Quantum Leap

University of South Carolina
Department of Physics and Astronomy

2014

UNIVERSITY OF SOUTH CAROLINA

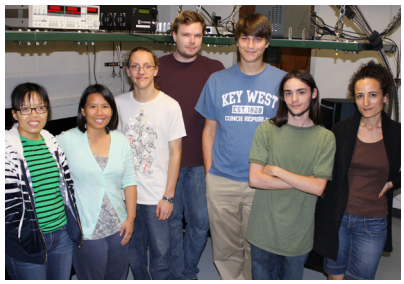
Experimental Nanoscale Physics: The Smart State Center

The Smart State Center for Experimental Nanoscale Physics has had an exciting year. Dr. Yuriy Pershin received the Office of the Vice President for Research's Rising Star Award, received tenure and was promoted to Associate Professor. Pershin also published a paper in Nature Physics (http://blog.physicsworld.com/2013/11/19/how-to-build-a-memcomputer). Longfei Ye (Crawford's group) and Shu Yan (Bazaliy's Group) received their Ph.D.'s, and Abdul Mohtasebzadeh (Crawford's group) received his M.S. degree. The center hosted three colloquium speakers from 2013 to 2014, two of them National Academy of Science members, and four of the faculty from our Smart State Center gave talks at international conferences over the past year.

Graduate students Shawn Draper (l), and Ken Stephenson pose with the ATL-160 Helium liquefier in Prof. Webb's laboratory

Beginning in December, a new helium liquefaction plant with a high-pressure recovery system was installed by Quantum Design in Prof. Richard Webb's "cryolab." Phase 1 was a direct recovery setup to recover helium boiled off from the Center's Physical Property Measurement System (PPMS). Phase 2 is installation of a high-pressure recovery system with two "gas bags" that will recover helium during both boil-off and LHe transfers.

In the winter of 2014, Dr. Yanwen Wu's group took possession of a newly renovated laboratory in the basement of the Jones Physical Science Center. It is now a fully functioning optical laboratory. Dr. Wu's group is conducting research on the construction and investigation of a metamaterial building block capable of supporting quantum entanglement. The key is to use plasmonic waveguides to facilitate couplings between quantum emitters. Unlike previous schemes using high-finesse optical cavities or photons in free space, the entanglement achieved through nanoscaled plasmonic waveguides is nonlocal and broadband. She is currently mentoring two graduate students and one undergraduate student. As part of her outreach effort, she has hosted two high school students during the summer. They have worked on and completed a project that involved building a smartphone microscope with up to 100x magnification.



Prof. Yanwen Wu poses with her group in their newly renovated optics laboratory in the basement of Jones PSC

MagAssemble™ LLC

This spring, the Center's first start-up company, MagAssemble LLC, commercializing Prof. Mas Crawford's group's nanomanufacturing technology, received a National Science Foundation (NSF) Phase 1 Small Business Innovation Research (SBIR) Award to commercialize 2-D patterned diffractive optics for optical fiber components. MagAssemble now has two employees, recent USC Physics Ph.D. graduate Dr. Longfei Ye, and one of our B.S. recipients, Cameron Nickle, who are performing R&D (Research and Development) for MagAssemble in rented Center space in Sumwalt. In addition, Crawford received a new three-year NSF award in collaboration with the University of Florida to study magnetic field-directed assembly of multiferroic nanowires.

Prof. Scott Crittenden received a two-year extension to his three-year ARO Multiple University Research Initiative

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Message From the Chair

We've had a good year with a few awards and upcoming changes in the department, so I'm delighted to convey the good news.

First and foremost, Prof. Milind Kunchur continues to win awards and bring recognition to the Department while making us very proud of his achievements. He was recently named as the S.C. Governor's 2014 Professor of the Year for senior colleges and universities and also won the 2014 Donald S. Russell Award for Research in Science, Mathematics, and Engineering. Prof. Kunchur has made numerous contributions to the fundamental physics of superconductivity, which led to recognition last year by the American Physical Society when he was elected as a Fellow. He has also studied the neurophysiology of hearing and teaches a popular course in Musical Acoustics. Prof. Kunchur serves as an Advisory Board Member for the Physica C journal, on panels for the National Science Foundation and the U.S. Department of Energy, and was recently appointed to the University's prestigious Committee for Tenure and Promotion. Prof. Kunchur earned his Ph.D. at Rutgers University in 1988 and has worked at Oak Ridge National Laboratory and Wright Patterson Air Force Base. The 2014 S.C. Governor's Professor of the Year was awarded at a special state house ceremony on April 23, 2014. Prof. Kunchur has won many awards in the past, including the 2001 Michael J. Mungo Teaching Award and the 2012 Michael J. Mungo Distinguished Professor of the Year Award. As we go to press, Prof. Kunchur was also just awarded the George B. Peagram Award of the South Eastern Section of the American Physical Society for "Excellence in Physics Education in the Southeast."

Prof. Kunchur accepting his S.C. Governor's 2014 Professor of the Year award with Gov. Nikki Haley

Prof. Kunchur is popular with his students: both the undergraduates who enjoy his Musical Acoustics and other courses, as well as the graduate students who are delighted to be working in his lab. Indeed, the Dean of our College of Arts and Sciences, Mary Anne Fitzpatrick, said recently, "Professor Kunchur is an extraordinary communicator who excels in translating complex scientific concepts for the students and he helps them to develop a deeper understanding and appreciation for the physical world around us."

In other faculty news, Prof. Yuriy Pershin has been promoted to the position of Associate Professor, with tenure. This advancement comes in addition to the honor he received early in the Spring 2014 semester when he was first named as a Breakthrough Rising Star by the university, and then also named as a Fellow of the Institute of Physics, which is significant international recognition. Prof. Matthias Schindler was recently elected as a member of the Executive Committee of the American Physical Society Topical Group on Few-Body Systems. Prof. Yanwen Wu was named as the May Featured scholar. She and her fellow new faculty member Prof. Vincent Guiseppe have now established their research environment and are firmly into their teaching schedules.

Congratulations to all awardees!

In student news, graduate students Lei Wang and Colin Gleason received the Graduate Research Award and Teaching Award, respectively. There are twelve new incoming students this year, while three students completed their Ph.D.'s, and four students were awarded their M.S. degrees.

Finally, I would like to highlight important changes in our Astronomy program that were effected this year. First, we finally did away with our ancient introductory astronomy course, and replaced it with Astronomy 101, which is a modern updated version. This course is taught by Prof. David Tedeschi in a large lecture hall and uses clickers, a computerized homework using the same system as our physics courses. Additionally, this course features new labs. We expect this course to deliver better astronomy instruction by featuring more face-to-face interaction with the faculty.

At the same time, the Dean of our College authorized the hiring of another observational astronomer to join our faculty in academic year 2015-16. This will bring the size of our astronomy group back to where it was a decade ago and could mark a new beginning of growth in the astronomy sector.

Staff News

Over the last year, our staff has been busy keeping everything running smoothly here in the department. They have also been keeping busy outside of work!

On May 3, Robert Sproul (Factotum Emeritus) and Vickie Gibson got married at Folly Beach and had a ton of fun on their trip. Congratulations to them, and we wish them all the best!

In February, James Clawson (Laboratory Manager) and his wife, Staci, along with their son, Daniel, welcomed a beautiful baby girl, Katie, into their family. Congratulations on your new addition!

Mandy Davis (Graduate Program Coordinator) has settled in and has really enjoyed her first year here. She participated in a few races in her free time, including the Cleveland Marathon in May, some smaller races in Columbia, a few half marathons, and the Nike Women's Half Marathon in San Francisco in October. Mandy really enjoys all of the running and traveling, and has also had a lot of fun taking biology classes here at USC as well!

Evelyn Wong (Administrative Assistant) has also had fun this year traveling on road trips. Her artwork was accepted into two juried competitions—Artfields in Lake City, SC, and the 34th Annual Juried Art Competition at the Gertrude Herbert Institute of Art in Augusta, GA—as well as a juried exhibition series in Chapel Hill, NC, in which she exhibited her first out-of-state solo show at the Chapel Hill Public Library. She is also excited to be working on assembling an exhibition of botanical art for 2015 with a local tattoo and terrarium artist.

Beth Powell (Administrative Coordinator) and Lisa Saxon (Business Manager) are happy to report that they have managed to avoid any unnecessary stress over the last year.

News from The Graduate Director

New Students

At twelve, this year's incoming graduate class is the largest in recent memory. The Department of Physics and Astronomy welcomes students from Thailand, Iraq, Iran, Sri Lanka, and Taiwan, as well as the US. We now have over fifty graduate students in Physics and Astronomy.

Dehyaa Alameri began his graduate studies in Physics in the spring semester with a fellowship from the government of Iraq. Mr. Alameri is the first graduate student in Physics to progress from "provisional" status in the USC English Program for Internationals to "normal" status. These students spend a year perfecting their English before they begin their graduate studies.

