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M. Piccolo:

THE CASE FOR A Φ-FACTORY

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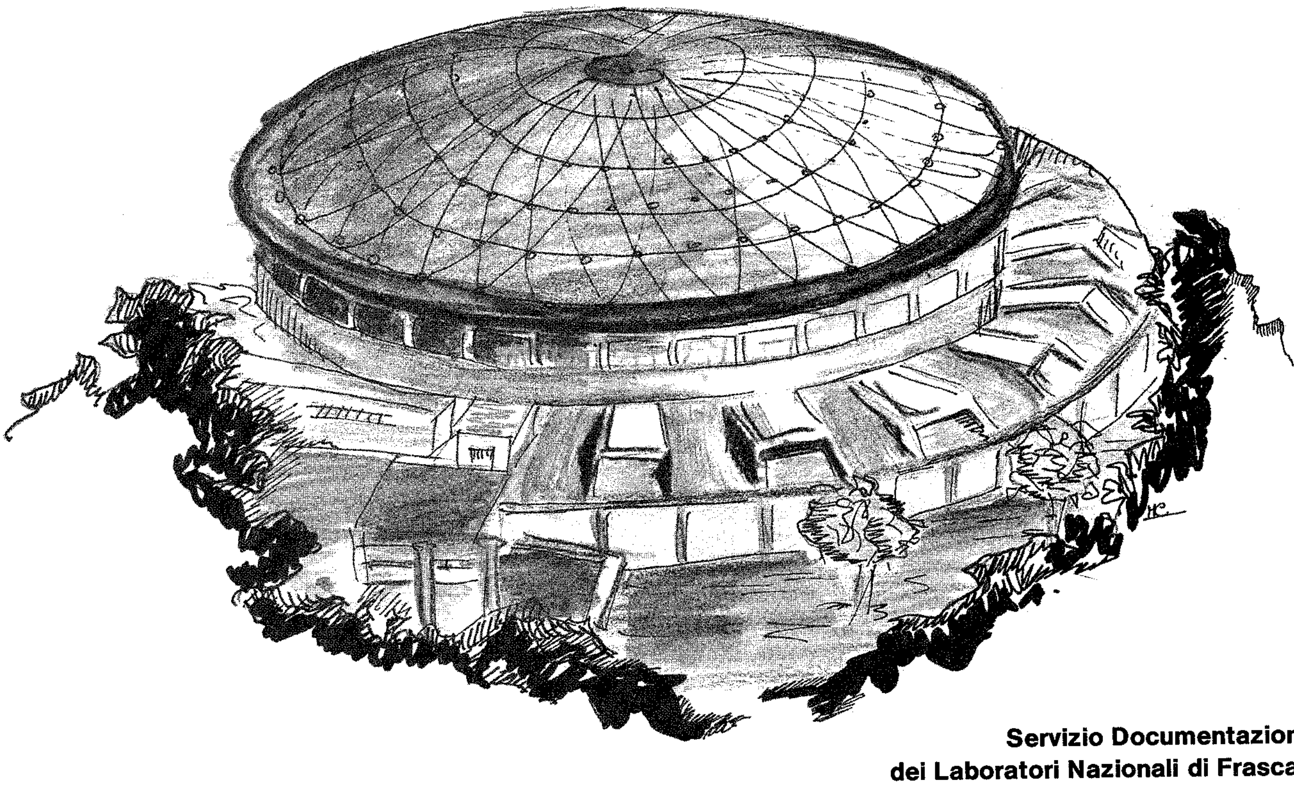

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THE CASE FOR A Φ–FACTORY

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

ABSTRACT

The experimental program of an e^+e^- based ϕ–factory is discussed: requirements on the machine and the experimental apparatus are presented. At a luminosity $\mathcal{L} = 1 - 2 \times 10^{32} cm^{-2} sec^{-1}$ an e^+e^- facility would allow a substantial improvement on the measurement of ϵ'/ϵ. A brief review of physics topics other than CP violation is also given.

1. Introduction

In the last few years the so called *Factories* have received an ever growing attention from the Community of high energy physicists: these proposed accelerators have the characteristic of being able to produce large quantities of one definite species of particles in a very well controlled environment, usually with an extremely favourable signal to background ratio and a well defined kinematical situation, allowing precise and detailed studies of the produced species.

The physics knowledge which can be gained at a factory is generally based on the fact that high order corrections to the values of a given physical quantity are sensitive to energy scale much higher than the one at which the process under consideration takes places, thus allowing an insight of processes further away in energy.

A typical example is the μ anomaly, which if measured to a precision of few tenth of a part per million, could lead to uncover interactions and particles in a range between 1 and 10 TeV.

B-factories and τ-charm factories have been studied extensively for the last few years; in the following we will examine the feasibility of a ϕ–factory, its physics possibilities and the requirements that both the machine and the detector have to meet in order to successfully carry out an interesting physics program.

Most of the work described in this paper was done in preparation for a ϕ–factory proposal to be presented to I.N.F.N. (the Italian agency for fundamental nuclear research) for a collider to be eventually built in the Frascati National Laboratory[1].

2. The Physics program

A ϕ–factory can be considered essentially a K factory: as a matter of fact both charged and neutral kaons are produced in a ϕ–factory copiously and in a well defined kinematical situation; the production of the ϕ at rest by e^+e^- interactions adds favourable features to the kaons produced from the ϕ decay. This resonance, infact, stands as a huge structure in the total e^+e^- cross section, the ratio between peak cross section and non resonant background being of the order of 100.

The study of K decays has been of extreme importance in the development of what is now called the Standard Model of fundamental interactions: experiments on kaons, especially the neutral ones, have been used to give proof of parity non conservation in weak processes[2], Cabibbo mixing[3] and, through the absence of flavour changing neutral currents, have *suggested* the idea of the GIM mechanism[4].

Moreover, only K decays up to now have given the experimental proof of the CP violation phenomenon[5]. More than 25 years after the original discovery, CP violation is still one of the puzzles of particles physics, in particular the question whether the violation is present only in the mass term or CP is violated also in the decay amplitude. The study of the $K_L^0 K_S^0$ pair originating from the ϕ decay, with the latter produced at rest by an e^+e^- interaction would allow a new precise measurement of the CP violation parameters.

The main purpose for building and operating a ϕ–factory, *i.e.* an e^+e^- collider at $\sqrt{(s)} = 2E \sim 1GeV$ is to perform a more precise measurement of ϵ'/ϵ with a different technique. Such a facility would allow to determine ϵ'/ϵ with a statistical and systematical uncertainty smaller than the one achieved up to now with K_L^0 beams, if the luminosity would be greater than $1 - 2 \times 10^{32}\ cm^{-2} sec^{-1}$. At higher luminosities ($\sim 1 - 2 \times 10^{33}\ cm^{-2}\ sec^{-1}$) a completely new field would open for experimental investigation, namely the study of rare and CP violating decays of the K_S^0.

