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# CP violation at DAΦNE, the Frascati Φ factory

A. Calcaterra

INFN - Laboratori Nazionali di Frascati, P.O.Box 13, I-00044 Frascati (Italy)

## Introduction

The $e^+e^-$ collider DAΦNE, expected to begin commissioning in Frascati by the late 1995, is a two-ring machine optimized to run with maximum luminosity at the peak of the $\phi$ meson, corresponding to a total energy of 1020 MeV/C in the center of mass. This choice for the total energy is motivated by the most important (although by no means the *only* important) issue in the DAΦNE physics program: the study of the pattern and entity of CP violation in the decay of the $\phi$ to a final $K\overline{K}$ pair: the $\phi$ meson is a pure laboratory for the production of *coherent* $K\overline{K}$ states, which makes possible to perform a variety of tests and measurements which have no counterpart for the "normal" K-or-$\overline{K}$ production at hadron machines.

The whole DAΦNE project poses a number of very hard problems to almost every component of a high-energy physics experiment: from the machine, designed to deliver a luminosity $\mathcal{L} \sim 10^{32}$ cm$^{-2}$ s$^{-1}$ shortly after turn-on, to the detector which will have to be able, for the first time in the history of $e^+e^-$ apparata, to reconstruct with high accuracy the decays of long-lived particles like the $K^{\pm}$ and $K^{\circ}$, to the data acquisition system which will be confronted with a "physics" trigger rate of $\sim$ 10 KHz.

In what follows, I will very sketchily describe the machine, already illustrated in much detail in the nice contribution of S. Guiducci to these Proceedings, and will concentrate on the list of physics topics to be addressed, and on the demands imposed to the detector by the characteristics of the events and by the smallness of the effects to be measured.

## Collider characteristics

In order to reach a high luminosity at an $e^+e^-$ machine, the list of most relevant parameters to be optimized appears in the frequently given formula:

$$\mathcal{L} \propto f \cdot \frac{\xi^2 \cdot \varepsilon \cdot (1+\kappa)}{\beta_y^*}$$

but unfortunately they are not independent, and can not be separately adjusted at will. For instance, a larger emittance $\varepsilon$ would mean not only a larger dynamical aperture for the machine, to keep a high lifetime, but also higher currents to get an equivalent beam-beam parameter $\xi$.

For what the beam aspect ratio $\kappa$ is concerned, while apparently one would expect a higher luminosity for round beams ($\kappa = 1$), the model worked out by M. Bassetti[1] for beam-beam interactions relates high values of $\kappa$ with high values of the energy exchanged between one electron and the opposite beam, leading to limitations on the maximum value attainable for $\xi$.

So one is left with increasing the collision frequency $f$ or reducing the betatron function and beam sizes, or increasing the beam-beam parameter $\xi$. A number of projects has been presented in the last months, each one trying to break a different barrier:

- The UCLA design[2] describes a small footprint, first-class technology machine, with high repetition rate, in which the beam length and vertical beta function are simultaneously reduced from the centimetre to the millimetre range close to the interaction point. The main drawback is that a small machine implies a small detector, with a consequent loss of rate due to the long life of the produced K mesons.

- The Novosibirsk collider[3] is being designed attempting to increase the beam-beam tune shift beyond the scarcely understood "phenomenological" limit of 0.04 up to a maximum of 0.1, with round beam optics and a set of 11 T superconducting solenoids, to get $\beta_{x,y} = 1$ cm at the interaction point. The disadvantage here is the rather short Touschek lifetime of the beams, which will force frequent injections and increase the detector dead time.

The Frascati project[4] plans instead the "conservative" approach of using present-time technology (*i.e.* conventional magnets) to achieve a single-beam configuration close to the one used at VEPP-2M[†], which has obtained in the past the highest luminosity at this energy: $4.3 \cdot 10^{30}$ cm$^{-2}$ s$^{-1}$. Increasing the number of circulating beams from a minimum of 30 up to 120 in each ring should then allow to correspondingly multiply $\mathcal{L}$ by the same factor. The challenge here is to keep multibunch instabilities carefully under control[‡].

A full discussion of the pros and cons of each design would take much more space (and technical proficiency) than can be afforded here, so the reader is referred to the presentations made to the DAΦNE workshop held in Frascati, 9-12 Apr. 1991[6].

## Physics program

The observed CP violation can, in a purely phenomenological way[7], be generated by the theory either introducing a small CP= $+1(-1)$ component in the $K_L(K_S)$ wavefunction,

$$K_S = K_+ + \varepsilon \cdot K_-$$

$$K_L = K_- + \varepsilon \cdot K_+$$

[†] with the exception of smaller emittance and accelerating voltage frequency in the Frascati case.

[‡] The KEK design also proceeds along a similar line[5].

or postulating non-zero values for amplitudes like $< \mp|H_{wk}|K_\pm >$ connecting a CP=±1 linear combination of $K^o$ and $\overline{K^o}$ to a final state having the opposite CP eigenvalue. The first case is usually referred to as "CP violation in the mass matrix", and can be visualized as oscillations between $K^o$and $\overline{K^o}$ states, described in the Standard Model by the $\Delta S=2$ box diagram in Fig.1, second-order in the weak interactions, and in the original model proposed by Wolfenstein[8] by a special "superweak" force, which has no other manifestation.

The second type of "direct" CP violation originates in the Standard Model by the penguin diagrams of Fig.1, and is forbidden in the superweak scheme.

Almost 30 years after the discovery of CP violation in $K^o$ decays, the only phenomena where experimental evidence for it can be found are the decays of the $K_L$:

- The very existence of $\pi\pi$ decays.
- The asymmetry in the semileptonic decays $K_L \rightarrow \pi\mu\nu$ or $K_L \rightarrow \pi e\nu$, where the $K_L$ happens to produce more $\pi^-$'s than $\pi^+$'s.
- The asymmetry in the Dalitz plot density for the $K_L \rightarrow 3\pi$ decays.

but none of the many experiments done since could shed any light upon the question whether CP violation occurs only in the mass term or also in the decay amplitude. The experimental situation started to address this issue in 1988, when the first results from the NA31[9] and E731[10] collaborations about the measurement of $K_S$, $K_L \rightarrow \pi\pi$ became available.