Ph.D. Recipients

Students who completed their Ph.D.'s in the past year are Shu Yan and Manlai Liang (Bazaliy, Theoretical Condensed Matter Physics), Hongyue Duyang (Mishra, High Energy Physics), Debopam Som (Kulkarni, Astronomy), and Longfei Ye (Crawford, Experimental Condensed Matter Physics).

M.S. Recipients

Rahman Mohtazebzebeh completed his Master's degree in Experimental Condensed Matter Physics with Professor Crawford and has returned to Afghanistan. Also completing M.S. degrees were Saptaparnee Chadhuri (Gothe, Experimental Nuclear Physics), John Campbell (Johnson, Network Theory) and Camilo Posada (Avignone, Cosmology).

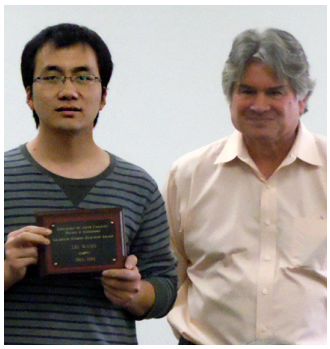
Rahman is happy to recieve his M.S. in Experimental Condenced Matter Physics!

Scholarships and Awards

Lei Wang, who is working with Professor Datta, received the Graduate Research Award and Colin Gleason, who is working with Professor Ilieva, received the Graduate Teaching Award for 2013-2014.

Hongyue Duyang received the University Research Association award to support his research at Fermi National Laboratory. Ye Tian has been awarded a Jefferson Lab Graduate Fellowship for the second time in 2014-2015. Dehyaa Alameri has a fellowship sponsored by the Iraqi government and Kedkanok Sitarachu is sponsored by the Thai government. Ken Stephenson is supported by an National Physical Science Consortium Fellowship.

The number of GAANN (Graduate Assistance in Areas of National Need) Fellows in our department has grown from four to five. The GAANN Fellowship is funded by the Department of Education and provides support for eligible students for three years.



Lei Wang received the Graduate Research Award and Colin Gleason received the Graduate Teaching Award for 2013-2014.

News from the Director of Undergraduate Studies

Undergraduate Physics award winners from 2013-2014 academic year: Nolan Miller won the College of Arts & Sciences Rising Senior Award and was also the first recipient of the Dr. Edwin R. and Mrs. Elizabeth F. Jones Endowed Scholarship. Kevin R. Wood was awarded the Nina and Frank Avignone Fellowship.

In addition to the Department of Physics and Astronomy awards, several physics students received awards from other departments: Elizabeth Alexandrovna Yankovsky received the Joseph R. Leconte Outstanding Junior Award in Earth and Ocean Sciences; Tanner Pearson received the Polston Family Mathematics Scholarship; Reid Harris and Kevin Wood received the Jeong S. Yang Award for Excellence in Undergraduate Mathematics; Reid Harris received the Outstanding Undergraduate Student in Mathematics award; Travis S. Dore received the Edna W. and Foster E. Tait Scholarship from the Department of Philosophy.

Congratulations to our outstanding undergraduate Physics students!

Something Funny Happened on the Way to the Lab...

by Prof. Jeffrey Wilson

One of my responsibilities as Undergraduate Director is to meet with prospective Physics majors and their parents when they come to campus for a visit, usually during their junior year of high school. I try to arrange tours of research labs if the members of our faculty are available to meet with us. Unfortunately, when a student came to visit last spring, no lab trips were available, so instead, I took the visiting student and her parents to see one of our undergraduate experimental physics courses, which was in progress at the time.

The course was our 500-level Condensed Matter Lab, and features several independent projects undertaken by the students. A big part of the lab is the final research project that the students choose and research on their own. A unique feature of the lab is that it contains a Clean Room with a thermal evaporation apparatus. This allows the students to build up layers of materials on substrates in much the same manner that manufacturers construct semiconductor chips. At the time we visited, the students were setting up to make micron-sized patterns on a silicon substrate.

Our visitor suited up with dustless coveralls and boots, and then got a personal tour of the clean room along with a detailed explanation of the workings of the thermal evaporator, all conducted by the undergraduates who were using the lab. After talking to our students for a while about their experiences in this course and USC Physics in general, our visitor got to go across the hall and look under the cover of the research-grade laser that is a cornerstone of our advanced undergraduate optics course.

The visitor and her parents left with a very positive impression of our physics program, and said that on their visits to other places, they had not seen anything as exciting as the lab they were able to walk through. Their impression agrees with mine, as we have done a good thing by trying to emphasize research experiences for our students. We do that by encouraging work with our faculty researchers, and by incorporating a research experience into our required courses.

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Retired Faculty News

Gary Blanpied, Professor Emeritus of the USC Department of Physics and Astronomy and Senior Nuclear Physicist at Decision Sciences International Corporation (DSIC), presented a paper in June at the 2014 Symposium on Radiation Measurements and Applications (SORMA XV) entitled "Material Discrimination Using Scattering and Stopping of Cosmic Ray Muons and Electrons: Differentiating Heavier from Lighter Metals as well as Low-Atomic Weight Materials." Nuclear Instruments and Methods will publish submitted papers from the contributors. A paper reporting additional measurements and simulations has been accepted for an oral presentation in November 2014 at the IEEE Nuclear Science Symposium & Medical Imaging Conference in Seattle.

Gary and his wife, Deborah, now live in Ramona, California. Deborah, who taught French at AC Flora High School in Columbia, retired and is now involved in many activities in Ramona, including hiking, water aerobics, and gardening. Additionally, she is active in the Ramona Woman's Club, the Ramona Concert Association, and the First Christian Church Choir. Their daughter, Isabelle Blanpied, received her M.F.A. from USC and also works for DSIC and is Chief Operator of the Detectors. She organizes all of the data acquisition activities and quality control.

Gary Blanpied in Death Valley California

Experimental Nanoscale Physics: The Smart State Center cont.

grant to study proteins on surfaces. This past summer he hosted two REU summer researchers and 2 high school students. One of his high school students, Krishna Gorrepati was selected to go to two different national competitions based on his Crittenden group research, as well as winning to the region II science fair.

Professor Milind Kunchur's group research group continues to work in the two areas of 'Superconductivity, Thin-Films, and Nanofabrication' and 'Psychoacoustics, Auditory-neurophysiology, and High-End Audio'. Ongoing experiments probe new phenomena in superconductors in confined geometries and extreme power densities. The research in sound reproduction is seeking to establish a more rigorous and comprehensive understanding of distortions that compromise fidelity. In 2014, Kunchur gave invited talks at two international conferences—"Superconductivity for Energy" in Italy and "Collaborative Conference in Materials Research" in S. Korea. He was the winner of the 2014 Russell Award for Research in Science, Mathematics, and Engineering.

Kunchur is actively involved in physics education and contributes regularly to the SACS-AAPT (a regional section of the American Association of Physics Teachers). Kunchur gave the keynote speech at the USC Doctoral Hooding Ceremony in May. In April, Professor Kunchur was named as the 2014 Governor's Professor of the Year for Senior Institutions in South Carolina, the state's highest academic honor. In the award's 27-year history, three other professors from the USC Columbia campus have won this honor. In October 2014, Professor Kunchur was announced as this year winner of the George B. Pegram Award for Excellence in Physics Education in the Southeast region.

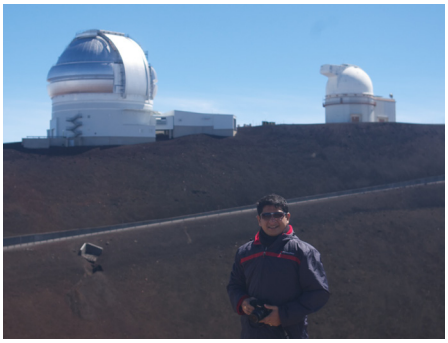
In 2014, three graduate students—Charles Dean, Nahid Moghaddam, and Dheyaa Almeri—worked in Kunchur's group. His former student Manlai Liang defended his Ph.D. thesis in December of 2013 and is now employed in industry. Three undergraduate students—Nate Moisson, Collin Johnson, and Janki Patel—worked in Kunchur's group. Janki Patel graduated in May of 2014, with Prof. Kunchur as the director of her Senior Honors Thesis.

Bacterial fermentation in petri dishes in Prof. Scott Crittenden's lab

Astronomy

What were galaxies like billions of years ago? How did the cycles of star births and deaths proceed in galaxies? How did our galaxy (including our Sun and the solar system) reach the current composition of different chemical elements? How do galaxies exchange matter with their surroundings? These are some of the questions that the USC Astronomy team and their collaborators are working on.