In addition to the two items mentioned beforehand, other physics topics will be addressed by a high luminosity collider operating in the $\sim$ 1 GeV region including:

1. An accurate measurement of the total hadronic cross section in the region of the ρ, ω and eventually above the ϕ.A precise knowledge of the total cross section especially in the ρ region will be needed in order to interpret the extra-precise measurement of the μ anomaly to be carried out at Brookhaven.[6]
2. Study of *moderately* rare K decays, with particular emphases on the K_S^0.
3. Measurement of $\eta - \eta'$ mixing and measurements of branching ratios of these particles.
4. Measurement of the parameters of 0^+ mesons which are accessible through the radiative decays of the ϕ and higher $s\bar{s}$ states.
5. Measurement of the ν_μ mass by means of the semileptonic decay of the K_L^0.

The various items listed above require different capabilities from the experimental apparatus; its design and optimization, should however be based on the ϵ'/ϵ measurement, which imposes the most severe requirements. A detector able to successfully measure ϵ'/ϵ with good control over systematic effects will be more than adequate for all these other purposes. For this reason I will concentrate essentially on the ϵ'/ϵ measurement which sets the standards for the machine and the apparatus.

3. Experimental considerations

Presently two experiments are measuring the $\mathrm{Re}(\epsilon'/\epsilon)$ ratio using the K_L^0 beams technique[7][8]. The overall error with which ϵ'/ϵ will be known once all the statistics of the two experiments will be analyzed is likely to be around 7×10^{-4} (combining statistical and systematic errors). A *minimum goal* for the ϕ–factory measurement would be to cut this error in half in one year running. Systematic uncertainties will not play a very important role in a ϕ–factory: we believe that they can be kept under control at the 1.5×10^{-4} level thus contributing in a negligible way to the overall error, if the statistical one is $\sim 3 \times 10^{-4}$.

The most common way to evaluate Re(ϵ'/ϵ), is to measure the so called double ratio :

$$double\ ratio = \frac{\Gamma_{K_L^0 \to \pi^0\pi^0}}{\Gamma_{K_L^0 \to \pi^+\pi^-}} \times \frac{\Gamma_{K_S^0 \to \pi^+\pi^-}}{\Gamma_{K_S^0 \to \pi^0\pi^0}} = 1 - 6 \times Re(\epsilon'/\epsilon) \tag{3.1}$$

If we use the double ratio method as a benchmark, it is possible to evaluate the product of the peak luminosity times the detection efficiency needed to reach the minimum goal we have defined above:

$$\delta(6 \times Re(\epsilon'/\epsilon)) \approx \frac{\delta(doub.ratio)}{(doub.ratio)} \approx \sqrt{\frac{3}{2} \times \frac{1}{N_{K_L^0 \to \pi^0\pi^0}}} \sim 0.0018 \tag{3.2}$$

The needed number of K_L^0decays in $\pi^0\pi^0$ is 450,000 and this translates in a requirement on the product $\mathcal{L}\times$ efficiency :

$$\mathcal{L} \times efficiency = \frac{4.5 \times 10^5}{10^7 \times 4.5 \times 10^{-30} \times 0.343 \times 9. \times 10^{-4}} \approx 3 \times 10^{31}\ cm^{-2}sec^{-1} \tag{3.3}$$

As usual the *physics year* has been considered as 10^7 seconds to take the various inefficiencies, luminosity averaging and other causes of running time losses into account. There are different ways of achieving this goal: we believe, however that the most realistic combination is provided by a machine with $\mathcal{L} \approx 1 \times 10^{32} cm^{-2}sec^{-1}$ and a detector capable of reconstructing 30% of the $K_L^0 \to \pi^0\pi^0$ decays. A higher reconstruction efficiency for the K_L^0 would push both the size and the cost of the detector to unreasonably large values and require quite unrealistic performances from the experimental apparatus, while much bigger values for the luminosity cannot be guaranteed for any type of collider operating at $\sqrt{(s)} \approx 1\ GeV$ with *conservative* extrapolations of present performances.

4. The machine

Several different designs have been proposed for an e^+e^- ϕ–factory: various technical approaches can be pursued in order to reach the target luminosity mentioned in the previous section[9][10][11][12][13][14] and to possibly go beyond it. It is important, however, to stress that even though a very high luminosity machine would allow a bigger physics reach, opening different fields of investigation, it would imply new experimental problems concerning the interaction of the detector with the collider itself. We believe that the most efficient way to implement a fruitful physics program at a ϕ–factory would be the design and construction of a machine able of delivering the *minimum goal* luminosity shortly after turn-on with possibility of a luminosity upgrade somehow built in, so that the luminosity improvement program would minimally disrupt the already undertaken experimental program. An example of such a machine is the one reported in ref. 14. The underlying philosophy of this type of design is heavily biased toward a the goal of obtaining physics output *as soon as possible* splitting risks between the detector and the collider almost evenly .

Different approaches, aiming toward a very high luminosity collider, might be, as mentioned before, too risky for what the physics program is concerned: both the machine and the detector would have to work in a completely new environment which might turn out to be unfriendly to the experimenters and difficult to control for the machine physicists.

Listed in Table I are some of the most relevant parameters of the collider described in Ref. 14: the design is based on a double racetrack type of storage ring with one or two bunch crossings.

Table I . Relevant parameters of the machine design from ref. 14

Parameter	Value	unities
Beam energy	510	MeV
Circumference	100.73	m
Bending radius	1.464	m
Luminosity	10^{32}	$cm^{-2}\ sec^{-1}$
# of bunches	24	
# of particle/bunch	8.9×10^{10}	
ξ_y	0.04	
ξ_x	0.04	
β_y	4.5	cm
β_x	4.5	m
Natural emittance (vert.)	1.83×10^{-11}	$mrad$
Natural emittance (horiz.)	$1. \times 10^{-6}$	$mrad$
Beam dim. @ I.P.(vert.)	21.	μ
Beam dim. @ I.P.(horiz.)	2.11	mm
Bunch length	3.0	cm
Total current	1.02	A
Sync. Rad. power/beam	11.5	KW

A sketch of the proposed machine with all its optic components is reported in fig. 1.

