symmetry

dimensions of particle physics

A joint Fermilab/SLAC publication

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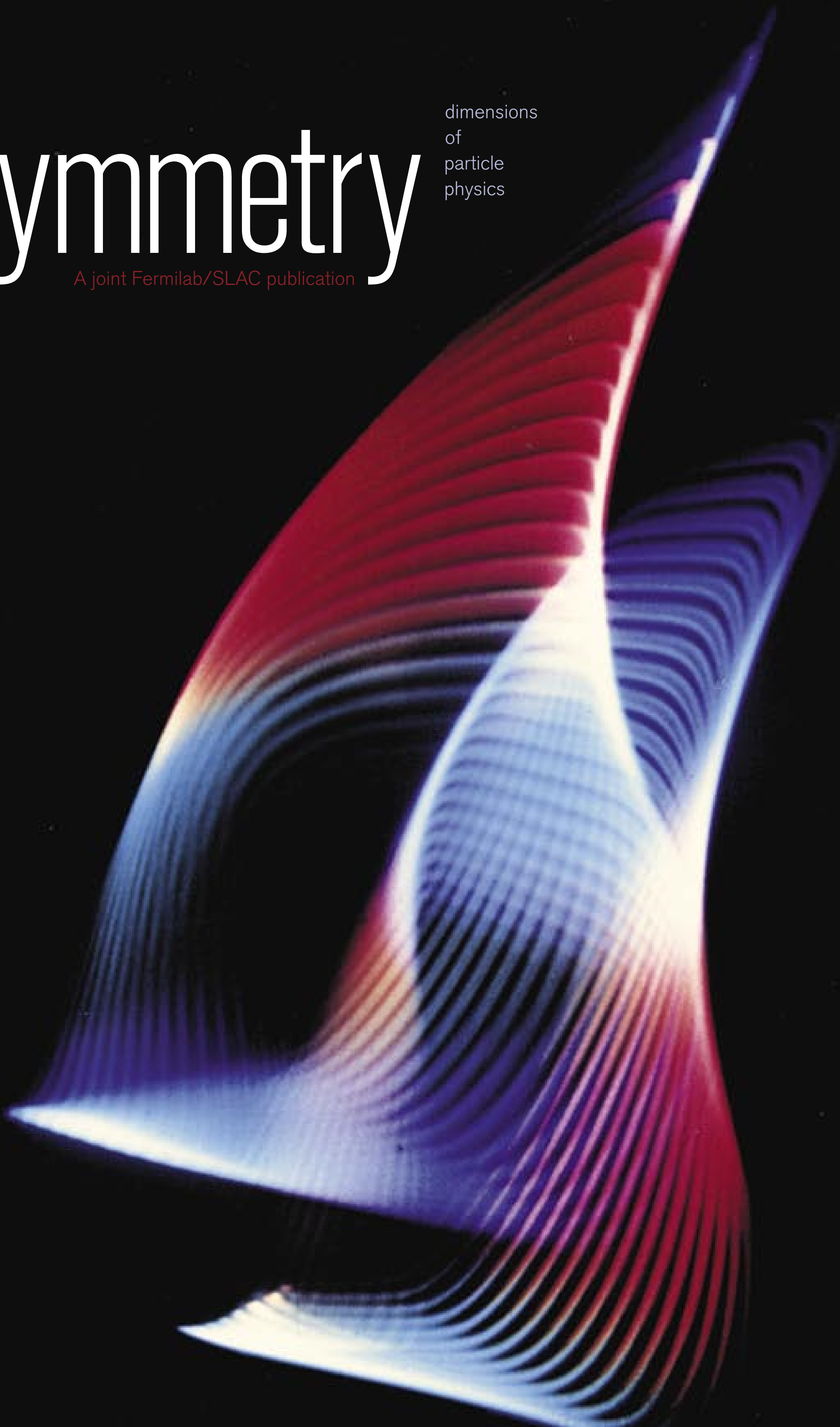
april 07



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On the Cover

Ben Laposky, a draftsman and lettering artist from Iowa, made some of the first graphic images generated by machine. He would set as many as 70 controls on up to 60 oscilloscopes at a time, and record the resulting patterns with high-speed film and special lenses. Laposky described his "oscillons" as "visual rhythms and harmonies of electronic abstract art." Interest in his work waned in the mid-1960s with the advent of computer graphics, and few of these pioneering images survive.

Image courtesy of Sanford Museum, Cherokee, Iowa

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Office of Science
U.S. Department of Energy

Photo: Reidar Hahn, Fermilab

symmetry evolves

Spring is in the air, and we at *symmetry* feel change all around us—not only in the content of the magazine, but in the contributors who come and go as they move careers and lives, including a constant flow of interns who provide us with so much hard work and vitality.

Two major changes you'll see are executive editor Mike Perricone heading off to other challenges and Glennda Chui arriving as deputy editor. Mike has been a fixture of Fermilab for a decade. He came to the lab after being a sportswriter for the *Chicago Sun-Times* and writing a book, *From Deadlines to Diapers: Journal of an At-Home Father*. At Fermilab, he held the reins of *FermiNews* for many years and helped to start *symmetry*, among other duties. We will miss Mike's wisdom and experience.

Glennda comes to us from the *San Jose Mercury News*, where she was a science writer and editor. Among her many accomplishments is a share in a Pulitzer Prize for coverage of the 1989 Loma Prieta earthquake in California.

Our magazine's content is evolving as well. We are looking for more feedback from you, tapping your knowledge and experience to come up with better, more interesting, and more entertaining stories (page 7). We hope to expand the letters section, and we're introducing contests, puzzles, and other challenges. While these won't be your average magazine fare, they won't require a PhD in particle physics, either.

Changes are also happening in the larger world of science communication, as explained by reporter Charles Petit (page 34). Coincidentally, US Representative Bart Gordon, who also contributes to this issue (page 24), has co-sponsored a bill that would fund training for graduate students to better communicate science.

As *symmetry* moves ahead, we ask that you join in, keep us on our toes, and help keep the magazine vital and exciting.

David Harris, *Editor-in-chief*

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symmetry

Photo: Reidar Hahn, Fermilab

TRIUMF in Canada

Canada, affectionately known to Americans as the "Great White North," boasts the world's largest reserve of fresh water and the biggest oil reserves outside the Middle East. It's the largest trading partner of the United States; and when it comes to science, it's destined to become the main regional partner of the United States, as well.

A key player in that partnership—and in the global physics community—is TRIUMF, the Canadian national laboratory for particle and nuclear physics, located on the Vancouver campus of the University of British Columbia.

TRIUMF opened 33 years ago with the world's biggest cyclotron. Now, with a staff of more than 550 and more than 1000 active users around the world, its mission has evolved to encompass everything from understanding the fundamental nature of matter to investigating new materials, such as warm superconductors, and treating eye tumors with beams of protons.

The lab's main thrust is the production and study of rare, short-lived isotopes. TRIUMF is a world leader in using rare-isotope beams to probe how nuclei form—including the exotic nuclear matter within white dwarfs and neutron stars. We are far from a complete understanding of these things, but expect major progress in the next two decades as new experimental facilities open around the world and theorists make significant strides of their own. The challenge for TRIUMF, and for Canada, will be to maintain a lead position in this field.

TRIUMF scientists also work in close collaboration with the particle physics community. Part of the lab's mission is to provide clean rooms, machine shops and the expertise needed to build high-energy detectors for experiments at other laboratories. The drift chamber for the BaBar experiment at Stanford Linear Accelerator Center was built here; so were the transition radiation detectors for the Hermes experiment at DESY, the German national laboratory. These contributions allow Canadian scientists to participate in large international collaborations at a level that otherwise would not be possible.

The lab also has major involvement in two projects at the frontier of high-energy physics: the ATLAS experiment at the Large Hadron Collider near Geneva, and Japan's T2K, projected to start up in 2009.

For T2K, which will aim a beam of neutrinos at an underground detector 295 km away, TRIUMF and its university collaborators are designing and building the near detector tracker and proposed a key concept for the overall design—aiming the neutrino beam slightly off-center. We also have a hand in monitoring the target area for the experiment—a natural fit, given TRIUMF's years of experience in remotely handling highly radioactive targets for its rare-isotope beams.

As for ATLAS, TRIUMF took a central role in the design, construction, and integration of half the modules for the Hadronic End-Cap Calorimeter. A TRIUMF scientist managed the project, the copper plates were machined at the University of Alberta and signal feedthroughs were assembled at the University of Victoria. Members of the TRIUMF staff, along with researchers from the University of Toronto and Carleton University, took key roles in designing and building two tungsten forward calorimeter modules. And in collaboration with the University of Alberta, TRIUMF led the Canadian contribution to the calorimeter front-end electronics.

TRIUMF also has been designated a "Tier 1" computing hub that will process data for the ATLAS collaboration and give Canadian universities access to that data.

Its participation in ATLAS puts TRIUMF in an excellent position to address some of the most exciting questions being posed by the global community. The quest to understand mass, find extra dimensions of space, and discover possible new symmetries in nature has a good chance of bearing fruit at the Large Hadron Collider over the next decade; candidates for dark matter may even turn up there.

Meanwhile, Canada's membership in T2K allows it to continue exploring the properties of neutrinos and their role in the matter-antimatter asymmetry of the universe.

TRIUMF will continue to develop exotic isotope beams and press for a fundamental understanding of the basic building blocks of nature, while finding new ways to use nuclear and particle physics to study new materials and identify and treat human disease. And our accelerator physicists look forward to the next high-priority project at the energy frontier, the International Linear Collider, which is still on the drawing board. Canadian scientists are already at the forefront of developing tracking detectors, and that involvement will grow as the collider looks for approval early in the next decade.

Nigel Lockyer

Nigel Lockyer starts as the new director of TRIUMF in Vancouver, Canada on May 1, 2007.

6000 hours of good works; hot review; translating physics and beer; walkway to heaven; blades on ice; life list for physics fans; letters.

Photo: Chris Riley, The Gilroy Dispatch

Life service

Somebody who's racked up thousands of hours of community service has either been very bad or very good. SLAC carpenter Michael Hughes has been very, very good. Having volunteered more than 6000 hours of service over the past 34 years, Hughes recently received the President's Call to Service Award, presented by Acting Under Secretary of Energy Dennis Spurgeon. The award honors those who have given at least 4000 hours of service in a lifetime.

Hughes' volunteer career began almost accidentally, after he enrolled in an adult education woodshop course at a local high school. "I first attended the class to work on my personal projects," he says. "Then I started helping people when they didn't know how to do things." For more than three decades he was a class mainstay, spending four hours each week assisting the teacher and helping instruct.

"Woodshop was always a big part of my life," he says. "It felt good to help people make their finished product."

Hughes earned more karmic points volunteering for 25 years at the annual Garlic Festival in his native Gilroy, California. He also volunteers for local Relay for Life chapters, for the Gilroy Police Department, and for special SLAC events.

Alison Drain

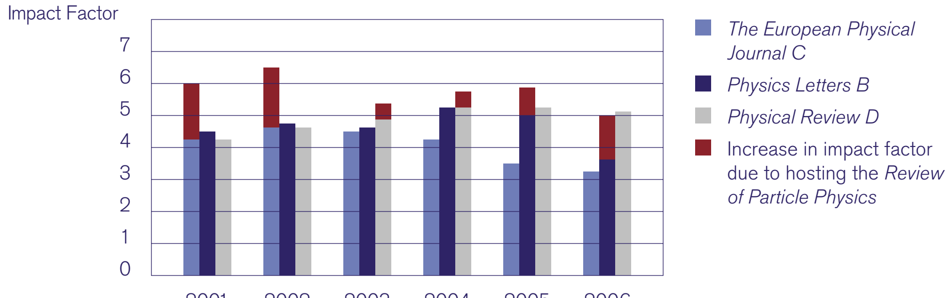
The hottest citation

The article at the top of the SPIRES lists of the most-cited articles in high-energy physics is, as always, the *Review of Particle Physics* (RPP), a compendium of experimental data and reviews put out by the Particle Data Group. This highly useful work is cited whenever the author of a paper refers to standard experimental results, and it gets more than 1000 citations every year.

Just as physicists often look at SPIRES' lists as a measure of which papers are "hot" at a given moment, librarians and journal publishers, in evaluating journals, look at something called the impact factor. It's based on the number of articles published in a journal in a two-year span and the number of citations those articles received in the following year. Impact factors, like other ranking systems based on article citations, may be pilloried as useless or vaunted as convenient measures of quality. In reality they are somewhere in between, and the RPP provides a good example of some subtle effects.

The RPP is run in one of the major particle physics journals

Impact of the Particle Data Group



Source: SPIRES

every two years, although it isn't submitted, reviewed, or edited like a typical journal article. Because the RPP gets more than 1000 citations a year, any journal in which it appears in gets a big but temporary lift in its impact factor.

In *Physics Letters B*, for example, 10% of the 10,000 citations received in 2005 were to the RPP. The resulting boost in impact factor from 4.5 to 5 was based on nothing more than the Particle Data Group's decision to publish the review in the journal that year. For this reason, among others, the group rotates the publication of the book among several journals, and the RPP effect, while pronounced in each year, does get spread around. In 2003 and 2004 the *Physical Review D* impact factor was boosted by about 5% due to the RPP, in 2005 and 2006 *Physics Letters B* saw a 10% rise, and for 2007 and 2008, we can expect the *Journal of Physics G* to see a near doubling of its impact factor due to the RPP.

