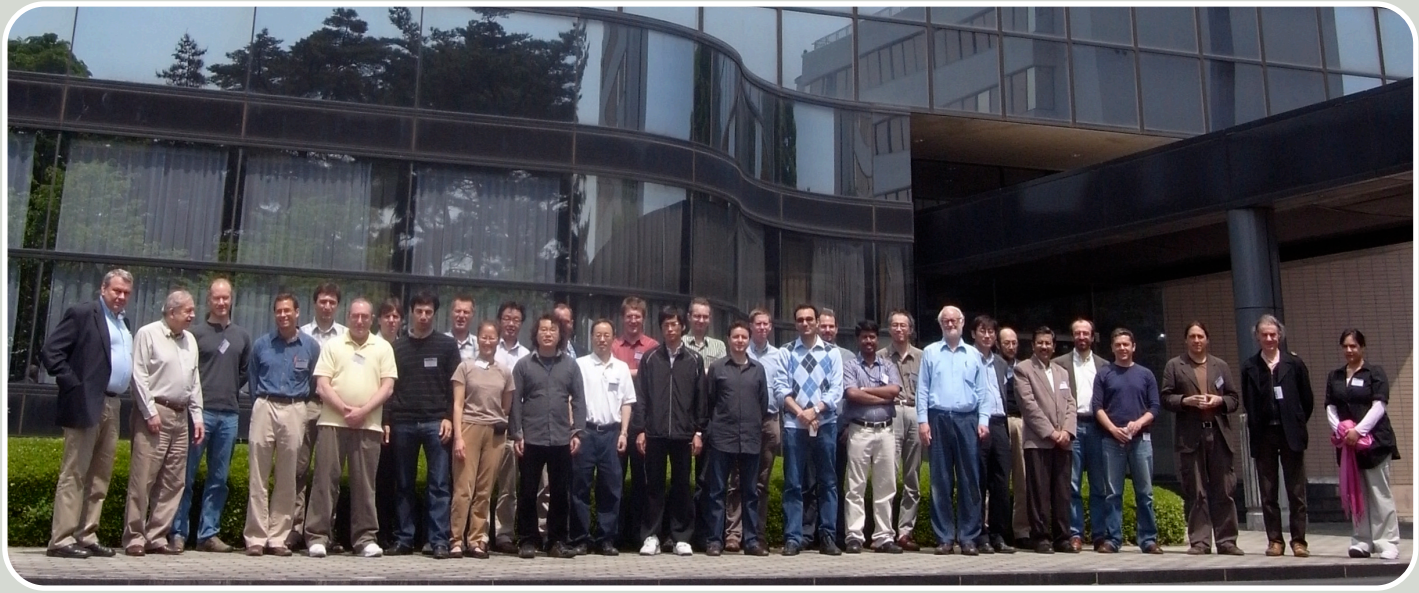
June 2, 2010

Feature Story



The participants of the second Physics of B Factories workshop held at KEK on May 17-18, 2010.

The legacy of Belle and BaBar

[B Factory, Belle, BaBar, Physics Book, Unitarity Triangle]

On May 18, 2010, the world's two major B Factory collaborations, Belle and BaBar, met in a seminar room to toss a coin. The two have used different sets of notation for more than a decade, but must now pick a consistent notation for their upcoming joint physics book. The book will discuss the detectors, the analysis tools used, the physics results, and the interpretation of these results. Read on for a short history of the two projects, and to find out the results of the coin toss.

