HADRON PHYSICS AT KLOE AND KLOE-2

C. Di Donato on Behalf of KLOE and KLOE-2 Collaborations
I.N.F.N., Complesso Universitario M.S.A. ed. 6,
Via Cintia 80126-Napoli, Italy

KLOE data allow to study many interesting processes related to light mesons. Several item have been investigated, among them we present the recently published search for the U boson produced with η meson and the last results on the dynamics of the $\eta \to \pi^+\pi^-\gamma$ decay. The KLOE-2 project aims to extend the KLOE program with detector upgrades and increased statistics: we describe the status of the art.

1 KLOE and DAΦNE

The e^+e^- collider DAΦNE, designed to operate at the center of mass energy $\sqrt{s} \simeq 1.02$ GeV, the ϕ meson mass, has delivered to the KLOE experiment an integrated luminosity of about $2.5 fb^{-1}$ on peak of the ϕ meson and also about $240 pb^{-1}$ at $\sqrt{s} \simeq 1$ GeV. The KLOE detector consists of a large volume cylindrical drift chamber [1] (DC), 3.3 m length and 2 m radius, surrounded by a calorimeter [2] (EMC) made of lead and scintillating fibers. A superconducting coil produces an axial field $B = 0.52$ T. In the DC charged particle momenta are reconstructed with resolution $\sigma_p/p \simeq 0.4\%$, while in the EMC energy clusters are reconstructed grouping calorimeter cells close in space and in time with energy and time resolution of $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$ and $\sigma_t = 57ps/\sqrt{E(GeV)} \oplus 100$ ps.

1.1 U Boson Search: $\phi \to \eta e^+e^-/\eta U$

In recent years several unexpected astrophysical observations have failed to find a common interpretation in terms of standard astrophysical or particle sources. All these unexpected observations [a] can be interpreted assuming the existence of a light hidden sector interacting with Standard Model particles through the mixing (ϵ) between a new gauge vector boson U, with mass lighter than O(GeV), and the photon. The U boson can be produced at e^+e^- colliders via different processes [3], we present the analysis of the process $\phi \to \eta U$, where the η meson is tagged by the $\eta \to \pi^+\pi^-\pi^0$ channel. The Dalitz decay $\phi \to \eta l^+l^-$, having the same signature, is an irreducible background for the U boson search. The SND [4] and CMD-2 [5] collaborations measured the branching fraction of $BR(\phi \to \eta e^+e^-) = O(10^{-4})$, which corresponds to a cross section of $\sigma(\phi \to \eta l^+l^-) \sim 0.7$ nb. For the signal the expected cross section is $\sigma(\phi \to \eta U) \sim 40$ fb, in the hypothesis of a mixing $\epsilon = 10^{-3}$ and a $\phi\eta\gamma^*$ transition form factor $|F_{\phi\eta}(m_U^2)|^2 = 1$. Even though the ratio between the overall cross section of the $\phi \to \eta U$ and $\phi \to \eta l^+l^-$ is not favorable to the signal, the di-lepton invariant mass should be different allowing to test the kinetic mixing parameter ϵ. We searched for the U boson in the e^+e^- final state, because the

[a] For an exhaustive list of references see the KLOE-2 paper [3]

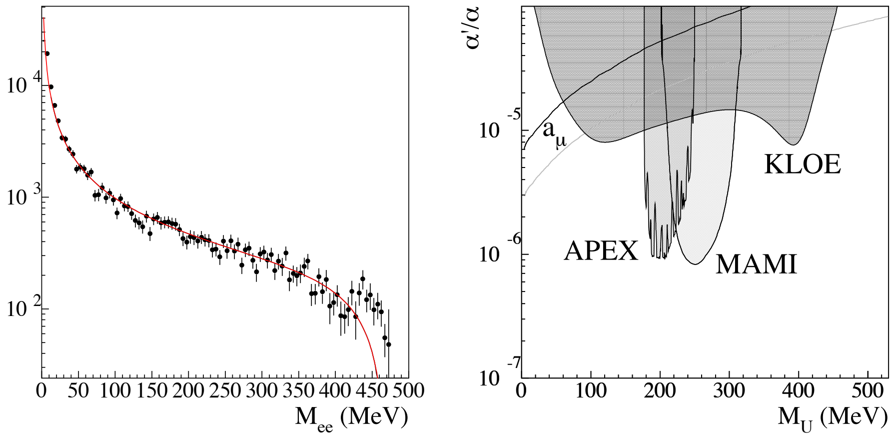

Figure 1: Left: Fit to the corrected M_{ee} spectrum for the Dalitz decays $\phi \to \eta e^+e^-$; Right: Exclusion plot at 90% C.L. for the parameter $\alpha'/\alpha = \epsilon^2$, compared with existing limits in our region of interest.

channel $U \to e^+e^-$ allow to search the U boson in a wider mass range and the $e^\pm$ are easily identified using TOF technique.
The M_{ee} spectrum has been studied using an integrated luminosity of 1.5 fb^{-1} of ϕ decays: about 14,000 $\phi \to \eta e^+e^-$, $\eta \to \pi^+\pi^-\pi^0$ candidates are present in the analyzed data set, with a negligible background contamination.

