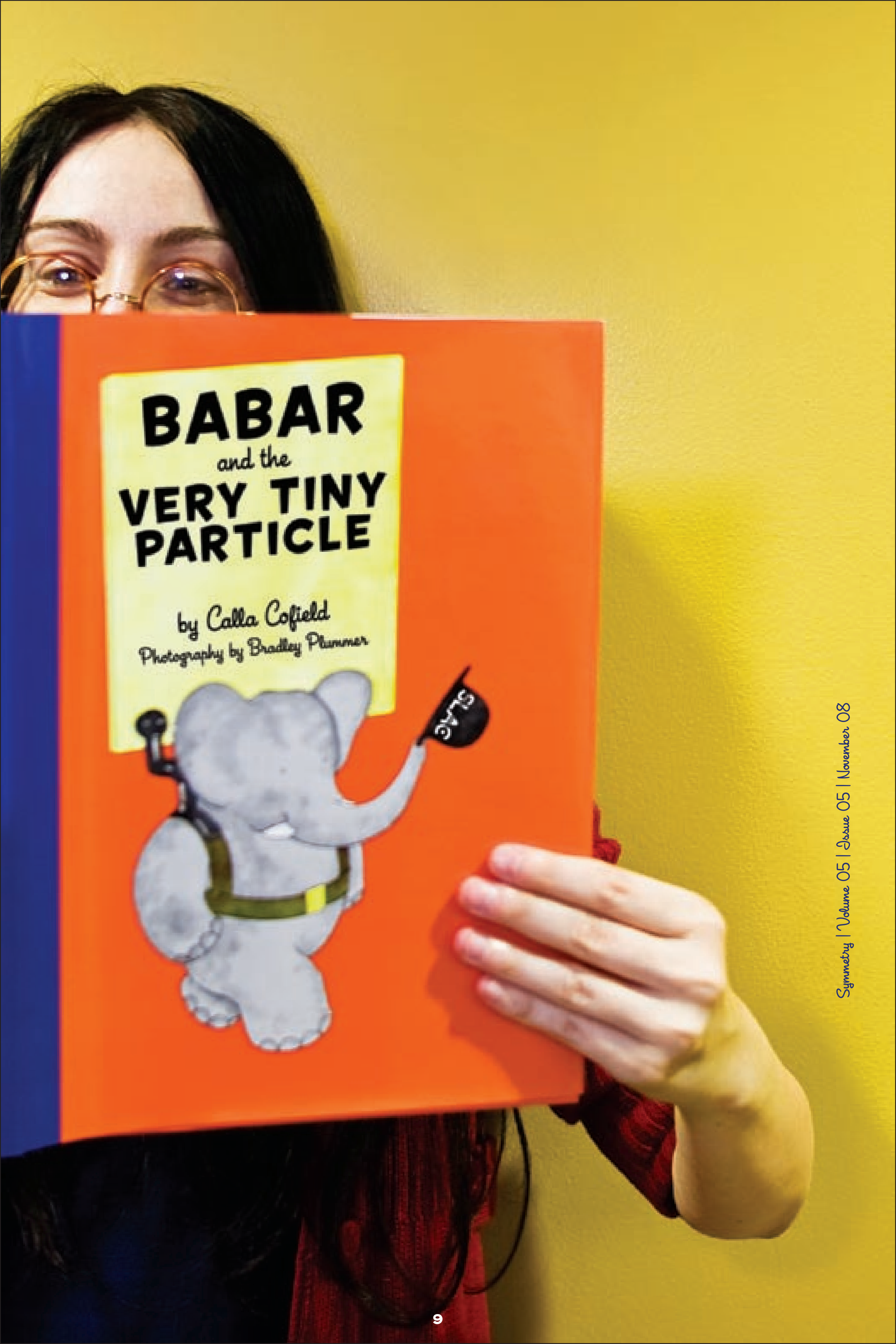
Postdoctoral researcher Veronique Ziegler is one of five analysts who pulled a new particle out of a deep pool of BaBar data.

Photo-illustration: Sandbox Studio


BABAR
and the
VERY TINY
PARTICLE
by Calla Cofield
Photography by Bradley Plummer
SLAC

King Babar, the cartoon elephant, captured the imaginations of millions of children. Despite his lumbering size he could walk upright, run, jump, dance the conga, and even do yoga.

But King Babar had the advantage of cartoon-hood, where anything is possible. His namesake, an experiment known as BaBar at SLAC National Accelerator Laboratory, did not.

With 500 collaborators from 10 countries and 74 institutions, BaBar had the potential to be as clumsy as any real elephant. Yet in nine years of data taking, the experiment produced more than 350 published papers and made major contributions to our understanding of how matter escaped annihilation after the big bang and formed the world we see today. BaBar had matured into an elephant of great agility and skill.

Then the storm struck.

In December 2007, BaBar scientists were preparing for a final year of data collection when they got the news: Rather than increasing the budget for high-energy physics for FY08 as expected, Congress cut it by nearly $100 million. US Department of Energy laboratories across the country, including SLAC, were forced to cut back experiments and, more painfully, jobs. BaBar had been scheduled to run for nine more months; now it would close down almost immediately.

