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Hadron physics results at KLOE-2

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In its two periods of data-taking the KLOE/KLOE-2 Collaboration has collected a unique data sample of 8 fb^{-1} at the peak of the $\phi(1020)$ resonance. The preliminary results of the latest studies on the light mesons and on the Dark Matter search are presented in this paper.

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1. Introduction

From 2001 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 2008, a new interaction scheme of DAΦNE has been adopted, to increase the luminosity, and from November 2014 to March 2018 a second data-taking campaign, the KLOE-2 experiment, has been carried out collecting 5.5 fb^{-1}. The total KLOE+KLOE-2 sample is the largest worldwide sample collected at the ϕ peak, and it amounts to about 2.4×10^{10} ϕ's produced. The KLOE detector consists of a large volume Drift Chamber surrounded by a hermetic Calorimeter, both immersed in an axial magnetic field of 0.52 T. The Drift Chamber, filled with a gas mixture of He - isobutane, provides a momentum resolution $\sigma_{p_t}/p_t = 0.4\%$ and a space resolution of 150 μm in the plane transverse to the beam line, and 2 cm along the beam direction. The Electromagnetic Calorimeter (EMC), made of Pb-scintillating fibers, covers 98% of the solid angle, with resolutions $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$ and $\sigma_t = 55\text{ps}/\sqrt{E(GeV)} \oplus 100$ ps. For the KLOE-2 data-taking the detector has been upgraded with the insertion of an Inner Tracker close to the DAΦNE Interaction Point (IP), made of four layers of cylindrical GEMs, a tagging system for scattered electrons in $\gamma\gamma$ processes and new small angle calorimeters. The tagging system consists of two different detectors, a High Energy Tagger (HET: scintillator hodoscopes readout by PMTs) placed after the first bending magnet of the machine, and Low Energy Tagger (LET: LYSO crystal calorimeters with SiPMs) placed 1 m far from the IP. The QCALT (tungsten and scintillator tiles with SiPMs) as instrumentation of the quadrupoles, and the CCALT (LYSO crystals with SiPMs) constitute the small angle calorimeter system.

2. $\eta \to \pi^0\gamma\gamma$

The doubly radiative decay $\eta \to \pi^0\gamma\gamma$ provides a good test of Chiral Perturbation Theory (ChPT), since the tree level contributions at $O(p^2)$ and $O(p^4)$ vanish because neutral mesons are involved, and the $O(p^4)$ contributions from kaon or pion loops are suppressed. Therefore the first sizeable contribution comes from $O(p^6)$. On the experimental side, the two most recent measurements have been performed with essentially the same detector, $Br = (2.21 \pm 0.24 \pm 0.47) \times 10^{-4}$ from Crystal Ball at AGS [1], and $Br = (2.52 \pm 0.25) \times 10^{-4}$ from A2 at MAMI [2]. These two values are significantly higher of the KLOE old result $Br = (0.84 \pm 0.27 \pm 0.14) \times 10^{-4}$ based on 68 signal events[3]. A new sample of 1.7 fb^{-1} of data, has been analyzed, looking for 5 prompt photon events from the decay $\phi \to \eta\gamma$ with $\eta \to \pi^0\gamma\gamma$. The main background comes from the process $\phi \to \eta\gamma$ with $\eta \to 3\pi^0$, with photons lost or merged in the EMC. In Fig.1-left it is reported the invariant mass distribution of the four photons from η decay, showing a clear evidence of the signal, superimposed to a large irreducible background. The yield of signal events is 1422 ± 138, which gives a $Br(\eta \to \pi^0\gamma\gamma) = (1.21 \pm 0.13 \pm 0.28) \times 10^{-4}$ when normalized to the very clean and abundant sample of seven prompt photon events from $\phi \to \eta\gamma$ with $\eta \to 3\pi^0$. This result is consistent with the old KLOE result, and about a factor of two lower than the measurements obtained with the Crystal Ball. By performing the analysis in bins of the invariant mass of the two photons not coming from the π^0, the differential decay rate has been obtained and compared with refs.[1, 2]in Fig.1-right. The superimposed curve is a recent calculation based on Vector Meson Dominance and Linear Sigma Model[4].

