Department Happenings

— by Daniel Gauthier

As usual, this has been a very active year at the Department of Physics, with many exciting research results, student and faculty awards, and alumni in the news. We hope that you enjoy this annual print edition of our newsletter.

There have been many changes in the leadership in the department, which is presenting us with new challenges and opportunities. First, I would like to express my sincere thanks to Prof. Haiyan Gao, who did an excellent job of leading the department as chair for the last few years. Professor Gao stepped down as chair in December 2014 to take on a new and important leadership role as the Vice Chancellor for Academic Affairs at Duke Kunshan University (DKU). We are fortunately have Prof. Gao taking on enormous job of formulating the new DKU curriculum, which will be especially informed by her vast experience in both US and Chinese higher education. Already, Prof. Gao has identified Duke physics faculty who will teach at least part of the coming academic year at DKU. With Prof. Gao taking on this new position, I agreed to serve as interim chair of the department and I very much appreciate the help and support of the department during this transition.

I would also like to take this opportunity to thank Prof. Ashutosh Kotwal, who stepped down as Associate Chair on June 30, 2015. Prof. Kotwal helped oversee the review and assessment of our graduate and undergraduate curricula over the past three years, has identified new courses and mini-courses that will augment and refresh our offerings, and has regularly advised the chair on all department matters. Professor Steffen Bass became the new Associate Chair on July 1, 2015 and is especially interested in working with Prof. Kate Scholberg, Director of Undergraduate Studies, to identify new ways to increase the number of undergraduate physics and biophysics majors and to bring computational methods into our curriculum. One way that computational methods are already entering our curriculum is through our re-envisioning of the laboratories associated with the introductory physics courses for majors, which you can read more about in the article by Yuriy Bomze and Ken McKenzie.

On other faculty news, I am happy to report that Profs. Thomas Barthel and Sara Haravifard arrived safely in Durham in summer 2015 (see the 2014 Newsletter for a description of their research and other activities). On the staff side, Ms. Connie Cox joined the department in summer 2014 as the International Exchange Coordinator as well as supporting faculty and Mr. Matthew Paul joined the Duke Free Electron Laser Laboratory in fall 2014 as a Staff Assistant. Welcome to Duke! Sadly, Ms. Brenda West has left as a TUNL Staff Assistant after many years of dedicated service supporting the center. We will miss you!

Regarding undergraduate student recruitment, I am very pleased to report on a new endowment created by an anonymous donor with a focus on undergraduate research. The funds made available each year from this endowment will be used to support ambitious research projects by our students, including projects over the summer or during the academic year. These funds will allow a student to access or purchase equipment for their project or to fund travel to a remote research location. The endowment funds will also be used each year to recognize excellence in undergraduate research.

As you will read in the newsletter, our alumni are involved in a wide range of activities, from probing the very earliest moments of the universe through measurements of the cosmic microwave...
Department Happenings  

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background to taking on complex projects in computer networks and in optical systems design entrepreneurship. On the faculty research side, you will learn more about our activities in the emerging area of quantum information science and new discoveries in quantum chromodynamics.

Finally, I am happy to report that the new Pratt Engineering/Physics Building continues to develop. This project will provide high-end, state-of-the-art research space for our faculty and students, which will greatly enhance our ability to recruit and retain the best physics scholars. Furthermore, the space will strengthen our interactions with the Pratt School of Engineering through shared teaching and interaction spaces. The final concept design was approved in spring 2015, followed by approval for the architectural firm (Bohlin-Cywinski-Jackson) to move on to the detailed design phase. I show three artistic renditions of the building BJC, an aerial view, the main entrance from a vantage point of Science Drive in front of the Physics Building looking toward the traffic circle, and oner from the backside of the new building showing the wing where the physics research laboratories will be located. This wing will run parallel to the physics building and will take over the steep hill that goes from the main entry of the Physics Building parking lot down to the Putnam gardens by the Levine Science Research Center. Current, we are awaiting full funding for this project so that it can move forward in a timely fashion.

Main entry of the proposed Pratt/Physics building as seen from the traffic circle in front of the Physics Building. The physics laboratory space will be in the wing extended to the left of the entry way (all labs will be below this grade level to attain high isolation and stability). (credit: Bohlin-Cywinski-Jackson)

Back view of the proposed Pratt/Physics building where the wing with the physics laboratory space is to the right. Offices will face into this green-scape and the labs will be slab on ground on the interior of the building to attain high isolation and stability. (credit: Bohlin-Cywinski-Jackson)
Graduate News

- by Director of Graduate Studies, Gleb Finkelstein

As the new Director of Graduate Studies (DGS) I am happy to update you developments in our graduate program and the accomplishments of our students over the past year (June 1, 2014 – May 31, 2015).

Degrees Awarded
Ten students passed their PhD examinations during the past year. The table below lists the names of all degree recipients along with the names of their advisors. These students are taking up positions in academia or industry. I congratulate all of them on their accomplishments and wish them success in their future endeavors.

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<tr>
<th>Student</th>
<th>Advisor</th>
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<th>Advisor</th>
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<tbody>
<tr>
<td>Shanshan Cao</td>
<td>Prof. Bass</td>
<td>Georgios Laskaris</td>
<td>Prof. Gao</td>
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<tr>
<td>Ben Cerio</td>
<td>Prof. Kotwal</td>
<td>Mauricio Pilo-Pais</td>
<td>Prof. Finkelstein</td>
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<tr>
<td>Sean Finch</td>
<td>Prof. Tornow</td>
<td>Chris Pollard</td>
<td>Prof. Kotwal</td>
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<tr>
<td>Hannah Guilbert</td>
<td>Prof. Gauthier</td>
<td>Yu Song</td>
<td>Profs. Raghavachari and Behringer</td>
</tr>
<tr>
<td>Mia Liu</td>
<td>Prof. Baranger</td>
<td>Chris Varghese</td>
<td>Prof. Socolar</td>
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Preliminary Exams
This year ten students took their preliminary exam. Their names along with their advisors are listed in the table below. I extend my very best wishes to these students and look forward to an exciting PhD thesis from each of them in the next few years.

<table>
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<tr>
<th>Student</th>
<th>Advisor</th>
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<th>Advisor</th>
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<tbody>
<tr>
<td>Reginald Bain</td>
<td>Prof. Mehen</td>
<td>Scott Moreland</td>
<td>Prof. Bass</td>
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<tr>
<td>Nick Haynes</td>
<td>Prof. Gauthier</td>
<td>Dong Wang</td>
<td>Prof. Behringer</td>
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<tr>
<td>Jianni Huang</td>
<td>Prof. Mikelsen</td>
<td>Anne Watson</td>
<td>Prof. Finkelstein</td>
</tr>
<tr>
<td>Emilie Huffman</td>
<td>Prof. Chandrasekharan</td>
<td>Xiaojun Yao</td>
<td>Prof. Bass</td>
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<tr>
<td>Yiannis Makris</td>
<td>Prof. Mehen</td>
<td>Gu Zhang</td>
<td>Prof. Baranger</td>
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Fellowships, Awards and Accomplishments
Over the past year students have obtained many new exciting research results and have continued to help the department in its teaching mission. Many students received fellowships and awards for their work.

Every year exceptional graduate students within the department are considered for three different endowed fellowships. The Walter Gordy Graduate Fellowship recognizes excellence in research by a physics graduate student in the area of microwave physics and spectroscopy or closely related topics. This year’s award went to Willie Ong (advisor: John Thomas) and Bonnie Schmittberger (advisor: Dan Gauthier). The Fritz London Graduate Fellowship is awarded to exceptional students working in the field of condensed matter physics. This year the recipient was a sixth year student Chung-Ting Ke (advisor: Gleb Finkelstein). Recipient of the Henry W. Newson Fellowship, which recognizes excellent research in experimental nuclear physics, are Peifan Liu (advisor: Ying Wu) and Collin Malone (advisor: Calvin Howell). These students, who begin their graduate careers this Fall term, received the fellowship so that they may be released from teaching duties for one semester in order to participate in research in experimental nuclear physics their first year. Finally, a rising second year student Andrew Seredinski (advisor: Gleb Finkelstein) received a fellowship from the Graduate Program in Nanoscience (GPNano), which is an interdisciplinary graduate certificate program at Duke. The GPNano fellowship supports a student engaged in nanoscale research for one semester.