Not two days after the budget crisis hit, BaBar management and spokesperson Hassan Jawahery finished a proposal asking the DOE to keep the experiment running long enough to pursue one more avenue of great scientific interest.

It would mean facing international competition, tight deadlines, and intense peer review—a real test of the skills BaBar had shaped and polished over the years. The elephant would have to learn to dance.

Matter domination

It had taken five years to build the BaBar particle detector. Twenty-five feet tall and just as wide, weighing around 1200 tons, it required more than 100 people per shift to keep it running and to gather and process the resulting data. The detector rested in a cavernous cement hall, where it received beams of electrons and their antimatter counterparts, positrons. The fast-moving beams swung around a 1.4-mile circular track before they entered the detector and collided, giving rise to sprays of new particles.

BaBar earned the title of *B*-factory because it produced hundreds of millions of particles known as *B* mesons for scientists to study. It generated both regular *B* mesons and their antimatter counterparts, known as *B*-bar mesons; hence the acronym *B* and *B* Bar, or BaBar.

Matter and antimatter are like the black-and-white Spy vs. Spy cartoons: Whenever they get together they annihilate. This volatile relationship poses a troubling question: If equal amounts of matter and antimatter were created after the big bang, as scientists believe, why didn't they annihilate each other? How did enough matter survive to form everything we see?

BaBar's observations of *B* mesons support the theory that explains how matter came to dominate. This asymmetry, known as CP violation, means that the laws of physics are slightly different for matter than for antimatter. It fits the pre-

dictions of the Standard Model, a theory held in high regard because of its beauty and, thus far, its accuracy in describing the building blocks of the universe. Although the experiment was a success, the results did not completely account for the dominance of regular matter in our universe, and there are still many questions left to be answered.

B mesons are not the only interesting things that come out of electron-positron collisions. Meet the bottomonia: a whole family of particles that each contain both a bottom, or *b*, quark and an anti-*b* quark. A treasure chest of information about the particle physics world, the bottomonium particles would take scientists down a yet-untraveled path.

The proposal BaBar management put together would focus the collaboration's efforts on certain members of the family. At the top of the to-do list was finding a particle called η_b (pronounced eta sub bee), the lowest-energy member of the bottomonium family. The missing piece of a larger puzzle and the subject of multiple theories, η_b had thus far eluded scientists. Its discovery would not only help complete the bottomonium family portrait, but add to the understanding of the strong force that holds subatomic particles together. "We saw that this was a chance to do something new," says Jawahery, tapping the table for emphasis. "A chance to do new physics."

The US Department of Energy granted BaBar an extra three months to switch course and collect more data.

Racing against time

BaBar wasn't alone on this treasure hunt. The Belle *B*-factory experiment at the KEK laboratory in Japan had also produced strong results, and had collected a small pool of data at the energy level required to produce η_b. Perhaps Belle was also close to nabbing the particle. BaBar set a goal of getting its results published in time for the International Conference on High Energy Physics, or ICHEP, in late July. That left six months to complete a process that can sometimes take years.

As the collaboration switched gears, Silke Nelson, one of five physicists on the analysis team, was laboring under her own deadline. Her second child was due a few weeks before ICHEP. While many members of the collaboration would contribute to the particle's discovery, and other analysis teams would pursue it from different angles, Nelson and four other analysts—fellow postdoc Veronique Ziegler, SLAC staff scientists Philippe Grenier and Peter Kim, and PhD student Chris West—would be the ones to dip into the deep pool of data and, with luck, pull out the tiny bottomonium.

This particular analysis team, like most, was a mix of senior experts and younger scientists—postdocs and graduate students—eager to get their hands on raw data, and willing to put in long hours to make sense of it. Jonathan Dorfan, the former SLAC director who helped found BaBar, says this practice gives "young tigers" a chance to directly participate in the data evaluation with oversight from more experienced scientists.

Data analysis is a complex process. The BaBar detector does not simply illuminate single particles. It collects the entire splatter of particles and light that comes out of electron-positron collisions. Scientists sift this tangled nest of data for particular events or signals. To further complicate things, bottomonia cannot be seen directly. Finding them is akin to identifying a car that just raced the Indy 500 by looking for the tread marks it left on the track. In this case, the tire track is a photon released as one of the more energetic bottomonia, Upsilon 3S, decays into η_b. What has stumped scientists is how to pick out this particular photon from millions that look similar.

"You might be searching for a rare event that happens once in a million other events," says Owen Long, BaBar's new physics coordinator. "Sometimes the event is not rare, but we're trying to measure it extremely precisely. We have to understand exactly how our detector responds to certain types of particles and events. This is why some measurements can take years." BaBar had only a few months.

A grueling analysis

Early in the life of the experiment, collaborators had been placed in Analysis Working Groups based on areas of expertise. The AWGs are the moving parts of the elephant's body, working together to achieve a larger function.

