2 Editorial: Diversity and Mentoring in Particle Physics
A consultant hired to look at diversity issues at Fermilab found no evidence of bias against women and minorities. But he did find a lack of support and mentoring for some visiting scientists at the lab. This observation is important for any institution with a large proportion of visiting students, postdocs, and scientists, and addressing it will require a coordinated approach.

3 Commentary: Karin Fornazier Guimares
"If more scientists start to use it, Twitter can be a tool for developing new relationships, networks, collaborations, and communities. I believe it can help us send messages and get unexpected answers, talk to different kinds of people, get instant feedback."

4 Signal to Background
Shooting down UFO rumors; growing a physics family tree; driving an eco-trend; feeling a mine's deep, earthy vibes; baby detector on board; quake-shaken lab reaches out to neighbors.

8 symmetry breaking
A summary of recent stories published online in symmetry breaking, www.symmetrymagazine.org/breaking

On the cover:
For some reason, Brookhaven National Laboratory has always attracted more than its share of UFO buffs. So it was that the crew of UFO Hunters, a weekly TV show on the History Channel, went to the lab recently to film an episode about an alleged 1992 UFO crash nearby. The burning question: Had the lab shot down a UFO with a particle beam? The answer: Of course not. There was no UFO, and particle beams from the lab’s accelerator can’t be used as weapons (see page 4).

Illustrations: Sandbox Studio
10 **Growing a Diverse Workforce**
When it comes to training, hiring, and retaining women and members of ethnic minorities, particle physics lags far behind other fields of science. Staffers at three national labs—Fermilab, SLAC, and Brookhaven—are tackling the problem at every level.

18 **Dark Energy Camera Scans Ancient Skies**
Gazing into space, scientists wonder why the universe is expanding ever faster. What mysterious force is at work? By recording the light from hundreds of millions of galaxies from a mountaintop in Chile, they hope to find out what’s going on.

24 **Helium’s Shrinking Bubble**
Helium is the lifeblood of large particle accelerators. As the world’s supply dwindles, the particle-physics community must take steps to preserve this precious commodity or learn to live without it.

30 **Gallery: Accidental Beauties**
These exquisite test samples transcend their original purpose, which is to ensure that all the metal parts of SLAC accelerators and detectors are flawless.

34 **Deconstruction: Periodic Table**
What are the most important elements for building accelerators, detecting particles, and solving the mysteries of the universe?

36 **Essay: Tom Nelson**
The community of Lead, South Dakota, “has always been about mining, and will continue to be about mining. Now, however, we are no longer mining gold, but science.”

C3 **Logbook: Pierre Auger Observatory**
In 1991, James Cronin traveled to Leeds, England, to visit Alan Watson, an expert on cosmic-ray physics. Cronin, a Nobel Prize winner in physics, was eager to see the construction of a large array of detectors designed to unravel the mysteries of the highest-energy cosmic rays in the universe.

C4 **Explain it in 60 Seconds: Virtual Particles**
Virtual particles are short-lived particles that cannot be directly detected, but which affect physical quantities—such as the mass of a particle or the electric force between two charged particles—in measurable ways.
from the editor

Diversity and mentoring in particle physics

Women and minorities are significantly underrepresented in physics. There are many possible reasons for the imbalance, and understanding the causes is a challenging task. In this issue of *symmetry*, we look at how particle physics laboratories and the science community are tackling parts of the problem and trying to create a more diverse workforce (see page 10).

Fermilab recently commissioned an independent consulting firm to study issues that influence diversity at the lab. The firm convened a series of focus groups consisting of randomly selected participants, whose identities were withheld from laboratory leadership to encourage honest feedback.

On the positive side, the consulting group reported that discrimination against women and minorities was not a contributing factor to lack of diversity. On the other hand, participants revealed a number of general management weaknesses among line managers, potentially due to lack of training and mentoring, and some significant issues for visiting scientists from outside Fermilab. The visitors, typically graduate students and postdoctoral fellows, often do not have mentors and have trouble getting the support they need to do their work effectively.

This observation is important for all institutions that have a large proportion of visiting students, postdocs, and scientists. Because people tend to learn institutional processes better from other people than from an abstract handbook or set of rules, mentoring is vital. Good mentoring would certainly help institutions in many ways, quite likely helping to create a more diverse workforce.

But the issue of mentoring young visiting scientists also reveals that no institution can solve by itself the challenges of changing a culture within a scientific discipline. Cultural change is needed to improve workforce diversity throughout physics. There is so much mixing of people among institutions in particle physics that cultural change will need a coordinated approach. This is a serious challenge but we think it is worth the investment of time and resources.
 Commentary: Karin Fornazier Guimares

Twitter: micro blogging for a macro science network

From the beginning, science and communication have been connected. Writing is a good exercise for inquiring minds; this is not just a saying, but a fact. If you look at scientific biographies, you probably will find mention of a notebook in which the scientist writes down ideas, questions, and quick observations. Those notes give us a perspective on what the scientist was doing at the time.

Today we have not only notebooks, which are usually used to jot down private thoughts, but also blogs in which we can make public all of our work, our ideas, and our opinions. Examples of communities of blogs are Science Blogs, Quantum Diaries, US LHC blogs, Nature Network, and Discover blogs. Some of these were set up as experiments in scientific communication. These blogs are a powerful tool for divulging and discussing scientific research, as discussed a few months ago at ScienceOnline09. But not enough scientists have taken up blogging.

Many more of us could be using this tool to bring science to a different public, in different countries, and across social levels as an opportunity to understand what scientists do day to day. That would translate to more adults interested in science, more high school students interested in science, more girls interested in science, and more people learning the latest news about science from real scientists.

However, science blogging is not an easy task; not everyone is comfortable with writing at such length and in a relatively formal way. To link people who don’t want to write so much but still want to share their ideas, why not consider Twitter? It allows a sort of micro blogging in which you describe what you’re doing in 140 characters or fewer. How you use this tool is entirely up to you. You can just talk about your life, your tasks, etc., or you can project and promote yourself and your work, letting ideas, insights, difficulties, and achievements flow in a very easy, rapid way. You can point out scientific papers, lectures, and proceedings you find interesting or relevant, as well as blogs with relevant science news and high-level discussion. In this way you can indirectly help a science teacher or novice physicist find the appropriate references for improving their knowledge, tackling school work or demystifying particular issues.

You could also point out some workshop or summer/winter school Web sites that your regular network of colleagues might know about but which other interested people, such as a PhD student from another university, did not know anything about. As you have only 140 characters with which to deliver your message, you will just point it out, and your “followers” will decide to read or re-tweet (re-broadcast to their followers) your post.

If more scientists start to use it, Twitter can be a tool for developing new relationships, networks, collaborations, and communities. I believe it can help us send messages and get unexpected answers, talk to different kinds of people, and get instant feedback. This makes Twitter a very useful tool. It can allow scientists to make unexpected connections both with other scientists and with other people who are valuable to know and work with.

In my own case, I have used Twitter to meet other scientists, to find out about useful physics information I wouldn’t have seen otherwise, and also to practice writing in other languages. How you use Twitter would be up to you, but you might also find it useful for building a network of colleagues around the world who share interests and information, and help make the scientific world better connected.

Karin Fornazier Guimares is a PhD student in particle physics at Instituto Tecnológico de Aeronáutica, SP Brazil. You can follow her as @charmqgp on Twitter. She met the editor-in-chief of symmetry, and they decided to publish this article, through conversations on Twitter. You can read Fornazier Guimares’ tweets at twitter.com/charmqgp. symmetry tweets as @symmetrmag, and the editor as @physicadavid.
Nope, no UFOs at Brookhaven Lab

The spotlight caught Todd Satogata. The camera zoomed in. “Did your particle beam shoot down a UFO?” the TV host asked.

The accelerator physicist at RHIC, Brookhaven National Laboratory’s Relativistic Heavy Ion Collider, smiled. “Of course not.”

With a friendly countenance and confident tone, Satogata kept steering the dialogue back to physics concepts and giving the hosts of UFO Hunters, a weekly series on the History Channel, a reality check on their extraordinary claims.

Each week, UFO hunters Bill Birnes, Kevin Cook, and Pat Uskert travel to the sites of purported alien encounters. They visited Brookhaven in April to probe an alleged UFO crash Nov. 24, 1992, in South Haven Park, about five miles from the lab. UFO buffs tell of the lab’s fire department responding to the crash and extinguishing massive brush fires.

Brookhaven lab Fire Chief Chuck La Salla showed the film crew a logbook entry for that evening, which noted nothing out of the ordinary and no off-site response by firefighters.

Later versions of the tale claim that firefighters brought parts of the wreck back to the lab, where scientists analyzed alien tissue. They even have the laboratory’s Alternating Gradient Synchrotron, which injects particles into RHIC, shooting down the spacecraft with a high-power plasma beam.

