CP- Violation in K^0 – decays at CERN

M.Holder
Fachbereich Physik, Universität Siegen
D- 5900 Siegen, Germany

ABSTRACT

Two experiments will be discussed, NA31 and CP–LEAR. The main results of NA31 on CP- and CPT- violation will be reviewed . A recent measurement of the decay $K_L \to \pi^0\gamma\gamma$, which has some relevance for CP–violation in the decay $K_L \to \pi^0 e^+ e^-$,will be presented in some detail, and a new proposal for a more precise measurement of ϵ'/ϵ will be outlined. For CP–LEAR the aims of the experiment and a brief status report will be given.

1. CP– and CPT– violation parameters

There are two distinct possibilities of CP– violation in K^0 decay: by state mixing and in the decay matrix. Mixing between K^0 and $\bar{K}^0$ occurs because K^0 and $\bar{K}^0$ couple to the same intermediate states via the weak interaction. The eigenstates K_L and K_S with definite masses and lifetimes are not necessarily identical with the eigenstates K_1 and K_2 of the CP– operator. In general one has

$$K_L = \frac{1}{\sqrt{2(1+|\epsilon_L|^2)}}(K_2 + \epsilon_L K_1) \tag{1}$$

$$K_S = \frac{1}{\sqrt{2(1+|\epsilon_S|^2)}}(K_1 + \epsilon_S K_2) \tag{2}$$

and $\epsilon_L = \epsilon_S = \epsilon$, if CPT is conserved. If the time evolution of the K^0 and $\bar{K}^0$ states is parametrized by the mass matrix M and the decay matrix Γ, viz.

$$i\partial\Psi/\partial t = (M - i\Gamma)\Psi \qquad ,\Psi = \begin{pmatrix} K^0 \\ \bar{K}^0 \end{pmatrix}, \tag{3}$$

the parameter ϵ is related to the matrix elements by

$$\epsilon = \frac{\epsilon_S + \epsilon_L}{2} = \frac{\Gamma_{12} - \Gamma_{12}^* + i(M_{12} - M_{12}^*)}{\gamma_S - \gamma_L - 2i(m_L - m_S)}. \tag{4}$$

In the traditional phase convention (A_0= real, see below) Γ_{12} is practically real and the phase of ϵ is determined by the phase of the denominator of (4), with

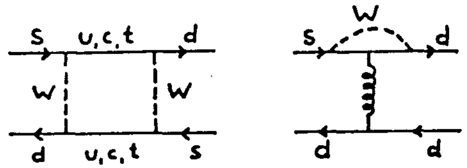

*Fig.1.*a) Box diagram b) Penguin diagram

the numerical value $\phi_\epsilon = (43.7 \pm 0.2)^0$. With this admixture of ϵK_1 in its wave function, the K_L-state can now decay to $\pi^+\pi^-$ or $\pi^0\pi^0$, which are even under CP because of Bose- statistics. Since $< 2\pi|K_L >= \epsilon < 2\pi|K_S >$, the ratio of decay rates into charged and neutral pions is the same for K_L and K_S, if state mixing is the only source of CP- violation, as for example in the superweak model[1]. With quark diagrams the mixing is described by the famous box graph (Fig.1a). The real part of the amplitude is related to $\Delta m = m_L - m_S$, the imaginary part to ϵ. As first noticed by Kobayashi and Maskawa[2], with three generations of quarks it is possible to have a unitary quark mixing matrix with complex phase factors that cannot be absorbed in the definition of quark states. The smallness of CP- violation is then due to the smallness of the product of the three generation- mixing angles. If these angles were large, CP-violation would be a prominent effect.

A second possibility is that CP is violated in the transition itself (*direct CP- violation*). This happens if the matrix elements A_0 and A_2 between K^0 and the two possible I=0 and I=2 eigenstates of two pions do not have the same phase. Denoting the strong interaction phase shifts with δ_I , the transition amplitudes are given by

$$< 2\pi|_I|T|K^0 >= A_I \exp(i\delta_I) \qquad (5)$$

$$< 2\pi|_I|T|\bar{K}^0 >= \bar{A}_I \exp(i\delta_I). \qquad (6)$$

One phase is free; in the usual convention , A_0 is taken to be real. Direct CP- violation is then linked to a nonzero value of

$$\epsilon' = \frac{i}{\sqrt{2}} \frac{Im A_2}{A_0} \exp(i(\delta_2 - \delta_0)). \qquad (7)$$

Note that the phase of ϵ' is given by the strong interaction phase shifts [3]

$$\phi_{\epsilon'} = \frac{\pi}{2} + \delta_2 - \delta_0 \approx (45 \pm 15)^0 \quad . \qquad (8)$$

In the standard model, ϵ' can be calculated, in principle, from Penguin- diagrams (Fig.1b). These involve exchange of gluons. More recently, exchanges of photon and Z_0 were also computed [4], with the effect of decreasing ϵ'/ϵ for higher masses of the top quark.

Quite independent of the details of these calculations it is worthwhile to find out experimentally whether there is CP- violation in a Δ S = 1 transition. If there is, it seems indeed plausible that CP- violation is related to quark mixing. Even though ϵ' is a small number, in fact suppressed by a factor $A_0/A_2 \approx 20$,the highest chance to establish direct CP- violation anywhere is still in $K \to 2\pi$ decay .

Assuming CPT -conservation, the measurable CP-violation amplitudes

$$\eta_{+-} = \frac{< \pi^+\pi^-|T|K_L >}{< \pi^+\pi^-|T|K_S >} \qquad (9)$$

$$\eta_{00} = \frac{< \pi^0\pi^0|T|K_L >}{< \pi^0\pi^0|T|K_S >} \qquad (10)$$

are related to the parameters ϵ and ϵ' by

$$\eta_{+-} = \epsilon + \epsilon' \qquad (11)$$

$$\eta_{00} = \epsilon - 2\epsilon'. \qquad (12)$$

The experimental values as of two years ago are graphically represented in Fig.2. Within the given framework, and with the phases of ϵ and ϵ' as quoted, it is however impossible to have ϕ_{00} and ϕ_{+-} different by more than a degree, as suggested by these data. If the data are right, CPT cannot be conserved.

Allowing for CPT- violation, there are again two effects: CPT- violation in the state mixing, and CPT- violation in the transition. If in the state mixing $\epsilon_S \neq \epsilon_L$, then

$$\delta = \frac{\epsilon_S - \epsilon_L}{2} = \frac{(\Gamma_{11} - \Gamma_{22}) + i(M_{11} - M_{22})}{\gamma_S - \gamma_L - 2i(m_L - m_S)} \qquad (13)$$

is a measure of CPT- violation.

