INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-91/044 (R)
9 Luglio 1991

DETECTOR SUBSYSTEMS INTERPLAY IN THE ε'/ε MEASUREMENT AT DAΦNE

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

ABSTRACT

The optimization of the components of an experimental apparatus able to perform a 1×10^{-4} measurement of ϵ'/ϵ at DAΦNE is discussed. The requirements of each subsystem are examined, with particular emphases on the problem of systematic errors. A possible scenario for the detector is described.

1. Introduction

Among the many physics problems that can be studied at a ϕ–factory the most challenging is the measurement of the module and phase of ϵ', the parameter that describes the direct CP violation in Kaon decay.

A ϕ–factory, based on a high luminosity e^+e^- colliding beam machine with a peak luminosity $\mathcal{L}{\sim}5\times10^{32}\text{cm}^{-2}\ \text{sec.}^{-1}$, will allow a $\mathcal{R}e(\epsilon'/\epsilon)$ measurement with a statistical error $\sim 1.5\times10^{-4}$ in a *canonical* year of running (100 days), should the experimental apparatus have an acceptance for K^0_L decays of $\sim$25%. The statistical accuracy with which the imaginary part of ϵ'/ϵ would be measured will be, in the same luminosity hypothesis, $\sim$0.02[1]. It is extremely important, however, to design an experimental apparatus for which systematic errors would not spoil the statistical analyzing power just mentioned.

I will review in the following the prescriptions that stem out of the requirement of having systematic errors at the level of one half or less than the statistical error for the measurement of the $\mathcal{R}e$ (ϵ'/ϵ), and point out correlations between the various components of the experimental setup.

The results that I will discuss in the following have been obtained using a Geant based Montecarlo program, Geanfi[2] , developed in Frascati, that contains the simulation of the relevant features of the ϕ and K decays.

2. The systematics in the measurements of $\mathcal{R}e(\epsilon'/\epsilon)$

The systematic errors in the measurement of $\mathcal{R}e$ (ϵ'/ϵ) at a ϕ–factory can be divided into three broad categories:

1. Detection efficiency evaluation
2. Background subtraction
3. Geometric acceptance evaluation

If the double ratio method will be used to evaluate the $\mathcal{R}e(\epsilon'/\epsilon)$ and systematic errors have to be less than one half the statistical ones, each of the three quantities mentioned above has to be known with a precision of ~0.03%. This requirement must be fulfilled by carefully designing the experimental setup as a whole, because as we will see in detail in the following, the reconstruction of K^0_L (K^0_S) decays will exploit all the components of the detector, introducing correlations in the required performances of each subsystem.

2.1. DETECTION EFFICIENCIES

The measurement of the double ratio requires the knowledge of the partial widths of K^0_L (K^0_S) into $\pi^+\pi^-$ and $\pi^0\pi^0$. For the $\pi^+\pi^-$ channel, events originated by K^0_L (K^0_S) decay will populate different regions of the tracking device. The means to precisely define the efficiency of the latter as a function of the distance from the luminous spot is given by the known value of the K^0_L lifetime: this quantity allows to predict the number of decays occurring at increasing distances from the interaction point, yielding a very precise determination of the relative behavior of the detection efficiency (η_{det}) versus the decay distance. The absolute value of η_{det} can be obtained using a semileptonic K_L^0 tag, which, in turn, signals a K_S^0 decay. If the calorimetric coverage of the experimental setup is close to 100%, events in which no photon is detected will clearly indicate a charged K_S^0 decay. The described procedure provides a completely unbiased sample of charged K_S^0 decays with which η_{det} can be obtained at the needed precision level.

For what the neutral decays is concerned, the γ detection process does not depend much on decay distances, if the boundary of the fiducial volume is not extremely close to the inner window of the calorimeter itself; a distance of the order of 50 cm would prevent photons from entering the latter at a grazing incidence angle and change the detection properties of the device.
The π^0 reconstruction efficiency can be obtained from the analysis of the process:

$$\phi \rightarrow K^{\pm}K^{\mp} \tag{2.1}$$

If one selects events in which one of the two charged Kaons does not decay, while the second decays into $\pi^{\pm}\pi^0$, the reconstruction of the charged prongs completely tags momentum, energy and vertex of the neutral pion, thus allowing a completely unbiased measurement of the neutral π reconstruction efficiency. The determination of the π^0 vertex with this algorithm will allow the intercalibration between the decay point determination with the tracking device (charged decays) and the calorimeter (neutral decays). As a last remark I want to stress that efficiency determination relies upon physics processes generated through the same luminosity that allows the measurement of $\mathcal{R}e(\epsilon'/\epsilon)$.

