symmetry

dimensions
of
particle
physics

A joint Fermilab/SLAC publication

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On the cover
What could a radial tire possibly have in common with particle physics? Accelerator technology. In physics, it boosts particles to nearly the speed of light; in industry, it's used in creating the materials that go into tires. As a bonus, this avoids the use of solvents that can pollute the environment.

Inside front cover
There's no question that particle physics is good for society in a number of ways—from boosting the economy to enhancing our quality of life and developing vital tools used in medicine, industry and other realms of research. Is there any way to put a dollar value on those benefits? See story on page 10.

Photos: Reidar Hahn, Fermilab

U.S. DEPARTMENT OF ENERGY

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Today's particle accelerators and MRI machines wouldn't exist without superconducting electromagnets. The road to the first patent for this technology took nearly six decades and ended in a photo finish.

C4 **Explain it in 60 Seconds: Particle Accelerators**
Particle accelerators (often referred to as "atom smashers") use strong electric fields to push streams of subatomic particles—usually protons or electrons—to tremendous speeds. They're used by the thousands worldwide in physics, medicine, and industry.

The benefits of particle physics

Basic science research, by definition, is done to better understand the fundamental nature of the universe. Although there is plenty of evidence that investment in basic research brings long-term returns to the economy far greater than the initial investment, tight economic times bring questions of "What is this investment getting us right now?"

The benefits arising from particle physics research are myriad, but usually reported anecdotally, not in the economists' and policy makers' preferred terms of quantifiable economic impact. So what does it mean for the economy that particle physics technology has led to life-saving medical treatments and equipment? What does it mean that computer hardware and infrastructure are improving faster than they would otherwise, or that the tires on our cars are cheaper, safer, and greener due to the use of accelerator technology? What does it matter that particle physics produces a highly trained, expert workforce that contributes to science, industry, and commerce, in ways far beyond basic research? To be honest, we can't yet quantify these impacts with anything but the roughest of estimates.

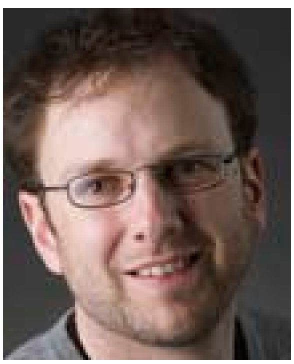

Photo: Reidar Hahn, Fermilab

We do know that investment in particle physics represents a significant outlay. For example, the US Department of Energy has contributed about $600 million to the Large Hadron Collider over the past decade. Over that period, that sum could have paid for a mere three or four top-level CEO salaries at $15-$20 million per year. Instead, it has employed hundreds of US physicists and engineers, provided work opportunities for thousands more, and invested in US industries that supplied LHC components. These industries are now better equipped to produce high-tech equipment and services needed by other areas of US society, especially in medical fields. How do we quantify those benefits?

Funding agencies can justify their investments more easily when they can point to concrete numbers to show how these investments affect the economy. Although those agencies are convinced of the value of particle physics in the long term, they don't yet have a shorthand description to demonstrate to their constituents that their decisions to support basic science result in net contributions to the economy. Particle physics needs to commission an independent, authoritative, transparent economic impact study to help funding agencies make their case: that investment in basic research returns much more than scientific results and benefits society in many concrete ways.

The particle physics community is convinced the assessment will be very positive. And that assessment won't even take into account the value of discovering answers to the most fundamental questions humans can ask about the universe.

David Harris, *Editor-in-chief*

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Photo courtesy of Alan Boyle

Fear factor

Can physics rock you in the head? Or destroy the world?

These aren't the kinds of questions you usually associate with particle accelerators. But over the past year, such questions have drawn the attention of millions of viewers and readers to particle physics in general, and Europe's Large Hadron Collider in particular.

There are several reasons behind the interest: Physicists might point to the fact that the LHC is the biggest, most expensive science experiment on Earth, bringing together brainy people from scores of countries. They might delve into a discussion of supersymmetric particles, quark-gluon plasma, and, of course, the elusive Higgs boson.

But I think the main factor is something less scientific, and more psychological: It's the sense of wonder and fear that surrounds the unknown.

Wonder and fear may sound like polar opposites, yet I argue that the LHC wraps them together. Scientists are fond of saying that this miles-wide contraption could create phenomena never seen before on Earth, and its experiments could produce totally unexpected results. That acknowledgment of the limits of our understanding opens the door to a sense of wonder about the unknown—and fear of it.

Fear is the more powerful response—especially when it's been so well-visualized in the form of a globe-gobbling black hole. For six months, I covered every twist and turn in a lawsuit filed in the United States that played on the fear of black holes and other unknowns. The "doomsday lawsuit" sought to have the LHC put on hold because scientists couldn't prove to the plaintiffs' satisfaction that there was absolutely no possibility of creating a catastrophic black hole.

Some scientists wondered whether it did more harm than good to write about this case. I had to wonder myself when I heard that particle physicists were receiving threats because of the doomsday talk. I worried even more when I received online comments from kids pleading with me to stop the end of the world. "I really enjoy my life and I don't want it to end soon because of science," one wrote.

The Internet can amplify such worries through Web sites, blogs, and forums that are sometimes dominated by people who don't seem to know the difference between science and science fiction. But that's the best reason for addressing the fear head-on. The best way to fill the knowledge gap is by providing answers when you can, rather than scoffing at the questions.

CERN, to its credit, expanded upon its previous safety studies and explained why the LHC won't cause the world's end, even under the unlikeliest scenario. The court ultimately dismissed the doomsday lawsuit. There's still the possibility of an appeal, and the fear factor may well come up again in mid-2009 when the LHC is back on line. But CERN's action demonstrated that the scientific community is willing to help ordinary folks face and understand their fear of the unknown—and explain the beauty of the wonders ahead.

Here are a few ideas for building on that foundation:

- Address the perceived risks—and revel in the benefits: Physicists might find it worth their while to get their message to the public via YouTube videos, blog postings, and even late-night call-in shows. The LHC rap video that attracted nearly 4 million views on YouTube is the best example. It shows that physicists can rock your world and have fun doing it. Next, show how advances in particle physics can lead to new applications in medicine, materials science, and energy.
- Prepare teachers for tough questions from their students: Based on the comments I received from kids, I got the impression that their teachers weren't getting enough information to address the doomsday questions adequately. It might be worth giving a helping hand to teachers at all school levels.
- Visualize the discoveries: One reason why the Hubble Space Telescope is such a crowd-pleaser is because its products are so visible to the public. Hubble is essentially a machine for manufacturing wonders. Are there ways to show in graphic terms what the LHC will discover? Can parts of the subatomic world ever become as familiar as, say, the Eagle Nebula in Hubble's "Pillars of Creation"?

The task ahead may be trickier than finding the Higgs boson—but anything that makes the weird world of the microcosmos more accessible is sure to make the unknown less fearsome in the future.

Alan Boyle, science editor for msnbc.com, blogs about particle physics, space exploration, and other topics at his Cosmic Log, http://cosmiclog.msnbc.msn.com

151-year-old recording sings for the first time; labs in *Jeopardy!*; fueling up on grass; cosmic rays point to better solar panels; electronic circuits with altitude; letters

Photo-illustration: Sandbox Studio

Physicist revives oldest recording of the human voice

In 1860, Parisian inventor Édouard-Léon Scott de Martinville set out to capture the beauty of a French folk song, "Au Clair de la Lune," using pig hair and soot.

He had a singer croon into a speaking horn, sending sound waves into a diaphragm. This vibrated a stylus—a hair plucked from a pig's ear—that scratched wavy lines into soot-covered paper.

Scott never intended to play back his recording. His apparatus, called a phonoautograph, was meant to preserve only a paper record of sound vibrations; Thomas Edison would not invent the phonograph until 17 years later.

So it was all the more remarkable when particle physicist Carl Haber of Lawrence Berkeley National Laboratory pulled the sound from Scott's soot-covered paper and brought the snippet of song back to life in March 2008. It was the earliest recording of the human voice ever successfully played back.

"It has been a really great way to use physics and technology to impact other areas of society," Haber says of his technique, which sprang from computer algorithms and imaging methods used to design particle detectors for CERN, the European particle physics center.

Giving voice to Scott's recordings is the latest of Haber's contributions to the preservation of historic sound. Currently, he's digitizing and recording turn-of-the-century stories and songs in Native American dialects, some now extinct, that had been captured on 3000 cylinders stored at the University of California, Berkeley.

The challenge is to restore those sounds without damaging their delicate cylinders of wax, foil, shellac, lacquer, or plastic. To do that, Haber takes a 3-D, high-resolution photo of the cylinder's grooves, which reflect various wavelengths, or colors, of light. Each color comes into focus at a different depth, allowing Haber to plot the topography of the area inside the grooves within a fraction of a hair's width.

A computer translates the images into sound pitches and durations. It also filters out damage to reduce static, remove skips, and fill in portions that are chipped, moldy, or worn, creating the equivalent of a retouched photograph.

Haber says that when the US Library of Congress finishes constructing a new center to store the world's sound recordings, he will move his imaging machine there.

You can hear Scott's recording, and others restored by Huber and his colleagues, at firstsounds.org.

Tona Kunz

I'll take particle accelerators for $200, Alex

Knowing accelerator trivia may someday earn you cash and a shot at fame.

During the past few months, the TV quiz show *Jeopardy!* visited Brookhaven National Laboratory in Long Island, NY, and SLAC National Accelerator Laboratory in California to shoot footage for rounds of questions on particle accelerators.

In a twist on traditional quiz shows, Jeopardy! host Alex Trebek gives contestants answers for which they must provide the questions. For example, under the category "Accelerators: Science at Nearly the Speed of Light from the Stanford Linear Accelerator Center," one clue stated: "In the two-mile-long linear accelerator, an electromagnetic wave pushes these particles along, kind of like surfers." The correct question: "What are electrons?"

The show's roving "Clue Crew" filmed video clues eight to 12 seconds long at various locations in the labs.

At Brookhaven, this involved standing in the accelerator tunnel for the Relativistic Heavy Ion Collider, or RHIC, to illustrate how magnets help push particles to nearly the speed of light. The segment has not been scheduled to air yet, but a local TV news report on the filming can be seen at http://tinyurl.com/55zvb9.

At SLAC, the camera crew filmed in the main control room as staffers worked in the background, seemingly undisturbed. But filming in the lab's klystron gallery was not so easy; the buzz from the microwave-generating klystrons that provide power to the accelerator's beam line nearly drowned out the speaker's voice. The episode aired in September; you can find clips at http://tinyurl.com/58r4q9.

What is the sound of discovery, Alex?

Calla Cofield

Photo: Fermilab

Fermilab grasses may thwart damaging greenhouse gases

Michael Miller watches grass grow for a living—super grass, of sorts, grass that could fuel a car and reduce carbon dioxide emissions at the same time.

He and other researchers from Argonne National Laboratory and the University of Chicago have turned 13 acres at Fermilab into an outdoor laboratory. Their goal is to find the best ways to use native prairie grasses to attack the global warming and fuel crises.

"I believe nature has given us a lot of variety to work with," says Miller, a senior Argonne scientist. "It is just identifying those traits that fit best with what man needs."

Miller and his colleagues are studying seven combinations of prairie grasses, including plots of switchgrass and big bluestem planted in June as well as native grasses that thrive on Fermilab's restored prairie.

He's trying to determine which factors produce the most durable, bountiful grasses for use as fuel. He'll also determine their carbon footprints, balancing the amount of carbon needed to grow the plants and turn them into fuel against the amount of carbon they sequester, or store, in the soil as their roots die and decompose.

By the end of 2009, Miller and his team hope to have a clearer picture of which combinations of grasses would create the most efficient, environmentally friendly feedstock for fuels.

Switchgrass already has known advantages over corn as a feedstock for biofuels. It grows four to eight feet tall in dense patches across the Midwest, flourishing in areas not normally tilled for crops. The grass needs replanting only once every decade, can grow with little or no fertilizer, tolerates drought, and sequesters the same amount of CO_2 that would be released by burning it for fuel. That makes the production of fuel from switchgrass carbon neutral or even carbon negative.

Even if native grasses are not harvested for fuel, they still provide a benefit by trapping greenhouse gases. Miller says 900 acres of Fermilab prairie store as much carbon dioxide in soil as 250 compact cars emit in a year.

"What we are trying to do is take advantage of our prairie system," Miller adds. "Fermilab's long history of maintaining and restoring the prairie gives us a lot of knowledge about the grasses."

Tona Kunz

Pierre Auger tests solar technology

As the Pierre Auger Observatory in Argentina collects cosmic rays for science, its thousands of solar panels are collecting data that could make solar power cheaper, more efficient, and more reliable.

Pierre Auger is "a fantastic experimental test," which is the best in the world right now for solar panels and their batteries, says Angeles Lopez Aguera, dean of physics faculty at Santiago de Compostela University in Spain. "Industry never, never will be able to have this large an amount of experimental data."

Spain is a global leader in the production and design of solar panels and home to the 11 biggest photovoltaic power plants in the world (see image below). Much bigger plants are on the drawing board worldwide, including a 550 MW installation proposed in California that would generate enough electricity for roughly 550,000 homes.

Battery outages in these large solar parks can take two weeks to reach and repair. Reliability is also an issue for solar panels in remote areas, from isolated villages in developing countries to the Colorado site where a second Pierre Auger Observatory is planned.

So Santiago University is working with two Spanish corporations—including ISOFOTON, the second-largest producer of solar panels in Europe—to monitor the performance of the 3320 solar panels that power Pierre Auger's detectors, which are scattered across 1200 square miles of semi-arid pampas. Spain provided most of the solar panels and Brazil most of the batteries as their contributions to the international observatory.

