SUMMER 2010

physics [FORUM]

IU COLLEGE OF ARTS & SCIENCES ALUMNI ASSOCIATION ~ FOR ALUMNI & FRIENDS OF THE IU DEPARTMENT OF PHYSICS

Research prompts innovation

Physics Department work often leads to discoveries, patented inventions, and even new companies.

ProcureTraining and Development Center in Bloomington, Ind., is one innovative company founded by Professor Emeritus John Cameron. Below, work at IU's Cyclotron facility is impacting students, science, and medicine. See story on page 11.

Research by the Physics Department faculty and staff often leads to discoveries that become patented inventions and may also lead to new companies. Recent examples include two companies founded by Professor Emeritus **John Cameron** and collaborators.

PartTec, founded in 2002, works on outsource manufacturing solutions for scientific laboratories including neutron detection for neutron scattering and security applications. ProCure, founded in 2005, has the mission of bringing proton therapy to patients with cancers and is developing and operating proton therapy centers in collaboration with leading radiation oncology practices and hospitals. The company has offices in Bloomington, Ind., and New York City, and has experienced rapid growth with a center operating in Oklahoma City and several others under construction.

LK Technologies, a company founded by Professor **Larry Kesmodel**, based on electron scattering research in his laboratory in the late 1980's, has expanded its surface science product line in recent years and in 2006 moved to a much larger facility in Bloomington.

In a recent innovation, Professor Emeritus **Hans-Otto Meyer** (with coworkers P. Smith and G. Visser) has developed a high-voltage power supply based on photovoltaics. It may have commercial application for example as a power source for charged particle detectors and has been patented by the IU Research and Technology Corporation. Learn more about the IURTC at innovate.indiana.edu/iurtc.

Courtesy IU College of Arts & Sciences

in this issue

Greetings!

First, allow me to introduce myself: I was elected department chair in fall 2007, taking the reins from the very capable hands of former Chair **Jim Musser** before he returned recently to full-time research and teaching.

I am an experimental particle physicist working at colliders at the energy frontier, and am honored to be serving the department as it continues to pursue a wide-ranging and vigorous research program. I am also thrilled to help transmit this excitement to students in their training and education.

Getting back in touch

As a department, we have not contacted you for several years. We sincerely aim to remedy this with a revived annual newsletter. This edition was organized by a newly formed committee who will also be leading efforts to arrange and advertise events specifically for Physics Department alumni: stay tuned.

As part of this, we'd be delighted if you could drop us a line or connect with the IU Alumni Association. Let us know what you are currently up to, and we'll publish your news in future issues.

Since it has been a while since our last newsletter, this issue presents a brief survey of the highly compelling and creative research in our traditional fields of subatomic, condensed matter, and accelerator physics. We also highlight our tremendously successful new research direction: biophysics. This area has been wildly popular with our graduate students since its inception.

Changes and transitions

This has been a time of transition as well. The transformation of the cyclotron at IUCF from a research machine to supplying a cancer-fighting proton beam to the Midwest Proton Radiotherapy Institute is now complete.When it opened in 2004, it was the third such facility in the country, and today it remains one of only a handful nationwide.

As part of this transition, cyclotron operations have been split from research activities with the formation of the new Center for the Exploration of Energy and Matter (CEEM). The CEEM opens a window to new research opportunities and currently includes our nationally ranked nuclear physics program, as well as condensed matter and materials research (see page 10), and our highly respected accelerator physics program.

The department has weathered challenges presented by the ongoing global economic crisis in the form of budget cuts in the IU College of Arts & Sciences.

However, we've worked to minimize negative impacts to the department's research and teaching missions. One of my most rewarding activities is faculty hiring, and despite general hiring slow-downs and freezes at the university, since I came on as chair, we have welcomed professors **Josh Long**, **Radovan Dermisek**, and **Sabine Lammers** to our teaching faculty.

Courtesy IU College of Arts & Sciences

Professo Rick van Kooten assists an undergraduate student with a pyrofusion setup. This image was part of "A Day in the Life of the College," featured here: **www.indiana.edu/~college/gallery.**

We now also eagerly look forward to the arrival of **Lisa Kaufman** (experimental nuclear and neutrino physics) and **Jorge Jose** (theoretical condensed matter and vice president for research for IU) this coming Fall.

I am also happy to announce the promotion of **Hal Evans**, **Rex Tayloe**, **John Beggs**, and **Sima Setayeshgar** to tenured associate professor. **Mark Messier** was named a full professor this year.

We extend warm congratulations. They are national and world leaders in their fields, and we look forward to their future contributions to the university in research, mentoring, teaching, and service.

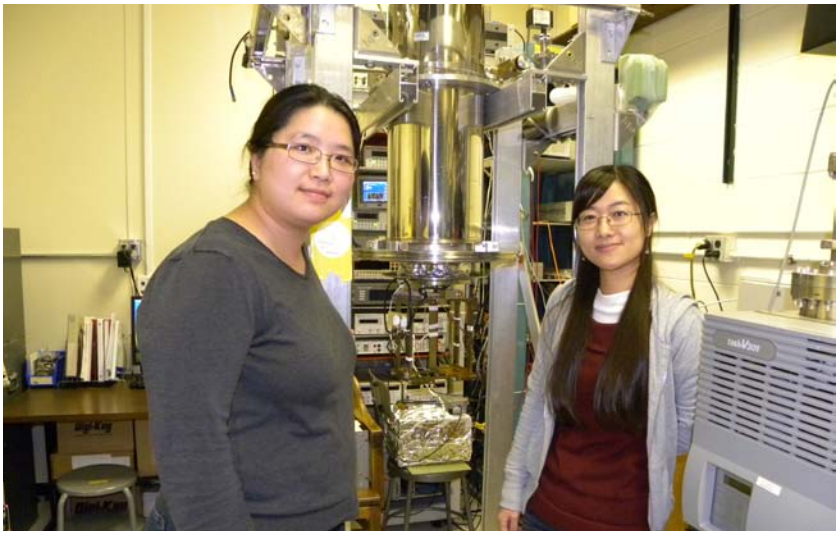
Our future alumni

On the side of our students, we are exhilarated by a doubling of the number of incoming Physics undergraduate majors to the department over the last few years. Students are attracted by our Applied Physics Program and its internships (see page 6). Our graduate student-recruiting program was highly successful in 2009–10, and we will welcome a near-record 30 new PhD students in September.

I encourage you to stop by the department for a visit whenever you are in the area, and feel free to stop by the chair's office the next time you are in Bloomington. On behalf of the department, I thank you for your continued interest and support, for which we are humbly indebted.

Rick Van Kooten, department chair and professor of physics

Meet our new faculty members



Courtesy IU College of Arts & Sciences

Chen-Yu Liu works with student Young Jin Kim at the IU Cyclotron Facility.

Dobrin P. Bossev joined the department in fall 2004 after research scientist and postdoctoral positions at National Institute for Science and Technology. He received his PhD from Kyoto University, Japan. His interests include soft-matter physics and in particular self assembly of amphiphilic molecules and colloidal particles in solutions, complex fluids, properties of bio-membranes and interfacial phenomena. He has expertise in elastic and quasielastic neutron scattering techniques.

Chen-Yu Liu joined the department as an assistant professor in 2005 following graduate work at Princeton University and a postdoctoral appointment at Los Alamos National Laboratory. Her research interests include developing new sources to produce ultra cold neutrons and applying them for fundamental physics research. She is currently working on experiments to test time reversal symmetry violation through the search of the electric dipole moment of the neutron and the electron.

Hal Evans joined the department in 2005 as an associate professor. He received his PhD from UCLA in 1991 and was a postdoctoral fellow and a research scientist at the University of Chicago until joining the faculty at Columbia University in 1998. He is an experimental high-energy physicist with interests in high-speed electronics systems, the physics of the b-quark, and searches for new phenomena. His work is done mainly at large accelerators, currently as part of the DZero collaboration at Fermilab and the ATLAS collaboration at CERN.