If in the transition amplitudes $\bar{A}_I \neq A_I^*$ for I=0 or I=2, there is CPT-violation. Defining for convenience the CPT- violating amplitudes as

$$\alpha_0 = \frac{A_0^* - \bar{A}_0}{A_0 + \bar{A}_0} \qquad \alpha_2 = \frac{1}{\sqrt{2}} \frac{A_2^* - \bar{A}_2}{A_0 + \bar{A}_0} \exp(i(\delta_2 - \delta_0)), \qquad (14)$$

the measurable amplitudes η_{+-} and η_{00} become

$$\eta_{+-} = \epsilon + \epsilon' - \delta + \alpha_0 + \alpha_2 \qquad (15)$$

$$\eta_{00} = \epsilon - 2\epsilon' - \delta + \alpha_0 - 2\alpha_2 \qquad (16)$$

$$\eta_{00} - \eta_{+-} = 3(\epsilon' + \alpha_2). \qquad (17)$$

A nonzero phase difference $\phi_{00} - \phi_{+-}$ requires then a nonzero value ofα_2. In the case $\alpha_2 = \alpha_0 = 0$ the mass difference $M_{11} - M_{22}$, that is $M_{K^0} - M_{\bar{K}^0}$, can be measured by looking at the projection $\delta_\perp$ of δ perpendicular to ϵ,

$$\delta = \epsilon - (\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) \qquad (18)$$

$$\delta_\perp \approx |\eta|(\frac{2}{3}\phi_{+-} + \frac{1}{3}\phi_{00} - \phi_\epsilon) \qquad (19)$$

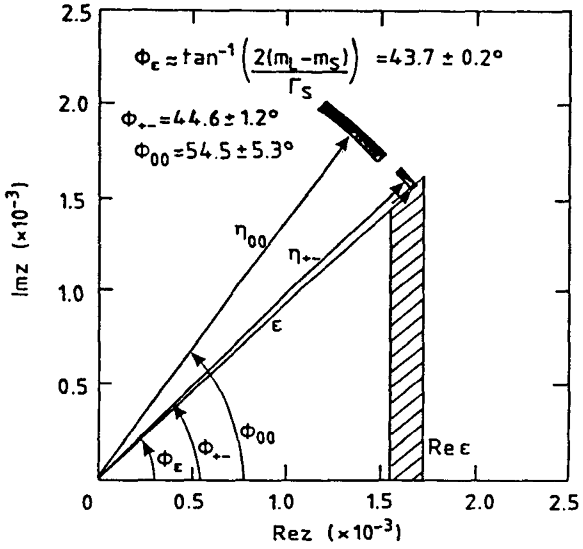

Fig.2. Status of CP-violation parameters as of 1988.

2. Measurements of ϵ'/ϵ by NA31

The NA31 experiment has been presented at many occasions[5] since the publication of the first result. More data were taken in 1988 and 1989 ; they will triple the original statistics and improve on the systematic error. Yet, there is no result so far.In the following discussion I will summarize the main points and indicate why and how a new experiment may be done.

Direct CP-violation is most conveniently measured as a deviation of the double ratio

$$R = \frac{\dfrac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)}}{\dfrac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}} = 1 - 6Re(\epsilon'/\epsilon) \tag{20}$$

from unity. Experimentally, it is necessary to measure at least two of the four rates $K_S \to \pi^0\pi^0, K_S \to \pi^+\pi^-, K_L \to \pi^0\pi^0, K_L \to \pi^+\pi^-$ at the same time. The NA31 group has chosen to detect charged and neutral decays concurrently, and to switch in regular intervals from a K_L to a K_S beam. Neutral beams were derived at (3.5 ± 0.5) mrad from targets hit by 450 GeV protons. In K_S running the target station was close to the decay fiducial volume, and moveable along the beam to cover a 50m decay length almost uniformly with K_S decays (seeFig.3). Geometrical acceptances cancel therefore in the double ratio (20) of K_S and K_L decays. The beams are contained in vacuum throughout the apparatus to avoid background from neutron and photon interactions.

The detector[6] includes two wire chambers and an iron scintillator calorimeter for the measurement of decays into charged pions, and a fine grain liquid argon calorimeter segmented laterally in 1 cm wide strips and longitudinally in two groups of 40 cells, for the measurement of photons. Four rings of veto counters surrounding the decay volume detect large angle photons from $3\pi^0$ decays. $K_{\mu 3}$ decays are suppressed by two planes of muon counters behind 1.5m and 2.3m of iron equivalent, K_{e3} decays are suppressed in the trigger and also offline by the longitudinal pattern of energy deposition in the liquid argon counter. $K \to \pi^+\pi^-\pi^0$ decays are identified, if at least one photon is visible.

The main problem for all CP- violation experiments in $K \to 2\pi$ decays is the suppression of $K_L \to 3\pi^0$ decays. For events in which two photons escape the detector and the veto system, the kinematical constraints of the π^0 and K^0 masses and the direction of the reconstructed K^0 momentum vector are the only tools to separate signal and background. To maintain a high rate the decay point is not measured — one would have to convert at least two photons — but is reconstructed using the K^0 mass as constraint. The reconstruction is therefore sensitive to the photon energy scale. This in turn provides a method to calibrate the photon detector : the upstream end of the decay region in the K_S mode is defined by an anticounter preceeded by 8mm of Pb. The reconstructed position of this counter is used to determine the scales of neutral and charged energies with an accuracy of 0.1 %. Background from $3\pi^0$ decays in which two photons miss the detector is uniformly distributed in the space of two-photon invariant masses (Figs.4a,b). It culminates at large distance from the collimator(Fig.4c), since the kinematic constraint shifts the decay point downstream, compensating the energy lost in the missing photons by an increase of the opening angle for the visible photons.

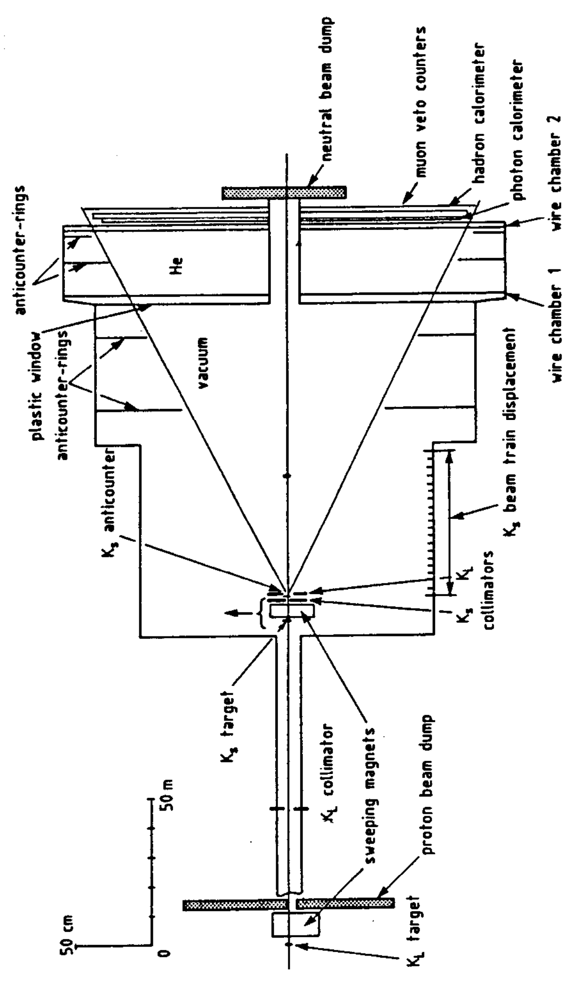

Fig.3. Layout of the NA31 experiment.

