A violation of *CP* symmetry in *B* meson decays

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Thirty-seven years after the surprising discovery of a small amount of *CP* violation in neutral kaon decays, two international teams in the US and in Japan announced in summer 2001 the observation of large CP asymmetries in the decay of neutral *B* mesons. New results from both experiments have been presented recently at the Rencontres de Moriond 2002, a yearly conference in Les Arcs in the French Alps.

The *C, P* and *T* discrete symmetries

Most theories of modern physics are based on the invariance of the equations describing a physical system under symmetry operations. In quantum mechanics, symmetries of physical laws correspond to conservation laws, and are associated with conserved quantum numbers. There are continuous symmetries and discrete symmetries. Three space-time discrete symmetries play an essential role in particle physics: charge conjugation, *C*, in which particles are replaced by their anti-particles; parity inversion, *P*, in which all three spatial coordinates are reversed; and time reversal, *T*.

The *CPT* theorem states that all fundamental interactions must be invariant under the succession of the three operations, *C, P* and *T*, taken in any order. (The *CPT* theorem rests on Quantum Field Theory with minimal assumptions; it implies that particles and antiparticles, which have opposite quantum numbers, must have exactly the same mass and lifetime.) The fact that the combination of all three symmetries, *CPT*, is an exact symmetry does not require however that any of the three individual symmetries is also exact. In fact, only three out of the four fundamental interactions do respect individually the *C, P* and *T* symmetry operations: the laws of gravitation, of electro-magnetism and of strong nuclear force.

The fourth interaction is the weak nuclear force, which is responsible for the β decay of certain unstable nuclei. The weak interactions do not respect the *C* and *P* symmetries. In fact, these symmetries are maximally violated in weak interactions. To understand what this means, let us consider the neutrino, a spin 1/2 charge-less extremely light particle that interacts only through the weak force. There are three kinds of neutrinos; the one associated with the electron is produced left-handed together with a right-handed positron (anti-electron), while its anti-neutrino is produced right-handed together with a left-handed electron. (Here, left-handed means that the projection of the spin on the line of flight is opposite to momentum.) Applying parity *P* to a left-handed neutrino gives a right-handed neutrino, a particle that is not observed in Nature. Applying charge conjugation *C* to a left-handed neutrino gives a left-handed anti-neutrino, a particle that is not observed either. Hence, the parity and charge conjugation symmetries are both maximally violated. However, if the combination of parity and charge conjugation *CP* is applied to a left-handed neutrino, then one obtains a right-handed anti-neutrino, which is a physical particle observed in Nature. Therefore, the *CP* symmetry, which transforms a left-handed neutrino into a right-handed anti-neutrino, is a good symmetry of the weak interactions. At least as far as leptons are concerned.

Leptons and quarks

In the Standard Model of particle physics, elementary particles are classified into three families of leptons and quarks. One of the ingredients of the model is the electroweak theory, unifying electromagnetism and weak interactions, which is based on an internal symmetry called the weak-isospin symmetry. Under this symmetry, a left-handed charged lepton—electron, muon or tau—and its associated neutrino are viewed as two possible quantum states of the same entity. In each family, there is a weak-isospin doublet of left-handed leptons (an electrically-charged lepton and an associated charge-less neutrino), and weak-isospin doublet of left-handed quarks (an up-type quark of charge +2/3 and a down-type quark of charge −1/3), and corresponding doublets of right-handed antiparticles.

Like leptons, quarks are spin 1/2 particles and appear as point-like, but with fractional electric charge. Quarks experience both weak and strong interactions and are the fundamental constituents of the strongly interacting particles, the hadrons. Quarks are not observed as free particles and are always confined inside hadrons: either baryons consisting of three quarks, or mesons consisting of a quark-antiquark pair. There are six so-called flavours of quarks.

The first family is composed of the *u* and *d* quarks, which constitute the nucleons of ordinary matter, protons and neutrons, as well as light mesons such as the charged and neutral pions π.