## CP violation in neutral kaon decays

In the $K^o$ decay modes, mass-matrix and direct CP violation are parameterized by two complex numbers, resp.$\varepsilon$ and $\varepsilon'$:

$$\eta_{+-} = \frac{< \pi^+\pi^-|V|K_L >}{< \pi^+\pi^-|V|K_S >} \simeq \varepsilon + \varepsilon'$$

$$\eta_{00} = \frac{< \pi^o\pi^o|V|K_L >}{< \pi^o\pi^o|V|K_S >} \simeq \varepsilon - 2\varepsilon'$$

Any difference in modulus or phase between these two amplitudes would be a signal for $\varepsilon' \neq 0$, meaning CP violation in the decay amplitude, and giving yet another confirmation of the Standard Model as a sound theory[§].

Measuring the squared ratio of $\eta_{+-}$ to $\eta_{00}$, information about $\Re e(\varepsilon'/\varepsilon)$ was obtained:

$$\begin{array}{ll} \Re e(\varepsilon'/\varepsilon) = (2.7 \pm 0.9) \cdot 10^{-3} & \text{(NA31)} \\ \Re e(\varepsilon'/\varepsilon) = (-0.4 \pm 1.5) \cdot 10^{-3} & \text{(E731)} \end{array}$$

From an experimentalist's point of view the situation could not be better: the NA31 result shows a $3\sigma$ deviation from zero, E731 denies any effect, but the two

[§]The converse would not be true: the Standard Model can accommodate for $\varepsilon' = 0$, and indeed it predicts a smaller and smaller $\varepsilon'$ for higher and higher values of the mass of the $t$ quark mass[11].

results cannot be taken as totally inconsistent with each other. The two collaborations do not expect essential reductions of the errors, and the possibility of a fluctuation in either of both measurements is not to be ruled out, calling for a third measurement by a third experiment.

One proposal has already been presented by a CERN-based collaboration[12], to obtain a tenfold increase in luminosity with respect to NA31 in a fixed target configuration, by raising the beam intensity, and at the same time control systematics by observing simultaneously $K_S$ and $K_L$ decays in the same fiducial region. If approved, this experiment has the capability of reducing the error on $\Re e(\varepsilon'/\varepsilon)$ down to the level of $\sim 2 \cdot 10^{-4}$.

The principal goal of the DAΦNE collaboration is to bring the present error down by a factor 3 one year after turn-on, and to ultimately increase statistics and understanding of systematics, obtaining an error of $\sim 10^{-4}$.

### The double ratio

Both NA31 and E731 have used the method of double ratio (DR), *i.e.* the statement that if $\Re e(\varepsilon'/\varepsilon) \neq 0$ then the $K_L$ decays to two charged pions are not as many as those to two neutral pions (when normalizing to the corresponding decay rates for the $K_S$):

$$\frac{\mathrm{B.R.}(K_L \to \pi^+\pi^-)/\mathrm{B.R.}(K_S \to \pi^+\pi^-)}{\mathrm{B.R.}(K_L \to \pi^o\pi^o)/\mathrm{B.R.}(K_S \to \pi^o\pi^o)} = 1 + 6 \cdot \Re e(\varepsilon'/\varepsilon)$$

So the relative error on $\Re e(\varepsilon'/\varepsilon)$ turns out to be $1/6^{th}$ of the relative error on the DR, or:

$$\frac{1}{6} \cdot \sqrt{\frac{1}{N_L^{+-}} + \frac{1}{N_L^{oo}} + \left(\frac{\delta N_{syst}^{+-}}{N^{+-}}\right)^2 + \left(\frac{\delta N_{syst}^{oo}}{N^{oo}}\right)^2}$$

where $N_L^{+-}$ and $N_L^{oo}$ are the number of *detected* decays in the two combinations of charge. Taking into account all relevant branching ratios, and assuming a spherical sensitive volume of radius $r = 1.5$ m, this formula shows that, to reduce the relative error on $\Re e(\varepsilon'/\varepsilon)$ at the $3 \cdot 10^{-4}$ level in one "physics" year of $10^7$s, the number of required $\phi$ events is of $\sim 5 \cdot 10^9$. Given the peak cross section at the $\phi$ of $4\mu$b, this translates directly into a minimum luminosity of $\sim 10^{32}$ cm$^{-2}$ s$^{-1}$.

### Time-integrated observables

The DR method used at hadronic machines is the best suited for them (probably the only one possible), but does not exploit the full power of a $\phi$ factory: though one *can* use the $\phi$ as a factory of simultaneous, essentially independent, $K_S$ and $K_L$, different methods are possible here to measure $\Re e(\varepsilon'/\varepsilon)$ and $\Im m(\varepsilon'/\varepsilon)$, due to the well-defined quantum-mechanical characteristics of the $K\overline{K}$ state.

F. J. Botella et al.[13] have actually shown that the DR is just a special case of a class of time-integrated observables:

$$O_1 = \frac{N(+-,+-)}{N(00,00)} \cdot \frac{\mathrm{B.R.}(K_s \to \pi^o\pi^o)^2}{\mathrm{B.R.}(K_s \to \pi^+\pi^-)^2}$$

$$O_2 = \frac{\mathrm{N}(+-,+-)}{\mathrm{N}(+-,00)} \cdot \frac{\mathrm{B.R.}(\mathrm{K_s} \to \pi^o\pi^o)}{\mathrm{B.R.}(\mathrm{K_s} \to \pi^+\pi^-)}$$

$$O_3 = \frac{\mathrm{N}(+-,+-)}{\mathrm{N}(00,00)}$$

In each formula $\mathrm{N}(X_1, X_2)$ is the number of observed events with a decay in the $X_1$ charge combination in the proper time interval $[t_1^{start}, t_1^{end}]$ and a decay to the $X_2$ combination in another time interval $[t_2^{start}, t_2^{end}]$.

The first observable, $O_1$, has actually the same value in every pair of time intervals:

$$O_1 = 1 + 6 \cdot \Re e(\varepsilon'/\varepsilon)$$

The other two observables are linear combinations of $\Re e(\varepsilon'/\varepsilon)$ and $\Im m(\varepsilon'/\varepsilon)$, with coefficients dependent upon the choice of time intervals. For the "physical choice", the one in which one takes one interval as $[0, \sim 5\tau_S]$ and the other one as $[\sim 20\tau_S, \infty]$, $O_2$ reduces to the well known double ratio.

