CP and CPT Violation: Status and Prospects

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Abstract

I review the status of CP violating phenomena and CPT tests in the neutral Kaon system. Comparisons of present data with the expectations of the Cabibbo Kobayashi Maskawa model are presented, with particular emphasis being focused on the role of the theoretical uncertainties in this comparison. In addition, novel tests of CPT at DAFNE and Fermilab are briefly discussed.
1 Introduction

The study of CP violating phenomena is by now a mature phenomena in particle physics, as the subject matter is nearly 30 years old! Unfortunately, even after having performed very sophisticated experiments, our information on CP violation is still very limited. Basically, at present, we have:

i.) Some positive evidence for the violation of \( CP \) in the \( K^0 - \bar{K}^0 \) complex, as a result of measuring non vanishing values for the parameters \( \eta_{+-}, \eta_{00} \) and \( A_{KL} \).

ii.) Some bounds on the electric dipole moments of various particles (e.g., for the neutron we know that \( d_n < 1.2 \times 10^{-25} \) ecm, while for the electron present data gives \( d_e = (-0.3 \pm 0.8) \times 10^{-26} \) ecm [1]).

Our theoretical understanding of CP violation is marginally better. In the standard model of the electroweak interactions there is a paradigm - the CKM paradigm - which accounts for CP violation. According to this paradigm, CP is violated because of the presence of a complex phase in the mixing matrix for quarks - the so, called, Cabibbo Kobayashi Maskawa matrix [2] - with this phase originating in the symmetry breaking sector of the theory. However, at present this paradigm is only qualitatively, but not quantitatively, confirmed by the data. Furthermore, serious theoretical uncertainties plague this comparison.

The situation is perhaps better regarding CPT tests. First of all, CPT invariance, is expected to hold on the basis of deep theoretical principles. Any theory which is described by a local, Lorentz invariant Lagrangian, and in which there is a normal connection between the spin and the statistics obeyed by the particle excitations, respects CPT exactly [3]. Experimentally, no significant violations of CPT exist. Nevertheless, even here, the most accurate present tests of CPT which are carried out in the neutral Kaon complex are not totally unambiguous and could mask some possible CPT violations [4].

In this talk, I would like to review the status of CP violating phenomena and of the present tests of CPT in the neutral Kaon system. After this brief review, I shall focus on two special topics:

i.) How much do theoretical uncertainties influence the comparison of data with the expectation of the CKM model.
ii.) What novel tests of CPT can be expected from the Phi factory now being built at Frascati, as well as from a recently proposed experiment to measure the antiproton lifetime at Fermilab.

2 Status of CP Violation and CPT Tests in the Neutral Kaon System

To study CP violation and CPT tests in the $K^0 - \bar{K}^0$ complex it has been traditional to describe this system by an effective $2 \times 2$ Hamiltonian

$$H_{\text{eff}} = M - \frac{i}{2} \Gamma,$$

where both the mass matrix $M$ and the decay matrix $\Gamma$ are Hermitian matrices. The time evolution of the system is then described by the Schrödinger equation

$$i \frac{\partial}{\partial t} \left( \begin{array}{c} K^0 \\ \bar{K}^0 \end{array} \right) = H_{\text{eff}} \left( \begin{array}{c} K^0 \\ \bar{K}^0 \end{array} \right).$$

(2)

It is possible to imagine, however, that CPT violating phenomena are connected with violations of quantum mechanics. In this case, clearly, the above simple Schrödinger equation is no longer adequate and a more general analysis is required. In what follows, I will not consider this more radical suggestion and describe possible CPT violating phenomena within the usual 2-state formalism of quantum mechanics.

The physical eigenstates, describing the $K_L$ and $K_S$ states, are obtained by diagonalizing the above $2 \times 2$ Schrödinger equation and these states evolve in time in the expected fashion:

$$|K_{L,S}(t)\rangle = e^{-im_{L,S}t} e^{-\frac{i}{2} \Gamma_{L,S}t} |K_{L,S}(0)\rangle.$$

(3)

The eigenstates $|K_{L,S}(0)\rangle$ are linear combinations of $|K^0\rangle$ and $|\bar{K}^0\rangle$. If CP and CPT are conserved by $H_{\text{eff}}$, the physical eigenstates are CP eigenstates, otherwise they are not. Diagonalizing the Schrödinger equation one finds in the general case, when there are no CP or CPT restrictions:

$$|K_S\rangle \simeq \frac{1}{\sqrt{2}} \left\{ (1 + \epsilon_K + \delta_K)|K^0\rangle + (1 - \epsilon_K - \delta_K)|\bar{K}^0\rangle \right\}$$

$$|K_L\rangle \simeq \frac{1}{\sqrt{2}} \left\{ (1 + \epsilon_K - \delta_K)|K^0\rangle - (1 - \epsilon_K + \delta_K)|\bar{K}^0\rangle \right\}.$$

(4)
Here $\epsilon_K$ is a parameter that details the amount of CP violation in $H_{\text{eff}}$,

$$
\epsilon_K = e^{i\phi_{sw} \left[-ImM_{12} + \frac{i}{2} Im\Gamma_{12}\right]} \sqrt{2\Delta m},
$$

while $\delta_K$ details possible CPT violation in $H_{\text{eff}}$:

$$
\delta_K = ie^{i\phi_{sw} \left[(M_{11} - M_{22}) - \frac{i}{2}(\Gamma_{11} - \Gamma_{22})\right]} \frac{2}{2\sqrt{2\Delta m}}.
$$

In the above $\Delta m = m_L - m_S$ is the mass difference between the eigenstates and $\phi_{sw}$ is a kinematical phase related to the ratio of this mass difference to the difference in the $K_S$ and $K_L$ widths

$$
\phi_{sw} = \tan^{-1} \frac{2\Delta m}{\Gamma_S - \Gamma_L} \approx 45^0.
$$

CP and CPT violations in the $K^0 - \bar{K}^0$ system, besides through $\epsilon_K$ and $\delta_K$, can enter also directly in the decay amplitudes. Essentially CP violation introduces further phases in these amplitudes, while CPT violation is described by introducing further amplitudes - since particle and antiparticle decay amplitudes are then no longer related. For semileptonic decays and for $K$ decays into $2\pi$, which will be of interest here, one can write [7]

$$
\begin{align*}
A(K^0 \to \pi^- \ell^+ \nu_\ell) &= a + b ; & A(\bar{K}^0 \to \pi^+ \ell^- \bar{\nu}_\ell) &= a^* - b^* \\
A(K^0 \to 2\pi; I) &= (A_I + B_I) e^{i\delta_I} ; & A(\bar{K}^0 \to 2\pi; I) &= (A_I^* - B_I^*) e^{i\delta_I} \quad (8)
\end{align*}
$$

In the above, $\delta_I$ is the usual $\pi\pi$ rescattering phase for states in isospin $I$ ($I = 0, 2$). Having nonvanishing $b$ and $B_I$ amplitudes signals CPT violation, while any CP violation makes the $a$ and $A_I$ amplitudes complex. Of course, observable effects in the $K^0 - \bar{K}^0$ complex will measure a mixture of CP (and CPT) violating decay and mixing parameters.

