FINAL REPORT: High Energy Physics at the Energy Frontier at Louisiana Tech

From the
Louisiana Tech University
Center for Applied Physics Studies

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Institution:	Louisiana Tech University
Street Address:	1 Adams Blvd
City/State/ZIP:	Ruston, LA 71272
Principal Investigator	Dr. Lee Sawyer
Postal Address:	P.O.Box 10348, Ruston, LA
Telephone Number:	318-257-4053
Email Address:	sawyer@phys.latech.edu
DOE Grant Number:	DE-SC0009859
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DOE/Office of Science Program Office:	Office of High Energy Physics
DOE/Office of Science Program Office Technical Contact:	Dr. Abid Patwa abid.patwa@science.doe.gov
Co-principal Investigators:	Dr. Zeno D. Greenwood greenw@phys.latech.edu Dr. Markus Wobisch wobisch@latech.edu

Executive Summary

Since June, 1999, the Louisiana Tech University High Energy Physics group has been funded by the Dept.of Energy, most recently by the grant described in this Final Technical Report. This funding has facilitated the establishment of a High Energy Physics research group Louisiana Tech University, led to major involvement with the upgraded DØ experiment at the Fermilab Tevatron collider and the ATLAS experiment at the CERN Large Hadron Collider, contributed to the growth of the Louisiana Tech physics program from a terminal Masters program to a PhD-granting program, supported several Masters and PhD students in the completion of their graduate research work, and underwritten several postdoctoral researchers in the field.

The Louisiana Tech University High Energy Physics group is a medium-sized experimental particle physics research group with faculty, postdoctoral researchers, doctoral and master's students, and undergraduate students engaged in operations and data analyses at hadron collider-based experiments. After several years of collaborating on the DØ experiment at the Tevatron $p\bar{p}$ collider at Fermi National Accelerator Laboratory (Fermilab), our primary focus is now centered on the ATLAS experiment at the LHC pp collider at the CERN laboratory near Geneva, Switzerland.

The goal of this project was to create, maintain, and strengthen a world-class, nationally and internationally recognized experimental high energy physics group at Louisiana Tech University, focusing on research at the energy frontier of collider-based particle physics, first on the DØ experiment and then with the ATLAS experiment, and providing leadership within the US high energy physics community in the areas of fundamental measurements of the Standard Model of particle physics and searches for new phenomena beyond the Standard Model, as well as developing leadership in high performance computing. This research aids the understanding of the basic constituents, forces, and interactions of Nature. The ATLAS experiment at the LHC provides the technical facility with which to investigate these phenomena at the energies accessible currently accessible in an accelerator.

1 Introduction

Since May 2013, the Louisiana Tech University High Energy Physics group has received base funding from Dept. of Energy grant DE-SC0009859. This funding, which amounted to a total of $731,000 has facilitated our involvement with ATLAS experiment at the CERN Large Hadron Collider, contributed to the growth of the Louisiana Tech physics program from a terminal Masters program to a PhD-granting program, supported several Masters and PhD students in the completion of their graduate research work, and underwritten several postdoctoral researchers in the field.

The Louisiana Tech University High Energy Physics group is a medium-sized experimental particle physics research group with faculty, postdoctoral researchers, doctoral and master's students, and undergraduate students engaged in operations and data analyses at hadron collider-based experiments. After several years of collaborating on the DØ experiment at the Tevatron $p\bar{p}$ collider at Fermi National Accelerator Laboratory (Fermilab), our primary focus is now centered on the ATLAS experiment at the LHC pp collider at the CERN laboratory near Geneva, Switzerland.