While physicists generally nod their heads in agreement when they see the RPP at the top of SPIRES' lists, confirming that the Particle Data Group's efforts are quite useful, journal publishers and librarians who don't know about the RPP may wonder at the strange cycle of bumps in impact factors for the journals of particle physics.

Travis Brooks, SLAC

You wanted what?

Sometimes even the language of mathematics isn't universal. This realization came during March at the German lab DESY where a party was thrown by the Asian ECal team in thanks for the use of the DESY Calorimeter Group's test beam. At the multinational gathering, physicists compared the way they use their fingers to count: Most of them trying to order a beer in Japan by holding up one finger would receive four beers! The Asian team also gave a crash course in katakana, Japanese phonetic writing, and kanji, symbolic characters of Chinese origin. According to them, accelerator translates literally as "add-velocity-machine."

Barbara Warmbein, ILC Global Design Effort

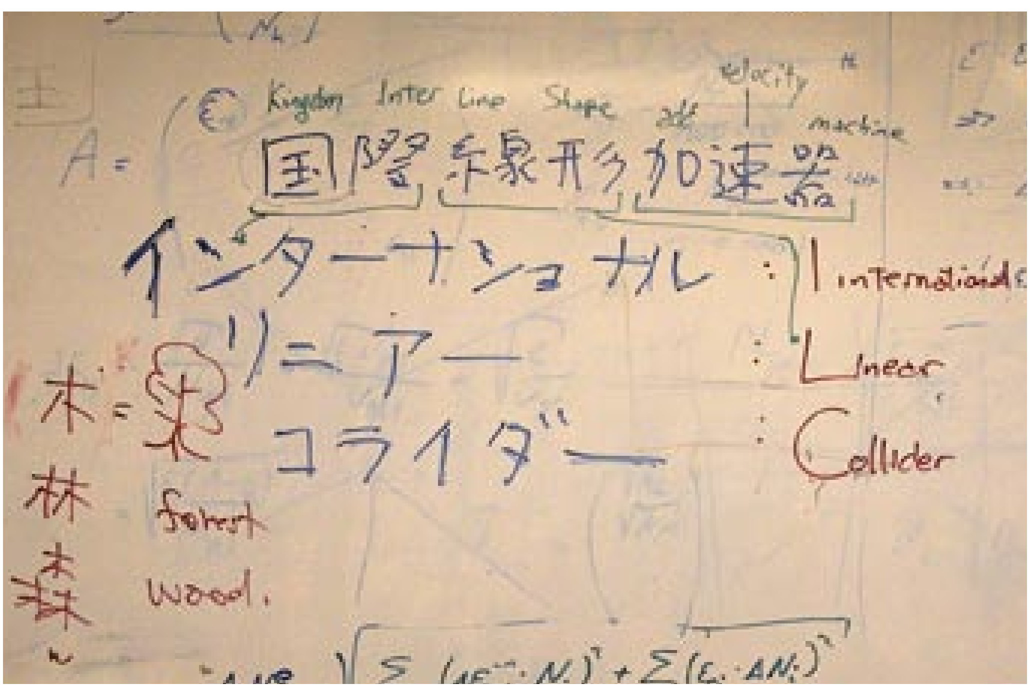


Photo: Barbara Warmbein

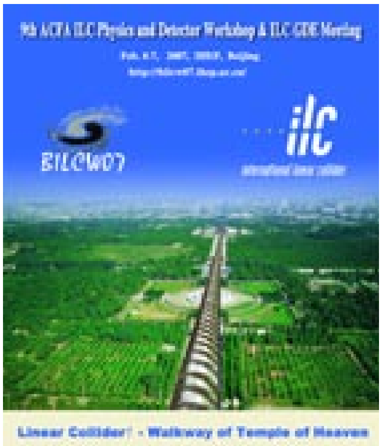


Photo: IHEP, Beijing

Walkway to heaven

The Temple of Heaven, a masterpiece of architecture and landscape design in Beijing, symbolizes the relationship between Earth and heaven—human society and the universe—which stands at the heart of Chinese cosmology.

It was the central image on the poster for the 9th ACFA ILC Physics and Detector Workshop and ILC GDE Meeting in February 2007 at the Institute of High Energy Physics (IHEP) in Beijing, where the International Linear Collider's reference design and preliminary cost were officially announced.

Although the walkway towards the ILC is as long as that at the Temple of Heaven, China is now taking steady steps towards increasing its contribution to the realization of the ILC. Interest in this endeavor has manifested itself in unanimous support from Chinese scientists for China's participation in the ILC, demonstrated at the Fragrant Mountain Meeting held at the end of 2006 and the ILC GDE Meeting this past February, and continues to be evident in the various research and development efforts in progress at IHEP and other institutions as well as in the country's expanding collaboration with KEK in Japan and other labs worldwide.

Jiyuan Zhai, IHEP, Beijing

Slippery science

Why is ice slippery? Alain Haché has two kinds of first-hand knowledge. A veteran amateur hockey goalie, he learned to skate outdoors on frozen ponds. As a professor of physics at the University of Moncton in New Brunswick, Canada, he has combined his professional and personal passions in *The Physics of Hockey* (Johns Hopkins University Press, 2002; Raincoast Books, Vancouver; a Finnish edition, *Jääkiekon fysiikka*, is published by Terra Cognita in Helsinki).

"The collisions in hockey are probably most similar to particle physics," said Haché, in his distinctive French-Canadian accent, "but there are many physics aspects to hockey, maybe even more than other sports."

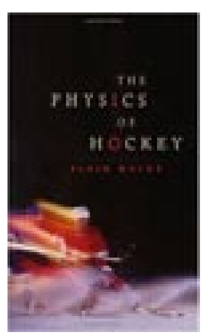
Ice is the prime differentiating ingredient, with players skating at 30 mph and launching slap shots at 100 mph on a frozen surface about ¾ of an inch thick, maintained at about 16°F. "The physics of ice is condensed matter physics, and what happens at the surface of ice is fascinating," said Haché. "Many people have wondered for a long time what makes ice slippery. We've only recently learned the reasons, using powerful atomic force microscopy."

At the macroscopic level, materials like wood and plastic have a coefficient of friction around 0.5; ice has a coefficient of friction of 0.005, which Haché said might be matched only by biological structures such as the joint in a knee. He added that traditional models of ice's slipperiness—surface melting caused by the pressure of a skate blade or friction rubbing from the blade's motion—offer insignificant temperature changes. But atomic force microscopy, which offers resolution on the order of fractions of an ångstrom (0.1 nanometer), provides a compelling new vision of ice formation.

"The top layer of ice is a bulk crystalline structure arranged like the structure of graphite," Haché said. "At the top of the ice the molecules are tightly bound but below them are dangling bonds that are very mobile. So the first few layers at the very top are not quite solid, and not liquid, but something in between. This semi-wet layer or film exists whether or not there is pressure, and whether or not there is friction rubbing, down to something like -200°F. Below this semi-wet layer the coefficient of friction is about 0.6, so ice is like plastic or wood below the surface. But the semi-wet top layer that lowers friction is a property of the ice itself."

The book had its origins at a physics conference, when Haché struck up a conversation with someone who happened to be an editor. "He said, 'You must be Canadian. Do you play hockey?'" Haché recalled. "When I said I did, he said, 'There's a book I'd like someone to write.' Nothing really came of it for a while, but then I wrote half a chapter and sent it to him. He liked it, and there we went."

Mike Perricone



Photos: FNAL, SLAC, CERN, LBNL

CALL TO ACTION!
Help Us Compile a Physics Life List

Bird watchers have life lists of sightings. We think fans of particle physics need a checklist of their own, full of not-to-be missed places, experiences, and artifacts: Fermilab's newborn baby buffalo; America's longest building, at the Stanford Linear Accelerator Center; the six places in the bowels of the Large Hadron Collider where you can stand with one foot in Switzerland and the other in France; a hand-held prototype of the first cyclotron built by E.O. Lawrence, on display at Berkeley Lab. If Einstein's wig or Newton's false teeth existed, we'd throw them in, too.

And so we announce the particle physics life list, which will appear in an upcoming issue of *symmetry*. You probably have some secret gems of your own to add. Send us your entries for consideration to letters@symmetrymagazine.com with subject line "Life List"; contributors will be acknowledged in the magazine.

The Editors

Letters

Plans for antimatter

Congratulations to 12-year-old Austin Ellsworth on his fun model of a linear accelerator (*symmetry*, Mar 2007). However, using antimatter for fueling spaceships or energy storage, as in Dan Brown's book *Angels and Demons*, will never happen.

Fermilab is now the only place in the world to make and collect antiprotons. Going flat out we are able to collect about 5 trillion per day, to inject into the Tevatron collider. Capturing even a few of these in a "magnetic bottle" is extremely hard, but suppose we could capture all of them. If we then let them annihilate with matter, and converted the resulting energy into electricity with 100% efficiency, we could light up a 60-watt bulb for 25 seconds. The power bill to do that would be about 50 megawatts for a day!

So antimatter bombs or antimatter-powered spaceships have absolutely no scientific foundation, unless we could suck them through a wormhole from a parallel antimatter universe! (I am not serious about that!)

Mike Albrow, Fermilab

Magnetic experiences

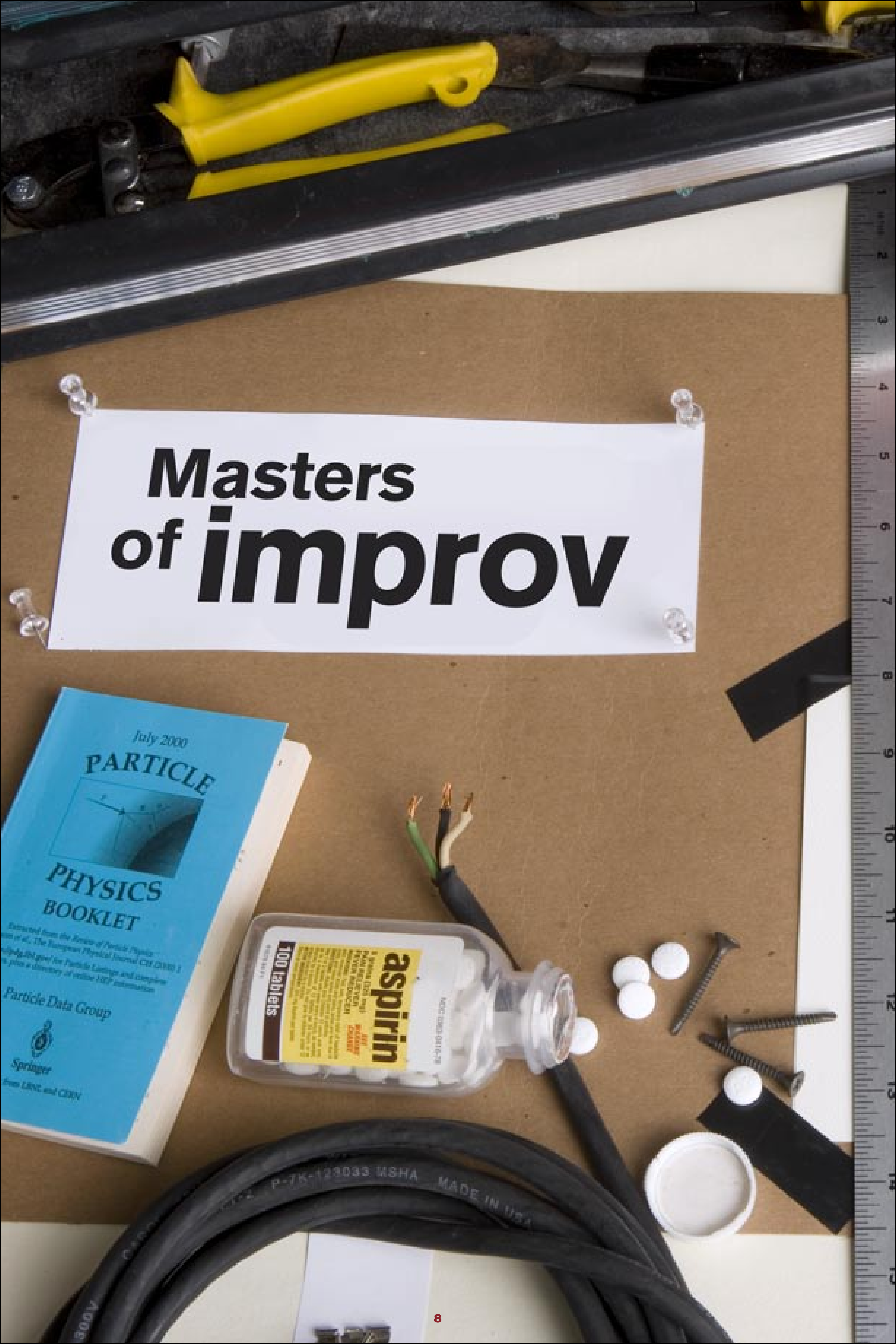
Before conversion to a superconducting magnet, the Fermi Chicago Cyclotron Magnet (*symmetry*, Dec 2006) was used in the Neutrino Area as an analyzing magnet for muons. I worked on the deep inelastic muon scattering experiment E203 in the late 1970s, and we needed to calibrate the magnet for our experiment. At the time, the magnet pole tips were about 4 meters in diameter and the gap was about 80 cm high. For some reason (probably convenience) we decided to put the NMR (nuclear magnetic resonance) probe in the center of the magnet while it was running at about 1.5 Tesla.