The *s* quark, down-type quark of the second family, is contained in hadrons such as the charged and neutral kaons. The so-called strange particles are copiously produced in strong interactions, but can only decay via weak interactions, which explains their relatively long lifetimes. This is expressed by a quantum number, called the strangeness *S*, which is conserved in the associated strong production of particles of opposite strangeness, but violated in the weak decay of strange particles into non-strange particles.

The remaining three quarks are the "*c*", up-type quark of the second family, and the "*b*" and "*t*", down and up-type quarks forming the third family. The *c* quark had been predicted to explain the absence of certain neutral kaon decays, and was discovered in the mid-1970's simultaneously at SLAC (Stanford Linear Accelerator Center), and at BNL (Brookhaven National Laboratory). Even before the *c* quark hypothesis was confirmed experimentally, two Japanese theorists, Makoto Kobayashi and Toshihide Maskawa, proposed that the four-quark pattern be extended to six quarks in order to accommodate the possibility of *CP* violation. The discovery of the *b* quark came shortly thereafter. It took more than fifteen years (and several experiments!) to finally observe the very massive top quark, in proton-antiproton collisions at FNAL (Fermi National Accelerator Laboratory).

CP violation in kaon decays

At the time of the discovery of *CP* violation, in 1964, particle physicists generally accepted the assumption that *CP* is an exact symmetry of weak interactions. It was therefore a real sensation when the observation of a small violation of *CP* symmetry was reported in the decay of neutral kaons.

The neutral kaon K^0 is a strange meson that contains an anti-s quark bound with a d quark. The K^0 and its anti-particle, called the $\bar{K}^0$, have common final states: both can decay to either 2 or 3 pions by the weak interactions, with $|\Delta S| = 1$. There is therefore a possibility of transition between a K^0 and a $\bar{K}^0$. This $|\Delta S| = 2$ process (second-order in weak interactions) is called $K^0\bar{K}^0$ mixing: starting with a pure K^0 state, at any later time one would have a superposition of both K^0 and $\bar{K}^0$. In fact, the physical states that decay by weak interactions are not the states of well-defined strangeness at production, K^0 or $\bar{K}^0$, but states that are distinguished by the value of the *CP* quantum number of their decay modes: either the 2-pion decay mode, which has a $CP = +1$, or the 3-pion decay mode, with predominantly $CP = -1$. These particles are called the K^0_S (short-lived neutral kaon) and the K^0_L (long-lived neutral kaon). Because the decay into 3-pions is strongly suppressed by kinematics, the K^0_L has a much longer lifetime, 500 times larger, than the K^0_S. The $K^0\bar{K}^0$ system oscillates with a characteristic time of the order of the K^0_L lifetime (50 nanoseconds).

In their famous 1963 experiment at BNL, James Christenson, James Cronin, Val Fitch and René Turlay observed that about one out of every 500 of the long-lived K^0_L (those with *CP* number -1) decays into 2 pions. If *CP* were an exact symmetry, such decay would be absolutely forbidden. What a surprising result! Since then, *CP* violation in K^0_L decays has been studied with great precision. Recently, the NA48 collaboration at CERN (European Laboratory for Particle Physics) and the KTeV collaboration at FNAL have even confirmed the existence of a very infrequent phenomenon in kaon decays, called *direct CP* violation [1].

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So, why has *CP* violation, a tiny effect, been the subject of such sustained attention by experimentalists and theorists for so many years?

One implication of *CP* violation makes it fascinating: within the strong constraint that *CPT* is an exact symmetry it implies that the time reversal symmetry *T* is also violated. Another fascinating aspect is that *CP* violation is one of the three necessary conditions to achieve a mechanism that can generate the global asymmetry in the Universe between matter and antimatter, starting with symmetric initial conditions at the time of the Big Bang. Most theorists today are convinced that the amount of *CP* violation that is observed experimentally in the quark decays is too small by several orders of magnitude to explain the observed matter-antimatter asymmetry of the Universe. However, there is a strong link between this phenomenon and the dynamics of the early Universe.