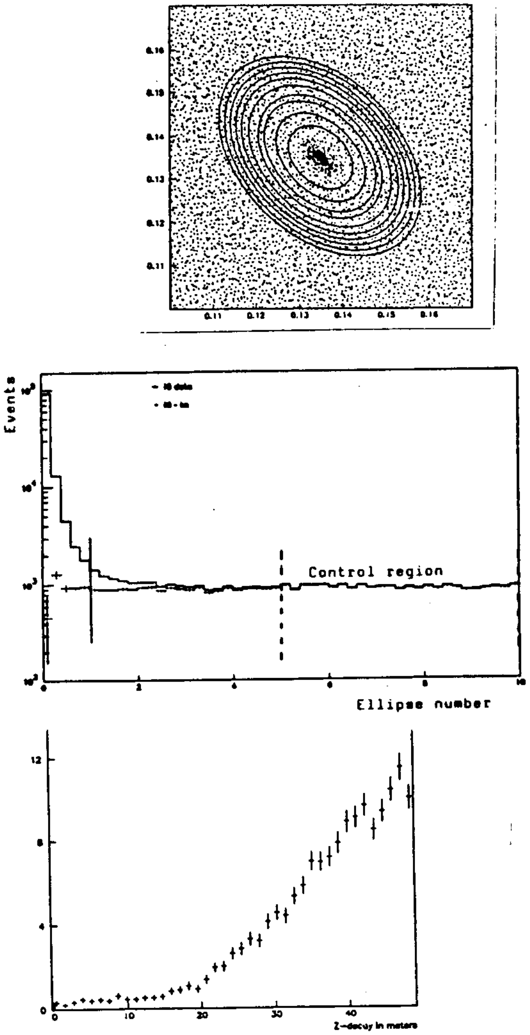

Fig.4. a) Invariant masses of best photon pairs in $K_L \rightarrow \pi^0\pi^0$.
b) events in rings of equal area of Fig.3a.
c) z- distribution of neutral background.

In $K^0 \rightarrow \pi^+\pi^-$ candidates the background from three-body decays can be suppressed by measuring the distance d_t between target and decay plane. The resolution in d_t is measured with K_S decays; the remaining background, visible at large d_t, consists mainly of K_{e3} events and can be safely extrapolated into the signal region using Monte Carlo or data (Fig.5) . The published result[7] of NA31, based on 109 000 $K_L \rightarrow \pi^0\pi^0$ events, is

$$Re(\epsilon'/\epsilon) = (3.3 \pm 1.1)10^{-3}$$

with about equal contributions from statistical ($0.67 \cdot 10^{-3}$) and systematic ($0.83 \cdot 10^{-3}$) errors. A breakdown of the systematic errors is given in Tab.1. Among the larger items are the difference of charged and neutral energy scales and the background subtraction in $K_L \rightarrow \pi^+\pi^-$ decays. Both of these errors should be reduced in the data taking of 1988 and 1989; the former, because the K_S and K_L spectra were more equalized by choosing a larger target angle and a lower proton energy (360 GeV) for K_S running ; the latter, because a transition radiation detector[8] was inserted to identify electrons in K_{e3} decays, the most important background.

In the meantime a null result[9] from the FNAL experiment E731,

$$Re(\epsilon'/\epsilon) = (-0.4 \pm 1.4(\text{stat.}) \pm 0.6(\text{syst.})) \cdot 10^{-3}$$

made it likely, that the true value of ϵ'/ϵ is rather on the lower than on the higher side of the NA31 value — the average of the two results is $(2.1 \pm 1.0) \cdot 10^{-3}$— and therefore a new attempt may be necessary to establish CP–violation with sufficient (say 5 standard deviations) confidence.

The theoretical value of ϵ'/ϵ has been decreasing over the years. Figure 6 shows some older calculations with indication of theoretical uncertainties, and a more recent evaluation of a most likely value, as a function of the unknown mass of the top quark. The theoretical uncertainties are a subject of sometimes controversial statements — so they are still large. A discussion is given, for example , in Ref.10.

A proposal to measure ϵ'/ϵ with systematic and statistical errors of $2 \cdot 10^{-4}$ was recently submitted [12] by a collaboration involving members of the NA31 team. The proposed experiment differs from NA31 in many respects; apart from running at about ten times higher K_L intensity there are various conceptional changes:

- K_S and K_L beams run at the same time. A small fraction of the primary proton beam is deflected by a bent crystal and transported to the K_S target.
- The decay volume is kept short and proportional to the Lorentz factor of Kaons. The K_S target is in a fixed position.
- The affiliation of an event to the K_S or K_L beam is done by timing. The primary protons in the K_S beam can be recorded individually at an intensity of 10^7 /spill by a thin counter in the beam. If an event is a K_S decay, it must be correlated in time with a primary proton.

Further changes in the design are a magnetic spectrometer for the measurement of charged decays and the suggestion to use a liquid Xenon calorimeter for the detection of neutrals. The proposed layout of the experiment is shown in Fig.7 .

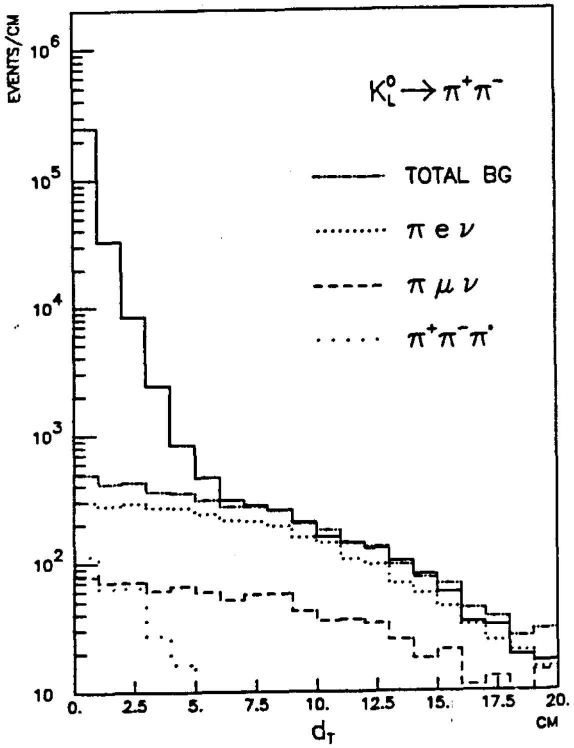

Fig.5. Acoplanarity in charged decays .
The composition of the background is indicated.

