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KLOE-2 PHYSICS PROGRAM*

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In the next few months the KLOE-2 detector is expected to start data taking at the upgraded DAΦNE ϕ-factory of INFN Laboratori Nazionali di Frascati. It aims to collect 25 fb^{-1} at the $\phi(1020)$ peak, and about 5 fb^{-1} in the energy region between 1 and 2.5 GeV. We review the status and physics program of the project.

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1. Introduction

The scientific program with a high-performance detector such as KLOE covers several fields in particle physics: from measurements of interest for the development of the Effective Field Theory (EFT) in quark-confinement regime to fundamental tests of Quantum Mechanics (QM) and CPT invariance. It includes precision measurements to probe lepton universality, CKM unitarity, the $\gamma\gamma$ physics and settles the hadronic vacuum polarization contribution to the anomalous magnetic moment of the muon and to the fine-structure constant at the M_Z scale. For a detailed discussion see Ref. [1].

2. KLOE-2

From 2000 to 2006 the KLOE experiment has collected 2.5 fb^{-1} of data at the $\phi(1020)$ peak plus additional 250 pb^{-1} off-peak ($\sqrt{s} = 1$ GeV) at the DAΦNE ϕ-factory of INFN Laboratori Nazionali di Frascati. Many important results have been obtained, particularly in the kaon sector, light

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meson spectroscopy and on the precise measurement of the hadronic cross-section below 1 GeV [2]. During 2008 a new interaction scheme of DAΦNE has been successfully tested, allowing to reach a peak luminosity of about 5×10^{32} cm^{-2} s^{-1}, a factor of 3 larger than previously obtained. Following this achievement, new data taking with an upgraded detector will start in 2010.

Several upgrades have also been proposed for the detector. In a first phase, two different devices (LET and HET) will be installed along the beam line to detect the scattered electrons/positrons from $\gamma\gamma$ interactions.

In a second phase, a light-material internal tracker (IT) will be installed in the region between the beam pipe and the drift chamber to improve charged vertex reconstruction and to increase the acceptance for low $p_{\rm T}$ tracks [4]. Crystal calorimeters (CCALT) will cover the low θ region, aiming at increasing acceptance for very forward electrons/photons down to 8°. A new tile calorimeter (QCALT) will be used to instrument the DAΦNE focusing system for the detection of photons coming from $K_{\rm L}$ decays in the drift chamber. Implementation of the second phase is planned for late 2011. The integrated luminosity for the two phases, will be 5 fb^{-1} and 20 fb^{-1}, respectively.

DAΦNE can run in a range of ± 20 MeV from the ϕ peak without loss of luminosity, with the same magnetic configuration. Minor modifications, *i.e.*, a new final particle focusing system, are needed to extend the range up to ± 100 MeV while a major upgrade of the machine is required to extend it above this limit. The improved KLOE detector is perfectly suited for taking data also at energies away from the ϕ mass. Therefore, a proposal to perform the challenging and needed precision measurements of (multi)hadronic and $\gamma\gamma$ cross-sections at energies up to 2.5 GeV has also been put forward.

3. $\gamma\gamma$ physics

The term "$\gamma\gamma$ physics" (or "two-photon physics") stands for the study of the reaction

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- + X\,,$$

where X is some arbitrary final state allowed by conservations laws. One of the important issues which can be addressed by studying this process is the question of the existence of the σ meson. This meson was suggested many years ago within the context of the linear sigma model for the pion–nucleon interaction but no clear observation of it was provided by the experiments, so that its existence and nature (*i.e.* quark substructure) is still controversial.

Recently, the situation has changed. It has been shown [3] that the $\pi\pi$ scattering amplitude contains a pole with the quantum numbers of vacuum with a mass of $M_\sigma = 441^{+16}_{-8}$ MeV and a width $\Gamma_\sigma = 544^{+25}_{-18}$ MeV. The σ has been looked for also in D decays by the E791 Collaboration at Fermilab [5]. From the $D \to 3\pi$ Dalitz plot analysis, E791 finds that almost 46% of the width is due to $D \to \sigma\pi$ with $M_\sigma = 478 \pm 23 \pm 17$ MeV and $\Gamma_\sigma = 324 \pm 40 \pm 21$ MeV. BES [6] has looked for the σ in $J/\psi \to \omega\pi^+\pi^-$ giving a mass value of $M_\sigma = 541 \pm 39$ MeV and a width of $\Gamma_\sigma = 252 \pm 42$ MeV.

It is worth to notice that the interest in assessing the existence and nature of the σ meson is not confined to low energy phenomenology. Just to mention a possible relevant physical scenario in which the σ could play a role, consider the contamination of $B \to \sigma\pi$ in $B \to \rho\pi$ decays (possible because of the large σ width). This could affect the isospin analysis for the CKM-α angle extraction [7]. Similarly studies of the γ angle through a Dalitz analysis of neutral D decays need the presence of a σ resonance [8].

