Tests of $T$ and $CPT$ symmetries at the $B$-Factories

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Abstract. Precision tests of the discrete symmetries $T$ and $CPT$ have been performed relying on large samples of clean events from $e^+e^-$ annihilations, which have been collected by the Belle and BABAR $B$-factories. In particular, large samples of coherently produced $B$-meson pairs have provided especially favorable conditions for testing the Standard Model predictions regarding indirect $T$ and $CPT$ violation in $B$-mixing. The most interesting and recent results are reported in the following.

1. Introduction
To date, there is no evidence of $CPT$ violation in physical phenomena, and the Standard Model (SM) – being a local, Lorentz-invariant theory of point-like particles – predicts that $CPT$ exactly holds. In the context of the SM, the sole source of $T$ violation is the irreducible Kobayashi-Maskawa phase [1]. Observation of $CPT$ violation or of $T$ violation incompatible with the SM predictions would be an indication of new physics beyond the SM. The Belle and BABAR $B$-factories produced unprecedented samples of coherent $B$-meson pairs, which are particularly suited for testing indirect $CPT$ and $T$ violation in mixing. Additional tests on discrete symmetries have been performed on $B$-mesons decays and on precision measurements of the tau lepton mass and lifetime.

2. Discrete symmetries in $B^0\overline{B}^0$ oscillations
The neutral-$B$-meson system can be described by the complex effective Hamiltonian $H_{ij} = M_{ij} - i\Gamma_{ij}/2$, where $i, j = 1$ indicates $B^0$ and $i, j = 2$ indicates $\overline{B}^0$, while $M_{ij}$ and $\Gamma_{ij}$ are two-by-two Hermitian matrices that describe the mass and decay-rate amplitudes, respectively. The solutions (the physical states) can be written as [2]:

$$|B_L\rangle = p\sqrt{1-z}|B^0\rangle + q\sqrt{1+z}|\overline{B}^0\rangle, \quad |B_H\rangle = p\sqrt{1+z}|B^0\rangle - q\sqrt{1-z}|\overline{B}^0\rangle.$$  \hfill (1)

where $H$ and $L$ denote the Heavy and Light eigenstates, respectively, and $p$, $q$ and $z$ are defined as follows:

$$\frac{q}{p} \equiv -\sqrt{\frac{M_{12}^* + \frac{i}{2}\Gamma_{12}^*}{M_{12}^* - \frac{i}{2}\Gamma_{12}}}; \quad \frac{q}{p} \approx 1 - \frac{\Gamma_{12}}{M_{12}};$$ \hfill (2)

$$z \equiv \frac{\delta m - \frac{i}{2}\delta\Gamma}{2\sqrt{(M_{12}^* - \frac{i}{2}\Gamma_{12}) (M_{12}^* + \frac{i}{2}\Gamma_{12}) + \frac{1}{4}((\delta m - \frac{i}{2}\delta\Gamma)^2)} = \frac{\delta m - \frac{i}{2}\delta\Gamma}{\Delta m - \frac{i}{2}\Delta\Gamma};$$ \hfill (3)
with:

\[
\begin{align*}
m & \equiv \frac{1}{2}(M_{11} + M_{22}), \\
\omega_{H,L} & \equiv m_{H,L} - \frac{1}{2}\Gamma_{H,L} = m - \frac{1}{2}\Gamma \pm \sqrt{(M_{12} - \frac{1}{2}\Gamma_{12})(M_{22} - \frac{1}{2}\Gamma_{12}) + \frac{1}{4}(\delta m \pm \frac{\delta \Gamma}{2})^2}, \\
\Delta m & \equiv m_{H} - m_{L} \approx 2|M_{12}|, \\
\delta m & \equiv M_{11} - M_{22}, \\
\Delta \Gamma & \equiv \Gamma_{H} - \Gamma_{L} \approx 2|M_{12}| \text{Re}(\Gamma_{12}/M_{12}), \\
\delta \Gamma & \equiv \Gamma_{11} - \Gamma_{22}.
\end{align*}
\]

In \( B^0\bar{B}^0 \) mixing, \( CPT \) conservation implies \( z = 0 \), while \( T \) (and \( CP \)) conservation implies \( |q/p|^2 - 1 = 0 \approx \text{Im}(\Gamma_{12}/M_{12}) \). The SM predicts no indirect \( CPT \) violation in mixing (\( z = 0 \)), a small amount of \( T \) (and \( CP \)) violation (\( |\text{Im}(\Gamma_{12}/M_{12})| < 10^{-3} \)), and approximately equal lifetimes (\( \Delta \Gamma/\Gamma \approx 3 \times 10^{-3} \)) \cite{3, 4, 5}.

