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CP, T and CPT Symmetries at the Turn of a New Millenium [1]

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Abstract

After summarizing the status concerning CP violation in 1998 I describe the exciting developments of the last two years and extrapolate to the future. I comment on recent lessons about T and CPT invariance maninly from CPLEAR and emphasize the potential of finding New Physics by analyzing $K_{\mu 3}$ and charm decays and searching for electric dipole moments.

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[1] Lecture given at LEAP2000, Venice, Italy, Aug. 21 - 26, 2000

1 Introduction

During my talk I want to focus on three topics, namely

- the exciting developments in heavy flavour physics of the last two years and what can be expected in the foreseeable future,
- the lessons on T and CPT invariance learnt from CPLEAR as well as KTeV and NA48 including some comments on a program for the AD program at CERN, and
- other non-mainstream trends.

More specifically my talk will be organized as follows: after reminding you of why CP violation represents such a fundamental phenomenon and sketching the CP phenomenology as it existed in 1998 in Sect.2, I will describe the new insights and developments since then and what can be expected in the next decade or so in Sect.3; in Sect.4 I discuss T and CPT invariance and what has been learnt about it from CPLEAR with some additional information from $K_L \to \pi^+\pi^-e^+e^-$; in Sect.5 I comment on 'exotica', namely direct CP violation in hyperon decays, on $K_{\mu 3}$ decays, electric dipole moments and CP violation in charm transitions before presenting an outlook in Sect.6.

2 CP invariance and its limitations through 1998

2.1 CP violation as a fundamentally new paradigm

The discovery in 1957 that parity was broken in weak decays certainly caused a shock in the community. Yet the latter recovered remarkably fast largely due to arguments put forward by leading physicists like Landau. They suggested one had been hasty in requiring full invariance under parity. Invoking somewhat obliquely Mach's principle they instead argued in favour of CP symmetry pairing *left*-handed neutrinos with *right*-handed *anti*neutrinos; 'left' and 'right' is then defined in terms 'positive' and 'negative'. [2] A world of left-handed fermions and right-handed antifermions is thus a completely symmetric one. Indeed it was found that maximal parity violation in weak interactions is balanced by maximal violation of charge conjugation. This

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[2] This is similar to a German saying that the thumb is 'left' on the 'right' hand: it is as factually correct as it is useless since circular.

might remind you of the literary figure of ‘a man without a future and a woman without a past’.

The observation of $K_L \to \pi^+\pi^-$ in 1964 was totally unexpected by almost all theorists, and they did not give up without a fight. Interpretations other than CP violation were entertained: the existance of a particle U escaping detection in $K_L \to \pi^+\pi^-[U]$ was postulated [3] ; cosmological background fields were invoked and even the idea of *nonlinear effects* in quantum mechanics were floated [1] – to no avail! The fact that CP invariance appeared to be a ‘near-miss’ – BR($K_L \to \pi^+\pi^-$) $\sim 0.002 \ll 1$ in contrast to maximal P violation – made it even harder to accept. Nevertheless the whole community soon came around to accept CP violation as an empirical fact [2, 3].

I am telling this story not to poke fun at my predecessors. There were very good reasons for theorists’ slowness in embracing CP violation. For it was clearly realized that CP violation represented a more fundamental and radical shift to a new paradigm than parity violation.

- CP violation means that ‘left’- and ‘right’-handed can be distinguished in an *absolute* way, independant of any convention concerning the sign of charges. This is most obvious from the observation on semileptonic K_L decays:

$$\Gamma(K_L \to l^+\nu_L\pi^-) > \Gamma(K_L \to l^-\bar{\nu}_R\pi^+) \ . \tag{1}$$

- Due to CPT symmetry CP violation implies T violation, i.e. that nature distinguishes between ‘past’ and ‘future’ on the *microscopic* level.

- One can add (at least in retrospect) that CP violation is a necessary ingredient in any effort to understand the baryon number of the Universe as a *dynamically generated* quantity rather than as a parameter reflecting *initial conditions*.

- On a more technical level one can point out that CP violation represents the smallest observed violation of a symmetry: Im$M_{12} \simeq 1.1 \cdot 10^{-8}$ eV or Im$M_{12}/m_K \simeq 2.2 \cdot 10^{-17}$.

- The peculiar role of T violation surfaces also through *Kramers’ Degeneracy* [4]. With the time reversal operator T being *anti*unitary, T^2 has eigenvalues ± 1 meaning the Hilbert space has two distinct sectors. It is easily shown that each energy eigenstate in the sector with $T^2 = -1$ is at least doubly degenerate. This degeneracy is realized in nature through fermionic degrees of freedom. I find it quite remarkable that the operator T anticipates this option (and the qualitative difference between fermions and bosons) through $T^2 = -1$ *without* any explicit reference to spin.

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[3] It is an argument analogous to Pauli’s introduction of neutrinos into β decay: an ‘invisible’ particle is postulated to save a conservation law, namely that of energy-momentum there and CP here. While this idea worked there, it failed here.

2.2 Basic CP [& T] phenomenology

Due to CPT symmetry CP and T violation can enter through complex phases only. For them to become observable, one needs two different amplitudes to contribute coherently. This can be realized in different ways:

- *Particle-antiparticle oscillations followed by a decay into a common final state:*

  Such asymmetries are often referred to – with less than Shakespearean flourish – as indirect CP violation. The decay rate evolution in proper time then differs from a *pure exponential*, and the difference between CP conjugate transitions becomes a nontrivial function of time. Well-known examples are $K^0(t) \to \pi^+\pi^-$ vs. $\bar{K}^0(t) \to \pi^+\pi^-$ or $B_d(t) \to \psi K_S$ vs. $\bar{B}_d(t) \to \psi K_S$ with [5]

  $$\Gamma(B_d(t)[\bar{B}_d(t)] \to \psi K_S) \propto e^{-t/\tau(B_d)} \left(1 - [+] A \sin(\Delta m_d t)\right) \tag{2}$$

  Final state interactions (FSI) in general will affect the signal, although not for $B_d \to \psi K_S$. On the other hand they are not required and they cannot fake a signal.

- *Direct CP violation:*

  Within the SM it can occur in CKM suppressed modes only. There are several classes of such effects differing in the role played by final state interactions; they all share the feature that the signal is independant of the time of decay.

