

STANFORD LINEAR ACCELERATOR CENTER

Summer/Fall 1999, Vol. 29, No. 2

# *Beam Line*



# Beam Line

A PERIODICAL OF PARTICLE PHYSICS

SUMMER/FALL 1999 VOL. 29, NUMBER 2

## Editors

RENE DONALDSON, BILL KIRK

## Contributing Editors

MICHAEL RIORDAN, GORDON FRASER  
JUDY JACKSON, AKIHIRO MAKI  
PEDRO WALOSCHEK

## Editorial Advisory Board

GEORGE BROWN, PATRICIA BURCHAT  
LANCE DIXON, JOEL PRIMACK  
ROBERT SIEMANN, GEORGE TRILLING  
KARL VAN BIBBER

## Illustrations

TERRY ANDERSON

## Distribution

CRYSTAL TILGHMAN

The *Beam Line* is published quarterly by the Stanford Linear Accelerator Center, Box 4349, Stanford, CA 94309. Telephone: (650) 926-2585 INTERNET: beamline@slac.stanford.edu FAX: (650) 926-4500

Issues of the *Beam Line* are accessible electronically on the World Wide Web at <http://www.slac.stanford.edu/pubs/beamline>. SLAC is operated by Stanford University under contract with the U.S. Department of Energy. The opinions of the authors do not necessarily reflect the policy of the Stanford Linear Accelerator Center.

Cover: Simulated beams of electrons (blue) and positrons (pink) travel along the PEP-II accelerator ring at SLAC. John Seeman describes the PEP-II commissioning in his article on page 29. (Courtesy David Parker/Science Photo Library)

Printed on recycled paper



## FEATURES

### 2 FOREWORD

*SLAC's new Director shares his thoughts about the race to understand why the Universe is made of matter.*

Jonathan Dorfan

### 4 TAKE YOUR MARKS!

*The race is on to find the answer to why there is more matter than antimatter in the Universe. A theoretical physicist and participant describes the excitement as well as the players.*

Robert N. Cahn

### 10 *After All These Years* CORNELL STILL PRODUCING B MESONS

*10 million B meson pairs isn't bad, but nevertheless CESR and CLEO eagerly push forward to unlock the secrets of the b quark.*

Persis S. Drell

### 15 HERA-B VARIATIONS ON A STANDARD MODEL THEME

*A member of the HERA-B collaboration describes DESY's unique approach of colliding protons and nuclei to solve the mystery of a matter-dominated Universe.*

Roy Schwitters

# CONTENTS

## 19 CDF—THE PARTY CRASHERS

*Although it wasn't specifically designed to study the matter versus antimatter puzzle, Fermilab's first detector joins the race to discover CP violation in B decays.*

Manfred Paulini

## 23 THE KEK B-FACTORY EXPERIMENT

*One of two new asymmetric colliders designed to study B mesons, this Japanese facility recorded its first events on June 1.*

Shin-ichi Kurokawa & Stephen L. Olsen

## 29 COMMISSIONING OF THE PEP-II ASYMMETRIC B FACTORY

*The PEP-II collider at SLAC is producing initial data aimed at understanding the matter-antimatter question in the early Universe.*

John Seeman

## DEPARTMENTS

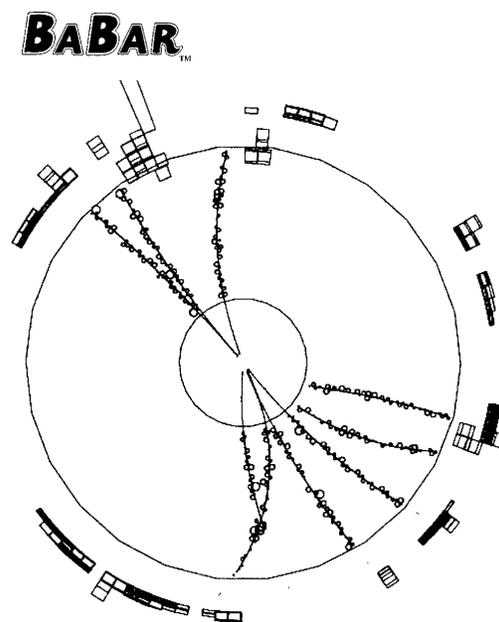
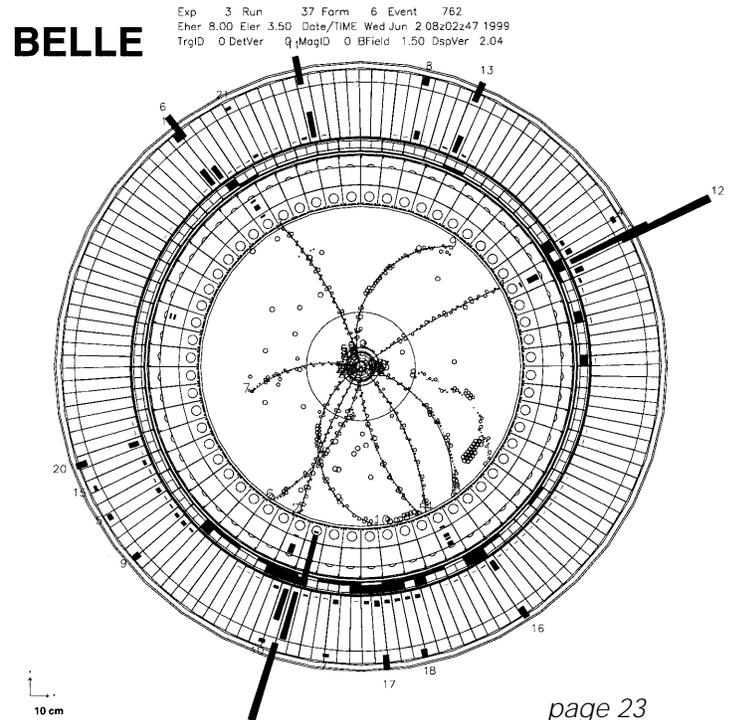
### 34 THE UNIVERSE AT LARGE

*C-to-Z Physics*

Virginia Trimble

### 42 CONTRIBUTORS

DATES TO REMEMBER



---

## FOREWORD

---

*SLAC's new Director  
shares his thoughts  
about the race  
to understand why  
the Universe is made  
of matter.*



**C**ONSERVATION LAWS IN PHYSICS represent simplification in Nature. They arise due to underlying symmetries in the mathematical description of our physical world. Thus, violations of expected symmetries have wide-ranging impacts on our perception of Nature. The unequivocal demonstration in 1957 of the violation of mirror symmetry (better known as parity violation) in the weak interactions shook the physics community. What was particularly shocking to purists was the fact that parity violation was pervasive in the weak interactions and that the size of the violation was maximal. Order was restored when physicists realized that parity was simply the wrong symmetry; the weak interactions are symmetrical under the combined operation of charge conjugation and parity, known as CP.

But this tidy picture fell apart in 1964, when Val Fitch, James Cronin, James Christenson, and Rene Turlay observed small, but significant, violations of CP symmetry in the decays of long-lived, neutral *K* mesons. Further experiments demonstrated that these particles decayed ever so slightly less often to electrons than to

---

their antiparticles, positrons—thereby providing a possible link between the phenomenon of CP violation and the asymmetry between matter and antimatter. In 1967 Andrei Sakharov proposed an idea for how our matter-dominated Universe might have emerged from the Big Bang, which produced equal amounts of matter and antimatter. One of the key elements in this theory is the requirement of CP violation. What appears as a tiny violation of CP symmetry in the weak interactions could well be a critical reason why we exist.

While the dominant Standard Model of particle physics incorporates the phenomenon of CP violation, the correctness of this implementation is not experimentally verified. In addition, the Standard Model fails miserably in its ability to predict correctly the observed ratio of protons-to-photons in our Universe. The size of this ratio, a key relic of the Big Bang, is directly related to the “strength” of CP violation, whose role was to transform a matter-antimatter symmetric birth into an ever-so-slightly matter-favored infancy. As the matter-antimatter soup cooled, pairwise annihilations produced the sea of photons recognized today as the cosmic background radiation. Because of the tiny asymmetry, however, some matter was left intact, leading to our proton-dominated Universe. The larger the strength of CP violation, the greater the initial asymmetry and thus the larger the relic proton-to-photon ratio. There exist alternative models of CP violation beyond the Standard Model that predict proton-to-photon ratios in line with observations. It is crucial to make detailed measurements of CP violation that have the capability of challenging all these models and establishing an experimental basis for its origin.

The study of CP violation in the neutral kaon system continues to be fruitful. Recent results from Fermilab and CERN are achieving impressive levels of precision, establishing the evidence for direct CP violation. The Phi Factory in Frascati will soon begin producing data to add to this knowledge. But to challenge the Standard Model in a definitive way requires measurements of the decays of the *K* meson’s heavy “brother,” the *B* meson. Neutral *B* meson decays offer a broad spectrum of channels whose measurements will directly confront the predictions of the Standard Model. What ten years ago was just a gleam in experimenters’ eyes is now becoming reality as facilities capable of producing and studying huge samples of *B* mesons are coming to fruition. The CDF experiment at Fermilab has shown that it is capable of making CP-violation measurements of *B* mesons; along with the D0 experiment, it awaits the first run of the new Main Injector. At DESY, the HERA-B experiment will soon commence data taking. But, the broadest attack on CP-violation will likely come from the two asymmetric *B* factories, one at SLAC and one at KEK. These two facilities have recently begun taking data and should produce their first results within a year. The articles in this issue describe the capabilities of these different approaches to the great challenge of understanding the origin of CP violation.

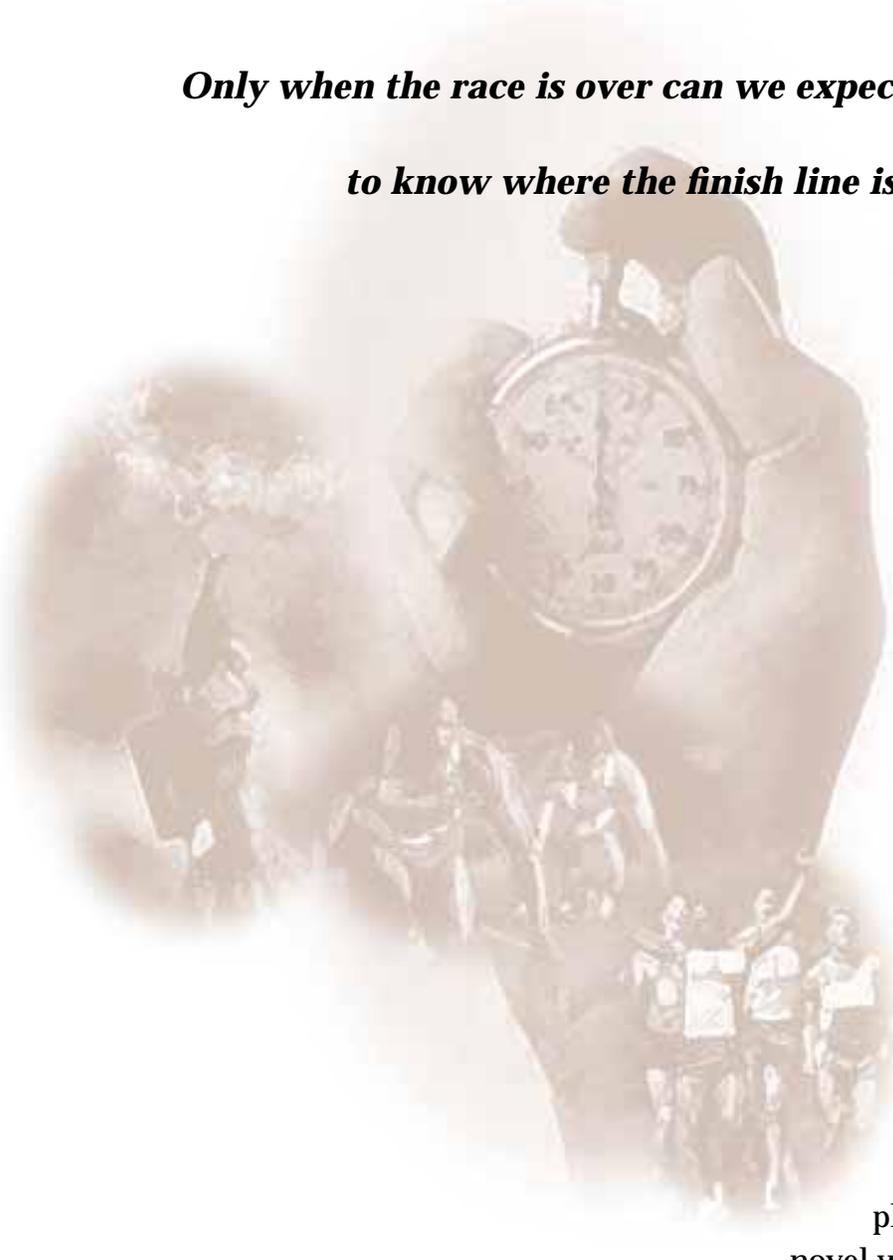
We are now poised at the onset of what will surely be an important chapter in our understanding of CP violation. The next few years should be exciting indeed.



# TAKE YOUR MARKS

by ROBERT N. CAHN

*Only when the race is over can we expect  
to know where the finish line is.*



**I**T'S A RACE with no starting point, no fixed course, and really no rules at all: walk, run, ride, do anything you want. Form a team, as big as you like. Build any sort of machine you wish with whatever money you can get your hands on. Just get to the finish line first.

That finish line isn't a particular place but a new understanding of a symmetry (or rather, an almost symmetry) of the Universe. This rather inchoate race is just now coming into focus. Teams in Tsukuba, Hamburg, Chicago, Ithaca, and Palo Alto have been preparing for the final stretch the last year or two.

No one announced this race. It began spontaneously in the 1980s when physicists realized that they could use the newly discovered *B* mesons to explore the violation of CP symmetry in novel ways. This was welcome because ever since its discovery in 1964, CP violation has been a particularly

enigmatic, if subtle, phenomenon. CP symmetry was salvaged from the wreckage of the separate symmetries parity (P) and charge conjugation (C). For thirty-five years its violation has been a preoccupation of particle physics.

Just as the human eye searches for symmetries, patterns of identical appearance, particle physicists seek symmetries in Nature. Some of these are symmetries of space and time: Nature looks pretty much the same in every direction and in every place, and the same today as yesterday. Other symmetries are less obvious, especially symmetries that assert that one particle is the look-alike partner of another. For example the neutron and proton form such a pair, related by a symmetry called isospin invariance; their masses differ by only 0.13 percent, and their interactions with other neutrons and protons are quite similar. Nonetheless, in matter they behave in dramatically different ways, because one is neutral and the other electrically charged. The isospin symmetry that relates the neutron and proton is not respected by the electromagnetic force: the symmetry is said to be broken by electromagnetism.

The progress in understanding elementary particles is a story of uncovering unsuspected symmetries and then struggling to understand what breaks them. The Standard Model of particle physics is based on a symmetry like the one that connects the neutron and proton, but it makes much more improbable pairs. The electron, the stuff responsible for all chemistry (and thus, life) is appointed the partner of a scarcely observable neutrino. More precisely, the electron that spins clockwise around its direction of motion (a left-handed electron) is the partner of the neutrino whose spin is similarly oriented. The evidence for this bizarre identification is compelling.

Why is a distinction made between left-handed and right-handed particles? Before 1956 physicists thought such a distinction could hardly be fundamental. Surely one could build one laboratory and another that was its mirror image and obtain identical results in the two. To be thorough, you could hire left-handed graduate students to work in one and right-handed ones for the other. Each setup would simply be the mirror image of the other. In 1956, Tsung-Dao Lee and Chen Ning Yang pointed out that there



*Madame Chen-Shing Wu and Wolfgang Pauli. In 1930, Pauli proposed that in nuclear beta decay the emitted electron was accompanied by a light neutral particle, the neutrino. In 1957, Madame Wu, with her collaborators, Raymond Hayward, Dale Hoppes, and Ralph Hudson from the National Bureau of Standards, showed that parity is violated in beta decay. (Courtesy AIP Emilio Segrè Visual Archives)*

was no evidence, at least for the weak interactions like the beta-decay of radioactive nuclei, that these laboratories would be equivalent. Indeed, in 1957 when Madame Chen-Shing Wu and her collaborators tested the parity symmetry (P) that connects left-handed arrangements to right-handed ones, they found that the weak interactions could tell the difference between them. The two mirror-image laboratories got different results.

One manifestation of this parity violation was that electrons emitted in beta decay were overwhelmingly left-handed (instead of being equally right-handed and left-handed), showing that parity was violated as much as it possibly could be. On the other hand, when positrons were emitted, they emerged predominantly right-handed. This violated another possible symmetry: charge conjugation

(C). If C symmetry were respected, the antiparticle of the electron would be emitted left-handed like the electron itself.

Even though both C and P symmetries were lost, if they were combined, the result might still be a true symmetry. CP would change the left-handed electron into the right-handed positron. These were both seen in nuclear decays, so it appeared that the combination CP, though not either C or P separately, was respected by the weak interactions.

