INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-91/045 (R)
9 Luglio 1991

CP PHYSICS AT DAΦNE

Paolo Franzini

Columbia University, New York, NY 10027, USA
and
INFN - Laboratori Nazionali di Frascati, P.O.Box 13, I-00044 Frascati (Italy)

ABSTRACT

We briefly review K^0–meson physics, in particular the observation and phenomenology of CP violation which was discovered 27 years ago and, to date, is still only observed in K_L decays. During the intervening time much effort has been devoted to the search for *direct* CP violation, trying to detect whether K_S's and K_L's decay to $\pi^+\pi^-$ and $\pi^0\pi^0$ in different ratios. Since long ago e^+e^- colliders, pioneered at Frascati, have been considered as possible factories of clean physical states. We show the potential of DAΦNE to provide enough data to improve by an order of magnitude the sensitivity of such searches. We discuss the spatial accuracy required to measure the difference in phase of the amplitude ratios $A(K_L{\rightarrow}\pi^+\pi^-)/A(K_S{\rightarrow}\pi^+\pi^-)$ and $A(K_L{\rightarrow}\pi^+\pi^-)/A(K_S{\rightarrow}\pi^+\pi^-)$. We examine problems of regeneration and other physical backgrounds. Finally we discuss some requirements for electromagnetic calorimetry at DAΦNE and briefly describe a possible solution.

1. Introduction

1.1 28 AND 27 YEARS AGO

In 1963 the Anello di Accumulazione, AdA,[1] conceived and built at Frascati and tested at Orsay, first proved the possibility of colliding counter rotating beams of electrons and positrons, realizing the vision of Bruno Touschek. In 1964 CP violation was observed in K^0 decays.[2]

In the following quarter of a century, e^+e^- colliders have become the most powerful tools for the study of elementary particle physics. The first e^+e^- collider to provide adequate energy and luminosity, W=2.5 GeV and $\mathcal{L} \sim 10^{30}$ cm^{-2} s^{-1}, was ADONE, again a Frascati machine. Adone began operations for physics in 1971, soon discovering that the cross section for the production of hadrons was larger than expected, an observation heralding the beginning of a new era in physics. Since AdA's days, the energy of e^+e^- colliders has increased from 500 MeV to 100 GeV and the luminosity from 10^{27-28} to 10^{32}. During the same period, extensive experimentation has not much advanced our understanding of CP violation.

Today it is widely believed that e^+e^- colliders will open new possibilities for performing experiments of greatly improved precision and statistical accuracy in many fields of particle physics. Advances in the understanding of storage ring dynamics have in the last few years stimulated wide interest in the use of e^+e^- colliders as particle "factories". LEP can certainly be considered a Z^0 factory. In addition in all major laboratories around the world there is today very strong interest in ϕ–factories, τ–charm–factories and b– factories.

A ϕ–factory allows a new approach to the experimental study of CP violation through its capability of producing tens of billions of almost backgroundless K_S-K_L pairs, in a well prepared quantum state, per year. $K_S K_L$ and K^+K^- pairs come from the decay of ϕ–mesons. The first suggestion to employ an e^+e^- collider of energy W=1020 MeV, the ϕ mass, to study CP violation in K^0 decays was put forward in 1968 at Frascati.[3]

It seems quite appropriate that Frascati will take the lead in this new use of e^+e^- colliders with the DAΦNE[4] project, among whose physics goals are the probing of direct CP violation in the two pion decays of neutral kaons with much greater sensitivity than has been possible so far. Interest is large in the world about the possibility of building ϕ–factories of appropriate luminosity as evidenced at this workshop by the description of plans at Novosibirsk,[5] KEK,[6] UCLA,[7] and Mainz.[8] The quite different approach at TRIUMF,[9] where protons are used to produced very intense kaon beams, is truly a K–factory an will offer unique opportunities for searches of very rare decays of the kaons.

1.2 K MESONS

The study of K meson physics has led to many new ideas such as the concepts of strangeness and flavor mixing in the weak interactions. Parity violation was in fact first observed through the θ–τ decay modes of kaons. In 1955 Gell-Mann and Pais predicted[10] that there should be two physical neutral K meson states of different lifetimes, which were supposed to be eigenstates of CP:

$$\begin{aligned} |K_1\rangle &= \frac{|K\rangle + |\overline{K}\rangle}{\sqrt{2}} \qquad \mathrm{CP}|K_1\rangle = |K_1\rangle \\ |K_2\rangle &= \frac{|K\rangle - |\overline{K}\rangle}{\sqrt{2}} \qquad \mathrm{CP}|K_2\rangle = -|K_2\rangle. \end{aligned} \tag{1.1}$$

Lederman and his group observed the existence of the long lived neutral K^0's in 1956.[11] In 1964 $K_2 \to 2\pi$ decays where observed,[12] an unambiguous proof of CP violation. To date CP violation has not been observed in any other process.

