BABAR TESTS OF LORENTZ AND *CPT* SYMMETRY

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Tests of CPT and T symmetries and a limit on the difference between the decay rates of the two mass eigenstates in B^0-mesons oscillations are reported. The reconstructed B decays, comprising both CP and flavor eigenstates, are obtained from $\Upsilon(4S) \to B\overline{B}$ decays collected by the *BABAR* detector at the PEP-II asymmetric-energy B Factory at SLAC. Sensitivity projections for sidereal time modulation of the CPT-violating parameter based on an explicit and general CPT-breaking standard model extension are also discussed.

1. Introduction

The original observation of CP violation in the B^0-meson system to states like $J/\psi K_s^0$ [1,2] and the current and foreseen high integrated luminosities at B factories have opened the window for more detailed investigations in B-meson decays. Among them, those which are receiving today a great deal of experimental and theoretical attention are CP asymmetries and other Unitarity Triangle related measurements, using the large number of different B-decay channels (with branching ratios of the order of $10^{-4} - 10^{-6}$) accessible in these experiments. Nevertheless, these are not the only studies required to fully understand the CP violation mechanism, and more generally the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix, of the standard model (SM). Moreover, although the mass difference between the B^0-mass eigenstates is known with high precision [3], our knowledge of other aspects of the reach phenomenology of B^0-meson oscillations is meager. In particular, the violation of CP symmetry may include the possibility of CPT violation in oscillation, as well as violation of the T symmetry and a difference between the lifetimes of the mass eigenstates. In addition, an explicit and general CPT-breaking standard model extension (SME) pre-

dicts that the CPT-violating effects, if present, should reveal a dependence with the magnitude and orientation of the B-meson momentum and a corresponding variation with sidereal time. All these CPT-violating effects could provide clear signature for GUT-scale physics [4].

2. Quark-Flavor oscillations in the B^0 system

The B^0-meson system is usually described by the effective Hamiltonian $\mathbf{H} = \mathbf{M} - i\mathbf{\Gamma}/2$, where $\mathbf{M}$ and $\mathbf{\Gamma}$ are two-by-two Hermitian matrices describing, respectively, the mass and decay-rate components. Under CP or CPT symmetry, $M_{11} = M_{22}$ and $\Gamma_{11} = \Gamma_{22}$[a]. In the limit of CP or T invariance, $\Gamma_{12}/M_{12} = \Gamma_{21}/M_{21} = \Gamma_{12}^*/M_{12}^*$, so Γ_{12}/M_{12} is real. The masses $m_{H,L}$ and decay rates $\Gamma_{H,L}$ of the two eigenstates of $\mathbf{H}$ form the complex eigenvalues $\omega_{H,L} \equiv m_{H,L} - \frac{i}{2}\Gamma_{H,L}$. The light and heavy B-meson mass eigenstates are superpositions of B^0 and $\overline{B}^0$ [5],

$$
\begin{aligned}
|B_L\rangle &= p\sqrt{1-\mathsf{z}}|B^0\rangle + q\sqrt{1+\mathsf{z}}|\overline{B}^0\rangle \ , \\
|B_H\rangle &= p\sqrt{1+\mathsf{z}}|B^0\rangle - q\sqrt{1-\mathsf{z}}|\overline{B}^0\rangle \ ,
\end{aligned}
\tag{1}
$$

where

$$
\mathsf{z} \equiv \frac{\delta m - \frac{i}{2}\,\delta\Gamma}{\Delta m - \frac{i}{2}\Delta\Gamma} \ , \quad
\frac{q}{p} \equiv -\sqrt{\frac{M_{12}^* - \frac{i}{2}\,\Gamma_{12}^*}{M_{12} - \frac{i}{2}\,\Gamma_{12}}} \ ,
\tag{2}
$$