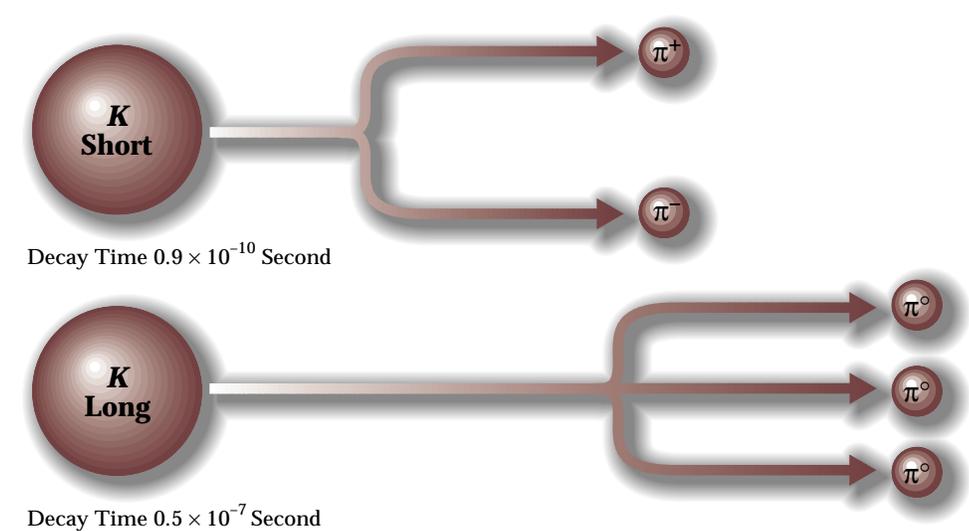
But in 1964 CP symmetry, too, fell in a study of decays of neutral  $K$  mesons. There are two such particles. One “ $K$ -short” ( $K_S$ ) decays in less than a billionth of a second. The “ $K$ -long” ( $K_L$ ) lives 500 times as long (see bottom illustration on the next page). This difference could be understood in terms of CP. When CP acts on an object it generally changes it into something quite different: a left-handed electron becomes a right-handed positron. Some systems, though, are turned into themselves and these fall into two categories: CP-even and CP-odd. In 1964 the  $K_S$  was thought to be purely even, which would permit it to decay to CP-even states  $\pi^+\pi^-$  and  $\pi^0\pi^0$ , while these decays would be forbidden for the CP-odd  $K_L$ . Because the  $K_L$  lacks these opportunities to disintegrate, it lives longer. However, a careful experiment by James Christenson, James Cronin, Val Fitch, and Rene Turlay showed that about two  $K_L$ 's in a thousand decay to  $\pi^+\pi^-$ , in violation of the supposed CP symmetry.

In the subsequent thirty-five years, CP violation has been the subject of investigation by ever more thorough experiments. Why has such

enormous effort been expended? First, CP is clearly a very fundamental symmetry, or rather near symmetry. When combined with time-reversal invariance, it gives the combination CPT, which is believed on very fundamental theoretical grounds to be a true, unbroken, symmetry. Thus if CP fails, T must fail in an exactly compensating way. Second, Andrei Sakharov argued convincingly in 1967 that CP violation is probably essential to the creation of the apparent preponderance of matter over antimatter in the Universe. In other words, without CP violation probably all matter and antimatter would have annihilated leaving nothing tangible behind. Thus CP violation is evidently at the heart of the material world.

If CP symmetry held true, the  $K_S$  and  $K_L$  would be purely even and odd respectively. One could not be changed into the other. Since CP symmetry is not completely respected, the odd and even states can change back and forth, one into the other. Physicists say they “mix.” Is this the only source of CP violation? Very careful study of the decays of the neutral  $K$  meson can answer this question, and just such studies have been going on ever since the discovery of CP violation. Experiments at CERN and Fermilab now seem to have convincing evidence that CP violation comes not just from the mixing of the CP-odd and CP-even states of the  $K$ .

In 1972, Makoto Kobayashi and Toshihide Maskawa proposed an explanation of CP violation within the Standard Model. They recognized that if there were three generations of quarks, as we now know there are,



there could be a misalignment among them. If that misalignment were simply like a spatial rotation, described by three angles, no CP violation would arise. But in general the misalignment needs four angles for its description, and in that case, CP symmetry is violated. The misalignment is often represented by a complex  $3 \times 3$  matrix, called the Cabibbo-Kobayashi-Maskawa (CKM) matrix.

This dramatic prediction is about to be tested in experiments at SLAC, KEK (in Japan), DESY (in Germany), Fermilab (in Illinois), and at CESR (in New York). The experiments with  $K$  mesons are not easily compared with the theory of Kobayashi and Maskawa. The new experiments, which use  $B$  mesons instead of  $K$  mesons, will confront the theory directly.

$B$  mesons are a lot like  $K$  mesons. Every meson is made of a quark and an antiquark. In a  $K^0$  meson there is a  $d$  quark and an  $s$  antiquark. The meson with a  $d$  antiquark and an  $s$  quark is called a  $\bar{K}^0$  (“kay-zero-bar”). The  $K_S$  and  $K_L$  are combinations of  $K^0$

*K mesons have two different life spans. One type of kaon, the K-short, decays quickly into two pions, whereas the other decays slowly into three pions. The difference in behavior comes from the two kaons having opposite CP symmetry. Only rarely however, the K-long can also decay into two pions, proving that CP can be violated.*



Toshihide Maskawa, left, currently Director of the Yukawa Institute at Kyoto University, Kyoto, Japan, and Makoto Kobayashi, professor at the Institute of Particle and Nuclear Studies at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan. For a photograph of the pair when they were students, see page 24.

and  $\bar{K}^0$ . The  $B$  mesons are exactly analogous, except that they have a very heavy  $b$  quark in place of the much lighter  $s$  quark. Although the  $b$  quark itself became known in 1977,  $B$  mesons were discovered only in 1982.

The  $B$  meson is a master of disguises. It disappears in dozens of ways, using each no more than a few percent of the time. An especially nice decay is  $B^0 \rightarrow J/\psi K_S$ . It is attractive because the  $J/\psi$  is an extraordinary particle. Called  $J$  by Samuel Ting and his collaborators who found it at Brookhaven and  $\psi$  ( $\psi$ ) by Burton Richter and his collaborators, who found it simultaneously at SLAC, this particle decays into the stunningly simple states  $e^+e^-$  and  $\mu^+\mu^-$ —pairs of charged particles that are easily identified. Unfortunately, only one  $B$  meson in 2000 decays to  $J/\psi K_S$ , and only 12 percent of these have the wonderful  $e^+e^-$  or  $\mu^+\mu^-$  signature.

How can we test CP symmetry with  $B$  mesons? The simplest way is to ask whether the decays  $B^0 \rightarrow J/\psi K_S$  and  $\bar{B}^0 \rightarrow J/\psi K_S$  happen in exactly the same way. CP symmetry would require them to be identical since the action of CP on a  $B^0$  makes a  $\bar{B}^0$  while it turns  $J/\psi K_S$  into itself.

But if we observe  $J/\psi K_S$  in a detector, how can we determine whether it came from a  $B^0$  or a  $\bar{B}^0$ ? This requires a physicist-detective to examine telltale clues in the remainder of the event. The  $b$  quark is always produced together with an anti- $b$  quark. If evidence can be found for a  $b$  quark elsewhere in the event, then it must have been an anti- $b$  quark (and thus a  $B^0$  meson) that decayed into the  $J/\psi K_S$ . This detective work is called “tagging.”

Actually, neutral  $B$  mesons are more cunning than this. They change into their antiparticles and back on a regular basis, seventy billion times a second. This makes tagging somewhat harder. When the  $b$  and anti- $b$  are produced so that they act independently, we can forget about all these oscillations and simply take an average. This is what happens when  $B$ 's are produced in high-energy collisions of protons, as they will be at Fermilab and at the HERA accelerator at DESY.

At the electron-positron colliders coming on line at SLAC and KEK, the situation is totally different. There the machine energies are fixed so that the electron and positron combine with just the right energy to make exactly one  $B^0$  and one  $\bar{B}^0$ . Each oscillates back and forth between particle and antiparticle, but with their oscillations synchronized so that if one decays as a  $B^0$  then the

***Will the clean events  
of the electron-positron  
annihilation prove  
more effective than  
the messier but much  
more copious ones found  
in proton-antiproton  
collisions?***

other must be a  $\bar{B}^0$  at that very instant. To test CP violation in this case, we need to tag one  $B$  and measure the time until the other decays, for during that time it continues to oscillate. A typical  $B$  makes only about a quarter of an oscillation before decaying, but some live much longer.

At SLAC and KEK physicists study the behavior of  $B$  mesons as a function of the time interval between the decays of the two mesons produced in a single event. To do this, their electron-positron colliders are operated in a novel way: the energies of the electrons are raised to about 9 GeV while the positrons have only 3 GeV. When the two collide, the resulting resonant state,  $\Upsilon(4S)$ , is moving at more than half the speed of light in the direction of the electron beam. The  $\Upsilon(4S)$  itself decays nearly instantaneously into a  $B^0$  and  $\bar{B}^0$ . These mesons themselves decay, first one then the other, after traveling typically about a quarter of a millimeter. By carefully tracing the paths of the decay products, the locations of the two decays can be determined. The distance between these points is a measure of the time that elapsed between the two decays.

The “gold-plated” decay  $B^0 \rightarrow J/\psi K_S$  will be the immediate goal of every CP violation experiment using  $B$  mesons because it occurs not so infrequently and is easy to spot. Moreover, the interpretation of the results will be straightforward.

CP violation measurements are conveniently displayed in a figure called the “unitarity triangle,” which represents the CKM matrix and thus the Kobayashi-Maskawa model of CP violation (see the article by David

Hitlin and Sheldon Stone in the Winter 1991 *Beam Line*, Vol. 21, No. 4). Three sides of the triangle and its three angles can all be measured independently. The CP measurements using  $B$  mesons determine the angles of the triangle. By measuring  $B^0 \rightarrow J/\psi K_S$  the angle known as  $\beta$  can be determined. Information on the sides come from a variety of experiments including  $B$  decays not involving CP violation. The goal is to check the consistency of all the measurements by seeing whether the triangle constructed from the knowledge of its sides has angles that agree with those measured independently in CP violation experiments.

The Cornell electron-positron collider, CESR, has equal energies for electrons and positrons and so the detector there, CLEO, cannot measure CP violation in the same way as the SLAC and KEK experiments BABAR and BELLE. The CLEO collaboration and the ARGUS collaboration at DESY discovered much of what is known so far about  $B$  mesons. CESR will contribute to tests of CP violation by extending its measurements of the sides of the unitarity triangle and by another kind of CP-violation measurement that does not require knowing time differences.

The decays of neutral  $B$  mesons into two pions can determine the angle known as  $\alpha$ . This measurement will take much longer because these decays are very infrequent. Moreover, the interpretation of these results will not be straightforward. The third angle  $\gamma$  is also very difficult to measure. There will be very intense competition to measure  $\beta$  over the next two years or so. This will likely be followed by more detailed and difficult measurements directed at the remaining angles.

The competition between experimental teams, some using nearly identical techniques, and others using utterly different approaches, will surely provide stringent checks on the results obtained. Naturally, each team is anxious to show that its approach to CP violation experiments is a good one. Will the clean events of the electron-positron annihilation prove more effective than the messier, but much more copious, events found in proton-antiproton collisions? Will the stationary target used at HERA prove a better geometry than the colliding beams at Fermilab?

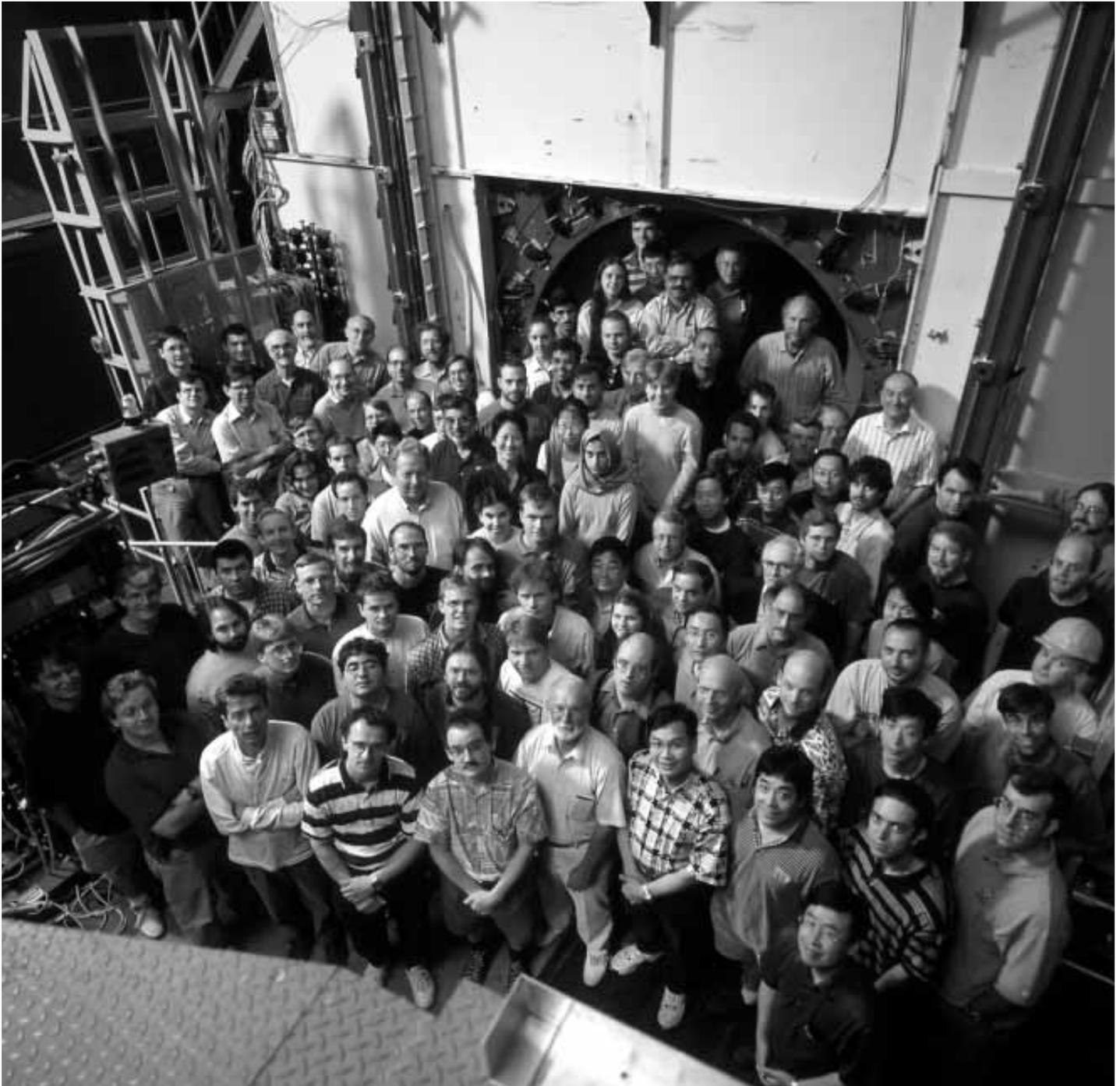
Will all the groups reach the end? And will they all reach the same end—the same picture of CP violation? Only when the race is over can we expect to know where the finish line is. This issue of the *Beam Line* serves as a program for this competition, outlining the teams and their strategies. Handicapping the race is left to the readers.



*After All These Years*

# Cornell Still Producing I

by PERSIS S. DRELL



# Mesons

**T**HE CORNELL ELECTRON STORAGE RING CESR was designed in 1975 to produce collisions of 8 GeV beams of positrons and electrons. Its accompanying all-purpose solenoidal detector CLEO surrounds the electron-positron collision point and records the fragments emerging from their annihilations. During the construction of CESR, in 1977, Leon Lederman's group at Fermilab discovered the first evidence for the bottom, or  $b$ , quark. It was an incredible stroke of good fortune for us. The 5 GeV mass of this quark meant that CESR could easily produce particles containing them. Although the original goal of CLEO was to explore the physics of electron-positron collisions up to an energy of 16 GeV, it quickly became clear that the physics of the  $b$  quark was going to dominate the experimental program. Indeed,  $B$  mesons were discovered in 1982 using the CLEO detector, which has studied them ever since.

CESR's luck didn't stop there. Not only was the machine serendipitously well suited to produce  $B$  mesons, but the  $B$  meson has also turned out to be much more interesting than anyone ever expected.

The initial studies at CLEO (and the ARGUS detector studying  $B$  mesons at DESY in Germany) focused on establishing the bottom quark as the partner of another heavy quark known as top. There were important measurements of the semileptonic decay rate and the energy spectrum of resulting leptons, which established that decay via the charm quark  $c$ ,  $b \rightarrow cW^-$ , is the dominant decay mode of the  $b$  quark. These studies, combined with measurements elsewhere of the  $B$  meson lifetime, allowed the  $b \rightarrow cW^-$  coupling strength of the CKM matrix,  $V_{cb}$ , to be determined.

**10 million  $B$  meson**

***pairs isn't bad,***

***but nevertheless***

***CESR and CLEO***

***eagerly push***

***forward to unlock***

***the secrets of the***

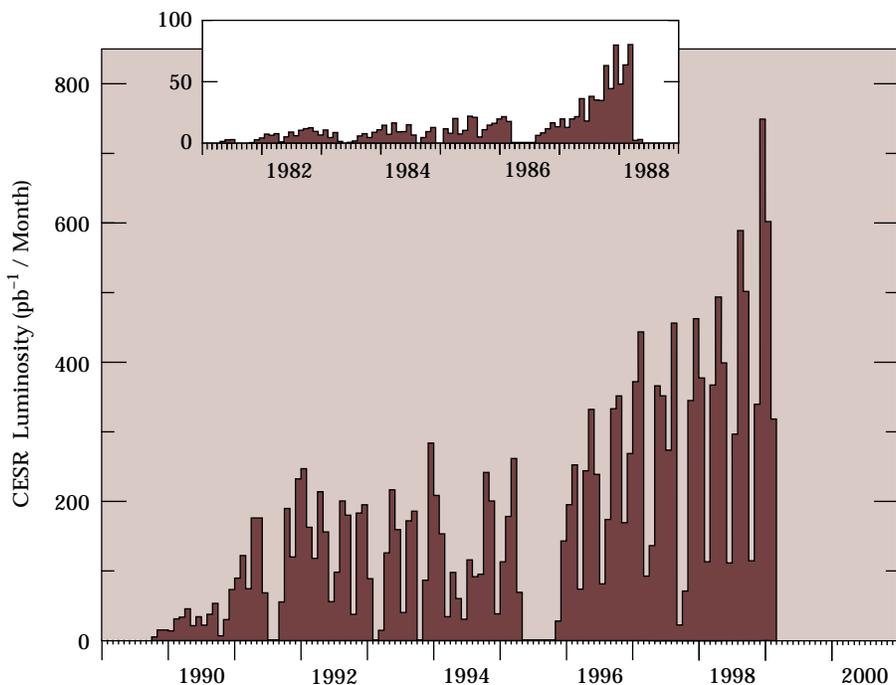
***$b$  quark.***

However, two measurements made the  $B$  meson front-page news in the physics community. In 1987, the ARGUS collaboration observed a large rate for  $B\bar{B}$  mixing. The two species can change into each other billions of times per second. One interpretation of this behavior (which turned out to be correct) was that the top quark is very massive. The second important result came in 1989 from CLEO, which observed that  $B$  mesons can decay to final states without a charm quark in them. This result meant that  $B$  mesons were prime candidates to help elucidate one of the great mysteries of Nature: the question of the matter-dominated Universe. The first result meant that rare  $B$  meson decays are an excellent probe of new physics beyond the Standard Model. Nobody really expects that  $B$  meson decays will provide conclusive answers to why

matter dominates in the Universe—or that the  $B$  meson will silence the lingering questions about potential sources of new physics beyond the Standard Model. But many hope that  $B$  mesons will probe the role that CP violation might play in creating the cosmic matter/antimatter asymmetry, as well as provide hints of new physics at or below the TeV scale. Interest in the  $B$  meson has grown dramatically in the two decades since its discovery!

