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Hadron physics at KLOE and KLOE-2

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The most recent results from the KLOE experiment on hadron physics are presented. η mesons produced in the radiative decay $\phi \to \eta\gamma$ have been used to measure the rare decays $\eta \to \pi^+\pi^-\gamma$ and $\eta \to e^+e^-e^+e^-$. The decay $\phi \to \eta e^+e^-$ has been used to search for light dark vector mesons. $\gamma\gamma$ collisions have also been exploited to study the single η production, and the $\pi^0\pi^0$ final state looking for the contribution of the scalar $\sigma(600)$.

Some prospects for the new data-taking of KLOE starting at the beginning of 2012 at the upgraded DAΦNE are also discussed.

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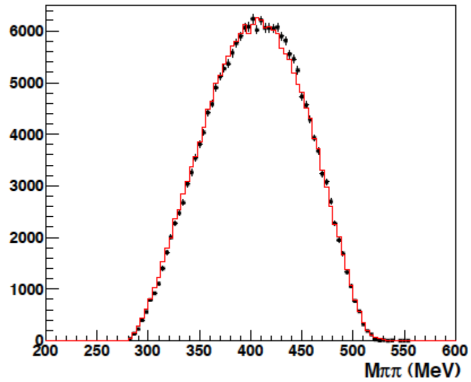


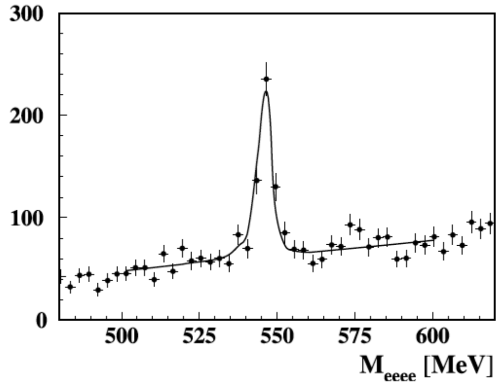
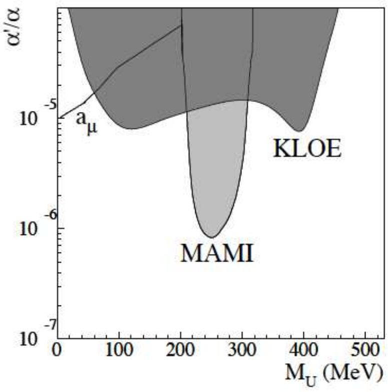


Figure 1: Left - Two pion invariant mass distribution for $\eta \to \pi^+\pi^-\gamma$, points: data; histogram: fit function. Right - Invariant mass distribution of $\eta \to e^+e^-e^+e^-$.

Introduction. From 2000 to 2006 KLOE has collected 2.5 fb^{-1} of data at the peak of the $\phi(1020)$ plus 250 pb^{-1} off-peak at the e^+e^- collider DAΦNE in Frascati. In this paper the recent KLOE results on hadron physics are reported. During 2008 a new interaction scheme of the DAΦNE ϕ-factory has been succesfully tested, reaching a peak luminosity of about a factor of three larger than what previously obtained. Following these achievement, a new data-taking with an improved detector will start at the beginning of 2012 (KLOE-2 experiment). The KLOE-2 present upgrade consists in the installation of two different $e^\pm$ taggers for $\gamma\gamma$ physics: the Low Energy Tagger, made of two crystal calorimeters placed very near the DAΦNE Interaction Point (IP), and the High Energy Tagger, made of two position sensitive detectors placed far from the IP, after the first bending dipoles of DAΦNE. After the collection of about 5 fb^{-1} in one year, a major detector upgrade is planned, aiming to collect about 20 fb^{-1} of data to complete the KLOE physics program [1].

