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DAΦNE

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Abstract

The physics items that can be studied at the Frascati Φ factory $DA\Phi NE$ are reviewed. The design of $DA\Phi NE$ has the potential to increase by an order of magnitude the sensitivity in detecting CP violating processes. Detailed studies of Kaon mesons physics and tests of Chiral perturbation theory can be done. Kaon -nucleus interactions at very low energies, hypernuclei formation with stopped Kaons can also be studied at $DA\Phi NE$,showing the possibility to accomplish also a large nuclear program.

1 Introduction

The $DA\Phi NE$ Φ factory is a e^+ e^- collider, with a target luminosity $\mathcal{L} = 1 \div 8 \cdot 10^{32} cm^{-2} s^{-1}$ at the $\phi(1020)$ production threshold [1].

The construction of this collider has started in January 1991; it is expected to be ready for the experimental activity at the end of 1995. The ϕ production cross section peaks at $\simeq 4.0 \mu b$. A one year data taking $(10^7 s)$ at a luminosity $\mathcal{L} = 1 \cdot 10^{33} cm^{-2} s^{-1}$ provides $\simeq 2 \cdot 10^{10}$ charged Kaon pairs, $\simeq 5 \cdot 10^8$ η and $\simeq 5 \cdot 10^7$ π^0 [2],[3].

Final states with $K^0 \bar{K}^0$ are produced with a cross section of $\simeq 1.2 \mu b$ from the ϕ decay, whose $C = -1$ assignment forces the $|K_S K_L >$ state only to be selected. The ϕ is produced at rest in the laboratory and therefore K's are monochromatic with a momentum $P_{K^0} = 110 Mev$.

In contrast to high energy e^+ e^- collisions the number of decay modes is low,the multiplicity of particles in the final state is small and also the particle species are limited.

The main drawback of a Φ factory is connected to the low energies of the particles produced.For example the photons coming from $K_{S,L} \rightarrow \pi^0\pi^0$ have energies as low as 15 Mev and this puts special requests on the energy resolution and efficiency of the electromagnetic calorimeter. Besides the big difference in the decay length of K_S (0.6 cm) and K_L (342 cm) is a big constraint in the design of detectors able to measure the decay point of K_S with a reasonable efficiency for K_L.

With this considerations in mind the physics potential of a Φ factory has been recognized by many people and several proposals to build Φ factories have been considered[1],[2], [4], [5]. The main item is the study of CP violating phenomena. A measurement of the $Re(\frac{\epsilon'}{\epsilon})$ ratio with a total error $\Delta(Re(\frac{\epsilon'}{\epsilon})) \simeq 10^{-4}$ in 1-2 years running at $DA\Phi NE$'s luminosity seems to be possible.

At present, $Re(\frac{\epsilon'}{\epsilon})$ has been measured by only two fixed target experiments [6],[7], with results in disagreement at the 2σ level. Several experimental procedures have been proposed to measure $Re(\frac{\epsilon'}{\epsilon})$ via the integrated decay rates of $K_{S,L}$ in two and three pion final states, the most demanding request being an accurate measurement of photon energies and K_L decay lengths in the $K_L \rightarrow 2\pi^0, 3\pi^0$ channel [8].

CP violation does not exhaust the physics capabilities of a ϕ factory. Detailed studies of K mesons physics can be accomplished. Rare Kaon decays[3] with a $BR \simeq 10^{-6}$ are accessible to a ϕ factory, such as radiative decays $K \rightarrow \gamma\gamma, \pi\pi\gamma$, etc. Radiative ϕ decays are of big importance to clarify the problematic associated to $\eta - \eta'$ mixing, as well as to study scalar states such as $f_0(975)$, whose excessively small width has caused a bulk of hypotheses [9] ($K\bar{K}$ molecule, $q\bar{q}q\bar{q}$ states,gluon plasma).The K_SK_L system offers also an ideal playground for the study of paradoxes concerning the foundations of Quantum Mechanics [10].

2 The $DA\Phi NE$ machine

The $DA\Phi NE$ project consists in the construction of a two rings colliding beam Φ Factory and a 510 Mev e^+ e^- injector [1],[11].

The project has been approved and funded; the engineering design has started in January 1991;construction and commissioning is scheduled for the end of 1995.A general layout of the complex,inside the existing buildings, is shown in Fig.[1].

The luminosity goals are $\mathcal{L} = 10^{32} cm^{-2} s^{-1}$ for the end of 1995 and a factor 10 higher for the end of 1996.

The design philosophy to achieve this goal has started from the experimental fact that the highest luminosity reached up to now at the ϕ energy,with flat beams and two interactions per turn, is $\mathcal{L} = 4.3 \cdot 10^{30} cm^{-2} s^{-1}$ obtained at VEPP-2M in Novosibirsk.Taking into account that

$$\mathcal{L} = h\mathcal{L}_0$$

($\mathcal{L}_0$ is the single bunch luminosity and h the number of bunches) ,the conservative approach has been chosen to construct a machine with many bunches since the increase of $\mathcal{L}_0$ requires the assumption of luminosities never achieved until now.

The choice of a low $\mathcal{L}_0$ should help in keeping the beam luminosity lifetime to a reasonable value (20 hrs). This solution forces to construct two separate rings in which electrons and positrons circulate in opposite directions and collide at a horizontal half angle θ_x=10 mrad.