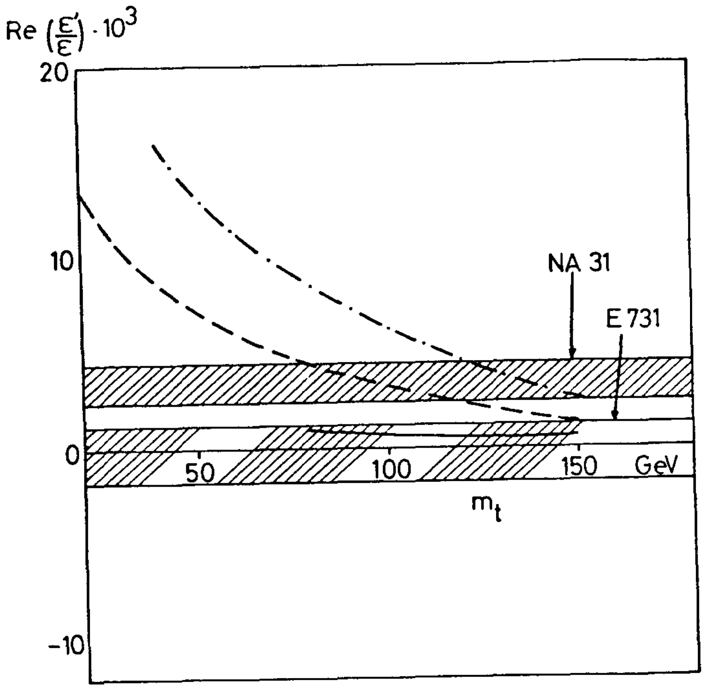

Fig.6 Theoretical predictions for ϵ'/ϵ as a function of the top quark mass . Solid line Ref.4,dotted (dash-dotted) line Ref.11 with B= 2/3 (1/3).

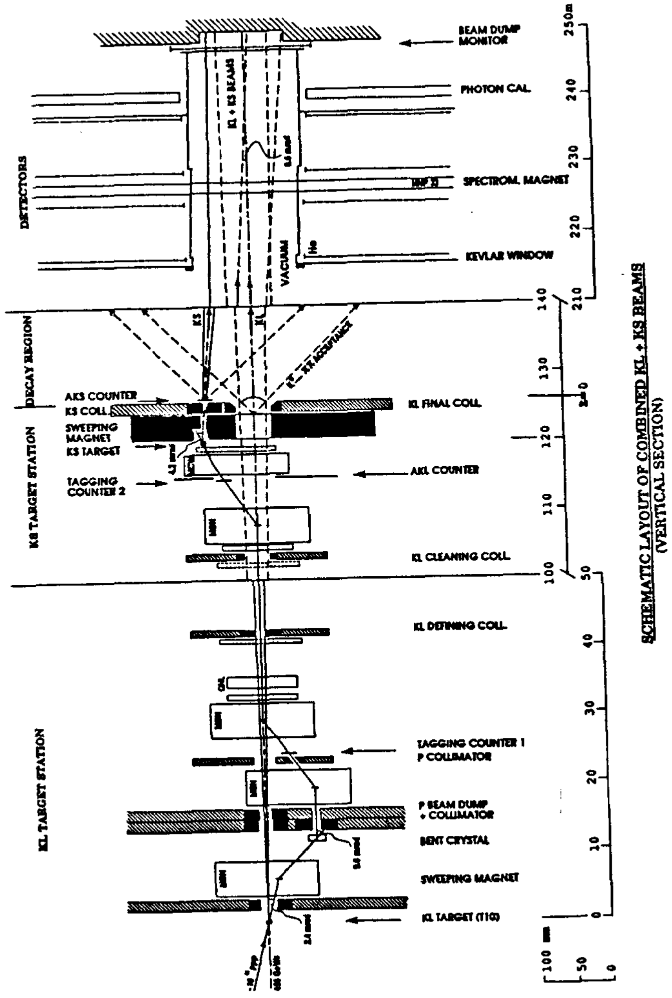

Fig.7 Layout of a proposed SPS -experiment for a measurement of ϵ'/ϵ .

Tab.1 Systematic uncertainties on the double ratio (in %)

background subtraction for $K_L \to 2\pi^0$	0.2
background subtraction for $K_L \to \pi^+\pi^-$	0.2
$2\pi^0/\pi^+\pi^-$ difference in energy scale	0.3
regeneration in the K_L beam	< 0.1
scattering in the K_S beam	0.1
K_S anticounter inefficiency	< 0.1
difference in K_S/K_L beam divergence	0.1
calorimeter instability	< 0.1
Monte Carlo acceptance	0.1
gains and losses by accidentals	0.2
pretrigger and trigger inefficiency	0.1
total systematic uncertainty	± 0.5%

3. Measurement of ϕ_{00} and $\phi_{+-}$by NA31

An initial K^0 particle decays to two pions with a rate proportional to

$$\exp(-\Gamma_S t) + 2|\eta| \exp(-\Gamma_S/2\,t)\cos(\Delta m t - \phi) + |\eta|^2 \exp(-\Gamma_L t), \qquad (21)$$

because of the different time evolution of K_S and K_L in the initial wave function. The sign of the interference term changes for a $\bar{K}^0$ initial state. The phase
ϕ_{00} (or ϕ_{+-}) can be extracted from the observed interference pattern behind a proton target, in which K^0 and $\bar{K}^0$ are produced incoherently with different rates. The NA31 group measured[13] the individual phases, ϕ_{00} and ϕ_{+-}, and the phase difference $\phi_{00} - \phi_{+-}$, from the interference behind a target. To be independent of Monte Carlo detection efficiency calculations, data were taken with two different target positions (L=48m and L=33m in front of the collimator) corresponding to an average phase difference of $\pi/2$. Frequent changes, about once per day, between Near and Far runs assure approximately the same running conditions. For each decay point there are two sets of data. For a given K^0 momentum the ratio of Near and Far data can be calculated directly from ( ) , independent of acceptance. Figure 8 shows this ratio, as a function of the decay point position , for three different momenta. The ratio approaches the value $\exp(-\Delta L/\gamma\beta\tau_S)$ at early life times, and unity at late times. The data show a clear interference pattern, from which the cos term can be isolated (Fig.9).The results are summarized, together with a recent measurement[14] of the E731 group, in Tab.2. The phase difference is compatible with zero; there is no evidence for CPT– violation in the decay amplitude A_2.

There is , however, in the NA31 experiment, a 1.5 standard deviation discrepancy between ϕ_{+-} and ϕ_ϵ, which relates to a possible CPT- violation in the state. Since ϕ_{+-} and Δm are strongly correlated in this experiment, the correlation is explicitely shown in Fig.10. A similar discrepancy was observed in the most precise previous experiment [15] on ϕ_{+-}. It is desirable to clarify this point by more precise determinations of ϕ_{+-} and Δm.