To address these questions, we use state-of-the-art telescopes around the world, such as the Gemini and Keck telescopes in Hawaii, the Large Binocular Telescope in Arizona, the Magellan Clay telescope and the European Southern Observatory's Very Large Telescope in Chile. We have also been using NASA's Hubble, Spitzer, and Chandra Space Telescopes, and the Herschel Space Telescope operated by the European Space Agency and NASA. Our work is funded by the NSF and NASA.



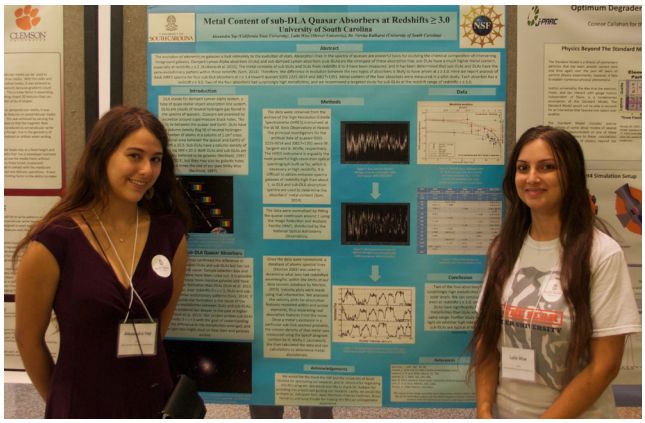
Debopam Som at the Mauna Kea Observatories

In the past year, we received observing time on the Keck telescope in Hawaii (the largest existing optical telescope in the world) to "mine" for rare elements in the most gas-rich galaxies. We also received observing time on the Very Large Telescope in Chile to study the compositions of some of the most distant galaxies and to study kinematics of gas flows near distant galaxies. We have also been awarded time on the Hubble Space Telescope to study spatial variations in the interstellar matter within distant galaxies along multiple sightlines using ultraviolet spectra of gravitationally lensed quasars, and to obtain high-resolution images of galaxies we have detected recently with integral field spectroscopy. We also received observing time on the Chandra telescope to obtain deep X-ray observations of active galactic nuclei formed in proto-galaxies associated with quasar absorbers. Additionally, we received a NASA Astrophysics Data Analysis Program grant to investigate the relations between the gaseous and dust components of galaxies. Our research resulted in eight publications within the past academic year, with two other papers currently under review, and more papers in preparation. Several members of our team gave presentations at national and international institutions and conferences.

Sean Morrison at the Mauna Kea Observatories

Graduate student Debopam Som gave a talk about his dissertation at the American Astronomical Society meeting in Washington, D.C., and completed his Ph.D. in August 2014. Debopam has been a key member of our group for several years. Graduate student Sean Morrison continued analysis of far-infrared spectra of distant galaxies obtained with the Herschel Space Observatory to search for molecules. Graduate student Francie Cashman has been assisting in improving atomic data needed for astrophysical spectroscopy, and the associated modeling of the spectra of distant galaxies. Two new graduate students, Suraj Poudel and Saba Arash, have just joined our group, and are beginning to work on images of nearby galaxies probed by quasars. Post-doctoral researcher Dr. Monique Aller (USC postdoctoral researcher, 2010-2014) continued studies of interstellar dust in distant galaxies. Using infrared spectra obtained with the Spitzer Space Telescope, we have been making the first detections of silicate dust grains in distant galaxies.

Undergraduate student Kyle Lackey won a Magellan Fellowship for his ongoing research on polar ring galaxies with the Gemini and Spitzer telescopes. Kyle also won an NSF-sponsored REU (Research Experiences for Undergraduates) internship at the National Optical Astronomy Observatories in Tucson, Arizona. Undergraduates Franco Godoy, Bryan DeMarcy, and Brittany Busto continued work on various aspects of quasar spectroscopy. An exciting addition to our undergraduate research team this year were REU students Laila Wise and Alexandra Yep, who visited from Georgia and California, respectively. It was a pleasure to host Laila and Alexandra, who worked with us during Summer 2014 on projects related to the chemical composition of very distant galaxies.



Alexandra Yep and Laila Wise

In other news, Dr. Monique Aller started a faculty position at Georgia Southern University in August 2014. We are sorry to see Monique leave, but are excited about her new appointment, and continue to collaborate closely with her. A past student from our group, Lorrie Straka (Ph.D., 2012), who was a postdoctoral researcher at the University of Chicago for the past two years, took up a position at the Leiden Observatory in the Netherlands. Recent USC graduate Bryan DeMarcy (B.S., 2014) started working with the new observatory and planetarium at the SC State Museum, and continues to do research with us.

Our staff and students continue to do outreach efforts at the Melton Memorial Observatory, where public nights are held on all clear Monday nights. Our other outreach activities in the past year included popular talks at the Astronomy Club of Augusta and the Charlotte Amateur Astronomers Club, as well interviews with local newspapers and TV stations. As Director of the Astronomy Center, Dr. Soheila Gharanfoli continued her excellent undergraduate teaching work. Our department hosted the 2014 Meeting of Astronomers in South Carolina, which brought together astronomy faculty and students from USC, Clemson, SC State University, College of Charleston, Francis Marion University, Lander University, and Bob Jones University.

Additionally, our department hosted the Fall 2012 meeting of the Southern Atlantic Coast Section of the American Association of Physics Teachers. Prof. Kulkarni will be organizing the next annual Meeting of Astronomers in South Carolina at USC in Spring 2014.

To make a long story short, the Astronomy Group here at USC is having a great time digging up the many mysteries of galaxies far, far away!

Particle Astrophysics Group

Faculty members: Professors Frank Avignone, Richard Creswick, Horacio Farach, Vincente Guiseppe, Carl Rosenfeld, and Jeffrey Wilson
Graduate Students: Nicholas Chott, Dawei Li, and Clint Wiseman.
Recent Ph.D. Graduates: Katarina Leila Mizouni (2013).

Particle Astrophysics focuses on the study of phenomena in astrophysics and cosmology associated with the properties of elementary particles such as neutrinos and Weakly Interacting Massive Particles (WIMPS), a candidate for Cold Dark Matter (CDM). In 1933 Fritz Zwicky discovered that far more mass is needed to explain the dynamics of the Coma Cluster of galaxies than can be accounted for by stars, gas, and dust alone. The gravitational effects of CDM on the velocity distribution of stars in spiral galaxies is also well established by Galactic Rotation Curves. The USC group was a pioneer in particle astrophysics when, in 1985, it led the first terrestrial search for CDM in the Homestake goldmine in Lead, South Dakota. This experiment used a unique detector developed in collaboration with the Pacific Northwest National Laboratory (PNNL). This experiment was able to eliminate heavy Dirac neutrinos as the major component of CDM over a very large range of neutrino masses. The collaboration between USC and PNNL remains active today and several Ph.D.'s from the Particle Astrophysics Group are on the PNNL staff.

The Silver Jubilee of the publication of the seminal paper resulting from this experiment was celebrated in an international conference at the Pacific Northwest National Laboratory in June 2012. Following the publication of these first results, dozens of dark matter searches have been carried out all around the world, with vast improvements in detector technology. In 1994, Frank Avignone was awarded the Jesse Beams Medal of the American Physical Society for his leadership role in the first experiment.

The USC Group also led the first search, and several later searches, for elementary particles called axions emitted by the sun. Axions are predicted by the theory of Roberto Peccei and Helen Quinn that explains why the strong interaction, described by quantum chromodynamics (QCD), does not violate charge-parity (C-P) symmetry. Without the Peccei-Quinn solution, or some alternative one, the C-P-violation predicted by QCD would lead to an electric dipole moment of the neutron about ten orders of magnitude larger than the experimental bound. One USC-led axion search was based on an analysis developed at USC by an international collaboration led by Richard Creswick. It uses the coherent Bragg conversion of axions to photons in single crystals to predict a characteristic time-dependent event rate. This technique has been used by other groups worldwide. Dawei Li is making a further development of this technique. It will be applied to the data from the Cryogenic Underground Observatory for Rare Events (CUORE) under construction in the Laboratori Nazionali del Gran Sasso (LNGS) in Assergi, Italy. Last year, the USC group led a new search for solar axions produced by the bremsstrahlung mechanism in the core of the sun. They used the MALBEK detector, a prototype test detector for the MAJORANA DEMONSTRATOR Experiment.

The USC group is currently concentrating on two searches for the exotic zero-neutrino nuclear double-beta decay ($0\nu\beta\beta$- decay), which is only possible if neutrinos have mass and are their own antiparticles (Majorana particles). The $0\nu\beta\beta$- decay mode also violates the law of lepton-number conservation. Neutrino oscillation experiments clearly demonstrate that neutrinos have mass, but they can only measure mass differences. The measurement of the rate of $0\nu\beta\beta$- decay would determine the absolute masses of all three neutrino-mass eigenstates.

