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P. Franzini and the KLOE Collaboration

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Physics with KLOE at DAΦNE

Paolo Franzini

Dipartimento di Fisica dell'Università e Sezione INFN, Roma I, "La Sapienza"
P.le A. Moro, I–00185, Roma, Italy

On behalf of the KLOE Collaboration

Abstract

Experimental measurements which can be done at DAΦNE, the ϕ-factory under construction at the Laboratori Nazionali di Frascati dell'INFN, are presented. We also describe the KLOE detector, optimized for performing these measurements.

1. Introduction

The Frascati ϕ–factory, DAΦNE,[1] is a bright source of neutral K's in a pure quantum state, of charged K pairs and also of ρ's, η's and η''s. ϕ radiative decays are also observable. Unique to DAΦNE is the possibility of studying *kaon interferometry*, which allows accurate determinations of the parameters of the neutral kaons. These studies will be performed with the KLOE detector proposed by the KLOE collaboration and under construction at present.[2] At full DAΦNE luminosity, KLOE can collect some 10^{11} events per year. KLOE is "self-calibrating" via numerous K decay channels and Bhabha scattering. An absolute normalization of the K_S, K_L fluxes is also available.

2. *CP* and *CPT* at DAΦNE

The KLOE program at DAΦNE is aimed at measuring CP and possible CPT violation in neutral K decays, with a sensitivity comparable to that of the next generation fixed target experiments ($\delta\Re(\epsilon'/\epsilon)\sim 10^{-4}$), both by using pure K_S, K_L beams and from observing interference effects due to the coherence of the K_S, K_L state. The quantities $\Re(\epsilon'/\epsilon)$, $\Im(\epsilon'/\epsilon)$, Δm, $|\eta_{\pi\pi}|$, $\phi_{\pi\pi}$, can be measured with improved accuracy.[3] Assuming CPT and defining the usual amplitude ratios and epsilon parameters $\eta_{+-} = \epsilon + \epsilon'$ and $\eta_{00} = \epsilon - 2\epsilon'$ where η's and ϵ's are all complex, experimental observation of $\epsilon' \neq 0$ would be proof that CP is violated in the decay amplitude. The standard model, in the context of the CKM quark mixing mechanism, predicts $\Re(\epsilon'/\epsilon)\sim 10^{-3}$ with large uncertainties and possible cancellations.[4,5] The relationships between $\eta_\pm$, η_{00} and ϵ, ϵ', when one allows for CPT violation, remain as above but both ϵ, ϵ' each acquire terms which violate CP and CPT separately.[3]

At DAΦNE neutral K-pairs are produced in a C-odd state. Defining $\eta_i = \langle f_i | K_L \rangle / \langle f_i | K_S \rangle$, $\Delta t = t_1 - t_2$, $t = t_1 + t_2$, $\Delta\mathcal{M} = \mathcal{M}_L - \mathcal{M}_S$ and $\mathcal{M} = \mathcal{M}_L + \mathcal{M}_S$, the decay intensity $I(f_1, f_2, \Delta t = t_1 - t_2)$ to final states f_1 and f_2 is :

$$I(f_1,\ f_2;\ \Delta t) = \frac{1}{2}\int_{\Delta t}^{\infty} |A(f_1,\ t_1;\ f_2,\ t_2)|^2 \mathrm{d}t =$$

$$\frac{1}{2\Gamma}|\langle f_1 | K_S \rangle \langle f_2 | K_S \rangle|^2 \times \Big(|\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-\Gamma \Delta t/2}\cos(\Delta m \Delta t + \phi_1 - \phi_2)\Big),$$

with $\eta_i = A(K_L \to f_i)/A(K_S \to f_i) = |\eta_i| e^{i\phi_i}$, exhibiting interference terms sensitive to phase differences. We can perform "kaon-interferometry" by using the decay intensity of the previous equation with appropriate choices of the final states f_1, f_2.

1). $f_1 = f_2$: we can measure Γ_S, Γ_L and Δm, since all the phases disappear. Rates can be measured to $\times 10$

improvement in accuracy and Δm to $\times 2$.