The group consists of three faculty members: Dr. Lee Sawyer (Charles & Newllyn Spruell Professor of Physics and Director of Chemistry & Physics at Louisiana Tech, and member of the DØ and ATLAS experiments), Dr. Zeno D. "Dick" Greenwood (W. W. Chew Professor of Physics and Louisiana Tech team leader on ATLAS), and Dr. Markus Wobisch (Eva J. Cunningham Associate Professor of Physics, member of the DØ and ATLAS experiments, and coordinator of the FASTNLO project). We have had three postdoctoral researchers who have made significant contributions to many aspects of the ATLAS experiment. We have had several students in the Computational Analysis and Modeling PhD program who have worked with our group. During this grant period we graduated two PhD students, Rajivalochan Subramaniam and Debottam Bakshigupta. Our focus is on the ATLAS experiment at the LHC. We have established important service roles in two major areas: Triggers and Data Quality. These will discussed in detail below.

Our physics research is also focused in three areas: Top quark physics in final states containing tau leptons, searches for new phenomena in events with leptons plus jets and in events with multi-jet final states, and studies of the strong interaction in jet production. Louisiana Tech has developed a reputation as one of the leading institutions pursuing jet physics studies at the Tevatron, and we are building a similar reputation on ATLAS, with several jet analyses in progress. Focusing on closely related topics in the jet and top analyses and in the searches has led to high efficiency and increased visibility inside the ATLAS collaboration and beyond.

The goal of this project was to create, maintain, and strengthen a world-class, nationally and internationally recognized experimental high energy physics group at Louisiana Tech University, focusing on research at the energy frontier of collider-based particle physics with the ATLAS experiment, and providing leadership within the US high energy physics community in the areas of jet physics, searches, top quark and charged Higgs decays involving tau leptons, as well as developing leadership in high performance computing.

2 Group Description

The Louisiana Tech High Energy Physics research group currently consists of three physics faculty members: Dr. Markus Wobisch, Dr. H. Lee Sawyer, and Dr. Zeno D. “Dick” Greenwood. All have been involved in the ATLAS experiment since Louisiana Tech joined in 2007, while Sawyer was also involved in the early design and test beam studies of the ATLAS calorimeter in the mid-1990s. We anticipate that Greenwood will retire and be appointed professor emeritus before the start of the proposed funding period; therefore, we include him as a major participant in the project. The Physics program at Louisiana Tech University has committed to search in Fall 2017 for a new faculty member in experimental High Energy Physics.

Since joining ATLAS in 2007, the Louisiana Tech group has had a number of excellent postdocs working on the experiment. These have included Catrin Bernius (currently with SLAC), Matthew Tamsett (currently with the University of Suffolk), Dilip Jana (currently in private industry), and most recently Guilio Grossi, who was with the group until May, 2017. Due to the interruption in our funding, we do not have a postdoc on the experiment at the moment, but we propose to hire a postdoc to be stationed at CERN, if funded.

We have had success recruiting students into our group. Our last graduate student on ATLAS, Debottam BakshiGupta, received his PhD in August 2017, joining four previous PhD recipients from our group, along with several Masters recipients and undergraduate students who performed their senior research projects with us on ATLAS.

The Louisiana Tech group has focused it efforts in a few areas in which it can be successful in producing high-quality physics results, leading detector operations in the ATLAS experiment, and training undergraduate and graduate students. We work as a very closely integrated team; often, for example, with one faculty member supervising students’ or postdocs’ service work while another faculty member supervises their physics analyses.

Major group activities also include the training of incoming students and the professional development of students and postdocs. This has lead to the creation of a specialized graduate class on Hadron Collider Physics by Wobisch, with close one-on-one interactions with the students.

Our former postdoc Catrin Bernius was honored with the 2015 ATLAS Outstanding Achievement Award and PhD student Debottam Bakshi Gupta received a MCnet short-term studentship in 2015 which he performed in Glasgow, Scotland, together with Andy Buckley, from October 2015 to January 2016. This work, on matching PYTHIA8 with POWHEG-BOX, resulted in the publication on “Powheg-Pythia matching scheme effects in NLO simulation of dijet events” in Ref. [1].