I was designated to put the probe in the center of the magnet, so I removed all metal objects from my pockets, watch, belt, wallet, etc., and, crouching over, I stepped over the magnet coils and proceeded into the gap with the probe. After a mishap (fall) due to my Fermilab-issued steel-toed "safety" shoes, I again proceeded into the gap sans shoes.

We needed a non-magnetic stand to position the probe midway in the gap, so my companions scrounged around for pieces of scrap wood or boxes without nails. Finally someone found a 50-cm long, 30-cm high section of aluminum I-beam. It took about 15 seconds to wrestle it through the fringe field. With the probe in place, I exited the magnet slowly so as to minimize whole-body eddy current effects.

Robert Shafer, Fermilab (retired)

Letters can be submitted via letters@symmetrymagazine.org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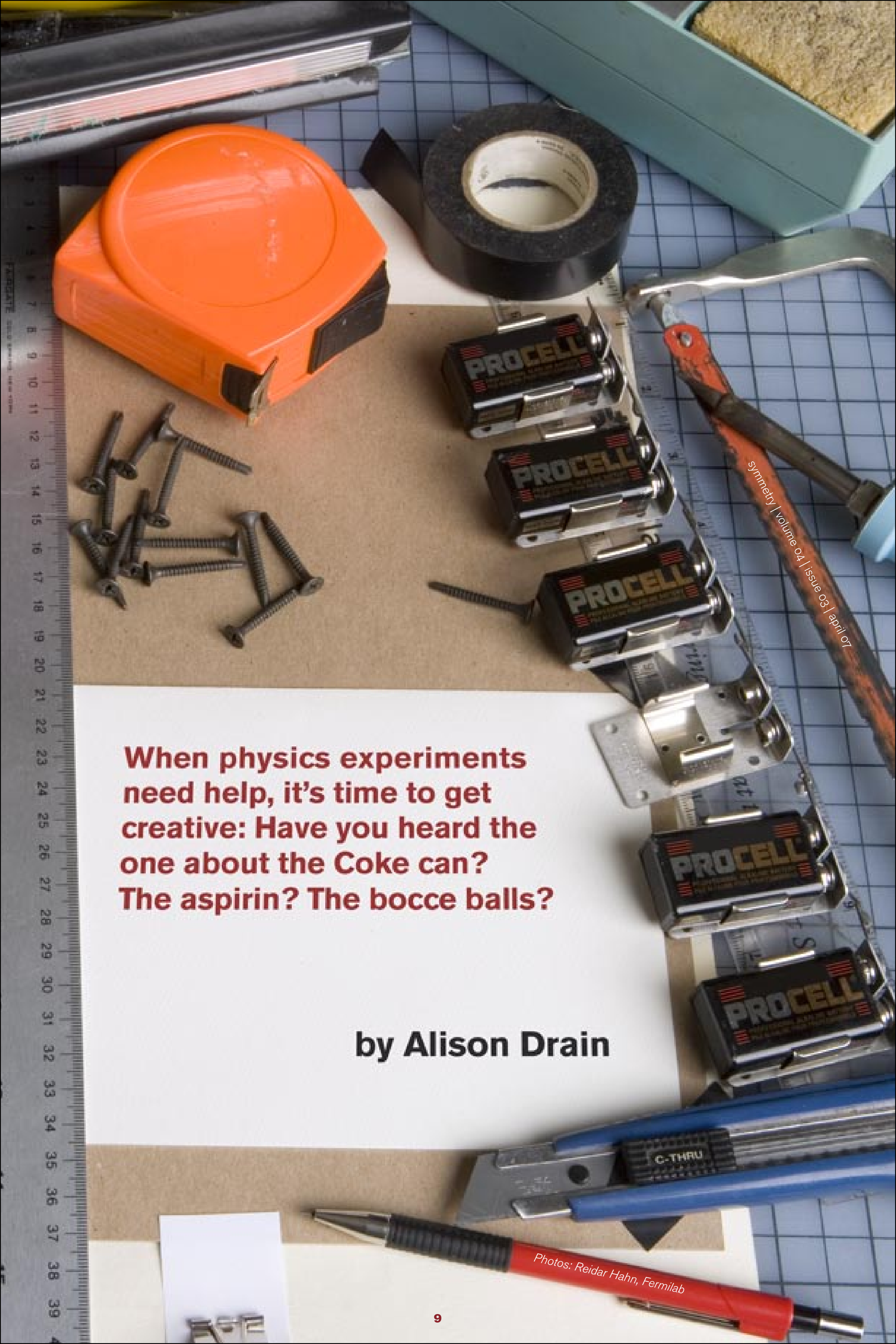


When physics experiments need help, it's time to get creative: Have you heard the one about the Coke can? The aspirin? The bocce balls?

by Alison Drain

Photos: Reidar Hahn, Fermilab

symmetry | volume 04 | issue 03 | april 07

An improvised grinder sanded welds along the long, straight sections of 10,000 feet of pipe at Fermilab. The sander within the rotating silver cylinder cleaned each weld.

Photo: Fred Ullrich, Fermilab

World-class detective Angus MacGyver of the hit 1980s television show *MacGyver* could jury-rig almost anything with duct tape and a pocket knife. High-energy physics labs demand as much and more from technicians and engineers, relying on their creativity and intelligence to navigate technical quagmires. And when a problem demands it, they deliver—engineering tiny cameras mounted on bocce balls that snake through 10,000 feet of steel piping; rigging a 13-ton cement block to bash deformed brass into shape; or aiming a high-powered laser around corners to unblock water lines. Unlike MacGyver's fixes—such as the fuse he repaired with a chewing-gum wrapper—some of these devices last.

Leon Lederman, the Nobel Prize-winning former director of Fermilab, is a legendary lab MacGyver. He used a pocket knife, tape, and items on anyone's grocery list to confirm that interactions involving the weak force do not show perfect mirror symmetry, or parity, as scientists had long assumed. Just as a watch hand always sweeps clockwise, nuclei of atoms eject electrons in a preferred direction as they decay, rather than spraying them randomly. The technical term for this is "parity violation."

Intrigued by the experiments of Madame Chien-Shiung Wu, Lederman called his friend, Richard Garwin, to propose an experiment that would detect parity violation in the decay of the pi meson particle. That evening in January 1957, Lederman and Garwin raced to Columbia's Nevis laboratory and immediately began rearranging a graduate student's experiment into one they could use. "It was 6 p.m. on a Friday, and without explanation, we took the student's experiment apart," Lederman later recalled in an interview. "He started crying, as he should have."

The men knew they were onto something big. "We had an idea and we wanted to make it work as quickly as we could—we didn't look at niceties," Lederman said. And, indeed, niceties were overlooked. A coffee can supported a wooden cutting board, on which rested a Lucite cylinder cut from an orange juice bottle. A can of Coca-Cola propped up a device for counting electron emissions, and Scotch tape held it all together.

"Without the Swiss Army Knife, we would've been hopeless," Lederman said. "That was our primary tool."

Their first attempt, at 2 a.m., showed parity violation the instant before the Lucite cylinder—wrapped with wires to generate the magnetic field—melted.

MacGyver-mania

MacGyver aired in more than 40 countries between 1985 and 1992, in some cases leaving a lasting imprint on the local language. In South Korea, for instance, call a knife a "Maekgaibeo kal" and people know you mean the Swiss Army-type knife the TV character carried. Malaysians call their pocket knives "Pisau MacGyvers" or just plain "MacGyver knives." In Norway and parts of Finland, duct tape is sometimes called "MacGyver tape."

"We had the effect, but it went away when the instrument broke," Lederman said. "We spent hours and hours fixing and rearranging the experiment. In due course, we got the thing going, we got the effect back, and it was an enormous effect. By six o'clock in the morning, we were able to call people and tell them that the laws of parity violate mirror symmetry," confirming the results of experiments led by Wu and by Chen Ning Yeng's and Tsung-Dao Lee's group at the University of Chicago the month before.

Another giant figure in physics, founding Fermilab director Robert Wilson, is the hero of a widely circulated tale.

Ernie Malamud, a physicist at Fermilab, remembers working with Wilson during his graduate studies at Cornell. The pair wanted to use helium gas, often used to fill balloons, to locate a leak in the glass vacuum chamber; but they discovered the hose from the helium supply wouldn't reach the area where they perceived the leak to be. Wilson filled his mouth with helium from the hose, ran to the tank and blew on a gasket to find the leak. He turned to Malamud and grinned.

"This typifies to me everything great about the man: his decisiveness, his knowledge, his originality, and a 'can do' attitude," Malamud says.

Changing times

With today's expensive and complex experiments, there's less room for spontaneity. A solution often involves a team of MacGyvers, long hours of strategic planning, and lots of execution time.

Safety is of the utmost importance, and today's problem-solvers carefully review their unconventional fixes to make sure they aren't hazardous.

"High-energy physics is becoming a very industrialized science with projects lasting for years, so elegant solutions are possible," says Dmitri Denisov, spokesperson for Fermilab's DZero experiment. "It's strongly inadvisable to do anything unapproved in government-funded labs. Yes, some fun of doing science is gone. But taking into account the size and complexity of the experiments, this is the right way to proceed."

Technicians and engineers continue the tradition today, albeit more carefully, finding clever solutions to problems of ever-increasing complexity. Duane Plant, senior operations specialist in the Accelerator Division at Fermilab, is one such MacGyver.

"One of the things that Duane is known for is figuring out that something's going to be a problem before anyone else does," says Patrick Hurh, who works in the division's Mechanical Support Department. "He's invaluable for that. He's a really inventive, creative scientist."

His specialty: designing and building, along with partner Todd Johnson, tiny cameras for tricky fixes. "In my office, I've got 10 different cameras to look at things," Plant says. His cameras go where humans can't: one inched along thousands of feet of pipe to survey microbe corrosion, making way for a string of bocce balls and a cylindrical weld grinder to sand and

clean offending welds. Plant is loathe to take credit for his ingenuity, which over the years has included identifying a snow plow as the cause of disturbances in the Tevatron beam and using a toy dart to open the insides of some magnets for inspection.

"You kludge things together using what you have lying around," he says. "At the lunch table, we can fix anything. Our lunch table has come up with more solutions than we could on our own."

Kludges that last

Some kludge jobs are used only once; others, such as a brass-bashing technique used at Stanford Linear Accelerator center, can be recycled.

In 2002, Jim Krebs, chief mechanical engineer for SLAC's BaBar detector, was helping install one-ton brass plates in the detector when he and his team realized that one of the plates was too bowed to fit. Krebs came up with an inelegant but clever solution.

"I remembered visiting a steel factory in Gary, Indiana, years before, where they flattened bowed steel plates with concrete," he says. "I watched them do it for a while and it was pretty crude."

Nevertheless, Krebs thought the technique would work perfectly for his deformed brass. He supported the plate with beams and shims, and used a crane to lower a 13-ton concrete block onto the bent portion. One hour and a few tries later, the brass plate was flat and the crew slipped it into position. When the opposite problem occurred in 2004, Krebs and others used the same method on a flat plate that needed bending.

Some inspired techniques become permanent fixtures. And some work so well they spread beyond their original homes—such as the aspirin tablets used to detect water leaks in the radio frequency cavities of accelerators.

These RF cavities, which are used to boost the particle energy in accelerators, contain cooling systems that are prone to leakage over time. It's important to detect small leaks before they become big enough to

damage equipment. But detecting teaspoons of water in a cavity that could hold many gallons is difficult.

Each cavity has two holes in the bottom to drain accumulated water. To detect a leak, technicians cap the outsides of the holes with aspirin tablets, which are held in place by spring-loaded switches. When water seeps through a hole and dissolves the aspirin, the switch clicks, indicating a leak. In most cases, leaks are found before any damage is done.

"This was started so many years ago that the names of the original technicians and engineers who invented the treatment are lost in history," Plant says. "But the practice lives on, and I understand other labs have used this idea."

Success and satisfaction

Legendary stories like Lederman's and Wilson's may be few, but engineering triumphs abound. Satisfaction often comes not with formal recognition, but with the success of an unconventional solution—such as Doug Glenzinski's epoxy-blasting lasers, which restored an overheating portion of Fermilab's then-newly installed CDF detector.

"Everything we did was at the very brink of possible," says Glenzinski, who worked with a small team on the project in 2001. "At every stage, we would think, 'Oh, God. How are we going to do this?' Each subsequent stage seemed more difficult. It was very challenging, but in the end it was fun because we succeeded."

First, the team wriggled custom-ordered bore scopes—long, thin fiber-optic cables commonly used in surgery—into the thin cooling lines of the silicon detector to identify areas where epoxy had leaked out of joints and blocked water flow. The next challenge was to clear the epoxy globs without damaging the aluminum cooling lines. The team snaked a flexible laser fiber into the tubes and attached a prism at the end so they could aim the laser around corners. Reflections viewed on an oscilloscope allowed them to distinguish the epoxy clots from the aluminum tube before blasting the epoxy away. The whole process took two years of intermittent work, but the lines have worked perfectly ever since.

The fix was so seamless that the former blockages are undetectable today.

