DESY

Towards the ALPS-II Experiment

Status Report to the DESY PRC

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This document summarizes the preparatory work under way for a future ALPS-II experiment. The PRC is asked to take note and support further studies toward a Technical Design Report in the beginning of the year 2012.

Table of Contents

Introduction

Since decades it is well known, that the solution to the problem of Dark Matter in the Universe might not only be found at the TeV scale, but could also hide at very low mass scales as so-called WISPs (weakly interacting slim particles). The QCD axion predicted in 1978 is still one of the most promising Dark Matter candidates. With the discovery of Dark Energy WISPs gained additional support as very light scalar or pseudoscalar particles could offer a natural explanation for this phenomenon. In addition string theory predicts a zoo of WISPs. Astrophysics phenomena like the surprising transparency of the Universe for TeV photons or the cooling of white dwarfs may find an easy explanation with the help of WISPs.

Since about the year 2005 there has been a revival of laboratory based WISP experiments, partly triggered by the surprising, but later not confirmed, PVLAS result, and by new theoretical insights. Searches for axions as Dark Matters particles and for axion emission from the sun are ongoing since much longer times. In the last few years a first generation of new light-shining-through-a-wall experiments (LSW) have finished data taking and published their results. The most stringent limits on the existence of WISPs of laboratory based experiments have been placed by the ALPS (Any Light Particle Search) experiment at DESY in the year 2010 [1].

Now activities towards a second generation of larger LSW experiments have started, most notably at CERN, FNAL and DESY [2]. Basically these plans foresee scaled-up versions (with some fancy add-ons) of the first generation LSW experiments. This is complemented by ideas to exploit high power lasers for WISP searches in KEK and Korea as well as new ideas to search for WISP emission from the sun and axion Dark Matter searches [2]. The new laboratory experiments basically strive for two achievements:

- The indirect limits on the existence of WISPs derived from astrophysics provided the strongest bounds by now. However, these data are always hampered by uncertainties in the production mechanism of WISPs. With new laboratory experiments, where one has full control on WISP production and detection, this fundamental uncertainty is avoided. New laboratory experiments should surpass the indirect limits from astrophysics. For example, couplings of axion-like particles below $g = 10^{-10}$ GeV^{-1} are to be probed [2].
- In spite of some intriguing astrophysics phenomena hinting at the existence of WISPs, is seems to be unlikely that from astrophysical data alone one can get a “bullet-proof” evidence of WISPs. Their existence is to be demonstrated in the

laboratory. For axion-like particles this demands again reaching sensitivities below 10^{-10} GeV^{-1}.

Thus the sensitivity of an experiment searching for axion-like particles is to be improved by about three orders of magnitude in the coupling g of axion-like particles to photons compared to ALPS-I. Note that the counting rate of photons shining through the wall varies with g^4.

At DESY preparations towards an ALPS-II experiment have started. Details will be described below after some theoretical considerations and motivations.

Physics motivation and theory

96% of the energy-matter content of the universe has been classified as dark content. Unraveling its nature is one of the most exciting goals of experiments worldwide. Among others, it has been suggested that some dark matter could reside in what has been called the hidden sector of particle physics. Many well motivated string theory scenarios predict such a hidden sector of low mass particles that interact only very weakly with our visible sector. These particles have been dubbed WISPs (Weakly Interacting Slim Particles) due to their extreme low mass and weakly coupling to matter. However, they provide a unique opportunity to probe high energy physics beyond the Standard Model, with low energy experiments, because the properties of the hidden sector particles are related to the string scale (see [3] and references therein).

As first WIPS candidates we find the axion and axion-like particles (ALPs). The QCD axion was postulated in order to solve the well known strong CP problem - absence of CP violation in the quark sector- and it is by now still the most plausible explanation. Recently it has been found that the axion and axion-like particles arise in many extensions of the Standard Model and even more, they are unavoidable in string theory. Their typical couplings to visible matter and their masses are inversely proportional to the string scale.

In the effective low energy theory, axions and ALPs interact very weakly with photons through a two-photon-coupling. Thus, in a magnetized background ALPs and photons can mix coherently, resembling the familiar neutrino oscillations. In spite the stringent bounds, mostly from astrophysical observations, on these particles, the mass region, where the QCD axion could dominate the Dark Matter, is hardly probed at all. Furthermore, there are interesting cosmological hints for the existence of ALPs. Prime examples are puzzling astrophysical observations, such as the anomalous transparency of the universe to high energy photons – could be accounted with photon-ALPs oscillations in intergalactic magnetic fields – or White Dwarf cooling, which according to recent observations seems to require an extra cooling mechanism that could be provided by the emission of ALPs.

A second example of WISP is the so-called hidden U(1) or hidden photon, which couples to our visible sector through a kinetic mixing with photons. As with the ALPs mechanism, an oscillation phenomenon between both arises, but this time no background magnetic field is needed. An exciting cosmological implication would be the creation of a thermal population of hidden photons, through resonant oscillation with the cosmic plasma, before the decoupling of the Cosmic Microwave Background (CMB). The existence of this "hidden CMB" (hCMB), conformed by hidden photons with masses in the milli electron-volt range, could be used to explain the puzzling tendency of the available cosmological data to an increased cosmic energy density in invisible radiation at decoupling, beyond the expectations from the Standard Model [2].

In both cases, the coupling to photons is very weak; therefore the probability of conversion is quite small, thus very precise optical experiments are needed in order to reproduce the mixing phenomenon suggested by cosmological observations.

Fortunately, such oscillations can be searched for also in the laboratory. In fact the ALPS experiment at DESY aims to probe the hCMB hypothesis in a clean and controlled environment already next year.

Towards the ALPS-II experiment at DESY

The aim of ALPS-II is to boost the sensitivity for WISP couplings to visible matter by about three orders of magnitude. This is only possible by pushing all components (laser power, detector sensitivity, magnetic length) to its limits. The following table shows a set of parameters we are striving for. For further detailed studies see [3].

Parameter	**Achieved at ALPS-I**	**Aimed for at ALPS-II**	**Sensitivity to ALP coupling g**	**Sensitivity Gain compared to ALPS-I**
Effective Laser power LP	1 kW	150 kW	$g \sim LP^{-1/4}$	3.5
Magnetic length BL	0.5+0.5 Hera Dipole	12+12 HERA Dipoles	$g \sim 1/BL$	24.0
Detector Efficiency QE	0.9	0.9	$g \sim QE^{-1/4}$	1.0
Detector Noise DC	0.01 1/s	0.0001 1/s	$g \sim DC^{-1/8}$	1.8
Power built-up in a regeneration cavity PB	1	40,000	$g \sim PB^{-1/4}$	14.1
Total				**2,100**

Table 1: A set of parameters for an ALPS-II experiment which allow to boost the sensitivity achieved at ALPS-I by more than three orders of magnitude.

Please note that the major contribution to the gain in sensitivity originates from two set-screws:

- Enlarging the string of magnets to its maximum value given by the laser beam properties and
- Introducing a second optical cavity behind the wall to increase the back-conversion efficiency of WISPs into photons.