2.2. BACKGROUND SUBTRACTION

Many estimates have been made for the background rejections[3] [4] needed to keep systematic effects at the level mentioned in the introduction; only K_L^0 decays exhibit background contamination; K_S^0 decays are essentially background free. The evaluation of the various rejections can be obtained using the following formula:

$$Rej.ratio \leq \frac{Br_{K_L^0\rightarrow\pi\pi}}{Br_{Backgr}} \times \frac{1}{3\alpha\sqrt{N_{\pi\pi} + N_{Backgr}}} \tag{2.2}$$

where α indicates the relative precision with which the background is known.
A list of possible background decays with the relative branching ratio and rejection ratios required are given in Table 1 ($\alpha \sim 15\%$).

Signal	Background	Relative B. R.	Rejection Ratio
$K_L^0 \rightarrow \pi^0\pi^0$	$K_L^0 \rightarrow \pi^0\pi^0\pi^0$	1: 241	1.2×10^{-5}
$K_L^0 \rightarrow \pi^+\pi^-$	$K_L^0 \rightarrow \pi\mu\nu$	1:135	1.6×10^{-5}
$K_L^0 \rightarrow \pi^+\pi^-$	$K_L^0 \rightarrow \pi e\nu$	1:189	1.1×10^{-5}
$K_L^0 \rightarrow \pi^+\pi^-$	$K_L^0 \rightarrow \pi^+\pi^-\pi^0$	1:61	3.0×10^{-5}

Table 1: Rejection ratios for relevant K_L^0 decays

The figures in Table 1 imply that photon detection coverage has to be complete; also threshold energy for γ detection has to be as low as 20 MeV, to cover the full kinematic range.

As for what the calorimetric energy resolution is concerned, the optimization, once that the efficiency at the low end of the spectrum is established, relates this quantity to the angular coverage of the calorimeter. A less than complete angular coverage would require a good energy resolution, because a way of rejecting the $\pi^0\pi^0\pi^0$ background, short of detecting at least 5 of the 6 produced photons, is to reconstruct the total energy pertaining to the photon combination under scrutiny. To put things into perspective, using the criterion of Table 1, a 99% coverage requires a scaled energy resolution of $5\%/\sqrt{(E)}$ (E in GeV)[5]. For what the charged decay is concerned, the required rejection ratio, suggests the need of some particle identification capability, since kinematics alone do not provide such a discrimination power. To meet Table 1 specifications, a π/μ discrimination of 100:1 and a π/e discrimination of 150:1 should suffice.

2.3. GEOMETRIC ACCEPTANCES

The next experimental effect I will discuss is the distortion of the exponential decay curve of both K_L^0 and K_S^0.

The effects that need to be corrected are related to both the machine and the detector. The source dimensions, in the DAΦNE project, require a correction in the radial and longitudinal directions: the real shape of the beam spot can be inferred from the distribution of Bhabha events and then folded in.

The detector related effects concern the determination of the fiducial volume for the relevant decays and the evaluation of the total rate in the assigned volume. For what the determination of the fiducial volume is concerned, the boundaries for the charged and neutral decays can be controlled at the level of few parts $\times\ 10^{-7}$, if the decay vertex is reconstructed with a precision of few cm. Such resolution is achievable both for charged and neutral decays. A more severe problem is connected with the rate loss due to the finite resolution with which the K_L^0 (K_S^0) decay point is measured. In particular for neutral decays the decay point has to be determined by kinematic fitting and resolution of the order of few (up to one) centimeters[5] [6] [7] are foreseen.

If the resolution functions obtained from the fitting procedure, were absolutely symmetrical, practically no problem would arise in the evaluation of the total rate: effects due to a finite but symmetrical resolution function would be negligible up to a value of the resolution itself of few (≤ 10) centimeters. The resolution function, however, is skew because the decay point is obtained through a complicate, non linear fitting technique that does not guarantee symmetry.