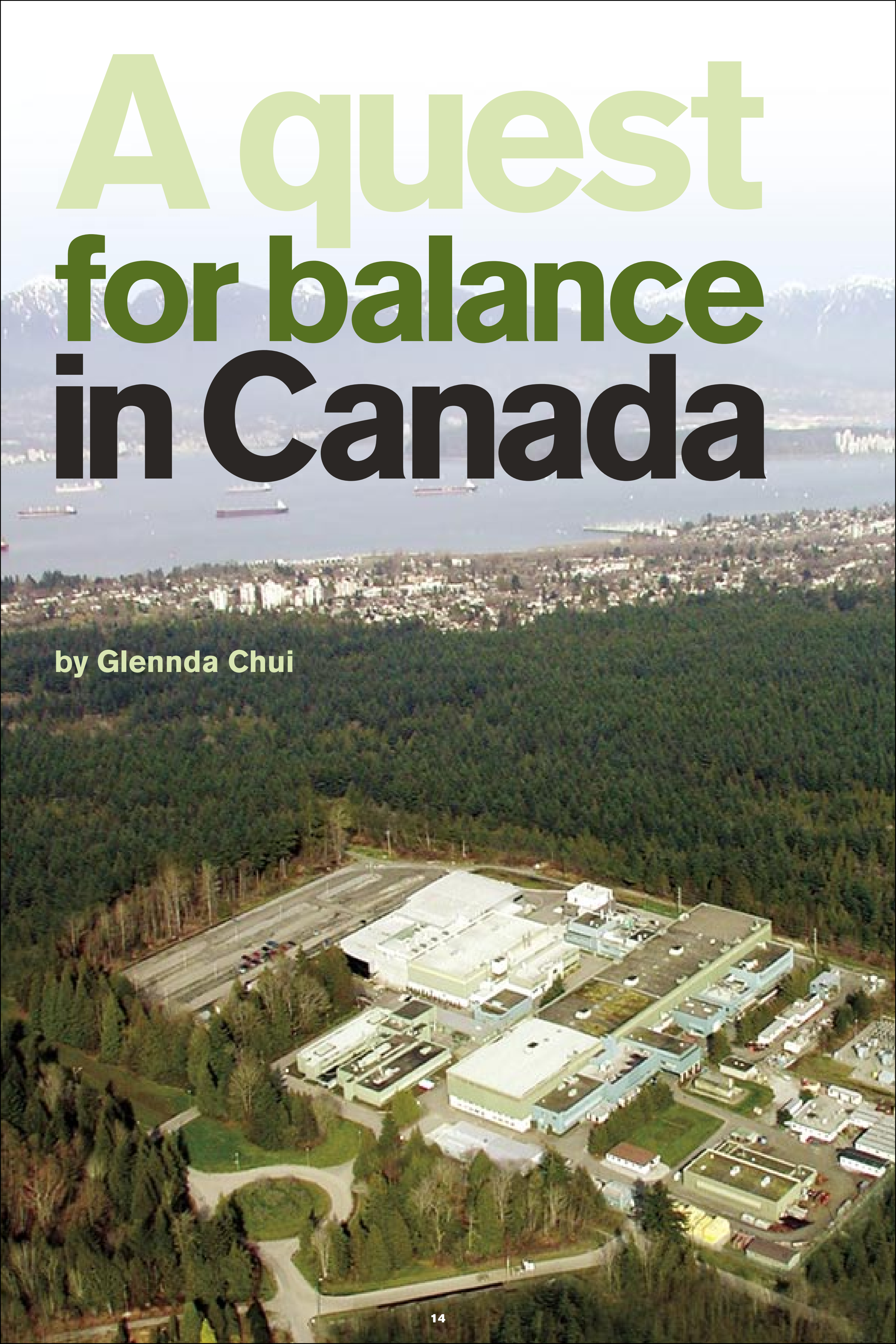
"The new people who have joined the CDF collaboration didn't know about the epoxy blockage until we mentioned it later," Glenzinski says. "I think that's a good definition of success."

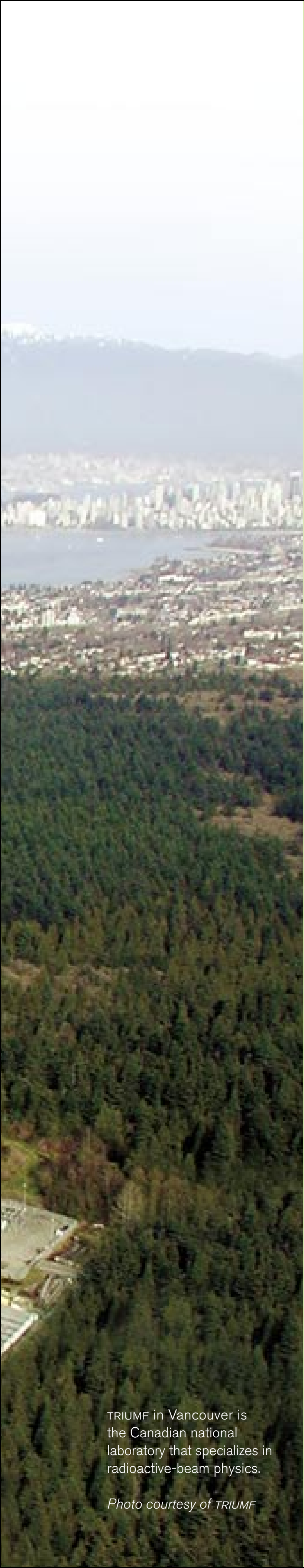
At Fermilab, a string of balls navigated tight corners within the pipes to clean welds out of the weld grinder's reach.

Photo: Fred Ullrich, Fermilab

A quest for balance in Canada

by Glennda Chui





TRIUMF in Vancouver is the Canadian national laboratory that specializes in radioactive-beam physics.

Photo courtesy of TRIUMF

Canadian subatomic physics has a lot going for it: sparkling new hardware, an influx of bright young minds, and key roles in international projects. But only by doubling its operating budget can it live up to that potential, a new report suggests.

Brigitte Vachon is taking full advantage of a happy collision of events in Canadian particle physics.

Lured to McGill University by a program aimed at attracting talented researchers to Canada, she collaborates on experiments at the world's most powerful particle accelerator and is gearing up to do the same at the Large Hadron Collider in Geneva, which will be seven times more powerful still.

Her status as a Canada Research Chair gives her a bit of extra research money and special access to grants, allowing her to buy a high-performance 160-processor computer system that is used exclusively for particle physics.

"This money has really made a difference," says Vachon, who now works about three hours away from the small town in Quebec where she grew up. "We can do anything in a short period of time. We don't have to wait to access other people's computing resources."

There's just one thing: "We have not been able to hire a full-time technician to look after it and fix things when anything goes wrong," she says. "We don't have a choice—everyone has to chip in. But if these people are busy trying to maintain a computer system, they are not doing physics."

That, in a nutshell, is the predicament for physicists all over the country, according to a recent report that defines the aspirations of people in the field. *Perspectives on Subatomic Physics in Canada 2006–2016* was drawn up by a committee of 14 prominent scientists for the Natural Sciences and Engineering Research Council, or NSERC.

While the field has enjoyed an injection of C$75 million for hardware over the past five years, operating budgets have not kept pace. If this continues, the report says, Canadians could find themselves running cutting-edge labs in which their own scientists cannot afford to do experiments.

The report comes at a time when a burst of growth and revitalization is bringing Canada more young physicists and more sophisticated machines with which to probe the universe.

SNOLab, an extension of Sudbury Neutrino Observatory with three times the floor space, will be the world's deepest underground laboratory for years to come, an ideal place to search for dark matter and other shadowy phenomena. TRIUMF, the Canadian national laboratory in Vancouver, is the world leader in producing radioactive beams of fast-moving, exotic isotopes. The beams are used, among other things, to simulate conditions in the hearts of exploding stars, where all but a few of the elements that make up our world are violently wrenched into being and flung out into the universe.

Canada collaborates

Because the Canadian subatomic physics community is relatively small—fewer than 250 researchers working in particle, nuclear, and theoretical physics—it concentrates on a few well-chosen areas, leveraging its expertise and brainpower by connecting to international projects.

Vachon, for instance, is part of the DZero experiment at Fermilab's Tevatron collider, which announced in February that it had observed an extremely rare type of collision that creates a single top quark. She also shuttles back and forth to CERN, the European particle physics facility near Geneva, where the Large Hadron Collider will soon launch a long-awaited

Photo courtesy of Fermilab

Above: Brigitte Vachon was able to buy a high-performance 160-processor computer system for her research group but still needs to do the maintenance by herself or with her postdocs. She is shown here at Fermilab's DZero experiment, on which she collaborates.

search for the Higgs boson and other fundamental quantum weirdness just beyond our reach. Canada is making important contributions to one of the collider's experiments, called ATLAS.

"Part of my responsibility is training scientists," Vachon says, "and you can't get away with not spending time at the lab, seeing and participating and knowing what it's like to be there in the middle of the action, trying to make the detector work and trying to fix things when they go wrong." Although funding constraints have not had an impact on travel yet, she adds, "I certainly worry about the future."

Canada also participates in T2K, which beams neutrinos from Tokai, Japan, to a detector more than 295 km away in Kamioka in the hope of learning more about these elusive particles. Canadians make up one of the largest non-Japanese groups involved in those experiments. "We have been there from the start. We contributed to the design of the facility itself," says Jean-Michel Poutissou, science director at TRIUMF.

Canadian researchers built major components of the BaBar detector at Stanford Linear Accelerator Center and collaborate on the ZEUS experiment at DESY, the German national particle physics laboratory.

As for the next big thing—the International Linear Collider—the long-range report says Canada should be "a strong player" in the project, vigorously carrying out research and development over the next few years to prepare itself for major involvement. TRIUMF is already involved in the detector development for the collider.

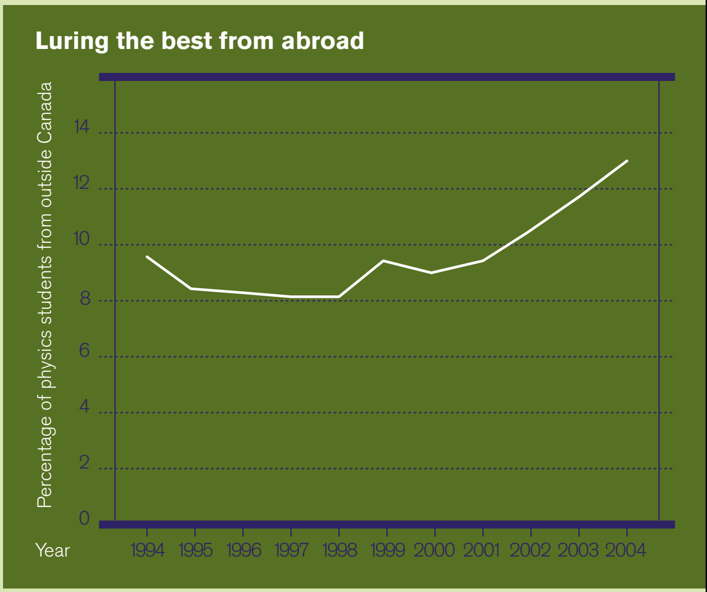
In late April, TRIUMF for the first time sent representatives to a meeting of the TESLA Technology Collaboration, which is a key player in designing superconducting components for the linear collider. "For want of a better word, it's a fishing trip to see if we have any expertise that is needed or overlaps with what is needed for ILC," says Shane Koscielniak, an accelerator physicist at the laboratory and the only Canadian member of the collider's Global Design Effort.

Photo courtesy of Lawrence Berkeley National Laboratory

Right: There's been a sharp upturn in the number of foreign students studying physics in Canada.

Source: Statistics Canada

Left: The Sudbury Neutrino Observatory was one of the early underground experiments in a site that has expanded to become SNOLab.



Above: A beamline at TRIUMF used in studies of the behavior and interactions of rare nuclear isotopes.

Photo courtesy of TRIUMF

An influx of internationals

More and more these days, the traffic is flowing in the other direction, too, as scientists from around the world travel to Canada to take advantage of what its research institutions have to offer.

The number of graduate students enrolled in subatomic physics in Canada rose 42 percent between 2001 and 2005, in part due to an influx of foreign students after the September 11 attacks led to tighter visa restrictions in the United States.

At the same time, about 35 percent of the subatomic-physics faculty at the nation's universities were hired in the past five or six years, replacing a wave of retirees.

"We've hired a whole bunch of smart young whippersnappers, and it's great to see," says Kenneth Ragan, professor of physics at McGill and chairman of the committee. "These are really first-rate scientists. And as people are ramping up their research programs, more students are attracted into the discipline."

Keeping the labs running

But money is tight when it comes to running the new facilities and allowing Canadian researchers to take full advantage of them; attracting experiments from other countries; supporting the growing number of graduate students and postdocs; and keeping up with increasing travel demands as the Large Hadron Collider and other foreign facilities come online.

"We now have the strongest arguments we've had in a generation for more operating funds," Ragan says. "We'll hopefully come out of it being able to use this infrastructure we've developed, which in many cases is world-class."

SNOLab, for instance, is nearing completion, its caverns and tunnels carved out of solid rock two kilometers deep—providing nearly twice the protection from interfering cosmic rays as the next-deepest lab, Italy's Gran Sasso National Laboratory.

A dark matter experiment called PICASSO is already taking data there, "shoehorned into a little corner until we can get some space and build it up," says lab director Tony Noble. "There's only enough space in existing facilities for people to fit small prototypes while they wait for the rest of the lab to appear."

An advisory committee is in the process of reviewing 20 proposals for SNOLab experiments, of which about half a dozen will be chosen.

"It really is meant to be an international facility," Noble says. "Obviously we want to be both the hosts and participants."

