DUKE UNIVERSITY PHYSICS DEPARTMENT

2018 NEWSLETTER

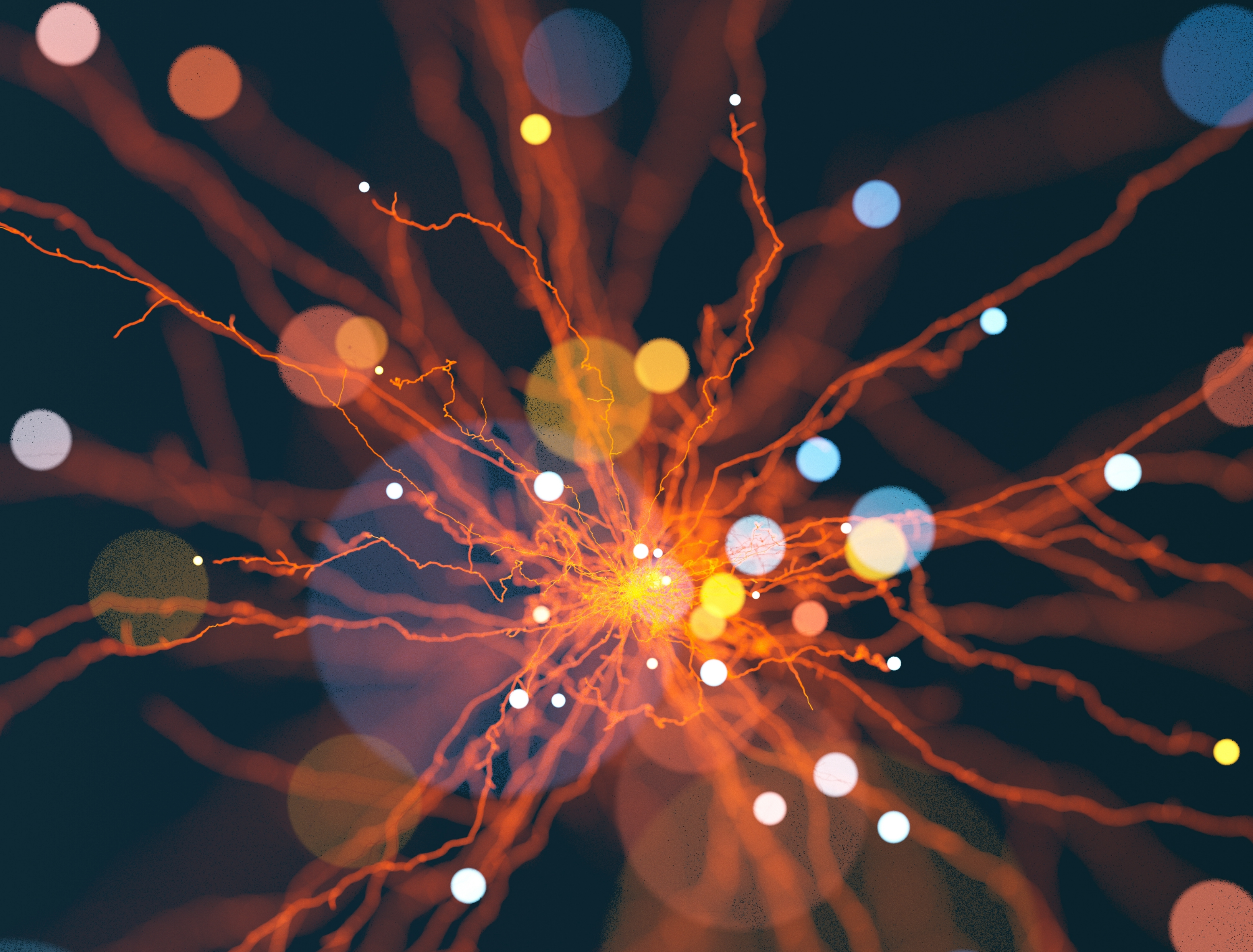


TABLE OF CONTENTS

Physics matters.

Physicists explore the most fundamental questions in science. Less than 5% of what fills the universe is atoms and ordinary matter: what is the rest? Why do different measurements give different sizes for the proton? Can a deeper understanding of symmetry unravel the mysteries of the subatomic scale, or help understand materials science?

Physicists create the tools which underpin most scientific and societal advances. The transistor, the integrated circuit, the laser, the world-wide-web and virtually every medical imaging method started as basic physics. In the 1940s, studying the properties of nuclear spin was the height of esoteric science; today it is the basis of magnetic resonance imaging, and can even be used to watch people think. Every day at Duke, dozens of patients have tumors imaged with antimatter. Bizarre effects in quantum mechanics, such as forbidden states and entanglement, show promise to improve computing, secure communications and diagnose disease.

Physicists at Duke work on these problems, and many more. We operate from a tradition of great scientists, including Nobel Laureates, going back to the beginning of the university. And the best is yet to come. We are hiring first rate faculty, expanding our research into near areas such as cosmology and soft matter physics, and are exploiting the wonderful Duke environment for interdisciplinary science.

We invite you to look through these pages, to get a sense of the excitement of Duke Physics and the promise of the future.

CHAIR'S WELCOME

BY STEFFEN BASS

Welcome to our newsletter!

The past year has brought a lot of changes to our Department. We mourn the sudden and unexpected loss of our colleague **Robert P. Behringer**, who passed away last summer. You can read more about Bob's remarkable life and many contributions to our department in a dedicated article in this newsletter. We welcome two new faculty in observational cosmology – **Prof. Daniel Scolnic** and **Prof. Michael Troxel** – their research is featured in this newsletter as well. Our front office has seen changes as well – **Timothy Fields** is our new Assistant to the DUS and **Todd Lewis** has joined our team as Staff Assistant.

We have had a change in departmental leadership: **Prof. Warren Warren** stepped down as Chair in November 2018. Under his stewardship a lot has been accomplished. We hired seven new faculty members (some jointly with other departments), we started an initiative in cosmology, overhauled our bylaws and have undergone an external departmental review. Prof. Warren has worked tirelessly to advance our faculty through promotions and early tenure and to secure desperately needed resources for the current operations and future growth of our department – the Department is grateful for his service!

Going forward I am delighted to announce that **Prof. Kate Scholberg** has agreed to transition into the role of Associate Department Chair by the end of the Spring Semester. **Prof. Ayana Arce** will become the new Director of Undergraduate Studies at that time. **Prof. Stephen Teitsworth** has agreed to serve a second term as Director of Graduate Studies. Stephen is planning on taking a sabbatical next fall prior to his second term - during that semester **Prof. Shailesh Chandrasekharan** will serve as DGS.

These are exciting times for our department – we have several searches and recruitment efforts ongoing this spring, hoping to add additional faculty in cosmology, soft and hard condensed matter. We have added an Astrophysics concentration to our Major to capitalize on our new strength in this exciting research direction and to attract more undergraduate students to our department. Duke University is investing heavily into the Sciences and our department is looking forward to the exciting new opportunities that these investments will provide!

GRADUATE STUDIES NEWS

BY STEPHEN TEITSWORTH

Over the past year, I have enjoyed my extensive interactions with our students, faculty, staff and departmental friends as we all work to sustain and enhance the performance and visibility of the graduate physics program at Duke. It is my distinct pleasure to provide you with an update on exciting milestones and developments in our graduate program as well as to highlight the accomplishments of our students over the past year (October 2017 – October 2018).