The companies hope the 70 million bits of data the panels provide each year will help them produce solar panels and batteries that last longer, withstand long periods of extreme temperatures, better respond to peak power needs, and optimize the amount of sunlight converted to electricity.

Researchers recently created a prototype "intelligent" regulator for the solar panels that will be tested in Spain and at the Colorado observatory. The regulator will sound an alarm when a battery is about to go out so it can be replaced, avoiding power outages and optimizing the life spans of batteries.

"This is important for Pierre Auger, that is clear," Aguera says, "but it is also important for the big solar parks."

Tona Kunz

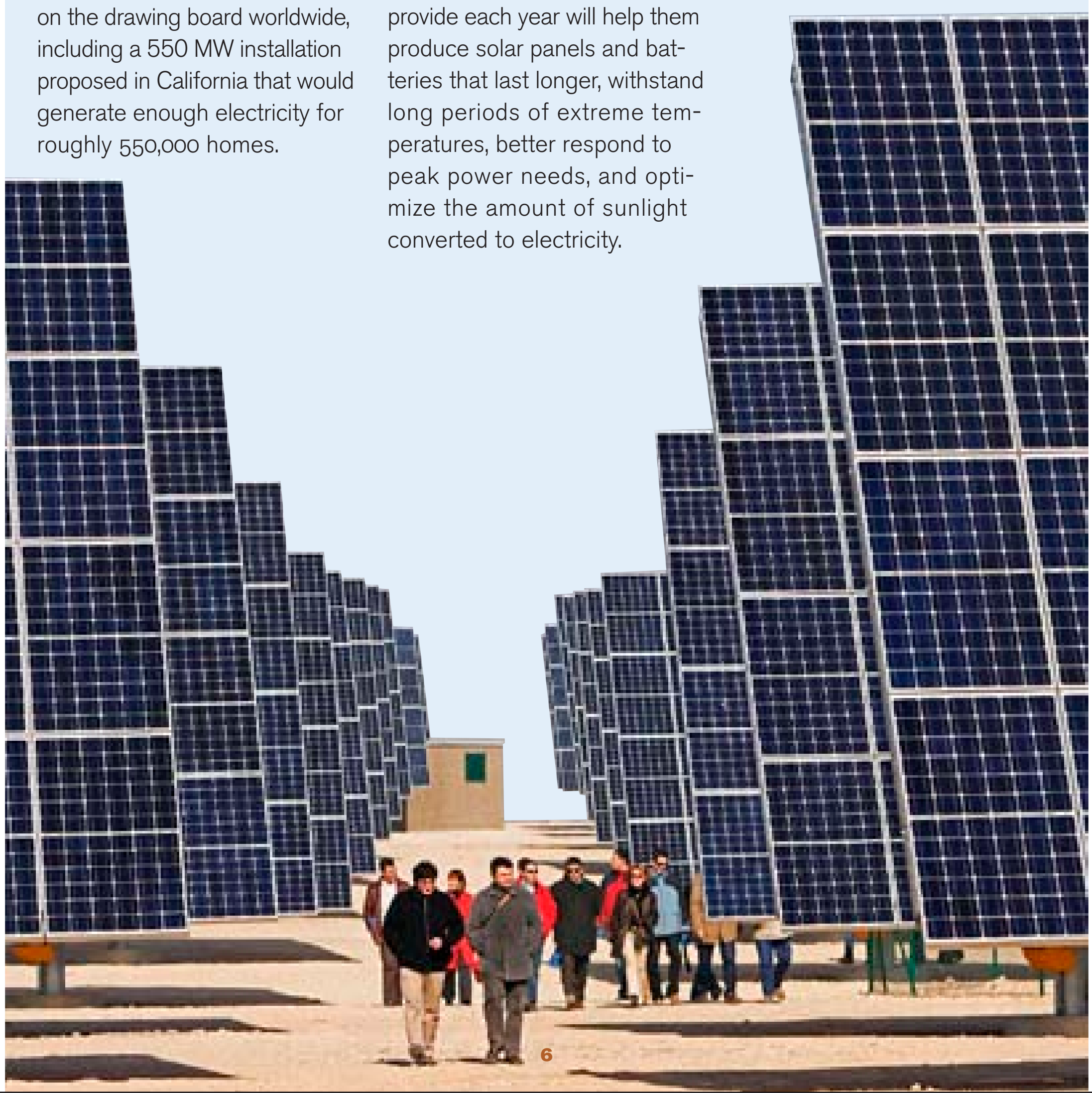


Photo courtesy of Acciona Energia

Labs and industry perfect 3-D chip

High-tech businesses must constantly innovate or become obsolete. But when it comes to investing in new machinery and adopting new techniques, industry can be timid, says Bob Patti, chief technical officer of Tezzaron Semiconductor.

That's where research laboratories come in. Freed from market constraints, they can afford to break new ground and demonstrate that an innovative technology works. Companies can then adapt the technology, with minimal risk, for products with mass appeal.

In this case, Fermilab has recruited more than a dozen other research labs to work with Tezzaron to develop three-dimensional computer chips.

Fermilab has been working on 3-D chips since 2006 as a way to make detectors that track particles coming out of high-energy collisions more precise and compact. Now it hopes to use industry's economy of scale to accelerate the production of the new chips.

Tezzaron benefits by sharing the cost of developing new prototypes and by demonstrating to potential customers that the 3-D chip is cost-effective.

Once companies see others out there using a new technology, "they feel more comfortable placing bets on it," Patti says.

For almost a decade, Tezzaron has been developing 3-D chip technology to give devices such as cameras and cell phones more memory and to improve the speed and energy efficiency of information processors.

Traditional integrated circuits are flat and connect at the edges like tiles. "They were like one-story buildings built on different lots," Patti says.

In the late 90s, companies began stacking the flat chips and connecting them at the edges like buildings with multiple stories—but with no way for electrical currents to move up and down, aside from outdoor fire escapes.

Photo courtesy of IBM

In today's 3-D circuits, wires run directly from one layer to the next, a shorter distance that uses 40 percent less energy.

"We're installing elevators," says Gretchen Patti, a member of Tezzaron's technical staff.

Working with research laboratories pushes the company to improve its product, she says.

"If you're working with a client who is not afraid to push the envelope," she says, "you're more likely to come up with something better than expected."

Kathryn Grim

letters

Unfair dice

I enjoy the magazine very much, but must register my complaint about the illegal dice depicted on the rear cover of the March/April 2008 issue. The opposite faces on each legal die must add up to seven, obviously not possible with those on the cover unless they have really been "doctored." Anyway, don't shoot craps with this guy!

Nils I. Larson

After sifting through the 14 dice on the back cover of the March/April 2008 issue, I discovered and confirmed that ten of them are very rare indeed. Or at least they are rare in any legitimate gaming house. As shown, these ten dice could dramatically change the outcome of the game, but would definitely affect the user's ability to roll again, if caught using them.

Guy R. Martino

Antimatter novels

I'm surprised that William Higgins' brief article about antimatter in science fiction (September 2008) ended so abruptly, especially without any reference to Jack Williamson's *Seetee Ship* and *Seetee Shock*. I've enjoyed those two so often that the pages are falling out, needing glue for rebinding.

What's great about your article is it reminded me about my favorite sci-fi topic, which I've overlooked for some time. I've been busy re-reading my A.E. van Vogt collection.

Now I need to check eBay for other antimatter novels, as well as the missing van Vogt books I'd planned to repurchase!

Walter P. Kraslawsky

Highlights from our blog

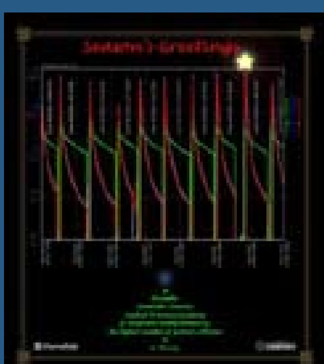
Project X collaboration forms, project moves forward

December 18, 2008

Project X, a Fermilab-hosted international accelerator facility, could break ground as soon as 2013. Accelerator experts from around the world gathered at Fermilab last month to work toward establishing a formal collaboration and further plans for Fermilab's proposed proton accelerator.

Physics lab holiday cards

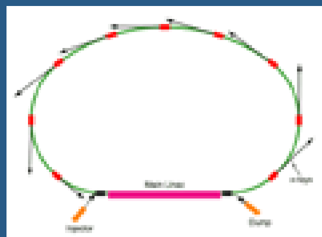
December 18, 2008



A tradition in many organizations is to send out a holiday card. With the near ubiquity of the Web among lab audiences, many of these cards are solely electronic, leaving the wood that would have gone into cards for Christmas trees or other uses! Here is a selection from a few science organizations, showing the usual geeky tendency to incorporate some kind of scientific imagery as a visual metaphor.

Energy recovery linac demonstration successful

December 16, 2008



An ERL is a combination of a linear accelerator and storage ring with a few twists thrown in to make the machine incredibly efficient. They allow particle acceleration at much lower power use for the facility, or much higher-energy acceleration for the same power use. Now one has been shown to work at Accelerators and Lasers In Combined Experiments, or ALICE, at the Daresbury lab in Cheshire, England.

In person at Nobel week in Stockholm

December 12, 2008

A guest essay from David Hitlin, Caltech physics professor and founding spokesperson for the BaBar collaboration at SLAC National Accelerator Laboratory, recounts the celebrations and festivities of the Nobel week in Stockholm, where he attended the ceremonies as a guest of Makoto Kobayashi.

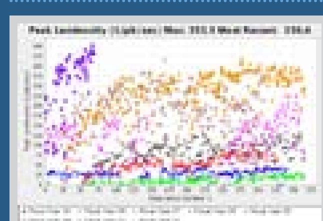
Do neutrinos and antineutrinos behave differently?

December 12, 2008

Stretch out your hand, and a trillion neutrinos cross it within three seconds. Yet little is known about these invisible particles. Scientists do know that neutrinos have mass and that they can morph from one type into another—a process called neutrino oscillation. The MiniBooNE collaboration at Fermilab has a preliminary result that sheds more light on neutrino oscillation. This is the collaboration's first result with antineutrinos, the antiparticles of neutrinos.

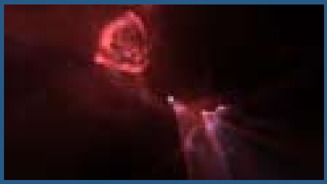
Another record! Tevatron accelerator surpasses expectations repeatedly

December 11, 2008



In the past five years, Tevatron's, luminosity—the number of collisions per second—has increased six fold. In the last six weeks alone, overall luminosity has improved 10 percent, generating more than a dozen luminosity records, sometimes multiple records in one week. Just since October, the Tevatron has had nine of the top 10 stores in its history.

Lights, camera, render
December 9, 2008



A red plume of hydrogen gas streams in three dimensions across a movie screen that almost spans the width of a dark conference room. Within the plume a brilliant white spot forms. The spot expands and quickly explodes into an orange and red cloud. Soon this cloud dissipates and a new bright dot grows elsewhere on the screen. In less than a minute, the movie has told the story of a young galaxy forming.

Flat Children visit labs by mail
December 8, 2008

Hand-drawn by 8-year-old Johnny, Flat Johnny took a tour of the Large Hadron Collider with researcher Sarah Demers. Flat Maya did the same with SLAC's Travis Brooks.

Free multimedia education material on particle physics, accelerators
December 4, 2008

If you want to explain particle physics, accelerators or colliders to friends, family, students, or others you encounter, you won't want to miss this Web site. The University of California, Santa Barbara has announced the winners of a contest to make particle physics accessible in high school classrooms. You can see them at www.kitp.ucsb.edu/

Should you care about particle physics or the Higgs boson?
December 2, 2008

In an era of tight budgets, why care about basic research—science done for knowledge's sake? The documentary *The Atom Smashers* put the question on the screen and drew some compelling answers.

The Panofsky turkey constant
November 26, 2008

Just in time for the Thanksgiving holiday, Nicholas Panofsky shares a flavorful tidbit of Panofsky family lore with the precise equation for determining the cooking time for a turkey.

Gorgeous physics photos from the *LIFE* archives
November 19, 2008

The archive released by Google yesterday contains a number of gems, from Einstein's messy desk to a 1939 cartoon from a Berkeley cyclotron bulletin board, portraits of famous physicists, and a chain of nails.

Particle physics gives boost to areas of Latin American
November 18, 2008

In the quest to improve the quality of life in developing countries, people focus on key barometers of affluence, such as literacy rates and affordable food supplies. Few think of high-energy physics as a grassroots growth engine. But it can be. A good example is the Pierre Auger Observatory in Malargüe, Argentina, a rural area of isolated ranches nestled at the base of the Andes.

You can find the full text of these and others at www.symmetrymagazine.org

Photos: Reidar Hahn, Fermilab

Particle physics benefits: Adding it up

By Elizabeth Clements

Stories abound about how particle physics benefits education, the economy, and society as a whole. Quantifying those benefits would help particle physics better demonstrate its value to the country.

As a lead machinist at Argonne National Laboratory, Frank Meyer recognized the need for industry to supply complex equipment for scientific research. So in 1966 he started Meyer Tool & Manufacturing on a part-time basis in his garage. Three years later, he left Argonne to expand his machine shop into a full-time manufacturing facility.

Around the same time, Fermilab, then called the National Accelerator Laboratory, began construction. The fledgling Meyer Tool became the lab's key supplier of cryogenic equipment needed to cool the accelerator's superconducting magnets.

Today Meyer Tool's list of customers includes CERN in Geneva, Switzerland; Lawrence Livermore National Laboratory in California; the National Synchrotron Radiation Research Center in Taiwan; and the Canadian Light Source in Saskatoon, Canada.

Particle physics has many episodes like this. They are real and sometimes very powerful stories. But in a time of severe fiscal challenges, individual stories are not enough.

