

# BSM photon interaction for ALPS-II and beyond

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High-intensity photon beams can provide for a viable probe for many particles of Standard Model extensions. This workshop contribution briefly reviews the status of the second stage of the Any Light Particle Search (ALPS-II) at DESY, an experiment of the light-shining-through-a-wall type, as well as an idea to test asymptotically safe quantum gravity in a photon-scattering experiment.

## 1 An enlightening way of looking for new physics

Several considerations (e.g., UV-completions for the Standard Model) and observations (e.g., Dark Matter) lead us to assume the existence of particles beyond the Standard Model. In order to have evaded detection so far, such new particles can be either very heavy, or rather light (e.g., at sub-eV scale) if they have extremely small coupling to known particles [1].

The most renowned example of such proposed weakly interacting slim particles, “WISPs” for short, is arguably the axion [2], which is a consequence of the Peccei-Quinn solution to the strong CP-problem. In addition, strong interest has emerged recently for so-called axion-*like* particles (ALPs), whose mass-coupling relation is relaxed compared to the QCD axion: ALPs can, e.g., appear in intermediate string scale scenarios [3], and constitute Dark Matter [4]. Moreover they could explain yet puzzling observations<sup>1</sup> in some astrophysical processes such as anomalous White Dwarf cooling [6] and the transmissibility of the universe to high-energetic photons [7].

Further WISPs can be particles of hidden sectors in string- and field-theoretic extensions of the Standard Model, see, e.g., [8]: Particularly hidden photons (HPs), i.e., gauge bosons of an extra U(1) gauge group as well hidden sector matter. The latter can acquire an electromagnetic fractional charge and thus can constitute so-called minicharged particles (MCPs), see [1] for an overview. Hidden photons are also a viable Dark Matter candidate [4] and could be responsible for the phenomenon of Dark Radiation [9]. In addition, WISPs can appear as scalar modes in theories of massive gravity [10].

If such WISPs exist, it is expedient to search for them also by their interactions with photons. Amongst others, this is advantageous because photons can be easily produced at high rates and do not have tree-level self-interactions within the Standard Model. Thus, beyond-Standard-Model physics becomes readily accessible. Experiments particularly apt to look for WISPs with photons are of the ‘light-shining-through-a-wall’-type (LSW) [11]: Laser photons can be converted into a WISP in front of a light-blocking barrier (generation region) and reconverted

<sup>1</sup>Note that astrophysical observations of course also put strong constraints on the existence of ALPs. A recent comprehensive overview of the corresponding parameter space can be found in [5].

Parameter	Scaling	ALPS-I	ALPS-IIc	Sens. gain
Effective laser power $P_{\text{laser}}$	$g_{a\gamma} \propto P_{\text{laser}}^{-1/4}$	1 kW	150 kW	3.5
Rel. photon number flux $n_\gamma$	$g_{a\gamma} \propto n_\gamma^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
Power built up in RC $P_{\text{RC}}$	$g_{a\gamma} \propto P_{\text{reg}}^{-1/4}$	1	40,000	14
$BL$ (before& after the wall)	$g_{a\gamma} \propto (BL)^{-1}$	22 Tm	468 Tm	21
Detector efficiency $QE$	$g_{a\gamma} \propto QE^{-1/4}$	0.9	0.75	0.96
Detector noise $DC$	$g_{a\gamma} \propto DC^{1/8}$	0.0018 s <sup>-1</sup>	0.000001 s <sup>-1</sup>	2.6
Combined improvements				3082

Table 1: Parameters of the ALPS-I experiment in comparison to the ALPS-II proposal. The second column shows the dependence of the reachable ALP-photon coupling on the experimental parameters. The last column lists the approximate sensitivity gain for ALP searches compared to ALPS-I. For hidden photons, there is no gain from the magnetic field. Thus the sensitivity gain follows as above except for the factor coming from  $BL$  and amounts to 147.

into photons behind that barrier (regeneration region). Depending on the particle type, these conversion processes are induced by magnetic fields<sup>2</sup> or are manifest as oscillations.

The most sensitive LSW laboratory setup thus far is the first stage of the Any Light Particle Search (ALPS-I) [13] at DESY. With major upgrades in magnetic length, laser power and the detection system, the proposed ALPS-II experiment aims at improving the sensitivity by a few orders of magnitude for the different WISPs. Following last year’s workshop contribution [14] we shortly present an updated status of ALPS-II.

## 2 ALPS-II status and prospect

The reason for proposing to realize an upgraded version of ALPS is its sensitivity to particularly interesting parameter regions for various WISPs, as indicated in the previous section.