Charged weak currents

The basic symmetry of the electroweak theory implies the existence of four fields, called gauge fields, and their associated quanta, called vector bosons. The boson of the electromagnetic force is the photon, with zero mass and infinite range. The bosons of the weak force are the Z^0, W^- and W^+ particles, which play a role similar to that of the photon, except that their range, which is inversely proportional to their mass, is extremely short. The *W* bosons connect left-handed particles (or right-handed anti-particles) inside weak-isospin doublets: they are vectors of the charge-changing weak interactions.

Both leptons and quarks participate in the charge-changing weak interactions. The patterns, however, appear to be radically different. Each charged lepton undergoes charge-changing transitions to or from its own associated neutrino. On the other hand, the quarks participate in a rich pattern of charge-changing transitions. This pattern is summarised in the Cabibbo-Kobayashi-Maskawa (CKM) matrix.

The Cabibbo-Kobayashi-Maskawa matrix

The CKM matrix is a 3 × 3 unitary matrix, entirely defined in terms of four real parameters. This is a remarkably concise description of all we know at present about the weak interactions of quarks. One of the parameters of the CKM matrix is a phase, called the KM phase, which makes the CKM matrix complex. *CP* violation in the Standard Model requires that this phase be non-zero.

The unitarity requirement leads to nine equations that relate the CKM matrix elements. Six of these equations can be represented by triangles in the complex plane. All six triangles have the same area, which is proportional to the strength of the KM phase and is therefore a measure of the amount of *CP* violation in the theory. One of the triangles has come to be called *the* Uni-

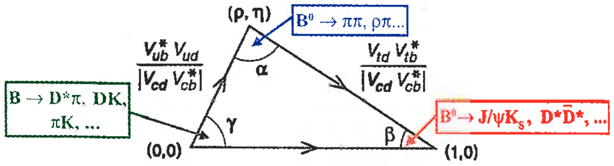

Fig. 1: The Unitarity Triangle is a geometrical representation of one of the unitarity relations that relate the elements of the Cabibbo-Kobayashi-Maskawa matrix CKM. The CKM matrix is a 3 × 3 unitary matrix whose nine complex elements measure the strength of the transitions of down-type quarks of charge −1/3 to up-type quarks of charge +2/3 with emission of a W^- particle. Thanks to the unitarity constraints that connect its different elements, the CKM matrix can be described by a set of four real parameters. Two of the parameters, which are the less-well known, are taken as the real and imaginary parts of a complex number $\rho + \imath\,\eta$ that defines the coordinates of the apex of the Unitarity Triangle in the complex plane. The argument of this complex number, called the KM phase γ, is the origin of all *CP* violation effects in the Standard Model. The size of the sides of the Unitarity Triangle can be deduced from measurements of various *B* meson decay rates and from the frequency of $B^0\bar{B}^0$ mixing oscillations. The interpretation of these measurements however are ultimately limited by theoretical uncertainties. In contrast, the measurement of angle β from time-dependent *CP*-violating asymmetries in the $B^0 \to J/\psi K^0_S$ decay mode is free from theoretical uncertainty. The *CP* parameter $\sin 2\beta$ is now measured by the *BABAR* and Belle experiments with an combined accuracy of 10%. The measurement of angle α is not only challenging experimentally, because it involves extremely rare decay modes such as $B^0 \to \pi^+\pi^-$, but also very uncertain theoretically. Likewise, the direct extraction of angle γ necessitates very large statistics of *B* mesons and complex theoretical analyses. Progress on the knowledge of the two angles α and γ are among the main goal of the two experiments in the future years. Over-constraining the Triangle tests the Standard Model explanation of *CP* violation, and may lead to the discovery of new physics.

tarity Triangle because it has the nice feature that the lengths of its three sides are of the same order theoretically, and therefore its angles are neither close to 0 nor π (see Figure 1).