3 Goals and Accomplishments

The Louisiana Tech University High Energy Physics group proposed funding for our research program aimed at experimentally testing the Standard Model of particle physics and searching for new phenomena through a focused set of analyses in collaboration with the ATLAS experiment at the Large Hadron Collider (LHC) at the CERN laboratory in Geneva. This research program included involvement in the operation and maintenance of the ATLAS experiment and full involvement in Phase 1 and Phase 2 upgrades in preparation for future high luminosity (HL-LHC) operation of the LHC.

We have accomplished these goals in the following ways:

- Completed measurement of the cross section for top production through the decays into tau leptons.
- Developed and completed the search for SUSY in lepton-jet events.
- Developed and completed the search for R-parity violating stop decays and coloron decays into four-jet final states.
- Developed and competed the measurement of the jet azimuthal decorrelation ration $R_{\Delta\phi}$.
- Developed the measurement of the jet neighbor ratio $R_{\Delta R}$ (Subramaniam's dissertation.)
- Developed the measurement of transverse jet event shapes (Gupta dissertation.)
- Held leadership positions in the Jet Trigger and Data Quality operations groups.
- Developed upgrade plans for HL-LHC jet triggers.

Details of each of these accomplishments are discussed under Project Activities below.

4 Project Activities

ATLAS measurement of multi-jet cross section ratio $R_{\Delta\phi}$ and determination of α_s

Starting with our contributions to the pioneering analysis in the DØ experiment in 2005 [2] and the repetition using the early ATLAS data [3], the Louisiana Tech group has continued to develop strategies for analyses of dijet azimuthal decorrelations, as in the PhD thesis work by Dhullipudi [4] (based on ATLAS data at $\sqrt{s} = 7$ TeV). In 2012, the Louisiana Tech group published a proposal for the new quantity $R_{\Delta\phi}$ [5] and performed a first measurement of $R_{\Delta\phi}$ in the DØ experiment [6]. In parallel, we started the ATLAS $R_{\Delta\phi}$ measurement at $\sqrt{s} = 8$ TeV, which extends the DØ measurement to smaller values of $\Delta\phi_{\,\mathrm{dijet}}$ and to larger energies ($200 < Q < 1670$ GeV). The $R_{\Delta\phi}$ measurement is also used for a novel determination of α_s at the LHC. The new α_s results extend this range to $Q > 1.6$ TeV, the highest Q ever accessed. The publication will be submitted to Phys. Rev. D by the end of 2017 and the results will constitute one of the highlights of the LHC physics program. Sawyer, Wobisch, previous postdoc Tamsett, and previous PhD student Subramaniam performed this work. Tamsett performed the whole experimental measurement and he was editor of the backup note. Subramaniam did additional studies for one experimental effect and he determined the $t\bar{t}$ contributions. Sawyer computed the non-perturbative corrections and was co-editor of the article. Wobisch performed the pQCD calculations, and the α_s determinations, and he was the main editor of the article.

Phenomenology of dijet azimuthal decorrelations

During the work on our ATLAS analysis on dijet azimuthal decorrelations (the $R_{\Delta\phi}$ measurement), Wobisch noticed an inconsistency in how the pQCD calculations in some of the earlier publications in DØ, CMS and ATLAS were obtained. This affects the data and theory comparison in the kinematic range where the azimuthal angle between the two leading p_T jets is

