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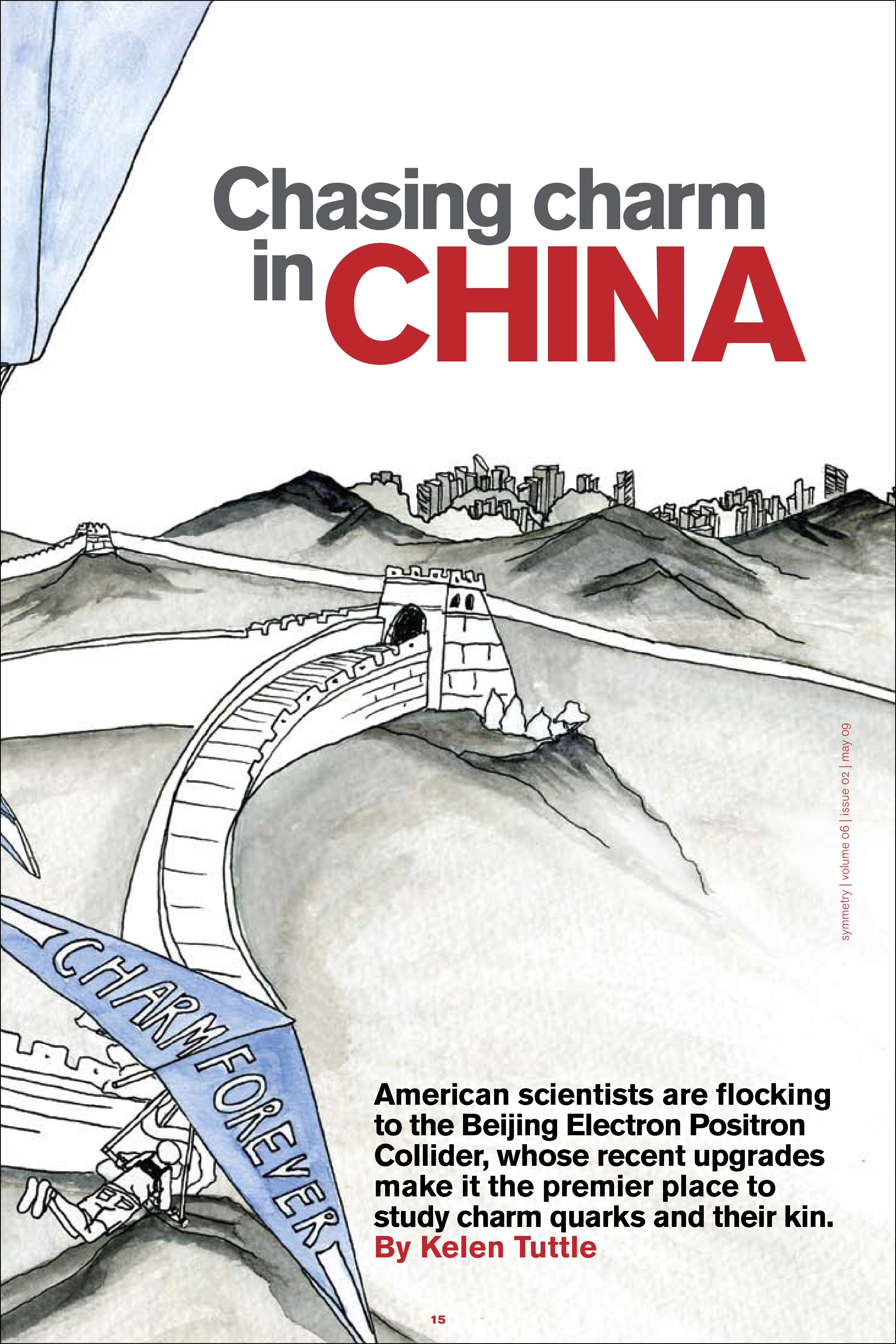
Chasing charm in CHINA



American scientists are flocking to the Beijing Electron Positron Collider, whose recent upgrades make it the premier place to study charm quarks and their kin.

By Kelen Tuttle

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The flight plan of today's particle physicist can be a dizzying thing. Like migratory creatures, researchers circle the globe in search of the best data, working on one experiment for several years and then moving on to the next, all in the hope of answering fundamental questions about the way the world works.

One of particle physics' most recent migrations involves researchers from the United States. For several years, scientists with Cornell University's CLEO-c experiment in New York studied charm quarks produced in collisions of electrons with positrons. Yet just as they began to find intriguing hints of the unexpected, CLEO-c reached the end of its allotted funding and shut down.