As the  $B$  meson has become increasingly well understood through detailed studies of its decays, the desire has grown to produce and detect many more of them. Ever since it was first turned on, the CESR accelerator has been continuously upgraded to satisfy the seemingly insatiable demands of experimenters. The figure at left shows the integrated luminosity (which is directly related to the number of  $B$  mesons) delivered per month, and always the demand is for more. When CESR first operated in September 1979, it had a single bunch of electrons and a single bunch of positrons in the same circular orbit colliding head-on at two opposite places in the ring. A steady series of upgrades followed; a “pretzel” orbit scheme allowed the storage of up to seven bunches in each beam without their colliding at multiple points around the ring. The final focusing quadrupole magnets were inserted inside the CLEO detector to decrease the cross-sectional area of the beams when they intersect, thus increasing the luminosity. A small crossing angle of 2 milliradians introduced at the intersection point allowed 45 bunches in each beam to circulate in side-by-side

*A plot of the integrated luminosity per month of the CESR accelerator from 1981 until the February 1999 shutdown for the current upgrade. The height of each bar is directly proportional to the number of  $B$  meson pairs produced each month.*



***The greatest triumph***

***of all will be***

***to find surprising***

***new physics where***

***we least expect it.***

pretzel orbits, colliding at a single point in the center of the detector.

By February 15, 1999, when a much-improved CESR turned off for another upgrade, the collider had achieved a world-record peak luminosity of  $8 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  and had produced over 10 million pairs of  $b$  quarks for the CLEO detector. The main components of this current upgrade are to replace the copper microwave cavities in the machine with niobium superconducting ones and to install new superconducting quadrupole focusing magnets around the interaction point. In addition to providing stronger focusing of the beams, the new quadrupole magnets also help minimize the long range beam-beam interaction, where different electron and positron bunches interact as they approach and depart from the actual point of collision. The superconducting cavities will feed power to the beams much more efficiently and also lower the impedance of the machine, thus helping reduce multi-bunch beam instabilities. Additional work is being done so that the CESR vacuum system will be able to handle the increased currents, and the linac will feed electrons and positrons to the machine more rapidly. When the upgrade is finished, the rate of  $B$  meson production should increase by yet another factor of 2; when it turns back on this fall, the luminosity will approach  $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ .

The CLEO collaboration has steadily upgraded its detector as well. When it first turned on in 1979, its main goal was to establish the basic properties of the  $b$  quark. The essential features of the detector were excellent particle-tracking capabilities

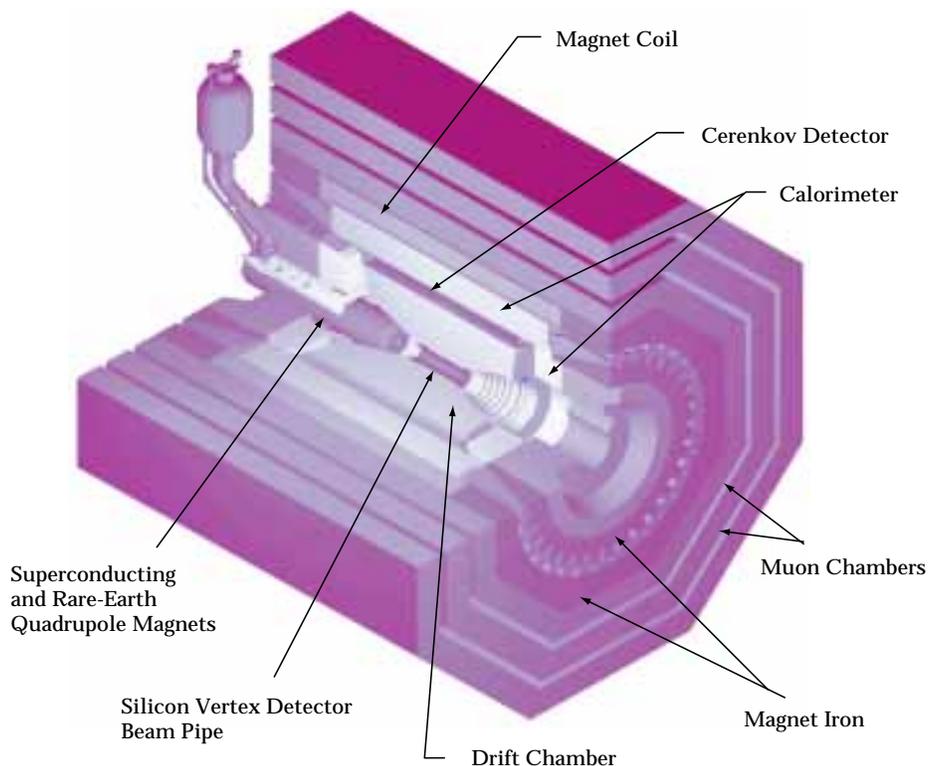
and the ability to detect the charged leptons that would be the smoking gun for the weak decay of a heavy quark. As the CLEO effort matured, the importance of high-efficiency detection of photons from decays of neutral pions became clear. Upgraded in 1989 to CLEO II, the detector included even better tracking with a new drift chamber and vertex detector, as well as a spectacular cesium iodide calorimeter with high efficiency and good resolution for detecting 10 MeV to 5 GeV photons. Further upgraded in 1995 with the addition of a three-layer, double-sided silicon detector, the CLEO detector has now recorded the decays of 10 million  $B$  meson pairs.

In CLEO II the physics focus shifted from the initial measurements of the basic properties of  $b$  quarks to detailed studies of quark mixing. The  $B$  meson is a wonderful laboratory for determining the parameters of quark mixing, and CLEO II has made measurements of two of them— $V_{cb}$

and  $V_{ub}$  with ever increasing precision. It has also done detailed studies of the dynamics of  $B$  meson decays and verified that (at least at tree level) the Standard Model picture of quark mixing is correct.

While not all of the CLEO II data are fully analyzed, many rare decays are also being measured. This will continue as the large data set is fully exploited. New higher-order processes that have been discovered offer useful windows on new physics. As one example, measurements of the rate for the  $b \rightarrow s\gamma$  decay are already probing physics at the 600 GeV mass scale; a new particle this heavy could significantly alter the rates for such decays from those predicted by the Standard Model. Rare decays (which occur once in every 10,000 or 100,000  $B$  decays) are definitely a growth industry right now. One of the goals for CLEO's future is to continue to use  $B$  mesons to look for physics beyond the Standard Model by studying these highly suppressed processes.

The current upgrade of the detector to CLEO III, now being completed, is designed to meet the challenges of these physics goals. Two major areas of investigation will be continued studies of rare decay modes and studies that probe direct CP violation through the decays such as  $B \rightarrow \pi\pi$  and  $B \rightarrow K\pi$ . A crucial aspect of the detector upgrade is the addition of a high-performance ring-imaging Cerenkov detector to improve CLEO's ability to distinguish pions from kaons with high efficiency. The CLEO III detector will also have improved tracking capabilities with a new silicon vertex detector and drift chamber. In addition, upgraded data-handling capabilities



*A cutaway view of the CLEO III detector. The calorimeter, magnet, and muon system are preserved from CLEO II. The Cerenkov detector, drift chamber, and silicon detector are new. Also shown are the new CESR superconducting and rare-earth quadrupole magnets that are part of the machine upgrade.*

will help us cope with CESR's increased luminosity. The figure on the left shows a schematic of the new detector. The components are now being assembled and tested, with installation scheduled to be completed in September 1999.

If the CKM matrix (see the previous article by Robert Cahn) provides the complete explanation for quark mixing—and if there are no new and surprising heavy particles to be discovered—then the work accomplished in the next decade or so by CLEO III and our colleagues at Belle and BABAR will be a triumph of detailed and precise measurements. They will expose the  $B$  meson system in all its complexity and elegance. What we hope, however, is that our luck will continue and that the  $B$  meson is in fact much richer than we can currently imagine. Perhaps the value of the mixing angle  $\beta$  will be inconsistent with the measurements of the sides of the CKM triangle, or the CP violation pattern observed in  $K$  decays. Perhaps the rates of certain rare  $B$  decays will turn out surprisingly large or startlingly small when compared with Standard Model expectations. The greatest triumph of all will be to find surprising new physics where we least expect it!



# HERA-B

## Variations on a Standard Model Theme

by ROY SCHWITTERS

W

ORLDWIDE INTEREST in learning more about the inner-workings of particles containing *b* quarks which prompted the con-

struction of new *B* factories at Stanford and Tsukuba for the

BABAR and BELLE experiments also led to a radically different approach in Hamburg called HERA-B. The scientific

goals of HERA-B are similar to those of the new electron-positron collider experiments—searching for new phenomena beyond the realm of the Standard Model of particle physics by testing whether its ideas can explain subtle asymmetries among electric charge, space, and time on the subatomic level—but the experimental techniques employed are very different.

HERA-B uses protons from the 920 GeV HERA proton storage ring\* at the Deutsches Elektronen Synchrotron (DESY) in Hamburg, Germany. Protons hit stationary nuclei in fine wire

*\*HERA is an electron-proton collider, but the electrons are not used by HERA-B.*

**One of the advantages  
of the proton-wire  
approach is that  
sufficient collision  
rates are relatively  
easy to obtain and  
have already been  
demonstrated at HERA.**

targets surrounding the beam producing hosts of subatomic particles, among which are particles containing  $b$  quarks that are detected and measured by the HERA-B apparatus.

**ACCELERATORS & DETECTORS CHOICES, CHOICES!**

HERA-B, BABAR, and BELLE offer textbook examples of the diverse choices possible between types of beam and target particles, accelerators, and detectors for pursuing outstanding physics questions. These choices involve technical and financial trade-offs of many kinds, but ultimately come down to judgments that are the art of experimental science.

HERA-B grew out of the pioneering studies of the  $b$ -quark system by the ARGUS group working on the DORIS electron-positron collider at DESY. In the early 1990s physicists associated with ARGUS also sought a higher-intensity collider to compete with new machines then being proposed at SLAC, KEK, and Cornell. DESY chose not to construct a  $B$  factory because of the cost and effort required, but as is so often the case, compelling science became the “mother of invention.” ARGUS physicists recognized that  $b$  quarks could be produced in proton-nucleus collisions using the *existing* HERA ring. The choice puts severe demands on detector technology but eliminates the need to build two new storage rings.

The key new idea was ingenious: place a fine wire beside the beam stored in HERA and protons moving relatively far from the center of the beam will preferentially strike it because there are no other obstructions

nearby. The proton-nucleus collisions are energetic enough to produce pairs of particles containing  $b$  and anti- $b$  quarks that can be measured in an experiment. The fine wire would also precisely locate the point of collision, a significant technical advantage for experiments.

Protons behave quite differently than electrons in high energy storage rings because of their two thousand times larger rest-mass. Synchrotron radiation dominates the performance of high energy electron-positron storage rings but plays essentially no role in even our highest energy proton accelerators, the Fermilab Tevatron and HERA. Minor errors in the fields that guide electrons around storage rings can be completely masked by the ebb and flow of synchrotron radiation and the radiofrequency power needed to compensate for it. This is not the case with protons—their motion feels the sum of all minor perturbing influences over the millions and millions of miles they travel around a storage ring in the hours they are captured. The mechanics of chaos come into play and individual

protons gradually migrate outward from ideal paths at the center of the beam, forming the “halo” of particles which hit the HERA-B target wires, while not affecting the other collider experiments; HERA-B runs simultaneously with them with little or no interference.

A critical factor in the success of the next-generation  $b$ -particle experiments will be the yield of “gold-plated” events, events displaying certain decay modes like  $B^0 \rightarrow J/\psi K^0_S$  that are expected to manifest the particle-antiparticle asymmetries most eagerly sought. One of the great challenges to the accelerator physicists of the electron-positron  $B$  factories is achieving unprecedented luminosities required to produce sufficient numbers of events. One of the advantages of the proton-wire approach is that sufficient collision rates are relatively easy to obtain and have already been demonstrated in HERA.

On the other hand, producing  $b$  quarks through collisions of protons and nuclei (or other protons) is considerably “messier” than by electron-positron annihilation—the strong interaction produces them frequently in many forms, but, unfortunately, at the HERA-B energy only about one pair of  $b$  quarks is produced for every *million* collisions. When one seeks particular gold-plated examples of  $b$ -quark events of most interest, *one-hundred billion* proton-wire collisions take place for every nugget found! The central challenge for HERA-B is how to find the desired events while rejecting enormous backgrounds. To do this, new levels of speed and complexity in the digital processing and selection of detector information—called

“triggering”—will be required. It is interesting that, on paper, the projected capabilities of HERA-B, BABAR, and BELLE are quite similar even though the accelerator and detector challenges are vastly different. Our confidence in the proton approach is strengthened by the pioneering work of the Collider Detector at Fermilab (CDF) group who have published the best measurements to date on asymmetries involving the gold-plated events; CDF becomes a strong competitor after improvements to their detector and accelerator are completed next year.

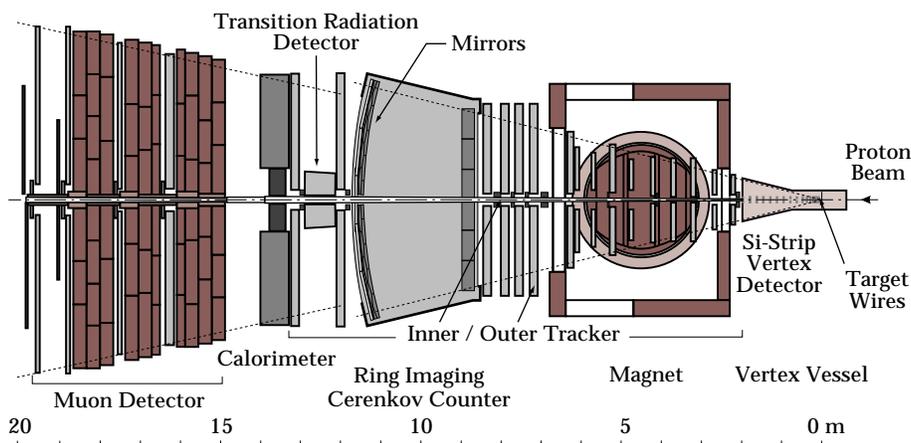
HERA-B target wires present a “fixed-target” to HERA’s protons. Kinematic rules dictate that the  $b$  quarks and all others produced in a collision are thrown forward into a relatively small range of angles about the proton beam direction. This has important implications for the design of the detector: one need only instrument a relatively small range of angles, but the number of particles passing through detector components is large, imposing severe requirements on detector element size and performance. In addition, components must stand up to all the other proton-wire collisions taking place. To collect enough gold-plated events in a reasonable period of time, the rate of ordinary collisions will be in the range 10–40 million per second. These particle rates are comparable to what will be encountered at CERN’s Large Hadron Collider (LHC). Our ability to design and build detector components suitable for the formidable HERA-B environment rests on detector R&D carried out in anticipation of the LHC and the Superconducting Super Collider.

## COLLABORATION & DETECTOR—STATUS AND PLANS

HERA-B is being built and commissioned by an international collaboration comprising approximately 280 physicists from institutes in China, Denmark, Germany, Italy, Netherlands, Norway, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and the United States. The collaboration formed in the early 1990s to design a detector optimized for  $b$ -quark physics. HERA-B was formally approved by DESY management in 1995. In spring 1999, major parts of the detector were commissioned with HERA beams while other components are still being built and installed during pauses in the program. The apparatus is expected to be completed by the end of 1999, and initial physics running is planned for winter/spring 2000.

*HERA-B collaboration members in front of the electromagnetic calorimeter. Parts of the muon detector can be seen in the left background.*





Plan view of HERA-B indicating the major detector components and scale. The proton beam passes through the apparatus from right to left.

A basic principle underlying the design of HERA-B is to record events exhibiting highly distinctive decays of  $B$  particles such as  $J/\psi K^0_s$  mentioned previously, and to “tag” whether the trigger particles come from decays of  $B$  particles or anti- $B$  particles by observing properties of the *other* particles in the same event. The decision to record an event is made by means of a specialized trigger processor that examines information from several detector subsystems within the 96 nanosecond period of time between collisions, followed by subsequent levels of processors using successively more computation and more time to reach a decision. Tagging is achieved by examining all the data recorded for the event from a multiplicity of detector types that respond differently to various kinds of particles. The choice of detector components and layout follows from these considerations.