The $DA\Phi NE$ design parameters are shown in Tab.1. Remembering that

$$\mathcal{L}_0 = \propto \frac{h f_0 \xi^2 \epsilon (1+\kappa)}{\beta_y}$$

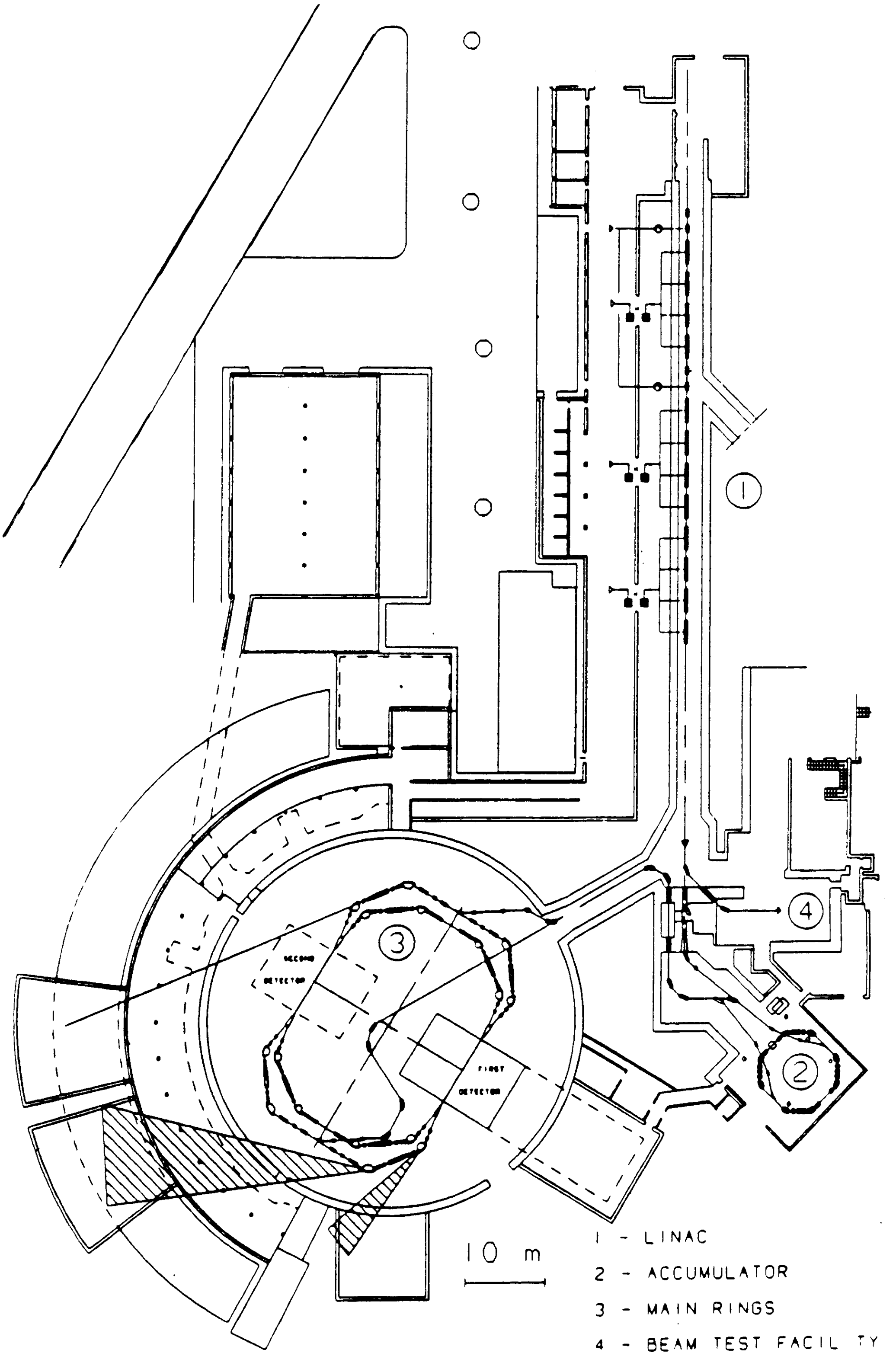

Figure 1: $DA\Phi NE$ General Layout.

(f_0 is the revolution frequency,β_y is the value of the vertical β function at the interaction point,ξ the linear tune shift parameter,ϵ the emittance and κ the coupling coefficient), we see that the $DA\Phi NE$ parameters are very similar to the VEPP-2M ones with the exception of f_0 , ϵ and the number of crossing.The beam-beam parameter ξ that enters quadratically in the luminosity formula has a value that is normally achieved in the e^+ e^- colliders. The value chosen for the emittance is very high and this implies a large physical and dynamical aperture of the lattice of the machine. Also the collision frequency has been pushed upward in order to gain luminosity. The very low β_y implies a small bunch length ($\sigma_z < \beta_y/1.5$);considering also the large values of h and f_0 this means that very high peak and absolute currents will circulate in the machine.

$L_0(cm^{-2}sec^{-1})$	4.510^{30}
ξ	.04
$\epsilon^{max}(m-rad)$	10^{-6}
κ	.01
$\beta_y(IP)(m)$	.045
$\beta_x(IP)(m)$	4.5
$N^{max}(particles/bunch)$	8.910^{10}
$h^{max}(N^{er}ofbunches)$	120
$f_0(MHZ)$	3.17
$\sigma_x(IP)(mm)$	2.11
$\sigma_y(IP)(mm)$	0.021
$\sigma_z(IP)(m)$	0.03

Table 1: $DA\Phi NE$ design parameters at 510 Mev.

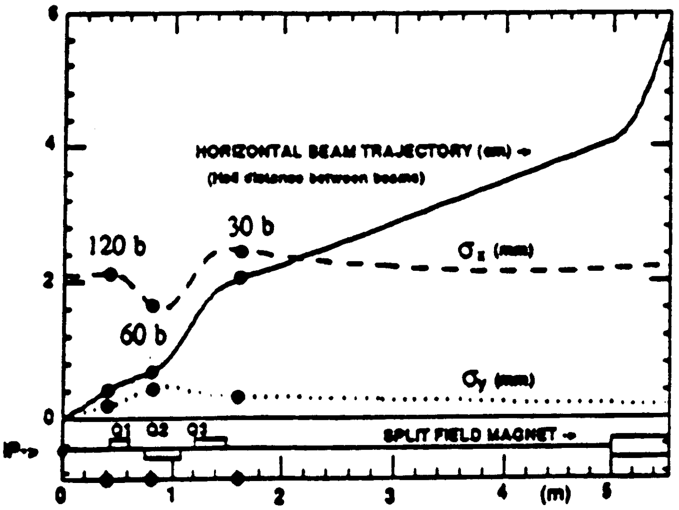

Figure 2: Beam half-separation in the low-β region;the heavy dots mark the parasitic crossing points.

In conclusion the design of the machine, for what concerns the optimization of the luminosity, is quite conservative if we consider the single bunch luminosity; but is very demanding if we consider the necessity to maintain very high currents circulating in the rings. This requests a careful study of the multibunch instabilities that can be excited in the radio frequency (RF) cavities.

The low-β insertion(Fig.[2] from [11]) is composed of a quadrupole triplet followed by a long drift and a special designed split field magnet. In order not to reduce too much the solid angle covered by the experimental apparatus, the low-β insertion is confined within a cone of half-aperture angle 8.5^0,over a length of ± 5 m. This constrains the outer diameter of the first quadrupole to 12.9 cm, requiring a good design of this element.