Congratulations to all these students for receiving these prestigious awards!

Graduate students also play an important role in the teaching mission of the department and the department recognizes the best teaching assistants through two types of teaching fellowships, one is sponsored by the American Association of Physics Teachers (AAPT) and the other is the Mary Creason Memorial award for outstanding undergraduate teaching in physics. Second year student Andrew Seredinski and third year student Ron Malone received the Mary Creason Memorial Award. Third year graduate students Kevin Holway and Xiaojun Yao received the AAPT Outstanding Teaching Assistant Award for 2015, which also offers the students one year of free AAPT membership. Their performances as Teaching Assistants have been exemplary and highly appreciated by their colleagues in the department. Certificates were presented to
Graduate News  continued from page 3

thestudents during the annual departmental picnic, scheduled on August 22, 2015. I thank these students for contributing to the success of our teaching mission and congratulate them for their achievements.

In addition to the above awards many graduate students have published important research articles in various journals, have given research presentations at various conferences and have become recognized in the world through their research work at Duke. We refer the reader to the web site https://www.phy.duke.edu/news/graduate-studies-news for detailed information about these other graduate student accomplishments. Congratulations to all graduate students on their accomplishments over the past year.

Graduate Admissions
This year the graduate school authorized the department to matriculate 13 students for the Fall 2015 class. This number varies every year based on departmental needs and available funding from Duke Graduate School. The Graduate Admissions Committee (GAC) reviewed 291 applications during the winter break and made 46 offers to students all over the world. The department held an open house on March 19th and 20th so accepted applicants could get a better perspective of our graduate program. I thank all the senior students who helped during the open house for their time and effort in making the event a great success. Due to all their efforts we were successful in recruiting 13 students this year. The incoming class contains students from China (6), India (2), Germany (1) and USA (4). There are 11 male and 2 female students in the incoming class. The new class arrived mid-August for a variety of orientation activities, which culminated with the departmental picnic on August 22, 2015.

Graduate Student Organization News

– by David Bjergaard

As I walk in to Physics from the sweltering heat of summer I stop by the front office and check my empty mailbox. It has shifted from its normal position and the name label’s color has changed, a poignant reminder that another year has passed. It forces me to pause and reflect on the past year. The Graduate Student Organization (GSO) has continued to perform its role in the past year as it has in other years. We have instituted a few new changes.

One of the more interesting changes was the organization and execution of a Thanksgiving meal, an event for all graduate students who stay Durham for Thanksgiving day. On the topic of free food, we also provided pizza dinners for the first years during final exams in the spring. I’m sure the pizza provided a much needed morale boost after trying to digest Cohen-Tannoudji and Jackson all within a week! Many will also be pleased to know that we have found room for cookies in the budget. This may not appear to correlate with the frequency of Cookie Times now but I assure you we will address the issue in the next year.

The GSO performs an important function for graduate students, we represent the student body to the faculty, and we organize events that benefit our graduate student experience. The GSO is responsible for organizing Graduate Student Seminars, as well as the weekly Tea Time. These two events serve the important role of giving us opportunities to hone our public speaking skills and socialize with faculty respectively. Some of you may have noticed that Tea Time and GSS didn’t happen with a very regular frequency this year. This was not for lack of funding and is something that I am rather embarrassed of and hope to work to address in the next year (not in the capacity as President of course).

All of us in the Physics Department share one thing in common: a drive to understand the world around us, and to communicate that understanding to a wider audience. The GSO works hard to foster interactions that allow us to improve both our understanding of Physics, but also our ability to communicate it. It is important that there be enthusiastic participation by everyone in order for us all to benefit from the experiences.

Let me close by thanking everyone on the GSO (and those appointed by the GSO) who helped work to improve our graduate school experience. My experience as president has taught me that the GSO performs an essential role in the quality of life of a graduate student and that it should not be neglected.
At this year’s graduation ceremony in May, thirteen students with first majors in physics and two with secondary majors received their diplomas. In addition, seven students with first majors in biophysics graduated. It’s now the third year that our successful new biophysics program has graduated students.

The members of the 2015 graduating class will be taking many paths, including pursuit of advanced degrees in physics and applied physics, medical physics, computer science, engineering and math, dental school, as well as careers in high-school teaching, finance and consulting.

We had a bumper year for graduation with distinction: a total of nine seniors completed research theses. Two juniors, Melody Lim and Connor Hann, also completed theses which will qualify them for graduation with distinction next year. Connor also received the prestigious honor of Faculty Scholar, which is the highest honor given by Duke to its undergraduates. He worked with Professor Socolar on a thesis entitled “Growth of Isocahedral Quasicrystals”. Melody Lim is the recipient of the Daphne Chang Memorial award for excellence in undergraduate research, for work with Professor Behringer and a thesis entitled “Forces and flows during high speed impacts on a non-Newtonian suspension”, which comes with a $1000 prize.

Many other students in the department in all years were involved in research, and presented progress and results at the lively annual department poster session in April. We had eleven impressive posters describing projects in many subfields, including high-energy physics, condensed matter and biophysics.

The poster session program can be found here: http://tinyurl.com/pt83djo

Attendees voted for the best posters. The first prize winner was Melody Lim, for a poster on work done with Professor Behringer, “Observation of Shockwaves in a Suspension of Soft Particles”. Second prize went to Connor Hann, and there was a tie for third place between Katrina Miller and Lydia Thurman. We are very proud of our students’ achievements.

The poster session also marked the induction of six physics majors into the Sigma Pi Sigma, the nationwide physics honor society. This recognition is given to students who excel academically or who have made outstanding research or service contributions via research.

The Undergraduate Curriculum Committee completed two major tasks this year. First, a subcommittee did a review of the content of Physics 141 and 142, the introductory sequence for the life science majors, to evaluate the relevance of the content to students with interest in biological sciences and broader interests. The committee recommended a modified Physics 141L course, incorporating about two-thirds “core” material and one-third new material oriented towards students with biological and pre-health interests. The new recommended material, previously only touched upon in the course, if at all, include topics such as diffusion, fluids, and thermodynamics. There are several possibilities for new material to be chosen at the instructor’s discretion. The recommended Physics 142L syllabus is more similar to the traditional course, but omit a few topics in favor of biologically-oriented applications. We hope that the revised course content will engage students as they recognize its relevance to their interests. Several professors are continuing to use the “active learning” approach, which has been shown by much pedagogical research to improve learning outcomes, in Physics 141L and 142L (and other courses).

The introductory course sequence for physics majors (and prospective majors) is undergoing significant changes. This year we implemented for the first time a separate experimental physics component to this sequence, 161L and 162L. These are half-credit lab courses, both offered each semester, and decoupled from the lecture courses. Students learn programming and laboratory skills to enable them to engage more quickly in research in the later years of their degree. These have been quite successful. More changes are underway: the Undergraduate Curriculum Committee also completed a restructuring of the introductory course sequence. Starting in 2016, the introductory sequence will be shifted forward one semester, bringing it in sync with the engineering sequence. We will also be introducing a new “gateway” course on “Big Questions” in physics, designed to introduce beginning students to exciting current research topics.

Another new development is enabled through the generosity of an endowment for the physics undergraduate research and education program. Starting next summer, we expect to award summer grants to undergraduate students doing research projects in the physics department. The goals of the summer research awards include strengthening undergraduate research opportunities, enlarging the scope of undergraduate research on and off campus during the summer, and enabling undergraduates to extend the period over which they may engage in research. Awards to sophomores will be prioritized, to help get students involved in research early.

An exciting event that occurred in January was the American Physical Society Conference for Undergraduate Women in Physics in the NC Research Triangle (http://www.aps.org/programs/women/workshops/cuwip.cfm). This national series of conferences has been underway since 2000 (Duke hosted it in 2010). The Triangle was selected by the national organizing committee as one of the sites for the 2015 conference. In collaboration with North Carolina Central University, North Carolina State University, and the University of North Carolina at Chapel Hill, we held it on Duke East Campus over Martin Luther King weekend, at the same time as the other conferences nationwide. There were 136 student attendees as well as many senior physicists giving presentations and running workshops. Several Duke undergraduates (some of who attended previous conferences in the series) were active in the organizing committee. For more information on the Undergraduate Women in Physics conference, see page 19.