In the neutral Kaon system one has, at present, 5 measurements related to CP and CPT violation. These involve two (complex) amplitude ratios $\eta_{+-}$ and $\eta_{00}$ and the semileptonic asymmetry $A_{KL}$:

$$
\eta_{+-} = \frac{A(K_L \to \pi^+ \pi^-)}{A(K_S \to \pi^+ \pi^-)} = |\eta_{+-}| e^{i\phi_{+-}} = \epsilon + \epsilon',
$$

(9a)
\[\eta_{00} = \frac{A(K_L \rightarrow \pi^0\pi^0)}{A(K_S \rightarrow \pi^0\pi^0)} = |\eta_{00}| e^{i\phi_{00}} = \epsilon - 2\epsilon' \quad (9b)\]

\[A_{K_L} = \frac{\Gamma(K_L \rightarrow \pi^-\ell^+\nu_e) - \Gamma(K_L \rightarrow \pi^+\ell^-\bar{\nu}_e)}{\Gamma(K_L \rightarrow \pi^-\ell^+\nu_e) + \Gamma(K_L \rightarrow \pi^+\ell^-\bar{\nu}_e)} \quad (9c)\]

Experimentally one finds, to a good approximation, that

i) \(|\eta_{+-}| \simeq |\eta_{00}|\)

and

ii) \(A_{K_L} \simeq 2Re \eta_{+-}\) and \(\phi_{+-} \simeq \phi_{00}\).

The first result shows that CP (or CPT) violation is essentially due to mixing, since only the \(\epsilon\) parameter, related to \(\Delta S = 2\) processes, is important. The second results, as we shall see, indicate that experiments are consistent with CP violation, but CPT conservation.

For the study of CP violation and for comparing with the CKM paradigm it is important to know if \(\epsilon' \neq 0\). After all, \(\epsilon'\) is a \(\Delta S = 1\) parameter and, if CP violation arises from quark mixing, that is precisely where one would expect to see an effect. Unfortunately, here the present experimental evidence is conflicting. One has information on \(Re \epsilon'/\epsilon\) from the ratio of rates, while \(Im \epsilon'/\epsilon\) can be gleaned from the phase difference between \(\phi_{+-}\) and \(\phi_{00}\):

\[\frac{|\eta_{+-}|^2}{|\eta_{00}|^2} \simeq 1 + 6Re \frac{\epsilon'}{\epsilon} ; \quad \phi_{+-} - \phi_{00} \simeq 3Im \frac{\epsilon'}{\epsilon} \quad . \quad (10)\]

Experimentally the most recent results obtained by the NA31 [8] and the E731 [9] collaborations are

\[Re \frac{\epsilon'}{\epsilon} = \begin{cases} (23 \pm 7) \times 10^{-4} & \text{NA31} \\ (7.4 \pm 5.9) \times 10^{-4} & \text{E731} \end{cases} \quad (11)\]

and

\[\phi_{+-} - \phi_{00} = \begin{cases} (-0.2 \pm 2.6 \pm 1.2)^0 & \text{NA31} \\ (1.6 \pm 1.0 \pm 0.7)^0 & \text{E731} \end{cases} \quad (12)\]

I will return to discuss the CKM expectation for \(\epsilon'/\epsilon\), after discussing how the present data in the \(K^0 - \bar{K}^0\) complex constrains CPT violating
parameters. I note here only that because these CPT tests are somewhat less
stringent numerically, and $\epsilon'$ is small compared to $\epsilon$, it suffices for these tests
to assume simply that $\epsilon \simeq \eta_{+-}$, both in magnitude and phase. The first test
of CPT arises from a comparison of the measured value of the semileptonic
asymmetry $A_{K_L}$ and $Re \epsilon$. Straightforward calculations \cite{4} yield the following
expressions for $A_{K_L}$ and $\epsilon$, to first order in small quantities,

\begin{align*}
A_{K_L} &= 2Re \epsilon_K + \left[2 Re \frac{b}{Re a} - 2 Re \delta_K \right] \\
\epsilon &= \epsilon_K + i \frac{Im A_0}{Re A_0} + \left[ Re B_0 - \frac{Re a}{Re A_0} \right] \\
&\simeq \frac{1}{\sqrt{2}} \left\{ - \frac{Im M_{12}}{\Delta m} + \frac{Im A_0}{Re A_0} \right\} e^{i\phi_{sw}} + \frac{i}{\sqrt{2}} \left[ \frac{M_{22} - M_{11}}{2\Delta m} - \frac{Re B_0}{Re A_0} \right] e^{i\phi_{sw}}.
\end{align*}

In the above, all quantities which violate CPT are enclosed in square brackets.
The second expression for $\epsilon$ arises from saturating the $2 \times 2$ width matrix $\Gamma$
by the $2\pi, I = 0$ states - which is an extremely good approximation \cite{10}. In
this approximation the CP and CPT violating components of $\epsilon$ are $90^0$ out
of phase \cite{10}

\begin{equation}
\epsilon = \epsilon_{cp} e^{i\phi_{sw}} + \epsilon_{cpt} e^{i(\phi_{sw} + \frac{\pi}{2})},
\end{equation}

with the CP violating component having the superweak phase $\phi_{sw} \simeq 45^0$. Using the $PDG$ \cite{1} values for $A_{K_L}$ and $\eta_{+-}$, one finds for the CPT violating amplitude difference

\begin{equation}
\frac{Re B_0}{Re A_0} - \frac{Re b}{Re a} = Re \epsilon - \frac{1}{2} A_{K_L} = (-0.6 \pm 0.7) \times 10^{-4} \quad PDG
\end{equation}

The difference between $\phi_{\epsilon}$, the phase of $\epsilon$ (essentially the phase of $\eta_{+-}, \phi_{+-}$),
and the superweak phase $\phi_{sw}$ provides a second test of CPT. Using again
$PDG$ values \cite{1}, there is about a $2\sigma$ difference between $\phi_{\epsilon} \simeq \phi_{+-} = (46 \pm 1.2)^0$
and the superweak phase $\phi_{sw} = (43.73 \pm 0.14)^0$. As is clear from Figure 1,
Figure 1: Plot of $\epsilon$ in the complex plane. Note that the difference (if any) between $\phi_\epsilon$ and $\phi_{sw}$ is grossly exaggerated.

