Brief Report

The Observation of Dark Photons in PHELEX with a Multi-Cathode Counter

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The Observation of Dark Photons in PHELEX with a Multi-Cathode Counter

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Abstract: In this paper we report the results obtained in experiment PHELEX during 208 days of measurements on the search for dark photons with a multi-cathode counter with an iron cathode that revealed in 4 runs with a confidence level better than 5 σ a systematic excess of single electron events in the time interval from 8-00 till 12-00 sidereal time. The fact that we see this effect in stellar frame and do not in solar frame can be considered as evidence that the observed effect is due to dark photons.

Keywords: dark matter; dark photons; diurnal variations

1. Introduction

We have developed a technique to search for dark photons with a multi-cathode counter [1] based on the detection of single electrons emitted from a metallic cathode during conversion of dark photons as particlelike solutions with the flux of magnetic or electric field [2,3] into single electrons emitted from the surface of cathode. The method has shown its efficiency in setting upper limits for the parameter of kinetic mixing [4]. It was discussed in [5] that if dark photons are polarized, i.e., vector of **B** or **E** – field of dark photons has a certain direction in stellar or solar frame, one can observe diurnal variations of the count rate of single electrons in the corresponding frame due to rotation of the Earth. Here we take just as a reference model the angular dependence of the effect from dark photons as $\cos^2\theta$ where θ is the angle between vector of **B** (**E**) field and the surface of the cathode. Because we still don't have a robust theory of dark photon, the real angular dependence can be different. We should check this in experiment. But in any case, the curve of diurnal variations should be symmetrical relative some moment of time when vector of **B** or **E** – field of dark photons is in the plane of a meridian where the detector is situated because it is just the effect of rotation of the Earth. Dark photons, because they have a mass, presumably have transverse and longitudinal modes for **B** (**E**) - field. If the motion of dark photons is ordered due to possible interaction between dark photons themselves, this can result in a certain polarization at least for the longitudinal mode. It is the subject of our further study. If the effect is observed in stellar frame and is not observed in solar frame this proves that it is of galactic origin. This can be used as an argument in favor that one really observes dark photons. In this paper the results of our experiment to search for diurnal variation of the count rate of single electrons obtained with a multi-cathode counter with an iron cathode are presented.

2. Materials and methods

The aim of this experiment was to observe possible diurnal variations of the count rate of single electrons from the conversion of dark photons on the surface of the cathode [6]. We used a gaseous proportional counter with a cylindrical iron cathode 166 mm in diameter and 500 mm long. Cathode was incapsulated in a stainless-steel housing with a quartz window for calibration by UV lamp. The counter was filled with a mixture of $Ne + CH_4$ (10%) at 0.1 MPa. The detector was placed at the ground floor of a building in Moscow, Troitsk in a special cabinet with 30 cm steel shield and 10 cm of boronated polyethylene. The steel shielded from external gamma radiation, boronated polyethylene – from thermal neutrons. The counter was placed in horizontal position with the axes of the cathode at 23° to the direction North-South [7]. A gold-plated tungsten-rhenium wire 25 μm thick was stretched along the axis of the cathode. This was an anode of the counter. Around it we had three cylindrical cathodes [1]: the first one at 40 mm of diameter around an anode wire and the second right near the third one – the outer iron cathode, 8 mm from its surface. Both were made from nichrome wires 50 μm thick tighten along the cathode with a pitch about 5 mm. All three cathodes were under high voltage. The first cathode provided a high gas amplification. The second one acted as a barrier for electrons emitted from iron cathode. In first configuration electrons passed to the anode through this barrier, in the second – they were repulsed back to the surface of the cathode. In the first configuration we counted electrons emitted from the surface of the iron cathode and electrons generated in the gas of the volume of the counter. In the second configurations, only electrons generated in the gas were counted. The signal from the anode of the counter was applied to the input of charge sensitive preamplifier. Preamp output voltage was applied to ADC board [1]. The counter was calibrated with UV radiation of a mercury vapor lamp. The signal from the preamp output was digitized by an ADC board with a sampling rate of 10 MHz and we have been collecting 1 TB of data each day. Data treatment was carried out offline. The measured count rates were grouped by 2 h intervals in sidereal and terrestrial times. If the vector of B or E – field had a certain orientation in stellar or solar frame, diurnal variations could be observed in corresponding frame due to rotation of the Earth. This would be a strong argument in favor of real observation of dark photons. Figure 1 shows the results obtained in 4 runs of measurements in sidereal time, Figure 2 – the same in terrestrial time. Each run had a duration of 52 days and contained 544 points of measurements. Each point contained 270 ÷ 370 events of single electrons collected in 5000 frames 0.2 s each. So, each point at the graphs of Fig.1 and Fig.2 contained in total 12000 ÷ 16000 single electron events. Each frame contained 2M records for each timeslot of 100 ns.