Degrees Awarded

Seventeen students earned their Doctor of Philosophy in Physics, one received his Masters of Science in Physics. Their names, advisors and thesis titles (Ph.D. only) are listed in the table below. These students have accepted positions in academia, industry, as well as national and international laboratories. I would like to take this opportunity to congratulate them all on their impressive accomplishments and to wish them every success in their future endeavors!

Doctor of Philosophy in Physics

Student	Advisor	Thesis Title
Jonah E. Bernhard	Steffen Bass	*Bayesian Parameter Estimation for Relativistic Heavy-Ion Collisions*
Anne W. Draelos	Gleb Finkelstein	*Thermal and Electronic Transport in Graphene Superconducting Devices*
Emilie S. Huffman	Shailesh Chandrasekharan	*Fermion Bag Approach for Hamiltonian Lattice Field Theories*
Nurul T. Islam	Daniel Gauthier	*High Rate, High Dimensional Quantum Key Distribution Systems*
Chao Peng	Haiyan Gao	*Measurement of Generalized GDG Integrand for the Neutron and 3He at Low Q2*
Dong Wang	Robert Behringer	*Response of Granular Materials to Shear: Origins of Shear Jamming, Particle Dynamics and Effect of Particle Properties*
Yang Zhang	Haiyan Gao	*A Precision Measurement of Neutral Pion Lifetime*
Kristen N. Collar	April Brown	*GaAsBi Synthesis: From Band Structure Modification to Nanostructure Formation*
Yao-Lung Fang	Harold Baranger	*Waveguide QED: Multiple Qubits, Inelastic Scattering and Non-Markovianity*
Jiani Huang	Maiken Mikkelsen	*Valley Dynamics and Tailored Light-Matter Interaction in Two-Dimensional Transition Metal Dichalcogenides*
Chung Ting Ke	Gleb Finkelstein	*Superconducting Electron Transport in Graphene-Based Josephson Junctions*
Arman Margaryan	Roxanne Springer	*Transverse Asymmetry in Nucleon Deuteron Scattering in Pionless Effective Field Theories*
Margaret Shea	Daniel Gauthier	*Fast, Nondestructive Quantum-state Readout of Single, Trapped Neutral Atom*
Ming-Tso Wei	Gleb Finkelstein	*Transport of Quantum Hall Supercurrents in Graphene Josephson Junctions*
Xuefei Yan	Haiyan Gao	*Unpolarized SIDIS Cross Section from a 3He Target*
Gu Zhang	Harold Baranger	*Studies in the Effect of Noise in Boundary Quantum Phase Transitions*
Yue Zhang	Robert Behringer and Joshua Socolar	*Pull-Out Experiment in Granular Material*

Masters of Science in Physics: Ruiyang Zhao, Warren Warren *(Advisor)*

2018 Graduate Student Awards

Saturday, August 28, 2018

It is my great privilege to report on the 2018 graduate student awards and fellowships which were officially announced and bestowed at the Welcome Picnic, August 28, 2018 by the Chair, **Professor Warren Warren, Associate Chair**, **Professor Steffen Bass** and Director of Graduate Studies, **Professor Stephen Teitsworth**. Congratulations to all recipients in recognition of their impressive research and teaching accomplishments!

The Fritz London Graduate Fellowship was awarded to **Moritz Binder** in recognition of his outstanding achievements in the area of condensed matter physics, in particular, to the advancement of numerical techniques for the investigation of low-energy excitations in strongly correlated quantum systems and their application to one-dimensional quantum magnets.

The Goshaw Family Endowment was awarded to incoming 1st year students: **Tyler Johnson** and **Elise Le Boulicaut**.

The Goshaw Family Endowment was also awarded to **Douglas Davis** in recognition of his outstanding achievements in High-Energy Particle Physics. Achievements include development of analysis techniques for studying the rare Standard Model process of a single top-quark production in association with a W boson at the Large Hadron Collider, and his leadership on software development for the Transition Radiation Tracker, one of the particle tracking components for the ATLAS detector.

The Townes/Perkins-Elmer Graduate Fellowship
The Townes/Perkin-Elmer Graduate Fellowship Prize was awarded to incoming 1st year student, **Yikang Zhang .**

The Mary Creason Memorial Award
The 2017 Mary Creason Memorial Award was awarded to **Erin Conley**. This award was established to honor students who excel in teaching physics in the Introductory Physics Laboratories at Duke. Dr. Mary Creason was a Lecturer and coordinator of instructional laboratory activities in the department of Physics at Duke University until her untimely death in May 2007.

The Walter Gordy Memorial Endowment was awarded to **Xin Zhang** in recognition of his achievements in the area of microwave quantum optics, in particular, correlation of photons and entanglement of qubits in waveguide QED, with implications for quantum information transfer.

Robert C. Richardson Fellowship, funded by a generous donation from an anonymous supporter of the Department, is open to Physics graduate students in any subdiscipline. For the Fall 2018 semester, this fellowship was awarded to **Andrew Seredinski** in recognition of his outstanding achievements in the area of Experimental Condensed Matter Physics, primarily for his work on graphene-based Josephson junctions with potential application to quantum information processing.

Robert C. Richardson Fellowship, also awarded to **William Steinhardt** in recognition of his outstanding achievements in the area of Experimental Condensed Matter Physics, in particular, for his efforts in studying the exotic magnetic properties of Quantum Materials with potential applications to quantum computing and energy related technologies.

Oustanding Teaching Assistant of the Year, American Association of Physics Teachers (AAPT): Alexey Bondarev *(left pictured below with Professor Steffen Bass* and **Jake Lindale** *(right pictured below with Professor Steffen Bass)*

External Awards:

· Consortium for Nonproliferation Enabling Capabilities (CNEC), DOE: **Samuel Hedges** and **Connor Awe**

· GPNANO Fellowship: Alexey Bondarev, **Trevyn Larson** and **Yuheng Liao**

· JB Duke International Research Travel Fellowship, Duke Graduate School: **Minyu Feng**

· Jo Rae Wright Pre-Doctoral Fellowship in Medical Imaging Training Program, Duke Biomedical Engineering: **Xiaomeng Jia**

· The Molecular Sciences Software Institute Fellowship: **Aaron Mahler**

· SLOAN Fellowship, Duke Graduate School: **Tyler Johnson**

Graduate Admissions

I would like to extend a warm welcome to our entering class of new graduate students. Fifteen students matriculated in the Fall of 2018 and one student will matriculate in January of 2019. I look forward to working with these students in the coming months and years as they progress through our core curriculum... courses, and then on to an exciting array of cutting-edge Ph.D. research projects.

Finally, I would like to take this opportunity to thank faculty members of the Graduate Admissions Committee for their diligent work in carefully assessing more than 250 applications. In addition, I would like to thank our current students, faculty and staff for their effective work in planning and assisting in the numerous activities of the Open House held annually in late February/early March. This event provides a great opportunity for accepted applicants to get a firsthand sense of the graduate program, departmental and extra-departmental research, and the University more broadly.

Left to right: Ethan Mancil, Professor Warren Warren, Elise Le Boulicaut, Matt Ennis, Derek Soeder, Reed Hodges, Lalit Yadev, Utsav Patel, Jingyi Zhao, Tyler Johnson, Xiaoxuan Jian, Tianyi Chen, Yu Feng, Yikang Zhang, Son Nguyen and Professor Stephen Teitsworth.

UNDERGRADUATE STUDIES NEWS BY KATE SCHOLBERG

At this year's graduation ceremony in May 2018, 12 students with first majors in physics and one with a secondary major received their diplomas. In addition, four students with first majors in biophysics and one with a second major in biophysics graduated. It's now the sixth year that our successful and now very well-established biophysics program has graduated students!

