PROCEEDINGS OF SCIENCE

Physics with the KLOE2 experiment at the ϕ-factory

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A new data-taking with the KLOE detector will start in 2010 at an upgraded ϕ-factory DAΦNE, with luminosity increased by a factor of about three with respect to the previous KLOE data-taking. In this paper the main KLOE-2 physics items concerning hadronic physics are reviewed.

European Physical Society Europhysics Conference on High Energy Physics
July 16-22, 2009
Krakow, Poland

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PoS(EPS-HEP 2009)047

1. The KLOE-2 project

From 2000 to 2006 the KLOE Collaboration has collected 2.5 fb^{-1} of data at the peak of the $\phi(1020)$ plus other 250 pb^{-1} off-peak. During 2008 a new interaction scheme of the DAΦNE ϕ-factory has been succesfully tested, reaching a peak luminosity of about 5×10^{32} cm^{-2} s $^{-1}$, a factor of 3 larger than what previously obtained. Following these achievement, a new data-taking with an improved KLOE detector will start in 2010. The KLOE present upgrade consists in the installation of an electron tagger for $\gamma\gamma$ physics. Two different tagging detectors will be installed: the Low Energy Tagger (low energy refers to the $e^{\pm}$ energy), made of two crystal calorimeters placed very near the DAΦNE Interaction Point (IP) in symmetrical positions, and the High Energy Tagger, made of two position sensitive detectors placed (symmetrically) far from the IP, after the first bending dipoles of DAΦNE. A major detector upgrade has been proposed for a second phase of the next data-taking, with the insertion of a light internal tracker between the beam pipe and the drift chamber, and crystal calorimeters to cover the polar angle regions down to 9°. A further upgrade of the machine to increase its center of mass energy up to 2.5 GeV, has also been proposed. The KLOE-2 physics potential covers many different items: tests of CKM Unitarity and Lepton Universality with kaons, tests of discrete symmetries and of Quantum Mechanics with entangled kaon states, rare kaon decays, light meson spectroscopy (scalar and pseudoscalar mesons), measurement of the hadronic cross-section, search for possible Dark Matter signals at low energy. In this paper only a small selection from the above list is described, while a detailed description of the KLOE-2 physics program can be found in ref.[1].

2. $\gamma\gamma$ physics

In $\gamma\gamma$ processes, $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$ (fig.1), the hadronic state X can only have C=+1, then it is suitable to study scalar and pseudoscalar mesons. The number of produced events as a function of the $\gamma\gamma$ invariant mass can be written as $dN/dW_{\gamma\gamma} = L_{int}(dF/dW_{\gamma\gamma})\sigma(X \to \gamma\gamma)$, where $dF/dW_{\gamma\gamma}$ is the flux function, shown in fig.1 for 3 different center of mass energies. Threshold openings for different hadronic states are emphasized. Accessing center of mass energies up to 1.4 GeV will allow to study the $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\eta$ final states and to detect resonances in these channels, namely the scalar mesons $a_0(980)$, $f_0(980)$, and $\sigma(600)$. On the other hand by exploiting the final states with a single pseudoscalar meson ($X = \pi^0$, η or η'), the two photon decay widths can be measured, which are relevant for the extraction of the pseudoscalar mixing angle and to test the gluon content in the η' wavefunction[2]. The pseudoscalar channels also allow for the measurement of the $P\gamma^*\gamma^*$ transition form factors, which enter the theoretical evaluation of the hadronic light-by-light scattering contribution to $g-2$ of the muon[3].

$\gamma\gamma \to \sigma(600) \to \pi^0\pi^0$. In the last years, new evidence of the $\sigma(600)$ meson has been reported by several collaborations[4]. Moreover the presence of a pole in the $\pi\pi$ scattering amplitude with $J^{PC} = 0^{++}$, m = 441 $^{+16}_{-8}$ MeV, and width $\Gamma = 544$ $^{+24}_{-18}$ MeV, has been pointed out[5].
At KLOE-2 the reaction $e^+e^- \to e^+e^-\pi^0\pi^0$, is the golden channel [6] to study the $\sigma(600)$, because a possible structure would just show up in the $\pi^0\pi^0$ invariant mass, with no need to perform a Dalitz plot study. $\sigma(\gamma\gamma \to \pi^0\pi^0)$ at $W_{\gamma\gamma} < 800$ MeV, measured by Crystal Ball[7], is shown in fig.2. The large uncertainties in the data does not allow any conclusion about the existence of a resonance-like

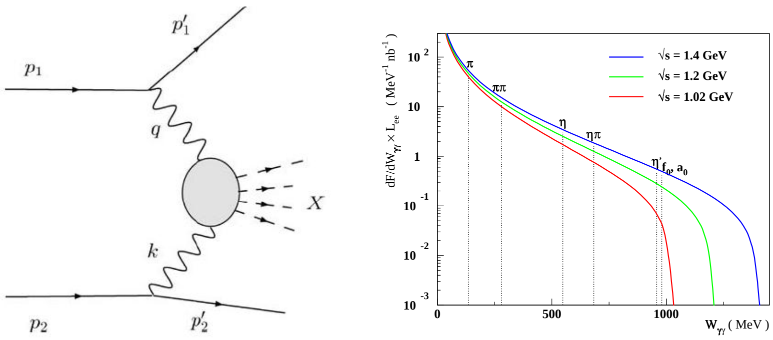

Figure 1: Left: $\gamma\gamma$ process. Right: four photon invariant mass; crosses are KLOE data, histograms are several sources of background evaluated from MC. Right: differential photon-photon flux function for different center-of-mass energies.