If CP is violated, the physical states of short and long lifetimes must acquire some small admixture of the wrong CP component and we can write them, assuming CPT invariance, with small loss of generality, as:

$$K_S = \frac{K_1 + \epsilon K_2}{\sqrt{1+|\epsilon|^2}} \quad K_L = \frac{K_2 + \epsilon K_1}{\sqrt{1+|\epsilon|^2}} \tag{1.2}$$

$$\frac{\mathrm{d}}{\mathrm{dt}}|K_i\rangle = -i\mathcal{M}_i|K_i\rangle, \quad \mathcal{M}_i = M_i - i\Gamma_i/2 \tag{1.3}$$

where the various parameters are measured to be:[13]

$$\Gamma_S = 1.12 \times 10^{-10}\ \mathrm{s}^{-1} \qquad \Gamma_L = 1.93 \times 10^{-7}\ \mathrm{s}^{-1} \qquad |\epsilon| \sim 2.26 \times 10^{-3}$$
$$M_S = 497.7\ldots\ \mathrm{MeV} \quad M_L - M_S = 3.57 \times 10^{-12}\ \mathrm{MeV}$$

While the CP impurity, due to second order weak $K \Leftrightarrow \overline{K}$ transitions, allows for $K_L \to 2\pi$ decays, due to its small K_1 component, we still do not know, 27 years later, whether there is a direct, $\Delta s = 1$, CP violating amplitude, so that $\langle 2\pi|K_2\rangle \neq 0$.

Defining the usual amplitude ratios and epsilon parameters:[14]

$$\frac{\langle\pi^+\pi^-|K_L\rangle}{\langle\pi^+\pi^-|K_S\rangle} = \eta_{+-} = \epsilon + \epsilon', \quad \frac{\langle\pi^0\pi^0|K_L\rangle}{\langle\pi^0\pi^0|K_S\rangle} = \eta_{00} = \epsilon - 2\epsilon' \tag{1.4}$$

where η's and ϵ's are all complex, experimental observation of $\epsilon' \neq 0$ would be proof that CP is violated directly in the decay amplitudes. From eq. (1.4) it trivially follows that the so called double ratio measures $\Re(\epsilon'/\epsilon)$:

$$\frac{BR(K_L \to \pi^+\pi^-)}{BR(K_S \to \pi^+\pi^-)} \Big/ \frac{BR(K_L \to \pi^0\pi^0)}{BR(K_S \to \pi^0\pi^0)} = 1 + 6 \times \Re(\epsilon'/\epsilon) \tag{1.5}$$

Many experiments have attempted to measure $\Re(\epsilon'/\epsilon)$ with continuously improving sensitivity. The most recent results are:

Experiment	$\Re(\epsilon'/\epsilon) \times 10^3$	Year	Ref.
E731	-0.5 ± 1.5	'89	15
NA31	2.7 ± 0.9	'90	16

clearly not yet providing conclusive evidence whether $\Re(\epsilon'/\epsilon) \neq 0$.

A fundamental question about CP violation is whether it can be accommodated in the standard model or whether it is a signal about a new phenomenon such as the so called superweak interaction.[17] CP violation can indeed be accommodated in the standard model, since the CKM flavor mixing matrix allows for an arbitrary phase for three quark families,[18] which implies CP violation to all orders in the weak interaction. Therefore if the K_S, K_L impurity is due to this mechanism then $\epsilon' \neq 0$, except for accidental cancellations of different amplitudes. It is today generally believed that $\Re(\epsilon'/\epsilon)$ is of the order of 10^{-3} and could possibly vanish for very large values of the top mass.[19]

2. DAΦNE's Potential for Studying Direct CP Violation

In view of the latest results mentioned above, the next round of experiments searching for direct CP violation should aim for a ten–fold increase in sensitivity, *i.e.* should measure $\Re(\epsilon'/\epsilon)$ to an absolute accuracy of 10^{-4}. Mannelli[20] has described a new improved experiments with such aims, to be performed at CERN. Our first question is: does DAΦNE provide the appropriate statistics? In the following I will use $\mathcal{L} = 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1} = 10^3\ \mu\mathrm{b}^{-1}\mathrm{s}^{-1}$ or

$$\int\limits_{\text{1 calendar year}} \mathcal{L}dt = \frac{1}{3}\mathrm{y} \times 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \sim 10\,000\ \mathrm{pb}^{-1}$$

for the target luminosity of DAΦNE,[21] *although 1/10 as much is a very worthwhile beginning*, and assume a 1 year run with a goal of measuring $\Re(\epsilon'/\epsilon)$ to an absolute accuracy of 10^{-4}. I also arbitrarily choose the example of measuring the so called double ratio

