論文の内容の要旨

Search for the scalar top quark in the final state with jets and missing transverse momentum with the ATLAS detector at the LHC (LHC-ATLAS 実験におけるジェットと消失横運動量を持つ終状態を用いたスカラートップクォークの探索)

氏名　楊易霖

Supersymmetry theory (SUSY) can explain unsolved problems in the Standard Model of particle physics, such as, dark matter observed in the universe, the unification of coupling constants of the electromagnetic, weak, and strong interactions and hierarchy problem of the mass of the Higgs boson. The 125 GeV mass of the Higgs boson, which was observed at the LHC is too light for the naturalness in the Standard Model unless new mechanism to stabilize the Higgs mass is introduced. The superpartners of the top quarks, which are called scalar top quarks, can provide a key solution for the observed Higgs mass according to the prediction of natural SUSY, but they have not been observed so far. The search for the scalar top quarks has been performed at the ATLAS. The scalar top quark decays into a top quark and a neutralino if it is kinematically allowed. In the hadronic final states of top quarks, the method of the top reconstruction is one of the principal features in the analysis for the production of boosted tops due to the large mass difference of a scalar top quark and a neutralino.

The stop (scalar top) mass can be as low as several hundred GeV if the mixing of right-handed stop $\tilde{t}_{\mathrm{R}}$ and left-handed stop $\tilde{t}_{\mathrm{L}}$ is large, which is needed to be 125 GeV Higgs mass. Since the lower mass limit of the stop quark has reached up to about 1 TeV, it is naturally important to explore even higher mass region. In this thesis, we focus on the search in the $\tilde{t} \rightarrow t\tilde{\chi}^0$ channel with the hadronic decay of the top quarks in the boosted region, where the $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$ is much larger than the top mass. The top can be fully reconstructed from the decay products in the absence of $E_{\mathrm{T}}^{\mathrm{miss}}$, and the boosted topology allows us to exploit small angular separation of the decay products for the reconstruction.

A new method, DNN top tagger, is introduced for both jet reconstruction of top-quark decay products and top-quark tagging on the reconstructed jets. For the jet reconstruction, the signals of calorimeter cells are clustered by using the topological-clustering algorithm. The topo-clusters are further reclustered to reconstruct jets with radius $R = 1.0$ by the anti-k_t algorithm. The jets are called large-R jets. The grooming technique is applied to the large-R jets to reduce the effect of the pileup and soft radiations. The topology of topo-clusters inside a large-R jet is called "substructure". The jet substructure efficiently distinguish signal jets from the background jets since the top decay produces separated constituents, corresponding to $t \to bqq'$, while a quark or a gluon produces a single dense constituent surrounded by the soft radiation in a jet. Many studies show how to use the variable to describe the substructure. For the top-quark tagging, A multivariate deep neural network (DNN) algorithm is used to identify boosted top quarks reconstructed by using the substructure variables of large-R jets and reject the background jets. The new method shows high top-tagging efficiencies and good background rejections. The taggers are trained using MC simulation, but it is calibrated using data and MC to evaluate the deviation of efficiencies between the data and MC. The scale factors of signal and background for the individual tagger are introduced for quantifying the deviations. The comparison between the reclustering method used in the ATLAS paper and the DNN top tagger method used in this thesis is also presented. The reclustering method shows very high tagging efficiencies but low background rejections. The DNN top tagger method has the comparable tagging efficiencies (80%) with five times higher background rejections.

For the search for the scalar top quarks, the events are preliminary selected by using preselections based on the feature of the stop signal. After the event selections are applied by using the signal signatures, further selections and the DNN top tagger method are introduced to define 12 signal regions (SRs) to enhance the purity of the stop signal and increase the search sensitivity. The backgrounds in the SRs need to be correctly estimated by introducing the control regions (CRs) for main background process, $t\bar{t}Z$, Z+jets, and $t\bar{t}$. By selecting a control region dominated by a given background process and contaminated with negligible signal, we can control the background by comparing with the data sample in the control region. The topology in the CRs is as close as possible to the topology in SRs. The validation regions (VRs) are used to validate the background estimations from control regions. The VRs are defined in the phase space close to the SRs and have relatively low signal contamination. The presence of the signal can be examined by using a simultaneous fit to the SRs and CRs.