**Asymmetries in decay paths**

As originally shown by Dunietz et al.[14], there is another opportunity to use the unique characteristics of a $\phi$ factory to measure $\varepsilon'/\varepsilon$ , and it can be stated in a simple way:

- take the events $\phi \to \pi^+\pi^-\pi^o\pi^o$
- define $\Delta d = d_\pm - d_{oo}$, measuring the distances to the decay points in units of $\mathrm{K_S}$ lifetimes
- plot the intensity of decays $\mathrm{I}(\Delta d)$

The difference $\Delta d$ can have both signs: it is positive for (most of) $\mathrm{K_L} \to \pi^+\pi^-$ and negative for (most of) $\mathrm{K_L} \to \pi^o\pi^o$ and the expected intensity for it is shown in Fig.2: the real part of $\varepsilon'/\varepsilon$ is proportional to the difference between the two "wings":

$$\mathrm{I}(\Delta d) - \mathrm{I}(-\Delta d) \quad \text{for} \quad |\Delta d| > \text{a few } \tau_S$$

while the shape of the hole in the interference region gives information on $\Im m(\varepsilon'/\varepsilon)$[¶].

By an accurate study of this method[15], one can conclude that, assuming the expected luminosity of DAΦNE, the sensitivity to $\Re e(\varepsilon'/\varepsilon)$ is essentially given by the radius of the detector (*i.e.* by the number of observed events), and it will be possible to obtain a measurement of $\Im m(\varepsilon'/\varepsilon)$ if the apparatus will measure the $\mathrm{K_L} \to \pi^o\pi^o$ vertex with an accuracy better than 7 mm. The first Montecarlo simulations show[16]that such a fine resolution can be obtained by measuring the TOF's of the photons, and applying a constrained fit (see Fig.3).

[¶] strictly speaking, this is true only if CPT is not violated. What is actually measured in the plot is the phase difference between $\eta_\pm$ and $\eta_{00}$. If CPT were violated along with CP, this single measurement would not be sufficient to measure $\varepsilon'/\varepsilon$ .

### CP violation in charged kaon decays

These decay modes of the $\phi$ are of great importance, because here CP violation can only occur directly in the decay matrix, oscillations being forbidden by charge conservation. This means two things:

1) experimental asymmetries will in any case be proportional to $\epsilon'$.

2) they will be much smaller, and more difficult to detect.

The most favourable channels to study are probably

$$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-} \qquad (\text{“ } \tau \text{ ” mode})$$
$$K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o} \qquad (\text{“ } \tau' \text{ ” mode})$$

For both decays, the theoretical predictions[17] are quite difficult, and they tend to disagree with each other. The measurements which are experimentally accessible are of two types:

- Charge asymmetries like

$$\delta_{\tau,\tau'} = \frac{\Gamma_{\tau,\tau'}(K^+) - \Gamma_{\tau,\tau'}(K^-)}{\Gamma_{\tau,\tau'}(K^+) + \Gamma_{\tau,\tau'}(K^-)}$$

Following the analysis of ref.[18], $\delta_{\tau,\tau'}$ are proportional to a direct CP violation parameter $\kappa$, while the DR-like quantity

$$\frac{\Gamma_{\tau}(K^+)/\Gamma_{\tau}(K^-)}{\Gamma_{\tau'}(K^+)/\Gamma_{\tau'}(K^-)} = 1 + 4 \cdot \kappa$$

has more predictive power than both. Given the smallness of the predicted effect, even for a luminosity of $10^{33}$ cm$^{-2}$ s$^{-1}$ these measurements would be on the border of sensitivity.

- Asymmetries in the linear slopes of the $3\pi$ Dalitz plot.

These are usually expressed in terms of “g” parameters in an expression for the density of expected points[19], and one can measure

$$\delta_{\tau,\tau'} = \frac{g_{\tau,\tau'}(K^+) - g_{\tau,\tau'}(K^-)}{g_{\tau,\tau'}(K^+) + g_{\tau,\tau'}(K^-)}$$

Here theoretical predictions differ by orders of magnitude[20]: from values of $\sim 10^{-4} - 10^{-5}$ which would place the signal (if any) out of reach, to estimates as big as $10^{-3}$, which would give a $3\sigma$ effect for a luminosity at the level of $10^{33}$ cm$^{-2}$ s$^{-1}$[‖].

‖ Unfortunately, these last “big” estimates seem now to be challenged[21]

## CPT violation measurements

If CPT is to be conserved, CP violation implies also T violation, in a pattern and with an entity which exactly match those observed in kaon decays: a direct measurement of T-invariance, besides to being the first sensitive enough to meet the effects predicted by the Standard Model, could also reveal that T is violated *more* or *less* than CP, leading to the discovery of non-conservation of what is believed to be an exact symmetry.

The possible measurements are essentially of two kinds[18]. The most difficult one is the study of the transition rates $K^o \leftrightarrow \overline{K^o}$ as a function of the proper time difference between the two decays, and using semileptonic decays to tag the kaons' strangeness. In other terms, one takes the events with two semileptonic decays in which *both leptons have the same sign* and measures (assuming validity of the rule $\Delta S = \Delta Q$):

$$A_T = \frac{N_{l^-l^-} - N_{l^+l^+}}{N_{l^-l^-} + N_{l^+l^+}} = 4 \cdot [\Re e(\varepsilon) - \Re e(\delta_{direct})]$$

in which $\delta$ parameterizes in an appropriate way direct CPT violation.

This particular asymmetry has two properties: it originates from CPT violation *in the decay* so $\delta$ is probably very small (if nonzero), but does not depend on the proper time difference $\Delta t$ between the two decays, so it can be summed over decay lengths to yield a bigger effect. Other asymmetries can be devised, which will probe CPT violation in the mass matrix, but they will generally depend on $\Delta t$, and will probably need huge statistics and less-than-realistic vertex reconstruction.

Another type of asymmetries, in which one essentially looks separately at $K_L$ and $K_S$ semileptonic decays, can be written as a mixture of direct and mass-matrix CP and CPT violation parameters:

$$\delta_{L,S} = \frac{\Gamma(K_{L,S} \to \pi^-\mu^+\nu) - \Gamma(K_{L,S} \to \pi^+\mu^-\nu)}{\Gamma(K_{L,S} \to \pi^-\mu^+\nu) + \Gamma(K_{L,S} \to \pi^+\mu^-\nu)} = 2 \cdot \Re e(\varepsilon \mp \delta_{oscil.} - \delta_{direct})$$

One can see that $\delta_S + \delta_L \neq 4 \cdot \Re e(\varepsilon)$ will indicate direct CPT violation, and $\delta_S - \delta_L$ will measure CPT violation in the mass matrix, provided that $\Delta S = \Delta Q$ holds: the effect (if any) measured by $\delta_S - \delta_L$ could be due to both CPT violation and/or $\Delta S \neq \Delta Q$, while $\delta_S + \delta_L$ remains not affected.