One has

$$\tan(\phi_\epsilon - \phi_{sw}) = \frac{\epsilon_{cph}}{\epsilon_{cph}} = (4.0 \pm 2.2) \times 10^{-2} \quad PDG.$$ \hspace{1cm} (16)

Drawing any conclusion about a possible violation of CPT from the above is quite premature. Indeed, the actual value of $\phi_{+\mp}$ (and thus of $\phi_\epsilon$) obtained from experiment is quite sensitively dependent on the values of $\Delta m$ and, to a lesser extent, of $\Gamma_S$ one uses. This is very clear from the recent analysis presented by the $E731$ collaboration\cite{11} and it is worthwhile to repeat their arguments here.

$E731$ first fits the time evolution of their signal after the regenerator\cite{11}

$$\frac{dN}{dz} = |\rho_{reg} e^{-\frac{iz\Gamma_s}{2}} e^{i\Delta m z} + \eta_{+\mp} e^{-\frac{iz\Gamma_s}{2}}|^2$$ \hspace{1cm} (17)

to obtain $\Delta m$ (and $\Gamma_S$), keeping $\phi_{+\mp}$ fixed at $\phi_{+\mp} = \phi_{sw}$. When they do this, they obtain a value for $\Delta m$ about $2\sigma$ below the value of $\Delta m$ quoted in the PDG\cite{11}. [$\Delta m = (0.5286 \pm 0.0028) \times 10^{10}$ sec$^{-1}$\cite{11} versus $\Delta m = (0.5351 \pm 0.0024) \times 10^{10}$sec$^{-1}$\cite{11}]$. Next, they let both $\Delta m$ and $\phi_{+\mp}$ float, getting a value for $\Delta m$ consistent with the value they obtained earlier (but with bigger errors) and find

$$\phi_{+\mp} = (42.2 \pm 1.4)^0 \quad E731,$$ \hspace{1cm} (18)
a value entirely in agreement with $\phi_{sw}$ \[\text{(1)}\]. Perhaps most importantly, if one uses the new E731 $\Delta m$ value to renormalize some of the older experiments, whose values for $\phi_{+-}$ were used to get the PDG value for $\phi_{+-}$, one gets a considerable shift downward for $\phi_{+-}$. This is summarized in Table 1, adapted from \[\text{(1)}\]. Combining these new values for $\phi_{+-}$ with the value of $\phi_{+-}$ obtained by E731 \[\text{(1)}\], yields a new average value

$$\phi_{+-} = (42.8 \pm 1.1)^0 \text{ New} \text{.}$$

Using this value (and the value of $\phi_{sw}$ from \[\text{(1)}\]) gives for the two CPT tests discussed above the results:

$$\frac{Re B_0}{Re A_0} - \frac{Re b}{Re a} = (0.3 \pm 0.7) \times 10^{-4} \text{ New} \text{.}$$

$$\frac{\epsilon_{cpt}}{\epsilon_{cf}} = (-1.1 \pm 2.0) \times 10^{-2} \text{ New} \text{,}$$

which are perfectly consistent with CPT conservation.

Table 1: Old and New Values for $\phi_{+-}$

| Experiment          | $(\phi_{+-})$ Old | $(\phi_{+-})$ New |
|---------------------|-------------------|-------------------|
| Geweniger et al \[\text{12}\] | $(49.4 \pm 1.0)^0$ | $(43.0 \pm 1.0)^0$ |
| Carithers et al \[\text{13}\] | $(45.5 \pm 2.8)^0$ | $(44.0 \pm 2.8)^0$ |
| NA31 \[\text{8}\]       | $(46.9 \pm 1.6)^0$ | $(43.4 \pm 1.6)^0$ |

I should remark that, since $\phi_{sw} \simeq 45^0$, one can simply relate some of the other CPT violating parameters to $\epsilon_{cpt}$. One finds \[\text{(1)}\]

$$Im \delta_K \simeq \frac{Re B_0}{Re A_0} - Re \delta_K \simeq \frac{1}{\sqrt{2}} \epsilon_{cpt} \text{.}$$

It is straightforward to show from the above, using the $2\pi I = 0$ approximation in $\Gamma$, that the bounds on $\epsilon_{cpt}$ obtained imply the following bound for the $\phi_{sw}$

\[\phi_{sw} = (43.4 \pm 0.2)^0\].
diagonal parameters in \( M \) and \( \Gamma \):

\[
\frac{(M_{11} - M_{22}) + \frac{1}{2}(\Gamma_{11} - \Gamma_{22})}{4\Delta m} = \begin{cases} 
(0.64 \pm 0.36) \times 10^{-4} & \text{PDG} \\
(-0.18 \pm 0.32) \times 10^{-4} & \text{New}
\end{cases} \tag{22}
\]

There is a third test of CPT which is possible with present data. This test uses the fact that also in \( \epsilon' \) terms that violate CPT are 90\(^\circ\) out of phase compared to terms that violate CP. One finds, \[4\]

\[
\epsilon' = \frac{ReA_2}{\sqrt{2}ReA_0} e^{i(\delta_2 - \delta_0 + \frac{\pi}{2})} \left\{ \frac{ImA_2}{ReA_2} - \frac{ImA_0}{ReA_0} + i \left[ \frac{ReB_0}{ReA_0} - \frac{ReB_2}{ReA_2} \right] \right\}, \tag{23}
\]

where I used again the convention that CPT violating terms are put in between square brackets. The phase of \( \epsilon' \) depends on the \( \pi \pi \) phase shifts \( \delta_0 \) and \( \delta_2 \) and, remarkably, turns out also to be near 45\(^\circ\). Indeed, recent analyses give

\[
\phi_{\epsilon'} = \delta_2 - \delta_0 + \frac{\pi}{2} = \begin{cases} 
(45 \pm 6)\degree & \text{[14]} \\
(43 \pm 6)\degree & \text{[15]}
\end{cases}
\tag{24}
\]

