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KLOE/KLOE-2 results and perspectives on dark force search

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Different astrophysical anomalies could find explanation on the existence of a new kind of matter, dark matter, stimulating the search for mediator of a new force, called dark photon (U boson, A'), coupling weakly with Standard Model particles. The KLOE experiment searched for the existence of the dark photon investigating three different processes: dalitz decays of the Φ meson $\Phi \to \eta U$, the production from continuum $e^+e^- \to U\gamma$, the dark Higgsstrahlung $e^+e^- \to Uh'$. No evidence was found and limits on the model parameters have been set at 90% confidence level. A reanalysis on the $e^+e^- \to U\gamma$ with U decaying into muon pairs at 1.93 fb^{-1} was performed and new preliminary 90% CL upper limits obtained with this data sample and by the combination of these events with the U boson decaying into pions pairs will be presented. The upgraded detector KLOE-2 is collecting data with new beam crossing scheme of DAΦNE since November 2014. The analyses of new data could improve the sensitivity of these investigated processes by a factor two profiting of the higher statistics and the improvement on the momentum and interaction vertex resolution. Moreover, a single photon trigger has been implemented in data taking and will allow the search of the dark photon through its invisible decays in light dark matter particles.

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1. Introduction

During the last years, several Dark Sector Models [1–5] have been proposed in order to address striking astrophysical observations [6–12] which fail standard interpretations. In the minimal hypothesis a new vector particle, the so called dark photon (U or A' boson), is introduced, with small coupling with Standard Model particles. Moreover, the existence of a dark Higgs boson h' is postulated [13], in analogy with the Standard Model, to give mass to the dark photon through the Spontaneous Symmetry Breaking mechanism. Dark photon search is also motivated because it could explain the observed discrepancy between the measured and calculated muon magnetic moment anomaly [14], a_μ, for dark photon masses of 10-100 MeV and coupling constant ε of about 10^{-3} [15]. The experiment KLOE, which collected 2.5 $^{-1}$ of integrated luminosity at the DAΦNE [16], performed different search for dark force investigating three different processes in six different final states: vector to pseudoscalar meson decay [17,18], radiative U boson production $e^+e^- \to U\gamma$ [19–21], Higgsstrahlung process [22]. Here, we present a review of the limit on the model parameter set in the KLOE search, the status of the present analysis on the search of radiative U boson production with U boson decaying in muons and pions pair. The updated detector KLOE-2 is running at DAΦNE since November 2014, the perspectives with the new KLOE-2 data will be discussed.

2. KLOE and the upgraded KLOE-2 detectors

The KLOE detector operates at DAΦNE the Frascati ϕ-factory. DAΦNE [16] is an e^+e^- collider usually operated at a center of mass energy, $W \sim m_\phi \sim 1.019$ GeV. Positron and electron beams collide at an angle of $\pi - 25$ mrad, producing ϕ mesons nearly at rest. The KLOE detector consists of a large cylindrical drift chamber (DC) [23], surrounded by a lead scintillating-fiber electromagnetic calorimeter (EMC) [24]. A superconducting coil around the EMC provides a 0.52 T magnetic field along the bisector of the colliding beams. The trigger uses both EMC and DC information. Events used in this analysis are triggered by at least two energy deposits larger than 50 MeV in two sectors of the barrel calorimeter [25]. KLOE has been upgraded in the KLOE-2 setup with the following new detectors: the inner tracker [26] (four layers of triple GEM) and two calorimeters, the CCALT [27], made of LYSO crystals, and the QCALT [27], surrounding the DAΦNE quadrupoles and made of tungsten and plastic scintillator tiles. These detectors allow to achieve a better vertex reconstruction near the interaction point (IP), an higher acceptance to low p_t tracks and to increase the tightness of the detector. Moreover, in both arms of the DAΦNE layout two couple of tagger stations, (LET) [28] and (HET) [29], have been installed to study $\gamma\gamma$ physics.

