Status of ALPS-II at DESY

Jan Eike von Seggern (DESY) for the ALPS collaboration
Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

DOI: http://dx.doi.org/10.3204/DESY-PROC-2011-04/von_seggern_jan_eike

The light-shining-through-a-wall (LSW) experiment ALPS at DESY provides the current best lab-based bounds for WISP couplings. Based on this success, preparations for ALPS-II have started. The aim is to increase the sensitivity by three orders of magnitude to probe parameter regions with astrophysical hints for the existence of WISPs from white dwarf energy loss and the TeV transparency of the intergalactic medium. To reach this sensitivity, ALPS-II will be considerably longer, making use of 2 × 12 HERA dipole magnets. The laser power in the WISP-production region will be increased and a second optical cavity in the regeneration region will be constructed. Additionally, a very low-noise transition-edge photo-detector is in development. In a pre-experiment, it will be possible to probe the hidden-photon interpretation of the WMAP-7 excess in sterile neutrinos.

1 Introduction

The solution of the strong CP-problem of [1] postulated the axion, giving rise to a new class of particles called *weakly-interacting slim particles* (WISPs). Among these are axions, axion-like particles (ALPs) and hidden photons (HPs). While axions and ALPs couple to photons via a two-photon vertex, hidden photons mix kinematically with ordinary photons. WISPs are appealing because they can explain observations from astrophysics (*e.g.* TeV transparency of the universe, anomalous cooling of white dwarfs [2, 3]) and cosmology (*e.g.* Dark Matter, hCMB [4, 5]).

To detect WISPs via their interaction with photons one can use the principle of light-shining-through-a-wall (LSW): One points a strong light source on an opaque wall. While most photons will be absorbed or reflected by the wall, some photons can convert to WISPs before the wall and these can then easily traverse the wall. Behind the wall a fraction of these WISPs can re-convert to photons and can be detected by a low-noise photon detector. In the case of axions and ALPs a strong magnetic field is necessary. Fig. 1 shows schematic set-ups for this kind of experiments.

The probability for a WISP → γ or γ → WISP conversion is given by [6]

$$\mathcal{P}_{\gamma\leftrightarrow a} = g_a^2\,(BL)^2\ \sin^2\left(\frac{M^2L}{4\omega}\right)\Big/\left(\frac{M^2L}{4\omega}\right) \qquad \text{and} \qquad \mathcal{P}_{\gamma\leftrightarrow\gamma'} \simeq \chi^2\frac{m_{\gamma'}^4}{M^4}\sin^2\left(\frac{M^2L}{4\omega}\right)$$

for axions and ALPs and HPs, respectively, with $M^2 = m_{a,\gamma'}^2 + 2\omega(n-1)$, g_a and χ being the respective couplings, B the magnetic field strength, L the length of the baseline, n the index of refraction of the medium and ω the photon energy.

Hence, for an experiment conducted in vacuum that measured N_{meas} photons after shining N_{in} photons on the wall using a detector with efficiency ε and production and regeneration

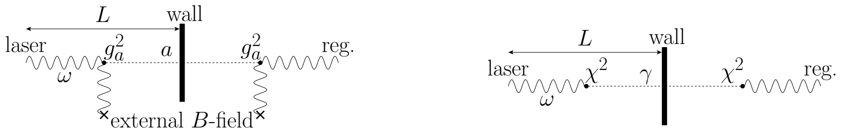

Figure 1: Schematic set-up of a light-shining-through-a-wall experiment searching for axions and ALPs (left) and hidden photons (right). The right-hand side of the wall is the production side, the left-hand side the regeneration side.

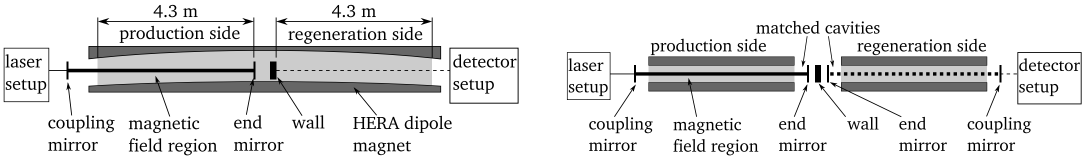

Figure 2: *Left:* Schematic set-up of ALPS-I. The production cavity is indicated by the coupling and end mirrors. The region of the magnetic field of the HERA dipole magnet is marked by the gray area. The length of the production cavity in the magnetic field and the length of the regeneration part in the magnetic field were both $L = 4.3\,\mathrm{m}$. For more details see Fig. 1 of [8]. *Right:* Schematic set-up of an improved LSW experiment utilizing an optical cavity in the regeneration side. The power build-up in the two cavities is indicated by the stronger strokes.