Now the researchers are refocusing their work on the Beijing Electron Spectrometer, located at China's Beijing Electron Positron Collider. When the machine ramps up to full strength after a recent upgrade, it will be the world's premier instrument for studying particles that contain a charm quark, as well as for many other types of physics.

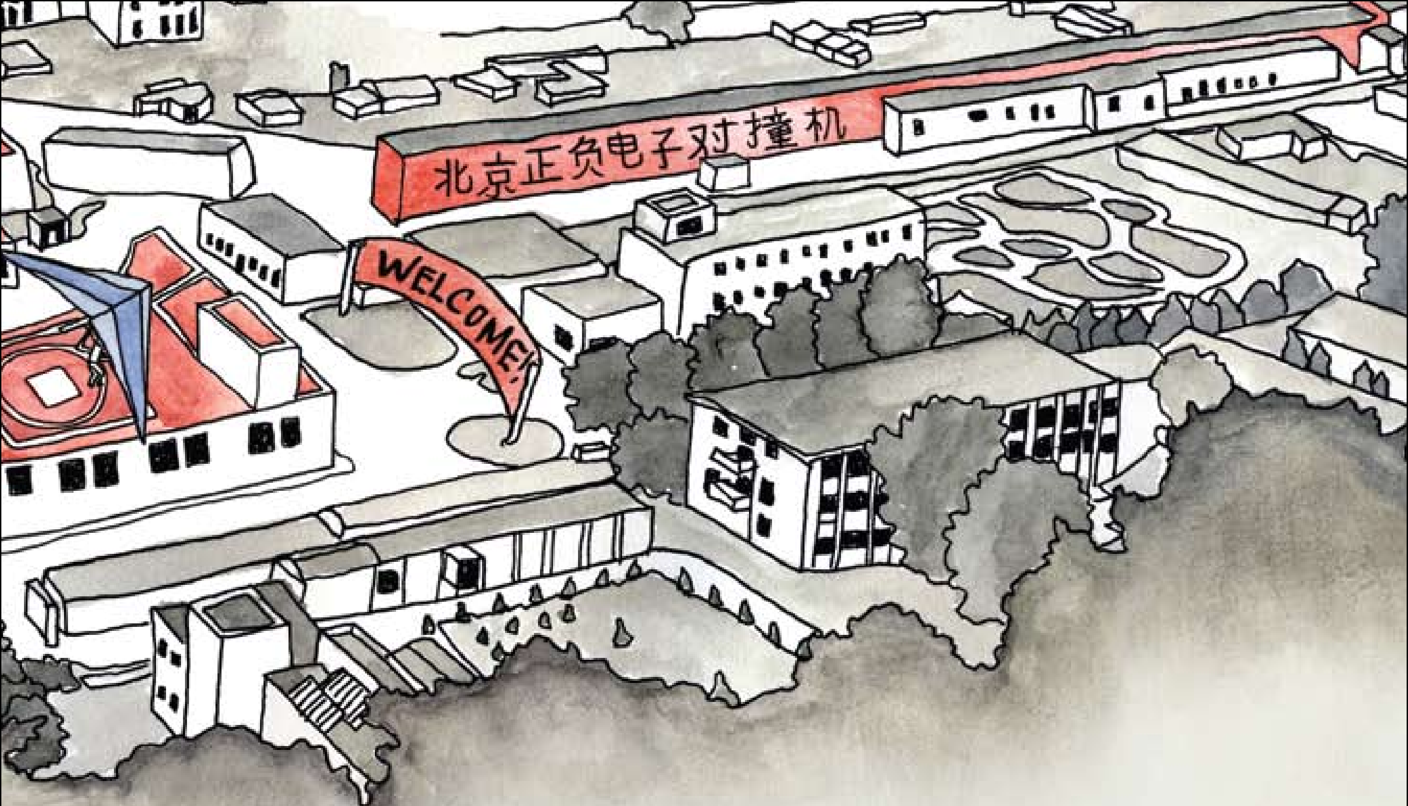
This is not the first time Americans have migrated to Beijing collider experiments. They have come and gone over the facility's two decades, although in recent years it was more of the latter, with all of the American collaborators—except a core group from the University of Hawaii—leaving Beijing to join experiments in the United States. But recently, as US electron–positron colliders shut down, the Americans have returned.