with the definitions $\delta m \equiv M_{11} - M_{22}$, $\delta\Gamma \equiv \Gamma_{11} - \Gamma_{22}$, $\Delta m \equiv m_H - m_L$ and $\Delta\Gamma \equiv \Gamma_H - \Gamma_L$. The CPT-violating and phase-convention–independent quantity z [5b] either vanishes by the CPT theorem, or it depends on the 4-momentum of the B meson [4], as discussed in Sec. 3. A non-zero value of either δm or $\delta\Gamma$ is only possible if both CP and CPT are violated. Assuming CPT invariance ($\delta m = 0, \delta\Gamma = 0$), and anticipating $|\Delta\Gamma| \ll \Delta m$, $\Delta m \approx 2|M_{12}|$ and $\Delta\Gamma \approx 2|M_{12}|\,\mathrm{Re}(\Gamma_{12}/M_{12})$. Detailed SM calculations [6] find values for the ratio $\Delta\Gamma/\Delta m$ in the range -0.2% to -0.3%.

A state that is initially B^0 ($\overline{B}^0$) will develop a $\overline{B}^0$ (B^0) component over time, whose amplitude is proportional to the complex factor q/p (p/q),

$$
\begin{aligned}
|B^0{}_{\mathrm{phys}}(t)\rangle &= \left[g_+(t) + \mathsf{z}g_-(t)\right]|B^0\rangle - \sqrt{1-\mathsf{z}^2}\frac{q}{p}\,g_-(t)\,|\overline{B}^0\rangle \ , \\
|\overline{B}^0{}_{\mathrm{phys}}(t)\rangle &= \left[g_+(t) - \mathsf{z}g_-(t)\right]|\overline{B}^0\rangle - \sqrt{1-\mathsf{z}^2}\frac{p}{q}\,g_-(t)\,|B^0\rangle \ ,
\end{aligned}
\tag{3}
$$

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[a]The index 1 indicates B^0 and 2 indicates $\overline{B}^0$.
[b]The parameter z is equivalent to $\cos\theta$ in the $DE\theta\phi$ formalism, and to δ (to leading order) in the ϵ, δ (kaon system) formalism, see for example [4].

where $g_\pm(t) = (e^{-i\omega_H t} \pm e^{-i\omega_L t})/2$. Invariance under CP or under T requires that $|\langle B^0|\overline{B}^0{}_{\mathrm{phys}}(t)\rangle| = |\langle \overline{B}^0|B^0{}_{\mathrm{phys}}(t)\rangle|$, i.e., $|q/p| = 1$. Since the magnitude of $|q/p|^2 \approx 1 - \mathrm{Im}\frac{\Gamma_{12}}{M_{12}}$ is very nearly unity in the SM, this factor is usually assumed to be a pure phase. A detailed SM calculation yields $|q/p| - 1 = (2.5 - 6.5) \times 10^{-4}$ [6].

At the $\Upsilon(4S)$ resonance, B^0 mesons are produced in coherent p-wave pairs. If $A_{1,2}$ and $\overline{A}_{1,2}$ are the amplitudes for the decay of B^0 and $\overline{B}^0$, respectively, to the states f_1 (at time t_1) and f_2 (at some later time t_2), then the overall amplitude is given by $A = a_+ g_+(\Delta t) + a_- g_-(\Delta t)$, where $\Delta t = t_2 - t_1$ is the difference in proper decay times and

$$a_+ = -A_1\overline{A}_2 + \overline{A}_1 A_2 \; ,$$

$$a_- = \sqrt{1 - \mathsf{z}^2}\left[\frac{p}{q}A_1 A_2 - \frac{q}{p}\overline{A}_1\overline{A}_2\right] + \mathsf{z}\left[A_1\overline{A}_2 + \overline{A}_1 A_2\right] \; . \tag{4}$$