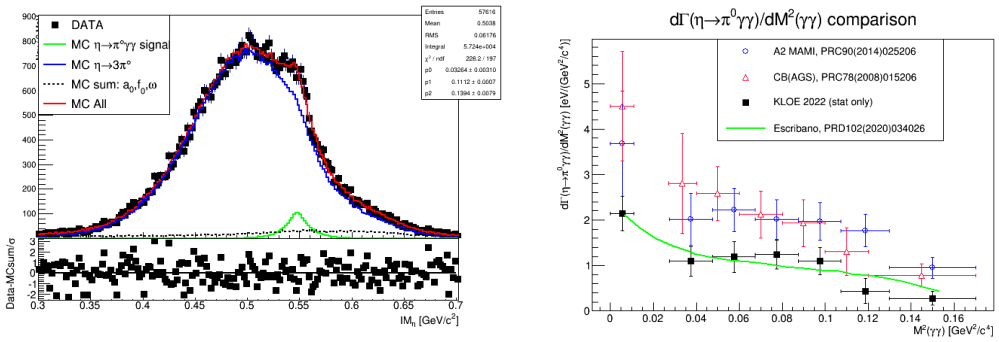

Figure 1: Left: Four photon invariant mass distribution, signal (green) and $\eta \to 3\pi^0$ background (blue), the red histogram is the sum of all the contributions; right: differential decay rate as a function of the invariant mass of the two photons not coming from π^0, compared to previous experiments and to the latest theoretical prediction[4].

3. $e^+e^- \to \pi^+\pi^-\pi^0\gamma_{ISR}$

The cross section of $e^+e^- \to \pi^+\pi^-\pi^0$ constitutes the second largest contribution to the theoretical calculation of the Hadronic Vacuum Polarization for the muon anomaly $(g-2)_\mu$ and also to its uncertainty. This cross section has been extensively measured with the energy scan method by the SND and CMD-2 Collaborations[5]. At KLOE the Initial State Radiation (ISR) method can be used to measure the cross-section at $\sqrt{s} < M_\phi$, including the region of the $\omega(782)$ resonance. In a sample of 1.7 fb^{-1} of data collected at the $\phi(1020)$ peak, events with at least two charged tracks with opposite curvature, and three neutral clusters in the EMC have been selected. A kinematic fit has been applied to improve the detector resolutions. The three pion invariant mass distribution after background subtraction is shown in Fig.2-left, and from a fit to a Breit-Wigner curve, convoluted with the smearing matrix and taking into account the corrections for the ISR, the $\omega(782)$ parameters reported in Tab.1 have been obtained. The parameters are in good agreement with

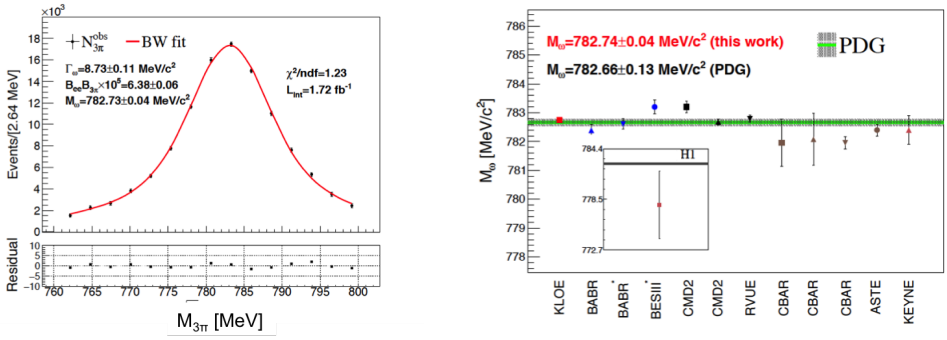

Figure 2: Left: Three pion invariant mass distribution, in red the result of the fit to a Breit-Wigner curve; right: comparison of all the recent measurement of the $\omega(782)$ mass .