Meanwhile, the NA31 result on ϕ_{+-} and ϕ_{00} can be used [13] to give an upper limit

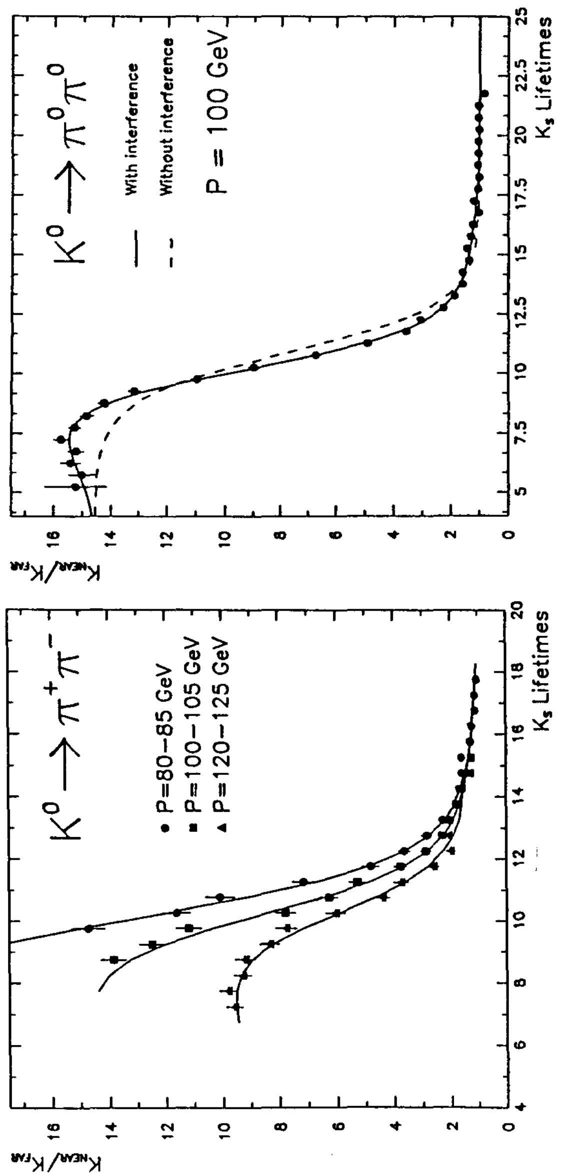

Fig.8 Ratio of Near and Far data as a function of proper time, calculated from a fixed point between the two targets. In b) the data are normalized to a momentum of 100 GeV.

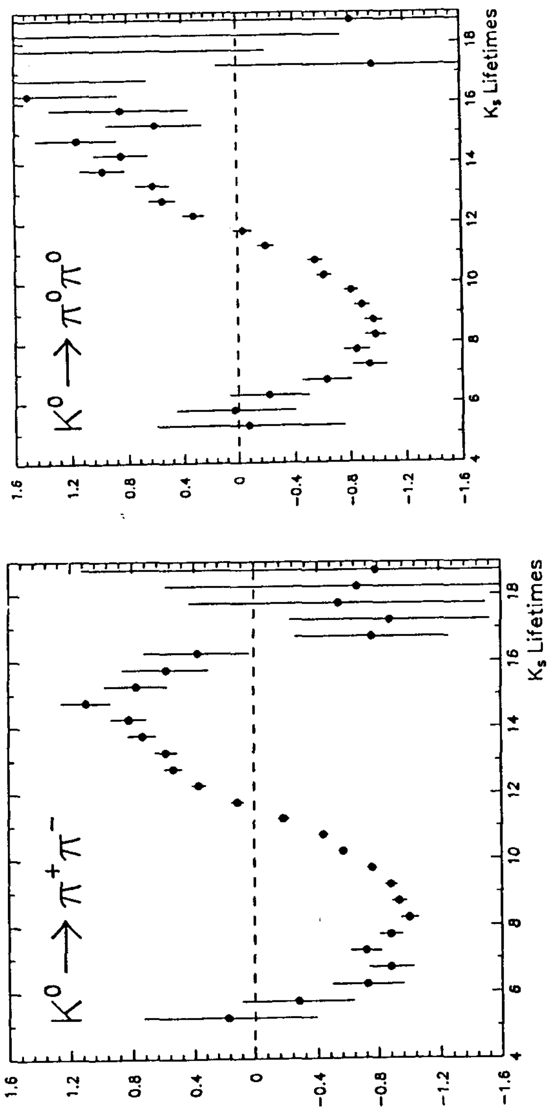

Fig.9 $K_L - K_S$ interference terms in neutral and charged decay modes.

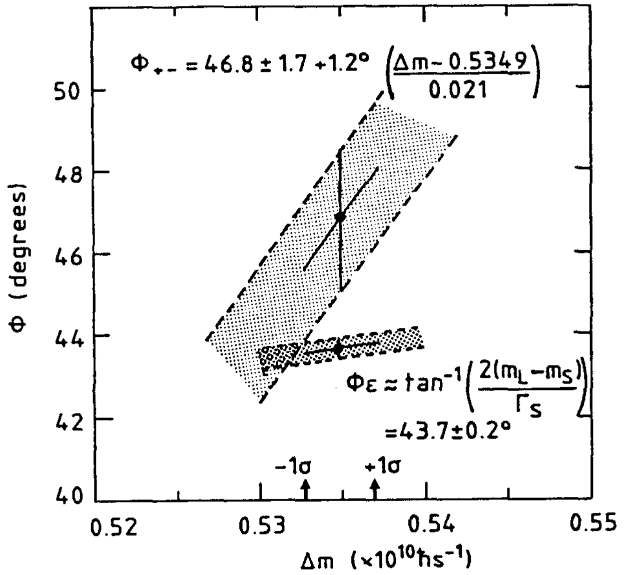

Fig.10 Correlation between ϕ_{+-} and Δm from NA31.

Tab.2 Phase measurements

	NA31	E731
ϕ_{+-}	$(46.8 \pm 1.4 \pm 0.7)^0$	$(47.7 \pm 2.0 \pm \cdots)^0$
ϕ_{00}	$(47.1 \pm 2.1 \pm 1.0)^0$	$(47.4 \pm 1.4 \pm \cdots)^0$
$\phi_{00} - \phi_{+-}$	$(0.3 \pm 2.6 \pm 1.0)^0$	$(-0.3 \pm 2.4 \pm 1.2)^0$

The errors are the statistical (1^{st}) and the systematic (2^{nd}) error

for CPT- violation in the state. The value

$$\delta_\perp = (1.3 \pm 0.8) \cdot 10^{-4} \qquad (22)$$

$$\delta_\perp < 2.6 \cdot 10^{-4} \text{ at } 90\% \text{ C.L.} \qquad (23)$$

$$\text{implies} \quad \left| \frac{M_{K^0} - M_{\bar{K}^0}}{M_{K^0}} \right| < 5 \cdot 10^{-18} . \qquad (24)$$

4. The decays $K_L^0 \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \gamma\gamma$

As a possible way to observe CP- violation, both direct and indirect, in another channel, the decay $K_L^0 \to \pi^0 e^+ e^-$ has been much discussed [16]. If the intermediate state to which e^+ and e^- couple, is a one photon state, the decay is forbidden by CP conservation (the decay $K_S \to \pi^0 e^+ e^-$ is allowed). With a two-photon intermediate state, however, the decay is allowed by CP. If the two photons are in a state with total angular momentum J=0, the coupling to e^+e^- vanishes in the limit of zero lepton mass, and is negligiable (BR≈ 10^{-14}) for electrons. There is however the possibility[17] that a two-photon intermediate state with nonzero angular momentum can be formed by " vector-dominance"- diagrams, in which case the CP- conserving contribution to $K_L \to \pi^0 e^+ e^-$ could be substantial.