Most physicists would agree that

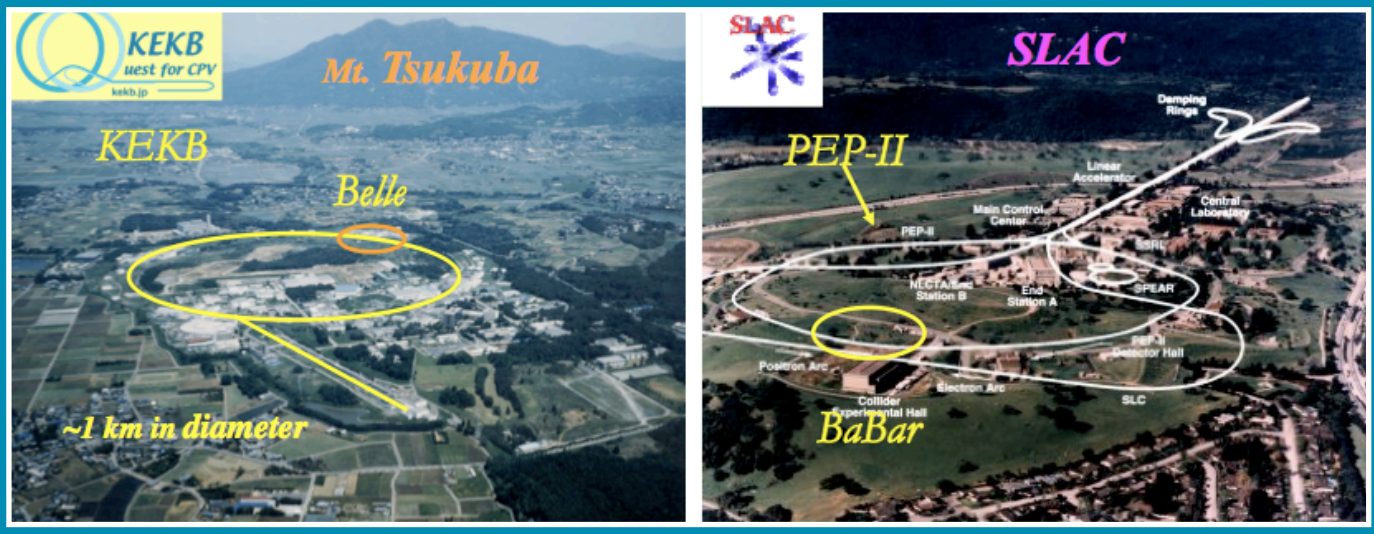
the specific set of symbols used to describe physics is not important. Rather, the physics itself is what's important. Unfortunately, that doesn't mean physicists can easily agree on what notation to use. Change can be hard, especially when they've used a particular notation for over a decade. This time, physicists' conventional method of decision making, called 'discussion,' provided agreement on a way to find a solution through a rather unscientific method: a coin toss.

The discussion finally came to a head at KEK on May 17-18, 2010. Here, the world's two giant B-Factory collaborations, Belle at KEK and BaBar at SLAC, met for the second time to discuss the editing work of their B-Factory physics book, straightforwardly titled The Physics of the B-Factories. The ceremonial coin toss was scheduled for the end of the workshop.

The parameters that sparked the discussion are the angles of the unitarity triangle, an abstract triangle representing the interactions of quarks, the elementary constituents of matter. The shared objective of the two B-Factory experiments was to determine the shape of the triangle. For as long as they have existed, the two collaborations have had different notation for the physical parameters of this triangle. The most prominent example is that Belle has called the angles phi-1, phi-2, and phi-3, while BaBar has called them beta, alpha, and gamma, respectively.

Now, the two B-Factory collaborations are putting heads together, to write their first and last joint physics book. "We are in the stage where both collaborations have invested twenty years in doing [B-Factory] physics. The

One of the general editors of the Belle-BaBar Physics Book, Dr. Bruce Yabsley of the University of Sidney tosses a coin to decide between the notations to be used for fundamental B-Factory parameters in the book.



The world's two giant B-Factory collaborations, Belle at KEK and BaBar at SLAC, have successfully completed their missions to find and quantify CP violation.

job now is to bring the whole community from around the world together, to write one definitive book on the work we've done," says Dr. Adrian Bevan of Queen Mary, University of London, one of the five general editors of the book. During the first book workshop, held in last October at SLAC, the issue of notation became soon apparent.