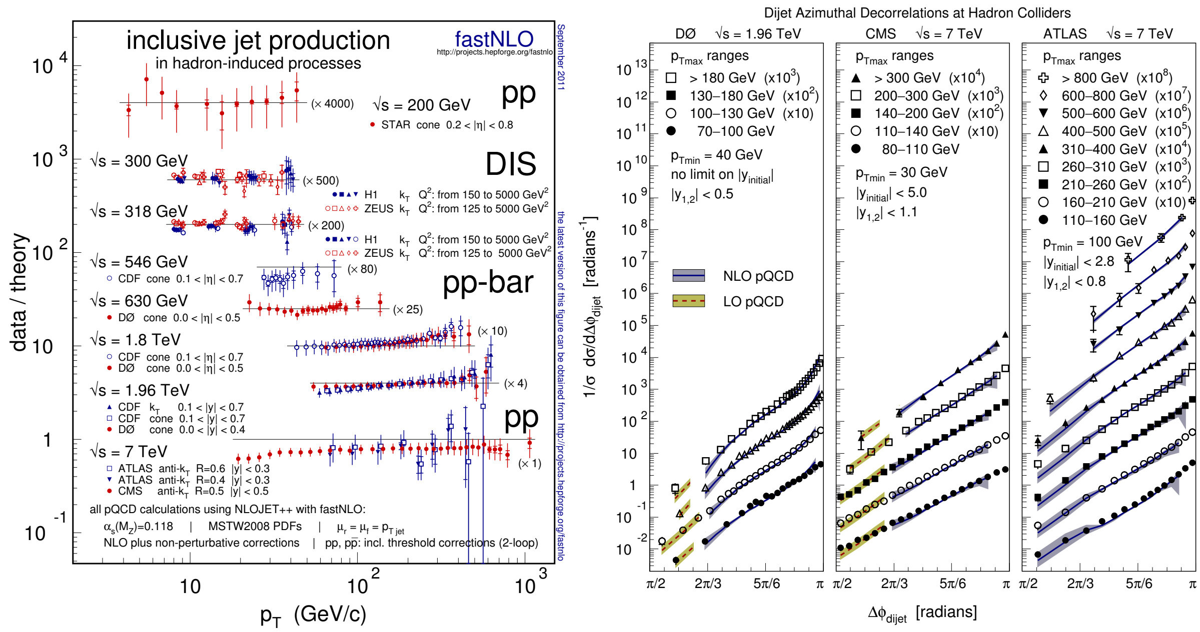

Figure 1: FastNLO world summary figure of data-theory ratios for inclusive jet production at central rapidities in different processes and at different center-of-mass energies, as featured in the PDG 2014 review (left). Summary of measurements of dijet azimuthal decorrelations in the DØ CMS, and ATLAS experiments (right) as published in Ref. [7].

$\Delta\phi_{\rm dijet} < 2\pi/3$. In the publication [7], we have pointed out how the inconsistency arises, and demonstrate how the pQCD calculations can be modified to obtain consistent results. It is shown that the modified calculations exhibit a smaller scale dependence and also give a better description of the experimental data, as compared to the older, inconsistent calculation (Fig.1, right). It is also discussed how theoretical calculations improve, when the dijet phase space is chosen appropriately. Some of the conclusions of this publication have been adapted in our ongoing ATLAS $R_{\Delta\phi}$ measurement and future analyses of dijet azimuthal decorrelations will strongly benefit from these. Wobisch was the main author of this publication, providing most of the required pQCD calculations, producing the figures, and was main editor of the article.

The fastNLO project

Wobisch started the fastNLO project in 2005, together with collaborators T. Kluge (University of Liverpool) and K. Rabbertz (University of Karlsruhe). The fastNLO project is building on methods, developed by Wobisch during his work at HERA, to determine α_s and the proton PDFs from jet data. The fastNLO project [8, 9] was designed to provide very fast calculations of cross sections in hadron-induced processes.

Using advanced interpolation techniques, fastNLO stores perturbative coefficients for a given observable independently of α_s and PDFs. Later, the multiplication of the precomputed coefficients with arbitrary α_s and PDFs allows very fast repeated calculations for different values of these parameters. This faciliates the presentation of experimental results when comparing data to theory for a series of different PDFs and when computing PDF uncertainties. But the ultimate application of fastNLO is the use of jet data in global PDF determinations. While older global PDF analyses used restricted jet data sets, based on weak theoretical approximations, the fastNLO code allows inclusion of larger jet data sets using exact theory calculations. This is being used in many global PDF analyzes, by the MSTW group (MSTW2008 [10, 11]), the CTEQ group (CT10 [12]) and also in the PDF analyses in Refs. [13, 14, 15]. Using FastNLO, Wobisch has provided the world summary figure on inclusive jet production at different colliders for the PDG “Review of particle physics” books in 2010, 2012, and 2014. The 2014 version of the figure (Fig. 1, left), was updated to include the LHC measurements at $\sqrt{s} = 7$ TeV and 2.76 TeV.