The decay rate then is [5]

$$\frac{\mathrm{d}N}{\mathrm{d}\Delta t} \propto e^{-\Gamma|\Delta t|}\left[\frac{|a_+|^2 + |a_-|^2}{2}\cosh\left(\frac{\Delta\Gamma\Delta t}{2}\right)\frac{|a_+|^2 - |a_-|^2}{2}\cos(\Delta m \Delta t) - \right.$$
$$\left. \mathrm{Re}(a_+^* a_-)\sinh\left(\frac{\Delta\Gamma\Delta t}{2}\right) + \mathrm{Im}(a_+^* a_-)\sin(\Delta m \Delta t)\right] \; , \tag{5}$$

where $\Gamma \equiv \frac{1}{2}(\Gamma_{11} + \Gamma_{22})$. Note that if the decay f_1 occurs second, we would need to redefine Δt, a_+ and a_- by interchanging the labels 1 and 2, which would leave Eq. (5) unaffected. Thus, we can retain the definitions $\Delta t = t_2 - t_1$ and those of Eq. (4). Terms proportional to $(q/p)\overline{A}_1\overline{A}_2$ and $(p/q)A_1 A_2$ ($A_1\overline{A}_2$ and $\overline{A}_1 A_2$) are associated with decays with net (no net) oscillation. Thus, the phase-convention-independent quantity

$$\lambda_f = \frac{q}{p}\frac{\overline{A}_f}{A_f} \tag{6}$$

can be associated to each final state f. This is the usual parameter used to characterize CP violation which involves interference between decays with and without net oscillation [7]. If one of the B mesons decay to a CP eigenstate f_{CP}, $\lambda_{CP} \equiv (q/p)(\overline{A}_{CP}/A_{CP})$, where A_{CP} ($\overline{A}_{CP}$) is the amplitude for $B^0 \to f_{CP}$ ($\overline{B}^0 \to f_{CP}$). CP violation is in this case characterized by $\lambda_{CP} \neq \eta_{CP}$ where $\eta_{CP} = \pm 1$ is the final state's CP eigenvalue. This is the type of CP violation observed in decays like $B \to J/\psi K_S^0$ [1,2]. Note that the other possible sources of CP violation contained in λ_{CP} are T violation ($|q/p| \neq 1$) and $|\overline{A}_{CP}/A_{CP}| \neq 1$ (direct CP violation).

The combined time dependence of B mesons decaying either to flavor (B_{flav}) or CP (B_{CP}) eigenstates provides sensitivity to the full set

of physical parameters, since they are determined either from different samples, or from different proper time dependence [5]. The sensitivity to $(\mathrm{Re}\,\lambda_{CP}/|\lambda_{CP}|)\,\mathrm{Re}\,\mathsf{z}$ and $\mathrm{Im}\,\lambda_{CP}/|\lambda_{CP}|$ is provided by B_{CP} decays, for which the Δt dependence is even for the former ($\cosh(\Delta\Gamma\Delta t/2)\approx 1$ coefficient) and odd ($\sin(\Delta m\Delta t)$ coefficient) for the latter. B_{flav} decays lack explicit dependence on $\mathrm{Im}\,\lambda_{CP}/|\lambda_{CP}|$ and the dependence on $\mathrm{Re}\,\mathsf{z}$ is scaled by the $\sinh(\Delta\Gamma t/2)$ term, which is small for small $\Delta\Gamma^{\mathrm{c}}$. In contrast, the parameters $|q/p|$ and $\mathrm{Im}\,\mathsf{z}$ (and Δm) are determined by the B_{flav} decays due to its relative abundance compared to B_{CP} decays, where the former is associated with a Δt-even distribution and the latter with a Δt-odd ($\sin(\Delta m\Delta t)$ coefficient) distribution. The sensitivity to $|q/p|$ comes mostly from the B_{flav} sample since violation of CP and T in mixing leads to a difference between the $B^0 \to \overline{B}^0$ and $\overline{B}^0 \to B^0$ oscillation amplitudes proportional to $|q/p|^4 - 1$ [8]. For small values of $\Delta\Gamma/\Gamma$, the determination of $\Delta\Gamma/\Gamma$ is dominated by the B_{CP} sample, since the leading dependence on $\Delta\Gamma$ is linear for B_{CP} decays, while it is quadratic for B_{flav} states. Moreover, the contribution of $\sinh(\Delta\Gamma t/2)$ do not depend on whether the other B meson (B_{tag}) is identified ("tagged") as B^0 or $\overline{B}^0$, so untagged data can be included to improve the sensitivity to $\Delta\Gamma$. We cannot determine $\Delta\Gamma/\Gamma$ and $\mathrm{Re}\,\mathsf{z}$ directly because both occur multiplied by $\mathrm{Re}\,\lambda_{CP}$ in their dominant contributions to the decay rate.