The graduation program can be found here.

The members of the 2018 graduating class will be taking very diverse paths, including pursuit of advanced degrees in physics, engineering and other fields, and professional school.

This year a total of nine seniors completed research theses, five with Distinction and four with High Distinction.

Jeong Min (Jane) Park is the recipient of the Daphne Chang Memorial award for excellence in undergraduate research, for work with **Professor Sara Haravifard** and a thesis entitled "Synthesis, Characterization, and Inelastic Neutron Scattering Studies of Breathing Pyrochlore $Ba_3Yb2Zn_5O_{11}$". The award 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 annual department poster session in April. We had 13 posters describing projects in many subfields.

The poster session program can be found here.

Attendees voted for the best posters. The first prize winner was Jane Park; second prize went to **Kya Sorli**, and third place to **Micaela Kulvaranon**. All the students' work was impressive!

The poster session also marked the induction of seven 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.

Through the generosity of an endowment for the physics undergraduate research and education program, the department has been able to support summer research for physics majors for the past three years. In 2018, we were able to fund the summer research of **Isabel Ruffin**, for a project entitled "Quark-Gluon Jet Tagging in the LHC ATLAS Detector" with **Professor Ayana Arce**. Isabel spent time at CERN during the summer.

A new course offering this year is a new, advanced half-credit lab course, Physics 364L, which started with the implementation of biophysics-oriented experiments in the style of our current Advanced Laboratory course. This now has a full-credit version, Physics 365L. This course was developed by **Professor John Mercer** and **Dr. Yuriy Bomze**, and was offered for the first time in spring of 2018.

New developments are underway in the Undergraduate Curriculum Committee: we are working on the creation of a new track focusing on Astrophysics and Cosmology. Given our new faculty hires **Daniel Scolnic** and **Michael Troxel**, who join **Professor Christopher Walter** in cosmology research, we now have enough personnel with expertise in the field to teach a range of undergraduate level courses. Astrophysics courses are a common request of prospective and current students, and we're excited to launch this new program. We hope to offer this for the first time in the next academic year.

As final news, this year Professor Ayana Arce has taken on the position of Associate DUS, and she will be taking over as DUS in July of 2018.

GRADUATE STUDENT ORGANIZATION NEWS

BY RYAN KOZLOWSKI

The Duke Physics Graduate Student Organization (GSO) exists to develop a sense of community among graduate students, provide opportunities for professional development, and be the collective voice of the students. This year, we have had many events that address these goals.

Annual Summer Picnic:

The class of 2017 did a fantastic job organizing our annual picnic in September – there were at least 100 attendees from the department, including graduate students, faculty, post-docs, and visiting scholars! Warm weather, food, discussion, slackline, volleyball, and awards for students demonstrating excellence in the lab and as TA's made for a fun afternoon. Additionally, the class of 2017 presented **Professor Harold Baranger** with the Excellence in Teaching Award for his instruction in graduate level quantum mechanics. This award was developed by students in recent years to recognize and express gratitude for quality core curriculum instruction each year.

Gradate Student Seminars (GSS):

This year, **Yuchen Zhao** and **Yiqiu Zhao** did an excellent job recruiting speakers for GSS talks, making sure that the talks were well advertised to physics graduate students and that everyone who attended was well fed. These seminars serve as a way for students to develop professionally as they prepare for conferences, preliminary exams, and defenses. Students are also always encouraged to present work that they find interesting, such as a newly published article or a side project, even if it is not in preparation for a "real" presentation! This is a great way for students to learn what their peers are doing and to ask each other challenging questions. The GSS talks given in the last year are listed below.

2018 Spring

Chao Peng: The Generalized Gerasimov-Drell-Hearn (GDH) Sum Rule Measurement at Jefferson Lab

Emilie Huffman: The Fermion Bag Approach to Hamiltonian Lattice Field Theories

Hersh Singh: Direct Detection of Dark Matter as Three-Body Bound States

Xiaomeng Jia: Probing the Change of Energy Dissipation Pathways of Eumelanin upon Structure Degradation

Sam Hedges: NaI[Tl] Prototype Detector for Studying Properties of the CEvNS Interaction

Hanqing Liu: Exact QFT on 2-sphere

Meg Shea: Fast, Nondestructive Quantum-State Readout of a Single, Trapped, Neutral Atom

2018 Fall

Erin Conley: Detecting Supernova Neutrinos in the Deep Underground Neutrino Experiment

Ethan Arnault: Topological States of Josephson Junctions Based on van der Waals Heterostructures

Andrew Seredinski: Quantum Hall Supercurrent in Sidegated Graphene

Jonathan Yuly: Physical Aspects of Electron Bifurcation

Ryan Kozlowski: Stick-Slip and Clogging Dynamics on the Single-Grain Scale

Open House:

Jonathan Yuly spearheaded the organization of the student-led events in the March Open House for two days. Prospective physics graduate students explored the research options in physics and beyond, had a nice dinner at the Doris Duke Center near the Gardens, and met with current graduate students to discuss life in Durham and in the department.

Social Events:

Students have had many opportunities to get to know each other outside of an academic context through a variety of GSO social events. Each Friday, students have Cookie Time to celebrate another week passed and the coming weekend. In the Spring semester, every two or three weeks, students met for Tea Time with faculty to have informal conversations about research and Durham life under the leadership of **Dripto Debroy**; in the Fall semester, thanks to the diligent efforts of **Adryanna Smith**, students started to meet for a variety of special occasions: celebrating the beginning of Autumn (and a coming hurricane, incidentally), writing Thank-You cards in November for faculty and staff, playing 4-Square in the TUNL parking lot, and more. The graduate physics community has benefited greatly from these events and we expect many more in coming months!

Colloquium Lunches:

Emily Phillips Longley organized spring lunches with colloquia speakers; **Achint Kumar** organized fall lunches. Both made sure that students were able to connect with speakers that interested them – a vital part of the professional development for which GSO advocates! In total, there were 21 colloquia in the Spring and Fall 2018 semesters – many more than usual in the Spring because a cosmology faculty search.

Leadership:

The GSO would like to thank all leadership board members and committee members for making this past year a success. The GSO Executive Leadership Board consists of Ryan Kozlowski (President) and **Brodie Popovic** (Secretary/Treasurer). The class representatives are **Yingru Xu** (6th+ years), Yuchen Zhao (5th year), **Aaron Mahler** (4th year), Ryan Kozlowski (3rd year), **Wenkai Fan** (2nd year), **Utsav Patel** (1st year), and **Gleb Sinev** (at-large). The GSO committee members are Adryanna Smith (Social Activities), Yiqiu Zhao (GSS), Ethan Arnault and Andrew Seredinski (Curriculum Development), Achint Kumar (Colloquium Lunches), **Tyler Johnson** (Graduate and Professional Student Council Representative), **Justin Raybern** and Yuchen Zhao (Code of Conduct Development), Erin Conley (Ombudperson), Jon Yuly (Election Commissioning), and **Trevyn Larson** (Computing). GSO would also like to extend a huge thank-you to DGS **Professor Stephen Teitsworth** for all of his support of GSO and the graduate student body.