$$\mathcal{R}^{\pm}/\mathcal{R}^{0} = \frac{N_L^{\pm}/N_S^{\pm}}{N_L^0/N_S^0} = 1 + 6\Re\Big(\frac{\epsilon'}{\epsilon}\Big),$$

although *"time asymmetries"* also give information about $\Im(\epsilon'/\epsilon)$ as we will discuss later. We recall that the cross section for $e^+e^- \rightarrow \phi$ is ~5 μb, the branching ratio for $\phi \rightarrow K_S K_L$ is 34% and that a ϕ at rest decays into a $K_S K_L$ pair of ~110 MeV/c momentum. Thus the mean free path for decay of K_L and K_S are 350 and 0.59 cm respectively. Finally the branching fraction for $K_L \to \pi^0\pi^0$ is $\sim 10^{-3}$. Use of the double ratio results in a statistical error on $\Re(\epsilon'/\epsilon)$ that can be expressed in terms of the number N_L^0 of observed $K_L \to \pi^0\pi^0$ decays as:

$$\delta\Re\Big(\frac{\epsilon'}{\epsilon}\Big) = \frac{1}{6}\frac{1}{\sqrt{(2/3)N_L^0}}.$$

From the above we find that 4.2×10^6 decays must be observed to achieve the desired statistical accuracy. Chosing a fiducial decay volume for K_L decays of 150 cm gives:

$$N_L^0 = (5\ \mu\mathrm{b}) \times (10^3\ \mu\mathrm{b}^{-1}\ \mathrm{s}^{-1}) \times (10^7\ \mathrm{s}) \times (0.34) \times 10^{-3} \times \Big(1 - e^{-150/350}\Big) = 5.9 \times 10^6$$

which, including the K_L tagging efficiency,[22] does satisfy our requirements.

In the remainder of this talk, after presenting a few necessary formulae, I will concentrate on some question about what spatial accuracy is required of the detector, briefly discuss resolution and present a possible approach to the measurement of the decay path length for K_S, $K_L \to \pi^0\pi^0$.

3. CP at a ϕ–Factory

3.1 THE DECAY AMPLITUDE

One of the advantages of studying K^0 mesons at a ϕ–factory, is that they are produced in a well defined quantum and kinematical state. K^0 meson are produced in collinear pairs, with a momentum of about 110 MeV/c, thus detection of one K^0 gives the direction of the other. In the reaction $e^+e^- \to \phi \to K^0\overline{K}^0$, $C(K^0\overline{K}^0) = C(\phi) = C(\gamma) = -1$. Let $|\,i\,\rangle = |\,K^0\overline{K}^0,\ t = 0,\ C = -1\,\rangle$, then:

$$|\,i\,\rangle = \frac{|\,K^0,\mathbf{p}\,\rangle|\,\overline{K}^0,-\mathbf{p}\,\rangle - |\,\overline{K}^0,\mathbf{p}\,\rangle|\,K^0,-\mathbf{p}\,\rangle}{\sqrt{2}} \tag{3.1}$$

which, using eq. (1.2), can also be written as:

$$|\,i\,\rangle = \frac{1}{\sqrt{2}}\frac{1+|\epsilon|^2}{1-\epsilon^2} \times \left(|\,K_S,-\mathbf{p}\,\rangle|\,K_L,\mathbf{p}\,\rangle - |\,K_S,\mathbf{p}\,\rangle|\,K_L,-\mathbf{p}\,\rangle\right), \tag{3.2}$$

so that $e^+e^- \to \phi \to K^0\overline{K}^0 \to K_SK_L$ at $t = 0$ and, in vacuum, the K pair remains in a pure K_SK_L state. The K_S and K_L states evolve in time according to eq. (1.3). The amplitude for decay of the K pair into a final state f_1, $\mathbf{p}$ at time t_1 and f_2, $-\mathbf{p}$ at time t_2 is therefore:

$$\begin{aligned}\langle f_1, t_1, \mathbf{p};\ f_2, t_2, -\mathbf{p} | i \rangle = &\frac{1+|\epsilon|^2}{(1-\epsilon^2)\sqrt{2}} \times \\ &\langle f_1 | K_S \rangle \langle f_2 | K_S \rangle e^{-i\mathcal{M}t/2} \Big(\eta_1 e^{i\Delta\mathcal{M}\Delta t/2} - \eta_2 e^{-i\Delta\mathcal{M}\Delta t/2} \Big).\end{aligned} \tag{3.3}$$

where $\eta_i = \langle f_i | K_L \rangle / \langle f_i | K_S \rangle$, $\Delta t = t_2 - t_1$, $t = t_1 + t_2$, $\Delta\mathcal{M} = \mathcal{M}_L - \mathcal{M}_S$ and $\mathcal{M} = \mathcal{M}_L + \mathcal{M}_S$.