3. Sidereal time modulation of *CPT*-violating effects

Using the SME, a perturbative calculation to leading order returns

$$\delta m, \delta\Gamma \approx \beta^{\mu}\Delta a_{\mu} , \tag{7}$$

where $\beta^{\mu} = \gamma(1, \vec{\beta})$ is the four-velocity of the B-meson state in the laboratory frame, and Δa_{μ} are the *CPT*- and Lorentz-violating coupling coefficients [4]. Equation (7) reveals that the *CPT*-parameter z will be affected by the meson-momentum magnitude and orientation in the laboratory frame. As a consequence, since laboratory frame rotates with Earth, if *CPT*-violating effects exist, z will exhibit a sidereal time dependence after converting to a non-rotating frame. Defining the non-rotating frame to be compatible with celestial equatorial coordinates [9] with Z-axis aligned along the Earth's rotation axis, and taking the laboratory z-axis aligned

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[c] Note that a non-zero value of either δm_d or $\delta\Gamma_d$ is only possible if both CP and CPT are violated.

with the direction of the colliding beams, the expression for $z \equiv z(\tilde{t}, \vec{p})$ is found to be [4]

$$z \approx \frac{\gamma}{\Delta m - \frac{i}{2}\Delta\Gamma} \left[\Delta a_0 + \beta\Delta_Z \cos\chi + \beta\sin\chi \left(\Delta a_Y \sin\Omega\tilde{t} + \Delta a_X \cos\Omega\tilde{t} \right) \right] \ ,$$

(8)

where $\tilde{t}$ denotes the sidereal time, Ω the Earth's sidereal frequency and χ the angle between the laboratory (beam) z-axis and the Earth's rotation axis ($\cos\chi = zZ = \cos\theta\cos\phi$, θ and ϕ being the polar and azimuthal coordinates of the detector with respect to the non-rotating frame). Therefore, in addition to the proper-time dependence, Eq. (5) also contains sidereal-time and momentum dependence from $z(\tilde{t}, \vec{p})$. In deriving Eq. (8) it is assumed that the B mesons move along the z-axis with equal momenta, which is a good approximation at B factories operating close the $\Upsilon(4S)$ resonance. Since the meson decays occur quickly on the sidereal-time scale, we can treat $\tilde{t}$ as a parameter independent of Δt, and therefore it is appropriate to take z as independent of Δt but varying with $\tilde{t}$. Note that any measurement that ignores the dependence on $\tilde{t}$ and meson momentum eliminates sensitivity to Δa_X and Δa_Y components, being only sensitive to an average value of the first two terms of Eq. (8). Thus direct comparison of *CPT* results must be done carefully since the results are experiment dependent.