But the sci-fi-like sniper attack couldn’t have occurred. The beams that circulate in RHIC and other particle accelerators are confined to a prescribed path. Even if they did escape, they would dissipate as soon as they interacted with air.

With its history of operating research reactors and particle accelerators, Brookhaven has long been a focus of UFO fans; a Google search of the two brings up 4620 postings.

Brookhaven scientists hope that if they show UFO buffs what the laboratory really does, alien tales will carry less weight.

During the TV crew’s visit, RHIC was delivering protons to the STAR and PHENIX detectors. Satogata, interviewed in the main control room, found time during tape changes and sound checks to teach the crew about the science going on in the background. “It’ll be interesting to see how it’s edited and how it turns out,” Satogata said after the crew wrapped up.

Mona Rowe
Detectors shipped in cooking pots

Looking for an inexpensive and safe way to transport delicate particle detectors? Try pressure cookers and child safety seats.

When researchers at the Max Planck Institute for Physics in Munich drive fragile germanium crystals across Europe, they resort to conventional household equipment to keep the crystals safe.

The fist-size crystals have to remain under clean-room conditions to keep their particle detection prowess. Pressure cookers, normally used to cook food and steam vegetables, are the perfect solution. The MPI Mechanics Division has outfitted seven pots with connectors and pressure gauges. After placing the crystals in the pots, researchers pump the air out of the pressure cookers to protect the crystals from contaminants. The team then straps the pots into child safety seats, creating a low-tech solution for the transportation of high-tech equipment.

The crystals, produced at Canberra France, are prototype detectors developed for the Germanium Detector Array, or GERDA. Located deep underground in the Gran Sasso mountains in Italy, GERDA will search for the existence of the nuclear process known as neutrinoless double beta decay to gain more information on neutrinos, elusive particles produced in the center of the sun. Scientists want to determine the masses of neutrinos and find out whether neutrinos are their own antiparticles.

The first crystals have already made the trip from Strasbourg to Munich, a distance of about 400 kilometers. Later they will travel to the Gran Sasso National Laboratory. Fortunately, border controls have disappeared in most of Europe. Imagine how difficult it would have been to explain to officers the transport of these precious GERDA “babies.” Just in case, the drivers carry with them documents to prove that the pressure cookers are tested transport containers.

Silke Zollinger

The DUSEL cavern is getting restless

You can’t feel it. Yet the moon’s gravitational pull shifts the ground ever so slightly, creating “earth tides” that rhythmically raise and lower the ground.

That’s enough to throw off delicate scientific equipment, such as the systems used to aim two hair’s-width particle beams into a head-on collision.

And that’s not the only slow, subtle movement going on. At Fermilab, for instance, the spring thaw shifts the magnets that focus particle beams. So the lab developed sensors that track ground tilt to within 1/44th the diameter of a hair over a distance of 30 feet, allowing them to correct for the motion at one-tenth the previous cost.

Now those sensors are offering a new way to cheaply monitor the effects of sucking seven megatons of water out of granite caverns that will house the world’s deepest underground lab.

In January, Fermilab physicist Jim Volk (photo, right) helped Larry Stetler (left), a geological engineer from the South Dakota School of Mines & Technology, and a few graduate students install 12 of the ground sensors at the 2000-foot level of Homestake Mine, proposed future home of DUSEL.

They lugged cables, wires and water lines through puddles of muck in 75-degree heat with 95 percent humidity. More sensors will go in at the 4000-foot level this summer and at the 4850-foot level later this year.

“It was hot and dirty,” Volk says. “That brown iron ore dust, it gets in everywhere.”

After the South Dakota gold mine closed in 2001, the pumps were turned off and groundwater submerged half of its 8000-foot depth. As that water is pumped back out, the ground shifts. Monitoring those movements, as well as earth tides and shifts in the rock triggered by excavation, will be key to calibrating research equipment.

“It is not pure high-energy physics, but it is useful science,” Volk says of his work in the mine. “We are helping those guys get data and understand what is going on with the rock.”

As a bonus, he says, he’s learning a lot of geology that will come in handy for other projects. Despite the discomforts of working deep underground, “I can’t wait to get back there.”

Tona Kunz
It’s cute! It’s clean! It’s a SLACmobile!

Plugged into a weatherproof outlet behind SLAC’s Test Laboratory, what looks like an oversized green-and-silver go-cart waits with its load of tools and paint supplies. It’s part of a fleet of pint-sized economobiles that have carried people, materials, and equipment around SLAC National Accelerator Laboratory since the lab’s early days.

It all started with trikes. “The linac was full of three-wheeled bicycles way back when,” says SLAC fleet services garage supervisor Al Manuel. In the mid-60s, he says, SLACers pedaled tricycles up and down the Klystron Gallery that serves the lab’s two-mile linear accelerator.

Over time the trikes gave way to three-wheeled Cushman carts, former US Post Office vehicles powered by gasoline. By the early 1980s, electric four-wheelers began to appear. More than 50 of those jaunty flatbeds and microvans, some painted orange, red, or purple, carry ladders, mail, or library books across the site and around the mile-long PEP Ring Road. Manuel’s group keeps them running, alongside the mopeds and low-speed gas vehicles that have since joined the fleet.

For some of the older vehicles “a lot of repair parts are not available any more,” says SLAC Transportation Manager Ken Rubino, so workers salvage parts from others that are beyond repair.

As SLACmobiles go out of service, the fleet changes composition. At one time, Rubino says, scores of mopeds zipped around SLAC. Now the balance has shifted in favor of small-appetite gas vehicles and electric carts. The fleet’s users treat their wheels with some affection. One cart’s cab sports a pair of bull’s horns. Volunteers spruced up a second with removable flame stickers and a set of fuzzy dice for founding SLAC Director Pief Panofsky, who died in 2007.

“This is Pief loved it,” says Ellie Lwin, Panofsky’s assistant at the time, who spearheaded creation of the Piefmobile—even paying for the materials herself—as a surprise for him.

SLAC’s 15 gas-powered mini-pickups and vans get up to 50 miles to the gallon, thanks to their three-cylinder engines and light weight. But most of today’s fleet runs on electricity. If the United States plays its cards right with solar and wind power, more SLACmobiles could run on sunshine and fresh air in the years to come.

Shawne Workman
this case, each senior scientist trains successive waves of graduate students and postdocs, who become siblings of sorts as they work together and go on to train descendants of their own.

John Beacom, a physics professor at Ohio State University, says looking at a colleague’s scientific relatives is helpful in understanding his or her school of thought. “There is some family resemblance,” he says. “It’s really about understanding the context of who someone is.”

HEPNAMES is part of the SPIRES service, which is jointly operated by DESY, Fermilab, and SLAC. HEPNAMES itself is managed by Fermilab. It gets about 2000 hits per day, mostly from people combing through its 80,000 individual monikers to find current contact information for colleagues, says Heath O’Connell, Fermilab’s head of information services.

Enrico Fermi has 27 Fermilab physicists in his family tree, including Winslow Baker, Norman Gelfand, King-Yuen Ng, Jim Strait, and Gong Ping Yeh. Ten Fermilab physicists had Nobel Prize winners as advisors. Jim Strait, project manager for US participation in the Large Hadron Collider, has three Nobel Prize winners in his physics family.

Beacom primarily uses the database to get background on students. “When I’m trying to judge letters of reference, and professors say a student was their best student, I can look up their other students,” says Beacom. HEPNAMES also can help prevent bias in peer review: Beacom makes sure he doesn’t send students’ papers to their advisors for review, and vice-versa.

Beacom has been using HEPNAMES regularly since SLAC started it in the early 1980s. “It’s interesting and fun just to understand how long and how slow the scientific process is,” he says. “What we are doing today resembles what scientists were doing hundreds of years ago.”

Kristine Crane

Unharmed in quake, Gran Sasso lab goes to the rescue

When an earthquake flattened buildings in a number of towns across central Italy, physicists turned their focus from research to rescue and rebuilding.

The 6.3-magnitude earthquake on April 14, 2009, killed more than 300 people and left towns near Gran Sasso National Laboratory, a particle physics research center studying neutrinos and dark matter, nearly obliterated. With the laboratory itself mostly unscathed, scientists and engineers rushed to the aid of villagers and the physics department of L’Aquila University.

A laboratory building was quickly converted into a guest house for employees and users who had lost their homes, and space was made to relocate the physics department on-site. With the village of Assergi in rubble, the laboratory offered to shelter the villagers’ tent city inside its boundaries. When villagers chose instead to stay close to their damaged homes, the laboratory came to them. Chairs, tables, and just about anything moveable that could improve life in the camps was toted to the nearby village. Lab Director Eugenio Coccia and other staff visited the camp regularly to offer a lifeline of aid and support.