Meyer Tool & Manufacturing made key components for the cooling system in the Large Hadron Collider at CERN.

Photo: Fred Ullrich, Fermilab

"What does the US lose if we trade away elementary particle physics?" asked Mike Holland of the US Office of Management and Budget at Fermilab's Users' Meeting in June. "My guess is that the nation would be less competitive and innovative without you, but I don't have anything other than a few anecdotes to make that case."

The Particle Physics Project Prioritization Panel (P5) believes that an objective and rigorous study of the benefits of particle physics on the nation's economy could help make the case. Economic impact studies quantify the amount of new income that a facility or service adds to the economy. In a report published in May 2008, the panel stated:

"At this time there exist few quantitative analyses of the economic benefits of particle physics applications. A systematic professional study would have value for assessing and predicting the impact of particle physics technology applications on the nation's economy."

As envisioned by the P5 group, the proposed study would not focus on the local effects of just one laboratory or institution. Rather, it would cover the broad impacts of the entire field of particle physics across the United States.

The ripple effect

Some economic impacts are easy to quantify, such as dollars spent on payrolls and equipment. Then there are the non-fiscal impacts that add social value, such as training teachers and maintaining open space.

"The waves of that pebble going out into the water must be huge," says Dave Brummel, mayor of Warrenville, a town of 14,000 just to the east of Fermilab.

Opposite page: The semiconductor industry relies on accelerator technology to implant ions in silicon chips, making them more effective in consumer electronic products, such as computers, cell phones, and MP3 players.

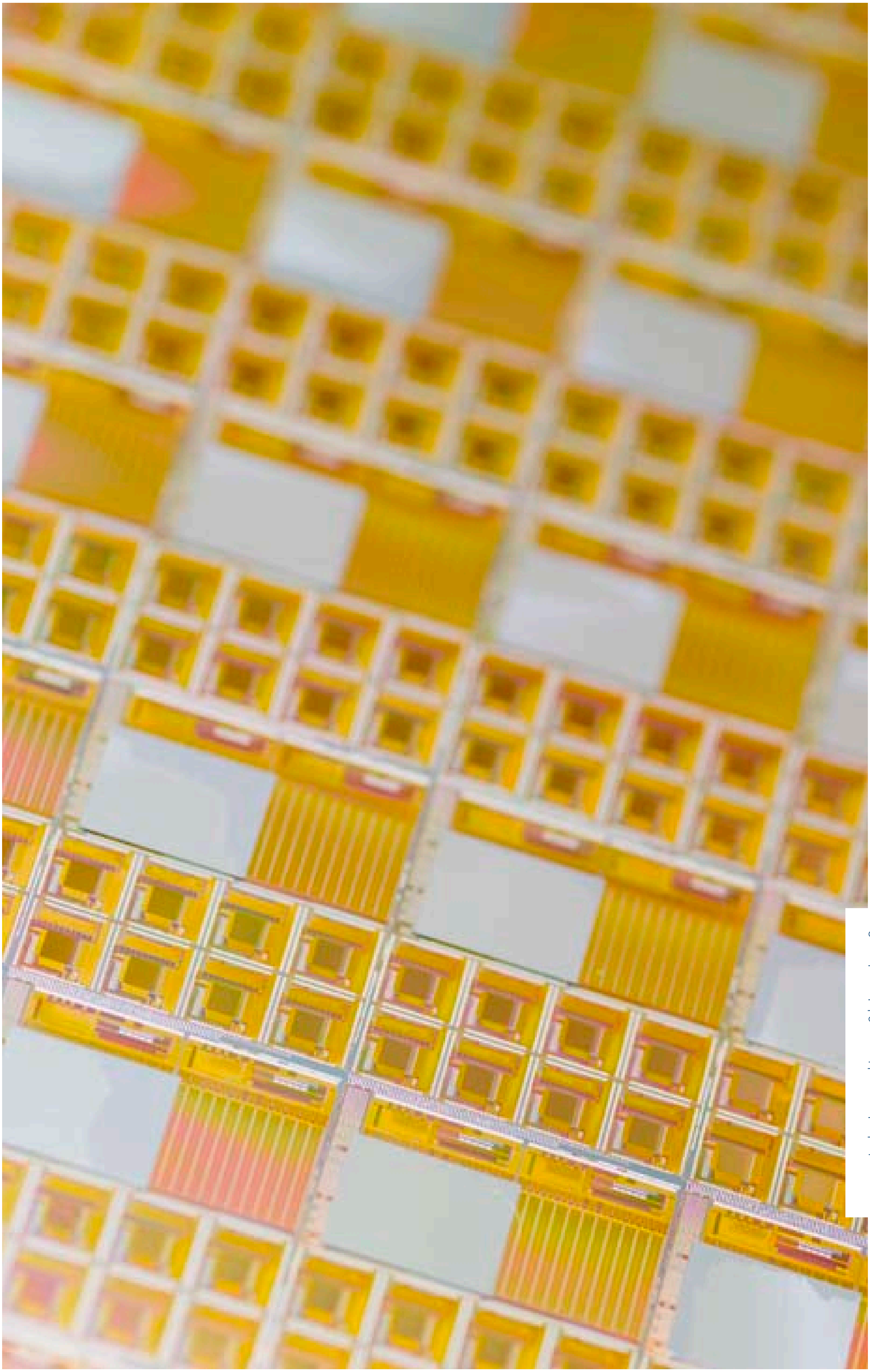
Photo: Reidar Hahn, Fermilab

Fermilab, for example, employs about 2000 people with a total payroll of $148.7 million. Ninety percent of the lab's employees live in the local area surrounding Batavia, a suburb 40 miles west of Chicago, and pay an estimated $4 million annually in Illinois income tax. On average, the lab spends about $115 million each year in procurements—purchases of everything from high-tech equipment to paper clips. A significant percentage of that total goes to small businesses in Illinois, such as Meyer Tool and Manufacturing.

"Projects can range from a few thousand dollars to large ones for hundreds of thousands to millions," says Ed Bonnema, vice president of operations at Meyer Tool. "Depending on the year, national laboratory work can vary from 50 to 80 percent of our work."

While the numbers are easy to count, Bonnema believes they are small compared to the indirect effects that should be appraised. "A direct line of descent between the basic research done at particle physics labs and things like the World Wide Web, MRI machines, cancer therapy, and superconductors can be made," he says. "That's the stronger case of economic impact that should be described."

Brummel also recognizes the ripple effect that particle physics has on society. Warrenville and West Chicago will each soon be home to $200



million proton therapy treatment centers that together will care for 3000 cancer patients each year. The development of this technology, he says, "would not be possible without particle physics."

He adds that the most immediate benefits of having a research facility like Fermilab next door are the simplest. "I raised two kids biking out at Fermilab," Brummel says. "A lot of the benefits, such as the open space, are esoteric. But then there is the prestige of having this kind of place right there."

Researchers used the Advanced Photon Source at Argonne National Laboratory to develop Kaletra, one of the world's most-prescribed drugs to fight AIDS.

Photo courtesy of Abbott Laboratories

Boosting schools and businesses

Fermilab's cutting-edge research has attracted world-class scientists for decades. In the 1970s, when physicist Bob Kephart was a postdoctoral researcher at Stony Brook University in New York, the prestige of working at the nation's premier particle physics laboratory drew him to Illinois. "After working at Fermilab for two years on an experiment, I had offers from several universities," he says. "However, I realized that I could either live at the place where I was doing research, or I could be on planes all the time. So I chose to live here."

Like many staff scientists who came to Fermilab early in their careers, Kephart stayed. He married another Fermilab employee, built a house in nearby Elburn, had two kids who went to local schools and is now one of the directors at the lab.

Not every scientist will relocate to Fermilab, but thousands visit every year to attend meetings and workshops. They stay in local hotels, eat in local restaurants, and shop at local stores. During peak times at the lab, the Comfort Inn in Geneva estimates that 25 percent of its business comes from Fermilab.

"Fermilab is one of three or four companies that we consider our base business," says Mary Bonner, general manager of the inn. "A facility like Fermilab stays busy all year long. It always drives traffic to us."

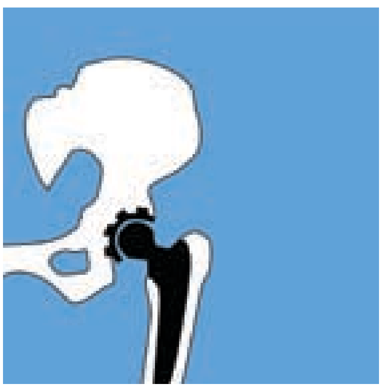
As a result of that steady business, the Comfort Inn is able to reinvest money into upgrading the hotel.

For Robin Dombeck, a middle-school science teacher at Northbrook Maple School in the northern suburbs of Chicago, a laboratory like Fermilab adds social values that indirectly benefit the economy.

In 1983, Dombeck participated in a Fermilab pilot program called "Beauty and Charm," a professional development course for teachers, which was named for the two types of quarks now usually known as bottom and charm. At the time, she was in her second year of teaching science at a middle school in LaGrange, Illinois. "As a result, my little school got affiliated with a world-class institution like Fermilab," she says.

The following year, the program leaders asked Dombeck to come back as a workshop instructor, combining her teaching experience with Fermilab's expertise in particle physics to create a strong, ongoing program.

"The idea of teaching middle-school students particle physics was a new concept then," Dombeck says.



Artificial human joints, such as those for the hip, last longer when industry uses particle accelerators to implant ions and harden the metal material.

Illustration: Sandbox Studio

Because of Fermilab's professional development courses, teachers like Dombeck learned how to bring hands-on lessons and inquiry-based learning practices into their classrooms. She says, "The strategies that I learned at Fermilab enable me to look at a lesson that is less than exciting and make it into something good."

Better teachers improve schools. Good school systems attract people to live in the area. While placing a numerical value on a service like professional development would be tough, and not advisable according to economists, the social benefit is significant.

"Laboratories like Fermilab create social values that are being made available to many other organizations. They are hard to trace, but they are very real," says Bill Batte, president of Capital Management Solutions, a financial consulting firm in St. Charles, Illinois.

The need for numbers

On the local level, particle physics laboratories create jobs and support small businesses. As a field, particle physics helped develop cancer therapies, medical diagnostic tools, and the World Wide Web. All of these add value to particle physics, but their benefits have never been properly assessed.

Holland, who reviews the budget for the US particle physics program, told an audience of Fermilab scientists that he hears examples like these every day, but needs better data to make a convincing case for physics. "Equip me to make your case," he said. "Ideas and tools are your calling cards, but you need robust theory to help explain them. An avalanche of spin-offs is not enough."

A systematic study would go beyond a mere list of examples and demonstrate how the knowledge and highly skilled workforce that particle physics produce percolate through the US economy. It would document the connections between particle physics and the science and technology that other fields of industry use today, and it would quantify how the national economy would suffer if funding for particle physics continued to diminish.

Holland stressed that for such a study to achieve street credibility, particularly on Capitol Hill, the process—which should be rigorous, expert, and independent—is more important than the outcome.

"Get professional help," he says. "Engage economists, sociologists, science policy scholars, and historians. They will have the tools and credibility to help."

The Office of High Energy Physics in the US Department of Energy has already conferred with economists and supports the idea of conducting an economic impact study.

"The innovative ideas and technologies of particle physics have helped transform the way we live," says Dennis Kovar, associate director for the Office of High Energy Physics. "A rigorous and honest study is necessary to fully appraise and attribute the contributions of particle physics to the economic impacts associated with these transformations."

The auto industry uses particle accelerators to treat the material for radial tires, eliminating the use of solvents that pollute the environment.

Photo: Reidar Hahn, Fermilab

Economic methods

Economists acknowledge that conducting an economic impact study on particle physics will not be simple. But the right tools and an objective approach make it possible.

"We find it interesting. You could make an entire academic career out of a study like this one," says George Tolley, a professor of economics at the University of Chicago and president of RCF Economic and Financial Consulting.

Tolley explains that one possible way of approaching the study is to select four or five technologies that have come from particle physics. Economists could analyze specific case studies that represent the benefits of particle physics research to society and illustrate the ongoing innovation process. Tangible products that economists can count, such as ion-implantation devices, make it possible to quantify their impact on the national economy.

Don Jones, vice president at RCF Economic and Financial Consulting, advises that a study should try to identify things that could not have been done without key contributions from particle physics. "This kind of study hasn't been done yet in particle physics, but it is the kind of aggregation that economists have the techniques to do," Jones says.

For example, accelerator technology made it possible to create ion implantation devices, which generate ion beams that scientists use to modify semiconductors and harden materials for hip-replacement joints.

Using the case-study method, economists would work closely with scientists and members of industry to determine which products to analyze and just how much of their economic impact can be attributed to particle physics.

Then, to quantify the value that a technology such as ion implantation contributes to the marketplace, economists would subtract the cost of producing it from the total sales reported by US companies.

"You know that you are going to get a low estimate because you're not going to capture everything, but this number will be credible," Jones says.

That is important because credibility has been an issue for some previous attempts to quantify the impact of scientific development.

In many instances, particle physics cannot claim full credit for creating a new product, but economists can measure the impact the field had in speeding up its development.

For example, if particle physics didn't exist, it is likely that sooner or later someone would have invented the World Wide Web. But because particle physics collaborations needed a way to quickly share large amounts of data, a computer scientist at CERN invented it and physicists pushed it forward.

"Particle physics may have accelerated its introduction by 10 years," Jones says. "What is the value of having something like the World Wide Web for those 10 years?"

Opposite page: Superconducting wire developed for particle accelerators made it possible to create powerful magnets for medical diagnostic tools such as magnetic resonance imaging, or MRI.

