Some remarks on 2-gamma physics with KLOE-2

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(The note is organized to be an KLOE-2 internal document and supposed to be useful for the collaboration)

I. INTRODUCTION

Two γ-physics gives us excellent opportunity to be sensitive to the dynamics of the strong interactions in the systems of hadrons. From the one hand, the processes contain the calculable by QED part of an amplitude, from the other hand - a non-perturbative part, that can be predicted by the number of theoretical models.

The KLOE-2 experiment, being the undisputed leader from the point of view of collected luminosity at $\sqrt{s} \approx 1$ GeV, has deep potential opportunities for the physics related to the production of hadrons by two-photons interactions. In order to prove the last statement I am writing this note.

The two-gamma physics at KLOE-2 can be represented by very wide program. But here I just consider the interaction of a single pseudoscalar meson (P) with photons, i.e. ($\gamma^{(*)}\gamma^{(*)}P$) vertex., that is described by the transion form factor. The TFF shows the deviation of P from a particle with point-like structure and can be defined with a following amplitude:

$$T = -i4\pi\alpha\epsilon_{\mu\nu\alpha\beta}\varepsilon_1^\mu\varepsilon_2^\nu q_1^\alpha q_2^\beta F_P(Q_1^2, Q_2^2), \tag{1}$$

where $\epsilon_{\mu\nu\alpha\beta}$ is the totally anti-symmetric Levi-Civita tensor, $\varepsilon_{1,2}$ and $q_{1,2} = -Q_{1,2}^2$ - vectors of polarization and four-momenta of internal photons, respectively, $F_P(Q_1^2, Q_2^2)$ - the TFF of meson P, and α - fine structure constant. The value of $F_P(0,0)$ can be obtained from the prediction of the axial anomaly in the chiral and large-N$_c$ limits of QCD [1]:

$$F_P(0,0) = \sqrt{\frac{1}{(4\pi\alpha)^2}\frac{64\pi\Gamma_{P\to 2\gamma}}{m_P^3}},$$

The most important two-photon processes related to the production of a pseudoscalar meson $P(\pi^0, \eta, \eta')$, that can realized at the electron-positron collider DAFNE, are shown in Fig. 1.

Each vertex of photons leads to the suppression of correspond cross section by factor "α". There is also additional suppression of the sub-vertex ($\gamma^{(*)}\gamma^{(*)}P$) by transition form factor $F(Q_1^2, Q_2^2)$, that decreases rapidly with the growth of $Q_{1,2}^2$.

II. 2γ PHYSICS AT KLOE

Almost all two-photon physics capabilities of KLOE are completely described if ref. [2] with the an explanation of physics interest and advantages in studying two-photon reactions at DAFNE as well as the feasibility of realizing such facility. The two-photon prospects at KLOE-(2) are also considered in ref. [3]. KLOE results on this topic can be found elsewhere, e.g. [4].

Let us step-by-step discuss the processes shown in the Fig. 1.

- **A:** The such processes is unuseful for two-gamma physics due to the fact that the energy of DAFNE beams was almost fixed and it is impossible to measure a spectrum $\frac{d\sigma}{dQ_1^2}$. There is just a way to produce the events is the using of ISR, that significantly decreases the production frequency. It should be mentioned, that this events were used at KLOE to measure the $\eta - \eta'$ mixing angle [5]. Also KLOE published the cross section $e^+e^- \to \eta\gamma$ at $\sqrt{s} = 1$ GeV [6] that allows to caculate $F_\eta(q_1^2 = 1\ \text{GeV}^2, 0)$.

- **B:** The processes was analyzed at KLOE in the modes $e^+e^- \to \pi^0 ee$ [7] and $e^+e^- \to \eta ee$ [8] (31k events) using a data set of 1.7 fb^{-1}. The $F_{\pi^0}(q_1^2 = m_\phi^2, q_2^2)$ was measured in region $q_2^2 = 10 \div 630$ MeV^2, while the $F_\eta(q_1^2 = m_\phi^2, q_2^2)$ - in region $q_2^2 = 2.5 \div 460$ MeV^2. Also the branching fraction of ϕ meson to the final states was calculated.

- **C:** I didn't find KLOE paper related to this diagram.