Physicist Roberto Aloisio, who fled the collapse of his own home in L’Aquila, spent the days after the quake searching the rubble for survivors and then, with the help of friends, installing free wireless Internet access for all of the town’s tent camps.

Other Gran Sasso employees who lost their homes found temporary shelter in towns outside the earthquake zone, commuting 120 miles or more to work.

The faculty of the university physics department will remain at Gran Sasso for the rest of the year. The laboratory management continues to discuss other ways of helping the university and the villages.

Tona Kunz
Highlights from our blog

The latest, greatest particles
June 8, 2009
Every second year for more than 50 years, the Particle Data Group has been compiling the best-of data about all the observed particles studied by particle physicists. The 2009 interim update was just released today and you can dig through all the gory details.

A young mad scientist’s first alphabet blocks
June 1, 2009
Turning over the blocks, I suddenly came face to face with a miniature etched image of the ATLAS experiment at the Large Hadron Collider. It sat on the face Q for Quantum Physics. Other faces include Invention, Experiment, Bioengineering, and the whimsical Nanotechnology, which is etched with just a small dot.

Theorists reveal path to “true muonium”
May 29, 2009
True muonium, a long-theorized but never-seen atom, might be observed in future experiments, thanks to recent theoretical work by researchers at SLAC and Arizona State University. Until now no one had uncovered an unambiguous method by which it could be created and observed.

Peering at the people and process of particle physics
May 26, 2009
For years, Large Hadron Collider documentaries focused on the project’s engineering and construction challenges, scientific goals, or doomsday scenarios. The online documentary series Colliding Particles follows a new trend, delving into the lives and work of one of the hundreds of research groups working on the LHC experiments.

A side of cloud with your grid, ma’am?
May 21, 2009
As the cloud becomes a more popular computing solution in the commercial world, it is starting to pique the interest of the academic research community. Collaborators at KEK in Japan are considering supplementing their computing with Amazon’s Elastic Compute Cloud, or EC2, which provides on-demand, virtual computing resources over the Internet.

The mural a half-mile underground
May 20, 2009
Even if the employees of the Soudan Underground Laboratory cannot watch the clouds roll by as they sit at their desks, many of them gaze through the blinds at a color-soaked 25-by-60-foot mural painted on the rock wall.

Fermilab in seven minutes
May 14, 2009
Have you ever tried to tell a story in seven minutes or less that mentions the sun, bison, neutrinos, and the world’s most powerful particle accelerator? Well, Gabriel Spitzer, reporter for Chicago Public Radio, has done it.

Rep. Foster draws from history for humorous groundbreaking address
May 13, 2009
Illinois Rep. Bill Foster, a Fermilab-particle-physicist-turned-Congressman, showed off his stand-up comedy chops in a speech at the groundbreaking ceremony for the NOvA neutrino experiment with his own take on President Abraham Lincoln’s famous Gettysburg address.
Nuclear masses measured to within a hair’s precision
May 6, 2009

No one likes to say exactly how much they weigh. Rare atomic nuclei are similarly coy. Michigan State University researchers have made precise mass measurements of four such nuclei. The results may make it easier to understand X-ray bursts, the most common stellar explosions in the galaxy.

Gamma-ray bursts may last longer than previously thought
May 5, 2009

Gamma-ray bursts, the most powerful explosions in the universe since the big bang, are thought to last mere seconds or a few short minutes. But new data from the Fermi Gamma-ray Space Telescope show at least some of them have much more staying power.

Finding 1 atom in 10, 000,000,000,000,000,000,000,000,000,000
May 3, 2009

Physicists are used to dealing with rare events and very small quantities, but rarely do they tackle a challenge of the kind facing the Enriched Xenon Observatory, or EXO. To find what they’re looking for, they will need to find a single barium atom in the 10-ton bath of liquid xenon—10\(^{28}\) atoms.

The stuff you can do with accelerators
May 2, 2009

There are 15,000-17,000 particle accelerators in the world. Yes, those numbers are correct! So where are they all? Synchrotrons and neutron sources are just a small fraction of them but they have applications in nearly every area of science.

Making 3D images of the proton
May 2, 2009

The proton is a surprisingly complicated object. Far from the two up quarks and one down quark you might have heard make up the proton, it is actually a seething sea of quark pairs and gluons that surround the “bare” up and down quarks. In fact, 99 percent of the mass of the proton comes from this sea.

Pulsars or dark matter might be the source of high-energy cosmic electrons
May 2, 2009

Something in our galactic neighborhood seems to be producing large numbers of high-energy electrons, according to new data gathered by the Fermi Gamma-ray Space Telescope. The electrons could be coming from nearby pulsars—or they could be a longed-for signal of dark matter, the elusive, invisible material thought to make up nearly a quarter of the universe.

Officials break ground for the world’s most advanced neutrino experiment
May 1, 2009

Construction begins this month on NO\(\nu\)A, a cutting-edge physics laboratory in northern Minnesota. Managed by Fermilab under a cooperative agreement between the DOE and the University of Minnesota, it will house a 15,000-ton particle detector that will investigate the role of subatomic particles called neutrinos in the origin of the universe.

Gamma signature, Astronomer’s Telegram cast light on dazzling blazar
April 30, 2009

The Fermi Gamma-ray Space Telescope’s Large Area Telescope collaboration has released a paper giving the gamma-ray perspective on an astronomical object that flared last summer. News of unexpected astronomical events such as this is distributed among the research community via the Astronomer’s Telegram service, a Web evolution of actual telegram distribution of alerts.
Percentage of PhDs earned by women

Source: National Science Foundation

- **2006**
  - All Fields: 45%
  - Science and Engineering: 38%
  - Physics: 17%

- **1996**
  - All Fields: 40%
  - Science and Engineering: 32%
  - Physics: 13%

- **1986**
  - All Fields: 36%
  - Science and Engineering: 27%
  - Physics: 9%

- **1976**
  - All Fields: 23%
  - Science and Engineering: 17%
  - Physics: 47%
Growing a diverse workforce

When it comes to training, hiring, and retaining women and members of ethnic minorities, particle physics lags far behind other fields of science. Staffers at three national labs—Fermilab, SLAC, and Brookhaven—are attacking the problem at every level. By Rhianna Wisniewski

When Cherrill Spencer started at SLAC National Accelerator Laboratory as a postdoctoral researcher in 1974, she was one of only three female physicists there.

“I wanted to have more women around me, enough so that we could get our own bathroom,” Spencer says. “I could see no good reason why more women weren’t becoming scientists.”

Today Spencer, who designs magnets that focus and steer beams of particles in accelerators, has many more female colleagues. But she still works hard to encourage the next generation of female scientists.

In 1978, Spencer became involved with the Expanding Your Horizons Network, which works to motivate middle school and high school girls to pursue careers in science, technology, engineering, and math.

The group’s conferences give girls a chance to interact with female scientists and engineers and complete hands-on scientific activities. In a typical year, about 26,000 girls, including 10,000 members of ethnic minority groups, participate in more than 80 conferences in 31 states.

“In just a day-long program you can actually change someone’s mind,” Spencer says. “You can go into a workshop led by a marine biologist and come out wanting to be a marine biologist.”
Many more women and members of minority groups work at Department of Energy laboratories now than 30 years ago. In fact, Asians are represented in far greater numbers than their percentage in the population, mostly because of an influx of immigrant engineers and scientists. But women, blacks, Hispanics, American Indians, and Pacific Islanders are still vastly underrepresented. Statistics compiled from Brookhaven National Laboratory, Fermi National Accelerator Laboratory, and SLAC, for instance, suggest that 22-32 percent of their employees—everyone from cafeteria workers and technicians to administrative staff and scientists—are members of underrepresented minority groups, and 20-28 percent are women. Among lab physicists, the percentages are far smaller.

National laboratories are working with educators to change that—offering training for science teachers, employing college students during the summer, and mentoring students. They're also working to recruit already-molded minds and to create a workplace culture that entices them to stay.

At Fermilab, a major effort is under way to boost diversity in the workforce by attracting a broad range of job candidates and creating a welcoming environment for people of all backgrounds. The laboratory recently held a series of focus groups to examine the lab's climate, and is adding cultural programs and creating task forces and committees to address diversity issues.

“When you have done your homework, hopefully you'll end up with people who represent different cultures and a good gender mix,” says Sandra Charles, equal opportunity specialist at Fermilab. “That requires the entity to take a look at including all people in a respectful workplace environment.”

**Progress steady but slow**

Women and members of underrepresented minorities have gained ground in scientific fields.

From 1966 through 2006, the percentage of PhDs earned by women in all science and engineering fields increased from 8 percent to 38 percent. But while women were earning 34 percent of all chemistry PhDs by 2006, they were awarded only 17 percent of physics PhDs that year, according to the National Science Foundation.