To conclude, we have had a successful year in GSO, and there is more to come: The results of our t-shirt design contest will soon come in, giving us an update from the shirts developed in Spring 2017 with the Lorentz Equations. Outreach opportunities in the community (organized primarily by **Derek Leadbetter**) will be more thoroughly advertised to students to make sure everyone has the chance to talk about science with young students and community members. GSO leadership will likely be restructured to find more effective ways to encourage student activity. The list goes on – and so there is much to be grateful for and to look forward to.

ROBERT P. BEHRINGER 1948-2018

Written by Alfred Goshaw, Henry Greenside, David Schaeffer, and Joshua Socolar. | Reproduced from Physics Today **71**, 12, 60 (2018), with the permission of the American Institute of Physics.

Robert Paul Behringer, a James B. Duke Professor of Physics at Duke University, died unexpectedly on 10 July 2018 in Durham, North Carolina, following complications from surgery. At the time of his death, Bob was an active, highly respected experimental physicist in the areas of fluid dynamics and soft condensed matter; a leader in the American Physical Society (APS); a caring, successful mentor of young scientists; and a devoted husband, father, and grandfather.

Bob was born on 26 October 1948 in Baltimore, Maryland, and obtained his undergraduate and graduate degrees, both in physics, from Duke. Under the guidance of Horst Meyer, he earned his PhD in 1975 for work on critical phenomena in helium-3 and ^{3}He–^{4}He mixtures.

As a postdoc, Bob went to Bell Labs, where he worked with Guenter Ahlers on heat transport and the onset of Rayleigh–Bénard convection in liquid helium. In the late 1970s, there was great interest in understanding the general principles governing the properties of sustained nonequilibrium systems. Bob and Guenter published several seminal papers on the onset of irregular dynamics in fluids, including the first definitive evidence for deterministic chaos in a fluid. After spending four years as an assistant professor at Wesleyan University in Connecticut, Bob moved back to Duke in 1982 and continued his studies of transport and fluid flow in liquid helium. He remained on the Duke faculty for 36 years.

In the late 1980s, Bob became interested in techniques for observing the internal dynamics of flows in porous media and in sand. The possibility of explaining the generic emergence of power-law scaling in nonequilibrium systems enticed physicists with the promise of insights into a diverse array of systems previously studied primarily by engineers and geophysicists. Bob saw an opportunity to perform experiments that could reveal the intricate structures of stresses and flows in granular materials at the grain scale. His observations had a dramatic effect on our understanding of the rheology of granular systems and on the broader topic now known as jamming. Beginning in 2011 and continuing to the present, his group discovered and elucidated the surprising phenomenon of shear jamming in systems with densities below the critical value for random packing.

Bob's images of force chains in two-dimensional packings of plastic disks have become icons of the science of granular materials and of the emergence of complex structures in nonequilibrium systems. Those images have captured the imagination of children and adults at science museums around the country and of physicists around the world. In recognition of his research accomplishments, Bob received the 2013 Jesse W. Beams Award from the Southeastern Section of APS.

Bob made several notable contributions to APS and to the broader scientific and engineering communities through his organizational efforts. For many years Bob helped organize the annual Dynamics Days international conference, which brings together physicists, mathematicians, engineers, and researchers in various other fields to share ideas about nonlinear and complex dynamics. He helped found the APS topical groups on statistical and nonlinear physics and on the physics of climate, and he served as chair of both groups in their infancy. Bob also co-founded the journal *Granular Matter* in 1998 and served as its editor-in-chief. At Duke, Bob co-founded and served as the director of the Center for Nonlinear and Complex Systems, which led to a significant boost in the university's support of interdisciplinary science.

Bob was an exceptionally encouraging and nurturing adviser of young scientists. He saw the potential for excellence in a diverse group of advisees and exchange students, and he found ways to help them succeed. Through his Magic of Science shows, he extended his passion for science to elementary school students. Outside physics, Bob had many talents that he generously shared with others. He was an accomplished pianist and singer, and he loved French language, culture, and history.

Bob was author or coauthor of some 260 articles. He also leaves behind a rich legacy of 28 PhD students, more than 20 postdoctoral mentees and visitors to his lab, and many students, friends, and colleagues who greatly benefited from and enjoyed his mentorship, innovation, and leadership. We miss him greatly.

NEW FACULTY PROFILE

DANIEL SCOLNIC

USING SUPERNOVAE TO CONSTRUCT EXPANSION HISTORY OF THE UNIVERSE

BY MARY-RUSSELL ROBERSON

At age 10, **Dan Scolnic** had his life all planned out: go to Duke, play basketball as a walk-on, then head to the NBA. These dreams were quashed when a pediatrician plotted Scolnic's height on a growth chart and informed him he'd probably max out at 5'2". "It was one of the worst days of my childhood," Scolnic says.

The growth chart turned out to be wrong--Scolnic is 5'11"--and he ended up going to MIT for his undergraduate education. But he is coming to Duke after all, as an assistant professor of physics, focusing on cosmology, beginning in January 2019.

To Scolnic, that childhood growth chart is a metaphor for our understanding of how the universe is evolving over time. A couple of decades ago, cosmologists discovered that the universe's rate of expansion was increasing, which was a surprise. Now, there's another surprise: Measurements of the universe's current rate of expansion don't agree with predictions of that rate using measurements of the universe soon after the Big Bang. In other words, there's a problem with the "growth chart" astrophysicists have been using to describe the universe's evolution. "There are three possibilities," Scolnic says. "We messed up the measurement of the universe as a 'kid,' we messed up the measurement of the universe as an 'adult,' or the model is wrong. What I'm so excited about is this last possibility. Maybe our model is wrong."

Scolnic is using supernovae to get ever more accurate measurements of the size of the universe at different times in its history. He analyzes Type Ia supernovae, called "standardizable candles," because they all have essentially the same brightness. Their apparent brightness here on Earth indicates how far away they are. He measures their redshift to find out how old they are. "You can put this together and get an expansion history of the universe," he says.

He hopes this expansion history will get him closer to his ultimate goal, which is to figure out dark energy--the mysterious energy that is causing the universe's expansion to accelerate. "It's 70% of the universe and we don't have a clue what it is," he says. "It's literally the biggest problem in astrophysics."

The supernovae technique is becoming more useful and precise as the amount of available data proliferates. The first teams used data from about 30 supernovae. Scolnic is now working on a sample that has 1,000-2,000 supernovae, and his next big project will have close to a million supernovae. "This is a golden age of big data cosmology," he says. "We have all these telescopes that are streaming huge amounts of data."

Scolnic participates in many of the international collaborations that are collecting measurements in unprecedented quantity and quality, including (to name a few) Pan-STARRS; the Dark Energy Survey (DES); the Large Synoptic Survey Telescope (LSST); and the Wide Field Infrared Survey Telescope (WFIRST). As part of his work on Pan-STARRS, he recently published the most precise measurements of dark energy to date.

Aside from his supernova work, Scolnic also does research looking for optical counterparts to gravitational waves.

Scolnic earned his PhD at Johns Hopkins before becoming a fellow at the Kavli Institute for Cosmological Physics at the University of Chicago. Although his path to Duke was different than what he imagined as a 10-year-old, he couldn't be happier with the way things worked out. He's ready and eager to help start a new cosmology program at Duke with **Chris Walter**, professor of physics, and **Michael Troxel**, assistant professor of physics, who is also starting in January 2019.

"I'm super excited," Scolnic says. "Duke is very committed to this and it's a chance to get in on the ground floor and try to build a very prestigious cosmology program."