In 2011, two collaborators, Daniel Britzger (MPI Munich) and Fred Stober (Karlsruhe University) joined the fastNLO project. Since then the fastNLO project has published version 2 of the code, a major update, with more flexibility in the data structures, and with additional features. The new data structures allow to implement calculations for different processes (e.g. diffractive jet production, which is used at HERA to determine the pomeron PDFs). Separating contributions which depend on the renormalization scale, the factorization scale, and the scale independent contributions gives more flexibility for studies of the scale dependence of the theoretical results.

The ALPOS project: global α_s determinations

The precision of α_s determinations is usually limited by the scale dependence of NLO pQCD calculations. Recently, however, NNLO calculations have become available for inclusive jet production in hadron collisions [16] and in deep-inelastic scattering [17], which will reduce these uncertainties, resulting in a larger impact of inclusive jet data on the future world average of α_s. Therefore, a group of experts (including Wobisch) who have performed the recent relevant α_s analyses at HERA, at the Tevatron, and at the LHC have formed the ALPOS project, in which they develop a framework for a combined analysis of different inclusive jet data sets, resulting in the most precise α_s value from inclusive jet production. The project is hosted at DESY: `http://desy.de/~britzger/alpos`. While we are still working on interfacing the new NNLO calculations to fastNLO, we have published a first feasibility study [18, 19] of an α_s determination (based on NLO pQCD) from inclusive jet cross section data from the H1, ZEUS, STAR, CDF, DØ ATLAS, and CMS experiments, over a wide kinematic region, and for various center-of-mass energies. The consistency of the various data sets is examined and the benefit of their simultaneous use in the α_s analysis is demonstrated. We find a good consistency between most of the data sets and find that the combined analysis yields significantly reduced experimental uncertainties, as compared to the α_s results from data of single experiments. This analysis (which is limited to NLO precision), yields a result of $\alpha_s(M_Z) = 0.1192\,(\pm 0.0012)_{\rm exp}\,(^{+0.0060}_{-0.0041})_{\rm theo}$ [19]. The extension of this work to NNLO precision is planned for the future. Wobisch contributed to this work through the development of the concepts and analysis strategies, producing result figures, and as co-editor of the article.

Searches for RPV stop and coloron production in four-jet final states

While most supersymmetric (SUSY) extensions to the Standard Model presume a symmetry, called R-parity, that suppresses baryon- and lepton-number violating decays, models with R-parity violation (RPV) are not experimentally ruled out. Naturalness arguments suggest that

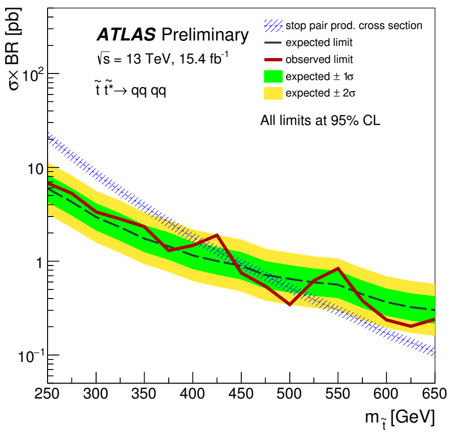

Figure 2: Limits on the stop mass in RPV production from the four-jet search.