As for minorities, their numbers are still so low that Roman Czujko, director of the statistical research center at the American Institute of Physics, does not like to state them in percentages.

“To tell you the truth, when I produce reports that say that the numbers have grown by 0.4 percent, people read right past it,” he says. “That's the kind of thing we're talking about here.”

But when people learn that of the 41,446 PhDs granted in physics from 1973-2005, only 303 went to blacks, 504 to Hispanics and 43 to Native Americans, “it has a startle effect,” Czujko says.

In addition, large percentages of physics students and researchers in the United States are foreign. American citizens earned 75 percent of physics PhDs in 1973, but only 40 percent in 2006, according to the National Science Foundation.

As opportunities in their home countries increase, an increasing number of foreign scientists are expected to go back, and not enough Americans are being attracted into the workforce to replace them.

With the United States on track to become a majority-minority nation by 2042, it needs to attract more American women and minorities into science to ensure a robust scientific workforce in the future and boost the country’s competitiveness, security, and defense, says Ernestine Psalmas, senior program officer for the National Academy of Sciences.

As Bill Valdez, director of the US Department of Energy's Office of Workforce Development for Scientists and Teachers, puts it, “We have a stewardship responsibility to ensure that the next generation of physicists exists out there.”

**Barriers persist**

On paper, there are no reasons why women and minorities shouldn't be rapidly gaining representation in science, engineering, and technical fields. Legal, academic, and governmental actions within the past few decades have addressed open discrimination.

But experts taking a closer look have found cultural, societal, and academic factors that hamper the pursuit of science by these groups.

Ted Hodapp, director of education and diversity at the American Physical Society, believes physics carries a stigma.

“We don't market physics,” Hodapp says. “You tell people, 'I am a physicist' and they are put off. You tell them what you're working on and it becomes interesting.”

However, the problem goes far beyond a negative reputation.

Math and science, historically, were categorized as male fields. According to *New Formulas for America’s Workforce: Girls in Science and Engineering*, a report published by the National Science Foundation in 2003, biases persist in schools, and teachers may offer more encouragement to male students in science and math than to female students. Female students were also encouraged to pursue the less mathematical sciences.

“One thing seems pretty evident: Females are more pervasive in the biological and life sciences,” says Ken White, manager of Brookhaven's Office of Educational Programs. “There is a much smaller population of female students in physics,
JoAnne Hewett

2012
Leads exploration of extra dimensions

1999-2009
Shepherds four grad students to PhDs

1994
Joins SLAC, now full professor

1988-1991
Postdoctoral research at University of Wisconsin
Argonne National Lab

1988
Earns PhD in theoretical physics from Iowa State

1979
Takes first physics course at Iowa State
and is hooked

1978
Graduates Pleasant Valley High; excels at math and science but wants to be a musician

Photo: Brad Plummer, SLAC
Duane Doles

2015
Creates computer simulation of dark energy in inflationary cosmology model

2012
Howard University
Earns PhD in theoretical astrophysics

2008-2011
Conducts theoretical astrophysics research at Fermilab during GEM fellowship

2006
University of the District of Columbia
Earns undergraduate degree in physics, with honors

2004
Discovers theoretical physics can be a career, applies for Fermilab internship

1990
Graduates F.W. Ballou Senior High
Exceles at math and computer science; interested in the big questions
chemistry, engineering, and computer science."

Although high school students are required to take science classes, they don’t always have access to physics. It’s offered in only about 45 percent of New York City high schools, according to Angela Kelly, assistant professor and coordinator of the Graduate Program in Science Education at Lehman College, City University of New York.

“At least 75,000 students in New York City attend schools where physics isn’t an option,” Kelly says. "In urban areas with a very high underrepresented minority population, the numbers are even lower. Only 31 of 82 Bronx high schools offer physics.”

Whether physics is offered depends on many factors, including the school's size and ethnic makeup. When she asked school administrators why they don’t offer physics in their schools, Kelly says the response was often, "Our kids can't do it." They thought physics would be too difficult for most of their students to pass, and were unwilling to spend money to take that risk.

Instructor attitudes also play a role, says Sharon Fries-Britt, an education researcher at the University of Maryland at College Park.

She and her students conducted a four-year study on minority high achievers in the classroom as part of a project by the National Society for Black Physicists and National Society for Hispanic Physicists.

In interviews with 100 undergraduate students who were members of underrepresented minorities, Fries-Britt says she saw clear evidence of verbal and non-verbal behaviors discouraging the students from pursuing physics.

Minority students said they felt as if they had to prove themselves in every situation. Their instructors often called their work into question, criticizing sub-par work while speculating that students who turned in excellent work were cheating. This led some students to aim for mediocrity.

"Long-term coping is a challenge for these students," Fries-Britt says.

Stoking a passion for science
To produce more female and minority scientists, educators and laboratory staff members know they have to start by making science attractive.

“We have to introduce science to children in junior high and high school,” says Shirley Kendall, diversity manager for Brookhaven. “We have to get them at the very beginning and we have to sell science as a cool, integrated part of their future.”

An activity at Fermilab reveals stereotypes elementary school children have about scientists.

Before visiting the lab, students are asked to draw their impressions of what a scientist looks like. Most often, they draw white male scientists in white lab coats. After touring Fermilab and meeting with scientists, students tend to draw both male and female scientists of varying ethnicities in a variety of hair styles and attire.

Providing role models and mentors is another approach.

Some national lab scientists, like Spencer, reach out to young people through non-profit groups. Others participate in lab-sponsored education and outreach programs, such as lab open houses, science bowl competitions, and field trips.

Nearly 100 high school students come to SLAC each February for the DOE’s regional science bowl, an academic competition that tests students’ knowledge of mathematics and science.

Brookhaven brings in faculty members from historically black colleges and universities to conduct science at the laboratory.

“These faculty from minority-serving institutions develop strong relationships and collaborations with researchers at Brookhaven,” says White. They bring students with them, and take their science experience and enthusiasm back to the classroom.

Fermilab also offers teachers three consecutive summers of training as part of Academies Creating Teacher Scientists, a DOE-funded program. They do scientific research the first year, learn teaching techniques the second and focus on reaching out to other teachers during the third.

Michael Johnson, a former electronics engineer, switched to teaching in 2003. He entered the program to learn how to teach science at the Robert Emmet Academy in Chicago, one of the lowest-scoring schools on the LSAT in 2006.

“This program is making me look at science from a whole new perspective,” Johnson says. “I'm learning leadership skills and other skills that I can take back to other teachers and other schools. I'd like to teach teachers how to teach science.”

Building momentum through mentoring
Of full-time freshmen at American four-year colleges who said in a 2006 survey that they would probably major in physics, 21 percent were women, according to the Higher Education Research Institute at the University of California, Los Angeles.

That's a dramatic increase from 1973, when only nine percent were women.

But while 21 percent of bachelor's degrees and 23 percent of master's degrees in physics went to women in 2006, they earned only 17 percent of the physics PhDs that year, according to the National Science Foundation.

To plug leaks in the educational pipeline for women and minorities, laboratories are trying to engage and mentor college students such as Duane Doles.

Growing up in a predominantly black neighborhood in northwest Washington DC, Doles was always interested in life's big questions, and traveled across town to attend a public high school specializing in math and science. But until he met Fermilab scientist Herman White at
Brianna Stephens

Future
Exciting adventures await!

2010
Freshman, High School
Takes geology and as many other science classes as possible

2008
8th grade physics field trip for Beauty & Charm Physics workshop

2007
Dissects frogs in 7th grade science class

2005
Spends summer in Fermilab Science Adventures, hands-on experiments are her favorites
the National Society for Black Physicists annual meeting in 2004, he never knew that his interests could become a career.

Doles applied for a summer internship at Fermilab that year, and spent the summer after his sophomore year at the laboratory in the Students in Science and Technology program.

"Before the internship, I didn't know that becoming a theorist was a career option," Doles says. Today, he is a third-year graduate student from Howard University working at Fermilab, where he is simulating the design of a new astrophysics project.

"The scientists here were mentors for me at the undergraduate level and continue to be at the graduate level," he says.

For graduate students like Doles, the National Consortium for Graduate Degrees for Minorities in Engineering and Science, known as GEM, offers fellowships to members of underrepresented minorities who are pursuing masters' degrees in science and engineering. The program has paid part of Doles' tuition, enabling him to continue to study and work at Fermilab.

Many of the national laboratories participate in DOE's Science Undergraduate Laboratory Internship Program, which is dedicated to motivating students who may not otherwise pursue careers in the sciences. Another DOE program, Community College Initiatives, encourages students to continue to pursue science majors after transferring to four-year institutions.