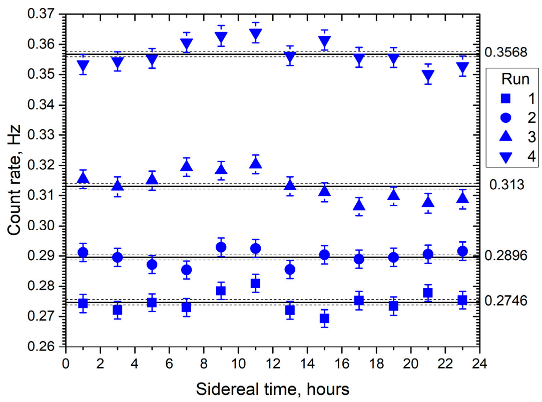

Figure 1. Diurnal variations obtained in 4 runs in sidereal time. Solid lines – average values, dashed lines: ± σ for average values.

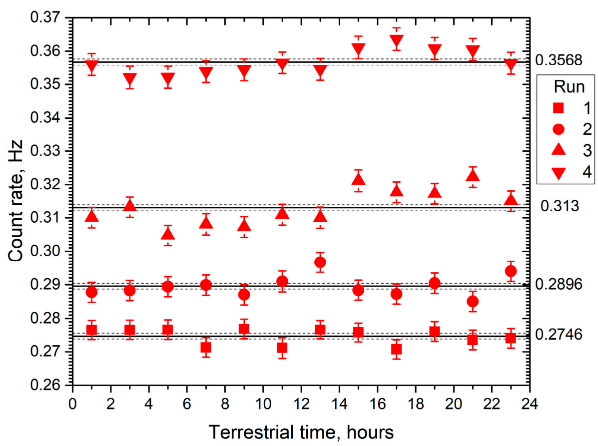

Figure 2. Diurnal variations obtained in 4 runs in terrestrial time.

3. Results

One can see in Figure 1 that we observe a systematic excess of events in all 4 runs in time span from 8-00 till 12-00 in sidereal time. The fact that we observe in all four runs the excess of measured count rates exactly at the same time span from 8-00 till 12-00 makes the possibility that this is just a result of pure statistical fluctuation extremely unlikely. The possibility that doing a Monte Carlo one can obtain the similar excess in all four runs in the same time span looks improbable. The significance of this effect was estimated by the probability p defined by the expression:

$$p = 12\prod_{i=1}^{2n}\left(0,5erfc\left(\frac{x_i}{\sqrt{2}}\right)\right) \quad (1)$$

Here p – the probability to get the observed temporal pattern of the excess in two bins in n runs, x_i – excess value of the count rate in i-th bin in units of σ over the average value. In each run the counting rates only in two bins are counted: first - for the interval in sidereal time from 8-00 till 10-00 and second – for the one from 10-00 till 12-00. The probability that this is a pure statistical fluke has been found to be $2{\cdot}10^{-10}$ that corresponds to confidence level better than 5σ.