  - *Partial width differences:* The prime example is provided by comparing the strength of the two CP violating transitions $K_L \to \pi^+\pi^-$ and $K_L \to \pi^0\pi^0$:

    $$\eta_{+-} \equiv \frac{T(K_L \to \pi^+\pi^-)}{T(K_S \to \pi^+\pi^-)} \equiv \epsilon + \epsilon' \tag{3}$$

    $$\eta_{00} \equiv \frac{T(K_L \to \pi^0\pi^0)}{T(K_S \to \pi^0\pi^0)} \equiv \epsilon - 2\epsilon' \tag{4}$$

    While the quantity ϵ characterizes the decaying state K_L, ϵ' differentiates between the CP properties of the final states $\pi^+\pi^-$ versus $\pi^0\pi^0$. Its value can be determined from decay rates:

    $$\mathrm{Re}\frac{\epsilon'}{\epsilon} = \frac{1}{6}\left[\frac{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)} - 1\right] \tag{5}$$

    This situation can be generalized. If the final state consists of two pseudoscalar mesons or one pseudoscalar and one vector meson, then CP violation can manifest itself only in a partial width difference. FSI are necessary to transform CP violation into an observable. While they cloud the numerical interpretation of a signal (or its absence), they cannot fake a signal.

- *Final state distributions:* If a final state is more complex, i.e. consists of at least three pseudoscalar mesons not forming a resonance or of two vector mesons etc., then there are several potential layers of dynamical information. There could be asymmetries in subregions of a Dalitz plot that are substantially larger than when integrated over the whole Dalitz plot.

  Going one step further one can study decays of a particle P into four pseudoscalar mesons: $P \to a + b + c + d$. Such a final state allows to construct non-trivial *T-odd* correlations:

  $$C_T \equiv \langle \vec{p}_a \cdot (\vec{p}_b \times \vec{p}_c) \rangle \tag{6}$$

  with $C_T \to -C_T$ under time reversal. T violation can produce $C_T \neq 0$ irrespective of FSI; yet $C_T \neq 0$ does not necessarily establish T violation. Since T is described by an *anti*unitary operator, FSI can induce $C_T \neq 0$ with T-invariant dynamics. In contrast to the situation with partial widths where FSI play the role of a necessary evil, here they can act as an imposter. Yet comparing this observable for particle and antiparticle decays and finding $C_T + \bar{C}_T \neq 0$ establishes CP violation.

  The muon polarization transverse to the decay plane in $K^+ \to \mu^+ \pi^0 \nu$ represents such a T-odd correlation: $P_\perp(\mu) = \langle \vec{s}(\mu) \cdot (\vec{p}(\mu) \times \vec{p}(\pi)) / |\vec{p}(\mu) \times \vec{p}(\pi)| \rangle$, which in this case could not be faked realistically by final-state interactions and would reveal genuine T violation.

- The leading, namely linear term for the energy shift of a system inside a weak electric field $\vec{E}$ is described by a static quantity, the electric dipole moment $\vec{d}$:

  $$\Delta \mathcal{E} = \vec{d} \cdot \vec{E} + \mathcal{O}(E^2) \tag{7}$$

  For a non-degenerate system with spin $\vec{s}$ one has $\vec{d} \propto \vec{s}$; therefore $\vec{d} \neq 0$ reveals T (and P) violation.

2.3 Theory of CP violation

Initially it had been suggested that electrodynamics might violate CP invariance; yet it was soon cleared of that suspicion. There was then no theory of CP violation till 1972. The community can be forgiven for not being overly concerned about explaining $\text{BR}(K_L \to \pi^+\pi^-) \simeq 0.002$ when there are still infinities arising in the theoretical description of weak decays. Yet I find it highly remarkable that even after the SM had been formulated as a *renormalizable* theory by the late 1960's the lack of a theory for CP violation was not noticed till 1972 [6]. It is often said in response:"Well, we had the superweak model put forward by Wolfenstein already in 1964". However I view the superweak model [7] as a *classification* scheme for theories rather than a theory itself. Whenever one suggests a theory of CP violation, one has to analyze whether it provides a dynamical implementation of the superweak scenario or not, and to which accuracy it does so.

In 1973 the celebrated paper by Kobayashi and Maskawa appeared in print [8]. It pointed out that the electroweak SM with two full families – i.e. charm included – conserves CP; secondly it demonstrated how different types of New Physics – more families, more Higgs doublets, right-handed currents – allow CP breaking [4] [5]. Only one of these variants, namely the one with (at least) three families is now referred to as KM ansatz.

This KM ansatz removes the mystery from the apparent 'near miss' of CP invariance in $K_L \to \pi\pi$: this transition requires the interplay between three families; yet the third family is almost decoupled from the first two – not surprisingly (again at least in retrospect) considering its much heavier masses.

A second milestone was reached in the 1970's when the relevance of the so-called Penguin operators was realized, first in the context of the $\Delta I = 1/2$ rule [9], then also for allowing for $\epsilon'/\epsilon \neq 0$ [10]. Since then the treatment of Penguin operators and operator renormalization has reached a high level of sophistication [11].

A third milestone is represented by the formulation of the 'Strong CP Problem'; it still awaits its resolution [13]!

Another milestone was the realization in 1980 that the KM ansatz unequivocally predicts large CP asymmetries in some nonleptonic decay channels of neutral B mesons like $B_d \to \psi K_S$ [14, 5]. It was stated explicitely that asymmetries could be 1- 20 % and possible larger – at a time when neither the 'long' B lifetime nor the large $B_d - \bar{B}_d$ oscillation rate nor the huge top mass were known; at that time a top mass exceeding 60 GeV would have been seen as a frivolous notion!

With only three families the unitarity constraints of the CKM matrix are conveniently expressed through triangle relations in the complex plane. The one most relevant for B physics is given by

$$V^*(tb)V(td) + V^*(cb)V(cd) + V^*(ub)V(ud) = 0 \tag{8}$$

Various CP asymmetries are described in terms of the angles of this triangle; an ecumenical message in PDG2000 endorses two different notations, namely

$$\phi_1 \equiv \beta = \pi - \arg\left(\frac{V(tb)^*V(td)}{V(cb)^*V(cd)}\right), \phi_2 \equiv \alpha = \arg\left(\frac{V(tb)^*V(td)}{-V(ub)^*V(ud)}\right) ,$$

$$\phi_3 \equiv \gamma = \arg\left(\frac{V(ub)^*V(ud)}{-V(cb)^*V(cd)}\right) . \tag{9}$$

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[4] It had been noted first by Mohapatra that the SM with two families conserves CP. He suggested right-handed currents as the origin of CP violation [6].