Because of this circumstance, to a very good approximation, \( Im \frac{\epsilon'}{\epsilon} \) will measure only the CPT violating combination of parameters entering in \( \epsilon' \):

\[
\epsilon'_{\text{cåft}} = \frac{ReB_0}{ReA_0} - \frac{ReB_2}{ReA_2}.
\tag{25}
\]

Using experimental information on the magnitude of the \( K^0 \to 2\pi \) amplitudes and of \( |\epsilon| \), one can write

\[
Im \frac{\epsilon'}{\epsilon} \simeq \left( \frac{ReA_2}{\sqrt{2}ReA_0|\epsilon|} \right) \epsilon'_{\text{cåft}} \simeq 14\epsilon'_{\text{cåft}}. \tag{26}
\]

A value for \( \epsilon'_{\text{cåft}} \) then follows from the experimental values for the phase difference \( \phi_{++} - \phi_{00} \simeq 3Im \frac{\epsilon'}{\epsilon} \). Using data from NA31 and E731 gives the third CPT test:

\[
\epsilon'_{\text{cåft}} = \frac{ReB_0}{ReA_0} - \frac{ReB_2}{ReA_2} = \begin{cases} 
(-0.8 \pm 11.9) \times 10^{-4} & \text{[8]} \\
(6.7 \pm 5.1) \times 10^{-4} & \text{[5]}
\end{cases} \tag{27}
\]
Before concluding this section, it is useful to make two remarks concerning tests of CPT in the neutral Kaon complex. First, as the results presented show, CPT is tested in the ratio of CPT violating to CPT conserving amplitudes (or in the ratio of diagonal element differences of $M$ and $\Gamma$ to $\Delta m$) at the $10^{-4}$ level. Improving the experimental accuracy of these CPT tests much beyond this level appears very difficult to do. However, and this is the second remark I wanted to make, all present day tests involve differences of CPT violating quantities [4]. Thus, although unlikely, one could imagine that the null tests of CPT violation obtained so far result from an accidental cancellation! As I will discuss in some detail below, a $\Phi$ factory like DAFNE is ideally suited to test this notion. Before doing so, however, I want to discuss how well data in the neutral Kaon system, along with some information from $B$ decays, tests the CKM paradigm.

3 Comparison with the CKM model - the role of theoretical uncertainties

The measurements of $\epsilon$ and $\epsilon'$, in principle, should provide confirmation of the CKM paradigm. In practice, however, one is hampered by various theoretical uncertainties. To discuss this comparison, it is useful to adopt the Wolfenstein parameterization [16] of the mixing matrix $V_{CKM}$, in which one expands the three mixing angles $\theta_1, \theta_2$ and $\theta_3$ in terms of powers of the Cabibbo angle. One write for these angles, in the parameterization of $V_{CKM}$ adopted by the PDG [1], $\sin \theta_1 = \lambda$ ; $\sin \theta_2 = A\lambda^2$ ; $\sin \theta_3 = A\sigma\lambda^3$. Here $\lambda = \sin \theta_C \simeq 0.22$ is the sine of the Cabibbo angle and the parameters $A$ and $\sigma$ - which turn out to be of $0(1)$ - need to be fixed by experiment. To $0(\lambda^4)$ one can write $V_{CKM}$ as:

$$V_{CKM} = \begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} = \begin{vmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\sigma\lambda^3 e^{-i\delta} \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \sigma e^{i\delta}) & -A\lambda^2 & 1 \end{vmatrix}.$$  \hspace{1cm} (28)

The phase $\delta$ in the above is the phase responsible for CP violation in the CKM paradigm. Many authors, including Wolfenstein [16], instead of using the parameters $\sigma$ and $\delta$ in $V_{CKM}$ use two other parameters $\rho$ and $\eta$, with $\eta$
being connected to CP violation. One has

\[ \sigma e^{-i\delta} = \rho - i\eta \]  

(29)

or

\[ \rho = \sigma \cos \delta \quad ; \quad \eta = \sigma \sin \delta \]  

(30)

To extract the phase \( \delta \) (or the parameter \( \eta \)) from the measured values of \( \epsilon \) and \( \epsilon' \), one needs to know the value of the matrix elements of certain weak operators involving quark fields between hadronic states. Besides these hadronic matrix elements, one also needs to know the value of the \( A \) and \( \sigma \) (or \( A \) and \( \rho \)) parameters in the CKM matrix, as well as a value for the top quark mass, \( m_t \). All of these quantities are known with a varying degree of accuracy and, as a result, the tests of the CKM paradigm through the measurements of \( \epsilon \) and \( \epsilon' \) are more qualititative than quantitative. Nevertheless, it is worthwhile to trace the sources of the uncertainties and try to see what the implications of these uncertainties are for testing the CKM paradigm.

The uncertainty in the parameters \( A \) in \( V_{CKM} \) is essentially that of the \( V_{cb} \) matrix element of this matrix. The parameter \( \sigma \) or \( \sqrt{\rho^2 + \eta^2} \), on the other hand, depends on how well one can determine the ratio of \( V_{ub} \) to \( V_{cb} \) in \( V_{CKM} \). Although \( \delta \) (or \( \eta \)) reflects the presence of CP violation, constraints on this phase (or on this parameter) can also be inferred from the magnitude of \( |V_{td}| \). This matrix element of \( V_{CKM} \) can be deduced from the experimentally measured rate for \( B - \bar{B} \) mixing. However, also here to extract \( |V_{td}| \) one needs both information on \( m_t \) and on the value of certain other hadronic matrix elements. It is a vexing fact that the experimental errors on all the measured parameters which are needed for testing the CKM paradigm, are much less than the corresponding theoretical uncertainties which enter in the analysis. For instance, the experimental errors on \( \epsilon \) and on the \( B_d - \bar{B}_d \) mixing parameter \( x_d \) are, respectively, of order 1% and 10%. On the other hand, the theoretical uncertainty which enters when one tries to compare these parameters with the predictions of the CKM paradigm is of order 50%!