"This was a good deal for all," says University of Minnesota Professor Ron Poling, whose group was one of the first in this new wave of American collaborators. "Beijing had an upgraded accelerator and a new detector, and we had physics we wanted to do on just such a machine—but nowhere to do it. We couldn't have made this transition more seamless if we had planned it from the beginning."

Cranking out the charm

About 200 miles northwest of the buzz of New York City, the CLEO-c detector operated at a low hum from 2005 to 2008. The machine's energy was tuned to produce particles containing charm quarks against a limited background of other processes, allowing for very precise studies of charm quark decays. These decays offer researchers a means to test the Standard Model of particle physics, which describes the interaction of all visible matter in the universe. The Standard Model has been validated in many experiments; by looking at exceedingly precise data like that from CLEO-c, researchers check whether the model holds true there, too.

Charm factories like those at Cornell and Beijing tend not to make front-page discoveries as often as their high-energy cousins, such as Fermilab's Tevatron. Charm factories don't operate at energies high enough to produce never-before-seen, super-heavy particles. But despite their lower profiles, charm factories do groundbreaking work.



At the Beijing Electron Positron Collider, the real action takes place in shielded tunnels. The 200-meter-long linear accelerator, beneath the long, skinny building on the right, accelerates electrons and positrons and injects them into an underground storage ring, left, that is 240 meters around. The Beijing Electron Spectrometer detector records those collisions, which offer clues to the nature of subatomic processes and particles, including the charm quark and its kin.

By taking very precise measurements, charm factories can very accurately test theories, see the minuscule secondary effects of new physics, and even discover new low-mass particles.

"If a rare process shows up at an abnormally large rate or you see something forbidden by the Standard Model, it's evidence of new physics," says University of Minnesota Professor Dan Cronin-Hennessy, who worked on the CLEO experiment for more than a decade.

One of the ways that researchers at CLEO-c tested the Standard Model and searched for this new physics was by observing decays of mesons containing charm quarks.

Hint of new physics

Mesons are subatomic particles that each contain a quark, an antiquark, and some gluons, the elementary particles that help bind them together. The inside of a meson is a tumultuous place. Quarks constantly exchange gluons and those gluons constantly exchange other gluons. To make things even more complicated, the laws of quantum mechanics govern this swarm of particles, which means not only that researchers can never know precisely where a particle is located, but also that particles in this dynamic mix appear and disappear in the blink of an eye.

Nonetheless, researchers strive to understand the world around them, right down to the chaos within the meson, and so have found a way to explain the interaction between quarks and gluons using the theory of Quantum Chromodynamics, or QCD for short. QCD works well at high energies, but calculations of what exactly goes on at the lower energies at play within a meson are exceedingly complex—so complex, in fact, that even the world's most powerful computers find it impossible to make these calculations with a high degree of precision.

So researchers simplify those dynamics with a method called lattice quantum chromodynamics, or LQCD. It envisions particles interacting not within space and time as we experience them, but in finite increments—as if the particles existed only on the vertices of a three-dimensional grid, with time ticking forward in discrete clicks. By running computer simulations of this grid-world, physicists can apply QCD to lower-energy situations and make increasingly precise predictions.

At CLEO-c, researchers did find a small disagreement between those predictions and the observed decay of D_s mesons. Was this proof of new physics? A flaw in the LQCD simulations? Or nothing more than a blip in the data?

A timely switch

Before they could answer these questions, funding for CLEO-c dried up. The machine stopped taking data in the spring of 2008.

"CLEO-c was very successful, but we didn't get the accelerator performance that we had hoped, and our goals are not yet fully met," says University of Rochester Professor Ed Thorndike, who has worked on data from a series of collider experiments at Cornell for more than two decades. "We very much want to repeat these measurements at another machine to see what's going on."

China's accelerator offers just such an opportunity.