structure in the region 400 - 500 MeV.
A feasibility study has been performed with 11 pb^{-1} of KLOE data, taken at $\sqrt{s} = 1$ GeV without $e^{\pm}$ taggers, to develop the algorithms for an efficient selection. The signal efficiency, evaluated by MC[6], is 30%. The four photons invariant mass, fig.2, shows an excess of events in the region below 400 MeV, which is due to genuine $e^+e^- \to e^+e^-\pi^0\pi^0$ events. This study indicates that KLOE-2, with an integrated luminosity $L = 5$ fb^{-1}, can measure the $\gamma\gamma \to \pi^0\pi^0$ cross-section, with the same energy binning of Crystal Ball, reducing the statistical uncertainty at 2% level.

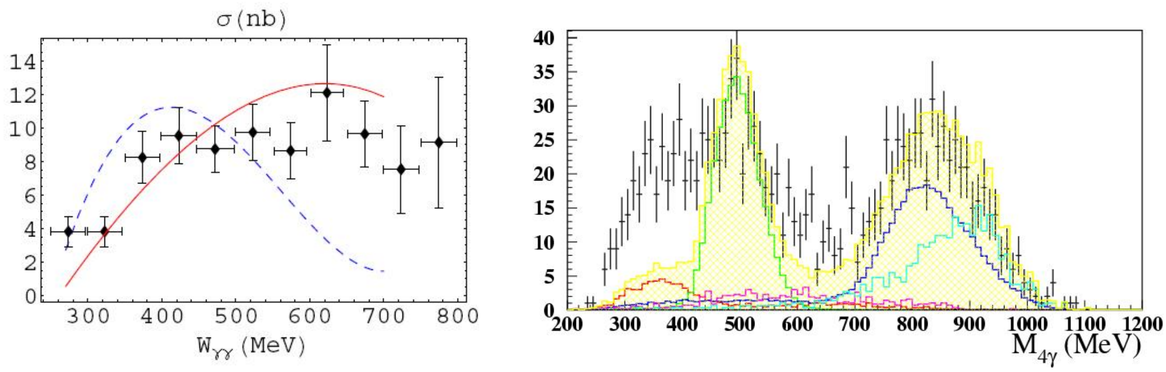

Figure 2: Left:Crystal Ball data compared with a two-loop ChPT prediction (red), and the cross-section of $\gamma\gamma \to \sigma \to \pi^0\pi^0$ obtained from ref.[6] (blue). Right: four photon invariant mass; crosses are KLOE data, histograms are several sources of background evaluated from MC.

$\gamma\gamma \to \eta'$. The η' meson, being almost a pure SU(3)$_{\text{Flavour}}$ singlet, is considered a good candidate to host a gluon condensate. KLOE[2] has extracted the η' gluonium content, $Z_G^2 = 0.12 \pm 0.04$ (3 σ from zero) and the η-η' mixing angle in the constituent quark model, $\varphi_P = (40.4 \pm 0.6)^\circ$. These quantities have been extracted from a fit of the ratio $R_\phi = (\text{Br}(\phi \to \eta'\gamma))/(\text{Br}(\phi \to \eta\gamma)) = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}$, measured by KLOE[8], together with other ratios of partial decay widths of magnetic dipole trantitions, $V \to P\gamma$, and $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$, see fig.3.

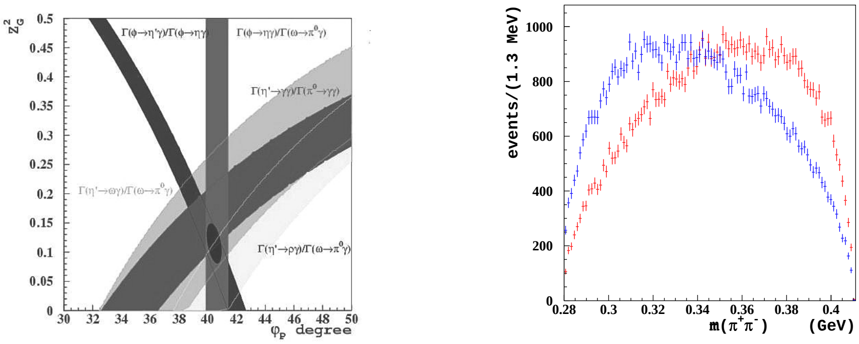

Figure 3: Left: result of the gluonium fit[8]. Right: $m_{\pi^+\pi^-}$ distribution in $\eta' \to \eta\pi^+\pi^-$ with (blue) and without (red) $\sigma(600)$, from a MC simulation.