[5] One can point out that Kobayashi and Maskawa benefitted from some 'insider' information: both were working in the Physics Department of Nagoya University at that time where, due to Sakata and his school, the notion of quarks as real rather than merely mathematical objects had been readily accepted, as had been the existence of charm due to the discovery of Niu [12].

2.4 The 'unreasonable' success of the CKM description

The observation of the 'long' B lifetime of about 1 psec together with the dominance of $b \to c$ over $b \to u$ revealed a hierarchical structure in the KM matrix that is expressed in the Wolfenstein representation in powers of $\lambda = \mathrm{tg}\theta_C$. The triangle defined by Eq.(8) then takes on a very special form: its three sides are all of order λ^3 and its angles therefore of order unity – as are the CP asymmetries they describe! Details are given in Sect.2.6.

We often see plots of the CKM unitarity triangle where the constraints coming from various observables appear as broad bands. While the latter is often bemoaned, it obscures a more fundamental point: the fact that these constraints can be represented in such plots at all is quite amazing! The quark box *without* GIM subtraction yields a value for Δm_K exceeding the experimental number by more than a factor of thousand; it is the GIM mechanism that brings it down to within a factor of two or so of experiment. The GIM subtracted quark box for ΔM_B coincides with the data again within a factor of two. Yet if the beauty lifetime were of order 10^{-14} sec while $m_t \sim 180$ GeV it would exceed it by an order of magnitude; on the other hand it would undershoot by an order of magnitude if $m_t \sim 40$ GeV were used with $\tau(B) \sim 10^{-12}$ sec; i.e., the observed value can be accommodated because a tiny value of $|V(td)V(ts)|$ is offset by a large m_t.

This amazing success is repeated with ϵ. Over the last 25 years it could always be accommodated (apart from some very short periods of grumbling mostly off the record) whether the *correct* set [$m_t = 180$ GeV with $|V(td)| \sim \lambda^3$, $|V(ts)| \sim \lambda^2$] or the *wrong* one [$m_t = 40$ GeV with $|V(td)| \sim \lambda^2$, $|V(ts)| = \lambda$] were used. Yet both $m_t = 180$ GeV with $|V(td)| = \lambda^2$, $|V(ts)| = \lambda$ as well as $m_t = 40$ GeV with $|V(td)| = \lambda^3$, $|V(ts)| = \lambda^2$ would have lead to a clear inconsistency!

Thus the phenomenological success of the CKM description has to be seen as highly nontrivial or 'unreasonable'. This cannot have come about by accident – there must be a profound reason.

2.5 New QCD technologies of the 1990's

Since we have to study the decays of quarks bound inside hadrons, we have to deal with nonperturbative dynamics [6] – a problem that in general has not been brought under theoretical control. Yet we can employ various theoretical technologies that allow to treat nonperturbative effects in special situation:

- For *strange* hadrons where $m_s \leq \Lambda_{QCD}$ one invokes chiral perturbation theory.
- For *beauty* hadrons with $m_b \gg \Lambda_{QCD}$ one can employ $1/m_b$ expansions in various incarnations; they should provide us with rather reliable results, whenever an operator product expansion can be applied [16].

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[6] Since top quarks decay before they can hadronize, their interactions can be treated perturbatively [15].

- It is natural to extrapolate such expansions down to the charm scale; this has to be done with considerable caution, though: while the charm quark mass exceeds ordinary hadronic mass scales, it does not do so by a large amount.
- Lattice QCD on the other hand is most readily set up at ordinary hadronic scales; from those one extrapolates *down* towards the chiral limit (which represents a nontrivial challenge) and *up* to the charm scale and beyond.

Let me add a few more specific comments:

Lattice QCD, which originally had been introduced to prove confinement and bring hadronic spectroscopy under computational control is now making major contributions to heavy flavour physics. This can be illustrated with very recent results on decay constants where the first *un*quenched results (with two dynamical quark flavours) have become available [17].

- $$f(D_s) = \left\{ \begin{array}{l} 240 \pm 4 \pm 24,\ 275 \pm 20 \text{ MeV},\ \text{lattice QCD} \\ 269 \pm 22 \text{ MeV},\ \text{world average of data} \end{array} \right. \tag{10}$$
- $$f(B) = 190 \pm 6 \pm 20^{+9}_{-0} \text{ MeV},\ \text{lattice QCD} \tag{11}$$
  $$f(B_s) = 218 \pm 5 \pm 26^{+9}_{-0} \text{ MeV},\ \text{lattice QCD} \tag{12}$$

The $1/m_Q$ expansions have become more refined and reliable qualitatively as well as quantitatively:

- The b quark mass has been extracted from data by different groups; their findings, when expressed in terms of the socalled 'kinetic' mass (which is distinct from both the pole as well as $\overline{\text{MS}}$ mass), read as follows:
  $$m_b^{\text{kin}}(1\,\text{GeV}) = \left\{ \begin{array}{ll} 4.56 \pm 0.06 & \text{GeV}\ \ [19], \\ 4.57 \pm 0.04 & \text{GeV}\ \ [20], \\ 4.59 \pm 0.06 & \text{GeV}\ \ [21] \end{array} \right. \tag{13}$$
  The error estimates of 1 - 1.5 % might be overly optimistic (as it often happens), but not foolish. Since all three analyses use basically the same input from the $\Upsilon(4S)$ region, they could suffer from a common systematic uncertainty, though.
- For the form factor describing $B \to l\nu D^*$ at zero recoil one has the following results:
  $$F_{D^*}(0) = \left\{ \begin{array}{l} 0.89 \pm 0.08\ \ [22], \\ 0.913 \pm 0.042\ \ [23], \\ 0.935 \pm 0.03\ \ [18] \end{array} \right. \tag{14}$$
  where the last number has been obtained in lattice QCD.

There is a natural feedback between lattice QCD and $1/m_Q$ expansions: by now both represent mature technologies that are defined in Euclidean rather than Minkowskian space; they share some expansion parameters, while differing in others; lattice QCD can evaluate hadronic matrix elements that serve as input parameters to $1/m_Q$ expansions.