Eight remotely positioned target wires surround the HERA proton beam. During a run, one or more wires are moved into the beam halo; a feedback system makes fine adjustments to wire positions to maintain the desired rate of proton-target-wire collisions. Downstream from the target wires, in the beam vacuum, are 136,000 channels of silicon detectors for accurately measuring trajectories

of charged particles. The silicon detectors determine the proton-wire collision point and detect secondary vertices arising from decays of  $B$  particles. Decay vertices occur over distances of millimeters to centimeters from the wires because of the high energy kinematics involved, making them easily recognizable in the silicon detectors. Products of  $B$ -particle decays and other particles produced in the target wires next pass through a ten-meter-long system of tracking detectors and a dipole magnet for determining momenta. There are nearly 300,000 channels in the tracking system. Finally, a large ring-imaging Cerenkov detector, electron/photon calorimeter, and muon absorber/tracker aid in particle identification and photon detection. In total, HERA-B is about twenty meters in length and comprises roughly one-half million detector channels.

To date, the most vexing technical problem has been aging of tracking chambers—degradation in performance when exposed to the large fluxes of particles expected in the actual experiment. Extensive tests involving new fabrication techniques and operating procedures indicate that aging problems can be mitigated, but the effort has resulted in delays. The knowledge gained in these studies, however, is of great utility

to future high-intensity hadron collider experiments such as those planned for the LHC.

## OUTLOOK

The next few years promise to be landmarks in the study of the building blocks of matter with the new experiments HERA-B, BABAR, and BELLE starting up and joining ongoing and upgraded efforts at other laboratories. The multiplicity of approaches will ensure full exploration of today’s open questions and will provide road maps to future inquiries which become imperative in the happy event that the  $b$ -quark system reveals new mysteries not anticipated by the Standard Model. HERA-B plays a central role in this process both scientifically and in lessons to be learned about detecting  $B$  particles in intense proton collisions, the likely future path for this physics because of the superior numbers of  $B$  particles that can be produced in high energy proton collisions.

The technical challenges of building a new kind of detector system within tight constraints of time and resources, and the future promise of the proton approach make HERA-B a demanding, yet rewarding experience for the relatively small group of people creating this interesting variation among modern detectors.



# CDF—The Party Crashers

by MANFRED PAULINI

*You see things as they  
are and ask 'Why'? I  
dream things as they  
never were and ask*

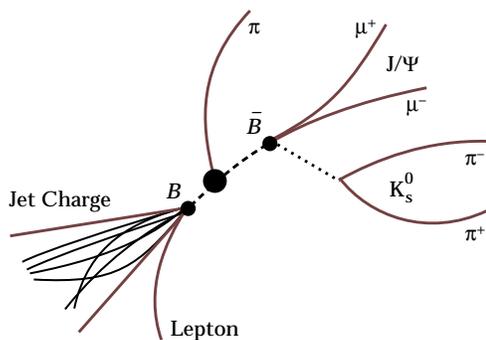
*'Why not'?*

*—George Bernard Shaw*

**I**MAGINE A WELL PREPARED celebrity affair. Everything is perfectly planned. The candles match the color of the napkins. The program has been rehearsed many times. Everybody is anxiously awaiting the appearance of the two superstars. Everything is expected to go smoothly, but something unexpected happens. This is the story of some uninvited party crashers.

The Collider Detector at Fermilab (CDF) studies proton-antiproton collisions at the world's highest energy accelerator, the Tevatron Collider. The study of *B* mesons, subatomic particles containing a bottom quark, *b*, is among the most exciting goals for CDF—although this was not at all anticipated when the detector was designed. The collision of a proton with an antiproton had been considered too complex an environment, in which it seemed to be too hard to identify the *B* meson. CDF was built primarily to study the properties of the *W* boson, a particle mediating the weak force, and to find the top quark, which was indeed discovered in 1995 (see the article by Bill Carithers and Paul Grannis in the Fall 1995 *Beam Line*, Vol. 25, No. 3).

Several features in the original detector design were however advantageous for studies of *B* mesons. CDF has a large magnetic tracking volume, in which the flight paths of electrically charged particles are bent, a well-segmented calorimeter to detect electrons and to measure their energy, as well as muon chambers that allow the detection of muons even at low momentum. But it was the later installation of a silicon micro-vertex detector in 1992 that made the study of *B* particles possible in a competitive way. This device finds the point of origin (vertex) of particles, indicating how far a *B* meson traveled before it broke down and thus how long it lived. In 1993, CDF physicists presented their first measurements of



*B particles emerging from the collision between a proton and antiproton are relatively long-lived, traveling on average about 1 mm (dashed lines) before decaying. Here a  $\bar{B}$  meson decays into a  $J/\psi$  and a  $K_s^0$  particle. The  $J/\psi$  further disintegrates into two muons ( $\mu^+$ ,  $\mu^-$ ) while the  $K_s^0$  decays further into two pions. To determine whether the B particle was born as a  $B^0$  or its antiparticle  $\bar{B}^0$  certain clues are used: another pion produced in conjunction with the B decay products, a jet, or a lepton produced by the second B particle in the event.*

the lifetimes of  $B$  mesons, demonstrating the capabilities of its silicon micro-vertex detector. Since then, the collaboration has pursued a broad program studying the decays of  $B$  particles. With a detector not specifically designed for  $B$  physics, we are now participating in the race to discover CP violation in the  $B$  meson system, competing with physicists whose accelerators and detectors are optimized for this single purpose. In this article, I illustrate why we feel confident in joining the celebrants setting out to reveal the nature of CP violation in  $B$  decays.

There are particular advantages to pursuing  $B$  physics at the Tevatron Collider. It produces all species of  $B$  particles, in contrast to the  $B$  factories, where only certain kinds of  $B$  mesons appear. But the primary motivation is that the  $B$  meson production rate is about 3000 times larger at the Tevatron than at the  $B$  factories. About 5 billion  $b\bar{b}$  pairs were produced during the 1992–96 run of the Tevatron Collider, called Run I. Producing  $B$  particles at high rate is thus easy. But isolating events that contain them is a major issue, since they are produced in only one in every thousand collisions.  $B$  mesons appear in every fourth event at the  $B$  factories. The task at CDF is therefore identifying the desired events while rejecting copious backgrounds. The “trigger” decides whether an event is interesting enough to be recorded. In Run I, all triggers used to find  $B$  particles were based on easily identified leptons, electrons or muons.

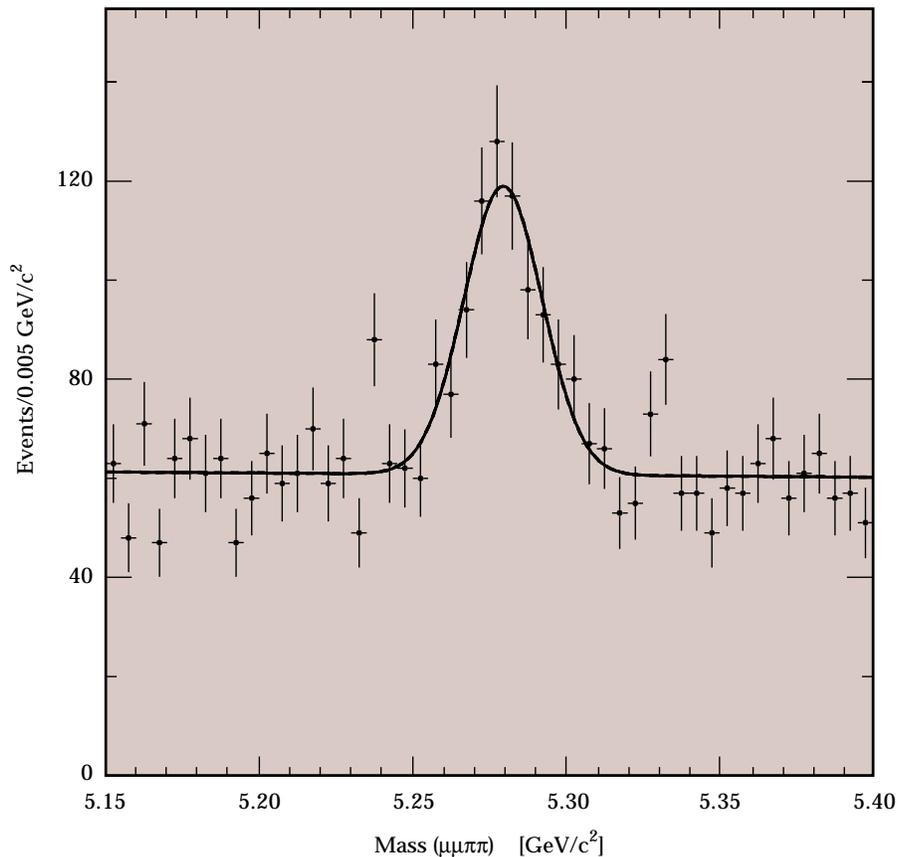
Soon after CDF presented its first  $B$  lifetime results in 1993, the collaboration embarked on a program to explore whether CDF would be able

to study CP violation in the  $B$  meson system. The best chance is with the “gold-plated” decay mode  $B^0 \rightarrow J/\psi K_s$  (see the illustration on the left). In general, there are three ingredients that are essential to measure CP violation in this decay. First, one needs to reconstruct the decay by finding  $\pi^+\pi^-$  pairs that come from  $K_s$  decays in events where two muons from a  $J/\psi$  set off the trigger. Approximately 400 signal events, currently the world’s largest sample of  $B^0 \rightarrow J/\psi K_s$ , have so far been reconstructed at CDF (see the graph on the next page). Now the lifetime of the  $B^0$  meson that decayed to  $J/\psi K_s$  must be measured. Since  $B$  mesons are produced independently at the Tevatron, the clock starts ticking with the initial proton-antiproton collision whereas at the  $B$  factories the clock runs from the decay of the first  $B$  meson to the decay of the second one. As the third ingredient, we must determine whether the  $B$  meson involved was a  $B^0$  or its antiparticle  $\bar{B}^0$ . This detective work—usually called  $B$ -flavor tagging—requires examining the remainder of the event. CDF physicists use certain clues to tag the  $B^0$ : another pion produced in conjunction with the  $B$  meson disintegrating to  $J/\psi K_s$ , or a jet or lepton produced by the other  $B$  particle in the event (using the fact that  $B$  particles always come in pairs). The charge of the pion, jet, or lepton tells us whether a  $B^0$  or  $\bar{B}^0$  decayed to the  $J/\psi K_s$ . All these methods are imperfect, however, and cause uncertainties in the measurement of the CP asymmetry. Since  $B$  flavor tagging is the crucial element of a CP violation measurement, CDF has done extensive studies of the various methods

which do indeed work. However, they are not as effective as they are at the SLAC and KEK  $B$  factories. On the other hand, the Tevatron's much higher production rate for  $B$  mesons compensates for this disadvantage.

CDF recently demonstrated its ability to measure CP violation in the  $B$  meson system by applying these three tagging methods to its sample of 400  $J/\psi K_S$  events. If there were no asymmetry, 200 of the 400 events would come from  $B^0$ 's and the other 200 from  $\bar{B}^0$ 's, and there would be no evidence for CP violation. The existence of an asymmetry would then indicate that CP symmetry is violated in the  $B$  meson system, resulting in a non-zero value for the CP violation parameter  $\sin 2\beta$ . As it turned out the measured CDF value for  $\sin 2\beta$  is  $0.79 \pm 0.44$ . While this result is a tantalizing indication that  $\sin 2\beta$  is non-zero, it is not conclusive proof for CP violation in  $B$  meson decays. But it clearly establishes the feasibility of measuring CP asymmetries at CDF and is the best direct measurement of the CP violation parameter  $\sin 2\beta$  in the  $B$  meson system to date.

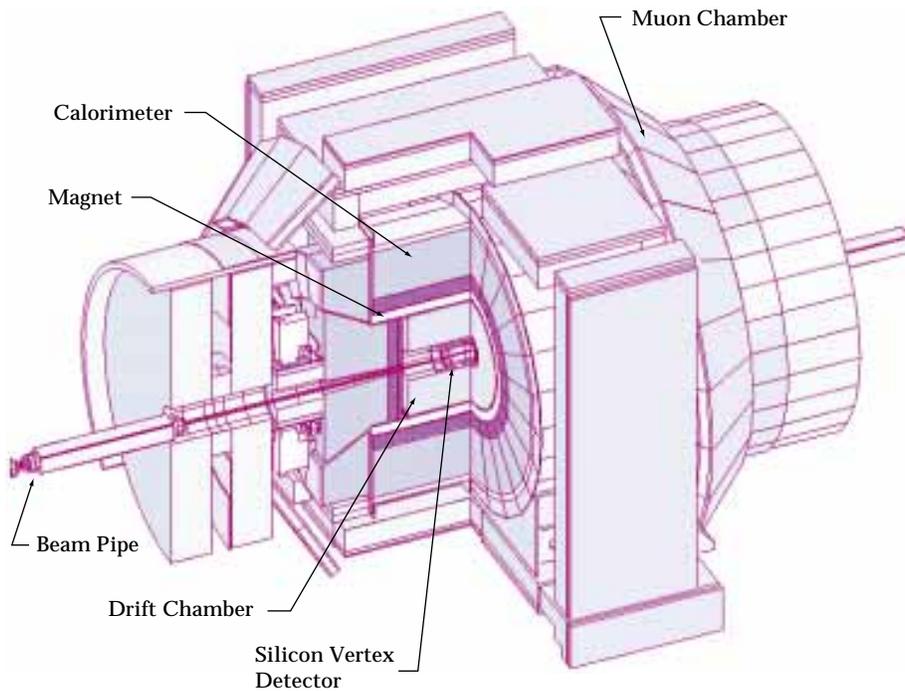
The Fermilab accelerator complex is currently being upgraded to produce an order of magnitude higher event rates in the Tevatron Collider—scheduled to run again in the summer of 2000. Within two years thereafter, the current data set is expected to be eclipsed by another that is 20 times larger. The CDF detector (see illustration on the next page) is also undergoing major upgrades, including the charged particle tracking system vital for the study of  $B$  particles at CDF. Among these improvements are a next-generation silicon micro-



*Invariant mass distribution of  $J/\psi K_S$  events at CDF comprising about 400 signal events in the peak.*

vertex detector and a new drift chamber filled with gas and wires used to reconstruct the trajectories of particles from  $B$  decays. A trigger upgrade allows for higher data rates and increases the sophistication of the triggering decision. For the first time, CDF plans to operate a track trigger that identifies  $B$  decay modes with no leptons, such as  $B^0 \rightarrow \pi^+ \pi^-$ . This trigger will use information from the new silicon micro-vertex detector. In addition, two projects that will significantly enhance the  $B$  physics capabilities of CDF have recently been approved: an additional layer of silicon detectors just outside the beam pipe and a time-of-flight system to determine the velocity of particles and give clues about their identities.

With the improved detector, CDF physicists expect to identify 10,000  $B^0 \rightarrow J/\psi K_S$  events in two years of running. Together with enhanced tagging capabilities, this data set will allow the observation of CP violation and a measurement of  $\sin 2\beta$  with a precision of  $\pm 0.08$ , comparable to the



*Schematic cut-away view of the upgraded CDF detector.*

uncertainties projected for the  $B$  factories. Another goal of future  $B$  physics is the observation of an asymmetry in  $B^0 \rightarrow \pi^+ \pi^-$  decays, thus measuring the CP violation parameter  $\sin 2\alpha$  and further checking the consistency of the unitarity triangle. The key to this measurement is the ability to trigger on the  $\pi^+ \pi^-$  decay mode. The CDF collaboration plans to do this using the new track trigger and expects to record about 10,000  $B^0 \rightarrow \pi^+ \pi^-$  events in two years. This would result in an estimated precision on the measurement of  $\sin 2\alpha$  similar to that of the  $B$  factories (although theoretical uncertainties in the extraction of this parameter from just the  $B^0 \rightarrow \pi^+ \pi^-$  mode still need to be addressed). Better instrumentation will also allow the collection of large samples of other  $B$  decay modes, especially decays of  $B_s^0$  mesons which offer further ways of probing CP violation. In particular, CDF is equipped to observe oscillations between a  $B_s^0$  meson and its antiparticle  $\bar{B}_s^0$ . The physics of  $B_s^0$  mesons represents a unique capability for CDF until at least the year 2005.

Thus the CDF collaboration is well prepared to search for the nature of CP violation in the  $B$  meson system. With data taking just beginning at the  $B$  factories and the next run of CDF following in the summer of 2000, there will be a heated race for the answer. Armed with the knowledge from Run I, the party crashers are ready to knock on the door!



# The KEK B-Factory Experiment

by SHIN-ICHI KUROKAWA & STEPHEN L. OLSEN

*Japan's new asymmetric B factory recorded its first events on June 1.*

*Designed to study the B-meson system, this collider may give us important clues to the differences played by matter and antimatter in the evolution of the Universe.*

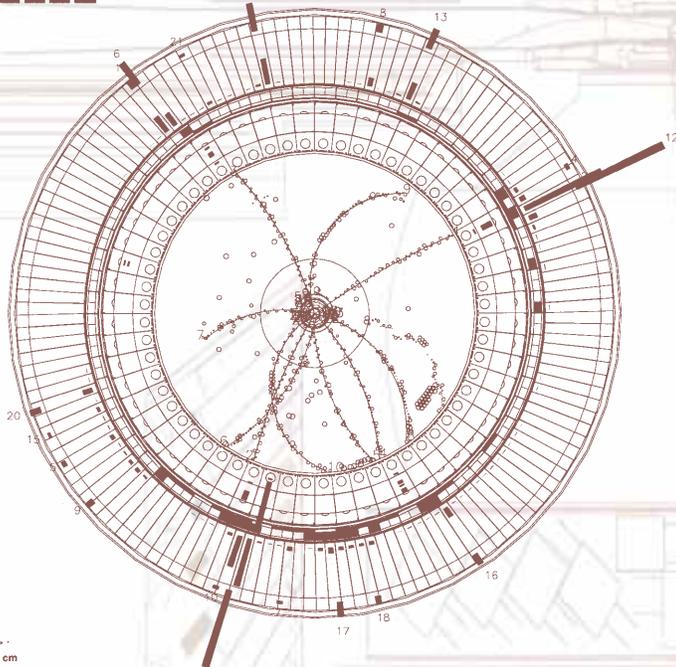
**O**N THE AFTERNOON OF JUNE 1, 1999, collision events were recorded for the first time by the BELLE detector at the KEKB collider, the new electron-positron “B factory” at the High Energy Accelerator Research Organization in Tsukuba, Japan. This facility is specifically designed to study the matter-antimatter asymmetries in decays of *B* mesons predicted by the theory proposed by Makoto Kobayashi and Toshihide Maskawa in 1972.