The USC group was heavily involved in the CUORICINO double-beta decay experiment in the LNGS laboratory from the very beginning until it was discontinued in July 2008. CUORICINO was an array of ~42 kg of TeO_2 cryogenic detectors operating at ~0.008K, and it set a lower limit on the half-life for the $0\nu\beta\beta$- decay of ^{130}Te. Currently, the particle astrophysics group is involved in the construction of CUORE, a 760-kg detector using the same low-temperature technique. The group's main responsibility is the production of the electronic system led by Carl Rosenfeld, and the construction and operation of the first tower of CUORE (CUORE-Zero), which began operation in Spring 2013. The USC group maintains a research associate and graduate students at the Gran Sasso Laboratory year-round.

Our group is also playing a leading role in the MAJORANA DEMONSTRATOR, a 21-million dollar research and development project designed to establish the feasibility of building and operating a ton-scale ^{76}Ge double-beta decay experiment. The principal technology being used in MAJORANA is a vastly improved version of the IGEX experiment, also led by the USC group in the 1990s. Funding for the ton-scale experiment will depend on the level of success of the DEMONSTRATOR project. All the USC activities are supported by major grants from the National Science Foundation.

In 2012, Jeff Wilson joined the USC Particle Astrophysics Group. He brings computational expertise including Monte Carlo simulations using GEANT codes as well as the most up-to-date data analysis techniques. He most recently worked on data analysis for the BaBar experiment at the Stanford Linear Accelerator Collider (SLAC) facility. We were fortunate to have recruited Dr. Vincente Guiseppe last year, who was formerly of the University of South Dakota. Guiseppe is a Task leader in the MAJORANA DEMONSTRATOR Experiment in charge of the construction of the complex shield. The shield was completed over the summer of 2014, and is housing the MAJORANA DEMONSTRATOR prototype detector array. Dr. David Tedeschi recently joined our group as well, and has been working with Guiseppe on the MAJORANA DEMONSTRATOR. Tedeschi brings significant experience from his years doing accelerator nuclear physics at the Jefferson Laboratory.

Presently, and for the past few years, the USC Group has been deeply involved in the major construction issues for CUORE-0, CUORE and MAJORANA. Upon their commissioning, the role of the group will transition to mainly running shifts and analyzing data. In addition, the group is introducing a new concept of using the inner detectors of the CUORE array to study the $0\nu\beta\beta$- decay of ^{130}Te to the first excited 0+ state in ^{130}Xe. The decay to the excited 0+ state is followed by a gamma-ray cascade to the ground state; by tracking these gamma rays it is possible to eliminate a large part of the background. Jeff Wilson is leading the team in carrying out the complex simulations needed to compute the efficiencies of the many possible gamma-ray interaction scenarios, and the design of the associated data analysis codes.

Nicholas Chott is living onsite near the Laboratori Nazionali del Gran Sasso (LNGS) working on his Ph.D. research, and on the construction of the CUORE detector. He played a major role in the vacuum leak checking during the assembly of the main cryostat. Clint Weisman spent most of the summer of 2014 working with Dr. Guiseppe on the assembly of the shield of the MAJORANA DEMONSTRATOR. Carl Rosenfeld spent the first part of his sabbatical in Italy, at the University of Milan and at LNGS.

This field continues to produce exciting research opportunities and has attracted excellent funding support for faculty and student participation.

Theoretical Physics Group

Faculty members: Profs. Brett Altschul, Vladimir Gudkov, Pawel Mazur, and Matthias Schindler; Research Assistant Faculty Dr. Kenneth Nollett; Graduate Student Rasha Kamand

We are excited to announce that Research Assistant Professor Ken Nollett has accepted a tenure-track assistant professor position at San Diego State University, starting in Fall 2015. Ken is an expert in nuclear astrophysics and in ab initio calculations of nuclear reaction properties. We wish him all the best for the future and are looking forward to continuing our collaboration with him until Fall 2015 and beyond.

Contrary to what most people might think, theoretical physicists do not simply sit behind their desks all the time. While research in theoretical physics does not directly require elaborate laboratories or underground facilities, the interaction and exchange with other researchers, both theoretical and experimental, plays an important role in sustaining successful research programs. National and international conferences, workshops, and collaboration visits to other universities and laboratories are invaluable in exchanging ideas and communicating important results. In this regard, the past year has been very successful for the members of the USC Theoretical Physics Group. They traveled near and far, from places such as North Carolina and Tennessee to Turkey and Japan, and presented their ongoing work to large audiences. And while most trips do not take very long, Dr. Mazur spent two and a half months as a visiting scientist in the Theory Division at CERN, Switzerland, where he continued his work on the theory of quantum black holes and the cosmological theory of the early universe.

In the theory of quantum black holes, which Dr. Pawel Mazur has been developing for some time, black holes are considered to be macroscopic quantum states of matter, i.e., superfluid Bose-Einstein Condensates. Dr. Mazur has shown in his research that for small angular velocity, the moment of inertia of a spinning black hole is reproduced exactly by a model in which the source of the external gravitational field is considered to be a spinning superfluid droplet. One of the predictions of the theory is that old black holes should have low nonclassical moments of inertia. This should be tested observationally in the case of a giant and very old black hole residing in the center of our own Milky Way galaxy. Dr. Mazur has also worked on unique predictions for three-point correlations in the Cosmic Microwave Background.

Dr. Brett Altschul has continued to work on exotic physics beyond the standard model of particle physics. This includes studying the possibility that certain symmetries that are normally taken for granted, such as Lorentz and CPT symmetry, might not hold exactly. All physics as we know it is invariant under Lorentz symmetry and CPT, but experimental evidence of violations of these normally sacrosanct symmetries would be a discovery of paramount importance and would provide a window onto a kind of new physics that would be completely different from anything previously encountered. If Lorentz boost symmetry is broken, charged particles might be able to move faster than photons and thus produce Cerenkov radiation. Cerenkov radiation ordinarily occurs in matter; however, if Lorentz symmetry is broken, it could also occur in vacuum. Until 2014, nobody has been able to answer basic questions about whether there was vacuum Cerenkov radiation in one of the most popular Lorentz- and CPT-violating theories of modified electrodynamics, the Chern-Simons theory. In a recent paper, published as a Rapid Communication in Physical Review D, Dr. Altschul showed, using a direct calculation of the electromagnetic field of a moving charge in this theory, that Cerenkov radiation does not receive any contributions from the long-wavelength instability modes occuring in the Chern-Simons theory; this solved the most important outstanding question in this area of research.

Drs. Gudkov and Schindler are continuing their efforts with researchers at Oak Ridge National Laboratory to better understand the breaking of parity invariance in nuclear systems. At Oak Ridge, neutron beams are used to study scattering and capture reactions in which such symmetry breaking effects can occur. In principle, photon beams can also be used to gain data that will improve our understanding of parity violation. However, such effects are extremely small, making their experimental detection very difficult. Over the last year, Dr. Schindler has been involved in efforts to determine whether an experiment involving the break-up of a deuteron by a photon into a proton and a neutron can be performed at the High Intensity Gamma-Ray Source at Duke University. Dr. Schindler attended several workshops to discuss the feasibility of such a measurement, and together with a postdoctoral researcher at Duke University performed calculations to provide guidance in assessing at which energies to best perform the experiment.

But not only do we participate in workshops, the members of the Theoretical Physics Group are also active in creating opportunities for the exchange of new ideas: Dr. Gudkov is one of the organizers of a workshop on "Time-reversal Tests in Nuclear and Hadronic Processes," to be held at the Amherst Center for Fundamental Interactions at the University of Massachusetts in November 2014. The test of time-reversal invariance is an important research area, most prominently represented by the ongoing search for an electric dipole moment of the neutron in laboratories around the world. Dr. Gudkov's research focuses on complementary opportunities to search for the violation of time-reversal invariance using the interactions between neutrons and nuclei. He is collaborating with physicists at Oak Ridge National Laboratory in planning an experiment to measure such effects.

Dr. Altschul also oversaw the department's first Research Experience for Undergraduates (REU) summer program. The REU program, which is funded by the National Science Foundation, offered an opportunity for eight undergraduates to come to the USC campus for ten weeks to do cutting-edge research under the supervision of departmental faculty members. The students, most of whom came from the southeastern United States, got to work side-by-side with professors and graduate students, on projects in astronomy, nuclear physics, particle physics, biological physics, and magnetism. At the end of the summer, the physics and astronomy REU students participated in a research poster session, along with the participants in all the other REU programs operated by other departments at the university. Our departmental REU program will continue in the summers of 2015 and 2016 and possibly beyond.