4. The experimental setup

The PEP-II machine consists of two rings (2.2 km circumference), one of 9.0 GeV (e^-) and one of 3.1 GeV (e^+), housed in the former PEP tunnel, with a single collision point. The machine uses the SLAC linac as injector. Table 1 summarizes some of the most relevant design and achieved parameters of the machine. The high luminosities (instantaneous and integrated) are achieved through strong focusing, high currents, large number of bunches and continuous ("trickle") injection. The asymmetric energy of the beams results in a boost $\beta\gamma$ for the B mesons along the e^- direction (z-axis) of about 0.56 in laboratory frame. The collider has delivered since the November 1999 until July 2004 a total of 254 fb^{-1} (about 266 million $\Upsilon(4S) \rightarrow B\overline{B}$ decays), of which 244 fb^{-1} (256 million) have been recorded by *BABAR*. Current luminosity projections estimate a total integrated luminosity of $1 - 2$ ab^{-1} by the end of the decade. At the single PEP-II collision point is placed the *BABAR* detector, which is described in detail elsewhere [10]. Figure 1 shows an schematic view of the detector and its components together with their main performances.

Table 1.   PEP-II design and reached main parameters.

	Design	Reached
$E[\,\mathrm{GeV}]\ e^-/e^+$	9.0/3.1	yes
$I[mA]\ e^-/e^+$	0.6/1.3	0.98/1.54(1-05-04)
Number of bunches	1658	1588
$L[\,\mathrm{cm}^{-2}s^{-1}]$	3×10^{33}	9.2×10^{33}(21-05-04)
$L_{int}[\,\mathrm{pb}^{-1}/\mathrm{day}]$	135	710.5(24-05-04)
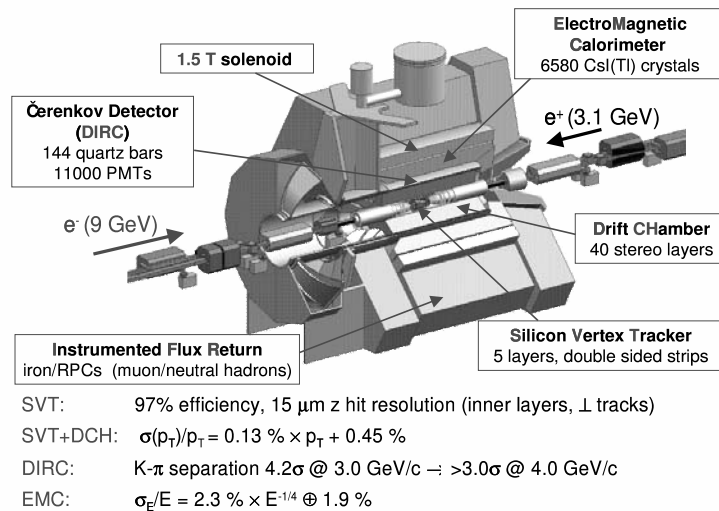
Figure 1.   Schematic view of the *BABAR* detector and its subsystems, together with some of the main performances.

5. Results with fully reconstructed B decays

The measurement of $\Delta\Gamma/\Gamma$, and CP, T, and CPT violation in mixing has been performed by analyzing $\Upsilon(4S)$ decays in which one neutral-B meson is fully reconstructed and the other is identified as being either B^0 or $\overline{B}^0$ on the basis of the charges of leptons and kaons, and other indicators of flavor [5], assuming constant CPT-violating parameters. We reconstruct the flavor states [d] $B_{\mathrm{flav}} = D^{(*)-}\pi^+(\rho^+, a_1^+)$ and $J/\psi\,K^{*0}(\to K^+\pi^-)$ and the CP eigenstates $B_{CP} = J/\psi\,K_S^0$, $\psi(2S)K_S^0$, $\chi_{c1}K_S^0$, and $J/\psi\,K_L^0$. The data sample consists of 88 million $\Upsilon(4S) \to B\overline{B}$ decays (only about one third of the

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[d]Charge conjugation is implied throughout this letter, unless explicitly stated otherwise.

total recorded statistics), which corresponds to approximately 31,000 B_{flav} and 2,600 CP eigenstates. The time interval Δt between the two B decays is calculated from the measured separation Δz between the decay vertices of B_{rec} and B_{tag} along the boost direction (z-axis) [7], $\Delta t \equiv t_{\text{rec}} - t_{\text{tag}} \approx \Delta z/(\beta\gamma c)$.

