experiment

The LHC [24] was operated at the world-highest center-of-mass energy of 8 TeV in 2012. The maximum instantaneous luminosity recorded with the ATLAS detector was $\mathcal{L} = 0.7 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ [25]. The ATLAS detector is a multi-purpose apparatus at the LHC. Detailed descriptions about the ATLAS detector is found in Ref. [26]. The data collected with the ATLAS detector in 2012 corresponding to an integrated luminosity of $20.1\,\mathrm{fb}^{-1}$ are analyzed. Physics signatures e.g. electrons, muons and hadron jets are reconstructed by a combination of signals at several sub-detectors, and calibrated using the dedicated criteria [27–31]. Precision measurements of charged-particle tracks at the inner detector make it possible to identify the b-quark-induced jet [32]. The LSP do not interact with any detector materials, but consequently, existence of neutrinos are determined by the missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$.

3 Event selection

If the mass difference between stop and the LSP:

$$\Delta M = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \tag{2}$$

is also small in addition to Δm, all of decay products are expected to be soft, yielding the much lower acceptance to the signal. In this thesis, two independent analyses are prepared according to the target event topologies:

1. The small ΔM channel;
2. The moderate ΔM channel.

Event selection is optimized to enhance a benchmark signal for each search channel against the Standard Model backgrounds. The small ΔM channel requires an initial-state-radiation jet with high transverse momentum (p_{T}) and stop pair system produced in the boosted frame to the opposite direction to that is explored. The Lorentz boost factor improves the acceptance to soft particles. Since b-tagging efficiency is not sufficient at the low p_{T} region, at least one b-quark-induced jet is required in this channel. Signals are enhanced at the higher tail of the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution. Two signal regions are defined, namely the small ΔM channel (high) and (low), which cover the range of $\Delta M < 30$ GeV and $30 < \Delta M < 70$ GeV, respectively, by different thresholds on the $E_{\mathrm{T}}^{\mathrm{miss}}$. The binned likelihood fit using the lepton p_{T} distribution is performed to improve the sensitivity. On the other hand, the moderate ΔM channel requires two b-quark-induced jets in the event and a variable, asymmetric m_{T2} (am_{T2}), which is sensitive to the stop mass is introduced as the signal discriminator. The shape fit is employed on the am_{T2} distribution. Also two sub-channels are defined: the moderate ΔM channel (low) and (hight) to cover $200 < m_{\tilde{t}_1} < 350$ GeV and $350 < m_{\tilde{t}_1} < 600$ GeV, respectively, by the different $E_{\mathrm{T}}^{\mathrm{miss}}$ thresholds.

4 Background estimation

The main components of the Standard Model background are top quark pair production and W boson production associated with hadronic jets. These backgrounds are estimated by a semi-data-driven way. The normalization factors for the simulated events of top quark pair and W boson plus hadronic jets are estimated from the observed data in the dedicated control regions and extrapolated to the signal region using the maximum likelihood fit. The mis-identified lepton background is estimated by a pure data-driven method. The other minor backgrounds are estimated by the Monte-Carlo simulation. Systematic uncertainties are implemented as nuisance parameters in the fit. Common uncertainties in the signal and control regions are cancelled out in this procedure.

5 Results and conclusions

Figure 1 shows the lepton p_{T} and am_{T2} distributions in the signal regions. No significant signals exceeding the Standard Model background are observed in all four signal regions. The results are interpreted as limits on the SUSY masses. Figure 2 shows the 95 % confidence level (CL) exclusion region by this analysis on the plane of $m_{\tilde{t}_1}$-$m_{\tilde{\chi}_1^0}$ at $\Delta m = 20$ GeV. The observations in the small ΔM channel exclude signals with $\Delta M < 70$ GeV for the first time in the range of stop masses less than 210 GeV. The moderate ΔM channel excludes stop signals with

