

What's new in ALPS-II

B. Döbrich¹, for the ALPS-II collaboration

¹Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

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This proceedings contribution gives a brief experimental update of the ‘Any light particle search (ALPS) -II’ at DESY which will be sensitive to sub-eV, very weakly coupled particles beyond the Standard Model. First data on hidden sector photon parameter space through photon-hidden photon oscillations in vacuum is expected in 2014. Axion-like particle search (implying the installation of superconducting HERA magnets) could be realized in 2017.

1 ALPS-II setup and goals review

ALPS-II is an experiment of the light-shining-through-a-wall (LSW) type [1], and succeeds the experiment concluded in [2]. In brief, the concept is to keep a large number of $\mathcal{O}(\text{eV})$ photons stored in an optical cavity before a ‘wall’, i.e., a light-proof environment. Measuring photons beyond that wall would indicate beyond-Standard Model (BSM) physics¹: If the photons are stored in a magnetic field in vacuum, the BSM process could be due to photons oscillating into axion-like or minicharged particles: Axion-like particles have a coupling to photons similarly to the QCD axion, but a relaxed mass-coupling relation; minicharged particles are electrically fractionally charged fermions or bosons, arising typically in hidden-sector models. Even without magnetic field, the photons could have oscillated into hidden photons (kinetically mixed, massive extra U(1) gauge bosons) cf., e.g., [3, 4].

Note that the LSW setup is generically sensitive only to particles with masses lower than the photon energy, i.e., to sub-eV masses in our setup. In addition, for maximum sensitivity, the conversion should be coherent such that the 200m long ALPS-II will be most sensitive below the 10^{-4}eV regime for axion-like particles and minicharged particles and in between 10^{-4}eV and 1.17eV for hidden photons getting mass from a Stückelberg mechanism². For details on the here accessible as well as the physically most interesting parameter space of these light BSM particles, see [6].

ALPS-II will boost its sensitivity to light particles mainly due to the following components: Firstly, the resonator on the ‘production-side’ before the ‘wall’ will be complemented by a frequency-locked resonator behind the barrier (in the ‘regeneration-region’). This increases the probability of reconversion of the light BSM particle through ‘photon-self interference’ [7]. Also, the power buildup and the amount of in-coupled light will be enhanced such that one has 150kW circulating power in ALPS-II in comparison to 1kW in ALPS-I. Secondly, the magnetic length is enhanced by the use of 10+10 superconducting HERA dipoles instead of only 1 dipole

¹The contribution to such a process through a Standard Model background of neutrinos is negligible due to the large mass of the involved mediators.

²The situation in the case of mass from a Higgs mechanism is slightly more involved [5].

at ALPS-I. Thirdly, for single-photon detection, a Transition Edge Sensor is employed. Note that ALPS-II is set out to be about three orders of magnitude more sensitive than ALPS-I in the search for axion-like particles and about two orders of magnitude for hidden photons.

The experiment is structured in three phases. In ALPS-IIa (ongoing), meeting the optics and detector experimental challenges at a 10m+10m setup (cavity length before and after the ‘wall’, respectively) are addressed and a search for hidden photons can be performed. In addition, the magnet straightening-techniques (see below) are studied. ALPS-IIb will show the viability of the setup at 100m+100m length in the HERA tunnel. Finally, ALPS-IIc (still to be approved) will include the HERA dipole magnets, in order to be sensitive to axion-like (ALP) and minicharged particles.

After a thorough review of the ALPS-II Technical Design Report (an excerpt is published in [6]) by appointed, external referees, the DESY management has approved the first two phases of ALPS-II. In addition, an ALPS group has been established in the DESY high energy division. The ALPS-II collaboration comprises DESY, the Albert-Einstein Institute (AEI) in Hanover and the University of Hamburg.

In the following, this proceedings contribution briefly updates the status presented at last year’s workshop [8].

2 Experimental status of optics, magnets and detector

Optics:

In brief, the optics challenge is due to the necessity of frequency-locking and aligning the production and regeneration resonators whilst requiring sensitivity to possible single photon-events from BSM physics: To keep both cavities frequency-locked, laser light must also oscillate in the regeneration cavity (to stabilize the cavity, Pound-Drever-Hall locking is employed).

The production cavity is set out to host 35W of *infrared* (1064nm) light at a power build-up of 5000 ($\sim$ number of photons reflections inside the cavity). Thus, to discriminate signal photons (e.g., due to axion-like particles), the regeneration cavity on the other hand is locked with only a few mW of frequency-doubled, *green* light, from the same laser source as the light oscillating in the production resonator. The power build-up for infrared light in the regeneration cavity, however, amounts to 40000 (amplifying the signal photons).

This setting requires great care to avoid that infrared light enters the regeneration region when coupling the green light into the regeneration cavity. In addition, no infrared photons should be created from the green due to down-conversion processes. Both these effects: light-tightness of the production region and down-conversion effects are quantified stepwise with the integration of components to the setup. So far no show-stopper has occurred.

On top of that, the simultaneous locking of both cavities must be shown, this is done at a 1m test-setup at the AEI in Hannover and reported on in [9]. Note that in principle, other locking schemes are conceivable [10], and studying both complementary methods is worthwhile.