The Duke Society of Physics Students (https://spsduke.wordpress.com/) coordinated three major events this year. The students hosted a tour of the TUNL Tandem lab, as well as the Free Electron Laser lab. In addition, SPS sponsored a trip for a dozen students to see Neil deGrasse Tyson speak at NCSU, and visited with him afterward.
Barbeau Receives DOE Early Career Research Award

Prof. Phil Barbeau, assistant professor in Physics, has been awarded a Department of Energy Early Career Research Award from the Office of High Energy Physics. The program supports the development of individual research programs of outstanding scientists early in their careers and also stimulates research careers in the areas supported by the DOE Office of Science. Barbeau is one of 44 early career selectees this year; there were 27 from universities and 17 from national laboratories.

The grant will help fund Barbeau’s research effort searching for Coherent Neutrino-Nucleus Scattering. Predicted over forty years ago, it has long been one of the “hard” problems in neutrino physics due to the technological challenges in detector construction. A precision measurement of the process can open the door to a number of searches for New Physics. More information about the program can be found here: http://tinyurl.com/pk5msBl

Duke Today also picked up this story. View it online here: http://tinyurl.com/ozpzz8z

Bass Elected APS Fellow

Prof. Steffen Bass was elected as an APS Fellow in 2014 for his pioneering work on the development of transport models for the description of relativistic heavy-ion collisions and their application to the extraction of the properties of the quark gluon plasma. The election to APS fellowship is a great honor for an APS member. Warmest congratulations to Prof. Bass!

Bass Selected as Outstanding Referee

Prof. Steffen A. Bass has been selected for APS Journals’ Outstanding Referee Program. Annually the program recognizes 150 of the roughly 60,000 currently active referees. You can find more information on their website here: http://tinyurl.com/qbgy7dn

Behringer and Others Awarded Research Grant

Prof. Bob Behringer and collaborators Bulbul Chakroborty (Brandeis) and Corey O’Hern (Yale) have been awarded a W. M. Keck Foundation Science and Engineering Research Grant for their study “Self-Assembly in the Macro-World”. This project will involve studies to understand the jamming transition and the assembly of complex structures for collections of particles. The Keck Foundation has provided $1,000,000 for the support of this project.
Kotwal Appointed US Coordinator for VLHC

Prof. Ashutosh Kotwal has been appointed the US Coordinator for a global effort to motivate and design a new proton-proton collider of much higher energy than the Large Hadron Collider (LHC) currently operating at CERN.

Prof. Kotwal has recently concluded studies that motivate a major upgrade of the LHC. This upgrade project has been ranked as the highest priority in the medium term by the US and Europe. As a result, the LHC will continue to operate for another 15-20 years and we are optimistic that it will shed light on the mystery of dark matter and the origin of the Higgs field. If these big questions are answered by Supersymmetry or new forces with particle masses of 1-2 trillion electron-Volts (TeV), the LHC will reveal these new frontiers of fundamental science.

It is expected that detailed exploration of these frontiers will require collider energies in the 100-200 TeV range, about 10 times higher than the LHC. This new collider can also guarantee the production of Dark Matter particles. It is time to start planning for new technologies that can be used 25-30 years from now to build this Very Large Hadron Collider (VLHC) of about 100 km in circumference. Expressions of interest have been presented by Europe and China, and Prof. Kotwal is leading the US participation in this global planning.

Meyer Honored with Duke University Medal

Prof. Emeritus Horst Meyer was honored with the University Medal at this years Founders’ Day ceremony held Friday, September 29, 2014. Prof. Meyer received this award in recognition of his generous and energetic support of the Duke Gardens and chamber music at Duke as well as his extraordinary research and mentoring contributions to the Physics Department. Watch video from the event here: http://tinyurl.com/nv9ng2p where Prof. Meyer can be seen from 49:10 to 52:05.

Mikkelsen Receives 2015 Air Force YIP Award

Prof. Maiken Mikkelsen is a recipient of the 2015 Air Force Young Investigators Research Program (YIP) award. The Air Force YIP supports scientists and engineers who have received Ph.D. or equivalent degrees in the last five years and show exceptional ability and promise for conducting basic research. Read the official press release and see the full list of recipients here: http://tinyurl.com/pyolcug

Mikkelsen Receives CAREER Award

Prof. Maiken H. Mikkelsen has received a CAREER award from the National Science Foundation. The CAREER award is NSF’s most prestigious award and supports faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research. Information about Prof. Mikkelsen’s award can be found here: http://tinyurl.com/q7389sg and general information about the program here: http://tinyurl.com/29wnt2l
Exotic Charmonium: A New Frontier for Quantum Chromodynamics

— by Thomas Mehen

For over four decades physicists have known that the proton and neutron consist of more fundamental entities called quarks. A theory called Quantum Chromodynamics (QCD) describes the interactions of the quarks and gluons, which mediate the strong force between quarks. Despite its seeming simplicity, it is often difficult to use QCD to make quantitative predictions about the particles built out of quarks and gluons called hadrons. A complete description of the physics of hadrons still eludes us. My research attempts to improve our understanding of hadrons, especially those containing heavy quarks. Much of my work is motivated by unexpected experimental results from the last twelve years that have changed our understanding of how QCD works.

A basic yet poorly understood question is: what kinds of hadrons exist in nature? Because of a phenomenon known as confinement, quarks do not exist as isolated particles. According to QCD, quarks come in one of three different “colors”. Confinement means that the force between colored objects is too strong to allow them to separate, so the hadrons we see in nature must be colorless combinations of quarks. Until recently, all observed hadrons could be classified into two types: baryons, like the proton and neutron, which are made of three quarks, and mesons that consist of one quark and one antiquark. An example of a meson is the pion, which is responsible for the long-range force between nucleons. The existence of baryons and mesons is understood because one can make a colorless object in QCD by putting together three quarks of different colors, or a quark and antiquark of opposite colors.

But QCD allows for other colorless combinations of quarks, such as two quarks and two antiquarks (called a tetraquark) or four quarks and one antiquark (called a pentaquark). Another possibility is that of a hadronic molecule, which is a pair of mesons and/or baryons bound by forces similar to the nuclear force, much like the deuteron is a weakly bound state of a proton and neutron. Bound states of quarks that are not mesons or baryons are called exotic hadrons. Though they have been predicted to exist since the discovery of QCD, decades of experimental searches for exotics failed to turn up any.

This changed twelve years ago when the Belle experiment in Japan discovered a particle called the X(3872) [1]. The number refers to the mass of the particle in mega-electron volts/c² (MeV/c²); the mass of the X(3872) is slightly over 4 times the mass of the proton. The quantum numbers \( J^P = 1^- \) and other properties of the X(3872) suggest that it is a weakly bound hadronic molecule made of a neutral spin-0 meson containing a charm quark, known as a \( D^0 \), and a spin-1 meson with an anticharm quark, \( D^{(*)} \), as well their image under charge conjugation. The charm quark is identical to the up quark, one of the three quarks, and mesons that consist of one quark and one antiquark of opposite colors.

The X(3872) is now only one of many unexpected charmonia that have been observed in particle physics experiments over the last twelve years. The most recent discovery was in July of this year, when the LHCb experiment [5] at the Large Hadron Collider (LHC) announced the observation of two resonances, \( P(4450)^+ \) and \( P(4380)^+ \), that decay into a proton and a \( J/\psi \), which is an S-wave charmonium. This is the first evidence for the existence of a pentaquark. Earlier the BESIII and Belle experiments [6,7] discovered a particle called the \( Z(3900)^- \), which decays to \( J/\psi \) and a charged pion and is the first known example of a tetraquark. Predicting the spectrum and properties of the new charmonia is an outstanding problem in QCD. One mystery is why exotic hadrons appear so prominently in the spectrum of excited charmonia while they have been so difficult to see in the light hadron spectrum. As more of these exotic charmonia are observed and studied, one hopes that a deeper understanding of QCD and its hadrons will emerge.

How To Make Photons Interact and Become Strongly Correlated

— by Harold Baranger

Correlations among photons are typically very weak; because photons do not interact with each other, the position of one photon does not depend on the position of another photon. However, if “matter” is present, it mediates an effective interaction between the photons—the first photon strongly affects the matter which then affects the second photon. This leads to photon-photon correlation. Interactions in one dimension are particularly interesting since the photons cannot miss each other as they propagate and scatter, leading to enhanced correlations.