3.2 HOW TO MEASURE ϵ'/ϵ AT A ϕ–FACTORY

If we concentrate on the final states $\pi^+\pi^-$ (in the following indicated as $\pm$) and $\pi^0\pi^0(0)$, we can obtain informations on ϵ'/ϵ. From the definitions of eq. (1.4) or from equation (3.3) and equivalent ones, one can derive, to lowest order in ϵ'/ϵ, the following expressions:

$$\begin{aligned}\frac{N(\pm,\pm)}{N(0,0)} \times \Big(\frac{BR(K_S \to 0)}{BR(K_S \to \pm)}\Big)^2 &= 1 + 6 \times \Re(\epsilon'/\epsilon) \\ \frac{N(\pm,\pm)}{N(\pm,0)} \times \frac{BR(K_S \to 0)}{BR(K_S \to \pm)} &= 1 + 3 \times \Re(\epsilon'/\epsilon) \\ \frac{K_L \to \pm}{K_S \to \pm} \Big/ \frac{K_L \to 0}{K_S \to 0} &= 1 + 6 \times \Re(\epsilon'/\epsilon) \\ \frac{N(\Delta t > 0) - N(\Delta t < 0)}{N(\Delta t > 0) + N(\Delta t < 0)} &= -3 \times \Re(\epsilon'/\epsilon)\end{aligned} \tag{3.4}$$

The last expression, unique to a ϕ–factory and first proposed by Duniez et al.,[23] is a typical example of measurements in which knowledge of the time order with which $K_S K_L$ decay to $\pi^+\pi^-$ and $\pi^0\pi^0$ final states is used. Time asymmetries,[24] at time differences of the order of the K_S lifetime, and therefore at decay times of the same order, give information on $\Im(\epsilon'/\epsilon)$ as we shall discuss in the following. All relations above can be used at a ϕ–factory, although they do not provide statistically independent methods for measuring $\Re(\epsilon'/\epsilon)$. They will in general however have different sensitivity to systematic errors and should all be used to acquire confidence in the final result.

3.3 THE "TIME ORDERED" DECAY INTENSITY

We consider in the following events in which the $K_S K_L$ pair decays to $\pi^+\pi^-$ at time t_1, followed by a decay to $\pi^0\pi^0$ at time t_2. The time difference $\Delta t = t_2 - t_1$ ranges from $-\infty$ to $+\infty$, with the sign determined by the previous sentence. The intensity as a function of Δt is obtained by integrating eq. (3.3) over $\{|\Delta t|, \infty\}$ and multiplying by $1/2$. Dropping all constants, ignoring the finiteness of the K_L lifetime and all the terms in ϵ'^2, to avoid too complicated formulae, we have:

$$\begin{aligned} I(\Delta t > 0) =&|\epsilon|^2\Big\{1 + 2\Re\frac{\epsilon'}{\epsilon} + \Big(1 - 4\Re\frac{\epsilon'}{\epsilon}\Big)e^{-|\Delta t|\Gamma_S} + \\ &\Big[\Big(-2 + 2\Re\frac{\epsilon'}{\epsilon}\Big)\cos(\Delta m\Delta t) - 6\Im\frac{\epsilon'}{\epsilon}\sin\Delta m|\Delta t|)\Big]e^{-|\Delta t|\Gamma_S/2}\Big\} \\ I(\Delta t < 0) =&|\epsilon|^2\Big\{\Big(1 + 2\Re\frac{\epsilon'}{\epsilon}\Big)e^{-|\Delta t|\Gamma_S} + 1 - 4\Re\frac{\epsilon'}{\epsilon} + \\ &\Big[\Big(-2 + 2\Re\frac{\epsilon'}{\epsilon}\Big)\cos(\Delta m\Delta t) + 6\Im\frac{\epsilon'}{\epsilon}\sin(\Delta m|\Delta t|)\Big]e^{-|\Delta t|\Gamma_S/2}\Big\}, \end{aligned} \tag{3.5}$$

where Γ_S is the K_S decay rate ($\Gamma_L \sim \infty$). The function $I(\Delta t)$ is shown in figure 1, for $\Re(\epsilon'/\epsilon) = 0.01$ and $\Im(\epsilon'/\epsilon) = 0$.