He adds, "This first year we're cobbling together funds to run on, but I don't think that's a viable long-term solution. I just can't believe that after putting all that time and money into it, the government would not give us

Photo: Perimeter Institute

Photo courtesy of Queen's University, Canada

Above: Perimeter Institute for Theoretical Physics is funded by the Canadian national, provincial and local governments, and major private donations.

The PICASSO dark matter detection experiment, one of the first experiments to start operating in the new SNOLab facilities.

enough money to operate it. Canada has a very good track record of looking after the things that it builds."

Injections of funds

SNOLab is the single biggest beneficiary of the Canada Foundation for Innovation, an independent corporation created by the federal government in 1997 to manage the distribution of money for research infrastructure. The foundation has pumped C$54.5 million dollars into 23 subatomic physics projects, including $38.9 million to develop SNOLab.

Theorists also got a big shot of new money, in this case from both private and government sources. In 2000, Mike Lazaridis, founder of Research in Motion, which makes the popular BlackBerry wireless device, dug $100 million out of his own pocket to create the Perimeter Institute for Theoretical Physics. Other private donors came up with more than $20 million, the national and provincial governments kicked in more than $100 million, and the city of Waterloo offered a free site. The institute now has more than 60 resident researchers working in string theory, cosmology, quantum gravity, quantum foundations, and quantum computing, and it's starting to build a particle-physics group, with two half-timers hired so far, says Cliff Burgess, who is one of the two.

In March, the Canadian government announced that it would give Perimeter an additional $50 million over the next five years. "That's a huge plus for theory," Burgess says. "That's the kind of thing I never expected to see in my lifetime in Canada."

Meanwhile, the same Canada Research Chairs program that allowed McGill University to recruit Brigitte Vachon continues to spend $300 million per year on the effort. The goal of the program is to establish 2000 research professorships by the end of 2008. As of December, 1755 of those positions had been created, 244 of which are occupied by Canadians who had been working in other countries.

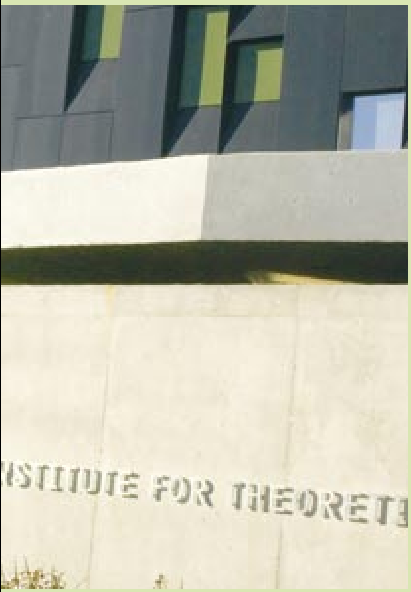


Photo courtesy of Fermilab

Right: Control room scientists keep a watchful eye on the status of beams and experiments at TRIUMF.

However, funding for the experimental side of subatomic-physics has remained flat when inflation is taken into account. The proposed national budget released last month appears to continue that trend, says William Trischuk of the University of Toronto, director of the Institute for Particle Physics and an ex-officio member of the NSERC report committee.

Budgeting for the future

The committee's report called for a doubling of the subatomic-physics budget by 2015. This would allow SNOLab to operate at full speed with full Canadian participation and allow the country to play a role in both the International Linear Collider and future upgrades of the Large Hadron Collider, without having to choose between the two.

Instead, Trischuk says, it looks like science and engineering research funded by NSERC will get a 3 or 4 percent increase at best; the full picture will not emerge until summer, when details are released. While NSERC did agree to provide half the operating money for SNOLab in the fiscal year that just began, it's a one-time-only grant. The lab has asked the provincial government to make up the difference in operating funds for this year, but does not expect an answer for some time.

"We're really being backed into a corner," Trischuk says. "It was a pretty bad budget for science."

However, the figures are far from final. The process of approving the budget will take months, and with a minority government in power, there undoubtedly will be many bumps along the way.

"Here in Canada, historically we haven't been as politically plugged in," Ragan says. "So that's what we're struggling with now. We have pretty good reasons for arguing for increased funding; now how do we go to the political scene and make that happen?"

As for Vachon, "I would like in Canada to continue to have the freedom to pursue different avenues of research that I might find interesting," she says. "From my point of view it's an exciting time to be a physicist. We're young, we're eager, and we want to build our group. We want to participate in this new generation of experiments."

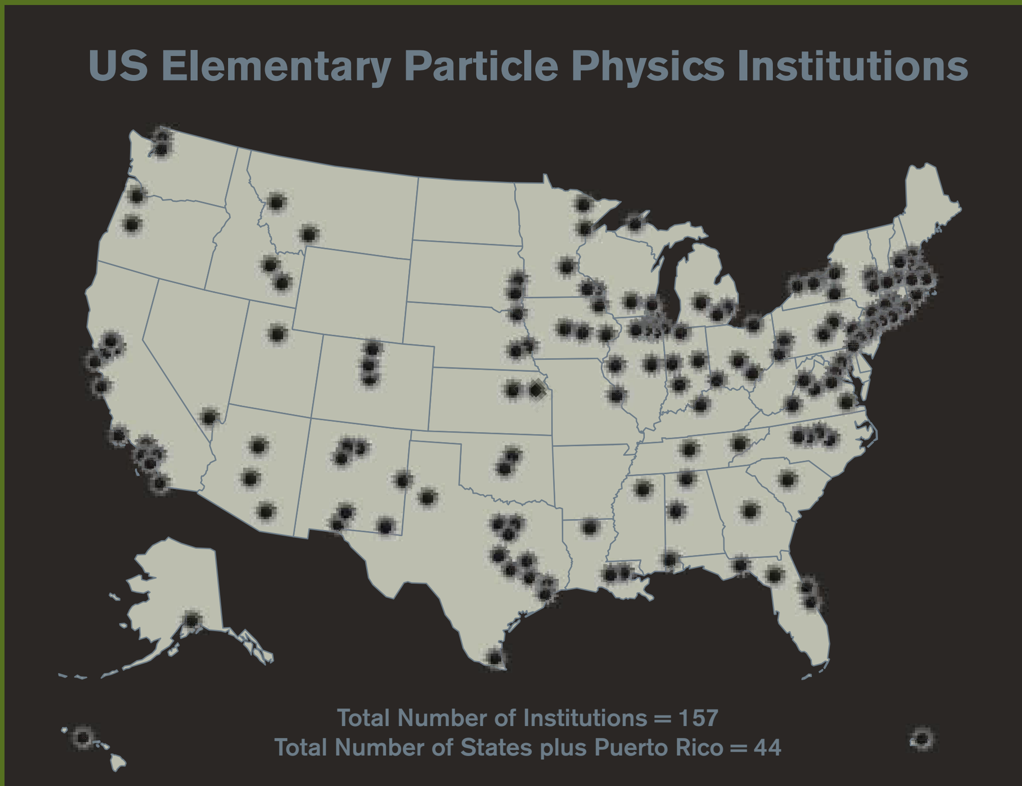
See the full version of Canada's long-range plan in subatomic physics along with a non-experts guide at www.subatomicphysics.ca

Small cogs drive

Photos: Fred Ullrich, Fermilab
Maps courtesy of Google-Imagery

a big machine

by Christine Buckley



Previous pages and backgrounds: The multitude of institutions that contribute to the Large Hadron Collider at CERN act as the many small cogs needed to keep a big machine operating.

Above: Many US institutions play a role in the global particle physics enterprise, whether by conducting research at their own laboratories or participating in projects elsewhere.

University scientists are the backbone of particle physics; like cogs in a complex machine, they deliver expertise, funding, and equipment exactly where needed. At Vanderbilt, they're developing ways to handle a flood of data from the Large Hadron Collider.

Will Johns lugs his computer everywhere. This wouldn't be a big deal if the computer wasn't a desktop PC, and if his travel didn't include frequent trips across the United States and Europe. For this formidable task, he claims to own the largest suitcase in the world.

"I've learned to covet huge hard-side luggage," he says. "I need it for the world's worst laptop."

Johns is an assistant professor of physics and astronomy at Vanderbilt University in Tennessee, an urban campus just a few blocks from Nashville's "Music City USA" of country-music fame. He needs that big, unwieldy desktop and its custom features to test electronics being assembled around the world for a massive detector at the Large Hadron Collider at CERN, the European laboratory for particle physics in Geneva, Switzerland.

Vanderbilt is one of 157 US institutions involved in high-energy physics, and one of 49 American universities collaborating on the collider's Compact Muon Solenoid (CMS) detector. Like many others, the university faces the challenge of operating an experiment that's on the other side of the ocean. By developing and constantly improving the technology that allows them to access data from very far away, Vanderbilt physicists are making it possible for their own group, and more than 2000 of their colleagues around the globe, to fully participate. The high-energy physics community is a leader in demanding fast, high-bandwidth networking, and advances in the field expand that capability each year.

Universities contribute a large part of the funding, equipment, manpower, and expertise needed for large collaborations such as the CMS detector. They hold more than half the project contracts for the US part of the collaboration and are involved in designing and operating the detector and analyzing the data from it. The University of Wisconsin, for example, designed and coordinated the assembly of the discs that form the end caps of the detector, while Ohio State University designed and built a portion of the electronics that will go into them.

"Many universities have specialty mechanical shops, which allow them to contribute to the design and manufacture of specialized electronics," says Fermilab's Dan Green, former head and current member of the US CMS collaboration. He adds that university groups have the unique advantage of seeing the process from the start, which gives them the best perspective on the results: "The people who discover something will be the people who really understand the detector."

Universities are breeding grounds for technological development as well as for scholarship. Vanderbilt is part of a multi-university collaboration, led by Caltech, setting world records in computer networking that will allow data from the LHC to be transmitted across the Atlantic. The Massachusetts Institute of Technology, the University of Florida, and the University of Maryland will be leading physics analyses once the LHC is commissioned. In addition, universities nurture the future by training the next generation of particle physicists. For graduate students and post-doctoral researchers, participation in an experiment the size of CMS develops practical skills that can't be learned from a textbook.

"University physicists are at the heart of modern particle physics. They develop theories, construct detectors, analyze data, and attract students to science," says Robin Staffin, associate director for high-energy physics at the Department of Energy's Office of Science. "The physicists at Vanderbilt carry out their research at Fermilab and CERN, a strong testament to the partnership between DOE, its laboratories, and the university community."

Tony Chan, director of Math and Physical Sciences at the National Science Foundation, values NSF's unique role among federal funding agencies in supporting physics research. "It is always satisfying for us at NSF to support basic science in universities, where most of the future generations of scientists are trained," he says. "This education role is recognized by the research community as critical to the health of the field."

The Department of Physics and Astronomy at Vanderbilt doubles as a high-performance computer science group. Vanderbilt's physicists develop and test software to handle the massive amounts of data produced at the scale of the CMS. Each LHC detector will observe up to 600 million collisions per second, storing data from about 100 million "interesting" collisions.

The 12,500-ton CMS detector will include the largest solenoid magnet ever built. Four layers of sub-detectors will identify particles splintering off from proton-proton collisions, recording mass, speed, and electric charge.

"The LHC and CMS are a whole new scale of activity," says Bob Scherrer, head of the physics department. "Everybody's feeling like it's new."

Where's my data?

The innermost part of the CMS detector, called the silicon pixel tracker, contains thousands of tissue-thin silicon squares densely packed around the beam pipe. They record changes in electrical charge left by particles whizzing away from collisions. Each signal goes to one of 38 readout boards, which then converts the energies to a format that can be read by a computer.

After all the data are read out, the trigger system selects only the most interesting particle collisions for storage. Even so, the data accumulated in one day would fill more than 50,000 home computers, and researchers need a way to access it from their home institutions.

"Say I want to grab CMS data and manipulate it myself from my office at Vanderbilt," says Professor Paul Sheldon, a founder of Vanderbilt's

US Representative Bart Gordon

Chair of the House Committee on Science and Technology

Photo courtesy of Representative Gordon

As the father of a six-year-old daughter, I am concerned that our children could be the first generation of Americans not to inherit a better standard of living than their parents did. Ensuring that our country's economic strength remains the envy of the world means ensuring that American students and workers remain competitive with their global counterparts.

The work of physicists and graduate students at Vanderbilt University for CERN's Large Hadron Collider is helping maintain our country's scientific leadership in particle physics and many other areas. Vanderbilt's efforts also highlight the irreplaceable support and "institutional mentoring" of the Department of Energy's Office of Science and the National Science Foundation.

Pre-college science education must also be a national priority. More than 60 percent of this country's middle school math teachers, and more than 85 percent of our physical science teachers, are working with neither a major nor a certification in these fields. Strengthening NSF's leading role in math and science education programs can expand the possibilities for younger students and provide our teachers with the resources they need.

As chair of the House Committee on Science and Technology, I have introduced an innovation package based upon the recommendations of the widely acknowledged National Academy of Sciences report, *Rising Above the Gathering Storm*. The components of that package—the "10,000 Teachers, 10 Million Minds" Science and Math Scholarship Act (HR 362) and the "Sowing the Seeds Through Science and Engineering" Research Act (HR 363)—have both cleared the committee and will soon be considered by the full House.

The National Academies told us in their report that without immediate action to improve science and math education, this country faces an uncertain future. I hope to help provide our kids with a solid foundation in science education, and our country with a solid foundation in research. I hope to be able to tell my daughter I was part of the solution.

Bart Gordon

Bart Gordon represents Tennessee's 6th Congressional District.

