Preliminary study of the influence of the parameters of the piezoelectric element on the possible piezoaxionic effect

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ABSTRACT

The piezoaxionic effect was recently proposed to introduce a possible solution ensuring the detection of an elementary particle called axion predicted by theory. With our experience in research on the improvement and characterization of quartz oscillators and other materials allowing the propagation of acoustic waves. We are interested in contributing to the improvement of the precision of measurement means to determine if it is possible to have sufficient sensitivity for detecting effects of elementary particles which would be characteristic of dark matter. This potential effect of axions manifests through acoustic waves. We are interested in knowing the parameters which could potentially be a source of complications for this detection. This involves being able to estimate the knowledge of the accuracy and frequency stability used and the uncertainty terms which could affect the construction of an experimental device. Different piezoelectric materials are considered as candidates to help to highlight this piezoaxionic effect. We propose to present this work during the conference.

Keywords: Axion, Photons, quartz, uncertainty, uncertainty analysis.

1. INTRODUCTION

Action is a particle that was theorized in the late seventies. This hypothetical particle could explain the 26% of the energy in the universe called "dark matter." The axion, a hypothetical particle, could solve two puzzles at once. It could be the key to dark matter, the mysterious substance that appears to make up most of the matter in the Universe, and explain the puzzling symmetry properties of the strong force that binds protons and neutrons inside atomic nuclei.

A team of astrophysicists has just discovered that the anomalies observed in gravitational lenses can be explained much better by considering that dark matter is composed of axions rather than WIMPs, an advance which could prove to be major [1]. The international Darkside cooperation is designed for this purpose to directly track dark matter. Based in Italy, at the Gran Sasso Underground Laboratory, at a depth of 1,400 meters, its design composed of double shielding of 30 tons of liquid argon and 1,000 tons of ultrapure water is conditioned to detect the slightest wake of black matter [2]. A team of scientists from the CAST experiment at CERN explains how they repurposed part of the experiment to target a previously unexplored region of space [3]. CAST is an experiment originally designed to track axions coming from the Sun. For its new study, the

CAST team installed a resonator, composed of four cavities, inside one of the two tubes of the experiment's magnet, to constitute an axion detector which this time seeks axions in the dark matter “halo” of the Milky Way. In a strong magnetic field, like that provided by the CAST experiment's magnet, axions should transform into photons. An axion haloscope resonator is a kind of radio that researchers can tune to find the frequency of these photons coming from axions. The frequencies are between 4.774 and 5.434 GHz, which corresponds to axions with masses between 19.74 and 22.47 microelectronvolts. They analyzed this 660 MHz frequency band in 200 kHz increments. For lower frequencies, less than one GigaHetrz, it would be interesting to investigate other sources. Recent work was published about Low frequency 100–600 MHz searches with axion cavity haloscopes [4].

We are investigating the improvement of the precision of the means of measurement to determine if it is possible to have sufficient sensitivity to the detection of the effects of elementary particles, which would be characteristic of dark matter [5]. A particle has been proposed and is called axion. There would be an interaction between the axions and the photons using the Primakoff effect [6] under strong magnetic field. Radio frequencies from 460 to 810 MHz would be assumed to be suitable for the mass of the axion, if it exists. It is then interesting to focus on the piezoaxionic effect [7].

If the frequency of the axions could match the natural frequency of a normal mode bulk acoustic of a piezoelectric crystal, one would expect the piezoaxionic effect to occur. One could then rely on the piezoelectric effect to observe the variations on the resonant frequency, which can be read out electrically using the best piezoelectric materials [8]. Through this example of development and applications in detection, we propose to decrypt this subject and to show how multidisciplinary skills are necessary to hope that small fluctuations can be detectable.

2. BEST QUARTZ OSCILLATORS AS GOOD CANDIDATES

There has been no significant change in the noise floor of commercial oscillators during the years 1995-2010: the best commercial crystal oscillators operate with a short-term frequency stability of 8×10^{-14}. But the best frequency stability ever measured on a quartz crystal oscillator was then obtained in 2010. This new BVA oscillator has an estimated flicker frequency modulation (FFM) floor of 2.5×10^{-14} at 5 MHz [8]. This was highlighted as an important step. It was obtained using a double-rotated SC cut quartz with low phase noise, good aging characteristics and low sensitivity to drive level dependence [9], placed in a suitable thermostat in the first oscillator prototype oven-controlled crystal (OCXO) made in Switzerland by the company Oscilloquartz [10]. Such frequency stability is equivalent to a variation of only one second for 1.3×10^6 years, but measured in terms of frequency stability over an integration time of a few seconds, because the main interest of such oscillators is to deliver an ultra stable signal in the short term. The recent results obtained show that it was too early to “bury” research on quartz and that it certainly has the potential to reach the level of 1×10^{-14}.

