DELPHI 97-98 CONF 80
28 July, 1997

Study of Inclusive CP(T) Asymmetries in B Decays

Preliminary

DELPHI Collaboration

M. Feindt, C. Kreuter, O. Podobrin
CERN, PPE-Division

Abstract

Using 1.8 million multi-hadronic Z^0 events recorded with the DELPHI detector at LEP tests of CP and CPT violation are performed. The possibility of observing CP violation in partially inclusive B decays with DELPHI data is discussed. Measurements of the CP violation parameter Re (ϵ_B) and the CPT violation parameter Im (δ_B) are extracted from totally inclusive and semileptonic B decays. The lifetime difference of B hadrons and $\bar{B}$ hadrons is studied, thereby testing the CPT theorem. All results are preliminary.

Paper submitted to the LP'97 Conference
Hamburg, July 28 - August 1st

1 Introduction

CP violation has so far been observed only in the $K^0 - \bar{K}^0$ system, but it is also expected to occur in the $B^0 - \bar{B}^0$ system. Studying CP asymmetries in B decays promises to reveal crucial information about quark mixing and the nature of CP violation. A rich phenomenology is expected and has been discussed in the literature [1]. Predictions for $\mathrm{Re}\,(\epsilon_B)$ are of the order 10^{-3} in the Standard Model for the B_d system [2], and up to an order of magnitude larger in superweak models [3].
CPT violation may occur in certain string description models of fundamental particles. Although CPT conservation has been tested with high precision in the $K^0 - \bar{K}^0$ system, CPT violation effects could be larger in the $B^0 - \bar{B}^0$ system [4].
In this note the possibility of observing CP violation in the B system in partially inclusive final states, as suggested recently [5], is discussed. Measurements of the CP violation parameter $\mathrm{Re}\,(\epsilon_B)$ and the CPT violation parameter $\mathrm{Im}\,(\delta_B)$ are obtained from studies of the charge symmetry of totally inclusive and semileptonic B decays. Furthermore the lifetime difference between B hadrons and $\bar{B}$ hadrons is investigated, leading to an additional test of the CPT theorem in the B system.

2 Detector and Data Taking

The data were taken with the DELPHI detector at the LEP collider at centre of mass energies around the Z pole in the years 1994-1995. DELPHI is a 4π detector with emphasis on precise vertex information, particle identification, three-dimensional reconstruction and high granularity. A complete description can be found in Ref. [6], and performance figures are summarised in Ref. [7]. The detectors most relevant to this study are the tracking chambers (Vertex Detector, Inner Detector, Time Projection Chamber and Outer Detector), the barrel electromagnetic calorimeter (High-density Projection Chamber), and the muon chambers. The DELPHI vertex detector consists of three concentric cylindrical shells of Si-strip detectors at radii of 6.3, 9.0, and 10.9 cm parallel to the beam pipe for precision reconstruction of the $R\phi$ and Z coordinates near the interaction region. Since the algorithms for the $b\bar{b}$ enrichment and the inclusive B reconstruction rely on good vertex measurements, the analyses are restricted to the barrel region ($|\cos\theta| < 0.7$, θ denoting the polar angle with respect to the beam axis), where there is complete vertex detector coverage. To calculate efficiencies, backgrounds, biases, and resolutions the DELPHI simulation package DELSIM [8] is employed; this is based on the JETSET 7.3 generator [9] with parameter adjustments from previous QCD studies [10].

3 Inclusive B Reconstruction

The analysis starts with the standard DELPHI multi-hadronic event selection [11], leading to a sample of 1 800 000 events recorded in the years 1994-1995. A cut on the polar angle ($|\cos\theta| < 0.7$) is applied and $b\bar{b}$ events are enhanced using the DELPHI B confidence method [12], which measures the probability ratio that a given event is a $b\bar{b}$ event in contrast to any other flavour, based on the lifetime signed impact parameter, energy and angular distributions of the reconstructed charged tracks. A cut on the B confidence variable at 0.9 corresponds to a $b\bar{b}$ purity of 87% at an efficiency of 53%.

An inclusive reconstruction of B hadrons is performed using a dedicated program package. Details on the algorithms and the performance of the inclusive B reconstruction are summarised in Ref. [13, 14]. The total efficiency of the package is 45% with a B hemisphere purity of 90%. The inclusive B reconstruction, which is based on a rapidity argument, provides an estimate for the four-vector of a B hadron in a given hemisphere. An energy resolution of 8% is achieved with an angular resolution of approximately 18 mrad in θ and ϕ, plus some non-Gaussian tails. The B hadron lifetime is derived from an inclusive secondary vertex fit with additional correction for the Lorentz boost. The resolution on the B hadron lifetime is 0.25 ps with a bias of 0.10 ps due to the finite D meson lifetime. Estimates for the charge Q_B and the flavour Q_{flav} of B hadrons are obtained from algorithms based on the combination of several charge sensitive variables using neural networks [14]. First a track classification into two classes is performed: (1) tracks from fragmentation, (2) tracks from B decays. This is done using a neural network with the following input variables: rapidity, energy, track probability to primary vertex, and track probability to secondary vertex. The result is the probability p_i for each track i to originate from a B hadron decay. Then the charge Q_B is determined using $Q_B = \sum_i q_i \cdot p_i$, where q_i is the charge of track i. The index i runs over all particle in a given hemisphere. To inclusively distinguish b from $\bar{b}$ jets a neural network with the following input information is constructed: inclusive vertex charge, error on the inclusive vertex charge, jet charge, charge of the leading fragmentation particle, charge of identified kaon from B decay, and charge of high momentum lepton. The resulting variable Q_{flav} provides a clear separation between b and $\bar{b}$ jets. The Q_{flav} distribution for data and Monte Carlo is shown in Figure 1. The charge algorithms are the main tools for the following analyses.