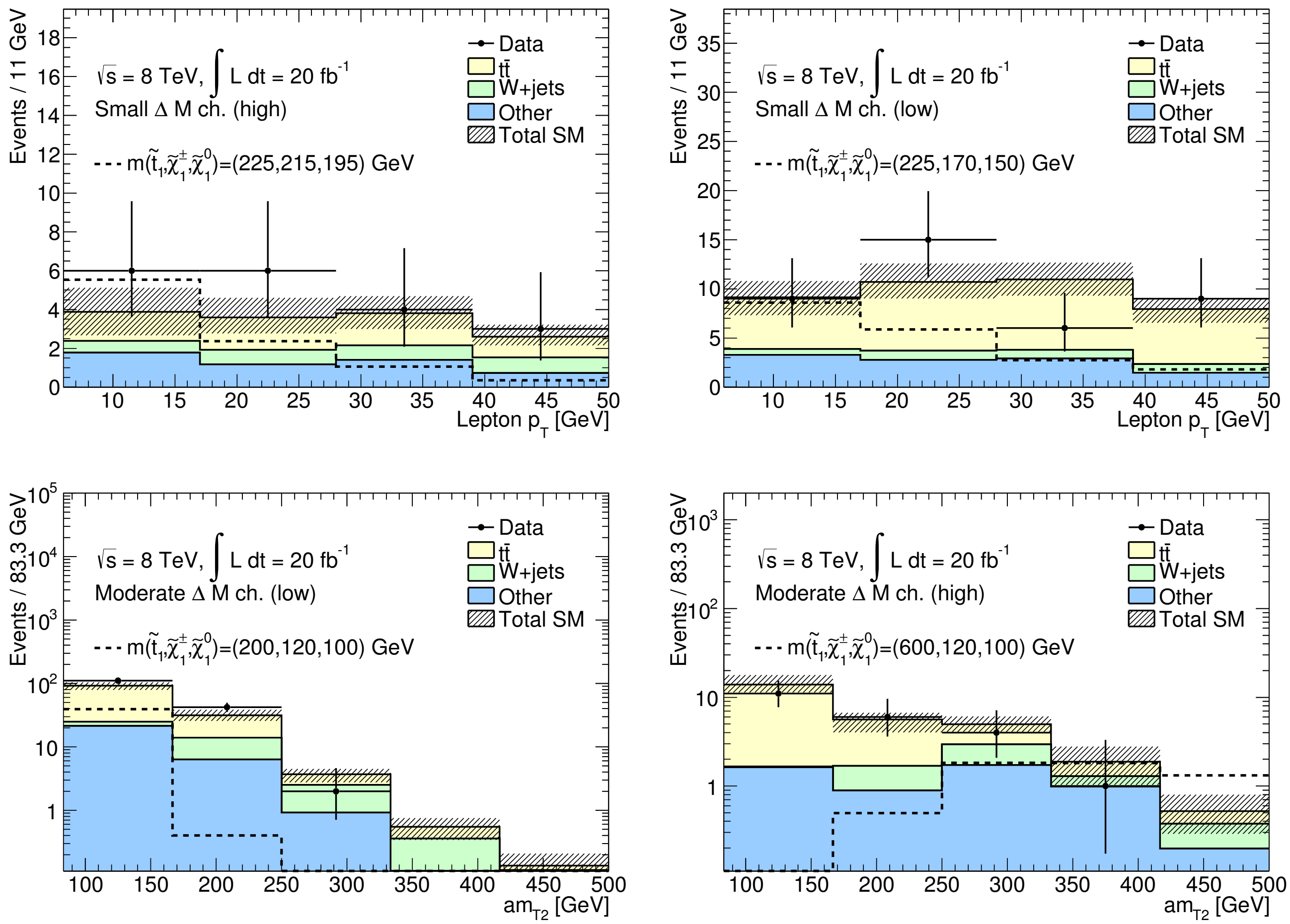

Figure 1: The lepton p_{T} (top) and am_{T2} (bottom) distributions in signal regions for the small ΔM channel (high) and (low) and the moderate ΔM channel (low) and (high), respectively. Data and expected Standard Model backgrounds are indicated by black dots and colored histograms, respectively. Shaded band shows the systematic uncertainties on the background estimation. The corresponding benchmark signal to each signal region are overlaid by the dashed line.

$200 < m_{\tilde{t}_1} < 610$ GeV for $m_{\tilde{\chi}_1^0} < 280$ GeV, which improves the limits from the 0-lepton analysis by approximately 120 GeV to higher stop mass direction. The small ΔM channel also excludes stop pair production signals in which stop decays in four body into b quark, soft fermion pair and the LSP, with stop masses less than 250 GeV for the first time. By taking a combination with other ATLAS stop searches, a wide range of stop masses less than approximately 600 GeV has been excluded in several SUSY scenarios. The result gives a strong constraint on physics beyond the Standard Model.

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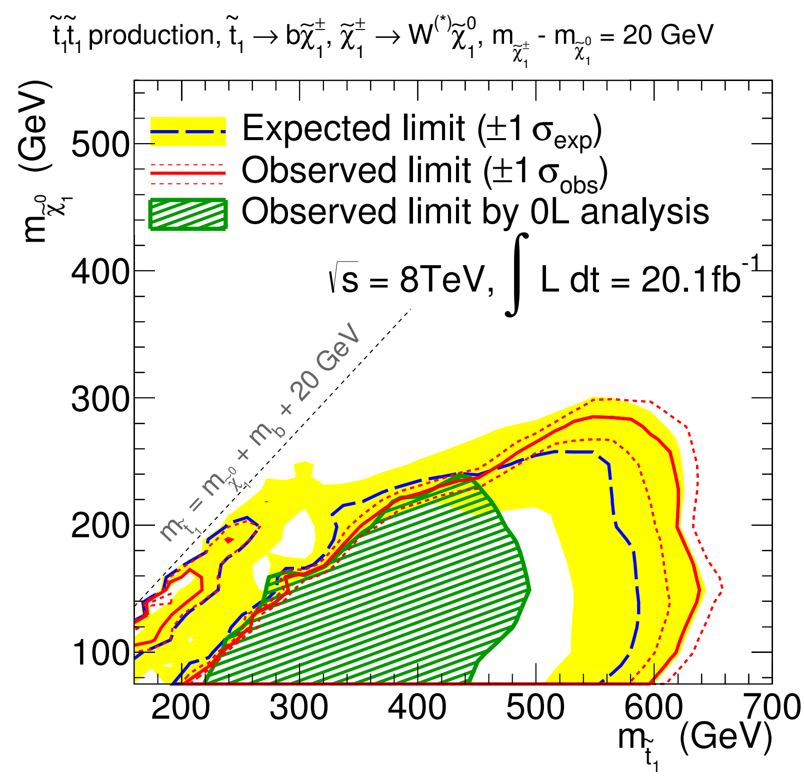

Figure 2: Expected (blue dashed with yellow band showing the the uncertainty) and observed (red solid with dashed showing the uncertainty) 95 % CL excluded region in the plane of $m_{\tilde{\chi}_1^0}$ v.s. $m_{\tilde{t}_1}$, assuming the branching fraction of $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to bff'\tilde{\chi}_1^0$ is 100 % with fixed $\Delta mx = 20$ GeV. Green shaded area indicate the 95 % CL exclusion region by the 0-lepton analysis [15].

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