2), $f_1 \neq f_2$: a). with $f_1 = \pi^+\pi^-$, $f_2 = \pi^0\pi^0$, we can measure $\Re(\epsilon'/\epsilon)$, and $\Im(\epsilon'/\epsilon)$. The former by concentrating on large time differences, the latter for $|\Delta t| \leq 5\tau_s$. b). with $f_1 = \pi^+\ell^-\nu$ and $f_2 = \pi^-\ell^+\nu$, we can measure the CPT–violation parameter δ_K, the real part by concentrating on large time difference regions; and the imaginary part for $|\Delta t| \leq 10\tau_s$, fig. 1. c). If $f_1 = 2\pi$, $f_2 = K_{\ell 3}$, this leads to measurements of CP and CPT violation parameters at large time differences, since we measure the asymmetry in K_L semileptonic decays. At small time differences, we obtain Δm, $|\eta_{\pi\pi}|$ and $\phi_{\pi\pi}$, figs. 2, 3. Choosing appropriate f_1 and f_2 channels one can perform 16 independent measurements in neutral K decays. If the validity of the $\Delta S = \Delta Q$ rule is assumed there are only 13 paramaters to determined. Experiments at DAΦNE can thus test CPT invariance, in addition to studying CP violation. If the $\Delta S = \Delta Q$ rule does not hold (it is violated to $\sim 1/10^7$ in the SM), there are in fact 17 independent parameters,[5]therefore we need to also use strangeness tagged K^0 obtained from charge exchange of K^+ mesons, in turn tagged by observation of a K^- meson, from $\phi \rightarrow K^{\pm}$ decays.

3. Measuring $\mathcal{R}^{\pm}/\mathcal{R}^0$

In addition, we can also use the classical method of the double ratio $\mathcal{R}^{\pm}/\mathcal{R}^0 = 1 + 6 \times \Re(\epsilon'/\epsilon)$, and other ways of measuring $\Re(\epsilon'/\epsilon)$ from selected final states. Very different systematics are involved, thus allowing a self check of the results.

4. Other *CP* Violations at DAΦNE

So far CP violation has been observed only in the K_L system. Observation of $K_S \rightarrow 3\pi^0$ would constitute a new proof of CP violation. One can collect $\sim$30 events in one year, with zero background. At DAΦNE one can also easily measure the difference in rates between $(K_S \rightarrow \pi^{\pm}\ell^{\mp}\nu)$ to 4×10^{-4}.

Evidence for direct CP violation can be also be obtained from the decays of charged kaons which are copiously produced at DAΦNE. CP requires equality of the partial rates for $K^{\pm} \rightarrow \pi^{\pm}\pi^+\pi^-$ $(\tau^{\pm})$ and for $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ $(\tau'^{\pm})$. One can improve the present rate asymmetry by two orders of magnitude. One can also observe differences in the Dalitz plot distributions for K^+ and K^- decays in both the τ and τ' modes; at DAΦNE one could reach sensitivities of $\sim 10^{-4}$. Rate differences in the radiative decays $K^{\pm} \rightarrow \pi^{\pm}\pi^0\gamma$, are also proof of direct CP violation. The reachable sensitivity is $\sim 1.4\times10^{-3}$.

5. Chiral Perturbation Theory

In the last decade chiral perturbation theory (CHPT) has been extended to the next order terms in the chiral expansion ($\mathcal{O}(m^4)$, $\mathcal{O}(p^4)$, $\mathcal{O}(m^2p^2)$). Many new amplitudes can then be predicted.