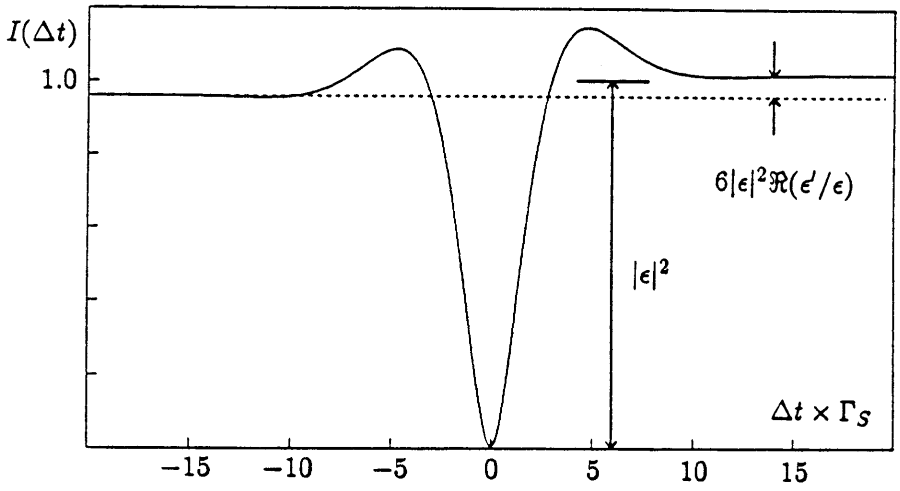

Fig. 1. The intensity vs time difference, in arbitrary units.

We notice several things:

1. Both intensities are of order $|\epsilon|^2$ but vanish for Δt=0. Taking into account higher terms, I(Δt=0)=$9|\epsilon'|^2$, unfortunately too small to be measurable.
2. The sine term appears multiplied by $6|\epsilon|^2\Im(\epsilon'/\epsilon)$, with opposite sign for $\Delta t > 0$ and $\Delta t < 0$.
3. The sum and difference of the two intensities, for large Δt are $2|\epsilon|^2$ and $6|\epsilon|^2\Re(\epsilon'/\epsilon)$ while at short times the difference has a sine term modulation with a coefficient $12|\epsilon|^2\Im(\epsilon'/\epsilon)$ and no cosine term.

In figure 2 we show the contribution to the intensity from terms $\propto \Re(\epsilon'/\epsilon)$ and from terms $\propto \Im(\epsilon'/\epsilon)$. There is no information at small time differences about $\Re(\epsilon'/\epsilon)$ while information about $\Im(\epsilon'/\epsilon)$ is maximal at $|\Delta t| \sim 1.6 \times \tau_S$ and disappears at about 5 lifetimes.

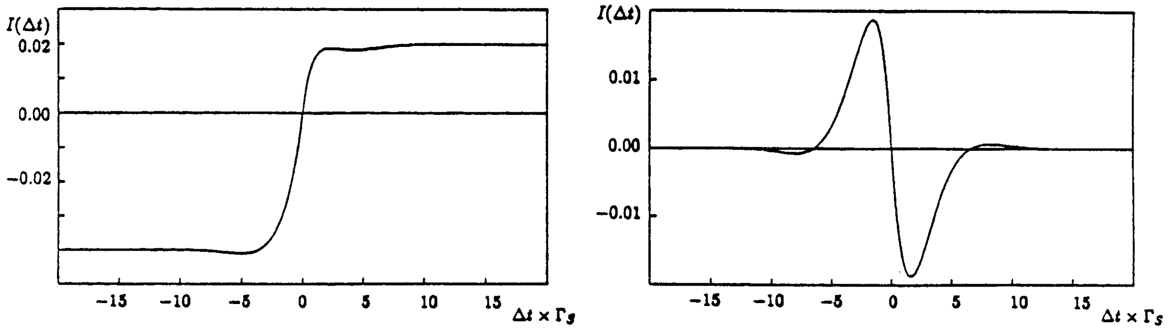

Fig. 2. Contributions to $I(\Delta t)$ from, left, $\Re(\epsilon'/\epsilon)=0.01$, $\Im(\epsilon'/\epsilon)=0$ and, right, $\Re(\epsilon'/\epsilon)=0$, $\Im(\epsilon'/\epsilon)=0.01$, in the same arbitrary units as fig. 1.

3.4 PATH LENGTH ACCURACY REQUIREMENTS

From the discussion above and figure 2, it is quite clear that determinations of $\Re(\epsilon'/\epsilon)$ are quite insensitive to the accuracy with which the path lengths are measured. This is not the case for the imaginary part of ϵ'/ϵ. The important point is of course what accuracy is required. Again, from figure 2, we might guess that a measuring accuracy of the order of the mean decay length off the K_S should not affect seriously the capability of measuring $\Im(\epsilon'/\epsilon)$. A complete study of this has been performed by Patera.[25] His conclusions are that measurement of $\Re(\epsilon'/\epsilon)$ are essentially independent of the path accuracy and just improve as $\sqrt{N}$, *i.e.* they require a large decay volume to collect adequate statistics. A decay path measuring resolution of 1 cm does not affect seriously the possibility of measuring $\Im(\epsilon'/\epsilon) \sim 0.01$.[26] It is however very important not to have long tails in the path length error distribution. This point was also studied in ref. 25. For values of the resolution smaller than the mentioned value, the number of available events becomes the limiting factor. We shall discuss later a possibility for obtaining adequate path length resolution in a realistic detector at DAΦNE.