Experimental Nuclear Physics Group

The experimental intermediate-energy nuclear physics group consists of three faculty members: Ralf Gothe, Yordanka Ilieva, and Steffen Strauch. Other members of our group include two postdoctoral researchers: Gleb Fedotov and Nicholas Zachariou; eleven graduate students: Tongtong Cao, Colin Gleason, Gary Hollis, Hao Jiang, Yuqing Mao, Aneta Net, Evan Phelps, Ye Tian, Arjun Trivedi, Nick Tyler, and Iulia Skorodumina, and many undergraduate students.

The study of the atom's nucleus and its constituents on the quark level is the core of our research. We are leading experiments at one of the flagship facilities for nuclear physics research in the U.S., the Thomas Jefferson National Accelerator Facility (JLab). We are also engaged in collaborative research at the J-PARC proton accelerator in Japan, the electron accelerator MAMI in Mainz, Germany, and the Paul Scherrer Institute (PSI) in Switzerland. Our studies focus on Quantum ChromoDynamics (QCD) and nuclei and are recognized as U.S. nuclear science frontiers. The main questions our research addresses include: What is the internal structure of the nucleon? How do the properties of strongly interacting particles change in the nuclear medium? What governs the transition of interacting quarks and gluons to pions and nucleons? What is the nature of the nuclear force that binds quarks into protons and neutrons and nucleons into nuclei? In the past year, the members of our group presented our research and findings on these topics in 30 invited and contributed talks at national and international levels, which is a token of the international recognition of our group, as is the fact that we published more than a dozen articles on our collaborative research.

The past year was full of challenges and rewarding experiences. Congratulations to Prof. Steffen Strauch who was elected into the Board of Directors of the JLab User's Group. We wish you a very interesting and productive tenure, Steffen! Congratulations to Prof. Ralf Gothe who was appointed to the initial Core Faculty of the South Carolina Honors College! We are very proud of our postdoctoral fellow Dr. N. Zachariou, who co-organized the very successful First Frontiers and Careers in Photonuclear Physics Conference at MIT in Summer 2014. Well done, Nick! Kudos also to our graduate student, Ye Tian, who won the very competitive JSA/JLab Graduate Fellowship for the 2014-2015 academic year!

In the past year, we got approval for our workshop at the European Centre for Theoretical Studies in Nuclear Physics (ECT*) in Trento, titled "Nucleon Resonances: From Photoproduction to High Photon Virtualities" in 2015 and for the JLab experiment proposal on Exclusive N* →KY Studies with CLAS12. Both activities further strengthen our efforts to build a scientific network and to strengthen our experimental program to investigate the evolution of QCD in the still unexplored domain between non-perturbative nuclear physics and perturbative high-energy physics phenomena.

We have continued the preparation for the Muon Scattering Experiment (MUSE) at PSI (S. Strauch). After another test beam time at PSI and a comprehensive review from DOE and NSF in Washington, we got recommended for funding to continue our R&D efforts. At USC we are going to build the time-of-flight, veto, and beam-monitor scintillator detectors for the experiment. We are also in charge of the development of a full Geant4 simulation of the experiment. This past summer, Mary Mulholland, one of our two REU students, worked with us on simulations to optimize the geometry of the MUSE beam-monitor detector (see Fig. 1). Our other REU student, Connor Callahan, worked on simulations to find an optimum degrader thickness for a stopped Kaon beam at J-PARC (see Fig. 1). This work supports our collaborative effort to test lepton universality and to search for physics beyond the Standard Model in measurements of Kaon decays (E36) at J-PARC. Esme Bajo, a local high-school student, joined the group for the summer, learned the simulation and analysis tools, and studied the interaction of photons and electrons with matter.

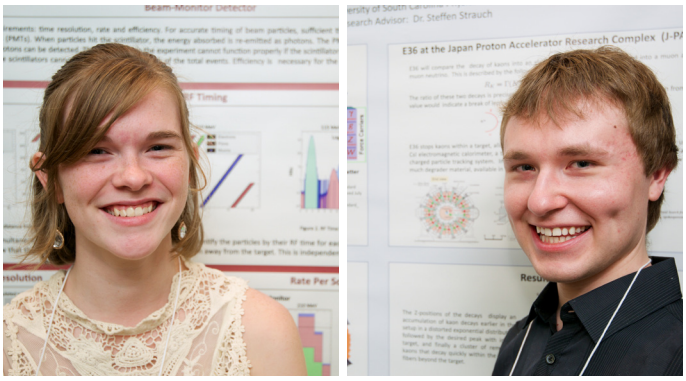


Figure 1: REU students Mary Mulholland (left) and Connor Callahan (right) presenting the results of their research with our group at the University's Summer Research Symposium.

Our group plays a major role in the 12-GeV JLab upgrade project with the development and construction of a new addition to the Time-of-Flight (TOF12) spectrometer for the CLAS detector in Hall B. R. Gothe leads this effort. In the past year we completed the production and construction of all detector elements and installed them into the final TOF12 sector frames at Jefferson Lab, which have now been fully integrated into the CLAS12 detector (see Fig. 2). This is a milestone achievement of our group that involved efforts over many years, not only of senior personnel, but also of a large number of graduate and undergraduate students.

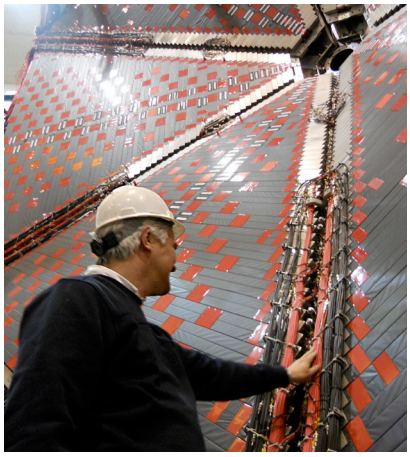


Figure 2: Dr. Gothe inspects the final implementation of our USC-built Time-of-Flight spectrometer into the CLAS12 detector at Jefferson Lab.

As part of the JLab R&D efforts related to building an Electron Ion Collider (EIC), we are responsible for the development of a dedicated test facility at Jefferson Lab where the performance of small-size photon sensors in high magnetic fields can be evaluated, and to carry out a series of tests of micro-channel plate photomultipliers (MCP-PMT) and other sensors in magnetic fields of up to 5 T. We have secured funding for this activity through the collaborative proposal, DIRC-based PID for the EIC Central Detector (Y. Ilieva). This past year has been very eventful as we installed, calibrated, and commissioned the facility. Our setup is quite unique as it not only provides high fields, but also allows for rotation of the sensor around two independent axes. The latter allows detailed mapping of the sensor's gain for various orientations with respect to the magnetic field. The project has prompted interest among photomultiplier manufacturers, with Photonis, Photek, and Hamamatsu providing several MCP-PMTs free of charge for test measurements. In Summer 2014 we took measurements of the gain of a single-anode MCP-PMT with a pore size of 6μm. Our data in magnetic fields larger 2 T are the first in the world and we are looking forward to analyze

and publish our results. We plan more measurements in Fall 2014, Summer 2015, and Summer 2016. Graduate student Tongtong Cao and undergraduate Eric Bringley contributed to this project (see Fig. 3). Once established, the facility will be of long-lasting value not only for nuclear physicists, but also for colleagues developing instrumentation for PET scans for small-animal or organ-specific imaging where the interest of using small-size sensors as readout elements is growing.

Figure 3: USC undergraduate student Eric Bringley working on the installation of the high-magnetic field sensor test facility at Jefferson Lab.

Last, but not least, we want to share a word about mentoring and training of junior personnel, into which we have invested quite a significant effort in the past years. We are very proud to say that we have accomplished to build a well-functioning and well-integrated research group with a healthy mix of postdocs, graduate, and undergraduate students, all at various levels of their career development in which everyone is continuously and actively engaged by building and sharing expertise. Through regular weekly meetings and rigorous sessions throughout each year, we not only ensure that each student is progressing well in their research, but we also provide training in preparation and delivery of oral and poster presentations, as well as in writing competitive funding proposals. We encourage and support our students to participate in conferences appropriate for their level where they can network with other professionals in the field, promote their work, and enhance their visibility. In the past year alone, our students have presented at meetings, such as USC Graduate Student Day, USC Discovery Day, collaboration meetings, the semi-annual meetings of the Division of Nuclear Physics of the American Physical Society, the Gordon Research Conference on Photonuclear Reactions (see Fig. 4) and the student – postdoc conference Frontiers and Careers in Photonuclear Physics.

With Jefferson Lab's approval to start initial 12-GeV operations (CD-4a) and the successful extraction of the first 12 GeV beam on target in Spring 2014, our commitment to publishing the 6-GeV physics results and developing future JLab12 experiments, as well as our involvement in several non-JLab projects, we are looking forward to another intense and productive year.