Advanced Computing Center for Research and Education. "I'm looking for something specific, and I want it to be fast. I want to compute with it, transform it, and even write it out temporarily. The less I have to think about where it comes from, the better." With Vanderbilt's Daniel Engh, Sheldon is helping develop and deliver a US-based computing infrastructure to handle and distribute CMS data.

As the data are transmitted, they must immediately be written to disk. This will require massive storage centers.

Sheldon leads a team of US researchers who have developed a network of data storage clusters at nine universities and institutions across the Americas, including Vanderbilt and Fermilab. It's called the Research and Education Data Depot Network, or REDDnet, and it works as a grid-computing system, with each institution acting as a separate storage drive. When a file is saved to the system, it's split into many smaller pieces and distributed among the institutions. Later, when a scientist retrieves that file, the pieces travel back all at once from different locations and are pieced together. These small chunks of data load into the researcher's

local system much faster than they would in one large lump, greatly speeding access.

"Half of the file might be at Caltech and half of it somewhere else," explains Sheldon. "As a user, I don't care about where it is, as long as it works."

Researchers across the US and at several institutions in Brazil already use REDDnet to store and access data from a number of disciplines, including medicine, geology and astrophysics. Sheldon hopes physicists will soon do the same.

Deciphering the code

Once data are available and accessible, physicists need to understand what they are seeing. The detector records a jumble of energy measurements at many places within its many layers. Like detectives following a trail of clues, researchers use these measurements to trace events back through the layers to the center of the detector and find out what happened in the instant after the collision.

Vanderbilt's Eric Vaandering writes software that will reconstruct these events. The pathways are based on data from previous and current collider experiments, as well as theoretical expectations. To detect new physics, such as supersymmetry or the Higgs boson, this software must be able to handle a vast range of data at a precise scale.

"We want to make sure we can do this reconstruction accurately with as many different kinds of input as possible," says Vaandering. "This gives us some confidence that we will do okay when the real data come in."

Branching out

Vanderbilt capitalizes on a strong ongoing connection with Fermilab, which has been designated as an LHC Tier 1 data center; that means it will receive much of the CMS data directly from the experiment at CERN.

"The Vanderbilt group has had a tradition of computing success on many experiments at Fermilab," says Joel Butler, director of US CMS.

Group members often travel to the LHC Physics Center at Fermilab and meet with other CMS physicists to work out the kinks. "I can work on a problem for two weeks and just get really stuck on it," says Engh, who travels to the physics center about once every other month. "Then I go to Fermilab and get the whole thing worked out in two hours by talking to five of the right people."

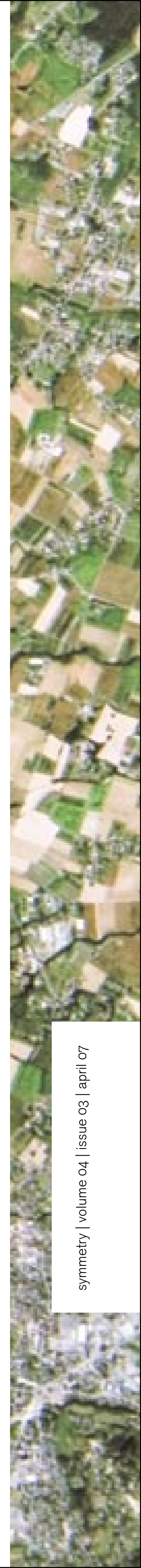
Great expectations

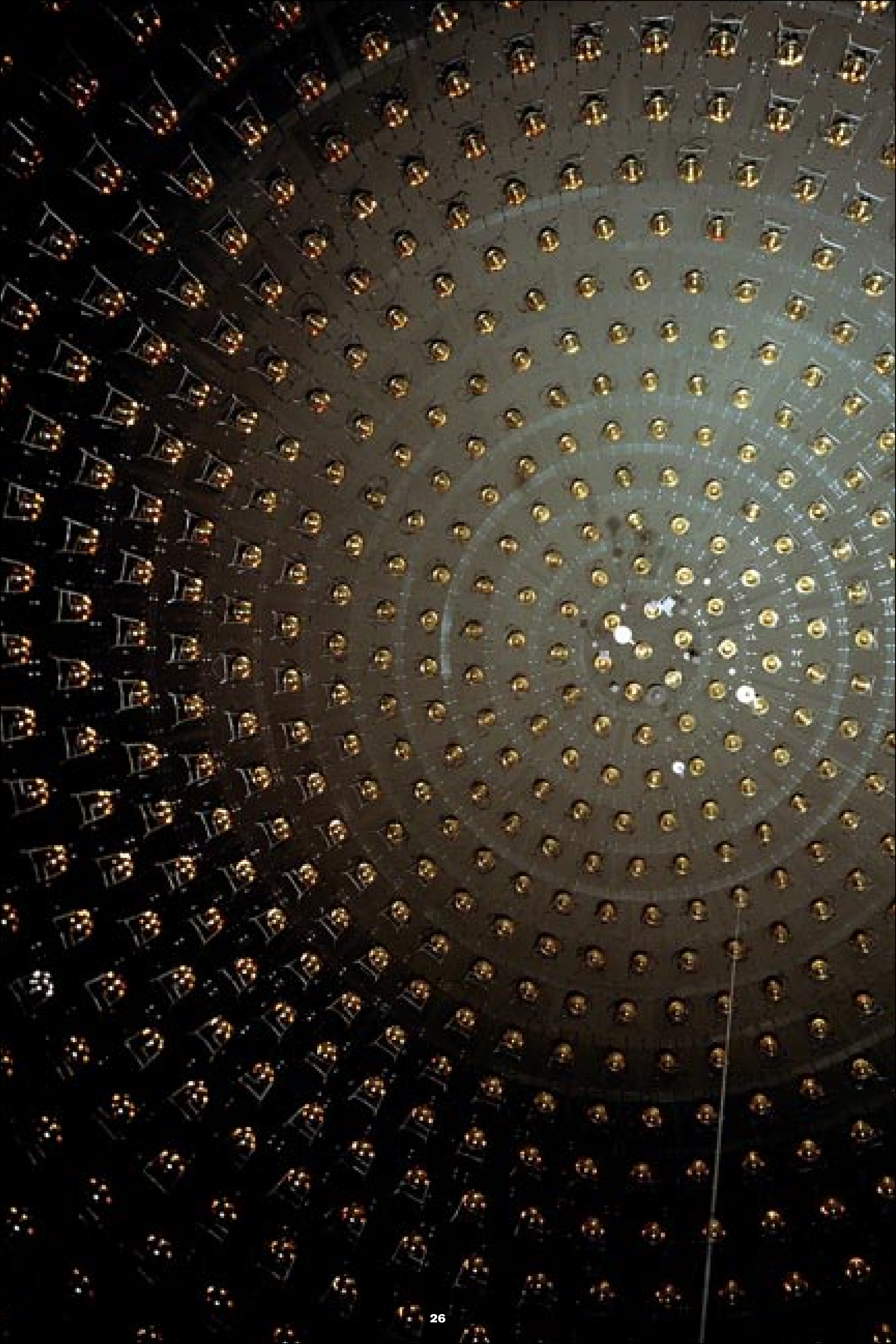
Once LHC switches on, the Vanderbilt group will join the ranks of experts sifting the data for inklings of new physics at the world's highest-energy collider.

"Particle physics has been waiting a long time for something like the LHC," says Scherrer. "If amazing discoveries are going to happen, that's where they will be."

This summer, Will Johns will move to Vienna to test final changes to the readout boards before they are installed to the CMS detector. He's hoping advances in technology will someday make it unnecessary to lug the "world's worst laptop" and its specialized data acquisition card.

"They just made a new card that works with a non-special computer," he says, "so maybe my schlepping days are drawing to a close."





No-show neutrino, and a new mystery

By David Harris

The inside of the MiniBooNE tank is covered with 1280 inward-facing photomultiplier tubes. The picture shows a section of the upper hemisphere of the tank.

Photo: Reidar Hahn, Fermilab

The first results from the MiniBooNE neutrino experiment, released in April, showed no hints of a fourth neutrino. But they contained a puzzling signal that could lead to new physics.

Heather Ray sat in a roomful of people and computers with her finger above a button. Her heart skipped a beat as she pressed it and initiated a chain of analysis. “It was the most nerve-wracking 90 minutes of my life,” she says. At stake were the long-awaited results from an experiment designed to resolve a mystery that had puzzled physicists for more than a decade.

Fermilab’s MiniBooNE experiment had been collecting data since 2002, looking for a particular kind of neutrino “oscillation” in which one type of neutrino changes into another. An earlier experiment had shown evidence for that type of oscillation, but it had not been observed elsewhere. If it were real, a huge change would be needed in how physicists think about the behavior of neutrinos and the foundations of particle physics.

After a wait that felt interminable, Ray, a scientist from Los Alamos National Laboratory (LANL), and the rest of the MiniBooNE collaboration saw a clear result: There was no evidence of the anomalous neutrino oscillation. And yet, there was something else in the data, a hint of a new mystery, in the form of extra low-energy electron neutrinos that had not been predicted or previously observed.

“More data is needed,” says particle-physics theorist Boris Kayser of Fermilab, echoing the call of physicists since there have been physicists. Kayser, currently teaching at Columbia University, is not connected with the MiniBooNE results except through his own 30 years of neutrino ponderings. “The question,” he continues, “considering what MiniBooNE has reported, is this: What do we do now?”

Columbia University’s Janet Conrad, one of two spokespeople for MiniBooNE, emphasizes “This is only our first step.”

The other, Bill Louis of LANL, says, “I’ve spent the last 18 years investigating neutrino oscillations, and it keeps getting more and more interesting. As in many particle physics experiments, we have a result that answers some questions and raises others.”

Photo: Jenny Mullins, Fermilab

MiniBooNE co-spokesperson Bill Louis, here checking the MiniBooNE data acquisition system, is a scientist at Los Alamos National Laboratory. In the 1990s, he worked on an earlier experiment that triggered the idea for the MiniBooNE experiment.

Photo: Reidar Hahn, Fermilab

Photo: Reidar Hahn, Fermilab

Above: MiniBooNE Collaboration
Below: Filling of oil into MiniBooNE Tank

Ubiquity

Neutrinos are everywhere. There are billions of them passing through everyone on Earth all the time, unnoticed because they rarely interact with other forms of matter. Even so, they play a role in some of the most significant physical processes in the universe, such as the nuclear reactions that make the Sun shine.

"Even though they interact so weakly, neutrinos represent one of the dominant particles in the universe, along with photons," says Louis. "There are somewhere on the order of a billion times as many neutrinos as there are protons in the universe. They have played a crucial role in the evolution of the universe." In fact, he says, "We can almost regard neutrinos as the particles that tell us how much we don't know about the universe."

The particle wasn't even theorized until 1930, when physicist Wolfgang Pauli found that some of the energy expected from the decay of an atomic nucleus was missing. Pauli proposed a new particle as the famous "desperate remedy" to save the law of conservation of energy. He described the particle, which he thought might never be detected, in his letter to "Dear Radioactive Colleagues" at an upcoming conference in Tubingen, Germany. (See *symmetry*, Mar 2007).

Pauli was not completely correct: The particle was detected, although it took more than 25 years. The first observation of the neutrino was confirmed in 1956 by Frederick Reines and Clyde Cowan with a detector at the Savannah River nuclear reactor. Since then, physicists have confirmed the existence of three types of neutrinos—the electron neutrino, muon neutrino, and tau neutrino—and have learned a lot about how they change from one species to the next.

A challenge to past results

During the 1990s, the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos National Laboratory showed evidence for a new type of neutrino oscillation. That oscillation would have implied the existence of a fourth species of neutrino, a surprising addition to the standard picture of three neutrinos. The LSND result suggested that muon neutrinos could first turn into a fourth species of "sterile" neutrinos before turning into electron neutrinos.

"Two kinds of oscillations could be explained with three neutrinos, but three kinds could not," says Louis, who was involved with LSND beginning with its design in 1989. "Our result was viewed skeptically, and that's a strength of our field. People have to be convinced. Because of the far-reaching consequences of this interpretation, the LSND findings cried out for independent verification."

MiniBooNE was designed (and approved as an experiment in 1998) specifically to confirm or refute this puzzling claim of a possible fourth neutrino.

The experiment's first scientific results, announced at Fermilab on April 11, 2007, found no evidence for the extra type of oscillation, confirming the picture of three types of neutrino laid out in the Standard Model of fundamental particles and forces, the foundation of particle physics for more than 30 years. Although it didn't completely rule out the earlier observation, MiniBooNE did show that there is no way to explain it using only simple back-and-forth oscillations between pairs of neutrino species. If the LSND result is correct, there must be some new physics at play.

Easy as pion

MiniBooNE sends a beam of pure muon neutrinos toward a detector. Some of the muon neutrinos turn into electron neutrinos during their journey and the detector counts how many electron neutrinos appear. The number of electron neutrinos provides information about the types of oscillations that occurred along the way.

Creating neutrinos in the large quantities needed is not easy and takes multiple steps. First a proton beam from Fermilab's Booster accelerator hits a beryllium target. The proton bombardment creates many debris particles, some of which are short-lived pions, or pi mesons.

An intense focusing magnet called the horn sends the pions down a 50-meter pipe. As they travel, the pions decay into muon neutrinos, which then pass unimpeded through 440 meters of rock beneath the Fermilab site to the detector, a 12-meter-diameter spherical steel tank filled with 250,000 gallons—more than 800 tons—of ultra-pure mineral oil, and lined on the inside with 1520 photomultiplier tubes.