Unfortunately, the possibilities for these measurements rely on a non-zero partial width for $K_S \to \pi l \nu$, and semileptonic $K_S$ decays *have not yet been seen.* One expects the B.R. to be of the order of $5 \cdot 10^{-4}$, which could yield $10^5$ semileptonic decays in the first year, with a sensitivity of the order of $10^{-3}$.

These measurements seem to be on the border of feasibility for a $\phi$ factory, but their importance is evident enough to justify any attempt to do them.

## Experimental considerations

The most difficult measurements to perform at DAΦNE seem to be the ones aimed at $\Re e(\varepsilon'/\varepsilon)$ and even more at $\Im m(\varepsilon'/\varepsilon)$: one can be confident that a detector designed to successfully measure direct CP violation will have ample capability for any other physics topic, so in the following I will take the DR method as a benchmark and try to deduce some of the most stringent demands imposed to the detector.

### Statistical errors

Few things can be added to the previous remarks, except that the statistical significance of the measurement will clearly scale as the square root of the detection volume. At the $\phi$ energy the average decay length of the $K_L$ will be of $\sim$ 350 cm, giving a geometrical acceptance of $\sim$ 30% for a spherical detector volume 1.5 m in radius. A bigger detector would imply unrealistic figures for almost every mechanical parameter, and also for costs.

The statistical significance will also depend on the tagging efficiencies: the $K_L \rightarrow \pi^+\pi^-\pi^o$ and $K_{l3}$ *outside a central region* can be used to tag the $K_S$ with high efficiency ($\sim$ 75%) and high purity, since no other physical process can simulate this "two charged prongs" signature: photon conversion is clearly separable kinematically and, apart from $K_L \rightarrow K_S$ regeneration (see later), $K_S$ contamination can be made absolutely negligible by an appropriate choice for the minimum radius of the detection volume.

On the other side, the use of just the $K_S \rightarrow \pi^+\pi^-$ channel to tag the $K_L$ would mean a lower detection efficiency of $\sim$ 65%. So one important request for the detector is that it must be able to *reconstruct entirely neutral events*, to allow also use of the $K_S \rightarrow \pi^o\pi^o$ decay mode for $K_L$ tagging. Then, since the $K_S$ decays close to the beam spot, a variety of processes can mimic it, but (again) the well-defined kinematics should reject any possible contamination.

### Systematics involved

It is easy to see that an incorrect knowledge of the tagging efficiencies does not introduce systematics, since they will cancel in the expression for the DR: the tagging efficiency for $K_L$ will not depend on the subsequent $K_L$ decay mode. Open problems remain of course for those effects which do *not* cancel in the double ratio and will have to be measured. For example, detection and reconstruction efficiencies will certainly not be the same for $K_L \rightarrow \pi^+\pi^-$ and $K_L \rightarrow \pi^o\pi^o$, as well as resolutions in determining the decay vertices. Let us take a closer look:

• Detection and reconstruction efficiencies: the decays of the $K_S$ do not seem to be crucial, while two methods[22] can be used to determine them for the $K_L$, directly from the data in a completely unbiased way: efficiency *variations* will be obtained fitting the radial distribution of found decays to a known exponential distribution times an efficiency, while the *absolute value, i.e. the point at* $r = 0$ will be found using a semileptonic $K_L$ tag, and looking at the $K_S$ decay products: no photons, and an almost hermetic e.m.calorimeter, will signal a charged $K_S$ decay, to be seen or lost by the charged tracking. Moreover, the efficiency for single-$\pi^o$ reconstruction can be also measured without any bias by looking at the $K^\pm \rightarrow \pi^\pm\pi^o$. In fact, the kinematics is the same as the one for $K_L$ decays to two $\pi^o$, and one will be able to find the $\pi^o$ momentum from the difference between the momenta of the first and second part of the charged trajectory, as well as the decay vertex from the fit of the two semi-tracks.

•Geometric acceptances again affect $K_L$ decays more than $K_S$ ones: for the latter, given their short lifetime, the main uncertainty comes from the finite size of the beam spot, but its average position and size could be obtained from Bhabha events and folded in. For the decays $K_L \rightarrow \pi^+\pi^-$ a 1-2 mm resolution is expected from the vertex fit, while the vertex resolution for $K_L \rightarrow \pi^o\pi^o$ turns out to be *the hardest request to e.m. calorimetry.*

Let us consider for instance the inner surface of the fiducial volume: the vertex resolution will not vary much around it, but more $K_L$ will decay in a $\Delta r$ shell immediately before it (closer to the origin) than in a $\Delta r$ shell immediately beyond it, so the number $N_{out \rightarrow in}$ of events feeding inside the fiducial volume will be *more* than the analogous number $N_{in \rightarrow out}$ of events escaping from it. A similar imbalance will occur at the outer surface, but with the opposite sign and a smaller entity.

It has been shown[23] that, to achieve a relative change of $10^{-5}$ in the number of accepted events, vertex reconstruction has to be made with a $\sigma \leq 1$ cm in the radial direction, *if a "small", symmetric resolution is assumed.* A more realistic simulation[24] shows that even a small asymmetry, as the one induced by the systematic over-evaluation of the $K_L$ velocity due to (unmeasurable) radiation from the initial state can have a high impact on the double ratio: the resolution obtained from Montecarlo studies is plotted in Fig.4a, and the relative rate change in Fig.4b, as a function of the width of the gaussian part of the resolution.

