PROCEEDINGS OF SCIENCE

Beyond the standard model searches in the top quark sectors at ATLAS and CMS

Suman Chatterjee *
on behalf of the ATLAS and CMS Collaborations

Institute of High Energy Physics (HEPHY), Austrian Academy of Sciences (ÖAW), Nikolsdorfer Gasse 18, 1050 Vienna, Austria

E-mail: suman.chatterjee@cern.ch

Searches for new physics are one of the most active fields of research at LHC. Due to its large mass, the top quark is predicted to have an enhanced coupling with the fields of new physics in several theoretical models. Multiple techniques are developed to probe new physics using the top quark as a tool in different phase space regions. A number of results from new physics searches by the ATLAS and CMS Experiments with final states involving top quarks in proton-proton collisions at a center-of-mass energy of 13 TeV are presented.

The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022
16-20 May 2022
online

*Speaker

PoS(LHCP2022)100

1. Introduction

Since the discovery of a Higgs boson in 2012, measurements at the CERN LHC have solidified the standard model (SM) of particle physics. Nevertheless, the existence of new physics beyond the SM (BSM) is needed to explain several observed phenomena, as well as the fine tuning required for the insensitivity of the Higgs boson mass to quantum corrections in the SM. The top quark, the heaviest fermion discovered so far, plays an important role in electroweak symmetry breaking. A large number of theoretical models which attempt to solve the limitations of the SM often contain new heavy states that couple to the top quark with an enhanced coupling. Depending on the new physics models, a few possible heavy states are vector-like quarks (VLQs), whose left- and right-handed components transform independently under the SM electroweak gauge group $SU(2)_L \times U(1)_Y$, leptoquarks (LQ), which decay to quarks and leptons, new massive gauge boson, W', a hypothetical partner of W boson, dark matter mediators among others. BSM effects can also modify top quark properties, which may lead to the violation of discrete symmetries in top quark production and decay. In the following, a few recent results from BSM searches performed by the A Toroidal LHC Apparatus (ATLAS) [1] and Compact Muon Solenoid (CMS) [2] Experiments are reported.

2. Searches for production of vector-like quarks

The ATLAS and CMS Experiments have performed searches for VLQs decaying to a top quark and a Z or a Higgs boson. The CMS Experiment has recently released results on the search for pair production of VLQs using leptonic final states [3]. A multilayer perceptron is used in the single-lepton final state and kinematic variables are utilized in the multi-lepton case to separate the VLQ signal from the SM background. The search excludes both top- and bottom-like quarks (T and B, respectively) of masses up to 1.5 TeV at 95% confidence level (CL) depending on the branching fraction scenario. Lower exclusion limits on VLQ masses as functions of branching ratios of T and B quarks to Higgs and W bosons, respectively, are shown in Fig. 1 (left). The ATLAS Experiment has conducted a search for singly-produced VLQ decaying to a top quark and a Higgs boson in the hadronic final state [4] targetting the topology where both the top quark and the Higgs boson have large transverse momenta so that their decay products are merged into single large-radius jets. Deep neural network based algorithms are used to identify large-sized jet from hadronic top decay, and an n-subjettiness variable τ_{21} [5], sensitive to 2-prong structure, is used to select the jet from $\mathrm{H} \rightarrow \mathrm{b\bar{b}}$ decay. No excess is observed. Lower exclusion limits on VLQ masses are shown in Fig. 1 (right) as a function of its decay width and branching fraction. The CMS Experiment has also looked for the electroweak production of VLQ, which decays into a hadronically decaying top quark and a Z boson decaying to a pair of neutrinos [6]. This search has set an upper limit at 95% CL ranging between 15 and 602 fb, depending on T quark mass, on the product of production cross section and branching fraction for a T quark of small decay width.

3. Searches for production of heavy gauge bosons

The CMS Experiment has performed a search for W' boson decaying to a top and a B quark, as well as to a bottom and a T quark, where T and B quarks further decay into a top and a bottom quark,

respectively, and Higgs or Z bosons [7]. The search targets the topology with highly energetic top quarks decaying hadronically and identifies jets containing those using jet images in such a manner that the identification efficiency does not depend on the jet mass. The soft-drop mass [8] is used to identify hadronically decaying Higgs or Z bosons along with a double-b tagging algorithm [9] and τ_{21}, respectively. No excess is observed in the invariant mass spectrum of top quark, bottom quark, and Higgs or Z boson candidates. For democratic branching fraction of VLQ, W′ bosons of masses less than 3.1 TeV are excluded. Lower exclusion limits on W′ masses at 95% CL are shown in Fig. 2 (left) as a function of VLQ branching fractions for a particular mass splitting between VLQ and W′. Both the ATLAS and CMS Experiments have also searched for massive W′ bosons decaying to a top and a bottom quarks [10, 11]. Deep neural networks are used by both experiments to identify jets of two different sizes containing decay products of the top quark. The ATLAS Experiment has put the most stringent limits on right-handed W′ (W'_R) bosons, excluding those with masses less than 3.6 TeV at 95% CL, as shown in Fig. 2 (middle). The CMS Experiment, on the other hand, has provided the strongest constraints on left-handed W′ (W'_L) bosons, interfering with the s-channel single top production in SM, and excluded those up to 3.4 TeV at 95% CL as shown in Fig. 2 (right).