3 CP violation measurements at $DA\Phi NE$

A new measurement of $Re(\frac{\epsilon'}{\epsilon})$ is the most important result to be achieved at a Φ factory. These parameters measure the amplitude of the K_S, K_L system to two pions final states:

$$\frac{<\pi^+\pi^- \mid K_L>}{<\pi^+\pi^- \mid K_S>} = \eta_{+-} = \epsilon + \epsilon'$$

$$\frac{<\pi^0\pi^0 \mid K_L>}{<\pi^0\pi^0 \mid K_S>} = \eta_{00} = \epsilon - \epsilon'$$

The experimental observation of $\epsilon' \neq 0$ would be proof that CP is violated directly in the decay amplitudes. Two fixed target experiments NA31[6] and E731[7] have presented in the last years contrasting results for the measurement of this quantity. They measure the ratio

$$\frac{R^\pm}{R^0} = \frac{\mid \eta_{+-} \mid^2}{\mid \eta_{00} \mid^2} \simeq 1 + 6Re(\frac{\epsilon'}{\epsilon})$$

The last results [12] obtained with the analysis of the full sample of data

$$Re(\frac{\epsilon'}{\epsilon}) = (2.30 \pm 0.70)10^{-3}\ (NA31)$$

$$Re(\frac{\epsilon'}{\epsilon}) = (0.60 \pm 0.69)10^{-3}\ (E731)$$

are still inconsistent; the confidence level of their compatibility is less than 10 %. In particular the NA31 results don't agree at 99 % c.l. with the superweak model ; E731 is consistent with this model.

A prudent interpretation of these results is that they impose an upper bound on $Re(\frac{\epsilon'}{\epsilon})$ of the order of 10^{-3}; the difference between the two results is a measurement of the true level of the statistic and systematic uncertainty $\Delta(Re(\frac{\epsilon'}{\epsilon})) \simeq 10^{-3}$. Remembering that the present theoretical predictions for the direct CP violation, at the presently preferred range of the top mass ($100 < M_t < 180Gev$)), indicates $Re(\frac{\epsilon'}{\epsilon}) =\simeq 10^{-3}$[13], measurements with statistical and systematic errors $\Delta(Re(\frac{\epsilon'}{\epsilon})) \simeq 10^{-4}$ are required to pin down this question.

NA31 has proposed an upgrade of the experiment that should produce about 10^6 $K_L \rightarrow \pi^0\pi^0$ for 1995[14];this number is consistent with a statistical error $\Delta(Re(\frac{\epsilon'}{\epsilon})) \simeq 10^{-4}$.

In 1996 $DA\Phi NE$ should get a similar measurement with roughly the same statistical error but with better and in any case different systematic errors. In the following we will analyze the potentiality of $DA\Phi NE$ to improve by an order of magnitude these searches and the physical constraints on the detector design.

3.1 Statistical accuracy in a measurement of $Re(\frac{\epsilon'}{\epsilon})$

The rates for the process

$$e^+e^- \rightarrow \phi \rightarrow K_L K_S \rightarrow \pi^+\pi^-\pi^0\pi^0$$

are calculated in the exemplifying case of a $(\frac{\epsilon'}{\epsilon})$ vanishing phase, as required if CPT invariance holds; the interference term between K_S and K_L amplitudes may be neglected as far as higher order terms in $\frac{\tau_S}{\tau_L} = 1.72 \cdot 10^{-3}$ are negligible. In this approximation the time integrated rates N_i are:

$$\frac{N(K_S \to \pi^+\pi^-)\,N(K_L \to \pi^0\pi^0)}{N(\phi \to K_S K_L)} \simeq \frac{\epsilon^2}{2}(1 - 4\frac{\epsilon'}{\epsilon})$$

$$\frac{N(K_S \to \pi^0\pi^0)\,N(K_L \to \pi^+\pi^-)}{N(\phi \to K_S K_L)} \simeq \frac{\epsilon^2}{2}(1 + 2\frac{\epsilon'}{\epsilon})$$

$$\frac{N(K_S \to \pi^+\pi^-)\,N(K_L \to \pi^+\pi^-)}{N(\phi \to K_S K_L)} \simeq \epsilon^2(1 + 2\frac{\epsilon'}{\epsilon})$$

$$\frac{N(K_S \to \pi^0\pi^0)\,N(K_L \to \pi^0\pi^0)}{N(\phi \to K_S K_L)} \simeq \frac{\epsilon^2}{4}(1 - 4\frac{\epsilon'}{\epsilon})$$

Any of these rates is suitable to evaluate $(\frac{\epsilon'}{\epsilon})$, the latter may be too difficult to handle from an experimental point of view. Contributions proportional to $(\frac{\epsilon'}{\epsilon})$ have different signs in different rates and overall coherence reduces statistical and systematical errors.

A weighted mean has a statistical error

$$\sigma_N(\frac{\epsilon'}{\epsilon}) = \frac{1}{6\sqrt{N_1}},$$

where $N_1 = N(K_S \to \pi^+\pi^-)N(K_L \to \pi^0\pi^0)$. Therefore to achieve $\sigma(\frac{\epsilon'}{\epsilon}) \simeq 2 \cdot 10^{-4}$, with an ideal fully efficient apparatus, in 100 typical running days, a mean luminosity $\bar{L} = 0.8 \cdot 10^{32} cm^{-2} sec^{-1}$ is required.

The asymmetry

$$A = \frac{N_2 - N_1}{N_2 + N_1} \simeq 3\frac{\epsilon'}{\epsilon}$$

is also a suitable quantity to evaluate $(\frac{\epsilon'}{\epsilon})$; only CP violating events are selected and systematical errors would be reduced.

The corresponding statistical error is

$$\sigma_A(\frac{\epsilon'}{\epsilon}) = \frac{1}{3\sqrt{2}\sqrt{N_1}}.$$

Therefore to achieve $\sigma(\frac{\epsilon'}{\epsilon}) \simeq 2 \cdot 10^{-4}$ in 100 days from the asymmetry measurement, a mean luminosity $\bar{L} = 1.5 \cdot 10^{32} cm^{-2} sec^{-1}$ is required.

A simulation has been done for a spherical fiducial volume with a radius $R = 1.5\,m$, taking into account a finite resolution $\sigma = \pm 3\,mm$ in the vertex reconstruction. No background has been simulated. The t_1, t_2 distribution has been fitted[10] with the expected distribution. To achieve $\sigma(\frac{\epsilon'}{\epsilon}) = 2 \cdot 10^{-4}$ in 100 running days the required mean luminosity is $\bar{L} = 2.5 \cdot 10^{32} cm^{-2} sec^{-1}$.