4 Partially Inclusive CP Asymmetries

The Study of CP asymmetries in B decays promises to reveal crucial information about quark mixing and the nature of CP violation. A review can be found in Ref. [1]. While many authors discuss the implications from a few "gold plated" modes, there is not much known on (partially) inclusive B decays. Theoretical studies on inclusive asymmetries have been performed for charged B decays [15], which require a strong interaction phase difference, or for dilepton asymmetries [16] in semileptonic decays of neutral B mesons. Mixing-induced asymmetries in partially inclusive B decays have been analysed recently in Ref. [5]. The following discussion is based on this study.
The possibility of observing CP violation in the inclusive final states (1) $\bar{u}u\bar{d}d$, (2) $\bar{c}c\bar{d}d$, (3) $\bar{c}u\bar{d}d$, and (4) $\bar{u}c\bar{d}d$ of the B_d meson is discussed. The relevant inclusive branching ratios range between 1% and 50%, orders of magnitude larger than their exclusive counterparts. Furthermore some asymmetries are expected to be large due to substantial CKM phases. The inclusive sum partially dilutes the asymmetry, but (according to Ref. [5]) the dilution factor is calculable assuming local quark-hadron duality. At first sight an observation of CP violation in the B system appears promising even with existing data samples. Given an inclusive final state f, the time-dependent asymmetry

$$\mathcal{A}(t) \equiv \frac{\Gamma(B(t) \to f) - \Gamma(\bar{B}(t) \to \bar{f})}{\Gamma(B(t) \to f) + \Gamma(\bar{B}(t) \to \bar{f})} \tag{1}$$

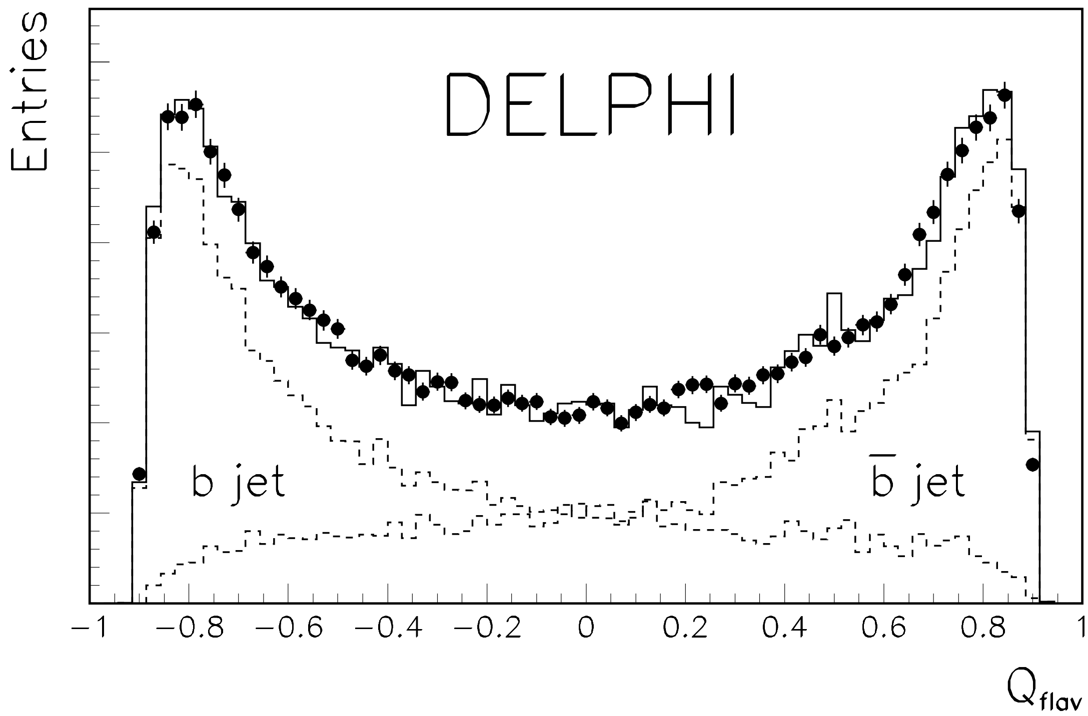

Figure 1: Comparison of the inclusive flavour charge Q_{flav} between data (points) and simulation (histogram). The dashed curves show the contributions from b and $\bar{b}$ jets.