3. Results and perspectives

The KLOE Collaboration searched for dark photon signature by investigating three processes:

ϕ-Dailitz Decay:

The dark photon is expected to be produced in vector to pseudoscalar meson decays with a rate ε^2 times suppressed with respect to the ordinary transitions, producing a peak in the invariant mass distribution of the electron-positron pair over the continuum Dalitz background. The KLOE Collaboration set a constraint at 90% CL on the U-boson coupling ε^2, by exploiting the $\phi \to \eta e^+e^-$

decay, where the η meson is tagged by $\pi^+\pi^-\pi^0$ [17] (1.5 fb^{-1}) and $3\pi^0$ decays [18] (1.7 fb^{-1}). This first upper limit (UL) has been then updated, improving sample statistics and background rejection (2% of background contamination), and combined with a new limit derived by tagging the η meson by its neutral decay [18]. For each channel, the irreducible background is extracted directly by a fit to side bands. A combined UL on the parameter ε^2 at 90% CL has been derived by using the Vector Meson Dominance expectation for the transition form factor slope ($b_{\phi\eta}$ $\sim$1 GeV^2) resulting in $\varepsilon^2 < 1.7\times10^{-5}$ for $30 < M_{\rm U} < 400$ MeV, and $\varepsilon^2 < 8.0\times10^{-6}$ for the sub-region $50 < M_{\rm U} < 210$ MeV. The above final combined limit is shown in Fig. 1 and dubbed as KLOE$_{(1)}$. This limit [18] rules out a wide range of U-boson parameters that could explain the a_μ discrepancy in the hypothesis of visibly-decaying dark photon.

Higgsstrahlung process:

The KLOE Collaboration investigated also the Higgsstrahulung process, sensitive to the dark coupling constant $\alpha_{\rm D}$, with an expected cross section up to 1 pb at KLOE. The invisible scenario, where the dark Higgs is lighter then the U boson and escapes detection, in the energy range between the dimuon mass threshold and 1 GeV was considered [22]. In this case, the expected signal is a muon pair from the U-boson decay plus missing energy. The analysis has been performed on two data samples of 1.65 fb^{-1} (collected on the ϕ peak) and 0.2 fb^{-1} collected at $E_{\rm cm} = 1000$ MeV (off-peak sample) which is not affected by resonant backgrounds. No signal signature has been observed and a Bayesian limit on the number of signal events at 90% CL has been evaluated, bin-by-bin, for the on-peak and off-peak sample separately. Results have been translated in terms of $\alpha_{\rm D}\times\varepsilon^2$ by using the integrated luminosity information, the signal efficiency, the dark Higgsstrahlung cross section and the branching fraction of the $\rm U \to \mu^+\mu^-$ decay [13]. Values of the order of $10^{-9} \div 10^{-8}$ in $\alpha_{\rm D}\times\varepsilon^2$ are excluded at 90% CL for a large range of the dark photon and dark Higgs masses. In the hypothesis of $\alpha_{\rm D} = \alpha$, the upper limits on the the kinetic mixing parameter ε ranges between 10^{-4} and 10^{-3}.

U boson radiative production:

KLOE investigated both leptonic and hadronic decays of the U boson. The searches for $\rm U \to \mu^+\mu^-$, $\pi^+\pi^-$ exploited a statistics corresponding to an integrated luminosity of 239.3 pb^{-1} and 1.93 fb^{-1} respectively, and the events selection requires a Initial State Radiation (ISR) photon at small angle and two charged tracks in the polar angle acceptance 50°–130°. To explore the di-electron mass threshold, the search for $\rm U \to e^+e^-$ has been performed by applying a large angle event selection for both ISR photon and charged leptons ($55^\circ < \theta_{{\rm e},\gamma} < 125^\circ$) to a data sample of about 1.5 fb $^{-1}$. No significant dark photon signature has been observed and limits at 90% CL have been extracted for all processes on the number of U events. The expected backgrounds have been estimated by a fit to side bands for electron and pion decay channels while for the muon channel a `PHOKHARA` [30] MC generation has been used. The limits on U events have been converted in limits on the kinetic mixing parameter ε^2 by using the formula reported in Refs. [19–21]. These published limits are reported in Fig. 1 (KLOE$_{(2,3,4)}$).