The different items will be described in more detail below. This chapter offers a brief overview.

Usually LSW experiments shine laser light through long and tight magnet bores, which provides stringent requirements on quality of the laser beam. With the help of resonant optical cavities effective laser light powers around 150 kW might be possible in future instead of 1 kW in ALPS-I. The ALPS collaboration is presently preparing such a setup.

ALPS has used one spare HERA dipole magnet to achieve the results mentioned above. At DESY we study now the possibility of an experiment with up to 12+12 HERA dipoles.

Most of the present-day LSW experiments use commercial CCD cameras to search for reconverted photons from WISPs behind the wall. In the future the detection sensitivity might be enhanced considerably by using superconducting transition edge sensors (TES). Here a sensor is cooled down to about 100 mK and operated in the transition region between a superconducting and normal conducting state. Due to the very low heat capacity of such a state the energy deposit of a single photon results in a significant temperature rise and is well measurable. TES detectors allow for essentially background-free counting of individual photons, register their arrival times and allow to estimate their energies.

A new technology will be exploited to boost the sensitivity of LSW experiments even further: the challenge is to realize a second resonant optical cavity in the part of an experiment behind the wall. The idea of such a resonantly enhanced axion photon regeneration was put forward first in 1991 by F. Hoogeveen and T. Ziegenhagen and independently rediscovered in 2007 by P. Sikivie, D.B. Tanner and K. van Bibber [4]. The basic idea is to set up an optical resonator also in the regeneration part of a LSW experiment very similar to the optical resonator in the first part. The second resonator effectively increases the conversion probability of a WISP into a photon.

At present it is planned to realize ALPS-II in three different main steps:

1. All technical components except the magnets will be installed in a new laser laboratory (at present under construction) in the HERA-hall West. This laboratory allows for a set-up with 10 m long vacuum tubes for the generation and regeneration part of the experiment. Besides testing the components (namely the laser as well as the generation and regeneration cavities) hidden photons will be searched for with unprecedented sensitivity. This step will be concluded in 2012.
2. If everything works well, the equipment will be moved down into the HERA tunnel to search for hidden photons with generation and regeneration vacuum

tubes of roughly 100 m length. This will extend the search in step 1 to smaller mass scales. Results should be available in 2014.

3. Provided the necessary funding and full success in steps 1 and 2, the year 2016 could see the first HERA dipoles being installed in the HERA tunnel for ALPS-II. Searches for axion-like particles beyond the sensitivities of indirect astrophysics data could take place in the year 2017.

In the following chapters some details and the ongoing work on the different work packages will be sketched.

Laser and optics

The ALPS-I experiment used a green laser with a wavelength of 532 nm. This light was generated by a frequency doubling crystal from a 1064 nm laser. However, in the course of the experiment is was observed that the mirrors could not stand the high intensity 532 nm radiation by more than a couple of 10 hours. Similar effects have been observed also in studies for laser driven gravitational wave antennas. Therefore we decided to base the layout of the optical system of ALPS-II on infrared laser light at 1064 nm. Here we can fully profit from the quality management for the optical components of laser interferometers searching for gravitational waves.

On the one hand the optical setup has to provide a flux of primary particles that is as large as possible. Therefore an amplification scheme for the primary flux known as production cavity (PC) will be implemented. This concept was already demonstrated in the ALPS-I phase by "recycling" the laser photons inside the production region [1] by which the photon flux could be increases by a factor of 275 from about 5 W of green light. For ALPS II we anticipate a power build-up factor of 5000 amplifying 30 W of 1064 nm radiation. On the other hand to make the step into uncharted territory of axion-photon coupling the optical setup must also include some amplification device for the regenerated flux. Such a device can be realized in form of a so-called regeneration cavity (RC) [4] which is set up around the second string of magnets behind the wall. The Eigenmode of the regeneration cavity must be an extension in space of that one of the production cavity and its length has to be controlled such that regenerated light can be resonantly enhanced.

Overview Optical Layout

The main goals of the optical design of ALPSII are to achieve stable operation of the cavities with high optical build-up factors and to maintain a co-linear alignment of both cavities such that the tiny electric field caused by the regenerated process from potential WISP can be resonantly enlarged. In parallel the leakage of light from the generation region to the detector has to be kept very small. Some light is required to control the regeneration cavity. This light as well as all photons generated due to any process from this control light (via fluorescence, down-conversion, …) has to be kept away from the detector. In addition the coupling of laser light into the PC, the matching of the PC and RC modes as well as the detection process of regenerated photons should be as efficient as possible.

Resonance of the cavities

The laser frequency is controlled in a way to maintain the resonance condition for the PC. For this the Pound-Drever-Hall scheme is utilized and the control signal is fed back to the master laser. Alignment control loops are installed to keep the injected laser beam well aligned with the RC mode.

To gain in sensitivity from the implementation of the RC its length has to be controlled such that possible regenerated light is resonant. To achieve this requirement 532nm light is generated via a SHG process from the main laser beam leaking out of the PC at the central mirror. This light is used in another Pound-Drever-Hall scheme to gain an error signal for the RC length control loop. By feeding back to its length the RC is kept on resonance with the green light and by opening the “wall” it can be checked if the 1064nm light is resonant as well. An acousto optical modulator can shift the frequency of the green beam by a small amount to account for possible phase lags the green beam has acquired with respect to the 1064 nm light.

Co-linearity

The co-linearity of the PC and RC modes is achieved via two steps: The cavity mirrors on the central breadboard are chosen to be flat and mounted with parallel surfaces. This ensures the parallelism of the Eigenmodes of the cavities. Furthermore the position of the beam on those mirrors is sensed via quadrant photo detectors mounted on the central breadboard. This information is used in feedback control loops to keep these spots on predefined positions such that the cavity modes are co-linear.