We don't see anything like that in Figure 2 in terrestrial time. This is an argument that the effect we observe in Fig. 1 in time span from 8-00 till 12-00 is very likely to be from dark photons. We currently have no other explanation for this. In terrestrial time in the last 2 runs (see Fig. 2) after 2 p. m. we have observed the effect from terrestrial activity (presumably from electrical equipment interference during the construction work at the site of the institute). The increase of the average count rate in runs from 1 to 4 is determined by the rise in ambient temperature. The last run was carried out in July while the first run – in January. By comparing the average rates in different runs the effect of a sharp rise in temperature in Moscow region in July can be clearly seen.

Here we should remind that earlier we performed measurements in two configurations [1,4]: in the first one when we detect electrons emitted from the surface of the cathode of the counter and electrons generated in the gas of the volume of the counter and in the second one when we detect only electrons generated in the gas of the volume of the counter. We derived the upper limits for the constant of kinetic mixing from the comparison between the count rates measured in these two configurations. By observation of diurnal variations, we don't need to compare count rates measured in two configurations: we observe only in first configuration and look for the excess of count rate at certain time span. Of course, a due question is: how do we know that the source of this excess are the electrons emitted from the surface of the cathode, not electrons generated in the gas in the volume of the counter? We exclude the latter case because we can't suggest any possible mechanism of galactic origin for diurnal variations in this case. But now, when we observe the effect presumably from dark photons, we still need to be sure that it is the surface of the cathode not the gaseous volume in the counter that is responsible for the effect we observe. The results obtained in measurement in second configuration with a rather limited statistics shows that this is very unlikely, but to say this with complete certainty we need to collect the similar statistics of about 200 days of measurement we had in first configuration. At present time we are doing measurement in second configuration, and we hope to clear this question completely by the end of this year.

We still have to some extent an open question whether the effect depends on the type of metal we use for the cathode of the counter. Here we used a cathode made of iron that is magnetic material. We are planning to use in future cathode made of aluminum that is non-magnetic material. It will be interesting to see whether the effect observed in stellar frame presented in Figure 1 with the counter having an iron cathode will be observed with aluminum cathode also.

What must be done to check this result? The main difficulty is that these measurements require a lot of time. To find what is a real magnitude of this effect one should conduct about 20 runs 50 days each. It takes 3 years. Now one can only say that the effect observed during time span from 8-00 till 12-00 sideral time is on the level of about 0.005 Hz, that is., close to 2 % of the count rate of our counter with a cathode with the surface 0.26 m^2. One can see from Fig. 1 and Fig. 2 that, for example, the effect from temperature changes is much higher. But this dependence from temperature affects the average values while the observed excess in all four runs is visible only within a certain period. Moreover, we see it only in stellar frame and do not see in solar frame. The only way to speed up the process of

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verification seems to be to do similar measurements in different laboratories with different location and with counters having the cathodes made from different metals. The effect should depend upon the position of the counter and upon geographical latitude of the site where the detector is located. It is worth also to mention that this effect could be observed only if the cathode of the counter has a mirror surface.

4. Conclusions

Due to our present data on diurnal variations of the count rate of single electrons emitted presumably during conversion of dark photons at the surface of the iron cathode of the gaseous counter, collected during 208 days of measurements, we observe the effect of systematic excess of the count rate in comparison with the average one. The excess is observed only in a stellar frame and is not observed in a solar frame. The confidence level to observe this excess in all four runs at the same time span is estimated to be on the level better than 5σ. We have collected data for 4 runs about 52 days each and observe in each run systematic excess of counts in time span from 8-00 till 12-00 sideral time. The fact that we observe this effect in stellar frame and do not observe in solar frame can be considered as evidence that we really observe the effect from dark photons. The probability that this is a pure statistical fluke for all 4 runs is estimated to be $2 \cdot 10^{-10}$. We continue measurements to collect more data to understand the details for more accurate interpretation of the results.

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Conflicts of Interest: The authors declare no conflict of interest.

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