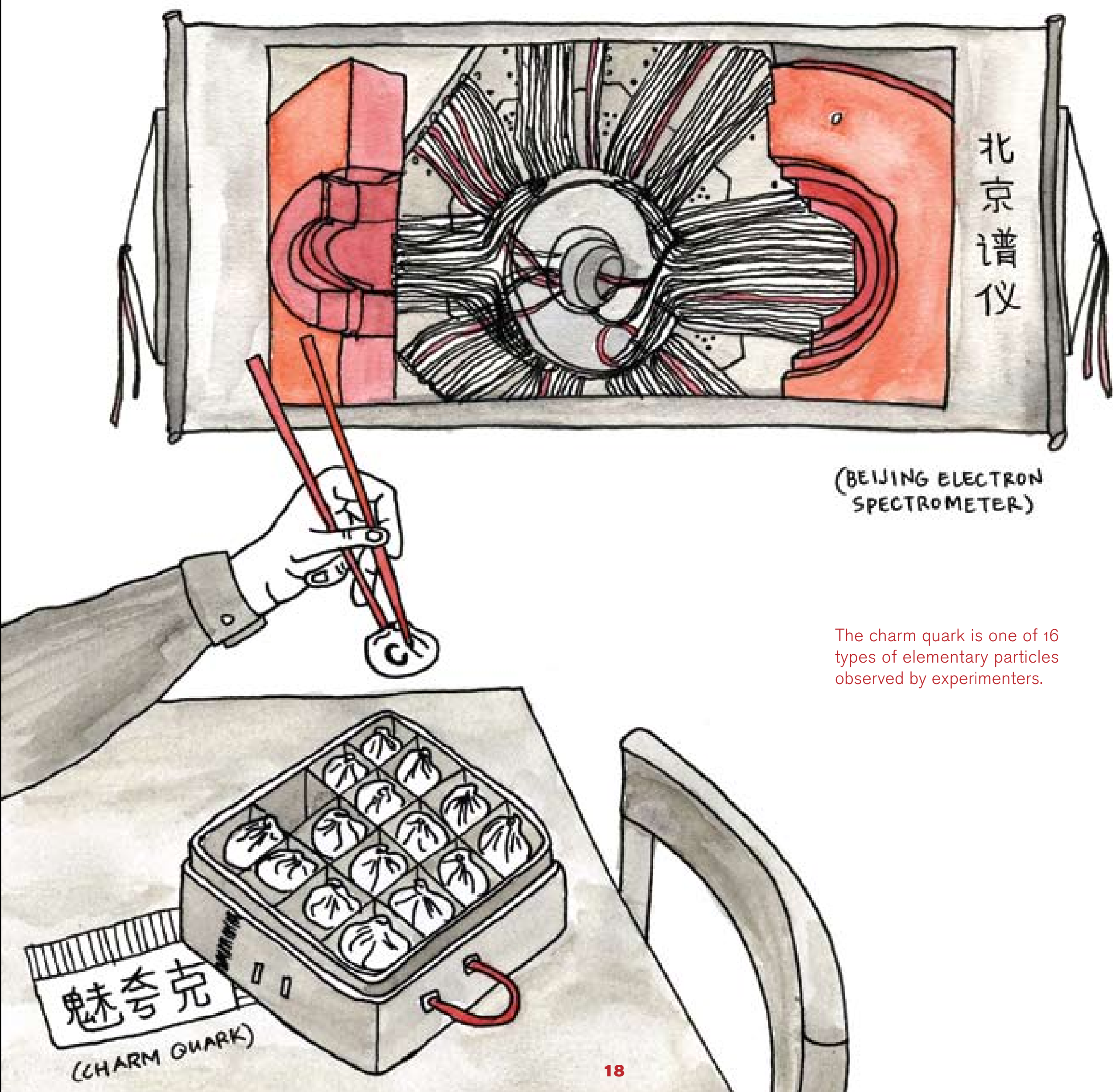
Just about the time that CLEO-c started running, the Chinese Institute of High Energy Physics started major improvements to the Beijing collider and began to construct a new Beijing Spectrometer detector, BES-III.

"When we started the upgrade construction, we were hoping that more US groups would get involved," Yifang Wang, spokesman for BES-III, says. "There's a complementary function between BES-III work and CLEO-c work. It's beneficial to the physics and to the community when we can collaborate in this way."

Ten times more data

The goal of the upgrade was to increase the detector's sensitivity and the collider's luminosity, a measure of the number of particles in each collision. To do this, the Chinese institute retained the original accelerator tunnel and infrastructure, but replaced nearly everything else. Instead of accelerating single electron and positron bunches inside one storage ring, the new machine accelerates 93 electron and 93 positron bunches at a time inside two storage rings. A pristine superconducting magnet, the first of its kind built in China, combines with the shiny new BES-III detector to more precisely measure particles' energies and speeds. And an innovative calibration system involving a diode laser built by the University of Hawaii ensures that the time-of-flight detector system, which identifies particles, is performing as designed. These and other improvements make collisions at the Beijing accelerator the best in the world for studying physics in this energy region.