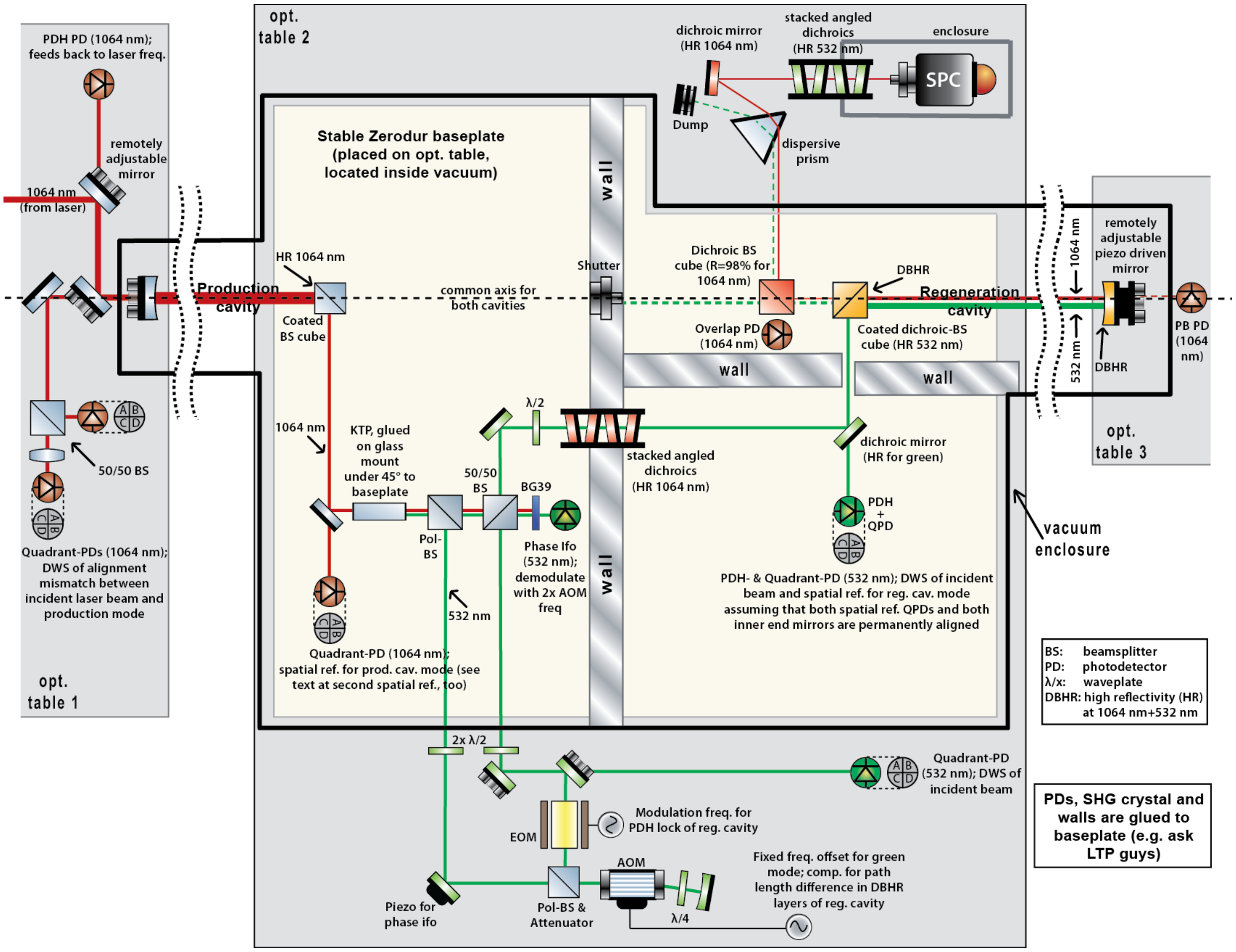

Fig. 1: Schematic layout of the main optics for the ALPS-II experiment.

Figure 1 shows a schematic optical layout. The 35W laser entering the drawing from the left side is omitted for clarity. Its beam is injected into the PC via two electrically controllable mirrors. The light reflected by the PC is sensed by two quadrant photodiodes (QPDs) and used in the Pound-Drever-Hall scheme to gain information about the frequency difference between a PC resonance and the frequency of the injected light. This information is used in a control loop feeding back to the frequency of the laser to keep the injected light resonant in the PC. In a similar way the photocurrents of the different quadrants of the photodiodes are conditioned to give error signals for the alignment control loop which feeds back to steering mirrors in front of the PC. By this the alignment of the laser is kept collinear with the PCs Eigenmode.

A small fraction of the light leaking out of the PC in the central area is detected by a QPD mounted on the central breadboard to control the spot position on the central mirror of the PC via feedback to the incoupling mirror of the PC. As the central mirror of the PC is rigidly mounted to the central breadboard the Eigenmode of the PC is strictly defined with regard to this central breadboard.

The larger amount of the PC leakage light is used in a frequency doubling process to generate light at 532nm which is then used to control the RC. This green light is injected into the RC and provides an alignment reference for the RC. A QPD sensing the green light reflected from the RC is used to gain error signals for the RC length and alignment control which uses the steerable mirror at the end of the RC as the actuator. As this QPD and the incoupling mirror of the RC are rigidly mounted to the central bread boars as well, the RC Eigenmode can be kept collinear with the PC Eigenmode. A shutter in the "wall" can be opened periodically to check if all control loop function as expected and allow for the resonant buildup of infrared light in the spatial mode of the PC which is identical to the one of regenerated photons.

Regenerated light leaking out of the RC is aligned onto a single photon detector. Several optical components inside this beam path ensure that no green light hits the detector.

Down conversion of 532 to 1064 nm light

Possible energetic down conversion from green to infrared light in the regeneration cavity or downstream of the cavity will be indistinguishable from signal photons generated by WISPs and spoil the sensitivity of the ALPS II experiment. The number of possible conversion processes, the uncertainty of the exact nonlinear properties of the employed substrates and coatings and of the according phase-matching conditions call for a suitable pre-experiment to rule these effects out. A setup has been built at AEI which takes the respective processes into account and is held as simple as possible.

A nearly monochromatic beam passing through an optical medium can be subject to several effects leading to the generation of photons with lower energies (frequency Down Conversion). As most of the filtering optical components absorb the undesirably light, fluorescence is a very likely way of down conversion to occur. The purpose of the down-conversion experiment is to observe and determine the presence of different types of down conversion effects while finding a way to eliminate or sufficiently suppress those effects.

In the down conversion pre-experiment we want to build an attenuation system which is able to protect the detector from both green photons –which are used for the stabilization between the production and regeneration cavity- and photons of any other wavelength within the detection spectrum generated from down conversion process anywhere in the light path. At the same time the attenuation system must be highly transmissive for infrared photons regenerated from WISPs. It is assumed that the input power required for the stabilization of both cavities is less than 10 µW (equivalent to $2.7 \cdot 10^{12}$ photons/s). Thus the required attenuation of the green intensity is above 10^{18} so that the background from down-conversion is lower than the background counts provided by the detector. At the same time a transmittance of above 90 % for 1064 nm photons should be feasible.

The set-up of the experiment is shown in Fig. 2.

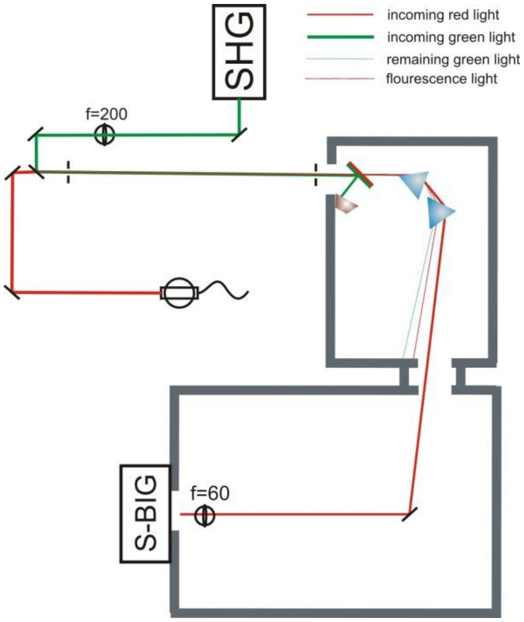

Fig. 2: Schematic layout of the down-conversion measurements.