Matthew Shepherd joined the department in the fall of 2005 as assistant professor. He received his bachelor's degree from Indiana University in 2000 and his PhD in elementary particle physics from Cornell University in 2005. His research work focuses on studying quantum chromodynamics by searching for exotic bound states predicted by the theory. Currently his research group is involved in building the GlueX experiment at Jefferson Lab and collaborating on analysis of data collected with the BES III experiment at the Institute for High Energy Physics in Beijing and the CLEO experiment at Cornell University

Sabine Lammers joined the department as assistant professor in 2008 following postdoctoral work at Columbia University and graduate work at the University of Wisconsin. She splits her time between Bloomington and Chicago, where she works on the DZero Experiment at Fermi National Accelerator Lab, and Geneva, Switzerland, where she works on the ATLAS experiment at the Large Hadron Collider. Sabine is interested in uncovering the nature of electroweak symmetry breaking and is currently working on measurements of vector and scalar bosons, including the elusive Higgs Boson.

Radovan Dermisek joined the department as assistant professor in 2008 following postdoctoral work at the University of California, Davis and the Institute for Advanced Study in Princeton. He received his PhD from the Ohio State University in 2002. He is a theoretical particle physicist and his work focuses on electroweak symmetry breaking, origin of particle masses, phenomenology of the Higgs boson, super symmetry, and grand unification.

Josh Long joined the department as assistant professor in 2008 after six years as a research scientist at Los Alamos National Laboratory and the IU Cyclotron Facility. He received his PhD from Johns Hopkins in 1997 and did postdoctoral work at the University of Colorado. His research concentrates on experimental tests of fundamental symmetries and gravity. One experiment is a search for a permanent electric dipole moment of the neutron. Another is a test of the Newtonian inverse square law at distance ranges less than 100 microns.

continued on page 4

Bossev

Lammers

Evans

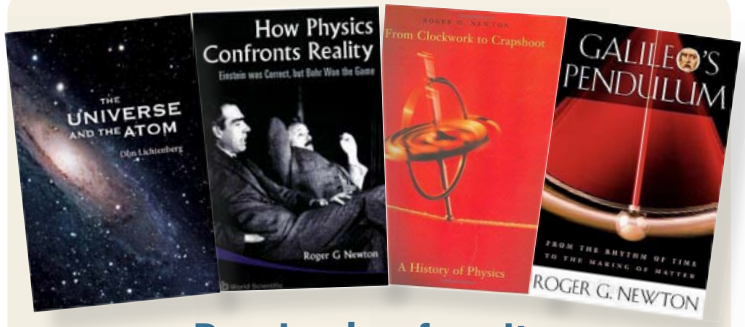
Long

Dermisek

Ortiz

Fertig

Sokol



By physics faculty

History of Physics at Indiana University

Mark Gebhard traces the study of physics at IU from its origins in 1830 — a class of six seminary students — through the granting of the department's first PhD in 1915, to today's department, populated by active research groups in particle physics, nuclear physics, condensed matter physics, and biophysics. Gebhard's interest was first piqued by the collections of old equipment stored in the basement of Swain Hall. When his searches for history didn't yield much, he said, "I decided I was going to have to write it myself if I wanted to read it." Self-published, available at Lulu.com.

The Universe and the Atom

"What is amazing is that one can't understand the development of the universe as a whole without understanding its constituents on the subatomic scale", says author Don Litchenberg. In the Universe and the Atom he sets the ambitious goal of providing the non-scientist with an understanding of the connections between the physics of the very small and the very big. His book been praised for its clarity. World Scientific Publishing, 2007.

How Physics Confronts Reality: Einstein was Correct, but Bohr Won the Game

Roger Newton's entry point into the sometimes counterintuitive subject of quantum mechanics is Einstein's objection to the theory, dialogue, and debates that ensued between he and Niels Bohr, an early pioneer of quantum mechanics. What Einstein got right was that quantum mechanics does not provide a direct description of reality. It does, however, provide answers that agree with experiment, winning the game for Bohr. World Scientific Publishing, 2009.

From Clockwork to Crapshoot

Roger Newton provides an up-to-date, comprehensive and well-written history of physics. While focusing heavily on astrophysics and atomic physics he explains the profound influence of mathematics on the development of physics. Belknap Press of Harvard University Press, 2007.

Galileo's Pendulum

Roger Newton explains the premise of his slim volume in a single sentence: "This book is about the rhythm of time, how that rhythm was finally regulated by Galileo's pendulum, the impact the oscillations of the pendulum had on our perception of that rhythm, and how these oscillations were later found to manifest themselves in many other natural phenomena." Harvard University Press, 2005.

(from page 2)

Gerardo Ortiz joined the department as full professor in 2006. He received his PhD in Theoretical Physics at the Swiss Federal Institute of Technology. He continued his career in the U.S., first as a postdoctoral fellow in the University of Illinois at Urbana-Champaign, and then as an Oppenheimer fellow at the Los Alamos National Laboratory where he stayed as a permanent staff member until 2006. His research spans several areas of condensed matter physics, such as unconventional superconductivity and magnetism, and quantum information theory.

Herb Fertig joined the physics department as full professor in 2004. He received his PhD from Harvard University in 1988. After postdoctoral work at the University of Maryland, he was a member (beginning in 1991) of the physics faculty at University of Kentucky. He is a condensed matter theorist, with interests in low-dimensional electron systems, superconductivity, and statistical mechanics in low dimensions. His most recent work has focused largely on the physics of graphene.

Roger Pynn joined the department as a full professor in the fall of 2005 from Los Alamos National Laboratory. He has a joint appointment with Oak Ridge National Laboratory. His principal research interests are in neutron scattering studies of complex fluids and magnetic films. He is also developing new techniques for neutron scattering at the Low Energy Neutron Source. Read about Pynn's Gunnar Research Prize on page 12.

Paul Sokol joined IU in 2004 as a full professor and Director of the Indiana University Cyclotron facility. He received his PhD from the Ohio State University in 1981. After postdoctoral work at the University of Illinois at Urbana Champaign he joined the faculty of Harvard University as an assistant professor in 1984. He joined the Physics Department of The Pennsylvania State University in 1988 where he remained until coming to IU. As director of IUCF he oversaw the completion of the Midwest Proton Radiotherapy Institute and the Low Energy Neutron Source. Following the successful FDA approval of MPRI he stepped down as director to focus on research and teaching. He is currently director of LENS and the principal investigator on a new electron storage ring (ALPHA) that is currently under construction. His research interests include x-ray and neutron scattering studies of quantum liquids, nanosystems and energy storage materials.

Courtesy IU College of Arts & Sciences

Matthew Shepherd met science teachers from all over the Hoosier state during the 2010 Hoosier Association of Science Teachers Inc (HASTI) Convention in Indianapolis.

Well wishes, continued work for retired faculty members

John Challifour retired in July 2007 and continues his interests in teaching and research. He is teaching P201 in the first summer session and works with graduate student Edward Timko on applying techniques from algebraic topology and functional analysis to the study of topological excitations in quantized gauge theories. A paper last winter was written with former graduate student **Dan Bowman**, MS'00, PhD'05, who is now teaching in Virginia.

Bill Schaich continues his research interest in surface physics, concentrating on simulations of light scattering from microscopically structured surfaces. A recent extension relevant to the LENS program has been to consider neutron scatting from similar surfaces. He also has become more involved in genealogy.

Andy Bacher, above, says he's "continued those activities he enjoyed most in Bloomington." Alex Dzierba, below left, worked for JLab and on the Glue X experiment, but he also spends four weeks a year in Bonaire.

Andy Bacher retired from teaching after fall 2007 semester. He writes, "I've continued those activities I enjoyed the most in Bloomington. For example, we are finishing up several articles related to our observation of Charge Symmetry Breaking - the final experiment at the IU Cooler Storage Ring. I also still run the IUCF (now CEEM) part of the Summer Undergraduate Research (REU) Program in Physics (with John Carini). In the evenings, in Bloomington, I'm often at some cultural activity. Or, out on the West Coast, I hassle a couple of new grandchildren."

