Approaching the first any light particle search II science run

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Abstract

The Any Light Particle Search II (ALPS II) is a light-shining-through-a-wall (LSW) experiment based at DESY in Hamburg, Germany, that will search for axions and axion-like particles down to the coupling of the axion to two photons of $g_{a\gamma\gamma}$ >2×10^{-11} GeV^{-1} for masses below 0.1 meV. ALPS II will use two strings of superconducting dipole magnets that are over one hundred meters in length, as well as optical cavities before and after the wall to boost the effective signal rate of the regenerated photons by more than 12 orders of magnitude when compared to previous generations of LSW experiments. Data taking with a simplified optical system is expected to begin in early 2023.

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1 Introduction

The Any Light Particle Search II (ALPS II) is an experiment based at DESY, in Hamburg, Germany, that will search for scalar and pseudo-scalar particles that lie beyond the standard model [1]. The most notable particle that ALPS II will hunt for is the axion [2]. Characterized by its low mass (< 0.1 meV) and feeble coupling to standard model particles, the axion is an excellent candidate to explain why there is no CP violation in the strong sector, as well as a number of astrophysical phenomena including the existence of dark matter, anomalies in stellar cooling rates, and the transparency of the universe for highly energetic photons [3–5].

One of the most common strategies to try to observe axions is to utilize their coupling to two photons [6]. In the presence of a magnetic field photons can generate axions and vice versa at a rate determined by the magnetic field strength, the coupling constant between the axion and two photons $g_{a\gamma\gamma}$, the interaction length, and the mass of the axion. One style of experiment which takes advantage of this are light-shining-through-a-wall (LSW). These experiments generate a beam of axions in the laboratory by shining a high-power laser (HPL) through a static dipole field. The axions travel through a wall which blocks the laser and then over a second region of dipole magnetic field where some of the axions convert back to photons.

This can be favorable to other types axion searches such as haloscopes and helioscopes, as LSW experiments do not rely on astrophysical models of the axion generation process. We should also note that LSW experiments could be sensitive to other particles that have low masses and exhibit coupling to two photons. Therefore, when we refer to axions in this article we are referring generally to this potential class of ‘axion-like’ particles.

ALPS II sets itself apart from previous LSW experiments in a number of ways. First, with two strings of modified superconducting dipole magnets that were formerly used by the HERA accelerator generating a 5.3 T field over a combined length of 212 m, the magnetic field (B) times length (L) is 4.5 times that of OSQAR [7]. As the regenerated photon rate after the wall is proportional to $(BL)^4$ this will lead to over a factor of four hundred increase in the measurement signal. In addition to this, ALPS II will be the first LSW experiment to use both a production cavity (PC) before the wall and a regeneration cavity (RC) after it. With power build up factors on the order of 10,000, the cavities will further increase the reconverted signal rate by a total of 8 orders of magnitude. Finally, ALPS II will utilize two independent detection systems, first a heterodyne detector, then in later runs a transition edge sensor, each capable of distinguishing signals from background with rates as low as 10^{-5} photons per second [8,9]. All together these improvements lead to ALPS II targeting a regenerated photon rate 12 orders of magnitude higher than its predecessors and a final sensitivity of $g_{a\gamma\gamma} > 2 \times 10^{-11}\,\mathrm{GeV}^{-1}$ for masses below 0.1 meV.

There has been incredible progress over the last year in the construction of the experiment. As we will discuss in the following sections, the magnet string is now fully operational and the commissioning of the optical system is nearing completion. To accelerate the schedule and facilitate the optics commissioning effort, the decision has been taken to perform the first axion search without a PC targeting a sensitivity of $g_{a\gamma\gamma} > 2 \times 10^{-10}\,\mathrm{GeV}^{-1}$. This will then be followed by axion searches first with the PC implemented and then with upgraded optics to reach the full design sensitivity of the experiment.

2 Demonstration of the Magnet String

In March of 2022 the magnet strings where demonstrated at full current for the first time. After two and a half weeks of cooling the magnets achieved the necessary cryogenic temperatures and were then operated for 8 hours with 5.7 kA of current, corresponding to a 5.3 T magnetic field inside the bore. In another test the magnets were ramped and discharged for four hours to show they are capable of generating an oscillating magnetic field. Here it was possible to generate a pulse rate in the magnet current of roughly one per hour, but faster modulation may be possible with upgrades. While an oscillating magnetic field is not directly applicable to ALPS II, it could be very useful for future studies with the magnet string, including a search for the vacuum magnetic birefringence effect predicted by quantum electrodynamics.