PDG [6] and with the recent measurement of the BaBar [7] performed with the same ISR method. In Fig.2 the ω mass value is compared to the previous measurements and the PDG average.

	M_ω [MeV]	Γ_ω [MeV]	$Br(\omega \to e^+e^-) \times Br(\omega \to \pi^+\pi^-\pi^0$ [$\times 10^{-5}$]
KLOE	782.73± 0.04	8.73± 0.11	6.38± 0.06
PDG ave.	782.66± 0.13	8.68± 0.13	6.60± 0.13
BaBar 2021[7]			6.56± 0.10

Table 1: $\omega(782)$ parameters, only the statistical uncertainty is reported for the KLOE measurement.

4. $\phi \to \eta\mu^+\mu^-$

By measuring the invariant mass spectra of the lepton pairs produced in the Dalitz decays $V \to P\ell^+\ell^-$, the Transition Form Factors (TFF) at time-like momentum transfers can be determined. While the decay of $\phi \to \eta e^+e^-$ has been extensively studied, being the most recent result from KLOE in 2015 [8], for the decay into muon pairs only an upper limit on the branching fraction by the CMD-2 Collaboration exists, $Br < 9.4 \times 10^{-6}$ at 90% C.L.[9] This decay, $\phi \to \eta\mu^+\mu^-$ can be studied at KLOE by selecting events with two charged tracks and two or six prompt photons to exploit, respectively, the $\eta \to \gamma\gamma$ and $\eta \to 3\pi^0$ channels. About 1.6 fb^{-1} of data are being analyzed, and in Fig.3.left the invariant mass of the $\gamma\gamma$ pair is reported, showing a clear signal corresponding to the η mass. The second peak on the right is from the decay $\phi \to \eta\pi^+\pi^-$, that can

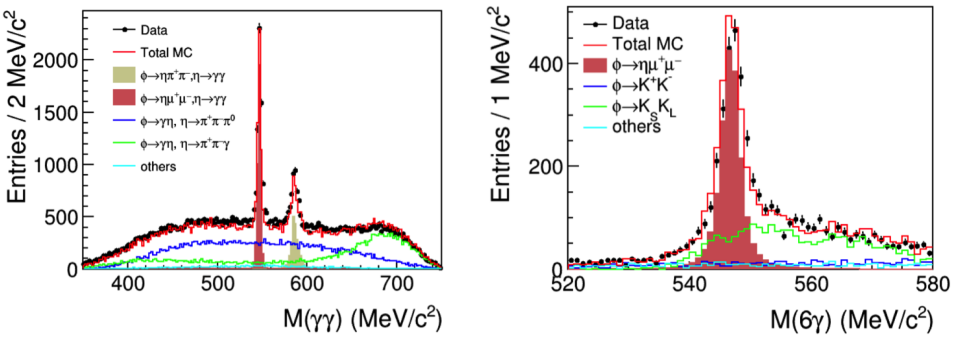

Figure 3: Left: Invariant mass of the $\gamma\gamma$ pair; right: invariant mass of the six prompt photons from $\eta \to 3\pi^0$.

also be studied with the same data sample, shifted with respect to the true η mass value due to the assumption of the wrong charged particle mass. In Fig.3.right the signal from the $\eta \to 3\pi^0$ decay is shown. Work is in progress to extract the branching ratio and the TFF.