In addition, individual labs have their own programs. For instance, SLAC's Youth Opportunity Program provides disadvantaged people ages 18-22 with full-time summer jobs to help offset their education expenses and motivate them to remain in school.

Attracting and keeping workers
Expanding the pool of strong female and minority candidates for jobs in the basic sciences is the primary focus of recruiting and outreach efforts, Kendall says.

"Progress is very slow," she says. "We all have the same goal—to attract top talent from all groups for the purposes of having a diverse workforce and inclusive work environment. Most organizations are in a similar position, which is not there yet."

Unfortunately, when it comes to competing against businesses in private industry, national labs often lose the salary war, says Dianne Engram, Fermilab's diversity officer. Retention can be even more challenging; she and Kendall note that they often see employees who trained at the lab take their skills to private companies.

To prevent this, the lab must offer competitive pay, clear career paths, and a welcoming, inclusive, and accepting culture.

Two committees of the American Physical Society visited Fermilab in May 2008 to assess the climate for women and minorities in physics and closely related fields and to advise the laboratory leadership on how to improve inclusiveness.

They concluded that Fermilab needs to implement a code of ethics requiring all lab employees and users to treat each other with respect; improve training among leaders at the laboratory; and increase communication and transparency regarding decision-making processes and results.

In response, Fermilab hired an independent facilitator who ran 25 focus groups to examine whether the report's findings stemmed from a systemic pattern of bias within the laboratory.

"The APS report presents some serious allegations and the lab wanted and needed to take it seriously," says Doug Sarno, principal of Perspectives Group, Inc. and facilitator of the focus groups.

Sarno invited a random cross section of lab employees to participate, and spent weeks interviewing laboratory staff and users from all fields.

"What we didn't find was a systemic condition," Sarno says. "The laboratory is diverse well beyond the normal workplace because of the many international cultures working together in every aspect of the lab. Fermilab employees have learned to handle this diversity really well."

At the same time, Sarno says that the APS committees did identify real problems.

"The APS heard some individual stories from graduate students and women," he says. "These absolutely happened, but they didn't happen as a result of Fermilab's current policies and culture and were not condoned."

To further increase diversity at Fermilab, Engram and Charles are leading an effort to create a more comprehensive and more inclusive program. They're establishing committees to address diversity issues and act as liaisons with the Diversity Office. The pair has also boosted the number of events celebrating the dozens of ethnicities and backgrounds of laboratory employees and users.

More needs to be done, Engram says. She hopes to get a mentoring program started for full-time employees, and wants to increase awareness of her office's diversity initiatives.

Although the climb is steep, Engram isn't about to back down. She, along with other diversity officers throughout the national lab system, is working to create a future that is open, inviting and inclusive.

They acknowledge it won't be easy or quick. But they're determined to get there.
The Fermilab team that will use the Dark Energy Camera to peer deep into the dark includes, from left, physicists John Peoples, Brenna Flaugher, Juan Estrada, and Tom Diehl.
Gazing into space, scientists wonder why the universe is expanding ever faster. What mysterious force is at work? By recording the light from hundreds of millions of galaxies from a mountaintop in Chile, they hope to find out what’s going on.

By Kristine Crane
Imagine a camera that takes pictures of the universe not only as we see it today but back through time, closer to when the universe began, capturing images of roughly 300 million galaxies.

At Fermilab in Batavia, Illinois, Brenna Flaugher and her colleagues are building such a device. Called the Dark Energy Camera, it will survey the skies of the Southern Hemisphere and peer far back in time, allowing scientists to see galaxies as they were when the universe was only a few billion years old.

The goal is to search for signs of dark energy—the ubiquitous, invisible substance believed to make up 70 percent of the universe.

For Flaugher, who spent 15 years studying subatomic physics, the prospects were so intriguing that she changed the focus of her career. “I have gone from studying the smallest known things in the universe—quarks—to galaxy clusters, the biggest things we know,” she says. “The thing that makes both fun is that you get to think about the origins of the universe.”

**A mysterious force**

Eighty years ago, Edwin Hubble discovered that our universe is expanding, with galaxies becoming increasingly distant from each other. Scientists reasoned that the gravitational attraction among galaxies must slow this expansion. But then in 1998, two independent teams of scientists discovered a perplexing change in the expansion rate of the universe: for the first eight billion years after the big bang, gravity indeed had slowed the expansion, as predicted. Then, roughly five billion years ago, the expansion began to speed up.

What caused this acceleration? The preliminary answer is dark energy, a mysterious “antigravity force.” When the universe was young, gravity was the dominant force. But over time, matter spread out enough to significantly diminish the gravitational attraction between galaxies. Dark energy, a repulsive force, began to overpower the gravitational force and push the galaxies ever faster apart.

Confirming the existence of dark energy and understanding its origin would have profound implications for our understanding of the universe. But an even more radical outcome would emerge if scientists discovered that dark energy does not exist. Instead, some theoretical models suggest that an extra spatial dimension causes the universe to expand ever more rapidly, unraveling Einstein’s general theory of relativity. The Dark Energy Survey, scheduled to be up and running in 2011, might reveal which explanation is correct.

“It’s throwing the tools of the digital age onto the old question of where we are,” says Craig Hogan, the director of the Center for Particle Astrophysics at Fermilab.

**A fateful conversation**

In the summer of 2003, former Fermilab director John Peoples and University of Chicago physicist John Carlstrom shared a cab on their way back from an astrophysics conference in Seattle. The subject of dark energy was already on Peoples’ mind, and Carlstrom was working on the South Pole Telescope, whose construction would soon begin in Antarctica. Since 2007, the telescope has recorded the microwave background radiation left over from the big bang, looking for distortions that mark giant clusters of galaxies. But the telescope is unable to determine how far away, and hence how old, galactic clusters are—information crucial for connecting its observations to dark energy calculations.

What they needed, the two physicists agreed, was a project that would fill the gap by determining how far these clusters are from Earth.

“The prospect was exciting,” Peoples recalls. At the time, he had just finished directing the Sloan Digital Sky Survey. The project, which makes observations from a telescope in New Mexico, has provided three-dimensional maps of nearly one million galaxies and 120,000 quasars in the Northern Hemisphere. Combined with data recorded at other observatories, the measurements indicate that 96 percent of the universe is composed of dark matter and dark energy.

**Is gravity the problem?**

Mounted on a telescope in Chile, the Dark Energy Camera will peer deeper into the sky and unveil more galaxies at greater distances than any previous project, including the Sloan Digital Sky Survey. It will collect data on the distances of supernovae from Earth; the large-scale clustering of galaxies; the abundance of massive galaxy clusters; and the bending of light caused by galaxies and clusters of galaxies.

Scientists will use these four methods to determine how fast the universe has been expanding and the rate at which galaxies and clusters formed over cosmic time. Two of those methods will yield answers that are independent of the role that gravity played in the evolution of the universe. The other two will provide answers that depend on the theory of gravity.

“If all four measures show the same result, it means that our current ideas about dark energy are correct; if they differ, there is either a problem in our understanding of gravity or some other explanation,” says Flaugher, who is spearheading the camera’s construction. The $50-million Dark Energy Survey involves 120 scientists from 13 institutions in the United States, Brazil, Spain, and the United Kingdom. University College London is responsible for polishing the five lenses that make up the optical system of the camera.
The Expansion of the Universe

Galaxy Formation
Over billions of years, gravity draws matter together into a web of structure. The bright spots are where galaxies form.

Size of the Universe
Not to scale

Energy and Matter Content

Simulations and visualization of galaxy formations by Andrey Kravtsov, The University of Chicago, and Anatoly Klypin, New Mexico State University
The Spanish groups provide the electronics that will process faint signals of light that traveled billions of years across the universe before landing in the “eyes” of the Dark Energy Camera.

Traveling back in time
At the forefront of Fermilab’s construction team is physicist Juan Estrada, who joined the project as a Fermilab Wilson Fellow in 2004. Estrada was a postdoctoral researcher studying the top quark at Fermilab’s DZero experiment when he became attracted by the prospect of working on the Dark Energy Camera.

As an undergraduate in Argentina, Estrada had studied the properties of the vacuum, and he was eager to revisit an issue that he considers the biggest problem in physics: the mysterious energy that seems to come from empty space in our universe.

To do that, he first had to learn astronomy. “Fermilab gave me the opportunity to learn something I had never done before,” Estrada says.

He learned how an astronomical camera works from a retired Fermilab engineer, Tom Droege, who practices astronomy from his home observatory. By taking apart and reassembling Droege’s camera, Estrada learned the basic steps of building a camera, valuable lessons for the construction of the Dark Energy Camera.

When complete, the Dark Energy Camera will be the size of a Smart car. What makes it so powerful are 74 delicate detectors, called charge-coupled devices or CCDs, each three by six centimeters in size and 0.250 millimeters thick. As in an ordinary digital camera, they are the camera’s “film” that records incoming light. The CCDs will sit on a plate about half a meter in diameter, located a few centimeters behind the camera’s set of lenses.