regions of same length L a naïve estimate of the coupling can be given in the limit of small masses for ALPs and HPs, respectively, by

$$g_a = \frac{1}{BL}\left(\frac{N_{\mathrm{meas}}}{\varepsilon \cdot N_{\mathrm{in}}}\right)^{1/4}, \qquad \chi \propto \frac{1}{m_{\gamma'}^2}\left(\frac{N_{\mathrm{meas}}}{\varepsilon \cdot N_{\mathrm{in}}}\right)^{1/4}. \tag{1}$$

2 ALPS-I

The LSW experiment ALPS at DESY used a superconducting HERA dipole magnet allowing for a magnetic field of $B = 5\,\mathrm{T}$ with a length of $L = 4.3\,\mathrm{m}$ in both parts of the experiment [7]. It finished data taking in 2009 [8]. It used a green laser of $\sim 4\,\mathrm{W}$ coupled into an optical resonator with a power build-up of up to 300 on the production side of the wall. This allowed for a continuously circulating power of up to $1.2\,\mathrm{kW}$ corresponding to 3.2×10^{21} photons/s. A commercial, liquid-cooled CCD device was used as detector. The left panel of Fig. 2 shows a schematic view of the set-up. The high photon-flux in the production cavity and the low background of the CCD rendered ALPS the most sensitive lab-based LSW experiment.

3 ALPS-II

In late 2010 work has begun to build a successor of ALPS-I. Increasing the sensitivity of an LSW experiment can be achieved by increasing the size of the experiment, improving the detection efficiency, increasing the power of the light source, and for axions and ALPs by using stronger magnets, where Eqs. 1 show that the length and magnetic field have the strongest effect. Since a stronger magnetic field could only be achieved by constructing new superconducting magnets,

	λ/nm	P_{prod}/kW	PB_{reg}	magn. set-up	L/m	eff.	noise/h^{-1}	rel. gain
ALPS-I	532	1.2	1	$0.5 + 0.5$	4.3	0.96	32	1
step 1	1064	150	40 000	–	10	0.02	32	
	(1.2)	(3.3)	(14)		(–)	(0.38)	(1)	21
step 2	1064	150	40 000	–	130	1.0	0.3	
	(1.2)	(3.3)	(14)		(–)	(1.0)	(1.8)	101
step 3	1064	150	40 000	$12 + 12$	105	1.0	0.3	
	(1.2)	(3.3)	(14)		(24)	(1.0)	(1.8)	2500
fall	1064	150	40 000	$4 + 4$	35	1.0	0.3	
back	(1.2)	(3.3)	(14)		(8.1)	(1.0)	(1.8)	822

Table 1: The experimental parameters for the different steps for ALPS-II. The last column shows the expected improvement in sensitivity compared to ALPS-I. The individual influence on the sensitivity of each parameter is given in parentheses. For step 1 and 2 the influence on the HP-sensitivity is given, for step 3 and the fall-back set-up the influence of the ALP-sensitivity.

the work for ALPS-II concentrates on the first three components. Further increase of sensitivity can be achieved by a second optical cavity in the regeneration part as shown in the right panel of Fig. 2 [9]. This increases the probability for an ALP or HP to convert back to a photon proportional to the power build-up of the cavity.

Laser and cavities The period of continuous operations during ALPS-I measurements was limited by the durability of the mirrors of the production cavity. We hope to improve this by using an infrared laser with $\lambda = 1064$ nm. This will allow for a higher continuously circulating power of approximately 150 kW with a much increased durability of the cavity mirrors as is known from gravitational wave experiments [10].

For the regeneration cavity an approximate power build-up of 40 000 for IR light is planned. The matching of the alignment and resonance frequency of the regeneration cavity eigenmode to that of the production cavity will be achieved by a green reference beam, which will be produced from the IR beam by second-harmonic generation and will be split from regenerated IR photons in the optical detector set-up [11].