Figure 4: Participants from our group at the 2014 Gordon Research Conference on Photonuclear Reactions in Holderness, NH. From Left to Right: Back row: Gary Hollis, Ralf Gothe, and Tongtong Cao; Middle row: Steffen Strauch, Nick Zachariou, and Gleb Fedotov; Front row: Nick Tyler, Iulia Skorodumina, Yordanka Ilieva, Ye Tian, and Hao Jiang.

Advanced Solutions Group

Prof. Joseph E. Johnson, Director

Since its inception in 1992, the Advanced Solutions Group (ASG) has received over $12M in grants and contracts with Dr. Johnson as Principal Investigator (PI). A major recent component of this funding was $2.5M from DARPA that substantially advanced our applications of Lie algebras & groups to continuous Markov transformations and the decomposition of the full general linear group. This latter funding specifically led to our poof that every possible network is isomorphic to the Lie algebra that generates all continuous Markov transformations in n dimensions thus allowing the techniques of three areas of mathematics (Lie algebras/groups, Markov theory, and network topologies) to each be used to inform the other domains. Further work showed that second order Renyi entropies, defined on the rows and columns of the Markov matrix generated by a network, can be sorted to provide an entropy spectral curve that partially classifies the topology and allows rapid comparison of large networks. This development also provides a means of tracking the changes in a given network over time and thereby identifying anomalies such as internet attacks and failures. This work led to a U.S. Patent for Dr. Johnson awarded last year. We also used representations of these Markov monoids to generalize the real (binary) numbers into outer products of bit vectors (Markov representations) that allow uncertainty by giving the probability that each binary digit in a number is '1' or '0' similar to quantum qbits. We developed an extended Boolean algebra to support the generalized mathematical operations, thereby providing a means for representing numerical uncertainty for which Dr. Johnson was awarded another U.S. Patent. The most recent work over the last two years has resulted in a proof that any network can be expanded in a nested series of spectral curves of Renyi entropies of increasing order with decreasing information content but collectively capturing all topological network information with the series much like Fourier, multipole, and other orthogonal series expansions serve in mathematical physics. More importantly, Dr. Johnson recently has proposed that the eigenvectors of the Markov matrix generated by a network identify all network clusters and that the associated eigenvalues define a metric of the degree and extent of that clustering. Bill Campbell's 2014 M.S. thesis research, directed by Dr. Johnson, provided evidence of this methodology for cluster identification using networks created from data on the chemical elements, IO matrices of the US economy, and artificially created networks that had clusters within clusters in complex patterns that were unraveled by this methodology. This work has a pending patent. It has been technically reviewed and was just accepted for presentation at a conference in Rome, Italy in October of 2014 and will be published in the proceedings. The importance of this network research issues from its mathematical generality in describing any form of network (internet & communication, transportation, financial and banking transactions, utility, health and disease networks, and certainly social networks). Secondly, while there are over 100 algorithms for detecting clusters, these are relatively arbitrary in their definition while our clustering detection is assumption agnostic and proceeds directly from the eigenvectors of the Markov transformation that is generated by the network using the associated Markov model of the flows of a hypothetical conserved substance. The ability to identify clusters in Big Data and large networks is critical to the classification schemes of science. Although our clustering algorithm only works on networks defined by numerical linkages among nodes, we have found an innovative way to generate a network from numerical tables. Entities are treated as nodes and properties of these entities are numeric allowing a useful definition of an associated Cij connection matrix among nodes.

A second domain of ASG research concerns three distinct components of a proposed numeric data standardization. Numeric data, in essentially all distributed forms (print and electronic), while easily read by a person, are presented with dimensional units, numerical uncertainty, and defining metadata tags all scattered in row and column headings, titles, and footnotes preventing the automated reading of such data by computers. Although these three descriptors of numeric data are essential, they are detached and listed in nonstandard means separate from the values which they modify. At the present time, data must be formatted prior to input for another user's data processing thus causing extensive delays, errors, and misinterpretations that could be avoided if every numerical value carried its associated units, uncertainty, and defining metadata directly attached to each value in a universal standardized format. Dr. Johnson has developed highly efficient methodologies in each of these three domains for algorithms to manage the units, uncertainty and metadata tags in an integrated fashion with the value. We require that these "MetaNumber strings" be processed automatically by computers and also instantly read by humans. In May of 2014, Dr. Johnson received a substantial USC Aspire Grant to lead a team of thirteen senior USC faculty and twelve graduate and undergraduate students to develop prototype data tables in multiple disciplines in order to explore and demonstrate proof-of-concept of this new standard for all numerical data. The objective is to use this prototype to attract federal and corporate funding to expand this MetaNumber standard, and to create a center for this work at USC. Dr. Johnson has designed and written the Python code for these algorithms. Other members of the team, under the direction of Dr. Phil Moore, director of the USC Research Cyberinfrastructure Center, are porting that code to two new high speed dedicated computer blades (each with four processors plus a 60-node coprocessor delivering over one Teraflop Peak Double Precision each) that will be the computational server for this system. This new computer system, securely housed at USC's UTS facility, along with a full multiuser web registration and management system is now fully operational for use by all 26 members of the ASG ASPIRE team. This will be one of the most extensive interdisciplinary projects ever in operation at USC involving a minimum of eleven diverse departments in the Colleges of Arts and Sciences, Engineering, Public Health, Library and Information Science, and USC's UTS components. The unit's algorithms automatically perform all dimensional analysis (with error traps) thereby converting all units invisibly from any unit's representation that the originator chooses to use. This allows scientists to record information in any convenient set of units including both personally defined units and also a new extension of the SI system. The current system also incorporates a methodology for tracking unlimited metadata tag information associated with a number and provides a unique name for every formatted metanumber using a structure similar to the sequential paths used for email addresses but here allowing unlimited associated metadata links. That unique name, assigned to every single numerical value, can be used to store and retrieve that specific data value and reference it in mathematical expressions while maintaining a full trace of the 'historical evolution of each numerical value' from its inception in detectors and observations, through modeling, and mergers with other metanumbers. This is performed with a minimal extension of memory and essentially no reduction in processing speed. The concept of the 'evolutionary history' of a numerical value is now possible along with a framework to study the loss of Shannon and Renyi information by different computational paths and thereby providing a foundation for new research directions in computational entropy. When the associated parsing of expressions is

compete for numerical uncertainty (early 2015) it will also automatically manage the numerical uncertainty with significant digits and standard Gaussian analysis. The system will operate totally on a server as a cloud system allowing any internet device to execute transactional computations (similar to Mathematica and Matlab). Thus it will function like an 'app' on a smart phone or tablet with no software downloaded. It will also be encapsulated as a single 'function' (.exe) that can be called from users existing programs in FORTRAN, C/C++, and Java to evaluate mathematical and Boolean expressions containing MetaNumber strings. MetaNumber values can also be stored as dynamic functions e.g. the speed of sound which is dependent upon temperature and which returns the associated value for the user's operational temperature. Our specific ASG team members are Dr. Bill Hogue (V.P. for Information Technology and USC CIO); Dr. Phil Moore (Director of the USC Research Cyberinfrastructure Center); Dr. Don Jordan (Professor of Mathematics); Dr Robert Mullen (Professor and Chair of Civil and Environmental Engineering); Dr. Paul Huray (Professor of Electrical Engineering); Dr. Camelia Knapp (Professor of Earth and Ocean Sciences and Director of the ESRI Institute); Dr. Tammi Richardson (Assoc. Professor of Biology); Drs. Dwayne Porter (Assoc. Professor) and Geoff Scott (Professor) (outgoing and incoming Chairs of Public Heath); Dr. Lisa Wicklifte (Public Health Post Doc.); Dr. Dan Ramage (Public Health database manager), and Dr. Kendra Albright and Dr. Susan Rathbun-Grubb (Assoc. and Asst. Professors of Library and Information Science) along with twelve graduate and undergraduate students.