At the \( \Upsilon(4S) \) resonance, neutral \( B \) mesons are produced in coherent \( p \)-wave pairs, where each meson then evolves as just described. The experimental measurements detect the final states of the two mesons \( f_1, f_2 \) at the times \( t_1, t_2 \) of their decay. The probability density functions (PDF) of each experimental observation \( [f_1, t_1, f_2, t_2] \) can be computed using the neutral \( B \) mesons time evolution, the decay amplitudes from each \( B \) flavor state \( B^0 \) and \( \bar{B}^0 \) to the experimental final states, and the experimental resolution and uncertainties. The PDF only depends on the time difference of the two decays, \( \Delta t = t_2 - t_1 \). By fitting a sufficient sample of experimental observations, most theoretical and experimental parameters can be individually determined, including \( |q/p|^2 - 1 \) and \( z \), which describe \( T \) and \( CPT \) indirect violation in mixing, respectively.

3. \( T \) and \( CPT \) tests with fully reconstructed \( B \) mesons

Tests on \( T \) and \( CPT \) symmetries have been performed by \( \text{BABAR} \) on \( \Upsilon(4S) \) \( B \) pair events containing one fully reconstructed \( B \) (\( B_{\text{rec}} \)), which corresponds to either a flavor eigenstate (\( B_{\text{flav}} \)) or to a \( CP \) eigenstate (\( B_{\text{CP}} \)) composed of charmonium and a \( K^0 \) or a \( K^0 \) \cite{2}. The state of the other \( B \) (\( B_{\text{tag}} \)) at decay time is identified (‘tagged’) as either a \( B^0 \) or a \( \bar{B}^0 \) by using the remaining particles in the events. Flavor tagging relies on the \( B \) flavor correlation with the sign of primary leptons, \( K \) mesons and low momentum pions from \( D^{*-} \) decay.

In addition to \( B \) oscillations, the theory model for such correlated \( B \) pairs depends on the amplitudes \( A_f \) and \( \overline{A}_f \) for the decay of \( B^0 \) and \( \bar{B}^0 \), respectively, to the final state \( f \). This dependence can be accounted by terms \( \lambda_f \) defined as

\[
\lambda_f = \frac{q}{p} \frac{\overline{A}_f}{A_f} \quad (5)
\]

where \( f \) can be “\( \text{rec} \)” (which can be itself “\( \text{flav} \)” or “\( \text{CP} \)” or “\( \text{tag} \)”)

For this analysis, \( A_f \) and \( \overline{A}_f \) must include the contribution of doubly-Cabibbo-suppressed transitions, therefore they are never exactly zero and the terms \( \lambda_f \) are always non-zero and finite. For tagged \( B \) mesons, there is a non negligible probability of mismeasuring the flavor (mistag fraction, \( w_f \)), which is included as a parameter in the model and fitted on data. Rather than fitting individual \( \lambda_f \) and \( w_f \) parameters for each final state, it is convenient to consider ensembles of final state which correspond to either flavor of \( CP \) eigenstates, and which can be with good approximation collectively modeled by single effective \( \lambda \) and \( w \) parameters. Of particular importance for the global fit results is the effective term \( \lambda_{\text{CP}} \), which corresponds to the ensemble of \( CP \) final states: this term cannot be entirely disentangled from the real part of the \( z \) parameter and only the product of the two is actually measured in this analysis.

All selected events are simultaneously fitted to a model that includes 58 parameters, including \( \Delta M \) and \( \Delta \Gamma \) but excluding \( M \) and \( \Gamma \), which are fixed from the measured neutral \( B \) mass and lifetime. About 88 million \( \Upsilon(4S) \to BB \) decays collected with the \( \text{BABAR} \) detector are analyzed,
resulting in samples of approximately 31,000 fully reconstructed flavor eigenstates and 2,600 CP eigenstates. The fit results are:

\[
\text{sgn}(\text{Re } \lambda_{\text{CP}}) \frac{\Delta \Gamma}{\Gamma} = -0.008 \pm 0.037\text{(stat.)} \pm 0.018\text{(syst.)} \quad [-0.084, 0.068],
\]
\[
|q/p| = 1.029 \pm 0.013\text{(stat.)} \pm 0.011\text{(syst.)} \quad [1.001, 1.057],
\]
\[
(\text{Re } \lambda_{\text{CP}}/|\lambda_{\text{CP}}|) \text{ Re } z = 0.014 \pm 0.035\text{(stat.)} \pm 0.034\text{(syst.)} \quad [-0.072, 0.101],
\]
\[
\text{Im } z = 0.038 \pm 0.029\text{(stat.)} \pm 0.025\text{(syst.)} \quad [-0.028, 0.104].
\]