The experimental goal is to perform a test of the description of *CP* violation in the Standard Model by providing an over-constrained set of measurements of the sides and angles of the Unitarity Triangle, or any other quantity that can constrain the apex of the Triangle. Inconsistency in triangle measurements would constitute an important clue of new physics beyond the Standard Model.

As it turns out, most of the physics quantities linked to the Unitarity Triangle are related to transitions that involve the *b* or *t* quarks. The physics of mesons that contain a *b* quark, *B* mesons, is therefore an important key to understanding *CP* violation.

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CP violation and *B* mesons

B mesons contain a anti-*b* quark associated with either a *u* (for the B^+), a *d* (for the B^0), or an *s* quark (for the B_s^0). (The corresponding anti-mesons are the B^-, the $\overline{B}^0$ and the $\overline{B}_s^0$.) The primary decay of the *b* quark is to the *c* quark. The strength of this transition is quite weak, which is one of the reasons why *B* mesons have relatively long lifetimes (1.5 picoseconds) despite their large mass (approximately 5 times that of the proton). As for the $K^0\overline{K}^0$ system, the neutral B^0 and $\overline{B}^0$ mesons can mix, with a characteristic time that is of the order of the B^0 lifetime. Some of the states that can be reached either by a B^0 or a $\overline{B}^0$ are called *CP* eigenstates because they have a well-defined value of *CP*. For instance, in the decay of a B^0 to a J/ψ and a K_S^0 (the J/ψ is the lightest vector meson made of a $c\overline{c}$ pair), the $J/\psi K_S^0$ system is in a $CP = -1$ state.

Some of the *CP* asymmetries in the neutral *B* meson decays are expected to be large. How can *CP* violation be observed in practice? *CP* violation always involves quantum mechanical interference. This occurs for instance when there are two paths for a particle to decay into a given final state. The interference between the mixing-induced amplitude ($B^0 \rightarrow \overline{B}^0 \rightarrow f$) and the decay amplitude ($B^0 \rightarrow f$) to a *CP* eigenstate *f* leads to a time-dependent *CP* asymmetry that can be interpreted in terms of the angles of the Unitarity Triangle. This interpretation is simple theoretically if a single amplitude dominates the decay process. This is the case for the $B^0 \rightarrow J/\psi K_S^0$ decay, also called the golden mode. Here, *CP* violation is parameterised in terms of the sine of an angle, sin 2β, where β is one of the angles of the Unitarity Triangle. *CP* violation occurs if and only if sin 2β is different from zero. Asymmetries in other modes, such as $B^0 \rightarrow \pi^+\pi^-$, are linked to another angle of the triangle, α, but the interpretation is not as clean theoretically.

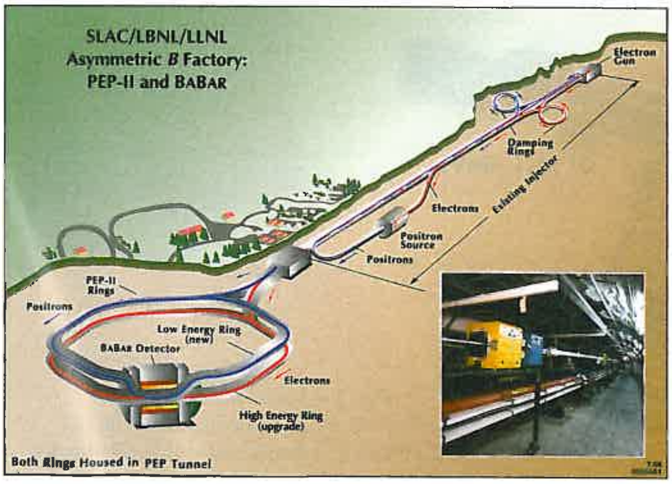

Fig. 2: The SLAC site of the linear accelerator and the PEP-II Asymmetric *B*-Factory. Electrons and positrons are stored in two rings and collide at one point where the *BABAR* detector is installed.