Challifour

Nann

Richard Heinz retired in 2005. He spent a year and a half editing a university physics text for McGraw Hill, and writes that, "Since then my physics involvement, beyond reading popular articles, has been limited to attending lectures at the Aspen Center for Physics. During the winter I can be found skiing Aspen/Snowmass, Co. outside of my ski condo. In the spring and fall I reside in my midtown Manhattan apartment. My summer home is in a golf-tennis-swim resort just outside of Aspen; I actively partake in all three of these activities as well as hiking and biking. Recently I have taken up acrylic painting, specializing in geometric patterns and the abstract. "

Alex Dzierba retired from teaching in mid-2006 at which time he started a two-year appointment as Distinguished Visiting Fellow at Jefferson Lab. He commuted to JLab every other week as he continued to lead the GlueX project (search for exotic mesons) at JLab and at IU. He was the founding spokesperson for GlueX starting in 1998 and was in that position until late 2007. In mid-2008 he joined EG&G (a division of URS Corp.) located in the WestGate Technology Park outside of the Crane Naval Base in Indiana. He is working on energy issues for Crane including understanding how Crane uses electrical energy and looking into re-activating an abandoned hydropower plant at the nearby Williams Dam on the White River. He and his wife, Linda, spend four weeks a year in Bonaire doing underwater photography and videography (www.dzre.com/alex)

Heinz

Schaich

Herman Nann is working with Mike Snow on the NPDGamma experiment. He writes that "We are presently preparing the experiment for running at the Spallation Neutron Source. My primary responsibilities are the safety aspects of the 16 L liquid hydrogen target. I am doing the dimensional calculations for the relief system and vent lines of the target. I am also responsible for the safety and design requirements for the target vessel and the target insulation vacuum chamber and main vacuum line in case of a worst possible credible accident." ■

faculty awards & honors

OUTSTANDING CONTRIBUTIONS TO TEACHING

2009: ALAN KOSTELECKY - GRADUATE
CHEN-YU LIU - UNDERGRADUATE
2010: MIKE BERGER - GRADUATE
MATT SHEPHERD - UNDERGRADUATE

At top, senior Applied Physics Program student Paul Rumbach presents work he did as an intern at the Low Energy Neutron Source (LENS) during the fall 2009 Applied Physics Internship and Research Symposium .

Applied physics degree program launched

In 2005 the department launched a new undergraduate degree program in applied physics. The goal of the Applied Physics Program was to provide students an alternate track to the physics bachelor of science degree that focused on practical applications of that are relevant for today's high-tech jobs.

The program curriculum closely parallels that of the traditional physics BS track, with a couple of notable changes. First, a new instrumentation course has been developed that allows students the opportunity to work with instrumentation and computer interfaces that are common in industry applications. A second element of the new degree program requires the completion of two summer internships, one each after the sophomore and junior years.

Current students have completed internships at locations including NSA Crane, a local naval technology base; Pro-Cure, a Bloomington-based proton therapy provider; and the Midwest Proton Radiotherapy Institute, located on the IU Bloomington campus.

Students often cite this internship experience as the most valuable part of the degree program. "There is a balance between the classical theoretical physics and practical applications of physics, making one more diverse than just the [traditional] Physics BS," said one recent graduate. "The internships are brilliant. They really give you a flavor of what a possible career in that field is like."

For more information about the program, please visit applied.physics.indiana.edu. If you are interested in becoming involved in the program by hosting applied physics students at your company, please contact Matt Shepherd, program coordinator, at mashepe@indiana.edu.

What's new in the classroom

'Clickers'

In most of the introductory physics lectures the professor still stops every 10 minutes or so and ask a question. But now, she or he actually expects to get an answer, not just from the intense student in the front row but from everyone! "Clickers" – student response pads that communicate directly with the instructor's receiver – are in widespread use in physics. The immediate responses engage the students during the class and initiate discussions among the students on the subject-at-hand. Plus, the instructor receives real-time feedback that often redirects the course of the class to clarify or expand on important concepts before moving on.

Cell Phones 101

Our catalog includes a number of new courses. One of the most popular has been Harold Ogren's take on P150 How Things Work, also known as "Cell Phones 101," about the science and technology that one finds in a cell phone, which spans all areas of physics from waves and sound, electromagnetism, batteries, light, and optics, to information theory. The "text" is online in the form of a Wiki that is updated as technology changes.

With support from the College of Arts & Sciences and the Astronomy Department, we were able to renovate the Physics Forum (Swain West 246) and convert the adjacent library storage area into a computer cluster for use by physics and astronomy courses and their students.

[News from the Society of Physics Students]

The IU Society of Physics Students (SPS) chapter was very busy this 2009-2010 academic year. Membership nearly doubled, with many new faces joining the group, and our activity is at the highest level it has been in quite some time.

Each fall, the group writes, produces, and performs the Physics Demonstration Show at the IU Physics and Astronomy Open House.

This year's event fell on Halloween, so we decided to base our show on the obviously related themes of Harry Potter and the Ghostbusters. In our story, Voldemort has stolen the magic from Hogwart's, and the Ghostbusters arrive on the scene to help the wizards get it back – using physics, of course! We packed the house for both performances, and the children (our main audience) seemed to particularly enjoy, as well as learn from, the presentation.

Professor Urheim enjoys a free pie, courtesy of the IU Society of Physics Students at their Pi Day fundraiser in March 2010.

We also continued the physics podcast project begun in spring 2009. The project's first four episodes are posted on YouTube, and we hope to continue to produce podcasts to act as supplementary material for the 200-level physics courses.

This year we also sent a representative to the McCormick Creek Elementary School Science Fair in fall 2009, where we amazed children with the standard assortment of physics demonstrations, including our new static electricity wands.

Late in the spring 2010, we hosted an SPS Zone Meeting in Swain West, and we hope to gather physics students from around the Midwest region to join us for a conference that will include speakers, undergraduate research presentations, a game of Physics Jeopardy, tours of Kirkwood Observatory and the Cyclotron, and many other activities. We concluded this semester with a trip to FermiLab in Chicago, where we toured the facilities, got a firsthand look at some of the experiments in which IU faculty are involved. The group also visited the Museum of Science & Industry.

For the incredible support we receive, the SPS would like to thank our faculty advisors **Fred Luehring** and **Mark Hess**, graduate student advisor Denver Whittington, and the IU Physics Department. – *Chris Faesi*

Graduate student Adam Washington prepares an experiment for the SESAME instrument on the Low Energy Neutron Source .

Courtesy IU College of Arts & Sciences

2010 Department Award Winners

Dissertation Year Fellowship
Aonan Tang, Denver Whittington, Gang Shen

College Grad Student Travel Grant
Gang Shen

McCormick Science Grant
Young Jin Kim

DoE Graduate Fellowship in Science
Daniel Salvat

Joseph & Sophia Konopinski Teaching Awards
Jorge Diaz, Helber Dussan

Outstanding Graduate Student in Experimental Research
Jiawei Mei

Outstanding Graduate Student in Theoretical Research
Jianhui Wang

Koss Award
Gang Shen

Barry M. Goldwater Scholarships
Carlo Angiuli, Christopher Faesi, Jennifer Kulow

Outstanding Undergraduate Award
Samuel Adams

Hugh Brown Memorial Scholarship
Carlo Angiuli

Gabriel Benman Memorial Award
Abigail Besemer, Paul Rumbach

Outstanding Undergraduate Associate Instructor
Alex Grannan

Sigma Pi Sigma, new members
Andrew Slemmon, Teresa Wright

Sigma Pi Sigma, graduates
Samuel Adams, Nathan Bower-Bir, Sarah Kaiser, Mark Moore, Thomas Petelik, Abigail Besemer, Timothy Gee, Marcus Lamaster, Daniel Oates, Paul Rumbach

Departmental Honors
Samuel Adams, Peter Lunt, Abigail Besemer, Patrick McChesney, Paul Rumbach

BIOPHYSICS

New courses, collaborations

The Biophysics Group is a sizable and active unit that now includes four faculty members: **James Glazier**, who arrived in 2002, and **Sima Setayeshgar**, **John Beggs**, and **Rob de Ruyter** since 2003. Biophysics is a highly multidisciplinary endeavor, and all members of the group have productive collaborations with other life scientists, both on campus (in the departments of Biology and Psychological and Brain Sciences, as well as the School of Informatics and Computing), and beyond.