It has been accepted for a long time now that heavy flavour decays can serve as high *sensitivity* probes for New Physics. I feel increasingly optimistic that our tools are and will be such that that they will provide us even with high *accuracy* probes!

2.6 Expectations and predictions 1998

The observed hierarchy in the CKM parameters

$$|V(ub)|^2 \ll |V(cb)|^2 \ll |V(cd)|^2 \tag{15}$$

tells us that the CKM matrix can conveniently be described by the Wolfenstein parametrization in powers of $\lambda = \mathrm{tg}(\theta_C)$:

$$V_{CKM} = \begin{pmatrix} V(ud) & V(us) & V(ub) \\ V(cd) & V(cs) & V(cb) \\ V(td) & V(ts) & V(tb) \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\lambda) & \mathcal{O}(\lambda^3) \\ \mathcal{O}(\lambda) & 1 & \mathcal{O}(\lambda^2) \\ \mathcal{O}(\lambda^3) & \mathcal{O}(\lambda^2) & 1 \end{pmatrix} \tag{16}$$

More specifically PDG2000 states as 90% C.L. ranges

$$|V_{CKM}| = \begin{pmatrix} 0.9750 \pm 0.0008 & 0.223 \pm 0.004 & 0.003 \pm 0.002 \\ 0.222 \pm 0.003 & 0.9742 \pm 0.0008 & 0.040 \pm 0.003 \\ 0.009 \pm 0.005 & 0.039 \pm 0.004 & 0.9992 \pm 0.0002 \end{pmatrix} \tag{17}$$

Without imposing three-family unitarity that is implicit in the Wolfenstein representation PDG2000 lists numbers that in particular for the top couplings are much less restrictive:

$$|V_{CKM}| = \begin{pmatrix} 0.9735 \pm 0.0013 & 0.220 \pm 0.004 & 0.003 \pm 0.002 & ... \\ 0.226 \pm 0.007 & 0.880 \pm 0.096 & 0.040 \pm 0.003 & ... \\ 0.05 \pm 0.04 & 0.28 \pm 0.27 & 0.5 \pm 0.49 & ... \\ ... & ... & ... & ... \end{pmatrix} \tag{18}$$

I would like to add three comments here:

- The brandnew CLEO number for $|V(cb)|$ from $B \to l\nu D^*$ – $|V(cb)F_{D^*}(0)| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$ [25] – falls outside the 90% C.L. range stated by PDG2000 for the expected values of $F_{D^*}(0)$.

- The OPAL collaboration has presented a new *direct* determination of $|V(cs)|$ from $W \to H_c X$: $|V(cs)| = 0.969 \pm 0.058$ [26].

- Using these values one finds

  $$|V(ud)|^2 + |V(us)|^2 + |V(ub)|^2 = 1.000 \pm 0.003 \; , \tag{19}$$

  which is perfectly consistent with the unitarity of the CKM matrix. Yet using instead $|V(ud)| = 0.9740 \pm 0.0005$ as extracted from nuclear $0^+ \to 0^+$ transitions, one obtains [27]

  $$|V(ud)|^2 + |V(us)|^2 + |V(ub)|^2 = 0.9968 \pm 0.0014 \; , \tag{20}$$

  i.e., a bit more than a 2 σ deficit in the unitarity condition.

With these input values one can make predictions on CP asymmetries, at least in principle and to some degree. I will confine myself to a few more qualitative comments.

- If there is a single CP violating phase δ as is the case in the KM ansatz one can conclude based on the $\Delta I = 1/2$ rule: $\epsilon'/\epsilon \leq 1/20$. The large top mass – $m_t \gg M_W$ – enhances the SM prediction for ϵ considerably more than for ϵ' for a given δ and therefore on quite general grounds

  $$\epsilon'/\epsilon \ll 1/20 \tag{21}$$

- Of course the KM predictions made employed much more sophisticated theoretical reasoning. Before 1999 they tended to yield – with few exceptions [28] – values not exceeding 10^{-3} due to sizeable cancellations between different contributions.

- Once the CKM matrix exhibits the *qualitative* pattern given in Eq.(16), it neccessarily follows that certain B_d decay channels will exhibit CP asymmetries of order unity. To be more specific one can combine what is known about $V(cb)$, $V(ub)$, $V(ts)$ and $V(td)$ from semileptonic B decays, $B_d - \bar{B}_d$ oscillations and bounds on $B_s - \bar{B}_s$ oscillations with or without using ϵ to construct the CKM unitarity triangle describing B decays. A crucial question to which I will return later centers on the proper treatment of theoretical uncertainties. A typical example is [29]:

  $$\begin{aligned} \sin 2\phi_1[\beta] &= 0.716 \pm 0.070 & (22) \\ \sin 2\phi_2[\alpha] &= -0.26 \pm 0.28 & (23) \end{aligned}$$

2.7 Status of the data in 1998

The relevant data read as follows in 1998:

- $$\begin{aligned} \mathrm{BR}(K_L \to \pi^+\pi^-) &\simeq 2.3 \cdot 10^{-3} \neq 0 & (24) \\ \frac{\mathrm{BR}(K_L \to l^+\nu\pi^-)}{\mathrm{BR}(K_L \to l^-\nu\pi^+)} &\simeq 1.006 \neq 0 & (25) \end{aligned}$$

- $$\mathrm{Re}\frac{\epsilon'}{\epsilon_K} = \begin{cases} (2.30 \pm 0.65) \cdot 10^{-3} & NA\,31 \\ (0.74 \pm 0.59) \cdot 10^{-3} & E\,731 \end{cases} \tag{26}$$

- The muon transverse polarization in $K^+ \to \mu^+\nu\pi^0$:

  $$\mathrm{Pol}_\perp(\mu) = (-1.85 \pm 3.6) \cdot 10^{-3} \tag{27}$$

- Electric dipole moments for neutrons and electrons

  $$\begin{aligned} d_N &< 9.7 \cdot 10^{-26} \;\; e\,cm & (28) \\ d_e &= (-0.3 \pm 0.8) \cdot 10^{-26} \;\; e\,cm & (29) \end{aligned}$$

  To get an intuitive understanding about the sensitivity achieved one can point out that the uncertainty in the electron's *magnetic* moment is about $2 \cdot 10^{-22}$ e cm and thus several orders of magnitude larger than the bound on its EDM! The bound on the neutron's EDM is smaller than its radius by 13 orders of magnitude. This corresponds to a relative displacement of an electron and a positron spread over the whole earth by less than 1 μ – much less than the thickness of human hair!