•Background subtraction is also more severe for $K_L$ than for $K_S$. The subtraction of any background $N_{bkg}$ from a total $N_{tot}$ will not affect the result if the number of events is much greater than the squared error on the measured background:

$$N_{good} = N_{tot} - N_{bkg}$$

$$\Delta N_{good} = \sqrt{N_{tot} + (\Delta N_{bkg})^2}$$

So if the background is known to a relative precision $\alpha = \Delta N_{bkg}/N_{bkg}$, one ends up with

$$\alpha \cdot N_{bkg} \lesssim \sqrt{N_{tot}}/3$$

and defining the rejection ratio against a particular background $r.r. = \varepsilon_{bkg}/\varepsilon_{signal}$, one obtains

$$\alpha \cdot r.r. \lesssim \frac{B.R.(signal)}{B.R.(background)} \cdot \frac{1}{3 \cdot \sqrt{N_{tot}}}$$

For the $K_L$case the most insidious backgrounds are given in Table 1, where the requested rejection ratios in the last column are calculated assuming every contamination to be known at the 15% level. One can see that the necessity to detect every $\pi^o$ implies an e.m.calorimeter almost totally hermetic and also very efficient for low-energy photons, to fight the combinatorial background in the $3\pi^o$ case. The Montecarlo simulations[25] begin to show that, if the right proportion of showering to sampling material is used, a scintillating fiber calorimeter seems perfectly able to do this job (see the curve labeled "detector C" in Fig.5): even at the low end of the $\gamma$ spectrum ($\sim$ 20 MeV) the efficiency for fibers with diameter $d$ = 2 mm is indistinguishable from 1 (for photons at normal incidence).

| signal | background | relative B.R. | rejection ratio |
|---|---|---|---|
| $K_L^o \rightarrow \pi^o\pi^o$ | $K_L^o \rightarrow \pi^o\pi^o\pi^o$ | 241 | $1.2 \cdot 10^{-5}$ |
| $K_L^o \rightarrow \pi^+\pi^-$ | $K_L^o \rightarrow \pi\mu\nu$ | 135 | $1.6 \cdot 10^{-5}$ |
| $K_L^o \rightarrow \pi^+\pi^-$ | $K_L^o \rightarrow \pi e\nu$ | 189 | $1.1 \cdot 10^{-5}$ |
| $K_L^o \rightarrow \pi^+\pi^-$ | $K_L^o \rightarrow \pi^+\pi^-\pi^o$ | 61 | $5.0 \cdot 10^{-5}$ |

Table 1: Needed rejection ratios for some $K_L$ backgrounds.

Rejection of the $K_L \rightarrow 3\pi^o$ decays below this level requires a spatial resolution $\sim$ 1 cm or better for the conversion apices of the photons in the calorimeter, and also an excellent energy resolution, not substantially higher than $5\%/\sqrt{E(GeV)}$ (see refs.[16],[23]).

On the other side, always according to Montecarlo, the separation of semimuonic $K_L$ decays from $K_L \rightarrow \pi^+\pi^-$ events at the required level seem to be difficult to do only with kinematics, and a system for particle ID with a $\pi/\mu$ discrimination of at least 100:1 will probably be needed.

•Regeneration of the $K_L \rightarrow K_S$ (all $K_S$'s will decay in vacuum before the beam pipe) will never create a $\Re e(\varepsilon'/\varepsilon) \neq 0$, it will only dilute the double ratio measurement according to[26]

$$DR_{obs} = DR_{true} \cdot [1 - 2 \cdot 10^3 \cdot \alpha \cdot \Re e(\varepsilon'/\varepsilon)]$$

where $\alpha$ is the integrated probability for regeneration in the matter of the detector, and should ideally be kept at the level of $\sim 10^{-4}$, by making the charged tracking system as "transparent" as possible. In terms of $\Re e(\varepsilon'/\varepsilon)$, and using common wisdom to guess the kaon-proton cross section at small momentum, this will translate into a 20% downward shift of the measured value, but using the fact that the regeneration cross section is isotropic, one should be able to find cuts which will reduce this shift to the 1–3% level.

## Detector ideas

The main subsystems of the detector will be a charged tracking device and an e.m.calorimeter. If a $\pi/\mu$ separation of 100:1 will be achieved by one of these (for example via dE/dx in the drift chamber, and/or energy vs. range in the calorimeter) there will be no need for particle ID. In any case, an additional device will have to be a "thin" one, of thickness $\sim 10\% \cdot X_0$. The coil must be placed outside the e.m.calorimeter, or the efficiency for detection of low-energy photons will drop drastically.

A spherical detector volume with radius $r = 1.5$ m will be needed, to keep high the rate of observed events. Then the outer radius of the tracking chamber must be at least 2m, to ensure a minimum track length for the $\pi^{\pm}$ from the $K_L$, and also to avoid that the photons from $K_L \rightarrow 2\pi^o$ enter the calorimeter at grazing incidence.

The charged track detector[27] will probably be a conventional drift chamber and not a TPC: there are concerns that a device with long memory could be more vulnerable to machine noise, due to the small interbunch time of 3 ns, and also regarding the separating plate at z=0, which will add multiple scattering and photon absorption for particles emitted at 90° from the beamline.

The gas mixture to be used in the drift chamber will not be Ar-based: the contribution of a heavy gas to multiple scattering would be unacceptable, and the regeneration problem more delicate. The most promising choice at the moment appears to be a He-based mixture with a small proportion ($\sim 5 - 10\%$) of a quenching gas. The chamber will be operated in proportional mode.

The momentum resolution in the drift chamber, equipped with axial and stereo layers for measuring the Z-coordinate, will be dominated by multiple scattering, and a point resolution better than 200 $\mu$m is not needed. The resolution will be of $\sim 1\%$ for a field of 0.3 T. The expected vertex resolution for the $K_S$ will be of $\sim 1 - 2$ mm, assuming a Be beam pipe 1 mm thick, 8 cm away from the beam axis.

The cell geometry is being designed; as for the geometry of the chamber, the usual one consisting of concentric cylindrical layers of wires may still be favoured for construction reasons, but other possibilities are not being excluded, due to the fact that the $K_L$ charged tracks do not come from the origin.

For what the calorimeter is concerned, the cryo-liquid option is felt as a difficult one to realize, due to complication of the mechanical structure, and to the requirement of a coverage as complete as possible**.

The option of glass electrode spark counters (GSC)[29] has led to the construction and beam test of a calorimeter made as a sandwich of 50·(GSC+1 mm of Pb) which showed adequate spatial resolution and excellent linearity (Fig.6a) as well as timing properties, but energy resolution (Fig.6b) somewhat worse than what is needed for rejection of $K_L \rightarrow 3\pi^o$.