Glazier directs the Biocomplexity Institute (biocomplexity.indiana.edu), through which researchers from a number of fields collaborate to study self-organization in biological systems.

The Biophysics Group sees considerable interest among graduate students, and has been active in curriculum development. Five new regular graduate courses were introduced: Introduction to Biophysics, Mathematical Methods for Biology, Biological and Artificial Neural Networks, Signal Processing, and Information Theory in Biology, as well as a seminar – Selected Topics in Biophysics. The most recent addition to the curriculum is an advanced undergraduate course, developed primarily for students in the newly established neuroscience major.

Research topics within the group span a considerable range in modern biophysics: Setayeshgar's focus is primarily theoretical, in close collaboration with microbiologists at IUB, and medical researchers at the IUPUI School of Medicine. Her research areas range from biochemical signaling networks to nonequilibrium pattern formation in physical and biological systems, including cardiac dynamics, and multiscale modeling of microbial biofilms, using techniques from statistical mechanics, applied mathematics, and scientific computing.

Glazier works on a combination of experimental topics in morphogenesis and pattern formation and his group has developed widely used computational tools to simulate tissue development.

Both Beggs and de Ruyter work in the area of experimental systems neuroscience. Beggs's projects focus on the use of multi-electrode arrays to record neural activity up to a few hundred neurons simultaneously in a slice of brain tissue. Using ideas inspired by statistical mechanics, his group tries to elucidate the nature of computations taking place within the cortex. De Ruyter's group uses the visual system and the brain of the fly as a starting point for asking questions about optimal processing and adaptation in sensory systems.

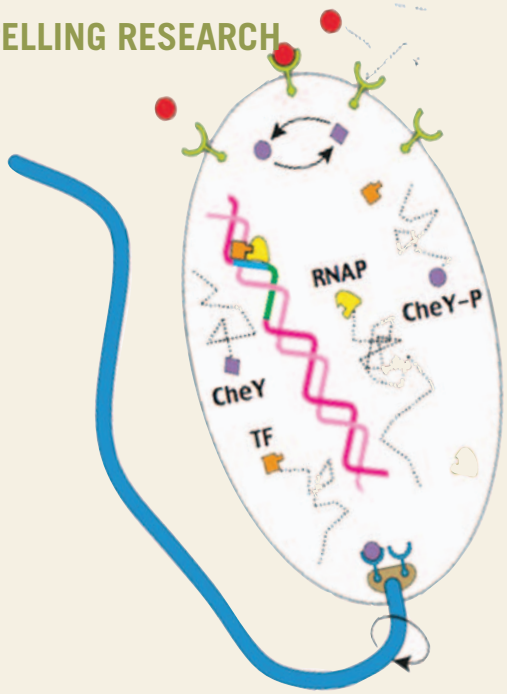


Fig. 1: This highly schematized model of the bacterium *E coli* illustrates its ability to sense molecules, e.g. the red "food" (amino acid) molecules that diffuse through its watery environment and may bind to external receptors — biology's equivalent of "particle detectors" — on the cell membrane. These events trigger a cascade of internal reactions that affect the rotation of the flagellum (long blue "tail"), which propels the bacterium, allowing it to move up or down concentration gradients. This classical problem, first studied by Howard Berg and Edward Purcell, has emerged as the "hydrogen atom" of signal processing by biochemical networks. Setayeshgar's group studies the physical principles underlying the organization of signaling networks.

PARTICLE PHYSICS

'The energy frontier'

There is tremendous excitement at the "energy frontier," as the Large Hadron Collider straddling Switzerland and France has recently recovered from setbacks. It successfully collides protons at energies more than three times higher than the Tevatron.

Harold Ogren has spent more than 15 years designing and building the "transition radiation tracker" now installed and working flawlessly in the heart of the gigantic ATLAS detector to trace the paths of charged particle produced in these collisions. Joined by professors **Hal Evans**, **Sabine Lammers**, and **Rick Van Kooten** as well as research scientists **Pauline Gagnon**, **Vivek Jain**, **Fred Luehring**, and **Daria Zieminska**, they lead a group of postdoctoral students and students hunting for the Higgs boson as the progenitor of all particle mass as well as for new particles such as those responsible for "dark matter" in the universe and disturbances of spacetime.

This group continues to study collisions in the DZero detector at the Fermilab Tevatron Collider near Chicago, where – in addition to exploring properties of old and new particles containing *b* quarks – they have measured the ultrafast frequency of particle-antiparticle oscillations of *b*+*s* quark mesons and tested for tiny differences between matter and antimatter in these oscillations.

Our group and the Physics Department were greatly saddened by the passing of Professor **Andrzej Zieminski** in 2007. He initiated and led IU's many contributions to the DZero experiment.

Another component of our effort uses spectroscopy to understand quantum chromodynamics (QCD) particularly the role that gluons play in the structure of matter. QCD predicts states known as hybrid mesons and glueballs in which gluons, mediating the strong force, play the role of matter constituents.

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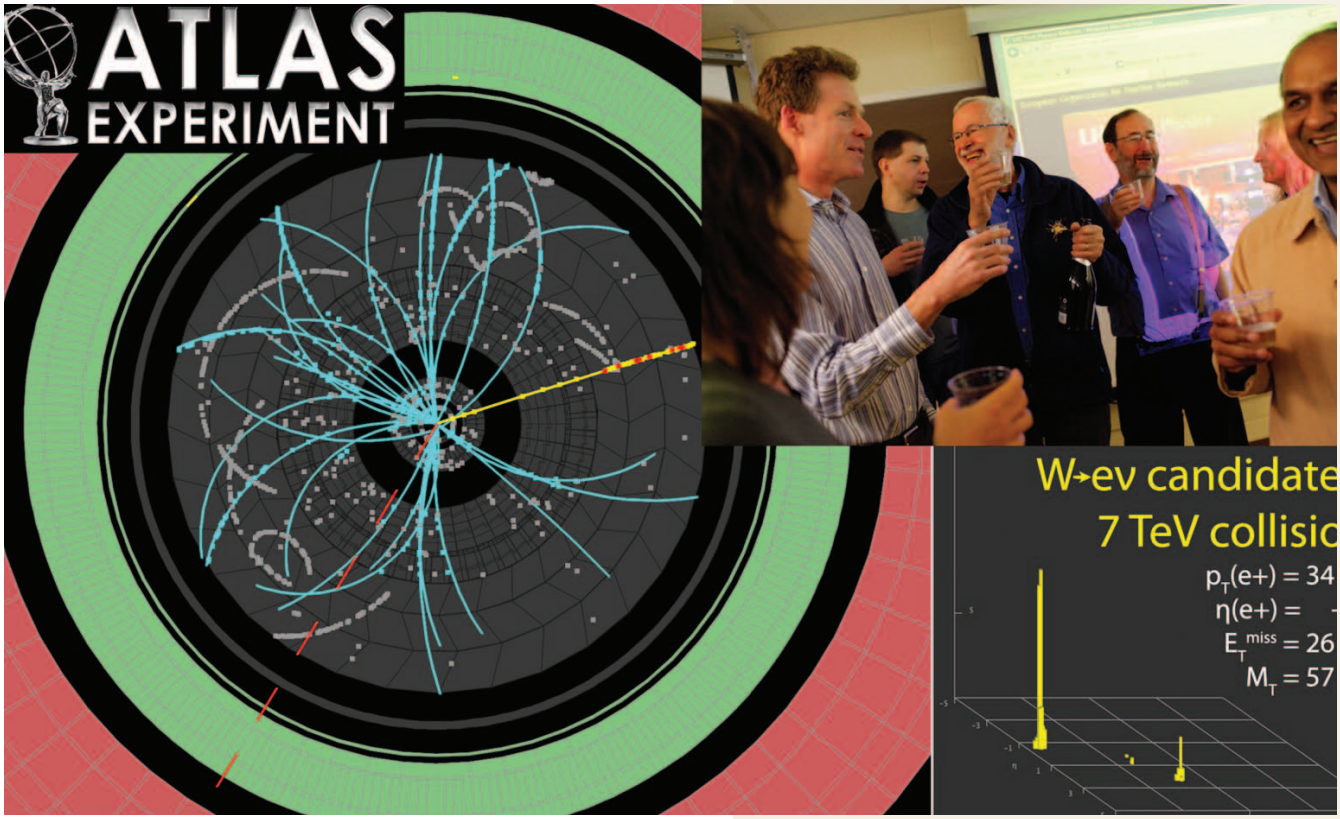


Energy frontier (from page 8)

Matt Shepherd leads efforts in two experiments searching for such states: the GlueX experiment, components of which are now under construction at IU, and the BES III experiment at the Institute for HEP in Beijing.