The situation in 1998 can then be described as follows: after 34 years of dedicated experimental work CP violation could still be described by a *single* number, namely ϵ, the situation concerning direct CP violation was in limbo, see Eq.(26), and no other manifestation had been seen.

3 New insights from 1999 and future developments

Direct CP violation has been established in K_L decays:

$$\mathrm{Re}\left(\frac{\epsilon'}{\epsilon'}\right) = \begin{cases} (2.80 \pm 0.41) \cdot 10^{-3} & \text{KTeV}, \\ (1.40 \pm 0.43) \cdot 10^{-3} & \text{NA48}\;; \end{cases} \tag{30}$$

its exact size, however, is still uncertain. It is a discovery of the first rank irrespective of what theory says or does not say.

Our theoretical interpretation of the data is very much in limbo. As I had argued before a rather small, but nonzero value is a natural expectation of the KM ansatz.

To go beyond such a qualitative statement, one has to evaluate hadronic matrix elements; apparently one had underestimated the complexities in this task. One intriguing aspect in this development is the saga of the $\Delta I = 1/2$ rule: formulated in a compact way [30] it was originally expected to find a simple dynamical explanation; several enhancement factors were indeed found, but the observed enhancement could not be reproduced in a convincing manner; this problem was then bracketed for some future reconsideration and it was argued that ϵ'/ϵ could be predicted while ignoring the $\Delta I = 1/2$ rule. Some heretics – 'early' ones [31] and 'just-in-time' ones [32] – however argued that only approaches that reproduce the observed $\Delta I = 1/2$ enhancement can be trusted to yield a re alistic estimate of ϵ'/ϵ. In particular it had been suggested that the scalar $\pi\pi$ resonance called σ plays a significant role here [31].

In all fairness one should point out that due to the large number of contributions with different signs theorists are facing an unusually complex situation [28]. One can hope for lattice QCD to come through, yet it has to go beyond the quenched approximation, which will require more time.

The second new element in 1999 was the start-up of the new asymmetric B factories BaBar and BELLE. Their first results again leave us in limbo [33]:

$$\begin{aligned} \sin 2\phi_1[\beta] &= 0.45^{+0.43+0.07}_{-0.44-0.09} \ \text{BELLE} && (31) \\ \sin 2\phi_1[\beta] &= 0.12 \pm 0.37 \pm 0.09 \ \text{BaBar} && (32) \end{aligned}$$

to be compared with the earlier data

$$\sin 2\phi_1[\beta] = 0.79 \pm 0.44 \ \text{CDF} \tag{33}$$

It is natural to ask what we would learn from a 'Michelson-Morley outcome', if, say, $|\sin 2\phi_1| < 0.1$ were established. Firstly, we would know that the KM ansatz would be ruled out as a major player in $K_L \to \pi\pi$ – there would be no plausible deniability! Secondly, one would have to raise the basic question why the CKM phase is so suppressed, unless there is a finely tuned cancellation between KM and New Physics forces in $B \to \psi K_S$; this would shift then the CP asymmetry in $B \to \pi\pi$, $\pi\rho$.

I expect those B factories to have established CP violation in at least one B decay mode by 2002. Yet that will not be the end of it – far from it! Experiments at the upgraded B factories at KEK and SLAC together with new experiments at the LHC – LHC-B – and at FNAL – BTeV – are expected to achieve experimental accuracies of a few percent, and they will measure many more observables. At the same time I expect that over the next five years or so we will be able to predict Standard Model effects with a few percent accuracy due to the improved theoretical tools sketched above and new measurements of CP *in*sensitive rates. We will then face the following type of challenge: how confident will we be in inferring the intervention of New Physics based on a difference between data and predictions?

In principle there are precedents for establishing the presence of New Physics in such an *indirect* way in heavy flavour decays: based on the apparent absence of flavour changing neutral currents some courageous souls [34] postulated the existence of charm quarks; the occurance of $K_L \to \pi\pi$ lead to the conjecture that even a third family of quarks had to exist [8]. However in all those cases we could rely on a *qualitative* discrepancy; i.e., the difference between observed and predicted rate amounted to several orders of magnitude or the predicted rate was zero – as for $K_L \to \pi\pi$. In the decays of beauty hadrons we predict many large or at least sizeable effects, and realistically in most cases we can expect differences well below an order of magnitude only! E.g., one predicts an asymmetry of, say, 40 %, but observe -40%: will we all be confident enough to claim the presence of New Physics then? What about 40% vs. 60 % or even vs. 50%? This would represent a novel challenge not encountered before; it will require that we gain quantitative control over that most evasive class of entities – theoretical uncertainties. I am confident we will make great progress in that respect. My optimism is not based on hoping that novel theoretical breakthroughs will occur although they might. But what will empower us is the fact that so many different types of observables can be measured in beauty decays. There are actually six KM unitarity triangles [44], and several of their angles can be measured in the dedicated and comprehensive research program that is being undertaken world-wide. Our analysis will then be able to invoke overconstraints – the most effective weapon in our arsenal against systematic uncertainties in general!

4 Status of T and CPT Invariance

It is often alleged that CPT invariance can boast of impressive experimental verification as expressed through the bound $|M(K^0) - M(\bar{K}^0)|/M(K) = (0.08 \pm 5.3) \cdot 10^{-19}$. However one might as well have divided this difference by the mass of an elephant since *intrinsically* the kaon mass is only marginally more related to the $K - \bar{K}$ mass splitting than the elephant's mass.

To put it differently: since this CPT breaking is expressed through a mass difference, one needs another *dimensional* quantity as yardstick. This can be provided by $\mathrm{Im}M_{12}$ expressing CP violation in the mass matrix:

$$|M(K^0) - M(\bar{K}^0)| < 2.5 \cdot 10^{-10} \text{ eV} \quad \Leftrightarrow \quad \mathrm{Im}M_{12} \simeq 10^{-8} \text{ eV} \; ; \tag{34}$$

i.e., CPT breaking still could be as 'large' as a few percent of the observed CP violation!

