University of Oklahoma – High Energy Physics (OU-HEP)
DE-FG02-04ER41305

Patrick L. Skubic, PI
Homer L. Dodge Department of Physics and Astronomy
440 W. Brooks Street, Norman OK 73019
email: pskubic@ou.edu; phone: 405-325-3961 (ext 36329)

Final Report

DOE/Office of Science Program Office: Office of High Energy Physics
DOE/Office of Science Technical Contact: SC.HEPFOA@science.doe.gov

Task A: Experimental HEP Physics – P. L. Skubic, PI
and B. Abbott, P. Gutierrez, M. Strauss, co-PI's

Experimental Physics Investigations using Colliding Beam Detectors at Fermilab and the LHC

DØ at Fermilab

Profs. B. Abbott, P. Gutierrez (contact person), P. Skubic, and M. Strauss
Dr. P. Svoisky (RA) and H. Severini (RS)
A. L. Jayasinghe(GS)

ATLAS at the LHC

Profs. Skubic (contact person), B. Abbott, P. Gutierrez, M. Strauss,
Dr. A. Marzin (RA), Dr. M. Saleem (RA), Dr. H. Severini (RS)
Mr. G. Boyd (EE), Ms. S. Norberg (GS), Ms. C. Bertsche (GS),
Mr. D. Bertsche (GS), Mr. A.A. Hasib (GS), Mr. B. Pearson (GS) and Mr. C. Walker (UGS)

Task B: Theoretical HEP Physics – K. A. Milton, PI
email: milton@nhn.ou.edu; phone: 405-325-3961 (ext 36325)
H. Baer, C. Kao, and Y. Wang, co-PI's

Nonperturbative Quantum Field Theory and Particle Physics Beyond the Standard Model

Profs. H. Baer, C. Kao and K. A. Milton (contact person)
Dr. B. Altunkaynak (RA), Dr. K. J. Bae (RA), Dr. P. Parashar (RA), Dr. E. Abalo (RA)
Mr. P. McCoy (GS), Mr. D. Mickelson (GS), Ms. M. Padeffke (GS), Mr. H. Serce (GS)
Mr. K. Yang (GS), and Ms. P. Wickramarachchi (GS)

Theoretical Tools for Measuring Dark Energy

Prof. Y. Wang, Dr. S. Wang (RA), Ms. M. Dai (GS), Mr. M. D. Hemantha (GS)

July 2013

Contents

1 Introduction and Overview

The University of Oklahoma (OU) High Energy Physics (HEP) research group began as an experimental task in 1979. The theory task was initiated in 1986. In 1990, the OUHEP group partnered with Langston University (LU), an Oklahoma historically black college, to develop a collaborative HEP group at Langston. The group has been continually funded since 1980, with cumulative funding of about 15.7 (3.8) million dollars from DOE and 3.2 (0.8) million dollars from other external sources (NSF, SSCL, TNRLC, TAC, URIP, Oklahoma State Regents) for the experimental (theoretical) program to date, in addition to substantial internal University funding.

The OUHEP group is composed of four experimental faculty, three theorists, and one astrophysicist. This report describes our past and proposed experimental work (Task A) with the DØ collaboration at the Fermilab Tevatron and the ATLAS collaboration at the CERN Large Hadron Collider (LHC), our past and proposed efforts on HEP theory, and theoretical tools for measuring dark energy, (Task B).

Over the last few years, supplemental funding on the order of $100,000 per year above our base DOE grant has helped us reach our stated physics analyses goals and milestones. In addition, from 2004-2010 a DOE EPSCoR implementation grant established the Oklahoma Center for High Energy Physics (OCHEP) and allowed our program to expand, including the establishment of OU as a participating member of the ATLAS Southwest Tier 2 computing Center, as well as starting an experimental HEP group at Oklahoma State University (OSU). LU, OSU, and OU personnel are currently members of OCHEP and are collaborating on HEP research. The University of Oklahoma continues to provide 100% of the support for Horst Severini, a Ph.D. research scientist involved in HEP high performance computing, as a long-term commitment originally initiated as part of the EPSCoR cost sharing agreement.

The HEP Experimental group is composed of professors Patrick Skubic, Phillip Gutierrez, Michael Strauss, and Associate Professor Braden Abbott. While our experimental research has been fairly evenly divided between DØ and ATLAS over the last few years, with this proposal we will be concentrating our efforts on ATLAS. With the completion of our ongoing analyses on DØ and with a recent influx of new students, it is an ideal time for us to make a major shift to the ATLAS experiment. The phenomenal success of the LHC and the prospect of new discoveries and measurements at the LHC has brought a greater number of experimental HEP graduate students to OU than at any other time in our existence. The research program that we are proposing will benefit tremendously from this influx of students, five that will be ready to participate by the end of the current calendar year assuming funds are available for their long term participation. In addition, there are two students finishing up their Ph.D. within a year. We have a fantastic group of students working in experimental HEP at OU.

Our theory group is composed of Professor Howard Baer, an endowed Homer L Dodge professor, Professor Kimball Milton, a George Lynn Cross Research Professor, and Associate Professors Chung Kao and Yun Wang. Baer and Kao work closely with the HEP experimentalists since their research concentrates on high energy phenomenology, especially supersymmetry, oriented toward the physics starting to emerge from the Large Hadron Collider. Milton works primarily on nonperturbative quantum field theory. Wang develops theoretical tools to measure dark energy from galaxy clustering and supernova data, in support of the experimental research program in the measurements of dark energy. Our theory group currently has eight graduate students and five postdocs.

In this report we will describe our recent progress and the current status of our work. We first describe our group effort to show the cohesive nature of our work followed by individual sections which discuss specific research history, progress, and status for each PI.

2 Status of Research and Future Plans - Experimental Task A: DØ

2.1 The DØ Experiment at the Fermilab Tevatron

The University of Oklahoma high energy physics (OUHEP) group has been a member of the DØ collaboration at Fermilab for the past 18 years. During this period, we have participated in the upgrade of the detector, its operation, data handling, generation of Monte Carlo samples, and physics analysis. When we first joined DØ, we participated in the design, construction, installation, and commissioning of the silicon vertex tracker. This was followed by a period of many years during which we were one of the lead institutions responsible for the operation of the level 2 trigger. We have also had a lead role in the monitoring of data quality and at the present time are leading the "Common Samples Group" (CSG) through OU postdoc P. Svoisky. The primary responsibility of this group is to provide the final stage of the data and MC production, and to prepare data files for use in analysis by the members of the collaboration in the CERN ROOT format. The group also maintains and upgrades the standard collaboration ROOT based analysis software tools and performs accounting of the available data and MC files. In addition, the CSG maintains a webpage that provides information to the collaboration on the current status of data sets, MC samples, and software upgrades.

In addition to the service tasked described above, we have made major contributions to the algorithm groups. M. Strauss has been a major participant with the charged particle tracking group, which included a 2 year period as convener. Over the past three years, graduate student A. Jayasinghe, under the supervision of Gutierrez, has been an active participant in the determination of the final jet energy scale for the experiment. The detector response is evaluated for the central region of the calorimeter and is then propagated to all η regions with the appropriate weighting, since the energy response is heavily dependent on detector η. A. Jayasinghe has performed studies on the instantaneous luminosity and the run number dependence on η dependent corrections. These studies lead to the responses derived for the RunIIb-1, RunIIb-2, RunIIb-3, and RunIIb-4 data sets separately. In addition, A. Jayasinghe performed a number of closure tests in order to validate the Jet Energy Scale (JES) corrections.

Over the 18 year period of OU participation in DØ, OU faculty, post-docs, and students have contributed to numerous Run I and Run II peer reviewed publications as primary analyzers, through active involvement in the editorial board process and as conveners of some of the major physics analysis working groups. In what follows, we summarize recent analysis in which we have participated over the past three years in addition to providing outlines toward the completion of those in progress.

The OU group has contributed to the DØ B physics program in a number of different areas. B. Abbott has served as B physics convener. He and Gutierrez participated in the measurement of B_s mixing, which resulted in the first double sided limits on the mixing frequency, and Abbott has studied the X(3872), the Ξ_b^- and Ω_b baryons. Most recently B. Abbott has been studying CP violation using $B_s^0 \to J/\psi f_0(980)$ and $B_s \to J/\psi f_2'(1525)$ decays. P. Gutierrez has also played a major role in the B physics program through his editorial board work on the DØ CP violation measurements.

The OUHEP group also has significant expertise in the study of Quantum Chromodynamics (QCD), the theory of strong interaction between quarks and gluons. From 2010 to 2012, M. Strauss served as a co-convener of the DØ QCD physics working group responsible for all DØ QCD publications. While M. Strauss was co-convener of the QCD group, nine QCD analyses were published which ranks among the most productive years ever for the DØ QCD collaboration analysis as far as the number of papers published. M. Strauss and P. Svoisky have also worked on a measurement of the differential di-photon production cross section, which should be published soon. B. Abbott has contributed to the QCD program through his editorial board work (chairing the dijet invariant mass analysis). More details on M. Strauss and B. Abbott's contribution to QCD and B physics can be found in their individual research sections.

2.1.1 Top Physics

The OUHEP DØ group has contributed to a number of top quark physics analyses over the past years. These include the search and discovery of single top quark production, search and limits on charged Higgs in top quark decays, and the $t\bar{t}$ production cross section measurement in the $\tau +$ jets final state. Members of the OUHEP DØ group (faculty member P. Gutierrez and graduate student A. Jayasinghe) have and are contributing to two top quark physics analysis. These are the $t\bar{t}$ production cross section measurement in the $\tau +$ jets final state and the top quark mass measurement in the all hadronic jets final state. The second of these analysis became A. Jayasinghe's Ph.D. dissertation.

$t\bar{t}$ Production Cross Section

The $t\bar{t}$ production cross section has been measured in various final states including $t\bar{t} \rightarrow \ell^{\pm} +$ jets, $t\bar{t} \rightarrow \ell^{\pm} + \ell^{\mp}$, $t\bar{t} \rightarrow \tau^{\pm} + \ell^{\mp}$, and $t\bar{t} \rightarrow$ all jets, where $\ell^{\pm}$ represents either an $e^{\pm}$ or $\mu^{\pm}$. In addition, former OU graduate student S. Hossain, under the supervision of P. Gutierrez, published the measurement of the $t\bar{t}$ production cross section in the $t\bar{t} \rightarrow \tau +$ jets final state with semihadronic τ decays using ≈ 1 fb^{-1} of integrated luminosity in Physical Review D Rapid Communications (2010) [1]; this is the first published $t\bar{t}$ production cross section measurement in this final state. The measurement of the $t\bar{t}$ production cross section in the $\tau +$ jets final state completes the production cross section measurement in all possible final states allowing for the self consistent check of the SM top quark decays. Extensions of the SM allow the top quark decay rate to tau leptons to be larger than allowed by the SM. For example, if a second Higgs doublet exists, in some regions of the associated parameter space the top quark can decay to charged Higgs bosons, which can subsequently decay to tau leptons. This would lead to an increase in the number of tau leptons produced in top quark decays.

P. Gutierrez is participating in the update to this analysis using ≈ 5 fb^{-1} of integrated luminosity. The procedure closely follows that of the 1 fb^{-1} measurement with the following improvements, a factor five increase in statistics, the use of the new multijet triggers that yield a 10% improvement in signal efficiency, the use of vertex confirmed jets, the implementation of the tau energy scale, reduction of the electron contamination to $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{0}\nu_{\tau}$ decays, and extensive optimization of the event topological neutral network. The analysis is currently under review by the DØ top group and will move forward toward publication by the end of this year.

Top Quark Mass

Since the top quark is the heaviest elementary particle, it results in large contributions to the electroweak radiative corrections to the W boson mass and provides a constraint on the mass of the Higgs boson. Improvements in the accuracy of the mass measurement are important for precision tests of the SM and for the investigation of its extensions. It is important to perform the mass measurement in all final states in order to reduce the different possible systematic effects that may appear in each channel. For example, the dilepton final state has little background, but there are two energetic neutrinos that cannot be reconstructed. On the other hand, the all hadronic final state can be fully reconstructed and has a significantly larger final state branching ratio, but is subject to very large backgrounds. Combining these two measurements with the lepton plus jets final state provides the best measurement of the top quark mass.

As mentioned earlier, A. Jayasinghe with his adviser P. Gutierrez, are performing a measurement of the top quark mass in the all hadronic final state using ≈ 10 fb^{-1} of integrated luminosity;

the full DØ dataset. When completed, this will be the first published run II DØ top quark mass measurement in this final state; a DØ run I measurement was published in 2005 and several run II measurements have been published by CDF in this final state. The major technical challenge in performing this measurement is the reduction of the multijet background which, after trigger selection, is 3 orders of magnitude larger than signal. Since at the present time there are no adequate Monte Carlo models of multijet QCD events, the background model is built from data in a manner similar to the DØ published all hadronic final state measurement of the $t\bar{t}$ production cross section. The signal consists of events with six or more jets, two of which are tagged as b-jets. Therefore, the background model must have the same characteristics with a minimal number of signal events. This is accomplished by starting with events having five jets with two of these being tagged as originating from a b quark, and adding an additional jet from a sample of six jet events with similar kinematics as the leading five jets. This maintains the correlation between the b-jets in the events and reduces the likelihood of real $t\bar{t}$ events in the background sample. At the present time, the background model provides a good representation of the data, even though we continue to refine it.

To extract the top quark mass, we use the template method. We parameterize the mass information derived from the minimization of a kinematic fitter that includes both the dijet mass (W) and trijet mass (t quark) and is performed as a function of the jet energy scale.

The data sample used in this analysis is selected from three and four jet trigger events using a set of loose selection criteria to reduce the background. The sample is further reduced using a boosted decision tree discriminate, which at the moment is built from 30 variables that have a weak dependence on mass. The minimum negative log likelihood is calculated for the optimal fit between data and each mass template and a similarly derived template for background. The minimum of the negative log likelihood of these fits is used to extract the mass.

A preliminary measurement of the top quark mass has been used for A. Jayasinghe's dissertation. This measurement lacked the final jet energy scale and several of the systematic uncertainties have to be recalculated due to improved understanding of b-tagging, the trigger efficiency, and the effect of higher order corrections on the measurement. In addition, in order to decrease the statistical uncertainty on the measurement, a measurement using a single b-tag sample will be performed and combined with the two b-tag measurement.

2.1.2 QCD

Di-Photon

The study of direct di-photon production provides an important test of the predictions of perturbative QCD and the methods of soft gluon resummation. The process occurs through $q\bar{q}$ annihilation at leading order and through a box diagram at next-to-leading order. In addition, direct di-photon production can be a significant source of background in searches for non-SM phenomena both at the Tevatron and the LHC. Therefore, the precise measurement and theoretical understanding of the various kinematic variables associated with direct di-photon production are important for future non-SM searches.

The DØ collaboration previously performed the measurement of the direct di-photon production differential cross section in 4.2 fb^{-1} integrated luminosity in the pseudo-rapidity region $|\eta| < 0.9$. The results of this analysis, published in PLB [2], were compared to theoretical expectations using the predictions of the Monte Carlo generators DIPHOX and RESBOS, with RESBOS giving better agreement but neither describing the data satisfactorily.

OU postdoc P. Svoisky, with contributions from M. Strauss and P. Gutierrez, is performing a new measurement of direct di-photon production using 8.6 fb^{-1} of integrated luminosity. This measurement will extend the pseudo-rapidity region to $|\eta| < 2.5$ and the restriction $M_{\gamma\gamma} > p_T^{\gamma\gamma}$, which was used to suppress fragmentation photons ($q \to \gamma X$) in the published analysis, has been removed and replaced with an improved photon isolation requirement. In addition, the acceptance modeling has been improved by using the SHERPA event generator processed through a full GEANT simulation of the DØ detector; in the published result this was done using the RESBOS event generator and a parameterized detector simulation. Finally, the photon energy scale has been improved through the use of improved modeling in GEANT. This analysis has now been published.

Using the same dataset as the di-photon analysis, P. Svoisky performed preliminary studies of $p\bar{p} \to \gamma\gamma + 2\,\text{jets}$ to confirm that the statistics in the dataset are sufficient to perform a cross section measurement in this channel. The motivation for this analysis is the study of multiple partonic interactions [3], which can lead to improvements in the description of the underlying event in event generators such as PYTHIA [4]. Two previous analysis have been performed that study multiple partonic interactions using $\gamma + 2(3)\,\text{jets}$ [5, 6]. It is expected that $\gamma\gamma + 2\,\text{jets}$ is a cleaner channel for this study. Having concluded this to be a clean channel from our preliminary studies, we are proceeding with this analysis.

3 Status of Research and Future Plans - Experimental Task A: ATLAS

3.1 Introduction

Four OU faculty members (B. Abbott, P. Gutierrez, P. Skubic, and M. Strauss) and an adjunct faculty member from Langston University (J. Snow) are working under the OU byline on the ATLAS experiment. In this proposal, funds for Prof. Snow are requested as a sub-contract with Langston University.

For many years, the OU group has been involved in the three major areas of experimental HEP research: Hardware, Computing, and Analysis. We believe it is important for our group and our students to have experience in all three of these vital areas. We, therefore, have taken a three-prong approach to our ATLAS research. Our hardware effort has been focused on the pixel detector with our engineer, G.R. (Rusty) Boyd, taking a leading role in the design and construction of the Insertible B-Layer (IBL). Our computing effort involves our Tier 2 center located at OU with our computing experts, H. Severini, J. Snow, and C. Walker ensuring its efficient and stable operation. Our physics analysis effort has been led by our faculty members and has been focused on the discovery of the Higgs Boson and measuring its properties, searches for Supersymmetric particles and measurements of the top quark properties.

Some contributions of OUHEP to the ATLAS collaboration have included the following projects:

(1) We have been analyzing data from the ATLAS detector, making contributions primarilly to $t\bar{t}$ cross section measurements, and SUSY/Higgs searches. Currently, P. Skubic has been the U.S. ATLAS physics forum co-convener for top physics and B. Abbott has been the U.S. ATLAS physics forum convener for QCD.

(2) We have developed tools for tagging jets containing b quarks in collaboration with UTA and OCHEP institutions.

(3) We designed, produced, assembled, and tested the flex-hybrid circuit that provides interconnections on all pixel modules. Thirty-five hundred circuits were assembled and tested in our lab at OU and used in the construction of the pixel detector.

(4) OCHEP universities and UTA have partnered together to create the Southwest Tier 2 Computing Center. Our local Linux cluster currently has 844 cores and provides significant dedicated computing resources for ATLAS production and analysis.

(5) We contribute to the ATLAS Grid testbed. We have tested and set up utilities which allow

remote job submission and managmenet. We have a Tier 3 cluster of Linux PC's with over 100 TB of storage for local and remote analysis.

(6) We have joined with Ohio State University, SLAC (Stanford Linear Accelerator Center) and Oklahoma State University (OSU) in an R&D project to develop radiation-hard optical link components for the upgrade of the ATLAS pixel detector. We are collaborating with OSU on optobox construction for the IBL that will be installed inside the existing pixel layers during the LHC 2013 shutdown. Funding for this project has been obtained through an NSF MRI grant.

Due to the exciting physics coming from ATLAS, we have seen an increase in the number of graduate students wanting to be involved in ATLAS. We currently have 5 graduate students working on experimental ATLAS research, the most our group has ever had in its 33 years. With all of our faculty, students, and post-docs transitioning to 100% of their research time devoted to ATLAS over the next year, our group will be in a position to make major advances and contributions to the ATLAS collaboration. To effectively do research and make an impact within the collaboration, it is imperative that each of our students reside at CERN for at least two years so they can be directly involved in the installation, testing, and commissioning of the IBL, and in other proposed hardware projects at CERN. Being resident at CERN will also allow our students to directly work with the other reseachers at CERN, allowing them to complete their Ph.D. research in a timely manner. In the past several years we have had 2 students located at CERN who have recently finished their thesis research (R. Meera Lebbai, Dilip Jana). We currently have 4 graduate students (S. Norberg, A.A. Hasib, D. Bertsche, C. Bertsche) located at CERN and 1 other (B. Pearson) who are pursuing full time research on CERN data in 2013.

The total OUHEP group on ATLAS consists of OU faculty members, 1 adjunct faculty member at Langston, 2 current and 1 future post-doctoral researcher who will be replacing P. Svoisky, 5 graduate students, 1 research scientist/computer specialist funded entirely by the university (H. Severini), 1 undergraduate part-time IT specialist funded through Tier 2 project funds (C. Walker), and 1 Electrical Engineer, Mr. Boyd, who was responsible for the design and layout for the pixel module interconnection circuit and is currently residing at CERN coordinating the hardware efforts of our group.

3.2 ATLAS Analysis

The OUHEP experimentalists have participated in a large number of physics analysis during the years that they have been members of the CLEO, DØ and ATLAS collaborations. Over the past few years, the OUHEP group has performed measurements in the subfields of SUSY searches, top quark properties, SM and non SM Higgs boson searches, QCD and b quark measurements using data collected with the DØ and ATLAS detectors. In addition, the OUHEP group has gained valuable experience in τ lepton and b jet identification, jet energy scale measurements and trigger efficiency studies. During the period of time the group has participated in the DØ collaboration, the group has been very successful, with each faculty member working in a different physics area. However, because of the large membership of the ATLAS collaboration, the group plans to have a much more focused physics analysis effort. The overall focus of the work will be the study of the electroweak symmetry breaking sector, which will include top physics, the measurement of Higgs boson properties and search for non-SM Higgs bosons and SUSY phenomena, with all faculty contributing to all areas applying their expertise to each specific analysis.

3.2.1 SUSY

Searches for SUSY have been ongoing for many years and have yet to uncover any evidence of particles not contained in the SM. However, even with this lack of experimental evidence, strong motivation for SUSY makes it a very compelling theory. An important motivation for SUSY third generation searches is that to avoid "unnatural" fine-tuning in the Higgs sector, the superpartners of the top quark ($\tilde{t}$, stop) must have relatively low masses. In addition, SUSY can allow for unification of the gauge couplings at high energies. In the framework of an R-parity conserving minimal supersymmetric extension of the SM (MSSM), SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable, providing a possible candidate for dark matter. In addition, OU theorist H. Baer has been working on the implications of supersymmetry and has developed SUSY scenarios based on recent data from HEP and cosmology. Thus our SUSY searches allow a tight connection between our theory and experimental group.

We (Abbott, Skubic, Marzin, Norberg) have primarily been focusing our efforts on studying the third generation of squarks. Fine tuning considerations require that the superpartner of the gluon ($\tilde{g}$, gluino) is not heavier than about 5 TeV due to its contribution to the radiative correction of the stop mass. Furthermore in the MSSM, the scalar partners of the right-handed and left-handed quarks, $\tilde{q}_R$ and $\tilde{q}_L$, can mix to form two mass eigenstates $\tilde{q}_1$ and $\tilde{q}_2$. The mixing effect is proportional to the masses of the SM fermion partners and can therefore be large for the third generation. This may lead to the lightest scalar bottom (sbottom, $\tilde{b}_1$) and scalar top (stop, $\tilde{t}_1$) mass eigenstates being much lighter than the other squarks. As a consequence, $\tilde{b}_1$ and $\tilde{t}_1$ could be produced with relatively large cross sections at the LHC, either directly in pairs, or through $\tilde{g}\tilde{g}$ production followed by $\tilde{g} \to \tilde{b}_1 b$ or $\tilde{g} \to \tilde{t}_1 t$ decays. Depending on the SUSY particle mass spectrum, the cascade decays of gluino-mediated and pair-produced sbottoms or stops result in complex final states consisting of missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$), several jets, among which b-quark jets are expected, and possibly leptons.

In particular, H. Baer has developed an SO(10) model [7] which predicts low gluino masses (300-500 GeV) and heavy squarks. We tested two SO(10) models (Higgs splitting(HS), and D-term splitting(DR3)) and excluded gluino masses of less than 650 GeV for the DR3 model and 620 GeV for the HS model [8]. The results of this analysis have highly contrained the parameters of these models, so H. Baer has redirected his research and has begun to focus more on "natural SUSY" models.[9]

In addition to the SO(10) models, we have studied other SUSY scenarios. A first analysis has been performed with the data sample of 35 pb^{-1} recorded in 2010 at a center-of-mass energy of $\sqrt{s} = 7$ TeV. Both 0- and 1-lepton channels have been investigated and the results have been interpreted in terms of 95% C.L. exclusion limits in several SUSY scenarios. The results of our analyses were used to calculate 95% C.L. exclusion limits in the MSUGRA framework with different values of tanβ and A_0. This analysis has been published in Physics Letters B [10]

These 0- and 1-lepton analyses have been updated with respectively 0.83 and 1.03 fb^{-1} and published as ATLAS public conference notes [11].

A search for direct sbottom pair production has then been performed with 2.05 fb^{-1}. This analysis assumes sbottom decay into a bottom quark plus a neutralino (LSP) with a branching ratio of 100%. Scalar bottoms were searched for in events with exactly 2 b-tagged jets and large $E_{\mathrm{T}}^{\mathrm{miss}}$, and several signal regions were defined with different cuts on the boost-corrected contransverse mass of the 2 jets. The results were interpreted in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0})$ plane and sbottom masses up to 390 GeV were excluded for neutralino masses below 60 GeV. This analysis has been published in PRL [12].

An update of the 0- and 1-lepton analyses targeting gluino-mediated sbottom and stop pair production has been done with 2.05 fb^{-1}. The results have also been interpreted in the context of several SUSY scenarios and the exclusion limits are significantly improved with respect to the previous limits. This analysis has been published in PRD [13] where A. Marzin is one of the editors of this paper.

Finally, a new analysis has been performed to extend the search for gluino-mediated $\tilde{b}_1$ and $\tilde{t}_1$ production at ATLAS. This analysis comprises the full 2011 dataset of 4.7 fb^{-1} and adopts an improved selection that requires large $E_{\mathrm{T}}^{\mathrm{miss}}$, no reconstructed electron or muon and at least three jets identified as originating from b-quarks (b-jets) in the final state. This analysis has been published in EPJC (Arxiv:1207.468).

Results are interpreted in simplified models where sbottoms or stops are the only squarks produced in the gluino decays, leading to final states with 4 b-quarks. In the context of the gluino-sbottom model, a $m_{\tilde{g}}$ below 1000 GeV is excluded for sbottom masses up to about 870 GeV in the most conservative hypothesis, $-1\sigma^{SUSY}_{Theory}$. This extends by approximately 100 GeV the limits derived in the same scenario by the previous analysis performed with 2 fb^{-1} and is complementary to the search for direct sbottom pair production. Gluino masses below 1020 GeV are excluded for neutralino masses up to about 400 GeV, improving the previous ATLAS limits by approximatively 100 GeV. In the framework of the gluino-stop model, gluino masses below 820 GeV are excluded for stop masses up to 640 GeV, extending the previous ATLAS limits by approximately 150 GeV. In the *Gtt* model, gluino masses below 940 GeV are excluded for $m_{\tilde{\chi}_1^0} < 50$ GeV while neutralino masses below 320 GeV are excluded for $m_{\tilde{g}} = 800$ GeV. This search extends the exclusion limits obtained with the ATLAS multi-jet analysis carried out with the same data set by approximatively 60 GeV. The limits derived with this analysis are also more stringent than the limits recently released by the CMS Collaboration in the same scenarios and carried out with 5 fb^{-1} of data.

SUSY prospects:

Our work on SUSY has been noticed by the ATLAS collaboration and our postdoc A. Marzin has been co-convener of the SUSY subgroup "Gluino mediated sbottom/stop pair production and direct sbottom pair production". Recently A. Marzin has been appointed convener of the SUSY background forum. The main task is to provide the background MC samples for the SUSY group, to maintain the common SUSY code for the object reconstruction and systematics uncertainties and to supervise the methods used in the SUSY group to estimate the backgrounds and determine the systematic uncertainties on these estimations.

We (Abbott, Skubic, Marzin, Norberg, D. Bertsche) are working on the extension of the current grids and on the generation of new signal grids. We are updating the multi-b-jets analysis with the data recorded in 2012 at a center-of-mass energy of $\sqrt{s} = 8$ TeV. The analysis has been improved by adding new signal regions and by extending them to binned distributions in a combined likelihood fit to increase the statistical power of the analysis. The shapes of specific kinematic distributions in the control regions are also being used to constrain some of the main systematic uncertainties of the analysis. We alos have extended our searches to additional SUSY models, such as $\tilde{b}_1 \rightarrow t + \tilde{\chi}_1^{\pm}$ or $\tilde{b}_1 \rightarrow b + \tilde{\chi}_2^0$ followed by $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + X$, $X = Z^*/h^*$ or Z or h. Finally, we plan to include in our analyses specific signal regions to increase our sensitivity to low mass splitting regions where the impact of initial state radiations (ISR) on the signal acceptance becomes important. This is especially relevant for sbottom pair searches with $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$ where we expect soft jets and low $E_{\mathrm{T}}^{\mathrm{miss}}$ for large neutralino masses.

Currently simplified models are only defined for $\tilde{t}_1$ and $\tilde{b}_1$ since their cross sections are always larger than $\tilde{t}_2$ and $\tilde{b}_2$. We are extending the number of simplified models to also study $\tilde{t} \rightarrow t + \tilde{\chi}_2^0$ and $\tilde{b} \rightarrow b + \tilde{\chi}_2^0$. This will allow some sensitivity for the 3 b-jet analysis due to the Higgs or Z decay into $b\bar{b}$. Additionally simplified models are also being generated with mixed decays of the $\tilde{t}/\tilde{b}$ (i.e one $\tilde{t} \rightarrow t + \tilde{\chi}^0$ and the other $\tilde{t} \rightarrow b + \tilde{\chi}^{\pm}$.)

The LHC data has greatly constrained the parameter space for MSUGRA/CMSSM models and now higher mass regions can be explored. H. Baer has proposed a search for SUSY where chargino-neutralino production is predominant. The decay would be primarily to WZ plus missing

E_T. We (Strauss, Bertsche, Skubic) are investigating such SUSY models and decay modes in the 7 and 8 TeV data and developing the tools to continue to look for SUSY signatures in the high energy data.