We use a 12 W laser and a second harmonic generation crystal as a light source enabling us to achieve an output power of 2 W at 532 nm. Photons are counted with the SBIG CCD camera used at ALPS-I. The attenuation will be realized with the help of dichroic mirrors and dispersive prisms. The green beam will be reflected to 99.9 % on the dichroic mirror (HR for 532 nm and HT for 1064 nm). The prisms will be used to separate the remaining amount of green light and the infrared fraction. They will also separate the diffuse fluorescence originating from the crossing of the green light through the dichroic mirror. This fluorescence light has a wavelength ranging from 900 nm to 1000 nm and can be easily separated from the infrared ray. The infrared ray is passing through a telescope with a small aperture blocking the angular misaligned beams (stray-Light). Green blocking RG850 filters are installed on the output facette of the box.

By now the sensitivity of our measurement nearly reaches the dark count level of the SBIG camera at an incident green light power of 50 mW. To achieve a higher sensitivity we will in future use incoming green light with higher intensity and a more sensitive detector like the PIXIS CCD used for the final ALPS-I results.

Magnets

The studies for the ALPS-II experiment base on HERA dipole magnets like the one used for ALPS-I. This is a natural choice as many of those magnets are available at DESY as former spare devices for HERA and as installed in the HERA tunnel. Clearly the development of magnets optimized for WISP searches is beyond the scope of our activities. However, it should be noted that in principle the optical system being developed for ALPS-II allows also for a combination with LHC dipole magnets, because they offer a larger aperture and less bending as HERA dipole magnets. LHC dipoles provide nearly twice the magnetic field strength of the HERA dipoles thus increasing the sensitivity of searches for ALP couplings to photons by a factor of two.

HERA dipole studies

For all LSW experiments one has to optimize between the length of a setup (the longer the more sensitive) and the effective power built-up in the optical cavities (the shorter the better). One has to take care that clipping losses (due to the laser beam divergence and limited apertures) does not limit the cavity performances. We’ve analyzed such an optimization for an experiment using HERA-dipoles.

The inner diameter of the vacuum pipe in the superconducting HERA dipoles (see Fig. 3) is 55 mm. Including tolerances of 3 mm this diameter would allow for a setup of 2 strings with 12 dipoles each supplying sufficient free area of sight for an optical cavity with a power buildup of 40,000.

However the iron yoke and the vacuum pipe are bent reducing the free sight for the laser beam horizontally to ~35 mm. With tolerances of 3 mm included this would only allow for a setup of 2x4 dipoles.

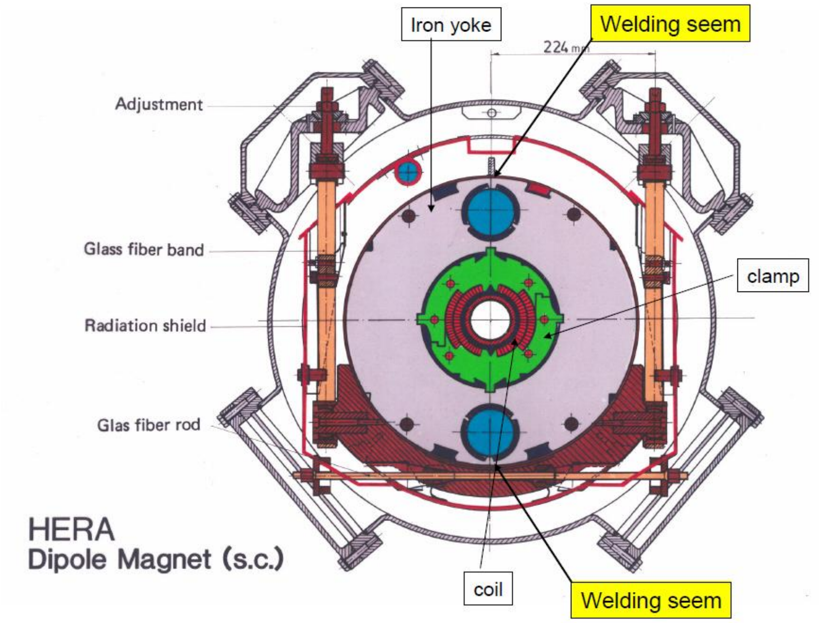

Fig. 3: Cross section of a HERA dipole magnet.

Originally the iron yoke, the clamps, the coils, and the vacuum pipe were fabricated straight. The welding of the half cylinders of the Helium vessel around the iron yoke was performed in a big tool which forced the cold mass to a given curvature. The beam pipe was forced to follow the curvature by spacers glued to the pipe.

Therefore by cutting the welding seem, straightening the yoke and welding two straight half cylinders around the yoke it should be possible to obtain a straight dipole magnet. However, this procedure requires the complete disassembly of the yoke and the rebuilding of part of the tooling used originally. The knowledge for this procedure still exists in one company which originally assembled half of the total number of dipoles. This method of straightening HERA dipoles seems feasible. The total cost for this operation is not known at present but is expected to be considerable.

We therefore looked for a simpler and thus cheaper way of straightening the dipole. Engineering studies showed that a straightening of the yoke and thus the beam pipe should be possible by a brute force deformation with ~4000 Kp from the outer vacuum vessel at the 3 planes of support of the dipole. At present the tools to deform the yoke are being fabricated. The test of this procedure is planned for within the next weeks. To check the merit of the procedure with respect to the straightening, the horizontal displacement along the length of 5 sample vacuum pipes has been measured for comparison at HERA dipole spares (see Fig. 4).

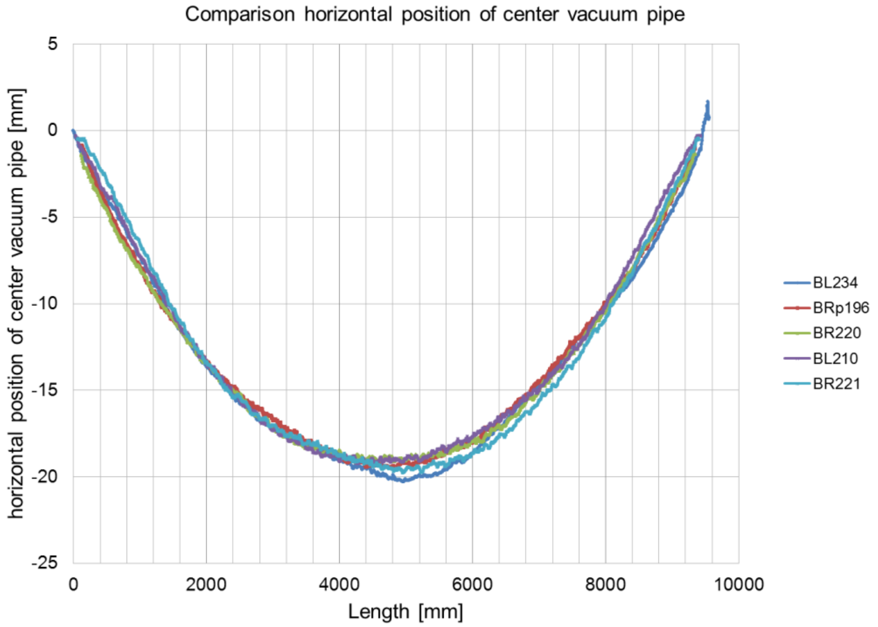

Fig. 4: Beam pipe curvatures measured for different HERA dipole magnets.