measures CP violation. Restricting ourself to self-conjugate final states common to both B and $\bar{B}$ (i.e. $\bar{u}ud\bar{d}$ and $\bar{c}cd\bar{d}$), the asymmetry can be parametrised as [1]

$$\mathcal{A}(t) = \mathrm{Im}\,\xi\,\sin\Delta Mt - a_d\,\sin^2\frac{\Delta Mt}{2}\,, \tag{2}$$

where ΔM is the mass difference between the two mass eigenstates $B_{H,L} = pB \pm q\bar{B}$. The quantity a_d is defined by $|q/p|^2 = 1 - a_d + \mathcal{O}(a_d^2)$. Theory predicts a_d to be $< 10^{-2}$ for the B_d meson [2]. $\mathrm{Im}\,\xi$ parametrizes mixing-induced CP violation. It can be expressed as the product of a CKM factor and a dilution factor d

$$\mathrm{Im}\,\xi = d \cdot \mathrm{CKM\ factor}\,. \tag{3}$$

Predictions of the dilution factor d and the CKM factor for different final states are derived in Ref. [5], and are listed in Table 1. The interfering amplitudes are also shown. For the final states which are not self-conjugate (i.e. $\bar{c}ud\bar{d}$ and $\bar{u}cd\bar{d}$) some generalization is required.

$$\mathcal{A}(t) = \frac{2\,\mathrm{Im}((M_{12}^*\Gamma_{f,12})/|M_{12}|)\sin\Delta Mt - a_d\Gamma_{f,22}(1-\cos\Delta Mt)}{(1+\cos\Delta Mt)\Gamma_{f,11} + (1-\cos\Delta Mt)\Gamma_{f,22}}\,. \tag{4}$$

M_{12} is the off-diagonal element in the mass matrix of the $B - \bar{B}$ system. $\Gamma_{f,ij}$ is given by $\sum_k \langle i|f_k\rangle\langle f_k|j\rangle$ with $|1\rangle = |B\rangle$ and $|2\rangle = |\bar{B}\rangle$. The sum runs over all final states f_k that contribute to the partially inclusive channel under consideration. These quantities

[1] Effects from direct CP violation are assumed to be negligible in this note.

Final state	Transition	d	CKM factor
$C=0, S=0$ no charm	$\bar{b}d \to \bar{u}ud\bar{d}$ $\bar{b}d \to b\bar{d} \to \bar{u}ud\bar{d}$	-0.11	$\sin 2\alpha$
$C=0, S=0$ with charm	$\bar{b}d \to \bar{c}cd\bar{d}$ $\bar{b}d \to b\bar{d} \to \bar{c}cd\bar{d}$	-0.41	$-\sin 2\beta$
$C=-1, S=0$	$\bar{b}d \to \bar{c}ud\bar{d}$ $\bar{b}d \to b\bar{d} \to \bar{c}ud\bar{d}$	-0.21	$\lambda\lvert V_{ub}/V_{cb}\rvert \sin(\alpha-\beta)$
$C=+1, S=0$	$\bar{b}d \to \bar{u}cd\bar{d}$ $\bar{b}d \to b\bar{d} \to \bar{u}cd\bar{d}$	-0.21	$\lambda\lvert V_{ub}/V_{cb}\rvert \sin(\alpha-\beta)$

Table 1: Dilution factor d and CKM factor for the inclusive final states (1) $C = 0$, $S = 0$, no charm, (2) $C = 0$, $S = 0$, with charm, (3) $C = -1$, $S = 0$, and (4) $C = +1$, $S = 0$ (Ref. [5]). The interfering amplitudes are shown in column 2.

are related by $\xi = (M_{12}^{*}\Gamma_{f,12})/(|M_{12}|\Gamma_{f,11})$.
The time-dependent asymmetries for the final states (1) $C = 0$, $S = 0$, no charm, (2) $C = 0$, $S = 0$, with charm, (3) $C = -1$, $S = 0$, and (4) $C = +1$, $S = 0$ are shown in Figure 2. Since the CKM factor is assumed to be close to unity, these asymmetries must be taken as upper bounds. Large time-dependent asymmetries are seen in the various final states, suggesting the possibility of observing CP violation in the B system even with LEP data. However the corresponding analyses turn out to be extremely challenging. For the final states $u\bar{u}d\bar{d}$ ($c\bar{c}d\bar{d}$), where asymmetries up to 11% (41%) are expected, a clean inclusive enrichment of the final states is difficult. The final state $\bar{c}ud\bar{d}$ ($B \to$ right-sign charm) looks promising due to the large branching ratio. However the maximum CP asymmetry (21%) is expected at lifetimes when most of the B mesons already decayed. The final state $\bar{u}cd\bar{d}$ ($B \to$ wrong-sign charm) has a small branching ratio. The maximum CP asymmetry (21%) is expected at small lifetimes where the separation between primary and secondary vertex is difficult.
In the following the feasibility of a possible measurement using DELPHI data is studied. The analysis is based on approximately 1 800 000 multi-hadronic events which where recorded with the DELPHI detector in the years 1994-1995. After applying a cut on the polar angle ($\cos\theta < 0.7$), performing $b\bar{b}$ enrichment and inclusive B reconstruction one finds approximately 180 000 $b\bar{b}$ events. Since (37.8 ± 2.2)% [1] of all b quarks fragment into neutral B mesons, one has 136 000 hemispheres containing a B^0 meson.
Assuming a branching ratio for $b \to u$ of 1% [1], leads to a total amount of 1 360 B^0 mesons decaying into the final state $u\bar{u}d\bar{d}$. For $b \to$ double charm a branching ratio of 15% [1] is assumed. This leads with the additional Cabibbo suppression to 1 190 B^0 mesons decaying in the final state $c\bar{c}d\bar{d}$. Since a clean inclusive enrichment of these final states with present techniques (e.g. by using secondary vertex probabilities) is not feasible, one has to compare these numbers with approximately 400 000 background hemispheres. The branching ratios for $B \to$ right-sign charm are fairly large. However the expected CP asymmetry is sizable only when the different interfering amplitudes have approximately the same magnitude. Therefore the contribution of the doubly suppressed transition $\bar{b} \to \bar{u}cd$ is crucial (suppression $\sim \lambda^2|V_{ub}/V_{cb}|^2$). Taking this into account only a small fraction of events can be used for an asymmetry measurement. In the DELPHI