We have contributed to a Moriond 2013 paper that includes an update of the 0-lepton + ≥ 3 b-jets + $E_{\rm T}^{\rm miss}$analysis using the full 2012 data set at 8 TeV. Then several improvements of this analysis are foreseen in 2013 during the shutdown of the LHC. First, it has been shown during the optimization of this analysis that the 0-lepton and 1-lepton + ≥ 3 b-jets analyses have a similar sensitivity to the gluino mediated stop pair production. Because of lack of manpower, and since the 0-lepton channel is the only one which is also sensitive to $\tilde{b}$ decay into $b+\tilde{\chi}^0$, we only performed the analysis in the 0-lepton channel with the full 7 TeV data-set. However, we have performed the analysis in both 0- and 1-lepton channels with the full 8 TeV data set and to combine them to significantly improve our sensitivity to gluino mediated stop pair production. We also plan to combine these analyses with the di-lepton same sign plus b-jets analysis and the three leptons analysis which will be done in parallel by other groups. Then we plan to use the data of the delayed streams which are recorded with softer trigger thresholds at the event filter to increase our sensitivity to compressed spectra scenarios. The events recorded in the delayed streams will be processed with a lower priority than the events of the standard streams, but will allow us to apply softer kinematic cuts offline to increase the signal acceptance at low mass splitting where softer jets and $E_{\rm T}^{\rm miss}$are expected. Furthermore, we plan to define new signal regions dedicated to very low mass splitting between the $\tilde{b}$ and the $\tilde{\chi}^0$ in the context of $\tilde{b}$ decay into $b+\tilde{\chi}^0$ to exploit the presence of an additional ISR jet. Studies are ongoing to generate such signal samples with ISR jets using the MadGraph program. Finally, we are extending the number of simplified models to look at direct $\tilde{t}$ and $\tilde{b}$ production with $\tilde{t} \rightarrow t+\tilde{\chi}_2^0$ and sbottom decay into bottom plus neutralino. We have shown that we have some sensitivity to these models with the 3 b-jets analysis due to Higgs or Z decay into $b\bar{b}$.

The sensitivity to SUSY particles will be increased significantly when the pp centre-of-mass energy will be increased to close to 14 TeV in 2015. Naturalness arguments require the stop to be relatively light, typically below 1.5 TeV, which implies that the gluino is not heavier than about 5 TeV due to its contribution to the radiative corrections of the $\tilde{t}$ mass. By isospin, the lightest $\tilde{b}$ is also required to be relatively light. We expect to be sensitive to such masses with the first hundreds fb^{-1} of data at 14 TeV, which will be an important milestone for SUSY searches.

3.2.2 Top Quark Physics

During the period of time that the OUHEP group has been a member of the ATLAS collaboration, we have and are in the process of performing several top quark analyses. These include the $t\bar{t}$ production cross section measurements in the $\ell^{\pm}+$jets and $\tau+$jets final states, with $\ell^{\pm}$ either an $e^{\pm}$ or $\mu^{\pm}$, and the $t\bar{t}+$jets production cross section, which we plan to use as the starting point for a charged Higgs search and possible future measurement of the tH Yukawa coupling.

One of the important priorities of the ATLAS collaboration was to establish a signal for the top quark using the first datasets. Given the OUHEP group's interest in the measurement of top quark properties, we have been a major contributor to these ATLAS analysis. Once a signal for $t\bar{t}$ was established, an important measurement is its production cross section in different final states. This is an important test of QCD and the evolution of the parton structure functions from lower energy measurements. In addition, since the quantity measured is $\sigma_{t\bar{t}} \times$ BR, a comparison of the different final states can provide a test of non-SM top quark decays.

Using 2.9 pb^{-1} of integrated luminosity, the OUHEP group contributed to the first ATLAS measurement of the $t\bar{t}$ production cross section in the $\ell^{\pm}+$jets and the $\ell^{\pm}\ell'^{\mp}+$jets final states, where $\ell^{\pm}$ represents either a $\mu^{\pm}$ or an $e^{\pm}$ [14]. The measurement was performed using an event counting procedure after a number of selections were applied to the data, and using a data derived background estimate. The primary contribution by the OUHEP group was in the b identification [15] and the study of $\ell^\pm$ fake rates [16], with OU postdoc M. Saleem taking the lead role for OU and contributions by OU faculty P. Skubic.

Before the start of data taking, the OUHEP group, in collaboration with OSU, carried out a detailed study of the extraction of $t\bar{t}$ signal in the $\ell^\pm$ + jets final state using a multivariate technique [17]. The OU contribution to this work was performed by D. Jana under the supervision of OU faculty P. Skubic, B. Abbott, and P. Gutierrez and help from OU postdocs M. Saleem, and G. Huang. The results of this study formed the basis of the 2012 published result [18]. This result used 35 pb^{-1} of integrated luminosity and combined two separate multivariate analysis, one that did not use b identification, which OU performed in collaboration with OSU. The second analysis required b identification. The resulting cross section measurement was found to be consistent with the predictions of NLO QCD [19].

Recently, the top quark production cross section measurement was extended to a measurement of $pp \to t\bar{t}+$jets. At the LHC, NLO QCD predicts an increase in $t\bar{t}$ events produced in association with additional jets ($pp \to t\bar{t}$ + jets) relative to the Tevatron. A comparison of the measured cross section and differential cross sections for this process relative to theoretical predictions can allow one to set limits on the pointlike behavior of the top quark and also on anomalous top quark gluon couplings. In addition, given the importance of measuring the properties of the Higgs boson, $pp \to t\bar{t}+$jets is predicted to be a large background to $pp \to t\bar{t}H$, which provides a direct measurement of the t-H coupling.

Using 4.7 $\text{fb}^{-1}$of integrated luminosity collected by the ATLAS detector at $\sqrt{s} = 7$ GeV, a preliminary measurement of the production cross section of $pp \to t\bar{t}$ + jets in the $\ell^\pm$ + jets final state was presented at ICHEP 2012 [20]. The result is compatible with NLO QCD predictions. This measurement is being performed in collaboration with the OSU group with OU postdoc M. Saleem taking the lead roll for our group.

Finally, OU postdoc Saleem in collaboration with the OSU group is in the process of performing a measurement of the $t\bar{t}$ production cross section in the $\ell^\pm$ + jets final state using 5.8 $\text{fb}^{-1}$of integrated luminosiy at $\sqrt{s} = 8$ TeV. The primary remaining issue in this analysis is the measurement of the ATLAS jet energy scale and its inclusion in this analysis. If all goes as foreseen, the analysis will be submitted later this year (2013).

The $pp \to t\bar{t}+$jets analysis provides a starting point for further studies. For example, requiring two of the additional jets to be $b\bar{b}$ can signal the presence of $pp \to t\bar{t} + H$, which is expected to have a production cross section of ≈ 0.13 pb at $\sqrt{s} = 8$ TeV and ≈ 0.6 pb at $\sqrt{s} = 14$ TeV. This final state allows for a direct measurement of the t-H Yukawa coupling, which according to the SM model is expected to be $g \approx 1$.

Our current plans are to continue our strong collaboration with the OSU HEP group and extend the analysis to a search for high mass charged Higgs ($H^\pm$), an area of OU expertise given Gutierrez's past work on low mass $H^\pm$. Taking the lead role on this analysis will be OU postdoc Saleem. The process that is being considered is $pp \to tbH^\pm$ with $H^\pm \to tb$, which then leads to $pp \to t\bar{t} + b\bar{b}$. This is the same final state as $t\bar{t}H$ and allows us to gain expertise in this channel. The model that is being considered assumes MSSM, but the confidence level limits will be set in model independent manner on the tH^+b coupling, which occurs both in the production and decay Feynman diagrams. The unique signature in these events is four b quarks in the final state and a large invariant mass tb combination. We estimate that we will be able to exclude a mass region from approximately 200 GeV to 500 GeV.

Continuing work started at the Tevatron by Gutierrez, the OUHEP group has begun a collaboration with Albany, LTU, and NIU, to work on the $t\bar{t} \to \tau$ + jets channel. This channel is unique in that the four Fermions of the third generation all participate in this process. In addition, since the three charged Fermions of the third generation have the three largest masses, they also have the largest coupling to the Higgs boson so provide the best probe of the electroweak symmetry breaking sector. A number of models have been proposed that modify the $t\bar{t} \rightarrow \tau + \text{jets}$ channel [21, 22].

Two ATLAS $t\bar{t} \rightarrow \tau + \text{jets}$ analyses are currently in progress with OUHEP participation (Gutierrez supervising OU graduate student Hasib, also participating are OU faculty Abbott and Skubic, and OU postdoc Saleem). The first analysis uses the 2011 dataset and the second uses the 2012 dataset and are directed at the measurement of the $t\bar{t}$ production cross section. Both analyses can then be used to set limits on non-SM processes using ratios of the measured $\sigma_{t\bar{t}} \times \text{BR}$ for $t\bar{t} \rightarrow \tau + \text{jets}$ relative to other final states.

3.2.3 Higgs

The Standard Model and the Higgs Boson

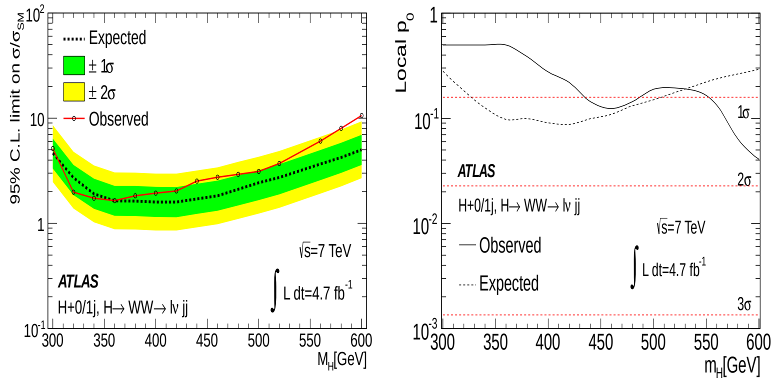
The ATLAS and CMS experiments at CERN have recently presented evidence for a new particle with a mass $\approx$ 126 GeV and having properties that are consistent with the SM Higgs boson. This opens up an new area of research, that of studying the properties of the new particle. The OUHEP group has already been participating in the Higgs search, with graduate student D. Jana and his adviser P. Skubic performing two searches for a Higgs boson with mass $>$ 200 GeV in the $H \rightarrow WW^{(*)} \rightarrow \ell^{\pm} + \nu + 2\,\text{jets}$ final state. The OUHEP group plans to participate in this research with an emphasis on the SM particle Yukawa couplings to the Higgs boson.

During the summer of 2011, Jana contributed to the analysis of ≈ 1 fb^{-1} of integrated luminosity in a search for the Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow \ell^{\pm} + \nu + +2\,\text{jets}$ final state. For $M_H \gtrapprox 160$ GeV, the dominant standard model decay mode is $H \rightarrow WW^{(*)}$, therefore, this channel was used to search for a high mass Higgs Boson. Since the W has leptonic and hadronic final states, there are two possible final states that can be investigated, $H \rightarrow \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$ and $H \rightarrow \ell^+ + \nu + 2\,\text{jets}$; the $H \rightarrow 4$ jets is overwhelmed by QCD background. Jana pursued the $\ell^{\pm} + \nu + 2$ jets final state, which has the advantage of being able to reconstruct the H mass using a kinematic constraint to estimate the component of the neutrino momentum along the beam axis. Since no evidence for signal was observed, 95% CL limits were set in the mass range 250 GeV to 600 GeV. The best sensitivity is reached for $m_H = 400$ GeV, where the 95% CL upper bound was 2.7 times the SM cross section prediction for $H \rightarrow WW^{(*)}$. The results of this analysis were published in PRL [24]. In addition, Jana presented the results of this analysis in the poster session at Lepton Photon 2011 in Mumbai, where he was awarded the prize for the best poster.

Using the full 2011 integrated luminosity (4.7 fb^{-1}) recorded by the ATLAS detector, the results on $H \rightarrow WW^{(*)}$ have been updated with OU graduate student Jana taking a leading role. Since again no evidence of signal was observed, a 95% CL upper bound on the production cross section $pp \rightarrow H \rightarrow WW^{(*)}$ was set for the m_H in the range 300 GeV to 600 GeV, with the best sensitivity achieved for $m_H = 400$ GeV corresponding to 1.9 (1.6) times the SM cross section for $H + 0\,\text{jets}$ ($H + 1\,\text{jets}$), see Fig. 1. The results of this analysis have been published in PLB [25].

Higgs Analysis

Given the discovery of a particle with SM Higgs properties at a mass $\approx$ 126 GeV, our plan is to study its properties using our past experience in t quark physics, τ lepton, jet physics, and b quark jet identification. Given that the BR($H \rightarrow WW^{(*)}$) has the second largest H branching ratio, we (M. Strauss, B. Pearson) will continue with the $H \rightarrow WW^{(*)}$ analysis for the full 2012-2013 dataset, but refocus the analysis to $m_H = 126$ GeV. Even though this channel was used in the discovery, we plan to focus on the measurement of the W-H coupling, which is $\propto M_W^2$. To



(a) (b)

Figure 1: (a) The expected and observed 95% CL upper limits on the Higgs boson production cross section divided by the SM prediction. The figure shows the combination of $H + 0j$ with $H + 1j$ limits. For any hypothesized Higgs boson mass, the background contribution used in the calculation of this limit is obtained from a fit to the $m(\ell\nu jj)$ distribution. The dark (green) and light (yellow) bands show the $\pm 1\sigma$ and $\pm 2\sigma$ uncertainties on the expected limit. (b) Local p_0 for the SM Higgs boson search in the $H + 0/1j$ channel. The dashed line shows the expected p_0 value for a Standard Model Higgs boson as a function of its mass.

decouple this final state channel from the production mechanism, we plan to combine this with $pp \to H \to ZZ^{(*)}$, which has a coupling $g \propto M_Z^2$. The ratio of $\sigma \times$ BR is then $\propto M_W^2/M_Z^2$ to leading order. This measurement fits in with the recently created ATLAS Higgs working group to explore the properties of the newly discovered Higgs boson. We will work within this group. We (Strauss, Pearson) in collaboration with Skubic and Walker have used this mode to search for higher mass non-standard model Higgs Bosons. This search is important as more data is collected and signals with lower cross sections may appear, and again, when the LHC energy is increased.

3.3 ATLAS Hardware

3.3.1 Introduction

The OU group has a long history of working on silicon detector technology. OU pioneered the development and use of silicon microstrip detectors for use as tracking detectors in HEP experiments. Our group (M. Strauss, P. Gutierrez) was heavily involved in the production and testing of the silicon microstrip detectors for the DØ SVX detector. Detector quality was tested at OU before assembly and fabrication at Fermilab. We (P. Skubic, G. Boyd) performed similar silicon detector tests for the CLEO III experiment at the CESR facility at Cornell University. We also developed high density flexible interconnects for use with silicon detectors for CLEO III. Prof. Skubic and Mr. Boyd worked closely with other scientists and engineers to achieve a specification for a reliable, low mass, high density interconnect. In the end, nearly one million successful wire bonds were made in the CLEO III silicon tracker, most of which were made on these innovative flexible interconnects. The advances pioneered in this collaboration led us to the opportunity to design and produce a much more demanding design needed for ATLAS.

OU joined the ATLAS Pixel Detector team in 1997 and Boyd and Skubic shared development responsibilities. Four prototype generations of flexible Printed Circuit Boards (Flex Hybrids), used to connect the 17 ICs and pixel sensor that comprise a Pixel module, were designed, constructed, and tested. We guided four "generations" of physics, engineering graduate, and undergraduate students through design, verification, qualification, production and quality control of over 3500 assembled and tested Flex Hybrids.

At that time, OU completed and tested the first working full Pixel module and completed construction and equipping of a 244 sq. ft. clean room for micro-electronics. Capabilites include automated, computer vision controlled wire bonding, O_2 plasma cleaning, an automated micro-probe station and many other machines for R&D and production. OU pioneered in the application of aggressive new technologies by forming critical partnerships in emerging technologies.

In addition to his design team leadership roles, Mr. Boyd serves in several other capacities that advance multiple projects within ATLAS:

1) **ATLAS Laser Safety Officer** - Besides the lasers in the Optoboxes for the IBL, there are other, more hazardous systems, installed and in R&D in ATLAS facilities.

2) **SR1 TSO** - The SR1 facility at CERN was built by the ATLAS inner detector collaboration and houses a 700 m^2 cleanroom. The Territorial Safety Officer at CERN is responsible for organizing and supervising the application of the CERN Safety Instructions to this facility, its contents, activities and personnel. For SR1, this is a critical position, as construction of all the ATLAS Inner Detector takes place in this facility, in addition to housing systems and resources for the LHC and the ATLAS Liquid Argon Calorimeter. SR1 is also host to ATLAS Inner Detector R&D, training and DAQ development. The R&D includes lasers, cooling systems and the SONAR Gas analysis project (to which Mr. Boyd has also contributed), in addition to small detector pieces of IBL, Pixel, SCT and TRT.

3.3.2 IBL Construction

In 2010, Oklahoma partnered with other U.S. Universities on an NSF MRI proposal to assist in the design and construction of a new layer of sensors in the ATLAS Pixel Detector. This layer, the Insertable B-Layer (IBL), will be installed inside the existing pixel layers. This project protects the physics quality of the Pixel Detector data after the inner-most layer, (B-layer), succumbs to radiation damage. The IBL is under construction and should be installed during the 2013 shut down.

OU agreed to several deliverables, including the design and construction of a miniature crate to house and cool the IBL Optoboards, which are the electrical $\leftrightarrow$ optical conversion point in the data, clock and control systems. However, a high failure rate in the VCSELs (Vertical Cavity SEmiconductor Lasers) of the transmitter boards in the readout crates created concern that the identical VCSELs inside the Pixel detector could fail long before the detector is planned to be replaced in 2023. The nSQP (new Services Quarter Panels) project was developed and tasked with reproducing the Pixel services with a few important changes that would add long-term reliability to the operation of the Pixel Detector. The nSQP requires an almost identical design for the Optobox, which holds, powers and cools the opto-boards used for optical fiber data transmission from the IBL. The two designs differ only in the number of Optoboards they accommodate.

Because of the common design for the optoboxes, Mr. Boyd was in charge of organizing a small team of engineers and technicians toward a final design for four projects, including the ATLAS Forward Proton effort - another detector requiring an Optobox. It has also been decided to include the Diamond Beam Monitors (DBM) optical services within the nSQP. At the recommendation of Mr. Boyd, these projects were strengthened by the addition of Steven Welch to the project team, an EE from Oklahoma State University. Oklahoma State University was thus able to leverage the extra support from the nSQP project to turn partial IBL support into support for the same four projects and another full time EE engineer resident at CERN supporting highly accelerated, design-to-succeed Pixel projects.

Mr. Boyd has also served as a point-of-contact for detailed information about existing Pixel systems and consults frequently with Ned Spencer of UCSC, the recognized system grounding and shielding expert for all of these projects. Besides designing and producing the Pixel module Flex Hybrid, Mr. Boyd also designed the power distribution and common grounding point board known as PP0 and the Pixel sensor bias distribution system known as HVPP4. His intimate knowledge of the installed detector and services grounding and shielding has been invaluable to both the nSQP and IBL system designs. It is critical that Mr. Boyd continue to be resident at CERN as this is the focal point for all of the Pixel upgrade and maintenance activities.

OU graduate student S. Norberg is currently performing irradiation studies to ensure that the IBL components will survive in a high radiation environment. She is also continuing to produce the schematic designs for DC, transient and AC simulation of the Pixel and IBL systems, started by Mr. Boyd. Preliminary schematic designs have already helped to confirm the existence of troublesome current sharing and voltage drops that are challenging the nSQP design. Similar problems must be avoided in the IBL, as the maximum voltage offset the LVDS (low voltage differential signaling) electronics can tolerate is less than 2V DC, compared to 3V DC for the current Pixel electronics.

Many opportunities exist for participation in the final construction, integration, installation and commissioning of the IBL and Pixel detector (with the nSQPs) and services, before and after installation. During the current shutdown all of our graduate students (S. Norberg, A. Hasib, B. Pearson, D. Bertsche, C. Bertsche) are helping with testing, installation and commissioning of the IBL.

3.3.3 R&D Projects

Mr. Boyd has initiated and negotiated material resources for several R&D projects. These projects are ideal for students as they address important issues for today's detectors: cost, reliability and safety. Mr. Boyd can provide guidance for students present at CERN. The OU students, under the supervision of R. Boyd and OU faculty members, can work on the following projects:

Remote 2-wire voltage regulation:

This is a novel approach to remote dc voltage regulation which exploits the energy storage and transmission properties of the existing Pixel LV (Low Voltage) cable plant to reduce costs and power consumption, while providing regulation at the modules from the radiation safe counting rooms, instead of on the detector. The goal of the R&D project is to show that by exploiting the ac properties of the existing Pixel cable plant, it is possible to deliver an isolated, regulated, safe power signal to each module in future semiconductor detectors at substantial savings, compared to the cost of commercial power supplies.

A less ambitious application of this technology provides the possibility to isolate every Pixel module LV power supply channel (using existing regulation). The usual brute force approach of adding more power supply channels is prohibitively expensive, so the Pixel detector presently operates 6 or 7 modules on a single LV supply channel. This causes offset voltages in the electronics that complicate the nSQP and IBL signal circuit designs.

Once a design exists, it will be tested on the Pixel detector in the SR1 R&D facility. If approved, the possibility exists to implement the isolation scheme during the 2013 shut down for both Pixel and IBL. It can also be installed after 2014, during shorter technical stops.

Signal Integrity (SI) testing, simulation, qualification, and reliability testing: Our current data rates are quite modest (160Mbps) but for the High Luminosity LHC it could be 6Gbps. Senior Pixel scientists would be very supportive of a young physicist wanting to take on this critical area. R. Boyd is working with the IBL interconnect and cable groups to build a complete model of our data readout, clock and control interconnects, through the end of installation. The inner detector group leadership is presently trying to obtain the very expensive instrumentation, software and training necessary to support such a long term effort. Mr. Boyd is developing systems to apply accelerated lifetime and stress screening techniques to nSQP and IBL to ascertain reliability. His efforts are chronicled in presentations to nSQP meetings, including the nSQP Production Readiness Review and as an invited reviewer for the flexible interconnects of the IBL project.

Low cost acoustic monitoring system: This is an interesting project that refocuses the implementation of common acoustic analysis principles to monitoring the health of reciprocating machines. This results in substantial savings that makes sophisticated long term remote monitoring for failure prediction affordable. This project receives material support from ATLAS.

Sonar gas analysis: Mr. Boyd is a member of a collaboration of Pixel institute engineers, headed by G. Hallewell of CPPM, Marseilles, developing ultrasonic gas analysis systems based on the speed of sound in the system; sonar. Designed to discern blend fractions in binary coolant mixtures, this technology has already been deployed to monitor the Pixel gas environment for C3F8 coolant, that has break-down products that can become a threat to the detector in the high radiation Pixel environment. The system has also allowed the identification of the few leaks that exist inside this volume.

Additional sonic and ultrasonic sonar applications under development include monitoring systems for the ID Thermosiphon cooling system currently being installed. These systems monitor atmosphere ingress in the storage tank and the velocity of the sub-atmospheric pressure return vapor in the system. Additional systems will soon be deployed to monitor the other ID sub-detector atmospheres. The original application has been realized in a cooling system for evaluating binary coolant mixtures that is operating in SR1.

All of the above projects will conform to the Open Hardware Initiative principles, adopted by CERN, as applicable. It is also advantageous to undertake all of these efforts at CERN, as this is where there already exists the expert and material resources to complete them, while having access to hands-on operational experience of ATLAS. The OUHEP group sees this as an ideal opportunity for our five graduate students to make significant contributions to the ATLAS hardware effort at CERN and to gain valuable experience working with hardware projects. We expect these projects to lead naturally into specific upgrade contributions by our group as they become further developed. We expect, for example, to participate in the replacement of major subsystems of the Inner Detector as part of the LHC luminosity upgrade.

4 Computing for Experimental High Energy Physics

The OUHEP group has been a major contributor to high performance computing for both the ATLAS and DØ experiments for many years. The ATLAS computing effort is centered in operating our Tier 2 Center (in collaboration with UT Arlington and Langston University), as well as testing, deployment, and integration of the ATLAS software and Open Science Grid (OSG) infrastructure. The DØ effort includes Monte Carlo (MC) production, data processing and reprocessing using the grid, and SAMGrid. We are also a member of DOSAR, a community grid organization. The OUHEP computing personnel consists of Horst Severini, who is also the computing coordinator of the Oklahoma Center for High Energy Physics (OCHEP), and Christopher Walker, who is a part time IT specialist, and Joel Snow from Langston University (LU) who participates in all aspects of OUHEP computing.

4.1 DØ Computing

The OUHEP group has made major contributions to DØ computing, most substantially in the production of official simulation data (Monte Carlo or MC) used in detector studies and physics analyses. Since 2002 remote computing clusters at OU and LU have been producing MC for the experiment, initially using a distributed data handling system (a data grid) developed by Fermilab and DØ in 1997 called Sequential data Access via Meta-data (SAM).

As distributed computing technology evolved so did the DØ production system. Before the Open Science Grid (OSG) or LHC Computing Grid (LCG) were production ready DØ deployed SAMGrid, developed at Fermilab, in 2004 for MC production. The early adoption of grid technology for production significantly increased stored simulation data and productivity per FTE involved in MC production. SAMGrid was deployed at OU and LU clusters in 2004. In keeping with the opportunistic nature of grid computing the OU OSCER supercomputing cluster was used as a SAMGrid MC production site. The use of this non-dedicated non-HEP cluster proved very successful and began the practice of using other non-dedicated resources at OU. Other resources not dedicated to DØ used or in use today include the OU/LU ATLAS Tier 2 and a cluster of virtual machines running on OU student laboratory machines outfitted with a grid gatekeeper node.

With the need for MC ever growing DØ adopted a dual pronged strategy of more automation and of leveraging resources. When the OSG and LCG were deployed for production in 2006 DØ demonstrated the interoperability of SAMGrid with those grids. To take advantage of those resources the ability to forward jobs submitted to SAMGrid to the OSG and LCG was added to SAMGrid and the DØ MC production system. That and the development of automated job submission software provided a large expansion of remote production sites and a “quantum leap” in MC production. Two OSG clusters at OU, and one OSG cluster and one SAMGrid cluster at LU are currently in use producing MC for DØ. The clusters at LU have produced 25 million MC events (25 TB) and clusters at OU have produced 450 million MC events (45 TB) for DØ. OU has produced more MC for DØ than any other U.S. academic institution.

In addition to MC production sites OU has contributed in other ways to DØ computing. Located at OU is a critical part of the MC production infrastructure for OSG sites not located at FNAL. OU provides several terabytes of storage used for SAM remote caches and “durable” storage of files used by OSG MC jobs remote from FNAL. OU maintains the software that provides this functionality.

Prof. Snow has been a coordinator of global MC production for DØ since 2004 overseeing the developments outlined above. In 2004 Prof. Snow wrote a Graphical User Interface for MC job submission to SAMGrid. This work led in 2006 to an automated centralized job submission system (AutoMC) developed and deployed at Fermilab and in use today. The AutoMC software has under gone continual development and refinement and is stable and robust. The system submits jobs and manages production at all the grid sites used except one.

Other contributions to DØ computing by OU include Prof. Abbott serving as the representative of the DØ Virtual Organization to the OSG, and Professors Abbott and Snow having served on the DØ Computing Planning Board.

4.2 ATLAS Computing

Over the last few years, the OUHEP group has been very active in ATLAS Computing. The 170 core OUHEP computer cluster and the 9 node testbed cluster are used for software integration and testing, while the bulk of the ATLAS production computing is done on the Tier 2 cluster and the OU Supercomputing Center for Education and Research (OSCER) computing cluster.

The 844 job slot and 500 TB Tier 2 cluster, operating continuously since its deployment in early 2006, is consistently out-performing most other US ATLAS Tier 2 clusters in terms of job throughput per core, with 100% uptime and close to 100% efficiency. The attached 500 TB storage space is seeing good utilization by ATLAS data, and therefore will need to be upgraded to at least twice this size with the next round of US ATLAS hardware funding.

The OSCER cluster hardware has been refreshed to now over 6750 cores and 250 TB and is now named “Boomer”. The cluster has been made available for our use in the last several years with a maximum cap of 250 batch slots for HEP computing, plus a recently added 'hep_killable' queue, which can be used to fill the cluster up completely if there are times during which there are empty slots, but these jobs can also be killed without notice when other researchers' jobs are being submitted. Nevertheless, we expect to see many additional jobs finish successfully in this opportunistic queue.

As Tier 2 Center demands increase we will need to add more compute nodes and more storage space to the cluster. Our goal is to double both computing power and storage space every year, which we plan to do with NSF funds ($60K per year) that support our Tier 2 effort. Additional funds have come from a small ARRA grant which has allowed us to add several nodes and 80 TB of storage to our local Tier 3 cluster which is used for data analysis (both athena and root based) for local users. This storage is nearly full with ATLAS data, so we will have to buy additional Tier 3 storage soon.

In addition to all the computing and storage hardware at OU, we will soon also have new computing resources at Langston University at our disposal. The very recently acquired Langston NSF MRI cluster named Lucille has 832 job slots and 100 TB of usable storage with 10GE connectivity. It is in the process of being configured for use. The facility will provide opportunistic resources for ATLAS computing in a manner similar to the OSCER - Tier 2 relationship.

The network connection from OU to BNL and CERN is now operating at 10 Gbps end-to-end. We have been able to get network transfer rates from OU to BNL up to 5 Gbps, and with our new fast storage system we are able to sustain data transfer rates upward of 700 MB/s to BNL and CERN, which are required for stable running of our Tier 2 Center. OU was also awarded a grant in conjunction with the DYNES project, as well as several OK state wide networking grants, which will allow us to guarantee dedicated bandwidth between OU and other ATLAS Tier 1 and Tier 2 centers, thereby improving our network topology even more, and eventually tie into the LHC Optical Network Environment (LHCONE).