The background shape is extracted directly from our data. A fit is performed to the M_{ee} distribution, after a bin-by-bin subtraction of $\phi \to \eta\gamma$ background and efficiency correction, using the following parametrization as from Vector Meson Dominance (VMD) model [6]

$$\frac{d\Gamma(\phi \to \eta e^+e^-)}{dq^2} = \frac{\alpha}{3\pi}\frac{|F_{\phi\eta}(q^2)|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right)\lambda^{3/2}\left(m_\phi^2, m_\eta^2, m_U^2\right) \tag{1}$$

with $q = M_{ee}$ and the transition form factor described by:

$$F_{\phi\eta}(q^2) = \frac{1}{1-q^2/\Lambda^2} \tag{2}$$

Free parameters of the fit are Λ and an overall normalization factor. A good description of the M_{ee} shape is obtained except at the high end of the spectrum see fig.(1.left), because of the contamination of a residual background from multi-pion events. The $\phi \to \eta U$ Monte Carlo signal has been produced according to Reece-Wang model [7], with a flat distribution of the U mass, M_U. The sample has been used to evaluate the resolution on the e^+e^- invariant mass as a function of M_U: resolution is ~ 2 MeV for $M_U < 350$ MeV and then improves to 1 MeV for higher values. The upper limit on $\phi \to \eta U$ as a function of M_U has been reported in terms of the kinetic mixing parameter $\epsilon^2 = \alpha'/\alpha$, where α' is the coupling of U boson to electrons and α is the fine structure constant. We include the opening $U \to \mu^+\mu^-$ threshold, in the hypothesis that the U boson decay only to lepton pairs and assuming equal coupling to e^+e^- and $\mu^+\mu^-$. The smoothed exclusion plot at 90% C.L. on α'/α, see fig.(1.right), is compared with existing limits from the muon anomalous magnetic moment a_μ and from recent measurement of MAMI [8] and APEX [9]. The gray line is where the U boson parameters should lay to account for the observed discrepancy between measured and calculated a_μ values. Our result improves existing limits in a wide mass range, resulting in an U.L. on $\alpha'/\alpha \leq 2 \times 10^{-5}$ @ 90% C.L. for $50 < M_U < 420$ MeV. Our result excludes that the existing a_μ discrepancy is due to U boson with mass ranging between 90 and 450 MeV. Preliminary study for $U-$boson search looking at

$\eta \to \gamma\gamma$ and $\eta \to 3\pi^0$ looks promising and they should in principle allow to improve U.L. by a factor 2.

1.2 Light Mesons: $\eta \to \pi^+\pi^-\gamma$

The decays $\eta \to \pi^+\pi^-\gamma$ and $\eta' \to \pi^+\pi^-\gamma$ are expected to get contribution from the anomaly accounted for by the Wess Zumino Witten (WZW) term into the ChPT Lagrangian [10]. Those anomalous processes are referred to as box anomalies which proceed through a vector meson resonant contribution, described by VMD. According to effective theory [10] the contribution of the direct term should be present together with VMD. In case of $\eta \to \pi^+\pi^-\gamma$ the ρ contribution is not dominant, this makes the partial width sensitive to the presence of the direct term. Recently CLEO [12] has measured the ratio $R_\eta = \Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0) = 0.175 \pm 0.007_{stat} \pm 0.006_{syst}$, which differs by more than 3σ from the average result [15] of previous measurements [13,14], $R_\eta = 0.207 \pm 0.004$. We present a preliminary measurement with the highest statistics and the smallest systematic error ever achieved.

The final state under study is $\pi^+\pi^-\gamma\gamma$, since at KLOE, the η mesons are produced together with a monochromatic recoil photon ($E_\gamma = 363$ MeV) through the radiative decay $\phi \to \eta\gamma$. In the considered data sample there are about $\simeq 25 \times 10^6$ η's. The main background comes from $\phi \to \pi^+\pi^-\pi^0, \pi^0 \to \gamma\gamma$ decaying to the same final state. Other backgrounds are $\phi \to \eta\gamma \to \pi^+\pi^-\pi^0 \to \pi^+\pi^-3\gamma$ with one photon lost, and $\phi \to \eta\gamma, \eta \to e^+e^-\gamma$ when both electrons are mis-identified as pions. The process $\phi \to \eta\gamma$ with $\eta \to \pi^+\pi^-\pi^0$ represents a good control sample, due to the similar topology. Moreover the ratio $\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$ is not affected by the uncertainties on the luminosity, the $\phi \to \eta\gamma$ partial width and the ϕ production cross section cancel in the ratio. We use the same preselection as for the $\eta \to \pi^+\pi^-\gamma$ signal. Concerning the control sample we select $N(\eta \to \pi^+\pi^-\pi^0) = 1190 \cdot 10^3$, with a selection efficiency of $\varepsilon = 0.2277 \pm 0.0002$ and a background contamination of 0.65%; concerning the signal we select $N(\eta \to \pi^+\pi^-\gamma) = 204950 \pm 450$ with $\varepsilon = 0.2131 \pm 0.0004$ and a background contamination of 10%. Combining our results we obtain the ratio:

$$R_\eta = \frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.1856 \pm 0.0005_{stat} \pm 0.0028_{syst} \tag{3}$$