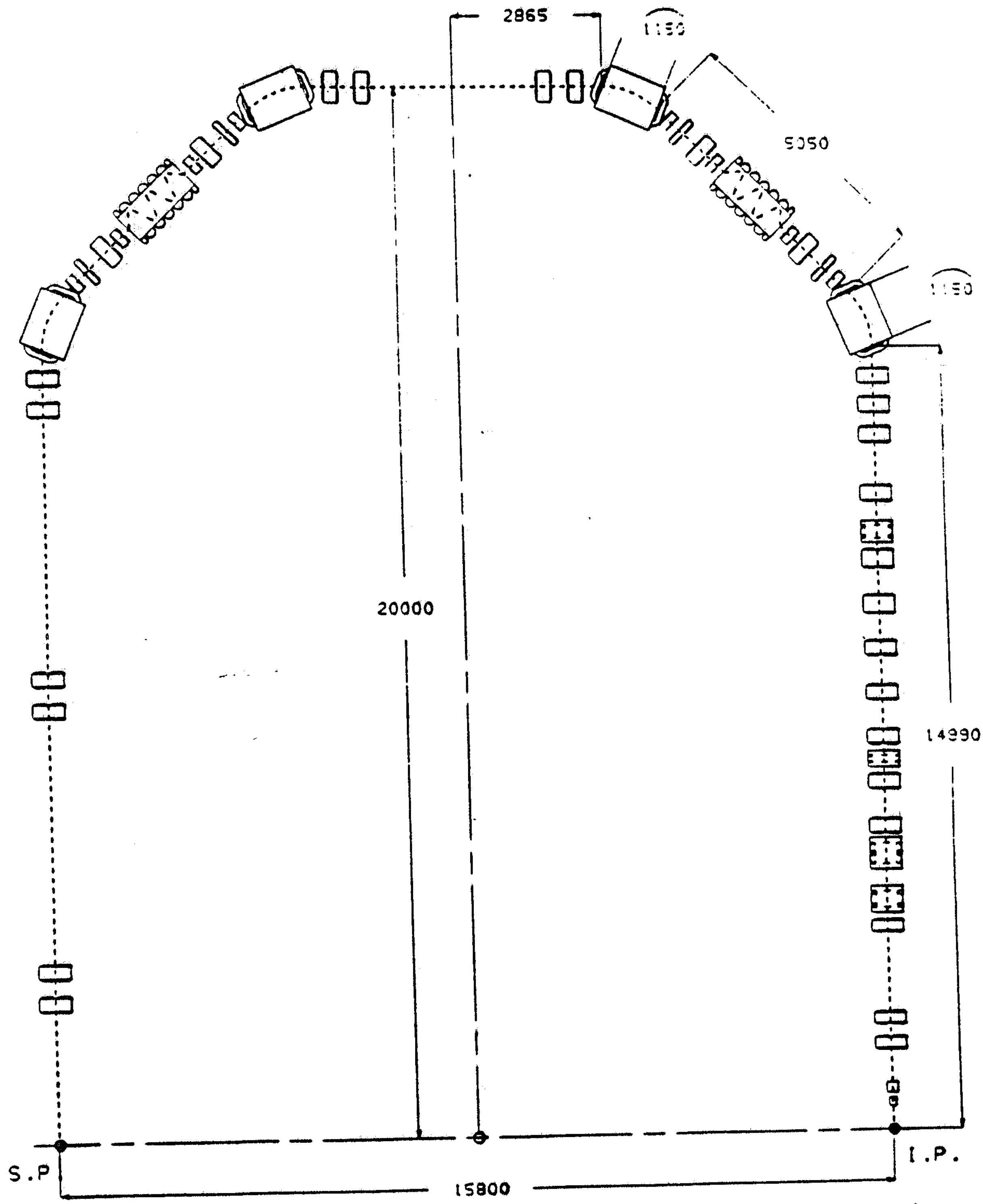

Figure 1. Schematic lay-out of the collider from ref. 14: only one half of one ring is shown.

5. The Measurement of Re(ϵ'/ϵ)

There are different observables leading to the measurement of Re(ϵ'/ϵ) at a ϕ–factory; in the following we will discuss four different techniques which use the neutral Kaons decay. It is extremely important to point out that, even if all these methods are correlated, (as rely on the reconstruction some decay mode of K_L^0 and K_S^0) they have different sensitivity to different systematic effects, thus allowing an indirect check of the systematic errors. The method originally proposed by Dunietz *et al.*[15] is based on the measurement of the asymmetry in path length for a definite final state , namely $\phi \rightarrow \pi^+\pi^-\pi^0\pi^0$:

$$A = \frac{N^{l_{\pi^0\pi^0} > l_{\pi^+\pi^-}} - N^{l_{\pi^0\pi^0} < l_{\pi^+\pi^-}}}{\Sigma} \approx -3 \times Re(\epsilon'/\epsilon) \tag{5.1}$$

where $l_{\pi^0\pi^0}$ ($l_{\pi^+\pi^-}$) are the decay distance for the implied decay. The results (5.1) holds if the minimum path-lengths on which the asymmetry is evaluated are much bigger the the decay length of the K_S^0.

The evaluation of the asymmetry A in the *interference* region leads to the determination of the phase difference between η_{+-} and η_{00}, allowing a test on the validity of CPT invariance. This measurement, however, is very difficult since it requires an extremely good vertex resolution for the $\pi^0\pi^0$ mode and is plagued by backgrounds coming from the radiative decays of the ϕ.

Alternative observables, essentially total rates in exclusive final (CP violating) states have been suggested by Bernabeu *et al.*[16]

$$\frac{\Gamma(\phi \rightarrow \pi^+\pi^-\pi^+\pi^-)}{BR(K_S^0 \rightarrow \pi^+\pi^-) \times BR(K_S^0 \rightarrow \pi^+\pi^-)} \times \frac{BR(K_S^0 \rightarrow \pi^+\pi^-) \times BR(K_S^0 \rightarrow \pi^0\pi^0)}{\Gamma(\phi \rightarrow \pi^+\pi^-\pi^0\pi^0)} = 1 + 3 \times Re(\frac{\epsilon'}{\epsilon}) \tag{5.2}$$

If one of the final states is completely neutral :

$$\frac{\Gamma(\phi \to \pi^+\pi^-\pi^+\pi^-)}{BR(K_S^0 \to \pi^+\pi^-) \times BR(K_S^0 \to \pi^+\pi^-)} \times \frac{BR(K_S^0 \to \pi^0\pi^0) \times BR(K_S^0 \to \pi^0\pi^0)}{\Gamma(\phi \to \pi^0\pi^0\pi^0\pi^0)}$$
$$= 1 + 6 \times Re(\frac{\epsilon'}{\epsilon}) \qquad (5.3)$$

One more method, which has already been mentioned as a possible benchmark, is the double ratio; it has the best statistical sensitivity of the four, since the measurement itself is proportional to $1 - 6 \times Re(\frac{\epsilon'}{\epsilon})$ and the overall branching ratio in the channels of interest is higher than the totally neutral decay of the ϕ, which holds the same analyzing power.

All these methods promise of a further step forward in statistical significance, if the machine will perform with a luminosity above 10^{32} cm^{-2} sec^{-1}. It's very important, however, to consider the sources of possible systematic uncertainties and evaluate their effects: these are the ones that will define the constraints on the design of the experimental apparatus.