I have similar reservations about expressing bounds on the mass difference between protons and antiprotons relative to the proton mass etc.

Similarly I find statements relating bounds on the mass difference between protons and antiprotons to the proton mass as merely mathematical and largely devoid of physical meaning.

I want to emphasize that our belief in CPT invariance is based much more on 'dogma', i.e. theory, than empirical facts. For it is an almost inescapable consequence of *local* quantum field theories based on canonized assumptions like Lorentz invariance, the existence of a unique vacuum state and weak local commutativity obeying the 'right' statistics. Some explicit examples of CPT breaking theories have been given, but they are highly contrived and unattractive [36, 37].

The new interest in experimental studies of CPT symmetry is fed by two more recent developments [38]:

- Novel tests of CPT as well as *linear* quantum mechanics can be performed at the Φ and beauty factories DAΦNE, BABAR and BELLE respectively by harnessing EPR correlations [39].

- Superstring theories are intrinsically *non*local thus vitiating one of the central axioms of the CPT theorem. Furthermore gravity could induce CPT breaking either as a true symmetry violation or as a background effect due to the preponderance of matter over antimatter in our corner of the universe. Then it would be not unreasonable to expect CPT asymmteries to scale like a positive power of E/M_{Planck}. *If* that power were unity one would guestimate $|M(K^0) - M(\bar{K}^0)| \sim M(K)/M_{Planck} \sim 10^{-19}$; yet the main argument in favour of such a scenario is 'why not?".

Unfortunately these suggestions do not yield any reliable benchmark figures for CPT violations. Searches for them still represent shots in the dark, although there is a wide field for them [40].

In this context there might be more interest in the even more unorthodox suggestion that the extra dimensions required by superstring theories are larger than the Planck length by many orders of magnitude [35]. This leads to the intriguing scenario where the Planck scale is actually a derived rather than a fundamental one; that role is played by a much lower energy scale M_X. It was noticed that the $1/r^2$ force law for gravity had not been tested in the sub-millimeter domain. With gravity (unlike gauge forces) operating in *all* dimensions, their dynamics would undergo a great qualitative change at distances comparable to the size of the extra dimensions. More specifically the $1/r^2$ law would change to $1/r^{2+n}$ with the natural number n depending on the number of extra dimensions and the new fundamental unification scale M_X. In such a case it just might be conceivable that studying the spectra of *anti-protonic* atoms could reveal an *apparent* violation of CPT symmetry. The picture I have in mind without having done a calculation that is certainly doable is the following: in an anti-protonic atom where the antiproton is as close to the nucleus as possible without entering the meson cloud around the latter the orbiting antiproton would experience a gravitational force exceeding the canonical one by many orders of magnitude if n were sufficiently large. Its gravitational mass could then differ significantly from the mass of protons *determined at larger distances*.

Although CP violation implies T violation due to the CPT theorem (and despite my skepticism concerning the observability of the latter), I consider it highly significant that more direct evidence has been obtained through the 'Kabir test':

CPLEAR has found [41]

$$A_T \equiv \frac{\Gamma(K^0 \to \bar{K}^0) - \Gamma(\bar{K}^0 \to K^0)}{\Gamma(K^0 \to \bar{K}^0) + \Gamma(\bar{K}^0 \to K^0)} = (6.6 \pm 1.3 \pm 1.0) \cdot 10^{-3} \tag{35}$$

versus the value $(6.54 \pm 0.24) \cdot 10^{-3}$ inferred from $K_L \to \pi^+\pi^-$. Of course, some assumptions still have to be made, namely that *semileptonic* K decays obey CPT or that the Bell-Steinberger relation is satisfied with *known* decay channels only. Avoiding both assumptions one can write down an admittedly contrived scheme where the CPLEAR data are reproduced *without* T violation; the price one pays is a large CPT asymmetry $\sim \mathcal{O}(10^{-3})$ in $K^\pm \to \pi^\pm\pi^0$ [43].

KTeV and NA48 have analyzed the rare decay $K_L \to \pi^+\pi^-e^+e^-$ and found a large *T-odd* correlation between the $\pi^+\pi^-$ and e^+e^- planes in full agreement with predictions [42]. Let me add just two comments here: (i) This agreement cannot be seen as a success for the KM ansatz. Any scheme reproducing η_{+-} will do the same. (ii) The argument that strong final state interactions (which are needed to generate a T odd correlation above 1% with T invariant dynamics) cannot affect the relative orientation of the e^+e^- and $\pi^+\pi^-$ planes fails on the quantum level [43].

The effect found represents a true CP asymmetry. Yet if one is sufficiently determined, it still could be attributed to CP and CPT breaking that leaves T invariant. A more detailed discussion of these subtle points is given in [42, 43].

5 Beyond the Mainstream

Considerable circumstantial evidence has been accumulated that the SM is incomplete. There are (at least) four central mysteries at the basis of flavour dynamics:

- Why is there a family structure relating quarks and leptons?
- Why is there more than one family, why three, is three a fundamental parameter?
- What is the origin of the observed pattern in the quark masses and the CKM parameters? This pattern can hardly have come about by accident.
- Why are neutrinos massless – or aren't they?

To a large degree studying flavour dynamics represents an indirect or high sensitivity search for New Physics, as already stressed in my discussion of B physics. Yet we have to be sufficiently openminded in where we look; i.e., search also in areas where the Standard Model does not predict observable effects.

One such area is represented by searching for direct CP asymmetries in hyperon decays where the SM effects are below the sensitivity level of the ongoing HyperCP experiment.

Others are even more radical and can be characterized as a ‘King Kong’ scenario: ”One might be unlikely to encounter King Kong; yet once it happens there can be no doubt that one has come across someting out of the ordinary”. Such a situation can be realized for $K_{\mu 3}$ decays and EDMs – as introduced in Sect. 2.2 – and to some degree for charm transitions.

5.1 $P_\perp(\mu)$ in $K^+ \to \mu^+ \pi^0 \nu$

With $P_\perp(\mu) \sim 10^{-6}$ in the SM, it would also reveal New Physics that has to involve chirality breaking weak couplings: $P_\perp(\mu) \propto \mathrm{Im}\xi$, where $\xi \equiv f_-/f_+$ with $f_-[f_+]$ denoting the chirality violating [conserving] decay amplitude. There is an on-going experiment at KEK (KEK-E 246) aiming at a sensitivity for $P_\perp(\mu)$ of 10^{-3} or better.