The values in square brackets indicate the 90% confidence-level intervals. When the fit is performed assuming CPT invariance, a more precise result is obtained for indirect CP violation.

\[
\text{sgn}(\text{Re } \lambda_{\text{CP}}) \frac{\Delta \Gamma}{\Gamma} = -0.009 \pm 0.037\text{(stat.)} \pm 0.018\text{(syst.)} \quad [-0.085, 0.067],
\]
\[
|q/p| = 1.029 \pm 0.013\text{(stat.)} \pm 0.011\text{(syst.)} \quad [1.001, 1.057].
\]

The dominant systematic uncertainties come from the Monte Carlo simulation of B pair events decays for |q/p| and Im z and from approximations on the phases of the doubly-Cabibbo-suppressed amplitudes for Re z.

All results are compatible with the SM predictions. Assuming CPT invariance, constraints can be set on the complex ratio \(\Gamma_{12}/M_{12}\), as shown in Fig. 1. Ellipses in the upper figure enclose the favored regions determined from the sgn(Re \(\lambda_{\text{CP}}\)) \(\Delta \Gamma/\Gamma\) and |q/p| measurements with z fixed to zero. Solid contours show the results assuming Re \(\lambda_{\text{CP}} > 0\) (as expected in the Standard Model based on other experimental constraints), while dashed contours are for Re \(\lambda_{\text{CP}} < 0\). Inner (outer) contours represent 68% (90%) confidence-level regions for two degrees of freedom. The lower figure is an enlargement of the region around the origin of the complex \(\Gamma_{12}/M_{12}\) plane. The black region close to the origin of the complex plane in the upper and lower figures shows the predictions of the Standard Model.
4. T and CPT tests with pairs of B mesons both decaying to leptons

Three different measurements [7, 8, 9] have tested indirect T and CPT violation on inclusive dilepton events, where the two B mesons produced in a coherent state at \( \Upsilon(4S) \) resonance both decay semileptonically \( b \to X \ell \nu \) (\( \ell = e \) or \( \mu \)). Dilepton events represent 4% of all \( \Upsilon(4S) \to B \bar{B} \) decays, and direct leptons from \( b \to \ell \) provide an effective way of identifying the state of B mesons at the time of their decay according to the charge of the lepton \( \ell^+(\ell^-) \); furthermore, the relatively high momentum leptons are useful to reconstruct the B mesons decay time.

Defining the difference between the decay times as \( \Delta t = t^+ - t^- \), where \( t^+ (t^-) \) is the decay time of the neutral B tagged by \( \ell^+ (\ell^-) \), and neglecting second order terms in \( z \), the decay rates for the three configurations \( \langle \ell^+ \ell^+, \ell^- \ell^- \rangle \) and \( \langle \ell^+ \ell^-, \ell^- \ell^+ \rangle \) are given by

\[
N^{++} \propto e^{-|\Delta t|/2} \frac{p}{q} \left\{ \cosh\left(\frac{\Delta t}{2}\right) - \cos(\Delta m \Delta t) \right\}, \\
N^{--} \propto e^{-|\Delta t|/2} \frac{q}{p} \left\{ \cosh\left(\frac{\Delta t}{2}\right) - \cos(\Delta m \Delta t) \right\}, \\
N^{+-} \propto e^{-|\Delta t|/2} \left\{ \cosh\left(\frac{\Delta t}{2}\right) - 2 \Re z \sinh(\frac{\Delta t}{2}) + \cos(\Delta m \Delta t) + 2 \Im z \sin(\Delta m \Delta t) \right\},
\]

where \( \Delta m \) is the \( B^0 - \bar{B}^0 \) oscillation frequency, \( \Gamma \) is the average neutral B decay rate and \( \Delta \Gamma \) is the decay rate difference between the two physical states.