A new analysis on $\rm U \to \mu^+\mu^-$ by using the same data sample and events selection acceptance used for U boson decay into pions search has been performed. The expected background was estimated by a fit to side bands and a new limit has been set (see the preliminary estimation in Fig. 1, KLOE$_{(5)}$). A combined limit, obtained by using the $\mu\mu\gamma$ and $\pi\pi\gamma$ selected events has been

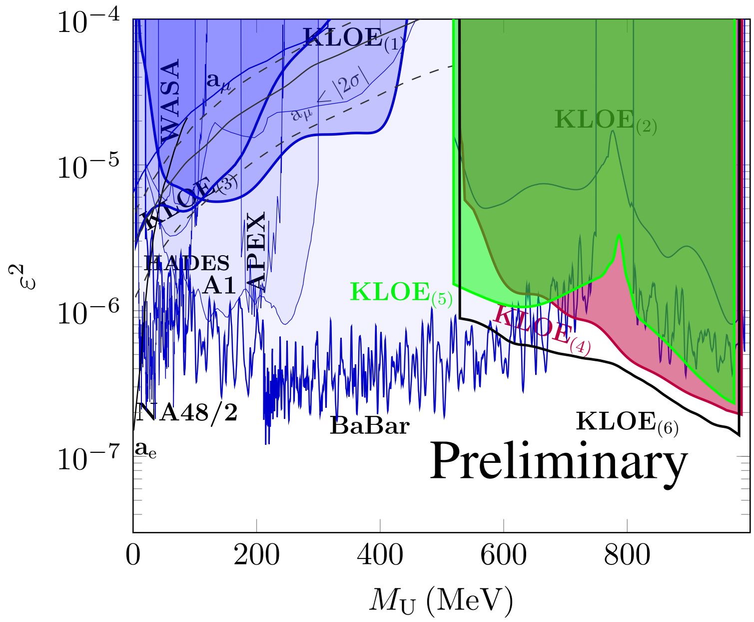

Figure 1: 90% CL exclusion plot for ε^2 as a function of the U-boson mass. The limits from the A1 [31] and APEX [32] fixed-target experiments, the limits from the ϕ Dalitz dacay (KLOE$_{(1)}$) [17, 18] and $e^+e^- \to U\gamma$, $U \to \mu^+\mu^-, e^+e^-, \pi^+\pi^-$ (KLOE$_{(2)}$, KLOE$_{(3)}$ and KLOE$_{(4)}$ respectively) [19–21], the WASA [33], HADES [34], BaBar [35] and NA48/2 [36] limits are shown. KLOE$_{(5)}$ is the preliminary limit in the $e^+e^- \to U\gamma$, $U \to \mu^+\mu^-$ process, while KLOE$_{(6)}$ is the preliminary limit obtained by the combination of KLOE$_{(4)}$ and KLOE$_{(5)}$ data. The solid lines are the limits from the muon and electron anomaly [14]. The gray line shows the U boson parameters that could explain the discrepancy between SM prediction and the experimental value of muon anomaly, a_μ, with a 2σ error band (gray dashed lines) [14].

estimated and the preliminary trend is reported as a full back line in Fig. 1 (KLOE$_{(6)}$). The new combined limit is more stringent of the existing ones in the mass region between 600-985 MeV.

Perspectives:

The KLOE-2 detector is collecting data at the DAΦNE facility, operating with a new beam crossing scheme in order to have a reduced beam size and increasing luminosity [37]. The new experiment has already collected 4 fb^{-1} in these new operating conditions. About a factor two in terms of sensitivity and discovery potential are expected with KLOE-2 because of the larger available integrated luminosity and the better momentum and vertex interaction measurement resolutions achievable thanks the new inner tracking detector. A single photon trigger is actually implemented in KLOE-2 data taking and it will allow to search for the dark photon through its invisible decays in light dark matter particles.

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