Rare η decays. The properties of the η meson can be studied through the radiative decay $\phi \to \eta\gamma$. The full KLOE data set corresponds to about 10^8 η produced. The process $\eta \to \pi^+\pi^-\gamma$ is described by the so called box anomaly, which is a higher order term of the Wess-Zumino-Witten Lagrangian. From the experimental point of view it is relevant to check if a contact term is needed besides the resonant contribution, dominated by the ρ meson. Both the branching ratio and the two pion invariant mass distribution are sensitive to the contact term [2]. The previous measurements date back to the '70's, the most recent result by CLEO shows a two σ discrepancy with the older ones. From a sample of 558 pb^{-1}, the measurement of the branching ratio normalized to $\eta \to \pi^+\pi^-\pi^0$ has been obtained, $\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0) = 0.1838 \pm 0.0005 \pm 0.0030$ in good agreement with the CLEO result. The normalization sample is clean and well kept under control as is demonstrated by the evaluation of its branching ratio: we selected about 1.2×10^6 events from which we obtain $Br(\eta \to \pi^+\pi^-\pi^0) = (22.41 \pm 0.03 \pm 0.35)\%$ to be compared with the PDG value $(22.74 \pm 0.28)\%$. In fig.1(left) is shown a fit to the $M_{\pi\pi}$ distribution, after the background subtraction, with the parametrization from ref.[3]. The $\pi^+\pi^-$ lineshape of the $\eta' \to \pi^+\pi^-\gamma$ is more sensitive to the contact term; in the first year of KLOE-2 we expect to collect 10^5 events of such process. The decay $\eta \to e^+e^-e^+e^-$ proceeds through two virtual photons intermediate state,



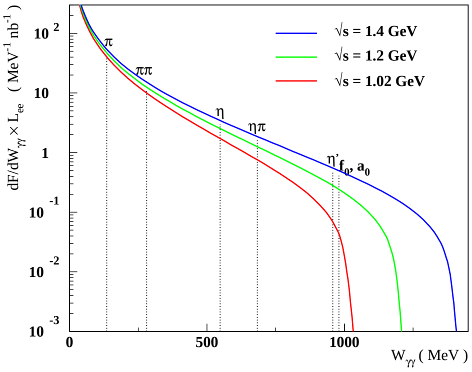


Figure 2: Left - Exclusion plot at 90% C.L. for α'/α compared with the existing limits in our region of interest. Right - Differential photon-photon flux function for different center of mass energies.

with photon conversion to e^+e^-. It is interesting to study the η transition form factor for time-like q^2 of the photons. The theoretical expectation for the branching ratio is around 2.5×10^{-5}. Two upper limits at 90% C.L., based on few events, have been set by the CMD-2 Collaboration, $Br(\eta\to e^+e^-e^+e^-) < 6.9\times10^{-5}$, and by WASA at CELSIUS, $Br(\eta\to e^+e^-e^+e^-) < 9.7\times10^{-5}$. From the analysis of 1.7 fb^{-1} we obtain the first evidence of this decay. In fig.1(right) the four lepton invariant mass of the final sample is reported: we evaluate 362± 29 signal events that correspond to $Br(\eta\to e^+e^-e^+e^-) = (2.4\pm0.2\pm0.1)\times10^{-5}$ [4].

Search for a light dark gauge boson. An explanation of recent astrophysical observations based on the existence of a dark sector that interacts with the Standard Model (SM) particles through the mixing of a new light gauge boson, U of $O(1$ GeV$)$ mass, with the SM hypercharge gauge field has been proposed [5]. The existence of such a new particle has been tested by using the decay chain $\phi\to\eta U$, $U\to e^+e^-$, selecting the decay $\eta\to\pi^+\pi^-\pi^0$. The irreducible background is the Dalitz decay $\phi\to\eta e^+e^-$. No evidence has been found in 1.5 fb^{-1} of data. The exclusion plot for the ratio of the U-boson coupling to the electric charge and the fine structure constant is shown in fig.2, $\alpha'/\alpha < 2\times10^{-5}$ at 90% C.L. in the range $50 < M_U < 420$ MeV [6].