It has become traditional to present the result of a CKM analysis of the data as contour plots in the \( \rho - \eta \) plane, as a function of the top quark mass \( m_t \). Mostly because of the above mentioned theoretical uncertainties, the measured values of \( \epsilon \) and \( x_d \) will map an allowed region in this plane. For fixed \( m_t \), the theoretical uncertainty in \( \epsilon \) arises from the uncertainty in the value of \( A \), as well as from a poor knowledge of the matrix element of
the $\Delta S = 2$ quark operator

$$0_{\Delta S=2} = (\bar{d} \gamma_\mu (1 - \gamma_5) s)(\bar{d} \gamma^\mu (1 - \gamma_5) s)$$  \hspace{1cm} (31)$$

between $K^0$ and $\bar{K}^0$ states. The most reliable estimates for $|V_{cb}|$, coming from the study of inclusive leptonic decays \[18\], as well as from the study of the exclusive decay $B^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ at zero recoil using heavy quark techniques, \[13\] determine $A$ to a 10% accuracy. In what follows, I shall use

$$A = 0.9 \pm 0.1 \hspace{1cm} (32)$$
corresponding to $|V_{cb}| = 0.043 \pm 0.005$.

The hadronic matrix elements uncertainty in $\epsilon$ is usually characterized by giving a value for the parameter $B_K$, which details the ratio of the matrix element of $0_{\Delta S=2}$ to that obtained by using vacuum insertion. The best estimates for $B_K$, coming from lattice gauge theory computations \[21\], give

$$B_K = 0.8 \pm 0.2 \hspace{1cm} (33)$$

The predicted value for the $B_d - \bar{B}_d$ mixing parameter $x_d$, for fixed value of $m_t$, also depends on knowing $A$, but it requires in addition, some knowledge of the $B_d$ decay constant $f_{B_d}$ defined by

$$i f_{B_d} k^\mu = < 0 | \bar{d} \gamma_\mu \gamma_5 b | B_d; k > \hspace{1cm} (34)$$

The best value for this parameter, which follows from lattice QCD computations, has also an error of about 10%. One finds \[21\]

$$\sqrt{B_{B_d} \eta f_{B_d}} = (200 \pm 35) \hspace{0.5cm} \text{MeV} \hspace{1cm} (35)$$

Theoretical formulas for $|\epsilon|$ and $x_d$ \[23\] \[24\] can be written in a handy approximate form \[25\], for $m_t > M_W$. These formulas make it quite obvious

\[\text{footnote}{2}{\text{Actually $x_d$ depends on the matrix element of an operator $0_{\Delta B=2}$ analogous to $0_{\Delta S=2}$. This matrix element can be related to $f_{B_d}^2 B_{B_d}$, with $B_{B_d}$ being the analogue of $B_K$ for the Kaon case. Because the $b$ quark is heavy, one expects the vacuum insertion approximation to work very well, so that $B_{B_d} \simeq 1$. In addition, the formula for $x_d$ contains an overall factor of $\eta \simeq 0.85$ multiplying $0_{\Delta B=2}$ which accounts for short distance QCD corrections to this operator \[24\]. In the text, we report the value for $\sqrt{B_{B_d} \eta f_{B_d}}$ which is needed in the comparison of theory with experiment.}}\]
what is the source of the theoretical uncertainties and, given the experimental
value for $|\epsilon|$ and $x_d$, what is the range allowed in the $\rho - \eta$ plane. Using the
values quoted for $B_K$ and for $\sqrt{B_{Bd} f_{Bd}}$, one has

$$
|\epsilon| \simeq [2.7 \pm 0.7] \times 10^{-3} A^2 \eta \left\{ 1 + \frac{4}{3} A^2 (1 - \rho) \left( \frac{m_t}{M_W} \right)^{1.6} \right\}
$$
$$
x_d \simeq [0.44 \pm 0.15] A^2 [\eta^2 + (1 - \rho)^2] \left( \frac{m_t}{M_W} \right)^{1.6} . \quad (36)
$$

To the theoretical errors shown above, coming from our uncertain knowledge
of $B_K$ and $f_{Bd}$, one has to add the 20% uncertainty present in $A^2$ to obtain,
from the experimental values for $\epsilon$ and $x_d$ [$|\epsilon| = (2.268 \pm 0.023) \times 10^{-3}$ [1];
$x_d = 0.64 \pm 0.08$ [26]] the allowed regions in the $\rho - \eta$ plane. Figure 2 shows
these regions for the two cases: $m_t = 140 \, GeV$ and $m_t = 180 \, GeV$.

Figure 2: Allowed regions in the $\rho - \eta$ plane coming from the measurement
of $|\epsilon|$, $x_d$ and the ratio $|V_{ub}|/|V_{cb}|$.

In Figure 2, in addition to the allowed regions allowed by $|\epsilon|$ and $x_d$, I
indicated also the region in the $\rho - \eta$ plane which is allowed by our present
knowledge of the ratio of $|V_{ub}|$ to $|V_{cb}|$. A value for $|V_{ub}|/|V_{cb}|$ fixes directly
σ, or the value of $\sqrt{\rho^2 + \eta^2}$. Including errors in $|V_{ub}|/|V_{cb}|$ gives, therefore, the annular region centered at $\rho = \eta = 0$ shown in Figure 2. It is worthwhile also here to discuss the source of the errors in $|V_{ub}|/|V_{cb}|$ since, again, these are mostly due to theoretical uncertainties.

To extract $|V_{ub}|/|V_{cb}|$ from experiment one studies the semileptonic decays of $B$ mesons ($B \rightarrow X \ell \nu_{\ell}$) in a region of momentum of the emitted lepton ($p_{\ell} > 2.3 \text{ GeV}$) which insures kinematically that the hadronic states $X$ do not contain a charmed quark. That is, for $p_{\ell} > 2.3 \text{ GeV}$ the data should only measure decays in which the transition $b \rightarrow u$ occurred. However, to extract a value of $|V_{ub}|$ from this analysis is non trivial, since one must be able to estimate precisely the hadronic matrix elements involved in the $B \rightarrow X$ transition. When one does this estimate by employing, as in the ACM model [27], a parton model - which is sensible in my mind, since one is summing over all states $X$ - one gets a fairly large value for the matrix element and hence a rather small value for $|V_{ub}|/|V_{cb}|$. On the other hand, if one estimates the transition $B \rightarrow X$ by summing only over some (assumed dominant) exclusive channels, as in the ISGW model [28], the strength of the transition is smaller and, consequently, one deduces a larger value for $|V_{ub}|/|V_{cb}|$.