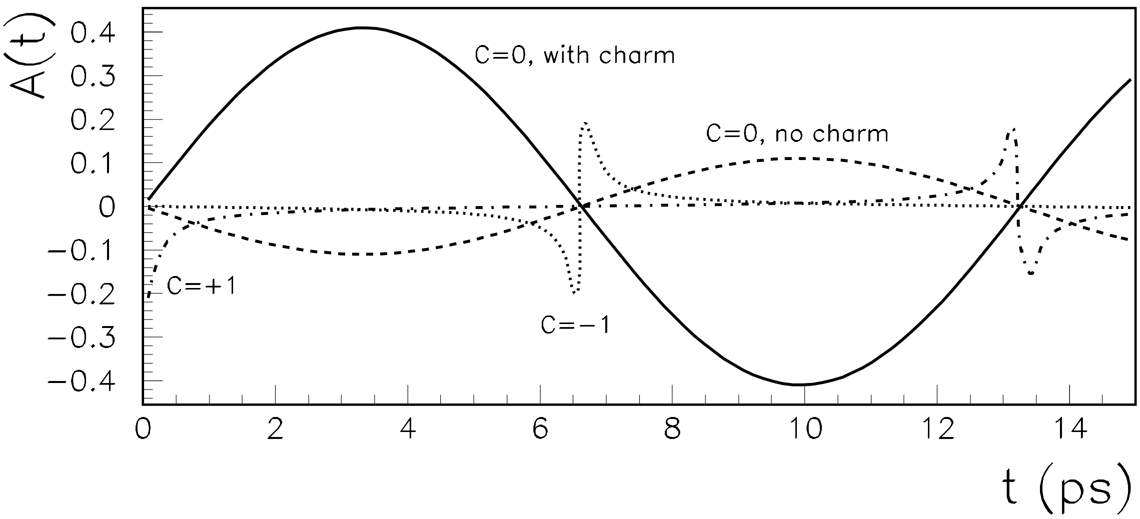

Figure 2: CP asymmetry for the neutral B meson as a function of lifetime for the final states (1) $C = 0$, $S = 0$, no charm, (2) $C = 0$, $S = 0$, with charm, (3) $C = -1$, $S = 0$, and (4) $C = +1$, $S = 0$. For λ a value of 0.21 [1] is used, $|V_{ub}/V_{cb}|$ is set to 0.08 [1]. The CKM factor is assumed to be close to unity. a_d is set to zero.

data sample one expects approximately 40 events. Without significant enrichment one has to fight huge backgrounds. Similar arguments hold for $B \to$ wrong-sign charm.
With present statistics and analysis techniques the suggested analyses to measure CP violation in the B system seem to be out of reach. At future B factories the study of these final states could provide additional insight in the mechanism of CP violation.

5 Totally Inclusive CP Asymmetries

A measurement of the totally inclusive time-dependent asymmetry $\mathcal{A}(t)$ is performed using all neutral B decays ($B \to$ anything). It is non-zero in general and measures a_d. For totally inclusive final states equation 2 simplifies to

$$\mathcal{A}(t) = a_d \cdot \left(\frac{x_d}{2} \sin \Delta M t - \sin^2 \frac{\Delta M t}{2} \right) , \tag{5}$$

where x_d represents the B^0 mixing parameter $\Delta M / \Gamma$. A similar expression holds for totally inclusive B_s decays. Since the B_s fraction in Z^0 data is small and the parameter a_s is expected to be an order of magnitude smaller than a_d, this is neglected in this note.
The analysis is based on the inclusive B reconstruction described in section 3. A cut on the B confidence variable is applied at 0.96 leading to a B purity of 94%. The data sample is divided into two classes according to the measured flavour $Q_{flav,o}$ in the opposite event hemisphere: (1) $Q_{flav,o} < -0.3$ - other hemisphere contains $\bar{B}$ hadron, (2) $Q_{flav,o} > 0.3$ - other hemisphere contains B hadron. From simulation the probability for a misassignment averaged over all hadron types is found to be 22%. Using the measured lifetime in a hemisphere and the given classification the time-dependent asymmetry $\mathcal{A}(t)$ is calculated, taking into account the B purity, the B^0 fraction, and the flavour misidentification. Figure 3 shows the time-dependent asymmetry $\mathcal{A}(t)$. The result is consistent