Walter, who has recently shifted the focus of his research from neutrinos to cosmology, is equally enthusiastic. "This science is just incredibly compelling and everyone is excited about it," he says. "Dan is an expert in using supernovae to probe cosmology, and Troxel is an expert in weak gravitational lensing, so the three of us working together will have a synergistic environment to accomplish things." Walter says the department is currently searching for another assistant professor in cosmology and is planning to add an astrophysics track for physics majors and new classes for graduate students.

Scolnic is also excited about teaching. Although work and family don't leave much free time (he and his wife have a three-year-old and a baby), he still loves watching basketball. . . and he's aware that Duke students do, too. He will be teaching "The Physics of Sports" this semester and he's also got an idea for a seminar combining statistics, basketball, and the Big Bang.

NEW FACULTY PROFILE

MICHAEL TROXEL

USING WEAK GRAVITATIONAL LENSING TO MAP THE INVISIBLE UNIVERSE

BY MARY-RUSSELL ROBERSON

"My business is understanding how the universe evolves, what it's made of, and what its fate is going to be," says **Michael Troxel**, assistant professor of physics at Duke beginning January 1, 2019.

At the heart of these questions lie dark matter and dark energy. Although together they make up most of the universe, they are little understood. Current estimates of the composition of the universe put dark energy at about 70%, dark matter at 25%, and baryonic (or ordinary) matter at 5%.

Troxel is working to find and quantify dark matter, which in turn will help elucidate just how much dark energy there is. Dark energy is the unknown form of energy that is causing the universe to expand at an ever faster rate.

Even though dark matter is invisible, it weakly distorts light traveling through space. The distortion, called weak gravitational lensing, can be used to infer the presence and amount of dark matter. Troxel began using weak gravitational lensing to probe the universe while completing his PhD under the advisement of Mustapha Ishak-Boushaki at the University of Texas at Dallas.

Now Troxel is looking for weak gravitational lensing in the data from a hundred million galaxies that's coming out of the Dark Energy Survey (DES), an observatory in the Andes. DES is surveying one-eighth of the sky over the course of 525 nights in unprecedented detail, gathering data on 300 million galaxies and thousands of supernovae.

"We're creating a map of the universe we can't see," Troxel says. "Once we've mapped where dark matter is, we can use some statistical tricks that can tell us what fraction of the universe is made of dark matter and baryonic matter and dark energy."

This kind of cosmological research is a new focus at Duke Physics. Troxel will be helping to build a new program in cosmology along with **Chris Walter**, professor of physics, and **Daniel Scolnic**, who is also joining the faculty in January 2019.

Walter, who recently shifted the focus of his research from particle physics to cosmology, explains that with the advent of large international collaborative observational projects in the past few decades, it's now possible to create a strong program at a university with fewer people than would have been necessary in the past.

"The department and the university realized that's something we can do, so we started to try to build a really strong group in cosmology," Walter says. "It's an exciting field with some of the most interesting questions of the time, and we can have a big impact by

This is the Blanco telescope (center dome) in Chile that we use for the Dark Energy Survey. You can see the Milky Way in the left of the sky, the Small and Large Magellanic Clouds in the center, and in the right is a red outline of the part of our survey footprint (where we target observations for cosmology) visible at the time the photo was taken. We have to avoid bright, star-filled areas like the Milky Way and even the smaller Magellanic Clouds that orbit the Milky Way when taking survey observations of the distant Universe. | Credit: Reidar Hahn, Yuanyuan Zhang, Fermilab.

having the best people working on it."

Troxel is looking forward to collaborating with Scolnic, who analyzes supernovae to infer the expansion rate of the universe at different times. "We will soon be combining our work into a combined constraint using DES data that will tell us nearly as much about dark matter and dark energy as all other cosmological measurements ever made combined," he says.

In addition to DES, other international collaborations will soon be pumping out huge data sets as well, including the Large Synoptic Survey Telescope (LSST) and the Wide Field Infrared Survey Telescope (WFIRST).

For the new cosmology program, dealing with this fire hose of information will be facilitated by the Information Initiative at Duke, an effort to share information and techniques across disciplines to make the most of big data.

"The really exciting thing about Duke is the ability to work across traditional subject lines [with the Information Initiative]," Troxel says. "It's an unsolved challenge how to take advantage of these huge data sets. Just managing that data and the statistics necessary to extract information from it is pretty cutting-edge. The group we're building at Duke will have a great impact in these unsettled pieces of analysis."

Troxel is also looking forward to teaching and mentoring students at Duke and in the community. He hopes to get involved at the North Carolina School of Science and Mathematics, a public boarding school in Durham for North Carolina juniors and seniors.

Troxel attended a similar high school called the Missouri Academy of Science, Mathematics and Computing. He calls it a formative experience. "It was the first time I had gotten to be around people smarter than I was," he says. "I grew up in a lot of ways that weren't possible at home, not just academically, but morally and personally. No one I knew in my family had gone to college--my father hadn't even finished high school. I don't know that I'd have accomplished what I have without those experiences at the Academy."

He thinks the kinds of questions he finds so fascinating will also be engaging to students. "We all want to know where we came from and where we can go in the future," he says.

TENSOR NETWORKS AND QUANTUM COMPUTATION FOR CONDENSED MATTER PHYSICS

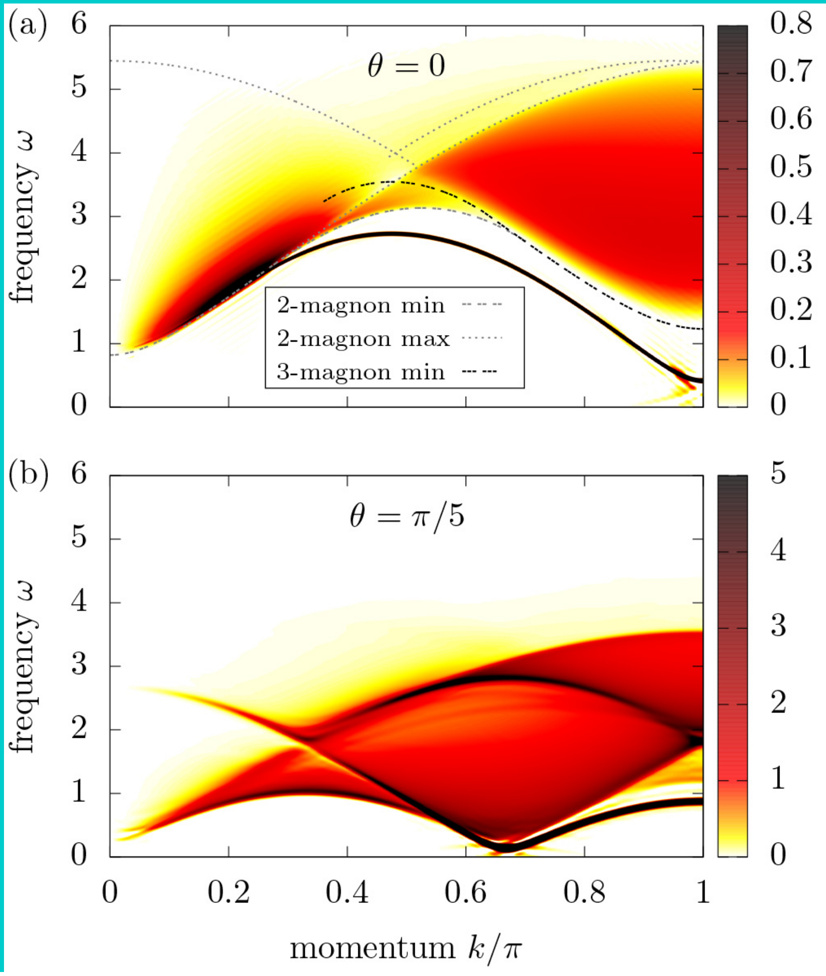
BY THOMAS BARTHEL

After studying in Germany at the University of Heidelberg and doing my PhD at RWTH Aachen University, working as a postdoc in Berlin, Munich, and Paris, I joined the Duke Department of Physics in July 2015 as Charles H. Townes Assistant Professor. It has been a great time since then with new possibilities, many new people (including our daughter Yuna Caroline), collaborations, and exciting research. It is a privilege to work at this beautiful place with so many great people.