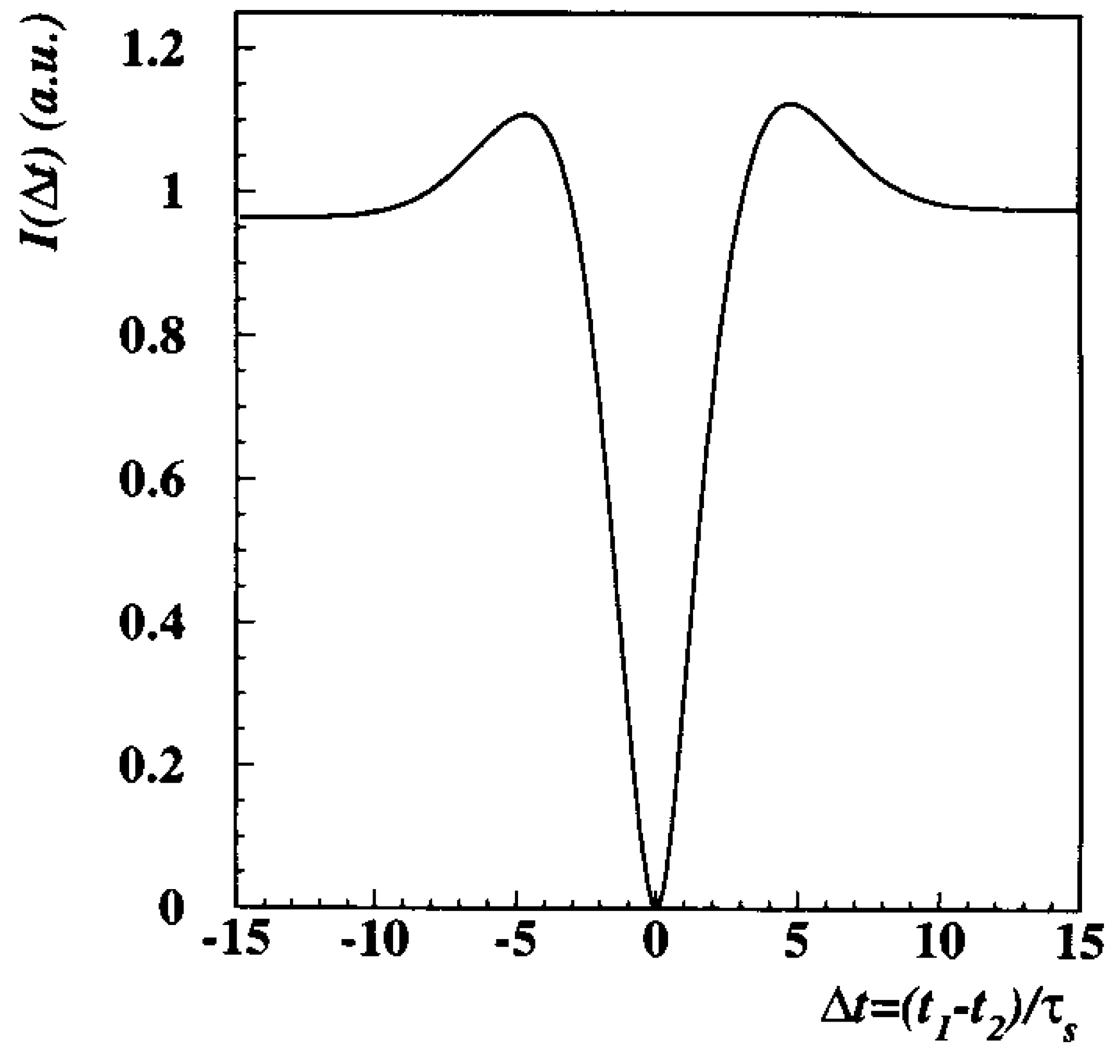

Fig. 1 Interference for $f_1 = \pi^+\pi^-$, $f_2 = \pi^0\pi^0$

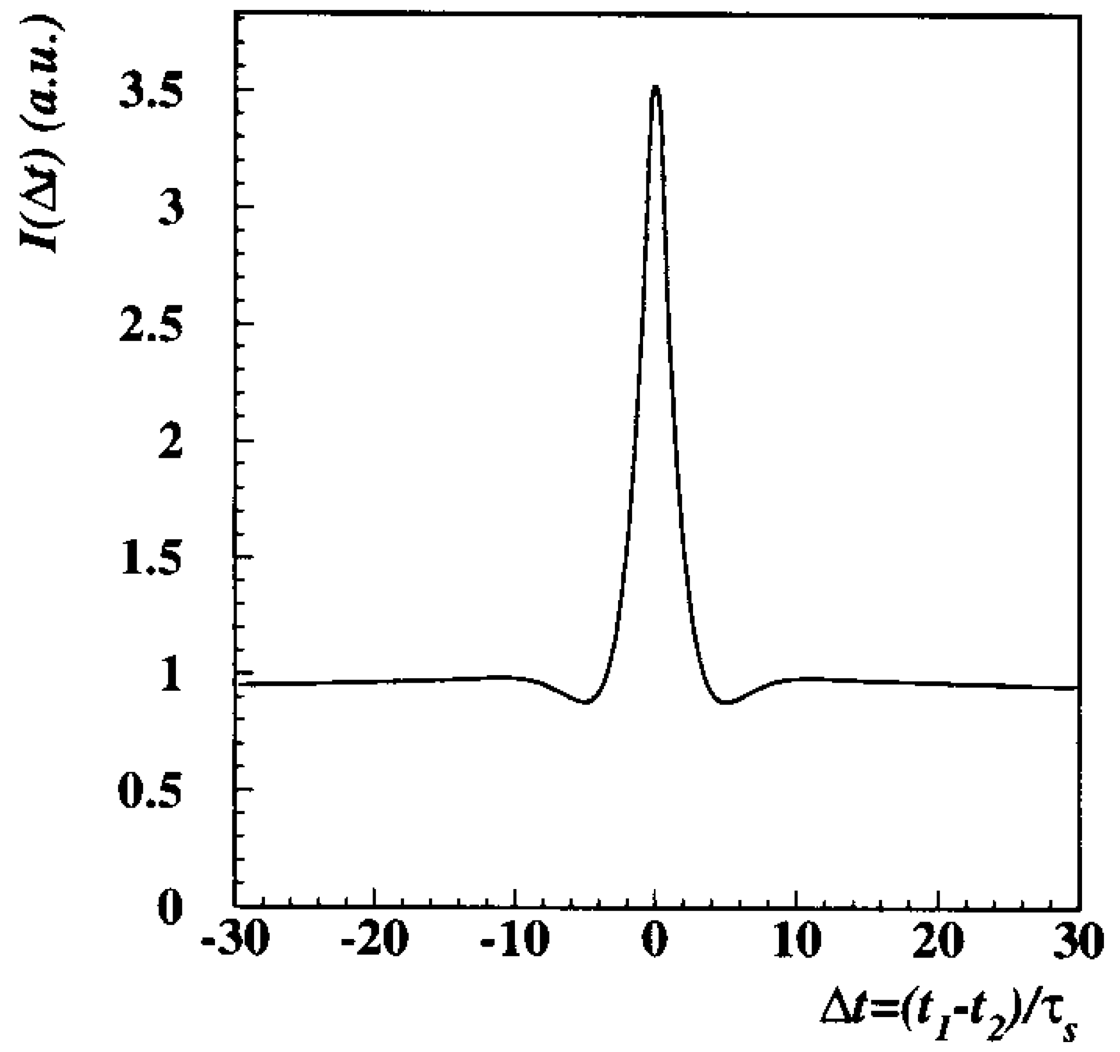

Fig. 2 Interference for $f_1 = \ell^+$, $f_2 = \ell^-$

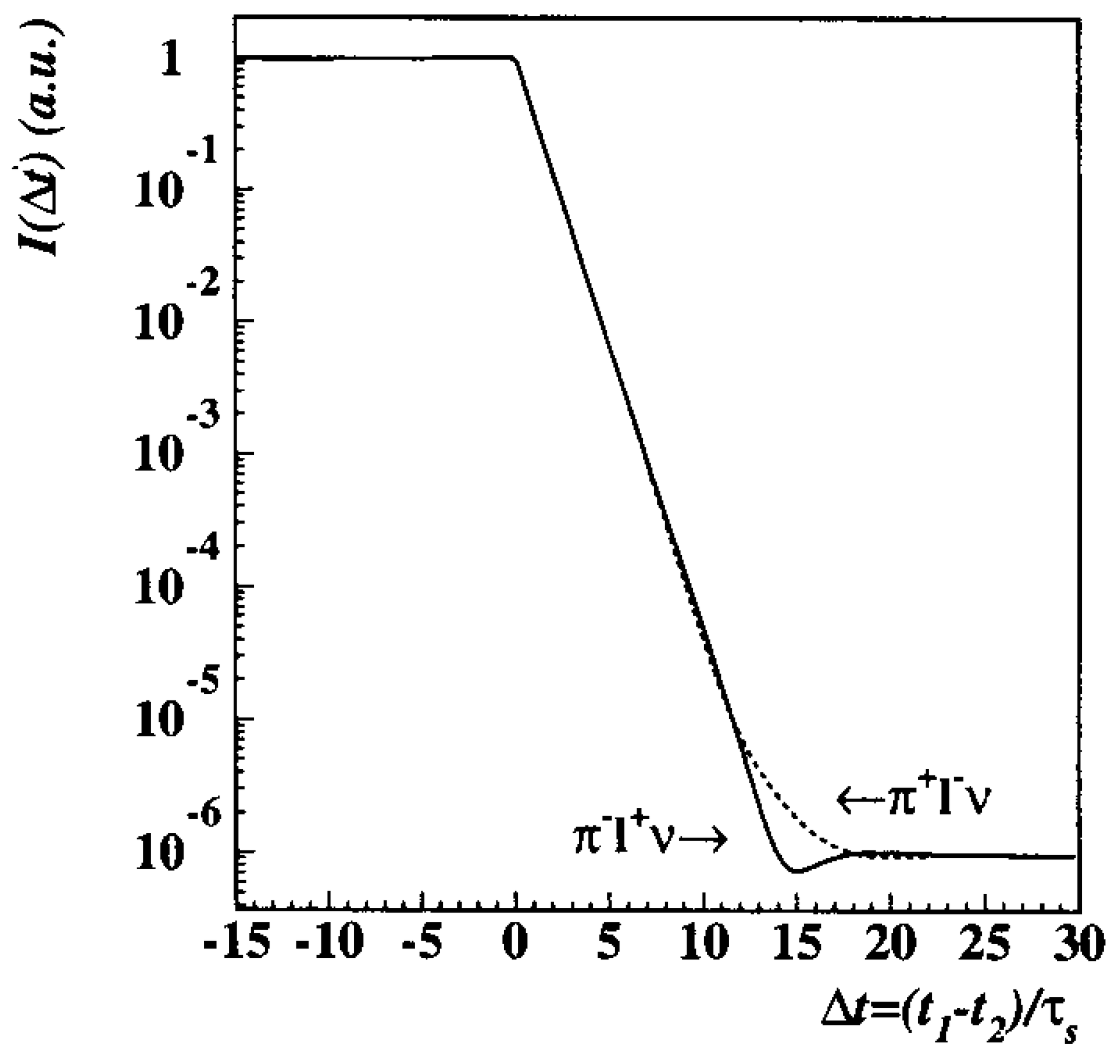

Fig. 3 Interference for $f_1 = \ell^{\pm}$, $f_2 = 2\pi$

At lowest order the CHPT relation predicts the slope of the scalar form factor, λ_0. There is at present disagreement from experiment with the CHPT prediction, 0.017 ± 0.004: one can measure λ_0 for K_L to an accuracy of 1.4×10^{-5}. Similar accuracy are obtained for $K^{\pm}$ and for λ_+. There is only one measurement of the relevant

$K_{\ell 4}$ form factors. These decays also provide another opportunity for the determination of the $\pi\pi$ phase shifts. The amplitudes for $K_{\ell 2,\gamma}$, $K_{\ell 2,e^+e^-}$ and $K_{\ell 3,\gamma}$ depend on the K charge radius.

The rate for $K^{\pm}\to\pi^{\pm}\gamma\gamma$ and the $\gamma\gamma$ distributions are uniquely predicted by the chiral lagrangian approach. Dalitz type decays of K mesons and two photon production of pions are also of great interest. At DAΦNE one can improve vastly on all these topics.

6. Radiative ϕ Decays

The study of light meson spectroscopy, rare radiative decays are possible at DAΦNE. The unique, lightest scalar meson state $f_0(975)$ is poorly described by current models, one can easily contribute to solving the puzzle.[6]