In order to measure the double ratio it is necessary to evaluate the $K_L^0(K_S^0)$ width into $\pi^+\pi^-$ and $\pi^0\pi^0$. This measurement, at the ϕ, can be performed by taking advantage of the peculiar Kaons' (pair) production mechanism and using tags. To tag K_S^0 the usable decay modes of the K_L^0 are : $\pi^+\pi^-\pi^0, \pi\mu\nu, \pi e\nu$ for a combined branching ratio of roughly 80%. The K_L^0 tags could be the total K_S^0 sample : if the decay $K_S^0 \to \pi^0\pi^0$ cannot be used to tag , then the statistical error increase on the ϵ'/ϵ measurement would be around 15-20%. This tagging technique guarantees an unbiased sample for the widths' measurement; it can be easily shown that the two widths' ratios are completely independent of the tagging efficiency.

6. The systematics of a ϵ'/ϵ measurement at a ϕ–factory

As we have pointed out before the ϕ–factory approach to the ϵ'/ϵ measurement promises to substantially reduce the contribution of systematics to the overall error.

The systematics of the ϵ'/ϵ measurement can be divided into three categories:

1 Background subtraction.

2 Detector efficiency.

3 Geometric acceptance.

The need of keeping the contribution of these three items below the 1.5×10^{-4} level sets strict requirements on the detector's performance: we will analyze them in detail to assess whether a detector with these requirements can be designed and built. In the following we will assume that the observable to be measured is the double ratio, having already mentioned that this quantity has the highest *usable* analyzing power.

6.1. Background subtraction

In order to keep the background subtraction related systematic on the double ratio at the level of 5×10^{-4} (the total systematic error on the double ratio has to be $\leq \; 9 \times 10^4$), two requirements have to be fulfilled by the experimental apparatus: the background contaminations have to be low and very well known. In general, the measurement of a decay probability, with a corresponding number of events N_{sig} obtained as the difference between N_{tot} and N_{back}, has a statistical error given by:

$$\delta N_{sig} = \sqrt{N_{tot} + (\delta N_{back})^2} \tag{6.1}$$

The precision with which N_{back} is known, then sets the value of the discrimination power of the experimental apparatus against the background process. If we require, for instance, that the background for a given decay must contribute less than one half of the statistical error to the double ratio's overall error and we know the background to a relative precision α, we find the following bound on the rejection ratio for the background decay :

$$Rej.\ ratio \leq \frac{Br_{K\rightarrow\pi\pi}}{Br_{back}} \times \frac{1}{2 \times \alpha \times \sqrt{N_{tot}}} \tag{6.2}$$

Table II shows the different rejection ratios needed against various background decays.

Table II . Rejection ratios for different background decays of the K_L^0; the assumed relative error on the backgrounds decays is 25%.

Decay	Background decay	Relative branching ratio	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	11.0×10^{-5}

The rejection ratios shown in the table imply that the detector must have a hermetic coverage for γ detection and and a minimum detectable energy for electromagnetic showers of $\sim$ 20 MeV; (shown in fig. 2 are the relevant momentum spectra for the K_L^0 decay products concerning the double ratio measurement) ; furthermore the rejection ratio needed against the semileptonic decays indicate that the detector must have some sort of particle identification capability: the kinematic alone, infact, does not give enough rejection power by quite a large factor ($\sim 50 - 100$).

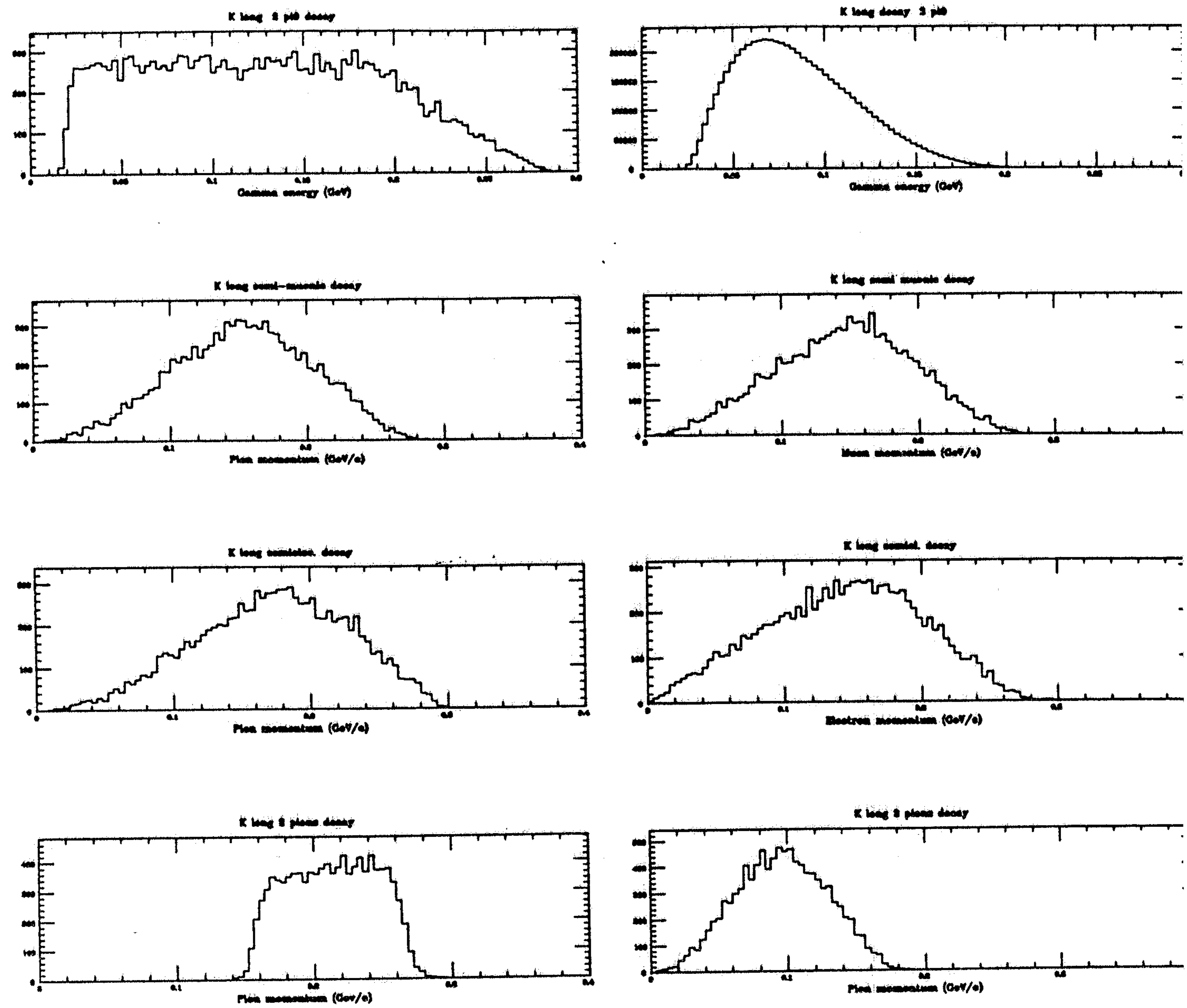

Figure 2. Relevant momentum/energy spectra for the K_L^0 decays: each graph is labelled with the decay to which refers

6.2. Reconstruction efficiency

A good knowledge of the reconstruction efficiency is extremely important: given the difference in decay length between K_L^0 and K_S^0, the efficiency for K_L^0 decay products might in principle be different from the one pertaining to the K_S^0. The extreme cleanliness of the e^+e^- environment and the simple production mechanism, however, allow the direct determination of the efficiency both for charged and neutral π's.