The measurement requires a precision analysis since competing physics and detector effects that can mimic the behavior we seek must be included [5]. First, the resolution for Δt is comparable to the B lifetime and is asymmetric in Δt. This asymmetry must be well understood lest it be mistaken for a fundamental asymmetry. Second, tagging assigns flavor incorrectly some fraction of the time. Third, interference between weak decays favored by the CKM quark-mixing matrix ($b \to c\bar{u}d$, e.g. $B^0 \to D^-\pi^+$) and those doubly-Cabibbo-suppressed (DCS) ($b \to u\bar{c}d$, e.g. $\overline{B}^0 \to D^-\pi^+$), roughly proportional to $|V_{\text{ub}}V_{\text{cd}}^*/V_{\text{cb}}^*V_{\text{ud}}| \approx 0.02$, has to be explicitly taken into account. Fourth, direct CP violation in the B_{CP} sample could mimic CP violation in mixing and must be parameterized appropriately. Finally, we have to account for possible asymmetries induced by the differing response of the detector to positively and negatively charged particles. To disentangle all these issues we rely mainly on data, making use of a simultaneous maximum-likelihood fit to the time distributions of tagged and untagged, flavor and CP eigenstates. Backgrounds are primarily due to misreconstructed candidates and are studied in data using sidebands. A total of 58 free parameters (32 modeling the signal and 26 the background) are determined with the likelihood fit [5]. The results are

$$
\begin{aligned}
\text{sgn}(\text{Re}\,\lambda_{CP})\Delta\Gamma/\Gamma = &\quad -0.008 \pm 0.037(\text{stat.}) \pm 0.018(\text{syst.})[-0.084, 0.068]\ , \\
|q/p| = &\quad 1.029 \pm 0.013(\text{stat.}) \pm 0.011(\text{syst.})[\ \ 1.001, 1.057]\ , \\
(\text{dileptons}) &\quad 0.998 \pm 0.006(\text{stat.}) \pm 0.007(\text{syst.})[\ \ 0.983, 1.013]\ , \\
(\text{Re}\,\lambda_{CP}/|\lambda_{CP}|)\,\text{Re}\,\mathsf{z} = &\quad 0.014 \pm 0.035(\text{stat.}) \pm 0.034(\text{syst.})[-0.072, 0.101]\ , \\
\text{Im}\,\mathsf{z} = &\quad 0.038 \pm 0.029(\text{stat.}) \pm 0.025(\text{syst.})[-0.028, 0.104]\ .
\end{aligned}
$$

The values in square brackets indicate the 90% confidence-level (CL) intervals. The measurements of $\text{sgn}(\text{Re}\,\lambda_{CP})\Delta\Gamma/\Gamma$ and $|q/p|$ in the limit when CPT conservation is assumed are unchanged. The largest statistical correlation among the physics parameters appears between $\text{Im}\,\lambda_{CP}/|\lambda_{CP}|$ and $\text{Im}\,\mathsf{z}$, which amounts to 17.4%. The second result of $|q/p|$ corresponds to the measurement performed when the two B mesons are reconstructed using high momentum leptons from semileptonic decays (dilepton events) [8]. This measurement constrains $|q/p|$ without assumptions on the value of

z. Figure 2 (left) shows the results in the $(|q/p|\text{-}1, |z|)$ plane, compared to the the SM expectations. If we express the CPT limits as ratios of the CPT-violating to the CPT-conserving terms we have

$$\frac{|\delta m|}{m} < 1.0 \times 10^{-14} \quad , \quad -0.156 < \frac{\delta\Gamma}{\Gamma} < 0.042$$