The most promising idea up to now consists of a sandwich of Pb+layers of scintillating fibers[30], to be laid parallel to the beam in the barrel and either orthogonal to it or in the head-on configuration in the endcaps. For this option, a prototype has also been built and tested in low-energy $\gamma$ beams at Fermilab and Frascati[31], showing (see Fig.7) good linearity and execellent energy resolution $\sim 6\%$. The spatial resolution in a dimension orthogonal to the fibers is given by the dimension of the PM's. Scintillating fibers with a small diameter make out an excellent timing (see Fig.8), so measuring the time difference between the ends of a (4 m long) fiber will give the Z-coordinate with the needed accuracy.

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**Although an intriguing idea for an "integrated", full imaging device employing a liquid-Argon TPC for both charged tracks and calorimetry has been presented[28].

## Conclusions.

The technology for realization of an $e^+e^-$ machine able to deliver a luminosity of $5\cdot \sim 10^{32}$ $cm^{-2}$ $s^{-1}$ at the mass of the $\phi$ meson already exists, and the conceptual ideas to build a detector able to exploit it are being developed.

A vigorous R&D program will be pursued in the next year to convert these ideas into the construction and tests of actual, real-size prototypes, with the goal of having a working detector ready to take data immediately after commissioning of the machine.

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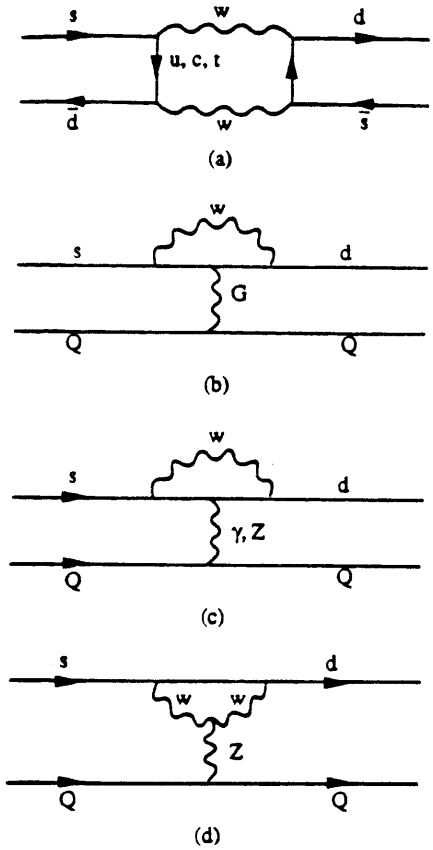


Fig.1: Standard Model diagrams generating CP violation[7].

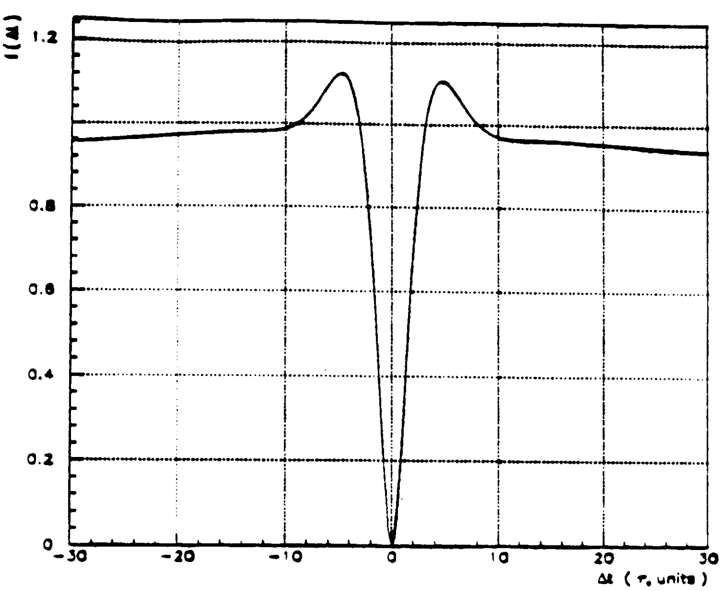


Fig.2: Distribution of $\Delta t$ for $\phi \rightarrow \pi^+\pi^-\pi^o\pi^o$[15].

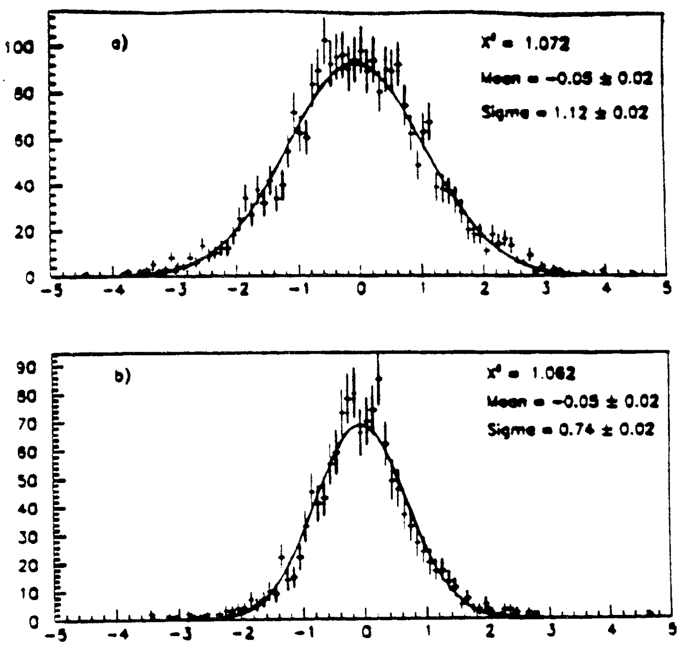


Fig.3: Differences between reconstructed and true values of decay length R (cm) for $K^o \rightarrow \pi^o \pi^o$ events with $R < 100$ cm, assuming a calorimeter time resolution: a)$\sigma_t = 300$ ps, and b)$\sigma_t$(ps) $= 45\sqrt{E(GeV)}$[16].