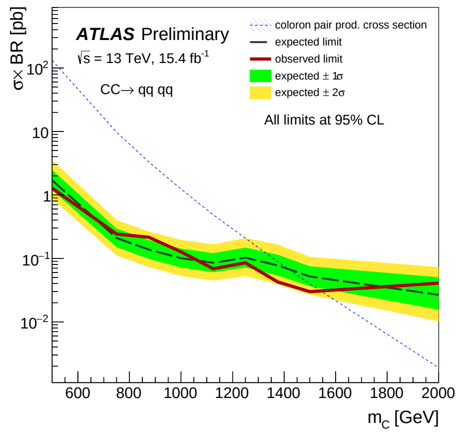

Figure 3: Limits on the coloron mass from the four-jet search.

the SUSY partner of the top quark, or "stop", may be light compared to the other squark states; therefore searches for stop decays are of particular interest. RPV decays of stop result in $\tilde{t} \rightarrow qq'$, for which we will assume a 100% branching ratio for the search described below, so that stop pair production would be characterized by a four-jet final state. Previous searches for pair produced resonances in four-jet final states have been performed at 7, 8 and 13 TeV by ATLAS [20, 21, 22] and at 7 and 8 TeV by the CMS experiment [23, 24].

Color octet vector bosons, or "colorons", appear in many extensions of the Standard Model, including axigluon, Topcolor, and vector-like confinement models. Colorons can also arise as Kaluza-Klein excitations of the gluon. Colorons can be pair produced and each subsequently decays into two quarks or gluons, leading again to a four-jet final state. Previous exclusion limits of $200 \leq m_C \leq 835$ GeV for colorons have been reported by the CMS Collaboration. As with the stop squark signal, signal event samples were produced using MG5_aMC@NLO[25] v2.2.3. The coloron samples are generated with the model described in[26].

The production rates of two pairs of high p_T jets in a sample of four-jet events were used for a search of the production of RPV stop production or the production of colorons. The initial search, carried out on 15.4 fb^{-1} of ATLAS data collected in 2015 and 2016, produced the observed and expected 95% CL upper limits on the allowed cross sections that are shown in Figs. 2 and 3. These limits were published in Ref. [27] and presented at the ICHEP2016 conference.

Over the past year, this search has been updated with additional data taken by ATLAS in the last half of 2016. New limits, derived based on 36.7 fb^{-1} of data, are currently part of a paper under internal review in the ATLAS experiment and expected to be submitted for publication shortly after the submission of this proposal. Sawyer and postdoc Grossi were part of the analysis team that also included Simone Amoroso of CERN and Max Goblirsch of MPI. Grossi was involved in all aspects of the analysis, and also created the reduced datasets used for the search. Sawyer served as the senior researcher, and specifically performed trigger studies and consistency studies of the search using different versions of the reconstruction software.

RNS-motivated strong SUSY searches

During Run 2, Greenwood has been conducting SUSY searches motivated by the Radiatively-driven SUSY (RNS), in particular the two-parameter non-universal Higgs model, NUHM2 [28, 29] In 2015–16, with postdoc Jana, Greenwood worked on two searches for Strong SUSY with signatures that included same dileptons, or three leptons, plus jets. Final states with two same-sign leptons and multiple jets are sensitive to a variety of New Physics scenarios. In supersymmetric models, such final states can be produced in the decays of heavy superpartners involving massive gauge bosons, sleptons or top quarks. Depending on the nature of the particles accompanying the leptons in the final states, a large variety of signatures can be obtained, notably in terms of the numbers of jets and b-tagged jets in the final state. Following their successful analyses in 2015 [30], the ATLAS Same Sign/3 Lepton working group in 2016 chose to analyze four R-parity-conserving (RPC) SUSY scenarios with the lightest neutralino χ_1^0 as lightest and stable superpartner, featuring gluino or bottom squark pair production with various exclusive decay modes, as well as four R-parity-violating (RPV) SUSY scenarios with gluino or down squark decays through baryon-number-violating couplings. The results of the 2016 analysis were presented at Moriond and published in JHEP [31].

Greenwood and Jana contributed to this analysis by performing b-tag optimization studies. The studies used a neural net algorithm, for looking into regions that emulate the analysis signal regions, to find the most performant b-jet tagging efficiency working point.

