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THE PHYSICS POTENTIAL OF THE ELECTRON–POSITRON COLLIDER *DAΦNE*

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The physics to be pursued at the electron–positron collider *DAΦNE* in Frascati with the detectors *DEAR*, *FINUDA* and *KLOE* is addressed, with particular emphasis on the test of discrete symmetries in the neutral kaon system, measurements of cross sections of hadron production following electron–positron annihilation and tests of chiral perturbation theory to be carried out with *KLOE* and *DEAR*.

Keywords: Discrete symmetries; *CP*-violation; Kaon decays; Hadronic contribution to vacuum polarisation; Tests of chiral perturbation theory; Storage ring *DAΦNE*; Detectors *DEAR*; *FINUDA* and *KLOE*

INTRODUCTION

The symmetric collider *DAΦNE* accelerates and stores electrons and positrons of 510 MeV to produce ϕ-mesons with the mass 1020 MeV/c^2 and the quantum numbers $J^{PC} = 1^{--}$ *via* the reaction $e^+e^- \rightarrow \gamma^* \rightarrow \phi$. The ϕ-mesons decay mainly into charged and neutral kaon pairs K^+K^- (branching ratio BR = 49.5%) and $K^0\bar{K}^0(K_SK_L)$ ($BR = 34.3\%$), but also into $\rho\pi$ and $\pi^+\pi^-\pi^0$ ($BR = 15.5\%$), $\eta\gamma$ ($BR = 1.3\%$), $\eta'\gamma$ ($BR = 1.2 \cdot 10^{-4}$). The neutral kaon pairs are produced in a well defined quantum and kinematical state with charge

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parity $C = -1$:

$$|K^0\bar{K}^0\rangle = \frac{1}{\sqrt{2}}(K^0_{\vec{p}}\bar{K}^0_{-\vec{p}} - \bar{K}^0_{\vec{p}}K^0_{-\vec{p}})$$
$$\approx \frac{1}{\sqrt{2}}(K^L_{\vec{p}}\bar{K}^S_{-\vec{p}} - \bar{K}^S_{\vec{p}}K^L_{-\vec{p}}).$$

The kaons are monochromatic (the momentum of the charged kaons is 127 MeV/c and that of the neutral ones 110 MeV/c) and are emitted back-to-back to be detected in an almost backgroundfree environment. Absolutely unique to *DAΦNE* is the possibility to study interferometric patterns of neutral kaons and the tagging of K_S (or K^0) by its K_L (or $\bar{K}^0$) companion and *vice versa* as well as the tagging of K^+ by K^- (and *vice versa*) facilitating the investigation of rare K_L and K_S as well as K^+ and K^- decays.

With a design luminosity of $\mathcal{L} \approx 5 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1} = 5 \cdot 10^2\,\mu\mathrm{b}^{-1}\,\mathrm{s}^{-1}$ corresponding to an integrated luminosity of $\int_{1\,\mathrm{techn.year}} L dt = 10^7\,\mathrm{s} \cdot 5 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1} = 5 \cdot 10^6\,\mathrm{nb}^{-1}$ (1 'technical' year to be taken as 10^7 s) $2 \cdot 10^{10}$ ϕ-mesons will be produced decaying into 10^{10} charged kaon pairs and $0.7 \cdot 10^{10}$ neutral kaon pairs. In the light of those numbers it seems to be justified to call *DAΦNE* [2] a 'ϕ-factory' or 'strangeness producing factory'. *DAΦNE* has two interaction regions. At present *DEAR* [3] is located in one of them to be replaced by *FINUDA* [4] in a later stage. In the second one *KLOE* [5] has been installed. *DEAR* (*DAΦNE Exotic Atoms Research*) has been designed to measure the shift and width of the $2p - 1s$ X-ray transition of kaonic hydrogen and kaonic deuterium. *FINUDA* (*FIsica NUcleare at DAΦNE*) will investigate the production, weak decays, life times and spectroscopy of hypernuclei. *KLOE* (*K LOng Experiment*) is a universal detector to study all kinds of K, ϕ, ρ, η, η' decays emphasising tests of discrete symmetries (CP-, CPT-, T-invariance), measurements of hadronic cross sections and tests of chiral perturbation theory (χPT). Due to the possibility to test χPT in a large number of decay modes *DAΦNE* has also been called a '*chiral*' machine [6].

K-PHYSICS

Kaons played always a crucial role in particle physics and led to fundamental discoveries. The observation of the so called *associated* *production* $\pi^- \rho \rightarrow \Lambda K$ inspired the introduction of a third (*flavour*) quantum number *strangeness*. *Strange* was the copious production of Λ hyperons (by the strong interaction) compared to their relatively long lifetime of 10^{-10} s (driven by the weak interaction). For the first time particle–antiparticle oscillations $\bar{K}^0 \Leftrightarrow K^0$ have been observed with neutral kaons. The '$\theta - \tau$ puzzle' observed in the decays of K^+ into 2 and 3 pions gave rise to the fall of parity and led finally to the discovery of the V-A structure of weak interactions. The quark model with the underlying group $SU_F(3)$ was formulated including the strange particles. The idea of chiral symmetry $SU_L(3) \otimes SU_R(3)$ was born (see below) and its spontaneous breaking into $SU_F(3)$. The light pseudoscalar particles π, K, η, (η') have been identified as the bosonic excitations (Goldstone bosons) of the spontaneous breaking of chiral symmetry. By comparing the strength of π and K decays the Cabibbo angle θ_c has been defined and the first step was done of establishing the more complete Cabibbo-Kobayashi-Maskawa Matrix. It turned out that the mass eigenstates of the *up* and *down* quarks are not the eigenstates of the weak interaction, but rather the quark doublet

$$\begin{pmatrix} u \\ d_c \end{pmatrix} = \begin{pmatrix} u \\ d\cos\theta_c + s\sin\theta_c \end{pmatrix}.$$

The extremely small branching ratio of $7 \cdot 10^{-9}$ observed for the decay $K_L \rightarrow \mu^+ \mu^-$ indicated that there exist no flavour changing neutral currents in nature. This could be understood by the *GIM* mechanism necessitating the existence of a second quark doublet and thus predicting the fourth (flavour) quantum number *charm*

$$\begin{pmatrix} c \\ s_c \end{pmatrix} = \begin{pmatrix} c \\ -d\sin\theta_c + s\cos\theta_c \end{pmatrix}.$$

CP-violation finally required the existence of a third generation of fermions and in particular the fifth and sixth (flavour) quantum numbers bottom and top. The weak eigenstates are given by the Cabibbo-Kobayashi-Maskawa Matrix (*CKM*)$\mathcal{V}$

$$\begin{pmatrix} d_c \\ s_c \\ b_c \end{pmatrix} = \mathcal{V} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

with

$$\mathcal{V} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & A\lambda^2 & 1 \end{pmatrix}$$
$$\approx \begin{pmatrix} 0.9751 & 0.221 & |0.0035| \\ 0.221 & 0.9743 & 0.041 \\ |0.009| & 0.040 & 0.9991 \end{pmatrix}$$

which is a very special unitary matrix with 4 real parameters (where the imaginary part $\eta \neq 0$ is responsible for CP-violation). It is almost diagonal, almost symmetric, while the matrix elements get smaller moving away from the diagonal. The matrix connects intimately CP-violation to basic questions of the standard model *SM*: *Why there are families*? *Why there are three*? *Why there are so different fermion masses*?