The experimental challenge comes from the fact that *B* decays to *CP* eigenstates such as $J/\psi K_S^0$ have very small branching ratios and in general low efficiencies for complete reconstruction of the final state. It is therefore necessary to produce a very large sample of *B* mesons to perform a *CP* measurement.

Dedicated experiment at the $\Upsilon(4S)$ resonance

The cleanest way to produce *B* mesons is to operate at an e^+e^- collider at a center of mass energy equal to the mass of the $\Upsilon(4S)$ resonance. The $\Upsilon(4S)$ is a $b\overline{b}$ bound state, which decays with equal probability into a $B^0\overline{B}^0$ or a B^+B^- pair. Neutral *B* meson pairs are produced in a well-defined coherent quantum state. Quantum coherence implies that after production the two *B* mesons oscillate in phase in such a way that at any instant the mesons have either opposite flavour (*i.e.*, there is exactly one B^0 and one $\overline{B}^0$ meson) or opposite *CP*. This holds until one of the mesons decays.

For *CP* analyses, one selects rare *B* decays to *CP* eigenstates, such as $B^0 \rightarrow J/\psi K_S^0$. Approximately one B^0 meson in a thousand decays in this final state. Only about 10% decay into final states with a clean experimental signature that can be reconstructed. Including selection criteria to reject backgrounds with efficiencies around 50%, one is left with the selection of about thirty fully reconstructed decays out of one million *B* meson pairs.

One needs to measure the time difference Δt between the two *B* decays. As the $\Upsilon(4S)$ mass is just above the production threshold of a pair of *B* mesons, the latter are produced almost at rest in the $\Upsilon(4S)$ rest frame. It is not possible to measure the distance between the two decay vertices in that frame. To make the measurement possible, a new type of e^+e^- collider, called Asymmetric *B*-Factory, has been designed. In Asymmetric *B*-Factories, the e^- and e^+ beams have unequal energies, typically 9 and 3 Giga electron-Volts. The *B* mesons are produced at the interaction point with a boost in the laboratory frame and their decay vertices are well separated. One deduces Δt from the measurement of the distance Δz along the boost axis between the *B* decay vertices. A time interval of the order of the *B* lifetime is translated into an average distance of 260 microns.

An important ingredient of the analysis is flavour tagging, which is the determination of the flavour of the B^0 meson at a given time. This is done by looking at the accompanying *B* meson, which, thanks to the quantum coherence, has the opposite flavour at the time of its decay. One looks typically at high-energy leptons in the decay products. A positively-charged lepton in the decay products tags a B^0 while a negatively-charged lepton tags a $\overline{B}^0$.

There are three main effects that complicate this picture and lead to a dilution of the experimental time-dependent *CP* asymmetry. First, the measurement of the time difference Δt is imperfect. Second, the flavour tagging sometimes gives the wrong answer. Finally, there is some background under the signal. The *BABAR* detector on the PEP-II B-Factory is optimised to minimise these sources of dilution.

PEP-II and the *BABAR* experiment

The PEP-II Asymmetric e^+e^- B-Factory and the *BABAR* [2] experiment are located at the Stanford Linear Accelerator Center in California. It took about 5 years to build the accelerator and the experiment designed to study *CP* violation with B mesons. Since the first data in May 1999, *BABAR* has collected more than 70 million $B\bar{B}$ pairs.