The same-sign dilepton asymmetry \( A_{T/CP} \), between the two oscillation probabilities \( P(B^0 \to B^0) \) and \( P(B^0 \to \bar{B}^0) \) probes directly the T (and CP) symmetry and can be expressed in terms of \( \frac{q}{p} \):

\[
A_{T/CP} = \frac{P(B^0 \to B^0) - P(B^0 \to \bar{B}^0)}{P(B^0 \to B^0) + P(B^0 \to \bar{B}^0)} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}.
\]

The opposite-sign dilepton asymmetry, \( A_{CPT/CP} \), between events with \( \Delta t > 0 \) and \( \Delta t < 0 \) compares the \( B^0 \to B^0 \) and \( \bar{B}^0 \to \bar{B}^0 \) probabilities and is sensitive to CPT (and CP) violation. This asymmetry is expressed as

\[
A_{CPT/CP}(\Delta t) = \frac{P(B^0 \to B^0) - P(\bar{B}^0 \to \bar{B}^0)}{P(B^0 \to B^0) + P(\bar{B}^0 \to \bar{B}^0)} = \frac{N^{+-}(\Delta t > 0) - N^{+-}(\Delta t < 0)}{N^{++}(\Delta t > 0) + N^{++}(\Delta t < 0)}
\approx 2 \Im z \sin(\Delta m \Delta t) - \Re z \sinh(\Delta m \Delta t/2).
\]

Since \( |\Delta \Gamma|/\Gamma \ll 1 \), then \( \Re z \cdot \sinh(\Delta \Gamma \Delta t/2) \approx \Delta \Gamma \times \Re z \cdot (\Delta t/2) \) and this asymmetry is not sensitive to the CPT-violating term \( \Re z \) alone, but rather but to the product \( \Delta \Gamma \times \Re z \).

The Babar collaboration has published results based on about \( 232 \times 10^6 B \bar{B} \) pairs [9]. B pair events have been selected by requiring 2 high momentum leptons and event shape variables compatible with the spherical features of B events. At the \( \Upsilon(4S) \) asymmetric-B-factories, B mesons have very small transverse momentum and mainly travel along the beam axis, therefore their decay time is reconstructed with good approximation from the position along the beam axis of the closest approach points of the leptons. The \( \Upsilon(4S) \) decay point is obtained by fitting the two lepton tracks to a common vertex in the transverse plane, requiring also consistency with the beam-spot position constraint. The selected candidates are composed by neutral B pairs (~40%), charged B pairs (~57%) and background (~3%). Figures 2 and 3 show the \( A_{T/CP} \) and the \( A_{CPT/CP} \) asymmetries in the selected dilepton events, respectively.

A maximum likelihood fit has been performed simultaneously on same-sign and opposite-sign dileptons with a model including parameters for T and CPT violation. With aid from Monte
Carlo simulations, selected event candidates are described as sum of components including either both leptons from direct decay of $B$ mesons (81% of the total), or leptons partly from direct $B$ decay and partly from cascade charm mesons decay (possibly also from the same $B$ than produces the direct lepton) or other sources like charmonium.

The experimental resolution on the decay times reconstruction is fitted on the data. Some theory parameters, like the neutral and charged $B$ mesons lifetimes and $B$-mixing ($\Delta m$) are fixed to the available experimental measurements; $\Delta \Gamma$ is fixed using the result of Ref. [9].

The resulting $T$ and $CPT$ violation parameters are:

$$|q/p| - 1 = (-0.8 \pm 2.7\text{(stat.)} \pm 1.9\text{(syst.)}) \times 10^{-3},$$
$$\text{Im} \ z = (-13.9 \pm 7.3\text{(stat.)} \pm 3.2\text{(syst.)}) \times 10^{-3},$$
$$\Delta \Gamma \times \text{Re} \ z = (-7.1 \pm 3.9\text{(stat.)} \pm 2.0\text{(syst.)}) \times 10^{-3} \text{ ps}^{-1}.$$  

The dominant systematic uncertainties on $|q/p|$ come from uncertainties regarding charge asymmetries in detector response, while uncertainties on $z$ come mainly from imperfection in the simulation of detector decay time resolution, from uncertainties on the available measurements of $B$ lifetimes, mixing and $\Delta \Gamma$, from detector alignment uncertainties and from the knowledge of the length scale of the detector along the beam axis. All measurements are consistent with the Standard Model predictions [3, 4, 5].