In many ways, the KEKB collider is similar to the PEP-II collider described by John Seeman on page 29. The KEKB collider consists of two rings of magnets; one ring stores 8 GeV electrons and the other 3.5 GeV positrons. The beams are brought into collision inside the detector, where they produce pairs of *B* mesons that move along the direction of the electron beam. This configuration is designed to measure charge-parity (CP) violations in *B* meson decays as described earlier in this issue by Robert Cahn and in the Summer 1996 *Beam Line* article by Michael Riordan and Natalie Roe.

Like PEP-II, the two magnet rings of KEKB occupy a tunnel that originally housed a higher energy electron-positron collider, in this case TRISTAN, and the high energy electron ring uses many recycled TRISTAN components. The center-of-mass energy of 10.58 GeV coincides with the mass of the  $\Upsilon(4S)$  resonance, which decays into *B* and  $\bar{B}$  meson pairs and nothing else. The different energies of the

**BELLE**

Exp 3 Run 37 Form 6 Event 762  
Eher 8.00 Eler 3.50 Date/TIME Wed Jun 2 08:02:47 1999  
TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 2.04



two beams cause the produced  $B$  mesons to travel about two tenths of a millimeter before they decay, a distance that is easily measured with modern silicon-strip detectors.

The BELLE detector is also similar in many ways to PEP-II's BABAR detector. In both cases the cores of the instrument are cylindrical tracking detectors; a large array of cesium-iodide crystals situated inside a superconducting solenoidal magnet that provides a 1.5 tesla magnetic field. There are, however, some important differences in the details between

the KEKB/ BELLE arrangement and that of PEP-II/ BABAR. In this article we highlight those that we consider to be the most significant.

### KEKB

The most fundamental differences between the KEKB and PEP-II storage rings are the schemes used to bring the beams into collision and the techniques used to provide the radio-frequency (rf) accelerating voltages. To appreciate these differences, some awareness of the behavior of beams in storage rings is necessary.

*Beam oscillations.* In general, particles in a storage ring beam do not all have exactly the same energy nor move in exactly the same direction. The magnet and accelerating systems are designed to accommodate beam

particles with energies and trajectories that deviate from the ideal on-energy central-orbit particle. A lattice of quadrupole focusing magnets acts as a series of lenses to deflect particles diverging from the beam back toward the ideal orbit, causing the particles to snake back and forth across the beam axis executing "betatron oscillations."

Particles circulating in the magnet rings radiate a few million electron volts of energy in synchrotron radiation during each turn. This lost energy is replaced in high voltage rf accelerating cavities. The particles in the storage rings cluster in bunches that are properly phased to "surf" on the rf accelerating voltage. The distance between bunches depends on the frequency of this voltage. In both KEKB and PEP-II the rf frequency is about 500 million hertz, and the minimum bunch-to-bunch spacing is 0.6 m. Both machines try to store as many bunches of particles as possible in order to achieve high luminosity.

The magnet systems are designed so that particles with energy above the central value take a little extra time to travel around the ring and thus tend to lag behind their on-energy neighbors. Since the particle bunches pass through the rf cavity while the voltage is decreasing, these late-arriving, higher-energy particles receive a less than average energy boost from the cavity. Likewise, particles with lower than average energy tend to lead their neighbors and arrive at the rf cavities early, where they get an above average energy boost. As a result, particles within each bunch alternate between lagging behind their neighbors and



Kyoto University 1972 or 1973. Standing left to right are Makoto Kobayashi, Tsuneo Uematsu, Hideo Nakajima, Koichi Yamawaki, and Masako Bando. Seated left to right are Toshihide Maskawa and Keiichi Ito. (Courtesy Makoto Kobayashi)

***The challenge to machine designers is to bring bunches from the two rings into collision inside the detector and then to separate them quickly enough to get them back into their respective magnet systems before they collide with the next bunch.***

having higher than average energy to leading their neighbors with lower than average energies, a phenomenon called “synchrotron oscillations.”

*Crossing scheme.* At the intersection point, where the electron and positron bunches pass through each other, the beams are focused to a very small size. Since the electron and positron beams have different energies, the two beams require magnets with different focusing strengths. The challenge to machine designers is to bring bunches from the two rings into collision inside the experimental detector and then to separate them quickly enough to get them back into their respective magnet systems before they collide with the next bunch—and to do so without producing large disturbances to the experimental detector.

In PEP-II, the beams are made to collide head-on; they are brought together and then separated by a system of “separation dipoles” made from permanent magnets that are common to both beams and located inside the detector. This scheme limits the minimum separation between bunches to 1.2 meters, twice the minimum bunch spacing.

In KEKB, the beams are made to cross at a 1.3 degree angle. Since the two beams are moving in different directions, they fly apart naturally, and no separation dipoles are necessary. In this case beam bunches can be as close together as the minimum distance of 0.6 meters.

The KEKB finite crossing angle scheme has the advantage of simplicity. With no separation dipoles, there is no bending of off-energy beam particles into the detector, resulting in more manageable

backgrounds. The main disadvantage is the introduction of a possible coupling of each beam’s transverse betatron modes of oscillations with the longitudinal synchrotron modes resulting in the dreaded “synchro-betatron” oscillations (see box on the next page). These were blamed for beam instabilities that limited the performance of the original two-ring configuration of the DORIS storage ring at DESY.

Using elaborate computer simulations, Kohji Hirata and Nobu Toge of KEK carefully reexamined the effects of beam-beam interactions in the case of finite-angle crossings. They concluded that the deleterious effects of a finite crossing angle would be manageable, provided that the frequency of synchrotron oscillations is a small fraction (about 1 percent) of the beam circulation frequency.

*Chromatic corrections.* The focusing strengths of the quadrupole magnets are set for particles that have exactly the nominal beam energy. As a result, off-energy beam

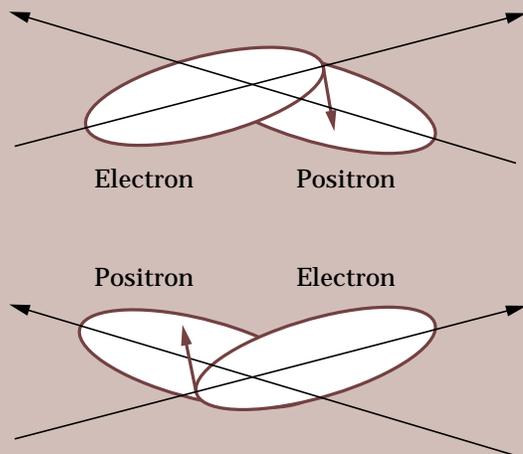
particles experience non-ideal focusing, producing effects that are similar to chromatic aberrations in ordinary optical systems and for which careful compensation must be made. These corrections are provided by sextupole magnets distributed around the ring.

Design studies for KEKB demonstrated that standard magnet lattice arrangements, such as the one used in PEP-II, could not provide the necessary chromatic corrections while also meeting the low synchrotron frequency requirement imposed by the finite-angle crossing arrangement. Instead, KEKB uses a novel new lattice arrangement developed by KEK physicists Haruyo Koiso and Katsunobu Oide that satisfies all of the requirements. In the Koiso-Oide scheme, the chromatic corrections are provided by pairs of sextupole magnets located far apart, at positions where the optical properties of the beams are nearly mirror images of each other. The mirror imaging provides a convenient cancellation of nonlinear effects, and the scheme has the additional practical advantage of making it possible for the high energy electron ring to use recycled bending magnets from the recently dismantled TRISTAN storage ring.

*Radio-frequency accelerating cavities.* In order to achieve the high luminosity requirements of the B factory, the stored currents in each beam must be as large as a few amperes. To maintain the proper match between the klystron (which provides the rf power) and the cavity, the resonant frequency of the cavity must be shifted by an amount proportional to the current passing through the cavity. If the shift in

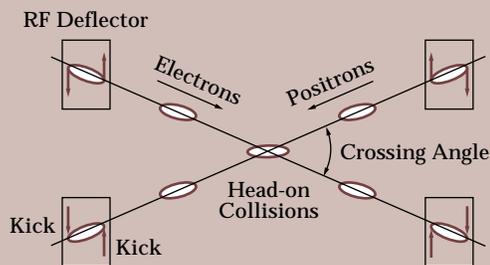
## Crossing Angles, Synchro-Betatron Oscillations and Crab Cavities

**T**HE DISADVANTAGE of a finite angle crossing of the beam bunches is the introduction of couplings between the transverse betatron oscillation modes of beam particles with their longitudinal synchrotron oscillation modes. This establishes an additional set of possible beam-destroying resonances that must be avoided.



The coupling mechanism illustrated above shows electron and positron beam bunches when they start and finish passing through each other at an exaggerated crossing angle. The positively charged positrons in the front end of the  $e^+$  bunch pull the negatively charged electrons in the back end of the  $e^-$  bunch sideways in one direction, while the positrons in the back end tug the electrons in the front end in the opposite direction. Changes in the front-to-back particle positions, caused by synchrotron oscillations, result in different excitations of the transverse betatron oscillations, giving rise to coupled “synchro-betatron” oscillations.

This coupling can be avoided using the “crab-cavity” trick invented by Robert Palmer of Brookhaven National Laboratory for use in high energy linear electron-positron colliders. In this scheme (shown below) rf



cavities on either side of the interaction point provide transverse electric fields that rotate the beam bunches by pushing the front of the beam bunch in one direction and the rear in the opposite direction. In this way, even though the beam bunches pass by each other at an angle, the bunches go through each other head-on, and the transverse-longitudinal coupling mechanism shown above is eliminated.

frequency exceeds the circulation frequency of the beam in the ring (100 kilohertz), beam-destroying instabilities can occur. Only large rings with large circulating currents, such as KEKB, suffer from this type of instability.

In order to reduce the effects of the beam currents on the cavity resonant frequency, KEKB uses cavity systems where the energy stored in the resonant mode is very large. The large stored energy provides sufficient inertia to reduce the effects of the beam current. Superconducting cavities naturally have lots of stored energy and these are used in the KEKB high energy ring. This is not the case for normal-conducting cavities, where heating in the cavity walls limits the amount of energy that can be stored in the cavity itself. However, it was not possible to supply all of KEKB’s radio frequency requirements with superconducting rf cavities. Normal-conducting rf cavities are also needed. Tsumoru Shintake of KEK proposed a two-cell system where the accelerating cavity is closely connected to a second, very large energy-storage cavity, thereby increasing the total stored energy by about a factor of ten. This idea was improved to include a third coupling cavity.

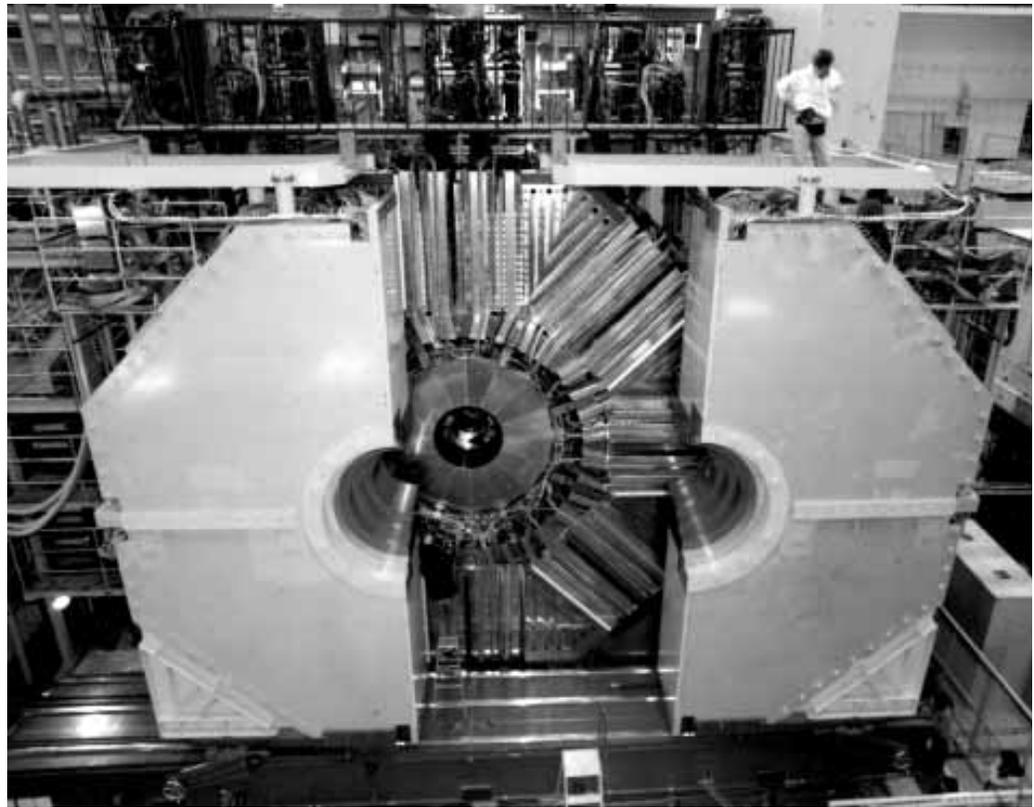
In KEKB, all of the rf power for the low energy ring and about half of it for the high energy ring is provided by normal-conducting systems based on this three-cell scheme.

### THE BELLE DETECTOR

The technical challenges presented by the *B*-factory physics program to the experimental detector are not

as severe as those faced by the machine builders. This is because there are existing detectors, primarily the CLEO detector at the Cornell Electron Storage Ring, that provide useful guidance. The relative maturity of detector technologies is reflected in the fact that differences between BABAR and BELLE are not nearly as pronounced as the differences in the storage rings. Both detectors surround the beam intersection region with a 1.5 tesla magnetic field, provided by large superconducting solenoids that encompass most of the detector elements. Immediately outside of the electron-positron collision point are high resolution track detectors made of silicon that pin down the decay position of the  $B$  mesons. Surrounding the silicon detectors are tracking chambers that measure the trajectories of charged particles from the  $B$  meson decays as they travel through the magnetic field. The curvature of the trajectories is used to determine the particle momenta. Outside of the tracking chambers but still inside the coil are large arrays of cesium-iodide crystals for detecting gamma rays. The major differences between CLEO-II, BABAR, and BELLE are the techniques used to distinguish between different species of charged particles. BELLE uses arrays of plastic scintillation time-of-flight counters and aerogel Cerenkov counters.

**Particle Identification.** For the CP violation measurements, it is essential to distinguish charged  $K$  mesons from other particles, especially from the more copiously produced  $\pi$  mesons. The  $\pi$  and  $K$  mesons from  $B$  decays are quite relativistic: typical  $\pi$  mesons have velocities that are



about 99 percent of the speed of light; the more massive  $K$  mesons are only a bit slower—their velocities are typically about 90 percent of the speed of light. Particle identification systems have to exploit these small differences in particle velocity.

One way to do this is to make a direct measurement of it. This is done in BELLE with an array of large plastic scintillation counters arranged in a barrel that surrounds the tracking system and measures the time-of-flight of particles as they cross the detector volume. Using state-of-the-art techniques, the BELLE time-of-flight system measures the particle transit times with a precision of about 100 trillionths of a second. This is good enough to distinguish  $\pi$  and  $K$  mesons up to particle energies of about 1 GeV.

At energies higher than 1 GeV,  $\pi$  and  $K$  mesons can not be reliably distinguished by the time-of-flight system; for these particles Cerenkov techniques are used. These techniques rely on the fact that when a charged particle passes through a transparent material with a speed that exceeds the speed of light in that material, it emits measurable

*Eiichi Nakano from Osaka City University checks the cabling of the endcap muon chambers in the completed BELLE detector while it sits in its "rolled-out" position in the Tsukuba experimental hall at KEKB. On May 1, the detector was moved into its final location at the electron-positron interaction point, which is inside the temporary tunnel of shielding blocks seen at the right in the photograph. (Courtesy KEK)*

amounts of light in the form of “Cerenkov” radiation. In BELLE, a cylindrical mosaic of nearly a thousand blocks of transparent silica aerogel with indices of refraction that range from  $n = 1.01$  to  $1.03$  occupies the radial space between the tracking region and the barrel of time-of-flight counters. Each aerogel block is viewed by very sensitive phototubes.

Charged pions with energy above about 1 GeV have velocities that are above the Cerenkov threshold and produce light as they traverse the aerogel material. In contrast, charged kaons, which are more massive, do not have velocities above the Cerenkov threshold until they have energy in excess of 3.5 GeV, which is near the highest energy possible for particles from  $B$  meson decays. Kaons below this energy do not produce any light. Thus, the response of the aerogel counters can be used to distinguish high momentum pions from kaons in BELLE.

The aerogel system can be nicely tailored to the variation in particle’s momentum range with polar angle that results from the asymmetric nature of the electron-positron collisions in KEKB, but it has the disadvantage of consuming a sizable volume inside the detector and interposing a considerable amount of material in front of the cesium iodide calorimeter in a complicated non-uniform pattern

#### KEKB AND BELLE—CURRENT STATUS

In 1994, when BELLE and the KEK  $B$ -factory project were started, the proposed date for the start of KEKB beam commissioning and the completion

of the BELLE detector was “the middle of Japanese Fiscal Year 1998,” which started in April 1998. Despite major changes from KEKB’s original plans for the injection scheme, the interaction region configuration, the magnet lattice and the rf cavities, both rings were completed in November 1998 and beam was first stored in the high energy ring on December 12. Also, in spite of a number of design changes, the assembly of the entire BELLE detector was finished on December 18.

