K meson semileptonic decays at KLOE: measuring form factors and phase shifts.

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Abstract

The excellent performances of the KLOE detector and the overcostrained kinematics of the ϕ decays of DAΦNE (which started its operation during spring '99) will give the opportunity to measure the Kaon form factors and the $\pi\pi$ scattering phase shifts differences with very good accuracy. We expect to improve up to an order of magnitude the precision on the existing measurements.

1. Introduction

The main goal of the KLOE experiment [1] at the Frascati ϕ-factory (DAΦNE) is the investigation of the CP violation parameters in the K system and the measurement of $Re(\varepsilon'/\varepsilon)$ with an accuracy of the order of 10^{-4}.

DAΦNE is a double-ring e^+e^- collider working at the ϕ peak energy with a designed instantaneous luminosity of $L_0 = 5 \times 10^{32}$ cm^{-2} s^{-1}. A sample of 5×10^{10} ϕ, 5×10^{10} charged K and 1.7×10^{10} $K_S K_L$ pairs will be collected in two years. In the first three months of data taking at $L_0 = 5 \times 10^{31}$ cm^{-2} s^{-1} (5×10^8 ϕ) KLOE can measure the form factors of K_{l3} decay both for $K^\pm$ and K_L^0, improving the present precision of, at least, one order of magnitude. With the full data taking we will produce about 2×10^6 $K^\pm \to \pi^+\pi^- e^\pm \nu_e$ which will give the possibility to improve the knowledge of the $\pi\pi$ scattering phase shifts differences.

2. The KLOE detector

The KLOE detector [2] consists of, in order of increasing radius, a cylindrical drift chamber (DC) and an hermetic electromagnetic calorimeter (EmC) made of lead and scintillating fibers, both embedded in a 0.6 T magnetic field provided by a solenoidal superconducting coil.

The tracking detector [3] is a large cylindrical drift chamber ($\sim$ 2 m radius, $\sim$ 3.3 m length), in which about 12600 single sense wire, square cells are arranged in 58 circular and coaxial stereo layers. The chosen gas mixture is 90%-10% He-iC_4H_{10}, allowing for good resolution ($\sigma_{\rho\phi} \sim 200\mu m$, and $\sigma_z \sim 2mm$) and efficiency, low multiple scattering and stable operating conditions. The drift chamber transverse momentum resolution is $\sigma_{p_\perp}/p_\perp \simeq 0.5\%$.

The EmC [4] is a very fine sampling lead-scintillating fiber calorimeter, covering $\sim$98% of the solid angle. The barrel calorimeter is a cylinder of 4 m inner diameter and 4.3 m length with fibers running parallel to the beam line, while the end-caps are made of C-shaped modules of variable length with fibers running perpendicular to the beam line. The EmC measured energy and time resolutions are $\sigma_E/E \simeq 4.7\%/\sqrt{E(GeV)}$ and $\sigma_t \simeq 55$ ps/$\sqrt{E(GeV)}$ respectively, with high efficiency for the detection of low energy γ as low as 20 MeV.

3. Form factors in K_{l3} semileptonic decays

Kaon semileptonic decays $K^\pm \to \pi^0 l^\pm \nu$ and $K_L^0 \to \pi^\pm l^\mp \nu$ can be described, in the Cabibbo Theory, by a local vector current-current coupling. The matrix elements of the hadronic current are parametrized in terms of the form factors $f_{+,0}(q^2) = f_{+,0}(0)(1 + \frac{\lambda_{+,0}}{m_\pi^2} q^2)$ [5]. The measurement of the Dalitz plot distribution, $\rho(\lambda_+, \lambda_0; E_\pi, E_l)$ of K_{l3} data allows us to determine the form factors in the allowed phase space range.