Using only the more recent and more accurate data obtained by CLEO II, Cassel [26] quotes the following values for $|V_{ub}|/|V_{cb}|$ extracted, respectively, using the ACM model [27] and the ISGW model [28]:

\[
\begin{align*}
|V_{ub}|/|V_{cb}| &= 0.07 \pm 0.01 \leftrightarrow \sigma = 0.32 \pm 0.06 \quad \text{ACM Model} \\
|V_{ub}|/|V_{cb}| &= 0.11 \pm 0.02 \leftrightarrow \sigma = 0.50 \pm 0.09 \quad \text{ISGW Model}
\end{align*}
\]

(37)

The larger annulus in Figure 2 corresponds to taking the average of these two results and somewhat expanding the errors by including other model uncertainties [28]. It corresponds to

\[
|V_{ub}|/|V_{cb}| = 0.085 \pm 0.045 \leftrightarrow \sigma = 0.39 \pm 0.21 .
\]

(38)

I have, however, also indicated in this figure the values of $\sigma = \sqrt{\rho^2 + \eta^2}$ allowed if one extracted $|V_{ub}|/|V_{cb}|$ from the data by using only the ACM model. As the figure makes clear, it is rather important to resolve the theoretical controversy surrounding the extraction of $|V_{ub}|/|V_{cb}|$ from experiment,
as this would considerably narrow the allowed region in the $\rho - \eta$ plane. For example, for $m_t = 140 \text{ GeV}$, the overlap region allowed by our present theoretical and experimental knowledge of $|\epsilon|, x_d$ and $|V_{ub}|/|V_{cb}|$ is that shown in Fig. 3. If one could trust the ACM model absolutely, however, this region would get reduced to the rather narrow shaded band shown in the figure.

Figure 3: Allowed region in $\rho - \eta$ plane for $m_t = 140 \text{ GeV}$. The shaded band is the result obtained by relying only on the ACM model.

Unfortunately, even assuming $\eta$ to be in its most restricted range ($\eta \simeq 0.2 - 0.3$), is not sufficient to allow for a sharp prediction for $\epsilon'/\epsilon$, due to other theoretical uncertainties arising in estimating the hadronic matrix elements of operators which contribute to $\epsilon'$. Nevertheless, considerable progress has been made recently in trying to tackle this question, notably by groups in Rome [29] and Munich [30] who have calculated the expectations for $\epsilon'$ at next to leading order and then tried to estimate the relevant matrix elements. Because these calculations are highly technical, I will limit myself here to give a more qualitative overview of the results obtained.

The ratio $\epsilon'/\epsilon$ - which is essentially the same as $Re \epsilon'/\epsilon$ - gets contribution from two kinds of operators: $\Delta I = 1/2$ operators and $\Delta I = 3/2$ operators. The former contributions are induced by gluonic Penguins and thus are of $0(\alpha_s)$. However, since they enter in the amplitude $Im A_0$, the $\Delta I = 1/2$ operators are affected by the whole $\Delta I = 1/2$ suppression factor of $Re A_2/Re A_0 \simeq 1/20$ [c.f. Eq. (23)]. On the other hand, the $\Delta I = 3/2$ contributions arise from electroweak Penguin diagrams and thus are only of
$Im A_2$ is measured relative to $Re A_2$ and so, effectively, it is not suppressed by the $\Delta I = 1/2$ factor of $Re A_2/Re A_0$. Furthermore, as first noted by Flynn and Randall [31], these contributions grow quadratically with $m_t$, while those of the gluonic Penguins only depends on $m_t$ as $\ell n m_t$.

In light of the above discussion, the structure of the result of the calculations of $\epsilon'/\epsilon$ can be written as follows [29] [30]:

$$\frac{\epsilon'}{\epsilon} = A^2 \eta \left\{ < 2\pi; I = 0 | \sum_i C_i 0_i | K^0 > (1 - \Omega_I) - < 2\pi; I = 2 | \sum_i \tilde{C}_i \tilde{0}_i | K^0 > \right\}$$

(39)

Here $0_i$ and $\tilde{0}_i$ are, respectively, $\Delta I = 1/2$ and $\Delta I = 3/2$ operators and their coefficients $C_i$ and $\tilde{C}_i$ have the characteristic dependence on $\alpha_s \ell n m_t$ and $\alpha m_t^2$ alluded to above. $\Omega_I$ is a correction to the $\Delta I = 1/2$ contribution, which arises as a result of isospin violation through $\pi^0 - \eta$ mixing [32] and is estimated to be $\Omega_I = 0.25 \pm 0.10$. Note also in the above the characteristic CKM dependence of $\epsilon'$ - for a fixed given $\epsilon$ - on the CKM parameters $A^2 \eta$. Thus, even if the hadronic matrix elements were perfectly known, present uncertainties in $A$ and $\eta$ would give about a 50% uncertainty in $\epsilon'/\epsilon$ - a bit less if one could restrict $\eta$ to the ACM range.

It is difficult to extract directly from the work of the Rome [29] and Munich [30] groups a value for the coefficient of $A^2 \eta$, typifying the hadronic uncertainty in $\epsilon'/\epsilon$. Nevertheless, from these papers, more to get a feeling for the expectations than as a hard and fast result, I infer the following. For moderate $m_t$ - say $m_t = 140$ GeV - gluonic Penguins dominate. Here the uncertainty in the matrix elements is more under control, perhaps being only of order 30%. A representative prediction for $m_t$ in this range appears to be

$$\frac{\epsilon'}{\epsilon} = (11 \pm 4) \times 10^{-4} A^2 \eta \quad (m_t = 140 \text{ GeV}) \, .$$

(40)

For larger $m_t$ values ($m_t \approx 200$ GeV) electroweak Penguins begin to be important and they tend to cancel the contributions of the gluonic Penguins. The error in the matrix element estimation remains similar in magnitude, but the central value for the overall contribution is considerably reduced. A representative prediction for $m_t = 200$ GeV is, perhaps,

$$\frac{\epsilon'}{\epsilon} = (3 \pm 4) \times 10^{-4} A^2 \eta \quad (m_t = 200 \text{ GeV}) \, .$$

(41)
If one takes the above numbers at face value, one sees that, with the present range of $\eta$ allowed by the information on $|\epsilon|, x_d$ and $|V_{ub}|/|V_{cb}|$, the CKM paradigm tends to favor rather small values for $\epsilon'/\epsilon$. Typically, perhaps, $\epsilon'/\epsilon \simeq 4 \times 10^{-4}$, with a theory error probably of the same order! Such small values for $\epsilon'/\epsilon$ are perfectly compatible with the results obtained by the E731 collaboration \[9\], but are a bit difficult to reconcile with the results of NA31 \[8\].