In a third active domain of ASG research, Dr. Johnson was awarded a second Aspire Grant in May of 2014 to upgrade the ASG built QRECT student response and data management system from Ruby code to Python code in order to incorporate a multi-tiered Expert Consensus (EC) algorithm along with other new features. This work is being programmed both by the USC Research Cyberinfrastructure (RCI) team for the system upgrade and by Dr. Johnson who is programming the associated EC algorithms in Python. The testing and evaluation of this system will be in partnership with the Co-PI, Dr. Bert Ely, (Professor of Biology and Director of the Center for Science Education). The two embodiments of this system apply to discrete and continuous student response selections such as responses which are discrete words or phrases and responses which are continuous real numbers with some level of allowed uncertainty. The QRECT student response system, which is free to USC faculty, has been in use at USC in several courses such as Physics 201/202, Biology, Statistics, and Business over the last five years but lacked these upgrades that will now be developed and tested. The system will track the performance level of each student and compute the probability of the correctness of the responses using the weighted responses of the students to estimate the optimal answer. Using the estimated correct answer, the students are graded and new probabilities for each student are computed. Then the probabilities of the correctness of each response and the individual scores of each student (probability that they will be correct in that domain of knowledge or class) are the solutions to two coupled nonlinear equations which are iteratively solved in a self-consistent manner. This methodology will also be tested with highly innovative educational evaluation environments such as the use of rapid response touch screens for students using smart phones or tablets (where the optimal response is here computed from the collective weighted student response). Another application to be tested will be to allow complex text response from students such as mathematical computations, critical reasoning in text form, drawings, photographs, and even videos to be graded by a set of about five other students in the class who in turn are themselves graded by the EC algorithm. This will allow novel methods of teaching where students can learn from the complex responses of other students. It also allows the grading of complex responses in large classes such as those found in distributed education. Our simulations suggest that these algorithms can be highly accurate (~1%) when a minimum of 20 to 30 students respond to 20 to 30 questions thereby establishing an accurate base of stable estimates of student probabilities of correctness. Thus the optimal responses (correct answers) are identified by the computer using the collective intelligence of the class! Questions must be in that domain of knowledge, unambiguous, and not too difficult for the class. The QRECT software also captures the exact time of response allowing very advanced educational metrics and analytics to be utilized with the resulting database. We are also investigating how these same algorithms can offer a very unique potential alternative mathematical formulation to traditional von Neumann game theory that overcomes the four core problems of (a) n players, (b) payoff matrix specification, (c) computational complexity, and, most important, (d) player collusion. We are currently utilizing the ASG QRECT student response system to teach fully web deployed USC Physics courses each semester. The MetaNumber system is encapsulated as a function in the QRECT software allowing a student to enter complex mathematical expressions which the MetaNumber software evaluates and submits as a response. The formal mathematical structure which the student uses is also captured as the input string which can be analyzed for errors and structure.

In addition to research in these three domains, Dr. Johnson continues to study problems connected to applications of Lie algebras/groups and Markov transformations as related to fundamental measurements in physics and the associated information theory. ASG has over 2,000 square feet of research space and offices for staff support in the Devine Street Research Center (730 Devine St.) and an office in the Physical Science Center (room 405).

Prof. Johnson and his team in a meeting.

High Energy Physics Group

HIRESMNU as the reference Near-Detector for LBNE

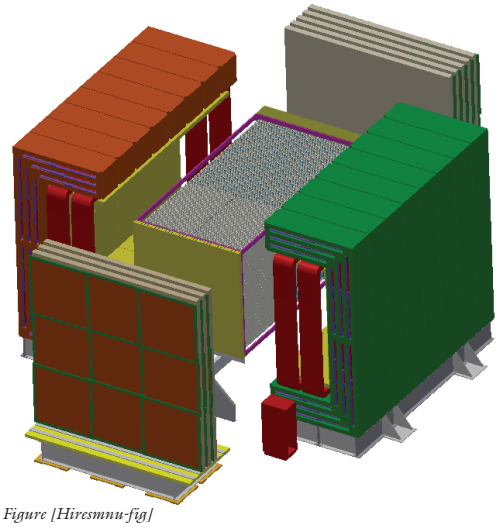


Figure [Hiresmnu-fig]

The unique capabilities and accelerator infrastructure at Fermilab, joined with a far detector 1,300 km away at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, present an extraordinary opportunity to develop a world-leading program of long-baseline neutrino science. This baseline distance between near- and far-neutrino measurements is optimal for oscillation studies and not currently available at any existing facility. The proposed Long-Baseline Neutrino Experiment (LBNE) aims to measure three out of the four parameters that characterize three-flavor neutrino oscillations: it will be the only oscillation experiment to simultaneously measure the CP-violation phenomenon, which may help explain the matter-antimatter imbalance, and determine the relative ordering of neutrino masses. The LBNE experiment plans to take physics data starting in 2023—initially with a 1.2~MW beam, but later with a 2.3~MW beam introduced by Project X. The core scientific capability of LBNE will be significantly enhanced by a high-resolution near neutrino detector.

Professors Sanjib Mishra and Roberto Petti proposed a high-resolution near detector, HiResMν, as a generational advance in the investigation of systematic errors affecting the neutrino oscillation and mass measurements in the precision neutrino-interactions made possible by the unprecedented neutrino fluxes foreseen in LBNE. The LBNE collaboration has chosen HiResMν as the reference Near-Detector (ND) design.

The HiResMν detector shown in Figure [Hiresmnu-fig], comprises a high-resolution, low-density (0.1 gm/cm^3) straw-tube tracker (STT), surrounded by a fine-grained electromagnetic-calorimeter (ECAL) embedded within a 0.4 T dipole magnetic field. Muon-detectors instrument the magnet and two stations downstream of the STT.

The HiResMν detector would combine for the first time an accurate reconstruction of the momentum and energy of the particles produced in neutrino interactions, together with an increase in statistics by two orders of magnitude over past experiments. This detector would perform over a hundred new measurements and searches, each surpassing the best previous result, and in the course of a ten-year operation would result in over three hundred publications and many potential physics discoveries.

The USC High Energy/Neutrino group, along with Fermilab, has been working with a consortium of Indian institutions to establish their collaboration with the neutrino experiments at Fermilab, especially with LBNE. In particular, the Indo-US nu-collaboration has proposed to the Indian funding agencies to design, R&D, and fabricate the HiResMν detector in India, which would then be shipped to Fermilab and installed in the LBNE near-detector hall. USC and Fermilab are the lead US institutions in this collaboration. The Indo-US proposal, requesting ~$75 million for equipment, and associated personnel, is a decade-long commitment, and is currently under review. In Summer 2014, a funding of about $10 million has been allocated by the Indian funding agency to support the R&D activities in preparation for the construction of the HiResMν detector. The USC group is expected to play a leading role in the R&D phase, which will last three years starting from October 2014.

Professors Mishra and Petti are leading the ND physics group in the LBNE collaboration. Post-doctoral fellows Dr. Xinchun Tian and Dr. Hongyue Duyang, graduate student Ms. Libo Jiang, and undergraduates Mr. Tyler Alion, Kevin Wood and Edward Dunton are participating in the LBNE related research.

NOvA Experiment

NOvA, a second-generation oscillation experiment, is under construction and scheduled to begin operation in 2014. The USC group's responsibilities on NOvA include Monte Carlo simulation, beam studies, data-acquisition system, and data analysis. Mishra, Petti, Tian, Duyang, and graduate student B. Chowdhury are currently working on NOvA.

Hands-On Research at KEK

by Alyssa Loos

Alyssa Loos (left), Prof. Milind Purohit (right)

I spent about a month at the international lab called KEK in Japan working with collaborators and attending meetings for Belle II. Belle II is a particle detector built around the collision point of positrons and electrons from SuperKEKB, soon to be the world's highest luminosity accelerator. Belle II is currently in the process of being transformed from the older Belle detector. A highlight of my trip was taking an up close tour of the magnificent Belle II detector.

Most of my time at KEK was spent four floors underground in a lab where I tested electronics and took data runs for the Belle II cosmic ray test. These tests were conducted outside of the detector to figure out the details of setting up and running the imaging time of propagation (iTOP) electronics.

Working on this experiment in Japan was such an amazing experience! The culture in Japan was drastically different than that in the US. Outside of the KEK campus (where Belle II is located) everything was in Japanese and hardly anyone spoke English. Trips to the local grocery store or restaurants were therefore always an interesting experience.

I had very knowledgeable collaborators who helped me learn a great deal about the electronics and data-taking software. They were very passionate about their work and were very happy to strike up conversations about particle physics during sushi bar runs.

I had a wonderful time in Japan learning about particle detectors and experiencing great food and culture.

Annual Meeting of the Southeastern Section of the American Physical Society

More than 200 physicists from the Southeastern US came to Columbia to attend the 81st Annual Meeting of the Southeastern Section of the APS (SESAPS), which was hosted by the Department of Physics and Astronomy. The meeting, organized by Profs. Crawford and Schindler, took place at the Columbia Metropolitan Convention Center, from November 12 through 15. It brought together senior researchers, graduate and undergraduate students from all fields of physics to present results of their research and to learn about exciting recent developments.

In addition to sessions dedicated to invited talks by senior researchers, the meeting provided a great opportunity for graduate and undergraduate students to give presentations about their ongoing projects. In particular, almost 60 students participated in the poster session on Friday, November 14. The USC Department of Physics and Astronomy was well represented by faculty, postdocs, and students giving invited and contributed talks and posters. Graduate student Colin Gleason, of the USC Experimental Nuclear Physics Group, was able to present his research for the first time at a conference during Friday poster session and he was excited to be able to talk to fellow physicists about his work. His topic was on "determining two polarization observables, which will provide information to help in identifying the excited states of baryons." Earlier in the day, graduate student Lei Wang gave a talk on "Universal Behavior of Magnetoresistance in 3-Dimensional Carbon Nanostructure." For Lei, this was the first time that he would give a major talk, and he was nervous and excited about giving his talk after three other speakers during the session on Condensed Matter. "I couldn't focus myself on their talks," said Lei, "but when I started my talk, I forgot all other things and became confident. I felt really good and finished my talk on time, and it was a very good experience for me."