3.2 The systematics in the measurement of $Re(\frac{\epsilon'}{\epsilon})$

We will analyze the systematic of the measurement of $Re(\frac{\epsilon'}{\epsilon})$ with the double ratio method. The double ratio R^{obs},directly constructed from observed number of events,

$$R^{obs} = \frac{\frac{N^{obs}(K_L \to \pi^+\pi^-)}{N^{obs}(K_S \to \pi^+\pi^-)}}{\frac{N^{obs}(K_L \to \pi^0\pi^0)}{N^{obs}(K_S \to \pi^0\pi^0)}}$$

can be factorized as

$$R^{obs} = R \times R_V \times R_\eta$$

(R_V and R_η are the double ratio of the decay rates and the product of the geometrical acceptance,detection and reconstruction efficiency for each individual decay mode, integrated on the fiducial volume of the detector).

The limit on the achievable accuracy is put by the measurement of $K_L \to \pi^0\pi^0$ that requires a powerful electromagnetic calorimeter. Because of the tagging of the other $K_{S,L}$ the knowledge of the four photon shower's apices is sufficient to determine the decay vertex and so the path length.The accuracy on the path length is of the order of the accuracy with which the apices are known. So in first approximation photon energy measurements are necessary to confirm the correct pairing of the γ to the parent π^0 but don't determine the accuracy in the measurement of the path length and so on R_V.

The determination of the geometric acceptance is connected to the rate loss due to the finite resolution with which the $K_{S,L}$ decay point is measured.The vertex resolution function of the π^0 detection can be obtained from a comparison of the vertex position determined from the $K^\mp$ and $\pi^\mp$ intersection to that obtained for the $\pi^0 \to 2\gamma$.The uncertainty of the difference in the vertices for the two modes is the error in the determination of the peak position of the vertex resolution function σ_{vert}. This error is related to the radius of the fiducial volume R_{fid}

$$\frac{\Delta R_V}{R_V} = \frac{\sigma_{fid}}{R_{fid}} = \frac{\frac{\sigma_{vert}}{R_{fid}}}{\sqrt{N(K_L \to \pi^0\pi^0)\frac{\sigma_{vert}}{R_{fid}}}} \simeq 1\ 10^{-4}$$

(To simplify we have considered only the measurement of the decay $K_L \to \pi^0\pi^0$). Assuming $\sigma_{vert} \simeq 1\ cm$ and $R_{fid} \simeq 1.5\ m$ we obtain $\frac{\sigma_{fid}}{R_{fid}} = \simeq 4 \times 10^{-5}$.

The determination of the vertex of the events can be also obtained from the measurement of the photon's time arrival to the calorimeter, because $K_{S,L}$ are produced with very low velocities $\beta = \simeq 0.216$.Assuming a time accuracy $\sigma_{tof} \simeq 300\ ps$ we get

$$\sigma_{vert} \simeq \sigma_{tof} \times \beta_L \times \frac{1}{\sqrt{\frac{1}{N_\gamma}}} + L \times \Delta\beta_L \simeq 1.2cm$$

So also this second method satisfies the precisions required for the measurement of R_V.

The detection efficiencies are given by $\phi \to K^+K^-$ where one of the charged Kaons decays via $\pi^\pm\pi^0$. This process provides a tagged sample of $\pi^\pm$ and π^0 that have almost exactly identical kinematics as those from $K_{S,L} \to \pi^+\pi^-$ and $\to \pi^0\pi^0$ The expected tagged event rate is $\simeq 10^9$, big enough to test the detector performances along the total fiducial volume with the desired precision.

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

Table 2: Rejection ratios for relevant K_L decays.

The error on R^{obs} is connected to the background events N_{Backgr} that are mis-identified as $K_{S,L}$ decays in two pions. The rejection factor κ necessary to get the required precisions is

$$\kappa \leq \frac{Br(K_L \to \pi\pi)}{Br(Backgr)} \frac{1}{3\lambda\sqrt{N_{\pi\pi} + N_{Backgr}}}$$

A list of possible background decays with the relative branching and rejection ratios required is given in Tab.2[15]; it has been assumed that N_{Backgr} can be estimated with a precision $\lambda \simeq 15\%$.

Another source of background is the process

$$\phi \to \gamma + f_0(975) \to \gamma K_S K_S$$

This background does not affect the measurement of $Re(\frac{\epsilon'}{\epsilon})$ because can be removed with simple cuts on the decay path length.It can affect the measurement of $Im(\frac{\epsilon'}{\epsilon})$ because $K_S K_S$ pairs decay with an intensity peaked at $\Delta(t) = 0$ if $Br(\phi \to f_0(975)\gamma)$is as large as 5×10^{-5} [16];recent estimates give for this branching ratio the values between 0.35×10^{-7} and 2×10^{-6}[17].

The effect of regeneration in $DA\Phi NE$ is due to $K_L \to K_S$ because all K_S decay in vacuum; the observed value is

$$Re^{obs}(\frac{\epsilon'}{\epsilon}) \simeq Re(\frac{\epsilon'}{\epsilon})(1 - 300\alpha)$$

where α is the regeneration probability of $K_L \to K_S$. No precise estimations exist on α because the total cross section $K-p$ is unknown at the $DA\Phi NE$ energy.Different estimations on the value of the cross section put the range of the error on $Re(\frac{\epsilon'}{\epsilon})$ from 40% to 7% [18]. This effect is however measurable in few days of running adding for instance some material around the beam pipe.

3.3 General requirements for a Φ factory apparatus

The detector for the measurement of $\frac{\epsilon'}{\epsilon}$ should cover as much solid angle as possible in order to optimize the statistical rates and minimize the error in the background subtraction; in any case due the 8.5^0 degree region covered by the quadrupoles it cannot be bigger than $\simeq 0.98\%$.

The tracking should be a Helium based drift chamber to minimize the multiple scattering contribution to momentum and vertex resolution and reduce the K_L regeneration effects as much as possible [19]. A large detection efficiency for K_L of $\simeq 25\%$ turns into a decay volume of $\simeq 1.5m$ and so the chamber radius should be $\simeq 2m$.Assuming a spatial resolution of 200μ, a momentum resolution of 1% requests a magnetic field of $\simeq 0.1T$.The inner radius of the chamber should be of $\simeq 8\ cm$ in order to get a negligible contribution from K_S regeneration.The expected vertex resolution for $\pi + \pi -$ decay will be around 1 mm([15].