The 9 GeV electron beam and 3 GeV positron beam, accelerated by the 2-mile long linear accelerator, Figure 2, are injected and stored in two different storage rings, which constitute the PEP-II B-Factory. Electrons and positrons collide with a center of mass energy equal to the mass of the $\Upsilon(4S)$ resonance at a single interaction point, where the *BABAR* detector is installed. Thanks to the high currents stored in the rings, about 1 A for the electrons and 1.8 A for the positrons, as much as one $B\bar{B}$ pair is produced per second.

The *BABAR* experiment consists of a series of sub-detectors surrounding the interaction point in a 1.5 T solenoidal magnetic field. Figure 3 shows schematically the detector. Charged tracks, which are used to located the B meson decay point, are reconstructed and their momenta measured in a five layer silicon vertex tracker surrounded by a 40-layer cylindrical wire drift chamber. The silicon vertex tracker consists of 340 double-sided silicon micro-strip sensors totalling about 150,000 read-out channels. The transverse position is measured on one side and the z coordinate on the other. The drift chamber is composed of 30,000 3 metre-long wires forming 7,100 drift cells. Charged hadrons are identified in a ring imaging Cherenkov detector surrounding the drift chamber, called the DIRC. The Cherenkov radiator of the DIRC is a barrel of 144, 5 metre-long, 1.7 centimetre-thick, quartz bars; the Cherenkov light is detected by an array of 10752 photomultipliers located at one end of the quartz bars inside a 6m^3 tank filled with ultra-pure water for optimal optical match. Electrons and photons are detected and their energy measured in the 6,580 Cesium Iodide crystal calorimeter surrounding the DIRC. Any hadrons which have not interacted with the crystal calorimeter are filtered in an iron shielding, allowing for muon identification.

This enormous amount of data... is processed off-line by hundreds of computers running sophisticated pattern recognition software

The data acquisition system accepts more than 1,000 events per second, which are reduced to 130 events by a farm of 60 computers running elaborate selection algorithms. The average event size is 30 kilo-bytes. This enormous amount of data (40 tera-bytes per year) is processed off-line by hundreds of computers running sophisticated pattern recognition software, and made available for worldwide physics analysis by the 550 *BABAR* collaborators.

The *BABAR* detector fulfils all the requirements for *CP* analysis: operational efficiency close to 100%, precision on Δz in the range 100-200 microns—better than the average distance between two B decay vertices—, superb calorimetry, and excellent particle identification, which allows for good flavour tagging efficiency, corresponding to 30% of perfect tags.

There is another Asymmetric B-Factory in Japan, called KEK-B, which hosts Belle [3], an experiment very similar to *BABAR*,