Our measurement is in agreement with the most recent result from CLEO [12], $R_\eta = 0.175 \pm 0.007_{stat} \pm 0.006_{syst}$. Combining our measurement with the world average value [11] $\Gamma(\eta \to \pi^+\pi^-\pi^0) = (295 \pm 16)$ eV, we get $\Gamma(\eta \to \pi^+\pi^-\gamma) = (55 \pm 3)$ eV, which is in agreement with the value expected taking into account the direct term [10], providing a strong evidence in favor of the box anomaly.

The $M_{\pi^+\pi^-}$ dependence of decay width has been parametrized in different approaches, in which VMD has been implemented in effective Lagrangians [10,16]. Recently a model independent method, based on ChPT and dispersive analysis, has been developed [17]. In this approach, the relative strength between tree level and resonance contribution are not fixed. The function proposed to describe the partial width as function of $s_{\pi\pi} = m^2_{\pi\pi}$ is the following:

$$\frac{d\Gamma(\eta \to \pi^+\pi^-\gamma)}{ds_{\pi\pi}} = |AP(s_{\pi\pi})F(s_{\pi\pi})|^2\, \Gamma_0(s_{\pi\pi}) \tag{4}$$

where A is a normalization factor; $\Gamma_0(s_{\pi\pi}) = \frac{1}{3 \cdot 2^{11} \cdot \pi^3 m_\eta^3} \left(m_\eta^2 - s_{\pi\pi}\right)^3 s_{\pi\pi}\sigma(s_{\pi\pi})^3$ with $\sigma(s_{\pi\pi}) = \sqrt{1 - 4m_\pi^2/s_{\pi\pi}}$; $F_V(s_{\pi\pi})$ is the pion vector form factor, the function $P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi}$ is reaction specific. For more details see Stoll's paper [17].

The α parameter was measured also by the WASA@COSY collaboration [18]: $\alpha = (1.89 \pm 0.25_{stat} \pm 0.59_{syst} \pm 0.02_{th})$ GeV^{-2}. Fig.2 shows the observed $M_{\pi^+\pi^-}$ spectrum, background subtracted, compared with the theoretical prediction of eq.(4) with the value $\alpha = (1.31 \pm 0.08_{stat} \pm 0.40_{syst} \pm 0.02_{th})$ coming as output of the fit to the $M_{\pi\pi}$ shape, corrected for acceptance and smearing.

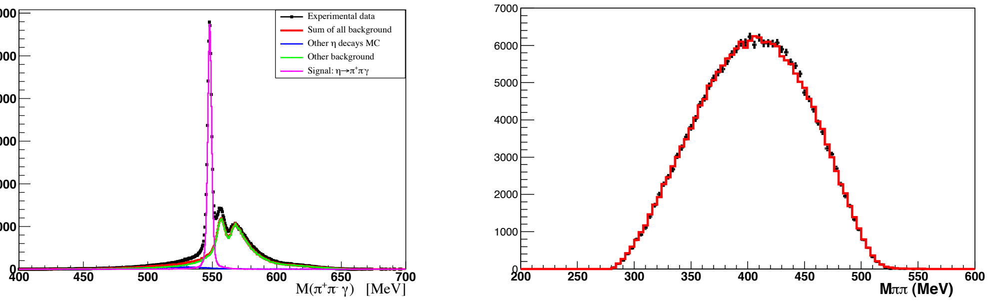

Figure 2: Left: The $\pi^+\pi^-\gamma_\eta$ invariant mass distribution: Data-MC comparison. Dots are data, Magenta is MC signal $\eta \to \pi^+\pi^-\gamma$, Red is all MC background contribution; Right:Measured spectrum $m_{\pi\pi}$ (dots); histogram is the prediction from eq.(4) with α as from the output of the fit, corrected for acceptance and experimental resolution

1.3 KLOE-2

High statistic samples of light mesons produced at KLOE allowed to perform precision measurement and to look for very rare decays. A new DAΦNE interaction region, with large beam crossing angle and sextupoles for crab waist, improved the performance of the collider: a factor 3 in the luminosity has been gained. Minimal detector upgrade for first KLOE-2 run are already available as taggers to detect momentum of leptons in $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$. Work is in progress to insert an Inner Tracker, a 4 layers of cylindrical triple GEM, and new calorimeters around the beam pipe to increase acceptance for γ's from interaction point. Nowadays a new data taking at KLOE-2 is waiting for stable run conditions.

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