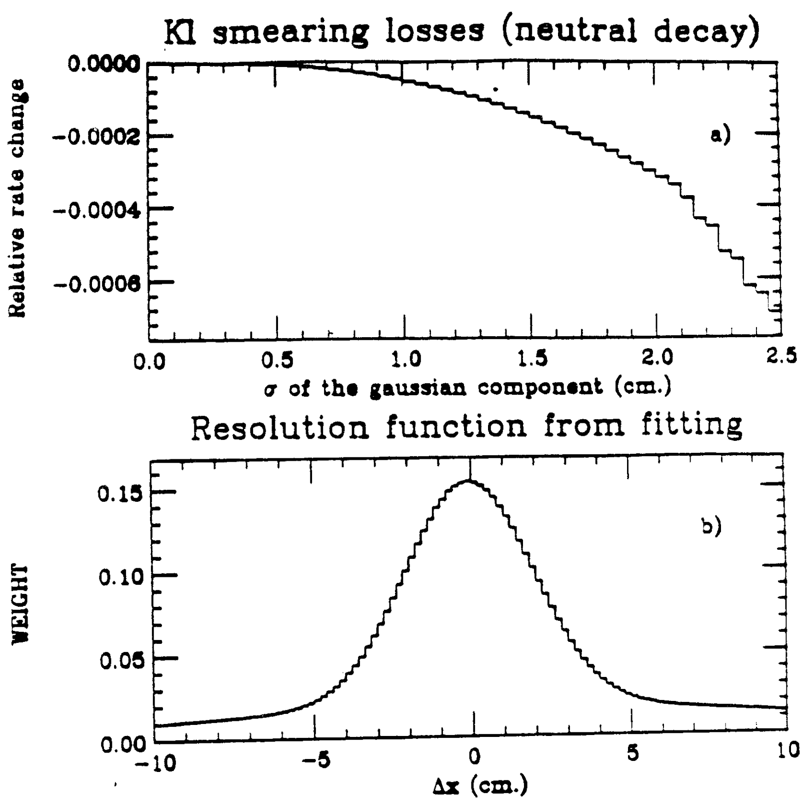


Fig.4: a) $K_L$ smearing losses as a function of the width of the gaussian part of the vertex resolution ($K_L \rightarrow \pi^o \pi^o$).
b) Resolution function; the $\sigma$ of the gaussian component is 2 cm[24].

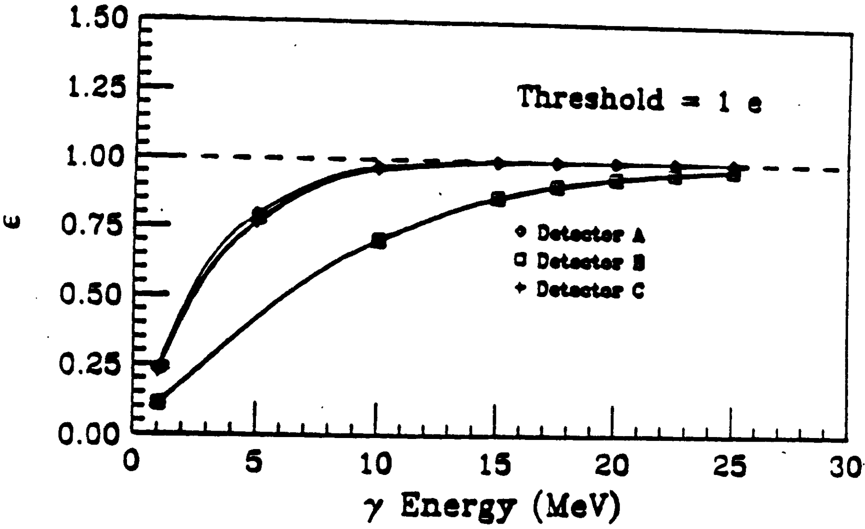


Fig.5:
Efficiency as a function of energy for a Sci-Fi calorimeter[25].

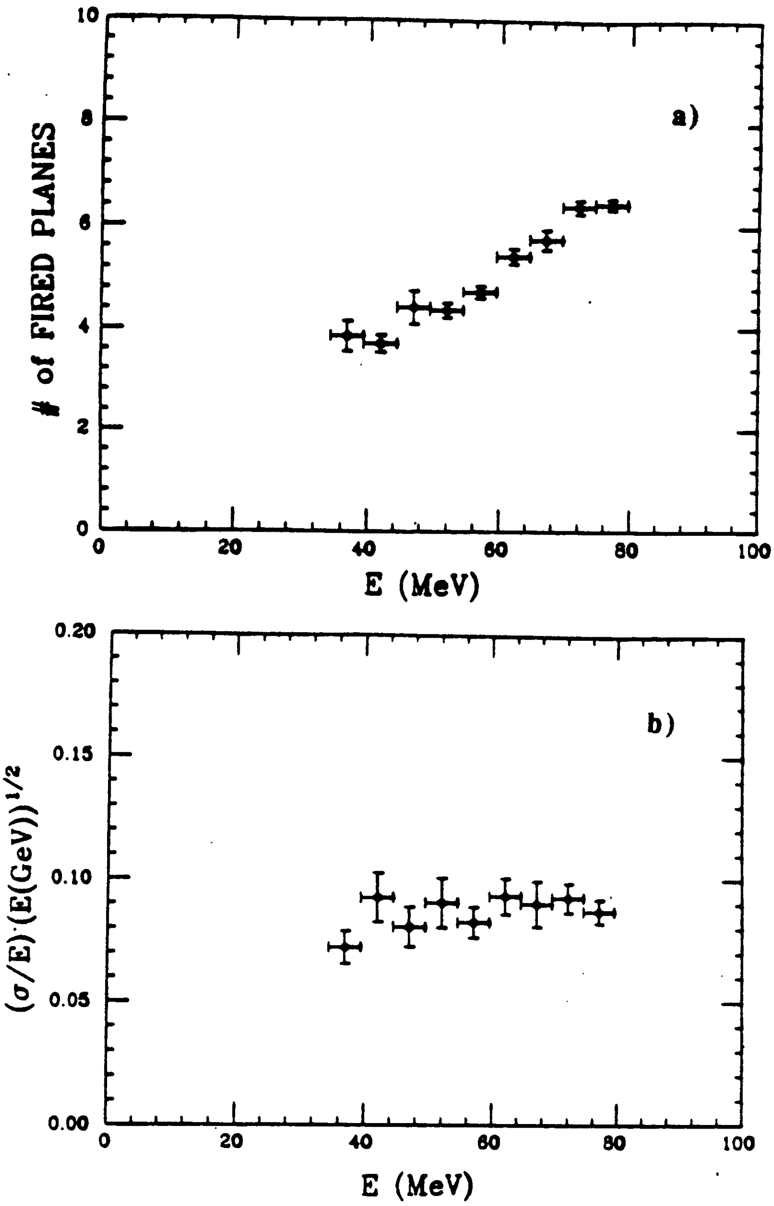


Fig.6: a) Average number of layers hit vs. photon energy.
b) $\sigma_E$ vs. photon energy obtained counting the number of fired, 8 mm wide, strips[29].