If successful, the next crucial step will be to design deforming tools, which keep the thermal flux from the vacuum vessel at room temperature to the yoke at liquid Helium temperature within acceptable limits. This will require - if possible - a few months of engineering effort. After the fabrication of prototype tools for one dipole, measurements at the magnet test stand will be necessary eventually to determine the thermal losses and assure the functionality of the magnet.

Until one other precondition for the experiment, namely the feasibility of an optical cavity with power buildup of 40000 for a length of 120m, has been demonstrated, the modification of a larger number of dipoles will be postponed. In case the straightening of dipoles does not work out as expected or turns out to be not affordable the 2*4 string option with standard bent dipoles will be followed.

All technical systems and special work needed to set up and operate the strings of superconducting dipoles have been considered. No show stopper has been detected up to now. However the technical manpower needed to build special systems like the quench protection system remains to be assigned.

Detector studies

For the ALPS-II experiment we follow two main lines of detector studies at present. On the one hand we test CCD cameras. However, they require long exposure times in order to minimize the impact of the read-out noise. At present it is unclear whether this will be compatible with the alignment of the optical system or whether frequent calibrations will be necessary. More ambitious is the use of a superconducting transition edge sensor (TES), which in principle combines high quantum efficiency with extremely low background noise and allows to measure arrival time and energy of single photons. However, even if a TES will be chosen as the final detector, sensitive CCD measurement are frequently required during the installation and alignment phases to image the beam spot, map possible background light distributions and register spurious events like radioactivity and cosmic ray interactions.

CCD

The ALPS-I experiment used a PIXIS 1024B CCD camera for photon detection. By means of cooling to temperatures as low as -70°C the dark noise of this device can be significantly reduced such that it could be used as a single-photon detector. Commercially available infrared cameras show much higher dark currents than our PIXIS CCD. Hence, in spite of high quantum efficiencies, one would not gain much in sensitivity with such costly devices compared to our camera, if the PIXIS still shows a few percent quantum efficiency at 1064 nm. For the visual spectrum the quantum efficiency of the PIXIS is tabulated by the manufacturer. Unfortunately, in the infrared (IR) spectrum the quantum efficiency is not specified. So we have to determine it ourselves.

In the last months, calibration measurements with an InGaAs CCD camera were performed at Hamburger Sternwarte, Bergedorf. A broad-band light-source and IR band-filters were used to produce quasi-monochromatic light. These measurements indicate that the PIXIS 1024B CCD is indeed sensitive in the IR. However, a precise estimation of the quantum efficiency could not be made because of insufficient attenuation of the available filters and a biased emission spectrum of the light source.

For an improved setup an IR-laser was purchased. The laser is equipped with a micro-focus optics that allows focusing of the beam on a few pixels of the CCD, allowing for local quantum efficiency measurements on the CCD chip. A calibrated photo-diode will be used as reference detector. In preparation for these measurements, a laser power meter will be used as reference detector. In parallel, systematic fluctuations of the CCD's fixed-pattern noise are analyzed and methods to correct for these are evaluated.

It is expected to conclude the measurements by the end of May 2011.

On the road for a TES detector

The development during the last two decades of Superconducting Transition-Edge Sensors (TES) has yielded a wide spectrum of applications including dark matter searches, spectroscopy, photon counting and near-infrared single photon detection [5]. Recent realizations of TES from other groups have shown a detection efficiency up to 99% [6, 7], an energy resolution about ~0.15 eV and a time resolution about ~0.1 µs for near infrared light (1310 nm and 1550 nm). In contrast to other photo detectors TES detectors have no equivalent to a dark current. So single photons with energy above a threshold given by sensor and amplifier noise can be detected essentially background free. Our goal is to optimize and operate such a low-noise infrared (1064 nm) single photon detector.

The sensor itself (TES chip) is a thin superconducting film, e. g. for infrared photons it could be about 40 nm thick with a detection area of 25 µm x 25 µm consisting of Tungsten (W) with a superconducting transition at 125 mK [8]. The TES chip is voltage-biased (in the electrical circuit) to bring it to its sharp resistive transition (~ 1 mK broad) as the working point of the sensor. Simultaneously the TES is connected to a cold bath (in the thermal circuit), so there is a negative electro-thermal feedback which stabilizes the sensor to its working point. If energy is deposited in the sensor, the change of the resistance causes a change of the current of the electrical circuit, which is coupled to a Superconducting Quantum-Interference Device (SQUID) inductively (see Fig. 5). Via the SQUID and its read-out electronics finally one gets the output signal, which can be recorded by usual DAQ systems.

To gain first experience in the handling of a TES detector we performed qualitative measurements at the Physikalische Technische Bundesanstalt (PTB) in Berlin, where the division of "Kryosensoren" uses TES detectors for SQUID measurements. Fig. 6 shows a TES on loan from INRIM (Italian Institute for Metrologic Research) as well as its transition temperature measurement. This TES will be used for first exercises.

We bought a SQUID device with its readout and control electronic from Magnicon GmbH [9]. In May this year we will install this device in a dilution cryostat in Camerino, Italy, to learn with our Italian partners how to handle and work with the SQUID as an amplifier. After that we will to try to detect some photons with a suitable TES and a light source insight the cryostat to determine typical signals. With this knowledge the remaining background noise will be measured. Up to now only upper limits of less than 10^{-3} background counts per second can be found in the literature.

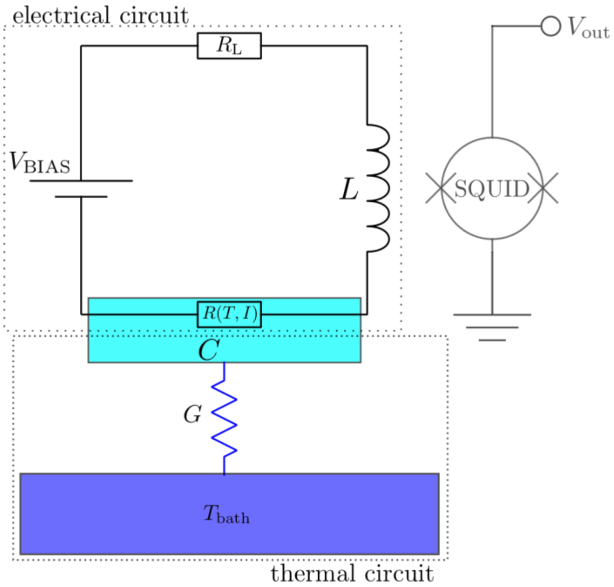

Fig. 5: A schematic drawing to sketch the TES operation: The TES with its resistance R(T,I) is connected via a voltage-biased (V_{bias}) electrical circuit (here in the Thevenin equivalent representation). The TES with its heat capacity C is coupled via a weak thermal link (conductance G) to a cold bath with temperature T_{bat},. The thermal and electrical circuits result in a negative electro-thermal feedback condition. The change of temperature, which causes a change of current, is read out via an inductance L which is coupled to a SQUID.