TESTS OF DISCRETE SYMMETRIES (*CP*- , *T*- AND *CPT*-INVARIANCE)

The main goal of the experiments at $DA\Phi NE$ are tests of discrete symmetries, *i.e.*, tests of CP-, T- and CPT-invariance [1, 7–10]. CP-violation is the least tested corner of the *SM* and its potential source is the Yukawa sector, the interaction of the fermions with the Higgs particles. CP-violation might be a reflection of physics at much higher energies, at the Grand Unification scale of $\approx 10^{15}$ GeV or even at the higher Planck scale of $\approx 10^{19}$ GeV. It might also be the origin of the asymmetric distribution of matter and antimatter in the Universe. The existence of CP-violation allows us to distinguish matter and antimatter, left and right without any convention and even defines an arrow of time, if CPT-invariance holds. The former is immediately seen remembering that the long living K_L decay more frequently into positrons than into electrons. If T invariance is violated, the principle of detailed balance does no hold:

$$K^0 \Rightarrow \bar{K}^0 \neq \bar{K}^0 \Rightarrow K^0.$$

The neutral kaon system is a very peculiar one. K^0 and $\bar{K}^0$ are not *CP*-eigenstates, but rather the linear combinations $K_1 = \frac{1}{\sqrt{2}}(K^0 + \bar{K}^0) \approx K_S$ and $K_2 = \frac{1}{\sqrt{2}}(K^0 - \bar{K}^0) \approx K_L$, being the short and long living neutral kaons with exponential decay laws and *CP*-eigenvalues of $+1$ and -1, respectively. With *CP*- and *CPT*-violation these wave functions are given by

$$
\begin{aligned}
|K_S\rangle &\approx \frac{1}{\sqrt{2}}[(1 + (\varepsilon_K + \delta_K))|K^0\rangle + (1 - (\varepsilon_K + \delta_K))|\bar{K}^0\rangle] \\
&= |K_1\rangle + (\varepsilon_K + \delta_K)|K_2\rangle \\
|K_L\rangle &\approx \frac{1}{\sqrt{2}}[(1 + (\varepsilon_K - \delta_K))|K^0\rangle - (1 - (\varepsilon_K - \delta_K))|\bar{K}^0\rangle] \\
&= |K_2\rangle + (\varepsilon_K - \delta_K)|K_1\rangle
\end{aligned}
$$

ε_K and δ_K are small complex numbers characterising unequal admixtures of K^0 and $\bar{K}^0$ to the K_S and K_L states. *CP*-conservation would mean: $\varepsilon_K = 0$ and *CPT*-conservation: $\delta_K = 0$.

If *CP*-conservation would hold the *CP*-even kaons $K_1 \approx K_S$ would decay exclusively into a *CP*-even state with *two* pions, while the *CP*-odd kaons $K_2 \approx K_L$ would decay exclusively into a *CP*-odd state with *three* pions. A decay of K_L into *two* pions obviously violates *CP*-invariance. This observation is known since more than 35 years. It has been found in hadronic and semileptonic decays: $K_L \to \pi^+\pi^-, K_L \to \pi^0\pi^0, K_L \to \pi^\pm \ell^\mp \nu(\ell = e, \mu)$. The only dynamical information, however, yielded after almost 4 decades of great efforts, are the moduli $|\eta_{+-}|$ and $|\eta_{00}|$ of the amplitude ratios

$$
\begin{aligned}
\eta_{+-} &= \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} = |\eta_{+-}|e^{i\phi_{+-}} = \varepsilon_K - 2\varepsilon' \quad \text{and} \\
\eta_{00} &= \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} = |\eta_{00}|e^{i\phi_{00}} = \varepsilon_K + \varepsilon'.
\end{aligned}
$$

The values are $|\eta_{+-}| = (2.285 \pm 0.019) \cdot 10^{-3}$ and $|\eta_{00}| = (2.275 \pm 0.019) \cdot 10^{-3}$. The phases $\phi_{+-} = (43.5 \pm 0.6)^\circ$ and $\phi_{00} = (43.4 \pm 1.0)^\circ$ agree within the error bars and with the so called superweak phase $\phi 1;_{sw} = \arctan(2\Delta m/\Delta\Gamma) = (43.44 \pm 0.09)^\circ$, therefore not revealing new information on *CP*-violation ($\Delta m = m_L - m_S$ and $\Delta\Gamma = \Gamma_S - \Gamma_L$).

The value for the charge asymmetry observed in semileptonic decays

$$\begin{aligned}\mathcal{A}_L = 2\mathrm{Re}\varepsilon_K &= \frac{\Gamma(K_L \to \pi^- \ell^+ \nu) - \Gamma(K_L \to \pi^+ \ell^- \bar{\nu})}{\Gamma(K_L \to \pi^- \ell^+ \nu) + \Gamma(K_L \to \pi^+ \ell^- \bar{\nu})} \\ &= (3.27 \pm 0.12) \cdot 10^{-3}\end{aligned}$$

does not provide new information. The value of ε_K measures *CP*-violation in oscillations between K^0 and $\bar{K}^0$ (traditionally called 'indirect' *CP*-violation): the oscillation probability $K^0 \Rightarrow \bar{K}^0$ is different from that of $\bar{K}^0 \Rightarrow K^0$, being of 2nd order in the weak interaction with a total change of strangeness $\Delta S = 2$ (Fig. 1), while the value of ε' measures *CP*-violation in the decay amplitude with $\Delta S = 1$ ('direct' *CP*-violation). Indirect *CP*-violation can be ascribed to an admixture of $\varepsilon_K \cdot K_1$ with the 'wrong' *CP*-eigenvalue to the K_2 state (or $\varepsilon_K K_2$ to the K_1 state). Hence, $A(K_L \to \pi\pi) = \varepsilon_K A(K_1 \to \pi\pi) \cong \varepsilon_K A(K_s \to \pi\pi)$ and $\eta \approx \varepsilon_K$. The *direct* *CP*-violation can be expressed *e.g.*, as the *direct* decay of *CP*-odd K_2 into a *CP*-even final state $A(K_2 \to \pi\pi) \neq 0$ without preceding oscillations. In the *SM* it is described by so called electroweak and gluonic penguin graphs (Fig. 2). There need

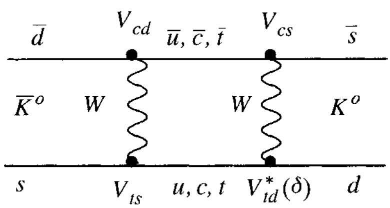


FIGURE 1 Oscillations (mixing) of K^0 into $\bar{K}^0$ and *vice versa* occur due to 2nd order weak interactions. The complex matrix element $V^*_{td}(\delta)$ is responsible for '*indirect*' *CP*-violation with a change of strangeness by two units $\Delta S = 2$.

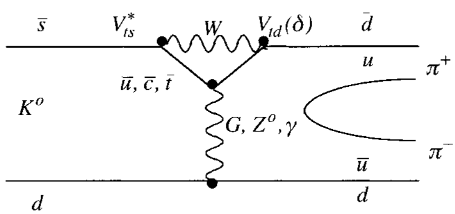


FIGURE 2 Penguin graphs are responsible for '*direct*' *CP*-violation in the amplitudes due to 1st order weak interaction with $\Delta S = 1$.

to be two interfering amplitudes: in the case of *two pions in the final state* an interference of two weak decay amplitudes A_0 and A_2 with different CP-violating weak phases ϕ_0 and ϕ_2 is required where the indices denote the *isospin* $I=0$ and $I=2$ of the two pions.

$$2\Re e\varepsilon' = \sqrt{2}\sin(\delta_0-\delta_2)\frac{\Re eA_2}{\Re eA_0}\underbrace{\begin{pmatrix} \dfrac{\overbrace{\mathcal{I}mA_2}^{Z^0 orphoton penguin = \tan\phi_2}}{\Re eA_2} & - & \dfrac{\overbrace{\mathcal{I}mA_0}^{gluon penguin = \tan\phi_0}}{\Re eA_0} \end{pmatrix}}_{=0, if \phi_0 - \phi_2}$$