A first measurement[18] of $K_L \to \pi^0 \gamma\gamma$ by the NA31 group excludes that possibility, by giving an upper limit to the vector - dominance type coupling.

To isolate the decay from a large background of $K_L \to 3\pi^0$, in which one of the photons misses the detector and the other overlaps in space with another photon, the fiducial decay region was limited to the first 20m behind the collimator. Decays with the correct signature are mostly compatible with estimated background from $K_L \to 3\pi^0$ decays upstream of the collimator with a photon lost in the collimator. This background , which peaks at the downstream end of the decay region, can be removed by requiring that no two photons in the observed event are kinematically compatible with a π^0 from a decay in the interval between 7m upstream of the reconstructed vertex and 15m upstream of the end of the collimator. To include the cases in which two photons from two different π^0's overlap, the overlap is undone, sharing the energy such that two π^0's from a common vertex can be formed. All 12 possibilities of such a configuration are tested. Only a third of the geometrically accepted $K_L \to \pi^0 \gamma\gamma$ decays are expected to survive this cut, but the background is almost completely removed (Fig.11).

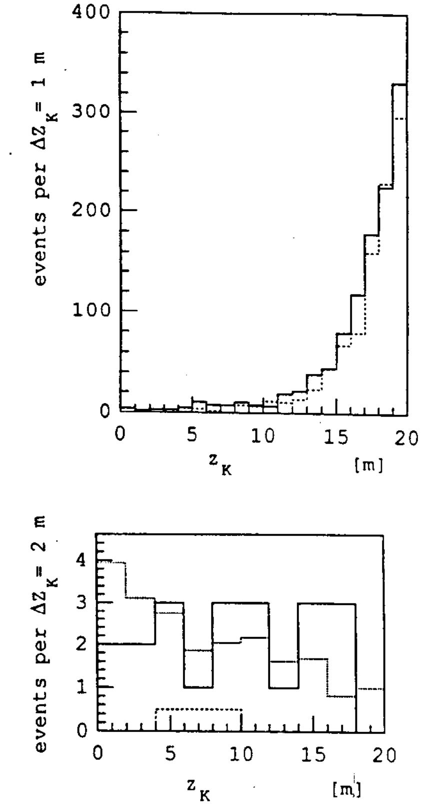

Fig.11 a) Vertex of $K_L \to \pi^0 \gamma\gamma$ candidates with expected background (dashed line) b) same as a) after cuts (see text).
The dotted line is the expected signal distribution.

Evidence for a signal comes from the $\gamma_1\gamma_2$ invariant mass distribution(Fig.12). The invariant masses of the other two photons, γ_3 and γ_4, peak at the highest allowed values, in agreement with expectation from chiral perturbation theory [19]. The experimental branching ratio for $K_L \to \pi^0\gamma\gamma$ into final states with $m_{\gamma\gamma}$ >280 MeV is $((2.1\pm0.6)\cdot10^{-6}$, not incompatible with the theoretical prediction[19] $0.67\cdot10^{-6}$.In contrast to a model, which includes also a vector-dominance term, no signal is observed at low $\gamma_3\gamma_4$ masses, limiting the vector coupling constant to $-0.3 < a_V < 0.5$. Since the branching ratio for the $K_L \to \pi^0e^+e^-$ decay is given by BR $=4.4\cdot10^{-12}|a_V|^2$, this result corresponds to a BR$< 1.1\cdot10^{-12}$, an order of magnitude below the expected contributions from direct or indirect CP-violation.

The best experimental upper limit [20] is BR$(K_L \to \pi^0e^+e^-) < 5.5\cdot10^{-9}$. A serious background to the decay is from radiative Dalitz decays ($K_L \to e^+e^-\gamma\gamma$ with BR $\approx 6\cdot10^{-7}$), as discussed recently in Ref.21. This background makes an experiment on $K_L \to \pi^0e^+e^-$ indeed very difficult.

5. CP - LEAR

A new method of production of neutral Kaons with known strangeness was proposed [22] by the CP-LEAR collaboration. The method is to stop antiprotons in a thin hydrogen gas target and measure the reactions

$$p\bar{p} \to \bar{K}^0K^+\pi^-$$

$$p\bar{p} \to K^0K^-\pi^+ \ ,$$

which have a branching ratio of $\approx 10^{-3}$. This is sufficiently large for CP- violation studies, if $2\cdot10^6$ stopping $\bar{p}$/sec from LEAR are available. The strangeness of the initial K^0 is tagged by the strangeness of the charged K. The asymmetry between K^0 and $\bar{K}^0$, proportional to the interference term in (21), can be used to measure the CP - violation parameters. The asymmetry

$$\begin{aligned} A_{+-} &= \frac{R(K^0 \to \pi^+\pi^-) - R(\bar{K}^0 \to \pi^+\pi^-)}{R(K^0 \to \pi^+\pi^-) + R(\bar{K}^0 \to \pi^+\pi^-)} & (25) \\ &= 2\frac{|\eta_{+-}|\exp(-\gamma_S/2t)\cos(\Delta mt - \phi_{+-}}{\exp(-\gamma_S t) + |\eta_{+-}|^2\exp(-\gamma_L t)} - 2Re\,\epsilon & (26) \end{aligned}$$

shown in Fig.13 ,can be used to measure η_{+-},ϕ_{+-} and Δm. The corresponding asymmetry A_{00} is measured with somewhat larger errors $(0.5\tau_S)$ on the vertex. A direct comparison of the fitted values of η_{+-} and η_{00} may therefore be limited by systematic errors. These can be avoided if one compares instead the time integrated rates. With

$$R = \int_0^T R(t)dt, \qquad T \approx 20\tau_S \tag{27}$$

one obtains for the time integrated asymmetries:

$$\begin{aligned} I_{00} &= 4Re\,\eta_{00} - 2Re\,\epsilon & (28) \\ I_{+-} &= 4Re\,\eta_{+-} - 2Re\,\epsilon & (29) \\ \frac{I_{00}}{I_{+-}} &= 1 - 6Re\,(\epsilon'/\epsilon). & (30) \end{aligned}$$