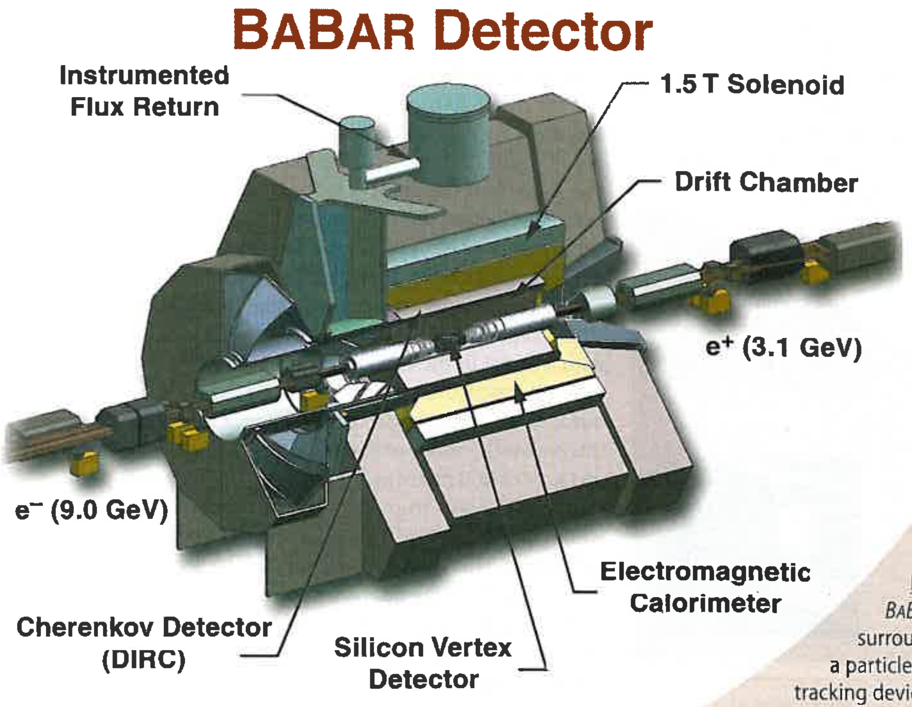

Fig. 3: A schematic view of the *BABAR* detector. A super-conducting coil surrounds a Cesium Iodide crystal calorimeter, a particle identification detector, and a precise tracking device formed by a cylindrical drift chamber and a silicon strip detector. The iron flux return is instrumented with Resistive Plate Chambers.

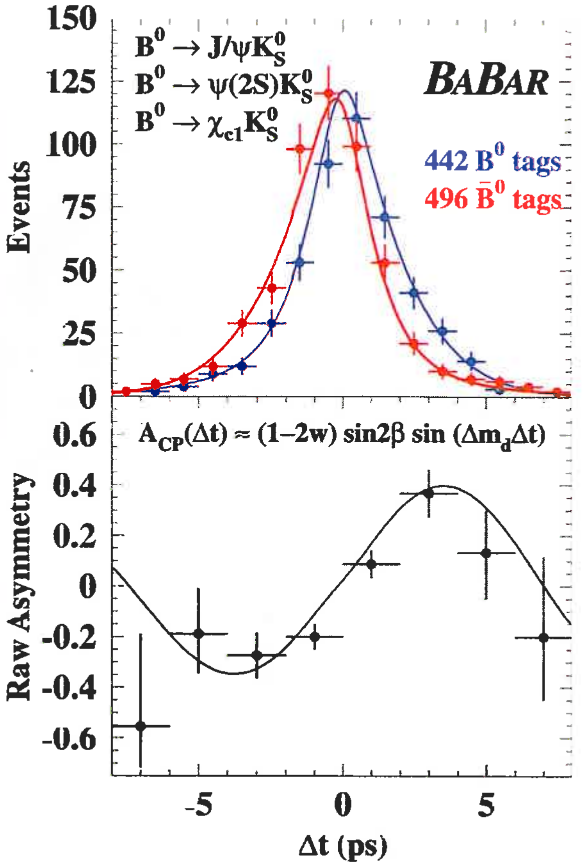

Fig. 4: Proper decay time difference (Δt) distributions for B^0 (in blue) and $\bar{B}^0$-tagged (in red) events. For a given Δt value, the decay rate to the same *CP* eigenstate depends on whether the decaying meson was tagged as a B^0 and $\bar{B}^0$ at the time the accompanying *B* meson decayed. This is a spectacular illustration of *CP* violation in the *B* system; matter and antimatter are clearly behaving differently. The corresponding raw asymmetry follows approximately a sine wave at the $B^0\bar{B}^0$ mixing frequency, whose amplitude is proportional to the *CP* parameter sin 2β.

and running simultaneously, producing physics results of equivalently high quality.