To summarise, there exist various ways to violate CP-invariance: the *indirect* CP-violation in oscillations (or mixing) with $\Delta S=2$, the direct CP-violation in the decay amplitudes with $\Delta S=1$ and mixing induced CP-violation as an interference between mixing and decay

$$\varepsilon = \varepsilon_K + i\frac{\mathcal{I}mA_0}{\Re eA_0} = \varepsilon_K + i\tan\phi_0$$

The measurement of ε' has a long history, yielding in a first round of experiments (*CERN NA*31 and *Fermilab E*731) contradictory results which only recently have been better converging (*Fermilab KTeV* and *CERN NA* 48):

$$\begin{array}{ll}
\Re e\varepsilon'\varepsilon = (23.0 \pm 6.5)\cdot 10^{-4} & CERN - NA31 1993[11] \\
\Re e\varepsilon'\varepsilon = (7.4 \pm 5.9)\cdot 10^{-4} & Fermilab E731 1993[12] \\
\Re e\varepsilon'\varepsilon = (15.0 \pm 8.0)\cdot 10^{-4} & world\ average\ value\ before\ 1999[13] \\
\Re e\varepsilon'/\varepsilon = (28.0 \pm 4.1)\cdot 10^{-4} & Fermilab KTeV 1999[14] \\
\Re\varepsilon'/\varepsilon = (18.5 \pm 7.3)\cdot 10^{-4} & CERN - NA48[15] \\
\Re\varepsilon'/\varepsilon = (12.2 \pm 4.9)\cdot 10^{-4} & CERN - NA48, January 2000[15]
\end{array}$$

KLOE intends to measure $\Re e\varepsilon'/\varepsilon$ with the same accuracy of a few 10^{-4} as is the goal of the *CERN* and *Fermilab* experiments, but with a completely different experimental set-up and consequently different systematic errors. A *finite* value of ε' is indicative for CP-violation within the *SM* (*i.e.*, in the *Cabibbo-Kobayashi-Maskawa matrix*). It rules out the superweak model of CP-violation with an one-step $\Delta S=2$ transition between $\bar{K}^0$ and K^0 in which the value ε' would be zero by definition. The method (as used by the *CERN* and *Fermilab experiments*) to measure ε' is the determination of the double ratio

$$R = \frac{N(K_L \to \pi^+\pi^-)}{N(K_s \to \pi^+\pi^-)} \Big/ \frac{N(K_L \to \pi^0\pi^0)}{N(K_s \to \pi^0\pi^0)}$$

$$= \left|\frac{\eta_{+-}}{\eta_{00}}\right|^2 = \left|\frac{\varepsilon + \varepsilon'}{\varepsilon - 2\varepsilon'}\right|^2 \approx \left|1 + 3\frac{\varepsilon'}{\varepsilon}\right|^2 \approx 1 + 6 \cdot \Re e\frac{\varepsilon'}{\varepsilon}$$

KLOE has been designed to use this method as well as kaon interferometry to be discussed below based, of course, on the same data sample.

KAON INTERFEROMETRY [1, 7–10]

At *DAΦNE* a novel phenomenon can be studied for the first time: interference patterns which arise due to the existence of two amplitudes in the initial quantum state of the neutral K system being produced in the ϕ-decay with the charge parity $C = -1$:

$$|K^0\bar{K}^0\rangle = \frac{1}{\sqrt{2}}(K^0_{\vec{p}}\bar{K}^0_{-\vec{p}} - \bar{K}^0_{\vec{p}}\bar{K}^0_{-\vec{p}}) \approx \frac{1}{\sqrt{2}}(K^L_{\vec{p}}\bar{K}^S_{-\vec{p}} - \bar{K}^S_{\vec{p}}K^L_{-\vec{p}}).$$

The interference patterns depend on the various final states f_i of K_S and K_L decays and on the difference of the proper times $\Delta t = t_1 - t_2$ at which the two kaons decay. The amplitude ratios $\eta_i = (\langle f_i|K_L\rangle / \langle f_i|K_s\rangle) = |\eta_i|e^{-i\phi_i}$ contain all relevant parameters which describe *CP*-violation and possible *CPT*-violation and parameters like Δm, Γ_S, Γ_L as well. In principle also possible effects of quantum gravitation or a violation of the validity of quantum mechanics would reveal in these patterns. With the given initial neutral kaon state the amplitude for the decay of K_S at time t_1 into the final state f_1 and of K_L at time t_2 into f_2 (and *vice versa*) is

$$A(f_1, t_1; f_2, t_2) = \frac{1}{\sqrt{2}}[\langle f_1|K_S(t_1)\rangle\langle f_2|K_L(t_2)\rangle - \langle f_1|K_L(t_1)\rangle\langle f_2|K_S(t_2)\rangle]$$

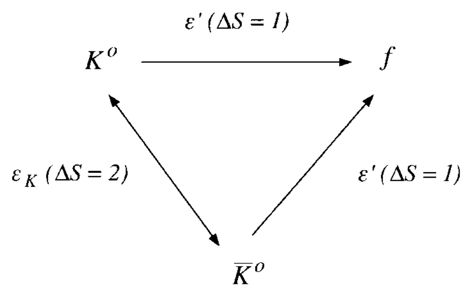
where $|K_{S,L}(t)\rangle = e^{-i\lambda_{S,L}t}|K_{S,L}\rangle$ with $\lambda_{S,L} = m_{S,L} - i/2\Gamma_{S,L}$.

Examples of Kaon Interferences:

1. With identical final states ($f_1 = f_2 = \pi^+\pi^-$) precise values Γ_L, Γ_S, Δm, ϕ_{SW} are determined. For equal proper times ($\Delta t = 0$) the amplitude $A(f_1, t_1; f_1, t_1) = 0$ and the rates are zero at $\Delta t = 0$ and symmetrical around $\Delta t = 0$ (destructive interference):

$$|A(\Delta t)|^2 = \frac{1}{2(\Gamma_S + \Gamma_L)} |\langle \pi^+\pi^- | K_S \rangle|^2 |\langle \pi^+\pi^- | K_L \rangle|^2$$
$$* \{ e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)|\Delta t|} \cos \Delta m \Delta t \}$$

   In this case no information on *CP*-violation is obtained, but tests of quantum mechanics (in the spirit of the Einstein-Podolski-Rosen paradoxon) are possible.
2. With almost identical final states ($f_1 = \pi^+\pi^-$ and $f_2 = \pi^0\pi^0$) $\Re e \varepsilon'$ is obtained for large time differences Δt and $\mathcal{I}m\varepsilon'$ for $|\Delta t| < 5\tau_S$, the latter determining $\phi_{+-} - \phi_{00} \approx 3\mathcal{I}m\varepsilon'/\varepsilon$. The interference is constructive (Fig. 4).
3. For semileptonic decays $f_1 = \pi^-\ell^+\nu$ and $f_2 = \pi^+\ell^-\bar{\nu}$ the *CPT* violating parameters $\Re e\delta_K$ and $\mathcal{I}m\delta_K$ are determined for large time differences and for $|\Delta t| < 5\tau_S$, respectively. The interference is destructive (Fig. 5).
4. For $f_1 = \pi\pi$ and $f_2 = \pi^+\ell^-\bar{\nu}$ or $\pi^-\ell^+\nu$ small time differences yield Δm, $|\eta_{\pi\pi}|$ and $\phi_{\pi\pi}$, while for large time differences tests of *T*- and *CPT*-invariance are possible.



$$\varepsilon = \varepsilon_K + i \frac{\Im m\, A_o}{\Re e\, A_o}$$

FIGURE 3 There are three ways of *CP*-violation: '*indirect*' *CP*-violation in mixing described by ε_K with $\Delta S = 2$, '*direct*' *CP*-violation in the amplitudes described by ε' with $\Delta S = 1$, and mixing induced *CP*-violation as an interference between oscillations and direct decay.