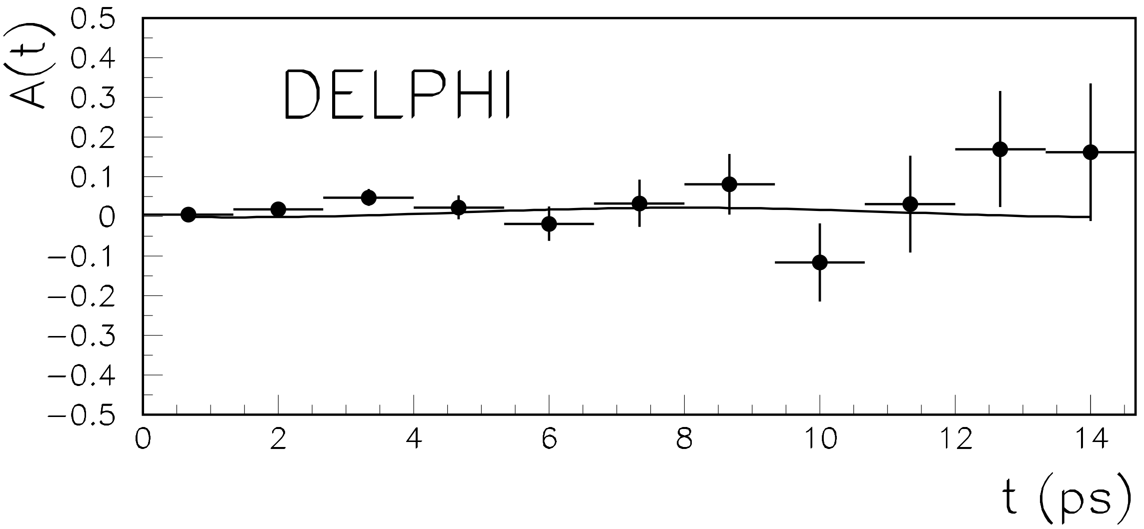

Figure 3: Totally inclusive CP asymmetry $\mathcal{A}(t)$ as a function of lifetime. The result of a one-parameter fit is superimposed.

with zero and no obvious time-dependent structure is observed. A one-parameter fit using formula 5 is performed, where the quantities ΔM and x_d are fixed to the PDG values ($\Delta M = 0.474 \pm 0.031\,\mathrm{ps}^{-1}$, $x_d = 0.73 \pm 0.05$ [1]). For the parameter a_d one obtains

$$a_d = -0.022 \pm 0.030 \pm 0.011\,. \tag{6}$$

Using relation $1 - a_d + \mathcal{O}(a_d^2) = |q/p|^2$ one can derive

$$|q/p| = 1.011 \pm 0.015 \pm 0.005\,. \tag{7}$$

The quantity $|q/p|$ is related to ϵ_B by

$$\frac{4\,\mathrm{Re}\,(\epsilon_B)}{1+|\epsilon_B|^2} = -\frac{|q/p|^4 - 1}{|q/p|^4 + 1}\,, \tag{8}$$

neglecting quadratic terms in $\mathrm{Re}\,(\epsilon_B)$ [2]. One obtains

$$\frac{\mathrm{Re}\,(\epsilon_B)}{1+|\epsilon_B|^2} = -0.005 \pm 0.007 \pm 0.003\,. \tag{9}$$

For $|\epsilon_B| \ll 1$ this result simplifies to

$$\mathrm{Re}\,(\epsilon_B) = -0.005 \pm 0.007 \pm 0.003\,. \tag{10}$$

The $\mathrm{Re}\,(\epsilon_B)$ measurement is consistent with previous measurements from CLEO [17], CDF [18], and OPAL [19]. The systematic errors are obtained by varying cuts on the $b\bar{b}$ enrichment and the flavour tagging algorithm. The level of agreement between data and simulation for the flavour tagging is assumed to be 2%. Furthermore the limited Monte Carlo statistics for the extraction of B purity, B^0 fraction, and flavour misidentification is taken into account. Effects from the finite lifetime resolution, histogram binning, and experimental errors on the quantities ΔM and x_d are considered.

6 CP(T) Asymmetries in Semileptonic B Decays

The previous section discussed the measurement of the CP violation parameter $\mathrm{Re}\,(\epsilon_B)$ in totally inclusive final states. General principles of relativistic field theory require invariance under the combined transformation CPT. The quantity $\mathrm{Im}\,(\delta_B)$ is used to parametrise effects from indirect CPT violation [4].
In this section a measurement of the quantities $\mathrm{Re}\,(\epsilon_B)$ and $\mathrm{Im}\,(\delta_B)$ using semileptonic B decays is performed. In semileptonic (or more general in flavour specific) B decays the flavour of the B hadron can be reconstructed from the charge of the lepton. This is impossible for the inclusive final states discussed in section 4. A key quantity for semileptonic B decays is the difference of time-dependent asymmetries of decay probabilities, given by

$$\mathcal{D}(t) \equiv \frac{\Gamma(\bar{B}(t) \to \bar{f}) - \Gamma(\bar{B}(t) \to f)}{\Gamma(\bar{B}(t) \to \bar{f}) + \Gamma(\bar{B}(t) \to f)} - \frac{\Gamma(B(t) \to f) - \Gamma(B(t) \to \bar{f})}{\Gamma(B(t) \to f) + \Gamma(B(t) \to \bar{f})} . \tag{11}$$