Photo: Reidar Hahn, Fermilab

In 1985, John Kay, a leading economist in Great Britain, and Sir Chris Llewellyn Smith, the former director general of CERN, published a paper that estimated what the economic impact would have been if electricity had been discovered one year earlier. It worked out to 5 percent of the annual income in Britain, or the equivalent of $40 billion at that time. Put another way, the economic benefit of accelerating the development of electricity by just one year exceeded the cost of all fundamental scientific research undertaken in Britain since the time of Newton.

"That is an astounding result," Jones says.

Naturally, a single study such as this one should be taken with a grain of salt, as it is just one example and this is a difficult problem to study. But it provides an approach that could be useful.

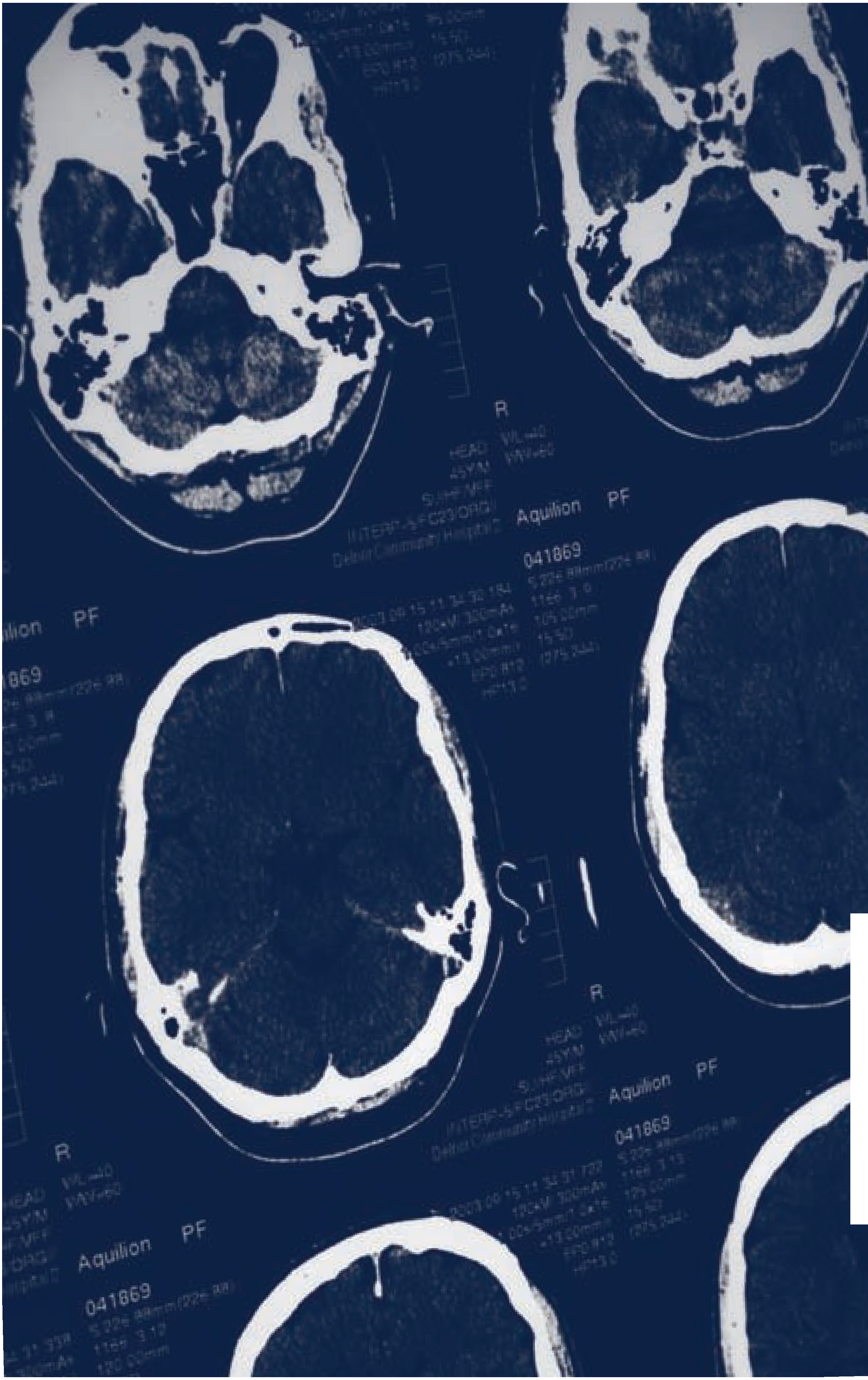
Making credible assessments

John Crompton, an economist at Texas A&M University, says that economic impact studies "are useful policy tools, but unfortunately they are often not used correctly." He considers most of these studies nothing more than political shenanigans: "Every now and then you find an honest one."

Crompton warns that certain methods make it very easy to manipulate a study to produce desirable numbers. An economic impact study on particle physics would need to steer clear of the pitfalls that have tarnished other efforts.

Ultimately, the study should illustrate what the national economy would lose if the field no longer existed.

"An economic impact has a technical meaning for economists—new money coming in," Crompton says. "It's powerful stuff when done correctly."



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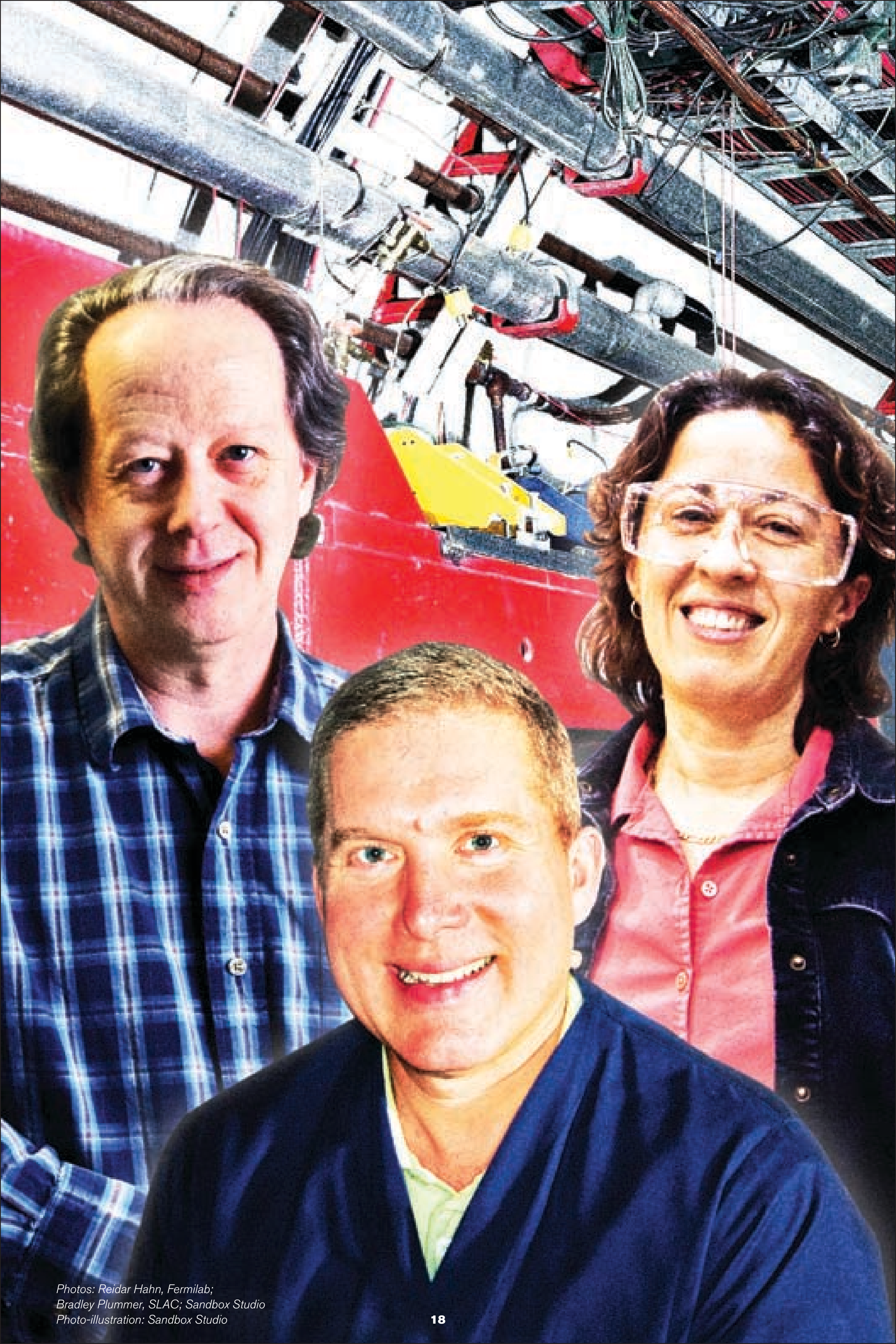


Photos: Reidar Hahn, Fermilab;
Bradley Plummer, SLAC; Sandbox Studio
Photo-illustration: Sandbox Studio

A fearlessly creative workforce

By Tona Kunz

Many of the people trained in particle physics move on to jobs in industry, where their skills are in high demand. There you can find a theorist exploring for oil or an accelerator scientist working on cancer treatments.

Theoretical physicist Jorge Lopez was looking forward to working with the world's largest atom smasher—the Superconducting Super Collider, then under construction in Texas—when Congress pulled the plug on the project in 1993. With the biggest opportunity in his field gone, he decided to give industry a look.

At his first job interview, he found himself explaining his work on string theory—a theory that attempts to unify all the fundamental forces but requires at least 11 dimensions, rather than the four currently observed—to a Shell Oil representative.

To his surprise, this esoteric chat didn't sabotage the interview.

"I got a job offer that day," Lopez says. "I guess I impressed them as someone who could address different problems and solve them. I've met a lot of people who have similar stories to mine, and some even work on my team."

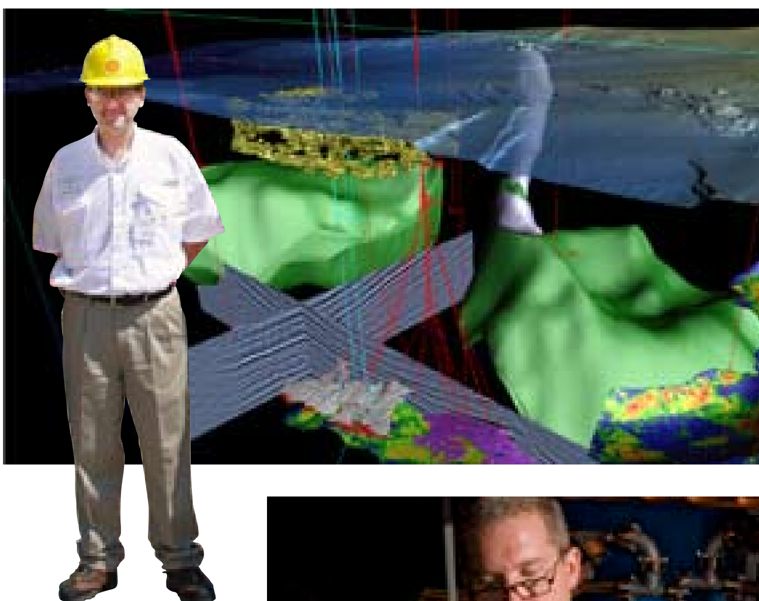
Unbeknownst to many, high-energy physics serves as a training pipeline for industries such as medicine, security, and finance that touch everyday lives.

Rather than mourn this migration of physicists, engineers, and computer analysts into the broader society, the field sees it as added value—a way to give back to taxpayers and the community.

"People may be your most important product," Michael Holland, who reviews science projects for the US Office of Management and Budget, told employees and users at Fermilab in June. "They create an important element of the national innovation system."

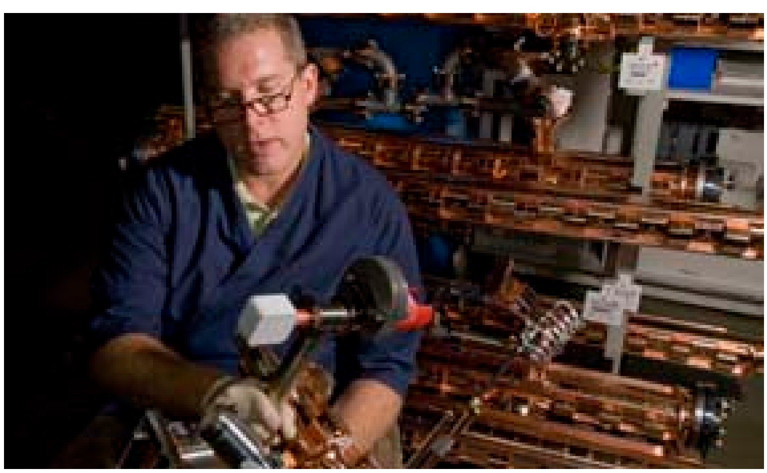
A unique training ground

High-energy physics provides training not found elsewhere: collaborating with hundreds of scientists all over the world; designing cutting-edge tools; working with machines much too large and expensive for any one university to build; and grappling with mathematical equations and abstract concepts on the edge of current understanding.



In his job at Shell Oil, Jorge Lopez (left) of Texas uses critical-thinking skills he learned as a theoretical physicist to develop 3-D integrated modeling programs such as the one behind him, which shows the Gulf of Mexico. This helps the oil company find the safest and most economically viable areas to drill.

Photo and modeling image courtesy of Jorge Lopez



Dave Whittum (right) works for Varian Medical Systems in California, designing accelerators like the one he's holding for cancer treatment and cargo scanning.

Photo: Bradley Plummer, SLAC

Just how large an impact this has on the workforces of other fields is difficult to assess. Anecdotes from former physicists and their employers abound; concrete statistics do not.