To evaluate the tracking and verticizing efficiency of the charged π's decay one can use the known value of the K_L^0 lifetime to predict , once that a K_S^0 tag has been found, the expected number of decays in spherical *shells* at increasing radial distance from the luminous region. With *shells* extending 15 cm. radially, the number of decays expected in each is of the order of 5×10^7, so the statistical error in determining the efficiency **in each shell** will be $\sim 5 \times 10^{-4}$, while the error due to the unperfect knowledge of the K_L^0 lifetime , given the small size of the extrapolation distance will be roughly one half of the statistical one. The momentum spectrum of the particles used, marginally differs from the two-body charged decay of the K_L^0 as most of the decays would be three body semileptonic.

For what the π^0 reconstruction efficiency is concerned it is possible to use the ϕ decay in to K^+K^- with one of the charged kaons decaying into $\pi^\pm\pi^0$. The reconstruction of the charged prongs in this type of event completely tags the remaining π^0, thus allowing to determine the momentum, emission angles and point of origin of the neutral π. Again the statistic is such that the needed accuracy on the reconstruction efficiency can be reached if the luminosity is at the $1 \times 10^{32} cm^{-2} sec^{-1}$ level.

It is worth noticing that , in the π^0 case the basic process of the γ detection is minimally affected by the K_L^0 decay length.

The efficiency determination based on the physics processes mentioned above has the nice property of automatically upgrading in case of a luminosity upgrade.

6.3. GEOMETRIC ACCEPTANCE

The geometric acceptance determination is also of extreme importance: the exponential distribution of the decay lengths can be distorted by experimental effects, and the correction of these effect at the 5×10^{-4} level must be established. The effects which need to be corrected are:

1. Finite beam overlap dimension

2. Resolution effects in vertex determination

For what the beam dimensions are concerned the luminous region has a small enough spatial extent in the radial direction not to cause any serious correction problems. In the longitudinal direction, however, the expected overlap is ~ 2 cm long: a correction then must be applied to the data. The exact shape of the beam overlap can be however determined with great precision by using, for instance, Bhabha scattering events: this effect can be kept under control at the 5×10^{-6} level.

Spatial resolution requirements for an ideal detector would include a vertex resolution of the order of one fifth of the K_S^0 decay length. This requirement may be easily fulfilled for the charged decay modes : a *low mass* drift chamber can easily deliver a 1 mm vertex resolution for track lengths of 50 cm or more and point resolutions of the order of 150 μ.

The neutral decay modes offer a more serious experimental challenge: in order to evaluate the *minimum* acceptable vertex resolution, one can calculate the integral rate, convoluting the exponential decay with a gaussian resolution function of given σ for the decay point, and compare it to the unsmeared case. Shown in Fig 3 is the relative loss in total rate for the K_S^0 decay .

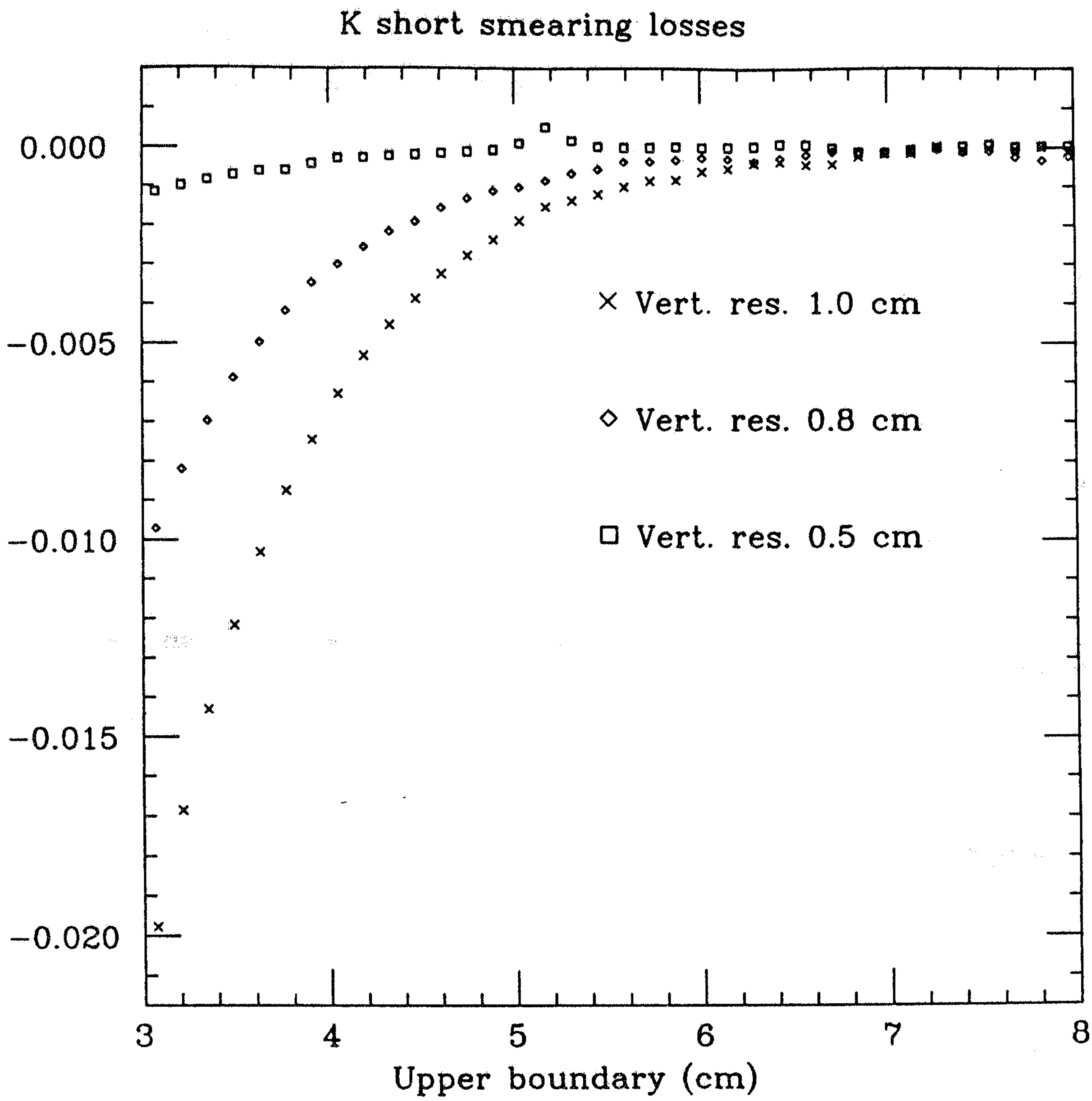

Figure 3. K_S^0 smearing losses for different vertex resolutions as a function of the upper (radial) bound of the decay region

It appears that a resolution of at least 1 cm is needed together with a decay region of 6 cm. or more , in order to get effects below the 5×10^{-4} level. It is worth noticing that the losses can in fact be measured by just evaluating the number of decays occurring in the region immediately beyond the fiducial volume.