MiniBooNE detected just the number of electron neutrinos predicted by simple muon- to electron-neutrino oscillation with no need for a fourth neutrino species. Many physicists find this is strong evidence that there is no fourth neutrino at all, but others point out that it is possible that more exotic physics could explain the LSND result. In fact, MiniBooNE did see an apparent excess of neutrinos with lower energies, an intriguing invitation for more analysis.

There are still loopholes in the results. MiniBooNE's experiment used a beam of neutrinos, while LSND used antineutrinos. "There is the possibility that neutrinos and antineutrinos oscillate differently," says Kayser.

As a further test of the LSND result, which will also explicitly probe similarities between neutrinos and antineutrinos, MiniBooNE started operating with an antineutrino beam in January 2006. Experiments around the world have been amassing data on the subtle but distinct differences in behavior between various particles of matter and antimatter. This phenomenon, called CP violation, is increasingly regarded as the solution to the mystery of the matter-antimatter imbalance in the formation of the universe, which ultimately enabled life as we know it. Seeing CP violation for neutrinos, says Kayser, "would be extremely interesting."

In the balance

"One possibility in the matter-antimatter imbalance involves CP violation in the early universe with heavy neutrinos that are not with us anymore," Kayser says. "If that had been the case, we would like to see related CP violation in light-neutrino oscillation today."

For Louis and the 77-member MiniBooNE collaboration, and for Kayser and the community of neutrino researchers standing by, the next critical goal is to understand what MiniBooNE's unusual low-energy signal represents.

"Is it a signal, or is it background?" says Louis. "Either way, it's very important to know for the future. It could indicate CP violation, or extra dimensions, or other violations. There is a whole slew of possibilities."

"In the 50 years since its discovery," he adds, "the neutrino has continued to surprise us. I wouldn't be surprised if the neutrino has more surprises in store."

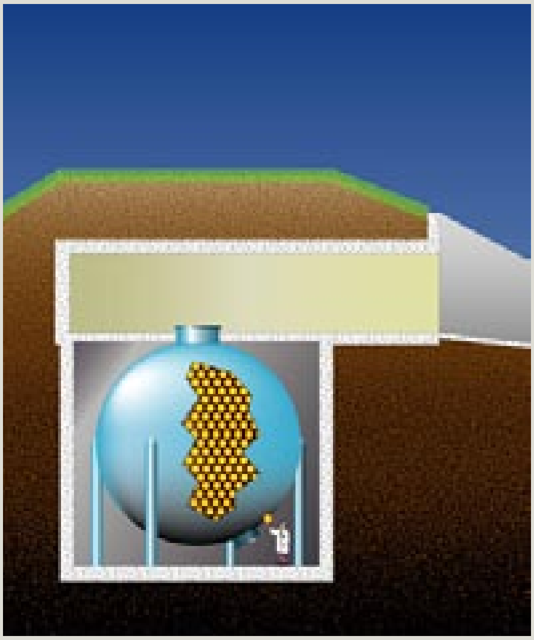


Illustration: Reidar Hahn, Fermilab

The MiniBooNE detector is a 250,000-gallon tank filled with mineral oil, which is clearer than water from a faucet. Light-sensitive devices inside the tank detect collisions between neutrinos and the nuclei of carbon atoms within the oil molecules.

Working at the same place in similar fields, Michael S. Smith and Chang-Hong Yu enjoy a situation not too unusual among married couples. Not so ordinary is their line of work. They are both physicists at Oak Ridge National Laboratory (ORNL), pursuing studies of the processes involved in cataclysmic stellar explosions and exotic, highly unstable nuclei.

Michael is an award-winning astrophysicist (among his recognitions are the Presidential Early Career Award); Chang-Hong's work in nuclear physics exploits the Holifield Radioactive Ion Beam Facility's ability to replicate conditions believed to occur in supernova explosions.

Two things about ORNL lured Michael there in 1992: the Holifield Facility, which was gearing up with new and unique capabilities for astrophysical studies; and Chang-Hong, a postdoc from the nearby University of Tennessee who he had met at a conference. Soon after arriving at the lab, however, there came a dramatic twist: Just as Michael began his research at ORNL, Chang-Hong left for the University of Rochester.

Nevertheless, love endured. They married in 1994 and Chang-Hong joined the ORNL physics staff the following year.

The Smiths, who include son, Kai, 10, and daughter, Alia, 4, embrace Chinese culture. Both children are bilingual and attend a weekend school on Chinese language and culture. Chang-Hong, a top student in her native Szechuan Province city of Chengdu, helped form a local Chinese dance ensemble that dazzles audiences with its precision and color.

Michael teaches the Asian martial art of Wu Shu and competes, often victoriously, in China. His skills come to the forefront as his hands slice the air during conversations about his research. Michael, in fact, was recently recognized as ORNL's top science communicator.

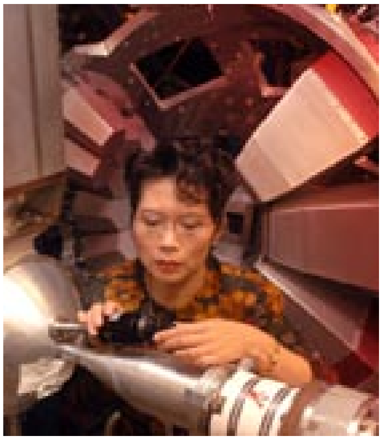
Michael and Chang-Hong prove that you can unlock the secrets of exotic nuclei and document the cosmic origins of elements, and still have time to raise a family and enjoy a hobby or two.

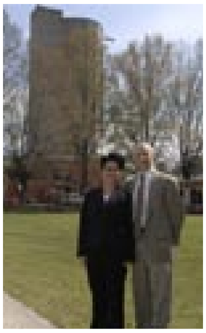
Text: Bill Cabage, ORNL
Photos: ORNL and courtesy of Michael Smith and Chang-Hong Yu

"By the time I can look in the refrigerator to see what is left over, Chang-Hong can whip up a gourmet spicy Chinese dish."
Michael Smith

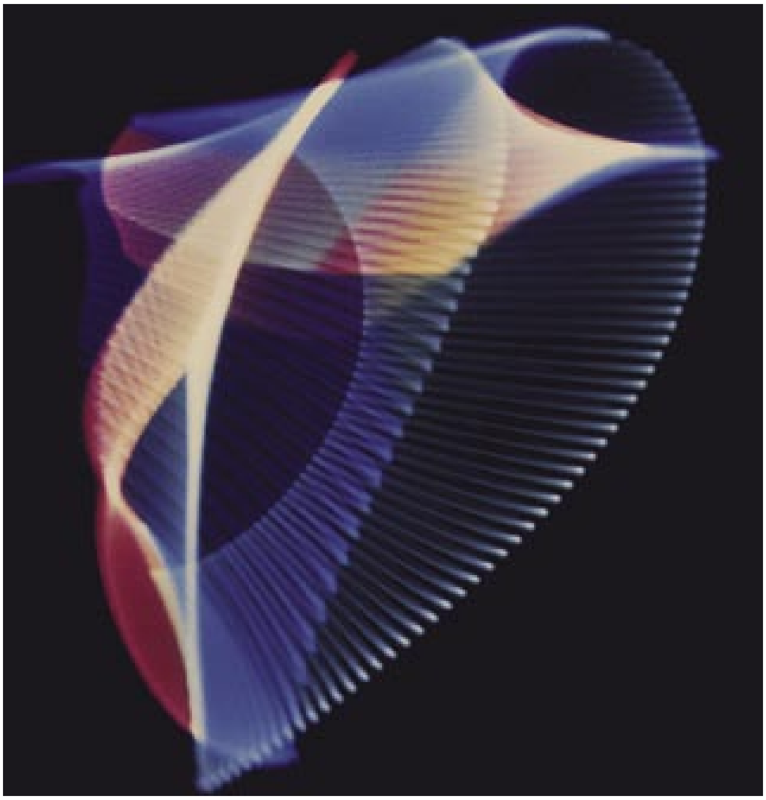
"People are always very surprised to learn that the dancer they just saw is a senior nuclear physicist! I really enjoy doing both and am proud that I can do both well."

Chang-Hong Yu





Laposky's Lights Make Visual Music



Ben Laposky, artist and long-time student of mathematical forms, poses in 1952 with his paintbrush: a boxy oscilloscope.

A boxy cathode-ray oscilloscope, covered with buttons and knobs and meters and lights, looks like something you know you shouldn't touch. The versatile electronic testing and analysis device—used as a prop in 1950s and '60s television and film to signal that science was being done—could double as a robot's midsection. It seems unlikely that someone could create wild gyrations of dancing light with such an unromantic instrument. But that's exactly what artist Ben Laposky did, creating some of the first graphic images generated by machine.

Laposky was a draftsman, a lettering artist, and a long-time student of mathematics who owned a sign shop in Iowa and dabbled in art in his spare time. Inspired by futuristic literature that envisioned "painting with light," he began turning undulating light from an oscilloscope into an electric trance dance. For 16 years beginning in 1950, he used the machine to manipulate basic waves into elegantly rhythmic designs he called "oscillons."

An oscilloscope turns electrical signals into lines on a screen; it can be used to measure everything from brain waves to engine vibrations. In a process he described as "analogous to the production of music by an orchestra," Laposky set as many as 70 controls on up to 60 oscilloscopes at a time to create his fleeting designs. He shot photos of the resulting patterns with high-speed film and special lenses; later, he added tinted filters to imbue the photographs with striking colors.

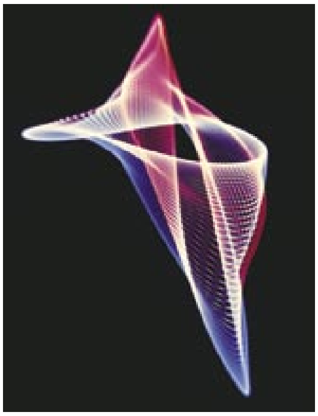
The artist said his "visual rhythms and harmonies of electronic abstract art" were "as pleasing to the eye as compositions of sound vibrations in music are pleasing to the ear." Oscillon photographs were often accompanied by electronic music from synthesizers made popular by Laposky's contemporary, Robert Moog, which were based on the same types of oscillators.

Laposky's musical art had been published more than 160 times and displayed at more than 200 exhibitions in the United States and abroad before the emergence of computer graphics upstaged him in the mid-1960s. "I believe my method is perhaps more in line with artistic effort than use of a computer," he said; but as interest in his art waned, so did his energy to create it. He stopped making oscillons altogether, but continued working at his sign shop until his death in 2000.

Much of his art has since disappeared. Laposky never tried to recreate any of his patterns, nor did he keep records of the control settings he used to make them. None of the 10,000 negatives he claimed to have taken have ever been found, and only 101 mounted images of the original set of 102 remain. What remains of his work, though, still impresses graphics gurus today.

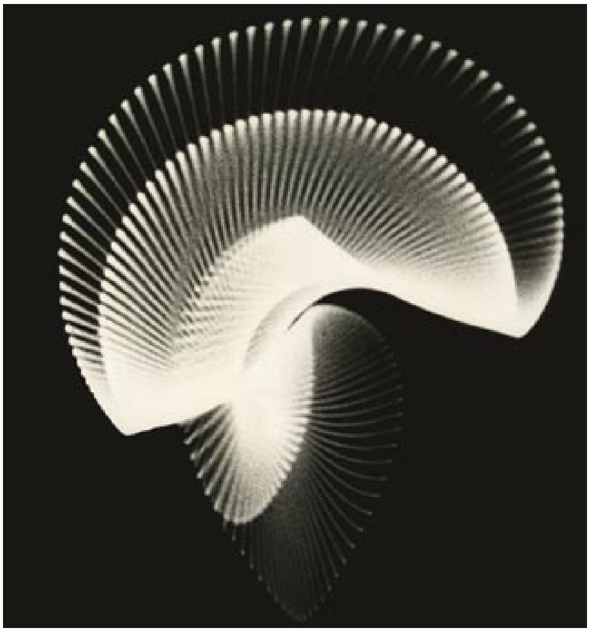
"The images are just spectacular. A lot of people can't believe they're looking at 50-year-old graphics," says Robert Krawczyk, Illinois Institute of Technology associate professor and director of Art@IIT Gallery. Last year, Laposky's 101-piece collection returned to IIT, where it had been exhibited from 1958 until 1961. "It was really nice to have the prints again," Krawczyk says. "It was as though his work had come home. Laposky's oscillons are still great examples of the relationship between science and art."

Text by Alison Drain
Images courtesy of Sanford Museum, Cherokee, Iowa



Above: Laposky tuned oscilloscope dials to make images and then snapped photos of them before they disappeared.

Below: The artist began making black-and-white pieces in 1950 and using filters to color his oscillons in 1957.