Despite the general civility of discussion on notation, many attendees felt strong loyalty to their notation. After all, they have lived and worked with their notation nearly every day for the past decade, with determining the angles of the unitary triangle as their main objective. Belle physicists argued that it is a little confusing to call the angles alpha, beta, and gamma, because there are already particles with those names. On the other hand, there are arguably more physicists who use the alpha, beta, gamma notation than those who use the phi notation.

"The argument is entirely irrelevant, because it makes no sense to have serious attachment to these symbols," says Prof. Francois Le Diberder, the spokesperson for the BaBar collaboration. On the other hand, he says that, for some people, changing notation causes a pain like having your "heart being pinched." It may be reassuring to both sides to know that, according to the Belle co-spokesperson Prof. Yoshihide Sakai of KEK, "the common notation will be just for the physics book." Whatever the coin would decide, the chance that the chosen notation is going to affect the notations in the future scientific publications is "none."

In this cooperative mood, another one of the five general editors, Dr. Bruce Yabsley of the University of Sydney, tossed the coin. Two other co-general editors, Prof. Bostjan Golob of the University of Ljubljana and Dr. Bevan were tasked with reading the coin, and their notational future. However, before revealing the results of the toss, it seems appropriate to review the history of both projects, and the important contributions they have made to the Standard Model of particle physics.

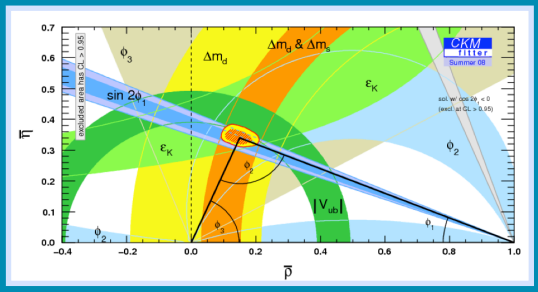
So what's the unitarity triangle?

"The main goal of the two B-factories was to measure the violation of CP symmetry in a B meson system," says Prof. Golob. "CP violation is one of the necessary conditions for the universe to have evolved to the current state, where matter almost completely dominates over anti-matter." To measure CP violation, physicists measure angles and sides of an abstract construct called the unitarity triangle. The story of the unitarity triangle begins with the search for symmetry between ordinary particles and their antiparticle counterparts.

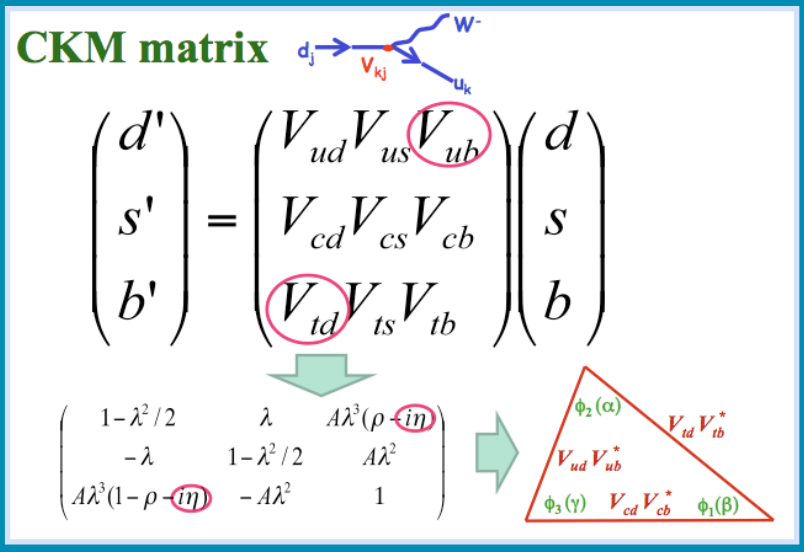
In 1957, Lev Landau proposed the theory of charge-parity symmetry (CP symmetry) as the true symmetry between particles and antiparticles. CP symmetry says that the laws of physics should not change when the charge is flipped (charge conjugation) and the mirror image of the system is taken (parity). This symmetry was incorporated into the Standard Model, though only for a short while.