The requests for the electromagnetic calorimeter are a good spatial resolution of the order of a few mm, good timing performances and a reasonable energy resolution. A fine grain lead-scintillating fiber sampling calorimeter can measure the apex of the γ with a σ of a few mm; energy resolutions of $\simeq \frac{6\%}{\sqrt{E(Gev)}}$,time resolutions of $\simeq \frac{400ps\%}{\sqrt{E(Gev)}}$ have been obtained with the present technology[20],[21]. A complete Montecarlo simulation of the reconstruction of $K_S K_L$ decays to $\pi^+\pi^-\pi^0\pi^0$ has been done [22]. The simulation has considered the radiative correction of the initial state,the energy spread of the machine,the energy,time and spatial resolution of the detector described.The results show a $\sigma_{vert} \simeq 8mm$ and a $\sigma \simeq 16Mev$ for the reconstruction of the K_S, K_L mass.

3.4 CP violation in 3 π decay

The observation of the decay $K_S \to 3\ \pi$ is also in the capabilities of an experiment at a powerful Φ factory. In particular $K_S \to 3\ \pi^0$ and isotropic $K_S \to \pi^+\pi^-\pi^0$ are CP violating decays. The decay $K_S \to \pi^+\pi^-\pi^0$ is allowed, but strongly reduced, if orbital angular momenta are involved. The CP violating amplitude is

$$B_{CPviol}(K_S \to 3\ \pi) \sim B(K_L \to 2\ \pi) \cdot B(K_L \to 3\ \pi) \cdot (\frac{\tau_S}{\tau_L})^2 \sim 3 \cdot 10^{-9}$$

if CP violation is mainly due to the mass mixing. The CP allowed decay

$$B_{CPcons}(K_S \to \pi^+\pi^-\pi^0) \sim (2 \pm 1) \cdot 10^{-7}$$

has never been detected. In the $\pi^+\pi^-\pi^0$ final state the two amplitudes may interfere, increasing the possibility to detect CP violation in this K_S decay. The $\pi^+\pi^-\pi^0$ Dalitz plot must be uniform for the CP violating decay. On the contrary the CP allowed decay must have a strong radial dependence: the simplest distribution [23],taking into account the spherical harmonics involved, is like $[(T_1 - T_2)(T_2 - T_3)(T_3 - T_1)]^2$. CP violation manifests itself as an interference with alternate signs in the six sectors of the Dalitz plot. A factor 2 is gained in sensitivity by looking at the interference in the $\pi^+\pi^-\pi^0$ final state, with respect to the $3\pi^0$ final state, taking into account the different branching ratios [24].

CP violation in the decay $K_L \to \pi^+\pi^-\pi^0$, with non zero orbital angular momenta, might be detected as well. The relative width is related to the above mentioned widths, if CP violation is mainly due to the mass mixing. Namely:

$$B_{CPviol}(K_L \to \pi^+\pi^-\pi^0) \simeq B_{CPviol}(K_S \to \pi^+\pi^-\pi^0)\frac{\tau_L}{\tau_S} \simeq 0.6 \cdot 10^{-9}.$$

This amplitude must interfere with the large, CP allowed, K_L decay amplitude.

4 Non CP Violation Physics at *DAΦNE*

Many physics items different from CP violation measurements have been presented at the 1991 workshop for *DAΦNE* at Frascati. I will summarize only a few of them; for a complete summary see [25]. These physics items refer to

1.) Open questions on K decay structure functions

	λ_0
Chiral perturbation theory	1.7 ± 0.4
Current algebra (Callan-Treiman)	$\simeq 2$
Dalitz plot ('74)	2.0 ± 0.5
Muon polarization ('76)	4.4 ± 0.8
Dalitz plot ('80)	4.6 ± 0.5

Table 3: λ_0 for $K_L \to \pi\mu\nu$

2.) $\gamma\gamma$ at low $\pi\pi$ mass.

3.) Scalar mesons.

4.) Nuclear physics at *DAΦNE*.

4.1 Open questions on K decay structure functions

The branching ratio of $K_L \rightarrow \pi\mu\nu$ is very large (27%) but the radius of the scalar form factor λ_0 is to be considered partly unknown and the experimental results contradictory [26]. Values for λ_0 both theoretical and experimental are given in 3. The disagreement with theoretical predictions has been observed either looking at the Dalitz plot distribution[27] or at the muon polarization[28]. A detector to pin down these discrepancies should be able to measure the muon polarization;to do this measurement the previously described electromagnetic calorimeter should have a very good tracking capability.

The improvement factor expected from *DAΦNE* will be 40[3]. Similar effects exist for $K^+_{\mu3}$ decays; in this case the improvement factor is 1000[3].

4.2 $\gamma\gamma$ Physics at low $M_{\pi\pi}$

The present data on $\gamma\gamma \rightarrow \pi\pi$ at low $M_{\pi\pi}$ are few,with large errors and contradictory. The total cross sections for

$$\gamma\gamma \rightarrow \pi^+\pi^+$$

from Pluto[29],DM1[30],DM2[31] disagree by a factor two the Mark-II[32] data and expectations from $\pi\pi$ phase shifts. The Mark-II data are in better agreement with Chiral perturbation theory (ChPT). Data on $\gamma\gamma \rightarrow \pi^0\pi^0$ published by the Crystal Ball[33] collaboration are also in contradiction with ChPT and this is quite surprising considering that the absence of the Born term for this process should allow better theoretical calculations; on the other hand ChPT at three level does not predict correctly the $\pi\pi$ phase shifts at low energies[34].

Another information that can be extracted from $\gamma\gamma$ interactions at low masses is the pion polarizability[35]. The electric α and magnetic β polarizabilities measure the amount of electric and magnetic dipole induced by an external electromagnetic field. Data on the electric polarizabilities can be extracted also from $\pi\pi$ photoproduction interactions in the Coulomb field of the nucleus, by radiative scattering of pions in the Coulomb field [36] or in radiative pion photoproduction[37]. Also the available measurements of the pion electric polarizability α are contradictory as can be seen in Tab.4.