Since data transfer is an integral part of our ATLAS Tier 2 activities, we had deployed two network machines in order to aid our throughput testing activities in collaboration with other ATLAS Tier 2 centers. The software package called PerfSonar has been installed on these machines to aid with Network Performance and Monitoring. New network testing machines with 10 Gigabit network interfaces have recently replaced the older 1 Gigabit testbed, since we need to be able to monitor the full 10 Gbps network infrastructure.

5 Experimental Investigators

5.1 P. Skubic's Research

Past Activities: OUHEP has been supported continuously by base research grants from DOE since it was started by George Kalbfleisch in 1979. Skubic joined the group in January 1981 as the second faculty member and has been PI on the grant since 2000. The group began a program to develop silicon microstrip detectors for use in HEP tracking systems. This R&D effort resulted in use of silicon microstrip detectors in Fermilab fixed-target experiment E653, the first U.S. experiment to use them. Later, Skubic contributed to the CLEO III silicon vertex detector by leading the development of high-density flexible interconnect circuits. In 1997, we joined ATLAS and took on a similar responsibility for the ATLAS pixel detector. This included design, fabrication, assembly, and testing of a flexible circuit called the Flex Hybrid (FH), a component of all the pixel detector modules. Skubic supervised an Electrical Engineer (Mr. G. Boyd) and 11 EE MS graduate students who worked on the project.

We have begun a very active collaboration between OCHEP institutions on ATLAS physics analysis and have initiated work on hardware R&D for an upgrade to ATLAS that is expected to be completed in 2014. We have joined with Oklahoma State U. and Ohio State U. and other U.S. institutions to develop another layer of silicon pixel detectors to be installed inside the existing layers (at lower radius). This new layer, called the Insertable B-Layer (IBL), will compensate for radiation damage that will be done to the existing innermost layer during initial running. NSF MRI funds were obtained to support the work done on this project by U.S. universities.

In addition to our base grant from DOE, Skubic is also PI on several other grants. We received funding for hardware efforts through a NSF MRI project ($340,000 for four years) and DOE ($45,663 for FY11). Both of these grants provide partial funding for Mr. Boyd. Finally, OUHEP received about $400,000 from NSF to support our ATLAS Tier 2 computing center over the last five years. The Tier 2 grant was just renewed ($550,000 over five years) and the first increment of new funding has been received. We would like to emphasize that all these projects support the objectives of this proposal. Our research is focused on our two main experiments, the DØ experiment at Fermilab and the ATLAS experiment at CERN.

Skubic's contributions to DØ have focused on improving our infrastructure for computing so that we can significantly contribute to DØ Monte Carlo production and data processing. This led us to join with other institutions in our region to establish the Distributed Organization for Scientific and Academic Research (DOSAR). This consortium was initially motivated by the need to produce DØ Monte Carlo data at remote sites and is designed to optimize use of computing resources in our region. We have bi-weekly video meetings to discuss software problems and to organize Monte Carlo production and data analysis by the participating institutions. DOSAR institutions are active users and developers of Grid software tools and are currently members of the DØ, ATLAS, or CMS collaborations. We have been early users of software tools such as Condor and Globus and have pioneered use of generic computing resources for HEP MC production. Skubic is currently Chair of the DOSAR Executive Committee. DOSAR has partnered successfully during the last five years with institutions in Brazil and South Africa to perform outreach and education services such as helping to establish customized grid sites and conduct tutorials on grid applications and operation. Over the last year we have organized and taught another such Grid Computing School in Ghana, Africa in August 2012.

DØ has completed data-taking and will finish analysis during the next year or two so we expect to phase out our DØ work during that time. We expect to continue to benefit from experience obtained from data analysis on DØ as we complete the transition to work on ATLAS.

Skubic was on sabbatical for the Fall 2010 and Spring 2011 semesters. He spent most of his time during the sabbatical at CERN contributing to operation of the ATLAS detector during the run and working on data analysis. This included taking many (25) Shift Leader shifts in the ATLAS detector control room during 2011. The sabbatical allowed Skubic to work closely with two postdoctoral associates (M. Saleem and A. Marzin) on analysis of ATLAS data along with two Ph.D. graduate students (R. Meera-Lebbai who graduated in fall 2011 and D. Jana who graduated in spring 2013). Both students had the opportunity to contribute to pixel detector commissioning and operation. Our data analysis efforts resulted in contributions to several papers and conference notes including SM cross sections measurements and searches for supersymmetry (SUSY) and Higgs bosons. These include:

(1) "Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC' [27]; the topic of R. Meera-Lebbai's thesis.

(2) "Search for supersymmetry in pp collisions at $\sqrt{s} = 7$ TeV in final states with missing transverse momentum and b-jets" [10].

(3) "Top Quark Pair Production Cross-section Measurements in ATLAS in the Single Lepton+Jets

Channel without b-tagging", ATLAS-CONF-2011-023, presented at Rencontres de Moriond conference March 13-20, 2011; "Measurement of the top quark pair production cross-section with ATLAS in the single lepton channel" [18].
(4) "Search for Scalar Bottom Pair Production with the ATLAS Detector in pp Collisions at $\sqrt{s} = 7$ TeV" [12]; This paper was a featured news item in the April 2012 issue of the CERN COURIER.
(5) "Search for the Higgs boson in the $H \rightarrow WW \rightarrow \ell\nu jj$ decay channel at $\sqrt{s} = 7$ TeV with the ATLAS detector", [25]; CERN-PH-EP-2012-162, submitted to Phys. Lett. B; the topic of D. Jana's thesis.

Current Status: We believe we are in good position to continue to contribute to the analysis of ATLAS data from the current run. ATLAS and CMS presented data indicating the discovery of a possible Higgs boson on July 4, 2012. It is of the utmost importance to study the properties of this particle and to continue searches for possible other new particles. Graduate student, Dilip Jana, has been active in the Higgs search effort. We have continued the Higgs and SUSY search efforts using data from 2012.

Top Physics: Skubic served as U.S. ATLAS Physics Forum Top Physics co-convener for several years. In this role, he aided in organizing U.S. ATLAS meetings such as physics analysis workshops (called Jamborees) and annual national conferences. In collaboration with OCHEP we have developed multivariate methods using the Likelihood method to separate $t\bar{t}$ events in the lepton+jets channel from background such as the primary background from W+jets. We documented this method in an internal note based on simulated data and employed it to measure the $t\bar{t}$ cross section using 2010 data.[17][18] We are currently using it to measure the $t\bar{t}$+jets cross section and a preliminary result was presented at ICHEP.[20] The Top Working Group conveners have asked us to repeat our $t\bar{t}$ cross section measurement using 2012 data.

Skubic has expanded the OUHEP role in top physics by joining with collaborators from Albany, LTU, and NIU to mount an effort to measure the $t\bar{t} \rightarrow$ jets+τ cross section. We are using both 2011 and 2012 data to make these measurements by employing a tau ID algorithm. Preliminary results have been presented at recent Top Cross Section meetings. This effort has been joined by OU faculty members Abbott and Gutierrez and will allow us to leverage on our experience in similar analyses at DØ. We expect this to lead to future Higgs searches for which $t\bar{t} \rightarrow$ jets+τ events are significant backgrounds.

Higgs Searches: Skubic has been working with his graduate student D. Jana and programmer C. Walker on the search for Higgs bosons in the $H \rightarrow WW \rightarrow \ell\nu jj$ channel. Jana served as an editor on the conference note based on 2011 data that was submitted to summer conferences. We have performed extensive QCD background studies for this channel and have contributed to the baseline cut-and-count method that was the main topic of Jana's thesis. Work to repeat this search with 2012 data is in progress. We plan to use the multivariate methods developed for top physics to increase the sensitivity of the Higgs search in this channel. Preliminary studies have been done to determine suitable variables and optimization studies will be started soon. Although Jana graduated this year, a new graduate student (B. Pearson) has joined this effort along with faculty member M. Strauss.

SUSY Searches: Before LHC data taking started, Skubic and Abbott, in close consultation with OU theory group members Baer and Kao, started an effort to search for particles predicted by SO(10) GUT SUSY models.[7] If correct these models predicted possible low mass particles that could be observed at the LHC. We teamed up with OU postdoc G. Huang and his replacement A. Marzin, and with the help of UTA group member N. Ozturk and H. Baer, started an effort to generate signal samples for such searches. Skubic was instrumental in our group joining the SUSY subgroup that focused on final states containing b-jets and MET which was well matched to predictions of the SO(10) models. Skubic and Ozturk performed SO(10) production cross section calculations using the PROSPINO program[28] in preparation for the signal sample generation. Analysis of the 2010 and 2011 data resulted in the two papers mentioned above [10][12] which significantly constrained the allowed parameter space for the SO(10) and MSUGRA models and resulted in a lower limit for gluino mass of about 550 GeV. Skubic provided HEPDATA[1] records for these papers to help disseminate the results to the world-wide community and calculate combined limits with CMS.

The LHC data has greatly constrained the allowed parameter space for MSSM models in general and it appears it may be harder to discover SUSY at the LHC then once hoped. These results are consistent with the idea of "natural SUSY" that is described in [9]. Such models predict chargino-neutralino events that can be produced at the current LHC CM energy of 8 TeV with final states containing a WZ pair and missing transverse energy.[29] The $H \to WW$ search described above would provide a natural transition to a SUSY search for these events which could be carried out by one of our new students such as C. Bertsche. Final state topologies that include MET, $Z \to \ell\ell$, and either $W \to \ell\nu$ or $W \to jj$ can be explored. We will continue the SUSY search effort using all available data from the current run as well as that from the the next run.

Hardware Work: We propose to contribute to the ATLAS upgrade during the extended LHC shutdown in 2013-14. The machine and detectors will be improved and the LHC should run at close to design energy (14 TeV) after the shutdown. Our hardware work will be done jointly by members of OUHEP and will be coordinated with the help of Mr. Boyd. Two of our new graduate students have relocated to CERN and are taking on IBL responsibilities during the current year. Skubic continues to supervise work done on the IBL Optobox that is funded by the MRI grant mentioned above.

5.2 P. Gutierrez's Research

Past and Current Work–DØ

Since 1994, Professor P. Gutierrez have been a member of the DØ collaboration. He has contributed to the design, construction, and installation of the silicon vertex detector, the maintenance of the level 2 trigger, numerous analysis either through direct primary participation, through the supervision of students and postdocs, and has been a member of a number of editorial boards reviewing analysis for presentation and/or publication. Gutierrez has directly supervised five graduate students four who have successfully completed their dissertations and one who will finish by the end of the 2012-13 academic year. In addition, Gutierrez has directly supervised the work of six postdocs who have contributed to the success of the DØ experiment.

For the period of the last DOE grant (2010-2013), Professor P. Gutierrez has concentrated his effort on the physics of the top quark. Since the top quark is the most massive of the known fermions, it also has the largest Yukawa coupling to the standard model (SM) higgs boson, $g_{tH} \approx 1$. Therefore, one might expect the properties of the top quark to provide information about the Higgs sector. In addition to general contributions to the DØ top group, Gutierrez has directly lead efforts on three top quark analysis during this period: the $t\bar{t}$ cross section in the $t\bar{t} \to \tau + \text{jets}$ final state, which has been published [30], update with improvements to the $t\bar{t} \to \tau+\text{jets}$ cross section analysis, which is in progress, and the top quark mass measurement in the all jets final state, which is also in progress.

According to the SM, the top quark decays to Wb approximately 100% of the time. Therefore, the observed final state of the produced $t\bar{t}$ system is determined by the various W decay modes.

[1]The HEPDATA project compiles and makes easily accessible a comprehensive database of high energy physics experimental scattering data - the Durham-HEP Database.

Non-SM processes can modify this. For example, the simplest extension to the SM Higgs sector involves the addition of a second SU(2) complex scalar doublet, which introduces four additional spin-0 Higgs particles, two that are neutral for a total of three neutral Higgs bosons and two that are charged. The charged Higgs can then replace the W in the top quark decay and depending on the ratio of the vacuum expectation values of the two doublets, plus other parameters that depend on the specific model that doublet is embedded in, an excess or deficit of τ leptons in the final state will be observed. Other models that enhance the number of events with τ leptons in the final state have also been proposed. One such model, which is in the context of R parity violating SUSY, would lead to an excess of τ leptons in the final state [21]. A topcolor assisted technicolor model predicts a $\mathrm{BR}(t \to \tau^+\tau^- c) \approx 10^{-7}$, which, even though it is not accessible at the tevatron, shows that one must measure all $t\bar{t}$ final states in order to test the limits of the SM [22].

The measurement of the $t\bar{t}$ production cross section in the τ_h+jets final state, where τ_h denotes hadronic final states of the τ lepton, was performed by former OU graduate student S. Hossain under the supervision of Gutierrez using 1 fb^{-1} of integrated luminosity. The results of this measurement are reported in Ref. [30], which is also the first reported measurement in this final state, and are found to be consistent with SM expectations.

P. Gutierrez is participating in the update to this analysis using $\approx$ 5 fb^{-1} of integrated luminosity. The procedure roughly follows that of the 1 fb^{-1} measurement with the following improvements: a factor five increase in statistics, the use of the new multijet triggers that yield a 10% improvement in signal efficiency, the use of vertex confirmed jets, the implementation of the tau energy scale, reduction of the electron contamination to $\tau^\pm \to \pi^\pm\pi^0\nu_\tau$ decays, and extensive optimization of the event topological neutral network. The analysis is currently under review by the DØ top group and should move forward toward publication this year.

The importance of the top quark mass measurement rests in the fact that it is one of the fundamental parameters of the SM. It along with the measured masses of the Higgs boson and the W boson constrain the SM. This occurs through radiative correction to the W boson mass from top quark and Higgs boson loops. At the moment, these constraints are approximately in agreement with the SM to within one standard deviation. DØ will be updating the measurements of both the W boson ($\delta M_W < 17$ MeV) and the top quark masses using the full 10 fb^{-1}dataset, the final jet energy scale corrections, which OU student A. Jayasinghe under the supervision of his adviser Professor P. Gutierrez is contributing to, and the improved b jet selection, which Gutierrez has recently contributed to.

It is important to perform the top quark mass measurement in all possible final states in order to reduce the possible systematic effects that may appear in each channel. For example, the dilepton final state has little background, but there are two energetic neutrinos that cannot be reconstructed. On the other hand, the all hadronic final state can be fully reconstructed and has a significantly larger final state branching ratio, but is subject to very large multijet backgrounds. Combining these two measurements with the lepton plus jets final state will provide the best measurement of the top quark mass.

A. Jayasinghe and his adviser P. Gutierrez, are performing a measurement of the top quark mass in the all hadronic final state using the full integrated luminosity. When completed, this will be the first published run II DØ top quark mass measurement in this final state; a DØ run I measurement was published in 2005 and several run II measurements have been published by CDF in this final state. The major technical challenge in performing this measurement is the reduction of the multijet background, which after trigger selection is 3 orders of magnitude larger than signal. Since at the present time there are no adequate Monte Carlo models of multijet QCD events, the background model is built from data in a manner similar to the DØ published all hadronic final state measurement of the $t\bar{t}$ production cross section[1]. The signal consists of events with six or more jets, two of which are tagged as b-jets. Therefore, the background model must have the same characteristics with a minimal number of signal events. This is accomplished by taking events having five jets with two of these being tagged as originating from a b quark, and adding an additional jet from a sample of six jet events with similar kinematics as the leading five jets. This maintains the correlation between the b-jets in the events and reduces the likelihood of real $t\bar{t}$ events in the background sample. At the present time, the background model provides a good representation of the data, even though we continue to refine it.

To extract the top quark mass, we use the template method. We parametrize the mass information derived from the minimization of a kinematic fitter that includes both the dijet mass (W) and trijet mass (t quark), and perform a simultaneous fit of both the top quark mass and the jet energy scale.

The data sample used in this analysis is selected from three and four jet trigger events using a set of loose selection criteria to reduce the background. The sample is further reduced using a boosted decision tree discriminate, which at the moment is built from 30 variable that have a weak dependence on mass. The minimum negative log likelihood is calculated for the optimal fit between data and each mass template and a similarly derived template for background. The minimum of the negative log likelihood of these fits is used to extract the mass.

At the present time, we are in process of adding the the one b-tag sample to reduce the statistical uncertainty. In parallel, the final corrections are being applied to the data. A. Jayasinghe has graduated using two b-tag sample for his dissertation and not including the final jet energy scale corrections, which were still in the process of being determined.

Once the top quark mass in the all hadronic final state is published, Gutierrez will reduce his participation on DØ to that of participating on editorial boards and reviewing analysis and papers being prepared for submission to refereed journals.

Past and Current Work–ATLAS

Professor P. Gutierrez has contributed to OU ATLAS effort, since the start of the OU involvement. Gutierrez contributed to the development of the flex hybrid used in the pixel readout, several projects involved in the testing of the pixel vertex detector during visits to CERN, and has contributed to physics studies and analysis. At the present time, Gutierrez is primarily participating in the measurement of $t\bar{t}$ cross section in the τ_h+jets final state using his experience from the DØ measurement. Gutierrez is supervising OU graduate student A. Hasib and working with other members of the OUHEP group. In addition, Gutierrez will be supervising the work of A. Hasib's work on the insertable B-Layer (IBL).

To improve the performance of the track and secondary vertex reconstruction as the instantaneous and integrated luminosities increased, it was foreseen to add a fourth layer to the pixel charged particle tracking detector, which would be placed inside the closest layer of the current pixel detector to the circulating beams. The primary physics motivation for the upgrade is to prevent the deterioration of the inner tracking caused by radiation damage and improve the b tagging capabilities of the ATLAS detector. The IBL will improve the robustness and precision of the charged particle tracking by compensating for module failures in the current pixel tracker and adding an addition layer of tracking detectors. In addition, the extra layer and closeness of the IBL to the circulating beams will help to mitigate pileup effects from the increasing instantaneous luminosity. At the present time, components for the IBL are being produced, with module assembly and testing in progress. The goal being to install the IBL during the 2013/14 LHC shutdown.

Since the OU group has responsibilities for the IBL and it is important for the education of HEP graduate students to acquire hardware experience, OU student Hasib under the supervision of Gutierrez will participate in the testing and installation of the IBL. It is also foreseen the Gutierrez will spend time at CERN contributing to the testing and installation of the IBL during the summer of 2013.

The study of $t\bar{t} \to \tau_h + \text{jets}$ at the LHC will allow the setting of much stricter limits on non-SM couplings relative to the tevatron. The cross section times branching ratio at $\sqrt{s} = 8$ TeV is $\approx 23^{-1.9}_{-2.0}$ pb for $m_{t\bar{t}} = 172.5$ GeV. Assuming a similar detection efficiency for this final state as in the DØ measurement and an integrated luminosity of 10 fb^{-1}, there will be ≈ 300 times more events by the end of the 8 TeV run, thereby reducing the statistical uncertainty relative to the DØ measurement by a factor of ≈ 20. By comparing the ratio of $\sigma \times \text{BR}$ of $t\bar{t} \to \tau_h + \text{jets}$ to $t\bar{t} \to e(\mu) + \text{jets}$ to the SM expectation, we find that a 0.9% shift in the $\sigma \times \text{BR}$ $t\bar{t} \to \tau_h + \text{jets}$ relative to the SM values would indicate a 3 standard deviation signal for non-SM processes. As an added note, using similar assumptions, the limits are approximately halved at $\sqrt{s} = 14$ TeV. This could be a quick early measurement when the LHC turns back on in 2015.

At the present time, Gutierrez is participating in the measurement of the $t\bar{t}$ production cross section in the $t\bar{t} \to \tau + \text{jets}$ using both the 2011 and 2012 datasets. This includes both the supervision of OU graduate student Hasib, and participation directly in the analysis and discussions. The goal is to complete the 2011 analysis by the end of the 2012. The 2012 analysis will depend on when the final 2012 dataset is available. Once the production cross section measurement is complete, limits on non-SM $t\bar{t}$ decays can proceed using the measured $\sigma \times \text{BR}$ for $t\bar{t} \to \tau + \text{jets}$ and $\ell^{\pm} \to \tau + \text{jets}$.

Outreach

Professor P. Gutierrez along with M. Strauss, have co-lead the quarknet program at OU. We have organized one and two week workshops since 1999, with the intent of providing Oklahoma high school teachers a basic understanding of HEP such that they can provide instruction to their students. The workshops provide the teachers with the basic information need to teach HEP to high school students, and we have helped the teacher develop curricula for incorporating it into the classroom. We have interacted with approximately fifty high school teachers over this period, which we estimate has impacted > 3500 Oklahoma high school students. Our plan is to continue this work into the foreseeable future.

5.3 M. Strauss's Research

For the past seventeen years, Professor Strauss has made contributions to, and held leadership positions on, the DØ experiment in areas of silicon vertex detector design and testing, B meson measurements, top quark physics, tracking reconstruction algorithms, and Quantum Chromodynamics (QCD) physics. Some details on his work over the last six years is given below. During the next year, he is planning on moving the focus of his research to ATLAS.

In every high energy physics (HEP) experiment, much of the effort required to make a measurement is comprised of taking data from the detector and reconstructing physics objects, jets and particles, that can be used for analysis. Between 2004-2007, Strauss served as co-convener of the tracking and vertexing algorithm group, responsible for developing the software and algorithms that measure the trajectory and momentum of charged particles using information from the Silicon Microstrip Tracker (SMT) and the Central Fiber Tracker (CFT). As co-convener, Strauss set priorities for the algorithm group, created software tools, and recruited people to assist in developing, checking, and improving algorithms. One of the major accomplishments during that time was the installation of an inner layer in the SMT, Layer 0, and the development of tracking algorithms using that new hardware. Strauss developed strategies for testing the efficiency of Layer 0 and directed the effort of characterizing the performance of that new detector. He wrote tools and algorithms to measure and analyze the track finding efficiency and purity. These tools served an essential role in understanding the tracking performance as the luminosity of the Tevatron increased, and in making decisions that led to a significant decrease in the time it takes to reconstruct tracks offline. Diminishing the reconstruction time was a particularly crucial development as the luminosity of the Tevatron increased. Without such improvements, the offline reconstruction of events could not have kept up with the data taking rate. In addition, under Strauss' leadership, the tracking group dramatically improved the simulation of the material in the tracking detectors, which led to a much better match between the resolution in the data and that predicted by the simulated detector.

From 2008-2009 Professor Strauss led the QCD Jet Editorial Board (EB). In the DØ collaboration, editorial boards serves a crucial role as an unbiased committee responsible for fully evaluating all analyses before being submitted for publication. A typical analysis takes a few months to work its way through the board until it is finally approved and sent to the collaboration for further review before being submitted for publication. During Strauss' tenure the EB was extremely active, reviewing eleven analyses, compared with just four in the previous three years. The analyses are listed in the bibliography as items [2, 5], [33]-[41].

During this time, Strauss and his graduate student Mandy Rominsky were the principle authors on a paper which measured the dijet mass spectrum in six rapidity regions up to a rapidity of |2.4|. This analysis can be used to measure gluon parton distribution functions (PDFs), to search for undiscovered particles that decay to two jets, and to look for physics beyond the standard model. The analysis involved a careful understanding and measurement of jet energy scale and detector resolutions in order to develop a fast detector simulation, D0JetSim, which was used to "unsmear" the data from detector level to particle level. The systematic uncertainties were smaller than any other published dijet mass measurement due to the extremely well understood jet energy scale, and the rapidity range was larger than any other published result. Figure 2 shows the data compared with NLO QCD calculations using MSTW2008 PDFs [42]. No evidence of new particles or physics beyond the standard model was observed. This analysis was the subject of M. Rominsky's Ph.D. dissertation which was completed in late 2009 and published in 2010 [41].

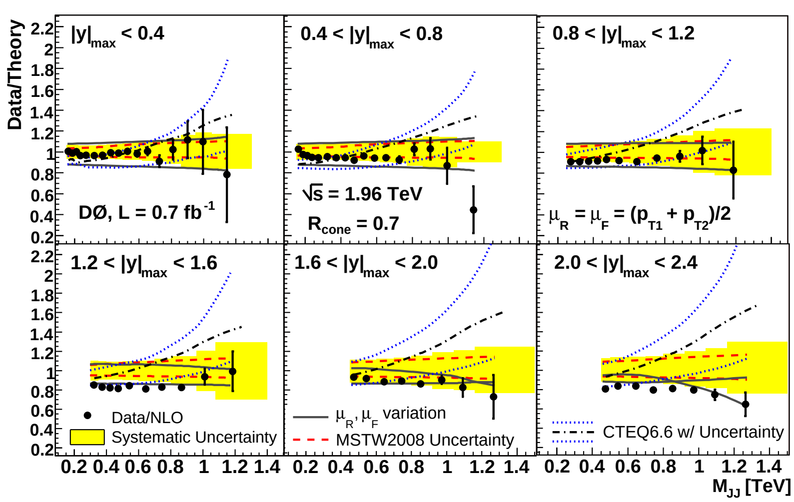


Figure 2: The dijet mass cross section showing data divided by NLO QCD theory using MSTW2008 PDFs. The six plots show the measurement in six rapidity regions. Different curves show other PDFs, PDF uncertainties, and renormalization and factorization scale uncertainties.

From 2010 through 2012, Professor Strauss held the position of DØ QCD physics analysis working group co-convener with Dmitry Bandurin. In this position, he directed and coordinated all QCD analysis projects and publications within the DØ collaboration. During this time, the QCD group published or submitted for publication nine QCD analyses. See [43]-[50]. Seven other publications had their analysis done primarilly when Strauss was convener and were published shortly after he left, [51]-[56]. Strauss and P. Svoisky were the primary authors on [56], a measurement of the di-photon production cross section at the Tevatron. This analysis probes proton PDFs and helps understand backgrounds to standard model and new physics.

The data taken at the Tevatron has provided an important opportunity to make precision QCD measurements and to probe the PDFs of the proton. The initial $\overline{p}p$ state probes regions of gluon PDF phase space that are difficult to access at the LHC. In addition, QCD measurements of jets plus photons or jets plus vector bosons provide precise measurements of final states which are backgrounds to many processes beyond the standard model.

Beginning in mid 2013 Professor Strauss has been doing research almost exclusively with data taken with the ATLAS experiment on the Large Hadron Collider (LHC) at CERN. Two graduate students who are working with Strauss as their Ph.D. advisor, Ben Pearson and Callie Bertsche, will be using data from ATLAS for their dissertation research. Strauss and Pearson have been looking at the decay of $H \rightarrow WW \rightarrow q\overline{q}\ell\nu$ in the 8 TeV data collected in 2012 by ATLAS. Beyond the standard model, other Higgs particles may exist and be detectable decaying to two W bosons with a branching fraction lower than current standard model limits. Consequently, there are good reasons to continue to look at the $H \rightarrow WW \rightarrow q\overline{q}\ell\nu$ decay channel. We have implemented a kinematic fitting technique for improving the resolution of the jets that come from the W decay and more accurately selecting the correct decay jets.

Even with a Higgs mass of about 125 GeV, the branching fraction of Higgs to WW is much higher than that to $\gamma\gamma$ and decays to WW may play a large role in measuring the Higgs properties. Though the best WW decay channel for a low mass Higgs particle is to two charged leptons, the decay to $q\overline{q}\ell\nu$ can be important when the hadronically decaying W is on the mass-shell and can, therefore, be more easily identified as a W boson as long as the lepton has high enough momentum to have triggered the event. We are looking into methods of reconstructing such a Higgs. using a boosted decision tree which may be able to see a signal above background.

Professor Strauss has also served as the Associate Director of the Oklahoma Center for High Energy Physics (OCHEP), a regional center of excellence dedicated to research and education in high energy physics. This Center was originally established from a six year DOE EPSCoR implementation grant beginning in 2004. The Center has brought together all of the universities in the state of Oklahoma with active high energy physics programs and established collaborative experimental projects among all the HEP experimentalists in the state. In addition, the Center originally established the grid computing facility for HEP physics at the University of Oklahoma (OU) that has become a part of the ATLAS tier 2 computing site.

Professors Strauss and Gutierrez are co-coordinators of the Quarknet program at OU. Quarknet is an educational program sponsored by the NSF and DOE which partners HEP professors and programs at major universities with local high school teachers. Its purpose is to help bring the excitement of particle physics research into the high school classroom and to provide teachers with professional development opportunities. Currently there are about 60 U.S. universities participating in the Quarknet program. The University of Oklahoma was one of the first twelve universities to participate during the inaugural year, 1999, and has worked with high school teachers every year since through workshops and research opportunities.

The Quarknet and EPSCoR programs have provided excellent opportunities for over 50 high school teachers in the State of Oklahoma to learn about particle physics, develop curriculum and tools to educate their students in HEP, and develop and maintain professional teaching and research relationships with the HEP faculty at OU. We estimate that this program has impacted over 3500 high school students throughout the state. We expect to continue our association with Quarknet and with high school teachers for the foreseeable future.

5.4 B. Abbott's Research

B. Abbott has been at the University of Oklahoma since 2000. During this time, he has been involved in two major experiments, DØ and ATLAS. B. Abbott has supervised one OU graduate student on DØ analysis (Isaac Hall) and has worked with multiple other graduate students on their DØ research. B. Abbott is currently supervising two OU students (S. Norberg and D. Bertsche) on ATLAS analysis.

DØ analysis

On DØ B. Abbott's research program has been almost entirely devoted to studying B physics where he has worked on discovering new B baryons and studying CP violation. B. Abbott was a B physics convenor for DØ and was primary author on a PRL on the $X(3872)$ [59].

After finishing his term as B physics convener, B. Abbott was involved in many aspects of the B_s mixing measurement and became the convener of the B mixing and lifetime group for DØ. B. Abbott was instrumental in using electrons for flavor tagging (previously only muons were used). DØ published the first two-sided limit on the B_s mixing frequency [60] and is one of the most cited publications from DØ.