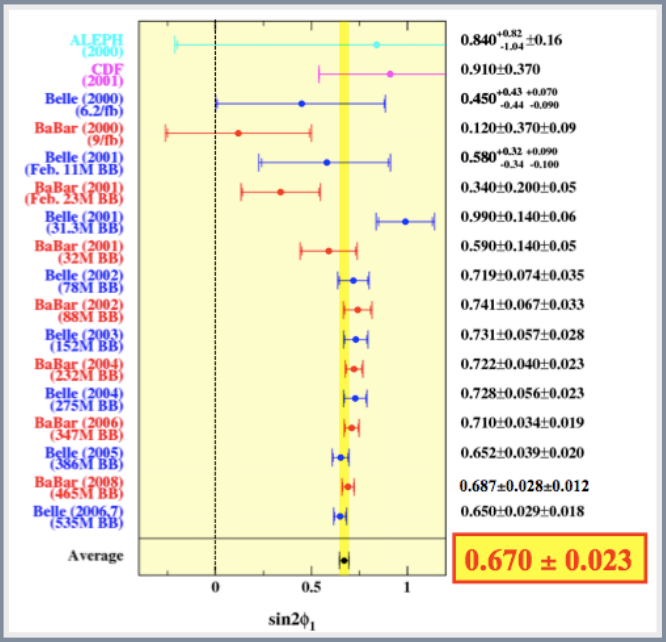
The theory was disproved in 1964, when James Cronin and Val Fitch with collaborators found indirect CP violation in weak interactions. Their

→The Cabibbo-Kobayashi-Maskawa (CKM) matrix is a three-by-three matrix of complex numbers (imaginary components in red circles). The imaginary phase gives the height to the unitarity triangle, with three angles phi-1, phi-2, and phi-3 in Belle notation, or beta, alpha, and gamma in BaBar notation.



↑The primary objective of the B-Factories was to find the angles of the unitarity triangle.





The degree of CP violation converged to 0.67 as the number of accumulated pairs of B meson and anti-B meson increased to 535 million for Belle (blue) and 470 million for BaBar (red) eventually.

discovery shook the world of particle physics to its very foundations. The Standard Model had been the solid foundation of particle physics for decades, an elegant and battle-tested explanation of everything that occurred in the subatomic world. After all this time, had they found a flaw in the Standard Model?

In 1973, Prof. Emeritus Makoto Kobayashi of KEK and University Prof. Emeritus Toshihide Maskawa of Nagoya University (then both at Kyoto University) showed that CP violation could be explained within the framework of the Standard Model. However, in order to do this, they had to make radical change. They added two new quarks, a third 'generation,' to the Standard Model. In total, there were now six types of quarks. The different types are known as 'flavors.' The first generation of quarks consisted of the up and down quarks, the second generation consisted of the charm and strange quarks, and the new third generation consisted of the new top and bottom quarks.

The additional generation of quarks affected the way that quarks were expected to interact with each other. In general, this interaction is described by a mixing matrix, a matrix of probabilities where each probability gives the likelihood of one kind of flavor change. In the four-quark Standard Model, the mixing matrix was a two-by-two matrix of real numbers, called the Cabibbo matrix after Italian physicist Nicola Cabibbo. In the new Kobayashi-Maskawa formulation, the mixing matrix, now called the CKM matrix, is a three-by-three matrix of complex numbers. However, the nine elements are not independent. All nine can be calculated from three real angles and one imaginary phase. These four fundamental parameters can be drawn as a triangle, the unitarity triangle, whose area corresponds to the degree of CP violation.

Proposing new particles to explain new phenomena is one thing, but predicting hidden particles is quite another. The bottom quark and top quark were both discovered at Fermilab in the US, in 1977 and 1995 respectively, proving that the Kobayashi-Maskawa prediction was correct.