Cooled to minus 100 degrees Celsius to reduce background noise, the Dark Energy Camera’s superb CCDs will record longer wavelengths of light than other optical cameras do. This will allow it to see light from fast-receding galaxies that has shifted to longer wavelengths, toward the red end of the spectrum, in the same way a siren drops in tone as it moves away. The fastest-moving galaxies are also the farthest away, as Hubble discovered. What’s more, the light we see from the farthest galaxies is the oldest because it has taken longer to reach us. And so through this chain of inferences from reddest to fastest to farthest to oldest, the Dark Energy Camera will be able to see distant galaxies as they looked billions of years ago, closer to the universe’s infancy.

“We are mapping the distribution of the galaxies from what the local universe looks like now to a time when the universe was just a few billion years old,” says Dark Energy Survey collaborator Joe Mohr, physics and astronomy professor at the University of Illinois, Urbana-Champaign.

Reviving an old scope
Crafting the CCDs requires a unique process developed by engineers at Lawrence Berkeley National Laboratory. The final steps of the manufacturing process take place in a clean room inside a dome-shaped building at Fermilab. The lab’s technicians were already familiar with the assembly of silicon detectors used in particle physics experiments; now they produce an average of four CCDs per week for the camera.

Once all the CCDs are ready—a milestone the team expects to reach next year—technicians will finish assembling the camera and ship it to the Cerro Tololo Inter-American Observatory in Chile, where it will be placed atop a four-meter telescope called the Blanco.

The Dark Energy Camera will give new life to the 40-year-old telescope, which met the survey’s criteria beautifully, according to Peoples: “It was a marriage made in heaven.”

From Chile to Illinois
The Dark Energy Survey collaboration will use the telescope for five years between September and February, taking images on 105 nights each year and sending a few hundred images per night to the University of Illinois, Urbana-Champaign. Each image comprises 520 million pixels, equivalent to about 1 gigabyte of data, with information on the redshifts and brightness of about 200,000 galaxies and other celestial objects too faint to be seen by a simple household camera.

A supercomputer, which Mohr calls the “mother ship,” will store all these images and automatically detect the objects they contain, producing a catalog of galaxies with their brightnesses, positions on the sky, and other properties. The science team will analyze and interpret this information, searching for clues that might help explain cosmic acceleration.

So what will scientists find out? “None of us is a prophet,” says Ofer Lahav, chair of astrophysics at the University College London, who co-chairs the scientific committee of the Dark Energy Survey collaboration with Fermilab’s Josh Frieman. Lahav says the findings will lead to a more complex view of dark energy, or perhaps a modified version of gravity.

Especially if it’s the latter, revisiting Einstein’s theory of relativity would be “a big shake-up to the foundations of physics,” says Lahav. “Either way it’s exciting.”

While future surveys aim to probe even deeper into the sky for answers about dark energy, the Dark Energy Survey will be the first to take a stab at solving the mystery, says Lahav.
“It is among the surveys that will push the subjects of dark energy and modified gravity to a new level,” he says. But that is not all.

The big payoff
The Dark Energy Survey collaboration expects that its data on stars, quasars, and galaxies will lead to hundreds if not thousands of scientific publications. The collaboration will make its data public a year after it has been taken, an approach also used for the data collected by the Sloan Digital Sky Survey and the Hubble Space Telescope.

The Sloan survey, which mapped a quarter of the sky, has generated more than 2400 scientific publications so far. Its results have been cited more often than those from any other observatory, including the Hubble.

The Dark Energy Survey collaboration hopes to be equally successful. Its survey of the southern sky will cover an area smaller than the Sloan survey of the northern sky, but it will go deeper, further back in time.

“It’s a small project for a really big scientific payoff,” says Flaugher. Most importantly, it might answer what she and her colleagues consider “the biggest question out there.”

Although Flaugher won’t wager a guess on whether the findings will confirm or deny the existence of dark energy, she is certain about one thing.

“I don’t want to argue about it anymore,” Flaugher says. “We need data, data, and more data.”

In a few years, she’ll have it.
Photography by Reidar Hahn
Helium’s shrinking bubble

Helium is the lifeblood of large particle accelerators. As the world’s supply dwindles, the particle physics community must take steps to preserve this precious commodity or learn to live without it.

By Calla Cofield
At a couple of degrees above absolute zero, far colder than any living organism can survive, liquid helium stirs to life the largest particle accelerators in the world. It pulses through the veins of the Large Hadron Collider, following thousands of dipole superconducting magnets around a 27-kilometer ring. Flowing through magnets in Fermilab’s Tevatron, it helps jump-start subatomic particles on their way. These and other vital organs at dozens of labs around the world depend on helium to help them thrive.

Hot air balloons, blimps, car airbag systems, welding, leak detection, scuba breathing mixtures, and NASA space shuttles all use helium. Cryogenics, which includes cooling for particle accelerators and detectors, consumes 28 percent of helium in the United States, with half of that chilling tens of thousands of Magnetic Resonance Imaging, or MRI, machines. And the market is growing.

At the turn of the 20th century, natural gas miners found helium coming from underground, produced by the radioactive decay of uranium and thorium. It appears in pockets of natural gas in small portions, with three percent helium considered a good ratio. Although helium is relatively easy to extract, it falls on the natural gas companies to capture the gas or let it go.

Lighter than air, helium released from the Earth escapes the atmosphere into space. As the second-smallest atom in the universe, the cunning gas finds its freedom through almost any opening, joint or crack, eventually leaking out of party balloons and even passing through some types of glass. Like oil, coal, and natural gas, Earth’s supply of helium will inevitably run out.

While the physics community is aware of this impending problem, says Fermilab cryogenic engineer Tom Peterson, “we’re just not sure what to do.”

The coldest liquid

“Helium,” says Serge Claudet, “is a very nice gas.”

Claudet is head of the Large Hadron Collider’s cryogenics operation team, and he has a very specific set of qualifications for a “nice gas.”

Placid helium is non-flammable, a big bonus for facilities storing large quantities of it. A noble gas, it is also easy to keep clean since it doesn’t tend to bond to other elements. Helium is the only element that is liquid at nearly absolute zero, and even at that frigid temperature solidifies only under pressure. Helium’s ultra-cool nature makes it the perfect option—the only option—for many superconducting applications.

At super-cold temperatures, certain materials—such as copper, aluminum, and niobium titanium—lose all resistance to electricity. This allows electrons to flow uninhibited, delivering current with 100 percent efficiency. Wrapped into coils, superconducting wires become electromagnets that substantially out-perform conventional magnets in the strength of their magnetic fields. With this strength, scientists can steer particle beams around circular tracks, as the particles move at nearly the speed of light.
To maintain these cold temperatures, superconducting magnets require a liquid coolant that will flow over them, pick up excess heat, and carry it away.

The helium refrigeration system at Fermilab rumbles with the get-up of 10,000 horsepower, cooling 10,000 liters of liquid helium—a little more than enough to fill two double-decker buses. Helium exits the refrigeration unit through pipes of stainless steel, one of the few materials that won’t become brittle and crack at 1.8 kelvin, or minus 456 degrees Fahrenheit. Peterson and the cryogenics team surround that pipe in a vacuum, seal it in a second pipe, box the pipes in a copper thermal shield, wrap that in another layer of shielding, and weld the whole package inside a vacuum-tight steel container. It’s the ultimate thermos, dedicated to reducing heat loss to zero.

“Liquid helium is a utility in the production of the particle beam, like power or water,” Peterson says. “When the cooling is available, experimenters don’t think much about it. It is when it goes away that you notice it.”

A knack for getting loose

In theory, a system carrying helium through a facility like Fermilab should never need to replenish its supply. It should carry cold helium to its target, bring warmed helium back to the refrigeration unit, and so forth.

But joints in miles of piping and hair-line cracks unseen by engineers leave helium just enough room to escape. Materials commonly used to seal up joints become brittle at 1.8 kelvin and cryogenics teams can dedicate only so much time to searching for leaks. Brookhaven National Laboratory holds 50,000 liters of liquid helium and loses 20 percent to leaks per year; after the LHC’s yearly shut-down, cooling-down, and starting up, the helium loss is about 25-30 percent. This leaked helium is rarely recovered. In addition, power outages cause helium to heat up and expand beyond what facilities can hold, forcing them to release it into the atmosphere.

In 1925, the US government recognized helium’s limited availability and began storing it in the Federal Helium Reserve in Amarillo, Texas. In the 1990s, in an effort to keep helium costs down, the government began selling off the reserve. Debate over this decision still rages between those who would like helium costs capped, and those who worry what will happen when the supplies run out. Even so, prices have nearly doubled in the United States in the past three years.