In a four-month beam commissioning run that ended in April, high current electron and positron beams (about 0.5 amperes each) were achieved with tolerable levels of background radiation at the ultimate location of the BELLE detector. These beam currents are sufficient for operation at a luminosity of about one-fifth of the ultimate design goal. The magnet lattice, chromatic corrections, and the rf systems all behaved as expected. During beam-beam collision studies, no evidence was seen for deleterious syncho-betatron oscillations.

During the KEKB commissioning run, the BELLE detector remained in the “rolled out” position, where it accumulated large samples of cosmic-ray events both with and without the magnetic field excited. These events were used to align and calibrate the detector components.

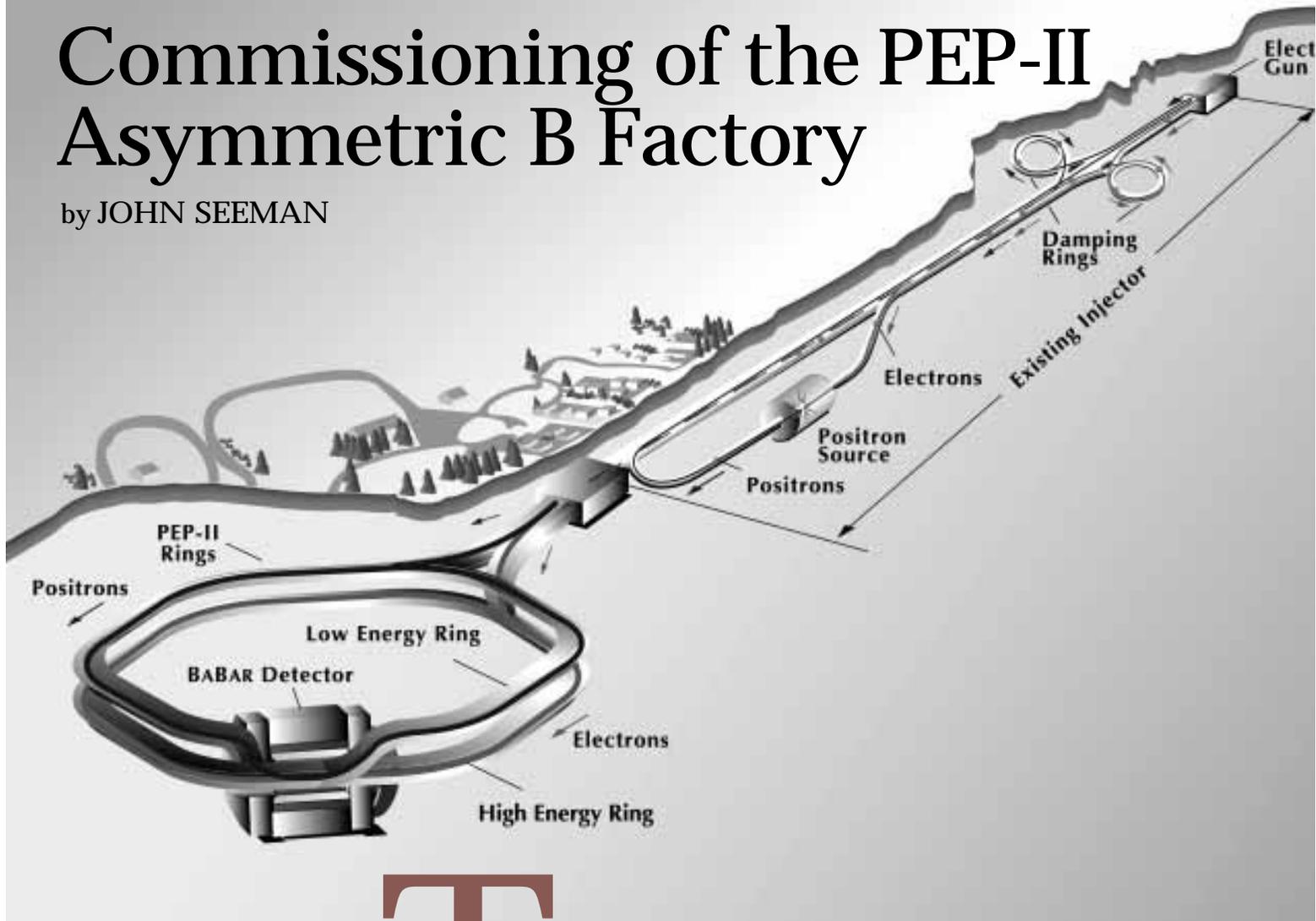
In May, the detector was moved into location at the KEKB interaction point and operations resumed. The first collision events were recorded by BELLE about a week later. This was an important proof of principle: all systems in BELLE and KEKB operated very nearly as expected. We

look forward to a rich program of measurements that will elucidate the nature of CP violations and confirm or reject the Kobayashi-Maskawa theory.



# Commissioning of the PEP-II Asymmetric B Factory

by JOHN SEEMAN



*The PEP-II collider, one of two asymmetric B factories in the world, is producing initial data aimed at understanding the matter-antimatter puzzle in the early Universe.*

**T**HIS SUMMER has been an exciting time for high energy physicists. In California and Japan, two new electron-positron colliders known as asymmetric *B* factories have begun producing events. Both are relatively low-energy devices, operating at center-of-mass energies just over 10 billion electron volts (10 GeV). They are the first of an imaginative new breed of particle colliders in which the electron and positron beams meet at *different* energies, producing many millions of short-lived subatomic particles known as *B* mesons. The associated particle detectors have begun recording data that physicists will employ to examine the mysterious phenomenon of CP violation—a small but fundamental difference between matter and antimatter expected to occur in these particles.

In late May the two *B* factories—PEP-II and its detector BABAR at SLAC, and KEKB and its detector BELLE at the Japanese KEK Laboratory in Tsukuba—independently began operations less than a week apart. They are now locked in a

head-to-head competition to determine the nature and extent of CP violation in the  $B$  meson system. Here I discuss the PEP-II collider and our experience in commissioning this state-of-the-art machine; Shin-ichi Kurokawa and Steven Olsen describe KEKB and BELLE in a companion article on page 23.

**T**HE DESIGN of asymmetric  $B$  factories began in 1987 when physicists recognized that neutral  $B$  mesons offer a powerful means to study CP violation. These particles have relatively long lifetimes and exhibit strong mixing between states. Pier Oddone of Lawrence Berkeley Laboratory had the revolutionary idea to collide electron and positron beams of different energies and create the  $\Upsilon(4S)$  resonance in motion.

The  $B\bar{B}$  system resulting from its disintegration allows separation of the two decay vertices, greatly enhancing experimenters' abilities to search for anticipated CP-violating effects. This idea soon made an asymmetric electron-positron collider the machine of choice for such research. At a center-of-mass energy of 10.58 GeV, with beam energies in the ratio of three to one, the  $B$  and  $\bar{B}$  decay at a mean separation of about 250 microns—easily resolvable with a good vertex detector. A surrounding particle detector can then determine the decay parameters of the two particles independently, giving experimenters a more direct look at the underlying CP-violation mechanism.

But even with this bold new approach, the total number of events needed is enormous (due to the small probabilities of the most interesting

decay modes), making necessary a very high-luminosity collider—over an order of magnitude higher than what was previously attainable. A luminosity of  $3 \times 10^{33}$  per square centimeter per second is needed to produce the desired 30 million pairs of  $B$  mesons per year.

Although an asymmetric collider makes it much easier for physicists to study CP violation, the need for two fairly different energies and high luminosity makes its design decidedly more difficult. Many issues constrain the design—from stored beams with amperes of circulating current to high-power microwave accelerating cavities to the intricate details of the interaction region.

Three Department of Energy laboratories built the PEP-II collider at a cost of \$177 million, provided by the U.S. government: SLAC, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory. Additional contributions came from the High Energy Physics Laboratory in Beijing, China, and the Budker Institute for Nuclear Physics in Novosibirsk, Russia. This work began in January 1994 with the dismantling of the existing PEP electron ring and ended in July 1998 with the completion of the new positron ring.

PEP-II has two separate rings located in an existing tunnel roughly 10 m below the rolling hills on the Stanford University campus. The positron beam energy is 3.1 GeV, while electrons circulate at 9.0 GeV. The design currents are 2.1 amperes for positrons and 0.75 amperes for electrons, distributed over 1658 bunches that are spaced 1.2 m apart, which results in the design luminosity of  $3 \times 10^{33} \text{ cm}^{-2}\text{sec}^{-1}$ . The



*The author struggles to indicate just how narrow the two beams are at the collision point of the PEP-II collider.*

**S**TARTING TO COMMISSION a particle collider is an exhilarating moment. The construction team, which has struggled to build the most perfect machine it can, is ending its job constantly pressed for time and money. Technical decisions must be made right up to the end; often several components are temporary. Every part of the collider has to work, or the machine won't perform.

The commissioning team (many of the same people) is anxious to begin. Questions abound. Is our design good enough? What mistakes have we made? What surprises has Nature in store for us? How is the competition doing? It's a great time—no known problems, but everything to make work. There's excitement about what will happen. Consisting of about three dozen hardy souls, the team is ready to work 24 hours a day, seven days a week.

The day finally arrives when the ring and injection line are completed. Vacuum systems, temperature interlocks, magnets and their power

# Tao of Commissioning



supplies, personnel protection systems, microwave cavities and their klystrons, feedback systems, controls, staff training and safety reviews—all are ready at last.

Let's push the button! But where's the beam? Now the real commissioning starts.

Work the beam down the injection line. Why has it stopped part way? Check the magnets, check that the vacuum valves are open, check that the beam instrumentation is working. Tweak all the knobs and look for a small signal. Now make the signal bigger! A diagnostic device is not working, so move on to the next. Keep pushing. Days go by.

Small victories start to occur: The beam makes it around one turn. We know the ring is complete!! Then two turns, then ten. Now adjust the injection energy, position, and angles. A few correctors have been wired backwards! We turn on and phase the microwave cavities. The beam goes around 100 turns, then 500, then 2000, and finally lasts a full second. Theorists do studies to explain why the beam acts as it does, not as it should. Try the corrections they suggest. Try steering the orbit, turning on the sextupole magnets, and activating the last

few vacuum pumps. Finally, the beam stays in the ring for 30 minutes! It stores!!

Keep pushing. Reschedule experiments to match the expertise of the people on shift. Broken hardware alters the schedule. A day is lost. Start the studies again. Look for an image of the beam in the synchrotron-light monitor. On the side, get the needed hardware upgrades going in the machine shops. Meanwhile, learn to accumulate multiple injection charges in a single bunch, then multiple bunches. Why does good injection keep getting lost? Push the beam lifetime with lattice adjustments and x-ray processing. (And take time off to see the family.)

Around this time new accelerator-physics effects start to appear. Take some data, followed by computer simulations, then more data, and further simulations. A publication takes form, and off it goes to a conference.

After several months, a down time finally allows us to replace temporary accelerator components. Then we restart the machine and push forward for several more months. At higher currents, we turn on and debug the feedback systems. In the end, we manage to store a respectable current for a respectable lifetime and with respectable parameters. The electron ring has officially been commissioned, except for half a dozen "minor" issues.

Now it's time to start the process all over again for the positron ring. And let's do both rings at the same time! Many common problems have been solved, but each ring has its own unique issues. Push the tests. Push the beams.

After a month of rapid progress, it's time to collide beams. We start with a single bunch in each ring, timing them with a position monitor near the collision point. Next move the beams up and down, back and forth, looking for the beams to interact. First the electron beam drastically reduces the positron beam lifetime, thus locating the collision point. After careful centering and size adjustments, the two

beam lifetimes are acceptable. The luminosity signal is sought and found. We have measured luminosity! Time to celebrate!

But the luminosity is still much too low. Try to increase the charge per bunch. Squeeze the beams at the collision point by reducing the beta function, beam emittances, energy dispersion and relative tilt of the two beams. Try to collide many bunches at once. Every few days, we achieve a new luminosity record. Sometimes, a problem stalls us for a week. With every new advance, the luminosity reaches a new plateau which requires us to take a fresh look at all the variables and knobs that didn't work before, but may now. Our understanding of the machine's subtleties grows daily. We soon find that raising all parameters to their present limit maximizes the luminosity. We must work on all frontiers at once.

At last, the luminosity is high enough that the experimenters want to collect data. The big detector rolls into position. Issues of sustained production now surface. Beam glitches cause backgrounds in the detector, which abort the beams. Higher currents mean higher backgrounds and trigger rates. The 100 Hz trigger rate must be reduced. The detector takes too long to ramp its voltages, and we lose a fill. The data-logging computers hang up. Interlocks cannot be cleared. These issues get solved one by one. Finally, the collider is producing actual physics events. The experimenters are happy with their data, while accelerator physicists take a brief pause to recharge. There is great sense of accomplishment.

But the experimenters find they need higher luminosity and want to do an energy scan. The push starts again. Our plan to adjust the energy will finally be put to the test. But accelerator physicists smile: "This is as good as it gets."

positron ring is mounted about a meter above the electron ring except at the interaction region, where they merge. There are six curving arcs each 250 m long and six straight sections each 120 m long for a total circumference of 2200 m. The BABAR detector sits in one straight section, while the others contain the microwave cavities, feedback systems, electron and positron injection lines from the SLAC linac, and other beam-monitoring and control systems.

At the interaction region where BABAR sits, the positron beam bends down to the same plane as the electron beam, then approaches it horizontally. Using two strong permanent magnets just before and

after the collision point, we steer the beams into a head-on collision (they have distinct orbits in the rest of the ring). We determine beam parameters using a luminosity monitor while scanning the beams across each other transversely to measure their heights and widths.

Injection of ampere-scale beams in a few minutes requires a good injector. Using the SLAC linac as modified for PEP-II, we inject beams swiftly, taking only three minutes to fill each ring. During normal operations we “top off” the beams by adding electrons and positrons after the luminosity has fallen by about 30 percent; such a top-off cycle lasts about 4 minutes. Any major beam

loss during operations must be handled with great care because of the vast energy (up to 50 kilojoules) stored in these intense beams. Abort systems can extract the entire charge from either ring during one turn if any of several abort signals—excessive detector backgrounds, a microwave cavity trip, a high vacuum-chamber temperature, an erratic beam orbit, or a large beam loss—occurs.

**T**HE PEP-II electron ring was finished in June 1997 and the commissioning process began that month. After several brief periods of commissioning spread over two years, it has reached its full design current of 750 mA distributed

## PEP-II In Review

### Milestones Achieved

January 1994	Start of PEP-II construction
June 1997	Electron ring installation completed
June 16, 1997	First electron beam stored
Jan 31, 1998	750 mA electron beam attained
July 10, 1998	Positron ring installation completed
July 16, 1998	First positron beam stored
July 23, 1998	First electron-positron collisions
February 8, 1999	Luminosity reached $5.2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$
February 22, 1999	1171 mA positron beam attained
March–April 1999	BABAR installed on beam line
May 15, 1999	Two beams stored with BABAR in place
May 26, 1999	First events recorded by BABAR
July 12, 1999	Luminosity reached $5.6 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$

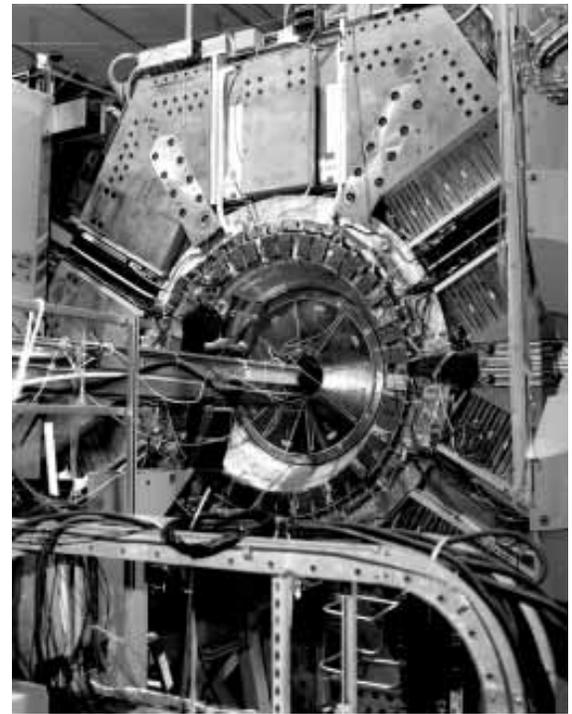
### Parameters

	Present	Design
Electron beam energy (GeV)	9.1	9.1
Positron beam energy (GeV)	3.0	3.0
Maximum electron current (mA)	750	750
Maximum positron current (mA)	1171	2140
Maximum luminosity ( $\text{cm}^{-2} \text{ sec}^{-1}$ )	$5.6 \times 10^{32}$	$3 \times 10^{33}$
Maximum number of bunches	1658	1658
Typical electron beam lifetime (h)	5	4
Typical positron beam lifetime (h)	2	4



*A view down the tunnel of the PEP-II B Factory. The positron ring sits just above the electron ring.*

The BABAR detector as it nears completion. Standing before its drift chamber is deputy spokesperson Gerard Bonneaud of École Polytechnique in Paris.



over 1658 bunches. Commissioning of the positron ring began in July 1998; by late February 1999 it had attained 1171 mA, which is 55 percent of the design current and a world record.

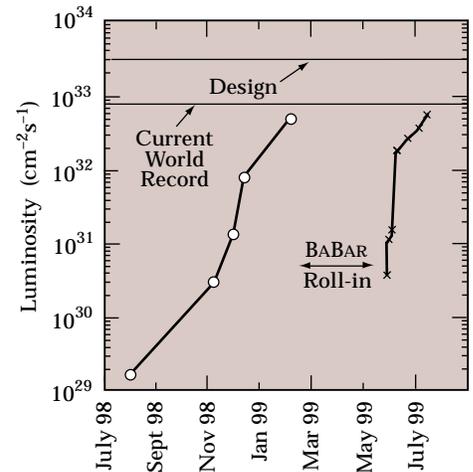
We brought the two beams into collision for the first time in late July 1998, shortly after storing the first positron beam, without the BABAR detector in place. At first, the principal evidence for these collisions was the observation that one beam was deflecting the other. Actual luminosity was measured in November; during the next three months the peak luminosity swelled by over three orders of magnitude, reaching  $5.2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$  on February 8, 1999 (see graph at right). This luminosity occurred with 786 bunches in each beam, amounting to currents of 680 mA in the positron ring and 354 mA in the electron ring.