Two procedures have been developed to measure the vertex in the $K_L^0 \to \pi^0 \pi^0$ decay: one uses the measured energy of the four showers and the conversion points with the known (the same as the K_S^0, modulo radiative corrections and energy resolution of the machine itself) direction of the K_L^0 to obtain through kinematic fitting[6]the decay point. A second technique exploits the low β of the K_L^0 to define the decay point, and uses the time of flight of the four photon showers in the calorimeter, again with a kinematic fitting procedure[7].

Fig. 1 shows the relative rate change due to a gaussian resolution function, plotted against the σ of the distribution for a K_L^0 decay region from 10 to 150 cm.

In the more realistic case of a non-gaussian resolution function the relative rate change is bigger and strongly dependent on the tails of the distribution. This situation is depicted in Fig. 2a, where the relative rate change is shown as a function of the width of the gaussian part of the resolution; Fig. 2b shows the shape of the resolution as obtained from the first fitting procedure[5].

The increase of the smearing losses in the realistic case of Fig. 2, about one order of magnitude with respect to the gaussian case of Fig. 1, implies that this systematic effect must be carefully kept under control, as one of the most dangerous.

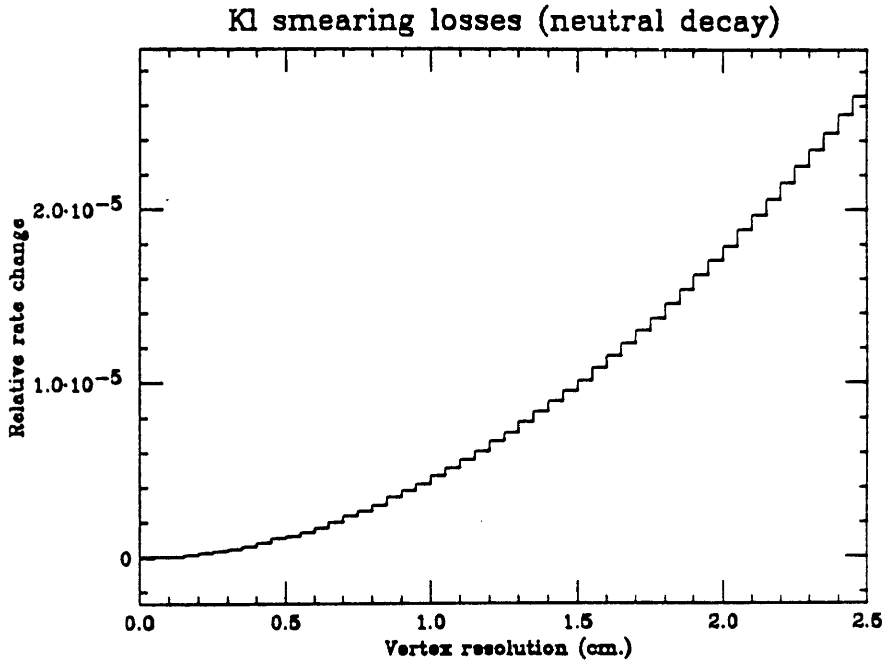

Figure 1. K_L^0 smearing losses as a function of the vertex resolution ($K_L^0 \rightarrow \pi^0\pi^0$); the decay region is taken from 10 to 150 cm. radially