For the K_L^0 case the analogous plot is shown in fig. 4 : here the decay volume extends to 150 cm. and the loss is depicted as a function of the vertex resolution. In this case it will be difficult to effectively measure the losses by evaluating the number of decays occurring beyond the fiducial region, as the resulting γ's would enter the calorimeter at grazing incidence.

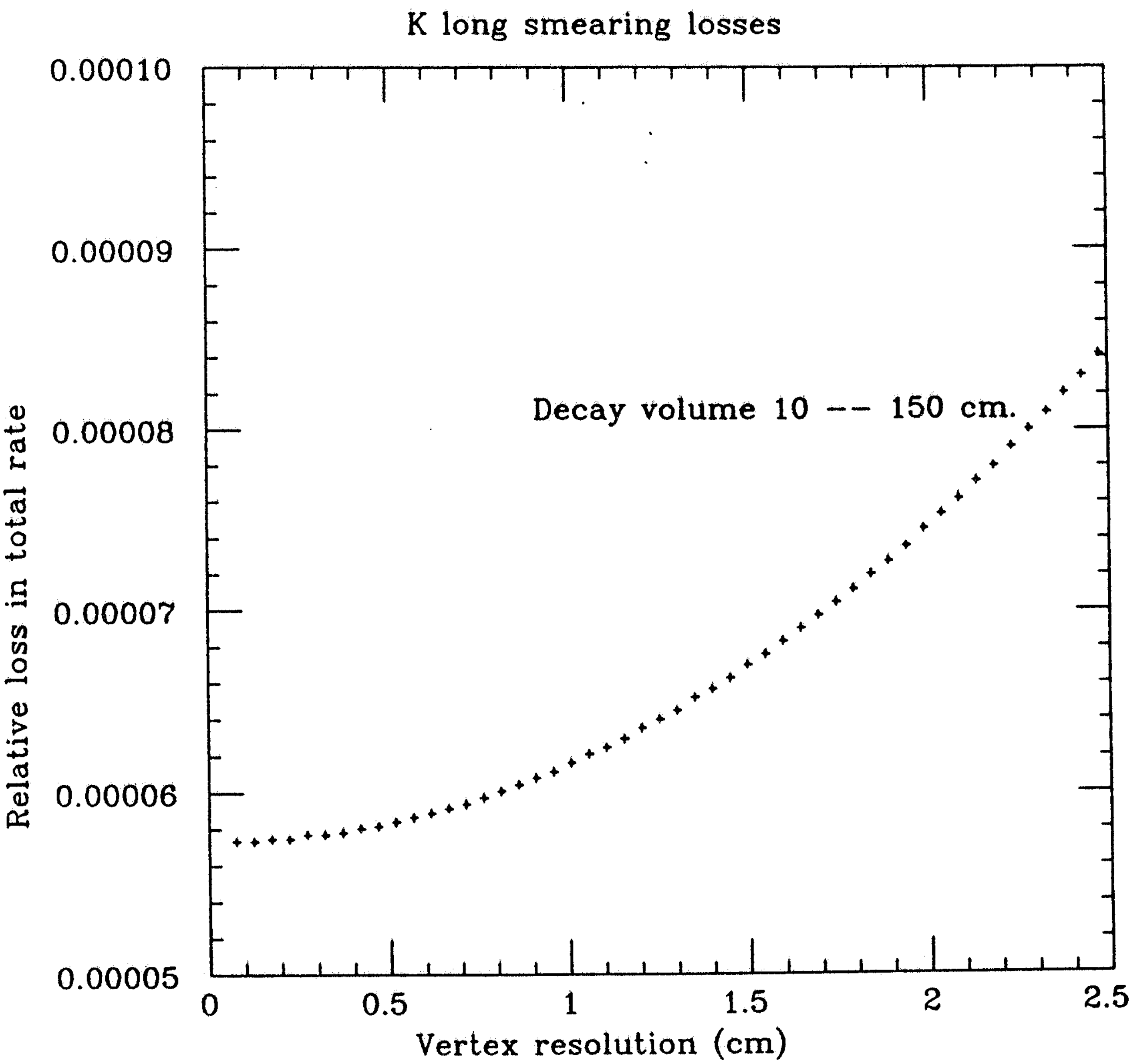

Figure 4. K_L^0 smearing losses as a function of the vertex resolution; the decay region is taken to extend from 10 to 150 cm. radially

A resolution of at least 1 cm is needed in order to keep systematics below the 5×10^{-4} level, allowing for some tails in the resolution function: the experimental distributions are never completely gaussian and small asymmetries in the resolution function would increase the magnitude of the smearing losses.

6.4. A COMPARISON WITH K_L^0 BEAM EXPERIMENTS

Here will give a quick comparison between the systematic effects at K_L^0 beams experiments versus a ϕ–factory.

Following the published analysis[7], the biggest systematic effects of such experiments are due, disregarding background subtraction, to differences in the energy scale for the charged/neutral decays of neutral kaons, and to accidentals: the effects (on the double ratio) are of the order of $2 - 3 \times 10^{-3}$ each. Both effects are absent in the ϕ–factory approach to the ϵ'/ϵ measurement, where produced kaons are monochromatic and the highest rate in the detector, apart from Bhabha scattering, is due to ϕ decays. On the other hand, the huge rates at hadron machines allow to use very small fiducial volumes and/or mimic similar decay lengths for K_L^0 and K_S^0; in this way systematics due to acceptance are canceled (to first order) in the double ratio measurement. It is worth noticing, however, that, in the analysis of Ref. 7, the systematics connected to the acceptance contribute at the 1×10^{-3} level to the double ratio error, even though for this experiment there is a first order cancellation of the acceptances. This is due to the fact that in K_L^0 beams the ultimate accuracy is achieved through Montecarlo calculations; at a ϕ–factory acceptances are very different for K_L^0 and K_S^0, but the experimental environment is such that a direct measurement of them can be performed.

7. The detector

The characteristics of the experimental apparatus capable of carrying out the measurement of ϵ'/ϵ are:

1. Ability to track charged particles with momenta between 50 and 300 MeV/c; two prong vertex resolution better than 1 mm.
2. Hermetic coverage for γ detection with a minimum detectable energy $\sim$ 20 MeV. Energy resolution of the order of 15% at 100 MeV. Spatial resolution in the measurement of the photons' conversion point of the order of 1 cm.
3. Particle identification: μ/π and e/π discrimination of the order of 50-100 to 1.