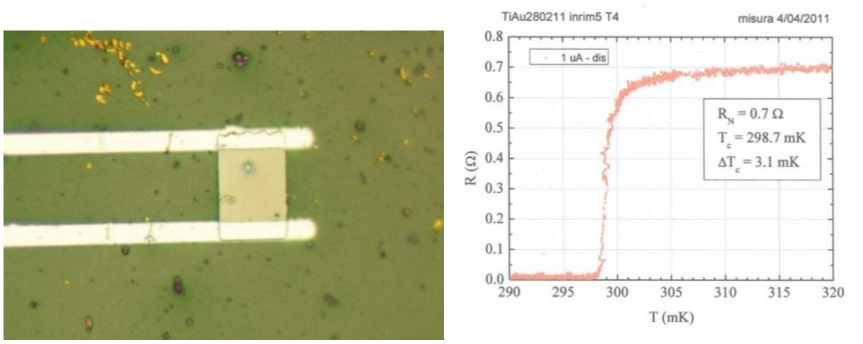

Fig. 6: A TES (25 µm x 25 µm), left, and its transition temperature on the right.

After the determination of the TES performance, we have to do extensive studies on efficient couplings of light from an experiment like ALPS onto the TES. This will be done with the help of an optical fiber attached to the TES [10, 11].

After the first measurements in Camerino it is planned to build up the detector at DESY in Hamburg (if a suited cryostat is available), where cross calibrations with the CCD cameras and calibrated photo diodes will be done to fully understand the efficiency of the TES detector for single 1064 nm photons.

Infrastructure

A new laser laboratory

A dedicated laser lab for the ALPS II experiment is being setup in room 607 in the HERA West-Hall. A 25 m long and 3 m wide area of the disused HERA RF supply room will be used for the ALPS II experiment (cf. Fig. 7).

This lab will at first be used for ALPS-II R&D work, allowing to set up and test all ALPS II optical components, especially the challenging two stage cavity system with ~ 10 m long beam tubes. Once functioning, this setup will be utilized for a first ALPS II physics run dubbed “step 1” above.

The lab consists of three separate laser rooms, each housing a 1.8 m x 0.9 m large laser table (Newport – M-RS4000-36-12) and providing clean room conditions and appropriate climatisation. Between the laser rooms two grey rooms are planned, which provide access / lock to the three laser areas. All walls are built in lightweight mode of construction. Laser safety will be implemented by treating as far as possible each laser room as a separate laser area, thereby facilitating independent work in all three areas. The lab is built up on a cohesive armored concrete floor of ~ 1 m thickness. First measurements of ground vibrations have been performed early this year with a broadband seismometer (Güralp CMG-T30-0010). Patterns of seismic noise are well pronounced, i.e. one observes larger values during usual working hours and it becomes much more silent during nights and weekends. Fig. 8 shows as an example the vertical spectral distribution for a quiet and a noisy 15 minute period. These first measurements indicate that the basic ground motion level in the room is sufficiently low.

Detailed studies are ongoing in order to optimize mounting of the laser tables with respect to the seismic noise. The goal is to have the same vibration noise level on all optical tables as on the floor. A partially synchronous motion of all three tables might hopefully reduce seismic noise. Further measures to improve the ground motion level are under consideration, like active control systems or passive attenuation.

The laser tables will be installed in May; the complete lab is intended to be ready before summer. In addition to the laser lab office space for ALPS-II is created on the 7th floor (room 701) of the West-Hall.

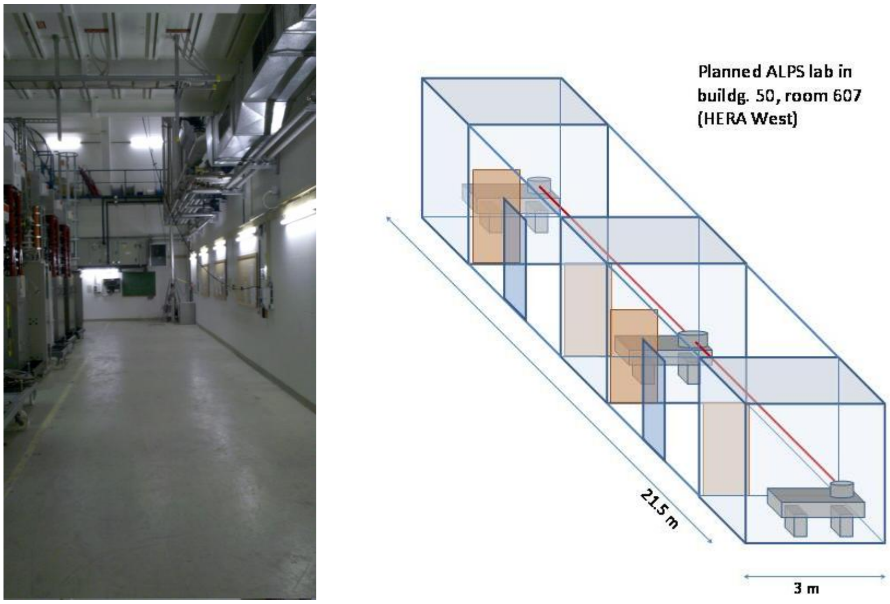

Fig.7: Sketch and location of planned laboratory.

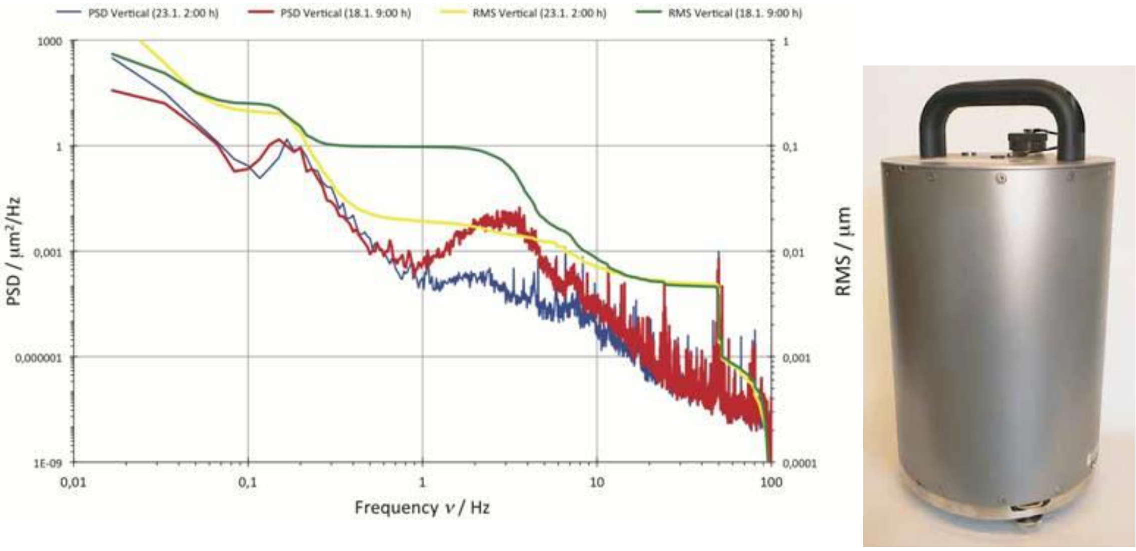

Fig. 8: Left: Vertical power spectra for a quiet (blue) and noisy (red) period together with its RMS values (in yellow and green, right x-axis) – integrated over a 15 min period. Right: Picture of the Güralp seismometer.