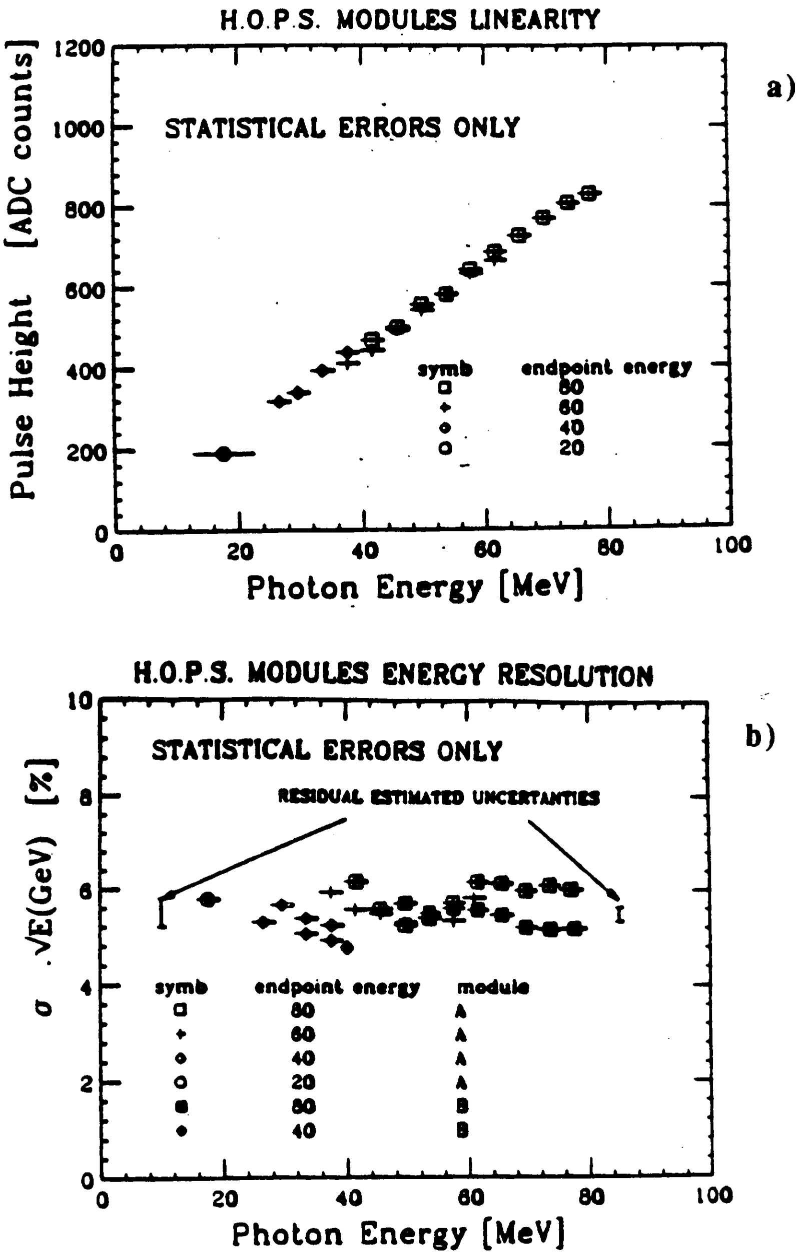


Fig.7: a) Linearity and b) resolution for head-on Pb-SciFi modules[31].

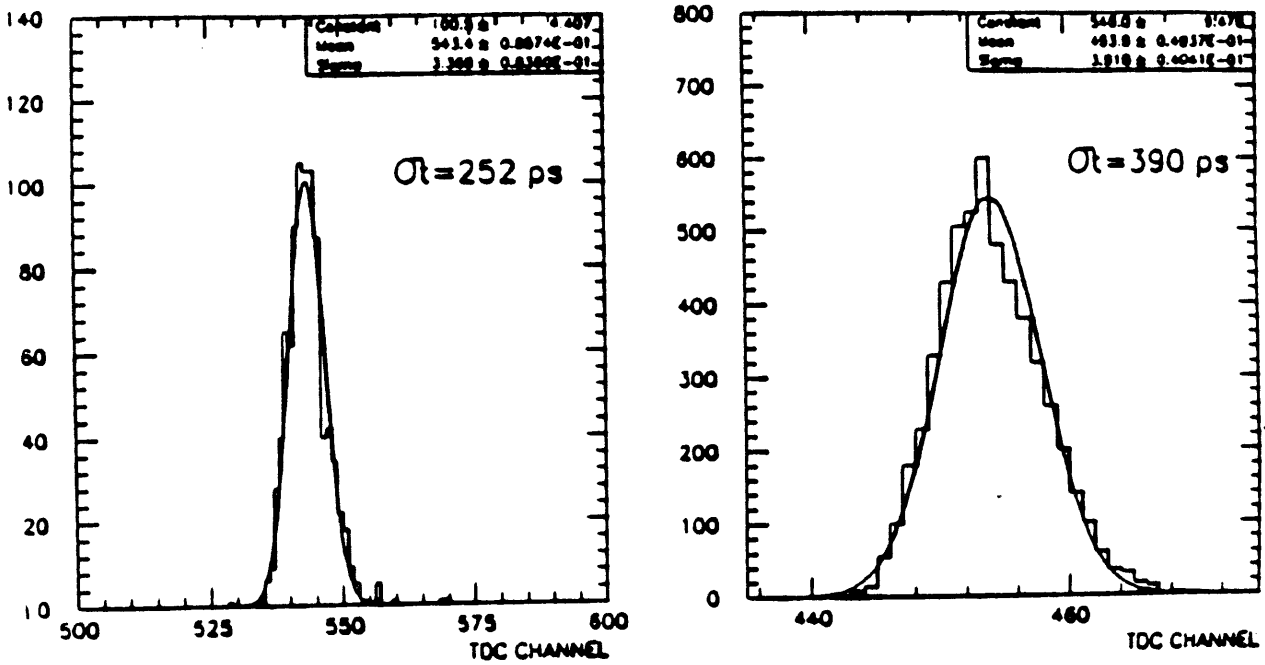


Fig.8: Experimental resolution for a) 50 cm long fibers, b) 200 cm fibers[30].