Dr. Datta and Lei Wang

Graduate student Anton Kravchenko was also eager to give his talk on "The Search for New Physics with Razor Kinematic Variables in Proton-Proton Collisions at 8TeV (in a Center of Mass Frame) with the ATLAS Detector at the LHC (Large-Hadron Collider)." Anton had been addressing questions on his analysis from the ATLAS SUSY Group and Editorial Board since August, and he states that the analysis will soon be approved and published. No doubt all the preparation has paid off at the SESAPS talk!

A number of special events also took place during the meeting. At the meeting banquet on Thursday, Nov. 13, SESAPS presented three awards for excellence in research (Jesse W. Beams Award), service (Francis Slack Award), and teaching (George B. Pegram Award). Our very own, Prof. Milind Kunchur, was the recipient of the Pegram Award for his dedication to teaching physics in the Southeast. The banquet was followed by a keynote address by cosmologist Ted Bunn from the University of Richmond.

The poster session was accompanied by a graduate recruitment fair, which offered departments from institutions throughout the Southeast to present their graduate programs to a large number of interested and highly talented undergraduate students. Graduate student Sara Fitzgerald had a great time offering advice to these students at the recruitment fair. "Volunteering at the recruitment table let me pass on my experiences to people who are at critical junctions in their physics careers."

Jason (left) and Cory (right) enjoying a silly moment at SESAPS

Graduate student Jason Giamberardino, often called our department's graduate "ambassador," agrees with Sara and was proud to share information about the USC physics and astronomy program. "The recruitment fair went very well and we had a lot of interest in our program. Cory Dolbashian, Sara, and I engaged with many students ranging from high school juniors to college seniors." Jason has been helping the department with recruitment for about two years now, and has given about ten tours of the physics department to prospective graduate students. So far, he has had a 100 percent recruitment rate. "I enjoy telling the story of the department and showing people the beauty of campus even though we rarely leave the Jones Physical Sciences Center as physics grad students," said Jason, "The department and various professors have done a lot for me through my undergraduate and graduate careers here, so it's nice to try to give back to the department in any way I can." We are very grateful to all of our student volunteers who helped to make everything run smoothly.

The SESAPS meeting turned out to be a great success, and was made possible with the help of dedicated faculty, graduate, and undergraduate students, as well as generous financial support provided by Prof. Richard Webb's SmartState Center for Nanoscale Experimental Physics.

The 4th Annual Pumpkin Chunkin' Competition

By Yanwen Wu

In the 2013 fall semester, a student in my PHYS 211 class asked me to be a faculty judge in the 3rd Annual Pumpkin Chunkin': a high school trebuchet competition hosted by the USC chapter of the Theta Tau Engineering Fraternity. That was also the first time I have learned about such an event in the University. When the fraternity organization contacted me again this year with information on expanding the competition to include a college division, I immediately felt that I should jump on board.

I have always believed in a hands-on approach to learning physical concepts. The Pumpkin Chunkin' event is a perfect playground where these concepts can be visualized and tested without the burden of an imminent exam. Besides, who would turn down a chance to build a Medieval weapon of war? It wasn't difficult to garner enough interest for this project, and we ended up with a finalized group of nine students (two from Engineering and seven from Physics, with most of them being freshmen). The main challenges of this project involved collecting the raw materials and tools needed to build the trebuchet in the short amount of time available to construct the device. We only had one and a half months to do this project.

The Department of Physics and Astronomy had generously agreed to fund the project. Nevertheless, I challenged the students to build the trebuchet with as few store-bought materials as possible. This restriction inspired a surge of innovation from the students. Introducing the students to the University's Consolidation Service, or "Surplus," was like bringing kids to a candy store. They quickly identified usable parts in the most unexpected "junk." In fact, the most crucial components of our trebuchet were free, recycled parts from Surplus. The students took time out of their packed schedule to design, build, and test the trebuchet on their own, and they enjoyed the creating and building process immensely. The final product functioned beautifully and demonstrated that it was truly a weapon of war during our test runs (we put a sizable pumpkin dent on someone's car!).

The Team

Despite the limitation of materials and time, our trebuchet performed extremely well. Our farthest throw was 175 feet. Even though we didn't throw the longest distance in the competition, our trebuchet was the most efficient. We were the only college team that managed to show up, and since the Engineering team didn't deliver, we won our division by default—although we had to admit that the high school teams were amazing. In particular, the Clover High School team blew everyone out of the water with a 352-foot throw. They are now our official nemesis! Some of the students were a little disappointed that we lost to high school students, but all of them agreed that this entire process was extremely fun and was a great learning experience.

The success of this event was due to the collective effort of the physics department (particularly to Dr. Richard Webb for donating his lab space, tools, and lead bricks for the trebuchet counterweights), the staff in the machine shop (Art Illington and Allen Frye), and the wonderland that is Surplus. This project not only provided the students a fun environment to translate what they learn in classes and on papers into tools for solving real world problems, but it also gave them a chance to experience teamwork and hang out with their peers in a setting other than the classrooms and homework cramming sessions. We can't wait to do this again next year!

The Chunkin' in action

A Few Words from the Students on Our Pumpkin Chunkin' Team

Physics undergraduate, Krystal Rolon, had a great time with the USC physics team ("The Cowtapulters") and enjoyed working with Prof. Wu and as well as fellow physics students. Krystal says that she was very excited that the team was so enthusiastic from start to finish. Her favorite part in all of this? "My favorite part of the experience has to have been [hearing and working with] with the skills and ideas that team members had to offer towards building the trebuchet. I'm excited to do this again next year and I strongly recommend for those looking for a fun challenge! Of course, no actual animals (including cows) were harmed during the testing of our trebuchet--only a stuffed lion!"

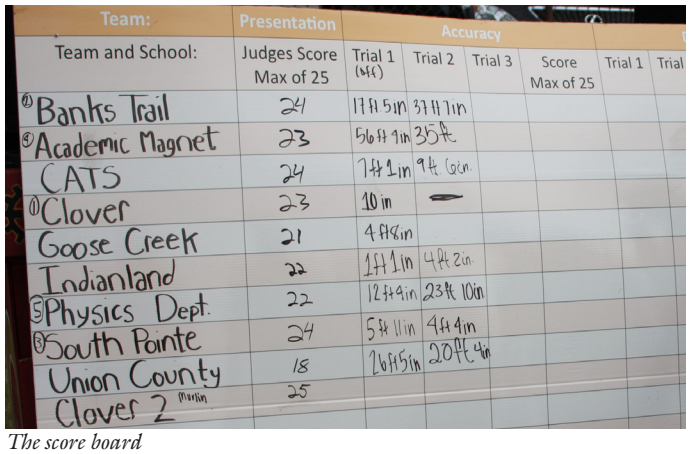
The Cow

Tyler Strampp decided to join the Cowtapulters after seeing the flyers announcing the call for student participants. Tyler says, "I was interested in the project because it was an opportunity to apply what I've learned in school and USC to a real world situation and have fun building launching and smashing. I was the only mechanical engineer major on the team so I shared my knowledge of statics and building practices. I like to think of myself as the engineering consultant on the team. From the initial idea brainstorm to final adjustments, I felt privileged to be a part of a team with such enthusiasm and dedication." What Tyler enjoyed most was the building process itself, was when the team was able to use the gathered materials to turn them into working parts for the trebuchet. "When launching we needed a counterweight, and it just so happened the lab we were working in let us borrow 200 pounds of lead, which until you pick up a four-inch by eight-inch by two-inch foil-wrapped lead brick, you realize just how

extremely dense lead is."

The application of classroom knowledge was a valuable part of this experience for Tyler. Being able spend time away from homework and studying for exams to do something fun, while still doing something directly related to the information learned in class was a breath of fresh air, too. "I would absolutely do this again, in the future I hope to see other departments compete and see the different design philosophies of different majors. What I hope everyone got out of this is that science and math, when you apply these formulas and facts out of the classroom, it can be, dare I say it, fun."

The cheerleaders



The score board

The doomed pumpkins

The awards table

The participants

Quantum Leap

Department of Physics and Astronomy
University of South Carolina
712 Main Street
Columbia, SC 29208

Telephone: 803-777-8105
Fax: 803-777-3065
Email: wonge@sc.edu
www.physics.sc.edu

Space Elements imaged by Alex Mowery from the Melton Observatory