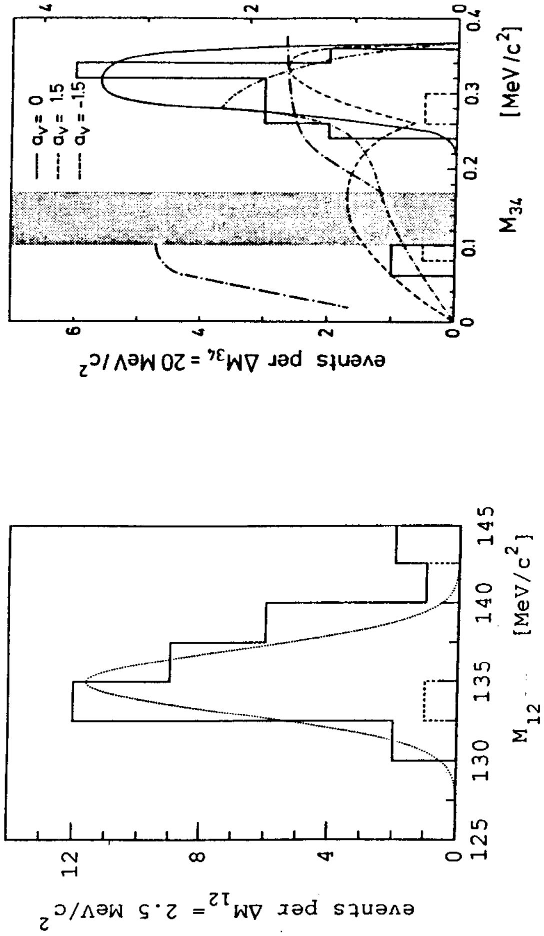

Fig.12 a) Invariant $m_{\gamma\gamma}$ distribution of π^0 candidates in $K_L \to \pi^0\gamma\gamma$.
b) Invariant mass of 3^{rd} and $4^{th}\gamma$ in $K_L \to \pi^0\gamma\gamma$ compared with various models. The acceptance is given by the wide dash- dotted line.

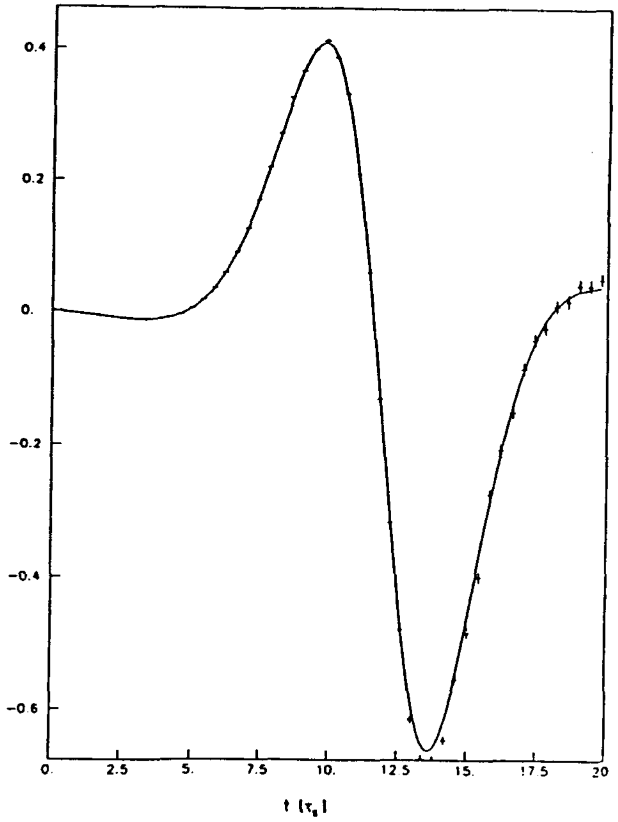

Fig.13 Expected asymmetry of $K \rightarrow \pi^+\pi^-$ decays in the CP -LEAR experiment.

Tab.3 Expected errors in CP- LEAR

	error	present value
η_{+-}	$3.5 \cdot 10^{-6}$	$(2.27 \pm 0.02) \cdot 10^{-3}$
η_{00}	$5 \cdot 10^{-6}$	$(2.26 \pm 0.02) \cdot 10^{-3}$
ϵ'/ϵ	$1.5 \cdot 10^{-3}$	$(2.1 \pm 1.0) \cdot 10^{-3}$
ϕ_{+-}	0.1^0	$(46.0 \pm 1.3)^0$
ϕ_{00}	0.17^0	$(47.5 \pm 2.2)^0$
Δm	$0.001 \cdot 10^{10}\hbar/s$	$(0.535 \pm 0.0022) \cdot 10^{10}\hbar/s$
η_{+-0}	$< 0.6 \cdot 10^{-3}$	< 0.12

In a cylindrical detector (see Figs.14 and 15) around the gas target charged particles are measured by tracking with drift chambers and identified by means of time of flight and liquid Cerenkov counters; photons are detected in a calorimeter made of lead plates interleaved with streamer tubes. The apparatus will be complete in the fall of 1990. A first look at the charged decays reveals a nice K^0 signal (Fig.16), with some background, which undoubtedly will be better understood as the analysis progresses.

The experiment should be ideally suited to look for the CPT- violating effect mentioned earlier, which implies a measurement of ϕ_{+-} and Δm. It will also be sensitive enough to observe CP- violation in the K_S system, by looking at $K_S \rightarrow \pi^+\pi^-\pi^0$. The expected statistical accuracies for a total exposure of $2 \cdot 10^{13}$ $\bar{p}$ are compared with the present values of the parameters in Tab.3.

Acknowledgements

It is a pleasure to thank the organizers of the SLAC Summer Institute, Profs. G.Feldman and D.Leith for a very enjoyable meeting . I am very greatful to Prof. P.Pavlopoulos for various discussions on the LEAR experiment. I also would like to take the opportunity to thank my colleagues from NA31 for a very fruitful collaboration over many years.

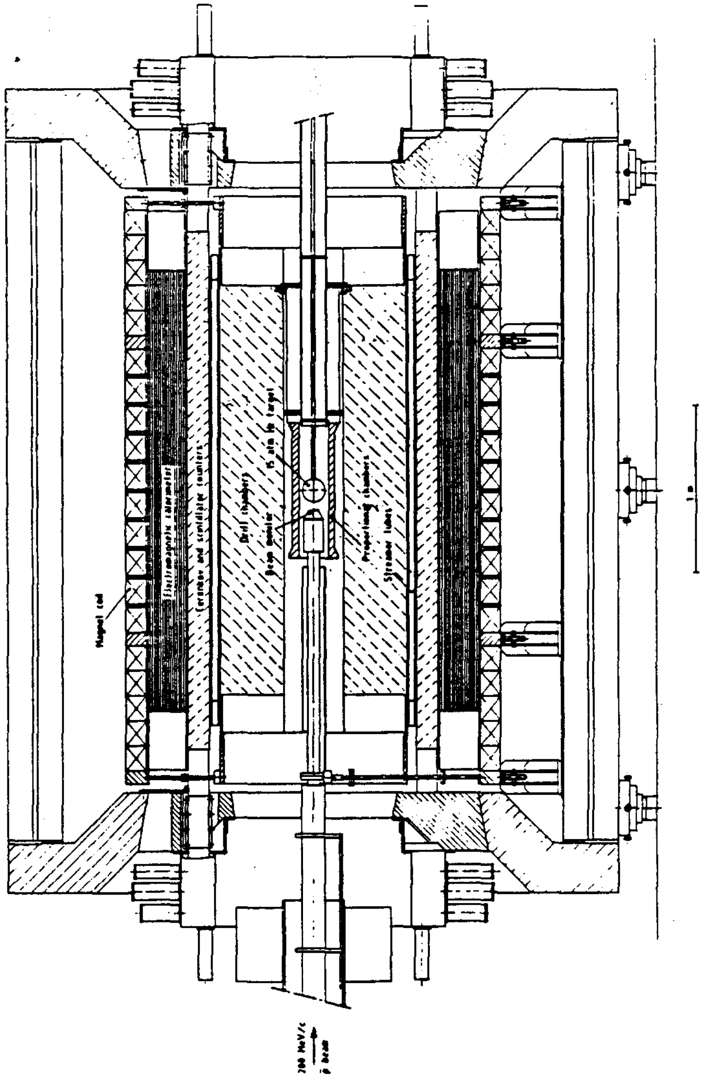

Fig.14 Side view of the CP-LEAR detector.