My research is in theoretical condensed matter physics, often also exploring at the boundary to quantum information theory. In my group (**Moritz Binder**, **Qiang Miao**, **Yikang Zhang**, and myself), we mostly study strongly-correlated quantum many-body systems – addressing some of the most complex physical systems in nature. In addition to analytical investigations, we develop and employ numerical tensor network state techniques. For these methods, the understanding and control of entanglement, i.e., information theoretic properties of the studied systems are decisive. While tensor network states allow us to study many experimentally relevant systems with high precision, classical computation has its limits. In a new collaboration funded by the Department of Energy, we are taking first steps to investigate strongly-entangled condensed matter systems using (small) quantum computers. Finally, in discussions with French colleagues, I realized that some of our numerical techniques for quantum systems can be adapted to study stochastic dynamics in classical networks such as spin glasses and technical, biological, or social networks.

Quantum states are superpositions of classical states. Consider for example spins-1/2 on a lattice. The quantum states can be written as a linear combination of classical states with either spin up or spin down on every lattice site. The issue is that the number of these states grows exponentially with the system size 2, 4, 8, 16, ... about a quadrillion for a benign number of only 50 particles. The corresponding huge number of degrees of freedom makes quantum many-body systems so interesting, challenging, and powerful. However, does nature explore this enormous complexity? According to our current understanding, it usually does not. While the systems are still much more complex than their classical counterparts, quantum states of typical condensed matter systems contain much less information than the theoretical maximum (think of quantum magnets, electrons in solids, cold atomic gases in optical lattices). Typically, nature tarries in some special corner of the enormous parameter space. With **tensor networks**, we can capture this relevant corner – a fact which, beyond numerics, can be rigorously proven in some cases! The parameters in the tensor networks describe the quantum correlations in the systems. We are developing and employing numerical techniques using tensor networks to investigate ground states (quantum phase transitions), thermal equilibrium states, time evolution (e.g., questions of equilibration and thermalization), spectral functions, decoherence and dissipation in open systems, and transport.

As **an example**, Figure **X** shows some recent theoretical results for spin structure factors in bilinear-biquadratic spin-1 chains that can also be measured in scattering experiments. The model describes spin-1 quantum magnets like $CsNiCl_3$, $Ni(C_2H_8N_2)_2NO_2ClO_4$ or $LiVGe_2O_6$ and has a rich phase diagram. It comprises a gapless ferromagnetic phase, a gapped dimerized phase, and the famous Haldane phase. The latter features topological order that is protected by a symmetry. Lastly, the system has a gapless phase. In this critical phase, period-three spin quadrupolar correlations dominate. While groundstate properties of these spin-1 chains are relatively well understood, much less is known about the low-energy dynamics as



Tensor network state data for dynamic spin structure factors in bilinear-biquadratic spin-1 chains (a) in the Haldane phase that features topological order (Θ = 0) and (b) close to the transition from the Haldane phase to the critical quadrupolar phase (Θ = π/5). Such spin structure factors, allow us to understand the low-energy physics of quantum magnets and can be measured by scattering experiments. Panel (b) exemplifies how strongly the nature of excitations varies, even within a given phase. The minimum of the magnon band has moved to $k = 2\pi/3$ and the multi-particle continua are now due to soliton-like excitations instead of the magnons. [Figure from M. Binder and T. Barthel, Phys. Rev. B **98**, 235114 (2018).]

probed by the spin structure factors. For example, an effective field theory for the Haldane phase is the nonlinear sigma model which suggests that the lowest-energy excitations should be a triplet of magnons around $k = \pi$. This is the black energy band with a minimum at $k = \pi$ in Fig. **X**(a). Other prominent features are two-magnon and three-magnon continua with minima at $k = 0$ and $k = \pi$, respectively. However, the description in terms of the nonlinear sigma model is limited to the immediate vicinity of $k = 0$ and $k = \pi$. Even there, it disagrees quantitatively with our quasi-exact tensor network simulations and also qualitatively: For example, the field theory suggests that the energy gap should decrease when increasing the biquadratic coupling whereas we find an increase. We are currently analyzing our data and compare it to different field-theoretic approximations and exact solutions for special points in the phase diagram. This allows us to explain many features of the low-energy physics of these quantum magnets and to provide precise data to experimentalists.

What I like a lot about Duke is the culture of aspiring to the greatest goals and seamlessly **collaborating across disciplines**. For example, **Jianfeng Lu** (Math) and I have worked on complexity-theoretic aspects of quantum measurements and convergence properties of tensor network state algorithms. In a new DOE collaboration, we work on demonstrating the use of quantum computers to investigate condensed matter systems. This includes the groups of **Jungsang Kim** and **Ken Brown** (ECE) who build ion trap quantum computers. My group will, for example, provide a numerical back-end to approximate condensed matter groundstate problems by small cluster problems that can be handled experimentally, provide benchmark data, and propose new classes of tensor network states that describe highly entangled systems and can only be optimized efficiently on quantum computers. With the group of **Harold Baranger**, we are studying nonequilibirum electric and spin transport including dissipation effects. With James Moody (Sociology) and others, I plan to study rare events in stochastic dynamics of classical network systems. These and further projects, will make 2019 very exciting!

THE SEARCH FOR PHYSICS BEYOND THE STANDARD MODEL AND MU2E

BY SEOG OH

With the discovery of the Higgs boson in 2012 at the Large Hadron Collider (LHC) at CERN (European Organization for Nuclear Research), the Standard Model was fully confirmed. The Standard Model, completed mid-1970s, describes the three fundamental forces in nature, namely, the weak, electromagnetic, and strong interactions. The model consists of two theories: the Electroweak theory for the weak and electromagnetic interaction combined, and the Quantum Chromodynamics (QCD) theory for the strong interaction based on color charges. The search for the Higgs boson lasted for over forty years and finally was realized from two experiments, the so-called ATLAS and CMS. It was one of humankind's triumphs both theoretically and experimentally.

Although the Standard Model (SM) has been very successful, it has several shortcomings. One is that there are 17 parameters that have to be fixed by experimental measurements, such as coupling constants, which represent the strength of interactions, and particle masses. Another limitation is what is called the unnaturalness problem – the Higgs particle mass correction in the SM calculation can become very large, unless the calculation is very finely tuned, which seems unnatural. In addition, the gravity, dark matter and dark energy are not in the SM. The dark matter was introduced to accommodate the observed gravitational lensing and rotational velocity of stars around the center of our galaxy, the Milky Way. This was because the two quantities depend on the amount of matter and the visible matter alone could not explain the data. The dark energy was incorporated to explain the accelerating expansion of the universe. At the present time we do not know what the dark matter and energy are. Finally, the SM does not explain the asymmetry between matter and antimatter in the universe, as the universe contains mostly matter. Because of these shortcomings, the Standard Model is viewed by some as an incomplete theory, with the expectation that new theories should contain the Standard Model as well as solve these problems. There is no shortage of alternative models, but without experimental guidance, it is difficult to choose one theory over another. This is why it is important to find signatures beyond the Standard Model (BSM).