This quantity is related to $\mathrm{Re}\,(\epsilon_B)$ and $\mathrm{Im}\,(\delta_B)$ [4]

$$\mathcal{D}(t) = -4\,\mathrm{Re}(\epsilon_B) \cdot (1 - \cos \Delta M t) + 4\,\mathrm{Im}(\delta_B) \cdot \sin \Delta M t\,. \tag{12}$$

In deriving this result, direct CPT violation and $\Delta B = \Delta Q$ violations are neglected. Furthermore $\Gamma_H = \Gamma_L$ is assumed.
The analysis is based on the inclusive B reconstruction described in section 3. Hemispheres containing a lepton with momentum greater than 3 GeV/c are selected, implying the standard DELPHI lepton identification routines [7, 20]. The identification efficiency for electrons (muons) in the barrel part of DELPHI is 70% (86%) with a hadron misidentification probability of 0.4% (0.7%). In order to enrich leptons from B decays, the lepton momentum p^* in the B rest frame has to be greater than 0.9 GeV/c. In the case more than one lepton is found in a hemisphere, the one with the largest p^* is retained. A cut on the B confidence variable is applied at 0.90 leading to a B purity of 97%. The data sample is divided into four classes according to the measured lepton charge Q_ℓ and the flavour $Q_{flav,o}$ in the opposite event hemisphere: (1) $Q_\ell > 0, Q_{flav,o} > 0$, (2) $Q_\ell > 0, Q_{flav,o} < 0$, (3) $Q_\ell < 0, Q_{flav,o} > 0$, and (4) $Q_\ell < 0, Q_{flav,o} < 0$. The misidentification probability for the assignment in the lepton hemisphere is 17%, the probability for a misassignment in the other hemisphere is 29%. These values are extracted from simulation. Using the measured lifetime in the lepton hemisphere and the given classification the asymmetry difference $\mathcal{D}(t)$ is calculated, taking into account the B purity, the B^0 fraction, and the flavour misidentification in the lepton hemisphere. Figure 4 shows the quantity $\mathcal{D}(t)$ as a function of time. The result is consistent with zero and no obvious time-dependent structure is observed. A two-parameter fit using formula 12 is performed, where the quantity ΔM is fixed to the PDG value ($\Delta M = 0.474 \pm 0.031\,\mathrm{ps}^{-1}$ [1]). For $\mathrm{Re}\,(\epsilon_B)$ and $\mathrm{Im}\,(\delta_B)$ one obtains

$$\mathrm{Re}\,(\epsilon_B) = -0.012 \pm 0.015 \pm 0.005 \tag{13}$$

$$\mathrm{Im}\,(\delta_B) = -0.011 \pm 0.017 \pm 0.005\,. \tag{14}$$

The result of the fit is superimposed in the Figure 4. Setting $\mathrm{Im}\,(\delta_B)$ to zero leads to

$$\mathrm{Re}\,(\epsilon_B) = -0.006 \pm 0.011 \pm 0.003\,. \tag{15}$$

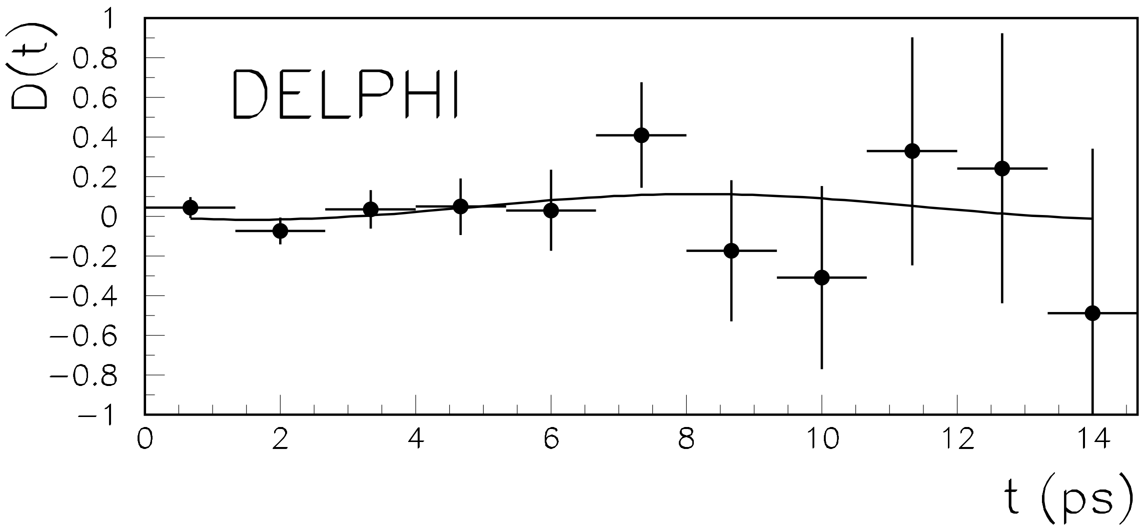

Figure 4: Asymmetry Difference $\mathcal{D}(t)$ for semileptonic B decays as a function of lifetime. The result of a two-parameter fit is superimposed.