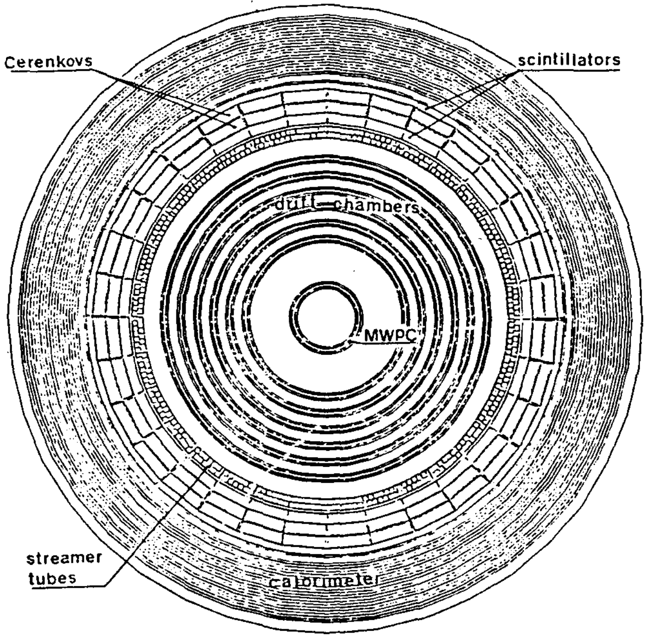

Fig.15 End view of the CP-LEAR detector.

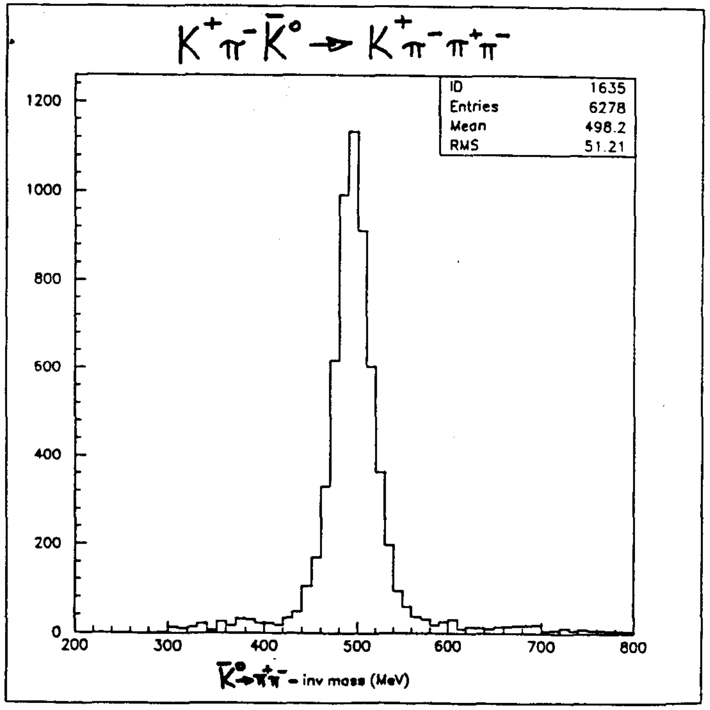

Fig.16 First signal of $K \to \pi^+\pi^-$ decays in CP-LEAR.

References

1. L.Wolfenstein, *Phys. Rev. Lett.* **13** (1964),562
2. M.Kobayashi and K.Maskawa, *Progr. Theor. Phys.* **49**(1973),652
3. M.F.Losty et al.,*Nucl. Phys.* **B69**(1974),185
   P.Estabrooke and A.D.Martin, *Nucl. Phys.* **D79** (1974),301
   N.N.Biswas et al.,*Phys.Rev. Lett.* **47** (1981), 1378
4. J.M.Flynn and L.Randall, *Phys. Lett.* **B224**(1989),221
   G.Buchalla, A.J.Buras and M.K.Harlander, MPI-PAE/Pth 63/89 and TUM-T31-3/89 (1989)
5. G.Zech, Observation of Direct CP-Violation and Status of the $\phi_{00} - \phi_{+-}$ Measurement in the NA31 Experiment at CERN, *Proceedings of the 1988 SLAC Summer Institute on Particle Physics*
   H.Wahl, in Ref.15
   D.Fournier, NA31 Results on CP- Violation in K-Decays and Test of CPT *Proceedings of the* 14th *International Synmposium on Lepton and Photon Interactions, Stanford, 7-12 Aug. 1989*
6. H.Burkhardt et al., *Nucl. Instr. Meth.* **A268**(1988),116
7. H.Burkhardt et al., *Phys. Lett.* **B206**(1988),169
8. G.D.Barr et al., *Nucl. Instr. Meth.*, to be published
9. J.R.Patterson et al., *Phys. Rev. Lett.* **64**(1990),1491
10. C.S.Kim,J.L.Rosner and C.-P.Yuan, *Phys. Rev.* **D 42**(1990),96
    G.Altarelli and P.Franzini, CERN-TH 4914/87
11. F.J.Gilman and J.S. Hagelin, *Phys. Lett.* **B133**(1983),443
12. G.D.Barr et al., CERN/SPSC/90-22
13. R.Carosi et al., *Phys. Lett.* **B237**(1990),303
14. M.Karlsson et al., *Phys. Rev. Lett.* **64**(1990),2976
15. C.Geweniger et al., *Phys. Lett.* **B52**(1974),119; see also
    H.Wahl, Cisatlantic Rare Kaon Decays,*Proceedings of the Rare Decay Symposium, Vancouver, December 1988* and CERN-EP/89-86
16. C.O.Dib, I.Dunietz and F.J.Gilman , *Phys. Lett.* **B218**(1989), 487; *Phys. Rev.* **D 39**(1989),2693
17. L.M.Sehgal,*Phys. Rev.* **D 38**(1988),808
18. G.D.Barr et al., *Phys. Lett.* **B242**(1990),523

19. G.Ecker, A.Pich and E. de Rafael, *Phys. Lett.* **B189**(1987),363; G.Ecker and A.Pich, *Phys. Lett.* **B237**(1990),481

20. K.E.Ohl et al., *Phys. Rev. Lett.* **64** (1990),2755

21. H.B.Greenly , *Phys. Rev. D, to be published*

22. CP-LEAR collaboration, proposal: CERN/PSCC/85-6, addendum :CERN/PSCC/85-30