The present day could be compared to the late 1800s, when it was thought that Newtonian mechanics, electromagnetic theory based on Maxwell's equations, and statistical mechanics could explain how nature worked. But there was the nagging problem of radiation spectrum measurements from black bodies that could not be explained. Within a couple of decades, a whole new field called Modern Physics was born mainly based on new experimental measurements. Today's dark matter problem could be compared to the black body radiation problem of that period, where we need more experimental evidence to forge ahead.

But the inability to obtain BSM signatures has not been for lack of effort. There have been numerous searches over several decades, the latest of which occurred at the LHC. These searches can be broadly divided into two categories. One is to search for new particles, including the dark matter particle that could signal BSM physics. The other is to look for specific processes that deviate from SM predictions. The former is best carried out at the large accelerators, for example, the Tevatron (now decommissioned) at FNAL (Fermi National Accelerator Laboratory), or ongoing work at the LHC. The searches for the dark matter particle are also performed at underground laboratories, looking for interaction signatures between the detector material and heavy dark matter particles (called WIMP) as we expect that they roam around the space with little interaction. There are also searches for a very light dark matter particle (called axion) using a table top size RF cavities.

The second category can probe for BSM signatures at a much higher energy scale than what can be provided by existing particle accelerators. Some examples are the electric dipole moment measurement of neutrons and electrons, the g-2 experiment, neutrinoless double beta decay and the search for rare decays. The SM prediction of the dipole moment of electrons and neutrons is essentially zero. Up until now, there has been no evidence of any dipole moment confirming the SM. The g-2 experiment measures the ratio of the muon magnetic moment to spin, and the SM provides a highly accurate ratio. An experiment in early 2000 at Brookhaven National Laboratory showed a somewhat significant deviation from the prediction, and new experiments are being carried out to verify this result. The neutrinoless double beta decay tests if neutrinos are a Dirac particle as in the SM, i.e., if the neutrino and antineutrino are different particles. The rare decay searches utilize the decay modes of particles that are either very small or forbidden by the SM. A signal exceeding the predicted value is indicative of new physics. A disadvantage of these approaches is that they do not concretely provide directions for BSM theory, as they cannot clearly differentiate between various explanatory theories. One example of the rare decay search is the flavor violating charged lepton decays in which I am currently involved, the Mu2e experiment.

Leptons are one type of fundamental particle (not made up of other particles, unlike protons and neutrons), and come in three charged and three neutral 'flavors' (nature loves the number three). The neutral ones are the electron, muon, and tau neutrinos and the charged ones are electron, muon and tau particles. The properties of the particles in a group of three are very similar, except for their mass. Another fundamental particle of the SM is the quark, which likewise comes in three up-type (up, charm, top quark) and three down-type (down, strange, bottom quark). There are also three color charges that quarks carry in the QCD model, and they are the carriers of the strong force. Another particle type is the gauge bosons (photon, W, and Z), which are the force carriers in the electroweak component of the SM. What is interesting is that some of these fundamental particles 'mix' within the group of three. The first quark mixing was measured in the early 1960s, and neutrino mixing was confirmed in early 2000. Since neutrinos as well as quarks can mix, the same could happen with charged leptons. One favorite search of the flavor violating charged lepton decays has been the conversion of a muon to an electron, which is the basis of the Mu2e experiment. The SM prediction of the decay rate for this process is effectively zero, implying that any clear observation is an indication of BSM physics.

After the discovery of Higgs particle at ATLAS, in which I played a major role by constructing one of the inner tracker systems called TRT (Transition Radiation Tracker), my interest shifted to the Mu2e experiment at FNAL. Observing the muon-to-electron conversion would be a major discovery and would signal the existence of new particles or new forces of nature. The Mu2e can search for new physics at energy scales far beyond the reach of the LHC — up to the energy scale of 10,000 trillion electronvolts (10,000 TeV), in contrast to LHC's 14 TeV. The Mu2e conversion could give the next generation of particle colliders an indication of the most promising, discovery-laden energy ranges to search.

The Mu2e detector system shown in Figure 1 is modest compared to ATLAS or CMS. The 8 GeV protons hit the Production Target and produce secondary particles, mostly a type of hadron called pion, with a mass close to 140 MeV/c^2, about 1/7 of the proton mass. These low-energy secondary particles are steered toward the Stopping Target by the Production and Transport Solenoids, which produce the magnetic field in the axial direction. The main function of the Transport Solenoid is to remove neutral particles and select for negatively charged particles. A negative pion decays to a negative muon plus a muon anti-neutrino as it travels down the solenoid, and muons come to rest at the Stopping Target. As they come to a rest, these muons are attracted to nuclei of the target aluminum atoms, replacing one of orbital electrons to form what is then called a muonic atom. While they are in orbit, some muons decay, producing an electron, electron anti-neutrino, and muon neutrino with a half-life of 1.6 microseconds. This phenomenon is referred to as a three-body decay, and is the main background to our

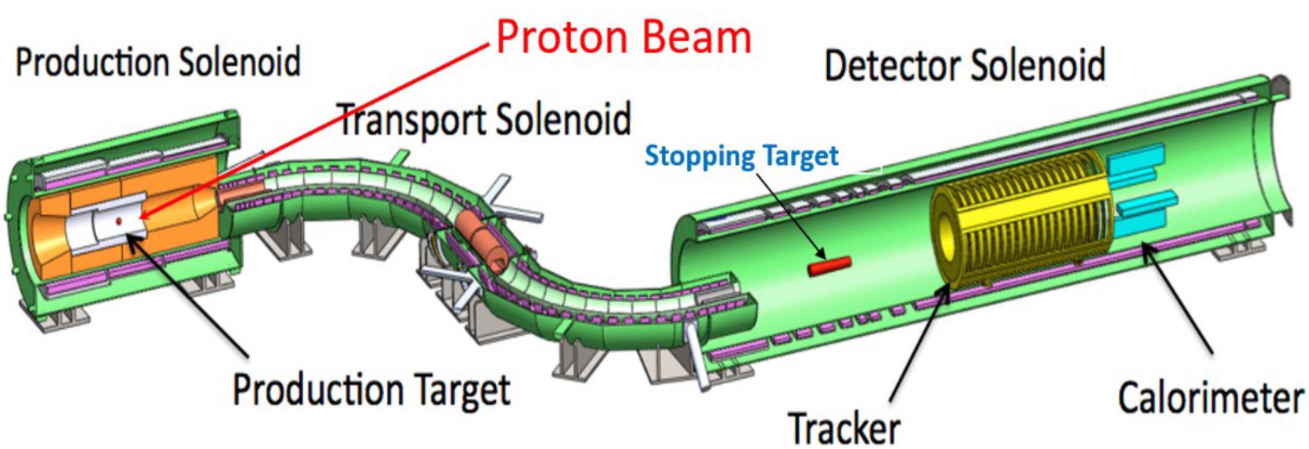


Figure 1. The Mu2e detector. For a scale, the diameter of the Detector Solenoid is about 2 meters. The Production and Transport Solenoid steer negative muons to the Stopping Target while removing other particles. The Calorimeter identifies electrons and muons.

signal. A muon can also be captured by a proton in a nucleus and produces a muon neutrino and a neutron. The signal we search for is the conversion of an orbiting muon to an electron and nothing else. These electrons are produced in all directions from the Stopping Target, and some are detected by the Tracker and Calorimeter. Because the muon is practically at rest before decaying to an electron, the muon mass (106 MeV/c^2) becomes mostly the electron energy plus a small amount of nuclear recoil (or bounce back) energy and the energy required for the electron to escape the nucleus. Thus, the signal is very distinct, a sharp peak close to the muon mass value, when the energy of the electrons is plotted.