In 2006 B. Abbott took a sabbatical and became a visiting scientist at Fermilab and became the DØ computing coordinator. This was one of the senior management positions and he was in charge of the overall computing needs for DØ. During this time DØ reprocessed over 400 million events using the Open Science Grid (OSG). A reprocessing of detector data of such a magnitude had never been accomplished before and was a major milestone for both the DØ experiment and OSG.

After finishing up on the $X(3872)$, B. Abbott turned his efforts to studying b baryons. Prior to RunII of the Tevatron, very little was known about b-baryons. In fact, only one b-baryon had been observed experimentally, the Λ_b. A major accomplishment for B. Abbott was the discovery of the Ξ_b^- baryon at DØ. which led to a a publication in PRL [61]. In 2008 B. Abbott also participated in was the observation of the Ω_b baryon. Using 1.3 fb^{-1} of data, a signal was observed and B. Abbott was a primary author on a PRL [62].

B. Abbott recently has moved his research program to studying CP violation and is leading a new group on DØ called the "B_s to $J/\psi X$" group. Recent DØ CP violation results from the dimuon asymmetry and from $B_s \to J/\Psi\phi$ show potential deviations from the SM predictions. Therefore this area of study is of importance interest at the moment. The CP-violating phase angle in B_s^0 mixing, ϕ_s, has been measured using $B_s^0 \to J/\psi\phi$ decays by a number of different experiments. The decay products of $B_s^0 \to J/\psi\phi$ are in an indefinite CP state, requiring CP-even and CP-odd components to be extracted through a time-dependent angular analysis. In contrast, the decay products in $B_s^0 \to J/\psi f_0(980)$ are in a CP-odd eigenstate, which provides a more direct measurement of ϕ_s relative to $B_s^0 \to J/\psi\phi$.

In order to determine if there will be enough events to measure ϕ_s in this channel, the relative branching ratio was measured and B. Abbott was a primary author on a PRD [63]. B. Abbott is currently working on extracting ϕ_s and measuring the lifetime from $B_s^0 \to J/\psi f_0(980)$ and this analysis should be complete by the end of 2013. The lifetime measurement in itself is interesting because this decay is a pure CP odd state and will provide information on $\Delta\Gamma_s$.

B. Abbott discovered a new decay while studying $B_s^0 \to J/\psi f_0(980)$, namely $B_s \to J/\psi f_2'(1525)$. This decay mode could potentially be used to measure ϕ_s and the branching ratio of this decay has only recently been measured by LHCb. In addition to measuring the relative branching ratio of this decay, an angular analysis was performed to study the spin of the $f_2'(1525)$. B. Abbott was a primary author on this analysis and a paper has been published in PRD [64]. In addition, B. Abbott has been working on a search for the $X(4140)$ in $B^+ \to J/\psi\phi K^+$ decays. This is a narrow resonance in the $J/\psi\phi$ system. This existence of this state is still in question as some experiments claim to see the resonance while other experiments do not.

In addition to physics measurement, B. Abbott has been involved in service work for DØ, namely he is on the OSG council representing DØ, he is a member of the computing planning board, he was chair of the editorial board for the RunII luminosity, a member of the QCD editorial board and he worked on helping to reduce the jet energy resolution to improve the Higgs Search.

In the past year, B. Abbott has been greatly reducing his time on DØ and has been focusing nearly all of his research efforts towards ATLAS.

ATLAS:Previous/Current Research

B. Abbott has also been involved in ATLAS for several years. where his research has been in three areas: top decays, SUSY and studying the inclusive photon cross section. B. Abbott has been the QCD forum convener for US ATLAS and has been involved in monitoring the silicon pixel detector remotely. He also helped develop the offline monitoring for the pixel detector and have taken a number of offline pixel monitoring shifts.

Working with OU postdoc Guangshun Huang, we performed a number of studies for the top muon liaison group. In particular we studied the muon efficiency, background rejection and have studied different methods to enhance our physics reach. B. Abbott was involved in the early studies for measuring the top cross section using a likelihood method. In order to better understand what parameters should be included in the likelihood, he studied many different variables using Boosted Decision Trees to try and understand what were the best parameters to use to enhance our top signal on ATLAS.

B. Abbott has also been supervising graduate student Scarlet Norberg. We helped design and maintain a website for monitoring the pixel detector. Scarlet received a fellowship in April 2011 which allowed her to spend a year at Argonne National Lab. While at Argonne, she started and completed her authorship qualification tasks by studying the Tile Calorimeter. Scarlet helped create and currently maintains a website to study the Tile Calorimeter trips to better understand their cause.

We have been studying the inclusive direct photon cross section using the 2011 data from ATLAS. We performed an optimization of isolation criteria for photons and studied the effects of bremsstrahlung photons in the Monte Carlo. An ATLAS note (where we are primary authors) has been written on the cross section analysis [65] and a paper is expected soon.

Scarlet is currently located at CERN where she has been helping analyze the tile calorimeter trips in 2012. Since our group wants to focus our efforts in a more directed fashion, we will begin studying SUSY in the 2012 data by focusing on gluino-mediated heavy flavor SUSY searches with missing transverse momentum and b-jets. We have been studying the b-jet trigger efficiencies for the 2012 data to determine which trigger is optimal for this SUSY channel. In addition, we have generating MC using Madgraph with an interface to Pythia which provides hadronization, initial state radiation(ISR) and final state radiation. Madgraph/Pythia may deal with ISR better than Herwig so at high P_T, where ISR affects are greatly reduced, we are comparing Herwig to Madgraph to verify that we are generating Madgraph properly. Once it is verified that Madgraph is being generated correctly at high P_T, we will start generating large samples of Madgraph MC for our SUSY studies. We are also working with our engineer R. Boyd on the pixel detector hardware. We will be working on reliability testing for the nSQP. Since the nSQP and IBL have many common components, this work will also lead into testing for the IBL once the components are available. We have studied how well the epoxy/acrylic stands up to irradiation to show that the components will last in a high radiation environment. Scarlet has been focusing her research efforts on a search for SUSY in the photon, lepton and large Missing E_T channel and should become her thesis project.

B. Abbott is also supervising a second graduate student David Bertsche. David has recently located to CERN where he is working full time on research. David is very interested in obtaining hardware experience and has been helping with the IBL testing at CERN. In addition David has been performing studies for top decaying to taus. In particular, David has been measuring the QCD background in $t\bar{t} \rightarrow \tau +$ jets using the matrix method for the 2011 data. David has also started studying the cross section for $t\bar{t} \rightarrow \tau +$ lepton for the 2012 data and hopes to use this topic as his thesis.

B. Abbott has also been working with the OU postdoc Antoine Marzin. In 2012 we continued our contribution to the ongoing effort within the ATLAS collaboration to search for supersymmetry (SUSY). We have pursued a number of various models (mentioned previously) which have resulted in numerous publications.

5.5 J. Snow's Research

DØ MC Production - Professor Snow has been a coordinator of global simulation data (MC) production for DØ since 2004. In that position he has overseen the introduction of grid computing into the production system and the subsequent the use of multiple grids for production. The initial grid used by DØ was SAMGrid, developed at Fermilab and first deployed in 2004 for production.

In 2004 Snow wrote a Graphical User Interface for MC job submission to SAMGrid. This work led in 2006 to an automated centralized job submission system (AutoMC) developed and deployed at Fermilab. The system handles the processing of physics requests for MC from their specification in a database to the uploading of the created data into the central storage at Fermilab. The AutoMC software has undergone continual development and refinement and is stable and robust. The system submits jobs and manages production at all grid sites (except one) on three continents. Job submission, bookkeeping, and error recovery are all automated. This development alone freed considerable personnel to work on other aspects of the experiment while also increasing production efficiency. The AutoMC system continues in use today at Fermilab and presumably through the end of MC production.

In 2006 Snow oversaw the transition of resources when the data handling system underwent a major version change while maintaining continuity of production. Tools and infrastructure needed to be re-written and deployed to accomplish this. Snow rewrote the MC request queuing system, the MC request page generation system, the job submission GUI, and the AutoMC software for the new version.

In 2008 Snow did a study of MC production job efficiency at OSG sites. The results came to the attention of OSG management via DØ and generated an initiative by OSG and DØ to deploy more Storage Elements (SE's) for DØ use. As a result additional SE's were deployed for DØ MC increasing production efficiency. The project was written about in articles on the OSG web site and was the featured story in the "International Science Grid This Week" online publication of 15 October 2008. The success of the project prompted a similar program of SE deployment for the CDF experiment by the OSG.

Snow created and maintains MC production monitoring tools including production statisitcs on the web, MC job status and system performance measures, and detailed MC request processing status in the production system.

During Snow's tenure as MC production coordinator for DØ production rates have increased substantially. This has been due to the adoption of grid technology enabling the use of opportunistic resources, the utilization of an automatic job handling system, and the increasing power available in new machines. Since September 2005 total MC event production per year increased by a factor of 50 and data stored by two orders of magnitude. During the same period grid production increased from 1% of production to two-thirds of total production.

LU Computing - Langston HEP has 2 grid enabled clusters that are producing simulation data as part of DØ MC production system. The facilities include OSG computing and storage elements. LU HEP has been producing MC for DØ since 2003. These resources will transition to ATLAS when DØ MC production ends.

ATLAS - LUHEP has contributed substantial assets to the creation, maintenance, and operation of the Atlas Southwest Tier 2 (SWT2) at OU. Through funds provided by a DOE EPSCoR Grant to the OCHEP collaboration (OK State U., OU, and LU), LUHEP contributed $31k to the cost of the initial 40 node cluster with 5 TB of disk storage in 2005, $5k for maintenance contracts in 2006, $153k for maintenance contracts, 18.5 TB of disk storage and 23 compute nodes in 2007, $121k for 100 TB of disk storage in 2009, and $70k for 23 compute nodes in 2010.

Snow will provide support for the ATLAS Southwest Tier 2 and Tier 3 clusters at OU by collaborating with Dr. Severini to operate, maintain, and expand the facilities. He will work to bring ATLAS computing to Langston University and collaborate with the top physics group at OU and other institutions.

The National Science Foundation has awarded a grant of $250,000 to Langston University for support of the project entitled "MRI: Acquisition of a High Performance Computing Cluster for Research and Education," under the direction of Joel M. Snow PI. The award is effective February 1, 2013 and expires January 31, 2016.

6 Experimental Summary

This is an exciting time for the OUHEP group. With the success of the LHC and ATLAS, with our commitment by all faculty members to focus our research on the ATLAS data, and with the influx of new graduate students interested in HEP, we are poised to increase our already outstanding contributions to the global HEP and scientific community. All of five our new graduate students have successfully completed classes and exams and are devoting 100% of their time to ATLAS research. With the funding of this project we have been able to investigate and publish outstanding physics results as well as make major contributions to ATLAS collaboration.

We are participating in the IBL installation and plan to contribute to future detector upgrades. We will continue to expand our Tier 2 computing center. We have a program of physics that strengthens the collaboration between OUHEP experimentalists and theorists and focuses on studying electroweak symmetry breaking and testing Standard Model physics through SUSY searches, Higgs studies, and Top physics, yet is flexible enough to investigate new and unexpected experimental results. Our faculty members have experience leading major algorithm and physics analyses groups within large collaborations and publishing important physics results. We have excellent personnel and many outstanding new graduate students.

The University of Oklahoma is extremely supportive of the HEP program. The university fully funds Horst Severini, a Ph.D. research scientist devoted to HEP high performance computing. The university also supports a departmental electronics shop and technician, A. Wade, who supervises it. The funding for this project has allowed the OUHEP experimental group to make an significant impact on ATLAS and to make major contributions to our understanding of elementary particle physics.

7 Work of Howie Baer's group: From colliders to cosmology in the LHC era

7.1 Introduction

The LHC era began in earnest during the past two years with Atlas and CMS gathering ~ 5 fb^{-1} of data at $\sqrt{s} = 7$ TeV (LHC7) and ~ 20 fb^{-1} at $\sqrt{s} = 8$ TeV (LHC8). The crowning achievement was the discovery of the HIggs boson with mass $m_h = 125.5 \pm 0.5$ GeV, While the value of $m_h \sim 125$ GeV falls squarely in the range predicted by weak scale supersymmetry (SUSY), so far there is no signal at all for sparticles. Back in the 1980s, Baer and Tata developed and fleshed out superparticle production with cascade decays. We also developed the first realistic event generator (Isajet, 1993) for SUSY cascade decays and the first sparticle mass spectrum generator (Isasugra, 1994). It is gratifying that many LHC SUSY analyses use sparticle cascade decays in their analyses. We also developed many of the SUSY simplified models in the 1980s and 1990s, which have been systematized over the past couple years and are now routinely used in LHC analyses.

Baer's group has been working in several directions the past several years, and we plan to continue these directions for the near future. One direction is implications of the LHC Higgs results for SUSY searches. Another direction is confronting LHC sparticle search results with expectations from weak scale naturalness: in this context, we found a paradigm shift as to the sort of model that would likely describe weak scale SUSY. We have dubbed this model "Radiatively-driven natural supersymmetry". Another direction concerns the future of high energy physics in the US and the world. In this context, Baer and Jenny List (DESY) have written the SUSY chapter for the ILC Detailed Baseline Design report and TDR, which was released suring summer 2013. Baer's group has also been contributing calculations of SUSY reach to the Atlas LHC luminosity upgrade study. He also contributed to the CERN WG2 report on missing E_T signatures, and to the University of Washington study of the future of axion physics. More details on all these studies will be presented below.

During the past several years, our group has supported postdocs Warintorn Sreethawong (2010-2012) and Kyu Jung Bae (2012-present) Sreethawong left OU for a new postdoctoral position with the Nuclear and Particle Physics group, Suranaree University of Technology in Thailand. Shibi Rajagopalan graduated from OU in 2010 and took a position at University of Torino (Italy). Andre Lessa graduated from OU in August 2011 and took a postdoc position at University of Sao Paolo in his native Brazil. Andre won the first ever APS Sakurai award for outstanding dissertation in theoretical physics! Newer graduate students Dan Mickelson, Maren Padeffke and Hasan Serce have been funded by a combination of TAships and Baer's Endowed Chair funds.

7.2 LHC reach for SUSY

With LHC up and running, it is important to establish exactly what its capabilities are. We have examined LHC potential for discovery of SUSY (A calculation pioneered by our group in the early 1990s), working for the most part in the well-established (but increasingly unlikely) benchmark mSUGRA/CMSSM model.

- *LHC discovery potential for supersymmetry with $\sqrt{s} = 7$ TeV and 5-30 fb^{-1}* (with V. Barger, A. Lessa and X. Tata), Phys. Rev. **D85** 051701R (2012).

We updated LHC SUSY reach for the upcoming 2012 run which expects to gain 20-30 fb^{-1} of data. For very heavy squarks, LHC should probe gluino masses up to about 1 TeV.

- *Wh plus missing-E_T signature from gaugino pair production at the LHC* (with V. Barger, A. Lessa, W. Sreethawong and X. Tata), Phys. Rev. **D85** 055022 (2012).

Here we note that in models with $m_{\tilde{q}} \gg m_{\tilde{g}}$ and gaugino mass unification, actually $pp \to \widetilde{W}_1\widetilde{Z}_2$ is the dominant SUSY production cross section at LHC14 for $m_{\tilde{g}} \gtrsim 1$ TeV. Thus, to maximize LHC reach, one may examine the dominant $pp \to \widetilde{W}_1\widetilde{Z}_2 \to Wh + E_T^{\rm miss}$ channel which offers the best reach for very high integrated luminosity ~ 1000 fb^{-1}.

- *WZ plus missing-E_T signal from gaugino pair production at LHC7* (with V. Barger, S. Kraml, A. Lessa, W. Sreethawong and X. Tata), JHEP **1203** 092 (2012).

At LHC7 or LHC8, for $m_{\tilde{q}} \gg m_{\tilde{g}}$, actually $pp \to \widetilde{W}_1\widetilde{Z}_2$ is the dominant SUSY production cross section for $m_{\tilde{g}} \gtrsim 0.6$ TeV. Here, one may examine the dominant $pp \to \widetilde{W}_1\widetilde{Z}_2 \to WZ + E_T^{\rm miss}$ channel which offers an additional discovery channel for SUSY at LHC8.

- *Discovery potential for SUSY at a high luminosity upgrade of LHC14* (with V. Barger, A. Lessa and X. Tata), Phys. Rev. **D86** (2012) 117701.

We joined an Atlas group working (A. Nisati *et al.*) on future luminosity upgrade plans for LHC14 with 300-3000 fb^{-1} of integrated luminosity. This will serve as input to the European Strategy for HEP workshop this fall. We find the LHC14 reach for 3000 fb^{-1} is to $m_{\tilde{g}} \sim 3.2(3.6)$ TeV for $m_{\tilde{q}} \simeq m_{\tilde{g}}$ and to $m_{\tilde{g}} \sim 1.8(2.3)$ TeV for $m_{\tilde{q}} \gg m_{\tilde{g}}$. The latter reach increases to $m_{\tilde{g}} \sim 2.6$ TeV if the above mentioned $Wh + E_T^{\rm miss}$ channel is used. This work has also been summarized as a Snowmass 2013 whitepaper.

7.3 Implications of 125 GeV Higgs signal for SUSY

- *Implications of a high mass light MSSM Higgs scalar for SUSY searches at the LHC* (with V. Barger, P. Huang and A. Mustafayev), JHEP**1111** (2011) 031.

Already in summer 2011, we showed that an excess of WW^* events in the LHC Higgs search channel with 1 fb^{-1} indictated a very heavy light SUSY Higgs scalar h, which in turn requires rather heavy squarks and a large A_0 term. This paper was prescient of later Higgs results announced in December 2011 where m_h was found to be ~ 125 GeV at 3σ level.

- *Implications of a 125 GeV Higgs scalar for LHC SUSY and neutralino dark matter searches* (with V. Barger and A. Mustafayev), Phys. Rev. **D85** 075010 (2012).

This paper was posted shortly after the December 2012 LHC Higgs announcement. We discuss the implications of a 125 GeV SUSY Higgs scalar h in mSUGRA and NUHM2 models. A value $m_h \sim 125$ GeV implies a multi-TeV spectrum of squarks and sleptons and large mixing in the top-squark sector. Gluinos and other gauginos may still be light and within LHC reach. This paper at present has over 80 citations.

- *Neutralino dark matter in mSUGRA/CMSSM with a 125 GeV light Higgs scalar* (with V. Barger and A. Mustafayev), JHEP**1205** 091 (2012).

Here we focus on implications of $m_h \sim 125$ GeV for neutralino DM in mSUGRA/CMSSM. Almost all of stau co-annihilation and A-funnel annihilation are ruled out. The HB/FP has moved out to the > 15 TeV range (due to large A_t) making this region highly fine-tuned. The paradigm of thermally-produced neutralino CDM in mSUGRA/CMSSM is on its last legs.

7.4 Theory of mixed axion-neutralino dark matter

- *Coupled Boltzmann calculation of mixed axion/neutralino cold dark matter production in the early universe* (with A. Lessa and W. Sreethawong), JCAP**1201** 036 (2012).

Here we develop a unique computer code to calculate mixed axion/neutralino CDM abundance using eight coupled Boltzmann equations tracking radiation, saxion, axino, axion, neutralino and gravitino abundances, and present results for the CDM abundance, while observing BBN constraints. In this model, it is possible to observe both the axion and the neutralino WIMP DM. However, it is exceedingly difficult to accommodate models which predict an overabundance of thermally produced neutralinos, since the WIMP abundance always tends to get enhanced even more by thermal axino production and decay in the early universe. We feel this mixed axion/neutralino dark matter model will ultimately become the new paradigm case due to its many attractive features, including solving the strong CP problem.

This project was the culmination of Lessa's thesis work. He assembled a Ph. D. thesis on mixed axion-LSP dark matter which he defended successfully in August 2011. His thesis won the first ever APS Sakurai prize for outstanding dissertation in theoretical physics, and also the local OU Department of Physics Nielsen prize for outstanding Ph. D. thesis.

Recently, we have included the effects of dark radiation from saxion decay to axion pairs:

- *Dark Radiation Constraints on Mixed Axion/Neutralino Dark Matter* (with K. J. Bae and A. Lessa), JCAP **1304** (2013) 041.

7.5 Natural SUSY: a paradigm shift

At first sight, lack of SUSY signals at LHC7 were disconcerting. However, when the new LHC SUSY limits confront electroweak finetuning (EWFT), it is clear that those SUSY parameters most directly connected with naturalness are not even being probed by current LHC searches.

- *Hidden SUSY at the LHC: the light higgsino-world scenario and the role of a lepton collider* (with V. Barger and P. Huang), JHEP**1111** (2011) 031.

This paper, posted during summer 2011, pre-saged the upcoming excitement in the theory community over *natural SUSY*. In this paper, we explore the SUSY model where all soft parameters are multi-TeV, except that the superpotential μ parameter is small (as required by EWFT). The scenario is difficult to ever see at LHC. However, a Linear e^+e^- collider would become a higgsino factory, in addition to a Higgs factory!

- *Natural Supersymmetry: LHC, dark matter and ILC searches* (with V. Barger, P. Huang and X. Tata), JHEP**1205** 109 (2012).

Electroweak naturalness prefers a SUSY mass spectrum typified by light higgsinos and sub-TeV spectrum of third generation squarks and moderately heavy gluinos. We generate such spectra using high scale boundary conditions, and discuss searches for natural SUSY at LHC, ILC and at WIMP detectors. The picture of light higgsino-like WIMPs fits well with mixed axion-neutralino dark matter in that the low thermal abundance of higgsinos is augmented by axino decays with room to spare for axions as well.

- *Radiative natural SUSY with a 125 GeV Higgs boson* (with V. Barger, P. Huang, A. Mustafayev and X. Tata), arXiv:1207.3343 (2012).

A problem with natural SUSY is that sub-TeV top squarks do not feed enough into Higgs mass radiative corrections to allow for $m_h \sim 125$ GeV. We show that a large negative trilinear soft parameter A_t not only increases the Higgs mass, but it also decreases radiative corrections involving the Z mass scale. The resultant model– call *radiative natural SUSY*– has heavier top squarks but lower EWFT than usual natural SUSY. Indeed, the spectra is very much the same as the above mentioned Hidden SUSY.

- *Post-LHC7 fine-tuning in the mSUGRA/CMSSM model with a 125 GeV Higgs boson* (with V.Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata), Phys. Rev. **D87** (2013) 035017.

This paper introduces in some detail the new finetuning measures Δ_{EW} and Δ_{HS} and shows that what remains of mSUGRA after LHC8 is finetuned in the EW sector.

- *Radiative natural supersymmetry: Reconciling electroweak fine-tuning and the Higgs boson mass* (with V.Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata), Phys. Rev. **D87** (2013) 115028.

This paper adds flesh to bones precisely describing the compelling new RNS model. IN this model, light higgsinos are the hallmark signature of SUSY naturalness. They are difficult to see at LHC but should be readily apparent at a linear e^+e^- collider such as ILC.

7.6 Yukawa-unified SUSY

- *Sparticle mass spectra from $SU(5)$ SUSY GUT models with $b\tau$ Yukawa coupling unification* (with I. Gogoladze, A. Mustafayev, S. Raza and Q. Shafi), JHEP**1203** 047 (2012).

Data from LHC7 with 1-2 fb^{-1} of integrated luminosity rule out gluino pair production with dominant three-body decays to b-quarks for $m_{\tilde{g}} \lesssim 500$ GeV, which is the range expected from $t-b-\tau$ Yukawa unified SUSY. We relax the constraint to only $b-\tau$ unification as required by $SU(5)$ SUSY GUTs, which allows for much heavier gluinos.

- *A heavier gluino from $tb\tau$ Yukawa-unified SUSY* (with S. Raza and Q. Shafi), Phys. Lett. **B712** 250 (2012).

We re-examine $t-b-\tau$ Yukawa coupling unified theories as expected in simple $SO(10)$ SUSY GUTs in light of LHC7 data. While light gluinos are prefered by these models, we show many cases where $t-b-\tau$ Yukawa unification can occur with gluinos in the 0.5-3 TeV regime, beyond initial limits from LHC7 searches.

7.7 Higgs production in association with b-jets

More on these issues can be found in Prof. Chung Kao's contribution.

- *Exploring neutralino dark matter resonance annihilation via $bA, bH \to b\mu^+\mu^-$ at the LHC* (with A. Belyaev, C. Kao and P. Svantesson), Phys. Rev. **D84** (2011) 095029.

We show that $bA \to b\mu^+\mu^-$ can be observable at LHC and further that the decay $A \to \mu^+\mu^-$ can be observable which would allow a high precision LHC extraction of the $A,\ H$ mass and width.

- *Prospects for Higgs Searches with the Tri-bottom Channel in Unified SUSY Models* (with C. Kao and J. Sayre), Phys. Rev. **D85** 035021 (2012).

We delineate parameter space regions of mSUGRA, mAMSB and mGMSB where the $bA,\ bH \to 3b$ signature should be visible at LHC14, and compare to constraints from B-decay data.

7.8 Linear Collider forum and LC report

Howard Baer and Jenny List (DESY) wrote the following article for the Linear Collider Forum, which will be published in EPJC as part of a workshop report:

- *Post LHC7 SUSY benchmark points for ILC physics* (with J. List), arXiv:1205.6929 (2012).

Here, we survey the landscape of SUSY models post LHC7 and present a new set of benchmark points especially suited for ILC studies.

Baer serves as co-editor of the SUSY chapter with Battaglia and Kalinowski, and will also write up a chapter summarizing the various contributions, and the current status of LC physics.

7.9 ILC Detailed Baseline design (DBD) report: SUSY chapter

- *The International Linear Collider Technical Design Report - Volume 2: Physics* (with M. Peskin et al.) arXiv:1306.6352.

Howard Baer and Jenny List (DESY) are co-authors of the SUSY chapter for the ILC Detailed Baseline Design (DBD) report, TDR chapter 2, Physics. This report is needed to re-authorize the global effort on promoting ILC construction. At the moment, prospects for building such a machine in north Japan look very promising.

7.10 Future of axion physics

The University of Washngton hosted a several day workshop on *Vistas in Axion Physics: A Roadmap for Theoretical and Experimental Axion Physics through 2025* which was to take stock of the current status of axion physics and draw up plans for future experiments. Baer gave an invited talk here on axions in SUSY theory: here, one wants to solve simultaneously the gauge hierarchy problem and the strong CP problem. The axion lives in an axion superfield, accompanied by a spin-0 saxion and a spin-1/2 axino. The emergent cosmology solves several problems involved in the axion-only or WIMP-only approach and is very attractive, but it can allow for axions at much smaller masses: sub-micro eV scale than are currently being searched for. Baer advocated looking into possibilities to detect axions associated with much larger PQ scales than usually looked at.

7.11 European Strategy Preparatory Group:

Baer has been participating in the Open Symposium of the European Strategy Preparatory Group via the W2 group: Implications of LHC results for TeV-scale physics: new physics with missing energy signatures. He gave two talks at these group meetings. A report by this title has been assembled with several key contributions from our group, especially establishing SUSY reach possibilities for various LHC upgrade options, plus a section on implications of light higgsinos.

7.12 Isajet

In 2012, Baer, Paige and Tata released Isajet 7.83. This version includes a new measure of electroweak fine-tuning for SUSY theories and also evaluates the $B_u \to \tau\nu_\tau$ branching fraction. It also improves output for the Isasusy pMSSM model.

7.13 Particle Data Book

The 2012 version of the Particle Data Book has been released, which includes Baer and Bob Cahn's (LBL) section on cross sections for reactions in both the Standard Model and in some popular extensions:

- *Review of Particle Physics (RPP)* (with J. Beringer *et al.* [Particle Data Group Collaboration], Phys. Rev. D **86** (2012) 010001.

8 Final Report of K.A. Milton's group—Nonperturbative Quantum Field Theory

Milton's group has published or submitted 23 papers since the last renewal of this grant in May 2010. Milton and his group of students and postdocs have given many talks in international venues duing this time. We organize this past and ongoing work into two catagories, *$\mathcal{PT}$-symmetric quantum field theory* and *Casimir effects.*

8.1 $\mathcal{PT}$-symmetric quantum field theory

Milton was one of the founders of $\mathcal{PT}$-symmetric quantum mechanics, in which Hermiticity of the Hamiltonian is replaced by symmetry under the product of parity and time reversal, in a paper published ahead of the official founding paper on the subject by Bender and Boettcher. His main interest has been in extending this idea to quantum field theory, principally to quantum electrodynamics. This modification of QED consists in replacing the electric charge by an imaginary coupling, at the same time having the electric and magnetic fields behave anomalously under parity. The initial issue is not that this might be directly applicable to realistic physics, but whether such a theory is internally consistent.

Although a formal construction of a positive norm was given a number of years ago, it has proved difficult to establish that the unitarity of the scattering matrix, for example, the Källén spectral representation for the photon propagator, can be maintained in this theory. This became particularly acute when it was recognized that ordinary Feynman rules for perturbation theory in the $\mathcal{PT}$ domain may be applied without reference on the new definition of the norm. This realization has led to questions of whether, in fact, even quantum mechanical systems are consistent with probability conservation when Green's functions are examined, since the latter have to possess physical requirements of analyticity. In a paper published this year we show, quite definitively, that both in quantum electrodynamics and in analogous quantum mechanical theories, the residue or spectral function for the two-point function is not positive definite as required by probability conservation. So this suggests that these theories are in fact not viable candidates as alternatives to standard quantum mechanics and quantum field theory. However, we are continuing to investigate alternative ideas along these lines.