Yet in a time of shrinking federal funds and stiff competition for research investment, policymakers want to know: Does the "big bang" science offer a wider-reaching bang for the federal buck?

Increasingly, Congress is asking where people who have trained in the field go on to work, says Usha Mallik, a physicist at the University of Iowa who is involved in efforts to track physics graduates.

"It is not everyone who becomes a high-energy-physics professor or a researcher at Fermilab," she says. "From looking at past surveys and listening to anecdotes from professors and laboratories, a tremendous number of high-energy-physics students go into industry. Some go into government. Some even go on to Wall Street."

Finding oil, treating cancer

Lopez is a case in point. He taught physics at Texas A&M and Rice universities. He worked with Fermilab's DZero experiment when it discovered the top quark in 1995. Now he helps Shell Oil tap into hard-to-reach oil fields, and leads an international team developing new technology to monitor the oil and gas that fields contain.

"You want to place a drill bit where you have the most chance of success, the least expense, and optimal safety," he says. "All of the knowledge I have from basic physics is applicable today"—in particular, the concept of using computer models to test theories and simulate how equipment will work.

"We are always looking for people who can think creatively," Lopez adds. "Here we have a lot of physicists."

David Whittum used to teach students at Stanford University how to design microwave linear accelerators for research at Fermilab and SLAC National Accelerator Laboratory. Now with Varian Medical Systems in California, he develops accelerator-based tools for treating cancer. The technology also has potential for scanning cargo to find bombs.

Katherine Harkay uses skills honed in particle accelerator classes to improve the quality of the brightest X-ray beams in the Western Hemisphere—the Advanced Photon Source at Argonne National Laboratory. Scientists use those beams in studies aimed at engineering heartier crops, developing more effective medications, designing better fuel injectors for vehicles, and building more durable industrial materials, to name a few examples.

"The applications for the science done with the X-rays—measuring chemical reactions over time and imaging the structure of material at the smallest scale—are directly related to people's lives," Harkay says.

More than 50 lightsource facilities exist across the globe, with more in the planning stages. Yet university programs in accelerator physics don't produce enough scientists to support the field. Particle physics laboratories and the US Particle Accelerator School help fill the void, Harkay says, supplying the knowledge and manpower needed now to have the next generation of light sources ready in a decade.

Fearless creativity

Physicists find that their creativity, critical thinking, and training in mathematical analysis lend themselves to addressing energy issues, tracking risk for insurance agencies, and predicting fluctuations of the stock market. Some move into the computer and technology industries.

Every accelerator is uniquely made for the experiment it supports. Often they are their own prototypes, forcing those who use and maintain the machines to think outside the box to increase efficiency and fix unanticipated breakdowns. The result is not only a good experimental tool but also a creative, fast-thinking workforce.

And because high-energy physics projects can take years or decades to plan and build, scientists and engineers must design technology well beyond the current generation; otherwise it will become outdated before the experiment starts.

Joseph Dehmer, director of the Division of Physics for the National Science Foundation, told Fermilab employees in June that the need to measure the smallest constituents of matter makes particle physics stand out from other sciences.

"Particle physicists are the most fearlessly creative group of people I know," he said. "If the technology doesn't exist to do a measurement, the particle physics community is not bothered by that. They just create it." This need for precise measurement, he said, drives technological innovation.

John Brining is executive director of the Illinois-based Construction Industry Service Corporation, which promotes union construction and brings contractors together with skilled laborers. He says contractors specifically seek out people who have worked at Fermilab in areas from general construction to electrical and maintenance. "Fermilab has been an important component of construction in Chicago over the years," he says.

Paul Mantsch, who as long-time head of the lab's Technical Division oversaw workers in the machine shop, says, "These people are highly skilled, so once they leave Fermilab it is very easy for them to find jobs. They work here a while and then they go out to industry. We feel that is fine. We are a taxpayer-funded industry so helping the community is one of our missions."

A faint, sporadic trail

Fewer than 10 percent of particle physics students entering US graduate schools can expect to attain tenured academic positions in related fields, according to a report Mallik wrote for the High Energy Physics Advisory Panel, or HEPAP. It was based on data from a 2007 survey of the field.

Where the remaining 90 percent end up is less clear.

The American Physical Society tracks physics graduates, but does not break out statistics for specialties such as high-energy physics. According to the APS initial employment report for 2004—the most recent available—about two-thirds of people with bachelors' degrees in physics and half of those with physics PhDs find their first permanent jobs in the private sector.

"A lot of people do their PhD thesis on accelerator work because it's a great training ground, and then go on to work in industry," says Mike Syphers, who teaches at the US Particle Accelerator School. Based at Fermilab, the school is held about twice a year at universities across the country and overseas. It has trained more than 3000 people from more than 25 nations in accelerator technology and design since 1987. Participants have backgrounds in physics, engineering, the military, medicine, and life sciences.

The accelerator school also has difficulty tracking former students, Syphers says: "They jump between jobs, fields, or locations, and they don't just jump one time—they jump two or three times, and we lose track of them."

Building a better survey

The US Department of Energy began surveying universities and laboratories in 1995 to find out where particle physicists went. But a lack of uniform recordkeeping limited the agency's ability to see clear trends, Mallik says.

Some institutions didn't complete the whole survey form. Some counted summer students, engineers, or computer programmers as physicists. Few listed the specific industries physicists moved to, and many lost track of graduates after their first jobs.

But that is changing.

In 2003, HEPAP formed a demographics survey committee to fine-tune both the survey and the system for tracking people trained as high-energy physicists.

During the last few years, Mallik has worked with Mike Ronan and Bill Carithers of the University of California, Berkeley, to find gems of information in a mountain of previously generated DOE data. They created a more user-friendly survey for 2008, along with software to cross-check the data and look for inconsistencies in it. Mallik's next goal is to track individuals by ID number as they move through specific institutions, labs, and industries.

Katherine Harkay (right) does research aimed at improving accelerated electron beams at Argonne National Laboratory's Advanced Photon Source. The photon source is a multipurpose tool used to improve drug design and other consumer products, as well as for basic research.

Photo: Sandbox Studio

Mike Syphers (left) teaches accelerator science not only to physicists, but also to people working in medical, military, and manufacturing fields.

Photo: Reidar Hahn, Fermilab

"The census has been vastly improved since the committee got involved, and a work plan has been established," she says. "After a couple of years of vigilance, the quality of the census data will improve."

Passing the torch

Some of those who leave high-energy physics labs for other careers find ways to stay connected to their first love, whether by selling parts to the labs or teaching at the US Particle Accelerator School.

Harkay, for instance, who works in the related field of photon science at Argonne, says the school's classes "were certainly useful for my entry into accelerator physics." She occasionally returns to teach at the school to give others the educational boost that she got.

Whittum also teaches at the accelerator school. And as Varian's manager of microwave applied research, he sends all the company's engineers who work on accelerator manufacturing to study there.

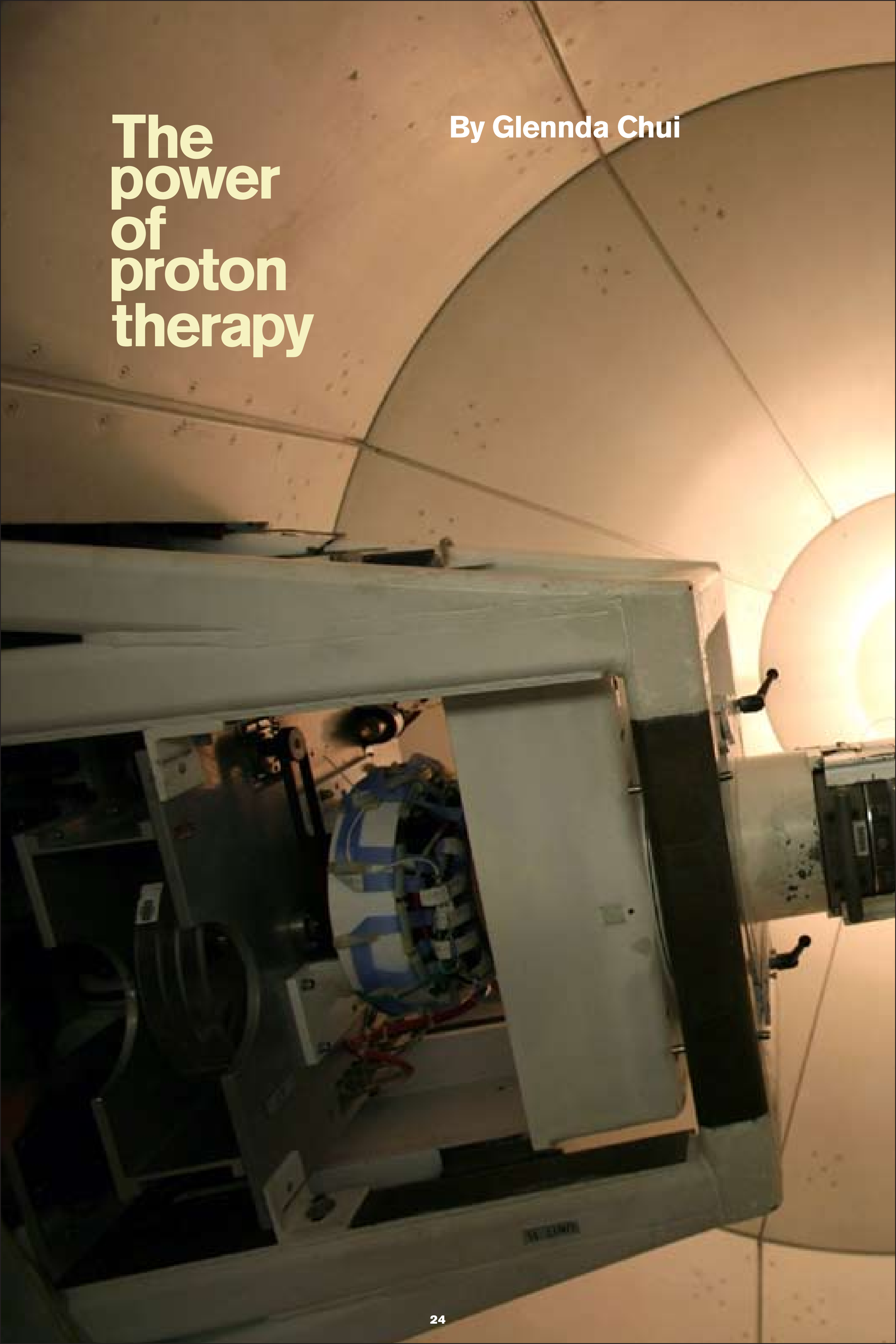
Varian's development was driven, in part, by the demands of high-energy physics. It has adapted accelerator technology for cancer treatment and for screening technology that can penetrate through steel four times farther than previous methods, improving weapons detection and the ability to inspect cargo at ports.

The efficiency of these machines depends on the quality of their accelerator components, and the US Particle Accelerator School is one of the few places where engineers can get a continuing education in the technology.

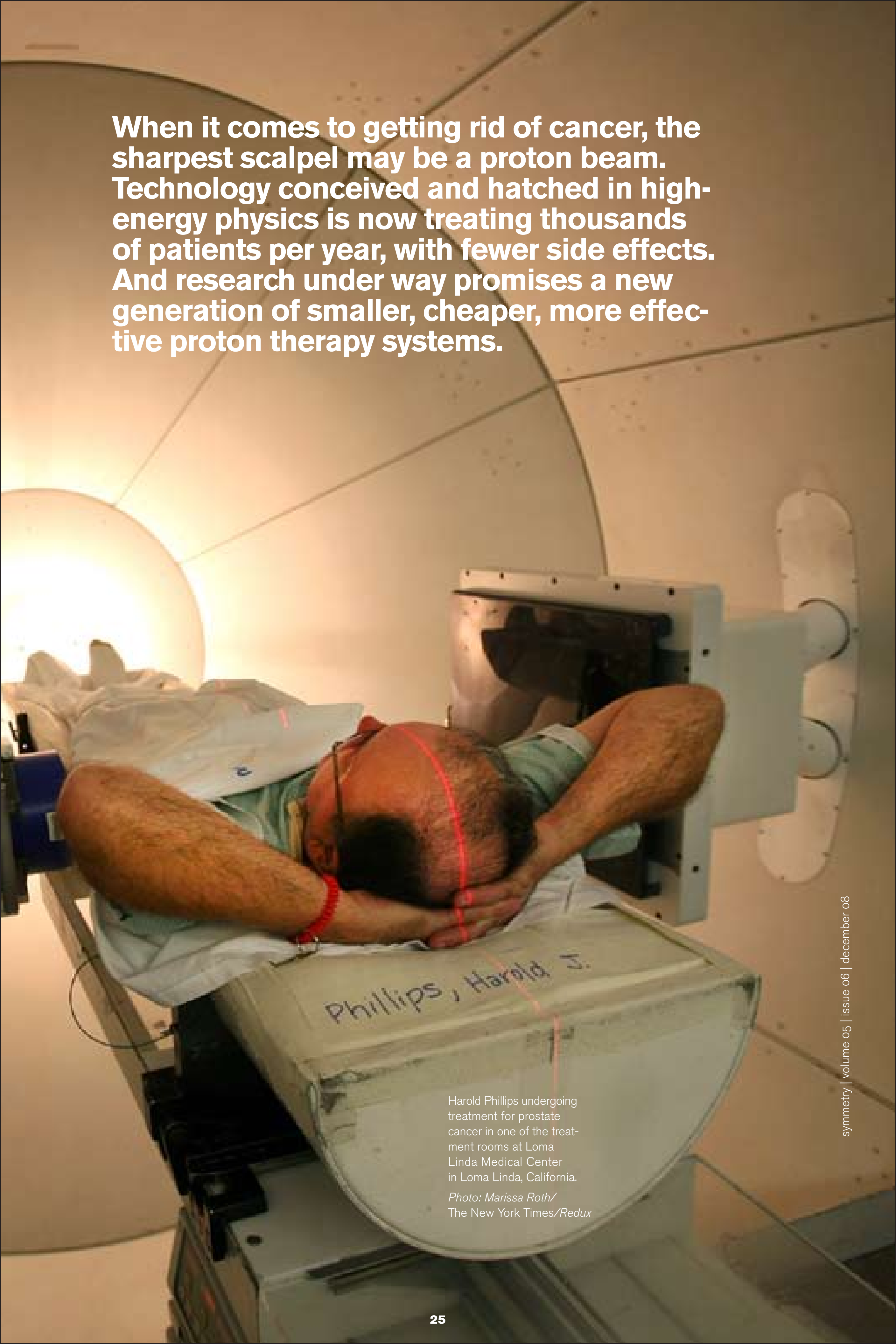
"The accelerator schools preserve an important body of knowledge," Whittum says. "In the United States, there are not many people who are doing accelerator design for academia or industry. It is a benefit to society that you share this knowledge."