$\gamma\gamma$ physics. In $\gamma\gamma$ processes, like $e^+e^-\to e^+e^-\gamma^*\gamma^*\to e^+e^-X$, $C=+1$ hadronic states can be produced. If both photons are quasi-real, the event yield evaluated in the Equivalent Photon Approximation is $N_{eeX} = L\int\frac{dF}{dW_{\gamma\gamma}}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})dW_{\gamma\gamma}$, where $W_{\gamma\gamma}$ is the $\gamma\gamma$ invariant mass, L is the integrated luminosity and $dF/dW_{\gamma\gamma}$ is the flux function (fig.2). At the DAΦNE energy the final states with a single π^0 or η as well as the $\pi\pi$ one can be detected. The latter is interesting for the study of the $\sigma(600)$, via the reaction $\gamma\gamma\to\sigma(600)\to\pi\pi$. Since KLOE took data without taggers for scattered leptons the off-peak sample, 250 pb^{-1} collected $\sqrt{s}=1$ GeV has been exploited to avoid the large background from the ϕ. The cleanest channel is $\gamma\gamma\to\pi^0\pi^0$; events with only four prompt photons have been selected, the scattered leptons are not detected as they escape in the beam-pipe. In fig.3 the distribution of the four photon invariant mass is shown; the background has been evaluated according to the expected cross-sections of the various processes. Work is in progress to extract $\sigma(\gamma\gamma\to\pi^0\pi^0)$. In the same data sample the η meson production has been also

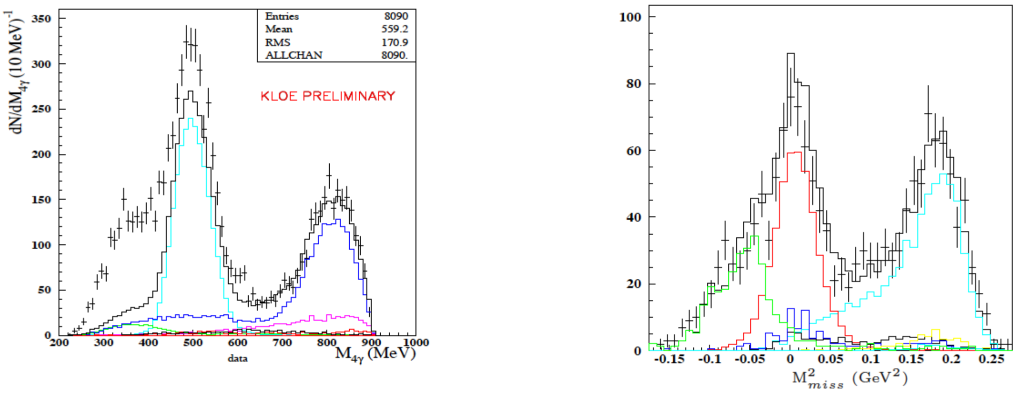


Figure 3: Left - $e^+e^- \to e^+e^-\pi^0\pi^0$, four photon invariant mass: points = data, histograms = background from MC. Right - Missing mass for $e^+e^- \to e^+e^-\eta$: points = data, light blue histogram = signal MC.

studied by selecting $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^0\pi^0\pi^0$. In fig.3 the missing mass for the charged channel is reported. After the background subtraction 650 signal events have been found; the corresponding missing mass distribution is shown in fig.3. In the neutral channel 921 signal events have been obtained. Work is in progress to exract $\sigma(e^+e^- \to e^+e^-\eta)$. As a by-product we measured the cross-section of the main background process for the two photon production of η mesons, $\sigma(e^+e^- \to \eta\gamma, \sqrt{s} = 1\text{ GeV}) = = (0.866 \pm 0.009 \pm 0.093)$ nb. The KLOE-2 data-taking will be mostly at the peak of the ϕ, then the taggers will be essential to suppress the background and to close the kinematics of the events by detecting the scattered leptons. A precision measurement of $\sigma(\gamma\gamma \to \pi^0\pi^0)$, to improve the present experimental knowledge in the region of $W_{\gamma\gamma} < 800$ MeV, is planned [1]. Concerning single pseudoscalar final states, the two photon decay width of π^0 and η can be measured, as well as the transition form factor, $F_{\pi^0\gamma^*\gamma^*}(q_1^2, q_2^2)$, relevant for the calculation of the hadronic light-by-light scattering contribution to $g-2$ of the muon.

Conclusions. KLOE has given a relevant contribution to hadron physics with the 2.5 pb^{-1} collected during the 2001-2006 data-taking. In 2008 has been shown that with a new interaction scheme DAΦNE could increase the luminosity by a factor of about three. A new data-taking campaign is now starting with the KLOE detector upgraded, at first with taggers for $\gamma\gamma$ physics, and then with an Inner Tracker and new small angle calorimeters. We plan to collect about 20 pb^{-1} in the next three years, improving the precision on many of the performed measurements and studying new final states.

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