3.5 REGENERATION AND K_SK_S BACKGROUND

We close this review of the DAΦNE promises by a brief discussion of regeneration effects in various parts of the detector. First we remark that the effect of regeneration at DAΦNE are due to $K_L \rightarrow K_S$ conversion (all K_S's decay in vacuum). If ϵ' is zero, K_S's and K_L's decay into $\pi^+\pi^-$ and $\pi^0\pi^0$ in the same ratio and therefore regeneration does not lead to an apparent non zero value for ϵ'. Regeneration is relatively large in solid matter, however 3.1 cm later the number of regenerated K_S's has decreased by a factor 200. So a little care and thin walls can well take care of this aspect of the problem, as discussed for instance in ref. 22. A gross over estimate of regeneration in 150 cm of gas and the wires of the tracking devices, assuming a helium based gas and 50 μm tungsten

4. Calorimetry at DAΦNE

4.1 GENERAL CONSIDERATIONS

Calorimetry at DAΦNE has definitely different requirements than in most other experiments. One reason for this is that although DAΦNE is an e^+e^-collider, with an essentially point–like luminous region, many of the particles to be detected do not originate at the collision point. K_L– mesons decay essentially uniformly along their flight path. Their decay products, $\pi^+\pi^-$ and $\pi^0\pi^0$ or rather $\gamma\gamma\gamma\gamma$ originate therefore more or less uniformly inside the detector volume. Determination of the path length for $K^0 \rightarrow \pi^0\pi^0$ decays requires that the electromagnetic calorimeter provide a three dimensional measurement of a point on the decay photon trajectory, typically the point where the photon converts (shower apex). This is necessary in order to reconstruct the K^0 decay point to a good accuracy and to obtain the path length L_0. In addition, photons down to 20 MeV energies must be efficiently detected over a large solid angle, to achieve good rejection for the τ and τ' decay modes of K_L-mesons. The energy resolution requirements can in fact be relatively loose but superb timing is of fundamental importance. Thus an optimal solution requires an imaging calorimeter with very fast time response. An additional advantage of such calorimetry is the possibility to use range, energy and specific ionization for particle identification. Finally we remark that due to the uniform spread of the origin of the four photon in the detector volume, walls containing or supporting the calorimeter become much more harmful do to the frequency of grazing incidence.

The requirement of a three dimensional apex measurement make (projective) crystal calorimeters unusable. Cryogenic liquid calorimeters always need cryostat, *i.e.* walls, in fact two walls separated by a gap which, in addition to absorbing low energy photons, can severely scatter the photons. Another problem commonly generated by cryostats is lack of hermetic coverage. We will argue in the following that a sampling calorimeter, consisting of very thin layers of lead and scintillating fibers might be the most promising approach. In particular this approach provides a solution of the problems of dead regions and allows simple modular construction. It also gives a good sampling fraction with almost zero low Z material. Scintillator and photubes are probably the best understood technique in high energy physics and offer very good reliability and stable operation.

4.2 PATH LENGTH MEASUREMENT

In the ideal case of a K^0 traveling along a known direction, because of tagging with the other K^0, the knowledge of the four photon shower's apices is enough to determine L_0, if correct pairing of the photons is used. The accuracy on L_0 is of the order of the accuracy with which the apices are known. Photon energy measurements are necessary to confirm the correct pairing but, to first order, the accuracy of L_0 does not depend on the energy resolution. Errors on the K^0 direction due to measurements of the other K^0, luminous spot size, beam energy spread and initial state radiation introduce very long, non gaussian tails which severely degrade the ability to measure $\Im(\epsilon'/\epsilon)$, as mentioned earlier and ultimately affect all other measurements by the uncertainties they introduced about the knowledge of the edge of the fiducial volumes used to count decays.

The length L_0 can also be independently obtained from the photon's time of arrival to the calorimeter, because K^0's are produced in ϕ-decays with very low velocity, $\beta = 0.216$. Again assuming that the direction of the K^0 is known, the photon shower apex is measured and the time interval from K^0 production to photon arrival is measured, the length L_0 ca be obtained, up to a two fold ambiguity. For four photons, L_0 is therefore determine four times. The time accuracy for obtaining an error of 1 cm on L_0 is 155 ps. This is in fact a very modest time resolution requirement with modern techniques and especially with fibers. Since the energy from a 510 Mev $K^0 \rightarrow 4\gamma$ event is sampled repeatedly in many layers and for four photons, the overall timing accuracy scales as $1/\sqrt{E}$. Assuming that only 10% of the energy is deposited in the inner core of the fibers, the required time resolution is $0.15\times\sqrt{51}\sim 1$ ns per MeV of energy deposited in the fiber core. This is in fact a quite modest resolution, and many groups have reported better results.