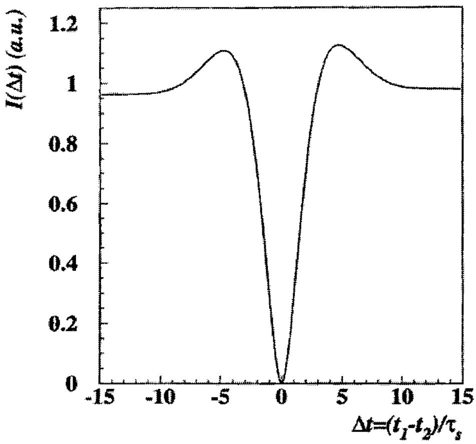


FIGURE 4 Interference pattern of almost identical final states as to be observed in the decay of neutral kaon pairs which have arisen from the decay of ϕ-mesons, where one kaon decays into the final state $f_1 = \pi^+\pi^-$ and the other into the final state $f_2 = \pi^0\pi^0$.

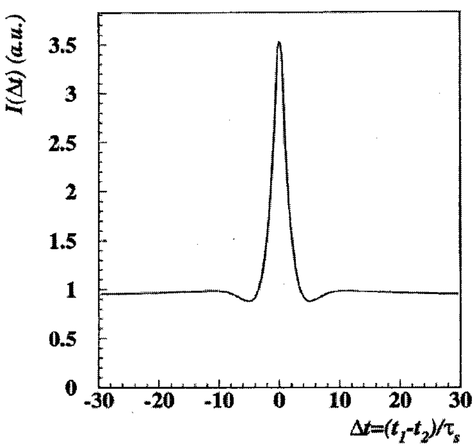


FIGURE 5 Interference pattern of semileptonic decays as to be observed in the decay of neutral kaon pairs which have arisen from the decay of ϕ-mesons, where one kaon decays into the final state $f_1 = \pi^-\ell^+\nu$ and the other into the final state $f_2 = \pi^+\ell^-\bar{\nu}$.

CP-VIOLATION IN K_S AND CHARGED KAON DECAYS

The production of about $5 \cdot 10^9$ K_S/year in an almost backgroundfree environment is absolutely unique to *DAΦNE*. Hence, for the first time the *CP*-violating decay $K_S \to \pi^0\pi^0\pi^0$ with a branching ratio $BR \approx 2 \cdot 10^{-9}$ can be observed. The expected rate is about 15 events per year. The present limit is $BR < 1.9 \cdot 10^{-5}$. Also the '*direct*' *CP*-violation in charged kaon decays $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ ($\tau^{\pm}$-mode decays) or $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ ($\tau'^{\pm}$-mode decays) revealed by an asymmetry like $\mathcal{A}_\tau = (\Gamma(K^+ \to \pi^+\pi^+\pi^-) - \Gamma(K^- \to \pi^-\pi^+\pi^-)/\Gamma(K^+ \to \pi^+\pi^+\pi^-) + \Gamma(K^- \to \pi^-\pi^+\pi^-))$ can be investigated. Theoretically it is expected, however, to be of the order of $10^{-6} \cdots 10^{-8}$, beyond the sensitivity of *KLOE* which is $10^{-3} \cdots 10^{-5}$.

SUMMARY

In Table I *CP*- and *CPT*-violating and other parameters of the neutral *K* system to be determined with *KLOE* are summarised together with the present values. An integrated luminosity per year of $\int L dt = 5 \cdot 10^{39}\,\mathrm{cm}^{-2}$ has been assumed. Possible highlights are printed in bold letters.

TABLE I *CP* -, *CPT*-violating *KLOE* 'highlights'.
CP- and *CPT*-violating parameters to be measured with *DAΦNE*- *KLOE* (integrated luminosity per year of $\int L dt = 5 \cdot 10^{39}\,\mathrm{cm}^{-2}$) and the present values (possible highlights are printed in bold letters)

Quantity	*Present values PDG* 1998	*Expected at DAΦNE*
$\Gamma_S(10^{10}\,\hbar\mathrm{s}^{-1})$	(1.1193 ± 0.001)	$\pm 0.000\,010$
$\Gamma_L(10^{10}\,\hbar\mathrm{s}^{-1})$	$(0.001\,934 \pm 0.000\,015)$	$\pm \mathbf{0.000\,001}$
$\Delta m(10^{10}\,\hbar\mathrm{s}^{-1})$	(0.5301 ± 0.0014)	± 0.0012
$\phi_{sw} = \arctan 2\Delta m/(\Gamma_S - \Gamma_L)$	$(43.49 \pm 0.08)^o$	
$\|\eta_{+-}\|$	$(2.285 \pm 0.019) \cdot 10^{-3}$	$\pm \mathbf{0.000\,6 \cdot 10^{-3}}$
$\|\eta_{00}\|$	$(2.275 \pm 0.019) \cdot 10^{-3}$	$\pm \mathbf{0.000\,9 \cdot 10^{-3}}$
ϕ_{+-}	$(43.5 \pm 0.6)^o$	
$\Re e\ \varepsilon'/\varepsilon$	$(21.2 \pm 2.8) \cdot 10^{-4}$	$\pm \mathbf{1.6 \cdot 10^{-4}}$
$\mathcal{I}m\varepsilon'/\varepsilon$	$(3.50 \pm 14.0) \cdot 10^{-3}$	$\pm \mathbf{1.2 \cdot 10^{-3}}$
$\phi_{+-} - \phi_{00}$	$(-0.1 \pm 0.8)^o$	
$\|\varepsilon\| = (2\|\eta_{+-}\| + \|\eta_{00}\|)/3$	$(2.282 \pm 0.014) \cdot 10^{-3}$	$\pm 0.000\,6 \cdot 10^{-3}$
$\mathcal{A}(K_L)$	$(3.27 \pm 0.12) \cdot 10^{-3}$	$\pm 0.04 \cdot 10^{-3}$
$\mathcal{A}(K_S)$		$\pm \mathbf{0.25 \cdot 10^{-3}}$
$\Re e\varepsilon$	$(1.652 \pm 0.026) \cdot 10^{-3}$	$\pm 0.01 \cdot 10^{-3}$
$\Re e\delta$	$(-0.3 \pm 0.35) \cdot 10^{-3}$	$\pm \mathbf{0.06 \cdot 10^{-3}}$
	$(0.24 \pm 0.28) \cdot 10^{-3*}$	
$\mathcal{I}m\delta$	$(1.5 \pm 2.3 \pm 2.3 \pm 0.3) \cdot 10^{-2}$	
	$(0.024 \pm 0.050) \cdot 10^{-3*}$	
$(m_{K^0} - m_{\bar{K}^0})/m_K$	$(1.4 \pm 5.6) \cdot 10^{-19*}$	
	**global information*	

CLOSING REMARKS ON *CP*-VIOLATION

KLOE is part of a worldwide venture to find an answer to the question of *CP*-violation. Other efforts regard very rare decays of neutral kaons: $K^+ \to \pi^+ \nu\bar{\nu}$ [order $O(10^{-11})$], $K_L \to \pi^0 \nu\bar{\nu}$ [order $O(10^{-10})$] (*Fermilab-KTeV*, *Brookhaven-AGS*, *KEK*), the decay of *B*-mesons (*SLAC* - *BABAR*, *KEK* - *BELLE*, *Cornell* - *CLEO*, *DESY* - *HERA B*, and future projects *Fermilab-BTeV*, *LHC-ATLAS*, *CMS*, *LHC B*) and of charmed particles (*B* factories, *Fermilab*), hyperons (*Fermilab*) and τ leptons (*CERN*, *B*-factories, *BES-Beijing*). Also searches for non *SM* origins of *CP*-violation are pursued, *e.g.*, in the investigation of the transverse polarisation of muons in $K^\pm \to \mu^\pm \nu\pi^0$ (*KEK*, *AGS*), in measurements of the electric dipole moment of neutrons (*ILL*) and electrons (*Seattle*, *Berkeley* and *Amherst*).