5.2 EDM’s

With the KM scheme predicting unobservably tiny effects (with the only exception being the ‘strong CP’ problem) – namely $d_{N,e} < 10^{-30}$ e cm – and many New Physics scenarios yielding d_N, $d_e \geq 10^{-27}$ ecm, this is truly a promising zero background search for New Physics! The next round of experiments is aiming at 10^{-28} e cm for d_N and 10^{-30} e cm for d_e [45].

The game one is hunting is actually much more numerous, since many effects from the domain of nuclear physics can be employed here [45].

5.3 D^0 Oscillations & CP Violation

It is often stated that D^0 oscillations are slow and CP asymmetries tiny within the SM and that therefore their analysis provides us with zero-background searches for New Physics.

Oscillations are described by the normalized mass and width differences: $x_D \equiv \frac{\Delta M_D}{\Gamma_D}$, $y_D \equiv \frac{\Delta\Gamma}{2\Gamma_D}$. A conservative SM estimate yields x_D, $y_D \sim \mathcal{O}(0.01)$. Stronger bounds have appeared in the literature, namely that the contributions from the operator product expansion (OPE) are completely insignificant and that long distance contributions *beyond* the OPE provide the dominant effects yielding x_D^{SM}, $y_D^{SM} \sim \mathcal{O}(10^{-4} - 10^{-3})$. A recent detailed analysis [46] revealed that a proper OPE treatment reproduces also such long distance contributions with

$$x_D^{SM}|_{OPE},\ y_D^{SM}|_{OPE} \sim \mathcal{O}(10^{-3}) \qquad (36)$$

and that $\Delta\Gamma$, which is generated from on-shell contributions, is – in contrast to Δm_D – insensitive to New Physics while on the other hand more susceptible to violations of (quark-hadron) duality.

Four experiments have reported new data on y_D:

$$y_D = \left\{ \begin{array}{l} (0.8 \pm 2.9 \pm 1.0)\% \;\; \text{E791} \\ (3.42 \pm 1.39 \pm 0.74)\% \;\; \text{FOCUS} \\ (1.0^{+3.8+1.1}_{-3.5-2.1})\% \;\; \text{BELLE} \end{array} \right. \tag{37}$$

$$y'_D = (-2.5^{+1.4}_{-1.6} \pm 0.3)\% \;\; \text{CLEO} \tag{38}$$

E 791 and FOCUS compare the lifetimes for two different channels, whereas CLEO fits a general lifetime evolution to $D^0(t) \to K^+\pi^-$; its y'_D depends on the strong rescattering phase between $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$ and therefore could differ substantially from y_D if that phase were sufficiently large. The FOCUS data contain a suggestion that the lifetime difference in the $D^0 - \bar{D}^0$ complex might be as large as $\mathcal{O}(1\%)$. *If* y_D indeed were ~ 0.01, two scenarios could arise for the mass difference. If $x_D \leq$ few $\times 10^{-3}$ were found, one would infer that the $1/m_c$ expansion yields a correct semiquantitative result while blaming the large value for y_D on a sizeable and not totally surprising violation of duality. If on the other hand $x_D \sim 0.01$ would emerge, we would face a theoretical conundrum: an interpretation ascribing this to New Physics would hardly be convincing since $x_D \sim y_D$. A more sober interpretation would be to blame it on duality violation or on the $1/m_c$ expansion being numerically unreliable. Observing D^0 oscillations then would not constitute a 'King Kong' scenario.

Searching for *direct* CP violation in Cabibbo suppressed D decays as a sign for New Physics would also represent a very complex challenge: within the KM description one expects to find some asymmetries of order 0.1 %; yet it would be hard to conclusively rule out some more or less accidental enhancement due to a resonance etc. raising an asymmetry to the 1% level.

The only clean environment is provided by CP violation involving D^0 oscillations, like in $D^0(t) \to K^+K^-$ and/or $D^0(t) \to K^+\pi^-$. For the asymmetry would depend on the product $\sin(\Delta m_D t) \cdot \mathrm{Im}[T(\bar{D} \to f)/T(D \to \bar{f})]$: with both factors being $\sim \mathcal{O}(10^{-3})$ in the SM one predicts a practically zero effect. Yet New Physics scenarios can induce signals as large as order 1 percent for $D^0(t) \to K^+K^-$ and even larger for $D^0(t) \to K^+\pi^-$.

6 Outlook

I want to start with a statement about the past: *The comprehensive study of kaon and hyperon physics has been instrumental in guiding us to the Standard Model.*

- The $\tau - \theta$ puzzle led to the realization that parity is not conserved in nature.
- The observation that the production rate exceeded the decay rate by many orders of magnitude – this was the origin of the name 'strange particles' – was explained through postulating a new quantum number – 'strangeness' –

conserved by the strong, though not the weak forces. This was the beginning of the second quark family.

- The absence of flavour-changing neutral currents was incorporated through the introduction of the quantum number ‘charm’, which completed the second quark family.
- CP violation finally led to postulating yet another, the third family.

All of these elements which are now essential pillars of the Standard Model were New Physics at *that* time!

I take this historical precedent as clue that a detailed, comprehensive and thus neccessarily long-term program on the dynamics of heavy flavours – on the quark as well as lepton side – in general and on CP violation in particular will lead to a new paradigm, a *new* Standard Model. For we are addressing the problem of fermion mass generation – a central mystery in our present SM. Such studies are of fundamental importance, they will teach us lessons that cannot be obtained any other way and cannot become obsolete.

It will not be an easy journey on a straight path, nor will it be short, nor can we anticipate where we will end up. Yet we know that we are at the beginning of an truly exciting adventure.

Finally we should never loose sight of the fact that by any historical standard we are generously supported by the public. Therefore we better appreciate how highly privileged we are in participating in this adventure. I do not know of a sufficient justification for this privilege, only of a necessary one: to work with as much dedication as we can possibly muster and never be satisfied with a second-best effort!

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While I have enjoyed meetings at many beautiful places in the world, I have to say that San Servolo is second to none. Its setting in the laguna of Venice, the views and sunsets it offers, how it combines its own tranquility with the nearby vibrancy of Venice, its sparkling light – all of this is beyond description, it has to be experienced. Prof. Faessler deserve our enthusiastic thanks for introducing this jewel into the conference scene of particle physics. This work has been supported by the NSF under the grant PHY 96-05080.