In Hamburg, at the ALPS-IIa site (HERA West facility, one floor below ground level), infrastructural measures are mostly completed and successful studies with a low-finesse cavity have been performed throughout this year: As the mirrors of the ALPS-II resonators will be located on different optical tables in the 10m+10m setup, such studies were necessary to assess whether a stable operation with the high-finesse dichroitic mirrors will be possible with available vibration dampening. Our measurements show an integrated RMS noise for the free-running cavity on the order of a few $\times 10^{-9}$ m down to 10Hz, allowing to operate the envisaged cavities

in principle. Similar studies to evaluate the conditions in the HERA tunnel (where ALPS-IIb and ALPS-IIc will be located) are in their initial phases.

To facilitate the alignment of the 2+2 cavity mirrors, the plane, rectangular central mirrors will be fixated on a common, very smooth central ‘breadboard’ [6]. Considering the locking mechanism as described above, we have devised a shutter box which must match the following criteria: Sealing off the regeneration cavity from infrared photons (except for calibration purposes) whilst allowing for an in-coupling of the green light for locking purposes. The light-tightness of the box (through milling of a labyrinth) must be realized without interfering with the planarity of the breadboard surface.

The delivery of the entire set of the set of highly reflective mirrors with 250m ROC is expected soon (choosing this ROC ensures that the mirrors can be used also in the succeeding stages of ALPS-II).

Magnets and vacuum:

As reviewed in detail in [6], achieving the foreseen power-buildups in the optical resonators whilst using a setup with 20 magnets requires reinstating the full aperture of the proton beam tube inside the HERA magnets. For the accelerator-use, the beam pipe was bent such that the free aperture amounts to $\sim 35\text{mm}$, instead of $\sim 55\text{mm}$. Note that if the aperture would be not reinstated approximately, the envisaged power buildup would only allow for an installation of 4+4 magnets (a high power buildup necessitates to have little clipping losses). However, with 4+4 dipole magnets only, probing couplings beyond the range of CAST [11] and in the physically most interesting parameter region of ALP-photon couplings of $g \lesssim 10^{-10}\text{GeV}^{-1}$ would not be possible.

We have devised a method to reversibly straighten the beam pipe to an effective aperture of $\sim 50\text{mm}$ by the insertion of ‘pressure props’ that stabilize the cold mass against the cryostat wall. This was demonstrated first conceptually in a non-functional ‘PR’-magnet and subsequently, the deformation ‘props’ were inserted at the ALPS-I magnet in a dipole test bench. The magnet was quenched on purpose several times to demonstrate the stability of the setup in September 2012. The quench current was higher than during the last runs of ALPS-I.

Note that ALPS-IIc will only require to use *spare* dipole magnets. The dipole magnets in the HERA ring itself will remain in place. Straightening of the 20 dipoles for ALPS-IIc is not foreseen before 2014. Thus, at the moment, the required tools for this procedure are optimized. Fast surveying techniques of the cold and warm dipole bore, respectively, are being studied.

As HERA is equipped with ion getter and titanium sublimation pumps, detailed studies of the light emission in getter pumps have been started this year to assess the possibility fake-signals on our detector, if getter-pumps are used in the regeneration region [12]. In any case, the titanium sublimation pumps will suffice if a problem with light emission is inferred.

Detector:

For detecting photons at ALPS-II, fiber-guiding the photons to a Transition-Edge Sensor detector (TES), is foreseen. In a nutshell, the current-change in a sophisticated multilayer superconductor, operated at the superconducting edge, is picked up by an inductively coupled SQUID at cryogenic temperatures. The cryostat used in ALPS-II to host the TES and the SQUID is an adiabatic demagnetization refrigerator (ADR). Such a setup is perfectly suited for single-photon detection due to its extremely low dark count rate.

Earlier this year, two TE sensors were lent to our collaboration from NIST in the US and AIST in Japan, respectively. In close coordination with the PTB in Berlin, the detection system with these sensors is set up at DESY as reviewed in [13]. Note, that in principle two channels

are available such that two TE sensors can be used in parallel (e.g., one could be used to record solely background events, first background studies have been performed [13]).

In a separate setup, we have studied the in-coupling of an ALPS-II-like photon beam (i.e., diameter as foreseen in experiment but different laser source) into a single-mode fiber. Focusing on a fiber-coupler, an efficiency of more than 80% was achieved. Note that for the overall detector sensitivity, quantifying the coupling of the fiber to the TES inside the ADR is also foreseen.

As a detector fall-back option and for calibration purposes, the Princeton Instruments ‘PIXIS CCD’ used in ALPS-I has been characterized with respect to the detection of 1064nm photons [14].

3 To take home

With (yet) little stringent indications towards BSM physics in laboratory experiments, it is worthwhile, besides the high-energy frontier, *also* to keep in mind the sub-eV scale as potential host of something undiscovered [15], including Dark Matter [16, 17]. ALPS-II aims at exploring a large parameter space of new sub-eV particle physics by combining idle accelerator infrastructure with pioneering optics and detector techniques. In summary, we hope to report to the next, 10th PATRAS workshop 2014 at CERN with first ALPS-IIa measurement data.

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