Final Technical Report
Searching for New Physics with Top Quarks and Upgrade to the Muon Spectrometer at ATLAS

The University of Michigan

Summary of period April 2014 - March 2015 (1 Year)

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My research with the ATLAS experiment at the Large Hadron Collider has been in two directions:

(1) Searching for top quark partners that could stabilize the Higgs boson mass against divergent quantum corrections. Naturalness has been a driving force in high energy theory for the last 30 years. However, with the Higgs mass so low, either a top partner must be somewhere near the energy scale of the LHC or we will have to accept a great deal of fine-tuning – essentially requiring the field to abandon the idea of naturalness.
(2) Searching for new physics associated with the Higgs boson. The Higgs boson is the most recently discovered new particle. It certainly makes sense to search for new physics around the newest fundamental particle, and there is no shortage of models that predict an extended Higgs sector.

Through a combination of these interests/beliefs and the skillset of my personnel, my approach with the ATLAS experiment has been to search for new physics in top quark events, and in events with tau leptons. Top quarks and tau leptons are exciting objects as they connect to multiple new physics scenarios related to these questions and others. The top quark is dominantly produced by the strong interaction at the LHC, and therefore top events serve as very high energy probes for new physics associated with the strong force. The top quark also has unity coupling to the Higgs boson, which suggests it may play some special role in electroweak symmetry breaking – this also motivates the necessity of a top partner. Studying events with tau leptons is a promising direction to search for new physics that could be associated with the Higgs boson. Tau decay modes in some Higgs models have a larger event rate then other leptonic decays modes and suffer less from backgrounds. Several new physics signatures predict appreciable rates in events associated with tau leptons, most notably two-Higgs doublet models (2HDM), which are considered the simplest extension to the Higgs sector.

My ATLAS team during the funding period consists of physics postdoc (*Allison McCarn*), PhD electrical engineer (*Xueye Hu*), and two second-year graduate students (*Hao Liu and Daniel Marley*), along with a few undergraduate students. Within the award period, I have developed a research program that has produced several results in searching for new physics in the extended Higgs sector and in studying top quark production - both hot topics in the high-energy physics community. McCarn and Liu played a primary role in developing a search for charged Higgs bosons decaying to taus, recently submitted to JHEP, and in the search for a pseudo-scalar boson connected with an extend Higgs sector, to be submitted to PLD – both utilizing 20 fb^{-1} of 8 TeV data. McCarn served as an editor in these analyses and as group leader for the lep-had decay channel of the pseudo-scalar analysis. McCarn and Marley recently completed a measurement of the top quark charge asymmetry with 20 fb^{-1} of 8 TeV data. This analysis probes symmetries of the strong interaction at high energy, and is sensitive to several new physics scenarios. A paper will be submitted to EPJC. McCarn and I both served as editors for the analysis. Myself, Marley and McCarn have also been involved with the development of a new re-clustering algorithm to identify so-called boosted top quark events – high energy events where the decay products of top quarks become collimated. The re-clustering algorithm is highly flexible and allows for far simpler calculations of associated systematic uncertainties. Marley played a primary role in developing documentation and in initial results presented at the 10th Hadronic Calibration Workshop at the Max-Planck-Institute for Physics in Munich, Germany. Finally, utilizing more standard boosted algorithms, we have developed a new measurement of the top quark charge asymmetry using boosted techniques, which will utilize 20 fb^{-1} of 8 TeV data. This novel measurement probes the charge asymmetry with the highest energy events available.

Performing both boosted and resolved measurements of the charge asymmetry has led to a deeper understanding of the strengths, weaknesses, and overlap between the respective reconstruction algorithms, which will be very useful in maximizing the sensitivity of top quark analyses in run 2.

Beyond physics analyses, members of my team have been involved in several service tasks for the ATLAS experiment within the award period. McCarn was a coordinator for the estimation of W+jets backgrounds in top analyses, led the lep-had group for the pseudo-scalar higgs analysis, and is currently a member of the Higgs cross-section working group for BSM analyses. I have been serving as co-convenor of the top quark pair cross-section group. Top cross sections measurements will be important standard candles for the first data collected in run 2 and may show the first hints of new physics. In this role, it has been my responsibility to ensure the quality of cross-section analyses in the physics group, and to drive these first cross section analyses in run 2, including the first inclusive cross sections, as well as differential measurements.