WHERE DO WE STAND WITH *CP*-VIOLATION?

The violation of *CP*-symmetry is clearly established, because the long living neutral kaons decay into two pions: $K_L \to \pi\pi$. The origin of *CP*-violation is unclear. If the parameters ε and ε' measured in the decay $K_L \to \pi\pi$ are to be described within the *SM* (*i.e.*, within the *CKM* matrix) there must be large *CP*-violating effects in *B* decays because quarks of the third generation are already involved in first order. The predictions for *B* decays (*e.g.*, $B_d^0 \to J/\psi K_s$) are very precise in the *SM*. If no *CP*-violation will be found in *B* decays, the *SM* will be clearly in trouble. 'New physics' then drives the decay $K_L \to \pi\pi$. But which one? The measurements of ε' has given an important hint (*KTeV*, *NA*48), but *B* decays will be finally decisive.

MORE *KLOE* PHYSICS

Besides tests of discrete symmetries *KLOE* will address a wide field of important questions in particle physics. Among them are tests of chiral symmetry breaking schemes in *K*, ϕ ρ, η, η' decays, and measurements of cross sections of e^+e^- annihilation into hadrons. Tests of the *breaking of chiral symmetry* will comprise measurements of *form* *factors* in K_{ℓ_3} decays, the determination of $\pi\pi$ *phase shifts* in $K_{\ell 4}$ decays ($K^{\pm} \rightarrow \pi^{+}\pi^{-}e^{\pm}\nu_{e}$, $K^{\pm} \rightarrow \pi^{0}\pi^{0}e^{\pm}\nu_{\mathrm{e}}$, $K_{L} \rightarrow \pi^{0}\pi^{\pm}e^{\mp}\nu$), radiative *K* decays *etc*. The data can be compared with existing predictions of chiral perturbation theory [1]. These problems are discussed in more detail in a dedicated Section below.

Hadronic Cross Sections

Cross sections for the production of hadrons after the annihilation of electrons and positrons at energies between 0.3 and 1.4 GeV ($e^{+}e^{-} \rightarrow \gamma^{*} \rightarrow$ *hadrons*) will be measured with a precision below 1%. They are of great relevance mainly for two reasons [16]. They are needed to determine with better accuracy the hadronic correction of the vacuum polarisation according to $(e^{+}e^{-} \rightarrow)\gamma^{*} \rightarrow q\bar{q}$ (see Fig. 6) and, hence, are important for the interpretation of a new measurement of the anomalous magnetic moment of the muon a_{μ} as a precision test of the *SM* (going on in Brookhaven [17]) and for the determination of the value of the running fine structure constant at the Z^{0} resonance $\alpha(m_{Z}^{2})$ which is presently one of the limiting factors for further precision tests of the *SM* [18].

The various terms contributing to a_{μ} are given in the following sum together with the present values and corresponding errors

$$\begin{aligned} a_{\mu}^{\text{theor}} &= a_{\mu}^{\text{QED}} + a_{\mu}^{\text{hadr}} + a_{\mu}^{\text{weak}} + a_{\mu}^{\text{new phys.}} \\ &= (11658470 \pm 0.5 + 703 \pm 17 + 20 \pm 1 + ?) \cdot 10^{-10} \end{aligned}$$

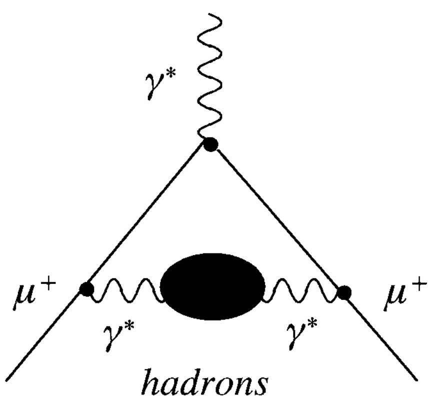


FIGURE 6 The hadronic correction to the vacuum polarisation of muons.

The first and by far largest contribution comes from *QED*, the second term denotes the virtual *hadronic* (*quark*) contribution, a_μ^{weak} summarizes the *weak* effects due to virtual *W*, Z^0 and *Higgs* particle exchanges and $a_\mu^{\text{new phys.}}$ stands for contributions from possible extensions of the *SM*. Within the present experimental accuracy of $a_\mu^{\text{exp}} = (11\ 659\ 192 \pm 18) \cdot 10^{-10}$ theory and experiment are in best agreement: $a_\mu^{\text{theor}} - a_\mu^{\text{exp}} = (-38 \pm 85) \cdot 10^{-10}$, but the electroweak corrections are still hidden in the uncertainties of both experiment and theory. This situation will change, if the Brookhaven experiment will succeed to achieve its goal of an experimental error of $\pm 4 \cdot 10^{-10}$ and if the hadronic correction can be determined with an error of $\pm 1.5 \cdot 10^{-10}$ using mainly new data from *KLOE*. Low energy experimental data are indispensible because the hadronic vacuum polarisation at low energies cannot be calculated by using perturbative *QCD*. One rather has to rely on a semiphenomenological approach using a dispersion integral which allows to compute the hadronic contribution as an integral over experimental data from electron–positron annihilation into hadronic state

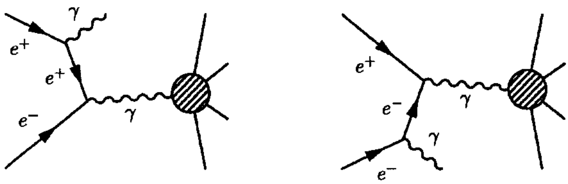
$$a_\mu^{\text{hadr}} = \left(\frac{a m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{R(s)K(s)}{s^2} \quad \text{with}$$

$$R(s) = \frac{\sigma_{\text{tot}}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma_{\text{tot}}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

where $K(s)$ is a smooth function. The energy denominator $1/s^2 \approx 1/E^4$ of the integral enhances dramatically the low energy (non perturbative) contributions. Actually 90% of the total hadronic contribution can be derived from hadronic cross section measurements below 1.4 GeV accessible at *DAΦNE*.

Hadronic data of electron–positron annihilation cross sections will also contribute to improve the accuracy of the shift $\Delta\alpha(m_Z^2)$ of the running fine structure constant at the Z^0 resonance. The value of $\alpha(s)$ plays a crucial role in precision tests of the *SM*. Most of the *SM* predictions depend on $\Delta\alpha(s)$ including the prediction of the Higgs mass. Like in the case of the anomalous magnetic moment of the muon the low energy hadronic contribution to $\Delta\alpha^{\text{hadr}}$ can only be obtained by a dispersion integral and is also limited nowadays by the unsufficient knowledge of the hadronic cross sections. It turned out recently that perturbative *QCD* calculations can be performed down to $\approx 2.5\,\mathrm{GeV}$ [19]. Therefore the need of precise hadronic cross sections at lower energies is even more mandatory than before.

In recent years the energy dependence of the hadronic cross sections has been measured by changing (scanning) the energy of the accelerator [20]. *DAΦNE* will, however, be operated at the ϕ-resonance for any foreseeable time. Therefore, it has been suggested [21] to use the emission of real photons in the initial state (*initial state radiation ISR*[1]) to measure the energy dependence of the dominant hadronic final states (see Fig. 7). *ISR* reduces the *c.m.* energy $s = Q^2 = m_\phi^2 - 2E_\gamma m_\phi$ of the annihilating electrons and positrons and consequently of the final hadronic state from the energy of the $\phi(1020)$ resonance down to the two pion threshold. Both methods to measure the energy dependence of hadronic cross sections (*ISR* and the energy scan) are totally complementary due to different systematic errors [22]. Using the *ISR* method has the advantage that the errors of the measured luminosity and of the energy of the electrons and positrons enter the photon spectrum and consequently the hadronic (Q^2) spectrum only once. The very good energy resolution to be obtained for the photon spectrum results most of all from the precise measurements of the momenta of the charged pions in the *KLOE* drift chamber $E_\gamma = |\vec{p}(\pi^-) + \vec{p}(\pi^+)| \cdot c$. As a consequence the overall normalisation error is the same for all energies of the hadronic system, if energy dependent efficiencies and cuts can be controlled reliably. Another advantage is that the data are taken as a by-product of the



$$e^+ e^- \rightarrow \gamma + hadrons$$
$$2m_\pi{}^2 < s_{e^+e^-} < m_\phi{}^2$$

FIGURE 7 Graphs showing the initial state radiation from electrons and positrons.