For example, it is known that for many theories, the non-Hermitian theory may be mapped on to a Hermitian one by a similarity transformation. That latter Hamiltonian is usually very complicated, and can only be constructed perturbatively. We have carried out such a construction for our $\mathcal{PT}$-QED, with the result for the leading term in the equivalent Hermitian Hamiltonian given by the following nonlocal expression, written in momentum space,

$$\begin{aligned}
h_{\text{int}} = i\frac{e^2}{4}\int &\frac{d^3p'd^3q'd^3r'd^3p\,d^3q\,d^3r}{(2\pi)^9}\delta(p'+q'+r')\delta(p+q+r)\\
\times\Big\{ &-i\delta(p-p')\psi^\dagger(-q')\gamma^0\gamma^i\psi(r')\psi^\dagger(q)\Gamma^i_E(p,t)\psi(-r)\\
&+\delta(r'-q)E^i(-p)A^m(p')\psi^\dagger(-q')\gamma^0\gamma^m\Gamma^i_E(p,t)\psi(-r)\\
&-\delta(r-q')E^i(-p)A^m(p')\psi^\dagger(q)\Gamma^i_E(p,t)\gamma^0\gamma^m\psi(r')\\
&+\delta(r'-q)B^i(-p)A^m(p')\psi^\dagger(-q')\gamma^0\gamma^m\Gamma^i_B(p,t)\psi(-r)\\
&-\delta(r-q')B^i(-p)A^m(p')\psi^\dagger(q)\Gamma^i_B(p,t)\gamma^0\gamma^m\psi(r')\Big\},
\end{aligned}$$

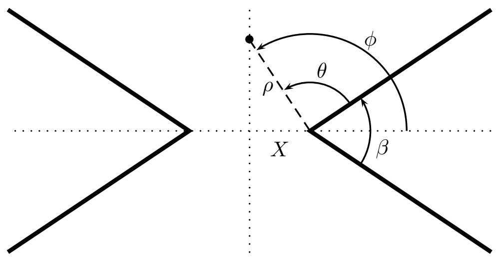


Figure 3: Two conducting wedges, with opening angles β, whose apexes are separated by a distance $2X$. The Casimir-Polder interaction between the two wedges and an anisotropically polarizable atom, located at coordinates ρ, ϕ relative to the apex of one wedge, is to be computed. In particular, we are studying the three-body interaction, which involves scattering off all three objects, as a correction to the more elementary calculation of the interaction between the atom and a single wedge, which was given in 2011. For the latter, repulsion can be achieved for the angle ϕ sufficiently close to π, provided β is smaller than 108°.

where with $\mathbf{t} = \mathbf{r} - \mathbf{q}$, $\mathbf{k} = \mathbf{p} \times \mathbf{t}$, and $\Delta = 4m^2p^2 + k^2$, we have the matrices

$$\mathbf{\Gamma}_E(\mathbf{p}, \mathbf{t}) = \frac{2}{\Delta}\left[- i\mathbf{k}\gamma_5 - 2im\gamma_5\boldsymbol{\gamma} \times \mathbf{p} - \frac{(\mathbf{p} \times \mathbf{k})}{p^2}\gamma^0\boldsymbol{\gamma} \cdot \mathbf{t} + \frac{2m}{p^2}\gamma^0\mathbf{p} \times \mathbf{k}\right],$$

$$\mathbf{\Gamma}_B(\mathbf{p}, \mathbf{t}) = \frac{2}{\Delta}\left[- 2m\boldsymbol{\gamma} \times \mathbf{p} + \frac{\mathbf{p} \cdot \mathbf{t}}{p^2}\mathbf{k} + \frac{i}{p^2}\gamma^0\gamma_5\boldsymbol{\gamma} \cdot \mathbf{p}\mathbf{p} \times \mathbf{k}\right].$$

The Green's functions of the theory may be unambiguously computed from this Hermitian theory; unitarity is, however, not guaranteed because fields must also be redefined by the similarity transformation.

8.2 Casimir effect

Milton has long been a leader in the field of quantum vacuum forces, or Casimir phenomena. These phenomena are rooted in the foundations of quantum field theory, the techniques we use are powerful Green's function and multiple scattering methods, familiar to field theorists, and solution to the divergence problems bear at the heart of renormalization, which is still more a way of dealing with a problem than solving it.

The projects we have been carrying out include the following:

- **Repulsive Casimir and Casimir-Polder forces.** On this topic, three papers were published in 2012, following on a major paper published in 2011. Casimir repulsion is receiving serious scrutiny because it may lead to practical control of Casimir forces in devices. A further substantial paper is nearing completion in which we incorporate three-body effects, so we should soon have an analytical calculation of the force on an anisotropically polarizable atom and a pair of facing half-planes, constituting a slit in a conducting plane, or more generally the force between such an atom and a pair of facing conducting wedges, as shown in Fig. 3. A paper examining three-body effects with two anisotropically polarizable atoms and a substrate has been published, which demonstrates that interesting non-monotonic effects can occur.

A region of repulsion will occur when the atom is sufficiently close to the aperture. We are also examining the effect of a circular aperture, which we treated classically in 2011. Then the question will arise, whether sufficiently anisotropic atoms can be prepared, so that this could be observed in the laboratory. This is a major stumbling block, because without coherent effects, atoms that are sufficiently anisotropically polarizable to exhibit repulsion cannot be prepared. In similar geometries we will also be looking at thermal effects, in particular at non-thermal equilibrium cases, where interesting nonmonotonic thermal transfer has recently been discovered in numerical calculations.

- **Forces between thin, corrugated, and curved surfaces.** In a paper published last year we made sense of the notion of an infinitesimally thin conducting plane, which could be described by a delta function potential, and presented a possible physical realization of such a plate. We considered the plate having both electrical permittivity and magnetic permeability and showed that only components of these tensors tangential to the surface of the plate are relevant for the optical properties of the material. This generalizes earlier work by Bordag and Barton. These results will allow us to include easily the effects of corrugation and curvature. We are now examining the generalization of these ideas to a spherical surface, and to elliptical or spheroidal bodies. These investigations will have implications for the repulsive studies, and to the general question of surface divergences to be described below. This project is a continuation of work on what we call "non-contact gears" in which not only normal forces are communicated between bodies, but lateral forces and torques as well.

- **Thermal and nonequilibrium effects.** A recent extended review by Milton highlights the continuing controversy over the magnitude of thermal Casimir forces. Actually, there is no theoretical controversy, only an apparent discrepancy with certain experiments, but not with others. From the theoretical side there is still work to do concerning out-of-thermal-equilibrium phenomena, where the Casimir-Polder force has been verified at different temperatures by Eric Cornell's group. Recently, for example, Steve Johnson's numerical group at MIT has found very interesting non-monotonic behavior in heat transfer between anisotropic bodies, which is closely related to the repulsive Casimir effect observed in such systems.

- **Universal edge effects.** There is good reason to suspect that there are universal expressions for edge effects. For example consider a finite plate above an infinite one. The proximity force approximation says when these objects are nearly touching, and parallel, the force is just the area of the finite plate times Casimir's energy/area for infinite plates. At larger separations, there are corrections. Recently it has been observed that corrections to the PFA can be computed for smooth bodies, but this procedure fails for bodies with sharp boundaries. This is an arena where our multiple-scattering techniques should enable use to get an analytic result for the leading edge correction. This will be useful for experiments and for device applications. Earlier work by our group on such effects sees just such universal effects in the weak-coupling (van der Waals) regime; analogous results are expected in strong coupling (perfectly conducting boundaries).

- **Magnetic effects.** Most work on multiple scattering calculations has concentrated on conducting bodies or perfect dielectrics. What if the bodies have both electric permittivity and magnetic permeability? This question, for the homogenous, isotropic case, has been treated for parallel slabs, but what about general bodies? The goal is to find an effective calculational scheme that will allow us to describe bodies with arbitrary electromagnetic properties in or without thermal equilibrium.

- **Surface divergences.** The quantum vacuum energy density near surfaces, be they conductors or insulators, diverges as the surface is approached. In general there is also a component of the energy that lives entirely on the boundary surfaces. Although much work has been done on these issues,

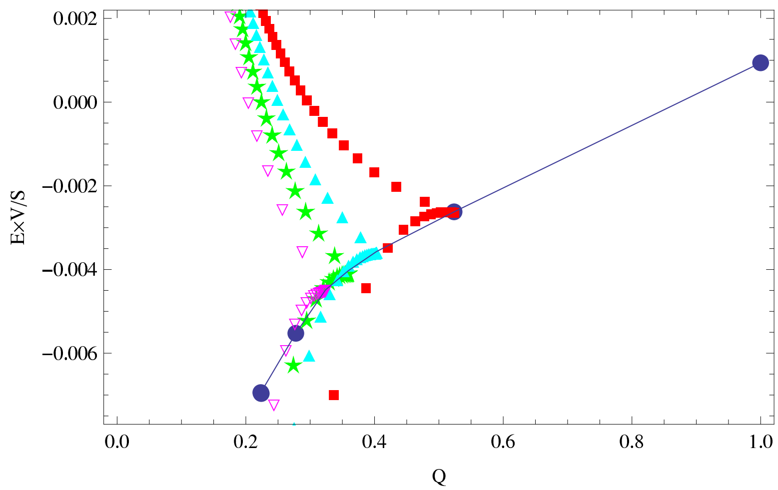


Figure 4: Scaled Dirichlet energies for tetrahedra, cubes, and sphere (filled circles), square prisms (squares) equilateral triangles (filled triangles), right isosceles triangles (stars), and hemiequilateral triangle (inverted triangles) plotted versus the isoreal quotient $Q = 36\pi V^2/S^3$, where V is the volume of the solid, and S is the surface area.

we have ever more questions. Do these terms in the energy have physical significance, manifested as a contribution to the pressure on the surfaces? Certainly these divergent energies must somehow couple to gravity, which we have elucidated. Questions of mathematical and physical consistency are being explored, as well as how such contributions are manifested in nature through, for example, renormalization. A summary of the status of this subject is contained in Milton's recent review. Milton further carefully examined the nature of the divergences in the presence of a hard, versus a soft, wall.

- **Self-energies.** Milton wrote a somewhat pedagogical oriented review article in 2010 summarizing the status and meaning of self-energies, starting from the old, but still surprising, result of Boyer that the self-energy of a perfectly conducting spherical shell is repulsive, not attractive as for parallel plates. Subsequently, with his recently graduated Ph.D. student Elom Abalo and Lev Kaplan at Tulane, he examined classes of cylinders and polyhedra for which unambiguous and finite internal Casimir self-energies can be extracted. It turns out, beyond the well known rectangular prisms, Casimir energies for prisms of infinite or finite length can be computed exactly and unambiguously, provided they possess one of the three integrable triangular cross sections, equilateral, hemiequilateral, and hemisquare (right isosceles), where the spectrum is known explicitly. The energies are finite, because no curvature is involved, and remarkably, there is amazing systematic behavior, which extends to cylinders of right triangular cross-section computed numerically. The first paper dealt with infinite triangular cylinders and similar remarkable systematics emerge for the three integrable tetrahedra. See Fig. 4. We are currently extending the latter calculation to electrodynamics, and to higher dimensions.

- **Torque anomaly.** Recently, it was suggested that there was some sort of breakdown of quantum field theory in the presence of boundaries, manifesting itself as a torque anomaly. In particular, Fulling et al. used the finite energy-momentum-stress tensor in the presence of a perfectly conducting wedge, calculated many years ago by Deutsch and Candelas, to compute the torque on one of the wedge boundaries, where the latter was cutoff by integrating the torque density down to a minimum lower radius greater than zero. They observed that that torque is not equal to the negative derivative of the energy obtained by integrating the energy density down to the same minimum radius. This motivated a calculation of the torque and energy in an annular sector obtained by the intersection of the wedge with two coaxial cylinders. In a paper just published we showed that for the analogous scalar case, which also exhibited a torque anomaly in the absence of the cylindrical boundaries, the point-split regulated torque and energy indeed exhibit an anomaly, unless the point-splitting is along the axis direction. In any case, because of curvature divergences, no unambiguous finite part can be extracted. However, that ambiguity is linear in the wedge angle; if the condition is imposed that the linear term be removed, the resulting torque and energy are finite, and exhibit no anomaly. In a second paper, recently submitted, we demonstrate the same phenomenon takes place for the electromagnetic field, so there is no torque anomaly present here either. This is a nontrivial generalization, since the anomaly found by Fulling et al. is linear for the Dirichlet scalar case, but nonlinear for the conducting electromagnetic case.

9 Research Activities–Chung Kao: Particle Theory beyond the Standard Model

In the past few years, our theoretical research has centered around several interesting and important topics in particle physics phenomenology at the CERN Large Hadron Collider (LHC) and neutralino dark matter.

The Co-PI, Kao, along with the postdoctoral research associate and a graduate student, have published six refereed papers and have submitted two papers to Physics Letters B. In addition, Professor Kao presented 12 talks at international conferences and workshops as well as 5 seminars at universities and national laboratories.

Last year, I gave two presentations on "Discovering Colorons at the Large Hadron Collider" and "Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC" at the 36th International Conference on High Energy Physics (ICHEP 2012), July 4–July 11, 2012, in Melbourne, Australia, and while there, I witnessed the live announcement of LHC Higgs discovery in Geneva and in Melbourne.

• **Personnel** Working with Co-PI Kao are one postdoctoral research associate and several graduate students: Phillip McCoy, Maren Padeffke, Priyangi Wickramarachchi and Kesheng Yang. Our former postdoctoral fellow (Dr. Joshua Sayre) has moved to the University of Pittsburgh and a new postdoctoral fellow (Dr. Baris Altunkaynak) has arrived at the University of Oklahoma.

9.1 Overview of My Research Activities

The Standard Model has been very successful in explaining almost all experimental data to date, culminating in the discovery of the top quark and the tau neutrino, and finally, a scalar particle that appears to be the long awaited Higgs boson has emerged at the Large Hadron Collider. The most important experimental goals of the CERN Large Hadron Collider (LHC) are the investigation of the mechanism for electroweak symmetry breaking (EWSB) and the search for new physics beyond the Standard Model (SM).

In this section, we present our results in Higgs phenomenology and particle theory beyond the Standard Model:

(a) confirming the LHC Higgs discovery with WW,

(b) Higgs phenomenology in supersymmetric unified models,

(c) Higgs searches with cosmic connection,

(d) flavor changing neutral Higgs interactions, and

(e) phenomenology of colorons.

9.2 Confirming the LHC Higgs Discovery with WW

We investigate the prospects of observing a neutral Higgs boson decaying into a pair of W bosons (one real and the other virtual), followed by the W decays into $qq'\ell\nu$ or $jj\ell\nu$ at the CERN Large Hadron Collider (LHC). Assuming that the missing transverse energy comes solely from the neutrino in W decay, we can reconstruct the W masses and then the Higgs mass. At the LHC with a center of mass energy ($\sqrt{s}$) of 8 TeV and an integrated luminosity (L) of 25 fb^{-1}, we can potentially establish a 6σ signal. A 5σ discovery of $H \to WW^* \to jj\ell\nu$ for $\sqrt{s} = 14$ TeV can be achieved with $L = 6$ fb^{-1}. The discovery of $H \to WW$ implies that the recently discovered new boson is a CP-even scalar if its spin is zero. In addition, this channel will provide a good opportunity to study the HWW coupling.

- C. Kao and J. Sayre, "Confirming the LHC Higgs Discovery with WW," Phys. Lett. B **722**, 324 (2013) [arXiv:1212.0929 [hep-ph]].

9.3 Prospects for Higgs Searches in SUSY Unified Models

We investigate the prospects for the discovery of a neutral Higgs boson produced in association with a b quark, followed by the Higgs decay into a pair of bottom quarks, $pp \to b\phi^0 \to bb\bar{b} + X$, or a pair of tau leptons, $pp \to b\phi^0 \to b\tau^+\tau^- + X$, at the CERN Large Hadron Collider (LHC) within the framework of unified supersymmetric models. The Higgs boson ϕ^0 can be a heavy scalar H^0 or a pseudoscalar A^0. Furthermore, this direct discovery channel is compared with the indirect Higgs searches in the rare decay $B_s \to \mu^+\mu^-$ at hadron colliders. Promising results are found for the minimal supergravity (mSUGRA) model, the anomaly mediated supersymmetry breaking (AMSB) model, and the gauge mediated supersymmetry breaking (GMSB) model. We find that the indirect search for $B(B_s \to \mu^+\mu^-) \geq 5 \times 10^{-9}$ is complementary to the direct search for $b\phi^0 \to bb\bar{b}$ with $\sqrt{s} = 14$ TeV and an integrated luminosity (L) of 300 fb^{-1}. In the AMSB and GMSB models, $b\phi^0 \to bb\bar{b}$ with $L = 300$ fb^{-1} covers a larger area in the parameter space than $B(B_s \to \mu^+\mu^-) \geq 5 \times 10^{-9}$. In addition, we present constraints from $b \to s\gamma$ and muon anomalous dipole moment (Δa_μ) on the parameter space.

- C. Kao and K. Yang, "Prospects for Higgs Searches with $b\tau^+\tau^-$ in Supersymmetric Unified Models," submitted to Phys. Lett. B, University of Oklahoma Report, OU-HEP-130729.

- H. Baer, C. Kao and J. Sayre, "Prospects for Higgs Searches with the Tri-bottom Channel in Unified SUSY Models," Phys. Rev. D **85** (2012) 035021 [arXiv:1112.5922 [hep-ph]].

9.4 Implications of LHC Higgs Searches for Neutralino Dark Matter

One of the main channels which allows for a large rate of neutralino dark matter (χ_1) annihilation in the early Universe is via the pseudoscalar Higgs A-resonance. In this case, the measured dark matter abundance can be obtained in the minimal supergravity (mSUGRA) model when $\tan\beta \sim 50$ and $2m_{\chi_1} \sim m_A$. We investigate the reaction $pp \to b\phi \to b\mu^+\mu^- + X$ (where $\phi = A^0$ or H^0) at the CERN LHC where requiring the tag of a single b-jet allows for amplification of the signal-to-background ratio. The rare but observable Higgs decay to muon pairs allows for a precise measurement of the Higgs boson mass and decay width. We evaluate signal and background using

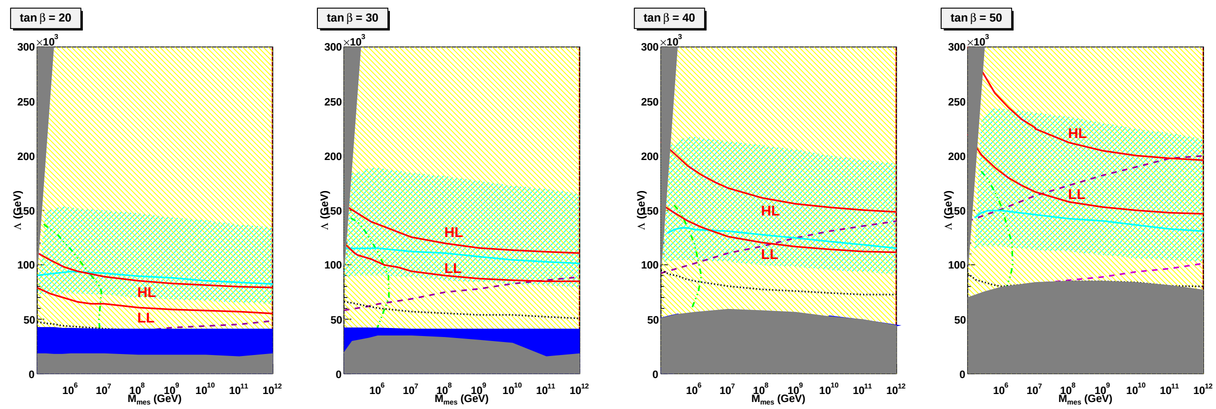


Figure 5: Discovery contours (solid red) for the 3 b-quark Higgs signal in mGMSB with 30 fb^{-1} (LL) and 300 fb^{-1} (HL). The experimental values with 2σ errors are shown for Δa_μ (cyan, forward-slant hatched) and $b \to s\gamma$ (yellow, backward-slant hatched; central value in green dash-dot-dot). $B_s \to \mu^+\mu^-$ limits of $1. \times 10^{-8}$ (current, lighter) and $5. \times 10^{-9}$ (darker) are indicated by dashed magenta lines. Current LHC exclusion limits are shown for $\phi^0 \to \tau^+\tau^-$ (dotted black).

CalcHEP, with muon energy smearing according to the CMS detector. We find that the Higgs width (Γ_A) can typically be determined with the accuracy up to $\sim 8\%$ ($\sim 17\%$) for $m_A \sim 400$ (600) GeV assuming 10^3 fb^{-1} of integrated luminosity. Therefore, the $pp \to b\phi \to b\mu^+\mu^- + X$ process provides a unique possibility for direct Γ_A measurement at the LHC. While the Higgs width is correlated with the parameter $\tan\beta$ for a given value of m_A, extracting $\tan\beta$ is complicated by an overlap of the A and H peaks, radiative corrections to the b and τ Yukawa couplings, and the possibility that SUSY decay modes of the Higgs may be open. In the case where a dilepton mass edge from $\chi_2 \to \ell^+\ell^-\chi_1$ is visible, it should be possible to test the relation that $2m_{\chi_1} \sim m_A$.

- H. Baer, A. Belyaev, C. Kao and P. Svantesson, "Exploring neutralino dark matter resonance annihilation via $bA, bH-> bmu^+mu^-$ at the LHC," Phys. Rev. D **84**, 095029 (2011) [arXiv:1106.5055 [hep-ph]].

9.5 When the Higgs meets the Top: Search for $t \to ch^0$ at the LHC

The newly discovered "Higgs boson" h^0, being lighter than the top quark t, opens up new probes for flavor and mass generation. In the general two Higgs doublet model, new ct, cc and tt Yukawa couplings could modify h^0 properties. If $t \to ch^0$ occurs at the percent level, the observed ZZ^* and $\gamma\gamma$ signal events may have accompanying cbW activity coming from $t\bar{t}$ feeddown. We suggest that $t \to ch^0$ can be searched for via $h^0 \to ZZ^*$, $\gamma\gamma$, WW^* and $b\bar{b}$, perhaps even $\tau^+\tau^-$ modes in $t\bar{t}$ events. Existing data might be able to reveal some clues for $t \to ch^0$ signature, or push the branching ratio $\mathcal{B}(t \to ch^0)$ down to below the percent level.

- C. Kao, H. -Y. Cheng, W. -S. Hou and J. Sayre, "Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC," Phys. Lett. B **716**, 225 (2012) [arXiv:1112.1707 [hep-ph]].

- K. -F. Chen, W. -S. Hou, C. Kao and M. Kohda, "When the Higgs meets the Top: Search for $t \to ch^0$ at the LHC," submitted to Phys. Lett. B, arXiv:1304.8037 [hep-ph],

9.6 Searching for Colorons at the LHC

Several theories of physics beyond the Standard Model give rise to massive spin-1 color octet particles (colorons). Examples are topcolor models and Kaluza-Klein excitations of the gluon in the universal extra-dimensional models. A new strong interaction with a broken $SU(3)_{\rm HC}$ hyper-color symmetry leads to hyper-quark bound states with spin-1 ($\tilde{\rho}$) or spin-0 ($\tilde{\pi}$). The effective Lagrangian for the massive color octets can be derived by analogy with the spontaneous breaking of chiral symmetry in the Standard Model.

We investigate the prospects for the discovery of massive hyper-gluons using data from the early runs of the CERN Large Hadron Collider with $\sqrt{s} = 7$ TeV and assuming an integrated luminosity of 1 fb^{-1}. A phenomenological Lagrangian is adopted to evaluate the cross section of a pair of colored vector bosons (coloron, $\tilde{\rho}$) decaying into four colored scalar resonances (hyper-pion, $\tilde{\pi}$), which then decay into eight gluons. The dominant physics backgrounds from the production of $8g, 7g1q, 6g2q$, and $5g3q$ are included. We find an abundance of signal events and that realistic cuts reduce the background enough to establish a 5σ signal for $m_{\tilde{\pi}}\lesssim$220 GeV or $m_{\tilde{\rho}}\lesssim$733 GeV. The cross sections of the coloron signal (σ_s) and the physics background (σ_b) from the production of $8g$, $7g1q$, $6g2q$, and $5g3q$ are evaluated with acceptance cuts and fixed mass cuts versus $M_{\tilde{\pi}}$. We have applied two sets of fixed mass cuts: (a) $|M_{2j} - M_{\tilde{\pi}}| < 0.10 M_{\tilde{\pi}}$ and $|M_{4j} - M_{\tilde{\rho}}| < 0.15 M_{\tilde{\rho}}$, or (b) $|M_{2j} - M_{\tilde{\pi}}| < 0.15 M_{\tilde{\pi}}$ and $|M_{4j} - M_{\tilde{\rho}}| < 0.20 M_{\tilde{\rho}}$. If the ATLAS and CMS detectors have excellent mass resolution, we will be able to apply the narrower fixed mass cut (a), which has the potential to discover the colorons and hyper-pions up to $M_{\tilde{\pi}} = 220$ GeV ($M_{\tilde{\rho}} = 733$ GeV). A wider fixed mass cut (b) will allow more background events, which results in a slightly reduced discovery reach of $M_{\tilde{\pi}} = 210$ GeV ($M_{\tilde{\rho}} = 700$ GeV).

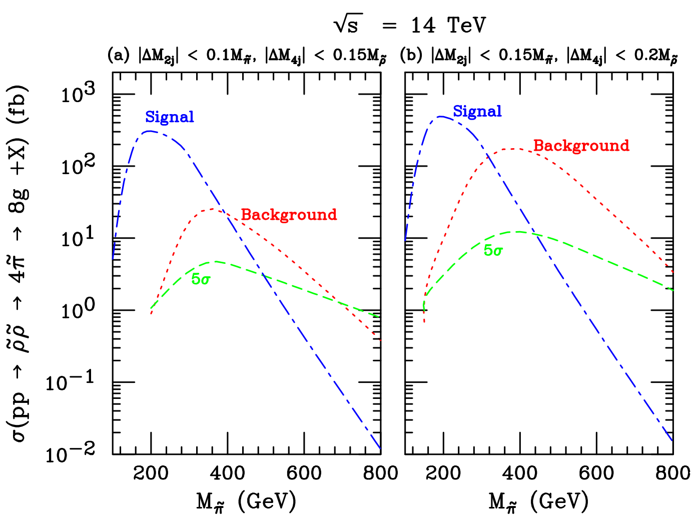


Figure 6: The cross section for $pp \to \tilde{\rho}\tilde{\rho} \to 4\tilde{\pi} \to 8g + X$ (blue, dot-dash) at the LHC with $\sqrt{s} = 14$ TeV, as a function of $M_{\tilde{\pi}}$ with acceptance cuts on p_T, η, and ΔR. We have applied two sets of fixed mass cuts: (a) $|M_{2j} - M_{\tilde{\pi}}| < 0.10 M_{\tilde{\pi}}$ and $|M_{4j} - M_{\tilde{\rho}}| < 0.15 M_{\tilde{\rho}}$, or (b) $|M_{2j} - M_{\tilde{\pi}}| < 0.15 M_{\tilde{\pi}}$ and $|M_{4j} - M_{\tilde{\rho}}| < 0.20 M_{\tilde{\rho}}$. Also shown are the SM background cross section (σ_b)(red, dash) and the minimal signal cross section required by a 5 sigma criterion (green, dot). For $M_{\tilde{\pi}} = 100$ GeV, the 5σ signal cross section and σ_b (green diamond, red cross) are calculated with lower p_T cuts.

In Fig. 6 we present cross sections of the coloron signal (σ_s) and the physics background (σ_b) from the production of $8g$, $7g1q$, $6g2q$, and $5g3q$ at $\sqrt{s} = 14$ TeV with acceptance cuts and fixed mass cuts versus $M_{\tilde{\pi}}$. Also shown is the minimal signal cross section that is required by a 5 sigma criterion for 30 fb^{-1} of integrated luminosity. We find an abundance of signal events and that realistic cuts reduce the background enough to establish a 5σ signal for the coloron mass of up to 733 GeV with an integrated luminosity of 1 fb^{-1} or 833 GeV with 5 fb^{-1} at early stage LHC. Furthermore, we find that a 5σ signal can be established for $M_{\tilde{\pi}} \lesssim 495$ GeV ($M_{\tilde{\rho}} \lesssim 1650$ GeV) at the LHC with $\sqrt{s} = 14$ TeV.

- D. A. Dicus, C. Kao, S. Nandi and J. Sayre, "Discovering Colorons at the Early Stage LHC," Phys. Rev. D **83**, 091702 (2011) [Rapid Communication] [arXiv:1012.5694 [hep-ph]].
- J. Sayre, D. A. Dicus, C. Kao and S. Nandi, "Searching for Colorons at the Large Hadron Collider," Phys. Rev. D **84**, 015011 (2011) [arXiv:1105.3219 [hep-ph]].

10 Status of Research and Future Plans: Task B (Yun Wang) Theoretical tools for measuring dark energy from galaxy clustering

10.1 Introduction:

Solving the mystery of dark energy is one of the most exciting challenges in particle physics and cosmology today. Galaxy clustering provides one of the primary methods of probing dark energy. Our group has done ground-breaking work developing an advanced analysis method for measuring dark energy from galaxy clustering. We have validated our method using mock data, and successfully applied it to available current data of the Luminous Red Galaxies (LRG) from the Sloan Digital Sky Survey (SDSS). We obtained the first simultaneous measurements of the cosmic expansion history $H(z)$ and the angular diameter distance $D_A(z)$ from data. Our work has significant implications for future surveys in establishing the feasibility of measuring both $H(z)$ and $D_A(z)$ from galaxy clustering data. Such measurements are essential in differentiating a cosmological constant (i.e., vacuum energy) from dynamical dark energy as the cause of the observed cosmic acceleration.

In the next year, our group plans to focus on developing theoretical tools for analyzing data that allow the simultaneous measurements of $H(z)$, $D_A(z)$, and the growth rate of cosmic large scale structure $f_g(z)$. This would allow us to differentiate dark energy and modified gravity models as the explanation for the observed cosmic acceleration. Modified gravity models can give identical $H(z)$ as dark energy models by design, but they generally give different $f_g(z)$.