4.1. Test on $CPT$ violation from Lorentz invariance violation

According to a proposed extension of the Standard Model that is characterized by violation of Lorentz invariance [10], the consequent $CPT$ violation in neutral $B$ meson oscillations depends on the 4-velocity of the meson [11] with respect to the distant stars, hence $CPT$ violation observed on Earth should vary with a period of one sidereal day ($\simeq 0.99727$ solar days) as the $\Upsilon(4S)$ boost direction follows the Earth’s rotation [12]. Specifically, the $CPT$ parameter $z$ is predicted to depend on the meson 4-velocity $\beta^\mu = \gamma(1, \vec{\beta})$ in each experiment’s observer frame as

$$z \simeq \frac{\beta^\mu \Delta a_\mu}{\Delta m - i\Delta \Gamma/2} \quad [11],$$

where $\beta^\mu \Delta a_\mu$ is real and varies with sidereal time due to the rotation of $\vec{\beta}$ relative to the constant vector $\Delta \vec{a}$.  

Figure 2. $A_{T/CP}$ asymmetry between $(\ell^+,\ell^+)$ and $(\ell^-,\ell^-)$. Experimental charge asymmetry of cascade muons, which dominate at small $|\Delta t|$, causes the deviation from flatness. The figure comes from Ref. [9].

Figure 3. $A_{CPT/CP}$ asymmetry between $(\ell^+,\ell^-)$ dileptons with $\Delta t > 0$ and $\Delta t < 0$. The figure comes from Ref. [9].
The time dependence of $CPT$ violation can be exploited to improve the experimental sensitivity. Therefore, the $ BABAR $ collaboration has searched for $CPT$ violation effects corresponding parametrized with $z$ varying with sidereal time [13] as

$$ z = z_0 + z_1 \cos (\Omega t + \phi). \tag{10} $$

It is worth noting that for long data-taking periods, any day/night variations in detector response tend to cancel over sidereal time. The same dilepton event sample that has just been described has been fit using the same model, but with $z$ varying as in Eq. 10. In Fig. 4 we plot the sidereal-time dependence of the measured asymmetry $A_{CPT/CP}$ for the opposite-sign dilepton events with $|\Delta t| > 3\text{ ps}$ versus sidereal time. The figure comes from Ref. [13].

**Figure 4.** Asymmetry $A_{CPT/CP}$ for opposite-sign dilepton events with $|\Delta t| > 3\text{ ps}$ versus sidereal time. The figure comes from Ref. [13].

Assuming that $z$ is periodic according to the sidereal time, the following results are obtained:

$$ \text{Im} \ z_0 = [-5.2 \pm 3.6 \text{ (stat.)} \pm 1.9 \text{ (syst.)}] \cdot 10^{-3}, $$
$$ \text{Im} \ z_1 = [-17.0 \pm 5.8 \text{ (stat.)} \pm 1.9 \text{ (syst.)}] \cdot 10^{-3}. $$

The real part of $z$ is dependent on the imaginary part according to Eq. 9. Like for the previously described measurement on dileptons, the experimental sensitivity for the real part of $z$ is suppressed by the small size of $\Delta \Gamma$, and the main systematic uncertainties come from imperfection in the simulation of detector decay time resolution, from uncertainties on the available measurements of $B$ lifetimes, mixing and $\Delta \Gamma$, from detector alignment uncertainties and from the knowledge of the length scale of the detector along the beam axis. There is no evidence of $CPT$ violation.

A periodogram method [14, 15] has been used to search for signals of $CPT$ violations at frequencies from $0.26 \text{ year}^{-1}$ to $2.1 \text{ solar-day}^{-1}$, spaced by $10^{-4} \text{ solar-day}^{-1}$: no statistically significant evidence for $CPT$ violation has been found.

### 4.2. Additional tests on $T$ and $CPT$ symmetries with dileptons

Using smaller samples of dileptons, the Belle collaboration has published two analyses containing measurements the $A_{T/CP}$ and $A_{CPT/CP}$ asymmetries.