By measuring the main η' branching ratios at 1% level, KLOE-2 can reach a 4 - 5 σ statistical significance of Z_G^2. This will be possible by producing η' in $\gamma\gamma$ events at $\sqrt{s} = 1.4$ GeV, see tab.1.

Table 1: Expected event yields, per fb^{-1} of integrated luminosity, for the dominant η' decay channels.

	Br($\eta' \to X$) (%)	preferable chain $\leftrightarrow$ Br$_{\text{eff}}$ (%)	events
$\pi^+\pi^-\gamma$	29.4 ± 0.9		12 000
$\pi^+\pi^-\eta$	44.6 ± 1.4	$\pi^+\pi^-\eta(\to 2\gamma) \leftrightarrow 17.5$	7 000
$\pi^0\pi^0\eta$	20.7 ± 1.2	$\pi^0\pi^0\eta(\to \pi^+\pi^-\pi^0) \leftrightarrow 4.7$	2 000
$\omega\gamma$	3.02 ± 0.31	$\omega(\to \pi^+\pi^-\pi^0)\gamma \leftrightarrow 2.7$	1 200
$\gamma\gamma$	2.10 ± 0.12		800

3. Physics at the $\phi(1020)$ peak: low mass scalars

It is still controversial whether the light scalars are $q\bar{q}$ mesons, $qq\overline{qq}$ states, or $K\bar{K}$ molecules. KLOE exploited the radiative decays $\phi \to PP\gamma$ to study $f_0(980)$ and $a_0(980)$, and to look for a signal of the $\sigma(600)$, and extracted the parameters of the scalar resonances from the two pseudoscalar invarant mass distributions[9]. Substantial improvements from KLOE-2 are foreseen for $\phi \to (f_0/a_0)\gamma \to K^0\bar{K}^0\gamma$: the KLOE upper limit, Br($\phi \to K^0\bar{K}^0\gamma) < 1.9 \times 10^{-8}$[10], can be lowered, with the KLOE-2 statistics, down to 1×10^{-8}. The insertion of the inner detector will provide a better vertex position resolution for $K^0, \bar{K}^0 \to \pi^+\pi^-$, then a further improvement down to 0.5×10^{-8} is expected. This value is in the range of the theoretical predictions for the Br, then the first observation of this decay is possible at KLOE-2.
In $\eta' \to \eta\pi\pi$ decays the $\pi\pi$ system has the same quantum numbers of a scalar meson. Moreover the available kinetic energy of the $\pi\pi$ system is in the range (0, 137) MeV, suppressing high angular momentum contributions, and the exchange of vector mesons is forbidden by G-parity conservation. So that only scalar mesons can participate to the scattering amplitude. The decay can

be mediated by the scalar (σ,a_0 and f_0) exchange and by a direct contact term due to the chiral anomaly [11], then the scalar contribution can be determined from a fit to the Dalitz plot. A MC simulation of the $\eta' \to \eta\pi^+\pi^-$ shows that KLOE-2 has a good sensitivity to $\sigma(600)$ (see fig.3).

4. Off-peak physics: measurement of σ_{had}

A high statistics measurement of $\sigma(e^+e^- \to \text{Hadrons})$ has relevant implications on the precision tests of the Standard Model, since it enters the theoretical calculation of both the $a = (g-2)/2$ of the muon and the effective fine-structure constant at the M_Z scale, $\alpha_{em}(M_Z)$[3]. The region below 1 GeV is dominated by $e^+e^- \to \pi^+\pi^-$, and has been studied by different experiments: CMD-2 and SND performed an energy scan at VEPP-2M, while KLOE and BaBar used the Initial State Radiation (ISR) method. The KLOE published result[12] led to a a_μ uncertainty of 0.9% in the range (0.6 - 0.97) GeV, dominated by systematics. The prospects for KLOE-2 are to perform an ISR measurement, with the requirement of an energetic photon, to access the low energy region down to the $\pi^+\pi^-$ threshold. The large background from $\phi \to \pi^+\pi^-\pi^0$ and $\phi \to \pi^+\pi^-\gamma$ can be reduced by running off-peak at $\sqrt{s} = 1$ GeV. Moreover the extraction of the cross-section from the measurement of the ratio $\sigma(e^+e^- \to \pi^+\pi^-)/\sigma(e^+e^- \to \mu^+\mu^-)$ will reduce the theoretical uncertainty. With 2 fb^{-1} KLOE-2 could allow to reach a 0.5% uncertainty on a_μ.
The region (1.0 - 2.5) GeV is much poorly known; in this region BaBar published results of e^+e^- into 3 and 4 hadrons obtained by ISR. KLOE-2 can improve both the exclusive and inclusive measurement if DAΦNE will be able to perform an energy scan of that energy region. Assuming 10^{32} cm^{-2} s^{-1} luminosity, and an energy step of 25 MeV, in one year of run the whole range (1.0 - 2.5) GeV will be scanned with 20 pb^{-1} per point, reaching statistical accuracy better than any other present experiment.

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