The Duke Mu2e group is a part of the Mu2e Tracker team. We have been working on the design, R&D, and prototyping of the device, and the construction is about to begin. The Tracker measures the trajectory of charged particles. Knowing the trajectory and the strength of the magnetic field (2 Tesla) of the Detector Solenoid, the momentum vector and particle energy can be calculated. The basic component is a 5 mm in diameter straw tube with a tensioned wire in the middle. The TRT was also based on straw tubes, but the diameter was 4 mm. A high voltage is applied between the tube and wire to collect ionized electrons produced as a charged particle traverses the gas (a mixture of 80% argon and 20% CO_2) inside the tube. These electrons produce a small pulse in the wire, and this pulse is then amplified and detected. Collectively, these pulses provide the particles' path. The basic unit of the Tracker is a panel consisting of 96 straws as shown in Figure 2. The length of the shortest (longest) straw is 47.5 (120.6) cm. Six panels form a ring-shaped 'plane', and two planes form a 'station'. There are 216 panels corresponding to 18 stations, which make up the Tracker shown in Figure 1.

Detectors constructed from small radius straw tubes are not uncommon nowadays, unlike when we were working on the TRT in 1990s, but the Mu2e Tracker is a very difficult detector to construct. One reason is that the thickness of the straw wall, which is made of metallized Mylar film, is only ~15 microns (0.0006 inch), which is about 1/4 the thickness of a human hair. This thin wall is necessary to reduce the scattering of particles to obtain a good momentum resolution that is critical to estimate the background. It however makes handling quite difficult and is contrary to the robustness needed to operate in a vacuum. The Tracker is to be installed inside the Detector Solenoid where the pressure is very low, implying that the pressure difference between the inside and the outside of the tube is 1 atmospheric pressure. Moreover, to preserve vacuum integrity, the leak rate is the most stringent of any gaseous detector ever constructed. When the Tracker was first proposed, there was a lot of skepticism that such straws could be made into a detector and meet the experimental requirements. Overcoming many difficulties, the Tracker community demonstrated otherwise. In addition to being involved in the detector design and construction, we developed and constructed a scanner using the transmission rate of an x-ray beam to measure the wire and straw positions in three dimensions with high accuracy (~ 20 microns in the wire plane and ~ 50 microns perpendicular to the wire plane) over a large area. This is necessary to locate the traversing particles accurately with respect to the wires. Our scanner is one of a kind, allowing us to map entire wires and straws.

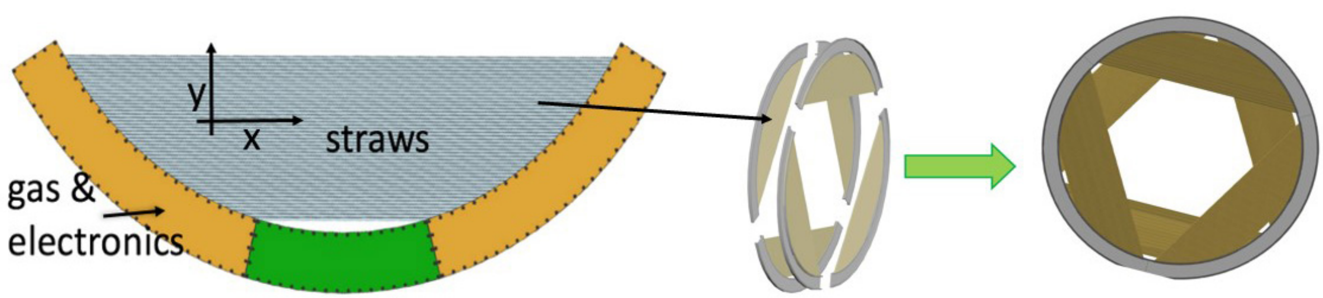


Figure 2. The process of making a station, starting from a panel (left) to a plane (middle) to a station (right). The magnetic field is perpendicular to the face of the station (into the paper) resulting in a helical motion of charged particles.

With many challenges behind us, we are poised to start tracker construction. We estimate it will take about two years to fully construct and test, and the data collection is expected to start early 2022. We anticipate that we will be able to improve the current muon to electron conversion sensitivity by at least 10,000-fold. This is as if we are building a camera that can take a picture with 10,000 times less light. The search for BSM physics is in full swing, and the Mu2e experiment could be the first one with a clean signature. I am sure that the entire physics community is eagerly waiting for these discoveries. Stay tuned; the best is yet to come.

NEW STAFF

Timothy Fields has been an employee of Duke University for 5 years. He began his career at Duke in Student Affairs at Counseling and Psychological Services. There he supported the Director of Training Programs. The internship Program consisted of 3 Psychology Interns, and 3 Social Work Interns. During his time with the department, he led their marketing efforts, training program support, and outreach on campus.

After his time in Student Affairs he switched departments and found himself working with the First Year students at Duke's Physician Assistant Program. He was responsible for 125 students in the cohort. He worked closely with the students, and provided administrative support to faculty.

With his background in Higher Education, Timothy is now working for the Physics Department as the Assistant to the Director of Undergraduate Studies and the Assistant to the Associate Chair for Teaching. He is eager to begin his career with the department. Timothy is looking forward to working with the students, marketing and design, and being back on campus.

When Timothy is not on campus, you can find him out and about in Durham. Born and raised in NC, Timothy loves to try new places in the area. One of his interest is photography. You can find him at coffee shops, great restaurants downtown, and local events throughout the year.

Todd Lewis is our new HR and Payroll Representative. Todd was born and raised in Durham and comes to us from Slavics and Eurasian Studies where he worked for the Honorable Dr. Jack Matlock, U.S. Ambassador to the U.S.S.R. under Presidents Ronald Reagan and George H.W. Bush. There he processed documents and created an archive for use by scholars studying U.S./Russian relations during the Cold War.

Todd is a United States Army veteran and former graphic designer who returned to school in 2012 and studied Cultural Anthropology graduating from NC State University in 2016. He is husband to wife Cathy who works at Duke as the Business Manager for Trinity College and father to daughter Jordan and sons Harlan and Isaac.

In his spare time, Todd enjoys spending time with family, cooking, wood-carving, attending Carolina Panthers games, and Sim racing. He also works part-time as a stage-hand for music venues in the Triangle.

Todd really likes being in academia and working in a place that searches for knowledge and a greater understanding of the world around us. It is for those reasons that he is excited to continue his professional development at Duke University and looks forward to the opportunities that will provide.

Duke University Department of Physics Box 90305 Durham, North Carolina 27708 | (919) 660-2500 | phy.duke.edu

The Department of Physics offers undergraduate degrees in physics and biophysics, and a doctoral program in physics. Our research ranges from astrophysics to condensed matter physics and nanoscale materials exploration, to non-linear and complex systems and biological physics with applications for medicine, energy and environmental science. Faculty conducts highly collaborative international research in high-energy physics; accelerator-based experimental nuclear physics; theoretical nuclear and particle physics; explorations of geometric and theoretical physics; and experimental quantum optical physics.

Look for us on Facebook
@dukephysics

News Editor: Shailesh Chandrasekharan
Designer: Cristin Paul