The era of two B-Factories

Physicists in 90's were tasked with the job of conducting a precise and accurate measurement of the angles of the unitarity triangle. In 1980, three theorists, Bigi, Carter, and Sanda, predicted a large CP violation in certain decay modes of neutral B mesons. These papers, by the way, are the first papers where phi angle notation appears. Two B-Factories, Belle at KEK and BaBar at SLAC, were built in 1999 and operated for the subsequent decade in order to produce as many pairs of B mesons and anti-B mesons as possible, and collect as much data as possible on the decay rates of these mesons.

The central goal of both experiments was to measure the angle known as phi-1, or beta. The specific mode of B meson decay used for this purpose was called J/psi-Ks mode. In this mode, a neutral B meson or a neutral anti-B meson decays into a J/psi meson and a short-lived neutral kaon. In early 2001, the first results were published by the two collaborations, just a few days apart. Both collaborations reported that the CP violation was real with more than 95 percent certainty. Over the following summer, both collaborations collected additional B-anti B meson pairs (Belle increased their sample size from 10 million to 30 million), and both collaborations were able to confirm the CP violation with a certainty of 99.99999 percent.

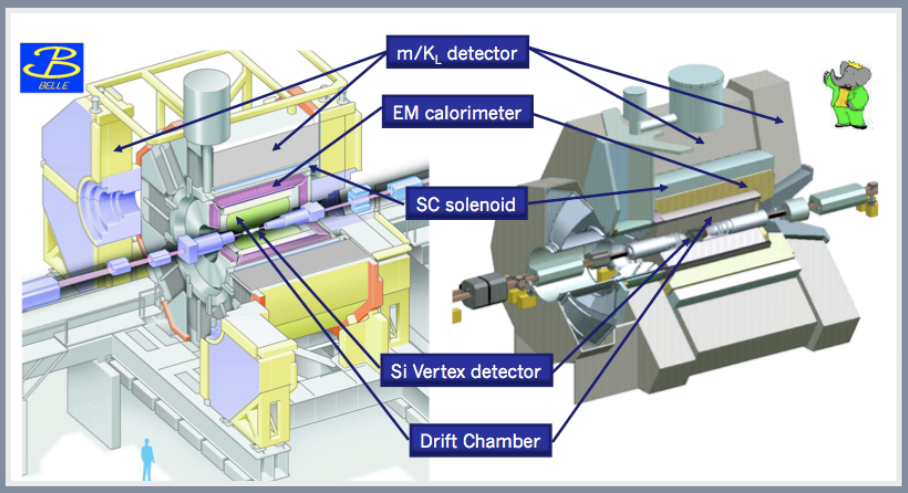
With the increased sample size, the measurements of both collaborations converged into one value. The degree of CP violation, expressed by the sine of twice phi-1 (beta), was 0.67, where zero meant no CP violation and one meant total violation of particle-antiparticle symmetry in the interested mode.

The analysis groups at both B-Factories employed the blind analysis technique, to ensure that the results would not be biased by the analysts' knowledge of the experiment. This is analogous to double-blind studies in medical research. In this case the charges of particles are not revealed to the analysts until all quantities are finalized. Thus, no one knows the results of the experiment until they open the box at the end of all the analysis runs.

“The most memorable moment for the collaboration was when we saw the large CP violation at the end of our analysis.” Prof. Sakai shares the exciting moments. “Initially, the CP violation was quite small, but the value eventually converged to the quantity expected from other experiments, which confirmed the Kobayashi-Maskawa model.” Prof. Kobayashi and Prof. Maskawa were subsequently awarded the Nobel Prize in Physics in 2008.

A physics book for the future

While there are over six hundred journal articles published by B-Factory experiments, Belle and BaBar have never before collaborated on a joint publication. This is not necessarily a bad thing. “The competition between the two increased our productivity as



The Belle-BaBar physics book will discuss the detectors, the analysis tools used, the physics results, and the interpretation of these results.

