Hadron Physics at KLOE and KLOE-2

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The KLOE Collaboration completed the full data taking on March 2006, acquiring 2.5 \textit{fb}\textsuperscript{-1} at the peak of the $\phi$ and other 240 \textit{pb}\textsuperscript{-1} off-peak. A new Collaboration is working on a new project, called KLOE-2, to refine and extend the KLOE physics program.

We present here some preliminary and published results from the KLOE Collaboration on the pseudoscalar $\eta$ meson and the study of $\gamma\gamma$ processes, that are among the main points of the KLOE-2 physics program.

1 Introduction

The KLOE experiment has collected 2.5 \textit{fb}\textsuperscript{-1} at the peak of the $\phi$ resonance at the $e^+e^-$ collider DA\textit{Φ}NE in Frascati. KLOE has performed several precision measurements, here we present the preliminary analysis of the $\eta \rightarrow \pi^+\pi^-\gamma$ decay channel to study box anomaly and the recently published branching ratio measurement of $\eta \rightarrow e^+e^-e^+e^-$ decay channel, never observed before. Pseudoscalar production at the $\phi$-factory associated to internal conversion of the photon into a lepton pair allows the measurement of the form factor $F(pq^2) = M(\phi)^2, q^2 \geq 0$ of pseudoscalar mesons in the kinematical region of interest for the VMD model: a preliminary study of $\phi \rightarrow \eta e^+e^-$ is based on 739 \textit{pb}\textsuperscript{-1}, using the $\eta \rightarrow \pi^+\pi^-\pi^0$ final state.

From a sample of 240 \textit{pb}\textsuperscript{-1} taken off the $\phi$ resonance, a preliminary analysis of the $e^+e^- \rightarrow e^+e^-\eta$ process, without $e^\pm$ tagging in the final state has been performed. The same data set has been used to search for the $f_0(600)$ produced in $\gamma\gamma$ interactions via the reaction $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$.

The KLOE detector is being upgraded with small angle tagging devices, to detect both high and low energy $e^\pm$ in $e^+e^- \rightarrow e^+e^-X$ events. The inner tracker and small angle calorimeters are scheduled to be installed in a subsequent step, providing wider acceptance for both charged particles and photons. This is the new KLOE-2 project\textsuperscript{[1]}: the detector is successfully rolled in the new DA\textit{Φ}NE interaction region, with a new beam crossing scheme allowing for a reduced beam size and increased luminosity. The main goal of KLOE-2 is to collect an integrated luminosity of about 20 \textit{fb}\textsuperscript{-1} in 2-3 years in order to refine and extend the KLOE physics programme.

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2 The Pseudoscalar $\eta$ meson

The decays $\eta, \eta' \to \pi^+ \pi^- \gamma$ are supposed to get contribution from the anomaly accounted by the Wess Zumino Witten term into the Chiral Perturbation Theory Lagrangian [2]. Those anomalous processes, known as box anomalies, proceed via a vector meson resonant contribution (VDM) and maybe via a direct term. The presence of this direct term affects the partial width value in the case of the $\eta \to \pi^+ \pi^- \gamma$ and the dipion invariant mass distribution, in the case of $\eta' \to \pi^+ \pi^- \gamma$.

A comparison of the experimental $M_{\pi^+ \pi^-}$ spectra and partial width for $\eta, \eta'$ meson with theoretical predictions is mandatory to clarify the role of non-resonant contribution to the processes. The $\eta \to \pi^+ \pi^- \gamma$ decay has been measured in 1970 by Gormley et al. (7250 events) [3] and in the 1973 by Layter et al. (18150 events) [4]. Theoretical papers trying to combine the two measurements found discrepancies in data treatment and problems in obtaining consistent results [2]. In 2007 CLEO Coll. has published the measurement $\Gamma_{\eta \to \pi^+ \pi^- \gamma}/\Gamma_{\eta \to \pi^+ \pi^- \pi^0} = 0.175 \pm 0.007 \pm 0.006$, based on 859 $\eta \to \pi^+ \pi^- \gamma$ events [5], which is more then 3$\sigma$ below the old measurements. KLOE result [6], obtained using 558 $pb^{-1}$, gives $\Gamma_{\eta \to \pi^+ \pi^- \gamma}/\Gamma_{\eta \to \pi^+ \pi^- \pi^0} = 0.1838 \pm 0.0005_{stat} \pm 0.0030_{syst}$, in agreement with the latest CLEO evaluation, providing strong evidence in favour of the box anomaly/direct term.