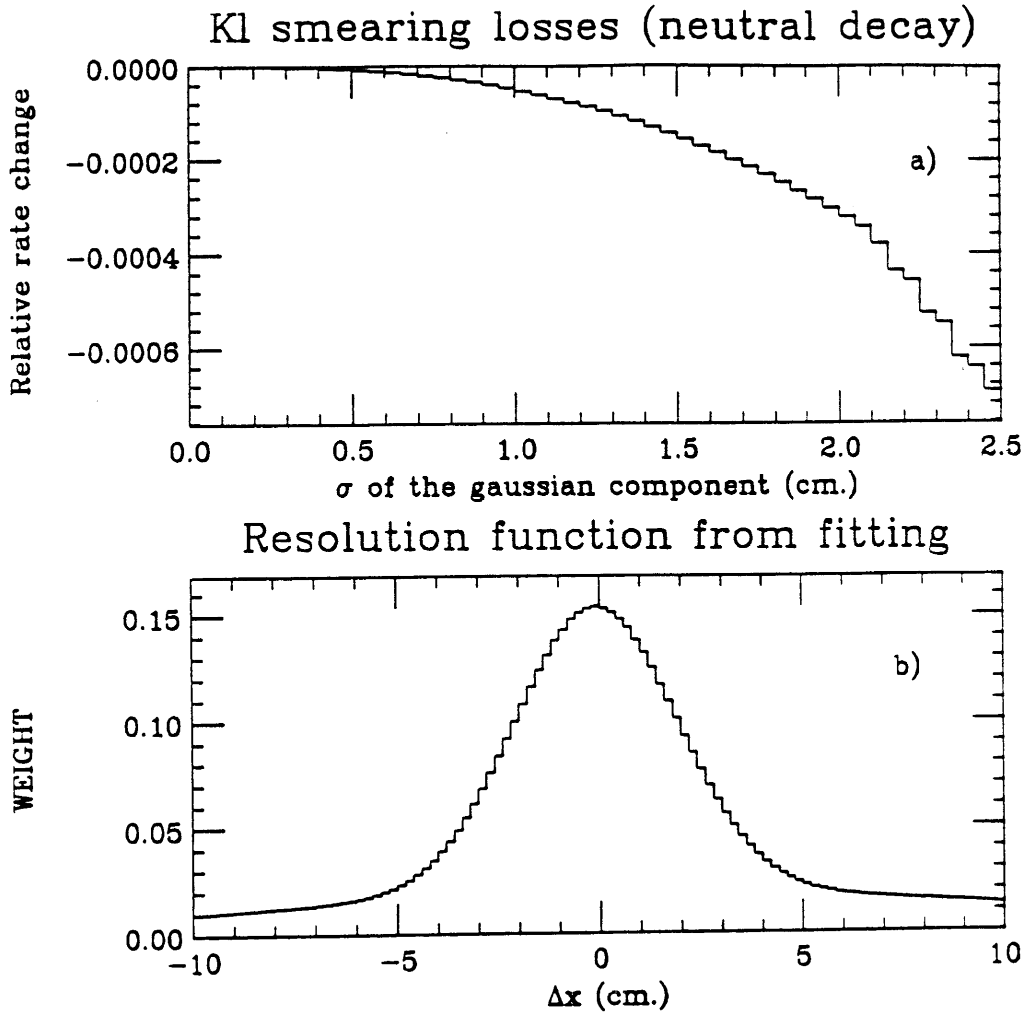

Figure 2. (a) K_L^0 smearing losses as a function of the width of the gaussian part of the vertex resolution ($K_L^0 \rightarrow \pi^0\pi^0$)

(b) Resolution function as obtained with the first fitting procedure described in the text; the σ of the gaussian component is 2 cm.

To complete the analysis of the geometric acceptance for the $\pi^0\pi^0$ decay of the K_L^0, I will discuss the relative importance of the performances of the various components of the experimental apparatus in the measurement of the decay vertex. I shall concentrate on the technique that uses the four photons conversion point and the energy, it's however possible to reach a slightly more optimistic conclusion in the case of the time of flight. Assuming as perfectly known the K_L^0 direction, the performances of the calorimeter directly relate to the decay point resolution, that is to say a better resolution in the conversion point and in energy translates in a better determination of the decay point. The situation changes drastically as soon as different effects leading to a less than perfect determination of the flight direction of the K_L^0 get into the picture.