4. Searches for lepto-quark production

Both the ATLAS and CMS Experiments have searched for LQs decaying to a top quark and a lepton. A recent ATLAS result, targetting the final state with exactly one muon or electron and jets, uses a neural network trained separately for scalar and vector leptoquarks to separate their signatures from the SM background [12]. No evidence for leptoquark production is found. Constraints are placed on LQ production for different coupling hypotheses. For democratic branching fraction, vector LQs with masses up to 2 TeV are excluded, whereas scalar LQs with masses up to 1.5 TeV are excluded at 95% CL. The ATLAS Experiment has released results summarizing leptoquark searches [13] and the exclusion limits obtained for down-type LQs are shown in Fig. 3 for the cases when the lepton coming from LQ is a τ (left) and when it is an electron or a muon (right). The CMS Experiment has also summarized the results from LQ searches in Ref. [14].

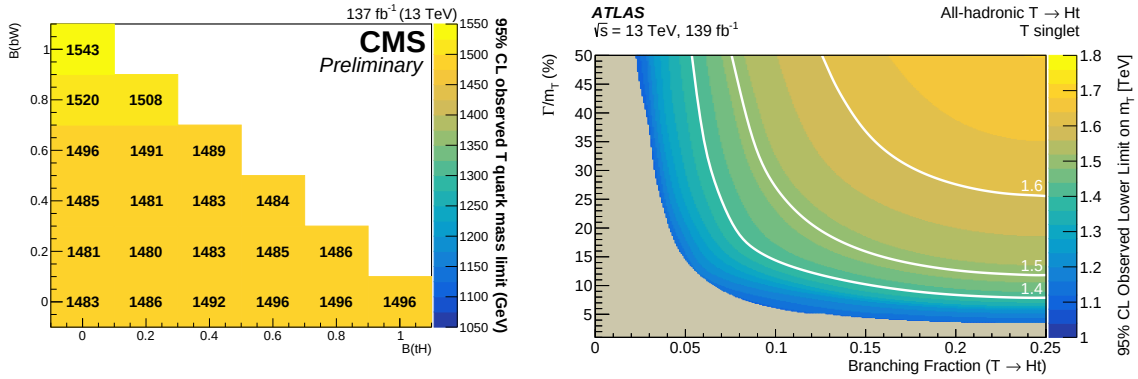

Figure 1: The 95% CL observed lower mass limits on pair-produced (left) and singly produced (right) top-like quark masses[3, 4].

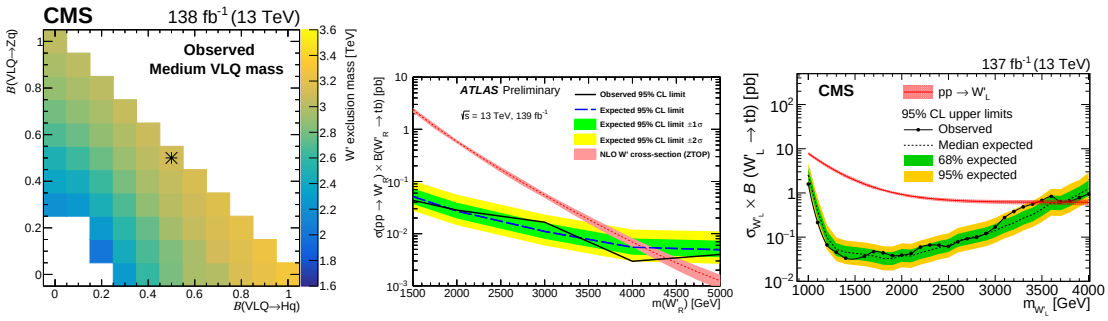

Figure 2: Observed 95% CL lower limits on W′ masses as a function of the branching fractions of VLQ coming from the W′ decay (left) [7]. Upper limits at 95% CL on the production cross section and branching fraction of right- (middle) and left-handed (right) W′ bosons decaying to a top and a bottom quark [10, 11]

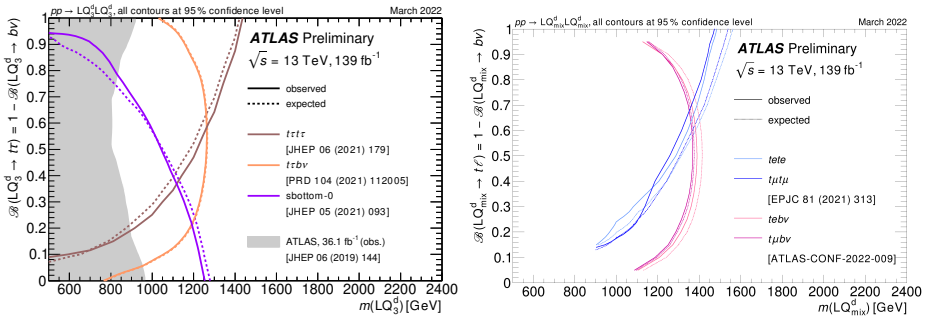

Figure 3: Exclusion contours at the 95% CL for pair-produced scalar third-generation down-type LQs decaying to final states with a τ lepton (left) and a muon or an electron (right) as a function of LQ masses and branching fractions [13].