The degree of photon-photon correlation depends on the strength of the light-matter interaction: strong interaction enhances the correlations. Interest in these quantum optics phenomena in one dimension, dubbed “waveguide QED”, has rapidly grown in recent years. The team at Duke (graduate student Yao-Lung (Leo) Fang, former grad student Huaxiu Zheng, and faculty Harold Baranger and Daniel Gauthier) was one of the early theoretical groups in the field.

The matter involved can take a wide variety of forms. In fact, several experimental systems are being actively pursued worldwide and, recently, strong light-matter interactions have been made. Examples include tapered fibers coupled to atoms, microwave transmission lines coupled to superconducting qubits, and semiconductor dielectric waveguides coupled to quantum dots.

The key ingredient in producing the photon-photon correlations is absorption by a nonlinear element followed by stimulated emission (see figure). Consider two uncorrelated photons propagating in the waveguide toward a qubit—a quantum system with two levels, ground and excited. If the energy of each photon is resonant with the qubit’s transition energy, the first photon is absorbed with high probability. The second photon cannot be absorbed—there is only one excited state, that is the nonlinearity! —but it can cause stimulated emission of the first photon as it passes the qubit. The emission of the photon from the qubit is most likely when the second photon is right at the qubit. Thus, the photons become in some sense “bound” to each other and propagate down the waveguide together.

Our group has calculated the photon-photon correlations in a variety of systems containing up to 10 qubits. A schematic of one such structure is shown in the figure. Notice the waveguide with photons propagating in it and three qubits side-coupled to it—the EM field from the photons in the waveguide can excite the qubit. The correlation function \( g_2(t) \) is defined as the probability to detect a second photon time \( t \) after detecting a first photon, normalized by the probability for this to happen in the absence of correlations. Thus, \( g_2(t)=1 \) signifies no correlation. The curve in the figure is \( g_2(t) \) for 10 qubits side-coupled to an infinite waveguide. \( g_2 \) starts out greater than 1, \( g_2(t)=0 \), indicating that the photons are bunched (more likely to come out together). A short time later, \( g_2(t) \) approaches 0, so the photons are anti-bunched. In a waveguide-QED system one can clearly get a complicated pattern of strong correlations between photons!

Another aspect of the photon correlations appears in the energy domain. In the absorption and reemission process, the energy of each photon need not be conserved. The photons can exchange energy of order the width of the qubit resonance, denoted \( \Gamma \). If the first photon is at energy \( \omega_1 \) above the resonance, then the second photon must be at energy \( \omega_2 \) below the resonance. The state of the photons cannot, then, be written as a product of the state of one times the state of the other—the two photons are correlated. The final panel of the figure shows on a color scale the probability of having a photon of energy \( \omega_1 \) and one of \( \omega_2 \) in the final state. This kind of correlation is called entanglement, and the two photons are said to be spectrally entangled.

In addition to the fundamental interest in this topic—interacting photons are quite an unusual system! —it is connected to two technological areas that are being intensively developed. The first is photonics, the manipulation of states of photons for purposes of information and communication. Correlated states of photons may, for instance, be useful in steering photons or in making photon transistors. Second, this topic is closely connected to aspects of quantum information and computation. Researchers are actively investigating ways to connect quantum nodes to each other; waveguide-QED based connections seem like a natural and promising method.
Exciting Times for Quantum Computing

— by Jungsang Kim

The possibility of utilizing unique properties of quantum systems that do not have classical analog for non-trivial advantage in information processing tasks started out as a stimulating scientific question in the 1980s. Richard Feynman first posed the idea of using a computing machine operating with full quantum capabilities (referred to hereafter as quantum computers) to simulate the behavior of a complex quantum system that evades conventional computational methods. The challenge is that a complete description of a complex quantum system requires exponentially large (classical) memory space, as the dimension of the Hilbert space needed to describe the system grows exponentially. This idea has stimulated the curiosity of several researchers for the next 10-15 years, who came up with examples of “toy” problems where a quantum computer can significantly outperform classical computers in finding a solution. While stimulating to think about, these problems were not practically useful ones, and remained in the domain of scientific curiosity.

In 1994, Peter Shor, a mathematician at Bell Laboratories, came up with an important algorithm that allows one to find prime factors of large integers much faster using a quantum computer than with any known classical computer. The factoring problem is an important example of a one-way problem, where going in one direction (multiplying two large prime numbers, for example) is known to be easy, but going the opposite direction (factoring a product of two large unknown prime integers) is believed to be very difficult. The “ease” and “difficulty” of the problem is defined in the context of computational complexity: if one has a known algorithm where the resources needed to solve the problem (size of the computer, time it takes to compute the answer, etc.) scales as a polynomial function of the problem size (defined as the number of digits or bits needed to describe the number being multiplied or factored), then it is considered “easy”. On the other hand, if the resource requirements scale exponentially with the problem size, then the problem is considered “difficult”. Mathematicians have built cryptosystems based on the belief that the factoring is a difficult problem, and Shor’s result showed that this is an easy problem for a quantum computer. To set a scale for this significance, the 1,024-bit encryption we use in today’s internet can be compromised if one can factor a 1,024-bit number: using a large (classical) computer cluster and the best classical algorithms known to date, it would take billions of years to factor such a number. However, if a quantum computer with comparable performance is built (in terms of processor size and speed), one could solve this problem in a fraction of a second. It is fortunate that we do not have such high-performance quantum computers today for internet security, but it is an intriguing possibility that a quantum computer can potentially outperform classical computers, even if the advantages apply only to a limited set of problems.

Many experimental efforts to realize a quantum computer ensued soon after its value was quantified by Shor’s algorithm. The first demonstration came in trapped atomic ion systems, led by Christopher Monroe and David Wineland’s team at the National Institute for Standards Technology (NIST) in Boulder, CO in 1995. They showed a “quantum logic gate” between an internal state of an atomic ion and its motional degree of freedom. A spree of systems have been proposed and experimentally pursued as candidate systems for implementing quantum logic in the past two decades since the first demonstration, and varying degrees of progress have been made in these systems. The quality of logic gate operation and the number of managed qubits in the system have shown dramatic increase in the past five years, especially in trapped ions and superconducting circuits. My research group at Duke, in collaboration Prof. Christopher Monroe (currently at University of Maryland) and many other institutions around the world, have been working on the technology development and system engineering research to assemble and operate a large-scale quantum information processor based on trapped ions. The road to a scalable system construction is long and filled with challenges, but we have made a lot of game-changing progress in the past five years to get us closer to this goal. Confidence is growing that a small quantum computer with sufficient number of qubits that evades classical description will be constructed within the next decade. Whether such a small computer will be useful for solving practical and useful problems that a classical computer cannot solve is a very interesting question. But to me, what’s more exciting is that we will have full access to a complex quantum system we have never had before. Whether this will lead to a useful quantum computer (leading to a new computing industry), or allow us to find new emergent quantum phenomena not observed before, we are at the verge of very exciting times ahead in the realm of quantum computing research.
Jamie Bock: Building Detectors to Look for Evidence of Cosmic Inflation

— by Mary-Russell Roberson

In his search for evidence of cosmic inflation, Duke Physics alum Jamie Bock (B.S. ’87) uses on-ground telescopes, high-altitude balloons, rockets, and satellites. Bock is a professor of physics at Caltech as well as a senior research scientist at the Jet Propulsion Laboratory (JPL). "Our groups build one-of-a-kind instruments to answer questions about the early universe," he says.

Cosmic inflation is the rapid expansion theorized to have occurred just after the Big Bang. "Inflation does make observable effects in the universe," Bock says, "and one way you can get at it is through measuring the polarization of cosmic background radiation."

Bock was one of four principal investigators on the BICEP2 project, which aimed to do just that. BICEP2 made headlines twice in the last couple of years. First, in March 2014, BICEP2 scientists announced they had measured a polarization pattern in cosmic background radiation that was consistent with the presence of gravitational waves—ripples in Einstein’s space-time continuum that are predicted in certain models of inflation.