3 First axion search

While the full ALPS II design has optical cavities before and after the wall [10], the first axion search will not use a PC to amplify the laser before the wall. As Figure 1 shows, instead 50 W will be injected from the HPL directly into the first magnet string. The overall control architecture of the experiment will remain the same, however, as the reference laser (RL) will be used as an intermediary between the RC and the HPL to sense the length changes of the RC with respect to the wavelength of the HPL. To achieve this, the local oscillator (LO) laser is frequency stabilized to the resonance of the RC, then RL is phase locked to the LO light that is transmitted by the RC by feeding back to the frequency of RL. Finally, the frequency of HPL is controlled via a phase lock loop with RL. With this, HPL will be held at a frequency offset from the frequency of the LO light circulating in the RC by some integer multiple N of the free spectral range (FSR) of the RC. While removing the PC will reduce the sensitivity of the experiment with respect to $g_{a\gamma\gamma}$, there are several benefits to this configuration that make it desirable for the initial science run.

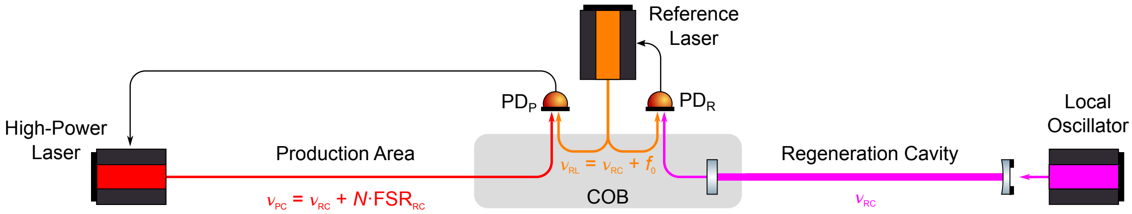

Figure 1: Control architecture of the optical system for the first axion search.

One of the most important advantages to this setup is that the resonance condition of the HPL with respect to the RC will be maintained by feeding back to the frequency of the HPL, eliminating the need to actuate on the length of the production cavity. This should increase the robustness of the setup as higher control bandwidths are possible in this arrangement.

Another advantage to this setup is that it will allow us to inject more power from the HPL to the COB. This will help during the commissioning phase when we open a shutter in the wall that allows a very small fraction of the HPL light to reach the RC. When operating the PC at full power with the current design, only 1 W of power will be available. This could make the characterization of the RC very difficult as the high reflectivity of the mirrors on the COB along the optical axis of the system will only transmit a very low power from the HPL to the RC (on the order of 10^{-17} W) when the shutter is open. By removing the production cavity mirrors we can increase this by a factor of 50 which significantly eases the commissioning of the optical system, as well as our initial calibration studies. This will also make it much easier for us to search for and mitigate stray light signals. This, of course, also means we may have a significantly higher background for the first axion search, but if we can mitigate the background due to light leaks to within a factor of 50 of our goal, we are confident that we could then meet our goal during follow-up runs with the PC in place.

4 Status of the optical system

The commissioning of the optical system is almost finished. The HPL is capable of generating 60 W with up to 90% of that power in the fundamental mode of a triangular mode cleaning cavity. The COB has been installed in the central vacuum tank, with all of its critical optics aligned. An RC has been built and demonstrates a power build up factor of over 5,000, while the frequency stabilization system for its corresponding laser is capable of maintaining the resonance condition for more than 24 hours. Finally, the control architecture of the experiment, shown in Figure 1, has been demonstrated with the HPL phase locked to the LO light transmitted by the RC, using a reference laser as an intermediary between the two fields.

5 Conclusion

ALPS II is on the verge of performing a first axion search with a goal of taking data in early 2023. The magnet string has been demonstrated and the optical system is almost ready. To expedite the commissioning of the optical system for the initial data taking, the PC will not be implemented for this phase and the search will target a sensitivity of $g_{a\gamma\gamma} > 2 \times 10^{-10}\,\mathrm{GeV}^{-1}$. Future data runs with a sensitivity goal of $g_{a\gamma\gamma} > 2 \times 10^{-11}\,\mathrm{GeV}^{-1}$ will then be performed with the PC installed along with upgrades to the optical system .

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