5. Search for a leptophobic B-boson

Among the different models proposed for Dark Matter, there is the possibility of a new weakly coupled force interacting preferentially with quarks. The simplest model[10] is provided by a new gauge boson, called B-boson, not coupled to leptons, that in the mass range below 1 GeV would decay essentially to $\pi^0\gamma$. This energy range is accessible with the KLOE data by looking for 5 prompt photon events from $\phi \to \eta B$ and $\phi \to \eta\gamma$ with $\eta \to B\gamma$, both followed by $B \to \pi^0\gamma$. The first decay is studied with a sample of 1.7 fb^{-1} of KLOE data, using the $\eta \to \gamma\gamma$ final state; the

background processes are $\phi \to a_0(980)\gamma$, and $\phi \to \eta\gamma$ with $\eta \to 3\pi^0$ with lost or merged photons. In Fig.4-left the $\pi^0\gamma$ invariant mass is shown, together with the background evaluated from a fit to the sidebands in a region of 5 σ, excluding the 1 σ central region, where $\sigma \sim 2$ MeV is the mass resolution. With the CL_S method an exclusion region for the coupling α_B of the B-boson to quarks

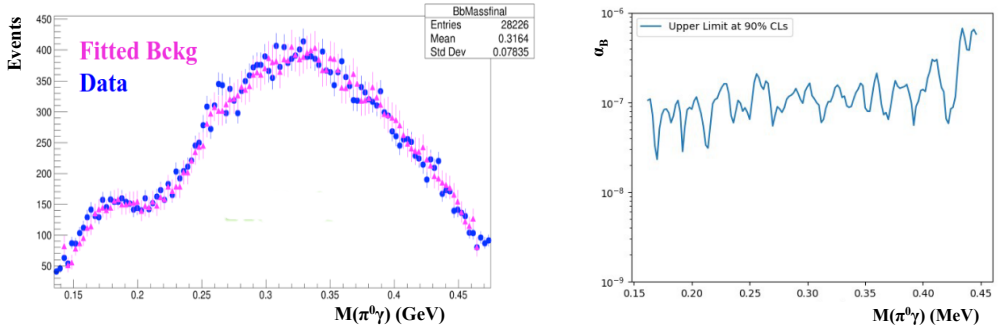

Figure 4: Left: $\pi^0\gamma$ invariant mass, data in blue, and background from sideband fit in magenta; right: upper limit on the coupling α_B as a function of the B-boson mass.

can be derived, as shown in Fig.4.right.

6. $\gamma\gamma \to \pi^0$

In the upgrade of the detector before the second phase of data-taking (KLOE-2), a High Energy Tagger (HET) has been installed to detect the scattered electrons in $\gamma\gamma$ interactions. The HET consists of two scintillator hodoscopes read out with standard PMTs, placed after the first bending dipoles of the DAΦNE rings. The goal is to measure the π^0 width at few percent level, by detecting π^0's produced in the process $e^+e^- \to e^+e^-\gamma^\star\gamma^\star \to e^+e^-\pi^0$. Also the TFF at very low space-like momentum transfer ($q^2 < 0.1$ GeV^2), relevant for the theoretical calculation of the Light-by-Light scattering contribution to the muon anomaly, can be measured. The HET has been acquired asynchronously with respect to the central detector, and HET signals corresponding to 2.5 DAΦNE revolutions were recorded for each KLOE-2 trigger. The analysis is based on the comparison of the samples with the HET-KLOE coincidences ("A+" sample) and without coincidences (pure accidental, "A" sample). Events with signal on one of the two HET stations in a time window of 40 ns around the KLOE-2 trigger, and with two neutral clusters in the EMC, are selected. The number of π^0's is estimated from a simultaneous fit to several variables, normalized to radiative Bhabha scattering events. By combining the two HET stations, a statistical uncertainty of 6.5% can be reached on the π^0 width. The evaluation of the systematics coming from the different detector acceptance for signal events and for radiative Bhabha scattering is in progress.

7. Conclusions

The KLOE/KLOE-2 Collaboration collected about 8 fb^{-1} of data at the peak of the $\phi(1020)$ resonance in two different data-taking periods. This is a unique worldwide data sample, from which

many interesting physics processes can be studied. In this paper the preliminary results on analyses concerning light mesons and Dark Matter search have been presented.

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