[1]At *LEP* the *ISR* leads to a 'radiative return' to the Z^0-resonance, at *DAΦNE* it is observed as the return to the ρ- and ω-resonances.

standard experimental program of *KLOE* without changing any details of the set up. Clearly the *ISR* method is restricted to energies below the ϕ-resonance and the analysis has to take into account radiative corrections and the emission of photons in the final state (*FSR*).

Hadron Spectroscopy

The structure of the two *scalar mesons* a_0 and f_0 with $J^{PC} = 0^{++}$ and masses lighter than the ϕ-meson which are generated in the radiative decays $\phi \rightarrow a_0/f_0\gamma$ is still puzzling. They might be *e.g.*, $q\bar{q}q\bar{q}$ states or $\bar{K}K$ 'molecules'. The decays of $a_0(980)$ into $\pi\eta$ and $\bar{K}K$ have been observed (a_0 being an isovector?), also the decays of $f_0(980)$ into $\pi\pi$ and $\bar{K}K$ (f_0 being an isoscalar $\bar{s}s$ state?). Measurements of ratios like $BR(\phi \rightarrow a_0\gamma)/BR(\phi \rightarrow f_0\gamma)$ would help to clarify those questions. G-parity violating (isospin breaking) decays as $\phi \rightarrow \pi^0\omega$, $\rho^{\pm} \rightarrow \pi^{\pm}\eta$ and $\eta' \rightarrow \rho^{\pm}\pi^{\mp}$ will be investigated. Radiative decays of ϕ-mesons into pseudoscalar mesons ($\phi \rightarrow \gamma\eta$, $\phi \rightarrow \gamma\eta'$) might help to constrain the glue content of the η' and reveal possible $\eta - \eta'$ mixing. The η' does not seem to be a pure $1S(\bar{q}q)$ but to have admixtures of $2S(\bar{q}q)$ and/or gluonic contents. The interest in the coupling of gluons to η' has been renewed by the abundance of η' in B-decays. The results should be compared with the decays $\eta \rightarrow \rho/\omega\,\gamma$ probing the $u\bar{u} + \bar{d}d$ contents of η and η'. In addition the branching ratios $BR(\phi \rightarrow \gamma\eta)/BR(\phi \rightarrow \gamma\eta')$ might probe the $\bar{s}s$ content of η and η'.

CHIRAL SYMMETRY AND ITS BREAKING IN *QCD* (*DEAR* AND *KLOE* PHYSICS)[2]

The strong interaction is successfully described by *Quantum Chromodynamics* (*QCD*), by the interaction of coloured quark and gluon fields, $q\bar{q}$ and $G^a_{\mu\nu}$, respectively. The interaction Lagrangian contains among many other terms a *quark mass term* which is most relevant at low energies as available at *DAΦNE* : $\mathcal{L}_{\mathrm{QCD}} = \mathcal{L}^0_{\mathrm{QCD}} - \sum_{q=u,d,s} m_q q\bar{q}$. This Lagrangian is invariant under the *local* colour gauge transformations

[2]This Section is indebted largely to J. Gasser and G. Colangelo.

$SU_c(3)$ by construction. Furthermore it would also be invariant under the *global* $SU_f(3)$ flavour transformation if the three light quark masses would be equal in nature ($m_u = m_d = m_s$). The quark fields transform then according to $q' = \exp(i\theta^a \lambda^a/2)q$. The indices run over the flavour quantum numbers isospin up, isospin down and strangeness. If the light quark masses would even be zero (which is called the *chiral limit* defined by $m_q = 0$) the Lagrangian would be invariant under separate left and right handed flavour transformations $SU_L(3) \otimes SU_R(3)$ and the left and right handed quark fields would transform independently

$$q'_{L,R} = \exp(\mp i\theta^a \lambda^a/2) q_{L,R} \left(q_{L,R} = \frac{1}{2}(1 \mp \gamma_5) q \text{ and } q = q_L + q_R \right).$$

This *chiral transformation* can be written analogously to the transformation $SU_f(3)$ as

$$q' = \exp(i\gamma^5 \theta^a \lambda^a/2) q.$$

As a consequence of this flavour symmetry eight vector and axial vector currents and the corresponding vector and axial vector charges are conserved

$$\partial^\mu V^a_\mu = \partial^\mu \bar{q} \gamma_\mu \frac{\lambda^a}{2} q = 0 \quad \text{and} \quad \partial^\mu A^a_\mu = \partial^\mu \bar{q} \gamma_\mu \gamma_5 \frac{\lambda^a}{2} q = 0$$

(the former is known as the theorem of Conserved Vector Current CVC). The *chiral* symmetry would cause a doubling of hadron multiplets, the existence of baryon partners with $J^\pi = 1/2^-$ and scalar meson partners with 0^+ and equal masses which are not observed in nature. This led to the idea of the *spontaneous breaking* of chiral symmetry. The combined transformation $SU_L(3) \otimes SU_R(3)$ is broken down to $SU_f(3)$. The Lagrangian is symmetric under the symmetry group but the ground state (the *QCD* vacuum) is not and the vacuum expectation value is unequal zero $\langle 0|\Phi|0\rangle \neq 0$. The spontaneously broken (hidden) global chiral symmetry results in the excitation of eight massless pseudoscalar bosons. These Goldstone bosons acquire their finite and different masses from those of the light quarks and appear in nature as real (the light) pions, kaons and η-mesons with $m_\pi \neq m_K \neq m_\eta \neq 0$. The quark mass term in the Lagrangian is thus responsible for the *explicit* symmetry breaking. *Low energy theorems* (previously derived in the chiral limit $m_\pi = 0$ by means of *Current Algebra* and *PartiallyConservedAxial vectorCurrent*) have become integral constituents of *QCD*. In spite of its breaking chiral symmetry is the most important guide in the realm of low energy (nonperturbative) *QCD* and follows in a unique way from the structure of the Lagrangian and explains many observations (meson nucleon scattering, hadronic mass spectrum, decays). At low energies energies we do not deal, however, with quarks and gluons but rather with hadrons (mesons and baryons). *Chiral perturbation theory* (χ *PT*) is the tool to bridge this gap [23, 24]. It is a well defined effective quantum field theory and allows to derive unambiguously the consequences of the approximate chiral symmetry of the strong interactions for any observable by searching for the most general effective *Lagrangian* which is compatible with chiral symmetry. Since pions, kaons, and η interact weakly at low energies the vertices can be expanded in powers of 4-momenta and quark masses in the neighbourhood of the chiral limit. Within this perturbative expansion all the good properties of a quantum field theory (like unitarity and analyticity) are automatically respected. All possible graphs are calculated and the parameters of the theory (effective coupling constants, masses) are renormalised order by order. At low energies ($\ll 1\,\mathrm{GeV}$) this framework allows to make in some cases very precise predictions (of the order of a few percent). At each order, however, appear parameters which are not constrained by chiral symmetry, but have to be determined by experiments. In the sector of strong interactions the lowest order Lagrangian $\mathcal{L}^{(2)}$ contains 2 constants, at the next-to-leading order $\mathcal{L}^{(4)}$ contains 7(10) constants if the numbers of flavours $N_f = 2$ ($N_f = 3$), and at the next-to-next-to leading order 53 (90). In the weak sector the Lagrangian $\mathcal{L}^{(2)}_{\mathrm{weak}}$ contains also 2 constants, while at the next-to-leading order $\mathcal{L}^{(4)}_{\mathrm{weak}}$ contains 37. A guide through the forest of $O(p^4)$ constants in the weak sector is shown in Figure 8 [25].