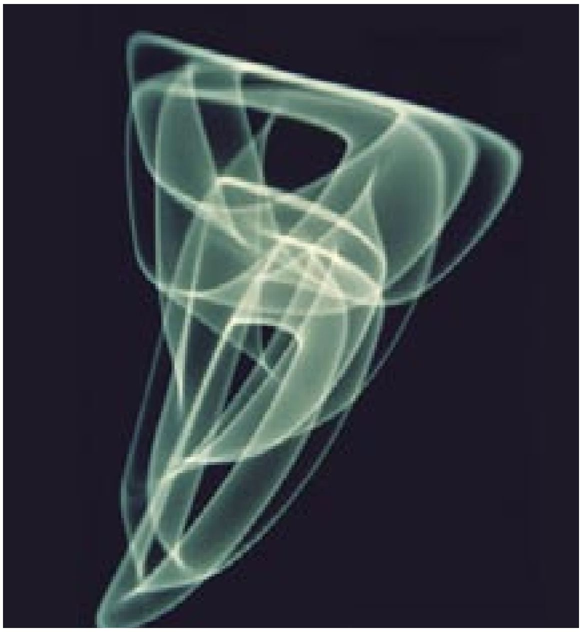


Photo courtesy of Charles Petit

Science writing: the changing landscape

About 40 years ago I was a University of California, Berkeley astronomy student with a summer job at the Mt. Wilson Observatory. I listened from a neighboring room as a solar specialist read, in the *Pasadena Star News*, an account of his own research. He moaned. He cursed. He exclaimed in frustration: "What this world needs is some good science writers!"

Angels sang. The clouds parted. Could I make a living reporting and writing the kinds of stories that nailed my eyeballs to the page—stories about the farthest galaxy, "living fossils," an even bigger rocket from Wernher von Braun? Sign me up!

Journalism has been my working life ever since, almost all on the science beat—first at a small newspaper in Livermore, then 26 years at the *San Francisco Chronicle* and another six at *US News & World Report*. It has been a good time.

Lately, though, times are not so good for many people like me.

Full-time science reporters covering breaking news in the traditional media are growing scarcer. Not only has the absolute number of newspaper science writers in the United States fallen, from about 90 twenty years ago to 80 or so now, as judged by the membership rolls of the National Association of Science Writers, but the percentage of members in that category has fallen by more than half to about 3 percent today. The rest are an increasing number of freelancers, public affairs officers for research institutions, book writers, and the like.

While there are still plenty of jobs in science writing, the loss of newspaper staff positions is critical because they are a key source of original reporting, the backbone on which many other layers of science journalism—magazines, radio, television—are built.

Science sections in newspapers are becoming rare. In 1989, there were at least 95 newspaper science sections; today there are about 30, and a rising share of them focus on health and medicine. The loss of this space makes it harder for staff writers to cover science topics in depth.

It's not that editors don't want science news. But in an era of steeply declining circulation and loss of traditional advertising, something has to go.

The Internet is a big factor in the decline. Want to see what the *Boston Globe* or *New York Times* has in its science section? It's free, a few clicks away—along with the rest of the paper's contents. Most traditional news outlets feel compelled to give their product away on the Web. That is not a winning business model.

As newspapers sag, surveys show that the public gets 40 percent of its science information from TV, 20 percent from the Internet, and just 14 percent from newspapers.

The changing state of the media ambushed me in late 2004. I took a more-or-less compulsory buyout from *US News*, which was scrapping everything in its science unit except for health and medicine coverage, and turned to freelancing.

At February's American Association for the Advancement of Science meeting in San Francisco I noticed a number of former newspaper writers—veterans not ready for retirement—without much to do. I heard from colleagues who were taking buyouts or simply quitting. Since then I have received a continuous stream of tips on who most recently left the daily news biz for university public relations, freelancing, book writing, or fishing.

So far, the fabric of newspaper science reporting is frayed, not shredded. The Associated Press has several full-time science writers in the United States and a few overseas, and big outfits with large corporate owners, such as the *New York Times* and *San Francisco Chronicle*, syndicate their articles widely. But fewer local papers have science writers on staff. We're all waiting for big media to find an online business model with fat enough profits to pay real reporters to dig out science news.

For me, science is an essential source of the purest sort of news. It is not just new names and places tacked onto familiar plots of crime, corruption, and catastrophe. It produces things new to human experience. Science stories bring to the public a world of rather smart people who usually have done something right and well. Given the usual run of news, that's a tonic. It would be a shame if these stories became even more rare.

Charles Petit

Charles Petit tracks science, medical, and environmental news in the English language press for MIT's Knight Science Journalism Fellowships at http://ksjtracker.mit.edu. His awards include the 1999 AAAS-Whitaker Prize for Science Writing, the 1995 C. Everett Koop Award from the American Heart Association, the 1991 American Institute of Physics Science Writing Award, and the 1990 Science in Society Award from the National Association of Science Writers.

Scientists have sought to create better medical imaging techniques ever since Wilhelm Röntgen's 1896 discovery that X-rays can reveal bones and other anatomical structures in a noninvasive way. These images of the skeleton of a mouse, taken by a small group of scientists at CERN in 1977, were an early attempt to improve a method now known as Positron Emission Tomography (PET).

The PET technique "illuminates" biological systems from the inside. The first step in this process is to inject short-lived radioisotopes into the subject. The isotopes decay and emit positrons, which annihilate and give rise to photons that emerge from the subject to be captured by a detector. A computer uses the resulting data to construct an image.

In this case, CERN radiobiologist Marilena Streit-Bianchi injected a mouse with a small amount of sodium fluoride labeled with the positron emitter fluorine-18, which was absorbed into the mouse's skeleton. As the fluorine-18 released its positrons, they annihilated immediately, creating pairs of photons that traveled in opposite directions along a straight line.

To record the pairs of photons, physicists Alan Jeavons and David Townsend placed a new type of particle detector—the high-density avalanche chamber—to the left and right of the mouse. The left column of images shows the raw data recorded by the detectors. A computer program, written by Townsend and stored on punch cards, used the data to reconstruct the actual annihilation locations. This revealed the distribution of sodium fluoride in the bones, shown in the right column with the mouse's skull on the left and its tail on the right.

Both Jeavons and Townsend went on to devote their careers to improving medical imaging. Jeavons started a company, Oxford Positron Systems, which still produces high-resolution PET systems to image small animals. Townsend is now a professor of medicine and radiology at the University of Tennessee. In 2004, he won the Clinical Scientist of the Year Award from the Academy of Molecular Imaging for his co-invention, with Ron Nutt, of the combined PET/CT scanner.

Kurt Riesselmann

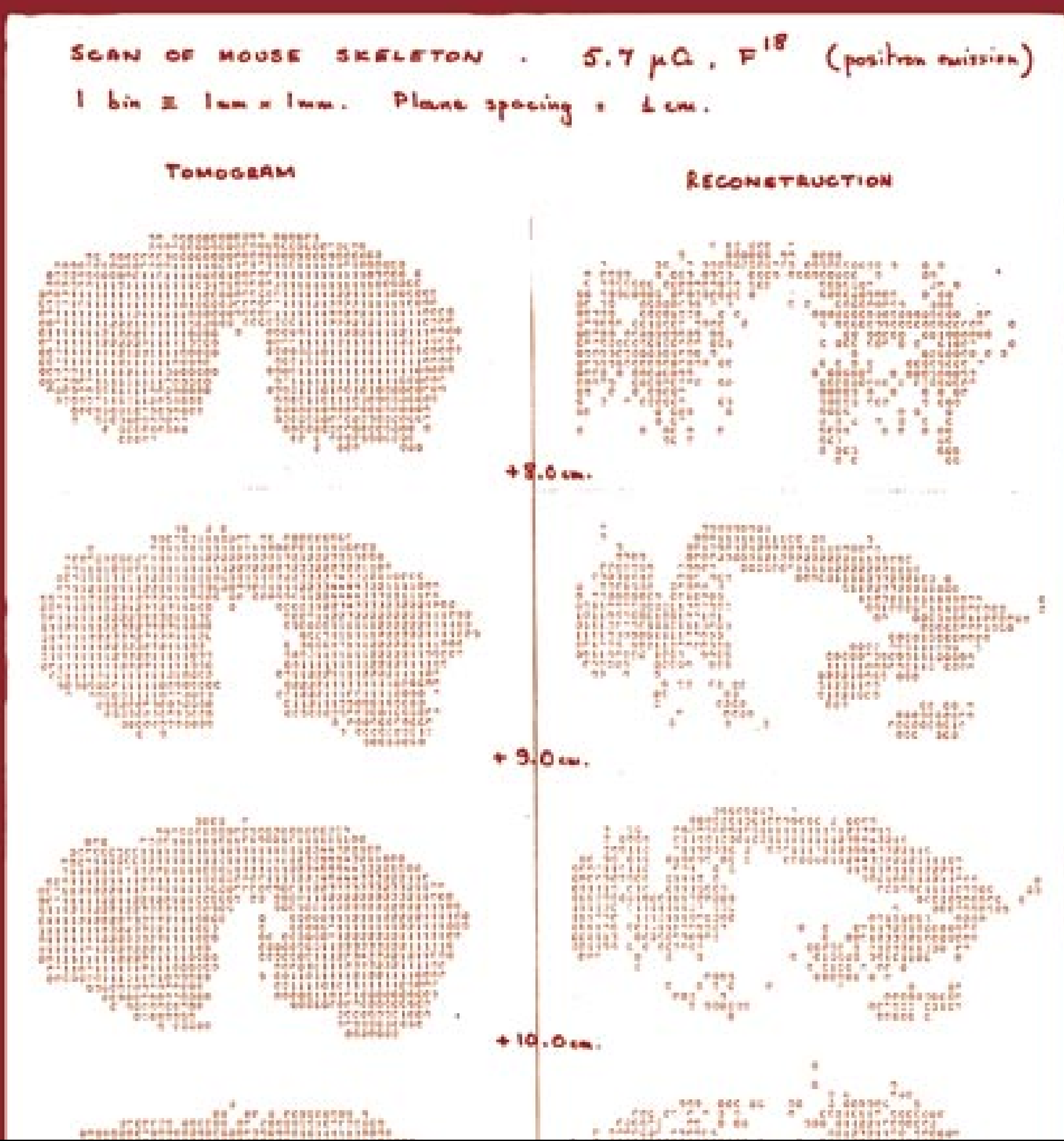


Image courtesy of CERN Courier. *Reprinted with permission.*

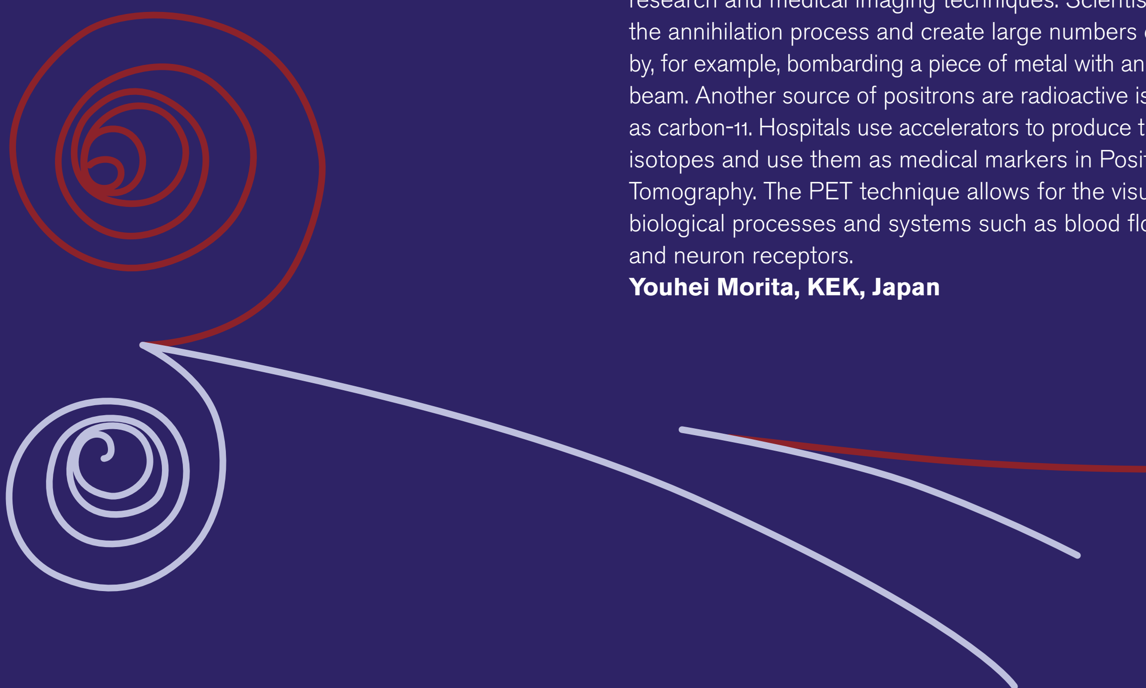
explain it in 60 seconds

A positron is the antimatter partner of an electron. It has exactly the same mass as an electron but has the opposite electric charge. When kept separate from matter, positrons can exist forever. However, when a positron meets an electron, the two particles annihilate into a flash of energy.

Theorist Paul Dirac predicted positrons and other antiparticles in 1928. Combining the classical description of an electron's motion with the new theories of relativity and quantum mechanics, Dirac found a puzzling solution to his equations: an electron moving with negative energy, which is impossible in classical physics. He interpreted his result as an antiparticle moving with positive energy. Four years later, physicist Carl Anderson observed in a cloud chamber experiment the positron predicted by Dirac. For their discoveries, both Dirac and Anderson received Nobel Prizes.

Today, positrons have numerous applications in particle physics research and medical imaging techniques. Scientists can "reverse" the annihilation process and create large numbers of positrons by, for example, bombarding a piece of metal with an intense electron beam. Another source of positrons are radioactive isotopes such as carbon-11. Hospitals use accelerators to produce these short-lived isotopes and use them as medical markers in Positron Emission Tomography. The PET technique allows for the visualization of biological processes and systems such as blood flow, metabolism, and neuron receptors.

Youhei Morita, KEK, Japan



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