4 Novel Tests of CPT at DAFNE and Fermilab

As we saw earlier, present tests of CPT in the neutral Kaon system involve in all cases differences of CPT violating parameters. Although I believe that cancellation among these parameters is unlikely, one should soon be able to clarify this situation, with experiments at DAFNE. DAFNE, the high luminosity Phi Factory being build at Frascati, may eventually reach a luminosity $\mathcal{L} = 10^{33} cm^{-2} sec^{-1}$, producing over $10^{10}$ correlated $K_L - K_S$ pairs from $\Phi$ decay. The possibility of studying such large samples of decays, as well as the particular features inherent from the way these states are produced, makes DAFNE a very interesting machine to further probe CP and CPT violation in the neutral Kaon sector. As far as CP goes, the KLOE detector at DAFNE should eventually be able to make a measurement of $\epsilon'/\epsilon$ competitive with what is expected from the next round of experiments at CERN and Fermilab - namely a measurement where the error on $\epsilon'/\epsilon$ is of the order of a few parts in $10^{-4}$. However, it is in the realm of CPT tests that DAFNE has a unique niche.

CPT can be further probed at DAFNE essentially because one can study there, in addition to $K_L$ decays, also decays of the $K_S$. To test CPT at DAFNE one can either:

i.) use $K_L$ decays as a tag to study $K_S$ decays

or

ii.) use the Phi factory directly as a $K^0 - \bar{K}^0$ interferometer.
In either case, one can make a direct measurement of $Re \delta_K$ and from this knowledge then reconstruct all the individual CPT violating parameters. Let me briefly discuss how this can be accomplished for both of the above methods. After doing so, I shall summarize the results of an in depth study [7] which tried to estimate the statistical accuracy with which one could measure CPT violating parameters in a high luminosity Phi factor $\gamma$.

In addition to the semileptonic asymmetry for $K_L$ decays, at DAFNE one will be able to measure, for the first time, the semileptonic asymmetry in $K_S$ decays. If CPT is conserved both of these asymmetries measure the same CP violating parameter, $2Re \epsilon_K$. However, if CPT is violated these asymmetries will be different. A simple calculation [?] gives

$$A_{K_L} = 2Re \epsilon_K + [2Re \frac{b}{Re \frac{a}{Re \frac{b}{}} + 2Re \delta_K}]$$

$$A_{K_S} = 2Re \epsilon_K + [2Re \frac{b}{Re \frac{a}{Re \frac{b}{}} - 2Re \delta_K}]$$

(42)

Thus the difference between $A_{K_L}$ and $A_{K_S}$ provides a direct measure of $Re \delta_K$. For an integrated luminosity of $\int \mathcal{L} dt = 10^{40} cm^{-2}$, one should be able to obtain through this comparison a measurement of $Re \delta_K$ to a statistical accuracy of $0(10^{-4})$[7].

One can also measure $Re \delta_K$, as well as $Im \delta_K$ (although this is already known from $\epsilon_{\text{cpt}}$), by using the Phi factory as a quantum interferometer [33]. The initial state in the Phi factory, coming from the decay of the $\Phi$ into $K_L$ and $K_S$, is a correlated superposition of $K_S$ and $K_L$ states. Taking the $\Phi$ to be at rest, one has

$$|\Phi> = \frac{1}{\sqrt{2}} \{|K_S(\vec{p})> |K_L(-\vec{p})> -|K_S(-\vec{p})> |K_L(\vec{p})>\}.$$  

(43)

By measuring the relative time decay probability for observing the decay by-products of the $K_L/K_S$ states into final states $f_1$ and $f_2$, one translates this initial state correlation into a final state interference pattern, whose precise shape will yield information on possible CP and CPT violating parameters in the system.

Let the ratio of decay amplitudes of $K_L$ and $K_S$ into a final state $f_i$ be denoted, as before, by

$$\eta_i = \frac{A(K_L \to f_i)}{A(K_S \to f_i)} = |\eta_i|e^{i\phi_i}.$$  

(44)
Then a simple calculation \cite{7} gives the following expression for the relative time decay probability for observing the states $f_1$ and $f_2$, which were produced at times $t_1$ and $t_2$:

$$I(f_1, f_2; \Delta t = t_1 - t_2) = \frac{1}{2} \int_{\Delta t}^{\infty} d(t_1 + t_2) |< f_1 f_2 | T | \Phi >|^2$$

$$= \text{const} \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} + 2|\eta_1||\eta_2| e^{-\frac{1}{2}(\Gamma_S + \Gamma_L) \Delta t} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}.$$  

(45)

Figure 4: Plot of the relative time decay probability for double semileptonic decay versus $\Delta t$ is units of $\tau_S$. From \cite{7}.

The above formula applies for $\Delta t > 0$. If $\Delta t < 0$, then the roles of $\Gamma_L$ and $\Gamma_S$ get interchanged. Because of this, in general, the pattern of the relative time decay probability is not symmetric between positive and negative $\Delta t$.

