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Search for dark photons using data from CRESST-II Phase 2

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Abstract. Understanding the nature and origin of dark matter is one of the most important challenges for modern particle physics. During the previous decade the sensitivities of direct dark matter searches have improved by several orders of magnitude. These experiments focus their work mainly on the search for dark-matter particles interacting with nuclei (e.g. Weakly Interacting Massive Particles, WIMPs). However, there exists a large variety of different candidates for dark-matter particles. One of these candidates, the so-called dark photon, is a long-lived vector boson with a kinetic mixing to the standard-model photon. In this work we present the preliminary results of our search for dark photons. Using data from the direct dark matter search CRESST-II Phase 2 we can improve the existing constraints for the kinetic mixing for dark-photon masses between 0.3 and 0.5 keV/c². In addition, we also present projected sensitivities for the next phases of the CRESST-III experiment showing great potential to improve the sensitivity for dark-photon masses below 1 keV.

1. Introduction

The dynamics of galaxies and galaxy clusters give several hints for the existence of cold dark-matter [1, 2, 3]. Clarifying the nature and origin of dark matter is one of the most important goals for modern particle physics.

CRESST-II is an experiment for the direct search for dark matter [4]. Its main focus is the search for dark-matter particles interacting with the nuclei of the detector material. CRESST-II



detectors are based on scintillating calcium tungstate (CaWO_4) and are optimized to distinguish between electron and nuclear recoils [4], i.e., interactions with the electrons or nuclei of CaWO_4 , respectively. This discrimination is achieved by a simultaneous measurement of the deposited energy and the scintillation light generated by a particle interaction in a CaWO_4 crystal. The light yield, i.e., the ratio of detected scintillation light and deposited energy is different for electron and nuclear recoils. Thus, the light yield can be used for an efficient background suppression for the search of dark-matter particles interacting mainly with nuclei [4].

However, there are many theories predicting a large variety of dark-matter candidates in different mass scales. Some of these particles would favor an interaction with electrons over an interaction with nuclei. One of these candidates is the so-called dark photon, i.e., a long-lived vector boson [5, 6]. Dark photons interact with the detector material via their kinetic mixing with standard model photons. Thus, the expected signal is a line corresponding to the dark-photon mass m_ν .

2. Data selection

In Phase 2 of CRESST-II (June 2013 - August 2015) in total 18 detector modules were operated [4, 7]. However, for the dark-photon search presented in this work, only data from the module with the best energy threshold and resolution has been taken into account. This data-set corresponds to an exposure of ~ 51 kg-days [4]. Using the same data-set the currently strongest constraints on the cross section for dark-matter particles scattering elastically off nuclei were achieved for dark-matter masses below $\sim 2 \text{ GeV}/c^2$ [4]. Figure 1 depicts the data with the

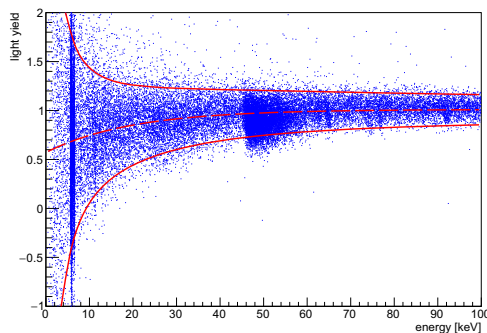


Figure 1. The (blue) dots represent the data surviving all quality and stability cuts. The (red) solid lines mark the electron-recoil band, i.e., the central 90 % region where electron recoils are expected. The (red) dashed line represents the median of the band. The most prominent features originate in an accidental irradiation with a ^{55}Fe calibration source ($\sim 6 \text{ keV}$) and external radioactive decay of ^{210}Pb ($\sim 45 \text{ keV}$).

deposited energy as abscissa and the light yield¹ as ordinate. Only events in the electron-recoil band are taken into account for the dark-photon search. The central 90 % region of the electron-recoil band is shown by the (red) solid lines and the median of the band is depicted as (red) dashed line [4].

3. Preliminary limits for the kinetic mixing

As already stated, the expected signal from dark photons is a line at their mass m_ν . Thus, to search for dark photons we fit the sum of a semi-empirical background model and a Gaussian to the selected data taking into account only the deposited energy². The semi-empirical background model is the sum of a constant and two Gaussians for the two x-ray lines at $\sim 5.9 \text{ keV}$ and $\sim 6.4 \text{ keV}$ of ^{55}Mn originating in the accidental irradiation with a ^{55}Fe calibration source. For both, the signal and the background model the cut efficiency³ is taken into account causing the drop in the spectrum for energies below $\sim 1 \text{ keV}$. We used the cut efficiency given in [4].

¹ The light yield of $122 \text{ keV } \gamma$ is set to one.

² The light yield is taken into account for data selection.

³ The probability that a recorded event survives all data-quality cut and the data selection.

Using the frequentist maximum likelihood ratio method we obtain an upper limit for the event rate of dark photons. This limit is then converted into a limit for the kinetic mixing parameter κ (see, e.g., [6] for the relation between event rate and kinetic mixing).

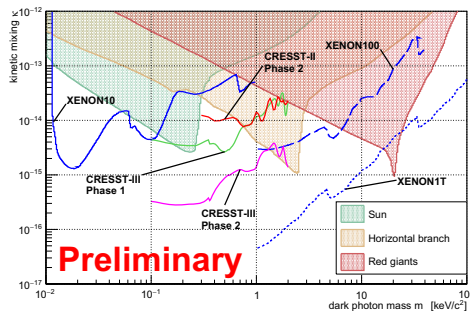


Figure 2. Limits on the kinetic mixing κ of dark photons as functions of their mass. The shaded regions are constraints from abnormal energy losses in the sun, horizontal-branch stars and red giants [6]. The lines represent the constraints from CRESST-II (this work), XENON10 [6], and XENON100 [6]. In addition, projections for CRESST-III (this work) and XENON1T [8] are shown. See main text for further details.

Figure 2 depicts the current constraints on the kinetic-mixing parameter κ [6]. The preliminary constraints from this work is depicted as (red) solid line setting the strongest limit on κ for dark-photon masses between 0.3 and 0.5 keV/c². The constraints from XENON10 and XENON100 are also shown as (blue) solid and dashed lines, respectively [6].

In addition, the projected limits for CRESST-III and XENON1T [8] are shown. The projected limits for the improved detectors used for CRESST-III are based on the numbers and design goals given in [9]. The great potential for low dark-photon masses m_ν of the recently (July 2016) started Phase 1 of CRESST-III and also for the succeeding Phase 2 is clearly visible.

4. Conclusions and outlook

In addition to searches for dark-matter particles interacting with nuclei (e.g., WIMPs), data from direct dark matter searches can also be used to detect or constrain other dark-matter candidates. In this work we show the preliminary results of a dark-photon search performed with data from CRESST-II Phase 2. This result further improves the constraints on the kinetic mixing of dark photons for masses between 0.3 and 0.5 keV/c². These constraints can be further improved by the recently started Phase 1 and the succeeding Phase 2 of CRESST-III.

Currently we are working on improving the dark-photon search by taking into account also the light yield while fitting. In addition, we are using Bayesian methods for a better handling of systematic uncertainties and correlations between fit parameters. A dedicated paper with the results of this improved fitting method will follow soon.

Acknowledgments

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