The results are performed with an integrated luminosity of 139 fb^{-1} of $\sqrt{s} = 13$ TeV proton-proton collision data acquired at the ATLAS. The dominant backgrounds in the SRs and VRs are estimated by the background-only fit in all the CRs. Figure 1 shows the yields in the SRs with the background estimations. No significant excess over the total Standard Model predictions. Comparing with the sensitivity for the signal ($m_{\tilde{t}}$,$m_{\tilde{\chi}_1^0}$) = (1300,1) GeV using the reclustering method, the expected significance is improved by 27% with the DNN top tagger method. Since no significant excess from total SM predictions is found, a model-dependent signal fit to all the SRs and CRs is performed in each signal point of ($m_{\tilde{t}}$, $m_{\tilde{\chi}_1^0}$) to extract the lower limits on the masses. Figure 2 shows the exclusion limits with the DNN top taggers in the $m_{\tilde{t}}$-$m_{\tilde{\chi}_1^0}$ plane. The expected (observed) limit of $m_{\tilde{\chi}_1^0}$ reaches up to 540 (610) GeV. The $m_{\tilde{t}}$ region below 400 GeV is not considered in the analysis since the mass region is already excluded in the previous ATLAS results at 36 fb^{-1}. The deviation between expected limit and observed limit around $m_{\tilde{t}}$ = 1300-1400 GeV is due to the smaller number of observed events in the SRAs with respect to the background expectation. Upper limits of event yields or cross sections for the new physics phenomena are set in each SR by using a model-independent fit to only one SR with all the CRs. The lowest cross section bound is down to 0.02 fb.

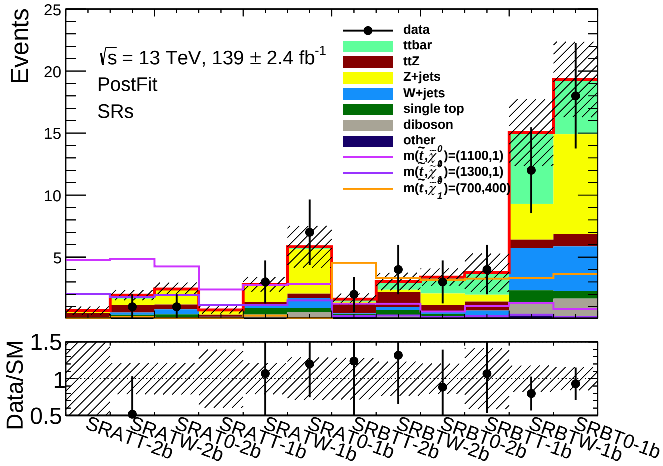

Figure 1: Summary plots for all the signal regions with data unblinded. All the SM backgrounds with the shaded band of the total uncertainties are included. ($m_{\tilde{t}}$,$m_{\tilde{\chi}_1^0}$) = (1300,1), ($m_{\tilde{t}}$,$m_{\tilde{\chi}_1^0}$) = (1100,1), and ($m_{\tilde{t}}$,$m_{\tilde{\chi}_1^0}$) = (700,400) are also shown.

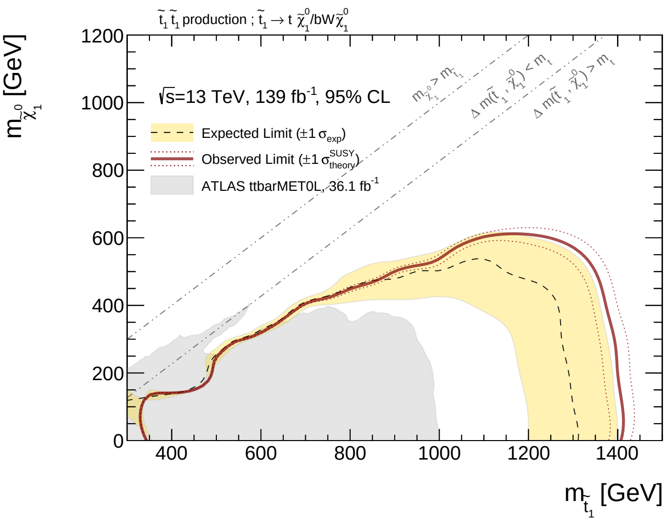

Figure 2: Observed (red line) and expected (black dash line) exclusion limit at 95% confidence level with 139 fb^{-1}of full Run2 dataset. $\pm 1\sigma$ of expected limit (yellow band) is also shown. Observed exclusion limit is also shown in grey area for the comparison. Grey dash-dotted lines indicate the mass regions of the two-body, three-body, and four-body decay.