The second set of headlines came in February of this year when Bock and colleagues collaborated with scientists on the Planck project (a satellite mission of the European Space Agency) to present evidence that the polarization pattern was at least partially due to galactic dust. "The Planck data, which weren’t available until this year, showed that galactic dust emission was more polarized and more variable over the sky than previously modeled," Bock says. However, he’s not convinced that dust is the only contributor to the polarization: "All we can say right now is at least 40% of the signal is associated with dust. Unfortunately, the remainder is instrument noise, mostly from Planck. It’s frustrating, but that’s simply the limit of what we can do today with the world’s best data."

To better understand the polarization pattern and what it represents, follow-up work is underway on BICEP3, which like its predecessor, is a ground-based telescope located at the South Pole. "The error bars will go down as our experimental observations at higher and lower frequencies surpass the [earlier] data," Bock says. "We’re now at the sweet spot for seeing an inflationary polarization signal. Cosmologists have been talking about testing this regime for the last two decades. In the next few years—or maybe less—we will find out the answer. That’s pretty exciting."

Bock is also working on a project called SPIDER, which uses a high-altitude balloon to make measurements of polarization. The balloon was launched on January 1 into the vortex of winds 120,000 feet above Antarctica. After a 10-day trip, it came down on the Chilean side of the continent which is “not a great place for access,” according to Bock. The data drives were recovered from the balloon in March, but excavating the rest of the equipment from a winter’s worth of snow, disassembling it, and flying it out will have to wait until the Antarctic winter subsides. Bock says the data look good at first glance, but full analysis will take a couple of years.

Another way to look for evidence of cosmic inflation is to study the large-scale structure and distribution of galaxies in the universe. Galaxies form in areas of high density, so understanding their structure could shed light on large-scale density fluctuations, which could contain clues to conditions immediately after the Big Bang.

Bock recently received a $1 million grant from NASA for an 11-month study to design a small satellite named SPHEREx. “With the satellite,” Bock says, “we will look at the distribution of galaxies in three dimensions over the whole sky and measure as many of them as we can. Together with the polarization measurements we can learn about exotic physics that powered inflation.” SPHEREx is competing with two other proposals for selection in 2017 to go forward with construction and launch in 2020.

As an undergraduate at Duke, Bock considered being pre-med but quickly discovered he loved science for its own sake. He sought out the astronomy classes, taught by Eric Herbst and John Kolena, and did some research with Hugh Robinson. Of his time at Duke, he says, “The one thing I definitely remember is the level of instruction in the physics classes was really excellent. Now that I’m teaching, I appreciate how hard that is.”

He also enjoyed playing the trombone and was in the marching band, wind symphony, and jazz band. Working with music professor and jazz great Paul Jeffrey, he and other members of the jazz band got to play with the likes of Wynton Marsalis and Dizzy Gillespie.

After Duke, Bock went on to earn his PhD at UC-Berkeley, where he discovered his aptitude for experiments. “It takes patience, but I find it very satisfying to build something and see it work—even if it does something that hasn’t been done before.”

He’s been at Caltech and JPL since 1994. When not at work, you might find him running or spending time with his three daughters—or doing both at the same time. The oldest two run cross country and will be attending a running camp in the Sierras in late August. “I’m going to go too,” he says, “and we’ll see if I can keep up.”
"I like to build things that don't exist," says entrepreneur William J. "Bill" Brown, who earned his PhD in physics from Duke in 1999. "In physics, I did tabletop experiments where I had to do it all—optics, electronics, mechanics, software, and theory. Now, I view a company as something new I'm building."

When Brown began his graduate studies at Duke, he was planning a career in academia. Halfway through, he realized that wasn't the path for him. He was more drawn to the idea of entrepreneurship. "I've always been reasonably comfortable with that kind of risk," he says. In fact, he cofounded his first start-up in 8th grade with his father, a computer science professor. They wrote a program to teach middle-school math and sold it to a couple of schools.

Before graduating, he took a class at the Fuqua School of Business. Although he didn't do an internship, it's something he recommends to others. "Any graduate student I talk to," Brown says, "I encourage them to at least think about an internship with a commercial entity to get some perspective, some experience, and to start to network."

Since graduating from Duke, Brown has been on the ground floor of several companies that use optics or photonics to create technological solutions to issues related to medical imaging and diagnostics.

Even though all the companies he's been involved in revolve around photonics, Brown says, "I don't do a whole lot of science on a day-to-day basis. I do a lot of systems-level engineering. One of the most powerful skills I bring to the table is that I can sit in the middle of a group of engineers and keep them all pointed in the same direction."

One of the companies he co-founded, Bioptigen, was sold in June 2015 to Leica Microsystems. (See related story here: http://bme.duke.edu/news/54156.) Brown co-founded Bioptigen with Joseph Izatt, the Michael J. Fitzpatrick Professor of Engineering, and CEO Eric Buckland. Izatt says, "Bill had a very strong background in physics and optics and brought deep understanding as well as great hands-on engineering skills to the company."

Bioptigen manufactures medical instruments that use optical coherence tomography (OCT) to produce images of tiny structures in the eye, skin, heart, and other organs. Unlike MRI, CT, or ultrasound imaging technology, OCT has a resolution on the cellular level, allowing doctors and researchers to see more clearly than ever before into structures such as the layers of the retina.

OCT has been in use since the 1990s, but the Duke team—including Cynthia Toth, the Joseph A. C. Wadsworth Professor of Ophthalmology—made improvements to make it faster, more robust, and easier to use. Before leaving Bioptigen in 2006, Brown brought in significant early funding through federal Small Business Innovation Research (SBIR) grants.

Currently, Brown is working on two early stage companies with Adam Wax, the Theodore Kennedy Professor of Biomedical Engineering at the Pratt School, who—like Brown—earned his PhD from Duke Physics in 1999. Wax says, "Bill's most outstanding quality that he brings to a start-up is that he's got a unique ability to take a technology and turn it into a product."

Brown previously collaborated with Wax in founding Oncoscope, a start-up that developed and tested a machine to identify pre-cancerous cells in the esophagus using low-coherence interferometry (LCI) to measure the diameter of nuclei.

One of the two projects he's working on with Wax now involves a faster and cheaper way to do complete blood counts (CBCs), which now take 2-3 days at the typical doctor's office or about 90 minutes in a hospital. For this project, he's secured Small Business Technology Transfer Program (STTR) money from the National Science Foundation.

As if his plate weren't full enough, Brown is also consulting with 8 Rivers Capital at American Tobacco Campus on another new product idea. "This is the first time in my career that I've had more than one viable idea in front of me at the same time," he says. "The overall economy has gotten much better and the interest in innovation has come back. In the photonics space, there continue to be tremendous advances, particularly in components. People are building new devices, new lasers, new detectors. That drives what I can do on a system level."

As for the future, Brown says, "Short term, I'll turn something into another company. Longer term I would like to actually build something I can stay with for more than four years. I want to see one of these things all the way through from the start to some finish."

After a pause he adds, "The reality may be that I'm an early stage guy. The early stage is total chaos—that doesn't scare me."
Abhijit Mehta earned his PhD from Duke Physics in 2013 and has been working at Akamai Technologies in Cambridge, Mass., ever since. “At Akamai, I’ve been encouraged to innovate and to take the initiative to come up with my own ideas,” Mehta says. “It’s really fun to have an outlet for that creativity and to have that freedom.”

Akamai routes and accelerates Internet traffic using its distributed platform of 175,000 servers around the world. “Anytime you use the Internet,” Mehta says, “you’re probably using Akamai. We deeply affect how the world works and we make the world a better place but most people haven’t heard of us because our customers are big companies, not consumers.”

According to Mehta, Akamai serves about one-third of the world’s Internet traffic. Its routing technologies and strategies allow millions of people to simultaneously watch events like the Olympics or the NCAA basketball tournament on the Internet.

When Mehta first started at Akamai, he did data analysis and modeling in the mapping division, which creates real-time maps of Internet routing and patterns of use (and abuse) worldwide. The company uses that information to make websites faster and more secure. “The way Internet routing works is a lawless jungle,” Mehta says. “A lot of it has to do with agreements on how companies charge each other for traffic. We have a global view of the Internet so we can optimize routing and act as a security buffer.”

Mehta recently moved to a new division, Akamai Labs, which creates innovative processes and products for the company. “In my time in Labs I’ve had a chance to learn about writing super-optimized low-level systems server code that concurrently handles hundreds of thousands or millions of connections at the same time,” he says. “I’ve also built web applications.”

