ALPS – WISP Search at DESY

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The ALPS experiment at DESY performs a *light shinning through the wall* experiment to search for *Weakly Interacting Slim Particles (WISPs).* Resonant laser power build-up with a large-scale optical cavity boosts the available power for WISP production and facilitates the experiment to provide the most stringent laboratory constraints on WISP production. Resent results as well as plans for the next phase are presented.

1 Low Energy Frontier: ALPs and other WISPs

In the last years it has been realized, that extensions of the Standard Model may manifest itself also at low energy scales. They predict very *weakly interacting slim particles (WISPs).* Potential WISP candidates are *axion-like particles (ALPs)* or *hidden sector photons (HPs).* The low energy frontier is a rich complement to the conventional high-energy particle physics landscape [1, 2, 3]. There exist several hints from astrophysics pointing to new physics in the sub-eV range and a QCD axion in the sub-meV would be a cold Dark Matter candidate.

There are prediction from theory which can be tested in dedicated high precision lab experiments and the search for these new particles initiated experimental activities around the world [2]. *Light shining through a wall (LSW)* experiments, cf. Fig. 1, are an old intriguing simple idea [4, 5, 6] to perform direct WISP searches with an enormous sensitivity [1, 3].

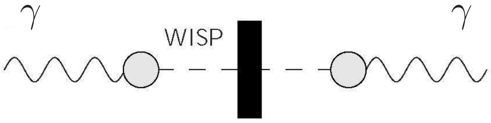

Figure 1: Sketch of a LSW experiment. Photons, typically from a laser, are shone on a light tight wall. Some photons may be converted into WISPs which traverse the wall. Behind the wall some of these WISPs reconvert into ordinary photons, with the same properties as the initial photons, which are observed with a detector.

The conversion of the incident photons to an axion-like particles ϕ and its reconversion in the presence of a magnetic field is governed by the Primakoff effect. Assuming that the mass m_ϕ and two photon coupling g of the ALPs are uncorrelated the LSW probability in a symmetric setup is given by

$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16\beta_\phi^2}(gBL)^4 \left(\frac{\sin(qL/2)}{qL/2}\right)^4 ,$$

with B the magnetic field strength, L the length of the conversion region, β_ϕ denoting the velocity of the ALP and $q = p_\gamma - p_\phi$.

For $qL << 1$ the oscillation is coherent along the full length and the transition probability reaches its maximum $P_{\gamma\to\phi\to\gamma} = 1/(16\beta_\phi^2)\cdot(gBL)^4$. For a larger ALP mass m_ϕ the momentum p_ϕ decreases, i.e. the wavelength rises and runs out of phase compared to the photon wave

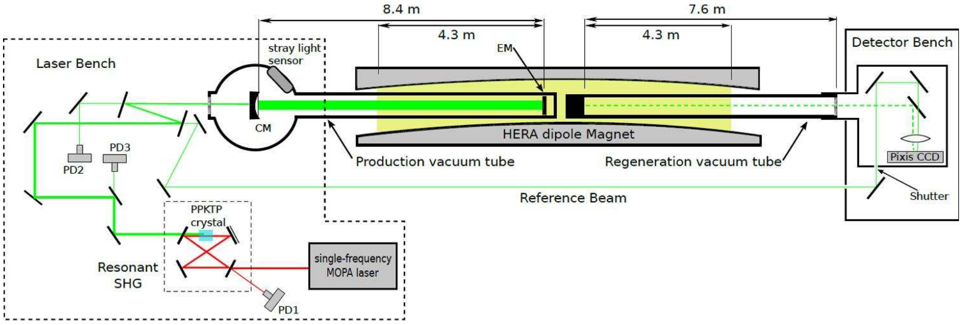

Figure 2: Sketch of the ALPS experiment. PD denotes various photo detectors, CM the coupling mirror and EM the end mirror of the resonant cavity. See the text and references for details.

function, causing a lower conversion probability, cf. Fig. 3. The sensitivity of LSW experiments is mainly determined by the number of incident photons, $B \cdot L$ of the magnet and the capability of the detector, cf. Tab. 1. The polarization of the beam allows to distinguish between scalar and pseudo scalar ALPs.

2 The ALPS Experiment at DESY

The ***A**ny **L**ight **P**article **S**earch (ALPS)* experiment located at DESY in Hamburg uses a spare superconducting HERA dipole magnet with a field $B \approx 5$ T and exploits resonant laser power build-up in a large-scale optical cavity to perform a *light shining through a wall* experiment [4, 5, 6] for direct WISP searches. The ALPS collaboration comprises besides DESY the Albert Einstein Institute in Hannover, the Laser Zentrum Hannover and the Hamburg observatory.