In 2007, several US helium refineries failed to come online as scheduled, due to a series of coincidental delays. Helium users felt the pinch. Roberto Than, a cryogenics specialist at Brookhaven, says the lab’s supplier warned of possible delays in delivery. It turned out to be a close call. “We were still able to get it on time,” Than says, allowing the lab’s Relativistic Heavy Ion Collider to start up on schedule.
Helium may be the second most abundant element in the universe, but on Earth it’s a non-renewable resource. Physicists and engineers are working on ways to conserve and recycle this essential gas so it doesn’t just float away.

Making recycling pay

Although experts know helium isn’t as rare as xenon nor as abundant as nitrogen, they have difficulty assessing just how much helium is left underground, and they can’t tell how much of that will be captured by natural-gas miners. It is possible that in as little as 30 years, world helium production could peak.

While there is no direct concern for tomorrow, Claudet says the particle physics community does have a focus on helium conservation, and notes that over the past 30 years helium recovery efforts have improved significantly. Large facilities like CERN, Fermilab, and DESY have always liquefied their own helium and have increased efforts to recapture it. At SLAC National Accelerator Laboratory, workers built a custom recycling unit to purify contaminated helium from the PEP-II accelerator when it was running.

“At CERN we’re working on diminishing losses,” Claudet says. “We’re trying to increase storage and become less dependent” on the helium market.

Many small particle physics facilities don’t use enough helium to make recovery cost-effective. Refrigeration machines need frequent maintenance and eat up a significant amount of power. So used helium is often released into the atmosphere.

But a new technology may change that. The Soudan Mine in Minnesota hosts the Cryogenic Dark Matter Search, CDMS, in a laboratory a half mile underground. There, protected from cosmic rays, physicists hope to identify the passage of dark matter particles. To reduce thermal noise, they cool their germanium and silicon detectors with liquid helium.

In May 2009, Soudan scientists carefully lugged a new type of helium refrigerator, called a “cryo-cooler,” down a 12-foot-wide, 2341-foot-deep mine shaft that provides the only entrance to the laboratory. These small helium liquefiers, about the size of a household refrigerator, cost less than one-fifth the price of a traditional liquefier. Bauer, who manages the CDMS project, explains that the lab’s 60-liter-per-day helium usage wouldn’t justify the cost of
a traditional liquefier, especially since the older units usually need maintenance every few weeks. But the cryocoolers are a perfect fit for Soudan, and need maintenance only every year or two.

Bauer says he learned about the cryocoolers less than two years ago and made a move to obtain them right away. With helium prices climbing the way they are, the coolers should pay for themselves in less than two years.

Pressing ahead

Peterson is now working on designs for the International Linear Collider, which would rely on liquid helium as well. But by the time it is built and running, physicists may already need to be on the lookout for alternatives.

High-temperature superconductors present one possibility. Scientists are working doggedly to understand the mechanics of superconductivity, and hope to achieve it at temperatures where elements such as nitrogen are still liquid and can be used as coolants. Nitrogen is cheaper than helium, represents about 80 percent of the air we breathe, and isn’t flammable or explosive like hydrogen. However, at this time there are no high-temperature superconductors that could fill the needs of particle accelerators.

While the particle physics community must do its part to preserve the world’s helium supplies, in some ways its hands are tied. Although facilities like Fermilab and CERN use helium on a larger scale than most, they represent only a very small percentage of overall helium consumption. For that reason, their conservation efforts alone won’t stop a helium shortage.

But that hasn’t stopped them from trying. Conservation efforts at large facilities continue to improve and grow, while physicists and engineers press ahead to create new technologies that could cut helium usage across the board. Slowly but surely, high-energy physics is preparing for a possible helium shortage. Only time will tell if it is acting fast enough.
These exquisite test samples transcend their original purpose—ensuring all the metal parts of SLAC accelerators and detectors are flawless.

By Lauren Schenkman
There is something undeniably appealing about these baubles, which were rescued by the boxful from the salvage yard at SLAC National Accelerator Laboratory. Each gemlike piece is at once simple, playful, and eloquent. One resembles an assortment of minuscule wrenches, another a face cracking a geometric grin. They seem to mean or symbolize something, to tell a tale in their glint and sparkle. Each one is unique, and uniquely compelling. But what are they?

The answer, it turns out, is everything.

"Every project that came through SLAC sent stuff through us," says former SLAC metallographer Will Glesener. Now a metallurgist with a company in New York, Glesener spent five years at SLAC inspecting the quality of materials that eventually found their way into particle detectors and accelerators. He would take snippets of every batch of metal SLAC purchased, whether it came from the United States, Finland, or Japan, and process them into these metallographic mounts, which he then examined under a microscope.

To the trained eye of a klystron engineer or accelerator physicist, the tiny wrenches become machined screws, a zigzag of copper and stainless steel becomes an electron-beam weld, two eyes and a nose become vacuum tubing.

**Finer and finer**

Crafting a mount is an art, a meticulous process with many steps. "It usually took, from start to finish, a couple of days for the whole procedure," Glesener says. To sample a bar of copper, he would slice off a small chunk with a diamond saw, place it in an epoxy mold, and bake it at high temperature and pressure. Then he’d begin the slow, painstaking work of polishing the sample’s surface with five different grit sizes, then with three progressively finer grades of diamond slurry, and finally an incredibly fine 0.05 micron-meter alumina polish that left the surface as smooth as a mirror. Then Glesener would dab the mount with a cotton swab dipped in an etching chemical, removing the smooth layer, and the sample would be ready for viewing.

"It was very time consuming, but the whole purpose was to get beyond this and then look at the microstructure, which is what you’re after. Then the story begins," says Jean Francis, who began working as a metallographer at SLAC in 1964, during the early days of accelerator construction. "After all the heating, pounding, and cutting, the challenge is to maintain what was done to [the metal], without altering the story."

In her 40 years at SLAC, Francis made thousands of samples, inspecting the raw materials for components ranging from the original accelerator cavities to flanges for the B-meson factory of the late 1990s. Viewing the samples through a specialized microscope called a metallograph, Francis could read the tale of a poorly executed braze or a flawless vacuum tube. She especially loved looking at extremely pure copper, whose microstructure held the story of the smelting and extraction processes.

"Copper to me is prettier than gold," says...
Francis, who now lives in rural Utah. “It has this pink cast to it. The purity that we were handling was outstanding, and I always remember that this is not what the material was before extraction from nature.” To think of the process this material went through, she says, “is truly a wonder.”

**Tiny flaws, big trouble**

Smelting processes for copper can go slightly awry. Gazing into the microscope, Francis and Glesener hunted for specks of copper oxide in a landscape resembling an aerial view of a desert crossed by one or two lonely highways, boundary lines dividing different grains in the metal. Impurities like these can lead to electric arcing, which causes the copper to warp and melt, undermining the performance of klystrons, the devices that feed microwave-frequency power into the linear accelerator.

“The klystrons are the pulse of the linear accelerator, so there was really critical analysis done,” Glesener says. “What we were actually looking for was oxygen contamination down in the parts per million.”

Accelerator and klystron components are joined by brazing, in which two parts are placed in a furnace with a filler metal that has a lower melting point. The metal melts and capillary action pulls it into the gap between the two components; removed from the furnace, the metal cools and hardens. But when contaminated copper parts are brazed together in a hydrogen furnace, hydrogen can seep into the copper to join trapped oxygen, forming water vapor.

“If you have enough it will turn it into Swiss cheese, and it no longer meets the requirements of being a nice vacuum material,” says Erik Jongewaard, head of SLAC’s klystron department.

**Pieces of lab history**

As they worked, the metallographers scratched a code of letters and numbers into the back of each mount, and kept the matching reports and images in black D-ring binders.

“We kept all the mounts from day one, so we could pull out a mount and retest it,” Glesener says. “I’ve had a request from the klystron department where a part they put in 20 years ago broke, and they wanted to test the material that part was made of.” The trays of gleaming mounts were also a popular attraction on lab tours.

When major budget cuts shook SLAC in January 2008, the Surface and Materials Science department, of which metallurgy was a part, was closed and the work contracted out. The department head tried to save as much of the scientific equipment as possible, but the large collection of mounts went to salvage. Although most have been lost, the survivors have found a new home in the SLAC archives.

The metallographic mounts are part of the physical record of the laboratory’s history, and a testament to the incredible challenges that were overcome in building such large-scale experiments. As Francis puts it, peering through a microscope at these samples was a first-hand glimpse of “man trying to do the impossible.”
Look at the periodic table of elements, and you’d be hard pressed to find an element that is not used in physics. But what are the most important elements for building accelerators, detecting particles, and solving the mysteries of the universe? The search for answers takes us on a winding journey that includes ancient shipwrecks, trendy earrings, and the sound of dark matter. *symmetry* intern Kristine Crane asks Fermilab physicists about the elements they could not live without.