Right now, he is developing a product to improve real-time video communication. Reporting directly to a vice president, he’s leading a team of people working on the prototype. “If you have used any of these video technologies you know they are cool but not perfect,” he says. “I had an idea for a way we could use our distributed platform to make these kinds of real-time Internet communications better. My boss liked the idea and he shopped it around to senior management. I got the green light so I have the freedom to build out this product that was my idea.”

His work at Akamai is not directly related to the quantum Monte Carlo research he did with Professor Harold Baranger at Duke, but some of the necessary skills are the same. “The overall ability to model interacting systems is incredibly useful,” he says. “In physics I was interested in quantum many-body systems. The Internet is different from that kind of physics, but there are philosophical similarities in that you have this big complex system and a lot of different things interacting with each other in complicated ways.” He also regularly uses mathematical tools such as statistics and probability, combinatorics, graph theory, abstract algebra, and topology, as well as teaching and presenting skills he honed at Duke.

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Mehta, who grew up in Cincinnati, first arrived at Duke as an undergraduate. He majored in physics and math with a minor in classical studies. An A.B. Duke Scholar, he graduated summa cum laude. During his graduate studies, he earned a master’s degree in electrical and computer engineering and an interdisciplinary graduate certificate in nanoscience in addition to his doctorate in physics.

As a graduate student, Mehta purposefully kept his options open. He worked with Duke’s Career Center early on to make sure he was preparing himself for a career in either academia and industry, and that he knew how to present himself well to either audience in his resume and CV. As part of that effort, he set up and maintained a LinkedIn site—which is how Akamai recruiters contacted him.

Mehta also did a lot of networking and recommends that current graduate students do the same. “Networking is a word that makes a lot of physicists uncomfortable,” he says, “but anytime you’re talking to another person and learning from them you are networking. There are so many interesting problems out there that haven’t been solved and so many interesting connections to be made, and one of the best ways to learn about those is to talk to people.”

He adds, “I’m always happy to talk to current grad students and alums if they have questions about life in industry—and I’m hiring!”

(See here for an article about Mehta’s networking at the Lindau Meeting of Nobel laureates in 2010: https://www.phy.duke.edu/news/mehta-attends-60th-annual-lindau-meeting-nobel-laureates-and-students)
The Postdoc Experience in the Duke Physics Department
— by Mary-Russell Roberson

In the field of physics, it’s considered de rigueur to complete a postdoctoral position, or postdoc, after earning a PhD and before beginning a faculty job. “It’s expected that you’re going to broaden beyond your PhD work,” says Duke Physics Interim Chair and Prof. Dan Gauthier. “Search committees want to see to what extent you were able to jump into another lab and another environment, and to what extent you’re able to come up to speed quickly and start to generate publications. If you do well at publishing and mentoring as a postdoc, then you’re probably going to do well as a junior faculty member.”

According to Administrative Manager Randy Best, there are 22 postdocs in the physics department this year.

The postdoc years are unlike any other phase of an academician’s life.

“We have more time to do research than any other members of the group,” says first-year postdoc Erin O’Sullivan. “A graduate student has classes and TA responsibilities, and a professor has teaching and administrative responsibilities. A postdoc is hired to focus all their time on the research agenda.”

O’Sullivan, who came to Duke from Queen’s University in Kingston, Ontario, works in the Neutrino Group led by Prof. Kate Scholberg and Prof. Chris Walter. She is working on improving a computer simulation that’s being used to design Hyper-Kamiokande, an underground facility that could, among other things, detect neutrinos and anti-neutrinos from distant supernovae and search for proton decay. If all goes according to plan, Hyper-K will be up and running in Japan in the mid-2020s.

O’Sullivan is coordinating a group of physicists at Duke and other institutions to work on different parts of the code. “The simulation looks at what kind of physics potential Hyper-K would have,” she says. “We want to optimize the detector during the design phase to be able to do the physics we want to do.”

Alex Himmel has been a postdoc with the Neutrino Group for three years. “Chris and Kate have provided outstanding mentorship,” he says. “He’s seen his own mentorship abilities grow as well. ‘That’s the flow of things—as you gain skills, your role evolves to pass those along to the younger people in the group.’ For example, on some of the earlier papers he published while at Duke, he did the analyses himself while on later papers, he advised graduate students who were doing the analyses.

Himmel worked mainly on the Super-Kamiokande and T2K neutrino experiments in Japan, traveling there about six times a year. He’s also been involved in Hyper-K and DUNE (Deep Underground Neutrino Experiment), which is in the Homestake Mine in South Dakota.

Both O’Sullivan and Himmel enjoy the fact that the Neutrino Group is involved in so many different experiments. “Kate is a world expert in supernova neutrinos and Chris is getting involved in cosmology,” Himmel says. “It’s been great to be exposed to all those things.” He is currently applying for faculty and research lab positions, and expects to continue pursuing neutrino research.

While most postdocs go on to a career in academia, not all do. Rui Zhang was a postdoc in Dan Gauthier’s research group for almost four years. Today she works as a research and development engineer at Coherent, a laser-technology company in Silicon Valley. “I’m grateful for my training in Dan’s group,” she says. “In industry, we need very broad knowledge to find the best solution for a technical problem, and in Dan’s group I was exposed to many topics like electrical chaotic networks, slow light, optical coherence tomography, and ultra-cold rubidium atoms.” Zhang says she was open to a career in either academia or industry, but a good industry job presented itself first.

Damien Rontani was also a postdoc in Gauthier’s lab, and the experience helped solidify his desire to pursue an academic career. “By the end of my PhD, I wanted to aim for an academic job but I wasn’t really sure I was a good fit. The postdoc was a really good test.” Today he is an assistant professor at CentraleSupélec in his native France. In Gauthier’s lab, Rontani and a graduate student worked together on experiments in the field of network science, using a device called a field-programmable gate array (FPGA), which is a processor made of reconfigurable logic circuits. “FPGAs are a versatile physical platform that allow us to design complex circuits quickly without having to do any soldering,” Rontani says. “Dan came up with the idea, but we were in charge of developing those concepts and pushing the idea into many different directions.”

While doing his research, Rontani was exposed to various aspects of being a faculty member, including writing and submitting grants, a skill he uses in his current position. In fact, he recently received an IBM Faculty Award to work on cognitive computing using physical systems rather than algorithms running on traditional computers. “Overall I really enjoyed my experience at Duke,” Rontani says. “And I’m really grateful to Dan because he inspired me in a lot of ways as to how I conduct myself as a scientist today.”
Despite the chilly weather over the fall break, physics graduate students maintained their excellent tradition of national lab expedition this year. On October 14, 2014, nine physics graduate students visited Oak Ridge National Laboratory (ORNL) at Oak Ridge, Tennessee, to experience the world-leading academic and research environment. ORNL, managed by the U.S. Department of Energy, is the largest multidisciplinary science and technology laboratory from fundamental physics such as nuclear physics and neutron physics, to biomedical science and engineering, super-computing and clean energy.

Overall, students were introduced to the current research topics and job opportunities at ORNL, and toured the fascinating facilities at various labs. In the morning, students received a warm welcome from Dr. Ian S. Anderson, the Director of Graduate Education and University Partnerships, and had wonderful presentations on research and opportunities by multiple ORNL researchers. Prof. Georgia Tourassi, who is an alumna of Duke, now Director of Biomedical Science and Engineering Center (BSEC), also gave the students an overview of BSEC. Later, students visited the historic Graphite Nuclear Reactor, which was built for the Manhattan Project during World War II. At noon, students had an informal lunch meeting with current ORNL professors, postdocs and graduate students. Many topics were discussed such as academic career developments, working at the national laboratory, carrying out interdisciplinary research and how to transfer knowledge from research to industry. Mary Jane Simpson, a recent graduate student from Prof. Warren Warren's lab in Duke Chemistry, also attended this meeting and talked with our students about her experiences at ONRL. The lectures and talks are beneficial, as physics graduate student Sourav Sen (entered '13) says: "It was very enriching to interact with the professionals and research scientists about their own research in frontier fields along with facilitating research in both academia and industry by their state-of-the-art facilities and expertise. I also learned more about the organizational structure of the National Labs."