Figure 2 shows a sketch of the experimental setup. The opaque wall sits in the middle of the magnet. Inside the dipole magnet two beam tubes are placed, which bound the $\gamma - \phi$ conversion and reconversion regions and are operated under vacuum conditions. On the left side is the laser setup, providing the incident photons. On the right is the detector bench with the commercial CCD camera PIXIS 1024B, which is attached light-tight to the detector tube. Operated at -70 ^{o}C it features a very low dark current of 0.001 e^-/pixel/s as well as a low read-out noise of 3.8 e^-/pixel RMS and a very high quantum efficiency of more than 95% for green light. The beam spot is focused onto one defined 42×42 μm^2 bin of 9 pixels. Usually one hour frames are taken in order to minimize the impact of read-out noise, providing a sensitivity to a photon flux of a few mHz. For details of the ALPS setup refer to [7, 8]. ALPS also exploits successfully a new method to cover the gaps in the sensitivity for higher masses, where the ALP wave runs out of phase w.r.t. the phase of the laser beam. Introducing Ar gas at a pressure of 0.18 mbar changes the photon momentum and the $\gamma -$ALP relative phase velocity increases thereby to have an extra half oscillation length. Even if the sensitivity is lowered compared to vacuum conditions this helps to cover the high mass gaps, cf. Fig. 3.

The most sophisticated part of the ALPS experiment is the laser system and the resonant photon generation. ALPS is the first experiment, which successfully exploit a large-scale optical resonator for WISP searches. A LIGO-type single frequency laser system which allows a frequency shift of ±100 MHz is used to produce 1064 nm laser light. In order to optimize the detection efficiency, the frequency of the laser beam is doubled to green light in a folded ring shaped resonator build around a nonlinear crystal. The length of the resonator is constantly changed in order to keep it resonant with the incident infrared laser light. The 532 nm laser beam is then redirected into the production vacuum tube in which photon-WISP conversions could occur. An optical resonator inside this pipe is used to buildup the laser power, enhancing

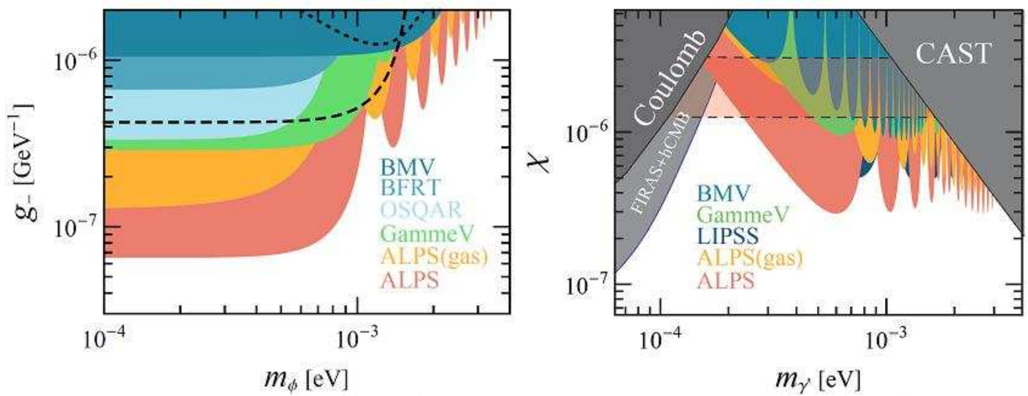

Figure 3: Exclusion limit (95% C.L.) for pseudoscalar axion-like particles (left) obtained by the ALPS experiment from vacuum and gas runs and for hidden photons (right) together with the results from various other LSW experiments, for details and references see [8].

proportionally the WISP flux. The frequency of the infrared laser is adopted in order to lock the cavity. Variations of the resonator frequency are dominated by length fluctuations of the setup. To avoid loses of the circulating laser light the complete cavity with both mirrors is housed inside the vacuum, cf. Fig. 2. This boosts the power build-up to $PB \approx 300$. During the measurement period in the year 2009 the green laser power feed into the cavity was kept below 5 W to minimize potential degradation of the cavity mirrors, resulting in a continuously circulating power inside the ALPS production region of around 1.2 kW.

ALPS took around 50 data sets (1 h frames) under different experimental conditions: with magnet on or off, laser polarization parallel or perpendicular to the magnetic field and different gas pressures. Details on the methodology and analysis are described in [7, 8]. From the non observation of any WISP signal a 95 % confidence level on the conversion probabilty was obtained, ranging between $P_{\gamma\rightarrow\phi\rightarrow\gamma} = 1...10 \times 10^{-25}$ for the different experimental setups. Fig. 3 shows the ALPS results for pseudoscalar axion-like particles and for hidden photon search together with the results obtained from other experiments.