Observation of *CP* violation by *BABAR* and Belle

In July 2001, at the International Europhysics Conference on High Energy Physics in Budapest, the *BABAR* collaboration reported a measurement of the *CP* parameter sin 2β that was significantly different from zero: sin $2\beta = 0.59 \pm 0.14 \pm 0.05$ (the first error is statistical, the second error is experimental). At the Lepton-Photon Conference in Rome, two weeks later, the Belle collaboration reported an even larger value of sin 2β with the same experimental uncertainty: sin $2\beta = 0.99 \pm 0.14 \pm 0.05$. Each result, based on samples of 30 million *B* meson pairs, established *CP* violation in the neutral *B* meson system. The two reports, both published in the Physical Review Letters issue of August 27 2001 [4] [5], are the first compelling observations of *CP* violation in any system other than the neutral kaon system (see detailed reports in [6] and [7]). The discrepancy between the two results at the time of the Summer 2001 Conferences is now understood to be purely statistical. Updated measurements have been presented in early March 2002 at the Rencontres de Moriond, a yearly conference of particle physics [8] [9]. *BABAR* now measures sin $2\beta = 0.75 \pm 0.09 \pm 0.04$ and Belle sin $2\beta = 0.82 \pm 0.12 \pm 0.05$, based on samples of 55 and 42 million *B* meson pairs, respectively. The measurements are now in very good agreement and can be combined. The new World average is sin $2\beta = 0.78 \pm 0.08$ (the error combines statistical and experimental contributions). This value is in excellent agreement with Standard Model predictions based on available experimental data. The evidence for *CP* violation is dramatically illustrated in Figure 4 where the Δt distributions for B^0 and $\bar{B}^0$-tagged events are clearly distinct. Our experiment can unambiguously determine which is the B^0 and which is the $\bar{B}^0$ sample, and therefore whether the detector, the laboratory, the physicists and the planet on which the experiment was performed are made of matter or antimatter.

Conclusions

After less than three years of operation of the new Asymmetric *B*-Factories, the *CP* parameter sin 2β is measured with an accuracy of the order of 10%. The present data are consistent with the four-parameter CKM description of *CP* violation in quark decays, which puts strong constraints on sources of *CP* violation introduced by any extension of the Standard Model. For the next 3 to 4 years, *BABAR* and Belle will increase their samples by a factor of five, and continue a rich program of *CP* violation and *B* physics. Experiments at large hadron colliders at FNAL and at CERN, as well as new experiments looking for extremely rare kaon decays, will provide important and complementary measurements. The aim of the substantial worldwide effort focused on *B* physics and *CP* violation is to perform as many redundant measurements as possible of quantities that determine the values of CKM matrix elements, and to search for hints of new physics beyond the Standard Model.

References

[1] P. Debu, *Testing discrete symmetries in K decays*, Europhysics News, May/June 2000.

[2] B. Aubert *et al.*, *BABAR* Collaboration, Nuclear Instruments and Methods A479, 1 (2002); hep-ex/0107061

[3] The Belle detector, Belle Collaboration, Nuclear Instruments and Methods A479, 117-232, 2002

[4] B. Aubert *et al.*, *BABAR* Collaboration, *Observation of CP violation in the B^0 meson system*, Physical Review Letters 87 (091801) 2001; hep-ex/0105044.

[5] K. Abe *et al.*, Belle Collaboration, *Observation of large CP violation in the neutral B meson system*, Physical Review Letters 87 (091802) 2001; hep-ex/0107061.

[6] B. Aubert *et al.*, *BABAR* Collaboration, *A study of time-dependent CP-violating asymmetries and flavour oscillations in neutral B decays at the* $\Upsilon(4S)$, submitted to Physical Review D, SLAC-PUB-9060, January 2002; hep-ex/0201020.

[7] K. Abe *et al.*, Belle Collaboration, *Observation of mixing-induced CP violation in the neutral B meson system*, submitted to Physical Review D, KEK-PREPRINT-2001-172, February 2002; hep-ex/0202027.

[8] Transparencies from speakers, K. Trabelsi for Belle and G. Raven for *BABAR*, can be found at: http://moriond.in2p3.fr/EW/2002/transparencies/index.html.

[9] B. Aubert *et al.*, *BABAR* Collaboration, *Improved measurement of the CP-violating asymmetry amplitude sin 2β*, SLAC-PUB-9153, March 2002; hep-ex/0203007.