The power of proton therapy

By Glennda Chui



When it comes to getting rid of cancer, the sharpest scalpel may be a proton beam. Technology conceived and hatched in high-energy physics is now treating thousands of patients per year, with fewer side effects. And research under way promises a new generation of smaller, cheaper, more effective proton therapy systems.



Harold Phillips undergoing treatment for prostate cancer in one of the treatment rooms at Loma Linda Medical Center in Loma Linda, California.

Photo: Marissa Roth/ The New York Times*/Redux*

Forty years ago, doctors broke the news to the family of a small boy: Their five-year-old had cancer. Fortunately it was a type of cancer, called lymphocyte predominant Hodgkin's disease, that responded well to radiation treatment.

The doctors repeatedly beamed X-rays at the areas where cancer had infiltrated the boy's lymph nodes—under his arms, on his neck, and in the middle of his chest—and the cancer went away.

The boy was cured, but his health would never be the same.

When he had a growth spurt at puberty, the irradiated parts of his body didn't grow as much or as fast as the rest. His neck was unnaturally skinny, his shoulders too narrow. Strange depressions appeared on his chest, like divots carved in a golf course green, where stem cells had been wiped out and muscles and other tissues failed to grow, says one of his physicians, Dr. Nancy Price Mendenhall, medical director of the University of Florida Proton Therapy Institute.

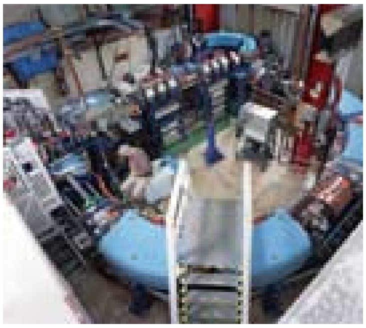
The boy's damaged thyroid gland no longer put out enough hormone; left untreated, this makes people fat and lethargic. He would have to take thyroid medication for the rest of his life.

By age 34, his heart valves leaked so badly that they had to be replaced. Even today he has a higher-than-normal chance of having heart attacks and developing new cancers.

While the bodies of growing children are especially vulnerable to the life-changing side effects of radiation therapy—including lower IQ from treating the brain—it also leaves a dismal trail in adults, from rectal bleeding in the case of prostate cancer to serious lung inflammation from radiating the chest.

The Loma Linda medical accelerator being built at Fermilab in 1989.

Photo: Reidar Hahn, Fermilab



Pete Freeman prepares for treatment for prostate cancer in a fixed-beam room at Loma Linda Medical Center in Loma Linda, California.

Photo: Marissa Roth/ The New York Times*/Redux*

Recent studies show that "for every unit of radiation there is a certain amount of damage. There's no threshold," Price Mendenhall says. It's just that the lower the dose, the longer it takes for injuries to show up. That's why doctors didn't appreciate how serious the fallout from radiation treatment can be until five or six years ago.

Even before radiotherapy became widespread, a young particle physicist named Robert Wilson came up with a better way—one that delivers more radiation to the tumor while sparing healthy tissue. Instead of using X-rays, he said, use protons.

Soon a handful of physics labs were offering experimental proton therapy on the side. In the late 1980s, Fermi National Accelerator Laboratory in Illinois built a proton accelerator for Loma Linda University Medical Center in southern California, making it the first hospital in the world to offer proton treatment.

Today, with five proton therapy centers operating in the United States and 26 world-wide, scientists are working on ways to make it cheaper, more compact, and more efficient.

Proton therapy is "a pure case of accelerator technology being used for the health of human beings," says Jay Flanz, an accelerator physicist and technical director of the Francis H. Burr Proton Therapy Center at Massachusetts General Hospital.

While the first wave of proton therapy was based on machines designed for physics research, he says, people are starting to tailor accelerator systems for the needs of medicine: "That's what's causing this breakthrough right now."

Reducing collateral damage

Doctors have treated cancer with radiation for more than 100 years by implanting small pieces of radioactive material in tumors, for instance. But the invention of the linear accelerator ushered in a new age and has saved many thousands of lives. Originally developed to accelerate particles for physics experiments, linacs can also generate X-rays for zapping tumors. The first routine treatments with the new technology began in 1953 at London's Hammersmith Hospital; the first in the United States took place three years later at the Stanford Department of Radiology. Today these machines are the work horses of radiotherapy.

The technology has come a long way since. Doctors can now get a clear 3-D picture of the tumor with CT or MRI scans and shape the radiated area to fit the tumor, using advanced treatment-planning software.

But collateral damage is still inevitable because most X-rays deposit their destructive energy in healthy tissue before they even get to the tumor, and some cause additional damage on the way out of the body.

In a seminal 1946 paper called "Radiological Use of Fast Protons," Robert Wilson, then based at Harvard University, laid out an alternative.

Wilson noted that people had never considered using protons in medicine because these massive particles slow down when they hit the body and quickly stop. However, a new generation of accelerators would soon push protons to high enough energies to penetrate deep into the body and reach tumors that had been out of range.

What's more, protons lose energy at an increasing rate as they slow down. So they would deposit very little of that damaging energy going in and deliver most of their punch when they come to a stop inside the tumor. By changing the protons' energy, doctors could get them to stop at any depth they chose.

"In the final half centimeter of a proton track," Wilson wrote in the journal *Radiology*, "the average dose is 16 times the skin dose."

The first experimental proton treatments took place in 1954 at what is now Lawrence Berkeley National Laboratory. Wilson went on to build research synchrotrons that were also used for proton therapy at Harvard and at Cornell University, and in 1967 became the founding director of Fermilab.

"He had the vision of having proton therapy done in a hospital, where it would be available only for proton therapy treatment and could be done on a large scale," recalls Phil Livdahl, former deputy director of Fermilab.

But it would take more than 40 years for Wilson's dream to be realized. He had already retired when a doctor at Loma Linda University Medical Center approached Fermilab for help.

From lab to hospital

Dr. James Slater, who was in charge of radiation medicine at Loma Linda, had sent cancer patients to Lawrence Berkeley and Los Alamos national laboratories for experimental treatment with protons and other particles. Since research took priority at the labs, patients had to be fit in between experiments; sometimes they were turned away.

Working with patients and physicists at the two labs "was priceless experience, really," Slater says. "I came to the conclusion, working with them, that this was really the way to go—that X-rays had been brought to their limits and we needed a new particle."

So in the early 1980s Slater invited about 30 representatives of leading medical technology firms to a meeting.

"They all came here to Loma Linda and they sat around the table and I told them what I wanted to do, and they turned it down. I was really surprised," he recalls. Later, he says, an engineer for one of the firms told him none of the companies were ready to jump into proton therapy; "Financially nobody thought it was worth it. I came to the conclusion that Fermilab was best equipped to do something for us."

Slater approached Livdahl, who became a key figure in the effort. It was agreed that Fermilab would build a synchrotron to accelerate the protons—"a big ring, just like a donut," Slater says, 20 feet in diameter and about five feet tall. He asked the lab to build it to last 50 years, "because there's going to be enormous room for improvement."

With $19.5 million in seed funding from the US Department of Energy, crews designed, built, and tested the machine at Fermilab, and broke it down into pieces for the move to Loma Linda. The new center treated its first patient in October 1990.

As it turned out, Livdahl was diagnosed with prostate cancer just before the center opened and became one of its first patients. When the cancer recurred in 1996, he went back for a second round.

Thinking back, "it really gives you a great feeling knowing that something you've done in your career is saving the lives of people on a daily basis," says Livdahl, now 86 and living in Dallas. And the life he feels best about saving is his own.

Pros and cons

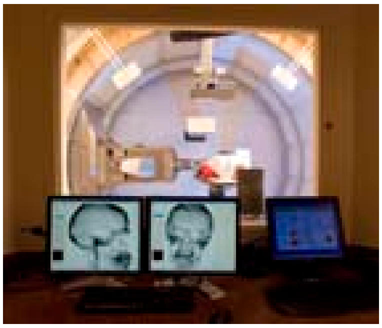
Studies have shown the effectiveness of proton therapy, especially where there's an urgent need to spare healthy tissue—for instance, in treating children, the eye, the base of the skull, the prostate, and tumors very close to sensitive organs. "Protons are especially good with large tumors that wrap around critical structures," Flanz says.

But the technology does have its critics.

The biggest drawback is the cost. Proton therapy centers are the size of a football field and cost in the neighborhood of $120 million to $180 million, including the building and all the associated medical equipment.

On the other hand, hospitals no longer have to design treatment systems from scratch. They can buy ready-to-install systems from companies such as IBA, Siemens Medical Solutions, Hitachi, and Varian Medical Systems.

That's the approach the Northern Illinois Proton Treatment and Research Center is taking. Now under construction in West Chicago, it will buy treatment equipment from Varian. The $160 million, 130,000-square-foot center expects to open by early 2010 and, when it's in full swing, treat up to 1500 patients per year.



From top: Images of a patient's skull show the area to be treated with protons; a patient is put into position; the treatment setup.

Photos courtesy of Kendall Reeves Spectrum Studio and the Midwest Proton Radiotherapy Institute

The center will also perform "a fair amount of research in terms of advancing the technology," says John Lewis, associate vice president for outreach at Northern Illinois University, which will build and operate the center. Although there is no formal relationship between the two labs, he added, "We think the proximity to Fermilab and expertise at Fermilab will be very fundamental to research projects going forward."

Skeptics say traditional radiation therapy has improved so much that in many cases it's just as effective, and much cheaper. The high cost and reluctance of some insurance companies to pay mean some people just can't afford proton therapy, raising equity issues. Further, there haven't been enough studies directly comparing the effectiveness of proton therapy to radiotherapy, chemotherapy, and other types of treatment.

Supporters counter that proton therapy is so much more precise, and can be given in such big doses while sparing normal tissue, that it would be unethical to ask patients to undergo an inferior treatment so the two could be compared.

Medical physicist George Coutrakon takes that position. He was involved in developing the Loma Linda center and left there last fall to work on the one in Northern Illinois. "Proton therapy is a sharper instrument," he says. "Would you ever test it against a duller instrument in a randomized trial? Would you ever use a machine that gives a higher dose to normal tissue? You can't just roll the dice when you have a better treatment."

Further, the economic comparisons are not as simple as they've been made out to be, according to Price Mendenhall.

Standard radiation treatment machines have to be replaced every seven or eight years, usually operate one shift a day and treat one patient at a time. Proton therapy equipment is built to last at least 30 years, operates two shifts a day and often feeds into three or more treatment rooms. This reduces replacement costs and allows proton centers to treat at least twice as many patients per year.

And because proton therapy spares healthy tissue, doctors can give higher doses and increase the cure rate, Price Mendenhall says. This has also cut the length of prostate cancer treatment from 8.5 to 6.5 weeks, and doctors at Loma Linda think they can prune that to just four weeks. If they succeed, she says, proton treatment for prostate cancer will cost less than conventional X-rays.

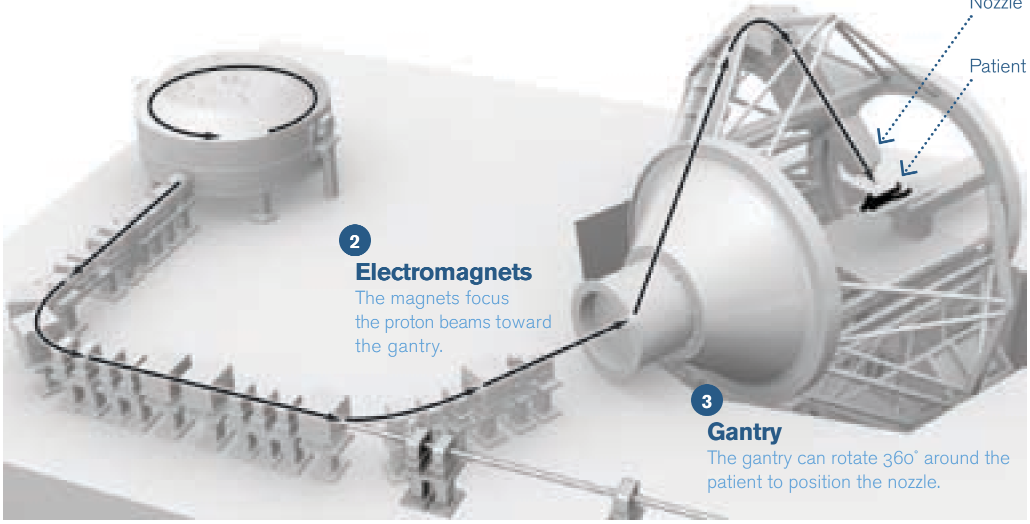
Then there's the much higher cost of treating side effects from radiation, she says, not to mention the cost of treating cancers that recur at higher rates than they would after proton treatment.