To test CPT one can study the relative time decay probability pattern for the case in which the final states $f_1$ and $f_2$ correspond to semileptonic decays, e.g. $f_1 = \pi^- \ell^+ \nu_\ell$ and $f_2 = \pi^+ \ell^- \bar{\nu}_\ell$. In this case, one has \cite{7}

$$|\eta_1|^2 = 1 - 4 Re \delta_K \ ; \ |\eta_2|^2 = 1 + 4 Re \delta_K$$

(46)
Table 2: Accuracy expected for CPT violating parameters in a high luminosity Phi factory. From [7]

| Parameter          | Expected Error |
|--------------------|----------------|
| Re δ_K             | ±0.7 × 10^{-4} |
| Im δ_K             | ±1.8 × 10^{-4} |
| Re b/Re a          | ±1.9 × 10^{-4} |
| ReB_0/ReA_0        | ±2.0 × 10^{-4} |
| ReB_2/ReA_2        | ±2.2 × 10^{-4} |

and

\[ \phi_1 - \phi_2 = \pi - 4Im \delta_K. \]  (47)

As a result, there is an asymmetry in the decay of \( I(f_1, f_2; \Delta t) \) for \( \Delta t > \tau_S \) relative to \( \Delta t < -\tau_S \), with the former decay being proportional to \( (1 - 4Re \delta_K)e^{-\Gamma_L \Delta t} \) and the latter being proportional to \( (1 + 4Re \delta_K)e^{-\Gamma_L |\Delta t|} \). Fig. 4 shows the shape of the expected relative time decay probability for this case. The interference dips near \( |\Delta t| \approx \tau_S \) are a measure of \( Im \delta_K \). In Table 2, I show the results of the comprehensive study of Buchanan et al [7] on the expected statistical accuracy with which one can hope to measure, with an integrated luminosity \( \int L dt = 10^{40} \text{ cm}^{-2} \), each of the CPT violating parameters discussed earlier. Note that none of these parameters, except \( Im \delta_K \), are measured individually at present. One sees from the above table that the results for each of the individual parameters at a high luminosity Phi factory should be of comparable in accuracy to present results on parameter differences.

Clearly, although current data in the \( K^0 - \bar{K}^0 \) system is consistent with CPT conservation, one will have to await the results from DAFNE for really unambiguous tests. This is perhaps best illustrated by means of Figure 5. Present measurements on the difference between \( \phi_c \) and \( \phi_{sw} \) only tell us how large \( \epsilon_{cpt} \) is, but not how large individually are \( ReB_0/ReA_0 \) and \( Re\delta_K \). At DAFNE, one will be able to measure \( Re\delta_K \) separately and thus deduce an unambiguous value for the \( K^0 - \bar{K}^0 \) mass difference. Although this mass difference relative to \( \Delta m \) will only be measured to the \( 10^{-4} \) level, on absolute
grounds one will measure

\[ \frac{m_{K^0} - m_{\bar{K}^0}}{m_{K^0}} \sim 0(10^{-18}) \]  

(48)

Figure 5: Measurements of various CPT violating parameters possible in a Phi factory.

This is a very interesting measurement, if CPT violating effects have anything to do with the Planck Scale, \( M_P \sim 10^{19} \text{ GeV} \). Indeed, if CPT violation occurs linearly in \( M_P^{-1} \) one would expect

\[ m_{K^0} - m_{\bar{K}^0} \simeq m_{K^0} \left( \frac{m_{K^0}}{M_P} \right) \simeq 10^{-19} m_K \]  

(49)

and one would be probing in the right parameter range at DAFNE!

Amazingly, this same range will be also probed by a forthcoming Fermilab experiment which is set to measure the antiproton lifetime. I would like to conclude this talk by briefly discussing this experiment. CPT conservation requires that the lifetimes of particles and antiparticles be the same. Thus, if CPT is valid, since there exist very strong bounds on the proton lifetime one expects that the antiproton lifetime should also be very long:

\[ \tau_{\bar{p}} = \tau_p \geq 10^{32} \text{ years} \]  

(50)

However, at present, the most stringent direct bound on \( \tau_{\bar{p}} \) is not even at the level of one year, being deduced from being able to store successfully about
10^3 \bar{p} \text{ in an ion trap. One has } \tau_\bar{p} < 3.4 \text{ months.} \tag{51}

The above direct limit for the antiproton lifetime will be considerably improved in the near future by the APEX experiment at Fermilab \[35\]. This experiment will search for \bar{p} decays in the Fermilab accumulator ring in a specially constructed vacuum tank, designed to reduce the beam-gas background. A test of the APEX experimental concept has already been performed, which has demonstrated that the beam-gas background is understood. In fact from this test one can already set a much better (preliminary) limit \[36\],

$$\tau_\bar{p} > 440 \text{ years} B(\bar{p} \to e^-\pi^0), \tag{52}$$

on the antiproton lifetime than that from \[34\].

The APEX experiments aims at reaching a limit for \(\tau_\bar{p}\) of the order \(\tau_\bar{p} \geq 10^6 - 10^8\) years. Such a limit is potentially interesting if CPT violating effects scale linearly with \(M_P^{-1}\). Indeed, imagine writing, for instance, the amplitude for the decay \(\bar{p} \to e^-\pi^0\) as

$$A(\bar{p} \to e^-\pi^0) = A(p \to e^+\pi^0) + C\left(\frac{m_p}{M_P}\right)^n, \tag{53}$$

where the second term above represents possible CPT violating contributions scaling as \(M_P^{-n}\). If \(n = 1\), then the proton decay amplitude in the above is negligible, and one has

$$\tau_\bar{p} = \frac{5 \times 10^{-31}}{C^2} M_P^2 \text{ GeV} \ BR(\bar{p} \to e^-\pi^0) \text{ years} \tag{54}$$

With \(C \sim O(1)\) one sees that, if \(n = 1\), then the \(\bar{p}\) lifetime range probed by the APEX experiment could begin to be interesting! Of course, all of this is extremely speculative. Indeed, if one thinks of CPT violating amplitudes at the quark and lepton level, purely on dimensional grounds one would expect \(n\) to be 2 rather than 1 \[37\].

5 Concluding Remarks

I hope the above discussion has made clear that present day experimental results on CP violation and on tests of CPT are tantalizingly close to answering two very interesting and probing questions. Namely:
i.) is there a $\Delta S = 1$ violation of CP, as expected in the CKM paradigm? and

ii.) is CPT conserved to $0 \left( \frac{m_{\text{hadron}}}{M_P} \right)$?

What is exciting is that it is likely that one will get an answer to both of these questions rather soon. Forthcoming experiments at CERN (NA48) and at Fermilab (E832) are likely to resolve the $\epsilon'/\epsilon$ issue once and for all. The KLOE collaboration at DAFNE has also the potential to help resolve the present controversy regarding this parameter ratio. Furthermore, KLOE as well as the APEX experiment at Fermilab will provide important information regarding CPT, at the level where logically there may be surprises. Interesting days are ahead!

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