4. $K_S \to \gamma^{(*)}\gamma^{(*)}$ / $K_S \to \pi^0\gamma\gamma$

We can divide kaon decays into three categories: *(i)* long-distance dominated (LD), *(ii)* with comparable short- and long-distance contributions and *(iii)* short-distance dominated (SD) decays. $K_S \to \gamma\gamma$ does not receive any SD contribution while LD terms starts at $\mathcal{O}(p^4)$ without counterterm structure. This implies that: *(i)* we have only one loop contribution and *(ii)* this contribution is scale-independent [9,10]. The $\mathrm{BR}(K_S \to \gamma\gamma) = 2.1 \times 10^{-6}$ is predicted at $\mathcal{O}(p^4)$ in terms of two known Low Energy Constants (LEC) of lowest order. From a naive dimensional analysis higher order contributions are expected to be suppressed by a factor $\mathrm{m}_K^2/(4\pi \mathrm{F}_\pi)^2 \sim 0.2$. This process is the ideal test of the Chiral Perturbation Theory (ChPT) (and in general of the EFT) at the quantum level. At present, for the branching fraction, we have

ChPT $\mathcal{O}(p^4)$	NA48	KLOE
2.1×10^{-6}	$(2.713 \pm 0.063) \times 10^{-6}$	$(2.26 \pm 0.13) \times 10^{-6}$

with the recent measurements differing by $\sim 3\ \sigma$s [11,12]. These results are based on different experimental methods. At the hadronic machines, the branching ratio has been obtained from the simultaneous measurement of K_L and K_S decays to the same final state, $K_{S,L} \to \gamma\gamma$. The subtraction of the K_L background has been performed on the basis of precision measurements of the ratio $\mathrm{BR}(K_L \to \gamma\gamma)/\mathrm{BR}(K_L \to 3\pi^0)$. At the ϕ-factory, the K_S decays are tagged by K_L interactions in the calorimeter and the $K_S \to \gamma\gamma$ signal has to be separated from the $K_S \to \pi^0\pi^0$ decays with lost or unresolved photon clusters for this reason we will install new detectors (QCAL and CCALT).

5. Low-mass scalars

The radiative processes $\phi \to \gamma S$, where $S = f_0(980)$, $a_0(980)$, $\sigma \equiv f_0(600)$, are followed by a decay of S into two pseudoscalar mesons (PP). The analysis of the M_{PP} invariant mass distribution in $\phi \to \gamma PP$ transitions is sensitive to the nature of light scalar states. If they are tetraquarks, quarkonia or KK molecules is one of the open questions of low-energy QCD. Interestingly, the tetraquark assignment [13, 14] naturally explains the mass pattern and decay widths, although different instanton-driven [15] or quark-antiquark processes [16] have been considered.

Two kinds of theoretical models for the $\phi \to \gamma S \to \gamma PP$ have been analyzed so far: *(i)* the "no structure" approach based on a point-like $\phi\gamma S$ coupling *(ii)* the kaon-loop coupling of the $\phi \to \gamma S$. Future analyses at KLOE-2 will certainly improve the comprehension of scalar meson states.

6. High energy option

Like the effective fine-structure constant at the scale M_Z, the SM determination of the anomalous magnetic moment of the muon a_μ is presently limited by the evaluation of the hadronic vacuum polarisation effects, which cannot be computed perturbatively at low energies. However, using analyticity and unitarity, it can be shown that the leading order hadronic contribution to a_μ, a_μ^{HLO} can be computed from hadronic e^+e^- annihilation data via the dispersion integral

$$a_\mu^{\mathrm{HLO}} = \frac{\alpha^2}{3\pi^2} \int\limits_{m_\pi^2}^{\infty} ds\, K(s) R(s)/s\,,$$

where the kernel function $K(s)$ decreases monotonically with increasing s.

The region below 2.5 GeV accounts for about 95% of the squared uncertainty $\delta^2 a_\mu^{\mathrm{HLO}}$, 55% coming from the region 1–2 GeV.

In order to clarify the nature of the well known observed difference Δa_μ between the theoretical and experimental value of a_μ and eventually reinforce its statistical significance, new direct measurements of $g-2$ with a factor 4 reduction in uncertainty have been proposed at Fermilab and J-PARC. With such measurements Δa_μ will be dominated by the uncertainty on the e^+e^- cross-section at low energies. By reducing the uncertainties on this quantity from 0.7% to 0.4% in the region below 1 GeV and from 6% to 2% in the region between 1 and 2 GeV the overall uncertainty on Δa_μ could be reduced by a factor 2. If the central value remains the same, the statistical significance will be 6–7 standard deviations [1].

This effort is challenging but possible, and certainly well motivated by the excellent opportunity the muon $g-2$ is providing us to unveil (or constrain) "new physics" effects.

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