We have already stated that K_L^0 decay volume should be at at least 150 cm; this sets the overall dimension of the detector: a cylinder, of $\sim 4\ m$ in radius and $\sim 8\ m$ in length.

7.1. The tracking system

The main optimization which needs to be done in the tracking system concerns field strength versus $p_\perp$ cut-off, for a given momentum resolution. With the assigned size of the decay volume (150 cm.) the radial extent of the tracking system should be of at least 2 m. so that enough track length would be available for prongs originating near the boundary of the decay volume. With a field of 1 KG the curl-up momentum would be of 60 MeV/c for tracks originating close to the I.P. and 15 MeV/c for tracks at the outer radius. As the track length varies by a factor of four, one might envisage a solution in which the number of measured points increases with the radial coordinate. The inner radius of the tracking system should be around 10 cm. so that the K_S^0 decay vertex could be determined with good resolution ($\sim 1\ mm$). At 1 KG field, the momentum resolution would be of the order of 1% , and roughly independent of the momentum, (using a Helium based drift chamber with $X_0 \sim 3000\ m$, $\delta(r\phi) \sim 150\mu$), as it would be completely dominated by multiple scattering. Lower fields would be unpractical to use, as the resolution scales as $\frac{1}{\sqrt{l_{track}}}$. As a last remark we want to mention that, given the bunch collision frequency foreseen for this type of colliders, a drift chamber seems to be the only viable solution for the tracking system.

7.2. Calorimetry

This item is the most important and demanding of the entire apparatus: the needed discrimination power between the 2 π^0 and the 3 π^0 decays, the spatial resolution necessary on the K_L^0 decay vertex are hard experimental challenges to be met, yet the very high signal to noise ratio and the pair production mechanism of the $K_L^0 K_S^0$ typical of the ϕ decay make possible to achieve the needed performances. The rejection against the $3\pi^0$ decay can be obtained with a completely hermetic coverage of the solid angle and an very low energy threshold. Rejection ratios against the $3\pi^0$ decays of few unities $\times 10^{-5}$ can be achieved from geometry alone; a moderately precise measurement of total energy will then reduce the $3\pi^0$ background to acceptable levels.

The hardest experimental problem to solve is the determination, with the needed precision, of the $K_L^0 \rightarrow \pi^0\pi^0$ vertex. The ordinary technique which uses the mass constraint of the parent particle (either π^0 and/or K_L^0) to determine the decay point, looses its power at low energy, where big opening angles privilege spatial measurements with respect to energy. The production mechanism of the kaons pair allow the use of kinematical constraint to fit the decay point, once the conversion point of the four photons and the flight direction of the decaying K_L^0 has been determined reconstructing the opposite K_S^0[1]. Fig. 5 shows the resolution in path length achievable with the fitting procedure, for different calorimeter performances. The decay vertex resolution called for in section 6.3 is obtainable with sophisticated imaging calorimeter[1].

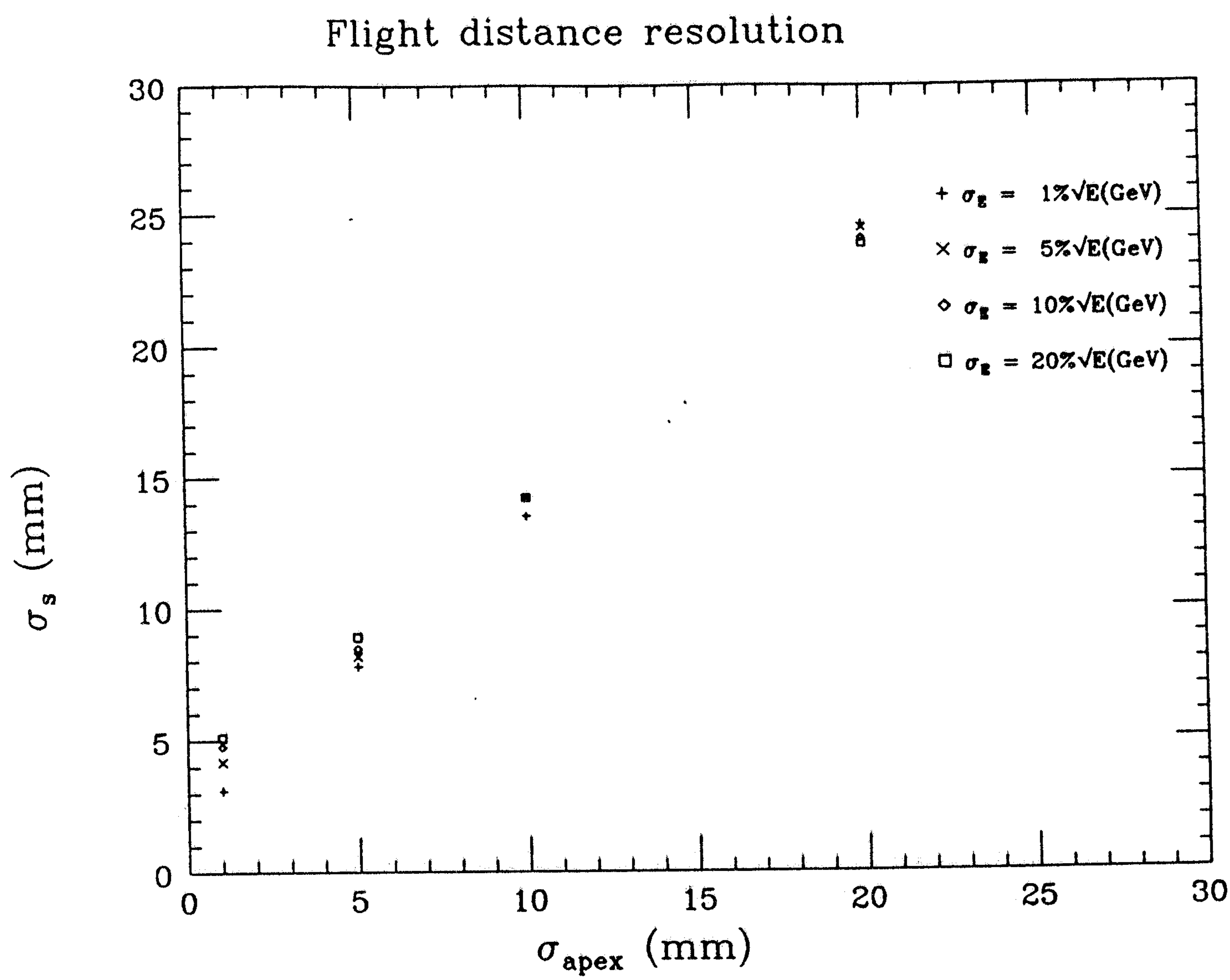

Figure 5. Flight path resolution for the decay $K_L^0 \rightarrow \pi^0\pi^0$ as a function of the spatial resolution of the γ conversion point measurement in the calorimeter: various scaled energy resolution are reported. The fitting procedure is described in the text and in Ref. 1.