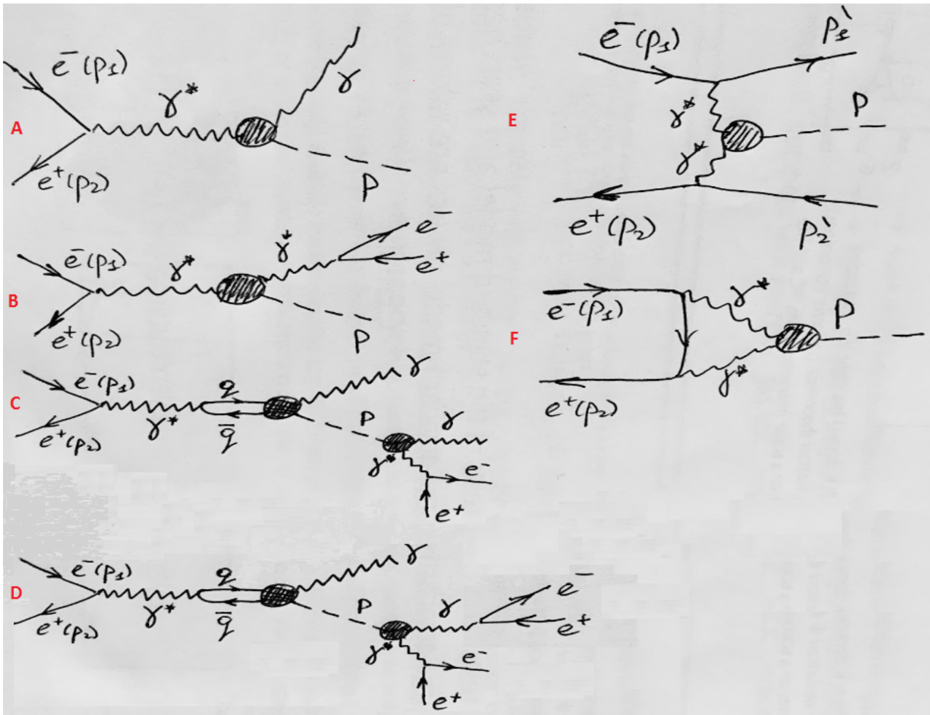

FIG. 1: The most important two-photon processes, realized at the electron-positron low-energy collider

- **D:** KLOE paper [9] reported about the results on study of η decay into $e^+e^-e^+e^-$ based on a data set of 1.7 fb^{-1} with $\sim$ 350 events. This process, in principle, allows to study the dynamics of transition form factor in dependence on both transfer momenta q_1^2, q_2^2. A precise experimental study of this process is very useful for the test of different models.

- **E:** KLOE collaboration has published paper [6] with the measurement of the cross section $e^+e^- \to e^+e^-\eta$ that equals to $32.7 \pm 1.3 \pm 0.7$ pb at $\sqrt{s} = 1$ GeV. The study is performed by untagged method, that does not allow to study the profile of TFF. An integrated luminosity of 0.24 fb^{-1} and both main η decay chains are used. The derived 2γ partial width of η meson is still the most precise measurement.

- **F:** This amplitude can be realized at KLOE just with additional ISR photon. It is higly suppressed in comparison with diagram A.

III. 2γ PHYSICS AT KLOE-2

- **Diagram B:** KLOE-2 can repeat the measurement of the processes $e^+e^- \to \eta e^+e^-$ and $e^+e^- \to \pi^0 e^+e^-$ using lager amount of collected luminosity in order to improve the current precision for $F_{\pi^0,\eta}(q_1^2 = m_\phi^2, q_2^2)$.

  Also KLOE-2 has a possibility to obtain at the first time the upper limits for the decays $\phi \to \pi^0\mu^+\mu^-$, $\phi \to \eta'\mu^+\mu^-$, and to measure the $\phi \to \eta' e^+e^-$. There is also opportunity to improve the upper limit $B(\phi \to \eta\mu^+\mu^-) < 9.4 \cdot 10^{-6}$ obtained by CMD-2 in 2001.