Mark Messier, **Jim Musser**, **Stuart Mufson** (Astronomy), and **Jon Urheim**, as well as Research Scientist **Chuck Bower**, are engaged in experiments at the forefront of long-baseline neutrino oscillation physics – an area of intense activity following the discovery of neutrino oscillations, and hence neutrino mass, over the past 15 years.

With its 5,000-ton magnetized steel and plastic scintillator 'Far' Detector, the MINOS experiment has taken data with the Fermilab NuMI neutrino beam since 2005 and now provides the best determination of the larger of the two neutrino mass-squared splitting.

particle projects

- ATLAS & THE DZERO PROJECT
- GLUEX QCD EXPERIMENT
- COSMIC RAY ELECTRONS
- NASA DARK ENERGY MISSION

Messier is co-spokesperson for a 200-member NOvA collaboration exploring neutrino mass ordering and constraining possibly large CP-violating effects with a huge 15,000-ton detector under construction near International Falls MN.

In astrophysics research, Musser is spokesperson for the balloon-borne CREST experiment, which will study cosmic ray electrons in the upper atmosphere via their synchrotron radiation with a flight to take place in Antarctica later this year.

To explore the nature of the "dark energy" responsible for the observed acceleration of the universe's expansion, Mufson leads the IU effort on the NASA/DoE satellite-based Joint Dark Energy Mission. The mission is now in its design phase.

HIGH ENERGY THEORY GROUP

With the recent hiring of **Radovan Dermisek** as assistant professor and Enrico Lunghi as associate scientist, the IU High Energy Theory Group has returned to its historical strength of five researchers. Our efforts underway span major areas in theoretical high-energy physics, including phenomenological studies of electroweak and QCD theory, calculations within non-perturbative QCD, investigations of physics beyond the Standard Model, and studies of observable effects from unified theories of quantum gravity.

Dermisek creates and studies models for electroweak symmetry breaking, with an emphasis on supersymmetric models and their implications for collider experiments around the world.

Mike Berger focuses on physics beyond the Standard Model, assessing new accelerator prospects, formulating phenomenological models with supersymmetry and grand unified theories, and investigating quantum gravity and cosmology.

Steve Gottlieb extracts non-perturbative predictions of QCD using large-scale numerical simulations, which impact on the interpretation of experiments at essentially every particle physics laboratory.

Alan Kostelecky explores Planck-scale effects of Lorentz and CPT violation, which are now being sought in experiments at laboratories and many universities throughout the world.

And **Enrico Lunghi** studies theoretical and phenomenological issues associated with the search for indirect effects of new physics, focusing on perturbative and non-perturbative QCD, model-independent analyses, and phenomenology beyond the Standard Model.

Five transformative years bring two major research facilities

New faculty and the LENS and ALPHA projects make strides in research, theory

Courtesy College of Arts & Sciences

Above, Postdoctoral Research Associate Claudia Pantalei (working with the Sokol group) prepares for an experiment on the Small Angle Neutron Scattering instrument at LENS. At right, an illustration of the structure of a graphene network and its band structure.

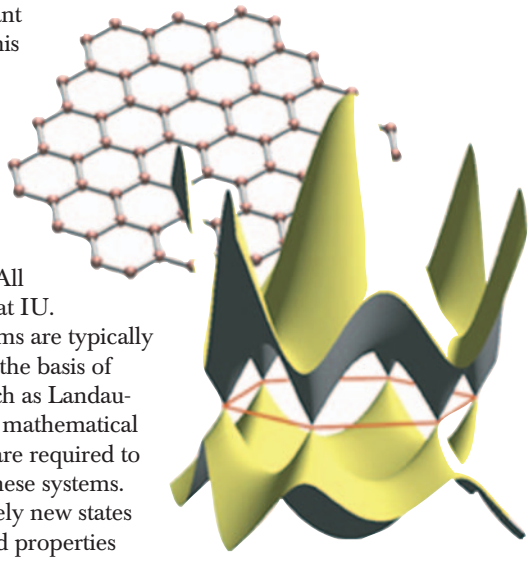
Over the last five years, the Condensed Matter Group (CM) has undergone transformation. Five new faculty members joined the group and several new research initiatives have been launched, including two major condensed-matter research facilities: the Low Energy Neutron Source (LENS) and the Advanced eLectron and PHoton Accelerator (ALPHA).

LENS is a pulsed neutron scattering facility that provides instrumentation for studying large-scale structures (polymers, nanoparticles and porous materials) with neutrons and provides a unique capability for neutron instrumentation development and education in the neutron sciences. The CM group has strong connections with several National Labs on instrumentation and neutron source development. A number of other sources similar to LENS are in various stages of development in China, Japan, and Europe, following IU's lead.

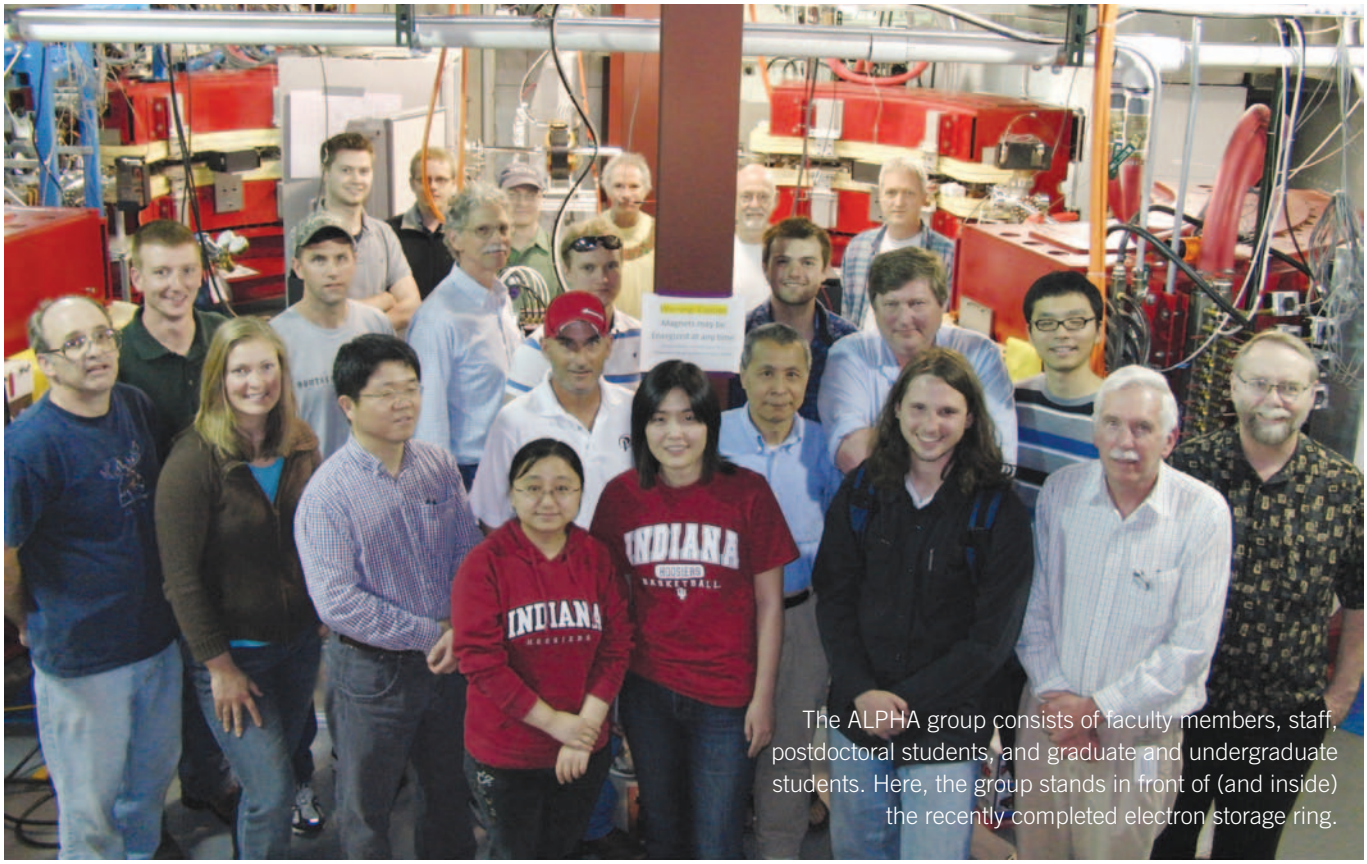
A second new major facility is a joint effort between the CM and Accelerator groups with the CRANE Naval Surface Warfare Center. The Cooler Injection Synchrotron is being recommissioned as an electron storage ring. ALPHA will provide a world-class facility for investigating radiation effects in electronics.