My future physics plans for run2 are to more directly address my interests in top partners and to search for new physics associated with an extended Higgs sector. Within the last year, we have begun collaborating with another faculty member at the University of British Columbia to search for vector-like top quarks (VLQ) in semi-leptonic decay channels. This is a very exciting dataset, and model, to search for possible top partners. The analysis has been under development by myself, McCarn and Marley. We will heavily rely on our experience in developing background predictions in top events, as well as boosted and resolved reconstruction algorithms. Myself, McCarn and Liu are developing a search for h/H/A in the tau-tau channel. This is a very important search for SUSY Higgs scenarios, especially for higher tan beta with the Higgs mass at 125 GeV.

Beyond analysis, we have also been heavily involved in both Phase-I and Phase-II upgrades of the ATLAS experiment. These upgrades ``constitute the highest-priority near-term large project'' (Recommendation 10) according to the strategic plan for US particle physics developed by the P5 committee in 2014. For Phase-I, I lead the development of the trigger signal packet router on the NSW – a critical component of the trigger electronics of the new small wheel detector. The development of this component was a significant uncovered hole in the front-end electronics for the NSW. ATLAS NSW management had been unable to identify an institution with the funding and expertise to take on this responsibility, and therefore the router became a substantial risk to the successful completion of the trigger electronics and the NSW upgrade for the ATLAS experiment. I brought significant additional expertise, personnel, and funding from Michigan for the NSW upgrade efforts. Further, with extensive discussions with ATLAS management, Michigan, and Academia Sinica in Taiwan, an agreement was reached with Academia Sinica to provide the production funds for the router, with my team at Michigan providing the design, prototypes and final production boards QA/QC tests. This has led to the mitigation of a substantial risk to the completion of the NSW upgrade. My engineer, Xueye Hu, has performed the entire electronics design and prototyping of the router board – including novel means to optimize the speed of the electronics and a flexible routing algorithm to minimize signal loss. The router project is currently three months ahead of schedule. Within the funding period, we constructed our first prototype, which was successfully tested in my laboratory. Our second prototype is currently in development.

With full support of Michigan faculty, I also lead the overall Phase II upgrade effort at Michigan. A large team is involved in this R&D, including myself and faculty Amidei, Chapman, Qian, Zhou, Zhu. Michigan is the largest contributor to R&D towards Phase II upgrades of the Muon system. The Phase-II upgrade will require the replacement for almost the entire ATLAS precision muon system front-end electronics. Our primary Phase II deliverable is the chamber service module (CSM), which is considered the highest priority component of the Phase II upgrade of the ATLAS muon system. We are currently developing multiple candidate designs, as well as testing components of the current system at Phase-II rates. Recently, I have been appointed to a two-year term by USATLAS as the Level-2 manager for the Phase II upgrade of the Muon System. In this role, I am responsible for defining and managing US deliverables for the upgrade, their costs, and the institutes responsible for them, as well as the division of the project between the NSF and DOE.

Publications

"Measurement of the charge asymmetry in top quark pair production in pp collision data recorded at sqrt(s) = 8 TeV with the ATLAS experiment", (ATLAS Collaboration), Paper at second circulation in the collaboration, to be submitted to EPJC.

"Search for a CP-odd Higgs boson decaying to *Zh* in *pp* collisions at sqrt(s)=8 TeV with the ATLAS detector", (ATLAS Collaboration), Physics Letters B 744 (2015) 163-183.

"Search for charged Higgs bosons decaying via $H^{\pm} \rightarrow \tau^{\pm} \nu$ in fully hadronic final states using pp collision data at sqrt(s) = 8 TeV with the ATLAS detector", (ATLAS Collaboration), JHEP03 (2015) 088.

"Properties of the Top Quark", F. Deliot, N. Hadley, S. Parke, and T. Schwarz, Annual Reviews: Nuclear and Particle Science. Vol. 64: 363-381 2014.

Conference Talks/Posters

"The Top Quark Charge Asymmetry using 4.7 /fb at sqrt(s) = 7TeV with the ATLAS Detector", LHCP 2014, Columbia University, NY (2014), Dan Marley

"The NSW Signal Packet Router for the Phase I Upgrade of the ATLAS Muon Spectrometer", LHCP 2014, Columbia University, NY (2014), Tom Schwarz

"Data-driven background estimations in H+ analyses", Prospects for Charged Higgs Discovery at Colliders, Uppsala, Sweden (2014), Allison McCarn

"Phase II Upgrade of the Muon Spectrometer", USATLAS Week, Seattle WA (2014), Tom Schwarz

"Boosted Boson Studies" USATLAS VLQ Workshop, Argonne National Lab (2015), Dan Marley

"Wb+X and Wq+X Summary", USATLAS VLQ Workshop, Argonne National Lab (2015), Dan Marley