- **Diagram C, D, F:** One of the most interesting possible KLOE-2 topic, related to 2γ physics, lepton universality check and NP search, can be addressed to the measurement/search of the decays $P \to l^+l^-$, $l^+l^-\gamma$, $l^+l^-l^+l^-$. Let us briefly consider the current experimental status of the processes. The measured branching fractions and upper limits are presented in Table I. From the other hand, the number of produced pseudoscalar mesons with $5 fb^{-1}$ of collected luminosity can be easily calculated using the following cross sections: $\sigma(e^+e^- \to \pi^0\gamma)_{\sqrt{s}=m_\phi} = 5.3 \pm 0.4$ nb [10], $\sigma(e^+e^- \to \eta\gamma)_{\sqrt{s}=m_\phi} = 22.2 \pm 0.6$ nb [10], $\sigma(e^+e^- \to \eta'\gamma)_{\sqrt{s}=m_\phi} \approx 0.14$ nb [11]. The obtained estimation of the produced mesons is reported in the Table I. The comparison of the production frequency and existing experimental data leads to optimistic possible prospects for KLOE-2 research performing more precise measurements and new searches in the case of η and η'. However, to be responsible for the conclusion the efficiency calculation and background estimation are required.

decay	π^0	η	η'
e^+e^-	$(6.46 \pm 0.33) \cdot 10^{-8}$	$< 2.3 \cdot 10^{-6}$	$< 5.6 \cdot 10^{-9}$
$\mu^+\mu^-$	forbidden	$(5.8 \pm 0.8) \cdot 10^{-6}$	no search
$e^+e^-\gamma$	$(1.174 \pm 0.035) \cdot 10^{-2}$	$(6.9 \pm 0.4) \cdot 10^{-3}$	$(4.73 \pm 0.30) \cdot 10^{-4}$
$\mu^+\mu^-\gamma$	forbidden	$(3.1 \pm 0.4) \cdot 10^{-4}$	$(1.09 \pm 0.27) \cdot 10^{-4}$
$e^+e^-e^+e^-$	$(3.34 \pm 0.16) \cdot 10^{-5}$	$(2.40 \pm 0.22) \cdot 10^{-5}$	no search
$\mu^+\mu^-\mu^+\mu^-$	forbidden	$< 3.6 \cdot 10^{-4}$	no search
$e^+e^-\mu^+\mu^-$	forbidden	$< 1.6 \cdot 10^{-4}$	no search
$\sigma(ee \to P\gamma)_{\sqrt{s}=m_\phi} \times 5fb^{-1}$	$26 \cdot 10^6$	$111 \cdot 10^6$	$0.7 \cdot 10^6$

TABLE I: Experimental results on the leptonic decays of pseudoscalar mesons.

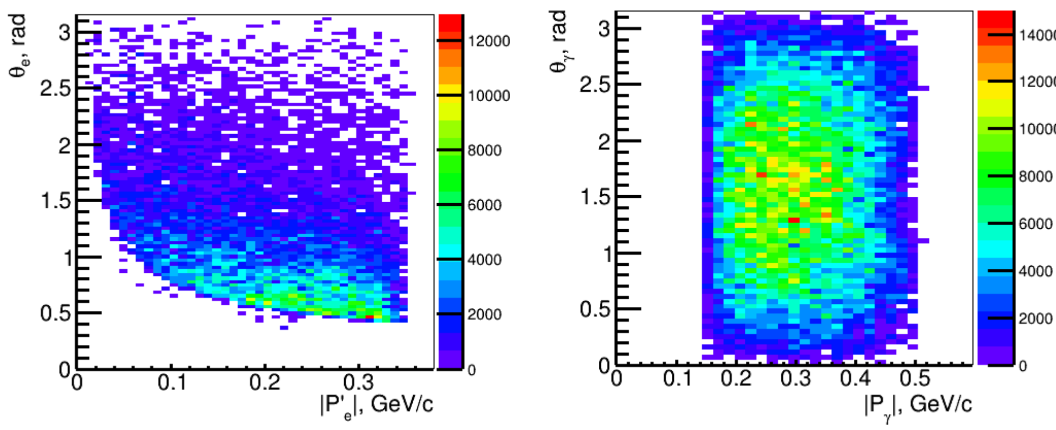

FIG. 2: Left: The polar angle vs momentum of scattered fermion in c.m.f. Right: The polar angle vs momentum of photons from the decay $\eta \to 2\gamma$.