The same ring can be combined with a high-powered pulsed laser to provide a very bright, tunable, hard X-ray source. This combination of neutrons and X-rays is unique – no other university in the world has such facilities – and we plan to make use of our competitive advantage in important areas such as research on new energy sources to diminish U.S. dependence on foreign oil, deal with climate change, and understand the rich physics to be found in materials.

The CM theory effort has also undergone a major transformation over the last decade but continues to have great strength in the area of low-dimensional and strongly correlated electron systems. (Meet some of our new faculty members on page 3.)



Among the many important phenomena included in this area are high-temperature superconductors, graphene, quantum Hall liquids, dilute ultracold atomic gases, Luttinger liquids, heavy fermion systems, and unconventional quantum magnets. All these systems are studied at IU. Interactions in these systems are typically crucial, often invalidating the basis of simplified descriptions such as Landau-Fermi liquid theory. New mathematical and physical approaches are required to understand and analyze these systems. Often one finds qualitatively new states of matter, with unexpected properties and, occasionally, useful functionalities. Topics of particular interest are graphene, which provides a solid-state realization of relativistic massless particles (at 1/300th the speed of light) and may also provide a base material for studying Majorana fermions and topological quantum computers. We are also studying the fundamental physics behind quantum computation and emergent phenomena in Mott Insulators.



The ALPHA group consists of faculty members, staff, postdoctoral students, and graduate and undergraduate students. Here, the group stands in front of (and inside) the recently completed electron storage ring.

ACCELERATOR PHYSICS

State-of-the art projects propel important efforts

Accelerator physics plays a major role in modern physics and technology applications. Many experiments in nuclear and particle physics test the fundamental laws of physics by colliding high-energy beam of particles, such as electrons or protons. Modern light sources, which are capable of producing high-energy photons such as X-rays, operate by "bending" the path of electrons in an accelerator with dipole magnets and wiggler magnets to generate radiation.

State-of-the-art cancer treatment facilities, such as the Midwest Proton Radiotherapy Institute (MPRI) located at the Indiana University Cyclotron Facility, utilize high-energy proton and heavier ion beams to treat inoperable tumors.

Accelerator physics is crucial in developing the accelerators that support these important and wide ranging efforts and the IU Accelerator Physics Group is at the forefront in developing new accelerators.

This group supports the design of novel accelerators for many different applications. They create theoretical and advanced computational methods that aid in the design and study of accelerators, design new components for existing accelerators, and develop new methods for studying data at existing accelerator facilities.

One of the major activities of the accelerator group is the development of the Advanced Electron Photon Facility (ALPHA). **S.Y. Lee** and **Paul Sokol** are currently leading the design effort of this multipurpose electron accelerator, which will operate through collaboration between CRANE NSWC and IU. This accelerator will serve the U.S. Department of Defense's requirements for testing radiation effects, as well as IU's interest in a compact, high-brightness x-ray source.

ALPHA will be composed of two parts: an injector which is an existing Crane linear accelerator that is capable of producing electron energies of up to 60 MeV; and a 20 m electron storage ring. The dipole magnets that will be used in the storage ring were previously used in the Cooler Injector Synchrotron.

The ALPHA accelerator will offer important new radiation testing capabilities for Crane, which is the largest employer in southern Indiana. ALPHA will also serve the IU community in a variety of scientific research areas. ALPHA's X-ray and VUV capabilities will benefit many different scientific disciplines.

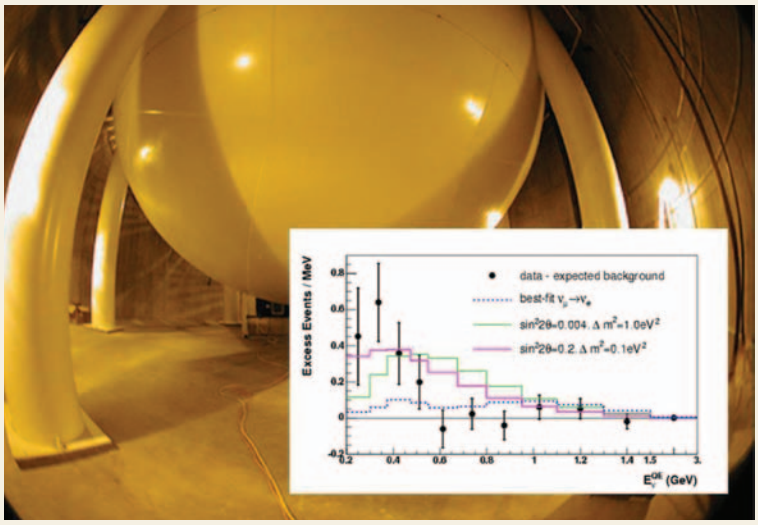
physics fact

THE MPRI AT THE IU CYCLOTRON FACILITY IS ONE OF ONLY SEVEN SUCH CENTERS IN THE U.S. — THE ONLY FACILITY IN THE MIDWEST.

EXPERIMENTAL NUCLEAR PHYSICS

A top-10 program

The IU Nuclear Physics Group has retained its top-10 ranking, despite significant changes in membership since 2003. **Steve Vigdor** moved to deputy director for nuclear and particle physics at Brookhaven, **Jim Sowinski** became a program manager in a new U.S. Department of Energy office devoted to nuclear physics facility operations, and several other faculty members and research scientists (**Bob Pollock**, **Andy Bacher**, **Hans Meyer**, **Hermann Nann**, and **Will Jacobs**) have retired but remain active members of the group. In the meantime, we welcomed assistant professors **Chen-Yu Liu** and **Josh Long**. **Lisa Kaufman** starts as an assistant professor in fall 2010. We are now one of the youngest nuclear experimental groups in the country, and with **Mike Snow**, **Ed Stephenson**, **Rex Tayloe**, and **Scott Wissink**, the research portfolio of the group has greatly expanded.



A fish-eye view of the MiniBooNE neutrino detector at Fermilab, filled with baby oil, on which Rex Tayloe and Hans Meyer work. The data insert shows neutrino events above background and predictions from other experiments. None of them fit the data, which is disturbing since this energy regime is where several other international neutrino experiments (including NoVA, led by IU professors) plan to operate. Tayloe and Meyer hope to resolve this puzzle with new measurements and help from IU nuclear theorists Chuck Horowitz and Brian Serot.

It is known experimentally that the angular momentum of the proton is *not* coming just from the spin angular momentum of the quarks. So we are analyzing the debris from collisions of high-energy polarized protons using the STAR detector at Brookhaven Lab's Relativistic Heavy-Ion Collider to look for other possible sources.