at the 90% CL. The parameters $\mathrm{Im}\,\lambda_{CP}/|\lambda_{CP}|$ and Δm are consistent with recent B-factory results [1,2,3]. The value of the CP- and T-violating parameter $\mathrm{Im}\,\lambda_{CP}/|\lambda_{CP}|$ increases by $+0.011$ when CPT violation is allowed, which is consistent with the correlations observed in the fit with CPT violation. The value of Δm remains unchanged between the two fits. Most contributions to the systematic uncertainties are determined with data and will decrease with additional statistics. The largest single source of uncertainty is the DCS contribution to $(\mathrm{Re}\,\lambda_{CP}/|\lambda_{CP}|)\,\mathrm{Re}\,z$ (0.032). This contribution will decrease since with additional statistics a better (and less conservative) treatment of DCS effects will be possible [5]. The $\mathrm{sgn}(\mathrm{Re}\,\lambda_{CP})\Delta\Gamma/\Gamma$ and $|q/p|$ measurements can be used to set constraints on the complex ratio Γ_{12}/M_{12}, as shown in Fig. 2 (right). Solid contours show the results assuming $\mathrm{Re}\,\lambda_{CP} > 0$ (as expected in the SM based on other experimental constraints), while dashed contours are for $\mathrm{Re}\,\lambda_{CP} < 0$. Inner (outer) contours represent 68% (90%) CL regions for two degrees of freedom. The black region shows the predictions of SM calculations when all available experimental inputs are used [5].
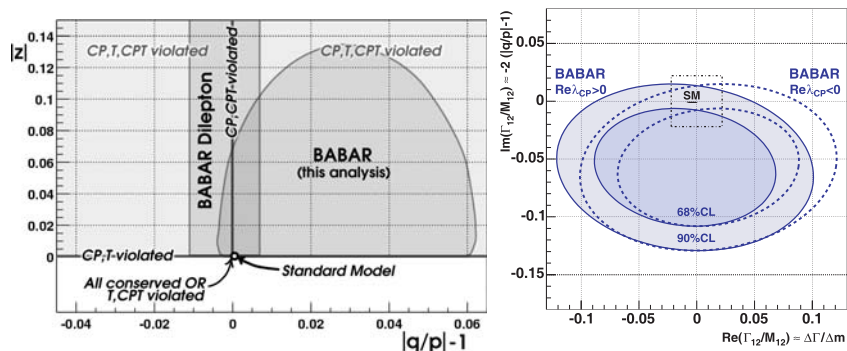

Figure 2.   (Left) Favored regions at 68% CL in the $(|q/p| - 1, |z|)$ plane, compared to SM expectation. The axis labels reflect the requirements that both CP and T be violated if $|q/p| \neq 1$ and that both CP and CPT be violated if $|z| \neq 0$. (Right) Constraints at 68% and 90% CL on Γ_{12}/M_{12} as determined from the $\mathrm{sgn}(\mathrm{Re}\,\lambda_{CP})\Delta\Gamma/\Gamma$ and $|q/p|$ measurements, compared to SM calculations.

6. Sensitivity to *CPT*-breaking sidereal time modulation

As discussed in Sec. 3 and explicitly shown in Eq. (8), the *CPT*-violating parameter z, if non-zero, depends on center-of-mass boost ($\beta\gamma$), latitude of the collider (θ) and azimuthal orientation of boost direction (ϕ). The approximate values of these parameters for *BABAR* (Belle) are estimated to be 0.554, 37.42°N, and S35°E (0.425, 36.15°N, and S45°E), respectively, from which we estimate $\cos\chi = -0.65(-0.57)$ and $\sin\chi = 0.76(0.82)$. This implies that Belle's boost direction benefits sidereal time varying terms, but *BABAR*'s boost is larger, enhancing slightly all terms of Eq. (8), as shown in Table 2. In order to estimate the sensitivity to *CPT*-breaking sidereal

Table 2. Sidereal time dependence coefficients of Eq. (8) at *B* factories.