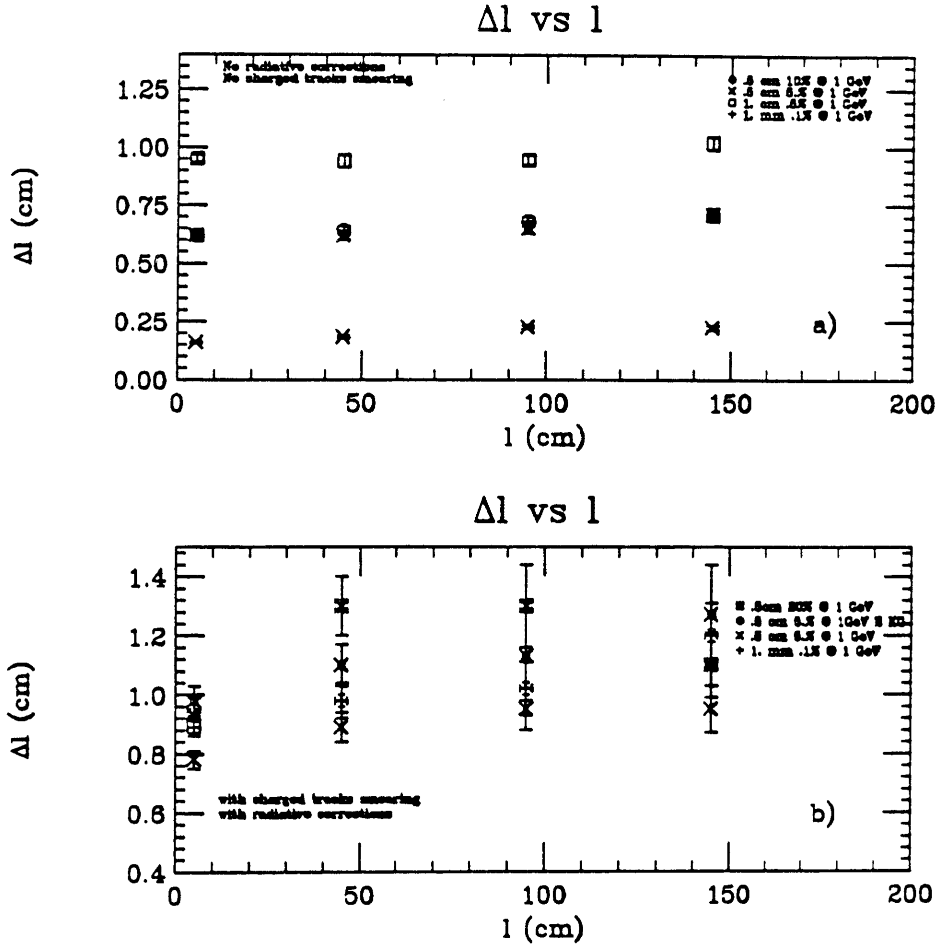

Figure 3. (a) K_L^0 vertex resolution as a function of the decay distance for different basic performances of the calorimeter. The K_L^0 direction is assumed known.

(b) The same as in fig 3a with the uncertainty in the flight direction of the K_L^0 folded in.

Fig. 3a shows the K_L^0 vertex resolution obtained by different calorimeters, parametrized in terms of scaled energy resolution at 1 GeV and shower conversion point resolution, with no radiative corrections, no machine energy spread and no charged tracks smearing. Fig. 3b shows the same quantity when the uncertainty on the K_L^0 direction is realistically taken into account.

From Fig. 3 the importance of the tracking system in the determination of the decay vertex of totally neutral K_L^0 decays is evident; therefore the optimization of the experimental setup must take this interplay of the different components of the apparatus with the characteristics of the machine itself into account.

3. A detector scenario

Let me now describe a detector with performances compatible with the requirements described previously, with the proviso that this is just *one* of the possible solutions to the experimental demands discussed before.

1. Tracking: a Helium based drift chamber[8] to minimize the multiple scattering contribution to momentum and vertex resolution and reduce K_L^0 regeneration effects in the tracking device as much as possible. In order to reach a K_L^0 detection efficiency of ~25% the decay volume has to be ~1.5 meters, and this in turn will imply a chamber radius of 2 meters. With a spatial resolution of 200 μ, a δp/p of 1% would be achievable with an axial field of 0.1 T. The inner radius of the chamber, which is essentially the machine beam pipe, is thought to be 8–10 cm, in order to get a negligible contribution from K_S^0 regeneration. The expected vertex resolution for the $\pi^+\pi^-$ decay of the K_S^0 will be 0.8-1.0 mm.
2. Calorimetry: a fine grain lead-scintillating fiber sampling calorimeter with a conversion point resolution $\leq$ 1 cm, a scaled energy resolution of $5\%/\sqrt{(E)}$ (E in GeV) and a timing resolution of ~300 psec. at 50 MeV[9] [10] [11]. The good timing performances of the calorimeter will greatly enhance the K_S^0 tagging efficiency, as a K_L^0 can be identified as a *late* (~30 nsec) substantial energy deposition.
3. Particle identification: the needed level of $\pi/\mu/e$ discrimination could be obtained by dE/dx measurement in the tracking chamber and/or by range measurement in the calorimeter. Should the dE/dx technique yield the necessary discrimination, one might consider working with higher magnetic fields, as low momentum particles do not need to enter the calorimeter to be identified.