Our searches for not-yet-seen "electric dipole moments" of the electron, neutron, and deuteron if found could help explain why the universe seems to have more matter than antimatter. Neutrinos are known to change type ("oscillate"), but all the evidence doesn't quite 'fit.' Using neutrino beams at FermiLab for the MiniBooNE experiment, we have answered some questions and raised others (see figure at left).

In an underground lab in New Mexico (WIPP) we are also searching for a so-far unobserved rare decay process ("neutrinoless double beta decay") which can only happen if neutrinos are their own antiparticles.

Finally, we are using slow neutrons to measure just how strong the "weak" force really is and investigating new ways to make "ultracold" neutrons, which are so slow that you can outrun them and are also very useful for precision experiments.

~ SPOTLIGHT ~

Pynn awarded Gunnar Randers Prize

In April 2009, **Roger Pynn** was awarded the prestigious Gunnar Randers Research Prize. Norway's King Harald V presented the prize to Pynn at a ceremony at the Institute for Energy Technology in Kjeller, Norway.

The Gunnar Randers Research Prize was established in 2001. It recognizes outstanding work in condensed matter physics by Norwegians or persons connected with Norwegian research. Pynn was awarded the prize for his pioneering work in the development of new neutron-scattering methods and applications within the field of advanced materials science. The international prize selection committee's commendation noted that Pynn, "has documented the most outstanding professional quality, and his work has led to increased fundamental understanding within the areas of complex fluids, biomolecular systems and magnetic structures. He is also a brilliant communicator with profound insight in research political questions."

At the ceremony, which was attended by many dignitaries, Pynn received the prize of 100,000 NOK, plus a work of art by Kåre Tveter.

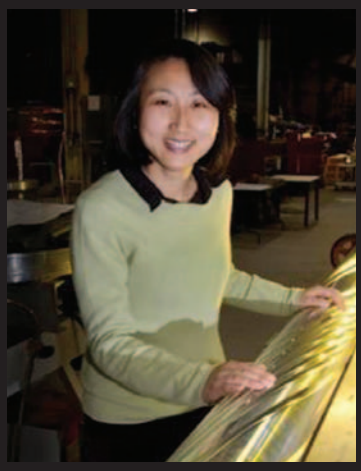
Einar Madsen, IFE

His Majesty King Harald V of Norway (left) presents the prize to Roger Pynn.

alumni [NOTES]

before [1960]

After graduating from IU, **Caroline Michel Cox**, BS'59, completed one year of graduate studies at the University of Colorado, and served as the chief financial officer of a Denver engineering company for 30 years. She was a candidate for Colorado's Second Congressional District in 2000. Cox, who is now retired, writes that she has worked for 10 years to reform Social Security into a voluntary privatized system for people under 55. She lives in Tucson, Ariz.



Courtesy Mei Bai

~ SPOTLIGHT ~

Alumna earns International Particle Prize

Mei Bai, MS'96, PhD'99, who received her doctoral degree in Accelerator Physics under S.Y. Lee, is now a staff scientist at Brookhaven National Laboratory on Long Island. In 2010, Bai was awarded the International Particle Accelerator Conference Prize for "her significant contributions to spin dynamics and polarized proton acceleration in circular accelerators – in particular AGS and RHIC, and to successful polarized proton beam collisions at 500 GeV centre of mass."

[1960s]

Dean A. Zollman, BS'64, MS'65, is a distinguished professor and head of the department of physics at Kansas State University in Manhattan. He is a 2006 Presidential Award winner for outstanding department head at the university. A faculty member at Kansas State since 1970, Zollman has headed the physics department since 2001, where he now holds the university's highest rank. He has received three major awards – the National Science Foundations Director's Award for Distinguished Teacher Scholars in 2004, the Carnegie Foundation for the Advancement of Teaching Doctoral University Professor of the Year in 1996, and American Association of Physics Teachers' Robert A. Millikan Medal in 1995. His present research concentrates on investigating the mental models and operations that students develop as they learn physics and how students transfer knowledge in the learning process. He also applies cutting-edge technology to the teaching of physics and to providing instructional and pedagogical materials to physics teachers, particularly those teachers whose background does not include a significant amount of physics.

David K. Lynch, BA'69, is owner of Thule Scientific, a Topanga, Calif., based research and educational organization specializing in astronomy, atmospheric optics, and geology. He also works as a senior scientist at The Aerospace Corporation, where he specializes in infrared spectroscopy of comets, novae, supernovae, young stars, and very old stars. Lynch has held research positions at the Sacramento Peak Observatory, Caltech, the University of California at Berkeley, and Hughes Research Laboratories. He has published more than 150 scientific papers and 10 books, including *Field Guide to the San Andreas Fault: How to See and Touch the World's Most Famous Fault.* In his spare time, Lynch plays the fiddle, enjoys camping, and collects rocks and rattlesnakes.

[1970s]

Steven J. Dick, BA'71, MA'74, PhD'77, is the chief historian for NASA and Director of the NASA History Office. He obtained his bachelor's degree in astrophysics, and an MA and PhD in history and philosophy of science from IU. Dick worked as an astronomer and historian of science at the U. S. Naval Observatory in Washington, D.C. for 24 years, including three years on a mountaintop in New Zealand, before coming to NASA Headquarters in 2003. Among his books are *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant* (1982), *The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science* (1996), and *Life on Other Worlds* (1998). His most recent books are *The Living Universe: NASA and the Development of Astrobiology* (2004), and a comprehensive history of the U. S. Naval Observatory, *Sky and Ocean Joined: The U. S. Naval Observatory, 1830-2000* (2003). The latter received the Pendleton Prize of the Society for History in the Federal Government. Dick is the recipient of the Navy Meritorious Civilian Service Medal, the NASA Group Achievement Award for his role in NASA's multidisciplinary program in astrobiology, and the 2006 LeRoy E. Doggett Prize for Historical Astronomy of the American Astronomical Society. He has served as Chairman of the Historical Astronomy Division of the American Astronomical Society, as President of the History of Astronomy Commission of the International Astronomical Union, and as President of the Philosophical Society of Washington. Dick lives in Ashburn, Va.

[1970s]

John M. Harris, BA'83, is an assistant professor of industrial technology and advanced manufacturing at Ivy Tech Community College in Sellersburg, Ind. He was an instructor in robotics and programming, including technologies related to automation in manufacturing, for 11 years and taught courses in various subjects the United States and abroad. Before joining Ivy Tech in 2008, Harris worked in industry as an electrical controls engineer for eight years, and served as the manager of an R&D laboratory for a major machine manufacturer for four years. He has published a number of articles in trade magazines serving the printed circuit board manufacturing industry. He lives in New Albany, Ind.

Salah M. Aziz, MS'85, PhD'88, has accepted the position of president at Kurdistan University of Science and Technology in Sulaymani, in the Kurdistan region of Iraq. He writes, "I'd like to thank IU Bloomington for being my educational institution and the

continued on page 14

(from page 13)

first stage in my graduate learning." Aziz previously worked for Florida State University and Florida A&M University.

R. Chris Smith, BS'86, is the director of the Cerro Torolo Inter-American Observatory, based in La Serena, Chile. The CTIO is part of the National Optical Astronomy Observatory, the US national observatory for nighttime optical/infrared astronomy funded by the National Science Foundation. Smith received a bachelor's degree in astrophysics from IU in 1986, and joined CTIO as a postdoctoral fellow after earning a Ph.D. from Harvard University in 1991. While an undergraduate at IU, he participated in NOAO summer student programs both at the National Solar Observatory in Sunspot, N.M., in 1985, and at Kitt Peak National Observatory in Tucson, Ariz., in 1986. Pursuing his interest in student programs, he restarted the Research Experiences for Undergraduates program at CTIO. Smith served as a member of the High-z Supernova Search Team, one of two groups of scientists that discovered the accelerating expansion of the universe in 1998. The team was a co-recipient of the 2007 Gruber Cosmology Prize, a highly prestigious annual award in the field of cosmology. He was also the principal investigator of the Magellanic Cloud Emission Line Survey, which mapped the Magellanic Cloud, a nearby galaxy.