Pummeling Cancer With Protons

Proton radiation therapy is potentially a better way to treat cancer because it has fewer side effects, but the technology is still very expensive. The University of Florida Proton Therapy Institute required eight years and $125 million to build, and it can serve up to 150 patients a day.

1
Cyclotron
Using magnetic fields, the cyclotron can accelerate the hydrogen protons to two-thirds the speed of light.

4
Nozzle
A 21,000-pound magnet guides the beam to the patient through a nozzle.



2
Electromagnets
The magnets focus the proton beams toward the gantry.

3
Gantry
The gantry can rotate 360° around the patient to position the nozzle.

The Nozzle

The brass aperture and the Lucite compensator are designed to squeeze the proton beam to the size and shape of the area being treated.

Proton radiation therapy

By adjusting the speed of the protons, a physician can control how deep their penetration will be. The protons then release their energy at the tumor and cause less damage to the surrounding tissue.

Conventional X-ray therapy

Because conventional radiation doesn't release its energy at a specified depth, it can cause more damage to the tissue surrounding the tumor.

Credits: The New York Times *and University of Florida Proton Therapy Institute*

Smaller, cheaper approaches

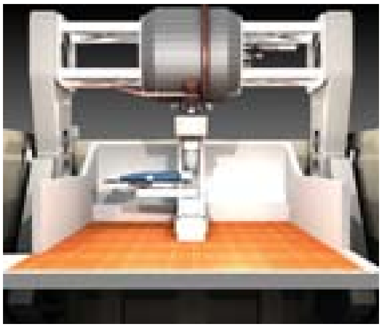
For all the advantages proton therapy has, researchers think it could be a lot better. Cheaper, for one thing: The high price tag is the main reason more centers haven't been built. A number of groups are hoping to cut the cost by delivering the same capabilities in smaller, lighter, simpler, more robust packages.

Still River Systems, for instance, is a small Massachusetts firm that is developing a proton therapy system that it says will weigh and cost one-tenth as much as today's technology. The approach was developed in partnership with the Massachusetts Institute of Technology Plasma Science and Fusion Center. It uses superconducting magnets rather than conventional magnets to accelerate protons around a cyclotron. This allows the protons to make tighter turns and the cyclotron to shrink to the point that it can fit into a treatment room, at a cost of about $20 million per room. However, since most proton therapy centers have multiple treatment rooms, some experts say it is not clear how these costs will compare with those of current proton treatment.

"We have a very flexible, very modular approach," Lionel Bouchet, the company's director of product management, says. "In this economy it does not make sense to go with a $200 million project when you can start with one room and expand from there."

Although the technology is still waiting for US Food and Drug Administration approval, the company recently announced it will begin delivery of its first system in 2009 to Barnes-Jewish Hospital at Washington University Medical Center in St. Louis, Missouri.

Flanz of Massachusetts General says, "In my view, attempts to build smaller systems—and I'm involved in some of them—result in giving up some of the features the bigger systems have. But their low cost will allow local hospitals and clinics to offer basic proton therapy, referring the most complicated cases to larger academic medical centers."



Above and below: Artist renditions of proton therapy equipment being developed by Still River Systems that's small enough to fit into a treatment room.

Images courtesy of Still River Systems

Another approach comes out of the US nuclear weapons testing program. Since there's a ban on testing the actual weapons, researchers use model bombs that contain only conventional explosives. (In a real bomb the job of the explosives is to compress and implode the nuclear inner core.) Scientists set off these dummy bombs in thick-walled buildings at Lawrence Livermore and Los Alamos national labs; and they use a particle accelerator to generate X-rays for documenting the implosions.

While looking for ways to make this accelerator smaller and cheaper, scientists came up with the Dielectric Wall Accelerator. It's basically a tube for carrying a particle beam, explains George Caporaso, beam research program leader at Lawrence Livermore. What's different about this beam tube is that the inner wall consists of alternating rings of electrical insulators and conductors. This allows the creation of a very strong electric field that permeates the inside of the tube; in principle it could boost protons to the energies needed for cancer treatment in just two meters.

"That's a very enabling technology," Caporaso says. "There's nothing exotic about the material; it's just the configuration that's novel. Pick your favorite insulator, and you can just slice and dice it and make this configuration." The technology is being developed by Compact Particle Accelerator Corp. in Madison, Wisconsin, a spinoff of the radiation therapy company TomoTherapy.

Scientists at Brookhaven National Laboratory are looking for commercial partners to develop a technology they just patented. It has two advantages: By focusing the proton beam to a much finer point than today's machines, it would reduce collateral damage and allow most of the system's components, such as pipes and beams, to shrink as well, says physicist Stephen Peggs, one of the project's lead scientists. And it can deliver 60 pulses of protons per second, compared to one pulse every four seconds now. The result, he says, is "a very sharp knife and a very flexible knife" that should be simpler, more robust, and more reliable.

Those are just a few of about a dozen projects aimed at cutting the cost, and in some cases increasing the effectiveness, of proton therapy.

Sharpening the proton knife

Meanwhile Loma Linda, true to James Slater's original vision, is undergoing a major upgrade that should increase the number of patients treated per day from 150-180 to more than 200, reducing the cost per treatment.

Changing the energy of the proton beam, and thus how far it penetrates the body, used to take an hour; now it's instantaneous. In 2009, Slater says, controllers will be able to do "spot scanning"—treating the deepest layer of the tumor, then the next deepest layer, and so on until the whole thing has been bombarded with protons. "We can move them in any direction so we can paint in virtually any configuration the tumor is growing in," he says. And robotic systems will be in place to position patients for treatment.

Loma Linda is developing a CT scanner that uses protons, rather than X-rays, to make detailed images of the area under treatment; this should reduce distortion and allow more precise placement of the beam.

Its researchers are also investigating the biological effects of proton treatment on both cancerous and healthy cells. Some of these experiments use technology directly borrowed from high-energy physics, such as silicon microstrip detectors, calorimeters, and GEANT4 software for modeling the paths of particles through tissue, says Vladimir Bashkirov, who worked as an experimental particle physicist before joining Loma Linda 10 years ago.

Flanz says he finds it interesting that all these advances—and many yet to come—are based on Robert Wilson's original idea, and on the foresight of administrators at Lawrence Berkeley and other national labs who made room for patients in their research halls.

"Basically, everything he said in his 1946 paper is used now," Flanz says. "It's incredible."

snapshot: LCLS construction

These photos represent an eye blink in the evolution of the Linac Coherent Light Source, a groundbreaking facility taking shape at SLAC National Accelerator Laboratory. During the past two years, workers excavated more than 180,000 cubic yards of earth and added more than half a mile of tunnel to the lab's existing linear accelerator to accommodate the world's first hard X-ray free electron laser. Its short, bright pulses will allow researchers to watch molecules in action and make freeze-frame movies of the chemistry of life as it unfolds. A range of fields stand to benefit from this new tool, including materials science, chemistry, biology, medicine, and environmental science. In September 2008, with civil construction completed and scientific equipment about to move in, the empty facility had a beauty all its own—spare and utilitarian, crafted expertly into a unique and sophisticated subterranean home for a remarkable machine. More photos of this facility are online in *symmetry.*

Text and photos: Brad Plummer


RCM

Image courtesy of Canadian Association of Radiologists

Particle physics' key role in producing breathtaking images of the human body

By Calla Cofield

The life-saving medical technology known as Magnetic Resonance Imaging, or MRI, makes detailed images of soft tissue in the body, nearly eliminating the need for exploratory surgery. Unlike X-rays, it can distinguish gray matter from white matter in the brain, cancerous from non-cancerous tissue, and muscles from organs, as well as reveal blood flow and signs of stroke.

The basic principles behind MRI emerged from early research in particle physics. Fifty years later, the field again played a critical role in making MRI machines commercially available.

In 1937, Isidor Isaac Rabi observed that hydrogen atoms respond to a strong magnetic field by pointing in the same direction, like compass needles. Scientists later discovered that the field was actually acting on the nuclei of the atoms, which are positively charged. When a second magnetic field, oscillating at just the right frequency, hits the atoms, some of the hydrogen nuclei get an energy boost and do a 90-degree flip. When the second magnetic field is removed, the nuclei return to their original positions. This realignment takes place at different rates in different materials, giving scientists a way to distinguish between them.

In 1946, Edward Purcell and Felix Bloch determined that the strength of the magnetic field and the frequency of the second magnet are linked by a phenomenon they called nuclear magnetic resonance, or NMR. Soon, NMR was being used to analyze the chemical natures of liquids and solids. Since the human body is 55-60 percent water, and each water molecule contains two hydrogen atoms, the technique would be ideal for studying living tissue.

In 1973, Paul Lauterbur found that by applying a gradient to the large magnetic field, he could identify the locations of individual hydrogen atoms in a sample. He used this additional information to make the first NMR image. The word "nuclear" was later dropped so as not to imply a threat of radiation, and the technique became known as MRI. Rabi, Purcell, Block, and Lauterbur all earned Nobel Prizes in physics for their work.

In 1974, just as Lauterbur's technique came onto the scene, Fermi National Accelerator Laboratory began building what would become the world's largest particle accelerator, the Tevatron.

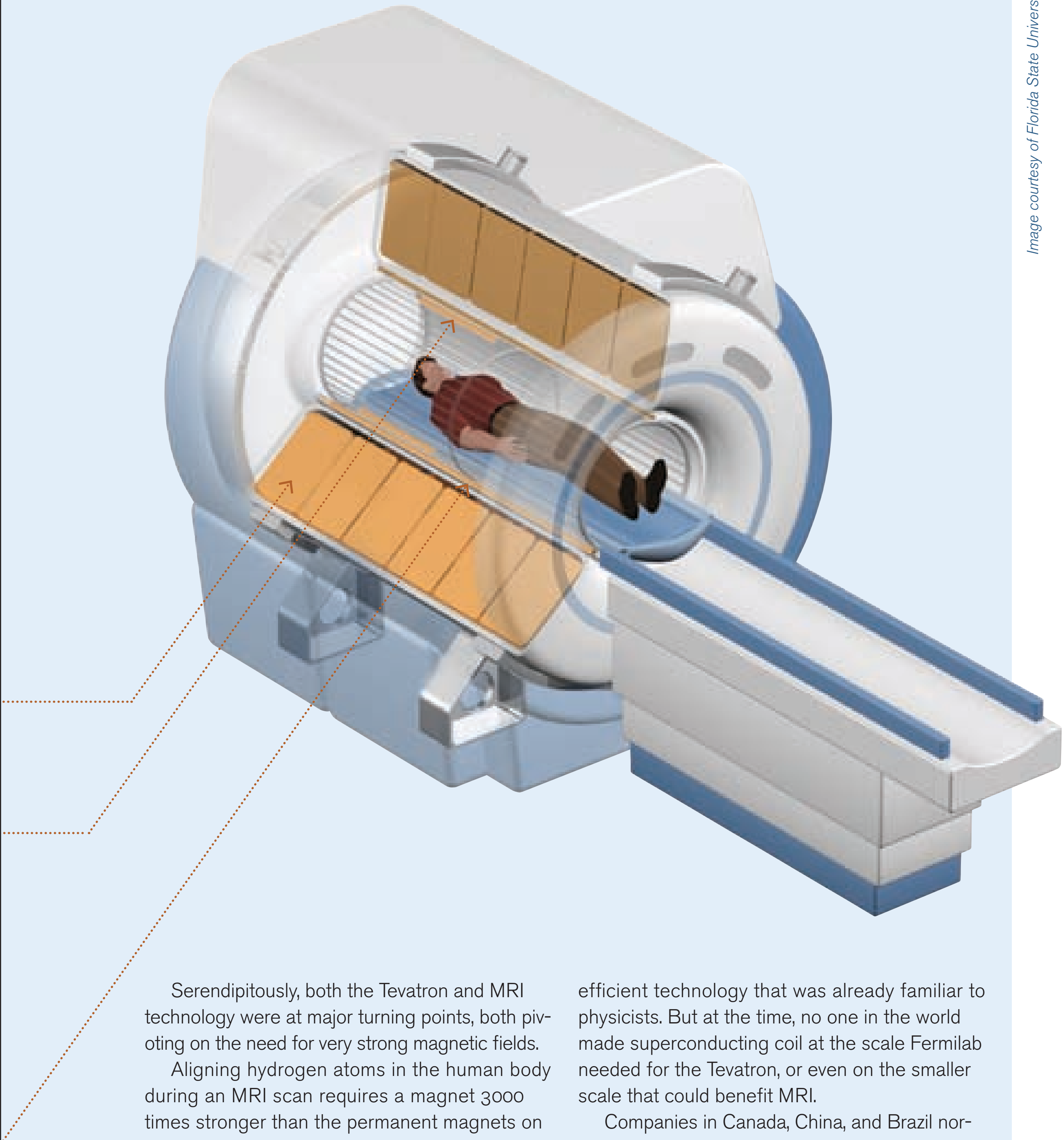


Image courtesy of Florida State University

Serendipitously, both the Tevatron and MRI technology were at major turning points, both pivoting on the need for very strong magnetic fields.

Aligning hydrogen atoms in the human body during an MRI scan requires a magnet 3000 times stronger than the permanent magnets on your refrigerator. But large permanent magnets are impractical because they can't be turned off, are extremely heavy, and generate magnetic fields that can become unstable.

Meanwhile, the Tevatron needed magnets 4000 times stronger than refrigerator magnets to propel particles along its four-mile-long particle racetrack. Previous accelerators used magnets made of electrical wire wrapped into cylindrical coils, but those electromagnets lose significant amounts of energy as heat, ultimately driving the electricity bill through the roof.

The solution, for both particle-smashers and advanced medical imaging, was superconductivity.