The measured FFM floor is $3.2 \times 10^{-14} \pm 1.1 \times 10^{-14}$ at 5 MHz. It is obtained for an average integration time of 20 s. This measurement result and its associated uncertainty are consistent with the best FFM floor measured previously [8]. It can be noted that the aging of the oscillator masks the FFM floor for a higher integration time. The level of performance can be ensured with good distribution of the radio frequency signals delivered by the quartz crystals [11]. Other relevant papers can also be consulted [12 – 15]. Discussions of the estimated errors are given here [16, 17]. For the assessment of possible associated uncertainties, refer to this reference [18]. More generally, the evaluation of uncertainties being an important point for the metrological aspect, other aspects make it possible to understand the methods used [19 – 23]. Fred Walls and his colleagues from NIST described the principle of phase noise and its calculation [24, 25]. Won Kyu Lee explained their work concerning uncertainty calculation [26]. Sources of uncertainties were discussed by Shinya Yanagimachi and his colleagues [27]. Several phase noise measurement techniques were investigated by Ulrich L. Rohde and Ajay K. Poddar [28]. The uncertainty is examined accordingly to main guideline of the Bureau International des Poids et Mesures (BIPM) in the guide “Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement” [29]. Actually, we followed a modern approach to express uncertainty in measurement [30 – 32].

3. AXION DETECTION VIA PIEZOAXIONIC EFFECT

The proposed method in this study revolves around leveraging the piezoaxionic effect as a novel approach for the detection of axions. The crux of this methodology lies in the anticipated interaction between axions and the normal mode bulk acoustic of a piezoelectric crystal, where the frequency of axions aligns with the natural frequency of the crystal. This innovative approach holds the promise of detecting subtle fluctuations induced by axion interactions. The integration of piezoelectric materials, particularly quartz, emerges as a critical element for ensuring a reliable readout and achieving precision in detecting these variations. The piezoaxionic effect is a theoretical phenomenon suggesting that when the frequency of axions corresponds to the natural frequency of a normal mode bulk acoustic of a piezoelectric crystal, an interaction occurs. This interaction could induce variations in the crystal's mechanical properties, providing a measurable signal. The exploration of the piezoaxionic effect introduces a unique avenue for the detection of axions, potentially unlocking a new dimension in precision measurement. The success of this method hinges on precise frequency matching. If the frequency of axions aligns with the natural frequency of a specific normal mode bulk acoustic in a piezoelectric crystal, the piezoaxionic effect is expected to manifest. Achieving this frequency match is a key consideration in designing experiments for axion detection. The integration of piezoelectric materials is paramount for the successful implementation of this method. Piezoelectric crystals, such as quartz, possess the unique ability to convert mechanical stress into an electrical charge and vice versa. In the context of axion detection, the choice of piezoelectric material influences the efficiency and sensitivity of the readout mechanism. Quartz, renowned for its exceptional piezoelectric properties, emerges as a suitable candidate for reliable and precise detection. The reliable readout of small fluctuations induced by axion interactions is crucial for the success of this method. Quartz is known for its ultra-high stability in crystal oscillators [8, 12]. Leveraging quartz as the piezoelectric material enhances the precision of the readout mechanism, ensuring that even subtle variations in the crystal's mechanical properties can be accurately detected and quantified. The proposed method not only opens avenues for the detection of axions but also suggests potential applications in precision measurement and fundamental physics research. Future investigations may explore the scalability of this approach, the optimization of experimental setups, and the extension of the method to other piezoelectric materials beyond quartz. The proposed method harnesses the piezoaxionic effect, offering a novel and innovative approach for the detection of axions. The careful consideration of frequency matching, the integration of piezoelectric materials, particularly quartz, and the emphasis on reliable readout and precision collectively contribute to the viability of this method. This pioneering approach exemplifies the intersection of particle physics and materials science, showcasing the potential for unlocking new realms of knowledge through multidisciplinary research. Quartz, renowned for its exceptional piezoelectric properties, occupies a central role in the investigation of precision measurement, particularly in the context of detecting small frequency variations induced by axion interactions. In the context of detecting small frequency variations induced by axion interactions, the stability of quartz crystal oscillators becomes paramount. The unique characteristics of quartz make it sensitive to subtle mechanical changes, offering a reliable means of capturing variations resulting from axion interactions. The piezoaxionic effect, as discussed earlier, aligns with the capability of quartz to register such minute alterations in frequency.