Using a sample of dilepton candidates corresponding to an integrated luminosity of $29.4 \text{ fb}^{-1}$ recorded at the $\Upsilon(4S)$, the $CPT$ violation parameter $z$ has been measured as [7]:

$$ \text{Re} \ z = [0 \pm 120 \text{ (stat.)} \pm 10 \text{ (syst.)}] \cdot 10^{-3}, $$
$$ \text{Im} \ z = [30 \pm 10 \text{ (stat.)} \pm 30 \text{ (syst.)}] \cdot 10^{-3}. $$
Using a sample of dilepton candidates corresponding to an integrated luminosity of 78 fb$^{-1}$ recorded at the $\Upsilon(4S)$, the $T$ violation parameter $|q/p|$ has been measured as $|8|$

\[ |q/p| - 1 = (0.5 \pm 4.0 \text{ (stat.)} \pm 3.5 \text{ (syst.)}) \times 10^{-3} \]

In both cases, the results are consistent with the Standard Model predictions and no evidence for $T$ or $\text{CPT}$ violation has been found.

5. Tests on $T$ violation with triple products in $B$ decays

In $B$ decays to two vector mesons it is possible to construct triple vector products of the form $\vec{q} \cdot (\vec{e}_1 \times \vec{e}_2)$ where $\vec{q}$ is the momentum of one of the vector mesons and $\vec{e}_1$, $\vec{e}_2$ are the polarization vectors of the two mesons. The polarizations are reconstructed from the angular distributions of the decay products of the two vector-mesons. Triple product asymmetries with respect to the $B$ flavor are $T$-odd $\text{CP}$-violating observables, which are significantly suppressed in the Standard Model.

Belle has published two measurements of $T$-odd $\text{CP}$-violating asymmetries based on 253 fb$^{-1}$ of data recorded at the $\Upsilon(4S)$ resonance: one on $B \to \phi K^*$ decay candidates [16] and one on $B \to J/\psi K^*$ decay candidates [17]. In both cases, no evidence of $T$ violation has been found.

6. $\text{CPT}$ tests on tau leptons

Mass or lifetime differences between positive and negative tau leptons would be evidence of $\text{CPT}$ violation. Measurements of the tau mass by the $B$-factories are less precise than the ones obtained at threshold but have the advantage that the masses of $\tau^+$ and $\tau^-$ are separately measured. Measurements of tau lifetime are difficult but a preliminary result has been presented by $\text{BaBar}$ [18].

Belle has measured the tau mass using a pseudomass technique [19]. Momenta of charged pions from the decay $\tau^\pm \to \pi^\pm \pi^\pm \pi^\mp \nu_\tau$ are combined with information on the beam energy to compute a mass that is bound to be not larger than the tau mass by assuming that the undetected neutrino momentum is parallel to the three pion total momentum. The edge of the measured pseudomass distribution is highly correlated with the tau mass and rather insensitive to details of background contamination, permitting a statistically precise fit for the mass. Systematic uncertainties limit the attainable precision, but mostly elide when measuring the mass difference between $\tau^+$ and $\tau^-$. Analyzing 414 fb$^{-1}$ of data, Belle measures:

\[ M_{\tau^+} - M_{\tau^-} = (0.05 \pm 0.23 \text{ (stat.)} \pm 0.14 \text{ (syst.)}) \text{ MeV}/c^2. \]

The systematic uncertainty is determined by comparing reconstructed positive and negative charged mesons masses in the Belle detector, assuming $\text{CPT}$ is conserved for them.

$\text{BaBar}$ has recently presented preliminary results on the tau mass based on 432 fb$^{-1}$ of data [20] and reported the following $\text{CPT}$ test on the mass difference:

\[ M_{\tau^+} - M_{\tau^-} = [-0.61 \pm 0.23 \text{ (stat.)} \pm 0.05 \text{ (syst.)}] \text{ MeV}/c^2 \quad \text{(preliminary)}. \]

Also in this case, the systematic uncertainty is determined by comparing reconstructed masses of charged mesons. Both results do not provide evidence of $\text{CPT}$ violation.

7. Conclusions

The $B$-factory collaborations performed several tests of $T$ and $\text{CPT}$ symmetries, mainly on the neutral $B$ system but also on other $B$ decays and on tau leptons. In all cases, results are consistent with the Standard Model predictions, i.e. no $\text{CPT}$ violation and just a small amount of $T$ violation, which is undetectable in the measurements that have been listed here. These
precision tests demand large event samples, a very accurate control of systematic effects, and often also complex multi-parameter fits. So far, only a fraction of the entire collected data samples have been used, therefore both the Belle and BaBar collaborations have the potential of producing further more precise results in this area.

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