From these considerations it seems very important to do $\gamma\gamma$ measurements at *DAΦNE*; considering that [38] for a given e^+e^- luminosity the untagged $\gamma\gamma$ luminosity is about 20% of

Process	$\alpha \times 10^4 (Fm^3)$
Theory (ChPT)	2.7 ± 0.1
$\gamma\gamma \rightarrow \pi^+\pi^-$[29]	19.1 ± 4.80
$\gamma\gamma \rightarrow \pi^+\pi^-$[30]	17.2 ± 4.60
$\gamma\gamma \rightarrow \pi^+\pi^-$[31]	26.3 ± 7.40
$\gamma\gamma \rightarrow \pi^+\pi^-$[32]	2.2 ± 1.60
$\pi Z \rightarrow \pi Z\gamma$[36]	6.80 ± 1.40
$\gamma Z \rightarrow \pi Z$ [37]	20.0 ± 12.0

Table 4: Pion electrical polarizability α

Process	Number of events
$e^+e^- \rightarrow \pi^0\pi^0$	0.7×10^4
$e^+e^- \rightarrow \pi^+\pi^+$	0.9×10^6

Table 5: Events/year $(e^+e^- \rightarrow e^+e^-\pi\pi)$

the $\gamma\gamma$ luminosities at PEP/PETRA we see that also with a moderate luminosity $DA\Phi NE$ can do much better than Crystal Ball. The events/year for

$$e^+e^- \rightarrow e^+e^-\pi\pi$$

at $\mathcal{L} = 2.5\ 10^{32} cm^{-2}s^{-1}$ are given in Tab.5[39].

Finally $DA\Phi NE$ gives the unique opportunity to perform double tagging at zero degrees; this is very important [38] because it could be possible to measure azimuthal correlations and so to separe helicity amplitudes.

4.3 Scalar mesons

The main search in hadron spectroscopy is for states beyond $q\bar{q}$; scalar mesons exist just below the ϕ mass [40],the $a_0(980Mev)$ and $f_0(970Mev)$ that decay into $\pi^0\eta, \pi\pi, KK$; the f_0 has the vacuum quantum numbers; their widths are 35 and 57 Mev. The nature of these particles is controversial. Many questions arise;why $M_{f_0} \simeq M_{a_0}$;why their widths are so small.

There is now a considerable body of evidence that these particles are not simple $q\bar{q}\ {}^3P_0$ mesons and the hypothesis has been considered that they are $K\bar{K}$ molecules [9], roughly analogous to the deuteron. The close values of masses and widths strongly suggests an ideally mixed pair of mesons, like ρ and ω, hence the 2π decay width should be much larger than observed. On the contrary, in the $K\bar{K}$ molecule interpretation masses, widths and decay modes are naturally explained.

The radiative ϕ decay into these resonances is a discriminant measurement between these different models.A width

$$\Gamma(\phi \rightarrow f_0\gamma) \simeq 10^{-3}MeV$$

is expected [17] if the f_0 is also a $s\bar{s}$ state, yet a much smaller width is expected if a molecular state must be produced in the radiative decay.

We remember that $\phi \rightarrow K^0\bar{K}^0\gamma$ has been considered [17] as a possible source of background in the measurements of $(\frac{\epsilon'}{\epsilon})$. It can be eliminated on the basis of the relative decay times distributions;but in any case the detector proposed for $(\frac{\epsilon'}{\epsilon})$ should be able to measure it, unless very small.

4.4 Nuclear Physics at $DA\Phi NE$

Many authors at the Frascati 1991 workshop [41] on $DA\Phi NE$ have emphasized the possibility to use this machine as a unique, monochromatic,background free, source of very low energy Kaons; as the Kaons are produced in pairs it is possible to tag one and look at the interaction of the other with the matter. In 1995 $DA\Phi NE$ will be the unique source of $K^\pm$ at very low energy in Europe with a moderate intensity $(4 \cdot 10^3 s^{-1})$,emitted over 4π at a luminosity $\mathcal{L} = 1\ \cdot 10^{33} cm^{-2}s^{-1}$

At the ϕ mass the Kaon momentum is 110 Mev/c and there are very few data for momenta lower than 300 Mev/c concerning elastic and total Kaon-Nucleon interactions. To understand the reasons of this lack of data, we remember[41] that the survival probabilities for Kaons after a given distance from the production point go down quickly at the increase of the distance;radiation safety reasons at proton machines fix this distance to $10 \div 15$ m; to have a resonable intensity in experiments where lower energies are needed, a moderator is put in front of the experimental apparatus in order to decrease the momentum of the particles. The moderator introduces a large uncertainty in the momenta of the produced particles.For experiments with stopped K^-, thick targets (of the order of 1 g/cm^2) are used in order to have an acceptable stopping rate; this introduces a big error on the momentum of the emitted charged particles due to the uncertainty of the interaction point.On the contrary the 15 Mev Kaons produced at $DA\Phi NE$ stop in 100 mg/cm^2 and the error introduced in the determination of the interaction point matches the present day magnetic spectrometers.

T. Bressani[41] has sketched an apparatus that fully exploits the quality of this beam and is optimized for studies of Λ and Σ hypernuclei production with K^- at rest. The production of hypernuclei is signalled by the detection of monochromatic pions emitted in the decay[42]

The interest of the study of hypernuclei is based on the s quark content of these nuclei that provide informations not normally accessible in usual nuclear reactions. Particular interest should offer the possibility to produce deeply bound π^- states, predicted but never observed[43],from Λ decay in heavy nuclei,like ^{208}Pb. Hypernuclei weak decays are also interesting because the presence of outgoing nucleons modifies,by the Pauli principle,the rates; therefore the detection of these decays is a mean to study weak interactions in a peculiar environment.

Another relevant open question concerns the Kaon-Nucleon scattering lengths; the real part is positive according to the scattering data and negative according to the X ray emission from Kaonic atoms[44]; to clarify this point low energy Kaon-nucleon data are needed.

Concerning the K^+ nucleus interactions the present data on K^+ nucleus total cross sections show evidences for a puzzling anti-shadowing effect that increases at lower Kaon momenta[45]. In fact plotting as a function of the Kaon momenta the ratio

$$R = \frac{\sigma(K^{+12}C)}{6\sigma(k^+d)}$$

of the cross section for K^+ scattering on ^{12}C and deuterium, we get R bigger then one. The swelling of nucleons in K^+ interactions is very surprising because due to the antiquark content, the K^+ mesons don't couple strongly to the nucleon;below 1 Gev/c the typical K^+N cross section is an order of magnitude smaller than $\pi - N$ and $K - N$ cross sections. This translates in the fact that unlike other hadrons the K^+ interactions with nuclei can be considered, to first order,as a single scattering with the nucleons ; K^+ are a sort of heavy electron; but this picture seems to be wrong and needs further study from both theoretical and experimental sides.