Today's 13 AWGs have names like "charmless quasi two-body *b*-decays" and "hadronic particle spectra." Each consists of 30 to 40 members and oversees a number of smaller analysis teams, offering them feedback, suggestions, and sometimes criticism.

Each analysis team also has its own three-member review committee, and can seek guidance from the entire collaboration through BaBar's private section on Hypernews, an online discussion board. "People get back to you so fast," Ziegler says, as West nods in agreement. "Whatever problem you're having, no matter what it is, there's someone out there who has encountered it before."

For four hectic months the analysis group pored over the incoming data, looking for signs that the tiny η_b particle had appeared where theory predicted it would be. Nelson's belly grew larger, members dropped other projects they were working on, and the small-group structure became even more important as the deadline approached.

"By the end we were meeting every day," Grenier says. "We would discuss what each person had done in the last 24 hours and what they would do over the next 24 hours."

The review committee insisted that the analysis team blind its study, protecting the results from bias. As Dorfan explains, "It's not that anyone is deliberately changing anything, but if you expect an answer then you might give more attention to one area and less attention to another."

As the final analysis program ran, the analysts paced up and down the hall. It took two hours for the program to search through millions of data points, tally all the photons that looked like companions of η_b, and stack them into a graph. When the run ended and the group unblinded the analysis, lifting the veil from the results, they saw a small yet significant bump. It proclaimed, like scratchings on a high school desk: η_b was here.

The real grunt work starts

One week later the group poses for a photograph after announcing its results. Nelson looks refreshed as she rests her hands on her swollen belly and shines a wide smile. Ziegler turns her petite frame just a little while West faces his broad shoulders front and center, and the group talks about running the final program. Two different computers ran the program simultaneously to cross check the results. "I wanted to run it on my computer at the same time, but it crashed!" says West, getting laughs from the group. "I was hoping mine would finish before yours," Ziegler says to Grenier, "but then you called and said it was done." Dorfan recalls walking into his office building and seeing one of the AWG members walking out. "I asked if they had just unblinded the analysis, and he said, 'Yes.'" Dorfan says he didn't have to ask what the results were; it was obvious from the big smile on the analyst's face.

That celebration didn't last long, Ziegler says: "After that is when the real grunt work starts."

Like other physics collaborations, BaBar reviews its own results before submitting them for publication and scrutiny by the wider scientific community. "The BaBar peer review process is very thorough," Grenier says. "It's very tough and very long. Sometimes it can take weeks."

Here BaBar's size can be its greatest strength and its greatest weakness. The intense review by so many members of the collaboration ensures that BaBar consistently produces strong results. But obtaining the approval of so many scientists takes time, and differing opinions can halt an analysis in its tracks. Some of the collaboration's analyses have been floating around for years, waiting for new developments to push them forward. Some need to develop, some await new data, and some may quietly die.

Once a paper makes it through the review committee and the AWG, other members of the collaboration have two weeks to comment on it. The experiment's publication board also invites 13 to 15 institutions to review the paper. In most cases, about half will comply, but the η_b analysis drew comments from all 15. Grenier shakes his head and says, "That almost never happens." An exceptionally high percentage of collaboration members reviewed the paper as well. "Since this was a very important analysis, many people wanted to read it," Dorfan says, "to make sure it was accurate."

With ICHEP rapidly approaching, BaBar's publication board reduced the usual two-week window for review to just two days. A few reviewers worked non-stop to pelt the analysts with questions and critiques, polishing the paper into a form everyone could endorse. Only then did the publication board declare it signed by the collaboration. In the lingo of particle physics, the results had now been blessed.

The group immediately submitted the paper to *Physical Review Letters*, where it was accepted on July 15—two weeks before ICHEP.

New beginnings

During a follow-up interview, Grenier breathed a deep sigh. He looked forward to a week's vacation at home in France after presenting the η_b results at ICHEP.

Jawahery arrived in Maryland in time for his child to begin school, passing the title of spokesperson to François Le Diberder on October 1. At the same time, Sören Prell, who as physics coordinator had overseen the many analyses going on at BaBar, handed off that job to Long. Although the machine has shut down, analysts will keep digging through the data for at least a decade, searching for more discoveries.

Three days after the paper was submitted, Nelson and her husband welcomed their son into the world. Discussing her quick return to work, one of her colleagues mentioned that the infant was present at a particle physics seminar earlier that week. "They're starting them younger and younger," another joked.

Nelson and Ziegler will soon be looking for permanent positions at laboratories or universities, and West may seek a postdoctoral position somewhere. Ziegler says she might see what the ATLAS experiment at the Large Hadron Collider in Geneva has to offer. Wherever they go, these three, like other young BaBar scientists, will bring with them lessons about how to make a large collaboration function quickly and efficiently—dance lessons for future elephants.

One month after his first appearance, the reclusive particle known as eta sub b (η_b) granted an exclusive interview to our reporter. *See page 28.*

BaBar physicists catch up with their favorite cartoon elephant. Clockwise from left: Peter Kim of the eta sub b analysis team; Steve Sekula, who helped write the proposal that set BaBar on a new course; Owen Long, the current BaBar physics coordinator; and Chris West of the analysis team.