The results are consistent with the analysis in section 5 and with previous measurements [17, 18, 19]. The systematic errors are obtained by varying cuts on the $b\bar{b}$ enrichment, the flavour tagging, and the lepton identification algorithm. Furthermore the limited Monte Carlo statistics for the extraction of the B purity, the B^0 fraction, and the flavour misidentifications is taken into account. Effects from the finite lifetime resolution, histogram binning, and the experimental error on the quantity ΔM are considered. In addition different samples with varying B^0 enrichment are studied.

7 CPT Lifetime Analysis

One of the simplest tests of CPT invariance is the equality of lifetimes of a particle and its antiparticle. In the presented analysis the lifetime difference is measured between B hadrons and $\bar{B}$ hadrons. The measurement is based on the inclusive B reconstruction described in section 3. A cut on the B confidence variable is applied at 0.98 leading to a B event purity of 97%. Then the data sample is divided into two classes. In order to avoid a bias in the lifetime measurement this is done according to the flavour $Q_{flav,o}$ in the opposite event hemisphere: (1) $Q_{flav,o} < -0.4$ - other hemisphere contains $\bar{B}$ hadron, (2) $Q_{flav,o} > 0.4$ - other hemisphere contains B hadron. Events with $|Q_{flav,o}| < 0.4$ are discarded. The misidentification probability for this assignment is 19%. The B hadron lifetime is derived from the inclusive secondary vertex fit with additional correction for the Lorentz boost. A resolution on the B hadron lifetime of 0.25 ps is achieved, with a bias of 0.10 ps due to the finite D meson lifetime. The obtained lifetime distributions for the two samples are shown in Figure 5. Fits to the distributions using exponential functions in the range 2 - 8 ps are performed and superimposed in Figure 5. The region below 2 ps is discarded in the fit because of the drop of reconstruction efficiency. Furthermore non-$b\bar{b}$ backgrounds become sizable in that region. For the lifetimes in the two samples one finds $\tau_{raw}(B \text{ hadron}) = 1.609 \pm 0.013 \pm 0.025$ ps and $\tau_{raw}(\bar{B} \text{ hadron}) = 1.589 \pm 0.013 \pm 0.025$ ps, in agreement with the known average B hadron lifetime. Including the correction for the

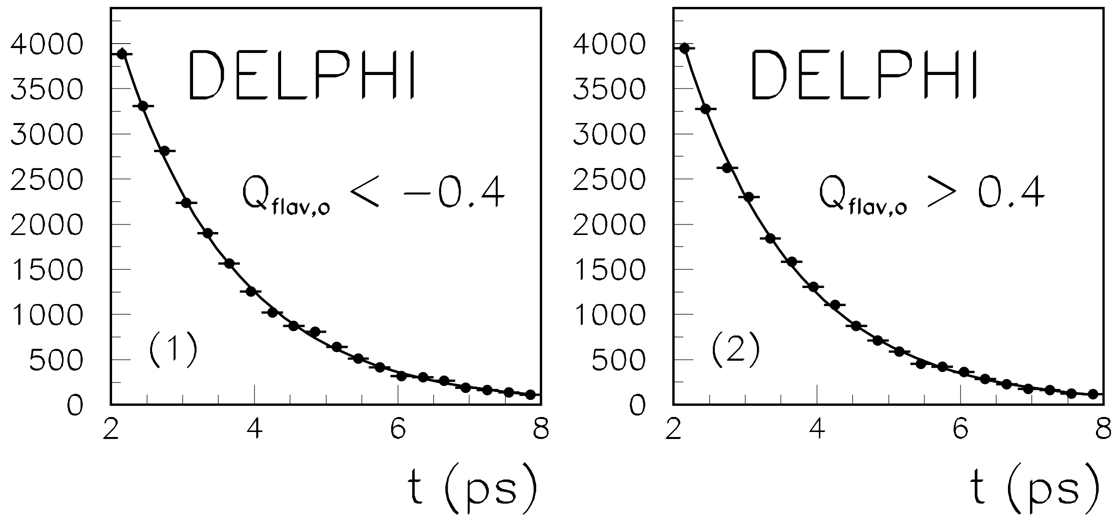

Figure 5: Lifetime distributions for B hadrons with (1) $Q_{flav,o} < -0.4$ and (2) $Q_{flav,o} > 0.4$. The result of fits to exponential functions are superimposed.

flavour misidentification one finds

$$\frac{\tau(B \text{ hadron}) - \tau(\bar{B} \text{ hadron})}{\tau(\text{average})} = 0.019 \pm 0.018 \pm 0.016\,. \tag{16}$$

The systematic errors are obtained by varying cuts on the $b\bar{b}$ enrichment and the flavour tagging algorithm. The limited Monte Carlo statistics for the extraction of the flavour misidentification is taken into account. The level of agreement between data and simulation for the flavour tagging is assumed to be 2%. Effects from different fit methods and varying fit ranges are considered. A large correlation between the systematic errors in the B hadron and the $\bar{B}$ hadron sample is assumed.
The result is consistent with zero. It is the first measurement of the lifetime difference for particle and antiparticle in the B system.