Charles W. Lynn, BS'89, is a senior quality engineer at Integra LifeSciences, a manufacturer, developer, and marketer of surgical implants and medical instruments used primarily in neurosurgery, extremity reconstruction, orthopedics, and general surgery. He previously worked as a quality engineer at Pole/Zero Corporation and as director of quality and risk management at Sekuworks. He lives in the Greater Cincinnati area.

~ PROFILE ~

Atom-smasher discovers element 117

Hamilton, with Yuri Oganessian from Dubna; and Jim Roberto from Oak Ridge National Laboratory

Joseph Hamilton, MS'56, PhD'58, is the Landon C. Garland Distinguished Professor of Physics at Vanderbilt University in Nashville, Tenn. He also is director of the Joint Institute for Heavy Ion Research and a University Distinguished Laboratory Fellow at Oak Ridge National Laboratory.

He received his PhD in nuclear physics from Indiana University in 1958, working with L.M. Langer. In his more than 50 years as an experimental nuclear physicist, Hamilton has conducted pioneering research on the structure of atoms and the physics of rare isotopes, always favoring collaboration. During the Cold War of the 1970s, Hamilton established close ties with Russian, Chinese, and East German nuclear physicists.

Dubbed by a colleague as "the Energizer bunny," he also is known as a tireless fundraiser, a passionate teacher with a flair for the dramatic, and a prolific writer of more than 950 published papers.

Hamilton is currently leading a team of U.S. and Russian scientists with Yuri Oganessian of Dubna, Russia. While working at an atom-smasher in Dubna – about 75 miles north of Moscow – the group discovered element 117. This finding plugs what had been a hole in the periodic table of elements.

The gap had existed since 2002, when element 118 was created. Thereafter, experts in the field eagerly sought an element with 117 protons in its nucleus (and considerably more neutrons). Hamilton's team made the element by shooting ions of calcium 48 at a target composed of atoms of berkelium.

Calcium 48 has, in its nucleus, 20 protons (and 28 neutrons), while berkelium has 97 protons in its nucleus (and, in the isotope used in the experiments, 152 neutrons): 20 and 97 add up to 117, the atomic number of the long-sought-after new element.

Doing the arithmetic to get the number of protons right for the new element was easy; doing the experiment was anything but. In the end, months of smashing calcium and berkelium nuclei together produced just six atoms of the element 117 – or, rather, six events that were seen as evidence of the momentary existence of element 117, before it decayed radioactively. The discovery requires confirmation – replication in additional experiments – before it is officially recognized on the periodic table.

Courtesy Joseph Hamilton

[1990s]

Mark A. Bishop, BS'95, BA'99, is a principal software engineer for Citrix Systems in Goleta, Calif. He lives in Santa Barbara, Calif.

[2000s]

Kareem Elsayad, PhD'07, is a postdoctoral research scientist for the Research Institute of Molecular Pathology in Vienna, Austria, where he lives.

Andrew J. McIntire, BA/BS'08, was accepted into the 2009 Woodrow Wilson Indiana Teaching Fellows program. The Woodrow Wilson Teaching Fellowship seeks to recruit, prepare, and retain effective teachers for the students and schools who need them most. It is open to college seniors, recent graduates, and career changers with undergraduate degrees in the arts and sciences. Fellows attend enriched, school-based master's-level teacher education programs, complemented by intensive mentoring during the first three years of teaching at high-need urban and rural schools. Upon completing the fellowship program, McIntire will be certified to teach mathematics. He lives in Indianapolis.

~ IN MEMORIAM ~

ANDRZEJ ZIEMINSKI

Zieminski

Born Oct. 15, 1945, in Warsaw, Poland, **Andrzej Zieminski** immigrated to the United States in 1980 and lived in College Park, Md., before moving to Bloomington in 1982. Before that, he was a professor at the University of Warsaw, from which he graduated in 1968.

At IU, Zieminski's research focused on elementary particle physics. Under his leadership, IU joined a large international research project at the Fermi National Laboratory near Chicago in 1985. The greatest achievement of the D-Zero experiment was the landmark 1995 discovery of the Top quark, a fundamental building block of nature. The discovery helped scientists understand the forces of the universe.

Zieminski loved life and he loved people. He enjoyed world travel, mountains, opera, and world history, and was passionate about politics, both in his home country and in his adopted country. He climbed Mount Rainier in Washington State to celebrate his 40th birthday, and on his 50th birthday he accepted his son's invitation to travel to Tanzania to climb Mount Kilimanjaro. During his 62 years, Zieminski visited every continent except Antarctica, and was a frequent visitor to New York City, where he enjoyed performances, often standing, at the Metropolitan Opera.

He is survived by his wife, Daria, and son Nick, daughter-in-law Alexis, and grandchildren, Max and Anna.

A physics graduate student fellowship fund has been established in Zieminski's name. Gifts to support graduate fellowships may be made to the IU Foundation (ATTN: Anzej Zieminski Fellowship) and sent c/o Dept. of Physics, Indiana University, Swain West 117, Bloomington, IN 47405.

MALCOM MACFARLANE

Macfarlane

Malcom Macfarlane was born in Brechin, Scotland. Macfarlane earned an MA in mathematics from the University of Edinburgh. He came to the U.S. in 1956, to the University of Rochester, where he met and married his wife, Ellie Carman. Macfarlane received a PhD in physics from the University of Rochester in 1960 and did postdoctoral work at Argonne National Laboratory in Illinois.

Macfarlane's career included research and teaching at the University of Rochester, New York, at Argonne, at the University of Chicago, and at Indiana University. He became director of the IU Nuclear Theory Center in 1980. He received a Guggenheim Fellowship and was a Visiting Fellow at All Souls College in Oxford, and he received a 1986 Alexander von Humboldt Foundation Senior Scientist Award. He carried out physics research in Juelich, Germany, and mentored students from the University of Bonn during visits over a period of many years.

Macfarlane was a member of the American Physical Society and served on numerous scientific advisory and review committees. He was associate editor of the journal *Physical Review Letters* and a member of the Nuclear Science Advisory Committee, which advises the US Department of Energy and the National Science Foundation on research priorities for nuclear physics.

His work on single-particle transfer reactions represented a major advance in understanding. His survey of this topic, published in *Reviews of Modern Physics,* became one of the most frequently cited nuclear physics articles. Later in his career, Macfarlane turned his attention to studying the stability of mathematical techniques used in numerical computation and in statistical theories of nuclear reactions.

As a teacher, he was known for his clear, careful explanations of difficult topics and a deep commitment to helping students succeed, both on the graduate and undergraduate level. He was especially appreciated for his effective mentoring of graduate students who were studying for our PhD qualifying exam. After retirement from IU, he continued to work with graduate students at IU and to serve as a consultant at Argonne National Laboratory.

Supporting the Department of Physics

Development funds administered by the IU Foundation play an immense role in enriching the academic and intellectual life of the department. They support many activities of great value to the department, but also to the university as a whole and to the Bloomington community.

The Konopinski Fund supports the department's colloquium series as well as distinguished lecturers. Recent Konopinski Lectures have included Nobel Prize-winners John Mather, Frank Wilczek, William Phillips, and Douglas Osheroff.

The Physics Enrichment Fund supports hospitality for visitors to the department, travel for faculty candidates and visitors, undergraduate awards, and other physics activities.

The Physics Library Fund is used for the acquisition of materials for the Physics Library.

The William Koss Memorial Fund — started with a generous contribution from Dr. and Mrs. K. William Koss — supports the William L. Koss Award for Excellence in Teaching and Scholarship awarded to an outstanding graduate student.

Swain Hall

The Andrzej Zieminski Fellowship started with a contribution by Daria Zieminska and other donors. It supports graduate fellowships awarded to outstanding candidates in graduate study. Preference is given to students conducting research in elementary particle physics.

The Physics Department Distinguished Alumni Graduate Fellowship Fund and the **Prithe Paul Singh International Graduate Fellowship** support fellowships for graduate students in the department.

physics[FORUM]

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