Magnet string The HERA dipole magnets have a curved beam pipe with a free aperture of 35 mm. Without modifications, this allows to use 2 × 4 HERA dipoles. For longer set-ups the power build-up decreases due to clipping of the laser beam resulting in a reduced overall sensitivity. Since the length of the experiment has the strongest influence, a method to straighten the beam pipes is developed. First tests showed that a free aperture of 50 mm can be achieved, allowing for lengths of $L = 130$ m (2 × 12 HERA dipoles).

Detector Switching from green to infrared light complicates the detection of single photons, especially when using a silicon-based CCD as was used in ALPS-I, because the photon energy is of the order of the Si band gap. This results in a much lower quantum efficiency of $\sim 2\,\%$.[1] But since the background of the CCD camera is known to be low and the efficiency influences the limit only by the fourth root, it is prepared to be used as fall-back detector.

---

[1] For comparison, the quantum efficiency for green light in ALPS-I was 96 %.

As prime detector a transition-edge-sensor device (TES) is developed in cooperation with the BaRBE project [12]. This should result in a detector with almost zero intrinsic noise and a (limited) energy resolution. By coating the TES a quantum efficiency close to 100 % should be possible.

Realization The above improvements will be realized stepwise: In the first step, a 2 × 10 m long, HP-only experiment will be built, which will serve as proof-of-concept for the matching of the production and regeneration cavities and will eventually use the TES as detector. Second, this set-up will be enlarged to 2 × 130 m to prove that cavities of this length can be controlled, and finally this set-up will be equipped with 2 × 12 HERA dipoles for an ALP search.

The experimental parameters of the different steps are shown in Tab. 1 together with the resulting improvements on the sensitivity compared to ALPS-I. The parameter space of the hCMB interpretation of the WMAP-7 data of [5] should easily be reached with the 2 × 10 m HP-search set-up.

4 Conclusion

ALPS-I is the most sensitive lab-based LSW experiment up to now. The preparations for ALPS-II have begun at DESY. The experiment will be conducted in three steps. The first pre-experiment will serve as proof-of-concept for the matching of the production and regeneration cavities and reach the parameter region of the hCMB. The final set-up will be installed by 2017 and will improve the sensitivity by three orders of magnitude compared to ALPS-I.

References

[1] R. D. Peccei and H. R. Quinn, “CP Conservation in the Presence of Instantons,” Phys. Rev. Lett. **38**, 1440 (1977).

[2] M. Meyer, “Indications for a highly transparent universe at very high energies,” Contribution to this workshop (2011).

[3] J. Isern, “White dwarfs as physical laboratories: the axion case,” Contribution to this workshop (2011).

[4] M. Drees and G. Gerbier, “Dark matter” in K. Nakamura *et al.* [Particle Data Group Collaboration], “Review of particle physics,” J. Phys. G G **37**, 075021 (2010).

[5] J. Jaeckel, J. Redondo and A. Ringwald, “Signatures of a hidden cosmic microwave background,” Phys. Rev. Lett. **101**, 131801 (2008) [arXiv:0804.4157 [astro-ph]].

[6] J. Redondo and A. Ringwald, “Light shining through walls,” Contemp. Phys. **52**, 211 (2011) [arXiv:1011.3741 [hep-ph]].

[7] K. Ehret *et al.* [ALPS Collaboration], “Resonant laser power build-up in ALPS: A ’Light-shining-through-walls’ experiment,” Nucl. Instrum. Meth. A **612**, 83 (2009) [arXiv:0905.4159 [physics.ins-det]].

[8] K. Ehret *et al.* [ALPS Collaboration], “New ALPS Results on Hidden-Sector Lightweights,” Phys. Lett. B **689**, 149 (2010) [arXiv:1004.1313 [hep-ex]].

[9] P. Sikivie, D. B. Tanner and K. van Bibber, “Resonantly enhanced axion-photon regeneration,” Phys. Rev. Lett. **98**, 172002 (2007) [hep-ph/0701198 [HEP-PH]].

[10] LIGO Laboratory/LIGO Scientific Collaboration, “Advanced LIGO refenece design,” LIGO-060056-08-M (2007) http://www.ligo.caltech.edu/docs/M/M060056-08/M060056-08.pdf

[11] T. Meier, “High-Power CW Green Lasers for Optical Metrology and Their Joint Benefit in Particle Physics Experiments,” Thesis (2011), Chapter 4.

[12] G. Cantatore, “The BaRBE project and the perspectives of TES sensors in WISP searches,” Contribution to this workshop (2011).