3 Summary and Prospects for ALPS II

The ALPS experiment at DESY demonstrated successfully the feasibility of large scale optical cavities to boost the power available for WISP production. ALPS provides now the most stringent laboratory constraints on the existence of WISPs. This success is based on a close collaboration between particle physicist, laser physicists from the gravitational wave detector community and the infrastructure and support of a high-energy physics laboratory. Based on this background a detailed planing of a future large scale LSW experiments which improves the sensitivity by orders of magnitudes has started, aiming to surpass present day limits from astrophysics on the coupling of ALPs to photon [11]. This requires a sensitivity in the photon-ALP coupling of $g < 10^{-10}\mathrm{GeV}^{-1}$, an improvement of 3 orders of magnitude with respect to the ALPS results. Table 1 summarizes the dependence of the sensitivity in g on experimental parameters together with possible improvements. The sensitivity in g improves linearly with the magnetic field strength and length. Instead of half an HERA dipole magnet one may use e.g. six magnets on each side providing a $BL \approx 280$ Tm. Furthermore it looks feasible to increase the

Table 1: Dependence of the photon-ALP coupling g on experimental parameter together with the prospects of the ALPS II experiment w.r.t. the actual ALPS setup, see text for details.

Parameter	g dependence	ALPS	ALPS II	gain
Magnetic field	$g \propto BL^{-1}$	$BL = 23$ Tm	$BL = 300$ Tm	13
Laser power	$g \propto P^{-\frac{1}{4}}$	$P = 1$ kW	$P = 100$ kW	3.2
Detector sensitivity	$g \propto \epsilon^{\frac{1}{4}}$	$\epsilon = 2$ mHz	$\epsilon = 0.02$ mHz	3.2
Measurement time[1]	$g \propto t^{-\frac{1}{8}}$	$t = 10$ h	$t = 1000$ h	1.8
Resonant regeneration	$g \propto PB^{-\frac{1}{4}}$	$PB = 1$	$PB = 10000$	10

incident laser power to the cavity by a factor of 10 and to improve the power build-up in the resonant cavity by an additional factor of 10. Single photon counting techniques, e.g. with cryogenic transition edge sensors may provide in addition a factor up to 100 improvement in the sensitivity. This results in two orders of magnitude improvement in the sensitivity for g. More statistics, i.e. longer measurement time, will not really help.

An old idea from the 1990's was recently rediscovered, namely to set up similar to the generation part an additional optical cavity for resonant axion photon regeneration, which enhances the small electromagnetic photon component of a potential WISP wave behind the wall [9, 10]. The technical details are rather challenging, e.g. one can obviously not use laser light of the same wavelength for locking and for the WISP production. ALPS II intend to use 1064 nm laser light for the WISP production and frequency doubled laser light with 532 nm for the locking of the regeneration cavity [12]. A power build of $PB \approx 10000$ seems to be possible, which would increase the sensitivity to g by another order of magnitude, enabling ALPS II to surpass present day limits on g from astrophysics.

References

[1] J. Jaeckel and A. Ringwald, arXiv:1002.0329 [hep-ph].

[2] J. Jaeckel, *Lab Searches for WISPs*, http://axion-wimp.desy.de and these proceedings.

[3] K. Ehret [ALPS Collaboration], arXiv:1006.5741 [hep-ex].

[4] L. B. Okun, Sov. Phys. JETP **56** (1982) 502 [Zh. Eksp. Teor. Fiz. **83** (1982) 892].

[5] A. A. Anselm, Yad. Fiz. **42** (1985) 1480.

[6] K. Van Bibber *et al.* Phys. Rev. Lett. **59** (1987) 759.

[7] K. Ehret *et al.* [ALPS collaboration], NIM A **612** (2009) 83 [arXiv:0905.4159 [physics.ins-det]].

[8] K. Ehret *et al.* [ALPS Collaboration], Phys. Lett. B **689** (2010) 149 [arXiv:1004.1313 [hep-ex]].

[9] F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358** (1991) 3.

[10] G. Mueller, P. Sikivie, D. B. Tanner and K. van Bibber, Phys. Rev. D **80** (2009) 072004 [arXiv:0907.5387 [hep-ph]].

[11] P. Arias, J. Jaeckel, J. Redondo and A. Ringwald, arXiv:1009.4875 [hep-ph] and these proceedings..

[12] T. Meier [ALPS Collaboration], AIP Conf. Proc. **1274** (2010) 156 [arXiv:1003.5867 [physics.optics]].

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[1] For detectors limited in their sensitivity by background counting rates.