Possible sites for ALPS-II

Assuming the availability of straightened superconducting dipoles, a string of 2x12 dipoles would supply the necessary horizontal aperture for the laser beam with sufficiently low clipping losses. With the overall dipole length of 9.766 m and including the space required for the clean rooms and laser huts this ask for a total length of about 260m. A sufficient number of spare HERA dipoles are available. For the cryogenic and electrical connection of the two strings the use of the proton kicker bypass line now located in the HERA tunnel West left is being considered.

The natural choice for such a setup is one of the straight sections of the HERA tunnel due to the principal availability of infrastructure like cryogenics. The available space in the long straight sections East and West amounts to ~320 m allowing easily for a string of 2x12 dipoles, whereas the short straight sections HERA South and HERA North with a length of ~220 m would allow only for a string of 2x10 dipoles

An installation outside of the HERA tunnel on the DESY site has also been considered. There are three possible locations along the eastern borderline of the DESY site. Due to the additional costs of such an installation for buildings, cryogenics, and infrastructure, which have been estimated to about 12 Mio Euro, this possibility has not been followed any further.

To allow an installation of the long dipole strings connected properly to cryogenic boxes requires the removal of the existing accelerator installation in any straight section of HERA chosen for this purpose. This is mainly due to the necessary exchange of the cryogenic boxes from one end of the straight section to the other, to match the connection pattern of the dipoles. The effort in this respect is largest in the straight section West due the large number of special and complicated accelerator systems for example the proton injection line, the superconducting cavities of the electron ring, the RF cavities of the proton ring, and the proton beam dump. The removal of these components also requires proper storage areas to keep the option of reusing the components at some later time. These areas remain to be assigned. In case of the beam dump it also remains to be clarified whether it may be stored for later reuse or whether it has to be disposed of, which would require additional cost.

However, an installation of ALPS II in the straight section West allows for the use of the existing magnet power supply for the dipole strings. A transfer of the power supply to any other HERA hall would require –according the responsible group in the accelerator division- substantial additional cost for infrastructure like transformers (>200,000 €). Supplying cryogenics to an ALPS II setup is possible to any of the HERA halls in principal. The effort and the cost of operation are smallest in the straight section West. Assuming one cool down of the two magnet strings and 10 months of operation the additional operation costs compared to HERA-West would amount to about 150,000 € in HERA-East and approximately 70,000 € in HERA-North or South. Because of these cost arguments the collaboration favors at present the straight section West as potential location of ALPS II in spite of the larger effort to remove the existing accelerator components.

HERA tunnel preparations

After the completion of the experiment in the new laser laboratory searching for hidden photons with optical cavities of 10 m length each (step 1), an experiment with increased cavity lengths is being considered. The experimental setup of step 2 with optical resonators of about 100 m length is a necessary precondition for the ALPS-II experiment with two strings of 12 straight superconducting HERA dipoles each (step 3). To demonstrate the feasibility at the length required for the later experiment, a length of about 2*120 m is chosen for the hidden photon search.

To set up a new vacuum line of this length would require investments of ~80,000 €. To save these costs it has been investigated, whether the existing vacuum systems in the straight sections of HERA could be used for this purpose instead. The only straight vacuum line of the required length lies within the straight section HERA West, where a total length of ~320 m is available with sufficient aperture for the laser beam, compared to only 120 m total in the other straight sections.

In the straight section West adequate locations have been identified for the clean rooms and laser huts where only little effort would be required for the removal of the existing accelerator components. It is worth noting that the laser huts have to be removed again for a setup of 2x12 dipoles, thus there is no pre-selection of the straight section West by this hidden photon search experiment.

Timelines

For the layout of the optical system with its challenging two-cavity-setup the measurement of the down conversion is essential. If a significant irreducible background of down-converted photons remains, other setups for the optics are to be worked out. Possible alternative scenarios have been sketched already. However, at present there is no indication of problematic background photos. It is planned to conclude the down conversion measurements in August 2011. The layout of the optical system will be finalized end of 2011 in time for the Technical Design Report. After fabrication of the components tests with both cavities will start in March 2012 in Hannover. In parallel the setup of a 10 m long high power production cavity will start in the new laser laboratory in the HERA-hall West in January 2012.

In summer 2011 we know whether the purchase of a dedicated infrared camera is reasonable or whether the available CCDs show sufficient sensitivities. For the TES studies, the first essential step is a measurement of the background noise. This will allow for an estimation of the sensitivity which could be reached. We strive for concluding these studies using the cryostat in Camerino by late summer of 2011. We would like to compare different sensors from INRIM, Genoa and NIST (in the US), but delivery times are not fixed yet. Up to summer 2012 studies on the detection efficiency and energy resolution measurements will be carried through. We'll compare different ways to couple optical fibers to a TES (fortunately such schemes exist and we don't have to develop it ourselves) as well as different sensor types and coatings. Provided the funding for a suited cryostat is available a TES system for 1064 nm photons should become ready for operation at DESY in summer 2012.

The present time schedule foresees the completion of the hidden photon search experiment with 2x10 m optical cavities and the close-to-final detector system until the end of 2012. Assuming the timely recommendation of the PRC and the approval of the DESY directorate the hidden photon search experiment in the straight section HERA West could be build up from the beginning of 2013 and measurements performed until the end of 2014. The demonstration of the feasibility of a power buildup of 40,000 for an optical cavity of 120 m length should be completed by mid-2014. After this the straightening of dipoles could start either by the simple deforming method or by placing an order to a company. It should be noted that the straightening of dipoles in industry will need a longer time on the order of a year.

According to the planned activities at present at DESY, especially the completion of the XFEL facility, manpower required for the setup of strings of superconducting HERA dipoles for ALPS II and sufficient cryogenic capacity for magnet tests could be available from the beginning of 2015 on, again assuming the timely recommendation of the PRC and the approval of the DESY directorate. It has been estimated that the installation of the components including the cryogenic test of the superconducting magnets can be completed until the end of 2016, thus allowing first measurements of ALPS-II from the beginning of 2017. In case dipoles will have to be straightened in industry the additional time of about one year needed could be bridged by installing several existing so called cold straight sections of the HERA proton ring, thus allowing the installation of cryogenic boxes and laser huts in the proper position for the final setup from the beginning.