"BES has a long history of very important physics," says University of Hawaii Professor Fred Harris, who served as co-spokesperson of BES-II and continues that role for BES-III. In its previous incarnations, the Beijing detector made ground-breaking precision measurements of the tau particle mass and the R value, which measures



The charm quark is one of 16 types of elementary particles observed by experimenters.

the likelihood that electron–positron collisions will create particles made of quarks. The R value helped refine the prediction of the mass of the Higgs, the as-yet-unseen particle thought to lend elementary particles their mass.

With a design intensity 100 times that of the original Beijing Electron Positron Collider, Harris says, the upgraded accelerator "promises even more significant contributions."

Once the upgraded machine reaches full luminosity—which should happen in two to three years—it will produce significantly more data of the type sought by the CLEO-c physicists. The new detector is noticeably more sensitive than BES-II and when commissioning is complete, will produce collisions at a rate more than 10 times higher than at CLEO-c, thanks in large part to the new storage rings. This increase in power and sensitivity should lead to a better understanding of the disagreement previously glimpsed at CLEO-c.

"With limited statistics, you can find a hint that maybe something is going on," Thorndike says. "But with ten times more data you can see if it's just a fluctuation or if it's a real effect and you've found something exciting."

Forging new partnerships

In July 2008, just a few months after CLEO-c shut down, the new BES detector recorded a beam from the upgraded collider for the first time. The Americans were ready and waiting; with encouragement from University of Hawaii researchers and BES management, the universities of Minnesota, Florida, and Rochester and Carnegie Mellon University had officially joined the collaboration earlier that year.

The newcomers are now working to integrate themselves into the collaboration. For instance, the University of Minnesota repurposed a computing farm, originally built to run simulations for CLEO-c, to serve as a North American data hub for BES-III. Now the university will serve as a middleman, importing large chunks of data from Beijing and making it available to US researchers, who will analyze data with this same computing farm.

"Working remotely has always been difficult, but it's getting easier," Carnegie Mellon Professor Roy Briere says. "Spotty connections make transferring data from China rather difficult; instead of every group trying to transfer the data and run the software individually, we do it in one centralized location."

With the Beijing data, US scientists will dive back into much of the research they conducted at CLEO-c, searching for new physics and testing LQCD. If researchers confirm the earlier CLEO-c results that seemed to disagree with theory, theorists will have a lot of thinking to do; it would mean that either the LQCD calculations are flawed, or some sort of physics beyond the Standard Model is at play. If, on the other hand, the LQCD calculations prove accurate, researchers will know that they understand the intricacies of the chaos within the meson well enough to predict how it behaves.

"Understanding this is an essential ingredient for particle physics," Poling says.

A multipurpose tool

While testing the CLEO-c results is one of the major goals of the Americans who moved to Beijing to work with the new detector, it is not by any means the only physics that will be done there.

The upgraded Beijing collider operates in an exciting energy range called the tau/charm region. Here, electron–positron collisions are energetic enough to form the charm quarks that interest the CLEO-c researchers. But by changing the beam energy in this region, scientists can also produce very large numbers of *J*/psi particles as well as excited forms of *J*/psi called psi' and psi'' (pronounced "psi prime" and "psi double prime"). By observing the decays of these particles, BES collaborators from around the world will continue their explorations of many unresolved topics in physics, including searches for gluons bound into a difficult-to-observe particle called a glueball—something predicted by QCD but not yet unambiguously seen. Researchers will also look for new physics within the decays of the *J*/psi, psi' and psi''. And, as with charm quarks, they will use these three particles to test LQCD calculations.

Binding together this varied research is the desire to understand the minute workings of the physical universe and the knowledge that, as the years pass, fewer and fewer facilities around the world will offer researchers the opportunity to perform these studies.

"What's nice is that you can do many types of physics at a single machine," Cronin-Hennessy says. "We're approaching this in different ways, but we have the same final goal: to understand the fundamental forces of nature."

Right now, the Beijing accelerator is focused on churning out psi' particles, and has already recorded the world's largest sample of psi' data ever produced at an electron–positron collider. Once researchers have tripled that data set, they plan to move on to other energy ranges and other particles. In two to three years, the collaboration plans to begin producing the D_s mesons that will allow researchers to continue the research begun at CLEO-c.

"Thanks to the Chinese, we may be able to answer some of the most compelling questions in particle physics," Poling says. "The Chinese have built it, and we have come."