8 Summary

Using 1.8 million multi-hadronic Z^0 events recorded with the DELPHI detector at LEP tests of CP and CPT violation are performed. The possibility of observing CP violation in partially inclusive B decays with DELPHI data is discussed. A measurement of the CP violation parameter $\mathrm{Re}\,(\epsilon_B)$ using totally inclusive B decays yields

$$\frac{\mathrm{Re}\,(\epsilon_B)}{1 + |\epsilon_B|^2} = -0.005 \pm 0.007 \pm 0.003\,. \tag{17}$$

For $|\epsilon_B| \ll 1$ this result simplifies to

$$\mathrm{Re}\,(\epsilon_B) = -0.005 \pm 0.007 \pm 0.003\,. \tag{18}$$

From semileptonic B decays results on the CP violation parameter $\mathrm{Re}\,(\epsilon_B)$ and the CPT violation parameter $\mathrm{Im}\,(\delta_B)$ are extracted

$$\mathrm{Re}\,(\epsilon_B) = -0.012 \pm 0.015 \pm 0.005 \tag{19}$$

$$\mathrm{Im}\,(\delta_B) = -0.011 \pm 0.017 \pm 0.005\,. \tag{20}$$

Implying CPT conservation leads to

$$\mathrm{Re}\,(\epsilon_B) = -0.006 \pm 0.011 \pm 0.003\,. \tag{21}$$

One of the simplest tests of CPT invariance is the equality of lifetimes of a particle and its antiparticle. The lifetime difference between B hadrons and $\bar{B}$ hadrons is measured

$$\frac{\tau(B \text{ hadron}) - \tau(\bar{B} \text{ hadron})}{\tau(\text{average})} = 0.019 \pm 0.018 \pm 0.016\,. \tag{22}$$

The result is consistent with zero. It is the first measurement of the lifetime difference for particle and antiparticle in the B system. All results are preliminary.

Acknowledgements

We are greatly indebted to our technical collaborators and to the funding agencies for their support in building and operating the DELPHI detector, and to the members of the CERN-SL Division for the excellent performance of the LEP collider.

References

[1] Particle Data Group, Phys. Rev. **D54** (1996)

[2] A. Acuto, D. Cocolicchio, Phys. Rev. **D47** (1993) 3945

[3] D. Cocolicchio, L. Maiani, Phys. Lett. **B291** (1992) 155; J. Gerard, T. Nakada, Phys. Lett. **B261** (1991) 474; J. Liu, L. Wolfenstein, Phys. Lett. **B197** (1987) 537

[4] V. Kostelecky, R. Potting, Phys. Rev. **D51** (1995) 3923; V. Kostelecky, R. Van Kooten, Phys. Rev. **D54** (1996) 5585

[5] M. Beneke, G. Buchalla, I. Dunietz, *Mixing-induced CP Asymmetries in Inclusive B Decays*, FERMILAB-PUB-96/308-T, SLAC-PUB-7275

[6] DELPHI Collaboration, P. Aarnio *et al.*, Nucl. Instr. Meth. **A303** (1991) 233

[7] DELPHI Collaboration, P. Abreu *et al.*, Nucl. Instr. Meth. **A378** (1996) 57

[8] DELSIM User's Guide, DELPHI-Note 89-15 PROG 130; DELSIM Reference Manual, DELPHI-Note 89-68 PROG 143

[9] T. Sjöstrand, Comp. Phys. Comm. **82** (1994) 74

[10] W. de Boer, H. Fürstenau, *Comparison of DELPHI data with QCD models*, DELPHI Note 91-75 PHYS 129; K. Hamacher, M. Weierstall, *The next Round of Hadronic Generator Tuning heavily based on Identified Particle Data*, Wuppertal Univ. report WU B 95 07

[11] DELPHI Collaboration, P. Aarnio *et al.*, Z. Phys. **C54** (1992) 55

[12] W. Murray, *Improved B Tagging using Impact Parameters*, DELPHI-Note 95-167 PHYS 581

[13] C. Kreuter, PhD thesis, *Observation of Orbitally Excited B Mesons with the DELPHI Detector at LEP*, IEKP-KA/96-02

[14] M. Feindt, C. Kreuter, O. Podobrin, J. Yi, *Measurement of Inclusive Branching Ratios of the B^+ Meson*, contributed paper to the HEP'97 Conference, Jerusalem, 1997, Ref. 473, DELPHI-Note 97-100 CONF 82

[15] M. Bander, D. Silverman, A. Soni, Phys. Rev. Lett. **43** (1979) 242; J. Gerard, W. Hou, Phys. Rev. **D43** (1991) 2909; H. Simma, G. Eilam, D. Wyler, Nucl. Phys. **B352** (1991) 367; R. Fleischer, Z. Phys. **C58** (1993) 483

[16] A. Pais, S. Trieman, Phys. Rev. **D12** (1975) 2744; T. Altomari, L. Wolfenstein, J. Bjorken, Phys. Rev. **D37** (1988) 1860; M. Lusignoli, Z. Phys. **C41** (1989) 645

[17] CLEO Collaboration, J. Bartelt *et al.*, Phys. Rev. Lett. **71** (1993) 1680

[18] CDF Collaboration, F. Abe *et al.*, Phys. Rev. **D55** (1997) 2546

[19] OPAL Collaboration, K. Ackerstaff *et al.*, *A Study of B Meson Oscillations Using Hadronic Z^0 Decays Containing Leptons*, CERN-PPE/97-036

[20] C. Kreuter, *Electron Identification using a Neural Network*, DELPHI-Note 96-169 PHYS 658