Collaboration and responsibilities

The team preparing the ALPS-II experiment has increased compared to the ALPS-I collaboration. The group of Prof. D. Horn (University of Hamburg) has joined and four PhD students (three from DESY / University of Hamburg, one from AEI Hannover) have started their work end of 2010. At present the following people are involved in ALPS-II:

- DESY:
  P. Arias Reyes, J. Dreyling-Eschweiler, K. Ehret, S. Ghazaryan, R. Hodajerdi, E.-A. Knabbe, A. Lindner, D. Notz, A. Ringwald, J. E. v. Seggern, D. Trines
- Albert-Einstein-Institute Hannover (Max-Planck-Institute for Gravitational Physics and Leibniz University Hannover):
  R. Bähre, T. Meier, B. Willke
- Hamburger Sternwarte (University of Hamburg):
  G. Wiedemann
- Max-Planck-Institute for Physics (Munich):
  J. Redondo
- University of Hamburg:
  D. Horns

The institutes share the tasks in the following manner:

- Theory:
  DESY, MPI Munich.
- Infrastructure:
  DESY
- Laser and Optics:
  AEI Hannover, DESY
- Magnets:
  DESY
- Detectors:
  DESY, Hamburger Sternwarte, University of Hamburg.

In addition the collaboration is supported by the Laser Zentrum Hannover (M. Frede) on laser issues.

The development of a superconducting Transition Edge Sensor (TES) is performed with a (still in-official) collaboration beyond the ALPS scope, because many groups are interested in such a low background detector. The institutes and people involved here are:

- DESY:
  J. Dreyling-Eschweiler, K. Ehret, E.-A. Knabbe, A. Lindner
- University of Hamburg:
  D. Horns
- Physikalisch-Technische Bundeanstalt (Berlin):
  J. Beyer, M. Schmidt
- University of Camerino:
  G. Di Guiseppe, M. Karuza, M. Lucamarini, R. Natali
- INRIM Torino:
  M. Rajteri
- INFN Frascati:
  R. Cimino
- University and INFN Genoa:
  D. Bagliani, F. Gatti
- University and INFN Trieste:
  G. Cantatore, A. Rachevski

Summary and outlook

The ALPS-II experiment as sketched above will provide access to parameter regions in the WISP world not probed in the laboratory before. This is shown in Fig. 9 and 10.

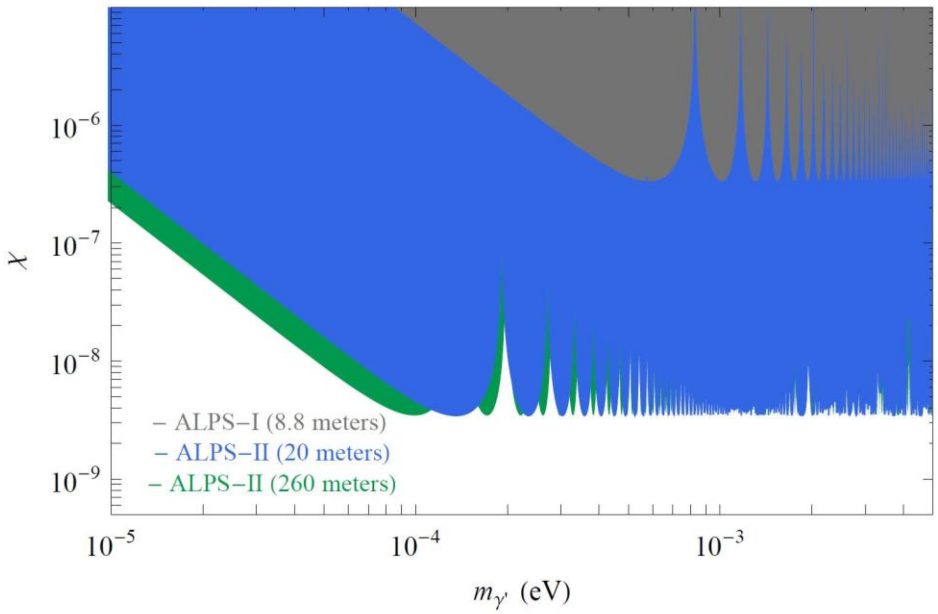

Fig. 9: Reach of the ALPS-II experiment in the search for hidden photons.

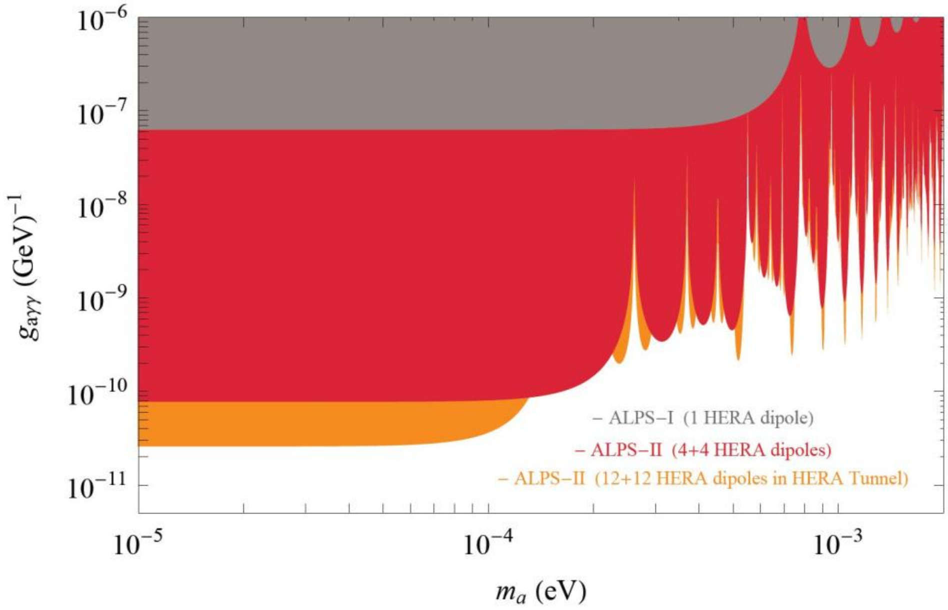

Fig. 10: Reach of the ALPS-II experiment in the search for axion-like particles.

It is reminded that the results for the hidden photon searches do not require any magnets so that the final results could be available already in 2014.

In parallel to the ALPS-II activities several other new WISP enterprises have started. We study the possibilities of a large telescope searching for hidden photons from the sun (dubbed “SHIPS”, see http://www.ships.uni-hamburg.de) which could be installed in the HERMES hall. Discussion with CERN are ongoing concerning CAST-like activities, WISP searches using synchrotron radiation, searches for axions as Dark Matter constituents or Chameleon particles causing the Dark Energy in the Universe. There are strong synergies (for example regarding photon detectors) among all these activities.

With ALPS-II and these many ideas for small and medium-sized experiments together with the world-leading accomplishments in DESY’s theory division DESY and its collaborators could remain at the forefront of WISP searches. Such local activities would complement contributions of DESY to high energy experiments elsewhere in a close-to-ideal manner.

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