Three key ingredients are responsible for this sensitivity boost [15], cf. Tab. 1: Foremost, the magnetic length of ALPS-II is expected to be 468 Tm. This can be achieved by a string of 10+10 HERA dipoles which can be taken from a reserve of 24 spare magnets manufactured for HERA at DESY. Note that the setup of this string requires an aperture increase by straightening the beam pipe to avoid clipping losses for the laser. The viability of this undertaking has been proven with the straightened ALPS-I magnet achieving quench currents above values measured for the unbent magnet [15]. Secondly, the effective photon flux in the setup is planned [16] to be increased through a higher power buildup in the production cavity and by virtue of ‘resonant regeneration’ [17], i.e., an optical resonator in the regeneration region, locked to the resonator in the generation region<sup>3</sup>. To assure long-term stability of the cavity mirrors, ALPS-II will employ infrared light at 1064nm wavelength (instead of green 532nm for ALPS-I). Thirdly, ALPS-II will feature a nearly background-free transition edge sensor allowing for high detection efficiency even to infrared light. Whilst this sensor is under development, the ALPS-I CCD can be used as a fall-back option.

<sup>2</sup>Note that for the test of ALPs and MCPs the optimal direction of these fields is rather different [12].

<sup>3</sup>Note that ‘resonant regeneration’ is already successfully used in related setups with microwaves [18]. For the optical regime, different locking schemes have been proposed [15, 19].

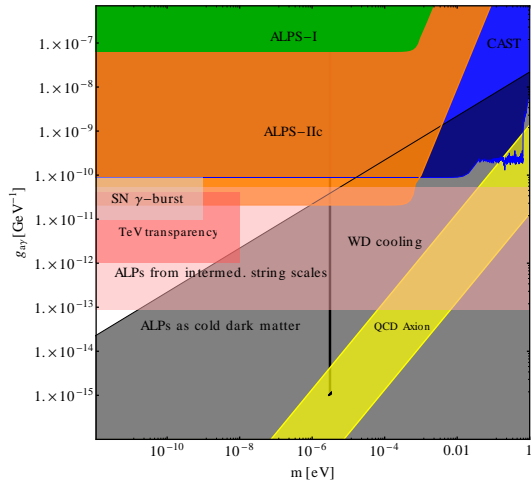


Figure 1: Sketch of the prospective reach of ALPS-IIc (orange) in the axion-like particle parameter space, see text for details.

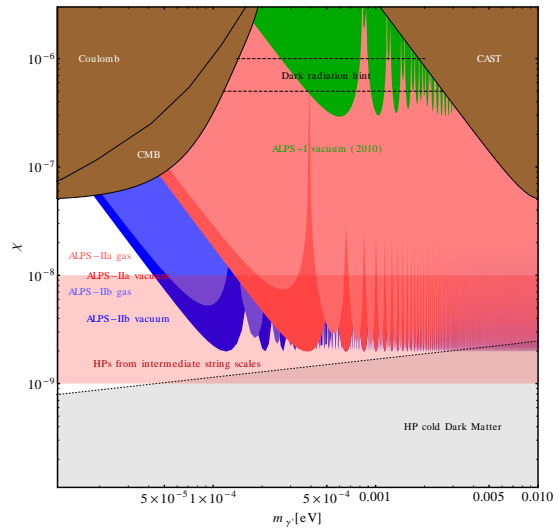


Figure 2: Expected sensitivity range of ALPS-IIa/b (red/blue) for hidden photons, cf. text for details.

ALPS-II is set out to be realized in three stages: ALPS-IIa is already well under way and will search for hidden photons in a 10m+10m LSW-setup without magnets. It is meant to demonstrate the viability of the optics setup, particularly the locking scheme of the regeneration cavity. As physics benefit, it will be sensitive to the Dark Radiation hint [9] as well as to parameter regions favored in intermediate string scale scenarios and a small region compatible with HP Dark Matter, see Fig. 2. As already successfully used at ALPS-I [13], also gas will be inserted into the vacuum tube at each stage to close the gaps arising from at minima of the conversion probability. ALPS-IIb, still without magnets is planned to test a smooth operation at 100m+100m length in the HERA tunnel. Only the final stage, ALPS-IIc, is planned to operate with magnets and thus explore the parameter space of axion-like particles, cf. Fig. 1.

### 3 Photons as probe for asymptotically safe gravity

A further field of search for physics beyond the Standard Model in which lasers-based setups could yield insight, is the search for a quantum theory of gravity. As there is no tree-level background within the Standard Model, it is tempting to explore if measuring the cross-section of photon-photon scattering at high energies can teach us about quantum gravity (QG), since the small QG signal is easier accessible without a tree-level background.

To achieve high photon energies in a collider mode, different future options are advanced: Compton-backscattering is possible within linacs or from wake-field-accelerated charged particles using pulsed high-intensity lasers [20]. The tiny cross section for photon-photon scattering through graviton exchange [21] may be drastically enhanced in scenarios with extra dimensions [22]. This is not a new idea, but strongly deserves a revisit [23] in the context of UV-complete theories, that do not rely on an energy cutoff scale, such as asymptotically safe gravity, see [24]

for reviews. It is worth exploring the possibility further if laser-based searches could eventually even shed light onto QG.

## 4 Summary

Laser-based laboratory searches can be a strong tool to address various questions of beyond the Standard Model physics. In this contribution we have discussed the status and prospect of ALPS-II, which is designed to explore particularly motivated parameter regions of different WISPs. Further, we have briefly pointed at the possibility of even testing quantum gravity scenarios with purely laser-based setups.

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