References

[1] B. Laurent, M. Roos, *Phys. Lett.* **13** (1964) 269; *ibid.* **15** 104.

[2] For an exciting historical account, see A. Pais, ‘CP violation: the first 25 years’, *CP Violation in Particle and Astrophysics*, J. Tran Than Van (ed.), Edition Frontieres, 1989.

[3] For a more detailed recounting, see: I.I. Bigi, A.I. Sanda, *CP Violation*, Cambridge University Press, 2000.

[4] For a more recent reference, see: A. Messiah, *Quantum Mechanics*, Vol. II, North-Holland, Amsterdam, 1965, p. 675.

[5] I. Bigi, A.I. Sanda, *Nucl. Phys.* **B 193** (1981) 85.

[6] R. Mohapatra, *Phys. Rev.* **D 6** (1972) 2023.

[7] L. Wolfenstein, *Phys. Rev. Lett.* **13** (1964) 562.

[8] M. Kobayashi, T. Maskawa, *Prog. Theor. Phys.* **49** (1973) 652.

[9] A. Vainshtein, V. Zakharov, M. Shifman, *Sov. Phys. JETP* **45** (1977) 670.

[10] F. Gilman, M. Wise, *Phys. Rev.* **D 20** (1979) 2392.

[11] A. Buras, P. Gambino, M. Gorbahn, S. Jager, L. Silvestrini, hep-ph/0007313.

[12] K. Niu, E. Mikumo, Y. Maeda, *Prog. Theor. Phys.* **46** (1971) 1644.

[13] For a clear review, see: R. Peccei, in: *CP Violation*, C. Jarlskog (ed.), World Scientific, Singapore, 1988.

[14] A. B. Carter, A.I. Sanda, *Phys. Rev.* **D 23** (1981) 1567.

[15] I. Bigi, Y. Dokhshitzer, V. Khoze, J. Kühn, P. Zerwas, *Phys. Lett.* **B 181** (1986) 157.

[16] I.I. Bigi, M.Shifman, N. Uraltsev, *Annu. Rev. Nucl. Part. Sci.* **47** (1997) 591, with references to earlier work.

[17] R. Kenway, Invited Plenary Talk given at ICHEP2000, July 27 - August 2, 2000, Osaka, Japan, to appear in the Proc.

[18] J. Simone et al., *Nucl. Phys. Proc. Supp.* **83** (2000) 334.

[19] K. Melnikov, A. Yelkhovsky, *Phys. Rev.* **D 59** (1999) 114009.

[20] A. Hoang, *Phys. Rev.* **D 61** (2000) 034005.

[21] M. Beneke and A. Signer, *Phys. Lett.* **B 471** (1999) 233.

[22] I. Bigi, hep-ph/9907270.

[23] The BABAR Physics Book, P. Harrison & H. Quinn (eds.), SLAC-R-504.

[24] I.I. Bigi, Invited Plenary Talk given at ICHEP2000, July 27 - August 2, 2000, Osaka, Japan, to appear in the Proc., hep-ph/0009021.

[25] D. Cinabro, Invited Plenary Talk given at ICHEP2000, July 27 - August 2, 2000, Osaka, Japan, to appear in the Proc.

[26] The OPAL Collab., preprint CERN-EP-2000-100.

[27] I.S. Towner and J.C. Hardy, in: Proceed. of the 5th Int. WEIN Symposium "Physics beyond the Standard Model", Santa Fe, June 1998, P. Herczeg et al. (eds.), World Scientific, Singapore (1999), p. 338, preprint nucl-th/9809087.

[28] M. Fabbrichesi, Invited talk given at CPconf2000, Intern. Conf. on CP Violation Physics, Sept. 18 - 22, 2000, Ferrara, Italy, to appear in the Proceed.

[29] F. Parodi, Invited talk given at CPconf2000, Intern. Conf. on CP Violation Physics, Sept. 18 - 22, 2000, Ferrara, Italy, to appear in the Proceed.

[30] M. Gell-Mann, A. Pais, *Proc. Glasgow Conf. Nuclear and Meson Physics*, E.H. Bellamy and R.G. Moorhouse (eds.), Pergamon Press, Oxford, 1955.

[31] T. Morozumi, C.S. Lim and A.I. Sanda, *Phys. Rev. Lett.* **65**(1990) 404.

[32] S. Bertolini, J. Eeg, M. Fabbrichesi, *Rev. Mod. Phys.* **72** (2000) 65.

[33] A. Golutvin, Invited Plenary Talk given at ICHEP2000, July 27 - August 2, 2000, Osaka, Japan, to appear in the Proc.

[34] S. Glashow, J. Illiopoulos and L. Maiani, *Phys. Rev.* **D 2** (1970) 1285.

[35] L. Hall, Invited Plenary Talk given at ICHEP2000, July 27 - August 2, 2000, Osaka, Japan, to appear in the Proc.

[36] A.I. Oksak, I.T. Todorov, *Commun. Math. Phys.* **9** (1968) 2146.

[37] I.I. Bigi, *Z. Phys.* **C 12** (1982) 235.

[38] A. Kostelecky, preprint hep-ph/9912528; M. Kobayashi, A.I. Sanda, *Phys. Rev. Lett.* **69**(1992) 3139.

[39] A. Einstein, B. Podolsky, N. Rosen, *Phys. Rev.* **D 47**(1935) 777.

[40] N. Russell, preprint hep-ph/0011162.

[41] A. Apostolakis et al., *Phys. Lett.* **B 444** (1998) 43; *Phys. Lett.* **B 456** (1999) 297.

[42] L. Sehgal, M. Wanninger, *Phys. Rev.* **D 46**(1992) 1035; 5209 (E).

[43] I.I. Bigi, A.I. Sanda, *Phys. Lett.* **B 466** (1999) 33.

[44] I.I. Bigi, A.I. Sanda, hep-ph/9909479.

[45] E. Hinds, Invited talk given at CPconf2000, Intern. Conf. on CP Violation Physics, Sept. 18 - 22, 2000, Ferrara, Italy, to appear in the Proceed.

[46] I. Bigi, N. Uraltsev, hep-ph/0005089, to appear in *Nucl. Phys.* **B**.