The five general editors are the organizers of the physics book workshop. From left: Prof. Soeren Prell of Iowa State University (BaBar), Prof. Bostjan Golob of the University of Ljubljana (Belle), Dr. Adrian Bevan of Queen Mary, University of London (BaBar), and Dr. Bruce Yabsley of the University of Sidney (Belle). The final general editor, Prof. Thomas Mannel of University of Siegen (Theory) was not present due to other commitments.

a result, advancing physics," says Prof. Diberder. He is the original proposer of the book. "Now that BaBar has finished experimenting, and Belle is starting the next phase as Belle II, it is time to cooperate, to share our experiences, techniques, and strengths. This is a good way to foster collaboration between the two B-Factories."

The idea of the book started in 2007, a year before Prof. Diberder took the BaBar spokesperson chair. He had long been interested in the possibility of a joint B-Factories book, and so he brought the idea to the head of the Institute of Particle and Nuclear Research at KEK, Prof. Yamauchi. Even though Prof. Yamauchi was enthusiastic, it was not until March 2009, when the BaBar and Belle managements met during the Belle collaboration meeting at KEK, that the book project was brought out for general discussion.

During the discussions, Belle proposed that the book might be more than a history, but that it might also be for the future B-Factory. According to Prof. Golob. "Our main motivation is to document the achievements of the B-Factory community in heavy flavor physics over the last decade, and to explain the methods to be used at the two next generation experiments, the Super B-Factories at KEK and in Italy."

The book will include the descriptions of the Belle and BaBar detectors, the analysis tools developed by each collaboration, the physics results, and the interpretation of these results. "This information has never been published [in one place] before. Both students and postdocs will benefit from this. This is really an investment for the future," says Dr. Bevan.

The number of contributors to the book has grown to more than a hundred, around half from Belle and half from BaBar. Altogether, the contributors come from 16 different countries. "It's really beautiful to see people coming from different worlds, the Belle world and BaBar world, sharing their secrets and techniques, and willing to do the best science possible," smiles Prof. Diberder. "I've already heard voices saying that the book will be an invaluable source to future physicists."

Lights, camera, and drum rolling…

"The point is to decide between notation conventions for angles and other quantities," announced Dr. Yabsley. "We will use one notation scheme, and we will share the pain." The collaborations had decided to split the notation. The notation from one collaboration would be used for the angles of the unitarity triangle, while the notation from the other collaboration would be used for all other parameters. The coin would decide which was used for what.

Another of the five general editors, Prof. Soeren Prell of Iowa State University, took out a silver coin. "This is a commemorative silver coin that depicts Alexander von Humboldt, a naturalist and scientist in the 18th century. He was one of the first to suggest that the continents were united originally. This unity perhaps suggests that two experiments can agree on one notation, at least for the book."

After this short commemoration, Dr. Yabsley tossed the coin. "I do believe, that is the tail," announced he. "The angles will be called phi-1, phi-2, and phi-3. We will use BaBar notations for other differently noted variables. Belle people will have to get used to calling energy substituted mass m_{ES} in your write-ups."

At the meeting, the 52 participants developed a detailed plan for the book, defined the contents, and discussed contributors for the individual sections. Prof. Golob says, "The meeting was a very positive exchange of ideas. We were able to identify possible problems and their solutions." The book will be published in 2012 in two different editions, as a special volume of European Physics Journal C, and a hardcover issue in the Advances in the Physics of Particles and Nuclei (APPN) series printed by Springer.

"Tail." (Photo courtesy of Dr. Tagir Aushev.)

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Physics beyond the Standard Model at Belle

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Physics Book White Paper

HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION (KEK)

Address : 1-1 Oho, Tsukuba, Ibaraki 305-0801 JAPAN
Home : http://www.kek.jp/intra-e/feature/
Mail : misato@post.kek.jp