**H**

Hydrogen provides the protons for proton beams. Made of only one proton and one electron, the hydrogen atom is the lightest element. It is also the most abundant, comprising 90 percent of the visible universe by mass.

**Nb**

Niobium helps push and steer particles. Of all the elements, it superconducts at the highest temperature—9.2 kelvin. It is the material of choice for the superconducting magnets that keep beams moving in the right direction and superconducting cavities that accelerate beams. Niobium is also used for stylish earrings and superconducting magnets in MRI machines.

**Fe**

Iron is the most stable element in the universe: it takes more energy to break apart an iron nucleus than any other type. At the European laboratory CERN, an iron yoke weighing approximately 10,500 tons channels the magnetic field of the CMS detector.

**Pb**

Lead shielding protects supersensitive particle detectors from naturally occurring radiation. But lead itself can be radioactive. The melting of lead ore isolates heavy isotopes, but short-lived lead-210 remains. Hence the best kind of lead is at least 200 years old and can be found, for example, in shipwrecks.
Liquid helium cools the superconducting magnets that steer particles and bend their paths. It is the only element that remains liquid at the ultracold temperature of 4.5 kelvin. Fermilab and CERN have two of the world's largest plants for converting helium gas to its liquid form.

Liquid nitrogen cools magnets and other devices to 77 kelvin. Fermilab uses about 80,000 liters of it each day. At six cents per liter, it's a cheap commodity.

Argon is an inexpensive noble gas. Scientists are drilling wells in Texas to find non-radioactive argon, which they prefer in their particle detectors to avoid signals caused by the decay of radioactive isotopes.

Xenon is an expensive cousin of argon. A liter of liquid xenon costs $1000. Xenon is used in lasers, light bulbs, and anesthesia, as well as in the neutrino research at the Enriched Xenon Observatory.
Mining a rich vein of science

Gold! That precious metal has been a constant measure of value to mankind. Fortunes have been made or lost, empires have risen or fallen, all in the pursuit of the Mother Lode.

Such is the case of Lead, South Dakota. Not long after General George Custer and his expedition to the northern plains discovered gold in 1874 on the western edge of Dakota Territory, prospectors populated the area in hopes of getting rich quick. Several of these nomadic miners made their way to the heart of the Black Hills.

Californian George Hearst, who went on to build a fortune on mining, sent emissaries to the territory and began buying up claims. Thus were born Homestake Mining Company, the famous Wild West town of Deadwood, and the neighboring company town of Lead (pronounced ‘leed’).

For 125 years Homestake and Lead were one and the same. Generation upon generation worked for and in the mine, and people were born, lived their lives, and sometimes died for the company name.

Homestake was behind much of the modernization that came to Lead, and ultimately the entire region. The company needed power, lumber, water, and medical care; so it started an electric company, a sawmill, a water distribution and treatment system, and a hospital. The company wanted culture and activities for its workers, so it built an opera house and recreation center.

Because of Homestake, the city of Lead boasted a quality of life seen at that time only in places like St. Louis and San Francisco.

At its peak, Homestake’s Black Hills mine employed nearly 4000 workers. School children would learn the names of the company’s general managers just as they would the presidents of the United States. The high school boasted a wood-shop and metal shop that technical schools today would envy.

The 8000-foot-deep mining operation began to fade in the 1990s. The price of gold was falling and the cost of production skyrocketing. Despite a major downsizing and reinvestment in the capital plant in 1998, Homestake was doomed.

Around Lead it had often been said, “When hell freezes over or Homestake closes!” Hell finally froze over on September 11, 2000. Homestake announced that the Lead property was being shut down.

But the citizens of Lead had very little time to mourn. Within weeks, Richard Gowen of the South Dakota School of Mines & Technology, along with physicists from a variety of institutions, brought forth the idea that Homestake should be the site for a deep-level underground laboratory. Suddenly, the folks in Lead began to learn about some very strange and foreign things—beta decay, dark matter, and, of course, neutrinos.

The community embraced the next concept of what its hometown might become. The next February, and on the 23rd of that month every year since, Lead has celebrated the National Science Foundation’s initial visit to the proposed lab site with “Neutrino Day.” There is a “Miss Neutrino,” and school children participate in contests to determine exactly what they think a neutrino looks like.

The NSF's designation of Lead and Homestake as the site of the Deep Underground Science and Engineering Laboratory, or DUSEL, took much longer than originally hoped. In fact, the journey turned out to be a roller coaster! When the announcement came that the pumps that were keeping groundwater out of the mine were to be decommissioned, it seemed as though the project was lost. Legal maneuvers delayed the inevitable, but the pumps shut down and water began filling the mine at a rate of about 300 gallons a minute.

The greatest catalyst for the project came when Mike Rounds became governor of South Dakota in 2003. He and his staff recognized the paramount importance of this proposal and made it a priority early in his administration. His efforts to form strategic alliances and develop a cooperative consensus among government, the private sector, and the scientific community demonstrated that Homestake was just too good a site to pass by.

All that led to the formal donation of the site from Barrick Gold Corp. to the state, the creation of the South Dakota Science and Technology Authority, a gift of $70 million from South Dakotan T. Denny Sanford for infrastructure improvements and educational outreach, and finally the July 2007 designation of Lead as the home of DUSEL.

Lead boasts a wonderful past, an exciting present, and an awesome future. The community has always been about mining, and will continue to be about mining. Now, however, we are no longer mining gold, but science.

Tom Nelson, whose grandfather came to Lead at the age of 12 to work for Homestake Mining Company, is the mayor of Lead, a state senator, and the general manager of Gold Dust and Four Aces Gaming in Deadwood.
In 1991, James Cronin travelled to Leeds, England, to visit Alan Watson, an expert on cosmic-ray physics. Cronin, a Nobel Prize winner in physics who had worked on accelerator-based particle physics experiments, wanted to discuss ideas for cosmic-ray projects. Inspired by a proposal by Russian physicist Georgii Khristiansen, he was eager to see the construction of a large array of detectors to unravel the mysteries of the highest-energy cosmic rays in the universe.

Based on his conversations with Watson and other scientists, Cronin combined what he considered the best ideas and developed an ambitious conceptual design for an array of almost 3000 detector stations to be installed across an area larger than the state of Rhode Island.

To stimulate discussions with other scientists, Cronin distributed his concept through an Enrico Fermi Institute preprint, also published in the proceedings of a symposium held in Zuoz, Switzerland, in April 1992. This sketch, made by Richard Armstrong, head of the engineering group at the University of Chicago, is Figure 12 of the article. It shows one of the proposed detector stations, powered by a solar collector and communicating by microwave transmitter. The detector array would record the extensive showers of secondary particles produced by high-energy cosmic rays and transmit their data to a central receiver station.

Cronin and Watson became the co-leaders of the proposed project. In 1995, researchers met for six months at Fermi National Accelerator Laboratory to carry out a detailed design study. The design evolved: To reduce cost, researchers decided to use cylindrical, 3000-gallon tanks filled with water instead of the rectangular containers with scintillators depicted in the sketch.

When scientists began to discuss names and acronyms for the project, Cronin rejected all of them. Instead he chose to name the cosmic-ray observatory after Pierre Auger, who discovered air showers created by high-energy cosmic rays in 1938. “I hate acronyms,” Cronin says. “People relate to the history of science much better than to an acronym.”

In 1999, scientists broke ground for the Southern Pierre Auger Observatory in Argentina. Nine years later, the collaboration celebrated the inauguration of the project. Funding agencies in 19 countries contributed to the construction. Plans for a northern observatory in Colorado are under way.
Virtual particles are short-lived particles that cannot be directly detected, but that affect physical quantities—such as the mass of a particle or the electric force between two charged particles—in measurable ways.

The existence of virtual particles is a purely quantum-mechanical phenomenon. The particles can appear out of nothing—the vacuum—only to quickly disappear back into the vacuum. Or they can be emitted by real particles, travel a short distance, and disappear again as they interact with other particles. The Heisenberg uncertainty principle limits the duration of their fleeting existence and the distance they can travel.

Virtual particles are both a curse and a blessing. A curse because their presence makes calculations of seemingly simple phenomena, such as the electric force between an electron and a proton, vastly more complicated. A blessing because their indirect contributions to subatomic processes can reveal new particles and forces that elude direct production by our highest-energy particle accelerators.

Scientists have measured, for example, the contributions of virtual particles to the mass of the proton and to the attractive force between two metal plates. Experiments also have identified virtual contributions from the yet-to-be-discovered Higgs particle, which is a key to explaining the origin of mass. Hence, not only are we quite confident that the Higgs particle does indeed exist, but we have a pretty good idea of where to find it.

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