DAΦNE and Tests of the Breaking of Chiral Symmetry

DAΦNE, as mentioned above, has been baptised a ‘chiral’ machine [6] because it allows a wealth of investigations and tests in the realm of chiral symmetry. In preparation of the forthcoming data taking with

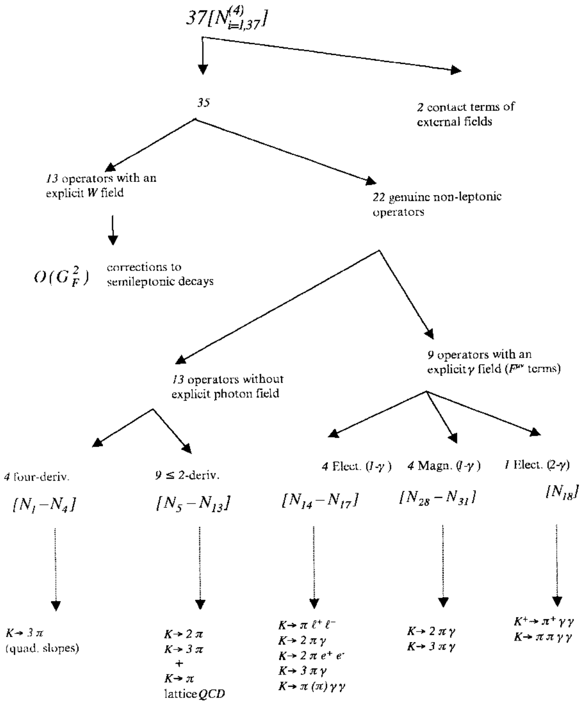


FIGURE 8 A guide through the forest of $O(p^4)$ constants (courtesy G. Isidori) [25]. In the weak sector the Lagrangian $\mathcal{L}^{(2)}_{\text{weak}}$ of chiral perturbation theory contains 2 constants, while at the next-to-leading order $\mathcal{L}^{(4)}_{\text{weak}}$ contains 37.

DEAR, *FINUDA* and *KLOE* enormous theoretical efforts [1] have been undertaken to calculate cross sections, scattering lengths, decay rates *etc*.

$\pi\pi$ Scattering (*KLOE* Physics) [24]

A 'golden' testing ground of χPT is the determination of the $\pi\pi$ isospin $I=0$ and $I=2$ *S-wave* scattering lengths a_0^0 and a_0^2. It will be an important challenge for *KLOE* to determine those numbers in the $K_{\ell 4}$ decays of $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e, K^{\pm} \to \pi^0\pi^0 e^{\pm}\nu_e$ and $K^0 \to \pi^0\pi^{\pm}e^{\mp}\nu$. The expansion parameter is small ($m_\pi^2/1\,\text{GeV}^2 \approx 0.02$) and a tree level calculation is already relatively accurate. But it turned out that one-loop and two-loop calculations present substantial corrections confirmed by a preliminary analysis of a recent experiment by means of dispersion relations (Roy equations):

$$a_0^0 = \frac{7m_\pi^2}{32\pi f_\pi^2}\left(1 - \frac{9}{2}\mathrm{Log} + \frac{857}{42}\mathrm{Log}^2 + \cdots\right) \quad \text{with} \quad \mathrm{Log} = m_\pi^2/(4\pi f_\pi)^2 \ln(m_\pi^2/\mu^2)$$

$$a_0^0 = \underbrace{\overbrace{0.156}^{\text{tree}} + \overbrace{0.039 + 0.005}^{1-\text{loop}}}_{0.201} + \overbrace{0.013 + 0.003 + 0.001}^{2-\text{loop}} = 0.217$$

μ being the scale parameter.

MESON-NUCLEON (πN AND KN) σ-TERMS AND THE STRANGE CONTENT OF THE NUCLEON (DEAR PHYSICS)

During recent years the determination of the πN σ-term has received much attention [23, 26]. It appears as one of the most important numbers of non perturbative *QCD* because it determines not only the size of the explicit breaking of chiral symmetry but provides also hints as to the size of the nucleon matrix element $\langle N|\bar{s}s|N\rangle$ of the scalar operator $\bar{s}s$ that is on the content of the strange sea quark pairs in the nucleon. A non vanishing value of $\langle N|\bar{s}s|N\rangle \neq 0$ would determine the contribution of strange sea quark pairs to the mass of the nucleon. Similarly non zero matrix elements of the *axial vector* operator $\langle N|\bar{s}\gamma_5\gamma_\mu s|N\rangle$ and of the *vector* operator $\langle N|\bar{s}\gamma_\mu s|N\rangle$ would contribute to the *spin* and *magnetic moment* of the nucleon. Within the naive quark model with explicit chiral symmetry breaking ($m_q \neq m_u \neq m_d \neq m_s$) the πN σ-term is given by

$$\sigma_{\pi N} = \frac{\tilde{m}}{2m_N}\frac{\langle N|\bar{u}u + \bar{d}d|N\rangle}{1 - y} \quad \text{with}$$

$$\tilde{m} = \frac{1}{2}(m_u + m_d) \quad \text{and} \quad m_N \text{ the nucleon mass}$$

where an unknown contribution of strange sea quarks is parametrised by

$$y = \frac{2\langle N|\bar{s}s|N\rangle}{\langle N|\bar{u}u + \bar{d}d|N\rangle}.$$

In KN scattering two σ-terms can be determined

$$\sigma_{KN}^{(I_t=0)} = \frac{1}{2}(m_s + \tilde{m})\langle N| - \bar{u}u + 2\bar{d}d + \bar{s}s|N\rangle \frac{1+y}{1-y} \quad \text{and}$$
$$\sigma_{KN}^{(I_t=1)} = \frac{1}{2}(m_s + \tilde{m})\langle N|\bar{u}u + \bar{s}s|N\rangle \frac{1+y}{1-y}$$

where $I_t = 0, 1$ are the isospins in the t-channel. The factor $(1+y)/(1-y)$ indicates a higher sensitivity to changes of the parameter y than in the πN case. In the chiral limit ($m_q = 0$) the σ-terms would all be zero proving that they are a direct measure of the explicit breaking of chiral symmetry. In first order perturbation theory the πN and $KN\sigma$-terms can be expressed by hadron masses

$$\sigma_{\pi N} = \frac{3}{4}\frac{m_\pi^2}{m_K^2 - m_\pi^2}\left(M_\Xi - M_N + \frac{1}{2}(M_\Sigma - M_\Lambda)\right) \approx 27\,\text{MeV}$$
$$\sigma_{KN}^{(I_t=1)} - \sigma_{KN}^{(I_t=0)} = \frac{1}{2}\frac{m_K^2}{m_K^2 - m_\pi^2}\left(M_\Xi - M_N - \frac{3}{2}(M_\Sigma - M_\Lambda)\right) \approx 140\,\text{MeV}$$
$$3\sigma_{KN}^{(I_t=1)} + \sigma_{KN}^{(I_t=0)} = \frac{3}{2}\frac{m_K^2}{m_K^2 - m_\pi^2}\left(M_\Xi - M_N + \frac{1}{2}(M_\Sigma - M_\Lambda)\right) \approx 680\,\text{MeV}$$

yielding $\sigma_{KN}^{(I_t=0)} \approx 275\,\text{MeV}$ and $\sigma_{KN}^{(I_t=1)} \approx 65\,\text{MeV}$. By means of heavy baryon chiral perturbation theory approximate values of $\sigma_{KN}^{(I_t=0)} \approx 493\ldots703\,\text{MeV}$ and $\sigma_{KN}^{(I_t=1)} \approx 73\ldots216\,\text{MeV}$ have been obtained [27].

