Belle experiment steams ahead with CP violation

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High Energy Accelerator Research Organization (KEK)

The Belle collaboration, an international research group working at the KEKB accelerator of the High Energy Accelerator Research Organization (KEK), reported updated results on CP violation at the 32nd International Conference on High Energy Physics, which is taking place this week in Beijing, China.

The KEKB accelerator is an electron-positron collider for producing a large number of very short-lived subatomic particles called B mesons and anti-B mesons (the anti-matter counterparts of B mesons). These particles, each with a mass somewhat greater than that of the helium atom, disintegrate after a few trillionths of a second into lighter and more long-lived daughters, are detected by the Belle apparatus.

Studies of large samples of these B mesons play a crucial role in our understanding of the behavior of matter at its most elementary level, notably in investigating the origin of the tiny difference that is known to exist between matter and anti-matter, called CP violation.

The performance of KEKB has improved steadily since it started operating in 1999. It has provided a total of 274 million B-meson anti-B-meson pairs, of which 122 million were delivered in the past year alone. This accelerator is colloquially called a "B factory," because of its copious rate of production. Indeed, KEKB is the most luminous colliding beam accelerator ever built.

The first clear evidence that CP violation occurs in B meson decays was reported three years ago by the Belle and the BaBar collaborations, the latter working at the Stanford Linear Accelerator Center in California. The two experiments found that the way B mesons decay into particles called J/ψ mesons and K^0 mesons is clearly different from the way anti-B mesons go through the same decay. The size of CP violation for this process is characterized by a quantity called $\sin 2\phi_1$. (This quantity would be zero if there were no CP violation, but could be as large as 1 or -1 according to the accepted theory of particle physics —the so-called Standard Model.)

Based on repeated measurements by Belle and BaBar, the value of $\sin 2\phi_1$ is now known to be 0.736 with an accuracy of ± 0.049 (expressed as 0.736 ± 0.049). It is now considered to be one of the fundamental parameters of the Standard Model. For a firm confirmation for the 1973 theory of M. Kobayashi and T. Maskawa, which elegantly describes the origin of CP violation in the Standard Model, another type of particle-antiparticle asymmetry, known as "direct CP violation" must still be found.

1 Direct CP violation

The first evidence for direct CP violation in B meson decay was reported by the Belle group in January 2004 in the disintegration of the B meson into two π mesons. From a sample of 152 million B meson pairs, Belle observed 264 anti-B meson decays but only 219 B meson decays, establishing direct CP violation with more than 99.8% probability.

In the case of the $\sin 2\phi_1$ measurement, the difference between B mesons and anti-B mesons appears only when the decay time distributions are measured but washes out when all of the decays are counted. This "indirect CP violation," with its inherent time dependence, stands in marked contrast to the more straightforward comparison of the total number of B (or anti-B) meson decays in "direct CP violation."

Most recently, Belle has found clear evidence of direct CP violation in the process of B mesons decaying to a K meson and a π meson. From a sample of 274 million B meson pairs, Belle found 1165 B meson decays but only 974 anti-B meson decays, establishing direct CP violation with a confidence level of more than 99.99%.

The observation by Belle of direct CP violation in $K\pi$ decay, was foreshadowed by an earlier Belle result on reactions where B mesons were seen to decay into two π particles. Since that reaction is thought to involve both direct and indirect CP violation, the situation is a bit more complicated. Taken together, the $K\pi$ and $\pi\pi$ results lend strong support to the Kobayashi-Maskawa theory.

2 Hint of a new phenomenon

If the Standard Model is correct, several B meson processes other than the decay to $J/\psi\, K^0$ must show CP violation of a size that is determined by $\sin 2\phi_1$. A particularly interesting case is the decay into the ϕ meson and the K^0 meson. This process is believed to occur through a process involving so-called "quantum fluctuations" where the beauty quark within the B meson splits, for a brief instant, into a top quark and a W boson. It is possible that the top quark and/or W boson could occassionally be replaced by new particles that have never been seen and are not part of the Standard Model. Their hidden presence might appear as an anomalous value for $\sin 2\phi_1$.

In summer 2003, the Belle group reported that the value of $\sin 2\phi_1$ determined using the ϕK^0 decay mode deviated significantly from the well-established value of +0.736 mentioned earlier. That result, based on a sample of 68 events of this type, created a stir in the high energy physics community, and an updated result with a larger data set has been eagerly waited.

Further investigation requires a large data sample, and the experimenters are steaming ahead toward resolving what is probably the most serious challenge to the Standard Model in recent days. Using a 274 million B meson sample, the Belle group collected 175 ϕK^0 decays, and also extended its analysis to five other decay processes that are believed to behave similarly to the ϕK^0. Now, the value of $\sin 2\phi_1$ after combining all these decays is $+0.43 \pm 0.11$, which represents a deviation from the Standard Model value with 99% probability.

Further improvement of the measurement remains one of the most important issues in high energy physics.

3 Search for new particles

The discovery by Belle of the enigmatic $X(3872)$ particle in 2003 has been confirmed subsequently by three other experiments. Its peculiar properties continue to evoke much speculation about its nature, and Belle has now provided more experimental evidence to better establish its internal structure.

This latter discovery has proved that the KEKB accelerator serves as a powerful tool for searching for new particles. Most recently, the Belle group found strong evidence for yet another particle, tentatively called $X(3940)$, that is produced together with J/ψ meson in the electron-positron collision. Its properties are under investigation.