4.3 ESTIMATES OF THE PATH LENGTH ACCURACY

Because of the above arguments, several studies within a realistic MC frame developed in Frascati[30] have been performed. Tests of lead-scintillating fiber prototypes have also ben carried out at various beams. Results of the MC simulations are verified by test beam results and it is in general felt that the results obtained are not optimistic and some room for improvement is still available. Results with a back scattered laser beam at the Ladon facility have shown good efficiency and linear response down to photon energies of 20 MeV.[31]

A complete MC simulation of the reconstruction of $K_S K_L$ decays to $\pi^0\pi^0$and $\pi^+\pi^-$ has been presented by Bloise.[32] In this study all information available about charged an neutral particles is used in a geometric and kinematic fit of the event, taking into account machine energy spread and initial state radiation, the size of the luminous region of DAΦNE and using timing resolution from tests and energy and angle resolutions as obtained from Geant. In particular the timing resolution used is 400 ps/$\sqrt{E/20\ \text{MeV}}$ (input energy) and the calorimeter energy resolution is 7%/$\sqrt{E/1\ \text{GeV}}$. A result of this simulation is that the *rms* spread of L_0 is about 8 mm for events where all four photons from the K^0 are detected. In addition, as expected, if one photon is lost, the error on L_0 is hardly affected and the K^0 mass is reconstructed to an *rms* accuracy of 16 MeV, considerably better then necessary for rejection of the τ and τ' decay modes of K_L's.

4.4 TIMING RESOLUTION MEASUREMENTS

Time measurements with fiber are expected to be better than with bulk scintillator, especially in sheets or strips, because of the smaller spread of the paths the light can travel in the former case, especially if care is taken not to utilize the light propagating in the cladding. Also light transmission is excellent over meters of length, because of the superior reflectivity of the core–cladding interface.

Bertolucci[33] reported on results from tests of small and medium–small fiber bundle prototypes. For a bundle of 19 layers of fiber 50 cm long, with an average energy deposit in the fibers of 2.6 MeV an *rms* resolution of 252 ps was measured. A two meter long bundle of 9 layers, corresponding to an energy deposit in the fiber of 1.3 MeV gave an *rms* resolution of 392 ps. From the two measurements we can compute the ratio of the resolutions: 392/252=1.56, quite close to $\sqrt{2}$, showing the expected scaling as $1\sqrt{E}$ and very little light loss for the two meter fibers. All these results were obtained with "available" fibers and phototubes, without any attempt to optimization. Faster fibers and phototubes can be used, as well as fibers with more light output. It is worth recalling that there are no radiation damage problems at a ϕ-factory!

5. Conclusions

I have tried in the above presentation to show that DAΦNE has the potential to provide a ten fold improvement in sensitivity in the measurement of ϵ'/ϵ in the two pion decays of neutral kaons.

Physics at DAΦNE should begin by the end of 1995, a time when the present large physics ventures, LEP and TeV–II, will be reaching the conclusion of their more exciting phases and the large new projects, LHC and SSC will be still far from beginning to produce physics. The DAΦNE project is unique in this way too, as pointed out by Nicola Cabibbo in his address to this workshop.

By the time DAΦNE will begin producing physics we should however expect new experiments for measuring ϵ'/ϵ to be ready at CERN and/or FNAL. The complementarity of the DAΦNE approach, as compared to more conventional experiments on CP violation, makes the effort even more valuable, especially if ϵ'/ϵ will turn out to be as small as current expectations. I have completely ignored many other possible ways of searching for evidence for direct CP violation in K^0 and $K^{\pm}$ decays to three pions. While in general theoretical predictions are somewhat discouraging, they *must* be checked by experiment. The almost backgroundless conditions, the well defined kinematics and the ability to tag K meson species, give DAΦNE unique advantages and the possibility of improving present knowledge by one to a few orders of magnitude.

For example the CP violating process $K_S \rightarrow \pi^0\pi^0\pi^0$ has not yet been observed but can be detected at DAΦNE at the level of a few dozen of events. The CP impurity of K_L makes the branching fraction prediction unambiguous

$$BR(K_S \rightarrow \pi^0\pi^0\pi^0) = |\epsilon|^2 \frac{\Gamma_L}{\Gamma_S} \times BR(K_L \rightarrow \pi^0\pi^0\pi^0) \sim 2 \times 10^{-9},$$

while direct CP violation is expected to be undetectable. Apart from any other consideration, observation of this decay would prove for the first time that CP is violated in processes other than the two pion decays of kaons. Likewise I have not mentioned other non CP violating physics, Maiani[34] did that. There is a rich program which will complement the CP violation studies.