All meson-nucleon σ-terms are defined in an unphysical kinematic region unaccessible to a direct measurement. Generations of theoreticians and experimentalists have worked on the problem of the πN σ-term the only one which has been established with reasonable confidence. Its history has not come to an end even until today due to still some contradictory experimental data and also due to unfinished theoretical work.

To determine the πN σ-term input is required both from experiment and theory. On the experimental side precise data on πN scattering (scattering lengths, cross sections, polarisation data) are needed in a wide energy range (theoretically up to infinity) to determine the physical scattering amplitudes. These amplitudes have to be continued analytically by means of dispersion relations into the unphysical region. A low energy theorem states that the isospin even πN on-shell amplitude $\Sigma = f_\pi^2 \bar{D}^+(0.2m_\pi^2)$ at the unphysical Cheng Dashen point $\nu = (s - u/4m_N) = 0$, $t = 2m_\pi^2$ (the bar denotes that the Born term has been subtracted) is related to the πN σ-term $\sigma(0,0)$ at $\nu = 0$, $t = 2m_\pi^2 = 0$. More exactly it is given by

$$\Sigma = \sigma(0,0) + \Delta_\sigma + O(m_\pi^4 \ln m_\pi^2).$$

The term Δ_σ has been obtained by dispersion relations $\Delta_\sigma = \sigma(2m_\pi^2) - \sigma(0) \approx 15\,\mathrm{MeV}$ [28], and $O(m_\pi^4 \ln m_\pi^2) \approx 0.35 \ldots 2.0\,\mathrm{MeV}$ [29] has been calculated within chiral perturbation theory yielding the relation between the 'experimentally' determined amplitude Σ and the theoretical value of the πN σ-term as $\Sigma \approx (\sigma + 15)\,\mathrm{MeV}$. By comparison of $\Sigma(0.2m_\pi^2) = (64 \pm 8)$ MeV [26] and $\sigma(0,0) = (50 \pm 8)$ MeV a value of the parameter $y \approx 0.2 \pm 0.2$ was deduced, a result compatible with zero.

The determination of the *KN* σ-terms has to follow the same route as in the πN case, but is an even more ambitious task due to the present lack of data and also due to theoretical complications involving the larger breaking of $SU_f(3)$ flavour symmetry, and a Cheng Dashen point located much farther from the physical region. Recently it has been argued, however, that *DEAR* could determine the *KN* σ-terms with an accuracy of about 20% [30].

EXPERIMENT *DEAR*

DEAR [3] has been designed to measure the isospin dependent *KN* scattering lengths by a measurement of the *shift* ε (with an accuracy of 1%) and of the *width* Γ (to a few %) of the K_a line of kaonic hydrogen ($K^- p$) and kaonic deuterium ($K^- d$). This would be an order of magnitude improvement over recent results [31]

$$\varepsilon = E^{\mathrm{exp}}_{2p \to 1s} - E^{\mathrm{em.}}_{2p \to 1s} = -327 \pm 63(\mathrm{stat.}) \pm 11(\mathrm{syst.})\,\mathrm{eV}$$
$$\Gamma = 407 \pm 208(\mathrm{stat.}) \pm 100(\mathrm{syst.})\,\mathrm{eV}$$

and represent an important contribution to low energy *KN* scattering, and insofar to the determination of the *KN* σ-terms and to information on the strangeness content of the nucleon. The scattering lengths $a_{K^- p}$

and a_{K^-d} are obtained from ε and Γ by

$$\varepsilon + \frac{i}{2}\Gamma = 2\alpha^3 \mu_{K^-p}^2 a_{K^-p} = (412\,\mathrm{eV}fm^{-1}) \cdot a_{K^-p} \quad \text{and}$$
$$\varepsilon + \frac{i}{2}\Gamma = 2\alpha^3 \mu_{K^-d}^2 a_{K^-d} = (601\,\mathrm{eV}fm^{-1}) \cdot a_{K^-d}$$

with μ_{K^-d} being the reduced mass and α the fine structure constant, while the isospin dependent scattering lengths a_0 for $I=0$ and a_1 for $I=1$ can be obtained by $a_{K^-p} = (1/2)(a_0 + a_1)$ and $a_{K^-d} = 2(m_N + m_K/(m_N + m_K/2))a^{(0)} + C$, where $a^{(0)}$ is the isoscalar scattering length $a^{(0)} = (1/2)(a_{K^-p} + a_{K^-n}) = (1/4)(a_0 + 3a_1)$, and the constant C takes into account higher-order scattering effects.

EXPERIMENT *FINUDA*

FINUDA [4] represents a fixed target experiment at a collider. The main goals are the production, weak decays, life time measurements and spectroscopy of hypernuclei, and in a later phase the investigation of low energy KN and kaon nucleus scattering. Hypernuclei are produced by stopped negative kaons K^- according to

$$K^-_{\text{stop}} +^A Z \rightarrow^A_\Lambda Z + \pi^-$$

which are tagged by their positive companions K^+. There are important improvement of *FINUDA* over previous experiments which have been carried with extracted (secondary) K^- beams. Very thin targets can now be used ($0.2\,\mathrm{g/cm}^2$), the energy resolution of hypernuclear levels is of the order of 700 keV, the event rates will be of the order of 400/hour at the design luminosity of $\mathcal{L} \approx 5 \cdot 10^{32}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, almost forty times more than previously, also due to the large acceptance of the detector. Hypernuclei can decay weakly in various ways, in

$$\text{mesonic decay modes} \quad {}^A_\Lambda Z \rightarrow^A (Z+1) + \pi^- \quad \text{and} \quad {}^A_\Lambda Z \rightarrow^A Z + \pi^0,$$
$$\text{nonmesonic ones} \quad {}^A_\Lambda Z \rightarrow^{A-2} Z + n + n, \quad {}^A_\Lambda Z \rightarrow^{A-2} (Z-1) + n + p,$$

where the basic processes are $\Lambda \rightarrow n + \pi^0$, $\Lambda \rightarrow p + \pi^-$, $\Lambda + n \rightarrow n + n$, $\Lambda + p \rightarrow n + p$, respectively. Measuring the corresponding partial decay rates Γ_{π^-}, Γ_{π^0}, Γ_n, Γ_p the lifetime $\tau = \hbar/\Gamma_{\text{tot}}$ of hypernuclei can be determined by $\Gamma_{\text{tot}} = \Gamma_{\pi^-} + \Gamma_{\pi^0} + \Gamma_n + \Gamma_p$, while the ratio Γ_n/Γ_p might allow conclusions on the isospin structure of the weak decays, *e.g.*, on a possible violation of the $\Delta I = 1/2$ rule.

High resolution spectroscopy of hypernuclei will be pursued by detecting the π^- of the production reaction. There is a long list of hypernuclei, the production, decays and lifetimes of which will be studied, low mass nuclei ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{10}_{\Lambda}B$, ${}^{5}_{\Lambda}He$, ${}^{6}_{\Lambda}Li$ as well as medium heavy and heavy mass nuclei ${}^{27}_{\Lambda}Al$, ${}^{28}_{\Lambda}Si$, ${}^{51}_{\Lambda}V$, ${}^{89}_{\Lambda}Y$, ${}^{133}_{\Lambda}Cs$, ${}^{65}_{\Lambda}Ho$, ${}^{209}_{\Lambda}Bi$.

Acknowledgements

I am grateful to my colleagues and friends of the *DEAR*, *FINUDA* and *KLOE* colaborations at *DAΦNE* in Frascati for many discussions and for providing material for this talk.

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