7. KLOE

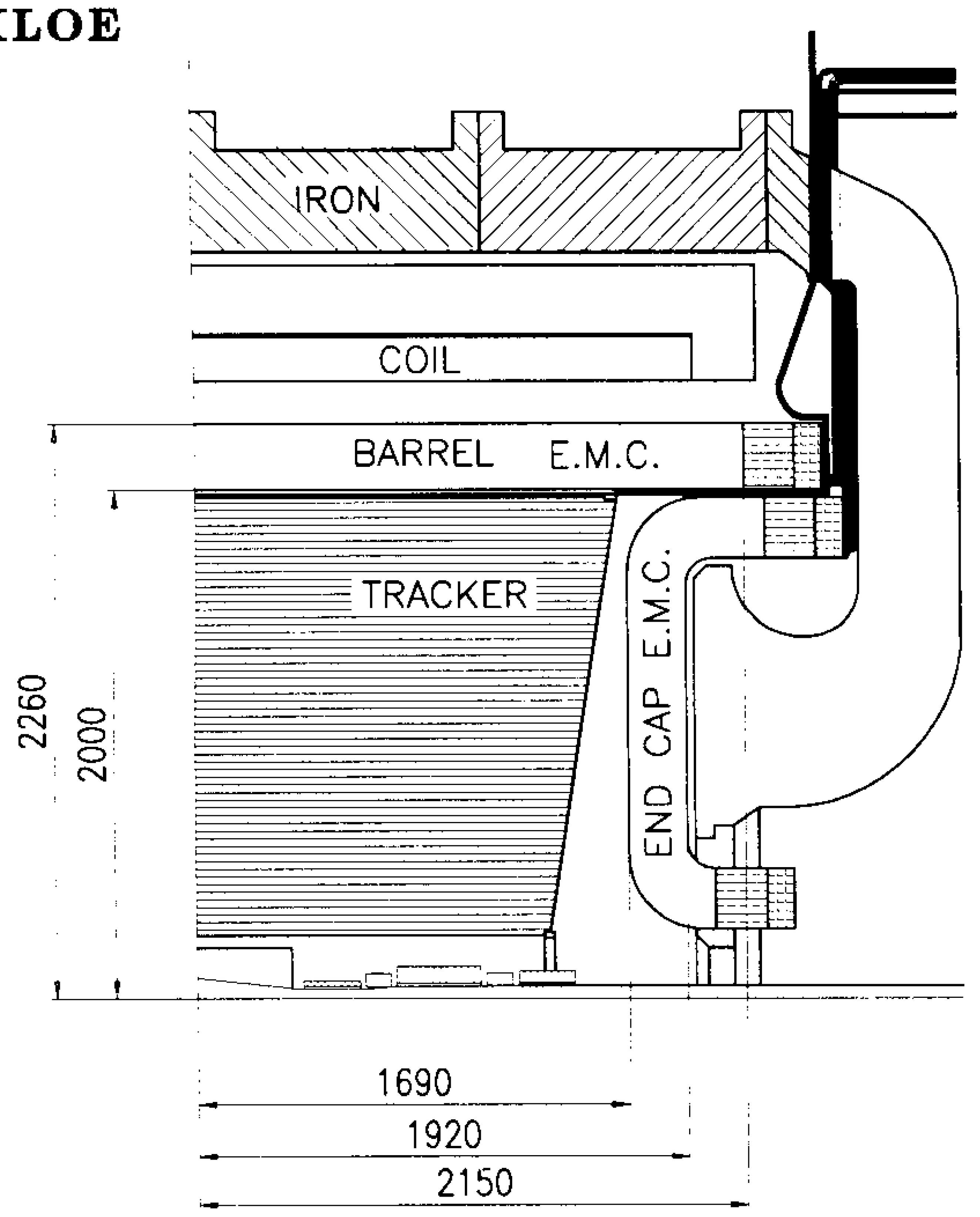

Fig. 4 KLOE cross section along the beam axis.

The KLOE Collaboration[7] has designed[8] and begun construction of the KLOE detector whose main mission is to study CP violation with a sensitivity of $\mathcal{O}(10^{-4})$ and is fully capable of investigating a whole range of other physics described above. The scale of KLOE is driven by a fundamental parameter, the mean decay path length of the long lived K^0-meson $L(K_L)$. At DAΦNE, $\beta(K)$=0.216 and $L(K_L) = \gamma\beta c\tau = 3.44$ m. Which is a large number indeed! Economical reasons and technical problems as well lead to a choice of a 2 m drift space for the K_L decays.

The experimental apparatus must be able to track charged particles of momenta between 50 and 250 MeV/c. It must also detect with very high efficiency γ's with energy as low as 20 MeV, measure their energies with a resolution $\delta E_\gamma/E_\gamma \sim 15\%$ at 100 MeV and provide the space coordinates of the photon conversion point. Thus while the general features of the KLOE detector are similar to those of a *typical* general purpose collider's apparatus: a cylindrical structure surrounding the beam pipe, consisting of a highly efficient, large tracking device for detecting the charged K^0 decay products, an electromagnetic calorimeter with exceptional timing ability, which also provides some particle identification, enclosed in a solenoidal field. A cross section view of KLOE is shown in fig. 4.

8. Detector Performance.

Some parameters of the detector are given in table 1.

Calorimeter	
δ(Shower Apex)	=1 cm
$\delta E/E$	$= 5\%/\sqrt{E\ (\mathrm{GeV})}$
δt	$= 66\ \mathrm{ps}/\sqrt{E\ (\mathrm{GeV})}$
Drift Chamber	
δpoint	$= 200\ \mu$m, r and ϕ
	= 2 mm, z
δp_t	$= 0.5\% \times p_t$
$\delta(\tan(\theta))$	$= (3.5 \oplus 2.5) \times 10^{-4}$

Table 1. DAΦNE Detector Performance.

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