While data and theory agree fairly well for λ_+, the situation on parameter λ_0, which can be measured

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	KLOE	Ref. [6]
$N(K^0_{\mu 3})$	3×10^6	1.5×10^6
$\sigma(\lambda_0)$	5×10^{-4}	4×10^{-3}
$N(K^{\pm}_{\mu 3})$	10^6	6527
$\sigma(\lambda_0)$	7×10^{-4}	1.5×10^{-2}

Table 1. *Expected $K_{\mu 3}$ events and estimated error on λ_0 for a sample of 5×10^8 ϕ. Statistics and error of the most precise measurements obtained up to now is shown for comparison.*

channel	$Br(10^{-5})$	# events	DAΦNE
$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$	3.9	3×10^4	1.9×10^6
$K^{\pm} \to \pi^+\pi^- \mu^{\pm}\nu_\mu$	0.1	7	4.8×10^4
$K^{\pm} \to \pi^o\pi^o e^{\pm}\nu_e$	2.1	< 50	1×10^6
$K_L \to \pi^o\pi^{\pm} e^{\mp}\nu_e$	5.2	729	1×10^5

Table 2. *Expected number of events in KLOE for each of the K_{l4} channels, compared with the events collected until now from previous experiments*

only in $K_{\mu 3}$ decays, is not yet well understood. New measurements of these parameters will then help to check the Chiral Perturbation Theory (χ_{PT}) predictions.

At DAΦNE the Kaons are produced in pairs and this allows for very clean K_L tagging using the $K_S \to \pi^+\pi^-$ decay. The reconstruction of this decay will allow to determine the K_L direction of flight and its momentum with good resolution.

Without any π/μ identification a simmetrized density function should be built: the effect will be a slight increase of the expected precision in the determination of the λ_+ and λ_0 parameters. A small contamination in this channel is represented by the CP violating $K_L \to \pi^+\pi^-$ decay which can be easily removed through kinematical cuts.

With 5×10^8 collected ϕ's , about 3×10^7 $K^0_{\mu 3}$ decays will be produced. The expected number of reconstructed $K^0_{\mu 3}$ decays will be about 3×10^6 giving "a priori" estimated errors on the λ_+ and λ_0 parameters shown in table 1.

The main background to the $K^{\pm} \to \pi^0\mu^{\pm}\nu$ decays is represented by $K^{\pm} \to \pi^{\pm}\pi^0$ decay, which has a branching ratio 7 times larger than the signal. It can be reduced using a constrained fit procedure and π/μ discrimination using TOF measurements. In table 1 are shown the expected number of events and the "a priori" estimate of the error on λ_0 evaluated taking into account only the statistics and resolution contributions.

4. K_{l4} semileptonic decays

The full kinematic of the K_{l4} decay requires 5 variables [7] to be described. The K_{l4} partial decay rate, after a partial wave expansion of the involved form factors, can be written as a function of the phase shifts δ^I_l in elastic $\pi^+\pi^-$ scattering and of the isoscalar S-wave scattering length a^0_0 [8], whose χ_{PT} prediction is $a^0_0 = 0.20 \pm 0.01$ [9]. The central value of the best experimental measurement $a^0_0 = 0.26 \pm 0.05$ [8] has uncertainties which do not allow to confirm the χ_{PT} predictions, so a new measurement is eagerly needed.

Two complementary methods will be exploited at KLOE: the Pais-Treiman method [10] which is model independent and the Maximum Likelihood Method [11] which requires some approximations and assumptions.

The MLM implies a detailed amplitude analysis of the $K^{\pm}_{e4}$ decays to be performed with respect to all the five kinematic variables. This method [11] gives an "a priori" estimate (obtained with a perfect detector) of the error on the isoscalar S-wave scattering length, $\Delta a^0_0 = 0.029$ at the same statistic (30k events) of Ref. [8].

This statistical improvements on the number of events (Tab. 2) will allow KLOE to understand the dependence of the form factors on s_l and s_π, which was not possible in previous experiments and will also permit to do independent checks on the form factors for different decays that are related, because of the Bose symmetry and the $\Delta I = 1/2$ rule.

Taking into account, for example, only the decay $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$, the analysis will be based on the reconstruction of the 4 charged tracks vertex and the reduction of the background due to the $K^{\pm} \to \pi^+\pi^-\pi^{\pm}$ decay, whose branching ratio is $\simeq 5.59\%$. A constrained vertex fit will allow easily the reduction of this backgound due to the big mass difference between electrons and pions. The main difficulty in reconstructing this kind of events is due to the low momenta of the particles involved, especially for electrons which will often spiralize in the KLOE magnetic field.

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