In the afternoon, staff members led students to many scientific facilities, such as the state-of-the-art computing machine the Titan, High Temperature Material Laboratory, Spallation Neutron Sources and Center for Nanophase Materials Sciences. Besides being fascinated by the laboratory facilities such as various high resolution electron microscopes, advanced accelerator and neutron sources, innovative knowledge transformation from science to technology and many existing resources such as user facilities, fellowships and internships at ORNL also broaden our students’ horizon. Physics graduate student Andrew Seredinski (entered ’14) says that he was very impressed by the way the national lab emphasizes making extensive applications for industries and developing various technologies to solve problems, such as cleanrooms for advanced functional material research. Andrew also says it is very helpful to know that many advanced user facilities in the national lab are free and open to public.

Another physics graduate student Weiyao Ke (entered ’14) summarizes his experiences: “Maybe the most valuable gain from this trip is the realization that there are many opportunities at the national lab. Postdocs and fellows here enjoy a great degree of independence in research... It seems you are always faced with a problem not seen before by anyone.”

Special thanks to physics graduate student Forrest Friesen (entered ’11) who volunteered for driving. Thank you to Justin Raybern (entered ’14) for the photographs. See all pictures on Flickr here: http://tinyurl.com/ot2k9pk
New Hands-On Lab Classes Launch for Physics Majors

— by Yuriy Bomze and Ken McKenzie

In Fall 2014, our department launched two exciting new 1/2 credit laboratory courses, Introduction to Experimental Physics 1 and 2. These are meant to be the first of a new sequence of experimental courses for physics majors and other students who are interested in having a strong foundation of experimental skills. IntroEP 1 and 2 have emerged out of a recognition that physics students’ experimental education up to the Junior year could be significantly improved by implementing a progressively developed sequence of courses, a sequence designed to build the important experimental skills that students will use on the intermediate and advanced physics lab level and in their research.

The new courses represent significant innovations by comparison to the way that laboratories were formerly taught to physics majors. Now, IntroEP 1 and 2 focus at least as much on the experimental process itself -- the measurement systems and process of measurement and analysis -- as they do on the topical physics subject matter. For example, in the new courses, students are exposed to computer programming, real experimental instrumentation, and error analysis as part of experimental coursework beginning from day 1. Record-keeping in laboratory notebooks has been given a central role. Students learn how to make and to question measurements, to think about uncertainty, to build models, and to undertake data analysis using a computer language.

Pre-packaged “educational” equipment has been discarded in favor of real instrumentation; nothing about the function of apparatus has been hidden from the students. They gain experience with equipment such as strain gauges, oscilloscopes, function generators, and DAQ interfaces. Furthermore, students encounter -- and receive guidance about -- day to day problems that might arise in a research setting, things like sensor calibration, thinking about systematic errors, processing raw data computationally. They are taught about statistics, sampling rate and bit resolution, aliasing. Likewise, the new experiments are often open-ended, in order to create opportunities for guiding students in the process of critical thinking about data and measurements. Student projects at the end of each term allow groups to design, build and undertake their own experiments, too.

In IntroEP 1 and 2, we have introduced a plethora of new and interesting laboratory experiments. Some experiments are purely empirical, allowing students to study and characterize a system and to create a model which fits the observed behavior. Others are meant to show the interplay between theory and experiment.

In IntroEP 1, student experiments frequently use magnets to study kinematic and mechanical phenomena. Magnets are interesting. They allow mechanics topics to be studied on a novel footing that nonetheless doesn’t require any knowledge of magnetism itself -- simply that a force of some kind exists. Students empirically measure the force between two magnets as a function of distance, and propose an empirical model to fit to their data. This data is then used in many subsequent experiments: for example studying static equilibrium with “levitating” magnets, or using numerical integration to study work and kinetic energy in the context of dropping a magnet down a low-friction rod towards a second magnet that repels it. To take another example, students may “collide” two magnets, which exchange momentum without ever touching each other. The impulse and momentum transfer can be measured with strain gauges or with high speed cameras.

In one typical experiment during their second semester, IntroEP 2 students use a high voltage power supply to energize an electrostatic oscillator, a metal pendulum that ping-pongs between two charged plates. There is an interplay between theory and empirical data. From the empirical side, students figure out how to precisely measure the relationship of the oscillator frequency to applied voltage. From the theoretical side, they must resurrect their knowledge of kinematics from the previous term, and also think about how electric forces within electric fields lead to the behavior they observe. Students are shown that there are varying degrees of approximation that can be used to understand a system of this kind.

Student responses to IntroEP 1 and 2 have been overall very positive, with most feeling that the new courses have thus far been challenging but worthwhile, despite the hiccups that must be expected in the first year of a complex new course. One student writes, “I had much enjoyment in this course experimenting with different apparatuses and experimental procedures and ideas. This course grabbed hold of my interest in physics and amplified it.” Another writes, “I’m so glad this is a separate course than the lecture and discussion component! It allows for an entirely different mindset and approach to learning and is a great introduction to experimental physics.” A third student comments, “The equipment was very neat. It was much more accurate than anything I’ve used before, and some of the experiments we did were amazing!”

Our hope is that we have created a new lab curriculum that is rigorous from the point of view of the skills and experience it provides, but which is nonetheless extremely engaging for students and allows them some freedom to explore the phenomena they are taught in their lecture courses. We believe the new sequence has the potential to eventually be among the strongest in the country as far as teaching experimental skills and methods. We are still in the process of revision and improving the experiments, and we look forward to an even more positive and interesting experience for students in Fall 2015 and Spring of 2016.
This past summer, undergraduates from the Duke physics department worked alongside physicists at research hotspots around the world, contributing to work on neutrino detection, the Higgs boson, a next-generation telescope, and more. In the process, they not only learned how to apply classroom concepts to real-world problems, but also gained insight into themselves and their plans for the future.

Aaron Webb, a senior from Arizona, worked on the ATLAS project at the Large Hadron Collider at CERN in Switzerland. "It gives you a different perspective because it's a very different dynamic than in a classroom where there's a clear distinction between professors and students," he said. "It almost surprised me how much people there treated me as if I was just another scientist." Webb, whose advisor is Prof. Al Goshaw, worked on data analysis related to scattering of electroweak bosons, a project he intends to turn into his senior thesis.

Webb traveled to CERN as part of the REU program (Research Experience for Undergraduates). Fourteen undergraduates from colleges and universities around the country participated in the NSF-funded program at Duke this summer, which is a joint venture between TUNL and Duke's high-energy program. Four of the REU students—including Webb—spent the first half of their summer at Duke and the second half at CERN.

Jincheng "Louis" Xu, a sophomore from Beijing, also worked on the ATLAS project at CERN, although via a different route: a Deans' Summer Research Fellowship. These fellowships are awarded to students each summer by the academic deans of Trinity College to support undergraduate research experiences on or off campus.

"It's the best summer I've ever had so far," said Xu, whose advisor is Prof. Ayana Arce. "It's not just about the research projects—I also got to talk to physicists, computer scientists, and students from all around the world." Xu, who is thinking of double majoring in physics and computer science, wrote computer code to help sort through the enormous amount of data being generated to describe the Higgs boson.

Two other physics undergraduates also received funding from the Dean's office: Max Duncan and Andrew Walsworth, who both worked at Brookhaven National Lab in Upton, New York, under the advisement of Prof. Chris Walter.

Max Duncan, a physics major and theater minor, worked on the Large Synoptic Survey Telescope (LSST). At the heart of the telescope, scheduled to go online in 2020, will be a 3.2 giga-pixel camera made out of 189 charge-coupled device sensors. Duncan worked on a computer simulation to quantify the distortion created by a positive-charge guard rail that surrounds each sensor. "It was valuable for me to get a glimpse at what a job in physics actually is," he said, "and also to see what kind of work goes into building a telescope. I underestimated how much conceptual work and problem-solving goes into the creation of the telescope and how much you have to know before you physically start building it."

Justin Raybern also worked at a national lab—Oak Ridge National Lab in Tennessee. Raybern, an incoming graduate student who did his undergraduate work at Kansas State, knew he wanted to do research on neutrinos, so he contacted Prof. Kate Scholberg. She invited him to work on the coherent neutrino-nucleus scattering project at ORNL. He did so, taking background measurements at the Spallation Neutron Source there. He's continuing his work on that project with Prof. Phil Barbeau this semester.