The energy resolution necessary is set by efficiency requirements in the fitting procedure and by the need of correctly pairing the right γ's in the reconstruction of the decay chain $K_S^0 \rightarrow \pi^0\pi^0 \rightarrow 4\gamma$. A resolution of 5% @ 1 GeV would satisfy all the experimental demands.

7.3. Particles identification

The need of particle identification has been outlined in section 6.1. We have seen, on the other hand, in the previous section how important it is the detection of low energy γ's. Adding a subsystem to identify μ, π and e would completely spoil the ability of the calorimeter to detect low energy photons. The only way out of this dilemma would be to have a calorimetry capable to provide the needed $\pi - \mu$ and $\pi - e$ discrimination.

The range of momenta involved is such that calorimetric identification of π, μ and e is indeed feasible. If we assume, for instance, the calorimetric device to be a liquid Argon homogenous calorimeter, both kinetic energy and range of the K_L^0 decay products can be measured with good resolution. For a 200 MeV/c track the difference in kinetic energy between a μ and a π is 14% , while the difference in range is $\sim$ 30% (straggling effects are of the order of 3-5%). The needed discrimination seems then to be on hand; as a matter of fact preliminary Montecarlo simulation (depicted in fig. 6) seem to indicate the rejection ratios of the order of 200:1 could be achievable.

The kinetic energy difference between π's and e's, in the momentum range of interest, is such that rejection ratios of the order of 200:1 will not cause insoluble problems.

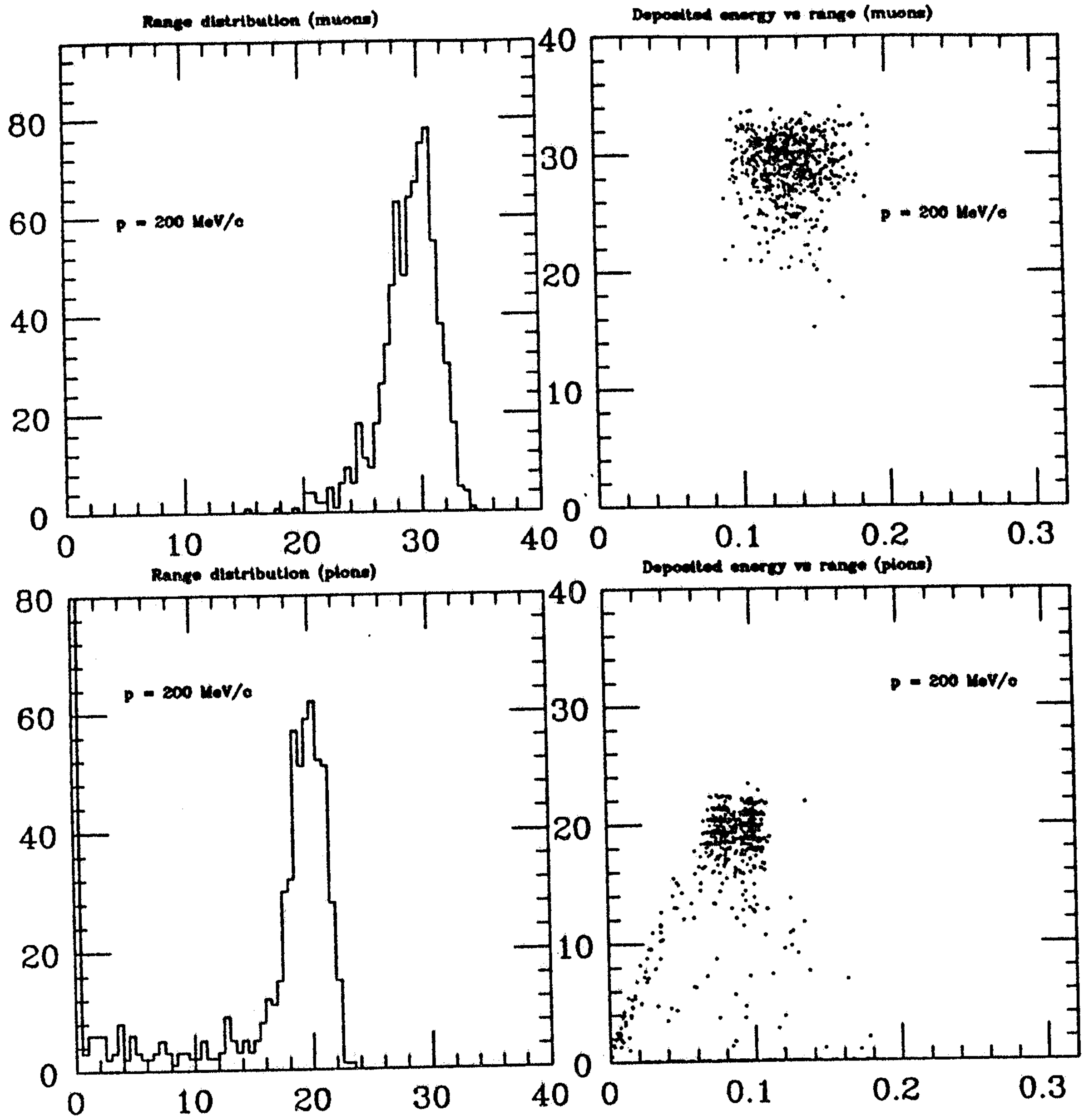

Figure 6. Range distribution and scatter plot of the energy lost versus range for 200 MeV/c μ and π in Liquid Argon.

8. Conclusions

The measurement of ϵ'/ϵ which can be carried out at a ϕ–factory is a very important piece of experimental information, because it is obtained under completely different conditions compared to K_L^0 beams. Achievable luminosities, with reasonable extrapolations of the operating parameters for existing machines, guarantee an improvement in the statistical sensitivity of the measurement, while systematic errors will be reduced substantially thanks to the extremely favourable (experimental) environment of K^0 production at the ϕ.

Several other physics topics will be addressed by a ϕ–factory, from rare K_S^0 decays to total hadronic cross section measurement. CP violation phenomena could be searched for in the charged K decays , where violation in the decay amplitude is the only one possible.

The detector which has to be built to implement the physic program presents hard challenges, especially the electromagnetic calorimetry requires performances quite difficult to achieve, not so different in any case from the ones required in B and/or τ-charm factories, for what energy resolution is concerned. Such a detector, optimized for the ϵ'/ϵ measurement, would be capable of carrying out most of the other physics. We believe that the facility (collider and detector) should be designed in such a way that the physics program could start shortly after commissioning, and this implies a conservative choice of the operating parameters. Improvements of the machine should not constitute a major disruption for the experimental physics program.

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