Electroweak SUSY searches

In 2017, Greenwood began exploring possible SUSY searches, based on predictions of the NUHM2 [28, 29] model in the Electroweak sector with the Higgsino group. He joined forces with Pat Skubic and his PhD student Yu-Ting Shen at the University of Oklahoma and Judita Mamuzic, a postdoc in the Valencia group. Together they convinced the ATLAS Higgsino analysis group to include an interpretation based on NUHM2 in their Compressed SUSY search. This analysis, based on 2015–2016 data, searches for direct production of new colorless states with compressed mass spectra, which are favored by naturalness and dark matter arguments in supersymmetric extensions of the Standard Model. Such scenarios are characterized by soft visible decay products and pose challenges for triggering, reconstruction, and background estimation. This analysis will be the first dedicated search by ATLAS for direct production of new colorless states with compressed mass spectra. Greenwood contributed to this analysis in the Higgsino group by performing Madgraph and MadSpin based studies to motivate MC production (now in progress) of NUHM2 SUSY predictions at five mass points.

ATLAS operations

The Louisiana Tech group has developed significant roles in the operation of the ATLAS experiments through our contributions to the Jet Trigger, Jet/Missing E_T Combined Performance, and Data Quality Monitoring working groups.

The Louisiana Tech group is very active in the **ATLAS jet trigger signature group**, playing a leading role in the development of the Level 1.5 jet trigger in Run 1 and developing jet trigger menu items for 2015 running. Sawyer is part of this effort, and in particular, has been studying the implementation of various jet finding algorithms at the High Level Trigger (HLT). This work intended both for the current running and as a study for possible upgrades to the Level 1 jet trigger. During 2014, Sawyer took on additional responsibilities within the Jet Trigger group, and is now the coordinator for monitoring and performance of the Jet Trigger slice. This also leads to the planning of additional monitoring tools for jet trigger upgrades. Our group has contributed to studies of the trigger-level Jet Energy Scale, implementation of pile-up mitigation techniques, and trigger data quality monitoring. During 2015 and 2016 Wobisch adopted existing ATLAS software for the purpose of the trigger jet energy calibration on the EM scale, performed the calibration for all relevant jet collections, and demonstrated the closure of the procedure. Detailed documentation of the procedure, the software tools, and the results is currently in progress. Wobisch and students Debottam Gupta and Andrew Touchet have also studied and developed the implementation of the SoftKiller pile-up mitigation tool in the HLT.

The Louisiana Tech group also has been the primary group responsible for the **data quality monitoring of the jet trigger**. Sawyer developed and wrote the software for the initial version on TrigJetMonitoring for Run 2, and under his supervision postdoc Grossi maintained the online and offline jet trigger monitoring code. Sawyer coordinates jet trigger monitoring activities. In addition, Sawyer took on the additional collaboration-wide responsibilities as the overall trigger monitoring coordinator during the last half of the 2016 data taking period.

Data Quality monitoring of reconstructed physics objects; including calorimeter-based topological clusters, jets, missing E_T, electrons, photons, and taus has also been a primary responsibility of the Louisiana Tech group, with members of the group maintaining important leadership and coordination tasks. Louisiana Tech has a long history of participation by Sawyer and graduate students on combined calorimeter data quality monitoring. Sawyer and several former students have been involved in maintaining and improving the CaloMonitoring software as well as taking Jet/Etmiss data quality and Liquid Argon detector shifts. Since 2014, Louisiana Tech has had sole responsibility for maintaining and updating this important monitoring package.

Sawyer is also the coordinator of the **CaloCombined data quality shift**, which is the group of experts who inspect data quality monitoring plots for calorimeter-based physics objects and make an initial assessment of the quality of the data taken for physics analyses. He was the sole CaloCombined coordinator during the 2015 and 2016 data runs, and shares the coordination responsibilities with Bertrand Laforge (Paris) for the 2017 and 2018 runs. Sawyer is also the primary contact within the Jets/Missing E_T Combined Performance group for data quality monitoring, and served as the co-convener of the group's Software and Validation working group during 2015-16.