The challenges of building a machine which will deliver 200 times more luminosity than currently obtained at 1 GeV are of course great. The Frascati approach to the problem is however very conservative,[4] placing most of the burden on better understood places, such as the construction of single mode RF cavities, rather than trying to increase the single bunch-bunch luminosity.[5,7]

This workshop was called with the purpose of helping to understand what are the requirements for a detector at DAΦNE. Much work still remains to be done to this end. The many ideas aired at the workshop will help during the future months to reach past the stage of the conceptual design and begin the building phase of such detector.

ACKNOWLEDGEMENTS

I would like to thank Giorgio Salvini, the first Frascati director, and the entire organizing committee for getting us all together. I also wish to thank all the young people, in particular Bossi, Bloise, Calcaterra, Campana, Patera and, yes, Sergio Bertolucci for the enthusiasm with which they worked and continue to work with a gleam in their eyes, looking forward to doing physics at DAΦNE. I wish to thank the present Frascati director, Enzo Iarocci, for his drive and support of the DAΦNE project and his encouragement and help. Gaetano Vignola, head of the DAΦNE project is always willing to listen and to help, many thanks to him also. Finally I wish to thank Juliet Lee–Franzini, who ultimately always clarifies my ideas by often asking embarrassing questions.

REFERENCES

1. C. Bernardini, G. F. Corazza, G. Ghigo and B. Touschek, Nuovo Cimento, **18**, 1293 (1960)
2. V. Fitch, these Proceedings.
3. G. K. O'Neil, preprint Laboratori Nazionali di Frascati, LNF–68/43 (1968).
4. G. Vignola, these Proceedings.
5. A. Skrinski, these Proceedings.
6. T. Oshima, these Proceedings.
7. C. Pellegrini, these Proceedings.
8. A. Streun, these Proceedings.
9. J.-M. Poutissou, these Proceedings.
10. M. Gell-Mann and A. Pais, Phys. Rev. **97**, 1387 (1955).
11. K. Lande *et al.*, Phys. Rev. **103**, 1901 (1956).
12. J. H. Christenson *et al.*, Phys. Rev. Lett. **13**, 138 (1964), see also ref. 2.
13. Review of Particle Properties, Particle Data Group, Phys. Lett. B **239**, 1 (1990).
14. T. T. Wu and C. N. Yang Phys. Rev. Lett. **13**, 380 (1964).
15. J. R. Patterson *et al.*, Phys. Rev. Lett. **64**, 1491 (1990).
16. H. Wahl, these Proceedings.
17. L. Wolfenstein, Phys. Rev. Lett. **13**, 562 (1964).
18. M. Kobayashi and K. Maskawa, Prog. Theor. Phys. **49**, 652 (1973); L. Maiani, Phys. Lett. **62B**, 183 (1976) and in *Proceedings of the 1977 International Symposium on Lepton and Photon Interactions at High Energies* (DESY, Hamburg, 1977), p. 867; N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963).
19. For a recent review, see Paula J. Franzini, *Les Rencontre the Physique de la Valleé d'Aoste* (La Thuile, Italy, March 3-10 1991); for a new evaluation of ϵ' on accounts of recent results from lattice gauge numerical simulation see M. Lusignoli *et al.*, Preprint, Rome-792-1991.

20. I. Mannelli, these Proceedings.
21. G. Vignola, these Proceedings. See also J. P. Delahaye *et al.*, DAΦNE Project Review, DAΦNE technical note G-5, 1991
22. P. Franzini, Physics at a ϕ–Factory, *Proceedings of the 1991 Lake Louise Winter Institute on New Frontiers in Physics, The Factory Era.* (Chateau Lake Louise, Canada, February 1991).
23. I. Duniez *et al.*, Phys. Rev. **D35**, 2166 (1987).
24. J. Bernabéu *et al.*, Phys. Lett. **B211**, 226 (1988) and F. J. Botella *et al.*, these Proceedings.
25. V. Patera, these Proceedings.
26. Some of the calculations of ref. 25, were repeated in a less complete way by G. Battignani.
27. R. Barret, these Proceedings
28. D. Cocolicchio, Laboratori Nazionali di Frascati report No. LNF-90/031(R) (1990).
29. S. Nussinov and T. N. Truong, Phys Rev. Lett. **63**, 2003 (1989).
30. G. Capon, these Proceedings.
31. S. Bianco, these Proceedings.
32. C. Bloise, these Proceedings.
33. S. Bertolucci, these Proceedings.
34. L. Maiani, these Proceedings.