10.2 Personnel: (Yun Wang, Chia-Hsun Chuang, Shuang Wang, Maddumage Hemantha, Mi Dai)

Wang supervised graduate students Chia-Hsun Chuang, Maddumage Hemantha, and Mi Dai on this project. Chuang graduated in December 2011, and was a postdoc with the project until September 2012. Hemantha expects to complete his thesis work approximately in December 2013. Shuang Wang has been a postdoc on this project since October 2012. He is expected to leave in September 2013, when the funding runs out for a postdoc on this project. Mi Dai began work on this project in January 2013.

Currently, our focus is on developing and improving theoretical tools for measuring dark energy and testing gravity using real and simulated data. Wang also works on improving the data analysis of type Ia supernovae to minimize systematic effects and constrain dark energy. We are collaborating with Carlton Baugh (Durham, U.K.), Alex Merson (Durham, U.K.), Will Percival (Portsmouth, U.K.), Luigi Guzzo (INAF, Italy), and Rick Kessler (Unov. of Chicago).

10.3 Completed Work

1. *Effects of cosmological model assumptions on galaxy redshift survey measurements,* by Lado Samushia, Will J. Percival, Luigi Guzzo, Yun Wang, Andrea Cimatti, Carlton Baugh, James E. Geach, Cedric Lacey, Elisabetta Majerotto, Pia Mukherjee, and Alvaro Orsi, MNRAS, 410, 1993 (2011)

   We investigate the link between geometric and growth rate constraints on dark energy from galaxy redshift surveys, and argue that it strongly depends on the cosmological assumptions adopted when analyzing data. Using representative assumptions for the parameters of the Euclid survey in order to provide a baseline future experiment, we show how the derived constraints change due to different model assumptions. We argue that even the assumption of a Friedman-Robertson-Walker (FRW) space-time is sufficient to reduce the importance of the coupling to a significant degree. We consider different possible ways in which the Universe could deviate from the ΛCDM model, and show how the coupling between geometrical constraints and structure growth affects the measurement of such deviations.

2. *Neutrino constraints from future nearly all-sky spectroscopic galaxy surveys,* by Carmelita Carbone, Licia Verde, Yun Wang, Andrea Cimatti, JCAP 03 (2011) 030

   We examine whether future, nearly all-sky galaxy redshift surveys, in combination with CMB priors, will be able to detect the signature of the cosmic neutrino background and determine the absolute neutrino mass scale. We also consider what constraints can be imposed on the effective number of neutrino species. We find that, in combination with Planck, the next generation galaxy probes will be able to detect at better than 3σ level and measure the mass of cosmic neutrinos: a) in a cosmology-independent way, if the sum of neutrino masses is above 0.1 eV; b) assuming spatial flatness and that dark energy is a cosmological constant, otherwise. We find that the sensitivity of such surveys is well suited to span the entire range of neutrino masses allowed by neutrino oscillation experiments, and to yield a clear detection of non-zero neutrino mass.

3. *Wide-Field InfraRed Survey Telescope (WFIRST) Interim Report,* by the WFIRST SDT, arXiv:1108.1374

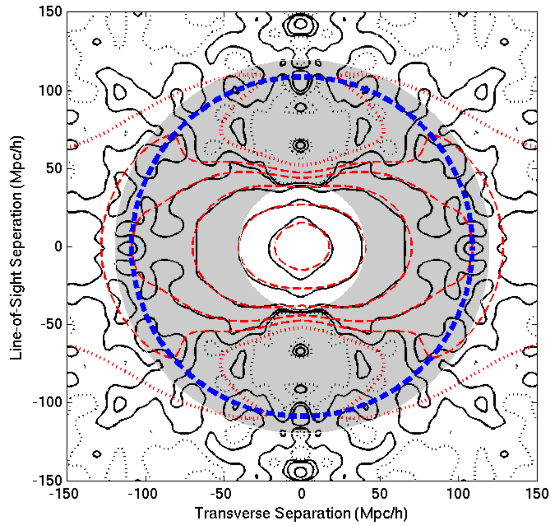
   WFIRST was recommended by the Astro 2010 Decadal Survey as the highest priority for a large space mission. The WFIRST Science Definition Team (SDT) was chartered to work with the WFIRST Project Offices at GSFC and JPL to produce a Design Reference Mission (DRM) for WFIRST. This paper describes an Interim DRM. The DRM will be completed in summer 2012. Wang led the science study of galaxy clustering as a dark energy probe.

4. *Euclid Definition Study Report,* by Laureijs, R., et al., arXiv1110.3193

   The Euclid mission will use weak gravitational Lensing and galaxy clustering as two independent primary cosmological probes to explore the nature of dark energy. Euclid is a Medium Class mission of the ESA Cosmic Vision 2015-2025 programme, with a foreseen launch date in 2019. This report (also known as the Euclid Red Book) describes the outcome of the Phase A study. Wang was one of the main contributors to the galaxy clustering and dark energy science study.

5. *Measurements of $H(z)$ and $D_A(z)$ from the Two-Dimensional Two-Point Correlation Function of Sloan Digital Sky Survey Luminous Red Galaxies,* by Chia-Hsun Chuang, Yun Wang, MNRAS, 426, 226 (2012)

   We present a method for measuring the Hubble parameter, $H(z)$, and angular diameter distance, $D_A(z)$, from the two-dimensional two-point correlation function, and validate it using LasDamas



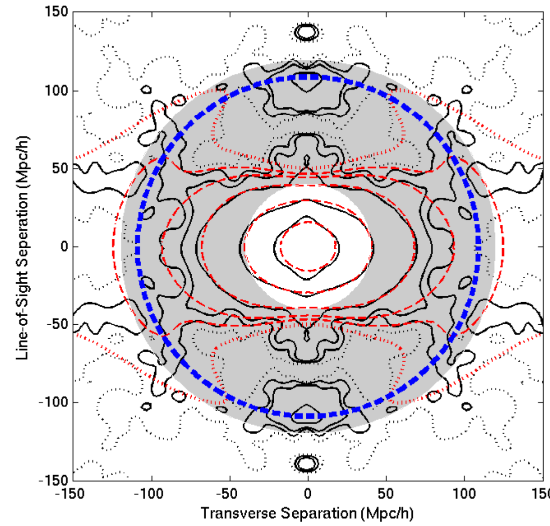


Figure 7: The two-dimensional two-point correlation function (2D 2PCF) measured from SDSS DR7 LRGs (top panel) and a LasDamas SDSS LRG mock catalog (bottom panel) in a redshift range $0.16 < z < 0.44$ (solid black contours), compared to a theoretical correlation function with parameters close to the best fit values in the likelihood analysis (dashed red contours). In both figures, the shaded disk indicates the scale range considered ($s = 40 - 120\ h^{-1}$Mpc) in this study. The thick dashed blue circle denotes the baryon acoustic oscillation scale. The observed 2D 2PCF has been smoothed by a Gaussian filter with rms variance of $2h^{-1}$Mpc for illustration in these figures only; smoothing is not used in our likelihood analysis. The contour levels are $\xi = 0.5, 0.1, 0.025, 0.01, 0.005, 0$. The $\xi = 0$ contours are denoted with dotted lines for clarity. (Chuang & Wang, 2012)

mock galaxy catalogs. Applying our method to the sample of luminous red galaxies (LRGs) from the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7), we measure $H(z = 0.35) \equiv H(0.35) = 82.1^{+4.8}_{-4.9}\mathrm{km\,s^{-1}Mpc^{-1}}$, $D_A(z = 0.35) \equiv D_A(0.35) = 1048^{+60}_{-58}$ Mpc without assuming a dark energy model or a flat Universe. We find that the derived measurements of $H(0.35)\, r_s(z_d)$ and $r_s(z_d)/D_A(0.35)$ (where $r_s(z_d)$ is the sound horizon at the drag epoch) are nearly uncorrelated, have tighter constraints and are more robust with respect to possible systematic effects. Our galaxy clustering measurements of $\{H(0.35)\, r_s(z_d), r_s(z_d)/D_A(0.35)\} = \{13020 \pm 530(\mathrm{km/s}), 0.1518 \pm 0.0062\}$ (with the correlation coefficient $r = -0.0584$) can be used to combine with cosmic microwave background and any other cosmological data sets to constrain dark energy. Our results represent the first measurements of $H(z)$ and $D_A(z)$ (or $H(z)\, r_s(z_d)$ and $r_s(z_d)/D_A(0.35)$) from galaxy clustering data. This work has significant implications for future surveys in establishing the feasibility of measuring both $H(z)$ and $D_A(z)$ from galaxy clustering data. Fig.7 shows the 2D 2PCF measured from the SDSS LRGs and a single LasDamas SDSS LRG mock catalog for comparison. The similarity between the data and the mock in the range of scales used (indicated by the shaded disk) is apparent. Due to the current limitations in the modeling of systematic effects, only the quasi-linear scale range of $s = 40 - 120\, h^{-1}$Mpc is used for a conservative estimate in this analysis.

6. *A Comparative Study of Dark Energy Constraints from Current Observational Data,* by Yun Wang, Chia-Hsun Chuang, & Pia Mukherjee, Phys. Rev. D 85, 023517 (2012)

We examine how dark energy constraints from current observational data depend on the analysis methods used: the analysis of Type Ia supernovae (SNe Ia), and that of galaxy clustering data. We generalize the flux-averaging analysis method of SNe Ia to allow correlated errors of SNe Ia,

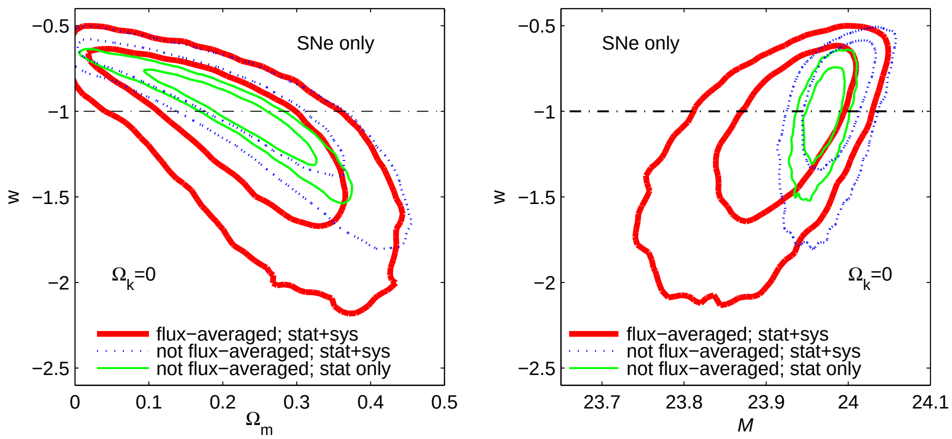


Figure 8: The 2D marginalized contours of $(w, \Omega_m, \mathcal{M})$ for SNe data compiled by Conley et al. (2011) (with and without flux-averaging), assuming a flat universe. The contours are at 68% and 95% confidence levels. (Wang, Chuang, & Mukherjee 2012)

in order to reduce the systematic bias due to weak lensing of SNe Ia. We find that flux-averaging leads to larger errors on dark energy and cosmological parameters if only SN Ia data are used (see Fig.8). When the latest SN Ia data are combined with WMAP 7 year results, the latest Hubble constant (H_0) measurement using the Hubble Space Telescope (HST), and gamma ray burst (GRB) data, flux-averaging of SNe Ia increases the concordance with other data, and leads to significantly tighter constraints on the dark energy density at $z = 1$, and the cosmic curvature Ω_k. The galaxy clustering measurements of $H(z = 0.35)r_s(z_d)$ and $r_s(z_d)/D_A(z = 0.35)$ by Chuang & Wang (2011) are consistent with SN Ia data, given the same priors (CMB+H_0+GRB), and lead to significantly improved dark energy constraints when combined. Current data are fully consistent with a cosmological constant and a flat universe, but the uncertainties are large (see Fig.9). The supernova flux-averaging code from this work has been made publicly available.

7. *Observational Probes of Dark Energy,* by Yun Wang, Proceeding paper for an invited plenary talk at Spanish Relativity Meeting 2011 (ERE2011), arXiv:1201.2110

   In this review, Wang examined Type Ia supernovae and galaxy clustering as dark energy probes, and discuss recent results and future prospects.

8. *Robust constraints on dark energy and gravity from galaxy clustering data,* by Yun Wang, MNRAS, 423, 3631 (2012)

   Galaxy clustering data provide a powerful probe of dark energy. We examine how the constraints on the scaled expansion history of the universe, $x_h(z) = H(z)s$ (with s denoting the sound horizon at the drag epoch), and the scaled angular diameter distance, $x_d(z) = D_A(z)/s$, depend on the methods used to analyze the galaxy clustering data. We find that using the observed galaxy power spectrum, $P_g^{obs}(k)$, $x_h(z)$ and $x_d(z)$ are measured more accurately and are significantly less correlated with each other, compared to using only the information from the baryon acoustic oscillations (BAO) in $P_g^{obs}(k)$. Using the $\{x_h(z), x_d(z)\}$ from $P_g^{obs}(k)$ gives a DETF dark energy FoM approximately a factor of two larger than using the $\{x_h(z), x_d(z)\}$ from BAO only; this provides a robust conservative method to go beyond BAO only in extracting dark energy information from galaxy clustering data. We find that a Stage IV galaxy redshift survey, with $0.7 < z < 2$ over 15,000 (deg)^2, can measure $\{x_h(z), x_d(z), f_g(z)G(z)\tilde{P}_0^{1/2}/s^4\}$ with high precision (where $f_g(z)$ and

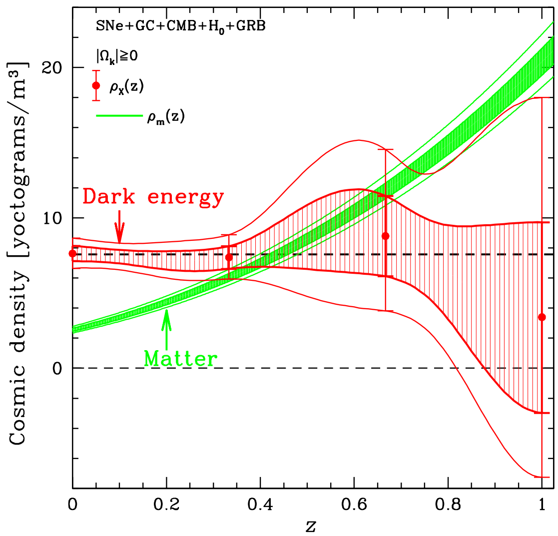


Figure 9: Dark energy density as a function of redshift measured from cosmic microwave background anisotropy (CMB) data from WMAP 7 year observations, 472 Type Ia supernovae (SNe Ia) (compiled by Conley et al. 2011), galaxy clustering measurements from Sloan Digital Sky Survey Luminous Red Galaxies (Chuang & Wang 2011), 69 Gamma Ray Bursts (Wang 2008), and the latest Hubble constant (H_0) measurement using the Hubble Space Telescope (Riess et al. 2011). (Wang, Chuang, & Mukherjee 2012)

$G(z)$ are the linear growth rate and factor of large scale structure respectively, and $\tilde{P}_0$ is the dimensionless normalization of $P_g^{obs}(k)$), when redshift-space distortion information is included. The measurement of $f_g(z)G(z)\tilde{P}_0^{1/2}/s^4$ provides a powerful test of gravity, and significantly boosts the dark energy FoM when general relativity is assumed.

9. *Probing deviations from General Relativity with the Euclid spectroscopic survey,* by Elisabetta Majerotto, Luigi Guzzo, Lado Samushia, Will J. Percival, Yun Wang, Sylvain de la Torre, Bianca Garilli, Paolo Franzetti, Emanuel Rossetti, Andrea Cimatti, Carmelita Carbone, Nathan Roche, Giovanni Zamorani, MNRAS, 424, 1392 (2012)

   We discuss the ability of the planned Euclid mission to detect deviations from General Relativity using its extensive redshift survey of more than 50 Million galaxies. Constraints on the gravity theory are placed measuring the growth rate of structure within 14 redshift bins between $z = 0.7$ and $z = 2$. The growth rate is measured from redshift-space distortions, i.e. the anisotropy of the clustering pattern induced by coherent peculiar motions. This is performed in the overall context of the Euclid spectroscopic survey, which will simultaneously measure the expansion history of the universe, using the power spectrum and its baryonic features as a standard ruler, accounting for the relative degeneracies of expansion and growth parameters. The resulting expected errors on the growth rate in the different redshift bins, expressed through the quantity $f\sigma_8$, range between 1.3% and 4.4%. We discuss the optimisation of the survey configuration and investigate the important dependence on the growth parameterisation and the assumed cosmological model. We show how a specific parameterisation could actually drive the design towards artificially restricted regions of the parameter space. Finally, in the framework of the popular "γ -parameterisation", we show that the Euclid spectroscopic survey alone will already be able to provide substantial evidence (in Bayesian terms) if the growth index differs from the GR value $\gamma = 0.55$ by at least ~ 0.13. This will combine with the comparable inference power provided by the Euclid weak lensing survey, resulting in Euclid's unique ability to provide a decisive test of modified gravity.

10. *Using Multipoles of the Correlation Function to Measure $H(z)$, $D_A(z)$, and $\beta(z)$ From SDSS Luminous Red Galaxies*, by Chia-Hsun Chuang, & Yun Wang, MNRAS, 431, 2634 (2013)

    Galaxy clustering data can be used to measure the cosmic expansion history $H(z)$, the angular-diameter distance $D_A(z)$, and the linear redshift-space distortion parameter $\beta(z)$. Here we present a method for using effective multipoles of the galaxy two-point correlation function ($\xi_0(s)$, $\xi_2(s)$, $\xi_4(s)$, and $\xi_6(s)$, with s denoting the comoving separation) to measure $H(z)$, $D_A(z)$, and $\beta(z)$, and validate it using LasDamas mock galaxy catalogs. Our definition of effective multipoles explicitly incorporates the discreteness of measurements, and treats the measured correlation function and its theoretical model on the same footing. We find that for the mock data, $\xi_0+\xi_2+\xi_4$ captures nearly all the information, and gives significantly stronger constraints on $H(z)$, $D_A(z)$, and $\beta(z)$, compared to using only $\xi_0+\xi_2$. We apply our method to the sample of luminous red galaxies (LRGs) from the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7) without assuming a dark energy model or a flat Universe. We find that $\xi_4(s)$ deviates on scales of $s < 60\mathrm{Mpc}/h$ from the measurement from mock data (in contrast to $\xi_0(s)$, $\xi_2(s)$, and $\xi_6(s)$), thus we only use $\xi_0+\xi_2$ for our fiducial constraints. We obtain $\{H(0.35), D_A(0.35), \Omega_m h^2, \beta(z)\} = \{79.6^{+8.3}_{-8.7} km/s/Mpc, 1057^{+88}_{-87} Mpc, 0.103 \pm 0.015, 0.44 \pm 0.15\}$ using $\xi_0+\xi_2$. We find that $H(0.35)r_s(z_d)/c$ and $D_A(0.35)/r_s(z_d)$ (where $r_s(z_d)$ is the sound horizon at the drag epoch) are more tightly constrained: $\{H(0.35)r_s(z_d)/c, D_A(0.35)/r_s(z_d)\} = \{0.0437^{+0.0041}_{-0.0043}, 6.48^{+0.44}_{-0.43}\}$ using $\xi_0+\xi_2$.

11. *Modeling the Anisotropic Two-Point Galaxy Correlation Function on Small Scales and Improved Measurements of $H(z)$, $D_A(z)$, and $f(z)\sigma_8(z)$ from the Sloan Digital Sky Survey DR7 Luminous Red Galaxies*, by Chia-Hsun Chuang, & Yun Wang, MNRAS accepted (2013), arXiv:1209.0210

    We present a simple and efficient phenomenological model for the two-dimensional two-point galaxy correlation function that works well over a wide range of scales, from large scales down to scales as small as 25Mpc/h. Our model incorporates nonlinear effects, a scale-dependent galaxy bias on small scales, and allows the redshift-space distortions to be scale and direction dependent. We validate our model using LasDamas mock catalogs, and apply it to the Sloan Digital Sky Survey (SDSS) DR7 Luminous Red Galaxies (LRGs). Using only the monopole and quadrupole of the correlation function measured from the SDSS DR7 LRGs, we obtain improved measurements $H(z)r_s(z_d)/c = 0.0433 \pm 0.0042$, $D_A(z)/r_s(z_d) = 6.59 \pm 0.46$, and $f(z)\sigma_8(z) = 0.429 \pm 0.089$ at $z = 0.35$, using the scale range of 25¡s¡120Mpc/h. We expect our results and model to be useful in tightening dark energy and gravity constraints from the full analysis of current and future galaxy clustering data.

12. *Toward More Realistic Forecasting of Dark Energy Constraints from Galaxy Redshift Surveys,* by Yun Wang, Chia-Hsun Chuang, Christopher M. Hirata, MNRAS, 430, 2446 (2013)

    Galaxy redshift surveys are becoming increasingly important as a dark energy probe. We improve the forecasting of dark energy constraints from galaxy redshift surveys by using the "dewiggled" galaxy power spectrum, $P_{dw}(k)$, in the Fisher matrix calculations. Since $P_{dw}(k)$ is a good fit to real galaxy clustering data over most of the scale range of interest, our approach is more realistic compared to previous work in forecasting dark energy constraints from galaxy redshift surveys. We find that our new approach gives results in excellent agreement when compared to the results from the actual data analysis of the clustering of the Sloan Digital Sky Survey DR7 luminous red galaxies. We provide forecasts of the dark energy constraints from a plausible Stage IV galaxy redshift survey.

13. *Linear dark energy equation of state revealed by supernovae?* by Vincenzo Salzano, Yun Wang, Irene Sendra, Ruth Lazkoz, MPLA submitted (2013)

    We propose a test to detect the linearity of the dark energy equation of state, and apply it to two different Type Ia Supernova (SN Ia) data sets, Union2.1 and SNLS3. We find that: a. current SN Ia data are well described by a dark energy equation of state linear in the cosmic scale factor a, at least up to a redshift $z = 1$, independent of the pivot points chosen for the linear relation; b. there is no significant evidence of any deviation from linearity. This apparent linearity may reflect the limit of dark energy information extractable from current SN Ia data.

14. *Distance Priors from Planck and Dark Energy Constraints from Current Data*, by Yun Wang, and Shuang Wang, PRD submitted (2013), arXiv:1304.4514

    We derive distance priors from Planck first data release, and examine their impact on dark energy constraints from current observational data. We give the mean values and covariance matrix of $\{R, l_a, \Omega_b h^2, n_s\}$, which give an efficient summary of Planck data. The CMB shift parameters are $R = \sqrt{\Omega_m h^2}\, r(z_*)$, and $l_a = \pi r(z_*)/r_s(z_*)$, where z_* is the redshift at the last scattering surface, and $r(z_*)$ and $r_s(z_*)$ denote our comoving distance to z_* and sound horizon at z_* respectively. We find that Planck distance priors are significantly tighter than those from WMAP9. However, adding Planck distance priors does not lead to significantly improved dark energy constraints using current data, compared to adding WMAP9 distance priors. This is because Planck data appear to favor a higher matter density and lower Hubble constant, in tension with most of the other current cosmological data sets. Adding Planck distance priors to current data leads to a marginal inconsistency with a cosmological constant in a flat Universe.

15. *Exploring the Systematic Uncertainties of Type Ia Supernovae as Cosmological Probes,* by Shuang Wang, and Yun Wang, PRD accepted (2013), arXiv:1306.6423

    We explore the systematic uncertainties of using Type Ia supernovae (SNe Ia) as cosmological probes, using the Supernova Legacy Survey Three Year data (SNLS3). We focus on studying the possible evolution of the stretch-luminosity parameter α and the color-luminosity parameter β, by allowing α and β to be function of redshift, z. We find no evidence for the redshift evolution of α. We find that without flux-averaging SNe, β is consistent with being a constant when only statistical uncertainties are included, but it increases significantly with z when systematic uncertainties are also included. The evolution of β becomes marginal when all the SNe are flux-averaged, and β is consistent with being a constant when only SNe at $z \geq 0.04$ are flux-averaged. Our results are insensitive to the lightcurve fitter used to derive the SNLS3 sample, or the functional form of $\alpha(z)$ and $\beta(z)$ assumed. It is likely that the apparent evolution of β with z for SNe without flux-averaging is a consequence of unknown systematic effects; flux-averaging reduces the impact of these effects by averaging them within each redshift bin. Assuming constant α and β, we find that the flux-averaging of SNe has a significant impact on the distance-redshift relation.

10.4 Current and future projects

Wang is developing robust methods for measuring $H(z)$, $D_A(z)$ and $f_g(z)$ from galaxy clustering data. Wang and Hemantha are developing advanced methods for measuring $H(z)$ and $D_A(z)$ from the galaxy power spectrum; this is complementary to Chuang & Wang (2011), and provides a cross-check with different systematic effects.

Wang is collaborating with Baugh and Merson to simulate future galaxy clustering data, and develop methods that are applicable to both real and simulated data. This will result in realistic forecasts for future galaxy redshift surveys.

Shuang Wang is investigating the impact of flux-averaging on dark energy constraints from supernovae. Mi dai is studying optimized methods for supernova light curve fitting.

11 Appendix 1: Bibliography & References Cited

References

[1] DØ Collaboration, Phys. Rev. D **82**, 032002 (2010).

[2] "Measurement of Direct Photon Pair Production Cross Sections in $p\overline{p}$ Collisions at $\sqrt{s} = 1.96$ TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B690**, 108 (2010).

[3] M. Drees and t. Han, Phys. ReV. Lett. **77**, 4142 (1996).

[4] T. Sjöstrand and M. van Zijl, Phys. Rev. D **36**, 2019 (1987).

[5] "Double Parton Interactions in γ+3 Jet Events in $p\overline{p}$ Collisions at $\sqrt{s} = 1.96$ TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D 81**, 052012 (2010).

[6] "Azimuthal Decorrelations and Multiple Parton Interactions in γ+2 Jet and γ+3 Jet Events in $p\overline{p}$ Collisions at $\sqrt{s} = 1.96$ TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D83**, 052008 (2011).

[7] "Testing Yukawa-unified SUSY during year 1 of LHC: the role of multiple b-jets, dileptons and missing E_T," H. Baer, *et al.*, JHEP 1002 055 (2010), arXiv:0911.4739

[8] "Search for supersymmetry in pp collisions at $\sqrt{s}$=7 TeV in final states with missing transverse momentum and b-jets with the ATLAS detector," G. Aad *et al.*, ATLAS Collaboration, Phys Rev. D **85** 112006 (2012).

[9] "Natural supersymmetry: LHC, dark matter and ILC searches," H. Baer, *et al.*, JHEP05 (2012) 109, arXiv:1203.5539

[10] "Search for supersymmetry in pp collisions at $\sqrt{s}$=7 TeV in final states with missing transverse momentum and b-jets with the ATLAS detector," G. Aad *et al.*, ATLAS Collaboration, PLB 701 398 (2011).

[11] ATLAS-CONF-2011-098 and ATLAS-CONF-2011-130.

[12] "Search for Scalar Bottom Quark Pair Production with the ATLAS Detector in pp Collisions at $\sqrt{s}$=7 TeV." G. Aad *et al.*, ATLAS Collaboration, *Phys. Rev. Lett.* **108** 181802 (2012).

[13] "Search for supersymmetry in pp collisions at $\sqrt{s}$=7 TeV in final states with missing transverse momentum and b-jets with the ATLAS detector. G. Aad *et al.* (ATLAS Collaboration) arXiv:1203.6193.

[14] ATLAS Collaboration Eur. Phys. J. C **71** 1577 (2011).

[15] "B-tagging for top physics analyses with early ATLAS data at $\sqrt{s} = 7$ TeV" M. Saleem, et. al, (ATL-PHYS-INT-2010-133).

[16] "Mis-identified lepton backgrounds to top quark pair production" M. Saleem, et. al (ATL-PHYS-INT-2010-139).

[17] "Prospects of measurement of $t\bar{t}$ inclusive cross-section using the likelihood template method with early ATLAS data at $\sqrt{s} = 10$ TeV" B. Abi, D. Jana, et. al (ATL-PHYS-INT-2010-003).

[18] "Measurement of the top quark pair production cross-section with ATLAS in the single lepton channel", ATLAS Collaboration, Phys. Lett. **B711** (2012) 244-263.

[19] FS. Moch and P. Uwer, Ohys. Rev. D **78** 034003 (2008); U. Langenfeld, S. Moch, and P. Uwer, Proc. XVII Int. Workshop on Deep-Inelastic Scattering and Related Topic, dx.doi.org/10.3360/dis.2009.131, arXiv:hep-ph/0907.2527 ; M. Beneke *et al.*, Phys. Lett. B **690** 483 (2010);

[20] "Measurement of the cross section for $t\bar{t}+$jets production using a kinematic fit method with the ATLAS detector", ATLAS Collaboration, (ATLAS-CONF-2012-083).

[21] T. Han and M.B. Magro Physics Letters B **476**, 79 (2000).

[22] C. Yue, H. Zong, and L. Liu Mod. Phys. Lett. A **18**, 2187 (2003).

[23] C. Kao arXiv:1112.1707v1 [hep-ph] (2011).

[24] ATLAS collaboration, Phys. Rev. Lett. **107** 231801 (2011).

[25] "Search for the Higgs boson in the $H \to WW \to \ell\nu jj$ decay channel $\sqrt{s} = 7$ TeV with the ATLAS detector", ATLAS collaboration, arXiv:1206.6074v1.

[26] C. Kao, "Discovering the Higgs Bosons of Minimal Supersymmetry with Tau Leptons and a Bottom Quark", arXiv:0711.0232v1 (2007).

[27] "Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC",ATLAS Collaboration, New J. Phys., **13** (2011) 053033.

[28] W. Beenakker, R. Hopker and M. Spira, hep-ph/9611232.

[29] "WZ plus missing E_T signal from gaugino pair production at LHC7", H. Baer, *et al.*, JHEP03 (2012) 092 arXiv:1201.5382

[30] Abazov, V. M. *et al.* (D0 Collaboration) Phys. Rev. D **80**, 051107 (2010).