During March and April, engineers and technicians rolled BABAR into position at the interaction region while experimenters in the big collaboration made final installations and adjustments. The accelerator physicists could hardly wait to begin commissioning the collider again, this time with the detector in place and its solenoidal superconducting magnet turned on. Because this magnetic field strongly perturbs PEP-II, it took us several days of beam tuning to get the beams back into collision. We finally resolved these problems and collided beams again on May 25. At 4 o'clock the next morning, BABAR physicists observed the first events in their detector.

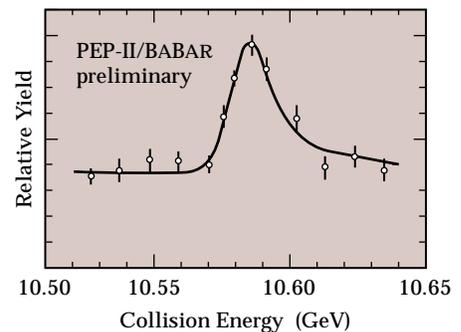
During the next six weeks, the luminosity of PEP-II again grew steadily, this time with BABAR in

place and its magnet turned on. Sufficient events were being recorded to permit us to scan the electron beam in energy; we located the  $Y(4S)$  resonance peak on June 16 at close to the expected value of 10.58 GeV (see bottom graph at right). And on July 12, just before a brief shutdown for repairs, the luminosity exceeded the previous record, reaching  $5.6 \times 10^{32}$ . This is almost 20 percent of the design value and 70 percent of the current world's record, set recently at Cornell's CESR collider.

As the Asymmetric  $B$  Factory begins operations and produces millions of  $B$  mesons over the coming year, our goals include reaching design luminosity by next summer and understanding the machine so thoroughly that we can try to exceed this level. Future upgrades will be required to increase the PEP-II luminosity to  $10^{34}$ . To triple the design luminosity will probably require increasing the positron current to 3 A and squeezing the beam size vertically by an additional 30 percent. Exactly how these parameters can be improved will become clearer over the next few years. But the accelerator physicists who designed, built and commissioned this pioneering machine over the last decade can already take great pride in their work. The decade of data collection just now beginning promises to open broad new vistas on CP violation and its impact on the early Universe.



Luminosity achieved in PEP-II during commissioning.



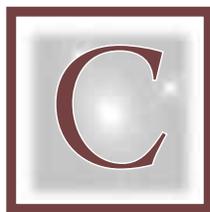
Preliminary data for the  $Y(4S)$  resonance. (Courtesy BABAR collaboration)

# THE UNIVERSE AT LARGE

## C-to-Z Physics

by VIRGINIA TRIMBLE

*In which we explore 24 issues to which some part of physics other than B may be relevant. Each item includes a puzzle or thought question. Some of these are meant to be taken seriously, if not as physics, then perhaps as sociology.*



**C** IS FOR CLUSTER. You may be thinking of a few atoms or molecules, clinging perilously together, and the question of how many does it take before they belong in *Physical Review B* rather than *A*. Somebody once told me the answer to this is 6–10. I, however, am thinking of clusters of stars. The physics is plain old Newtonian gravity, and the computer programs that imitate clusters are called *N*-body simulations, at least by their friends. You may or may not be surprised to hear that clusters of point masses reveal “emergent properties” that could not have been guessed from integrations of 2- or 3-body systems. These get names like gravithermal oscillations, dynamical friction, and violent relaxation. Curiously, these cluster properties also start to show up when you have 6–10 particles. What, if anything, does this coincidence mean?



**D** IS FOR DNA. We all have heard the story of how X-ray crystallography provided a critical hint leading to the double helix structure. That is, the physics came at the beginning. Now here they are sequencing the genome by chemical methods and occasionally deducing what a particular sequence does by the very biological method of seeing what happens to an organism when one of the sequences is changed or deleted. This feels backwards to closet reductionists, and we expect some day a second epoch of triumphant physics, when it will become possible to work forward again from some particular molecular bond to some particular malady or mercy. Any takers for a bet on when this might happen?



**E** IS FOR EARTHQUAKE FORECASTING. And a sad story it is. When first I taught introductory geophysics, in the warm afterglow of the rapid conquest by mantle convection, seafloor spreading, and plate tectonics, there were a whole flock of warning signs. These included uplift of land around faults, changes in the rate of microseisms and in their *p*-wave velocities, radon in wells, changes in the electrical conductivity and helium content of soils, and even animal behavior, lightning flashes, and what my grandmother used to call “earthquake weather”. And they all made sense, in terms of laboratory behavior of stressed granite and expectations for quakes occurring along different kinds of faults. The



general idea is that the stressed rock swells, lifting up the land and leaving empty pores that slow the  $p$ -waves and make the rock harder to break. Then ground water flows into the pores, concentrations of dissolved gases rise, the waves speed up again, the rock softens and begins to slip, and . . . “drop” as the teacher used to shout in earthquake drills in the Los Angeles public schools. The lightning and distressed dogs were effects of piezoelectricity (also a laboratory phenomenon). There was even a success story, in the form of a five-hour warning of a February 1975 quake in Haicheng (NE China) that permitted evacuation and significant saving of lives.

Probably much of this is still true, but it has proven so nearly useless in practical contexts that even the most optimistic government agency (a Japanese one) has pretty much stopped funding projects in earthquake prediction per se. Is there any plausible explanation of Gram's earthquake weather? The only information I have is that she was right about Tehachapi (1952). But then she also bought stock in Minute Maid frozen orange juice shortly before every American discovered that it was absolutely essential to drink the stuff for breakfast every morning, or all your teeth would fall out.



**IS FOR FRACTAL.** Some things are (coast lines, so they say) and some are not (spider webs). The astronomical community has, of late, expended considerable sums in page charges arguing whether the distribution of galaxies, clusters, and voids in the Universe is best described as a fractal with dimension  $D$  about 1.2. The alternative is homogeneity on sufficiently large scales, and the problem has been that surveys did not envelop quite enough space to tell the difference. The Sloan Digital Sky Survey (and other projects) will soon remedy this. A more serious problem will then stand out more starkly: how can the Universe have made the matter be as clumpy as it is while leaving the microwave background radiation as smooth as it is? This issue of the formation of large-scale structure is arguably the most important unsolved problem in modern astrophysics. Which

topology (meatballs, honeycombs, sponges, or something else) gravitational processes prefer to produce is one aspect of it. Meanwhile, if you can't help with the key question, did you know that mandelbrot is also edible? (This is the sort of culturally-biased item that should never appear on an IQ test.)



**IS FOR GLOBAL WARMING.** A paper in the March 15, 1999, issue of *Geophysical Research Letters* announced that 1998 had been the warmest year since 1001 or thereabouts. The relative contributions from sunlight, atmospheric effects, and heating by vigorous discussion were not estimated. There is, in any case, a cleaner example of global warming elsewhere in the solar system. The atmosphere of Neptune's moon Triton has increased its scale height since it was imaged by Voyager 2 in 1989. Since the value of local  $g$  hasn't dropped,  $T$  must have gone up. The best bet is increased insolation at the south polar cap, resulting from a tilted rotation axis being carried around as Neptune orbits the sun. If so, the warming is part of a cyclic pattern and will reverse itself in 50 years or so. Arguments for cyclic patterns on Earth have also been made, especially by people who study activity cycles on stars like the sun. Astronomers can afford to wait to be sure. Can terrestrial policy makers?

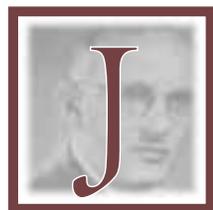


**IS FOR HUBBLE,** the only astronomer to make *Time Magazine's* March 1999 list of greatest scientists and thinkers of the 20th century. A complete list of his accomplishments would be quite long. But his two most fundamental contributions, the recognition that those fuzzy things in the sky are other galaxies like our own (his word was “nebulae”; Shapley preferred “galaxies”) and the discovery that they and we are moving apart from each other at speeds proportional to separations, both grew directly out of his careful studies of variable stars, especially Cepheid variables. He was, in other words, more a hedgehog than a fox. Progress in science surely demands both

kinds of approaches, but, at least in modern astronomy, there does not seem to be much room for hedgehogs, who run the risk of being described as “the world’s foremost expert on dynamics of triple galaxies” or “on rapidly oscillating Ap stars” (but only because nobody else is interested in them). On the anti-science side, one should probably add two more classes, the science writer “who misunderstands many things” and the crank, “who misunderstands one big thing” (often quantum mechanics or general relativity). And I hasten to include myself in the former class, at least for this issue of the *Beam Line*.

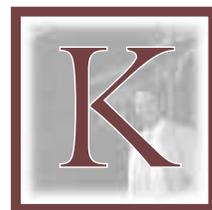


**I** **IS FOR ISING MODEL.** And, according to the obituary in the March 1999 issue of *Physics Today*, the eponymous Ernst remained unaware of the importance and wide applicability of his 1924 thesis work for about a quarter of a century. Can you think of any branch of physics where this could happen today? Kruskal coordinates in general relativity (a way of seeing around the Schwarzschild horizon) also went incompletely appreciated by the inventor for some time, but that too was many years ago.



**J** **IS FOR JANSKY.** He was, quite by chance, the world’s first radio astronomer. Seeking sources of short-wave interference to communications for Bell Laboratories, he found emission from the center of our Milky Way. “Shortwave” back in 1931 meant 14.6 meters. Jansky soon turned to other Bell-oriented problems, leaving the field (literally, for both the New Jersey and Illinois installations) to Grote Reber, who was the *only* radio astronomer between 1937 and 1946. Bell Labs and serendipity re-entered the picture, as you undoubtedly know, in 1965, with the discovery of the 3K cosmic background radiation by Arno Penzias and Robert Wilson, who were also concerned about communication problems. We have all heard (and perhaps tried to make) the case for curiosity-based, as well as focused or applied,

research. The lesson of Jansky, Penzias, and Wilson is that starting out to work on a practical problem does not preclude learning things that even your purest colleagues will find interesting.



**K** **IS FOR KUIPER BELT.** The Dutch-born Gerard P. Kuiper, long headquartered in Arizona, was for a decade or two nearly the only senior planetary astronomer active in the United States. His belt was a hypothetical one of potential short-period comets, located outside the orbit of Neptune, but closer to us than the Oort cloud of potential long-period comets. The first object with a Kuiper belt orbit turned up in 1993, and some dozens are now known. As the number increased, solar system astronomers began to ask whether Pluto might have begun life in the belt and have been perturbed to its present orbit thereafter. And, went on kibbitzers, was Pluto even entitled to be called a planet at all?

This quibble met head on with the more serious question of “what is a planet?” that has arisen from the discovery of Jupiter-size companions to many nearby stars (so far only one per star). At least three answers are possible, with definitions in terms of mass (between brown dwarfs and asteroids), composition (some segregation, like the earth’s iron core and the rocky centers of the Jovian planets), or formation process (in a disk around a central mass that is in the process of becoming a star). Naturally, the only definition we can apply outside our solar system is the mass criterion, least interesting of the three.

You have a wide choice of questions here: Is Pluto a planet? (Yes, because it has been one for 60-some years if for no other reason.) How do you get things from the Kuiper and Oort zones into the inner solar system? How do you get giant planets as close to their stars as most of the extra-solar-system discoveries? (three-body processes all). And, when you have taken care of those, should you drink your champagne on December 31, 1999, or 2000? (Both please, as Pooh said).



**L** IS FOR LIGHT YEAR. The serious issue here is how to think about, and perhaps more important, how to explain about, enormously large or small numbers and entities. The methods that appeal to us tend to involve logarithmic steps and nearly always fail. Watching “Powers of Ten” has no effect on students’ tendency to ask, “Are there any other galaxies in our solar system?” And I have completely given up on trying to disabuse a very dear and well-educated friend of the notion that visiting Egyptian antiquities carries one most of the way back to the Big Bang. Allan Sandage (the only person who can really claim to have been a student of Edwin Hubble) see “H”) says that he always thinks of an elliptical galaxy as being about the size of a football. My mental time ribbon is always about 18 in. long, but the markers can be anything from Gyr to hours, depending on the problem at hand, and moving between scales is a sort of zoom lens process. Incidentally, light years are a very bad unit to start with, since they inevitably suggest time rather than distance. The astronomers’ unit is the parsec.



**M** IS FOR MAGNETOSTRICTION. It makes perfectly good sense (rotate domains into alignment with an imposed field and you will surely open up cracks between them), and the phrase “110 to 130 or 140 micro-inches per inch” will live in my ears all my life. It probably applies to some ferrite, and of course micrometers per meter would say the same thing with political correctness. Now consider the following system(?):

Make 5–10 micron-sized particles of three different magnetostrictive materials with different curves of expansion versus field strength. Coat them with something brittle and encapsulate with a solution of some substance with which each of the three materials will react to form a different-colored product (preferably red, yellow, and blue). Coat a thin layer of the capsules on film or paper. Encode a color image as a scan (like a TV scan) of

electric currents that will produce different levels of magnetic field when the current passes through a micron-sized probe that can be moved across the surface of the film or paper. The three field levels must, of course, be those such that the three kinds of materials will break their brittle coatings in order from weak to strong, interact with the surrounding solute, and produce a colored image made of dots smaller than normal visual resolution (again like TV or a dot-matrix printer). Believe it or not, this actually worked after a fashion. My father patented it and tried to sell it for years. (This is the sort of background that really makes one appreciate tenure!). The engineering question is this: A new technology, when it first appears, is never as good as the one that has been in use for years for the same general purpose. Is there any reliable way to recognize the small subset of new methods that are eventually going to be better than existing ones? Probably not, or we would all have gotten rich on xerography, chips, or frozen orange juice.



**N** IS FOR NOCTILUCENT (“night shining”) CLOUDS. These are the highest clouds found on earth. Formed at about 80 km, they catch the last rays of the setting sun when it is as much as 9 degrees below the horizon for a ground-based observer. (Draw the picture and persuade yourself that  $\cos^{-1} 6400/6480$  is bigger than you thought it was.) Particles collected in situ consist of ice mantles on cores containing iron and nickel and probably derived from evaporated meteors. Proper cloud stuff is, of course, built around terrestrial dust seeds. The official puzzles are (a) how does the water vapor get up this high? and (b) why are the clouds confined to a narrow height range around 80–85 km while the trails of disintegrating meteors extend far above and below? My own private puzzle (which probably involves some branch of physics other than atmospheric and meteorology) is: Why did the only person I ever knew who worked seriously on noctilucent clouds have a secret clearance and refuse to talk about them?



**O** IS FOR ORTHORHOMBIC, one of the seven possible crystal systems. From most to least symmetric, these are cubic (with three symmetry directions, all cell edges equal, and all angles equal 90 degrees), rhombohedral, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic (with no symmetry directions, no equal edges, and no right angles). I once, for a high school science project, carved them all out of Styrofoam, made cell edges out of pipe cleaners, and grew seven examples from saturated solutions (most of which would not today be allowed in any high school). I wondered at the time why there weren't at least a few other possibilities, for example, one that might be called "biclinic" with a single 90 degree angle. The high school chemistry teacher did not understand the question, and I did not understand father's answer. Explanations (suitable for bears of very little brain) from knowledgeable readers would be appreciated. If you happen also to be puzzled, a substitute question is: How would you pronounce orthorhombic if it didn't have the second "h"?



**P** IS FOR PLUMBER, which Einstein is reputed to have said he would have chosen to be if he had it all to do over again. The expanded version of the story has the plumbers' local immediately sending him a union card. Normal plumbing, as you may have noticed, works best in the laminar flow mode, standard in pipes up to a Reynolds number around 2000 and sustainable with care up to perhaps 100,000. Incidentally, conduction is no more satisfactory than turbulence in the household context: the bathroom floor gets nice and warm, but nothing happens when you turn the tap.

Turbulence and convection are important in a whole range of astronomical contexts, from star formation to the poorly-understood neutrino-driven convection that is supposed to eject the stellar envelope in the kind of

supernova that happens when an iron core collapses to a neutron star (see S). Neither the efficiency of energy transport nor the spectrum of eddy scales can be calculated except by simplifying the problems beyond recognition. Thus you can choose from an enormous number of residual questions, with or without these two: (a) given that all critical dimensionless numbers are supposed to be of order unity, isn't there some way of redefining the Reynolds number to make  $Re_{crit} \approx 1$ ? (b) can you name even one theoretical physicist who never in his life tried to calculate  $1/137$  from something else?



**Q** IS FOR QED, which might mean Quod Erat Demonstrandum or Quantum Electrodynamics. The former QED, at least to those of us with an old-fashioned "falsifiability" criterion for what constitutes a meaningful scientific hypothesis, has no place in physics. The latter clearly does, at least until another quintet of geniuses comes up with something better (the inventors having said they never meant it to last forever). It also gives me an opportunity to tell a previously unrecorded Feynman story. At a fall 1965 Caltech party (celebrating you know what), a few of us gave him a black plastic box, then readily available at novelty stores. It had a metallic toggle switch sticking out of the top of its 4x4x6 inch volume, some eccentric gears on the bottom, and (one deduced) batteries inside. You placed it on a table and displaced the switch. The box rocked and shook and groaned for a minute or two. Then the top opened, a small green hand came out, returned the switch to the original position, and disappeared back inside, leaving the box quiescent. The recipient contemplated this for some time and then declared (you must imagine the voice and accent for yourself), "Yes. It's very interesting. And I can see that it's very useful. But I'm not quite sure what it's useful for. Sort of like quantum electrodynamics." Was it by design or chance that QED stands for these two very different concepts?