When cooled to temperatures near absolute zero, wires made from certain metal alloys, such as niobium-titanium, allow electric current to flow freely without losing heat. Wound into a coil, they become superconducting magnets, an energy-efficient technology that was already familiar to physicists. But at the time, no one in the world made superconducting coil at the scale Fermilab needed for the Tevatron, or even on the smaller scale that could benefit MRI.

Companies in Canada, China, and Brazil normally sold these metal alloys only by the kilogram; Fermilab started buying them by the ton. The lab provided the raw metals to manufacturers, along with specifications for how best to achieve long lengths of perfect wire. To work correctly, superconducting wire must be heated, molded, and shaped using special techniques. Rather than patent these procedures, Fermilab made them freely available, opening the door for both domestic and foreign companies to manufacture superconducting cable on a larger, more affordable scale. This paved the way for the commercial development of superconducting magnets for MRI machines. While modern MRI machines still cost anywhere between $1 million and $3 million, more than 25,000 of them are in use in hospitals and medical facilities, and that number continues to grow.

Photos courtesy of Jordan Sorokin

A future in physics

My body is a tiny composition of molecules, insignificant compared to the three-story-high particle detector towering over the various tanks, wires, and steel tubing from which it had been constructed.

I can hear the workers busily discussing a compilation of data to create a coherent model; I can smell and taste the metallic ashes and electrical wiring running through the accelerator; I can feel the curious atmosphere—the atmosphere of scientific breakthroughs and historical significance—resting gently on my shoulders, and I smile.

My legs carry the mass of my body through the endless corridors of the particle accelerator at Fermilab in Illinois, as I tune in to a private lecture about the work being done at the multi-computer monitor station to my left, and the various Standard Model particles discovered, to my right. As we slowly wander through the lab, Jacobo Konigsberg—a renowned scientist at Fermilab who helped discover the top quark—describes to my father and me the steps he and his colleagues took in facilitating the discovery of the particle.

My eyes water from not blinking, but I don't care; I continue to absorb every ounce of information I can as I learn about the top quark, neutrinos, and the fundamental questions of dark matter, dark energy, the formation of gravity, and the big bang theory. I crawl down a flight of stairs towards the superconducting magnets lined up evenly along the accelerator's boundary, and I feel my heart skip a beat, pounding at my chest in marvel.

The personal appointment comes to an end, and Dr. Konigsberg asks, "So Jordan, do you have any questions?" Oh boy, he certainly doesn't know what he just got himself into!

After visiting Fermilab, I knew that I had only one passionate aspiration, one life-long quest: to become a physicist. The visit sparked an interest inside of me, like an electrical wire jerking sporadically with every ounce of new knowledge; I began researching particle physics, as well as astrophysics last year, and have continued my research since. Virtually every day I find myself peering at my computer monitor, searching for answers to my questions: What is dark matter? How was time suddenly created? Theoretically, isn't it possible to accelerate a particle faster than the speed of light with an indefinite amount of energy, and if so, wouldn't it travel back in time to a point when the Tevatron that accelerated it did not exist?

There are so many questions, so many theories that I have weaving throughout my mind, yet that I have never found a definite answer for. This constant search for answers, although a burden to many, is the only plausible path that I see myself taking as I grow older (not necessarily finding the answers, merely seeking them). My happiness is only guaranteed when my temples ache with information, my eyes film near the edges, and my knowledge and questions expand.

Fermilab has not only exposed to me the processes and research involved in fundamental breakthroughs in the understanding of our world and the technology available, but has also demonstrated the potential wealth of understanding and wisdom the human mind can obtain if the desire and zeal is strong enough.

I have seen first-hand what it means to be a physicist, and I love it. I love the sounds, the smells, the tastes…I even love the stress that comes along with data! Moreover, I love the fact that I have found something I am truly and undeniably passionate for, something that I know I will be researching and theorizing about in my soon-to-be professional career.

Jordan Sorokin is a senior at La Costa Canyon High School, Carlsbad, CA, and plans to major in physics at a university.

Jordan Sorokin takes a tour of Fermilab with Jacobo Konigsberg.

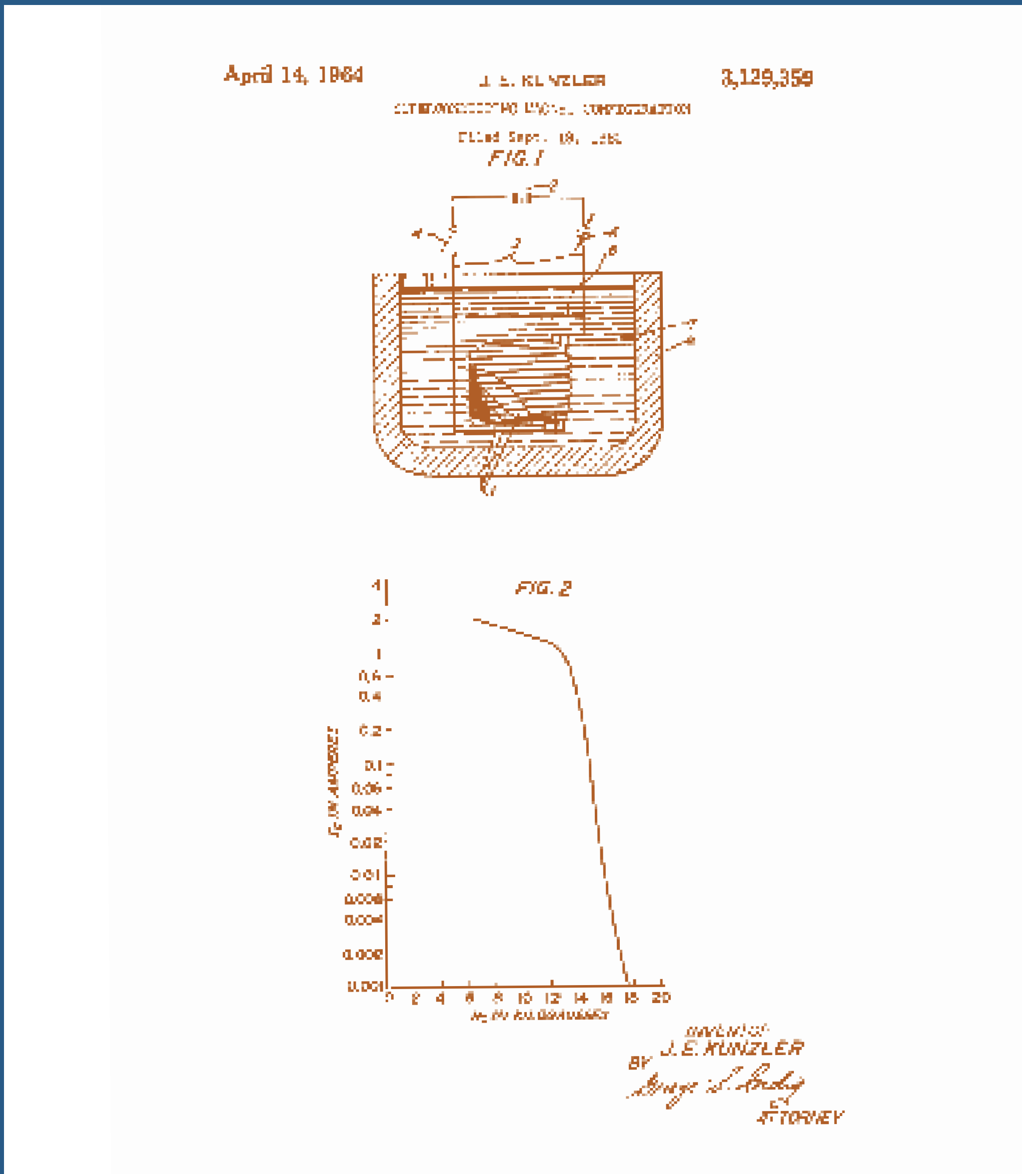


Image courtesy of US Patent and Trademark Office

Today's MRI machines and particle accelerators wouldn't exist without superconducting electromagnets, which generate powerful magnetic fields at a fraction of the energy cost of conventional electromagnets. The road to the first patent for this technology took nearly six decades and ended in a photo finish.

Heike Kamerlingh Onnes discovered superconductivity in 1911, when he cooled mercury to near-absolute zero and found its electrical resistance disappeared. However, when he wound superconducting lead wire into a coil and ran current through it to generate a magnetic field, the superconductive property vanished at magnetic fields only a few times stronger than that of a refrigerator magnet.

In 1954, G.B. Yntema at the University of Illinois and, in 1959, Stanley Autler at MIT, independently wound superconducting coils with cold-worked niobium and produced magnetic fields close to 10 kilogauss, an order of magnitude higher than before. The gauss race was on. The prize went to metallurgist John E. “Gene” Kunzler, whose group at Bell Labs produced 15 kilogauss using an alloy of molybdenum-rhenium. Kunzler filed for a patent (see image) on September 19, 1960, beating Autler's patent filing by 15 days. Kunzler's patent was issued first, on April 14, 1964.

“Those tiny, primitive magnets were, of course, terribly unstable,” John Hulm, who led a Westinghouse group, said in a 1982 talk. “One had to have faith to believe that these erratic toys of the low temperature physicist would ever be of any consequence as large engineered devices.”

The construction of Fermilab's Tevatron accelerator in the 1970s—with 1020 magnets containing enough superconducting wire to circle the Earth 2.3 times—created a new industry that went on to supply wire and cable for an emerging medical technology that also needed powerful superconducting magnets: magnetic resonance imaging, or MRI. For a more detailed account, see symmetry online.

Madolyn Bowman Rogers

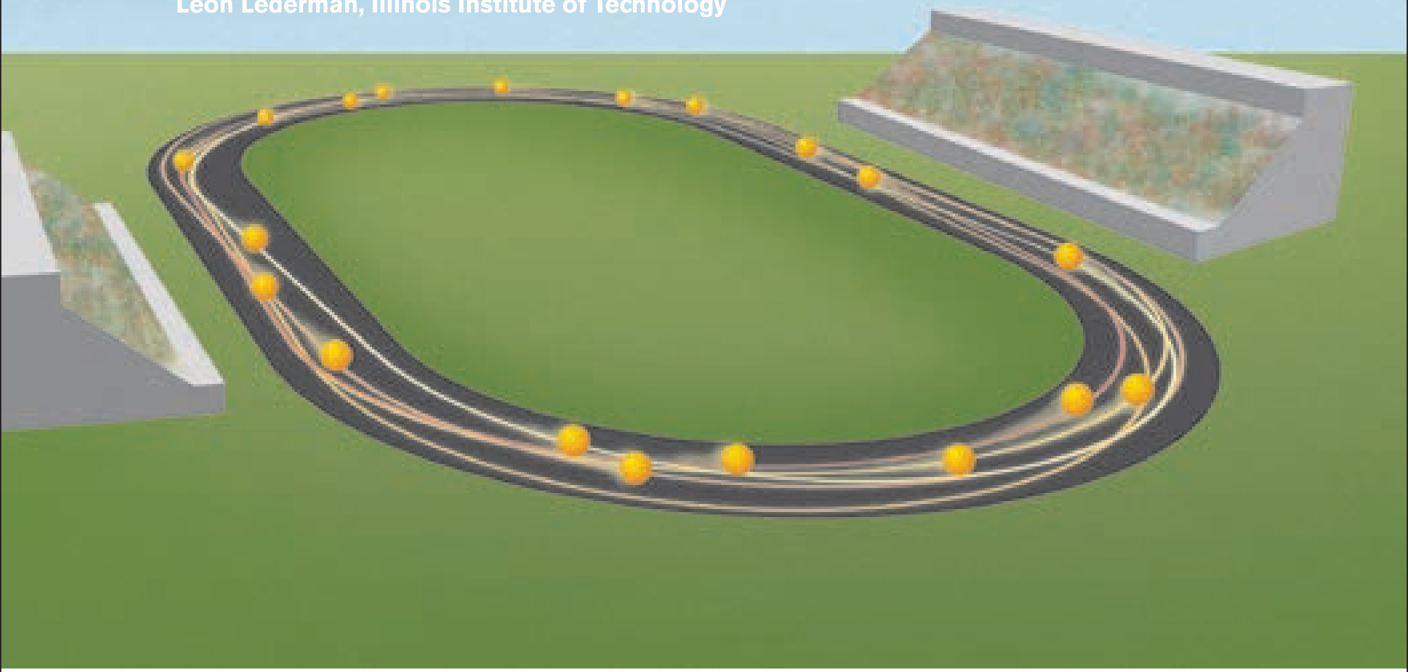
Particle accelerators (often referred to as "atom smashers") use strong electric fields to push streams of subatomic particles—usually protons or electrons—to tremendous speeds.

Accelerators by the thousands are at work worldwide. The particle beams they generate are used to zap tumors, aid in medical diagnosis, and study and control manufacturing processes in industry. In specialized accelerators known as lightsources, the particles race around a ring to generate bright X-rays that illuminate complex biological structures and other phenomena.

The most powerful accelerators are dedicated to basic research, advancing our knowledge of the structure of matter and the nature of our universe. These machines function as super-microscopes and reveal the smallest constituents of matter. They smash particles into stationary targets or accelerate two beams to almost the speed of light and make the particles collide head-on. The particles instantly transform into energy in accordance with Einstein's famous equation, $E=mc^2$. Then all the energy released by the collision converts back into matter, creating new particles that perhaps have never been seen before.

The higher energy an accelerator achieves, the heavier the particles it can create, and the more detailed are its studies of the laws of physics at the smallest scales. At the Tevatron accelerator at Fermilab, collisions routinely take place at an energy corresponding to two trillion volts. In the near future, the Large Hadron Collider in Europe will explore matter with seven times the Tevatron energy.

Leon Lederman, Illinois Institute of Technology



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