Danielle Riggin, a junior from Rhode Island, spent part of her summer two kilometers underground in the Sudbury Neutrino Observatory (SNOLAB) in Ontario. Riggin, who is majoring in physics and minoring in computer science, worked on the HALO project, which is designed to detect neutrino bursts created by supernovae. Getting to the underground lab required donning mine gear, descending two vertical kilometers in a mine-shaft elevator, walking two horizontal kilometers, then showering and putting on a clean suit and a hairnet before entering the lab. "The underground lab was a huge surprise," she said. "It was incredible, and it was so amazing being there and being able to talk to
people from all the other experiments."

Belowground, she helped outfit parts of the detector, which consists of helium-filled tubes surrounded by lead blocks. Aboveground, she wrote code for a computer simulation that will help determine the efficiency of the detector. "It was cool to get to apply my computer-science experience to research," she said. "And it was really fun. I would spend all day coding and go home and code more." Riggin's project was funded through an NSF grant of her advisor Prof. Scholberg.

Eugene Rabinovich, a double major in physics and math from Cleveland, attended the two-week Cargèse Summer Institute on String Theory and Holography on the island of Corsica in France. He was the only undergraduate accepted to the 65-person conference, which is attended mostly by graduate students and postdocs. Rabinovich had already been studying a string-theory technique called localization under Prof. Ronen Plesser. "The great thing about this conference is that I saw the bigger picture of how localization fits into really interesting questions that are being asked and investigated on string theory," he said. "It gave me some interesting ideas about what kind of a new direction to take my research this year for my thesis."

As an A. B. Duke Scholar, Rabinovich was able to apply for funding through that program to support his trip. "I feel really lucky, one, that I've been able to find so easily the funding to go to such a program and, two, to get to a point as an undergraduate to be able to understand better what the big picture in string theory is these days, which will help me make better choices as to which graduate school I want to go to."

Many of the students said their summer experience helped shape their vision of their future. "It definitely confirmed that I'm on the right path, not just that I like research but that I'm the type of person that likes research," said Webb of his CERN experience. "It gave me a perspective on what sort of qualities you need to enjoy research—patience and being able to be comfortable not understanding something or not really getting anywhere for days at a time. Some people are very goal-oriented and don't enjoy not getting results right away. I enjoy the process and the tinkering just as much."

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**SPIN Symposium 2014 in Beijing**

— by Haiyan Gao

The 21st International Symposium on Spin Physics (Spin2014) took place in the week of Oct 20-24 on the campus of Peking University (PKU), in Beijing, China. The International Spin Physics Symposium series combined together the High Energy Spin Symposia and the Nuclear Polarization Conferences since 2000. The most recent symposium took place in Charlottesville, Virginia, USA (2008), Forschungszenrum Juelich, Germany (2010), and JINR, Dubna, Russia (2012). Spin 2014 was co-chaired by Bo-Qiang Ma (PKU) and Haiyan Gao (Duke).

The scientific program of this symposium included topics related to spin phenomena in accelerator, condensed matter physics, nuclear and particle physics, quantum computing and quantum information, medical imaging, etc. The symposium format consisted of talks in plenary and parallel sessions, a poster session, and a public lecture. About 250 physicists from Armenia, Austria, Belgium, China, Croatia, Czech Republic, France, Germany, India, Italy, Japan, Mexico, Netherlands, New Zealand, Poland, Portugal, Russia, South Korea, Switzerland, Taiwan and United States participated in this international symposium. Prof. Warren Warren from Duke Chemistry and Physics gave a plenary talk on medical imaging at this symposium. Prof. Mohammad Ahmed from Triangle Universities Nuclear Laboratory and Duke Physics reported on Few-body Physics Results from the HIGS facility at the Duke Free Electron Laser Laboratory in another plenary talk at this symposium.

The International Spin Physics Committee (ISPC), a prestigious panel advising this series of symposia, met during Spin2014 and elected Prof. Haiyan Gao as chair-elect for ISPC. ISPC also selected University of Illinois, Urbana-Champaign as the site for the 22nd International Symposium on Spin Physics (Spin2016), which will take place in 2016. Prof. Gao will become chair of ISPC when the committee meets next time during Spin2016. The photo above shows members of ISPC who attended the ISPC meeting during Spin2014 at PKU.

The Hanscom endowment from Duke University sponsored the outstanding poster competition at this symposium where three graduate students from China Institute of Atomic Energy, Tsinghua University, and Institute of Modern Physics of Chinese Academy of Sciences, respectively, received the first prize, second prize and the third prize.
2015 APS Conference for Undergraduate Women in Physics Held at Duke University

— by Kate Scholberg

Over the weekend January 16-18, 2015, Duke University hosted the American Physical Society Conference for Undergraduate Women in Physics (CUWiP: http://tinyurl.com/nqpodtl) in the North Carolina Research Triangle on East Campus, in collaboration with North Carolina State University, University of North Carolina at Chapel Hill, and North Carolina Central University. It’s the tenth year the conference has been held (it was at Duke in 2010 and NCSU in 2011).

For the past few years, CUWiP has been organized centrally by the American Physical Society and held simultaneously at several sites around the country (http://tinyurl.com/njmq85y). The series is sponsored by the APS, the Department of Energy and the National Science Foundation, and our local conference was sponsored as well by Duke, NCSU and UNC.

About 135 undergraduate physicists from around the Southeast attended presentations and panel discussions on careers for physicists (including alternates to the academic path), professional skills and work-life balance. Parallel workshops and roundtables on many topics facilitated small-group discussions on issues for women in physics, graduate school, involvement in research, and opportunities to learn about specific career paths. Christina Hammock, NASA astronaut-in-training of the class of 2013, made the conference banquet particularly memorable. A final “open mic” session was particularly lively. Students also presented talks and posters on their research. Our own Melody Lim was one of the talk prize-winners, for her presentation “Forces and flows during high speed impacts on a non-Newtonian suspension.”

About this honor, Lim said, "I’m very thankful for the opportunity to interact with so many other students in similar positions, and for the encouragement and expertise offered by the many speakers.

towards my mentor, Prof. Bob Behringer, and his research group, without whom none of this would be possible!"

A number of Duke undergraduate physicists attended, and several were also very active on the local organizing committee, including Melody Lim and Jenny Su. Undergraduates Katrina Miller and Danielle Riggin did a fantastic job of organizing and chairing the student presentations. Graduate student Kristen Collar organized a plenary panel, and graduate student Meg Shea took care of AV. Finally, Connie Blackmore and Jenni Solis were invaluable in handling logistics. It was a busy and exciting weekend for all.

The Passing of Charles H. Townes

— by Daniel Gauthier

Prof. Charles Townes passed away January 27, 2015 at the age of 99. As many of you may know, Prof. Townes received the Nobel prize in the 1960’s for his contribution to the invention of the laser. What you may not know is that he received his MS degree from Duke Physics in 1936. Prof. Townes visited Duke many times over his career, including giving a keynote address in the Fitzpatrick Institute for Photonics during one of its annual meetings a few years back. We also have a graduate fellowship partially funded by Prof. Townes and the corporation Perkin Elmer from many years ago, and an anonymous donor has endowed a named faculty position in his honor. Prof. Townes was still quite active in research up until this past year - Prof. Daniel Gauthier met him at a conference in summer of 2013 and says he was as insightful as always. The LA Times, UC Berkeley and Washington Post featured obituaries and Townes can be seen in a video interview from 2001 on the Nobel Prize’s website: http://tinyurl.com/psjd2nj
In Professor Maiken Mikkelsen’s lab, in collaboration with Professor David Smith, a plasmonic optical antenna is used to enhance the rate at which molecules emit light by a factor of 1,000 using the Purcell effect. As shown in the illustration, this is done by sandwiching fluorescent molecules in a ~10 nm gap between a silver nanocube (~75 nm in size) and a gold film, which creates an ultra-small volume optical cavity. From Akselrod et al, Nature Photonics, 8, 835 (2014). Image credit: Gleb Akselrod.

Cover banner image: A neutrino is shown interacting with the giant Super-Kamiokande detector and making signals recorded by its light detectors. It was directed 295 kilometers underneath Japan from the JPARC accelerator to Super-Kamiokande as part of the T2K experiment.