5 Quantum Mechanics paradox on a macroscopic scale

The ϕ decay into a neutral Kaon pair is a very suitable process to test Quantum Mechanics (QM) on a large scale. Many authors have emphasized paradoxes related to this process[46], which are a good illustration of the celebrated Einstein, Podolsky, Rosen arguments [47].

Actually paradoxes arise because the ϕ and the neutral Kaons are both superposition of states. Namely the ϕ is

$$|\phi >= \frac{1}{\sqrt{2}}[|K^0(p) > |\bar{K}^0(-p) - |\bar{K}^0(p) > |K^0(-p) >]$$

to achieve a $C = -1$ eigenstate.The strongly interacting neutral Kaons are superposition of the short-living and long-living mass eigenstates

$$|K_S >= a|K^0 > +b|\bar{K}_0 >$$

$$|K_L >= c|K^0 > +d|\bar{K}_0 > .$$

If CPT is conserved: $a = c$, $b = -d$. If CP is also conserved: $a = c = b = -d = \frac{1}{\sqrt{2}}$. Therefore, if neutral Kaons decay without interacting, it is also

$$|\phi> = \frac{1}{\sqrt{2}}[|K_S(p)>|K_L(-p) - |K_L(p)>|K_S(-p)>]$$

and only events $K_S(p), K_L(-p)$ will be detected.

Let us consider the following paradox as an example. If a thin regenerator is introduced on one side coherent regeneration takes place and a fraction of the events, decaying downstream the regenerator, will be either $K_S(p)K_S(-p)$ or $K_L(p)K_L(-p)$.

Yet coherent regeneration cannot arise for a spherical regenerator. Things are as if a neutral Kaon, crossing a regenerator, knows what is occurring simultaneously to the other neutral Kaon, no matter how far one Kaon is from the other. This paradox is predicted by QM because the ϕ decomposition is invariant under the simultaneous transformations

$$|K^0(\pm p)> = |K^0(\pm p)> + \alpha|\bar{K}^0(\pm p)>$$

$$|\bar{K}^0(\pm p)> = |\bar{K}^0(\pm p)> + \beta|K^0(\pm p)>$$

where α and β are the coherent regeneration amplitudes.

The doughnut of the storage ring is an appropriate regenerator to verify this prediction.

For example[25] let us assume that 1 cm of Cu regenerator is brought close to the interaction region;some thousands of collinear K_SK_S events will be detected in few days,due to the K_S coherent regeneration in the Cu slab.However, if two regenerator are put symmetrical on both sides collinear K_SK_S events will never be detected(Fig.[3]). So Quantum Mechanics is such that if a Kaon interacts with matter on one side,the other Kaon immediately interacts or not,exactly in the same way on the opposite side,no matter how far it is.

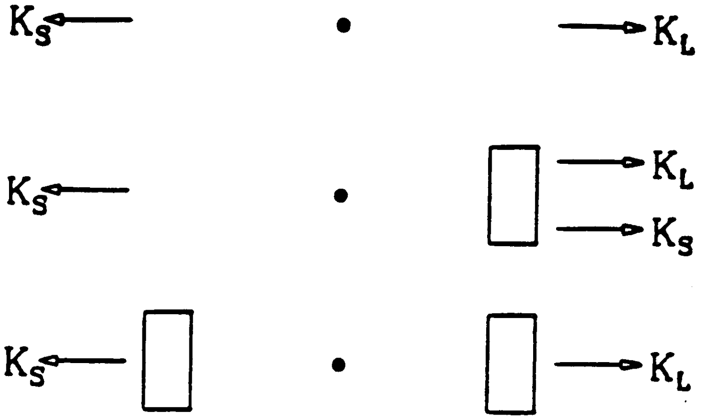

Figure 3: Illustrating the regenerators E.P.R. paradox.

By the way this argument supports the suitability of a Φ factory to study CP violation in neutral Kaon decay. In fact this effect reduces in practice K_S regeneration in the apparatus, which may simulate a CP violating decay.

6 Conclusions

Physics at $DA\Phi NE$ will start at the end of 1995 with as main program the measurement of $\frac{\epsilon'}{\epsilon}$.

In 1995 experiments at CERN and Fermilab will have new results with an increase in statistic and precision but the $DA\Phi NE$ measurement will be in any case complementary. If $Re(\frac{\epsilon'}{\epsilon})$ will be not too small, $DA\Phi NE$ has the unique chance to see CP violation also in 3 π decays. If one considers the importance to test the presence of CP violation in weak decays per se,not only to test the Standard Model, it seems worthwhile to fulfill a program that should be able to give a definitive answer.

The other physics items that can be exploited at $DA\Phi NE$,as tests of chiral dynamics,$\gamma\gamma$ production near threshold, nuclear physics put very stringent constraints on fundamental physical quantities; many of these measurements can be done only at $DA\Phi NE$.

Finally it should be considered that the possibility to achieve luminosities of $\simeq 10^{33}$ will mean in any case a big improvement in the quality of low energy datas produced at e^+e^- machines.

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References

[1] **Proposal for a Φ factory**, LNF 90/031(R).

[2] M. Fukawa et. al., **Physics at a Φ factory**, KEK Report 90-12 Aug., 1990.

[3] R. Barbieri et. al., **Report from the ϕ factory working group**, LNF-90/041(R),May 29,190;LNF-91/020(R),May 3,1991.

[4] G.M. Tumakin, **Proposal for B and Φ factories in Novosibirsk**, Proceedings of the 1989 AEEE Particle Accelerators Conference, 441(1989).

[5] F. Aghamir et al., **The UCLA Particle beam physics (PBP) and ϕ factory conceptual design**, CAA-0053-UCLA-2/90.

[6] H. Burkhardt et al., **First evidence for direct CP violation**, $Re(\frac{\epsilon'}{\epsilon})$ Phys. Lett. **B206**,169 (1988).

[7] J.R. Patterson et al., **A determination of $Re(\frac{\epsilon'}{\epsilon})$ by the simultaneous detection of the four $K_S, K_L \rightarrow \pi\pi$ decay modes**, Phys. Rev. Lett. **64**, 1491 (1990).

[8] G. Barbiellini and C. Santoni, **A measurement of $\frac{\epsilon'}{\epsilon}$ in a Φ Factory**, CERN EP/89-88.