[31] ATLAS Collaboration, arXiv:1207.7214v1 (2012), and CMS Collaboration, arXiv:1207.7235v1 (2012)

[32] ATLAS Collaboration ATLAS-CONF-2012-83 presented at ICHEP Melbourne, Australia (2012).

[33] "Measurement of the Inclusive Jet Cross Section in $p\overline{p}$ Collisions at $\sqrt{s}$=1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **101**, 062001 (2008).

[34] "Measurement of the Differential Cross Section for the Production of an Isolated Photon with Associated Jet in $p\overline{p}$ Collisions at $\sqrt{s}$=1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B666**, 435 (2008).

[35] "Measurement of Differential $Z/\gamma^* +$ jet $+ X$ Cross Sections in $p\overline{p}$ Collisions at $\sqrt{s}$=1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B669**, 278 (2008).

[36] "Measurement of Dijet Angular Distributions at $\sqrt{s}$ = 1.96 TeV and Searches for Quark Compositeness and Extra Spatial Dimensions," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **103**, 191803 (2009).

[37] "Measurements of Differential Cross Sections of $Z\gamma^*$ + jets + X Events in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B678**, 45 (2009).

[38] "Measurement of $\gamma + b + X$ and $\gamma + c + X$ Production Cross Sections in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **102**, 192002 (2009).

[39] "Determination of the Strong Coupling Constant from the Inclusive Jet Cross Section in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D80**, 111107 (2009).

[40] "Measurement of $Z/\gamma*$+jet + X Angular Distributions in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B682**, 370 (2010),

[41] "Measurement of the Dijet Invariant Mass Cross Section in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B693**, 531 (2010).

[42] A.D. Martin, W.J. Stirling, R.S Thorne, G. Watt, *Eur. Phys. Jour.* **C63** (2009).

[43] "High Mass Exclusive Diffractive Dijet Production in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B705**, 193 (2011).

[44] "Measurements of Inclusive W+Jets Production Rates as a Function of Jet Transverse Momentum in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B705**, 200 (2011),

[45] "Measurement of Three-Jet Differential Cross Sections $d\sigma_{3jet}/dM_{3jet}$ in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B704**, 434 (2011),

[46] "Measurement of the Ratio of Inclusive Cross Sections $\sigma(p\overline{p} \to Z + b$-Quark Jet) / $\sigma(p\overline{p} \to Z$ + Jet) at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D83**, 031105 (2011).

[47] "Measurement Inclusive Jet Cross Section in $\sigma(p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D85**, 052006 (2011).

[48] "Measurement of the Differential Cross Section $d\sigma/dt$ in Elastic $\sigma(p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D86**, 012009 (2012).

[49] "Measurement of angular correlation of jets at $\sqrt{s}$ = 1.96 TeV and determination of the strong coupling constant at high momentum transfers." DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B718** 56, (2012).

[50] "Measurement of the Photon +b-Jet Differential Cross Seciont in $\sigma(p\overline{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B714** 32, (2012).

[51] "Measurement of the $p\overline{p}$ to $W + b = X$ production cross sectcion at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B718** 1314, (2013).

[52] "Measurement of the $\gamma + c$-jet cross section and the ratio $\gamma + c$ and $\gamma + b$ cross sections in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B719** 354, (2013).

[53] "Measurement of the ratio of three-jet to two-jet cross sections in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B720** 6, (2013).

[54] "Measurement of the combined rapidity and p_T dependence of dijet azimuthal decorrelations in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B721** 212, (2013).

[55] "Measurement of the ratio of differential cross sections $\sigma(p\overline{p} \to Z + b$ jet$)/\sigma(p\overline{p} \to Z+$ jet$)$ $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev.* **D87** 092010, (2013).

[56] "Measurement of differential cross section for isolated direct photon pair production in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Lett.* **B726** 6, (2013).

[57] "First Search for Multijet Resonances in $\sqrt{s} = 1.96$ TeV $\sigma(p\overline{p}$ Collisions," CDF Collaboration, T. Aaltonen *et. al.*, *Phys. Rev. Lett.* **107**, 042001 (2011).

[58] "Search for Three-Jet Resonances in pp Collisions at $\sqrt{s}$ = 17 TeV," CMC Collaboration, S. Chatrchyan *et. al.*, *Phys. Rev. Lett.* **107**, 101801 (2011).

[59] "Observation and Properties of the $X(3872)$ Decaying to $J/\psi\pi^+\pi^-$ in $p\overline{p}$ Collisions at $\sqrt{s}$=1.96 TeV," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **93**, 162002 (2004).

[60] "Direct Limits on the B^0_s mixing frequency," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **97**, 021802 (2006).

[61] "Direct Observation of the Strange b Baryon Ξ^-_b," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **99**, 052001 (2007).

[62] "Observation of the Doubly Strange b Baryon Ω^-_b," DØ Collaboration, V.M. Abazov *et. al.*, *Phys. Rev. Lett.* **101**, 232002 (2008).

[63] "Measurement of the Relative Branching Ratio of $B^0_s \to J/\psi f_0(980)$ to $B^0_s \to J/\psi\phi$," DØ Collaboration, V.M. Abazov *et. al.*, Phys Rev.D **85**, 011103(2012).

[64] "Study of the Decay $B^0_s \to J/\psi f'_2(1525)$ in $\mu^+\mu^-K^+K^-$ Final States," DØ Collaboration, V.M. Abazov *et. al.*, Submitted Phys. Rev. D, arXiv:1204.5723.

[65] ATL-COM-PHYS-2012-758

12 Appendix 2: Recent Ph.D recipients

Name	Dissertation	Graduation Date	Advisor
Sohrab Hossain	Measurement of Top Quark Pair Production Cross Section in the tau + jets Final State Using 1 fb^{-1} of Data	2009	Gutierrez
Mandy Rominsky	Measurement of the Double Differential Dijet Mass Cross Section	2009	Strauss
Shibi Rajagopalan	LHC Phenomenology and Dark Matter Considerations for Various Anomaly Mediated Supersymmetry Breaking Models	2010	Baer
Prachi Parashar	Geometrical investigations of the Casimir effect: Thickness and corrugation dependencies	2011	Milton
Andre Lessa	Cosmology of the PQMSSM	2011	Baer
Chia-Hsun Chuang	Probing dark energy using galaxy clustering data	2011	Wang
Elom Abalo	Casimir energies of cavities: The geometry question	2012	Milton
M. Razzak Meera Lebbai	Studies of Cosmic Rays and Minimum Bias Measurements in pp Collisions at $\sqrt{s} = 0.9$ and 7 TeV with the ATLAS Detector at the LHC	2011	Skubic
Ayesh Jayasinghe	Measurement of the Top Quark Mass in the all Hadronic Final State	2013	Gutierrez
Dilip Jana	Search for the Standard Model Higgs boson production and decay to W boson pairs using the lepton + MET + jets channel using 4.7 fb^{-1} of data recorded by the ATLAS detector at $\sqrt{s}$ = 7 TeV proton-proton collision.	2013	Skubic

Table 1: Recent HEP Ph.D recipients at the University of Oklahoma.

13 Appendix 3: Talks and Publications

Experimental Talks in 2010

Physics Talks

D. Jana
$t\bar{t}$ Cross Section Measurement in μ + Jets Channel at ATLAS Using Kinematic Information
APS April Meeting
Feb 2010, Washington, DC

A. Marzin
Top physics in ATLAS
LHC Days in Split, Split, Croatia
4-9 Oct 2010

M. Saleem
Top Observation Status at Atlas (Invited talk)
US ATLAS Physics and Performance, Brookhaven National Laboratory(BNL), New York, USA
Oct 05, 2010

M. Saleem
Top cross-section measurements with early ATLAS data
3rd International Workshop on Top Quark Physics - Top2010, Brouge, Belgium
May 31- June 04, 2010

M. Saleem
Mistag Rate measurements on Atlas Data (Invited Talk)
Flavour Tagging Workshop Freiburg , Germany
Oct 13 - 15, 2010

P. Gutierrez
"Review of charged Higgs searches at the Tevatron"
Prospects for Charged Higgs Discovery at Colliders, Uppsala University, Sweden
27-30, September 2010,

M. Strauss
"Recent QCD Measurements at the Tevatron"
Rencontres de Blois, Blois, France
15-22, July 2010

P. Skubic
"Summary of Top Forum Workshop"
US ATLAS Physics and Performance Jamboree
Brookhaven National Laboratory, Upton, NY, USA
February 10, 2010

P. Skubic
"Top Physics WG Status"
Analysis Jamboree
University of Texas at Arlington, Arlington, TX, USA
May 17-19, 2010

P. Skubic
"Summary of the SUSY with b-jets Work"
SUSY Jamboree
Brookhaven National Laboratory, Upton, NY, USA
January 11-14, 2011

Experimental Technical Talks

H. Severini
"Employing Open Science Grid to support National Grid Initiatives in South America and South Africa"
Invited Poster Presentation at CHEP 2010, Academia Sinica, Taipei, Taiwan
October 18-22, 2010

H.Severini
"BeStMan Storage Configuration at OU SWT2"
Invited Talk at the OSG Storage Forum, University of Chicago, Chicago, IL
September 22, 2010

H.Severini
"The State of DOSAR"
Invited Talk at the DOSAR IX Workshop, The University of Johannesburg, Johannesburg, South Africa
April 6, 2010

P. Skubic
"Wrap-up and Discussion of Goals and Action Items"
DOSAR IX Workshop
The University of Johannesburg, Johannesburg, South Africa
April 8, 2010

B. Abbott
"OSG : Status and Future from the perspective of D0/DOSAR"
Invited Talk at the DOSAR IX Workshop,
The University of Johannesburg, Johannesburg, South Africa
April 7, 2010

Experimental HEP Talks in 2011

Physics Talks

P. Skubic
"Summary of the SUSY with b-jets Work"
SUSY Jamboree Brookhaven National Laboratory, Upton, NY
January 11-14, 2011

M. Saleem
"Results from top Cross-section measurement at ATLAS with 2010 data(Invited Talk)"
ATLAS Physics Jamboree, University of Texas, Arlington, TX
Apr 15 - 17, 2011

A. Marzin
"Search for supersymmetry using final states with heavy flavour jets and missing transverse momentum"
U.S. ATLAS Southwest Jamboree, University of Texas at Arlington, TX
27-29 April, 2011

P. Skubic
"Top Physics Status"
U.S. ATLAS Southwest Jamboree University of Texas at Arlington, TX
April 27-29, 2011

P. Skubic
"Winter Conference 2010-2011 Review"
U.S. ATLAS Southwest Jamboree University of Texas at Arlington, TX
April 27-29, 2011

A. Jayasinghe
"Background model for measurement of top mass in fully hadronic channel at D0"
APS April Meeting, Anaheim, California
April 30 - May 3, 2011.

P. Svoisky
"Tevatron (CDF+D0) BSM Higgs results"
Higgs cross sections for the LHC, Brookhaven National Laboratory
May 4-6, 2011.

B. Abbott
"$B_s \to J/\psi\phi$ from DØ."
FPCP Conference, Maale Hachamisha, Israel
May 23 - 27, 2011

M. Saleem
"Results from Top Physics at ATLAS"
23rd Rencontres de Blois, Particle Physics and Cosmology at Chateau Royal de Blois, Blois, France.
May 29 - June 03, 2011

M. Saleem
"A Milestone towards the LHC discoveries: Recent Measurements on the top quark physics at

ATLAS." (Invited Talk in SLAC Seminar)
Stanford Linear Accelerator Center - SLAC, Menlo Park, CA, USA.
June 21, 2011

P. Svoisky
"Measurement of three-jet differential cross sections $d\sigma_{3\text{jet}}/dM_{3\text{jet}}$ in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1.96$ TeV"
Europhysics Conference on High-Energy Physics, Grenoble, France
July 20-27 2011.

B. Abbott
"Measurement of the relative branching ratio of $B_s \to J/\psi f_0(980)$ to $B_s \to J/\psi\phi$."
Meeting of the Division of Particles and Fields of the American Physical Society.
Brown University, Providence, Rhode Island, USA.
Aug 08 - 13, 2011

M. Saleem
"Measurement of the top-pair production cross-section at ATLAS"
Meeting of the Division of Particles and Fields of the American Physical Society, Brown University, Providence, Rhode Island, USA.
Aug 08 - 13, 2011

M. Saleem
"Measurement of the top pair production cross-section at Atlas"
US ATLAS Physics Meeting, Boston University, Massachusetts, USA
Aug. 15 - 17, 2011

S. Norberg
"Direct photon corss section with 1fb^{-1}"
US Atlas workshop, Boston, Massachusetts, United States
August 15-17, 2011

D. Jana
"Poster Presentation: Search for Higgs Boson Production and Decay to W boson Pairs using the Lepton + MET + Jets Channel"
Lepton Photon Conference, Mumbai, India
August 22-27, 2011

A. Marzin
"Search for supersymmetry using final states with heavy flavour jets and missing transverse momentum at the ATLAS and CMS experiments"
Implications of LHC results for TeV-scale physics, CERN, Geneva
29 August - 2 September, 2011

M. Saleem
"Top cross section measurements in ATLAS (special young scientist talk)"
Beyond the Standard Model: Results with the 7 TeV LHC Collision Data at International Center for Theoretical Physics (ICTP), Trieste, Italy.

Sep. 19 - 23, 2011

S. Norberg
"Inclusive direct photon rel 16 e/gamma workshop"
e/gamma workshop, Lago Maggiore, Italy
October 24-28, 2011

Technical Talks

H. Severini
"Lustre Storage Configuration at the OU Southwest Tier2 Cluster"
Invited Talk at the ATLAS Technical Interchange Meeting,
JINR, Dubna, Russia, June 2, 2011

S. Norberg
"Poster session Tile calorimer Low Voltage Power Supplies Supplies Monitoring"
US Atlas workshop, Boston, Massachusetts, United States
August 15-17, 2011

Experimental HEP Talks in 2012

Physics Talks

A. Marzin
"Searches for 3rd generation SUSY in ATLAS"
Rencontres de Moriond EW 2012, La Thuile, Italy
3-10 March, 2012

A. Marzin
"ATLAS stop searches with b-jets (direct and gluino-mediated)"
BNL Workshop on SUSY with 5 fb^{-1} at the LHC, BNL, USA
2-4 May, 201

M. Strauss
"Measurements of Differential W+Jets Production and α_s from Multijet Production."
ICHEP, Melbourne, Australia
4-11 July, 2012

M. Saleem
"Results from $t\bar{t}$ + jet Cross-section measurement at ATLAS with 2011 data" (Invited Talk)
US ATLAS Physics Meeting, University of Michigan in Ann Arbor, MI, USA.
Aug 13 - 15, 2012

S. Norberg
"Direct Photon Cross Section Using the ATLAS Detector with 2011 data"
APS meeting, Atlanta, Georgia
April 2, 2012

P. Skubic and C. Kao
"Experimental and Theoretical Aspects of the Higgs Discovery"
Colloquium, University of Oklahoma in Norman, OK, USA.
Sept. 6, 2012

Technical Talks

P. Skubic
"Introduction to Analysis Example Tutorial"
DOSAR Grid Computing School, KUNST, Kumasi, Ghana
Aug. 8, 2012

Experimental Publications in 2010

Publications with Major OU Contribution

1. "Measurement of $t\bar{t}$ production in the τ + jets topology using $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV", V.M. Abazov *et al.* (D0 Collaboration), Phys. Rev. D **82**, 071102 (2010)
2. "Measurement of the Dijet Invariant Mass Cross Section in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," V.M. Abazov *et al.* (D0 Collaboration) Phys. Lett. B 693, 531 (2010)
3. "Double Parton Interactions in γ+3 Jet Events in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV," V.M. Abazov *et al.* (D0 Collaboration) Phys. Rev. D 81, 052012 (2010)
4. "Measurement of the Direct Photon Producation Cross Section in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV" V.M. Abazov *et al.* (D0 Collaboration) Phys. Lett. B. **690**, 108 (2010).
5. "Teaching High Performance Computing via Videoconferencing" H. Neeman, H. Severini, D. Wu, and K. Kantardjieff ACM Inroads, Vol 1, No 1, March 2010, pp. 67-71
6. "Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s}$ = 7 TeV," arXiv:1012.1792

Experimental HEP Publications in 2011

Publications with Major OU Contribution

1. "Measurement of the top quark pair production cross-section in pp collisions at $\sqrt{s}$ = 7 TeV in single lepton final states with ATLAS", submitted in Phys. Lett. B.
2. "Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s}$ = 7 TeV", Published in Eur. Phys. J. C71 1577 (2011).
3. "Measurement of the Relative Branching Ratio of $B_s^0 \rightarrow J/\psi f_0(980)$ to $B_s^0 \rightarrow J/\psi\phi$" arXiv:1110.4272, Phys. Rev. D 85, 011103 (2012).

4. "Measurement of the CP-Violating Phase φ_s^{Jpsi} using the Flavor-Tagged Decay $B_s^0 \to J/\psi\varphi$ in 8 fb^{-1} of $\bar{p}p$ Collisions", Phys. Rev. D bf 85, 032006 (2012)
5. "Search for supersymmetry in pp collisions at $\sqrt{s} = 7$TeV in final states with missing transverse momentum and b-jets", Phys.Lett.B 701 (2011) 398-416
6. "Search for scalar bottom pair production with the ATLAS detector in pp Collisions at $\sqrt{s} = 7$ TeV" arXiv : hep-ex 1112.3832 (submitted to Physical Review Letters)
7. "Search for SuperSymmetry in pp Collisions at $\sqrt{s}$ =7 TeV in final states with missing transverse momentum and b-jets with the ATLAS detector." ATL-COM-PHYS-2011-1724 (To be submitted to PRD)
8. "Measurement of the Ratio of Inclusive Cross Sections $\sigma(p\bar{p} \to$ Z + b jet) / $\sigma(p\bar{p} \to$ Z + jet) at $\sqrt{s} = 1.96$ TeV," V.M. Abazov *et al.* (D0 Collaboration) Phys. Rev. D **83**, 031105 (2011).
9. "High Mass Exclusive Diffractive Dijet Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV" V.M. Abazov *et al.* (D0 Collaboration) Phys. Lett. B. **705**, 193 (2011).
10. "Measurements of Inclusive W+Jets Production Rates as a Function of Jet Transverse Momentum in $\mathrm{p\bar{p}}$ Collisions at $\sqrt{s} = 1.96$ TeV." Phys. Lett. B 705, 200 (2011)
11. "Measurement of Three-Jet Differential Cross Sections $\mathrm{d}\sigma_{3jet}/\mathrm{dM_{3jet}}$ in $\mathrm{p\bar{p}}$ Collisions at $\sqrt{s} = 1.96$ TeV. " Phys. Lett. B 704, 434 (2011)
12. "Azimuthal Decorrelations and Multiple Parton Interactions in γ + 2 Jet and γ + 3 Jet Events in $\mathrm{p\bar{p}}$ Collisions at $\sqrt{s} = 1.96$ TeV." Phys. Rev. D 83, 052008 (2011)
13. "Search for Higgs Boson Production and Decay to W boson Pairs using the Lepton + MET + Jets Channel." PRL 107, 231801 (2011)
14. "Limits on the production of the Standard Model Higgs Boson in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector." EPJC-11-06-035.R2

Experimental HEP Publications in 2012

Publications with Major OU Contribution

1. "Search for scalar bottom pair production with the ATLAS detector in pp Collisions at $\sqrt{s} = 7$ TeV" PRL 108, 181802 (2012). arXiv : hep-ex 1112.3832.
2. "Search for SuperSymmetry in pp Collisions at $\sqrt{s}$ =7 TeV in final states with missing transverse momentum and b-jets with the ATLAS detector." PRD 85, 112006 (2012), arXiv : hep-ex 1203.6193.
3. "Search for top and bottom squarks from gluino pair production in final states with missing transverse energy and at least three b-jets with the ATLAS detector" arXiv : hep-ex 1207.4686 (submitted to European Physical Journal C)
4. "Measurement of the Relative Branching Ratio of $B_s^0 \to J/\psi f_0(980)$ to $B_s^0 \to J/\psi\phi$," DØ Collaboration, V.M. Abazov *et. al.*, Phys Rev.D **85**, 011103(2012).

5. "Measurement of the Inclusive Jet Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV," V.M. Abazov *et al.* (D0 Collaboration) Phys. Rev.D **85**, 052006 (2012)

6. "Study of the Decay $B_s^0 \rightarrow J/\psi f_2'(1525)$ in $\mu^+\mu^-K^+K^-$ Final States," DØ Collaboration, V.M. Abazov *et. al.*, Submitted Phys. Rev. D, arXiv:1204.5723.

7. "Measurement of the cross section in $t\bar{t}$+jets using kinematics fit method with the ATLAS detector", Published as ATLAS-CONF-2012-083 ; https://cdsweb.cern.ch/record/1460395 (Presented in ICHEP 2012)

8. "Measurement of the top quark pair production cross-section in pp collisions at $\sqrt(s) = 7$ TeV in single lepton final states with ATLAS", Phys.Lett. B711 244-263 (2012).

9. DØ Collaboration, Study of the Decay $B_s^0 \rightarrow J/\psi f_2(1525)$ in $\mu^+\mu^-K^+K^-$ Final States, submitted to Phys. Rev. D.

10. DØ Collaboration, Measurement of the Semileptonic Charge Asymmetry using $B_s^0 \rightarrow D_s X$ Decays, submitted to Phys. Rev. Lett.

11. DØ Collaboration, Measurement of the Semileptonic Charge Asymmetry using B^0 meson mixing with the DØ detector, submitted to Phys. Rev. D.

Proceedings, Conference Notes and Internal Pub notes 2010

1. Top quark cross-section measurements with the early ATLAS data
Conference Proceedings for 3rd International Workshop on Top Quark Physics - Top2010, Il Nuovo Cimento C,
Vol. 33, Issue 4, pp. 331-334, 2010.

2. Calibrating the b-Tag Efficiency and Mistag Rate of the SV0 b-Tagging Algorithm in 3 pb^{-1} of Data with the ATLAS Detector
Approved Conference Note, ATLAS-CONF-2010-099.

3. Prospects of measurement of ttbar inclusive cross-section using the likelihood template method with early ATLAS data at 10 TeV ATL-PHYS-INT-2010-003

4. Lepton Trigger and Identification for the first Top quark observation (Top Note 1)

5. Technical Aspects of the first top pair analyses (Top Note 8)

6. Prospects for the Top Pair Production Cross-section at $\sqrt{s}$= 10 TeV in the Single Lepton Channel in ATLAS ATL-PHYS-PUB-2009-087

7. Search for top pair candidate events in ATLAS at sqrt(s)=7 TeV (ATLAS-CONF-2010-063)

8. Measurement of the Top Pair Production Cross Section in 7 TeV

9. Proton-Proton Collisions using Pretag Kinematics for Moriond 2011

10. Higgs Boson Searches using the H$\rightarrow$ WW $\rightarrow \ell\nu$qq Decay Mode with the ATLAS Detector at 7 TeV for Moriond 2011

Experimental Proceedings, Conference Notes and Internal Pub notes 2011

1. "$B_s \to J/\psi\phi$ from DØ." Published in conference proceedings for FPCP 2011, Maale Hachamisha, Israel.

2. "Measurement of the relative branching ratio of $B_s \to J/\psi f_0(980)$ to $B_s \to J/\psi\phi$", Published in conference proceedings for DPF 2011, Brown University, Providence, RI, USA.

3. "Invariant mass distribution of jet pairs produced in association with one lepton and missing transverse energy at the ATLAS experiment", Published as ATLAS-COM-CONF-2011-07

4. "Measurement of three-jet differential cross sections at Tevatron", published in the conference proceedings Europhysics Conference on High-Energy Physics, Grenoble, France, PoS(EPS-HEP2011)279.

5. "Calibrating the b-Tag efficiency and Mis-tag Rate in 35 pb^{-1} of Data with the ATLAS Detector", Published as ATLAS-CONF-2011-089 ; https://cdsweb.cern.ch/record/1356198

6. "Top Quark Pair Production Cross-section Measurement in ATLAS in the Single Lepton + Jets Channel without b-tagging", Published as ATLAS-CONF-2011-023 ; https://cdsweb.cern.ch/record/1336753

7. "Measurement of the Top Pair Production Cross section at ATLAS", Published in conference proceedings for DPF 2011, Brown University, Providence, RI, USA arXiv: hep-ex/0316874 , ATL-PHYS-PROC-2011-123.

8. "Search for supersymmetry in pp collisions at $\sqrt(s) = 7$ TeV in final states with missing transverse momentum, b-jets and no leptons with the ATLAS detector", ATLAS-CONF-2011-098

9. "Search for supersymmetry in pp collisions at $\sqrt(s) = 7$ TeV in final states with missing transverse momentum, b-jets and one lepton with the ATLAS detector", ATLAS-CONF-2011-130

10. "Offline LVPS trip monitoring. Software implementation", ATL-COM-TILECAL-2011-020.

11. "Analysis of TileCal fLVPS Trip Characteristics" ATL-COM-TILECAL-2011-019.

12. Analysis of TileCal fLVPS trip Characteristics" ATL-COM-TILECAL-2011-056

13. DØ note 6152 "Measurement of the Relative Branching Ratio of $B_s \to J/\Psi f_0(980), f_0(980) \to \pi^+\pi^-$ to $B_s \to J/\Psi\phi, \phi \to K^+K^-$.

14. DØ note 6282 "Analysis of decay $B_s \to J/\psi$ KK at M(KK)>1.35 GeV."

15. DØ note 6210 "Measurement of $\sigma(p\bar{p} \to t\bar{t}X)$ using the $\tau +$jets final state in DØ Run 2b"

16. "A search for the Higgs boson in the $H \to WW \to \ell\nu qq$ decay mode using 4.7 fb^{-1} of data collected with the ATLAS detector at $\sqrt{s}$=7 TeV." ATL-COM-PHYS-2012-068

17. "A Search for the Standard Model Higgs boson in the $H \to WW(*) \to \ell\nu jj$ decay mode using Multivariate Technique and using 4.7 fb^{-1} 1of data collected with the ATLAS detector at $\sqrt{s} = 7$ TeV." ATL-COM-PHYS-2012-064

18. "Search for Higgs Boson Production in pp collisions at $\sqrt{s}$= 7 TeV using the $H \to WW \to \ell\nu jj$ Decay Channel and the ATLAS Detector." ATL-CONF-2011-052

Proceedings, Conference Notes and Internal Pub notes 2012

1. "Monitoring the US ATLAS Network Infrastructure with perfSONAR-PS", S. McKee, A. Lake, P. Laurens, H. Severini, T. Wlodek, S. Wolff, and J. Zurawski, Proceedings of the 19th International Conference on Computing in High Energy and N uclear Physics, May 2012 (CHEP 2012)

2. "Multi-core job submission and grid resource scheduling for ATLAS AthenaMP", D. Crooks, P. Calafiura, R. Harring ton, M. Jha, T. Maeno, S. Purdie, H. Severini, S. Skipsey, V. Tsulaia, R. Walker, and A. Washbrook, Proceedings of the 1 9th International Conference on Computing in High Energy and Nuclear Physics, May 2012 (CHEP 2012)

3. "Example of shared ATLAS Tier2 and Tier3 facilities", S. Gonzalez de la Hoz, M. Villaplana, Y. Kemp, M. Gasthube r, H. Wolters, D. Benjamin, J. Pardo, A. Pacheco, F. Sanchez, X. Espinal, H. Severini, W. Bhimji, L. Levinson, D. Van De r Ster, and S. Campana, Proceedings of the 19th International Conference on Computing in High Energy and Nuclear Physics , May 2012 (CHEP 2012)

4. "Using Xrootd to Federate Regional Storage", L. Bauerdick, D. Benjamin, K. Bloom, B. Bockelman, D. Bradley, S. D asu, M. Ernst, R. Gardner, A. Hanushevsky, H. Ito, D. Lesny, P. McGuigan, S. McKee, O. Rind, H. Severini, I. Sfiligoi, M . Tadel, I. Vukotic, S. Williams, F. Werthwein, A. Yagil, and W. Yang, Proceedings of the 19th International Conference on Computing in High Energy and Nuclear Physics, May 2012 (CHEP 2012)

Theoretical Talks 2010–12

Talks from Howie Baer

1. $SO(10)$ SUSY GUTs with mixed axion/axino cold dark matter, Axions 2010 meeting, University of Florida, Jan. 15, 2010.
2. Capability of LHC to discover supersymmetry with $\sqrt{s} = 7$ TeV and 1 fb^{-1}, Cook's Branch meeting, Houston, TX April 14, 2010.
3. Beyond the Standard Model at LHC with $\sqrt{s} = 7$ TeV and 1 fb^{-1}, Atlas jamboree, University of Texas-Arlington, May 17, 2010.
4. Mixed axion/axino cold dark matter and the LHC, talk at GGI mini-workshop on LHC and dark matter, Florence, Italy, June, 2010.
5. Theoretical expectations for detection of dark matter at the LHC, plenary talk at Identification of Dark Matter, 2010 meeting, Montpellier, France, July 30, 2010.
6. Neutralino dark matter, plenary talk at 2010 Workshop on Major DUSEL Physics Topics, SDSMT, Rapid City, South Dakota, October 1, 2010.
7. Mixed axion/axino dark matter in supersymmetric models, at 18th International Conference on Supersymmetry and the Unification of Fundamental Interactions, Bonn, Germany, August 24, 2010.
8. Mixed axion axino cold dark matter from supersymmetric models with implications for LHC, seminar at CERN, March 5, 2010.
9. Prospects for anomaly-mediated SUSY breaking models at the LHC seminar at UW-Madison, April 22, 2010.
10. Prospects for supersymmetry during year 1 of LHC, seminar at University of Colorado, July 9, 2010.
11. Supersymmetric dark matter; Direct, Indirect and Collider Searches, Colloquium at University of Colorado, September 22, 2010.
12. Difficult scenarios for SUSY at LHC, talk at UC Davis SUSY Recast meeting, April 8, 2011.
13. Mixed axion/LSP dark matter, talk at U. New Mexico mini-workshop on Dark Matter, May 27, 2011.
14. Supersymmetry at the LHC, plenary talk at Cosmo 2011 conference, Porto, Portugal, August, 2011.
15. Axions, saxions and axinos: a new dark matter paradigm, plenary talk given at Scalars 2011 conference, Warsaw, Poland, August, 2011.
16. From simplified models to cascade decays and back, talk at CERN WG2 meeting, CERN, October 31, 2011.