The knowledge of the $\eta$ meson coupling to virtual photons is important for calculation of anomalous magnetic moment of the muon, because the pseudoscalar exchange is the major contribution to the hadron light-by-light scattering [1]. In the $\eta \to e^+e^-e^+e^-$ process we have conversion decays, which offer the possibility to precisely measure the virtual photon 4-momentum, via the $e^+$ and $e^-$ 4-momenta and we are directly sensitive to the $\eta$ meson transition form factor because there are no hadrons among the decay products. The first theoretical evaluation dates from 1967 [7] and predicts a branching ratio $BR(\eta \to e^+e^-e^+e^-) = 2.59 \times 10^{-5}$. Double lepton-antilepton $\eta$ decays have been searched by CMD-2 and WASA, obtaining upper limits at level of the theoretical expectation. KLOE has published the first observation of the $\eta \to e^+e^-e^+e^-$ decay, analysing 1.7 $fb$ and identifying 362 $\pm$ 29 events which results in a branching ratio of $(2.4 \pm 0.2_{stat+bkg} \pm 0.1_{syst}) \times 10^{-5}$, in agreement with theoretical predictions [8].

Vector-meson-dominance assumption provides good description of photon coupling to hadrons, and, implementing systematic corrections to standard VMD, it correctly describes the $\omega \to \pi^0 \mu^+ \mu^-$ experimental results too. In this framework deviation from standard VMD for the $\phi \to \eta e^+e^-$ decay spectrum is predicted. The only existing data available come from SND experiment, which has measured the $M_{ee}$ invariant mass distribution with 213 events [9]. KLOE has selected 7000 $\phi \to \eta e^+e^-$ with $\eta \to \pi^+ \pi^- \pi^0$ using a sample of 739 $pb^{-1}$. Preliminary fit to the $M_{ee}$ using decay parametrization from [10] and $F(q^2)$ as from [11], indicates the possibility to reach a 5% error on form factor slope.
2.1 Gamma-gamma Physics

The coupling of photons to scalar and pseudoscalar mesons brings information on meson’s quark structure and can be measured directly in $e^+e^-$ colliders via the reaction $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$. Using the Weizsäcker-Williams approximation [12] to understand main qualitative features of the process, when no cuts are applied to the final state leptons, it is possible to evaluate the event yields:

$$N_{eeX} = L_{ee} \int \frac{dF}{dW_{\gamma\gamma}} \sigma_{\gamma\gamma \rightarrow X} (W_{\gamma\gamma}) dW_{\gamma\gamma}$$

$L_{ee}$ is the integrated luminosity, $W_{\gamma\gamma}$ is the mass of the $\gamma^*\gamma^*$ and $dF/dW_{\gamma\gamma}$ the two photons flux function, defined as follows:

$$dF = \frac{1}{W_{\gamma\gamma}} \left( \frac{2\pi}{\alpha} \right)^2 (\ln \frac{E_b}{m})^2 f(z)$$

with $E_b$ beam energy and $f(z)$ is a function of $z = \frac{W_{\gamma\gamma}}{2E_b}$.

Single $\pi^0$ or $\eta$ production is accessible and this allows to improve determination of two photon decay width of these meson. In particular KLOE is looking for $e^+e^- \rightarrow e^+e^-\eta$ with $\eta \rightarrow \pi^+\pi^-\pi^0$ final state: in a preliminary analysis of 240 $pb^{-1}$ off-peak data about 600 events from $\eta$ meson, produced in $\gamma\gamma$ interactions have been disentangled, versus other processes, with a statistical accuracy on $\Gamma_{\gamma\gamma}$ comparable with existing measurements. The same off-peak data have been analysed to search for $e^+e^- \rightarrow e^+e^-\eta$ with $\eta \rightarrow \pi^0\pi^0\pi^0$ final state.

The question concerning $\sigma/f_0(600)$ meson has been debated for a long time. An indirect evidence comes from $\phi \rightarrow \pi^0\pi^0\gamma$ KLOE analysis [13]. The $e^+e^- \rightarrow e^+e^-\pi^0\pi^0\pi^0$ process is a clean electromagnetic probe to investigate the question, because it is expected to be plainly affected by $\sigma$ contribution. Our preliminary analysis on the off-peak data, shows a clear enhancement over estimated backgrounds at low $M_{4\gamma}$, see Fig.1. Background subtraction and study of differential cross section together with the understanding of the $\sigma \rightarrow \pi\pi$ contribution are in progress.

![Figure 1: Preliminary spectrum of 4-photons invariant mass with KLOE: dots are data, black line is total MC background, lightblue is $K_S K_L$ decays, blue is $e^+e^- \rightarrow \omega \pi^0$ and magenta is $\phi \rightarrow f_0(1500)$; a clear evidence of $e^+e^- \rightarrow e^+e^-\pi^0\pi^0\pi^0$ is given by the excess events at low $M_{4\gamma}$ invariant mass is visible.](image-url)
Due to large background from $e^+e^- \rightarrow \gamma\gamma(\gamma)$, information from $e^\pm$ taggers already installed at KLOE-2, will be crucial in the analysis of new data to look for the production of $\sigma$.

The KLOE experiment with 2.5 $fb^{-1}$ integrated luminosity at the peak of the $\phi$ resonance at the $e^+e^-$ collider DAΦNE, has published several interesting results. In the next future a new data-taking campaign will be realized by KLOE-2 at the upgraded DAΦNE, with the aim to collect about 20 $fb^{-1}$ in order to refine and extend the KLOE physics program.

References