- **Diagram E:** One of the main disadvantages of the diagram is caused by the fact that collected luminosity with KLOE-2 detector is done at the peak of ϕ meson, and its radiative decays constitutes the main background in this case. KLOE-2 prospects related to the Diagram E where the fermion is scattered at small angles (untagged and tagged modes) are described elsewhere, e.g. [12].

  Let us consider this process $e^+e^- \to e^+e^-\eta$ with the fermions scattered to large angle (double-tagged mode). Using GGResRc MC generator [13] I have calculated the cross section $\sigma_{e^+e^-\to e^+e^-\eta\to e^+e^-2\gamma}(Q^2_{1,2} > 0.03\ \text{GeV}^2)$ $= 0.8(4) \cdot B(\eta \to 2\gamma)$ pb, where the form factor $\sim \frac{1}{(1+Q_1^2/780^2)\cdot(1+Q_2^2/780^2)}$ was taken into account. The actual model uncertainty for the calculation is unknown because there are no measurement of the TFF in this region of momentum transfer. It is great possibility for KLOE-2 to measure this magnitude for the first time. The spectrum for the polar angle vs momentum of scattered fermion in c.m.f. is presented in Fig. 2 (Left), which illustrates that the condition $Q^2_{1,2} > 0.03$ GeV^2 corresponds to the $\theta_{min} \approx 25°$. The Fig. 2 (Right) shows the polar angle vs momentum of photons from the decay $\eta \to 2\gamma$. The Q^2_e versus $Q^2_{e^+}$ distribution for generated events is plotted in Fig. 3.

  The calculation of the $e^+e^- \to e^+e^-\eta$ cross section and plots show that the produced number of the events as well as the detection efficiency is sizable. Approximately the same conclusion can be made in π^0 case. The η' mode can be also considered.

  Besides the double-tagged mode there is opportunity to perform single-tagged analysis, where the cross section is significantly larger than what is mentioned above, while the background condition is worse.

IV. SUMMARY

I have tried to perform re-understanding of the KLOE-2 prospects in two gamma physics connected to the transition $\gamma^{(*)}\gamma^{(*)} \to 0^{-+}$. It is clearly seen that the huge amount of collected events allows to preform high level analyses that

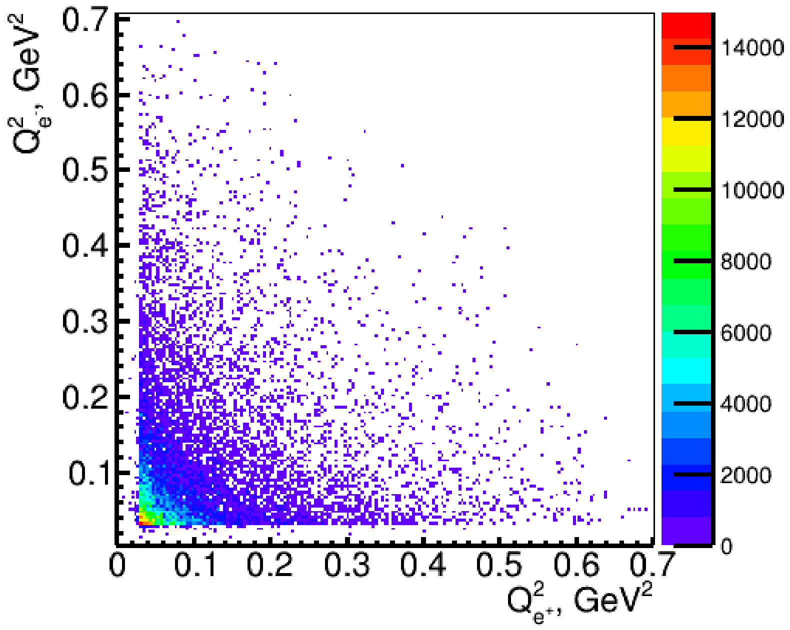

FIG. 3: The Q_e^2 versus $Q_{e^+}^2$ distribution for generated events

is still relevant to the list of physics topics. E.g., the g-2 puzzle, NP searches, non-perturbative approaches for TFF, light hadron spectroscopy.

I suggest to combine our "energy" for the analysis of data as well as for the developing of required tools, e.g. kinematic fits and new MC simulations.

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