[9] J.Weinstein and N. Isgur, **$K\bar{K}$ Molecules**, Phys.Rev. **D41**,2236(1990).
M. Pennington, **$F_0(S*)$: molecule or quark states**, Phys. Lett. **B258**,444(1991).

[10] R. Baldini-Ferroli at al., **Kaon physics at a Φ factory**, LNF-90/07(R) (1990).

[11] G. Vignola, $DA\Phi NE$ **design criteria and project overview**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,11(1991).

[12] J.M. Gerard, **CP Violation**, to appear in Proceedings of Lepton Photon Conference Geneva (Suisse),July 1991.

[13] G.Buchalla et. al., **The anatomy of $\frac{\epsilon'}{\epsilon}$ in the Standard model**, Nucl. Phys. **B337**,313(1990).

M. Lusignoli et al., **Mixing and CP violation in K and B mesons: a lattice QCD point of view**, Rome University preprint,n.810,June 1991.

[14] G.D.Barr et al., **Proposal for a precision measurement of $Re(\frac{\epsilon'}{\epsilon})$ in CP violating $K^0 \to 2\ \pi$ decays**, CERN-SPSC-90-22,1988.

[15] M. Piccolo, **Detector subsystems interplay in the $\frac{\epsilon'}{\epsilon}$ measurement at $DA\Phi NE$**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,707(1991).

[16] V. Patera, **Measurement of $Re(\frac{\epsilon'}{\epsilon})$ and $\Delta\phi$ parameters at a Φ factory by means of the $K_L K_S \to \pi^+\pi^- \text{-} \pi^0\pi^0$ decay time difference**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,499(1991).

[17] S.Nussinov and T.N.Truong, **Decay $\phi \to K^0\bar{K}^0\gamma$ and its possible effects on future Kaon factories**, Phys. Rev. Lett. **63**,1349(1989).

[18] R.C Barrett, **Calculation of the regeneration in He or Ar gas detector using a K_L beam from a Φ factory**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,487(1991).

[19] F. Grancagnolo, **$DA\Phi NE$: a case for a cylindrical drift chamber in a Helium based gas mixture**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,521(1991).

[20] D. Babusci et al., **Performances of Head-on PB-SCIFI calorimetric modules**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,581(1991).

[21] A. Antonelli et al., **A Pb-SCIFI calorimeter for** $DA\Phi NE$, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,557(1991).

[22] C. Bloise, **Decay length reconstruction : $K_{S,L} \to \pi^0\pi^0$**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,495(1991).

[23] D.H. Perkins, **Introduction to High Energy physics**, Add. Wesley (1982).

[24] N.W.Tanner, R. H. Dalitz, **The determination of T and CPT violations for the $K^0, \bar{K}^0$ complex by $\bar{K}^0 - K^0$ comparison**, Ann. Phys. **171**,463(1986).

[25] R.Baldini-Ferroli, **Physics items,different from $Re(\frac{\epsilon'}{\epsilon})$ at a Φ factory**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,665(1991).

[26] J. Gasser and H.Leutwyler, **Low energy expansion of meson form factors**, Nucl. Phys. **B250**,517(1985).

[27] Y. Cho at al., **Measurement of K_L form factors from $K_L \rightarrow \pi\mu\nu$ decays in the 12-feet bubble chamber**, Phys. Rev. **D22**,2688(1980).

[28] A.R. Clark at al., **Determination of the $K_L \rightarrow \pi\mu\nu$ muon neutrino form factor by muon polarization measurements**, Phys. Rev. **D15**,553(1977).

[29] J. Berger et al., **Pion pair production in $\gamma\gamma$ interactions**, Z.Phys., **C26**,199(1984).

[30] A.Courau et al., **Lepton and pion pair production in $\gamma\gamma$ collisions measured near the threshold at DCI**, Nucl. Phys., **D271**,1(1986).

[31] Z.Ajaltouni et al., **Photon Photon collisions**, Contr. to VII Inter. workshop on $\gamma\gamma$ collisions, Paris,April 1986.

[32] J.Boyer at al., **Two photon production of pion pairs**, Phys. Rev., **D42**,1350(1990).

[33] H.Marsiske al., **A measurement of $\pi^0\pi^0$ production for two photon collision**, Phys. Rev. **D41**,3324(1990).

[34] M.R. Pennington, **Two photons in:two pions out**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,361(1991).

[35] D. Babusci at al., **Chiral symmetry and pion polarizabilities**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,383(1991).

[36] Yu.M. Antipov at al., **Measurement of π meson polarizability in pion Compton effect**, Phys. Lett., **121B**,445(1983).
Yu.M. Antipov at al., **Experimental estimation of the Sum of Pion Electrical and Magnetic Polarizabilities**, Z.Phys., **C26**,495(1985).

[37] T.A.Aibergenov et al., **Radiative photoproduction of pions and pion Compton scattering**, Czech. J. Phys., **B36**,948(1986).

[38] A. Courau, **$\gamma\gamma \rightarrow \pi\pi$ near the threshold at $DA\Phi NE$**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,373(1991).

[39] L. Maiani, **Theory working group: summary of the results**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,719(1991).

[40] Particle Properties Data Booklet,Phys. Lett. **B239**,(1990).

[41] T. Yamazaki, **Hypernuclear spectroscopy at a Φ factory**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,315(1991).
T. Bressani, **Nuclear Physics at $DA\Phi NE$**, Proceedings of the Frascati Workshop for Detectors and Physics at $DA\Phi NE$, Frascati (Italy),April 9-12,475(1991).

[42] H. Tamura, **Λ-H^4 formation from K-absorption at rest on He^4, Li^7, Be^9, C^{12}, O^{16} and Ca^{40} targets**, Nuovo Cimento, **102A**,575(1989).

[43] R.Bando et al., **Formation of deeply bound π states from Hypernuclei decay**, Phys. Rev. **C40**,875(1989).

[44] R.C. Barrett, **The $\bar{K}-N$ system near threshold**, Nuovo Cimento, **102A**,179(1989).

[45] W. Weise, K^+N **Nucleus scattering**, Nuovo Cimento, **102A**,265(1989).

[46] H.J.Lipkin, Phys.Rev. **176**,1715(1968).
C.Bernardini, Fisica e strumenti matematici, Ed. Riuniti (1979).
F.Selleri, Lett.Nuovo Cimento **36**,521(1983).
D.Cocolicchio, Internal Report Universitá Bari TH/88-35.

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