Term	Coefficient	*BABAR*	Belle
Δa_0	γ	1.14	1.09
Δa_Z	$\beta\gamma\cos\chi$	-0.36	-0.24
$\Delta a_X/\Delta a_Y$	$\beta\gamma\sin\chi$	0.42	0.35

modulation a *CPT* asymmetry sensitive to z can be defined as [4]

$$A_{f\bar{f}}^{CPT}(\Delta t, \tilde{t}) = \frac{\Gamma_{f\bar{f}}(\Delta t > 0, \tilde{t}) - \Gamma_{f\bar{f}}(\Delta t < 0, \tilde{t})}{\Gamma_{f\bar{f}}(\Delta t > 0, \tilde{t}) + \Gamma_{f\bar{f}}(\Delta t < 0, \tilde{t})} \approx \frac{-2\,\mathrm{Im}\,\mathsf{z}\sin\Delta m\Delta t}{1 + \cos\Delta m\Delta t}, \quad (9)$$

only valid to first order in z and $\Delta\Gamma$, and where $f(\bar{f})$ denotes here a flavor eigenstate and its *CP* conjugate. Figure 3 shows this asymmetry for dimuon ($e^+e^- \to \Upsilon(4S) \to \mu^+\mu^-$) events as a function of sidereal and Pacific time, using a data sample of about 100 fb^{-1}. These events provide a $\Delta t = 0$ ($A_{f\bar{f}}^{CPT} = 0$) benchmark, which can be used to evaluate not only the sensitivity but also detector biases and systematic effects to be used for correcting the signal data. A sensitivity on $A_{f\bar{f}}^{CPT}$ at 10^{-3} level translates into a sensitivity on z of about 10^{-2}. With full *BABAR* statistics at the end of the decade, the sensitivity will reach 10^{-3}.

7. Summary

Using one third of the data already recorded by *BABAR*, we have performed a simultaneous measurement of the difference $\Delta\Gamma/\Gamma$ between the decay rates, and of *CP*, *T* and *CPT* violation in the B^0-meson system. The limits on $\Delta\Gamma/\Gamma$ and *T* violation in mixing have reached a precision at the level of 8% and 1% (90% CL), respectively, largely improving previous results [11]. The *CPT* measurements, $|\delta m|/m < 1.0 \times 10^{-14}$ and $-0.156 < \delta\Gamma/\Gamma < 0.042$,
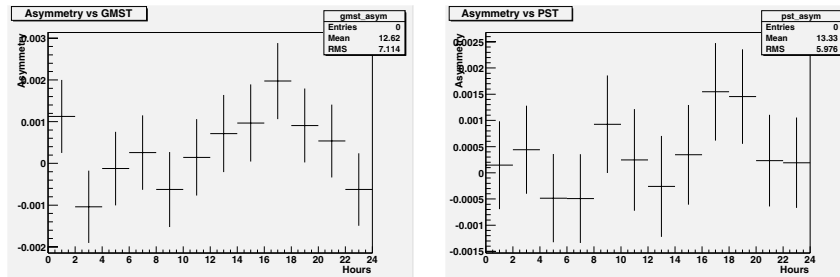
Figure 3. *CPT* asymmetry $A_{f\bar{f}}^{CPT}(\Delta t, \tilde{t})$ as defined in Eq. (9) for $e^+e^- \to \Upsilon(4S) \to \mu^+\mu^-$ events as a function of sidereal (left) and Pacific (right) time, from about 100 fb^{-1}.

represent the strongest and more general *CPT* invariance test in the B^0 system to date [12]. Previous mixing and *CP BABAR* measurements performed neglecting these effects are unaffected at this level of precision. We have also discussed within the framework of a general extension of the SM the sensitivity of the *CPT*-violating parameter to sidereal-time modulation. The magnitude and direction of the boost of the PEP-II machine and the latitude of the *BABAR* detector makes the experiment sensitive to sidereal modulation. The large data sample already recorded and the projections for the forthcoming years will provide the opportunity to perform high precision measurements in $B\overline{B}$ oscillations which may bring surprises.

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