Let me also mention other options that have been discussed:

Tracking: a time projection chamber has been proposed as a tracking device; in this case Neon would be the gas to use[12].

Calorimetry: Both noble cryo-liquid, crystal and glass spark counters based calorimeters have been proposed[13][14][15][16].

Particle identification: RICH type of systems[17][18], threshold Cerenkov counters[19] and extremely precise spark (Pestov) counters for timing measurements[20] have been discussed.

An in depth discussion of the various options concerning the mentioned devices can be found in the contribution by P. Franzini[21] .

4. Conclusions

The measurement of $\mathcal{R}e(\epsilon'/\epsilon)$ is a very challenging experimental project: the clean environment of DAΦNE, however, holds the promise of a big step forward in the understanding of the fascinating phenomenon of CP violation. The technology to build a detector capable of measuring $\mathcal{R}e(\epsilon'/\epsilon)$ at the 1×10^{-4} level seem essentially on hand, so construction efforts should begin as soon as possible, in order to be ready for the summer 1995, when beam collisions at DAΦNE will start.

Acknowledgements: It is a pleasure to thank the Organizing Committee, for a perfectly organized and stimulating Workshop. Particular thanks are due to the other Conveners of the study groups R. Baldini-Celio, P. Franzini, M. Giorgi and L. Maiani: I had a period of exciting and fruitful work together with them.

REFERENCES

1. V. Patera "Measurement of the $\mathcal{R}e(\epsilon'/\epsilon)$ and $\Delta\phi$ parameters at a ϕ–factory by means of the $K_L^0 K_L^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$ decay time differences" , Contribution to these Proceedings.
2. A. Antonelli *et al.*"Development of a Monte Carlo program for DAΦNE", Contribution to these Proceedings.
3. G. Barbiellini and C. Santoni, "A measurement of ϵ'/ϵ at a ϕ–factory. " CERN-EP/89-99.
4. M. Piccolo , "The case for a ϕ–factory" Contribution to Les Rencontres de Physique de la Vallèe d'Aoste, La Thuile, March 1990.
5. A. Calcaterra "Background to the $K_L^0 \rightarrow \pi^0\pi^0$channel", Contribution to these Proceedings.

6. A. Calcaterra, R. De Sangro, P. De Simone “Measurement of K^0_L decay point and mass via kinematic fit“ Nota interna Laboratori Nazionali di Frascati LNF-90/031
7. C. Bloise “Decay length reconstruction: $K^0_{l,s}\to\pi^0\pi^0$“, Contribution to these Proceedings.
8. F. Grancagnolo “DAΦNE: a case for a cylindrical drift chamber in a Helium based gas mixture“, Contribution to these Proceedings.
9. S. Bertolucci *et al.*“A Pb-SCIFI e.m. calorimeter“, Contribution to These Proceedings.
10. R. De Sangro “ Monte Carlo simulation of a lead-scintillating fiber calorimeter“, Contribution to these Proceedings.
11. D. Babusci *et al.*“ Performances of head-on Pb-SCIFI calorimetric modules“, Contribution to these Proceedings.
12. G. Batignani *et al.*“Preliminary study for the design of a tracking system at DAΦNE“, Contribution to these Proceedings.
13. P. Cantoni *et al.*“Liquid Kripton e.m. calorimetry“, Contribution to these Proceedings.
14. A. Bettini *et al.*“ The ICARUS liquid Argon TPC: a detector for low energy e^+e^- collider“, Contribution to these Proceedings.
15. G. Bencivenni *et al.*“Performances of a glass spark counter calorimeter prototype“, Contribution to these Proceedings.
16. S. Bianco *et al.*“Electromagnetic calorimeters for DAΦNE that make use of CsI(Tl) and Pb+fibers elements“, Contribution to these Proceedings.
17. P. Sartori *et al.*“ A fast Cerenkov device for a detector at DAΦNE“, Contribution to these Proceedings.
18. A. Castro *et al.*“ A fast Cerenkov device for momenta measurement at DAΦNE“, Contribution to these Proceedings.
19. V. I. Vorobiov *et al.*“On some peculiarities of Vavilov Cerenkov radiation aerogels“, Contribution to these Proceedings.
20. Yu.N. Pestov “ T.O.F. option “, Contribution to these Proceedings.
21. P. Franzini “ *CP* Physics at DAΦNE“, Contribution to these Proceedings.