5. Other searches of new physics with top quarks

Results from the following searches with top quarks are also presented at the LHCP conference.

- Search for dark matter production in association with a top quark and a W boson by the ATLAS Experiment [15].
- Search for charge-parity violation in top quark pair production and decay by the CMS Experiment [16].
- Search for production of a heavy scalar or a pseuoscalar in association with a top quark pair, where the BSM particle decays to a pair of top quarks by the ATLAS Experiment [17].

6. Conclusion

The top quark offers plenty of possibilities to look for the signature of new physics at LHC. The ATLAS and CMS Experiments have performed an extensive range of searches targetting both resonant and nonresonant signatures resulting in final states with top quarks. So far, no significant evidence for new physics has been observed. Nevertheless, experiments will continue efforts to spot any possible signatures of new physics, also exploiting the data to be collected in LHC Run-3.

References

[1] ATLAS Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider", *JINST* **3** (2008) S08003, doi:10.1088/1748-0221/3/08/S08003.

[2] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[3] CMS Collaboration, "Search for pair production of vector-like quarks in leptonic final states at $\sqrt{s}$ = 13 TeV", 2022. http://cds.cern.ch/record/2809519.

[4] ATLAS Collaboration, "Search for single production of a vector-like T quark decaying into a Higgs boson and top quark with fully hadronic final states using the ATLAS detector", *Phys. Rev. D* **105** (2022) 092012, doi:10.1103/PhysRevD.105.092012, arXiv:2201.07045.

[5] J. Thaler and K. Van Tilburg, "Identifying Boosted Objects with N-subjettiness", *JHEP* **03** (2011) 015, doi:10.1007/JHEP03(2011)015, arXiv:1011.2268.

[6] CMS Collaboration, "Search for single production of a vector-like T quark decaying to a top quark and a Z boson in the final state with jets and missing transverse momentum at $\sqrt{s}$ = 13 TeV", *JHEP* **05** (2022) 093, doi:10.1007/JHEP05(2022)093, arXiv:2201.02227.

[7] CMS Collaboration, "Search for a W' boson decaying to a vector-like quark and a top or bottom quark in the all-jets final state at $\sqrt{s}$ = 13 TeV", arXiv:2202.12988.

[8] A. J. Larkoski, S. Marzani, G. Soyez, and J. Thaler, "Soft Drop", *JHEP* **05** (2014) 146, doi:10.1007/JHEP05(2014)146, arXiv:1402.2657.

[9] CMS Collaboration, "Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV", *JINST* **13** (2018) P05011, doi:10.1088/1748-0221/13/05/P05011, arXiv:1712.07158.

[10] ATLAS Collaboration, "Search for vector boson resonances decaying to a top quark and a bottom quark in the hadronic final state using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", 2021. http://cds.cern.ch/record/2779178.

[11] CMS Collaboration, "Search for W' bosons decaying to a top and a bottom quark at $\sqrt{s}$ =13 TeV in the hadronic final state", *Phys. Lett. B* **820** (2021) 136535, doi:10.1016/j.physletb.2021.136535, arXiv:2104.04831.

[12] ATLAS Collaboration, "Search for pair-produced scalar and vector leptoquarks decaying into third-generation quarks and first- or second-generation leptons in pp collisions with the ATLAS detector", 2022. http://cds.cern.ch/record/2805213.

[13] ATLAS Collaboration, "Summary Plots from ATLAS Searches for Pair-Produced Leptoquarks", 2022. http://cds.cern.ch/record/2805984.

[14] CMS Collaboration, "Overview of leptoquark searches". https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV#Leptoquark_summary_plot.

[15] ATLAS Collaboration, "Search for dark matter produced in association with a single top quark and an energetic W boson in $\sqrt{s}$ = 13 TeV (pp) collisions with the ATLAS detector", 2022. http://cds.cern.ch/record/2805216.

[16] CMS Collaboration, "Search for CP violation using $\mathrm{t\bar{t}}$ events in the lepton+jets channel in pp collisions at $\sqrt{s}$ = 13 TeV", arXiv:2205.02314.

[17] ATLAS Collaboration, "Search for $t\bar{t}H/A \to t\bar{t}t\bar{t}$ production in the multilepton final state in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", 2022.

http://cds.cern.ch/record/2805212.