Despite the promise shown by the proposed method for detecting axion-induced effects through the piezoaxionic effect, significant challenges persist in achieving the necessary sensitivity. This section acknowledges these challenges and outlines the key factors that need to be addressed for the successful implementation of the method. The exploration of radio frequencies in the range of 460 – 810 MHz, aligned with the hypothetical mass of axions, presents an intriguing avenue for further investigation [6]. The primary challenge in the proposed axion detection method lies in achieving the required sensitivity to detect subtle variations induced by axion interactions. The expected effects may be inherently small, necessitating advanced techniques and materials to enhance the detection capabilities. Improving sensitivity is crucial for the method's effectiveness in capturing and interpreting the signals indicative of axion presence. The study recognizes the need for advanced materials to address the sensitivity challenge. Exploring materials with enhanced piezoelectric properties or unique characteristics that amplify the piezoaxionic effect could significantly contribute to overcoming sensitivity limitations. Collaborative efforts with materials scientists are essential to identify or develop materials tailored to the specific requirements of axion detection. Achieving precise frequency matching between the axion frequencies and the natural frequency of the piezoelectric crystal is critical. Any deviation from the expected frequency range may result in missed signals or false positives. Advancements in frequency tuning techniques and control mechanisms are necessary to ensure accurate and consistent frequency matching for reliable axion detection. The successful implementation of the proposed method relies heavily on robust readout mechanisms capable of capturing and interpreting subtle variations in the piezoelectric crystal induced by axion interactions. Developing sophisticated readout systems, possibly incorporating state-of-the-art electronics and signal processing techniques, is essential to extract meaningful information from the detected signals. As mentioned, the study highlights the exploration of radio frequencies in the range of 460 – 810 MHz, aligning with the hypothetical mass of axions. This choice reflects a strategic decision to focus on frequencies that correspond to the expected characteristics of axions. Further investigation into this frequency range offers an intriguing avenue for understanding the potential influence of axions on the piezoaxionic effect. Addressing the identified challenges and refining the proposed method requires a concerted effort from multidisciplinary teams. Collaborations between particle physicists, materials scientists, and electronics engineers will be crucial in advancing the sensitivity, materials, and readout mechanisms. Future directions may involve experimental validations, optimizations of frequency-matching techniques, and the exploration of alternative materials to push the boundaries of axion detection capabilities. While the proposed axion detection method holds promise, overcoming challenges related to sensitivity, materials, and precise frequency matching is imperative. The study emphasizes the need for collaborative efforts and acknowledges the complexities involved in achieving reliable and accurate axion detection. The exploration of radio frequencies in the hypothesized mass range of axions provides a compelling avenue for further investigation, offering potential breakthroughs in the understanding of particle interactions. Some consideration expressed here were already discussed in reference [33]. We note a recent interesting paper on this subject [34].

4. CONCLUSION

In this paper, we have reviewed the performances of the best quartz oscillators in the radio frequency domain. We hope that it can help by emphasizing that the best crystal oscillators may be good candidates to help set up an experiment. This would make it possible to participate in the possible detection of hypothetical particles, using the supposed piezzoaxionic effect. This investigation into precision enhancement for particle detection, focusing on axions and the piezoaxionic effect, exemplifies the intersection of particle physics, materials science, and electronics. The collaborative effort across disciplines is highlighted, emphasizing the importance of diverse skills in unraveling the potential of small fluctuations induced by axion interactions. The application of quartz crystal oscillators showcases the practicality of such multidisciplinary approaches, offering a glimpse into the future of precision measurement in the realm of particle physics.

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