**R** IS FOR RHEOLOGY, the Society of which is the smallest of those associated with the American Institute of Physics (am not sure why; the subject sounds important). The name is also the youngest, apparently first appearing in print in 1929 on the title page of the *Journal of Rheology*. There was enough disagreement about the name that a professor of Latin was coopted the next year to declare it the most suitable choice. Scientists are constantly having to invent names and acronyms. The April 1 issue of the *New England Journal of Medicine*, on my desk as I write this, has an editorial entitled “Annexinopathies—A New Class of Diseases.” Naively, I was expecting a yet more complex variant on Munchausen’s syndrome by proxy.\* In fact, annexins are a class of 20 or more proteins with repetitive domains, with which many physiologically unpleasant things can go wrong. The topic for consideration here is what we can do to keep down the incidence of new words and acronyms, or at least to make them as transparent as possible. I have a specific suggestion for acronyms: Don’t. It is almost never necessary. Of course you don’t want to repeat “Submillimeter Common-User Bolometric Array” twice in every paragraph. But with a little thought, you can use the complete name once every page or two, and then cycle among “the array,” “the bolometer,” “our submillimeter device,” and so forth, at least until the other users are not just common but many. For new words, you will receive conflicting advice. Purists will forbid the mixing of Latin, Greek, and Anglo-Saxon. My own prejudice is that ready interpretation and self-evident pronunciation are much more important. This brings us back to rheology, because there are also devices called rheometers, and which syllable gets the accent

\*Munchausen’s syndrome (named for the mythical baron) is pretending to be sick or making yourself sick to get attention. The “by proxy” version is, most often, making your children sick for similarly horrifying reasons. NEJM tries to get its issues into the hands of subscribers a few days before the cover date when associated articles will appear in the popular press.

presents the same set of problems as are encountered in kilometer versus thermometer (etc.). Presumably a “kilometer” as most often pronounced would be the same as an “odometer,” and no, I don’t know anyone who puts the stress on the third syllable there, either.



**S** IS FOR SUPERNOVAE. Type I events occur among population II stars and Type II events occur among population I stars. This sounds like a major failure of the principle advocated under R, but is really just bad luck. Worse luck, we are pretty sure we understand the physics of Type I events (explosive fusion of about a solar mass of carbon and oxygen to iron-peak elements) but have never seen even one example of the supposed progenitor systems (massive pairs of white dwarfs in short-period orbits); while for Type II events we see lots of progenitors (massive stars) but have not been able to model the physics that ejects the stellar envelope and produces the luminosity, spectrum, and expanding gas cloud that we see.

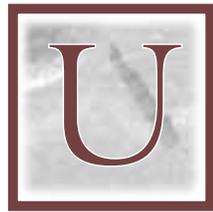


**T** IS FOR TENOR. I once read, stated as gospel, that the present shortage of outstanding tenors was a direct result of the increasing height of European and American men and their correspondingly longer vocal cords. This is the simplest possible sort of physics (see also X), and if it is right, the situation is likely to get worse. There are, on average, physiological differences between tenors and basses and between sopranos and altos that you can study for yourself.

We start by assuming that you are already aware of the differences between sopranos plus altos and tenors plus basses. Now examine the next large choir you see, and try to figure out which section is which. Position of the hair line among the men and shoulder breadth among the women are good places to start. There are probably



average height differences as well (though a small sample can be driven off-scale by a single Placido Domingo or Joan Sutherland). The lab assignment for this paragraph is to find as many differences as you can and attempt to formulate hypotheses to account for their correlation with vocal range. That's the easy part. Now try to test said hypotheses without getting into SERIOUS trouble. The serious aspect of this (not often of concern to physicists except obviously members of AAPM) is what constitutes "informed consent" for human experimental subjects and should it be regarded as a sufficient condition?



**U** IS FOR UFOs. Astronomers probably see more things in the sky we can't identify than the general run of humanity, if only because we spend more time looking at it. That we (and you) are pretty sure that the vast majority of them are not space ships sent by other civilizations, but are not always able to explain very clearly why to others, is another aspect of the general problem (see "L") of making clear the difference between a million and a billion. Teddy Bullard once said that the most important thing scientists had learned from World War II was the difference between a thousand dollars and a million dollars and what you could do with each (He meant that most scientists had never had access to either before.). Perhaps that is the right approach? Five million dollars will buy you enough gasoline to drive your car the distance to Mars at its closest to us. Five billion dollars worth of gas would take your car much less than 1 percent of the distance to the very nearest star.



**V** IS FOR VISION. The physics sounds simple—a couple of fairly imperfect lenses placed to provide a bit of parallax and detectors for wide-band, three-color photometry. But, when it comes to a functioning system, the physics-specified components are apparently neither sufficient nor necessary. On the sufficient side, readers of

Oliver Sacks will recall that attempts to commission the system late in life all more or less fail. (Does this mean there is a critical period in childhood for learning to see as there is for learning language?). On the necessary side, I know first hand how easily one dispenses with the parallax. You may well have seen, or read about, Edwin Land's experiments in reproducing what seemed to be a full range of colors with only two wavelength bands. And, indeed, a good many dichromats discover their disability(?) only by chance and well beyond childhood.

The late Fritz Zwicky of Caltech once got so annoyed with a colleague about assignment of a color to some star that he ordered a set of the Ishihara plates and insisted that everybody connected with Mt. Wilson and Palomar Observatories take the test. Sure enough, a couple of staff members were at least partly color blind and had never realized it. Based on that sample and some later ones, I have often wondered whether astronomers (only the men, of course!) are more likely to be color-challenged than the general run of humanity. And, if so, is there some physics-based biological reason for it?



**W** IS FOR W URSAE MAJORIS, WOLF-RAYET, AND W VIRGINIS STARS. Don't be surprised to find three interesting classes under one letter. We could easily have gone from A (AB Aurigae, an example of massive, pre-main-sequence objects with emission lines) to Z (ZZ Ceti stars, pulsating white dwarfs) with stellar prototypes alone. Each has associated puzzles, or we would not bother to name the class. The W UMA's are binaries whose component atmospheres touch, yet manage to maintain different temperatures. How they do it, and even how they get into this pickle (protostars are big; W UMA's cannot have formed with their present separations) "requires further work." The Wolf-Rayet stars are massive and considerably evolved. What is more, they have managed to discard most of their remaining hydrogen and show surfaces made of helium and carbon. Not all massive stars are allowed to do this or we



would see no Type II supernovae, with strong hydrogen lines in their spectra. How does a given star decide what to do?

The W Vir stars are the low-mass old analogs of young, massive pulsating variables called Cepheids. Confusion between the two at one time led astronomers to appraise the Universe as a factor of at least two more compact in space and time than it is. Models still do not well describe observed relationships between stellar masses and pulsation periods, especially where two or more modes are excited in the same star.



**IS FOR XYLOPHONE.** The standard question in this territory is, “Can you hear the shape of a drum?” meaning, roughly, how close is the connection between the geometry of a membrane (or a string, plate, or air column) and

the power spectrum of frequencies it emits when excited. The answers “yes” and “no,” that is, close and not so close, have both appeared in recent years in articles at the *Scientific American* or *Physics Today* level. The real answer, though, has to be “That’s the wrong question.” Otherwise, my “A” would sound more like Menuhin’s than it does. One of the lessons of music synthesizers is that what we hear is not just a power spectrum. Electronic keyboards can call out some remarkably unkeyboardlike sounds, but they are not really very xylophone-like or violin-like either, let alone Menuhin-like. Today, traditional and nontraditional instruments are being built to produce predictable sounds, so there must be progress. Alternate questions for non-acousticians include: Can you pronounce Chladni’s name so he would recognize it? or, Does one dare admit to liking Fritz Kreisler better?



**IS FOR YTTERBY,** the smallest town to have four elements named for it (in fact the only town). They are erbium, terbium, yttrium, and ytterbium. Three of the four are rare earths, or lanthanides, and the fourth falls

immediately above lanthanum. You will not need an interpreter for that sentence. But when did you first hear of the periodic table, when come to appreciate its enormous power, and (recently much discussed in California) when should our children be admitted to the same privilege? I have heard this issue debated by councils, boards, and committees of several learned societies. A large majority says, “Oh, I must have been 9 or 10, and third or fourth grade would be about right for my kids.” But other people’s kids should wait until high school at the earliest, and maybe even then only if they are college bound. Perhaps, but did we understand the periodic table because we were destined to become scientists, or did we become scientists partly because somebody took the trouble to explain the periodic table to us? NOW go to your local school board meeting.



**IS FOR ZENITH.** No deep mysteries here. It is the point of sky directly over your head and derived (“obscurely” according to the *New Complete Oxford English Dictionary*) from the Arabic *samt al ras* (“path over the head”). The astronomical point to ponder is the enormous skill of 19th century astrometrists, who managed to identify aberration of starlight, to measure parallaxes of an arc-second or less, and to recognize that the perihelion of Mercury’s orbit was advancing faster than expected, all without photographic emulsions to record the images they saw.

You were perhaps expecting “syzygy,” but, as you see, it starts with an “s,” means conjunction, roughly, and, according to a recent introductory text, is more used by crossword puzzle designers than by astronomers. Incidentally, if you don’t already own one, the new edition (in one volume, printed nine pages on one) of the Compact OED is a good investment, even at the open market price of \$295. I suspect, though, that it is not much fun to read if you actually need the magnifier they provide.



---

# CONTRIBUTORS

---



Lev Okun

**ROBERT CAHN** is a past member of the *Beam Line* Editorial Advisory Board. From 1991 to 1996 he directed the Physics Division at Lawrence Berkeley National Laboratory, where he did his thesis work two and a half decades earlier. A theorist by training, he is the author of *Semi-Simple Lie Algebras and their Representations* and co-author with Gerson Goldhaber of *The Experimental Foundations of Particle Physics*. He is now a Senior Scientist at LBNL and a member of the BABAR Collaboration.



A Professor of Physics at Cornell University, **PERSIS DRELL** has studied *B* mesons at the Cornell Electron Storage Ring with the CLEO detector since 1988. As a postdoctoral student at Lawrence Berkeley Laboratory she switched from atomic to particle physics and worked on the Mark II detector which was getting ready to take data at the Stanford Linear Collider at SLAC. In 1998 she studied astrophysics on a sabbatical.

Drell received her Ph.D. from the University of California, Berkeley. A Fellow of the American Physical Society, she has received many awards, the most recent being a Guggenheim Foundation Fellowship. She is presently a member of the SLAC Scientific Policy Committee.



**ROY SCHWITTERS** is the S. W. Richardson Professor of Physics at the University of Texas at Austin where he teaches and pursues research in particle physics. Before moving to Austin, he directed the Superconducting Super Collider Laboratory from its founding in 1989 until the project was canceled by Congress in 1993.

He received his B.S. and Ph.D. in physics from MIT after which he joined the SLAC staff in 1971 and participated in the historic experiments at SPEAR as a member of the SLAC-LBL collaboration.

In 1979 he joined the physics faculty of Harvard University until becoming SSC Laboratory Director. While at Harvard, he held a joint appointment at Fermilab where he was project manager and co-spokesman for the construction and initial physics of the Collider Detector at Fermilab (CDF).



As a postdoctoral fellow at the Lawrence Berkeley National Laboratory, **MANFRED PAULINI** is part of the CDF experiment at Fermilab. He started working at CDF in 1993 after receiving his Ph.D. from the University of Erlangen in Germany where he worked with the ARGUS experiment at DESY. From 1994–1997 he was in charge of the studies to determine whether a future measurement of CP violation would be feasible at CDF. He is currently co-convenor of CDF's *B* physics group responsible for driving the current and future *B* physics program there. In addition, he is working on the new silicon vertex detector for the CDF upgrade.



**STEPHEN OLSEN** received his undergraduate education at the City College of New York and his Ph.D. at the University of Wisconsin. He spent two decades at the University of Rochester, where he got his first taste of *B* meson physics as a member of the original CLEO experiment. A sabbatical year at KEK in Japan in 1982–83 led to full-time participation in the AMY experiment at TRISTAN, which was the world's highest energy electron-positron collider at that time. When the TRISTAN program started winding down, he joined with a number of his TRISTAN colleagues in proposing a reconfiguration of the facility into a lower energy asymmetric collider suitable for studying CP violations in *B* meson decays. When it became apparent that this project would be approved, Olsen moved to the University of Hawaii, six times zones closer to Japan. There, in his free time, he enjoys various ocean-related activities such as sailing and surfing.



**SHIN-ICHI KUROKAWA** received his B.S. and Ph.D. degrees from the University of Tokyo. In 1973 he began his career in the KEK Physics Department constructing secondary low-energy kaon and antiproton beam lines and experiments using these beams. He moved to the Accelerator Department in 1981 when KEK started construction of TRISTAN, serving as its coordinator in 1987–1989. He has been chairperson of a division of the Accelerator Department and since 1994 leader of the KEK B-Factory project.

Kurokawa also heads the KEK Accelerator School, which is jointly organizing the U.S.-CERN-Japan-Russia Accelerator School with U.S., European, and Russian colleagues. He also serves on the editorial board of the newly established journal, *Physical Review Special Topics, Accelerators and Beams*.

---

## CONTRIBUTORS

---



**JOHN SEEMAN** received his B.S. in physics from Iowa State University in 1973 and a Ph.D. in Accelerator Physics from Cornell University in 1979. For the next three years he was a research associate on the CESR collider studying injection and the beam-beam effect.

He moved to SLAC in 1982 and for the next ten years helped upgrade and operate (as the linac group leader) the linac for the SLC Linear Collider. In 1993 he joined the PEP-II B Factory, becoming the deputy for accelerator physics. Following the completion of PEP-II he became the head of the Accelerator Department at SLAC which operates PEP-II and the linear accelerator.

John enjoys hiking and in August organized a backpacking trek on Kauai's Kalalau Trail for a local boy scout troop.



**VIRGINIA TRIMBLE**, together with her mother Virginia Farmer Trimble and her grandmother Emily Paulson Farmer in 1957, about the time "Gram" sold her frozen orange juice stock at a Considerable Profit. She continued, however, to live alone for another 25 years in that same house, which she and Grandfather Farmer had built not long after their 1907 marriage. Cousin Joyce now has the oak table, built by Grandfather Farmer, at which the trio was sitting, and Virginia has many of the dishes faintly visible in the breakfront, some of which came from The Old Country. All four of them shared big Danish bones, nurtured on the traditional diet of milk, cheese, and butter. They almost never break, even in "late youth" or old age, and have seen the younger Virginia quickly and uneventfully through two rounds of titanium joint implantations this past spring.

---

# *DATES TO REMEMBER*

---

- Oct 13–15 11th US National Synchrotron Radiation Instrumentation Conference, Stanford, California  
(Conference Administrator, SSRL, MS 99, Box 4349, Stanford, CA 94309-0210 or  
<http://ssrl.slac.stanford.edu/SRI99/>)
- Oct 16 Symmetry Found and Lost: A Conference for Steve Adler's 60th Birthday, Princeton, New Jersey  
(Michelle Sage, Institute for Advanced Study, Olden Lane, Princeton, NJ 08540 or  
[michelle@sns.ias.edu](mailto:michelle@sns.ias.edu) or <http://www.sns.ias.edu/>)
- Oct 17–19 12th International Symposium on Superconductivity (ISS 99), Morioka, Japan (ISS 99 Secretariat,  
Japan Convention Services, Inc., Nippon Press Center Bldg., 2-2-1 Uchisaiwai-cho, Chiyoda-ku,  
Tokyo 100-0011, Japan)
- Oct 21–26 8th International Workshop on Linear Colliders (LC 99), Frascati, Italy (Manuela Giabbai, LC 99  
Secretariat, [lc99@lnf.infn.it](mailto:lc99@lnf.infn.it) or <http://wwwsis.lnf.infn.it/lc99/>)
- Oct 26–30 IEEE Nuclear Science Symposium and Medical Imaging Conference, Seattle, Washington  
(O. Nalcioglu, Research Imaging Center, University of California, Irvine, CA 92697-5020,  
or [nalci@uci.edu](mailto:nalci@uci.edu))
- Oct 26–30 2nd International SLS Workshop on Synchrotron Radiation, Brunnen, Switzerland (SLS Project,  
Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland)
- Nov. 1-5 9th Workshop on RF Superconductivity — Accelerator Technology for the 21st Century,  
Santa Fe, New Mexico (Los Alamos Neutron Science Center, c/o Lorraine Stanford, MS H845,  
Los Alamos National Laboratory, Los Alamos, NM 87545 or [rfsc99@lanl.gov](mailto:rfsc99@lanl.gov) or  
<http://mesa53.lanl.gov/rfsc99/>)
- Nov 3–5 INTERLAB 99, Menlo Park, California (Dennis Wisinski, SLAC, Box 4349, Stanford, CA 94309 or  
[interlab99-program@slac.stanford.edu](mailto:interlab99-program@slac.stanford.edu) or <http://www-project.slac.stanford.edu/interlab99/>)
- Nov 15–19 7th International Conference on Instrumentation for Colliding Beam Physics (INSTR99),  
Hamamatsu, Japan ([takayuki.sumiyoshi@kek.jp](mailto:takayuki.sumiyoshi@kek.jp) or <http://ccwww.kek.jp/INSTR99/index.html>)
- Dec 3–7 3rd International Conference on B Physics and CP Violation (BCONF99), Taipei, Taiwan  
(BCONF99, Department of Physics, National Taiwan University, Taipei, Taiwan or  
[bcp3@hepl.phys.ntu.edu.tw](mailto:bcp3@hepl.phys.ntu.edu.tw) or <http://www.phys.ntu.edu/english/bcp3/>)
- Dec 10-16 7th International Symposium on Particles, Strings, and Cosmology (PASCOS 99), Granlibakken,  
Tahoe, City, California ([pascos99@pc90.ucdavis.edu](mailto:pascos99@pc90.ucdavis.edu) or <http://pc90.ucdavis.edu/pascos99.html>)
- Dec 15–17 5th International Conference on Physics Potential and Development of Muon Colliders  
(MUMU 99), San Francisco, California (Department of Physics and Astronomy, Box 951547,  
UCLA, Los Angeles, CA 90095-1547 or [mumu99@physics.ucla.edu](mailto:mumu99@physics.ucla.edu))