Beyond data quality monitoring, the Louisiana Tech group has also been involved in validation tasks for the **Jets/Missing E_T Combined Performance group**. Jet validation has two aspects: software validation and physics validation. Software validation occurs through a series of test packages that are run with each new release of the ATLAS software packages. The validation team included Louisiana Tech postdoc Dilip Jana and student Debottam Gupta, as well as Wobisch, along with two graduate students from Canada. For physics validation, several tools were written to plot jet quantities and compare to references. Again, these tools are run over test samples as changes to the reconstruction and simulation are released. Sawyer coordinated the activates of this group, with the specific software being written by Sergei Chekanov of Argonne and Pierre-Antoine Delsart of Paris.

ATLAS upgrades

Our major recent activity on ATLAS upgrades has been with the ATLAS Trigger GPU Demonstrator. The ATLAS Trigger GPU demonstrator is a project to assess the potential of General Purpose Graphical Processing Units (GPGPUs) for use in the ATLAS HLT processor farm. The Trigger GPU Demonstrator has five modules which at the present time can operate independently of each other. These are the ID, Muon, Calo and Jet modules, which are to perform object reconstructions in the Inner Detector, Muon and Calorimeter systems. The goal of the GPU Demonstrator Project is to compare throughput of CPU-only nodes to CPU+GPU nodes. Assessment of the performance will be in terms of events/s/CHF and of the effort needed to port and maintain code. Estimates will be made of the fraction (by CPU-time) of ATLAS trigger code that could be ported to GPUs. The project will report its finding by the end of 2017.

Greenwood is responsible for the Jet module in the GPU Demonstrator. In this project, Greenwood and Wobisch directed the work of Computer engineers Aaron Elliott and Supapda Laosooksathit during 2015, and PhD students Andrew Touchet and Wenjing Xu in 2016-2017. Greenwood is the co-author of an ATLAS note in progress that documents the project. Parts of the note will be included in the GPU trigger feasibility summary in the ATLAS Phase I Upgrade final report.

As of 2015, Louisiana Tech is part of the L0GLOBAL upgrade, which is part of the overall Phase-II trigger upgrades to ATLAS. Plans are still under development for the Phase-2 upgrade, and Louisiana Tech will be part of the continuing upgrade planning and development for the jet trigger signatures. Our major area of emphasis currently is with the development of a jet finding module for the GPU demonstrator project. Sawyer is also directing this effort and coordinating activities as part of the larger US-ATLAS upgrade effort. In addition, Sawyer is involved in the evolution of the ATLAS software in his role as Jet/Etmiss Data Quality coordinator, and will continue to oversee the development of monitoring software for the Jet/Etmiss and Jet trigger groups for the start of Run 3. This includes the migration of the software to thread-safe configurations that can run in the future multi-threaded reconstruction environment.

4.1 The fastNLO Project

Wobisch started the fastNLO project [8, 9] in 2005, together with collaborators T. Kluge (University of Liverpool) and K. Rabbertz (University of Karlsruhe), designed to provide very fast calculations of cross sections in hadron-induced processes. FastNLO is currently being used in the most recent global PDF analyzes, by the MSTW group (MSTW2008 [10, 11]), the CTEQ group (CT10 [12]) and also in the PDF analyses in Refs. [13, 14, 15]. The fastNLO team has also provided a world summary figure on inclusive jet production at different colliders for the PDG books in 2010 and 2012. In 2011, two collaborators, Daniel Britzger (MPI Munich) and Fred Stober (Karlsruhe University) joined the fastNLO project. Since then the fastNLO project has published version 2 of the code [32], which is a major update, with more flexibility in the data structures, and with additional features. The new data structures allow to implement calculations for different processes (e.g. diffractive jet production, which is used at HERA to determine the pomeron PDFs).

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