17. Mixed axion/LSP dark matter talk at Pitt-PACC dark matter meeting, University of Pittsburgh, November 15, 2011.
18. Neutralinos, axions, axinos and saxions, talk at U. Maryland JSI meeting, Annapolis, MD, November 30, 2011.
19. Mixed axion/axino cold dark matter, at UW-Madison Pheno 2011 meeting, May, 2011.
20. Mixed axion/LSP dark matter with implications for LHC, seminar at McGill University, Montreal, March 16, 2011.
21. Mixed axion/LSP dark matter with implications for LHC, seminar at University of Minnesota, April 21, 2011.
22. Supersymmetry at the LHC, plenary talk at Cosmo 2011 conference, Porto, Portugal, August, 2011.
23. Axions, saxions and axinos: a new dark matter paradigm, plenary talk given at Scalars 2011 conference, Warsaw, Poland, August, 2011.
24. From simplified models to cascade decays and back, talk at CERN WG2 meeting, CERN, October 31, 2011.
25. Mixed axion/LSP dark matter talk at Pitt-PACC dark matter meeting, University of Pittsburgh, November 15, 2011.
26. Neutralinos, axions, axinos and saxions, talk at U. Maryland JSI meeting, Annapolis, MD, November 30, 2011.
27. $WZ + MET$, $Wh + MET$ and natural SUSY, talk at CERN WG2 meeting, March 29, 2012.
28. Axions in SUSY, and what we will learn from accelerators (talk at Vistas in Axion Physics meeting, University of Washington, April, 2012.
29. Mixed axion higgsino dark matter from Natural SUSY, talk at Center for Theoretical Underground Physics, Lead South Dakota, July 12, 2012.
30. Summary of dark matter session, talk at Center for Theoretical Underground Physics, Lead South Dakota, July 20, 2012.
31. Expectations for supersymmetry and dark matter post LHC7, colloquium at University of New Mexico, April 27, 2012.

Talks from Kim Milton 2010–12

1. Julian Schwinger's Contribution to Education and His Legacy, Joint APS/AAPT meeting, February 15, 2010.
2. Multiple Scattering: Dispersion, Temperature Dependence, and Annular Pistons, Workshop on Cosmology, the Quantum Vacuum, and Zeta Functions (Elizalde Fest), Barcelona, March 8, 2010.
3. Quantum Vacuum Forces Between Bodies—Multiple Scattering Results, Theoretical Seminar, University of Minnesota, April 1, 2010.

4. Quantum Vacuum Forces—Multiple Scattering, Dispersion, Temperature, and Self-Energies, Nonperturbative Quantum Field Theory, University of Oklahoma, April 9, 2010.

5. $\mathcal{PT}$-Symmetric Quantum Electrodynamics—$\mathcal{PT}$QED, Workshop on Pseudo-Hermitian Hamiltonians in Quantum Physics, Hangzhou, China, June 21, 2010.

6. Casimir Self-Energies Revisited—Old and New Results, Theoretical Seminar, East China University of Science and Technology, Shanghai, June 25, 2010.

7. Casimir Self-Energies Revisited—Old and New Results, Quantum Vacuum Meeting, Texas A&M University, July 9, 2010.

8. The Casimir Effect—How Julian Schwinger's Legacy Has Grown, Workshop on Spontaneous Energy Focusing Phenomena and Multiscale Physics, The Institute of Advanced Studies, Nanyang Technological University, Singapore, September 3, 2010.

9. $\mathcal{PT}$-Symmetric Quantum Electrodynamics and Unitarity, Workshop on $\mathcal{PT}$ Quantum Mechanics, Heidelberg, September 27, 2011.

10. Repulsive Casimir Effects, Plenary talk at Quantum Field Theory Under the Influence of External Conditions, QFEXT11, Benasque, Spain, September 20, 2011.

11. $\mathcal{PT}$-Symmetric Quantum Electrodynamics: $\mathcal{PT}$QED, seminar at Nuclear Physics Institute, Prague, July 27, 2011.

12. Casimir Repulsion, seminar at Physics Department, Technical University of Prague, July 26, 2011

13. Thermal Issues in Casimir Forces Between Conductors and Semiconductors, Invited talk at Frontiers of Quantum and Mesoscopic Thermodynamics, Prague, July 25, 2011.

14. Repulsive Casimir Effects, talk at Quantum Vacuum Meeting, OU, May 18, 2011

15. Casimir Energies and Forces: An Accelerating Subject, Colloquium given at the Department of Physics, Norwegian University of Science and Technology, Trondheim, January 28, 2011.

16. The Thermal Casimir Effect, Casimir Effect Workshop, Trondheim, Norway, January 26, 2011.

17. Developments in Casimir-Polder repulsion: Three-body effects, Mathematical Structures in Quantum Systems, Benasque, Spain, July 9, 2012.

18. Schwinger's Approach to Einstein's Gravity, or Einstein vs. Schwinger? Not!, invited talk given at AAS meeting, Anchorage, June 13, 2012.

19. Developments in Casimir-Polder repulsion: Three-body effects, Quantum Vacuum Meeting, TAMU, May 17, 2012.

20. Where Have All the Magnetic Monopoles Gone?, colloquium given at Texas Tech University, April 26, 2012.

21. Local and Global Casimir Stresses, lectures given at Casimir Physics School, Lorentz Center, Leiden, March 8, 2012.

22. Casimir Energies and Forces: An Accelerating Subject, colloquium at University of Illinois at Urbana-Champaign, January 25, 2012.

Talks given by Chung Kao: January 2011–July 2013

1. New Physics with Jets at the LHC
   National Central University, Jungli Taiwan
   January 10, 2011

2. Topics on New Physics at the LHC
   The Academia Sinica, Taipei Taiwan
   January 12, 2011

3. Discovering Colorons at the Early Stage LHC
   The 2011 Linear Collider Workshop of the Americas (ALCPG11) at the University of Oregon in Eugene, Oregon
   March 19–March 23, 2011

4. Discovering Colorons at the LHC
   The 2011 Phenomenology Symposium, University of Wisconsin, Madison Wisconsin
   May 9–May 11, 2011

5. Implications of LHC Higgs Searches for Neutralino Dark Matter
   The 7th TeV Particle Astrophysics Conference, Stockholm, Sweden
   August 1–August 5, 2011

6. Implications of LHC Higgs Searches for Neutralino Dark Matter
   The Symposium on Cosmology and Particle Astrophysics (CosPA2011), Peking University, Beijing, China
   October 28–October 31, 2011

7. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC
   The International Workshop on Physics Opportunities with LHC (POwLHC), at KEK, in Tsukuba, Japan
   February 16–February 18, 2012

8. Implications of LHC Higgs Searches for Neutralino Dark Matter
   The Tenth Symposium on Sources and Detection of Dark Matter and Dark Energy in the Universe, Marina del Rey Marriott
   February 22–February 24, 2012

9. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC
   The 2012 Phenomenology Symposium at the University of Pittsburgh (Pheno 2012), in Pittsburgh, Pennsylvania
   May 7–May 9, 2012

10. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC
    The 36th International Conference on High Energy Physics (ICHEP 2012), in Melbourne, Australia
    July 4–July 11, 2012

11. Discovering Colorons at the Early Stage LHC
    The 36th International Conference on High Energy Physics (ICHEP 2012), in Melbourne, Australia
    July 4–July 11, 2012

12. Prospects for Higgs Searches with the Tri-bottom Channel in Unified SUSY Models
The 20th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2012), at Peking University, in Beijing, China
August 13–August 18, 2012

13. The Higgs Miracle: from Quarks to Galaxies
Academia Sinica in Taipei, Taiwan
Janary 17, 2013

14. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC
National Taiwan University in Taipei, Taiwan
February 27, 2013

15. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC,
University of Texas at Austin, in Austin, Texas
March 25, 2013

16. When the Higgs meets the Top
The Snowmass Energy Frontier workshop at the University of Washington, in Seattle Washington
June 30–July 03, 2013.

17. Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC
The 2013 European Physical Society Conference on High Energy Physics (EPSHEP 2013), in Stockholm, Sweden
July 18–July 24, 2013.

Talks from Yun Wang

1. "Galaxy Clustering as a Cosmological Probe", invited review talk at "Tracing Cosmic Evolution with Clusters of Galaxies", Sesto, Italy, July 2013

2. "Probing the Nature of Cosmic Acceleration", invited colloquium at IPAC, Caltech, June 2013

3. "Galaxy Clustering Forecast for Euclid (An Update)", presentation at the Euclid Galaxy Clustering Science Working Group Splinter Meeting, Euclid Consortium Meeting, Leiden, May 2013

4. "Galaxy Clustering (inc. BAO) With WFIRST-AFTA", invited presentation, WFIRST-AFTA Science Definition Team meeting, NASA Goddard Space Flight Center, November, 2012

5. "Probing the Nature of Cosmic Acceleration", invited colloquium at Univ. of Illinois at Urbana-Champaign, November 2012

6. "Probing dark Energy", invited seminar at the University of Florida, October 2012

7. "Baryon Acoustic Oscillation and Beyond: Probing Dark Energy with Galaxy Clustering", invited lectures at II Jayme Tiomno School of Cosmology, August 2012, Rio de Janeiro, Brazil

8. "Observational Probes of Dark Energy", invited plenary talk at the VIII International Workshop on the Dark side of the Universe, Buzios, Brazil, June 2012

9. "Robust Constraints on Dark Energy and Gravity from Galaxy Clustering", Euclid Theory Science Working Group Workshop, Copenhagen, Denmark, May 2012

10. “Observational Probes of Dark Energy”, High Energy Division Seminar, Argonne National Lab, April 2012

11. “Observational Probes of Dark Energy”, Cosmology Seminar, Cambridge University, March 2012

12. “Cosmic Expansion History Measurements from Euclid Galaxy Clustering”, invited plenary talk at the Euclid Galaxy Clustering Science Working Group Workshop, London, England, March 2012

13. Observational Probes of Dark Energy, invited plenary talk at Spanish Relativity Meeting ERE2011, Madrid, Spain, August 2011

14. Galaxy Clustering as Dark Energy Probe, invited presentation at the WFIRST Science Definition Team meeting, Caltech, March 2011

15. Multi-Object Spectroscopy Using Digital Micro Mirrors, invited presentation at the WFIRST Science Definition Team meeting, Caltech, March 2011

Theoretical Publications in 2010–12

Publications from Howie Baer

1. Fine-tuning favors mixed axion/axino cold dark matter over neutralinos in the minimal supergravity model (with A. Box), EPJC**68**, 523 (2010).

2. Beyond the Higgs boson at the Tevatron: detecting gluinos from Yukawa-unified SUSY (with S. Kraml, A. Lessa, S. Sekmen and H. Summy), PLB**685** (2010) 72.

3. Testing Yukawa-unified SUSY during year 1 of LHC: the role of multiple b-jets, dileptons and missing E_T (with S. Kraml, A. Lessa and S. Sekmen), JHEP**1002** (2010) 055.

4. Gaugino Anomaly Mediated SUSY Breaking: phenomenology and prospects for the LHC (with S. de Alwis, K. Givens, S. Rajagopalan and H. Summy), JHEP**1005** (2010) 069.

5. Neutralino, axion and axino cold dark matter in minimal, hypercharged and gaugino AMSB (with R. Dermisek, S. Rajagopalan and H. Summy), JCAP**1007** (2010) 014.

6. Capability of LHC to discover supersymmetry with $\sqrt{s} = 7$ TeV and 1 fb^{-1} (with V. Barger, A. Lessa and X. Tata), JHEP**1006** (2010) 102.

7. Neutralino versus axion/axino cold dark matter in the 19 parameter SUGRA model (with A. Box and H. Summy), JHEP**1010** (2010) 023.

8. Effective supersymmetry at the LHC, (with S. Kraml, A. Lessa, S. Sekmen and X. Tata), JHEP**1007** (2010) 018.

9. Reconciling thermal leptogenesis with the gravitino problem in SUSY models with mixed axion/axino dark matter (with S. Kraml, A. Lessa and S. Sekmen), JCAP**1011** (2010) 040.

10. Review of particle physics. with Particle Data Group (K Nakamura et al.), J. Phys.**G37**, 075021,2010.

11. Computational Tools for Supersymmetry Calculations, book chapter for *Perspectives on supersymmetry*, edited by G. Kane, (World Scientific, 2010).

12. The Hunt for New Physics at the Large Hadron Collider, (with P. Nath et al.), arXiv:1001.2693 (2010).

13. SO(10) SUSY GUTs with mainly axion cold dark matter: implications for cosmology and colliders, arXiv:1002,4155, proceedings of Axion 2010 conference, edited by D. Tanner.

14. Theoretical expectations for dark matter detection at the LHC, arXiv:1012.0248, proceedings of IDM2010 meeting, Montpellier, France.

15. Testing the gaugino AMSB model at the Tevatron via slepton pair production (with S. de Alwis, K. Givens, S. Rajagopalan and W. Sreethawong), JHEP**1101** (2011) 005.

16. Thermal leptogenesis and the gravitino problem in the Asaka-Yanagida axion/axino dark matter scenario (with S. Kraml, A. Lessa and S. Sekmen), JCAP**1104** (2011) 039.

17. Mixed axion/neutralino cold dark matter in supersymmetric models (with A. Lessa, S. Rajagopalan and W. Sreethawong), JCAP**1106** (2011) 031.

18. Some necessary conditions for allowing the PQ scale as high as M_{GUT} in SUSY models with an axino or neutralino LSP (with A. Lessa), JHEP**1106** (2011) 027.

19. Exploring neutralino dark matter resonance annihilation via $bA, bH \to b\mu^+\mu^-$ at the LHC (with A. Belyaev, C. Kao and P. Svantesson), Phys. Rev. **D84**, (2011) 095029.

20. Hidden SUSY at the LHC: the light higgsino-world scenario and the role of a lepton collider (with V. Barger and P. Huang), JHEP**11** (2011) 031.

21. Implications of a high mass light MSSM Higgs scalar for SUSY searches at the LHC (with V. Barger, P. Huang and A. Mustafayev), Phys. Rev. D84, 091701R (2011).

22. Coupled Boltzmann calculation of mixed axion/neutralino cold dark matter production in the early universe (with A. Lessa and W. Sreethawong), JCAP**1201** (2012) 036.

23. Implications of a 125 GeV Higgs scalar for LHC SUSY and neutralino dark matter searches (with V. Barger and A. Mustafayev), Phys. Rev **D85** (2012) 075010.

24. LHC discovery potential for supersymmetry with $\sqrt{s} = 7$ TeV and 5-30 fb^{-1} (with V. Barger, A. Lessa and X. Tata), Phys. Rev. **D85** (2012) 051701R.

25. Prospects for Higgs Searches with the Tri-bottom Channel in Unified SUSY Models (with C. Kao and J. Sayre), Phys. Rev. **D85** (2012) 035021.

26. Wh plus missing-E_T signature from gaugino pair production at the LHC (with V. Barger, A. Lessa, W. Sreethawong and X. Tata), Phys. Rev. **D85** 055022 (2012).

27. Les Houches 2011: Physics at TeV Colliders New Physics Working Group Report (with G. Brooijmans *et al.*), arXiv:1203.1488.

28. Sparticle mass spectra from $SU(5)$ SUSY GUT models with $b - \tau$ Yukawa coupling unification (with I. Gogoladze, A. Mustafayev, S. Raza and Q. Shafi), JHEP**1203** 047 (2012).

29. WZ plus missing-E_T signal from gaugino pair production at LHC7 (with V. Barger, S. Kraml, A. Lessa, W. Sreethawong and X. Tata), JHEP**1203** 092 (2012).

30. A heavier gluino from $t-b-\tau$ Yukawa-unified SUSY (with S. Raza and Q. Shafi), Phys. Lett. **B712** (2012) 250.

31. Neutralino dark matter in mSUGRA/CMSSM with a 125 GeV light Higgs scalar (with V. Barger and A. Mustafayev), JHEP**1205** (2012) 095.

32. Natural Supersymmetry: LHC, dark matter and ILC searches (with V. Barger, P. Huang and X. Tata), JHEP**1205** (2012) 109.

33. Post LHC7 SUSY benchmark points for ILC physics (with Jenny List), arXiv:1205.6929 (2012).

34. Radiative natural SUSY with a 125 GeV Higgs boson (with V. Barger, P. Huang, A. Mustafayev and X. Tata), arXiv:1207.3343.

35. Discovery potential for SUSY at a high luminosity upgrade of LHC14 (with V. Barger, A. Lessa and X. Tata), arXiv:1207.4846.

36. Review of particle physics. with Particle Data Group (J. Beringer et al.), Phys. Rev. **D86** (2012) 010001.

37. Yukawa-unified natural supersymmetry (with S. Kraml and S. Kulkarni), arXiv:1208.3039 (2012).

38. Implications of LHC results for TeV-scale physics: new physics with missing energy signatures (Submitted to the Open Symposium of the European Strategy Preparatory Group, with R. Cavanaugh *et al.*).

39. Physics at the International Linear Collider (Physics Chapter of the ILC Detailed Baseline Design Report, with M. Peskin *et al.*).

Publications from Kim Milton

1. Kimball A. Milton, Prachi Parashar, E.K. Abalo, Fardin Kheirandish, and Klaus Kirsten, “Investigations of the torque anomaly in an annular sector. II. Global calculations, electromagnetic case,” arXiv:1307.2535, submitted to Phys. Rev. D.

2. Kimball A. Milton, F. Kheirandish, P. Parashar, E. K. Abalo, S. A. Fulling, J. D. Bouas, H. Carter, and Klaus Kirsten, “Investigation of the torque anomaly in an annular sector. I. Global calculations, scalar case,” arXiv:1306.0866, Phys. Rev. D, in press.

3. Prachi Parashar, K. A. Milton, Martin Schaden, and K.V. Shajesh, “Casimir interaction energies for magneto-electric delta-function plates,” arXiv:1302.0313, Proceedings of Mathematical Structures in Quantum Systems, Benasque, Spain, July 2012, Nuovo Cimento C **36**, 193–204 (2013).

4. K. A. Milton, Elom Abalo, Prachi Parashar, and K.V. Shajesh, “Three-body Casimir-Polder interactions,” arXiv:1301.2484, Proceedings of Mathematical Structures in Quantum Systems, Benasque, Spain, July 2012, Nuovo Cimento C **36**, 183–192 (2013).

5. Giulio Meille and Kimball A. Milton, “Electromagnetic Angular Momentum and Relativity,” arXiv:1208.4826.

6. Prachi Parashar, K. A. Milton, K. V. Shajesh, and M. Schaden, "Electromagnetic semitransparent delta-function plate: Casimir interaction energy between parallel infinitesimally thin plates," arXiv:1206.0275 [hep-th], Phys. Rev. D **86**, 085021 (2012).

7. K. A. Milton, Iver Brevik, and Simen Å. Ellingsen, "Thermal Issues in Casimir Forces Between Conductors and Semiconductors," extended version of presentation at Frontiers of Quantum and Mesoscopic Thermodynamics, Prague, July 2011, arXiv:1205.4903 [hep-th], Physica Scripta **T151**, 014070 (2012).

8. K. A. Milton, E. K. Abalo, Prachi Parashar, Nima Pourtolami, and J. Wagner. "$\mathcal{PT}$-Symmetric Quantum Electrodynamics and Unitarity," arXiv:1204.5235, Phil. Trans. R. Soc. A **371**, 20120057 (2013).

9. K. A. Milton, E. K. Abalo, Prachi Parashar, Nima Pourtolami, Iver Brevik, and Simen Å. Ellingsen, "Repulsive Casimir and Casimir-Polder Forces," arXiv:1202.6415, J. Phys. A **45**, 374006 (2012), special issue in honor of Stuart Dowker.

10. E. K. Abalo, K. A. Milton, and L. Kaplan, "Scalar Casimir Energies of Tetrahedra and Prisms," arXiv:1202.0908, J. Phys. A **45**, 425401 (20pp) (2012).

11. S. A. Fulling, K. A. Milton, and J. Wagner, "Energy Density and Pressure in Power-Wall Models," plenary talk at Quantum Field Theory Under the Influence of External Conditions, Benasque, Spain, Int. J. Mod. Phys. A **27**, 1260009 (2012).

12. E. K. Abalo, K. A. Milton, and L. Kaplan, "Scalar Casimir Energies of Tetrahedra," arXiv:1112.0079, talk at Quantum Field Theory Under the Influence of External Conditions, Benasque, Spain, Int. J. Mod. Phys. Conf. Ser. **14**, 230 (2012).

13. K. A. Milton, E. K. Abalo, Prachi Parashar, Nima Pourtolami, Iver Brevik, and S. Å. Ellingsen, "Repulsive Casimir Effects," arXiv:1111.5367, plenary talk at Quantum Field Theory Under the Influence of External Conditions, Benasque, Spain, Int. J. Mod. Phys. A **27**, 1260014 (2012).

14. K. A. Milton, Prachi Parashar, Nima Pourtolami, and Iver Brevik, "Casimir-Polder repulsion: Polarizable atoms, cylinders, spheres, and ellipsoids," arXiv:1111.4224, Phys. Rev. D **85**, 025008 (2012).

15. A. A. Saharian and K. A. Milton, "Casimir densities for a spherical boundary in de Sitter spacetime," arXiv:1109.1497, Phys. Rev. D **85**, 064005 (2012). .

16. K. A. Milton, "Hard and soft walls," arXiv:1107.4589, Phys. Rev. D **83**, 065028 (2011).

17. K. A. Milton, E. K. Abalo, Prachi Parashar, Nima Pourtolami, Iver Brevik, and Simen Å. Ellingsen, "Casimir-Polder repulsion near edges: Wedge apex and a screen with an aperture," arXiv:1103.4386, Phys. Rev. A **83**, 062507 (2011).

18. K. A. Milton, "The Casimir force: Feeling the heat," News and Views piece in Nature Physics **7**, 190–191 (2011).

19. K. A. Milton, "Resource Letter VWCPF-1: Van der Waals and Casimir-Polder forces," arXiv:1101.2238, Amer. J. Phys. **79**, 697–711 (2011).

20. K. A. Milton, J. Wagner, P. Parashar, I. Cavero-Peláez, I. Brevik, and S. A. Ellingsen, "Multiple Scattering: Dispersion, Temperature Dependence, and Annular Pistons," arXiv:1007.3462 [hep-th], contributed article to the Festschift in honor of Emilio Elizalde, *Cosmology, Quantum Vacuum and Zeta Functions*, eds. S. D. Odintsov, D. Saez-Gomez, and S. Xambo-Deschamps (Springer, Berlin, 2011), pp. 99–113.

21. K. A. Milton, "Local and Global Casimir Energies: Divergences, Renormalization, and the Coupling to Gravity," arXiv:1005.0031, in *Lecture Notes in Physics, 834: Casimir physics,* eds. Diego Dalvit, Peter Milonni, David Roberts, and Felipe da Rosa (Springer, 2011), pp. 39–91.

22. K. A. Milton, I. Cavero-Peláez, P. Parashar, K. V. Shajesh, and J. Wagner, "$\mathcal{PT}$-Symmetric Quantum Electrodynamics–QED," arXiv:0712.0045 [hep-th], revised version published in Int. J. Theor. Phys. **50**, 963 (2011).

23. E. K. Abalo, K. A. Milton, and L. Kaplan, "Casimir Energies of Cylinders: Universal Function," arXiv:1008.4778 [hep-th], Phys. Rev. D **82**, 125007 (2010).

Publications of Chung Kao since January 2011

1. C. Kao and K. Yang, "Prospects for Higgs Searches with $b\tau^+\tau^-$ in Supersymmetric Unified Models," submitted to Phys. Lett. B, University of Oklahoma Report, OU-HEP-130729.

2. K. -F. Chen, W. -S. Hou, C. Kao and M. Kohda, "When the Higgs meets the Top: Search for $t - - > ch^0$ at the LHC," submitted to Phys. Lett. B, arXiv:1304.8037 [hep-ph].

3. C. Kao and J. Sayre, "Confirming the LHC Higgs Discovery with WW," Phys. Lett. B **722**, 324 (2013) [arXiv:1212.0929 [hep-ph]].

4. H. Baer, C. Kao and J. Sayre, "Prospects for Higgs Searches with the Tri-bottom Channel in Unified SUSY Models," Phys. Rev. D **85**, 035021 (2012) [arXiv:1112.5922 [hep-ph]].

5. C. Kao, H. -Y. Cheng, W. -S. Hou and J. Sayre, "Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC," to be published in Phys. Lett. B (2012) [arXiv:1112.1707 [hep-ph]].

6. H. Baer, A. Belyaev, C. Kao and P. Svantesson, "Exploring neutralino dark matter resonance annihilation via $bA^0, bH^0 \to bmu^+mu^-$ at the LHC," Phys. Rev. D **84**, 095029 (2011) [arXiv:1106.5055 [hep-ph]].

7. J. Sayre, D. A. Dicus, C. Kao and S. Nandi, "Searching for Colorons at the Large Hadron Collider," Phys. Rev. D **84**, 015011 (2011) [arXiv:1105.3219 [hep-ph]].

8. D. A. Dicus, C. Kao, S. Nandi and J. Sayre, "Discovering Colorons at the Early Stage LHC," Phys. Rev. D **83**, 091702 (2011) [arXiv:1012.5694 [hep-ph]].

Publications from Yun Wang

1. Effects of cosmological model assumptions on galaxy redshift survey measurements, by Lado Samushia, Will J. Percival, Luigi Guzzo, Yun Wang, Andrea Cimatti, Carlton Baugh, James E. Geach, Cedric Lacey, Elisabetta Majerotto, Pia Mukherjee, Alvaro Orsi, MNRAS, 410, 1993 (2011)

2. Neutrino constraints from future nearly all-sky spectroscopic galaxy surveys, by Carmelita Carbone, Licia Verde, Yun Wang, Andrea Cimatti, JCAP 03 (2011) 030

3. Wide-Field InfraRed Survey Telescope (WFIRST) Interim Report (with the WFIRST Science Definition Team), arXiv:1108.1374

4. Euclid Definition Study Report (with the Euclid Consortium), arXiv1110.3193

5. A Robust Distance Measurement and Dark Energy Constraints from the Spherically-Averaged Correlation Function of Sloan Digital Sky Survey Luminous Red Galaxies, by Chia-Hsun Chuang, Yun Wang, Maddumage Don P. Hemantha, MNRAS, 423, 1474 (2012)

6. Measurements of H(z) and D(z) from the Two-Dimensional Two-Point Correlation Function of Sloan Digital Sky Survey Luminous Red Galaxies, by Chia-Hsun Chuang, Yun Wang, MNRAS, 426, 226 (2012), arXiv:1102.2251

7. A Comparative Study of Dark Energy Constraints from Current Observational Data, by Yun Wang, Chia-Hsun Chuang, and Pia Mukherjee, Phys. Rev. D 85, 023517 (2012)

8. Robust constraints on dark energy and gravity from galaxy clustering data, by Yun Wang, MNRAS, 423, 3631 (2012)

9. Probing deviations from General Relativity with the Euclid spectroscopic survey, by Elisabetta Majerotto, Luigi Guzzo, Lado Samushia, Will J. Percival, Yun Wang, Sylvain de la Torre, Bianca Garilli, Paolo Franzetti, Emanuel Rossetti, Andrea Cimatti, Carmelita Carbone, Nathan Roche, Giovanni Zamorani, MNRAS, 424, 1392 (2012)

10. Observational Probes of Dark Energy, by Yun Wang, invited plenary talk at Spanish Relativity Meeting 2011 (ERE2011), AIPC, 1458, 285 (2012)

11. Cosmology and fundamental physics with the Euclid satellite, with the Euclid's Theory Working Group (2012), arXiv:1206.1225

12. Wide-Field InfraRed Survey Telescope (WFIRST) Final Report, with the WFIRST Science Definition Team (2012), arXiv:1208.4012

13. White Paper of the Large Synoptic Survey Telescope: Dark Energy Science Collaboration, with the LSST Dark Energy Science Collaboration(2012), arXiv:1211.0310

14. Using Multipoles of the Correlation Function to Measure H(z), D_A(z), and β.q(z) From SDSS Luminous Red Galaxies, by Chia-Hsun Chuang, and Yun Wang, MNRAS, 431, 2634 (2013)

15. Modeling the Anisotropic Two-Point Galaxy Correlation Function on Small Scales and Improved Measurements of H(z), D_A(z), and f(z)σ_8(z) from the Sloan Digital Sky Survey DR7 Luminous Red Galaxies, by Chia-Hsun Chuang, and Yun Wang, MNRAS accepted (2013), arXiv:1209.0210

16. Toward More Realistic Forecasting of Dark Energy Constraints from Galaxy Redshift Surveys, by Yun Wang, Chia-Hsun Chuang, Christopher M. Hirata, MNRAS, 430, 2446 (2013)

17. Linear dark energy equation of state revealed by supernovae? by Vincenzo Salzano, Yun Wang, Irene Sendra, Ruth Lazkoz, MPLA submitted (2013), arXiv:1211.1012

18. Distance Priors from Planck and Dark Energy Constraints from Current Data, by Yun Wang, and Shuang Wang, PRD submitted (2013), arXiv:1304.4514

19. Exploring the Systematic Uncertainties of Type Ia Supernovae as Cosmological Probes, by Shuang Wang, and Yun Wang, PRD accepted (2013), arXiv:1306.6423

20. Wide-Field InfraRed Survey Telescope-Astrophysics Focused Telescope Assets WFIRST-AFTA Final Report, with the WFIRST-AFTA Science Definition Team (2013), arXiv:1305.5422