Chapter 10

CONCLUSION

In the first operation of the LHC, an analysis searching for new physics using the same simplified model [1, 2], observed no significant excess of events over the expected Standard Model (SM) background [3]. In 2014, the lower limit on the $\tilde{g}$ mass was set to be at 1.4 TeV at the 95% confidence level for this simplified signal model. The results presented in this thesis span the first two years of the second operational period of the Large Hadron Collider, during 2015 and 2016, utilizing new techniques of boosted object reconstruction to greatly extend the sensitivity to new physics and improve our understanding of the Standard Model. The lower limit of the gluino mass is now set at 1.95 TeV at the 95% confidence level using three different kinds of kinematic observables: missing energy-type, energy scale-type, and energy structure-type [4]. Even though no excess was observed and tighter limits were set, simplified models are useful to provide topology-based limits on searches to identify the boundaries of search sensitivity and derive limits on more general models by reinterpreting [5] the limits in the context of a different signal topology. Even though simplified models may not be motivated by realistic Supersymmetry (SUSY) scenarios, they help to understand the limits of the detector technology. Experimentalists and theorists alike can identify kinematic ranges for which existing searches are not efficient or sensitive, and then define new search strategies to attempt to cover the gaps in the exploration of phase-space. Experimentalists can use the results of searches being performed now to define goals and plans for covering regions of phase-space that are particularly hardware-limited. The second portion of this thesis has a focus on the instrumentation upgrades to be ready for the third operation of the Large Hadron Collider (LHC) physics program, to last for the forseeable lifetime of the LHC which is around 2045. As the current trigger system in ATLAS is not efficient at detecting many of the boosted objects that are copiously produced in the highly-energy proton-proton collisions today, the gFEX module is being built and designed to recover this efficiency. This instrumentation upgrade will benefit countless analyses using boosted objects in the future, including those that have not yet been considered as a potential model of new physics. This thesis is but a chapter in the rich story of boosted objects, a significant advance in the attempt to use boosted object reconstruction to find supersymmetry.

But there are still many areas for improvement. When I first started in 2014, the LHC was set to start up in 2015. For the entirety of 2015 and 2016, it has been a rapid sprint to get preliminary results on these crucial simplified models out to the theorists and the public. But now, this sprint becomes a marathon. The LHC will be shutting down for upgrades at the end of the year. By the end of 2018, experimental particle physicists in the ATLAS collaboration will have $150\,\text{fb}^{-1}$ of data to play with for the next 4-5 years. The increased lower limits on the mass of gluinos may have weakened the case for naturalness, though the possibility of natural supersymmetry still has not been excluded. While the simplified model is certainly unrealistic, what with gluinos decaying through stop squarks 100% of the time, and those stop squarks decaying to top quarks 100% of the time, the analysis of this model is crucial to reinterpration in other regions of phase-space. I look forward to seeing what neighboring physics models we are able to contribute some sensitivity to. The techniques presented in this thesis are brand new and there remains the opportunity to refine them during the next iteration of the analysis. There are also many areas of improvement that have been uncovered during my time with this analysis, such as the non-perturbative modeling of QCD in order to better model the tails of the important kinematic observables. The systematic uncertainties associated with jets and flavor-tagging, both of which this flagship SUSY analysis is very sensitive to, are generally the dominating uncertainties by far and modulating these uncertainties can strengthen the reach of this analysis. Similarly, many physics studies of gFEX are now being done for the first time and have been shown in **??** and will need to be redone using the most advanced and latest monte-carlo simulations and detector geometry definitions that exist. Just like substructure found its way into popularity of jet physics [6, 7, 8], I hope that the first studies of substructure in gFEX gain some momentum, enabling future physicists to design a trigger menu that provides sensitivity to the currently unobserved boosted Higgs decays [9] or the simultaneous production of four top quarks [10]. What more can we reveal of nature? Tune in and see!

Glossary

gFEX global Feature EXtractor.

LHC Large Hadron Collider. 1, 2

QCD Quantum Chromodynamics. A theory describing the strong interactions of SM particles.. 2

SM Standard Model. 1

SUSY Supersymmetry. 1, 2

Bibliography

[1] Daniele Alves. "Simplified Models for LHC New Physics Searches". In: *J. Phys.* G39 (2012). Ed. by Nima Arkani-Hamed et al., p. 105005. DOI: 10.1088/0954-3899/39/10/105005. arXiv: 1105.2838 [hep-ph] (cit. on p. 1).

[2] Johan Alwall, Philip Schuster, and Natalia Toro. "Simplified Models for a First Characterization of New Physics at the LHC". In: *Phys. Rev.* D79 (2009), p. 075020. DOI: 10.1103/PhysRevD.79.075020. arXiv: 0810.3921 [hep-ph] (cit. on p. 1).

[3] ATLAS Collaboration. "Search for strong production of supersymmetric particles in final states with missing transverse momentum and at least three b-jets at $\sqrt{s} = 8$ TeV proton–proton collisions with the ATLAS detector". In: *JHEP* 10 (2014), p. 024. DOI: 10.1007/JHEP10(2014)024. arXiv: 1407.0600 [hep-ex] (cit. on p. 1).

[4] Timothy Cohen et al. "Dissecting Jets and Missing Energy Searches Using n-body Extended Simplified Models". In: *JHEP* 08 (2016), p. 038. DOI: 10.1007/JHEP08(2016)038. arXiv: 1605.01416 [hep-ph] (cit. on p. 1).

[5] Kyle Cranmer and Itay Yavin. "RECAST: Extending the Impact of Existing Analyses". In: *JHEP* 04 (2011), p. 038. DOI: 10.1007/JHEP04(2011)038. arXiv: 1010.2506 [hep-ex] (cit. on p. 1).

[6] Jonathan M. Butterworth et al. "Jet substructure as a new Higgs search channel at the LHC". In: *Phys. Rev. Lett.* 100 (2008), p. 242001. DOI: 10.1103/PhysRevLett.100.242001. arXiv: 0802.2470 [hep-ph] (cit. on p. 3).

[7] Andrew J. Larkoski, Ian Moult, and Benjamin Nachman. "Jet Substructure at the Large Hadron Collider: A Review of Recent Advances in Theory and Machine Learning". In: (2017). arXiv: 1709.04464 [hep-ph] (cit. on p. 3).

[8] Jessie Shelton. "Jet Substructure". In: *Proceedings, Theoretical Advanced Study Institute in Elementary Particle Physics: Searching for New Physics at Small and Large Scales (TASI 2012): Boulder, Colorado, June 4-29, 2012*. 2013, pp. 303–340. DOI: 10.1142/9789814525220_0007. arXiv: 1302.0260 [hep-ph]. URL: http://inspirehep.net/record/1217434/files/arXiv:1302.0260.pdf (cit. on p. 3).

[9] Jonathan M. Butterworth, Ines Ochoa, and Tim Scanlon. "Boosted Higgs $\to b\bar{b}$ in vector-boson associated production at 14 TeV". In: *Eur. Phys. J.* C75.8 (2015), p. 366. DOI: 10.1140/epjc/s10052-015-3592-5. arXiv: 1506.04973 [hep-ph] (cit. on p. 3).

[10] Lana Beck. "Search for the production of four top quarks at the CMS experiment at $\sqrt{s}$ = 13 TeV". In: *Proceedings, 9th International Workshop on Top Quark Physics (TOP 2016): Olomouc, Czech Republic, September 19-23, 2016*. 2016. arXiv: 1611.09607 [hep-ex]. URL: https://inspirehep.net/record/1500694/files/arXiv:1611.09607.pdf (cit. on p. 3).